# Multiple Patchy Cloud Layers in the Planetary Mass Object SIMP0136+0933

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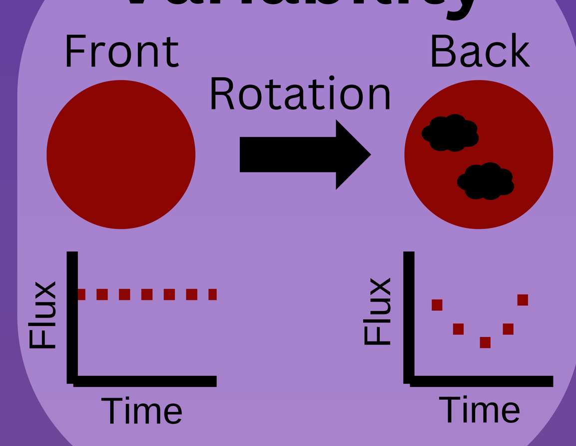
Multi-wavelength photometry of brown dwarfs and planetary-mass objects provides insight into their atmospheres and cloud layers. We present near-simultaneous *J*- and *Ks*-band multi-wavelength observations of the highly variable T2.5 planetary-mass object, SIMP J013656.5+093347. For the first time, we detect a phase shift between *J*- and *Ks*-band light curves, which we measure to be ~40°. Using the Sonora Bobcat models, we show that at least two different patchy cloud layers must be present to explain the measured phase shift, one just above the region in which *Ks*-band probes, and another within the region which *J*-band probes.

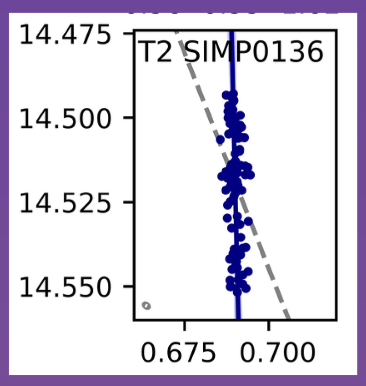
## SIMP0136

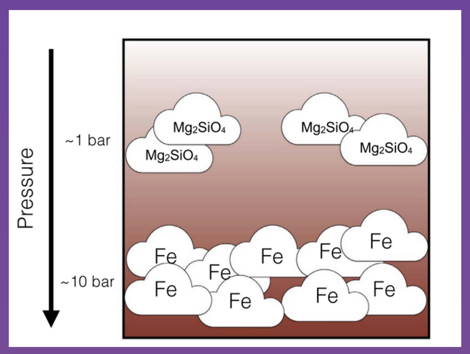
- SpT = T2.5
- R ≈ 1.22 $R_J$
- M ≈ 12.7 $M_J$
- $T_{eff}$ ≈ 1098 K
- Age ≈ 200 Myr
- P ≈ 2.4 hr

## Variability




Lew et al. 2020 found a lack of color-change (phase-shift) between *J*- and *H*-band.



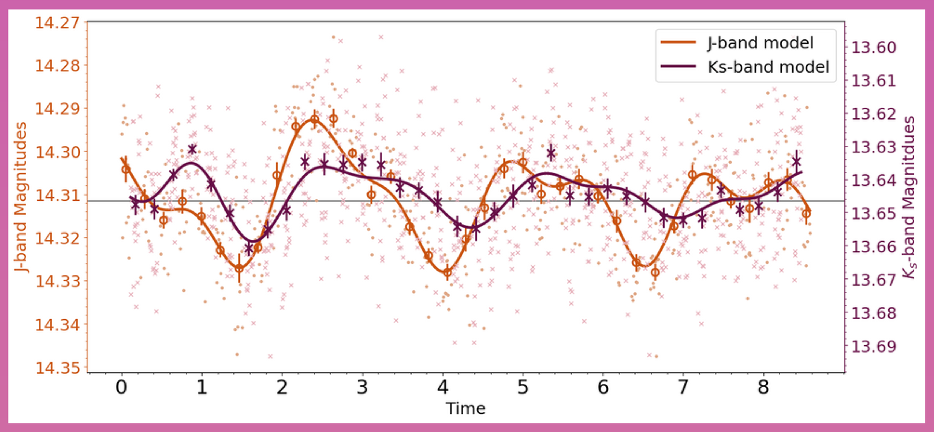

Vos et al. 2023 found evidence of two cloudy layers, forsterite and iron, in the atmosphere of SIMP0136.

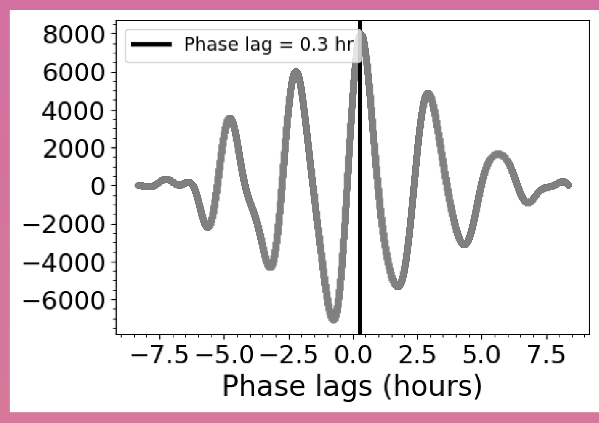
## Are the *J*- and *Ks*-band light curves in phase?

