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Polarimetry with the SMA: Workshop Summary
SMA Memo #129

David Wilner

ABSTRACT

This memo summarizes the discussions and recommendations from the SMA Polarimetry workshop held 9-10 November 1998 at the CfA.

1. Introduction

Although no mention is made of using the SMA for polarimetry in the 1984 Yellow Book proposal for the instrument, this technique was recognized soon after as an important capability for the SMA, and its scientific potential has been championed in later documents. Rough plans have been in place for many years for dual receiver operation at 345 GHz, a frequency chosen for maximum sensitivity to optically thin dust emission where polarization may provide information on magnetic field structure. In the last decade, the first submillimeter polarization observations have been made using single dish telescopes, and more recently extensive maps have been made using submm/fir bolometer arrays and millimeter interferometers. A small workshop was organized at the CfA to learn more about the latest polarimetry results and associated technical challenges, and to revisit the plans for polarimetry with the SMA in light of these developments. Experts involved in recent polarimetry experiments were invited to visit and advise the SMA staff. Representatives attended from groups using the BIMA array (Crutcher, Plambeck, Rao, Wright), the OVRO array (Akeson and Carlstrom, via telecon), the CSO (Hildebrand), the JCMT (Greaves), and the VLA/VLBA (Wardle). The workshop was organized by Alyssa Goodman.

2. Scientific Highlights

A session devoted to new scientific results highlighted several that are highly encouraging with regard to polarimetry with the SMA:

- Greaves presented extensive 850 μm polarization maps obtained with SCUBA on the JCMT. Examples of massive star forming regions, dark clouds, T-Tauri disks, and starburst galaxies all show linearly polarized emission at levels of a few percent or higher, at flux levels down to a few mJy, in some cases extending over areas much larger than the SMA field of view.

- Hildebrand discussed the "polarization spectrum", changes in the polarization level and direction with wavelength, that are seen from 60 to 350 μm from KAO and CSO observations of star forming regions. The effect may result from the presence of grains with different polarizing properties, and possibly different spatial distributions, a hypothesis that may be tested through higher angular resolution imaging.

- Rao showed BIMA maps of Orion-KL at 3 mm and 1 mm at approximately $4''$ resolution that demonstrate that the "polarization hole", a decrease in polarization at the position of maximum flux in fir/submm single dish maps, is to some extent explained by changes in polarization direction at size scales resolved with interferometry. Some caution was urged in the interpretation of polarization direction given multiple grain alignment mechanisms.

- Crutcher showed BIMA observations of spectral lines in Orion-KL that show the Goldreich-Kylafis effect. The ubiquity of the effect is not known, but it provides the potential to probe magnetic fields far from dust peaks.

- Akeson and Carlstrom presented OVRO 3 mm polarization maps of low-mass protostars, with polarization levels 2 to 4% at $3''$ resolution. These relatively simple systems show resolved structure and demonstrate that grain alignment is present at densities $> 10^8$ cm^{-3}.

- Wardle emphasized that the submillimeter regime was interesting for probing shocks and particle acceleration in extragalactic radio sources, in particular at the jet base that is opaque at longer wavelengths (though ultimately VLBI is needed to spatially resolve these regions).

3. SMA Polarimetry Options

3.1. Nominal Plan

Paine and Wilson described the nominal plan for SMA polarimetry in which two receivers that overlap in frequency near 345 GHz are mounted in the crysostat for simultaneous dual polarization observing. The optics chain has been designed with this mode of operation in mind, and instrumental polarization is expected to be small. However, important details of implementation remain to be specified in this plan. In particular, the cryostat can hold up to eight receivers, though only “high” and “low” frequency bands, arranged at 90 degree angles to each other, may operate at the same time. Since the initial complement of receivers will cover the 180-250, 250-350, and 600-720 GHz bands, a **first option** for the next phase would be to include a set of receivers spanning the 320-420 GHz band mounted to operate together with the 250-350 GHz receivers. *This arrangement would make an “overlap” frequency range of 320-350 GHz accessible for simultaneous dual polarization observations.*

