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TITLE OF PROPOSED PROJECT **Collaborative Research: Submillimeter Polarimetry with SHARP**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ **338,787**	**24** months	**07/01/05**	

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PI/PD DEPARTMENT **Department of Physics and Astronomy**	PI/PD POSTAL ADDRESS **Dearborn Observatory** **2131 Sheridan Road** **Evanston, IL 602082900** **United States**
PI/PD FAX NUMBER **847-491-3135**	

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Electronic Mail Address
PI/PD NAME **Giles Novak**	**PhD**	**1988**	**847-491-8645**	**g-novak@northwestern.edu**
CO-PI/PD				
CO-PI/PD				
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COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

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TITLE OF PROPOSED PROJECT **Collaborative Research: Submillimeter Polarimetry with SHARP**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ **295,802**	**24** months	**07/01/05**	

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PI/PD DEPARTMENT **Enrico Fermi Institute**	PI/PD POSTAL ADDRESS **5640 South Ellis Avenue** **Rm. ACC F113** **Chicago, IL 60637** **United States**
PI/PD FAX NUMBER **773-702-8212**	

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Electronic Mail Address
PI/PD NAME **Roger H Hildebrand**	**PhD**	**1951**	**773-702-7581**	**roger@oddjob.uchicago.edu**
CO-PI/PD				
CO-PI/PD				
CO-PI/PD				
CO-PI/PD				

Electronic Signature

PROJECT SUMMARY

Intellectual Merit

The investigators have received support from NSF to build SHARP, a polarimeter for the Caltech Submillimeter Observatory (CSO). SHARP exploits the observatory's new camera, SHARC-II, that has excellent sensitivity per pixel and has the most pixels of any submillimeter camera currently in use by astronomers. SHARP consists of an optics module that the investigators will mount in front of SHARC-II in order to form a polarimetric imager with excellent mapping speed and high angular resolution. SHARP will replace the Hertz polarimeter that the investigators have used at the CSO for the past decade, and will be the only polarimeter operating in the atmospheric windows at 350 and 450 microns near the peak of the spectrum of cold interstellar clouds.

The SHARP optics module splits the incoming radiation into two orthogonal components of polarization that are then recorded simultaneously by two 144-pixel sections of the SHARC-II detector. In this way, all incident photons are accepted and noise due to atmospheric fluctuations is greatly reduced.

The SHARP module can be quickly installed without moving SHARC-II or any other instrument on the CSO. Because it is thus well-adapted for queue scheduling and because of its unique capabilities, the investigators wish to prepare for a vigorous observing schedule. To this end, they will combine the efforts of the Northwestern University and University of Chicago groups and will draw on both observational and theoretical talent from several other institutions.

Proposed investigations include (a) detection of polarized emission from plasma near the event horizon of the black hole at the Galactic center; (b) observations of turbulent eddies in magnetized clouds, for the purpose of testing theoretical ideas concerning how turbulence controls star formation; and (c) determination of the shape of magnetic fields in the immediate vicinity of protostars where initial collapse has occurred.

Broader Impact

The investigators will continue to recruit undergraduate students to participate directly in the observations and analysis. The students will gain hands-on experience with state-of-the-art instrumentation and should thus become prepared for a variety of careers including technical and managerial jobs in academic or industrial laboratories, national observatories, research centers, or educational institutions.

TABLE OF CONTENTS

For font size and page formatting specifications, see GPG section II.C.

	Total No. of Pages	Page No.* (Optional)*
Cover Sheet for Proposal to the National Science Foundation		
Project Summary (not to exceed 1 page)	1	
Table of Contents	1	
Project Description (Including Results from Prior NSF Support) (not to exceed 15 pages) **(Exceed only if allowed by a specific program announcement/solicitation or if approved in advance by the appropriate NSF Assistant Director or designee)**	15	
References Cited	6	
Biographical Sketches (Not to exceed 2 pages each)	8	
Budget (Plus up to 3 pages of budget justification)	11	
Current and Pending Support	7	
Facilities, Equipment and Other Resources	1	
Special Information/Supplementary Documentation	2	
Appendix (List below.) **(Include only if allowed by a specific program announcement/ solicitation or if approved in advance by the appropriate NSF Assistant Director or designee)**		

Appendix Items:

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

TABLE OF CONTENTS

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1 Introduction

We request funds to commission and observe with a submillimeter polarimeter, SHARP, now under construction. We propose to extend the research previously supported by NSF grants to Northwestern University and the University of Chicago. We want to combine the efforts of the two groups and our collaborators from several other institutions. SHARP provides a fore-optics module for the existing photometer, SHARC-II, at the CSO to allow polarimetry in the 350 μm and 450 μm atmospheric windows. The design principles of SHARP may be applicable at other telescopes.

SHARP will complement the 850 μm polarimeter SCU-POL at the JCMT by sampling shorter wavelengths, by improving the angular resolution (from $14''$ to $9''$), by exploiting the longer chop throw of the CSO ($8'$ vs. $3'$), and by providing simultaneous detection of two components of polarization. It will surpass the capabilities of our previous polarimeter, Hertz, by adding a 450 μm channel, by increasing the number of pixels on the sky (from 32 to 144), by improving the angular resolution (from $20''$ to $9''$), and by improving the point source sensitivity by more than a factor of 2.

SHARP will allow investigations that were inaccessible or marginally accessible with Hertz. These include observations of nonthermal emission from Sgr A*, measuring magnetic structure in the vicinity of protostars, measuring the magnetic fields of nearby galaxies, and determining the structure of turbulence in dense clouds. In section 2 we discuss the value and feasibility of these and other investigations. In section 3 we discuss the principles of the instrument and give a table of specifications.

2 Science Goals

2.1 Sagittarius A*

The compact radio source Sgr A* marks the site of a $\sim$3–4$\times 10^6 M_\odot$ black hole lying at the dynamical center of the Galaxy (Ghez et al. 2003; Schödel et al. 2003). Sgr A* has now been detected at X-ray (Baganoff et al. 2001) and near-IR (Genzel et al. 2003; Ghez et al. 2003) wavelengths, and this spectral information along with the measured variability and polarization provide us with a set of constraints to probe black hole accretion physics. Strong X-ray and near-IR flaring of Sgr A* is seen with time scales of order one hour, and flux increases of up to a factor of $\sim$6 in the near-IR and $\sim$100 in the X-ray.

The radio spectrum of Sgr A* exhibits a "submillimeter bump" that is believed to originate within 10 Schwarzschild radii of the event horizon (Zylka et al. 1992; Falcke et al. 1998). JCMT measurements using SCU-POL revealed that this feature is polarized at the $\sim$10% level for wavelengths in the range of 2 mm–750 μm (Aitken et al. 2000), with the polarization rising towards the shorter wavelengths (Fig. 1). SHARP will extend these measurements to the 350 and 450 μm atmospheric windows which will help discriminate among models for Sgr A* and in particular should constrain the accretion rate as discussed below.

On the basis of mass-losing stars in its vicinity, Sgr A* should be accreting at a rate of 10^{-5}–$10^{-6} M_\odot \mathrm{yr}^{-1}$ (e.g. Coker & Melia 1997). If this accretion rate is correct, then the low luminosity of Sgr A* implies an efficiency for conversion of gravitational energy to radiation equal to $\sim 10^{-6}$, a surprisingly low radiative efficiency. Most theoretical models for the emission from Sgr A* fall into one of two classes. The first class accounts for the low luminosity by having a low radiative efficiency, while the second class has very low accretion rate in comparison with the range of values expected from stellar mass loss.

For the first class of models the observed emission is presumed to come from an accretion flow. For example, in the advection dominated accretion flow (ADAF) model (Narayan et al. 1998), suppression of radiation is obtained by assuming a temperature difference between electrons and protons, with $T_e \ll T_p$. This works because electrons are responsible for most of the radiation. Another model in this class assumes that the magnetic field is subequipartition, thus reducing the synchrotron emissivity (Coker & Melia 2000).

An example of the second class of models (low accretion rate) is the convection dominated accretion flow (CDAF). In this model, angular momentum is efficiently transported inward by radial convection, thus cancelling the outward transport of magnetic fields (Quataert & Gruzinov 2000). Low accretion rate models sometimes invoke a jet as the origin of the radiation and as the mechanism that reduces the accretion rate (Yuan et al. 2002).

The details of the accretion process are not resolved and we do not know whether the emission results from infalling or outflowing material.

The discovery of submillimeter polarization by Aitken et al. (2000) has now been confirmed by Bower et al. (2003) who used the BIMA array at 1.3 mm (230 GHz). Bower et al. (2003) obtained significantly higher angular resolution ($\sim 2''$) thereby strongly excluding the possible contaminating effects of polarized dust emission. No polarization measurements have yet been obtained shortward of 750 μm.

Figures 1 and 2 show the degree and position angle distributions of linear polarization based on BIMA and SCU-POL/JCMT measurements. The SCU-POL measurements show degrees of polarization near 10% for four wavelength bands ranging from 750 μm to 2 mm, and show a wavelength dependence in the polarization angle — specifically, an abrupt flip ($\sim 80°$) occurring near 1 mm, as seen in Figure 2. Although BIMA measurements of the degree of polarization at 1.3 mm are consistent with SCU-POL measurements, the position angle is not consistent between the two measurements. The constant position angle at the upper and lower sidebands at 1.3 mm places an upper limit to the Faraday rotation measure (RM) of the accretion environment of 2×10^6rad m^{-2} (Bower et al. 2003). This low value of RM suggests that the low luminosity of Sgr A* is due to a low accretion rate of $10^{-7} M_\odot \mathrm{yr}^{-1}$ and would appear to rule out a high accretion rate

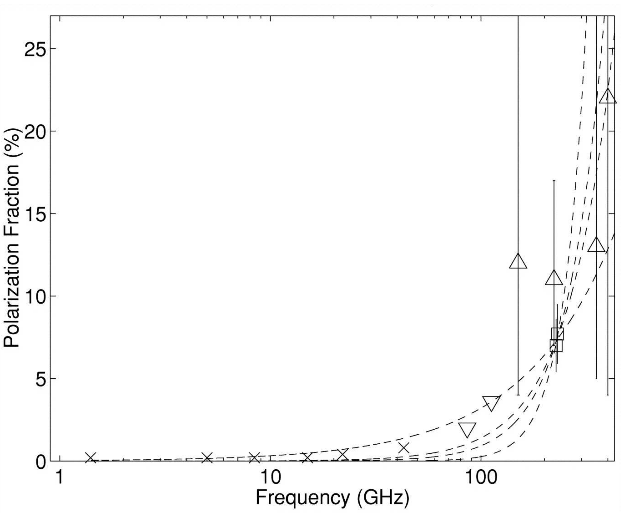

Figure 1: Magnitude of the linear polarization of Sgr A* as a function of frequency. Triangles and squares are from SCU-POL/JCMT (Aitken et al. 2000) and BIMA (Bower et al. 2003), respectively. The inverted triangles are BIMA upper limits and the crosses are VLA upper limits. The dashed lines are power law models (for details, see Bower et al. 2003)

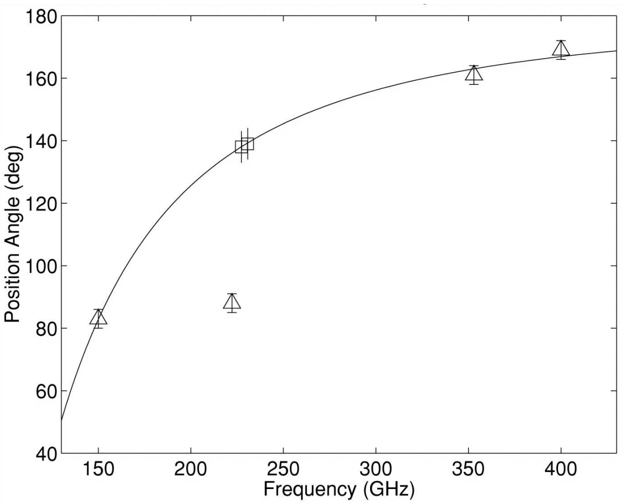

Figure 2: Position angle as a function of frequency. Triangles and squares are from Aitken et al. (2000) and Bower et al. (2003), respectively. The best fit is -4.3×10^5 rad m^{-2} with a zero-wavelength position angle of 181°.

