OBSERVING REQUEST
University of Arizona Observatories

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

Dynamical Mass Determination for a Very Nearby Brown Dwarf

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Abstract of Scientific Justification

Dynamical mass measurements provide essential tests for models of substellar objects. Currently, only one dynamical mass measurement has been published for a T dwarf. Here we propose for an additional astrometric monitoring observations of the very nearby (3.85 pc) M8.5 + T6 binary SCR 1845-6357AB (∼4 AU projected separation in 2006) with the goal of eventually determining a dynamical mass for this system. As the fifth closest brown dwarf to the Earth and one of the brightest T dwarfs in the sky, SCR 1845-6357B is an extremely valuable benchmark object. We estimate an orbital period between 17–60 years for this object. In our 2011-2013 data we found significant orbital motion since 2006, excluding numerous short period orbits. Further monitoring on at least a yearly basis is necessary for a full orbital determination. We propose here for a MagAO filler program to obtain an additional astrometric data point in order to maintain as long a baseline as possible on this object.

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		*	0.03	bright	Apr–Jul	Mar–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	SCR 1845	18:45:05.30	-63:57:48.0	H=9
2	Westerlund 1	16:47:05.50	-45:51:6.0	astrometric calibrator

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

Scientific Justification

Since 1995, over 800 L and T brown dwarfs have been discovered and characterized via photometry and spectroscopy. However, most physical properties (mass, effective temperature, surface gravity) presented from these observations are in fact estimates derived from models. Very few direct measurements of physical properties are available for substellar objects. For example, while dynamical masses have been determined for >100 stars, dynamical masses have been published for only 11 unambiguously substellar objects (in 7 binary systems, e.g. Stassun et al. 2006, Pravdo et al. 2006, Lloyd et al. 2006, Ireland et al. 2008, Dupuy et al. 2008, Liu et al. 2008, Dupuy et al. 2009a, Dupuy et al. 2009b, Dupuy et al. 2010, Dupuy et al. 2011). In fact, only one T binary dwarf currently has a published dynamical mass (2MASS J1534-2952, Liu et al. 2008), although dynamical masses for the T dwarf binary Eps Indi Ba/Bb should soon be available as well (Cardoso et al. 2009, 2011). Already these dynamical masses are challenging and helping to refine theoretical models for these objects. For instance, Dupuy et al. 2010 find a discrepancy in T_{eff} of 250 K between atmospheric model fits to late-M binary pair components vs. Dusty evolutionary model results given the measured masses and luminosities. Thus, direct mass measurements for even colder substellar binaries will enable such essential tests of models at the temperatures of T dwarfs. However, orbital monitoring data show that there are in fact very few late T dwarfs with the possibility of dynamical mass measurements in the near future. Therefore, dynamical mass measurements are especially valuable from the few T dwarf binary systems where such measurements are possible.

We discovered SCR 1845-6357B (henceforth SCR 1845B), a T dwarf companion to the very nearby (3.85 pc, Deacon et al. 2005) M8.5 star SCR 1845-6357A using VLT NACO SDI (Biller et al. 2006). As one of the closest brown dwarfs to the Earth and one of the brightest T dwarfs in the sky, it is an extremely valuable benchmark object (see Fig. 1). Our followup photometric and spectroscopic observations confirmed common proper motion with SCR 1845A and established a spectral type of T6 (Kasper et al. 2007). Fitting the measured spectra with model spectra yielded T_{eff}=950 K and surface gravity log g = 5.1 (cgs), corresponding to a model mass range of 40-50 M_{Jup} for ages of 1.8 - 3.1 Gyr.

This mass range is a model value, not a measurement; here we propose for astrometric followup with the eventual goal of determining a dynamical mass for this system. From the initial epochs of astrometry (2005-2006), we estimated the semimajor axis of SCR 1845Bs orbit from its observed separation following the Monte Carlo approach of Dupuy et al. (2010), Allers et al. (2009) and Torres (1999). Assuming a uniform eccentricity distribution between $0 < e < 1$ and random viewing angles, Allers et al. (2009) compute a correction factor between projected separation and semimajor axis of $1.10^{+0.91}_{-0.36}$ (68.3% confidence limits). At a projected separation of ∼4 AU (∼1 ″) in 2005-2006, we estimated a range of possible semimajor axes for the system of $4.4^{+4.0}_{-1.0}$ AU, corresponding to likely periods of 14 – 62 years (adopting a mass of 0.09 $M_\odot$ for the primary and 0.045 $M_\odot$ for the secondary). **Our high resolution imaging in Sept. 2011, May 2012, and May 2013 (Fig. 1 and 2) shows significant orbital motion since 2006.** Additionally, with observations taken in July, August, and September of 2011 and significant motion found even on month timescales, we are able to derive a velocity vector for the orbital motion. In 2005/2006 SCR 1845 B was at ∼1″ separations and moving inward. In 2011, SCR 1845 B was at ∼0.8″ and moving outward. Thus, between 2006 and 2011, SCR 1845 B passed within its closest projected approach to A. The position angle has also changed significantly by ∼60 degrees between 2006 and 2011. With orbital monitoring over 6 years, we can now reject the shortest estimated orbital periods (∼20 years), however, additional monitoring is necessary to distinguish between the numerous still-possible orbits.

