Two-Dimensional Eclipse Mapping of the Hot Jupiter WASP-43b with JWST MIRI/LRS

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Introduction

As part of the JWST Transiting Exoplanet Early Release Science programme, we used a JWST MIRI/LRS phase curve of the hot Jupiter WASP-43b to fit a 2D map of its day-side thermal emission from 5 to 10.5 microns [1,2]. WASP-43b has a radius of 0.16 R_J, a period of 0.81 days, and an equilibrium temperature of 1400 K. Its high impact parameter of 0.67 makes it well suited to eclipse mapping [3].

We simultaneously fitted models of the orbital system, instrumental systematic effects, and a global two-dimensional map [2]. Figure 1 shows the resulting time-series observation with the systematic trend in blue and the phase curve model in red.

We did not find any significant degeneracies between the model parameters. The eclipse map model found statistically significant differences in the orbital parameters to those found by a Fourier series phase curve model.

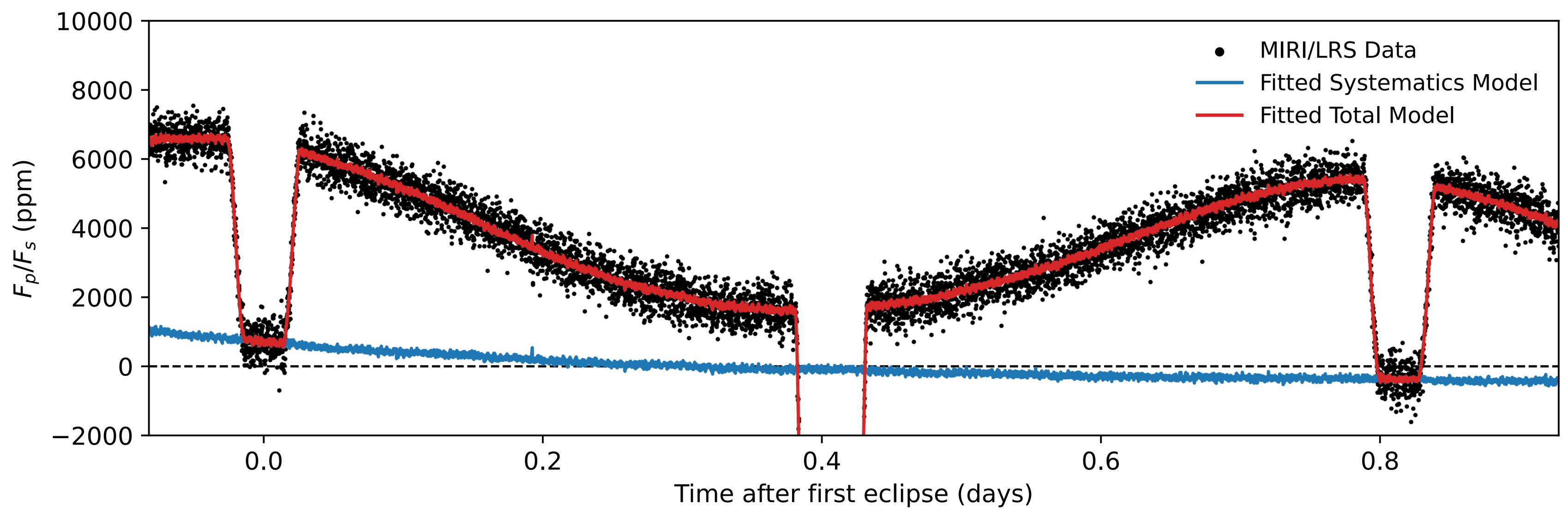

Figure 1: Time-series observation of thermal emission from WASP-43b with JWST MIRI/LRS, containing two eclipses and one transit, showing the astrophysical and instrumental models

Results

The black points in Figure 2 show the observed thermal emission in the eclipse ingress and egress, subtracted by a model of the eclipse assuming the planet emits like a uniform disk. The residual this leaves corresponds to the signal containing two-dimensional eclipse mapping information.

The below schematic shows how when the residual is positive, the strip eclipsed at that moment is brighter than the average disk, and vice versa [4]. The green points show data from the first eclipse, the purple points show the second eclipse, and the black points show their average.

