JWST Weather Report from an Isolated World:

Decoding the Causes of Variability on SIMP0136 using NIRSpec and MIRI

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NIRSpec & MIRI (each)
3:00 Hr

JWST

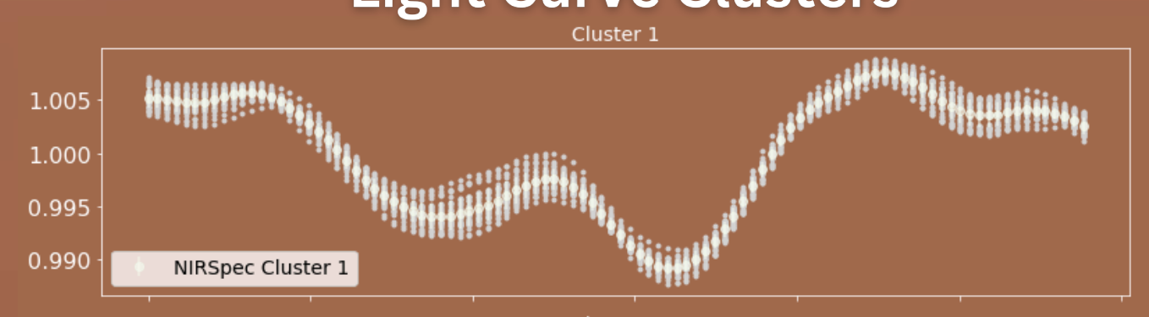
