**OBSERVING REQUEST**
**University of Arizona Observatories**

**Year:** 2015 **Term:** Sep–Dec **Proposal type:** short-term$^\star$

# Assessing the fundamental limits of (multiple) star formation and the origin of the brown dwarf desert

**P.I.:** Jennifer Patience (Arizona State University; *jennifer.patience@asu.edu*; (480) 727-8554)

**CoI(s):** Gaspard Duchêne (UC Berkeley), Kimberly Ward-Duong$^\star$ (Arizona State University), Rob De Rosa (UC Berkeley)

**Abstract of Scientific Justification**

We propose to continue a program initiated in semester 2015A to use the MMT adaptive optics systems with ARIES to conduct a survey for the lowest mass stellar companions to B-type stars in three young nearby open clusters. The immediate objective of the project is to determine the frequency of "extreme" mass ratio systems ($q < 0.1$) among close visual binaries. Such systems are remarkably rare for solar-type stars (≈1%), as indicated by the existence of the so-called brown dwarf desert. This phenomenon reveals a fundamental limit of the (multiple) star formation process which has two main possible interpretations: 1) an absolute companion mass limit that happens to roughly coincide with the substellar limit, or 2) a mass ratio limit, whereby accretion during the early stages of star formation precludes the existence of such asymmetric systems. The goal of this project is to take advantage of the independence of the mass ratio distribution with stellar mass to search for scaled up proxies of brown dwarf desert-like systems. By focusing on stars in the 3–8 $M_\odot$ range, we can unambiguously disentangle between the two possibilities mentioned above, thus shedding crucial new light on the limits of (multiple) star formation and on the origin of the brown dwarf desert. Here we propose to survey 63 B-type stars stars located in three nearby, young open clusters ($D \leq 350$ pc, 30–90 Myr).

**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 | ARIES | | * | 4 | bright | Nov | Nov–Dec | no | no |

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

*no text past this line*

A $^\star$ appended to the proposal type indicates a continuation proposal; a $^\star$ 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 | $\alpha$ Per | 03 22 00 | +48 37 00 | Open Cluster, 31 B-type stars |
| 2 | Collinder 65 | 05 26 05 | +15 41 59 | Open Cluster, 16 B-type stars |
| 3 | Platais 6 | 06 15 25 | +03 55 12 | Open Cluster, 16 B-type stars |

**Approval for Instrument Use from PI:** Please see attached email from Don McCarthy.

**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 |
|---|---|---|---|---|
| K. Ward-Duong | J. Patience | | no | no |

**Scientific Justification**

**Program Update:** This is the continuation of a project started during the 2015A semester. We were awarded 3 nights in early February, but we only got data for the equivalent of one half-night due to weather (humidity, wind, snow on dome) and technical problems (power supply switch related induced by road work that led to severe detector readout issues). Overall, we obtained data on only a dozen sources in mostly poor seeing, only 2 of which are part of the open clusters we targeted. Still, the run was useful in testing the basic strategy of the survey and in confirming that LOCI PSF subtraction could produce good results within the central arcsecond. While we are still working on pushing this subtraction to the limits, we are confident in our ability to achieve the goals stated in the proposal. The remainder of the proposal has only been adjusted to reflect slight changes to our target list and observing strategy.

This proposal aims at understanding one of the empirical limits of star formation, namely the formation of close visual binaries with extremely unbalanced mass ratios. These are extremely rare for solar-type stars but the fundamental reasons for this fact remain an open question, which we will tackle by searching for "scaled-up" systems consisting of low-mass companions to 3–8 $M_\odot$ stars.

Stellar multiplicity is thought to be the outcome of turbulent fragmentation of a collapsing prestellar core (Tohline 2002). Very low mass "seeds" (5–10 $M_{Jup}$) form and subsequently accrete from their parent core to reach their final mass. This inherently stochastic process is best probed by the ensemble population of multiple systems, i.e., the distribution of mass ratios ($q = M_2/M_1 \leq 1$). The observed distribution for visual binaries is remarkably uniform for stars with $0.3\,M_\odot \lesssim M_\star \lesssim 8\,M_\odot$ (Reggiani & Meyer 2013; Duchêne & Kraus 2013). This suggests that fragmentation and accretion on the seed binary proceed in a scale-free manner and can be studied by focusing on any population within this range (high-mass stars form through a different path; e.g., Zinnecker & Yorke 2007).

