Mapping atmospheric structures on the nearest brown dwarfs

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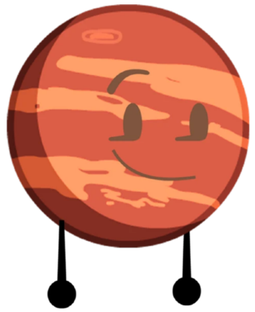
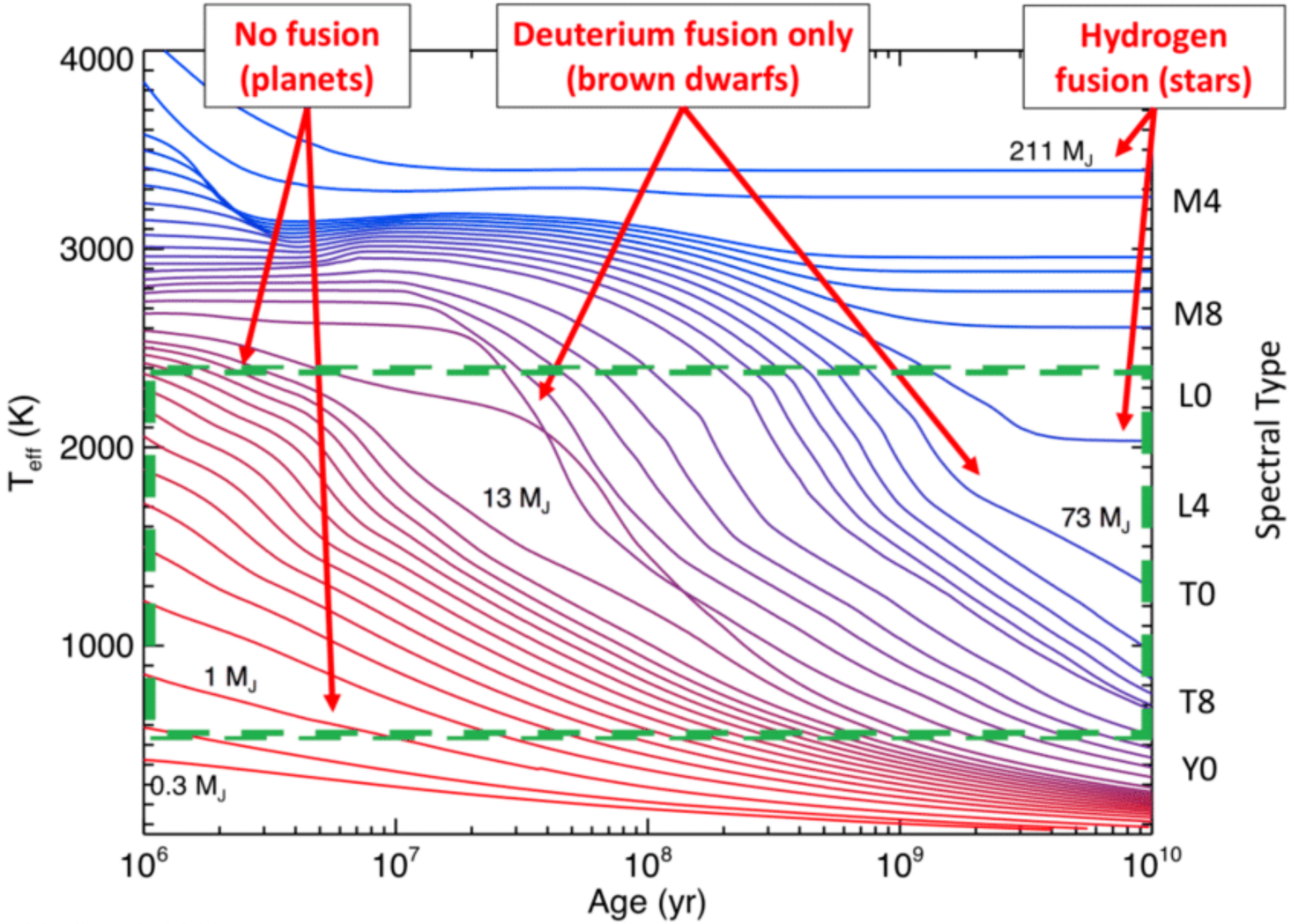
University of Edinburgh

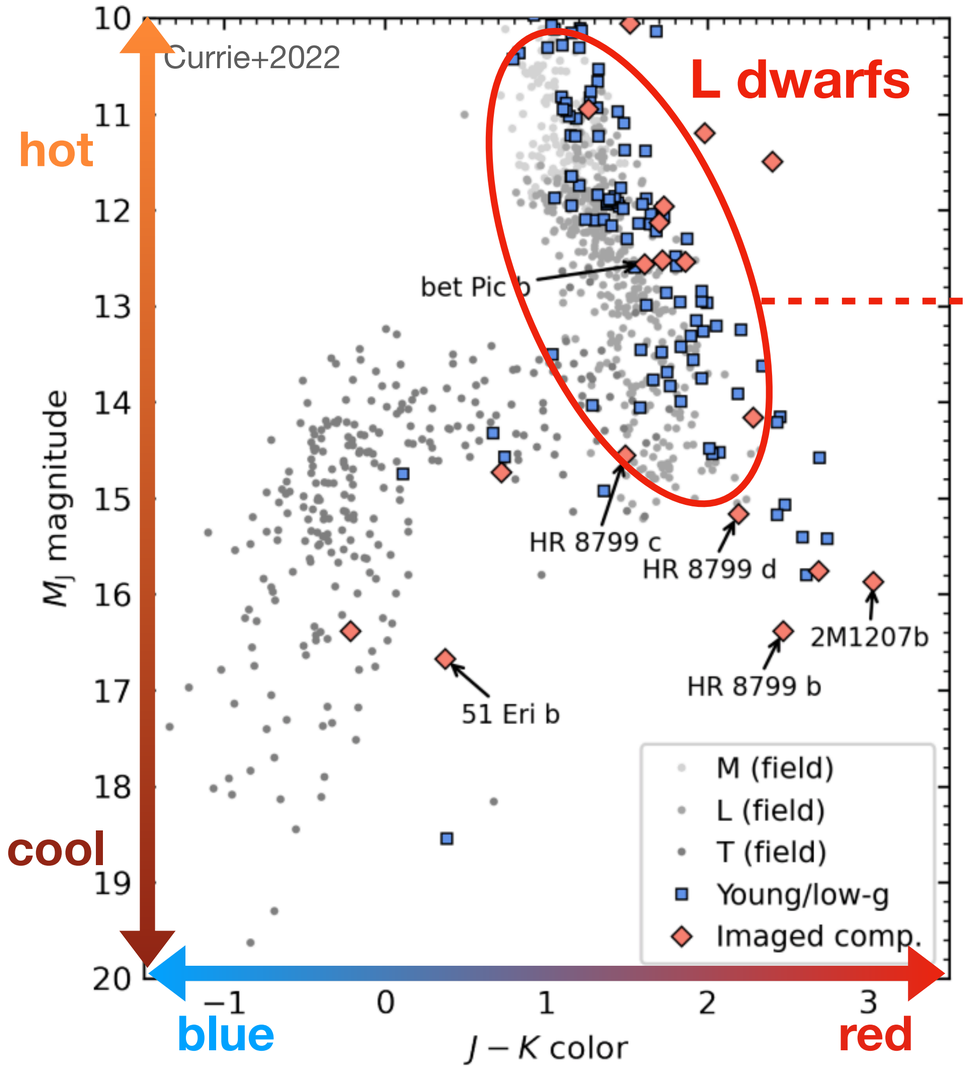
Brown dwarfs





Murihead+2019

Brown dwarfs, especially those in the L/T transition



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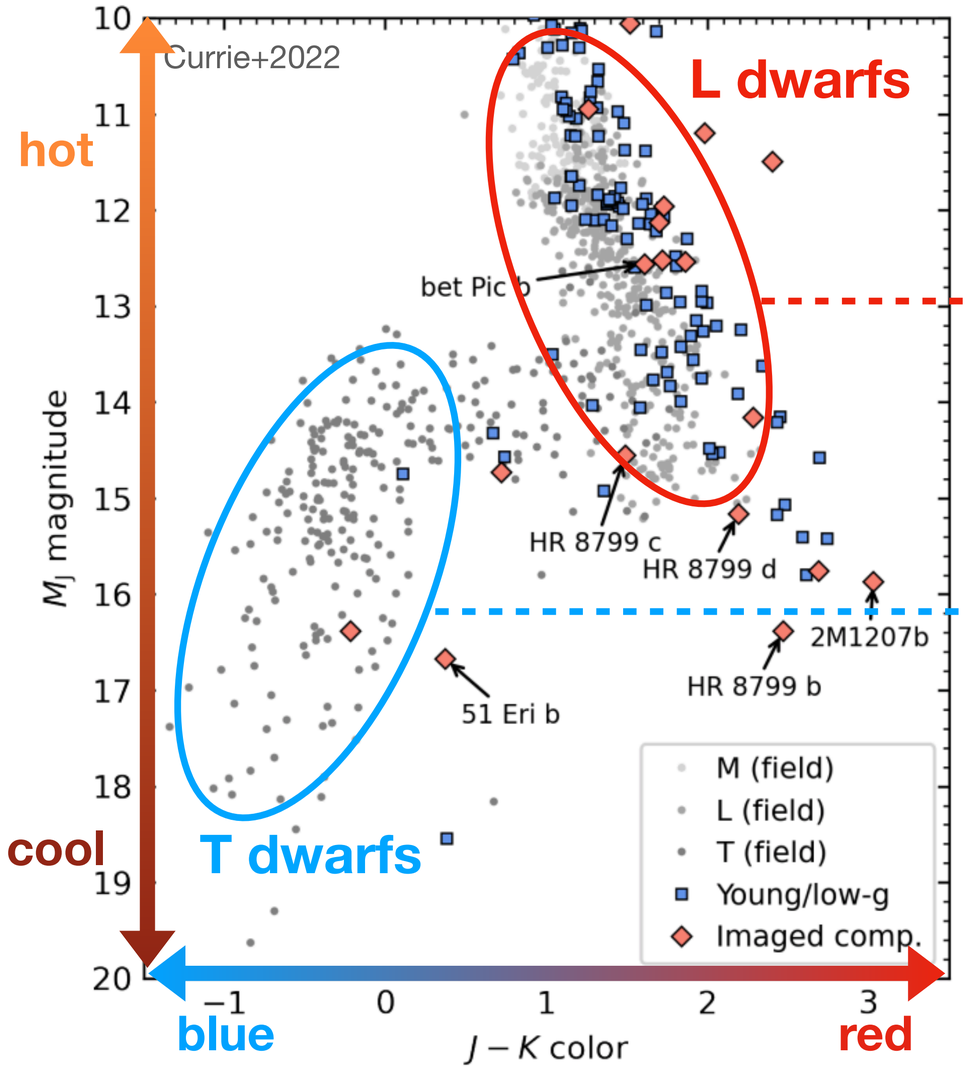

