Exoplanets and their Atmospheres

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Outline

- What is an exoplanet?
- Why do we care?
- Detecting exoplanets
- Exoplanets compared to planets in the solar system
- Exoplanet atmospheres

What is an Exoplanet?

- An exoplanet is a planet outside our solar system (Also called an extrasolar planet)
- The first exoplanet was discovered in the early 1990s
- To date over 450 exoplanets have been discovered

Why do we Care?

- We are continually trying to answer the following questions:
  - Is the Earth and our solar system common in the universe?
  - Are there other planets that might be habitable?
  - Can we detect indicators of life?

How do we Detect Them?

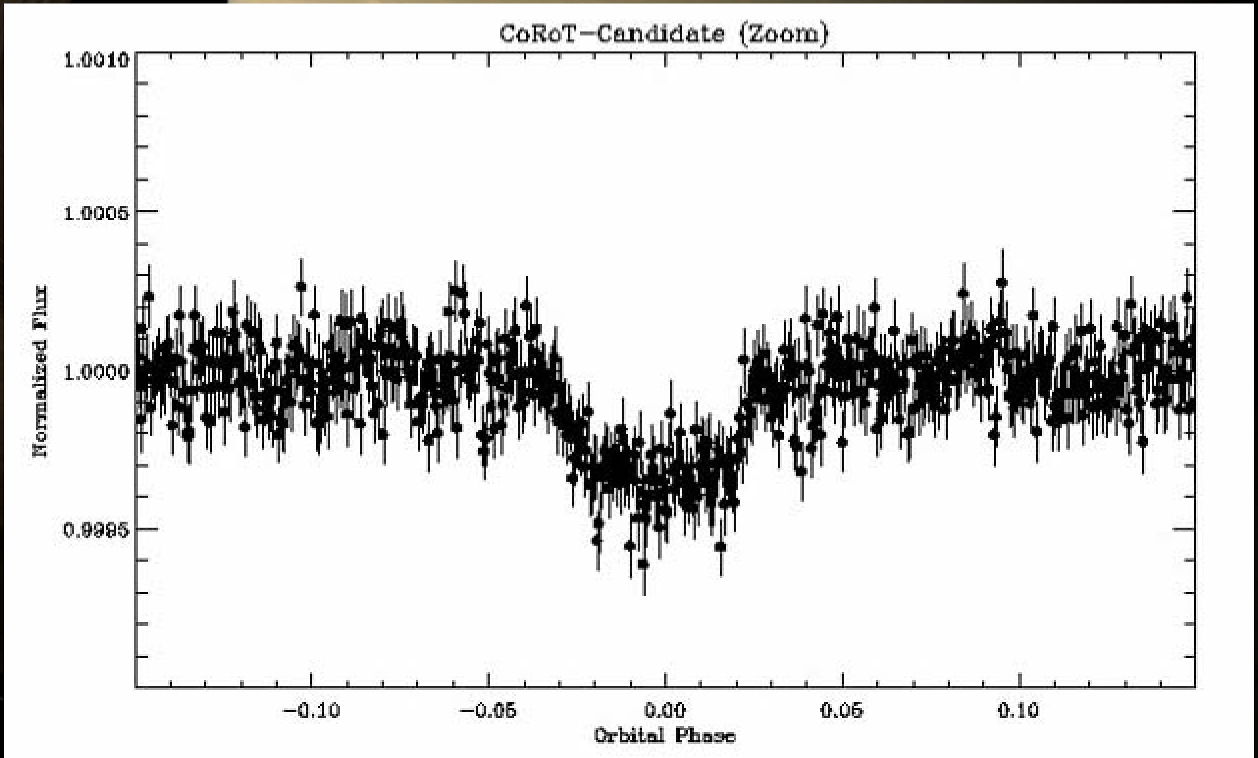
- Several ways:
  - Doppler Method
  - Transits
  - Directing Imaging
  - Astrometry, Microlensing, and Others...

Doppler Shift Detections

- The light from a star is shifted slightly in wavelength due to the velocity of the star
- As a planet orbits a star the velocity of the star will oscillate
- Larger planet = larger effect
- Close to star = easier to find