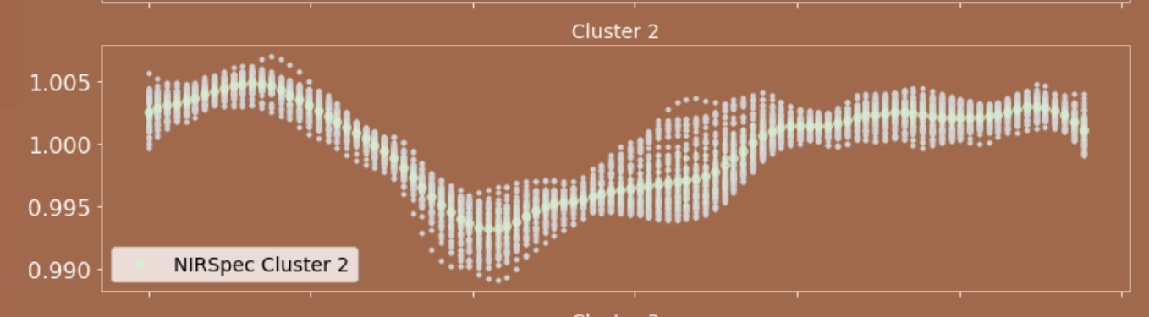
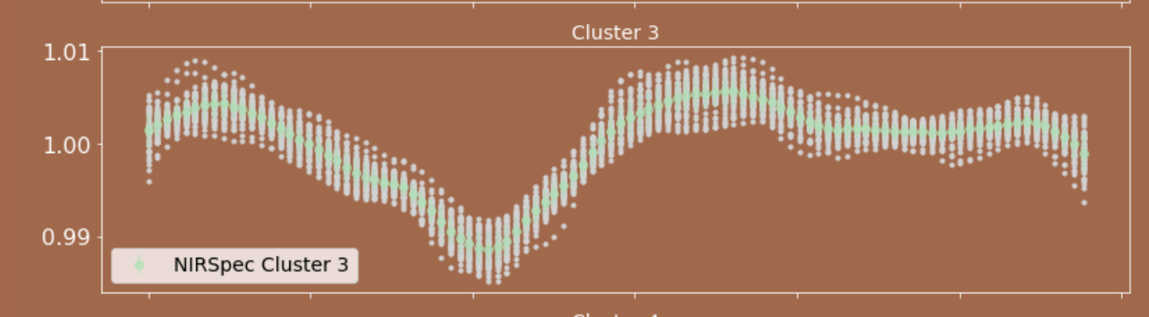
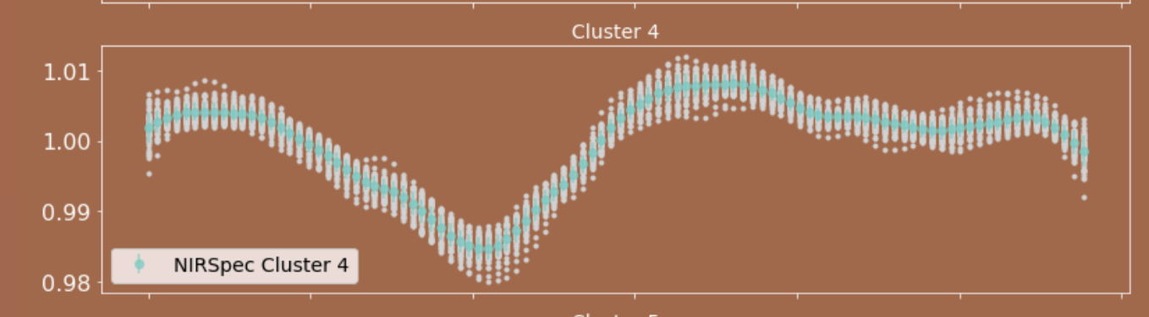
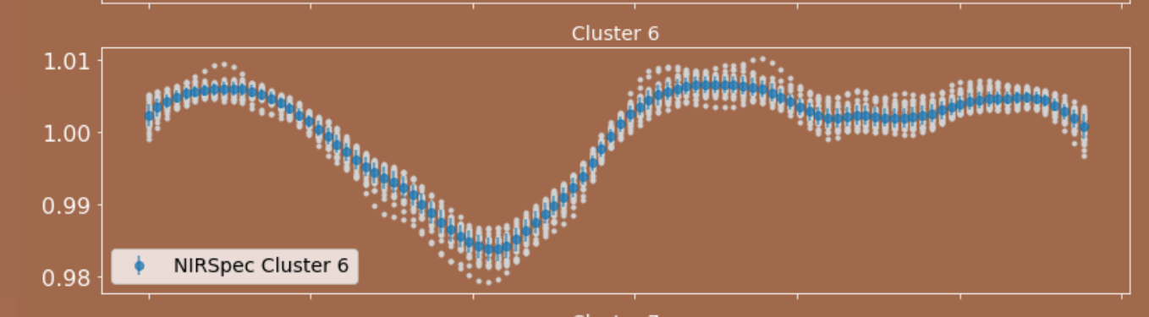
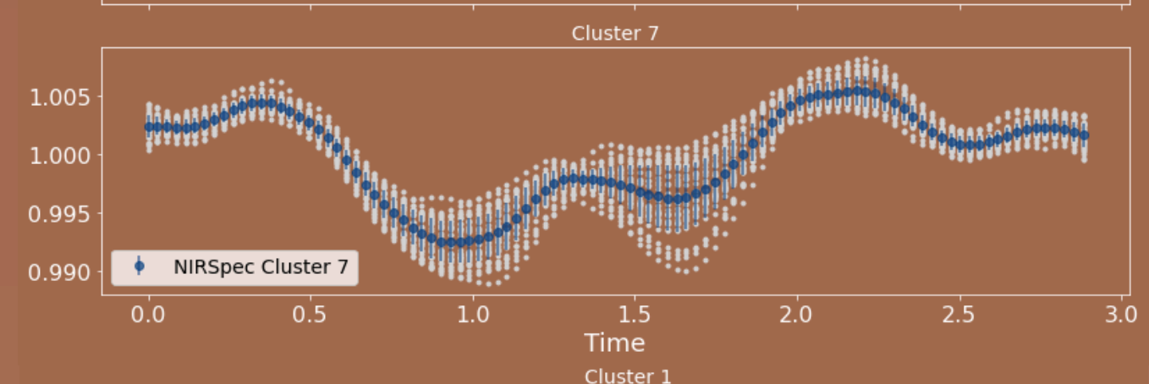
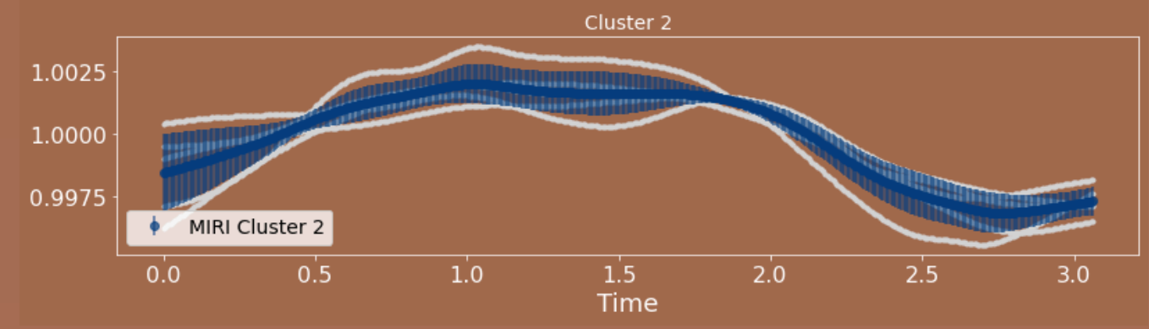
SIMP 0136

