APEX – The Atacama Pathfinder Experiment

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1. Introduction

APEX is a collaboration between the Max-Planck-Institut für Radioastronomie (MPIfR) in Bonn (together with Astronomisches Institut Ruhr-Universität Bochum, AIRUB), ESO and Onsala Space Observatory in Sweden (OSO). The idea is to construct and operate a 12-m diameter submillimetre telescope on the ALMA site of Llano de Chajnantor in Chile at an altitude of 5000 m. APEX will operate at submillimetre wavelengths as well as in the far infrared (at THz frequencies), which is possible because of the excellent atmospheric transparency that exists on the site at these wavelengths; it might be the best site in the world for sub-millimetre astronomy.

APEX will explore the southern sky, which is virtually unexplored at submillimetre wavelengths, and also serve as a pathfinder for ALMA, both by performing wide-field surveys for later follow-up by ALMA, and by obtaining experience in operations of telescopes at the site.

The project is shared between the partners in the ratio 50% MPIfR/AIRUB, 27% ESO and 23% OSO. 10% of the observing time will be dedicated to Chilean astronomy. The antenna is being purchased by MPIfR, OSO and MPIfR will provide instrumentation and ESO operations.

2. Science

APEX will be able to make significant contributions to the solution of a number of current astronomical problems that cannot be, or are insufficiently addressed with currently available telescopes: constraining cosmological models, studying star formation in the early and local universe, stellar evolution, interstellar chemistry at high frequencies, and the exploration of the southern submillimetre sky. At submillimetre wavelengths APEX will have a better spatial resolution than space or balloon borne instruments, by virtue of the larger dish size. Additionally, it will serve as a pathfinder for ALMA in all of its wavelength ranges. Surveys with APEX will be an outstandingly efficient means of finding target sources for ALMA, and for their line and continuum exploration prior to their detailed interferometric study with greater spatial resolution.

Figure 1: An artist's impression of the APEX antenna.

2.1 Exploring the star-formation history of the Universe

Among the fundamental cosmological questions being asked today are: when did galaxies and massive black holes form in the early universe, and how did they subsequently evolve? Modern telescopes are now detecting galaxies out to redshifts beyond 6, close to the "dark ages" where the first stars and galaxies may have formed. Because much of the stellar light emerging from massive star-formation regions is immediately absorbed by the surrounding dusty clouds, even the most luminous starburst galaxies are difficult to observe at optical and even NIR wavelengths. The absorbed radiation is re-emitted by the dust as long-wavelength infrared radiation which can easily escape the star forming regions – but cannot cross the Earth's atmosphere. However, for very distant objects this radiation is red-shifted to submillimetre wavelengths. This makes it accessible from the ground, at a very few places such as Chajnantor. The large 870-micron bolometer array (LABOCA, see below) at APEX will be ideally suited to detect and map the distribution of the earliest, most distant star-forming galaxies in the Universe. Follow-up observations at 350 micron will provide data on their distance and nature. The unprecedented size of its bolometer arrays and the ideal observing conditions all year round will make APEX the most powerful ground-based instrument to explore the star formation history of the Universe.

2.2 Constraining the Universe: the Sunyaev-Zel'dovich effect

Galaxy clusters are the largest collapsed structures in the Universe. Measuring their distribution and structure provides crucial information on the history and structure of our Universe. Galaxy clusters are embedded in vast amounts of hot, ionized gas. This gas scatters the passing photons of the Cosmic Microwave Background (CMB) and increases their average energy. The resulting distortion in the CMB is called the Sunyaev-Zel'dovich (SZ) Effect and can be used as a sensitive probe of cosmological models and cluster physics. Planned 2-mm bolometer arrays at APEX will have an ideal spatial resolution and sensitivity to measure the SZ effect toward distant clusters.

2.3 Unbiased searches for protostars

Another important scientific objective APEX will pursue is a search for protostars in heavily obscured star-formation regions in our Galaxy. Understanding the very earliest stages of star-formation ranks as one of the most important questions in astrophysics.

Stars and their surrounding planetary systems form from dense condensations within molecular clouds. Before and during their collapse, these dense gas cores, or protostars, remain very cold (10–30 K), and therefore escape detection with infrared instruments such as ISO, IRAS and MSX. APEX on the other hand will detect these objects in the submillimetre continuum and in molecular lines to study the kinematics of the collapsing objects, deepening our understanding of the sources discovered.

