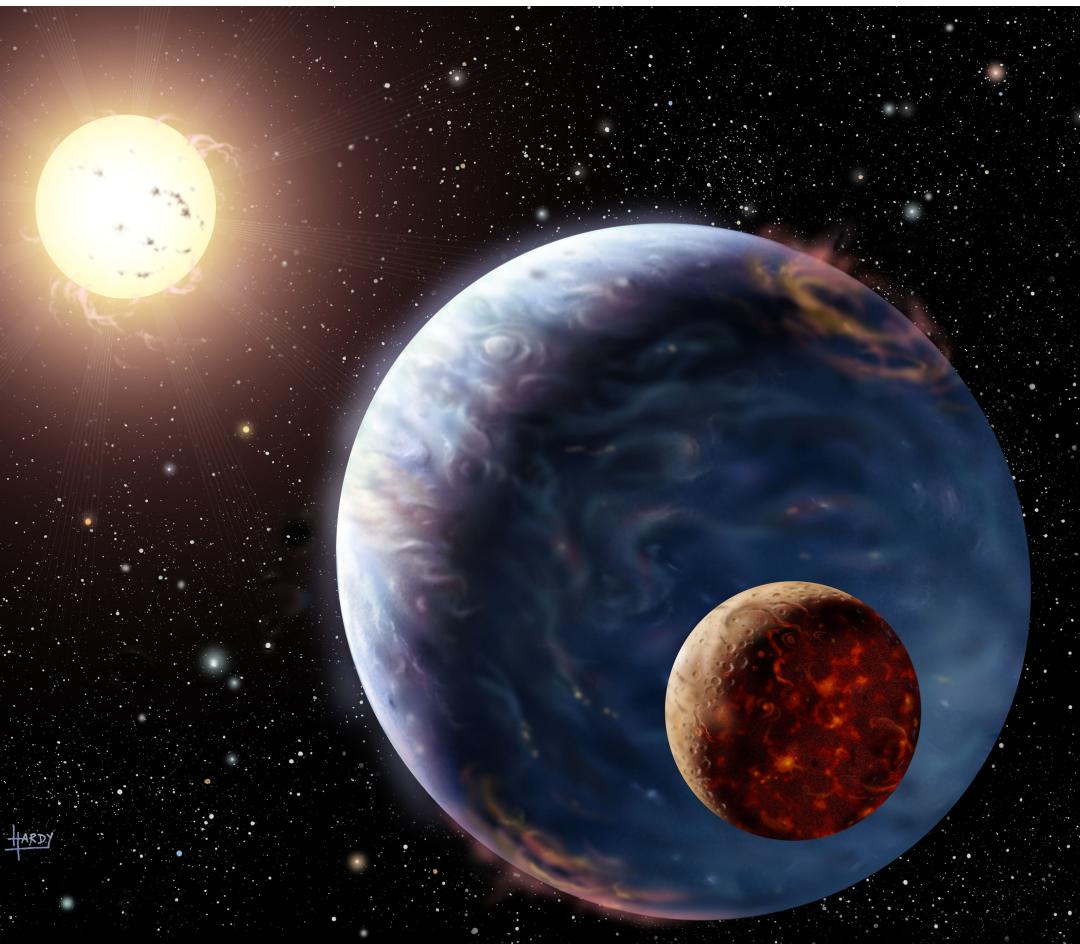
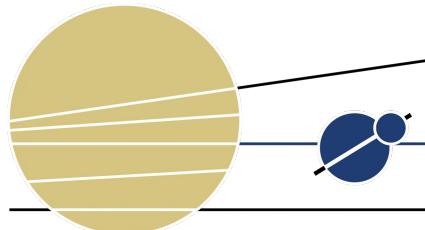


Studying Exoplanet Atmospheres with TMT



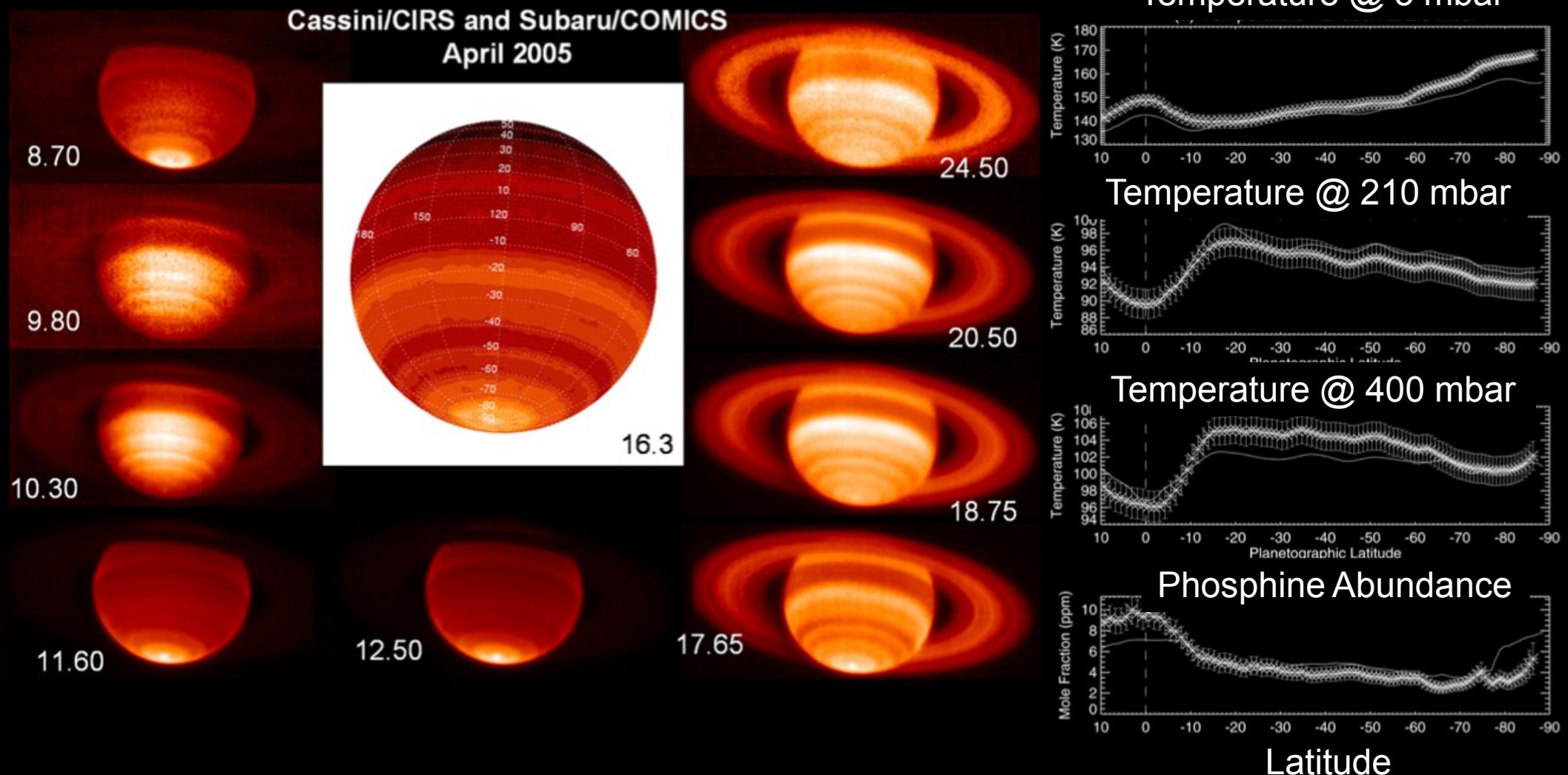
Ian Crossfield
Sagan Fellow, UA/LPL
2014/07/18



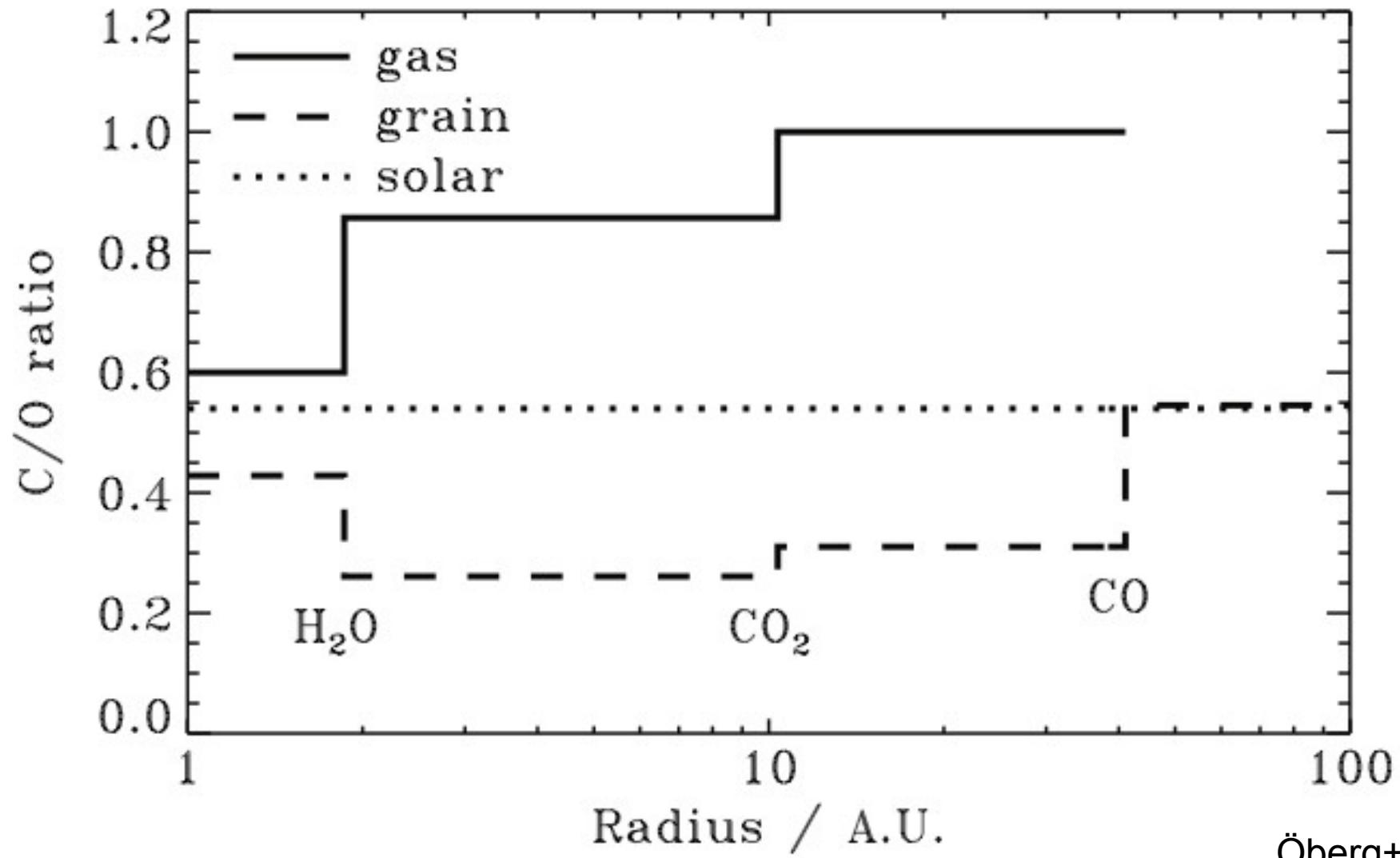
Lunar and Planetary Laboratory



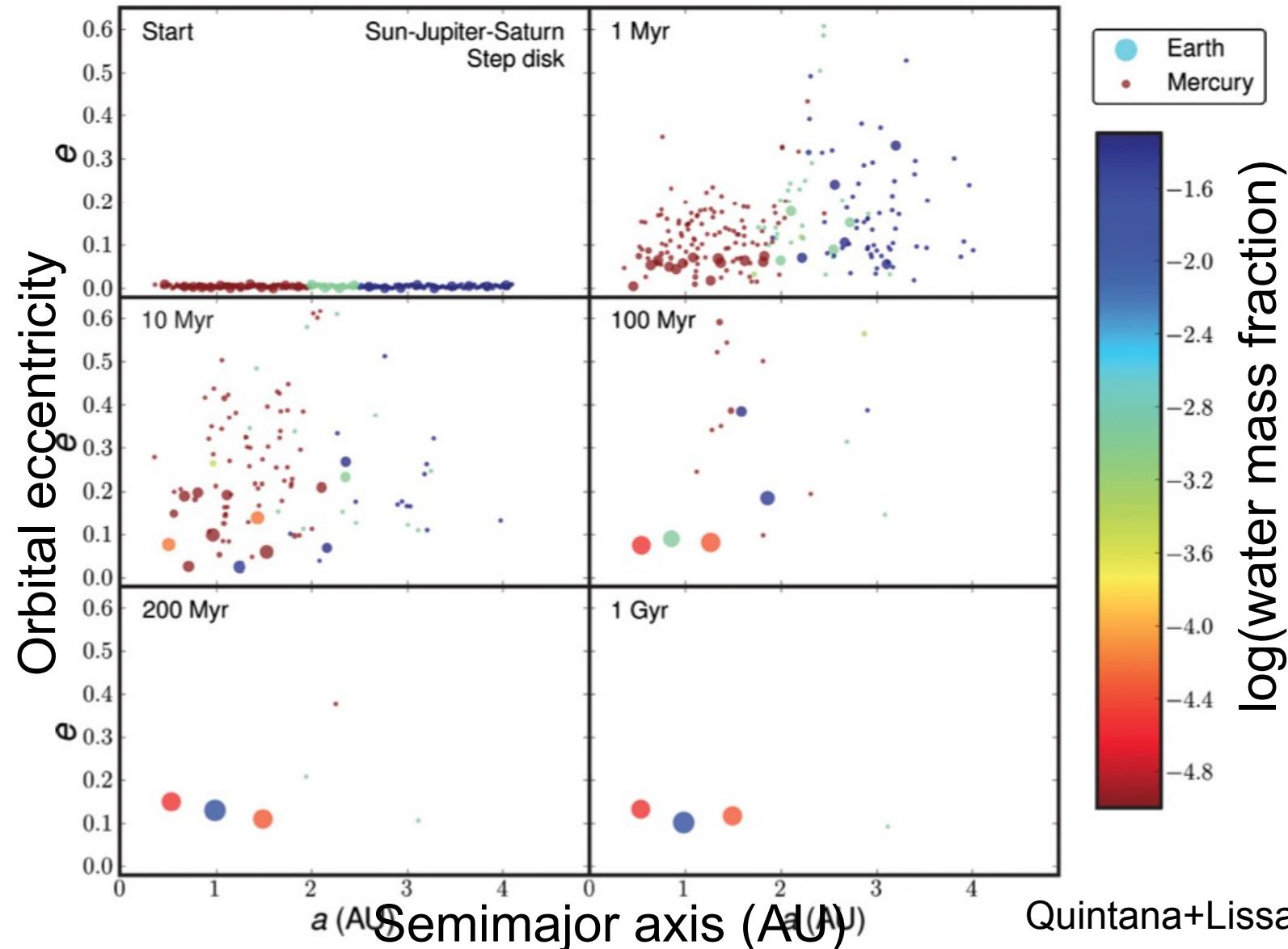
What are conditions like on other worlds?

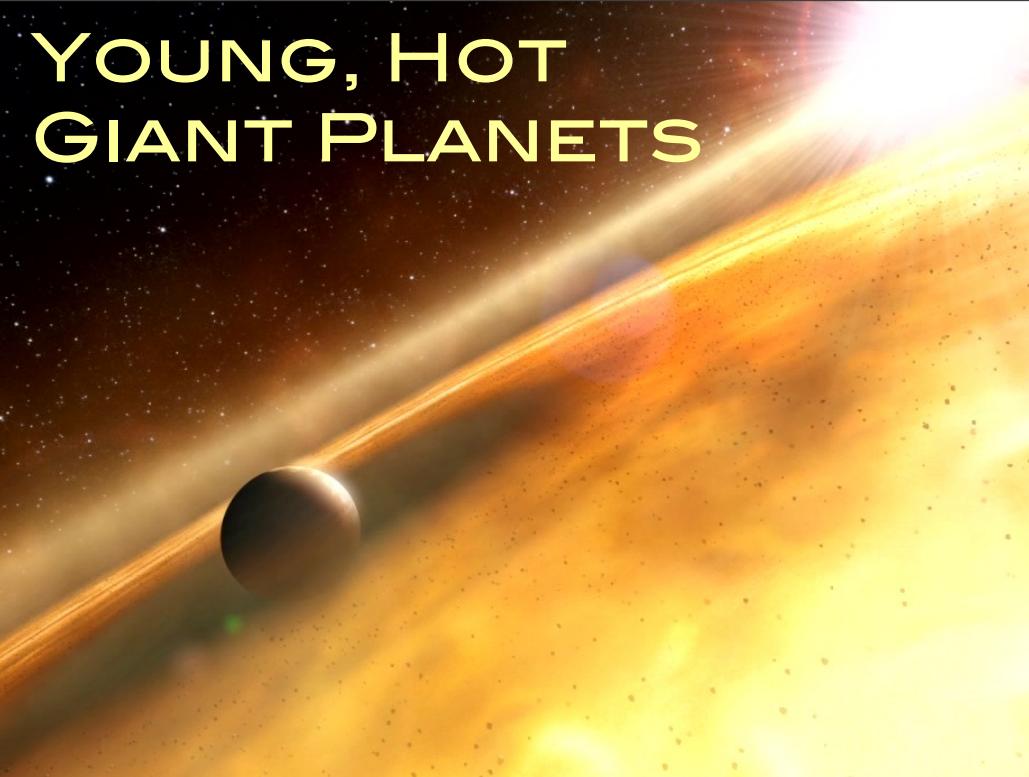


Where do gas giants form, and what are they made of?



Where do rocky planets form, and what are they made of?

