Mapping the Cloudy Atmospheres of L-T Brown Dwarfs with High-Precision Spectro-Polarimetry

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WIRC+Pol team:
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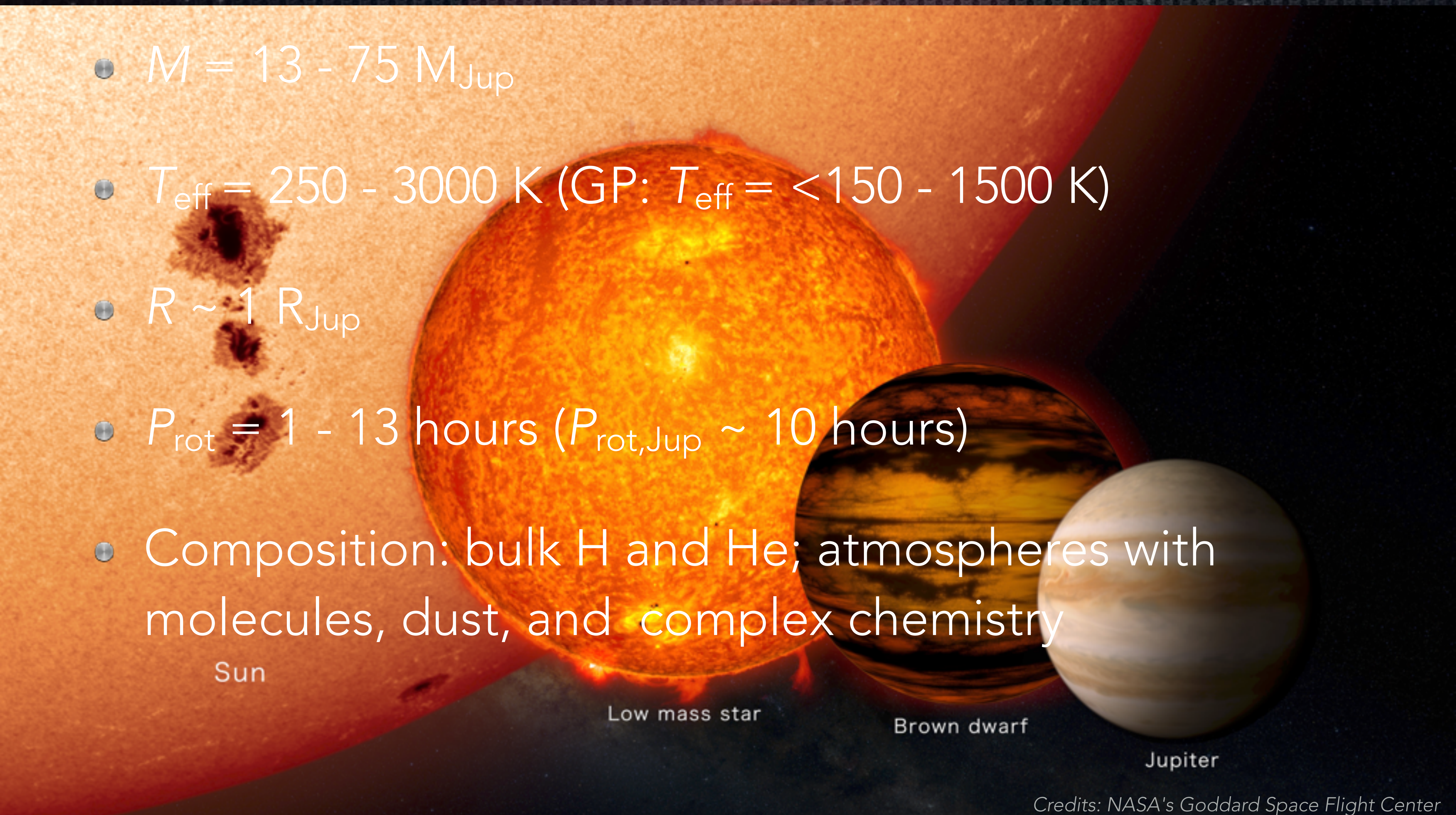
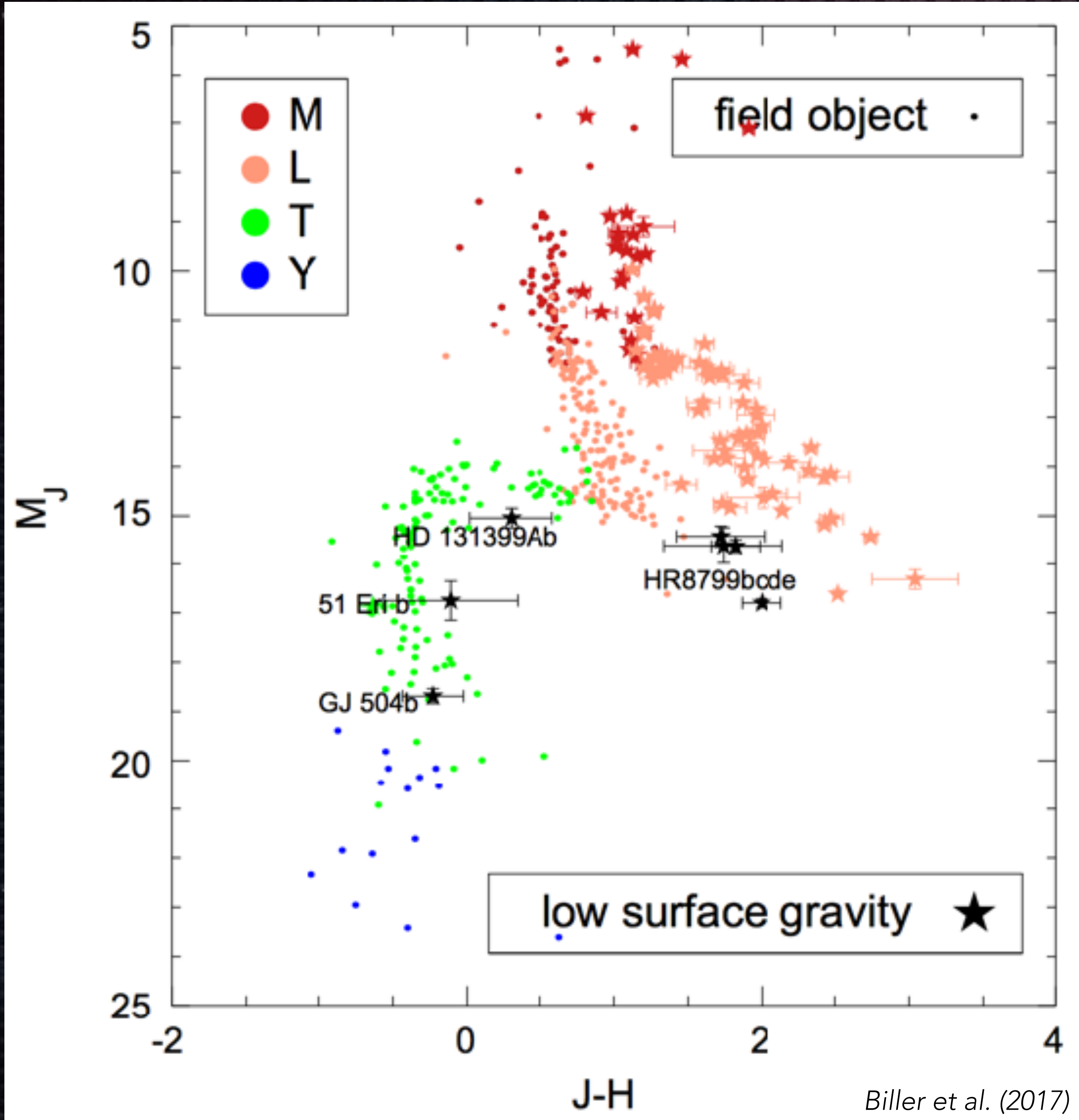
Brown Dwarfs as Proxies to Gas Giant Planets

- M = 13 - 75 M_{Jup}
- T_{eff} = 250 - 3000 K (GP: T_{eff} = <150 - 1500 K)
- R ~ 1 R_{Jup}
- P_{rot} = 1 - 13 hours ($P_{rot,Jup}$ ~ 10 hours)
- Composition: bulk H and He; atmospheres with molecules, dust, and complex chemistry



Credits: NASA's Goddard Space Flight Center

The L/T Transition

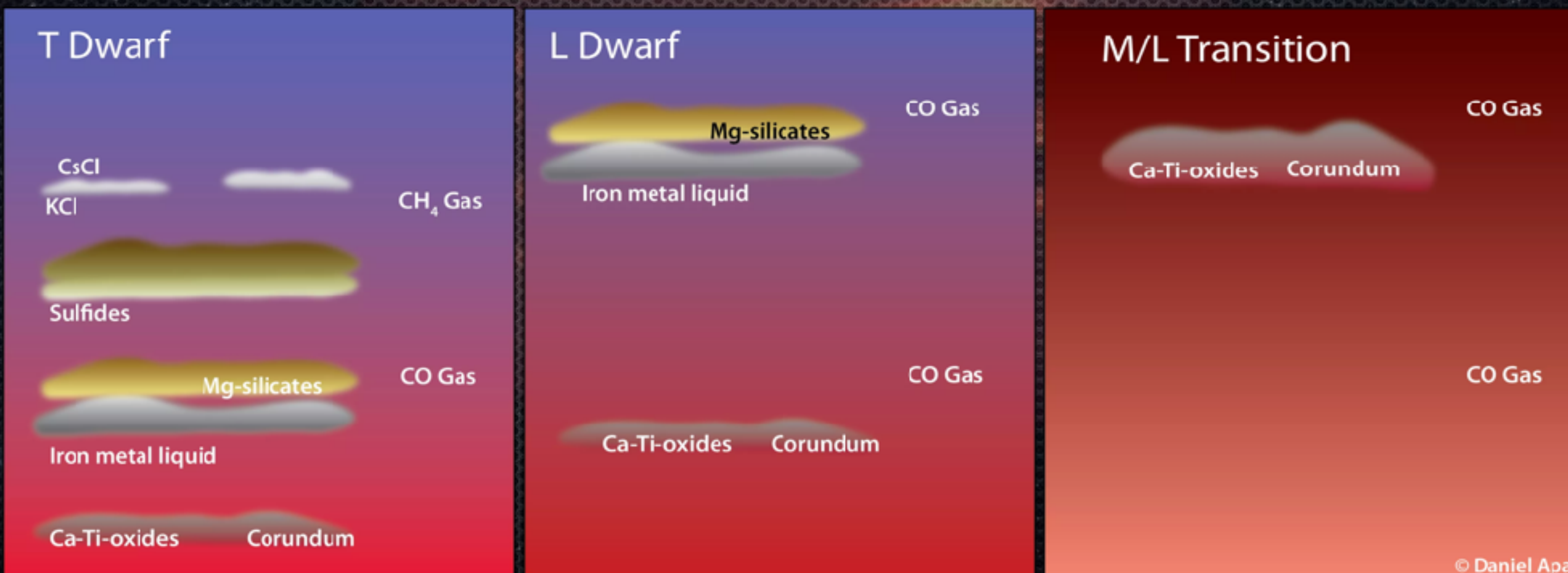


Biller et al. (2017)

