OBSERVING REQUEST
University of Arizona Observatories

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

Follow-up of two planet candidates in the HD 169142 transition disk with MagAO

P.I.: Jared Males (SO; *jrmales@email.arizona.edu*; 520-626-3900)

CoI(s): Beth Biller (Edinburgh), T.J. Rodigas (D.T.M.), Katie Morzinski (SO), Laird Close (SO), Kate Follette⋆ (SO), Phil Hinz (SO), Alycia Weinberger (D.T.M.), Mickaël Bonnefoy (Grenoble)

Abstract of Scientific Justification

Two point sources have recently been identified within the inner gap of the HD 169142 transition disk: an L' source was discovered independently by two teams using VLT/NACO, and while attempting to confirm this detection using MagAO, our team found a source in H and K_S very near to the original L' object. The two sources are astrometrically and photometrically distinct, and each is unlikely to be a background object. The most likely explanation of these observations is that we are witnessing planet formation within the disk of HD 169142, where the H/K_S source is the new planet and the L' source is an associated feature in the disk. We propose to conduct follow-up observations with MagAO in H, K_S, and L'. We will use these observations to confirm common proper motion of the sources and use the photometry to assess their planetary nature. These observations will take a total of 1.5 nights, and if the planetary nature of the sources is confirmed will provide the first bona fide detection of a protoplanet.

Summary of observing runs requested for this project

								Scheduling		Sharing	
Run	Telescope	Cage	Instrument	PI	AO	Nights	Moon	Optimal	Acceptable	Poss.	Adv.
1	MAG2	AO	MagAO+Clio2+VisAO		*	1.5	bright	Jun	May-Jul	yes	yes

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	HD 169142	18 24 29.78	-29 46 49.37	Primary: A7V, $R = 8.2$

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
Kate Follette	Laird Close		no	no

Scientific Justification

Background: Transition disks are an intermediate stage of planetary system evolution between the protoplanetary disk phase and debris disks, characterized by weak mid-IR emission relative to the Taurus median spectral energy distribution (Najita et al. 2007). While multiple mechanisms can produce the observed mid-IR depletion, in some cases it is produced by dust clearing by a forming planet. In particular, transition disks with imaged gaps such as HD 169142 (A7, Herbig Ae / Be) require embedded companions to clear out the relatively narrow imaged gap.

Quanz et al (2012) used the polarimetric differential imaging (PDI) capability of the VLT+NACO system to resolve several features of the face-on disk of HD 169142. Notably, inside $\sim 0.14''$ ($\lesssim 20$ AU) the disk is depleted in dust, and there is a ring-like bright maximum at $\sim 0.17''$ (~ 25 AU). There is then an annular gap in the disk from $\sim 0.28''$ to $\sim 0.48''$ (40-70 AU). These features are signposts of a massive object sculpting the disk.

Detected Sources: Two candidate companions were recently identified within $0.2''$ of the star, inside or on the ring like structure described above. An L' (3.8μm) point source at $\sim 0.11''$ was discovered using the VLT NACO instrument by Co-I Biller and collaborators. While attempting to confirm this detection with MagAO in April, 2014, we discovered a 2nd point source in H (1.6μm) and K_S (2.2μm) at $\sim 0.18''$, PA$\sim 33^o$. Both of these appear to be bona-fide detections (multiple nights, multiple filters and/or multiple groups). The positions are different astrometrically by $> 3\sigma$, which can not be explained by Keplerian orbital motion of a single object for reasonable stellar mass and distance.

The L' source was independently discovered by another ESO group in July, 2013, and followed up with the Gemini Planet Imager (GPI) in Apr, 2014 (Reggiani et al 2014). This team detected no sources, placing a 5σ limit of $J > 13.8$ mags at the location of the L' detection. Note that we adopt this as the limit at the location of our H/K_S source as well.

The observations of these sources to date are summarized in Table 1.

The brightness of the L' source corresponds to a more than $30-40M_{Jup}$ brown dwarf according to hot-start evolution models (Biller et al. 2014 and Reggiani et al. 2014). Such an object should have an H brightness 4 magnitudes brighter than the (different) source we detected with MagAO in H and K_S, and should have been readily detectable in the GPI J band observations of Reggiani et al. A high mass would also disrupt the ring-like structures in the disk that we described above. We also did not detect either source at z' with MagAO+VisAO, and combined with the non-detections at J with GPI and H/K_S with MagAO (for the L' source), the colors of these sources argue against a background star, which should be much bluer.

These arguments lead us to conclude that we are not detecting emission from the photosphere of a planet or brown dwarf at L'. However, at 16 AU projected separation, the luminosity of the L' point source is too high to be produced by a dust feature passively heated by the star. The energy source for the L' object is therefore a mystery.