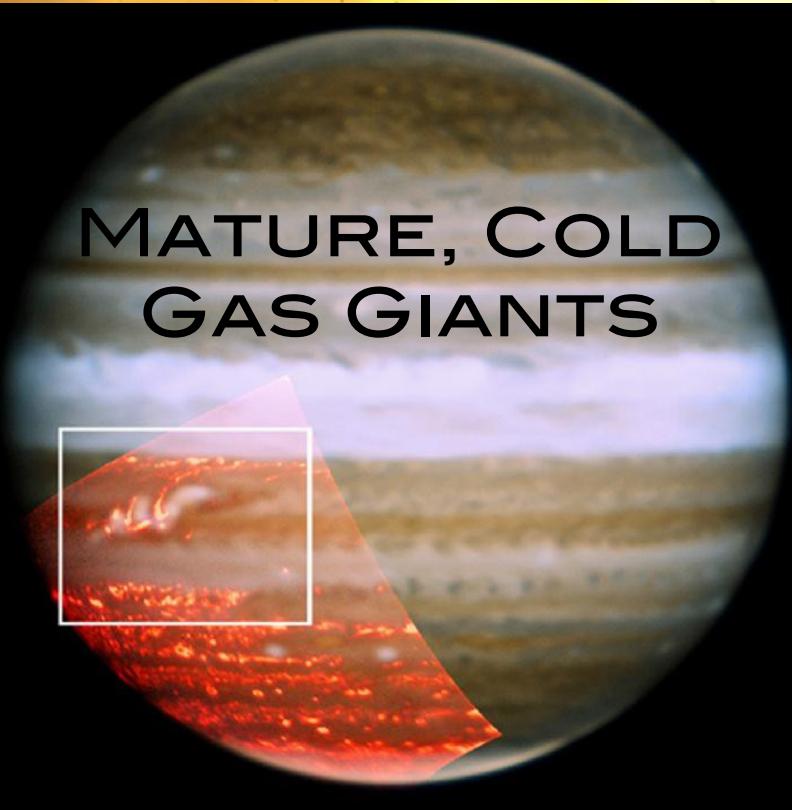




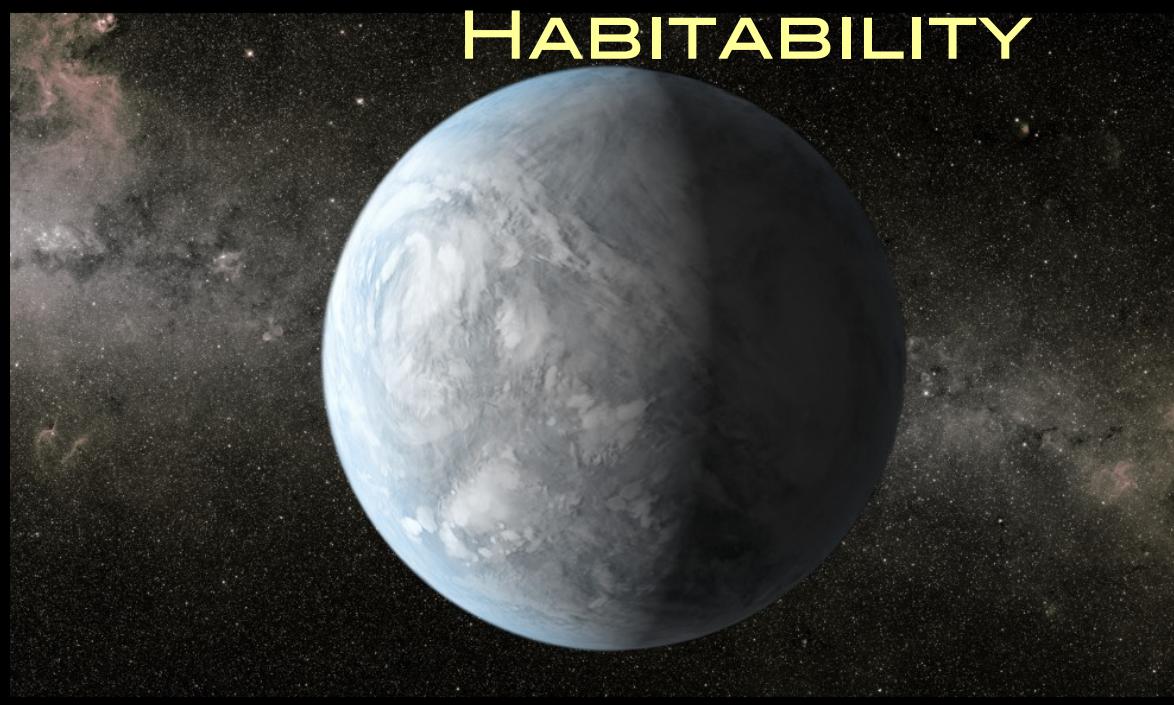
YOUNG, HOT
GIANT PLANETS



IRRADIATED
GAS GIANTS



MATURE, COLD
GAS GIANTS

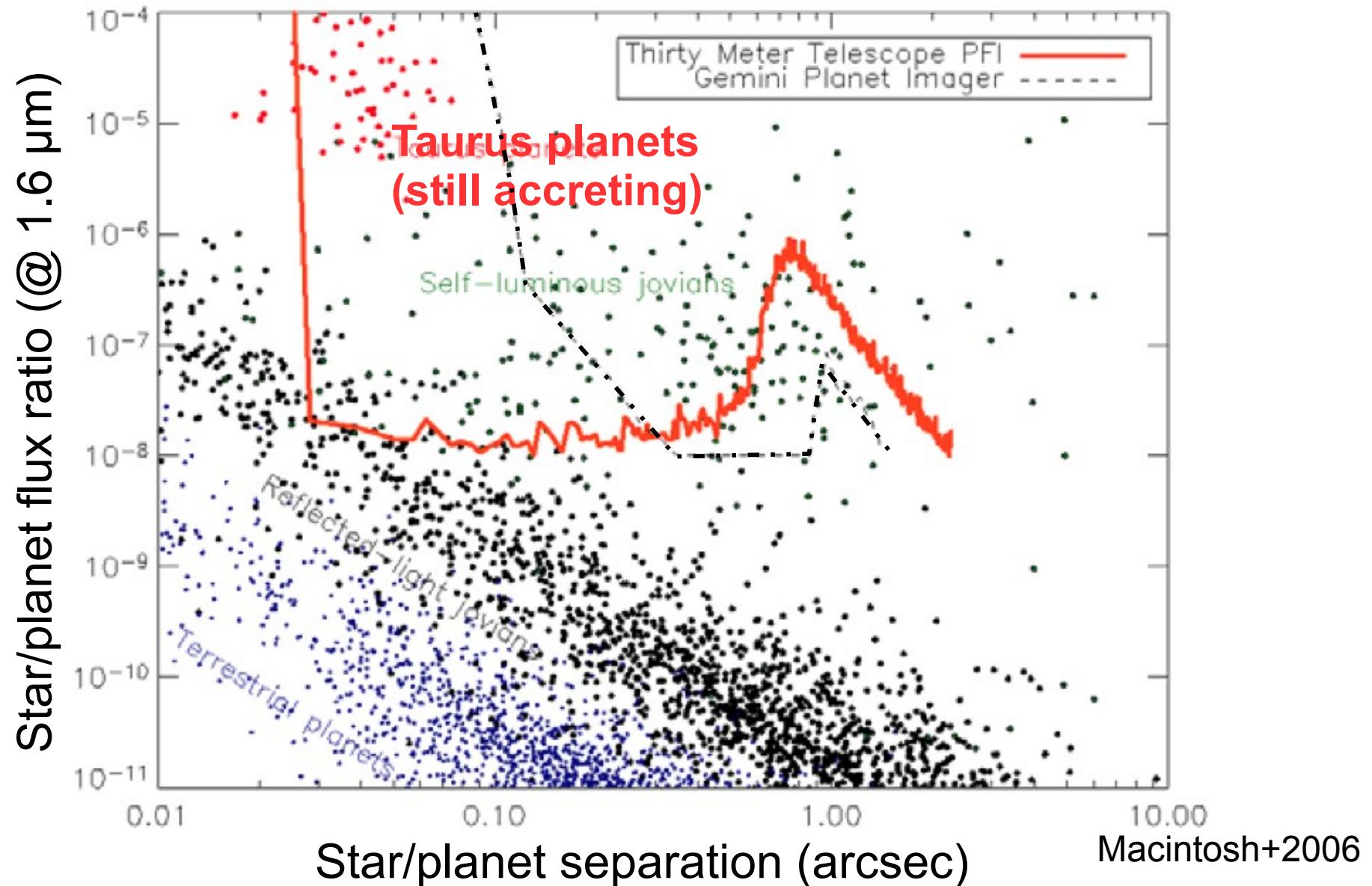


SMALL PLANETS &
HABITABILITY

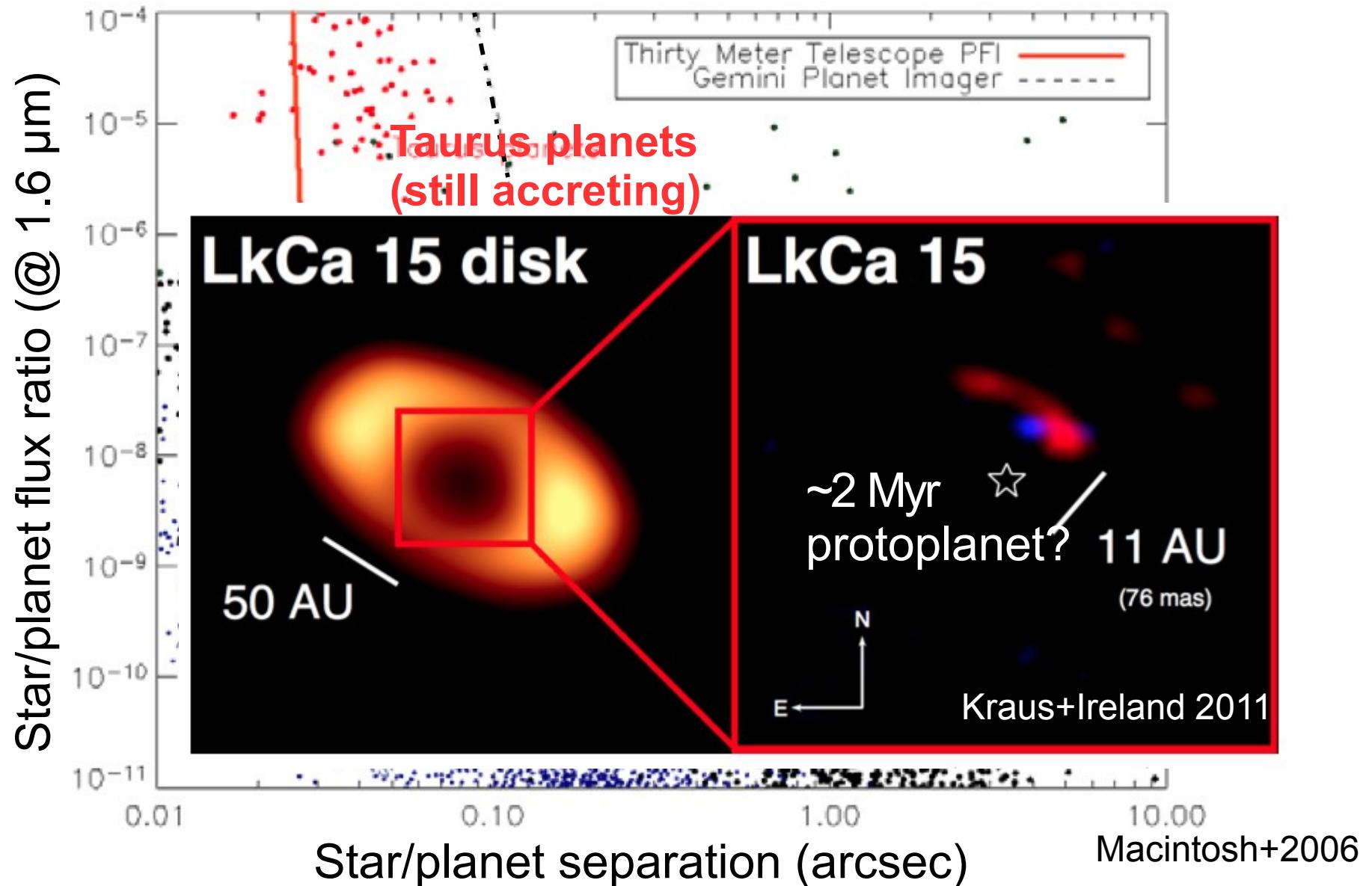


**YOUNG, HOT
GAS GIANTS**

PFI or IRIS: find & characterize many planets during formation.

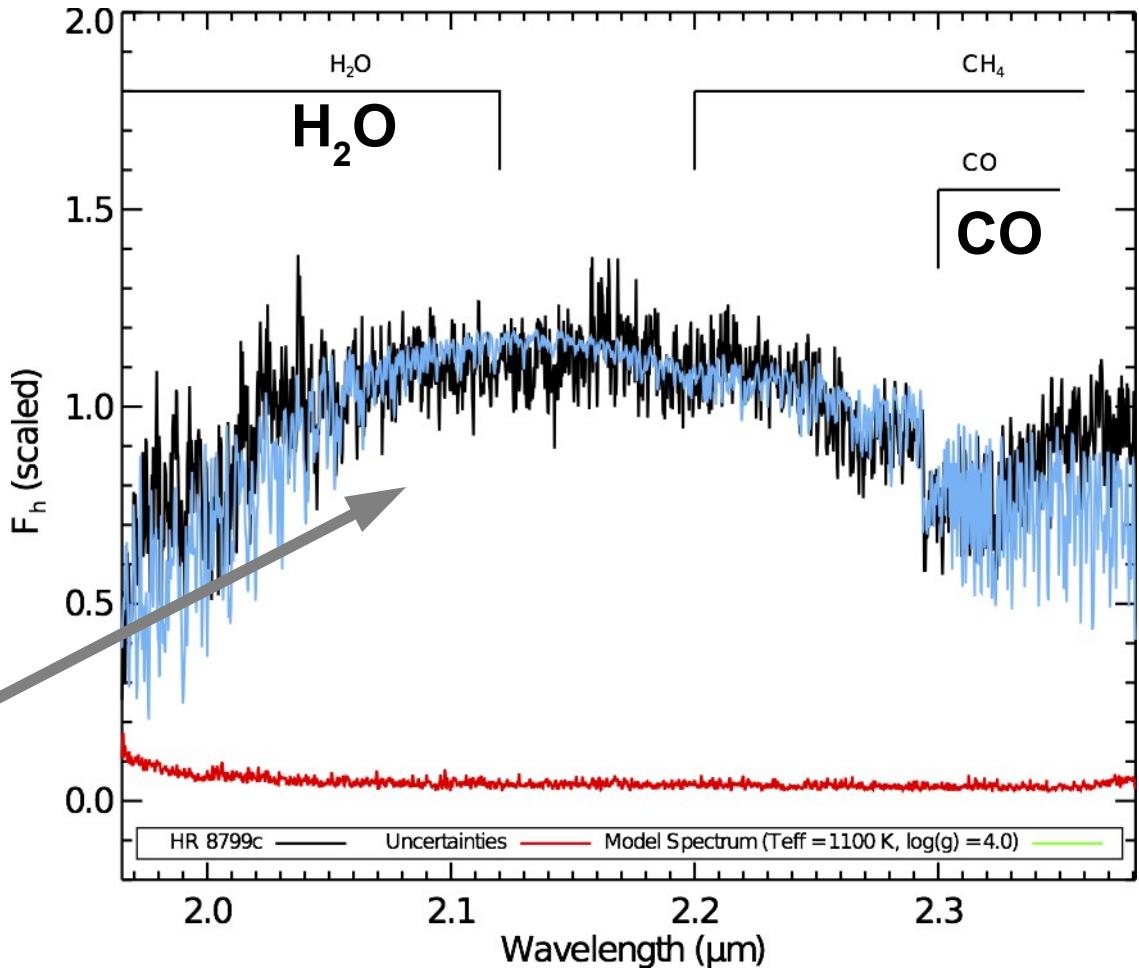


PFI or IRIS:discovery & study of many gas giants during formation.



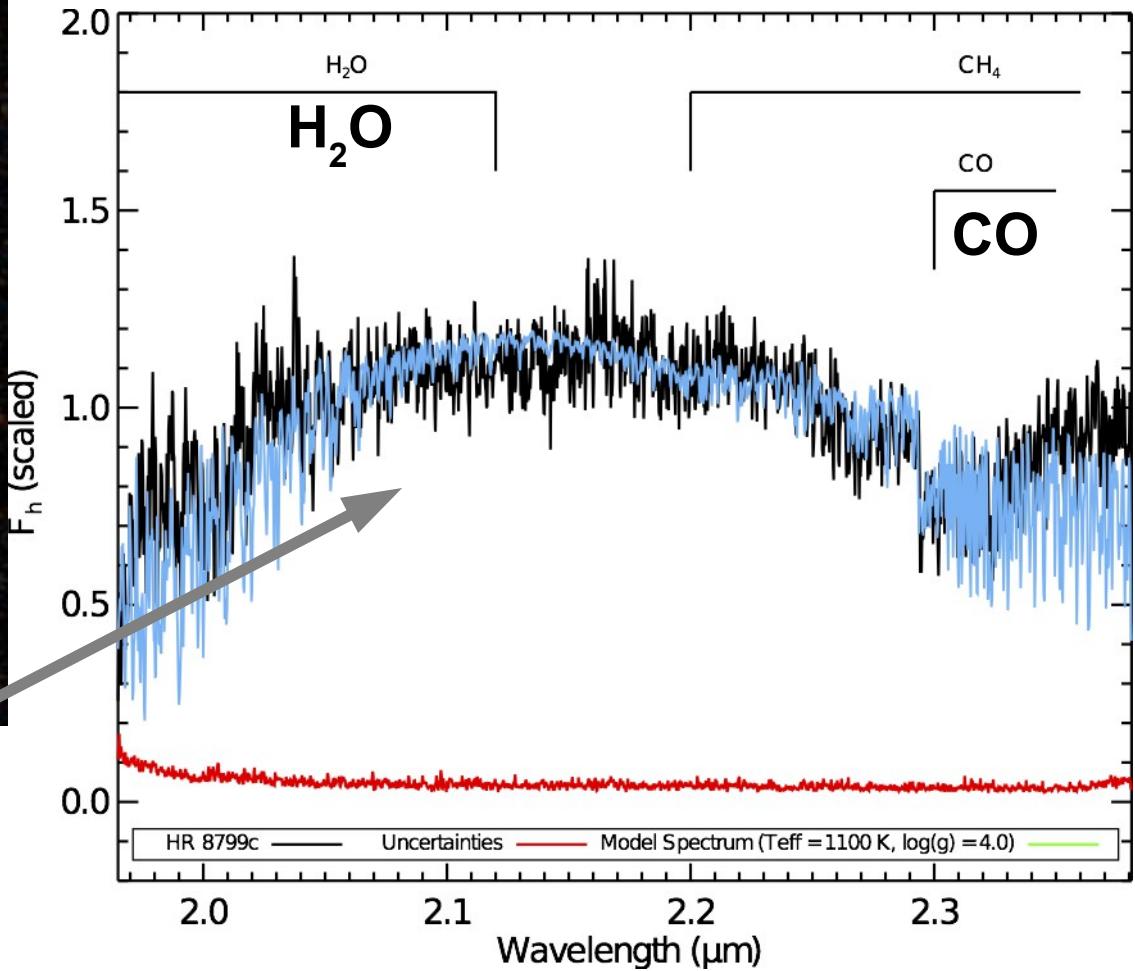
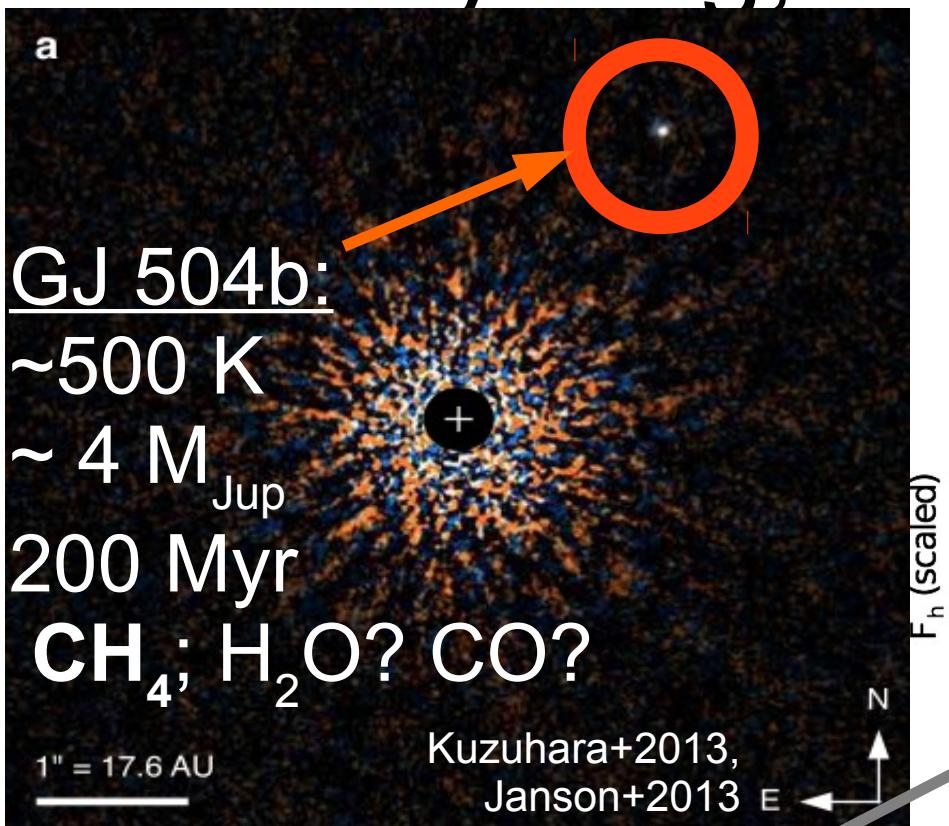
IRIS: $\lambda/\Delta\lambda \sim 4000$ spectroscopy of young, bright gas giants:

Keck/OSIRIS
HR 8799b:
 $T_{\text{eff}} \sim 1100 \text{ K}$
 $M \sim 5-10 M_{\text{Jup}}$
 $t \sim 30 \text{ Myr}$
CO & H₂O