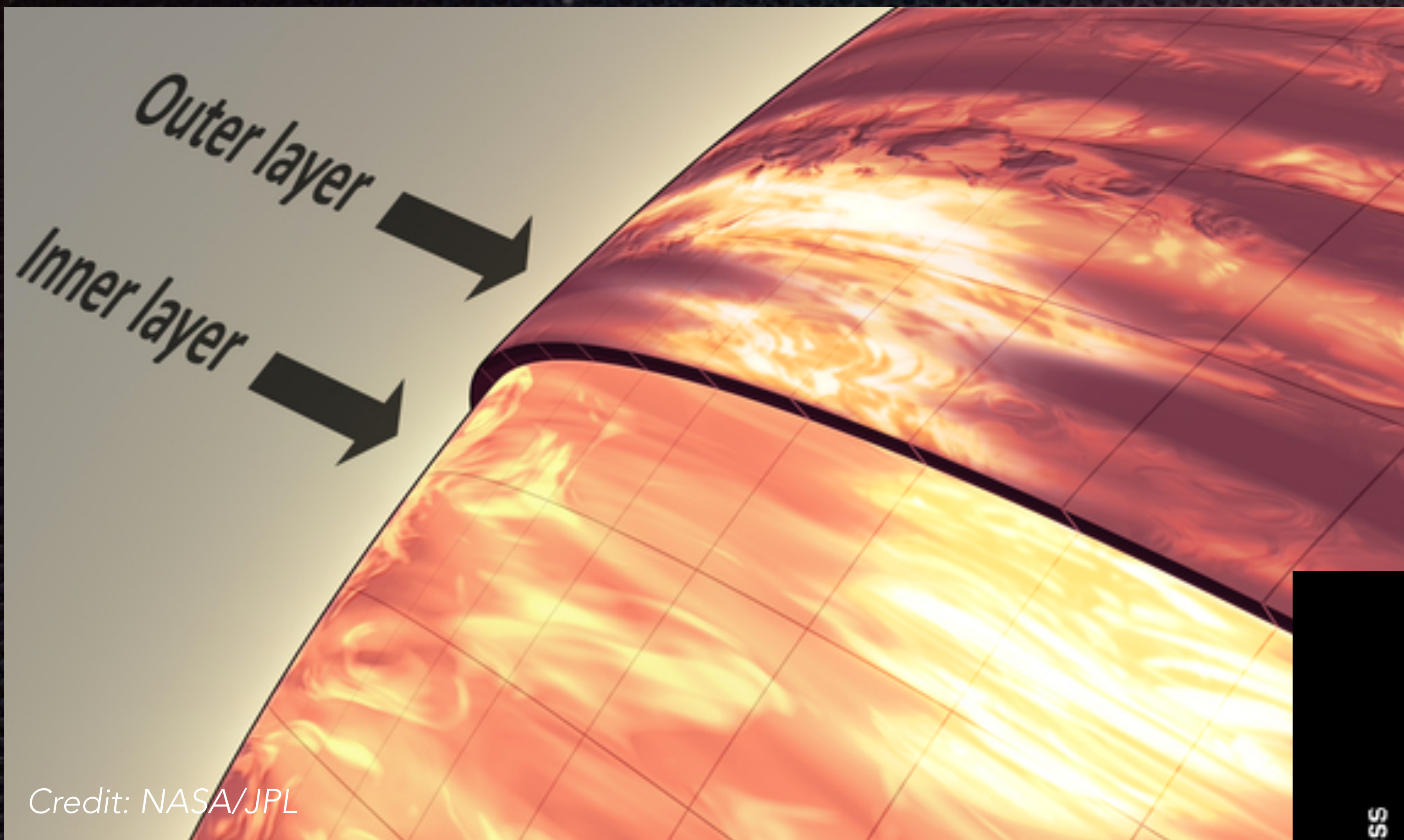
"The cooler T type brown dwarfs are notably bluer than the red Ls, due to significant methane absorption at 2.2 µm as well as the breaking up or sinking of silicate clouds below the photosphere. Low surface gravity objects are uniformly redder than objects with similar spectral types at field ages. Note the small population of extremely red exoplanets with 'T dwarf' luminosities, such as HR 8799bcde. These planets retain silicate clouds at considerably cooler temperatures than their brown dwarf counterparts, likely a result of their low surface gravities." - *Beth Biller*

Weather on Brown Dwarfs

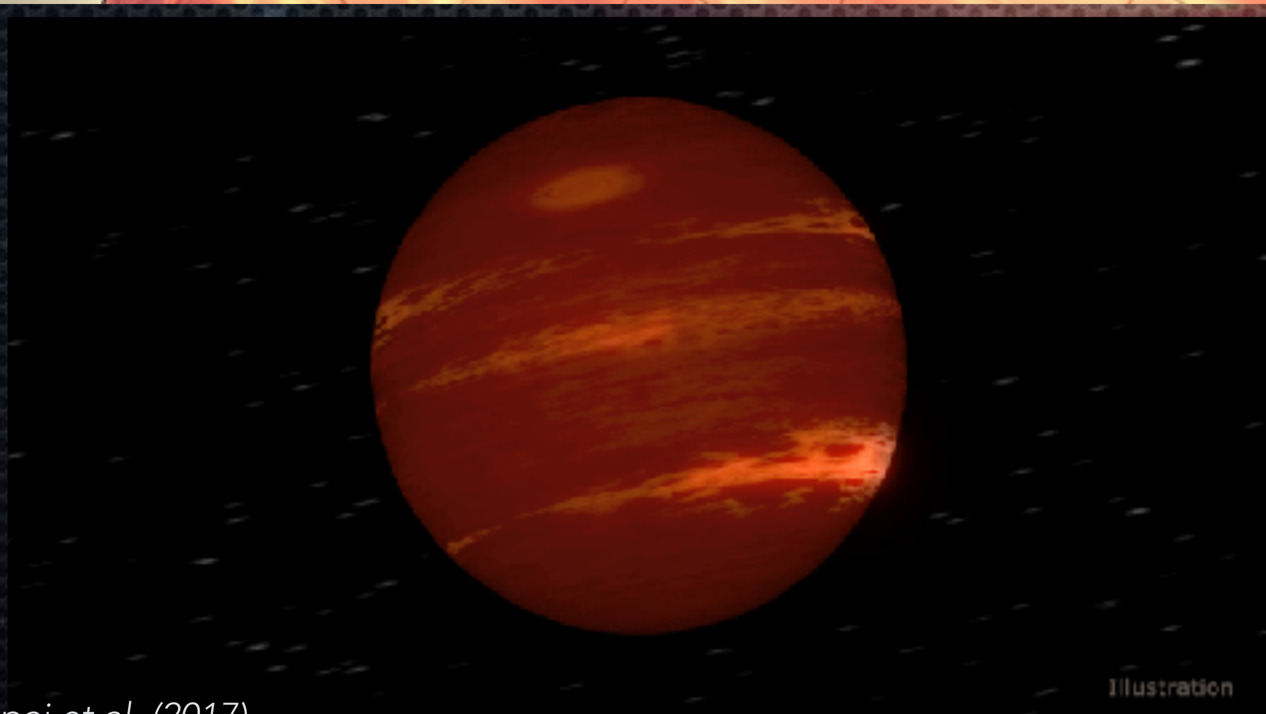
Image: NASA/JPL-Caltech/University of Western Ontario/Stony Brook University



