OBSERVING REQUEST
University of Arizona Observatories

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

SunCats: Surveying the Unique Nature of Companions Across The Substellar regime

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CoI(s): Laird Close (SO), Phil Hinz (SO), Jenny Patience (ASU), Travis Barman (LPL), Jared Males (SO), Andy Skemer (SO), Rob De Rosa (Berkeley), Vanessa Bailey⋆ (SO), Kim Ward-Duong⋆ (ASU), Abhi Rajan⋆ (ASU), Ya-Lin Wu⋆ (SO)

Abstract of Scientific Justification

Substellar objects from 5–30M_{Jup} include brown dwarfs (BDs) and extrasolar giant planets (EGPs). These objects are crucial stepping stones towards better understanding the astrophysical properties of planets. While spectral type encodes the properties of a main sequence star, there does not exist a comparable classification of substellar objects. This is due to the degeneracies of age, mass, temperature, gravity, and dust properties as they affect the SED of a BD or EGP. Therefore, it is critical to observe benchmark objects that are companions to main sequence stars with well-determined ages, in order to constrain and calibrate model atmospheres, ultimately leading toward a full picture of the properties and evolutionary pathways of substellar objects. Toward this end, our ASU-UA "SunCats" project (Surveying the Unique Nature of Companions Across The Substellar regime) is dedicated to investigating the properties of substellar objects. We are obtaining comprehensive O/IR SEDs of ∼50 low-mass companions ($< 30M_{Jup}$) to main-sequence stars. Our targets are selected for their viability as stepping stones along the pathway from brown dwarfs to extrasolar planets. MagAO is the *only* instrument capable of 0.5–5μm high-contrast imaging of faint companions near bright stars. Most of our sample were discovered in the near-IR; few have been followed up outside of $JHKL$. This semester, we propose to obtain spectrophotometry of ∼10 low-mass companions with MagAO/Clio2 in narrow bands from 3–5μm, while simultaneously searching for Hα accretion of the young objects with MagAO/VisAO. *Our observations across the O/IR will sample $\gtrsim$70% of the flux of these substellar companions for the first time — providing comprehensive constraints to model atmospheres for linking observable quantities to physical properties.*

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	MAG2	AO	MagAO+Clio2/VisAO		*	1.5	bright	May–Jun	May–Jun	yes	yes

Scheduling constraints and unusable dates *(up to 4 lines)*: Subject to MagAO observing schedule.