Konopacky+2013

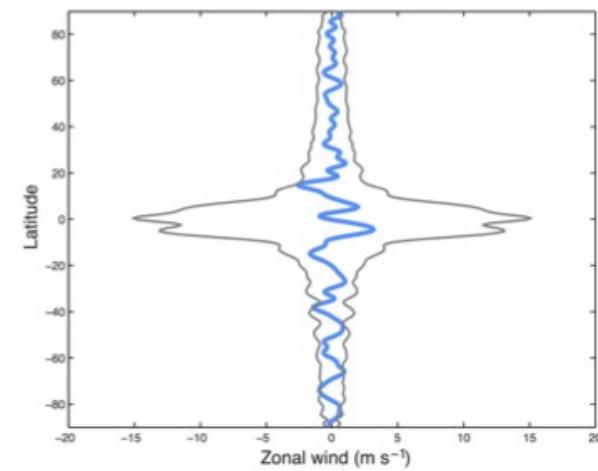
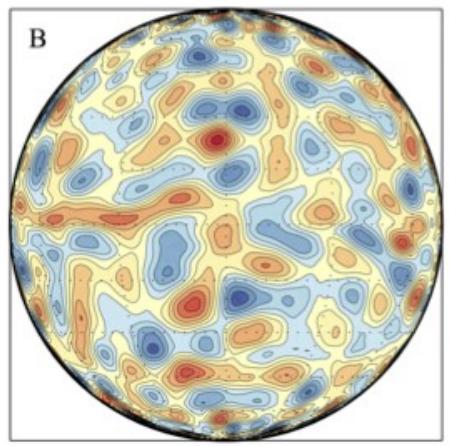
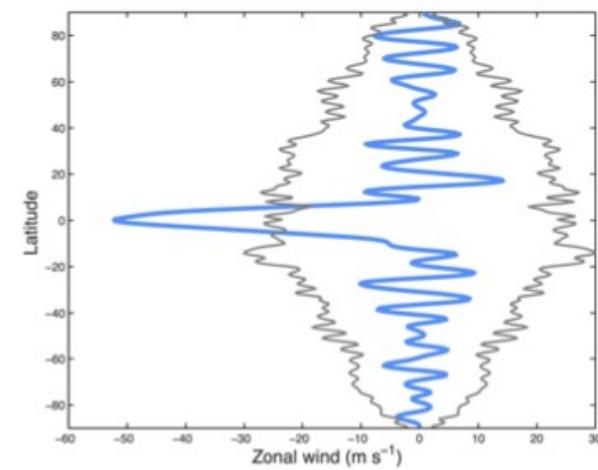
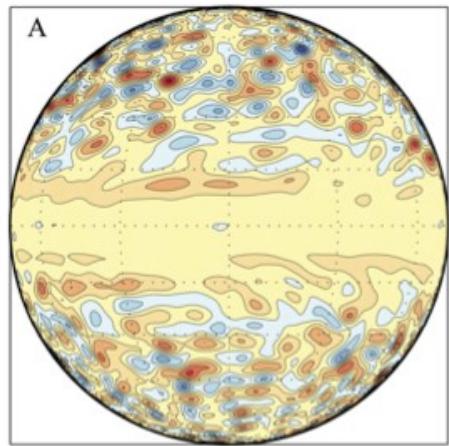
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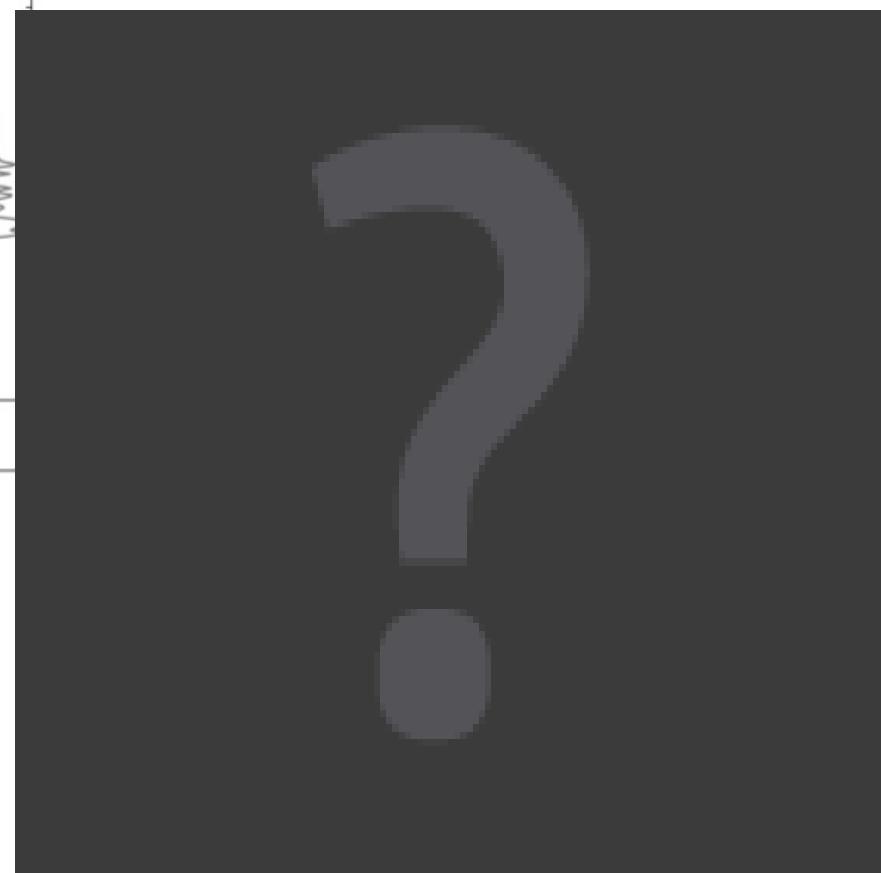
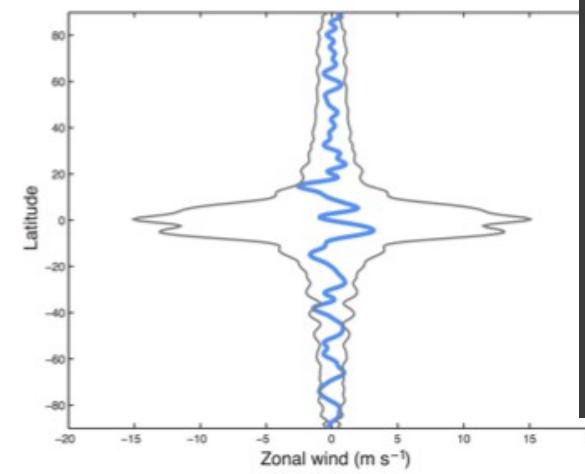
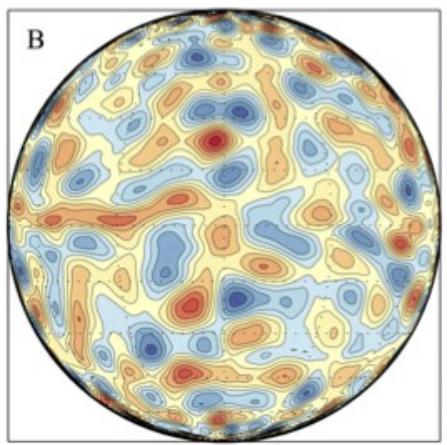
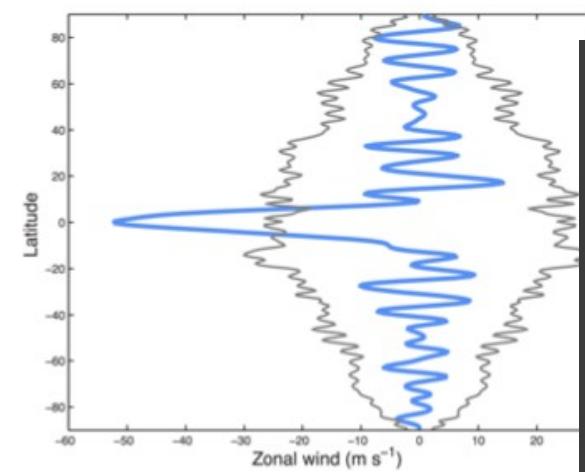
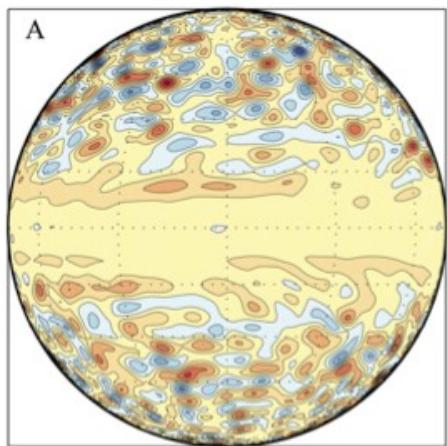
Konopacky+2013

Global Extrasolar Weather Patterns:

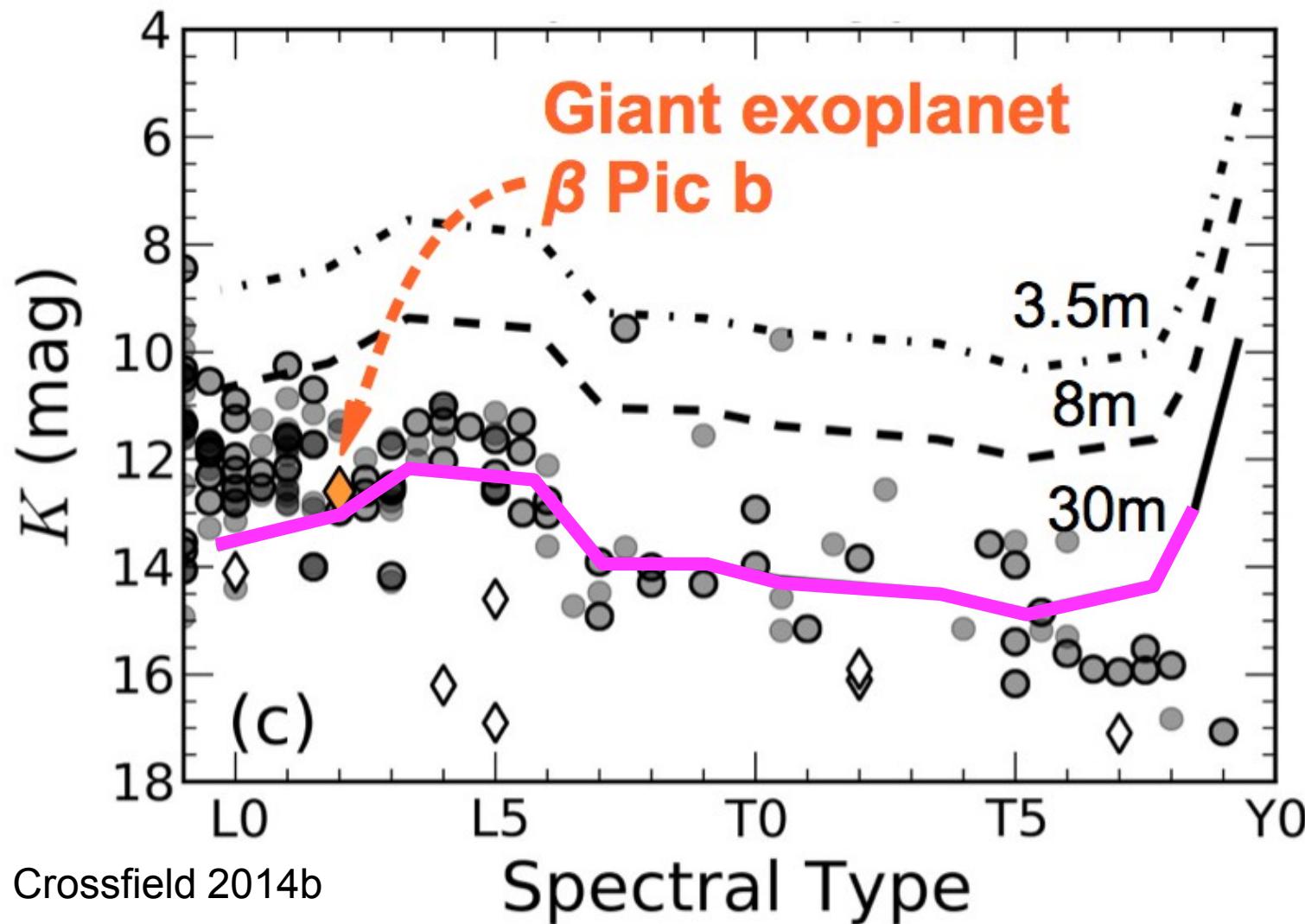


Global Extrasolar Weather Patterns: Doppler Imaging of Exoplanets and Brown Dwarfs

VLT/CRIRES:
Brown dwarf Luhman 16B

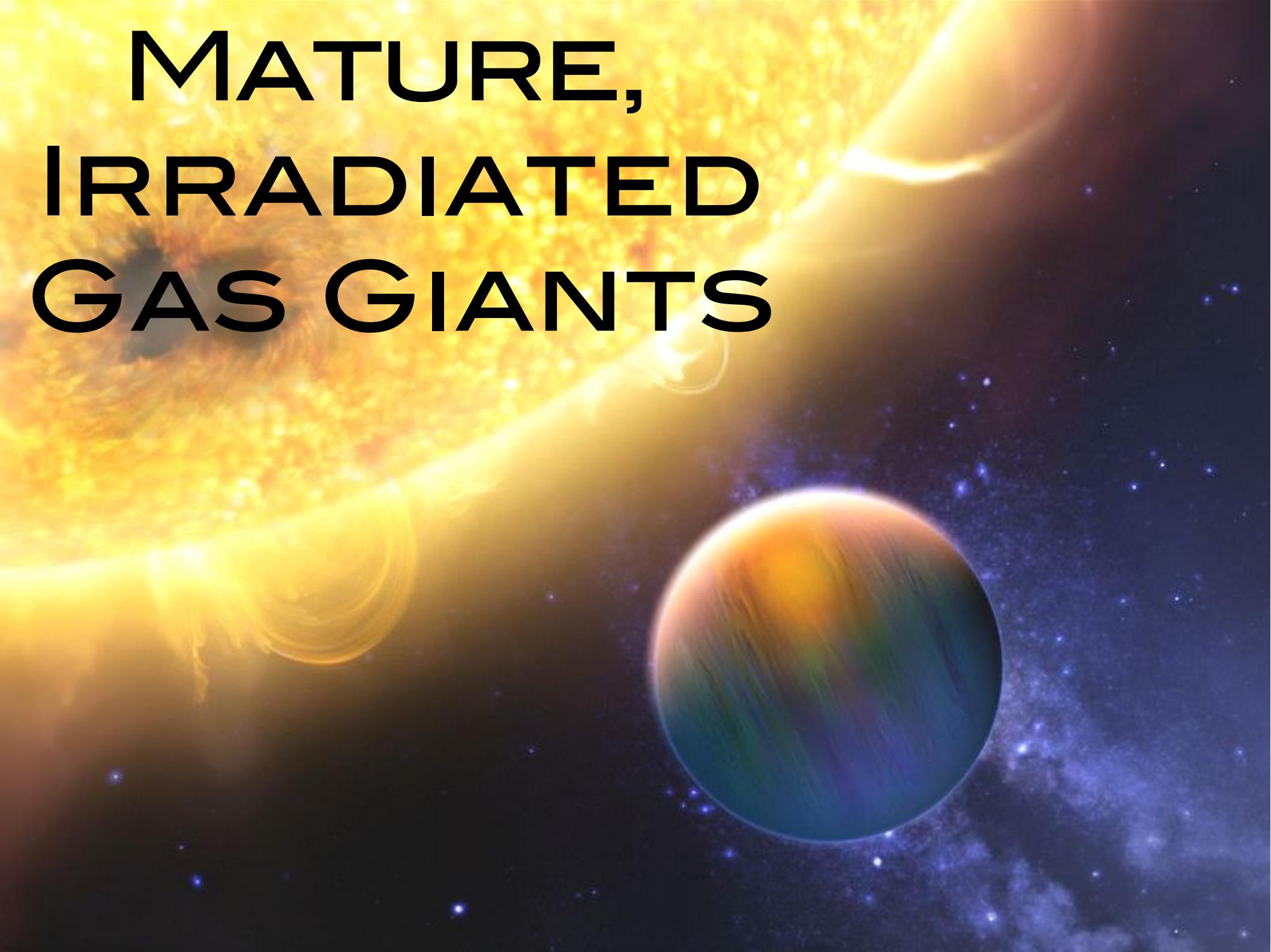


Global Extrasolar Weather Patterns: Doppler Imaging of Exoplanets and Brown Dwarfs

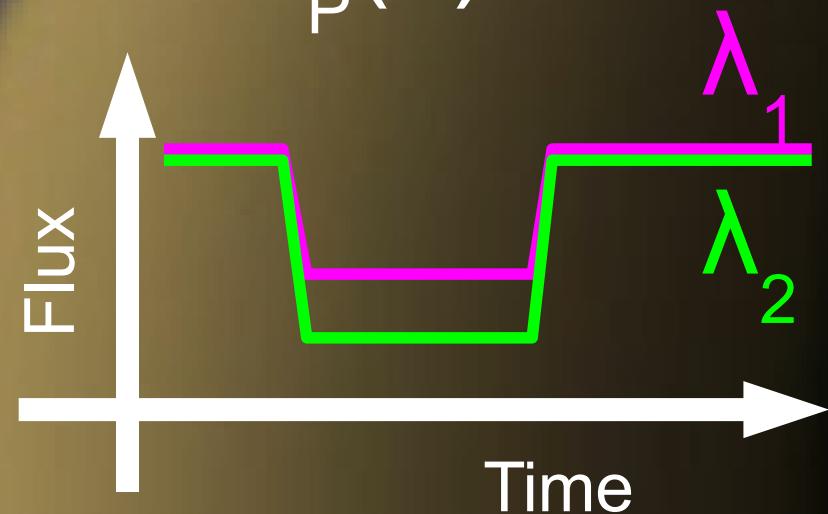
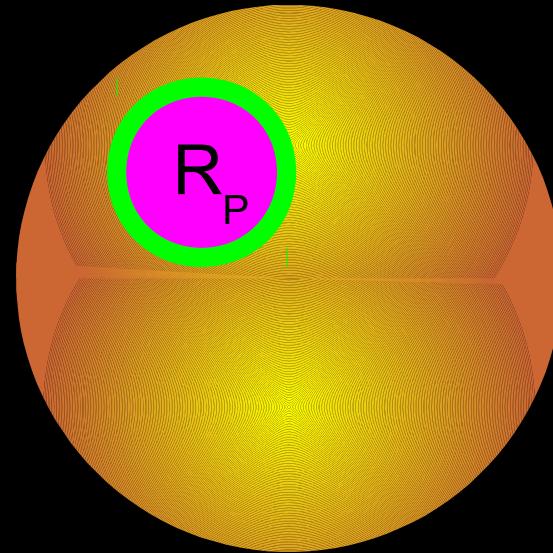


