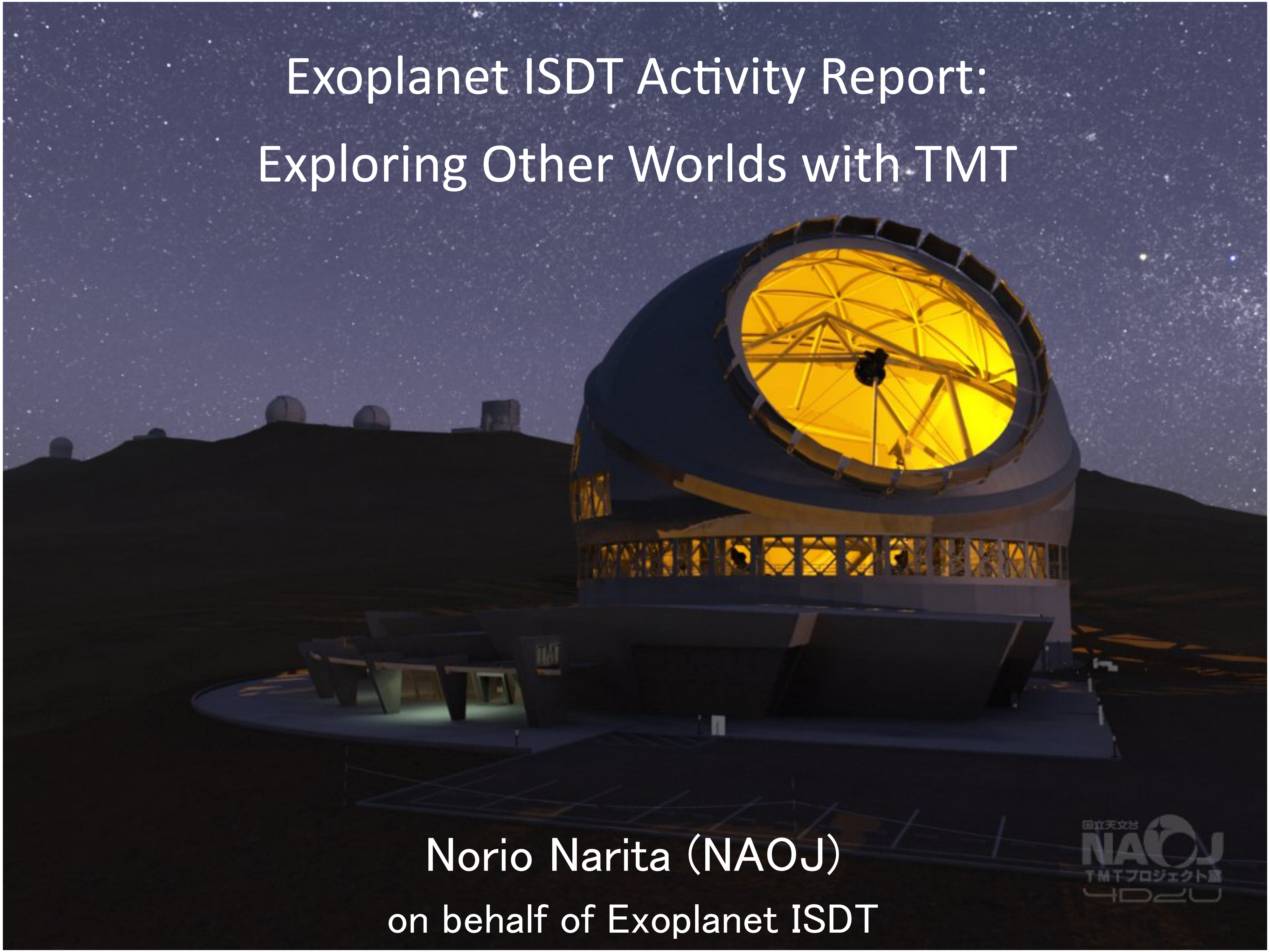
Exoplanet ISDT Activity Report: Exploring Other Worlds with TMT



Norio Narita (NAOJ)
on behalf of Exoplanet ISDT

Exoplanet ISDT Members

Conveners: Bruce Macintosh & Norio Narita

- Crossfield, Ian
- Currie, Thayne
- Dong, Subo
- Enya, Keigo
- Gaidos, Eric
- Ge, Jian
- Kane, Stephen
- Lin, Doug
- Liu, Michael
- Marois, Christian
- Matsuo, Taro
- Mazin, Benjamin A.
- Melis, Carl
- Sengupta, Sujan
- Tanner, Angelle
- Wang, Wei
- Zhou, Ji-Lin

Outline

- Summary of Updated Detailed Science Cases
  - What has changed from previous DSC
- Requirements for Instruments
- Possible Key Programs
- Timeline of TMT Exoplanet Studies

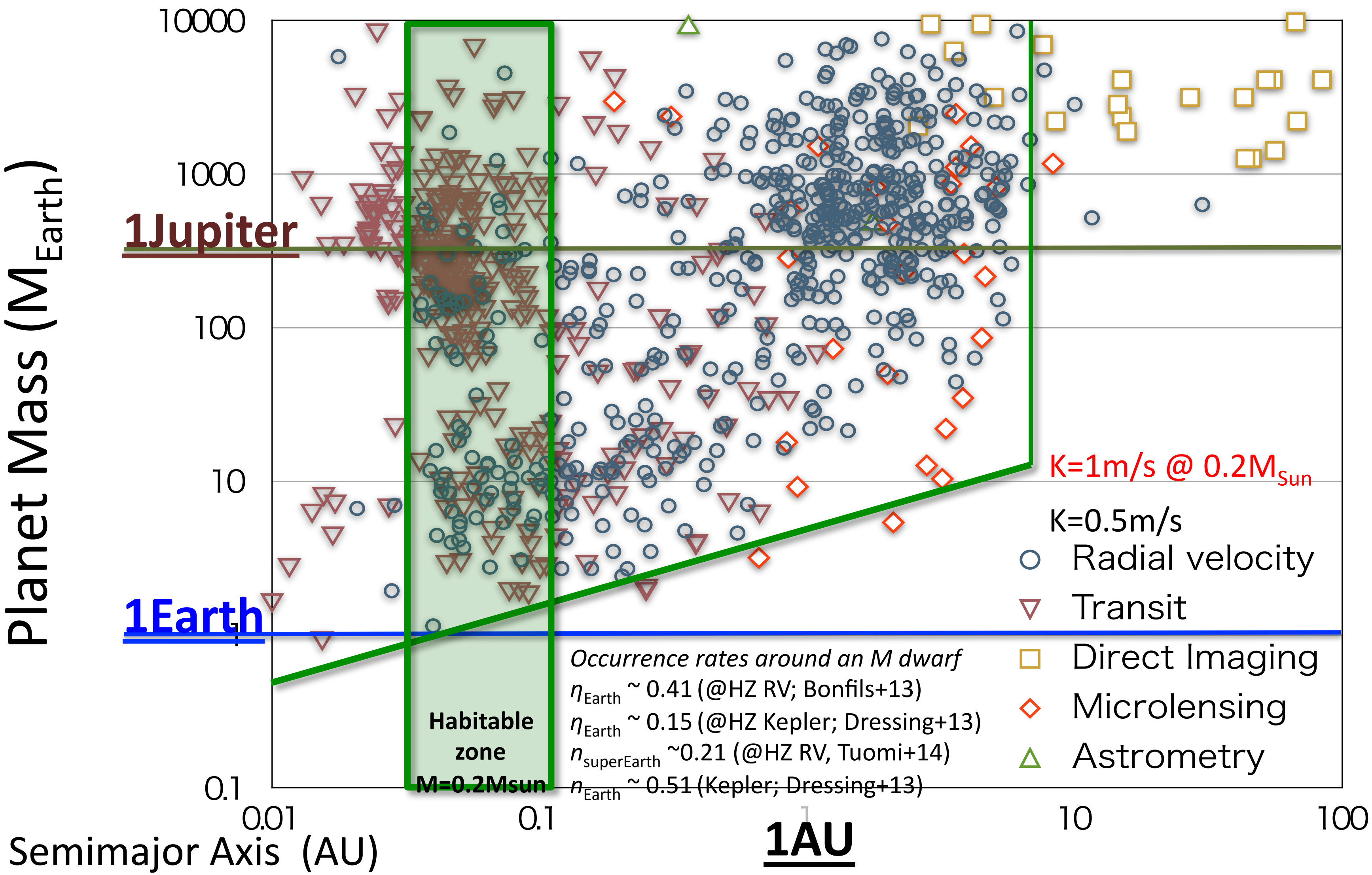
Updated DSC Contents: Main Writers

- Radial Velocity: Angelle Tanner
- Transit: Ian Crossfield
- Direct Imaging: Thayne Currie
- Microlensing: Subo Dong

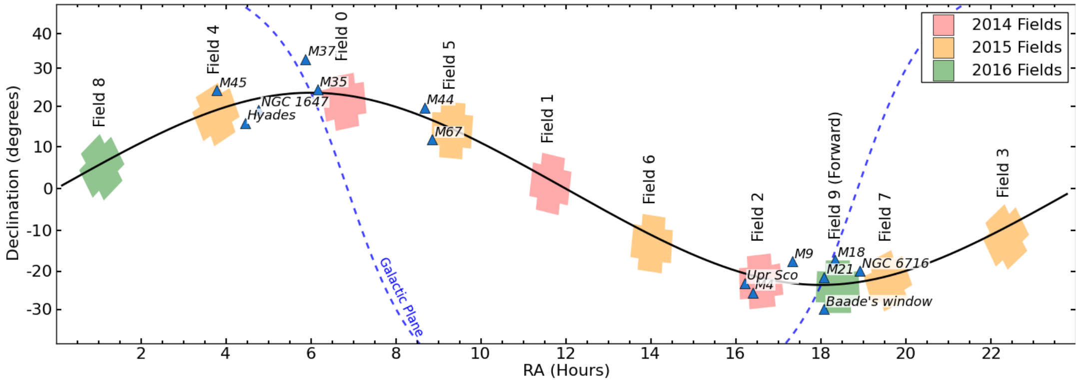
What will happen by TMT era?

