Spectroscopic characterization of extra-solar planet atmospheres

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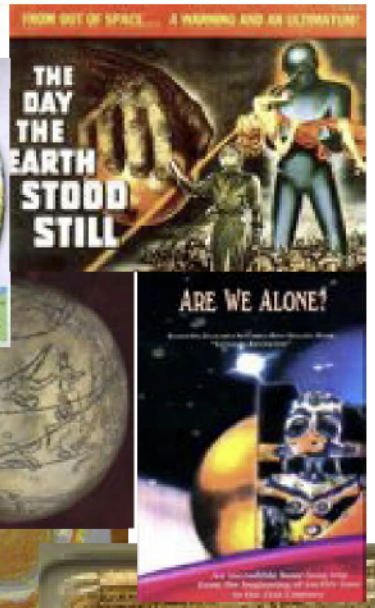
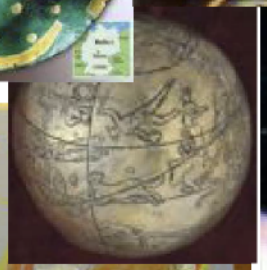
Are we alone?

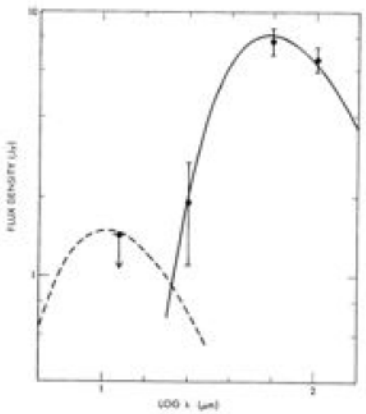
- Are there planets around other stars?
- Are there other planetary systems?
- Are there other Earth-sized planets?
- Are there Earth-like planets with life? With intelligent life? Is the Sun typical?
- Why not? What does it mean to be typical? What can other stars tell us about the Sun and its behavior?



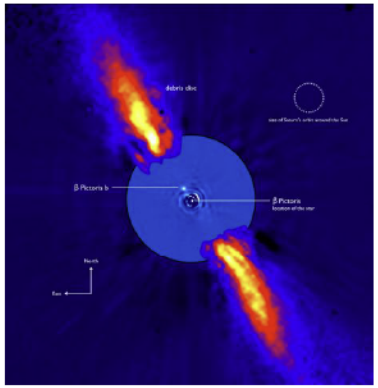


The search for planets

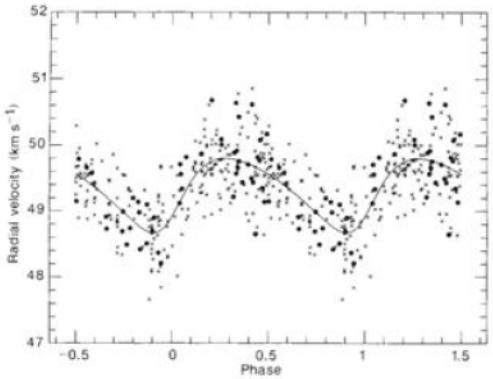
Dust around a star
Auman et al. 1984



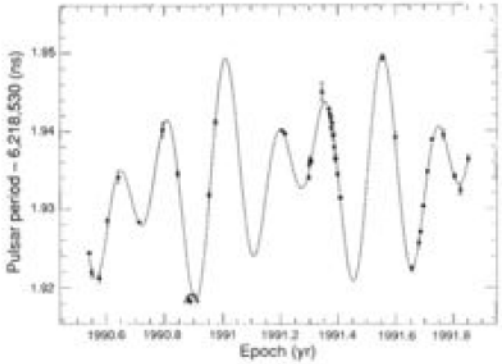
images of warm disk
Smith & Terrile 1984

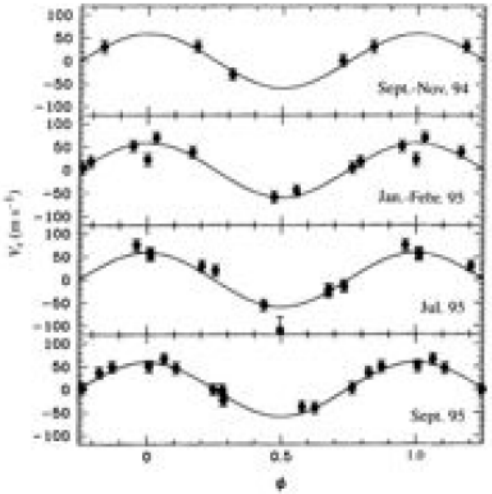


An unseen companion
Latham et al. 1989



Pulsar Planets
Wolszczan & Frail 1992

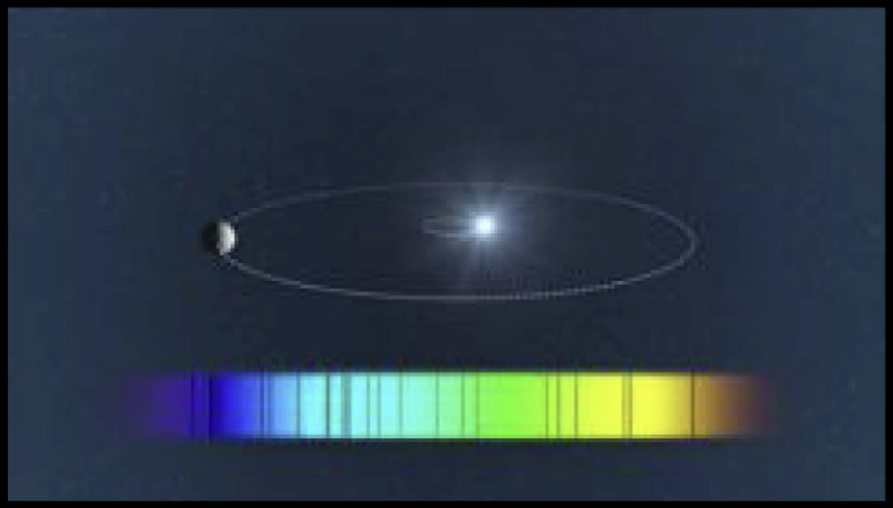


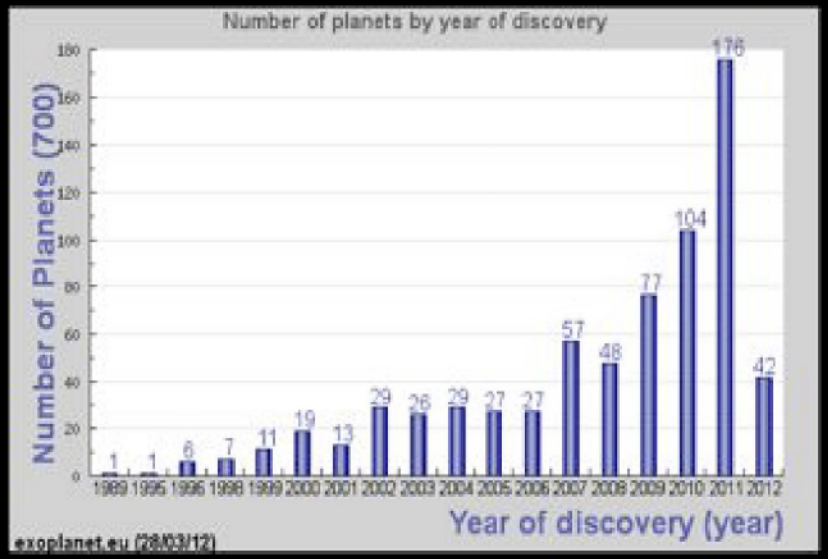


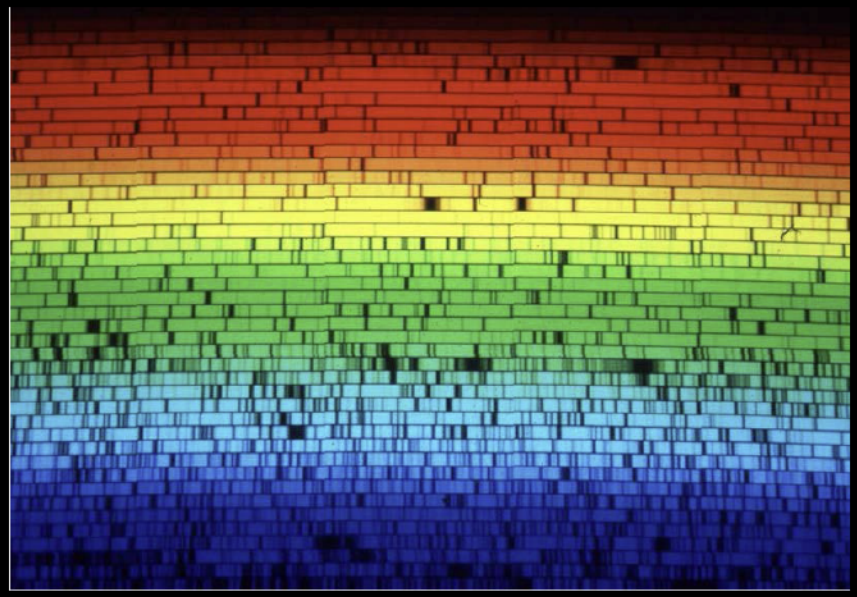
51 Peg, the first REAL planet
Major et al. 1995

Radial Velocity Planet finding

- Since 1995, a steady stream of planets discovered
- Radial velocity: 1 planet every other day
- 701 planets
- 91 multi-systems

