Mind the ~~Gap~~ Overlap:
Young Brown Dwarfs as Exoplanet Analogs

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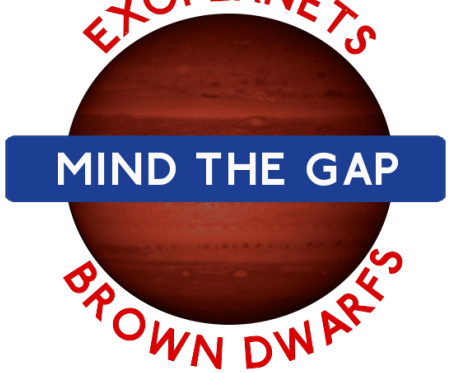
Mind The Gap
University of Hertfordshire, UK
September 2, 2013



Brown dwarfs cool, fade, and shrink with time

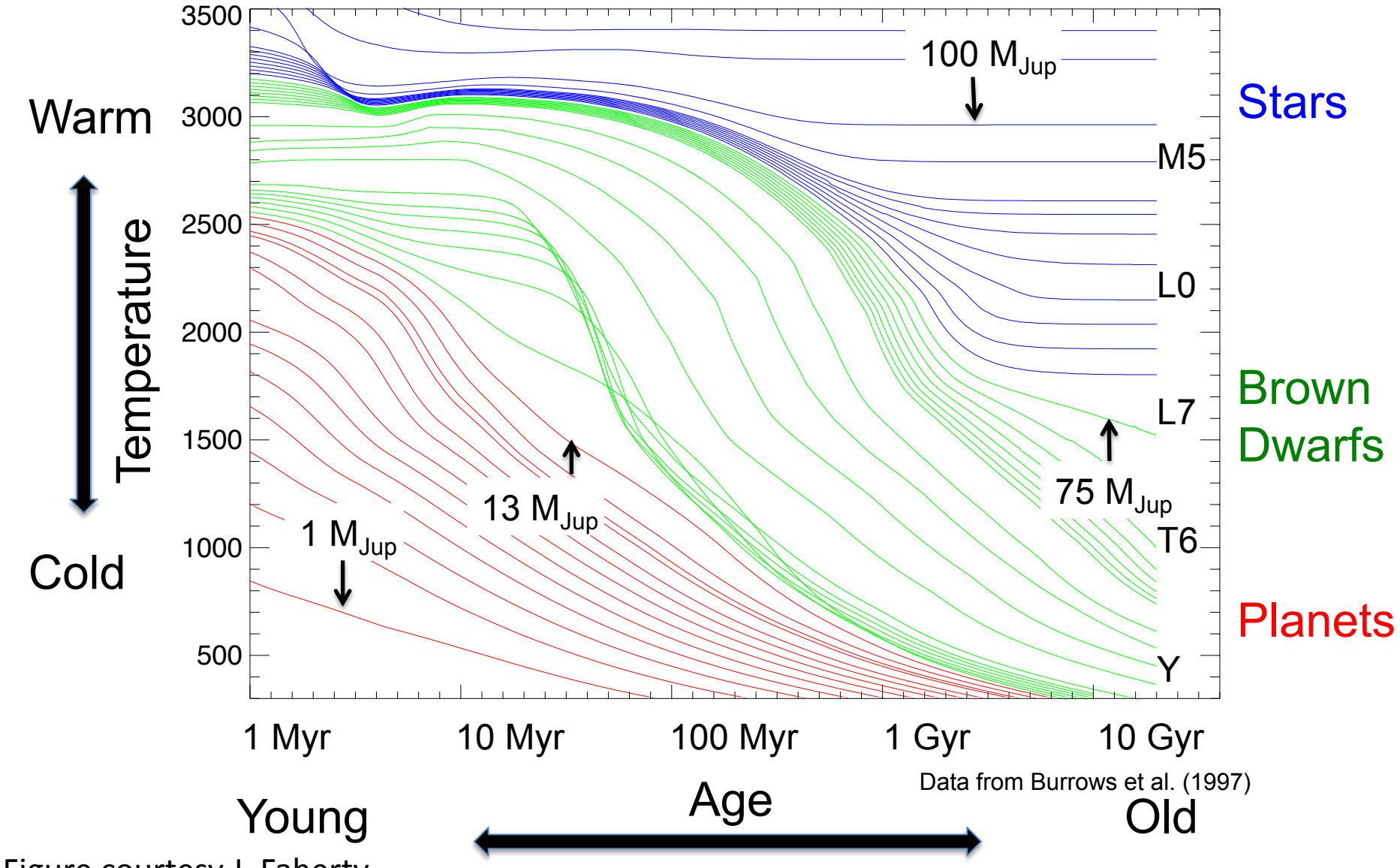


Figure courtesy J. Faherty

BDs & planets overlap in T_{eff} & log(g) at different ages

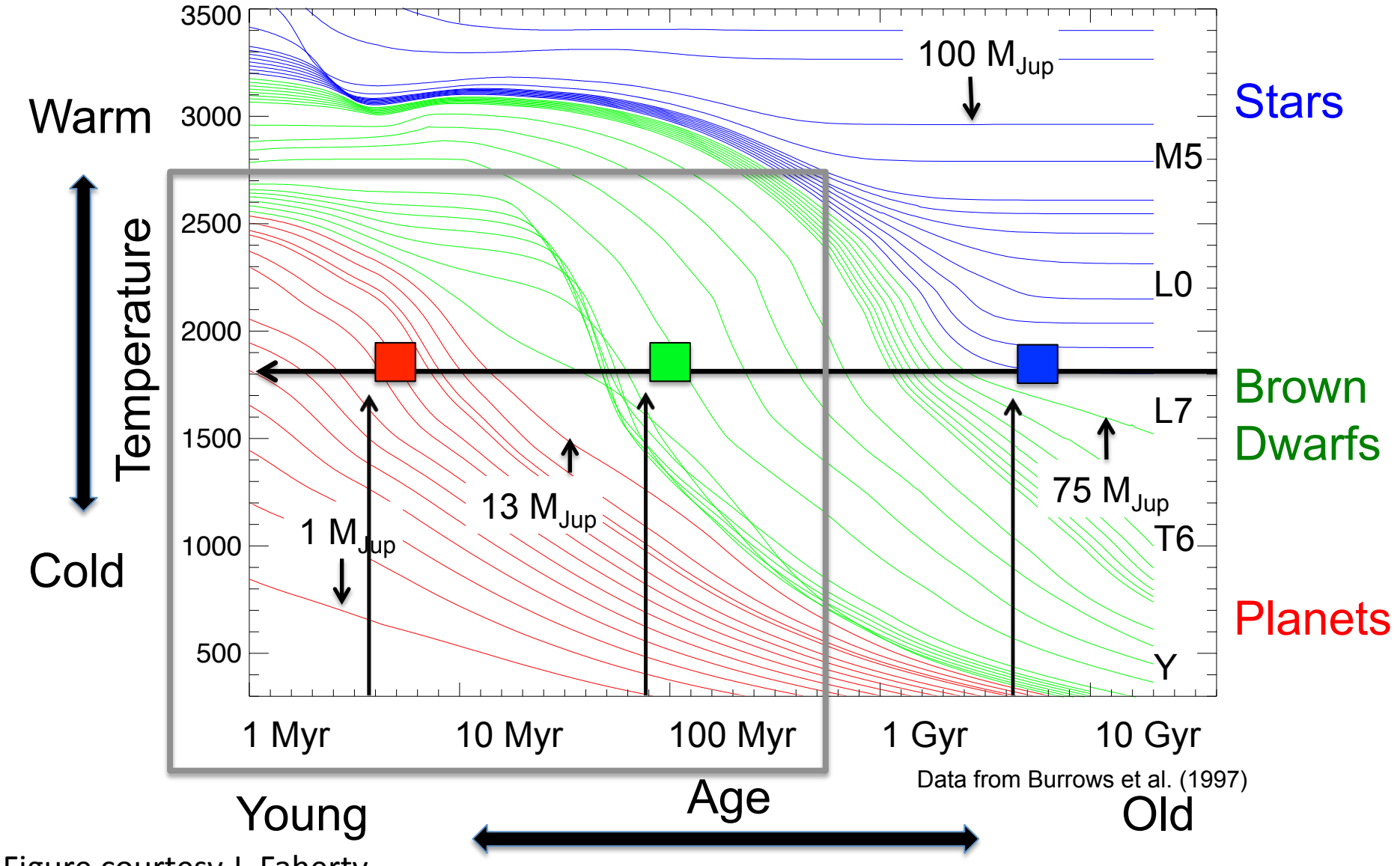
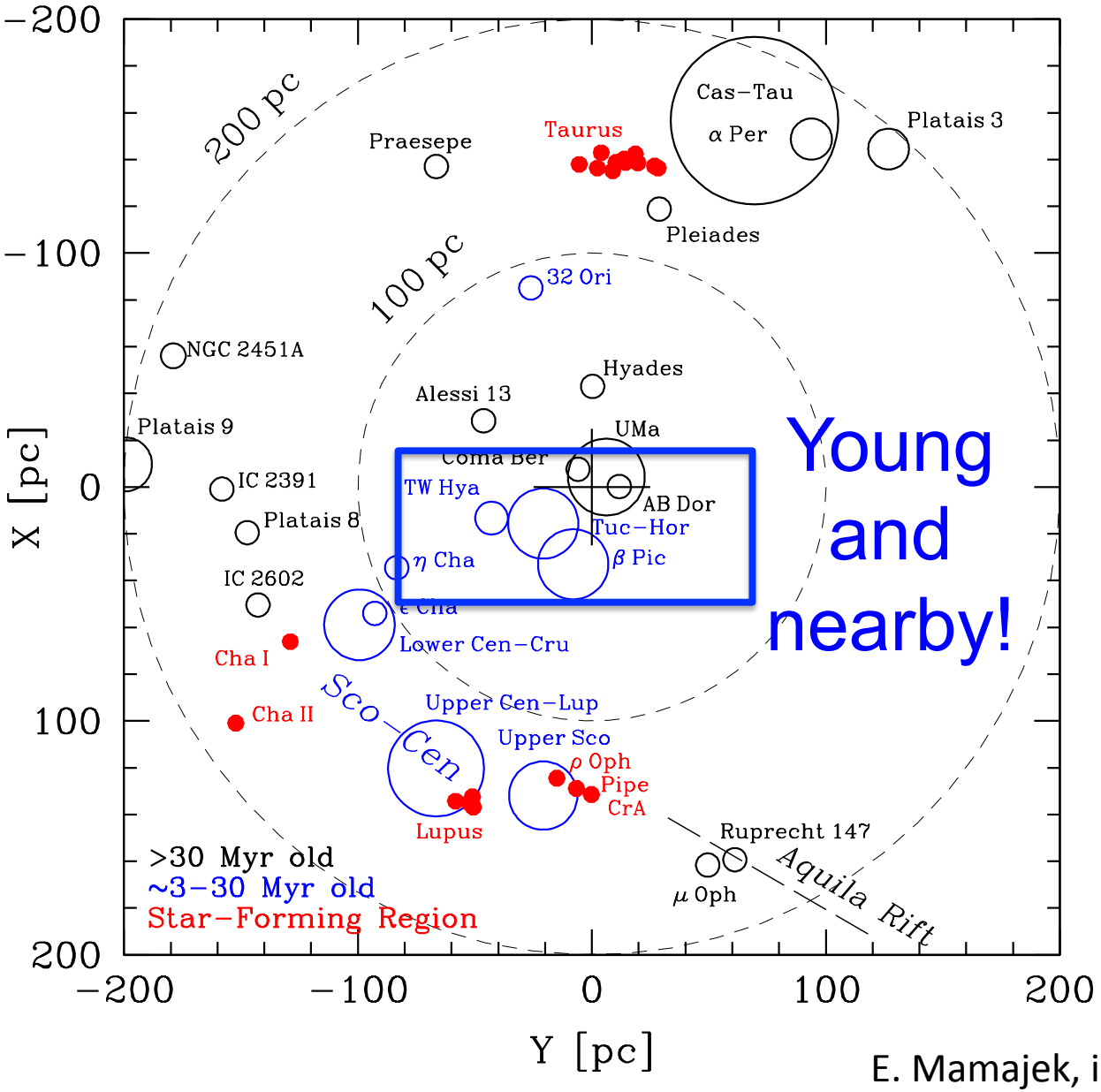


Figure courtesy J. Faherty

Where do we look for young brown dwarfs?



Young and nearby!

Too old for significant youth signatures

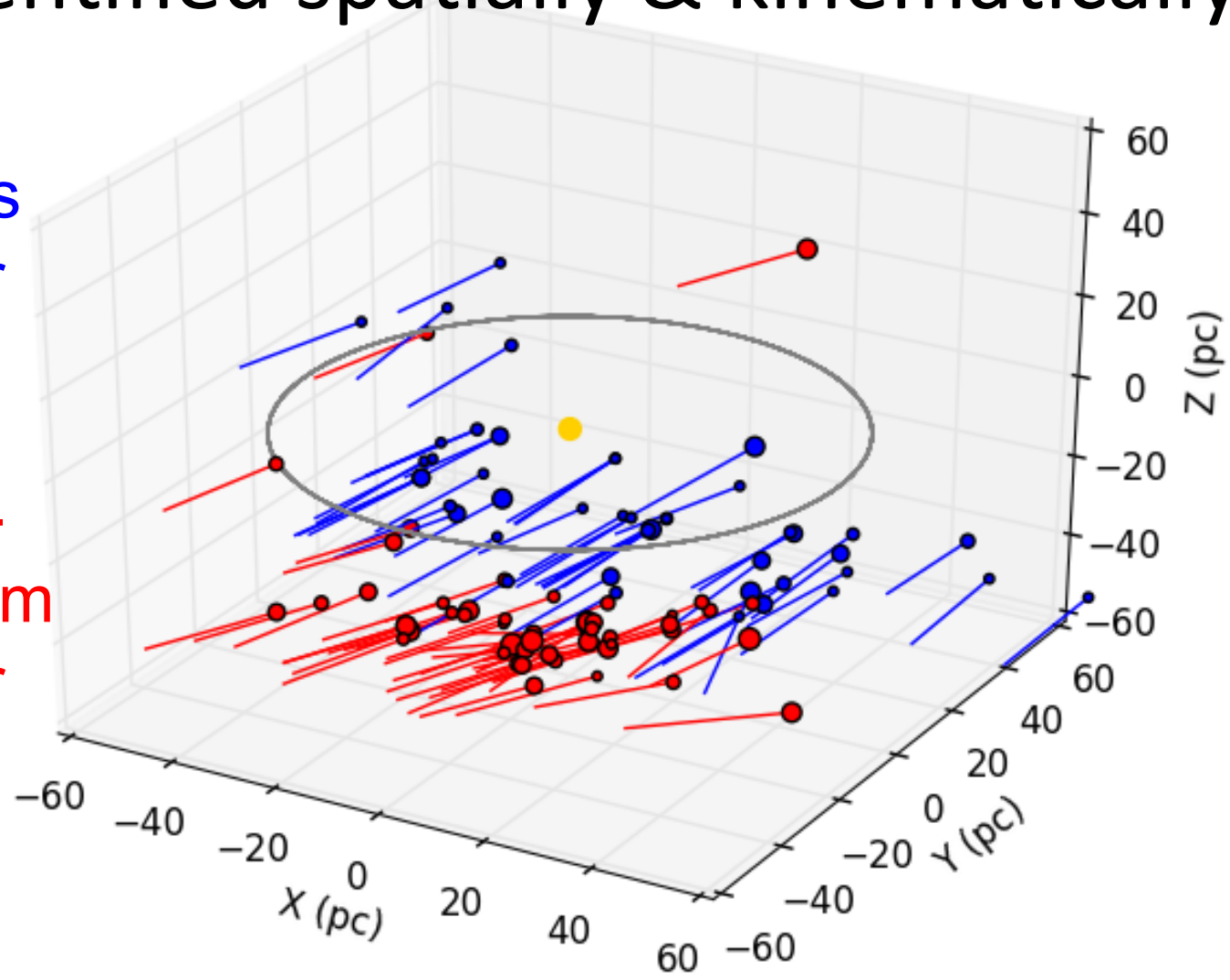
Too distant & embedded

E. Mamajek, in Rice et al. 2011

Nearby young moving groups (NYMGs) are identified spatially & kinematically

β Pictoris
~10 Myr

Tucana-Horologium
~30 Myr



Riedel et al. 2013, submitted & Faherty, Riedel et al. in prep.