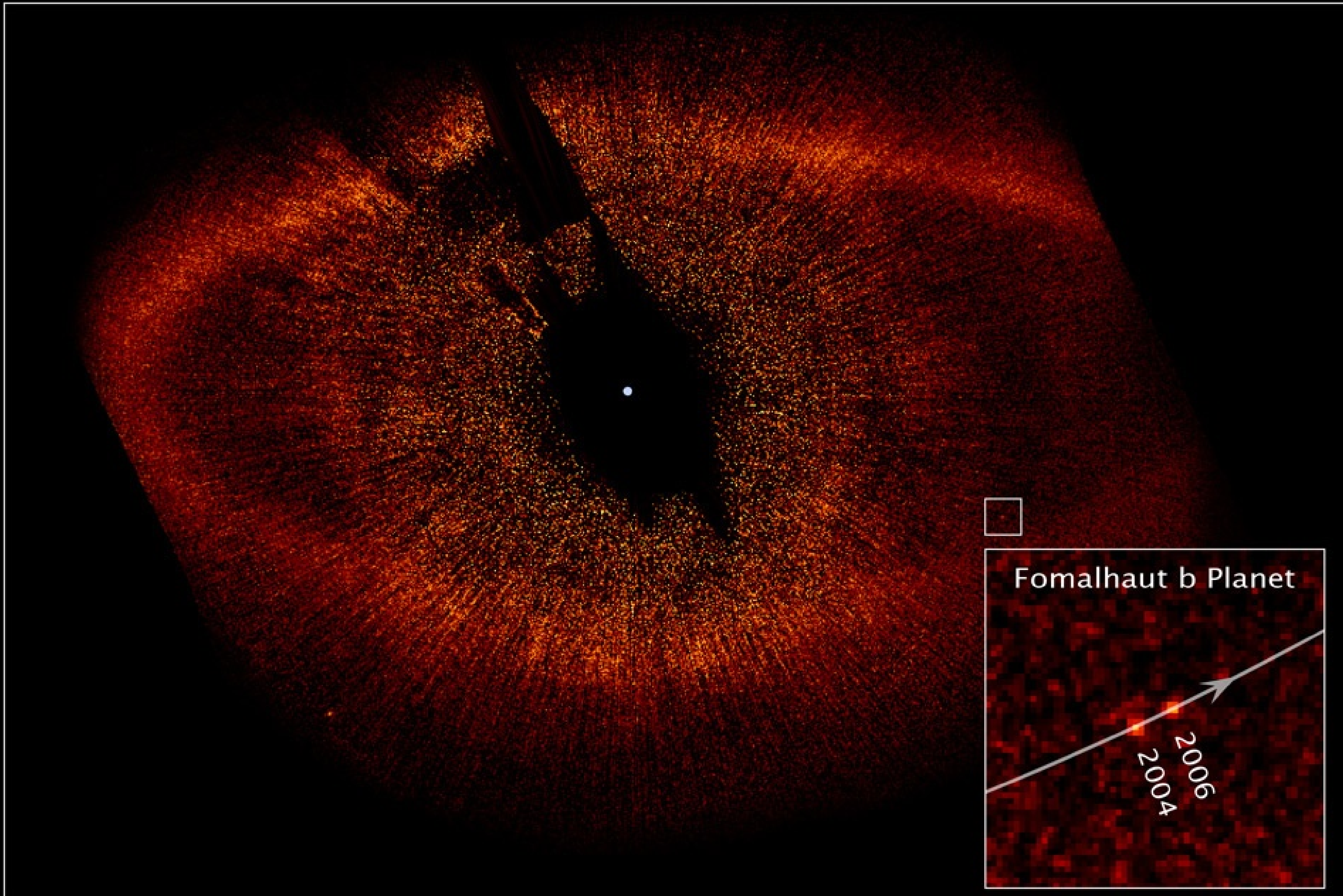
Transit Detections

- If the planet's orbit is oriented just right it can pass in front of the host star.
- We can detect the slight drop the star's brightness
- Larger planet = larger signal
- Closer to star = more likely



Direct Imaging

- In some cases we can directly photograph an exoplanet
- Works well with large planets far from their host star