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 95086 b	10:57:03	-68:40:02	$V\sim7.4$, $\rho=0''.6$, $\Delta L\sim10$
2	CT Cha B	11:04:09	-76:27:19	$V\sim12.4$, $\rho=2''.67$, $\Delta K\sim6$
3	CHXR 73 b	11:06:29	-77:37:33	$J\sim12.7$, $\rho=1''.3$, $\Delta K\sim4.7$
4	2MASS 1207 b	12:07:33	-39:32:54	$I\sim16$, $\rho=0''.88$, $\Delta L\sim4$
5	2MASS J12073100-3932281	12:07:31	-39:32:28	$R\sim14.2$ guide star, $38''$from 2M 1207
6	HD 106906 b	12:17:53	-55:58:32	$V\sim8$, $\rho=7''$, $\Delta L\sim8$
7	Ross 458(AB) c	13:00:47	+12:22:33	$V\sim9.8$, $\rho=10''.25$, $\Delta K\sim11$ (VisAO data for Wu's project)
8	GJ 504 b	13:16:47	+09:25:27	$V\sim5.2$, $\rho=2''.5$, $\Delta L\sim13$
9	CFBDS 1458 b	14:58:29	+10:13:43	$J\sim20$, $\rho=0''.11$, $\Delta K\sim2$
10	USNO-B1.0 1002-00236935	14:58:31	+10:14:29	$R\sim15.4$ guide star, $58''$from CFBDS 1458
11	GQ Lup B	15:49:12	-35:39:03	$V\sim11.4$, $\rho=0''.74$, $\Delta K\sim6$
12	HIP 77900 B	15:54:30	-27:20:19	$V\sim6.1$, $\rho=22''.$, $\Delta K\sim7.7$
13	HIP 78530 B	16:01:55	-21:58:49	$V\sim7.2$, $\rho=4''.53$, $\Delta K\sim7$
14	USco1602-2401 B	16:02:51	-24:01:50	$J\sim12.5$, $\rho=6''.9$, $\Delta K\sim2.7$
15	UScoCTIO 108 b	16:05:54	-18:18:43	$I\sim15.7$, $\rho=4''.6$, $\Delta K\sim2.5$
16	USNO-B1.0 0716-0343103	16:05:53	-18:19:13	$R\sim12.7$ guide star, $34''$from UScoCTIO 108
17	1RXS1609 b	16:09:30	-21:04:58	$R\sim12.4$, $\rho=2''.38$, $\Delta K\sim7.3$
18	USco1610-1913 B	16:10:32	-19:13:09	$J\sim13.9$, $\rho=5''.8$, $\Delta K\sim3.7$
19	USco1610-2502 B	16:10:19	-25:02:30	$V\sim11.4$, $\rho=5''$, $\Delta K\sim2.9$
20	USco1612-1800 B	16:12:49	-18:00:50	$K\sim13.2$, $\rho=3''.0$, $\Delta K\sim2.8$
21	GSC 06214-00210 b	16:21:55	-20:43:07	$R\sim12.1$, $\rho=2''.21$, $\Delta K\sim5.7$
22	Oph 16 B	16:23:36	-24:02:21	$R\sim17$, $\rho=1''.7$, $\Delta K\sim0.7$
23	ROXs 12 B	16:26:28	-25:27:25	$J\sim11.0$, $\rho=1''.8$, $\Delta K\sim5$
24	ROXs 42 b	16:31:15	-24:32:44	$I\sim11.7$, $\rho=1''.2$, $\Delta K\sim6$ (VisAO data for Wu's project)
25	SR 12 AB c	16:27:20	-24:41:40	$V\sim13.3$, $\rho=8''.66$, $\Delta K\sim6$
26	Fomalhaut b	22:57:39	-29:37:20	$V\sim1.16$, $\rho=14''.92$, $\Delta I\sim23$

Approval for Instrument Use from PI: N/A

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
Vanessa Bailey	Phil Hinz		no	no
Abhi Rajan	Jenny Patience		no	no
Kimberly Ward-Duong	Jenny Patience		no	no
Ya-Lin Wu	Laird Close		no	no

Scientific Justification

The H-R diagram is the "fundamental plane" of stellar astrophysics, uniquely describing main-sequence stars in terms of mass and spectral type. The spectral type of a substellar object, on the other hand, does not uniquely constrain its mass nor its evolution: brown dwarfs evolve from earlier to later spectral types as they age, due to cooling and contracting without the support of sustained nuclear fusion. Therefore, substellar objects must be described in a higher-dimensional parameter space. Models indicate that the effects of mass, temperature, gravity, and composition have degenerate contributions to the emergent flux from a brown dwarf (BD) or extrasolar giant planet (EGP) (see Fig. 1). This is due to the diversity of initial conditions (initial entropy), cooling rate (opacity), gravity (line profiles, dust content), mixing, and more (*e.g.* Allard et al. 2013, Liu et al. 2013, Marley et al. 2012).

Thus, brown dwarf models must sometimes be re-calibrated to accurately describe extrasolar giant planets — for example, the atmospheres of the four EGPs around HR 8799 cannot be self-consistently reproduced; instead, each new spectrophotometric measurement can only be explained by invoking different phenomena, from thick clouds to spatial inhomogeneities to non-equilitrium chemistry (*e.g.* Barman et al. 2011, Madhusudhan et al. 2012, Marley et al. 2012, Skemer et al. 2012, Skemer et al. 2014). On the other hand, the $\sim$12-M_{Jup} planet β Pic b is looking very much like an early L dwarf (Fig. 2a; Males et al. 2014, Morzinski et al. 2014).