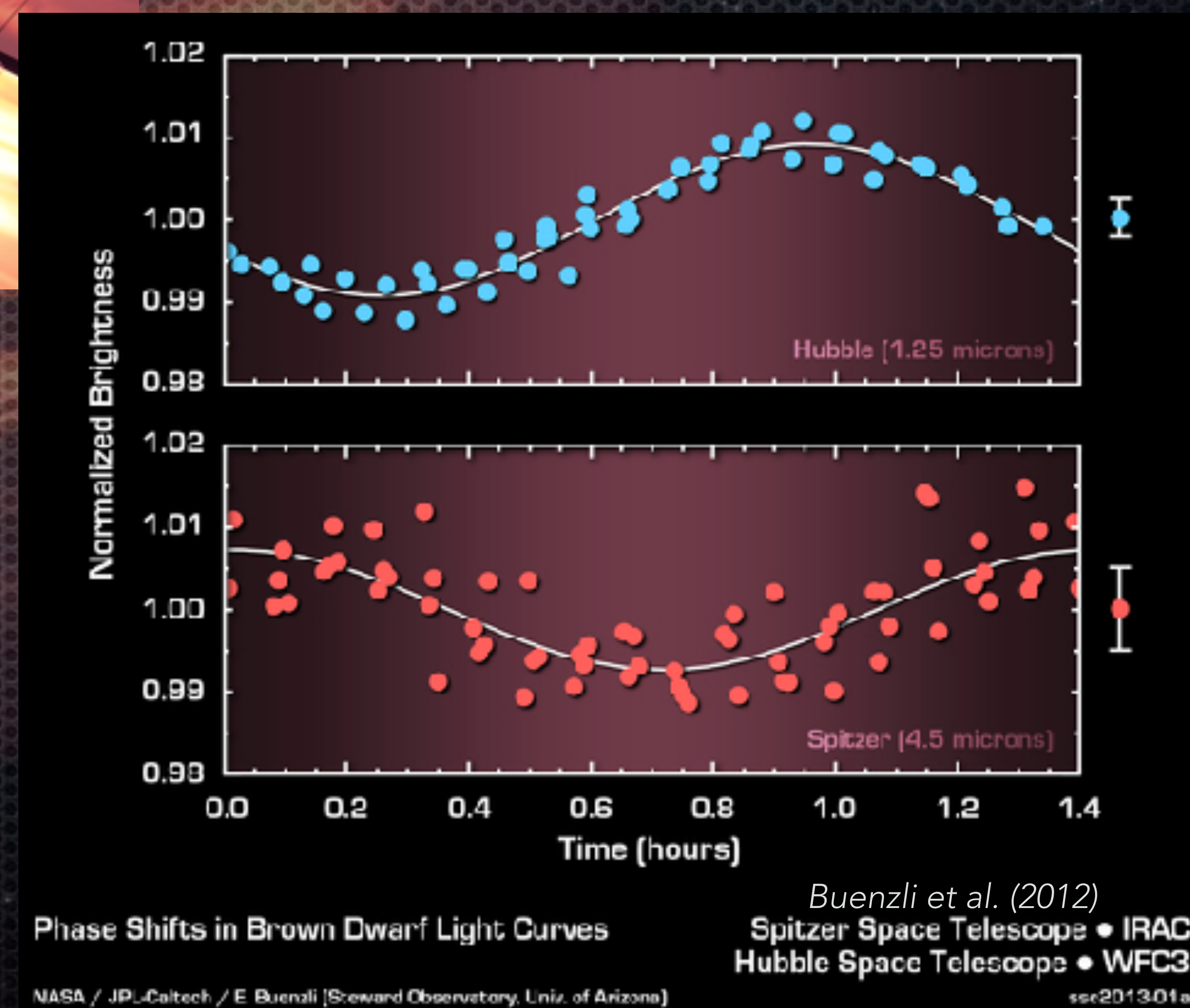
3-D Mapping of Atmospheres



- Simultaneous observations in multiple bands

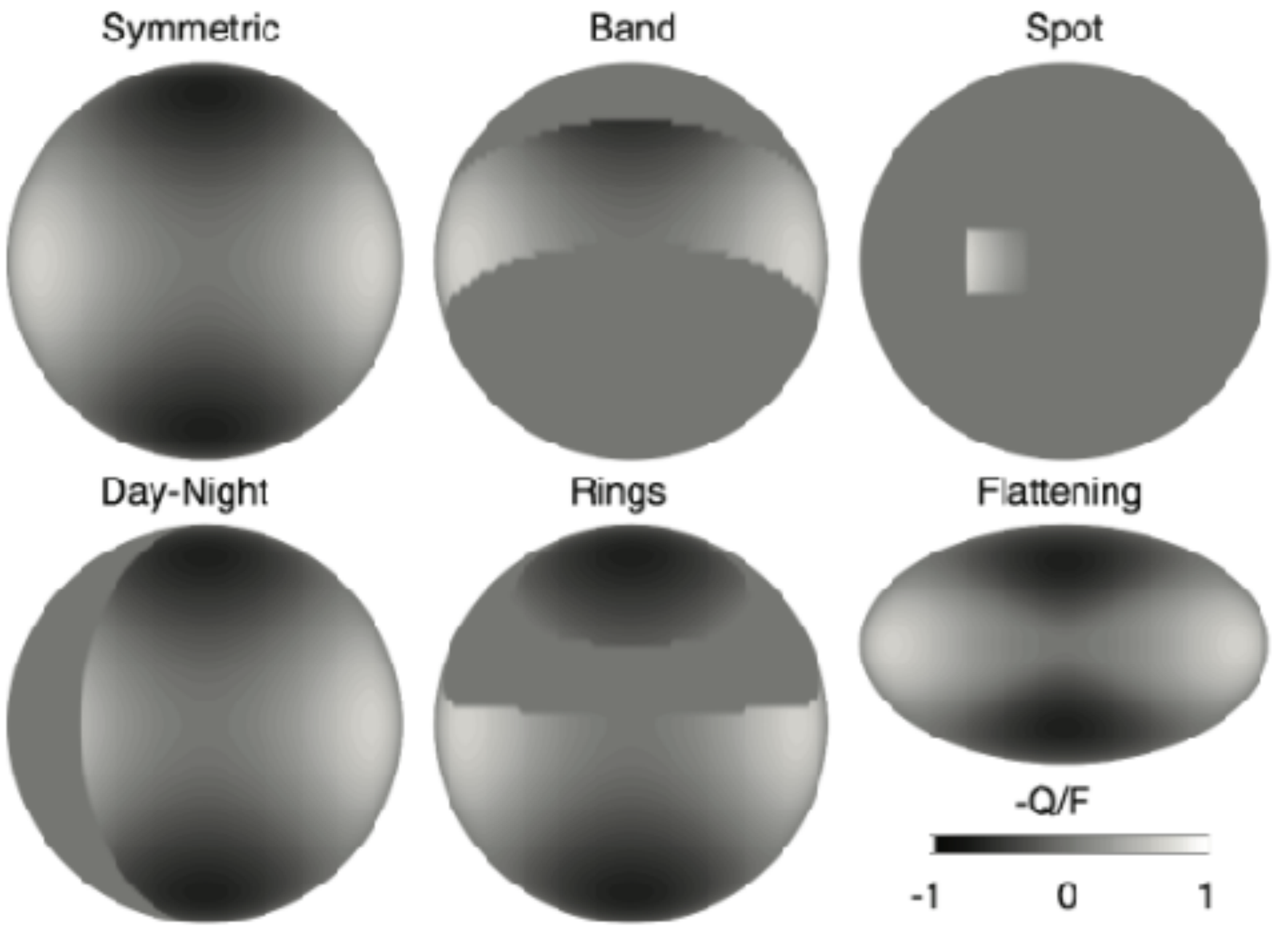


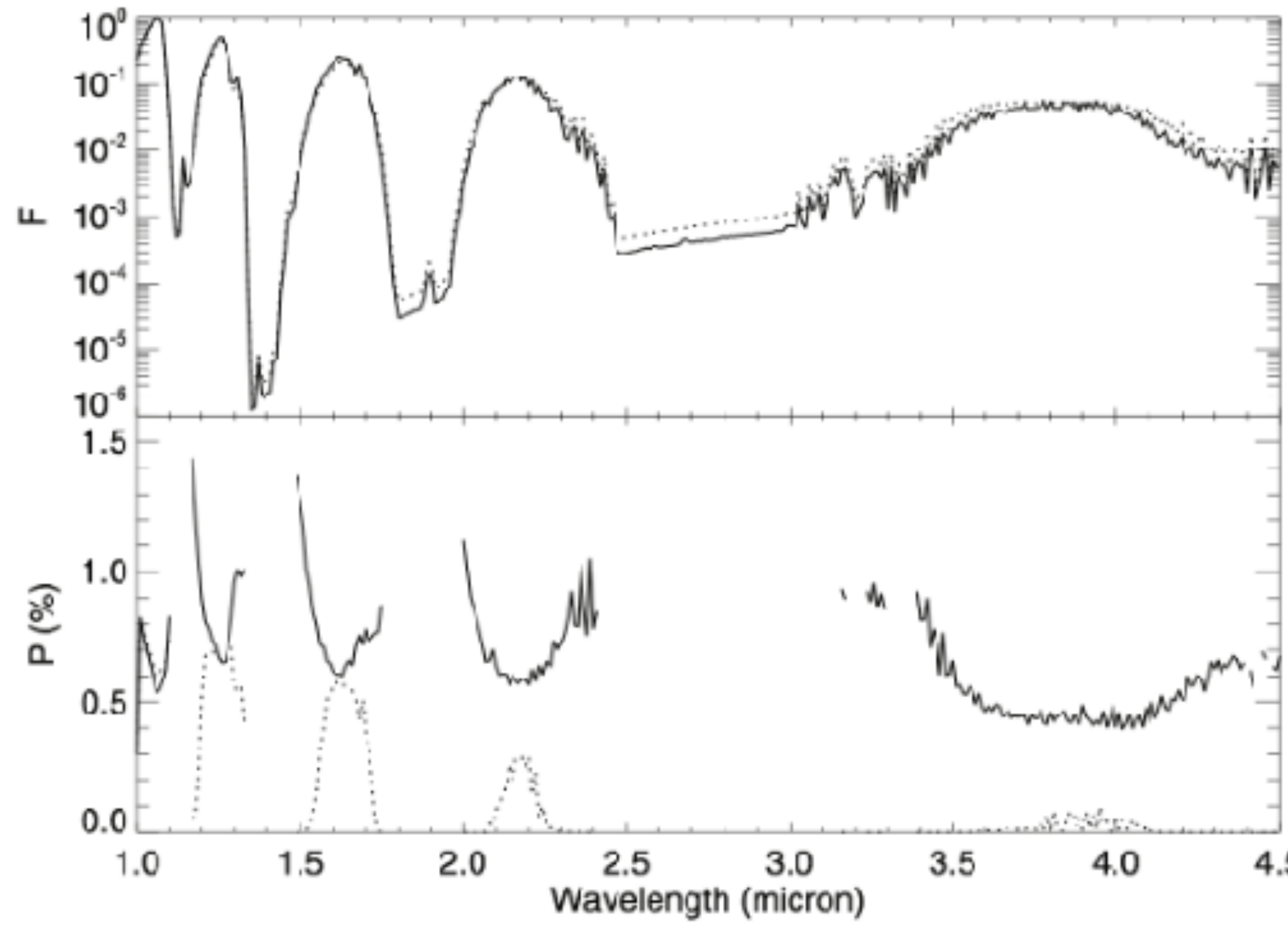
Apai et al. (2017)



Buenzli et al. (2012)

What do we gain from polarimetry?

