Detecting and Characterizing Exoplanets in Nearby Systems

Ian Crossfield, MIT
2019/01/06

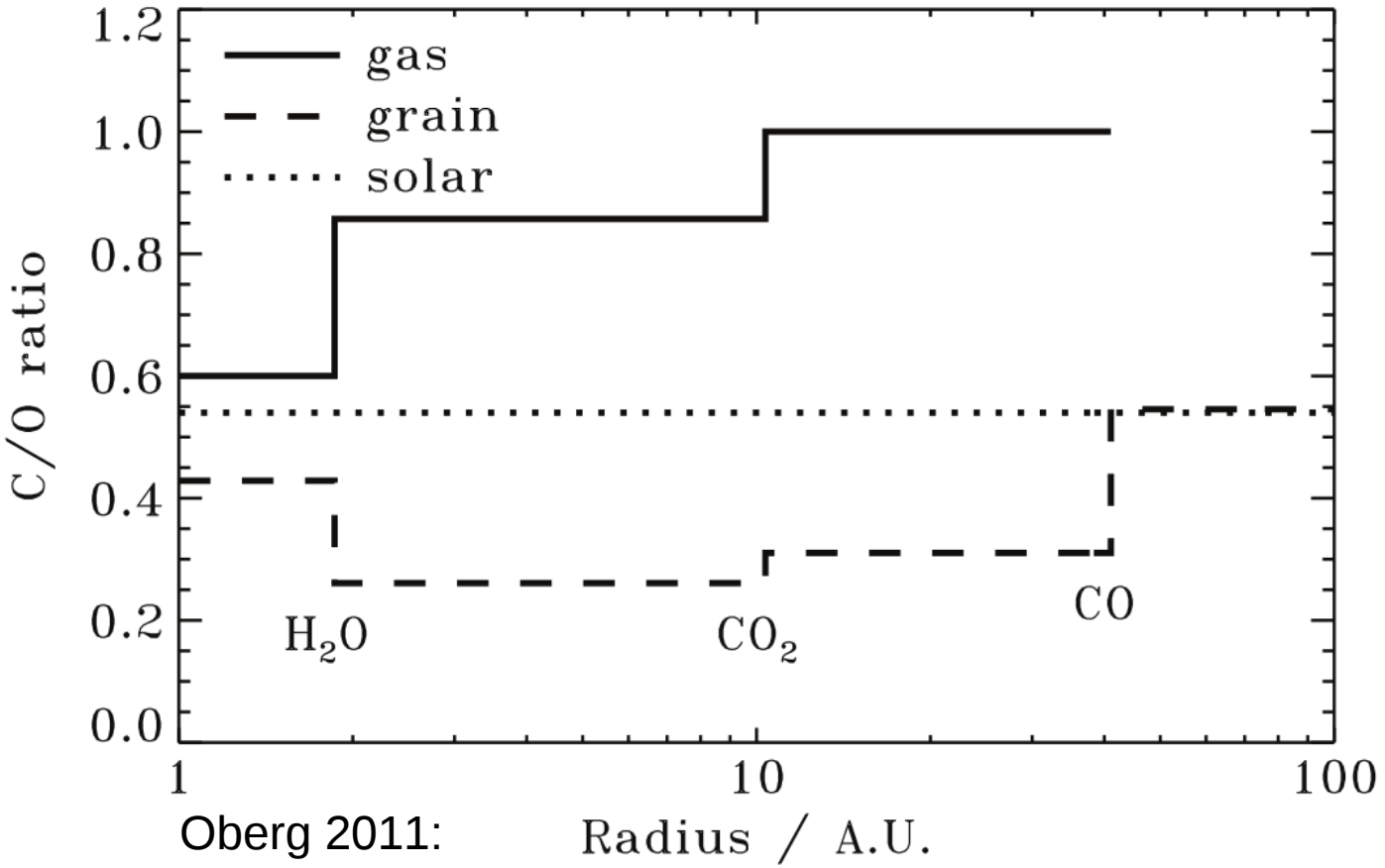
Massachusetts Institute of Technology

Why characterize exoplanets in nearby systems?

We want to know:

- How do planetary systems form and evolve?
- What are conditions like on other worlds?
- What (photo)chemical and dynamical processes dominate their atmospheres?
- Are there other habitable or inhabited worlds?

For example: Can we link atmospheric characterization to planet formation?



Oberg 2011:
"probably"

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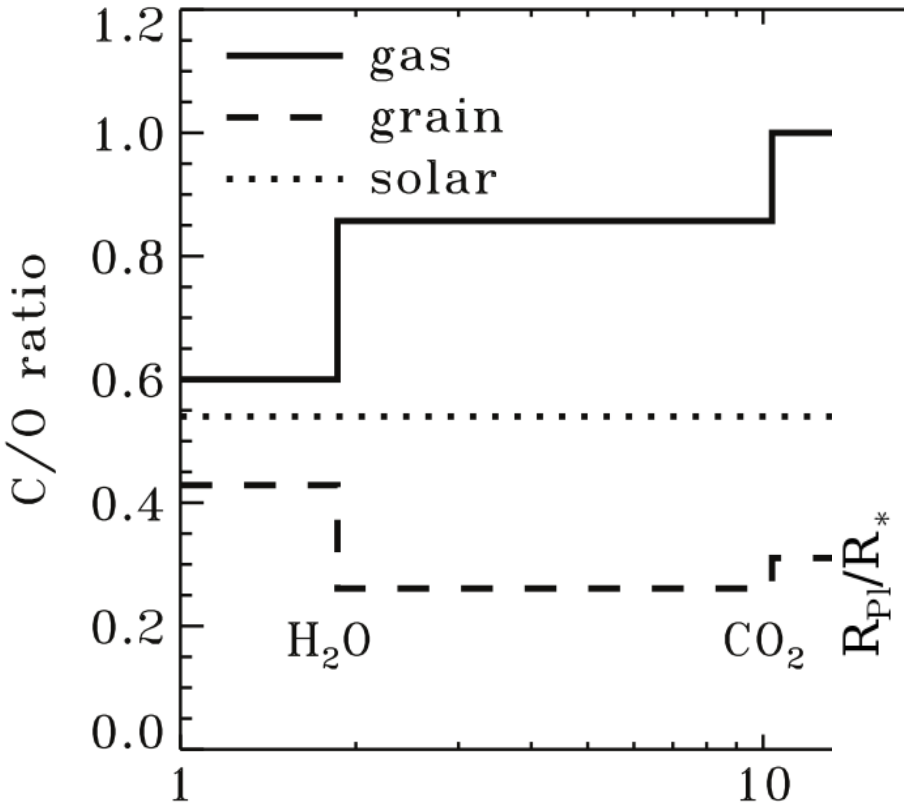

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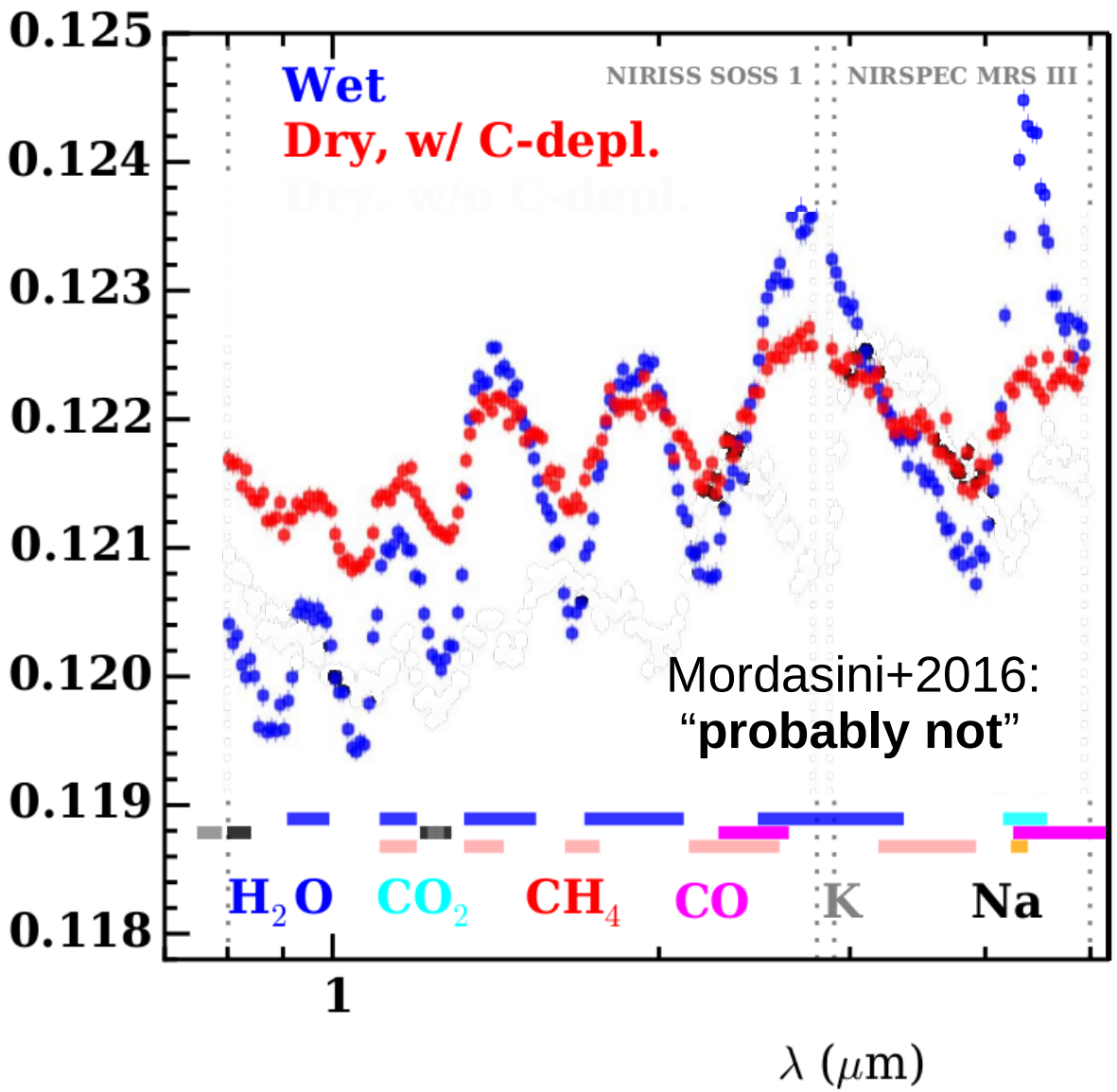
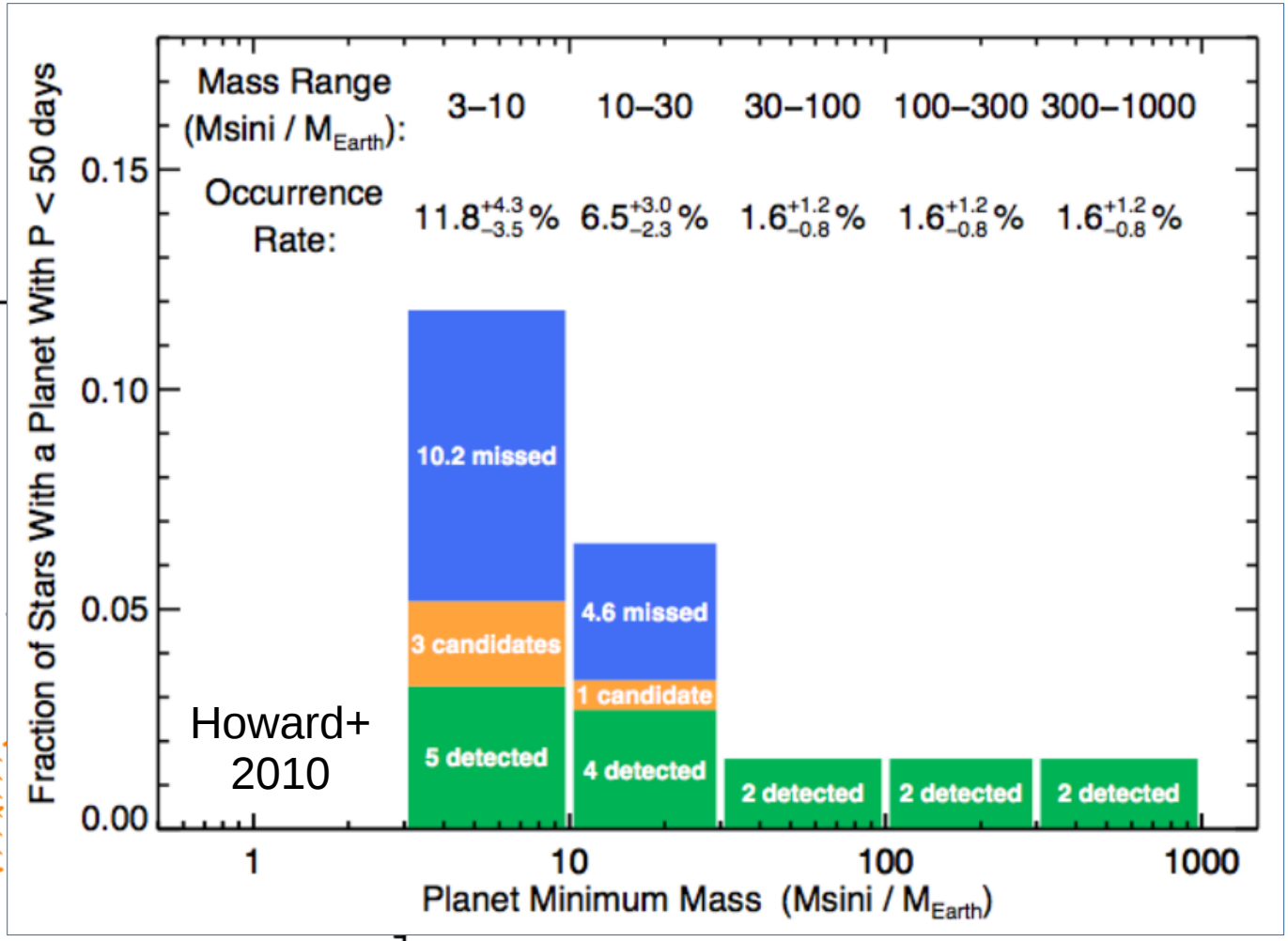
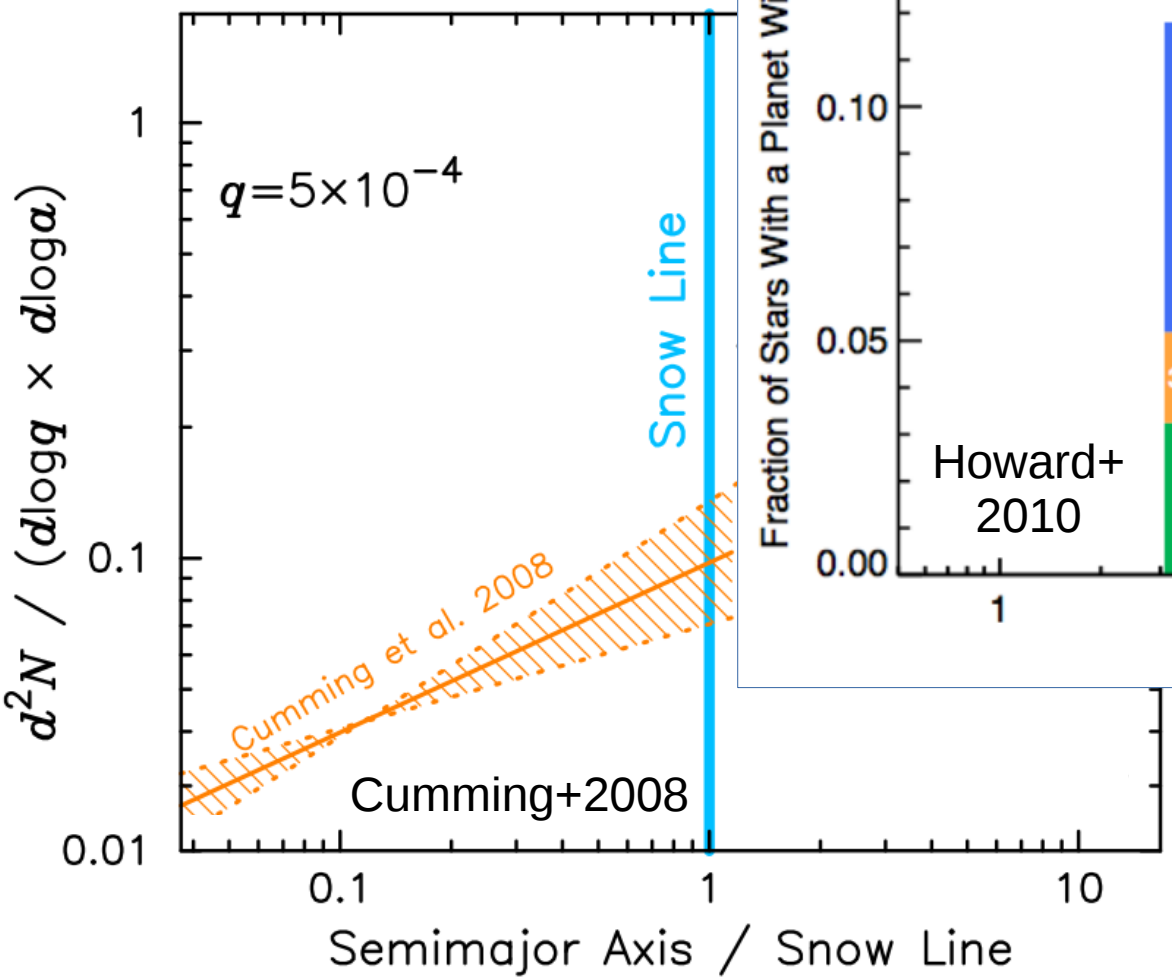