Crossfield+2014a

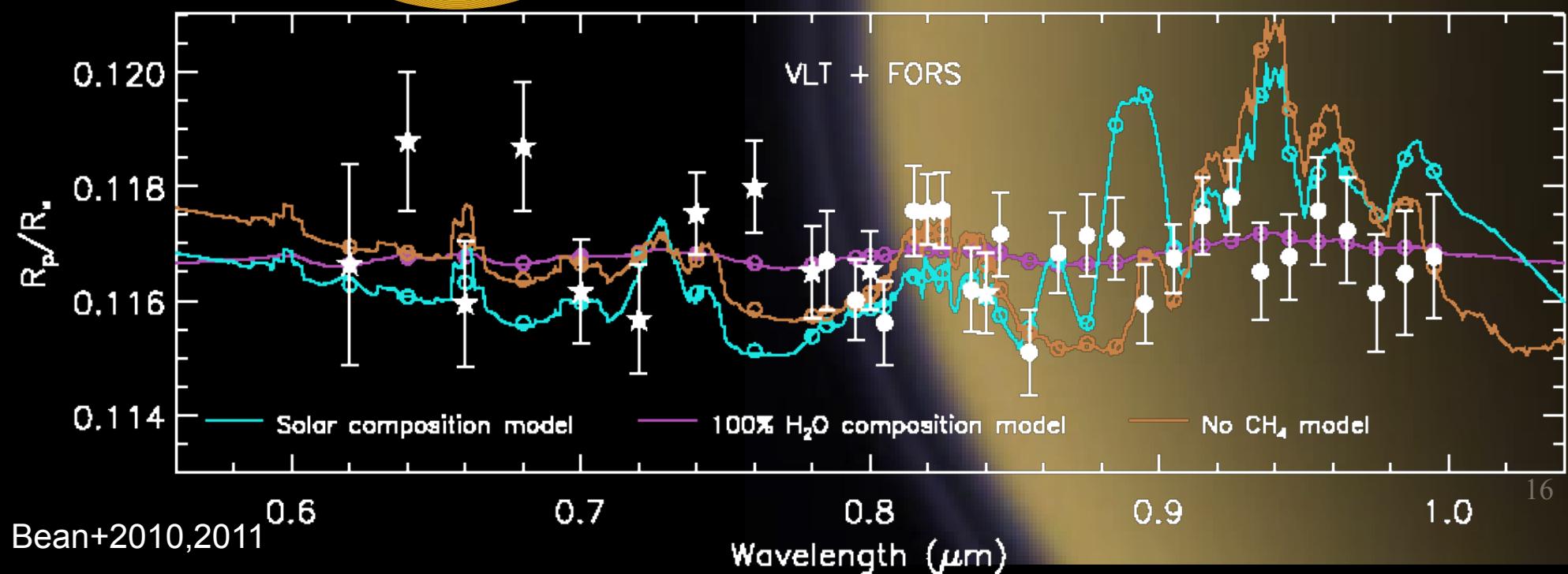
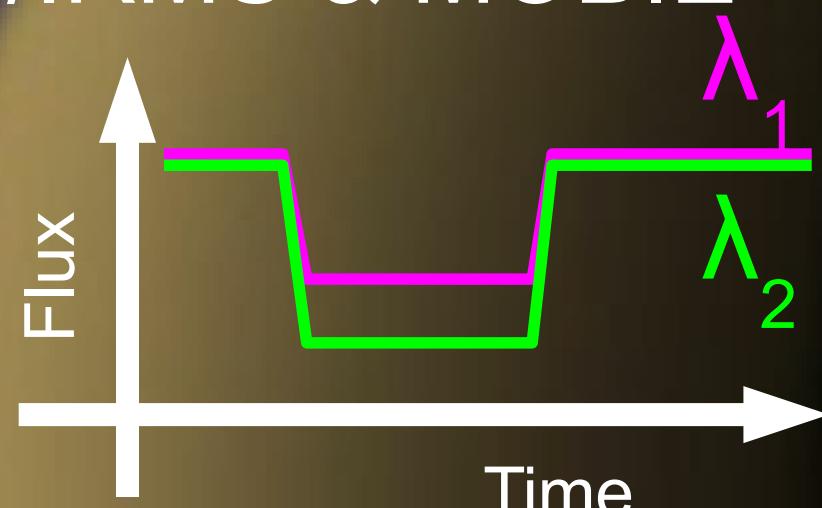
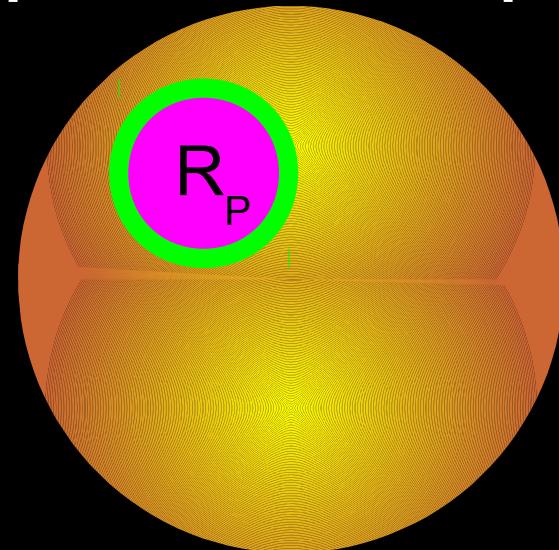
MATURE, IRRADIATED GAS GIANTS



Transmission spectroscopy: probe atmospheric composition via $R_p(\lambda)$

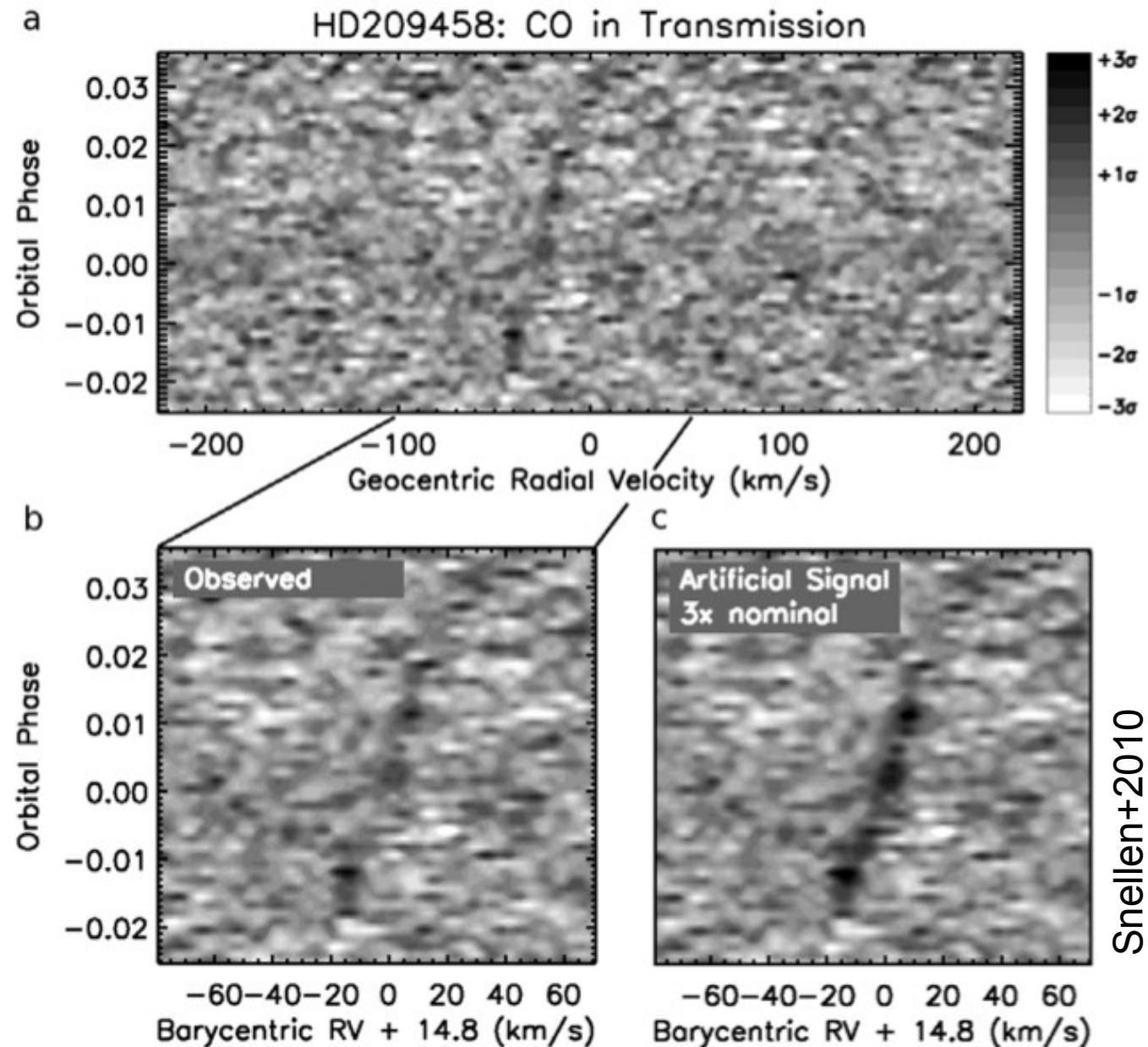


Transmission spectroscopy: probe atmospheric composition w/IRMS & MOBIE

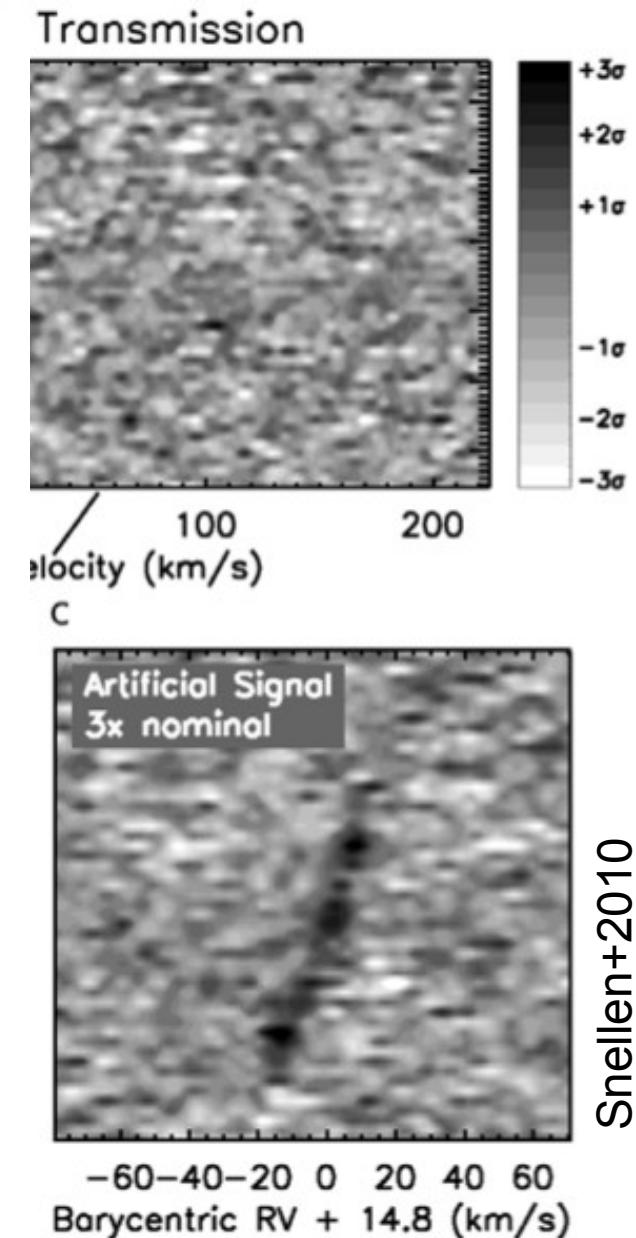
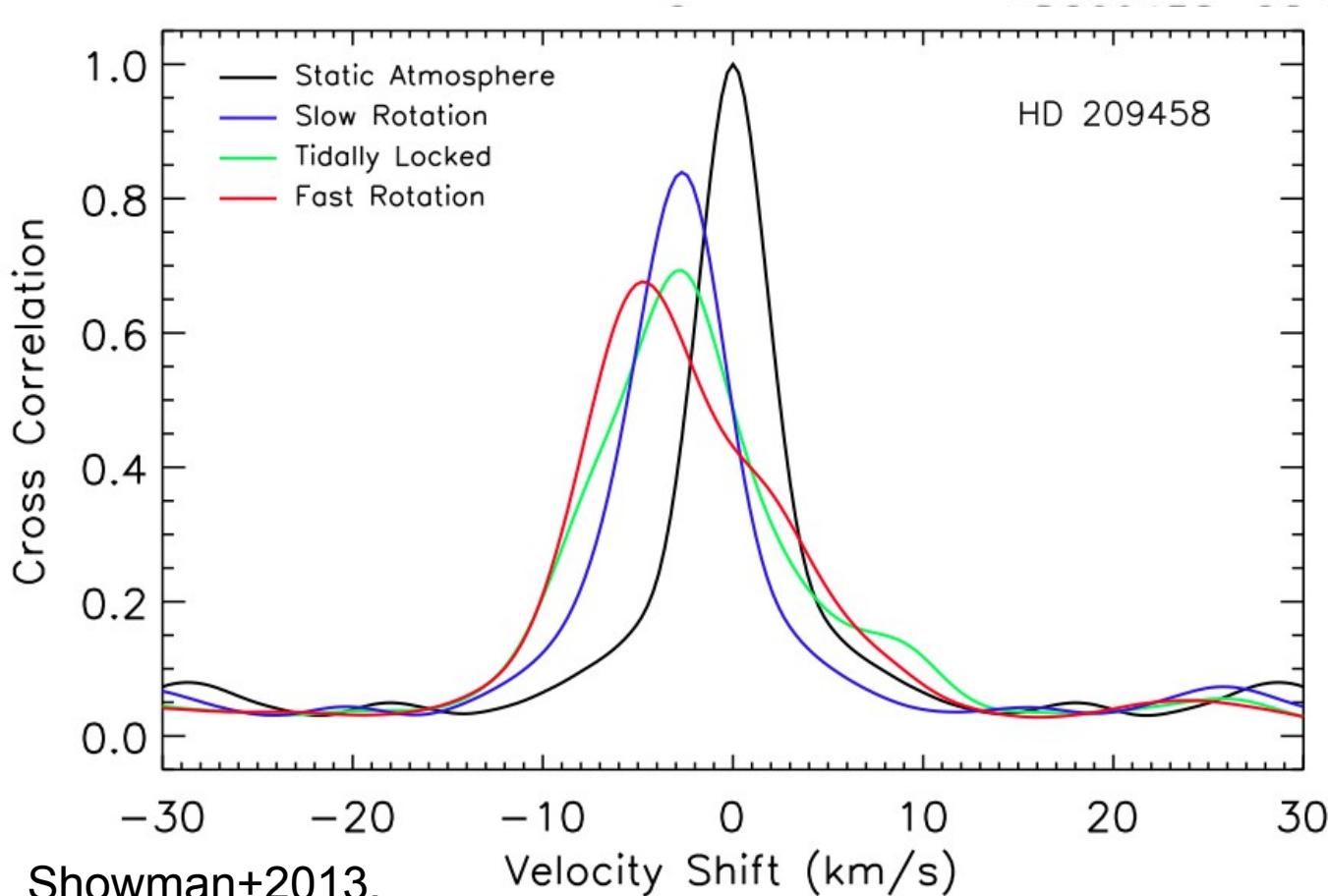


NIRES: Probe composition and atmospheric dynamics

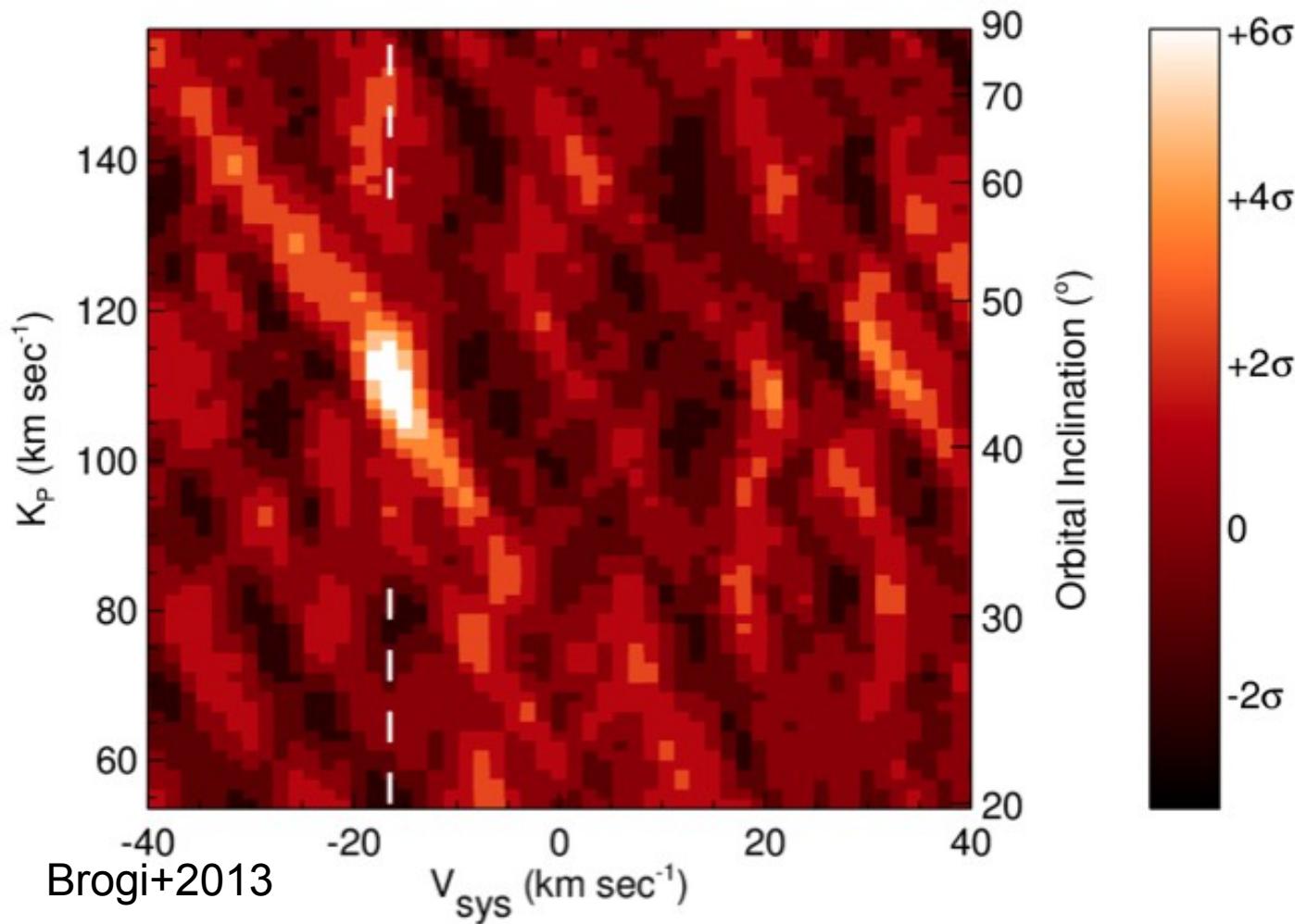
VLT/CRIRES: Transit of hot Jupiter HD 209458b. **CO** detected. Global wind? 2 ± 1 km/s



NIRES: Probe composition and atmospheric dynamics

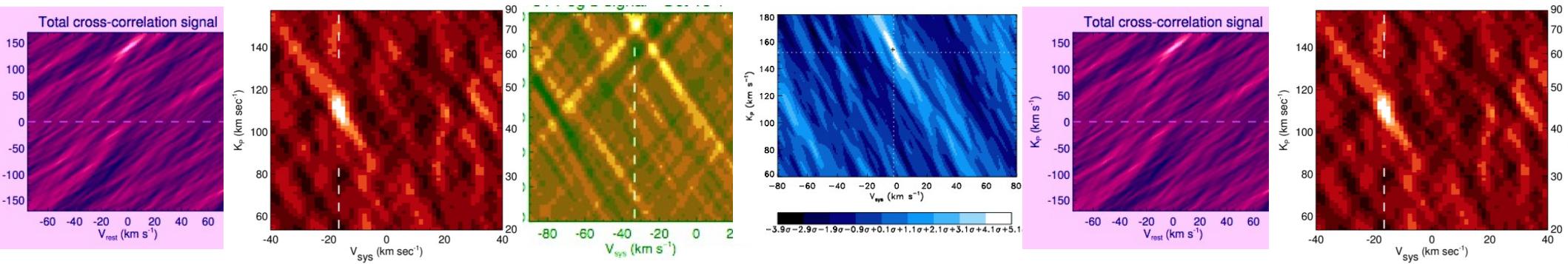
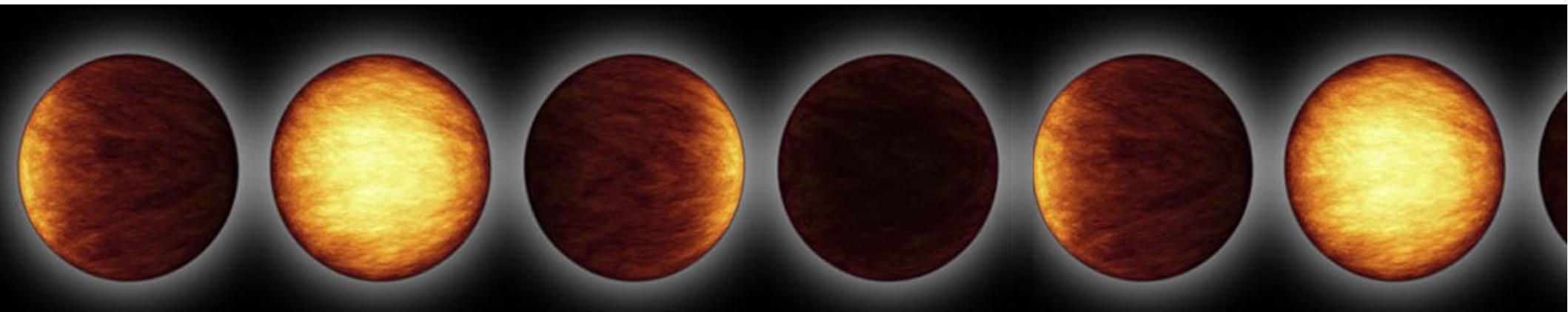


