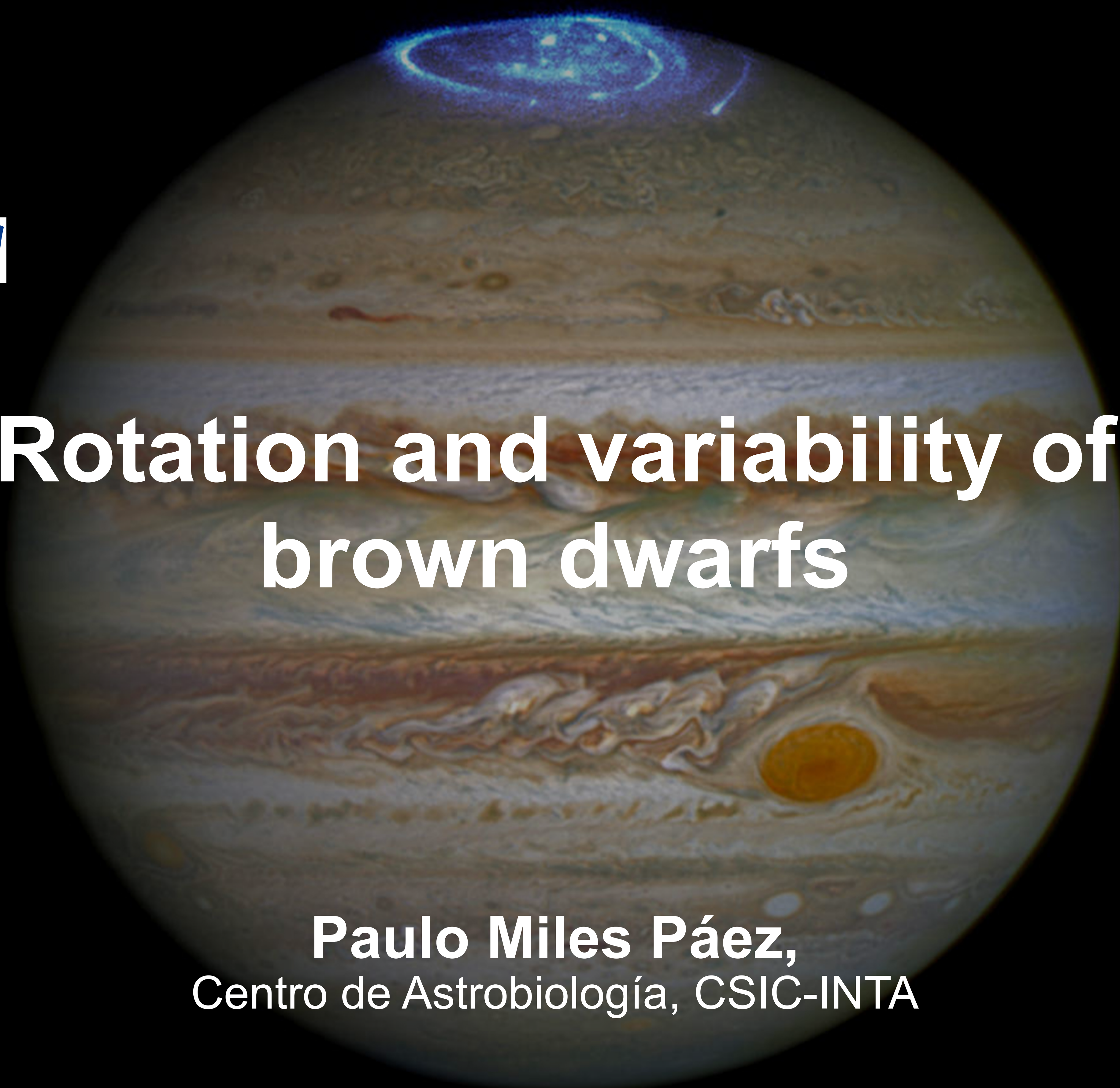


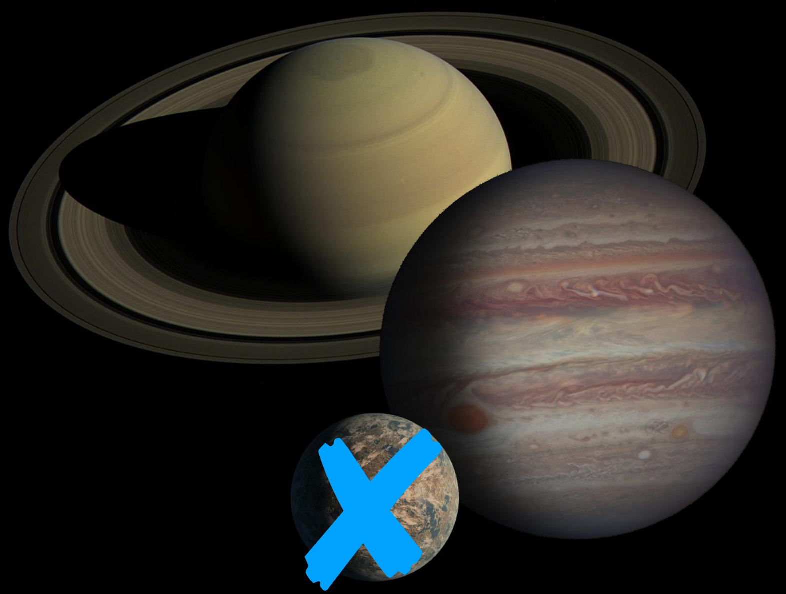
Rotation and variability of brown dwarfs

Paulo Miles Páez,
Centro de Astrobiología, CSIC-INTA

Brown Dwarfs Keep Their Cool: 30 year of substellar science. La Gomera, 2 September 2025

Ultra-cool dwarfs

Giant Exoplanets



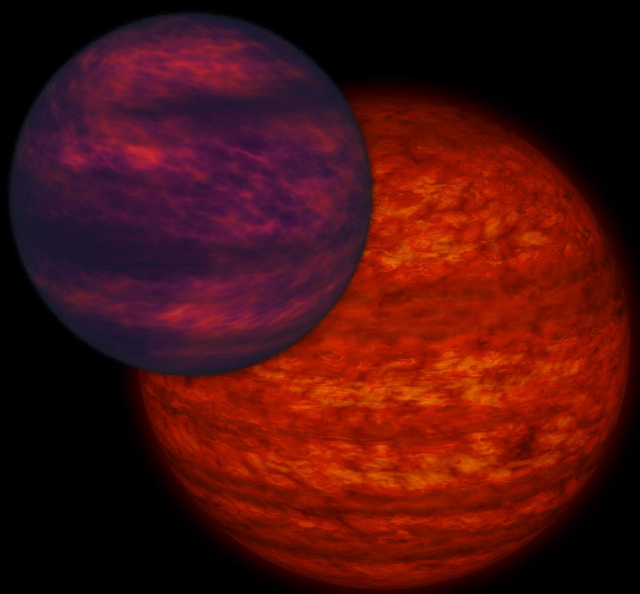
For solar metallicity →

Up to ~13x

Jupiter's mass

(not always orbiting a more massive companion)

Brown Dwarfs



~13x-72x

Jupiter's mass

Very low-mass stars

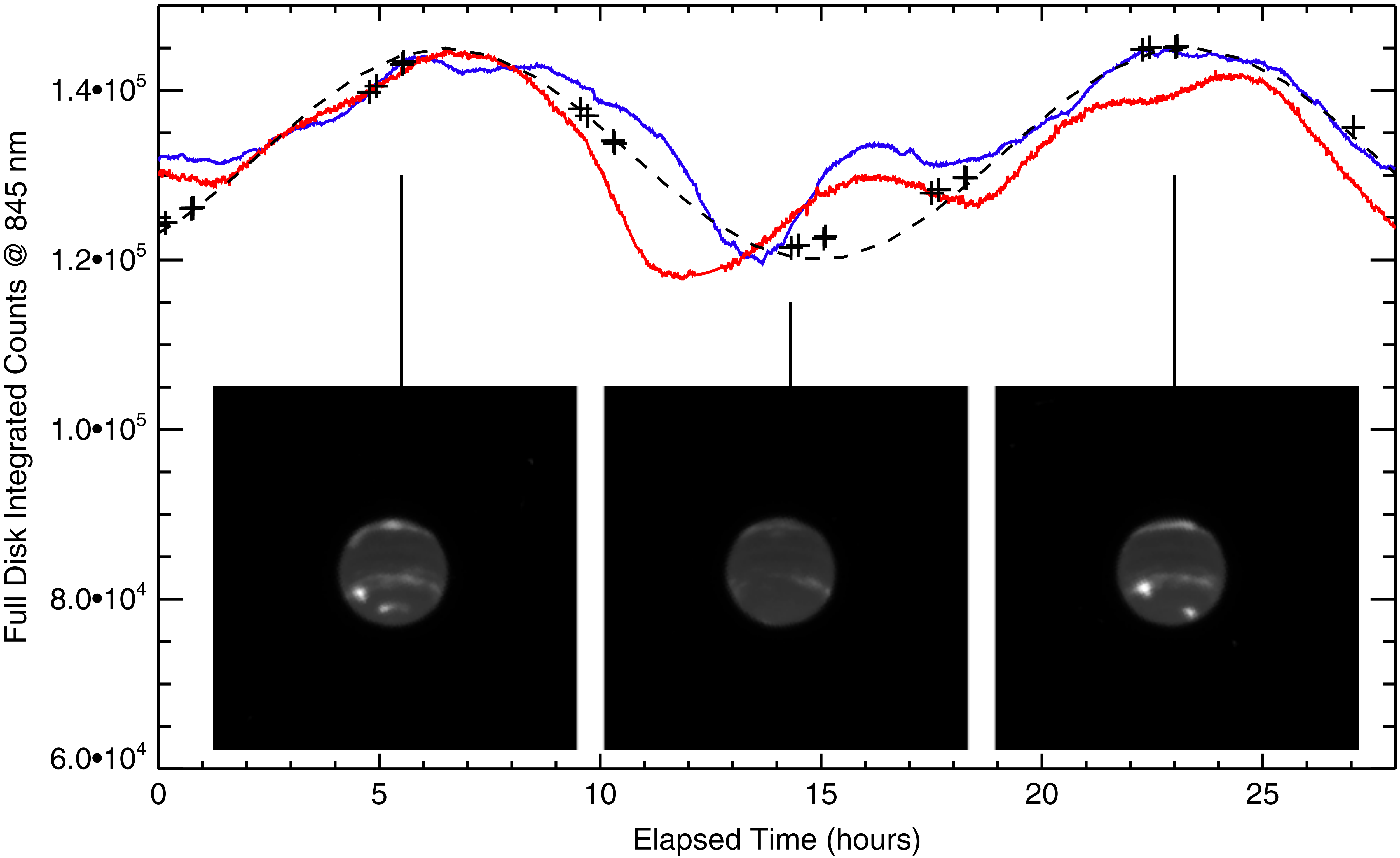
(Fueled by Nuclear Fusion)

