OBSERVING REQUEST

University of Arizona Observatories

Year: 2015 **Term:** Jan–Jul **Proposal type:** short-term

Imaging Polarimetry with MMTPol

P.I.: Terry Jones (U of Minn; *tjj@astro.umn.edu*; 6126248009)

CoI(s): Chris Packham (U of Texas San Antonio), Dinesh Shenoy⋆ (U of Minn)

Abstract of Scientific Justification

This is a U. Minnesota GTO request. We are requesting 3 nights of observing time to study Hypergiants, Seyfert galaxies, and edge-on spirals with MMTPol. MMTPol is a, precision, $1-5\ \mu m$ imaging polarimeter for use in conjunction with the AO secondary. Imaging polarimetry of hypergiants will allow us to probe the mass loss geometry deep into the circumstellar material surrounding these stars. Imaging polarimetry of Seyfert galaxies will probe dust scattering and the magnetic field geometry close to the nucleus of these AGN. Imaging polarimetry of the edge-on galaxy NGC 4013 will allow us to probe the magnetic field geometry in a normal spiral at 0.18" resolution.

Summary of observing runs requested for this project

Run	Telescope	Cage	Instrument	PI	AO	Nights	Moon	Scheduling Optimal	Scheduling Acceptable	Sharing Poss.	Sharing Adv.
1	MMT	f/15	MMTPol	*	*	3	bright	Any	Any	no	no

Scheduling constraints and unusable dates *(up to 4 lines)*: None

no text past this line

A ⋆ appended to the proposal type indicates a continuation proposal; a ⋆ appended to the name of a proposer indicates the proposer is a (graduate) student; a proposer whose name is underlined is certified on the proposed telescope/instrument combination; if a ∗ appears within the PI or AO box in the observations summary table, the instrument is a PI instrument and/or Adaptive Optics are requested – signatures are required on the next page.

Target list (attach list if longer than 26 objects)

#	Object	RA	Dec	mag / color / type / redshift / comment / etc.
1	IRC +10420	19 26 48.095	+11 21 16.74	warm hypergiant, I=8
2	NGC 4146	12:10:18.23	26:25:50.8	Seyfert, I=10
3	NGC 4151	12:10:32.6	39:24:21.0	Seyfert, I=10
4	NGC 4013	11:58:32.13	+43":56:54.0	Edge-On Spiral, I=12.0

Approval for Instrument Use from PI: ______________________

(have instrument PI signature appear on, or attach PI e-mail to, ***all*** *copies)*

Graduate students *(provide the following information for* ***each*** *student named as PI or CoI on the cover page. Have the advisor's signature(s) appear on* ***all*** *submitted copies)*

Student's Name	Advisor's Name	Advisor's Signature	2nd-yr	Thesis
Dinesh Shenoy	Terry Jay Jones		no	yes

Scientific Justification

The ability to combine high spatial resolution imaging with high precision polarimetry at infrared wavelengths has opened up an entirely new vista of observations for the study of protoplanetary systems, AGN, evolved stars, comets, and many other important classes of astronomical objects. By imaging with high spatial resolution, diluting unpolarized or competing polarized flux in the beam is reduced, and the polarization of finer structures can be more accurately delineated.

To obtain high precision polarimetry at high spatial resolution, a large aperture telescope with an Adaptive Optics (AO) capability is required. However, existing AO systems on 6-10m class telescopes, with the exception of the MMT AO system, have an optical path that includes dichroics and multiple, usually oblique reflections. Multiple reflections seriously compound the problem of instrumental polarization. In practical terms it is difficult to measure net polarization accurately at levels better than about 10% of the instrumental polarization, thereby placing severe limits on the types of objects that can be observed.

By using an AO secondary, oblique reflections are eliminated, and the instrument remains in the center of the Cassegrain focus. Other systems, such as the Gemini Planet Finder have a raw contrast ratio (inverse of the instrumental polarization) of about 100, MMTPol has a contrast ratio of 3000. Only at the MMT can we combine a large aperture with an AO system that minimizes instrumental polarization, making the MMT with its unique AO secondary the optimal combination for NearIR polarimetry. Performance of MMTPol is shown in Figures 1 and 2, which show images of a Seyfert galaxy at $2.2\mu m$ (paper almost submitted) and a red supergiant at $3.1\mu m$ (paper in preparation).

1) Cool and Warm Hypergiants

We are interested in defining the geometry of the circumstellar material as close as possible to the star. We can compare observed structure very close to the star with models of subsequent extended shells that are based on ad-hoc starting geometries. At visual wavelengths observed with the HST, these stars appear to be loosing mass in a very asymmetrical, and often episodic manner. In the NearIR, MMTPol can probe deeper into the circumstellar environment and use the fractional polarization to untangle the geometry of the mass loss wind.

2) AGN

The AGN paradigm accounts for the myriad of different classes and properties through the invocation of an isotropically emitting 'central engine' (most likely an accretion disk of material spiraling into a supermassive black hole), obscured from some lines of sight (LoS) by an optically and geometrically thick torus of gas and dust. Polarimetry provides us the opportunity to observe the object at a different LoS through scattering providing a 'periscope' view to the central engine, as scattered light is strongly polarized. At NearIR wavelengths, we can penetrate deeper into the environs of Seyfert nuclei and possibly determine the magnetic field geometry, or scattering geometry near the central engine.