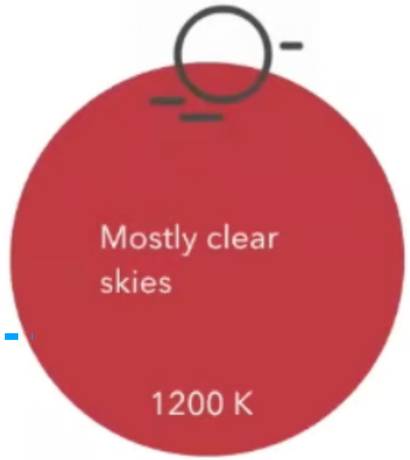

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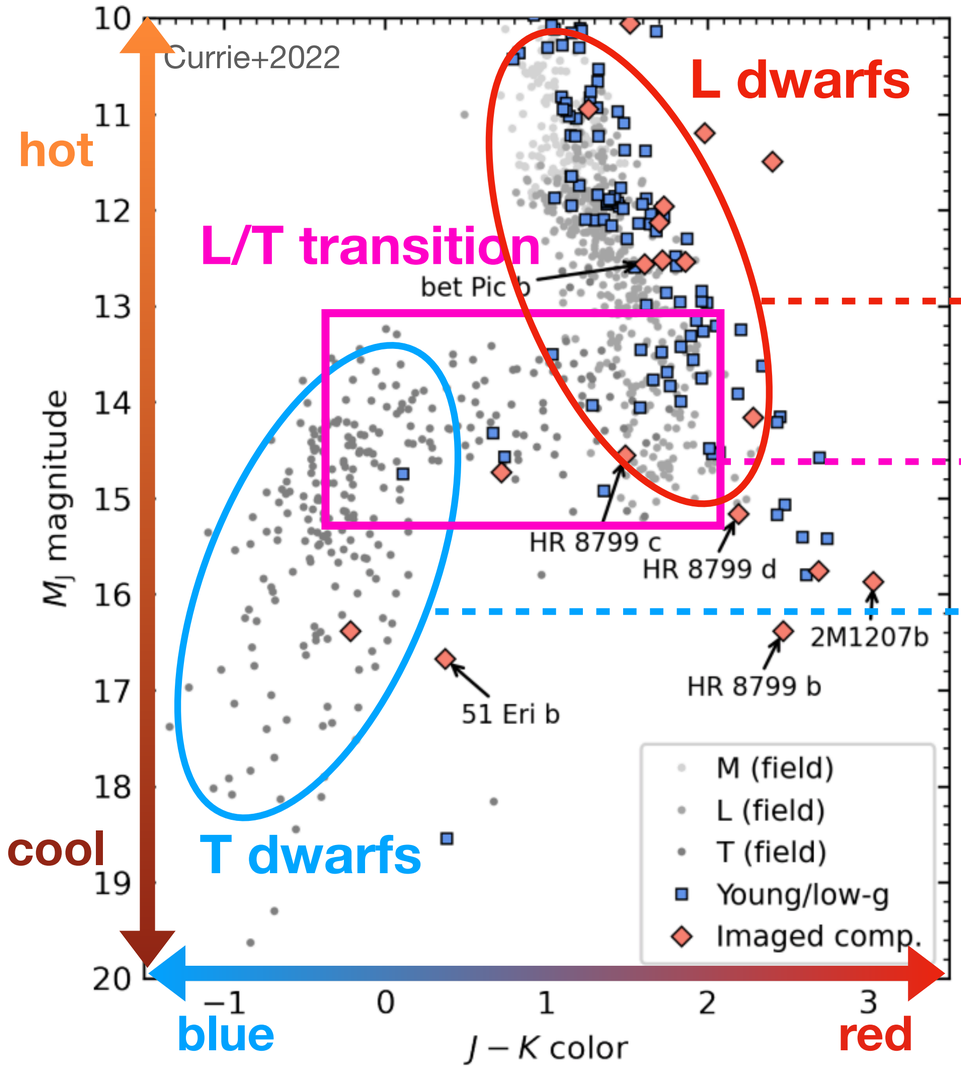

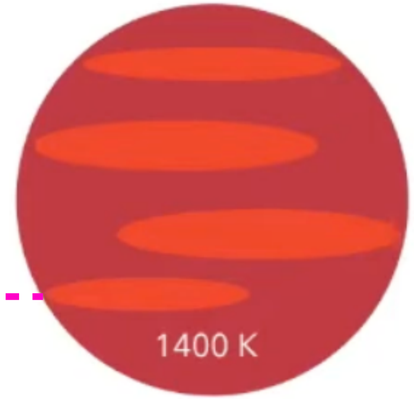

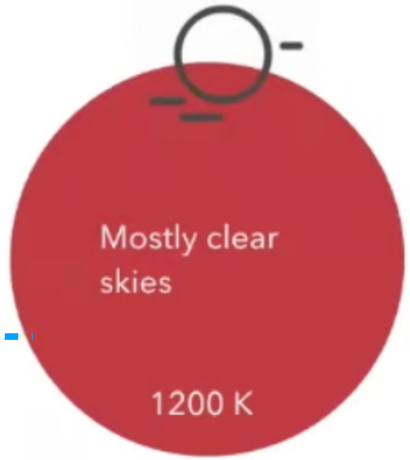

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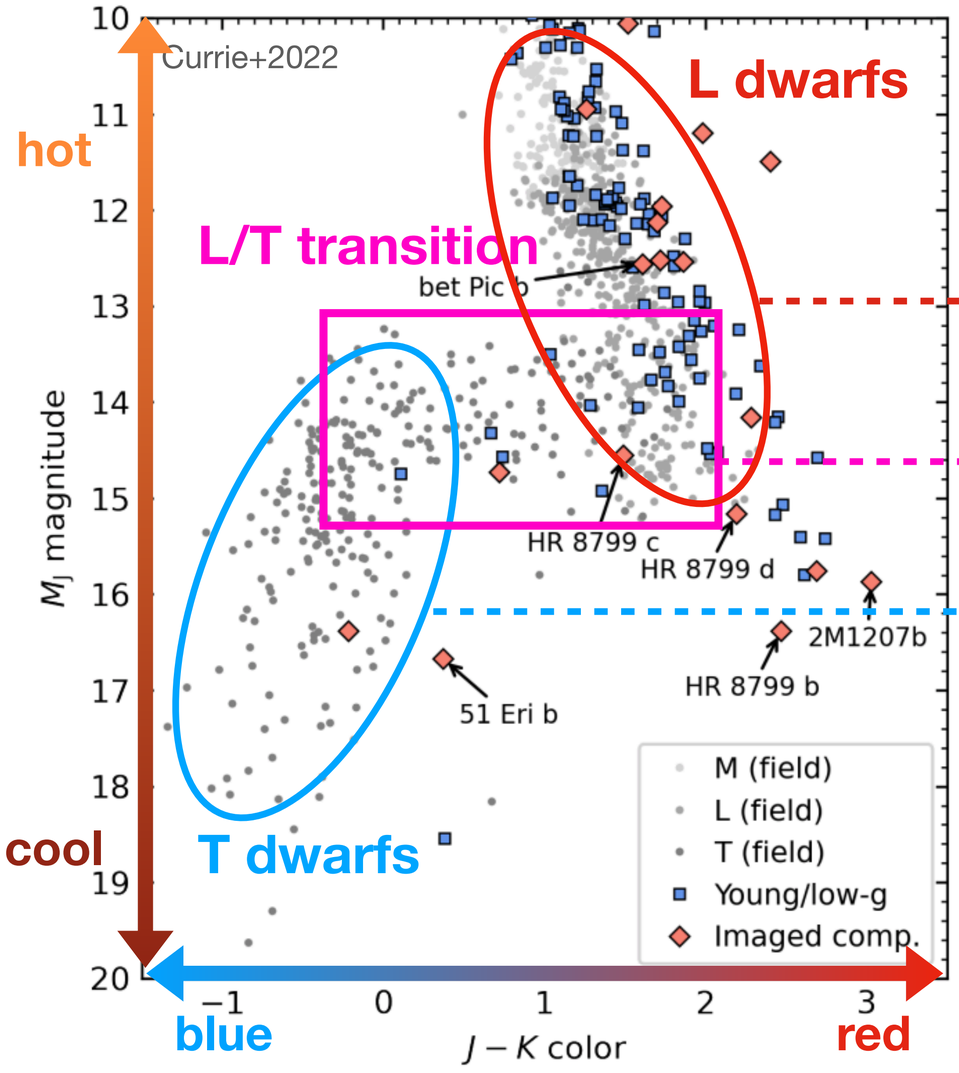
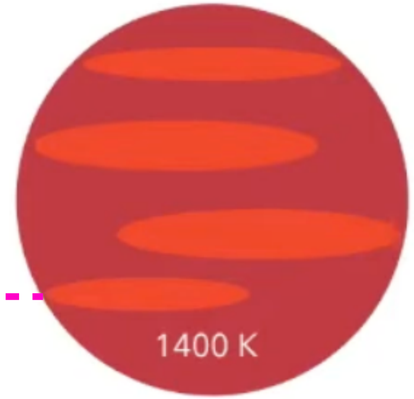
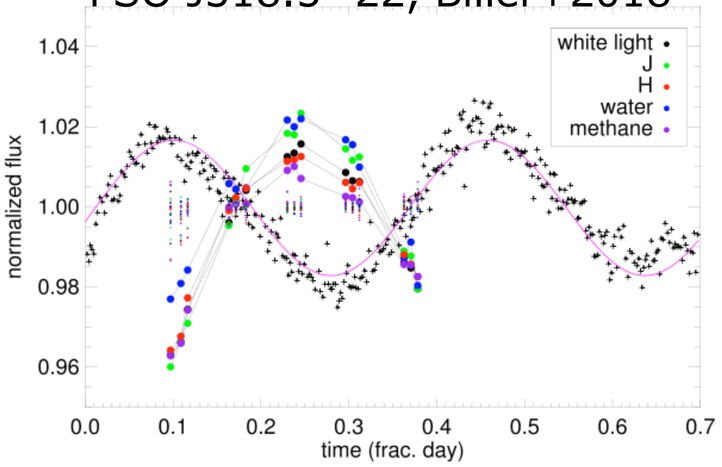




PSO J318.5−22, Biller+2018

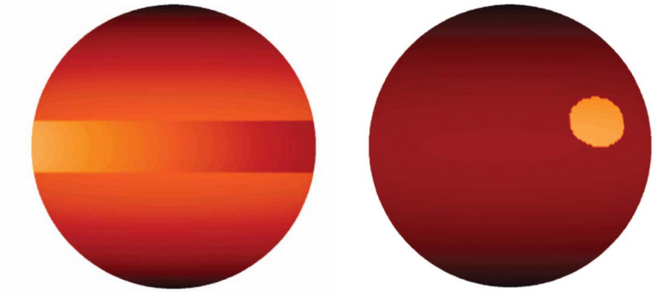


variable light curves!

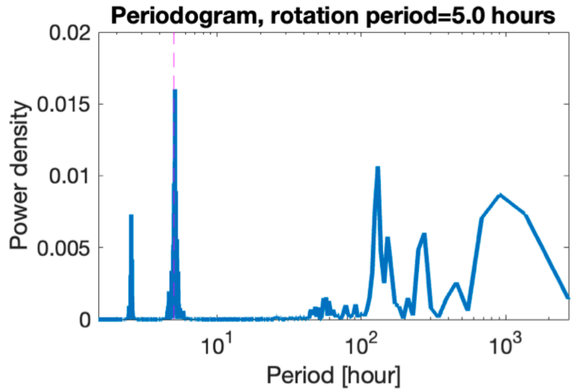
temporal → spatial

Understanding weathers on brown dwarfs…

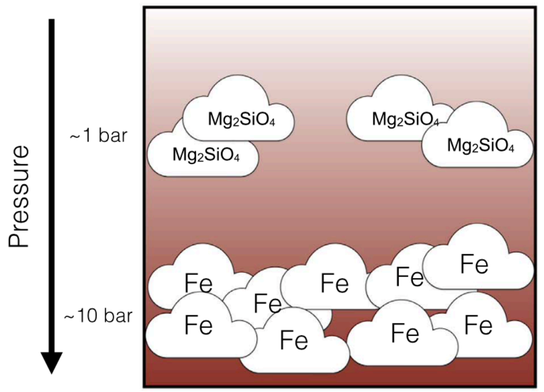
- What are the **morphologies** of atmospheric structures? Spots, planetary waves, or both?
- What are the **timescales** of the evolution of atmospheric structures?
- What are the **physical mechanisms** driving photometric variability? Clouds, hotspots caused by chemical disequilibrium, or both?