(Quataert & Gruzinov 2000; Agol 2000; Melia & Falcke 2001).

The dashed lines in Figure 1 show power law models predicting that the rise in polarization observed in the submillimeter should continue into the far-IR (Agol 2000; Melia et al. 2000). This is a fundamental consequence of the falling optical depth, and in the case of the model of Agol (2000), it leads to a predicted degree of polarization at 350 μm of 70 %(!). Note that the RM values based on millimeter and submillimeter measurements are not totally consistent (Fig. 2). The proposed SHARP measurements at 350 μm and 450 μm, when combined with longer wavelength measurements such as those shown in Figures 1 and 2, can be critical for determining the true RM value as well as the true zero-wavelength position angle of the polarization. If the low RM values suggested by Bower et al. (2003) are correct, then SHARP measurements will not be affected much by Faraday effects. Our measurements will provide a check on the claimed low RM and thus will have implications for the accretion rate onto Sgr A* and for the hotly disputed ADAF/Bondi-Hoyle and CDAF/jet models.

We imaged Sgr A* with SHARC-II at 350 and 450 μm during April and September 2004 as part of a multi-wavelength monitoring campaign. The observed fluxes during April were 0.5 Jy at 350 μm and 1.1 Jy at 450 μm. These values are on the low side (Zylka et al. 1995; Pierce-Price et al. 2000) indicating that the source may have been in a quiescent state in April. Figure 3 shows the 450 μm image.

It should be easy for SHARP to detect polarization in Sgr A* at 450 μm. Starting from the point source sensitivity given in Table 1 and the flux of 1.1 Jy, reducing the flux by a factor of two to account for the low observing elevation, and assuming a polarization magnitude of 6 % at 450 μm, we find that in 9 hours we can obtain a 3 σ detection. A polarization magnitude of 6 % is fairly conservative (see Fig. 1; 450 μm equals 660 GHz).

Contamination from polarized dust emission is a concern for this measurement as it was for Aitken et al. (2000). But Sgr A* is visible in Figure 3, and also in the 450 μm JCMT map of Zylka et al. (1995). Furthermore, the contrast between the Sgr A* non-thermal source and the surrounding dust clouds should be much greater in polarized flux than in total flux because the average dust polarization near Sgr A* is only 1.3 % (Novak et al. 2000). Note also that this dust polarization appears to have only smooth spatial variations near Sgr A* at the 20$''$ resolution of Novak et al. (2000).

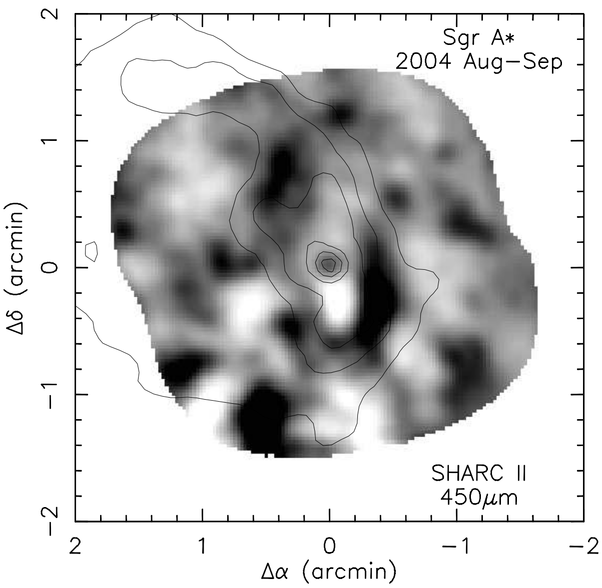

Figure 3: SHARC-II measurement of 450 μm emission from Sgr A* and surrounding dust clouds (black is positive emission) together with contours of 20 cm emission (Yusef-Zadeh 1989). Sgr A* is clearly visible at both wavelengths.

If the polarization does continue to rise shortward of 800 μm, as predicted, then a detection of 350 μm polarization with SHARP will also be easy. If it does not, we will set an upper limit that will contradict the predictions.

Even stronger constraints on the RM and hence on the models will require simultaneous observations over as wide a spectrum as possible. The Submillimeter Array (SMA) on Mauna Kea has installed half-wave plates for polarimetry at 860 μm. They have very recently used these to successfully observe Sgr A* (H. Shinnaga, private communication). We hope to collaborate on simultaneous polarimetric observations of Sgr A* at 350, 450, and 860 μm.

Leaders of the SMA team include J. Moran and former Hildebrand postdoc R. Rao.

2.2 External Galaxies and Galactic Center Region

Greaves et al. (2000) have made 850 μm polarization maps of M82, the nearest, edge-on starburst galaxy. They have reported detections of organized magnetic field lines in the nuclear region and "bubble-type" fields in the halo which they associate respectively with the star-forming circum-nuclear ring and supernova-driven winds or outflows. These observations complement those made by Jones (2000) in the optical and near-IR, and the radio polarization maps made by Reuter et al. (1994). The optical/near-IR measurements are only valid in the ring of M82; elsewhere they are contaminated by scattering. Radio emission maps the magnetic field in the diffuse ISM close to the axis of symmetry in the Halo. SMM measurements give the most information in the extended halo further from the axis. These results show a large-scale azimuthal field within the ring, a dipole field close to the axis of symmetry, and magnetic field lines further out that could be either part of the dipole or part of the azimuthal fields being blown out into the halo.

SHARP will extend the above investigation to warmer dust than was measured at 850 μm and will provide higher spatial resolution (Fig. 4). We will investigate whether the magnetic field lines in the halo trace dynamo-regeneration of fields or fields blown out by rapid star formation in the ring. We will measure with better resolution the field structure within the ring where magnetic dynamo theories predict azimuthal fields.

We anticipate comparable results for the nearest bright submillimeter starburst galaxy, NGC 253. In both M 82 and NGC 253, reliable, $3\,\sigma$ polarization measurements should be possible with SHARP in $\sim\frac{1}{2}$ hour over half of the field of view, and in $\sim$6 hours for almost the entire field of view. It will be feasible to map the bright regions of other galaxies including the LMC, SMC, M 31, M 51, M 81, M 87, NGC 891, NGC 1068, NGC 4631, and NGC 5128.

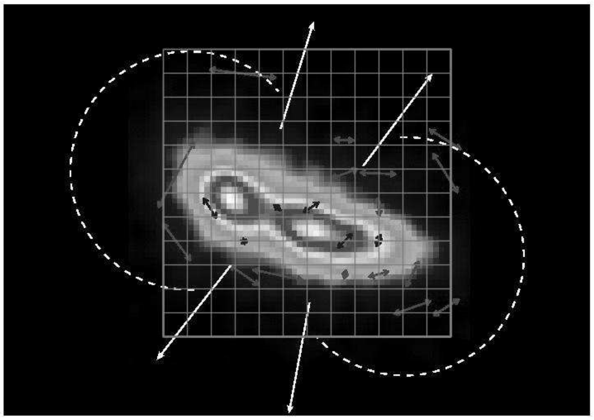

Figure 4: 850 μm image of M82 showing polarization vectors by Greaves et al. (2000) with the SHARP array superposed.

In our own Galaxy, radio observations show non-thermal filaments corresponding to a dipole field, while submillimeter observations (Novak et al. 2003b; Chuss et al. 2003) show azimuthal fields in self-gravitating clouds within the plane. SHARP is well adapted to polarimetry of the Galactic center because of its sensitivity and resolution, and because of the large chop throw available at the CSO. In particular SHARP will permit measurements of field structure in regions of cloud/filament interactions that may be the sites where the relativistic electrons that light up the filaments are generated.

2.3 Giant Molecular Clouds

2.3.1 Turbulence

Large-scale 3D simulations of compressible magnetohydrodynamic (MHD) turbulence in self-gravitating Giant Molecular Clouds (GMCs) have had success in reproducing observed size/line-width relations (Ostriker, Stone, & Gammie 2001), and also the IMF for stars produced in GMCs (Padoan et al. 2004). However, these results depend on several assumptions, and one of the biggest uncertainties concerns the magnetic field strength (Ostriker

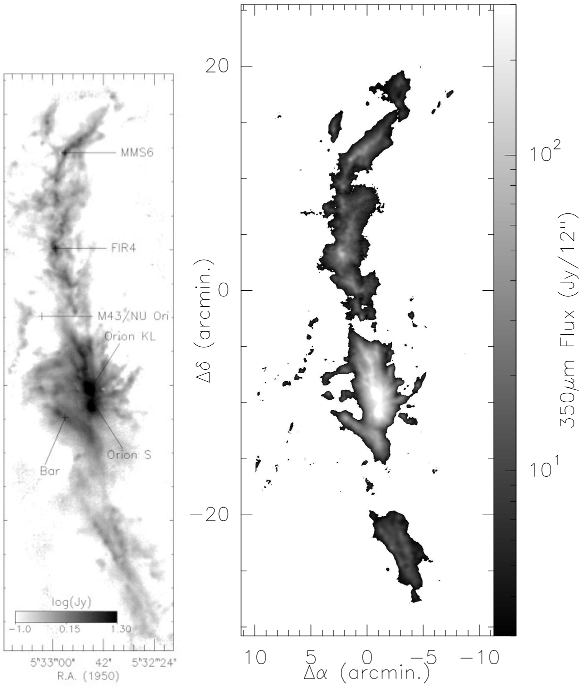

Figure 5: The integral shaped filament (ISF) that forms the northern portion of the Orion A molecular cloud. Left panel shows 850 μm intensity measured by SCUBA (Johnstone & Bally 1999), and right panel shows a SHARC-II 350 μm map. The SHARC-II image has been masked off to show only the extent of the area that can be mapped by SHARP in a total of $\sim$ 100 hours, producing $\sim$ 5000 vectors.

2003 and references therein). Ostriker et al. (2001) noted that due to difficulties associated with using the the Zeeman technique in GMCs, an impractically large number of measurements might be required for meaningful tests. They developed a procedure for estimating magnetic field strength from dispersion in polarization angles of background stars, based on the method of Chandrasekhar & Fermi (1953). Other theorists have focused on simulating the far-IR/submillimeter polarization emitted by a GMC (Padoan et al. 2001; Heitsch et al. 2001), again using dispersion in measured angles as a point of comparison.

Whittet et al. (2001) and Arce et al. (1998) show that optical polarimetry of background stars is not useful for mapping magnetic fields in moderately obscured regions (A_V > 1–2 mag), due to reduced optical polarization efficiency for such regions. This limits the usefulness of the background star technique for testing GMC models. However, the submillimeter emission from highly obscured regions, like prestellar cores with $A_V \sim 30$ mag observed by Crutcher et al. (2004) *is* polarized. One way to resolve this apparent contradiction is if the larger grains that dominate the emission (but not the extinction) are preferentially aligned.

Lazarian & Cho (2004) have proposed a mechanism that will have precisely this effect. They calculate alignment efficiency under the assumption that grains are brought into alignment with magnetic fields via the radiative torque mechanism (Dolginov 1972; Dolginov & Mitrofanov 1976; Draine & Weingartner 1996, 1997) for which there is significant observational support (Hildebrand et al. 1999; Lazarian 2003). For regions that are shielded from the interstellar radiation field, Lazarian & Cho (2004) find that the efficiency of radiative torques increases rapidly with grain size. Grains that are near the upper end of the size distribution of Draine & Weingartner (1997) can become aligned even for cloud optical depths as high as $A_V \sim 10$. Because clouds are likely to be inhomogeneous and thus leaky to outside radiation, the results of Lazarian & Cho (2004) can explain the observed grain alignment for clouds with $A_V < 30$ (Crutcher et al. 2004).

