MMA Project Book, Chapter 14 [WBS 11.1]

SITE CHARACTERIZATION AND MONITORING

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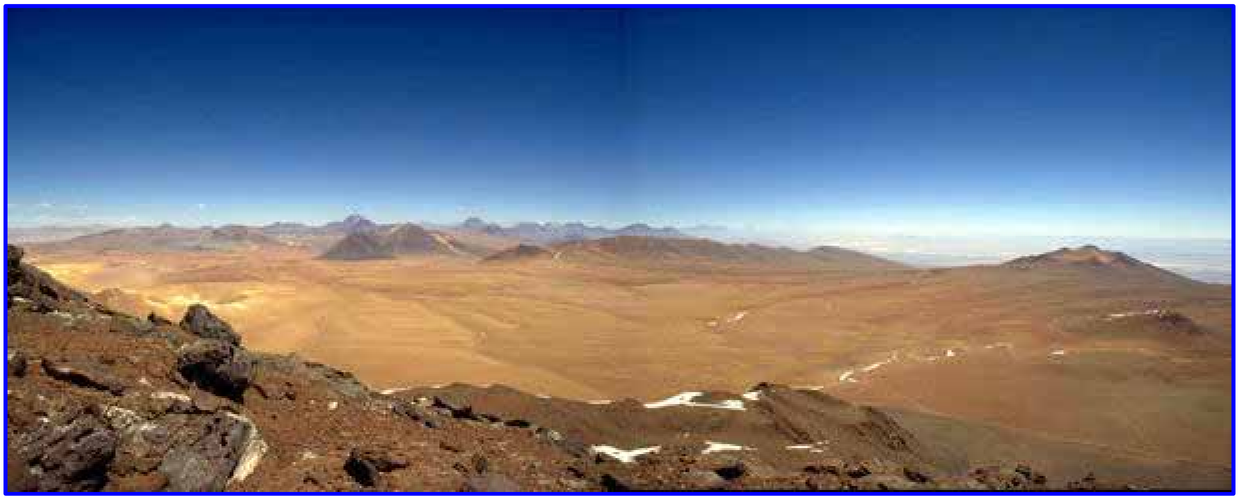

View south from Cerro Chajnantor of MMA site.
Photo: S. Radford, 1994 November.

Revision History:
1998 October 16: Reorganized to match WBS, added section numbers.
1998 July 15: Original version.

14.1 Goals

During the project's prehistory, NRAO conducted extensive measurements to characterize several candidate sites for the Millimeter Array. These studies culminated in the recommendation of an array site on the high (5000 m) plateau southwest of Cerro Chajnantor, Chile, about 40 km east of the village of San Pedro de Atacama. The goals of further site characterization and monitoring are:

- to identify and quantify site conditions and their influence the instrument design or operations concepts,
- to provide a historical record of site conditions to guide priorities for instrument development and operation,
- to maintain a continuous presence on the site through development and construction to the start of operations, and
- to maintain contact and coordinate efforts with other groups working on or near the site.

14.2 Areas of interest

At millimeter and submillimeter wavelengths, pressure broadened molecular spectral lines make the atmosphere a natural limitation to the sensitivity and resolution of astronomical observations. Tropospheric water vapor is the principal culprit. The translucent atmosphere both decreases the signal, by attenuating incoming radiation, and increases the noise, by radiating thermally. Furthermore, inhomogeneities in the water vapor distribution cause variations in the electrical path length through the atmosphere. These variations result in phase errors that degrade the sensitivity and resolution of images made with both interferometers and filled aperture telescopes. The site characterization effort addresses these areas:

- Radiometric properties of the atmosphere
  - stability [11.1.2]
  - transparency [11.1.3]
- Physical structure of the atmosphere [11.1.4]
  - meteorology
  - stratification
  - turbulence
- Physical characteristics of the site
  - topology
  - geology

14.3 Site Infrastructure [11.1.1]

The MMA operations base on Chajnantor is a 20 foot (6 m) long ocean shipping container that provides shelter for personnel and physical support for the instruments. The LSA project has a similar container 15 m north of the MMA equipment. A third container is installed 1 km west of the MMA container as a launch base for radiosondes.

14.3.1 Safety program [11.1.1.1]

Site inspections (every six months? year?); inventory, inspection, and, if necessary, repair or replacement of safety supplies and equipment; identification, and, if necessary, remediation of safety hazards; training (first aid, high altitude illness, oxygen therapy, fire safety, industrial safety). Note safety rules.

14.3.2 Solar power system [11.1.1.2]

An array of solar panels and a battery bank supply electrical power (24 VDC and 110 VAC 60 Hz). The system can supply about 500 W continuously, with sufficient reserve capacity to weather a storm of a few days. With current instrumentation, the system operates near capacity. A wind turbine has been installed on two occasions to augment the solar panels, but it broke quickly. System maintenance includes a periodic (yearly) check and refill of battery water.

