The Miyun 50 m Radio Telescope and Its Simultaneous Dual-Frequency IPS observing System

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Abstract

The new Interplanetary scintillation (IPS) observation system which is under construction at the National Astronomical Observatories, CAS (NAOC) is introduced and the principle of the solar wind speed observation by using normalized cross-spectrum of simultaneous dual-frequency IPS measurements is also described in this paper.

1. Introduction

To observe IPS, using ground based telescope has got many useful results. Several important IPS station such as Cambridge (UK) [3], Ooty (India) [8,4], Puschino (Russ) [10] adopt single station- single frequency observation (SSSF) with power-spectrum fit method to get solar wind speed and scintillation index while the STEL (Japan) [1] is a multi-station system which can measure the projected solar wind speed directly. The phased array of the Miyun telescope is also a SSSF system operating at 232 MHz. [13, 11]. The SSSF mode of IPS observation needs high sensitivity, for example better than 25 dB, to get reasonable spectrum fitting and the fitting accuracy is somehow easy affected by the variations of solar wind parameters. [12] Another technique of IPS observation using single telescope is single station dual-frequency method (SSDF) [7]. This method adopts simultaneous dual-frequency when observing an IPS source and then to calculate the normalized cross-spectrum (NCS) with the power spectra of the two different frequencies.

2. The principle of the SSDF IPS observation

The normalized co-spectrum (NCS) between two IPS signals obtained simultaneously at different frequency is used to get solar wind speed. The NCS is defined as formula 1 and Fig.1 shows a NCS example.

$$NCS(f) = \frac{\mathrm{Re}(S_{12}(f))}{\sqrt{P_1(f) \bullet P_2(f)}} \qquad (1)$$

Where f is the temporal frequency of the spectrum, Re is the real part of the co-spectrum S_{12}, P_1 and P_2 are the power spectrum at each frequency. According to the theory of thin scintillation screen [12], the relationship between spatial wave-number and temporal frequency is $k_x = 2\pi f / v_x$, then the S_{12}, P_1 and P_2 can be expressed as follows [9].

$$P_i(f) = Cr_e^2 \lambda_i^2 \int_0^\infty \frac{2\pi}{v} P(v) dv \int_{-\infty}^{\infty} \Phi_{ne}(\vec{k}) \sin^2\left(\frac{k^2 \lambda_i z}{4\pi}\right) \times F_s(\vec{k}) F_r(\vec{k}) dk_y \qquad (i = 1,2) \quad (2)$$

$$S_{12}(f) = Cr_e^2\lambda_1\lambda_2\int_0^{\infty}P(v)dv\int_{-\infty}^{\infty}\Phi_{ne}(\vec{k})\sin(\frac{k^2\lambda_1 z}{4\pi})\sin(\frac{k^2\lambda_2 z}{4\pi})\times F_s(\vec{k})F_r(\vec{k})dk_y \quad (3)$$

Where The terms of sin-functions are the Fresnel filters, $\vec{k} = (k_x = 2\pi f / v, k_{y,} k_z = 0)$ is the three dimension wave-number, $r_e = 2.8\times10^{-13}cm$ is the electron radius, λ_1 / λ_2 is the wave-lengths of the two frequency respectively and $\lambda_1 \rangle \lambda_2$, v is the velocity of solar wind along the x axis at the P point , $P(v)$ is the speed distribution function of solar wind, and Φ_{ne} is the spatial spectrum of the electron density. The Φ_{ne} is defined as in the formula (4).

$$\Phi_{ne}(\vec{k}) = Tr^{-4}[(k_x^2 + (k_y / AR)^2]^{-\alpha/2} \quad (4)$$

Where T is the fluctuation amplitude of the electron density, AR is axis ratio which represents the anisotropy of solar wind, r is the heliocentric distance of the P point, α is the spectrum index of the solar wind power.

F_s is the angular size of the scintillation source which is defined by the formula (5) [9, 12]. Here, the θ_0 is the angular diameter of the scintillation source and the brightness distribution model of the source is defined as $B(\theta) = \exp[-(\theta/\theta_0)^2/2]$. The F_r, the formula (6), is the receiver bandwidth ($\Delta\lambda$) filter.

$$F_s = \exp[-(k_x^2 + k_y^2)z^2\theta_0^2] \quad (5)$$

$$F_r = \exp[-(k_x^2 + k_y^2)/(\frac{4\pi\cdot\Delta\lambda}{\lambda^2\cdot z})^{1/2}] \quad (6)$$

The σ is the rms of solar wind speed fluctuation and T is a constant. The solar wind speed V can be obtained from the NCS according to the characteristic frequency, f_{zero} [9].

$$V = Kf_{zero}\sqrt{\lambda_1 Z} \quad (7)$$

Where f_{zero} is the first point at which the NCS=0, K is the correcting factor and has small variation for most solar wind parameters except for the larger σ / V, it is almost always 1.1. For the most cases, to take $K = 1$ will make the maximum error of solar wind speed measurement less than 10%. This is acceptable.

3. The new SSDF system at the NAOC

A receiving system for SSDF IPS observation at the NAOC is now under construction by installing a dual-frequency frond-end and a dual-channel multi-function back-end onto the 50 m parabolic radio telescope. The integrate time of the receiver system should be short enough because IPS phenomena various rapidly. This implies that the effective receiving area of IPS antenna should be large enough to ensure the system has good instant sensitive and the band-wide of it should be match to the system time resolution. Good low noise amplifiers (LNA) are needed to reduce the system noise level and it is better to install them as near as possible to the feeds. Because most IPS sources are random polarized, polarization observation of IPS is not very important, but observation with full polarization enable to increase the system sensitivity. Figure 1 shows the 50 m antenna. The main system parameters are listed in Table 1.

Fig. 1 The 50 m parabolic radio telescope at NAOC

There are two dual-frequency groups available in this system. One is 327/611 MHz and another is 2300/8400 MHz. A frequency synthesizer is used as the LO of the system so that the receiving frequency can be adjusted slightly around the center frequencies (327/611 MHz) to dodge strong interference. This operation can be done because the feeds have wide bands and the working bands are narrow, for example the band width of the 327 MHz feed is 35 MHz, while the working band width at 327 MHz is about 4 MHz. we found that there are some relative quiet areas, where there are less strong interference, in the spectra around 611 MHz. We have monitored the radio environment at the telescope site by using the 50 m telescope and a spectrometer for all the directions around the telescope. We planed to do this as a regular monitoring program. No serious interference was found in the S/X bands. It is easy to find out some areas with 80 MHz around 2300/8400 MHz.

Two selectable observing modes with this SSDF system are (1) tracking a scintillation source for a long time to get information of IPS at almost constant distant to the Sun, i.e. to monitor the solar wind variation with time, (2) observing scintillation source one by one around the Sun to get the space distribution information of solar wind. The new SSDF system can observe radio sources stronger than 1

Jy (SN > 5). There are many sources available.

Table 1 The main parameters of the antenna and SSDF system.

Aperture / F/D	50m / 0.35
Antenna efficiency（327/611/2300 MHz, 50m 8400 MHz 43 m）	>0.5
Gains at 327/611/2300/8400 MHz	43/48/60/68 dB
Frequency group	327/611，2300/8400
Band width	2/4/8/20 MHz
Sampling interval	20 ms
System noise level	327/611, 70 K; 2300/8400, 30 K
Minimum measurable temperature（1.2s/8MHz）	25mK/10mK

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