NIRES: probe composition and thermal structure of non-transiting planets



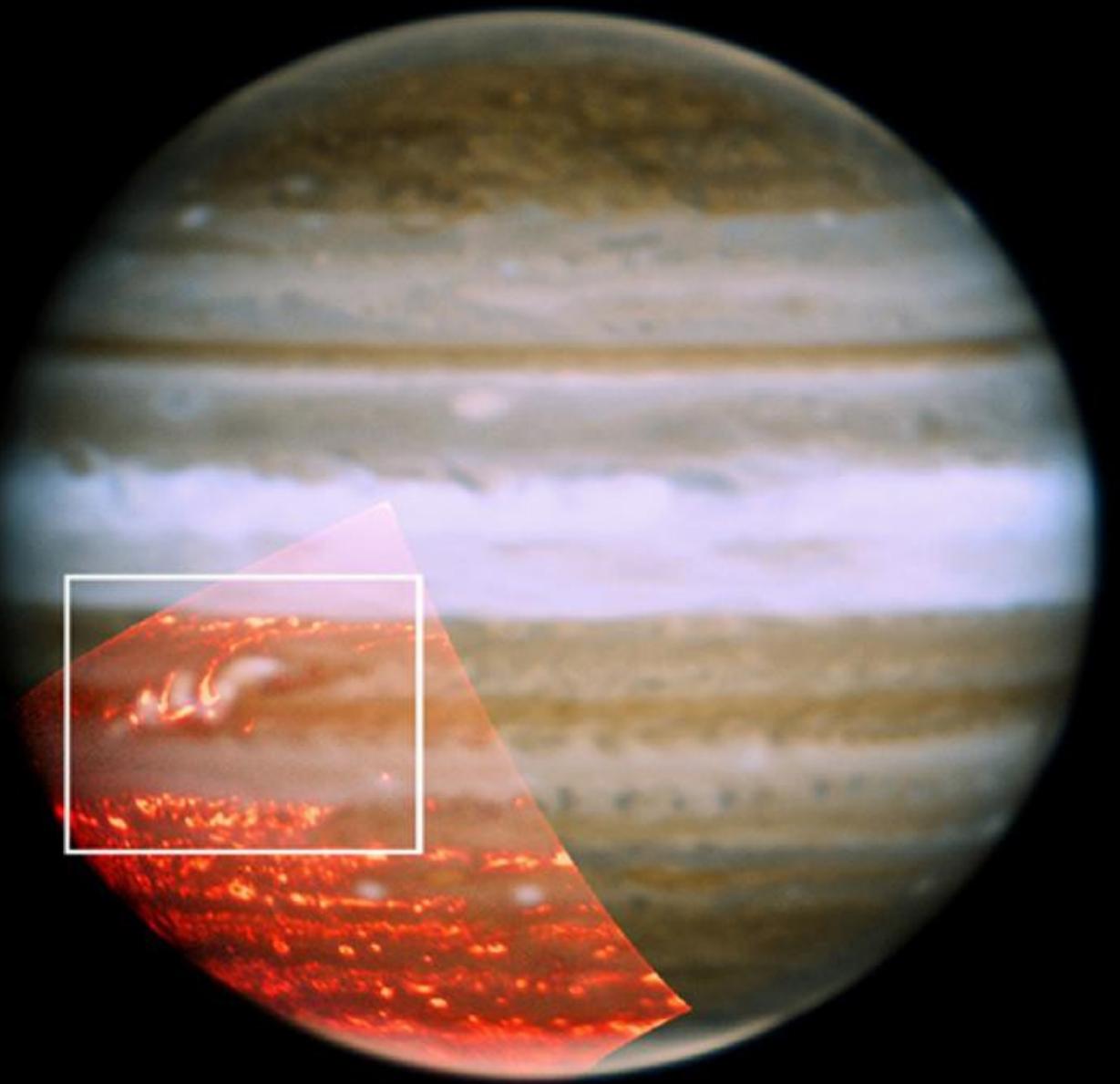
VLT/CRIRES:
Non-transiting
hot Jupiter
tau Boo b.
**CO detected;
No thermal
inversion.**

NIRES: probe composition and thermal structure of non-transiting planets as a function of longitude

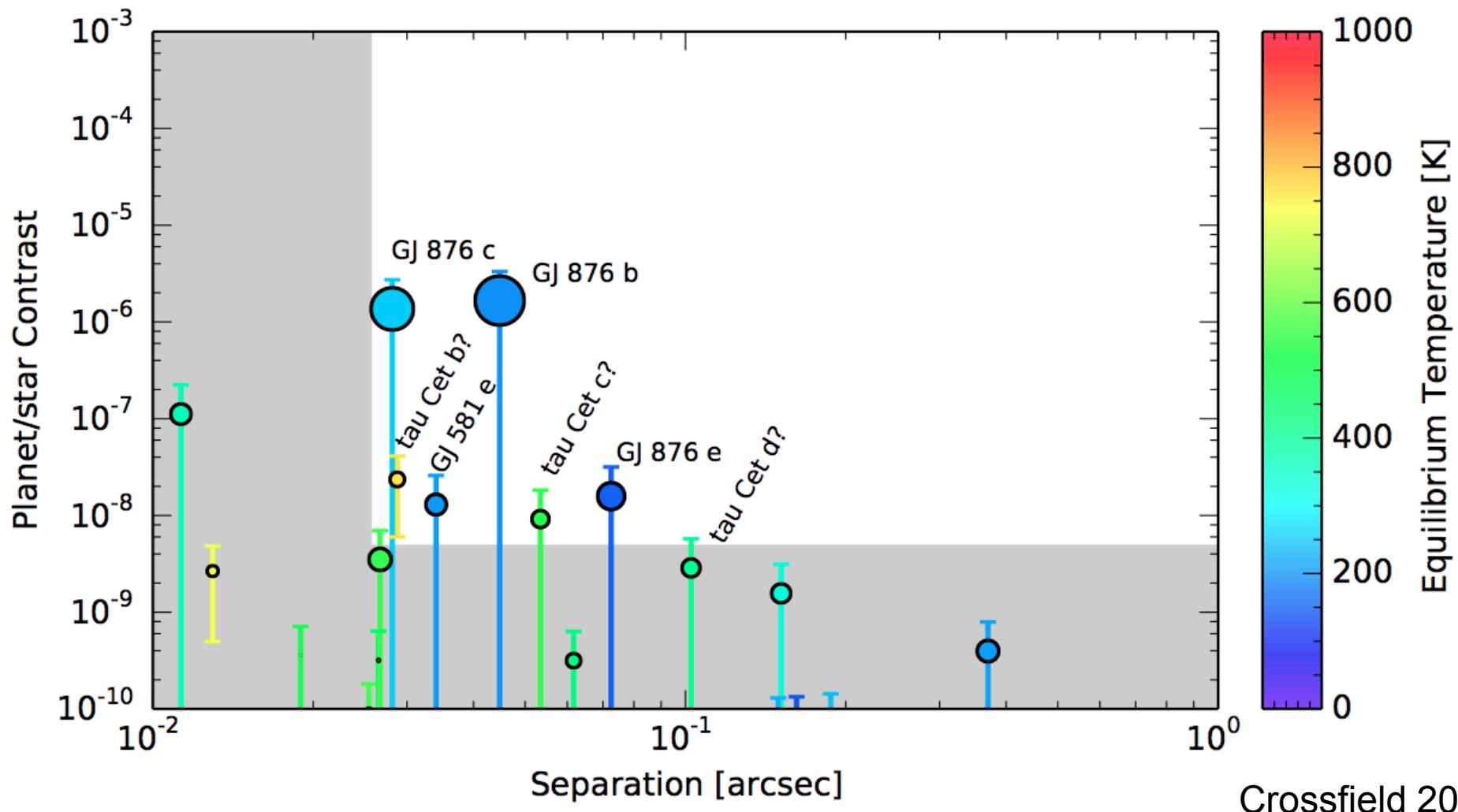


Brogi+2013, 2014, Birkby+2014,
de Kok+2013, Rodler+2013a, b

MATURE, COLD GAS GIANTS

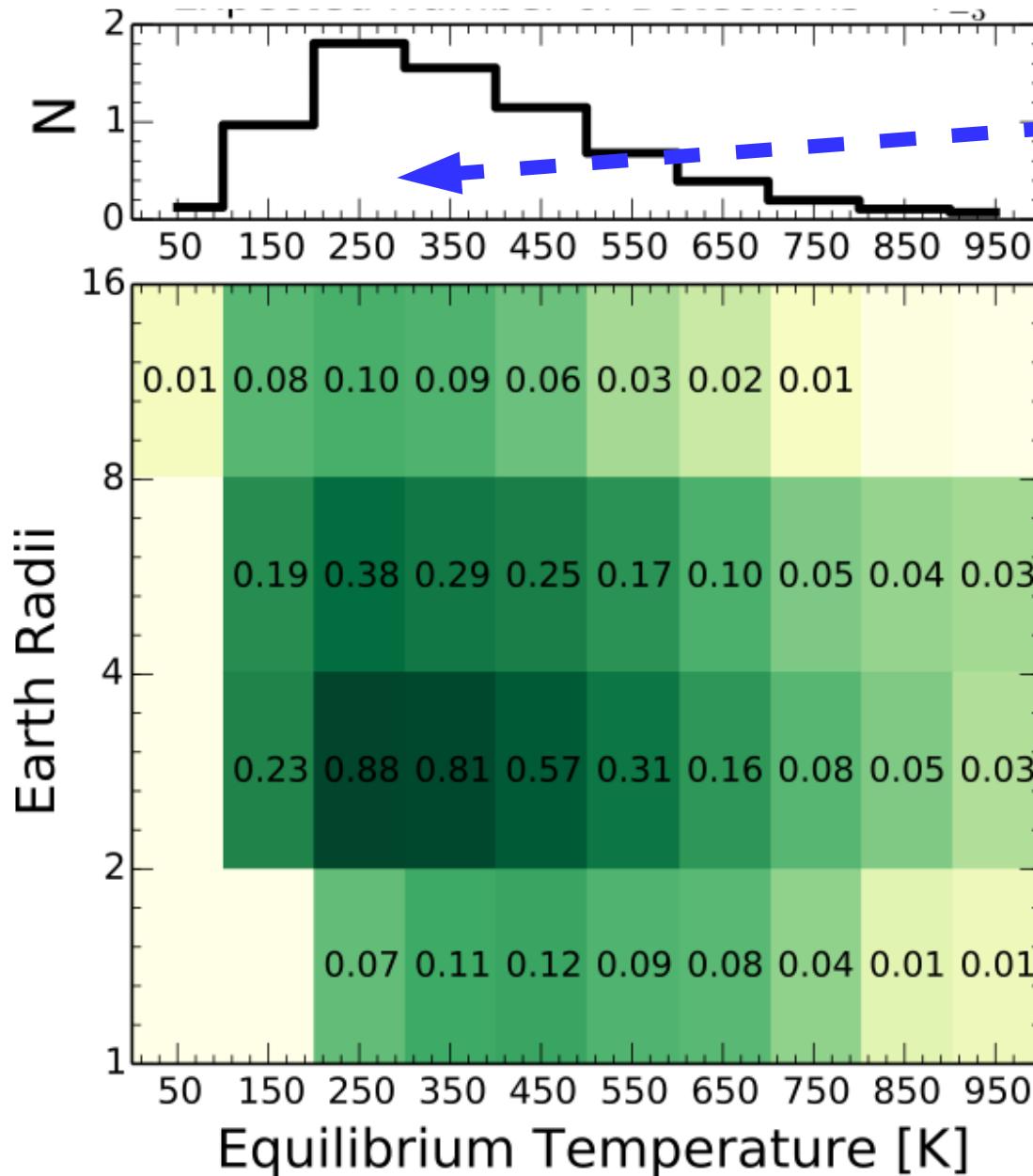


PFI: Will study albedo properties of known planets:

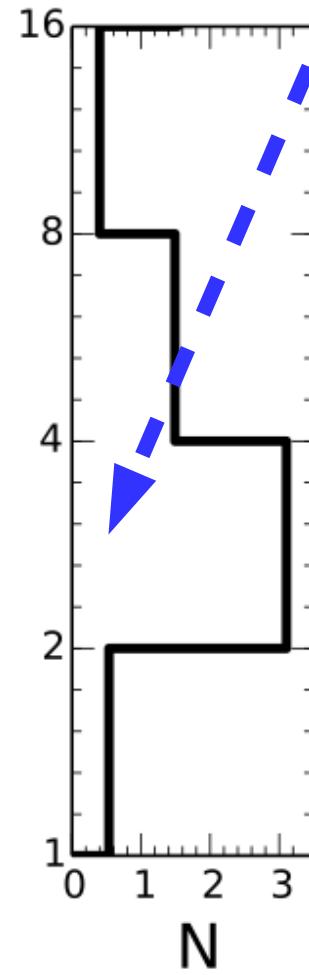


Crossfield 2013

PFI: would study 5-10 super-Earths around nearby stars:



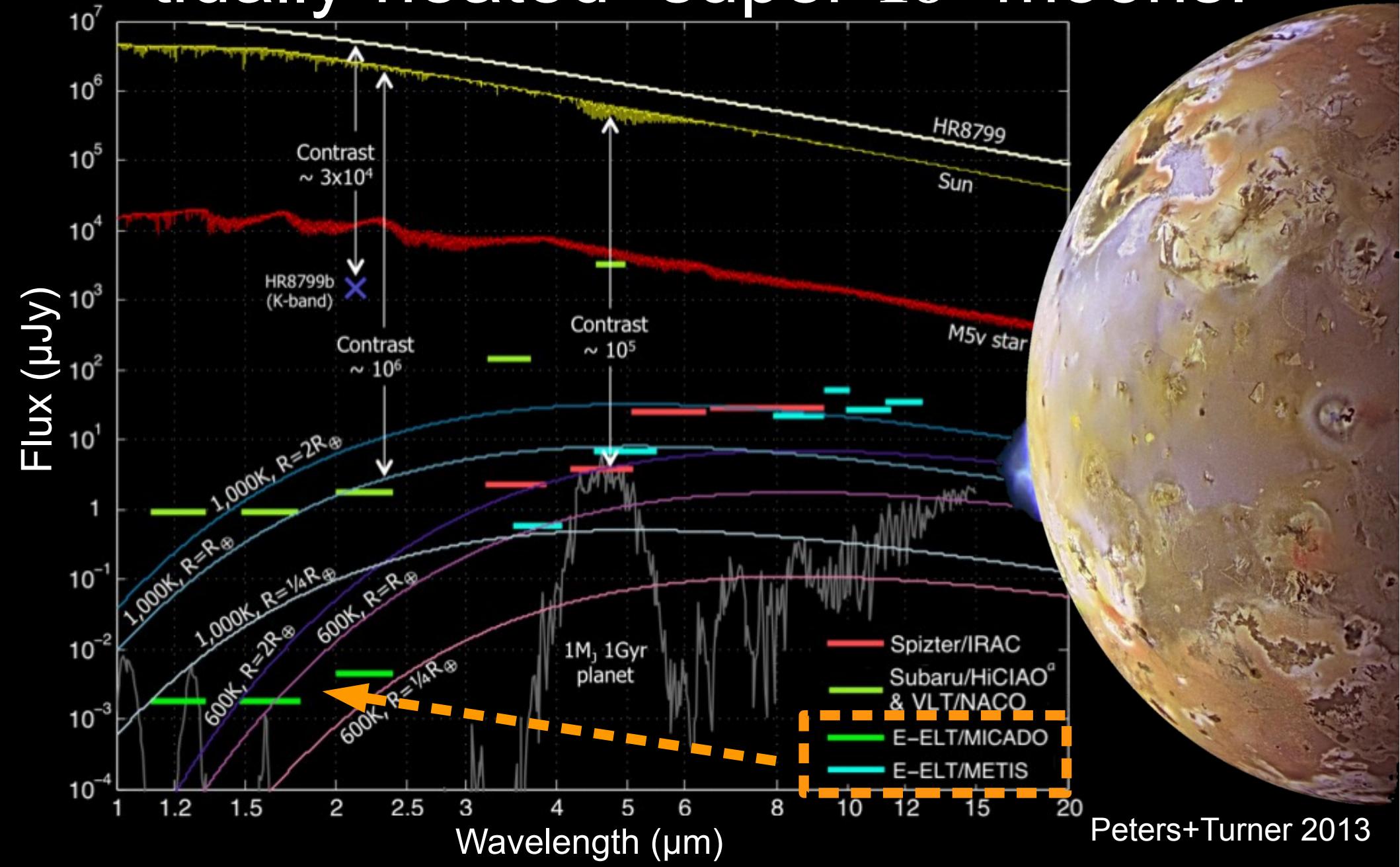
$\langle T \rangle \sim 250 \text{ K}$
 $\langle R \rangle \sim 3 R_{\text{Earth}}$



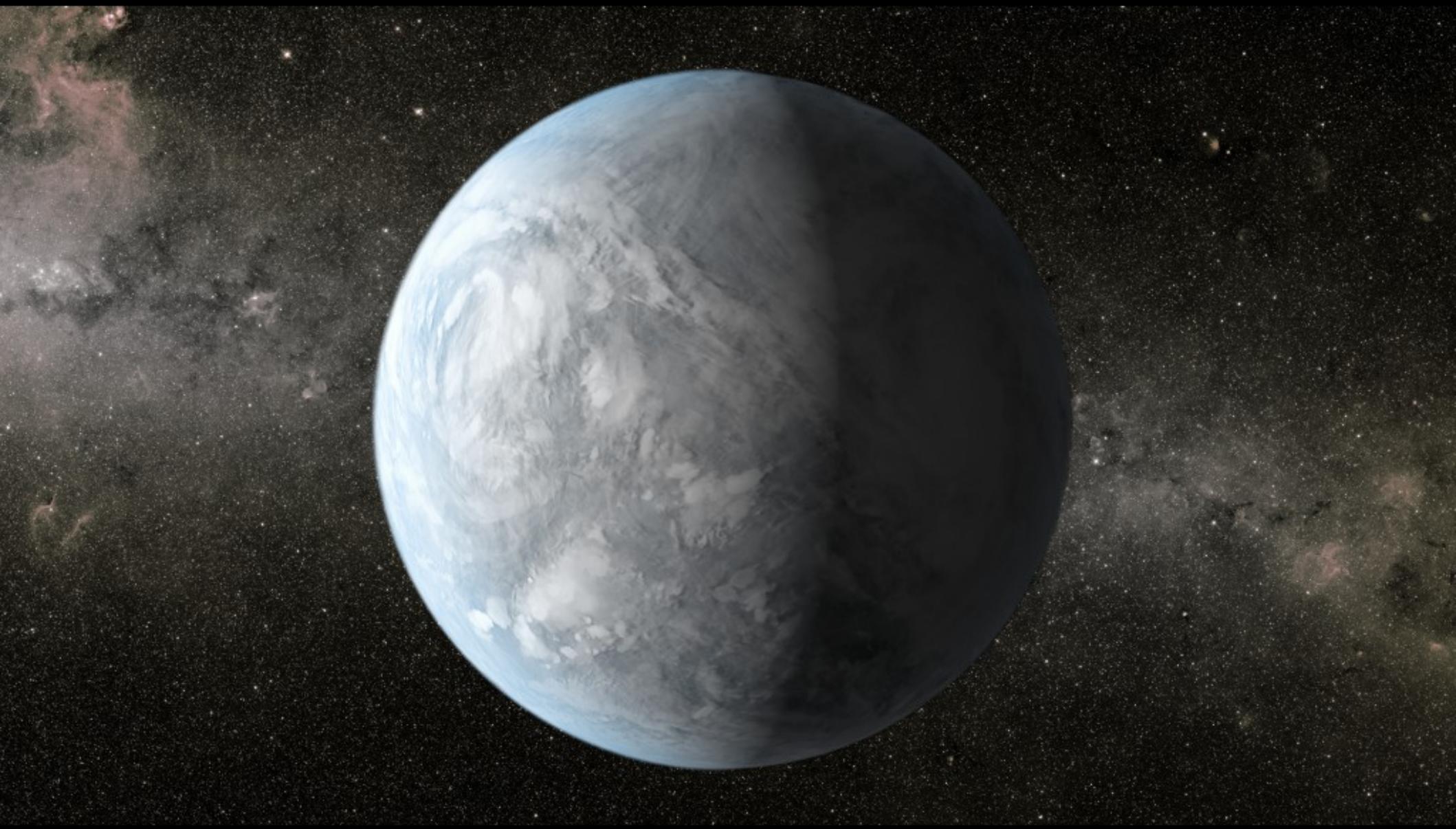
Not a blind search: Radial velocity surveys will find these systems!

