Installation of the Antarctic Sub-mm Telescope and Remote Observatory (AST/RO)

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Abstract. Atmospheric measurements by various observers indicate that the Antarctic Plateau is the best submillimeter-wave observatory site ever tested. AST/RO, a 1.7 m diameter telescope for astronomy and aeronomy studies at wavelengths between 200 and 2000 μm, was installed at the South Pole during the 1994-95 Austral summer, after some logistical difficulties were overcome. The instrument is now operational with four heterodyne receivers and three acousto-optical spectrometers. The optical design is Gregorian, offset in both azimuth and elevation, with the exit pupil at the chopping tertiary mirror: this arrangement provides for low switched-power offsets even when the beam is thrown several degrees. There is a Coudé focus in a warm, spacious receiver room and also a Nasmyth focus with optical and mechanical properties similar to the KAO.

Submillimeter-wavelength astronomy can be pursued only from extremely cold and dry sites, where the atmosphere contains less than 1 mm of precipitable water vapor. Water vapor is the dominant source of opacity at these wavelengths, although many other atmospheric molecules, both rare and common, also make contributions (1, 2). Measurements from the South Pole reported by Pajot *et al.* (3) and Dragovan *et al.* (4) indicate that the broad-band atmospheric opacity in the 650μm window is typically $\tau_{\rm zenith} \sim 0.2$. Chamberlin and Bally (5, 6) measured the 225 GHz opacity at the South Pole several times a day throughout 1992, using an NRAO tipping radiometer. These observations show that the λ1.3mm sky opacity at the South Pole exceeds 0.1 only fifteen days a year, significantly better than Mauna Kea where this value is exceeded about half the time. The atmospheric opacity at the South Pole changes only slowly, unlike Mauna Kea where diurnal effects are significant and the submillimeter-wave opacity may change significantly in less than an hour.

AST/RO is a 1.7-m diameter telescope at the South Pole (7). The immediate scientific goals of this instrument are heterodyne spectroscopy of galactic atomic and molecular clouds and molecular lines in the earth's stratosphere at wavelengths near 600μm, but the telescope was designed to be a general-purpose instrument for the millimeter, submillimeter and far-infrared. The 1.7-m aperture yields a beamsize of $96''(\lambda/600\mu m)$, large enough to

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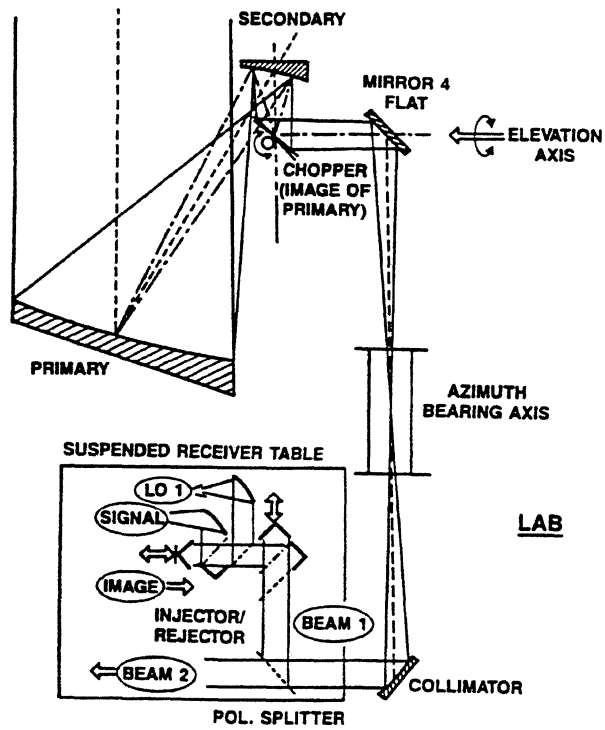

Figure 1: Schematic of the AST/RO optical system. For purposes of representation, the beam path has been flattened and the reader should imagine that the primary and secondary mirrors are rotated by 90° out of the plane of the page around a vertical line passing through the center of the secondary. The azimuth bearing is at the level of the building roof.

allow large-scale mapping programs, yet small enough to map distant clouds in the Galaxy and to just resolve hundreds of external galaxies. It is not small enough, however, to study distant galaxies or to study protostellar regions in any detail. The telescope was designed to be transported to the South Pole in a few large pieces and re-assembled on-site. It happened, however, that the amount of on-site work required was much greater than planned.

All of the optics in AST/RO are offset for high beam efficiency and avoidance of inadvertent reflections and resonances (8). Figure 1 shows the optical arrangement in its Coudé form. The primary reflector is made of carbon fiber and epoxy with a vacuum-sputtered aluminum surface having a surface roughness of 6μm and an rms figure of about 9μm (9). The Gregorian secondary is a prolate spheroid, and its offset angle was chosen using the method of Dragone (10), so that the Gregorian focus is aplanatic. The diffraction-limited field-of-view is 3° in diameter at λ3mm and $30'$ in diameter at $\lambda 200\mu$m. The chopper can make full use of this field-of-view, because it is located at the exit pupil and so does not change the illumination pattern on the primary while chopping. Note in Figure 1 that rays diverging from a point on the primary mirror reconverge at the tertiary mirror, since the tertiary is at the exit pupil of the instrument. Optimizing the optics this way requires that the primary mirror be cantilevered away from the elevation axis: this is accomplished with a truss of Invar rods which hold the primary-to-secondary distance invariant with temperature. When the fourth mirror shown in Figure 1 is removed, the telescope has a Nasmyth focus where the beam passes through an elevation bearing which has a 0.2m diameter hole. This focus is almost identical in its optical properties to the bent Cassegrain focus on the Kuiper Airborne Observatory, except for a larger field-of-view. Array detectors of various types could be used at this focus in the future.

