A. Project Summary

Astronomy is undergoing a revolutionary transformation, where for the first time we can observe the full range of electromagnetic radiation emitted by astronomical sources. One of the newly-developed and least explored bands is submillimeter-waves, at frequencies from about 300 Gigahertz up into the Terahertz range. Submillimeter wave radiation is emitted by dense gas between the stars, and submillimeter-wave observations allow us to study in unprecedented detail the galactic forces acting upon that gas and the star formation processes within it. This exciting prospect has led to plans for large, powerful submillimeter-wave telescopes like the Smithsonian Submillimeter Array (SMA), and the Atacama Large Millimeter Array (ALMA). These interferometers will have sub-arcsecond resolution over a field of view which is about an arcminute in size. These instruments will resolve the star-forming cores of nearby interstellar clouds, and will study the molecular material in thousands of galaxies, some at cosmological distances. This great undertaking will show how stars form throughout the universe.

The Antarctic Submillimeter Telescope and Remote Observatory (AST/RO) is a 1.7 m diameter single-dish instrument which has been operating for six years in several submillimeter-wave bands (Stark *et al.* 2001). It has made position-position-velocity maps of submillimeter-wave spectral lines such as ${}^3P_1 \rightarrow {}^3P_0$ and ${}^3P_2 \rightarrow {}^3P_1$ C I and $J = 4 \rightarrow 3$ and $J = 7 \rightarrow 6$ CO with arcminute resolution over regions of sky which are several square degrees in size. It can observe molecular clouds throughout the fourth quadrant of the Milky Way and the Magellanic Clouds, in order to locate star-forming cores and study in detail the dynamics of dense gas in our own Galaxy. AST/RO studies of molecular clouds with varying heavy element content under a variety of galactic environments are showing how molecular clouds are structured, how the newly-formed stars react back on the cloud, and how galactic forces affect cloud structure. AST/RO studies of the Galactic Center Region have shown, for example, that the smooth ring of molecular material 300 parsecs from the Galactic Center is on the verge of coagulating into a single, massive molecular cloud like the one surrounding Sgr B2, and will likely undergo a burst of star formation in a few hundred million years (Kim *et al.* 2000). AST/RO studies have shown that the structure of molecular clouds is affected by their heavy element content (Bolatto *et al.* 2000a) and by their proximity to spiral arms (Zhang *et al.* 2001). AST/RO has observed the isotopically-shifted ^{13}C I line, in order to study the gradient of heavy elements in the Galaxy (Tieftrunk *et al.* 2001). AST/RO has recently observed deuterated water, HDO, in order to better understand the chemistry of water in dense clouds.

Essential to AST/RO's capabilities is its location at Amundsen-Scott South Pole Station, an exceptionally cold, dry site which has unique logistical opportunities and challenges. Most submillimeter radiation from astronomical sources is absorbed by irregular concentrations of atmospheric water vapor before it reaches the Earth's surface. The dessicated air over South Pole Station allows an accurate intercomparison of submillimeter-wave power levels from locations on the sky separated by several degrees. This is essential to the study of submillimeter-wave radiation on the scale of the the Milky Way and its companion galaxies.

We propose to operate AST/RO as a survey instrument and user facility. Post-doctoral and Graduate Students will receive detailed training in submillimeter-wave observing techniques and instrumentation. AST/RO will also serve as a test bed for newly-developed detectors operating at Terahertz frequencies. We will devote equal effort to three initiatives:

1. Large-scale maps of $J = 4 \rightarrow 3$ and $J = 7 \rightarrow 6$ CO and ${}^3P_1 \rightarrow {}^3P_0$ and ${}^3P_2 \rightarrow {}^3P_1$ C I in the Galactic Center Region and the Magellanic Clouds. These observatory survey data will be made freely available.
2. Support of proposals from the worldwide community of astronomers. Proposals will be ranked by scientific merit and carried out as instrumental capabilities and weather permit.
3. Installation and use of Terahertz detector systems. Two very different high frequency detector systems using novel technology have already been funded and are under development for use on AST/RO. We will support the installation of these instruments and collaborate on using them for astronomical observations.

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C. Project Description

The interstellar medium in its relationship to star formation on the small scale and galactic structure on the large scale is among the central themes of modern astronomy, and touches on many of the outstanding problems in astrophysics today. Advances in understanding have come as technology has closed the wavelength gap between the radio and infrared, allowing detection of baryonic interstellar matter in all its phases. Interstellar line and continuum emission is now studied at all wavelengths. Submillimeter-wave line spectroscopy is an especially important diagnostic of the star-forming interstellar medium; in this wavelength range lie the dominant cooling lines of dense gas: fine-structure lines of ground-state atomic carbon (C I) and the mid-J rotational lines of the ground vibrational state of carbon monoxide (CO). Emission from these lines is bright and widely distributed—visible even in high-redshift galaxies (Brown and vanden Bout 1992, vanden Bout and Brown 1992, vanden Bout and Brown 1994). From the Galaxy as a whole, the $J = 4 \rightarrow 3$ CO line is the most luminous of all the CO lines, while the two C I lines are more luminous than all the CO lines combined (Wright *et al.* 1991).

Observing the submillimeter-wave cooling lines and their isotopomers allows constraints to be placed on the density and temperature of molecular gas wherever it is found. The distribution of molecular gas in the Galaxy is known from the extensive and on-going surveys in CO and ^{13}CO $J = 1 \rightarrow 0$ and $J = 2 \rightarrow 1$, whose line brightnesses are approximately proportional to molecular column density, provided that column density is less than $\sim 10^{23}$ cm^{-2}. These lines alone do not constrain the excitation temperature, density, or cooling rate of the molecular gas, however. Observations of C I and the mid-J lines of CO and ^{13}CO provide the missing information, showing a more complete picture of the thermodynamic state of the molecular gas, highlighting the active regions, and looking into the dense cores. Furthermore, when all the important radiative cooling lines are seen, it is possible to be quantitative about the energy balance in the molecular material, and better relate the radiative energy to gas dynamics on large and small scales.

The brightness of the submillimeter-wave cooling lines toward a given astronomical source cannot in general be predicted using other observations and is therefore fundamentally new information. The ratio of $^3P_1 \rightarrow {}^3P_0$ [C I] to ^{13}CO $J = 1 \rightarrow 0$ brightness is remarkably constant in nearby giant molecular clouds (Keene *et al.* 1985), but AST/RO observations show that this is not the case for translucent clouds (Ingalls *et al.* 2000), the Galactic Center (Ojha *et al.* 2001), or the Large Magellanic Cloud (Bolatto *et al.* 2000a). Maps of $J = 4 \rightarrow 3$ and $J = 7 \rightarrow 6$ CO are usually very different from the corresponding maps of $J = 1 \rightarrow 0$ CO. Observations of the submillimeter-wave cooling lines completes the panoply of information available about the dense interstellar gas from observations at other wavelengths.

The Antarctic Submillimeter Telescope and Remote Observatory (AST/RO) is an instrument designed and used for the measurement of submillimeter-wave spectral lines over regions several square degrees in size toward the Milky Way and Magellanic Clouds. This capability permits the study of astrophysical questions relating to the energetics, chemistry, and chemical evolution of the interstellar medium on a galactic scale:

- Do theoretical models of Photodissociation Regions (PDRs) (e.g. Hollenbach and Tielens 1999, and references therein) and dense molecular clouds (e.g. Goldsmith 1999) agree with observation under varying conditions of metallicity, ultraviolet background, and external pressure?
- What are the gradients of isotopic abundance in the Galaxy?
- What are the mechanisms behind starbursts in the Galactic Center?
- How does spiral structure affect star formation?
- What are the sources of energy driving turbulence in molecular clouds?
- How is star formation affected by the environment in which it occurs?
- How do protostars evolve?
- How do star formation processes react back on the molecular gas?

We propose to manage AST/RO research as a three part effort, where approximately equal time will be given to each of these initiatives:

1. large-scale surveys of regions of general interest: the Galactic Center and the Magellanic Clouds;
2. support of observations of special interest, through observing proposals solicited from the worldwide astronomical community;
3. support of technology development, by making the telescope available for installation and trial of novel detectors, especially detectors at Terahertz frequencies.

This is a proposal to the U.S. National Science Foundation (NSF) Office of Polar Programs to operate AST/RO for a three-year period as an astronomical survey and user-facility instrument. This proposal covers the operation and maintenance of the telescope and detectors in their current form; other proposals for additional new instrumentation have already been approved and funded. AST/RO was constructed, installed at the NSF Amundsen-Scott South Pole Station, and operated for six years, as part of the Center for Astrophysical Research in Antarctica (CARA), an NSF Science and Technology Center with an 11-year lifetime, supported by Cooperative Agreement OPP89-20223 to the University of Chicago. With the dissolution of CARA in Jan 2002, AST/RO will no longer be supported and this proposal seeks funds for continued operation. This proposal marks a turning point in AST/RO operations. Under CARA, AST/RO was an experimental prototype and its scientific effort was largely directed toward the acquisition of data for student theses (Staguhn 1996, Ingalls 1999, Hsieh 2000, Bolatto 2001, Huang 2001). Under the current proposal, AST/RO will become a general-purpose observatory for the astronomical community at large.

The following sections describe the current status of AST/RO and the scientific motivation for its continued operation:

§C 1 Description of AST/RO and South Pole Site—the telescope is at present fully operational with five receivers covering frequencies from 220 to 810 GHz. Submillimeter site testing and our observing experience show exceptionally good sky opacity and low sky noise at the South Pole.

§C 2 Results of Prior NSF Funding—highlights of AST/RO research results.

§C 3 Proposed Research:

Large Scale Mapping—selected regions, in particular the Galactic Center region and the Magellanic Clouds, will be mapped in the C I $^3P_1 \rightarrow {}^3P_0$ and $^3P_2 \rightarrow {}^3P_1$ lines and the ^{12}CO $J = 4 \rightarrow 3$ and $J = 7 \rightarrow 6$ lines. These data will be made publicly available on the World-Wide Web within a year of their observation, in addition to being analyzed by us.

Terahertz Initiative—AST/RO will serve as a platform for the installation, test and observational use of Terahertz detector systems currently under development. Two instruments intended for installation on AST/RO, TREND, a 1.5 THz heterodyne receiver (Gerecht *et al.* 1999, Yngvesson *et al.* 2001) and SPIFI, an imaging Fabry-Perot interferometer (Swain *et al.* 1998), have already been funded and are under development and test.

Support of Proposals—Proposals for observing programs will continue to be solicited from the worldwide astronomical community, prioritized by the AST/RO Time Allocation Committee (TAC), and observed as the instrument and weather permit.

1. Description of AST/RO and the South Pole Site

Fig. 1: **AST/RO at South Pole.** The Antarctic Submillimeter Telescope and Remote Observatory atop its building at the South Pole in February 1997. The main part of the Amundsen-Scott South Pole Station lies beneath the dome which is about 1 km distant. An LC130 cargo aircraft is parked on the skiway. (photo credit: A. Lane)

1.1. Available Instrumentation

AST/RO is a 1.7m diameter offset Gregorian telescope, with optics designed for wavelengths between 200 μm and 3 mm. The design of AST/RO is described in Stark *et al.* 1997b. AST/RO site testing, logistics, capabilities, and observing techniques are described in Stark *et al.* 2001. All of the optics in AST/RO are offset for high beam efficiency and avoidance of inadvertent reflections and resonances.