Radial Velocity Surveys around Nearby M Dwarfs

Numbers of NIR RV surveys aim to detect low-mass planets



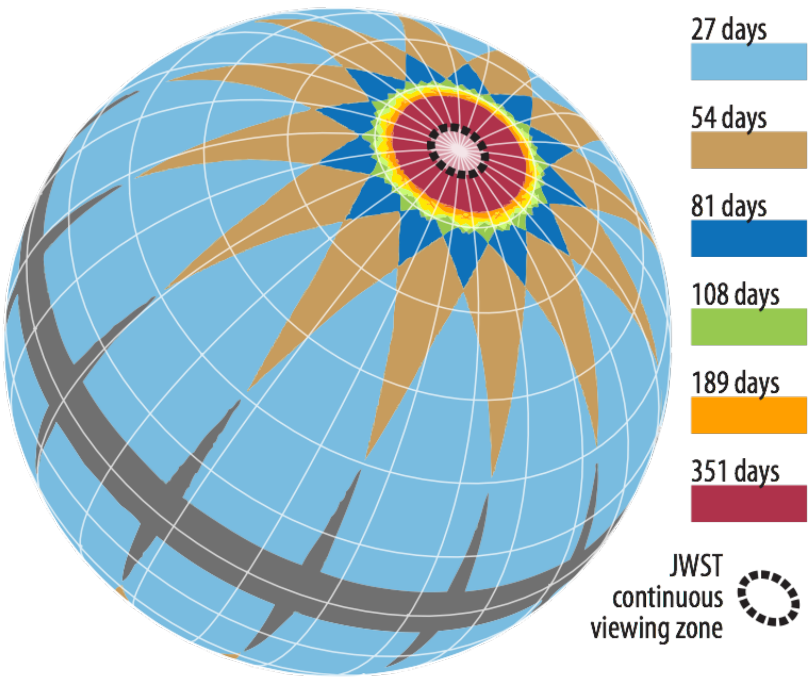
Space Transit Surveys around Nearby Stars

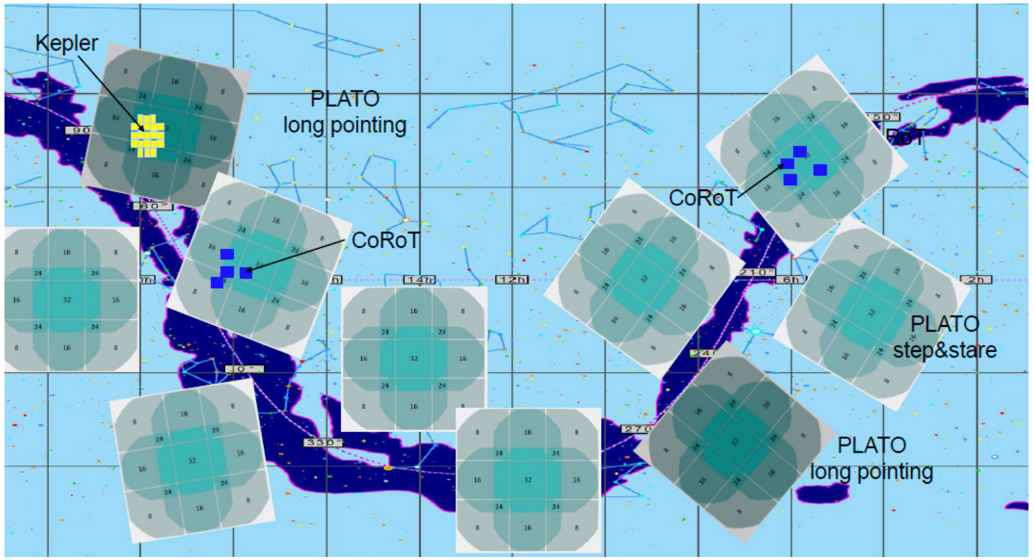


2014-
Kepler2

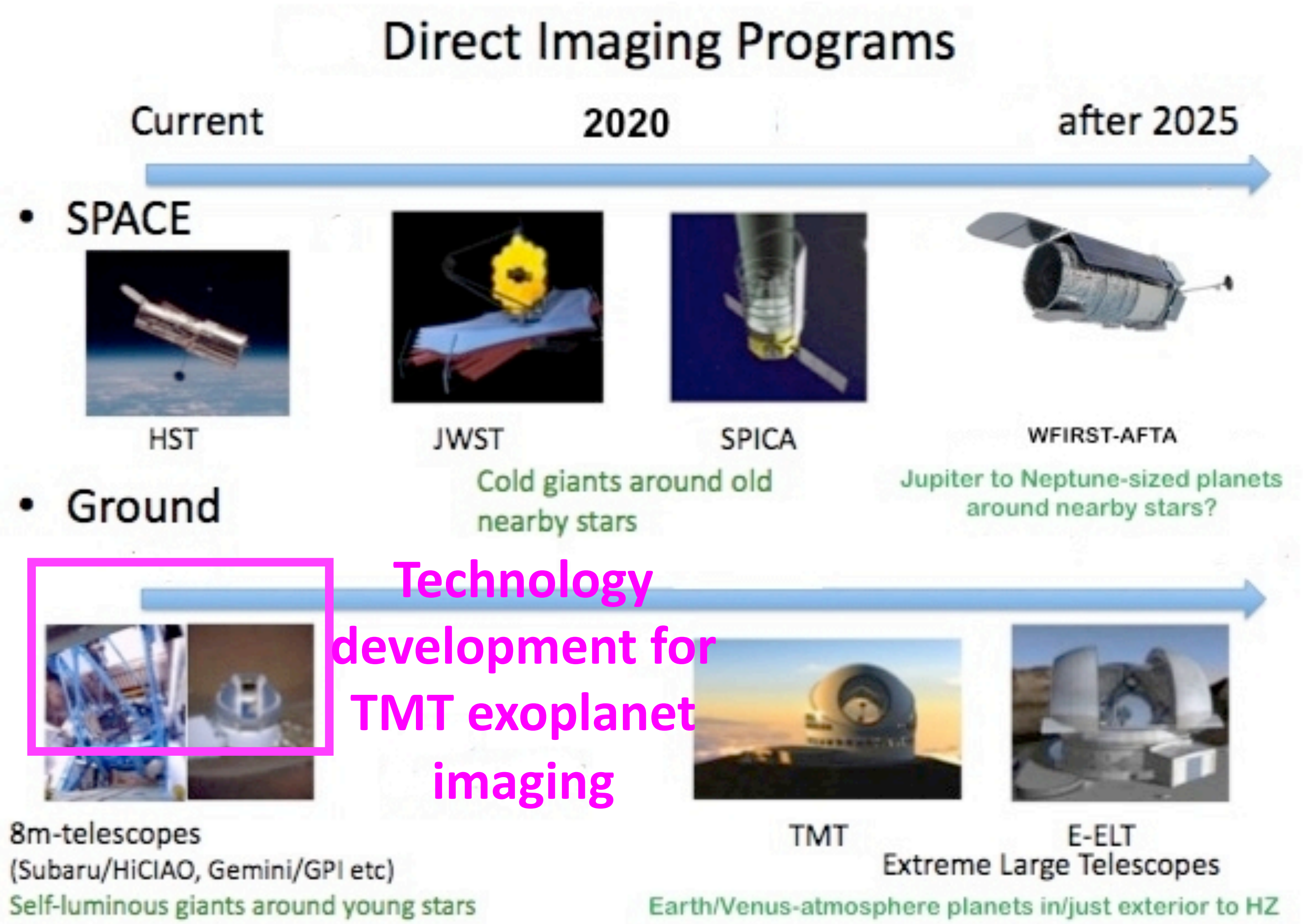
2024
PLATO
PLAnetary Transits and Oscillations of stars

2017
TESS
Transiting Exoplanet Survey Satellite





The Path to Exoplanet Imaging with the TMT



Ground & Space Microlens Survey

2.4m WFIRST-AFTA

- Existing Hardware: high quality mirror and optical system
- Easily used in Three Mirror Anastigmat
  - Wide field of view
  - 3rd mirror in Wide-Field Imager primary instrument

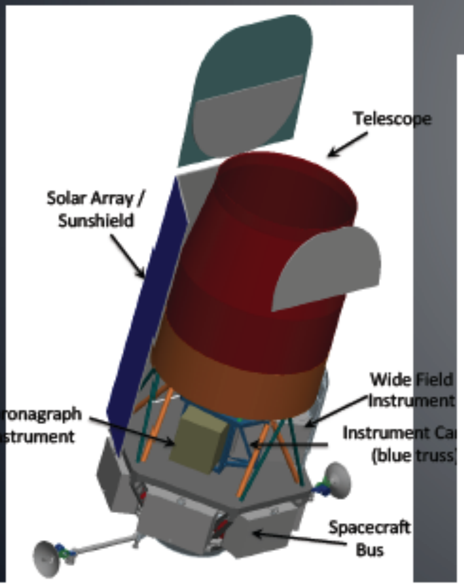
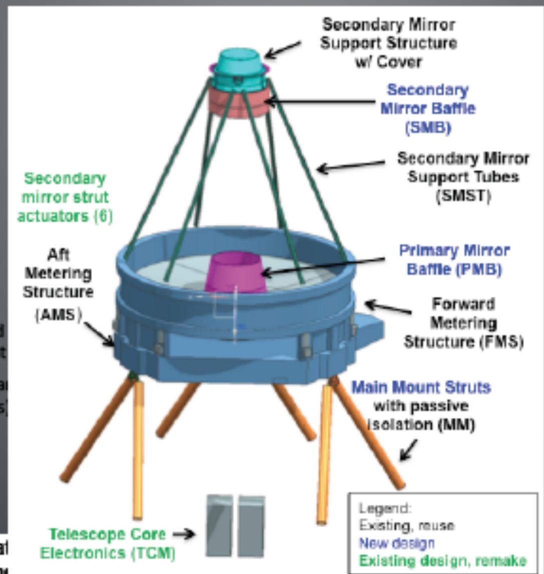


Figure 3-3: WFIRST-2.4 Observatory configuration featuring the 2.4-m telescope, two modular instruments and a modular spacecraft. bus



The telescope entrance pupil

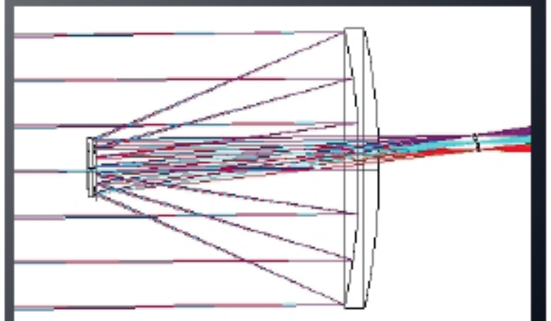


Figure 3-6: Ray trace through the telescope to the wide field channel intermediate focus.

