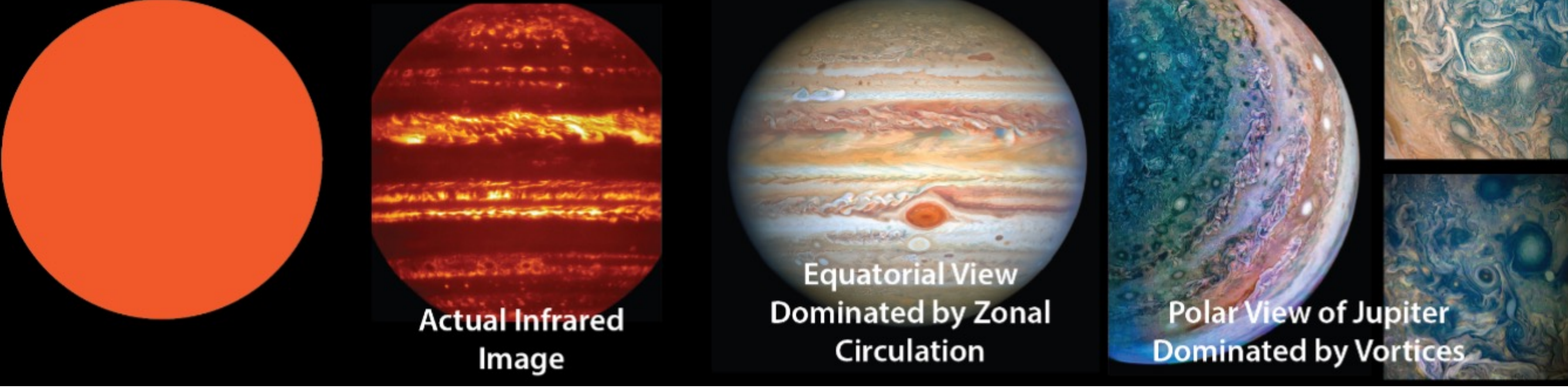


Latitude-dependent Atmospheric Waves and Long-period Modulations in Luhman 16 B from the Longest Lightcurve of an Extrasolar World

Fuda Nguyen, Daniel Apai, Domenico Nardiello, Luigi Bedin, Xianyu Tan, Theodora Karalidi

Biography

Fuda Nguyen (Nguyễn Phúc Đạt)
Interests: Exoplanet atmospheres, ultracool atmospheres, time-series observations.
Prof. Daniel Apai group.

2022 – Ph.D., Department of Planetary Science, Lunar & Planetary Lab, U. of Arizona
2021-2022 – Data Science, FPT Software
2020-2021 – Post-bacc, SOFIA Science Center @ NASA Ames
2016-2021 – B.Sc. Space Science, Vietnam National University (Đại Học Quốc Gia Việt Nam, TP.HCM)

Outline of talk

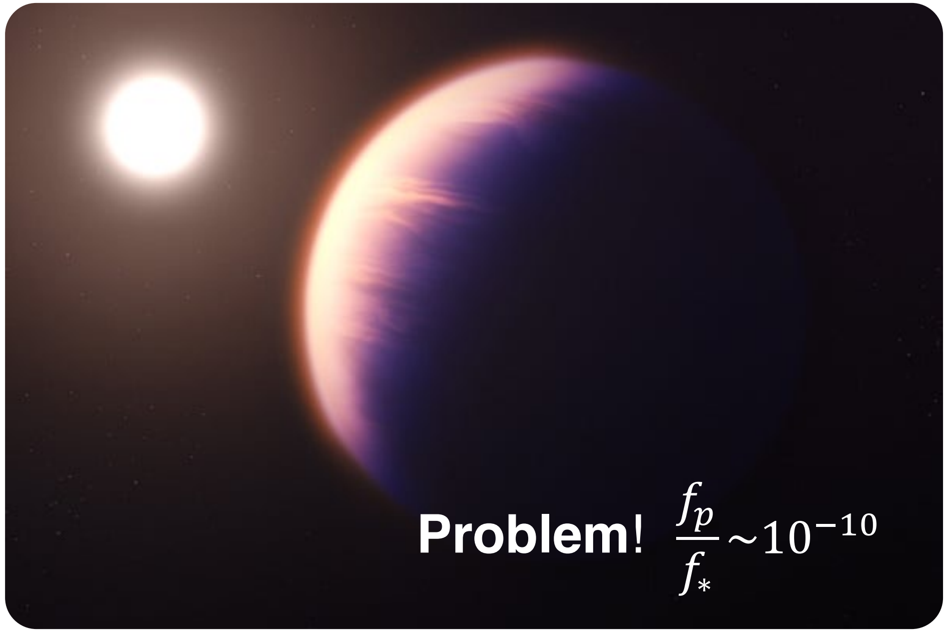
1. **Introduction**: The spectrum of planetary atmospheres
2. **Atmosphere time-series**: TESS longest photometric monitoring of Luhman 16 AB
3. **Polar Vortices:** The Spectrophotometric Approach
4. **Summaries**.

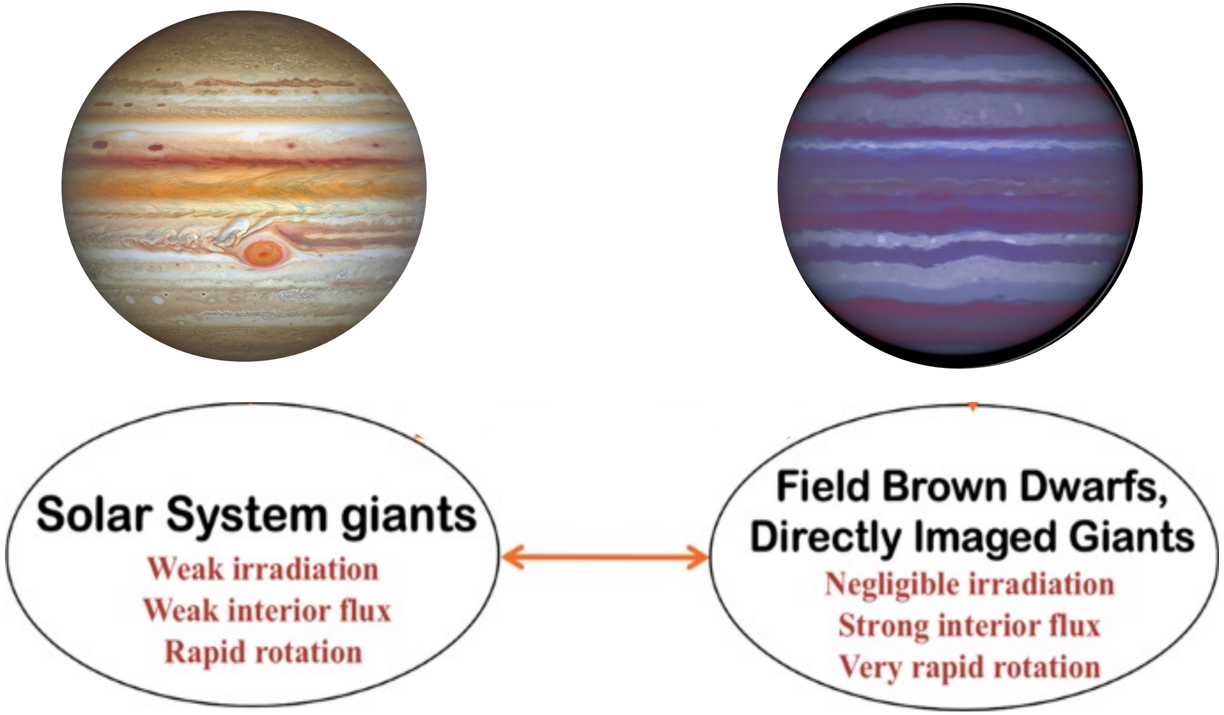
1. Introduction: The spectrum of planetary atmospheres

JunoCam Perijove-12 125-fold timelapse (NASA / JPL / SwRI / MSSS / SPICE)

I. Introduction: Cloudscape unrealized & parameter space

Very hard to characterize transitting exo-giants, unless …. analogs!



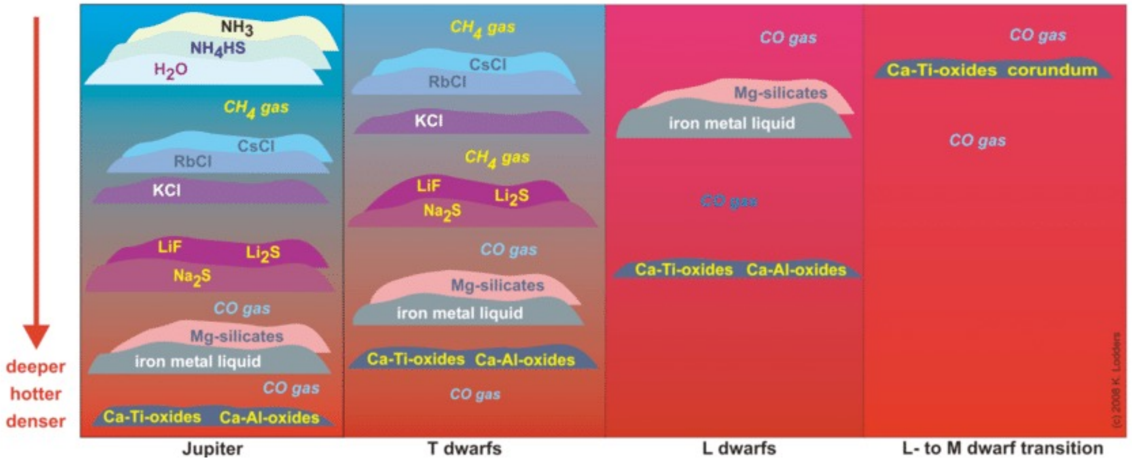


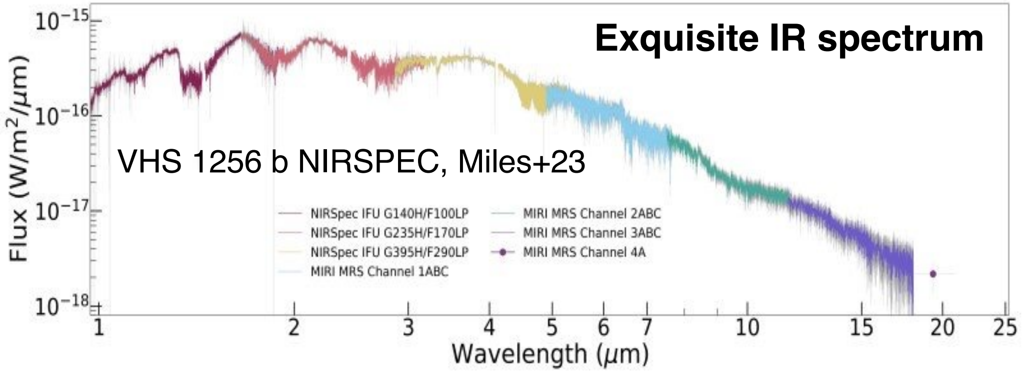
Showman+2020

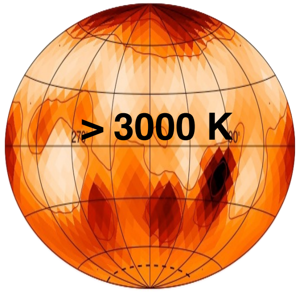
I. Introduction: Ultracool Atmospheres

Ultracool atmospheres: Weakly-irradiated brown-dwarfs, DI-planets, cold Solar-system giants.