SHARP will be able to map large areas of GMCs—in a single hour we can detect 350 μm polarization at any sky position having $A_V >$ 25 mag. Here we have assumed a temperature of 25 K (Johnstone & Bally 1999; Scoville & Good 1989; Sodroski et al. 1997), 2×2 pixel binning (one resolution element; see Table 1), polarimetric errors of 2%, which should be adequate because 350 μm polarization vectors at the edge of our Hertz map of Orion have $P > 4\%$ (Dowell et al. 2003b), and a relationship between submillimeter emissivity and A_V derived from Hildebrand (1983) and Spitzer (1978). The value $A_V = 25$ mag represents a column density about three times larger than the average value for a GMC (Shu et al. 1987, p. 46), but it is well below the value corresponding to a dense GMC core. Thus, although SHARP will not be able to map the field over the entire area of a GMC, it will be able to probe well outside the GMC cores and in this way will provide meaningful comparisons with simulations. Figure 5 shows an example of what we can achieve. The $8'$ maximum travel of the CSO's secondary mirror will be an important advantage, as the $3'$ throw that is available at JCMT is inadequate for this work.

With support from the current NSF grant to Northwestern, Alex Lazarian's group at U. of Wisconsin is developing simulated GMC polarization maps incorporating the latest progress in grain alignment theory for comparison with SHARP maps. The first step has been to develop prescriptions for radiative torque alignment (Lazarian & Cho 2004). During the coming year the Wisconsin group will fold these prescriptions into the results of compressible MHD turbulence simulations that include self-gravity (available from Lazarian collaborator Jongsoo Kim; Fig. 6). Computation of the degree of alignment will be carried out using Monte-Carlo radiative transfer code to be obtained from Lazarian collaborator Barbara Whitney (see Whitney & Wolff 2002). Comparisons between real and simulated GMCs will be used both to determine magnetic field strength and to test alignment prescriptions.

We propose to continue work on simulations during the first two years of operation of SHARP through partial support of U. of Wisconsin graduate student Andrey Beresnyak. Issues to be addressed are beam dilution correction and polarization statistics. When using methods based on the Chandrasekhar & Fermi formula to determine magnetic field strength from submillimeter polarization measurements, beam dilution can lead to overestimates of field strength (Heitsch et al. 2001). Although this will be less of a problem for SHARP than for SCU-POL or Hertz, it is an issue that we can address. Using knowledge of the MHD turbulence statistics (e.g. Cho & Lazarian 2003) we will analytically evaluate the effect of beam dilution and provide a quantitative estimate for the degree of field overestimate. Although the simulations of Cho & Lazarian (2003) were carried out without self-gravity, our more recent

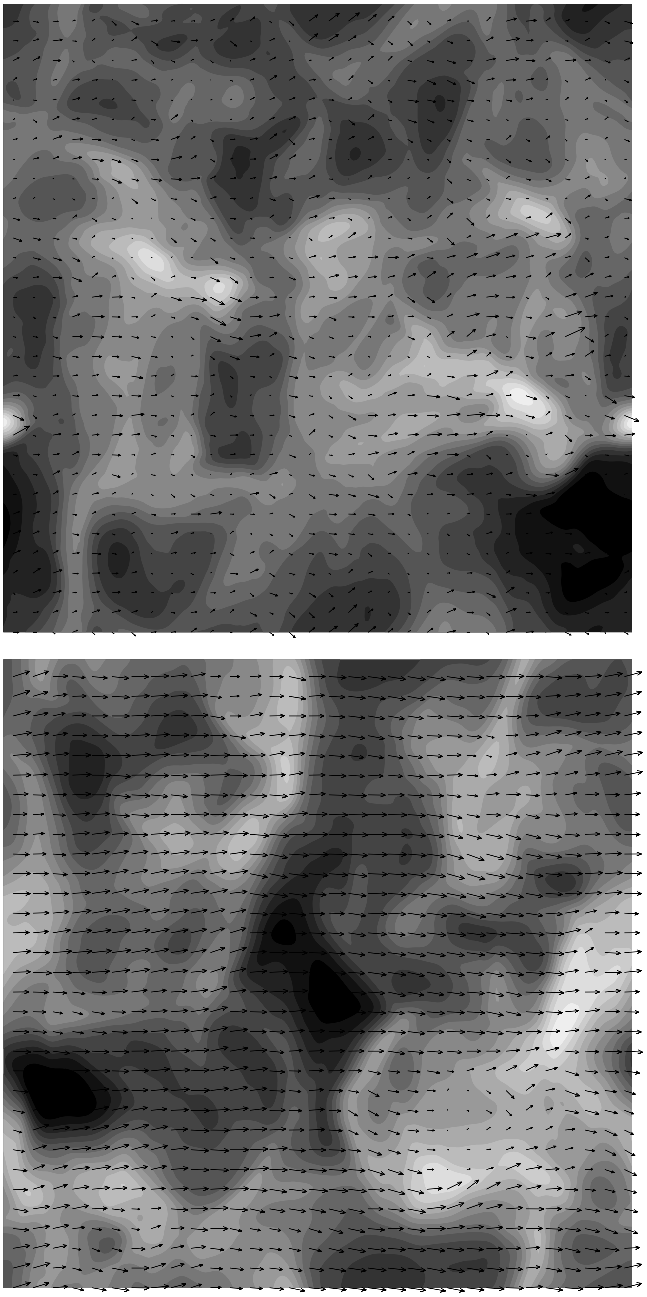

Figure 6: Top: Synthetic maps of polarization for marginal magnetic field $B_0^2/8\pi \approx 0.01\rho V_{turb}^2/2$. Bottom: Same for strong magnetic field $B_0^2/8\pi \approx \rho V_{turb}^2/2$. Simulations include self-gravity. Code needed to incorporate grain alignment prescriptions is under development at U. Wisconsin.

results for simulations that include self-gravity reveal deep similarities between the statistics in the two cases.

We will extend the comparisons between theory and experiment to include the statistics of variations of the polarization vectors, e.g. the structure function of the polarization degree (see Cho & Lazarian 2002, 2003), correlations of the fluctuations of the polarization directions $\langle \delta\phi_1 \delta\phi_2 \rangle$, where positional angles ϕ of the polarization vectors are correlated for a fixed angular distance with the statistics of the underlying magnetic field. Our new 512 cube MHD simulations (Cho and Lazarian, in preparation) reveal non-trivial relationships between the spectra of density, velocity, and magnetic fields. Information about density statistics (Padoan & Nordlund 2002) and velocity statistics using Velocity-Channel Analysis (Lazarian & Pogosyan 2000, 2004) and Modified Velocity Centroids (Lazarian & Esquivel 2003; Esquivel & Lazarian 2004) will be obtained through CSO observations of molecular lines by SHARP collaborator Martin Houde.

2.3.2 Polarization Spectrum

We have shown that the polarization spectrum of molecular clouds drops from 60 μm to 100 μm to 350 μm and then rises again to 850 μm and 1300 μm (Fig. 7). We have argued that this effect can be attributed to differences in degrees of grain alignment in cloud environments at different temperatures (Hildebrand et al. 1999, 2000). Simulations of cloud polarization may correct or refine the current explanation, but regardless of the correct model, we wish to improve the empirical description of the effect. The measurements at 350 μm are the only ones between 100 μm and 850 μm. (The large-beam 450 μm measurements by SPARO from the South Pole do not provide multi-wavelength comparisons.) Because this phenomenon is seen in bright molecular clouds it is an easy target for our first observations with SHARP. Simply by comparing degrees of polarization at 350 μm and 450 μm we can determine whether the wavelength of minimum polarization is less than, greater than, or approximately equal to 350 μm or whether the position of the minimum varies from cloud to cloud.

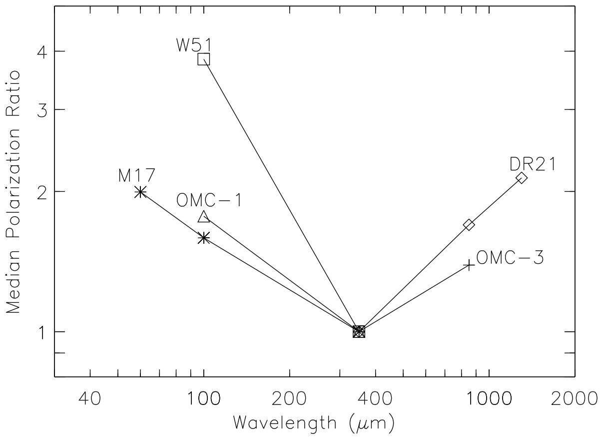

Figure 7: Polarization spectra for five molecular clouds normalized at 350 μm (Vaillancourt 2002).

Where possible, we will supplement SHARP measurements with results for other parts of the spectrum from SCUBA, from the highest frequency WMAP passband, and eventually from other instruments.

2.3.3 Complementary Techniques

In the Orion region (OMC-1, -2, -3, -4), Houde et al. (2004) have determined the shape of the magnetic field as projected on the sky from measurements at over 600 points. With SHARPs sensitivity and large arrays we should far exceed what was possible with our previous instrument.

Complementary measurements of Zeeman splitting can, in principle, give the strength of the line-of-sight field. However, there are still only a few cases in which Zeeman and polarization results are available in the same regions and in which they sample the same cloud components. Zeeman measurements in H I and OH favor lower density material. A CN measurement in Orion by Crutcher et al. (1999) more nearly samples the same environment as the dust emission. We will seek collaborations to improve the availability of complementary measurements.

Even when corresponding measurements are available, there remains the question of the inclination of the field with respect to the line-of-sight. A lower limit to the inclination can be inferred from the degree of polarization. In the entire Orion region the maximum degree observed, $P_{\max}$, is just below 10 %. Many factors can reduce the observed polarization but where P is close to that maximum we assume that the field must be close to the plane of the sky (inclination $\alpha \approx 90^\circ$) and in all cases we can expect $\sin^2 \alpha \geq P/P_{\max}$. Houde et al. (2002) have argued that the actual inclination of the field (not a limit) can be inferred by the combination of polarimetry and the ratio of ion-to-neutral spectral line widths from corresponding spectroscopic measurements. A test of this technique is that values of α derived from the ratio of line widths should fall in the region below $\sin^2(P/P_{\max})$. Figure 9 of Houde et al. (2004) shows that the inclinations derived in the Orion region and in M17 do satisfy this condition. We are thus encouraged to pursue this matter.

2.4 Formation of Low-mass Stars

2.4.1 Bok Globules

Bok Globules provide tests for low-mass star formation theories; they have simple environments with simple geometries and isolated conditions. Results using JCMT/SCU-POL (Vallée et al. 2000; Henning et al. 2001; Wolf et al. 2003) have shown that nine Globules have measurable polarization at 850 μm. The level of polarization ranges from a few to 14%. In addition, the number of detected polarization vectors within each globule ranges from 1 to 50, with an average of 15 vectors for the above sample of results.

These studies show that indeed Bok Globules can be used to test magnetic field aspects of star formation theory:

1. Do magnetic fields influence the structure of a primordial Globule?
2. Do magnetic fields alter the collapse process within a Globule forming a protostar and disk?
3. Does the structure of the field change over time (e.g., are the magnetic fields different for Globules with a Class 0 protostar vs. those with a Class 1 protostar)?
4. Are magnetic field and protostellar outflow directions correlated?

These questions are being addressed, in particular, by Wolf et al. (2003). Preliminary results show that the primordial magnetic fields within a Globule have a preferred alignment to the Globule's axis of symmetry, but that there may be an evolution in magnetic field structure within a Globule with protostar age. Outflows do not align with the primordial magnetic fields in general, but higher spatial resolution work is required to see how or whether the magnetic fields in the center of a Globule align with the outflows.

SHARP will complement the work of SCU-POL. On the CSO, SHARP will have better angular resolution ($9''$ vs. $14''$) and the required sensitivity to study the inner regions of these and other Globules. At 350 μm, the observations are weighted towards warmer dust. Hence, the 350 μm measurements favor the region of a Globule immediately surrounding an embedded protostar. It is this region that will be most affected by star formation and should be most relevant to outflows. It is within this region also ($20''$ at 200 pc) that magnetic "pinches" should be observed according to some theories (Galli & Shu 1993a,b).

For the sample of Globules studied by the SCU-POL observers, we can estimate the 350 μm surface brightness by starting from the 850 μm values and multiplying by a factor of ten to reflect a characteristic Globule spectrum. Spectral information is taken from Wolf et al. (2003), Henning et al. (2001), and Davidson (1987). We then correct downwards to reflect the difference in beam size. Using this result together with the sensitivity information given in Table 1 we find that for six of the nine Globules mentioned above, five hours of integration with SHARP should be sufficient to detect polarization vectors of order 1% in the inner regions and 8.5% in the outer regions. The studies with

SCU-POL show polarizations greater than 8% and as high as 15% in the outer regions. For the remaining three Globules in the SCU-POL studies, five hours should be sufficient to detect polarizations of the order of 2% in the inner regions.