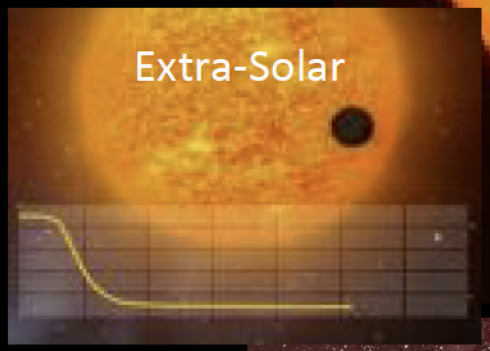


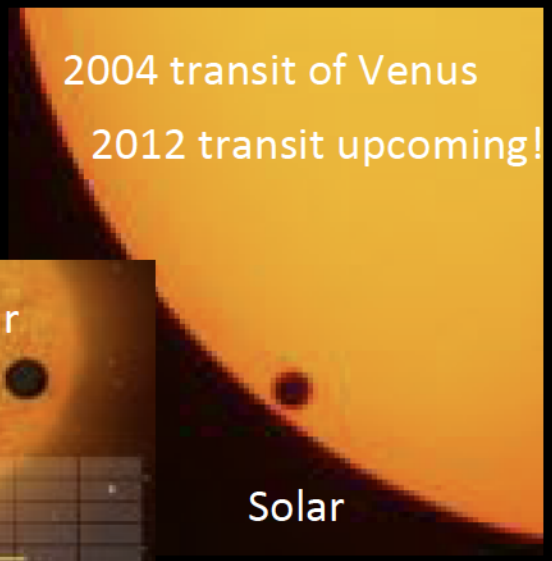


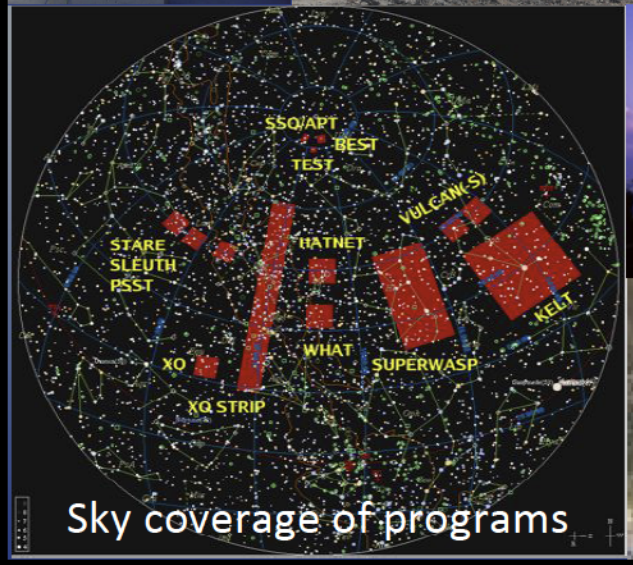


Transiting planets

- 1999: HD 209458b, Charbonneau et al.
- Simple hardware – anyone can join

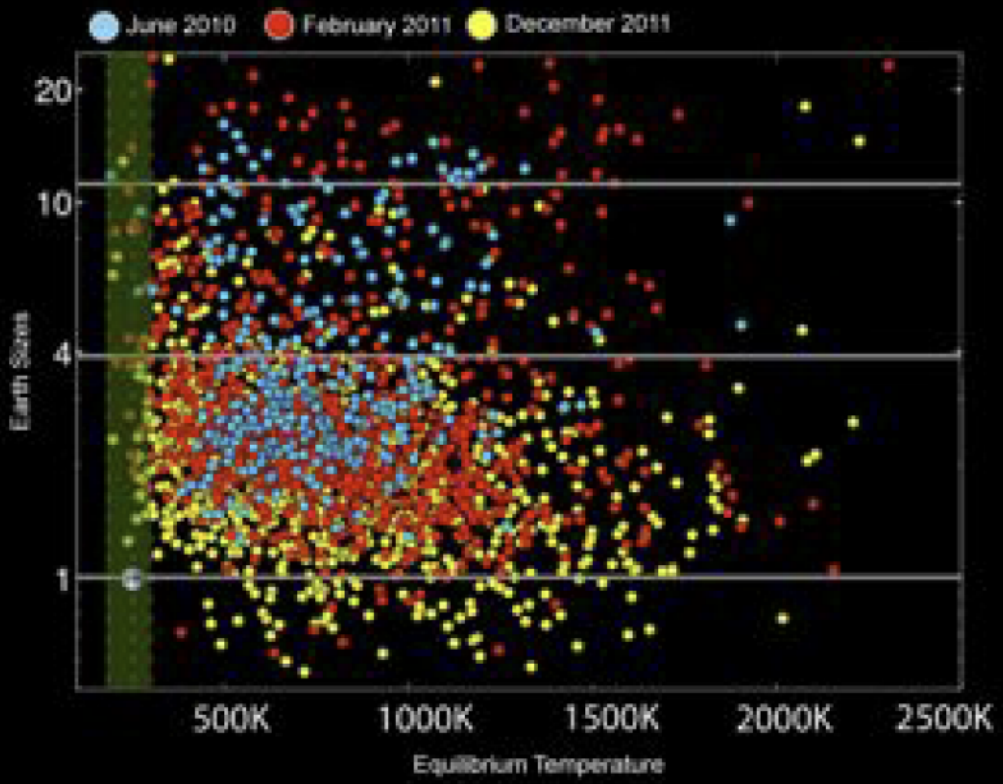


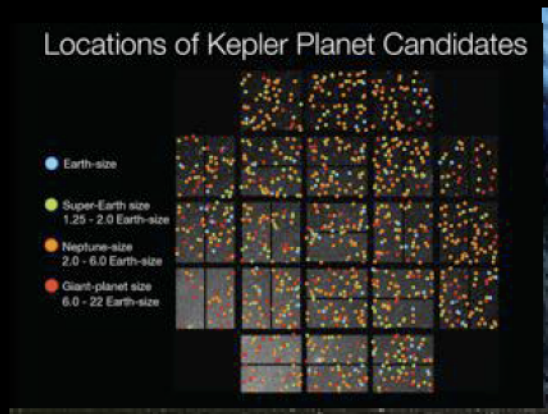


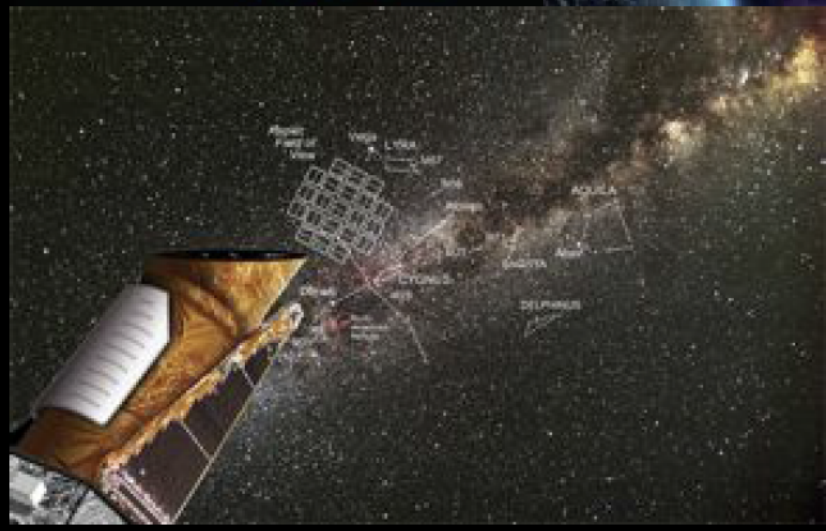


Space based transit search

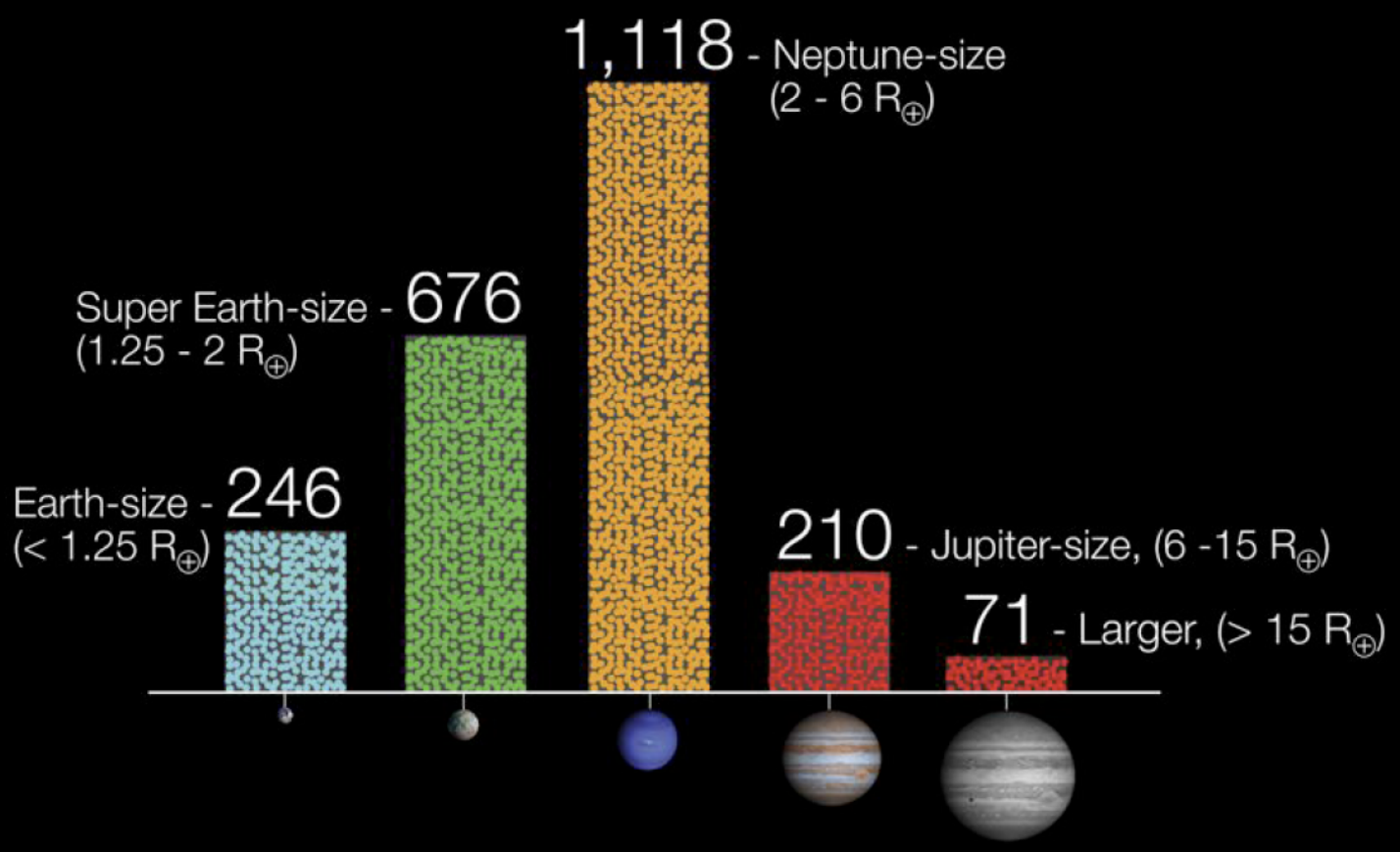
Thousands of planets in a small part of the sky!



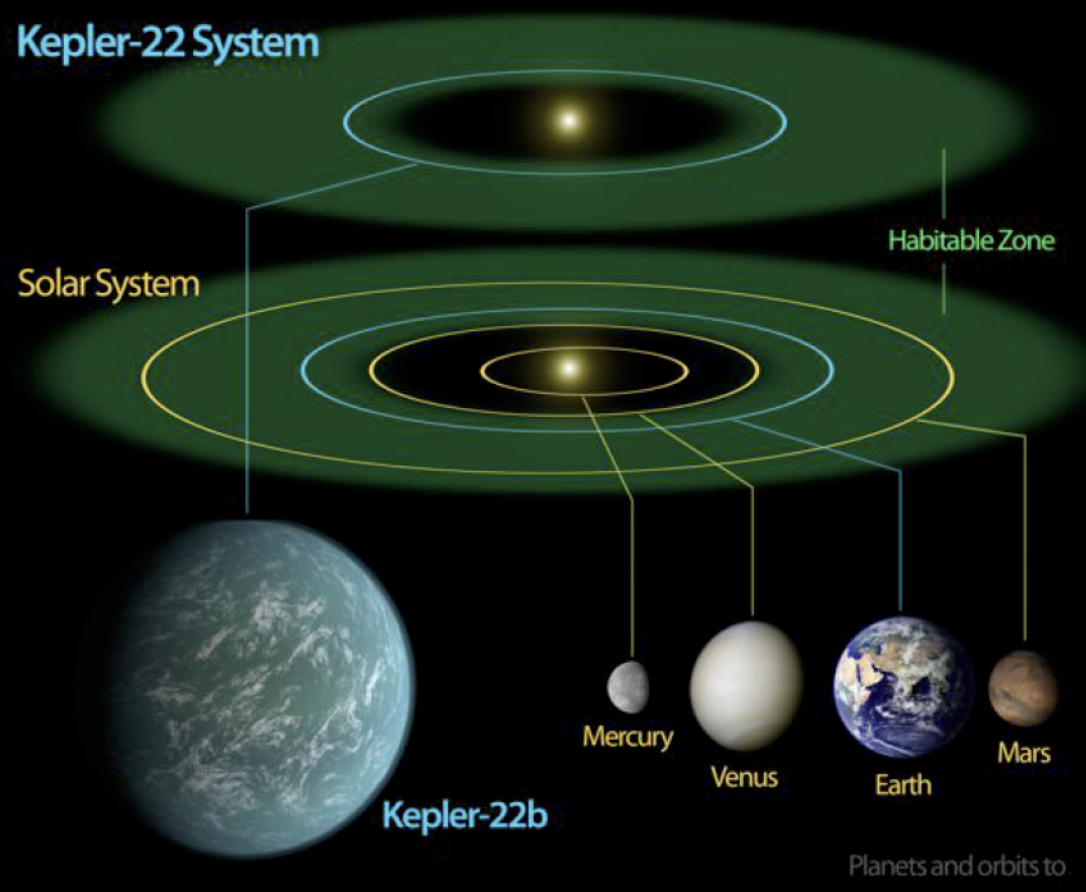




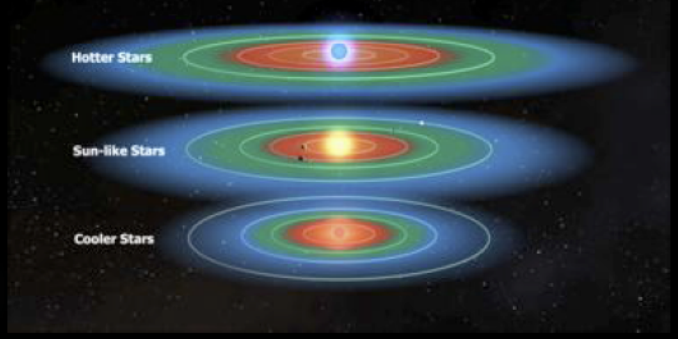
Planets are everywhere and the small ones dominate



