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Editorial

Dear URSI Correspondent,

In this issue, along with other contributions, we present three papers from the URSI 75th anniversary symposium on Space and Radio Science. With Prof. Schilizzi's VLBI's you are given an opportunity to look at the sky with an angular resolution in micro-arcseconds. Dr Gurnett invites you to the audio-visual show of space plasmas and Dr. Snyder explains how to design spacecrafts for a safe drive across these plasmas.

I hope you will enjoy these remarkable contributions. Besides let me recall that the Radio Science Bulletin welcomes articles and notes of interest to a large fraction of the Radio Science community, with a preference for those having a review, tutorial and/or prospective character.

P. Delogne, Editor.

Errata

The explanation of the photograph on the front cover of the last (June) issue of this magazine should have been : *President P. Bauer presents a framed photograph, taken during the second meeting of the "Commission Internationale de Telegraphie sans Fil" in Laken (Belgium) in 1914, to His Majesty King Albert II of Belgium at the occasion of the symposium "Space and Radio Science". From left to right : Prof P. Delogne (Chairman of the Technical Programme Committee of this symposium), Prof. P. Lagasse (URSI Secretary General), His Majesty King Albert II, Dr. P. Bauer (URSI President).*

Please accept our apologies for the inconvenience caused.

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The object of the International Union of Radio Science (Union Radio-Scientifique Internationale) is to stimulate and to coordinate, on an international basis, studies in the field of radio, telecommunication and electronic sciences and, within these fields:

a) to promote and organise research requiring international cooperation, and the discussion and dissemination of the results of this research ;

b) to encourage the adoption of common methods of measurement, and the intercomparison and standardisation of the measuring instruments used in scientific work ;

c) to stimulate and coordinate studies of :
   - the scientific aspects of telecommunications using electromagnetic waves, guided and unguided.
   - the generation and detection of these waves, and the processing of the signals embedded in them.

75th ANNIVERSARY

URSI - 75 Years Space and Radio Science Symposium

SOLAR SYSTEM PLASMA WAVES

Donald A. Gurnett

Abstract

An overview is given of spacecraft observations of plasma waves in the solar system. In situ measurements of plasma phenomena have now been obtained at all of the planets except Mercury and Pluto, and in the interplanetary medium at heliocentric radial distances ranging from 0.29 to 58 AU. To illustrate the range of phenomena involved, we will discuss plasma waves in three regions of physical interest: (1) planetary radiation belts, (2) planetary auroral acceleration regions, and (3) the solar wind. In each region we will describe examples of plasma waves that are of some importance, either due to the role they play in determining the physical properties of the plasma, or to the unique mechanism involved in their generation.

1. Introduction

This overview of solar system plasma waves is presented in celebration of the 75th anniversary of the International Scientific Radio Union (URSI).The study of naturally occurring plasma waves is an old subject that has its origins in early ground-based investigations of very-low-frequency (VLF) radio signals. The first known report of VLF radio signals of natural origin was by Preece [1894], who detected a variety of unusual audio frequency electrical signals while experimenting with a long-distance telephone line. Based on his description, the signals that he detected were probably spherics, which are lightning-generated signals that propagate in the Earth-ionosphere waveguide, and a type of VLF radio emission now known as chorus. Some years later, during World War I, Barkhausen [1919] described unusual whistling signals lasting several seconds that he detected while attempting to intercept enemy telephone communications using a rudimentary vacuum-tube amplifier. Initial progress on the understanding of these whistling signals, which soon came to be called whistlers, was slow. After several years of investigation, including detailed analyses of their frequency-time characteristics, Eckersley [1935] correctly postulated that whistlers were produced by lightning. However, the mechanism that caused the dispersion, and the long propagation paths required to achieve the several-second travel time were unknown. It was not until the 1950s that Storey [1953] was able to provide a satisfactory explanation of whistlers. He showed that the dispersion occurred as the signal propagated along the magnetic field line from one hemisphere to the other in a plasma mode of propagation now known as the whistler mode.

In addition to whistlers, which are produced by lightning, a number of other unusual VLF signals were discovered in this early era that were clearly not due to lightning. The best known of these are "chorus" and "hiss." The term chorus was introduced by Storey[1953] because the signals sounded like the early morning chorus from a colony of birds. The hiss signals produced a hiss-like sound in the audio output of the receiver. At high latitudes, hiss was soon found to be associated with the aurora, and this type of emission came to be know as "auroral hiss." Among the early investigators, Ellis [1957] had the distinction of being the first to propose a theory for the generation of these emissions. He suggested that auroral hiss was produced by Cerenkov radiation from the charged particles responsible for the aurora. As will be discussed later, elements of his ideas still exist in modern theories of auroral hiss. For a more extensive review of early ground-based observations, see Helliwell [1965].

The launch of the first Earth-orbiting satellites in the late 1950s opened up an entirely new era in the study of space plasma wave phenomena. VLF receivers on Earth-orbiting spacecraft soon revealed an extremely complex variety of plasma waves in the ionosphere and in the hot magnetized plasma surrounding the Earth known as the magnetosphere. Many of these waves had never been seen in laboratory plasmas. Because of the ideal conditions that

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existed in space, with negligible collisions and no walls, the study of space plasma waves soon became an important element of modern plasma research. The growth of plasma waves was found to play a crucial role in establishing an equilibrium in a plasma, in much the same way that collisions in an ordinary gas play a role in achieving thermal equilibrium. Plasma waves and radio emissions also often provided a useful diagnostic tool for determining various plasma properties, such as the electron density and magnetic field strength. Because of the importance of these measurements, radio and plasma wave instruments were soon routinely included on missions to other planets. Now, nearly forty years after the launch of the first Earth-orbiting satellite, in situ measurements of plasma waves and radio emissions have been obtained at all of the planets except Mercury and Pluto, and in the interplanetary medium at heliocentric radial distances from 0.29 to 58 AU (astronomical units). Since this subject covers such a broad area of research, this overview must necessarily be limited. To restrict the scope of this review, we will concentrate on three regions of physical interest: (1) planetary radiation belts, (2) planetary auroral acceleration regions, and (3) the solar wind. In each region, we will describe certain selected examples of some importance, either due to the role they play in determining the physical properties of the plasma, or to the unique mechanism involved in their generation.

2. Planetary radiation belts

A radiation belt consists of energetic electrons and ions that are trapped in the magnetic field of a planet. The Earth's radiation belt was discovered by Van Allen [1959] using Explorer 1, which was the first U.S. satellite. Since then radiation belts have been discovered at five other planets, Mercury, Jupiter, Saturn, Uranus, and Neptune, all of which have substantial magnetic fields. The energies of the radiation belt particles vary considerably from planet to planet, but are generally in the range from a few keV to several MeV. Jupiter has by far the most intense and energetic radiation belt. In situ measurements of plasma waves and radio emissions have been made in all of the known radiation belts, except for Mercury. A summary of the various types of plasma waves that have been observed is given in Table 1. Of these, we will describe two that are of particular importance. These are (1) whistler-mode

Type of Plasma Wave	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune
Whistlers (lightning)	X	X		X			X
Whistler-mode hiss		X		X	X	X	X(?)
Whistler-mode chorus		X		X	X	X	
Auroral hiss		X		X			
Cyclotron maser radiation		X		X	X	X	X

Table 1

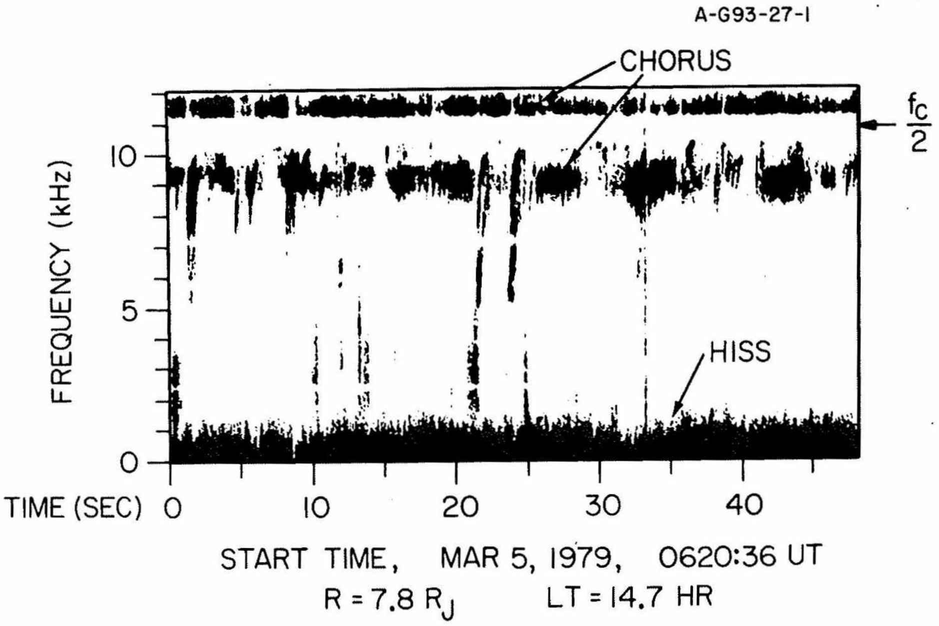

Fig. 1 - A frequency-time spectrogram showing whistler-mode chorus and hiss detected by Voyager 1 in the radiation belt of Jupiter. Chorus consists of the many discrete narrow band emissions, usually rising in frequency on time scales of a few seconds, and hiss consists of the nearly steady spectrum of band-mimited noise. In this case, the chorus occurs from about 8 to 12 kHz, and the hiss occurs below about 1 kHz.

emissions, and (2) electromagnetic ion cyclotron emissions.

A. Whistler-mode emissions

The whistler mode is an electromagnetic mode that propagates at frequencies below the electron cyclotron frequency, $f_c = eB/m_e$, where e and m_e are the charge and mass of an electron, and B is the magnetic field strength. The whistler mode is right-hand polarized with respect to the magnetic field. Two types of whistler-mode emissions, chorus and hiss, are commonly observed in planetary radiation belts. Chorus consists of numerous discrete narrow band emissions, usually rising in frequency on time scales of a few seconds. Hiss consists of a nearly steady level of band-limited noise, usually below the frequencies at which chorus is observed. A frequency-time spectrogram of chorus and hiss in the Jovian radiation belt is shown in Figure 1. These emissions were observed during the Voyager 1 flyby of Jupiter [Scarf et al., 1979], and are remarkably similar to the terrestrial chorus and hiss emissions detected during the early era of ground-based VLF studies.

Chorus and hiss are both believed to be generated by a cyclotron resonant interaction with radiation belt electrons. Cyclotron resonance occurs when the wave frequency in a frame of reference moving along the magnetic field with the particle matches the cyclotron frequency of the particle. The wave field in the moving frame of reference must also be rotating around the magnetic field in the same sense as the particle. Cyclotron resonance can occur for both electrons and ions. However, for the whistler mode the most important cyclotron resonance interactions occur with the electrons. In a classic paper on the subject, Kennel and Petschek [1966] showed that the parallel energy at which electrons are in cyclotron resonance with a whistler-mode wave is given by

$$W_{\|} = \frac{B^2}{2\mu_o N}\left(1-\frac{f}{f_c}\right)^3 \frac{f_c}{f}$$

where $B^2/2\mu_o$ is the magnetic field energy density, N is the electron number, and f is the wave frequency. Whistler-mode waves grow spontaneously if the electron velocity distribution is anisotropic in such a way that there is a deficit in the number of resonant electrons moving at small angles to the magnetic field. In a planetary radiation belt, this type of anisotropy always occurs, since any particle with a pitch angle within a cone of directions called the "loss-cone" will strike the planet and be lost from the system.

Although the whistler mode is always unstable due to the presence of the loss cone, the question of whether the wave grows to a large amplitude depends on the gains and losses along the ray path. Kennel and Petschek showed that the growth rate is proportional to the number of electrons in resonance with the wave. Therefore, the growth rate increases as the radiation belt intensity increases. Since the highest radiation belt intensities usually occur near the magnetic equator, the highest growth rates tend to be near the magnetic equatorial plane. Various types of losses exist. One of the main losses is simply due to the propagation of the wave out of the system. Because of the anisotropic nature of the propagation, whistler-mode waves tend to be guided along the magnetic field lines toward the planet, where they can escape through the base of the ionosphere. However, if the initial wave normal angle is sufficiently large, the wave tends to reflect as soon as the lower-hybrid-resonance frequency, $f_{LHR} = \sqrt{m_e/m_i}\,f_c$, exceeds the wave frequency. A typical ray path is shown in Figure 2.

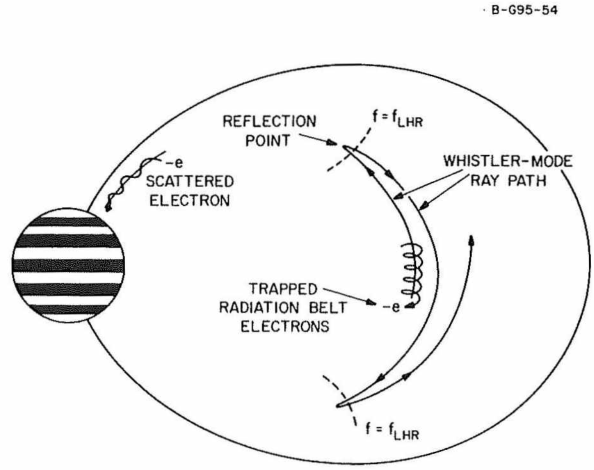

Fig. 2 - A sketch of whistler-mode ray paths in the Jovian radiation belt. For sufficiently large wave normal angles, whistler-mode waves reflect as soon as the lower-hybrid-resonance frequency, f_{LHR}, exceeds the wave frequency. The resulting ray paths are then similar to a laser, with repeated passes through the equatorial plane where wave growth occurs via cyclotron resonant interactions with energetic radiation belt electrons. These interactions then scatter the electrons into the loss cone, causing them to hit the planet.

This reflection process causes the waves to bounce back and forth along the magnetic field line from one hemisphere to the other. Reflections not only minimize the losses, but they also cause repeated passes through the equatorial region where the maximum growth rate occurs. From Figure 2, one can see that the growth of whistler-mode waves in a planetary radiation belt is similar to a laser, with the anisotropy in the trapped electrons providing the free energy source, and the reflections near $f = f_{LHR}$ playing the role of the mirrors.

The generation of whistler-mode waves would be relatively unimportant except for the effect these waves have on the radiation belt electrons. Since whistler-mode waves are right-hand polarized, these waves carry away right-hand angular momentum. The angular momentum must come from the resonant electrons. Since electrons rotate in the right-hand sense with respect to the magnetic field, the effect of the wave generation is to lower the pitch angle of the electrons, thereby driving them toward the loss cone. Those electrons that are scattered into the loss cone collide with the planet and are lost from the system. The growth of whistler-mode waves therefore leads directly to the loss of radiation belt electrons. This pitch-angle scattering mechanism is believed to be the primary mechanism that limits the intensity of energetic electrons in a planetary radiation belt. Whenever some process acts to increase the trapped electron intensity, whistler-mode waves grow, which increases the loss of electrons, thereby establishing a new equilibrium.

Before closing the discussion of whistler-mode emissions, it is worth commenting on the differences between chorus and hiss. Since chorus usually occurs at higher frequencies than hiss, one can see from the frequency dependence in Equation 1 that chorus resonates with lower electron energies than hiss. This difference is illustrated in Figure 3, which shows the spectrums of the chorus and hiss emissions in the top panel, and the corresponding resonance energies in the bottom panel. As can be seen, chorus resonates with electrons in the few keV range, and hiss resonates with electrons in the several hundred keV range.

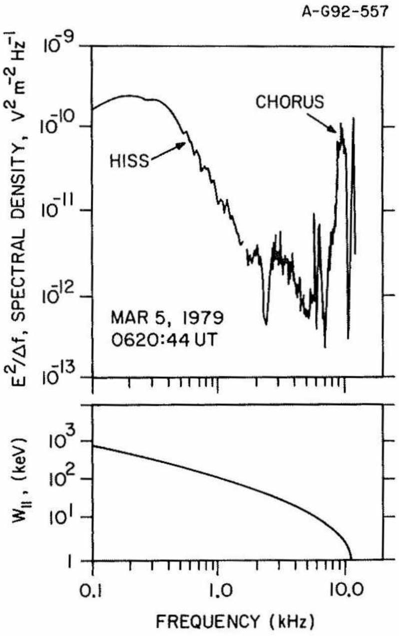

Fig. 3 - The top panel shows the spectrum of the whistler-mode chorus and hiss in Figure 1 and the bottom panel shows the parallel energy of electrons that are in cyclotron resonance with these waves. Chorus tends to resonate with relatively low energies, typically a few keV, whereas hiss resonates with much higher energies, typically several hundred keV or more.

Since there are more resonant electrons at lower energies, chorus has higher growth rates than hiss. The higher growth rate causes nonlinear saturation effects to occur sooner, before the wave has even reached the first reflection point in Figure 2. These nonlinear effects are thought to cause the wave to evolve into the nearly monochromatic wave packets that are characteristic of chorus. Hiss on the other hand has much lower growth rates, leading to many reflections from one hemisphere to the other. The superposition of these many reflected waves and the absence of strong nonlinear effects is believed to cause the emission to evolve into the nearly steady band-limited spectrum that is characteristic of hiss. It may be worth noting that the above views on the origin of hiss are not universally accepted. Recently, Draganov et al. [1993] have proposed that the hiss in the Earth's radiation belt (called plasmaspheric hiss) may not be due to an instability at all, but rather due to the superposition of many lightning-generated whistlers that have become trapped near the equatorial plane via reflections similar to those illustrated in Figure 2. This mechanism was first suggested by H.C. Koons [see Storey et al., 1991].

B. Electromagnetic ion cyclotron emissions

The electromagnetic ion cyclotron mode is an electromagnetic mode that propagates at frequencies below the ion cyclotron frequency, $f_{ci} = eB/m_i$. This mode is left-hand polarized with respect to the magnetic field. Since positively charged ions rotate in the left-hand sense with respect to the magnetic field, the ion cyclotron mode interacts primarily with positively charged ions. Kennel and Petschek [1966] have shown that the ion cyclotron mode can be driven unstable by a process very similar to the whistler mode, except that the ion anisotropy is responsible for the instability rather than the electron anisotropy. Since the ion cyclotron frequency is a factor of m_e/m_i smaller than the electron cyclotron frequency, ion cyclotron emissions occur at much lower frequencies than whistler emissions. Whereas whistler-mode emissions are usually at frequencies in the few kHz range, ion cyclotron emissions are usually at frequencies of a few Hz or less. Because of their extremely low frequency, ion cyclotron waves are difficult to detect. At present, electromagnetic ion cyclotron waves have only been observed in the radiation belts of two planets, Earth and Jupiter, and possibly in the radiation belt of Neptune (see Table 1). Although electromagnetic ion cyclotron emissions are weak and difficult to detect, they are still of considerable importance. At Earth, a mid-latitude type of aurora known as a stable red arc is believed to be due to the precipitation of radiation belt ions by electromagnetic ion cyclotron waves [Cornwall, 1970]. Similar processes are also believed to cause auroral ion precipitation at Jupiter [Thorne, 1983]. Thus, electromagnetic ion cyclotron waves play a role in the loss of radiation belt ions similar to the role that whistler-mode waves play in the loss of radiation belt electrons.

3. Planetary auroral acceleration regions

The aurora consists of light produced by energetic charged particles impinging on the upper levels of a planetary atmosphere. Five planets, Earth, Jupiter, Saturn, Uranus, and Neptune, are known to have auroras. At Earth, the aurora is usually confined to a narrow region from about 65 to 75° magnetic latitude known as the auroral zone. Strong electrical currents, known as field-aligned currents, flow along the magnetic field lines linking the auroral zones with the outer regions of the magnetosphere. These currents are carried primarily by electrons. For reasons that are not completely understood, large potential differences develop along the magnetic field lines in regions of strong field-aligned currents. These potential differences accelerate some of the electrons to high energies; typically several keV, thereby forming field-aligned electron beams. Both upgoing and downgoing electron beams are observed. The auroral light is produced when a downgoing beam strikes the atmosphere. Although relatively little is known about auroral processes at planets other than Earth, there are good reasons to believe that the processes are basically similar.

Many types of plasma waves and radio emissions are known to be generated in planetary auroral acceleration regions. Of these, we will focus on two in particular, (1) auroral hiss, and (2) cyclotron maser radiation.

A. Auroral hiss

Auroral hiss is a whistler-mode emission that is produced by auroral electron beams. Auroral hiss has been observed at Earth and Jupiter, and possibly Neptune (see Table 1). The absence of adequate high-latitude observations at Saturn and Uranus makes it impossible to say whether auroral hiss occurs at these planets. A frequency-time spectrogram illustrating auroral hiss observed during a high-latitude pass over the Earth's auroral zone is shown in Figure 4. The auroral hiss is the funnel-shaped emission that can be seen extending from about 100 Hz to 50 kHz. A sharp upper frequency cutoff can be seen at the electron cyclotron frequency, which is what one would expect, since the whistler mode cannot propagate at frequencies above the electron cyclotron frequency. Both upgoing and downgoing auroral hiss has been observed. The upgoing auroral hiss is associated with upgoing electron beams, and the downgoing auroral hiss is associated with downgoing electron beams. Upgoing auroral hiss is mainly observed at high altitudes, 1 to 3 R_E or more, as in Figure 4. Downgoing auroral hiss is only observed at low altitudes, 1 R_E or less. The funnel-shaped feature in Figure 4 is a propagation effect. At higher frequencies, the radiation propagates at larger angles to the magnetic field lines, thereby increasing the latitudinal region over which that radiation is observed.

Whistler-mode auroral hiss is believed to be generated by a Cerenkov-like radiation process similar to that proposed by Ellis [1957]. However, the radiated power cannot be accounted for by simply summing the Cerenkov power emitted from the individual electrons in the beam. Instead, a collective process that organizes the phase of emitting electrons must be involved so that the radiated power is increased. Using modern plasma theory, it can be shown that electrons of velocity v_b interact resonantly with the whistler-mode radiation if the frequency w and wave number k satisfy the condition $v_b \cong \omega/k_{\|}$, where the symbol $\|$ represents the component along the magnetic field. This condition is called the Landau resonance. The Landau resonance is essentially identical to the Cerenkov condition encountered in single particle radiation theory. It can also be shown that the growth rate is proportional to $\partial f/\partial v_{\|}$, where f is the electron velocity distribution. A beam always has a range of velocities where $\partial f/\partial v_{\|}$ is positive, so that wave growth will occur. This instability is often called the two-stream instability.

Auroral hiss is a very common plasma wave emission. Almost every pass over the Earth's auroral zones has intense auroral hiss. The interaction of the auroral hiss with the auroral electron beam has been extensively studied by Maggs [1976]. As the auroral hiss grows in amplitude,

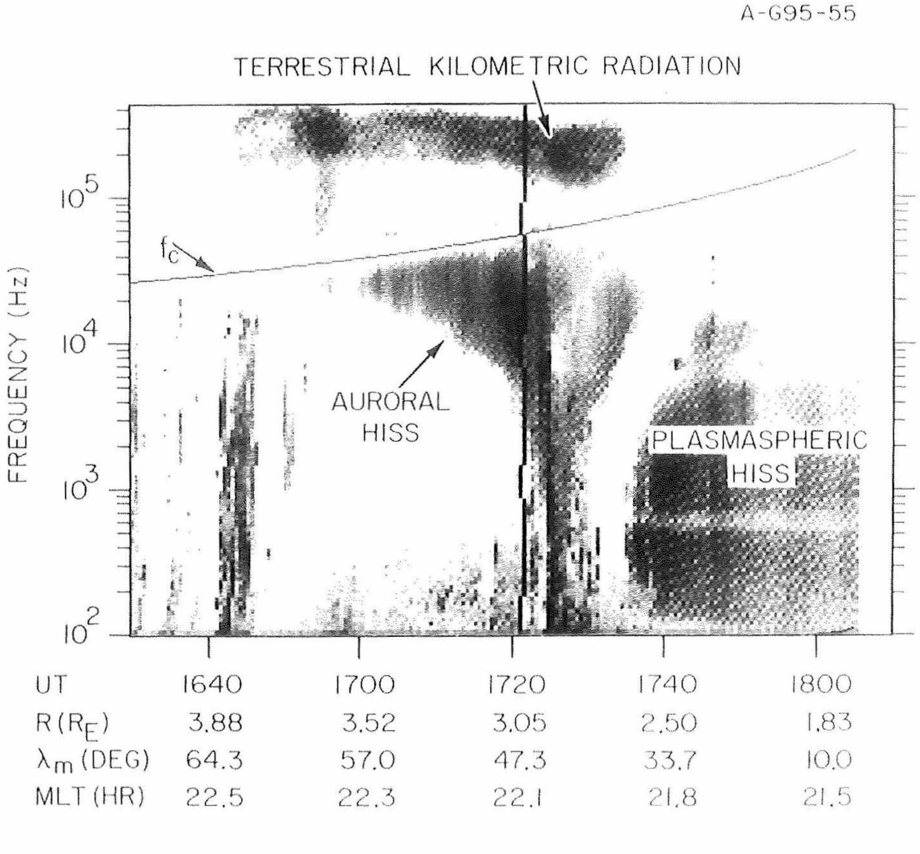

Fig. 4 - A frequency-time spectrogram from a pass of the DE-1 spacecraft over the Earth's northern polar cap. Two types of auroral radio emissions can be seen: (1) auroral hiss, and (2) terrestrial kilometric radiation. Auroral hiss is a whistler-mode emission, and terrestrial kilometric radiation is a free-space radio emission that propagates freely away from the Earth.

wave-particle interactions tend to flatten the electron velocity distribution function in the region where $\partial f/\partial v_{\parallel}$ is positive, thereby driving $\partial f/\partial v_{\parallel}$ to zero. Whistler-mode waves therefore act to drive the electron distribution toward a stable equilibrium. The presence of this stabilization process is confirmed by the fact that well-defined "beams" are seldom observed in the auroral zones. As soon as a beam starts to develop, whistler-mode wave-particle interactions quickly spread the beam into a flat distribution.

B. Cyclotron maser radiation

During the late 1960s and early 1970s, an entirely new type of terrestrial radio emission was discovered by eccentric Earth-orbiting satellites. This radio emission was first detected by Benediktov et al. [1965] using data from the Elektron 2 and 4 satellites. A few years later, Gurnett [1974] showed that this radiation, which has its peak intensity in the frequency range from about 100 to 500 kHz, was closely correlated with the occurrence of discrete auroral arcs. Gurnett also showed that the total radiated power was very large, up to 10^9 Watts. The high power levels came as a surprise, since this radiation had not been previously detected on the ground. The reason, of course, is the radiation cannot propagate downwards through the ionosphere. The Earth was therefore found to be an intense planetary radio source, comparable in some respects to Jupiter, which had been known for many years to be an intense radio emitter [Burke and Franklin, 1955]. Since the terrestrial radiation occurs in the kilometer wavelength range, this radio emission soon became known as "terrestrial kilometric radiation" or "auroral kilometric radiation". An example of terrestrial kilometric radiation can be seen in the upper part of Figure 4, at about 100 to 400 kHz, slightly above the electron cyclotron frequency. It is now known that this same basic type of radio emission occurs at five planets, Earth, Jupiter, Saturn, Uranus, and Neptune. A comparison of the radio emission spectrums from these five planets is shown in Figure 5. The characteristic features in all cases are that the radiation is (1) very intense, (2) right-hand polarized, and (3) generated at frequencies near the electron cyclotron frequency.

Since it is relatively easy to obtain in situ measurements of plasmas and radio emissions over the Earth's auroral zones, the discovery of the terrestrial kilometric radiation provided an unprecedented opportunity to investigate an astronomical radio emission mechanism of considerable significance. Now, after many years of study, we have a very good understanding of how this radio emission is produced. The basic mechanism is called the cyclotron maser instability. The cyclotron maser mechanism was first discussed by Melrose [1973], and later analyzed in more detail by Wu and Lee [1979] in connection with the terrestrial kilometric radiation. The basic instability is similar to the whistler loss-cone instability in that it involves an electron cyclotron resonance. However, the mode of propagation is the free space R-X mode rather than the whistler mode. One unusual feature is that relativistic effects are fundamentally involved in the resonance condition and cannot be omitted even though the electron energies are non-relativistic (i.e., only a few keV). The free energy source that drives the instability has been the subject of considerable debate. Originally, Wu and Lee [1979] proposed that it was the loss cone in the electron distribution that provided the free energy for the instability. However, more recent studies by Louarn et al. [1989] indicated that electrons trapped in the auroral acceleration region by magnetic mirror and electrostatic forces provide the primary free energy source. Once generated, the radiation escapes freely away from the Earth, following ray paths more or less as shown in Figure 6.

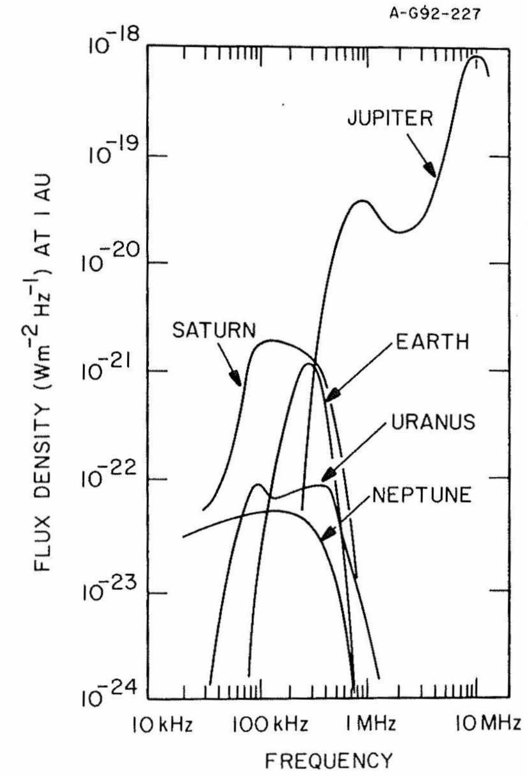

Fig. 5 - A comparison of the spectrums of cyclotron maser radiation from five planets. The spectrums are all referenced to a distance of 1 AU.

Although very detailed in situ measurements are available in the region where the cyclotron maser radiation is generated at Earth, comparable measurements are not available at the other planets. Even though the Voyager spacecraft flew by Jupiter, Saturn, Uranus, and Neptune, the trajectory did not pass through the source region, which in almost all cases is located at high latitudes. Thus, the only information that can be obtained about the cyclotron maser radiation mechanism at these planets is what can be gleaned from the radio emission spectrum. The Jovian cyclotron maser radiation (called decametric radiation) has one unusual feature that is worth noting. The intensity of the Jovian decametric radiation has been shown by Bigg [1964] to be strongly controlled by Jupiter's moon, Io. As Io moves through the Jovian magnetosphere, it induces a field-aligned current loop that closes in the auroral zone. This current system then causes electron acceleration, auroral light emission, and other effects comparable to the aurora at Earth. Recent pictures from the Hubble Space Telescope show that Jupiter also has an auroral zone that appears to be driven by a magnetospheric current system. Thus, at least two energy sources are probably involved in the generation of cyclotron maser radiation at Jupiter.