Two new observational additions have the potential to enable significant advances in modeling: 3-4 μm narrowband photometry and increased SED wavelength coverage. Firstly, finer SED sampling in the thermal wavelengths where a majority of the flux is emitted can distinguish between the degenerate effects of C/O ratio, $CO \leftrightarrow CH_4$ disequilibrium chemistry, and cloud opacity that obscures the CO and CH_4 bandheads. Secondly, a broader SED range (from visible to thermal-infrared) will allow us to sample the majority of the flux ($\gtrsim$70%) to improve estimates of bolometric luminosity, which gives an important constraint to radius, gravity, and bulk composition. This is an ideal science case that fully utilizes the powers of MagAO, exploiting its excellent thermal throughput and image quality, unique 3–5μm filters, and its superb high-order wavefront control that produces $\lesssim$20 mas resolved images at 0.5–1μm.

The SunCats project is focused on BDs and EGPs as companions, in order to allow the primary star to be leveraged both for AO correction and for determining the system age and composition. Most substellar companions are discovered in the near-IR, and some are followed up with JHK spectra or L' imaging. *MagAO has a unique capability to complete the O/IR SEDs of these objects with VisAO and Clio2.* This was demonstrated during commissioning, with detections of the β Pic b planet at Y_s, [3.1], [3.3], L', M' (Males et al. 2014, Morzinski et al. 2014). Our contrast is shown in Fig. 2b — $\Delta L' \sim 10$ at 0$''$.6 is sufficient to image our most challenging targets. We are acquiring new vector Apodizing Phase Plate (vAPP) coronagraphs and will use them to improve contrast at the closest inner working angles (see proposals by Close and Males).

Spectrophotometry, specifically with the addition of Arizona-specific 3–4 μm narrowband filters, has already proven a powerful tool for testing model atmospheres. Figure 3 shows recent atmospheric modeling of HR 8799 b (Skemer et al. 2012, 2014). The H and K spectra are best fit by a cloudy non-equilibrium model at T_{eff}=850 K. This same model also fits the JHK photometry, but the [3.3] and L' bandpasses are both sensitive to CH_4 opacity, and they cannot be simultaneously fit by the HK-spectra-preferred cloudy model. The M' photometry is also ill-fit by the model. Besides cloud opacity in M, CO opacity at the 4.5-μm bandhead could be due to either disequilibrium $CO \leftrightarrow CH_4$ chemistry or to C/O ratio. Therefore, resolving the [3.3] and L' discrepancy will also inform fitting the M' point. The 3.3-μm bandpass used in these first-light LBT AO observations of HR 8799 is unique to Arizona instruments, and is highly sensitive to the 3.4-μm CH_4 feature (Hinz et al. 2010). The difficulties in simultaneously fitting the [3.3] and L' photometry, even with disequilibrium chemistry, indicates the importance of this new photometric measurement to the models (Skemer et al. 2012). MagAO/Clio2 also has this filter (Phil Hinz, P.I.), and *an important outcome of our program will be to explore the [3.3]-L' colors and M' photometry in our sample of young planets and brown dwarfs.* Additionally, the flux of these low-temperature objects peaks in the thermal IR; therefore, 5μm imaging is crucial to constraining the bolometric luminosity of these objects.

During MagAO commissioning, we observed a subset of our sample: the $\sim$12-M_{Jup} 0$''$.46 companion to

A-star β Pic at Y_s, [3.1], [3.3], L', M' (Males et al. 2014, Morzinski et al. 2014); the $\sim$13-M_{Jup} 5.″8 companion to K-star AB Pic at i', z', Y_s, [3.1], [3.3], L', M' (Fig. 4; Patience, De Rosa, Ward-Duong et al. 2013); the $\sim$4-M_{Jup} 0.″88 companion to M-dwarf 2MASS 1207 at [3.3] (Skemer et al. 2014); and the $\sim$17-M_{Jup} 2.″7 companion to K-star CT Cha and the $\sim$12-M_{Jup} 1.″3 companion to M-dwarf CHXR 73 at $H\alpha$, [3.1], [3.3], L', M' (Wu et al. 2014; Morzinski et al. 2014). The data analysis has included a thorough commissioning and calibration of the VisAO and Clio2 instruments (linearity, throughput, photometric calibration, distortion, astrometric calibration, bad pixels, etc., by Morzinski for Clio2); papers are in preparation at this time.