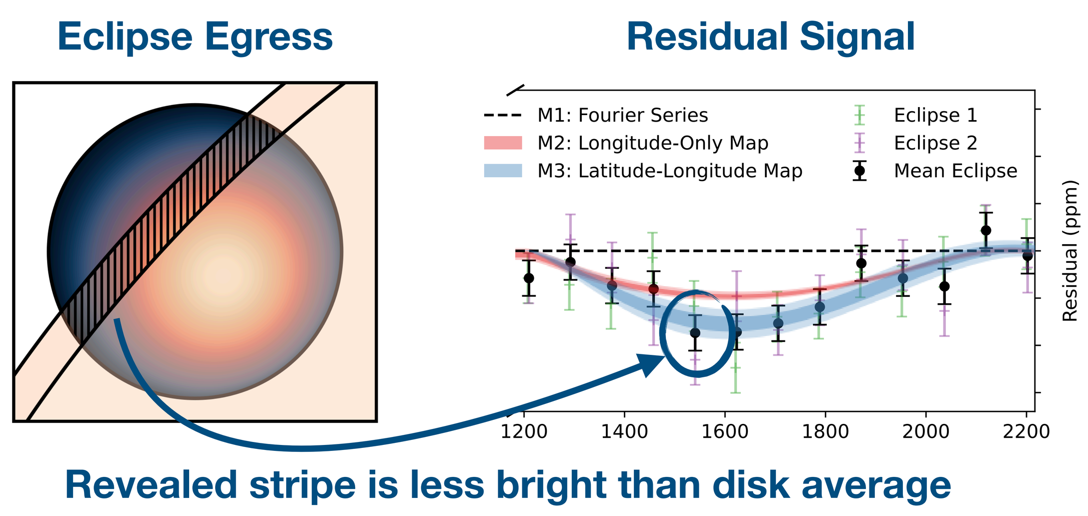

Figure 3 shows the two-dimensional eclipse map derived by fitting a combination of spherical harmonic functions up to order l=2. This results in the light curve shaded in blue in Figure 1 and Figure 2.

The width of the shaded region shows the posterior distribution of fitted maps. These fitted light curves match the residual shape of the eclipse in Figure 2 much better than the model assuming a uniform disk (the dashed line where the residual equals zero).

Figure 4 shows an eclipse map fitted assuming an emission structure that is uniform with respect to latitude, to test if we are sensitive to latitudinal structure. This map results in the red light curve shown in Figure 2, demonstrating how it does not fit the eclipse shape as well as the two-dimensional map in Figure 3.

There are approximately equal contributions to the residual signal from the latitudinal and longitudinal structure, as expected from the fact that the stellar edge crosses the planet at around 45 degrees.

