June 30, 2000

Requirements for Initial SMA Science Observations
SMA Memo #142

David Wilner, Mark Gurwell, Paul Ho

ABSTRACT

We list basic requirements for SMA science observations and suggest several initial science projects that will help develop calibration procedures and strategies and will lead to publishable results.

1. Introduction

Now that first fringes have been demonstrated on cosmic sources with two SMA antennas on Mauna Kea, there is the possibility of pursuing some first science projects. The projects for this interim period, though limited to simple structures and model fitting, are important for exercising the hardware, on-line software, and for developing calibration procedures and strategies. Many interesting projects are possible for the 230 GHz and 345 GHz bands, and very exciting science could be done in the 690 GHz band, provided the data can be calibrated.

2. Testing Goals and Calibration

Many aspects of the SMA system must be characterized prior to all but the most simplistic science observations. As a minimum goal, we would like the SMA to be characterized at a level comparable to the CSO-JCMT interferometer.

- Two antennas with reliable pointing, tracking, focus, and receivers. This requires adequate control software and hardware to make a sustained (several hour) observation where components operate properly with limited intervention. An additional goal should be to improve diagnostic software and hardware links to enable monitoring as much of the system as possible, and to log this information.

- Accurate application of fringe rotation, delay and Doppler tracking. Testing of the system should include precision measurement of a variety of sources and over time to verify that these parameters are handled correctly. An additional goal should be the ability to extract test data from the database and analyze it using offline tools; these tools should be standardized and made available to the SMA test community.

- At least one correlator configuration, preferably with the widest bandwidth allowed by the available hardware for the best sensitivity on continuum sources. Testing with astronomical sources and the beacon should verify that the correlator configuration software and the correlator data extraction software are compatible with each other and with the data storage software.

- Quantified system stability in amplitude and phase in time and for the bandpass. It must be demonstrated that the system hardware phase and amplitude are sufficiently stable over reasonable calibration timescales, i.e. 15-30 minutes. Bandpass calibration testing should demonstrate the stability of the spectral response of the system with time.

- Amplitude calibration capability. Some form of amplitude calibration is important, in order to correct to first order atmospheric opacity and to monitor system performance. Amplitude calibration is also necessary to combine observations obtained on different days. (Note that the current mirror door system is not sufficient because it has been demonstrated to give relatively poor results for system temperature measurements.) Software and hardware control for automatic, on-demand, system temperature measurements are necessary.

- The ability to observe a sequence of astronomical sources, including proper data storage for single and multiple source lists. Data extraction software should also be available for output of either the full data set or a user defined subset, into at least AIPS compatible FITS formats and MIRIAD formats for subsequent analysis.

These requirements define the operational capability for a science program, since any program will require: initial setup of observing program (script), configuration of the correlator, tuning and initial calibrations, a mix of program source and calibrator source observations, and final calibrations. With these elements in place, we can attempt to perform calibrations that

- account for complex gain drifts with time (including baseline length, cable lengths, thermal drifts in electronics, non-intersection of antenna axes, atmosphere, etc.),

- remove structure in the complex passband,
- convert correlation levels to effective antenna temperatures with system temperature measurements to account for the atmosphere,
- scale results to flux units using observations of planets.

Successful application of these calibrations will lead to publication quality results.

3. Initial Observations

We list several possible initial projects, including studies of Solar System bodies and Galactic and extragalactic sources. The primary goal is to promote the technical capabilities needed to realize these projects. The following descriptions should be considered illustrative; they are not meant for detailed planning purposes.

3.1. Baseline Determination/Calibrator Survey

The baseline determination, a necessary calibration procedure, tests many of the basic operational aspects of the system. The steps are to (1) observe the time variation of the phase of a bright calibrator across the sky to determine x,y components, (2) verify with other bright calibrators, and (3) observe time variation of the phase of several additional calibrators at a variety of declinations to determine the z component. All accessible "strong" calibrators (identified from longer wavelengths) should be included. The typical flux density is about 1 Jy at 230 GHz and somewhat lower at 345 GHz. Extended sources with poorly known structure, e.g. CO emission in Orion-KL, should be excluded. If planets are included and amplitudes are calibrated, then the calibrator flux list will be an important byproduct. The ability to make routine, efficient baseline measurements provides an excellent test of the full SMA system.