The brown dwarf (BD) desert is the remarkable dearth of 20–50 $M_{Jup}$ companions to solar-type stars from short orbital periods to projected separations of at least 300 au [1] (e.g., Grether & Lineweaver 2006; Chauvin et al. 2010; Leconte et al. 2010). Besides confirming that planetary mass and stellar companions are physically distinct, the BD desert raises the question of the physical mechanism that sets a lower limit to the mass of stellar companions. **Is the conjunction of this limit with the stellar/substellar boundary a mere coincidence or a profoundly revealing fact?** Specifically, is the lower limit for stellar companions effectively set at around the substellar limit ("fixed mass" limit), or is it instead an indication that binaries simply cannot form with more extreme mass ratios ($q \lesssim 0.1$, "fixed $q$" limit)? Either way, this phenomenon points to a fundamental limit in the physics of (multiple) star formation that is not yet understood.

Further observations of solar-type stars cannot resolve this ambiguity. Instead, the key idea behind this project consists in searching for extreme mass ratio companions to stars of different masses, for which the substellar boundary corresponds to a much different mass ratio. Low-mass stars seem to have a dearth of BD companion (e.g., Dieterich et al. 2012), hinting at a "fixed mass" limit, but detecting substellar objects around (on average very old) low-mass stars remains a steep observational challenge. Instead, **we propose to take the opposite route and to consider stars that are significantly more massive than the Sun, as a scaled-up proxy for BD-desert-like systems.**

Surveys of A- and F-type stars (1.5–2 $M_\odot$) have revealed a paucity of BD companions (e.g., Kouwenhoven et al. 2007; Janson et al. 2013), but the distinction between the "fixed mass" and "fixed $q$" scenarios is too narrow to be conclusive. To address this issue more effectively, **we propose to determine the mass ratio distribution of close visual binaries, and especially its low-$q$ end, for 3–8 $M_\odot$ (B3 to A0) stars, for which the gap between the "fixed mass" and "fixed $q$" limits is broad enough for a statistically significant conclusion.** Past companion searches to B-type stars (e.g., Duchêne et al. 2001; Shatsky & Tokovinin 2002; Leconte et al. 2010; Janson et al. 2011) could only detect faint stellar companions outside of 1″ ($\gtrsim$200 au), facing serious confusion issues and effectively probing a different separation range than

[1] While "extreme" binary systems ($q < 0.1$) may be somewhat more common at even wider separations (Metchev & Hillenbrand 2009), we note that these systems may form through different processes.

that of the BD desert. Here we propose to take advantage of the remarkable PSF stability provided by the MMT adaptive optcs system to probe low-mass stellar companions within the central $1''$. A substantial population of companions in the 0.075–0.5 $M_\odot$ range (well above the $\sim$1% characterizing the BD desert for solar-type stars) will readily exclude the "fixed $q$" limit scenario. On the other hand, a rarity of such companions would indicate that the accretion phase that follows the formation of "seeds" functions as an efficient regulator, precluding the formation of extremely unequal systems.

To ensure sample homogeneity and to maximize linear resolution for this present proposal, we have selected three Northern open clusters which share similar distances and ages: $\alpha$ Per, Collinder 65 and Platais 6. These clusters are nearby ($\approx$180–350 pc; van Leeuwen 2009; Kharchenko et al. 2005), ensuring that the proposed observations will probe companions at projected separations $\approx$50–300 au, i.e., well within the BD desert range. Also, these clusters span a range of age from 30 to 90 Myr (Stauffer et al. 1999; Kharchenko et al. 2005), i.e., young enough age that 3–8 $M_\odot$ stars are still on the Main Sequence, while their lowest mass companions are nearing the zero-age Main Sequence, which will enable a straightforward mass determination for the companions. Based on decades of studying these bright stars, the membership list of these clusters for intermediate- to high-mass stars is essentially complete and free of outliers. Specifically, we have used the following selection criteria: (extinction-corrected) $B - V \leq 0$ to select A0 and earlier -type stars; $R \leq 10$ to ensure good adaptive optics performance; and the absence of known close stellar companion in the Washington Double Star catalog as well as in archival HST and ground-based adaptive optics images to avoid adaptive optics guiding issues and saturation on bright companions. This leaves us with a list of 60 B3–A0 stars[2]. We will submit a proposal to observe B-type stars in three other clusters in semester 2015B to achieve sufficient statistical confidence. To place our results into a more global context, we also plan on surveying a significant population of field B-type stars, whose formation process may be different. In this proposal, we only plan on observing a few field stars when our targetted clusters are at too low elevations for good adaptive optics correction, but will later submit a dedicated proposal, based on a list of $\sim$100 field B-type stars within 100 pc of the Sun.