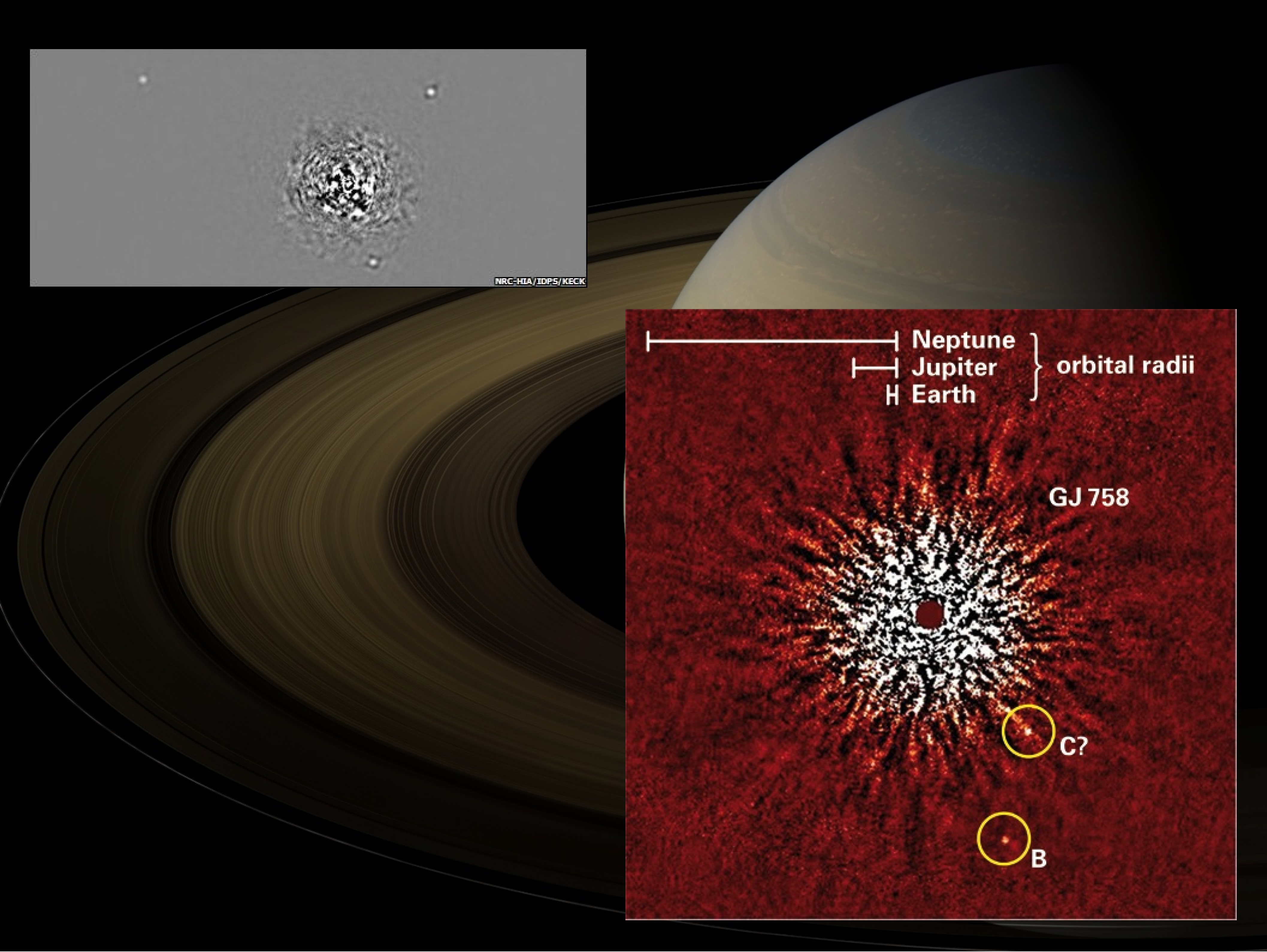


Fomalhaut System

Hubble Space Telescope • ACS/HRC

NASA, ESA, and P. Kalas (University of California, Berkeley)

STScI-PRC08-39a


NRC-HIA/IDPS/KECK
Neptune
Jupiter
Earth
orbital radii
GJ 758
C?
B

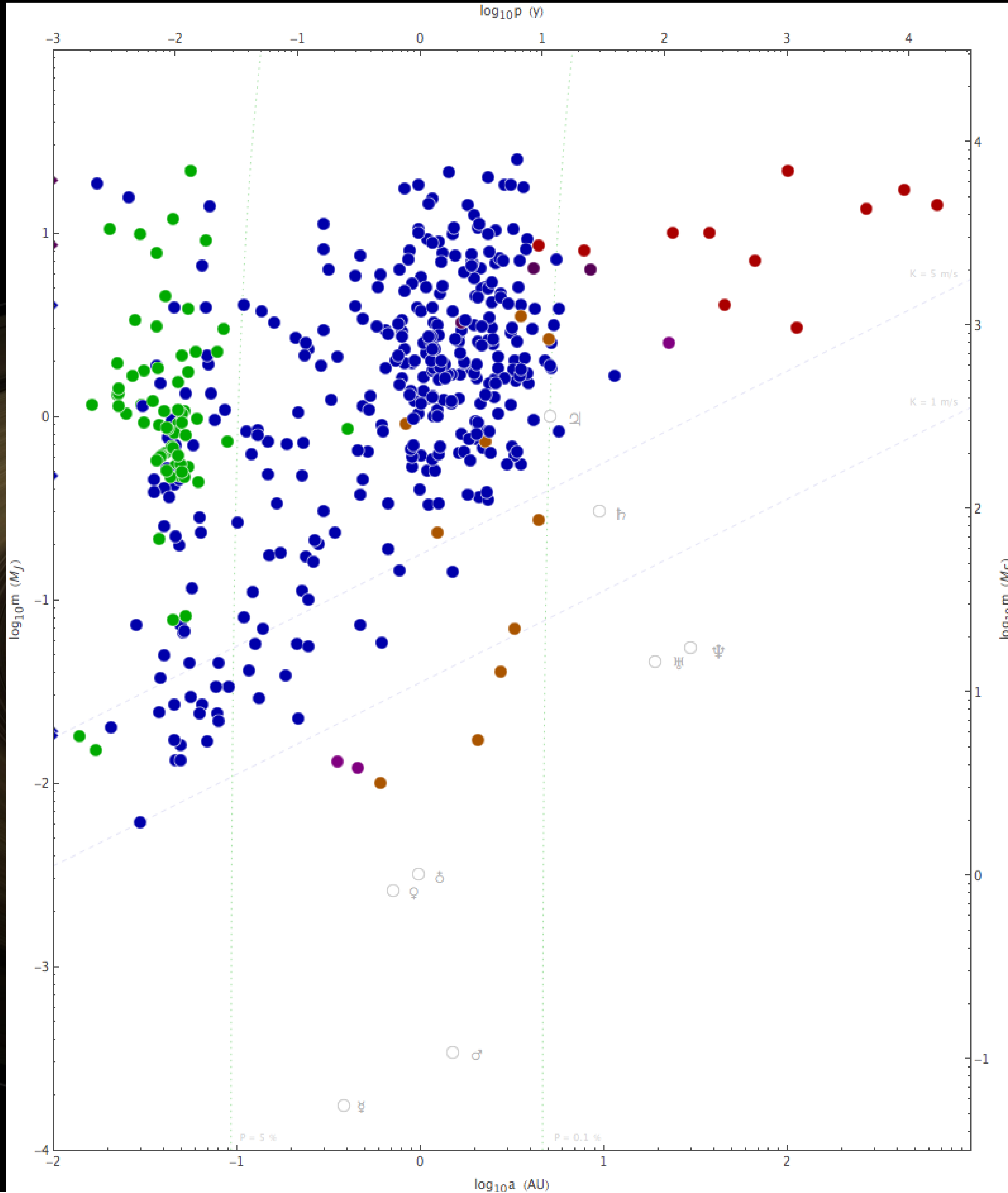
Are Exoplanets like the Solar System?