The large chop throws possible with the CSO will help minimize reference beam contamination, a more subtle and significant effect for polarimetry than for photometry (e.g. Schleuning et al. 1997; Novak et al. 1997). The concern is greatest where the outer regions of low surface brightness have much larger polarizations than the inner brighter regions.

2.4.2 Circumstellar Disks

Tamura et al. (1999) used SCU-POL to discover polarization in the 850 μm emission from two T Tauri star (TTS) disks. For both disks, the polarization magnitude is near 3 % and the E-vector is perpendicular to the apparent long axis of the disk. These results were interpreted as thermal emission from magnetically aligned grains, and in this case the projected disk magnetic field is parallel to the plane of the disk implying a toroidal magnetic field. However, it is also possible that the origin of the polarization is scattering by large grains. Polarization by scattering can be ruled out for grains much smaller than the wavelength, but much of the "dust" around TTSs may consist of particles of size ∼1 mm. At the relatively high densities that characterize TTS disks, rapid grain growth to > 1 mm size is expected on theoretical grounds (Beckwith, Henning, & Nakagawa 2000), and grain growth to ∼1 mm provides an explanation for the unusually flat submillimeter-millimeter spectrum of TTS disks (Koerner, Chandler, & Sargent 1995). Some models extend the grain size distribution to ∼1 mm with most of the mass tied up in the larger grains (Chiang et al. 2001).

If a substantial fraction of the dust mass is in grains of size ∼1 mm, then assuming a standard dust-to-gas mass ratio of 0.01, the $\lambda \sim 850\,\mu$m scattering optical depth through a typical TTS disk (mass $0.01 M_\odot$; diameter 100 AU; thickness 10 AU) should be of order unity. In this case polarization by scattering cannot be ruled out. For scattering, the polarization direction should be orthogonal to the major axis of the disk, as we observe. The polarization magnitude should depend on the disk's inclination to the line of sight.

The magnitude of polarization by scattering should increase towards shorter wavelengths (Novak et al. 1989), so 350 and 450 μm polarimetry with SHARP will test the scattering hypothesis. One of the TTSs observed by Tamura et al. (1999), DG Tau, was measured by Mannings & Emerson (1994) to have a 350 μm flux of 5 Jy. Table 1 shows that DG Tau is thus an easy target for SHARP, and Mannings & Emerson (1994) list several other TTSs with fluxes above 2 Jy.

3 The SHARP Polarimeter

3.1 Optical Design

SHARP will provide polarimetric capability for the SHARC-II camera of the CSO by inserting a module containing polarizing grids, mirrors, and a half-wave plate into the optical train ahead of the cryostat (see Fig. 8). The incoming beam will be split into orthogonal components of polarization that are directed to opposite ends of the SHARC-II bolometer array (see Figs. 9–11). The signals from the two components will be recorded simultaneously. In comparison with polarimeters like SCU-POL at the JCMT that sample a single component at a time, SHARP gains a factor of at least $\sqrt{2}$ in signal-to-noise but generally a much higher factor because "sky noise" due to atmospheric fluctuations affects the two components equally and is thus largely cancelled during the analysis (Dowell et al. 1998; Hildebrand et al. 2000; Novak et al. 2004). Without simultaneous detection the effects of sky noise are much worse at 350 and 450 μm than at 850 μm.

SHARP is designed for easy switching between between the 350 and 450 μm atmospheric windows and between the photometric and polarimetric modes (see Fig. 10). Following the

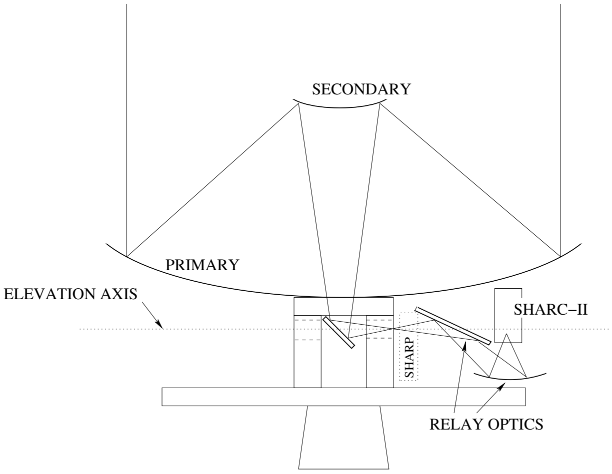

Figure 8: Schematic drawing of SHARC-II on the Nasmyth platform. A flat mirror below the secondary deflects the beam into the hollow elevation bearing, producing an image of the sky within the bearing. This "Nasmyth image" is re-imaged onto SHARC-II's detector array by the relay optics. The location for SHARP is shown.

recent relocation of SHARC-II from the Adelade platform to the Right Nasmyth location (Fig. 8), plans have been developed for priority (or queue) scheduling at the CSO. By the end of 2005 SHARP will be fully commissioned and permanently installed at the CSO. Our observing program will then benefit from the advantages of priority scheduling (see letter from T. Phillips attached to Novak proposal).

Because each pixel of the SHARC-II camera is inherently sensitive to *all* polarization components, the time reversed light beams corresponding to polarization components not used by SHARP are terminated to 4 K by redirecting them back into SHARC-II (Fig. 10). For the polarization components that *are* used, SHARP preserves the correct primary illumination by tuning the paraboloid separation and the tilts of the two mirrors that make up the beam combiner (Fig. 10).

We have carried out ZEMAX-EE simulations over the full range of chopping secondary tilt angles, telescope elevation angles, and pixel location within each 12×12 sub-array (Novak et al. 2004). We find that SHARP has low levels of aberration and distortion that are essentially identical to those already present in SHARC-II. We achieved this good performance by adopting the "crossed paraboloid" design of Serabyn (1995). We have also studied diffraction losses using the physical optics capabilities of ZEMAX-EE. By sizing the SHARP optical elements so as to preserve five Airy rings we find that we can reduce the diffraction losses introduced by the SHARP optics to very low levels. The simulations indicate that these are below 1%.

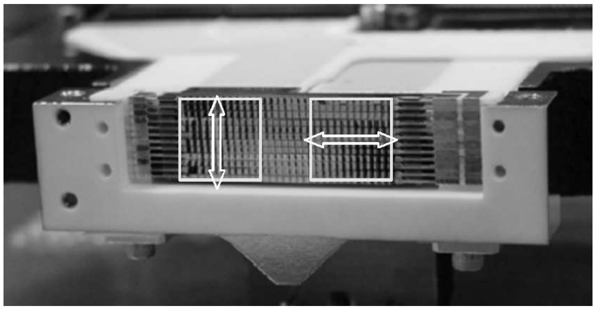

Figure 9: Photograph of the SHARC-II detector array, with markings that illustrate the effect of the SHARP polarization-splitting optics. When SHARP is installed the detector array will effectively be converted into two 12×12 sub-arrays that view the same $1.0' \times 1.0'$ sky field in orthogonal polarizations.

3.2 Software

Like SHARP, our polarimeters Hertz and SPARO (§6) are designed to simultaneously measure two polarization components. We have spent years developing techniques for combining signals from orthogonal polarizations with the goal of removing as much sky noise as possible (Dowell et al. 1998; Hildebrand et al. 2000) without introducing bias (Li et al. 2004).

As in the past, our data acquistion scheme will involve short observations at each of a series of half-wave plate positions. Each such observation involves rapidly "chopping" the secondary to switch the observed sky location between main and reference positions, while slowly "nodding" the telescope so as to alternate the reference position between two spots located symmetically on either side of the main

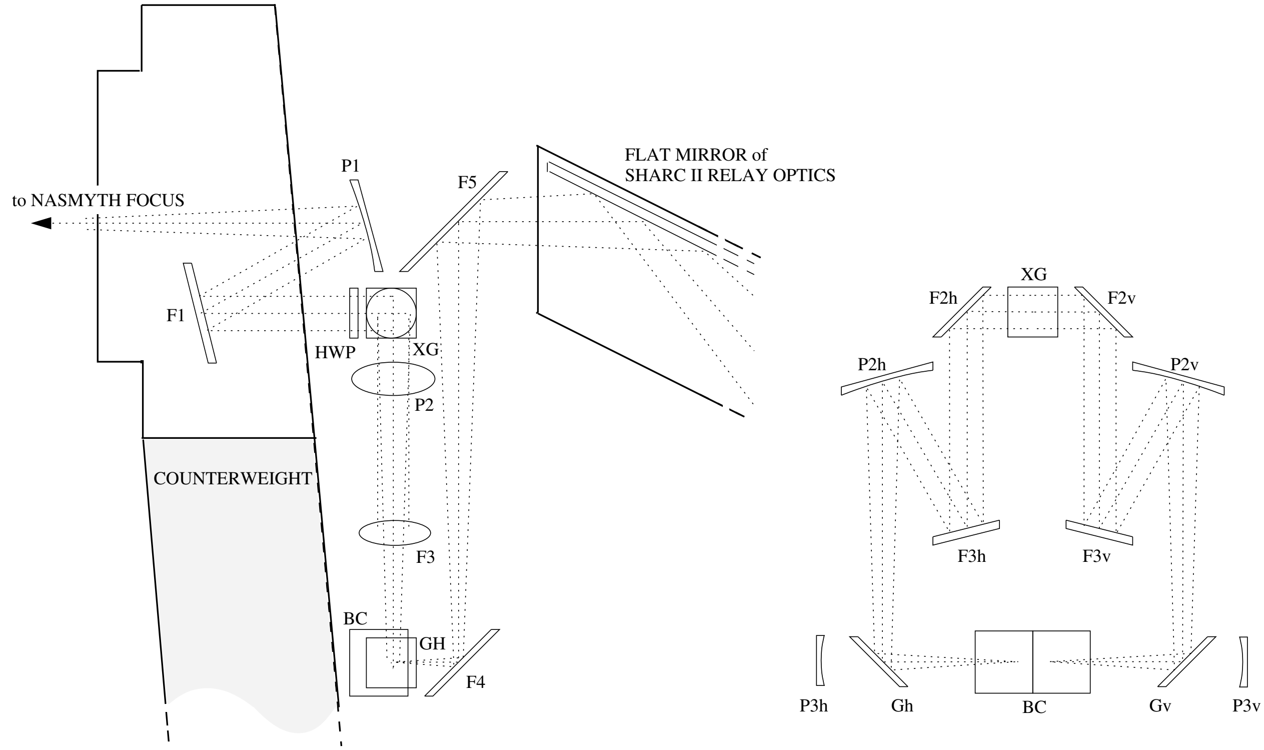

Figure 10: Two views of SHARP. Left: The expanding beam from the Nasmyth focus is reflected by paraboloid P1 and by flat F1, passes through the half-wave plate HWP, and reaches the crossed grid XG (Fig. 11). From XG, the vertical polarization component propagates into the plane of the paper while the horizontal component is directed towards the viewer. Right: View towards the Nasmyth focus. Vertical and horizontal components leaving the crossed grid undergo further reflections by mirrors and grids (F2v-F3v-P2v-Gv and F2h-F3h-P2h-Gh, respectively), ultimately bringing the components back together at the beam combiner BC which directs the recombined image towards the viewer. (BC consists of two mirrors joined at 90°, such that the reflective surfaces are analogous to the outside of a roof.) After reflection by BC, the two orthogonal polarizations are displaced laterally. The left view shows this reconstituted image being directed into the relay optics by flats F4 and F5. P1 and P2h (or P2v) form a pair of crossed paraboloids (Serabyn 1995). Paraboloids P3h and P3v ensure that for unused polarization components the time-reversed beams from SHARC-II are directed back into the cryostat, (e.g., via the paths F5-F4-BC-P3h-BC-F4-F5). SHARC-II is easily converted back to photometric mode by removing P1 and F5.

position (Hildebrand et al. 2000). SHARP collaborator C. Dowell will ensure that the SHARC-II data acquistion system software will be extended to include support for polarimetry (see letter of support from Dowell attached to Hildebrand proposal). The half-wave plate is controlled by an Ethernet Data Acquisition System (EDAS) that interfaces to a stepper motor indexer and an absolute encoder.