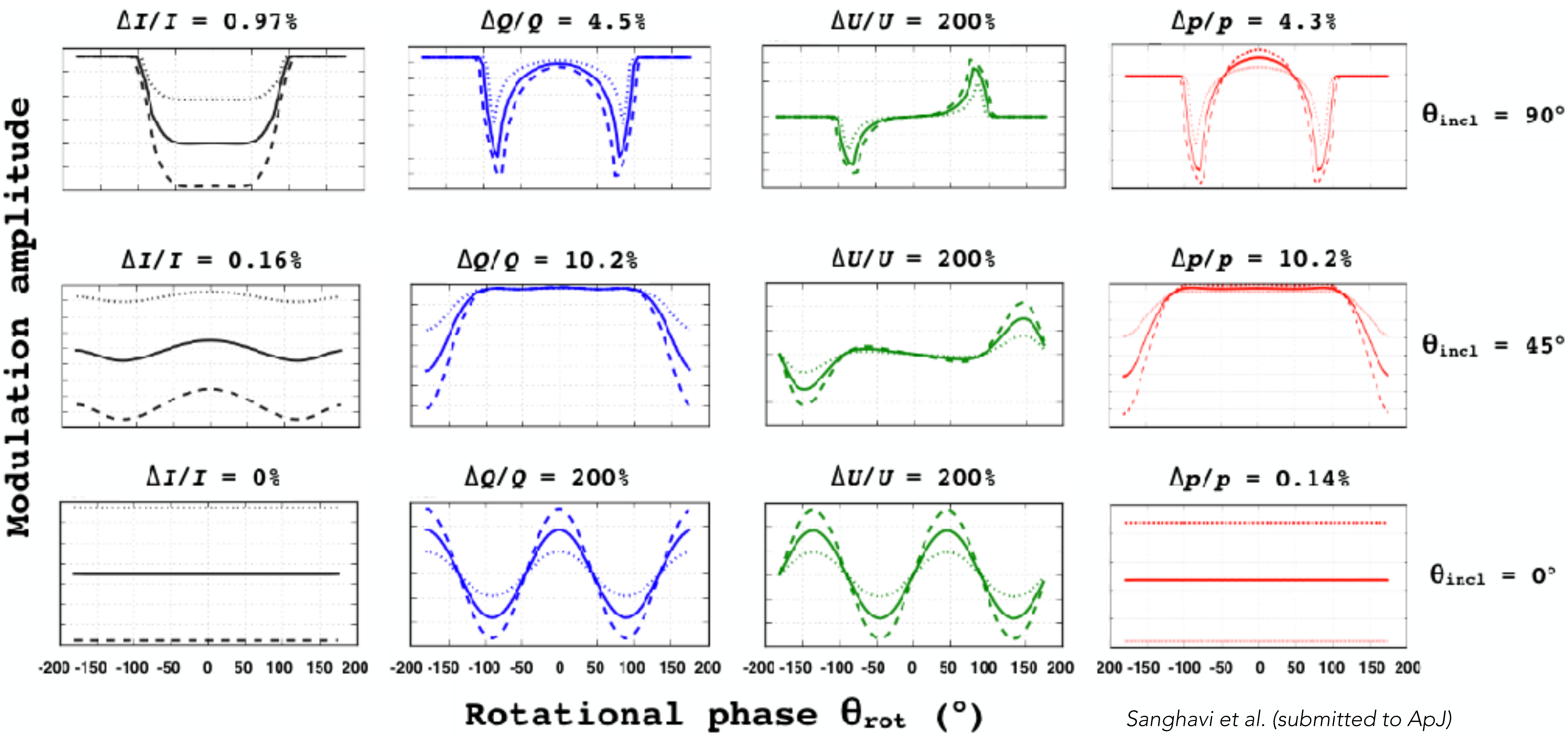




de Kok et al. (2011)

- Integrating -Q/F over viewing disk yields P≠0 for any present asymmetry
- Normalized F and P as a function of wavelength for a homogeneous, oblate object shows different polarization signals for cloud layers in top atmosphere (solid) and deeper in atmosphere (dashed)

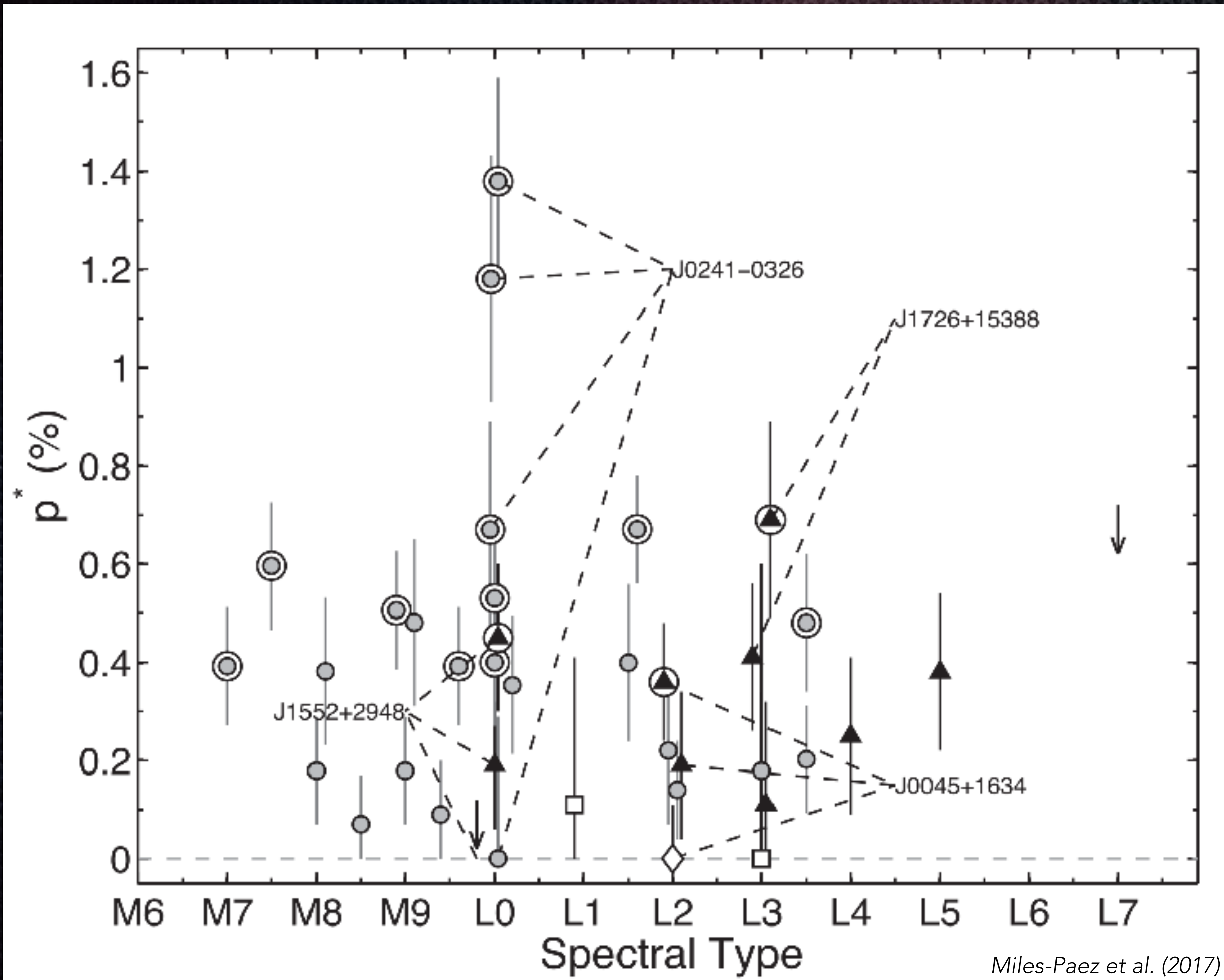
What do we gain from polarimetry?



Sanghavi et al. (submitted to ApJ)

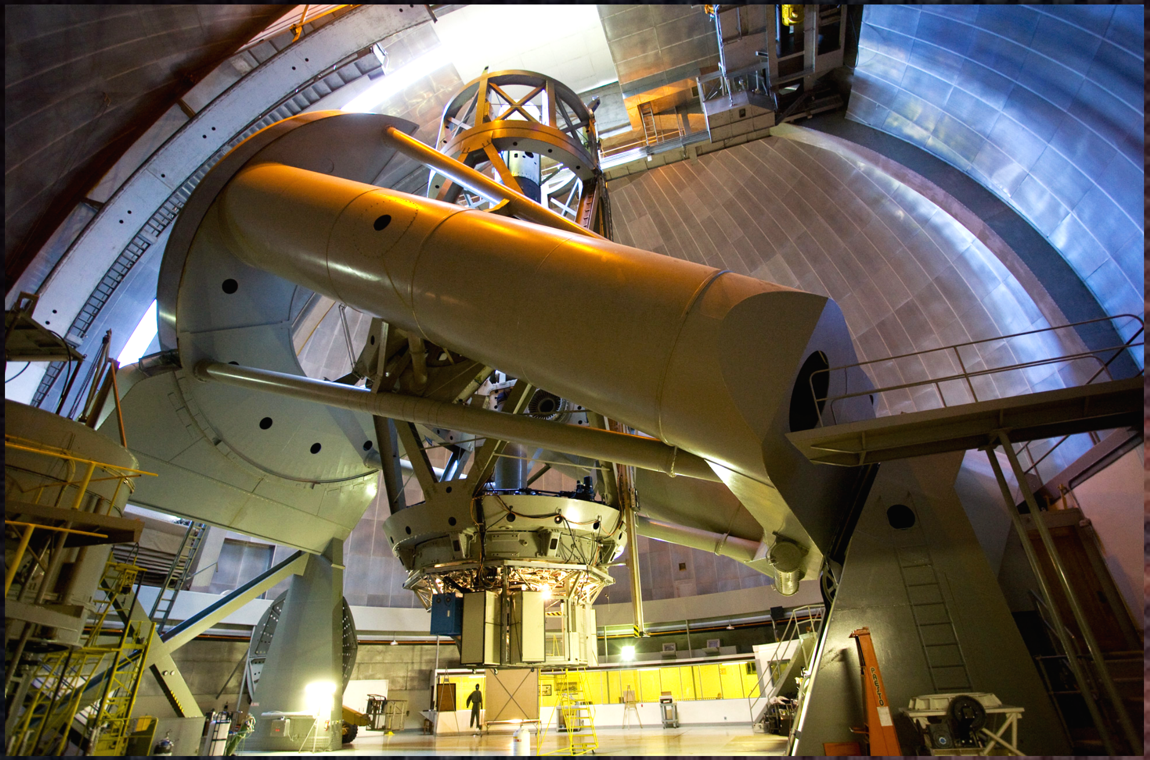
- Polarimetric monitoring can recover information about the spatial distribution of surface inhomogeneities from objects rotating pole on, for which photometric monitoring would yield no variability.

