Water Vapor Absorption in the Clear Atmosphere of a Neptune-Sized Planet (Fraine et al. 2014)

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Overview

- Motivation

Previous attempts to measure molecular absorption in smaller planets during transits were not successful. Smaller, warmer planets develop atmospheres that have little hydrogen or are too opaque to observe the composition of the atmosphere.

Observed transits of HAT-P-11b ($R = 4R_C$)

Detected water vapor absorption at 1.4 µm

Checked that the observed absorption was not caused by starspots

Placed constraints on the metallicity and mean molecular weight of the atmosphere
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Data

- **Hubble Space Telescope**
  - Observed two different transits at 1.1-1.7 $\mu$m
  - Used the Wide Field Camera 3 (WFC3) for spectroscopy
  - Integrated over wavelength to produce photometry

- **Spitzer**
  - Observed four different transits at 3.6 and 4.5 $\mu$m

- **Kepler**
  - Simultaneous observations with Spitzer of the transits
  - 280 archival transits to characterize starspot crossings
Starspots

![Diagram showing frequency of occurrence of Kepler/Spitzer spot crossing amplitude for different dates.]

- **UT 07/07/11**
- **UT 15/08/11**
- **UT 05/08/11**
- **UT 29/08/11**

Noise-dominated regime:
- 1800 K
- 1800 K
- 1350 K
- 1350 K
- 900 K
- 900 K
Starspot Absorption Amplitude

\[ Amplitude = f \epsilon \delta \]

- fraction of stellar disk that is covered by spots, \( f = 0.02 \)
- depth of transit, \( \epsilon = 0.0036 \)
- Depth of the feature, \( \delta \sim 0.024 \) for 1800 K
- Amplitude of predicted absorption is 2 p.p.m
- Amplitude of actual absorption is 250 p.p.m
Constraints on Atmosphere

Offset between WFC3 and best-fit model
Stellar activity uncertainty
White-light curve uncertainty

Best-fit model: 190x solar metallicity
Pure water model: 10,000x solar metallicity
Solar cloud-free model with low C/O
Solar model with clouds at 80 mbar
Solar cloud-free model
Atmospheric Pressure

- Scale height: height over which pressure changes by a factor of e
- Scale height is inversely proportional to mean molecular weight
- HAT-P-11b doesn’t have a large mean molecular weight since it is rich in hydrogen (larger scale height)
- The atmosphere is clear down to a pressure of 1 mbar
Conclusions

- Starspots in the host star are too hot to mimic the observed absorption
- The atmosphere has a metallicity ~ 700 solar
- Mean molecular weight ~ 10.2 g $mol^{-1}$
- HAT-P-11b is the smallest and coldest planet with an absorption feature measured by transmission