Spectroscopic Analysis of Unusually Red and Blue Brown Dwarfs

This research award will provide funding for publication costs, domestic travel, and supplies to support the completion and publication of the spectroscopic analysis of unusually red and blue brown dwarfs by PI Rice and two Macaulay Honors College (Hunter) students, Munazza Alam and Sara Camnasio. We are analyzing the photometric and spectral features of brown dwarf color outliers using optical spectra, multi-resolution near-infrared spectra, mid-infrared photometry, parallaxes, and kinematics to explore their underlying physical and atmospheric properties. This project is part of the PI's ongoing research using spectroscopy to study the atmospheric and kinematic properties of very low mass stars, brown dwarfs, and extra-solar planets.

Scientific Background

Brown dwarfs are astronomical objects that form, like stars do, from collapsing clouds of gas and dust. Unlike stars, the contraction of proto-brown dwarfs is halted by electron degeneracy pressure, keeping the core of the forming brown dwarf below the temperature required to initiate and sustain hydrogen fusion (Kumar 1963). Brown dwarfs radiate gravitational potential energy as they collapse, but after ~100 million years they reach a size of ~1 Jupiter radius and very little energy as they cool and fade for billions of years.

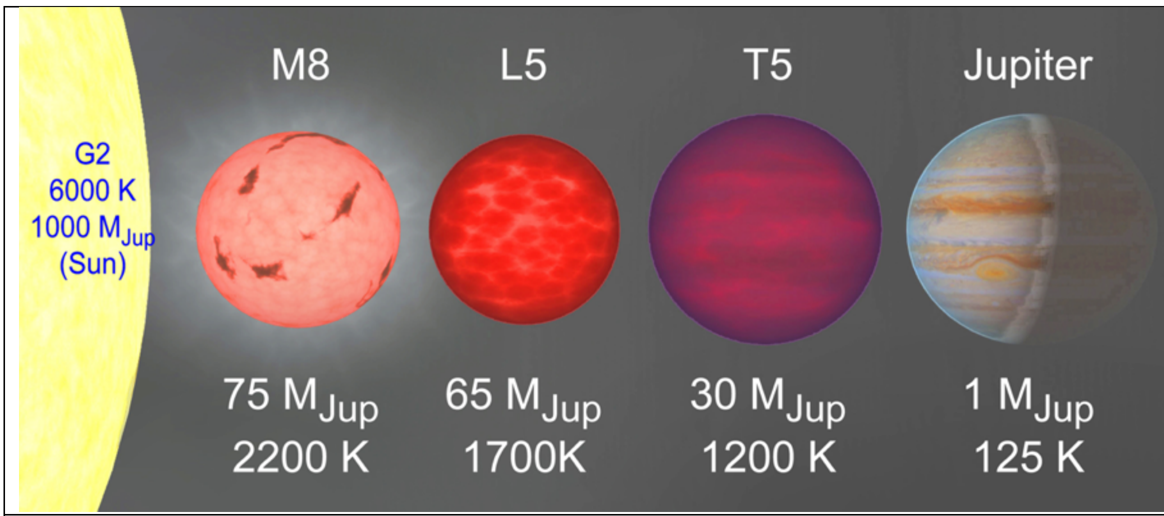

Figure 1 – Artistic representation of the Sun, M, L, and T dwarfs, and Jupiter listing their approximate masses (in Jupiter masses, M_J) and surface temperatures (in Kelvin). Credit: R. Hurt and K. Cruz

Figure 1 shows an artist's depiction of three very-low-mass objects relative to the Sun (left) and Jupiter (right). These objects are classified as spectral type M, L or T based on atomic and molecular absorption features in the optical for M and L dwarfs and near-infrared spectra for T dwarfs. Each spectral type is divided into subclasses from 0 to 9. Approximate masses in Jupiter masses and surface temperature in Kelvin are given for the subclasses M8, L5, and T5. M dwarfs are the lowest mass stars, L dwarfs are the hottest, highest mass brown dwarfs, and T dwarfs are cooler and lower mass (Kirkpatrick 2005). There is now a third even cooler brown dwarf spectral class, Y, but only a handful of objects have been discovered (Cushing et al. 2011). This project focuses on observations of L dwarfs because they are known in the largest numbers (nearly 1000, see http://dwarfarchives.org) and with the widest range of properties (see Table 1).