Apai+2017



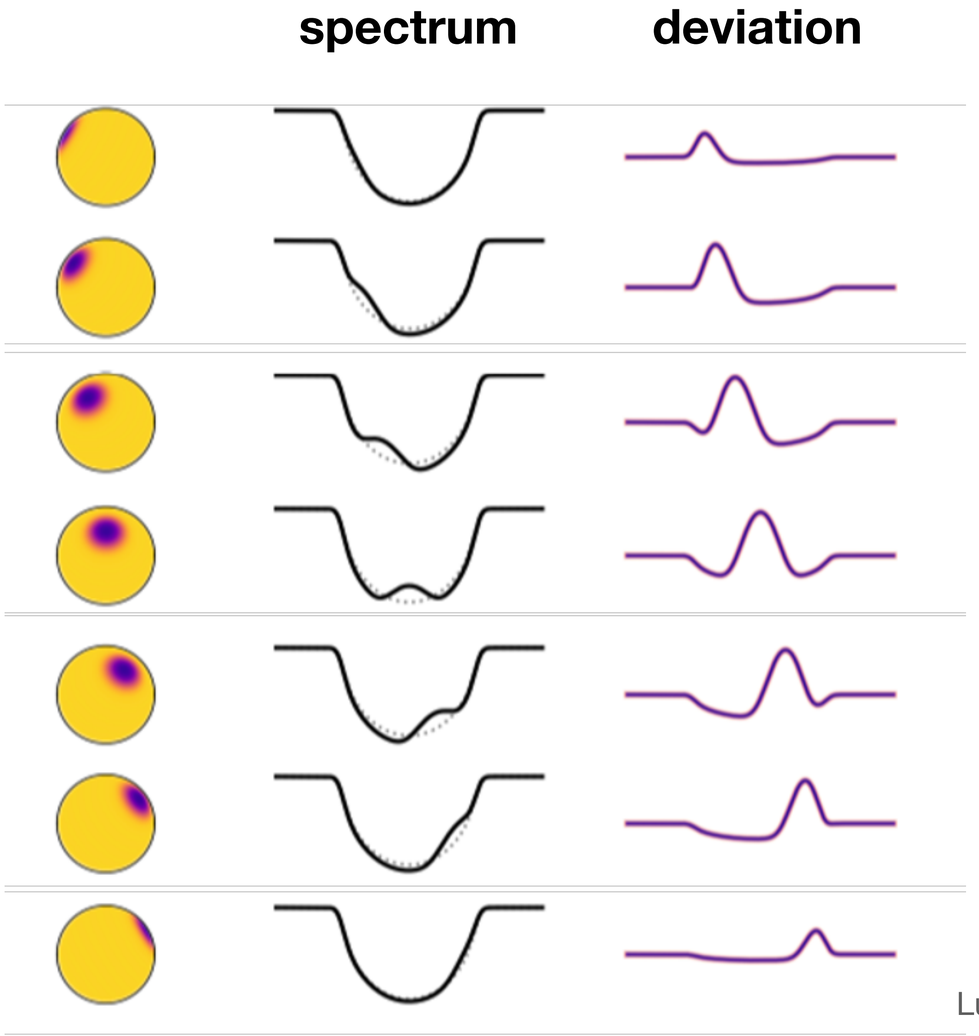
Fuda+2024



Vos+2023

Our method: Doppler imaging

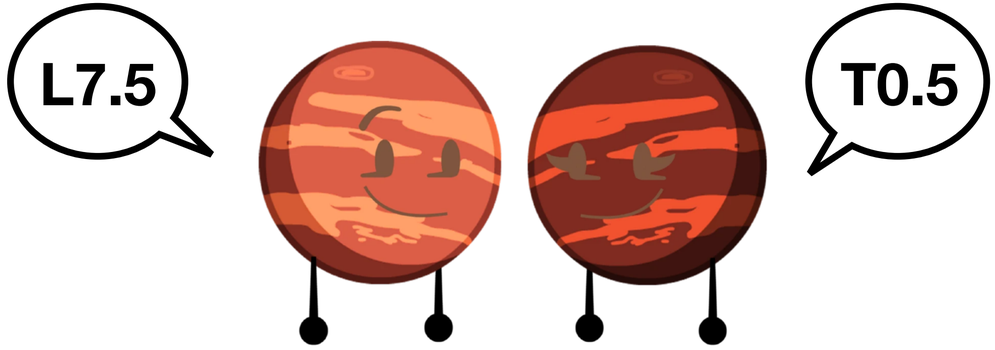
- Absorption line profiles (LPs) change shapes as a dark patch rotates across the visible face due to varied Doppler shifts
- This info can be used to infer a brightness map of the object



Luger 2021

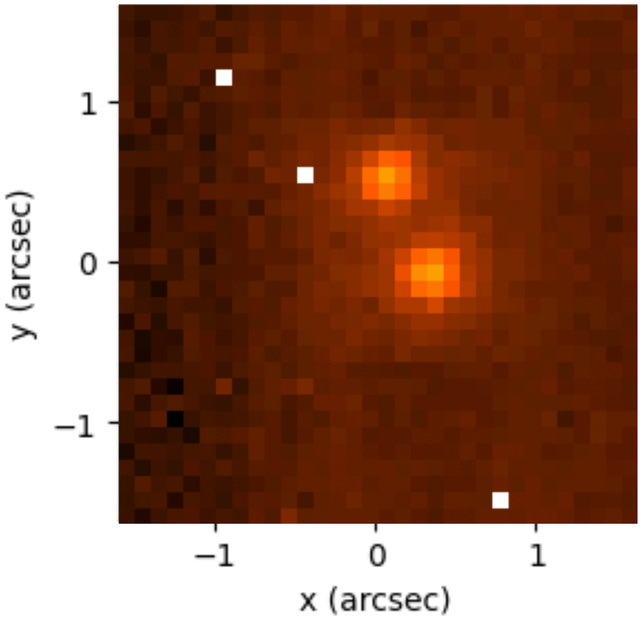
Our target: the nearest brown dwarfs

~ 2 pc
~ 30 M_{Jup}
~ 5hr period



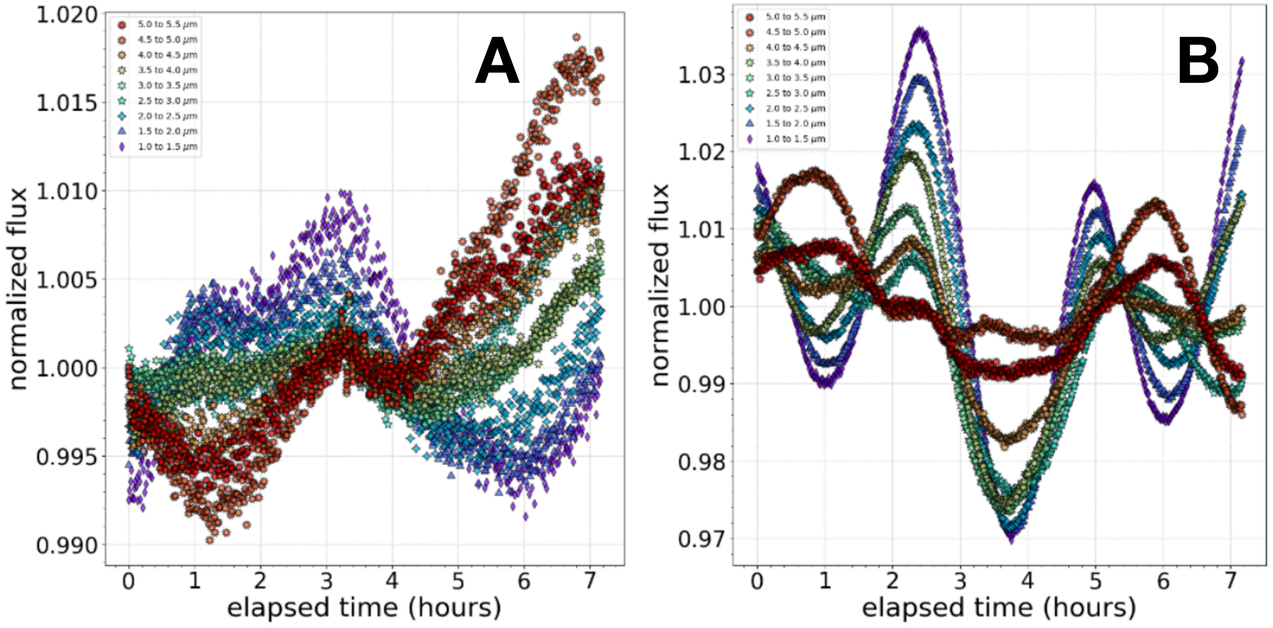
WISE 1049AB
aka Luhman 16AB

JWST NIRSpec F110W



JWST NIRSpec light curves

Biller+ submitted



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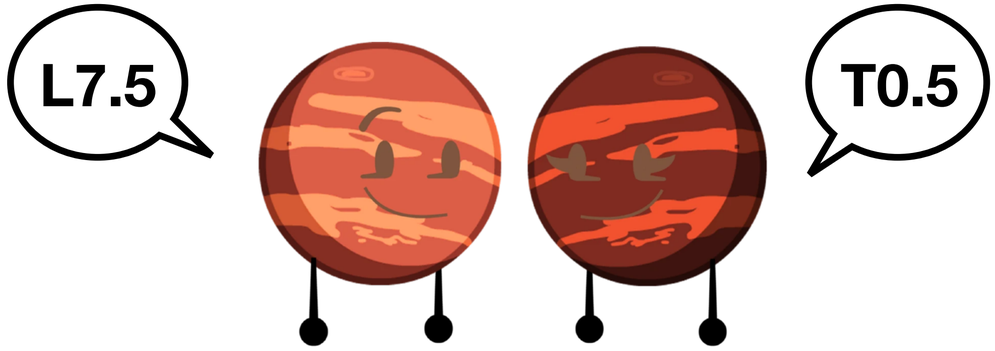
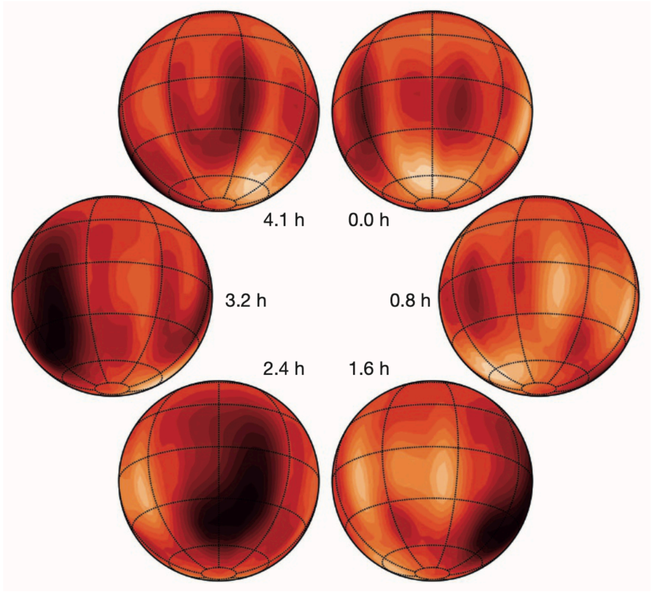