**One key advantage of studying 3–8 $M_\odot$ stars is that even extreme mass ratio systems have companions in the stellar regime**, which translates into much less stringent requirements on the achieved contrast compared to previous searches for substellar companions. As shown in Fig. 1, a contrast of $\Delta K \approx 9$ mag is sufficient to detect almost all stellar companions to stars with $M \leq 7\,M_\odot$. Still, such contrasts were only accessible outside of $1''$ in previous surveys and only companions with masses $\gtrsim$0.7 $M_\odot$ could be detected closer in. In other words, while the challenge of detecting extreme stellar binary systems is a comparatively easy one (relative to current exoplanet imaging searches), it has not been possible to address it in the separation range of the BD desert with past instrumentation (see Fig. 2). The proposed observations, taking advantage of the high quality and great stability of the PSF produced by the MMT adaptive optics systems will fill in this critical gap and help address the fundamental question of the nature of the brown dwarf desert.

**References:**

**Allard et al.** 1997, ARAA, 35, 137 – **Chauvin et al.** 2010, A&A, 509, A52 – **Dieterich et al.** 2012, AJ, 144, 64 – **Duchêne et al.** 2001, A&A, 379, 147 – **Duchêne et al.** 2007, A&A, 476, 229 – **Duchêne et al.** 2013, A&A, 555, A137 – **Duchêne & Kraus** 2013, ARAA, 51, 269 – **Grether & Lineweaver** 2006, ApJ, 640, 1051 – **Hunsch et al.** 2003, ApJ, 698 1989 – **Janson et al.** 2011, ApJ, 736, 89 – **Janson et al.** 2013, ApJ, 773, 170 – **Kharchenko et al.** 2005, A&A, 438, 1163 – **Kouwenhoven et al.** 2007, A&A, 464, 581 – **Lafrenière et al.** 2007, ApJ, 660, 770 – **Leconte et al.** 2010, ApJ, 716, 1551 – **van Leeuwen** 2009, A&A, 497, 209 – **Metchev & Hillenbrand** 2009 , ApJS, 181, 62 – **Raghavan et al.** 2010, ApJS, 190, 1 – **Reggiani & Meyer** 2013, A&A, 553, A124 – **De Rosa et al.** 2014, MNRAS, 437, 1216 – **Shatsky & Tokovinin** 2002, A&A, 382, 92 – **Smiljanic et al.** 2011, A&A, 535, A75 – **Stauffer et al.** 1999, ApJ, 527, 219 – **Tohline** 2002, ARAA, 40, 349 – **Zinnecker & Yorke** 2007, ARAA, 45, 481

[2]The list is available upon demand.