3.2. Duplicate Bands

A **second option** is to construct duplicates of the 250-350 GHz receivers to allow simultaneous dual polarization operation for this entire band. As compared to the nominal plan, this would allow for a wider range of frequency overlap, in a more stable and transparent part of the atmosphere, and also allow for common LO signals and a somewhat smaller receiver design effort. The major disadvantage of this option would be to render inaccessible the frequency range between 350-420 GHz where there are at least some spectral lines of interest (e.g. HCO^+ J=4-3 and HCN J=4-3) and an atmospheric window around 400 GHz for (modestly) high frequency continuum work. However, an ancillary advantage of duplicate 250-350 GHz receivers would be increased sensitivity for all observations in this band that is expected to be used heavily given the expected SMA performance.

3.3. The Triangle Scheme

A **third option** involving frequency overlap, suggested by Ho, is to construct three receivers that offer two common frequency ranges. This “triangle” scheme would have the 250-350 GHz receiver mounted at 90 degrees to a 320-420 GHz receiver mounted at 90 degrees to a 400-520 GHz receiver. In this way, the two frequency ranges of 320-350 GHz and 400-420 GHz would be available for simultaneous dual polarization operation. Some concern was raised about common LO distribution in this augmentation of the nominal plan, but the consensus was that this problem could be solved, if necessary.

3.4. Polarization Switching Schemes

The current millimeter arrays do not have duplicate receivers for simultaneous dual polarization operation. Instead, polarimetry at these facilities rely on single receivers and switching polarizations using computer controlled quarter wave plates (BIMA) or tunable wire grids (OVRO). The switching is performed in efficient patterns (Walsh cycles) to obtain all necessary polarization pairs on all baselines in a sufficiently short time to remain within a (u, v) cell. These time-multiplexed data are then averaged to produce quasi-simultaneous polarization products that can be calibrated using algorithms in the standard software packages.

The polarization switching schemes introduce considerable overhead and complexity in observing procedures and calibration strategy as compared to simultaneous dual polarization observations. However, these schemes are proven, and they provide a straightforward and inexpensive path to polarimetry with the SMA without the need for additional receivers. Therefore, an option for *all* SMA frequency bands is to make use of similar polarization switches, most likely placed in a slot or slots in the calibration load package between mirrors M4 and M5. Three positions will be required, L/R/empty, and the switch should take place in seconds. The simplest option would be switches made of rotating or sliding quarter wave plates manufactured for specific frequencies. A first choice might be 345 GHz if the dual receiver mode will not be available from the outset.

4. Correlator Issues

Young reviewed the impact of polarization on the correlator. The entire 2 GHz bandwidth will be available for dual polarization operation with a loss of a factor of two in spectral resolution (because four correlations must be performed instead of two). The full 8 station correlator is required for simultaneous dual polarization (or dual frequency) operation with all antennas, and therefore its completion must be a priority.

5. Recommendations

1. Simultaneous dual polarization operation is clearly desirable for the SMA. This requires at least two receivers per antenna and the construction of the full 8 station correlator. Also, more antennas providing many closure relations are especially important for the stringent calibration requirements of polarimetry.

2. The decision to either (1) duplicate the 250-350 GHz receivers or (2) create a 320-350 GHz "overlap" band with 250-350 GHz and 320-420 GHz receivers should be postponed until some experience is obtained with real observations on Mauna Kea. There is a trade off between the increased spectral coverage afforded by 320-420 GHz receivers, which will allow 350-420 GHz observations in a single polarization, and the simplicity of duplicate 250-350 GHz receivers that will in addition provide $\sqrt{2}$ increased sensitivity for all observations in this "bread-and-butter" band.

3. The SMA should provide for computer controlled rapid switching between polarizations using quarter wave plates. This simple hardware extension will allow for some polarization experiments, in any SMA band, without any new receivers and just half of the final correlator. This mode of operation requires the construction of appropriate polarizers for the frequencies of interest. Some investigation should be made into the availability of achromatic polarizers.

4. Preliminary testing with quarter wave plates on as few as two antennas may be useful to gain experience. If a situation develops where antennas lag and extra receivers are available, then dual polarization operation might be attempted at an earlier stage.