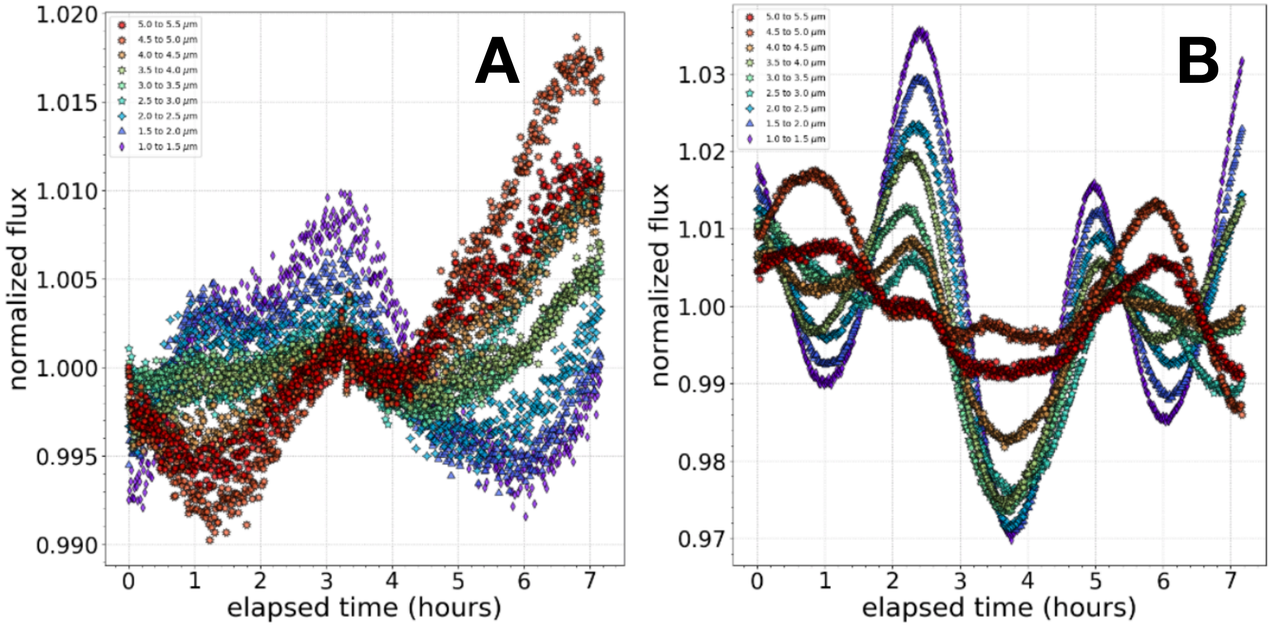
WISE 1049AB
aka Luhman 16AB

CRIRES Doppler map of B



Crossfield+2014

JWST NIRSpec light curves Biller+ submitted

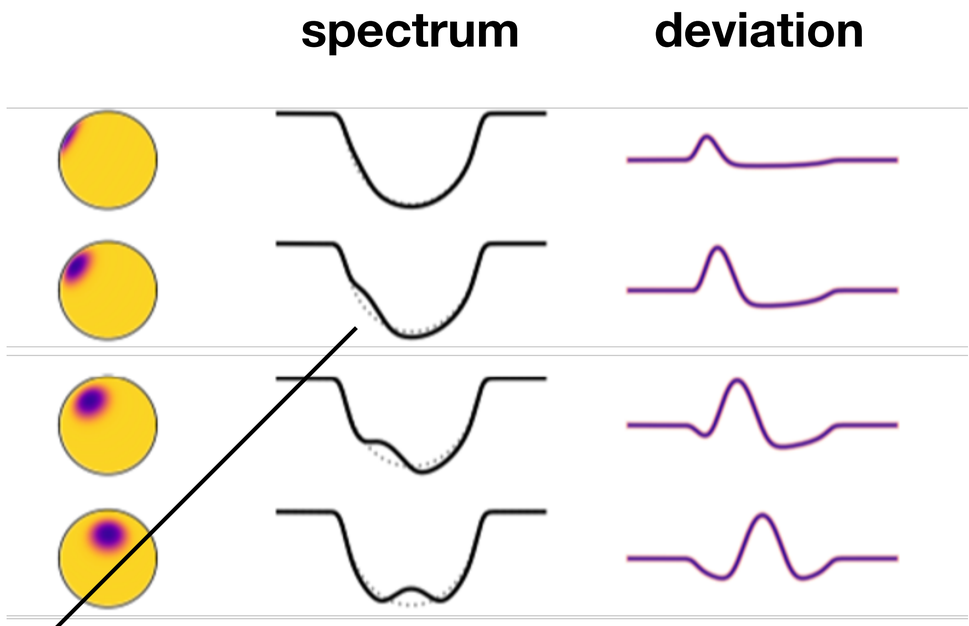


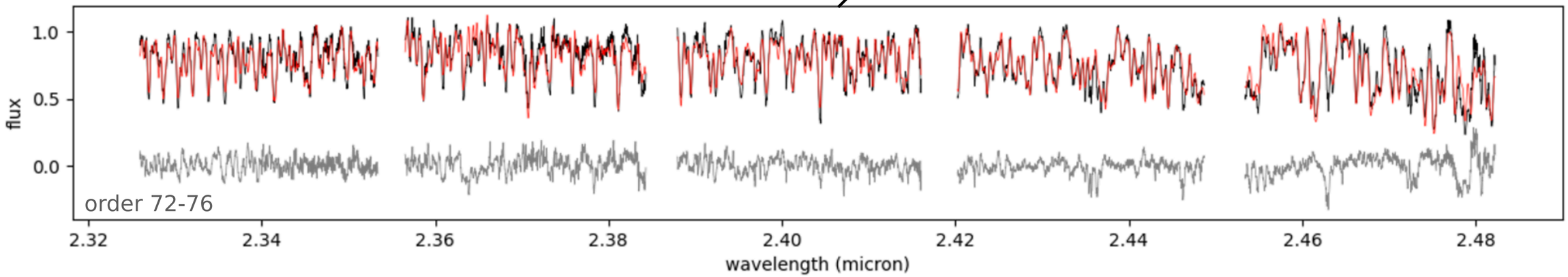
Our method: Doppler imaging

Gemini IGRINS (R~45,000)

H (1.5-1.8 μm) **and K** (1.9-2.5 μm)

Feb 9 & 11, 2020 ~5h each





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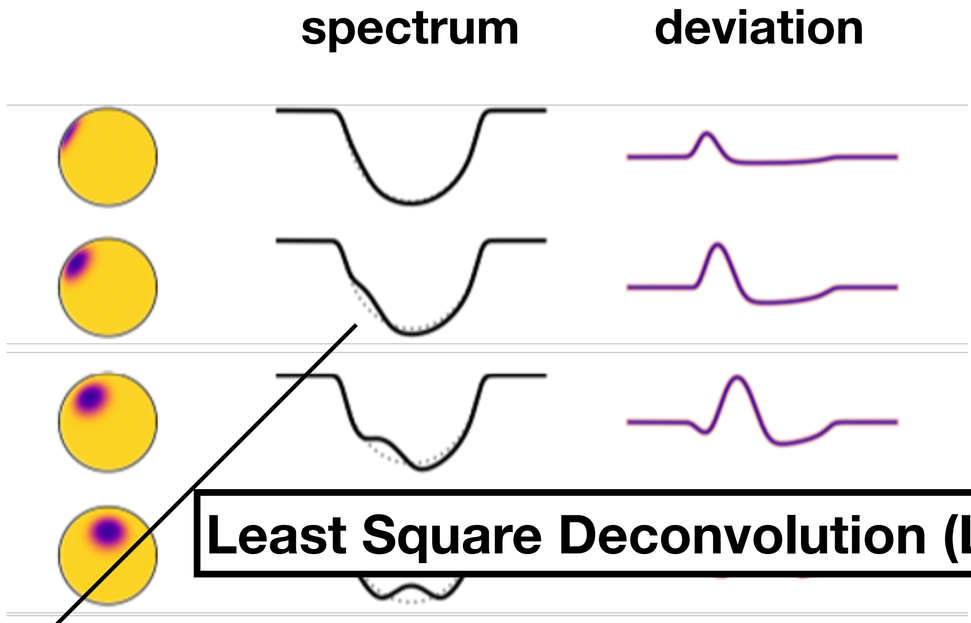
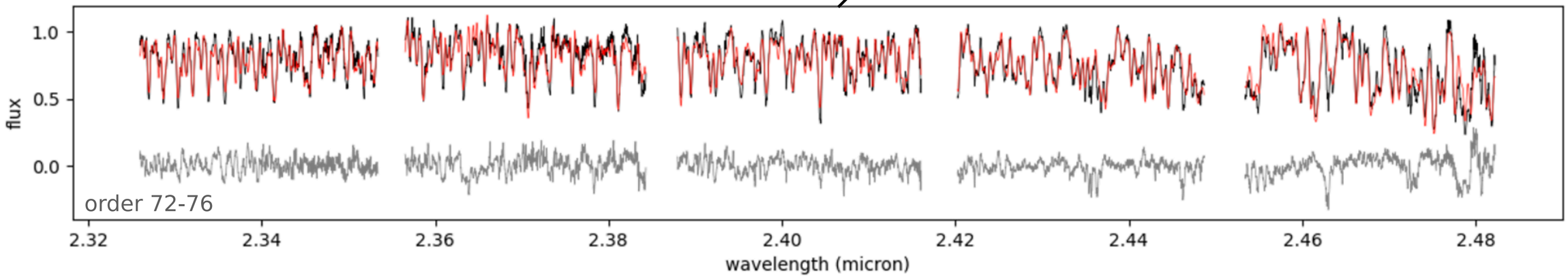
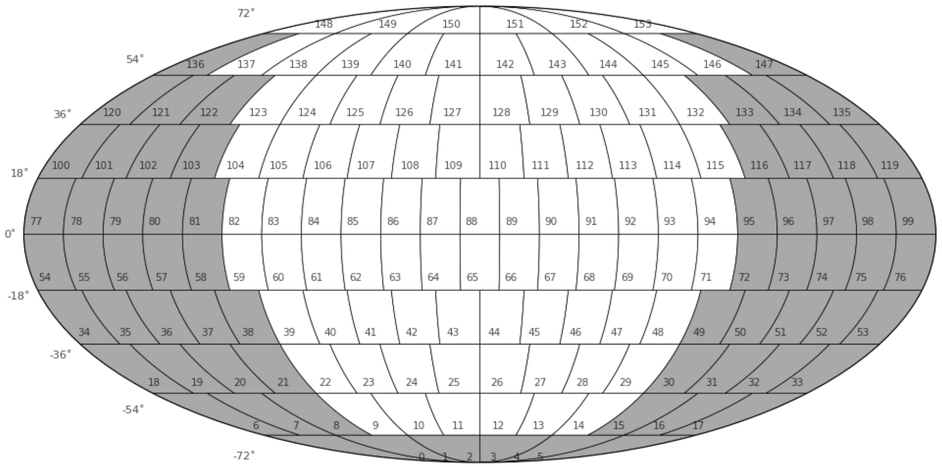




Map × Rmatrix = Spectral time series



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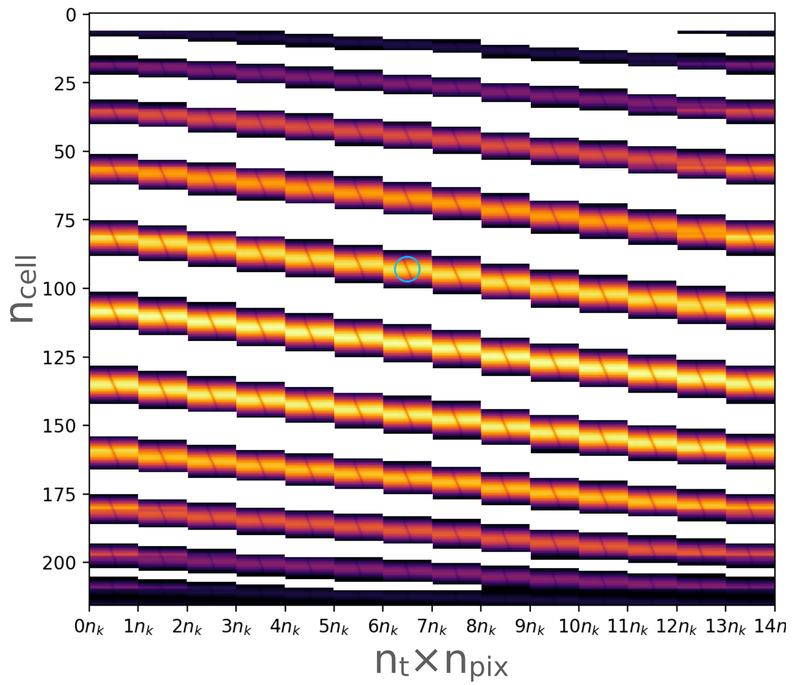

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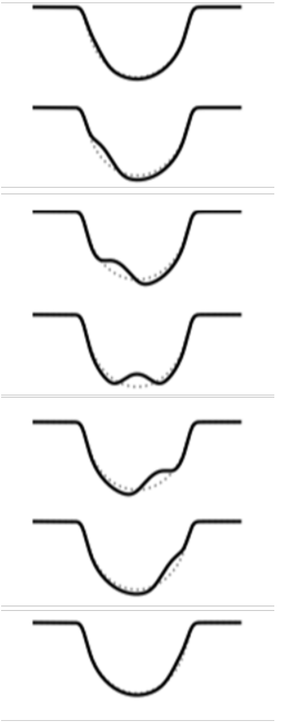