72x-80x

Jupiter's mass

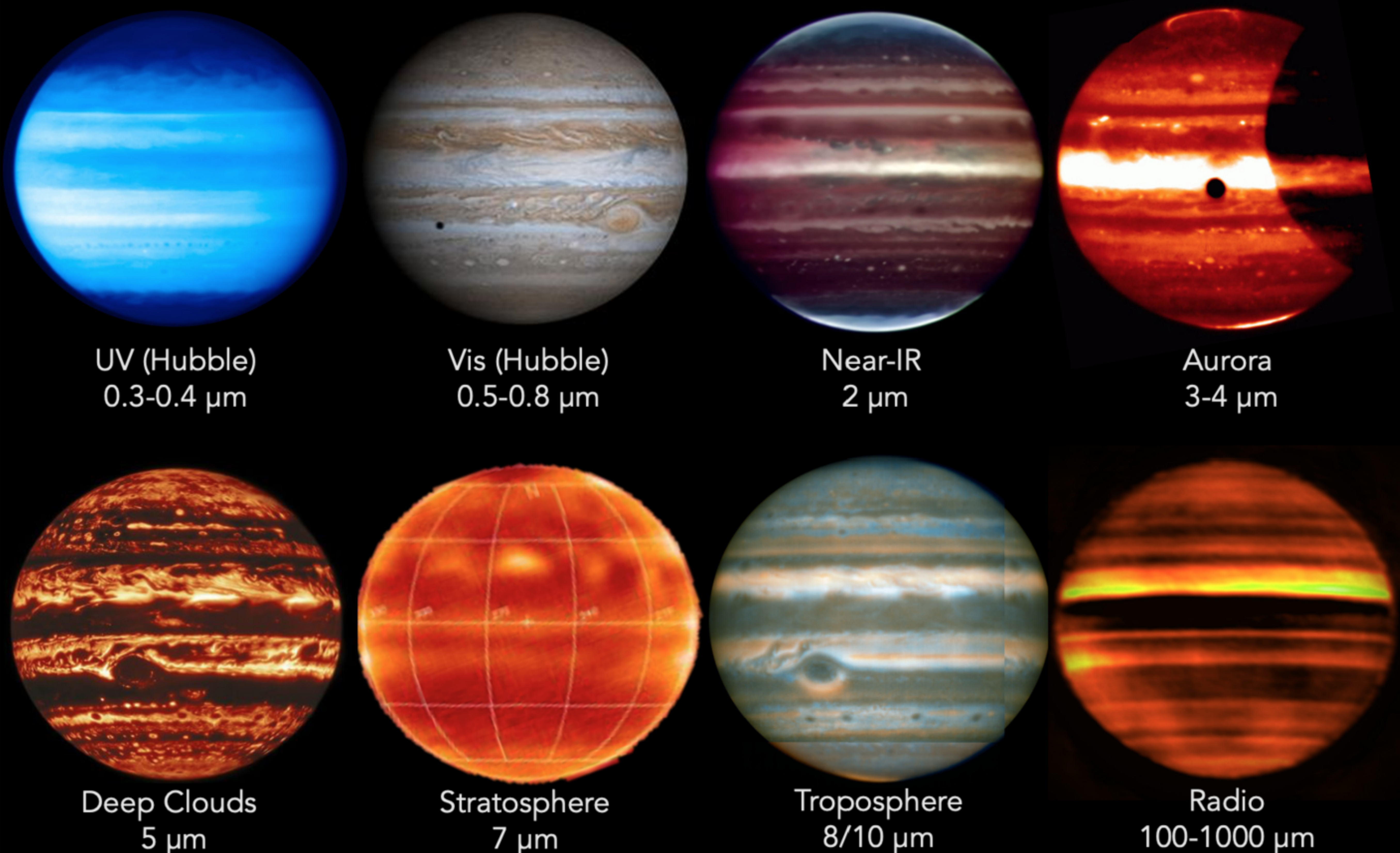
Credit: NASA/Caltech/R. Hurt

Variability monitoring to probe weather in unresolved worlds



Simon et al. (2016)

Every Wavelength Tells a Tale



(Fletcher et al. 2023)

The Pioneering Years: Optical Hints

Evolution of dusty photospheres through red to brown dwarfs: how dust forms in very low mass objects (1996)

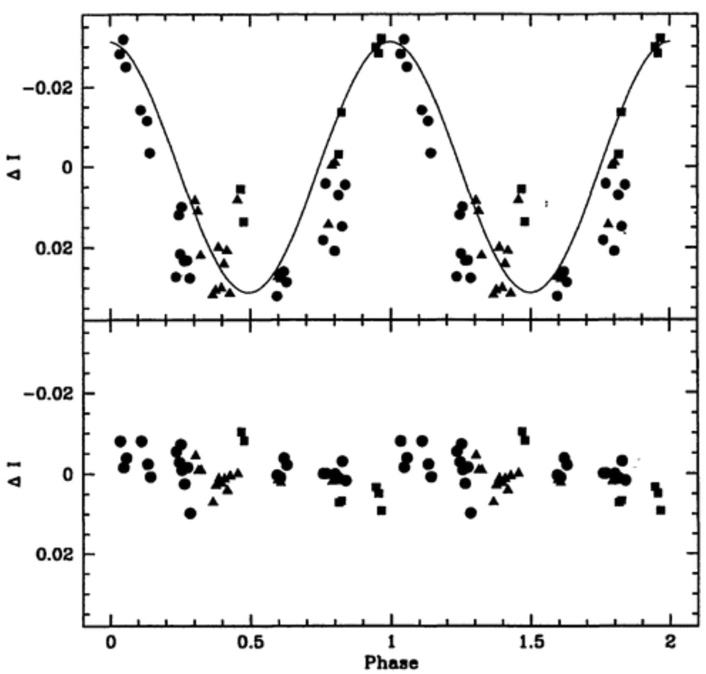
T. Tsuji[1], K. Ohnaka[1], W. Aoki[1], and T. Nakajima[2]

Then, a fog of corundum or of other Al-containing mineral such as sapphire will appear, clouds of iron or silicate may be formed, and even rain (but not of water!) may fall in real dusty photospheres.

... and planets. Now the method of meteorology should be extended to stellar and substellar atmospheres.

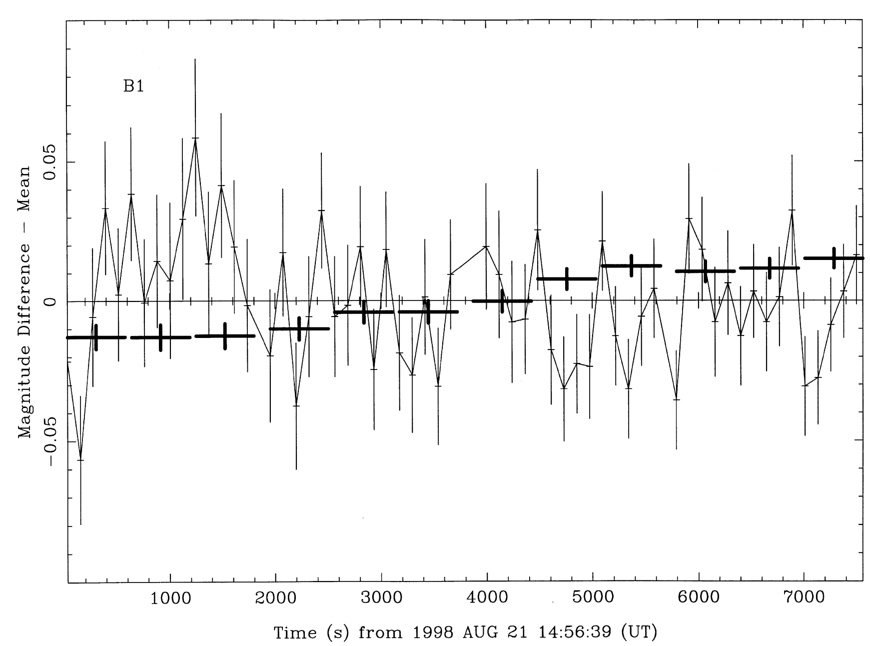
The rotation period of a very low-mass star in α Persei

E L. Martín and M. R. Zapatero-Osorio (1997)



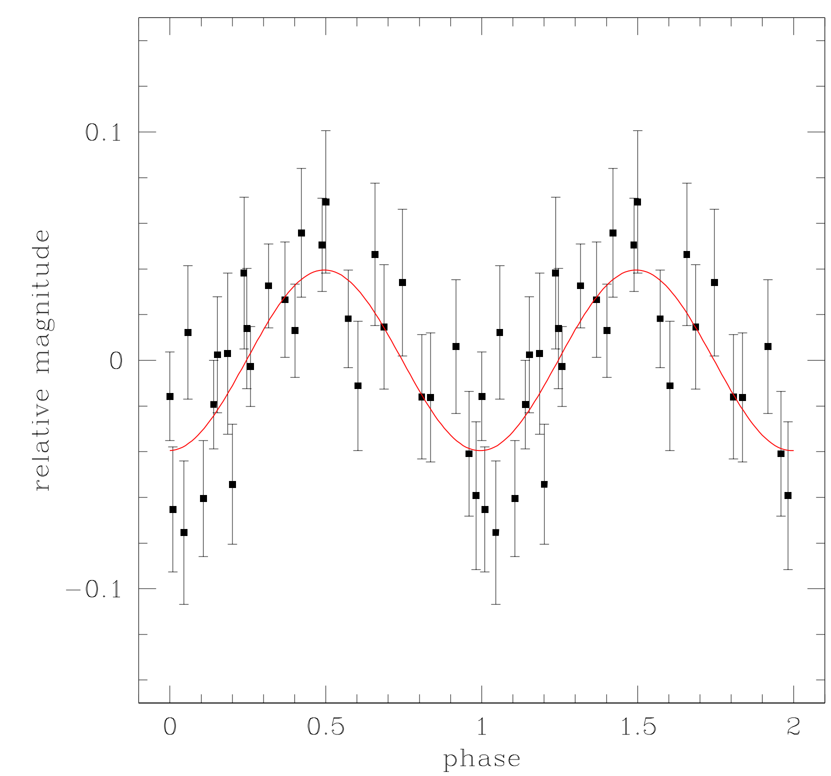
Searching for weather in brown dwarfs

C. G. Tinney[1★] and A. J. Tolley[1,2] (1999)



A search for variability in brown dwarfs and L dwarfs

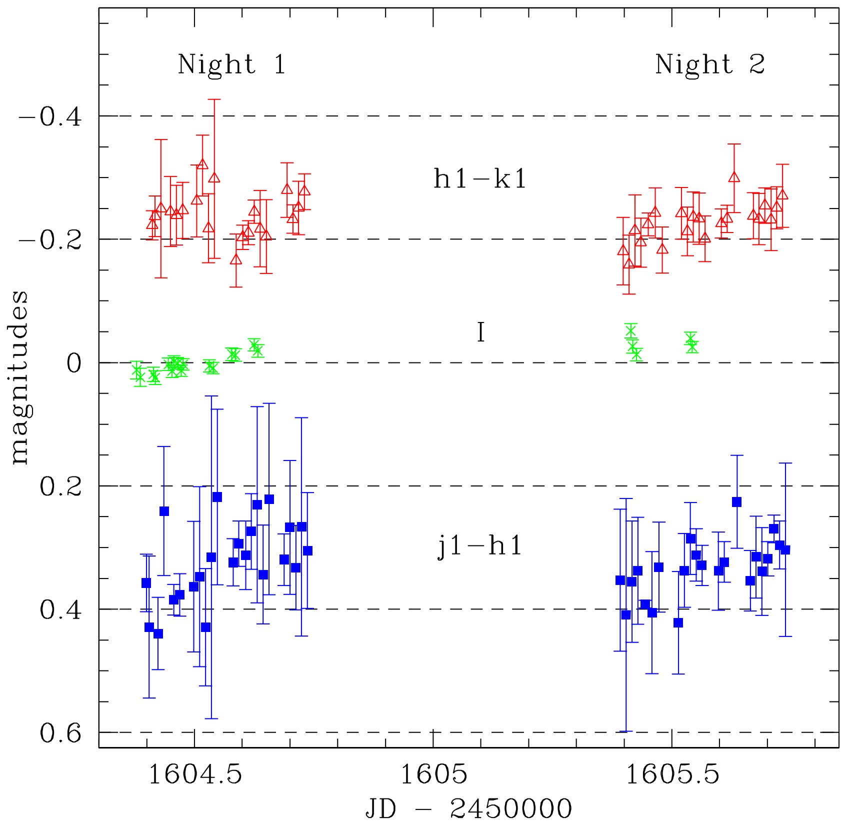
C.A.L. Bailer-Jones and R. Mundt (1999)