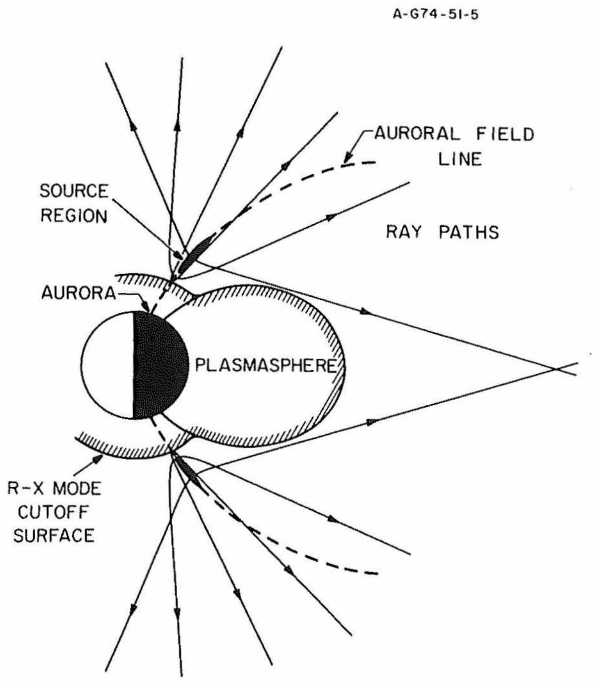

Fig. 6 - A sketch of typical ray paths of terrestrial kilometric radiation. This radiation is generated in the auroral acceleration region by an electron cyclotron maser mechanism. The radiation propagates away from the Earth in a broad conical beam, the axis of which is aligned along the magnetic field in the source region.

4. The solar wind

The solar wind is a hot, fully ionized gas that flows outward from the Sun at a supersonic speed. At the orbit of Earth, the solar wind density is approximately 5 cm^{-3}, and the speed is approximately 400 km/s. In situ measurements of plasma waves and radio emissions have been made in the solar wind as close to the Sun as 0.29 AU, and as far from the Sun as 58 AU. To illustrate the range of plasma wave and radio emission processes that can occur in the solar wind, we will focus on two examples: (1) Langmuir waves associated with type III solar radio bursts, and (2) heliospheric 2-3 kHz radio emissions.

A. Langmuir waves associated with type III solar radio bursts

Langmuir waves are electrostatic oscillations that occur in a plasma at the electron plasma frequency, $f_p = 9\sqrt{N}$ kHz, where N is the electron density in cm^{-3}. Langmuir waves are excited by electron beams and are of considerable importance in the theory of certain types of solar radio emissions. In a classic paper, Ginzburg and Zheleznyakov [1958] proposed that type III solar radio bursts are produced by a two-step process in which (1) electrons from a solar flare excite Langmuir waves at f_p via a two-stream instability, and (2) the Langmuir then decay into electromagnetic radiation at f_p and $2f_p$ via nonlinear wave-wave interactions. The two-step type III generation process has now been confirmed by a variety of space plasma wave measurements [see Gurnett and Anderson, 1976; and Lin et al., 1981]. An example of a type III radio burst detected in the solar wind near 1 AU is shown in Figure 7. Type III radio bursts are characterized by an emission frequency that decreases with increasing time. The downward frequency drift is caused by the decreasing electron plasma frequency encountered by the solar flare electrons as they move outward from the Sun. This process is illustrated in Figure 8, which shows a typical radial variation of the plasma frequency in the solar wind. Although the type III radiation can propagate great distances, the Langmuir waves, which are a locally generated oscillation, cannot be detected until the electron beam reaches the spacecraft.

In Figure 7, the type III solar radio burst is associated with a solar flare that occurred at about 0730 UT. The Langmuir waves excited by the energetic electrons arriving from this solar flare can be seen at the local electron plasma

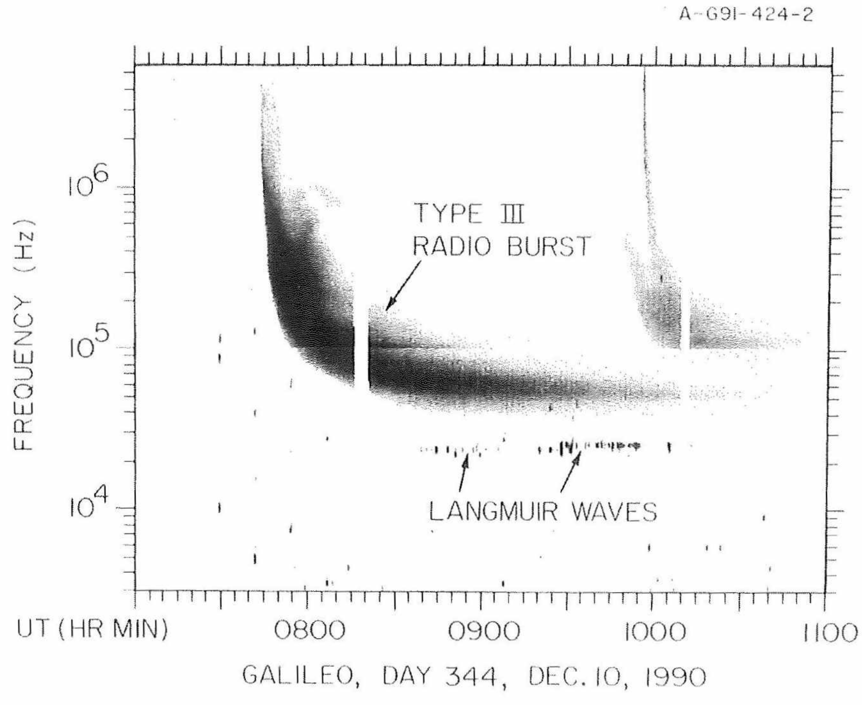

Fig. 7 - An example of a strong solar type III radio burst detected by the Galileo spacecraft at a heliocentric radial distance of about 0.98 AU. The Langmuir waves responsible for the radio emission can be seen at the local electron plasma frequency, which in this case is about 23 kHz. These waves are driven by electrons arriving from a solar flare that occurred at about 0730 UT.

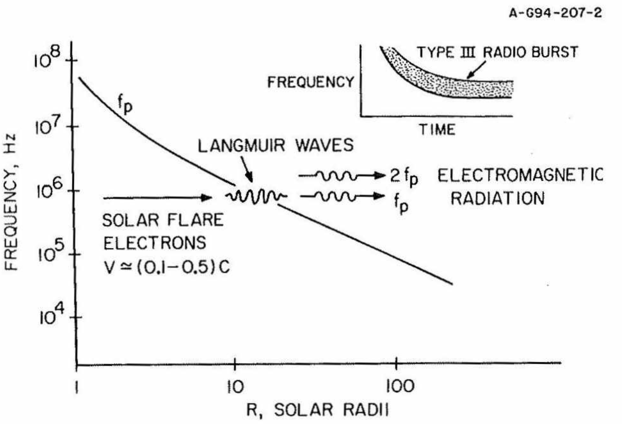

Fig. 8 - In the two-step mechanism believed to be responsible for type III radio bursts, electrons arriving from a solar flare excite Langmuir waves at the local electron plasma frequency, f_p. The Langmuir waves then generate radiation at f_p and $2f_p$ via nonlinear wave-wave interactions. The downward frequency drift of the radio burst is caused by the decreasing electron plasma frequency encountered by the solar flare electrons as they move outward from the Sun.

frequency ($f_p \approx 23$ kHz) starting at about 0835 UT and continuing to about 1020 UT. In this case the type III radio emission is generated at the harmonic $2f_p$. Harmonic radiation is believed to result from the interaction of two Langmuir waves, L and L', such that the emitted frequency is $f_{pL} + f_{pL'} = 2f_p$. Since the emitted transverse electromagnetic wave, T, has a wave number much smaller than the Langmuir waves, conservation of momentum ($\dot{k}_L + \dot{k}_L' = \dot{k}_T$) requires that the Langmuir waves, L and L', must be propagating in opposite directions. The origin of the oppositely propagating Langmuir wave is still a subject of debate. The current view is that this wave is produced by parametric decay from the original beam-driven Langmuir wave. Radiation at the fundamental, which is rare at these low frequencies, is believed to occur when a beam-driven Langmuir wave interacts with another low-frequency wave, such as a sound wave, to produce emission at $f = f_p + f_s$. Since $f_s << f_p$, the radiation occurs slightly above the plasma frequency.

B. Heliospheric 2-3 kHz radio emissions

In the early 1980s, as the Voyager 1 and 2 spacecraft were moving outward from the Sun beyond the orbit or Saturn, they began to detect an unusual radio emission in the frequency range from about 2 to 3 kHz. In the approximately twelve years since this radio emission was first detected, two particularly strong events have occurred, the first in 1983-84 [Kurth et al., 1984] and the second in 1992-93 [Gurnett et al., 1993]. A twelve-year frequency time spectrogram from Voyager 1 illustrating these two events is shown in Figure 9. Since the solar wind electron plasma frequency varies roughly as $f_p = 20$ (1/R) kHz where R is the heliocentric radial in AU, the source of these radio emissions must be located far from the Sun, at least R 10 AU. Initially, several possible sources were considered, including (1) planetary, (2) heliospheric, and (3) stellar. Based on the most recent 1992-93 event, Gurnett et al. [1993] have estimated that the total radiated power is at least 10^{13} W, which effectively rules out planetary sources (also see Gurnett and Kurth [1994]). Because of the great distance to the nearby stars, stellar sources are also considered unlikely, since they would require extremely high power levels ($>10^{20}$ Watts) to account for the observed intensities. A heliospheric source has recently been given strong support by the fact that the 1983-84 and 1992-93 events each followed a period of intense solar activity, the first in July 1982 and the second in May-June 1991. The delay time between the peak of the solar activity and the onset of the radio emission in both cases was approximately 400 days.

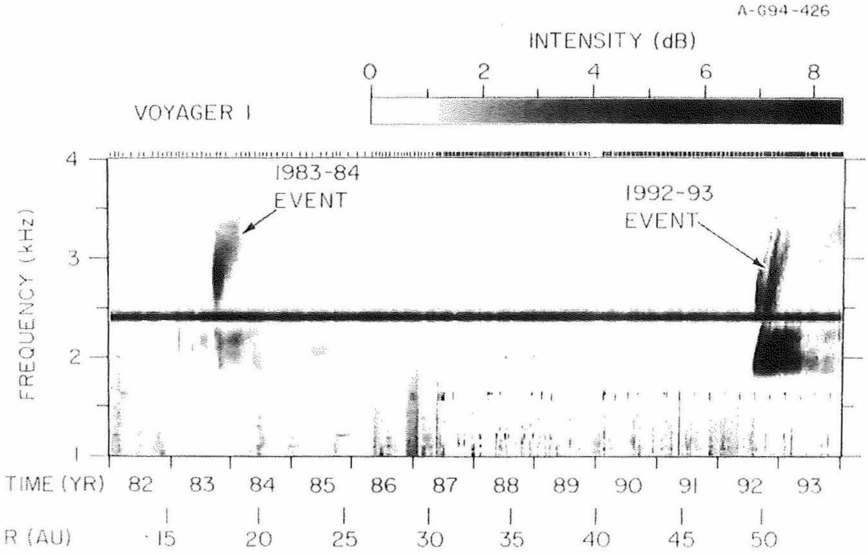

Fig. 9 - A 12-year frequency-time spectrogram showing the two intense heliospheric 2-3 kHz radio emission events detected by the Voyager 1 and 2 spacecraft in the outer regions of the solar system. These two events each occurred about 400 days after intense periods of solar activity, the first in July 1982 and the second in May-June 1991.

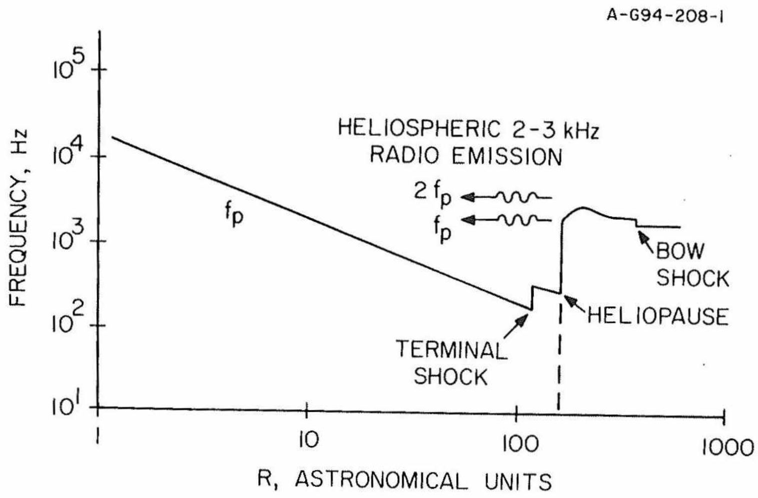

Fig. 10 - The heliospheric 2-3 kHz radio emissions are believed to be produced in the vicinity of the heliopause by an interplanetary shock wave moving outward from the Sun. The radiation is believed to be produced by a two-step process involving Langmuir waves generated by an electron beam accelerated by the shock.

The best current explanation of the 2-3 kHz radio bursts is that they are produced in the outer regions of the heliosphere by an interaction involving a shock wave or system or shock waves propagating outward from the Sun. There are two obvious boundaries where this interaction could occur, (1) the termination shock, where the solar wind undergoes a transition from a supersonic to a subsonic flow, and (2) the heliopause, where the solar wind is held off by the pressure of the interstellar medium. Because the Sun is moving through the local interstellar medium at a speed of about 26 km/s, the heliopause is expected to form a bullet-shaped boundary around the Sun [Axford, 1990]. Since the pressure in the local interstellar medium is poorly known, the distances to the terminal shock and heliopause are difficult to estimate. Pioneers 10 and 11, and Voyagers 1 and 2 are currently at 61.3, 42.2, 58.1, and 44.7 AU (as of January 1, 1995), and none have yet reach either the termination shock or the heliopause.

The most likely mechanism for generating the heliospheric 2-3 kHz radio emissions is thought to be similar to the two-step Langmuir wave mechanism, except that the electron beam is produced by an interplanetary shock. This is the mechanism by which type II radio bursts are believed to be produced. The radiation would then be generated at f_p or $2f_p$. If a two-step Langmuir wave mechanism is responsible for the radiation, then it is unlikely that the radio emission is produced at the termination shock, since the plasma frequency is too low. At Voyager 1 the plasma frequency in the solar wind is already down to about 350 Hz, so it must be even lower at the termination shock. At the heliopause, the situation is much better. Since the heliopause is a contact discontinuity, the plasma density can increase by whatever factor is necessary to maintain pressure balance with the interstellar medium. Current best estimates of the electron density in the interstellar medium [Lallement et al., 1993], indicate that the plasma frequency is in the range from 2.2 to 2.8 kHz. Thus, the plasma densities in the vicinity of the heliopause are in a suitable range to account for the 2-3 kHz radio emissions. A representative plasma frequency profile through the outer regions of the heliosphere is shown in Figure 10. If the radio emission is generated by the interaction of an interplanetary shock with the heliopause, then the distance to the heliopause can then be estimated from the travel time and speed of the shock. From the 400-day travel time, and the speeds of the interplanetary shocks (550 to 800 km/s), the distance to the heliopause can be computed, and is in the range from about 106 to 177 AU [Gurnett et al., 1995].

5. Conclusions

In the nearly forty years since the launch of the first Earth-orbiting satellites, considerable progress has been made in the understanding of solar system plasma processes. Measurements of space plasma waves and radio emissions have played an essential role in achieving this understanding. However, much remains to be done. Although our knowledge of the plasma environment of the Earth is very good, our knowledge of plasma processes at other planets is very limited. There is a strong need to obtain plasma and plasma wave measurements in the auroral acceleration regions at Jupiter, where strong radio emissions are generated over the high-latitude polar regions, most likely in association with the aurora. There is also a strong need to explore plasma wave processes much closer to the Sun, in the region where strong radio emissions are produced in response to flares and other energetic solar processes. In the meantime, most future space plasma wave research will probably focus on measurements obtained in the vicinity of Earth. At Earth there are still many avenues of research that remain to be explored. Although the linear growth phase of most plasma wave instabilities is well understood, the nonlinear mechanisms that limit the growth and saturate the instability are poorly understood. The continued pursuit of these and other areas of space plasma wave research is likely to continue well into the 21st century.

Acknowledgement.

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References

Axford, W. I., "Introductory Lecture- The Heliosphere"; ed. by S. Grzedzielski and D. E. Page, Physics of the Outer Heliosphere, COSPAR Colloquia Series, 1, Pergamon Press, Oxford, 7-15, 1990.

Barkhausen, H.; "Zwei mit Hilfe der neuen Verstärker entdeckte Erscheinungen"; Phys. Z.20, 401, 1919.

Benediktov, E. A., G. G. Getmantsev, Yu. A. Sazonov, and A. F. Tarasov; "Preliminary results of measurements of the intensity of distributed extraterrestrial radio-frequency emission at 725 and 1525 kHz frequencies by the satellite Electron-2"; Kosm. Issled., 3, 614-617, 1965.

Bigg, E. K.; "Influence of the satellite Io on Jupiter's decametric emission"; Nature, 203, 1008-1010, 1964.

Burke B. F., and K. L. Franklin; "Observations of a variable radio source associated with the planet Jupiter"; J. Geophys. Res.,60, 213-217, 1955.

Cornwall J. M., F. V. Coroniti, and R. M. Thorne; "Turbulent loss of ring current protons"; J. Geophys. Res., 75, 4699-2709, 1970.

Draganov, A. B., U. S. Inan, V.S. Sonwalkar, and T. F. Bell; "Whistlers and plasma spheric hiss: Wave directions and three-dimensional propagation"; J. Geophys. Res., 78, 11,401-11, 410, 1993

Eckersley, T. L.; "Musical atmospherics"; Nature, 135, 104-105, 1935.

Ellis, G. R.; "Low-frequency radio emission auroral"; J. Atmos. Terrestr. Phys., 10, 302-306, 1957.

Ginzburg, V. L., and V. V. Zheleznyakov; "On the possible mechanism of sporadic radio emission (radiation in an isotropic plasma)"; Sov. Astron., AJ2, 653, 1958.

Gurnett, D. A.; "The Earth as a radio source: Terrestrial kilometric radiation"; J. Geophys. Res., 79, 4227-4238, 1974.

Gurnett, D. A., and R. R. Anderson; "Electron plasma oscillations associated with type III radio bursts"; Science, 194, 1159-1162, 1976.

Gurnett, D. A., W. S. Kurth, S. C. Allendorf, and R. L. Poynter; "Radioemission from the heliopause triggered by an interplanetary shock"; Science, 262, 199-203,1993.

Gurnett, D. A., and W. S. Kurth; "Evidence that Jupiter is not the source ofthe 2-3 kHz heliospheric radio emission"; Geophys. Res.Lett., 21, 1571-1574, 1994.

Helliwell, R. A.; "Whistlers and related ionospheric phenomena"; StanfordUniversity Press, Stanford, CA, 1965.

Kennel, C. F., and H. E. Petschek; "Limit on stably trapped particle fluxes";J. Geophys. Res., 71, 1-28, 1966.

Kurth, W. S., D. A. Gurnett, F. L. Scarf, and R. L. Poynter; "Detection of a radio emission at 3 kHz in the outer heliosphere"; Nature, 312, 27-31, 1984.

Lallement, R., J.-L. Bertaux, and J. T. Clark; "Deceleration of interstellar hydrogen at the heliospheric interface"; Science 260, 1095-1098, 1993.

Lin, R. P., D. W. Potter, D. A. Gurnett, and F. L. Scarf; "Energetic electrons and plasma waves associated with a solar type III radio burst"; Astrophys. J., 251, 364, 1981.

Louarn, P., A. Roux, H. deFeraudy, and D. LeQueau; "Trapped electrons as a free energy source for the AKR"; J. Geophys. Res., 95, 5983-5995, 1989.

Maggs, J. E.; "Coherent generation of VLF hiss"; J. Geophys. Res., 81,1707-1724, 1976.

Melrose, D. B.; "Coherent gyromagnetic emission as a radiation mechanism"; Aust. J.Phys., 26, 229, 1973.

Preece, W. H.; "Earth currents"; Nature, 49(1276), 554, 1894.

Scarf, F. L., D. A. Gurnett,and W. S. Kurth; "Jupiter plasma wave observations: An initial Voyager 1 overview"; Science, 204, 991-995, 1979.

Storey, L. R. O.; "An investigation of whistling atmospherics"; Phil. Trans. Roy. Soc., London, A 246, 113-141,1953.

Storey, L. R. O., F. Lefeuvre, M. Parrot, I. Cairo, and R.R. Anderson; "Initial survey of wave distribution functions for plasmaspheric hiss observed by ISEE 1"; J. Geophys. Res., 96, 19, 469-19, 489, 1991.

Thorne, R. M.; "Microscopic plasma processes in the Jovian magnetosphere"; Physics ofthe Jovian Magnetosphere, ed. by A. J. Dessler, Cambridge Univ. Press, Cambridge,454-497, 1983.

Van Allen, J. A.; "The geomagnetically trapped corpuscular radiation"; J. Geophys.Res., 64, 1683-1689, 1959.

Wu, C. S., and L. C. Lee; "A theory of terrestrial kilometric radiation"; Astrophys. J., 230, 621-626, 1979.

CURRENT DEVELOPMENTS IN VLBI ASTRONOMY ON THE GROUND AND IN SPACE

R.T. Schilizzi

1. Introduction

World-wide Very Long Baseline Interferometry (VLBI) is undergoing a major expansion in capability at the present time.

The new US Very Long Baseline Array (VLBA) is already producing eye-catching results even before its full capabilities have been brought on line. Its counterpart in Europe, the European VLBI Network (EVN) is carrying out a major upgrade of the radio frequency performance and flexibility of its member telescopes and their VLBI equipment, as well as constructing a new state- of-the-art correlator. In the southern hemisphere, the Australian VLBI array is also expanding its capabilities with a new correlator and recording terminals, and together with radio observatories in the Asia Pacific region will begin regular coordinated VLBI observations for the first time in 1995 as the Asia Pacific Telescope (APT). Millimetre-wave observatories across the globe have also banded together to form the Coordinated Millimeter-VLBI Array (CMVA) which will observe at 86 GHz three times a year starting in 1995.

And perhaps the most spectacular of all, the space VLBI era will begin in 1996 with the launch of the Japanese Muses-B satellite carrying an 8-m diameter radio telescope into Earth orbit. The mission, called VSOP (VLBI Space Observatory Programme), will combine the space borne antenna with its ground-based counterparts around the world to form radio interferometers of dimension 32000 km and maximum angular resolving power of 80 micro-arcseconds. A year or two thereafter, Russia plans to launch its 10-m diameter RadioAstron satellite into an even higher orbit than VSOP to provide a further increase of three in angular resolving power to 30 micro-arcseconds.

In addition to these instrumental developments, considerable progress has also been made in observing and data reduction techniques, so that far weaker sources can be imaged than was possible even two or three years ago. With the VLBA leading the way, images of strong sources can be made with a quality approaching that of connected element arrays like the VLA and Westerbork.

In this contribution to the URSI 75thAnniversary Symposium, I will review these developments in ground and space VLBI, and highlight the new capabilities in terms of recent scientific results. I will not cover the technical basis of VLBI nor the theory of interferometry in radio astronomy; readers are referred to the book by Thompson, Moran and Swenson (1986) for that information. I will also not touch on the use of VLBI in geodesy. A very comprehensive account is given in volumes 23, 24 and 25 of Contributions of Space Geodesy to Geodynamics published by the American Geophysical Union in 1993.

2. Ground-based VLBI arrays

2.1. Organisations

VLBI is both a national and international endeavour. The VLBA is run as a single instrument by the US National Radio Astronomy Observatory (NRAO), whereas the EVN is run as a coordinated instrument by the European Consortium for VLBI. The Australian VLBI array is coordinated by the Australia Telescope National Facility (ATNF), and a Consortium for the Asia-Pacific Telescope is in the process of being established. The space VLBI missions are led by the Institute for Space and Aeronautical Science (ISAS) in Japan, and by the Astro Space Center of P.N. Lebedev Physical Institute (ASC) in Russia, but both missions have International Scientific Councils to advise them on all aspects of the missions. Other organisations also are contributing to the mission hardware and operations (see section 3). Coordination of the response of the ground VLBI arrays and other major unaffiliated telescopes to requests for observing time from the space missions is being carried out by the URSI Commission J Global VLBI Working Group (GVWG).

2.2. VLBA

After many years of preparation, the US VLBA came into regular operation in 1994. The array consists of ten 25-m telescopes at sites within the United States and its territories, chosen for optimum image quality as well as ease of access for operations and maintenance (Kellermann and Thompson, 1985). Figure 1 shows the locations of the VLBA telescopes on the world map. In the US frame of reference, they are to be found in New Mexico (2), Arizona, Texas, Iowa, California, Washington, New Hampshire, Virgin Islands and Hawaii. The Array Operations Center is at Socorro, New Mexico. The locations were chosen to provide both high resolution and the most uniform aperture coverage

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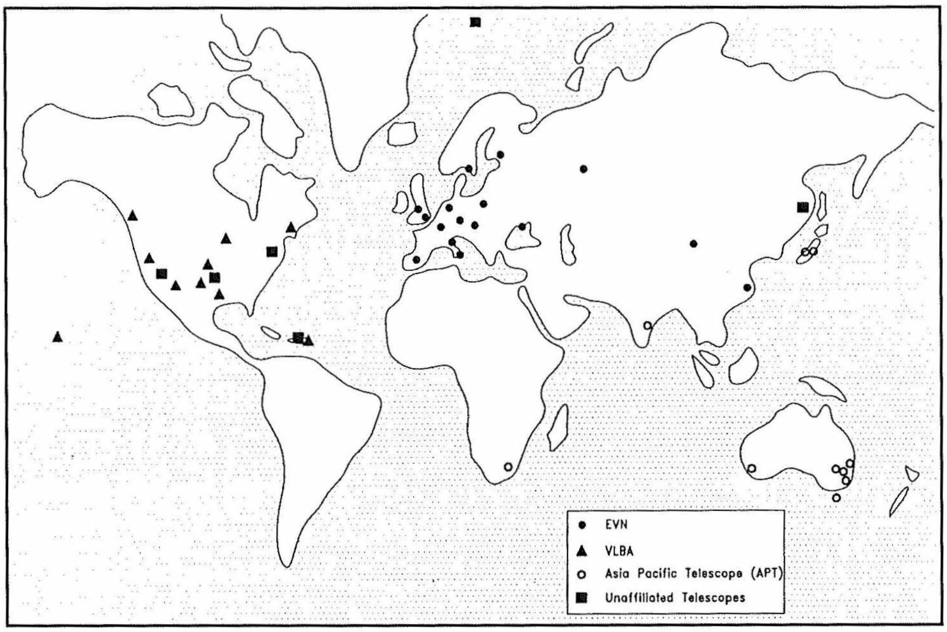

Fig. 1 - The world of VLBI; filled circles : EVN; filled triangles : VBBA; open circles : Asia-Pacific Telescope; filled squares : unaffiliated telescopes.

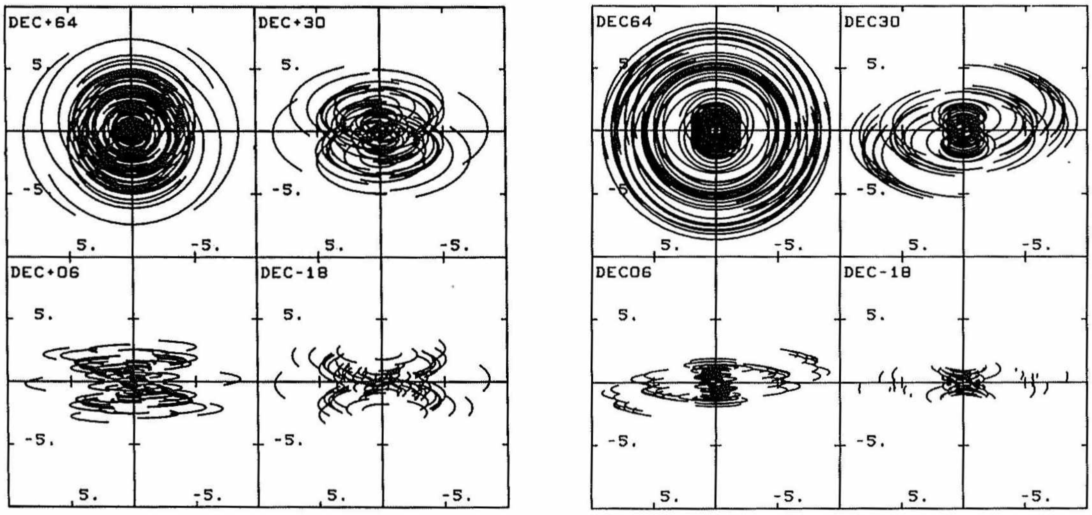

Fig. 2 - left : uv-coverage for the VLBA at declinations of°, 30°, 6°, and 18°. Unites are 10^3 km. right : uv-coverage of the EVN at 22 GHz. Telescopes in the EVN are Yebes, Jodrell Bank, Cambridge, Effelsberg, Onsala, Bologna, Noto, Mets"ahovi, Torun, Urumqi, and Shanghai (see Table 1). Units are 10^3 km.

that can be practically achieved (see Figure 2 left). The aperture plane or uv-plane coverage is one of the fundamental figures of merit of an interferometer and indicates the degree of filling of the hypothetical telescope aperture formed by the interferometers as they rotate with the Earth under the radio source. In general, the better filled the u-v plane, the better the image quality. Maximum baseline lengths of 8000 km are achieved in the VLBA.

The VLBA incorporates many features designed to yield maximum sensitivity for the observations and reduce the effects of systematic errors. A new high precision antenna was developed by the NRAO allowing efficient operation up to 43 GHz, and with reduced efficiency up to 86 GHz. Each array element is equipped with dual polarization receivers covering nine frequency bands between 327 MHz and 43 GHz; typical system noise temperatures at zenith are between 30 and 50 K for observing frequencies between 1.5 and 15 GHz, rising to 220 K at 327 MHz and 115 K at 43 GHz. Changes of receiver at the secondary focus are achieved in less than 30s by rotating the subreflector which allows multi-frequency observations to be obtained quasi-simultaneously. Since the array elements are identical, the instrumental polarization properties of the feed/receiver systems are uniform (and low: 1-2% on axis), and the filter characteristics are also uniform. Both these properties help reduce the effects of

COUNTRY	INSTITUTE	LOCATION	DIAMETER (m)	FREQUENCY RANGE (GHz)
Spain	National Astronomical Observatory	Yebes	14	2.3 - 43
			40^1	5 - 100
UK	Nuffield Radio Astronomy Laboratories	Jodrell Bank	76	0.3 - 1.6
			25	1.4 - 43
		Cambridge	32	1.4 - 43
Netherlands	Netherlands Foundation for Research in Astronmy	Westerbork	14 x 25^3	0.3 - 8.4
Germany	Max-Planck-Institut für Radioastronomie	Effelsberg	100	0.6 - 90
	University of Bonn	Wettsel	20	2.3 - 8.4
Sweden	Onsala Space Observatory	Onsala	25	1.4 - 5
			20	2.3 - 100
Italy	Istituto do Radioastronomia	Bologna	32	1.4 - 43
		Noto	32	1.4 - 43
Poland	Torun Radio Astronomical Observatory	Torun	15	0.3 - 15
			32^3	0.3 - 43
Finland	Metsähovi Radio Research Station	Helsinki	14	22 - 100
Ukraine	Crimean Astrophysical Observatory	Simeiz	22	0.3 - 43
China	Shanghai Observatory	Shanghai	25	0.3 - 22^4
	Urumqi Observatory	Urumqi	25	0.3 - 22^4

Table 1 - EVN telescopes with wideband recording equipment

Notes: [1]funding is being sought [2]equivalent diameter, 93 m [3]expected to be in operation in mid-1995
[4]upper limit to the frequency range may extend to 43 GHz

calibration errors in the data analysis thereby increasing the effective sensitivity of the array.