Crossfield 2013;
Quanz, Crossfield+2014

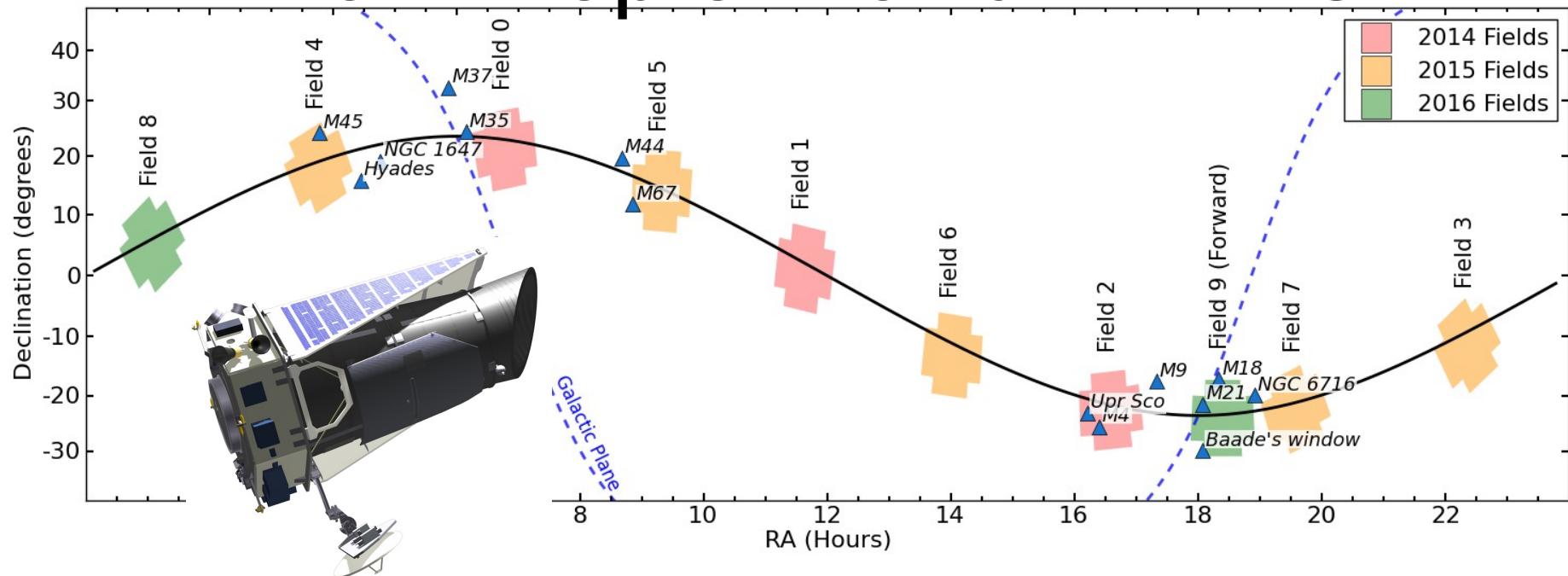
PFI: Might even find & study tidally-heated “super-Io” moons:



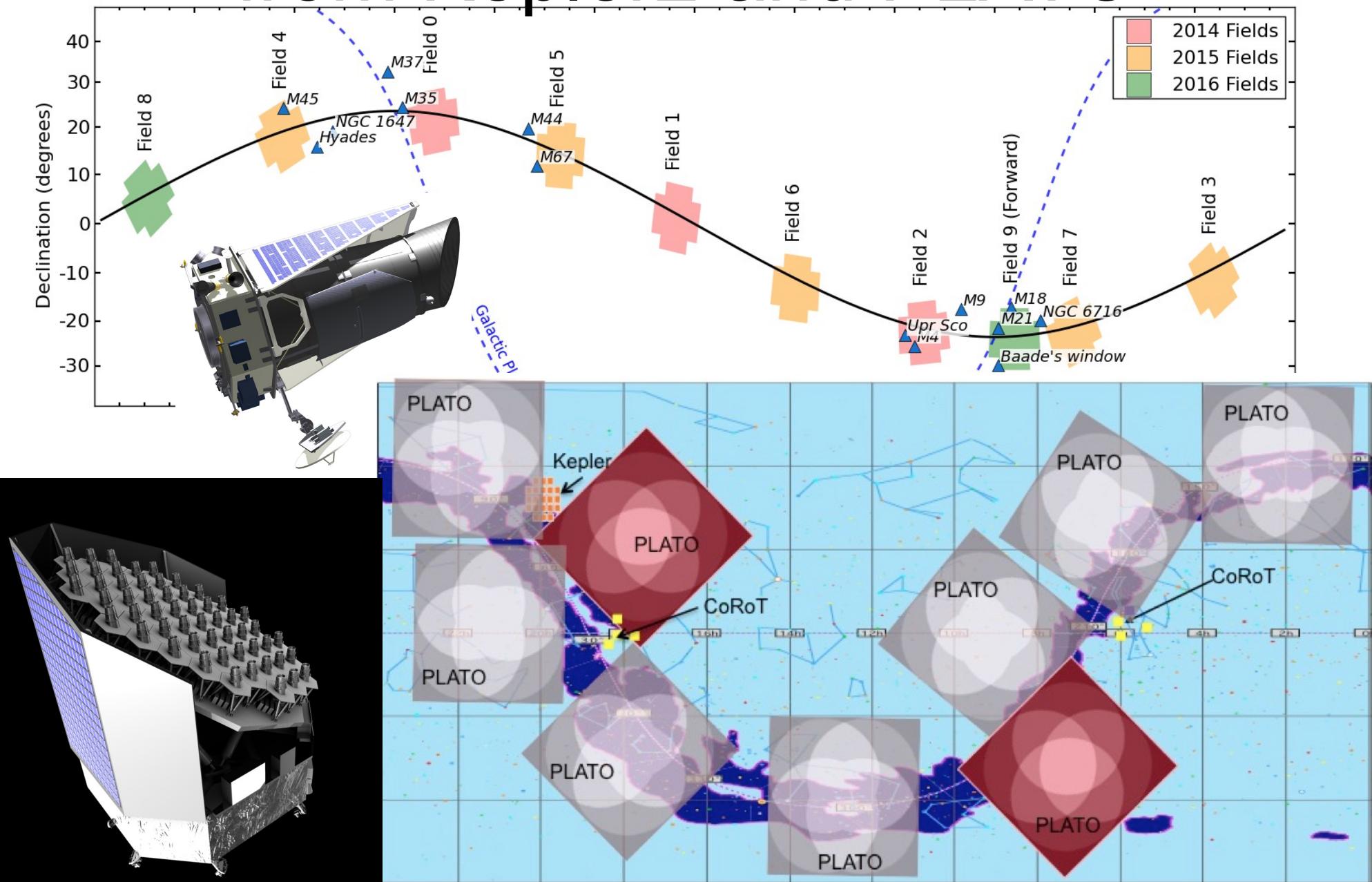
SMALL & ROCKY PLANETS; HABITABILITY & LIFE



IRMS: Transit followup of planets from Kepler2 and PLATO

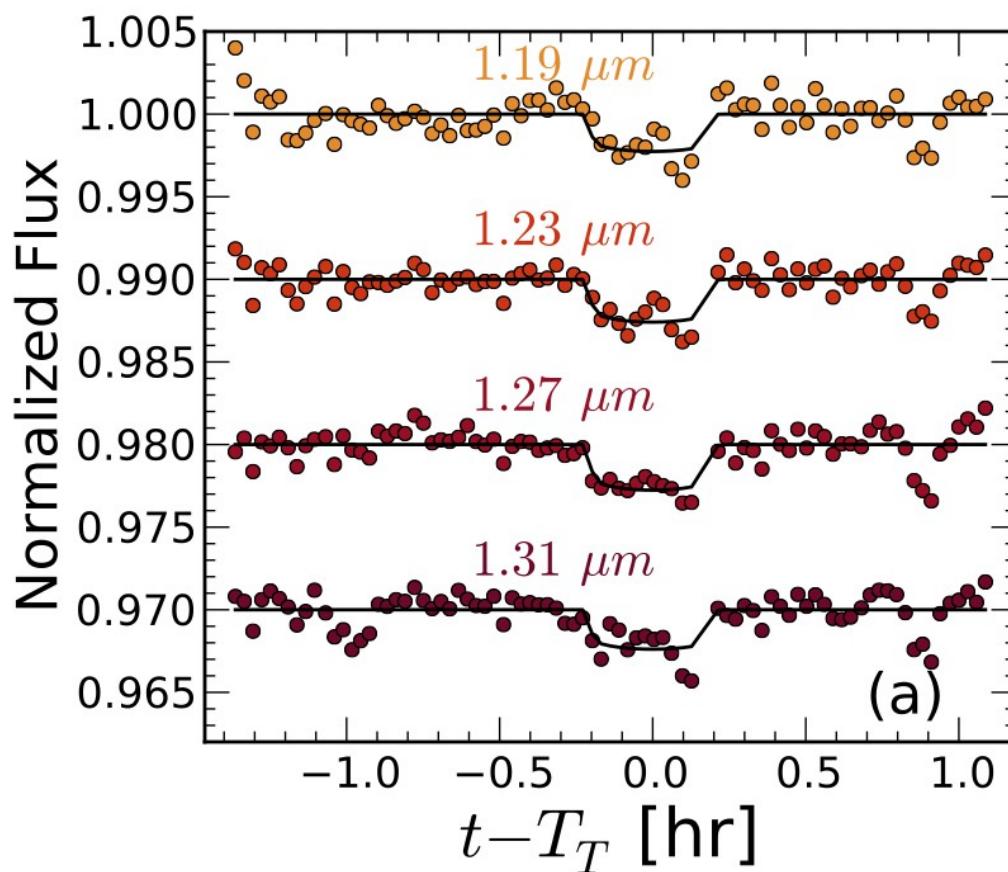


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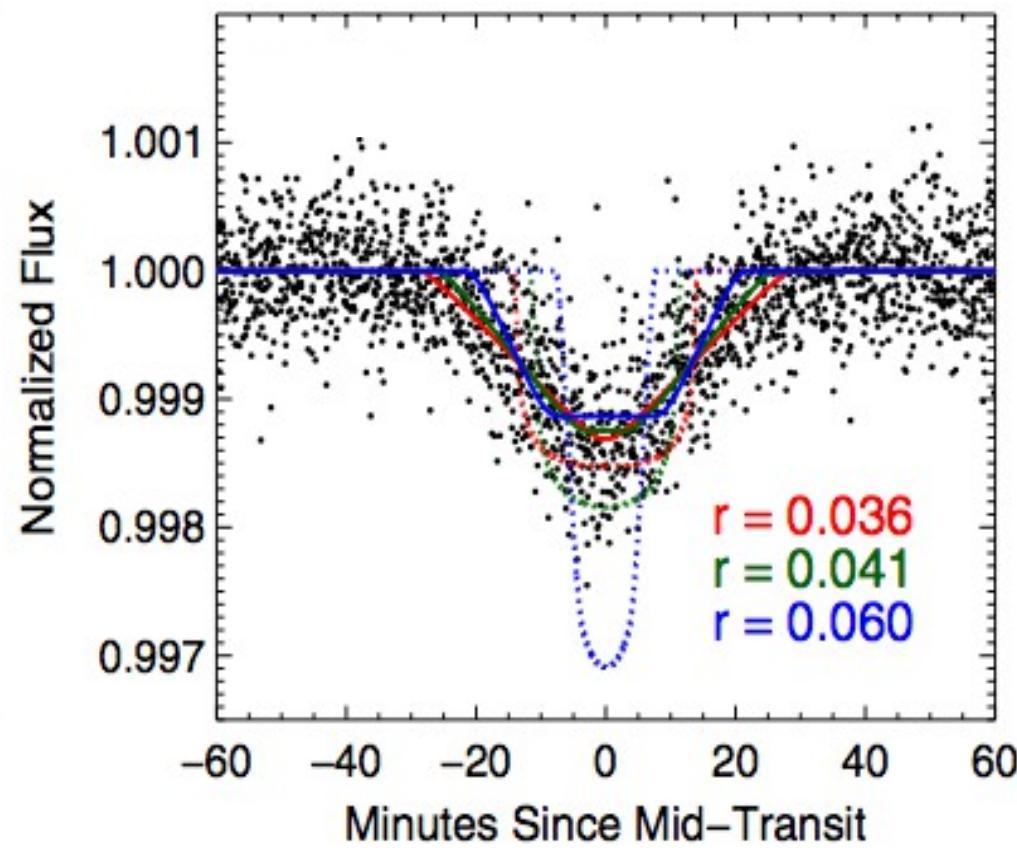
Ground-based studies of sub-Earth-sized planets:

Keck/MOSFIRE:



Crossfield et al. in prep

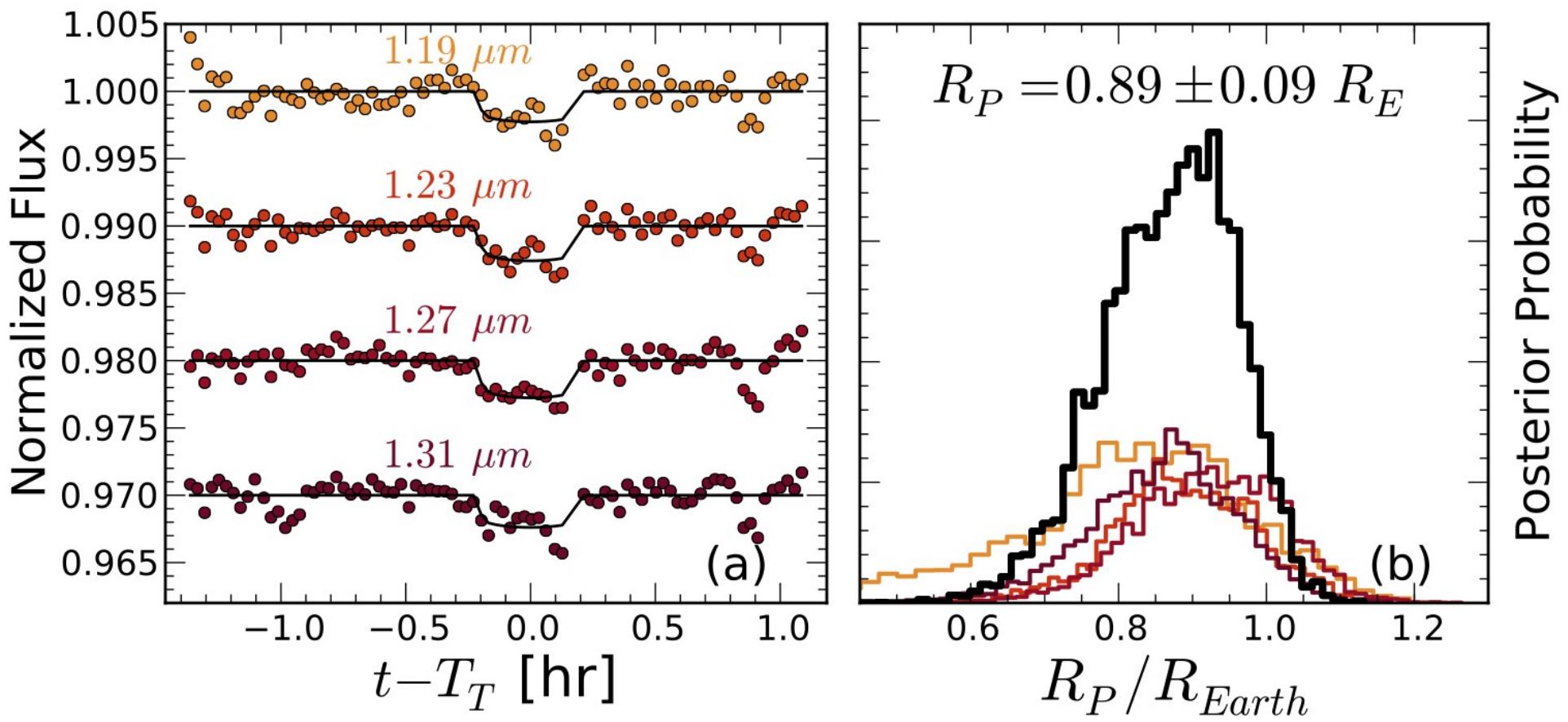
Kepler:



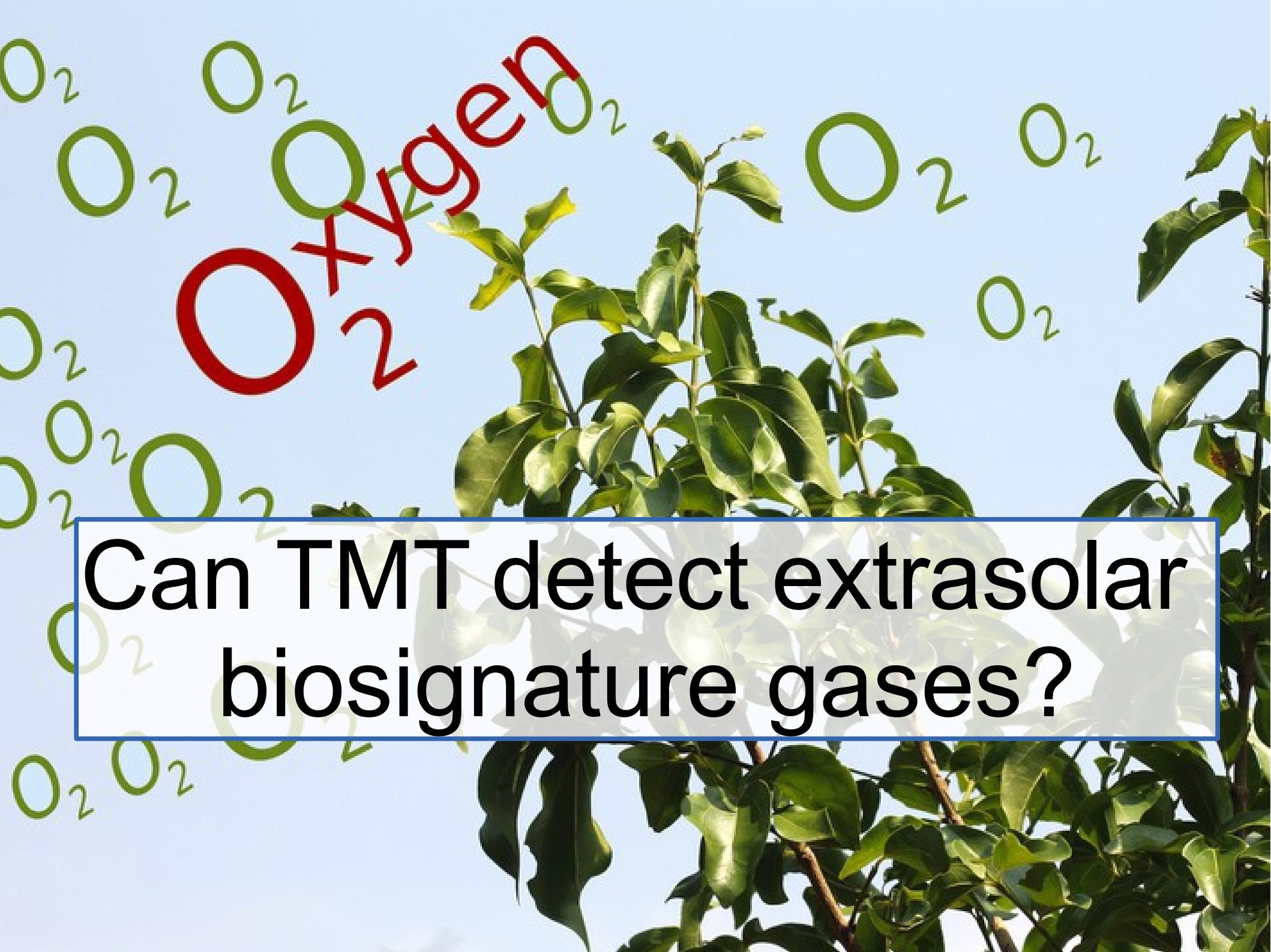
Muirhead et al. (2012)