Given the fast orbital motion for this system, it is vital to continue orbital monitoring on roughly yearly timescales. We propose to continue monitoring this system with MagAO We have monitoring data from VLT NACO from 2011-2013 – observations in 2015 are necessary to maintain the same cadence of orbital monitoring. We will combine any future imaging data with CRIRES (program 079.C-0569) radial velocity results in hand to eventually determine dynamical masses for both the system and the individual objects themselves.

Here we propose to obtain 1 additional epoch of astrometric monitoring for SCR 1845AB in 2015. Significant orbital motion is evident since May 2006; further datapoints on the degree and direction of this motion will allow a refined period estimate for this system from our Monte Carlo simulations. Our 2011-2013 data suggests continued yearly monitoring is critical to determining the orbit for this object. We will eventually be able to determine a dynamical mass for this system, but continued monitoring is vital to do so, as the orbital period of this system appears to be relatively long. At the median expected semimajor axis for the system (4.4 AU) the binary would have already completed $\sim$25% of its orbit by our observations in Spring 2012 (cf. the 30% of the orbit needed for dynamical mass measurements by Bouy et al. 2004, Liu et al. 2008, and Dupuy et al. 2009a). The motion to date, however, rules out such a short orbit.

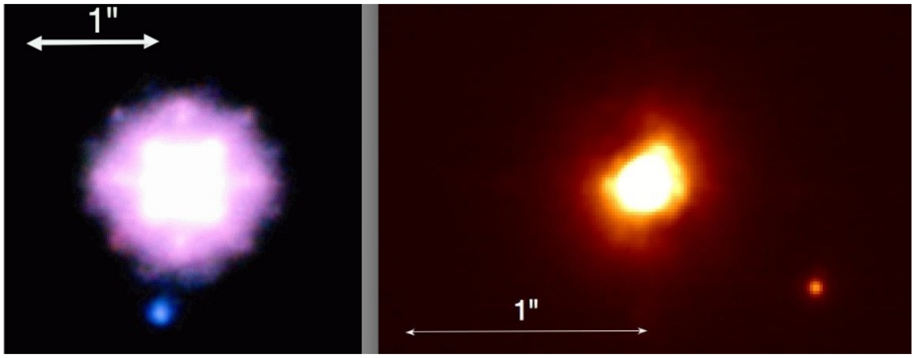

Figure 1: Fig. 1: Left: May 2005 Three color image of SCR1845-6357A and B generated from the three-filter SDI discovery images. Note the color difference between the white speckles of the primary and the considerably bluer companion (a hallmark of the T spectral type.) Right: H band image of SCR1845-6357AB from 4 September 2011. Significant orbital motion is apparent; SCR 1845 B has moved from a separation of 1.17″ and PA of 170.2 degrees in May 2005 to a separation of 0.82″ and PA of 239 degrees in September 2011.

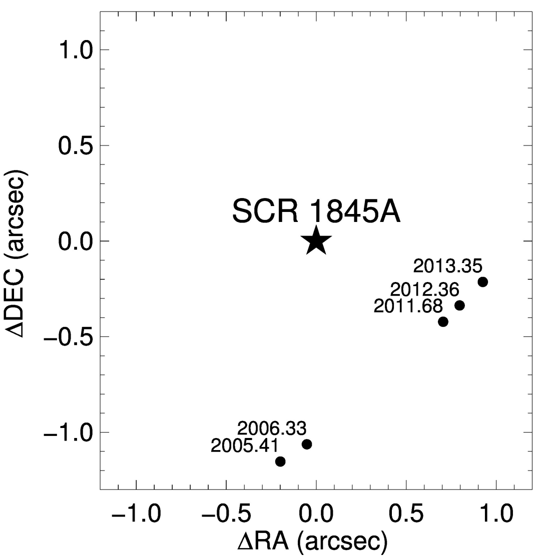

Figure 2: Fig. 2: On-sky motion of SCR 1845AB. Significant orbital motion is apparent from our 2011-2013 astrometry. Errors are 0.002 milliarcsec in RA and DEC for the 2005/2006 astrometry and 0.005 milliarcsec in RA and DEC for the preliminary reductions of our 2011-2013 data. From astrometry acquired between 2005-2012, we can now rule out the very shortest period orbital estimates (<20 years). Further astrometric measurements are necessary to constrain the orbit; given the observed orbital motion, roughly yearly observations are an appropriate cadence. The proper motion of SCR 1845A is 2444 mas/yr in RA and 696 mas/yr DEC. SCR 1845B clearly shares a similar proper motion vector with A and is a bound companion (as the probability of a chance alignment with a high proper motion object on almost the same proper motion vector is neglibly small).

We propose this observation as a fillter program for bad condition observing. At the relatively small angular separation and contrast to the primary, SCR 1845-6357B can only be observed efficiently by using Adaptive Optics or in superb seeing conditions. SCR 1845A is relatively faint in the optical (R$\sim$15) but considerably brighter in the NIR (H$\sim$9). Thus, we expect only moderate AO correction with MagAO – on a median night, we expect to get 0.2" images at K_S. However, given the $>$1" separation between components this should be suitable for continued astrometric monitoring of the companion. A quick 20 minute K_S observation of the target followed by a similar length observation of the calibration cluster Westerlund 1 will be sufficient to get a further astrometric monitoring point. Thus, we request 40 minutes for this entire program.

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 propose for 40 minutes of filler time during poor seeing conditions in order to obtain a further astrometric point for the orbit of SCR 1845AB. We will continue to propose for future astrometric observations with a roughly yearly cadence.

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**)*