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 (Stark 1995). The beamsize is $60'' \times$ (800 GHz/ν). The Gregorian secondary is a prolate spheroid with its offset angle chosen using the method of Dragone 1982, so that the Gregorian focus is equivalent to that of an on-axis telescope with the same diameter and focal length. The diffraction-limited field-of-view is 2° in diameter at λ3mm and $20'$ 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. When the fourth mirror is removed, the telescope has a Nasmyth focus where the beam passes through an elevation bearing which has a 0.2m diameter hole. Array detectors of various types can be used at this focus, and at present it is configured for the installation of SPIFI.

Currently, there are five heterodyne receivers mounted on an optical table suspended from the telescope structure in a spacious (5m$\times$5m$\times$3m), warm Coudé room: (1) a 230 GHz SIS receiver, 140 K double-sideband (DSB) noise temperature (Kooi *et al.* 1992); (2) a 450–495 GHz SIS quasi-optical receiver, 165–250 K DSB (Engargiola, Zmuidzinas, and Lo 1994, Zmuidzinas and LeDuc 1992); (3) a 450–495 GHz SIS waveguide receiver, 200–400 K DSB (Walker *et al.* 1992, Kooi *et al.* 1995); which can be used simultaneously with (4) a 800-820 GHz fixed-tuned SIS waveguide mixer receiver, 950–1500 K DSB (Honingh *et al.* 1997); (5)

an array of four 800-820 GHz fixed-tuned SIS waveguide mixer receivers, 850–1500 K DSB (the PoleSTAR array, see `http://soral.as.arizona.edu/pole-star` and Groppi *et al.* 2000). Spectral lines observed with AST/RO include: CO $J = 2 \rightarrow 1$, CO $J = 4 \rightarrow 3$, CO $J = 7 \rightarrow 6$, HDO $J = 1_{0,1} \rightarrow 0_{0,0}$, [C I] $^3P_1 \rightarrow {}^3P_0$, [C I] $^3P_2 \rightarrow {}^3P_1$, and [^{13}C I] $^3P_2 \rightarrow {}^3P_1$. A proposal is currently pending to the Smithsonian Institution to purchase a local oscillator to cover 650–700 GHz, a frequency range which includes the ^{13}CO $J = 6 \rightarrow 5$ line. There are four currently available acousto-optical spectrometers (AOS), all designed and built at the University of Cologne (Schieder, Tolls, and Winnewisser 1989): two low resolution spectrometers with a bandwidth of 1 GHz (bandpass 1.6–2.6 GHz); an array AOS having four low resolution spectrometer channels with a bandwidth of 1 GHz (bandpass 1.6–2.6 GHz) for the PoleSTAR array; and one high-resolution AOS with 60 MHz bandwidth (bandpass 60–120 MHz).

1.2. *Instrument Reliability*

AST/RO was installed at the South Pole during the Austral summer of 1994-95 (Lane and Stark 1996). AST/RO is a prototype, the first submillimeter-wave telescope to operate year-round on the Antarctic plateau. As such, its operation has been an experiment, minimally staffed and supported, intended to demonstrate feasibility and to identify areas of difficulty. Telescope operations always involve trade-offs between cost and reliability, and as a prototype instrument, AST/RO was designed to be reasonably reliable at minimum cost. The most serious operational problems have in practice come not from the instrument itself, but rather from the logistical difficulties of operation at the South Pole.

A unique challenge of South Pole operations is the lack of transport for personnel and equipment during the nine month winter-over period. During the three Austral summer months it is usually possible to move people and equipment between the Pole and anywhere in the world within a week, but during the winter the Pole is cutoff from all transport. Spare or replacement parts for most of the critical system assemblies have been obtained, shipped to South Pole station, and stored in the AST/RO building for winter use. In a typical year, failure occurs in two or three system subassemblies, such as a drive system power supply or a submillimeter-wave local oscillator chain. Usually a repair or workaround is effected by the winter-over scientist. There are, however, single points of failure which can cause the cessation of observatory operations until the end of the winter. Between 1995 and 2000, observations or engineering tests were planned for a total of 54 months, of which about half were successful. The most important cause of telescope downtime has been incapacitation of the single winter-over scientist, resulting in 14 months of lost time. Failure of the station-wide liquid helium supply was responsible for a further 11 months of lost time. In future, both of these causes for failure will be substantially reduced. Starting in 2002, it is planned that AST/RO will field two winter-over scientists. Beginning in 2003, the completion of a new liquid helium supply facility as part of the new South Pole Station Modernization plan will eliminate single points of failure for the liquid helium supply. With these logistical improvements in place, our experience suggests that AST/RO operations can be maintained at a level not significantly different from other observatories.

1.3. *Site Testing*

The South Pole is an excellent submillimeter-wave site (Lane 1998). It is unique among observatory sites for unusually low wind speeds, absence of rain, and the consistent clarity of the submillimeter sky. Schwerdtfeger 1984 has comprehensively reviewed the climate of the Antarctic Plateau and the records of the South Pole meteorology office. Chamberlin 2001b has analyzed weather data to determine the precipitable water vapor (PWV) and finds median wintertime PWV values of 0.3 mm over a 37-year period, with little annual variation. *PWV values at South Pole are small, stable, and well-understood.*

Submillimeter-wave atmospheric opacity at South Pole has been measured using skydip techniques. We made over 1100 skydip observations at 492 GHz (609 μm) with AST/RO during the 1995 observing season

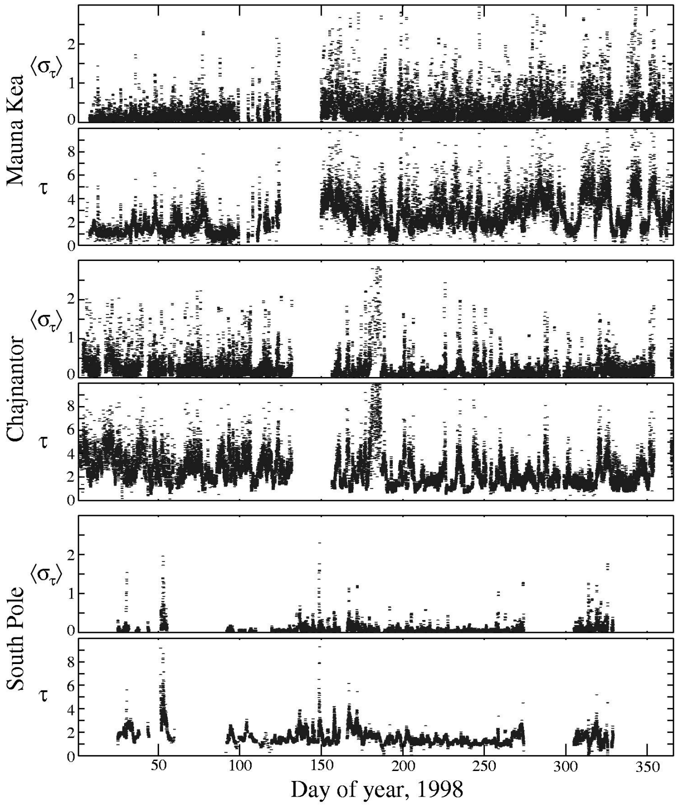

Fig. 2: **Sky Noise and Opacity Measurements at 350 μm from Three Sites.** These plots show data from identical NRAO-CMU 350 μm broadband tippers located at Mauna Kea, the ALMA site at Chajnantor, and South Pole during 1998. The upper plot of each pair shows $\langle\sigma_\tau\rangle$, the rms deviation in the opacity τ during a one-hour period—a measure of sky noise on large scales; the lower plot of each pair shows τ, the broadband 350 μm opacity. The first 100 days of 1998 on Mauna Kea were exceptionally good for that site, due to a strong El Niño that year. During the best weather at the Pole, $\langle\sigma_\tau\rangle$ was dominated by detector noise rather than sky noise.

(Chamberlin, Lane, and Stark 1997). Even though this frequency is near a strong oxygen line, the opacity was below 0.70 half of the time during the Austral winter and reached values as low as 0.34, better than ever measured at any ground-based site. The stability was also remarkably good: the opacity remained below 1.0 for weeks at a time. From early 1998, the 350μm band has been continuously monitored at Mauna Kea, Chajnantor, and South Pole by identical tipper instruments developed by S. Radford of NRAO and J. Peterson of Carnegie-Mellon U. and CARA. Results from Mauna Kea and Chajnantor are compared with South Pole in Figure 2. *The 350μm opacity at the South Pole is consistently better than at Mauna Kea or Chajnantor.*

The South Pole 25% winter PWV levels have been used to compute values of atmospheric transmittance as a function of wavelength and are plotted in Figure 3. For comparison, the transmittance for 25% winter conditions at Chajnantor and Mauna Kea is also shown.

Sky noise is caused by fluctuations in total power or phase of a detector caused by variations in atmospheric emissivity and path length on timescales of order one second. Sky noise causes systematic errors in the measurement of astronomical sources. Lay and Halverson 2000 show analytically how sky noise causes observational techniques to fail: fluctuations in a component of the data due to sky noise integrates down more slowly than $t^{-1/2}$ and will come to dominate the error during long observations. Sky noise at South Pole is considerably smaller than at other sites, even comparing conditions of the same opacity. The PWV at South Pole is often so low that the opacity is dominated by the *dry air* component (Chamberlin and Bally 1995, Chamberlin 2001b, cf. Figure 3); the dry air emissivity and phase error do not vary as strongly or rapidly as the emissivity and phase error due to water vapor. Lay and Halverson 2000 have compared the Python experiment at South Pole (Alvarez 1995, Dragovan *et al.* 1994, Ruhl *et al.* 1995, Platt *et al.* 1997, Coble *et al.* 1999) with the Site Testing Interferometer at Chajnantor (Radford, Reiland, and Shillue 1996, Holdaway *et al.* 1995). They find that the amplitude of the sky noise at South Pole is 10 to 50 times less than that at Chajnantor. The strength of South Pole as a submillimeter site lies in the low sky noise