SHARP collaborator M. Houde, at the University of Western Ontario, is sharing the responsibility for developing data reduction software with U. Chicago postdoc J. Vaillancourt. (See letter from M. Houde attached to Novak proposal.) This Canadian participation in SHARP is funded entirely by Canadian sources.

SHARP data reduction algorithms will differ from those we have used with Hertz at the CSO. The degree of polarization is obtained by dividing the polarized flux (derived from differences of orthogonally polarized signals) by the total flux. For observations of faint sources, however, the denominator is often the sensitivity-limiting factor. The solution (Li et al. 2004)

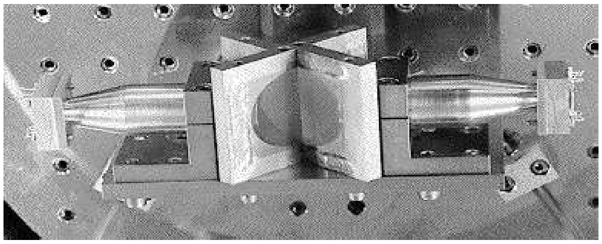

Figure 11: An example of a "crossed grid" (from manufacturer's web page). The crossed grid consists of two intersecting free-standing wire polarizing grids. The grid extending front left has wires running horizontally. The grid with vertical wires intersects this first grid at right angles. Radiation propagating "into the page" is split into two polarization components that are deflected left and right, respectively.

is to postpone the division of polarized flux by total flux until enough data is accumulated to make the latter a well measured quantity. Due to the complications of sky rotation and atmospheric transmission variations new algorithms will be required. These are being developed by M. Houde and his students.

A second difference relates to removing instrumental polarization. To achieve ∼0.1% systematic errors, one must take advantage of sky rotation (Platt et al. 1991), typically by carrying out a multiple regression involving several days of observations. With Hertz, we followed the rotation of the sky using an instrument rotator, but SHARP will not have an instrument rotator, so we will need a new algorithm, that will be developed by J. Vaillancourt. It also involves a multiple regression, but with sky positions binned on a $2''$ grid, and instrument and telescope polarizations modeled using spatial functions governed by free parameters, rather than as a set of discrete values.

3.3 Plans for Completion

We expect to finish fabricating SHARP by March 2005. We then allow four months to test and align SHARP in the lab, and to finish developing the software, prior to our 7-day commissioning run at the CSO in Summer 2005. (See letter from T. Phillips attached to Novak proposal.) Our existing NSF awards will cover expenses up to and including this first deployment. We request funds to finish commissioning SHARP and carry out two years of observations.

SHARP testing and alignment will be carried out collaboratively by Novak's group at Northwestern U. (graduate students Megan Krejny and Hua-bai Li) and Hildebrand's group at U. of Chicago (graduate student Larry Kirby and postdoctoral researchers John Vaillancourt and Lerothodi Leeuw). The tests will be done in Novak's lab, using the retired Hertz instrument to simulate SHARC-II, the CSO's spare relay ellipsoidal mirror in place of the real one, and the blackbody source and chopper from the SPARO optical test bench (Renbarger et al. 2004) to simulate the CSO's Nasmyth image.

3.4 Performance

The performance specifications are given in Table 1. Tabulated sensitivity specifications are derived as follows: In good submillimeter weather (27% of nights during December-April) SHARC-II achieves a 1σ r.m.s. error of 24 mJy in one hour of observations (http://www.submm.caltech.edu/~sharc/general/overview.html; see also Dowell et al. 2003a). Using this figure while taking into account the inefficiencies listed in Table 2, the inefficiency of using the chop/nod mode (Dowell et al. 2003a), the time to measure both Q and U, and the slightly better duty cycle for polarimetry as compared with photometry that requires frequent total power calibration (60% and 50%, respectively), we calculate that a point source with a $350\,\mu$m flux of 2.7 Jy is required in order to obtain in five hours a polarization measurement having a polarization error of 1%. We expect to be able to operate SHARP efficiently also at $450\,\mu$m and we have budgeted (Novak proposal) for a new half-wave plate optimized for this wavelength.

3.5 Adding Polarimetric Capability to other Large-format Cameras

Independently of this proposal, we are exploring the possibility of building a polarimeter

Table 1: Specifications of SHARP

Central Wavelength	*350 μm*	*450 μm*[a]
Bandwidth $\Delta\lambda/\lambda_0$	0.13	0.10
Field of view of 12 pixel × 12 pixel array	$55'' \times 55''$	$55'' \times 55''$
Pixel size	$4.6'' \times 4.6''$	$4.6'' \times 4.6''$
Pixel size, measured in terms of (λ/D)	0.66 λ/D	0.52 λ/D
Angular resolution	$9''$	$11''$
Point source flux for $\sigma_P = 1\%$ in 5 hours[b]	2.7 Jy	1.5 Jy
Surface brightness for $\sigma_P = 1\%$ in 5 hours[b]	0.46 Jy per SHARP pixel[c]	0.26 Jy per SHARP pixel[c]
Max. separation of main and reference beams	$8'$	$8'$
Systematic errors, σ_P(sys.)	$\leq 0.2\%$	$\leq 0.2\%$

[a] all estimates of required flux for 450 μm band are ±20%

[b] assumes binning over 4 SHARP pixels, which is approximately one resolution element

[c] one SHARP pixel = $4.6'' \times 4.6'' = 21$ arcsec^2

Table 2: Predicted Efficiency of SHARP

Source of Inefficiency	*Magnitude of Inefficiency*	*Basis for Estimate*
absorption in half-wave plate (HWP)	5–10%	Murray et al. 1992
imperfect A/R coating on HWP	1% (× 2 surfaces)	experience with SPARO
absorption by mirrors and grids	0.5% (× 10 reflections)	theory of classical skin effect
Ruze losses (curved mirrors only)	3% (× 2 mirrors)	5 μm r.m.s. surface error
loss due to grid imperfections	5% (total loss)	dominated by split element of crossed grid
HWP modulation inefficiency	2%	Novak et al. 1989
diffraction losses due to vignetting	∼0%	ZEEMAX-EE modeling (see §3.1)
imperfect termination of unused polarization components	0.5 – 5.0%	assumes termination to 30 K (BE and indep. photon statistics)
net efficiency of SHARP, relative to SHARC-II	∼73.5%	product of (1.0−inefficiency) for all terms above

for HAWC/SOFIA based on the SHARP concept. For these far-IR wavelengths, reflective retarders such as those described by Chuss et al. (2004b) and Siringo et al. (2004) will be required because crystals (at room temperature) are too lossy. It should also be feasible to use the SHARP concept to convert new large-format cameras currently being constructed for the LMT and SPT into sensitive polarimeters.

The PolKa collaboration at the Max Planck Institute (MPI) in Bonn is pursuing another approach to the problem (Siringo et al. 2004). Instead of rapidly chopping the secondary, they use a rapidly spinning reflective half-wave plate, with a polarizing grid installed between the spinning retarder and the camera. The technique removes much of the sky noise, but suffers from systematic errors due to polarization of background by off-axis reflections (Siringo et al. 2004). The MPI technique is expected to be implemented with the LaBoca 800 μm camera at APEX. For telescopes lacking a chopping secondary, the MPI technique is especially attractive, but it remains unclear whether it can achieve background limited polarimetric performance.

4 Management

As discussed, the organization of the technical effort will be led collaboratively by Hildebrand and Novak, and from the Canadian side by Houde. The scientific effort will benefit from the additional expertise of Jacqueline Davidson of NASA/Ames and Farhad Yusef-Zadeh also of Northwestern University. During the two year period of the proposed award we will focus most of our efforts on the following "key projects"

- *Monitoring of Sgr A** by Yusef-Zadeh and Dowell
- *Large-scale mapping of GMCs* by the Novak and Houde groups, with theoretical support from Lazarian's group.
- *Survey of Bok globules* by the Hildebrand group in collaboration with Davidson.

Other Ph.D. level collaborators bring expertise in external galaxies (Lerothodi Leeuw, Chicago), polarization spectrum (John Vaillancourt, Chicago), Galactic center region (David Chuss, NASA/Goddard), and complementary SMA polarimetry (Hiroko Shinnaga, Caltech).

5 Broader Impact: Training Students

In our research groups, students work with state-of-the-art astronomical instrumentation in the lab, on Mauna Kea, and in Antarctica. Our three most recent Ph.D. students John Vaillancourt (U. Chicago), Tom Renbarger (N.U.), and David Chuss (N.U.) worked on the development of new devices for spectropolarimetry at U. Chicago and on the SPARO South Pole experiment at N.U. (§6). Vaillancourt is now a postdoc with HAWC/SOFIA and SHARP at U. Chicago, Renbarger is a postdoc in experimental cosmology at U. California San Diego, and Chuss is a term civil servant astrophysicist at Goddard Space Flight Center. Current U. Chicago graduate student Larry Kirby has observed on Mauna Kea, and current N. U. graduate students Megan Krejny and Hua-bai Li have worked at the South Pole. All three are engaged in hands-on work developing SHARP. Undergraduates who have worked with us during the past five years and have gone on to do graduate work in astrophysics include Amanda Kepley (U. Chicago student now at U. Wisconsin, Madison), Jennifer Marshall (N.U. student now at Ohio State), Chris Greer (N.U. student now at U. of Chicago), and Janet Colucci (N.U. student now at U. of Michigan). Marshall and Greer traveled to the South Pole as part of their research with Novak.

We encourage teaching activities within our research groups by the judicious choice of undergraduate research projects. This kind of teaching provides effective learning and gives senior students the opportunity to organize their skills as they transmit these to younger students. This year, Novak took on a new undergraduate researcher, Phillip Man. The SHARP team will continue to provide hands-on experience with astronomical instrumentation to students at both the undergraduate and graduate levels.

6 Results from NSF Support

NSF Award AST 0204886 ($264,669): "New Roles for Polarimetry", to University of Chicago for the period 07/01/02 to 06/30/05. Roger Hildebrand, PI

NSF Award AST 0243156 ($458,109): "Diffraction Limited Polarimetry at the Caltech Submillimeter Observatory", to Northwestern University for the period 08/01/03 to 07/31/05. Giles Novak, PI

NSF Award OPP 0130389 ($347,467): "Mapping Galactic Magnetic Fields with SPARO", to Northwestern University for the period 05/01/02 to 04/30/05. Giles Novak, PI

Among the 19 published papers and four in preparation that have resulted from these awards, many are discussed in the text as indicated below. The list includes

- A cryogenic system to permit spectropolarimetry without shafts to external motors (Rennick et al. 2002).

- SHARP, the polarimeter module under construction (§3).
- Results from first South Pole winter-over of SPARO, the Submillimeter Polarimeter for Antarctic Remote Observations (Novak et al. 2003a,b; Renbarger et al. 2004; Chuss et al. 2004a, see §2.2). We determined that the large-scale magnetic field in the central molecular zone (∼200 pc) is toroidal.
- Extensive submillimeter polarimetry of the Galactic Center (§2.2) and Orion (§2.3.1; §2.3.3) using Hertz at CSO.
- A possible technique for determining the inclination of magnetic fields using ratios of ion to neutral line widths (§2.3.3).
- A review of astronomical polarimetry as of 2004 (Hildebrand 2004).
- Lectures on spectropolarimetry (Hildebrand 2001, Canary Islands Winter School)
- A method for determining temperatures, abundances, polarizing powers, and spectral indexes of different dust populations from observations at multiple FIR/submillimeter wavelengths and determination of the SED of the microwave foreground (Hildebrand & Kirby 2004).
- The polarization spectrum of Galactic clouds and estimates of polarization spectra for diffuse clouds (§2.3.2).
- Polarization spectrum of NGC 2024: first case of a single cloud measured both below and above 350μm (Hildebrand 2004).
- Hildebrand group's work on the microwave polarization spectrum of L1622 (in prep.). Goal is to settle whether the anomalous microwave foreground is due to electric or magnetic dipole radiation.
- Hildebrand student Larry Kirby's technique for reducing polarization errors due to atmospheric fluctuations during observations of faint objects (in prep.).