- We still don't know
- Selection bias has favored very large planets, often very close to their host star
- There has been some very surprising discoveries...

Transit

Doppler

Imaging



Hot Jupiters

- Massive planets up to 10 M_J ($M_J = 1.9 \times 10^{27}$ kg or about 300 Earths)
- Often closer to their star than Mercury
- Very Hot: 1000-2000 K
- High temperatures cause large atmospheric scale heights

Atmosphere Types

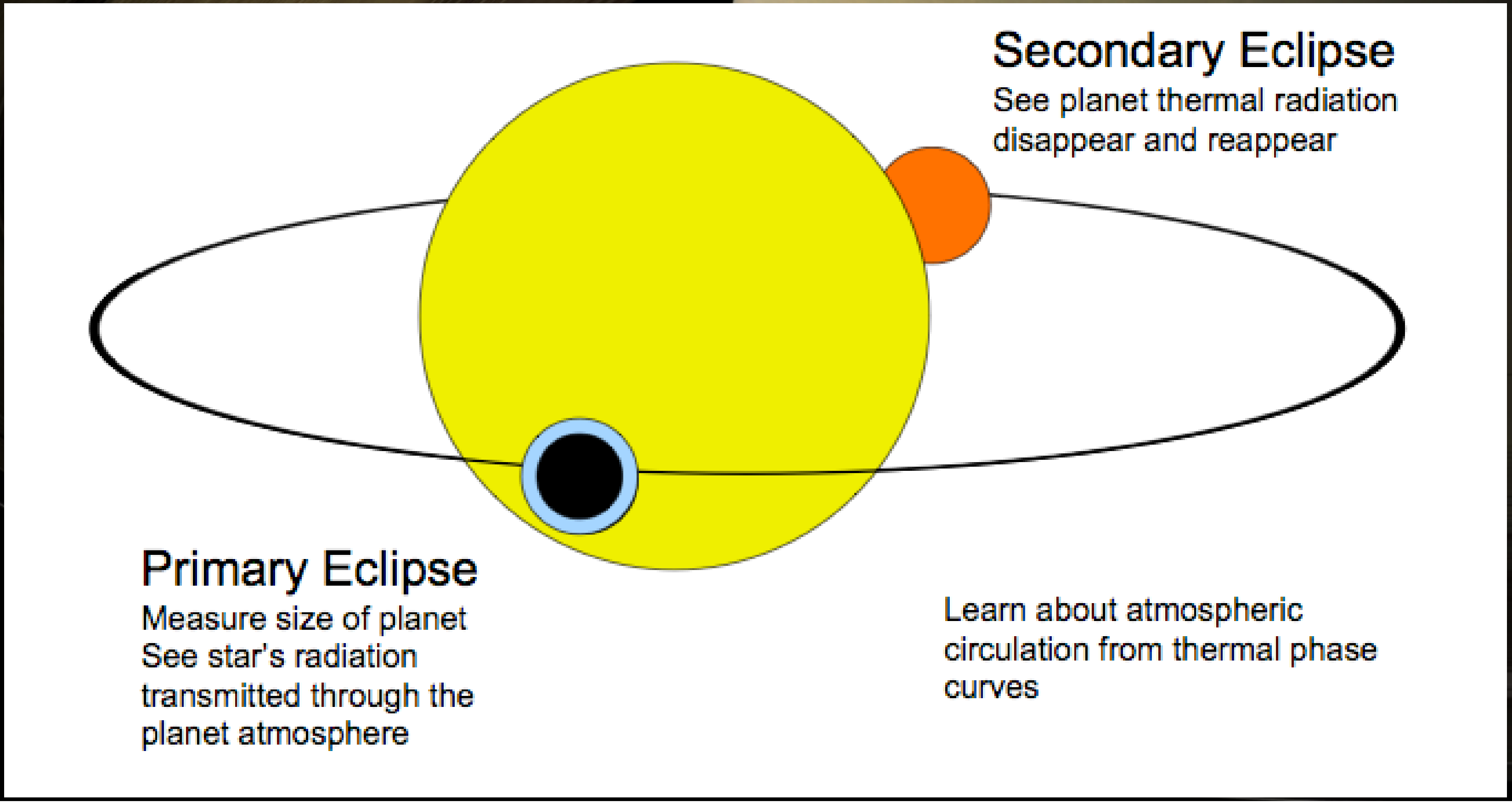
- What do we expect atmospheres to be like?
- Highly mass dependent:
  - Dominated by H and He – planet must be large so that these light elements won't escape
  - H-rich atmospheres – planets in the range of 10-30 Earth masses that are not too hot could have a mixture of H_2 as well as gases from outgassing. May be dominated by H_2, H_2O and CH_4 or CO.

