Probing the Heterogeneous Cloud Structure of Variable Brown Dwarfs with HST

Esther Buenzli[1,2], Dániel Apai[2,3], Jacqueline Radigan[4], Caroline Morley[5], Adam Burrows[6], Davin Flateau[3], Adam Showman[3], Mark Marley[7], I. Neill Reid[4], Nikole Lewis[8], Ray Jayawardhana[9]

1: MPIA Heidelberg, 2: Steward Observatory, University of Arizona, 3: Lunar and Planetary Lab, University of Arizona, 4: STScI, 5: University of California, Santa Cruz, 6: Princeton University, 7: NASA Ames, 8: MIT, 9: University of Toronto

Context

- Brown dwarfs have temperatures and atmospheric properties similar to young giant planets, but are easier to study.
- Cloud structure and evolution are very important for these objects. The transition from cloudy L-type to (mostly) clear T-type dwarfs at ~1200-1300 K is not well understood.
- Recent discoveries of variable brown dwarfs in the near-IR have indicated the presence of heterogeneous cloud structure and evolving weather patterns. Patchy clouds result in variable flux as the object rotates.

Summary

- We conducted the first time-resolved spectroscopic study of 3 variable brown dwarfs with HST/WFC3 covering their full rotation periods.
- Two early T dwarfs show evidence for a mixture of a thin and a thick cloud component but an absence of deep cloud holes.
- For a T6, the light curves at different wavelengths are not in phase, indicating complex vertical structure. There is a correlation between the phase shift and the pressure probed at a given wavelength.

Two cloud components in early T dwarfs

- See Apai, Radigan, Buenzli et al. 2013, ApJ 768, 121
- The T1.5 dwarf 2MASSJ2139+02 and the T2.5 dwarf SIMP0136+09 are L/T transition objects with significant cloudiness. They show very similar spectral time variability: the flux changes fairly uniformly in J and H band (no color change) and spectral features except water (Fig. 1).

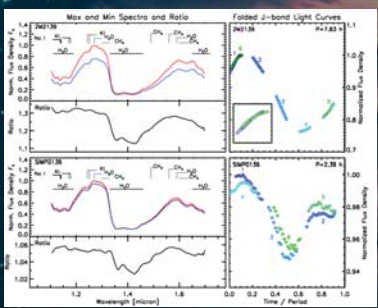

Fig. 1: HST/WFC3 minimum and maximum spectra, ratio and J-band light curves of the two early T dwarfs. Important absorbers are marked in the spectra. In the light curves, different colors mark subsequent HST orbits.

- Principal component analysis suggests only two varying spectral components. From model fits we find a thin and thick cloud component, but no cloud holes.

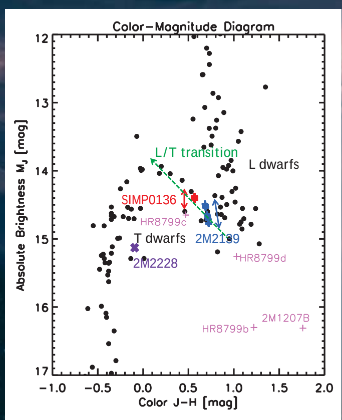

Fig. 2: Color magnitude diagram (J-H vs M_J) showing the L-T sequence. Black dots are L and T field dwarfs with known parallaxes. The two variable early T dwarfs are shown with the direction of the variability. The variable T6 (right panel) is also marked. Some directly imaged planets are shown for comparison.

- The short term variability is different from the long term evolution through the L/T transition (cloud disappearance) where the colors turn blue (Fig. 2) and the J band brightens. The variability is in the direction toward the directly imaged planets.

Pressure dependent phase shifts in a T6

- See Buenzli et al. 2012, ApJ 760, L31
- The T6.5 dwarf 2MASS2228-43 lies beyond the L/T transition but shows evidence of clouds. An atmosphere with T_{eff}=900 K with sulfide clouds provides a good match (Fig. 3).

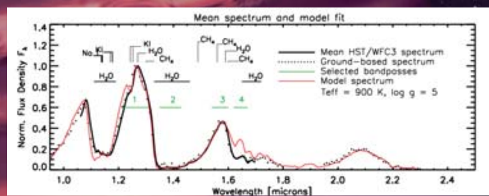

Fig. 3: Mean HST/WFC3 spectrum for 2M2228-43, ground-based SPEX spectrum and best model fit which includes sulfide clouds. The selected band passes are used to derive light curves.

- We selected wavelength regions that probe different pressures and derived light curves (Fig. 4). We also obtained simultaneous Spitzer/IRAC photometry at 4.5 microns. The light curves are out of phase, and the phase shift increases with decreasing pressure.

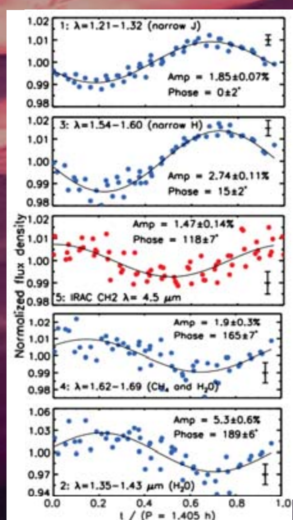

Fig. 4: Light curves for 2M2228-43 obtained by integrating the time-resolved HST/WFC3 spectra over different narrow wavelength regions (blue). The red plot is photometry from Spitzer/IRAC. The black lines indicate the best-fit sine-curve. The panels are arranged in order of decreasing pressure, making the shift in phase with pressure evident.

- A potential explanation is that we see variations in cloud opacity (likely in the deeper regions) as well as temperature fluctuations (likely at lower pressures), which may be caused by specific circulation patterns such as a stacked cell scenario.

Contact:
Esther Buenzli
Max-Planck Institute for Astronomy, Heidelberg
buenzli@mpia.de

Background image: Artist impression of the variable T6 dwarf 2MASSJ2228-43. Credit: NASA/JPL

We acknowledge support from NASA through the Space Telescope Science Institute for HST Program 12314 and through JPL/Caltech for the observations with the Spitzer Space Telescope.

THE UNIVERSITY OF ARIZONA.