The coupled impact of atmospheric dynamics and cloud microphysics on WASP-43b

DEPARTMENT OF ASTRONOMY

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Introduction

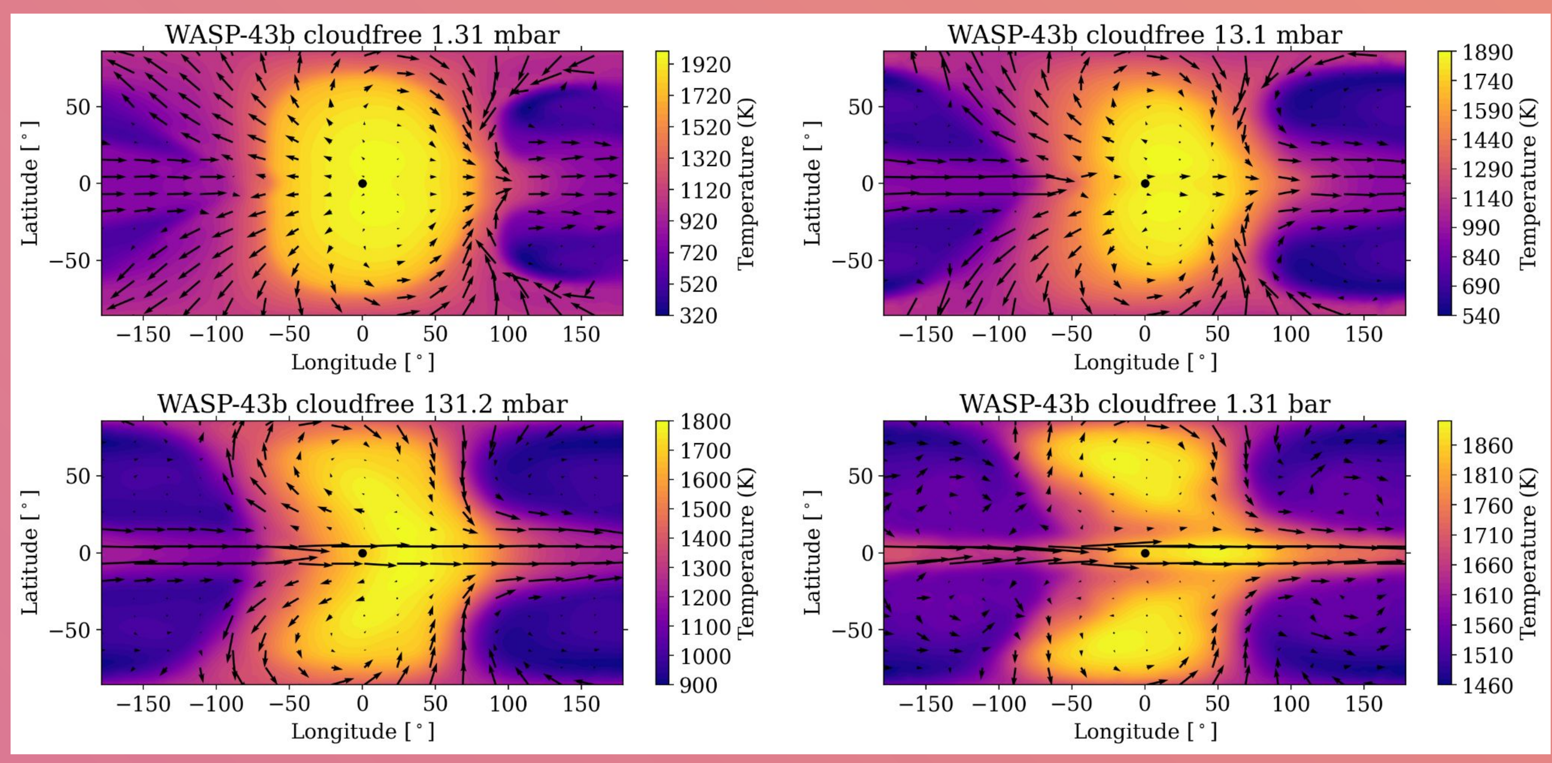
Clouds are ubiquitous in hot Jupiter atmospheres.

- Observations have found phase curve offsets, weak absorption features, and constant nightside temperatures with increasing instellation, all of which point to the presence of nightside clouds.

Current models of hot Jupiters still struggle to fully match observations.

- Previous simulations have included clouds in a variety of ways, but very few models couple the microphysics formation of clouds, the planet's atmospheric dynamics, and the radiative feedback of clouds on hot Jupiter atmospheres [4, 6, 7, 9, 14].

We are building a suite of models aiming to address the mismatch between observations and cloudy models of hot Jupiters.



