Improving the Cloud Model of Young Brown Dwarfs and Giant Exoplanets

Brown dwarfs are astronomical objects considered as “missing links” between gas giants like Jupiter and the lowest-mass stars. Like stars, brown dwarfs form from collapsing clouds of gas and dust but they are not massive enough to sustain hydrogen fusion in their cores and therefore their temperatures cool as they age. Brown dwarfs and massive exoplanets have similar physical properties such as compact radii (< 2 Jupiter radii) and cool temperatures (< 3000 K). Warm, young brown dwarfs (~ 2000 K, < 100 Myr) have thick clouds likely to be similar to those of hot young Jupiters.

Brown dwarfs are further classified as spectral types M, L, T, and Y. L dwarfs have clouds made of refractory particles in their atmospheres that shape their emergent spectra. Further, there are L dwarfs with redder spectral energy distributions in the near-infrared (NIR, ~1–2.5 microns) compared to most other L dwarfs (Kirkpatrick et al. 2008; Faherty et al. 2009). These red L dwarfs are suspected to be young (< 200 Myr) and low-gravity but gravity alone cannot explain the observed reddening.

Young L dwarfs have extended envelope atmospheres due to their low surface gravities. As brown dwarfs age, they contract and therefore their surface gravities get higher. In the higher-gravity atmospheres of field-aged L dwarfs, the clouds sediment and dissipate, resulting in thinner clouds.

The similarities of the observational properties of warm planetary-mass objects and typical young brown dwarfs suggest that cloud clearing might be gravity dependent and that clouds remain thick to much lower temperatures in objects with lower gravities. This would imply that the lowest mass objects (with the lowest gravities) remain dusty (and looking like warm, young brown dwarfs) down to cooler temperatures than higher mass objects.

Several atmosphere models have attempted to reproduce the observed L dwarf spectra. These atmosphere models reproduce the the general observed properties of L dwarf spectra but they all fail to explain the reddening in the NIR (Helling et al. 2008). Here, we propose to develop a better dust treatment that can account for the observed reddening in L dwarf spectra.

Goals:

Young L dwarfs and warm exoplanets are likely to have similar cloud properties, so explaining L dwarf atmospheres is also important to exoplanet atmosphere studies. Current atmosphere and evolution models broadly reproduce observational trends but they are often inconsistent and incomplete: for example, atmosphere and evolution models sometimes imply very different effective temperatures for young L dwarfs, there are significant missing opacity sources, and dust and cloud treatment is over-simplified (Helling et al. 2008).

We are working on developing a new brown dwarf atmosphere model with an improved dust treatment which incorporates a dust haze. By adding a dust haze to the atmosphere model, we will have a more realistic explanation and a firmer grasp of young L dwarf atmospheres. Our new model will also help explain the thick clouds observed in directly imaged planet atmospheres.

We are preparing to publish our work in the Astrophysical Journal on constraining the properties of the dust haze in red L dwarf atmospheres. We are also presenting our results at the 225th AAS meeting in Seattle, WA in January 2015. In this proposal, we request funds to support these activities.

Methods:

We hypothesize that an atmosphere model with a dust haze of small particles in addition to the regular clouds can better explain the observed phenomena. These grains in the upper atmosphere redden the spectra by absorbing and scattering the emergent light. Because the sizes of scattering particles are expected to be comparable to the wavelengths of NIR, where brown dwarfs emit most of their light, the relevant scattering regime is Mie scattering. We have compared the observed reddening in young L dwarf spectra with Mie extinction to find the particle size distributions that best reproduce the observed effect. We employed Hansen distribution (Hansen 1971), which is used to describe water droplets in the Earth's atmosphere.

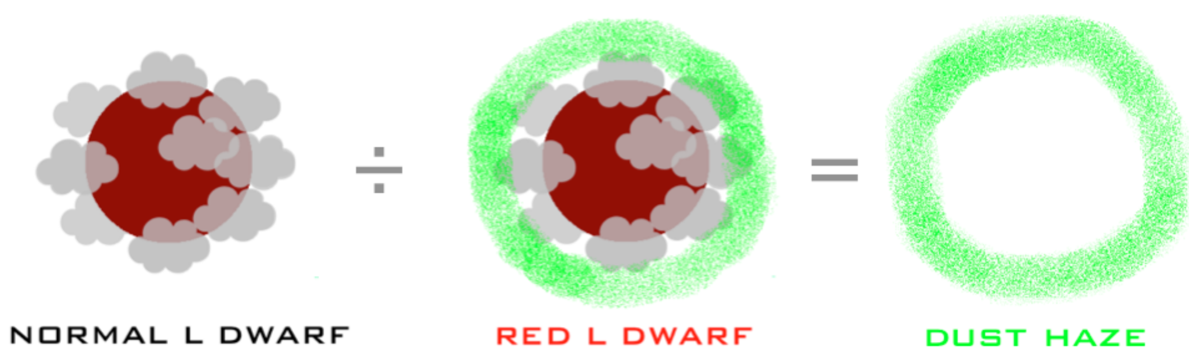

Figure 1. Cartoon model of normal and red L dwarf atmospheres. Clouds of refractory grains (grey) exist in all L dwarf atmospheres and Red L dwarfs have additional dust hazes (green). These dust hazes reddens the emergent spectra in the NIR. Comparing the normal and red L dwarf spectra allow us to constrain the dust haze properties.