14.3.3 Communications [11.1.1.3]

Voice and low-speed (<= 9600 baud) data are transmitted by cellular and satellite (INMARSAT-A) telephones. Handheld radios will be used for communications on and around the site.

14.3.4 Freight [11.1.1.4]

Expenses of equipment deployment.

14.3.5 Transportation [11.1.1.5]

Vehicles (4WD) for access to Chajnantor.

14.3.6 High resolution digital elevation model [11.1.1.6]

1n 1996, contour maps and digital elevation models were prepared from aerial photographs (MMA Memo 160). These cover two 8 × 8 km regions of the Chajnantor and Pampa la Bola areas at 5-10 m resolution. These maps will be extended to the entire science reserve (26 × 24 km). They will be used for hydrodynamic studies of airflow over the site, for planning the array configurations, and for planning civil works.

14.3.7 Computers and network [11.1.1.7]

All (NRAO) instruments are controlled by PCs running Windows 95. They are interlinked with ethernet, which extends to the LSA container. The PC clocks are synchronized to a GPS receiver that provides an absolute time reference good to about 1 s.

14.3.8 Auxiliary instruments [11.1.1.8]

- A surveillance camera, installed on 1997 June 15, takes pictures of the southwest horizon every two hours. Data are retrieved about once a month and the images posted.
- A subsurface temperature probe was operated 1997 June - October and 1998 March - May. Data analysis is ongoing.
- A seismometer was installed in 1995. Data are analyzed by Chilean group (K. Bataille). Status of GPS rollover unknown.

14.3.9 Physiology studies [11.1.1.9]

John West, MD (UCSD) is investigating strategies for improving worker comfort and performance at high altitude. These include enhancing the oxygen concentration of the air in working and living quarters (MMA Memo 191).

14.4 Atmospheric stability [11.1.2]

Inhomogeneities in the distribution of water vapor cause variations in the electrical path length through the atmosphere. The resulting phase errors degrade the sensitivity and resolution of observations with both interferometers and filled aperture telescopes.

14.4.1 12 GHz interferometer [11.1.2.1]

The site test interferometers directly measure the tropospheric phase stability. They observe unmodulated 11.5 GHz beacons broadcast from geostationary satellites and measure the phase difference between the signals received by two 1.8 m diameter antennas 300 m apart. Because the atmosphere is non-dispersive away from line centers, the results can be scaled to millimeter and submillimeter wavelengths.

Three instruments have been constructed by NRAO's Tucson office. The first was operated near the VLBA antenna (3720 m) on Mauna Kea, Hawaii, from 1994 September to 1996 June, then installed at the VLA in in 1997 May. The second has been operating on Chajnantor (5000 m) near San Pedro de Atacama, Chile, since 1995 May. A third was built for the LSA project. ESO installed it at Pajonales in 1997 April and moved it to Chajnantor in 1998 June.

The design and operation of these instruments are described in Site Test Interferometer (Radford, Reiland, & Shillue 1996, PASP 108, 441). From the phase time series, we obtain the r. m. s. path fluctuations on a 300 m baseline, the power law exponent of the phase structure function, and the velocity at which the turbulent water vapor moves over the array. MMA Memo 129 describes the site test interferometer data reduction in detail, and MMA Memo 130 illustrates the agreement between two different methods of deriving the mean velocity of the turbulent water vapor flow in the atmosphere.

In 1998 June, the LSA interferometer was set up alongside the MMA interferometer. They share essentially the same baseline, but observe different satellites about 5° apart on the sky. Lag correlation of the data from the two interferometers will indicate the height of the turbulent layer (see MMA Memo 196).

The interferometers operate autonomously. Status reports are received daily and data are retrieved about once a month. The data are analyzed in Tucson and monthly summaries are posted. Current activity includes operation and maintenance, including sporadic repair as required, data retrieval, and data analysis.

14.5 Atmospheric transparency [11.1.3]

Pressure broadened molecular spectral lines, principally of tropospheric water vapor, make the atmosphere semi-opaque at millimeter and submillimeter wavelengths. The translucent atmosphere radiates thermally, which increases the system noise, and attenuates incoming radiation, which decreases the signal.

14.5.1 225 GHz tipper [11.1.3.1]

The 225 GHz tipping radiometer is the benchmark instrument for site characterization. It measures the atmospheric transparency every 10 minutes and the stability of atmospheric emission every fifth hour. Operation is automatic. Daily and monthly data summaries are posted. The data are made available to interested parties in machine readable form. Current activity includes operation and maintenance, including sporadic repair as required, data retrieval, and data analysis.

14.5.1 Submm tipper [11.1.3.2]

A tipping photometer was been developed in collaboration with Carnegie Mellon University to directly measure the atmospheric transparency at 350 µm wavelength. This instrument is based on an ambient temperature, pyroelectric detector. The spectral response is defined by a resonant metal mesh. A compound parabolic (Winston) cone and offset parabolic scanning mirror together define the 6° beam on the sky. The detector is internally calibrated with two temperature controlled loads and views the sky through a woven Gore-tex window. Identical instruments have been deployed on Chajnantor (1997 October), at the CSO on Mauna Kea (1997 December), and at the South Pole (1998 January).