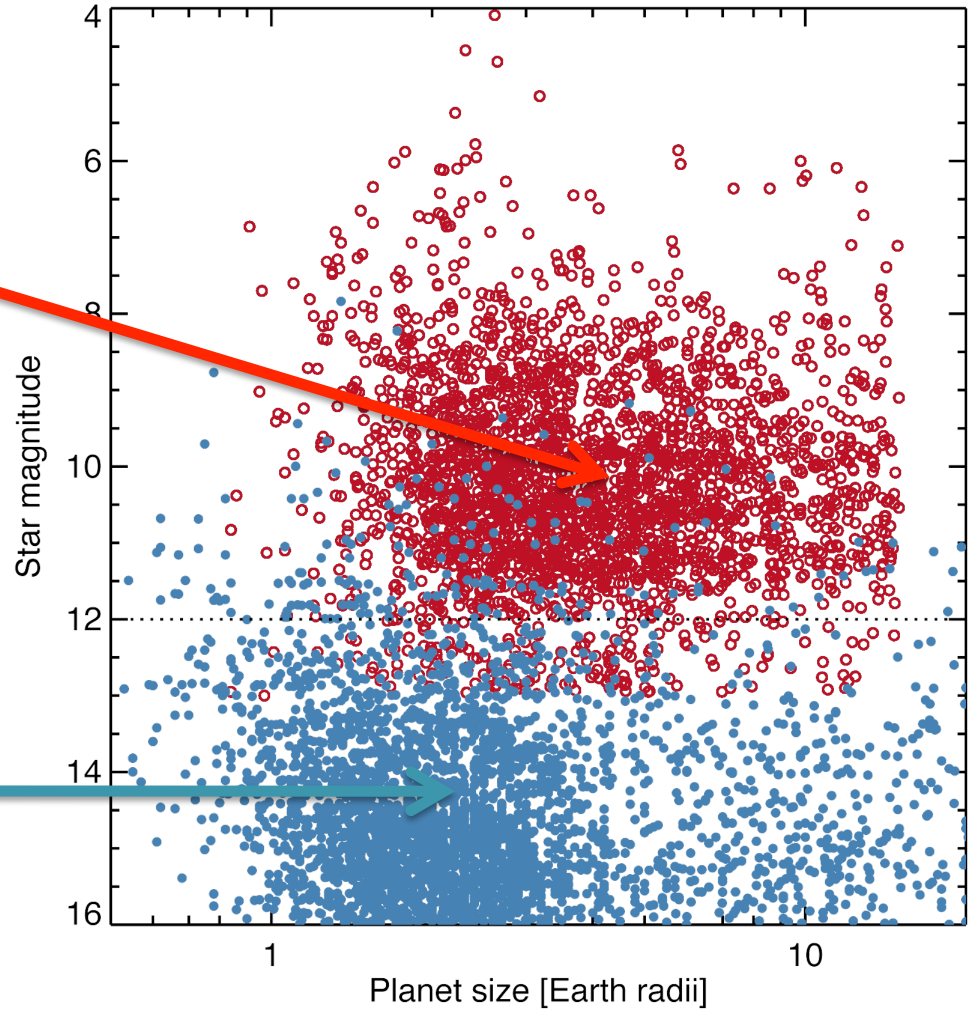
Landscape of TMT era has dramatically changed from previous DSC

What we can do with TMT?

TMT can provide essential RV follow-up observations for targets from Kepler, TESS, PLATO, GAIA to determine their masses and orbits

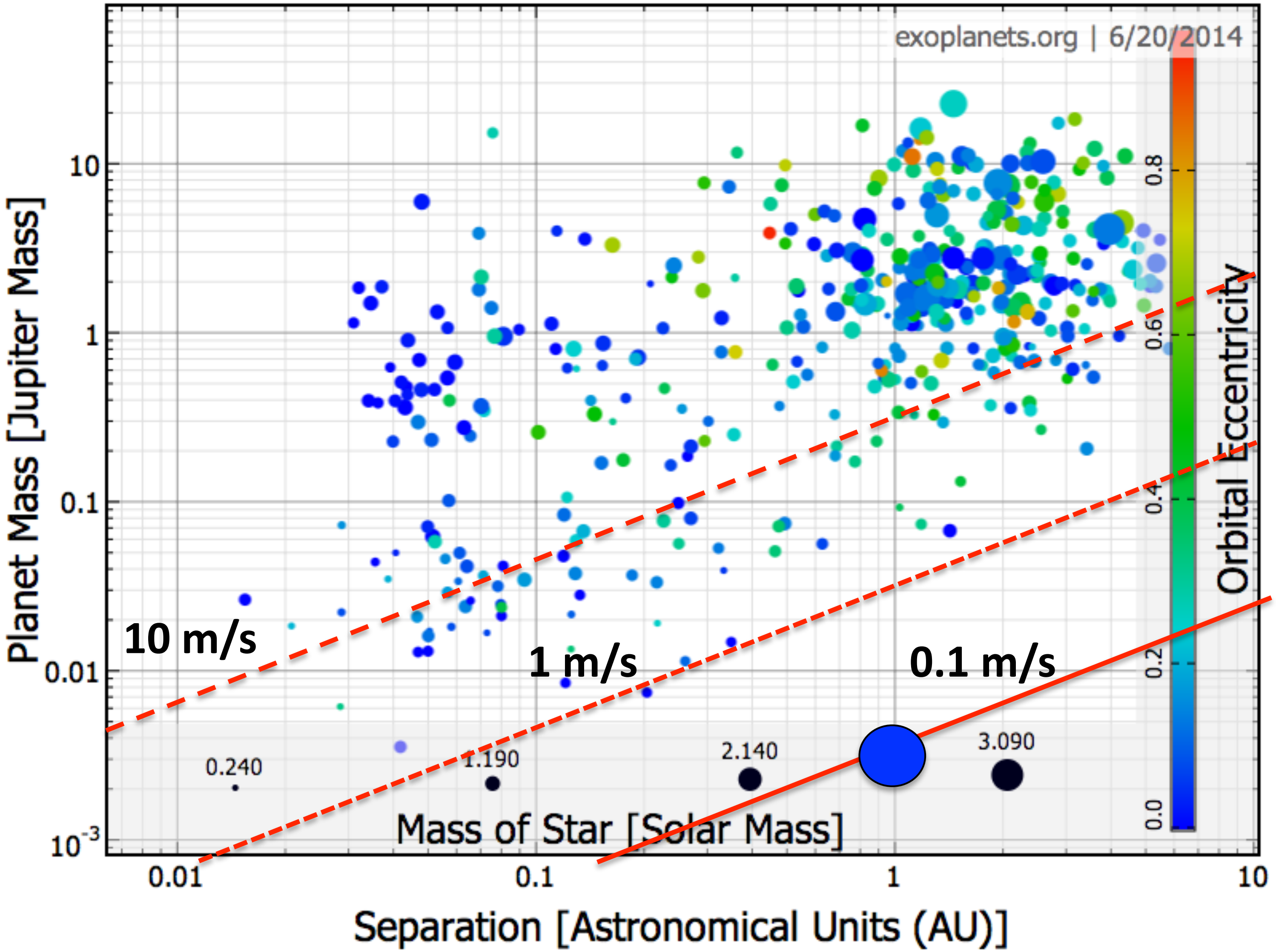
TESS will be focusing on the nearby bright stars

Kepler has many faint KOIs that still need RV follow up



Ricker et al. 2014

0.1 m/s for Solar-type & 1 m/s for M dwarfs can detect habitable Earth mass planets



Necessity of TMT for RV Studies

Most interesting targets are still faint for 8-10 meter telescopes

- TMT RV instruments are desired for targeted studies of stars from other programs like Kepler, K2, TESS, Plato, Gaia, etc

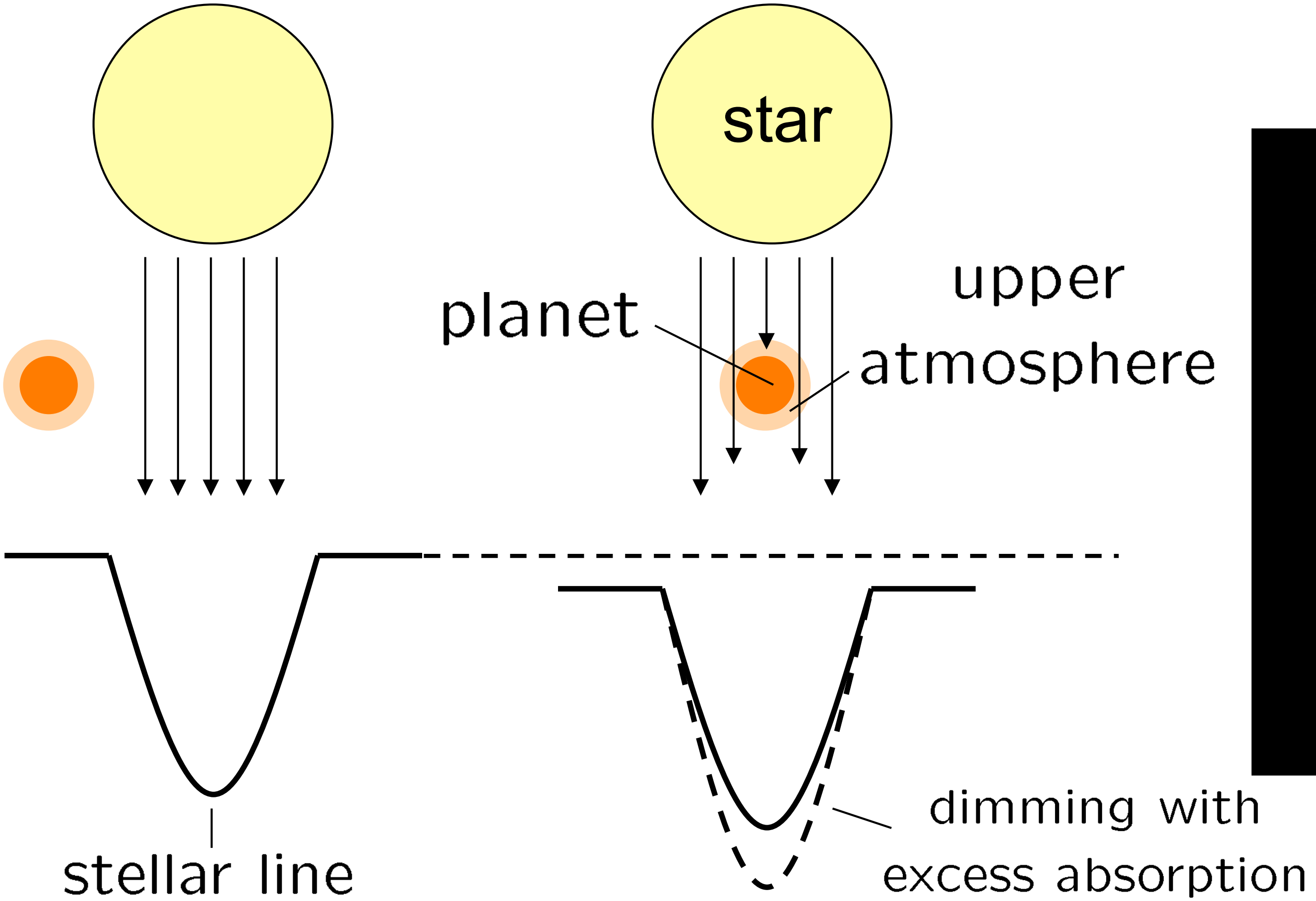
Compelling targets which would benefit from high SNR observations with small time resolution

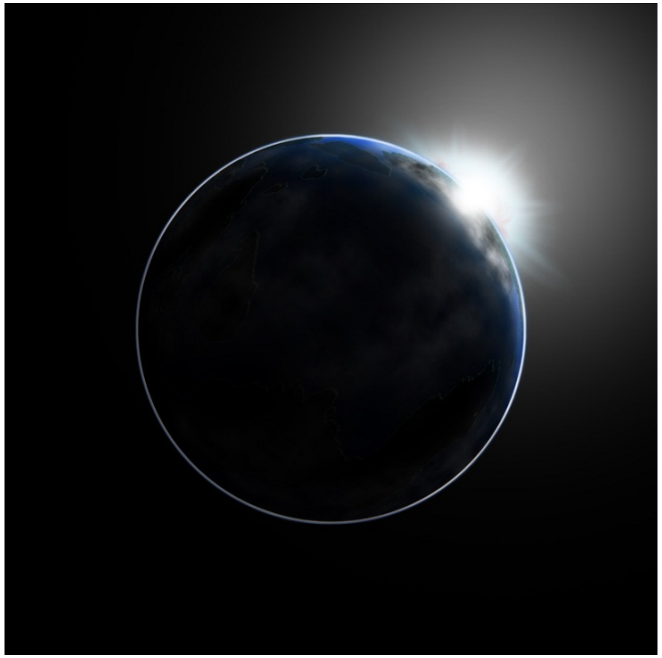
What TMT can do for transiting exoplanets