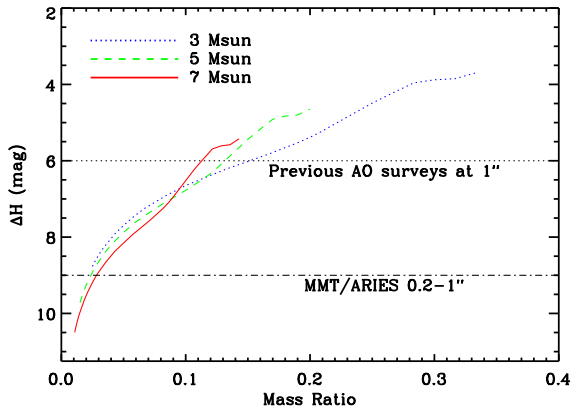


Figure 1: Relation between mass ratio $K$-band flux ratio for 3 $M_\odot$, 5 $M_\odot$ and 7 $M_\odot$ primary stars (blue, green and red curves, respectively) for an age of 50 Myr appropriate for our targets, based on the evolutionary models of Allard et al. (1997). Only stellar companions with masses in the 0.075–1 $M_\odot$ are shown here. The depth achieved by previous AO surveys of B-type stars at a separation of 1″ (Duchêne et al. 2001; Shatsky & Tokovinin 2002; neither could probe companions with $q \lesssim 0.1$ within 1″ of the target star) and the expected depth throughout the 0.″2–1″ range of of the MMT/ARIES observations proposed here are also indicated.

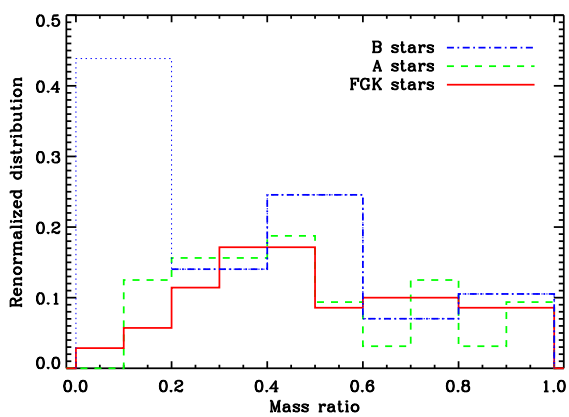


Figure 2: Mass ratio distribution for B-type, A-type and solar-type stars for visual binaries (blue, green and red histograms, respectively), renormalized over the whole [0,1] range for comparison purposes. The solar-type distribution (measured from 20 to 300 au; Raghavan et al. 2010) is the only one that is robustly estimated below $q$=0.1; the actual frequency of companions in this range is about 1–2% (Metchev & Hillenbrand 2009; Raghavan et al. 2010). The intermediate-mass stars distribution (measured from 20 to 125 au; De Rosa et al. 2014) is cut at the $q = 0.15$ completeness limit. Finally, the peak at low-$q$ for B-type stars (Shatsky & Tokovinin 2002) is overwhelmingly dominated by companions outside of 300 au and severely affected by confusion and small number statistics. That survey is therefore not a reliable probe of extreme mass ratio systems.

**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)***

The immediate objective of our program, finding the lowest mass *stellar* companions within 300 au of B-type stars requires a combination of high spatial resolution and high contrast that has long proved too challenging. The former is now routinely delivered by adaptive optics systems on large ground-based telescopes, such as the MMT system in the near-infrared. High contrast, such as necessary to discover substellar and planetary companions to nearby stars has focused on projected separations beyond $1''$, combining coronagraphy with advanced PSF subtraction methods (such as spectral and angular differential imaging). With state-of-the-art instrumentation (including so-called "extreme" adaptive optics systems), it now possible to achieve contrast ratios $\Delta K \gtrsim 12$ mag within the central $1''$. This is much more than necessary for the present project, for which a contrast of $\Delta K \approx 9$ mag is sufficient to detect virtually all stellar companions to B-type stars given the age of the clusters under consideration (see Figure 1). Instead, we propose to take advantage of the extremely stable PSF provided by the MMT adaptive optics system to build up high signal-to-noise and to reduce speckle noise in the immediate vicinity of the star to enable effective PSF subtraction. Typical surveys for stellar multiplicity use $\sim$10 short, unsaturated exposures, yielding a contrast of 6 mag outside of $0\farcs3$ and 8 mag at $1''$ on 8m-class telescopes (e.g., Duchêne et al. 2001, 2007, 2013). To achieve the deeper contrast needed for this program, we will gather many more such exposures for each target, which will allow for a good suppression of quasi-static speckles and for high signal-to-noise in the PSF wings.