3.2. Planetary Continuum and Spectral Line Survey

The ability to properly observe a planet is a good test of the entire system. Planets have precisely known positions, sizes, and velocities, and in addition known or modeled temperatures that can be used to provide the absolute flux scale. Planets are the brightest continuum sources available to the SMA, though resolution effects must be taken into account. At 220 GHz, Neptune and Uranus are 13 Jy and 30 Jy, respectively; at 330 GHz, they are 26 Jy and 60 Jy, respectively. The other planets are larger and vary in size with time (and therefore in resolved flux); for Venus and Jupiter the single dish fluxes can be 10^4 to nearly 10^5 Jy. Because the planets are such strong continuum sources, they will help in setting delays and calibrating the bandpass. Planets stress the system by moving at non-sidereal rates (some slow, some fast), and because they are strong can also be used to test the efficiency of daytime operation more easily than other objects.

We describe two areas of planetary science that can be addressed early in SMA commissioning. These programs are uniquely suited to the SMA since the JCMT-CSO interferometer did not provide publishable results on planetary atmospheres, none of the millimeter arrays operate above ~ 265 GHz, and the differential measurements discussed for each project rely on the unique capabilities of an interferometer (side-band separation, better continuum measurements) relative to single dish telescopes.

3.2.1. Spectral Line Survey

Most planetary atmospheres have a time-variable nature. Observations of strong, well-known line features such as CO(2-1) and CO(3-2) absorption on Mars and Venus are useful for constraining atmospheric temperature profiles and CO abundances. Other projects include a search for stratospheric HCN(3-2) in the giant planets, and measuring HDO emission from Mars and Venus. For the larger planets, very sensitive measurements can be made of more exotic spectral lines by accurate measurement of the spectral visibility functions near nulls in the continuum visibility function (e.g. the limb spectral emission is not resolved but the planet continuum is completely resolved). These observations may be done with relatively short baselines (10 to 30 m) but may need flexibility in the case of trying to measure the near null fluxes of the larger planets.

3.2.2. Continuum Survey

This “continuum” survey is simply a spectral line survey where the line features are pressure-broadened to widths of 3 to 30 GHz. Examples include tropospheric CO on Neptune and tropospheric PH_3 on Saturn and Jupiter. Accurate continuum measurements can help define the depths and widths of these features on the giant planets. A simple, straightforward SMA project is to measure CO(2-1) and CO(3-2) absorptions on Neptune relative to Uranus. Observations require two antennas, the ability to switch between

Neptune, Uranus, and perhaps also a nearby quasar calibrator with a relatively short duty cycle (of order 5 minutes), the ability to accurately calibrate amplitude gains (in a relative sense), and the ability to tune the receivers to several frequencies to cover the broad line shapes. This project requires only short baselines (10 to 30 m).

3.3. Isolated Massive Star Forming Cores

Make a snapshot survey of ultracompact HII regions and pre-ultracompact HII regions selected from JCMT/SCUBA and CSO/SHARC submillimeter continuum maps to show simple structure, in the 345 and 690 GHz bands. Little is known about the small scale structure of these deeply obscured star forming environments, and none were observed with the CSO-JCMT interferometer. These sources are very strong at single dish resolution, typically 10's of Jy at 345 GHz and 100's of Jy at 690 GHz (e.g. Hunter et al. 2000). Some of them may work as phase calibrators, particularly at short baselines, and especially at high frequencies where nearly all the quasars become marginal. Because these objects are strong enough to be detectable at high signal-to-noise in a short time, a snapshot survey of many 10's of sources is feasible. The variation of visibility amplitude as a function of projected baseline length constrains the structure of the core material that surrounds the embedded star(s), and multifrequency information provides information on the dust emissivity and perhaps evolution. Spectral lines should be included in the band at each frequency, for example the strong lines from the CS molecule (J=7-6 at 343 GHz, J=15-14 at 685 GHz) that provide a probe of the kinematics and excitation conditions of the immediate circumstellar environment. The linewidths are typically 10 km s^{-1}, from turbulence, infall, outflow and rotation. Another possible set of frequencies might be the hydrogen recombination line masers at 353 and 662 GHz, though only one two such maser sources are known (MWC349 and Eta Carina). This project requires only modest baselines (> 20 m).