For 2014B, we propose to complete the SEDs of our objects that are observable from Magellan in June. The target list shows our 23 objects that are up in June, which we will prioritize as follows. The target list shows 23 objects (plus 3 guide stars) on our list that are up in June. We will prioritize our targets based on science return and feasibility for the observing conditions, and we aim to complete the $[3.1]$, $[3.3]$, L', M' photometry of these objects. Furthermore, the visible-light data of most of these objects is almost completely unconstrained: we will exploit MagAO's dual-channel capabilities to simultaneously obtain VisAO images at 0.5–1μm, with narrow-band SDI and broad-band imaging.

In all, our observations will increase the SED range, obtaining a complete picture of the atmospheres of substellar companions with broad and well-sampled O/IR SEDs. Our targets — low-mass companions to main-sequence stars — are also viable as stepping stones along the pathway from brown dwarfs and EGPs to exo-earths.

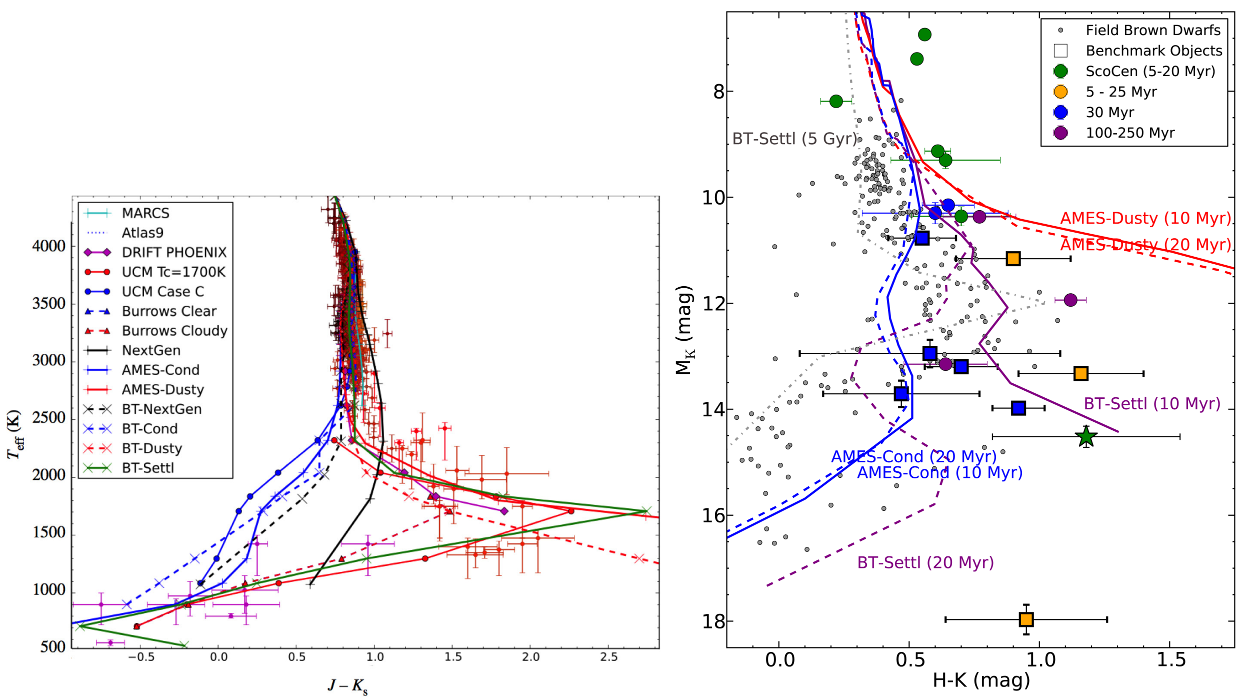