Atmosphere Types

- Outgassed Atmospheres – Planet not large or cold enough to keep its H. Likely to be CO_2 dominated.
- Hot Super Earths – High temperature has caused H, N, C, O and S to all escape. A thin atmosphere may contain silicates.
- No Atmosphere – Mercury and the moon are good examples of this

Studying Exoplanet Atmospheres

- How can we study the atmosphere of a planet that is light years away?
- Eclipses are Key:



Discoveries so Far

- About a dozen exoplanet atmospheres have been observed so far.
- Only hot Jupiters have been studied in a significant way
- Interpreting observations are often heavily based on models
- Largely based on two space telescopes: *Hubble* and *Spitzer*

Discoveries so Far

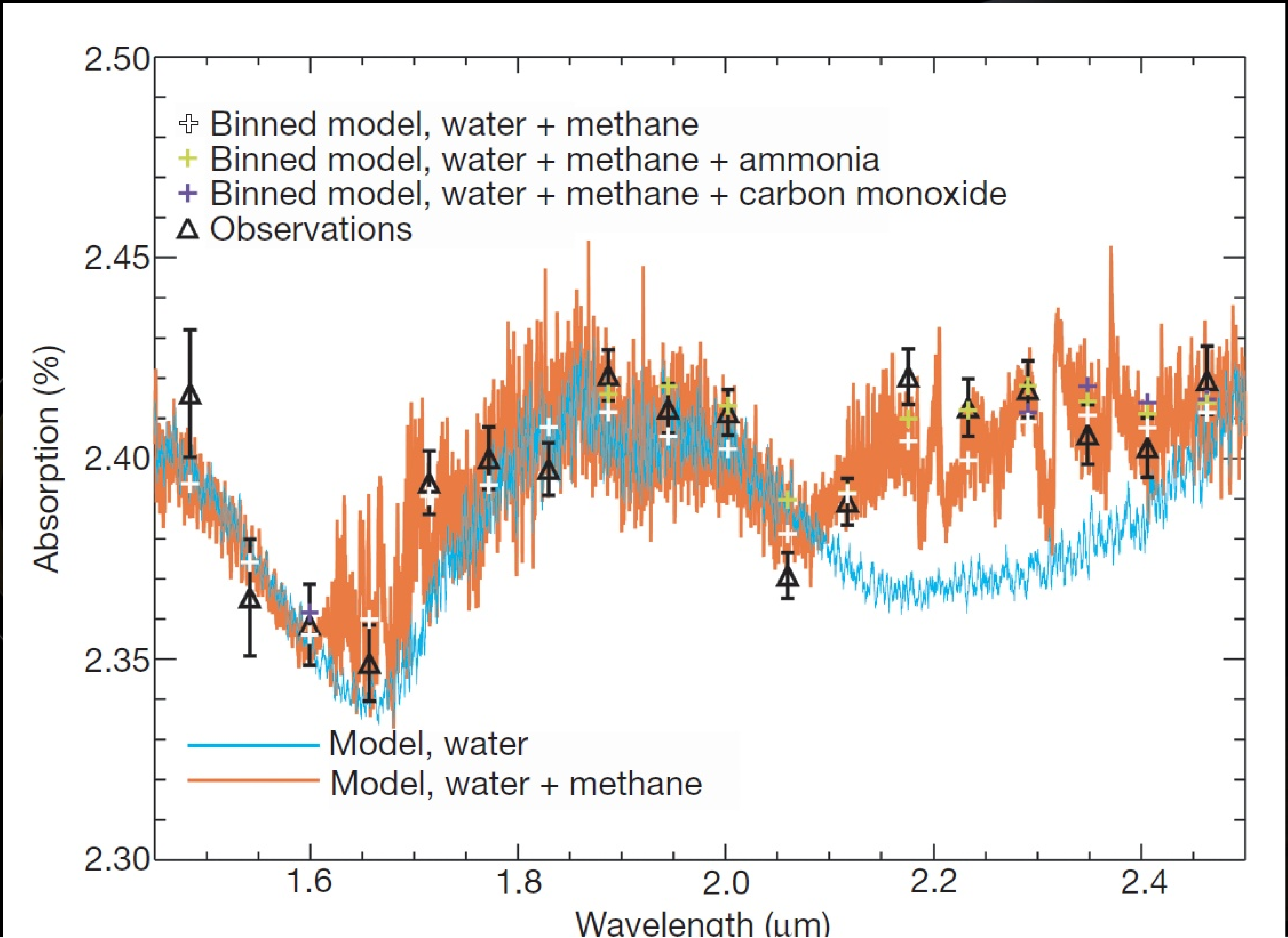
- Large IR emission – confirms that atmospheres are exceedingly hot.