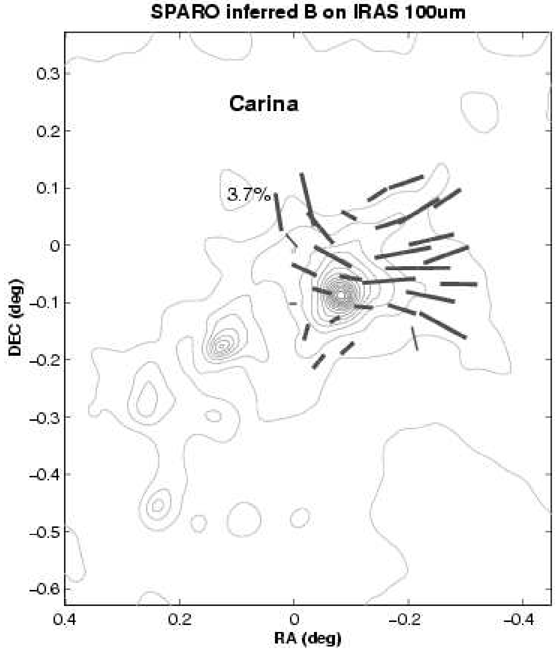
SPARO inferred B on IRAS 100um

Figure 12: 450 μm polarimetry of Carina molecular cloud from SPARO's 2003 winter-over at South Pole. Vectors show inferred magnetic field direction with length giving degree of polarization (note value of 3.7 % near vector at upper left). A strong magnetic pinch $\sim$ 20 pc in extent is detected. Large-scale magnetic field maps were also obtained for three other clouds, and we see a correlation between the strength of the pinch and the intensity of recent star formation. A paper is in preparation.

- Novak's review of Galactic center magnetic fields, for magnetic fields conference in Angra dos Reis, Brazil, November 2004 (in prep.).
- Novak group's ongoing work on analysis (Li et al. 2004; Krejny et al. 2004) and interpretation (in prep.; see Fig. 12) of results from SPARO's second winter-over.

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CURRICULUM VITAE

Name:	Giles Novak
Nationality:	US
Present Address:	Department of Physics and Astronomy Northwestern University Technological Institute, 2145 Sheridan Road Evanston, Illinois 60208

Professional Preparation:

Massachusetts Institute of Technology	Physics	B.S., 1981
University of Chicago	Physics	Ph.D., 1988
University of Massachusetts at Amherst	Postdoc	1988-1991
Princeton University	Postdoc	1991-1992

Appointments:

1999-present	Associate Professor, Dept. of Physics and Astronomy, Northwestern University
1993-1999	Assistant Professor, Dept. of Physics and Astronomy, Northwestern University
1992-1993	Instructor, Princeton University

Publications:

Closely related to proposed project

- Novak, G., Chuss, D.T., Davidson, J.A., Dotson, J.L., Dowell, C.D., Hildebrand, R.H., Houde, M., Kirby, L., Krejny, M., Lazarian, A., Li, H., Moseley, S.H., Vaillancourt, J.E., & Yusef-Zadeh, F., 2004, A Polarimetry Module for CSO/SHARC-II, *Proceedings of the SPIE*, **5498**, 278.
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Synergistic Activities:

- Served on NASA APRA panel review committee, 2004
- Member, SOFIA Science Steering Committee, 1997-2001
- NSF proposals reviewed: four since 2000
- Northwestern undergrad. research assistants supervised: seven since 1999
- Summer fellowship students from other universities supervised: three since 1999
- Public lectures on astronomy and elementary school visits: five since 1999

Collaborators & Other Affiliations:

Collaborators
Jacqueline A. Davidson, NASA-Ames
Jessie Dotson, NASA-Ames
C. Darren Dowell, CalTech
Roger Hildebrand, University of Chicago
Martin Houde, University of Western Ontario, Canada
Alex Lazarian, U. of Wisconsin–Madison
S. Harvey Moseley, NASA Goddard Space Flight Ctr.
Jeffrey B. Peterson, Carnegie Mellon University
Hiroko Shinnaga, Caltech
John Vaillancourt, University of Chicago
Farhad Yusef-Zadeh, Northwestern University

Graduate and Postdoctoral Advisors
Roger Hildebrand, University of Chicago
Paul F. Goldsmith, Cornell University

Thesis Advisor and Postgraduate-Scholar Sponsor
Jessie Dotson (postdoc), Northwestern University
Tom Renbarger (student), Northwestern University
David Chuss (student), Northwestern University
Hua-bai Li (student), Northwestern University
Megan Krejny (student), Northwestern University

Awards/Fellowships:

- Gregor Wentzel Award, U. of Chicago, 1982
- William Rainey Harper Fellowship, U. of Chicago, 1986
- “Outstanding Professor at Northwestern University”, Delta Zeta sorority,1997
- NSF Faculty Early Career Development Award 1997

CURRICULUM VITAE

Name:	Martin Houde
Title:	Assistant Professor
Present Address:	Univ. of Western Ontario, London, ON N6A 3K7, Canada

Professional Preparation:

Universite de Montreal	Ecole Polytechnique	BEng, 1987
Universite de Montreal	Physics Dept.	M.Sc., 1992
Universite de Montreal	Physics Dept.	Ph.D., 2001

Appointments:

2004-present	Assistant Professor, Physics & Astronomy, Univ. of Western Ontario
1993-2004	Senior Scientist, Submillimeter Observatory, Cal. Inst. of Tech., Hawaii
1987-1993	Systems & Design Engineer, Canadian Marconi Co., Montr

Publications:

Closely related to proposed project

- Evaluating the Magnetic Field Strength in Molecular Clouds, Houde, M. 2004, *ApJ*, in print (astro-ph/0410316)
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- Probing the Magnetic Field with Molecular Ion Spectra - II, Houde, M., Peng, R., Phillips, T. G., Bastien, P., and Yoshida, H. 2000, *ApJ*, **537**, 245
- New Molecules Found in Comet C/1995 O1 (Hale-Bopp). Investigating the Link between Cometary and Interstellar Material, Bockele-Morvan, D., Lis, D. C., Wink, et al., including Houde, M., 2000, *A&A*, **353**, 1101
- Submillimeter Array Polarimetry with Hertz, Dowell, C. D., Hildebrand, R. E., Schleuning, D. A., Vaillancourt, J. E., Dotson, J. L., Novak, G., Renbarger, T., Houde, M. 1998, *ApJ*, **504**, 588

Synergistic Activities:

- Supervision of one Physics undergraduate student from the California Institute of Technology during the student's internship in the summer of 2004.
- Research program plans for the training and supervision of at least three undergraduate students over a five-year period.

Collaborators & Other Affiliations:

Collaborators
Pierre Bastien, Université de Montréal
Jacqueline A. Davidson, NASA Ames Research Center
Jessie L. Dotson, NASA Ames Research Center
C. Darren Dowell, Jet Propulsion Laboratory/California Institute of Technology
Roger H. Hildebrand, University of Chicago
Lynn C. Holt, Caltech Submillimeter Observatory
Alex Lazarian, University of Wisconsin-Madison
Patrick M. Nelson, Caltech Submillimeter Observatory
Giles Novak, Northwestern University
Ruisheng Peng, Caltech Submillimeter Observatory
Thomas G. Phillips, California Institute of Technology
John E. Vaillancourt, University of Chicago
Hiroshige Yoshida, Caltech Submillimeter Observatory
Farhad Yusef-Zadeh, Northwestern University

Graduate and Postdoctoral Advisors
MSc, Rene Racine, Universite de Montréal
PhD, Pierre Bastien, Universite de Montréal

Thesis Advisor and Postgraduate-Scholar Sponsor
Michael Attard, graduate student, Department of Physics and Astronomy, The University of Western Ontario

CURRICULUM VITAE

Name: Alex Lazarian
Nationality: US
Present Address: Univ. of Wisconsin-Madison, 5534 Sterling Hall, WI 53706

Professional Preparation:

Moscow Inst. of Physics and Technology (MIPT)	Astrophysics	B.Sc., 1986
Moscow Inst. of Physics and Technology (MIPT)	Theor. Physics	M.Sc., 1995
University of Cambridge (U.K.)	Applied Mathematics	Ph.D., 1995
University of Texas-Austin	Postdoc	1994-1995
Smithsonian Astrophysical Observatory	Postdoc	1995

Appointments:

2004-present	Associate Professor, Dept. of Astronomy, Univ. of Wisconsin-Madison
1999-2004	Assistant Professor, Dept. of Astronomy, Univ. of Wisconsin-Madison
Sept. 1998-June 1999	Long-term Senior Fellow, CITA, Univ. of Toronto
Sept. 1995-Sept. 1998	Research Associate, Princeton University Observatory

Publications:

Closely related to proposed project

- Lazarian, A., Vishniac, E., & Cho, J. 2004, Magnetic Field Structure and Stochastic Reconnection in a Partially Ionized Gas, *ApJ*, **603**, 180-197
- Lazarian, A. & Finkbeiner, 2004, Microwave Emission from Aligned Dust, *New Astronomy Reviews*, **47** (11-12), 1107-1118
- Lazarian, A. 2003, Magnetic Fields from Polarimetry: Progress of Grain Alignment Theory, *Journal of Quantitative Spectroscopy and Radiative Transfer*, **79-80**, 881-902
- Cho, J., Lazarian, A., & Vishniac, E. 2003, Ordinary and Viscosity-Dampted MHD Turbulence, *ApJ*, **595**, 812-823
- Lazarian, A. & Esquivel, A. 2003, Statistics of Velocity from Spectral Data: Modified Velocity Centroids, *ApJ*, **592**, L37-L40

Other significant publications

- Cho, J. & Lazarian, A. 2003, Compressible Magnetohydrodynamic Turbulence: mode coupling, scaling relations, anisotropy, new regime and astrophysical implications, *MNRAS*, **345**, 325-339
- Cho, J. & Lazarian, A. 2002, Magnetohydrodynamic Turbulence as a Foreground for Cosmic Microwave Background Studies, *ApJ*, **575**, L63-L66
- Cho, J. & Lazarian, A. 2002, Compressible Sub-Alfvenic Turbulence in Low-β Plasmas, *Phys. Rev. Lett.*, **88**, number 24, 245001
- Fosalba, P., Lazarian, A., Tauber, J., & Prunet, S. 2002 Statistical Properties of Galactic Starlight Polarization, *ApJ*, **564**, pgs 262-272
- Cho, J., Lazarian, A., Vishniac, E. 2002 New Regime of MHD Turbulence: Cascade Below Viscous Cutoff, *ApJ*, **566**, L49-L52

Synergistic Activities:

- 2004 Supervision of an undergraduate student
- 2004 US-Georgia Science Review Panel
- 2004 Co-Organizer of 2 International Conferences
- Summer 2003 Supervision of a REU undergraduate student
- 2003 NASA ATP Program Proposal Review Committee
- Refereeing around 10 papers per year (ApJ, A&A, MNRAS, Phys. Rev., Phys. of Plasmas, Icarus)

Collaborators & Other Affiliations:

Collaborators
De Gouveia Dal Pino, E., Univ. of Sao Paolo
Dopita M. Aust. Nat. University
Hildebrand, R., Chicago
Novak, J., Northwestern University
Passot, T. Nice Observatory
Pogosyan, D., University of Alberta
Petrosian, V. Stanford
Vazquez-Semadeni, E., UNAM
Vishniac, E., Johns Hopkins
Finkbeiner, D. Princeton University Observatory

Graduate and Postdoctoral Advisors
Professor V. Ginzburg, FIAN, Moscow
Professor C. Jordan, Oxford University, Oxford
Professor N. Weiss, Univ. of Cambridge, UK
Professor E. Vishniac, Johns Hopkins
Professor B. Draine, Princeton Univ. Observ.