Our targets are bright at optical wavelengths ($R \lesssim 9$), ideal for adaptive optics guiding. We will conduct this survey in the $K$ band, giving up the highest possible angular resolution in exchange for optimum quality and stability of the adaptive optics correction. Companions detected in real time will be followed-up with $J$ and $H$ observations to obtain color information, which will prove important to confirm the physical link with the primary target. The extreme mass ratio systems we are interested in, however, will most likely not be detected before post-processing and we will request dedicated follow-up time in another semester. Since our targets are relatively bright ($6 \lesssim K \lesssim 9$), there is a risk of saturating the target with broadband filter imaging. During our 2015A observing run, we have used a narrow band filter to avoid this, which has the additional benefit of precluding significant changes in PSFs induced by differences in intrinsic stellar colors. It is important to conduct the entire survey with a single filter in order to build a large library of potential PSF stars.

Our observing strategy will use the fixed pupil orientation (and its associated pattern of quasi-static speckles) to improve the quality of PSF subtraction. This will enable PSF subtraction via the LOCI algorithm thanks to paralctic field rotation (Lafrenière et al. 2007) which will substantially improve the achievable contrast even in the central arcsecond. In addition, with such a large, uniform dataset, we will also construct libraries of independent PSF frames to avoid the intrisic self-subtraction of the LOCI algorithm; this will improve our ability to detect faint companions at short separations from the star, where the amount of rotation necessary for LOCI subtraction becomes prohibitive. Based on our 2015A experience, we expect to acquire images for about 30-minute (clock-time), leading to 150–200 frames per target.

Since our targets are bright and observations will be conducted on-axis (with dithers of a few arcsecond), we do not anticipate any complication beyond nominal overheads (primarily 15 min for the acquisition of each target). With 63 targets, we thus request about 47h of telescope time, or four Winter nights. The ideal schedule is late-November, so that we can track the targets at the highest possible elevation. Observations earlier in November or in December are acceptable, with the first/last two hours of the night devoted to observations of field B-type stars in order to compare their proposerties to their clustered counterparts.

We emphasize again that the performance requirements for this project are much less stringent than those of recent surveys for substellar and planetary-mass companions. These searches are now best conducted on "extreme AO" systems (e.g., GPI, SPHERE). Instead, the performance required here is best matched to the capabilities of the MMT AO system.

**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)***

**UAO Telescope Time**

This is our second submitted proposal to conduct this project. As mentioned in the main justification, our first 3-night run was almost entirely lost to weather and technical problems (we only obtained one half-night worth of data, under strong winds from the East that led to poor adaptive optics performance). In order to observe B-type stars in other nearby open clusters, as well as among a similar-sized sample of field B-type stars, we anticipate requiring an additional 7–8 nights over the course of the next three semesters. Particularly interesting systems, with companions just above the substellar limit, will warrant additional follow-up (spectroscopic and/or photometric) observations, which will be requested separately.

**Collaborations**

Patience and her group are involved in several large survey programs – the **MinMs** (M-dwarfs in Multiple Systems) snapshot survey, the **VAST** (Volume-limited A-STar) survey, the **TBOSS** ("Taurus Boundary of Stellar/Substellar") collaboration, the **BAM** (Brown dwarf Atmosphere Monitoring) Project, and the **IDPS** (International Deep Planet Search) current AO system survey. Patience is the PI of the VAST survey which combined AO telescope access across a partnership of $\sim$10 collaborators to observe $\sim$250 A-stars. Patience is a co-I of the IDPS survey, which targets $\sim$250 young M-B stars, with primary responsibilities related to the B/A-star sample. Patience is a co-I of the BAM program that was extended to observe fainter brown dwarfs at the MMT. Publications and papers in progress from these surveys are listed below. Patience, De Rosa, Rajan, and Ward-Duong are Co-Is of the recently initiated **LEECH** LBT survey. Patience, De Rosa, Bulger, Rajan, and Ward-Duong are also members of the **GPI Exoplanet Survey** team to search for imaged planets in the North and South, and the Patience group has contributed to defining the target sets for both programs and some early observations with both LBT and Magellan instruments and GPI.