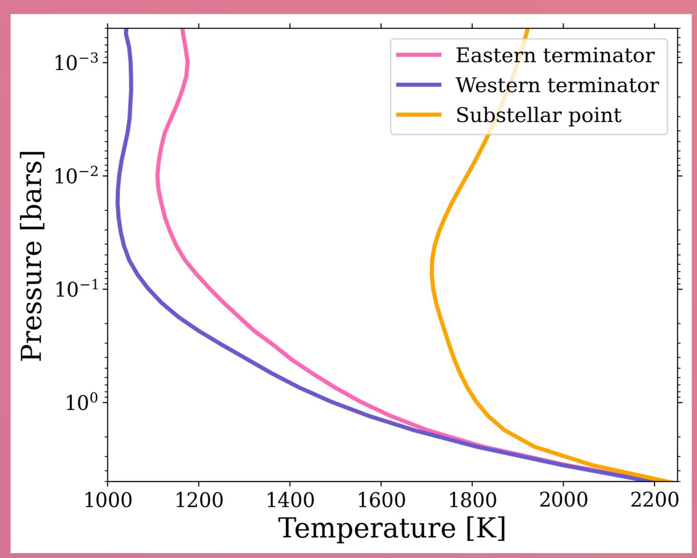


Fig. 1, top: Temperature and wind maps of the hot Jupiter WASP-43b from our SPARC/MITgcm cloud-free model. Each panel shows the atmosphere at different pressures (lower pressure = higher altitude).The colormap shows the temperature at different longitudes and latitudes, and the black arrows show the direction and magnitude of the winds. As expected, we see the typical pattern of the superrotating jet at the equator, as well as the chevron pattern on the dayside of the planet, which is caused by standing planetary waves [11, 12].

Fig. 1, left: Temperature-pressure profile of WASP-43b from the GCM at different longitudes: east limb (pink), west limb (purple), and sub-stellar point (orange). The western limb remains cooler than the eastern limb due to the eastward advection of hot air from the dayside to the nightside.