Mordasini+2016:
"**probably not**"

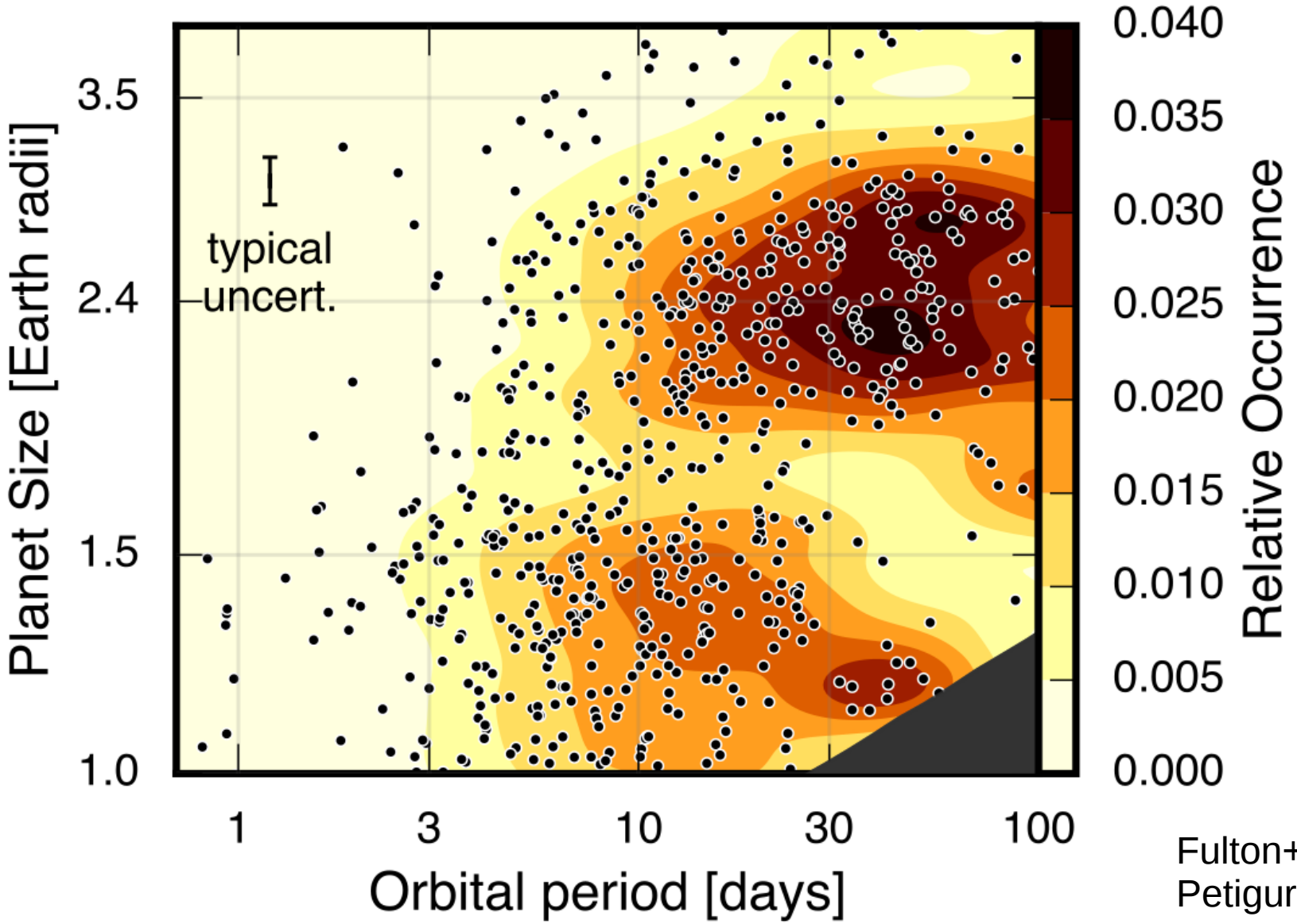
RV: Besides planet masses, measured the first occurrence rates:





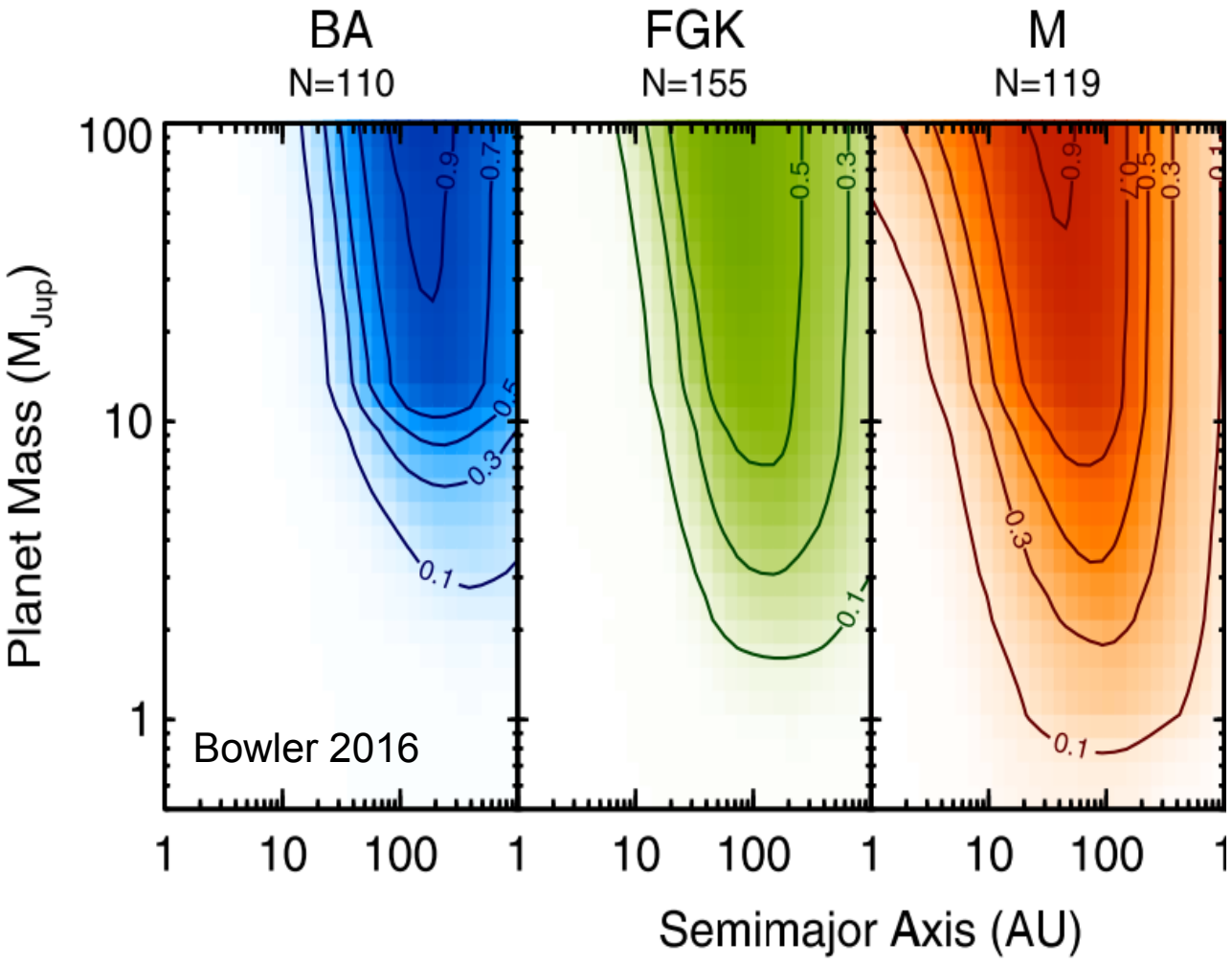
See upcoming talk by Debra Fischer

Transits revaled thousands of planets and revealed the Earth/Neptune “planet radius gap”:



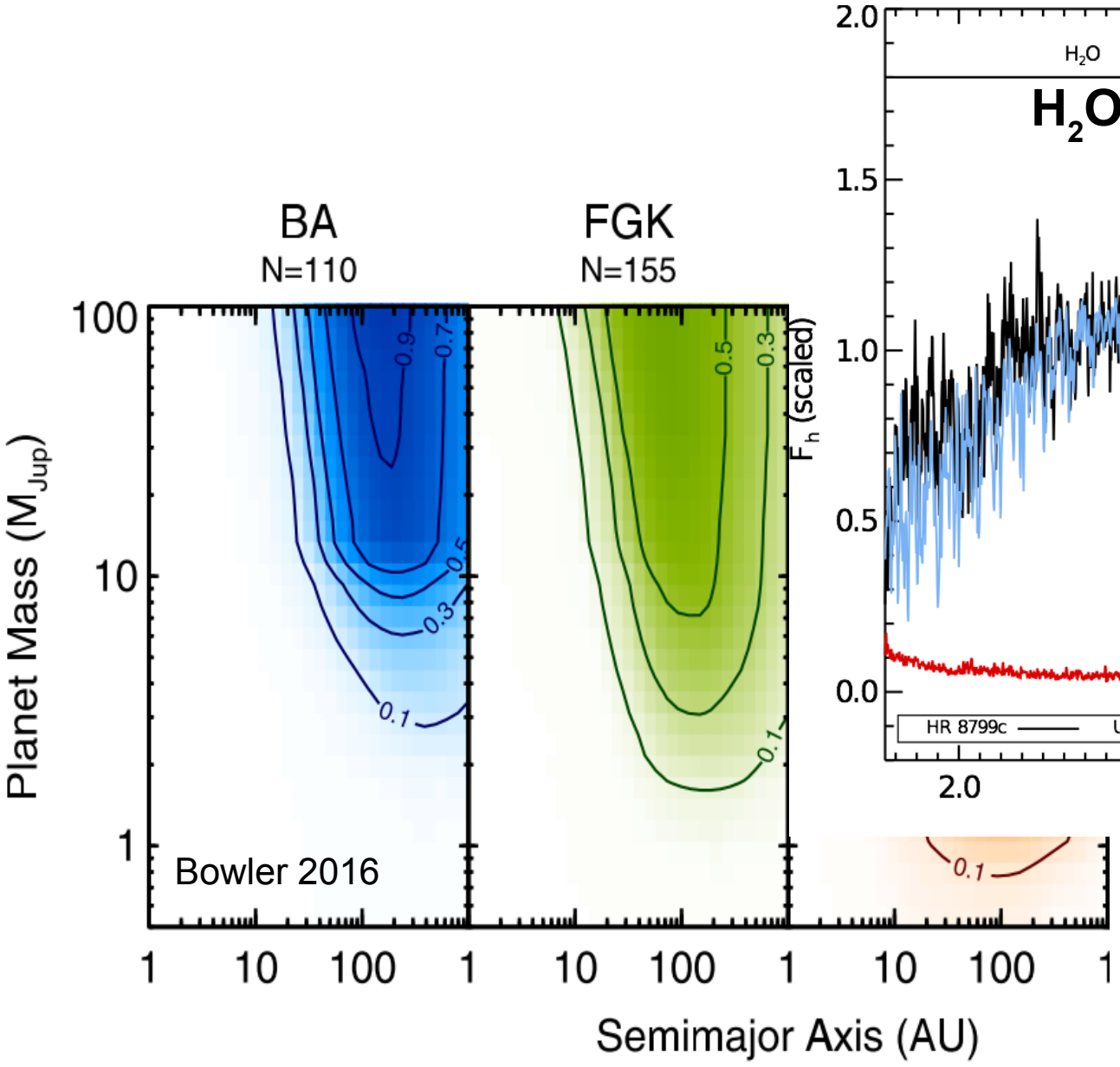
Fulton+
Petigura 2018

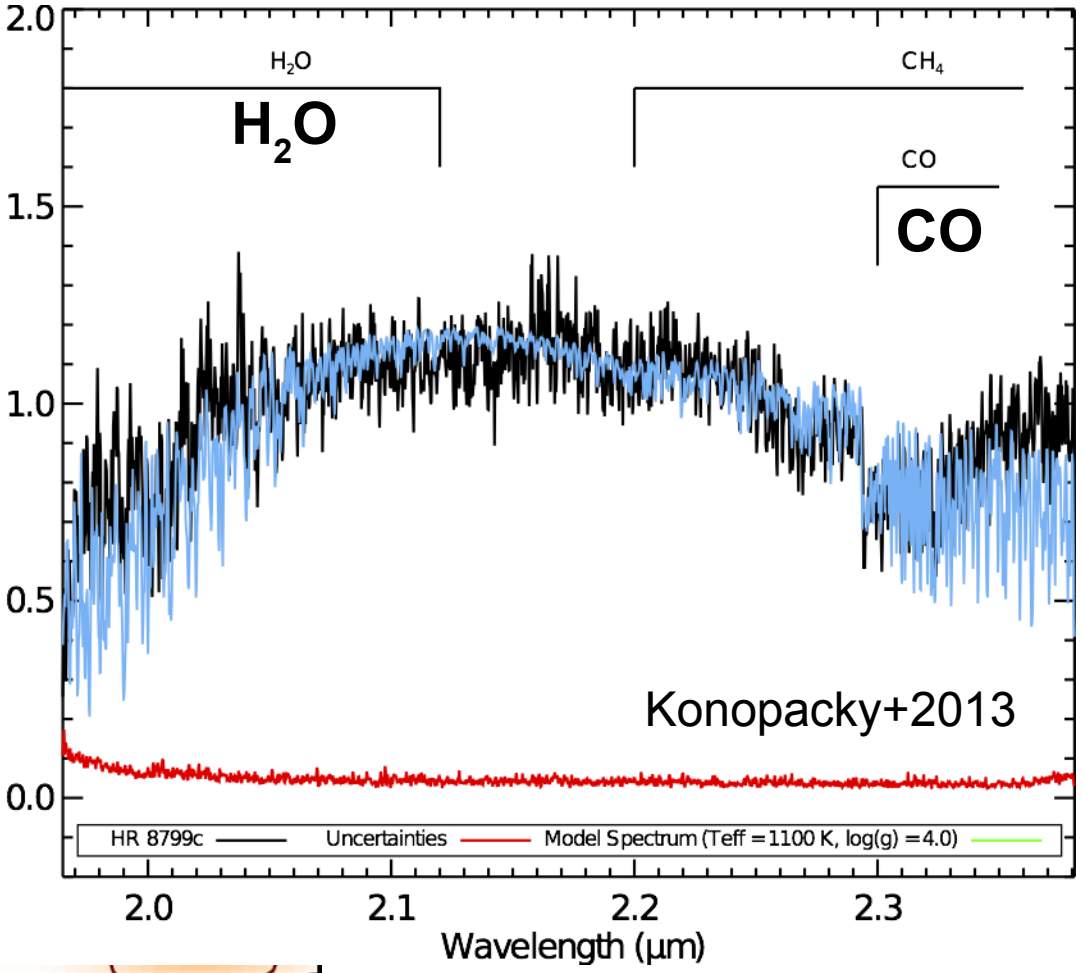
High-contrast techniques have mostly showed us where the planets aren't:



See upcoming talk by Quinn Konopacky

High-contrast techniques produce the best exoplanet spectra to date:





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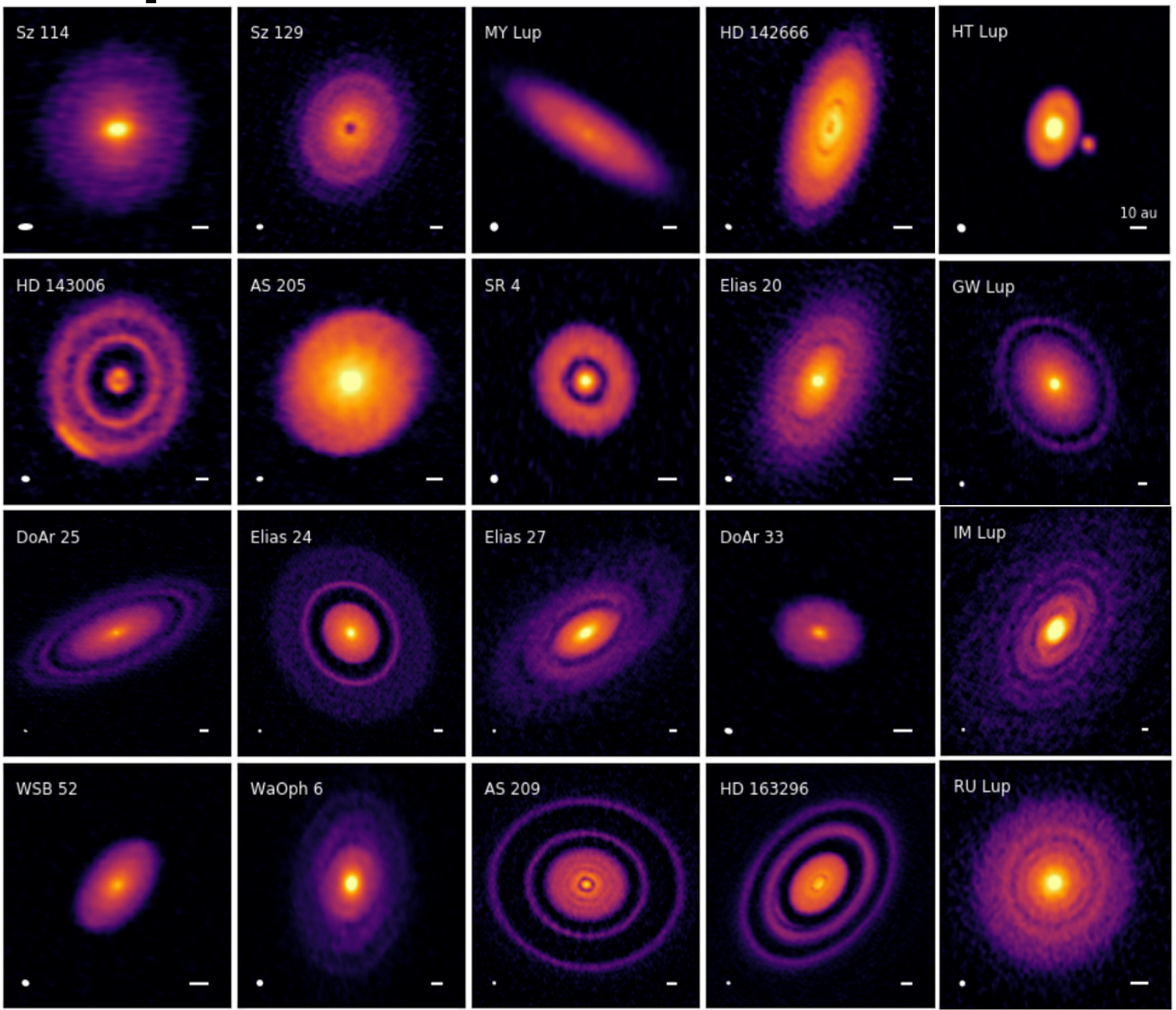
New ALMA disks point to active planet formation sites:



See upcoming by Meredith MacGregor

DSHARP collaboration, 2018

HST: low-res IR spectroscopy reveals atmospheric trends vs. planet properties:

Wakeford et al. 2017

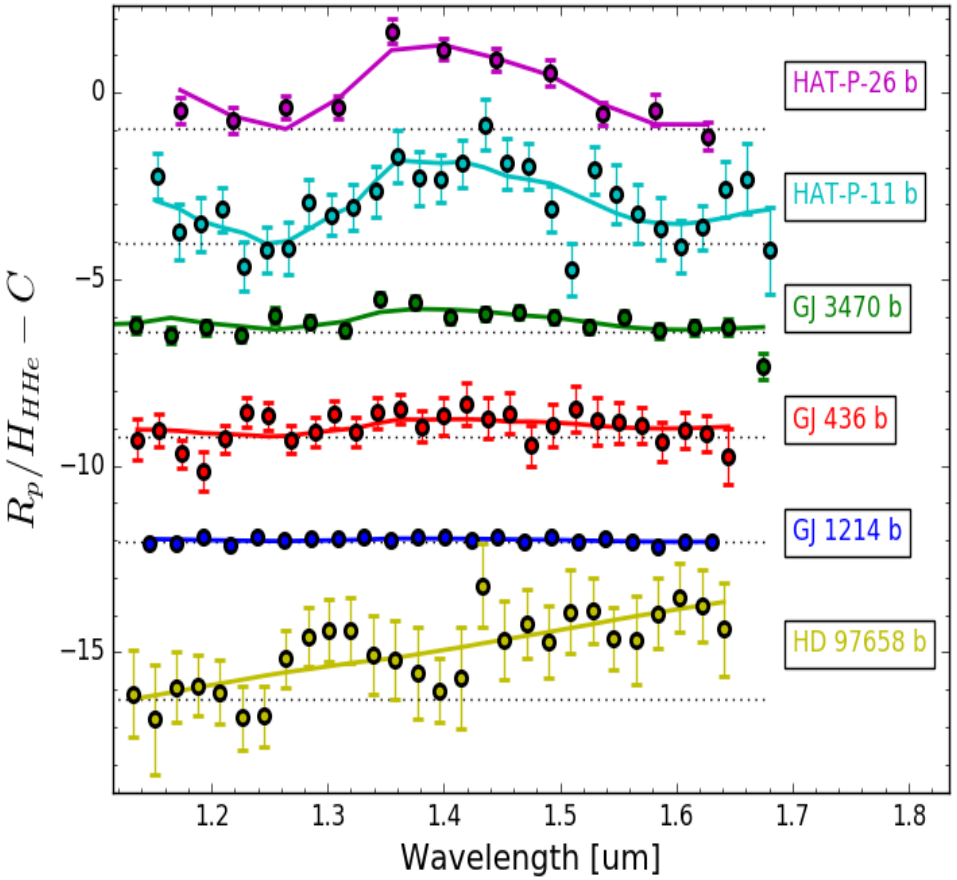
Fraine et al. 2014

Tsiaras et al. 2017

Knutson et al. 2014b

Kreidberg et al. 2014

Knutson et al. 2014a



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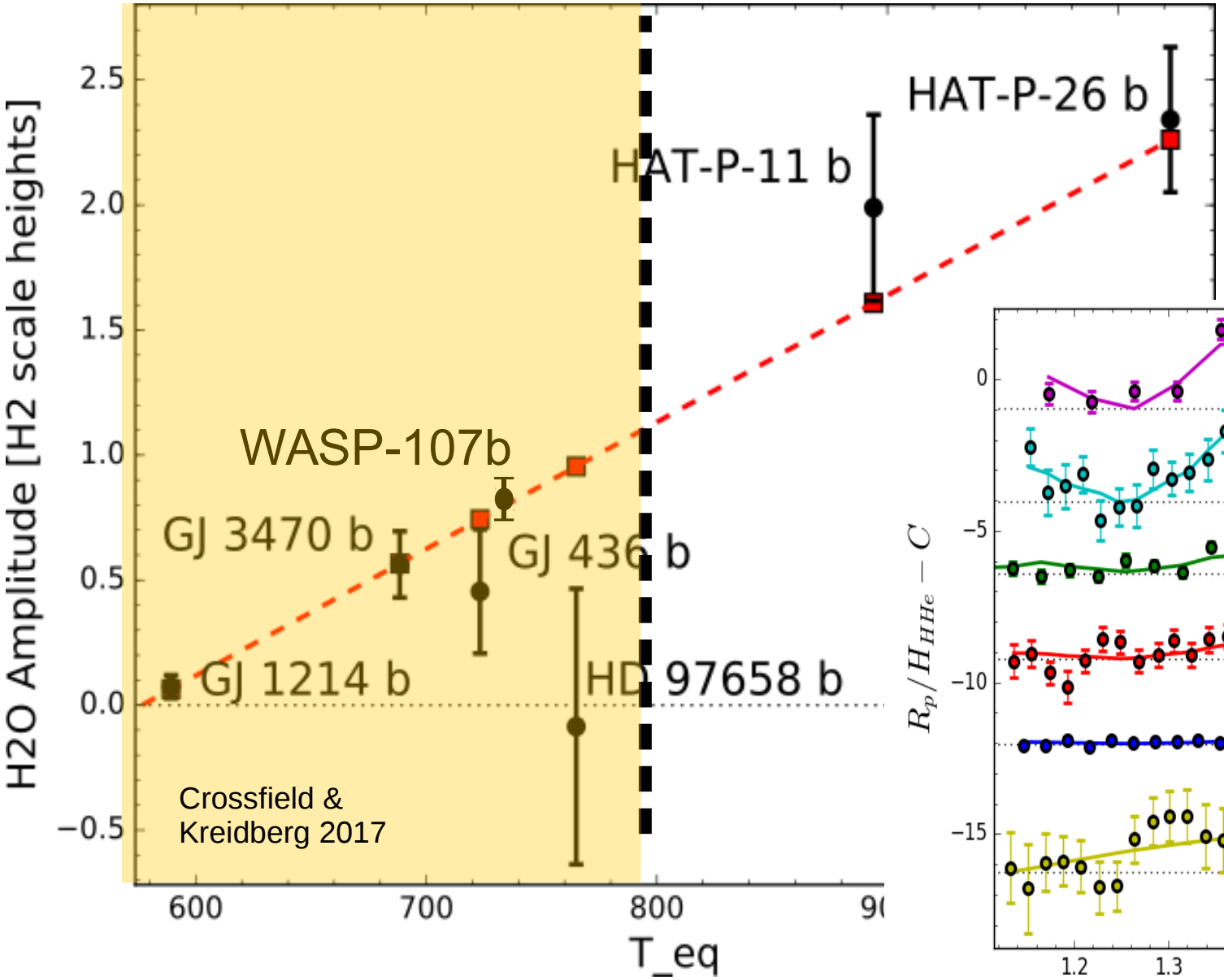