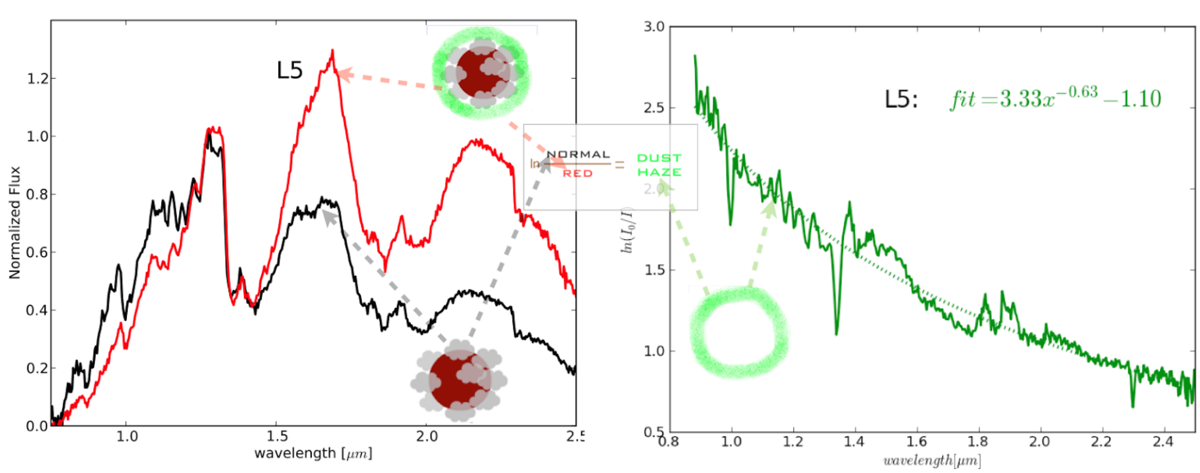

Figure 2. An example of a normal (black) and a red (red) L dwarf spectra on the left panel. The red spectrum has excess flux longward of 1.5 microns. On the right is the observed reddening (flux ratio of the normal L

dwarf to the red L dwarf) with the power law fit (dotted). This reddening was reproduced by Mie extinction curves.

We have found that the mean particle radii of the best fit cases are on the order of 0.1 micron, which is much smaller than the grain sizes in the regular clouds (~ 10 microns). This result is significant because it shows that the grains in the dust haze are different from the grains in the regular clouds.

Currently, we are trying to incorporate a dust haze into the atmosphere model so that it reproduces the effects seen in the spectra of young L dwarfs better. In particular, we are trying to find the altitude of the dust haze in the atmosphere that gives the best results. We are developing the next generation of atmosphere models, focusing on improved dust and cloud treatments while taking into account the interdependent roles of temperature, gravity, and chemical composition.

Budget Summary:

This project is the thesis project of a CUNY grad student, Kay Hiranaka, and this research award will provide funding for the student to attend the 225th AAS meeting in Seattle, WA in January 2015 to present the results of our project. It will be her last year of graduate school and she will be presenting a longer format "thesis talk." In addition, we are requesting funds to support the travel to NYC for analysis and manuscript preparation by our very close collaborator on this project, Dr. Mark Marley, who is based at NASA-Ames in Mountain Valley, CA. We are also requesting funds to cover the costs associated with publishing the results in a high impact, peer reviewed journal.

References

Faherty, J. K., Burgasser, A. J., Cruz, K. L., Shara, M. M., Walter, F. M., and Gelino, C. R. 2009, The Brown Dwarf Kinematics Project I. Proper Motions and Tangential Velocities for Large Sample of Late-Type M, L, and T Dwarfs, The Astrophysical Journal, 137, 1

Hansen J. E. 1971, Multiple Scattering of Polarized Light in Planetary Atmospheres. Part II. Sunlight Reflected by Terrestrial Water Clouds, Journal of the Atmospheric Sciences, 28, 1400

Helling, C., Ackerman, A., Allard, F., Dehn, M., Hauschildt, P., Homeier, D., Lodders, K., Marley, M., Rietmeijer, F., Tsuji, T., and Woitke, P. 2008, A Comparison of Chemistry and Dust Cloud Formation in Ultracool Dwarf Model Atmospheres, Monthly Notices of the Royal Astronomical Society, 391, 1854

Kirkpatrick, D., Cruz, K. L., Barman, T. S., Burgasser, A. J., Looper, D. L., Tinney, C. G., Gelino, C. R., Lowrance, P. J., Liebert, J., Carpenter, J. M., Hillenbrand, L. A., and Stauffer, J. R. 2008, A Sample of Very Young Field L Dwarf and Implications for the Brown Dwarf "Lithium Test" at Early Ages, The Astrophysical Journal, 689, 1295