Early multi-wavelength studies

Dust clouds or magnetic spots? Exploring the atmospheres of L dwarfs with time-resolved spectrophotometry

C. A. L. Bailer-Jones* (2002)



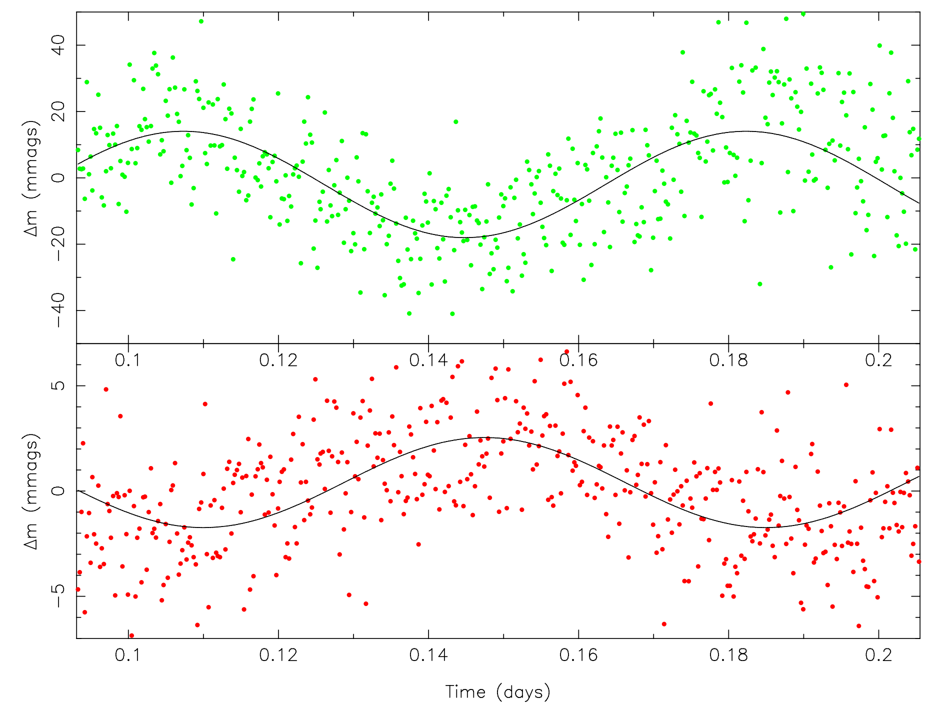
***JHK*$_s$ time-series observations of a few ultracool dwarfs**

C. Koen,[1,2]★ T. Tanabé,[3] M. Tamura[4] and N. Kusakabe[5] (2005)

The M8.5 object SSSPM J0109-5101 has recently been shown to be both a periodic and a flaring variable, based on optical observations in the extreme red. More than 16 h of monitoring in the near-infrared (NIR) reported here failed to show any variability.

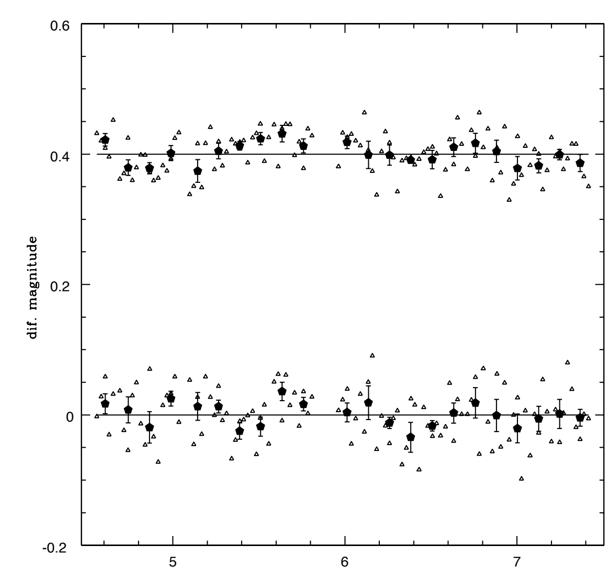
Optical variability of the ultracool dwarf TVLM 513-46546: evidence for inhomogeneous dust clouds★ (2008)

S. P. Littlefair,[1]† V. S. Dhillon,[1] T. R. Marsh,[2] T. Shahbaz,[3] E. L. Martín[3,4] and C. Copperwheat[2]



VARIABILITY IN BROWN DWARFS: ATMOSPHERES AND TRANSITS

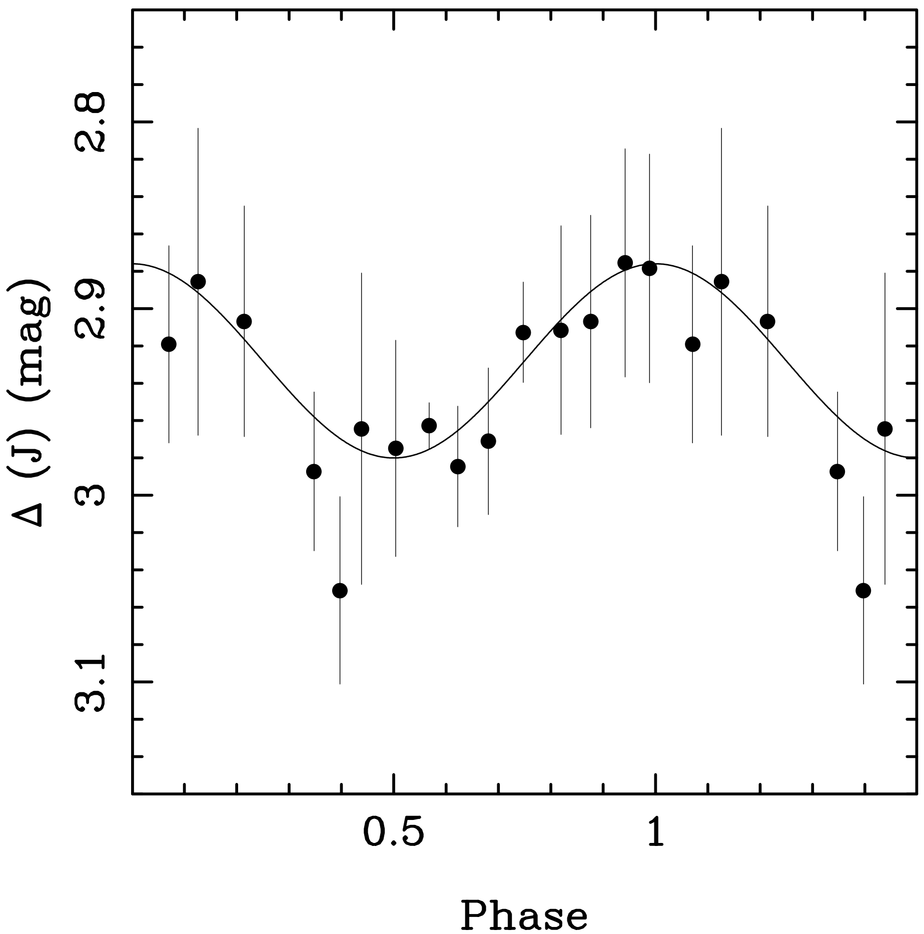
J. A. Caballero[1,2] and R. Rebolo[1,3] (2002)



Variability in Young Brown Dwarfs

Photometric variability of a young, low-mass brown dwarf★

M. R. Zapatero Osorio[1], J. A. Caballero[2], V. J. S. Béjar[2], and R. Rebolo[2,3] (2003)

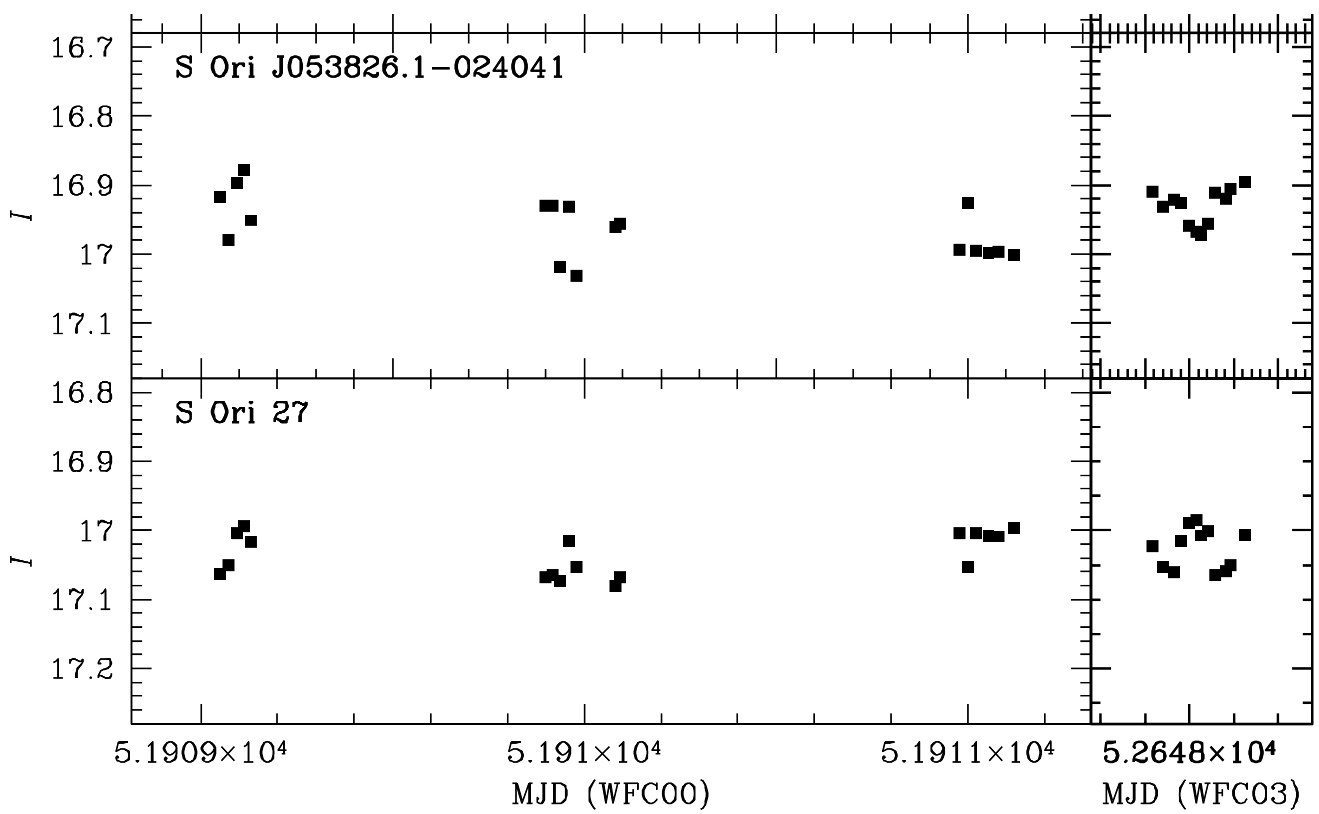


S Ori 45 (M8.5, ~20 M_{Jup})
P_{rot} = 2.5-3.6 h

Also, an intriguing ~46 min variability. Hints for pulsations due to deuterium burning? See Palla & Baraffe (2005)