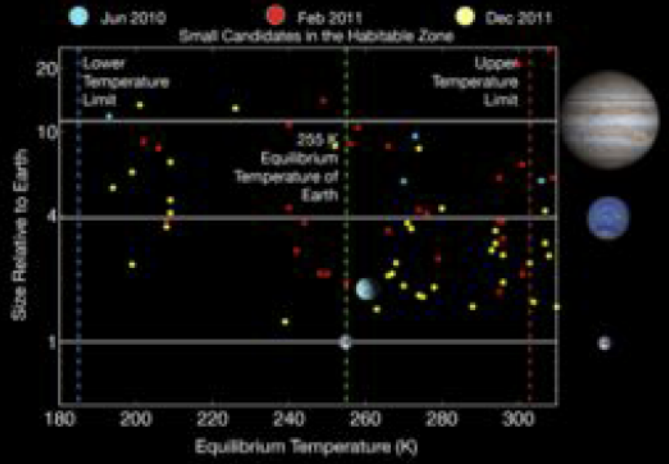
First habitable transiting planets being discovered



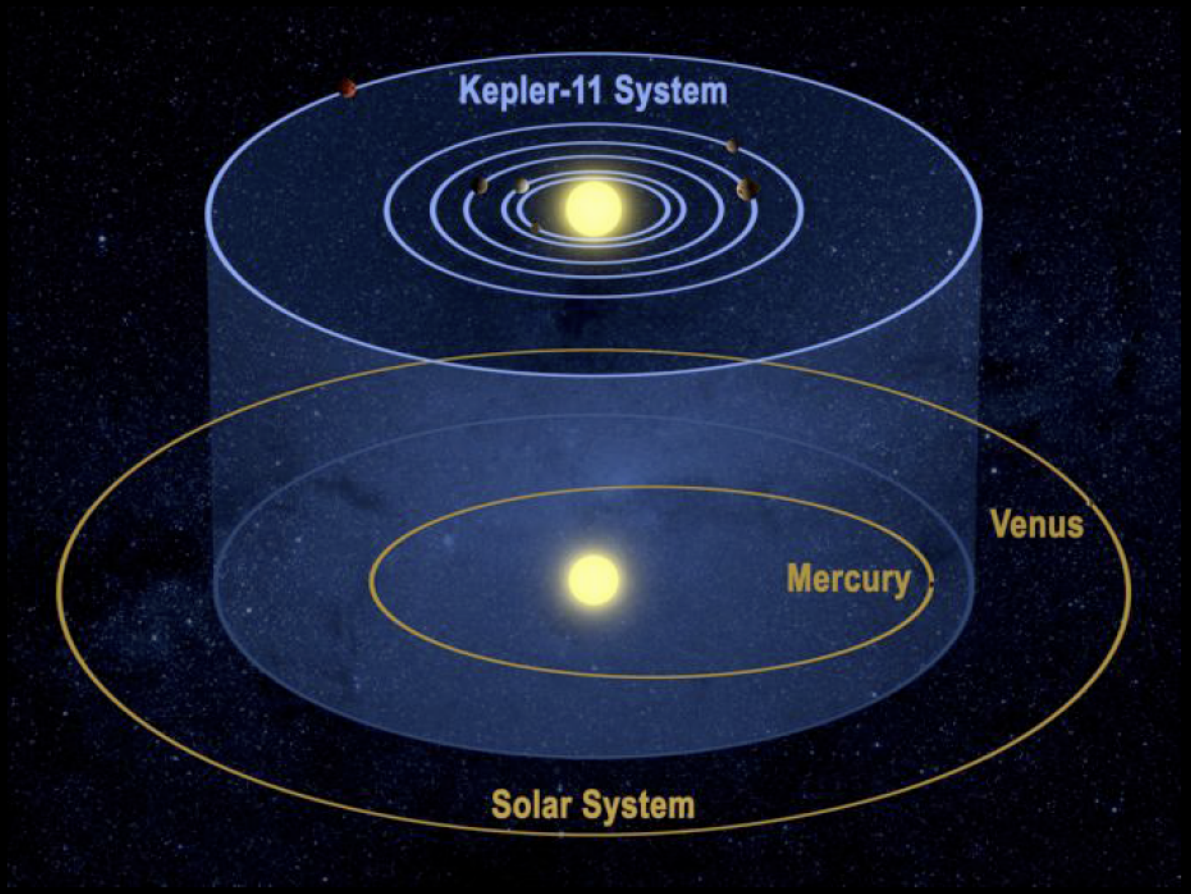
Habitable/Goldilocks zone



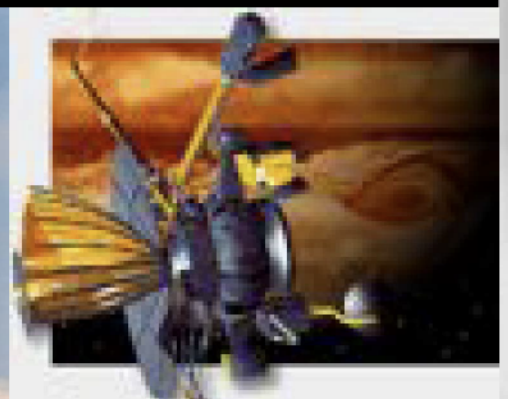
First Confirmed Kepler Planet In the Habitable Zone



multi-planet systems are common

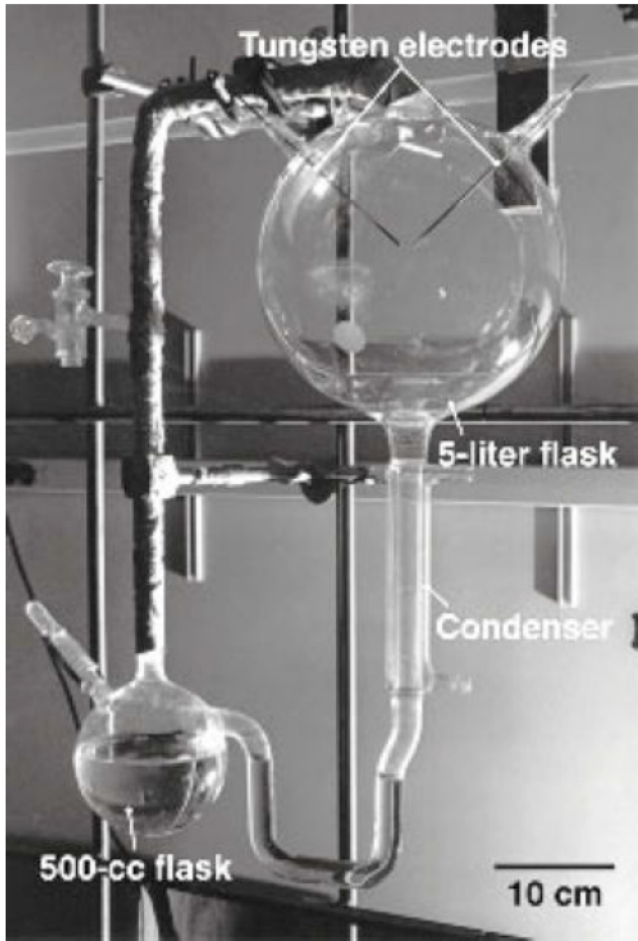


BUT: HOW ABOUT THE ATMOSPHERE?



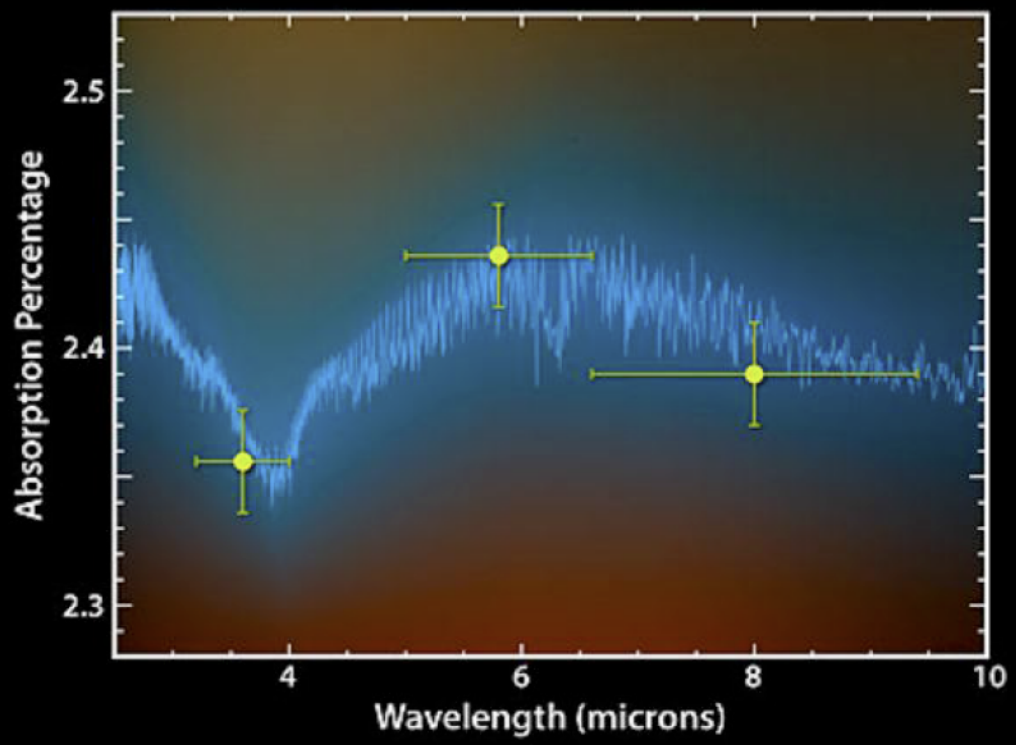
Molecules as probes

- Molecules are probes of conditions, composition, & chemistry
- The most powerful tool we have for characterizing exoplanet atmospheres
- Potential biological significance
  - Possible precursors
  - biomarkers