The MinMs and VAST publications thus far are student/postdoc-led: Ward-Duong et al. 2015 [**Stellar companions to M-dwarfs**], De Rosa et al. 2011 [**X-ray A-stars**], De Rosa et al. 2012 [**A-star orbits**], De Rosa et al. 2014, [**A-star binary statistics**], De Rosa et al. 2014 [**A-star brown dwarf detection**], Patience et al. 2015, in prep [**A-star debris disk binaries**], Schneider et al. 2015, in prep [**A-star binary age estimates**]. The TBOSS publications thus far are postdoc-led: Bulger et al. 2014 [**Herschel Disk Study**], Bulger et al. 2013 [**Submm Obs. of Debris Disks**] . The BAM publications thus far are student-led: Rajan et al. 2015 [**TY pilot study**], Wilson, Rajan, & Patience 2014 [**LT large scale survey**]. The IDPS A-star subset has been published by a postdoc working with Patience: Vigan et al. 2012 [**IDPS A-star initial results**].

**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**)*

**Companion Search - Allocations and Papers:**
**LBT: 2015A-UAO LBT low mass Taurus companion search** - *PI: Patience (1.5 nights)* - 60% useful.
**Magellan: 2014B-UAO - MagAO GPI target companion search** - *PI: Ward-Duong (2 nights)* - 100% useful, **2013B-UAO - FourStar GPI target companion search** - *PI: Patience (2 nights)* - not useful.
**MMT: 2015A-UAO-S236 - ARIES B-star companion search** - *PI: Patience (3 nights)* - 15% useful, **2015A-UAO-S239 - ARIES M-star companion search** - *PI: Ward-Duong (2 nights)* - 60% useful, **2014B-UAO-S39 - ARIES M-star comp. search** - *PI: Ward-Duong (4 nights)* - 20% useful, **2013A-UAO-S2 - ARIES A-star companion follow-up** - *PI: De Rosa (4 half-nights)* - 50% useful, **2013B-UAO-S2 - ARIES A-star comp. follow-up** - *PI: De Rosa (1 night)* - 75% useful.

⋆ **Patience et al. 2014**, *The TBOSS (Taurus Boundary of Stellar/Substellar) Survey of Disk Properties*, 2014 IAUS, 299, 224 - Sample for follow-up projects, including LBT proposal.
⋆ **Bulger et al. 2014**, *The Taurus Boundary of Stellar/Substellar (TBOSS) Survey I: far-IR disk emission measured with Herschel*, A&A, 570, 29 - Sample for follow-up projects, including LBT proposal.
⋆ **Skemer et al. 2014** *LEECH: A 100 Night Exoplanet Imaging Survey at the LBT*, 2014 IAUS, 299, 70.
⋆ **Ward-Duong et al. 2015**, *The M-dwarfs in Multiples (MinMs) survey - I. Stellar multiplicity among low-mass stars within 15 pc*, MNRAS, in press - Includes MMT data.

**Companion Characterization - Allocations and Papers:**
**LBT: 2013A - Thermal-IR substellar companion measurements:** - *PI: Patience (1 night)* - 50% useful.
**MMT: 2015A-UAO-S240 - ARIES substellar spec. characterization** - *PI: Rajan (1 night)* - 80% useful, **2013C-UAO-S11 - ARIES substellar spec. characterization** - *PI: Ward-Duong (2 nights)* - 0% useful, **2014A-UAO-S1 - ARIES substellar spec. characterization** - *PI: De Rosa (4 nights)* - 25% useful.

• **De Rosa et al. 2014**, *Debris Disks and Multiplicity within the 75pc Volume-limited A-Star (VAST) Survey* 2014 IAUS, 299, 334 - Includes MMT data.
• **De Rosa et al. 2014**, *The VAST survey - IV. A wide brown dwarf companion to the A3V star ζ Delphini*, MNRAS, 445, 3694 - Characterization most similar to MMT proposal, includes MMT data.
• **Maire et al. 2015**, *The LEECH Exoplanet Imaging Survey. Further constraints on the planet architecture HR 8799 system*, A&A, in press.
• **De Rosa et al. 2015**, *The VAST survey - V. Confirmation observations of low-mass companions to nearby A-type stars*, MNRAS - Analysis of MMT data complete, paper in progress.