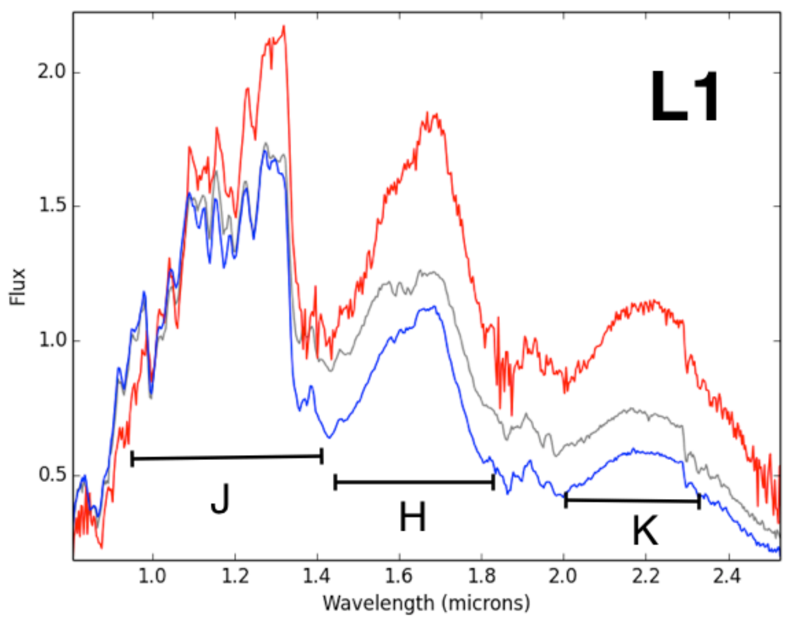

Figure 2 – Comparison of the near-infrared spectra of a normal L dwarf (gray) with red and blue L dwarf spectra in corresponding colors. All three objects are classified as L1 via their optical spectra (not shown). Labeled black bars show the wavelength ranges of the J, H, and K bandpass filters.

Credit: M. Alam & S. Camnasio.

Near-infrared colors of brown dwarfs are the ratio of fluxes at two bandpasses. The near-infrared bandpass filters most commonly used to study brown dwarfs are designated J (1.2 microns), H (1.5 microns), and K (2.3 microns) and are shown relative to three L1 dwarf spectra in Figure 2. An object with more flux at K-band has a redder J–K color (higher value), while a lower value is a bluer object with more flux at shorter wavelengths. Thus "blue" and "red" become shorthand to describe relative flux observed at non-visible wavelengths.

Table 1		**Property**			
		Gravity	**Age**	**Metallicity**	**Clouds**
Type of Object	**Young L Dwarf**	~4.0 dex [cgs]	< 1 Gyr	Solar to supersolar	Enhanced small dust particles?
	Red L Dwarf	???	???	Solar to supersolar?	Enhanced small dust particles?
	Normal L Dwarf	5.0 dex [cgs]	1–5 Gyr	Solar	"Normal" dust clouds
	Blue L Dwarf	>5.0? dex [cgs]	???	Subsolar?	Large grains and/or thin clouds?
	L Subdwarf	>5.0? dex [cgs]	> 5 Gyr	Subsolar	Large grains and/or thin clouds?

L dwarfs have a range of near-infrared colors at a given spectral type (Figure 3), leading to categories of unusually "red" or "blue" objects. Some of the extremes of these objects have been associated with spectral features caused by extreme physical properties that are then assumed to cause the unusual color as well. For example, many red L dwarfs also show spectral features indicative of low surface gravity, including weak and narrow alkali absorption lines. L dwarfs continually shrink for hundreds of million years after they form so low surface gravity is an indicator of youth (age < 1 Gyr, see Cruz et al. 2009). Similarly, several blue L dwarfs are classified as subdwarfs because their spectral features indicate subsolar metallicity, or a heavy element content less than that of the Sun (Burgasser et al. 2009). This is in turn associated with old age (> 5 Gyr) because the raw material for star formation becomes more enriched with heavy elements over time. These properties are summarized in Table 1.