State of the art today

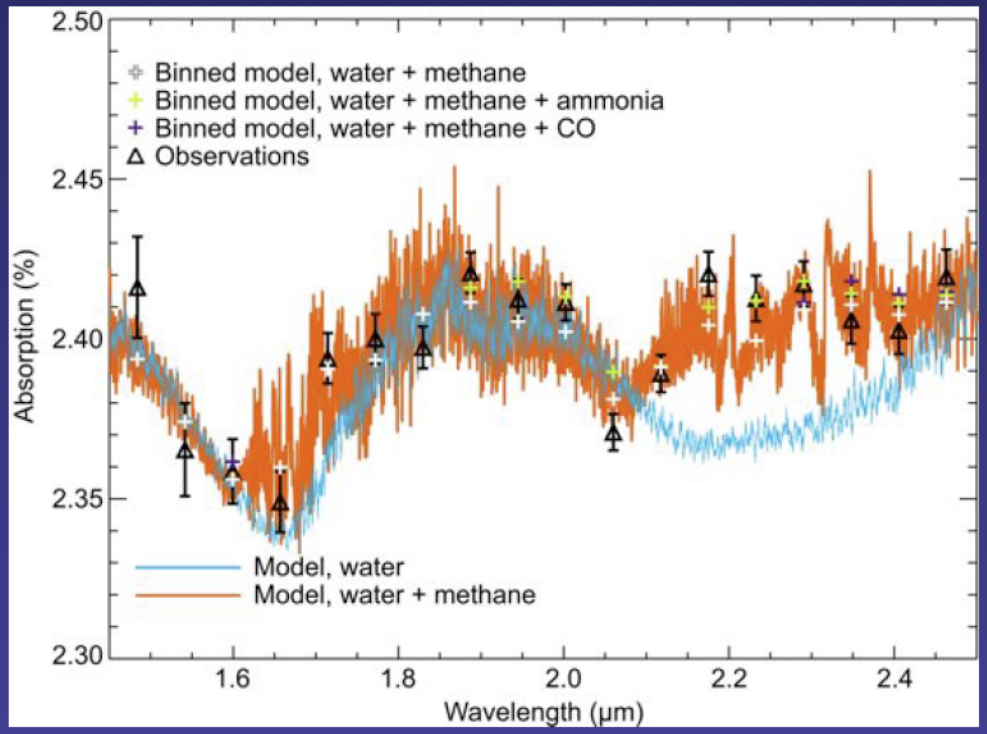
– Characterizing the atmosphere –
molecules: the story begins



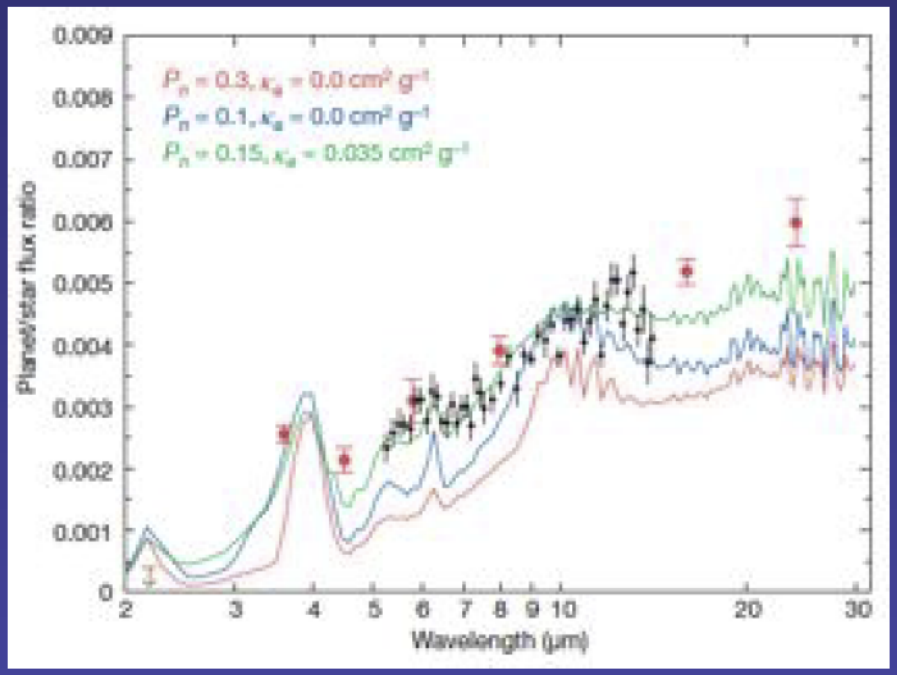
Water Signatures in Exoplanet HD189733b Spitzer Space Telescope • IRAC
NASA / JPL-Caltech / G. Tinetti (Institute d'Astrophysique de Paris) ssc2007-12a

Molecules in a hot-Jupiter

methane – an unexpected guest



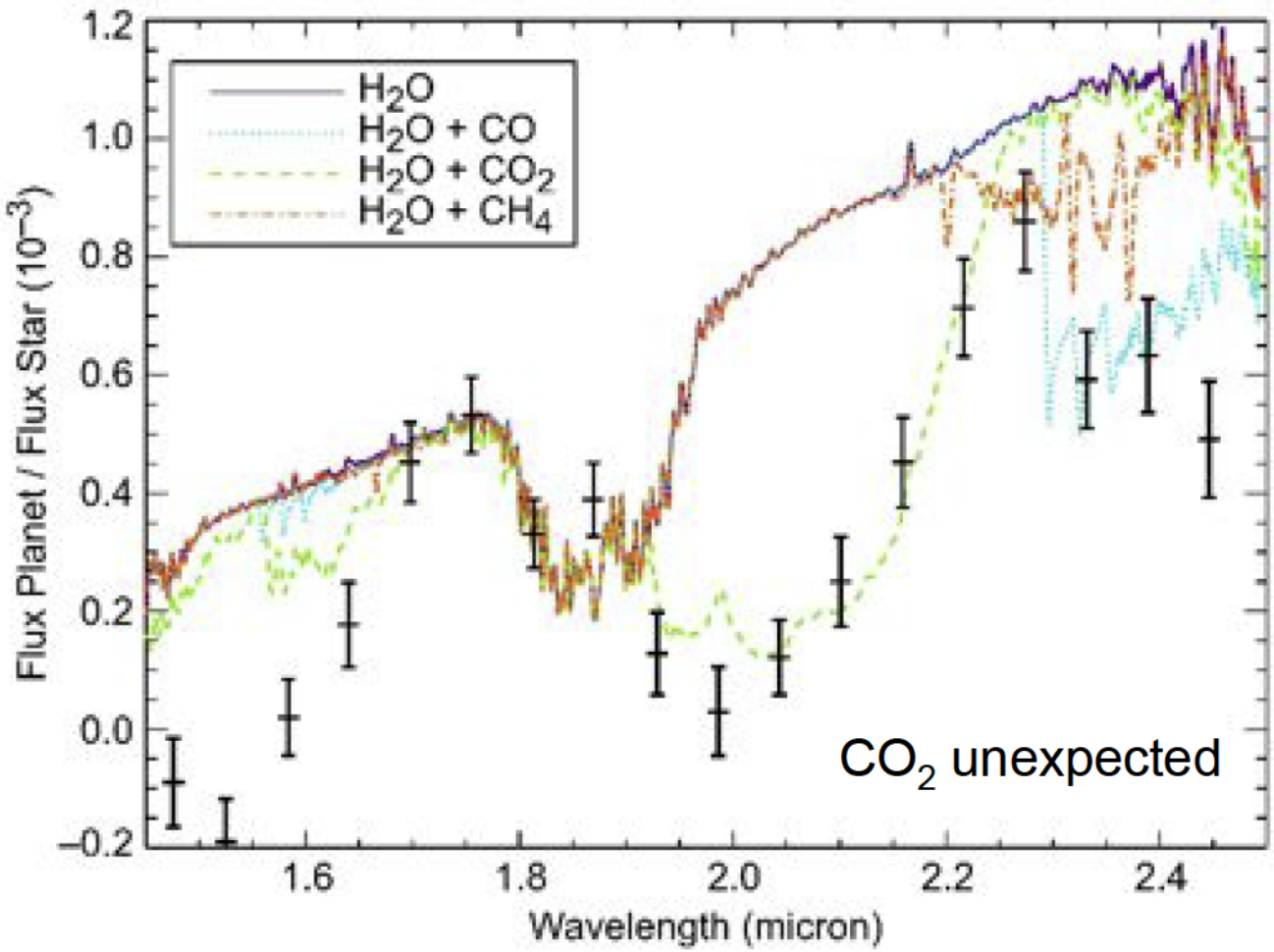
Swain, Vasisht & Tinetti 2008 Nature 452, 329



Grillmair et al. 2008 Nature 456, 767

Carbon Dioxide (HD 189733b)

Swain et al. 2009, Astrophys. Journ. Lettrs, 960, 114

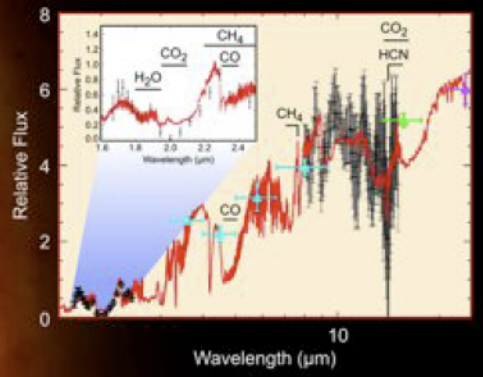


Dayside mixing rations

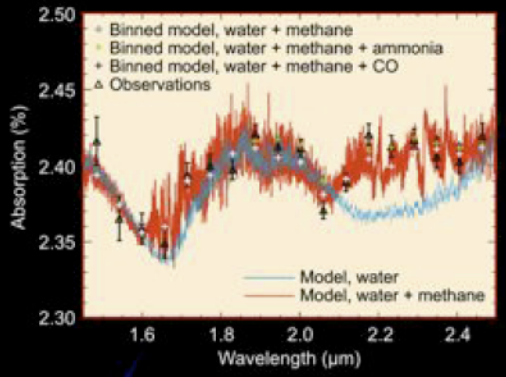
- H_2O ~ 0.1−1 × 10^{-4}
- CO ~ 1−3 × 10^{-4}
- CO_2 ~ 0.1−1 × 10^{-6}
- CH_4 ≤ 1× 10^{-7}