1100 K | Patchy Clouds

IMPORTANT INFORMATION

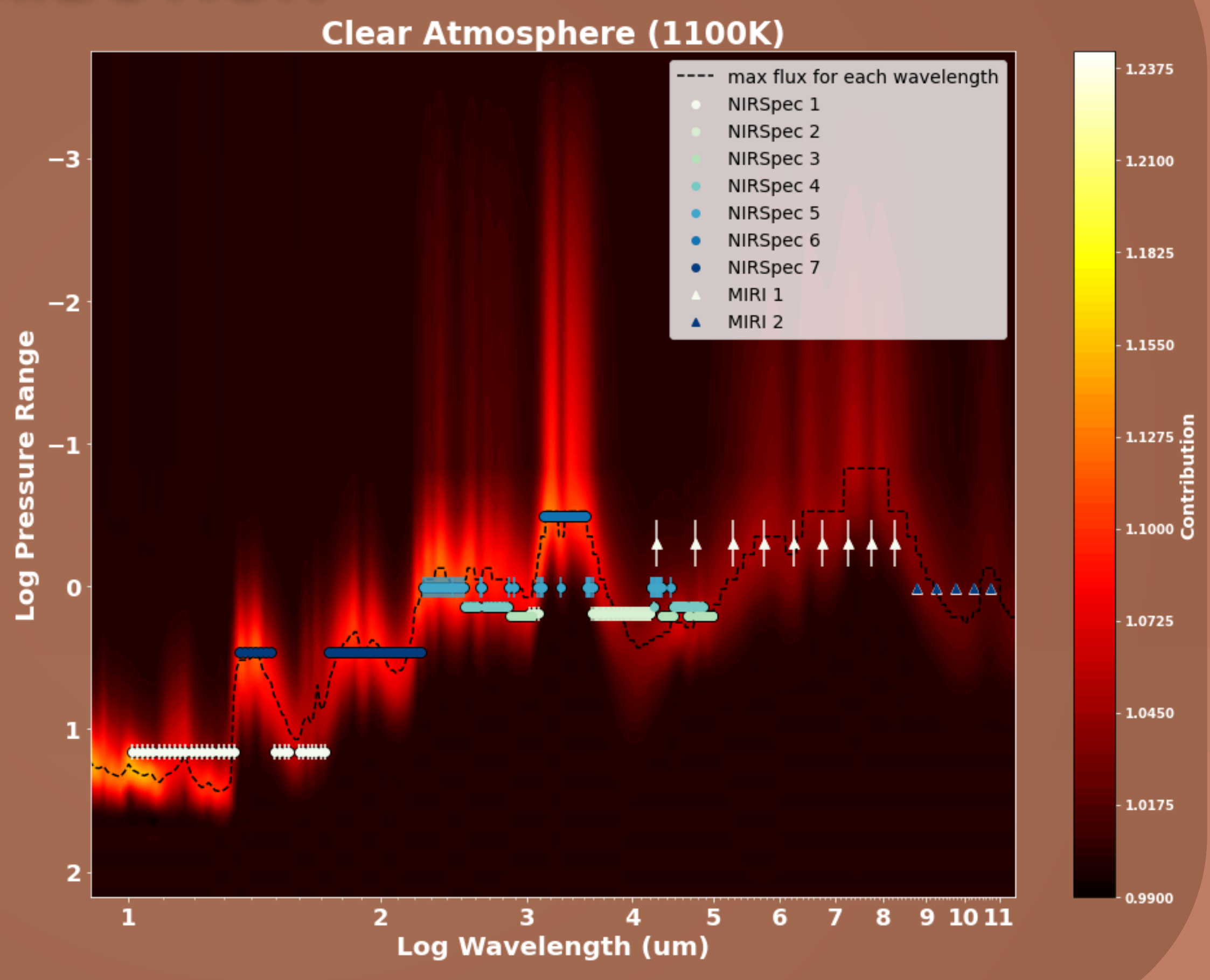
SpT	Radius (R_J)	Mass (M_J)	Age (MYr)	Period (Hr)	log(g) (cgs)
T2.5	1.22	12.7	200	2.4	4.3