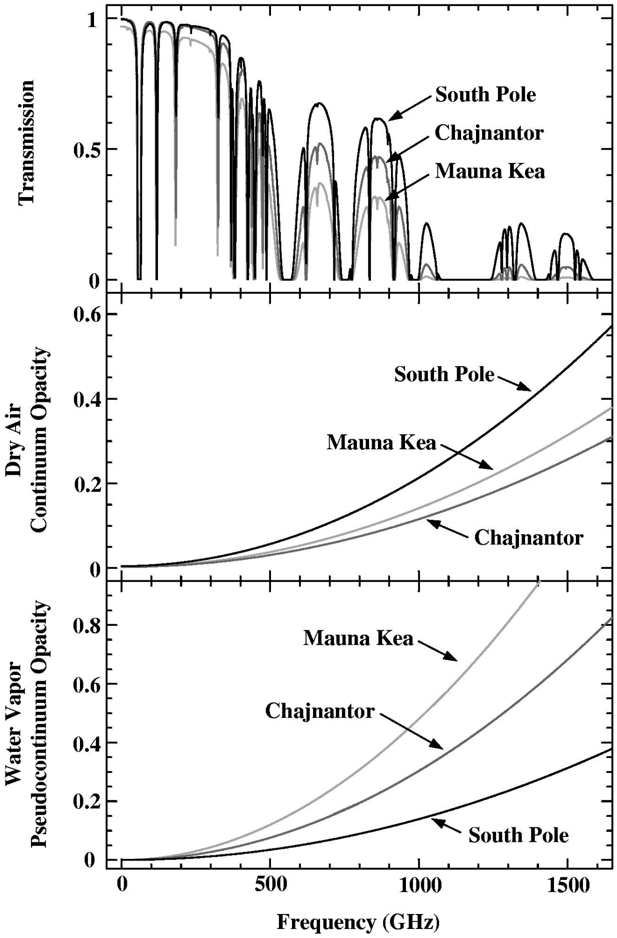

Fig. 3: **Calculated atmospheric transmittance at three sites.** The upper plot is atmospheric transmittance at zenith calculated by J. R. Pardo using the ATM model (Pardo, Cernicharo, and Serabyn 2001). The model uses PWV values of 0.2 mm for South Pole, 0.6 mm for Chajnantor and 0.9 mm for Mauna Kea, corresponding to the 25th percentile winter values at each site. Note that at low frequencies, the Chajnantor curve converges with the South Pole curve, an indication that 225 GHz opacity is not a simple predictor of submillimeter wave opacity. The middle and lower plots show calculated values of dry air continuum opacity and water vapor pseudocontinuum opacity for the three sites. Note that unlike the other sites, the opacity at South Pole is dominated by dry air rather than water vapor.

levels routinely obtainable for sources around the South Celestial Pole, and this is crucial for large-scale mapping observations like those proposed below.

2. Results of Prior NSF Funding

2.1. Major Accomplishments of AST/RO under CARA

- First operation of a submillimeter-wave telescope on the Antarctic Plateau in winter (Lane and Stark 1996, Stark *et al.* 2001).
- Comprehensive characterization of South Pole submillimeter sky; routine measurement of submillimeter sky quality year-round. (Chamberlin and Bally 1994, Chamberlin and Bally 1995, Chamberlin, Lane, and Stark 1997, Lane 1998, Chamberlin 2001a, Chamberlin 2001b),
- Measured [C I]/CO and [C I]/^{13}CO ratios in regions of the Galaxy and Magellanic Clouds having a variety of metallicities, to show that these ratios vary systematically with metallicity. (Stark *et al.* 1997a, Ingalls *et al.* 1997, Bolatto, Jackson, and Ingalls 1999, Bolatto *et al.* 2000a, Bolatto *et al.* 2000b, Ingalls *et al.* 2000, Ojha *et al.* 2001)
- First detection of [C I] in absorption. The [C I] line in ordinary molecular clouds outside the Galactic Center region appears in absorption against Galactic Center line emission. This is the first measurement

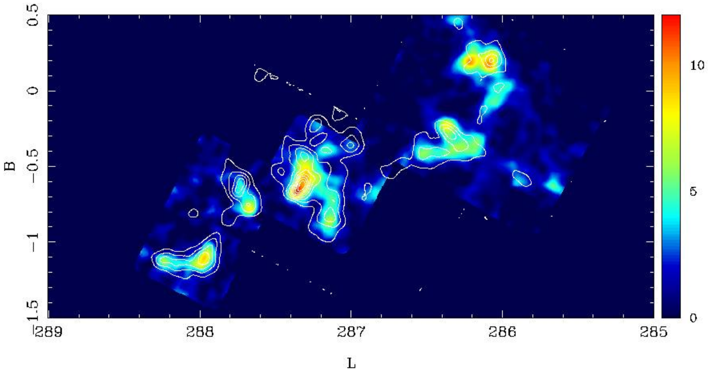

Fig. 4: **AST/RO observations of the Eta Carina Complex** (from Zhang *et al.* 2001). The tangent point of the Carina spiral arm observed in CO $J = 4 \rightarrow 3$ (contour units 5 K km s^{-1}) and ${}^3P_1 \rightarrow {}^3P_0$ [C I] (color scale units K km s^{-1}). The spectra have been integrated over a velocity range -50 km s^{-1} to -9 km s^{-1} to show total line brightness. The [C I] and CO lines show the effects of cloud assembly, heating, and disruption as a function of spiral arm phase.

of cool, diffuse carbon gas in the galactic disk. (Staguhn *et al.* 1997, Staguhn *et al.* 1998)

- First detection of [C I] in the Large Magellanic Cloud. This is the weakest submillimeter-wave line ever measured with a ground-based telescope. (Stark *et al.* 1997a)

- First detection of [C I] in the Small Magellanic Cloud. This is the lowest metallicity source in which neutral carbon emission has been detected. Studying the [C I]/CO ratio in sources having a variety of metallicities shows that [C I]/CO increases with increasing Z. This trend points to a photodissociation origin for most of the neutral carbon in molecular clouds. (Bolatto *et al.* 2000b)

- First detection of the CO $J = 4 \rightarrow 3$ line in the Large Magellanic Cloud. These data show anticorrelations between CO and C I in the low metallicity PDR regions of the LMC. (Bolatto, Jackson, and Ingalls 1999, Bolatto *et al.* 2000a)

- Coarsely-sampled mapping of the extended Galactic Center Region in the CO $J = 4 \rightarrow 3$ line and the ${}^3P_1 \rightarrow {}^3P_0$ [C I] line. These data show that the excitation temperature of CO exceeds 35 K throughout the Galactic Center region, even in relatively diffuse material, in contrast to outer Galaxy clouds (Ojha *et al.* 2001).

- Observation and analysis of emission mechanisms of [C I] and CO in giant molecular clouds (Hungerford *et al.* 2001; Yan, Lane, and Stark 2001), Bok globules (Scappini *et al.* 2000), translucent clouds (Ingalls *et al.* 1997, Ingalls *et al.* 2000), and H II regions (Huang *et al.* 1999), to show that the emission arises in interclump gas and numerous small, dense clumps.

- Study of submillimeter properties of molecular clouds across a spiral arm in the direction of η Carina (Zhang *et al.* 2001), to show that large-scale energy injection mechanisms are needed to explain the energy balance of the interstellar medium. Gravitational interaction between the spiral arm and molecular clouds may be the dominant energy injection mechanism.

- Detection of the isotopic [^{13}C I] ${}^3P_2 \rightarrow {}^3P_1$ fine-structure transition in three galactic regions: G 333.0-0.4, NGC 6334 A, and G 351.6-1.3. This is only the second time that these lines have been successfully observed, the previous detection being a single spectrum obtained with the Caltech Submillimeter Observatory toward the Orion Bar (Keene *et al.* 1998). The [^{13}C I] line was observed simultaneously with the CO $J = 7 \rightarrow 6$ line emission at 806 GHz. Analysis of the AST/RO detection in G333.0-0.4 with a line ratio between [^{12}C I] and [^{13}C I] of 23 ± 1, when compared to the intrinsic isotopic abundance ratio of 40-80, indicates moderate optical depths of the [^{12}CI] ${}^3P_2 \rightarrow {}^3P_1$ emission in the cooler, extended gas surrounding the HII region. (Tieftrunk *et al.* 2001).

- Detections of the $J = 1_{0,1} \rightarrow 0_{0,0}$ transition of HDO toward three molecular clouds.

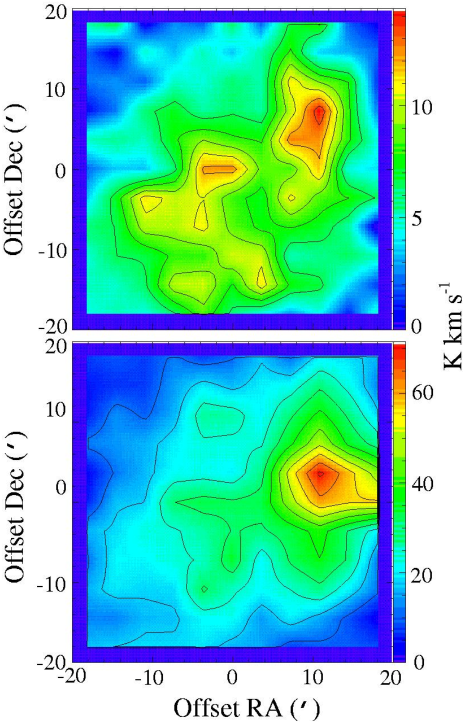

Fig. 5: **AST/RO Maps of C I $^3P_1 \rightarrow {}^3P_0$ and CO $J = 4 \rightarrow 3$ Emission in the ρ Ophiuchus Molecular Cloud (Hungerford *et al.* 2001)** The C I emission is extended on large scales, resembles the C^{18}O column density map, and generally follows the edges of warm dust emission observed in the infrared on the illuminated surface of the molecular cloud. Using a two- component PDR model, Hungerford et al. conclude that the C I emission arises predominantly from lower density interclump gas. In contrast, the optically thick CO $J = 4 \rightarrow 3$ emission is more highly peaked and appears to arise from dense clumps as well as interclump gas.

- Essentially all of the NGC6334 Giant Molecular Cloud was mapped in 492 and 810 GHz [C I] and in the CO $J = 7 \rightarrow 6$ and $J = 4 \rightarrow 3$ spectral lines. The data show that high excitation temperatures exist throughout most of the cloud volume. Detailed modeling is in progress to account for the observed line intensities and ratios (Yan et al. in preparation).
- Mapping of the ρ Ophiuchus Molecular Cloud (Hungerford *et al.* 2001).

An up-to-date bibliography of AST/RO journal articles, conference papers, student theses, and technical memoranda can be found at the AST/RO website `http://cfa-www.harvard.edu/~adair/AST_RO`.

2.2. Research and Training of Students and Post-Doctoral Fellows

AST/RO staff have served as participants in the CARA Education and Outreach as lecturers and student mentors (see `http://astro.uchicago.edu/cara/outreach`). We expect to continue these efforts.

AST/RO Winterover Scientist is a three-year research and training position at the Post-Doctoral level. The first year includes an Austral summer season at the telescope, learning its systems and participating in engineering and maintenance work. Hands-on experience is gained in all techniques of submillimeter-wave observatory work: electronics, cryogenics, submillimeter-wave detectors, vacuum technology, data acquisition and reduction software. Research plans with AST/RO are developed while in residence at SAO in Cambridge. The second year is the winterover, and the AST/RO Winterover Scientists are responsible for all on-site aspects of observatory operations. Winterover scientists carry out their own proposed projects in addition to all other observations. The third year is again in residence at SAO, preparing data for publication and helping to train the new winterovers. The intensive instrumental and observing experience afforded by AST/RO provides valuable hands-on training with state-of-the-art equipment. Past Winterover Scientists have found this experience to be a valuable contribution to their scientific skills.