Figure 1 Left: J-K CMD of substellar models compiled by Allard et al. 2013. Field objects are shown, and the range of models used to explain them. The main sequence M-stars give way to LTY brown dwarfs and planets. Scatter is due to the diversity of physical phenomena in substellar atmospheres. Right: H-K observational CMD by Patience. The SunCats targets include the 5–20 Myr ScoCen association, which show the properties of young forming planets. Substellar atmospheres are degenerate in mass, temperature, age, and dust properties.

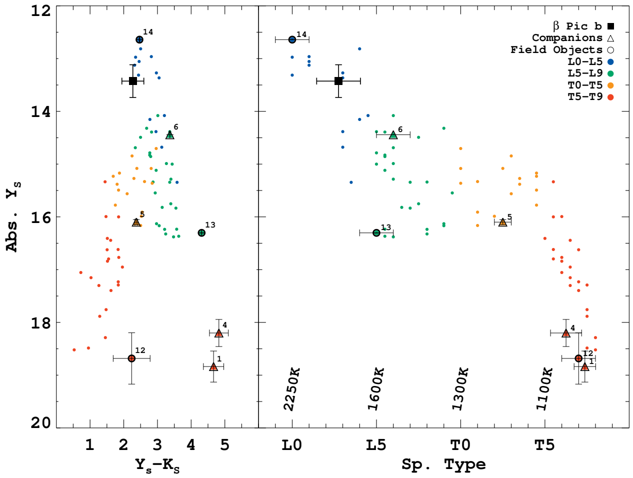

Figure 2 Photometry of β Pic b in Y_s (MagAO/VisAO), compared to field dwarfs and other planets (Males et al. 2014). Our results imaging β Pic b at 5 filters during first light demonstrate the superb performance of MagAO.

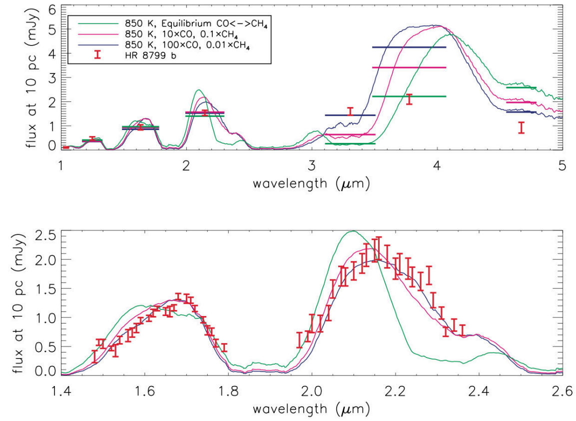

Figure 3 LBT AO observations and atmospheric model spectra of HR 8799 b (Skemer et al. 2012). Particular difficulties are encountered with fitting the HK-spectra-preferred model to the [3.3] and L' photometry simultaneously. This illustrates the importance of the 3.3-μm, L', and M' measurements.