Photometric variability of young brown dwarfs in the σ Orionis open cluster (2004)

J. A. Caballero[1], V. J. S. Béjar[1], R. Rebolo[1,2], and M. R. Zapatero Osorio[3]

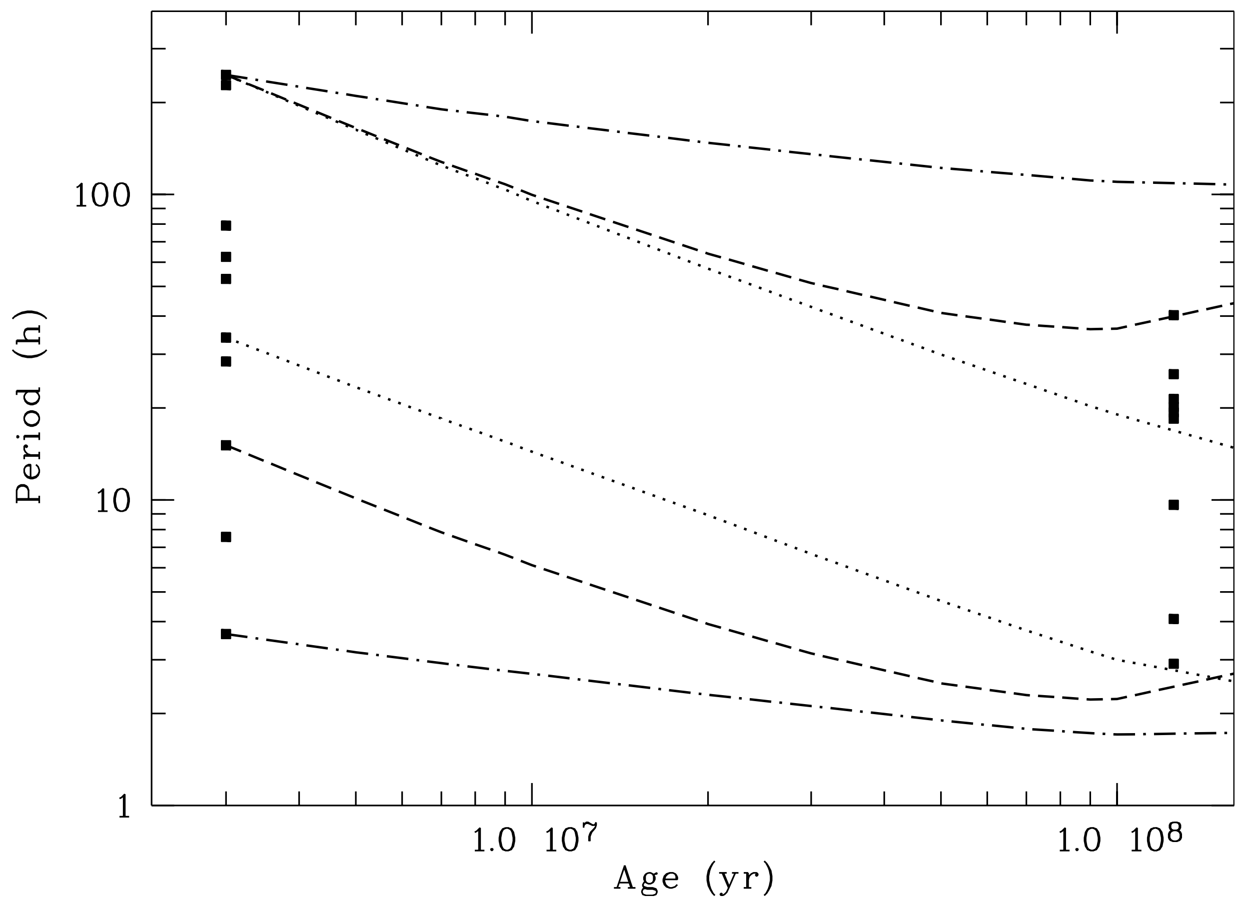


30 Dec 2000 - 01 Jan 2001 08 Jan 2003

Rotation Statistics & Angular Momentum Evolution Studies

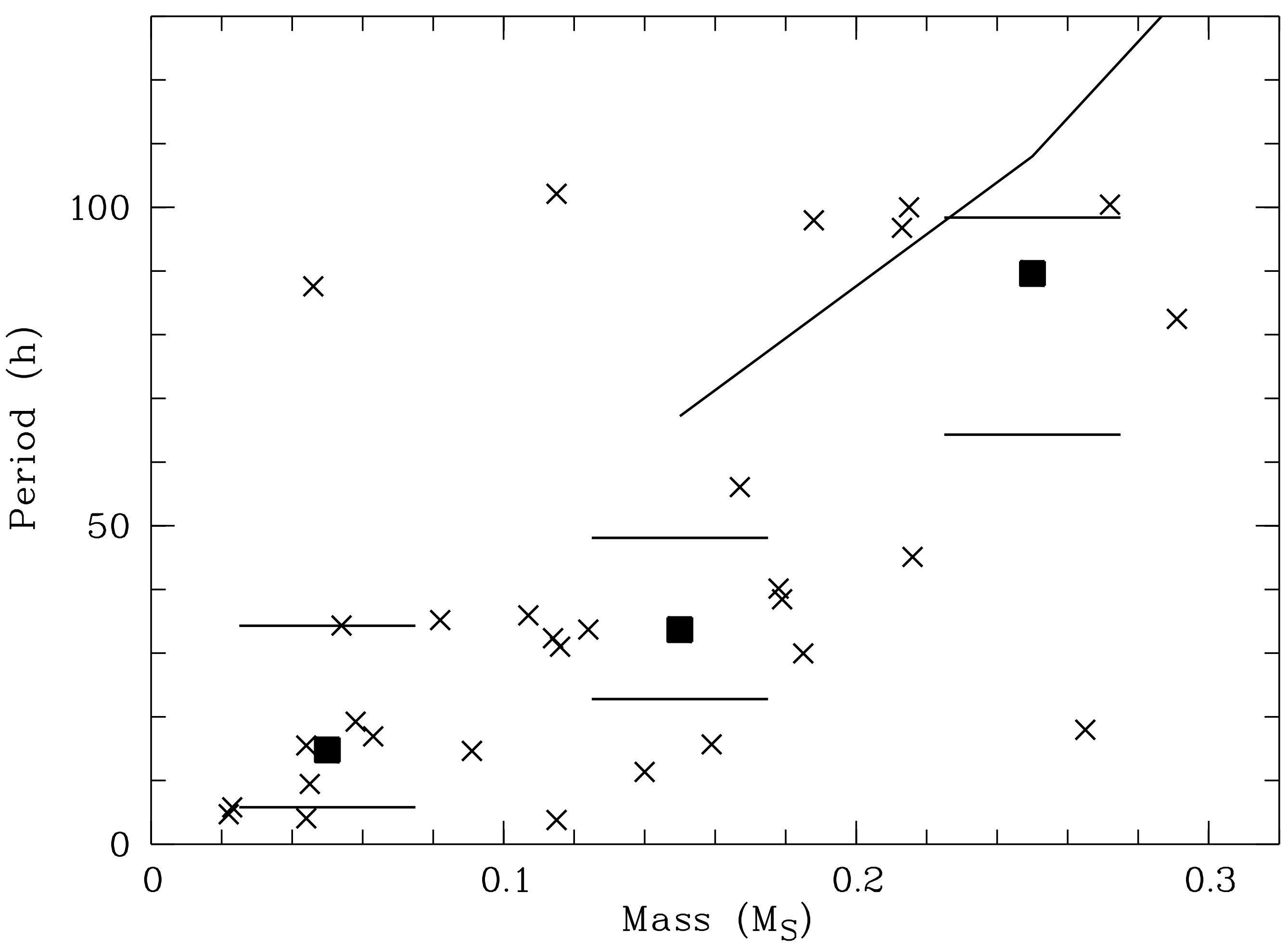
Rotation periods for very low mass stars in the Pleiades

A. Scholz* and J. Eislöffel (2004)



Rotation and variability of very low mass stars and brown dwarfs near ϵ Ori*

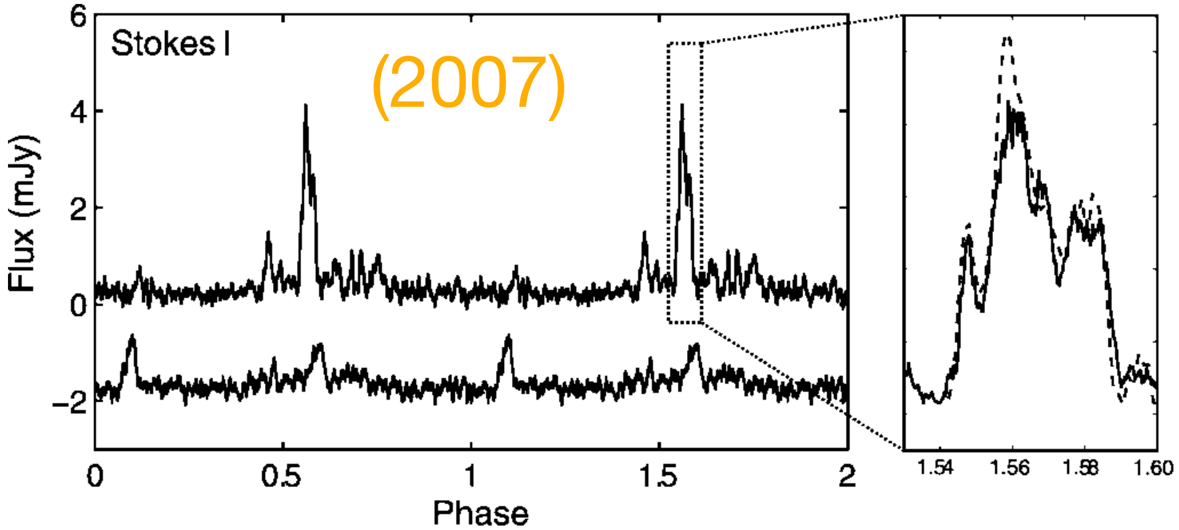
A. Scholz and J. Eislöffel (2005)