Cloud formation & condensates



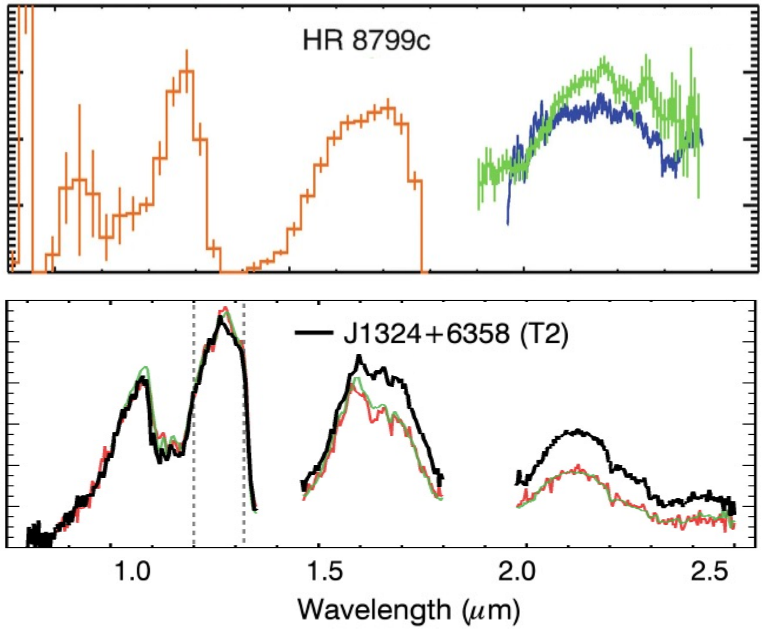




Magnetically-coupled spots

Uncoupled, vigo-rous circulation

Brown-dwarf // DI planets overlap



HR 8799c: Barman+2011, 2015, Oppenheimer+2013, Ingraham+2014
2M1324: Gagné+2018

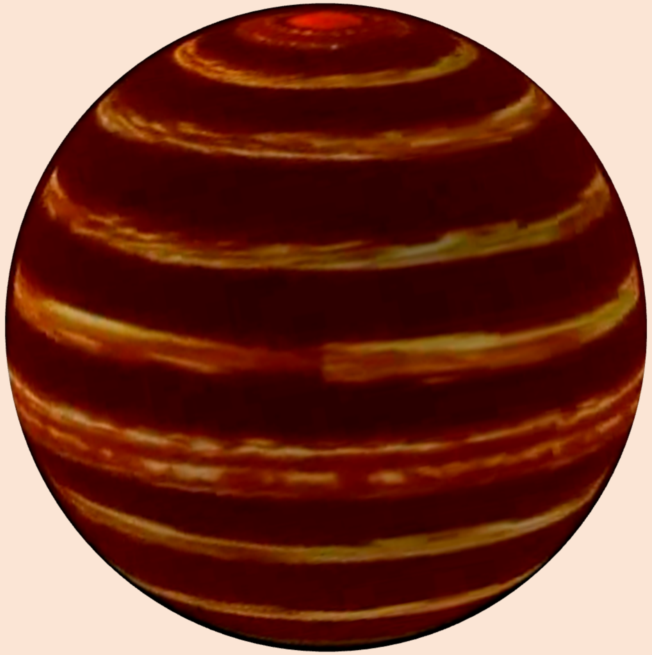
I. Introduction: Ultracool Atmospheres as Giant Analogs