3. Edge-on Spirals

We are interested in the interstellar polarization and magnetic field geometry in normal spiral galaxies. By observing edge-on spirals in the Near-IR, we can penetrate deep into the dust lane and sample the magnetic field geometry along a line-of-sight through to the nucleus (e.g. Jones 1997). One galaxy, NGC 4013, conveniently has a foreground star 9" off the nucleus, perfectly placed to use for the AO lock without interfering with the nuclear region. Using MMTPol, we will be able to achieve 16pc resolution at $2.2\mu m$, which which allows us to sample an optical depth 11 times what is possible in V band.

References:

Barthel P.D., 1994, in The First Stromlo Symposium: the Physics of Active Galaxies, p.175, eds Bicknell G.V., Dopita M.A. & Quinn P.J., (Astronomical Society of the Pacific Conference Series, San Francisco).

Jones, T. J. & Klebe, D. I., 1988, PASP, 100, 1158.

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Jones, T. J., & Packham, C. C., 2007, BAAS, 38, 748 .

Jones, T. J., Humphreys, R. M., Helton, L. A., Gui, C., & Huang, X., 2007, AJ, 133, 2730

Packham, C., Jones, T. J., Krejny, M., Dewahl, K., Warner, C., & Lopez Rodriguez, E., 2010, SPIE, 7735, 215.

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Potter, D.E., 2003, Ph.D. Thesis

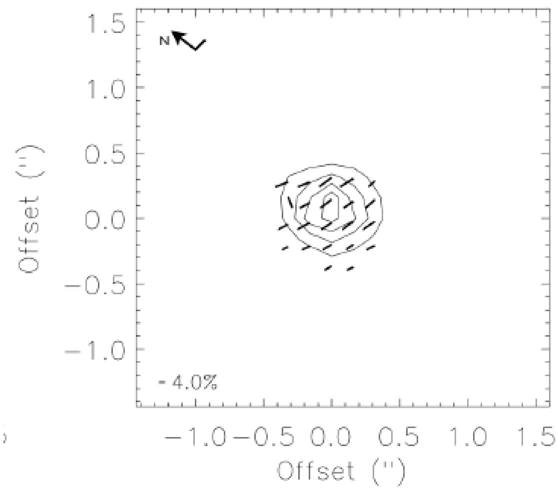

Figure 1: Imaging polarimetry at $2.2\mu m$ of the well known Seyfert galaxy NGC 1068.

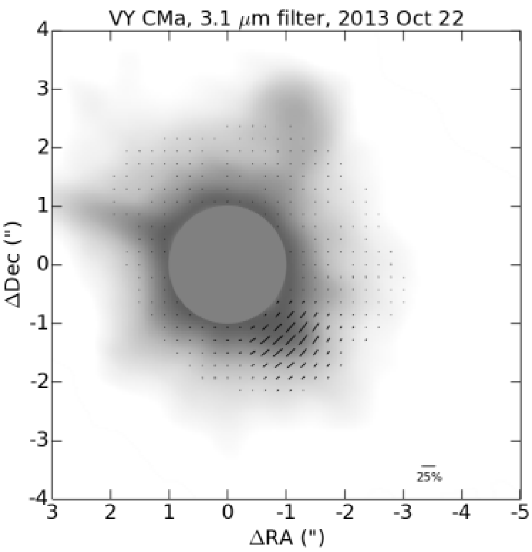

Figure 2: Imaging polarimetry at $3.1\mu m$ of the red supergiant VY CMa showing the highly polarized ejecta to the SW of the star.

Experimental Design & Technical Description *Describe your overall observational program. How will these observations contribute toward the accomplishment of the goals outlined in the science justification? If you've requested long-term status, justify why this is necessary for successful completion of the science.* ***(up to one page)***

Weather prevented both our Fall 2011 and Fall 2012 commissioning runs from achieving their scientific goals, but we were able to assess the performance of the instrument at some level. The AO and MMTPol worked together correctly, and we were able to work down to the +/- 0.03% level for fractional polarization. We achieved +/- 0.17", FWHM images through the polarization optics. We were able to lock the AO onto the diffuse nucleus of NGC 1068, so there should be no problem with Seyfert galaxies that are not too faint at I. Our observations of IRC+10420 (through clouds) demonstrate that MMTPol is capable of imaging polarimetry within 0.2" of a bright central star.

There are no significant time or operations constraints on our program to observe warm hypergiants, nearby Seyfert nuclei and an edge-on spiral. We have demonstrated this capability during the Fall 2012 observing run. However, since MMTPol must be prepped well ahead of time and requires the AO system, it is impractical to split up the observing time across several runs. We do require plumbing from the compressor in the basement to run our cyrocooler.

Summary of Time Requested and Awarded *The TAC needs to understand the scope of this project — (1) tell us how many UAO nights you've already had for this project, how many you request this time, and (a good guess of) how many you need to complete the project; (2) if a substantial amount of observing for this project comes from non-UAO telescopes, tell us about that observing, and how the UAO part fits in; (3) if you are collaborating with people who have telescopes, especially if you are part of a large collaboration, tell us who is leading the project, and how UAO time and your participation fit in. (**up to one page**)*

We are requesting 3 night for scientific observations of hypergiants, protoplanetary disks and nearby Seyfert galaxies using MMTPol. MMTPol will be available to Steward and CFA staff as a PI instrument.

Previous Use of Steward Facilities *List **all** allocations of telescope time for the present project and allocations for other projects on facilities available through UAO during the past 2 years, together with the current status of the data (cite publications where appropriate). Mark those allocations related to the present proposal (i.e, precede text with* `\related` *command). (**up to one page**)*

Commissioning in November, 2011 and September 2012. Observations through clouds and wind, September 2012, some science (IRC+10420) achieved. Good runs in October 2013 and January 2014. Two papers near submission on the results from these runs.