The map vector
n_{cell}

The Doppler Imaging Response Matrix
$[n_{cell}, n_t \times n_{pix}]$

The spectral time series
$n_t \times n_{pix}$

Maximum entropy image reconstruction $Q = \chi^2 - \alpha S$

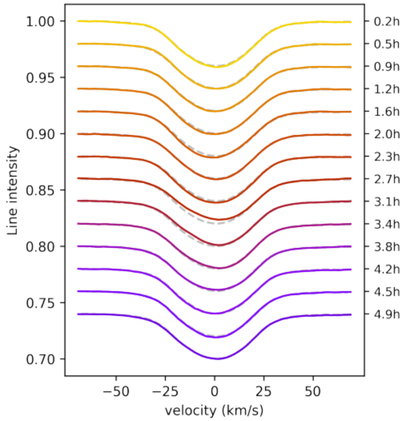
WISE 1049B Doppler Maps - 1st night

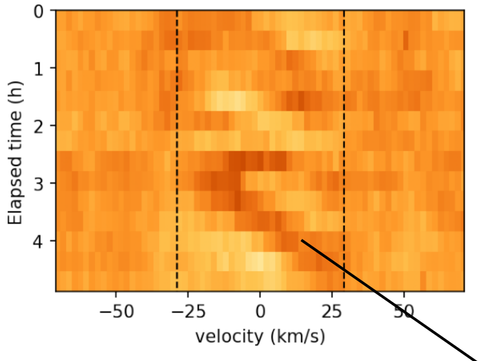
LSD line profiles

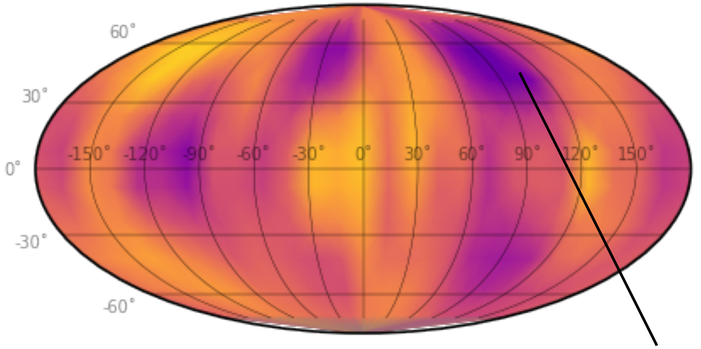
deviations

reconstructed map

K band



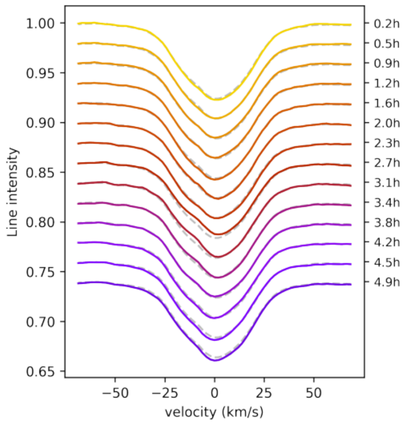


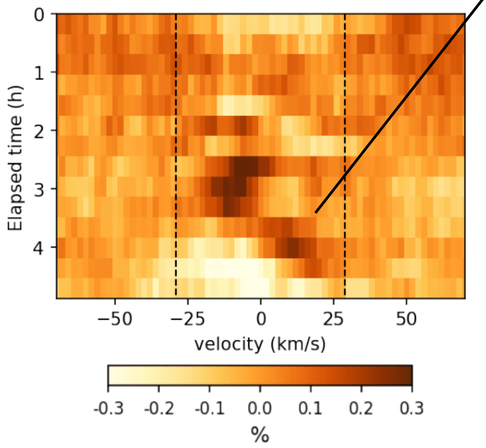


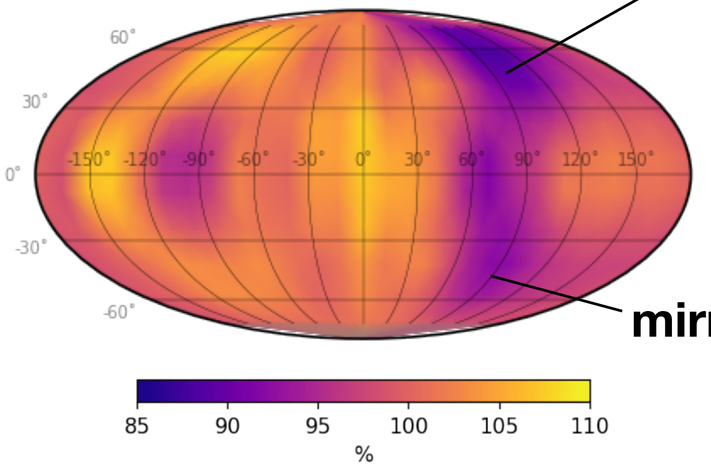
dark trace 3-5h

mid-latitude dark patch

H band







mirroring effect

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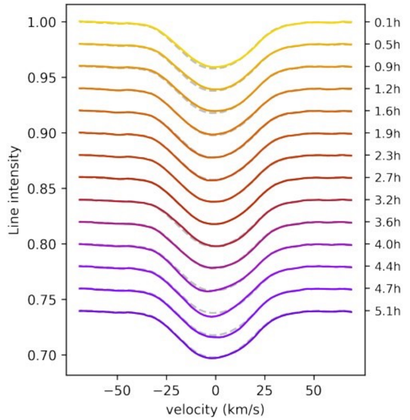
WISE 1049B Doppler Maps - 2nd night

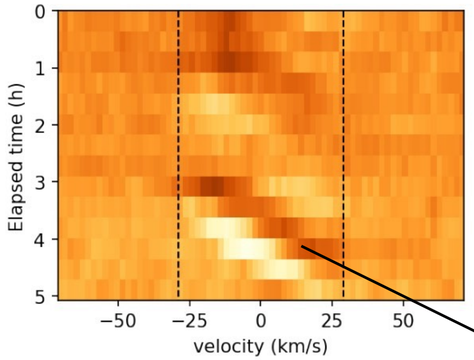
LSD line profiles

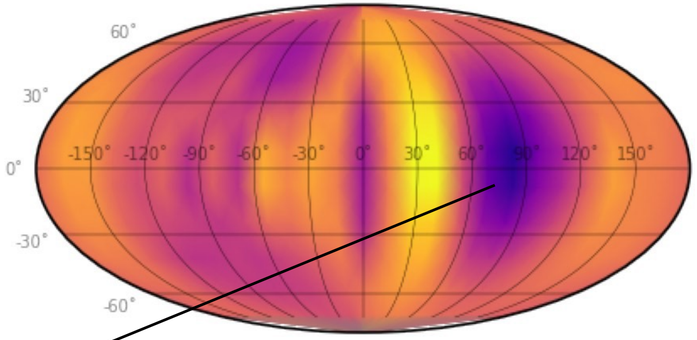
deviations

reconstructed map

K band

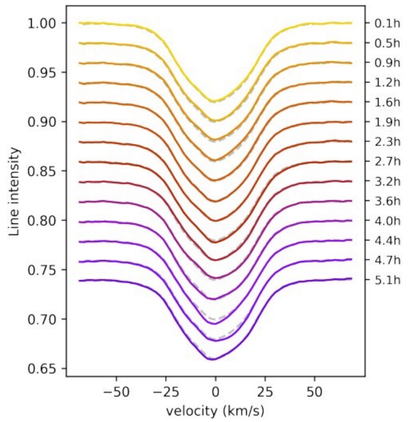


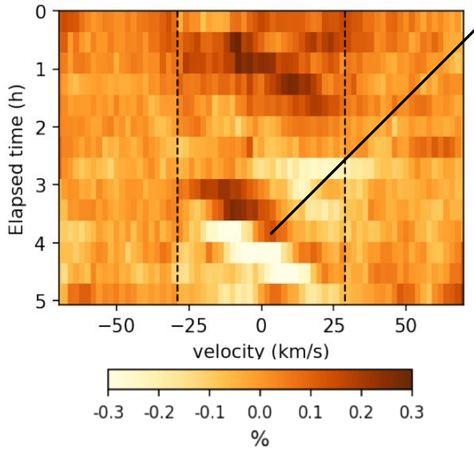


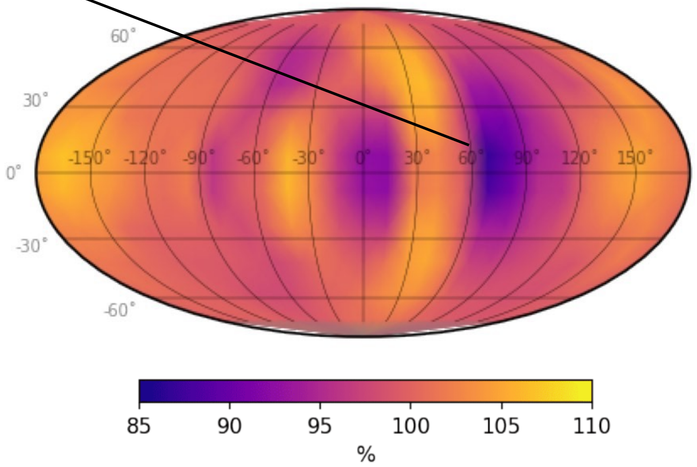


equatorial dark spot 3-4.5h

H band







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WISE 1049B Doppler Maps - 2nd night

LSD line profiles

deviations

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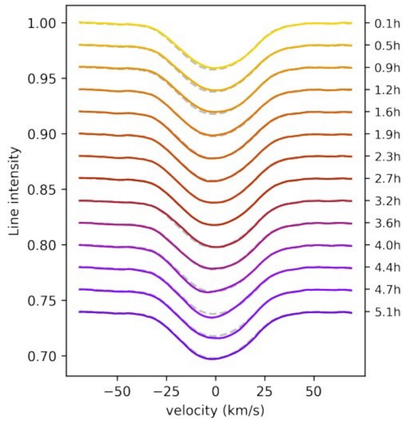
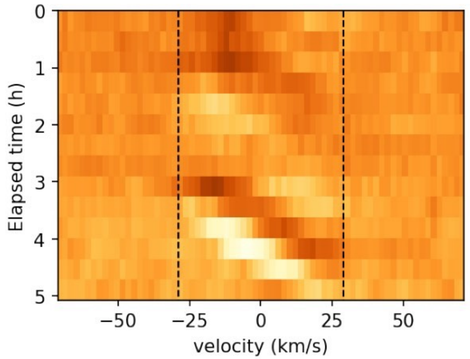
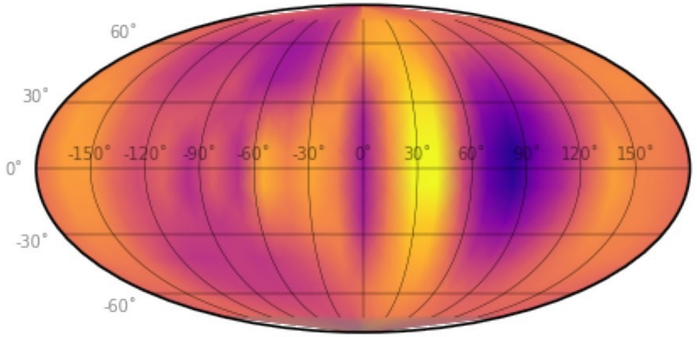
K band