Current Polarimetry of BDs



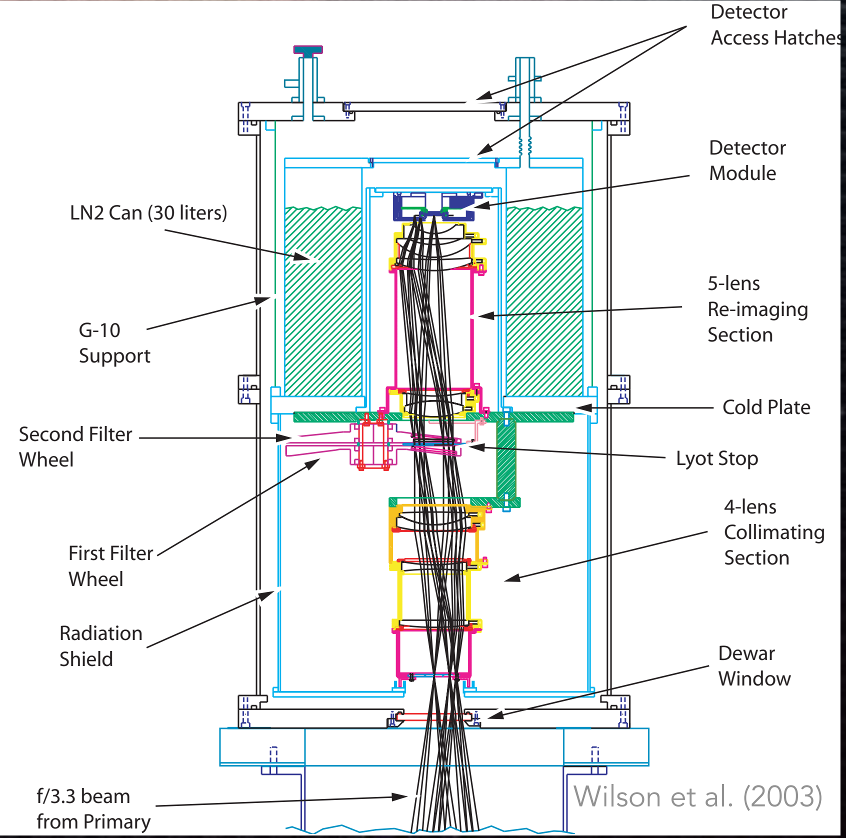
- A few smaller broadband polarimetric surveys have been made in the optical and infrared.
- Using Wollaston prisms and retarder plates at different angles, or wedged double Wollaston, to get full Stokes
- Bulky, inefficient, low througput

Palomar 200-inch and WIRC+Pol

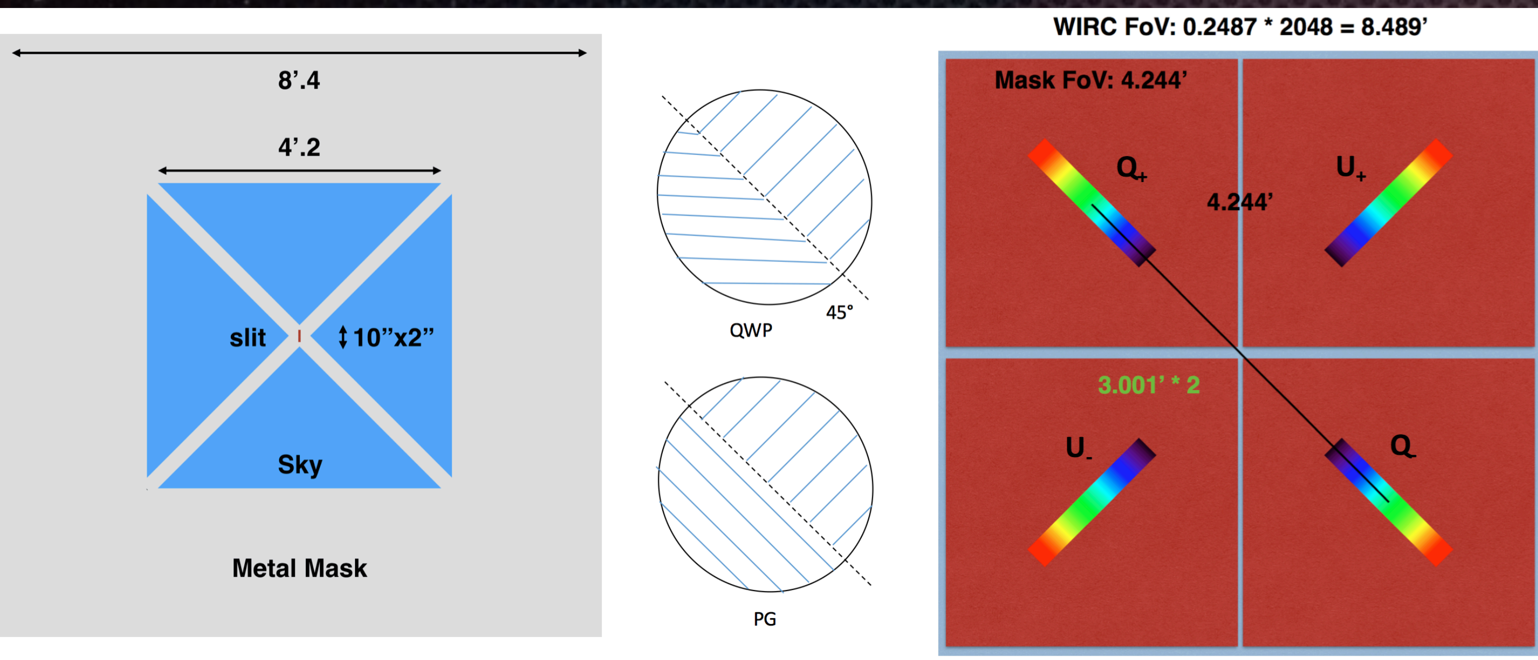


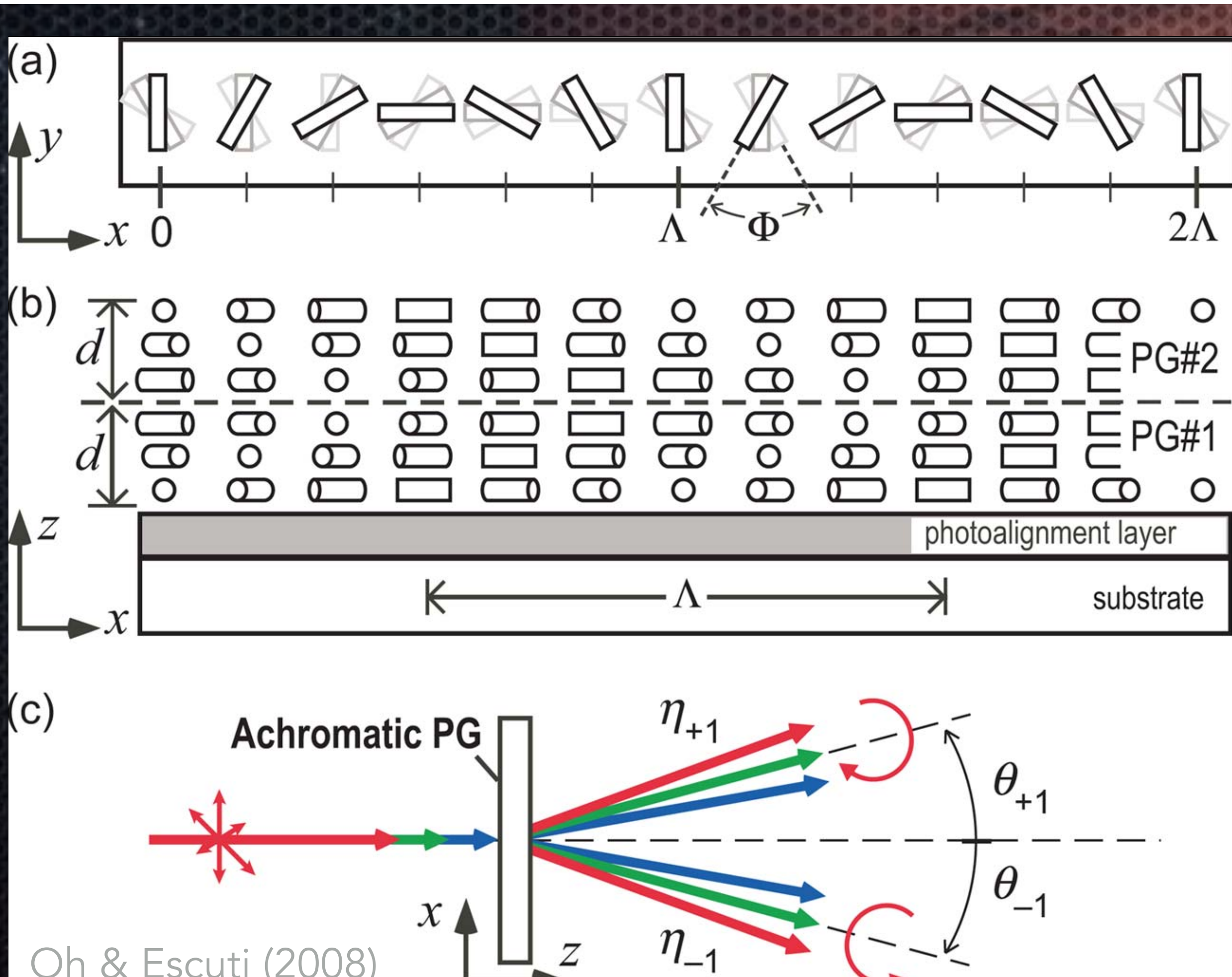
- Largest equatorial mounted telescope in the world
- Extremely stable tracking
- No differential motion of optics
- Low and stable instrument polarization
- 100 ppm precision demonstrated with WIRC (Wide-field InfraRed Camera) at prime focus