Possible Interpretations of Both Sources:
Single Background Object: One possible interpretation is that we have detected the same unassociated background object at two epochs. We consider this to be very unlikely for the following reasons. The astrometry is different between the two epochs by $> 3\sigma$, and shows a proper motion difference of ∼140 mas/year to the NE. This is much greater than expected from the 40 mas/year due south proper motion of the primary. Combining the photometry indicates an extremely red object. Though this could possibly be explained by reddening of a distant background object, we would not expect such an object to exhibit such high proper motion. In any case, if this is the correct interpretation the observations we propose here will be definitive.

One Source Is Background: Another possible outcome is that one object is background, and the other is bound. This is a priori unlikely geometrically. As discussed above, non-detections at blue wavelengths disfavor either being a background star. If this unlikely explanation is correct, MagAO is uniquely capable of showing this with our ability to follow up at both H and with our (to be installed) coronagraphic L' imaging capabilities.

Table 1 HD 169142 Candidates

Object	Sep[1] ["]	PA[1] [deg]	J [mag]	H [mag]	K_S [mag]	L'[1] [mag]
1 (L' Disk Feature)	0.13 ± 0.02	4.5 ± 8.8	> 13.8	—	—	12.15 ± 0.26
2 (H/K_S Source)	0.18 ± 0.03	33 ± 10	> 13.8	17.9 ± 0.5	18 ± 0.5	—

[1]Values for the L' feature are weighted means of Biller et al and Reggiani et al results

Planet Plus Disk Feature: The most intriguing possibility is that we are witnessing an on-going planet formation process in the disk of HD 169142. We consider this to be the most likely case given all of the above arguments. At least superficially these features resemble those of LkCa 15 (Kraus and Ireland 2012), where a K point source is associated with extended trailing L emission. For HD 169142 this interpretation means that the H/K_S detection is the photosphere of a $< 10\ M_{Jup}$ planet (using COND or Dusty hot-start evolution) and the L' detection is an associated feature in the disk, possibly heated by jets from the protoplanet.

A Mystery For MagAO: The detection of two point sources near or within the inner ring of the HD 169142 transition disk raises the tantalizing possibility that we have a chance to study a still forming planet. The sources are close to each other, but both astrometry and photometry make either being a background object unlikely, while they can not be the same bound object. The MagAO follow-up observations we present here will allow us to evaluate whether these objects are bound to the star, analyze their planetary nature, and further study their relationship to each other. If their planetary nature is confirmed, these observations will yield the first bona fide detection of a protoplanet.

References

Biller et al., ApJ 792:L22, 2014
Close et al., ApJ 781:30, 2014
Kraus & Ireland, ApJ 745:5, 2012
Najita et al., MNRAS 378:369
Quanz et al., ApJ 766:L2, 2013
Reggiani et al., ApJ 792:L23, 2014

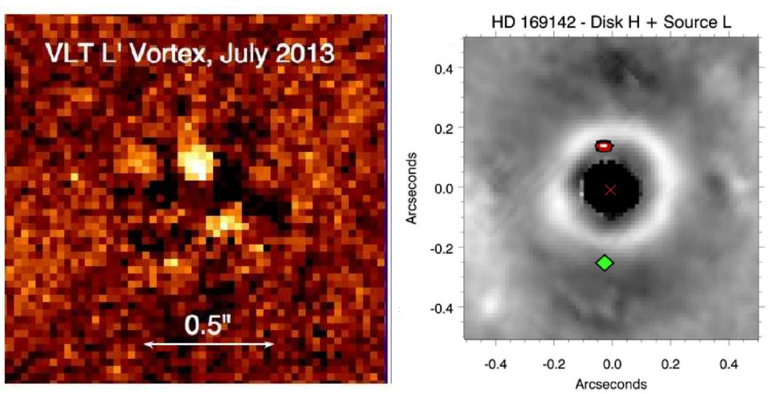

Figure 1 The L' sources in the HD 169142 transition disk. **Left:** the VLT+NACO detection from Biller et al (2014). **Right:** The location of the (independent) VLT+NACO detection of Reggiani et a (2014, figure from that paper), indicated in red, overlaid on the H-band PDI image of the inner ring of the disk. The green diamond marks the location of a compact radio source not detected in either study, nor in our MagAO follow-up.

