Phil

National Radio Astronomy Observatory
Charlottesville, Virginia

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MEMORANDUM

To: Dave Hogg

From: Richard Barvainis

Subject: 1 mm Polarimeter for the 12 m Telescope

Recent reconfiguration of the telescope surface and optics has left the 12 m without a polarimetry system. As we have discussed, I would like to see such a system for 1 mm continuum observations of dust in molecular clouds. The purpose of this memo is to review some of the ideas we've had toward realizing this end.

The Polarization Analyzer

In order to minimize engineering effort, it seems that the simplest course is to revive the old polarimeter from the 36' days. This device consists of a rotatable wave plate which, when placed in the telescope beam, allows one to rotate the fixed linearly polarized feed response to any angle on the sky or convert from linear to circular response. In the old configuration, two 1/4 wave plates were used to accomplish this, but in my opinion it is easier to use a single 1/2 wave plate for linear polarimetry or a 1/4 wave plate for circular polarimetry.

The plates can be fabricated from a microwave dielectric (Rexolite) by cutting narrow, parallel grooves into the material. This makes the dielectric constant anisotropic to waves of different polarizations, and allows the introduction of an arbitrary phase shift (depending on groove depth) between the orthogonal polarization components of an incoming wave. A $\lambda/2$ phase shift rotates linear polarization by twice the angle between the groove direction and the direction of linear polarization. A $\lambda/4$ phase shift produces linearly polarized output from an incoming circularly polarized wave, thus matching the circular polarization to the linearly polarized feed.

I am interested mainly in measuring linear polarization in continuum sources, and will concentrate on that in what follows. A common technique in polarimetry, especially at optical wavelengths, is to rapidly spin a polarization analyzer and detect the resulting sinusoidal output in the polarization signal. I used this method, with a half-wave plate as analyzer, in my thesis work at the FCRAO mm telescope, and found that it worked exceedingly well. The modulated polarization signal comes in at four times the rotation frequency (f) of the plate, and in effect one is polarization switching at this rate. Well understood instrumental effects produce sinusoids at 1 x f and 2 x f at the 1-3% level, and these are easily removed from the data in post-processing if enough samples are taken per plate rotation. At FCRAO we binned the data by plate angle into 32 channels, rotating the plate at 1 or 1/2 Hz. The rate should be made variable in order to tune out beating with the refrigerator pump cycle. Absolute position angle can be calibrated by observing the limb of the moon (polarized radially). Instrumentally induced polarization (due to the plate, optics, telescope, etc., and typically < 0.5% at FCRAO) can be corrected by observing the planets.

Within the current 1 mm optics it appears that there is room for the polarimeter above the receiver box, where the beam is about 4" in diameter (but check with John Payne on this). Buddy Martin has supplied me with information on the optical setup, and I have indicated the possible location of the polarimeter on the accompanying sketch.

Data Acquisition

Since we don't yet know the capabilities of the continuum backend receiver for the upcoming season, this section will be rather sketchy. I will just describe what I would like the system to do. As alluded to above, we simply need to sample the digital output of a total power detector/integrator at about 30 Hz, in phase with the rotation of the plate. A possible way of doing this is to monitor a signal from the polarimeter, corresponding to plate position angle, with an on-line computer. At, say, 11° intervals, the integrator would be dumped, its output binned, and a new integration would begin. This would continue for a minute or two on source, then off source, for several on/off cycles, storing the ons and offs as separate 32 element arrays. The accumulated on and off arrays would be differenced, yielding a 32 channel scan containing the four-period polarization sinusoid, which would be stored on disk in the normal way. The software for extracting the polarized signal (which I developed at U. Mass.) could be incorporated as a new function in the single dish reduction package. Whether this particular method is technically feasible will require discussion with John Payne and Betty Stobie, as well as someone familiar with the continuum backend. Certainly, other schemes could be envisioned.