Across the Spectrum: Optical, Infrared… and Radio

PERIODIC BURSTS OF COHERENT RADIO EMISSION FROM AN ULTRACOOL DWARF

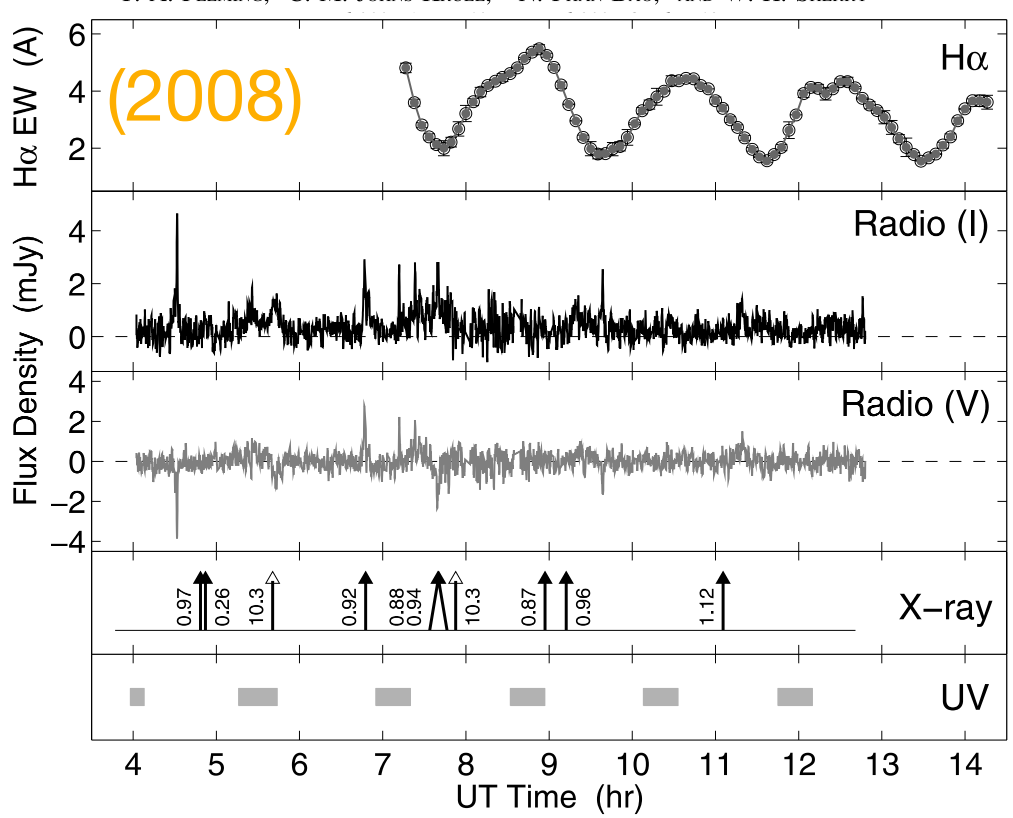
G. Hallinan,[1] S. Bourke,[1] C. Lane,[1] A. Antonova,[2] R. T. Zavala,[3] W. F. Brisken,[4] R. P. Boyle,[5] F. J. Vrba,[3] J. G. Doyle,[2] and A. Golden[1]



Variability is everywhere and it has many origins.

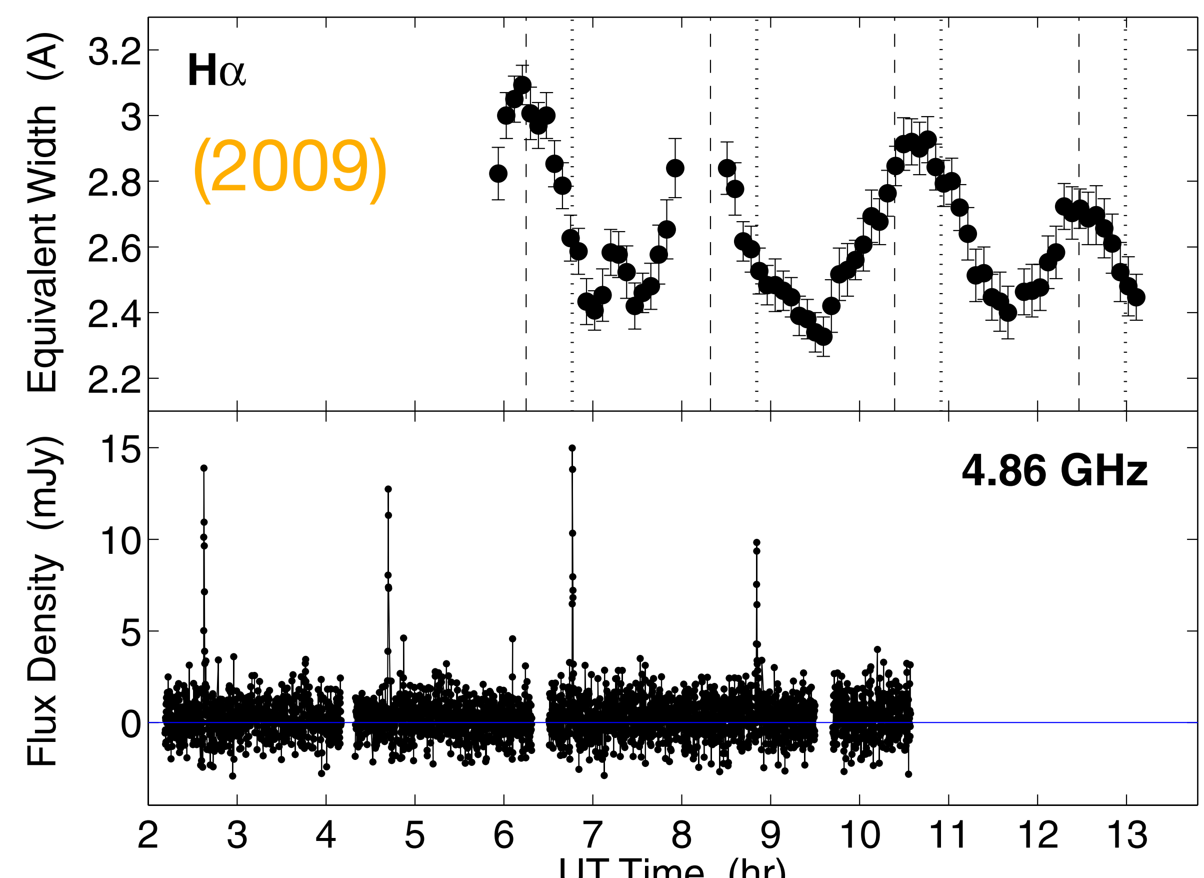
SIMULTANEOUS MULTIWAVELENGTH OBSERVATIONS OF MAGNETIC ACTIVITY IN ULTRACOOL DWARFS. I. THE COMPLEX BEHAVIOR OF THE M8.5 DWARF TVLM 513−46546

E. Berger,[1,2,3] J. E. Gizis,[4] M. S. Giampapa,[5] R. E. Rutledge,[6] J. Liebert,[7] E. Martín,[8,9] G. Basri,[10] T. A. Fleming,[7] C. M. Johns-Krull,[11] N. Phan-Bao,[9] and W. H. Sherry[5]



PERIODIC RADIO AND Hα EMISSION FROM THE L DWARF BINARY 2MASSW J0746425+200032: EXPLORING THE MAGNETIC FIELD TOPOLOGY AND RADIUS OF AN L DWARF

. Berger[1], R. E. Rutledge[2], N. Phan-Bao[3], G. Basri[4], M. S. Giampapa[5], J. E. Gizis[6], J. Liebert[7], E. Martín[8,9], and T. A. Fleming[7]



When the Eye Needs Help: Variability Detection Tools

LEAST-SQUARES FREQUENCY ANALYSIS OF UNEQUALLY SPACED DATA

N. R. LOMB (1976)
School of Physics, University of Sydney, N.S.W., Australia

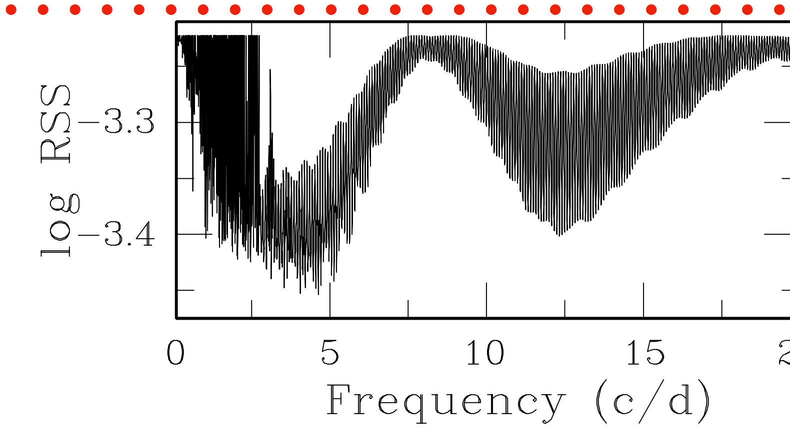
PERIOD DETERMINATION USING PHASE DISPERSION MINIMIZATION

R. F. STELLINGWERF
Department of Physics and Astronomy, Rutgers University (1978)

STUDIES IN ASTRONOMICAL TIME SERIES ANALYSIS. II. STATISTICAL ASPECTS OF SPECTRAL ANALYSIS OF UNEVENLY SPACED DATA

JEFFREY D. SCARGLE (1982)
Theoretical and Planetary Studies Branch, Space Science Division, Ames Research Center, NASA

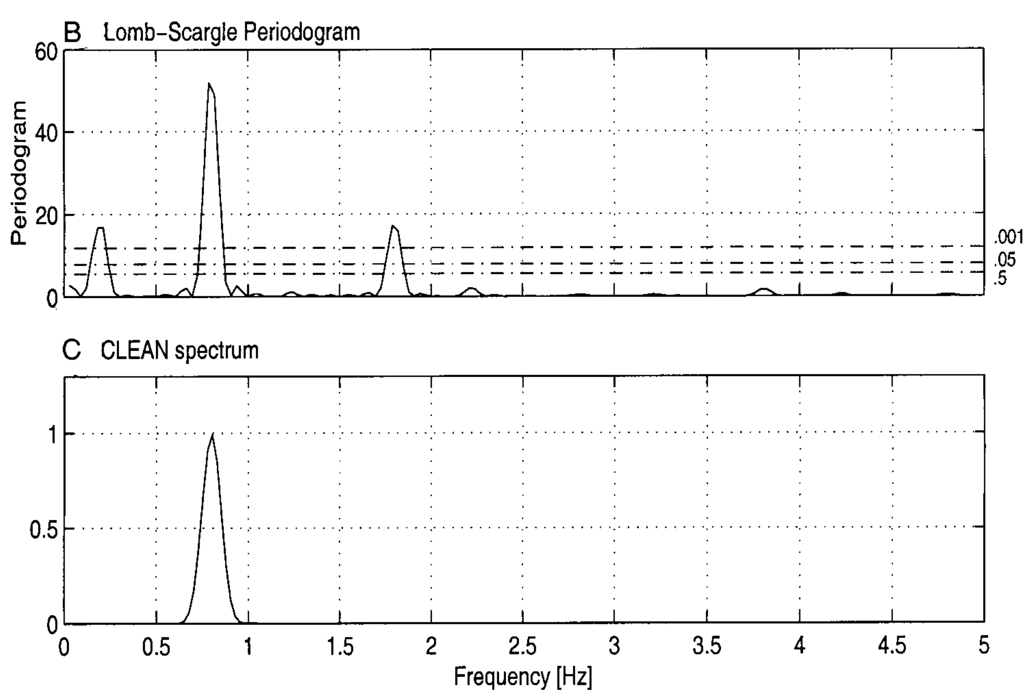
Residual sum-of-squares periodogram (Koen 2003)



