Optimizing JWST Observations of Transiting Planets with Atmosphere Retrieval Modeling

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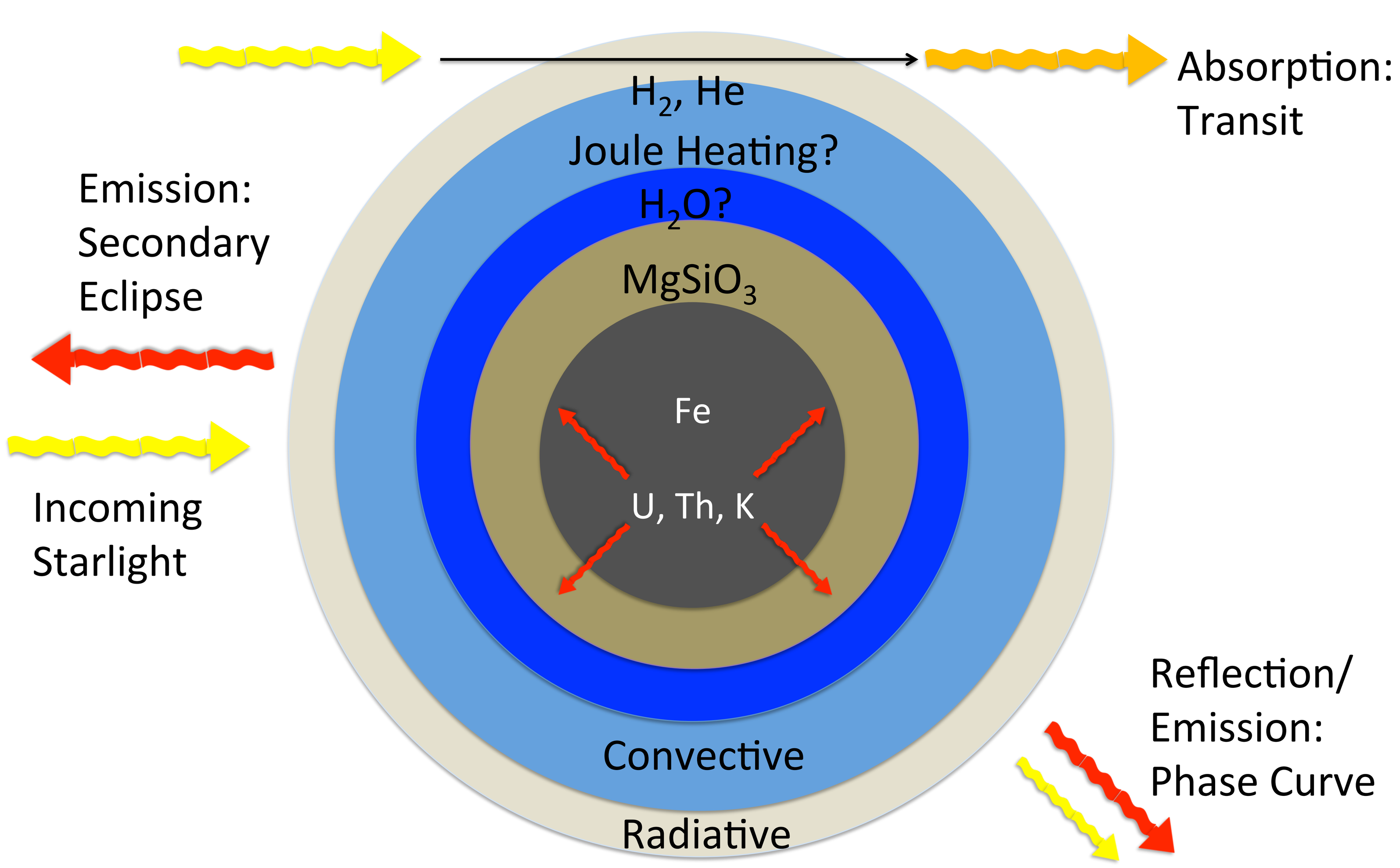
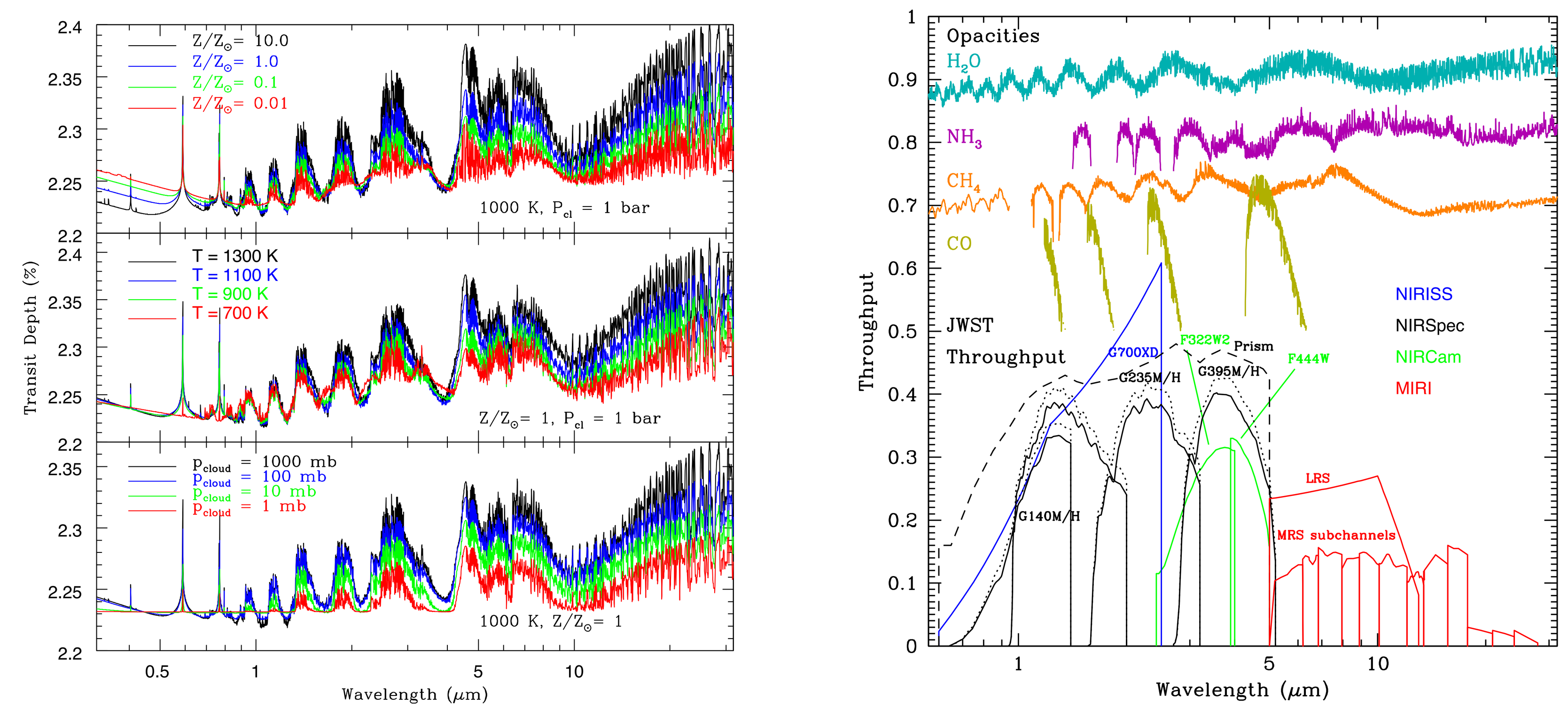
Abstract: We present theoretical models of extrasolar planet atmospheres in conjunction with a new atmosphere retrieval code to develop an optimized observing plan for hot jupiters with JWST. We build our atmosphere models based on self-consistent internal structure and evolution models incorporating thermal cooling and XUV-driven mass loss. We also incorporate a range of compositions and cloud models into our atmosphere models and compute transit spectra with a 1-D radiative transfer model. These complimentary model sets are designed for efficient retrievals of atmosphere parameters from JWST data. We perform statistical retrievals from synthetic JWST data for multiple observation strategies and use information theory to determine which strategy yields the greatest amount of useful information from limited observing time. We present our findings in the form of an observing program for characterization of transiting hot jupiters.

