Exoplanet Atmospheres: from Discovery to Characterization and Beyond

Sara Seager
Massachusetts Institute of Technology

NASA/JPL-Caltech
R. Hurt (SSC)
Overview

Introduction

Data Alone: Hot Jupiters

Models + Data: Hot Jupiters

Prospects: Super Earths
Known Planets 1996

Based on data compiled by J. Schneider
Known Planets 1999

Based on data compiled by J. Schneider
# Table of Spitzer Data

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Identification of Atoms and Molecules

HD 189733b
Na, H₂O, CH₄, CO₂, CO, hazes

HD 209458b
Na, H₂O, CH₄, CO, CO₂

H₂O and CH₄ in transmission from HST
Day-Night Temperature Variation

NASA/ESA/G. Bacon
Spitzer Space Telescope
Day-Night Temperature Variation

Knutson et al. 2007

Borucki et al. 2009

HD 189733
Atmospheric Escape

Vidal-Madjar et al. 2003
Thermal Inversion

Evidence for thermal inversion assuming $\text{H}_2\text{O}$ and CO
Data from Knutson et al. 2008
Burrows et al. 2007
Variability

Variability: CO$_2$

Carbon dioxide images from PNNL, in microns

From VPL website
A Comment on Data


Disagreement in the literature in Spitzer data has been largely resolved over time, due to understanding different approaches to systematics' removal.
Summary of Data Alone

Identification of molecules
Day-night temperature gradients
Atmospheric escape
Thermal inversion for HD 209458
Variability at 2-σ level
“Exoplanet Atmosphere Modeling is Like Cooking” -- S. Aigrain

Get a recipe

Vary ingredients

Everything other than g and F*

Fit the data
A New Temperature and Abundance Retrieval Technique

Run millions of models to constraint T and abundances
Temperature Profiles

HD 189733

Grillmair et al. 2008
Charbonneau et al. 2008
Deming et al. 2006
Swain et al. 2008

Variability:
True uncertainty in the data? Then no useful limits on molecular abundances
Or the atmospheres are variable both in the energy redistribution state and in the concentrations of molecular abundances

HD 189733b

IRS spectrum

Madhusudhuan & Seager, in press
HD 189733b

IRS spectrum + IRAC

Madhusudhuan & Seager, in press
HD 189733b

IRS spectrum
+ IRAC
+ HST

Overview

Introduction
Data Alone
Model + Data
Prospects
Hot Jupiter Atmospheres
1998 - 2008
2005 - 2010
2009-????
2013 - (JWST)
Exoplanet Atmospheres
Hot Jupiters 1998-2018
Super Earths 2008-2023 Earths 2025 - ?
Super Earth Atmospheres

Super Earth Uncertainties
Atmosphere mass
Atmospheric composition
Host star past and present EUV radiation
Atmospheric escape
Photochemistry
Atmospheric circulation for tidally-locked exoplanets
Super Earth Atmospheres

Hot Jupiters: “primitive atmospheres” means we were able to predict the basics. But we were still surprised (CO$_2$, thermal inversions, possible variability)

Terrestrial planets: “secondary or tertiary atmospheres” much more diversity. Modeling terrestrial atmospheres is more of an art than a science …

Biosignatures:
- Quiet M stars 😊
- Active M stars 😞

Same super Earth, different composition
Miller-Ricci, Seager, Sasselov, 2009
We will study transiting super Earths orbiting small stars akin to Spitzer/HST observations of hot Jupiters transiting sun-like stars
Summary

• HJ Atmosphere Highlights
  – Identification of atoms and molecules
  – Day-night temperature gradients
  – Atmospheric escape

• HJ Model-Dependent Highlights
  – Thermal inversions
  – Variability
  – We may have to live with uncertainty, but we can quantify it

• Super Earths
  – Observations will lead theory
References

- Seager and Deming ARAA Spring 2010