Figure 2: The APEX antenna seen from the back. Note the Cassegrain focus cabin and the two Nasmyth focus cabins. The container below and behind the focus cabins will contain the spectrometers and other electronics.

2.4 Submillimetre spectroscopy of the Milky Way and external galaxies

The frequency bands between 600 GHz and 1.5 THz are relatively poorly explored, especially in the southern hemisphere, but the spectral windows in this range contain low-lying transitions of many molecules that are known, or expected to be abundant in interstellar clouds, protostars, the circumstellar envelopes of evolved stars, and comets. Important lines are those of the light hydrides, of particular interest in astrochemistry, and some fine

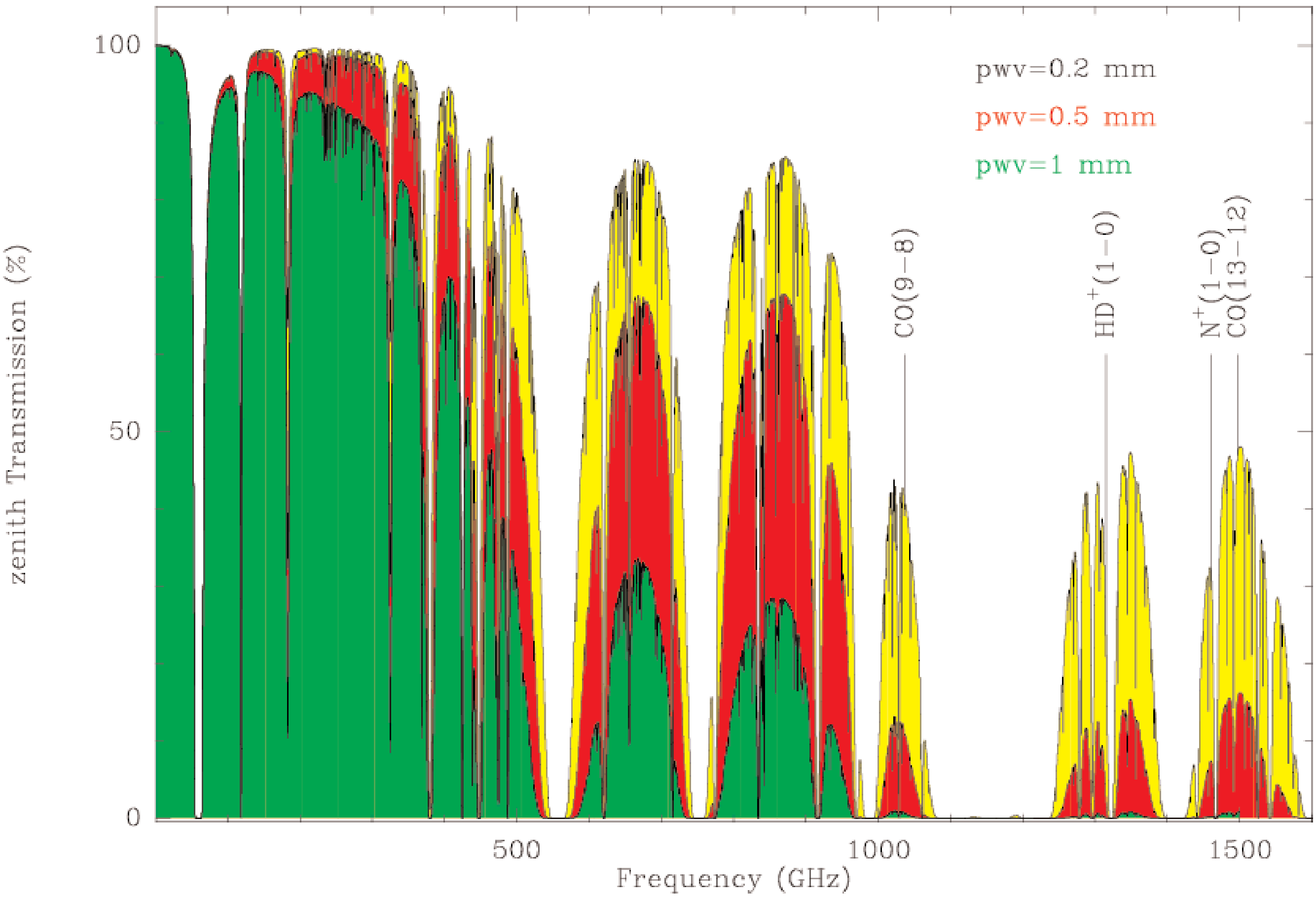

Figure 3: The atmospheric transmission curve for Chajnantor with different amounts of precipitable water vapour (PWV). The THz windows open at PWV levels below 0.5 mm.

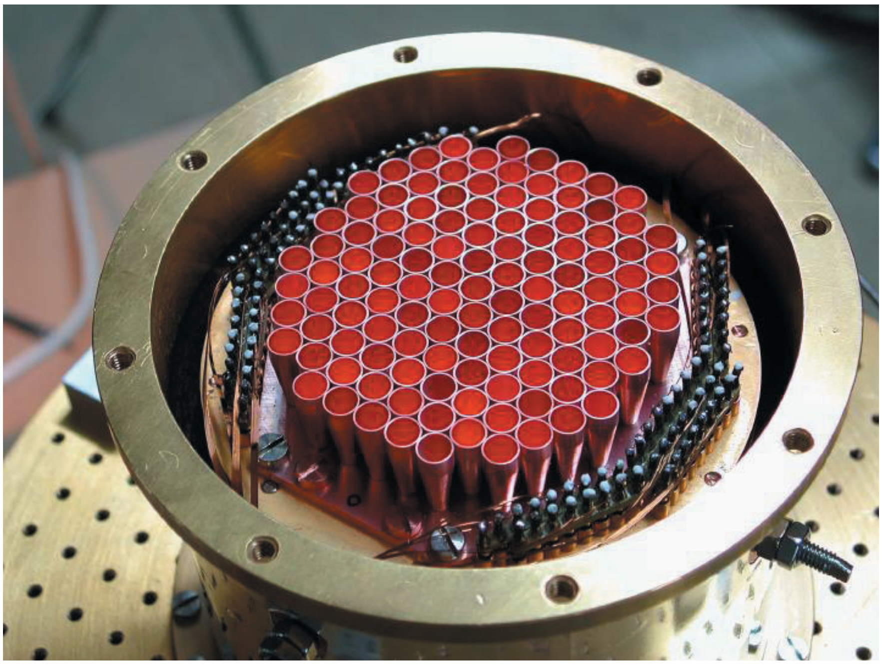

Figure 4: An example of a bolometer array: MAMBO2, the 117-channel bolometer array built by the Max-Planck-Institut für Radio-Astronomie for the IRAM 30-m telescope.

structure atomic lines like the CI lines at 809 GHz and 492 GHz as well as the excited nitrogen line [NII] at 1.46 THz, which is very common in the ISM. The excitation requirements of most atomic and molecular transitions at THz frequencies select the densest gas nearest to a young stellar object. As a result it is expected that the most intense radiation will be concentrated in regions with angular scales of a few arcseconds, corresponding to the beam size of APEX at these frequencies. The luminous star bursts in interacting galaxies also produce intense emission at THz frequencies, also on angular scales of a few arcsec in the nearest regions. Thus, the highest (THz) observing bands which may be reached through the combination of the superior Chajnantor site and the excellent performance of the APEX antenna are ideally suited to the study of chemical evolution, energetics and dynamics of star-forming regions.

2.5. Objects of special interest

APEX will be able to completely map unique objects at submillimetre wavelengths. Some of the most interesting sources in the sky can best (or only) be studied from the southern hemisphere. These include four out of five of the nearest sites of low-mass star formation (within about 150 pc), the Galactic centre (an important prerequisite study for the future understanding of the central regions of other galaxies), the Magellanic Clouds (the nearest galaxies to our own and prototypes of metal-poor galaxies in an earlier stage of evolution), and Centaurus A (the nearest galaxy with an active nucleus).