The Atmosphere and Spectrum Code



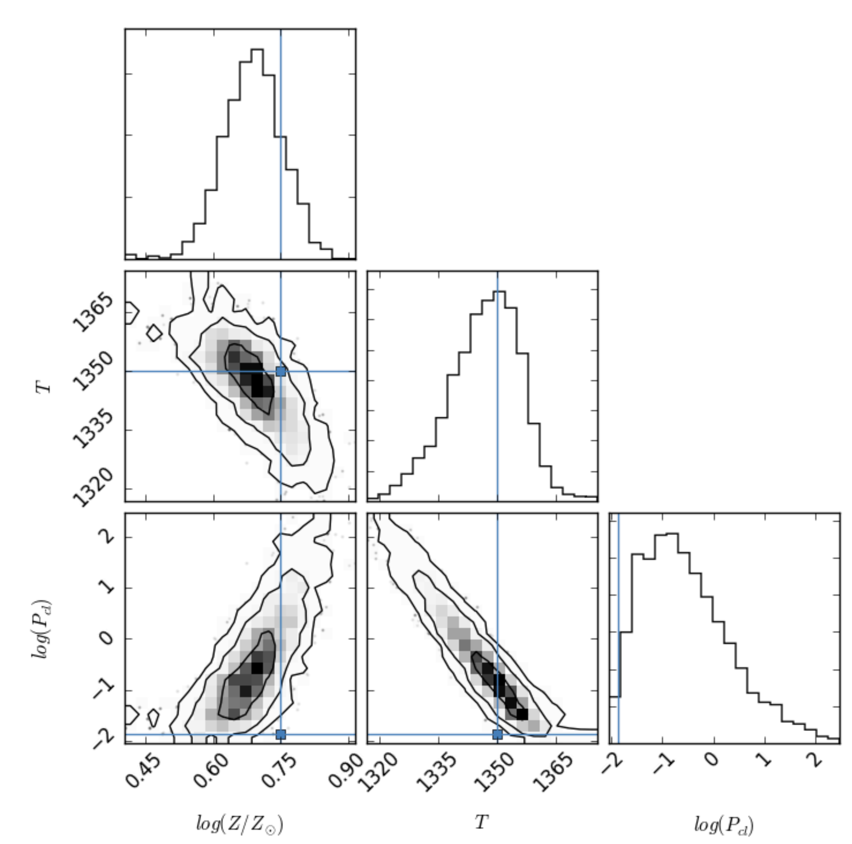
The full version of the code includes a layered internal structure computed with the hydrostatic structure equations and a self-consistent atmosphere model in quasi-static equilibrium with long-term cooling. It also accounts for UV-driven mass loss with an energy-limited model. We have used these features in our prior work to generate structure and evolution models of planets (Howe & Burrows, 2015). We have also generated spectral models of GJ 1214b to fit transit observations (Howe & Burrows, 2012).

In order to simplify the task of fully exploring the space of observing programs with *JWST*, we implement a simple, three-parameter forward model for atmospheres of hot jupiters with measured masses and radii, including metallicity, equilibrium temperature (based on irradiation level), and a cloud top pressure level.