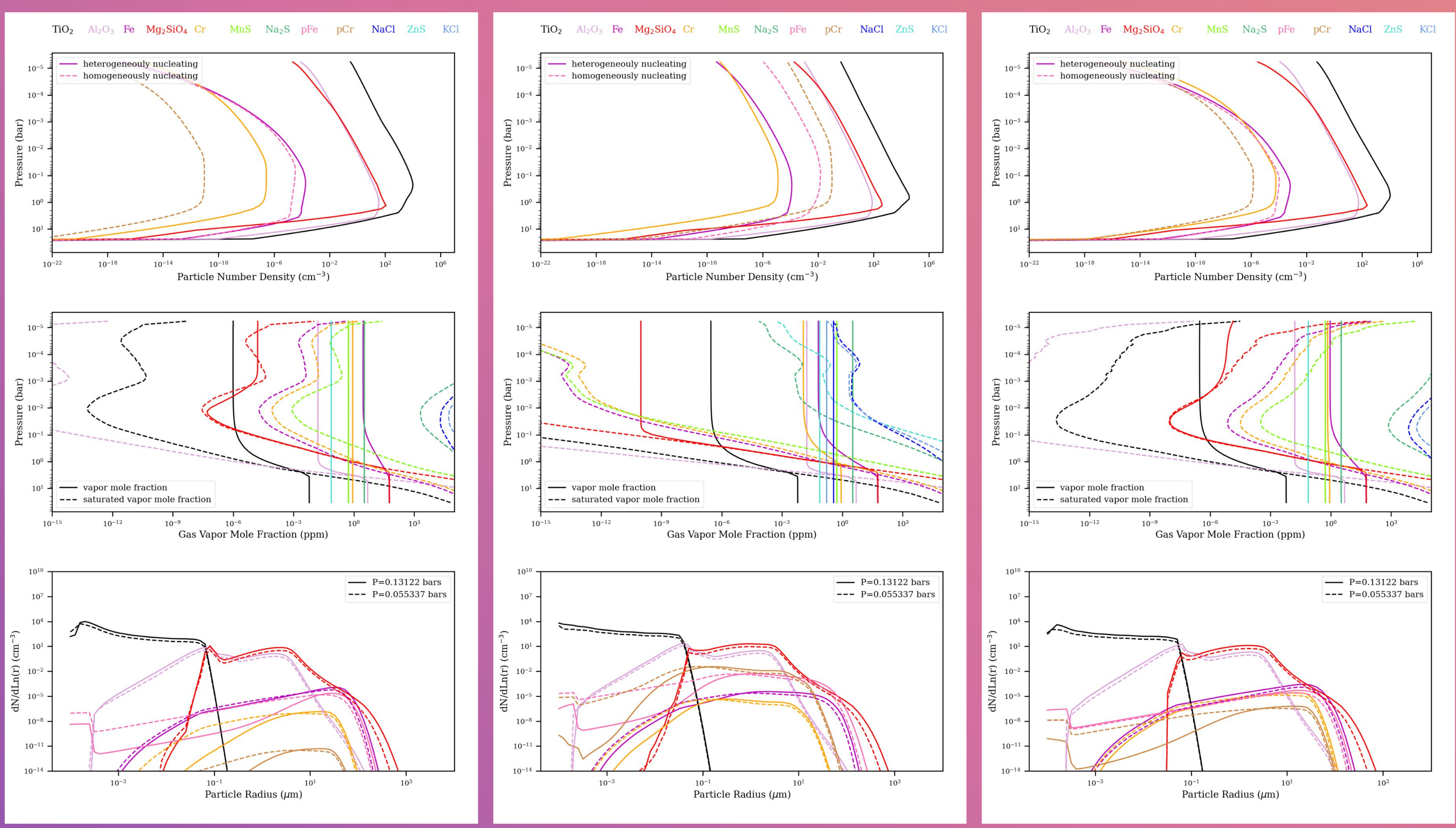
Methods

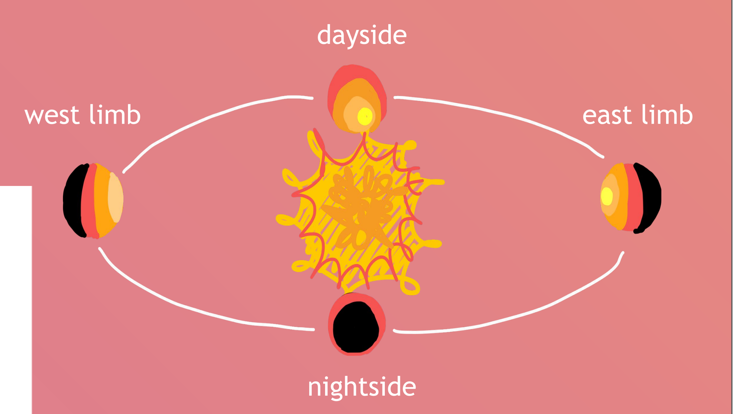
We explore the effects of clouds on emission spectra and phase curves.

- We indirectly couple a global circulation model (GCM) with a cloud microphysics model and post-process their results with a radiative transfer code.
- We model the atmospheric dynamics of WASP-43b, a well-studied hot Jupiter with high quality HST and JWST data [1, 5, 13], using the 3D SPARC/MITgcm [10].
- We then extract the temperature-pressure profile of WASP-43b from the GCM and feed it into CARMA, a 1D microphysics model that simulates the formation of clouds [2].

Our goal is to couple dynamics and microphysics by feeding information back and forth between MITgcm and CARMA to accurately model clouds.

East limb (a) Night side (b) West limb (c)





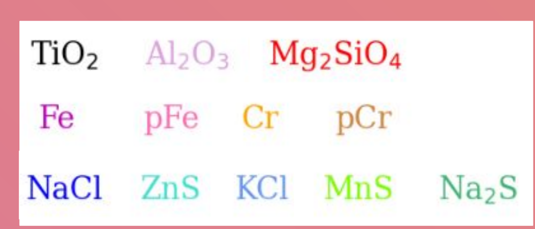


Fig. 2: CARMA simulations of the vertical cloud structure of WASP-43b at different longitudes: east limb (a), anti-stellar point on nightside (b), and west limb (c).

The top panel shows the particle number density of different condensing species as a function of pressure/altitude, and the third panel shows those same species' radius distribution as a function of particle number density per bin. We can see that the number density of most species peaks around 1 bar, and these species have varying size distributions.

The middle panel shows the gas vapor mole fraction of each species as a function of pressure/altitude. Most species whose vapor fraction curves cross their condensation curves will eventually "quench", or maintain the same abundance throughout the upper atmosphere, due to vertical mixing dominating over chemical reaction times. The sub-stellar point on the dayside is not shown here, as no clouds formed due to the high dayside temperatures.

Preliminary Results

MITgcm

- We run global circulation model simulations for WASP-43b (Fig. 1) and WASP-121b (not shown here), and find that the resulting TP profiles and temperature maps agree well with previous simulations by Kataria et al. (2015) and Parmentier et al. (2018) using the same GCM [3, 8].
- Our model reproduces the superrotating jet, the east-facing chevron shape on the dayside, and the eastward hotspot offset as expected.

CARMA

- We simulate the cloud formation in WASP-43b's atmosphere (Fig. 2), and find that TiO_2 dominates as the homogeneously nucleating/seed species, and that 4 other main species condense: Al_2O_3, Fe (homogeneously and heterogeneously), Mg_2SiO_4, and Cr (hom. and het.).
- The substellar point is devoid of any condensing species, due to the high temperatures that WASP-43b's dayside experiences.

Future Works

- Currently in progress are the CARMA simulations for WASP-121b. We are also working on post-processing the CARMA runs for both planets, in order to obtain synthetic spectra that we can compare to existing observations.
- Moving forward, we will use the optical properties of the CARMA clouds to inform **new cloudy MITgcm runs**, which will parameterize clouds as radiatively active cloud tracers.
- Finally, we will post-process these cloudy GCM runs using a radiative transfer code to obtain full phase curves of WASP-43b and WASP-121b, and compare these with JWST phase curve observations of the planets.

Our long term goal is to eventually create a grid of cloudy GCMs to investigate the properties of clouds and their impact on hot/ultra-hot Jupiter atmospheres.

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