NYMGs provide objects with known ages

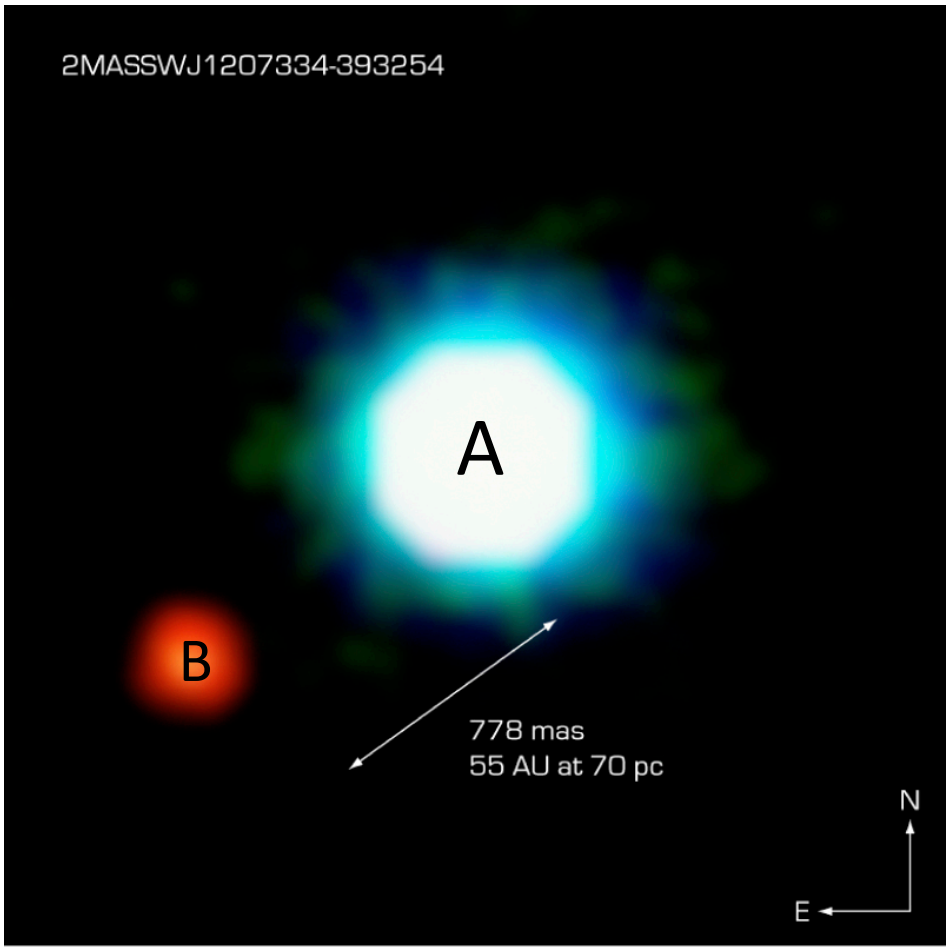
2MASS 1207-39

member of ~10 Myr old
TW Hydrae moving group

A: ~25 M_{Jup}

B: ~5 M_{Jup}

Gizis 2002
Chauvin et al. 2004

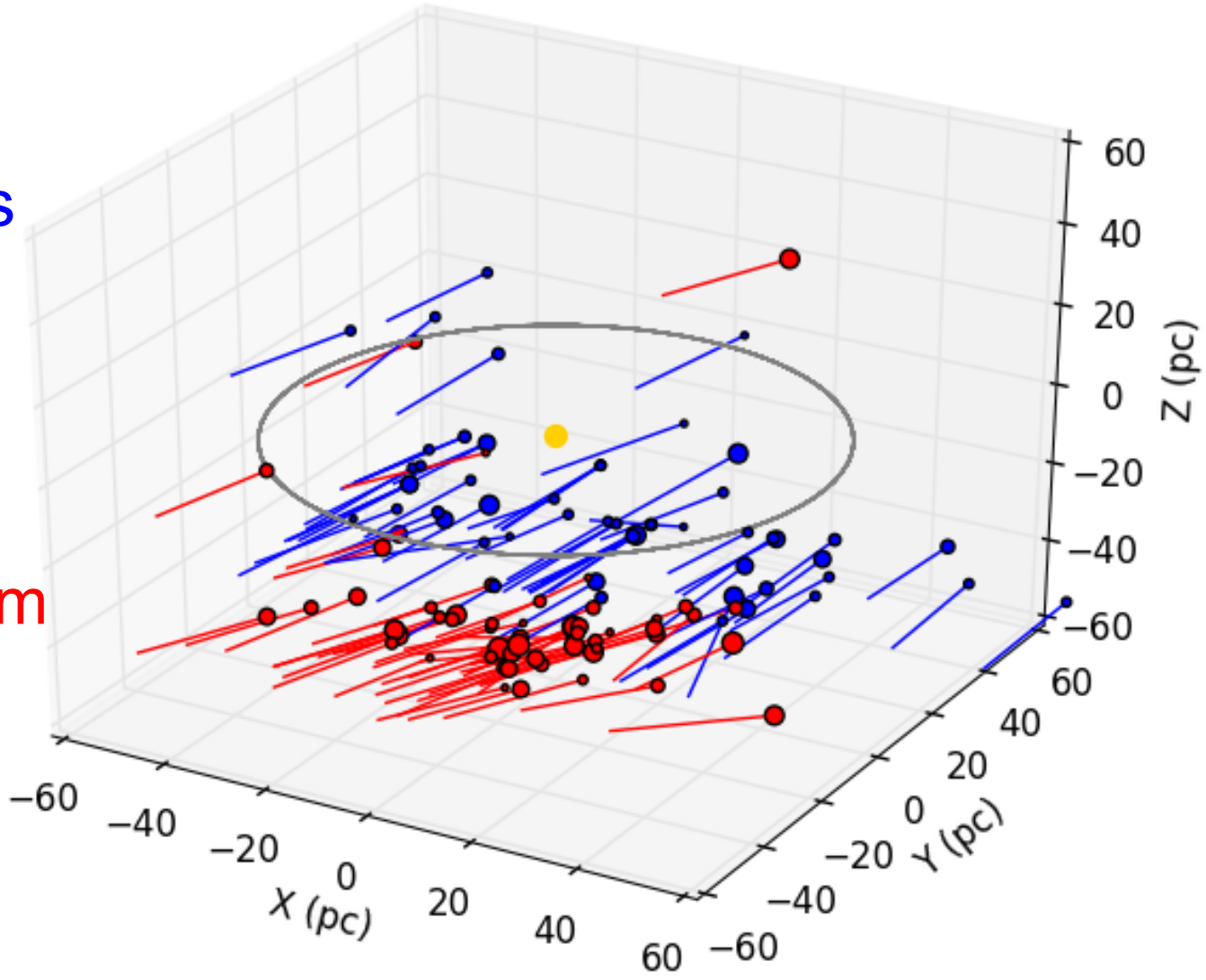


More in Young Brown Dwarfs session
Wednesday at 11 am!

New young objects confirmed via kinematics

β Pictoris
~10 Myr

Tucana-
Horologium
~30 Myr

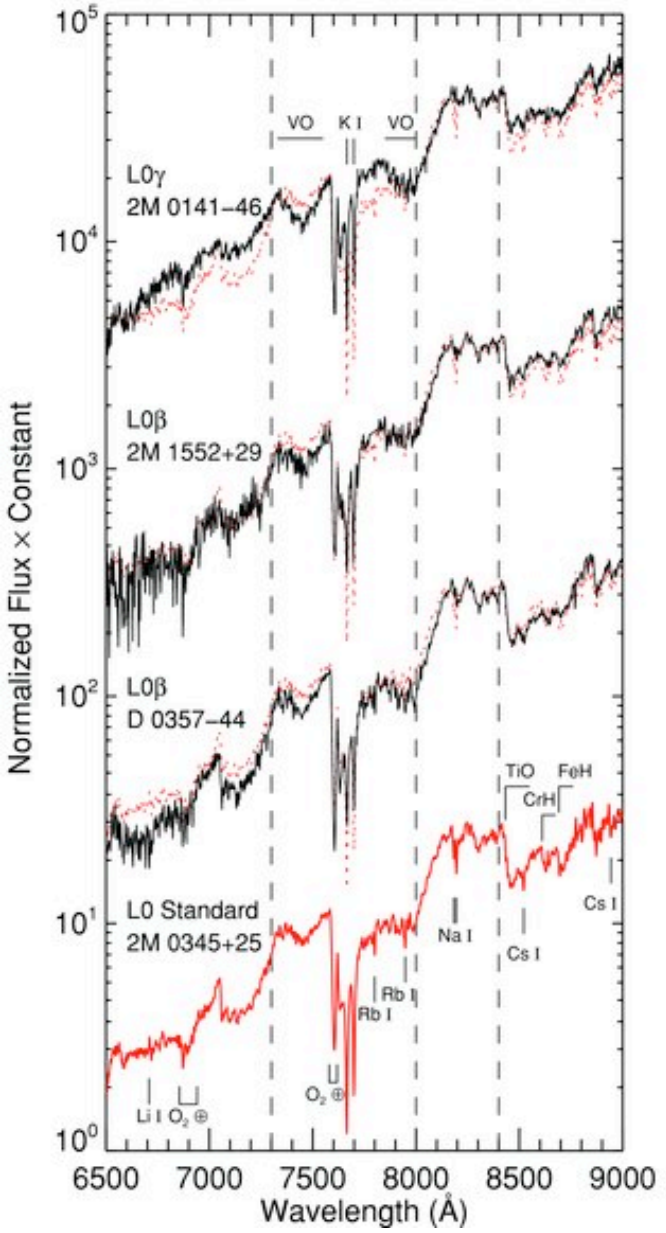


J. Faherty's talk on Wednesday in 11 am session

Spectral youth indicators for M & L dwarfs

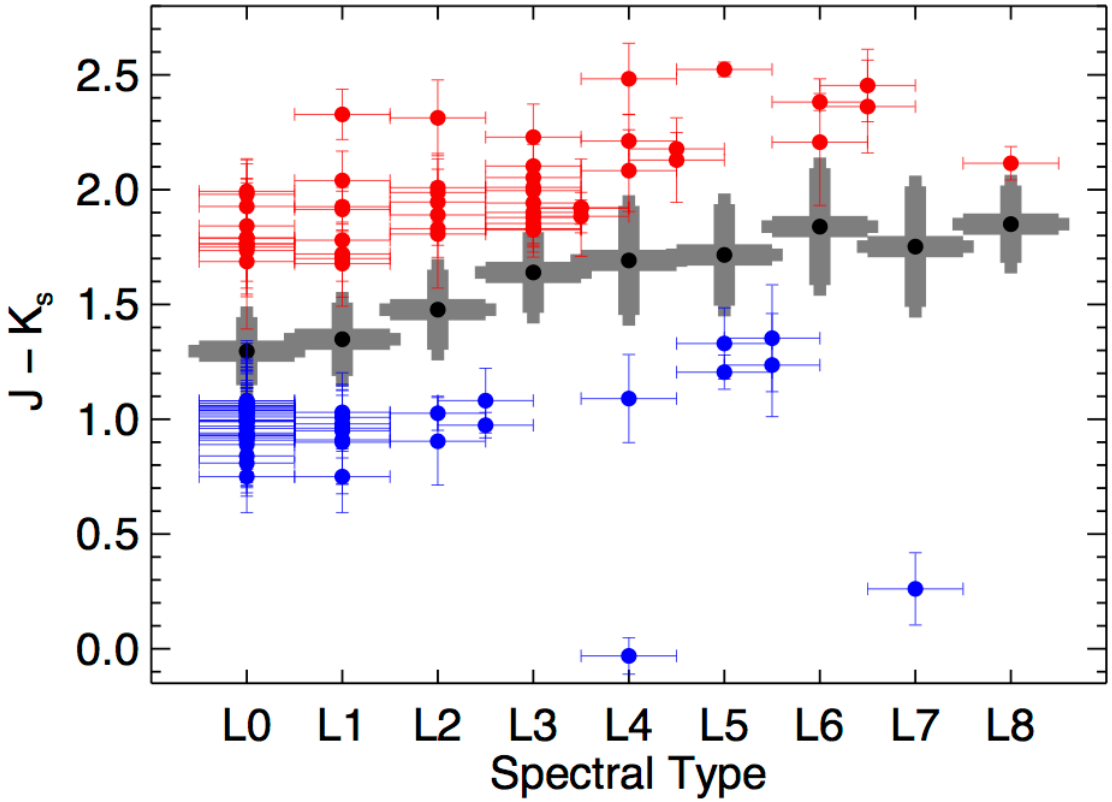
- Stronger VO and weaker TiO & K in red-optical spectra