- Characterizing exoplanetary atmospheres
  - by MOS observations of transmission spectroscopy
  - by Doppler-shifted line absorptions and emissions
  - both are new observing techniques developed after the previous DSC

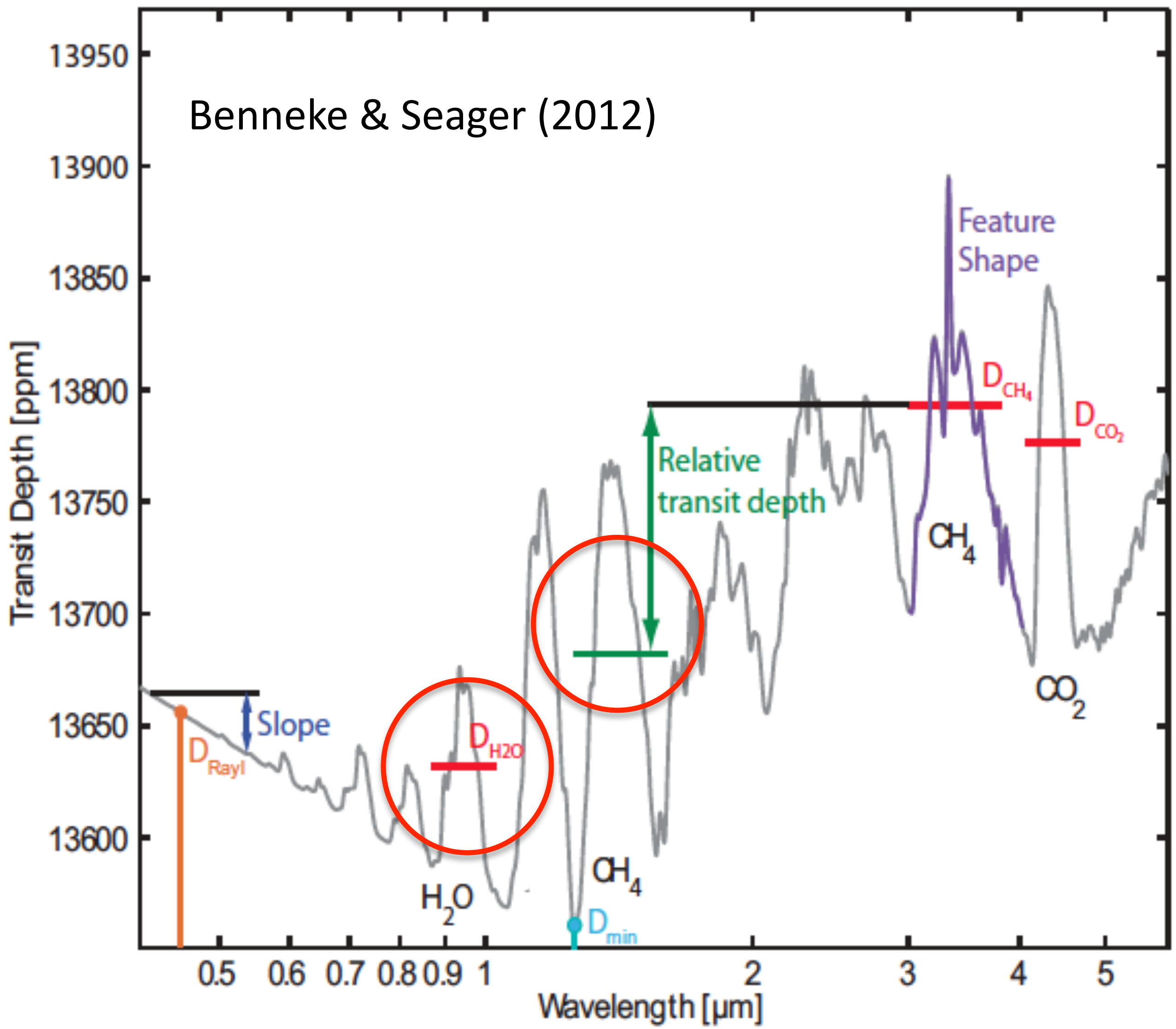
Characterizing Exoplanet Atmospheres

Transmission Spectroscopy



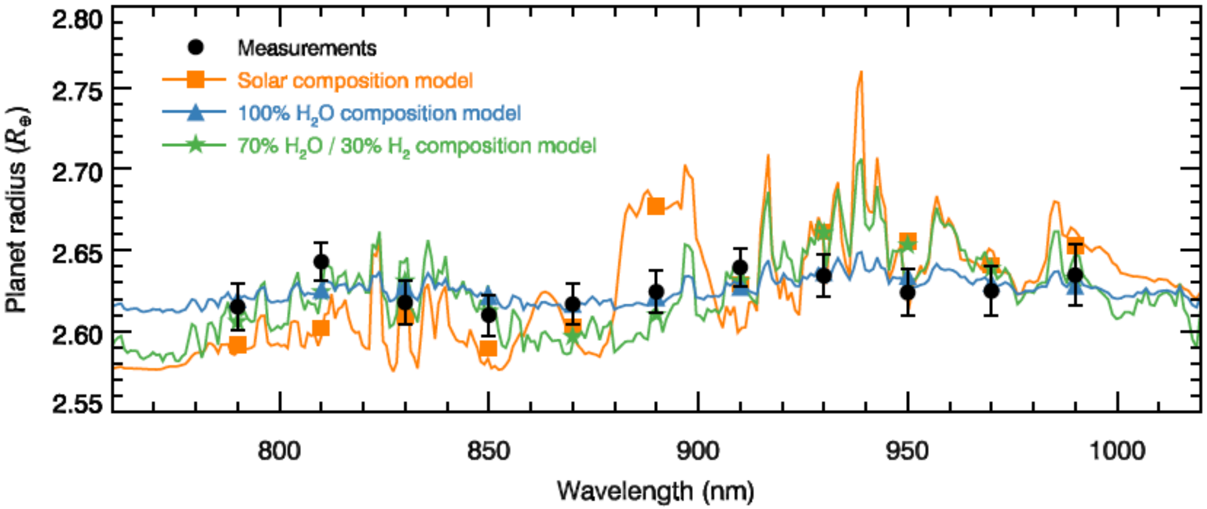


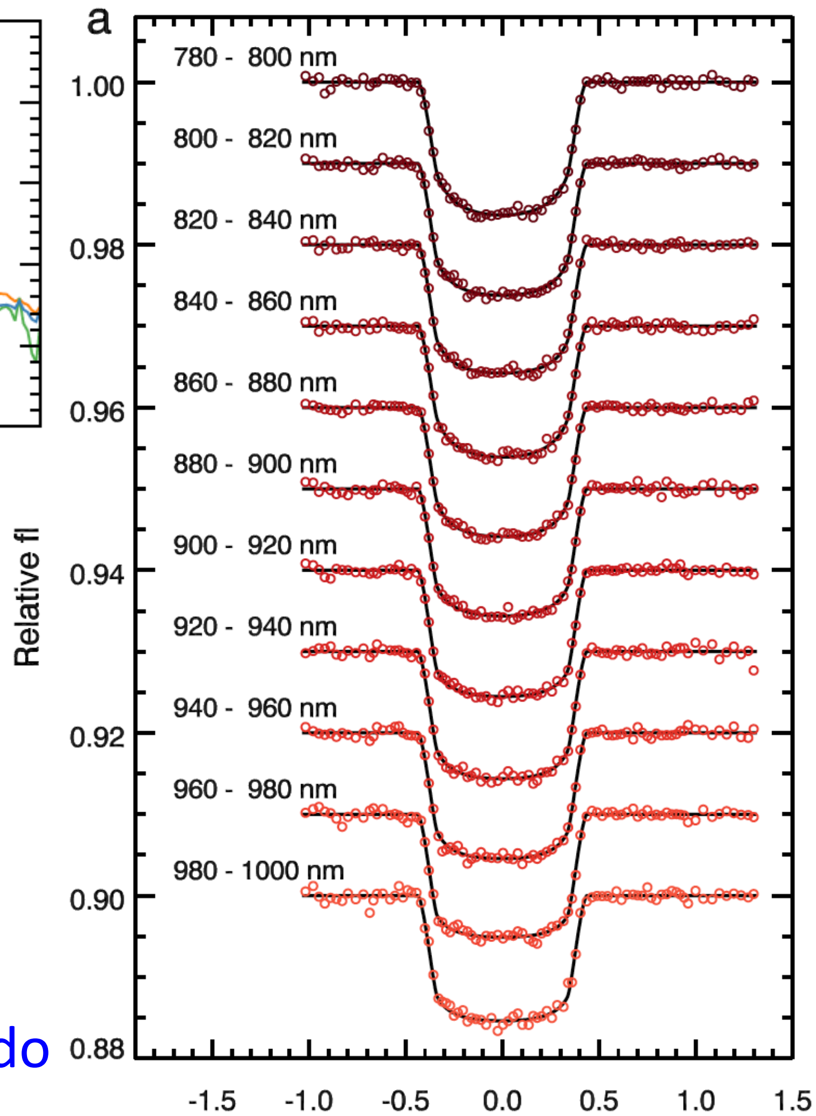
Transit depths depend on lines / wavelength reflecting atmosphere



Optilal-NIR region has features of atmospheric compositions

MOS is a powerful tool for this purpose





- Instrument: VLT/FORS2
- Target: GJ1214b (V=14.7)
- Integration: 20 nm (R ~ 30)
- Precision: ~400 ppm
- TMT's FL instruments (MOBIE, IRMS) can do