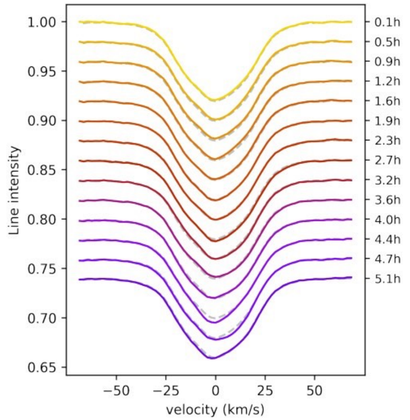


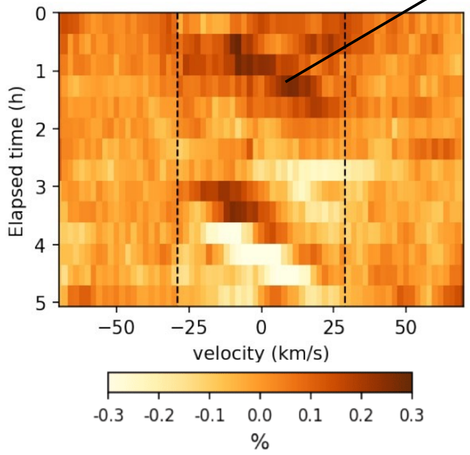


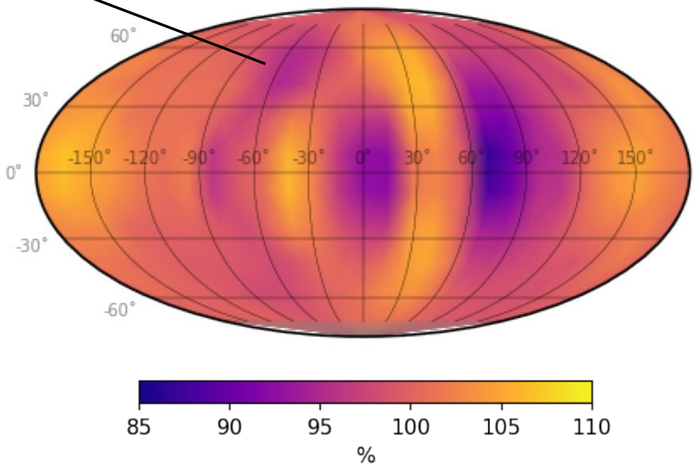


possible secondary spot

H band







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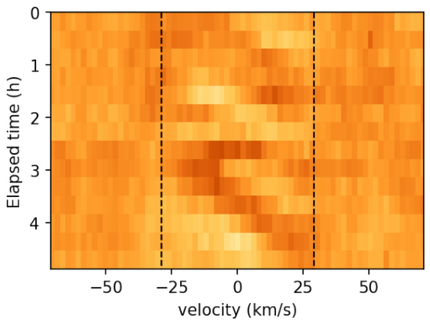
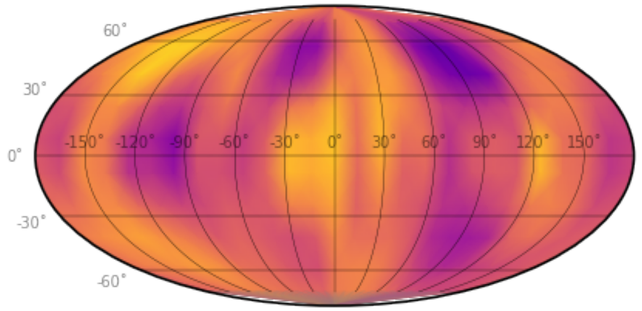
WISE 1049B - Comparing two nights

deviations

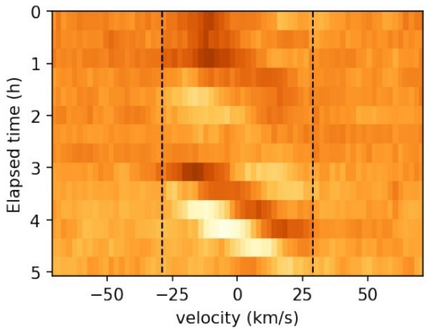
reconstructed map

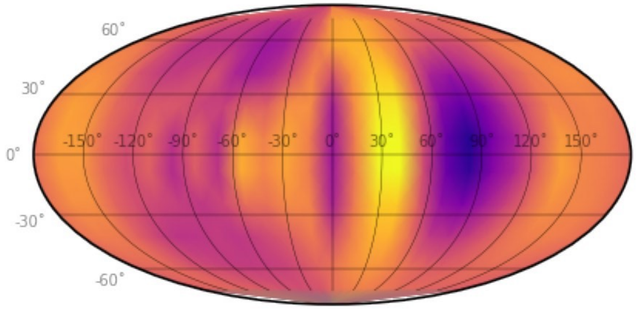
1st night
Feb 09, 2020





2nd night
Feb 11, 2020



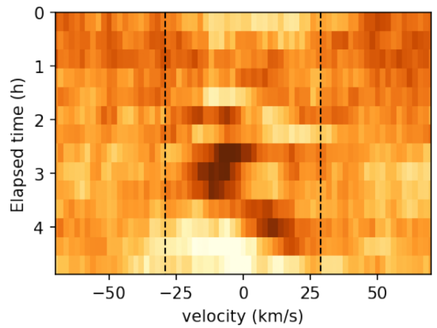


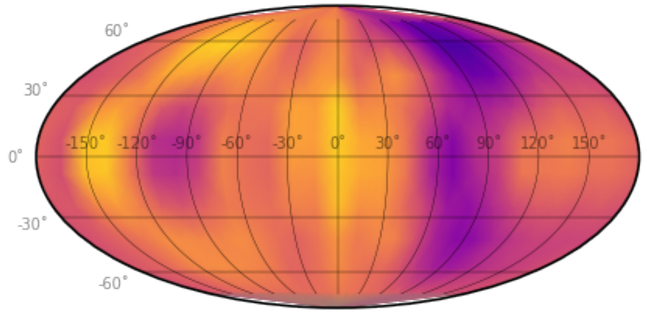
- traces of the dominant feature have almost same shape, extent and gradient
- structure stayed over 2 days — time scale of short-term evolution?

Comparing with 2014 map (Crossfield et al)

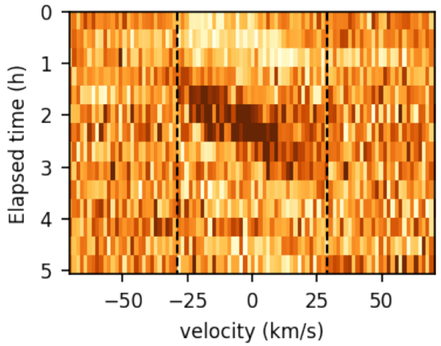
deviations **reconstructed map**

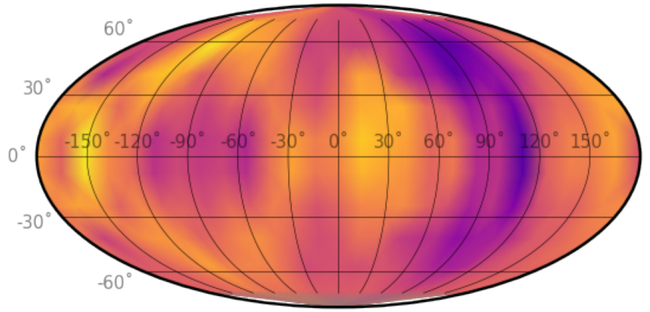
IGRINS K 2020





CRIRES K 2014

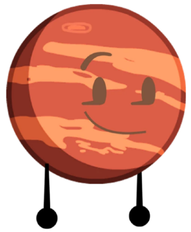




(rotated to align the dominant feature)

- similar features over 6 years — stable structure or recurring formation
- preferred length scale of atmospheric structures