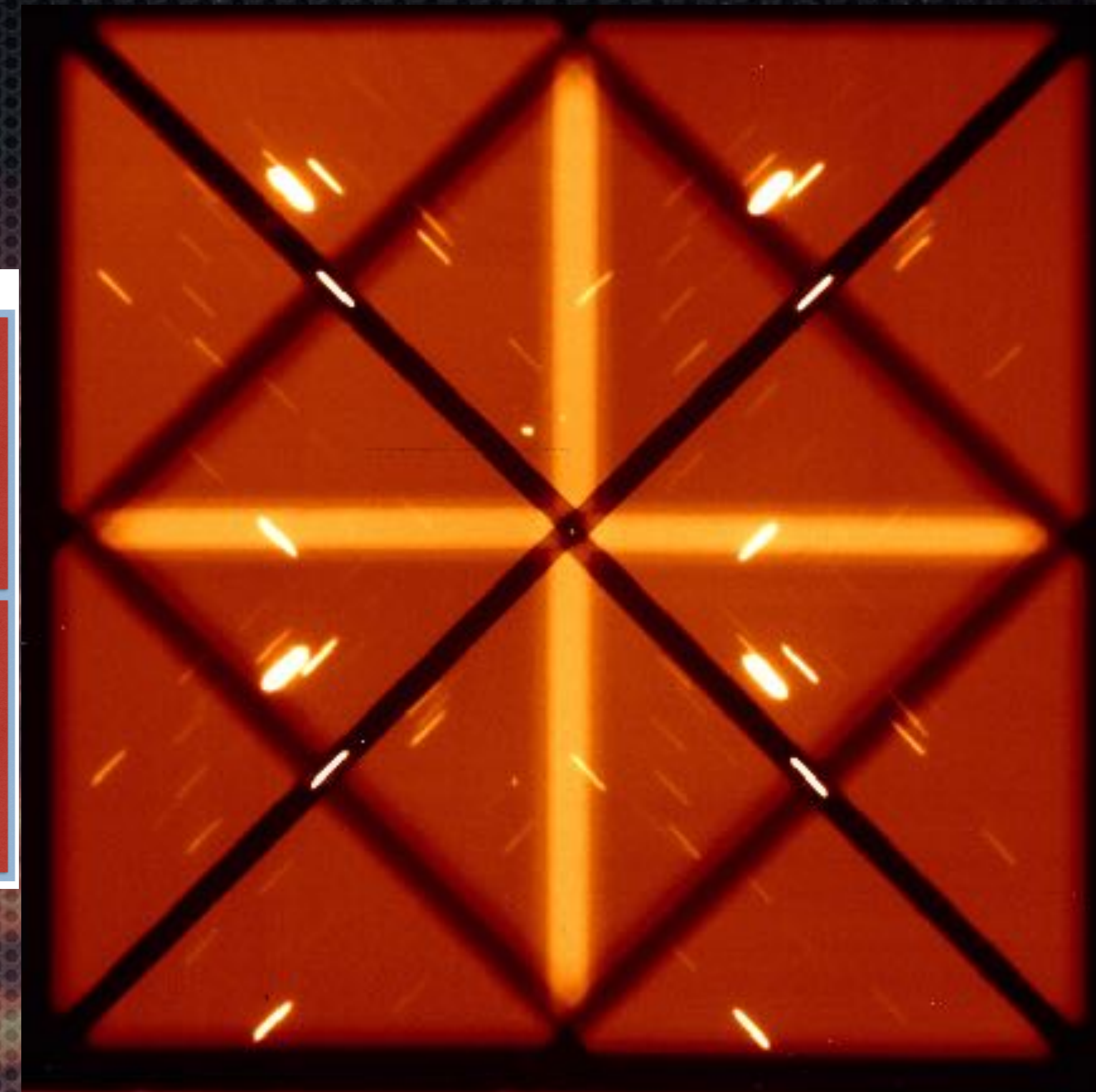
- New Hawaii-2 detector
- 32 channel read-out mode
- Polarization grating (PG) and quarter wave plate (QWP) for spectro-polarimetry
- Retractable focal plane mask for spectro-polarimetry mode
- Grism for integral-field spectroscopy
- Commissioned in 2017A. Started 2-year key science program to survey hundred of L/T dwarfs



Polarization Grating





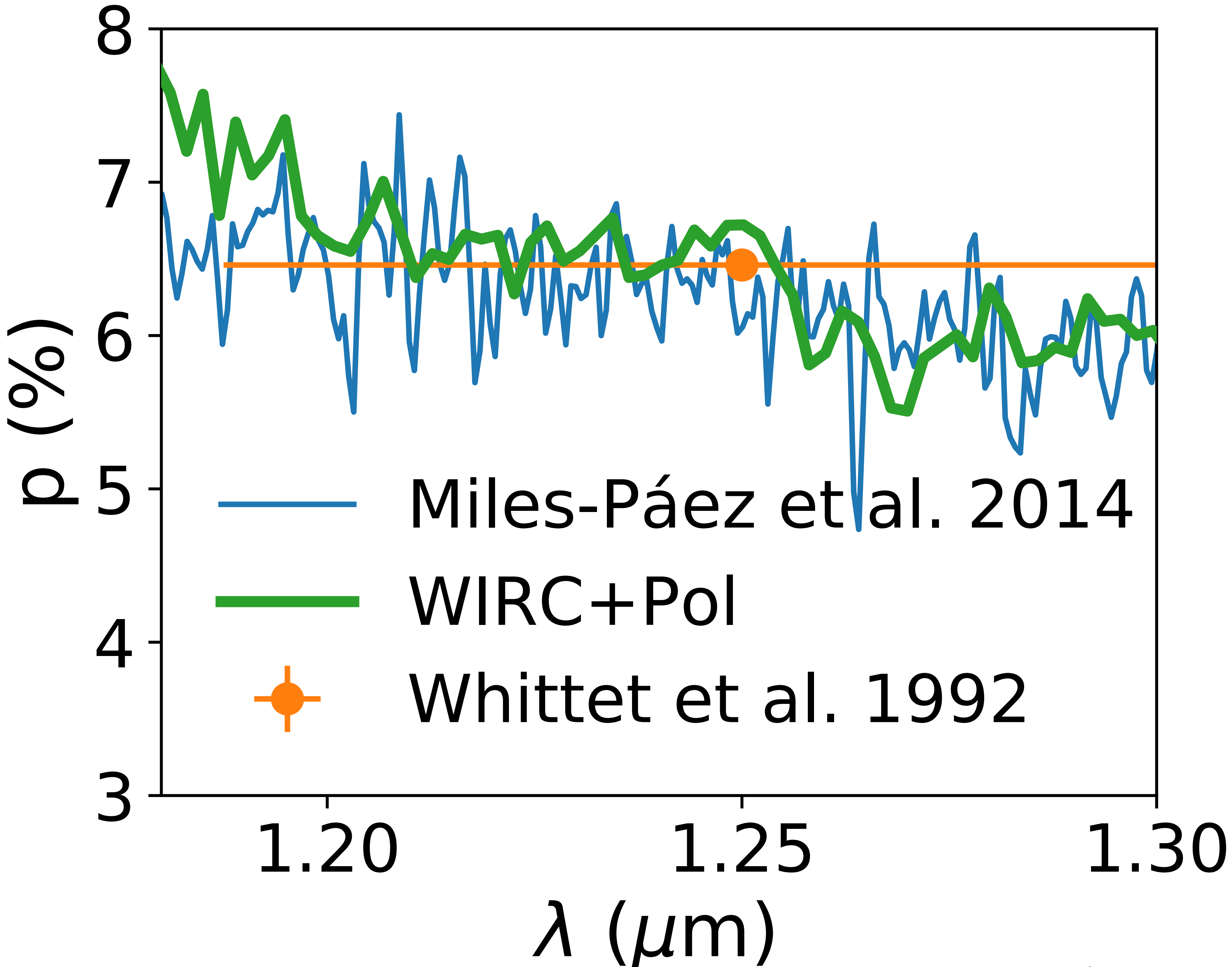


WIRC+Pol image

WIRC+Pol Specifications

- 8.4 arcmin full FOV, ~0.25 arcsec/pixel
- Seeing limited
- Spectro-polarimetry mode:
  - Split-pupil configuration, 4.2 arcmin FOV
  - Simultaneous Stokes Q+/- and U+/-
  - 1.1-1.8 μm (J and H band) with R~120-150
- Spectroscopy mode:
  - Full FOV
  - Wide-field spectroscopy in (J), H, and K with R~200