Ultracool atmospheres as giant analogs

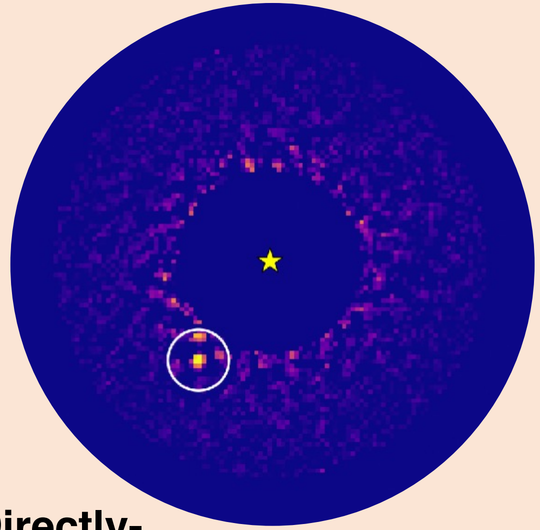
Solar System giants

Cassini (north pole), JPL, SSI, Maksim Kakitsev

Ultracool atmospheres

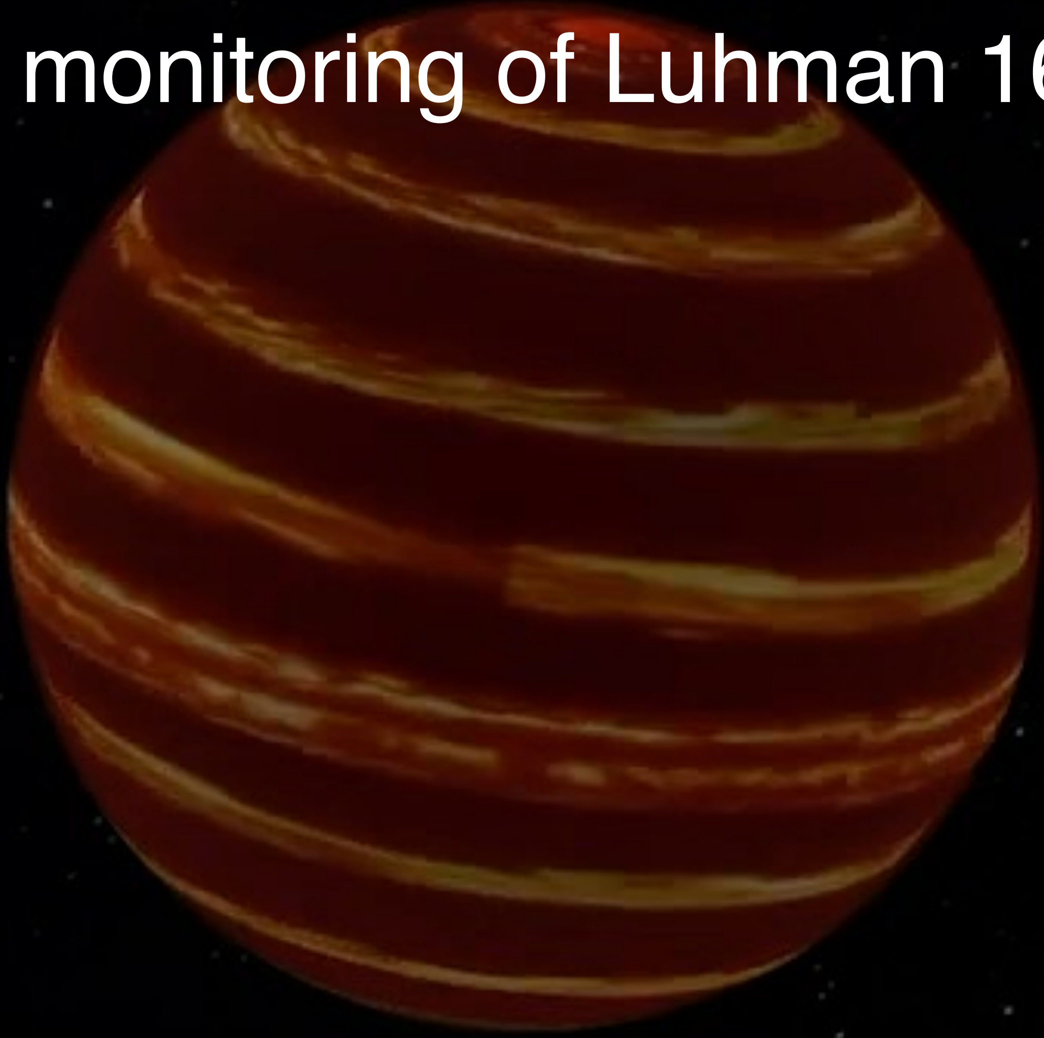


Brown dwarfs



Directly-imaged planets

2. Atmosphere time-series: TESS longest photometric monitoring of Luhman 16 AB

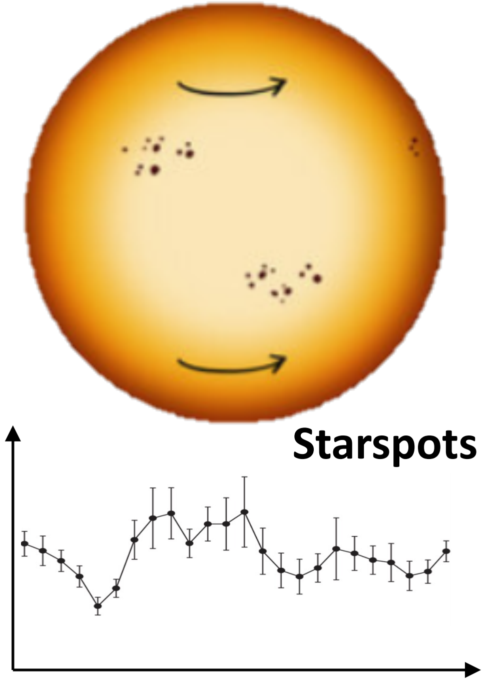


Apai+21, IOPScience

II. Atmosphere time-series: Rotation Modulation

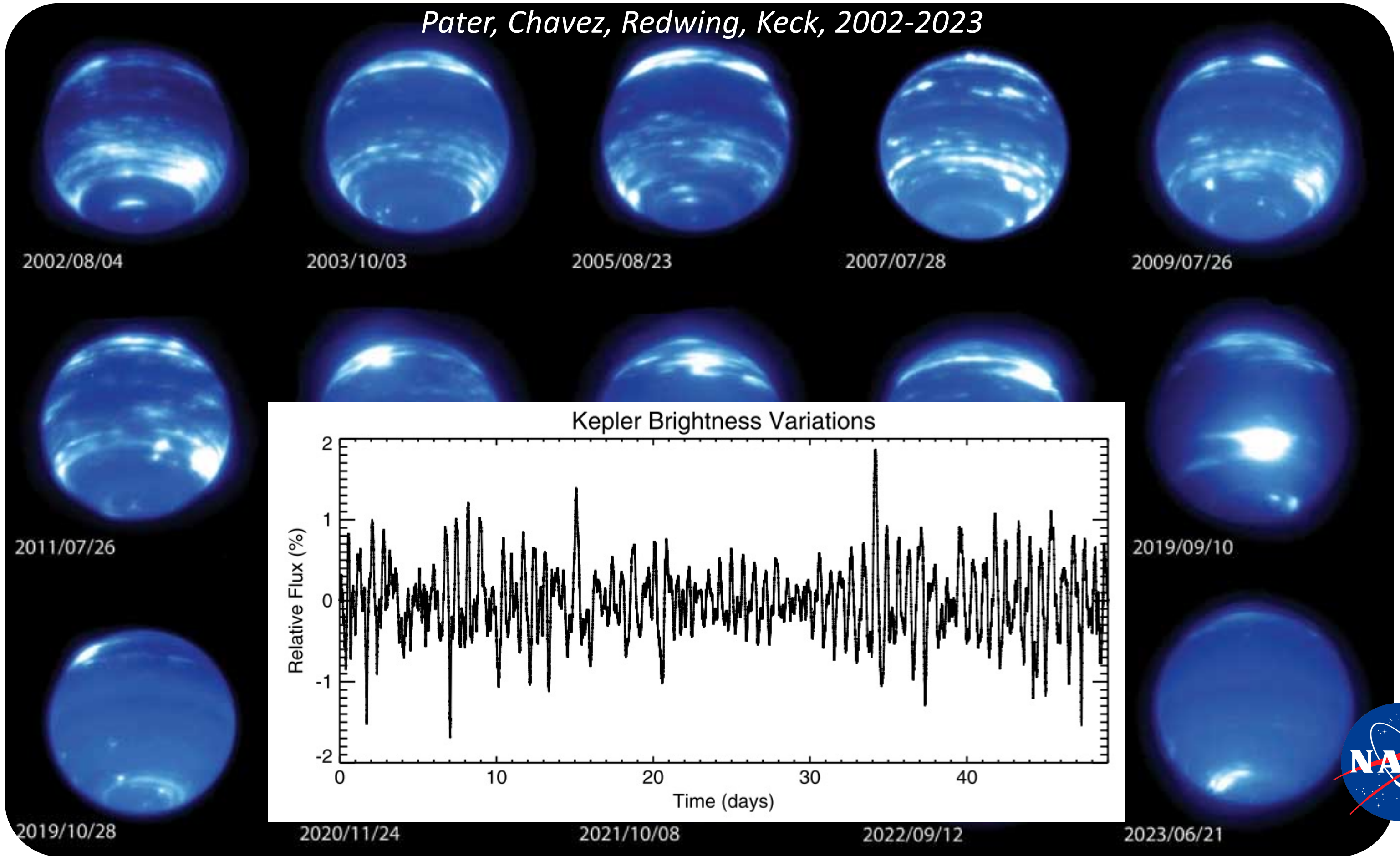
Common causes of rotational modulation: spots, clouds, waves.

Neptune ice clouds

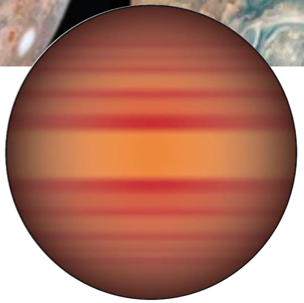


Starspots

Credit: MPS/Taylan Ayık

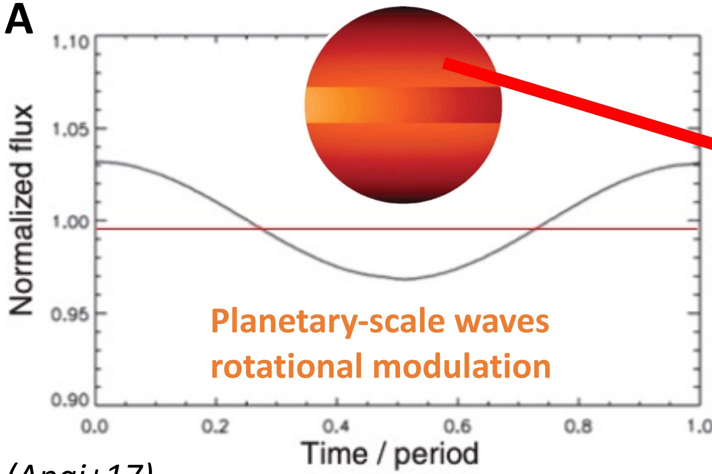


II. Atmosphere time-series: Planetary-scale waves.

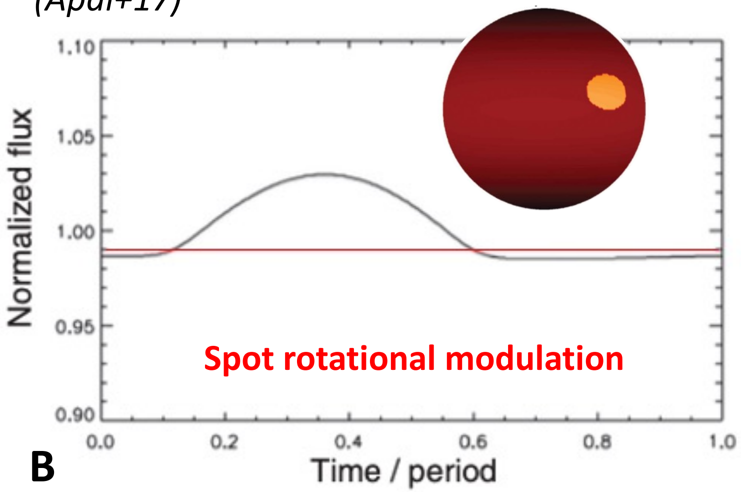


Cloud thickness variation → Brightness variariation modulated over rotations.

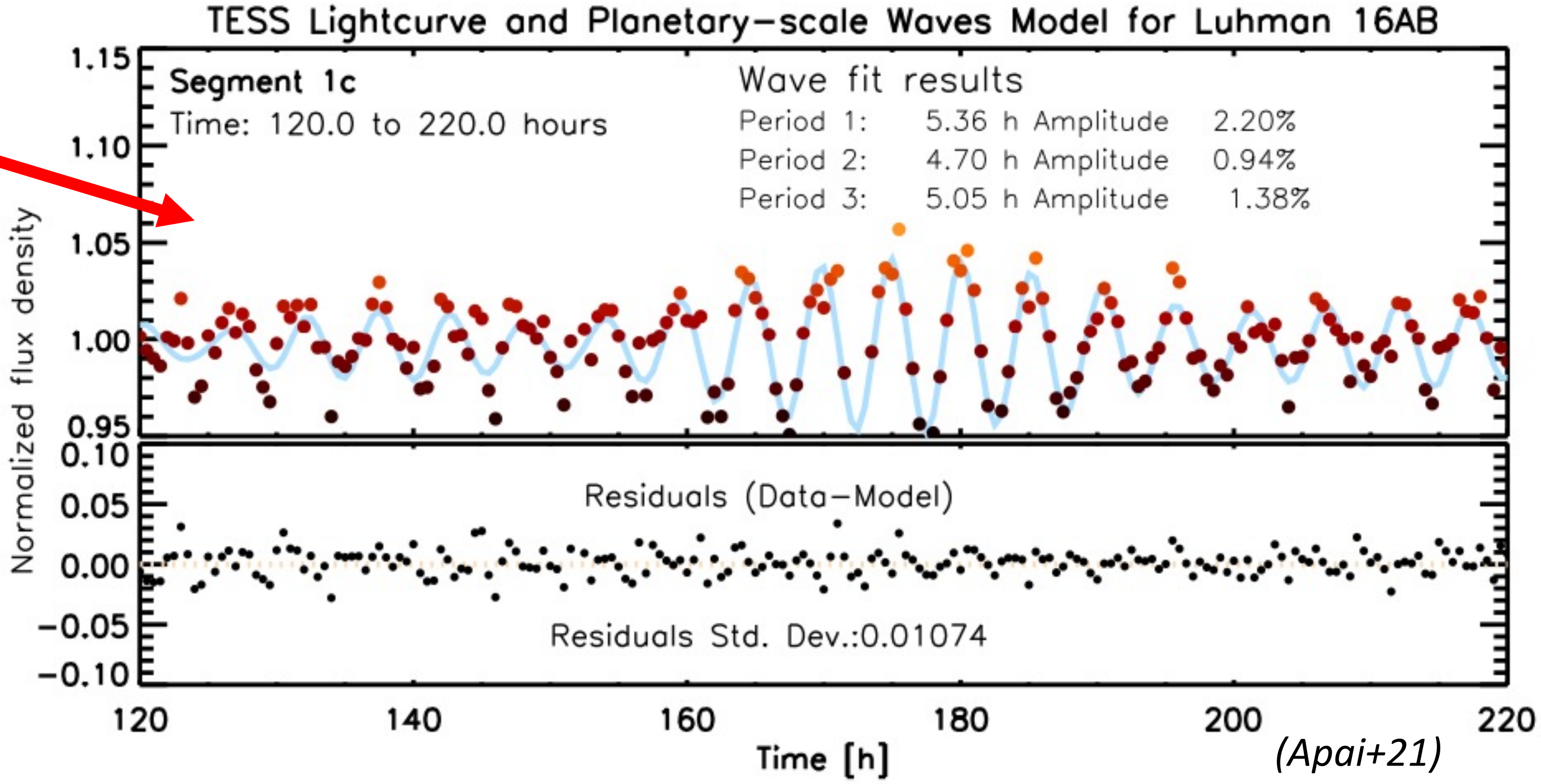
A



(Apai+17)



B



(Apai+21)

NASA

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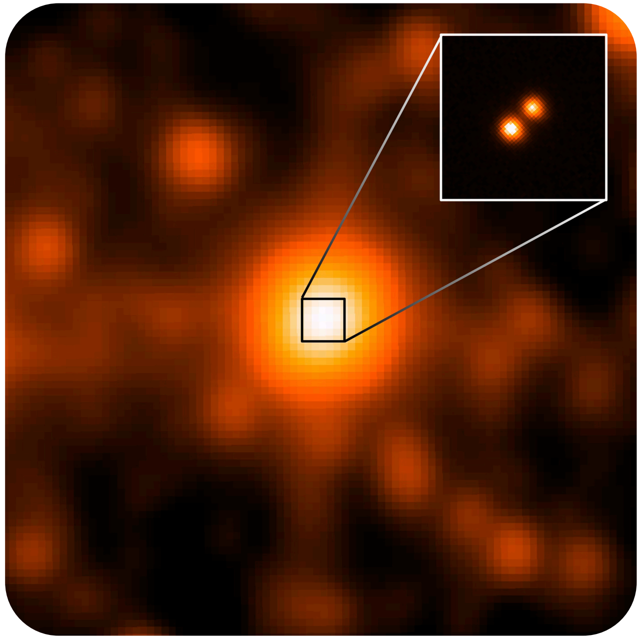
II. Photometry: Luhman 16 AB