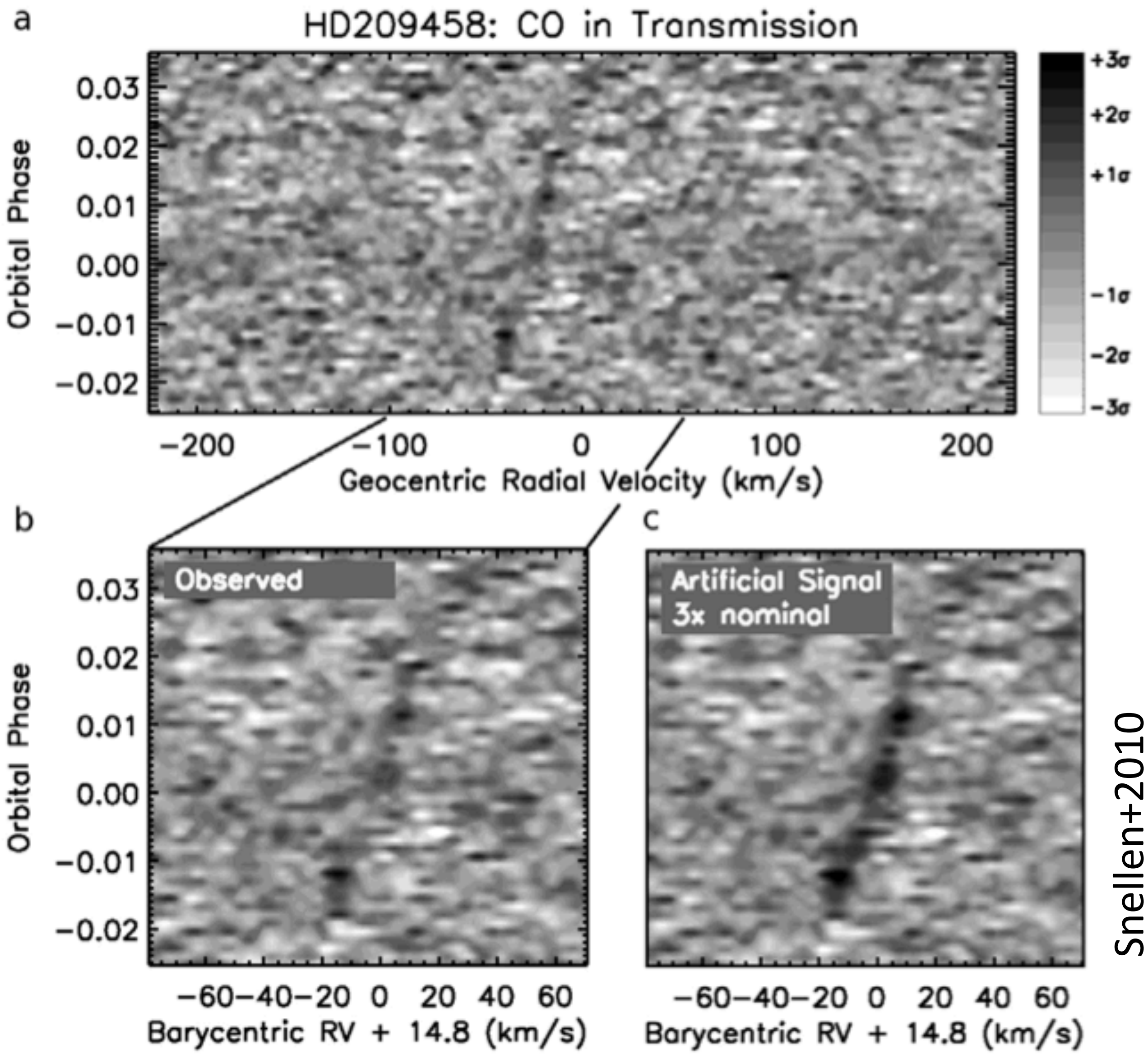
NIRES can probe atmospheric compositions and dynamics

- VLT/CRIRES:

Transit of a hot Jupiter HD 209458b detected as Doppler-shifted line absorption (namely, planet's shadow).

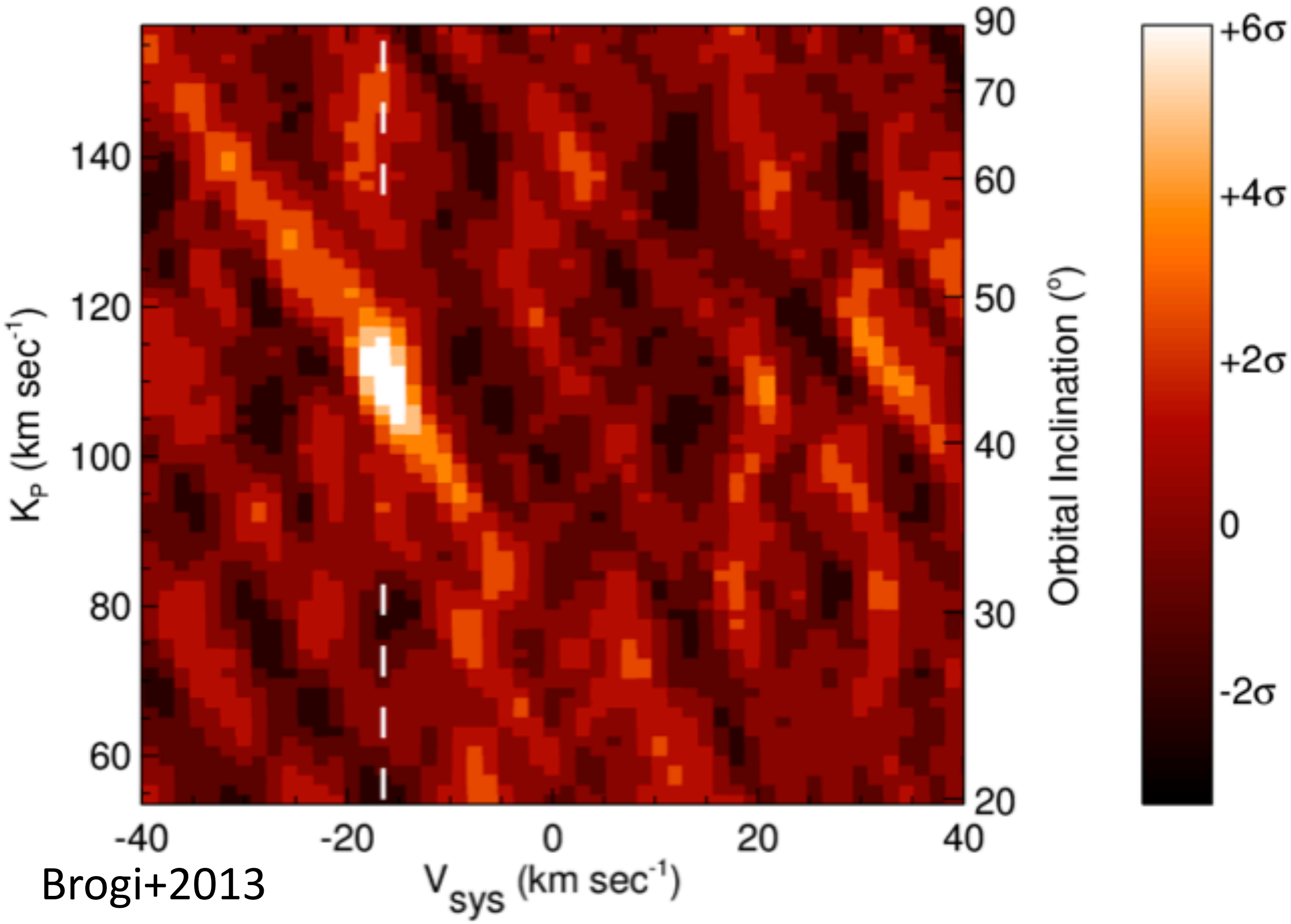
- **CO** detected.
- Global wind?

2 ± 1 km/s



Snellen+2010

NIRES can probe compositions and thermal structure of non-transiting planets



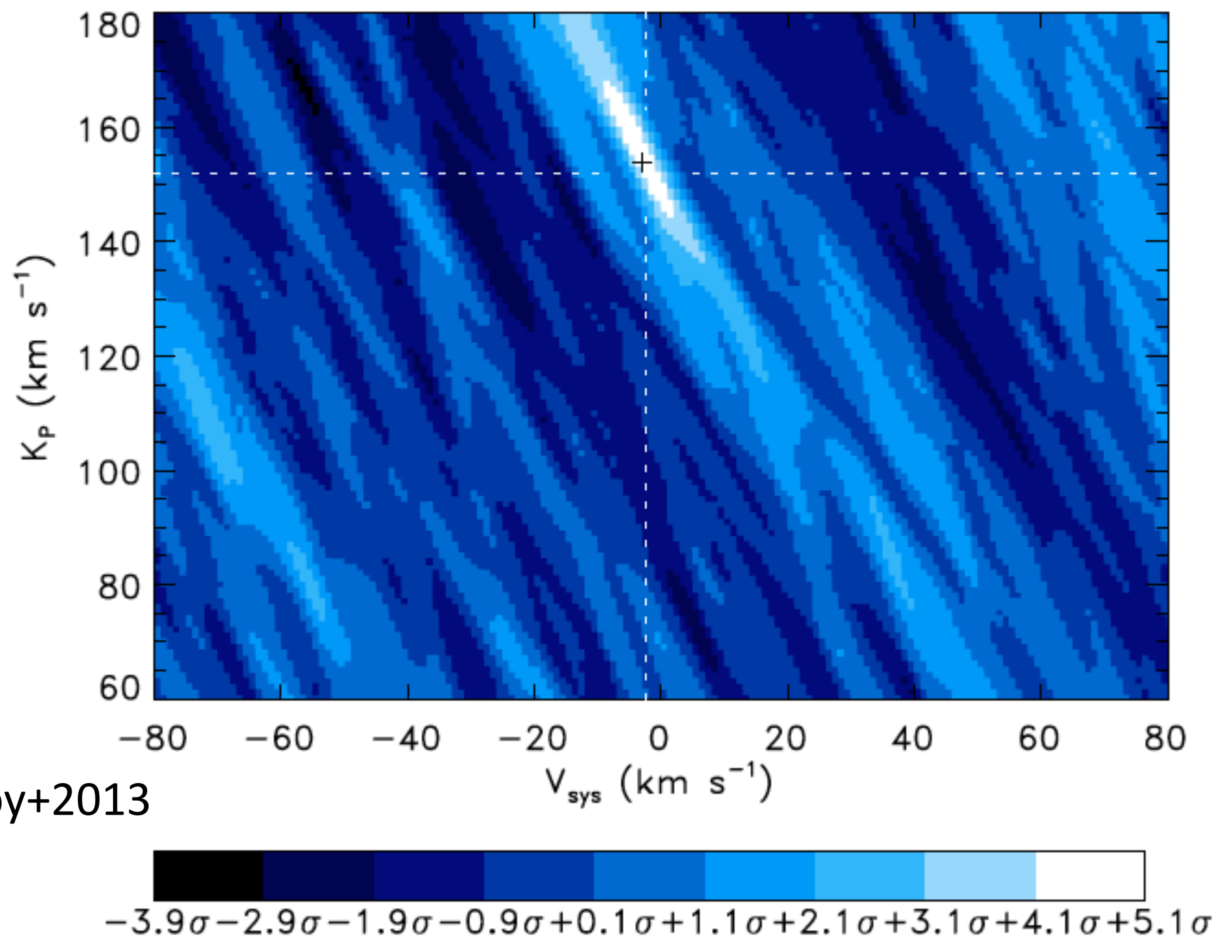
Brogi+2013

- VLT/CRIRES:

Non-transiting hot Jupiter tau Boo b detected as Doppler-shifted line emission.