Thesis Advisor and Postgraduate-Scholar Sponsor
Dr. J. Cho (postdoc), Chugnam Univ.
Mr. A. Esquivel (student), Wisconsin
Mrs. H. Yan (student), Wisconsin

Awards/Fellowships:

- Visiting Professor at Nice Observatory: September 2004
- Visiting Professor at Stanford/NASA-Ames: June-July 2004
- Visiting Professor at Cologne University: Jan.-Feb. 2004
- Visiting Professor at Ecole Normale: July 2003
- Visiting Professor at Stanford: July 2002
- Visiting Professor at Sao-Paolo: March 2001
- Visiting Professor at Caltech, June-July 2000
- Visiting Fellowship at CfA, Harvard Univ.: May-July 1995
- The Isaac Newton Scholarship at Cambridge Univ.: 1991-1994
- Cambridge Overseas Trust Award: 1991-1994
- Soros Foundation Visiting Scholarship (Award to the winner of an All-Soviet Union Competition of Young Scientists): 1990-1991
- The Best Young Inventor Prize, 1988
- The Honored Inventor, USSR, 1987

CURRICULUM VITAE

Name:	Farhad Yusef-Zadeh
Nationality:	US
Present Address:	Department of Physics and Astronomy Northwestern University, Evanston, IL 60208

Professional Preparation:

SUNY at Stony Brook	Physics and Math	B.A. 1977
Columbia University	Astronomy	M.S.1980
Columbia University	Astronomy	M.Phil. 1981
Columbia University	Astronomy	Ph.D. 1986

Appointments:

Sept. 1999-Present	Professor, Northwestern University
Jan. 1989 -Sept. 1999	Assistant Professor, Northwestern University
Jan. 1987-Dec. 1988	National Research Council Resident Associate, NASA/Goddard Space Flight Center
June 1986-Aug. 1986	Teaching Assistant Professor, Columbia University
Nov. 1986-Dec. 1986	Research Associate, UCLA

Publications:

Closely related to proposed project

- Yusef-Zadeh, F., Cotton, W., Wardle, M., Melia, F. and Roberts, D.A., Anisotropy in the Angular Broadening of Sgr A* at the Galactic Center, 1994, *Astrophysical Journal*, **434**, L63.
- Yusef-Zadeh, F., Choate, D. and Cotton, W., The Position of Sgr A* at the Galactic Center, 1999, *Astrophysical Journal (Letters)*, **518,** L33
- Yusef-Zadeh, F., Stolovy, S. R., Burton, M., Wardle, M. & Ashley, M. C. B., High Spectral and Spatial Resolution Observations of Shocked Molecular Hydrogen at the Galactic Center, 2001, *Astrophysical Journal*, **560,** 749
- Yusef-Zadeh, F., Wardle, M. and Parastaran, P., The Nature of Faraday Screen Toward the Galactic Center Nonthermal Filament G359.54+0.18, 1996, *Astrophysical Journal (Letters),* **475**, L119-L122
- Roberts, D.A., Yusef-Zadeh, F., and Goss, W.M., Kinematics of the Ionized Gas in Sgr A West: Mass Estimates of the Inner 0.13 pc of the Galaxy, 1996, *Astrophysical Journal,* **459**, 627-631

Other significant publications

- Yusef-Zadeh, F., Roberts, D.A. and Biretta, J., Proper Motions of Ionized Gas at the Galactic Center, 1998, *Astrophysical Journal (Letters),* **499,** L159-L162
- Yusef-Zadeh, F., Shure, M., Wardle, M. and Kassim, N., Radio Continuum Emission from the Central stars of M20, 2000, *Astrophysical Journal*, **540,** 849
- Yusef-Zadeh, F., Law, C., Wardle, M., Wang, Q.D., Fruscione, A., Lang, C.C. & Cotera, A., Detection of X-ray Emission from the Arches Cluster Near the Galactic Center, 2002, *Astrophysical Journal*, **570,** 665.

- Yusef-Zadeh, F., Melia, F., and Wardle, M., The Galactic Center: An Interacting System of Unusual Sources, 2000, *Science,* **245,** 85
- Wardle, M. and Yusef-Zadeh, F., Supernova Remnant OH Masers: Signposts of Cosmic Collision, 2002, *Science*, **296,** 2350-2354

Synergistic Activities:

- Teaching a yearly public lecture course on my research at Adler planetarium for the last ten years. (e.g " Masers: Lasers in the Sky" in May 2000 for two weeks).
- Participated in the Astro-Science Workshop lectures for gifted high school students in the ten years at Adler planetarium.
- Collaborated in launching a public outreach site (http://spaceimages.northwestern.edu) and initiated a gallery of Astronomical images displayed at Block Gallery during January and February of 2000.
- Initiated in launching public lecture series at Northwestern University with online video recording of the lectures (http://www.physics.northwestern.edu)
- Web-based Homework Assignments using image calculator toolkit for undergraduate Astronomy students (http://vislab.northwestern.edu/hst-assignments.html)

Collaborators & Other Affiliations:

Collaborators
Burton, M., UNSW
Cernicharo, J., CSIC, Spain
Cotton, W., NRAO
Fatuzzo, M., U. Arizona
Frail, D.A., NRAO
Geballe, T., JAC
Goss, W.M., NRAO
Kassim, N., NRL
Lang, C., UMASS
Lazio, J., NRL
Melia, F., U. Arizona
Reynolds, S., N.C.U.
Roberts, D.A., Northwestern U.
Shure, M.M., U. Georgia State
Stolovy, S., Cal. Tech
Wang, D., UMASS
Wardle, U. Sydney

Graduate and Postdoctoral Advisors
Morris, M., UCLA
Hollis, M., NASA/GSFC

Thesis Advisor and Postgraduate-Scholar Sponsor
Law, C., Graduate Student, Northwestern University

BIOGRAPHICAL SKETCH: Roger H. Hildebrand

University of Chicago
Enrico Fermi Institute, 5640 Ellis Avenue, Chicago, IL 60637
roger@oddjob.uchicago.edu

EDUCATION: U. of California, Berkeley; B.A. (Chemistry) 1947; Ph.D. (Physics) 1951

ACADEMIC APPOINTMENTS; University of Chicago:
Department of Physics and Enrico Fermi Institute 1952-
Department of Astronomy and Astrophysics 1978-
Assistant Professor 1952-55, Assoc. Prof. 1955-60, Professor 1960-85
Samuel K. Allison Distinguished Service Professor 1985-. (Emeritus 1992 -)

ADMINISTRATIVE APPOINTMENTS:
Associate Director, Argonne National Laboratory 1958-64
Director, Enrico Fermi Institute 1965-68
Dean of the College, University of Chicago 1969-73
Chairman, Department of Astronomy and Astrophysics 1984-88

ADVISORY APPOINTMENTS:
NSF, Kavli Center for Cosmological Physics. Advisory Committee. 2001-2002,
Associate Member 2003 ñ
NASA/JPL Review Board for Planck High Freq. Inst. Detectors, 2000-2002
NASA, Panel to review Small Explorer proposals ñ April, 2000
Universities Space Research Association - Member, SOFIA Science Council 1997-02
U. Mass/Mexico - Sci. and Tech. Adv. Comm., Large Millimeter Telescope 1995-
Observatories Visiting Committee. AURA 1992-96. Chairman 1995-96
American Institute of Physics - Chairman, Dannie Heineman Prize Committee
(Astrophysics). 1990.
Astronomy and Astrophysics Survey Comm., National Academy of Sciences,
Panel for Infrared Astronomy 1989-90
Center for Astrophysics - Sci. and Tech. Adv. Comm. for the Submillimeter Array 1989-93
Space Science Board - Committee on Space Astron. & Astrophys., 1987-90
Columbus Project - Council, 1986-1988
Ames Research Center, Chairman Consulting Group on the Stratospheric
Observatory for Infrared Astronomy 1985-1989
NASA, Chairman Airborne Observatories Users Group 1983-84
AEC/NSF, Chairman Committee to Review U.S. Medium Energy Science, 1974
Lawrence Berkeley Laboratory, Scientific and Educational Advisory Committee 1971-79
National Accelerator Laboratory, Physics Advisory Committee 1967-69
Physics Survey Committee, Panel on Elementary Particle Physics,
National Academy of Sciences 1964
Stanford Linear Accelerator Center, Chairman Scientific Policy Committee 1962-66

FELLOWSHIPS, AWARDS:
Fellow, American Physical Society
Quantrell Award for Excellence in Undergraduate Teaching 1960
Fellow, John Simon Guggenheim Foundation (at University of California,
Berkeley) 1968-69
Fellow, Alfred P. Sloan Foundation 1975
Fellow, American Academy of Arts and Sciences 1991-
Norman Maclean Faculty Award, University of Chicago, 1999

Selected Publications (Closely related and significant)

Magnetic Fields and Stardust. R. H. Hildebrand. 1988, *Q. Jl. R. astr. Soc.,* **29**, 327-351

The Far-Infrared Polarization Spectrum: First Results and Analysis. R. H. Hildebrand, J. L. Dotson, C. D. Dowell, D. A. Schleuning, and J. E. Vaillancourt. 1999, ApJ, 516: 834-842

A Primer on Far-Infrared Polarimetry. R. H. Hildebrand, J. A. Davidson, J. L. Dotson, C. D. Dowell, G. Novak, and J. E. Vaillancourt. 2000, PASP, **112**, 1215

Interstellar Magnetic Fields and Infrared-Submillimeter Spectropolarimetry. R. H. Hildebrand In ì Astrophysical Spectropolarimetryî Ed: J. Trujillo-Bueno, . F. Moreno-Insertis, and F. Sanchez. Cambridge University Press (2002). pp 265-302.

Experiences with Airborne and Ground-Based Polarimetry. Roger Hildebrand. In *The Cosmic Microwave Background and its Polarization,* New Astronomy Reviews 47 (eds. S. Hanany and K. A. Olive) Elsevier, 2003, pp1009 ñ 1015

Polarization of FIR/SUB-mm Emission. Roger Hildebrand & Larry Kirby. In *Astrophysics of Dust*. ASP Conference Series. Vol. 309, Eds. Adolf N. Witt, Geoffrey C. Clayton, & Bruce T. Draine 2004, pp 515 ñ 527

Summary: Astronomical Polarimetry, 2004. Roger Hildebrand In *Astronomical Polarimetry ñ Current Status and Future Directions,* AIP Conference Series. 2004, In press

Synergistic Activities

Four REU summer students
Lecture to undergraduate students at Kenyon College
Series of lectures at Canary Island Winter School

Collaborators in last four years

P. Bastien (Montreal), D. T. Chuss (Goddard), J. A. Davidson (UCRL), J. L. Dotson (Ames). C. D. Dowell (JPL), S. J. Heimsath (Chicago), L. M.Hobbs (Chicago), M. Houde (U. Western Ont.), G. Kelderhouse (Chicago), L. Kirby (Chicago), M. Krejny (Northwestern), A. Lazarian (Wisconsin), H. Li (LANL), R. F. Loewenstein (Chicago), S. Lucero (Chicago), S. H. Moseley (Goddard), G. Novak (Northwestern), R. Peng (CSO), T. G. Phillips (Caltech), C. M. Rockosi, D. B. Sandford, J. L. Sundwall, D. G. York, J. A. Thorburn (Chicago), J. E. Vaillancourt (Chicago), S. Wang (Chicago), D. G. York (Chicago), H. F. Yoshida, (CSO), F. Yusef-Zadeh (Northwestern).

Graduate Advisor: Burton J Moyer (deceased)
Post Doc Advisor: None

PhD. Graduate Students: 24

Post Graduate-Scholar Sponsor: Romano Bizarri (Rome), Dan Jaffe (Texas), Susan Trammell (North Carolina), John Vaillancourt (Chicago), Lerothodi Leeuw (Chicago).

Biographical Sketch

Jacqueline A. Davidson

a. Professional Preparation

University of Western Australia	Physics	B.Sc. (Honors), 1980
University of Chicago	Physics	Ph.D, 1986
NRC Associate @ NASA Ames Res. Ctr.	Astrophysics	1986 – 1988

b. Appointments

1997-present	SOFIA Project Scientist (Universities for Space Research Association)
1993	Visiting Professor (University of California, Los Angeles)
1989-1995	SOFIA Assist. Proj. Scientist (SETI Institute - NASA/Ames Res. Ctr.)
1988-1989	Principal Investigator (SETI Institute - NASA/Ames Research Center)
1986-1988	NRC Associate (NASA Ames Research Center)

c. Publications

(i) Publications associate with current proposal:

M. Morris, J.A. Davidson, M.W. Werner, J. Dotson, D.F. Figer, R. Hildebrand, G. Novak, and S. Platt, "Polarization of the Far-Infrared Emission from the Thermal Filaments of the Galactic Center Arc", Ap.J. 399, L63 (1992).