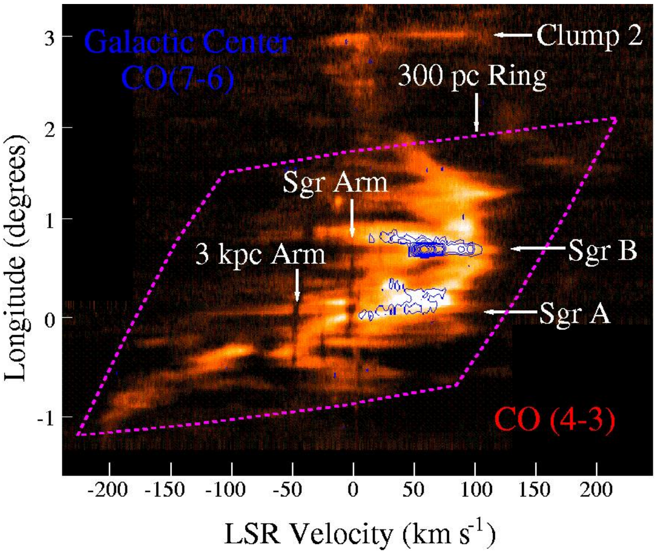

Fig. 6: **AST/RO observations of the Galactic Center Region** (from Kim *et al.* 2000). The CO $J = 4 \rightarrow 3$ (pseudo-color) and $J = 7 \rightarrow 6$ (blue contour) lines observed in an $l - v$ strip, sampled every $1'$, at $b = 0$. These data have been used in conjunction with CO and ^{13}CO $J = 1 \rightarrow 0$ data to determine the the density and temperature in the features shown here (Kim *et al.* 2000). The 300 parsec ring is just below the critical density at which instabilities will cause it to coagulate into a single cloud like those surrounding Sgr B2 and Sgr A. We propose to fully sample the entire Galactic Center Region, which would be about seventy times as much data as is shown here.

3. Proposed Research

3.1. Large-Scale Mapping Initiative

The detector systems currently operational give AST/RO unprecedented capability for studying the nature of atomic and molecular clouds in the Galaxy and the Magellanic Clouds. AST/RO instruments can be used to determine the excitation temperature and optical depth of CO and C I over large regions under a variety of conditions. Observations made with AST/RO provide evidence for an improved conceptual understanding of the interstellar medium:

1. The excitation temperature of molecular material is often 35 to 45 K under a wide variety of conditions, both near and far from obvious heating sources such as H II regions and embedded stars. This suggests that the dominant source of energy heating molecular clouds acts on a large scale, and may be the result of galactic effects such as the spiral density wave, rather than smaller-scale effects like stellar outflows.

2. Our [^{13}C I] observations show that the [^{12}C I] in molecular clouds is often optically thin, and Keene et al. (1998) have shown that [^{12}C I] is often well-mixed with CO. Line formation analysis of our observations of these species in the ρ Oph molecular cloud, NGC6334, translucent clouds, and Bok globules provides strong evidence for the "mist model" for all of these objects, where every line of sight contains many dense ($\sim 10^5\,\mathrm{cm}^{-3}$) cores embedded in (and in approximate pressure equilibrium with) a lower density ($\sim 10^3\,\mathrm{cm}^{-3}$) substrate. Comparison between observations and models shows that the models can be quantitative and predictive (Hungerford *et al.* 2001; Yan, Lane, and Stark 2001; Bolatto, Jackson, and Ingalls 1999).

3. Although CO and C I are well-mixed, their line ratios vary as a function of physical conditions and metallicity. This may allow a measurement of metallicity in distant galaxies.

These interpretations of our observations suggest hypotheses which will guide large-scale AST/RO mapping projects. What is needed are large-scale maps of atomic and molecular material under varying conditions of external pressure, metallicity, galactic radius, spiral arm phase, and proximity to massive stars, in multiple transitions of CO and C I. The expectation is that from these data will emerge a comprehensive picture of the excitation and structure of dense gas in the Milky Way and the Magellanic Clouds, and an understanding of how this picture relates star formation processes to galactic environment.

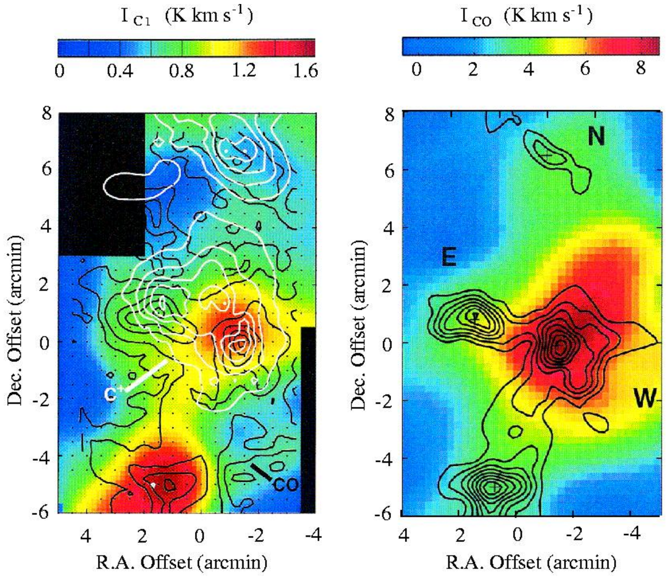

Fig. 7: **AST/RO Maps of C I $^3P_1 \to {}^3P_0$ and CO ($J = 4 \to 3$) Emission in the LMC.** Distribution of the three dominant forms of gas phase carbon in the N159/N160 regions of the Large Magellanic Cloud (from Bolatto *et al.* 2000a): (Left) The pseudo-color image shows the AST/RO C I $^3P_1 \to {}^3P_0$ observations at $4'$ resolution ($1\,\sigma$ sensitivity ~ 0.1 K km s^{-1}). In black contours are CO ($J = 2 \to 1$), at $33''$ resolution (contours 2, 5, 15, 25,..., 55 K km s^{-1}). In white contours is [C II] (Israel *et al.* 1996), at $55''$ resolution (contours start at 6.8×10^{-5} in steps of 6.8×10^{-5} ergs s^{-1} cm^{-2} sr^{-1}). (Right) Color image of the AST/RO CO ($J = 4 \to 3$) integrated intensity map with CO ($J = 1 \to 0$) data overlaid. Since these data were taken, the beamsize, efficiency, and sensitivity of the AST/RO beam have been improved.

AST/RO will survey the CO $J = 4 \to 3$ and $J = 7 \to 6$ lines and the [C I] $^3P_1 \to {}^3P_0$ and $^3P_2 \to {}^3P_1$ lines. Full sampling with the AST/RO beam implies spatial gridding of $30''$ or better, and all data will be fully sampled. AST/RO mapping capability could be used to advantage toward many regions of the sky, but in the three year period of the current proposal, we will concentrate on two surveys:

- The Galactic center clouds show quite different physical conditions compared to local clouds: the average density and temperature are substantial higher; and the clouds have much broader lines, presumably being stirred up by strong tidal forces. Dissipation of this internal motion my contribute a substantial fraction of the thermal balance. Combined observations of CO $J = 4 \to 3$ and CO $J = 7 \to 6$ (plus ^{13}CO $J = 6 \to 5$) probe this high density/high temperature regime and allow to derive detailed physical parameters. Neutral carbon, originating from the dissociation of CO and the recombination of C$^+$, can trace the strength of the interstellar radiation field and thus discriminate between internal shock heating and photo-heating. In this context, it is important to cover both fine structure lines of [C I] simultaneously, as this allows precise determination of the physical conditions in the [C I]-emitting gas. The comparison between the morphology and the physical conditions derived from both the CO and [C I] multi-line studies is crucial to identify wether they come from the same material or trace different phases of the Galactic center ISM.

  The inner two square degrees of the Milky Way. Our Galactic Center affords the opportunity to study in detail the complex processes occurring in the centers of large spiral galaxies, such as starbursts, galactic jets, and active nuclei. The energetics, dynamics, and chemistry of these processes in the Galactic Center region is the subject of active investigation (e.g. Morris and Serabyn 1996, Lis *et al.* 2001, Englmaier and Gerhard 1999, Huettemeister *et al.* 1998). AST/RO data will be comparable in resolution and extent to the widely-used CO $J = 1 \to 0$ (Oka *et al.* 1998, Bitran *et al.* 1997, Bally *et al.* 1987, Bally *et al.* 1988) and continuum surveys (Pierce-Price *et al.* 2000, Lis and Carlstrom 1994). Samples of the data collected by AST/RO are shown in Figure 6 and Ojha *et al.* 2001. We will use the AST/RO data together with existing data sets as input to a large velocity gradient (LVG) or Sobolev model (e.g. Ossenkopf 1997) to produce three-dimensional excitation and density data maps for the Galactic Center region. We will analyze these data in the context of gas dynamical models (e.g. Binney *et al.* 1991) to estimate the gas inflow and star formation rates (Stark *et al.* 1991, Sakamoto *et al.* 1999, Sakamoto 2000). We will compare our data to the magnetic field geometry (Novak *et al.* 2000).

- The regions in the Large Magellanic Cloud which show bright CO $J = 1 \rightarrow 0$ emission (Cohen *et al.* 1988). Little is known at present about the detailed physical conditions of the molecular material in the lower metallicity environment of the LMC (and SMC). It is well established that the CO emission as well as the [CI] are relatively week compared to [CII], as is expected in a scenario of low metallicity PDR clumps (REF to Bollato). AST/RO is at present the only submm facility that can observe the Magellanic clouds and the planned AST/RO data thus will play a crucial role in understanding the ISM in the LMC. Mid-J CO lines ($J = 4 \rightarrow 3$, $J = 7 \rightarrow 6$) play a crucial role in the proper interpretation of cloud properties derived from CO observationsl. With the low CO column densities expected in this low metallicity environment, the low-J CO lines are relatively much weaker than the mid-J lines; depending on the source density, the optical depth (increasing $\propto J^2$ for thermalized optically thin emission, peaks at a rotational level whose critical density is approximately equal to the cloud density (and then drops rapidly in the subthermally excited higher states). Multi-line observations thus allow a sensitive determination of the density and temperature in the emitting gas.

  Observations of the two [C I] fine structure lines provide an important complement to the CO lines, in particular together with the [C II] lines (the latter have been mapped partially with the KAO, but velocity resolved spectra will become available with SOFIA and Herschel). Only the combination of all three tracers (CO, [C I], [C II]) allows discrimination via appropriate PDR modelling between the different scenarios of the low metallicity ISM presently discussed.

  A sample of AST/RO LMC data is shown in Figure 7. The Magellanic Clouds provide an opportunity to study star formation in low metallicity, low dust, high inclination angle systems which in some respects resemble primeval galaxies (e.g. Johansson *et al.* 1998, Spaans and Norman 1997, Chin *et al.* 1997, Pak *et al.* 1998).

Large-scale maps of the CO and C I cooling lines are an astronomical resource of broad scientific interest. The AST/RO data will strongly constrain the density, excitation, and cooling rates in these objects, and will serve as a guide to high resolution studies with the Atacama Large Millimeter Array and the Smithsonian Submillimeter Array. We will make these data publicly available as calibrated FITS data cubes (Wells, Greisen, and Harten 1981) published on the World Wide Web within one year of their acquisition.