- **CO** detected.
- No thermal inversion

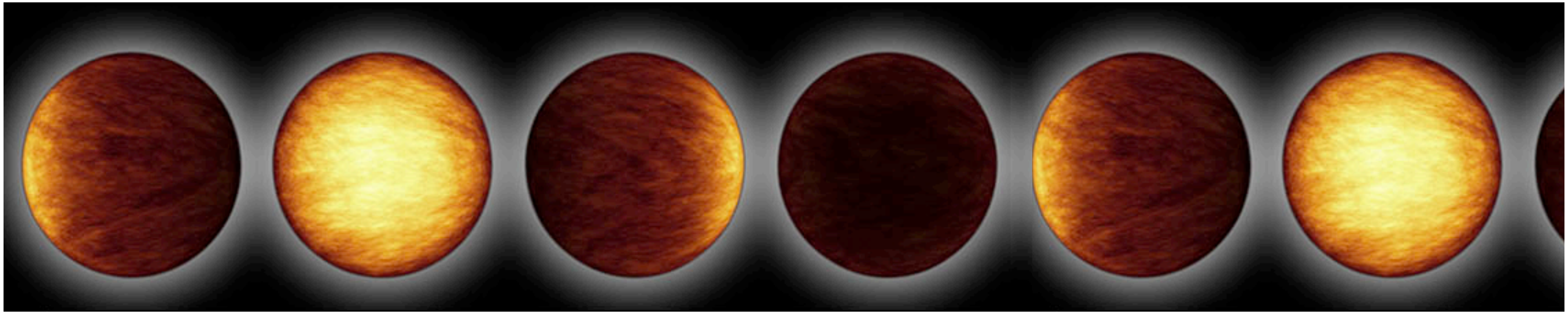
NIRES can make direct detections of water in Exoplanet atmospheres

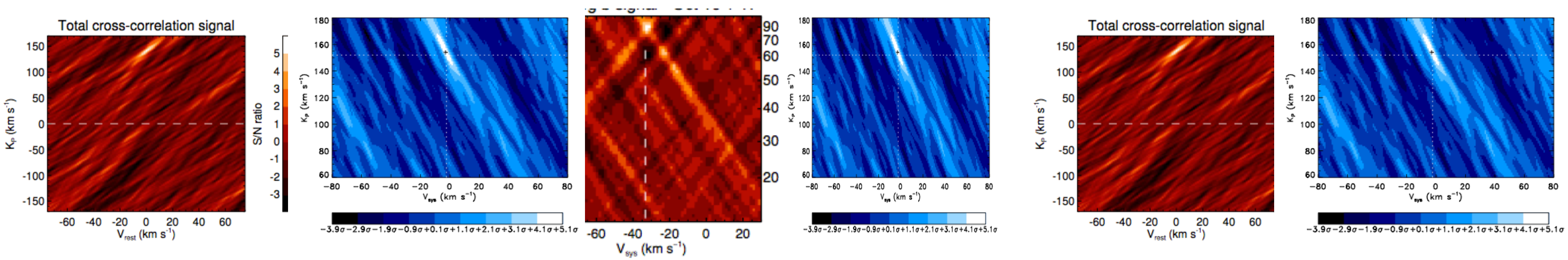


Birkby+2013

Water emissions from HD189733b were detected even in heavy telluric contamination in L band

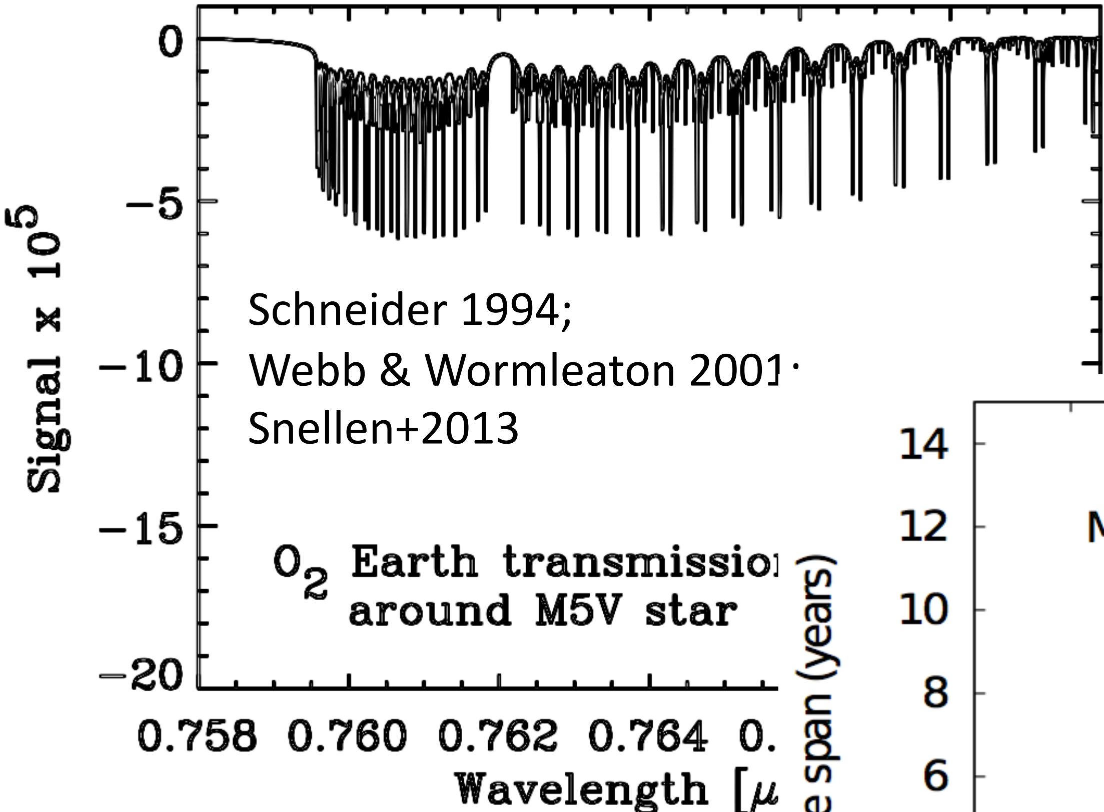
NIRES can probe compositions, orbital motion, atmospheric dynamics and thermal structure of (non-)transiting planets **as a function of longitude**

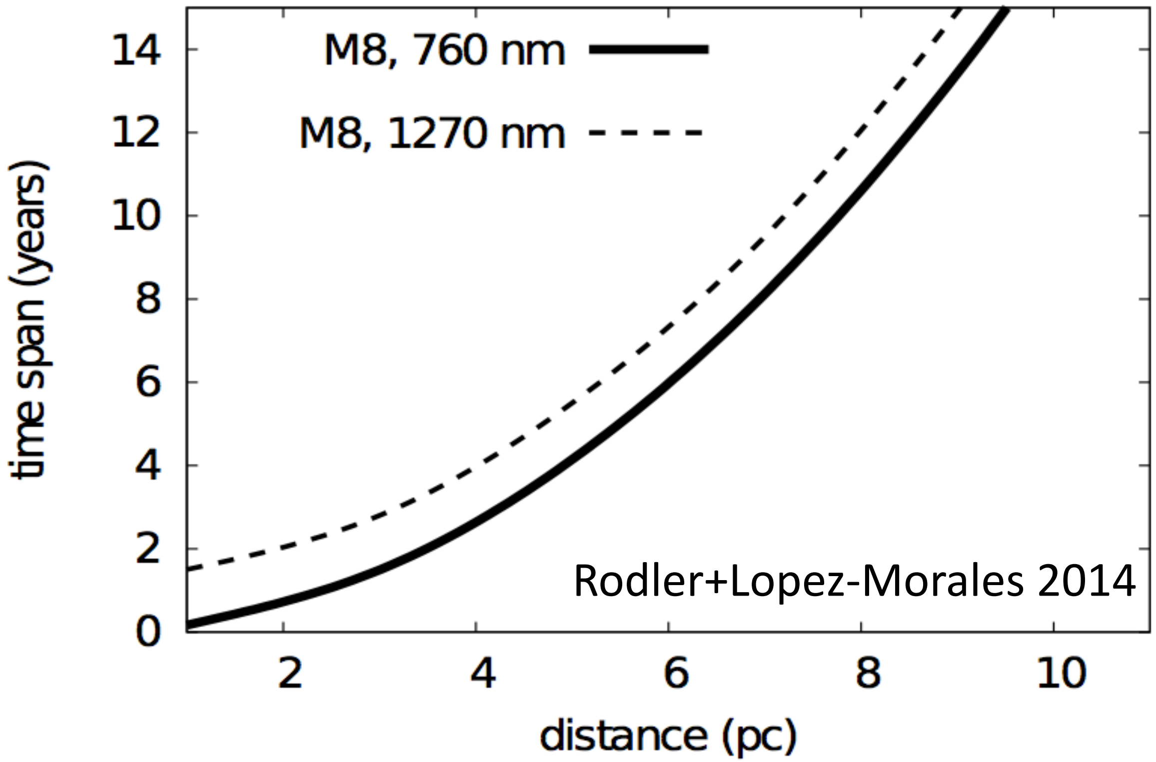




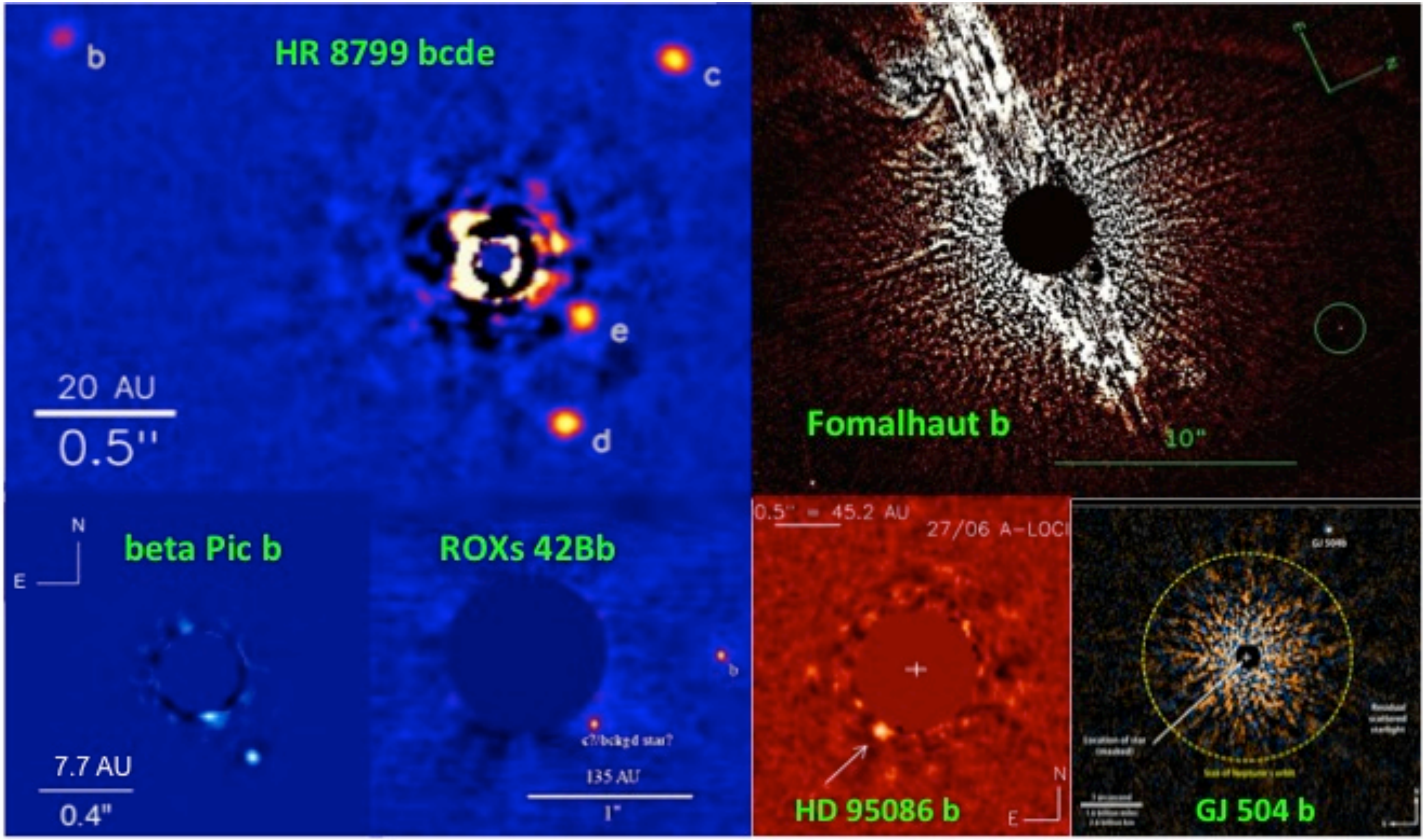
Brogi+2013, 2014, Birkby+2014, de Kok+2013, Rodler+2013a, b