R.H. Hildebrand, J.A.Davidson, J.Dotson, D.F.Figer, G.Novak, S.R.Platt, and L.Tao, " Polarization of the Thermal Emission from the Dust Ring at the Center of the Galaxy", Ap.J. 417, 565 (1993).

J.L. Dotson, J.A. Davidson, C.D. Dowell, D.A. Schleuning, and R.H. Hildebrand, “Far-IR Polarimetry of Galactic Clouds from the Kuiper Airborne Observatory”, ApJS 128, Issue 1, 335 (2000)

D.A. Schleuning, J.E. Vaillancourt, R.H. Hildebrand, C.D. Dowell, G. Novak, J.L Dotson, and J.A. Davidson, “Probing the Magnetic Field Structure in the W3 Molecular Cloud”, Ap.J. 535, Issue 2, 913 (2000)

D. T. Chuss, J.A. Davidson, J. L. Dotson, C.D. Dowell, R.H. Hildebrand, G. Novak, and J. E. Vaillancourt “Magnetic Fields in Cool Clouds within the Central 50 Parsecs of the Galaxy”, Ap.J. 599, 1116 (2003)

(ii) Significant Publications

J.A.Davidson, "Low-Luminosity Embedded Sources and Their Environs", Ap.J. 315, 602 (1987) (Ph.D. Thesis).

J.A. Davidson, M.W.Werner, X. Wu, P.M.Harvey, D.F.Lester, M. Joy, and M.Morris, "The Luminosity of the Galactic Center", Ap.J. 387, 189 (1992).

J.A. Davidson, "The Magnetic Field Structure in the Galactic Center" review paper in Polarimetry of the Interstellar Medium, eds. W. Roberge and D. Whittet, San Francisco: ASP (1996).

R.H. Hildebrand, J.A. Davidson, J.L. Dotson, C.D. Dowell, G. Novak, and J.E. Vaillancourt "A Primer on Far-Infrared Polarimetry", PASP 112 Issue 775, 1215 (2000)

C.M. Bradford, T. Nikola, G.J. Stacey, J.M. Jackson, & A.D. Bolatto, J.A. Davidson, M.L. Savage, & S.J. Higdon, "CO (J=7->6) Observations of NGC 253", ApJ. 586, 891 (2003)

d. Synergistic Activities

(i) Project Scientist for SOFIA (Stratospheric Observatory for Infrared Astronomy) – as such, developing a new facility for far-infrared astronomy. Also, the SOFIA program has an Education and Public Outreach portion to it that is in the process of developing science curricular material and textbooks for K-13. This part of the SOFIA program will also transfer SOFIA technical and scientific knowledge, as well as general scientific discoveries, to the general public.

(ii) Was part of the development team for SPIFI (South Pole Imaging Fabry-Perot Interferometer) - as such, developed a new observational tool for sub-millimeter astronomy.

e. Collaborations & Other Affiliations

(i) Collaborators:

Eric Becklin	U. of California, Los Angeles
Mat Bradford	CalTech
Sean Casey	USRA
David Chuss	NASA-GSFC
Jessie Dotson	NASA Ames Research Center
Darren Dowell	CalTech-JPL
Roger Hildebrand	U. of Chicago
Brenda Matthews	U. of California, Berkeley
Giles Novak	Northwestern U.
Goeran Sandell	USRA
Gordon Stacey	Cornell U.
Bill Vacca	USRA
John Vaillancourt	U. of Chicago

(ii) Graduate and Postdoctoral Advisors:

Roger Hildebrand	U. of Chicago (thesis advisor)
Michael Werner	JPL (postdoctoral advisor)

(iii) Thesis Advisor to and/or Postgraduate-Scholar Sponsor of:

Lerothodi L. Leeuw (Postgraduate-Scholar)

C. Darren Dowell

Jet Propulsion Laboratory, Caltech
Mail Stop 169-506
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 393-5032
FAX: (818) 354-8895

754 N. Mar Vista Ave.
Pasadena, CA 91104
(626) 797-5741

cdd@submm.caltech.edu

EDUCATION/APPOINTMENTS

Scientist/Research Scientist, Jet Propulsion Laboratory, 2003-present
Sr. Postdoctoral Scholar, California Institute of Technology, 2000-2003
Postdoctoral Scholar, California Institute of Technology, 1997-2000
Ph.D. Astronomy and Astrophysics, University of Chicago, 1997.
M.S. Astronomy and Astrophysics, University of Chicago, 1992
B.A. Physics (Space Physics and Astronomy), cum laude, Rice University, 1991.

HONORS AND MEMBERSHIPS

NASA Graduate Student Researchers Program Fellowship, 1995-1997
Nathan Sugarman Award, University of Chicago, 1994
American Astronomical Society, 1996-present

SELECTED PUBLICATIONS

C. D. Dowell, C. A. Allen, S. Babu, M. M. Freund, M. B. Gardner, J. Groseth, M. Jhabvala, A. Kovacs, D. C. Lis, S. H. Moseley, T. G. Phillips, R. Silverberg, G. Voellmer, & H. Yoshida, in "Millimeter and Submillimeter Detectors for Astronomy", ed. T. G. Phillips & J. Zmuidzinas, *Proc. SPIE*, 4855, 73 (2003) – "SHARC II: a Caltech Submillimeter Observatory facility camera with 384 pixels"

C. D. Dowell, R. H. Hildebrand, D. A. Schleuning, J. E. Vaillancourt, J. L. Dotson, G. Novak, T. Renbarger, & M. Houde, *Astrophysical Journal*, 504, 588 (1998) – "Submillimeter Array Polarimetry with Hertz"

C. D. Dowell, *Astrophysical Journal*, 487, 237 (1997) – "Far-Infrared Polarization by Absorption in the Molecular Cloud Sagittarius B2"

P. K. Day, H. LeDuc, A. Goldin, C. D. Dowell, & J. Zmuidzinas, in *Proc. SPIE*, 5498, 857 (2004) – "Far Infrared/Submillimeter Imager-Polarimeter Using Distributed Antenna-Coupled Transition Edge Sensors"

M. Houde, C. D. Dowell, R. H. Hildebrand, J. L. Dotson, J. E. Vaillancourt, T. G. Phillips, R. Peng, & P. Bastien, *Astrophysical Journal*, 604, 717 (2004) – "Tracing the Magnetic Field in Orion A"

D. T. Chuss, J. A. Davidson, J. L. Dotson, C. D. Dowell, R. H. Hildebrand, G. Novak, & J. E. Vaillancourt, *Astrophysical Journal*, 599, 1116 (2003) – "Magnetic Fields in Cool Clouds within the Central 50 Parsecs of the Galaxy"

M. Jhabvala, S. Babu, C. Monroy, M. M. Freund, & C. D. Dowell, *Cryogenic*s, 42, 517 (2002) – “Development of low-noise high value chromium silicide resistors for cryogenic detector applications”

J. L. Dotson, J. Davidson, C. D. Dowell, D. A. Schleuning, & R. H. Hildebrand, Astrophysical Journal Supplement Series, 128, 335 (2000) – “Far-Infrared Polarimetry of Galactic Clouds from the Kuiper Airborne Observatory”

R. H. Hildebrand, J. L. Dotson, C. D. Dowell, D. A. Schleuning, & J. E. Vaillancourt, *Astrophysical Journal*, 516, 834 (1999) – “The Far-Infrared Polarization Spectrum: First Results and Analysis”

J. A. Agostinelli, J. M. Chwalek, C. J. Baron, G. Lubberts, & C. D. Dowell, *Physica C*, 207, 203 (1993) – “YBCO-based ramp-edge Josephson junctions and DC SQUIDs with a cubic-YBCO barrier layer”

COLLABORATORS 1998-PRESENT

C. A. Allen (NASA/GSFC)
T. Ames (NASA/GSFC)
P. Bastien
D. J. Benford (NASA/GSFC)
J. J. Bock (JPL)
C. Borys (Caltech)
D. T. Chuss (NASA/GSFC)
D. P. Clemens (Boston U.)
J. A. Davidson (NASA/Ames)
P. K. Day (JPL)
J. L. Dotson (NASA/Ames)
M. M. Freund
R. H. Hildebrand (U. Chicago)
W. Holzapfel (U.C. Berkeley)
M. Houde (U. W. Ontario)
T. R. Hunter (Harvard/CFA)
M. Jhabvala (NASA/GSFC)
T. J. Jones (U. Minnesota)
B. Keating (U.C. San Diego)
J. Keene (JPL)
J. Kovac (Caltech)
A. Lange (Caltech)
A. Lazarian (U. Wisconsin)
D. C. Lis (Caltech)
K. Marsh (JPL)
S. H. Moseley, Jr. (NASA/GSFC)
G. Novak (Northwestern U.)
R. Peng (Caltech)
T. G. Phillips (Caltech)
T. Renbarger (U.C. San Diego)
D. A. Schleuning
E. Serabyn (JPL)
R. F. Silverberg (NASA/GSFC)
J. E. Vaillancourt (U. Chicago)
N. Wang
M. W. Werner (JPL)
J. P. Williams (U. Hawaii)
J. Zmuidzinas (Caltech)
E. G. Zweibel (U. Wisconsin)

CALIFORNIA INSTITUTE OF TECHNOLOGY

GEORGE W. DOWNS LABORATORY OF PHYSICS 320-47
PASADENA, CALIFORNIA 91125

October 26, 2004

Professor Giles Novak
Department of Physics and Astronomy
Northwestern University
Evanston, IL

Dear Giles:

I am writing in support of your National Science Foundation proposal to operate SHARP at the Caltech Submillimeter Observatory. SHARP will enhance the capabilities of the observatory in an important way by enabling sensitive polarimetric measurements with the large-format SHARC-II camera.

I have assigned seven days of instrument commissioning time for SHARP in Summer 2005, with the exact dates to be arranged in the near future.

We have successfully moved SHARC-II from the Cassegrain focus to the Nasmyth platform, in preparation for the implementation of queue scheduling that will increase the overall data rate for the CSO. We expect that by the end of 2005, SHARP will also be able to take advantage of queue scheduling.

Sincerely,

Dr. Thomas G. Phillips, Altair Professor of Physics
Director, Caltech Submillimeter Observatory
California Institute of Technology

28 October 2004

Professor Giles Novak
Northwestern University
Department of Physics and Astronomy
2145 Sheridan Road
Evanston, Illinois 60208

Dear Giles,

I am pleased to participate in the SHARP collaboration. My students and I will work with U. of Chicago postdoc John Vaillancourt to develop the data reduction software needed for SHARP.

John is now developing the low-level software that will process SHARC-II images obtained during a single observation at one half-wave plate position. This will compute the sum and difference of the two polarization components. My group will develop algorithms that start with these individual files and compute from them the normalized Stokes' parameters for each observed sky position. The final step of correcting these data for instrumental polarization will be carried out by John.

I look forward to working with you and the SHARP team on the GMC mapping project and other scientific investigations with this new instrument. My work on SHARP is being supported by my start-up funds, and I have submitted proposals to Canadian funding agencies for continued support of this research.

Best Wishes,

Martin Houde
Assistant Professor
The University of Western Ontario
Department of Physics and Astronomy
London, Ontario
Canada N6A 3K7

CALIFORNIA INSTITUTE OF TECHNOLOGY
GEORGE W. DOWNS LABORATORY OF PHYSICS 320-47
PASADENA, CALIFORNIA 91125

October 27, 2004

Professor Roger Hildebrand
Department of Astronomy and Astrophysics
University of Chicago
Chicago, IL

Dear Roger:

I am looking forward to working with you on the development of SHARP, and as the principal designer of SHARC-II, I will take responsibility for the interface between SHARP and SHARC-II. In particular, I will ensure that the SHARC-II data acquisition system will support a new polarimetric mode including communications with the EDAS-based half-wave plate controller that is being developed by your group at University of Chicago.

Sincerely,

C. Darren Dowell

Dr. C. Darren Dowell
Visiting Associate, California Institute of Technology
Research Scientist, Jet Propulsion Laboratory