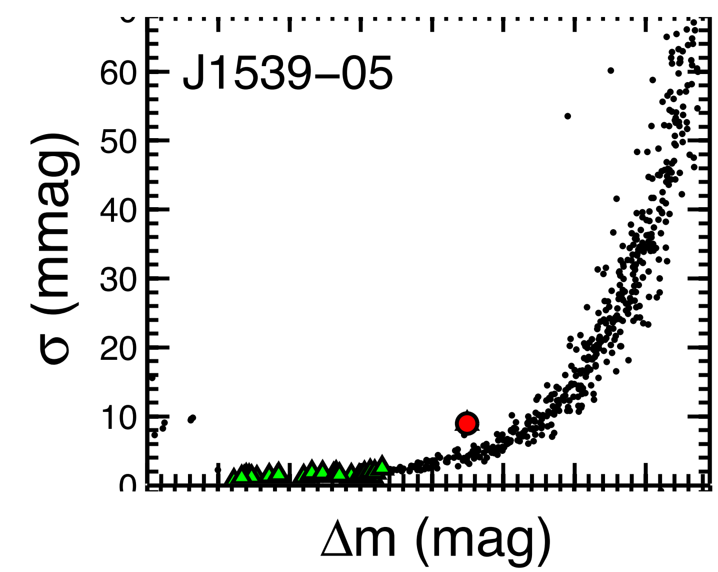
TIME SERIES ANALYSIS WITH CLEAN. I. DERIVATION OF A SPECTRUM

DAVID H. ROBERTS
Physics Department, Brandeis University, Waltham, Massachusetts 02254
JOSEPH LEHÁR AND JOHN W. DREHER
Physics Department, 26-315, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

(1987)

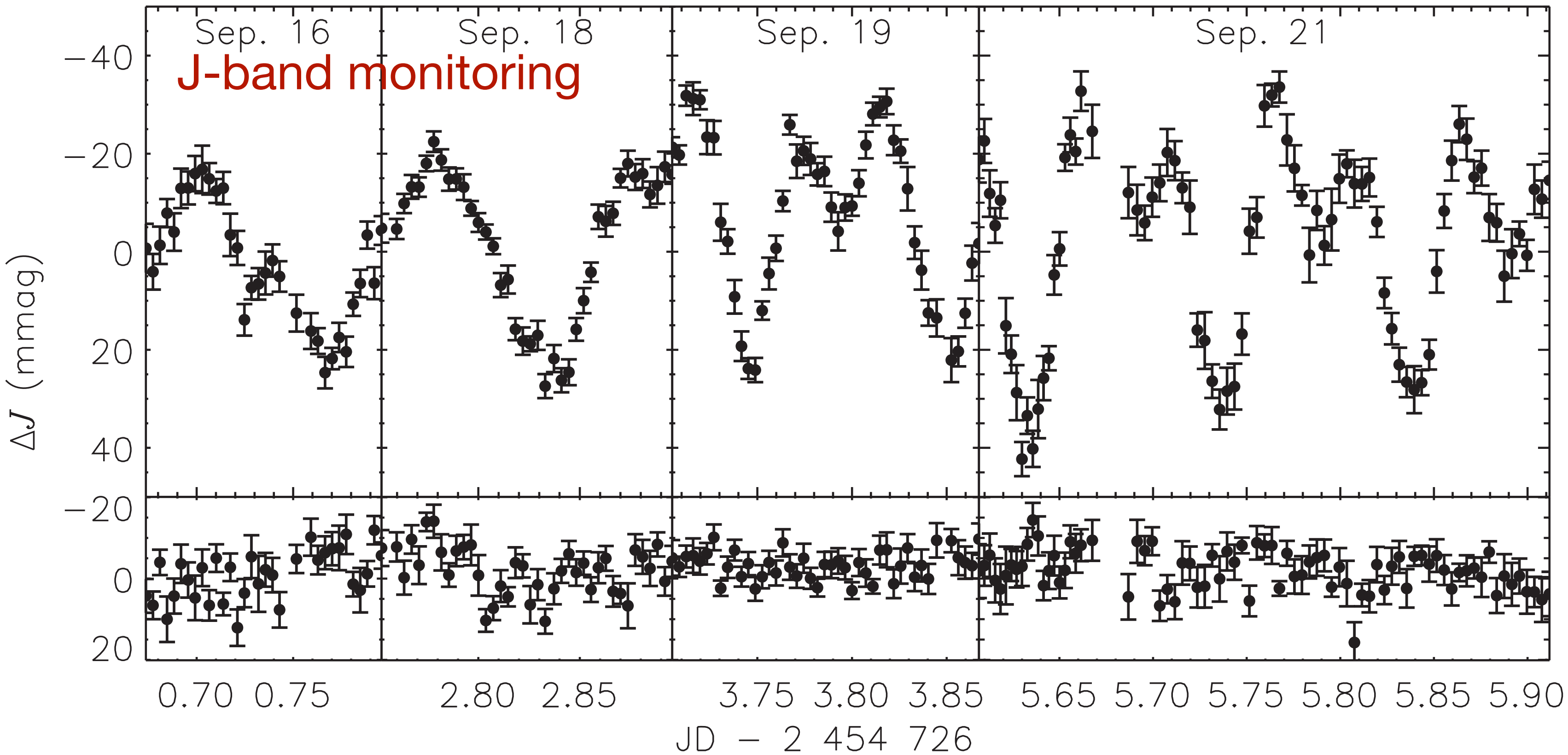


Comparison with field stars (several works)



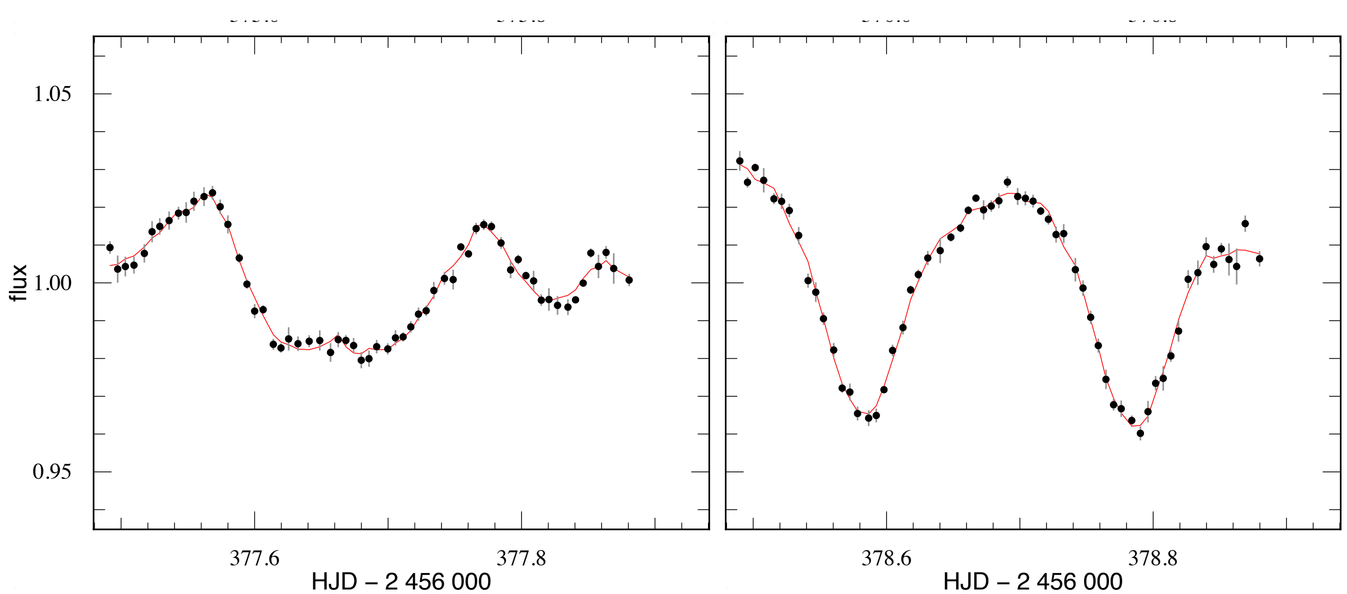
More recently:
Principal Component Analysis
Gaussian process regression

Infrared Breakthroughs: SIMP J0136+0933 (T2.5)

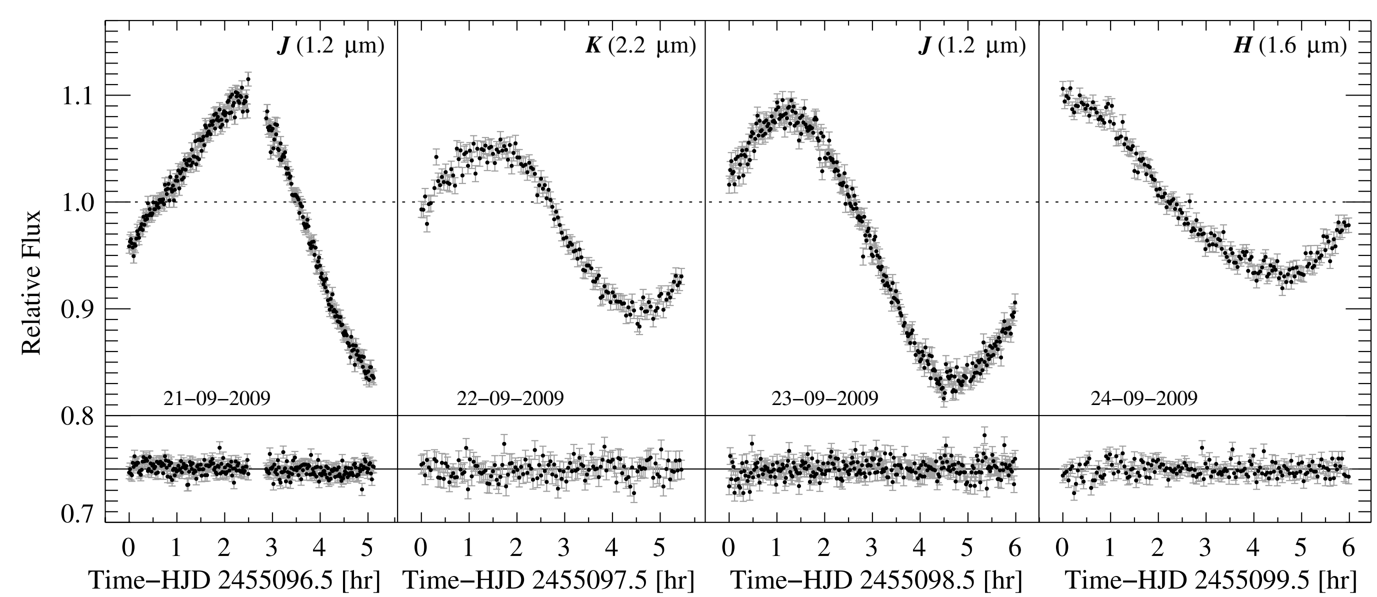


Artigau et al. (2009)

- Light curve shape varies on a timescale of days.
- Evidence for fragmentation of dust clouds at the L/T transition.
- Variability amplitudes > 1%