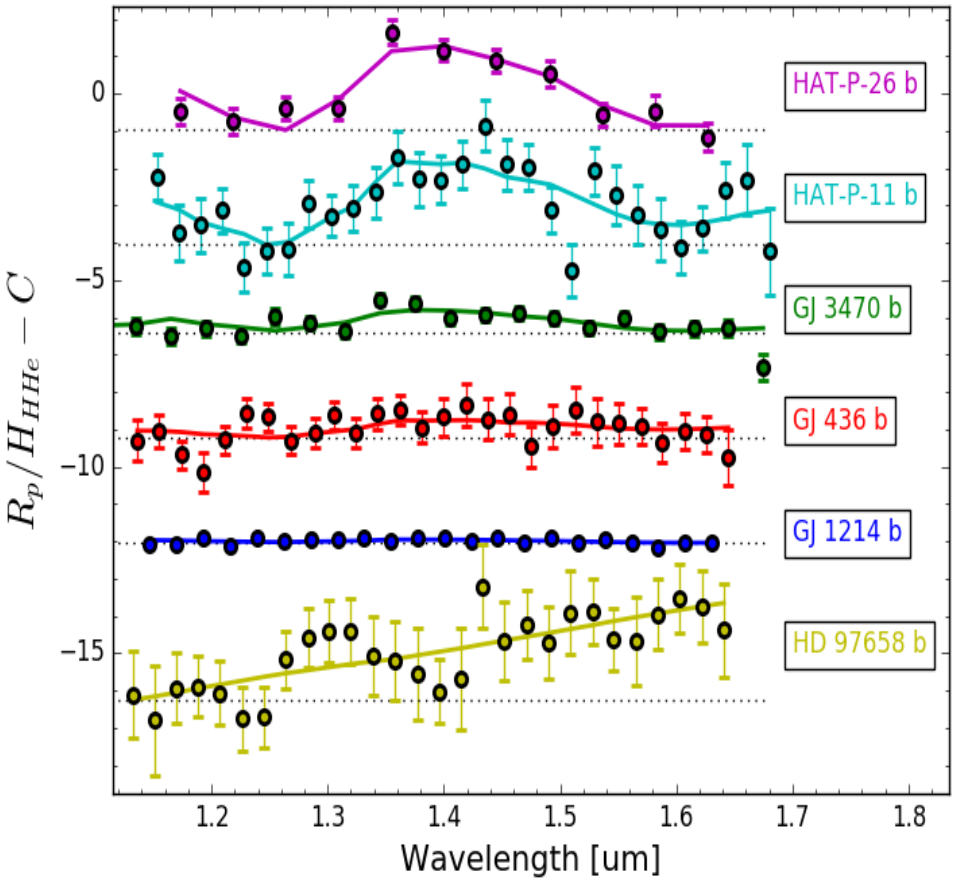

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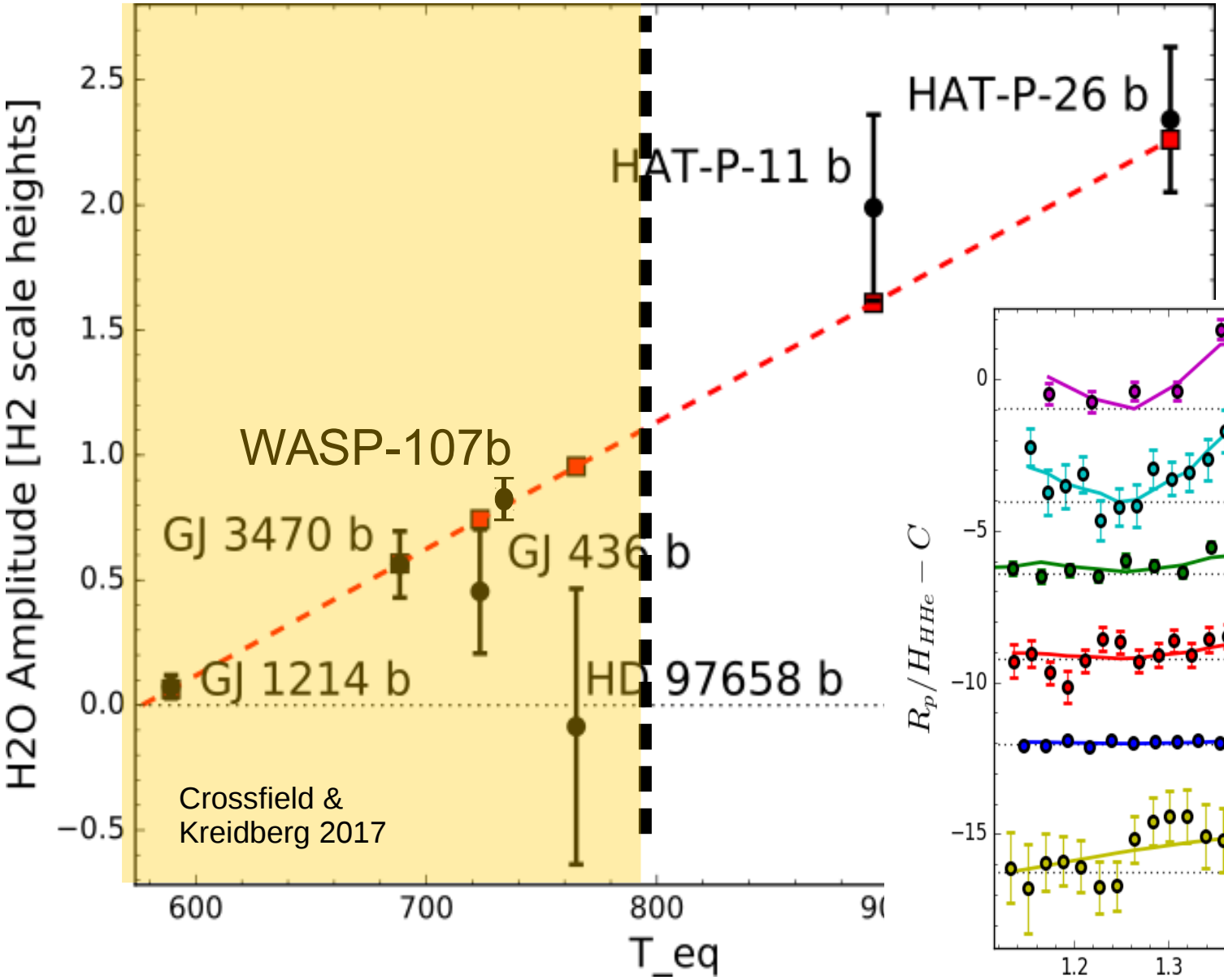
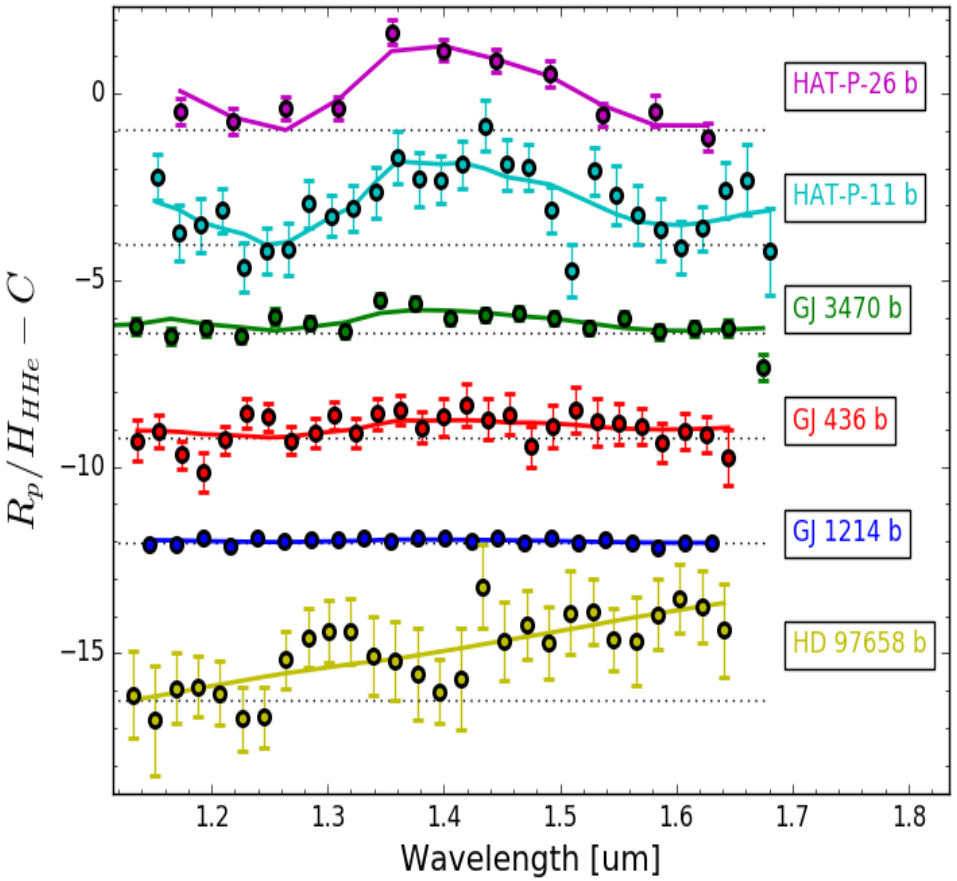
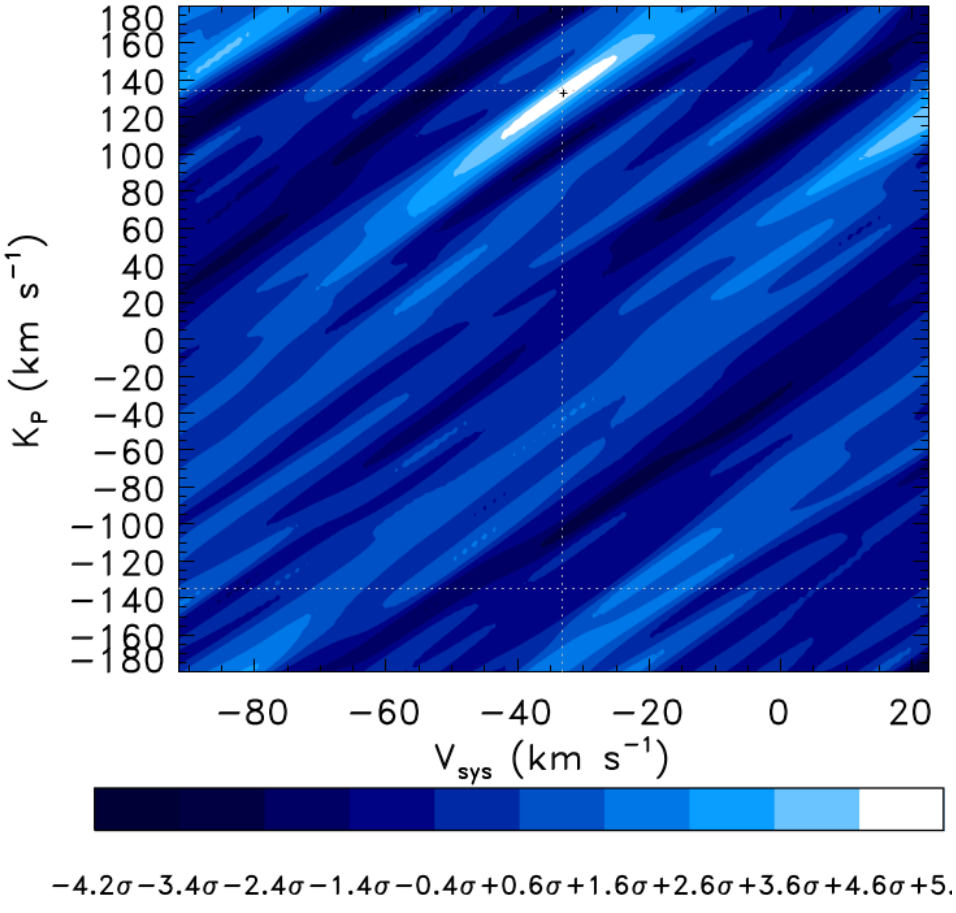


(RV masses are essential to properly interpret these spectra)

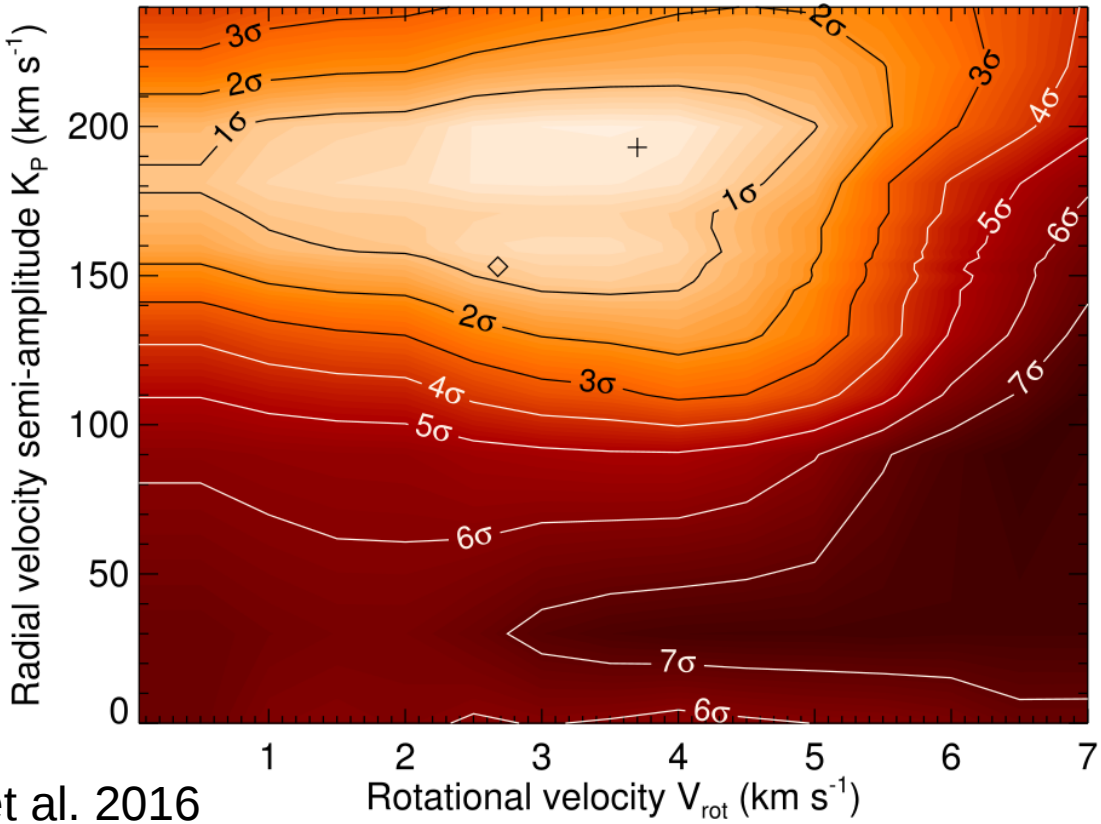


High-resolution spectroscopy: uniquely determines, composition, thermal structure. and atmo. dynamics:



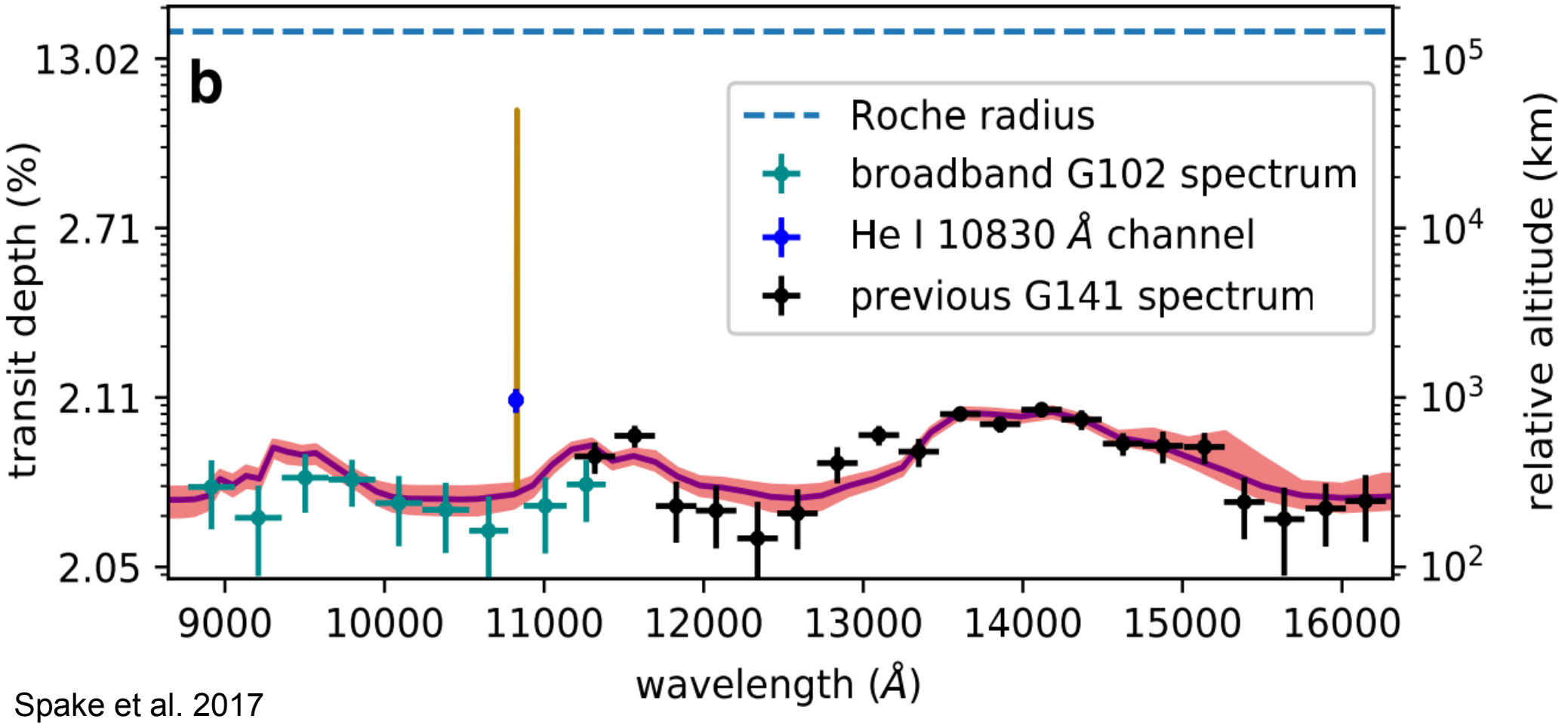
Birkby et al. 2017

See upcoming talk by Emily Rauscher!