Ks-band

### Figure 1

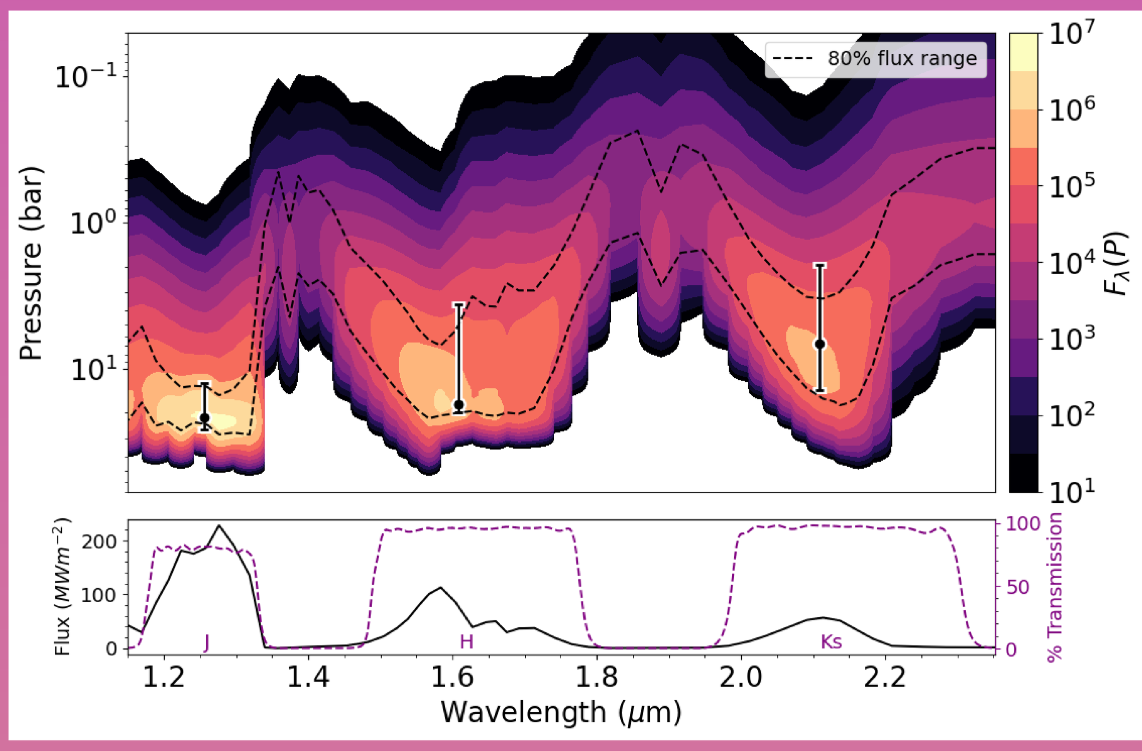
**Right:** The maximum likelihood solution of the MCMC fits for the *J*- and *Ks*-band data in magnitude space. **Bottom:** The results of a cross-correlation on the two maximum likelihood solutions of the MCMC fits.




**No! We found a 39.°9$^{+3.6}_{-1.1}$ (~0.3 hr) phase shift between the two light curves.**

## Which pressures does each band probe?




### Figure 2

**Top:** The contour plot shows the distribution of flux as a function of wavelength and pressure for a cloudless atmosphere with $T_{eff}$ = 1100K, log(g)=4.5, [M/H]=-0.5, and solar C/O. The color bar distribution is logarithmic. The dotted black lines represent the pressure levels of the atmosphere where 10% and 90% of the flux is emitted. The circle markers are located on the weighted average wavelength and peak flux emission pressure level for each bandpass while the bars show the range of pressure levels where 80% of the emitted flux is weighted by the band transmission. **Bottom:** This plot displays the Near Infrared spectra of the Sonora Bobcat model in black, and the transmission curves for *J*-, *H*-, and *Ks*-band in purple.