The RF signals from the receivers are mixed down to baseband and divided into as many as 16 channels with bandwidths from 16 MHz to 62.5 kHz. The filtered signals are sampled at rates ranging from 0.5 to 32 Msamples/sec with sample quantization at two or four levels. A peak data rate of 256 Mbits/sec is possible per acquisition system. The sustainable data rate is 128 Mbits/sec which fills a tape in about 10h. This rate is set by the lack of staff at the individual antennas to change tape any more frequently. With two recorders per site, unattended operation is possible for most of one day at this rate, but peak rates of 512 Mbits/sec are possible with the two recorders in operation simultaneously. Tapes can be recorded at 33 or 56 kbits/inch per track on 32 data tracks and up to 16 passes of the tape past the headstack are possible. Each tape has a capacity of 5.4 terabits.

The VLBA correlator at Socorro has 20 station inputs to accomodate global observations involving the 10 VLBA antennas with other networks, primarily the EVN. The 20 inputs will also allow correlation of 512 Mbits/sec recording using two recorders at the 10 VLBA sites, as well as the simultaneous correlation of two normal 10-station observations; neither of these two modes is yet operational at the correlator. The correlator first takes a fourier transform of each baseband channel from each station and then cross multiplies the resulting spectra to generate the correlation functions, a process first developed by Chikada et al. (1987) at Nobeyama in Japan, and also used in the VSOP correlator now under construction. The VLBA spectral-domain or FX correlator has 160 FFT engines each of which can operate at resolutions ranging in binary steps from 32 to 1024 spectral points. The 1024-point resolution (512 points in frequency space) is available for up to 4 channels per station in a single pass through the correlator for a 20 station array, but decreases by a factor of two for 8 channels or for dual polarization data. For a 10-station array, the maximum is 1024 spectral points.

The VLBA is pioneering a number of advances in VLBI: wide frequency coverage on one array, receiver agility essential for measurements of the continuum spectra of variable sources, ease of use, and high quality imaging (see section 4.7), while the dedicated nature of the array will make it easy to respond to Targets of Opportunity and to the demands of space VLBI. The NRAO has committed 30% of VLBA observing time to support the most highly rated VSOP and RadioAstron observing proposals, and will evaluate other space VLBI proposals in competition with purely ground-based VLBI proposals for possible additional time. It is undertaking the necessary changes to the online software in the correlator to enable it to cope with the higher fringe and delay rates encountered with orbiting interferometer elements.

2.3. The European VLBI Network

The second major VLBI facility in the northern hemisphere is the European VLBI Network (EVN). It is a part-time network operating for up to 17 weeks per year using national radio telescopes in 12 countries (see Figure 1). The EVN was formed in 1980 by a consortium of five of the major radio astronomy institutes in Europe. Since 1980, the EVN and the Consortium has grown to include 12 active institutes with 16 radio telescopes in 10 different countries from Spain in the west to China in the east. Table 1 lists the institutes and their telescopes, giving information on the diameter (or equivalent diameter for the Westerbork array) and the VLBI frequency range possible with the optics and surface accuracy. Depending on the frequency, between 7 and 10 telescopes can observe currently. The upgrade programme described later in this section includes construction of new receivers at a number of institutes so that up to a maximum of 12 telescopes will observe at any particular frequency in 1996 when the first space VLBI satellite is launched.

Considerable effort went into the optimum placing of the VLBA antennas for uv-coverage. No such licence was available for the EVN; the telescopes are where they are. Figure 2 depicts the uv-coverage for the EVN at 22 GHz in 1996. The coverage is good at northern declinations where radio sources pass overhead at the majority of telescopes, but gaps appear at lower declinations and the coverage becomes more one-dimensional the closer the source is to equatorial. A telescope near the equator between western Europe and the South African telescope at Hartebeesthoek would help solve this problem. The maximum baseline length in the EVN is about 9000 km.

Making full use of the VLBA correlator (and later the new EVN correlator) allows us to construct VLBI arrays with superb uv-coverage. Figure 3 shows as an example the uv-coverage for a 20- station array composed of the EVN and the VLBA. Such uv-coverage gives us the basis on which to image compact radio sources with unprecedented quality.

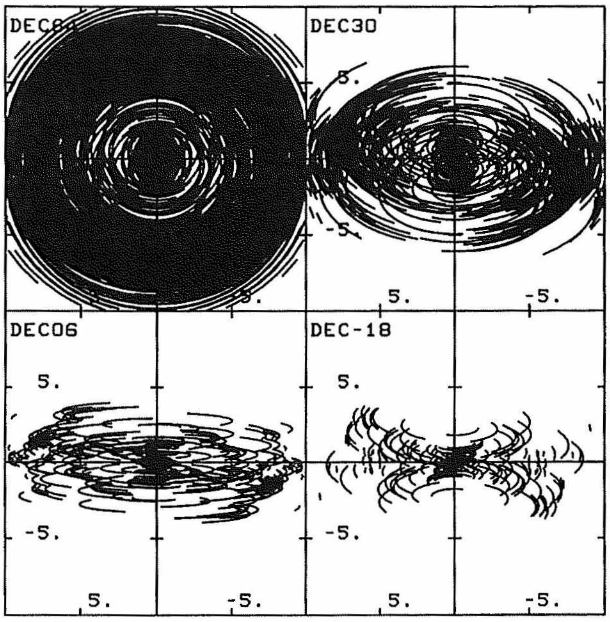

Fig. 3 - uv coverage for 20-station EVN+VLBA observations at $\leq$8.4 GHz. Units are 10^3 km.

A major upgrade of EVN facilities is in progress, made possible by funding from multi-national sources in Europe and from the European Union. The main aspects of the upgrade are the construction of a 16-station data processor at the newly established Joint Institute for VLBI in Europe (JIVE) in Dwingeloo (the Netherlands), upgrade of the data acquisition terminals at the individual telescopes to allow recording at 1024 Mbit/sec (the MkIV standard), and the employment of Support Scientists at JIVE and at some individual observatories to provide assistance for users of the EVN and other arrays. In addition, a number of nationally funded upgrades are being carried out at EVN member stations including receivers in new frequency bands as mentioned earlier, and replacement of older receivers with state-of-the-art HEMT-based systems.

The VLBA is pioneering a number of other instrumental features that will become standard in VLBI, such as the ability to switch receivers on timescales of less than a minute, and well-understood bandpass and polarization properties for the array. The EVN has taken on the task of achieving the same level of performance in these areas where possible.

The MkIV data acquisition system provides for up to 16 baseband channels with channel bandwidths of 62.5 kHz to 16 MHz like the VLBA. Sixty four tracks are recorded on tape simultaneously and since the tape can run at twice the speed of the VLBA acquisition system (320 inch/sec), the maximum bit rate per recorder is 1024 Mbit/sec. One tape will last about 1.25h at this rate. The increased bit rate of recording means increased sensitivity for continuum observations. The MkIV formatter will be capable of generating VLBA modes so that full backwards compatibility with the VLBA will be available for joint EVN-VLBA observations. The design of the MkIV acquisition system is due to the MIT Haystack Observatory, and the MkIV upgrade in Europe is being implemented by a team from the EVN institutes.

The EVN correlator at JIVE will have 16 station inputs and, in contrast to the VLBA, cross multiplication of the channel bitstreams will be done ahead of fourier transformation. The correlator design is a joint undertaking of JIVE supported by the EVN institutes, the Netherlands Foundation for Research in Astronomy, Haystack Observatory and NASA. The correlator is expected to handle three major types of observation: joint EVN-VLBA continuum at up to 128 Mbit/sec, EVN MkIV continuum at 1024 Mbit/sec, and EVN and EVN-VLBA spectral line at lower bandwidths. Multiple array pulsar gating and field centre correlation is alsoplanned. An array with more than 16 telescopes may require multiple passes through the correlator depending on which telescopes are in the array and the source declination. A standard mode of MkIV operation is likely to be 16-station, dual polarization, 2 bit/sample recording at 128 MHz bandwidth per polarization for a data rate per station of 1 Gbit/sec. The spectral resolution is better than 1% in full polarization mode for 16 stations, i.e. 128 complex channels per baseline for each of the four Stokes parameters. Recirculation of the data through the correlator is possible for lower sample rates than the correlator clock rate of 32 MHz, giving up to a factor of 8 higher spectral resolution.The correlator software now being developed will take account of the space VLBI requirements on fringe and delay rates. The correlator project is expected to be completed in 1997.

The EVN has agreed to reserve about 50% of its VLBI time per year (about 7 weeks per year) for the most highly rated space VLBI proposals and to evaluate other space VLBI observing proposals in competition with purely ground-based VLBI proposals for possible additional time.

2.4. The Asia Pacific Telescope (APT)

The APT has been formed to coordinate and schedule VLBI observations involving telescopes in the Asia Pacific region (Figure 1 and Tzioumis 1994a). It also provides a forum for discussion of issues of compatibility and sharing of resources for VLBI observations. The telescopes are distributed north and south of the equator giving good uv-coverage for sources in the equatorial and southern zones. At its heart is the Australian VLBI network (Jauncey et al., 1994, Tzioumis 1994b), a six-station array in Australia, plus the Hartebeesthoek telescope in South Africa, which carries out VLBI observations for 1 to 2 weeks every 4 months. The APT itself is due to have its first coordinated session in June 1995. The potential uv-coverage of the APT together with the VLBA is shown in Figure 4 for the active galaxy Centaurus A (from Tzioumis, 1994a).

A mixture of recording systems ar currently available on the APT including MkII, MkIII, Canadian S-2, and the K-4. The most widespread wide bandwidth system is the S-2. The Australian correlator is S-2 based and can handle 6 stations with a maximum bandwidth of 64 MHz in continuum mode. There are many spectral line modes including 2048 complex channels per baseline for 1 MHz bandwidth for 6 stations. Working together with the VLBA and correlation in Australia will require translation of VLBA tapes to S-2, something desirable for space VLBI in any case (see section 2.6), but not yet funded.

The ATNF has guaranteed 10% of the total observing time on its telescopes to support space VLBI. The APT is likely to take on a coordinating role for the region's telescopes during the VSOP and RadioAstron space VLBI missions.

2.5. The Coordinated Millimeter VLBI Array

VLBI at millimetre wavelengths has moved from observational "black art" to relative routine in the last ten years, so much so that a new organisation, the Coordinated Millimeter VLBI Array, has recently been established to coordinate observations at 86 GHz and higher frequencies

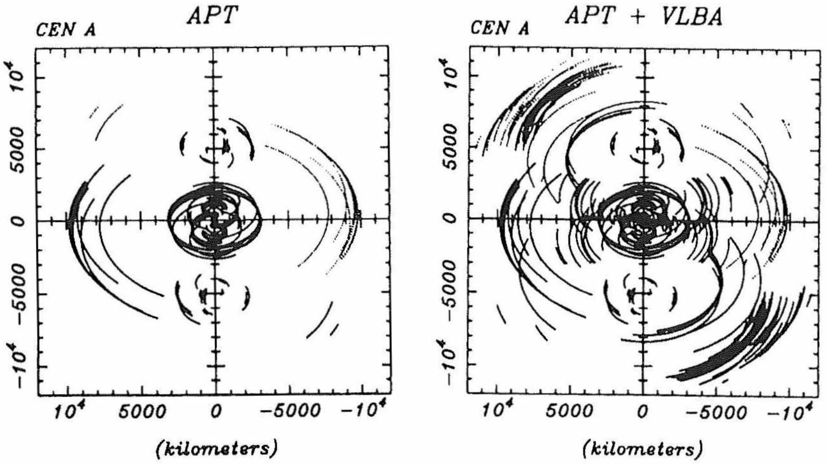

Fig. 4 - left : uv coverage of the APT for Centauris A; right : the same for APT+VLBA

Table 2 - The Asia-Pacific Telescope
Notes: [1] Receivers up to 9 GHz currently available, and up to 25 GHz available in late-1995.
[2] Also a member of the EVN. The frequency range may extend to 43 GHz.
[3] Available by special arrangement only. The frequency range may extend to 1.6 GHz.

COUNTRY	INSTITUTE	LOCATION	DIAMETER (m)	FREQUENCY RANGE (GHz)
Australia	Australia Telescope National Facility	Narrabri	22	1.4 - 115
		Mopra	6 x 22	1.4 - 115
		Parkes	64	0.6 - 43
	NASA Tidbinbilla	DSS43	70	1.6 - 22
		DSS45	34	2.3/8.4
	Univ. Tasmania	Hobart	26	1.4 - 12
	Univ. WA/Telstra	Guangara	27.5	5
South Africa	HartRAO	Hartebeesthoek	26	1.6 - 12
Japan	CRL	Kashima	34	1.4 - 43
	Nobeyama Radio Obs.	Nobeyama	45	8.4 - 115
	ISAS	Usuda	64	1.6 - 22
China	Shanghai Observatory	Shanghai	25	0.3 - 22 [1]
	Urumqi Observatory	Urumqi	25	0.3 - 22 [1]
India	TIFR	GMRT Pune	30 x 45	0.3 - 1.4 [2]
Russia	ISDE	Ussurijsk	70	0.3 - 22

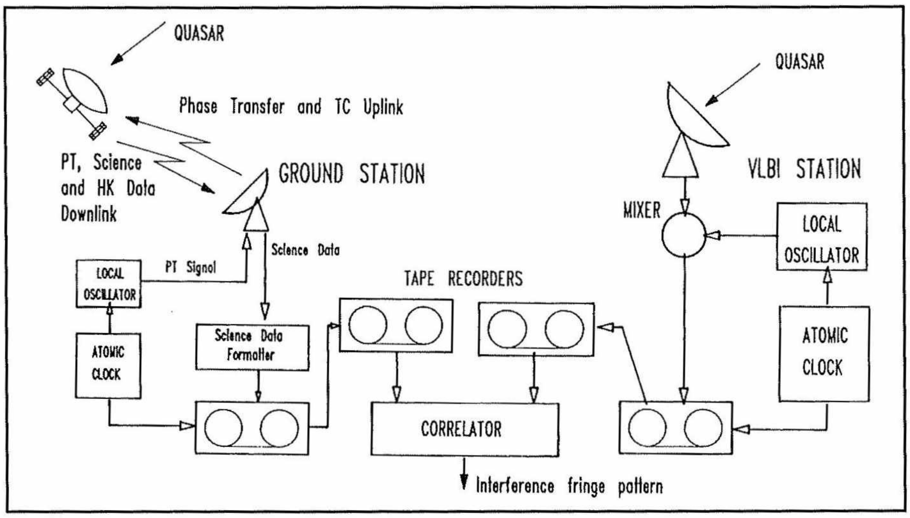

Fig. 5 - Space VLBI system

in a similar way to the EVN and the old US VLBI network. Three sessions per year are envisaged with telescopes in the USA, Europe, and Chile: Haystack Observatory (MA), FCRAO (MA), NRAO Kitt Peak (AZ), OVRO (CA), Onsala (Sweden), Effelsberg (Germany), IRAM Pico Veleta (Spain), and SEST (Chile). At these high frequencies, angular resolutions of 50 micro-arcseconds have already been achieved on strong sources. There is no overlap with the first generation space VLBI missions, but some concepts for second generation satellites include receivers at these frequencies.

2.6. Compatibility of data acquisition systems

An essential element of the cooperation necessary for VLBI is compatibility of recording system hardware and formats. Recently, however, some divergence has occurred as the result of the separate development, in different countries, of systems for wide bandwidth recording. The greatest measure of compatibility exists for the longitudinal reel to reel instrumentation recorders in use in the VLBA, EVN, and US-led geodesy networks. VLBA acquisition systems are backwards compatible with a subset of MkIII modes; MkIV systems will be backwards compatible with all MkIII and VLBA modes. However the cassette-based helical scan video recorders developed in Canada (S-2) and in Japan (VSOP/K-4) are not compatible with the VLBA/MkIII/MkIV systems or with each other. The S-2 system adopted by the Australian network stacks 8 commercial VHS recorders to provide a relatively cheap 128 Mbits/sec capacity; the VSOP/K-4 is based on the ID-1 standard and provides 256 Mbits/sec capacity. The VLBA, MkIII/MkIV and VSOP/K-4 are all of comparable (high) cost. This lack of compatibility between Europe/USA on the one hand and the APT on the other is of consequence for standard ground-based VLBI only for joint APT- VLBA observations (see section 2.4); there is very little common sky between Europe and Australia. However, it is of great consequence for space VLBI. VSOP observations in the southern sky will be recorded on S-2 at the radio telescopes in Australia, but on VLBA recorders at the tracking stations operated by NASA and by the US National Radio Astronomy Observatory, and on VSOP/K-4 at the Japanese radio telescopes and tracking station. The solution adopted is to develop tape copying machines for VLBA to VSOP/K-4 and S-2 to VSOP/K-4 so that VSOP observations can be correlated on the VSOP correlator being built at the National Astronomical Observatory. VLBA to S-2 tape copiers are also desirable to allow correlation of (i) VLBA and APT data on the S-2 correlator in Australia, and (ii) APT and RadioAstron data recorded on VLBA recorders at the tracking stations on the S-2 corelators in Australia and in Canada. However, no funding has been identified yet for this.

An international working group is being set up to try to coordinate future developments in acquisition systems and thereby avoid such problems in the future.

3. Space VLBI

Putting a radio telescope into orbit around the Earth to increase angular resolving power is an idea that goes back 30 years to the early discussions on VLBI (Preston et al., 1983, Burke, 1991). The first paraboloid radio telescope in space was the 10 m KRT-10 which underwent deployment tests from the Salyut-6 station in 1979. The first successful radio interferometry using a space-ground combination was achieved by the TDRSS-OVLBI experiments in 1986 and 1988 (Levy et al., 1986; Linfield et al., 1990). The 4.9 m antenna on one of NASA's Tracking and Data Relay Satellites was turned towards distant quasars to create interferometer baselines with large diameter ground- based telescopes in Australia and Japan which were twice as long as possible on Earth. During the 1980s and early 1990s, two projects were studied by international teams created by the European Space Agency: QUASAT (Schilizzi, 1988) and IVS (Pilbratt 1991). Neither project was selected for launch but, nevertheless, many of the ideas first demonstrated to be feasible in those studies have been incorporated in the first-generation missions VSOP and RadioAstron, and in plans for a second-generation mission, ARISE (Ulvestad et al., 1995).

Figure 5 shows the principles of space VLBI. The radio telescope is launched folded within the fairing of the rocket, and after reaching the desired orbit, it is deployed into its final configration. The radio signals received from cosmic radio sources are handled on board much as they are for the Earth bound telescopes, passing through various amplifiers and filters, before being digitised and formatted prior to transmission to the Earth for recording at the tracking stations. The frequency stability required for VLBI will be based on other local oscillator signals transmitted to the satellite from the tracking stations which are themselves controlled by a hydrogen maser standard, or on frequency standards carried on board the satellite. Both options will be implemented for the missions.

There are a number of substantial differences between space VLBI and ground-based VLBI (e.g. Murphy et al. 1994; Meier 1994): (i) the space antennas are of small diameter by Earth standards so interferometer sensitivity is less while the baselines are longer; (ii) spacecraft pointing constraints need to be taken into account - e.g. Sun, Moon, Earth, visibility of tracking stations by the on- board telemetry antenna, need to direct the passive cooling radiator on RadioAstron to cold sky; (iii) space VLBI uv-coverage is a strong function of the orbital elements and the spacecraft constraints; (iv) the uv-coverage changes with observation epoch due to orbital evolution, and it changes from day to day since the orbital periods are not commensurate with 24h; and (v) the locations of the tracking stations are such that data may be lost near perigee and when the spacecraft is in the south. Whereas for ground-based VLBI with a given ground array, the uv-coverage is a function of source declination only, for space VLBI it is strongly dependent on both source coordinates (Right Ascension and declination) and the epoch of observation due to a combination of the spacecraft constraints, the precessing orbital elements, and the limited tracking network. For VSOP, the dominant orbit perturbation is due to the oblateness of the Earth and this leads to rapid precession of the orbital elements and fast changing uv-coverage; for RadioAstron, the dominant perturbations are due to lunar-solar effects which do not change very fast so that the uv-coverage is more or less

	VSOP			**Radioastron**			
Country	Japan			Russia			
Lead Institution	ISAS			Astro Space Center			
Launch Date	Sept. 1996			1997/1998			
Launch Vehicle	M-V			Proton			
Launch Site	Kagoshima			Baikonur			
Mission Lifetime (years)	3			3			
Orbit							
Period (hours)	6.06			28.0			
Apogee Height (km)	20,000			77,000			
Perigee Height (km)	1,000			4,000			
Inclination (°)	31			51.6			
Tracking Stations							
Commanding	Kagoshima (Japan)			Ussurijsk (Russia)			
Data Acquisition + ø Link	Usuda			Ussurijsk			
Data Acquisition + ø Link	Green Bank (NRAO)			Green Bank (NRAO)			
Data Acquisition + ø Link	3 DSN sites (NASA/JPL)			3 DSN sites (NASA/JPL)			
Space Radio Telescope							
Antenna Diameter (m)	8.0			10.0			
VLBI systems	VLBA/K4			VLBA/S2			
Polarization	LCP			LCP/RCP			
Observing Bands (GHz)	1.6	4.8	22	0.33	1.6	4.8	22
System Temperatures (K)	100	120	200	100	50	50	150
Aperture Efficiencies	0.40	0.55	0.41	0.5	0.5	0.5	0.3
Integration Time (s)	100	100	100	20	100	100	100
Instanteneous Bandwidth (MHz)	32	32	32	8	32	32	32
Angular resolution (μas)	1200	400	90	2100	410	140	30
Minimal correlated flux density 8σ-level^a (mJy)	80	65	145	455	36	36	115
Science Programmes							
AGN / QSOs	AGN Imaging AGN Monitoring			High T_b Survey AGN Monitoring			
Interstellar Medium	-			Interstellar Scattering			
Extragalactic Masers	$H_2$0 masers			-			
Galactic Masers	$H_2$0 masers OH masers			$H_2$0 masers -			

Table 3 - Characteristics of the VSOP and the RadioAstron Space VLBI systems.

^{a}Co-observing with a 70m ground radiotelscope with aperture efficiences of 0.5, 0.6, 0.6, 0.5 and system temperaturesz of 100, 30, 30, 50 K at 0.33, 1.6, 4.8, 22 GHz respectively.

fixed for a particular source once the initial orbital elements have been chosen.

Both missions are being developed in close coordination, and this has led to common solutions to a number of operational and data acquisition issues. One of these issues is coordination with the ground based arrays and telescopes. Space VLBI is unique amongst the space astronomy missions in that the space and ground segments are of equal value in realising the scientific aims. Many discussions over several years have led to a workable operations plan, which includes an international Science Review Committee to judge the proposals.

Table 3 summarizes the salient characteristics and performance for both VSOP and RadioAstron.

3.1 VSOP

Space VLBI observations will be carried out with an 8 m antenna aboard the MUSES-B satellite developed by the Institute for Space and Aeronautical Science (ISAS) in Japan (Hirosawa, 1994). MUSES stands for Mu Space Engineering Satellite and this, the second in the series of engineering satellites, will be launched on the first flight of ISAS's new rocket, M-V. The expected capability of the M-V rocket sets constraints on the combination of satellite mass and apogee height of the orbit. VSOP will go into an orbit with an apogee height of 22000 km, a perigee height of 1000 km, and an inclination of 31°. The satellite mass is restricted to 820 kg and the volume to 3.65 m height by 2.2 m diameter, which has necessitated some ingenious engineering solutions, particularly in the realm of antenna construction and deployment.

In Figure 6, we can see the main elements of the MUSES-B satellite. The dominant feature is the 8 m reflector which is formed from wires and mesh stretched into parabolic form on a framework of six extendable booms. This design is based on the tension-activated truss concept developed by Miura (1986). The mass of the antenna is 225 kg and the goal for surface accuracy is 0.5 mm rms which will allow efficient observation at 22 GHz (=1.35 cm). Although the maximum structural diameter of the antenna is 10 m the effective aperture for radio astronomy is 8 m. The supporting tower for the sub-reflector is also extended in orbit to give a focal length of 3.7 m. The two major engineering challenges in developing this antenna have been the reliable deployment of the main reflector, and proving that a 0.5 mm rms surface accuracy is achievable in the zero gravity conditions in orbit while forming and tuning the antenna occurs on the ground in the 1 G environment.

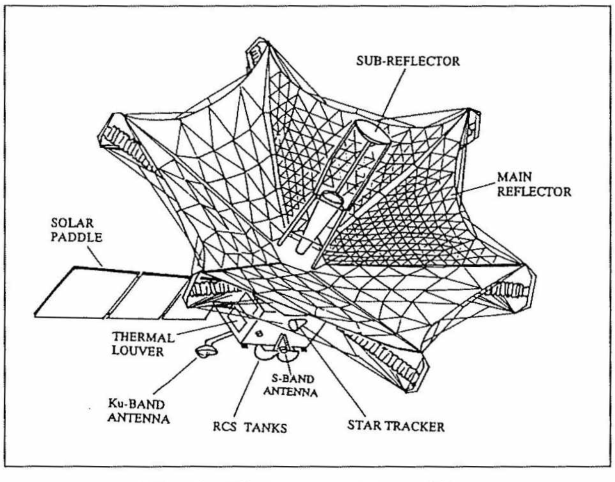

Fig. 6 - The MUSES-B satellite

The onboard radio astronomy systems comprise single-channel uncooled low noise amplifiers at 1.6, 5, and 22 GHz, down converters for these bands, an IF signal switch, two frequency synthesisers, two image rejection mixers, two A/D converters, a formatter, and calibration signal generators. The two baseband channels can operate in two modes: 16 MHz bandwidth and 2-bit sampling or 32 MHz bandwidth and 1-bit sampling. The output bit rate of the formatter is 128 Mbps. The science data and local oscillator transfer will occur in Ku-band: 14.2 GHz for the wideband science data downlink and 15.3 GHz for the narrow band two-way LO link. The 45 cm Ku-band antenna is attached to a deployable boom to increase the field of view of the antenna (see Figure 6). The data will be recorded at the Usuda tracking station on a VSOP/K-4 data acquisition system developed in Japan, and at the NASA and Green Bank tracking stations on VLBA terminals. Tape copying machines are under development in Japan to transfer the VLBA recordings from tracking stations and ground radio telescopes to VSOP/K-4 before correlation on the VSOP correlator at the National Astronomical Observatory in Tokyo.

With the orbit apogee allowed by the launch constraints, VSOP achieves baseline lengths about 3 times that possible on Earth. Considerable effort has gone into simulating the image reconstruction capability of the VSOP mission by Murphy and collaborators (Murphy et al., 1994) since that will be its strength compared to RadioAstron (see next section) which goes into a much higher orbit with ten times the angular resolution of the ground arrays but much poorer uv-plane coverage and thus poorer imaging potential. Figure 7 (left) shows a typical uv-coverage at a particular epoch as a function of source position for VSOP co-observing with the VLBA, and in Figure 7 (right) the uv-coverage obtained at monthly intervals in a 2-year period, for a 24h observation of VSOP with the VLBA. Figure 7(left) shows very clearly that good uv-coverage cannot be obtained for any random direction in the sky - therewill be seasons for the best observations just as for other space astronomy missions and ground-based optical astronomy. One-dimensional uv-coverage is produced when the source lies in the orbital plane (equatorial sources in Figure 7(left)), and two-dimensional coverage when it lies near the orbit normals. Figure 7(right) shows that the uv-coverage varies with epoch, an effect which will have to be taken into account when analysing observations monitoring structural changes in the target sources.

3.2 RadioAstron

The RadioAstron project is led by the Astro Space Center of the P. N. Lebedev Physical Institute in Moscow, with the major construction work being undertaken by the Lavoshkin Association (Kardashev and Slysh, 1988; Kardashev, Gurvits, and Tsarevsky, 1994). The satellite itself is called Spektr-R and is one of the Spektr series of

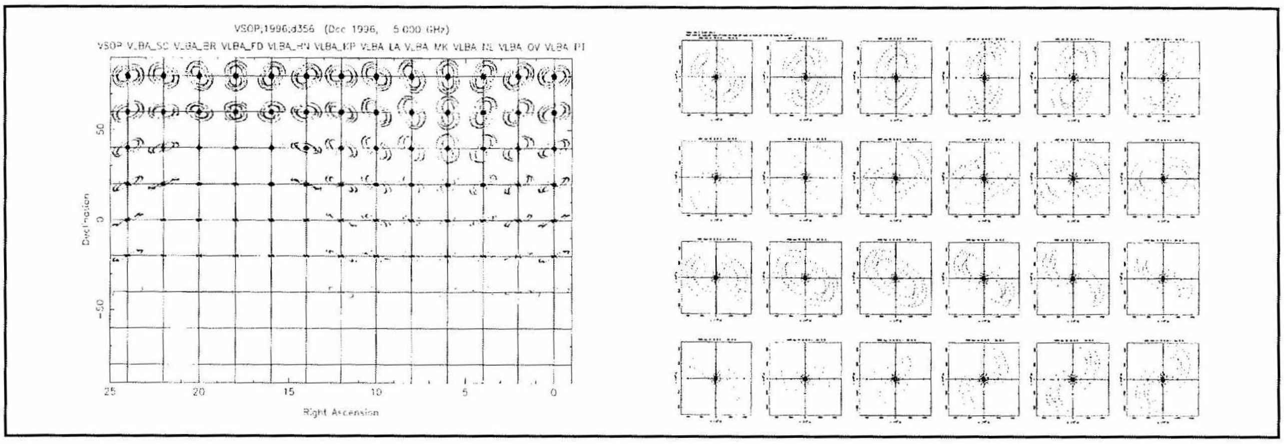

Fig. 7 - left : Typical uv-coverage as a function of source position for VSOP co-observing with the VLBA. right : uv-coverage obtained at monthly intervals in a two year period, for a 24th VSOP observation together with the VLBA of the superluminal source 1928+738. This figure illustrates how uv-coverage is a strong function of observation epoch. (Murphy et al., 1994)

astrophysical satellites under construction by the Russia Space Agency and the Russia Academy of Sciences. RadioAstron will be launched on a Proton rocket into a high eccentricity orbit with a 28h period and will generate baselines to co-observing earth telescopes of up to 85000 km in length. The Proton is a powerful launch vehicle, so the mass budget, 5000 kg, for the RadioAstron satellite is generous compared to VSOP. The launch date is currently set for 1997, but funding slowdowns in Russia are likely to delay this date.

As we have already seen for VSOP, the dominant feature of the RadioAstron spacecraft is the 10 m diameter antenna (Figure 8) with a mass of 1500 kg. It has a central 3m section and 27 solid panels each 3.5 m long which fold up around the focal package support during launch. The petals are made from a stiff carbon fibre composite material which should provide an rms surface accuracy of 0.5 mm, like VSOP, sufficient for 22 GHz operation. Testing of the thermal deformation properties of the panels has been carried out at the European Space Agency's Technology Centre (ESTEC).