^{12}C/^{13}C fractionation Up to now only the ^{13}[CI] line at 809 GHz has been detected. These results have shown, that the ^{12}C/^{13}C-ratio varies greatly from source to source. In combination with additional source parameters, in particular with simultaneous measurements of the ^{12}[CI] 492 GHz line, the combination of optical depth effects and abundance variations can be disentangled (REF to Tieftrunk et al.). The present AST/RO instrumention is ideally suited for these studies.

The relative abundance of ^{12}C and ^{13}C is determined by a balance between isotope selective shielding from UV and the slightly endothermic exhange reaction $^{12}CO +^{13} C^+ \rightarrow^{13} CO +^{12} C^+$; the first is sensitive to the strength of the interstellar radiation field, the second is very sensitive to temperature. The observed ratio, together with proper modelling, can thus be used as sensitive diagnostic of the physical conditions in the PDR transition region.

We propose to observe the ^{13}[CI] line at 809 GHz (together with ^{12}[CI] in the same IF-band, and with the 492 GHz ^{12}[CI]) in a sample of some 20-40 selected regions, including high mass star forming environments with strong UV flux, low mass star forming cores, condensations in high latitude clouds, selected (narrow line) Galactic center clouds, and outer Galaxy clouds. The corresponding low-J CO data are readily available and the important complementary ^{13}[CII] will be provided by SOFIA in the near future. These data will give an important, unbiased and complete census of the ^{12}C/^{13}C abundance variation throughout the Galaxy and in different environments, whereas optical data can only trace the diffuse ISM in the solar neighbourhood.

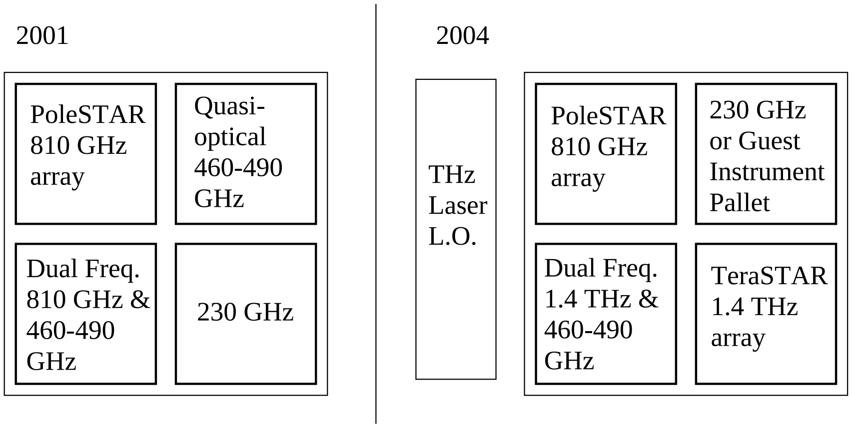

Fig. 8: **AST/RO Receiver Room Configurations.** On the left is the current configuration of pallets in the AST/RO receiver room, looking downwards to the Coudé focus. At right is a proposed configuration circa 2004, with the TREND 1.4 THz HEB mixer and its laser local oscillator installed. TeraSTAR is a yet-to-be proposed 3 × 3 array of 1.4 THz heterodyne mixers. A "Guest Instrument Pallet" would permit testing of high-frequency prototypes.

3.2. Terahertz Initiative

Two new short wavelength instruments are in development:

- Dr. G. Stacy and collaborators have developed the South Pole Imaging Fabry-Perot Interferometer (SPIFI, Swain *et al.* 1998), a 25-element bolometer array preceded by a tunable Fabry-Perot filter. This instrument was successfully used on the JCMT in May 1999 and April 2001 and is being modified with new instrumentation, cryogenics, and detectors for South Pole use. SPIFI is frequency agile and can observe many beams at once, but has limited frequency resolution ($\sim$ 100 km s^{-1}) and scans a single filter to build up a spectrum.
- Dr. S. Yngvesson and collaborators (Gerecht *et al.* 1999, Yngvesson *et al.* 2001) are developing a 1.5 THz heterodyne receiver, the Terahertz Receiver with Niobium Nitride Device (TREND). TREND has only a single pixel and is not frequency agile. Its HEB device requires relatively high local oscillator power levels; we will use a laser local oscillator source which requires that the gas be changed in order to change frequencies. The frequency resolution of TREND is high ($\sim$ 2 MHz), limited by the stability of the laser.

In addition, Dr. D. Prober and collaborators have proposed a low-noise, low-power 1.5 THz heterodyne receiver based on aluminum and tantalum HEB technology which they would like to test on AST/RO.

Some of the work to integrate these systems into AST/RO is complete. The original AST/RO tertiary chopper was replaced with a balanced unit that produces 90% smaller vibrations, to reduce microphonic pickup by the SPIFI bolometers. The cloth and aluminum deployable telescope cover was enlarged to eliminate interference with SPIFI. The SPIFI dewar has been brought to AST/RO and test-fit to its mount. A plan has been developed for installation of the TREND laser Local Oscillator (LO) system in the AST/RO receiver room. Both the rebuilt SPIFI and TREND are expected to be ready for full deployment in the 2002-2003 Austral summer.

South Pole site testing suggests that the 200 micron wavelength atmospheric window has a median winter transparency of order 10%. The atomic and molecular transitions accessible in the 200 micron atmospheric window are important diagnostics of a variety of astronomical phenomena including planetary atmospheres, star-forming regions, young stellar objects, circumstellar envelopes, planetary nebulae, starburst galaxies, and molecular clouds.

Deployment of these technologies on a ground-based telescope is a path of technological development that has exciting prospects. On AST/RO, the $\sim 35''$ beam size and high spectral resolution (~ 0.4 km s^{-1}) of Terahertz receivers will allow the study of galactic star-forming regions and large-scale studies of nearby galaxies. In future, these detectors could be used on the South Pole Submillimeter Telescope (SPST), an 8-meter telescope (see NRC 2001), which would have a beamsize of $\sim 7''$. The following sections describe several science objectives for Terahertz detectors on AST/RO.

[N II]: a probe of the Warm Ionized Medium. COBE observations show that the [C II] 158μm line is the dominant cooling line of the interstellar medium as a whole (Wright *et al.* 1991, Bennett *et al.* 1994). Because of the importance of the [C II] line as a coolant, detailed understanding of the emission mechanism is a prerequisite for understanding the structure, energy balance, and evolution of molecular clouds in the Milky Way and external galaxies.

Three sources for [C II] emission have been proposed: the galactic H I, Photodissociation Regions (PDRs), and the Warm Ionized Medium (WIM). The relative contribution of these components depends on the location within the galaxy and the size scale of the observations. Locally, diffuse H I clouds dominate the [C II] emission, with molecular clouds contributing little. Towards the inner galaxy, the ISM pressure increases, as does the density in the WIM (from $\sim$ 0.3 to 3 cm^{-3}). This increase in density leads to an increase in the contribution of the WIM to the [C II] emission.

Indeed, the WIM may contribute substantially to the [C II] emission from the inner galaxy and thus the total [C II] luminosity of the Galaxy. Since the ionization potential of N is slightly higher than that of H, the [N II] line at 205 μm must arise in regions where hydrogen is largely ionized, and thus can serve as an effective probe of both the WIM and low-density H II regions (Tielens 1997). There is an observed (nonlinear) relationship between [C II] and [N II] emission (Bennett *et al.* 1994). The [C II]/[N II] intensity ratio can be used as a powerful probe to investigate how much of the Galaxy's [C II] emission arises in these ionized regions.

COBE mapped the [N II] 205 μm line at very low spatial (7°) and spectral resolution ($\sim 200\,\mathrm{km\,s^{-1}}$). With Terahertz detectors on AST/RO, it will be possible to determine the sources of this emission within the Milky Way. By observing a variety of GMCs, isolated globules, and planetary nebulae in the 205 μm [N II] line, we will gain a deeper understanding of the relative importance of the WIM, PDRs, and diffuse H I in the production of [C II]. Using measured receiver noise temperatures for TREND detectors and the expected *median* transparency (5.5%) at the frequency of the [N II] line, an rms noise level of $\sim$ 0.35 K can be achieved in a single 24 hour period.

How bright will the 205 μm [N II] line be in the AST/RO beam? COBE showed that this is the second-brightest emission line from the Galaxy, about 1/10th as bright as the 158 μm line of [C II] (Wright *et al.* 1991). In the 7 degree COBE beam, the average antenna temperature of 205μm [N II] is 3.9 × greater than that of the $J = 4 \rightarrow 3$ line of CO (Wright *et al.* 1991), a line which is routinely and easily observed with AST/RO at antenna temperatures exceeding 10 K. It is likely that [N II] is even more concentrated to H II regions than is $J = 4 \rightarrow 3$ CO, so we expect [N II] line brightness which is often in excess of 40 K. Theoretical models of H II regions (Rubin 1985) predict [N II] antenna temperatures up to 200K for Warm Ionized Regions that fill the telescope beam.

H_2D^+: A Key to Understanding Gas-Phase Chemistry. The molecular ion H_3^+ plays a pivotal role in theories of ion-molecule, gas-phase chemistry (Herbst and Klemperer 1973, Dalgarno, Oppenheimer, and Berry 1973, Watson 1973). Without it, such ubiquitous molecules as HCO^+ and N_2H^+ could not exist. The high degree of symmetry of H_3^+ prohibits rotational transitions. Searches for it have been performed in the near-infrared by looking for rotational-vibrational lines in absorption against background stars. Such searches have yielded upper limits ($\sim 10^{15}$ cm^{-2}) to the column density of H_3^+ in molecular clouds (Geballe and Oka 1989).

Although H_3^+ has no rotational lines, its deuterated form, H_2D^+, has a significant electric dipole component, with transitions occurring at submillimeter wavelengths. Besides serving as a probe of the H_3^+ column density, H_2D^+ is itself important in the production of other deuterated molecules, particularly at the low temperatures characteristic of many molecular clouds (Boreiko and Betz 1993, Millar, Bennett, and Herbst 1989). H_2D^+ exists in both ortho and para forms, with the para species expected to be more abundant at temperatures between $\sim$ 12 and 40 K (Pagani, Salez, and Wannier 1992). Attempts have been made to detect the ground-state $1_{10} - 1_{11}$ ortho transition of H_2D^+ at 372.421 GHz (Phillips *et al.* 1985, Pagani *et al.* 1992, van Dishoeck *et al.* 1992) and the ground-state $1_{01} - 0_{00}$ para line at 1370 GHz. To date, the 372.421 GHz line has not been detected, most likely due to the location of the line in an unfavorable part of the atmospheric window and the requirement of relatively high excitation temperatures ($\sim$ 104 K). The lower excitation requirements ($\sim$ 65 K) and expected higher abundance led Boreiko and Betz 1993 to search for the 1370 GHz para transition toward bright sources using the KAO. A tentative detection of the transition was made in absorption toward IRc2. They found the absorption occurred in cool ($T < 40$ K), moderately dense ($< 10^6$ cm^{-3}), spatially extended ($> 25''$) gas. However, these gas properties are incompatible with conditions derived from emission line data along the same line of sight.

