APEX, the Atacama Pathfinder Experiment

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1. INTRODUCTION

A new sub-millimetre telescope, APEX, is now operational in the southern hemisphere on what is probably the world's best, while still reasonably accessible, site for submm observations – Llano de Chajnantor – at an altitude of 5100 m. The antenna is a modified version of the ALMA prototype built by the German company, VERTEX Antennentechnik in Duisburg, customized to accommodate two Nasmyth cabins for the heterodyne receivers and with a modified sub-reflector for wide field observations with bolometer arrays placed at the secondary focus. The APEX project is led by the Max-Planck-Institut für Radioastronomie (MPIfR) in collaboration with the group that ran the successful SEST project, the Swedish National Facility for Radio Astronomy, Onsala Space Observatory (OSO) and the European Southern Observatory (ESO), as well as the host nation, Chile. The observing time will be divided as follows: 45% MPIfR, 24% ESO, 21% OSO, 10% Chile. The project has been managed by Rolf Güsten of the MPIfR since the spring of 2004 and the site scientist is Lars-Åke Nyman.

On this excellent site spectroscopic and continuum observations will be conducted with APEX in all the atmospheric windows between 230 GHz and 1.5 THz, thereby closing one of the last spectral gaps for ground based astronomy, that between submm and far infrared wavelengths. At 1.5 THz the atmospheric transmission is there sometimes as good as 50%.

2. THE APEX ANTENNA

The APEX has a measured surface accuracy well within the originally specified goal of 18 µm, making it useful for THz observations. It consists of 264 aluminium panels in 8 rings on a CFRP backup structure of 24 sandwich shell segments. The backup structure (BUS) is supported by an INVAR ring and the total mass of the antenna is 125 ton.

The antenna contract was signed in July 2001 and the assembly of the partially constructed telescope was started in Chile, on time in Spring, 2003. It was erected on the Chajnantor plain somewhat north of the main ALMA array site, close to Cerro Chajnantor. In spring 2004, after installation of the subreflector, the commissioning began. Our optimistic date for first operations was projected to be in mid 2004 but bad weather, the complexity of operation at this remote site and teething problems with the antenna delayed its final acceptance (after successful commissioning) until the end of June, 2005.

2.1 Antenna reflector measurements

After erection the surface was set by photogrammetry to about 35 – 40 micron, rms. Subsequent holographic measurements using a transmitter on Chajnantor were conducted in April 2004 and again one year later. The results are quite spectacular with a final measured surface rms accuracy of about 15 – 16 microns at the elevation of the transmitter (circa 12 degrees). Differences between the two separate sets of measurement were shown to be due to cabin cooling which was not operational in 2004. This hypothesis was checked by making measurements while the cabin temperature was held at different settings.

During the 2005 campaign, checks were made of the repeatability of the measurements by subtracting maps made at different times during the night. Such measurements (after the system had reached thermal equilibrium) give an estimate of the measurement accuracy which was determined to be about 5.5 micron.

Finally, the Vertex finite element model of the antenna structure was used to pre-load the antenna to an elevation of 50 degrees to optimise the performance over a range of 30 – 80 degrees. The effective rms surface accuracy is estimated to be about 17 microns.

A check of the telescope surface setting may be obtained by measuring the beam size and shape. Measurements on the planets with the FLASH receiver at 460 and 810 GHz, give a good circular beam with low sidelobes and an excellent flat gain response over the elevation range 30 – 80 degrees. Main beam efficiencies are 47 and 65% at 810 and 464 GHz respectively, from our preliminary data reduction; these values will be refined in due course.

The holography was conducted by a team consisting of T.K. Sridharan (Harvard-Smithsonian Centre for Astrophysics), Albert Greve and Dave Morris, led by Rolf Güsten, supported by APEX staff. It is a pleasure to acknowledge the great help provided by the outside experts and to the CfA for the loan of the holography transmitter.

2.2 Telescope pointing

The telescope pointing (specification <2 arcsec, rms) has been checked using an optical telescope fixed to the structure. The accuracy determined from frequent pointing runs is 2 arcsec, rms. The actual radio pointing is still being refined for the different receivers. The optical measurements also give the tracking accuracy when following a single star. This is circa 0.5 arcsec. This is very important since the beam width at 1.5 THz is less than 4 arcsec FWHM.

3. APEX INSTRUMENTATION

The APEX receivers will consist of bolometers for continuum measurements and heterodyne receivers for spectroscopy. The planned suite of receivers is shown in the table below in which the nominal operating frequency is marked as well as the group building the receiver. Several receivers will have restricted use to MPIfR and their collaborators; they are marked PI.

Of the planned receivers, only one facility instrument is operational at the time of writing. This is a double sideband receiver for the 279 – 381 GHz range built in the Onsala receiver group (GARD) led by Victor Beltsky (Risacher et al, 2005). The noise temperature is <50K across the band.