RadioAstron has simpler optics than VSOP, utilizing prime focus feeds and locating the receiver electronics in the prime focus package (Figure 8). The feeds are of a novel concentric ring feed design to provide on-axis optics for all four frequencies. Each receiver is sensitive to both hands of circular polarization, which will allow VLBI polarimetry to be carried out. All receivers are cooled passively to 150 K through a 1 m^2 radiator on the side of the focal package which must point to free space at all times. In addition, the three higher frequency receivers are cooled to 80 K using closed cycle cryogenic cooling technology. Institutes in Finland (22 GHz), Netherlands, Germany, Italy, Sweden, and UK (5 GHz), Australia (1.66 GHz), and India (0.327 GHz) designed and built the receivers. The IF signals are down converted to video band (channel bandwidths 2, 4, or 8 MHz), digitized and formatted in the

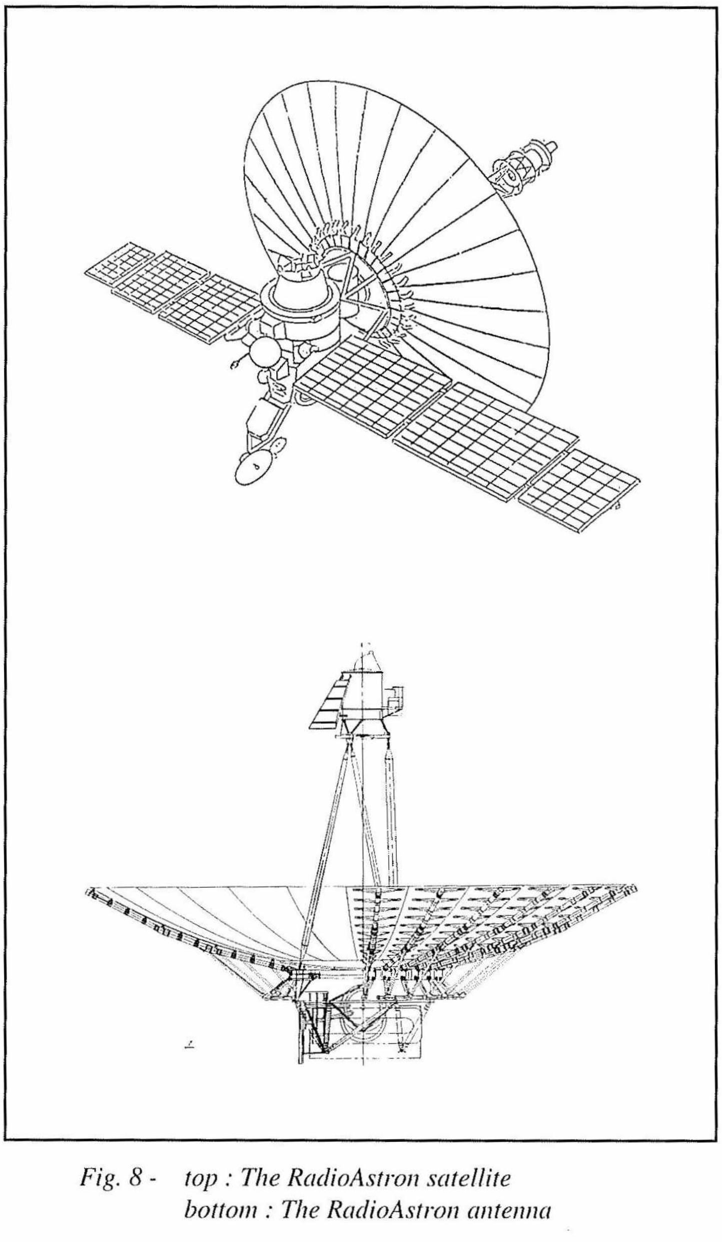

Fig. 8 - top : The RadioAstron satellite
bottom : The RadioAstron antenna

service module below the main reflector before transmission in two 32 MHz wide streams to the tracking stations. The bandwidth available at 0.327 GHz is restricted to 2x4 MHz due to interference problems for the co-observing radio telescopes.

At the tracking stations the downlinked data will be recorded on VLBA terminals at the NASA sites, the NRAO Green Bank site, and at Ussurijsk in Russia and the S-2 system at Ussurijsk and possibly at one of the NASA DSN stations at Tidbinbilla. Correlation will take place on the VLBA, EVN and S-2 correlators in Russia and Australia. The Dominion Radio Astrophysical Observatory in Canada is providing an S-2 correlator for RadioAstron operations in Moscow.

4 Ground-based VLBI - New results and new capabilities

Of the many new results coming out in VLBI, I have selected a small number that I regard as making a significant step forward in our understanding of astrophysical phenomena and/or which advance the state of the technique substantially.

4.1 Surveys

Imaging surveys of large numbers of sources are an essential element of astronomy in making possible discoveries of new classes of source and in defining or refining source characteristics. Until recently, the time involved in carrying out VLBI observations of individual sources has limited surveys to relatively small samples. However the use of "snapshot" observations with large numbers of telescopes made possible in the first place by the 16-station MkII correlator at Caltech in Pasadena has charged attitudes to VLBI Surveys. (This correlator has now been closed down for general astronomical use since the narrow band MkII recording system has been superseded by the broader band MkIII, VLBA and MkIV systems, and the VLBA correlator has even greater capacity - 20 stations.) With many telescopes in the array (e.g. Figure 3), the uv-coverage for three 20^m observations well spread throughout the apparition of the source is sufficiently good to generate good quality images, and yet allow observation of 20 sources per day.

The Caltech-Jodrell Survey (Polatidis et al, 1995, Taylor et al, 1994) has imaged two samples of sources with declinations north of 35° and galactic latitude 10° using global arrays composed of the EVN and the VLBA. The first segment (CJ1) imaged all sources with flux densities at 5 GHz between 0.7 and 1.3 Jy (N=132), the second (CJ2) was restricted to sources with flux densities between 0.35 and 0.7 Jy but with spectral indices flatter than 0.5 at 5 GHz (N=193). Images of 276 sources have been made at 5 GHz and 132 at 1.66 GHz. The CJ1 survey together with an earlier survey (Pearson and Readhead, 1988) was primarily aimed at classifying the structures of compact radio sources, whereas CJ2 had in addition three cosmological goals: (i) to place significant limits on the mass in 10^6 - 10^9 $M_\odot$ condensed objects in the universe by searching for gravitational lenses in the 1 - 200 milli-arcsecond range of separations, (ii) to look for evidence of cosmological evolution in the proper motions of superluminal sources and place limits on the cosmological deceleration parameter, q_0 (Vermeulen and Cohen 1994), and (iii) to explore the possibility of using the angular diameter - redshift diagram for compact objects to constrain q_0 (Kellermann 1993, Gurvits 1994). The analysis of the CJ2 data in pursuit of these goals is in progress.

The majority of sources found in the surveys have a core-jet structure (see Figure 9 for an example) generally thought to be indicative of outflow of relativistic electrons from an active core in the host galaxy or quasar. The one-sidedness is probably due to relativistic aberration caused by bulk motion of the electrons at speeds close to that of light more or less in the direction towards the observer. This causes the illusion of faster-than-light or superluminal motion (Zensus and Pearson, 1987). Some 5 to 10% are compact symmetric objects, CSOs, (see Figure 9) which are thought to be core-jets with the outflow more or less perpendicular to the line of sight to the source so that it is visible on both sides of the core. Their small size could be due to their being either young objects (10^6 years) or much

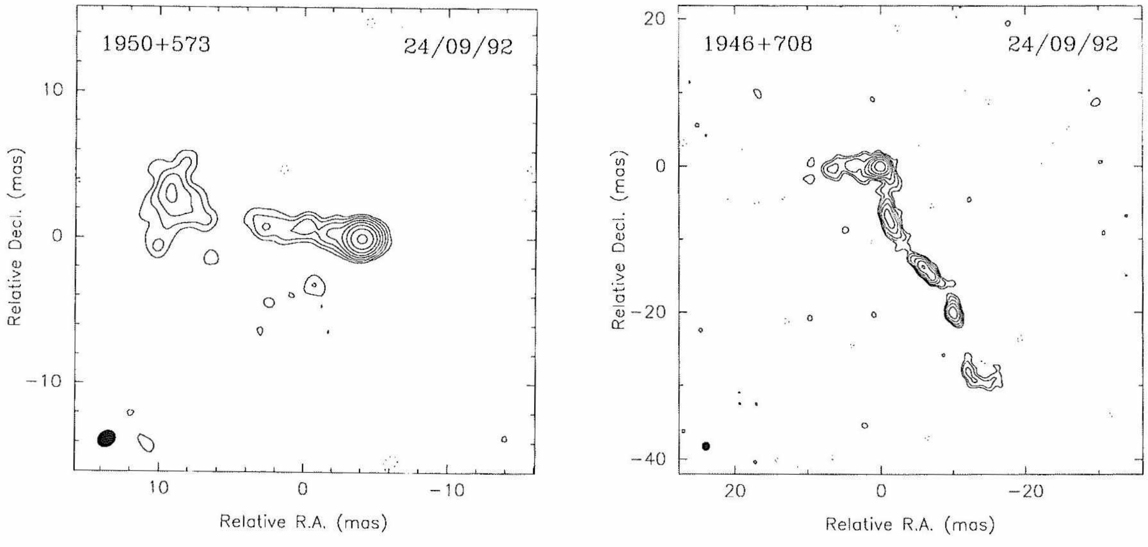

Fig. 9 - left : a typical core-jet structure ; right : a Compact Symmetric Object (Taylor et al., 1994)

older and unable to expand against an hypothesised dense interstellar medium in the host galaxy or quasar (Fanti et al, 1995, Readhead et al, in preparation).

4.2 A black hole in a nearby galaxy

Black holes are by definition impossible to detect in electromagnetic radiation, but their mass and density are such that they should be detectable through their influence on matter in their vicinity. Some stellar systems in our galaxy emit so copiously in X-rays that this is explainable only in terms of heating of material from a star as it is sucked into the accretion disk surrounding a black hole of 1 to 10 solar masses in orbit around the star. It is commonly assumed that much more massive black holes (10^6 to 10^9 solar masses) are to be found in the centres of galaxies and quasars, but evidence has proven to be elusive. The reason is that despite their great mass, the black hole is still a very small fraction (0.01 %) of the total mass of the whole galaxy and its influence is only to be seen within the inner light year of the centre. Extremely high angular resolution is required.

Recent observations of rotating gas in the centre of the nearby galaxy NGC4258 made by Miyoshi et al (1995) using the line emission from water masers, demonstrate the presence of a central mass of $4\times10^7 M_\odot$ in a region less than 5 light months (4×10^{12} km) in radius. Combination of VLBA spectroscopic images in the line at 22 GHz and single dish spectroscopy revealed that the masers are found in front of the compact nucleus of the galaxy and at the tangent points of a thin warped torus surrounding the nucleus (Figure 10), both locations where maser amplification is optimum. The positions of the high velocity features define a torus with inner radius of 4 and an outer radius of 8 milli-arcseconds, and their velocities decrease with distance from the centre of rotation exactly as expected for Keplerian motion (like that of the planets around the Sun). Single dish spectroscopic observations show that the central features drift at a rate of 9.5 km s^{-1} yr^{-1} which is assumed due to centripetal acceleration by the enclosed mass. This allows the distance and hence the physical size of the inner radius to be calculated. Combined with the radial velocities, this then allows the mass of the object dominating the gravity field to be determined. The mass density derived is so high that the object is most likely a black hole.

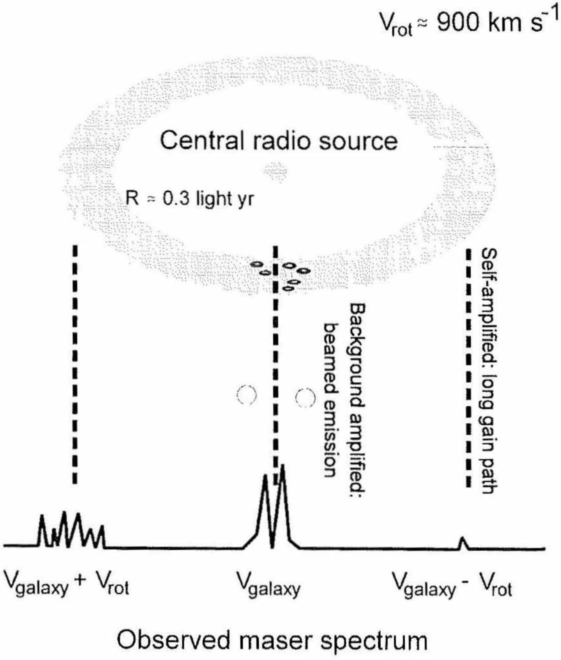

Fig. 10 - Illustration of the maser model taken from Barvainis (1995). The maser spectrum is sketched along the bottom.

4.3 The supernova in the nearby galaxy, M81

Stars explode in galaxies regularly. However no star has exploded in our Galaxy within view of our telescopes since their invention, so our knowledge of this final phase of stellar evolution comes from study of the faint remnants of explosions many centuries ago and from supernovae in nearby galaxies where several per year are detected. Details of the processes involved in the early phases of the explosion and its subsequent evolution are difficult to model theoretically since there has been very little spatial information available. The recent discovery of a radio luminous supernova in M81 (at a distance of 11.7 million light years) has provided an opportunity to investigate the early evolution of a supernova with the high angular resolution afforded by VLBI. Marcaide et al. (1995) used a global network at 8.4 GHz to image the remnant with a resolution of 0.25 milli- arcsec and showed that 8 months after the explosion a shell structure had developed, the youngest and smallest shell ever observed in a supernova event. Figure 11 shows that the shell is almost spherically symmetric in shape, but its intensity distribution is not uniform around the shell. The enhanced emission in the south-eastern part could be the result of an asymmetric distribution of pre-supernova circumstellar material. Comprehensive monitoring of SN1993J in the radio domain is continuing at a number of frequencies.

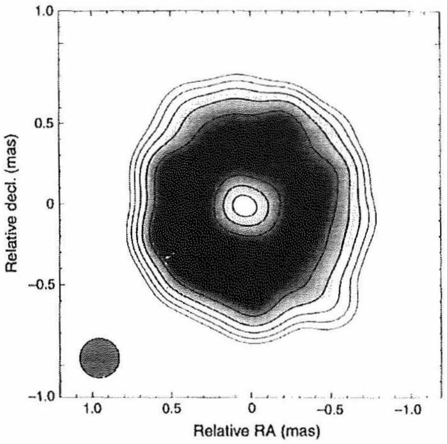

Fig. 11 - Grey-scale and contour map of SN 1993J from 8.4 GHz observations 239 days after the explosion. The gaussian beam used in the image is shown in the lower left and is 0.25 milli-arcsec in diameter. (Marcaide et al., 1995)

Using the estimate for the shell radius at the time of the observation in November 1993, and assuming zero size at explosion, the average rate of expansion for the shell radius is 2.430 micro arcsec/day. Making use of the maximum gas expansion speeds measured by the widths of optical absorption lines, a distance of 11.7 million lightyears is found, in good agreement with completely independent, but indirect, methods of measuring the distance to M81.

4.4 Gravitational lenses

In 1979, Walsh et al. discovered two radio sources with very similar structure close to each other on the sky, each associated with a quasar with almost identical properties. It was quickly realised that these were images of the same background object, gravitationally lensed by a foreground galaxy; predictions of this effect had been made by Einstein in the 1930's. When a sufficiently large mass concentration lies in the line of sight between the observer and a background source, space-time is distorted so much that radio and light rays are bent creating multiple images (e.g. Figure 12 top). A galactic-sized mass of $10^{11}M_\odot$ will cause the images to be separated by a few arcseconds, a smaller concentration of 10^6-$10^8M_\odot$ (a naked black hole?) would cause a separation of a few tens of milli-arcseconds. However, no confirmed small gravitational lenses were found in the Caltech-Jodrell VLBI surveys suggesting that the contribution to the total mass of the universe by a cosmologically distributed population of these lower mass objects in intergalactic space must be small. Even smaller masses of 10^4-$10^6M_\odot$ in the halos of lensing galaxies would cause distortions which would be different for each image on the milli-arcsec scale.

Gravitational images are recognizable as being related to each other because they have almost identical optical spectra, radio structures and radio spectra, which is very unlikely in unrelated objects. Small differences between the images and their changes in time carry information on the detailed mass distribution in the lensing galaxy; this is where VLBI observations make a unique contribution. Recent global 1.66 GHz VLBI measurements of the Walsh et al. lens, 0957+561, by Garrett et al. (1994) are shown in the lower part of Figure 12. Garrett et al. have derived a

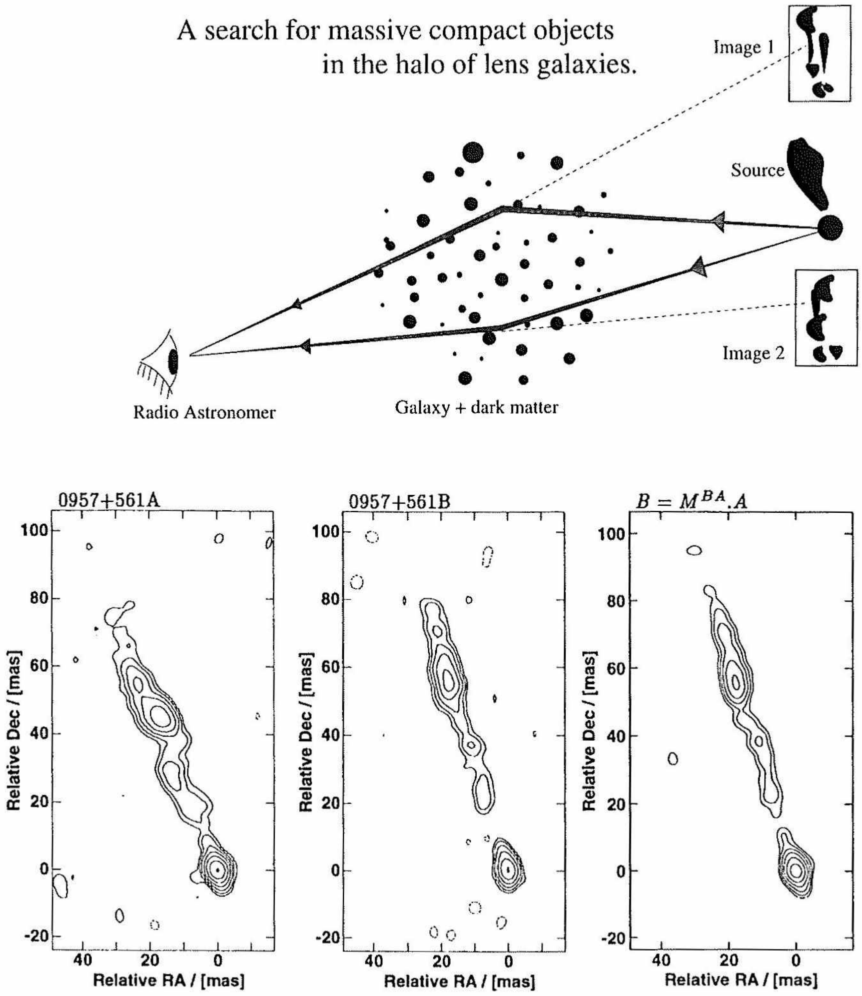

Fig. 12 - top: The geometry and principal elements required for small-scale lensing. Since the line of sight is different for each image, compact objects in the lens galaxy halo distort the lensed images in different ways. If the lens galaxy mass distribution is smooth, the images will appear very similar to each other. (Diagram from M. A. Garrett) bottom: Global VLBI observations of 0957+561 A,B. The image on the righthand side is the A image convolved with a linear transformation derived from these data. The agreement with image B (centre) is obvious. (Garrett et al., 1994)

linear transformation which relates quantitatively the brightness distributions of jet features in one image to those in the other. This transformation matrix is a function of the mass distribution in the lens and strongly constrains lens models for 0957+561. The similarity of the observed image B (centre of Figure 12) and the transformed image of A is striking, and leads to the conclusion that the mass distribution for the lens is smooth with the contribution of black holes of mass $3\times10^6 M_\odot$ being less than 10% of the dark matter in the halo of the lens galaxy. It is still an open question how much of the dark matter in the universe may be found in massive objects in the halos of galaxies. Perhaps VLBI measurements will provide crucial input to this (Garrett et al., 1994)

4.5 The most precise measurements of the motion and parallax of stars

The extragalactic reference frame set by the positions of several hundred compact radio sources in distant galactic nuclei is the primary celestial reference frame for astronomy. The average internal accuracy of this system is better than 1 milli-arcsecond (IERS Annual Report, 1994 published by the Observatoire de Paris). Linking the optical reference frame for our galaxy set by the Hipparcos satellite measurements to the extragalactic frame is important to unify the optical and radio coordinate systems, in particular for registration of images at both wavelengths and to calibrate the global rotation of the Hipparcos frame for dynamical studies. This link can be carried out by observing optically bright radio emitting stars in the Hipparcos catalogue with VLBI (Lestrade et al., 1992).

Since radio stars are usually weak, the technique of phase-referencing is used to increase the coherent integration time on the star so that it is well detectable after a few hours. This involves switching the telescopes between the star and a strong compact reference source within a few degrees on the sky from the star (Figure 13) every 2 or 3 minutes. The phase of the fringes detected for the reference source is used to lengthen the coherent integration time for the stellar radio emission. At the same time this allows high accuracy differential astrometry between the star and the reference source (Lestrade et al., 1990).

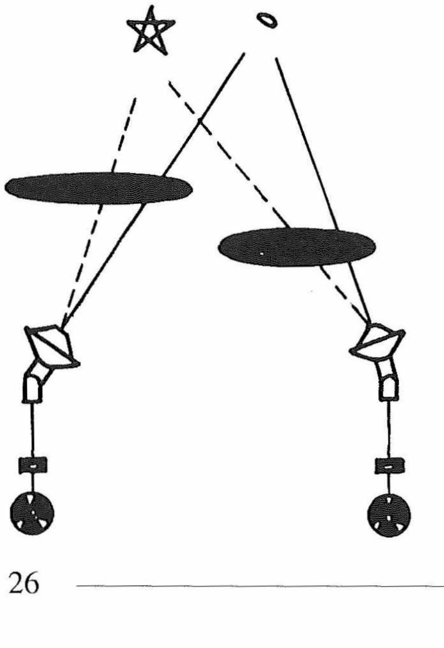

Fig. 13 - Illustration of phase referencing.

One of the objects in the Lestrade programme is s^2CrB, an RS CVn close binary radio star located 0.5° away from a strong quasar. Twelve epochs of global VLBI observation over a period of nearly five years have allowed the most precise determination of the 5 astrometric parameters (2 coordinates, 2 proper motions, and parallax) ever made for any object, except the Moon. The formal uncertainties in the least squares fit were 0.08 milli-arcsec for the position relative to the quasar, 0.04 milli-arcsec/year for the proper motion, and 0.08 milli-arcsec for the trigonometric parallax. The lack of a sinusoidal signature in the post-fit residuals sets a limit on the mass of any planet in orbit around the star system, to somewhat more than a Jupiter. This level of precision in determining parallax should permit direct determination of distances to radio stars in our galaxy out to about 10000 light years, about half as far as the centre of our galaxy.

4.6 VLBI polarimetry

Polarization sensitive data provide information on the magnetic field structure and on the physical conditions of thermal plasma inside radio sources as well as in their neighbourhood and along the line of sight to the observer. It is one of the few diagnostic tools available for the analysis of continuum radio emission. Figure 14 shows a fine example of a 5 GHz polarization image obtained with a global array for the quasar, 3C138 (Dallacasa et al., 1995). It shows that the polarized emission is dominated by the main jet and that the core is weakly polarized. The magnetic field geometry on scales of 10 milli-arcsec is mostly longitudinal with evidence of sub-structures at the end of the jet where the interaction with the ambient medium is most pronounced. Information of this sort for compact sources is important for models of jets mechanisms.

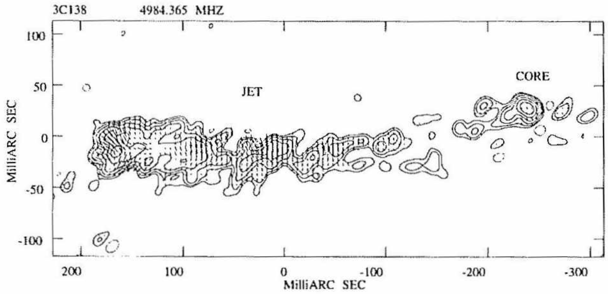

Fig. 14 - Global VLBI image of 3C138 at 5 GHz at 10 milli-arcsec resolution.The electric vectors superimposed have lengths proportional to the polarized flux density. The magnetic field directions are perpendicular to the electric vectors. (Dallacasa et al., 1995)

4.7 High quality images

For many years, VLBI image quality has been limited by poor uv-coverage, poor telescope system noise and instrumental polarization performance, and other systematic errors introduced by instrumental mismatches of one sort or another. Whereas phase-connected interferometers like the WSRT and VLA were able, with effort, to reach dynamic ranges (peak intensity in the image over rms noise) of several 100000 to 1, VLBI images seemed to be able to go no further than a few 1000 to 1. The VLBA was designed to remove or reduce the effects of the limiting factors just mentioned, so it was gratifying that test observations at 5 GHz on an almost unresolved source, DA193, have shown that a dynamic range of 120000 can be achieved using a recording bitrate of 128 Mbit/sec (Cornwell, Kemball, and Benson, VLBA Memo in preparation). Figure 15 shows this superficially uninteresting looking but nevertheless important result on DA193 which demonstrates that the VLBA can achieve noise-limited performance across a wide bandwidth (rms noise in the image 49 Jy/beam). Important factors in this result are the very careful editing out of bad data points, and the judicious use of deconvolution algorithms such as CLEAN and NNLS (non negative least squares matrix inversion, Briggs et al., 1994).

The European VLBI Network is inherently more sensitive to instrumental mismatches between the elements in the array because the individual telescopes are all different. However, a major programme is in progress to quantify possible systematic errors and correct these either in hardware or in post-correlation software. In principle, the rms noise in an EVN image at 5 GHz should reach 10 Jy/beam for an 8h measurement in the absence of systematic errors and with state of the art receivers and MkIV recording at 1024 Mbit/sec.

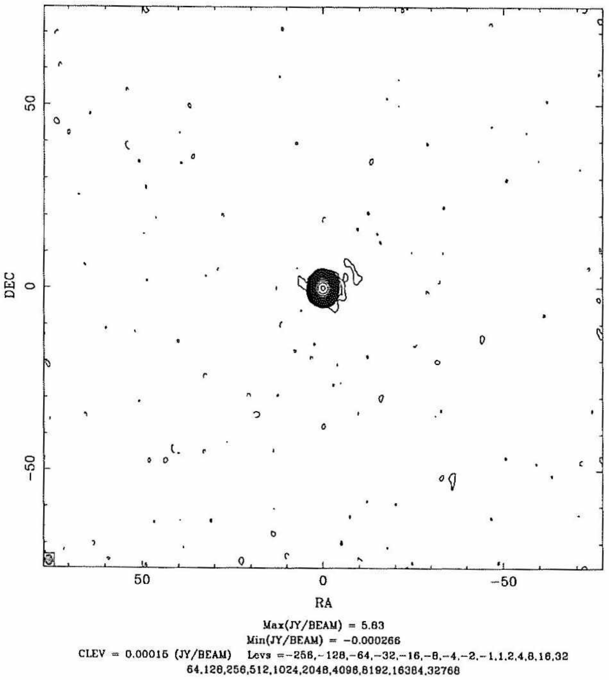

Fig. 15 - VLBA image of DA193 at 5 GHz. The dynamic range (peak intensity/rms noise in the image) is 120000, the highest ever achieved in VLBI (Cornwell et al. 1995, VLBA Memo in preparation)

5. Space VLBI - science drivers

The most exciting element of the VSOP and RadioAstron missions is the substantially increased angular resolution which allows us to explore new parameter space. One of the key projects will be a survey of compact sources. Theory leads us to predict that the maximum apparent brightness temperature in a compact radio source radiating incoherently should be about 10^{12} degrees Kelvin, which by chance is the limit that can be set on Earth. VSOP and RadioAstron will extend this limit by one and two orders of magnitude respectively which may lead to a new understanding of the physics obtaining in these extreme conditions.

Studies of active galactic nuclei will consume much of the mission time. Questions concerning the physical origin of the unresolved core component always seen in AGNs and pinning down the region where the jets are collimated will be of prime interest. In the nearest AGN, Centaurus A, in the southern hemisphere, the physical resolution achieved by RadioAstron will be less than $2x10^{15}$cm or 100 times the distance from the Earth to the Sun, and this at a distance of 12 million light years! We may be able to witness events in close proximity to the central black hole.

The third major area is likely to be detailed studies of water and hydroxyl masers. Masers provide powerful tools to probe, on very small spatial scales, the physical conditions (density, velocity, turbulence, magnetic field) in flows associated with the early and late stages of stellar evolution. The measured sizes of distant hydroxyl masers in particular may be affected by scattering in the interstellar medium so that we can map the density of the medium by observing a well-distributed sample.

Polarimetry will be possible with Radioastron, and with VSOP as well although with lower accuracy. Phase referencing will be possible with both satellites when the reference and target sources are simultaneously within the primary beam of the space radio telescope.

The scientific problems to be attacked by space VLBI are governed by the receivers available on the satellite, baseband channelization (which affects the spectral resolution for spectral line work), pointing constraints (which impact the ability to monitor changes in source structure as a function of time), orbit (which governs the angular resolution and uv-coverage), and sensitivity (see Table 3 and Figure 7).

The first call for observing proposals for VSOP will be issued in May 1995. When this closes in November, there will be a clear idea of the range of science that will be carried out with the first of the first generation space VLBI satellites.

6. Concluding remarks

My aim in writing this review was to give the non-specialist reader an overview of activity worldwide in VLBI astronomy. VLBI systems are being developed rapidly at many locations around the world: regional arrays like the EVN, VLBA, and Australian VLBI array are continuing to expand their facilities while the APT and the Coordinated mm VLBI Array are about to begin operation; new observing techniques and capabilities are being exploited to make exciting scientific discoveries; and the first of the two space missions VSOP (Japan) and RadioAstron (Russia) will be launched in August 1996 heralding in the age of space radio astronomy.

Coordination of these efforts is essential both for ground and space VLBI. The organisation of ground-based VLBI has run remarkably smoothly now for many years, and there is every hope that the largest coordination task of all so far, dovetailing the operations of a satellite with those of the ground-based arrays and other radio telescopes, will also run smoothly when put to the test next year.