Currently, there are four heterodyne receivers mounted on an optical table suspended from the telescope structure in a spacious, warm Coudé room:

- a 230 GHz SIS receiver, 500 K SSB noise temperature (11);
- a 460-500 GHz Schottky-barrier diode receiver, 950 K DSB (this receiver will work without a liquid Helium supply) (12);
- a 492 GHz SIS waveguide receiver, 340 K DSB with the current SIS junction (13);
- a 492 GHz SIS quasi-optical receiver, 170 K DSB (14, 15).

The laboratory space under the telescope holds three racks of electronics, including two 1.2-GHz wide acousto-optical spectrometers and one high-resolution acousto-optical spectrometer (16), cryogenic equipment, laboratory benches, and storage for tools. Other rooms in the AST/RO building are used for telescope control monitors, data analysis, additional laboratory space, and storage. The entire system is highly automated to reduce to a minimum the need for operator intervention and can be operated over the Internet.

The AST/RO telescope was fabricated between 1990 and 1992 at AT&T Bell Laboratories, Crawford Hill, NJ, and at the Scientific Instrument Facility at Boston University. In 1993 and 1994, it was installed at a test site in Boston and used for observational tests (17). In August 1994, this entire working observatory was packed into crates and shipped. Unfortunately, the truck carrying all the equipment was involved in a serious accident. Some of the parts which had been critically positioned in the shop during telescope assembly, such as the encoders, were knocked out of position. When mounted on the AST/RO building at the Pole, the telescope can be enclosed in a retractable cloth and aluminum "baby-buggy" cover. This sheltered working environment allowed an unplanned partial disassembly and realignment of the critical components, demonstrating that even delicate mechanical work can be accomplished on the Polar plateau.

The first observations from the South Pole were made in January 1995. Figure 2 shows a spectrum of the 492 GHz line of neutral atomic carbon toward the galactic center molecular cloud Sagittarius A taken by AST/RO. As of this writing (April 1995), AST/RO winter-over scientist Richard Chamberlin is carrying out engineering tests and observations. All

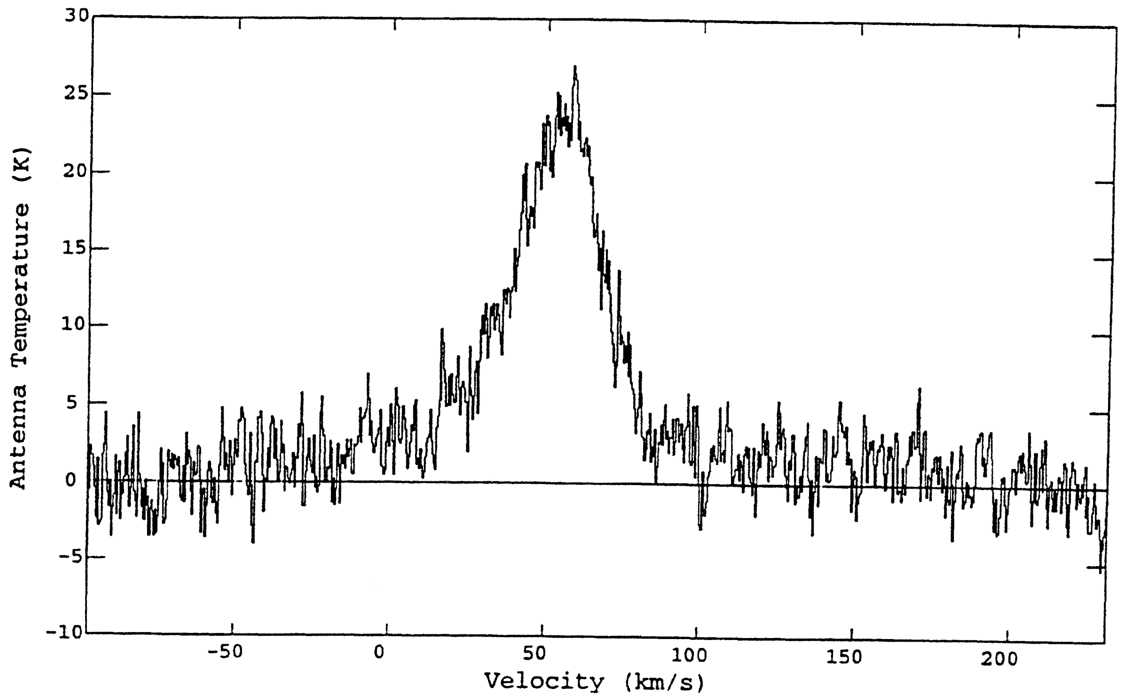

Figure 2: The 492 GHz line of neutral atomic carbon, in the direction of the galactic center molecular cloud Sagittarius A, taken by the AST/RO telescope from the South Pole. The calibration of the vertical scale is preliminary.

four receivers are operational. The liquid helium supply is expect to last for most of the winter season. Skydips at 492 GHz are made regularly and will be used to characterize the quality of the winter sky.

The AST/RO group is grateful for the logistical support of the National Science Foundation (NSF), Antarctic Support Associates, and CARA during the 1994-95 expedition. We also thank Rick LeDuc and Bruce Bumble at JPL for making SIS junctions and Jacob Kooi and Tom Phillips at Caltech for making them available to us. This work was supported in part by National Science Foundation grant DPP88-18384, and by the Center for Astrophysical Research in Antarctica and the NSF under Cooperative Agreement OPP89-20223.

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