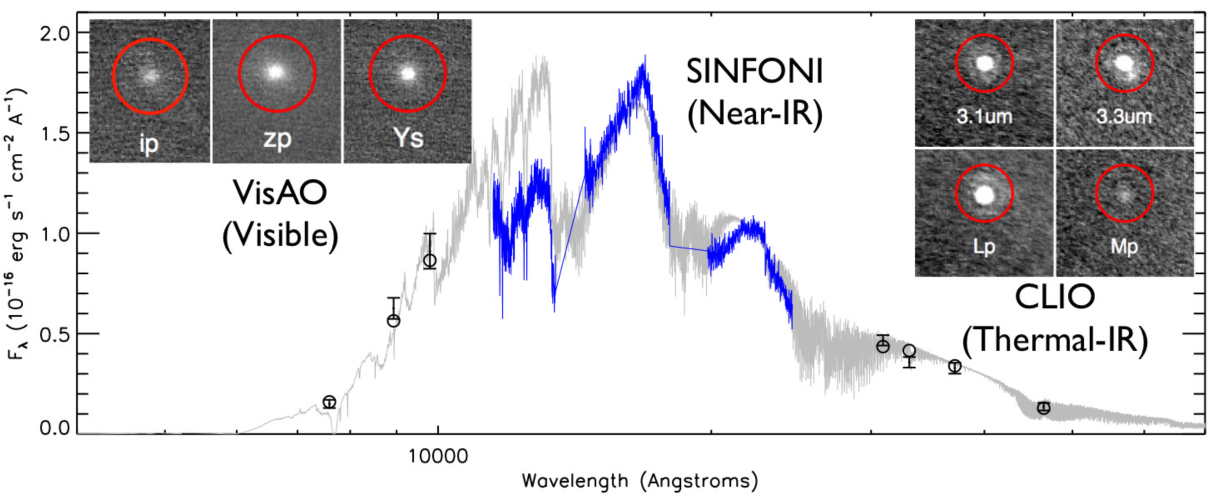

Figure 4 Spectral energy distribution of AB Pic b (Ward-Duong et al. 2014). VisAO and Clio2 imaging via De Rosa & Ward-Duong et al. 2013 (MagAO commissioning); SINFONI spectrum by Patience et al. 2012. This work nicely illustrates the observational goal of SunCats.

References

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Allard, F., et al., 2013, Memorie della Societa Astronomica Italiana Supplement, 24, 128.
Barman, T., et al., 2011, ApJ, 733, 65.
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Delorme, P., et al., 2013 A&A 553, L5.
De Rosa, L., et al., 2014, in prep.
Hinz, P., 2010, ApJ 716, 417.
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Madhusudhan, N., et al., 2011, ApJ, 737, 34.
Marley, M., et al., 2012, ApJ, 754, 135.
Males, J., et al., 2014, ApJ 786, 32.
Morzinski, K., et al., 2014, ApJ in prep.
Skemer, A., et al., 2012, ApJ, 753, 14.
Skemer, A., et al., 2014, ApJ 792, 17.
Ward-Duong et al. 2014, IAUS, 299, 74.
Wu, Y.-L., et al., 2014, in prep.

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)***

Observational procedure The magnitudes of the primaries are given in the target list, and are varied. For those targets with $R\lesssim$10–11 the AO system will give $\lesssim$125–175 nm rms WFE (Strehls of 15–35% at i' and 90–95% at L') and so high contrasts and SNRs will be reached in only $\sim$10–20 minutes per filter. For those targets with $R\lesssim$14 we expect $\lesssim$200 nm rms WFE, which is still $\sim$90% Strehl in the infrared but just barely providing a diffraction-limited core (Strehl $\sim$10%) in the visible. Finally, for those targets with $R\sim$15–16 we expect $\sim$250 nm rms WFE, which will be seeing-limited on the VisAO science camera, but still gives Strehls of $\sim$85% in the infrared. Therefore, exposure times will vary depending on the guide star magnitude. During commissioning, we spent $\sim$2–3 hours per filter (with overheads) on the challenging objects (β Pic), and $\sim$20 minutes per filter (with overheads) for the less challenging objects. Based on this past experience, we estimate we will need $\sim$18 hours total (1.5 nights) to observe $\sim$10 more companions, where the target selection will be prioritized based on scientific gain.