The instruments operate autonomously. Status reports are received daily and data are retrieved about once a month. The data from these instruments are being analyzed with the aim of making an unbiased comparison of the three sites. Current activity includes operation and maintenance, including sporadic repair as required, data retrieval, and data analysis. Further work includes

- cross calibration between the submm tipper and other instruments, namely the 225 GHz tippers, SCUBA, CSO, and AST/RO,
- continued development of the filter wheel to add 1300 µm and 200 µm channels, and
- possible deployment on Cerro Toco (5400-5500 m) to investigate the dependence of transparency with altitude in the area of Chajnantor.

14.5.2 Fourier Transform Spectrometer [11.1.3.3]

To measure the atmospheric emission spectrum at Chajnantor, the Smithsonian Observatory has deployed a Fourier transform (polarizing Martin-Pupplet) spectrometer. This cryogenic instrument covers 350 - 3000 GHz with 3 GHz resolution and a 3° beam. The instrument recorded data for most of the 1998 winter season. NRAO provides the base for field operations.

14.6 Physical structure of atmosphere [11.1.4]

The vertical profiles of atmospheric water vapor and turbulence may affect the success of radiometric phase calibration schemes.

14.6.1 Radiosonde campaign [11.1.4.1]

Radiosondes carried by weather balloons provide *in situ* measurements of pressure, temperature, humidity, and wind speed and direction over the launch site. From these data we may learn about the stratification of the water vapor over Chajnantor and about shear layers that may generate turbulence. A surplus radiotheodolite was acquired, upgraded by the manufacturer, tested in Tucson, and deployed at Chajnantor. Beginning in 1998 October, balloon flights will be made whenever appropriate personnel are at the site. This campaign is a collaboration between NRAO, Cornell, ESO, and SAO. The balloons will be launched from a container placed 1 km west of the main site.

14.6.2 Hydrodynamic models [11.1.4.2]

Calculations of airflow over Chajnantor, with emphasis on turbulence generated by local topography.

14.6.3 Sodar [11.1.4.3]

Acoustic sounding, or sodar, senses thermal turbulence in the lower atmosphere. Engineering tests of an ESO sodar unit were planned for 1998, but are postponed indefinately. After these tests, we will evaluate our interest we have in pursuing further measurements.

14.6.3 Weather stations [11.1.4.3]

Additional weather stations will be deployed to measure the variation of meteorological parameters over the site.

14.7 Technical planning with collaborators [11.1.5] and

neighbors

Several groups are carrying out site characterization studies or astronomical experiments nearby. NRAO encourages these groups and takes interest in their results. As needed, NRAO and the other groups coordinates activities.

14.7.1 ESO/LSA

In 1998 June, the LSA project redeployed its site characterization equipment to Chajnantor. The LSA equipment, located 15 m north of the MMA equipment, includes:

- Several weather stations. These are currently deployed adjacent to the containers, but will be deployed across the site in the last quarter of 1998.
- A 12 GHz interferometer. This is set up alongside the MMA interferometer, sharing essentially the same baseline, but observing different satellites about 5° apart on the sky. Lag correlation of the data from the two interferometers will indicate the height of the turbulent layer (see MMA Memo 196).
- Dual three channel 183 GHz radiometers. These instruments, designed and constructed by MRAO, OSO, and ESO, measures the H_2O line shape. They are installed at the ends of the LSA interferometer and look in the same direction as the interferometer. Variations in the line shape will then be compared to the phase fluctuations measured with the interferometers. [11.1.2.2]
- A single channel 22 GHz radiometer (deployment foreseen in late 1998).

The LSA project provides field support for the MMA site characterization program.

14.7.2 NRO/LMSA

At Pampa la Bola, about 7 km northeast of the MMA equipment, the LMSA project has installed:

- Dual 220 GHz tipping radiometers,
- A 12 GHz interferometer, and
- A Fourier Transform Spectrometer (temporary deployments).

14.7.3 Cornell

The CAT project is making optical seeing (DIMM) measurements. Campaigns in 1998 May, July, October, etc.

14.7.3 MAT

Observations of fluctuations in the Cosmic Background Radiation by a Princeton/Pennsylvania group. Campaigns in 1997 and 1998.

14.7.3 CBI

Observations of fluctuations in the Cosmic Background Radiation by a Caltech group. Deployment foreseen in early 1999.

14.8 Site Characterization Reviews [11.1.6]

Scientific reviews of site characterization data obtained by all groups.

14.8.1 USNC/URSI meeting [11.1.6.1]

At the USNC/URSI National Radio Science Meeting in 1999 January in Boulder, there will be a session on Atmospheric Transmission at Millimeter and Submillimeter Wavelengths. Results from the NRAO site characterization program will be presented.

14.8.2 Mid-term Review [11.1.6.2]

2000 March

14.8.3 Final Review [11.1.6.3]

2001 March

References

MMA Site Studies

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