Brown dwarfs binary

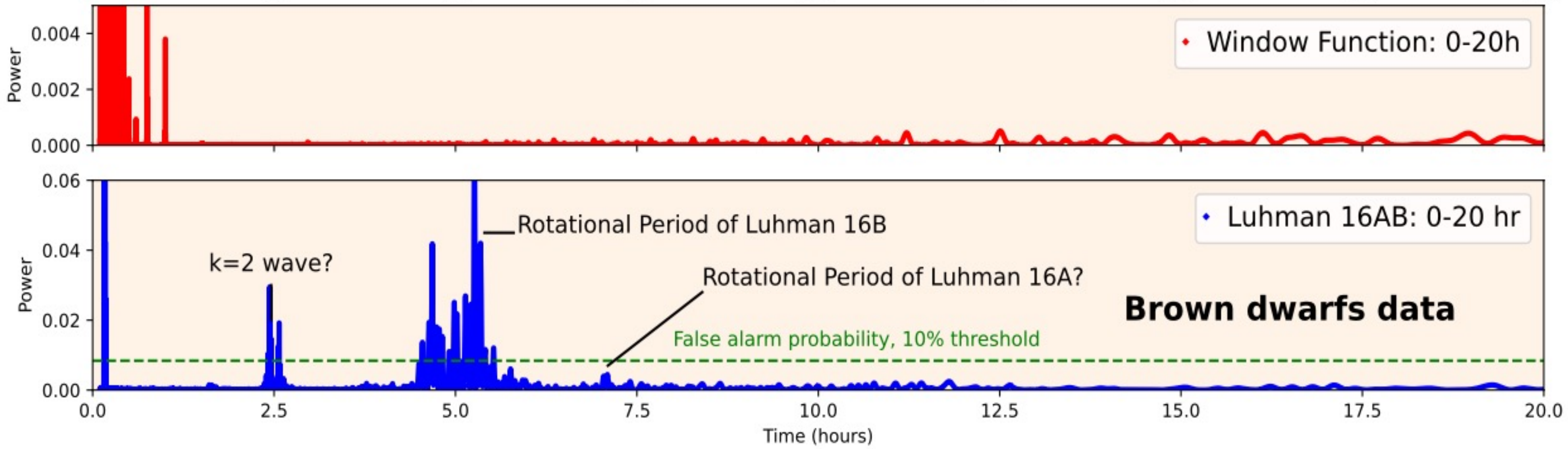


WISE image, GMOS image (inset)

	Luhman 16 A	Luhman 16 B
Mass	33.5 M_{jup}	28.6 M_{jup}
Temp.	1350 K	1210 K
Period	~5 hr (Apai+21)	~7.5 hr (Buenzli+15)
Radius	0.85 R_{Jup}	1.04 R_{jup}

Physical Properties

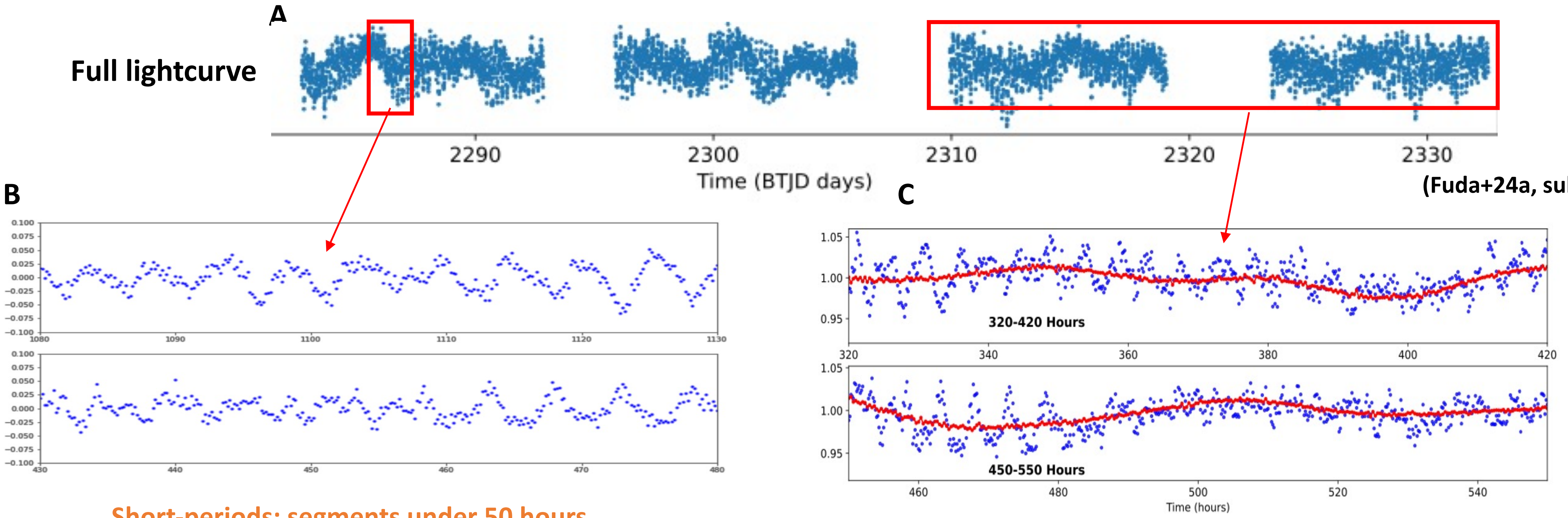
(Fuda+24a, submitted.)



Most variability comes from Luhman 16 B

II. Photometry: TESS Lightcurve of Luhman 16 AB.

TESS Lightcurve of Luhman 16 AB (sector 36 & 37): 1200-hour, full of time-complexity



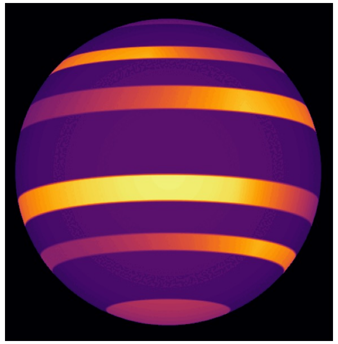
(Fuda+24a, submitted.)

Short-periods: segments under 50 hours

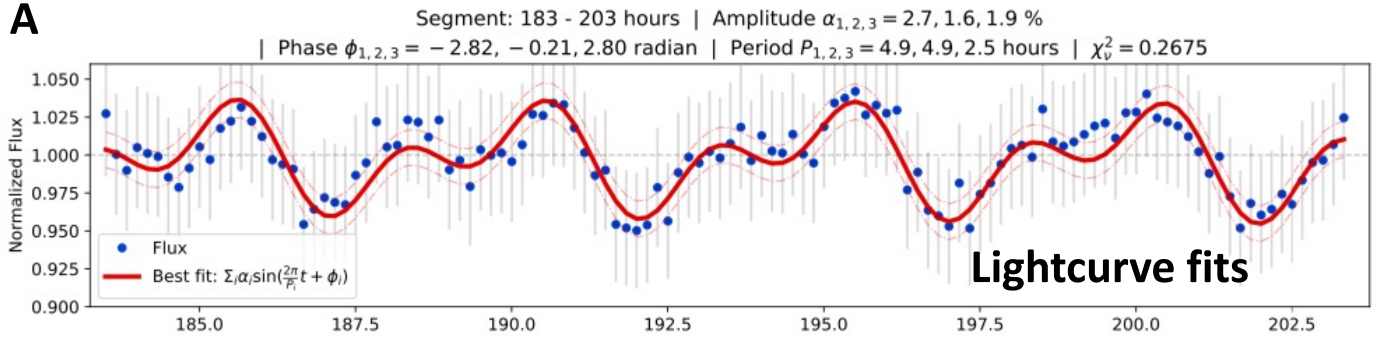
Long-period: segments more than 100s of hours

II. Photometry: Planetary-scale wave fits lightcurve well.

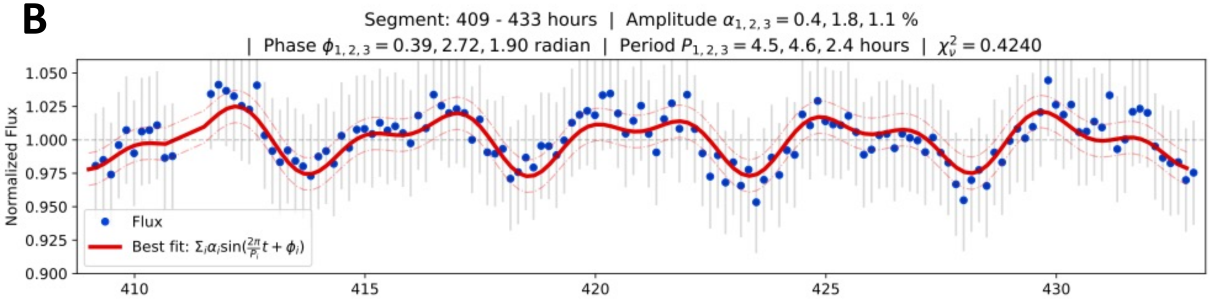
Best fit periods: [~2.5 and ~5] hours.