- Implies efficient absorption of visible light
- Albedos less than about 0.2
 (Earth = 0.37, Jupiter = 0.5)
- Several species have been detected:

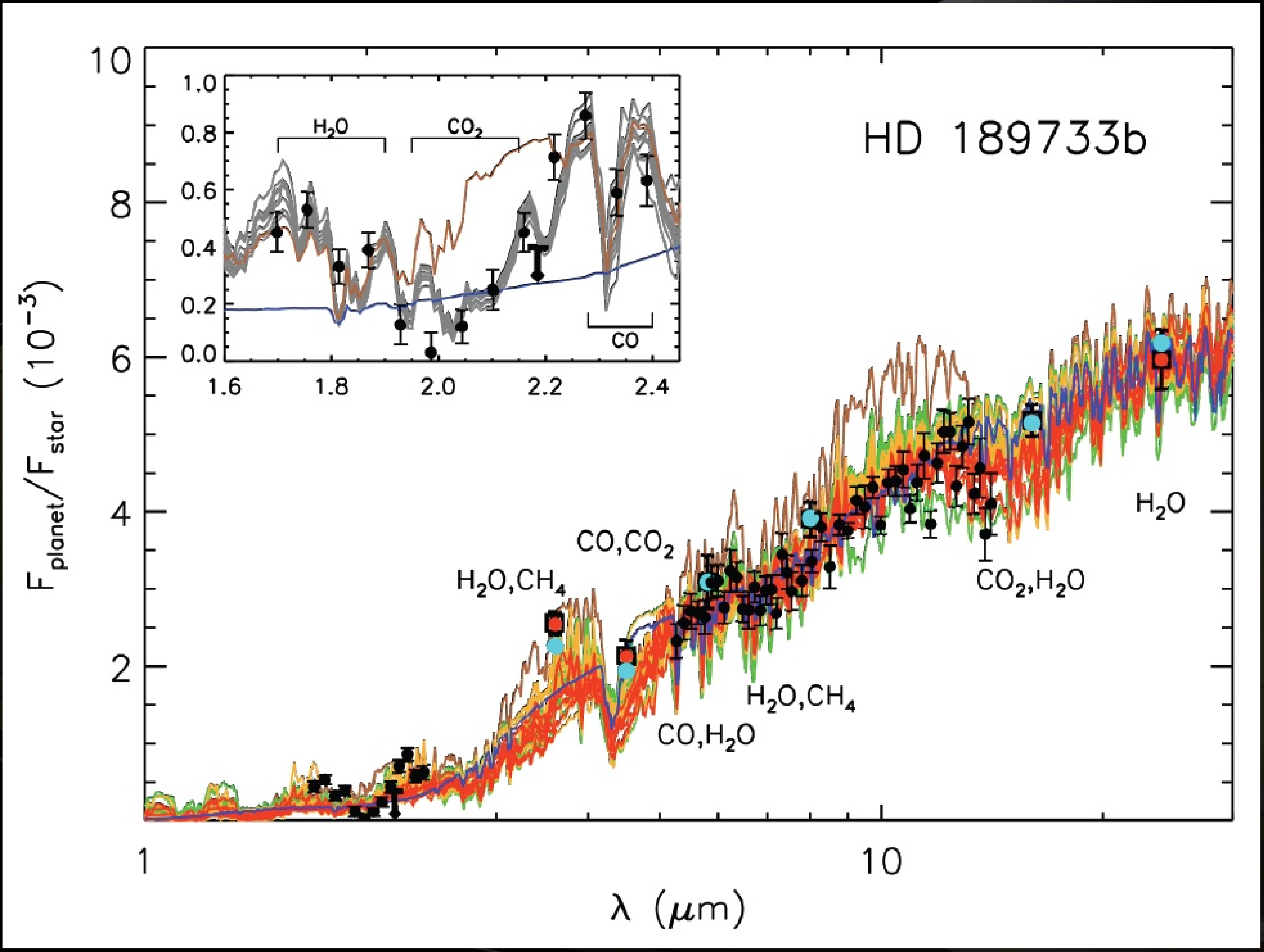
    Na, CH4, CO, CO2, H2O

H2O mixing ratio ~ 10^{-4}

Transmission spectrum of planet around HD 189733



Thermal emission of planet around HD 189733



CO_2 in the Atmosphere

- The abundance of CO_2 in the atmosphere of a Hot Jupiter was a surprise (CO_2 may be much larger than expected in one hot Jupiter studied)