3. Telescope

The APEX antenna, built by VERTEX Antennentechnik in Germany, is a modified copy of the ALMA-US prototype antenna. It has a diameter of 12 metres, and the reflector surface will be set to an accuracy of 18 micrometer or better in order to observe beyond 1 THz. The telescope is designed to give precision performance even with wind speeds up to 9 m/s, and the pointing accuracy is specified to be better than 2 arcsec (absolute). The main modifications to the original ALMA antenna design are the incorporation of Nasmyth focus cabins and a chopping secondary mirror. These modifications are required for single-dish operations of array receivers and bolometers. The antenna will have in total three focus cabins, one at the Cassegrain focus and two at the Nasmyth foci.

4. Instruments

APEX instrumentation will include both wide-band bolometer array receivers for continuum observations and heterodyne receivers for spectral line observations. Some of the instruments will be specifically designed and custom-built for APEX. Instruments in use at other sites may be transferred to APEX, where they are expected to provide better data than at their current home.

APEX will initially operate with a 300-element bolometer array at 870 microns, the ideal wavelength to search for high-redshift dust emission. It is called LABOCA (LArge BOlometer CAmera) and is being built through a Bonn/ Bochum/Jena collaboration. Additionally, a 37-element array at 350 microns will be constructed to determine the spectral index of the radiation and to study sources with higher angular resolution over smaller fields.

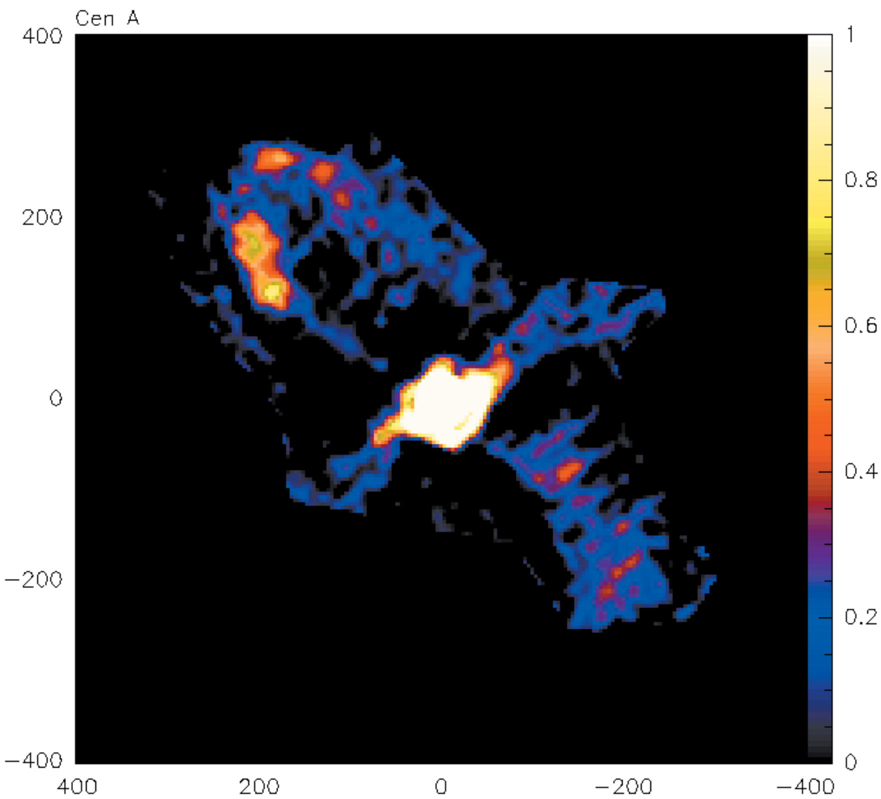

Figure 5: Centaurus A, the most nearby active galaxy, observed with the 37-channel bolometer array SIMBA (SEST IMaging Bolometer Array) at SEST. Note the emission from the dust lanes as well as the curved jets perpendicular to the dust lanes.

Heterodyne instruments will play an important role for observations from Chajnantor: APEX will be equipped with receivers covering all atmospheric windows from 200 GHz to 1 THz. In addition, several experimental receivers covering selected windows above 1 THz – uniquely observable from Chajnantor – will be provided. APEX will be equipped with autocorrelation spectrometers.