Acknowledgements

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References

Barvainis, R. (1995) Nature 373, 103

Briggs, D. S., Davis, R. J., Conway, J. E., Walker, R. C. (1994) VLBA Memo 697A

Burke, B. F. (1991) Advances in Space Research 11/2, 349

Chikada, Y. et al. (1987) Proc. IEEE 75, 1203

Dallacasa, D. , Cotton, W. D., Fanti, C., Fanti, R., Foley, A. R., Schilizzi, R. T., Spencer, R. E. (1995) Astron. Astrophys. in press

Fanti, C., Fanti, R., Dallacasa, D., Schilizzi, R. T., Spencer, R. E., Stanghellini, C. (1995) Astron. Astrophys. in press

Garrett, M. A., Calder, R., Porcas, R. W., King, L. J. Walsh, D., Wilkinson, P. N. (1994), Mon. Not. R. astr. Soc. 270, 457

Gurvits, L. I. (1994) Astrophys. J. 425, 442

Jauncey, D. L. et al. (1994) in Very High Angular Resolution Imaging (eds. J. G. Robertson, W. J. Tango) Kluwer Academic Publishers, Dordrecht, p. 131

Hirosawa, H. (1994) in VLBI Technology - Progress and Future Observational Possibilities (eds. Sasao, T., Manabe, S., Kameya, O., Inoue, M.) Terra Scientific Publishing Company, Tokyo, p. 3

Kardashev, N. S., Slysh, V. I. (1988) in The Impact of VLBI on Astrophysics and Geophysics, Proc. IAU 129 (eds. M. J. Reid, J. M. Moran) Kluwer Academic Publishers, Dordrecht, p. 433

Kardashev, N. S., Gurvits, L. I., Tsarevsky, G. S. (1994) in Very High Angular Resolution Imaging, Proc. IAU Symposium 158 (eds. J. G. Robertson, W. J. Tango) Kluwer Academic Publishers, Dordrecht, p. 477

Kellermann, K. I., Thompson A. R. (1985) Science 229, 123

Kellermann, K. I. (1993) Nature 361, 134

Lestrade, J. F., Rogers, A. E. E., Whitney, A. R., Niell, A. E., Phillips, R. B., Preston, R. A. (1990) Astron. J. 99, 1663

Lestrade, J. F., Phillips, R. B., Preston, R. A., Gabuzda, D. C. (1992) Astron. Astrophys. 258, 112

Levy, G. S. et al. (1986) Science 234, 187

Linfield, R. P. et al. (1990) Astrophysical Journal 358, 350

Marcaide, J. M. et al. (1995) Nature 373, 44

Meier, D. L. (1994) in VLBI Technology - Progress and Future Observational Possibilities (eds. Sasao, T., Manabe, S., Kameya, O., Inoue, M.) Terra Scientific Publishing Company, Tokyo, p. 39

Miura, K. (1986) 37th Congress of the International Astronautical Federation, Insbruck, IAF-86- 206

Miyoshi, M., Moran, J. M., Herrnstein, J., Greenhill, L., Nakai, N., Diamond, P. J., Inoue, M. (1995) Nature 373, 127

Murphy, D. W., Yakimov, V., Kobayashi, H., Taylor, A. R., Fejes, I. (1994) in VLBI Technology - Progress and Future Observational Possibilities (eds. Sasao, T., Manabe, S., Kameya, O., Inoue, M.) Terra Scientific Publishing Company, Tokyo, p. 34

Pearson, T. J. and Readhead, A. C. S. (1988) Astrophys. J. 328, 114

Pilbratt, G. (1991) in Radio Interferometry: Theory, Techniques, and Applications (eds. T. J. Cornwell, R. A. Perley) Astron. Soc. Pacific Conference Series 19, 102

Polatidis, A. G., Wilkinson, P. N., Xu, W., Readhead, A. C. S., Pearson, T. J., Taylor, G. B. , Vermeulen, R. C. (1995) Astrophys. J. Supp., in press

Preston, R. A., Burke, B. F., Doxsey, R., Jordan, J. F., Morgan, S. H., Roberts, D. H., Shapiro, I. I. (1983) in Very Long Baseline Interferometry Techniques (ed. F. Biraud) Cepadues Editions, Toulouse, p. 417

Schilizzi, R. T. (1988) in The Impact of VLBI on Astrophysics and Geophysics, Proc. IAU 129 (eds. M. J. Reid, J. M. Moran) Kluwer Academic Publishers, Dordrecht, p. 441

Taylor, G. B., Vermeulen, R. C., Pearson, T. J., Readhead, A. C. S., Henstock, D. R., Browne, I. W. A., Wilkinson, P. N. (1994) Astrophys. J. Supp. 95, 345

Thompson, A. R., Moran, J. M., Swenson, G. W. (1986) Interferometry and Synthesis in Radio Astronomy, John Wiley, New York

Tzioumis, A. (1994a) in VLBI Technology - Progress and Future Observational Possibilities (eds. Sasao, T., Manabe, S., Kameya, O., Inoue, M.) Terra Scientific Publishing Company, Tokyo, p. 211

Tzioumis, A. (1994b) in VLBI Technology - Progress and Future Observational Possibilities (eds. Sasao, T., Manabe, S., Kameya, O., Inoue, M.) Terra Scientific Publishing Company, Tokyo, p. 205

Ulvestad, J. S., Linfield, R. P., Smith, J. G. (1995) Proc. 33rd Aerospace Sciences Meeting, Reno, in press

Vermeulen, R. C. and Cohen, M. H. (1994) Astrophys. J 430, 467

Walsh, D., Carswell, R. F., Weymann, R. J. (1979) Nature 279, 381

Zensus, J. A. and Pearson, T. J. (1987) Eds. Superluminal Radio Sources CUP, Cambridge

Current Developments in VLBI Astronomy on the Ground and in Space

DYNAMIC INTERACTIONS BETWEEN IONOSPHERIC PLASMA AND SPACECRAFT

David B. Snyder

Abstract

In recent years, studies of the interactions between Space Station Freedom (SSF) and ionospheric plasma have led to an improved understanding of the dynamics of these interactions. Plasma currents from the ionosphere control surface potentials, but the charge stored across dielectric surfaces becomes an important consideration in predicting dynamics of arc development. Time scales for the resulting interactions can be scaled for specific circumstances. In addition, active surfaces such as antennae and switched solar array surfaces have fostered thought on the interactions of AC driven systems. These systems can, under certain conditions, give rise to radiation and enhanced sputtering of surfaces. This paper will review the work performed for the SSF program to understand the dynamics of spacecraft interactions, and will discuss implications to other spacecraft.

1. Introduction

During the previous decade, much work has been done to develop models to help understand and predict interactions between spacecraft and the plasma environment [1]. However, engineering leve codes such as NASCAP/Geo and NASCAP/LEO tend to rely on evaluating or tracing the evolution to, equilibrium conditions and drawing conclusions based on relatively constant conditions. While it is recognised that charging conditions are dynamic, the tools tend to assume rapid establishment of equilibrium conditions [2, 3]. However, with the development of new technologies for expensive spacecraft, and the need to predict and scale effects to new systems without extensive testing, it has become necessary to begin to study the dynamics of these interactions.

Early in the design of Space Station Freedom (SSF), issues of plasma were investigated with the ob- jectives of designing a plasma compatible space platform, and providing a platform suitable for ionospheric studies [1]. However, in during the several SSF redesigns and mission redefinitions, these issues were forgotten [4].

However the decision to ground SSF to the negative side of the solar arrays, Ferguson et al. raised several plasma compatibility issues [4]. This lead to the establishment of the SSF Grounding Tiger Team, which attempted to evaluate the impact of arcing of SSF [5]. While this work has raised additional questions for further research, it has also contributed to a better understanding of how spacecraft respond to various plasma interactions. As new technologies are applied to new spacecraft, in particular those performing various ionosphere investigations, some of these plasma compatibility issues may become relevant.

The purpose of this paper is to review some of the plasma compatibility issues raised in the course of the SSF investigations, and where possible discuss the dynamic characteristics of these effects, both to help spacecraft users better understand the implications of these effects on their measurements, and to suggest future directions for research in plasma-spacecraft interactions.

2. Interactions and Time Scales

If a spacecraft is not effectively 'grounded' to the ionosphere, fluctuations in spacecraft potential can occur on a variety of time scales, from DC to microseconds. There can be a DC offset driven by exposed portions of the powerpsystem, due to current density differences in positive and negative species. This is roughly driven by $\sqrt{T_e / T_i}$, where T_e refers to the electron temperature and T_i is the ion temperature. If the power generation system is sensitive to illumination (solar cells) there may be a voltage transient associated with entering and leaving eclipse. There may be transients associated with switching of systems on-board the spacecraft, for example solar array circuits, or operation of high voltage experiments. As the potential of the spacecraft changes, current is collected on the surface trying to bring the spacecraft back to equilibrium. In many cases the current collection mechanisms can be identified making it possible to estimate the times scale, and hence the frequency domain of the transients. We would like to be able to predict the magnitudes of some of these effects in order to assess their impact on measurements, or to justify requirements on spacecraft design.

In this work the term grounded is used in a couple of ways. The 'plasma ground' is used to describe the electrical connection between the spacecraft and the local environment, i.e. the ionospheric plasma. The 'spacecraft ground' refers to the internal process of referencing

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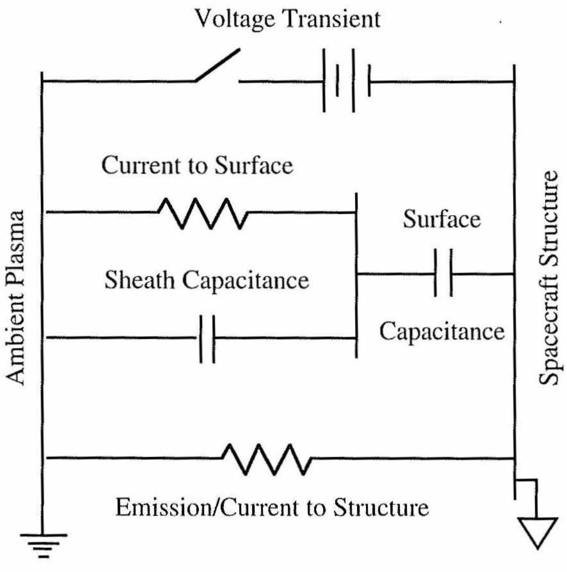

Fig. 1 - Spacecraft-Plasma interaction schematic diagram

potentials to a common place on the spacecraft, usually the structure. This is comparable to a chassis ground.

To track the potential changes during transients it is helpful to look at a simplified description of the spacecraft-plasma interaction. Figure 1 shows a schematic diagram to illustrate this. The electric potential of the spacecraft can shift by changes in the energy or current of ion or electron collection, or electron emission. The capacitance of the spacecraft to plasma, or across a surface coating, plays an important role in determining the magnitude of the interaction, while the current collection and emission mechanisms then contribute to the time scale of the transient.

The capacitance of the spacecraft sheath tends to be much smaller than the capacitance of the surface. The sheath thickness tends to be fractions of a centimeter, thicker with high potentials, while dielectric materials on surfaces tend to be fractions of a millimeter. The dielectric constant of surface materials tend to be higher than that of vacuum also contributing to a higher capacitance. An interaction that occurs on a completely insulated satellite, for example a voltage shift due to auroral interactions, will involve relatively small currents even if large voltage excursions occur, because of the small capacitance. However, interactions that involve the spacecraft structure, for example arcing, can access the energy due to the relatively large dielectric capacitance of the surfaces.

3. Arcing

Transients due to arcing are of interest because (1) they may lead to damage of the affected surfaces or contamination of other spacecraft surfaces, and (2) they are probably the most severe cases of voltage change and time scale, aside from planned antenna use. Our interest has been more in how these transients may damage spacecraft than in how they effect measurements. However, these assessments illustrate some of the issues involved in evaluating the impact of other transient effects.

Arc Evolution Mechanism

There are several known mechanisms which can initiate an arc; dielectric breakdown [6], micrometeor and debris impact [7, 8], solar cell (edges or interconnects) arcs [9]. The initiation mechanism is important to understanding some arc characteristics such as arc frequency and arc threshold potentials. However as will be seen later, if a large enough initiation event occurs and the substrate is biased negative relative to the ambient plasma, the evolution of the arc appears to be independent of the initiation mechanism [10]. The key common feature appears to be a substrate biased negative relative to the ambient plasma, covered or nearly surrounded by a dielectric layer. This produces electric fields which collect electrons on the dielectric surface and focus ions back to the metal or conductive arc surface. Three issues need to be addressed in an arc circuit mechanism; (1) Development of the arc plasma, (2) Transport of electron current to the surface, and (3) transport of current through the spacecraft. Figure 2 illustrates the hypothetical process.

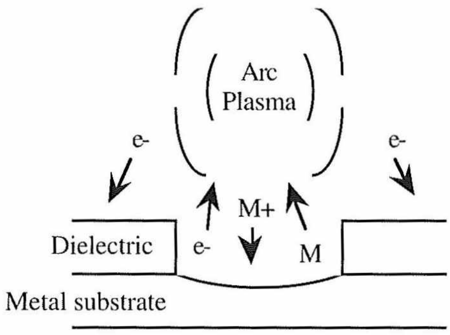

Fig. 2 - Proposed arc evolution mechanism

In this evolution model an initiation event provides an initial ignition plasma at the arc site and, if not already exposed, exposes the underlying conductor. Due to the dielectric material surrounding the arc site, a high electric field exists at the site, which focuses ions from the plasma back to the arc site. Bombardment of the site by the attracted ions may cause sputtering or sublimation of neutrals. Electrons can be emitted from the site by a combination of thermionic and field emission. If the collision lengths are such that the electrons can collect a few ten's of eV of energy, ionization may occur when they strike the emitted neutrals, thereby creating ions and sustaining the arc plasma.

As electrons are emitted from the arc site and arc plasma, the potential of the substrate rises. The potential of the dielectric surface also rises due to capacitive coupling with the substrate. The surface now collects electrons from both the arc plasma, or the ambient plasma. Since the capacitance to space is ordinarily much smaller than the capacitance across the dielectric, most of the potential change appears across the plasma sheath, the potential of the surface also rises. Then, as charge is attracted from the plasma, discharging the dielectric. If the arc continues on the time scale of the dielectric discharge, the energy available from the dielectric capacitance can continue to drive the arc.

The current available to drive the arc is limited by the ability of the spacecraft surfaces to collect current from the arc or ambient plasma. The arc source appears to be the principal limit on arc currents, from tenths of an amp for small capacitance systems [11] (few hundred picofarads), to a thousand amps for large capacitance systems [6] (a thousand microfarads). Unless provision is made in the design, spacecraft structure does not appear to affect arc development, except perhaps in the rise times. During the Electrical Grounding Tiger Team discussions, it was argued that spacecraft inductances might prevent arc development. But during tests, the inductance of the wiring and internal inductance of capacitors were not sufficient to prevent arcs nor did they obviously effect development. Arcs appear to develop slowly enough (microseconds) that inductive effects seem to be unimportant to the arc evolution.

So far it is assumed that the structure can return the current generated by the arc plasma. But what limits are there on the current that can move to the surface? Is this current sufficient to sustain an arc? Two independent mechanisms are examined for this part of the current loop. A lower bound on the current available can be estimated by the electron thermal current to the spacecraft, i.e. for large spacecraft, the product of the electron thermal current density with the spacecraft area. This is the current available to the spacecraft due to its changing voltage, neglecting geometric and plasma sheath considerations.

For normal spacecraft voltage shifts this probe-like collection is the mechanism that governs current collection. But for arcs there is an additional source of current.

The second mechanism assumes that the current is due to the expansion of the plasma arc. Vaughn et al. [12] noted a delay in the plasma enhancement seen by a movable Langmuir probe. For their configuration (anodized aluminum biased to -240 V) they estimated a primary expansion velocity of about $3x10^4$ m/sec. This model can be used to estimate the current due to an expanding arc plasma [13] of $I = CV\, dA/dt = 2\pi CV v$, were A is the dielectric area covered by the arc plasma, and v is the expansion velocity. This estimate represents an upper bound as it assumes that the coating capacitance is instantaneously and completely discharged as the arc plasma moves over it. However, this assumption will break down as the arc plasma density falls due to expansion. Eventually the density may fall sufficient to terminate the arc. This mechanism suggests a current limited by the expansion velocity of the arc plasma.

A third mechanism related to the second may produce higher currents for microsecond time scales. On this time scale the ions near the 'old' plasma sheath edge have not had time to leave and form a new plasma sheath. So electrons from the arc plasma sheath are not space-charge-limited, at least in the usual sense of the term.

We have seen immediate increases in electron current on a distance scale of 1/2 meter on a sample made of several plates [14]. Figure 3 shows return currents during an arc on a set of concentric anodized aluminum rings. The total area of the sample was about 2 m^2. The arcs, instead of occuring on the center plate as intended, occured on the outside ring. In spite of the 3 to 4 meters of wire forming the electrical connection, currents arrived simultaniously at all the plate.

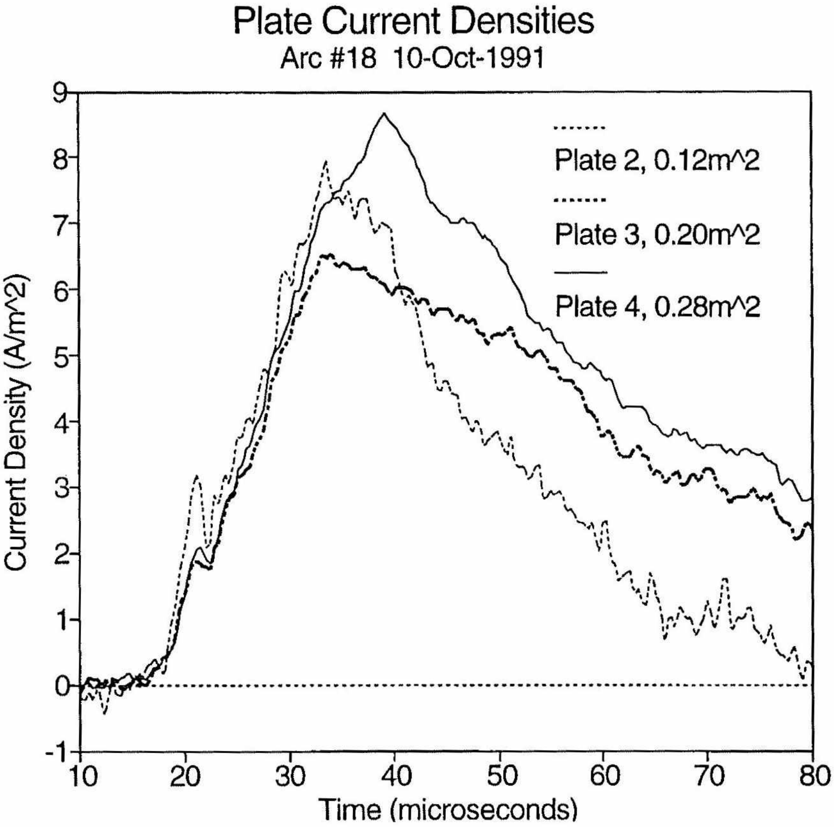

Fig. 3 - Arc return currents to a series of concentric rings

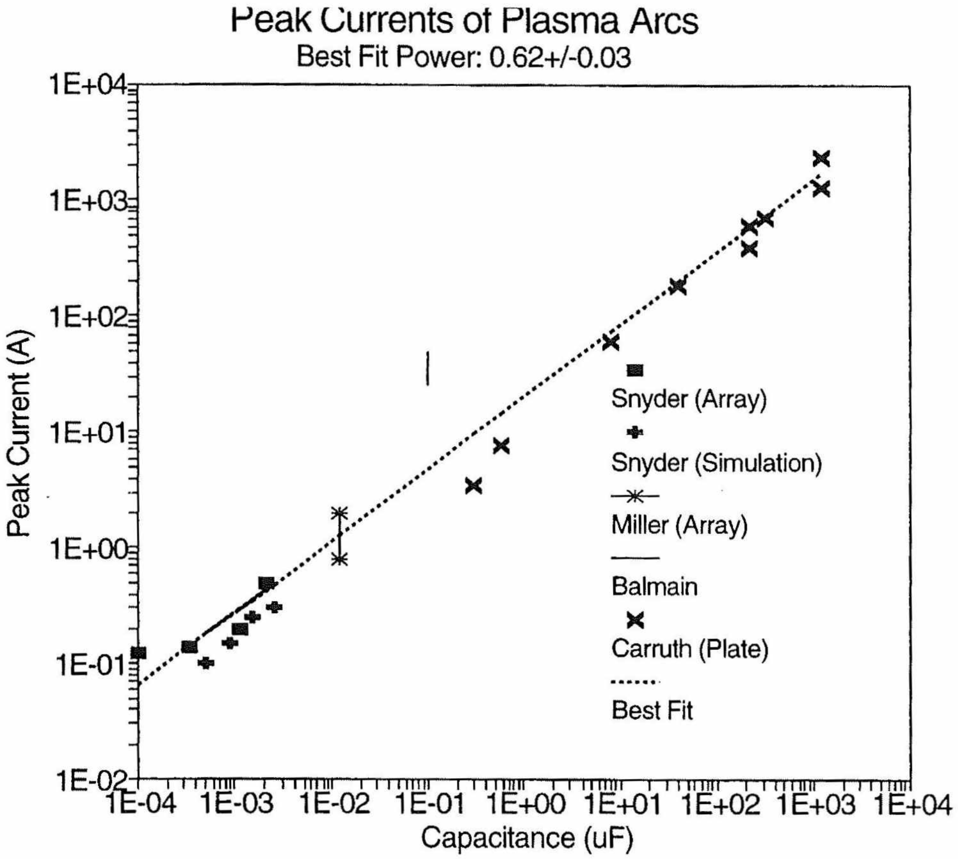

Fig. 4 - Observed peak arc currents as a function of capacitance

The magnitude of the currents were approximatly proportional to the ring area.

Arc Magnitude, time scales

An obvious parameter for scaling ground based studies to spacecraft is the system capacitance. The capacitance together with the potential difference to plasma at the arc site determines the charge and energy available for a discharge, and how the electric fields associated with the arc event will evolve over time. This hypothesis suggests

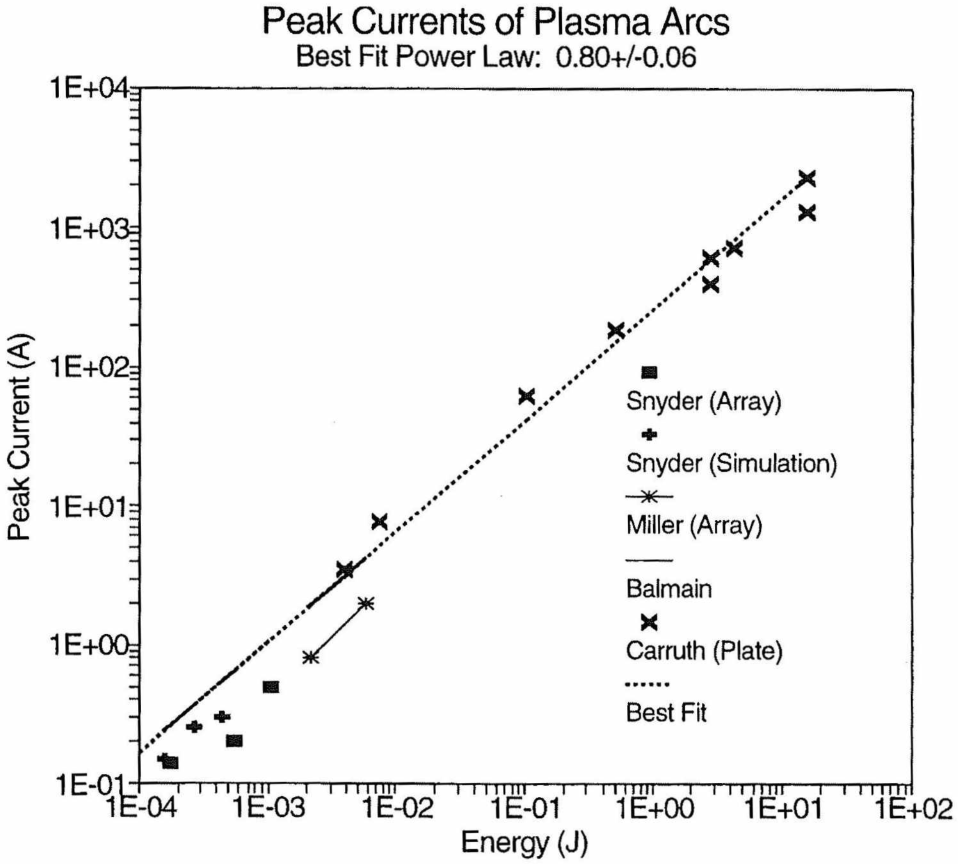

Fig. 5 - Observed peak arc currents as a function of energy

that it may be reasonable to study arcs from large space systems by simulating them with a comparable capacitance.

Figure 4 [10] illustrates an observed correlation between peak current and system capacitance. The peak current is an interesting parameter since it puts a lower bound on the duration of an arc, and on the magnitude of the EMI generated by the arc. The data is from a variety of sources [8, 10, 15-17]. During tests, wide variations in the peak currents are seen for a particular set of conditions. Calculated standard deviations of the peak currents are on the order of the average. Points in the figure generally indicate the average of a number of arcs, but sometimes a range is indicated instead. The data from Balmain [1] 6 was for a Helium plasma at millitorr pressures.

Figure 5 [10] shows the same sets of data plotted against energy instead of capacitance. The energy is calculated from $1/2CV_0^2$ where C is the capacitance and V_0 is the bias voltage. This introduces some dependence based on voltage. The high capacitance data was obtained in connection with space station tests at about 100 to 150 V while the low capacitance data was taken during studies of solar cell arcs with potentials closer to 1000 V. We note that the high capacitance data extrapolates to, and can be extrapolated from the low capacitance data. This is not quite the case when the energy data is examined. This suggests that capacitance maybe a better predictor of peak arc current than is energy. The increased voltage appears to extend the arc duration rather than increase the current.

As a working hypothesis we use the correlation between the peak arc current during an arc and the capacitance of the system to predict arc currents. But this hypothesis is not based on a rigorous arc model. Instead it is based on empirical observation. A correlation with bias voltage or energy stored in the system might be easier to understand. Development of a quantitative arc development model might suggest extrapolation procedure that could be used with more confidence.

The above technique is used as a way to estimate arc current to about a factor of two. Using time to deplete the charge stored in the system permits an estimate of the arc duration, i.e. $\Delta t = C\Delta V/I_p$, where Δt is a lower bound on thearc duration, ΔV is the change in voltage during an arc, i.e. a material dependent cutoff voltage subtracted from the bias voltage, and I_p is the estimated peak current. In practice the current dies down with the substrate voltage, but this method permits an order of magnitude estimate, enough to see in what frequency regime interference might be expected.

Mitigation

Presently we suspect that there are material dependent voltage thresholds. For silicon cells these appear to about -200V for silicon solar cells [18], and about -50V for anodic oxide coated aluminum [14], and kapton covered copper [17]. The solar cell arc threshold is an empirical observation, but coincides with the voltage where arcs appear to shut off. The copper and kapton thresholds are based on arc shutoff potentials, but simulated debris hit induced arcs have been observed at 75V on aluminum [19], and one sample arced repeatedly at 50V [14].

Two types of systems can easily develop potentials significantly different from the ambient plasma. For large spacecraft vxB induced potentials can be significant, tens of volts for ISSA (International Space Station Alpha) sized structures. More commonly the spacecraft potential will be determined by exposed biased conductive surfaces such as solar cells, or other active equipment such as high voltage experiments. It may be possible to electrically isolate these systems from the spacecraft structure and the rest of the spacecraft if they would otherwise cause excessive potentials. However, it may be difficult to provide sufficient isolation. If it is necessary to ground to the structure and both positive and negative potentials are exposed, grounding to the positive side is preferred. It is typically the exposed surfaces that provide the electrical connection to the ambient plasma. Since the positive surfaces tend to collect electrons while negative surfaces tend to collect ions, the positive surfaces have less effective resistance to plasma. It will normally be prudent to ground the positive side to structure.

It is possible to provide an electrical connection to the ambient plasma on a negative ground spacecraft using a hollow cathode plasma contactor, or some other device capable of providing relatively large currents. This is the technique being used for ISSA, where it is anticipated that about an ampere of current will be driven through ground cables to control the spacecraft potential.

4. A/C Interactions

Most studies of plasma interaction assume that a system eventually reaches some equilibrium condition, i.e. conditions stop changing. This is obviously not true of systems with a driven component. However, systems that are periodic may achieve a steady state where the changes are repetitive. This can apply to AC (Alternating Current) power distribution systems, antennae, some active experiments, and solar array power control systems. The criteria for reaching a 'steady state' is that the net charge collected during a period is zero. If both secondary emission and backscatter collisions are negligible, the electrons collected during the positive part of the cycle will be equal to the ion collection during the negative part. Except for very low frequencies, this tends to drive the system negative until the maximum negative potential on a dielectric surface is nearly twice the amplitude of the driving oscillation.

Our main concern has been that sputtering rates may be higher than expected due to ion collection at energies higher than otherwise anticipated. In fact this technique is commonly used at much higher plasma densities, voltages and frequencies to sputter dielectrics in plasma reactors. The effect may be particularly important in low earth orbit where thin atomic oxygen resistant coats may be sputtered away exposing underlying polymers to attack. Kennedy [20] has documented this sputtering for ionosphere-like conditions. However, even under more benign circumstances the effect may be of interest to experimenters as it results in larger plasma sheaths than otherwise anticipated and may cause significant fluctuations in spacecraft potential. It is conceivable that in extreme cases

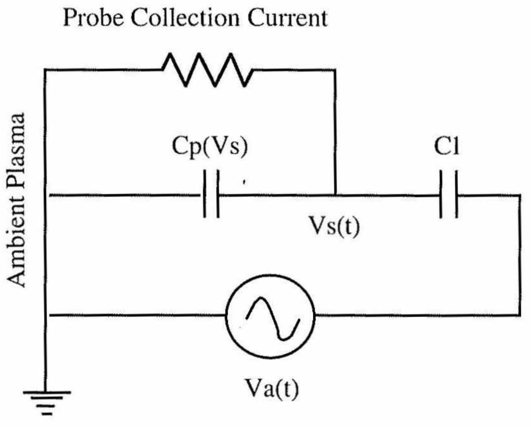

Fig. 6 - Schematic diagram of circuit to evaluate surface potentials, V_s

the spacecraft potential could fluctuate relative to plasma, disturbing some measurements.

Mechanism: AC Surface Potentials

Figure 6 shows the circuit diagram used to calculate the potential of the surface [21]. $V_a(t)$ is the electric potential of a driving conductor measured with respect to plasma and $V_s(t)$ is the potential of the surface with respect to plasma. C_1 is the capacitance between the driving conductor and the exposed surface. This will be related to the dielectric coating of the surface but may include other artificial capacitances between the underlying conductor at the surface and the power system or other power sources. $C_p(V_s)$ is the effective capacitance between the surface and the plasma. In general this will depend on the plasma sheath thickness, and will vary with surface potential. For the case of a weak plasma this will be small and the surface potential will be near the driving voltage. However, for high density plasma and thin plasma sheath, especially when the capacitive coupling of the surface to the driving conductor is weak, C_p may be important and the surface potential will be some fraction of the driving potential. $I(V_s)$ is the current from plasma to the surface and may be obtained from probe theory.

Since the displacement current through C_1 is equal to the displacement current plus the probe collection current through the sheath,

$$\frac{d}{dt}C_1\left(V_a(t)-V_s(t)\right)=I(V_s)+\frac{d}{dt}C_p(V_s)V_s(t) \qquad (1)$$

From equation (1) the rate of change of the surface potential can be obtained,

$$\frac{dV_s}{dt}=\frac{\dfrac{dV_a}{dt}-\dfrac{I(V_s)}{C_1}}{1+\dfrac{1}{C_1}\dfrac{d}{dV_s}C_p(V_s)V_s} \qquad (2)$$

Note that the factor dC_pV_s/dV_s is an effective capacitance of the plasma sheath. If C_p is independent of V_s, it reduces to C_p.

The capacitive term in the denominator is due to the voltage dividing effect of the two capacitances C_1 and Cp. Normally C_1 will be much greater than C_p, since C_1 is usually due to thin dielectric films and C_p has a minimum thickness of the plasma debye length (i.e. cm scale lengths). Thus the capacitive term will be negligible, and the surface potential, V_s will tend to track the driving potential, V_a.

The current term in the numerator serves to bring the surface toward plasma ground. If $V_a(t) = V_0 exp(iwt)$, the magnitude of $dV_a{=}dt$ will be on the order of V_0w, where V_0 is the amplitude of the driving voltage and w is the angular frequency. If I/C_1 is much larger than this, the surface is effectively shorted to plasma ground. In practice, however, the plasma current term will be smaller than V_0w, and instead this term determines a) what the time average of the surface potential is, and b) how long it takes to get there.