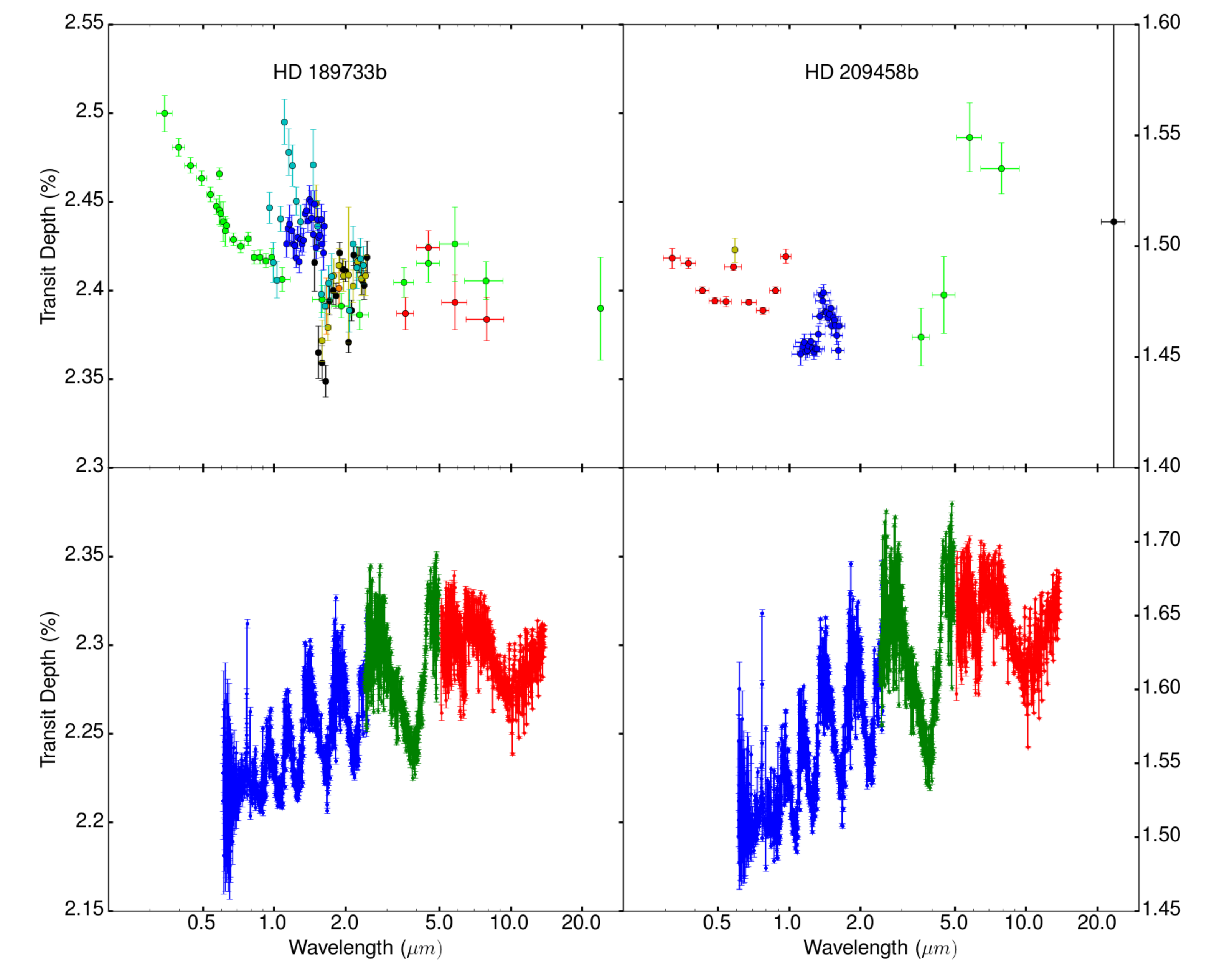
Left: forward model transit spectra for HD 189733b computed with our spectral code, plotted in percent transit depth versus wavelength in microns and showing the variation over our three model parameters. Right: throughput functions of all *JWST* spectroscopic observing modes versus wavelength in microns plotted with common molecular opacities (scaled and offset). For NIRSpec, high-resolution modes are plotted with solid lines, while medium-resolution modes are plotted with dotted lines. MIRI LRS corresponds to both Slit and Slitless modes. MIRI MRS is divided into twelve subchannels, which can be imaged in three visits.

We designed seven observing programs based on the spectroscopic capabilities of *JWST*. For each observing mode, we created a noise model including shot noise, thermal backgrounds and zodiacal light.



With our noise models, we generated synthetic observations of eleven hot jupiters spanning a range of planetary parameters and target brightnesses. Most notably, we explore three ranges of target brightness: *J*<8 (excluding NIRSpec), 8<*J*<11 (all 4 instruments), and *J*>11 (NIRSpec Prism and MIRI LRS only). We fit forward model spectra to the model data with an MCMC method to determine posterior likelihood distributions for the model parameters.

Above: a representative posterior distribution fit to model observations of 1 hour of observing time of HAT-P-1b with the NIRSpec G395H filter.



Above: comparison of the best currently available observational data for hot jupiters (mostly from *HST* and *Spitzer*) with the data that will be available from *JWST* with our Program 1.

We measure the effectiveness of our observing programs by computing the mutual information (the divergence between the joint distribution of the prior and posterior and the product of the two) for the results. Mutual information obtained increases logarithmically with observing time and roughly linearly with the scale height of the atmosphere. We plot these results below for eight planets observed with our Program 1. We also include the average value to better illustrate the trend with observing time. This method allows for a reliable comparison between proposed observing programs.