Table 1: Apex Instruments

Bolometers

LABOCA: 300 Elements at 870 µm (MPIfR [U. Bochum, IPHT Jena]) FOV: 12'
37 Elements at 350 µm (MPIfR)
300 Elements at 2 mm for Sunyaev-Zel'dovich effect (Berkeley/MPIfR, PI)

Heterodyne receivers

210 – 270 GHz single channel (OSO)
270 – 375 GHz single channel (OSO)
375 – 500 GHz dual channel (OSO)
420 – 495 and 780 – 887 GHz dual channel FLASH (MPIfR, PI)
600 – 720 GHz CHAMP+ 7 elements (MPIfR, PI)
790 – 920 GHz CHAMP+ 7 elments (MPIfR, PI)
FIR receivers: up to 1.5 THz (OSO, facility and MPIfR,PI with KOSMA and CfA)

For commissioning the telescope the dual frequency, DSB, MPIfR PI receiver (FLASH) (see table) has been used. The back-ends are novel fast Fourier transform spectrometers (FFTS) with 1 GHz bandwidth and 16k channels. This excellent receiver has borne the brunt of the commissioning and early science verification by Güsten et al., and is available, on a collaborative basis, for general scientific use.

4. APEX OPERATIONAL INFRASTRUCTURE

The telescope is operated remotely via a microwave link from a base in Sequitor, some 10 km south of the village of San Pedro d'Atacama. At the base are the laboratories and control room and staff offices, as well as a meeting room, 16 dormitories and a cafeteria. The staff of 25 people works the standard ESO duty cycle with 8 days on shift at APEX and 6 days off.

During the commissioning period, many technical staff have travelled daily up to the telescope where there is a site control room, a laboratory and kitchen. There is also a weather station and the microwave link connection. Electric power to the telescope is provided by diesel generators.

The site is accessed via the paved international highway to Argentina, for the first 60 km, and then by an unpaved section of about 14 km. Because of the high altitude, strict rules are applied to people going to the site and overnight stays are only sanctioned under extreme circumstances like the sudden onset of bad weather.

5. APEX SCIENTIFIC PROGRAMME

The frequency band between 0.8 and 3 THz is a largely unexplored frontier in astronomy. Interstellar clouds in general, and star forming regions in particular, radiate intensely at these frequencies. It has always been thought that observations must be carried out from airborne or orbiting platforms, which can support telescope apertures of only a few metres. Finding the high dry site of Llano Chajnantor changes all of this and the 12m APEX telescope and the Japanese 10m ASTE antenna on a nearby site of Pampa la Bola are set to make many new discoveries.

5.1 Surveys

APEX is seen as a pathfinder for new mm/submm telescopes but also as an important instrument in its own right for all areas of submm astronomy. The pathfinder exercise will be undertaken partly, at least, in terms of surveys. For example, there is a great interest in surveys for dust continuum and CO-line emission from distant galaxies found in deep optical surveys, such as the "Hubble Deeep Field". Toward a number of objects with the highest measured red-shifts (sub)mm dust emission has been detected. Further sources are found in "blind" deep continuum surveys. In most of the sources in which dust emission is detected red-shifted high excitation lines of CO are subsequently also detected.

In addition, there will be an MPIfR led continuum survey of the Galactic plane for protostars using the LABOCA array at 870 microns. Complementary observations at 350 micron, 1.4 and 2mm will provide information on the physical properties of the detected condensations, which are high-mass protostars and –clusters. Mass and temperature for all regions of massive star formation up to the distance of the Galactic centre will be measured. Finally a survey for detections of the signature of the Sunyaev-Zel'dovich effect will be conducted by a Berkeley/MPIfR collaboration using a 2mm bolometer array, which is a PI instrument built by a group at the University of California at Berkeley.

5.2 Individual objects

The southern sky is hardly studied at submm wavelengths but contains many spectacular objects which merit detailed studies: the Galactic centre – a black hole and molecular factory; the nearest regions of low mass star formation – e.g. Chameleon at 450 ly; spectacular regions of massive star formation – e.g. Eta Carina; dense dark cloud complexes – e.g. the Coalsack nebula; our nearest neighbouring galaxies, the Magellanic clouds, and Centaurus A, the nearest radio galaxy. These are but well known examples of the wealth of interesting objects to be found in the southerrn hemisphere. In addition, there are many well known galaxies for which millimetre/submillimetre observations will yield important information.

5.3 Astrochemistry

The largely unexplored frontier available to observations with APEX is in the atmospheric windows centred on 0.85, 1.0, 1.30 and 1,5 THz where, under the very best weather conditions, it will be possible to observe with useful efficiency. These spectral windows include low-lying transitions of many molecules that are known (or expected) to be abundant in interstellar clouds, protostars, circumstellar envelopes of evolved stars, and comets. Of particular interest in astrochemistry are ground-state transitions of some light hydrides. The photon energy $h\nu/k = 48(\nu/1\ \mathrm{THz})$ K is well matched to the kinetic temperatures 50 – 300 K that typify dense, star-forming cores of molecular clouds. The excitation requirements of most atomic and molecular transitions at THz frequencies select the densest gas near to a young stellar object. As a result it is expected that the most intense radiation will concentrate on angular scales of a few arcsec, or less in bright star-forming regions. This corresponds well to diffraction limited resolution of a 12m telescope.

The luminous bursts of star-formation that occur in centres of interacting galaxies also produce intense emission at THz frequencies, likewise on angular scales of the order of a few arcsec in the nearest such systems. In short , measurements at THz frequencies are well suited to the spectroscopic, as well as to continuum,studies of chemical evolution, dynamics and energetics of star forming regions.