Cruz et a. 2009



Spectral youth indicators for M & L dwarfs

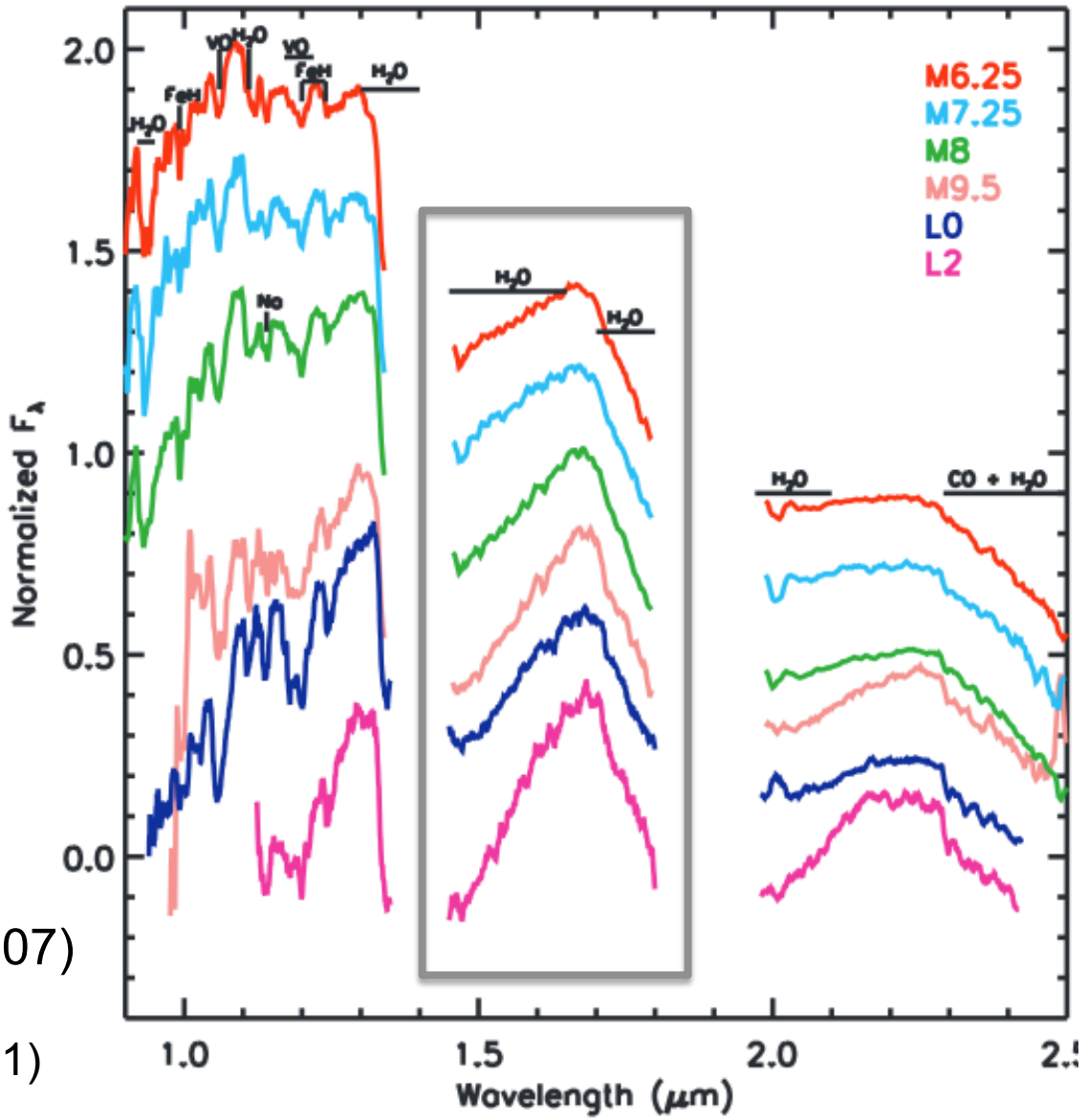
- Stronger VO and weaker TiO & K in red-optical spectra
- Red NIR colors



Faherty et al. 2012

Spectral youth indicators for M & L dwarfs

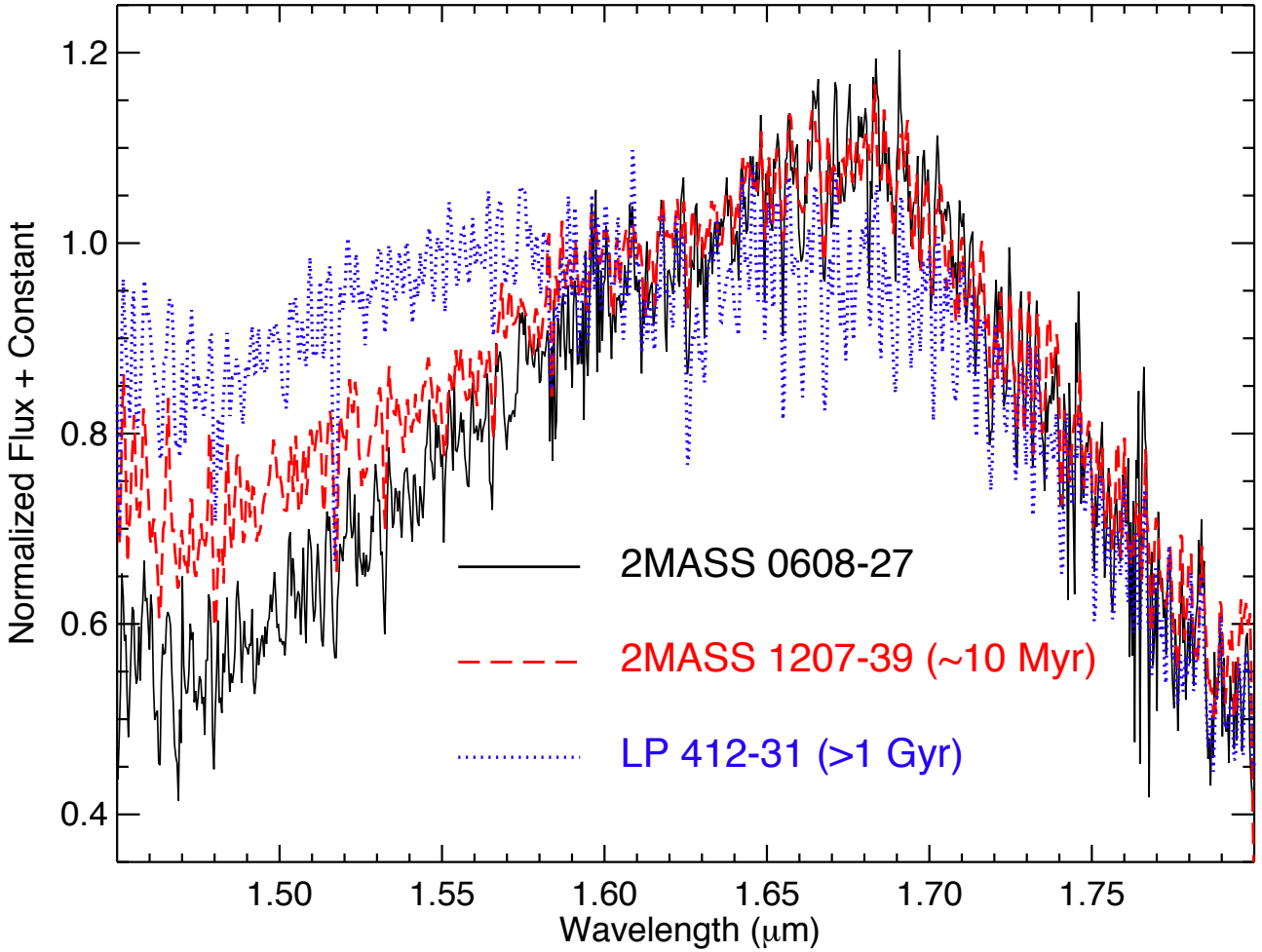
- Stronger VO and weaker TiO & K in red-optical spectra
- Red NIR colors
- Triangular H-band



Allers et al. (2007)
see also
Lucas et al. (2001)

Young M8.5 objects in H band

H band from SpeX on the IRTF

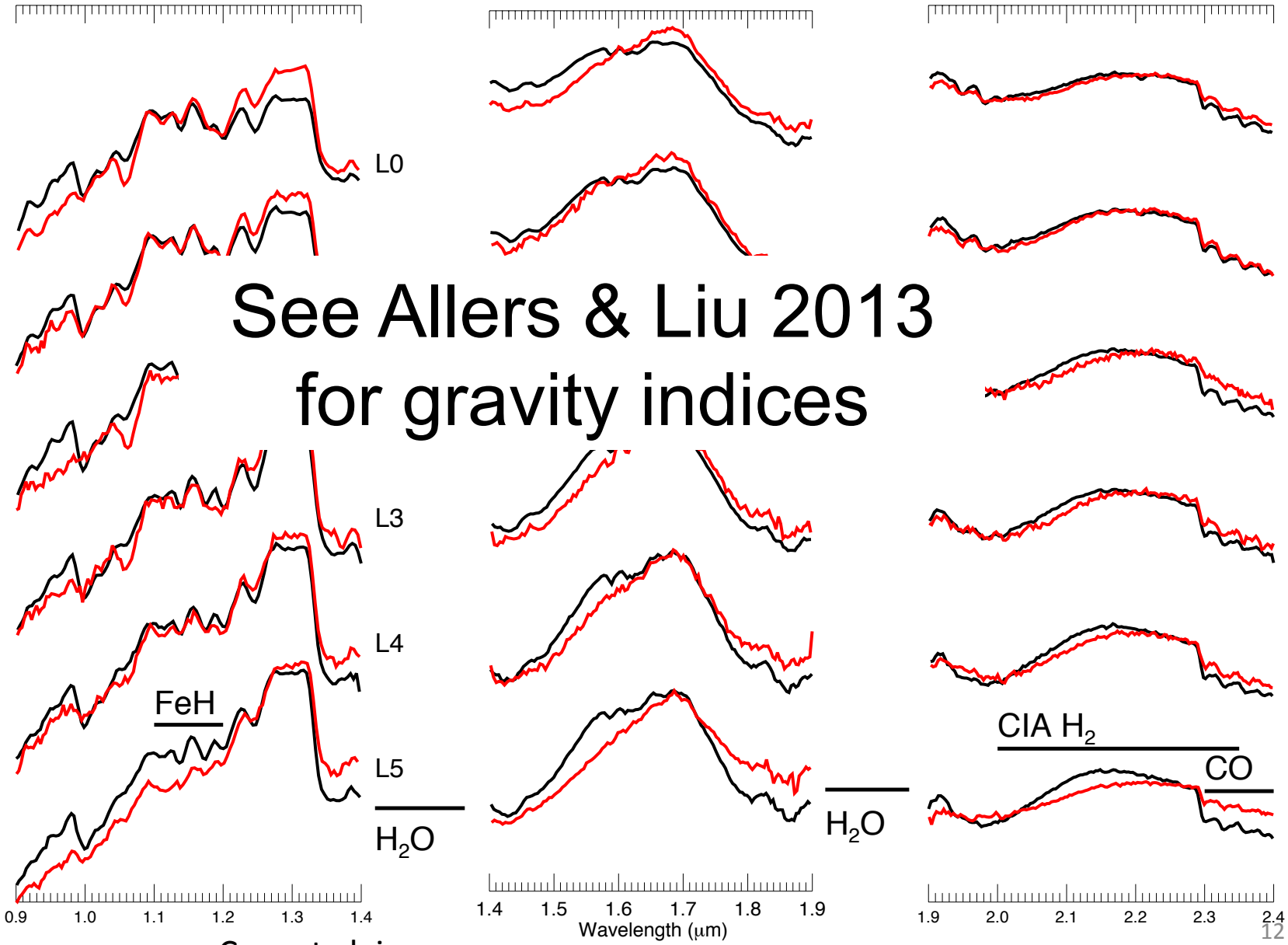


Young

Old

Rice, Faherty & Cruz 2010

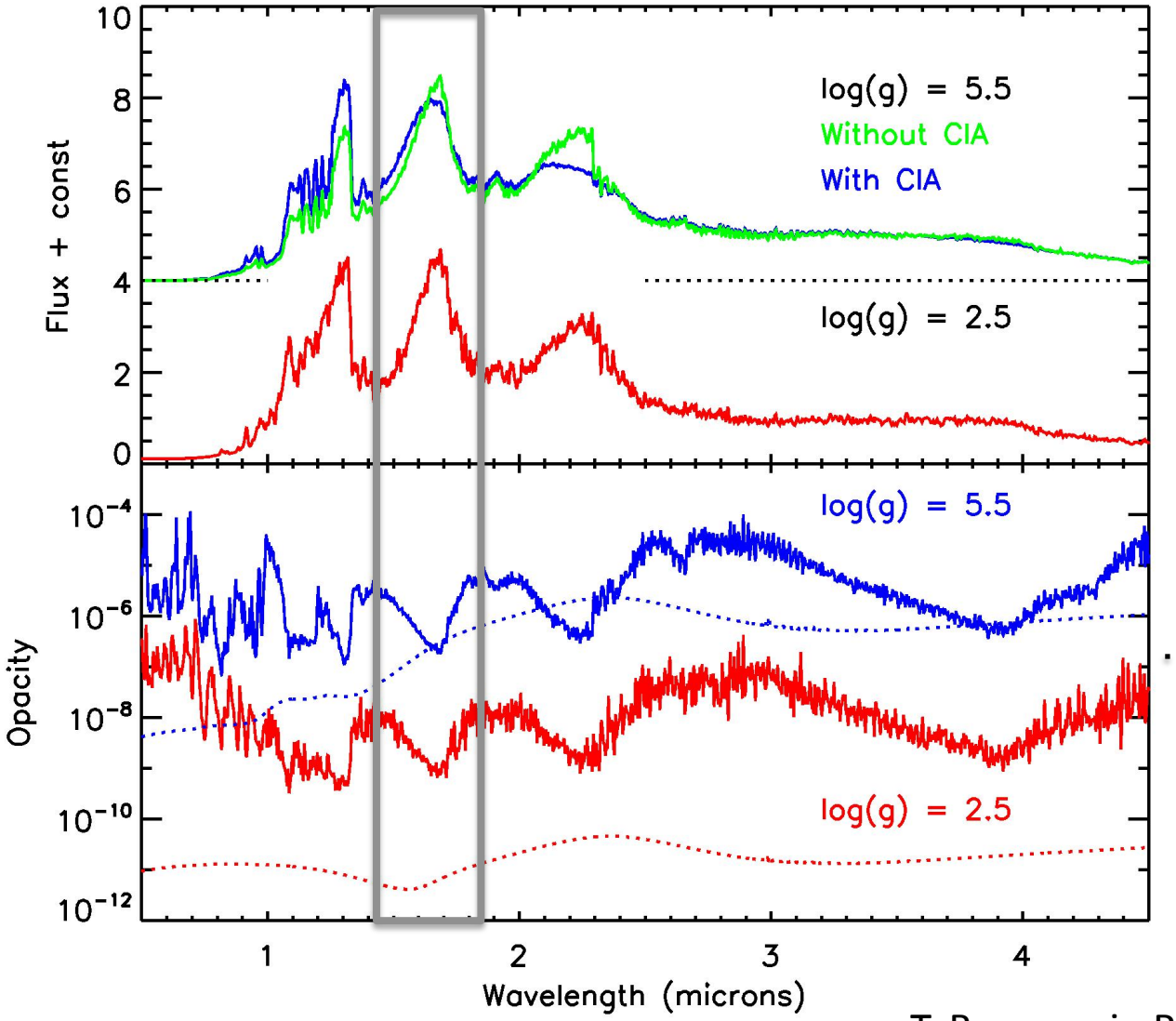
Triangular H-band diagnostic of young L dwarfs



See Allers & Liu 2013
for gravity indices

Cruz et al. in prep.