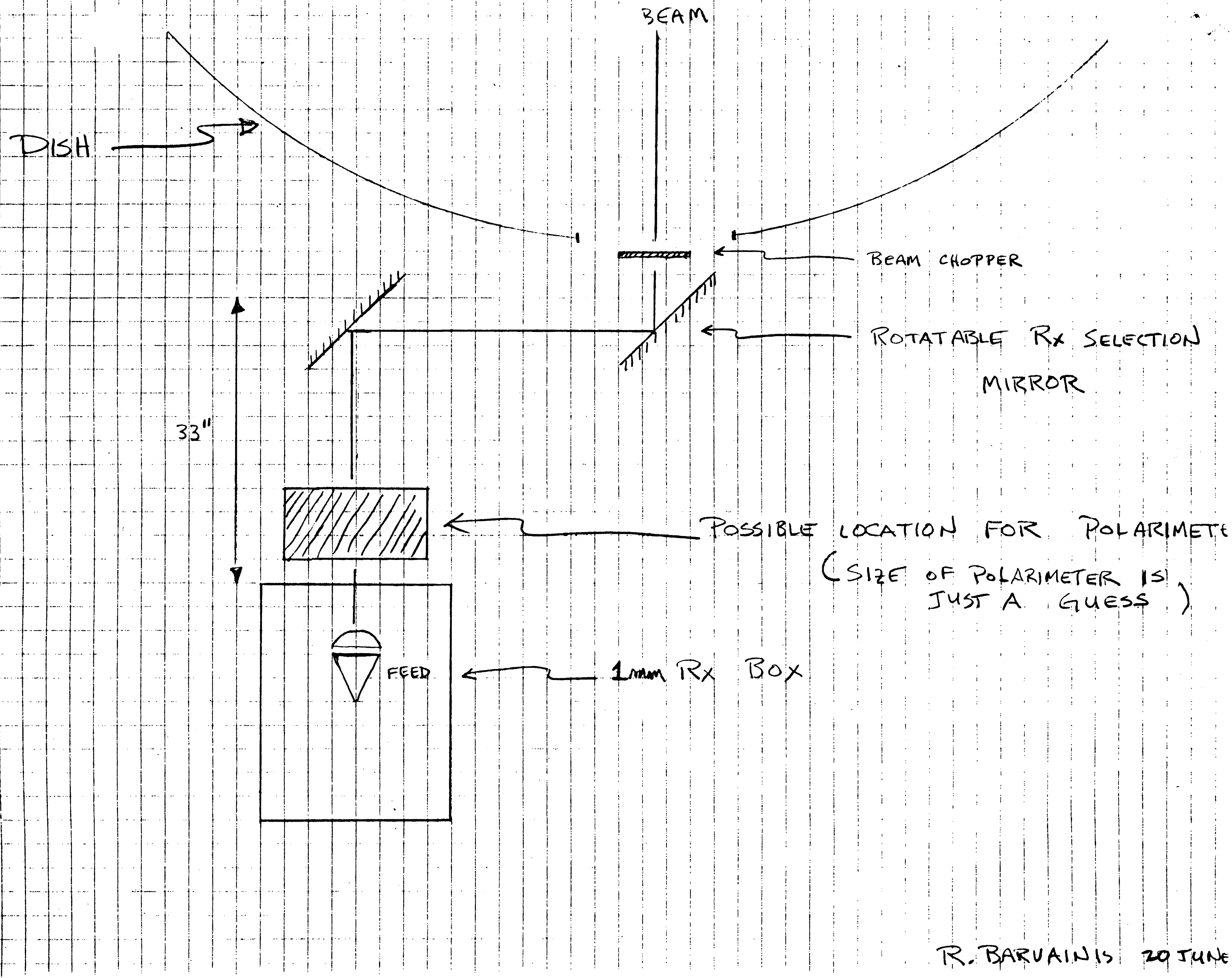
As described here, this system would only be useful for measuring continuum polarization. Spectral line work would require a substantially different observing and data acquisition program. Incorporating spectral line capability would make our task more difficult at this point, and unless there is a big demand I would recommend that it not be pursued.

Scientific Objectives

Here I'll briefly outline the science I'd like to accomplish using a 1 mm polarimeter. With the advent of sensitive 1 mm systems capable of continuum observations (primarily at U. Mass. and the 12 m) it is now possible to study dust emission from molecular clouds at this optically thin wavelength. In fact, sensitivities are now good enough to study the polarization of dust emission as well. It is widely accepted that polarization of dust is due to alignment of non-spherical grains in magnetic fields (due, e.g., to the Davis-Greenstein mechanism), so that the polarization can be used as a direct probe of magnetic field orientations in clouds. Optical and near-IR polarimetry delineate B directions in the general ISM and in low density molecular clouds, but in the dense cores of clouds, where the stars are forming, the field configurations are quite unknown. Since magnetic fields play a major role in many theories of star formation, observational determination of their properties seems clearly important.

The impetus for the project I'd like to carry out comes from work of Hildebrand, Dragovan, and Novak (Ap. J., 284, L51), who recently used the KAO to measure linear polarization from dust emission in Orion at 270 μm. With their 90" beam they measured polarizations of 2-3% at several positions, clearly demonstrating for the first time that the far-IR emission from dust is polarized. This work is certainly important, but I feel that a much better job can be done of it at the 12 m telescope. Probably the biggest advantage is in terms of resolution. The 25" beam of the 12 m is a factor of 3.5 times smaller than the 90" KAO beam, and this difference is very significant considering the scale size of structure in nearby molecular cloud complexes (e.g., bipolar outflows, disks, etc.). In a smaller beam the polarization would also be higher (and easier to detect) if, as is likely, the fields have structure which cancels polarization in the larger beam. In addition, beyond 400 μm the fractional polarization may increase due to a larger contribution from silicate grains, which are easily aligned in a magnetic field (Dal'Oglio et al. in "Planets, Stars and Nebulae Studied with Photopolarimetry," page 336). So, we might hope for polarizations of 5% or even higher at 1 mm.

To my knowledge, there are no 1 mm polarimeters in existence at this time. We have the potential for developing a unique instrument without expending a great deal of effort (I hope). Successful mapping of polarization would provide our only probe of the dynamically important fields in star forming regions, and would pave the way for similar work a few years down the line on the upcoming generation of submillimeter telescopes. Other potential sources of strong 1 mm polarization include quasars and supernova remnants, and these objects might also be profitably observed with the polarimeter.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ROTATABLE Rx SELECTION MIRROR
33"
POSSIBLE LOCATION FOR POLARIMETE
(SIZE OF POLARIMETER IS JUST A GUESS)
FEED
1mm Rx BOX
R. BARVAINIS 20 JUNE