Characterizing Transiting Planet Atmospheres: A Modeling Perspective

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• My point of view and main thrust of my talk is from the past 5 years of science, which is giant planets down to sub-Neptunes

• There are lessons for the future and for smaller planets

My Main Points

• In observations, we should focus on repeatability, high S/N, and broad wavelength coverage, over getting 1-2 data points for an ever increasing numbers of planets

• We should have continued comparison of reduction methods by different groups on public data

• Comparison between modeling efforts: not enough has been done
- Getting information on the light emitted, transmitted, or scattered by transiting planet atmospheres is hard to do.

- There is no getting away from the problem of small signals ($10^{-4}$ to $10^{-3}$) of the stellar flux.

- All things being equal, weighting towards having more data for a smaller number of systems is better than having data on more planets, but having less of it per planet. This helps in validating our tools.
The Planets We are Attempting to Characterize Appear Badly Behaved, Which is Very Interesting

With Spitzer IRAC we can compare brown dwarfs to planets at the same $T_{\text{eff}}$

The context for understanding mid-infrared photometry of brown dwarfs ONLY comes from near-IR spectra

More 2-band *Spitzer* detections may not be helpful. Even if we get a very large number and can cut it many ways, it likely won’t be clear *why* any such relations (if found) exist.

1200 K brown dwarfs from Cushing et al. (2008)
We Are Attempting to Classify with Small Amounts of Data

Fortney et al. (2008)

Madhusudhan (2012)
HD 189733b: The Lone Well-Characterized Hot Jupiter?

Spectroscopy is nice because you can’t hide anything like you can with photometry

Lee et al. (2012)

Gillet et al. (1969)
Things Like This Are Frustrating

Fortney et al. (2010)

• Given the small signals, subtle choices made in data reduction can lead to large impact
Molecules, Clouds, and Hazes in Atmospheres:

- There are the knowns
- There are the known unknowns
- There are the unknown unknowns
The Knowns: Molecules we’re “guaranteed” to see

- We’d like to know the abundances of these molecules within a factor of ~3
- Would allow connection to planet formation
The Known Unknowns: Molecules we expect to see depending on the effects of photochemistry and C/O ratio.
The Unknown Unknowns: Our imperfect understanding of these atmospheres, in the absence of spectral data

- Phosphorus compounds?
- Sulfur compounds?
- I don’t know (that’s why they’re called unknown unknowns)

- For smaller planets, the number of unknowns goes up, due to uncertain initial conditions and surface/interior/atmosphere interactions, and impacts of biology
We Are Attempting to Classify with Small Amounts of Data

We should think about:
How far out of radiative equilibrium these profiles are, and if there are dynamical reasons for that

How the known unknowns and unknown unknowns effect the results

Because one fits a 1D atmosphere to a 3D reality, we could be led astray
Shabram, Fortney, et al. (2011)
Clear and dramatic differences between Fortney et al. and Tinetti et al. transmission spectra
To my knowledge no one else has pursued this in the literature
Not a particularly fun and rewarding area of study
Berta et al. (2012)

- High MMW atmosphere (which dramatically shrinks scale height) or high obscuring clouds have been suggested
- With current data, solutions are degenerate
- With more planets, it is possible this degeneracy can be lifted
• Models from Mordasini et al. (2012a,b)
• Low mass planets from 5-15 $M_{\text{earth}}$ may have quite high $Z_{\text{env}}$
Perhaps we should expect higher MMW extremely ice-rich atmospheres to be the rule, for these low-mass planets

\[ H = \frac{RT}{\mu g} \]
“Realistic” MMW shrinks atmospheric scale height

Fortney et al. (in prep)
Conclusions

• Focus on repeatability, high S/N, and broad wavelength coverage
  • That is necessary to get broad agreement on where we are and what we can all agree we have learned

• I think that we’ll be in a lot better position after the results of HST Cycle 18 (Deming et al.) and Cycle 19 (Sing et al.). We should think about which planets should be observed again for higher S/N.

• GJ 1214b and similar planets may be difficult to characterize

• Continued comparison of reduction methods by different groups on public data

• Comparison between modeling efforts
  • Straight 1D vs. 1D comparisons
  • Inversions of 3D atmospheres with known molecular abundances to determine how well these are recovered in 1D
Ibn Yamin, Persian poet, 13th century

There are four types of men:

• One who knows and knows that he knows... His horse of wisdom will reach the skies.  [One day we’ll get there]

• One who knows, but doesn't know that he knows... He is fast asleep, so you should wake him up!  [Not an issue]

• One who doesn't know, but knows that he doesn't know... His limping mule will eventually get him home.  [Our best case right now]

• One who doesn't know and doesn't know that he doesn't know... He will be eternally lost in his hopeless oblivion!  [A potential problem]
Quantifying the Role of Clouds Seen in T and Y Brown Dwarfs

GJ 1214b Temperature-Pressure profile
Quantifying the Role of Clouds Seen in T and Y Brown Dwarfs

At a Neptune-like 50X solar metallicity atmosphere, equilibrium clouds appear inadequate.

Models from Caroline Morley, UCSC
Kempton et al. (2011)

Models from Caroline Morley, UCSC
Detailed Characterization: Going from light curves to “orange slice” brightness maps of planetary emission

Knutson et al. (2008)