CHARACTERIZING EXOPLANET ATMOSPHERES USING GENERAL CIRCULATION MODELS

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INTRODUCTION

• Exoplanet circulation modelling
  • Allows us to probe dynamical regimes beyond our own solar system, which expands our overall knowledge of atmospheric dynamics
• Provides insights to three-dimensional structure
  • Temperature, heating/cooling rates, composition, clouds, chemistry
• Complements 1-D models in interpreting observations of exoplanet atmospheres: transmission/emission spectra, phase curves, eclipse maps
• Now that we have a (relatively) large observational dataset for a range of planets over a large wavelength range, we can identify trends in atmospheric properties and conduct detailed comparative studies
SAMPLE STUDIES

**WASP-43b, an ultra-short period hot Jupiter**
**Dataset:** Spectrophotometric phase curves with HST/WFC3
**Objectives:** Place constraints on atmospheric metallicity

Large HST program, 10 hot Jupiters observed in transmission
**Dataset:** Transmission spectra of 10 HJs with STIS and WFC3
**Objectives:** Understand role of clouds on target sample

**55 Cnc e, an ultra-short period super Earth**
**Dataset:** Spitzer transit/eclipse measurements from 2011-2013
**Objectives:** Constrain composition and atmospheric variability
COMPARING GCMS TO SPECTROPHOTOMETRIC DATA: WFC3 OBSERVATIONS OF WASP-43B

Kataria et al. 2015
COMPARISON TO HST WFC3 OBSERVATIONS
SPECTROPHOTOMETRIC PHASE CURVES

Red: 1x solar model
Blue: 5x solar model

Kataria et al. (2015)
COMPARISON TO HST WFC3 OBSERVATIONS

EMISSION SPECTRA

Figure 14. Comparison of our predicted flux ratios of WASP-43b at 1× and 5× solar (red and blue lines, respectively), with the WFC3 emission spectrum at each binned phase (black squares, with error bars).

Red: 1x solar model
Blue: 5x solar model

Kataria et al. (2015)
HST LARGE PROGRAM STUDY

Cloudy versus cloud-free planets

Huitson et al. 2013; Wakeford et al. 2013; Sing et al. 2013, 2015; Nikolov et al. 2014, 2015; Ballester et al. in prep
WASP-19b

Ultra-short period (~19 hr) planet with a wide array of observational constraints

Preliminary reductions by N. K. Lewis and C. M. Huitson
DISENTANGLING CLOUDS

1D radiative equilibrium PT profiles from Jonathan Fortney
Figure 2: Wind/temperature profile at 100 mbar.
**VARIABILITY ON 55 Cnc e?**

Figure 10. 2013 occultation - RMS vs. binning.

Demory et al. 2015

Figure 11. 55 Cnc e Spitzer/IRAC 4.5 µm occultation and transit depths.

Top and bottom panels indicate the occultation and transit depths with time. Left panels are for 2011, middle panels for 2012 and right panels for 2013. The grey solid horizontal lines indicate the mean depths and the dotted lines the 1-σ credible intervals.

On the other hand, the velocity of the ejecta required to sustain \( \dot{H} \approx 1300^{-5100} \) km is between 8-17 km/s, which is below the escape velocity of the planet (24 km/s) and is significantly lower than the maximal ejection velocities of \( \sim 300 \) km/s observed on Io.

Alternately, the data may also be potentially explained by the presence of an azimuthally inhomogeneous circumstellar and/or circumplanetary torus similar to Io (Belcher 1987) that could contribute a variable gray opacity along the line-of-sight. While CO gas in the torus could provide the required opacity in the 4.5 µm bandpass, dust could provide the same in the visible/IR. For a circumstellar torus, the optical depth of the time-varying torus segment occulting the stellar disk governs the observed stellar radius.
TEMPORAL VARIABILITY

50x solar

H₂O-dominated

CO₂-dominated

Normalized Secondary Eclipse Depth

Time (Earth days)
CONCLUSIONS AND FUTURE WORK

• Three-dimensional circulation models can be used to lend insights on a variety of observational datasets, and help answer fundamental questions about their atmospheric properties.
• GCM-derived models can provide constraints, but they’re not perfect.
  • For example, model phase curves generally over-predict nightside flux.
  • Enhancement of C/O ratio, disequilibrium chemistry, and/or clouds can be invoked to explain discrepancy, but detailed models are needed to explore these effects.
• Need GCMs that encapsulate more complex physics.
  • However, with great complexity comes great responsibility.
  • Idealized models help identify fundamental dynamical mechanisms.