Relative strengths of H_2 CIA and H_2O opacity are gravity-sensitive



No CIA

High gravity

Low gravity

H_2O High

CIA H_2

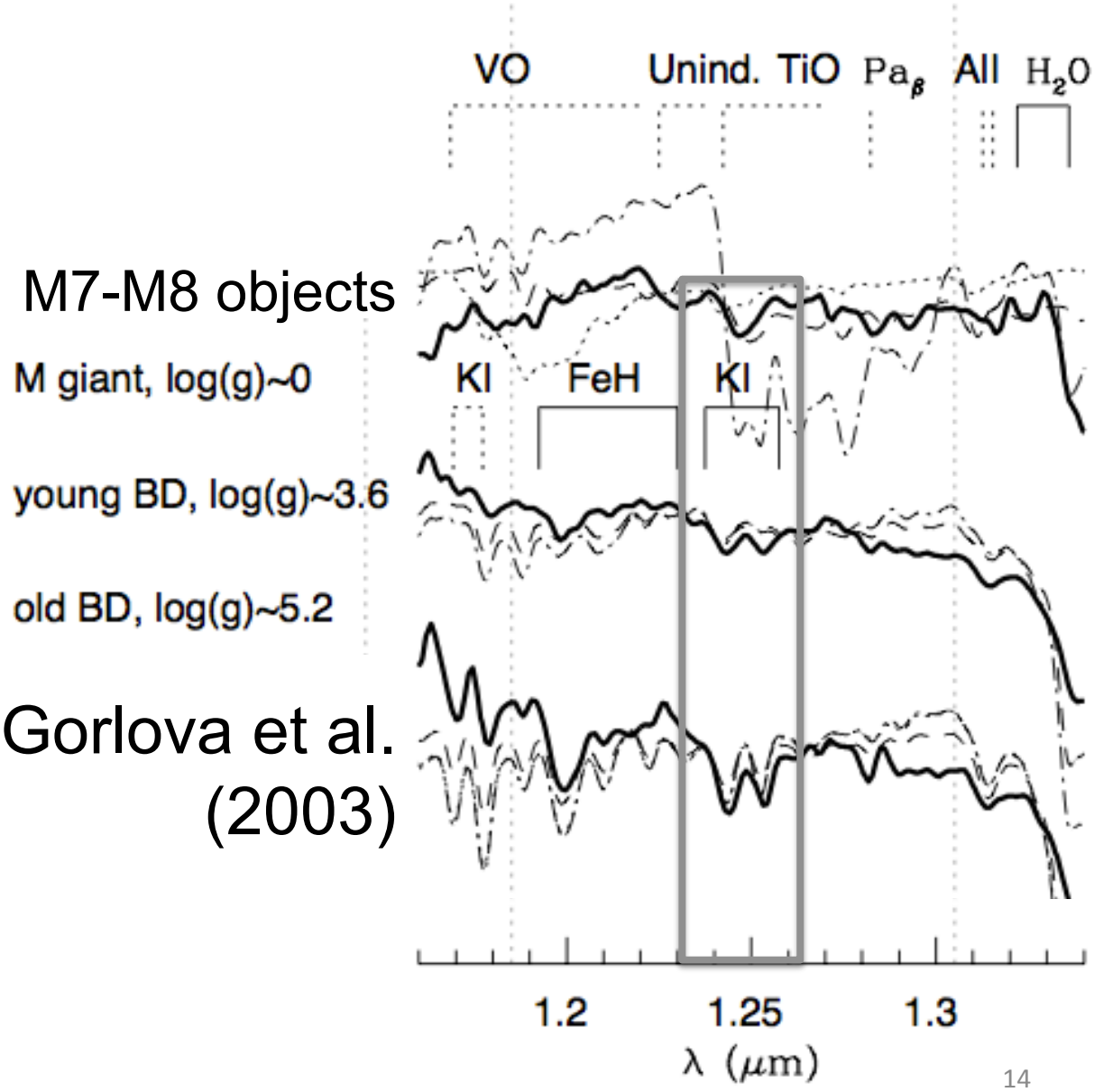
H_2O Low

CIA H_2

T. Barman, in Rice et al. 2011

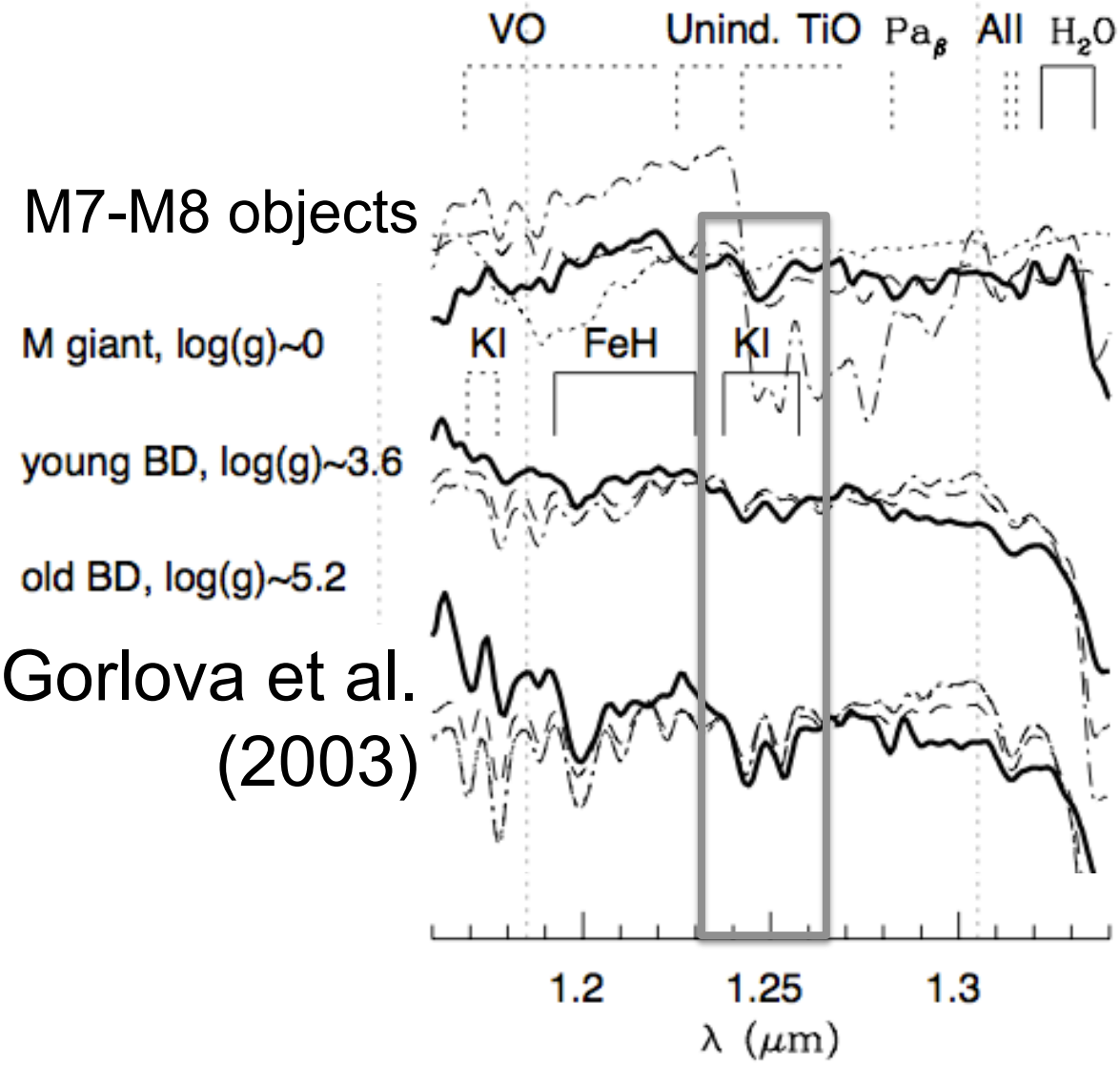
Spectral youth indicators for M & L dwarfs

- Stronger VO and weaker TiO & K in red-optical spectra
- Red NIR colors
- Triangular H-band
- Weak K & FeH in NIR spectra



Gorlova et al. (2003)

Gravity-sensitive atomic & molecular in optical & near-IR first identified relative to M giants

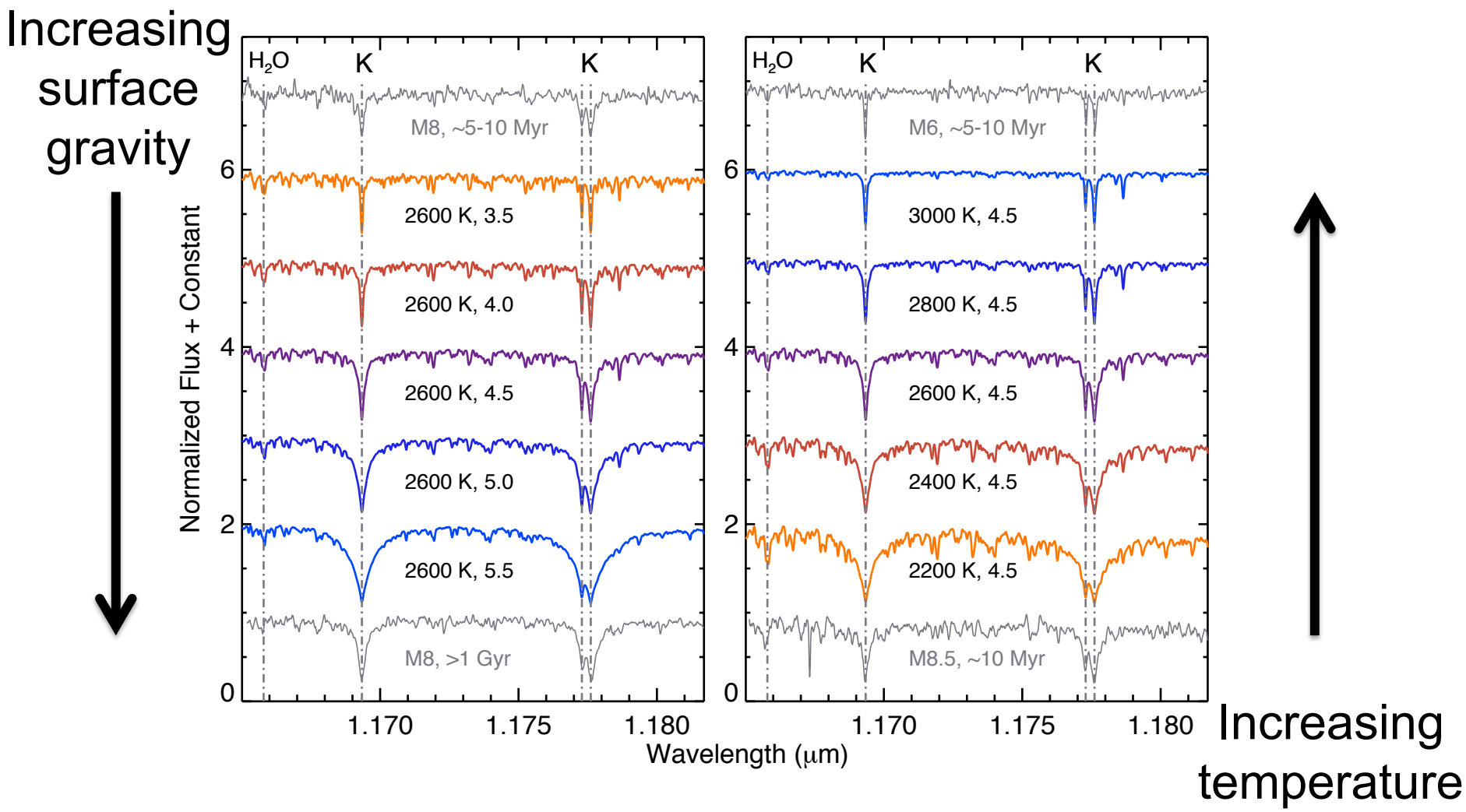


Gorlova et al. (2003)