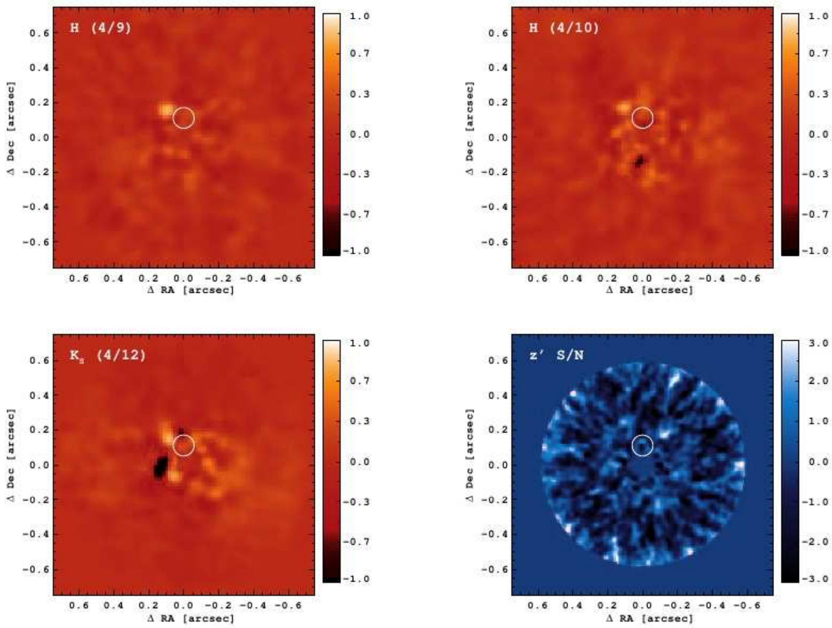

Figure 2 Observations with MagAO in H, K_s, and z'. The white circle shows the location of the L' source (see Figure 1. In the H and K_S images a source is visible to the NE of the circle. This is distinct from the L' emission. We believe the most likely explanation is that this H/K_S source is the photosphere of a planet, and the L' emission is a related consequence of on-going planet formation (see the scientific justification). Figure from Biller et all (2014).

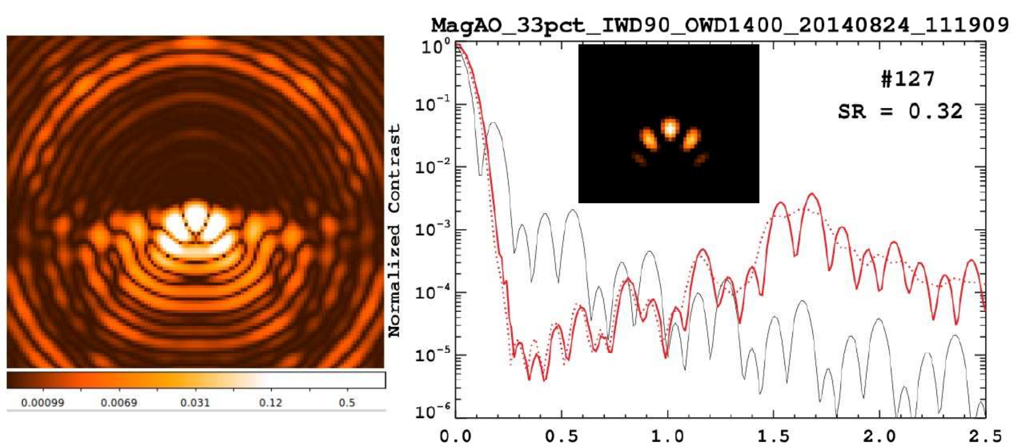

Figure 3 A new apodizing phase plate (APP) design for MagAO+Clio2 will be procured and installed for the 2015A MagAO run, allowing us to follow-up the L' detection. We have optimized this aggressive coronagraphic pupil plane apodizer for achieving very high contrasts at tight separations around bright stars. At left is the design PSF at L', and at right is the resultant dark-hole profile (solid red) compared to the Airy pattern for MagAO (solid black). Dashed red is the profile in a 10% bandpass. Note that these are raw (unprocessed) contrasts. We conservatively assume an $\times 10$ improvement over this from the advanced PSF subtraction techniques we will employ. The resultant $\Delta L' \sim 7$ detection limit (5σ) at $\sim 0.15''$ will allow us to clarify the nature of the sources along and within the dust ring at $0.17''$.

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)***

ADI: These observations require angular differential image (ADI) to support point spread function (PSF) subtraction. A key challenge is the declination (-29) of the target, which is nearly identical to the latitude of Las Campanas Observatory, resulting in a nearly 90^o transit and a high rotation rate. Our previous observations of this target have proven that the Magellan Clay telescope and MagAO can track through transit with no difficulties. This high transit means that only about 3 hrs per night can be utilized (1.5 hrs on either side of transit). The effectively 0 rotation rate beyond that limits the utility of further integration per night, and we are contrast limited, rather than photon-noise/exposure-time limited.