**Brown dwarf Atmosphere Monitoring - Allocations and Papers:**
**MMT: 2012A-UAO-S3 - SWIRC brown dwarf (BD) variability monitoring** - *PI: Patience (2 nights)* - 75% useful, **2013A-UAO-S99 - SWIRC BD variability monitoring** - *PI: Rajan (2 nights)* - 0% useful.

• **Rajan et al. 2014**, *Searching for Photometric Variability across the L, T & Y Dwarf Sequence*, 2014 IAUS, 299, 301 - Includes MMT data.
• **Wilson, Rajan, and Patience 2014**, *The Brown-dwarf Atmosphere Monitoring (BAM) Project I: Multi-epoch monitoring of extremely cool brown dwarfs*, A&A, 566, 111 - The paper established the code and observing practices for all current and future BAM projects, including the MMT proposal.
• **Rajan et al. 2015**, *The Brown-dwarf Atmosphere Monitoring (BAM) Project II: Multi-epoch monitoring of extremely cool brown dwarfs*, MNRAS, 448, 3775 - Includes MMT data.

**Debris disks and evolutionary analysis - Allocations and Papers:**
**MMT: 2015A-UAO-S291 - Evolutionary Analysis of Nearby Debris Disks** - *PI: Patience (2 nights)* - 100% (estimated from preliminary data reduction).

• **Bulger et al. 2013**, *Submillimeter observations of IRAS and WISE debris disk candidates*, A&A, 556, 119 - Debris disk identification project that includes MMT data.

**Kimberly Ward-Duong <kwardduo@asu.edu>**

# AZ proposal PI notes

**Don McCarthy** <dwmccarthy@gmail.com> Wed, Apr 1, 2015 at 12:02 AM
To: Jenny Patience <jpatienc@asu.edu>
Cc: "jennifer.patience@asu.edu Patience" <jennifer.patience@asu.edu>, Kimberly Ward-Duong <kwardduo@asu.edu>, Craig Kulesa <ckulesa@email.arizona.edu>

I approve these ASU requests to use ARIES with MMT adaptive optics. A bright time observing run at the end of October is preferred to avoid known conflicts.

On Tue, Mar 31, 2015 at 9:43 PM, Jenny Patience <jpatienc@asu.edu> wrote:

> Hi, Don. Yes, MMT AO with ARIES. Thanks and sorry this is near the deadline.
>
> -- Jenny
>
> On 31 Mar 2015, at 21:36, Don McCarthy wrote:
>
> > Jenny, do you mean ARIES in Oct/Nov/Dec?
> >
> > Don
> >
> > On Tue, Mar 31, 2015 at 9:09 PM, Jenny Patience <jpatienc@asu.edu> wrote:
> >
> > > Hi, All. My students and I are planning on submitting several AZ telescope proposals and I need to ask if you could send the PI notes to attach. If you could send them to both me and Kim (copied on this email), that would be ideal, since Kim and I both have flights to Chile tomorrow, though her flight is a bit later.
> > >
> > > The proposals are continuations of existing programs, and we will send updated proposals if you would like the final version tomorrow (they are all being finished up tonight).
> > >
> > > LBT AO imaging:
> > > Finish the Taurus project with remaining observations and follow-up of some of the new companions. Quick synopsis: a number of new detections, mostly at the very close separations LBT probes, and some indicate the ALMA disks are circumbinary.
> > >
> > > MagAO imaging:
> > > Continue project w/Katie to observe GPI targets. Quick synopsis: two new candidate substellar companions.
> > >
> > > MMT AO imaging:
> > > 1) New observations of unobserved M's as part of MinMs survey and follow-up of candidate substellar companions. Quick synopsis: 1st MinMs binary survey paper published, hoping to confirm substellar

candidates w/proposed time
2) Observations of massive stars for high mass ratio binaries. Quick synopsis: only able to get test data last run that was almost totally lost to weather

Thanks a lot. My students enjoyed seeing several of your students at the recent meeting in Biosphere, and perhaps we can all drive down to Tucson and meet at some other time now that the paper proposal pilgrimage has ended and there are electronic submissions.

-- Jenny