Commissioning Results



Credit: S. Tinyanont

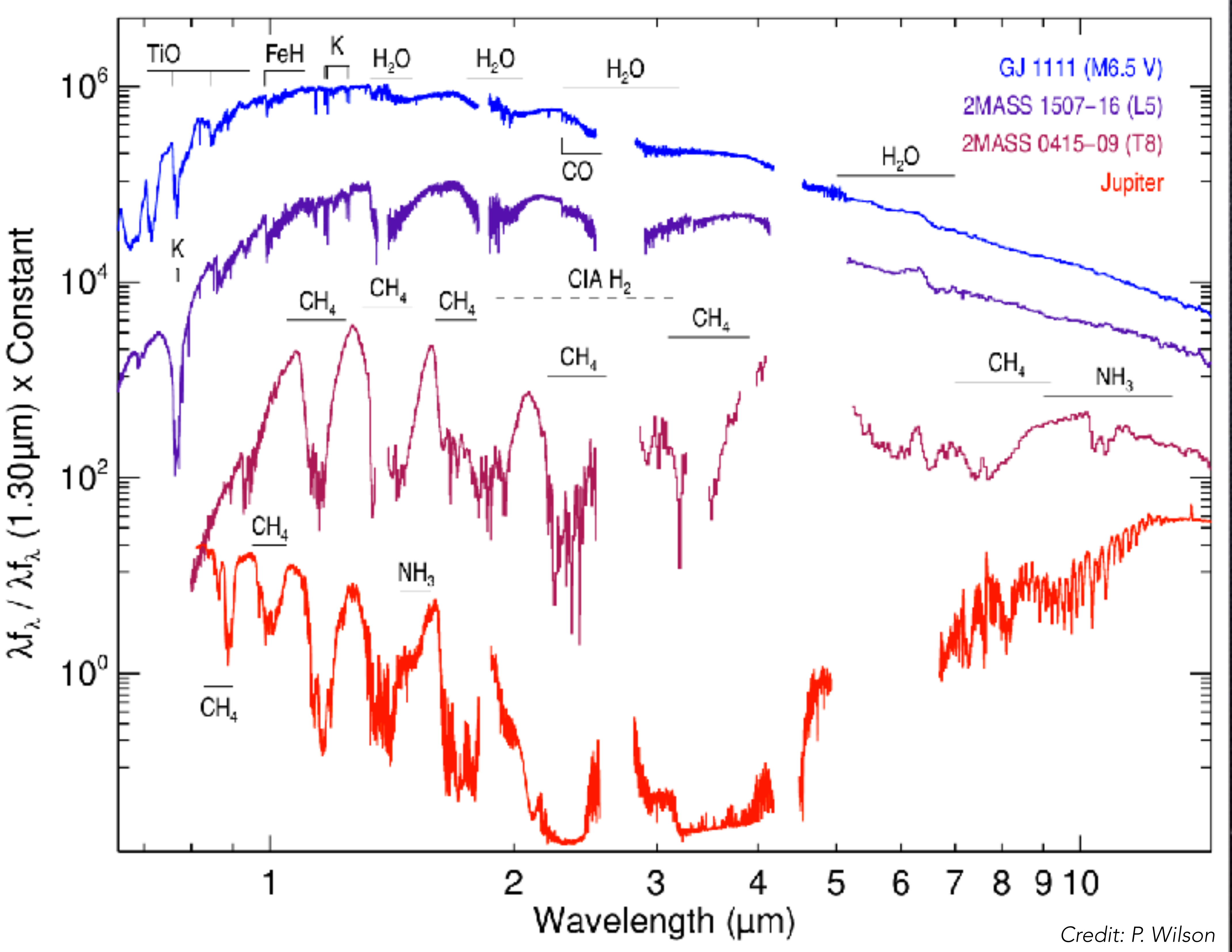
- Polarized and unpolarized standards
- ~20 science targets with know variability and/or polarization
- Linear polarization spectrum of a source in the J and H bands with 3-sigma precision of 0.5% in the degree of polarization within 1 hour exposure time for sources brighter than 14 mag

Summary

- Only smaller broadband polarimetric surveys of BDs exist to date.
- A comprehensive spectro-polarimetric survey and monitoring campaign of the full range of BD spectral types, from mid-L to late T and even Y dwarfs, with focus on the L/T transition, would add the scope and depth needed for detailed atmospheric characterization of BDs, and will help us develop the techniques to in the near future study atmospheres of exoplanets.

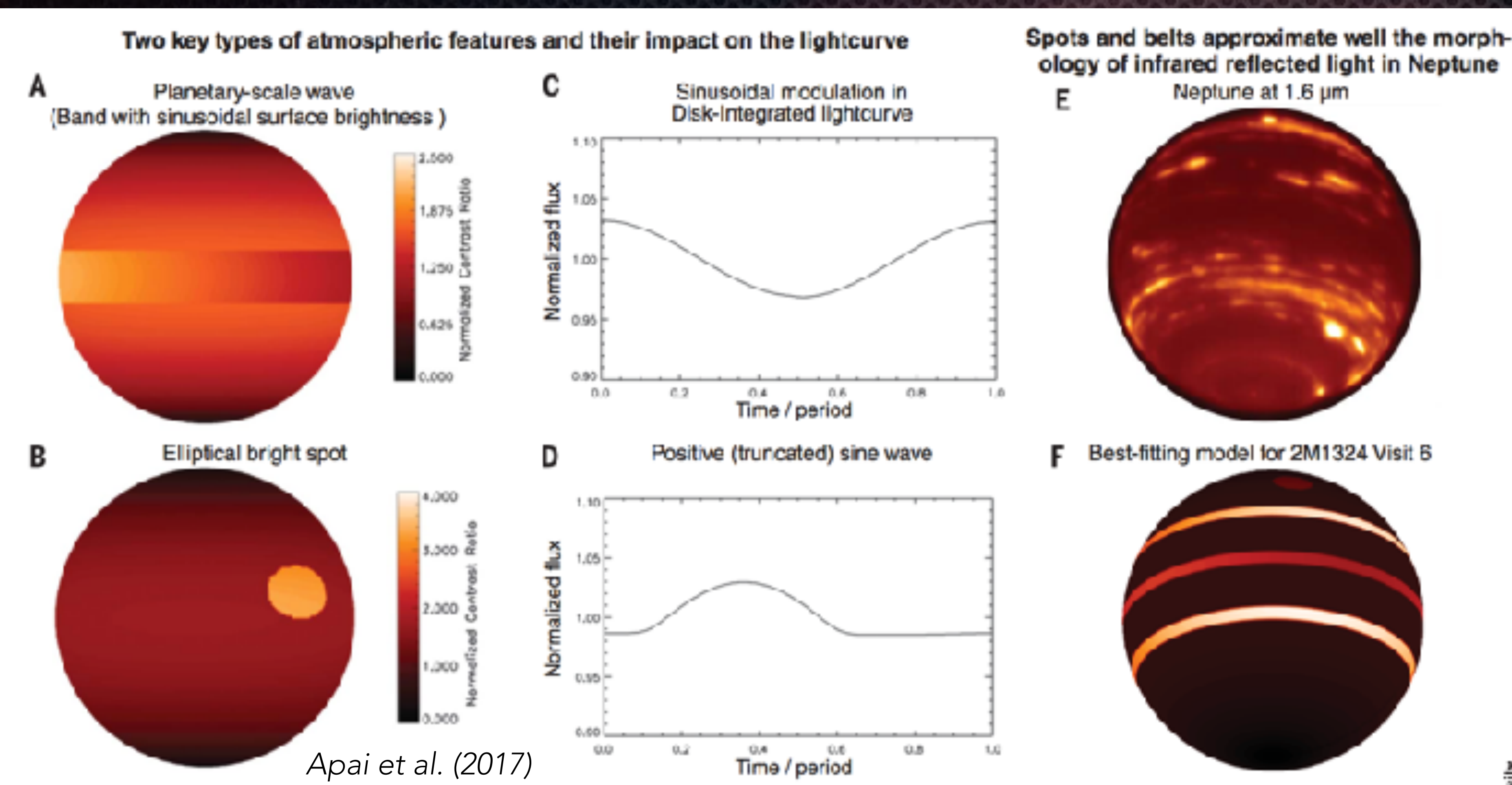

THANKS!