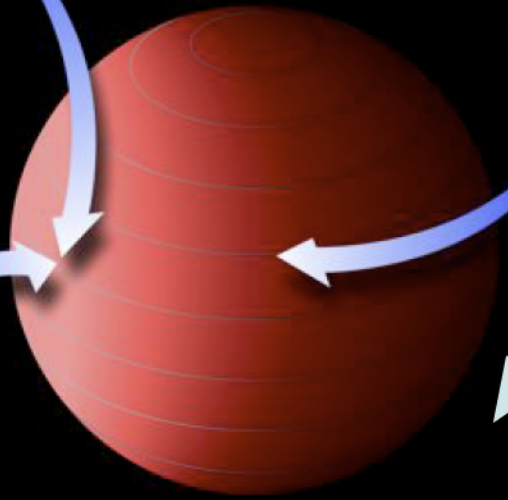
implies 0.5 ≤ C/O ≤ 1

Dayside
Emission Spectrum

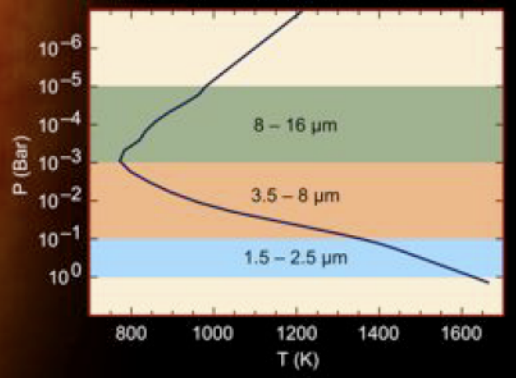


Terminator
Transmission Spectrum





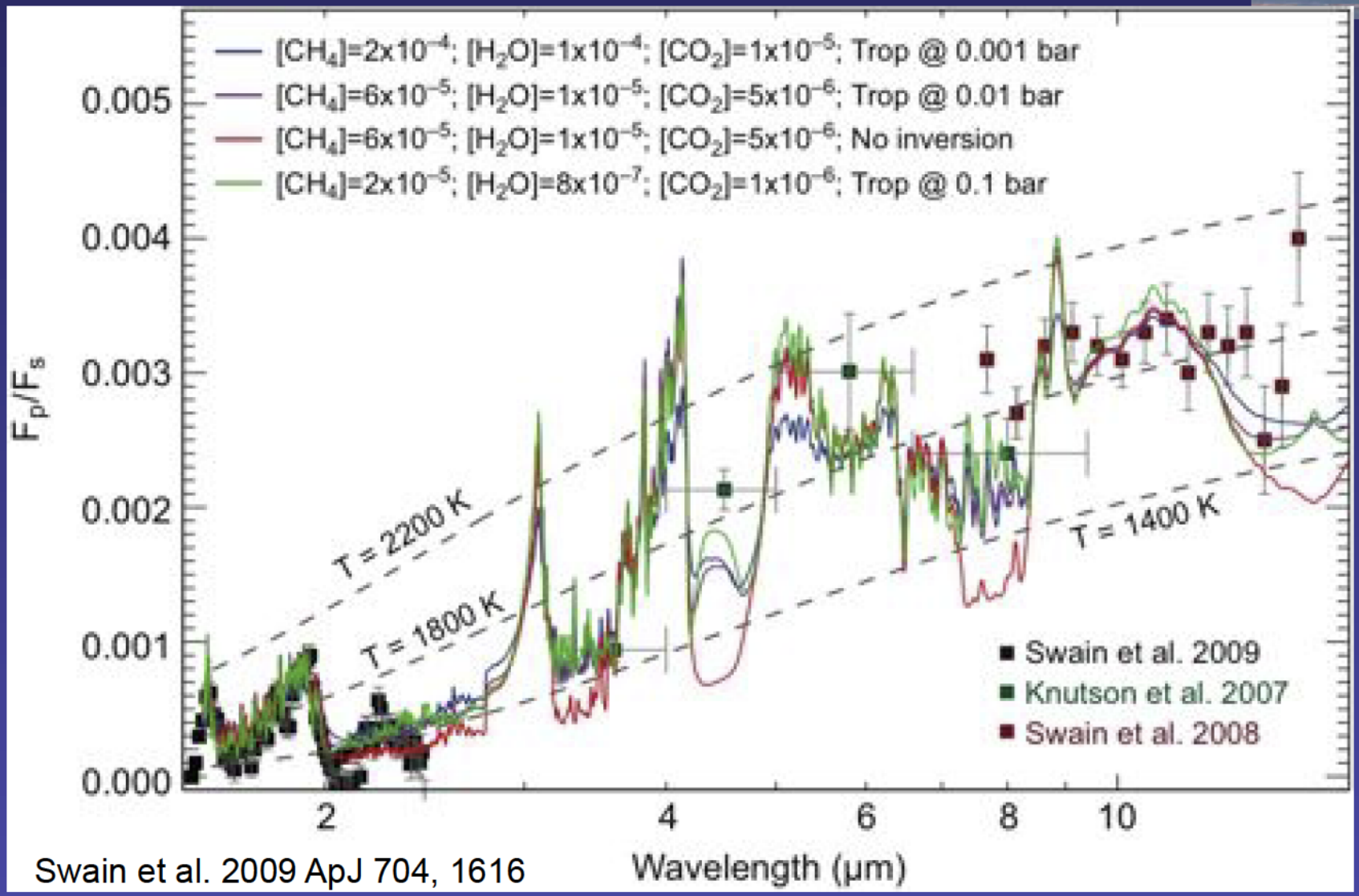
Dayside
Pressure-Temperature Profile



Nightside – we are working on it.