Brogi et al. 2016

New: He-10830 line measures atmospheric escape & star-planet links:



Spake et al. 2017

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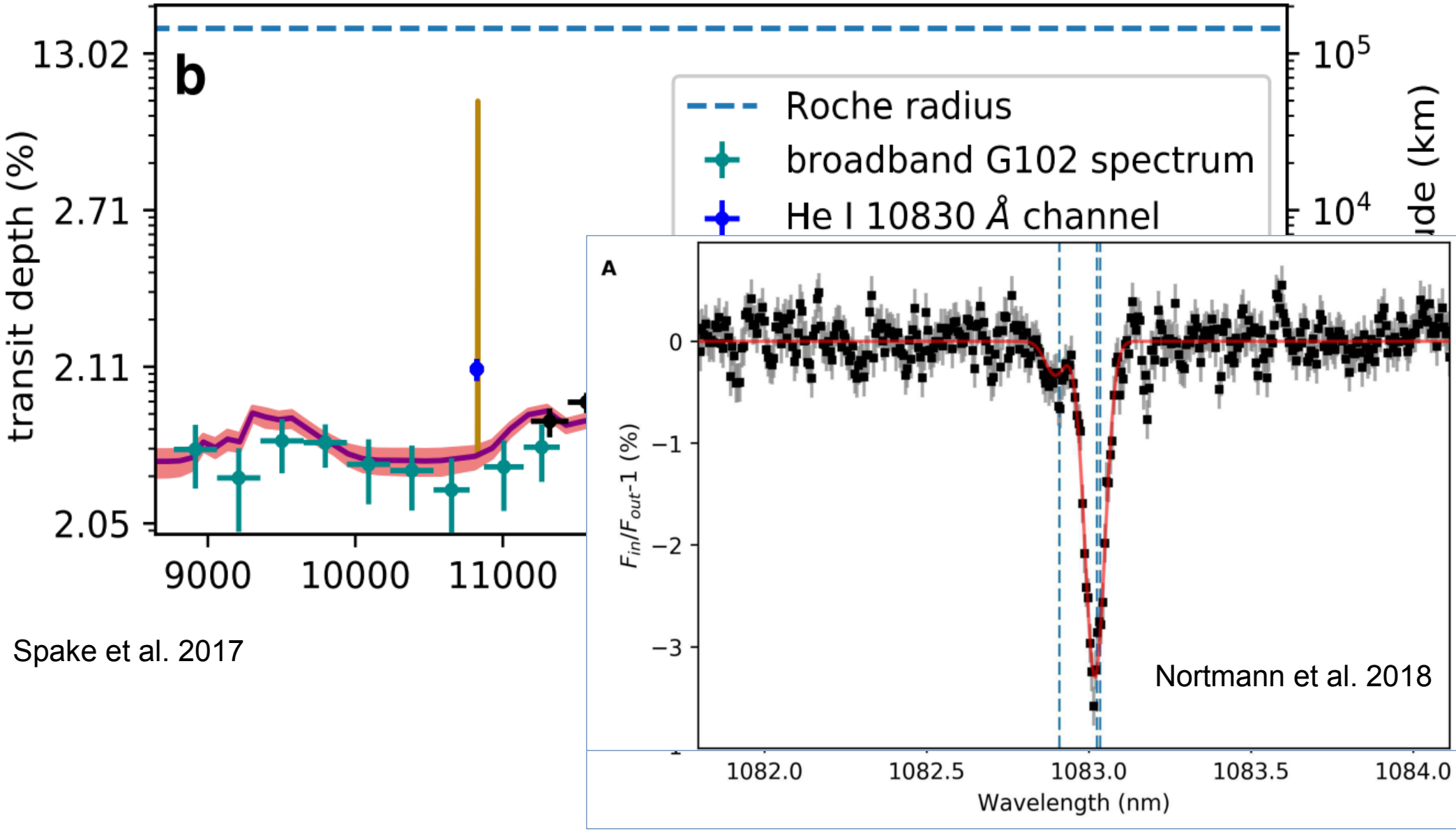


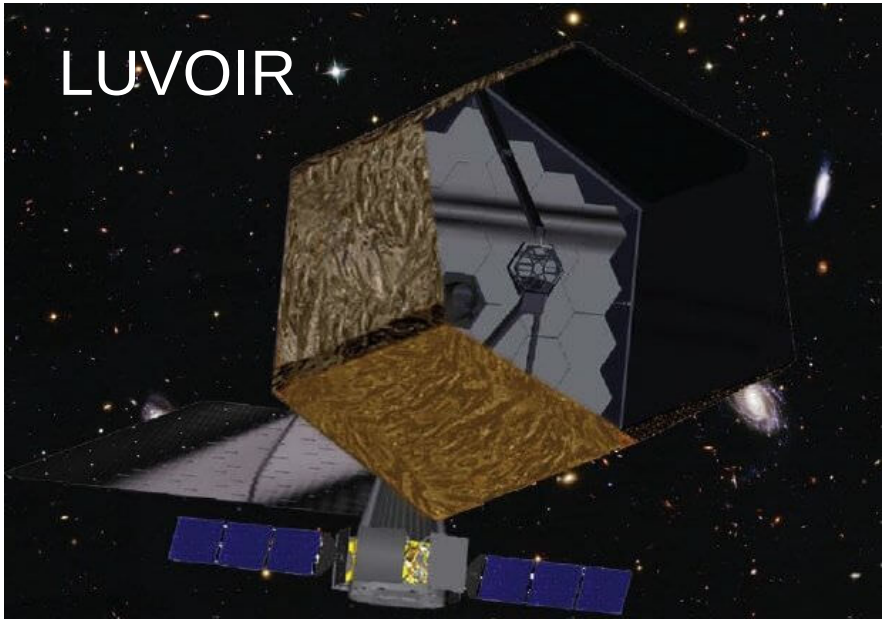
Spake et al. 2017

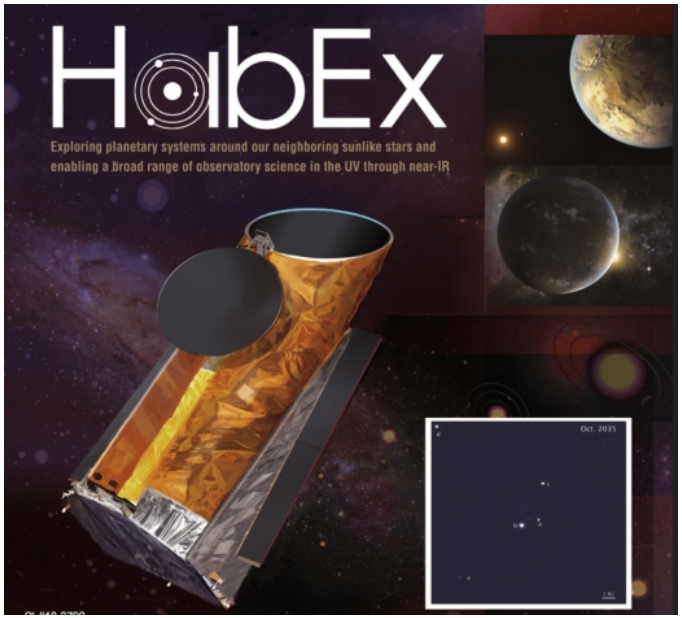
Nortmann et al. 2018

It’s an exciting time for the characterization of nearby exoplanets!

What does the future hold?

An effort has been underway to select the next facility for the next generation of exoplanet detection & characterization.





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The ExoPAG should recommend that NASA invest in the US ELT program

“NASA doesn’t do ground-based astronomy”

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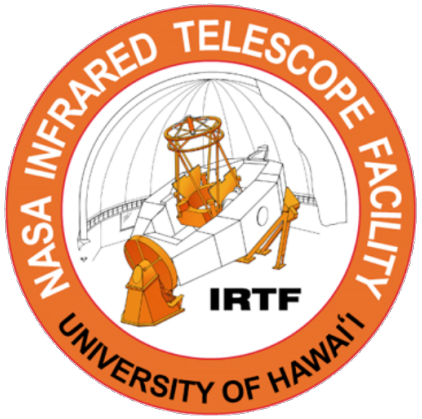
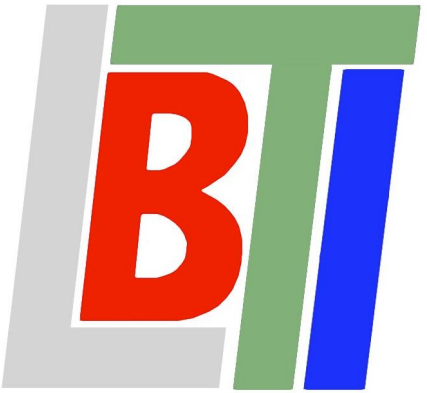
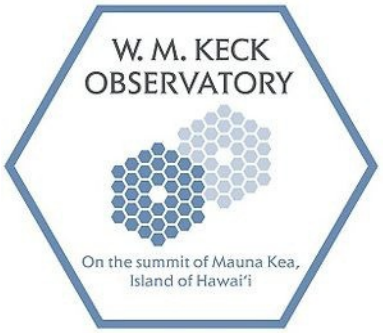
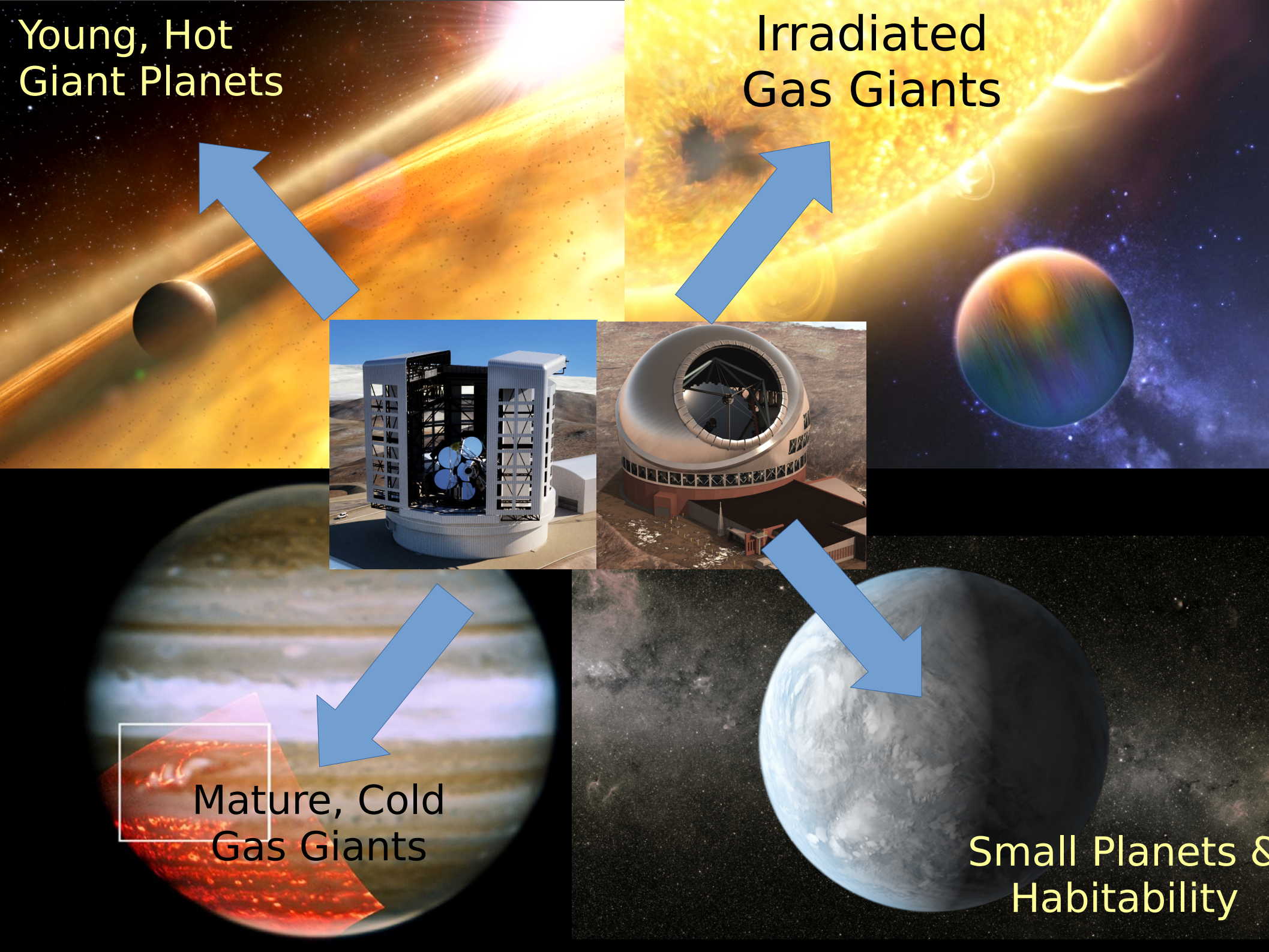
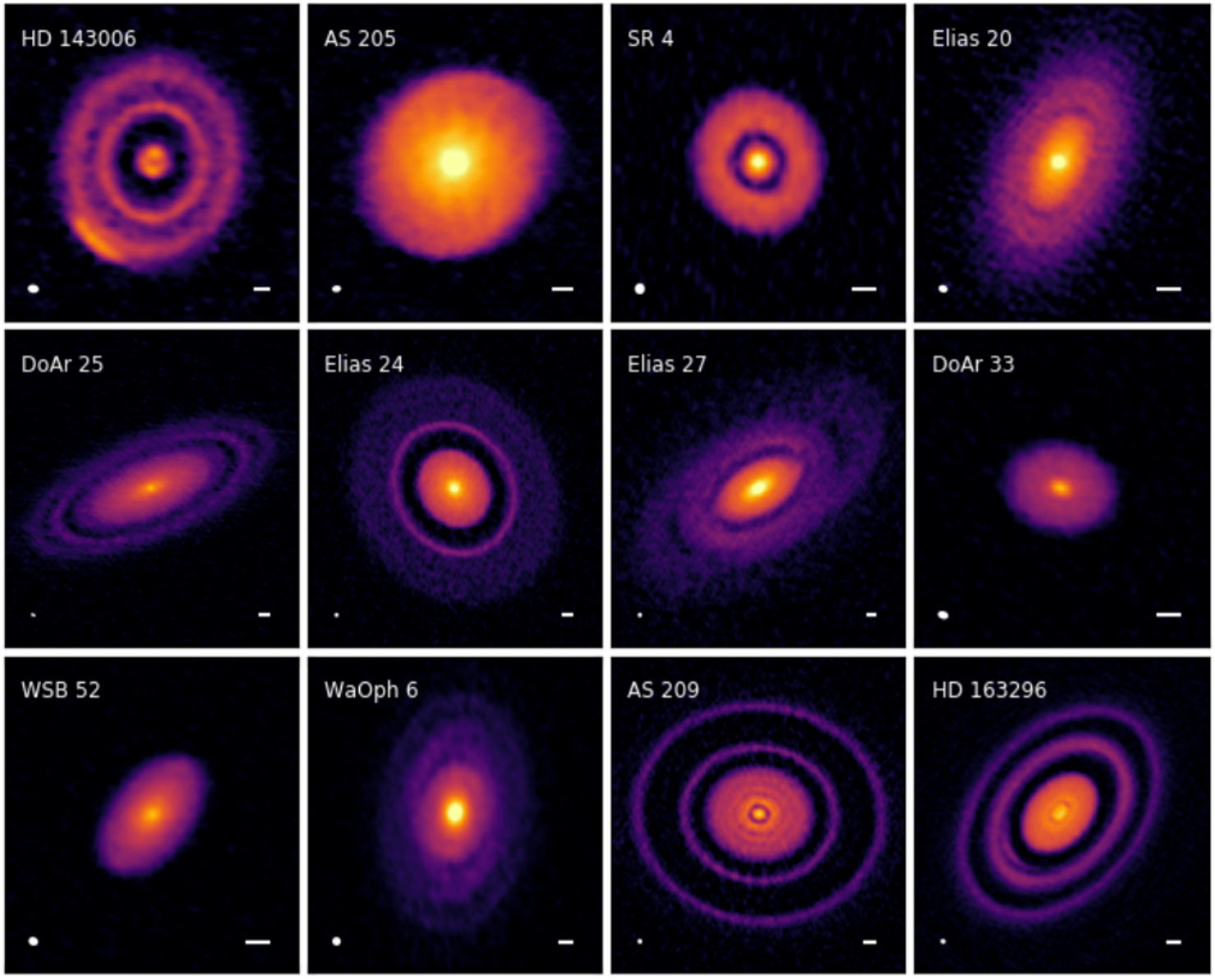