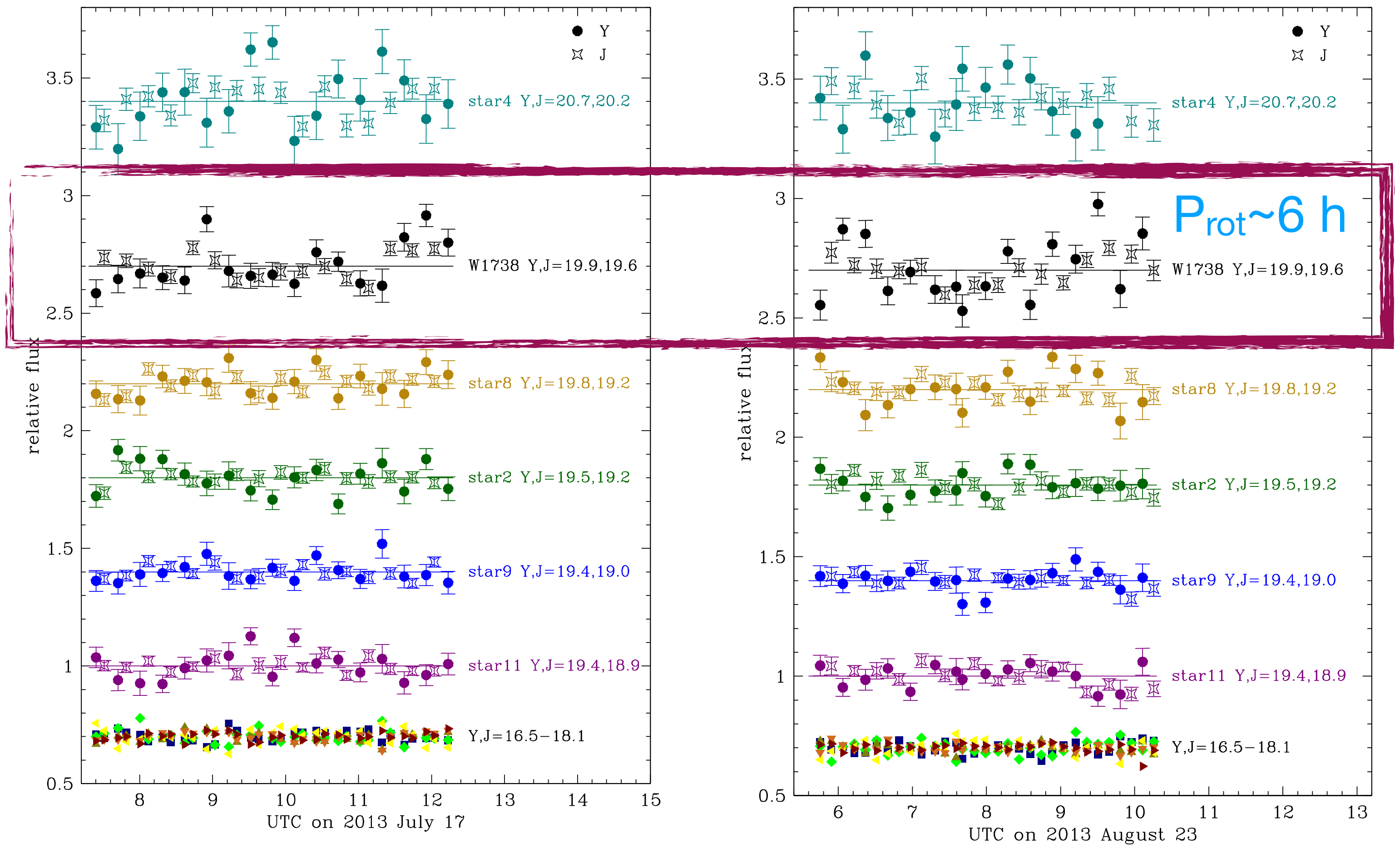


Luhman 16B (T1.5; Gillon et al. 2013)



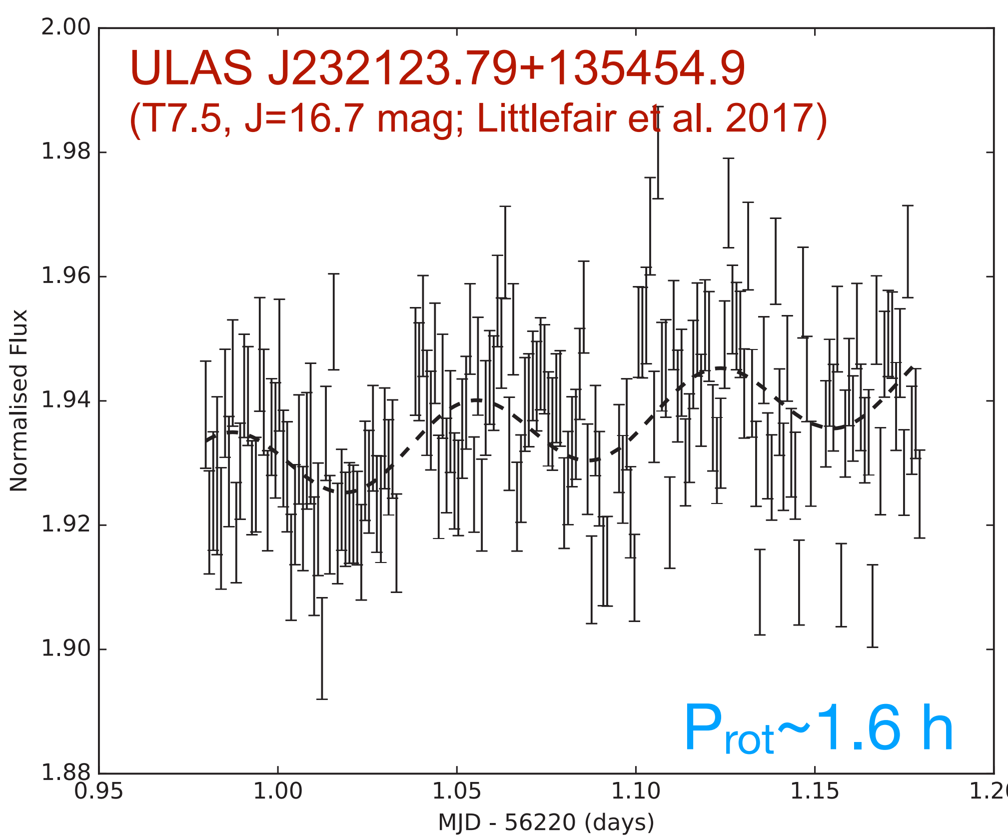
2MASS J21392676+0220226 (T1.5; Radigan et al. 2012)

Pushing Fainter: Late-Ts and Ys

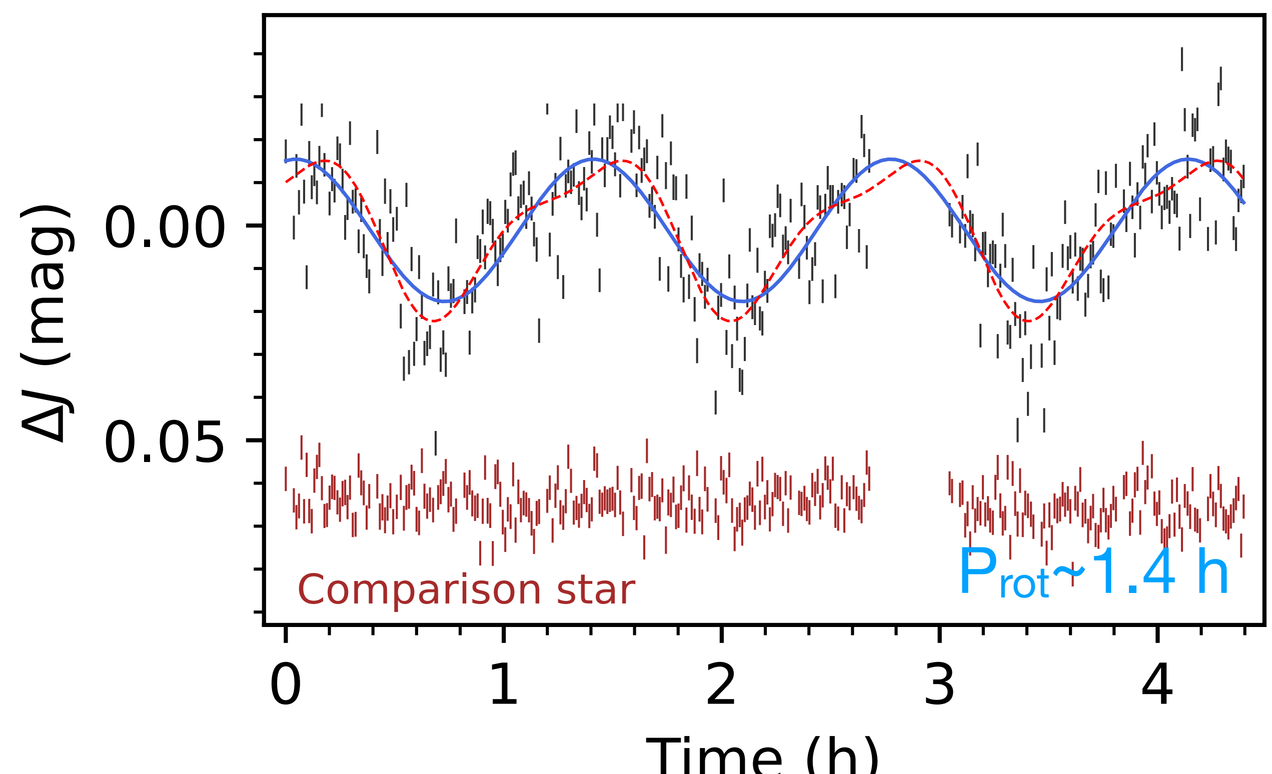


WISEP J173835.52+273258.9
(Y0, J=19.8; Leggett et al. 2016)

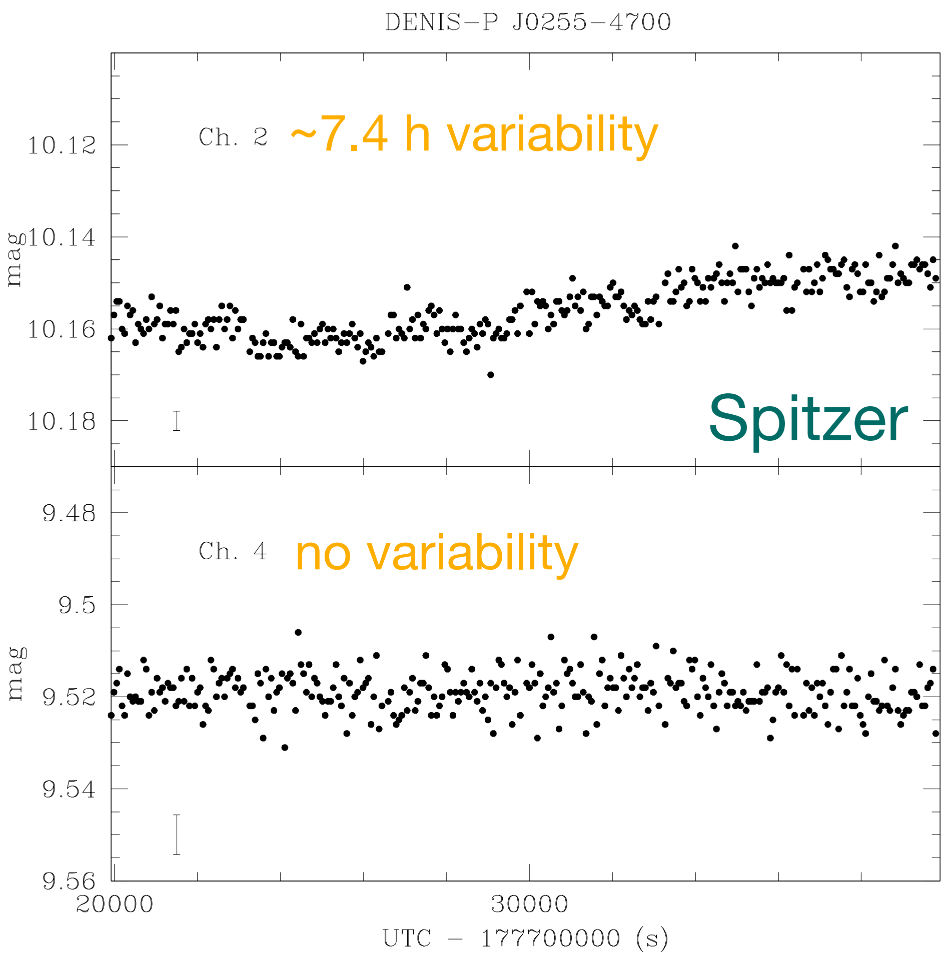
- Typically > 16 mag.
- Variability amplitudes < 1%
- 8-m class telescopes or space telescopes needed.



