Giant Storms on Brown Dwarf VHS 1256B

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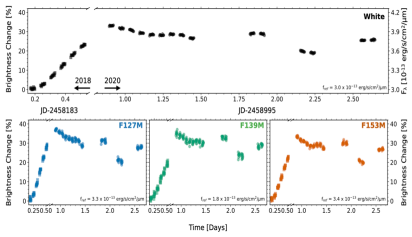
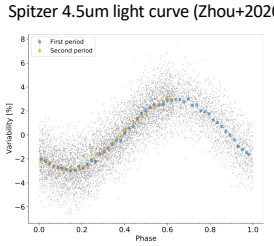
- VHS 1256B has the largest observed variability amplitude (nearly 40% at 1.27 micron) and an extremely red NIR color, indicating vigorous cloud formation in its atmosphere.

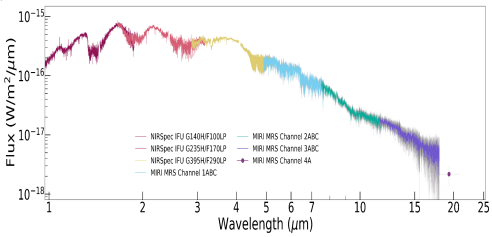
HST/WFC3 cross epoch light curves (Zhou+2022)



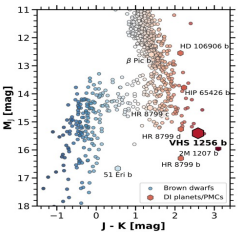
Spitzer 4.5um light curve (Zhou+2020)



JWST Spectrum (Miles+2023)



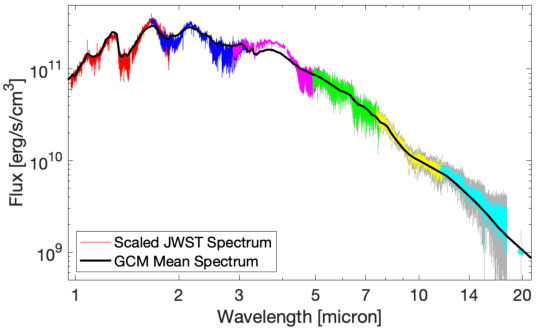
J-K CMD (Miles+2023)



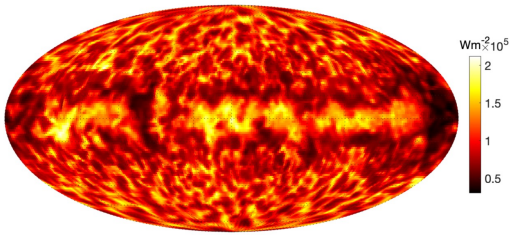
- What mechanism simoutaneouly generates such a large variability and the red NIR color? – **Cloud feedback driven circulation**.
- Brief model description: **General circulation model**: SPARC/MITgcm (Showman+2009), tracer-based clouds with radiative feedback for $MgSiO_3$ and Fe (Tan+2021). 3 log-normal size modes in $MgSiO_3$, large (7um), medium (0.7um) and small (0.02um); only 1 mode (7um) in Fe. Chemical equilibrium, convective adjustment, correlated-k 11 bin radiative transfer. **Radiative post processing**: 3D GCM structure read-in by PICASO (Batalha+2019) with higher spectral resolution correlated-k tables or resampled opacity grids, generating spectroscopic light curve variability, spectrum, and contribution functions. Chemistry and opacity source are consistent between the GCM and post processing.