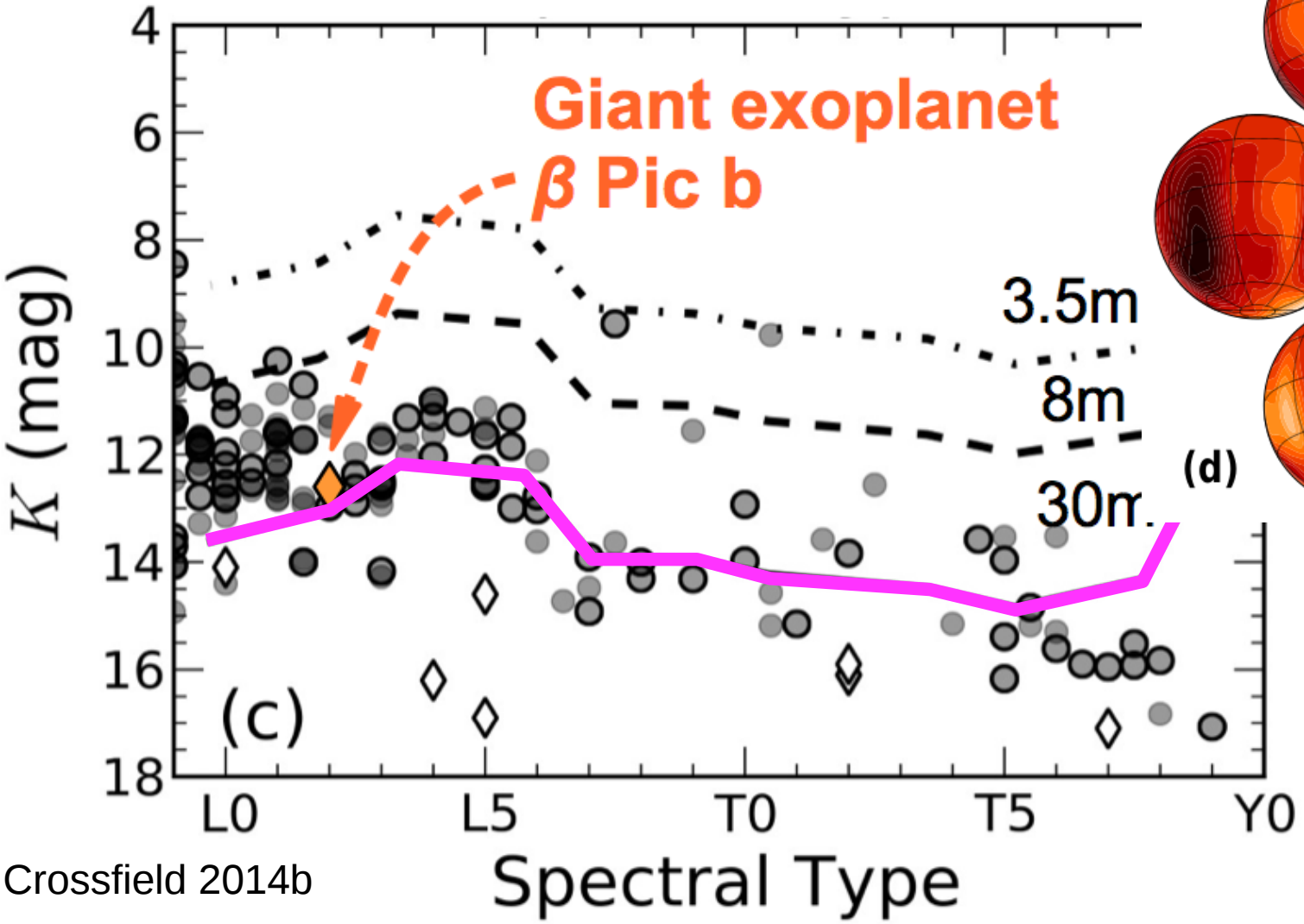

Young, Hot
Giant Planets
Irradiated
Gas Giants
Mature, Cold
Gas Giants
Small Planets &
Habitability

ELT high-contrast will access gas giants during formation:

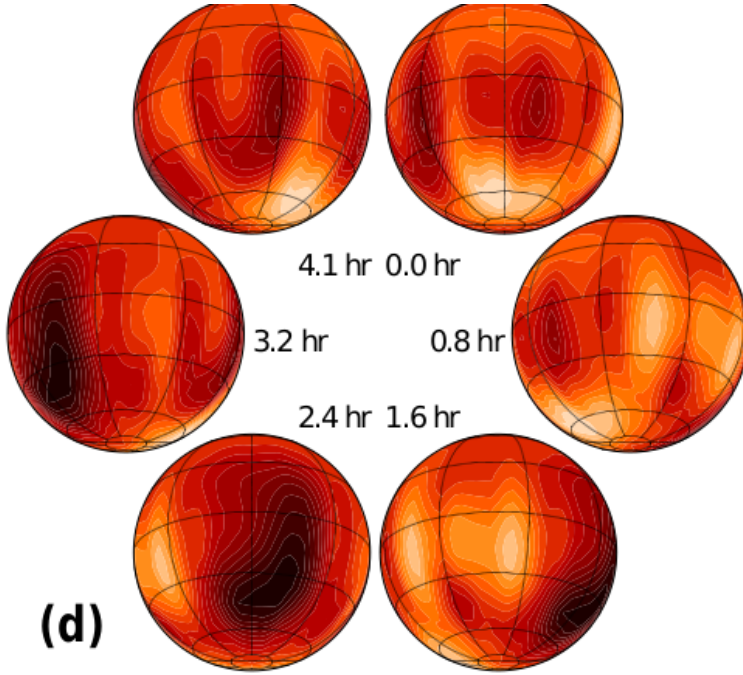


***All* planets inferred from ALMA disks lie at >5 λ/D for ELTs**

ELT Doppler Imaging will reveal global weather patterns of Exoplanets:

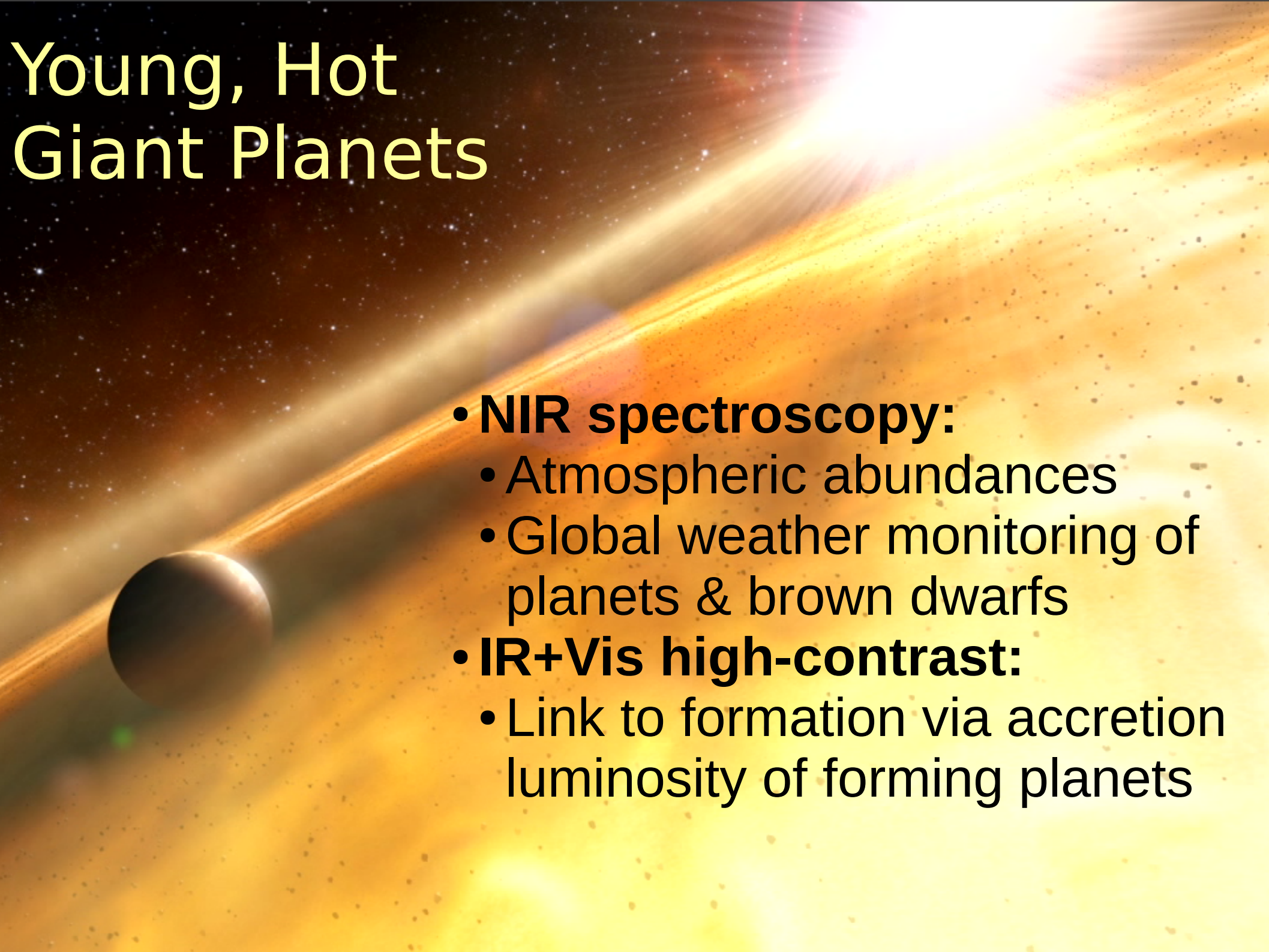


Crossfield 2014b



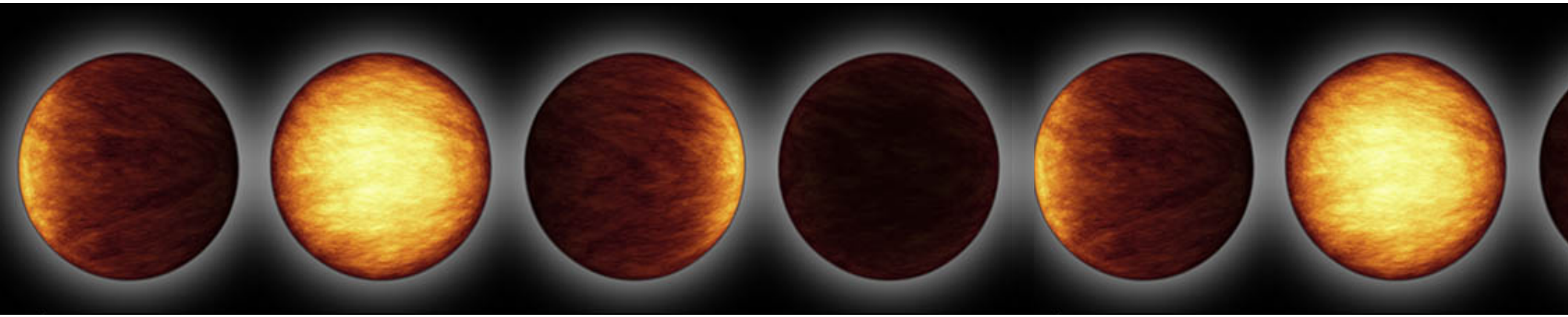
Crossfield+2014a

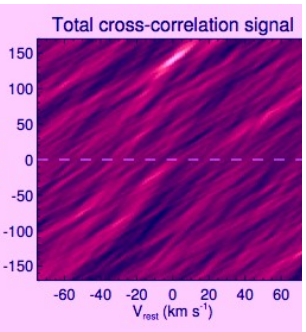
Young, Hot Giant Planets

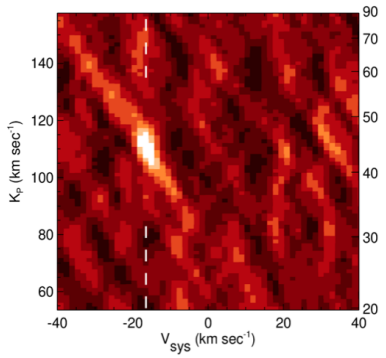


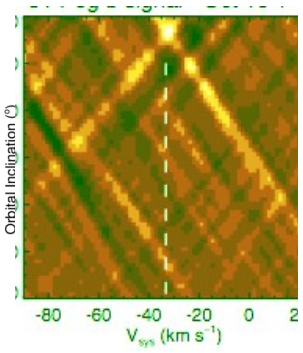
- **NIR spectroscopy:**
  - Atmospheric abundances
  - Global weather monitoring of planets & brown dwarfs
- **IR+Vis high-contrast:**
  - Link to formation via accretion luminosity of forming planets

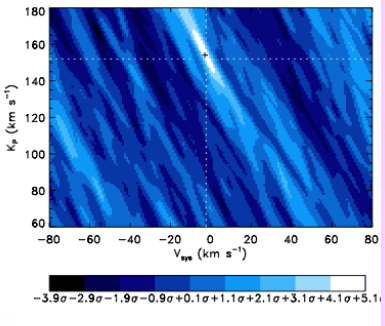
ELT high-resolution spectra will make global maps of composition & thermal structure, and track atmospheric dynamics:

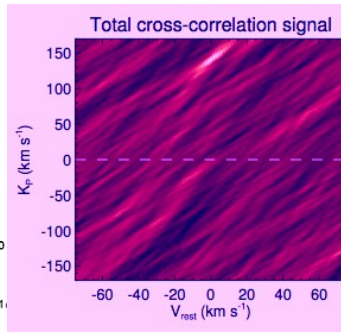


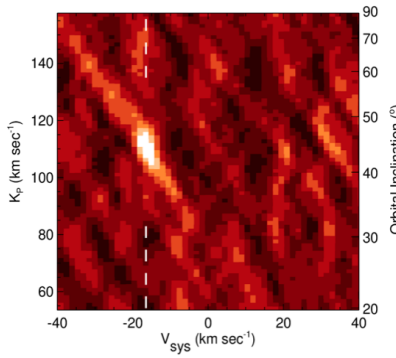




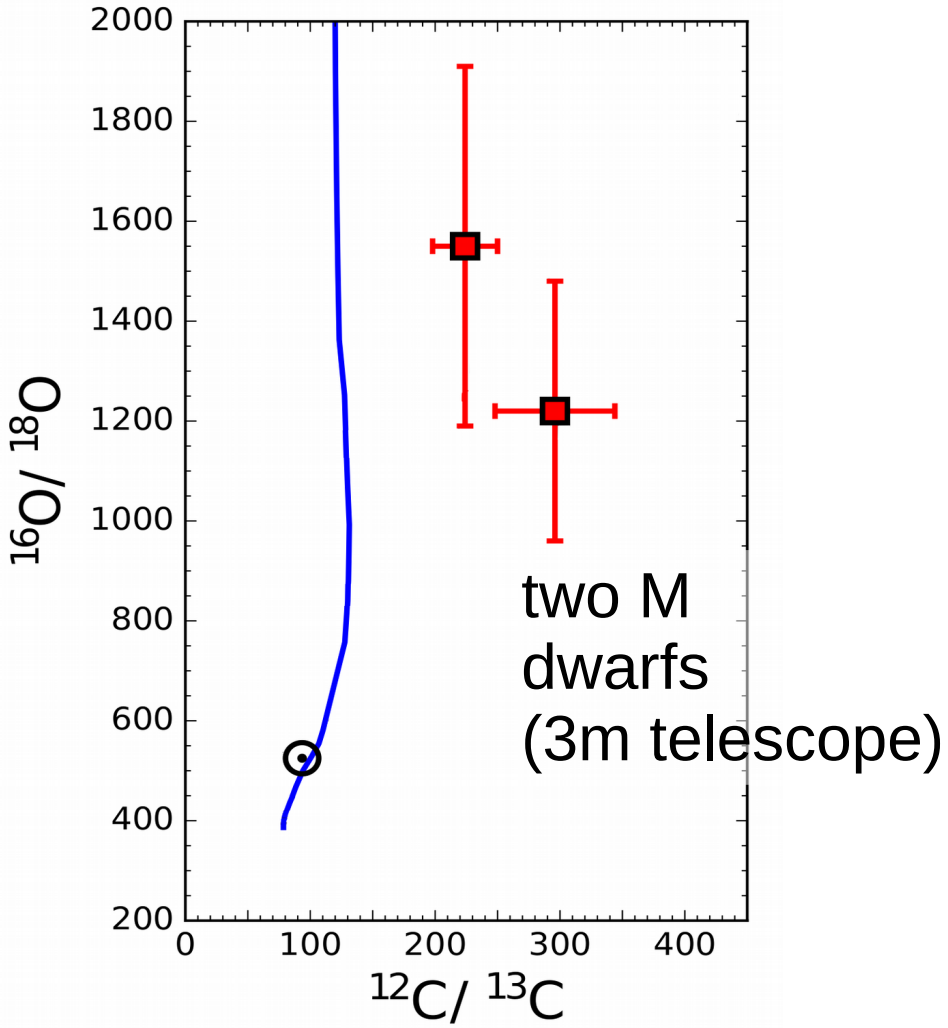








ELT High-res spectroscopy will also link planetary *isotopic* composition to formation:



ijmc et al., ApJ in press

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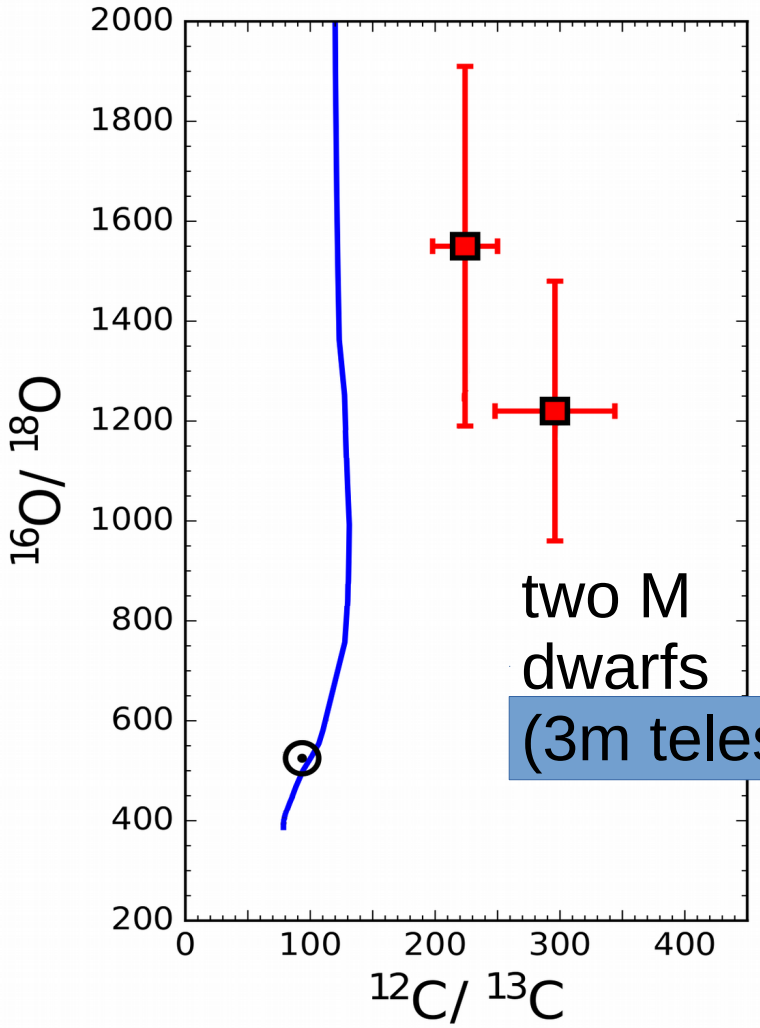
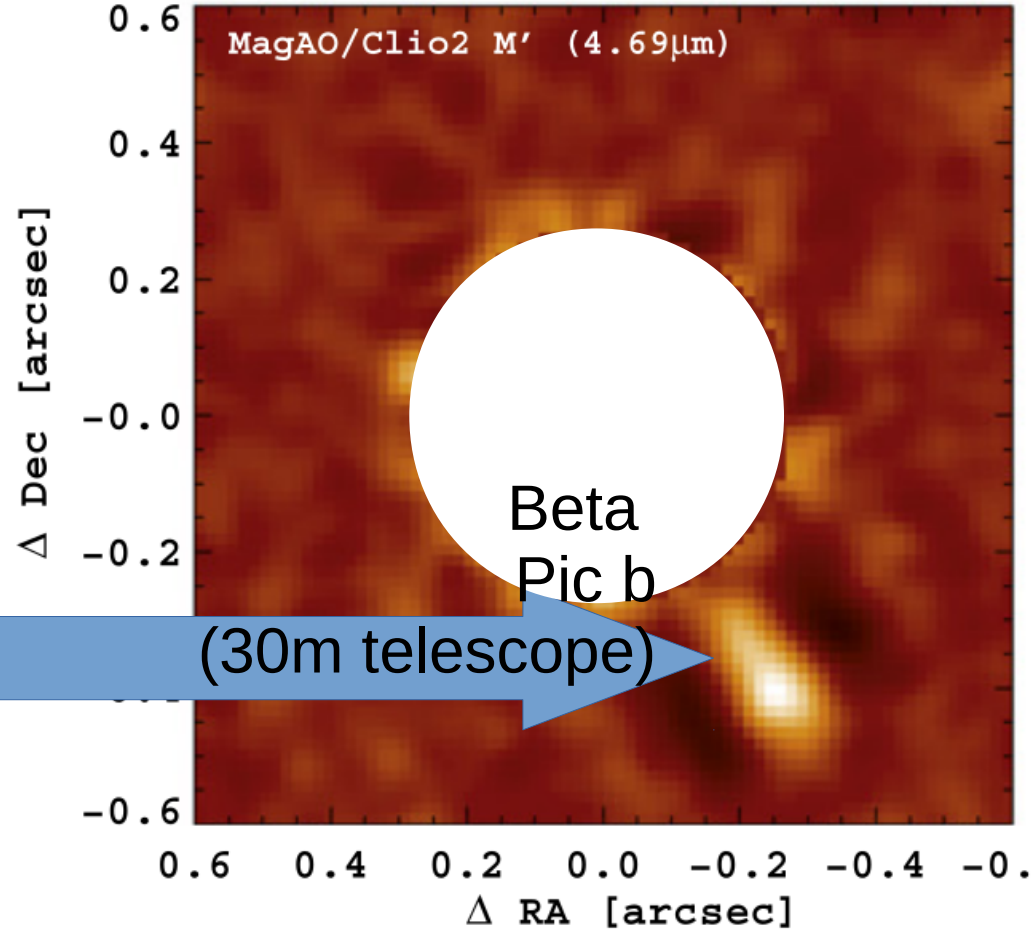


two M dwarfs (3m telescope)



Beta Pic b (30m telescope)

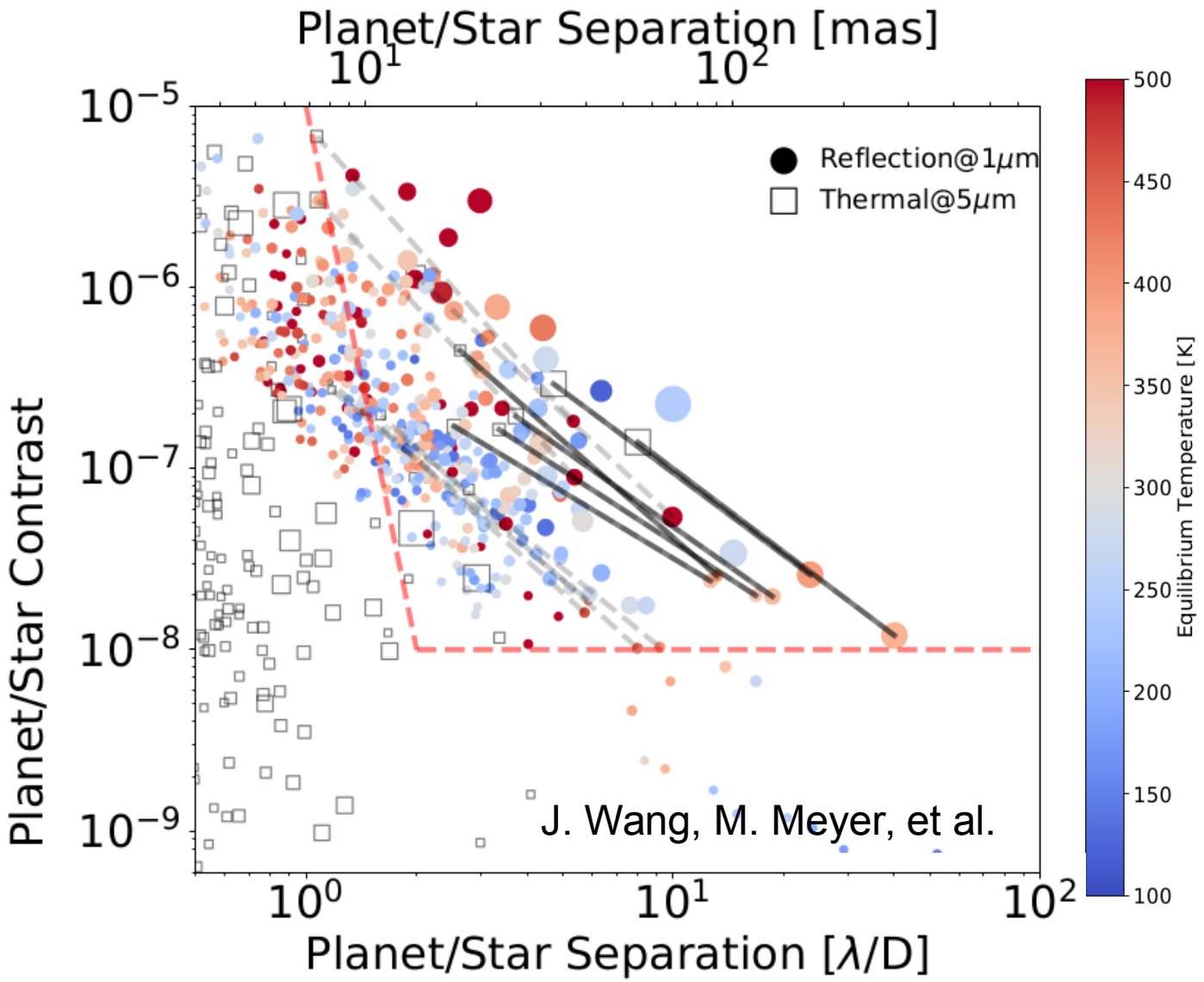
ijmc et al., ApJ in press

(image from Morzinski+2015)

Irradiated Gas Giants

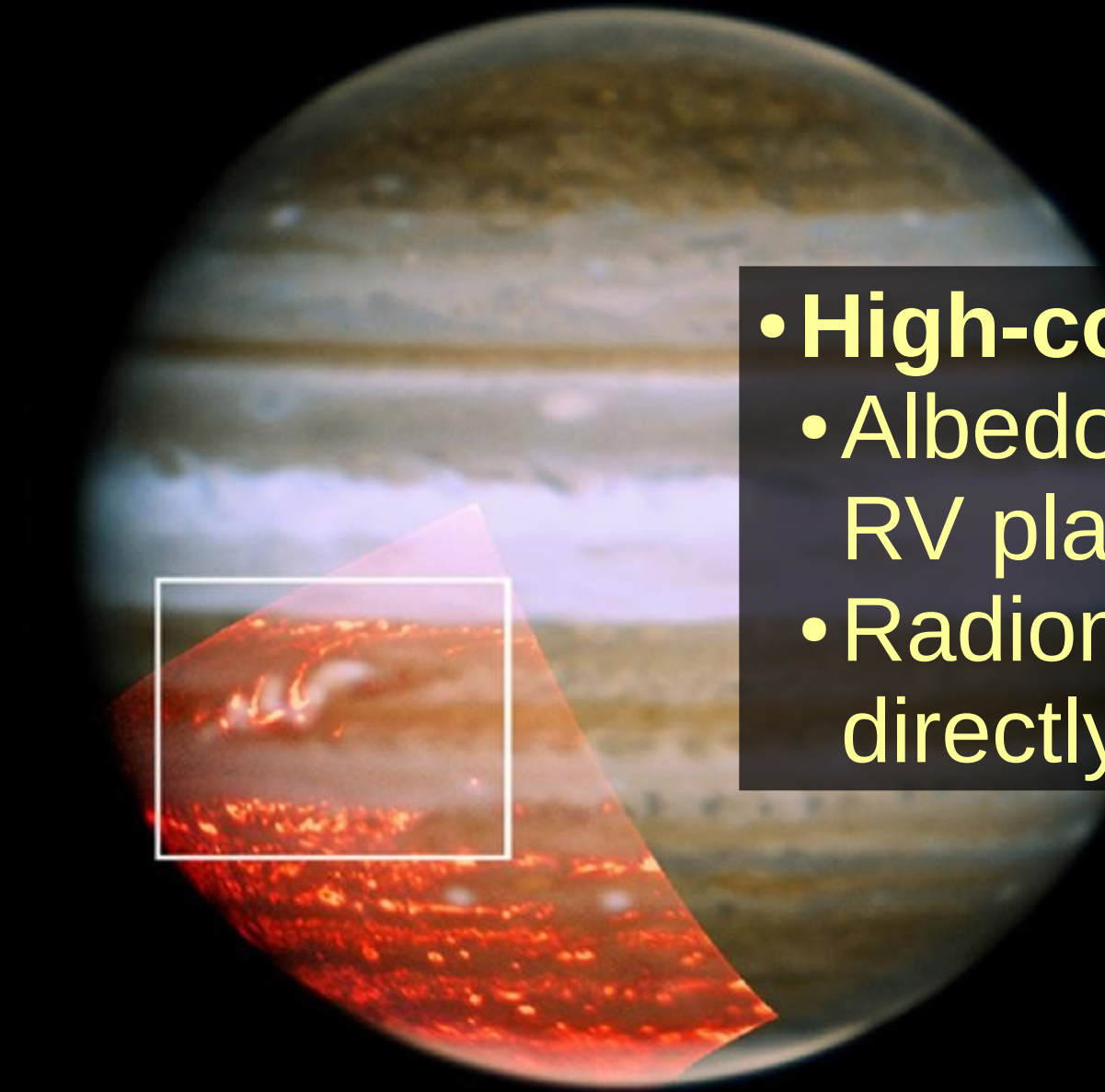
- **High-resolution spectroscopy:**
  - Composition and dynamics of transiting planet atmospheres
  - Global composition & thermal structure
  - Isotopic abundance analyses
  - Orbital architectures and system alignments

Many old, cold planets will be easily accessible to multispectral ELT characterization:



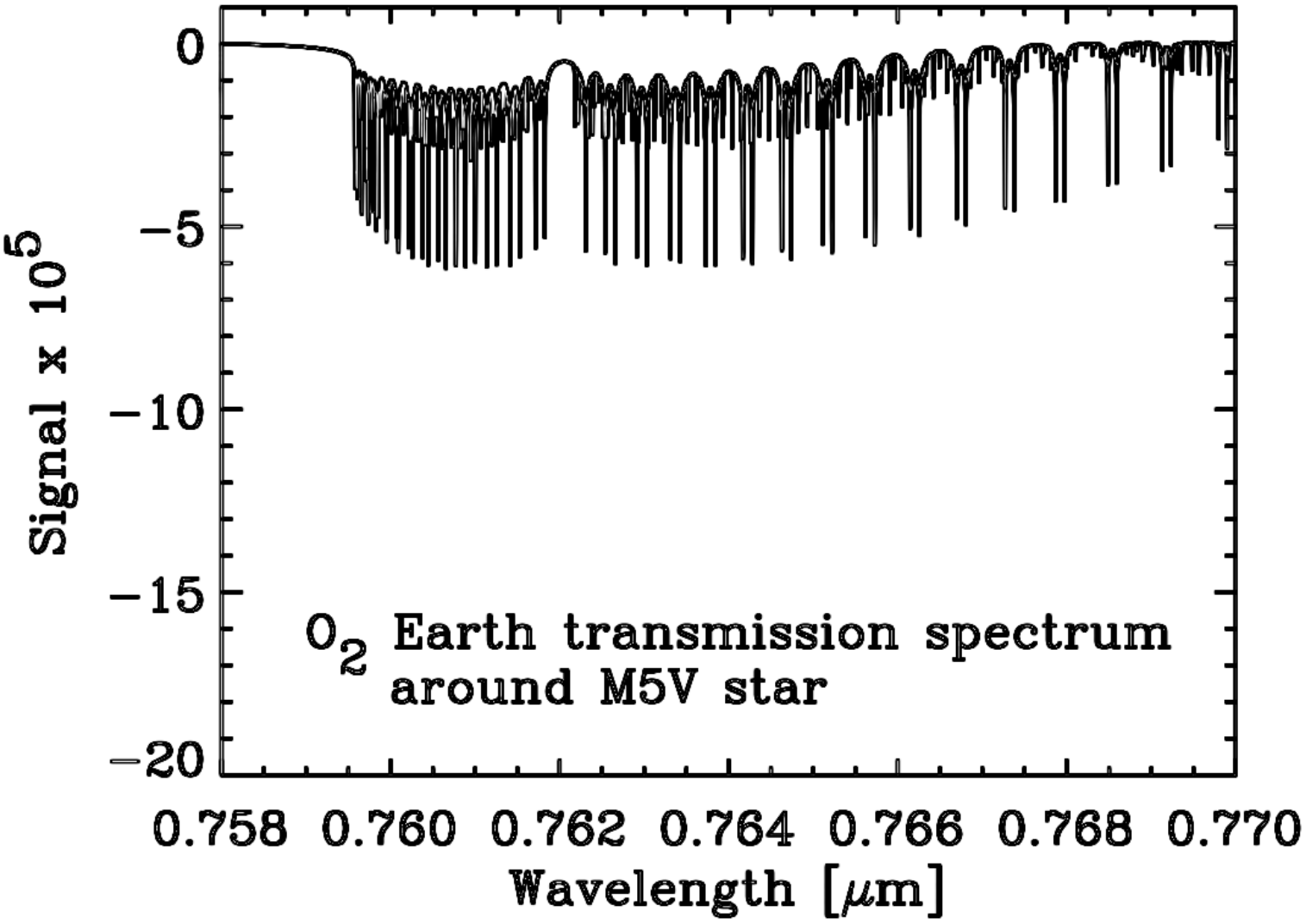
See Maggie Thompson's upcoming talk

Mature, cold nearby planets



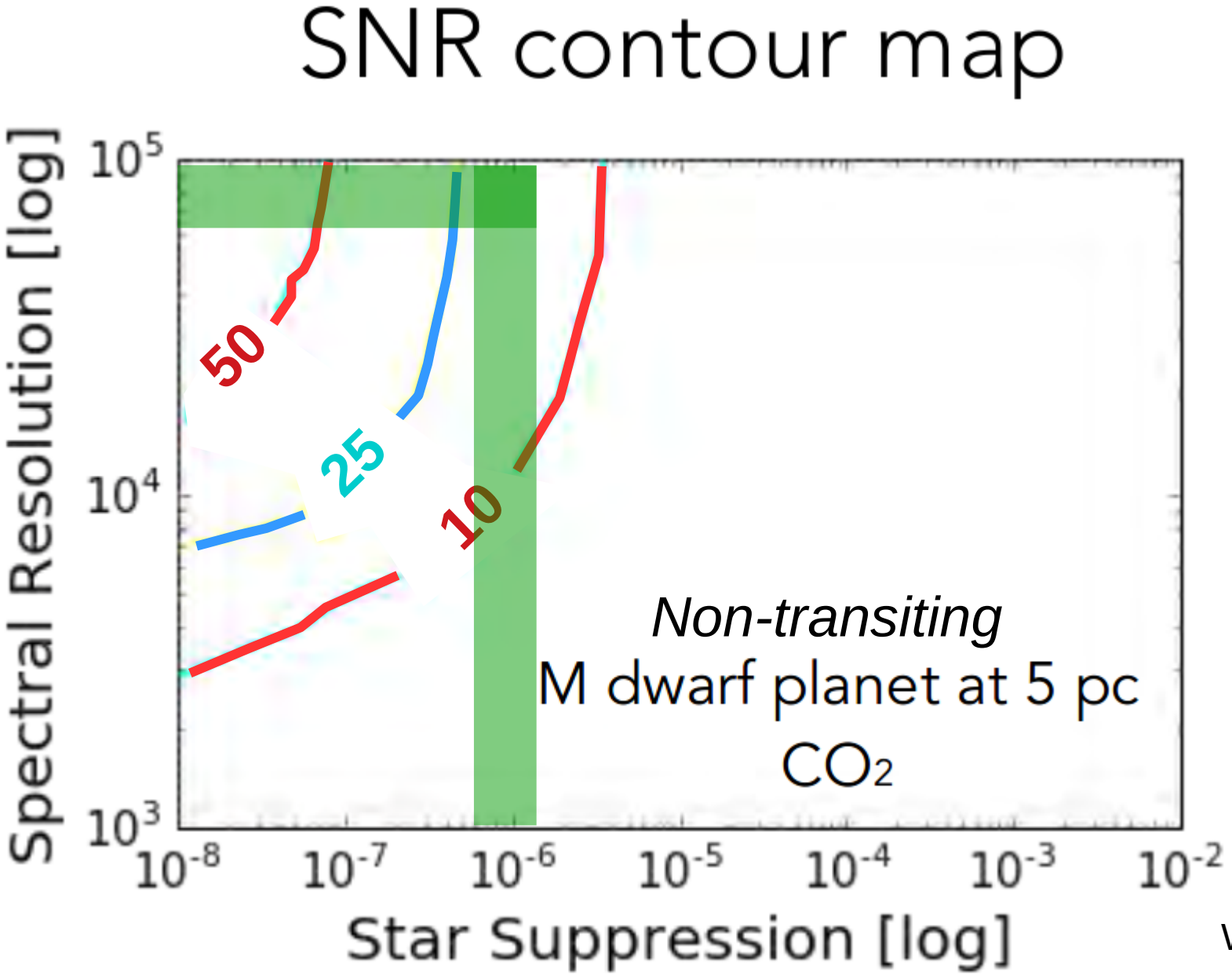
- **High-contrast Vis+IR:**
  - Albedo studies of known RV planets
  - Radiometric radii of directly-imaged planets

ELT high-resolution optical spectroscopy will **detect O_2 in transiting planets**:



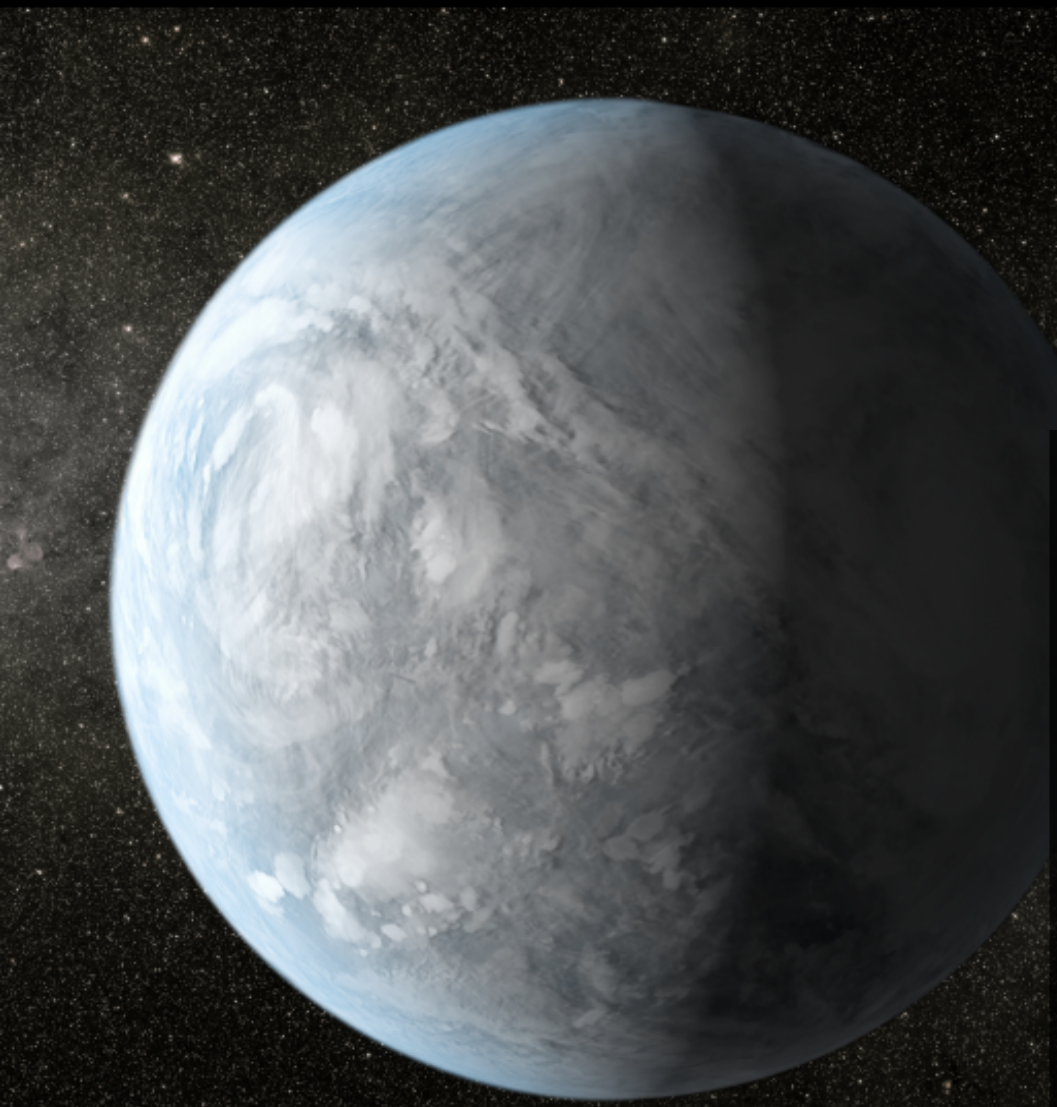
Snellen+2013; Rodler+Lopez-Morales 2014

High-contrast + high-resolution will characterize many **nearby HZ planets**:



Wang+2017

Small Planets & Habitability



- **High-contrast and high-resolution:**
  - Compositions of H_2-dominated atmospheres
  - Detecting O_2 and other biosignature gases!

Young, Hot Giant Planets

- **NIR spectroscopy:**
  - Atmospheric abundances
  - Global weather monitoring of planets & brown dwarfs
- **IR+Vis high-contrast:**
  - Link to formation via accretion luminosity of forming planets

Irradiated Gas Giants

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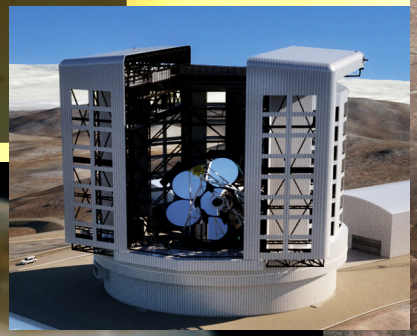

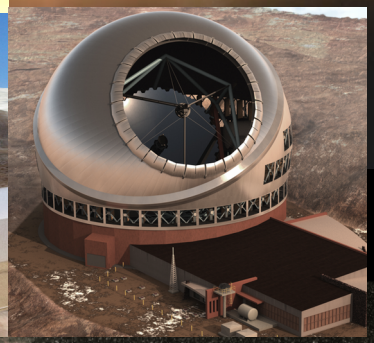

Mature, Cold nearby planets

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  - Radiometric radii of directly-imaged planets

Small Planets & Habitability

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"Nothing in space will be able to touch this science until probably the 2040s"

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Small Planets & Habitability

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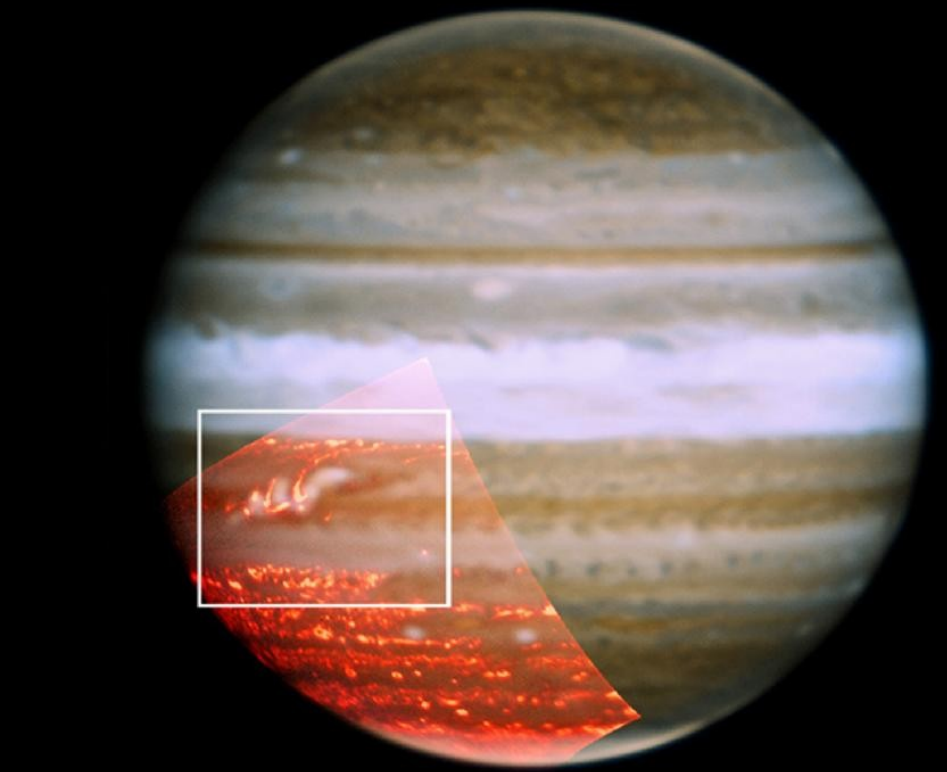
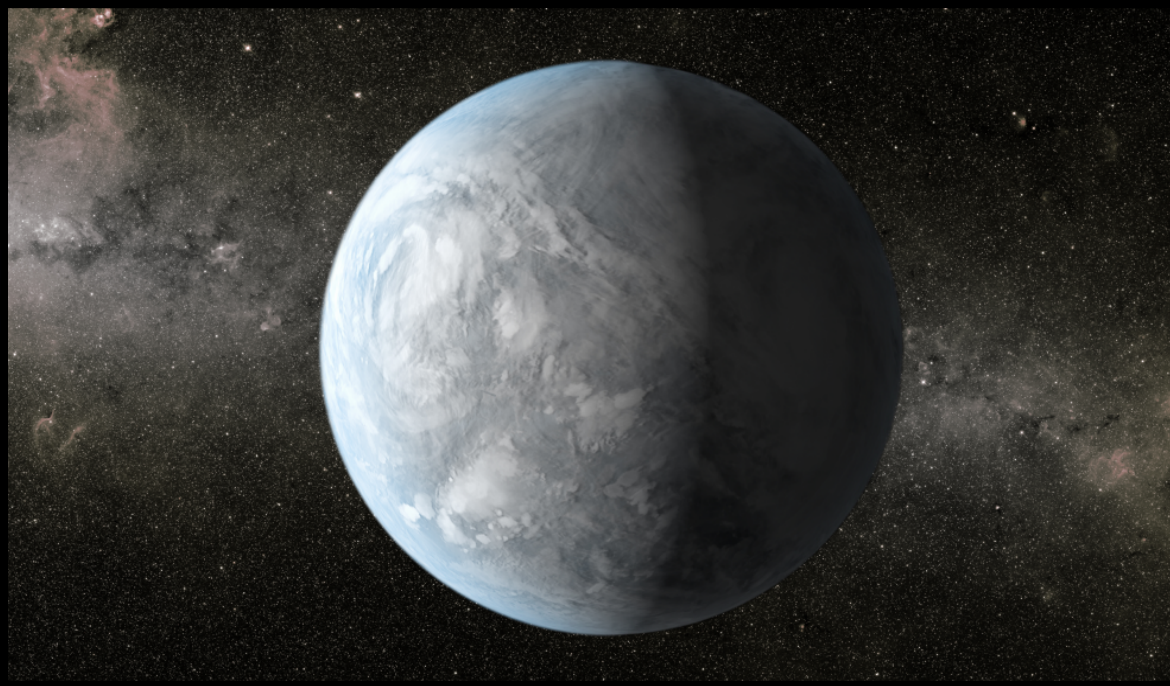
If we want to answer these questions:

- How do planetary systems form and evolve?
- What are conditions like on other worlds?
- What (photo)chemical and dynamical processes dominate their atmospheres?
- Are there other habitable or inhabited worlds?

The ExoPAG should recommend that NASA invest in the US ELT program

via a NEID-like instrument funding model or other substantive investment.





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