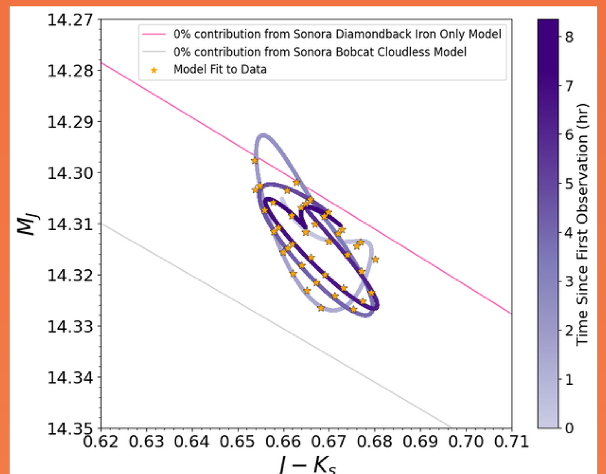
**J-band: 12.6 - 26.2 bar**
**H-band: 3.6 - 20.0 bar**
**Ks-band: 1.9 - 14.1 bar**

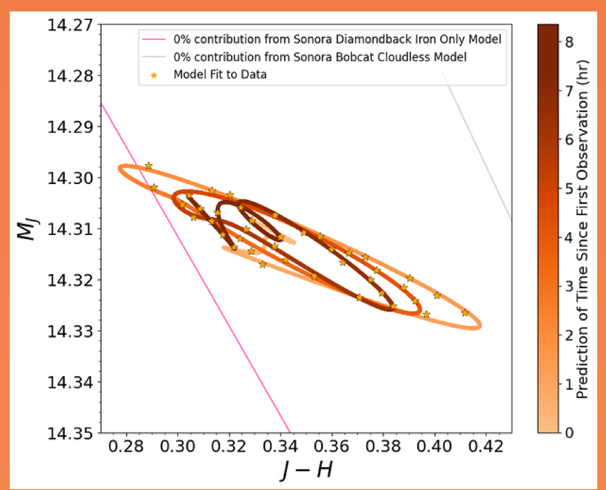
J-band

## Can a three patch atmospheric model match the observations?

### Figure 3

A 3-patch model where patch 1 uses the Sonora Diamondback models including a layer of forsterite clouds, patch 2 uses Sonora Diamondback iron-only models, and patch 3 uses the Sonora Bobcat clear atmospheric models. All three patches have a $T_{eff}$ = 1100K. Both cloudy atmospheres have an $f_{sed}$ = 3. **Top:** $M_J$ and *J–Ks* values from the highest posterior results of the MCMC of our data in purple. The orange stars represent the points in our model that most closely match our observed data. **Bottom:** The fractional coverage ratios from matching our data to our model (that the orange stars represent) translated into the *J-H* color space. The orange line traces the path that the three patch model predicts.

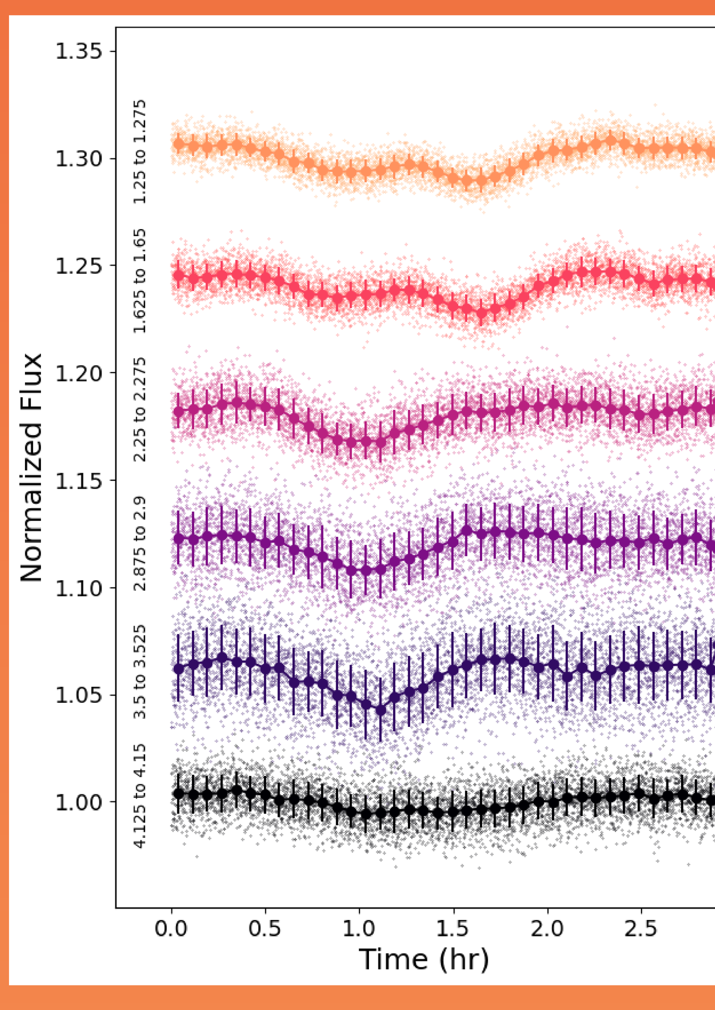



**Our models were unable to match both our observed *J*-*Ks* color change, and the lack of *J*-*H* color change observed by Lew et al. 2020.**

## Do JWST observations support the theory of multiple patchy cloud layers?

**Preliminary analysis of JWST observations (PI: J. Vos) show that there are wavelength (and thus, pressure) dependent light curve features, supporting the idea that there are multiple patchy cloud layers in the atmosphere of SIMP0136.**

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