HROS/NIRES: Detecting O_2 with high-dispersion Doppler spectroscopy



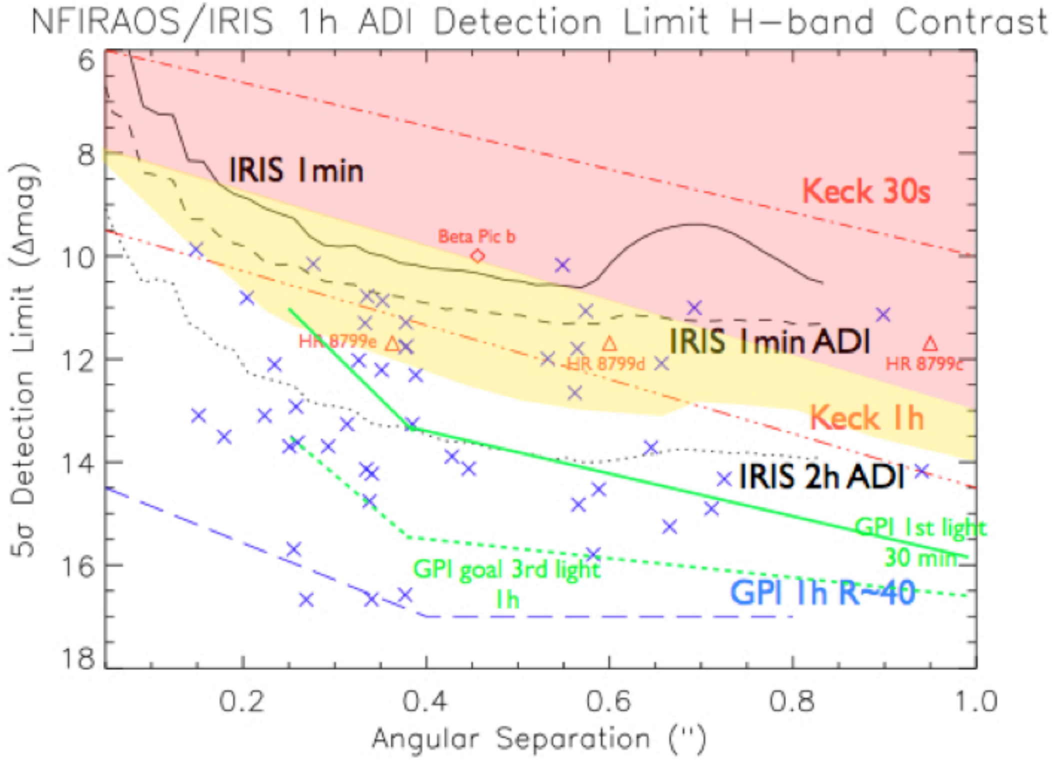


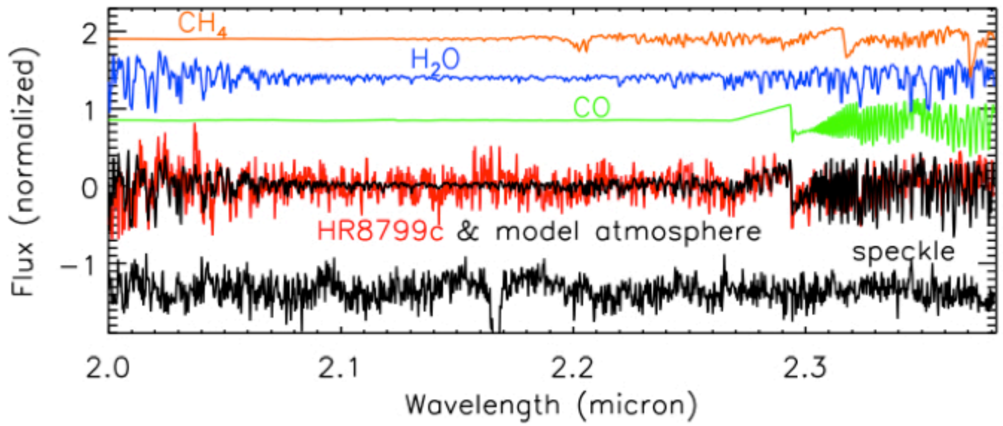
Exoplanet Direct Imaging with the TMT



(Marois et al. 2008, 2010; Kalas et al. 2008; Lagrange et al. 2010;
Currie et al. 2014; Rameau et al. 2013, Kuzuhara et al. 2013)

Exoplanet Imaging Science with TMT/IRIS: Characterizing Young Gas Giants



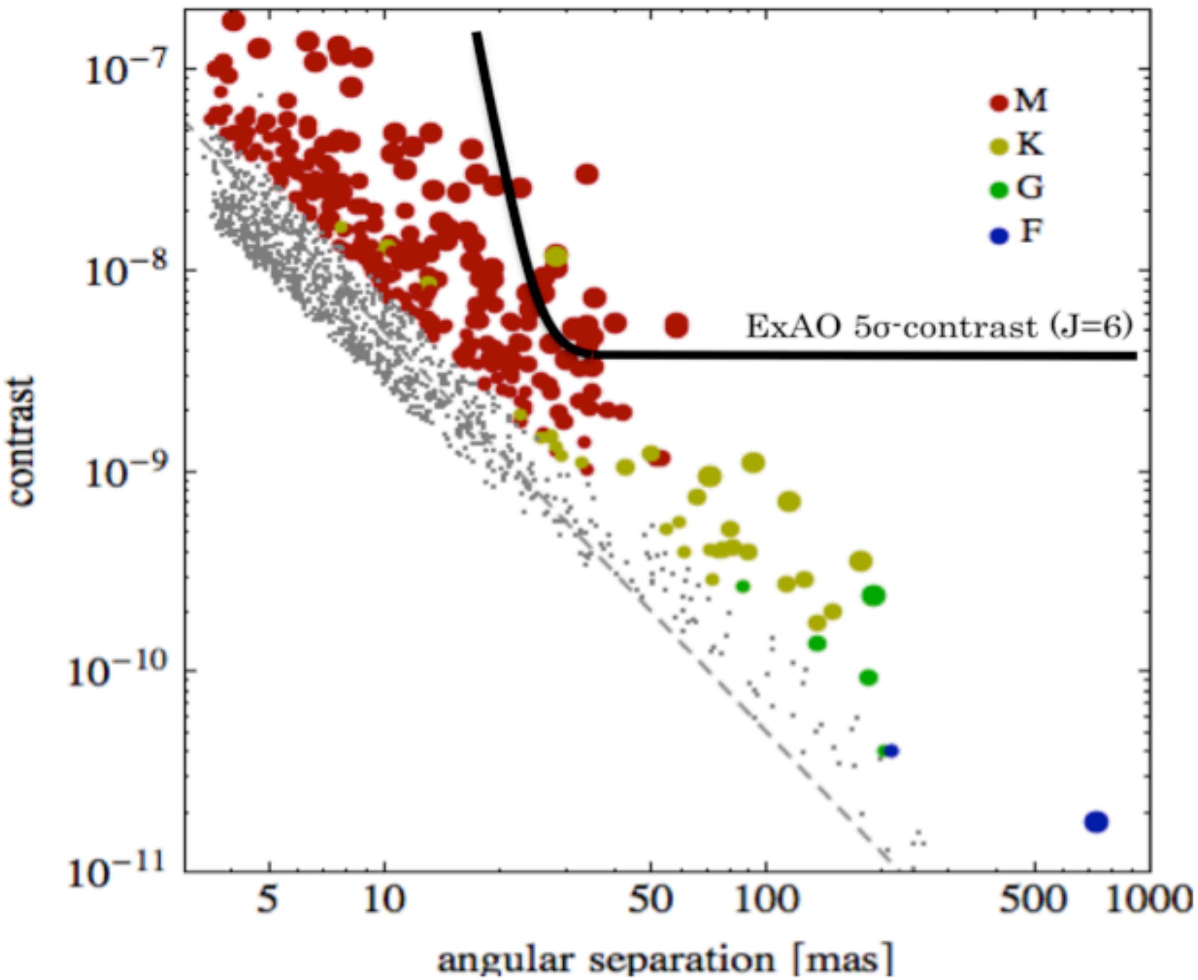


- Many/most of the planets detectable with GPI, SPHERE, and SCExAO can be followed up at **higher spectral resolution**

- Higher-resolution spectra → **multiple resolved molecular line transitions, C/O ratio, clues about the planet's formation**

(Marois et al. 2012; Konopacky et al. 2013)