CLUSTERED LIGHT CURVE SHAPES

Cluster #	Primary Mechanisms	Light Curve Clusters	Pressure Range Probed (bar)
NIRSpec			
1	☁ ☁		5.75 – 26.9
2	☁ 🌡		0.45 – 2.63
3	🌡		1.04 – 2.23
4	🌡		0.75 – 2.34
5	C≡O 🌡		0.30 – 2.34
6	🌡		0.30 – 0.45
7	☁ ☁		1.20 – 5.62
MIRI			
1	🌡		0.14 – 2.23
2	☁ ☁		0.60 – 1.65

FLUX CONTRIBUTION

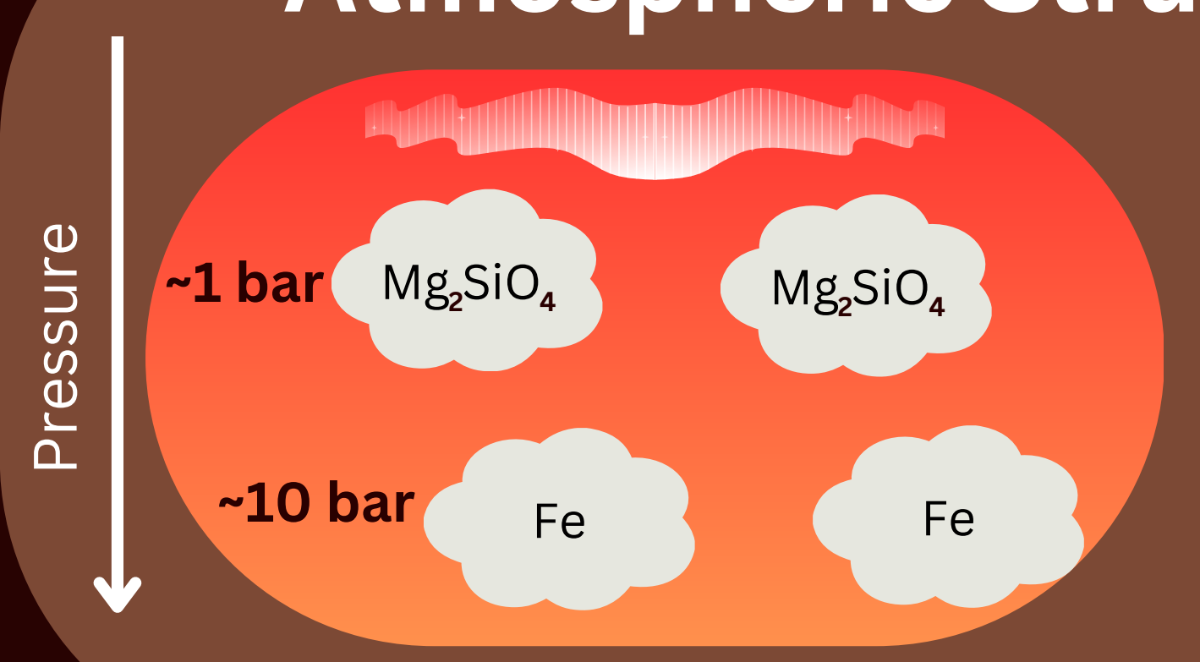
Here, we show the relative contribution of flux for a cloudless atmosphere with similar temperature and gravity to that of SIMP0136. This highlights which regions of the atmosphere are responsible for a majority of the flux for each wavelength we have sampled. We overplot our clusters, NIRSpec with round markers, MIRI with triangles, and the errorbars show the variance of the pressure of each cluster. NIRSpec clusters 1, 6, and 7 clearly show relation to pressure level probed, while clusters 2-5 show some relation to pressure, but also have a different wavelenth dependent component.



Variability in Planetary Mass Objects is Poorly Understood

Brown dwarfs and planetary-mass objects have several proposed mechanisms of variability including clouds, hot spots, aurora, and thermochemical instabilities. Each of these features would affect different wavelengths and pressures differently. By probing a large range of wavelengths, we can begin to untangle the multiple mechanisms of variability in an object.