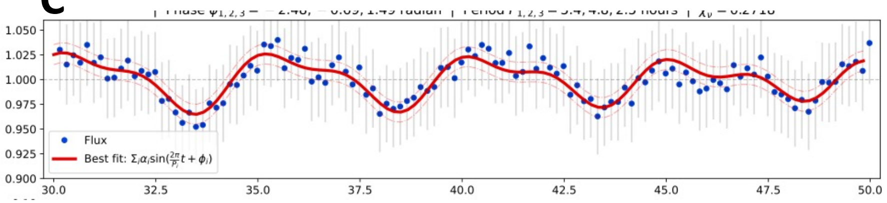
A



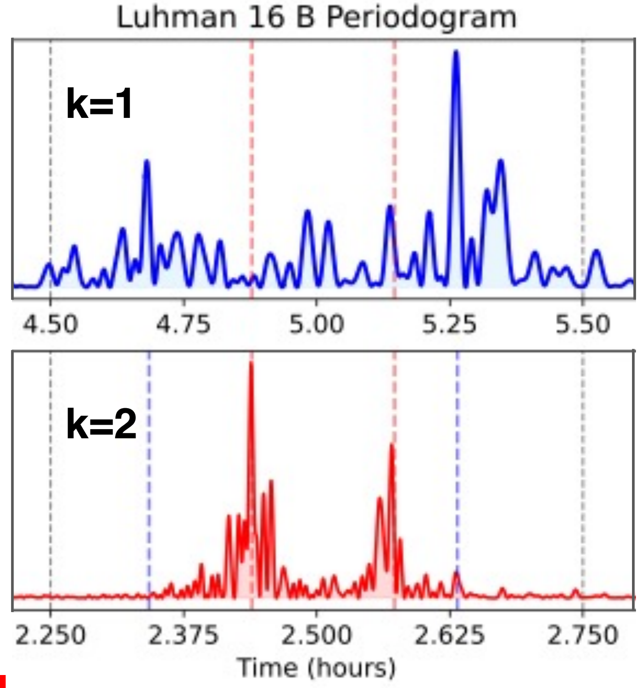
B

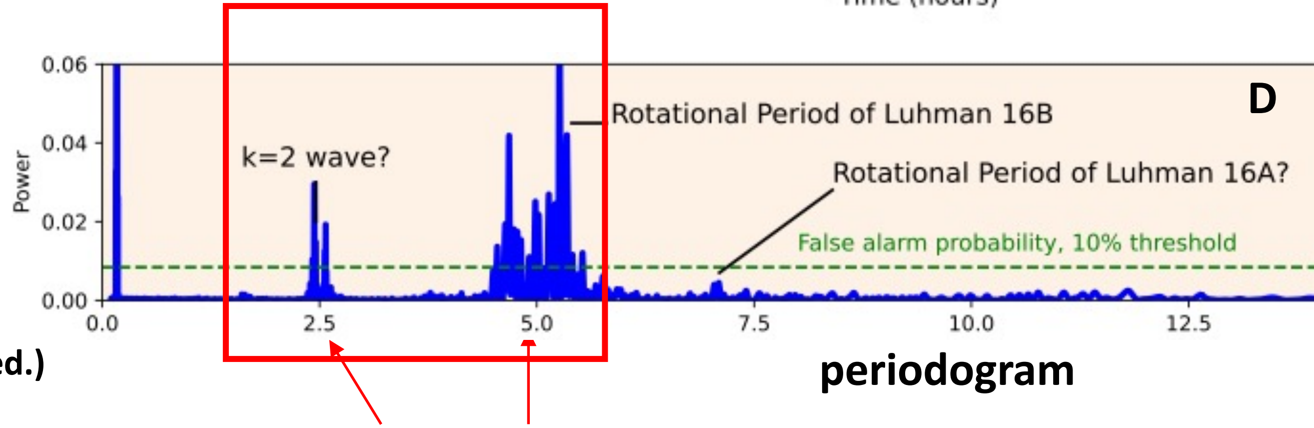


C



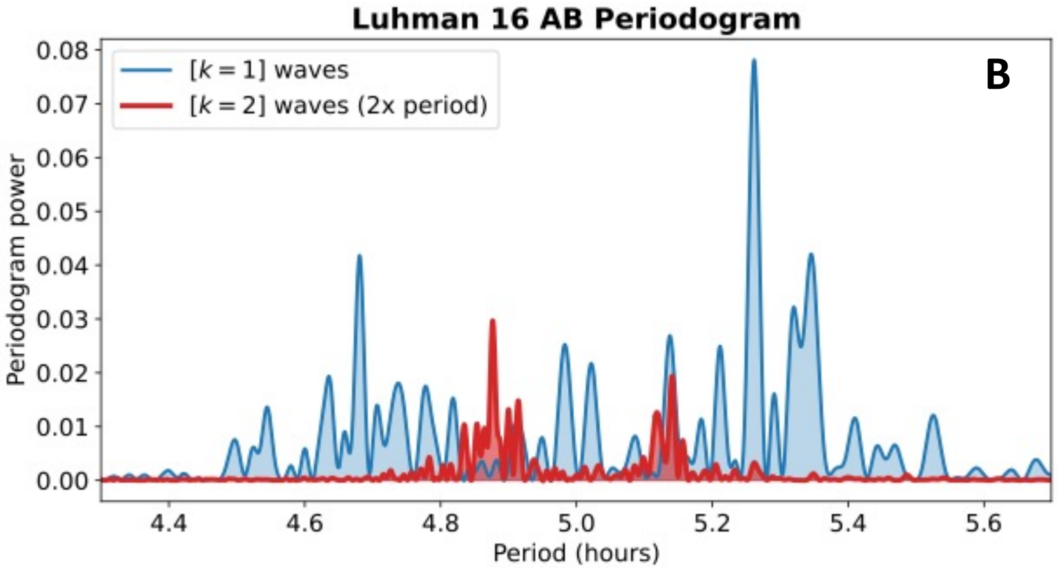
(Fuda+24a, submitted.)

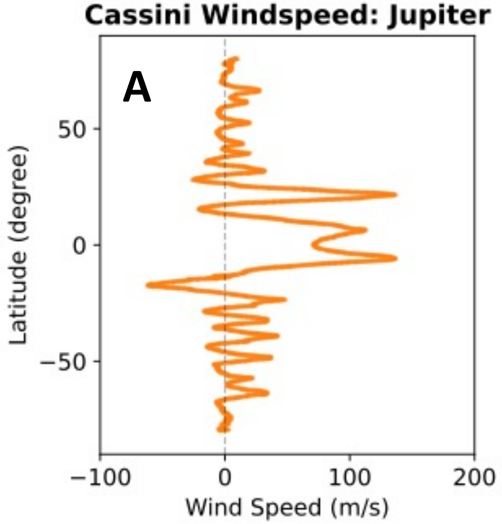


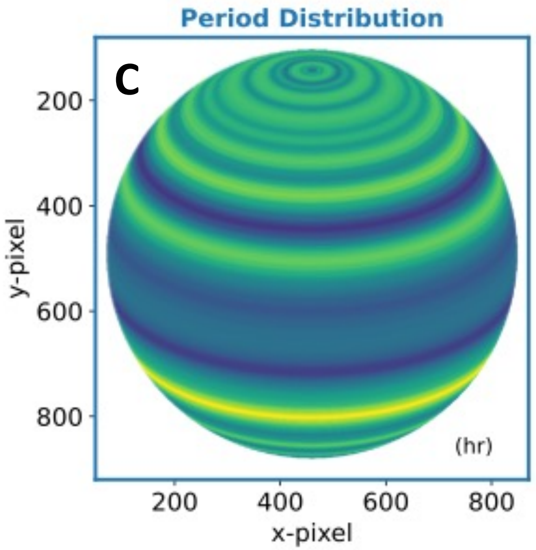


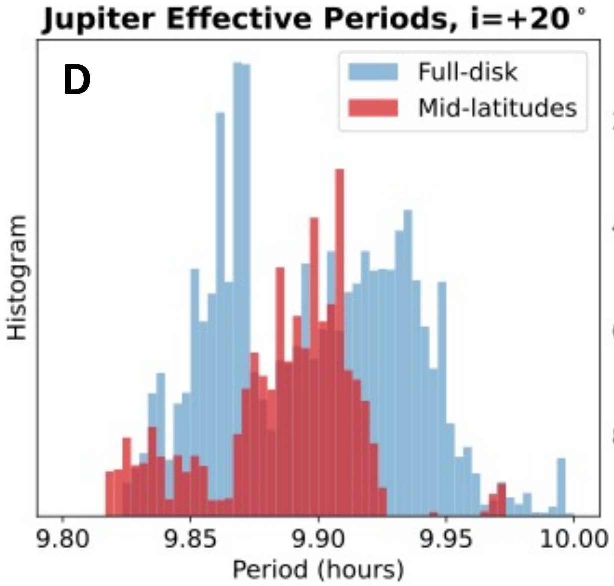
Strongest periods: 2.5, 5 hours

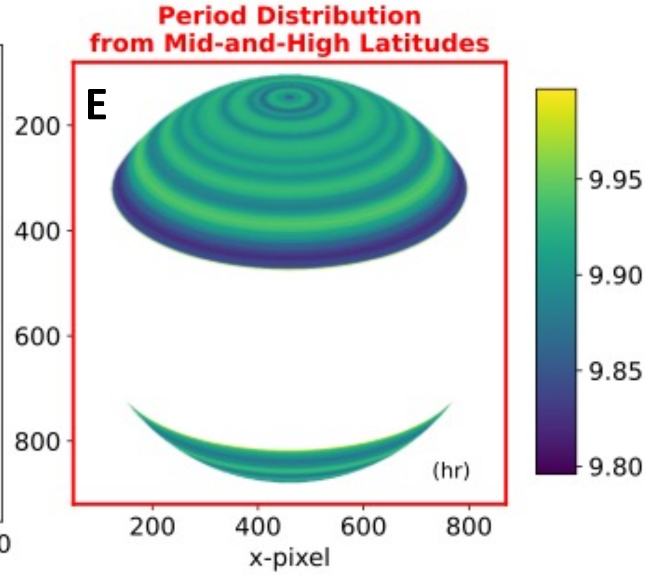
II. Photometry: k=1, k=2 waves and latitudinal dependence?





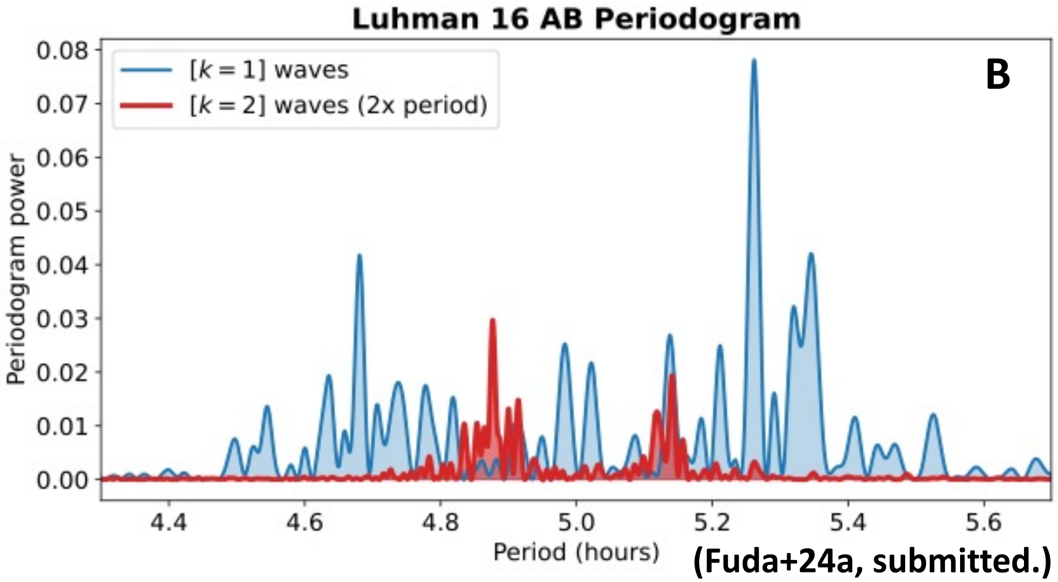






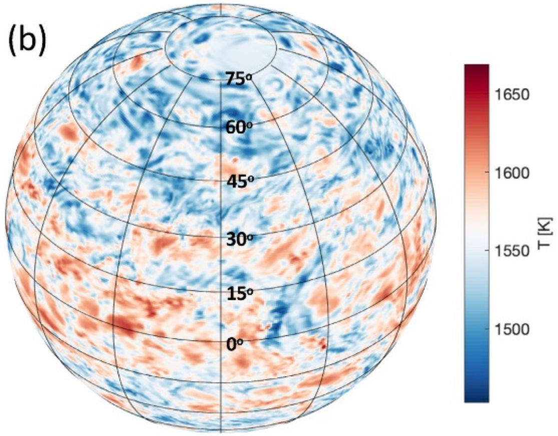
(Fuda+24a, submitted.)