The priority is to achieve completeness across the O/IR for each brown dwarf or planet, giving a complete set of $JHK[3.3]L'M'$ measurements. For many targets only the [3.3] and M-bands are lacking. VisAO observations are more challenging and exploratory, because few of these low-mass objects have been studied in the optical. In order to achieve a positive detection, we will start with imaging in the filter that is easiest to observe. If the companion is in the speckle-noise-limited regime ($\rho\lesssim0\farcs5$–$1\farcs$), Y_s is ideal for maximizing Strehl. If the companion is in the photon-noise-limited regime ($\rho\gtrsim1\farcs$), the z' filter maximizes throughput and still has a high Strehl. Finally, if the companion is expected to show accretion luminosity, the narrow-band Hα filter will be used in SDI (spectral differential imaging) mode. If a detection is confirmed above SNR$\sim$5, and if Clio2 is still imaging the target, photometry in other filters will also be obtained with VisAO. This was the plan we executed during commissioning, and as shown in Fig. 4, for *e.g.* AB Pic we were able to obtain detections in 3 VisAO filters at the same time as 4 Clio2 filters. On brighter guide stars, ($R\lesssim$10) VisAO science can be conducted simultaneously with Clio2 without impacting AO performance. On fainter guide stars ($R>$10) WFS-VisAO beamsplitter selections will be made to maximize AO performance in the mid-IR rather than VisAO throughput.

Both Clio2 and VisAO can be used with the instrument rotator turned off, such that angular differential imaging (ADI) can be used to calibrate and remove instrumental speckles from the images. ADI is vital to improve contrast by 2–3 mags when observations will be speckle-noise limited, which is for companions within the seeing halo, $\lesssim0\farcs8$ in the visible (=λ/r_0 where r_0 is the spatial coherence length of Kolmogorov turbulence). The radius of the seeing halo actually decreases slightly into the infrared because r_0 scales as $\lambda^{6/5}$, so the speckle-noise limited regime will be $\lesssim0\farcs5$ at M'-band. Therefore, at the longest wavelengths, background noise will limit the observations and ADI will not help for companions beyond $0\farcs5$ — normal nod-dither patterns will be used instead.

Targets The target list shows 23 objects (plus 3 guide stars) on our list that are up in June. Our priorities will be the following 10, and the others on the list as time allows:

1. HD 95086 b, 4.5 M_{Jup}, $T_{eff}\sim$750 K. We will also use this object to test the vAPP in Close's engineering proposal. However, we need SunCats time for full 3–5 μm coverage.
2. 2MASS 1207 b, 4 M_{Jup}, $T_{eff}\sim$1000 K — The 3.3 μm data were published in Skemer et al. 2014, and now we plan to tackle other narrowband filters within 3–4 μm.
3. HD 106906 b, a new planet discovered by Bailey using MagAO, 11 M_{Jup}, $T_{eff}\sim$1950 K.
4. CFBDS 1458 b, 6.5 M_{Jup}, $T_{eff}\sim$370 K.
5. Ross 458(AB) c, 8.5 M_{Jup}, $T_{eff}\sim$650 K — The VisAO data are for Wu's project.
6. ROXs 42 b, 10 M_{Jup}, a new planet as of late 2013 — The VisAO data are for Wu's project.
7. ROXs 12 B, 16 M_{Jup}, a new BD as of late 2013.
8. GQ Lup B, 22 M_{Jup}, $T_{eff}\sim$2400 K.
9. 1RXS 1609 b, 14 M_{Jup}, $T_{eff}\sim$1800 K, only M'-band is still needed.
10. GJ 504 b, 4 M_{Jup}, $T_{eff}\sim$510 K — A very interesting object and would be a much higher priority, but Skemer et al. have observed this planet with the LBTI/AO and it is very faint; we will try [3.9].

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**)*

P.I. Morzinski is a Sagan Fellow at Steward from Nov. 2011–Oct. 2014 and her fellowship was awarded specifically for this work: integrating and commissioning the high-contrast MagAO instrument and then using it to constrain EGP atmospheres at 0.5–5μm, as follow-up to Gemini Planet Imager (GPI) detections. Beginning Nov. 2014 she is the MagAO Instrument Scientist at Steward. The is the third request for this program; the first obsevations are reduced and analyzed, and in preparation for publication; the second observations are being conducted in Nov. 2014. Morzinski presented β Pic results at the AO4ELT conference in Florence in May, the IAU 299 conference in Victoria in June, and Protostars & Planets VI in Heidelberg in July, and has publications in prep regarding the previous observations.