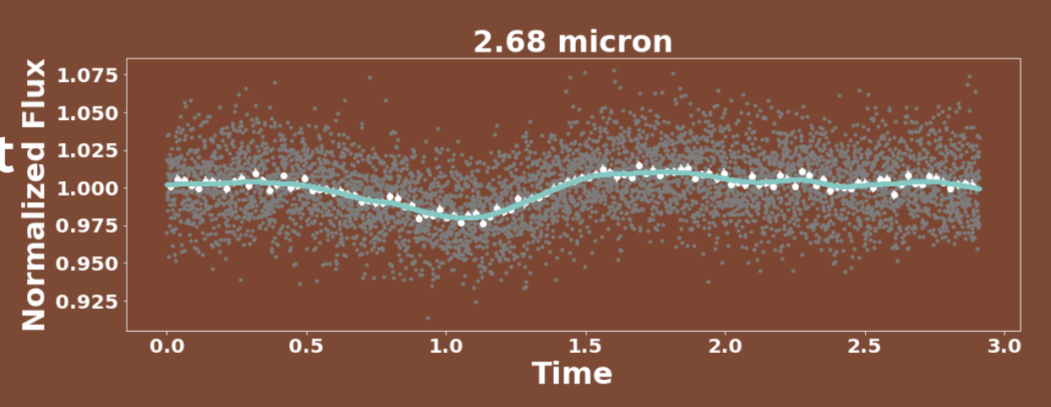
Atmospheric Structure of SIMP0136

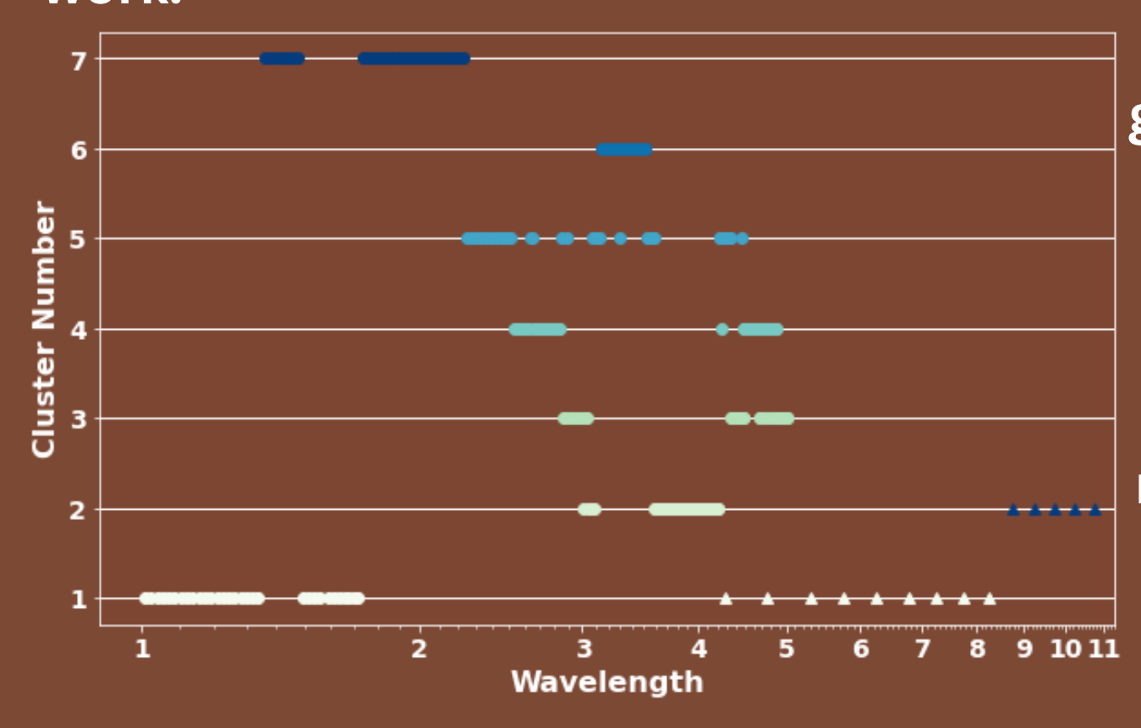


Vos et al. (2023) found there to be a patchy layer of Forsterite (Mg_2SiO_4) clouds and a layer of Iron (Fe) clouds. McCarthy et al. (2024) determined that both cloud layers need to be patchy in order to explain NIR variability. Kao et al. (2016, 2018) found there to be Aurora on SIMP0136.