- CO_2 is in equilibrium with CO:
  - $CO + H_2O \rightleftharpoons CO_2 + H_2$

- But at high temperatures and with H_2 dominating the atmosphere CO is expected to be much more abundant than CO_2

CO_2 in the Atmosphere

- It is likely that in this case photochemistry plays a significant role:

- CO_2 is also produced by OH:
  - $CO + OH \leftrightharpoons CO_2 + H$

- Where OH is from photolysis of H_2O
  - $H_2O + h\nu \rightarrow OH + H$

Other Hydrocarbons

There may be trace amounts of hydrocarbons in the atmospheres of Hot Jupiters – C2H2, C2H6 and NH3

Photolysis of CO can make C2H2, CH4 and C2H6

- $CO + h\nu \rightarrow C + O$

Just In Case you Care:

CH4 Production

$$CO + h\nu \rightarrow C + O,$$

$$C + H_2 + M \rightarrow {}^3CH_2 + M,$$

$$2\,{}^3CH_2 \rightarrow C_2H_2 + 2H,$$

$$C_2H_2 + H + M \rightarrow C_2H_3 + M,$$

$$C_2H_3 + H_2 \rightarrow C_2H_4 + H,$$

$$C_2H_4 + H + M \rightarrow C_2H_5 + M,$$

$$C_2H_5 + H \rightarrow 2CH_3,$$

$$CH_3 + H + M \rightarrow CH_4 + M.$$

Other Discoveries

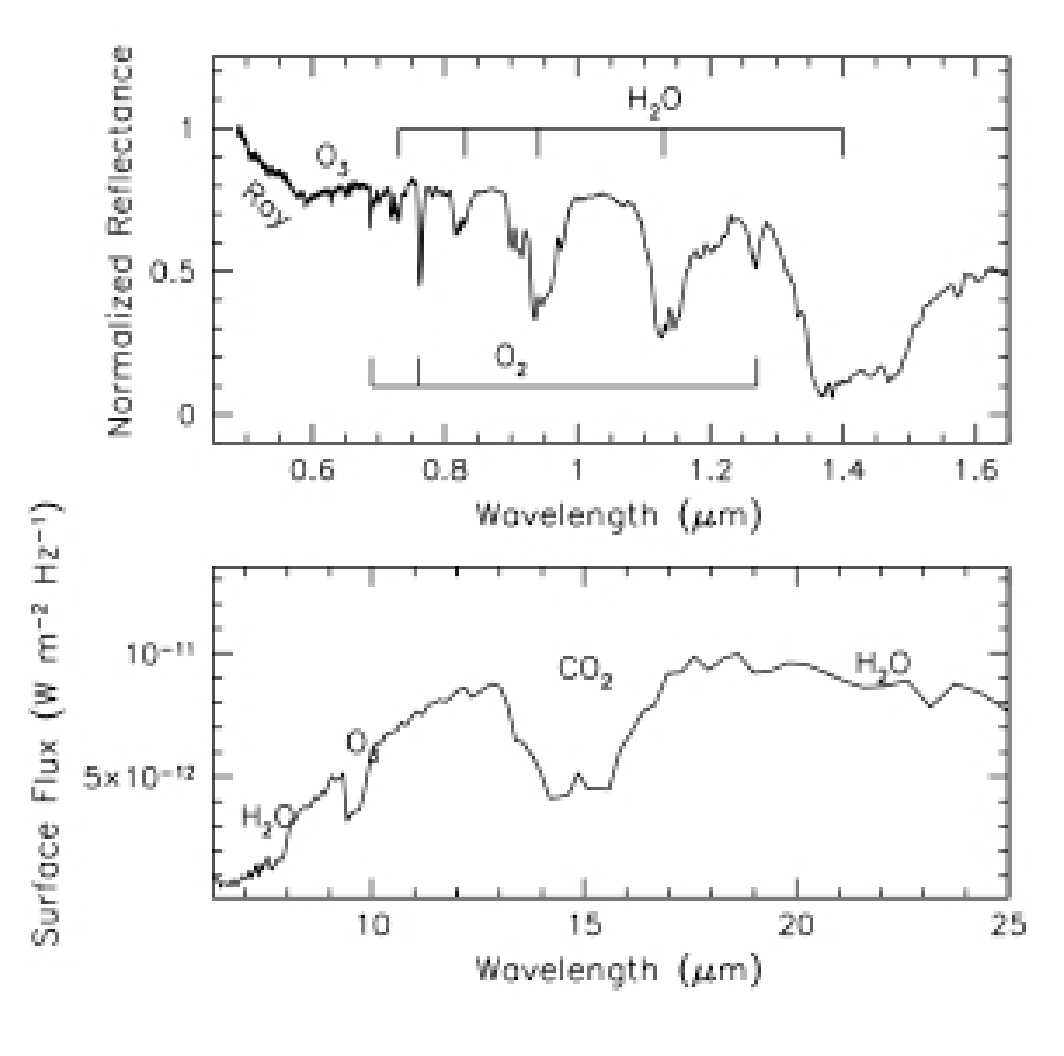
- Transmission spectra provide evidence for haze
  - Small particles
- Planets are likely tidally locked
  - Day/night temperature differences can be relatively small (200 K) or very large (1000K)
  - Strong winds likely