Multiplying equation (2) by the denominator of the right side and integrating over from t_0 to t gives,

$$V_s(t)\left[1+\frac{C_p(V_s(t))}{C_1}\right]-V_s(t_0)\left[1+\frac{C_p(V_s(t_0))}{C_1}\right] \qquad (3)$$
$$=\left(V_a(t)-V_a(t_0)\right)-\int_{t_0}^{t}\frac{I(V_s)}{C_1}dt$$

An equilibrium condition is reached, i.e. $V_s(t)$-$V_s(t_0) = 0$, for periodic V_a, i.e. $V_a(t)$-$V_a(t_0) = 0$, when the charge collected over a cycle, $\int_t^{t+\tau} I(V_s)dt$, is zero. Since electron current densities tend to be much higher than ion current densities in ionospheric plasmas, V_s will charge somewhat over each cycle resulting in a increase in the ion collecting part of the cycle at the expense of the electron collecting part, for high enough frequencies. This continues until V_s is nearly offset by $-V_0$, so that V_s varies from a small positive value to nearly $-2V_0$.

The long term behavior can be discussed by examining the change in V_s over one period, t, of the driving voltage. Equation 3 becomes instead,

$$V_s(t+\tau)\left[1-\frac{C_p(V_s(t+\tau))}{C_1}\right]-V_s(t)\left[1-\frac{C_p(V_s(t))}{C_1}\right]=-\int_{t_0}^{t+\tau}\frac{I(V_s(t'))}{C_1}dt'$$
$$(4)$$

If V_s changes so little over one period that $Cp(t_0+t)$ is nearly the same as $Cp(t_0)$, then

$$V_s(t_0+\tau)-V_s(t_0)=-\int_{t_0}^{t_0+\tau}\frac{I(V_s(t'))dt'}{C_1+C_p(V_s(t'))} \qquad (5)$$

Here, it can easily be seen that V_s will settle to an equilibrium condition once the charge accumulated over a cycle is zero. If $\langle I(t)\rangle$ is defined as $(q(t+\mathrm{t})-q(t))/t$, then

$$\frac{\Delta V_s(t)}{\tau}=\frac{\langle I(t)\rangle}{C_1+C_p(V_s(t))} \qquad (6)$$

Which suggests that for high driving frequencies, where V_0w is much greater than the maximum probe currents, the long term behavior of V_s ignoring the driving oscillations can be described by

$$\frac{dV_s(t)}{dt}=\frac{\langle I(t)\rangle}{C_1+C_p(V_s(t))} \qquad (7)$$

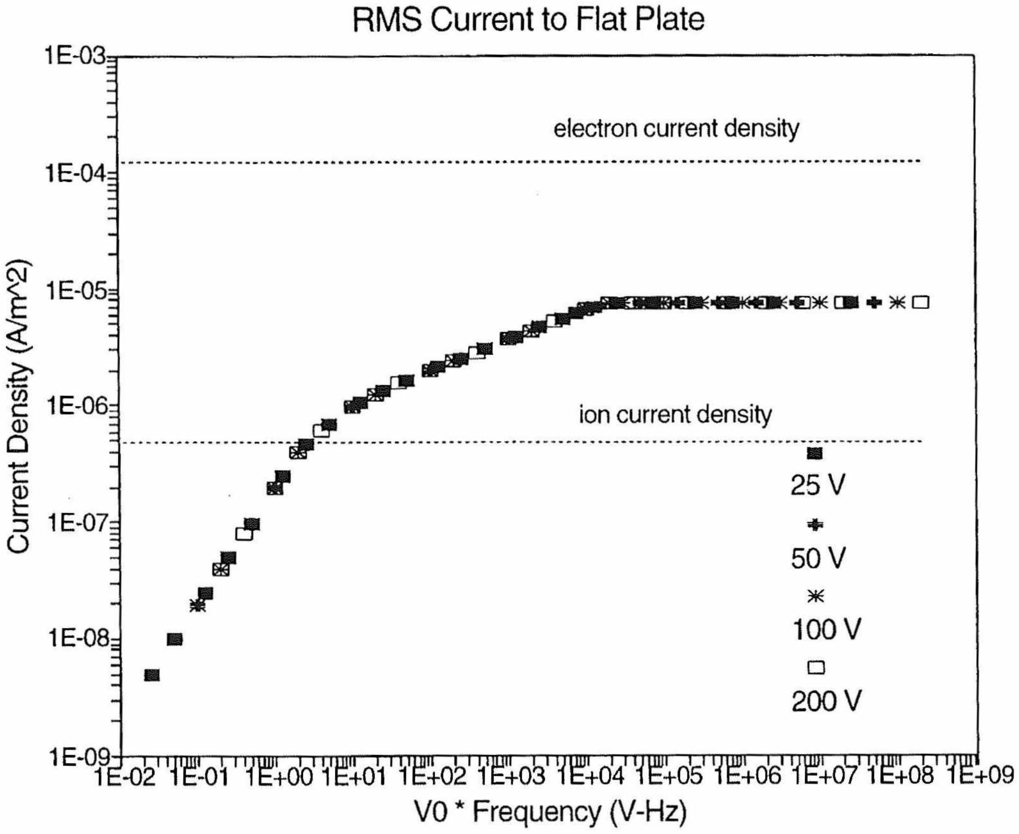

Fig. 7 - Root-Mean-Squared (RMS) currents to a flat plate

Flat Plate

Some implications of this model can be examined for a simplified case of a flat plate driven by a sinusoidal voltage. For this example edge effects and details of how the plasma sheath grows will be ignored. It is assumed that for positive potentials the surface collects electrons at their thermal current density, and at negative potentials the surface collects ions at their thermal current density. Figure 7 illustrates the three applicable frequency regimes. It was generated from the results from a computer model which integrated the collected current to track the surface potential. The electron current density, J_e for this case is $-1.2\text{x}10^{-4}$ A/m^2 and the ion current density J_i is $4.9\text{x}10^{-7}$ A/m^2. The capacitance, C_1, is $4.4\text{x}10^{-8}$ F/m^2, and C_p is considered to be negligible.

The three frequency regimes are determined by a comparison of amplitude of the rate of change of the driving voltage ($V_0 w$) with the thermal current density. At low frequencies $C_1 dV_a/dt$ is always less than the ion current density and the plasma can always supply enough current to keep the surface at 0 V. Once $C_1 dV_a/dt$ exceeds the ion current density then the surface can begin to develop negative voltages, and the average voltage begins to drop. At high frequencies, where the RMS current is saturated, the driving voltage changes rapidly enough that it is always collecting either the full electron current density or the full ion current density. For this flat plate case the steady-state charging condition dictates that ratio of time spent positive (electron collecting) to that spent negative (ion collecting) is the ratio J_i/J_e. For this case, only $4.1\text{x}10^{-3}$ of the cycle is spent with a positive surface. For the rest of the cycle the surface is negative, collecting ions, and the maximum negative potential attained is only slightly less that $-2V_0$.

At extremely high frequencies, near or above the sheath formation times, the mechanism for the transport of charge as the sheath develops becomes important and the above model does not hold.

Mitigation

The level of attention paid to addressing these issues will be mission and system dependent. Effects from some systems such as antennae will simply have to be tolerated. Hopefully antenna operate at frequencies high enough that the above analysis is not applicable. Sensitive equipment should be placed far enough away that they will not see the plasma sheath's from this equipment. Cables should be shielded, if not individually, at least collectively so the plasma does not see and react to them.

It may be possible to reduce fluctuations in spacecraft potential by including some kind of plasma contactor, i.e. a small electron emitter, to reduce the negative excursions.

Conclusions

An understanding of dynamic interactions with ionospheric plasma is beginning to be developed. The issues related to arcing are still quite controversial. This work has looked at some of the issues related to developing and sustaining arcs in ionospheric conditions. It has also presented a technique for estimating the amplitude and duration of arcs. This technique uses the capacitance of the system to estimate the peak current, and then uses the charge stored to estimate the duration of an arc.

In addition, as new technologies are implemented on spacecraft, new issues of environmental compati- bility will arise. This work has also looked at some of the issues related to driving dielectric surfaces with AC voltages. The steady-state charging criteria developed is that over an oscillation the ion charge collected is compensated for by the electron charge collected. This tends to drive the average potential negative, so that only for a small portion of the cycle is the dielectric surface positive.

The material discussed here only begins to touch on the issues related to dynamic interactions that will at least affect experiment operations and, if due care is not taken, may affect spacecraft reliability and lifetimes. Some of the work presented here is somewhat speculative, but may suggest ideas and hypotheses for future experimental and theoretical work.

References

[1] SSPIE Working Group Meeting, Cleveland, OH, April 26,27, 1987.

[2] Purvis, Carolyn K., Garrett, Henry B., Whittlesey, A. C., and Stevens, N. John, "Design Guidelines for Assessing and Controlling Spacecraft Charging Effects", NASA TP2361, Sept 1984.

[3] V.A Davis and L.W. Duncan, Spacecraft Charging Handbook, PL-TR-92-2232, Phillips Laboratory, Directorate of Geophysics, Air Force Materiel Command, Hascom Air Force Base, MA 01731-5000, 1992.

[4] Ferguson, Dale C., Snyder, David B., and Carruth, Ralph, "Findings of the Joint Workshop on Evaluation of the Impacts of Space Station Freedom Ground Configurations", NASA TM 103717, 1990.

[5] Clouber, D., and Tye, C., Space Station Freedom Program (SSFP) Electrical Grounding Tiger Team Preliminary Integrated Assessment Report,Under NASA Contract: NAS 9-18200/B, McDonnell Douglas Space Systems Company, Space Station Division, Houston, TX, 1991.

[6] Carruth, M.R., Vaughn, J.A., Bechtel, R.T, Gray,, P.A., "Experimental Studies on Spacecraft Arcing", Journal of Spacecraft and Rockets, 30(3), pp. 323-327, 1993.

[7] Schneider, E.,"Micrometeorite Impact on Solar Panels", Photovoltaic Generators in Space, European Space Agency, ESA SP-267, The Hague/Scheveningen, The Netherlands, pp. 171-174, Oct. 1986.

[8] Weishaupt, U., Kuczera, H., and Rott, M.,"Micrometeorite Exposure of Solar Arrays",Photovoltaic Generators in Space, European Space Agency, ESA SP-267, The Hague/ Scheveningen, The Netherlands, pp. 175-180, Oct. 1986.

[9] Thiemann, H. Schunk, R. W. and Bogus, K., "Where Do Negatively Biased Solar Arrays Arc?", Journal of Spacecraft and Rockets, 27, pp. 563-565, 1990.

[10] Snyder, David, "Arc Current Loop", Minutes of the Electrical Grounding Tiger Team Meeting, Boeing Trade Zone, Huntsville, Alabama, May 14-17, 1991.

[11] Snyder, David B., "Characteristics of Arc Currents on a Negatively Biased Solar Cell Array in a Plasma", NASA TM 83728, IEEE Transactions on Nuclear Science, NS-31(6), pp. 1584-1586, 1984.

[12] Vaughn, J.A., Carruth, M.R., and Gray, P.A., "Current Flow in a Plasma Caused by Dielectric Breakdown", Fifth Annual Workshop on Space Operations Applications and Research, NASA CP-3127 vol 2, pp. 724-731, 1992.

[13] Snyder, D.B., "Arc Current Loop", Minutes from the Joint Meeting of the Electrical Grounding Tiger Team and the Electrical Power System Working Group, Rocketdyne Building, Fairview Park, OH, Aug 5-7, 1991.

[14] Snyder, D.B. , "Arc Return Currents, Ring Test Analysis", Plasma Testing Meeting, Memphis, 29-31 Jan 1992.

[15] Miller, W., "An Investigation of Arc Discharging on Negatively Biased Dielectric-Conductor Samples in a Plasma", Spacecraft Environmental Interactions Technology 1983, NASA CP-2359, AFGL-TR-85-0018, pp.367-377, 1985.

[16] Balmain, K.G.,"Laboratory Measurements to Characterize Anodization Arc Discharges in a Plasma", Minutes of the Electrical Grounding Tiger Team Meeting, Boeing Trade Zone, Huntsville, Alabama, May 14-17, 1991.

[17] Snyder, D.B., "Ground Testing", Minutes Space Station Plasma Interactions and Effects (SSPIE) Working Group Meeting, NASA Lewis Research Center, Cleveland, OH, June 3-5, 1987.

[18] Ferguson, D.C., "The Voltage Threshold for Arcing for Solar Cells in LEO - Flight and Ground Test Results", NASA TM 87259, NASA Lewis Research Center, Cleveland, OH, 1986.

[19] Carruth, M.R., and Vaughn, J.A.,, "Debris Induced Arc Testing", Minutes from the Joint Meeting of the Electrical Grounding Tiger Team and the Electrical Power System Working Group, Rocketdyne Building, Fairview Park, OH, Aug 5-7, 1991.

[20] Kennedy, M., Low-Energy Radio Frequency Sputtering of Copper, Anodized Aluminum, Kapton, by Argon Plasma Ions, Ph.D. Thesis, Case-Western Reserve University, Cleveland, OH, 1995.

[21] Snyder, D.B., Grier, N., Domitz, S., "AC Current Collection from a Plasma", Minutes of the Electrical Grounding Tiger Team Meetng, Rocketdyne Building, Cleveland, Ohio, Oct. 31 - Nov. 2, 1990.

Radioscience at St. Petersburg Universities

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Abstract

This paper presents a review of radioscience in two main universities of St. Petersburg: St. Petersburg University and St. Petersburg State Technical University.

In the Russian language, *radioscience* as the main area of the *URSI* activities is usually termed as *radiophysics*. This branch of science studies all physical phenomena related to electromagnetic waves (including theoretical electromagnetics, wave propagation, media effects, non-linear circuits, novel physical principles for signal processing, etc.). That is why we mainly speak about Radiophysics divisions at St. Petersburg universities.

Introduction

This is a brief review of main scientific activities in radiophysics of the two biggest universities of St. Petersburg. St. Petersburg was founded by Peter the First (or the Great), the famous reformer tzar, in 1703. The new capital of the Russian Empire, this city historically has been one of the leading scientific research and educational centers of the country.

The Academy of Sciences and St. Petersburg University were established by Peter the Great in St. Petersburg in 1724, and St. Petersburg University (which gradually developed itself from the educational establishment of the Academy of Sciences) was for a long time the biggest University of the country. The new university campus is located in Petrodvoretz, a historical suburban place near the city, famous for its fountain parks and tzar palaces (Figure 1).

St. Petersburg Technical University has a shorter but also brilliant history. Its original name was *St. Petersburg Polytechnic Institute*. Founded in 1899, it was one of the first technical high schools in the country which were giving very deep fundamental education in mathematics and physics, combined with extensive studies of practical engineering in many areas of the modern technology.

Figure 1. Petrodvoretz fountains.

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Nowadays, research in radiophysics is conducted in the city not only at the two Universities we present. In the former Soviet Union, scientific research was done in institutions of three different systems, organized by different Ministries: in universities and educational institutions (under the Ministry of Higher Education), in scientific research institutions (under the Academy of Sciences), and in industry-oriented research institutions (under many Ministries of different industry branches). In the modern Russia this division is mainly still existing, although some of the industry-oriented research bodies have become private. Some independent laboratories funded by direct industry contracts have been formed also within some academician institutions and universities.

Among the most important institutions in St. Petersburg which do research in radioscience we list :

- Universities and other educational institutions : St. Petersburg University, St. Petersburg Technical University, St. Petersburg Electrotechnical University, Technical University of Precise Mechanics and Optics, St. Petersburg University of Telecommunications
- Academy of Sciences institutions : Ioffe Physico-Technical Institute, Institute of Earth Magnetism, Ionosphere, and Radiowave Propagation, Mendeleev Institute of Metrology, Steklov Mathematical Institute, Astrophysical Observatory, Applied Astronomy Institute
- Industry-oriented Institutions and Industrial companies : Institute of Television, Vavilov Optical Institute, Leninetz, Svetlana, Positron, Ferrite

For example, Ioffe Institute is most known for its works in solid state physics, including electromagnetic properties. Leninetz Company is specialized in radar technology, Ferrite Company and its research institution called Domen is the leading Russian company in magnetic media development and production. We are unfortunately not able to cover their activities in the present review.

In the former Soviet Union, there were three main academic degrees:

- Diploma engineer (or physician, mathematician, etc.) This degree required about five years of study and a diploma thesis.
- Candidate of Sciences. This degree was similar to that of Ph.D. degree in the USA and corresponding degrees in other Western countries.
- Doctor of Sciences. This highest degree required a much more extensive thesis than for Candidate of Sciences, or authoring important scientific monographs. This degree is an obligatory step on the career way leading to the full Prof. position.

At present, this system remains basically the same, but at the level of Diploma engineer there is now a transition to a new two-level system. Similarly to the American system, degrees of bachelor and master can be earned, although some institutions continue with the previous engineer diploma study curricula. The master degree usually requires about 6 years of university study.

Radiophysics at the University of St. Petersburg

At present, the school of radiophysics headed by Prof. G.I. Makarov is one of the leading scientific schools among schools in natural sciences existing at the University of Saint Petersburg. This school actually is comprised of two formal bodies one of which is the Chair of Radiophysics being a part of the Faculty of Physics and the other part is the Scientific Research Institute of Radiophysics (a research division within the University).

The radiophysical school at the University provides education in radiophysics offering the engineer, bachelor, and master degrees in radiophysics, as well as postgraduate programs leading to the doctor degree in radiophysics.

The origin of the school is dated back to the thirties and it is closely linked with the name of a world famous Russian scientist, Academician V.A. Fock (1898-1974). He had very wide scientific interests, including field theory, quantum mechanics, and the theory of diffraction and wave propagation. It was the Fock's scientific works on diffraction of radiowaves around the Earth that gave rise to the branch of science which we call now *theoretical radiophysics* considering the problems of radiowave propagation near the Earth surface. The mentioned results by Fock together with the classical Sommerfeld's solution for the dipole field above the ground have formed the basis of the modern theory of radiowave propagation being developed at the University of Saint Petersburg.

Influence of works of V.A. Fock in radiophysics as well as the results of V.I. Smirnov and S.L. Sobolev in developments of mathematical methods in the wave propagation theory can not be overestimated. Such well-known things as Fock's functions in the problem of diffraction by a smooth body, method of functional invariant solutions of V.A. Smirnov and S.L. Sobolev, generalization of the Kirchhoff formula for wave equation in non-uniform medium by S.L. Sobolev are the classical results of modern diffraction theory. (Outside of the field of radiophysics, one must remember, e.g.Fock's space in quantum electro-dynamics and Sobolev's functional spaces in mathematics).

We could compare the influence of the results by Fock on development of the high-frequency diffraction theory in the former Soviet Union with that of the results by J.B. Keller for the Western scientific community. The works of V.A. Fock initiated appearance of investigations in the mathematical aspects of diffraction theory studied at the Mathematical Physics Department of the Physics Faculty of the University.

Initially different refinements of this classical problems were performed. Detailed properties of the fields over the Earth have been investigated for arbitrary Earth electromagnetic parameters in planar and spherical geometries. In the most general case of arbitrary properties of the ground different novel types of waves have been discovered. Pulse propagation along the Earth surface have been studied, too. Later on, the exhaustive theory of the

Earth wave propagation has been completed and published in the monograph by G.I. Makarov, V.V. Novikov, and S.T. Rybachek. [**1**] This book includes the spectral theory of the Earth wave propagation.

At present, research in the area of the ground wave propagation is being performed by the Research Institute and University staff members based on a broad variety of modern mathematical tools, from modified physical optics and path integral analysis to rigorous methods of the diffraction theory. Over a long period of time, a notable advance has been made in creating the mathematical basis for analysis of the radiowave propagation over electrically non-uniform surfaces and terrain features, as well as within irregular waveguides with geometrical ad material discontinuities. A. Osipov, a researcher at the division of radiophysics, was awarded the 1994 *Academia Europea Prize* for outstanding young Russian scientists for his papers on novel developments of the Malyuzhinets technique and its applications to the diffraction by edges of imperfectly conducting bodies.

Another scope of propagation problems under consideration are the problems of radiowave propagation in the Earth-Ionosphere waveguide. Presently, the investigation of the low frequency wave propagation in anisotropic Earth-Ionosphere channels can be considered as completed within the scope of the WKB adiabatic approximation, when the transverse mode coupling is neglected. Nevertheless one finds a lot of problems when the coupling effects cannot be neglected. This is a part of the current activities of this school of radiophysics.

A recent development in the theory of waveguide propagation is the accounting of the effects due to local waveguide inhomogeneities which lead to strong mode coupling. Among these problems there is the case when the channel properties vary strongly along the propagation path. As an example, this can be the case of paths crossing the Equator or when complex eigenvalues of two adjacent modes experience strong confluence.

Rather complicated problems arise when the effects of considerable transversal dependence of path electrical properties must be taken into account. This is especially true if the medium parameters variations in the transverse direction are essential already at distances comparable to the main Fresnel zone or smaller. In this case the diffraction effects must be taken into account.

A question of special interest is a waveguide excitation by sources embedded in the ionosphere. This is one of the problems of waveguide propagation which are deeply investigated in the monograph by G.I. Makarov, V.V. Novikov, and S.T. Rybachek. [**2**]

A series of papers devoted to the investigation of radiowave propagation in inhomogeneous plane stratified ionospheric plasma has been published by collaborators of the chair of radiophysics. These are papers by G.I. Makarov, V.V. Novikov, and some other people, who use the method of comparison functions in the investigation of particular properties of horizontally and vertically polarized fields due to singularities of the coefficients of the conforming equations.

The problem of the influence of local ionospheric inhomogenieties (deterministic or random) are also under consideration. In papers by Dr. N.N. Zernov the integral representation of the field in smoothly inhomogeneous media with local inhomogeneities by the component waves taking diffraction effects into account has been developed. This gipossibility to study diffraction on local irregularities in smoothly inhomogeneous media, including areas near singular surfaces of the ray field of the corresponding undisturbed problem. The ideas of the approach can be found in the compendium of lectures given by N.N. Zernov in the Swedish Institute of Space Physics (Uppsala) [**3**]

Independent scope of problems being a subject of special consideration is the electromagnetic waves diffraction on obstacles moving with relativistic velocities. The group of collaborators going in for this range of problems is headed by Prof. V.N. Krasilnikov.

Finally, problems of the linear and non-linear dynamics of ionospheric plasma are under intensive investigation at the Chair of radiophysics. These problems are considered mainly by Dr. V.A. Pavlov.

Except the propagational problems investigations in radioastronomy are also performed at the Institute of Radiophysics. The scientific interests of the group of radioastronomy headed by Prof. A.P. Molchanov lie mainly in the field of solar radioemissions exploring.

Recent developments in the fields described above are regularly published in the series of paper collections *Problems of Diffraction and Wave Propagation*, published by the University of St. Petersburg. By present, 26 issues in the series have been published, since the year 1962.

St. Petersburg University is famous for its scientific traditions in the diffraction theory with applications in radiophysics. Prof.s V.M. Babich, V.S. Buldyrev, V.S. Buslaev, V.F. Lazutkin and their collaborators continue to work in this direction and they support strong traditions in the mathematical diffraction theory. We might point out here as an example the well-known book by Prof.s V.M. Babich and V.S. Buldyrev [**4**] devoted to asymptotic methods in the short-wave diffraction theory. The investigations conducting by the researchers of the Mathematical Physics Department of St. Petersburg University are now aimed to study of a new class of boundary-contact problems of electromagnetic theory, scattering by surfaces with thin material coatings, high-frequency diffraction theory, space-time ray method, inverse problems, scattering theory and some others.

For many years the University of St. Petersburg in collaboration with the Russian Academy of Sciences has been organizing annual Seminar on radiowave propagation. Initially, the scientific scope of the Seminar was restricted mainly to very-low-frequency wave propagation, but nowadays it covers a wider range of radiowave propagation problems. There is a strong intention to hold it as an international seminar.

Another annual event traditionally held at the University of St. Petersburg for many years is the International Seminar *Day on Diffraction*. It is organized by Chair of Mathematical Physics (University of St. Petersburg) in cooperation with Steklov Institute of Mathematics. The seminar is mainly devoted to the mathematical aspects of the diffraction theory and wave propagation problems.

Radiophysics Department at St. Petersburg Technical University

St. Petersburg State Technical University was founded in 1899 as St. Petersburg Polytechnic Institute. On the picture (Figure 2) you can see the main building of the University, completed in 1901. Among the fathers of the University were D.I. Mendeleev (1834—1907), the author of the table of chemical elements, mathematician A.N. Krylov (1863—1945), and a pioneer in radiocommunications A.S. Popov (1859—1905). The foundation of the Faculty of Radiophysics and the Radiophysics Department is closely related to the activities of Academician A.F. Ioffe (1880—1960) in 1920's. He has created novel programs for students who wanted to become researchers in new directions of applied physics. The teaching includes both engineer education and deep studies in modern physics and mathematics, about 30 percent of the curriculum time is devoted to scientific research. Among past Prof.s of the Faculty we can mention N.N. Semenov, Ya.I. Frenkel, G.A. Grinberg, A.A. Fridman. One of then established bodies developed into what is called now the Radiophysics Department.

At present, the Faculty of Radiophysics consists of several Departments (or Chairs): Radiophysics Department, Radioengineering Department, Department of Physical Electronics, Department of Applied Physics and Solid State Optics, Semiconductor Physics Department, Quantum Electronics Department.

Figure 2. The main building of the St. Petersburg State Technical University.

Study programs lead to the engineer-physicist, bachelor, master and doctor degrees in radiophysics or physics. Here we briefly review some past and present scientific activities of the Radiophysics Department. Its first Prof.s were D.A. Rozhanski (later to become academician and to be fired by the Stalin regime) and N.D. Papaleksi. Some pioneer works on radars were made here, and *State Prize* was awarded to several specialists for the first operating long-distance radar in 1941. For a long time, since 1940 to 1980, the chair in radiophysics was Prof. M.I. Kontorovich (1906—1987). He established a school in electromagnetics of grid structures. **[5]** He is one of the authors of the well-known Kontorovich-Lebedev integral transform. We should also cite here his books on non-linear oscillations **[6]** and on the Laplace transform applications in radiophysics. **[7]** At present, the director is Prof. V.M. Nikolaev, specialist in fiber optics technology.

A wide variety of research topics are of current interest and under intensive development and will be briefly discussed in the following.

Since the sixties, one of the main research directions was the diffraction theory and antenna techniques. At first, the main effort was concentrated on asymptotic theory of diffraction by complex-shaped bodies. These studies were lead by Prof. V.Yu. Petrunkin. Later on, different complex antenna systems, including systems in layered lossy media were analyzed (Prof.s M.I. Kontorovich, V.Yu. Petrunkin, N.A. Esepkina).

Theoretical electromagnetics is always one of the main scientific interests of the Department. Currently, Prof. M.I. Astrakhan leads some projects in electromagnetics of wire grid structures. Asymptotic diffraction theory is another study direction (Dr. V.A. Karatygin, Dr. V.A. Rozov et al.)

The research group of complex media electromagnetics (Dr. S.A. Tretyakov) works on electromagnetics of chiral, bi-isotropic, and bianisotropic artificial composite materials. Many novel developments in electromagnetics of chiral and bi-isotropic media resulted from cooperation with the Electromagnetics Laboratory of Helsinki University of Technology and were summarized in the monograph. **[8]** Among the most recent results of the group is an analytical antenna model of chiral and Omega-shaped small particles and composites with such inclusions. The theory of electromagnetic waves in the most general bianisotropic uniaxial structures has been recently developed, which can possibly lead to practical results in low-reflection screens design. **[9]**

Phased antenna arrays have been studied and developed for several decades. At present, some new principles in integrated millimeter wave phased antenna arrays are suggested and developed by Prof. E.F. Zaitsev and his colleagues. See the photo of a new antenna in Figure 3. Dr. V.V. Guriev with his group works on novel special antennas and radar systems for applications in archeology and for restoration of old historical buildings. Antennas for remote sensing, radioastronomy, and air traffic control applications are developed by research groups lead by Prof. D.V. Shannikov and Dr. V.N. Dikiy.

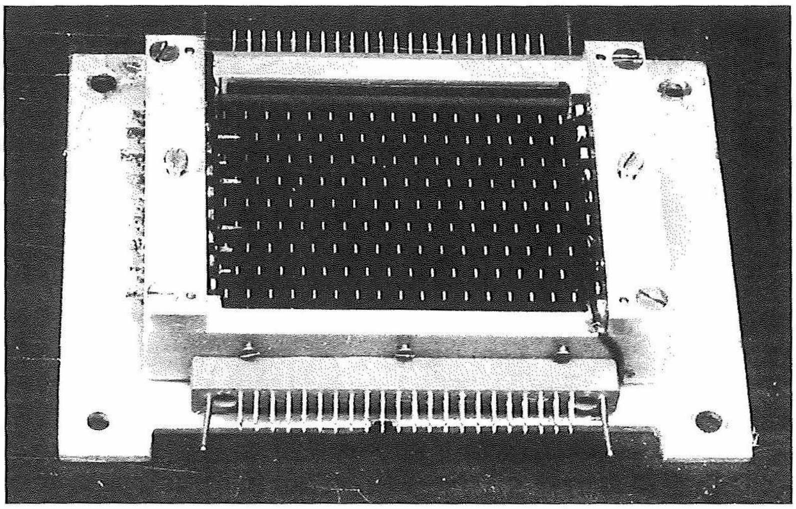

Figure 3. 8-millimeter planar scanning array antenna developed at the St. Petersburg State Technical University.

Long-time research and development of linear and non-linear microwave ferrite devices was summarized in a monograph by V.V. Rogozin and V.I. Churkin. [**10**]

Within the Department, there is a Laboratory of New methods in Microwave Signal Processing, directed by Prof N.A. Esepkina. The main direction of Laboratory activities is development of acousto-optic signal processors and information processing systems, mainly for applications in radioastronomy.

Radiophysical aspects of fiber optics systems are studied by Department Director, Prof V.M. Nikolaev, Dr. O.I. Kotov and their collaborators. The main emphasis here is on multi-mode optical guides with applications to various sensors of temperature, pressure, position, etc.

Conclusion

At present, the scientific research in Russia has facing extremely severe funding cuts. The funds for basic research are hardly enough to pay for heating and electricity, and the salary level hardly reaches the official survival minimum. This naturally leads to brain drain, since only few formalities needed now to obtain a passport. Existing and working research teams mainly rely on foreign sources of funding, such as private contracts, but that is not always possible for scientists conducting basic research. The International Science Foundation (or Soros Fund) is doing a lot to support prominent scientists in the former Soviet Union states. Also, a new system of funding from the State budget which is based on competitive evaluation of projects is taking its first steps in Russia. Hopefully when the economy in Russia and other regions of the former Soviet Union and Eastern Europe matures, the science will continue to develop there at its best possible pace.

We would of course very welcome any interest in more information about our works and publications, and we invite everybody to send us their requests.