Light Curve Analysis & Clustering

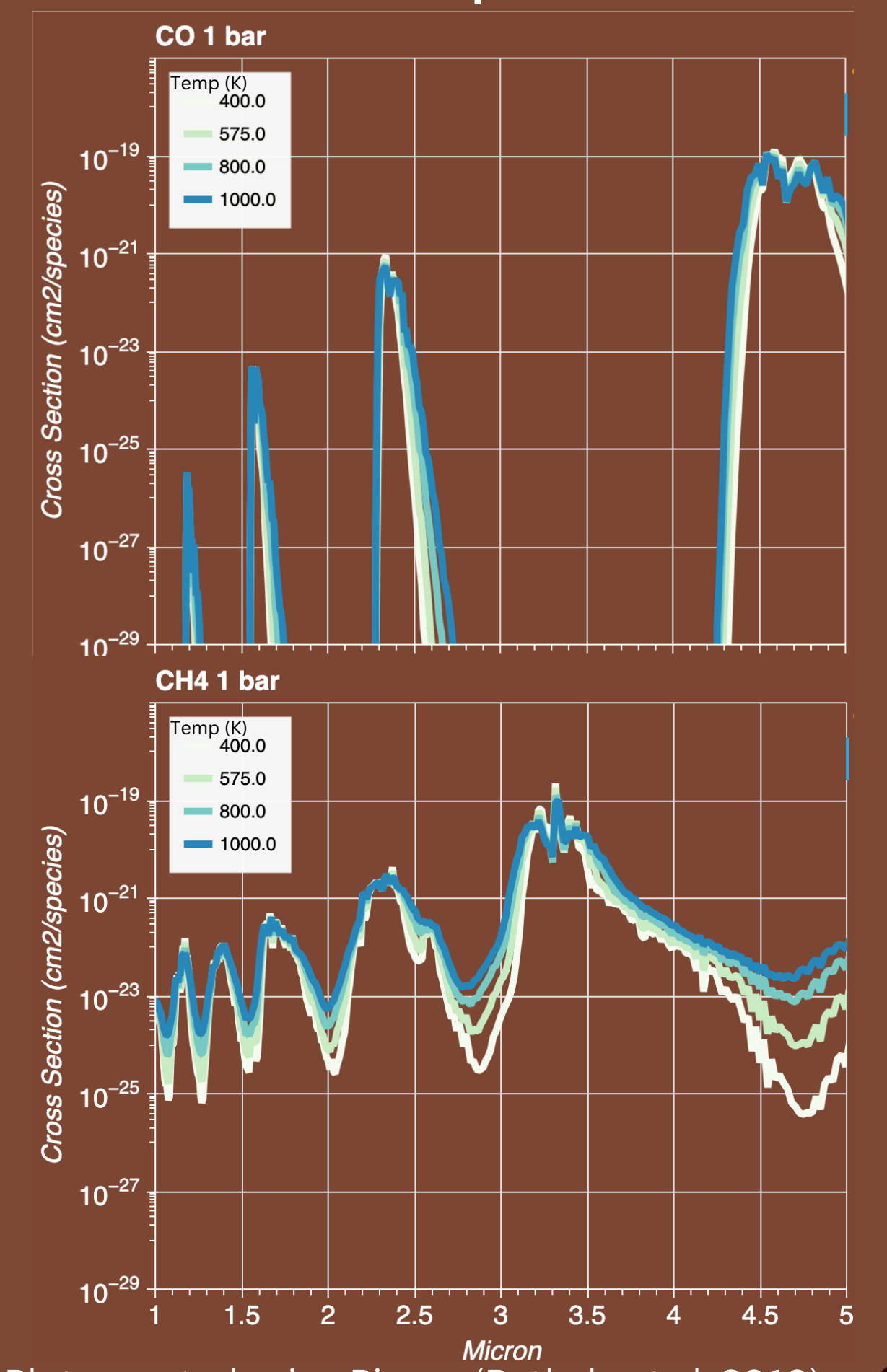
First, we use Celerite2 to create a best fit to our light curves. These fits help to smooth out noise in the data, and provide a better framework for the clustering algorithm to work.