3.4. Protostellar Disk Size Measurements

Repeat and extend the pioneering work of Lay et al. (1994) that used the CSO-JCMT interferometer to measure a 345 GHz size and orientation for disks around young sun-like stars (HL Tau and L1551). These observations require a baseline longer than ~ 100 m (e.g. inner ring to pad 14) to obtain sufficient resolution to resolve the targets (subarcsecond). A large sample of targets could be observed in the same configuration, providing good statistics. In addition, resolved observations could be made in the 690 GHz band, perhaps on a factor of two shorter baseline. These sources have 345 GHz fluxes of 2 to 3 Jy, and 690 GHz fluxes 10 to 20 Jy. Resolved observations would be a great step forward for studies of disk structure, especially in combination with recent size measurements from millimeter arrays. Observations of a spectral line, for example the CO(3-2) line within the 345 GHz observing band, would be a bonus. This project will verify the CSO-JCMT results, provide size measurements for an expanded sample, increase the frequency range of the measurements, and, by including the CO line, add new information on gas content and kinematics.

3.5. CO(3-2) in 3C48 or Arp 220

The radio loud quasar 3C48 at $z = 0.3695$ shows detectable emission in the CO(1-0) line (Scoville et al. 1993, Wink et al. 1997). This object may be important link between nearby ultraluminous galaxies, which are mainly mergers, and quasars. Strong non-thermal continuum emission makes measurements of the CO(1-0) line difficult (an 8 mJy line on top of 267 mJy of continuum). The situation should be much better for the CO(3-2) line since the CO emission will increase in flux (by a large factor if the excitation is sufficient), and the non-thermal continuum emission will decrease by about a factor of two. The CO(3-2) line is redshifted 252.498 GHz, and the fwhm of the line is ~ 260 km s^{-1}, or 220 MHz. The modest continuum signal provides a powerful diagnostic and will help in calibration. For a 1 GHz bandwidth, it should be possible to detect the continuum signal within a modest coherence time and thereby "self-calibrate" the data. This observation requires a stable bandpass, and it would be desirable to interleave observations of a bright calibrator as a control. Short baselines (10 to 30 m) are preferred to maximize coherence for detection. Since the lower frequency studies suggest a $1''$ size for the CO emission region, it may be possible to obtain minimal structural information on a ~ 200 m baseline (e.g. inner ring to pad 14). Although the line frequency is reachable at BIMA and OVRO (not IRAM), these observations would require the very best California weather, and correlator limitations are an impediment. Since the line frequency falls in the overlap region between two SMA receiver bands, this project could be used to compare their performance.

Arp 220 is the prototype ultraluminous galaxy in the local universe. High resolution observations of the CO(2-1) line show two compact nuclei separated within a rotating disk several arcseconds in extent (Sakamoto et al. 1999, Downes & Solomon 1998). The CO(3-2) line at 340.4 GHz is strong (a few Jy), as is the associated dust continuum (0.5 Jy). The full velocity extent of the line is about 1000 km s^{-1} and would likely require two LO settings of 1 GHz for complete coverage, including continuum, and these observations would require good bandpass calibration. The high frequency data could be used to constrain the CO excitation within the complex two nucleus structure, using a model based on the lower frequency images. These observations require a baseline longer than $\sim$ 100 m to resolve the individual nuclei. Arp 220 is well placed in the sky for non-Galactic plane time and– unlike 3C48– does not interfere with Taurus targets.

We thank the SMA team for comments on an early draft of this memo, especially Todd Hunter, Masao Saito, and Martina Wiedner.

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prepared with AASTEX