Unraveling the Mystery of GJ1214b with NIRSPEC


Keck Science Meeting
CIT, Pasadena, 23 Sep 2011
Earth
1 M⊕

GJ 1214 b
6.6 M⊕

Neptune
17 M⊕
GJ 1214 b

(data from exoplanets.org and the literature)
Earth-like composition

Radius [Earth radii] vs. Mass [Earth masses] graph showing an annotation for "Earth-like composition" and a point labeled "GJ 1214 b". The graph includes a note that the models are from Valencia 2011.
The graph plots the radius of a planet in Earth radii against its mass in Earth masses. The data points for GJ 1214 b are shown, along with curves for 0.1% and 1% H/He compositions. The graph is based on models from Valencia 2011.
Earth-like

50% H

20

100% H

20

0.1% H/He

1% H/He

Kepler-11 f

HD 97658 b

Gj 1214 b

55 Cnc e

CoRoT-7 b

Kepler 10 b

Earth-like

(models from Valencia 2011)
Transmission spectroscopy: probes atmospheric composition via $R_P(\lambda)$
Observations:
- Two half-nights with NIRSPEC
- One night has insufficient out-of-transit baseline
- One good night covers ~half of the K band
We get a high S/N spectrum of this K=8.8 M dwarf:

Crossfield, Barman, Hansen 2011
A full set of observations:

Spectrophotometric variations are dominated by a trend common to all wavelength channels.

Divide out this trend from every wavelength!

Spectrophotometric variations are dominated by a trend common to all wavelength channels.

Crossfield, Barman, Hansen 2011
Removing common-mode variations leaves differential transit signal:

Observed data: no residual transit spectrum visible by eye

Crossfield, Barman, Hansen 2011
Removing common-mode variations leaves differential transit signal:

Simulated observation: transit signal 10x stronger than expected
Removing common-mode variations leaves differential transit signal:

Observed data: no residual transit spectrum visible by eye
Initial transmission spectrum of GJ1214b:

We cross-correlate this spectrum with models to confirm or rule out atmospheric compositions.
Model cross-correlation can detect the ensemble of lines in a spectrum:

Crossfield, Barman, Hansen 2011
MODEL RULED OUT: Atmospheric signal expected, but not seen
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Crossfield, Barman, Hansen 2011
MODEL RULED OUT: Atmospheric signal expected, but not seen.
MODEL UNCONSTRAINED:
No significant signal expected; none seen.

Crossfield, Barman, Hansen 2011
Our Results

We rule out hydrogen-dominated atmospheres in or near chemical equilibrium:

- Solar, 10x solar, 30x solar abundances with mild-to-no methane depletion

We cannot constrain atmospheres with flatter spectra:

- H-dominated (Low carbon, substantial methane depletion)
- Hazes/clouds
- Low scale height (high mean molecular weight: e.g., H₂O)
Other results also agree (mostly) on a flat, featureless spectrum:

Bean+2011: 0.8-1.0 um spectrum; flat
Desert+2011: Spitzer/IRAC CH1+2; flat
Croll+2011: NIR photometry, $R_K > R_J$ (>4σ)
Bean+(1109.0582): 0.6-1.0 um + JHK; flat.
Berta+(in prep): 1.1-1.65 um spectrum; flat.
Conclusions

GJ 1214b has a flat transmission spectrum, meaning the planet either:

--Is covered in opaque clouds, OR
--Has a high mean molecular weight atmosphere (e.g., H\textsubscript{2}O)

If a 'water' world, GJ 1214b likely formed beyond the snow line and migrated inward without accreting substantial H\textsubscript{2}/He

NIRSPEC-like instruments can constrain exoatmospheres, and multi-object spectrographs like MOSFIRE (see Bean+2011) are poised to do even better.
Backup:

- Simulations and time-offset extractions to estimate uncertainties inherent in data
  - Estimation of non-detection confidence
Transmission spectra can constrain atmospheric composition:

GJ 1214b (models by T. Barman)
Several techniques can characterize exoplanet atmospheres:

<table>
<thead>
<tr>
<th>Method</th>
<th>Signal scales as:</th>
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</thead>
<tbody>
<tr>
<td>(A) Transit</td>
<td>$(R_p / R_s)^2$</td>
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<tr>
<td>(B) Transmission</td>
<td>$(T_p \cdot R_p / M_p) \cdot (R_p / R_s)^2$</td>
</tr>
<tr>
<td>(C) Eclipse</td>
<td>$T_p / T_s (R_p / R_s)^2$</td>
</tr>
<tr>
<td>(D) Phase curve</td>
<td>$\Delta T_p / T_s (R_p / R_s)^2$</td>
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</table>
Fit a transit model to each wavelength channel:

\[ f'_{i\lambda} = f_{0\lambda} e^{b_\lambda a_i} (1 + d_\lambda r_i) \left( 1 + \sum_{j=1}^{J} c_{j\lambda} v_{ji} \right) \]
Initial transmission spectrum of GJ1214b:

BUT: Tilt should not affect spectral features on the narrowest scales