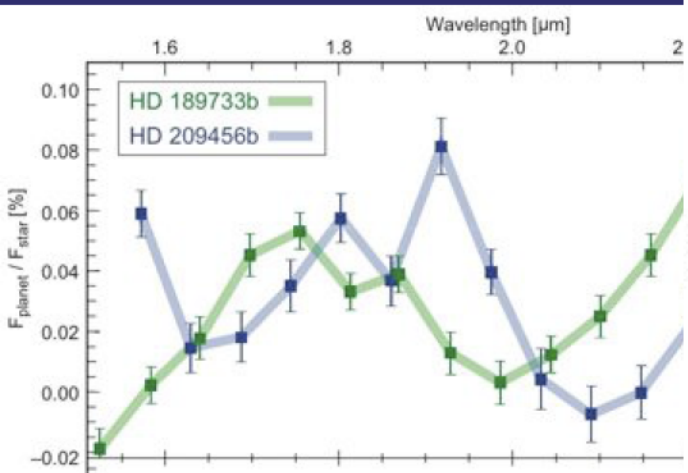
HD 209458b dayside

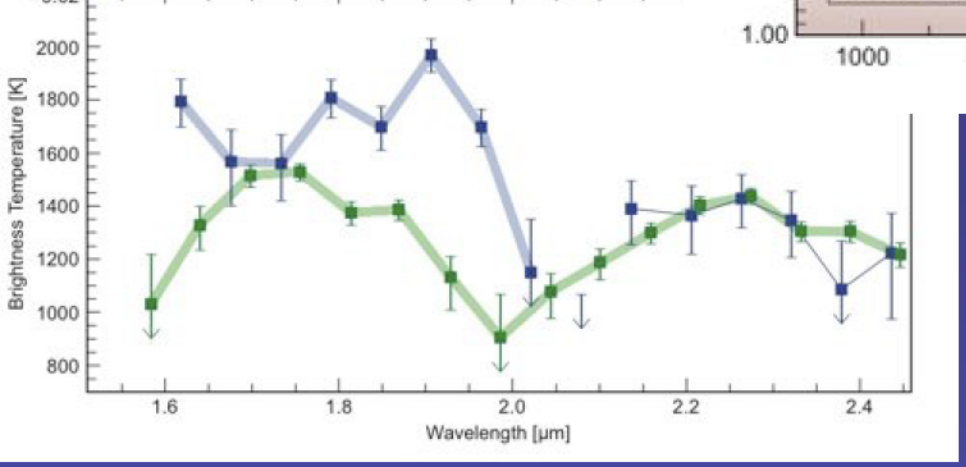
temperature/composition ambiguity

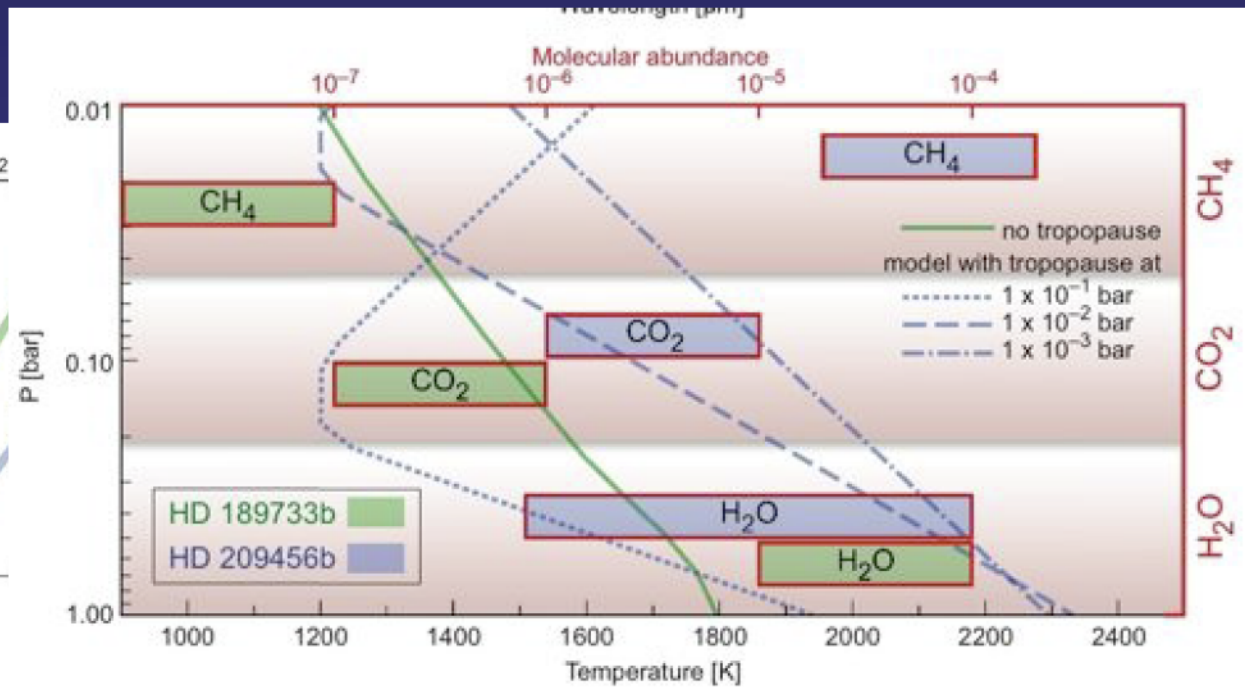


Swain et al. 2009 ApJ 704, 1616

First comparative exoplanetology



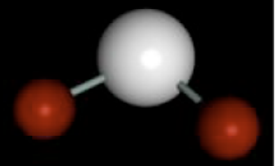


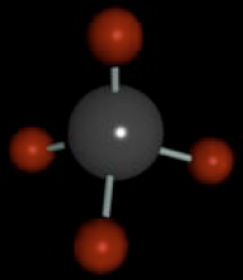


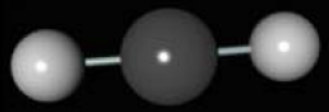
Swain et al. 2009 ApJ 704, 1616

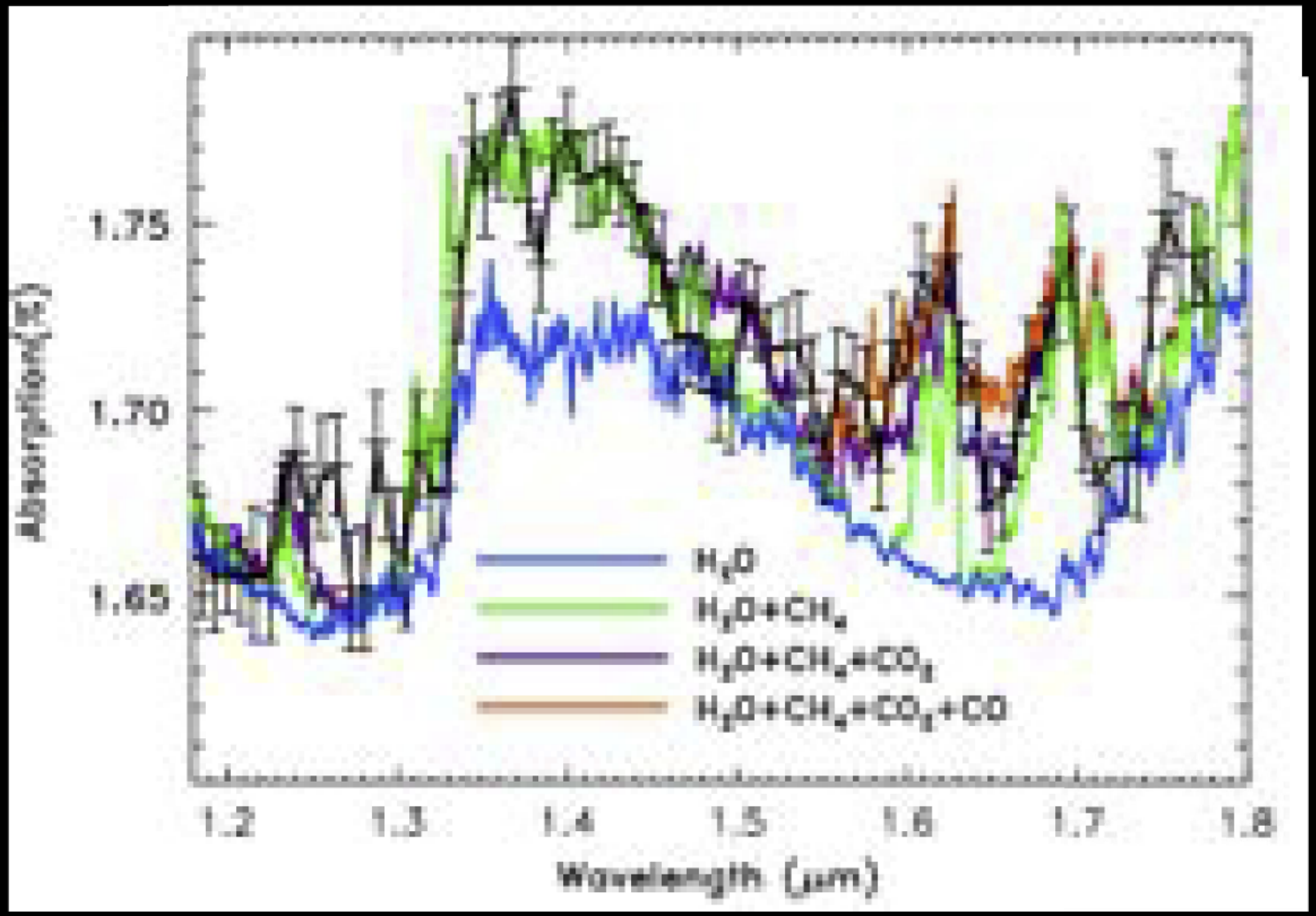
Interpreting the “wiggly line”

XO-1b







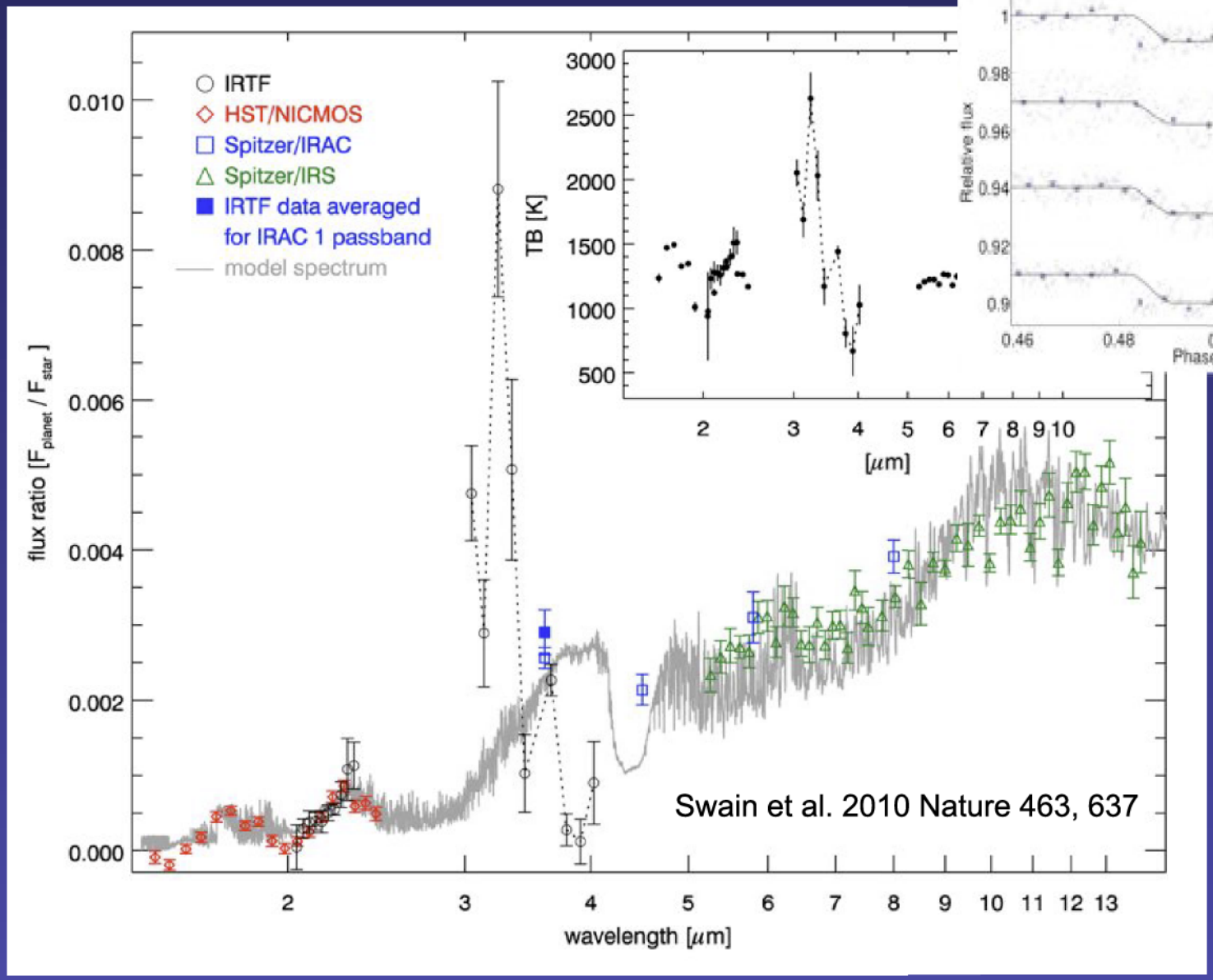


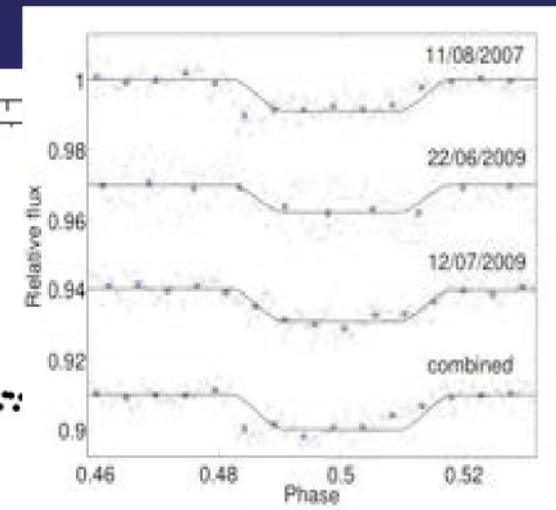
Tinetti et al. 2010 ApJ 712, 139

Ground-based observations

multi-instrument Hubble – IRTF – Spitzer

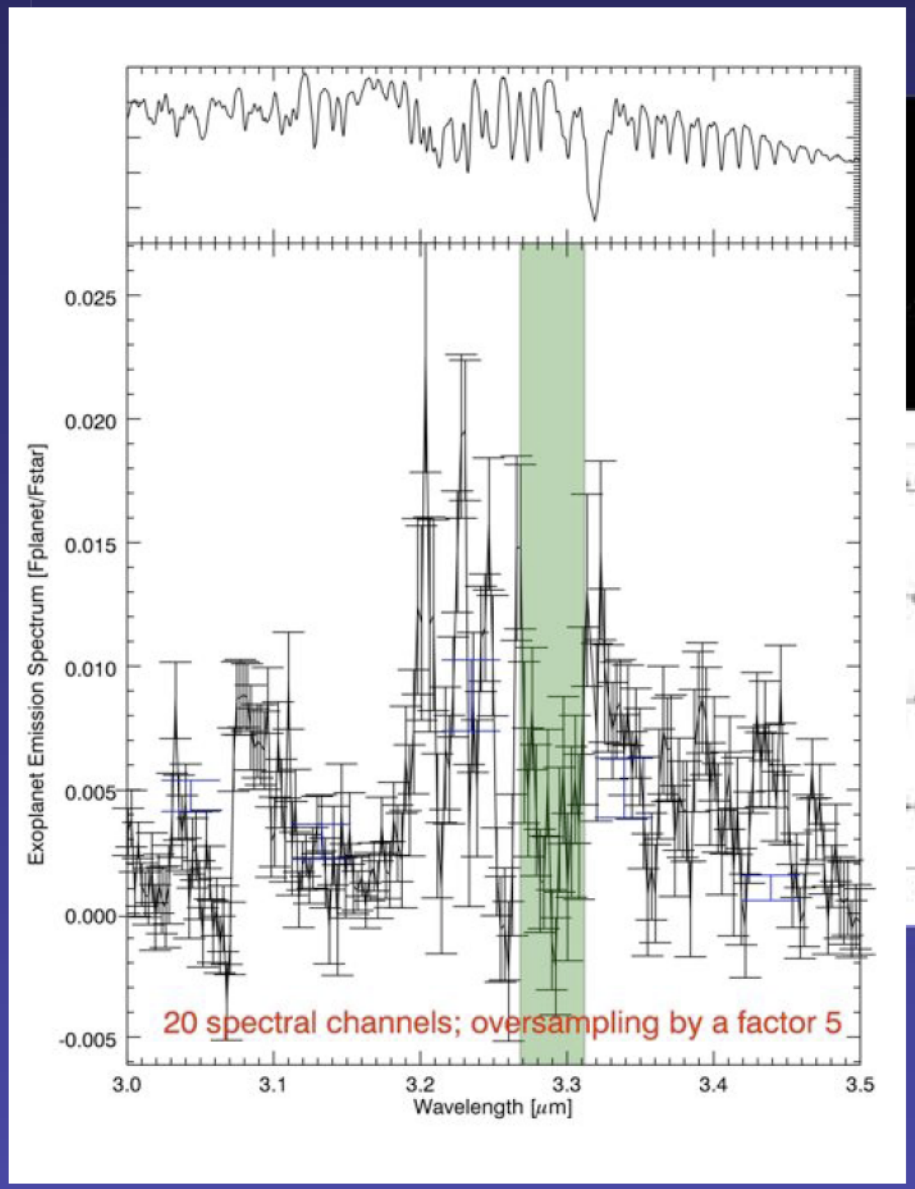
Hubble – Swain et al. 2009
Spitzer IRS – Grillmair et al. 2008
Spitzer IRAC – Charbonneau et al. 2008