II. Photometry: k=1, k=2 waves in GCMS

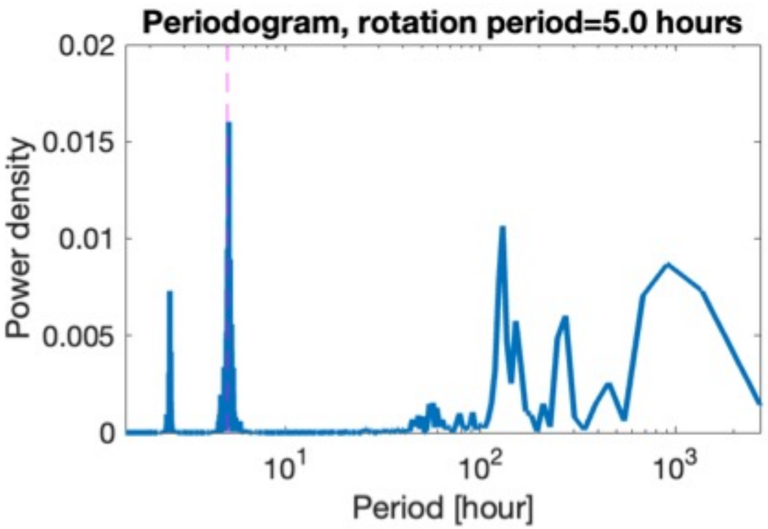


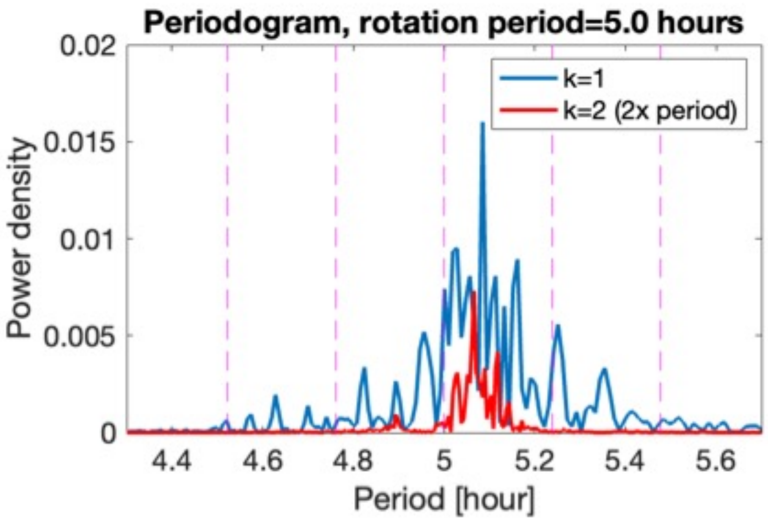
(Fuda+24a, submitted.)

(Tan,Showman+21)



(Model from Xianyu Tan, Fuda+24a, submitted.)

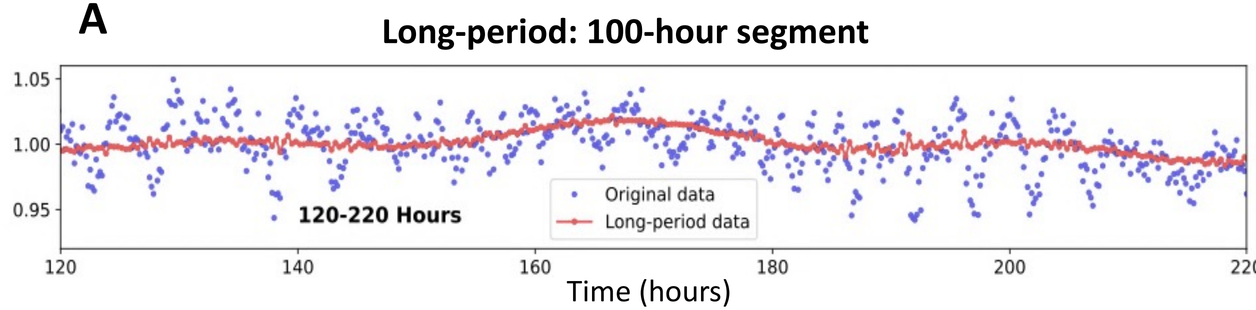




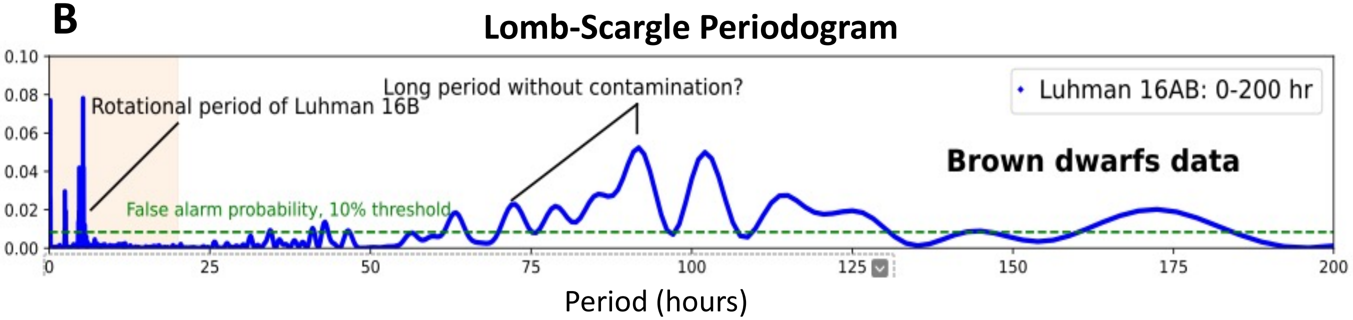
II. Photometry: Long-period variations

Periods: 75-hours to 125-hours. Nature=?

A



B



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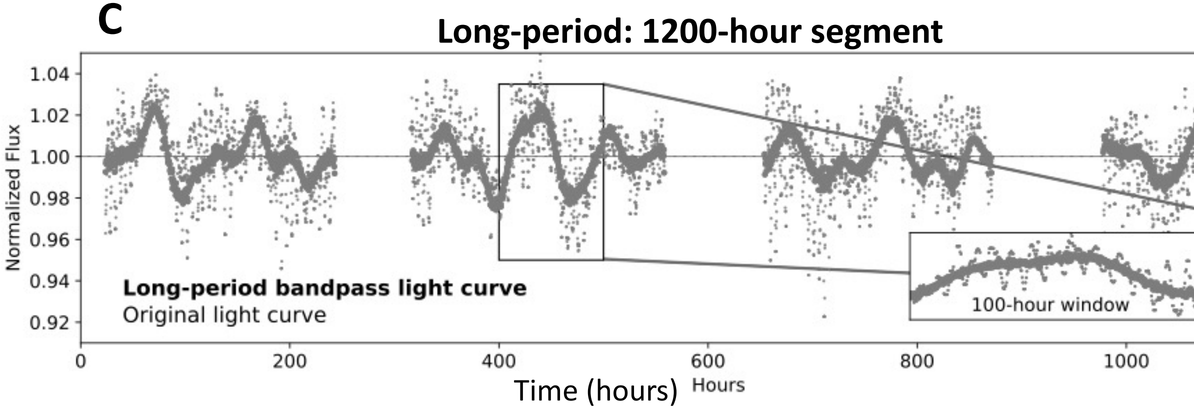
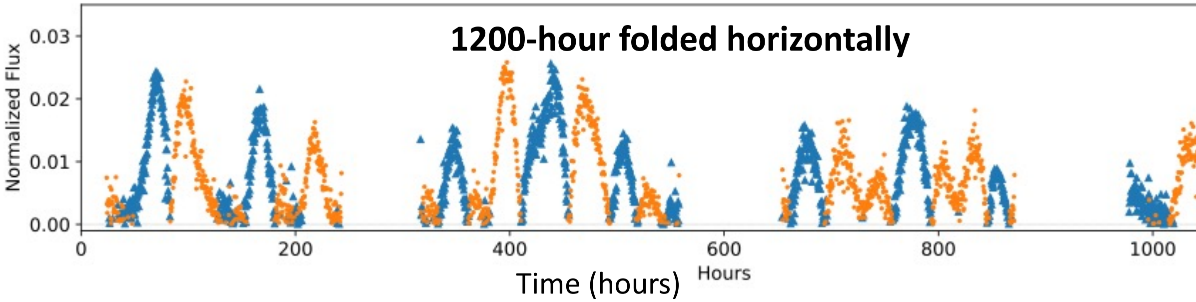


D



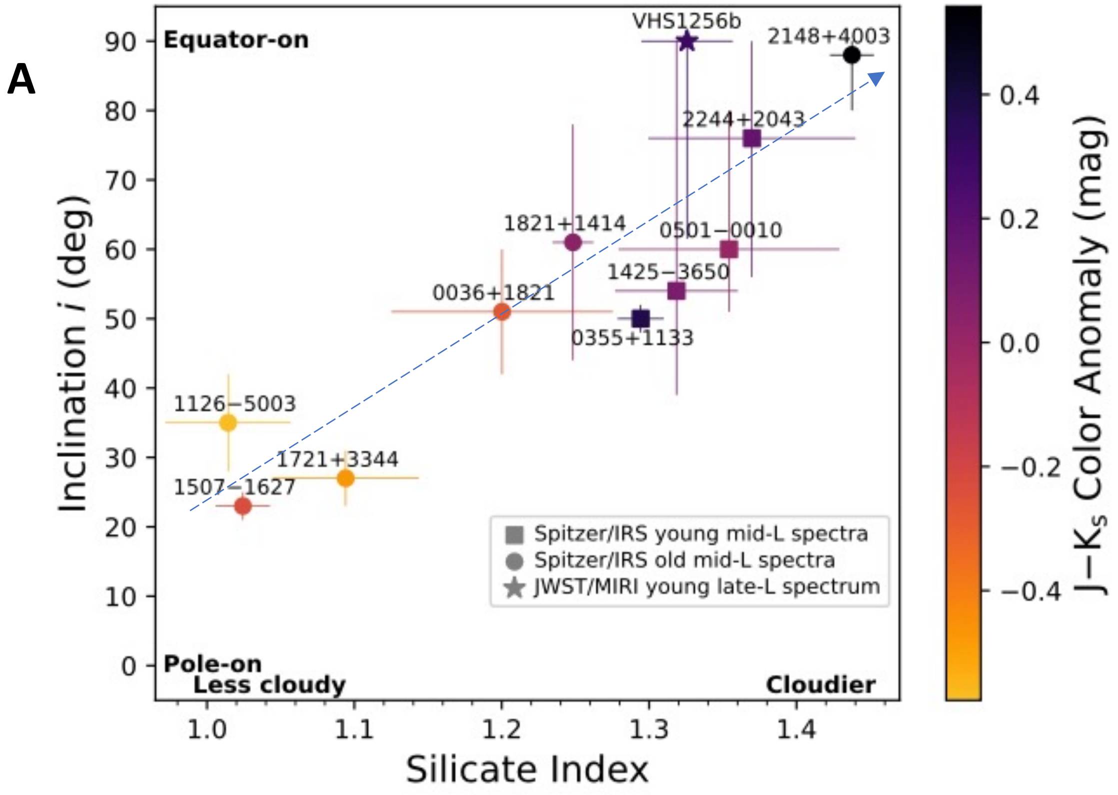
3. Polar Vortices: The Spectrophotometric Approach

Cassini north polar vortex
(JPL/SSI)

Fuda+24b, in prep.