With TREND on AST/RO, it will be possible to perform sensitive searches for the favorable 1370 GHz transition of H_2D^+ toward a variety of galactic sources, including NGC 6334, Eta Carina, and the Galactic Center. As with all objects observable from the Pole, they are available 24 hours a day, permitting uninterrupted observing when the atmospheric conditions are favorable. Using the expected *median* transparency (10%) at the frequency of the H_2D^+ line and the measured receiver noise temperature, the rms noise level of the Boreiko and Betz 1993 detection will be reached in a single 24 hour period.

CO $J = 13 \rightarrow 12$: A Probe of High Excitation Gas. One of the major goals of ground, airborne, and space-based observational astronomy is the identification and study of protostellar objects. A study of protostars provides insight into the initial conditions required for star formation, protostellar evolution, and the formation of solar systems like our own. Protostellar objects are characterized by elevated dust temperatures and both outflow and infall motions. The outflows appear as wing emission in low-J transitions of CO (Richer *et al.* 2000, Bachiller and Tafalla 1999, Bally and Lada 1983). By studying the line profiles of millimeter and submillimeter transitions of density-sensitive molecules such as CS, H_2CO, HCO^+ and NH_3, various authors (Walker *et al.* 1986, Walker, Carlstrom, and Bieging 1993, Walker, Narayanan, and Boss 1994, Zhou *et al.* 1993 and Narayanan, Walker, and Buckley 1998) have made tentative detections of infalling gas toward protostellar objects. In the past, studies of protostellar outflow and infall have been most sensitive to cold gas in the extended envelopes of these objects. The Terahertz detectors on AST/RO will be able to probe the physical conditions associated with shocks between the outflows and the ambient medium and the dense, hot gas located much closer to the protostar.

Ceccarelli *et al.* 1998 observed the $J = 14 \rightarrow 13$ to $21 \rightarrow 20$ rotational transitions of CO towards the protobinary system IRAS 16293-2422 using the LWS onboard *ISO*. Combining the LWS results with ground-based $J = 6 \rightarrow 5$ observations, they conclude the CO arises in C-shock heated gas ($\sim$ 1500 K) associated with the outflow. The large *ISO* beam ($\sim 85''$) prevented detailed maps from being made. With the $30''$ beam of AST/RO at the frequency of the CO $J = 13 \rightarrow 12$ line, the observer will be able to make detailed maps of the shocked regions associated with outflow sources. These maps can be compared to CO $J = 4 \rightarrow 3$ maps made simultaneously with the existing suite of receivers.

In an earlier effort, Ceccarelli, Hollenbach, and Tielens 1996 modeled in a self-consistent manner the FIR spectrum of gas freely-falling onto a protostar. They found the higher J transitions are generated in the warmer gas which is closer to the protostar and is therefore falling faster. They predict a correlation between CO linewidth Δv and J. From a comparison of linewidths it should be possible to infer the central mass of the protostar. We will search for such linewidth correlations between the CO $J = 13 \rightarrow 12$ line and the CO $J = 7 \rightarrow 6$ and $J = 4 \rightarrow 3$ transitions currently observable with AST/RO.

3.3. Support of Proposals

AST/RO has been open to proposals from the general astronomical community since 1997 for a relatively small fraction of the available observing time. Under the current proposal, time dedicated to proposals will be expanded. External proposals are received in response to a general solicitation and are reviewed by the AST/RO Time Allocation Committee (TAC) (currently consisting of J. Bally, N. Evans, A. Lane (Chair), J. Stutzki, and J. Zmuidzinas).

Several projects for external groups have been completed:

- Observations of [C I] emission from a translucent cloud in the Chamaeleon complex were obtained for W. Reach (IPAC) and his collaborators. These observations are being combined with mid-infrared and CO observations obtained elsewhere to study the composition of a bright halo around a molecular region.
- While the AST/RO key project observations of the LMC focus mainly on [C I] emission in low metallicity star-forming clouds, [C I] emission from cold, quiescent, atomic clouds in the LMC was studied last winter in a project for a group led by M. Marx of Bonn University. [C I] was detected toward a cold atomic hydrogen cloud which the group has studied in H I and CO emission, indicating that not all neutral carbon has a PDR origin. Upper limits at the 20-25 mK level were obtained for 3 other cool H I clouds in the LMC.
- A team led by P. Wannier of JPL is studying the [C I] emission across the boundaries of CO clouds in the Southern Coalsack and Chamaeleon regions. Eleven strips maps were obtained with AST/RO, each passing across a cloud boundary and through the sightlines to stars studied by the group in the far-ultraviolet with HST. It is expected that the UV spectra will enhance the AST/RO results by providing information about the physical and chemical state of the gas at one point along each strip.
- Maps in both [C I] and CO $J = 4 \rightarrow 3$ were obtained for T. Bourke (AAO/ATNF) and collaborators toward the globule/high-velocity outflow source BHR71 in a study of the effects of outflows on elemental and molecular abundances in globules.
- Observations of CO $4 \rightarrow 3$ in southern Bok globules were made for a project by F. Scappini and collaborators at the Instituto di Spettroscopia Molecolare in Bologna, Italy (Scappini *et al.* 2000). Detections of bright (several K) lines were made toward each of 12 sources. The sample of dark clouds contain no bright IRAS sources. From future data they plan to determine the evolutionary status and energetics of each cloud.
- Small maps in CO $4 \rightarrow 3$ of 90 regions suspected to be high-mass star forming cores were made for a group led by D. Clemens (BU) as part of a pilot study for a long term project aimed at obtaining a bolometric luminosity–temperature diagram for high mass protostars. The AST/RO observations are being used as a tracer of dense gas and will be combined with existing IRAS, ISO, 2Mass, and MSX data in the study.

Observing methodologies at AST/RO have been developed to fit the logistical requirements of the site. Most of the year, it is not possible to visit the telescope for short periods of time. It is essential to have personnel on-site throughout the year to transfer cryogens into the receiver dewars and troubleshoot and repair the instrument. Constructing the instrumentation to be fully automated like a space-borne system would involve either a dramatic increase in equipment costs or a substantial decrease in observatory flexibility and capability. Since the Office of Polar Program's plans for South Pole Station include a permanent year-round staff of about 24 scientists, it is most reasonable and cost-effective that two of them be associated with AST/RO. One benefit of the South Pole location is that observations can proceed without interruption, since sources never set and good observing weather can be relied upon. The way proposed observations are actually done is as follows:

1. Submitted proposals are reviewed and ranked by the TAC.
2. The top-ranked proposal compatible with the operational capabilities of the instrument is chosen for observation, and the proposers are contacted by the Project Manager or Principal Investigator. Details of the observations are discussed and refined.
3. The detailed observing plan is transmitted to the winterover scientist at the Pole by the Single Point of Contact. At any given time during the winter, the winterover scientist is responsible to only a single person outside South Pole station in order to avoid confusion and minimize the communications workload of the winterover.
4. The observing plan is executed by the winterover scientist on site. The data are usually transmitted to SAO within 24 hours, and can be monitored by the proposer on a day-to-day basis. The observations usually continue until pre-determined conditions for their completion are met.
5. The data are calibrated and baseline-subtracted by a member of the AST/RO group and delivered to the proposer in FITS format, unless the proposers wish to handle these tasks themselves.

AST/RO observational programs necessarily involve interaction between AST/RO scientists and the proposer(s). Collaboration between AST/RO staff and the proposers of observing projects can provide a valuable synergy, by bringing the best new ideas for use of the instrument from the worldwide astronomical community, while leaving the data acquisition and reduction to those most fluent with these telescope-specific tasks. One request we make of all proposers is that the winterover scientist be included as a co-author on all scientific papers resulting from her or his winterover year.

4. Instrumental Changes

Under this proposal, we will continue to maintain and upgrade the current suite of AST/RO receivers and we will modify the telescope systems as needed to accommodate new detectors proposed and developed by others. Improvements needed on the current AST/RO receivers: (1) The 230 GHz receiver was moved to install the dual frequency 460-500/810 GHz receiver, and now needs modified matching mirrors. (2) The local oscillator injection scheme on PoleSTAR would work better if the Martin-Puplett interferometer were replaced by a fixed half-wave plate. (3) Our currently-operating mixers between 230 and 500 GHz have now been superseded in the laboratory, and will be upgraded with tunerless mixers (Kooi *et al.* 2000) under development for the CSO. The move toward tunerless mixers enhances instrument reliability and eases operational complexity for the winterovers. (4) Our currently-operating mixers at 810 GHz have been superseded in the laboratory, and will be upgraded with mixers under development at the University of Cologne. (5) To support the upgrade of the current set of AST/RO receivers, we anticipate the need for additional IF and Local Oscillator hardware. (6) The automated bias control developed for PoleSTAR will be improved and extended to all the receivers, enhancing computer control of the system. (7) Automated intermediate frequency and local oscillator control signal switching will be implemented for all receivers, allowing completely computer-controlled switching between receivers.

D. References

Alvarez, D. L. 1995. *Measurements of the Anisotropy in the Microwave Background on Multiple Angular Scales with the Python Telescope*. PhD Thesis, Princeton University.

Bachiller, R. and Tafalla, M. 1999. Bipolar Molecular Outflows. In *NATO ASIC Proc. 540: The Origin of Stars and Planetary Systems*, pages 227+.

Bally, J. and Lada, C. J. 1983. The High-Velocity Molecular Flows Near Young Stellar Objects. ApJ, **265**, 824–847.

Bally, J., Stark, A. A., Wilson, R. W., and Henkel, C. 1987. Galactic Center Molecular Clouds. I. Spatial and Spatial Velocity Maps. ApJS, **65**, 13.

Bally, J., Stark, A. A., Wilson, R. W., and Henkel, C. 1988. Galactic Center Molecular Clouds. II. Distribution and Kinematics. ApJ, **324**, 223.

Bennett, C. L., Fixsen, D. J., Hinshaw, G., Mather, J. C., Moseley, S. H., Wright, E. L., Eplee, R. E., Gales, J., Hewagama, T., Isaacman, R. B., Shafer, R. A., and Turpie, K. 1994. Morphology of the Interstellar Cooling Lines Detected by COBE. ApJ, **434**, 587.

Binney, J. J., Gerhard, O. E., Stark, A. A., Bally, J., and Uchida, K. I. 1991. Understanding the Kinematics of Galactic Centre Gas. MNRAS, **252**, 210–218.

Bitran, M., Alvarez, H., Bronfman, L., May, J., and Thaddeus, P. 1997. A Large Scale CO Survey of the Galactic Center Region. A&AS, **125**, 99.

Bolatto, A. D. 2001. *The Interstellar Medium in Low Metallicity Environments*. PhD Thesis, Boston University.

Bolatto, A. D., Jackson, J. M., and Ingalls, J. G. 1999. A Semianalytical Model for the Observational Properties of the Dominant Carbon Species at Different Metallicities. ApJ, **513**, 217.

Bolatto, A. D., Jackson, J. M., Israel, F. P., Zhang, X., and Kim, S. 2000a. Carbon in the N159/N160 Complex of the Large Magellanic Cloud. ApJ, **545**, 234.

Bolatto, A. D., Jackson, J. M., Kraemer, K. E., and Zhang, X. 2000b. First Detection of Submillimeter [CI] Emission in the Small Magellanic Cloud. ApJ, **541**, L17.