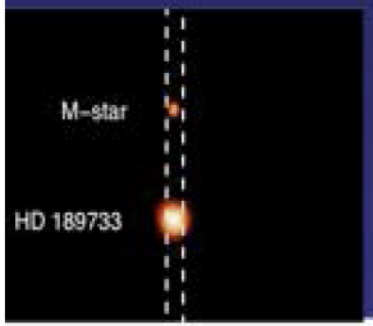


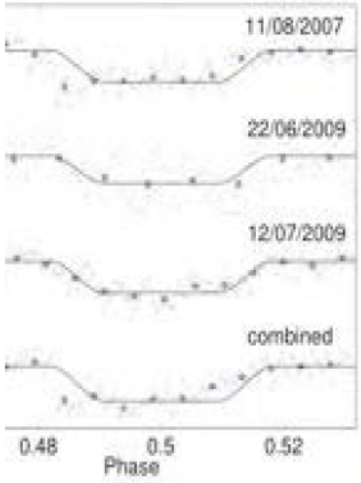


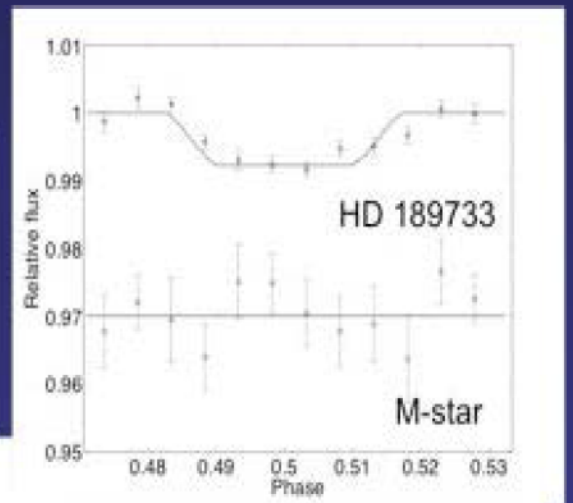
Ground-based observations

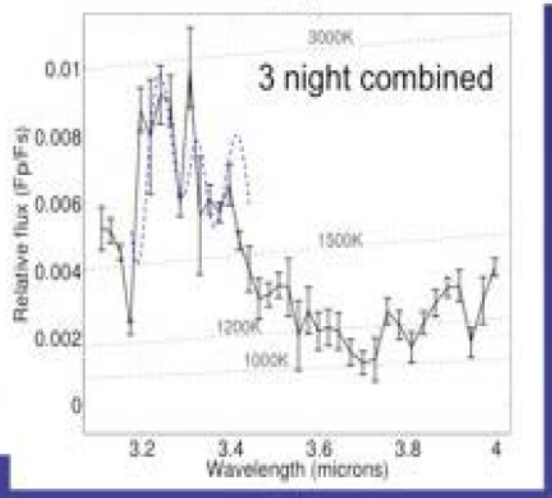
reproducible results







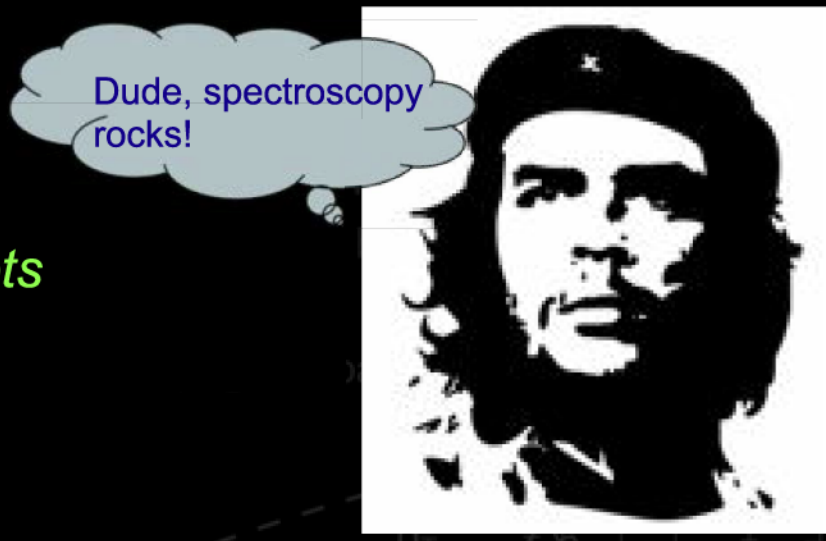




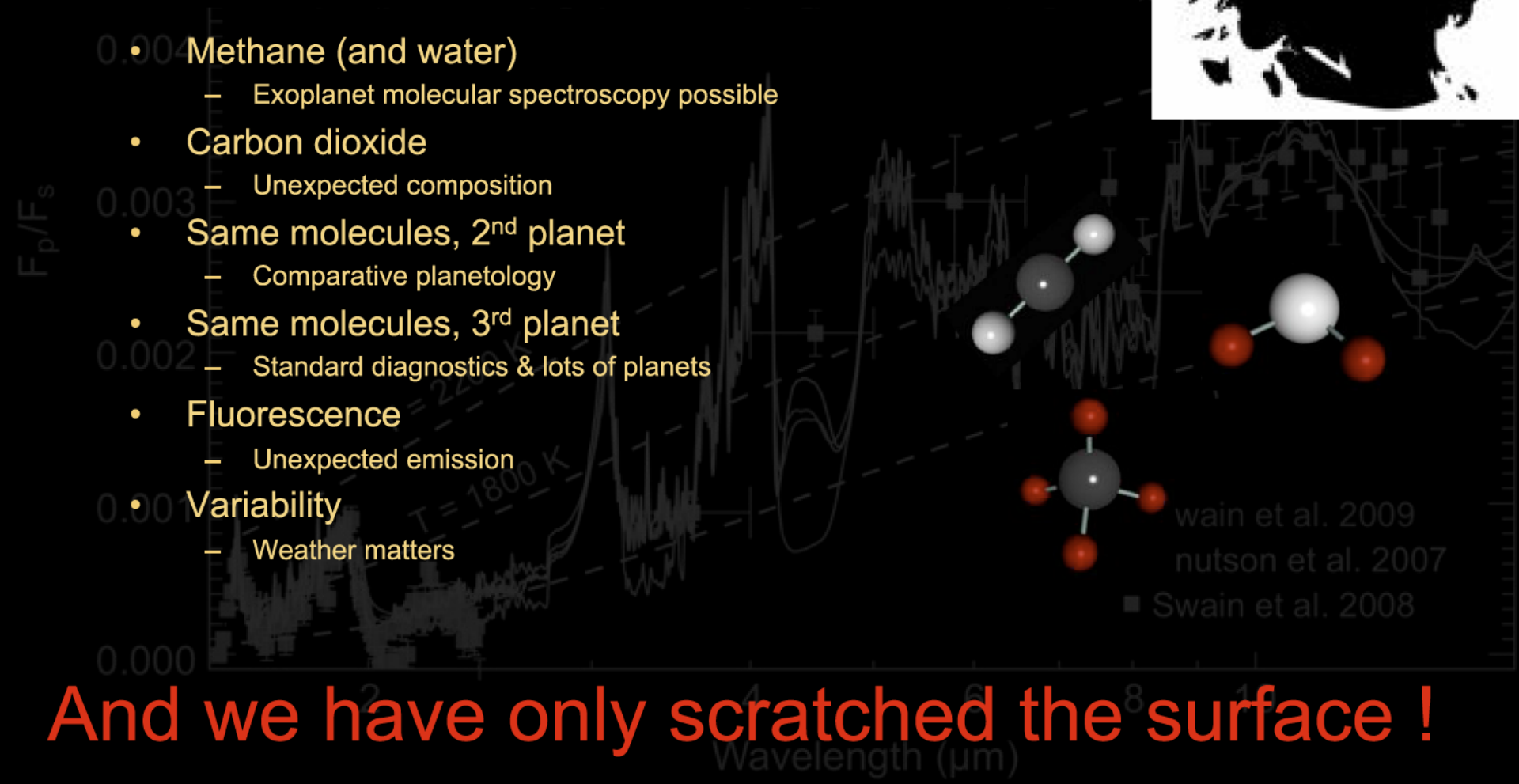
- Swain et a. 2010, Mandell et al 2011, Waldman et al 2011, unpublished
- It appears NIRSPEC falls in the emission gap

Viva La Revolution!

Spectra – changing our view of exoplanets



- Methane (and water)
  - Exoplanet molecular spectroscopy possible
- Carbon dioxide
  - Unexpected composition
- Same molecules, 2nd planet
  - Comparative planetology
- Same molecules, 3rd planet
  - Standard diagnostics & lots of planets
- Fluorescence
  - Unexpected emission
- Variability
  - Weather matters



And we have only scratched the surface !

– The near-term future –

10 m today

WM Keck Observatory

photo credit: WMKO

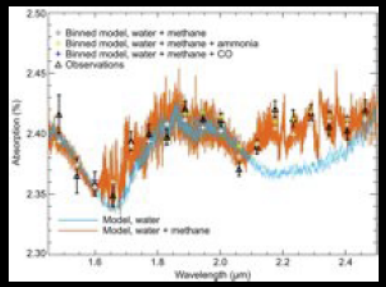
42 m in 2020?

ESO next generation telescope

image credit: ESO

60 x SNR

3600 x resolution



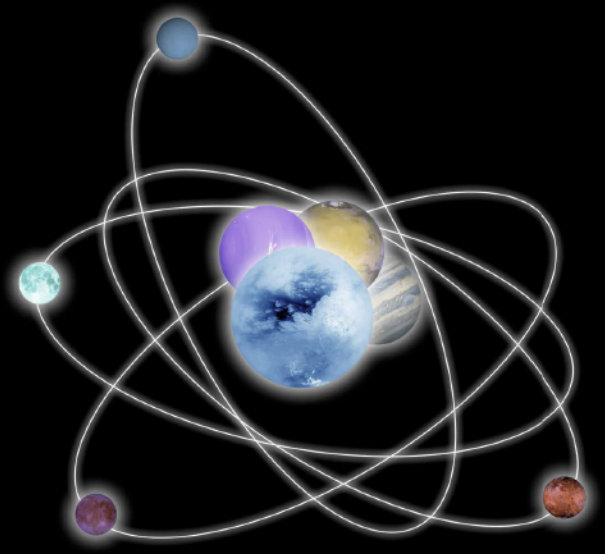
NESSI

The New Mexico Tech Exoplanet Spectroscopy Survey Instrument

- 1.1–2.4 μm “all at once”
- Multi-object spectroscopy for calibration
- Deployment on NMT 2.4 m Magdalena Ridge Observatory
- Survey many exoplanets with 40 nights/yr for NESSI observations

Goal: Understand exoplanets as a class of objects; develop the next characterization workhorses

ECho Exoplanet Characterisation Observatory



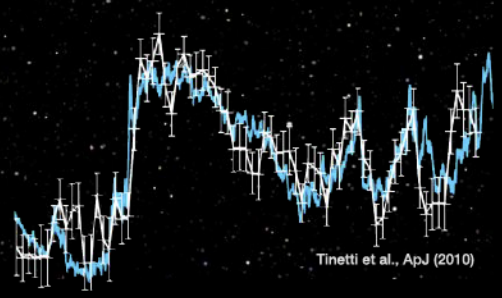
Exploring Atmospheres of Diverse Worlds Beyond our Solar System

FINESSE Fast Infrared Exoplanet Spectroscopy Survey Explorer

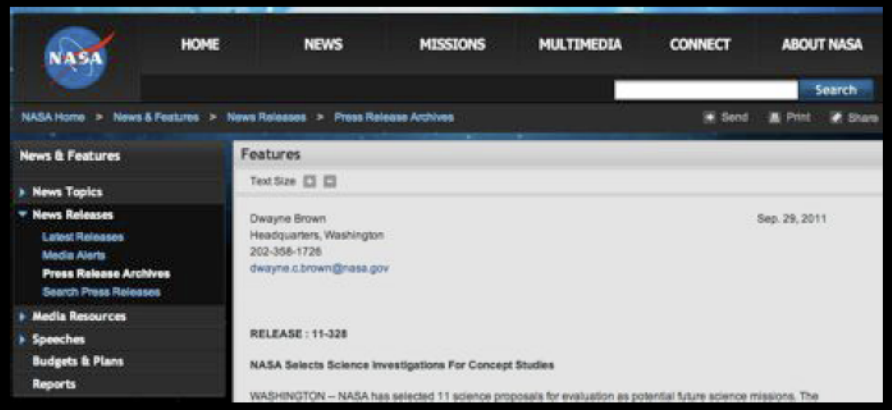
Exploring New Worlds Around Other Stars

Principal Investigator: Dr. Mark R. Swain, JPL Deputy Principal Investigator: Robert Green, JPL

FINESSE is the first mission dedicated to the characterization of the rapidly growing number of newly discovered worlds.