III. Polar Vortices in BDs: line of observations evidences

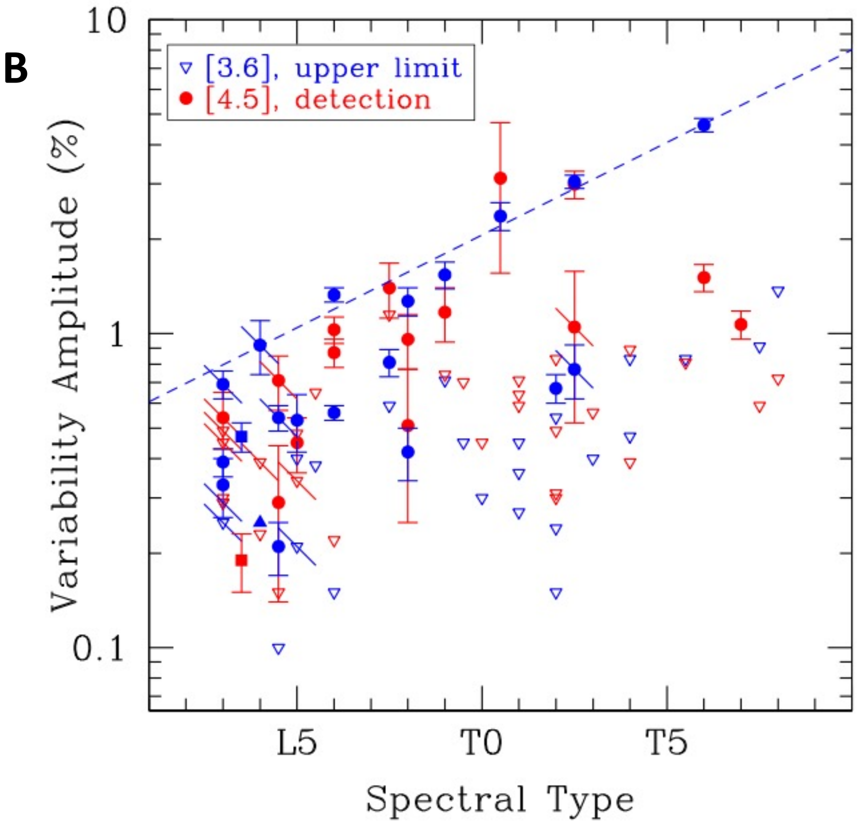
1) Brown dwarfs pole less cloudy (and redder) than the equator.



(Suarez+23, Vos+20)

2) Rotational modulation* amplitude larger in redder BDs

*(weakly correlated with inclination)



(Metchev+15)

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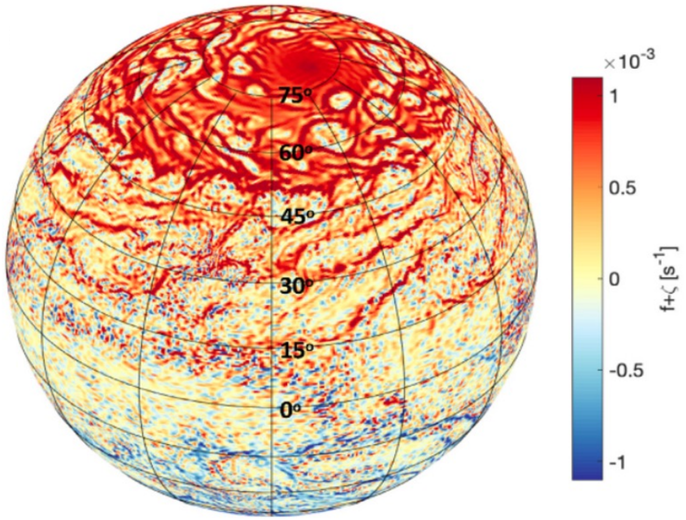
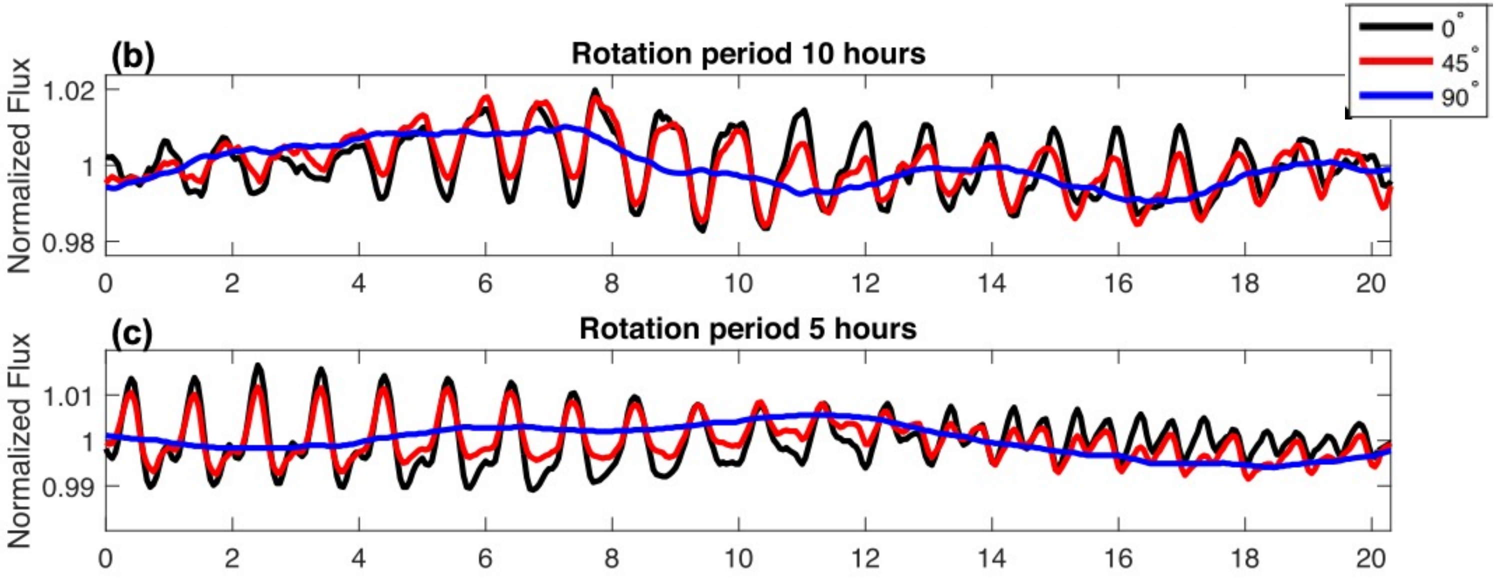
III. Polar Vortices in BDs: line of observations in GCMs

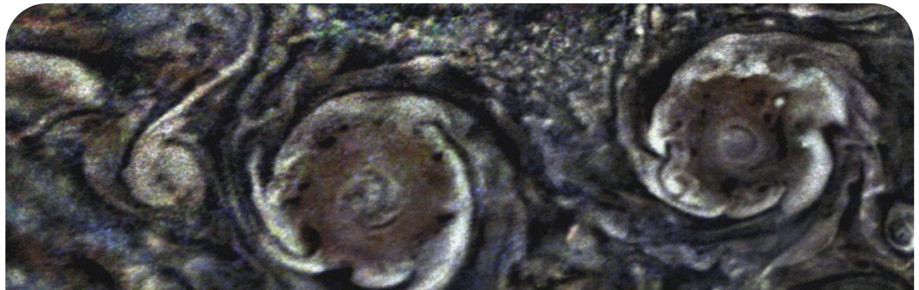
GCM indicates pole-to-equator difference in vorticity, and lightcurve changes.



Absolute vorticity, GCM
(*Tan & Showman 2021)*

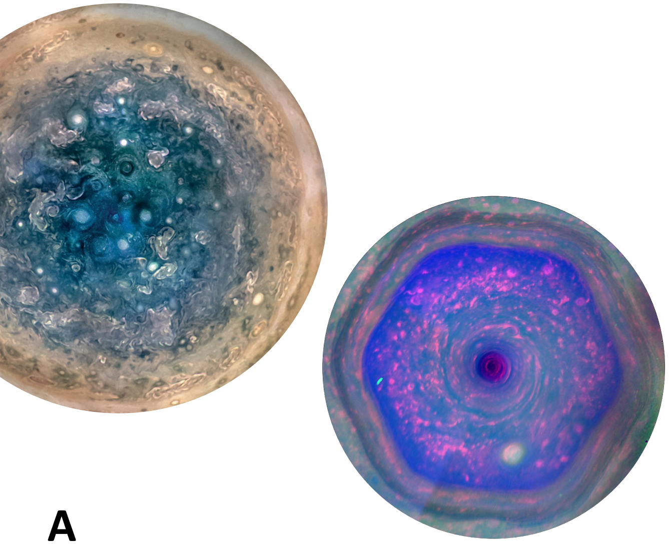


Light-curve with inclinations
(*Tan & Showman 2021b)*



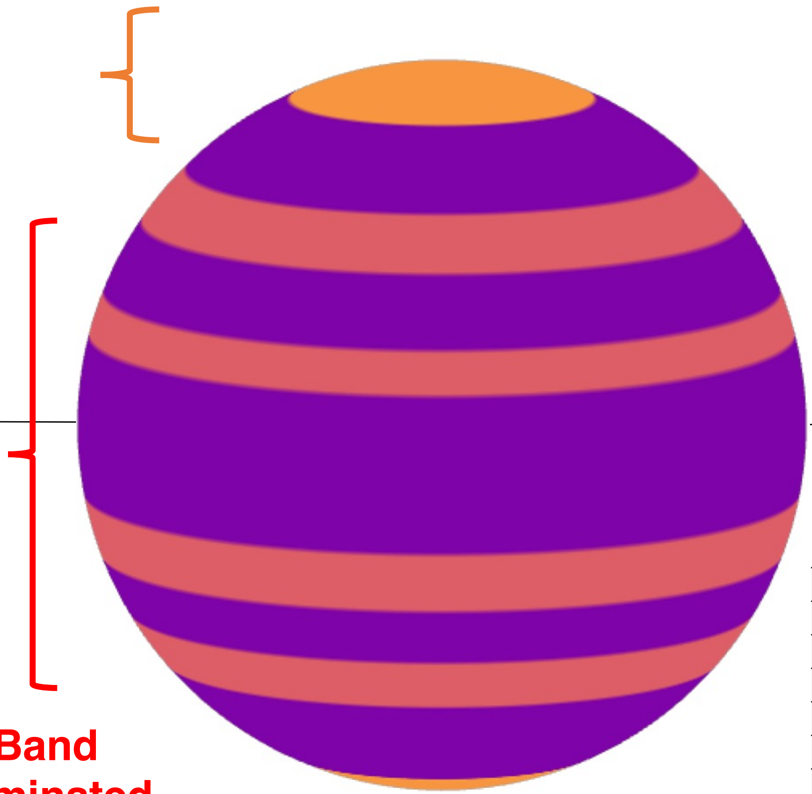
II. The Polar Vortices Hypothesis

Our hypothesis of BD's circulation regime:



A

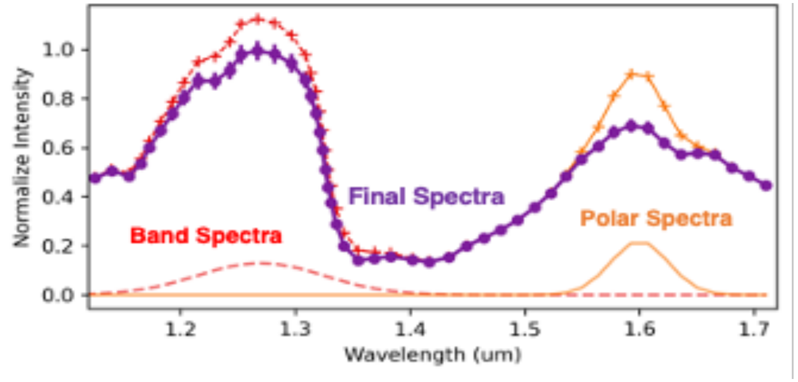
Vortex-dominated



Band dominated

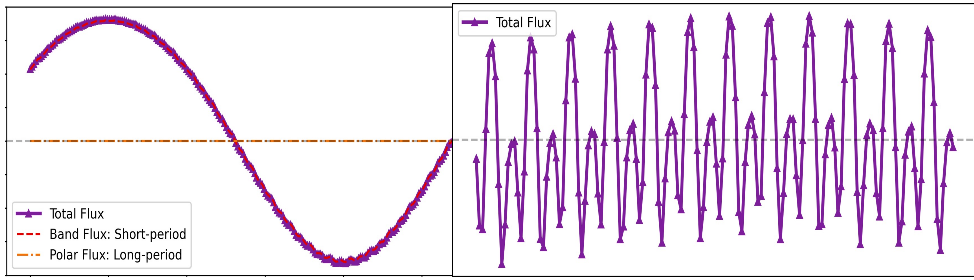
C

Spectral-domain



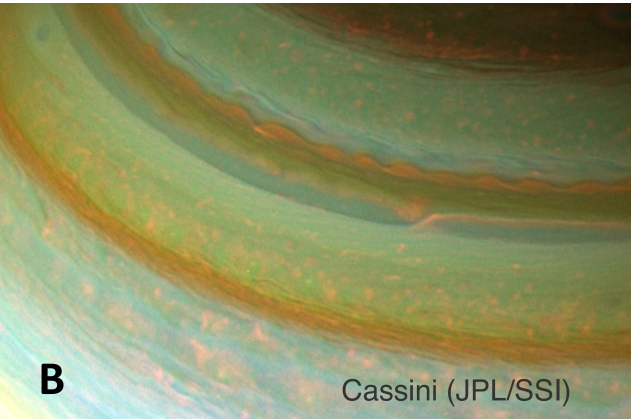
Time-domain

D



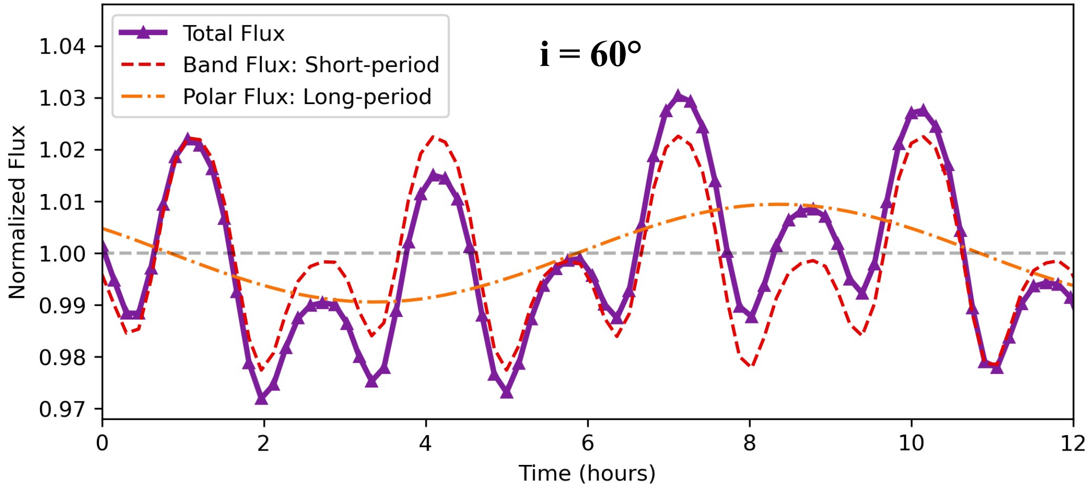
Long-period polar vortices

Short-period band



B

II. Polar vortices: A simple model



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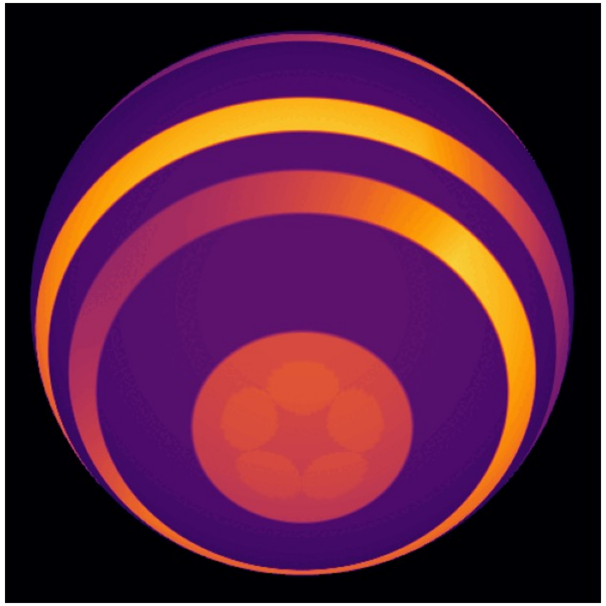

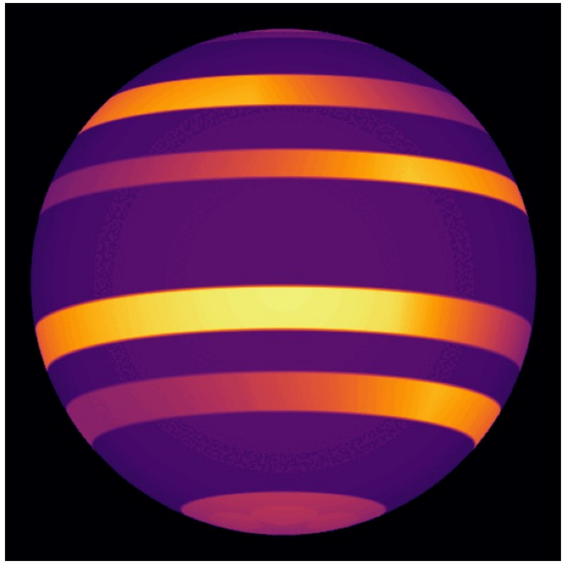

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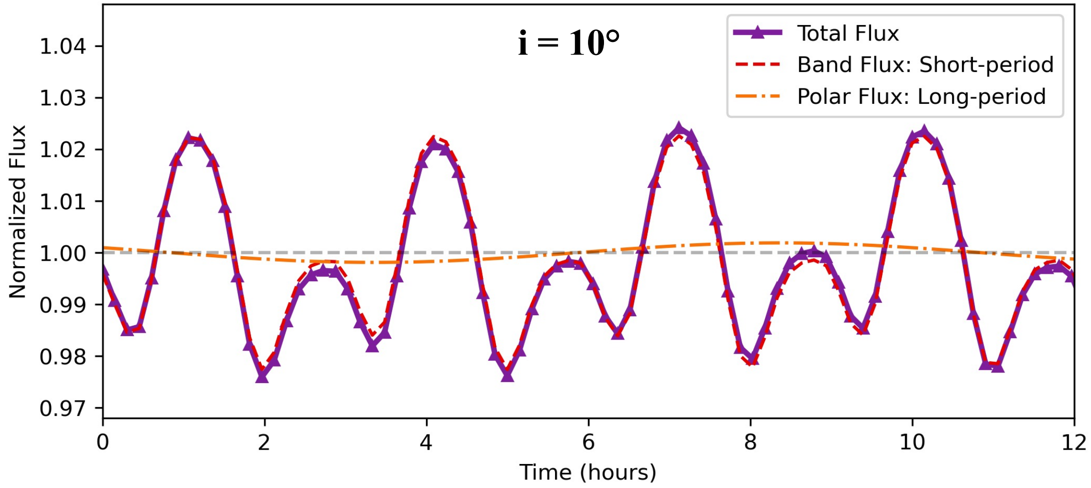

Fuda+24b, in prep.

4. Summaries

Summary

Context:

Ultracool atmospheres: giant planets analogs. **Solar System giants:** polar regions vortex-dominated. **Brown dwarfs:** Pole-to-equator color difference, latitudinal time-complexity in light curve.

Findings:

1. Longest TESS lightcurve of Luhman 16 AB, 1200-hour atmospheric monitoring.
2. Luhman 16 B: rotationally modulation <10-hour period well-explained by planetary-scale waves.
3. Luhman 16 B: multiple wavenumbers, k=1 & k=2 waves: implied latidudinal difference in windspeed distribution.
4. Multi-day long-periods variability: up to 125-hour periods (origin yet known, potentially polar vortices?)
5. Spectrophotometry can unravel polar vortices: preliminaries models show promises!