$\mathbf{H/K_s}$**:** As we have observed this target already, we will repeat the H and K_S observations in nearly identical fashion. We found that 164 msec reads in H were shallow enough to prevent primary star saturation while deep enough to limit the effects of read and background noise. These were coadded in 6.5 sec exposures prior to saving, which was not so long as to cause smearing at transit. In K_S we will use 400 msec exposures coadded to 6 secs. We plan to devote one observation each to H and K_S. Accounting for readout efficiency and nodding for background subtraction, total exposure time in each filter will be ~ 4300 sec. As noted above, we will rotation limited, not exposure-time limited.

$\mathbf{L'}$**:** The L' observations, due to the very tight separation ($< 2\lambda/D$), will require at least 2 observations. We will make use of an apodizing phase plate (APP) coronagraph which is funded, designed, and we are in the process of procuring. The PSF and resulting raw-contrast are show in Fig 3. This new APP design is optimized specifically for this type of observation: a very small separation planet candidate around a bright star. We anticipate needing at least 2 transits (2 nights) to provide enough PSF rotation to isolate the candidates from the PSF itself.

Optimum L' exposure times vary, but are typically short due to sky background. We will set readout time to avoid saturating the sky while minimizing the effect of readout noise, and coadd to no longer than 6 secs based on the results of our previous H and K_S observations.

Standards and Acquisition: We will need $\sim$ 20 minutes before and after each observation for standard and PSF star observations. PSF measurement will be especially important for using the APP coronagraph, which changes the instrumental PSF (see Figure 3). The MagAO acquisition sequence takes $5 - 10$ minutes depending on whether collimation is required (a function of slew size). We estimate a total of ~ 1 hr per night for acquisition and standard star observations.

VisAO: Though the primary focus of these observation is the infrared with Clio2, we will also utilize data from VisAO which can be taken at no cost. These will be in the SDI mode at $H\alpha$, attempting to go as deep as possible to search for any signatures of accretion in the disk.

Time Request: We ask for 1.5 nights (16 hrs) total time, to be spread over the 2nd half of 4 separate nights, to give 1 observation in H, 1 observation in K_S, and 2 observations in L'. As is usual for MagAO, we will coordinate sharing with other observers as necessary to maximize efficiency during the run.

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 devoted a $\sim 1/2$ night to following up the VLT L' candidate in 2014B.

We request 1.5 nights for this project in 2015A.

Though future observations will likely be warranted to further characterize this system (especially if either or both candidates are confirmed), the observations proposed here are self-contained and will provide a definitive answer about the nature of the candidates.

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**)*

⋆ We devoted a $\sim 1/2$ night to following up the VLT L' candidate in 2014B.

⋆ Biller, Males, et al., "An Enigmatic Pointlike Feature within the HD 169142 Transitional Disk." ApJ 792:L22, 2014

⋆ Close, Follette, Males, et al., "Discovery of Halpha Emission from the Close Companion inside the Gap of Transitional Disk HD 142527." ApJ 781:30, 2014

⋆ Co-I Follette was allocated 2.0 nights in 2014A for the GAPPlanetS project with MagAO, executed in April, 2014. This project is closely related to the present proposal, and several papers are in preparation based on these data. Observations of HD 169142 at $H\alpha$ are part of GAPPlanetS.

The PI was allocated 1.0 nights in 2014A for observations of $alpha$ Cen A with MagAO, which were executed in April, 2014. A paper is in preparation.

The PI received 0.5 nights in 2014A for observations of GJ 3629 A&B, a main sequence + brown dwarf binary. These observations were carried out successfully using the LBT, and the analysis is in progress.

In the last two years allocations of Arizona time to Magellan AO have resulted in the following publications from the MagAO team:

Males et al., "Magellan Adaptive Optics first-light observations of the exoplanet β Pic b. I. Direct imaging in the far-red optical with MagAO+VisAO and in the near-IR with NICI", APJ 786:32, 2014.

Follette, K. B., et al. "The First Circumstellar Disk Imaged in Silhouette at Visible Wavelengths with Adaptive Optics : MagAO Imaging of Orion 218-534". ApJ, 775, L13, 2013

Close, L. M., et al. "Diffraction-limited Visible Light Images of Orion Trapezium Cluster With the Magellan Adaptive Secondary AO System (MagAO)". ApJ, 774, 94, 2013

Wu, Y. L., et al. "High Resolution H alpha Images of the Binary Low-mass Proplyd LV 1 with the Magellan AO System". ApJ, 775, 45, 2013

Kopon, D., et al. "Design, implementation, and on-sky performance of an advanced apochromatic triplet atmospheric dispersion corrector for the Magellan adaptive optics system and VisAO camera". PASP, 125, 966, 2013

Morzinski et al., in prep. "Magellan AO First-Light Observations of Beta Pictoris b. II. High-contrast imaging at 2—5um with MagAO/Clio"