WISE 1049A Doppler Maps - 1st night

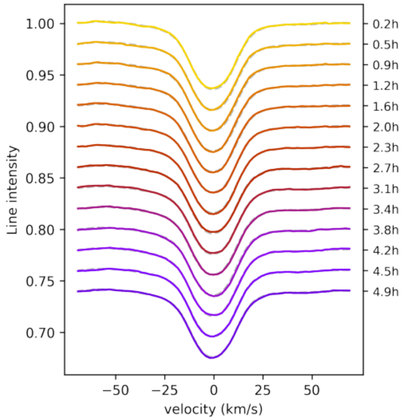


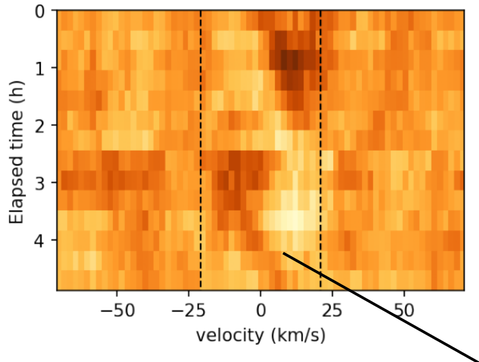
LSD line profiles

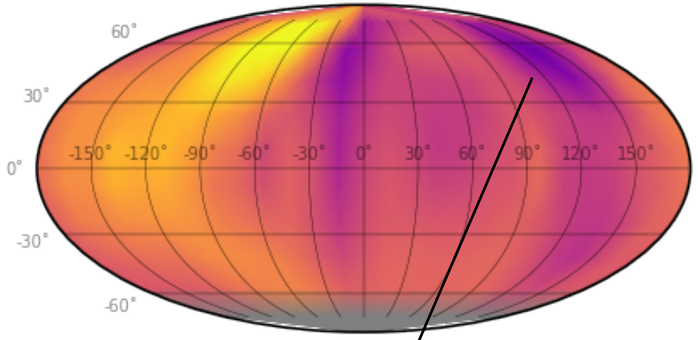
deviations

reconstructed map

K band

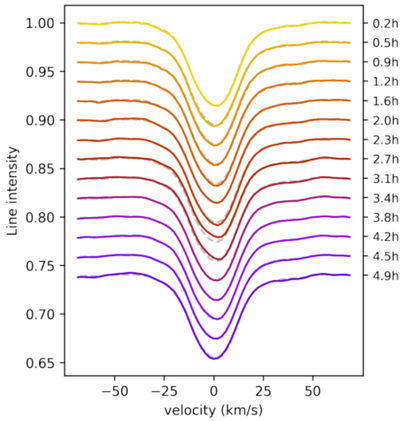


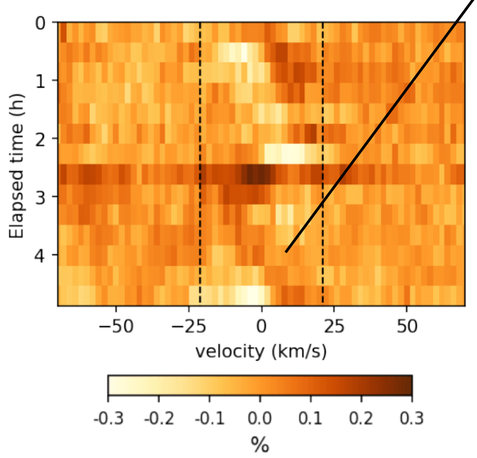


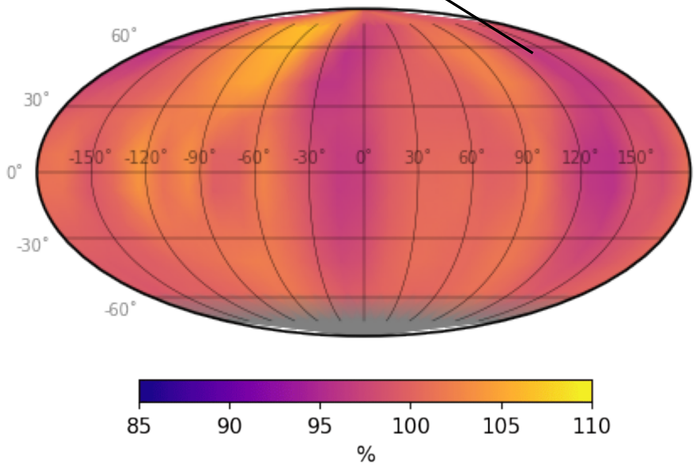


trace 3-5h, 140º faint polar spot

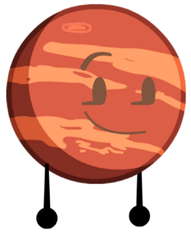
H band







WISE 1049A Doppler Maps - 2nd night

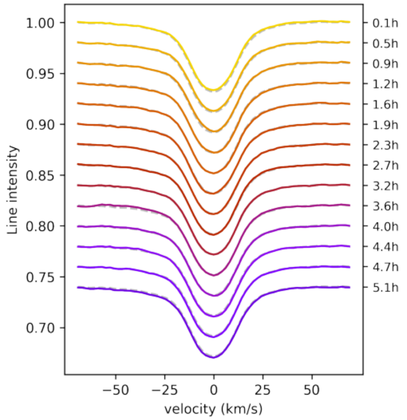


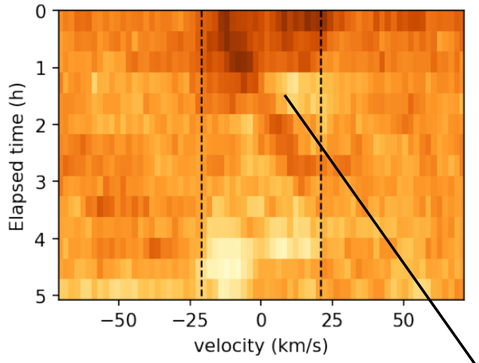
LSD line profiles

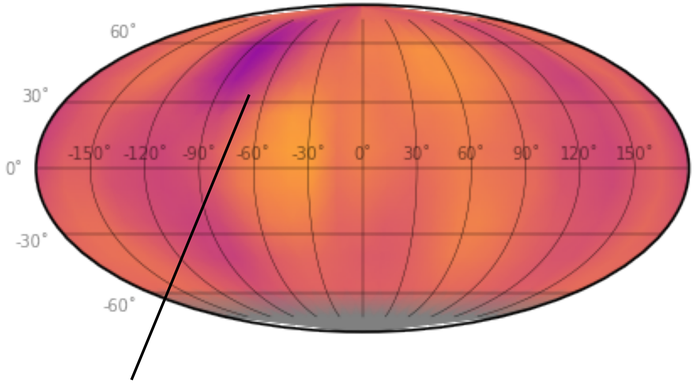
deviations

reconstructed map

K band

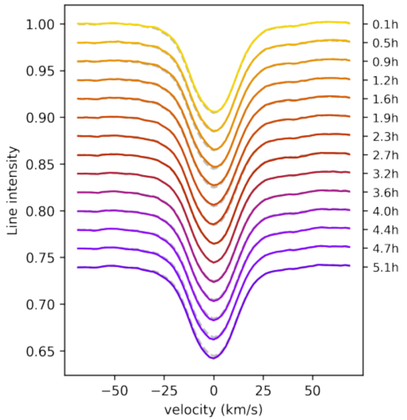


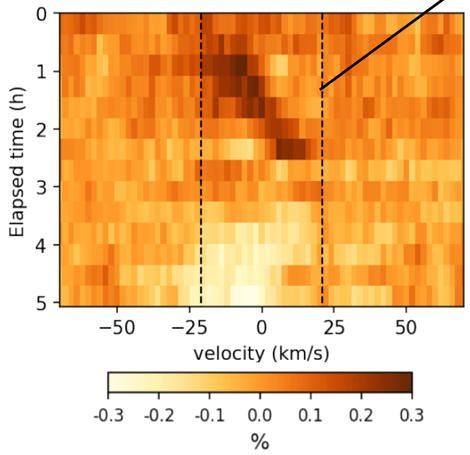


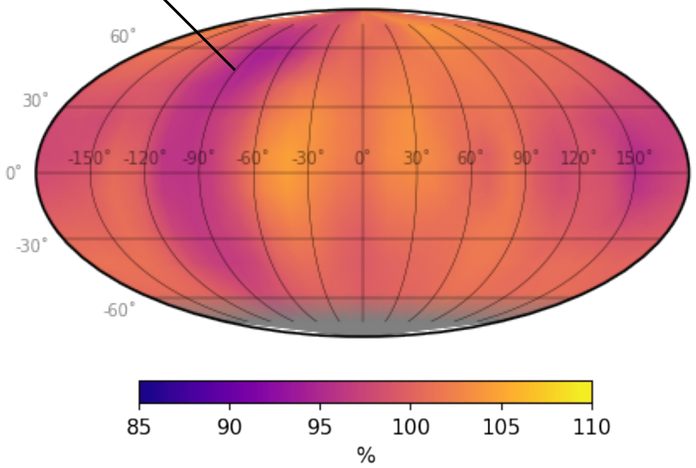


trace 0-2.5h, -80º faint polar spot

H band







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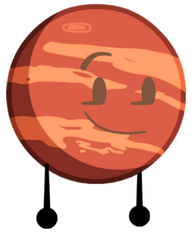
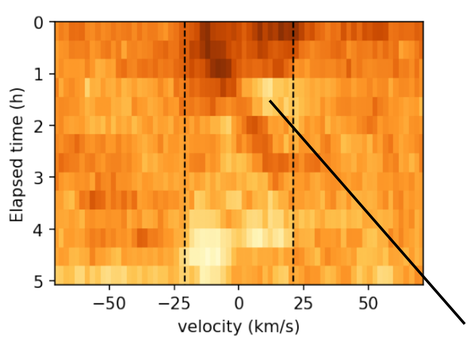
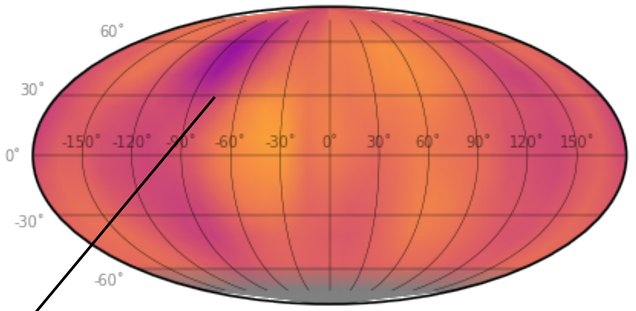
WISE 1049A - Comparing with 2014



deviations **reconstructed map**

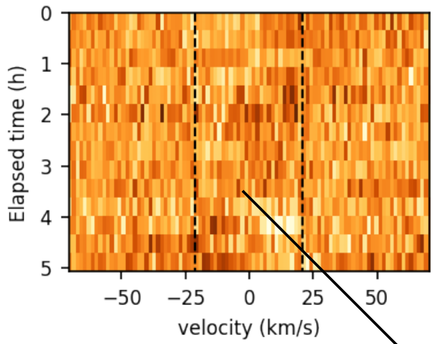
IGRINS K 2020

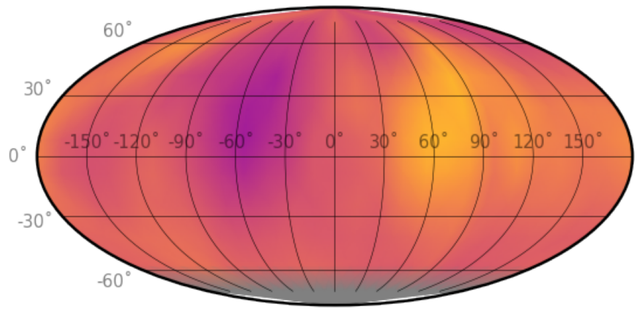




high-latitude spot found in 2020

CRIRES K 2014

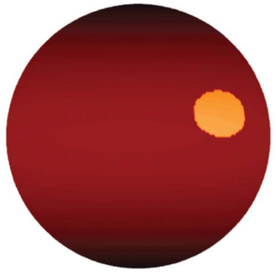




no significant signal found in 2014

Interpretation with simulated maps

spots

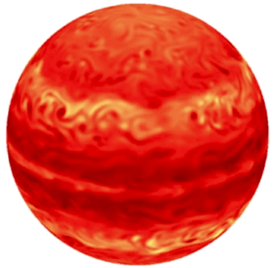


Elliptical spots of brightness difference
Apai+2013, Karalidi+2016

planetary waves

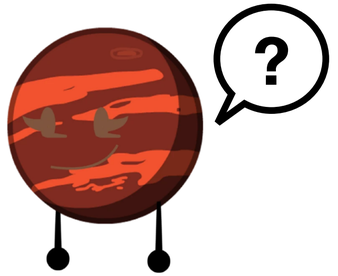
Bands with sinusoidal surface brightness,
Apai+2017, 2021

3D GCM



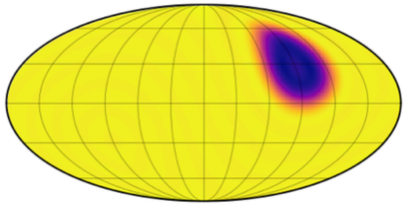
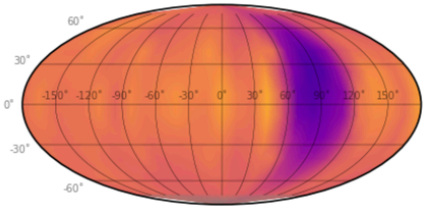
General circulation models
Showman+2020,
Tan+2021, 2022

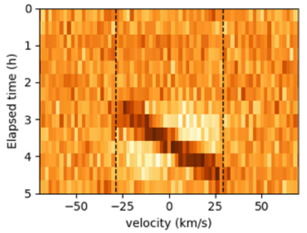
Interpretation with simulated maps



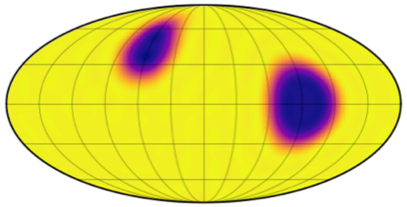
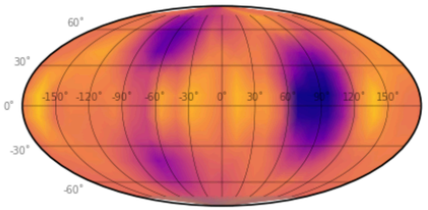
injected map | recovered map | deviations

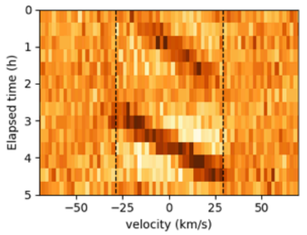
1 spot

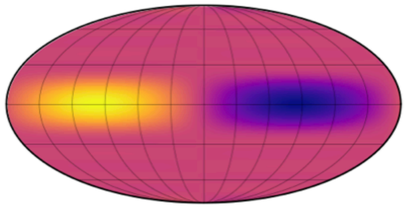
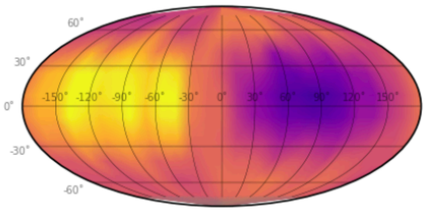


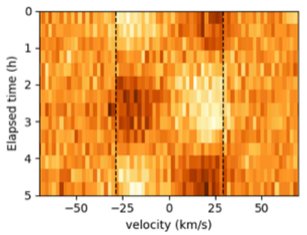
2 spots

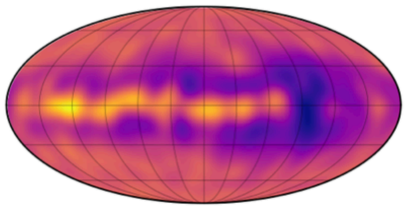
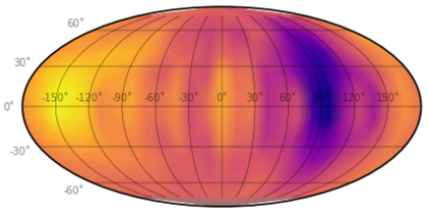


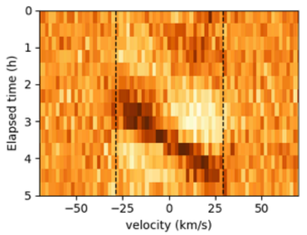
planetary wave

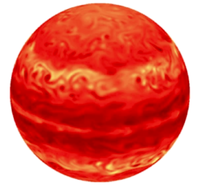





3D GCM
(cr. Xianyu Tan)