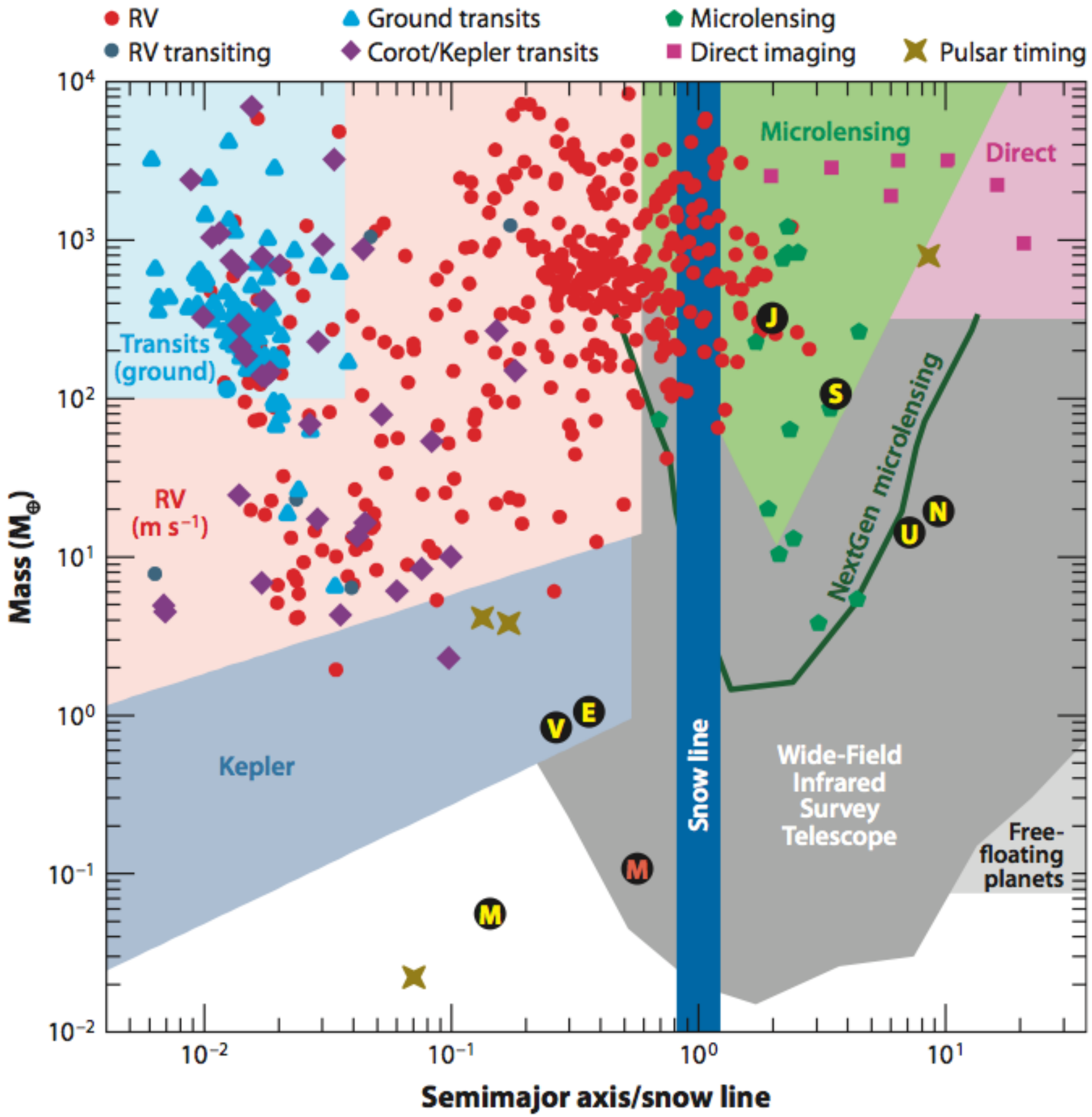
Exoplanet Science with a Dedicated Imaging Instrument (TMT/PSI-like): Rocky Planets



- Other imaging science: self-luminous Saturn and Jupiter-mass planets, imaging RV/transit-detected planets, molten Earths, tidally-heated exomoons

Microlensing Planets (2003 – 2014)

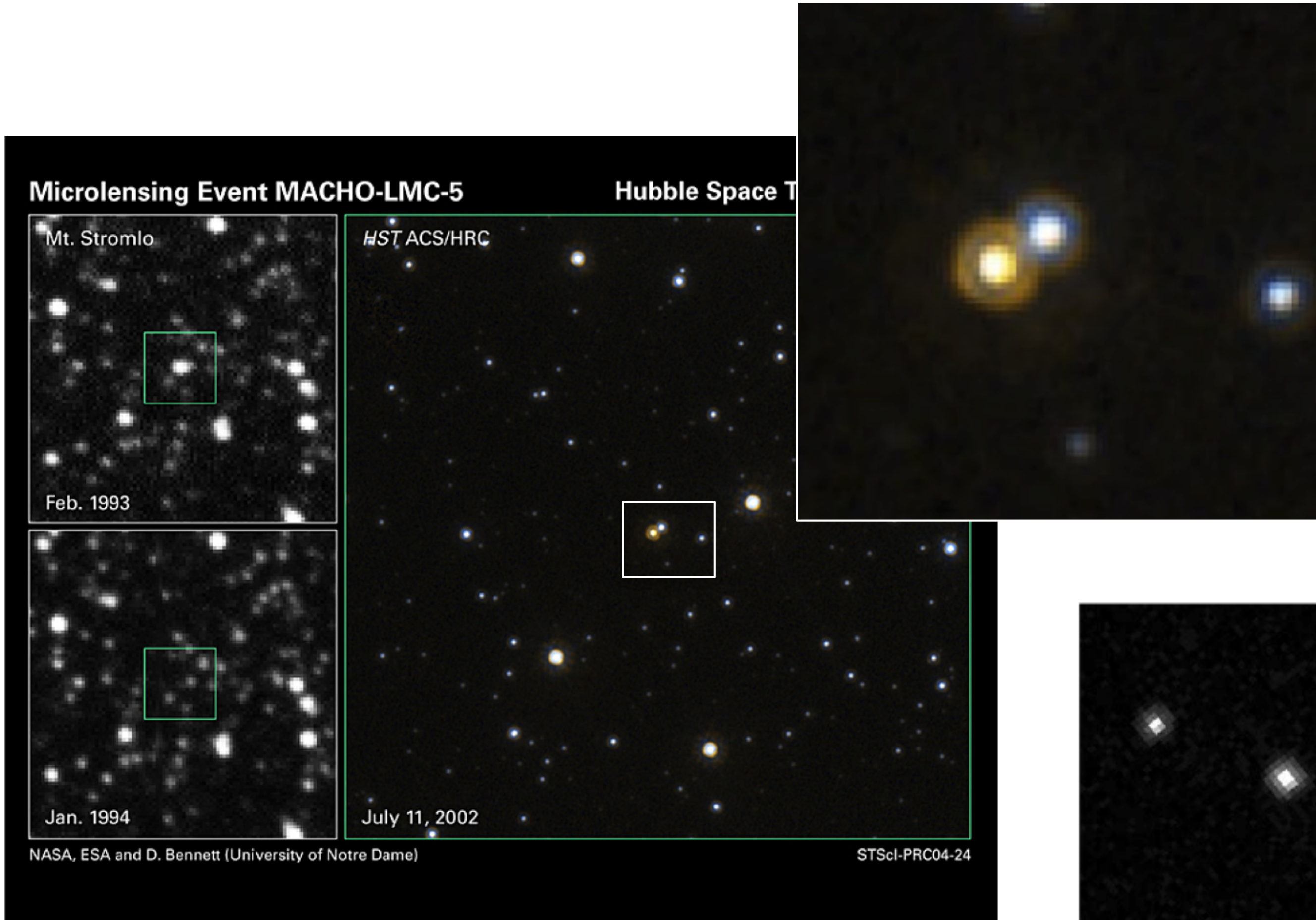
- Unique:
  - Most sensitive to planets at ~1-10 AU
  - both disk and bulge (up to ~8kpc)
  - free-floating planets
- ~30 planets down to ~few M_{earth} published
- Two order-of-magnitude leaps expected in the coming decade



Gaudi, 2012, ARAA, 50, 411

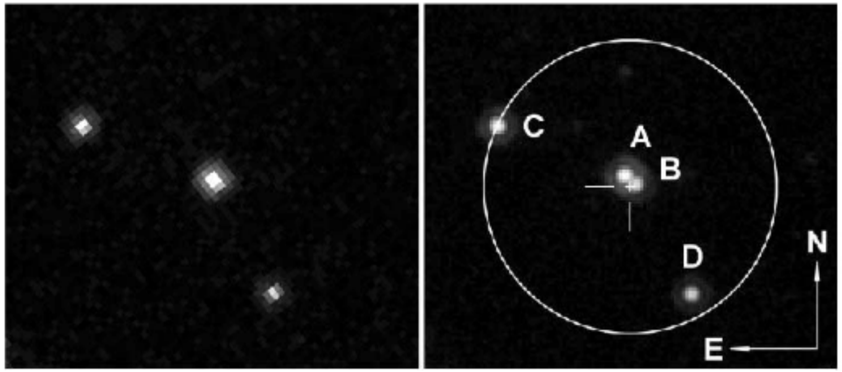
Planet host mass and distance need follow-ups

- So far lens and source have been separately resolved for only two (non-planetary) microlensing events.



MACHO-LMC-5:
Alcock et al (2001);
Drake et al (2004)
[exceptional large proper motion: ~20 mas/yr]

MACHO-95-BLG-37:
Kozlowski et al. (2007)
[~11 mas/yr]



TMT IRIS+NFIRAOS will critically enhance the science values of microlensing discoveries

- Host mass and distance measurements will enable:
  - Accurate determination of planet mass function
  - Many target: WFIRST-AFTA will discover ~3000 planets within 0.3-30 AU down to 2 Moon mass + free-floating Mars.
  - Studying planet distribution for different stellar environments:
    - ✓ Dependency as a function of stellar mass
    - ✓ Bulge vs. Disk
    - ✓ Metal Rich vs. Metal poor

Necessary Instruments for Exoplanet Studies

- Wide-Field MOS Instruments (MOBIE, IRMS, IRMOS)
- High Dispersion Spectrographs
  - HROS
  - NIRES
  - (simultaneous in future?)
- High Contrast Imagers
  - IRIS+NFIRAOS
  - PSI-like+ExAO

Important Instruments for Exoplanet Studies

- High Dispersion Spectrographs (R ~ 100,000)
  - Exoplanet community definitely needs optical-NIR high dispersion spectrographs to characterize the mass, orbit, and atmospheres of interesting exoplanets at an early stage
- High Contrast Imagers
  - Exoplanet ISDT sent a strong requirement for high contrast capability of IRIS+NFIRAOS last year to SAC
  - Future high contrast imagers (PSI-like+ExAO) are also desired

Necessary 2nd Generation Instruments

1. High Contrast Capability of IRIS+NFIRAOS
   - Atmospheres of imaged young planets
2. NIRES-like + RV Capability
   - Mass, orbits. atmosphere of small planets around cool stars

- HROS-like + RV Capability (simul. capability with NIRES?)
  - Mass, orbits of small planets around Sun-like stars
  - Oxygen around HZ planets around cool stars
- PSI-like + Extreme AO
  - Direct imaging of small planets and whole planetary systems

Possible Key Programs

1. Uncovering exoplanetary atmospheres
   - via transmission / emission spectroscopy
     - ✓Using MOS (MOBIE, IRMS, IRMOS)
     - ✓Using high dispersion spectrographs (HROS, NIRES)
   - via direct imaging + IFU
     - ✓IRIS + NFIRAOS
     - ✓PSI-like + ExAO

Possible Key Programs

2. Characterizing exoplanetary masses and orbits
   - Using high dispersion spectrographs + RV capability
   - for especially interesting transiting planets discovered by K2, TESS, PLATO

Timeline of TMT's Exoplanet Studies

- First light instruments
  - IRIS+NFIRAOS: direct imaging, microlens follow-up
  - MOBIE, IRMS: atmospheres of transiting planets
- NIRES, HROS
  - Follow-ups of Kepler, K2, TESS, PLATO targets
  - Mass, orbits, atmospheres of discovered planets
- PSI-like+ExAO
  - imaging of small planets and whole planetary systems
  - atmospheres of imaged planets

Summary

- We definitely need TMT for exoplanet studies

- NIRES, HROS, PSI-like instruments are desired for future instruments