Other Discoveries

- Inversions were not expected with the lack of molecules to efficiently heat the upper atmosphere (O_3 for example)
- Tentative evidence for temperature inversions in some hot Jupiters
- Possible absorbers could include TiO or photochemical hazes

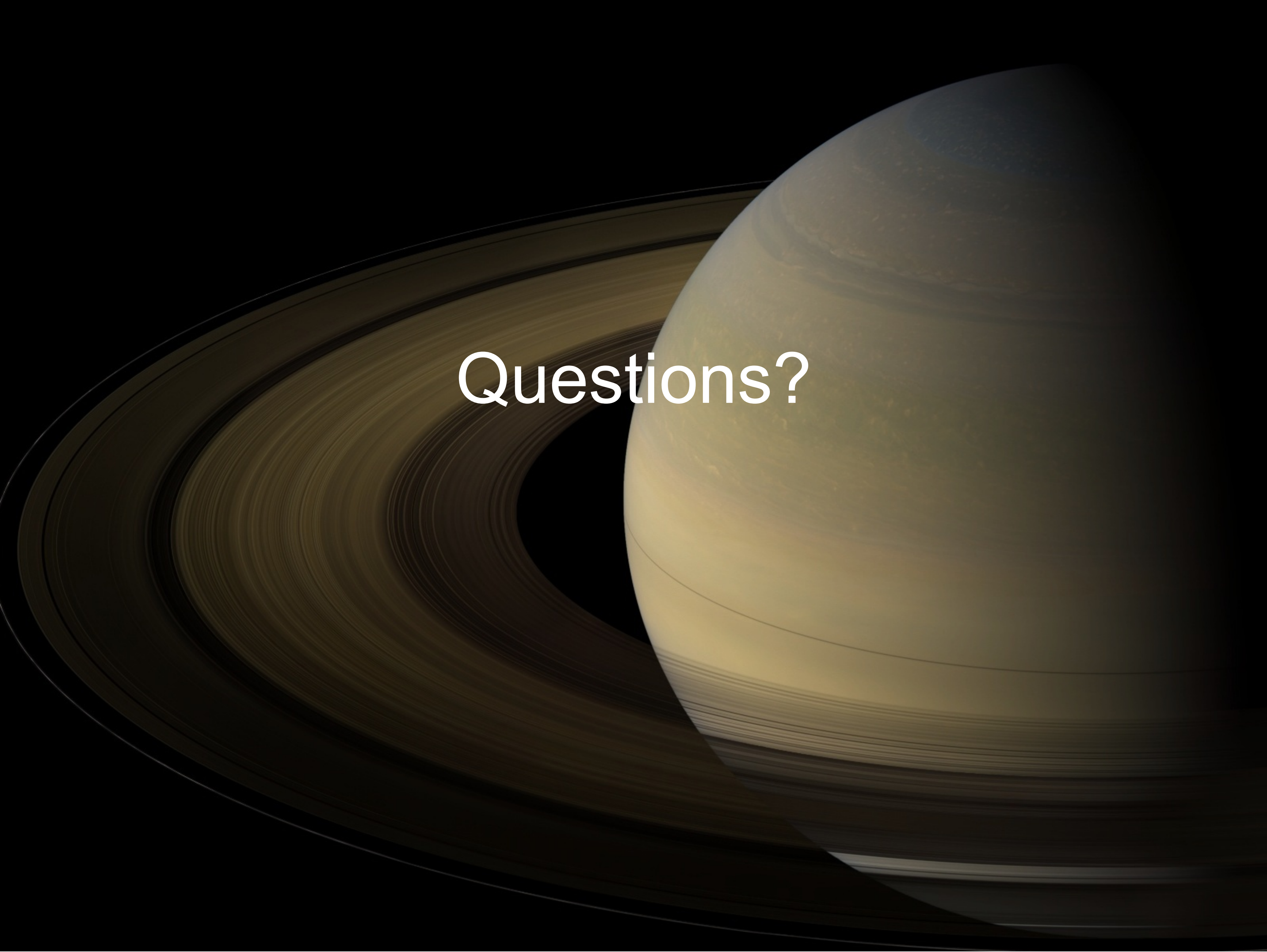
Future Research

- Continue to push to discover Earth-like planets or biosignatures
- What would Earth look like with these type of observations
- This would be VERY difficult to observe



Future Research - Biosignatures

- Biosignatures – gas whose abundance is completely out of equilibrium
- Eamples:
  - CH4 and O2 (both)
  - Large O2
- Must avoid other possible scenarios (O2 due to sudden loss of oceans)
- Most of the work so far has focused on O2, O3, N2O and CH4


Questions?

References

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