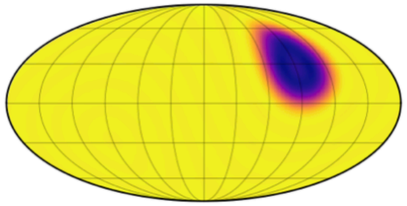
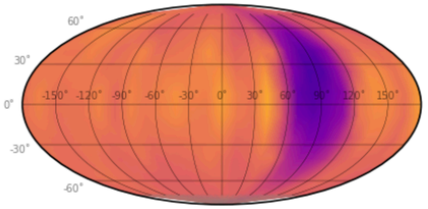
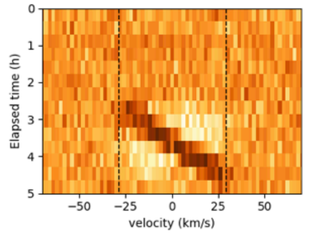




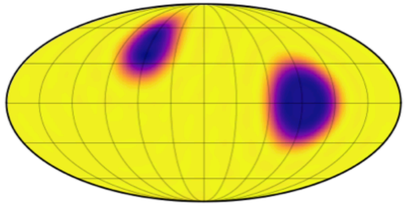
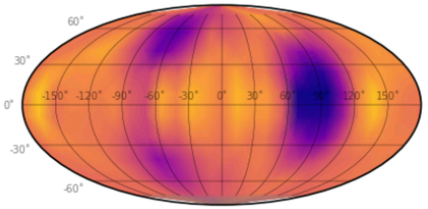
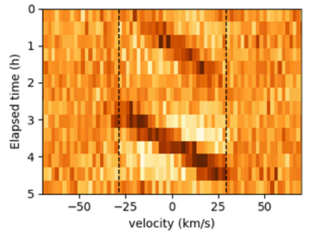
Interpretation with simulated maps

injected map | recovered map | deviations

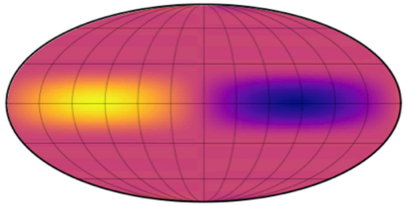
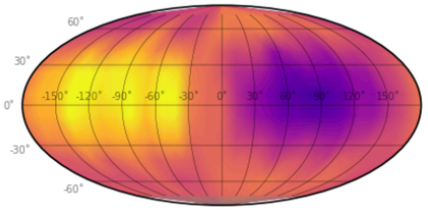
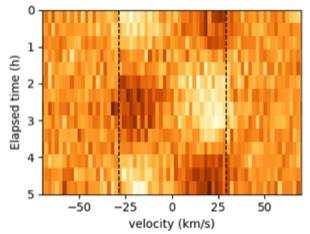
1 spot

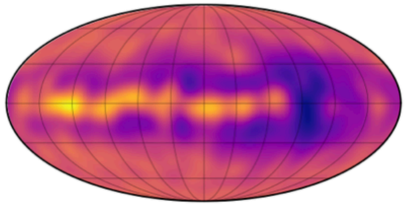
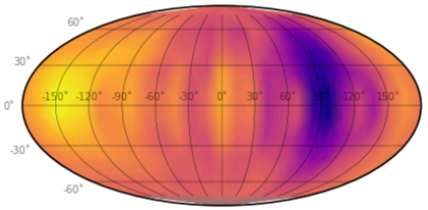
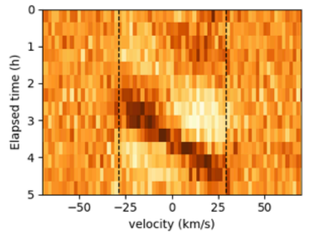
2 spots

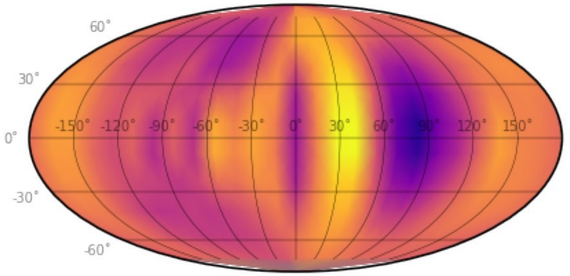
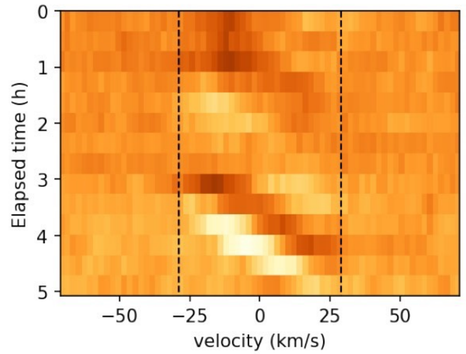
planetary wave

3D GCM
(cr. Xianyu Tan)

observed map for B

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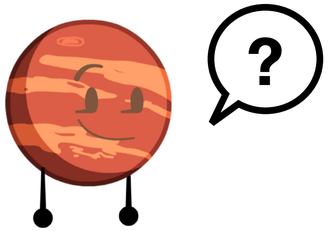
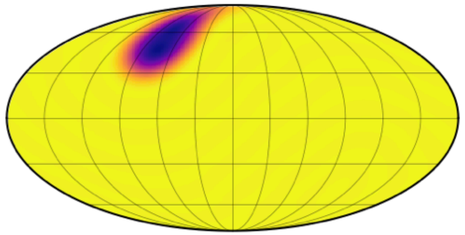
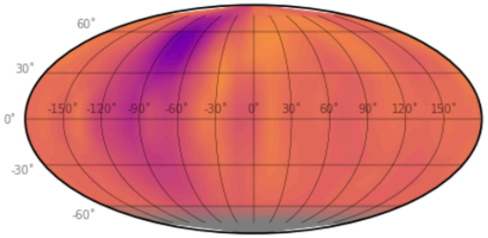
Simulation for WISE 1049A

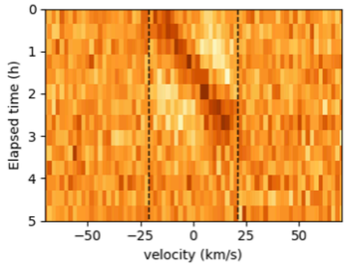


injected map | recovered map | deviations

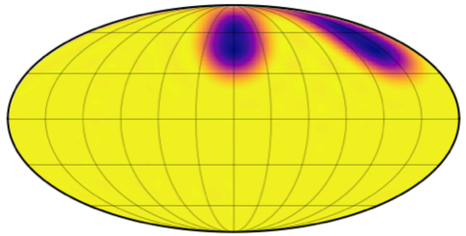
Feb 11
1 spot

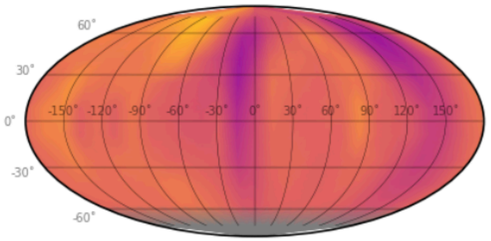


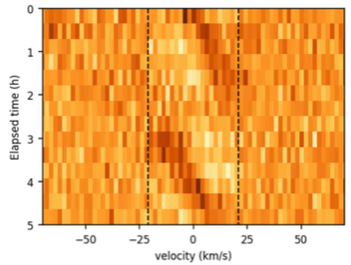




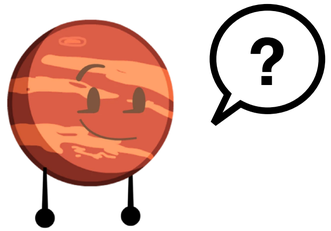
Feb 09
2 spots

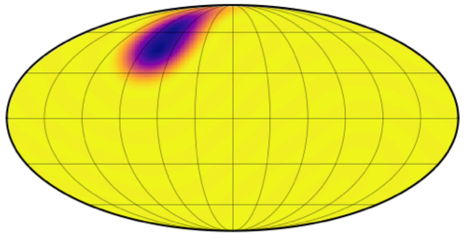
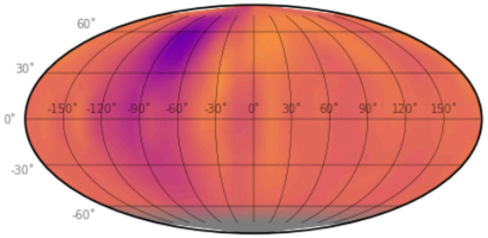
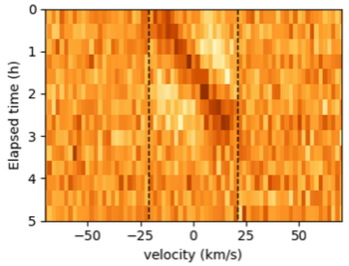
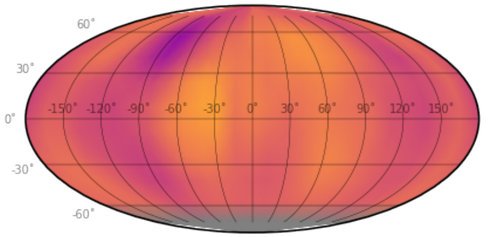
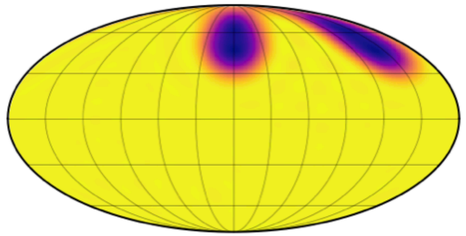
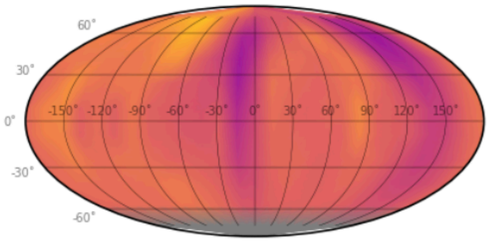
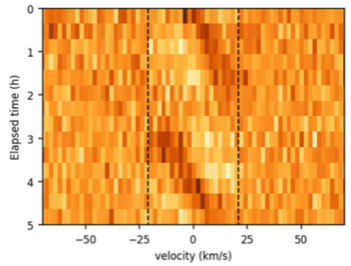
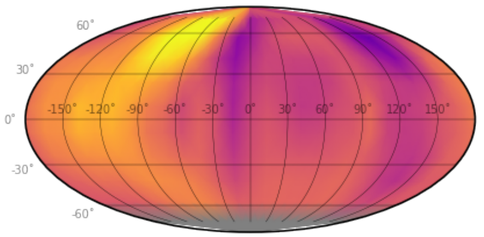






Simulation for WISE 1049A



	injected map	recovered map	deviations	observed map A
Feb 11 1 spot				
Feb 09 2 spots				

Summary

- What are the **morphologies** of atmospheric structures? Spots, planetary waves, or both?

- What are the **timescales** of the evolution of atmospheric structures?

- What are the **physical mechanisms** driving photometric variability? Clouds, hotspots caused by chemical disequilibrium, or both?

Summary

- What are the **morphologies** of atmospheric structures? Spots, planetary waves, or both?

  We found persistent spot-like feature on WISE1049B and new polar spots on A. Our maps shows preferred length scales of atmospheric structures. The method is mainly sensitive to spots, but likely both are present.

- What are the **timescales** of the evolution of atmospheric structures?

  Similar structure stayed over days, possible stable or recurring structure over years.

- What are the **physical mechanisms** driving photometric variability? Clouds, hotspots caused by chemical disequilibrium, or both?

  Clouds must be involved in the dark patches probed.


BDs are cool, but what about exoplanets?
Dozens of brown dwarfs and
a few directly-imaged exoplanets
wil be mappable with 30-m ELTs!
PG 18

Stay tuned…

Global weather map reveals persistent top-of-atmosphere features on the nearest brown dwarfs

Xueqing Chen,[1,2]★ Beth A. Biller,[1,2] Johanna M. Vos,[3] Ian J. M. Crossfield,[4] Gregory N. Mace,[5] Callie E. Hood,[6] Xianyu Tan,[7,8] Katelyn N. Allers[9], Emily C. Martin[6], Emma Bubb,[1,2] Jonathan J. Fortney,[6] Caroline V. Morley,[5] Mark Hammond[10]

and thank you!