References

1. G.I. Makarov, V.V. Novikov, S.T. Rybachek, *Electromagnetic wave propagation along the Earth surface*, Moscow: Nauka, 1991 (in Russian).
2. G.I. Makarov, V.V. Novikov, S.T. Rybachek, *Radiowave propagation in the Earth-Ionosphere waveguide and in the ionosphere*, Moscow: Nauka, 1994 (in Russian).
3. N. Zernov and B. Lundborg, *The statistical theory of wave propagation and HF propagation and scattering in the Ionosphere with local inhomogeneities*, IRF Scientific Report No. 215 (ISSN 0284-1703), Uppsala, Sweden, 1993.
4. V.M. Babich and V.S. Buldyrev, *Short-wavelength diffraction theory: Asymptotic methods*, Springer Series in Wave Phenomena, Ed. L.B. Felsen, Berlin: Springer Verlag, 1991.
5. M.I. Kontorovich, M.I. Astrakhan, V.P. Akimov, and G.A. Fersman, *Electrodynamics of grid structures*, Moscow: Radio i Sviyaz, 1987 (in Russian).
6. M.I. Kontorovich, *Nonlinear oscillations in radio engineering*, Moscow: Mir Publishers, 1976.
7. M.I. Kontorovich, *Operational calculus and processes in electric circuits*, Fourth edition, Moscow: Sovietskoye Radio, 1975 (in Russian).
8. I.V. Lindell, A.H. Sihvola, S.A. Tretyakov, A.J. Viitanen, *Electromagnetic waves in chiral and bi-isotropic media,* Boston and London: Artech House, 1994.
9. S.A. Tretyakov and A.A. Sochava, Novel uniaxial bianisotropic materials: Reflection and transmission in planar structures, Chapter 9 in *Progress in Electromagnetics Research (PIER 9),* edited by A. Priou, 1994.
10. V.V. Rogozin, V.I. Churkin, *Ferrite filters and power limiters,* Moscow: Svyaz, 1985 (in Russian).

Lille General Assembly 1996

SCIENTIFIC PROGRAMME

The first announcement of the General Assembly came out in July, and has been widely distributed by the French organizers. It is not practical to reproduce this document in full. We give, instead, an outline of the programme, mentioning titles of Symposia and names of convener(s). The letters I, C, P, which appear repeatedly in the text, have the following meaning:
I: oral session consisting of Invited papers only.
C: oral session open to accepted Contributed papers.
I+C: oral session open to accepted Contributed papers, including some Invited papers.
P: Poster session open to accepted contributed papers.

The announcement contains detailed instructions for submission of contributions. We note that authors of invited, contributed and poster papers should submit a one page abstract before January 8, 1996 to:

AG URSI
Dr. Martine Lienard
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F-59655 Villeneuve d'Ascq Cedex
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Fax:33-20-337207
E-Mail: agursi@univ-lille1.fr

Copies of the announcement may be obtained from Dr. Lienard's office.

Guest Lecture

Radio Science, pulsar and general relativity
Dr. J. H. Taylor, Nobel Prize (USA)

General Lectures

Lightwave communications
Dr. M. Joindot (France)

From coherence to confusion : a conservative SAR view
Dr. R. K. Raney (USA)

Nonlinear Physics and Chaos
Prof. W. Lauterborn (Germany)

Programme of Commission A (Electromagnetic Metrology)

AT Counting of single flux and single charge quanta for metrology
J. Niemeyer (Germany)

A1 Time keeping and time transfer (I)
M. Granveaud (France) and K. Dorenwendt (Germany)

A2 New RF-to-submillimeter wave standards and measurements (I+P)
D. Janik (Germany) and R. F. Clark (Canada)

A3 Material Measurements (I+P)
R. N. Clarke (UK)

A4 Lightwave communication metrology
K. Asatani (Japan) and F. Gauthier (France)

Programme of Commission B (Fields and Waves)

BT High frequency methods in electromagnetics
R. Tiberio (Italy)

B1 Guided and leaky waves (I+C)
R. E. Collin (USA) and T. Yoneyama (Japan)

B2 Non-linear electromagnetics (I+C)
J. M. Arnold (UK) and R. Ziolkowski (USA)

B3 Exotic and complex media (I+C)
D. L. Jaggard (USA) and I. V. Lindell (Finland)

B4 Reflector and feed antennas (I+C)
G. L. James (Australia) and M. Ando (Japan)

B5 Planar and microstrip antennas (I+C)
L. P. B. Katehi (USA) and J. Vokurka (Czech Rep.)

B6 Computational techniques (I+C)
B. A. Austin (UK) and D. De Zutter (Belgium)

B7 Integral equations and hybrid methods (I+C)
R. D. Graglia (Italy) and D. R. Wilton (USA)

B8 Inverse scattering (I+C)
T. M. Habashy (USA) and E. Heyman (Israel)

B9 Electromagnetic theory (I+C)
S. Strom (Sweden) and P. M. van den Berg (The Netherlands)

BP Poster session (P)
A. D. Olver (UK), C. M. Butler (USA) and D. Dudley (USA)

Programme of Commission C (Signals and Systems)

CT Communications by means of low earth orbiting satellites
R. L. Pickholtz (USA)

C1 High-frequency technology for mobile/personal communications (I+C)
I. Ohtomo (Japan)

C2 Recent research and development activities in millimeter and submillimeter waves (I+C)
K. Mizuno (Japan)

C3 Synthesis and analysis of systems (I+C)
B. Shishkov (Bulgaria)

C4 Mobile and personal communications (I+C)
A. Sumakic (Belgium) and E. Bonek (Austria)

C5 Wavelets, time-frequency analysis and modal decomposition (I+C)
D. J. Thomson (USA)

C6 Advances in channel coding and modulation (I+C)
M. G. Battail (France)

C7 Multimedia and broadband networking (I+C)
A. Danthine (Belgium)

C8 Multiple user satellite communications techniques (I+C)
L. J. Mason (Canada)

C9 Digital signal processing in telecommunications (I+C)
P. Delogne (Belgium)

Programme of Commission D (Electronics and Photonics)

DT Optoelectronics integration
H. Burkhard (Germany)

D1 Advances in MMIC (I+C)
R. J. Trew (USA)

D2 Low power integrated devices and circuits (I+C+P)
D. Skellern (Australia) and R. Brodersen (USA)

D3 Advances in III-V devices (I+C)
H. Hartnagel (Germany)

D4 Wide bandgap devices (I+C)
M. Shur (USA)

D5 Advances in device modeling (I+C)
C. Snowden (UK)

D6 Optical interconnects (I+C)
B. Mroziewicz (Poland)

D7 Optoelectronic devices and integration (I+C)
K. Tada (Japan)

D8 Squeezed light and photonic bandgap devices (I+C+P)
P. Edwards (Australia)

D9 Wireless circuits and components (I+C)
J. Henaff (France)

Programme of Commission E (Electromagnetic noise and Interference)

ET Topology-based modelling of very large EM-systems
J. P. Parmantier and P. Degauque (France)

E1.1 Dusty plasmas — meteorologico-electric environment and EHD (I+P)
H. Kikuchi (Japan) and E. Mareev (Russia)

E1.2 Self-organisation and chaos in meteorologico-electric environment (I+P)
S. S. Moiseev (Russia) and H. Kikuchi (Japan)

E2.1 Terrestrial electromagnetic environment (I+C+P)
M. Hayakawa (Japan) and A. P. Nickolaenko (Ukraine)

E2.2 Electric discharges from cloud-top to the ionosphere (I+C+P)
Z. I. Kawasaki (Japan) and V. Cooray (Sweden)

E3 Planetary lightning and related phenomena (I+P)
W. J. Borucki (USA) and M. Hayakawa (Japan)

E4 Spectrum management and utilization (I+P)
R. D. Parlow (USA) and R. G. Struzak (Switzerland)

E5 High power electromagnetics (I+P)
R. L. Gardner (USA) and C. Baum (USA)

E6 Electromagnetic topology for electromagnetic interference analysis and control (I+P)
P. Degauque (France) and J. Nitsch (Germany)

E7 Coupling to multiwire cables (I+P)
F. G. Canavero (Italy) and J. L. ter Haseborg (Germany)

E8 Susceptibility of electronic devices or equipment to high amplitude electromagnetic interference (I+P)
V. Scuka (Sweden) and B. Demoulin (France)

Programme of Commission F (Wave Propagation and Remote Sensing)

FT Impact of numerical methods on propagation modelling
K. H. Craig (UK)

F1 Remote sensing of cloud and precipitation (I+C+P)
K. Okamoto (Japan)

F2 SAR Interferometry and polarimetry (I+C+P)
J. van Zyl (USA)

F3 Remote sensing of the ocean (I+C+P)
W. Sobieski (Belgium)

F4 Remote sensing for ecology (I+C+P)
M. Hallikainen (Finland)

F5 Gaseous absorption 10 to 1000 GHz and remote sensing of water vapor (I+C+P)
A. J. Gasiewski (USA) and H. J. Liebe (USA)

F6 Remote sensing of ice sheets (I+C+P)
S. P. Gogineni (USA)

F7 SIR-C/X-SAR results (I+C+P)
H. Ottl (Germany)

F8 Climatic parameters in radiowave propagation prediction (I+P)
M. P. M. Hall (UK) and J. P. V. Poiares Baptista (The Netherlands)

F9 Depolarization due to hydrometeors (I+C+P)
A. Paraboni (Italy)

F10 Mobile and personal communications (I+C+P)
J. Bach Andersen (Denmark)

Programme of Commission G (Ionospheric Radio and Propagation)

GT The equatorial ionosphere
B. M. Reddy (India)

G1 Ionospheric models and indices (I+C)
D. Bilitza (USA)

G2 Ionospheric HF-propagation and telecommunication (I+C+P)
B. W. Reinisch (USA)

G3 Troposphere-stratosphere-ionosphere studies using the GPS/GLONASS system (I+C+P)
P. Hoeg (Denmark)

G4 Observations and modelling of high latitude E- and F-region ionospheric structures (I+C+P)
A. V. Shirochkov (Russia)

G5 Computer aided processing of ionograms and ionosonde records (I+C+P)
P. Wilkinson (Australia)

G6 Radio tomography of the ionosphere (I+C+P)
R. Leitinger (Austria)

G7 Open session and latest results (I+C+P)
N. Matuura (Japan)

G8 Advanced radar studies of the ionosphere and the middle atmosphere (I+P)
J. Rottger (Sweden)

Programme of Commission H (Waves in Plasmas)

HT Radio emission from instabilities in space plasmas: marginal stability, stochastic growth and fine structures
D. B. Melrose (Australia)

H1 Whistler-mode waves and their effects on the radiation belt (I+C+P)
A. J. Smith (UK), U. Inan (USA) and J. Lemaire (Belgium)

H2 Active experiments in space observed by in-situ and remote sensors (I+C+P)
W. J. Raitt (USA)

H3 Plasma wave observations by multiple spacecraft in geospace (I+C+P)
I. Kimura (Japan), W. L. Taylor (USA) and F. Lefeuvre (France)

H4 Nonlinear theory and computer simulations on waves and particles in geospace plasmas (I+C+P)
M. Ashour-Abdalla (USA) and H. Matsumoto (Japan)

H5 Open session on latest results (C+P)
F. Lefeuvre (France)

Programme of Commission J (Radio Astronomy)

JT Cosmics masers - a useful tool in radio astronomy
J. M. Moran (USA)

J1 Measurements of the cosmic microwave background (I+C+P)
R. D. Davies (UK)

J2 Pulsars and interstellar matters (I)
V. Radhakrishnan (India)

J3 Millimetre and sub millimetre astronomy (I+P)
S. Guilloteau (France)

J4 Next generation millimetre/sub millimetre arrays - technical and observational challenges (I+P)
R. S. Booth (Sweden) and M. Ishiguro (Japan)

J5 Next generation large cm/decimetre telescopes (I+C+P)
R. Braun (The Netherlands)

J6 New developments in VLBI (I+C+P)
C. Walker (USA)

J7 Highlights of the past three years (I+C+P)
R. Ekers (Australia)

J8 Observatory reports (C+P)
T. L. Wilson (Germany)

Programme of Commission K (Electromagnetics in Biology & Medicine)

KT Personnal communication services - technology and health concerns - is there a common solution?
M. A. Stuchly (Canada)

K1 Biological effects and mechanisms of interactions (I+C+P)
A. Chiabrera (Italy) and B. Veyret (France)

K2 Safety of ELF and LF applications (I+C+P)
C. Polk (USA) and L. D. Szabo (Hungary)

K3 Safety of wireless communication (I+C+P)
N. Kuster (Switzerland) and J. C. Lin (USA)

K4 Medical applications of electromagnetic waves (diagnostic and therapeutic) (I+C+P)
K. M. Reineck (South Africa) and S. Ueno (Japan)

Joint Sessions

AB1 Antenna and EM field metrology (I)
A: M. Kanda (USA) and B: J. Reddy (The Netherlands)

AB2 Time domain measurements (I+P)
A:M. Kanda (USA) and B: S. M. Riad (USA)

ABD Interconnection and packaging of high speed devices (I+P)
D: A. R. Mickelson (USA), B: T. A. Fjeldly (Norway) and A: M. Kanda (USA)

AD Lasers, stabilization and applications (I+P)
A: J. Helmcke (Germany) and D: P. Gill (UK)

AE Electromagnetic metrology applied to EMC (I+P)
A: J. Glimm (Germany) and E: M. Kanda (USA)

AF Spaceborne SAR: techniques, technology and applications for earth observation (I)
W. Keydel (Germany)

CD Integration technology of microwaves and lightwaves-systems and devices (I+C)
C: M. Akaike (Japan) and T. Berceli (Hungary)

CE Electromagnetic interference to the new generation of digital radio systems above 1 GHz (I+C)
C: T. Kobayashi (Japan) and E: B. Despres (France)

DA1 Advances in superconductor electronics (I+C)
D: O. Vendick (Russia) and A: H. Chaloupka (Germany)

DA2 Optical time domain measurements (I+C)
D: D. Jaeger (Germany) and A: T. K. Sarkar (USA)

DB1 Comprehensive electromagnetic modeling (I+C)
D: R. Sorrentino (Italy) and B: P. Russer (Germany)

DB2 Electronic microfabrication in manufacturing (I+C+P)
D&B: P. L. E. Uslenghi (USA)

DC Microwave/optical interactions (I+C)
D: C. Someda (Italy) and C: H. Ogawa (Japan)

EA Electromagnetic compatibility and E. M. pollution (I+P)
E: P. Degauque (France) and A: P. Corona (Italy)

EB Field Propagation and Coupling to Structures (I+P)
E: M. Ianoz (Switzerland) and B: F. M. Tesche (USA)

EF Radio noise and interference above 30 MHz (I+P)
E: E. K. Smith (USA), J. Gavan (Israel) and F: E. R. Westwater (USA)

EK Characterization of EM-sources and design of equipment for minimum coupling with the human body. (I+P)
E: R. De Leo (Italy) and K: H. Korniewicz (Poland)

HCJ Signal processing techniques with space radio and plasma wave aata (I+C+P)
H: L. J. Woolliscroft (UK) and C: W. Kofman (France)

HEG EM coupling between the ground (including seismic activity) and the upper ionosphere and the magnetosphere (I+C+P)
H: M. Parrot (France), O. A. Molchanov (Russia), E: T. Yoshino (Japan) and G: A. C. Fraser-Smith (USA)

HG1 Computer simulation of multiple scale processes in space plasmas (I+P)
H: G. Chanteur (France) and G: P. Janhunen (Finland)

HG2 Effects of lightnings and VLF waves on the ionosphere (I+C+P)
H: D. Nunn (UK) and G: M. Rycroft (UK)

HG3 Ionospheric modifications by high-power HF waves : coupling of plasma processes (I+C+P)
H: P. Bernhardt (USA) and G: S. Basu (USA)

HGCJ Turbulence and wave analysis for non gaussian signals (I+P)
G: A. W. Wernik (Poland), H: V. Krasnosselskikh (France), C: J. L. Lacoume (France) and J: Tatarski (Russia)

HJ Observations and interpretations of interplanetary and planetary emissions (I+C+P)
H: R. F. Benson (USA), H. Oya (Japan) and J: M. R. Kundu (USA)

JB1 Focal plane arrays
J: N. Whyborn (The Netherlands), B: G. L. James (Australia)

JB2 New antenna technology
J: P. Napier (USA) and B: R. C. Hills (UK)

JCE Interference problems in radio astronomy and communications -or cosmic ecology (I+C+P)
J: J. Whiteoack (Australia) and C: L. W. Barclay (UK)

KA Human exposure assessment and related Measurements (I+C+P)
K: L.E. Paulsson (Sweden) and A: S. Tofani (Italy)

KB Electromagnetic modelling in bioelectromagnetics (I+C+P)
K: O. P. Gandhi (USA) and B: P. Excell (UK)

Joint Sessions with Other Organisations

D-ICO Nonlinear optical phenomena and devices in transmission systems (I+C)
D: A. Seeds (UK)

D-IWGP Wideband characterization of printed circuits (I+C)
D: T. K. Sarkar (USA), D. Jaeger (Germany) and E. Miller (USA)

CONFERENCE REPORTS

11TH INTERNATIONAL ZURICH SYMPOSIUM AND TECHNICAL EXHIBITION ON ELECTROMAGNETIC COMPATIBILITY

Zurich, Switzerland, 7 - 9 March, 1995

The 11th International Zurich Symposium and Technical Exhibition on Electromagnetic Compatibility was held from March 7 to 9, 1995 at the Swiss Federal Institute of Technology in Zurich, Switzerland. The meeting was attended by 966 participants from 30 countries. The exhibition included 62 exhibitor booths.

Despite the fact that the growing number of international EMC conferences in Europe give rise to a certain saturation, these numbers confirm again the importance of this technical discipline and the high standing of the EMC Zurich Symposia. This biennial event has a significant place among others in Europe and overseas. Concluding from the origin of authors, participants and exhibitors, it is the most internationally oriented conference on that topic.

As in the preceding years, the Symposium has been organized by the Communication Technology Laboratory of the Swiss Federal Institute of Technology Zurich (ETHZ) under the auspices of F. Rosenberg, Director-General of the Swiss Telecom PTT. A number of international and national professional organizations were cooperating, e.g. ITU, IEEE and URSI, the latter also sponsoring the participance of young scientists. Prof. Dr. P. Leuthold (Zurich) and Dr. G. Meyer (Zurich) acted again as Symposium president and Symposium chairman, respectively. The technical program committee was chaired by Prof. Dr. C. Paul (Lexington).

A total of 122 carefully selected technical papers in 18 sessions outlined the frontiers of EMC science and technology, the sessions being devoted to: transient effects, EMC applications, power systems, transmission lines, standards, trends in spectrum management, circuit oriented techniques in EMC, EMC immunity testing, electromagnetic field hazards, EMC education and training, numerical techniques for EMC, immunity, lightning EMP, EMC instruments and measurements, shielding and coupling, electronic design under EMC constraints, alternatives to open area test sites and ESD dynamics (model/measurement).

The sessions covered virtually all EMC "hot" topics and reviewed the current status as well as future trends of EMC technology. The symposium proceedings with 664 pages of full texts of the presentations has been made available.

An insight into the work of URSI Commission E and K was offered by open meetings which took aim at the discussion of the progress in the different working groups and at the identification of outstanding topics and new lines of research for the future.

The program did not exclusively address the experts. An introduction to EMC technology was ensured by three tutorial lectures and two workshops. The full text of these joint events has been made available in the 176 page supplement to the symposium proceedings.

Overwhelming response by the audience have been given to the presentations on EMC standards, especially the European EMC-Directive, biological effects, coupling to transmission lines, PCB design, test methods and theoretical EMC models. It is difficult to point out general trends in the field of EMC but with the growing interests in theoretical models and numerical methods, the role of computers is becoming more and more important.

As usual, the Technical Exhibition has significantly contributed to the success of EMC Zurich'95 by demonstrating the fast conversion of theoretical knowledge into state-of-the-art hard- and software.

A representative inquiry showed that about half of the participants also attended EMC Zurich'93. 58% of the attendees visited at least one EMC conference in the past year, and 18% were present at more than one per year. Moreover, one third of the participants seems to prefer the two year rhythm, for another third there is a need for one or more symposia per year. The rest are "newcomers". Three quarters of the attendees rated the presented papers with the mark "good", about 20% with the mark "excellent". Once again the inquiry clearly showed that the real value of a symposium is its role as a platform of personal information exchange. More than two thirds of the participants stated that they found solutions to actual problems during the symposium and as much as 90% said that they could at least find valuable contacts.

The inquiry also returned some very interesting suggestions for the next EMC Zurich Symposium which is planned for February 18 to 20, 1997. Due to the rearrangement of the semesters at the Swiss universities including ETHZ, we are forced to move the conference to the second half of February. The call for papers of the 12th International Zurich Symposium and Technical Exhibition on EMC is scheduled for November 1995.

All information about EMC Zurich and much more may be found through our WorldWideWeb home page: http://www.nari.ee.ethz.ch

We also maintain a list of major recurrent EMC meetings and offer the possibility to announce further events. The dissemination of much more valuable information is planned for the future.

For further information, please contact :

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ETH-Zentrum, IKT
CH-8092 Zurich
Switzerland
e-mail: gmeyer@nari.ee.ethz.ch

THE NINTH INTERNATIONAL SYMPOSIUM ON EQUATORIAL AERONOMY INCLUDING THE MIDDLE ATMOSPHERE (ISEA)

Bali, Indonesia, 20 - 24 March, 1995

The Ninth International Symposium on Equatorial Aeronomy including the Middle Atmosphere was organized by the Radio Atmospheric Science Center of Kyoto University, hosted by the Indonesian National Institute of Aeronautics and Space (LAPAN), and cosponsored by the Union Radio-Scientifique Internationale (URSI), was held at the Bali Cliff Resort in Bali, Indonesia. It was sponsored also by the Scientific Committee on Solar-Terrestrial Physics (SCOSTEP), the International Association of Meteorology and Atmospheric Sciences (IAMAS), the International Association of Geomagnetism and Aeronomy (IAGA), and the Society of Geomagnetism and Earth, Planetary and Space Sciences (SGEPSS).

Prof. Dr. Wardiman Djojonegoro, Minister of Education and Culture of Indonesia, gave the keynote address at the Opening Ceremony held on March 20.

The Ninth ISEA was attended by more than 160 participants from 19 countries. The programme included approximately 180 invited, contributed, and poster papers which were related to recent progress and future perspectives on a wide range of issues concerning equatorial aeronomy including the middle atmosphere sciences. Some selected papers will be published in a Special Issue of the Journal of Atmospheric and Terrestrial Physics, which are currently being edited by Guest editor, Professor S. Fukao. The major topics were as follows:

- Equatorial and low latitude ionospheric irregularities
- Recent equatorial and low latitude aeronomy campaigns
- Equatorial mesospheric processes
- Equatorial and low latitude ionospheric electrodynamics
- Equatorial and low latitude ionospheric modeling
- Equatorial and low latitude facilities: Recent results and the future
- Dynamics of the middle atmosphere
- Ionosphere-thermosphere processes

Two tutorial talks were also given by Prof. D. T. Farley of Cornell University on the topic of "Equatorial *E*-region plasma waves," and by Dr. J. Röttger of EISCAT on the topic of "Aeronomy and dynamics of the mesosphere and lower thermosphere studied by Thomson scatter radar."

Dr. Erhan Kudeki of the University of Illinois, Urbana-Champaign, Illinois was elected as Chairman of the next ISEA.

The recommendations were adopted at the General Assembly for the following six issues:

- Additional support for Indonesian facilities and scientists working on ISEA and middle atmosphere sciences.
- Completion of the ionospheric observatory in Sao Luis, Brazil.
- Development of new equatorial radars for observations of 150 km echoes.
- Coordinated observations with ROC SAT and other satellite programs.
- October total eclipse in Asian sector.
- Additional stations in the American sector to complement Jicamarca observations.

Almost all participants stayed at the Bali Cliff Resort, which is located on the southernmost cliff of Bali and faced the panoramic Indian Ocean to the south, and could fully enjoy the tropical atmosphere.

The Symposium provided a Reception on the evening of March 20 at the outdoor restaurant, and the Symposium Dinner with Monkey Dance (Kecak) in a cave near the private beach of the hotel on the evening of March 23. The Symposium Tour to a volcanic highland (Kintamani) and local handycraft centers was attended by more than 100 participants. The Symposium was reported by a local TV and several newspapers of Indonesia.

The Symposium is very grateful to URSI for financial support to two participants from developing countries. Extended abstracts of the Ninth ISEA are available at the following address:

Prof. S. Fukao
Radio Atmospheric Science Centre
Kyoto University
Gokasyo, Uji-shi
Kyoto 611, Japan.

Shoichiro Fukao
Chairman of the Ninth ISEA

15TH INTERNATIONAL SYMPOSIUM ON ELECTROMAGNETIC THEORY

St.Petersburg, Russia, 23-26 May 1995

The main event which Commission B organises between General Assemblies is the International Symposium on Electromagnetic Theory. The 15th Symposium in the series took place over four days in St.Petersburg, Russia from 23 to 26 May 1995. The decision to hold the 15th Symposium in Russia was made in 1992 shortly after the end of the Cold War and the collapse of the Soviet Union. This led Commission members to warmly embrace the invitation from the Russian Commission B to hold the Symposium in St.Petersburg. There are a large numbers of electromagnetic theorists in the Former Soviet Union (FSU) and this was an opportunity to increase the level of contact.

The organisation presented considerable challenges but the results showed that it was successful, beneficial to participants and particularly rewarding to those in Russia and Ukraine who would not have the funds to travel to conferences outside the Former Soviet Union. Communication into and out of Russia were known to be problematic and the local committee had little experience of the international side of Commission B. It was therefore decided to split the organisation clearly into two parts. The St.Petersburg Committee, led by Professor Buldyrev of St.Petersburg University, handled the local arrangements and liaised with authors and participants from the Former Soviet Union. The technical programme and all communication with participant from outside the former soviet Union was handled by the Chair of Commission B in London. This dual site organisation worked much better than expected mainly due to the excellent collaboration between London and St.Petersburg and the hard work of the St.Petersburg team. It was also considerably helped by the existence of the Internet. E-mail communication proved extremely valuable. It was not only the most reliable method of communicating with St.Petersburg but also enabled participants to obtain answers to questions quickly.

The Symposium was held in the historic Smolny Institute. This was a late change of venue due to the high rental requested by the original venue. The Smolny Institute was the first headquarters of the Communist Party from which Lenin declared the Revolution complete. It is now the home of the City Government who gave us the use of the venue free of charge. It proved to be a good choice and the City Government were most cooperative. Particularly impressive was the main Lenin Hall which housed the plenary sessions with a gigantic portrait of Lenin adorning the end wall and sumptuous chandeliers.

A total of 348 participants took part in the Symposium from 33 countries. As expected the largest contingent came from the host country, Russia (133). Unfortunately the number attending from the other former Soviet Union countries was small. In the present economic situation, even travel from Moscow to St. Petersburg and the accommodation during the symposium were too expensive for many, and a number of Russian authors could not make it - the situation was even worse for Ukraine and Belarus participants. Salaries in the range 100 $ to 200 $ per month and they are often paid after long delays. In these circumstances it is good that so many managed to attend and their active participation was much appreciated by everyone.

The Technical Programme Committee had received 456 synopses, each of which was reviewed by at least three people. The led to the eventual selection of 293 papers which appeared in the Advance Programme. To be included in the final programme, authors had to submit a full paper be 1 March and pay the registration fee. This procedure reduces the problem of participants who do not show up at the Symposium and cause considerable annoyance to those who wait for a paper to be given. The final programme contained 269 papers.

There were 32 technical session which covered the following main areas: wave propagation in a wide variety of media, linear and nonlinear, anisotropic and bi-anisotropic, chiral, composite, with periodical and stochastic inhomogeneities, enclosed within waveguides, forward and inverse scattering, including microwave imaging, with various kinds of reflecting obstacles and surfaces, computation techniques: numerical, asymptotic, FDTD, transient responses, basic electromagnetic theory, antennas: apertures, horns, reflectors, slots, patches, dipoles, arrays, resonators, together with analysis and synthesis techniques.

There were many novel and original presentations which are in the Proceedings. This has 894 pages and contains a wealth of information that would be difficult to find elsewhere, covering in particular original developments made in Soviet institutions (orders can be placed with Professor David Olver, see below).

A popular feature of the EM Theory Symposia is the invited lectures which provides a good opportunity to hear an expert give a lecture on their subject. In St.Petersburg, the four invited lectures were: The Ideas of Short-Wavelength Diffraction Theory by V M Babich (Russia); Modeling at Low Frequencies in Integral and Partial Differential Equation Formulations by D R Wilton (USA); Spherical Multipole Analysis of Scalar and Electromagnetic Fields by S Blume (Germany); Electromagnetics: Present Position and Future Trends by P J B Clarricoats (UK). The latter was a review of some of the current research and application areas which determine the present research activities in electromagnetics together with a personal view of how the developments in technology will influence trends in the future. Peter Clarricoats gave his review lecture in the final, plenary, session. This format works well and provides a cohesive close for the Symposium.

The social side of the Symposium is as important as the technical sessions. St.Petersburg is one of the great historic cities in Europe and participants were able to sample some of the highlights, particularly the magnificent Hermitage Museum with its incomparable collection of art. There were organised social events each evening of the Symposium as well as a programme of tours for accompanying persons. The social events were a get-together party, a visit to the Kirov Ballet to see Swan Lake, a boat excursion along the main river and a banquet. The banquet was organised informally and the price was included in the registration fee so that everyone attended.

One of the most successful aspects of the EM Theory Symposium was the Young Scientist Award Programme. This operated similar to the Awards at General Assemblies and enabled 25 Young Scientists who would not otherwise have been able to go to St.Petersburg to participate in the Symposium. Funds for the Awards came partly from the Commission B triennial allocation from URSI and partly from the general registration fees. The Awardees received free registration and an amount to cover accommodation and costs in St.Petersburg. Those from developing countries also received a contribution towards travel costs. The enthusiasm of the Young Scientists was very evident. They fully participated and made every opportunity to make the best use of their time to interact with other EM scientists. The Young Scientists were asked to write short reports on their participation. Many positive comments were received. One Awardee wrote remarks which are representative of many when she said:

The Symposium was very attractive, with a very interesting technical content. There were papers on relevant topics of current interest. In all the sessions I attended, the subjects of the papers were closely related (which does not always happens in conferences). As well as the theoretical basis, you could also see that practical applications were presented. It was also very good that we did not have too many parallel sessions, it was easy to select the papers you wanted to attend. It was very useful for me as a Young Scientist to have the opportunity of attending the Symposium. This kind of meeting is a good way of trying to keep up-to-date with developments. You have the opportunity of meeting your colleagues, and for me, it is as important to be able to discuss with them outside the formal sessions. It is nice to talk with the people that you know only by their picture in an electromagnetic journal.

I would like to congratulate the organisers which was excellent, and I really appreciate the big effort done by St. Petersburg University as well, of course, as the URSI Commission.

In summary, the 15th Commission B Electromagnetic Theory Symposium was a great success which undoubtable furthered the URSI aim of international cooperation and provided a picture of electromagnetic theory in 1995. The 16th Symposium will take place during 1998 in Thessaloniki, Greece.

Copies of the Proceedings of the Symposium can be obtained ($30 plus postage) from :

Professor David Olver
Chair, Commission B
Department of Electronic Engineering
Queen Mary & Westfield College
Mile End Road
London E1 4NS, United Kingdom
Fax:+44 181 981 0259
E-mail: a.d.olver@qmw.ac.uk

"CO: TWENTY-FIVE YEARS OF MILLIMETER-WAVE SPECTROSCOPY"

Tucson, Arizona, USA, 29 May - 2 June 1995

This IAU Symposium 170 was sponsored by IAU, URSI, and National Radio Astronomy Observatory and Submillimeter Telescope Observatory.

The Symposium was organised to commemorate the discovery in 1970 of interstellar carbon monoxide. The 2.6 mm wavelength emission line of this molecule was first detected by R. W. Wilson, K. B. Jefferts, and A. A. Penzias with the NRAO millimeter telescope on Kitt Peak, near Tucson. This discovery lead to studies that revolutionized our understanding of the phases of the interstellar medium, the initial and final phases of stellar evolution, the chemistry of the dense interstellar matter, the structure of the Milky Way galaxy, and the content and structure of other galaxies. Since then a number of powerful telescopes for the millimeter and, more recently, the submillimeter region have contributed to an enormous growth in millimeter radio astronomy, which is now one of the most active areas of astrophysical research.