Boreiko, R. T. and Betz, A. L. 1993. A Search for the Rotational Transitions of H_2D^+ at 1370 GHz and H_3O^+ at 985 GHz. ApJ, **405**, L39–L42.

Brown, R. L. and vanden Bout, P. A. 1992. Forbidden C I Emission at $Z = 2.286$ in the Protogalaxy IRAS F10214 + 4724. ApJ, **397**, L11.

Ceccarelli, C., Caux, E., White, G. J., Molinari, S., Furniss, I., Liseau, R., Nisini, B., Saraceno, P., Spinoglio, L., and Wolfire, M. 1998. The Far Infrared Line Spectrum of the Protostar IRAS 16293-2422. A&A, **331**, 372–382.

Ceccarelli, C., Hollenbach, D. J., and Tielens, A. G. G. M. 1996. Far-Infrared Line Emission from Collapsing Protostellar Envelopes. ApJ, **471**, 400+.

Chamberlin, R. A. 2001a. Comparisons of Saturated Water Vapor Column from Radiosonde, and MM and Submm Opacities at the South Pole. In *IAU Technical Workshop: Site 2000 - Session III, Astronomical Site Evaluation in the Visible and Radio Range, 13-17 November 2000, in Marrakech, Morocco*. International Astronomical Union, Paris, FR.

Chamberlin, R. A. 2001b. South Pole Submillimeter Sky Opacity and Correlations with Radiosonde Observations. J. Geophys. Res. submitted.

Chamberlin, R. A. and Bally, J. 1994. The 225 GHz Opacity of the South Pole Sky Derived from Continual Radiometric Measurements of the Sky Brightness Temperature. Appl.Optics, **33**, 1095.

Chamberlin, R. A. and Bally, J. 1995. The Observed Relationship Between the South Pole 225 GHz Atmospheric Opacity and the Water Vapor Column Density. Int. J. Infrared and Millimeter Waves, **16**, 907.

Chamberlin, R. A., Lane, A. P., and Stark, A. A. 1997. The 492 GHz Atmospheric Opacity at the Geographic South Pole. ApJ, **476**, 428.

Chin, Y.-N., Henkel, C., Whiteoak, J. B., Millar, T. J., Hunt, M. R., and Lemme, C. 1997. Molecular Abundances in the Magellanic Clouds. I. A Multiline Study of Five Cloud Cores. A&A, **317**, 548.

Coble, K., Dragovan, M., Kovac, J., Halverson, N. W., Holzapfel, W. L., Knox, L., Dodelson, S., Ganga, K., Alvarez, D., Peterson, J. B., Griffin, G., Newcomb, M., Miller, K., Platt, S. R., and Novak, G. 1999. Anisotropy in the Cosmic Microwave Background at degree angular scales: Python V results. ApJ, **519**, L5. `astro-ph/9902195`.

Cohen, R. S., Dame, T. M., Garay, G., Montani, J., Rubio, M., and Thaddeus, P. 1988. A Complete CO Survey of the Large Magellanic Cloud. ApJ, **331**, L95.

Dalgarno, A., Oppenheimer, M., and Berry, R. S. 1973. Chemiionization in Interstellar Clouds. ApJ, **183**, L21–+.

Dragone, C. 1982. A First-order Treatment of Aberrations in Cassegrainian and Gregorian Antennas. IEEE Trans. Antennas and Propagation, **AP-30**, 331.

Dragovan, M., Ruhl, J., Novak, G., Platt, S. R., Crone, B., Pernic, R., and Peterson, J. 1994. Anisotropy in the Microwave Sky at Intermediate Angular Scales. ApJ, **427**, L67.

Engargiola, G., Zmuidzinas, J., and Lo, K.-Y. 1994. A 492 GHz Quasioptical SIS Receiver for Submillimeter Astronomy. Rev. Sci. Instr., **65**, 1833.

Englmaier, P. and Gerhard, O. 1999. Gas Dynamics and Large-scale Morphology of the Milky Way Galaxy. MNRAS, **304**, 512.

Geballe, T. R. and Oka, T. 1989. An Infrared Spectroscopic Search for the Molecular Ion H_3^+. ApJ, **342**, 855.

Gerecht, E., Musante, C. F., Zhuang, Y., Yngvesson, K. S., Goyette, T., Dickinson, J., Waldman, J., Yagoubov, P. A., Gol'tsman, G. N., Voronov, B. M., and Gershenzon, E. M. 1999. NbN Hot Electon Bolometric Mixers—A New Technology for Low Noise THz Receivers. IEEE Trans., **MTT-47**, 2519.

Goldsmith, P. F. 1999. Probing Molecular Clouds - Their Density and Structure. In Wall, W. F., editor, *Astrophysics and Space Science Library Vol. 241: Millimeter-Wave Astronomy: Molecular Chemistry & Physics in Space.*, page 57. Kluwer Academic.

Groppi, C., Walker, C., Hungerford, A., Kulesa, C., Jacobs, K., and Kooi, J. 2000. PoleSTAR: An 810 GHz Array Receiver for AST/RO. In Mangum, J. G. and Radford, S. J. E., editors, *Imaging at Radio Through Submillimeter Wavelengths*, volume 217, page 48, San Francisco. ASP Conference Series.

Herbst, E. and Klemperer, W. 1973. The Formation and Depletion of Molecules in Dense Interstellar Clouds. ApJ, **185**, 505.

Holdaway, M. A., Radford, S. J. E., Owen, F. N., and Foster, S. M. 1995. Fast Switching Phase Calibration: Effectiveness at Mauna Kea and Chajnantor. Millimeter Array Technical Memo 139, NRAO.

Hollenbach, D. J. and Tielens, A. G. G. M. 1999. Photodissociation Regions in the Interstellar Medium of Galaxies. Rev. Mod. Phys., **71**, 173.

Honingh, C. E., Hass, S., Hottgenroth, K., Jacobs, J., and Stutzki, J. 1997. Low-noise broadband fixed tuned SIS waveguide mixers at 660 and 800GHz. IEEE Trans. Appl. Superconductivity, **7**, 2582.

Hsieh, H. H. 2000. *^{12}CO $J = 4 \rightarrow 3$ and C I $^3P_1 \rightarrow {}^3P_0$ Observations of a Selection of Interstellar Clouds Located Throughout the Galaxy.* Senior Honors Thesis, Harvard University.

Huang, M. 2001. *Interstellar Carbon Under the Influence of H II Regions.* PhD Thesis, Boston University.

Huang, M., Bania, T. M., Bolatto, A., Chamberlin, R. A., Ingalls, J. G., Jackson, J. M., Lane, A. P., Stark, A. A., Wilson, R. W., and Wright, G. A. 1999. Atomic Carbon Observations of Southern Hemisphere H II Regions. ApJ, **517**, 282.

Huettemeister, S., Dahmen, G., Mauersberger, R., Henkel, C., Wilson, T. L., and Martin-Pintado, J. 1998. Molecular Gas in the Galactic Center Region. III. Probing Shocks in Molecular Cores. A&A, **334**, 646.

Hungerford, A., Kulesa, C., Walker, C. K., Zhang, X., and Lane, A. P. 2001. Large Scale CO and [C I] Emission in the ρ Ophiuchus Molecular Cloud. ApJ. submitted.

Ingalls, J., Chamberlin, R. A., Bania, T. M., Jackson, J. M., Lane, A. P., and Stark, A. A. 1997. Atomic Carbon in Southern Hemisphere High Latitude Clouds. ApJ, **479**, 296.

Ingalls, J. G. 1999. *Carbon Gas in High Galactic Latitude Molecular Clouds.* PhD Thesis, Boston University.

Ingalls, J. G., Bania, T. M., Lane, A. P., Rumitz, M., and Stark, A. A. 2000. Physical State of Molecular Gas in High Latitude Translucent Clouds. ApJ, **535**, 211.

Israel, F. P., Maloney, P. R., Geis, N., Hermann, F., Madden, S. C., Poglitsch, A., and Stacey, G. J. 1996. C^+ Emission from the Magellanic Clouds. I. The Bright H II Region Complexes N159 and N160. ApJ, **465**, 738.

Johansson, L. E. B., Greve, A., Booth, R. S., Boulanger, F., Garay, G., de Graauw, T., Israel, F. P., Kutner, M. L., Lequeux, J., Murphy, D. C., Nyman, L. ., and Rubio, M. 1998. Results of the SEST Key Programme: CO in the Magellanic Clouds. VII. 30 Doradus and its Southern H II Regions. A&A, **331**, 857.

Keene, J., Blake, G. A., Phillips, T. G., Huggins, P. J., and Beichman, C. A. 1985. The Abundance of Atomic Carbon near the Ionization Fronts in M17 and S140. ApJ, **299**, 967.

Keene, J., Schilke, P., Kooi, J., Lis, D. C., Mehringer, D. M., and Phillips, T. G. 1998. Detection of the $^3P_2 \rightarrow {}^3P_1$ Submillimeter Transition of ^{13}C I in the Interstellar Medium: Implication for Chemical Fractionation. ApJ, **494**, L107.

Kim, S., Martin, C. L., Stark, A. A., and Lane, A. P. 2000. AST/RO Observations of CO J=7-6 Emission from the Galactic Center. American Astronomical Society Meeting 197, BAAS, **32**, 4.04.

Kooi, J. W., Chan, M. S., Bumble, B., LeDuc, H. G., Schaffer, P. L., and Phillips, T. G. 1995. 230 and 492 GHz Low-Noise SIS Waveguide Receivers Employing Tuned Nb/AlO$_x$/Nb Tunnel Junctions. Int. J. IR and MM Waves, **16**.

Kooi, J. W., Chattopadhyay, G., Thielman, M., Phillips, T. G., and Schieder, R. 2000. Noise Stability of SIS Receivers. Int. J. of Infrared and Millimeter Waves, **21**, 689.

Kooi, J. W., Man, C., Phillips, T. G., Bumble, B., and LeDuc, H. G. 1992. A Low Noise 230 GHz Heterodyne Receiver Employing a 0.25 μm^2 Area Nb/AlO$_x$/Nb Tunnel Junction. IEEE trans. Microwaves Theory and Techniques, **40**, 812.

Lane, A. P. 1998. Submillimeter Transmission at South Pole. In Novak, G. and Landsberg, R. H., editors, *Astrophysics from Antarctica*, volume 141 of *ASP Conf. Ser.*, page 289, San Francisco. ASP.

Lane, A. P. and Stark, A. A. 1996. Antarctic Submillimeter Telescope and Remote Observatory (AST/RO): Installation at Pole. Antarctic J. of the U.S., **30**, 377.

Lay, O. P. and Halverson, N. W. 2000. The Impact of Atmospheric Fluctuations on Degree-Scale Imaging of the Cosmic Microwave Background. ApJ, **543**, 787. `astro-ph/9905369`.

Lis, D. C. and Carlstrom, J. E. 1994. Submillimeter Continuum Survey of the Galactic Center. ApJ, **424**, 189–199.

Lis, D. C., Serabyn, E., Zylka, R., and Li, Y. 2001. Quiescent Giant Molecular Cloud Cores in the Galactic Center. ApJ, **550**, 761.