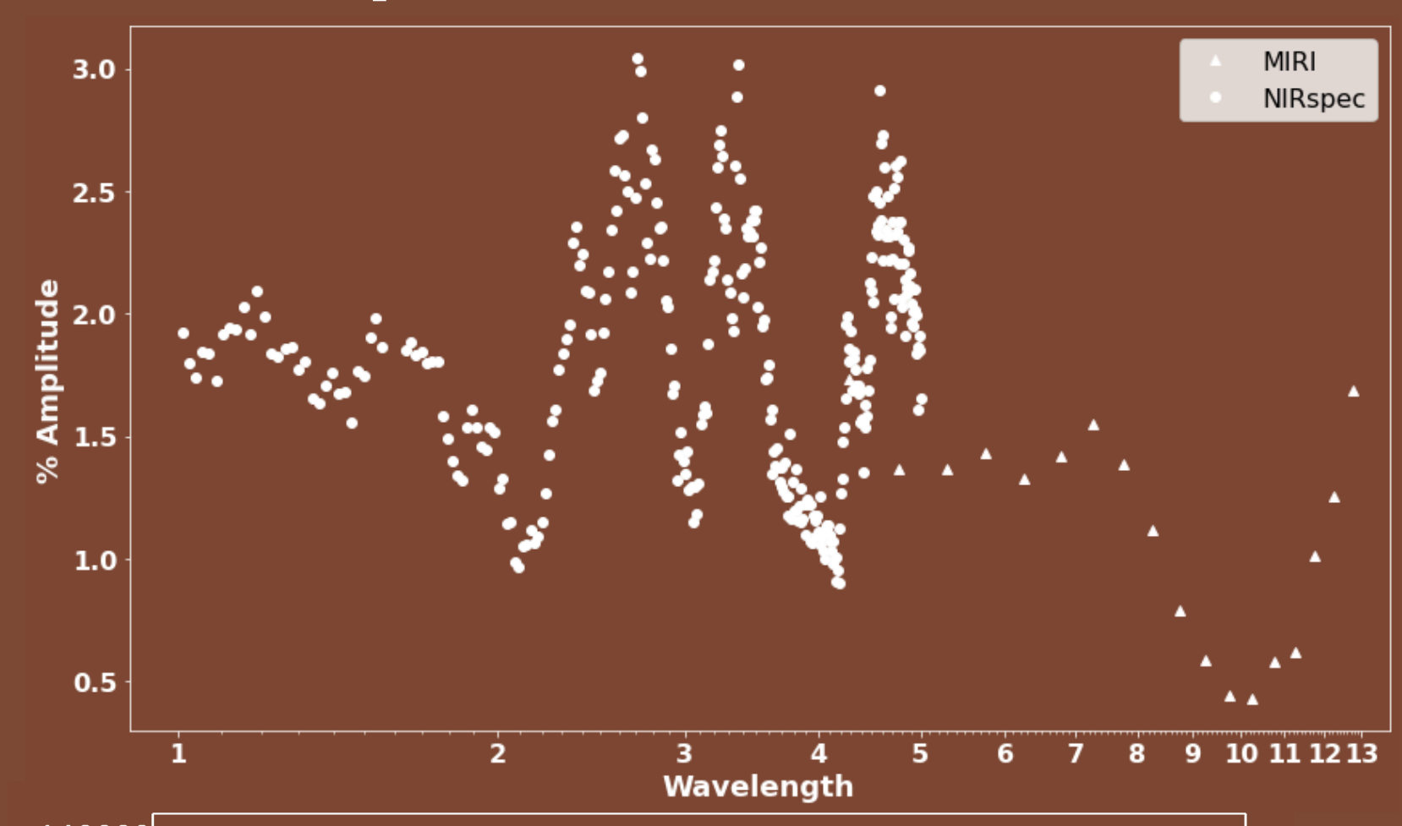
We use a k-means clustering algorithm to group the NIRSpec and MIRI Celerite fits by shape. For NIRSpec, the maximum is 50 clusters, and for MIRI, it is 10. The elbow method determines the optimal number of clusters based on the sum of square error, resulting in 7 clusters for NIRSpec and 2 for MIRI. Note that MIRI clusters 1 & 2 are not the same as the NIRSpec Clusters 1 & 2.