- No analog giants for L dwarfs!
- Beware degeneracies…

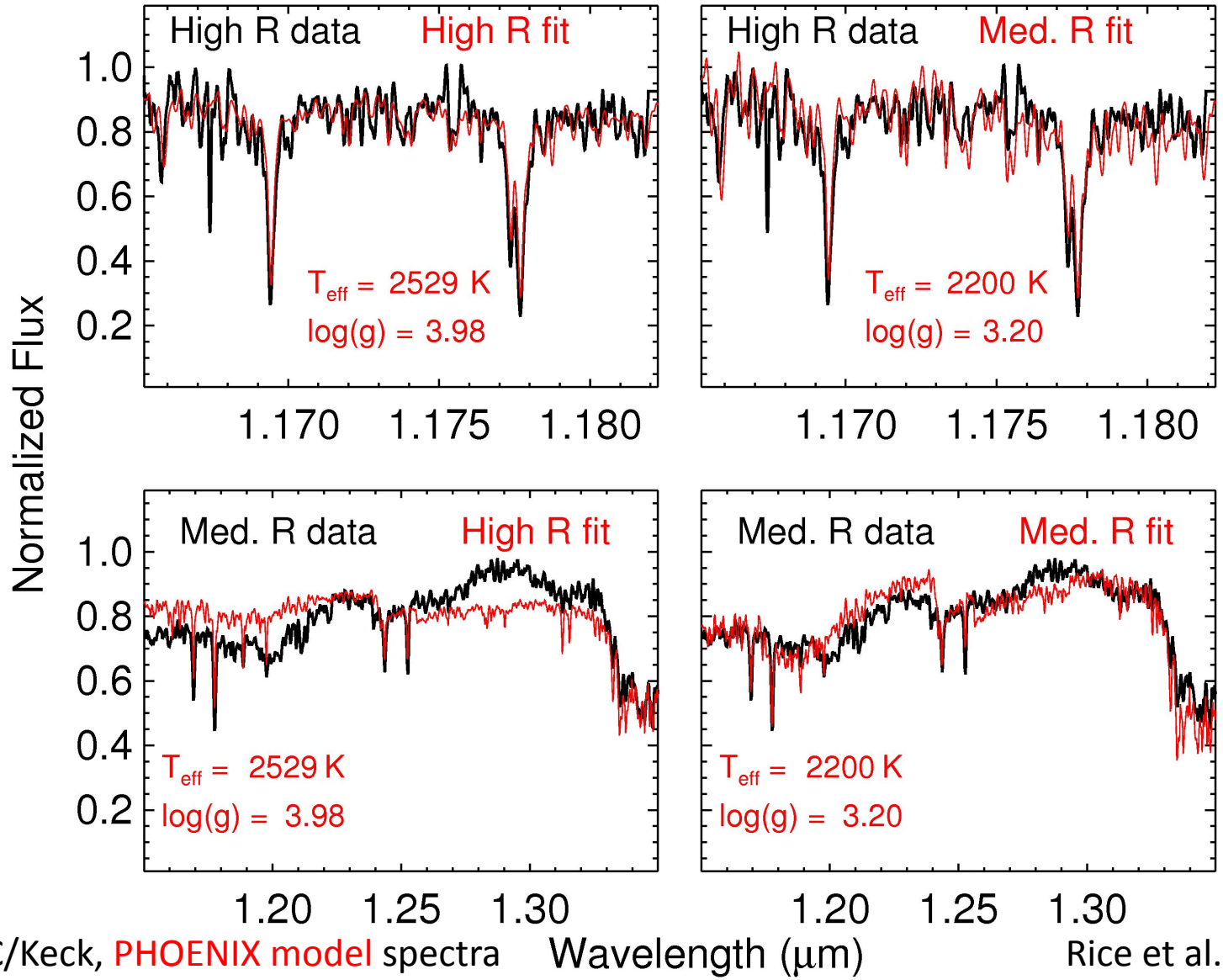
See also:
Martín et al. (1996)
Luhman et al. (1997)
McGovern et al. (2004)
Kirkpatrick et al. (2006, 2008)
Cruz et al. (2009)

K lines change with temperature and gravity



Rice et al. 2010

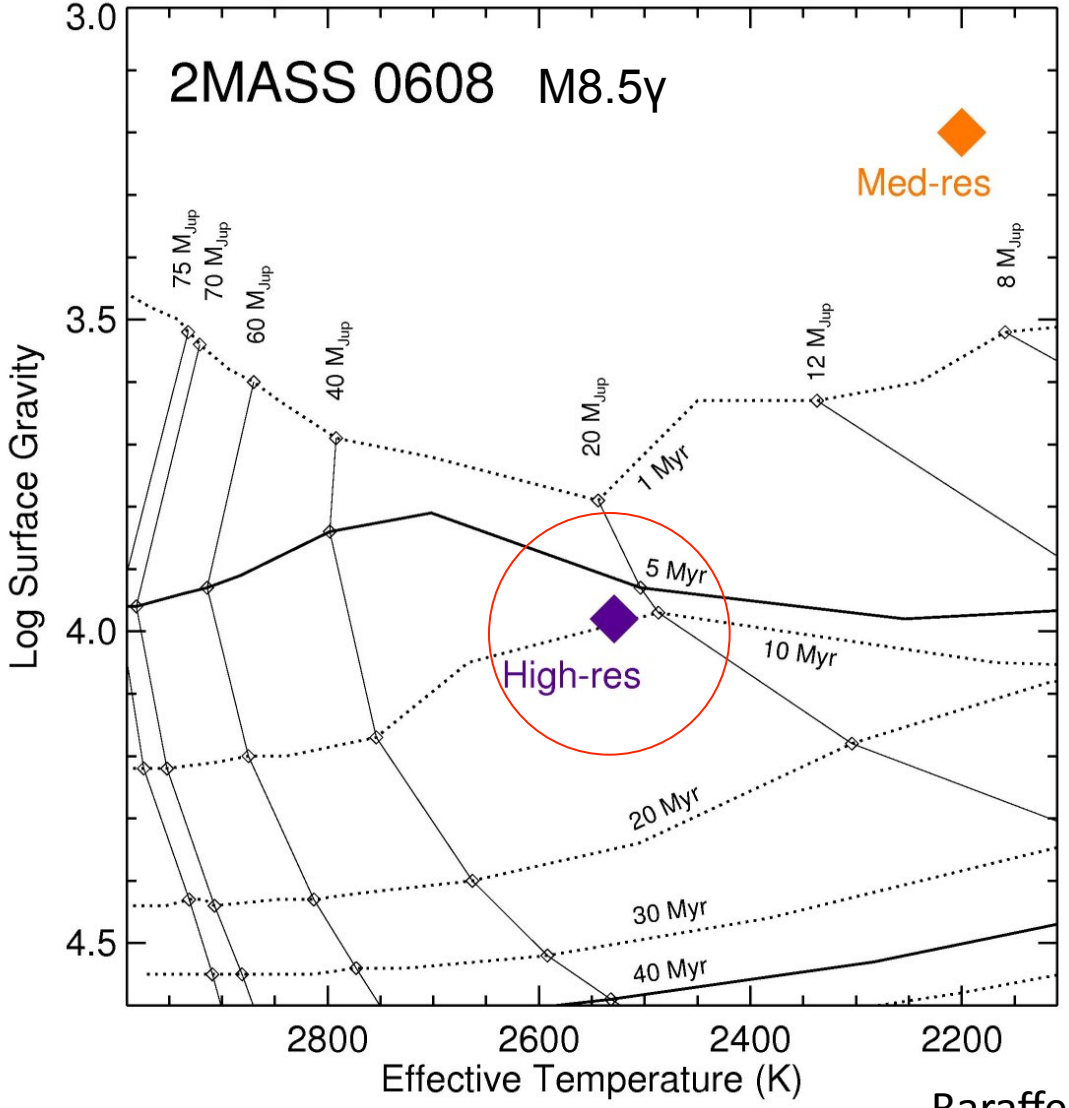
Model fits for late-type objects can be ambiguous