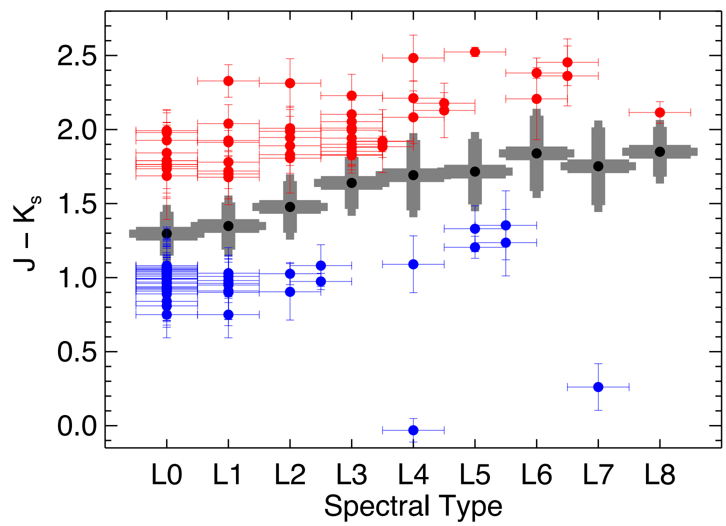

Figure 3 – $J–K_s$ color versus spectral type of the L dwarf population showing mean colors (solid black circle), 2σ dispersion (gray bar), and red and blue photometric outliers (red and blue solid circles) for each spectral type.

Credit: J. Faherty

There are numerous L dwarfs with unusually red or blue near-infrared colors that do *not* show spectral features associated with either low surface gravity or subsolar metallicity. There are several hypothesis to explain the color dispersion, including varying and properties of heavy metal condensates, or "dust". For example, Hiranaka et al. 2012 found that the red colors of young L dwarfs can be reproduced with an excess of small dust grains. Kirkpatrick et al. 2010 hypothesized a rotation-induced stratification of clouds so that colors correspond to viewing angle, red corresponding to pole-on viewing angle and blue to more common equator-on viewing angle. **We will examine these hypotheses by comparing spectral and photometric observations of unusually red and blue to our sample of normal L dwarfs (standards), known young L dwarfs, and known L subdwarfs.** The data include multi-resolution near-infrared spectra, WISE mid-infrared photometry, parallaxes, and kinematics to explore underlying physical and atmospheric properties. The analysis is anchored by optical spectra (as a proxy for effective temperature) and benchmarks such as confirmed young objects, subdwarfs, and companions. This is the largest, most diverse observational dataset of red and blue L dwarfs assembled to date.

Research Plan

1. Construct Sample of Unusually Red/Blue Brown Dwarfs and Comparison Objects

We will construct a sample of unusually blue and red L dwarfs along with known young L dwarfs and known L subdwarfs objects from the BDNYC (our research group), the NIRSPEC Brown Dwarf Spectroscopic Survey (BDSS, McLean et al. 2003, 2007), the literature, and unpublished data from collaborators. Alam and Camnasio have already begun to identify objects in the sample and create a detailed inventory of available data, including reducing new observations.

2. Photometric and Multi-Resolution Spectral Analysis

We will create spectral sequences and compare unusually blue and red L dwarfs to normal and confirmed young L dwarfs and L subdwarfs of the same spectral type to characterize similarities and differences in their spectral features and several spectral resolutions and wavelength regimes. We will use fits to synthetic spectra from models physical properties like temperature, gravity, radial velocity, and projected rotational velocity (e.g., Rice et al. 2010). PI Rice will present the sample and preliminary results of the project at the 223rd meeting of the American Astronomical Society (AAS) in Washington, DC, 5-9 January 2014.

3. Publication of Results

Students Alam and Camnasio will work with PI Rice during the award period to publish the results of this project in the Astronomical Journal (2012 Impact Factor of 4.965, http://iopscience.iop.org/1538-3881/). We will focus on writing and submitting the paper in fall 2014 and revising and publishing the paper in spring 2015. Alam and Camnasio will take the lead during the entire process, a relatively rare and invaluable experience for undergraduate students. Alam and Camnasio will further publicize results at the 225th Meeting of the American Astronomical Society (AAS) in Seattle, WA in January 2015, the largest professional astronomy research meeting in the U.S. and an excellent networking opportunity for undergraduate students. Rice's travel to the conference will be funded by an NSF grant.

Budget Justification

The grant will provide $6000 for research supplies, domestic travel, and publication costs for Rice, Alam, and Camnasio to complete and publish the research project.

$1000 Research Supplies: office supplies, computer accessories, poster printing, etc.
$3600 Domestic Travel from NYC to Seattle, WA in January 2015 for Alam and Camnasio to attend the 225th AAS meeting:

- $400: two junior registrations and membership dues
- $1400: two flights (estimated NYC to SEA)
- $1200: one hotel room for 6 nights
- $200: ground transportation
- $400: meals & incidental expenses

$1400 Publishing Costs: 40 quanta (350 words or 1 table/figure at $35 each) in the Astronomical Journal, http://iopscience.iop.org/1538-3881/page/Article%20charges

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