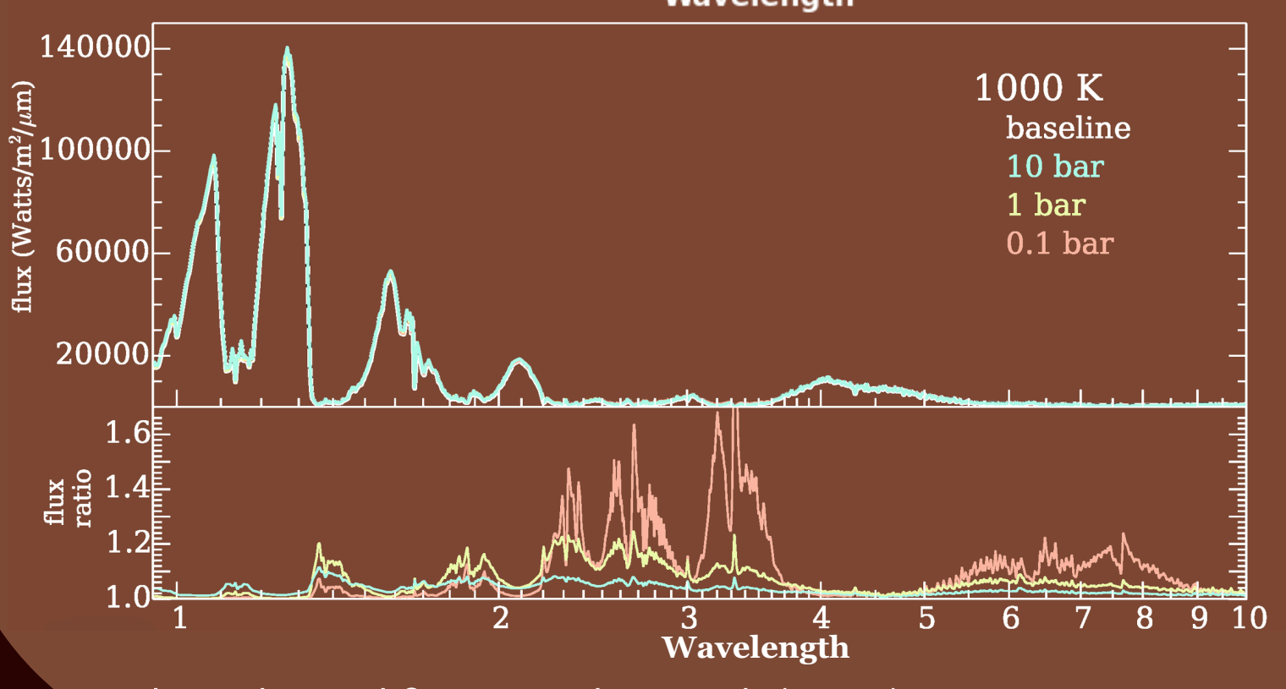
We believe that clouds, which exist at ~1 and ~10 bar (see infographic in bubble above), are the primary causes of variability within NIRSpec clusters 1 and 7, and MIRI cluster 2. NIRSpec cluster 2 shows some similar shape to NIRSpec clusters 1 and 7, showing that it likely has some influence from patchy clouds. However, the wavelengths which NIRSpec clusters 2-6 probe also roughly correspond to the wavelengths affected by a hot spot in the upper atmosphere (see Morley et al. 2014 figure in bubble below). Finally, NIRSpec cluster 5 has groupings of wavelength that appear to correspond to the CO bands (see right, top), while the wavelengths in cluster 6 match the prominent CH_4 feature from 3.2-3.5 micron. We suspect upper atmosphere heating is changing the opacity of these molecules and inducing variability.



Plots created using Picaso (Bathala et al. 2019)

Amplitude as a Function of Wavelength





Plot adapted from Morley et al. (2014)

We find that the wavelengths which have the highest amplitude variability in our data roughly correspond to the wavelengths most affected by the addition of a hot spot in the upper atmosphere (bottom), such as at ~2.7 and ~3.3 micron. Since SIMP0136 is known to have aurora, it is plausible that hot spots may be caused by upper atmospheric heating. We also note that we have high amplitude variability at ~4.7 micron which is not explained by the hot spot model in Morley et al. (2014). The hot spot does not explain the variability from 1 - 2 micron.

Clouds, Aurora, Hot Spots & Thermochemical Instabilities are all Responsible for Variability

Deep in the atmosphere and at bluer wavelengths, patchy iron and silicate clouds are likely responsible for the variability. Upper atmosphere heating has a limited effect from 1-2 micron. However, in the mid-IR, while silicate clouds may still be responsible for some of the variability, aurora and its energetic particles heating the upper atmosphere also likely come into play. From 9 micron onwards, upper atmosphere heating does not impact the observed flux and variability is likely due to patchy silicate clouds.

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