NIRSPEC/Keck, PHOENIX model spectra

Rice et al. 2010

Implications from evolution models help evaluate the spectrum fits

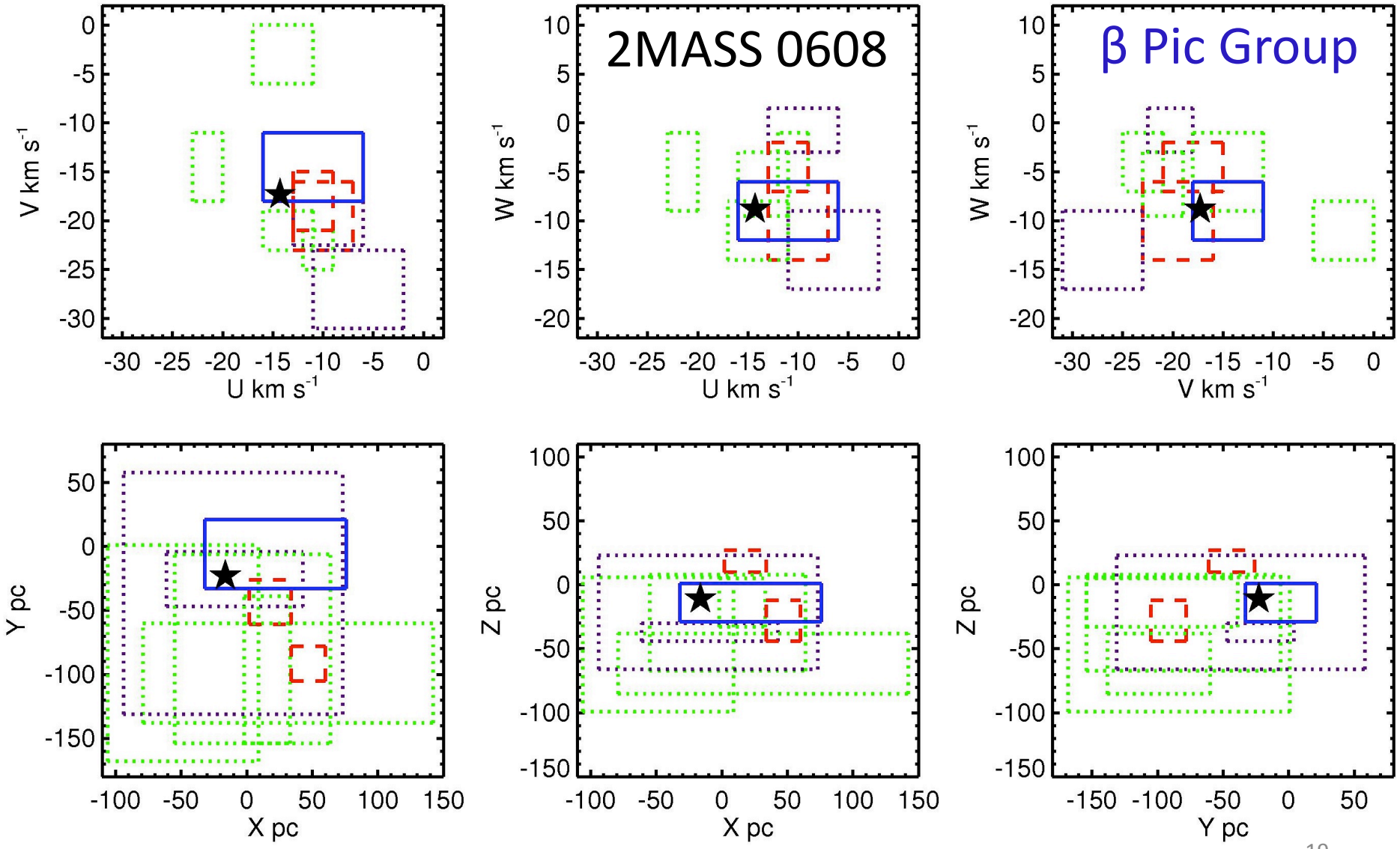


~25 M_{Jup}

~10 Myr

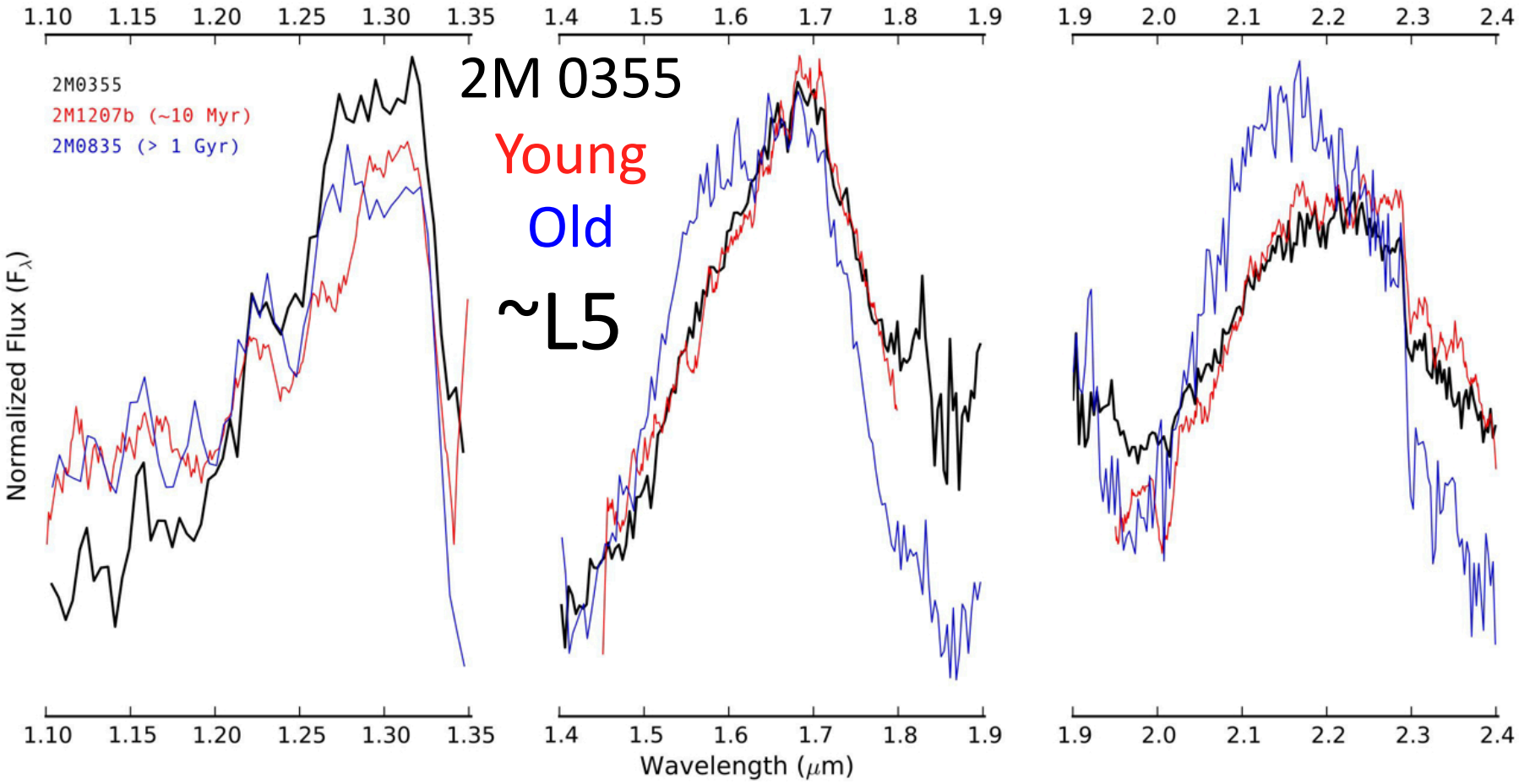
Baraffe et al. models

Kinematics confirm spectral youth indicators



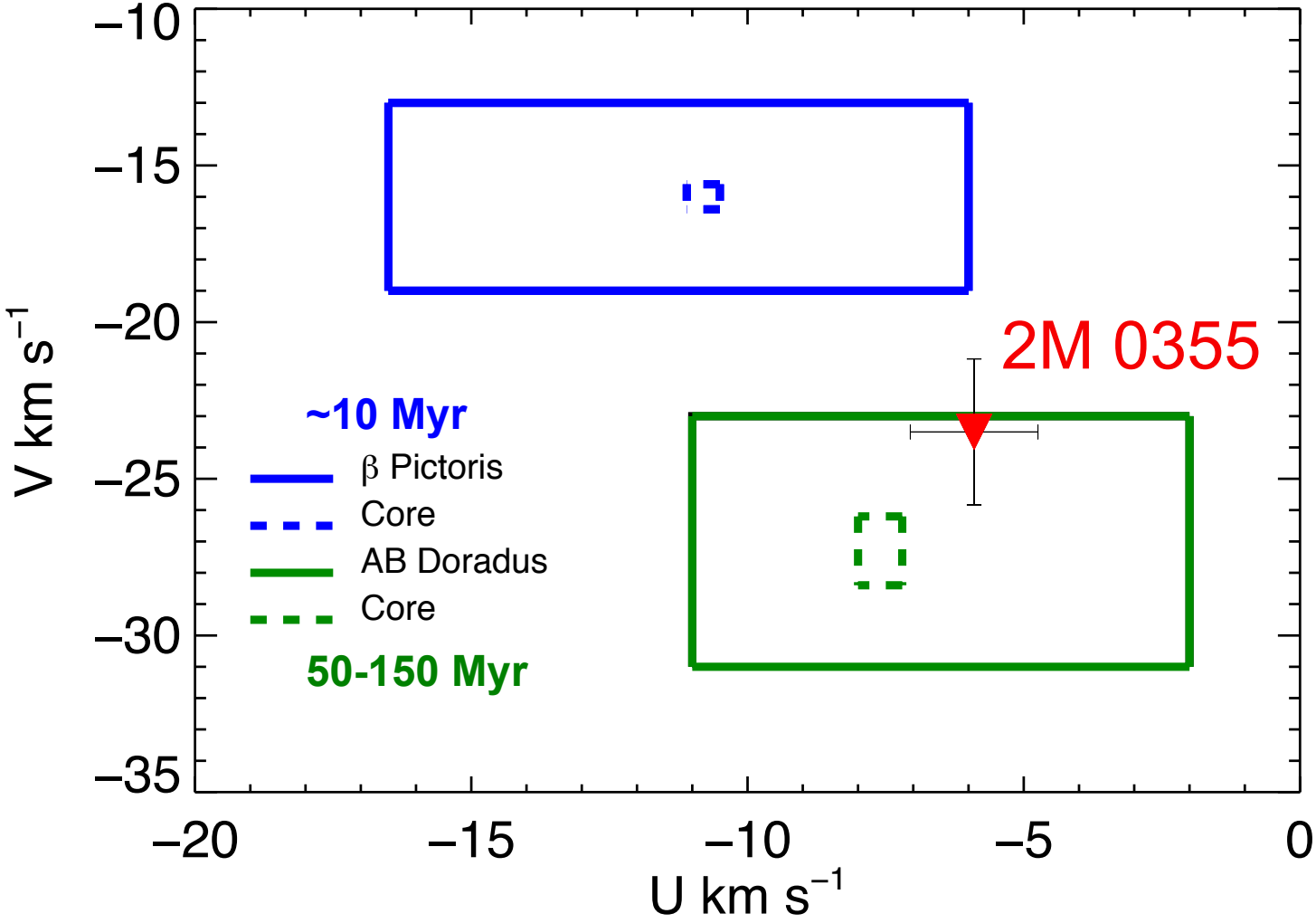
Rice, Faherty & Cruz 2010

Later type objects become more ambiguous…



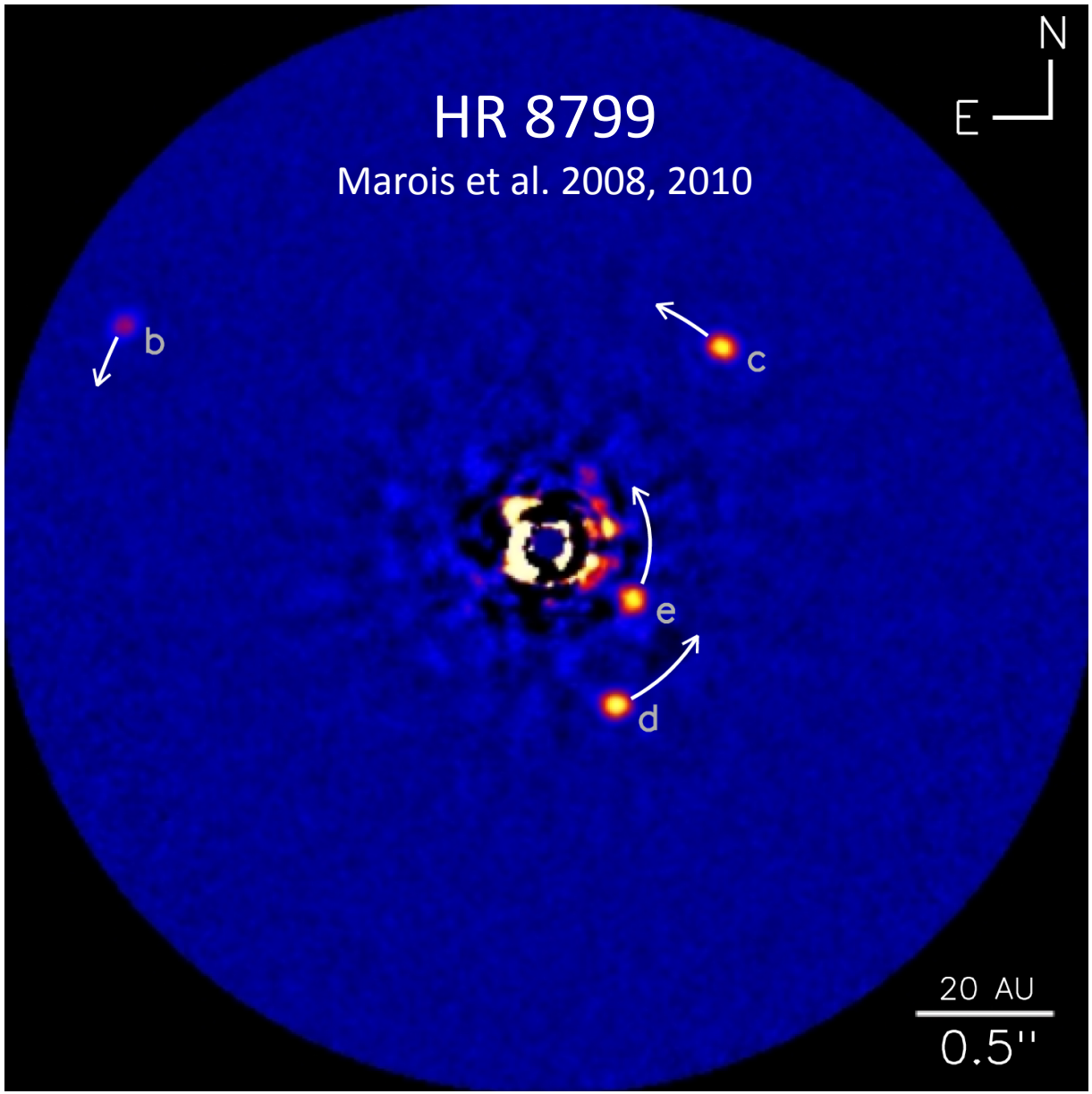
Faherty, Rice, Cruz, Mamajek & Nuñez 2013

Why do L5 dwarfs look so similar at very different ages?

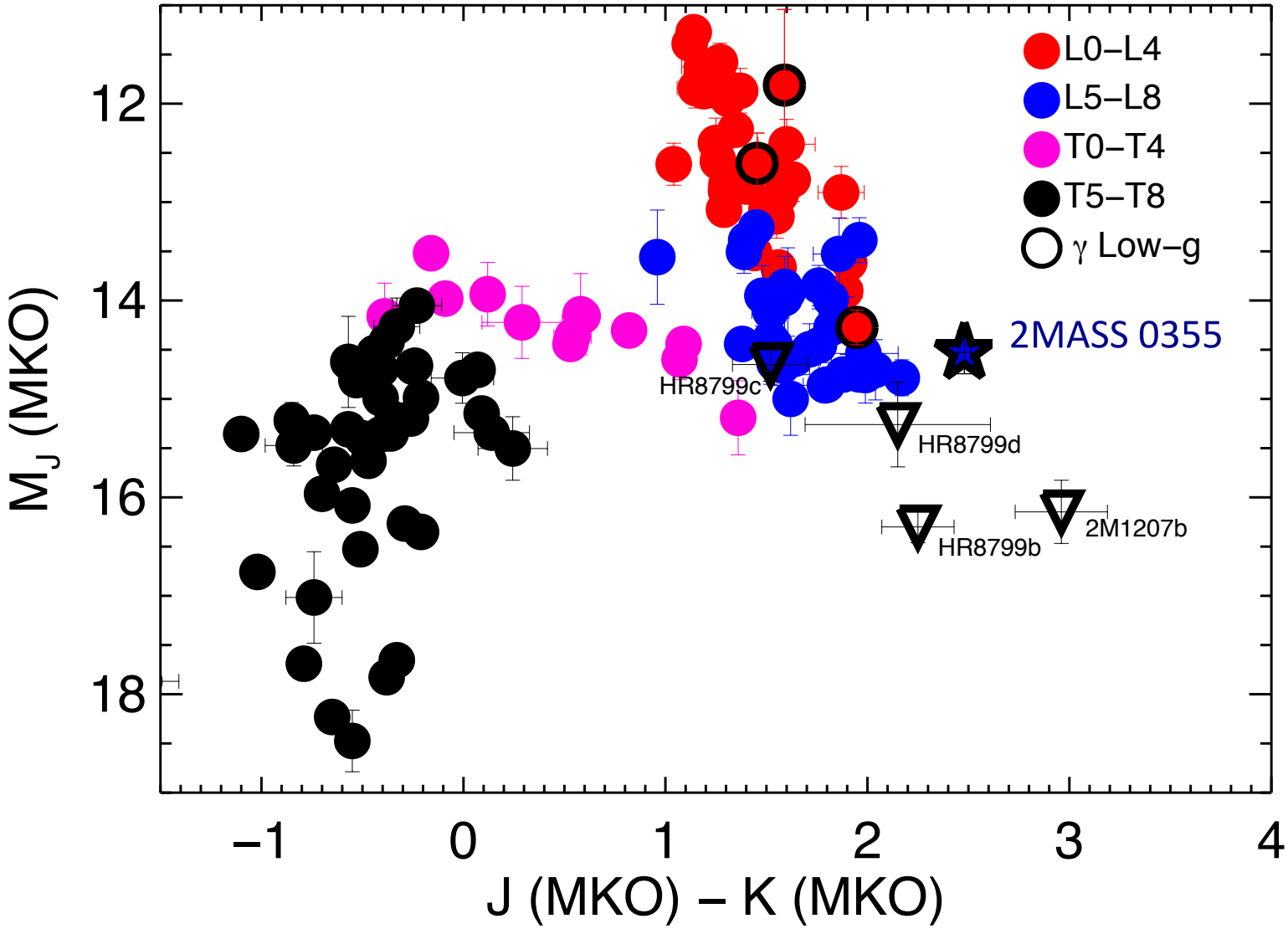


Faherty, Rice, Cruz, Mamajek & Nuñez 2013, see also Liu 2013, CS17

Directly imaged exoplanets are massive & young

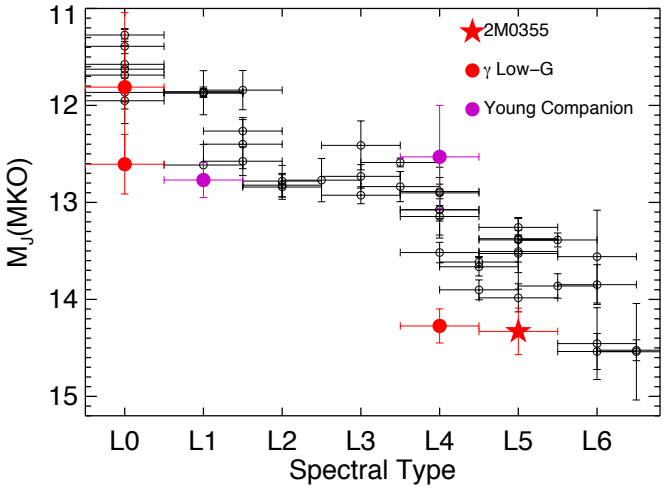


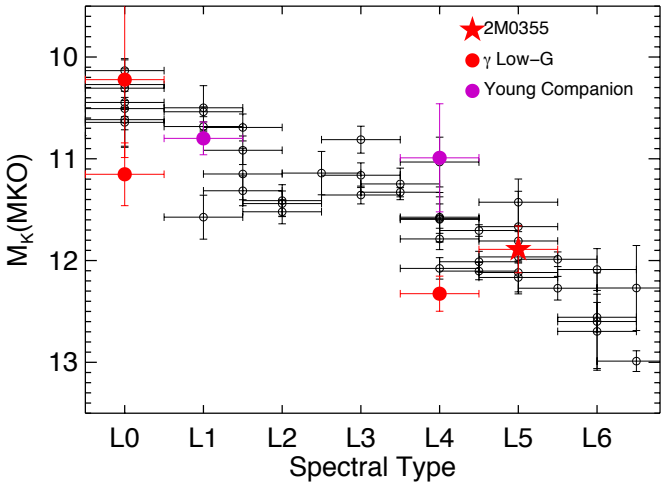
Young brown dwarfs occupy new color-magnitude space with directly images exoplanets