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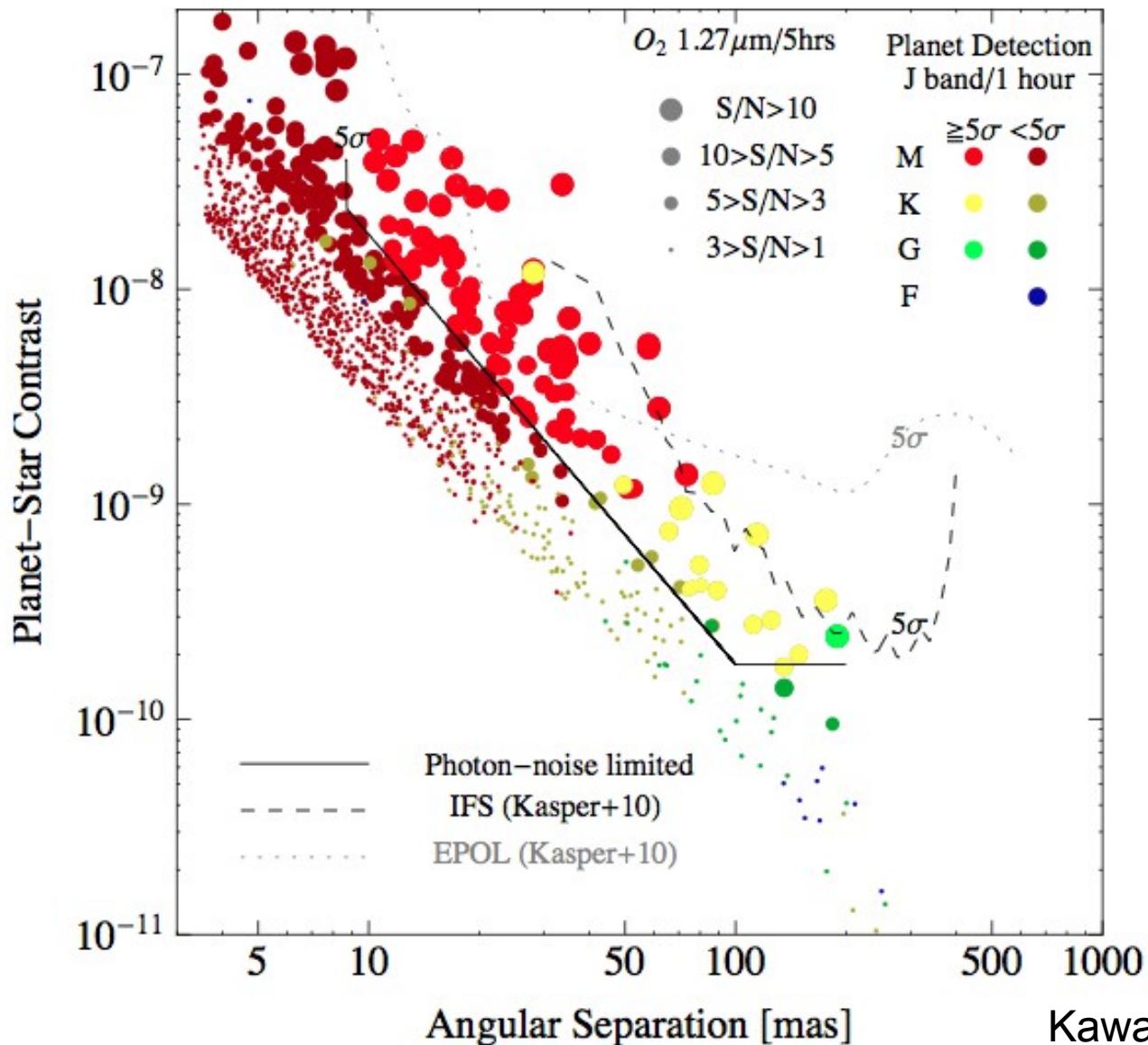


Crossfield et al. in prep



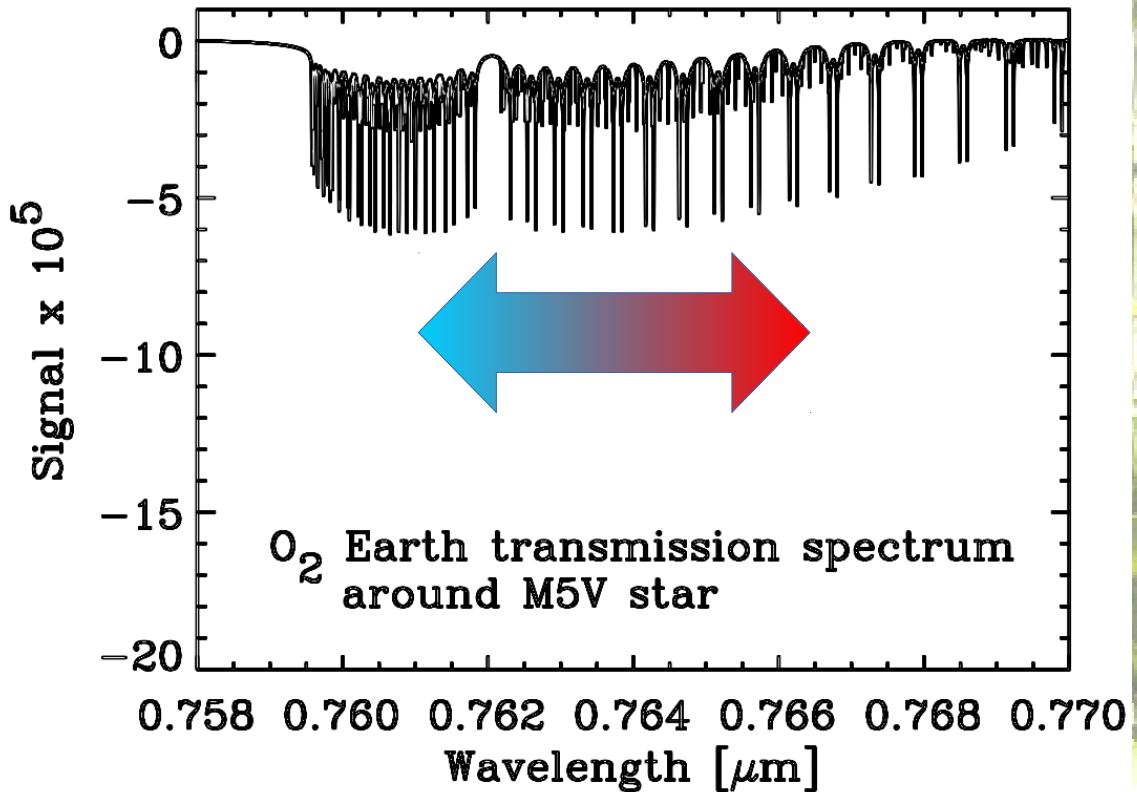
Can TMT detect extrasolar biosignature gases?

PFI/SEI + IRIS: Detecting O₂ in planets orbiting nearby M dwarfs?



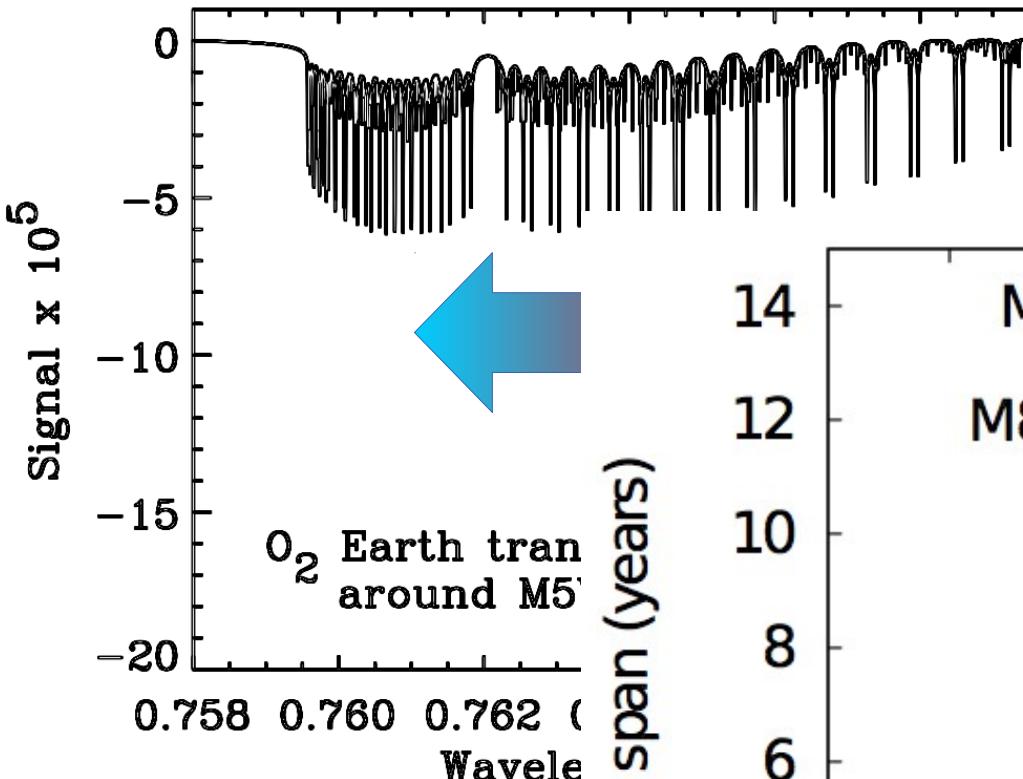
Kawahara+2012

HROS/NIRES: Detecting O₂ with high-dispersion Doppler transit spectroscopy.

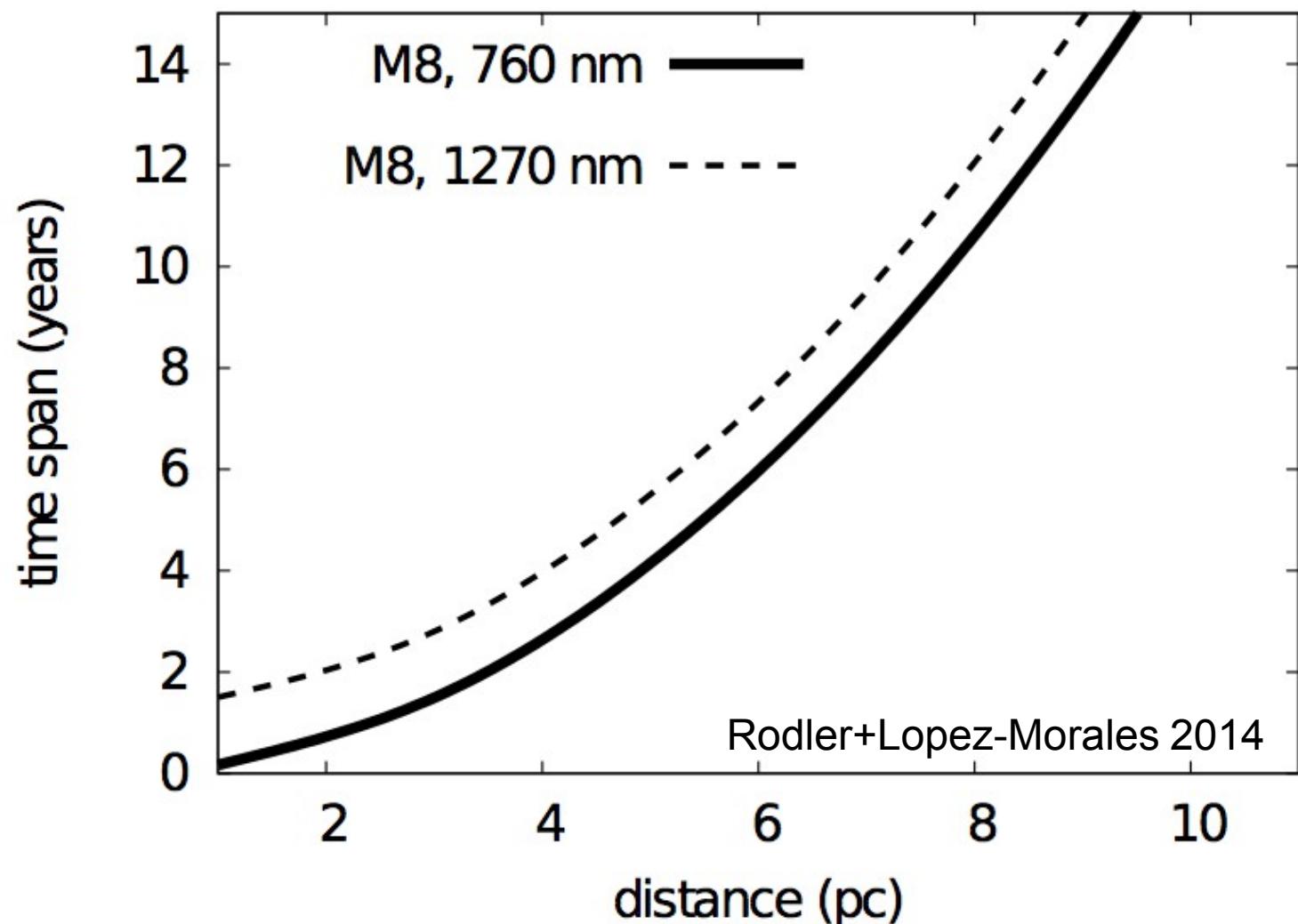


Schneider 1994; Webb & Wormleaton 2001;
Snellen+2013; Rodler+Lopez-Morales 2014

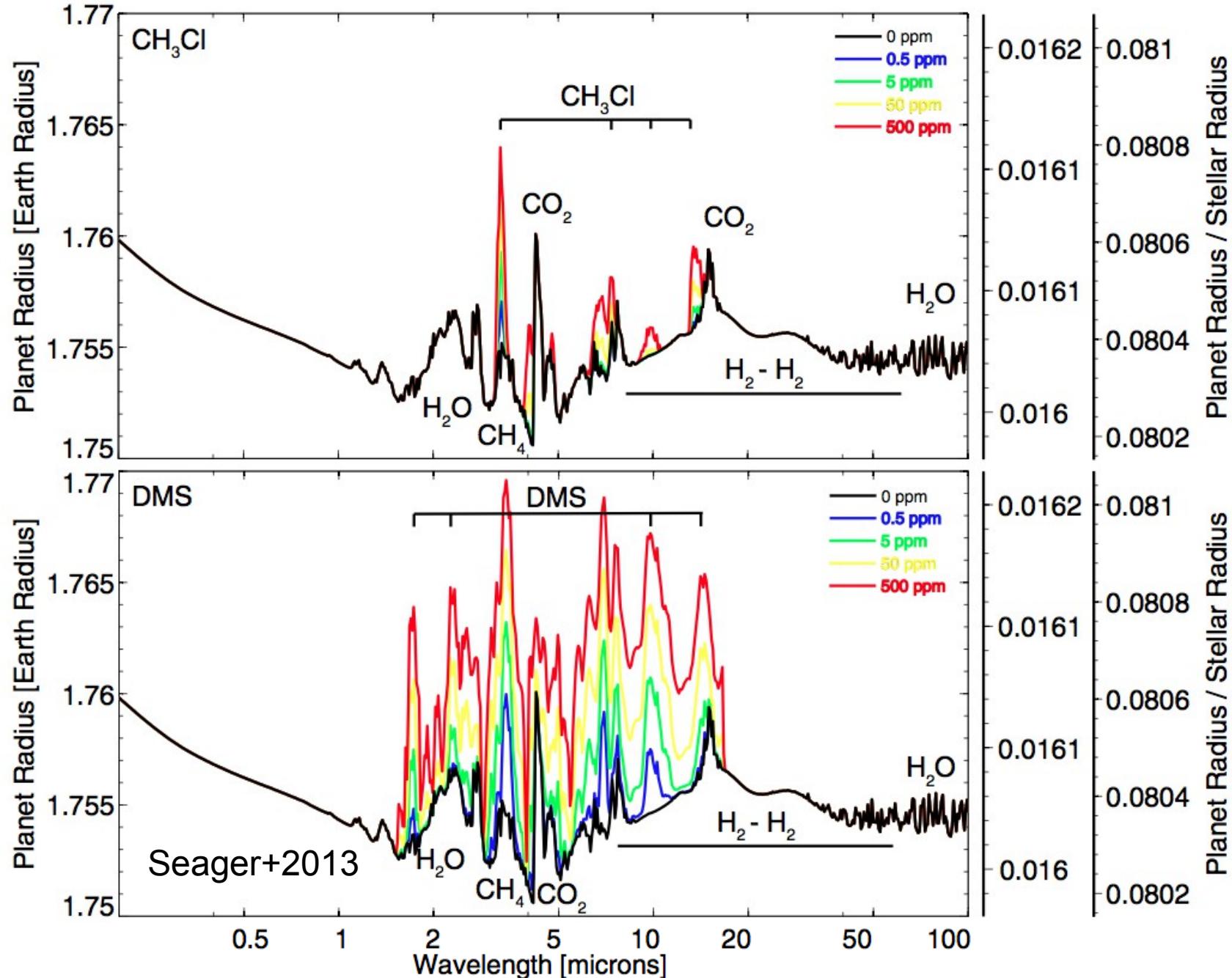
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Schneider 1994; Webb & W
Snellen+2013; Rodler+Lope



HRSC/NIRES: Alternative biosignature gases?



YOUNG, HOT GIANT PLANETS

- **IRIS spectroscopy:**
 - Atmospheric abundances
 - Thermal structure
- **PFI/SEI:**
 - Location, frequency, accretion luminosity of forming planets
- **NIRSPEC:**
 - Global weather monitoring of planets & brown dwarfs

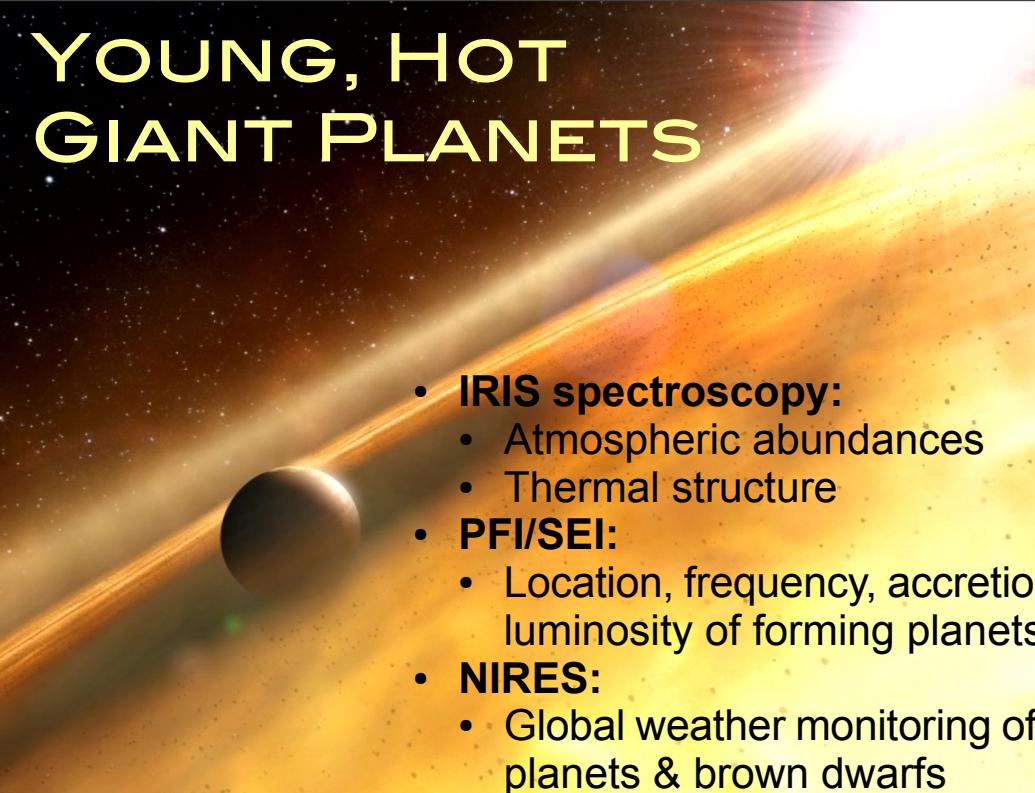
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IRRADIATED GAS GIANTS