The Symposium drew about 225 researchers to Tucson, among them several of the pioneers in this field. A large group of young astronomers from all over the world also participated in the presentations and discussions.

The core of the scientific program consisted of thirty invited review talks on all areas of millimeter astronomy. These presentations covered molecular clouds and the interstellar medium of the Milky Way, interstellar chemistry, cloud cores and star formation, CO in the Galactic center, CO in other galaxies, particularly in starburst galaxies and in galactic nuclei, CO in the Solar System, and circumstellar envelopes. Forty three oral contributions complemented the reviews and more than 150 posters presented a wealth of additional material. The available space allowed all the posters to be viewed throughout the entire duration of the Symposium.

Special evening sessions were devoted to instrumentation and to a panel discussion on the "X-factor," the ratio of CO line intensity to molecular hydrogen column density. In addition the URSI/IAU Joint Working Group on a Large Millimeter Array and the Large Millimeter Telescope Project held public sessions the day preceding the start of the regular sessions. The Symposium dinner was concluded with a delightful account by Robert Wilson of the discovery observations of CO, illustrated with historical slides.

The Symposium proceedings will be published by Kluwer in the IAU series. Since the size of this volume is limited, the space available for poster abstracts is quite restricted. Because so much interesting material was presented in the posters, however, the Symposium organizers have arranged to make expanded descriptions of the posters available over the Internet and as a companion printed volume with support from NRAO.

By all accounts, the Symposium was a great success: the contributions were uniformly interesting and well presented, the discussion was lively, and the audience remained attentive late into the evenings. With the growing observational potential of (sub)millimeter astronomy, this part of astronomy can look forward to great activity and exciting results over the next 25 years.

Simon Radford
Jacob Baars

FIRST INTERNATIONAL CONFERENCE ON RADIO SCIENCE (ICRS'95)

Beijing, China, 10-12 August, 1995

The first International Conference on Radio Science was held in Fragrant Hill Hotel, Beijing. The goal of this meeting is to discuss research achievements and some new ideas on radio science. The conference was organised by URSI and the Chinese Institute of Electronics (CIE, Beijing) and was co-sponsored by URSI-China, SRS (Taipei), Polytechnic University U.S.A., Hong Kong Polytechnic University, City University of Hong Kong and IEEE Beijing Section. It was also supported by National Natural Science Foundation of China.

Professor S.Z. Feng of the Chinese Institute of Electronics is the General Chairman of the ICRS'95. Professor Y.N. Huang from URSI-China, SRS (Taipei) and Professor K.K. Mei from the City University of Hong Kong are co-Chairmen.

ICRS'95 is an important activity of the URSI Committee of CIE. The overall aim was to exchange research achievements on radio science. The Proceedings of ICRS'95 are published and contain more than 205 papers (totalling 704 pages) about the following subjects : Electromagnetic Metrology, Field and Waves, Signals and Systems, Electronics and Photonics, Electromagnetic Noise and Interference, Wave Propagation and Remote Sensing, Waves in Plasmas, Electromagnetics in Biology and Medicine, Ionospheric Radio and Propagation, Radio Astronomy.

The invited papers of the Plenary Session are on the main achievements in Radio Science, to wit :

- *The Second Information Revolution and the Education for New Information Society*, by Saburo Matsuo from Software Consultant Co., Japan.
- *Past, Present and Future of Radiowave Propagation in China*, by Professor S.Z. Feng.
- *Electromagnetic Waves for the Underground Tomogram*, by Jung Woong Ra from Korea Advanced Institute of Science and Technology.
- *The Question of Invariance and Remote Progress in Measured Equation of Invariance*, by Professor K.K. Mei.
- *Ku Band Ionospheric Scintillation observed at Lunping during High Solar Activity Period*, by Professor Y.N. Huang.

There are more than 144 participants in ICRS'95, from the United States of America, Canada, United Kingdom, Germany, Australia, Bulgaria, Japan, Korea, Taiwan, Hong Kong and China. More than 50% of the participants are young scientists, with high quality papers and they are very active in the discussions of the meeting.

The Second International Conference on Radio Science (Beijing) will be held in 1998.

Prof. Da-Zhang Hu
Official Member, Commission F
for the China CIE Committee

IEEE FOURTH INTERNATIONAL SYMPOSIUM ON SPREAD SPECTRUM TECHNIQUES & APPLICATIONS (IEEE ISSSTA '96)

Mainz, Germany, 22-25 September, 1996

The IEEE Fourth International Symposium on Spread Spectrum Techniques and Applications (ISSSTA '96) continues the series of most successful spread spectrum symposia which doubtless are the major international forum for scientific and technical exchange in the area of spread spectrum techniques and applications from theory to implementation. The venue will be the Electoral Palace in Mainz, Germany. This old episcopal metropolis with a history dating back to the ancient Roman era is picturesquely located on the Rhine river. Frankfurt International Airport can be reached conveniently by commuter trains in 30 minutes. Connections to all places in Germany as well as the other European countries are excellent. During September the weather in Central Europe is usually pleasant and invites to enjoy sightseeing before or after the symposium.

Prospective Authors are cordially invited to submit papers in particular but not exclusively on the following topics:

- THEORY: Spreading codes and sequences, waveform design, spectral shaping; digital and analog spread spectrum signal processing, application of estimation theory, adaptive algorithms to track time varying channels; information security, ECM, ECCM, LPI; impact of distortions by filtering and nonlinear components, propagation effects, deterministic and stochastic channel modeling; antenna diversity, antifading techniques
- SYSTEM DESIGN: Tools for spread spectrum system design, modeling and simulation, application of AI; frequency allocation; standardization aspects, education in spread spectrum techniques; synchronization, acquisition, tracking; direct sequencing, frequency hopping, time hopping, hybrid concepts; power control; coexistence spread spectrum and other systems, overlay systems, EMC
- COMMUNICATIONS: Mobile & cellular, CDMA, SSMA; satellite; digital broadcasting; power line communications; radio relay; optical spread spectrum communications; wireless LANs; spread spectrum bus systems; consumer applications, remote control; packetized data & voice networks; ISDN, FDDI; multimedia; coding and modulation for spread spectrum, combined source and channel coding; principles to suppress interference, interference cancelation, joint (multiuser) detection, RAKE; capacity; networking, handover, dynamic channel allocation
- NAVIGATION, RANGING, CHANNEL SOUNDING: GPS, GLONAS; radar, SAR, lidar, pulse compression; identification systems; wideband channel sounding and analysis; deep space applications; correlation techniques to measure e.g. flow and speed; spread spectrum time domain reflectometry
- DEVICES AND CIRCUITS: ASICs for spread spectrum, chip sets, digital correlators, frequency synthesizers; application of signal processors; all digital transmitter and receiver implementations; ultrasonic signal processing, SAW tapped delay lines and convolvers, CCD; neural networks; antennas for spread spectrum, adaptive antennas for interference cancelation; amplifiers, AGC; RAKE implementations

Submission guidelines : Please mail five double-spaced copies and optionally email a PostScript version of original papers to :

Dr. Peter Jung
Secretary, Technical Program Committee
Research Group for RF Communications
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Bldg. 11, Rm. 532, P.O. Box 3049
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email wowbag@rhrk.uni-kl.de

as per schedule, and include name, affiliation, address of the author(s) on the title page. The manuscript should not exceed 3000 words. The official language of ISSSTA '96 is English.

Important dates :

Full manuscript:	January 15, 1996
Acceptance mailed:	March 31, 1996
Camera ready copy:	May 31, 1996

Congress organiser :

Dipl.-Ing. R. Rompel
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Stresemannallee 15, D-60596 Frankfurt, Germany
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59TH IEC GENERAL MEETING

Durban, South Afraica, 16-28 October, 1995

The International Electrotechnical Commission (IEC) will have its 59th General Meeting in Durban, South Africa, 16-28 October, 1995.

For further information, please contact :

IEC General Meeting Secretariat
c/o Mrs. Jo-Anne Byng
South African Bureau of Standards
Private Bag X191, 0001 Pretoria, South Africa
Tel. +27 12-428 6704, Fax +27 12-428 6441

EUROPEAN CONFERENCE ON MULTIMEDIA APPLICATIONS, SERVICES AND TECHNIQUES (ECMAST'96)

Bordeaux, France, 20-24 May, 1996

Sponsored by: EC, EBU and EUREL
Local organisation by SEE, IREST, ADERA
Co-located with Image'Com 96

Conference objectives

The information and communication technology landscape has changed fundamentally during the last few years. Considerable progress has been made in the digital signal representation and coding of data, sound and images. Wideband digital network technologies have been developed for broadcasting and telecommunication networks. The speed and power of processors is steadily increasing. Multimedia technologies needed to build the information society are thereby near at hand, although it is fair to say that, in many cases, they are just at the level of being "enabling" and will be continuously evolving over the next decade.

The objective of ECMAST is to provide an open forum to monitor and anticipate the development of technologies that make multimedia applications possible. ECMAST'96 is the first issue of a recurrent event launched by a group of major European industrialists together with the European programs RACE and ACTS on Image Communication and Multi Media and COST-237. People inside and outside Europe are invited to submit contributions and to share the discussion. Topics include but are not limited to:

1. Production, creation
Image analysis and synthesis tools (hardware and software). Multimedia tools for application creation in a workstation/PC environment, Information sensing and presentation devices, virtual reality, 3D vision, telepresence, Image quality assessment.

2. Coded representation of images, sound and data
Object/content/knowledge based representation of natural and synthetic images and computer graphics. Advanced compression techniques. Advanced signal processing architectures.

3. Multimedia delivery on broadcast networks
Digitisation of analogue delivery systems: DAB, DTTB, satellite, CATV/MATV, microwaves.
Interactivity, return channels and associated multiple access architectures.

4. Multimedia on telecom and professional networks
Core and access networks architectures requirements for MM services, Multimedia enhanced transport services, synchronisation issues, Multipeer/Multicast transport services, Multimedia in distributed systems platforms, WAN multimedia collaboration tools and services, QoS semantics for service users/providers, end-to-end QoS provision, Impact of multimedia on OSI and TCP/IP.

5. Servers, terminals and storage
Multimedia servers and data bases, Terminal equipment architecture, User ergonomics. Service information multiplexing and browsing.

6. Services
Multimedia contents and related requirements, Conditional access and copyright protection, Interoperability of multimedia services on telecom and broadcast networks, standardised interfaces, Mobility issues, Service management and maintenance.

Local Organising Committee:

J. Poufet; France-Telecom, France, Chairman

Important dates

Deadline for submission of papers :	9 January 1996
Acceptance/rejection notification :	1 March 1996
Final version of paper due :	1 April 1996

For more information, please contact :

ECMAST Programme Committee
Laboratoire de Télécommunications
Batiment Stevin, B-1348, Louvain la Neuve, Belgium
Tel. +32 2-296 3476/3467, Fax +32 2-296 1786
E-mail ecmast@postman.dg13.cec.be.

URSI CONFERENCE CALENDAR

September 1995

Biophysical Aspects of Coherence

Prague, Czech Republic, 11-15 September 1995

Contact : Faculty of Mathematics and Physics, Charles University Ke Karlovu 3, 12116 Prague 2, Czech Republic, Tel : +42-2-24915014, Fax: +42-2-299272, E-mail : pokorny@quantum.karlov.mff.cuni.cz

ISRAMT'95

Kiev, Ukraine, 11-16 September 1995

Contacts : Dr. B. Rawat, Dept. of Electrical Eng., Univ. of Nevada, Reno, NV 89557-0153, USA, Tel. +1702-784-1457, Fax +1702-784-6627

and : Dr. K.S. Sunduchkov, SRI "Saturn", Pr. 50, Let Oktyabrya 2B, 252148 Kiev, Ukraine, Tel. +044-477-6739, Fax +044-477-6208

ECOC'95

Brussels, Belgium, 17-21 September 1995

Contact : ECOC'95, INTEC Dept., Univ. of Gent - IMEC, St-Pietersnieuwstraat 41, B-9000 Gent, Belgium, Tel. +32-9-2643316, Fax+32-9-2644288, E-mail: ecoc95@intec.rug.ac.be

Int. Workshop on Direct & Inverse Electromagnetic Scattering

Gebze, Turkey, 24-30 September 1995

Contact : Prof. Dr. A. Hamit Serbest, Int. Workshop on Direct & Inverse Electromagnetic Scattering, Cukurova University, Faculty of Eng. & Architecture, Dept of Electrical & Electronic Eng., Tel. +90-322-338-6868, Fax +90-322-338-6326

October 1995

URSI Large Telescope WG Meeting 3 and Workshop on Spherical Radio Telescopes

Guiyang, Guizhou Province, China, 2-6 October 1995

Contact : Mr. R. Braun, NFRA, Postbus 2, NL-7990 AA Dwingeloo, The Netherlands, Tel. +31-5219-7244, Fax +31-5219 7332, E-mail: rbraun@nfra.nl

Asia Pacific Microwave Conference

Taejon, Korea, 10-13 October 1995

Contact : Prof. Dong-Chul Park, Programme Committee, APMC'95, Dept. of Radio Sciences& Engineering, Chungnam National University, 220 Kung-dong, Yusong-gu, Taejon 305-764, Korea, Tel. +82-42-821-5665, Fax +82-42-823-5436,2931, E-mail : dcpark@micro.chungnam.ac.kr

Extra Galactic Radio Sources - IAU Colloquium 175

Bologna, Italy, 10-14 October 1995

Contact : Dr. L. Padrielli, Istituto di Radioastronomia, Via P. Gobeti 101, 40129 Bologna, Italy, +39-51-6399431, E-mail padrielli@astbo1.bo.cnr.it

Retrieval of Geo-and Bio-Physical Parameters from SAR data for Land Applications

Toulouse, France, 17-20 October 1995

Contact : Mr. Michel Rouzé, Centre Spatial de Toulouse, 18, Avenue E. Belin, F-31055 Toulouse Cedex, France, Fax +33-6127-4013

ISSSE'95

San Francisco, USA, 25-29 October 1995

Contact : Prof. Ming C. Wu, UCLA, Electrical Eng. Dept., 405 Hilgard Ave, Los Angeles, CA 90095-1594, USA, Tel. +1-310-825-6859, Fax +1-310-825-6954, E-mail : wu@ee.ucla.edu

November 1995

7th MST & ISAR2 Workshop

Hilton Head, South Carolina, USA, 5-6 November 1995

Contact : Prof. M.F. Larsen, Dept. of Physics, Clemson University, Clemson, South Carolina 29634, USA, Tel. +1-803-656-5309, Fax +1-803-656-0805, E-mail: mlarsen@hubcap.clemson.edu

Commission F Open Symposium

Ahmedabad, India, 20-24 November 1995

Contact : Prof. O.P.N. Calla, SATCOM Area Space Applications Centre, Ahmedabad, India, Tel. +91-79-429-180, Fax +91-79-404-563, E-mail: calla@sac.ernet.in

January 1996

Pulsars

Sydney, Australia, 8-12 January 1996

Contact : Dr. Dick Manchester, Radiophysics, CSIRO, P.O. Box 76, Epping, NSW 2121, Australia, Fax +612-372 4400, E-mail : rmanches@atnf.csiro.au

March 1996

EUSAR'96

Konigswinter, Germany, 26-28 March 1996

Contact : Dr. R. Klemm, FGAN-FFM, Neuenahrer Str. 20, D-53343 Wachtberg, Germany, Tel. +49-228-852-377, Fax +49-228-348-953, E-mail: r.klemm@elserv.ffm.fgan.de

May 1996

IGARSS'96

Burnham Yates Conference Center, Cornhusker Hotel, Lincoln, Nebraska, USA, 27-31 May 1996

Contact: Ms. Tammy Stein, IEEE Geoscience and Remote Sensing Society, 2610 Lakeway Drive, Seabrook, Texas 77586-1587, USA, Tel. +1-713 291 9222, Fax +1-713 291 9224, E-mail : stein@harc.edu

June 1996

10th Int. Conf. on Atmospheric Electricity

Osaka, Japan, 10-14 June 1996

Contact : Prof. M. Hayakawa, The University of Electro-Communications, 1-5-1 Chofugaoka, Chofu Tokyo 182, Japan, Fax +81-424-80-3801, E-mail: hayakawa@aurora.ee.uec.ac.jp

Conference Precision Electromagnetic Measurements (CPEM'96)

Braunschweig, Germany, 17-20 June 1996

Contact: Mrs. Sabine Rost, Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany, Tel. +49-531-592-2129, Fax +49-531-592-2105, E-mail: erich.braun@ptb.de

13th International Wroclaw Symposium and Exhibition on Electromagnetic Compatibilty

Wroclaw, Poland, 25-28 June 1996

Contact : Mr. W. Moron, EMC Symposium 1996, Box 2141, 51-645 Wroclaw, Poland, Tel. +48-71-728812, Fax +48-71-728878

July 1996

Fifth International Symposium on Bio-Astronomy

Capri, Italy, 1-5 July 1996

Contact : Prof Stuart Bowyer, Space Sciences Laboratory, University of California, Berkeley, CA 94720-7450, USA, Fax +1-510 643-8303, E-mail: bowyer@ssl.berkeley.edu

COSPAR Scientific Assembly

Birmingham, United Kingdom, 14-21 July 1996

Contact : Prof. S. Grzedzielski, 51, bd de Montmorency, F-75016 Paris, France, Tel. +33-1-4525 0679, Fax +33-1-4050 9827, E-mail: cospar@paris7.jussieu.fr

August 1996

XXVth URSI General Assembly

Lille, France, 28 August -5 September 1996

Contact : Dr. M. Lienard, Université de Lille, Dept. Electronique, Bat. P3, F-59655 Villeneuve d'Ascq Cedex, France, Tel: +33 20-337134, Fax: +33 20-436523, E-mail : agursi@univ-lille1.fr

September 1996

8° Colloque internationale et exposition sur la Compatibilité électromagnétique

Lille, France, 3-5 September 1996 (co-located with the URSI General Assembly)

Contact : Prof. P. Degauque, Université des Sciences et Techniques de Lille 1, UFR/IEEA, Bâtiment P3, F-59655 Villeneuve d'Ascq Cedex, France, Tel. +33 20-434849, Fax +33 20-436523

Sixth International Conference for Mathematical Methods in Electromagnetic Theory (MMET'96)

Lviv, Ukraine, 10-13 September 1996

Contact : Prof. Z. Nazarchuk, Karpenko Physico-Mechanical Institute, 5 Naukova St., Lviv 290601, Ukraine, Tel. +380-322-637038, Fax +380-322-649427

22nd European Conference on Optical Communication ECOC'96

Oslo, Norway, 15-19 September 1996

Contact : ECOC'96 Secretariat, Norwegian Telecom Research, P.O. Box 83, N-2007 Kjeller, Norway, Tel. +47 - 63 - 80 93 41, Fax+ 47- 63 - 81 98 10, E-mail: krosby@tf.tele.no

IEEE ISSSTA'96

Mainz, Germany, 22-25 September 1996

Contact : Prof. P.W. Baier, Research Group for RF Communications, University of Kaiserslautern, P.O. Box 3049, D-67653 Kaiserslautern, Germany, Tel/Fax +49-631-205-2075/3612, E-mail: baier@rhrk.uni-kl.de

23rd International Conference on Lightning Protection (ICLP)

Firenze, Italy, 23-27 September 1996

Contact : Prof. Carlo Mazzetti, Dept. of Electrical Engineering, University of Rome "La Sapienza", Via Eudossiana 18, I-00184 Rome, Italy, Tel. +39-6-4458 5534, Fax +39-6-488 3235, E-mail: elettrica@ risccics.ing.uniromal.it

Int. Symp. on Antennas and Propagation

Chiba, Japan, 24-27 September 1996

Contact : Prof. Kiyohiko Itoh, Faculty of Engineering, Hokkaido University, Sapporo 060, Japan, Fax +81-11-706-7836, E-mail: itoh@densi001.hudk.hokudai.ac.jp

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News from the URSI Community

NEWS FROM URSI MEMBER COMMITTEES

THAILAND
NATIONAL COMMUNICATIONS DAY

Mr. Kitti Yupho, President of the URSI Member Committee in Thailand, asked us to publish this article about National Communications Day in this issue of our magazine.

In Thailand, the 4th August is proclaimed National Communications Day. Historically, on 4th August 1883, King Rama V founded the Post Department of the Telegraph Department which marked the beginning of activities in Thailand. The two departments were merged into one and named "The Post and Telegraph Department".

Over the past 112 years, the communication services in Thailand have developed continuously and rapidly, especially the public communication services and mass communication. Up until now, many governmental administrations and state enterprises dealing with communication activities were set up, i.e. the Public Relations Department, the Aeronautical Radio of Thailand Ltd., the Telephone Organisation of Thailand, the Communications Authority of Thailand and the Mass Communication Organisation of Thailand. Besides, many entities for special communications services were established accordingly. These include services attached to the army, police and educational institution such as the Faculty of Communication Arts of Chulalongkorn University and the Faculty of Journalism & Mass Communication of Thammasart University to name only a few. Presently, five television stations and more than three hundred radio stations nationwide broadcast news and information to remote area. Thus all people can access the information services.

As communications play a significant role in our daily life, particularly in the national social and economic development, culture and the security of the antion, the Thai Government is fully aware of this important role and decided on August 2, 1983 to proclaim the fourth of August of every year "The National Communications Day".

Consequently, the National Communications Day was first celebrated in 1983. The celebration coincided with the 100th anniversary of the Post and Telegraph Department and the "World Communications Year" of the International Telecommunication Union (ITU).

In celebrating the event, a National Communications Day Organizing Committee was set up by the Cabinet. The committee, which is chaired by the Minister of Transport and Communications, is composed of high ranking officials from governmental administrations, state enterprises and inter-governmental organisations.

The National Communications Day was celebrated each year under specific theme of interest. Whereas the venue of the event changes from year to year, the period is always scheduled during the first week of August.

This year the 13th celebration of the National Communications Day was celebrated under the theme "Communication to Develop the Information Technology" because communications are important got informtion infrastructure.

This year's programme included the following activities :

- A tribute was paid in memorance of his Royal Highness Prince Bhanu-Rangri Swangwong, the first Director General of the Post and Telegraph Department;
- The Minister of Transport and Communication, Chairman of the National Communications Day Organizing Committee gave his presidential address on air worldwide;
- An Exhibition on "International Telecommunications Technology - Thai Telecom 95" was organised during 4-7 August 1995 at Queen Sirikit National Convention Center. Exhiobitors are from both governmental and private sectors, from local and foreign companies showed thair brand new services and technologies;
- The commemorative books, consolidating 35 interesting articles on new communication services and technolgies written by scholars and distinguished authors were distributed to the visitors;
- The commemorative stamps were issued together with the first day covers to mark National Communications Day on 4th August 1995.

During the Thai Telecom 95 Exhibition, two technical seminars were organised with the following topics :

- "Information Technology in the World of Mass Communication"
- "Master Plan for Telecommunications Development".

Mr. Kitti YUPHO
President, URSI Committee in Thailand
Director General, Post and Telegraph Department

BOOKS PUBLISHED BY URSI CORRESPONDENTS

DUSTY AND DIRTY PLASMAS, NOISE, AND CHAOS IN SPACE AND IN THE LABORATORY

by Dr. Hiroshi Kikuchi
ISBN 0-306-44839-4

The volume *Dusty and Dirty Plasmas, Noise, and Chaos in Space and in the Laboratory* is now available at the special discount price of $83.70 per copy.

This book contains an updated version collected from papers presented at a sequence of URSI Working Group Meetings on "Extraterrestrial and Terrestrial Meteorologico-Electric Environment with Noise and Chaos" held in Tokyo on 25-26 March, 1992 and 23-24 August, 1993.

Advance payment is necessary. Order forms and additional information may be obtained from :

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New York, NY 10013-1578, USA
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UTC Time Step

Une seconde intercalaire positive sera introduite à la fin de décembre1995.

Le séquence des dates des repères de secondes de UTC sera:

1995 décembre 31, 23h 59m 59s
1995 décembre 31, 23h 59m 60s
1996 janvier 1, 0h 0m 0s

La différence entre UTC et le Temps Atomique International TAI est:

de 1994 juillet 1, 0h UTC, à 1996 janvier 1, 0h UTC :
UTC-TAI = -29 s
de 1996 janvier 1, 0h UTC , jusqu'à nouvel avis :
UTC-TAI = -30 s

Des secondes intercalaires peuvent être introduites à la fin des mois de décembre ou de juin, selon l'évolution de UT1-TAI. Le Bulletin C est diffusé deux fois par an, soit pour annoncer un saut de seconde, soit pour confirmer qu'il n'y aura pas de saut de seconde à la prochaine date possible.

Martine FEISSEL
Directeur, Bureau Central de l'IERS
Service International de la Rotation Terrestre

A positive leap second will be introduced at the end of December 1995.

The sequence of dates of the UTC second markers will be :

1995 December 31, 23h 59m 59s
1995 December 31, 23h 59m 60s
1996 January 1, 0h 0m 0s

The difference between UTC and the International Atomic Time TAI is:

from 1994 July 1, 0h UTC, to 1996 January 1, 0h UTC : UTC-TAI = -29 s
from 1996 January 1, 0h UTC , until further notice :
UTC-TAI = -30 s

Leap seconds can be introduced in UTC at the end of the months of December or June, depending on the evolution of UT1-TAI. Bulletin C is mailed every six months, either to announce a time step in UTC or to confirm that there will be no time step at the next possible date.

Martine FEISSEL
Director, Central Bureau of IERS
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TWAS

LECTURESHIPS AND PROFESSORSHIIPS IN SCIENCE AND SUSTAINABLE DEVELOPMENT

The Lectureship Programme, initiated in 1987 by the International Council of Scientific Unions (ICSU) and the Third World Academy of Sciences (TWAS), was joined in 1989 by the United Nations Educational, Scientific and Cultural Organisation (UNESCO) and the Commonwealth Science Council (CSC). As a follow-up to the 1992 United Nations Conference on Environment and Development, and in the spirit of strengthening existing initiatives, the Earth Council joined the Programme as co-sponsor in 1993 at which time the scope of the Programme was widened to include the contribution that science can make to sustainable development.

The objective of the Lectureship Programme is to provide those associated with scientific and other appropriate institutions in developing countries with the opportunity to establish and enhance collaboration with colleagues in all fields of science, technology and key areas of environment and development. Within this Programme, prospective host institutions can invite eminent experts in science, technology and sustainable development, to lecture and hold discussions in their countries. Lecturers and hosting institutions will be expected to provide comprehensive reports on completion of the visits.

Institutions in developing countries (*) wishing to invite a Lecturer under this Programme are requested to fill our a form providing information about the subject area to be addressed and, if available, the name of persons who might be invited to lecture. As the programme is striving towards providing equal opportunities, nominations for women will be particularly welcomed.

Request forms for Lectureships should be submitted to the TWAS Secretariat to meet one of the following deadlines :

- 30 June for lectures to take place between January and June of the following year;
- 31 December for lectures to take place between July and December of the following year.

* A limited number of Lectureships will be made available to institutions in Eastern Europe and the former Soviet Union which lack contacts with scientists from other parts of the word.

Application forms for Lectureship and Professorship Programmes can be obtained from :
The Third World Academy of Sciences (TWAS)
Strada Costiera 11, P.O. Box 586, I-34126 Trieste, Italy
Phone +39-40 224-0387, Fax +39-40 224-559, E-mail twas@ictp.trieste.it

The Visiting Professorship Programme established by the International Council of Scientific Unions (ICSU), the Third World Academy of Sciences (TWAS), the United Nations Educational, Scientific and Cultural Organisation (UNESCO), the Commonwealth Science Council (CSC) and the Earth Council allows for repeated visits by international experts to developing countries.

The objective of this Programme is to provide developing country institutions and research groups, especially those lacking outside contacts, with the opportunity to establish long-term links with world leaders in science, technology and key areas of environment and development.

Within the framework of the Professorship Programme, a number of international experts will be offered visiting professorship appointments to Third World institutions. The appointment will normally be for a period of five years, during which the appointed professor will be expected to visit the host institution at least three times for a minimum stay of one month each time. Visiting Professors and host institutions will be expected to provide comprehensive reports on completion of the visits.

An economy round-trip fare and additional travel expenses of the visiting professor, and a small honorarium will be provided by the sponsoring organisations, while the host institution will be expected to cover local expenses.

The visiting professor will be expected to closely interact with members of the host institution with the aim of strengthening its existing activities and/or assisting in the establishment of new lines of research. The visiting professor may also be requested to deliver a series of topical lectures and seminars to research students.

Institutions in developing countries (*) wishing to be considered for this Programme should fill in the relevant request form which can be obtained from the TWAS Secretariat at the address below. Information about the subject areas of current interest of the host institution should be provided, and if available, the name of person(s) who might be considered for the appointment. As the programme is striving towards providing equal opportunities, nominations for women will be particularly welcomed. Only persons who have attained international recognition in their fields of science, environment and development will be considered for appointment under this Programme.

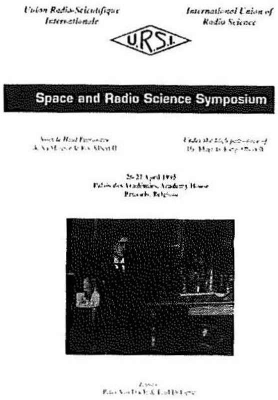
Request forms for Professorships should be submitted to the TWAS Secretariat to meet one of the following deadlines : 30 June and 31 December of each year.

* A limited number of Professorships will be made available to institutions in Eastern Europe and the former Soviet Union which lack contacts with scientists from other parts of the word.

URSI Publications

Proceedings of the "Space and Radio Science Symposium"

Editors: Peter Van Daele and Paul Delogne



Union Radio-Scientifique Internationale

International Union of Radio Science

Space and Radio Science Symposium

This "Space and Radio Science Symposium" was held on 26-27 April 1995, at the occasion of the 75th Anniversary of our Union.

Copies of these Proceedings are available at the URSI Secretariat for 500 Belgian francs per copy (for countries outside Europe we charge an extra 140 Belgian francs per copy for mailing costs).

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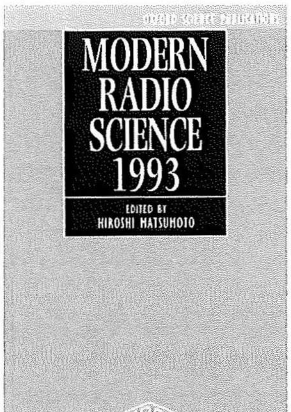

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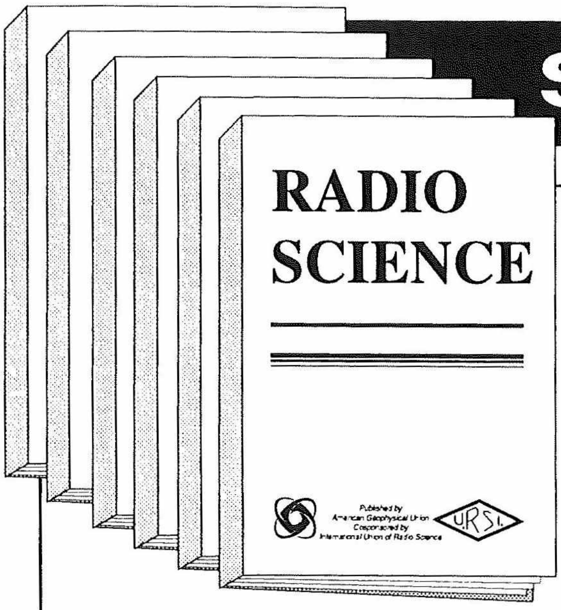

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