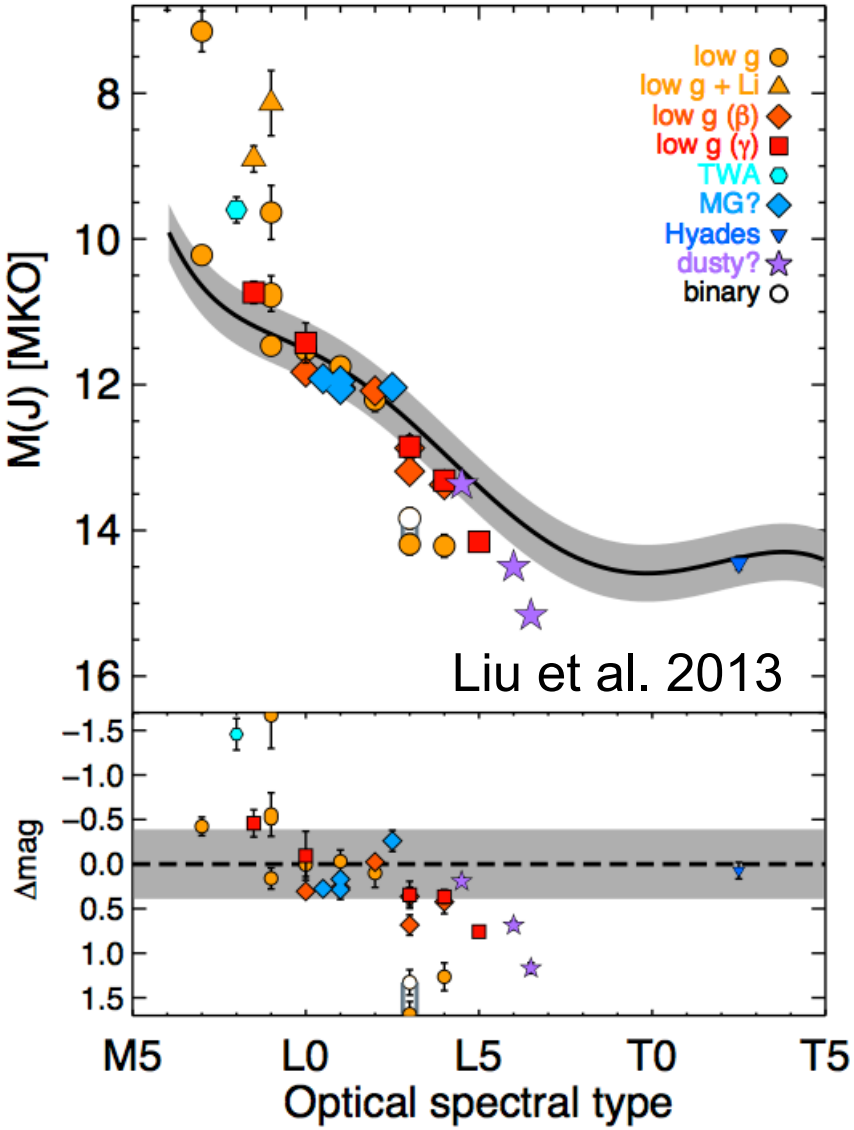
Faherty, Rice, Cruz, Mamajek & Nuñez 2013