Tinetti et al., ApJ (2010)

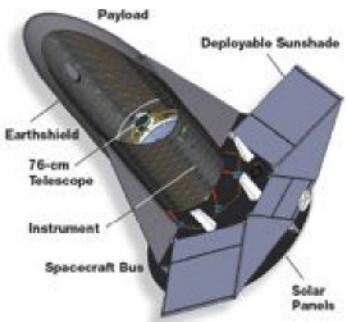


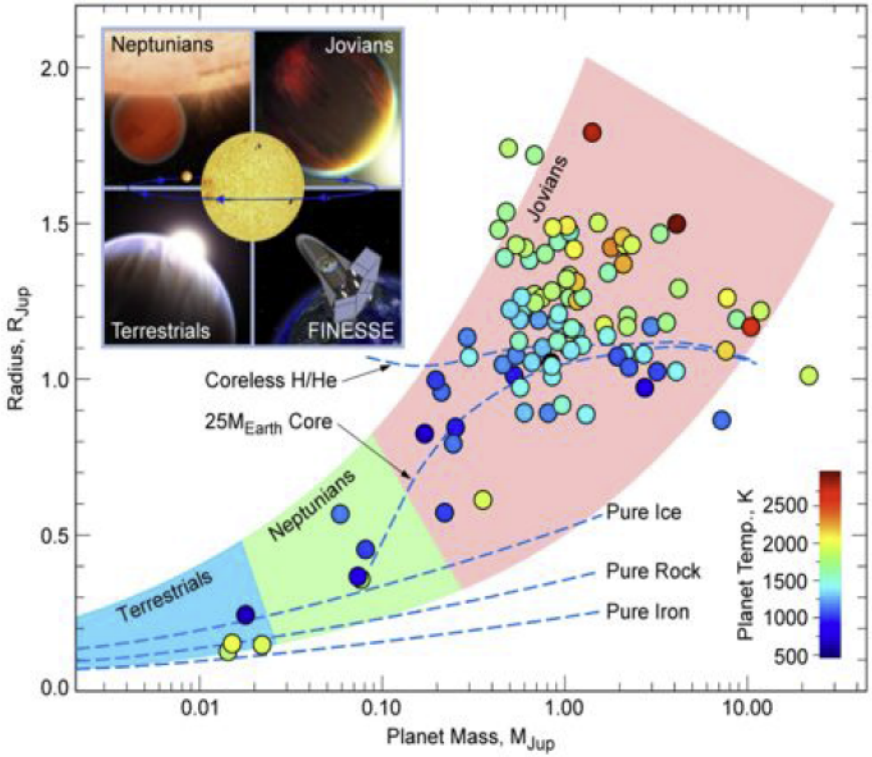
FINESSE Fast Infrared Exoplanet Spectroscopy Survey Explorer

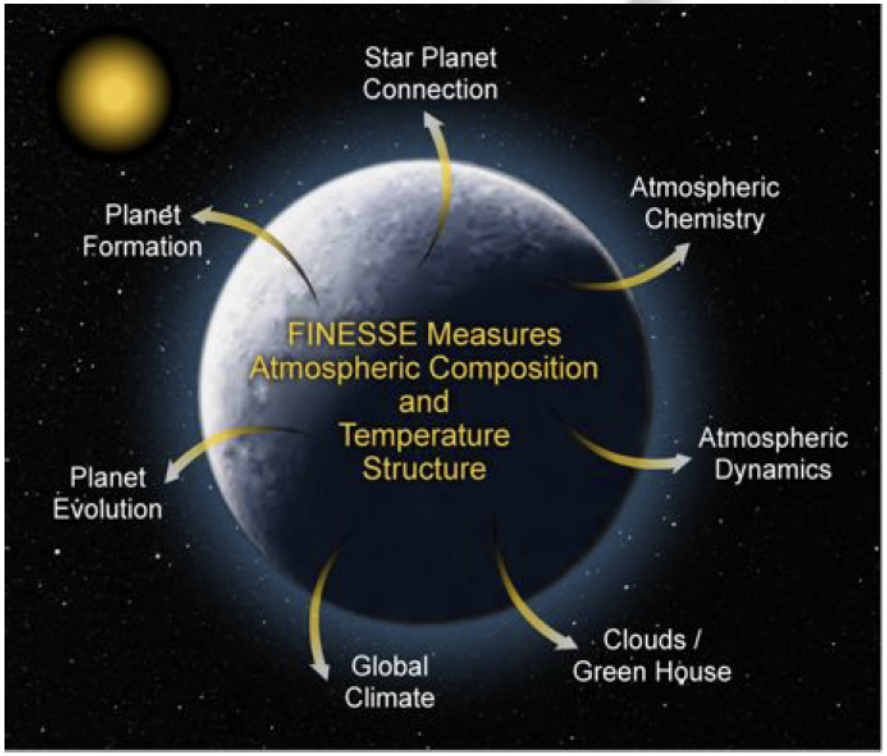
Exploring New Worlds Around Other Stars

Science Overview

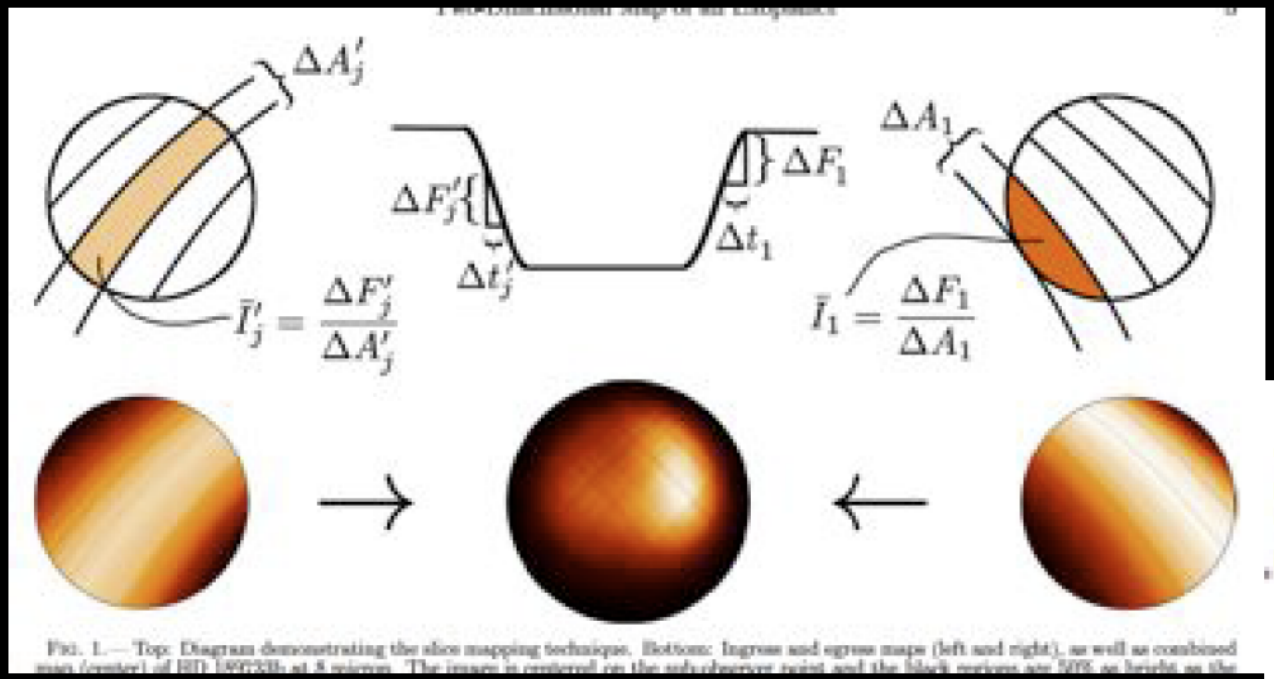
FINESSE is a two-year, high-heritage, Earth orbiting mission that **opens the new field of comparative exoplanetology** by probing the atmospheric composition and conditions of transiting exoplanets. FINESSE explores 200 newly discovered worlds ranging from Jovians to Terrestrials by measuring their characteristics with molecular spectroscopy.





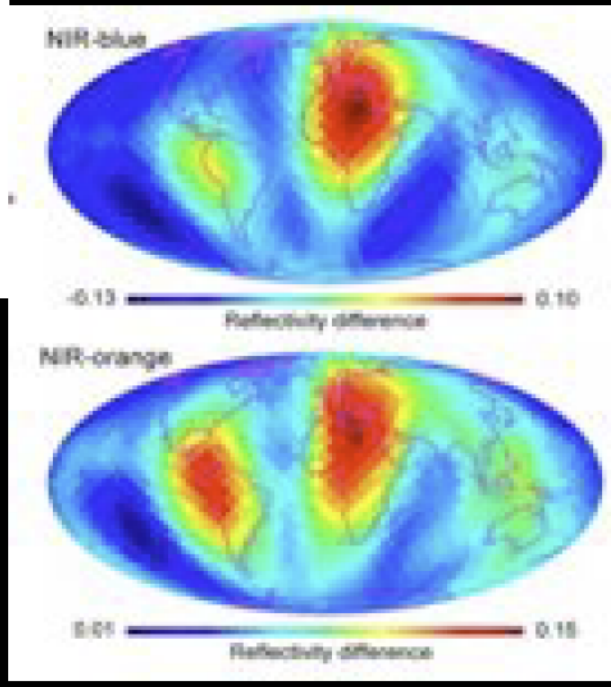


New Capability
Imaging Atmospheric Features



Majeau et a. ApJ submitted

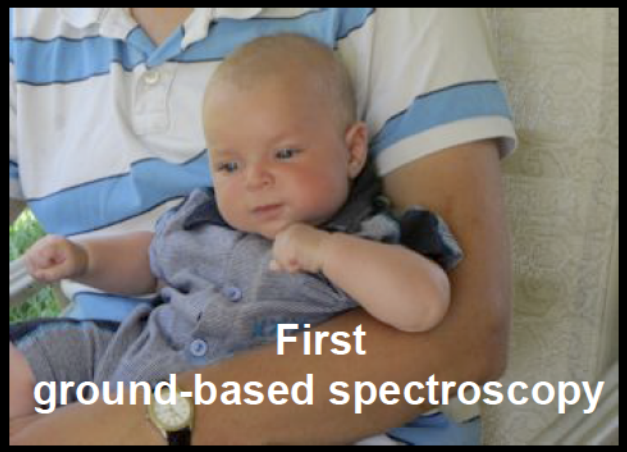
Kawahara & Fuji 2011



Color images of the planet surface are becoming available!

Five Myths:

exoplanet spectroscopic characterization requirements



- Transits
- Bright targets
- Large telescope
- New instrument technology
- Exceedingly difficult