

# Atmospheric Circulation on GJ1214b: Dependence on composition and metallicity

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## Abstract

The detection and characterization of exoplanets continues to be a burgeoning field of research, with the detection of Earth-sized exoplanets already being made by space-based and ground-based efforts (e.g. HARPS, Kepler, ESA's CoRoT, MEarth). The detection of super Earth GJ 1214b by the MEarth survey opened up a new door to characterizing a growing class of planets and their atmospheres. The atmospheric circulation of such an object—transitional between gas giants and terrestrial planets—is a fascinating problem with important implications for observables, yet almost no studies of the atmospheric circulation of super Earths have yet been performed. Therefore, we present three-dimensional atmospheric circulation models of GJ1214b using the SPARC/MITgcm, a general circulation model coupled to a plane-parallel, two-stream, multi-band radiative transfer model. Here, we determine the effects of metallicity and atmospheric composition on the circulation and vertical temperature structure of the atmosphere.

## 1. Introduction

Of the  $\sim 500$  extrasolar planets detected to date, much of the observational characterization has been for transiting hot Jupiters, Jovian-mass exoplanets that pass in front of their host star at semi-major axes less than 0.1 AU. Observations between transit and secondary eclipse have been obtained from ground- and space-based telescopes (e.g. [1]). One can use these observations (along with radial velocity data) to determine the planet's temperature structure, thus constraining the circulation of their atmospheres (e.g. [2]).

The next decade, however, will see a growth in the detection and characterization of terrestrial exoplanets, in particular the "super Earths", planets 1-10 times the mass of Earth. Already,  $\sim 30$  detections of such planets have been made (e.g. [3], [4]), not including the hundreds of additional planet candidates recently

announced by NASA's Kepler mission ([5]). Of particular interest is the detection of super Earths around M-dwarfs, ideal targets for exoplanet surveys because of their small star-planet contrast. The MEarth survey has detected a transiting super-Earth of mass  $6M_E$  orbiting M-dwarf GJ 1214A at an orbital distance of 0.014 AU ([3]). We can therefore observe this super Earth by similar techniques used for transiting hot Jupiters, allowing us to characterize the planet's atmosphere. Because the planet is closely orbiting its parent star, it is likely that the planet is tidally locked and synchronously rotating. Thus, like hot Jupiters, one side of the planet will be permanently illuminated while the other will be permanently dark.

Observations of GJ1214b have been obtained by numerous groups to characterize the planet's atmosphere, with little consensus. The first ground-based spectrum obtained by [6] is a generally featureless one, suggesting an atmosphere with a high mean-molecular weight (i.e., not hydrogen- and helium-dominated). Observations obtained by [7] agree with this result. Still, analysis of other observations favor a H/He dominated atmosphere, particularly if methane is depleted ([8], [9]). The fact that super Earths in general—and GJ 1214b specifically—could have either hydrogen-rich or hydrogen-poor atmospheres raises fundamental questions about their atmospheric circulation, since these limits have pressure scale heights differing by an order of magnitude and therefore may exhibit fundamentally differing atmospheric dynamics regimes.

In light of these considerations, we model the atmosphere of GJ1214b using the SPARC/MITgcm, a general circulation model coupled to a fast and efficient radiative transfer scheme applicable to a broad range of atmospheric compositions. In particular, we focus on the effects of metallicity and composition on the overall temperature structure and dynamical regime.

## 2. Model description and anticipated results

We model GJ1214b’s atmosphere using the Substellar Planetary Atmospheric and Radiation Circulation (SPARC) Model, which couples the MITgcm [10] with a plane-parallel, two-stream radiative transfer model by [11] (see [2] for more details). The MITgcm solves for the circulation of the atmosphere using the primitive equations, a simplification of the Navier Stokes equations assuming local hydrostatic balance. Each simulation utilizes a cubed-sphere grid with a horizontal resolution of C32 (64x128 in latitude and longitude) and a vertical pressure range from  $\sim 200$  bar to  $\sim 20$   $\mu$ bar split into 76 levels with even log spacing.

In this study, we model three atmospheric compositions: hydrogen-dominated, water-dominated, and CO<sub>2</sub>-dominated. For the hydrogen-dominated cases, we model cases with solar metallicity,  $30\times$  solar, and  $50\times$  solar as presented in [12] (Figure 1). Opacities for each case are binned using the correlated-k method ([13]). These various compositions affect not only the atmospheric opacities (hence absorption of starlight and emission of infrared radiation) but also the mean molecular weight, hence atmospheric scale height, dry adiabatic lapse rate, and other factors.

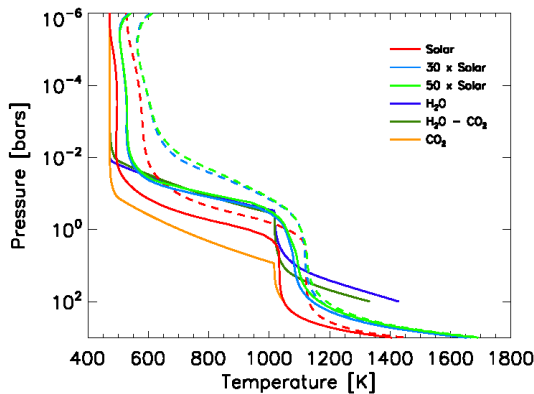


Figure 1: T-P profiles for hydrogen-dominated atmospheres from [12]). The profiles we use for the simulations are given by the red (solar metallicity), blue ( $30\times$  solar) and green ( $50\times$  solar) solid lines.

As seen in previous work by [14] and others, enhanced metallicity (and hence opacity) leads to shallower atmospheric heating. This affects the atmospheric temperature gradients and winds of the planet as a function of altitude. We anticipate similar results

in our study of GJ1214b. Ultimately, we will identify jet streams and waves that may arise, diagnose the mechanisms that drive their forcing, and understand how they depend on atmospheric composition and metallicity. Future work will involve the generation of synthetic lightcurves and spectra to see which of these best match current observations. This work serves as a first step towards characterizing the circulation regime and temperature structure of GJ1214b and other super Earths.

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