5. Site

The greatest problem for ground-based submillimetre astronomy is the absorption of incoming radiation by atmospheric lines, mainly by water vapour. This is why the submillimetre region of the spectrum is still relatively unexplored. Ground-based submillimetre astronomy can only be done from sites with extremely dry atmospheres, such as high mountain tops and in Antarctica.

Llano de Chajnantor is most likely the best place for submillimetre astronomy on Earth (possibly rivalled only by the far more inaccessible sites in Antarctica), because of its high altitude at 5000 m and also because of its location in the dry Chilean Atacama desert. Long-range monitoring to characterize the site for the ALMA project has been carried out since 1995, showing that the excellent atmospheric conditions on Cerro Chajnantor will allow observations in all submillimetre windows close to 50% of the time.

6. Infrastructure and operations

APEX will be operated as part of the La Silla Observatory. The staff of 18 will include astronomers, operators and engineers/technicians. There will be a base in San Pedro de Atacama (the nearest village at an altitude of 2500 m), which will consist of offices, laboratories, control room, cafeteria and dormitories, and the staff will sleep at the base. On the high site, APEX will be operated and maintained from a set of oxygenized and heated containers. Diesel generators will provide power, both at the base and at the high site. There will be a high-speed microwave link between the San Pedro base and the telescope, allowing APEX to be operated remotely from San Pedro in service mode and with flexible scheduling. There may also be a visitor mode with observations being done remotely from San Pedro. Part of the observing time will be dedicated to more experimental observations with PI instruments at THz frequencies.

7. Time scales

The antenna will be erected on the site in April 2003 by VERTEX Antennentechnik. At this time receivers operating at 90 GHz will be installed in order to do holography and to set the surface to 18 microns rms. First-light receivers will be installed soon after this, consisting of the SEST 1.3-mm receiver and perhaps also a single pixel bolometer. The first heterodyne receivers are expected to arrive at the end of 2003, and LABOCA, the 300 pixel bolometer array, in the beginning of 2004. APEX operations are expected to start in the beginning of 2004.

8. SEST and APEX

ESO and OSO are presently operating SEST on La Silla. In order to provide operational funds for APEX, SEST operations are expected to stop at the end of June 2003 and SEST will be closed. There is however a possibility that SEST may continue to be used after June 2003, by dedicated groups doing survey work.

More information on APEX can be found at: http://www.mpifr-bonn.mpg.de/div/mm/apex.html and http://www.oso.chalmers.se/oso/apex/index.html

VIMOS Commissioning on VLT-Melipal

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Introduction

In the mid-80s, multi-object spectroscopy (MOS) appeared as a new and powerful technique to perform the spectroscopy of many objects simultaneously. The idea is simple: instead of using a single slit as the input to a spectrograph, masks are manufactured with slits positioned facing the images of targets of interest in the entrance focal plane of the spectrograph. The technical implementation turned out to be more tricky, but the first successful experiments were conducted with punching machines, in particular at ESO and CFHT with the PUMA concept [1].

MOS was then quickly identified as the tool of choice to conduct deep galaxy surveys. Multi-object spectrographs on 4-m-class telescopes have been very powerful tools to quantify the evolution of galaxies over more than half of the age of the universe, up to redshifts ~1 [2][3]. This because the density of galaxies to I ~ 22 (reaching redshifts ~1 or about half the current age of the universe) projected on the sky is high enough that very efficient spectrographs with high-quality CCDs [4] can efficiently assemble samples of several hundreds of measured spectra and redshifts. The technique was then applied on the first 10-m Keck with the LRIS spectrograph [5] and produced most of the Lyman-break galaxies at redshifts 3–4 known today [6].

However, the study of galaxy evolution and of their space distribution over most of the age of the universe requires much more than the few thousand galaxies measured today, all surveys included. The need to study the distribution of galaxies in the local universe has prompted two major science and instrumentation programmes: the Sloan Digital Sky Survey (SDSS), and the 2dF Galaxy Redshift Survey. Both are acquiring several hundred thousands of galaxy spectra with dedicated MOS facilities [7][8]. Similarly, the need to acquire large numbers of spectra/redshifts over a redshift range 0–5 covering 90% of the current age of the universe, has been identified. This is required by the necessity to cover several time/redshift steps, study the evolution of various classes of galaxies in a wide range of environments, ranging from the low density of voids to very