Model Results

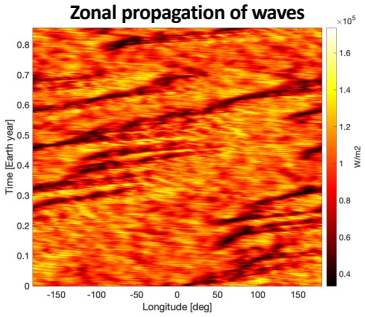
Spectrum comparisons



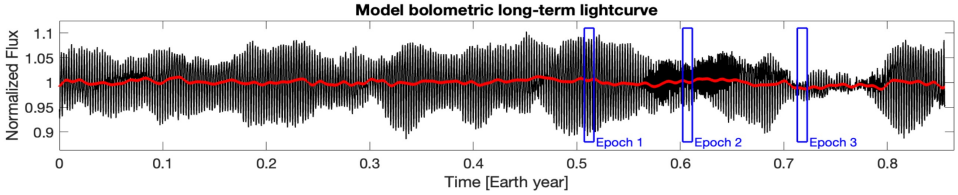
TOA Thermal Flux



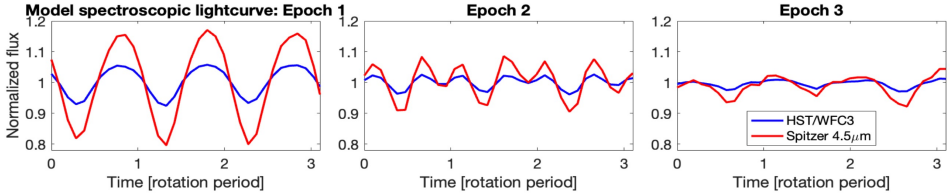
Zonal propagation of waves



Model bolometric long-term lightcurve



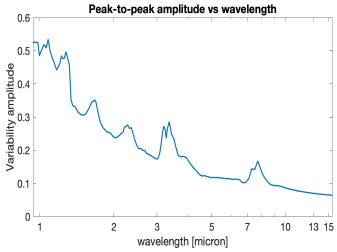
Model spectroscopic lightcurve: Epoch 1 / Epoch 2 / Epoch 3



Circulation, light curves, and spectrum

- Cloud radiative feedback drives global-scale equatorial waves, resulting in large rotational light curve variability with bolometric peak-to-peak amplitude up to 20%.
- Propagation, generation and dissipation of the equatorial storms are responsible for the irregular long-term light curve evolution.
- Nearly 40% amplitude in the HST/WFC3 bandpass and several to 10% amplitude in the Spitzer 4.5um bandpass.
- Cloud mixing by waves and vortices gives rise to the red NIR color and simultaneously explains the full observed spectrum of VHS 1256B.

Peak-to-peak amplitude vs wavelength



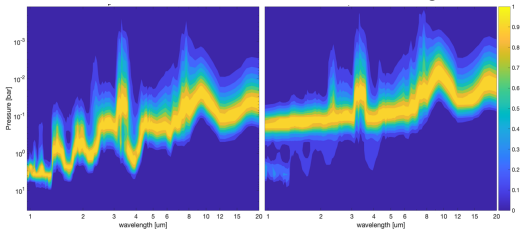
Variability amplitude generally decreases with increasing wavelegnth.

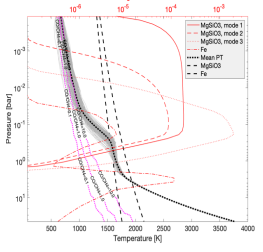
Fluxes generally escape from lower pressures as wavelength increases (see right panels), and brightness temperature variation decreases.

J, H, K bands show enhenced amplitudes as these H_2O windows span deeper regions.

3.3um and 7.7um exhibit enhenced amplitudes, because TP profiles go across the CO/CH4 transition regions and produces significant CH4 pathiness (see the right panel).

Contribution function, 20% bright regions 20% dark regions

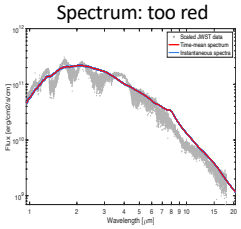




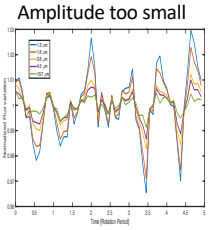
- The "right" amount of clouds provides the "right" level of heating to simultaneously generate the giant storm and red spectrum.

When the particle sizes are too small, for example, full of 1um particles.

Spectrum: too red

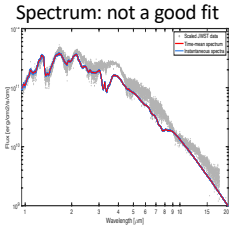


Amplitude too small

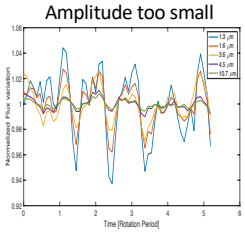


When all particles are large, for example, full of 7um particles.

Spectrum: not a good fit



Amplitude too small



Take-home messages

- Cloud radiative feedback drives global storms, manifesting as travelling equatorial waves.
- These storms simultaneously explain the observed large variability amplitudes of VHS 1256B in HST/WFC3 and Spitzer 4.5um bands, their cross-epoch behaviors, as well as the spectrum observed by the JWST.
- The emergence of giant storms requires a reasonable amount of clouds aloft in the atmosphere. The simultaneous interpretation to light curve and spectrum provides tighter constraints on the cloud properties of substellar atmospheres.