Young M dwarfs are overluminous, young L dwarfs are underluminous in NIR

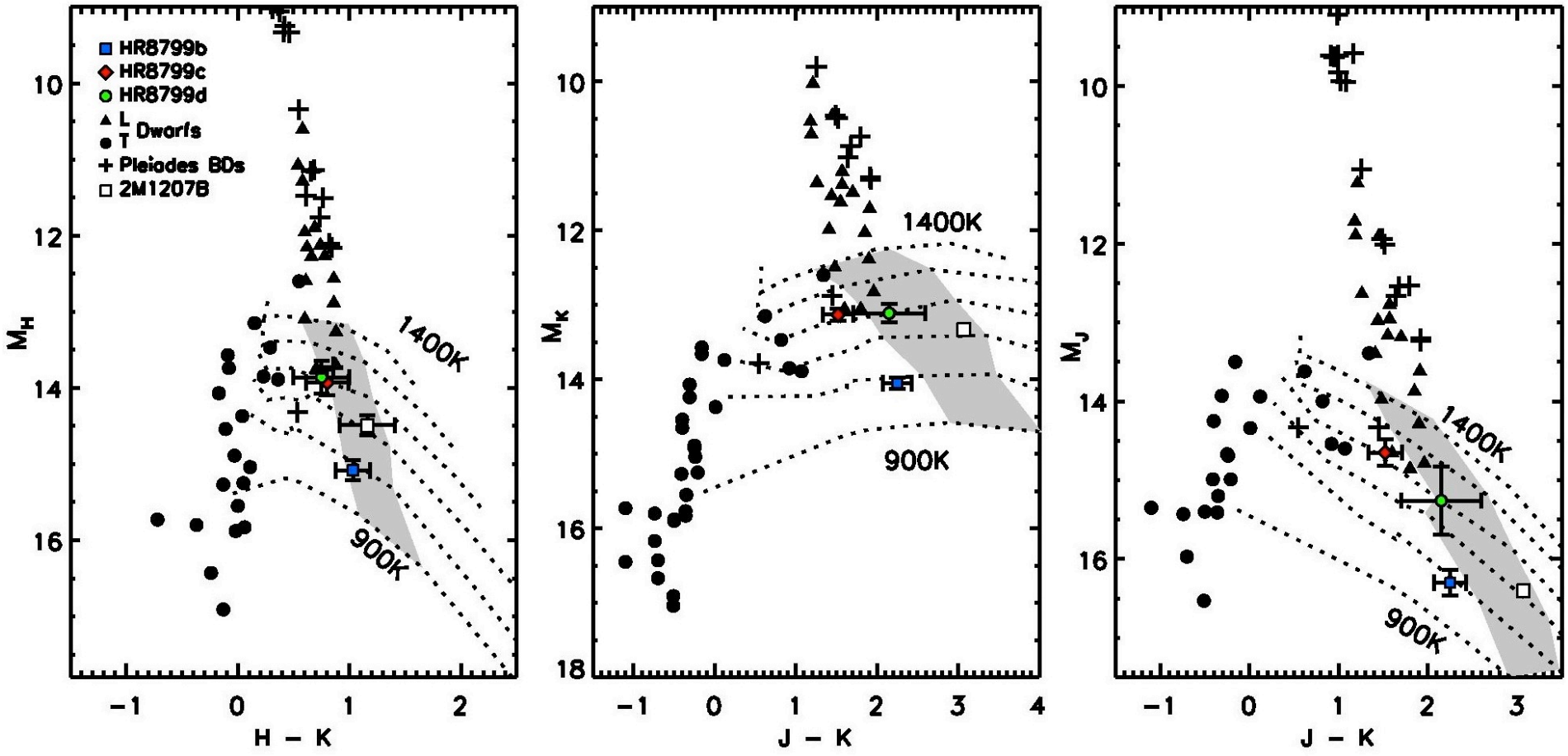




Faherty et al. 2012 & 2013

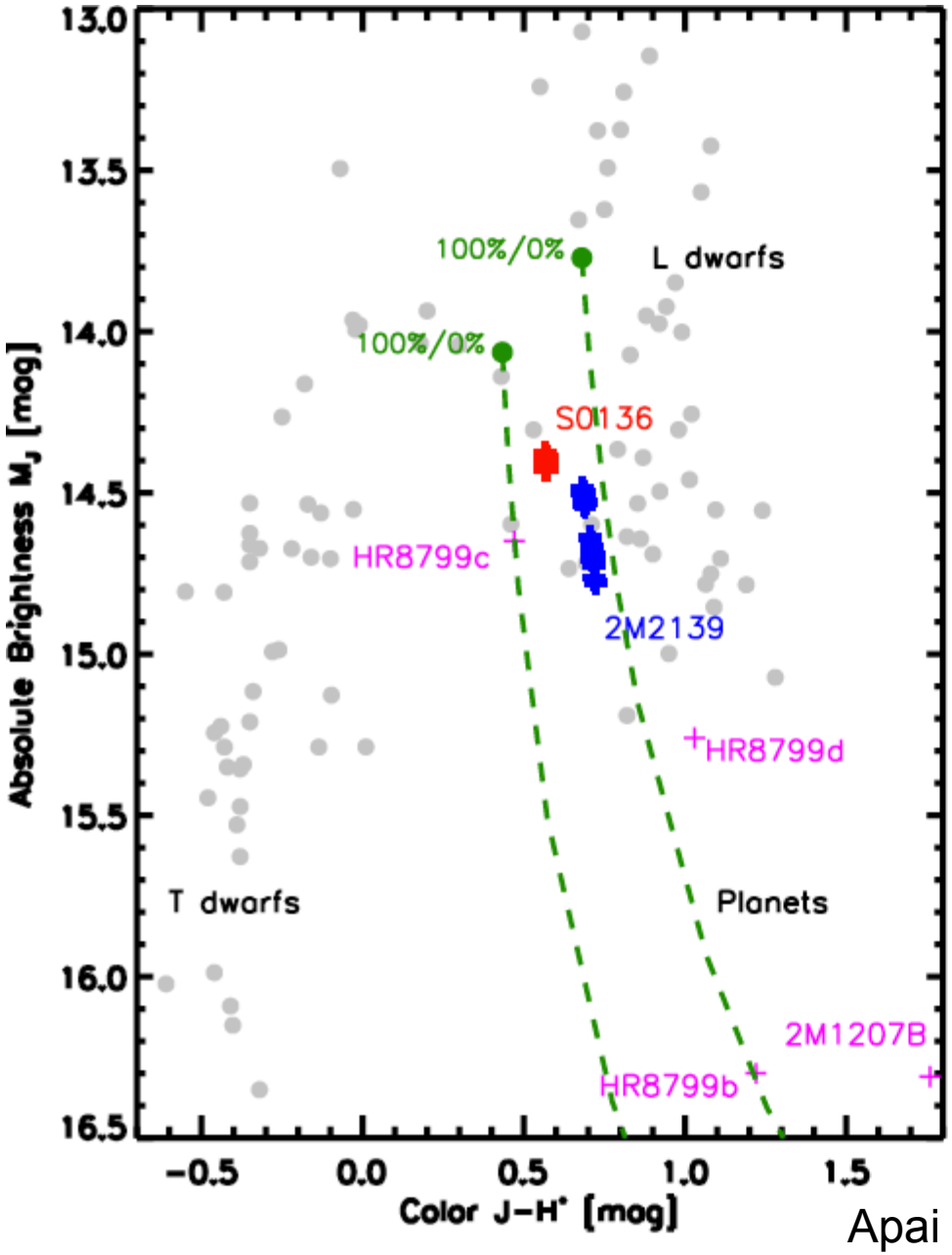


New model atmospheres produce fainter, redder tracks at low gravity



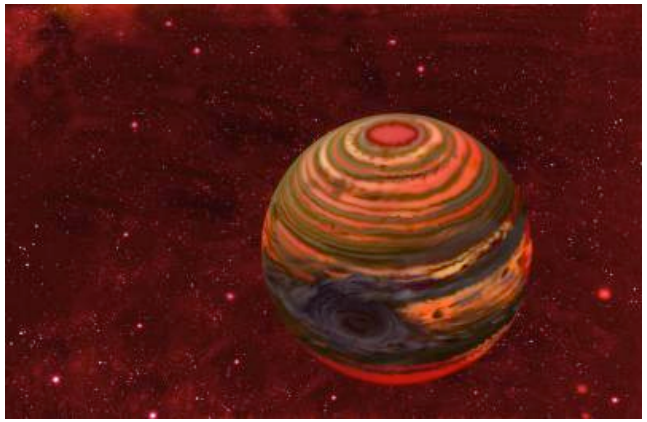
Barman et al. 2011

Cloud variations move brown dwarfs toward directly-imaged planets



T2.5 SIMP 0136

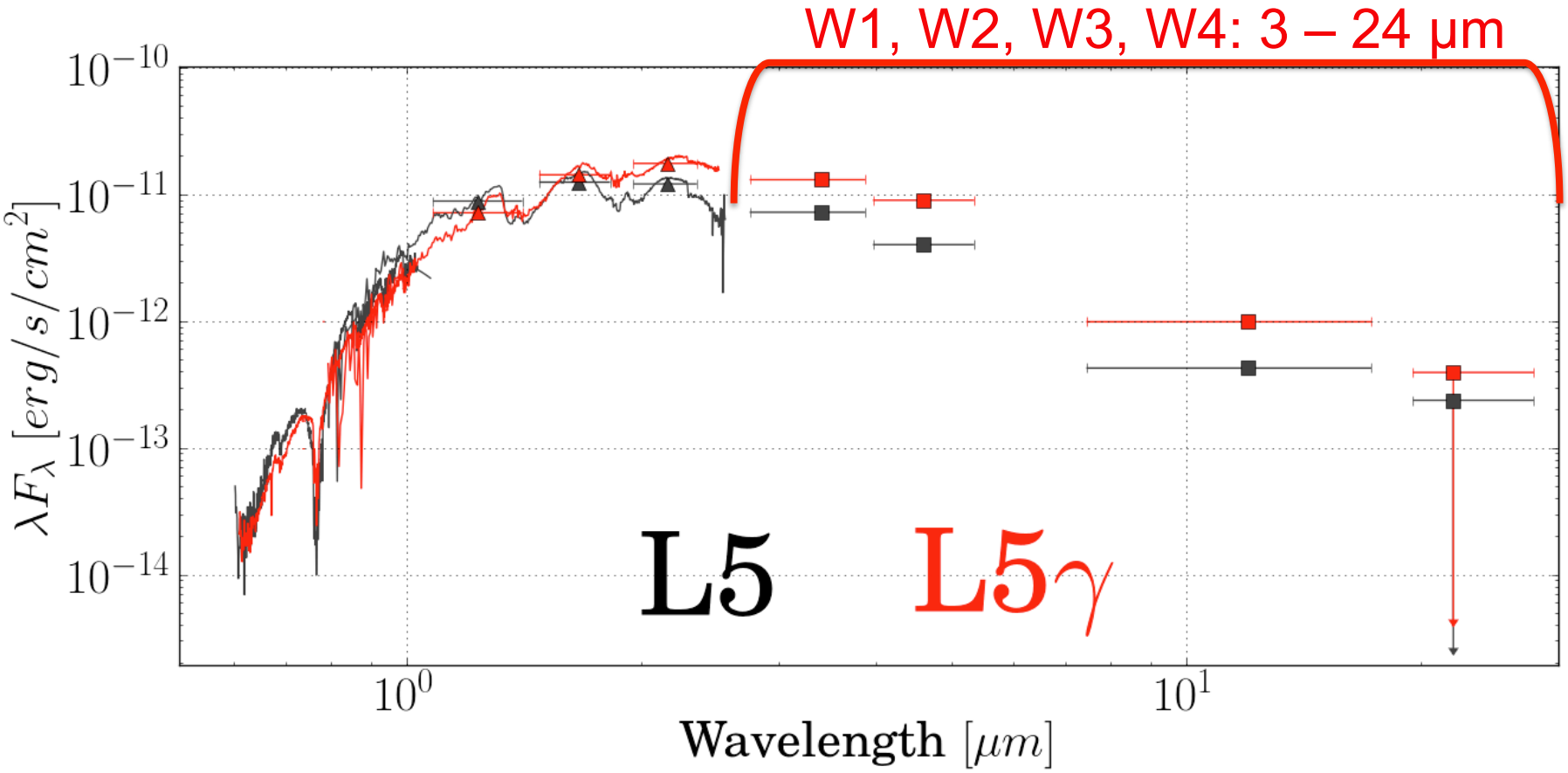
T1.5 2MASS 2139



Art by Jon Lomberg

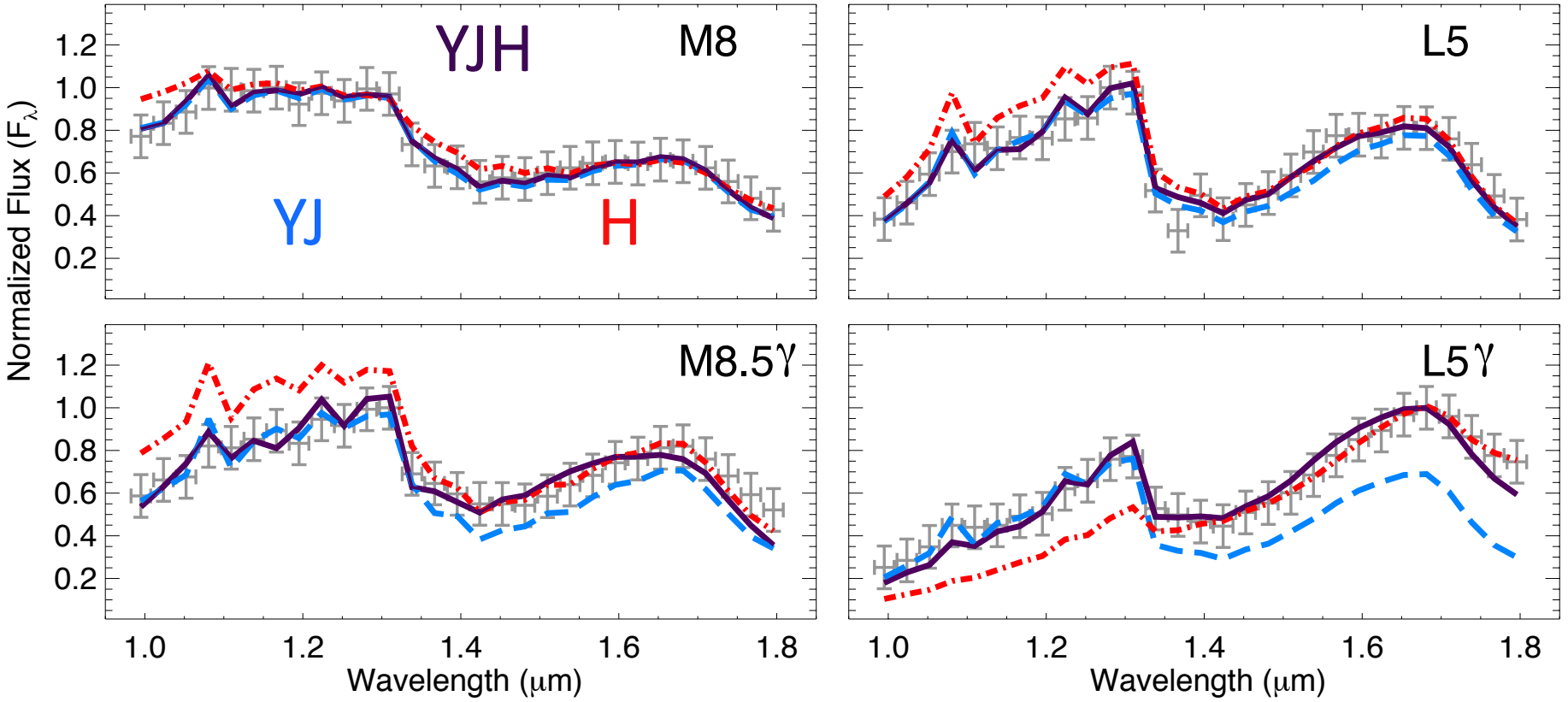
Apai et al. 2013, via A. Heinze

Parallax, photometry, and spectra provide calibrated comparison of luminosity & SEDs



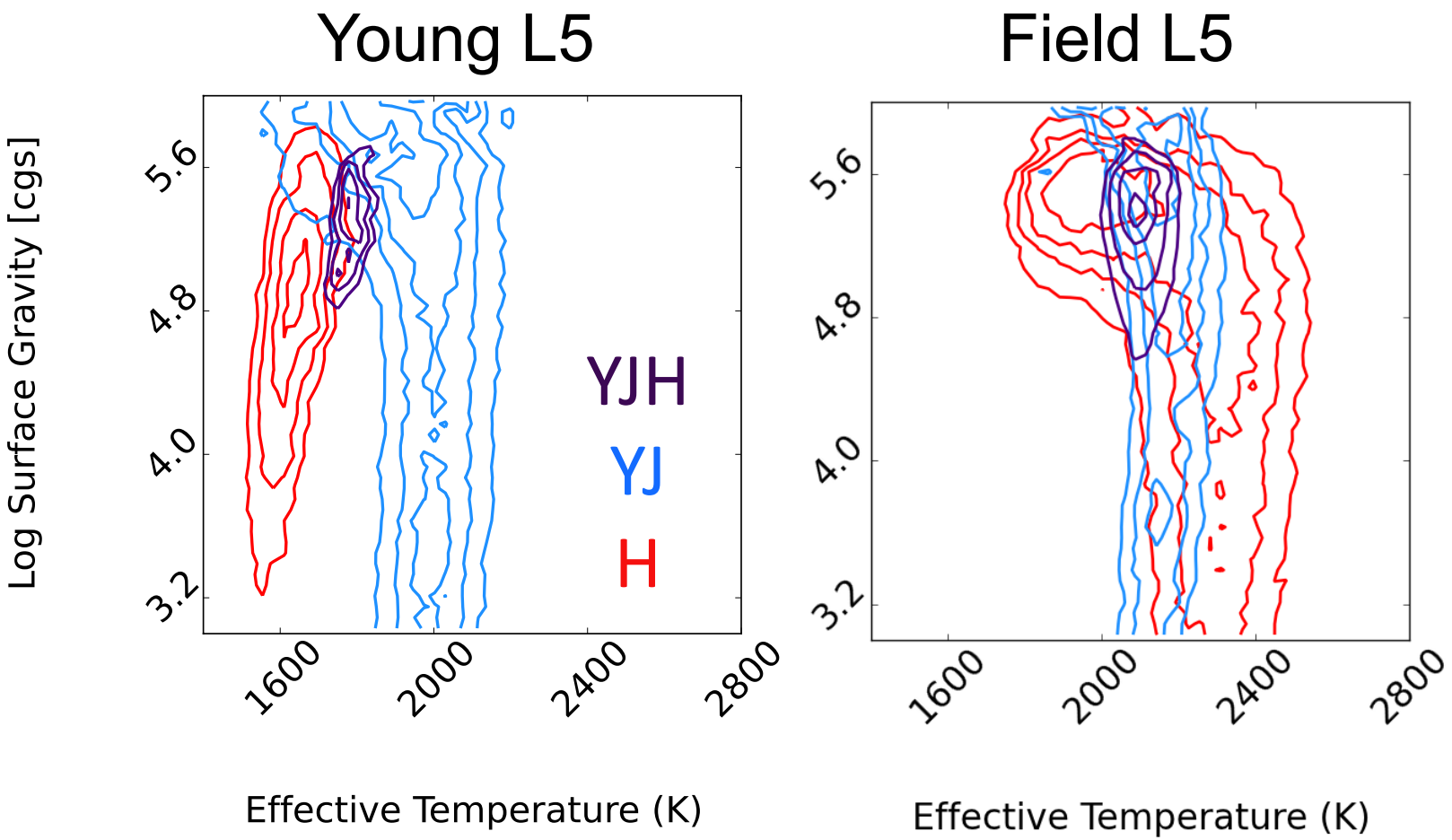
Filippazzo et al. in prep.

Exoplanets will be characterized in NIR at low resolution by Project 1640, GPI, & SPHERE



Rice et al. in prep.

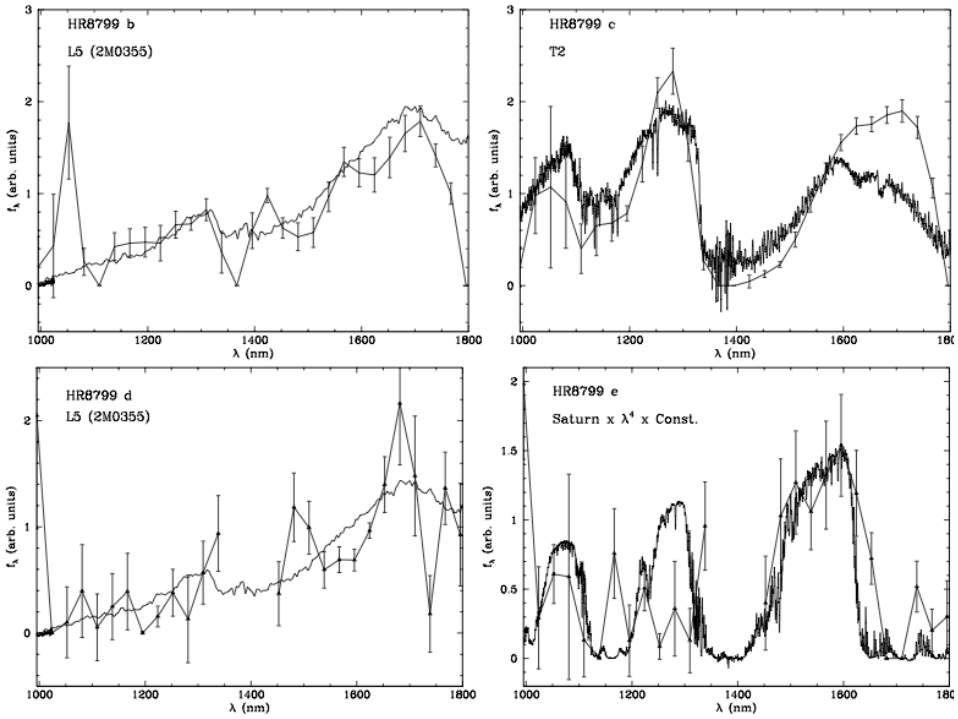
Temperature & gravity are degenerate in NIR



Rice et al. in prep.

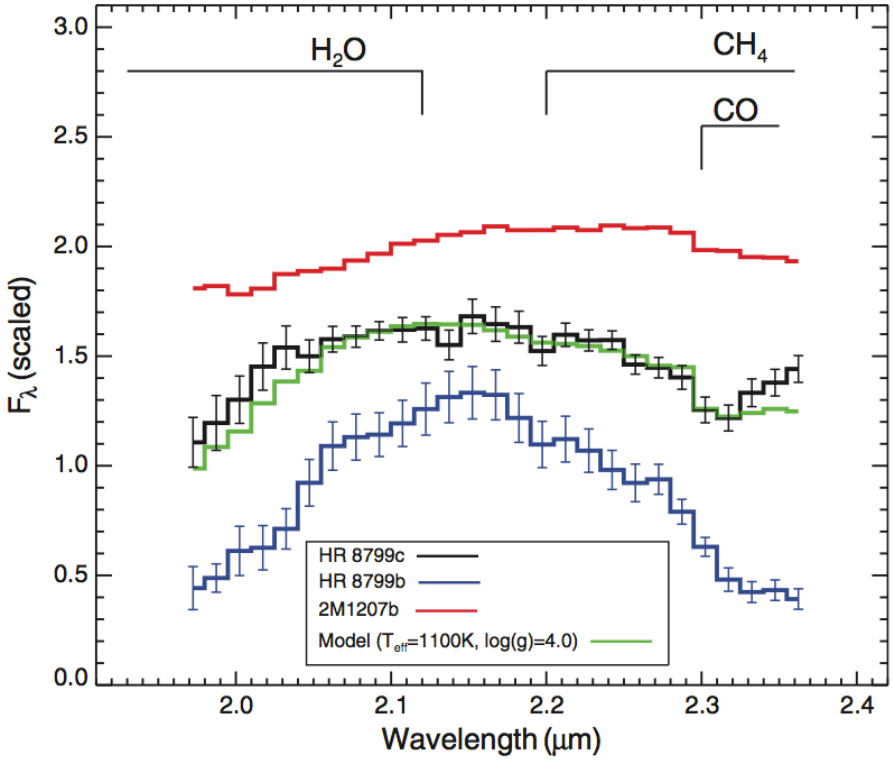
Exoplanet spectra indicate diversity of atmospheric properties

HR 8799 b,c,d,e from Project 1640

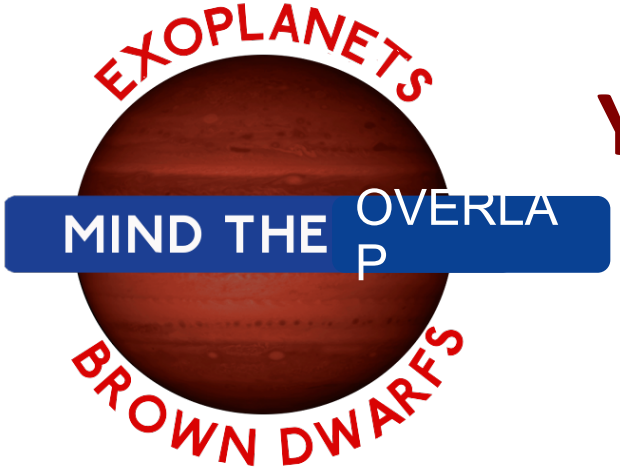


Oppenheimer et al. 2013

HR 8799 b,c from OSIRIS on Keck II



Konopacky et al. 2013,
Barman et al. 2011



Young Brown Dwarfs *are* Exoplanet Analogs

- Confirm BD youth with photometry, spectroscopy, & kinematics
- Use young BDs to relate observed & physical properties and to calibrate atmosphere & evolution models
- Improve spectroscopic analysis & cool, low gravity atmosphere models for directly-imaged exoplanets

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