Team Each member of the team is interested and experienced in exoplanets and instrumentation. Co-I.'s will be leading different aspects, such as looking at different research questions or objects. Core members of the MagAO/VisAO/Clio2 instrument team are listed because their work is critical to obtaining these observations. Professors Patience is a lead Co-I of the GPI science team and also interested in characterizing young exoplanet atmospheres, and brings with her a team of students and postdocs whose help will be critical to managing the data and analysis. Professor Barman is also a lead Co-I of the GPI science team and is an expert in modeling substellar atmospheres.

This proposed MagAO program will be coordinated and combined with related LBTAO programs (PI: Patience) to build a comprehensive understanding of young substellar atmospheres across mass, age, and temperature. We would like to see the community of Arizona astronomers capitalize upon our telescope resources to secure a leadership position in the observational aspects of the emerging field of comparative exoplanetology.

Scope In one sense, the 2015A semester is a pathfinder for a larger campaign to obtain follow-up observations at multiple bandpasses in order to characterize new exoplanets detected by GPI, which will be online from 2014. In another sense, of course, the scientific content of this proposal stands alone for its importance to understanding model atmospheres.

Other facilities No other facilities are being used for this project by Morzinski. However, Patience has a sample of objects that also includes northern-hemisphere targets to be imaged with LBTAO. No non-UAO telescopes are being used for the specific goal of this program, which is to characterize exoplanet and brown dwarf atmospheres across the O/IR spectrum.

Time We request 1.5 night for this program in 2015A. We will aim to complete 10 targets for this semester's program and on average each target will be imaged in 2–4 Clio2 bandpasses ([3.1], [3.3], L', M') with a characteristic integration time of 1.5 hours per target, which is then $\sim$15 hours for all the targets and filters, plus overhead brings us to $\sim$18 hours or $\sim$1.5 night.

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)***

Over the past 2 years, Morzinski has not applied for any time for the present project. Morzinski had 4 nights of MMTAO time in Jan. 2012 to follow-up brown dwarf candidates in the Hyades, resulting in the following publication:

Morzinski et al. (2012) Proc. SPIE, "High-contrast imaging in the Hyades with snapshot LOCI" and two publications in prep.

PI Morzinski is a core member of the MagAO team, and she was responsible for scheduling the queue, taking Clio2 data, and commissioning the Clio2 camera during both commissioning runs of 2012–2013, each time spending a month with the instrument at LCO.

Morzinski's science work related to this project from commissioning is nearing submission:

⋆ Morzinski et al., "Magellan Adaptive Optics first light observations of β Pic b. II. High-contrast imaging at 2–5μm with MagAO/Clio2", ApJ in prep, 2014.

(Preliminary results were presented orally at 3 recent meetings, including 2 conference proceedings: AO4ELT in Florence, and IAU 299 in Victoria).

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

⋆ Skemer et al., "First light LBT AO images of HR 8799 bcde at 1.65 and 3.3 microns: New discrepancies between young planets and old brown dwarfs", ApJ 753, 14, 2012.

⋆ Skemer et al., "Directly imaged L-T transition exoplanets in the mid-infrared", ApJ 792, 17, 2014.

⋆ Ward-Duong et al. 2014, IAUS, 299, 74

There is a related project PI'd by Patience, entitled "LBT: 2013A — Thermal-IR measurements of substellar companions", with preliminary results presented at the IAU 299 meeting in Victoria (Ward-Duong, 2013).

Other results from commissioning MagAO include, which are crucial pathfinders for our more challenging observations:

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.

Close, L. M., et al., "Discovery of Hα emission from the close companion inside the gap of transitional disk HD 142527", ApJL, 781, 2, L30, 5, 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.

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.