Millar, T. J., Bennett, A., and Herbst, E. 1989. Deuterium Fractionation in Dense Interstellar Clouds. ApJ, **340**, 906–920.

Morris, M. and Serabyn, E. 1996. The Galactic Center Environment. ARA&A, **34**, 645.

Narayanan, G., Walker, C. K., and Buckley, H. D. 1998. The “Blue-Bulge” Infall Signature toward IRAS 16293-2422. ApJ, **496**, 292.

Novak, G., Dotson, J. L., Dowell, C. D., Hildebrand, R. H., Renbarger, T., and Schleuning, D. A. 2000. Submillimeter Polarimetric Observations of the Galactic Center. ApJ, **529**, 241–250.

NRC 2001. *Astronomy and Astrophysics in the New Millennium*. National Research Council, National Academy Press.

Ojha, R., Stark, A. A., Hsieh, H. H., Lane, A. P., Chamberlin, R. A., Bania, T. M., Bolatto, A. D., Jackson, J. M., and Wright, G. A. 2001. AST/RO Observations of Atomic Carbon near the Galactic Center. ApJ, **548**, 253. `astro-ph/0008439`.

Oka, T., Hasegawa, T., Sato, F., Tsuboi, M., and Miyazaki, A. 1998. A Large-Scale CO Survey of the Galactic Center. ApJS, **118**, 455.

Ossenkopf, V. 1997. The Sobolev Approximation in Molecular Clouds. New Astronomy, **2**, 365–385.

Pagani, L., Salez, M., and Wannier, P. G. 1992. The Chemistry of H_2D^+ in Cold Clouds. A&A, **258**, 479–488.

Pagani, L., Wannier, P. G., Frerking, M. A., Kuiper, T. B. H., Gulkis, S., Zimmermann, P., Encrenaz, P. J., Whiteoak, J. B., Destombes, J. L., and Pickett, H. M. 1992. Search for H_2D^+ at 372 GHz in Dense Interstellar Clouds. A&A, **258**, 472–478.

Pak, S., Jaffe, D. T., van Dishoeck, E. F., Johansson, L. E. B., and Booth, R. S. 1998. Molecular Cloud Structure in the Magellanic Clouds: Effect of Metallicity. ApJ, **498**, 735.

Pardo, J. R., Cernicharo, J., and Serabyn, E. 2001. Atmospheric Transmission at Microwaves (ATM): An Improved Model for mm/submm Applications. IEEE Trans. Antennas and Propagation. in press.

Phillips, T. G., Blake, G. A., Keene, J., Woods, R. C., and Churchwell, E. 1985. Interstellar H_3^+ - Possible Detection of the 1(10)-1(11) transition of H_2D^+. ApJ, **294**, L45–L48.

Pierce-Price, D. *et al.* 2000. A Deep Submillimeter Survey of the Galactic Center. ApJ, **545**, L121–L125.

Platt, S. R., Kovac, J., Dragovan, M., Peterson, J. B., and Ruhl, J. E. 1997. Anisotropy in the Microwave Sky at 90 GHz: Results from Python III. ApJ, **475**, L1.

Radford, S. J. E., Reiland, G., and Shillue, B. 1996. Site Test Interferometer. PASP, **108**, 441.

Richer, J. S., Shepherd, D. S., Cabrit, S., Bachiller, R., and Churchwell, E. 2000. Molecular Outflows from Young Stellar Objects. In *Protostars and Planets IV (Tucson: University of Arizona Press; eds Mannings, V., Boss, A.P., Russell, S. S.)*, page 867.

Rubin, R. H. 1985. Models of H II Regions - Heavy Element Opacity, Variation of Temperature. ApJS, **57**, 349.

Ruhl, J. E., Dragovan, M., Platt, S. R., Kovac, J., and Novak, G. 1995. Anisotropy in the Microwave Sky at 90 GHz: Results from Python II. ApJ, **453**, L1.

Sakamoto, K. 2000. Bar-driven Transport of Molecular Gas in Spiral Galaxies: Observational Evidence. In *ASP Conf. Ser. 197: Dynamics of Galaxies: from the Early Universe to the Present*, pages 73+.

Sakamoto, K., Okumura, S. K., Ishizuki, S., and Scoville, N. Z. 1999. Bar-driven Transport of Molecular Gas to Galactic Centers and Its Consequences. ApJ, **525**, 691–701.

Scappini, F., Cecchi-Pestellini, Aiello, S., Sironi, G., Stark, A., Lane, A., and Zhang, X. 2000. Submillimeter CO Observations in Southern Bok Globules. In *Workshop on Astronomy and Astrophysics at Sub Millimeter Wavelengths*, volume 66 of *Proceedings of the Italian Society of Physics*, page 105.

Schieder, R., Tolls, V., and Winnewisser, G. 1989. The Cologne Acousto Optical Spectrometers. Exp. Astron., **1**, 101–121.

Schwerdtfeger, W. 1984. *Weather and Climate of the Antarctic.* Elsevier, Amsterdam.

Spaans, M. and Norman, C. A. 1997. Cosmological Evolution of Dwarf Galaxies: The Influence of Star Formation and the Multiphase Interstellar Medium. ApJ, **483**, 87+.

Staguhn, J. 1996. *Observations Towards the Sgr C Region Near the Center of our Galaxy.* PhD Thesis, University of Cologne.

Staguhn, J., Stutzki, J., Balm, S. P., Stark, A. A., and Lane, A. P. 1998. Sub-mm [C I] and CO Observations of Molecular Clouds Presumably Interacting with the G359.54+0.18 Nonthermal Filaments. In Sofue, Y., editor, *The Central Regions of the Galaxy and Galaxies*, Proceedings of IAU Symposium 184, page 175. Kluwer.

Staguhn, J., Stutzki, J., Chamberlin, R. A., Balm, S., Stark, A. A., Lane, A. P., Schieder, R., and Winnewisser, G. 1997. Observations of [C I] and CO Absorption in Cold, Low-Density Cloud Material toward the Galactic Center Broad Line Emission. ApJ, **491**, 191.

Stark, A. A. 1995. Installation of the Antarctic Sub-MM Telescope and Remote Observatory (AST/RO). In *Proceedings of Sixth International Symposium on Space Terahertz Technology*, page 150, Pasadena. Caltech.

Stark, A. A. *et al.* 2001. The Antarctic Submillimeter Telescope and Remote Observatory (AST/RO). PASP, **113**, 567. `astro-ph/0008253`.

Stark, A. A., Bolatto, A. D., Chamberlin, R. A., Lane, A. P., Bania, T. M., Jackson, J. M., and Lo, K.-Y. 1997a. First Detection of 492 GHz [C I] Emission from the Large Magellanic Cloud. ApJ, **480**, L59.

Stark, A. A., Chamberlin, R. A., Cheng, J., Ingalls, J., and Wright, G. 1997b. Optical and Mechanical Design of the Antarctic Submillimeter Telescope and Remote Observatory. Rev. Sci. Instr., **68**, 2200.

Stark, A. A., Gerhard, O. E., Binney, J. J., and Bally, J. 1991. On the Fate of Galactic Centre Molecular Clouds. MNRAS, **248**, 14p. TM11341-900906-13.

Swain, M. R., Bradford, C. M., Stacey, G. J., Bolatto, A. D., Jackson, J. M., Savage, M., and Davidson, J. A. 1998. Design of the South Pole Imaging Fabry-Perot Interferometer (SPIFI). SPIE, **3354**, 480.

Tieftrunk, A. R., Jacobs, K., Martin, C. L., Siebertz, O., Stark, A. A., Walker, C. K., and Wright, G. A. 2001. ^{13}C I in High-mass Star-forming Clouds. A&A. submitted, `astro-ph/0105176`.

Tielens, A. G. C. M. 1997. Heating and Cooling of the Interstellar Medium. In *ASP Conf. Ser. 124: Diffuse Infrared Radiation and the IRTS*, pages 255+.

van Dishoeck, E. F., Phillips, T. G., Keene, J., and Blake, G. A. 1992. Ground-based Searches for Interstellar H_2D^+. A&A, **261**, L13–L16.

vanden Bout, P. A. and Brown, R. L. 1992. [CI] Emission in the Z = 2.286 Protogalaxy IRAS F10214+4724 Observed in the J = 2-1 (809 GHz) and J = 1-0 (492 GHz) Transitions. In *American Astronomical Society Meeting*, volume 180, page 1609.

vanden Bout, P. A. and Brown, R. L. 1994. CO at High Redshifts. In *LNP Vol. 439: The Structure and Content of Molecular Clouds*, page 304.

Walker, C. K., Carlstrom, J. E., and Bieging, J. H. 1993. The IRAS 16293-2422 Cloud Core - A Study of a Young Binary System. ApJ, **402**, 655–666.

Walker, C. K., Kooi, J. W., Chan, W., LeDuc, H. G., Schaffer, P. L., Carlstrom, J. E., and Phillips, T. G. 1992. A Low-Noise 492 GHz SIS Waveguide Receiver. Int. J. Infrared and Millimeter Waves, **13**, 785.

Walker, C. K., Lada, C. J., Young, E. T., Maloney, P. R., and Wilking, B. A. 1986. Spectroscopic evidence for infall around an extraordinary IRAS source in Ophiuchus. ApJ, **309**, L47–L51.

Walker, C. K., Narayanan, G., and Boss, A. P. 1994. Spectroscopic Signatures of Infall in Young Protostellar Systems. ApJ, **431**, 767–782.

Watson, W. D. 1973. Formation of the HD Molecule in the Interstellar Medium. ApJ, **182**, L73.

Wells, D. C., Greisen, E. W., and Harten, R. H. 1981. FITS: A Flexible Image Transport System. Astron. and Astrophys. Suppl. Ser., **44**, 363.

Wright, E. L. *et al.* 1991. Preliminary Spectral Observations of the Galaxy with a 7° Beam by the Cosmic Background Explorer (COBE). ApJ, **381**, 200.

Yan, M., Lane, A. P., and Stark, A. A. 2001. AST/RO Mapping of NGC 6334 in the C I 492 GHz and CO $J = 4 \rightarrow 3$ 460 GHz Lines. in preparation.

Yngvesson, K. S., Musante, C. F., Ji, M., Rodriguez, F., Zhuang, Y., Gerecht, E., Coulombe, M., Dickinson, J., Goyette, T., Waldman, J., Walker, C. K., Stark, A. A., and Lane, A. P. 2001. Terahertz Receiver with NbN HEB Device (TREND) - A Low-Noise Receiver User Instrument for AST/RO at the South Pole. Twelfth Intern. Symp. Space THz Technology. in press.

Zhang, X., Lee, Y., Bolatto, A., and Stark, A. A. 2001. CO ($J = 4 \rightarrow 3$) and [CI] Observations of the Eta Carina Molecular Cloud Complex. ApJ. in press, `astro-ph/0101272`.

Zhou, S., Evans, N. J., Koempe, C., and Walmsley, C. M. 1993. Evidence for Protostellar Collapse in B335. ApJ, **404**, 232.

Zmuidzinas, J. and LeDuc, H. G. 1992. Quasi-Optical Slot Antenna SIS Mixers. IEEE Trans. Microwave Theory Tech., **40**, 1797.