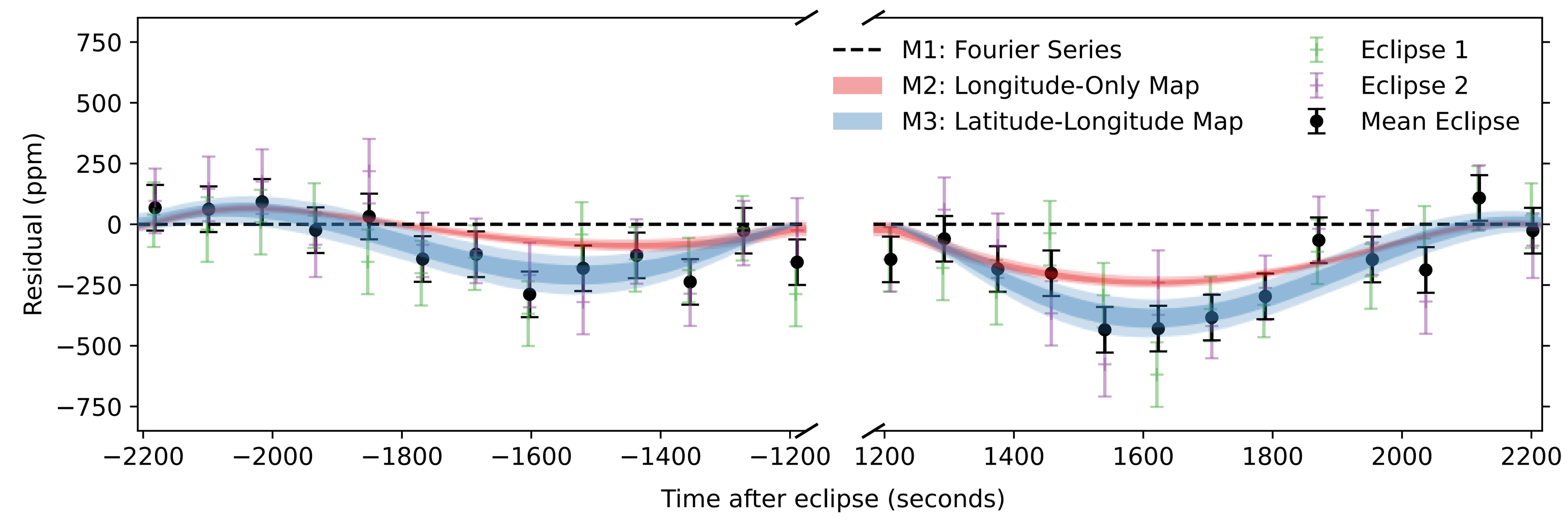

Figure 2: Residual signal in eclipse ingress and egress, defined as the data minus the eclipse shape for a uniform disk, fitted by the maps in Figures 3 and 4, showing 2D information

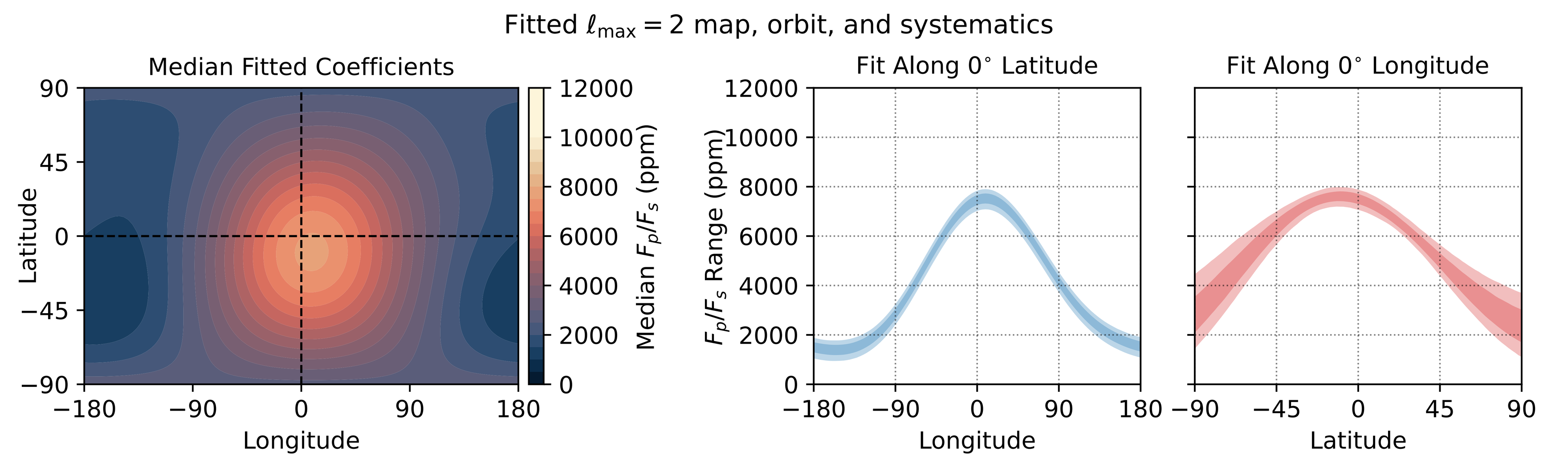

Figure 3: Eclipse map fitted with spherical harmonics up to l=2, plus its posterior distribution in latitude and longitude, showing a small longitudinal offset that differs from the phase curve peak