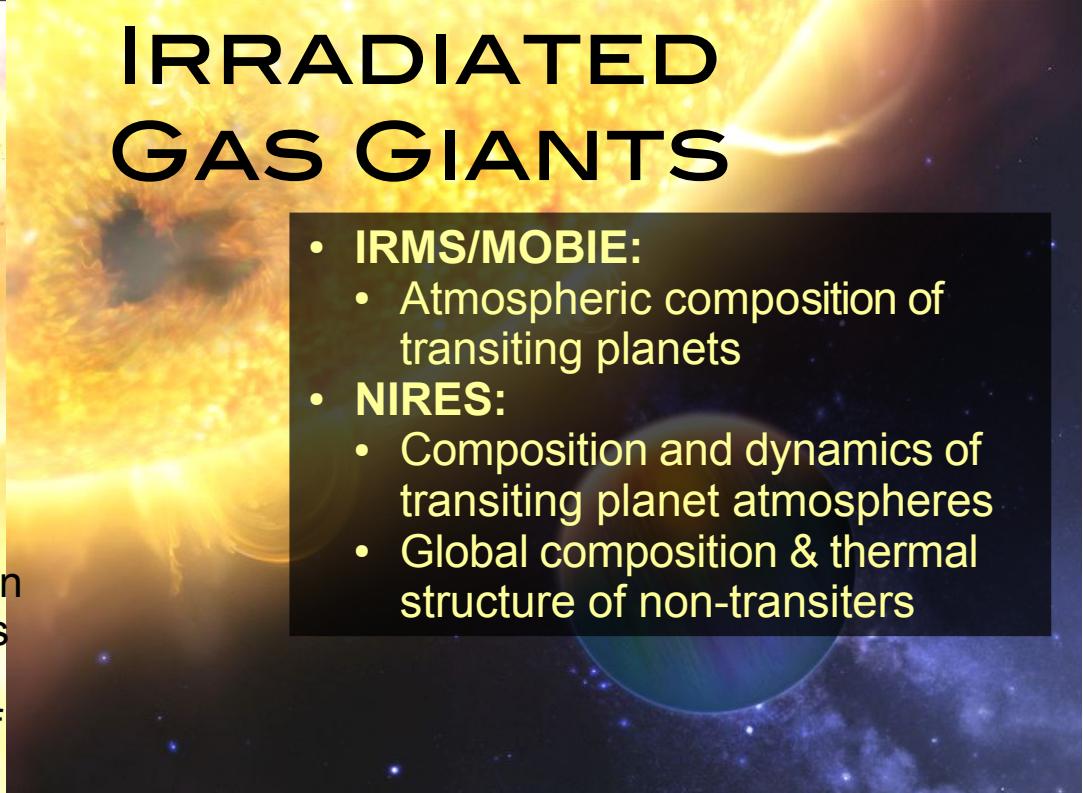
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- **NIRES:**
 - Composition and dynamics of transiting planet atmospheres
 - Global composition & thermal structure of non-transiters

YOUNG, HOT GIANT PLANETS



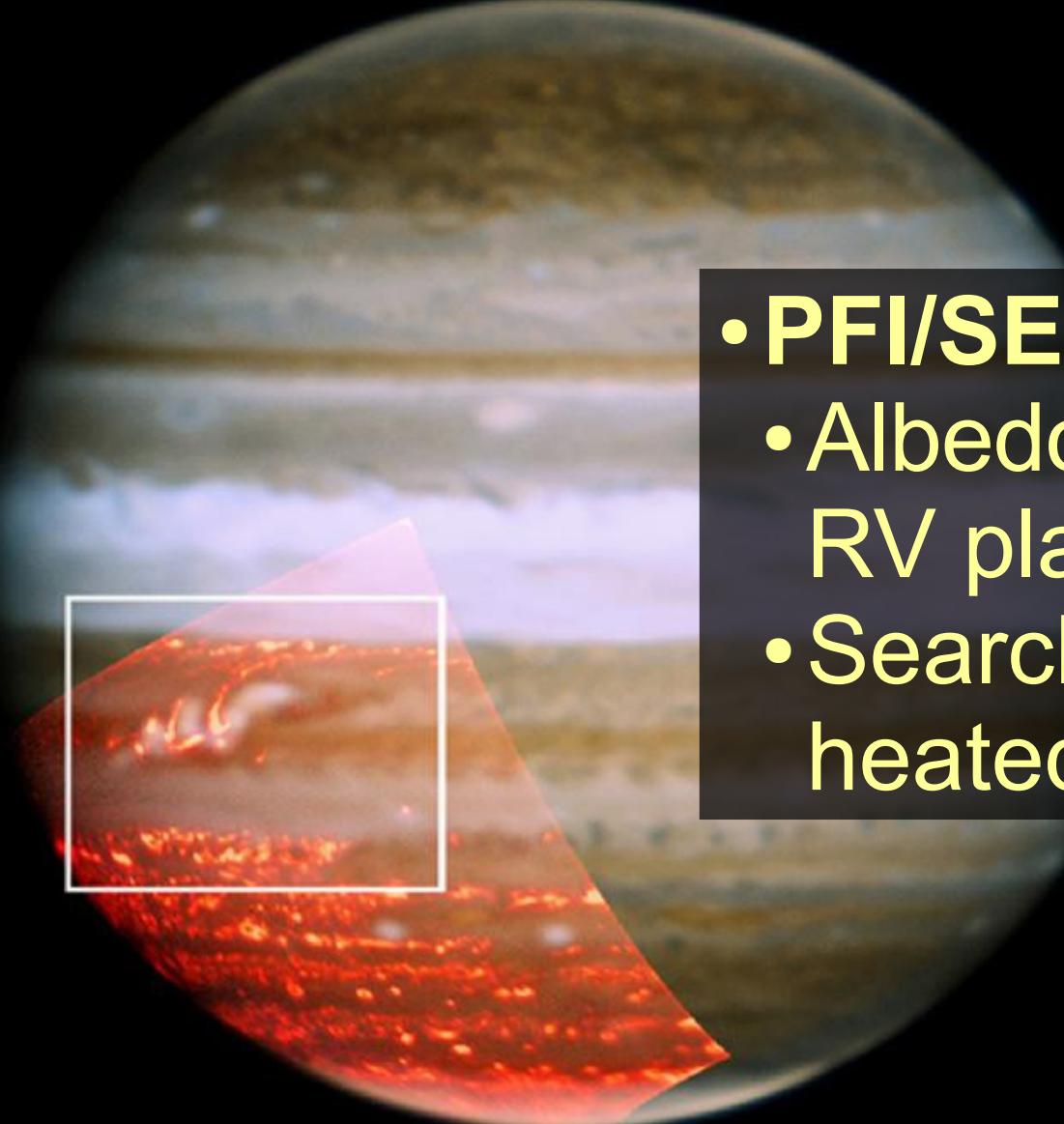
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MATURE, COLD GAS GIANTS

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 - Searches for tidally-heated “super-Ios”

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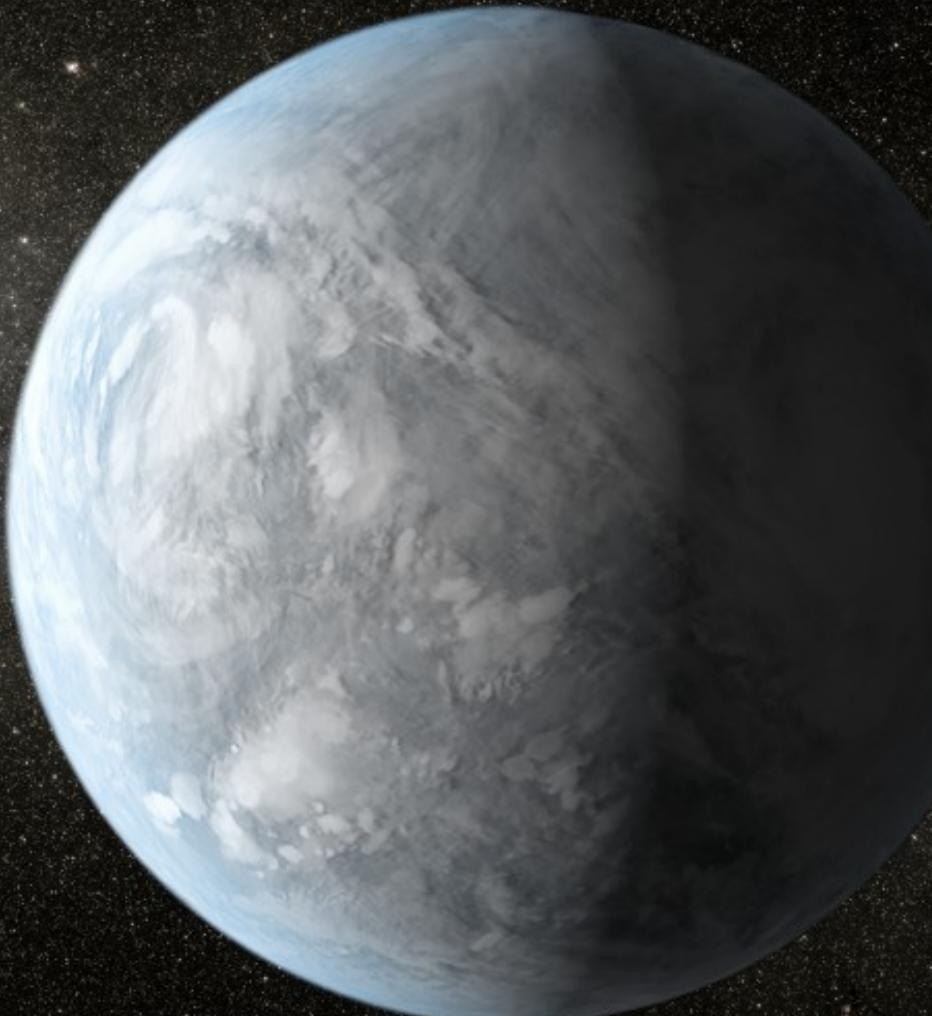
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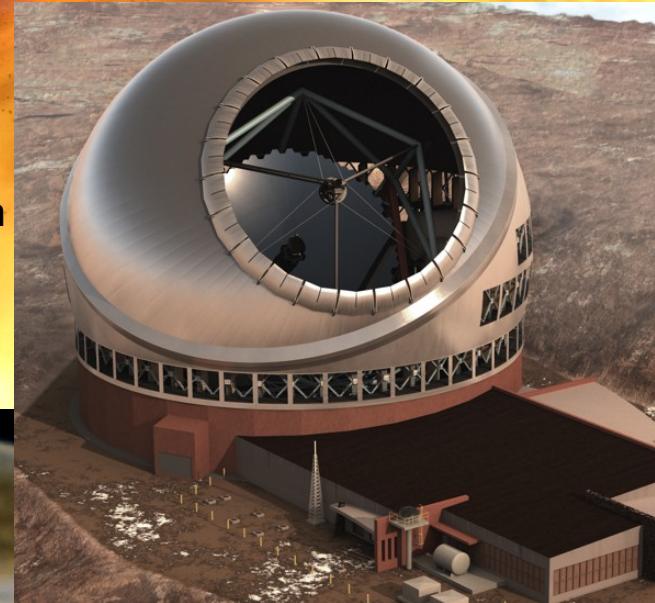
SMALL PLANETS & HABITABILITY



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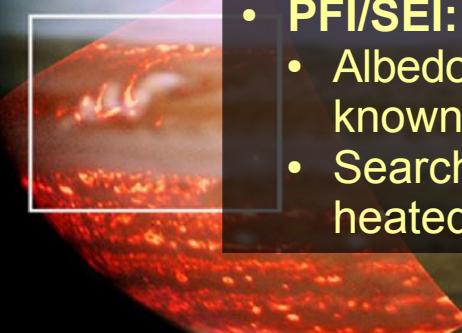
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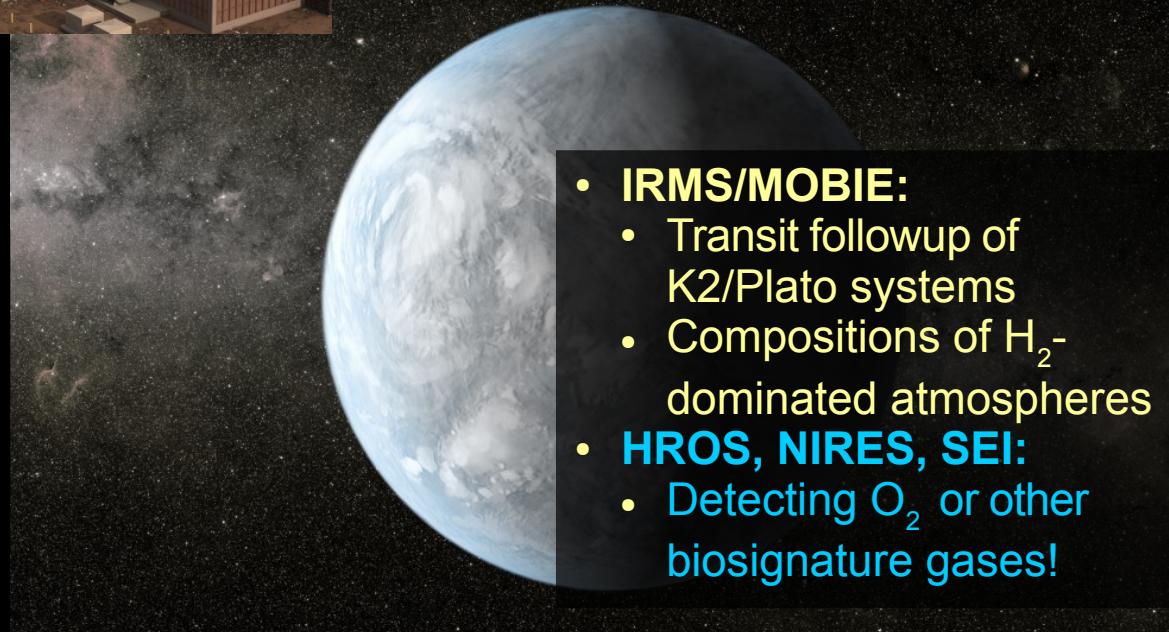


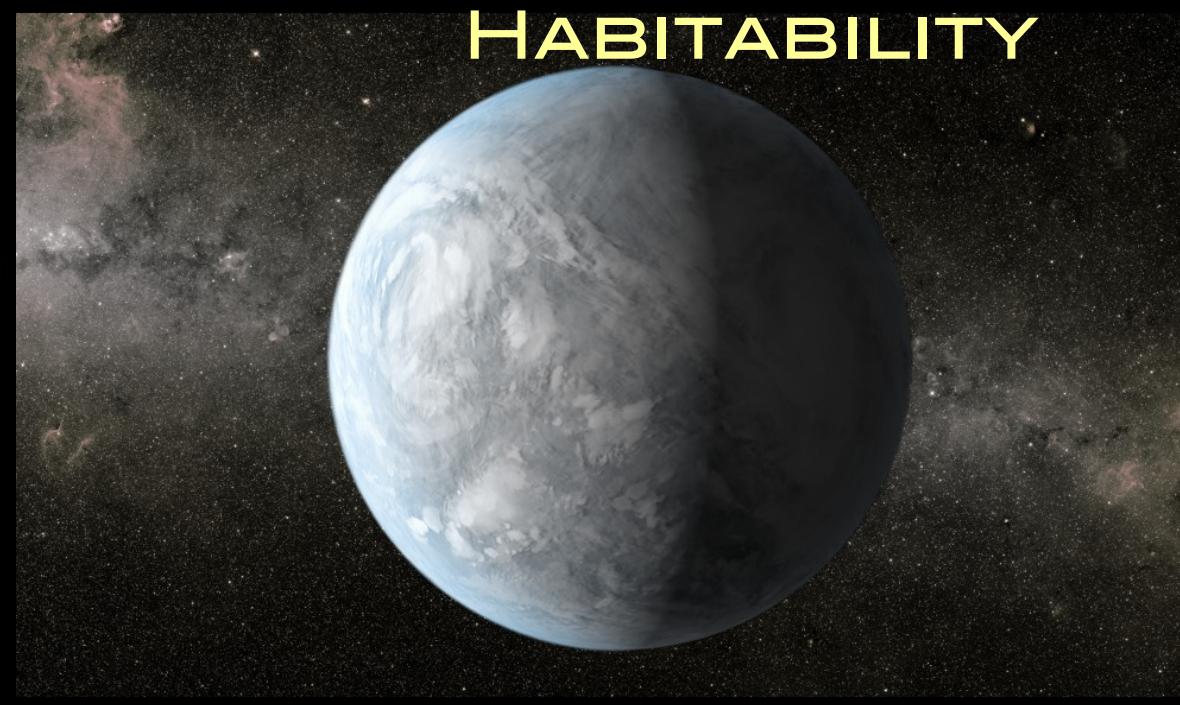
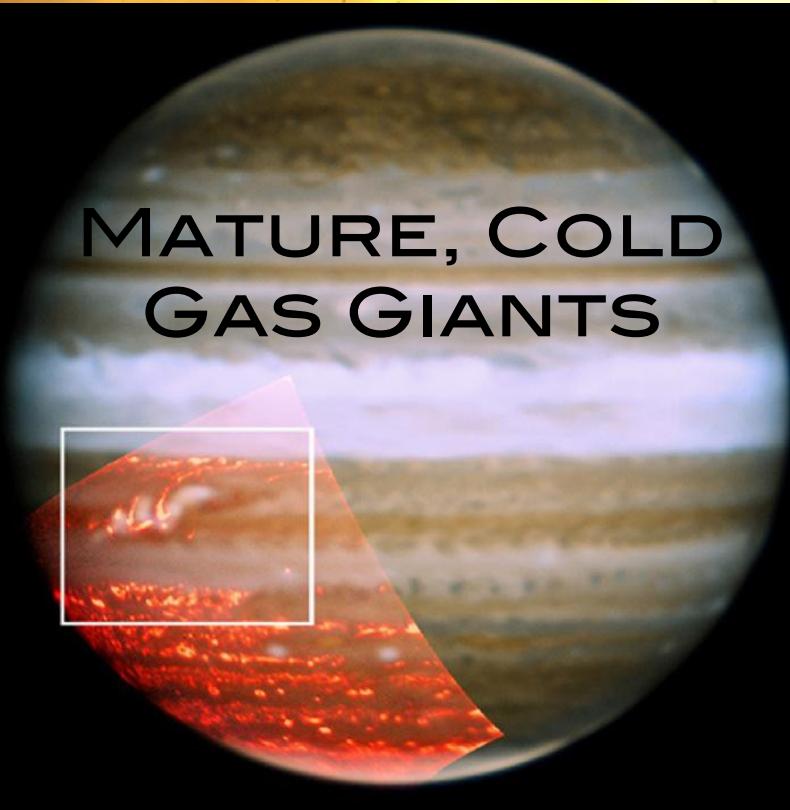
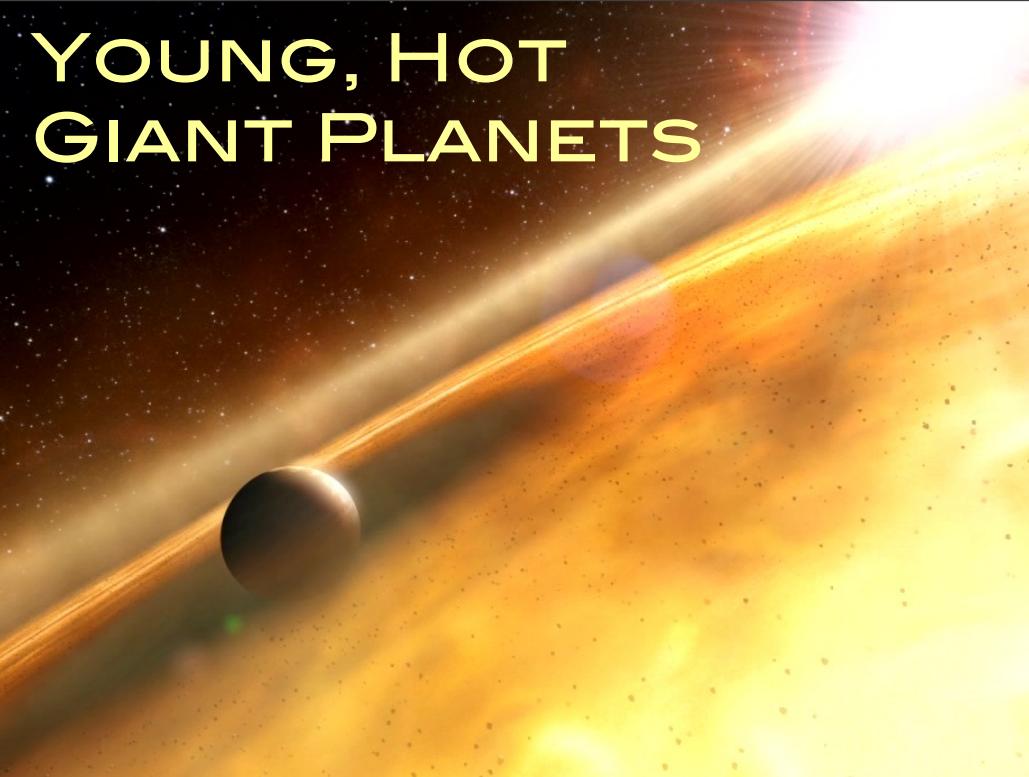
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YOUNG, HOT
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MATURE, COLD
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SMALL PLANETS &
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