Brown Dwarf Spectral Types

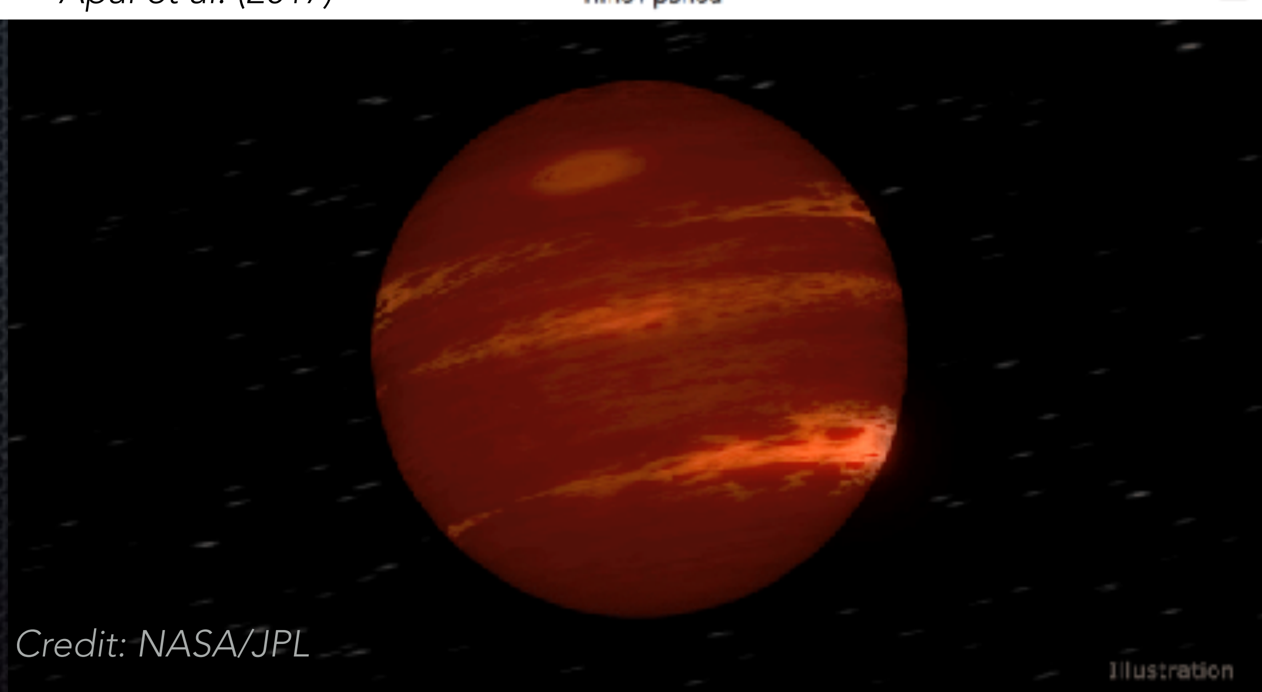


Credit: P. Wilson

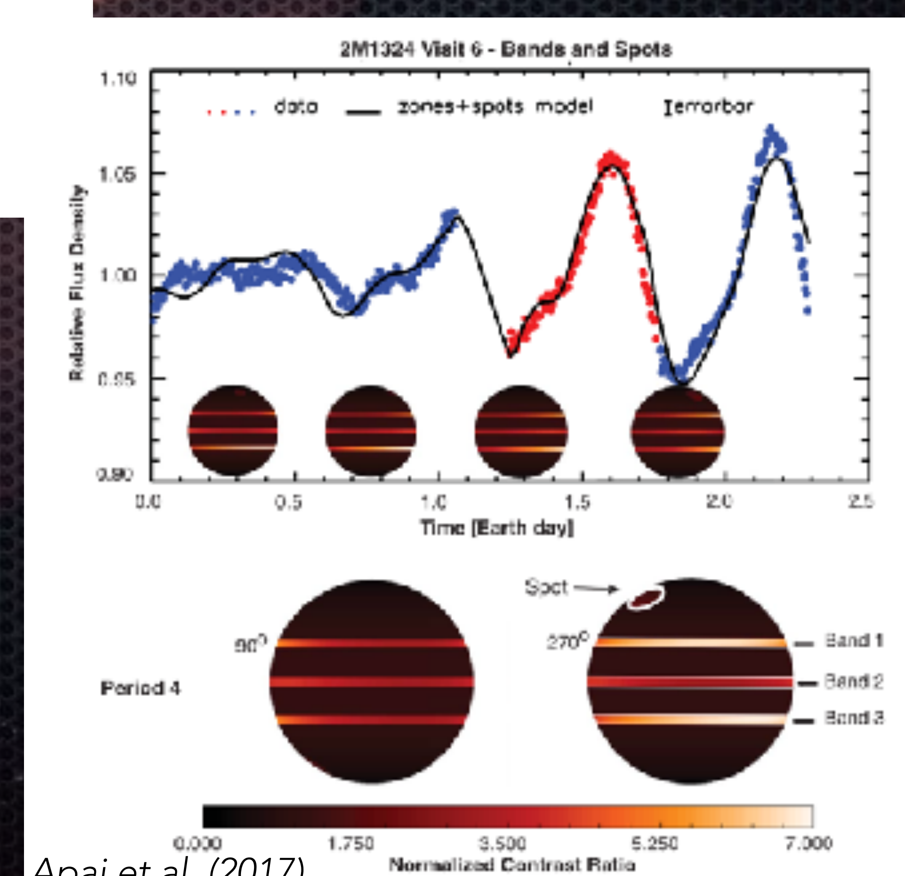
Rotational mapping



Apai et al. (2017)

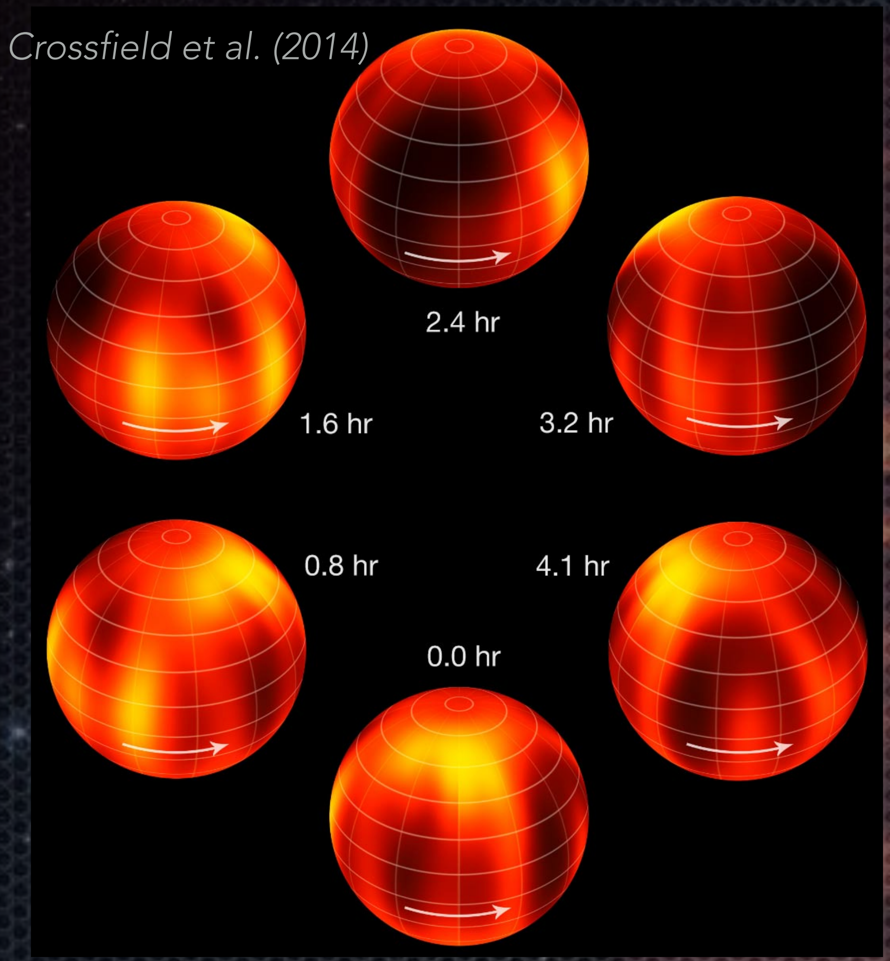


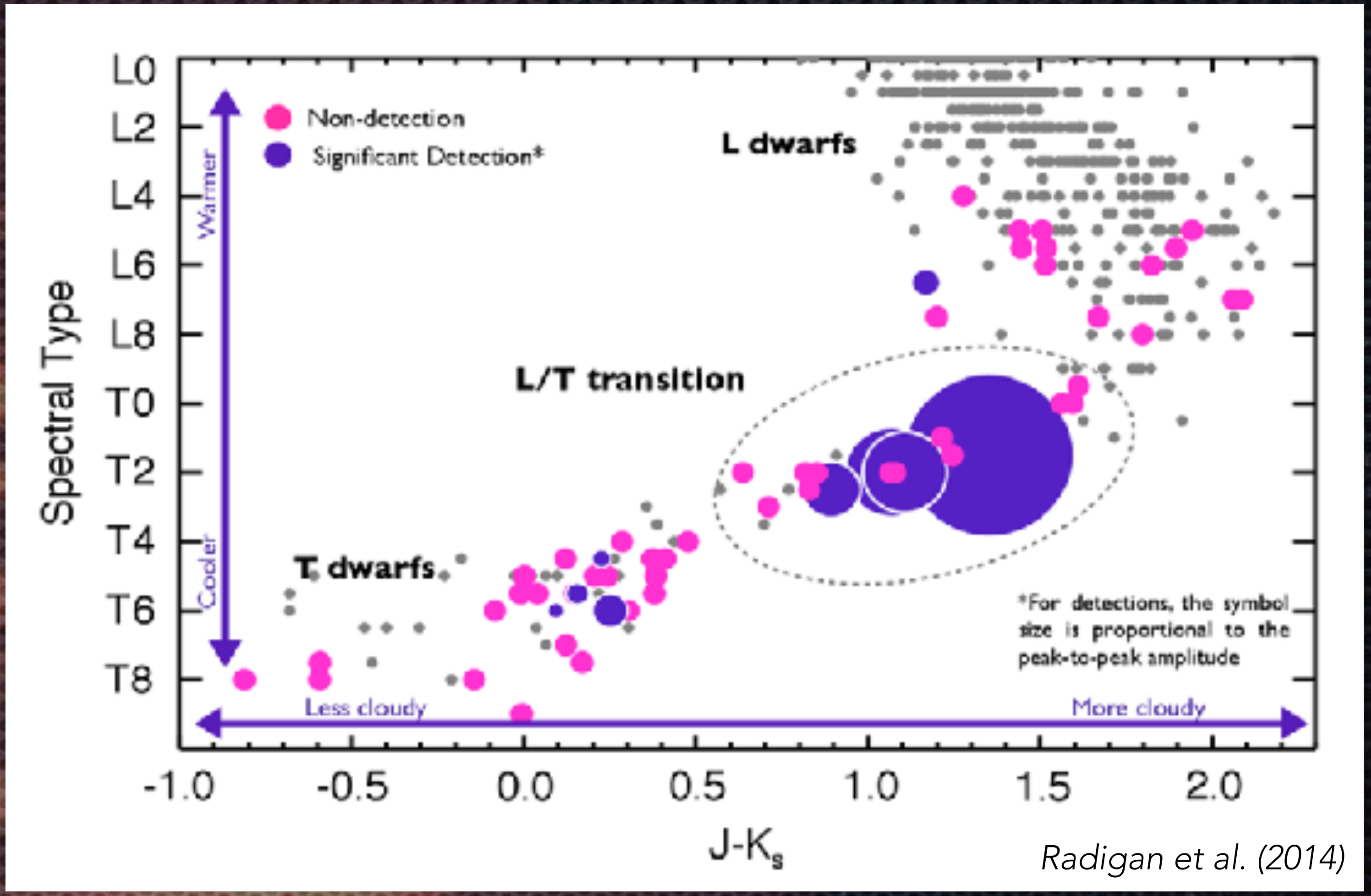
Credit: NASA/JPL



Apai et al. (2017)

Patchy Clouds and Variability





- Luhman 16B and other brown dwarfs in the L/T transition region show signs of patchy clouds