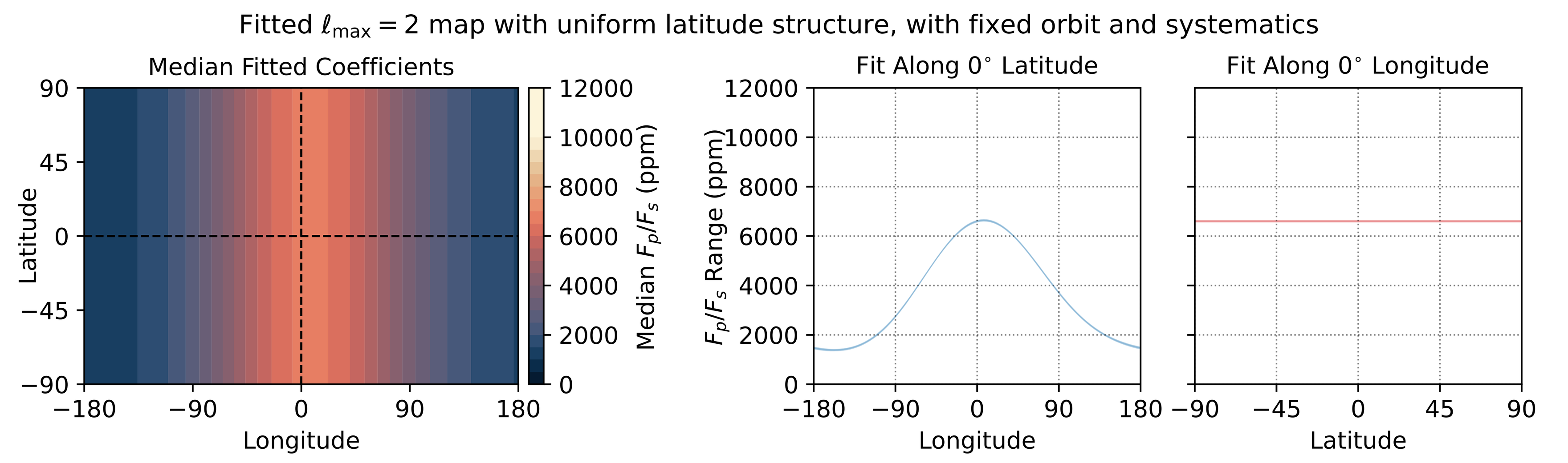

Figure 4: Eclipse map fitted with uniform emission as a function of latitude, plus its posterior distribution in latitude and longitude, resulting in a worse fit to the eclipse shape in Figure 2

Conclusion

We used an observed JWST MIRI/LRS phase curve of the hot Jupiter WASP-43b to fit a map of thermal emission from 5 to 10.5 microns. We found a clear residual signal in the eclipse shapes due to the two-dimensional structure of the day-side emission. This was similar to a selection of 3D atmospheric simulations, shown in Figure 5.

The fitted map is peaked near the substellar point, with a small eastward hot-spot shift and a small latitudinal offset that may not be statistically significant. See Hammond et al. (2024), "Two-Dimensional Eclipse Mapping of the Hot Jupiter WASP-43b with JWST MIRI/LRS" for more details.

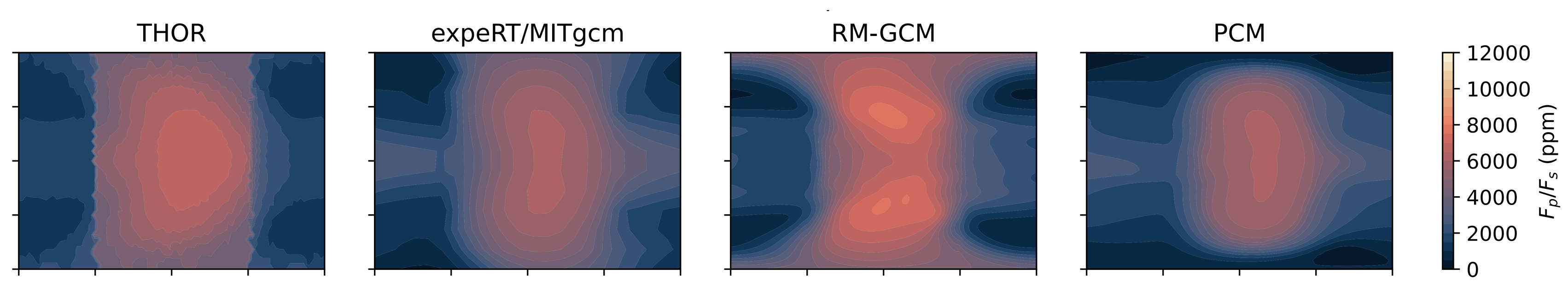

Figure 5: Four different GCM simulations of the emission from 5 to 10.5 microns, showing a variety of longitudinal and latitudinal structures, none of which exactly match the observations

References

1) Bell et al. (2024), Nightside clouds and disequilibrium chemistry on the hot Jupiter WASP-43b, Nature Astronomy
2) Hammond et al. (2024), Two-Dimensional Eclipse Mapping of the Hot Jupiter WASP-43b with JWST MIRI/LRS, AJ
3) Boone et al. (2024), An analytical theory for the resolution attainable using eclipse mapping of exoplanets, MNRAS
4) Majeau et al. (2012), A Two-Dimensional Infrared Map of the Extrasolar Planet HD 189733b, ApJ

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