EQ J1959-3338
(T8, J=16.8; Miles-Páez et al. 2025)

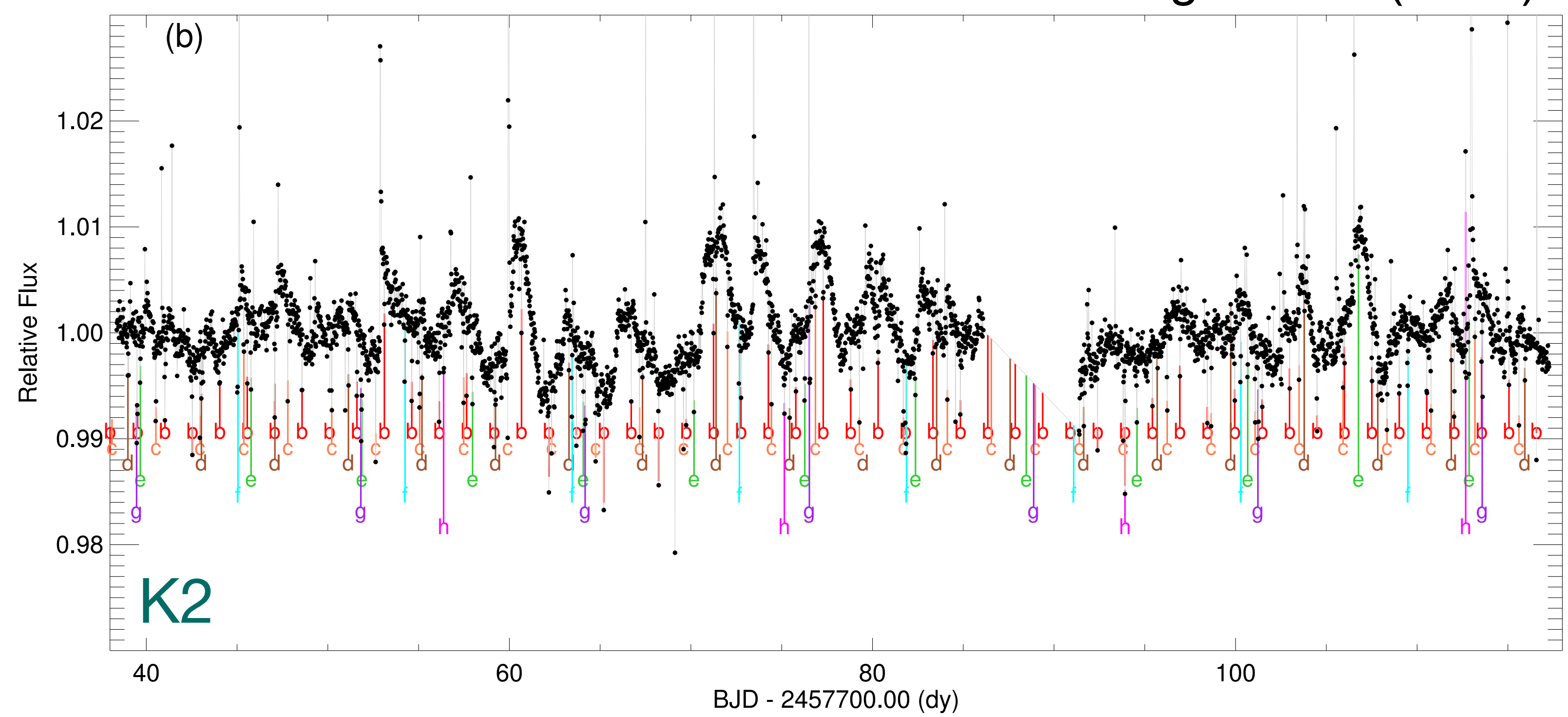


Space Telescopes Join the Hunt!



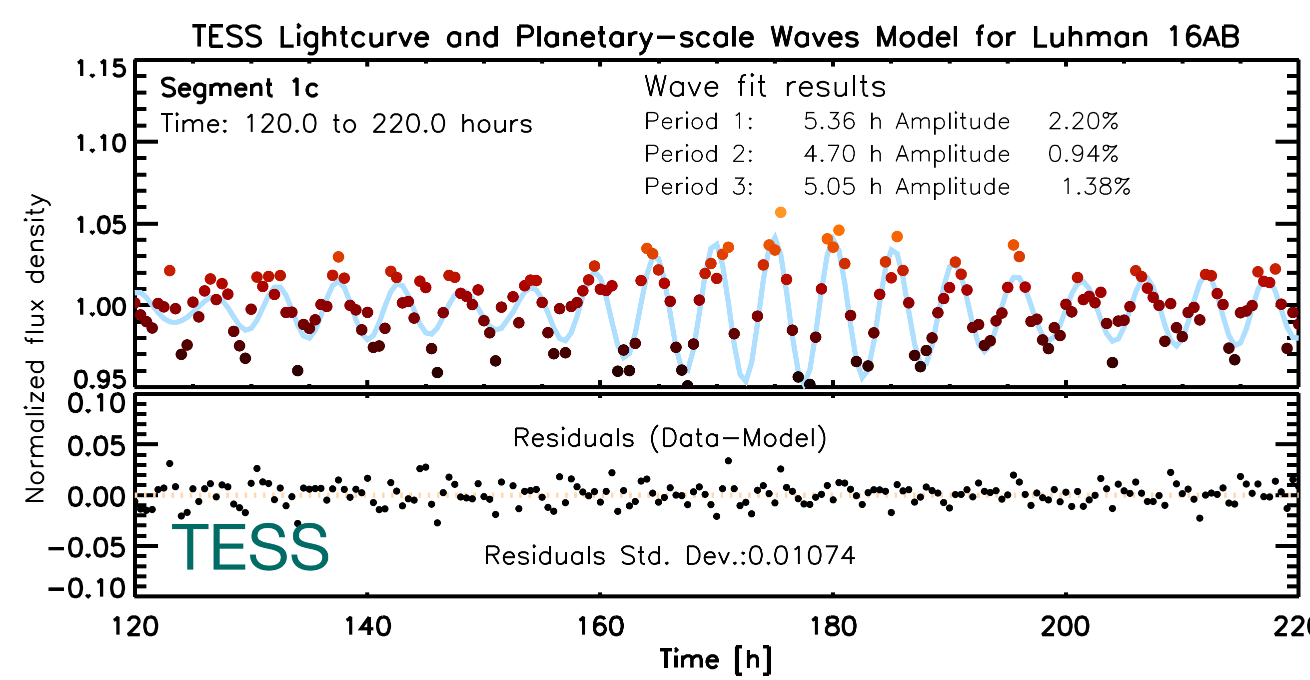
Morales-Calderón et al. (2006)

Luger et al. (2017)



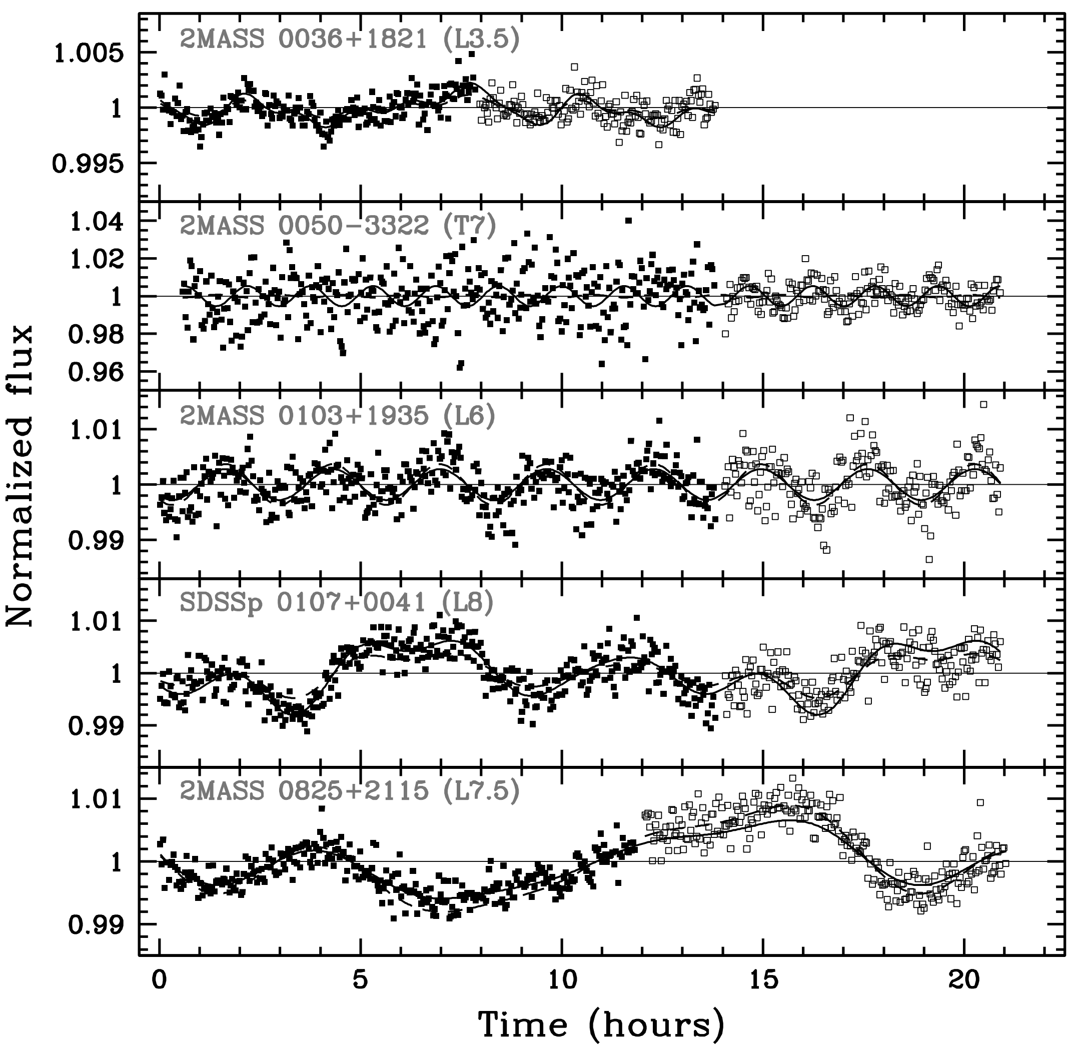
Variability studies in young regions:

- Scholz et al. (2018): K2 + Taurus
- Rebull, et al., (2020): TESS + Taurus
- Kumbhakar, et al., (2023): TESS + Taurus
- Ghosh, et al., (2024): TESS + IC 348
- Lambier et al., (2025): TESS + ABDMG, Argus, Carina

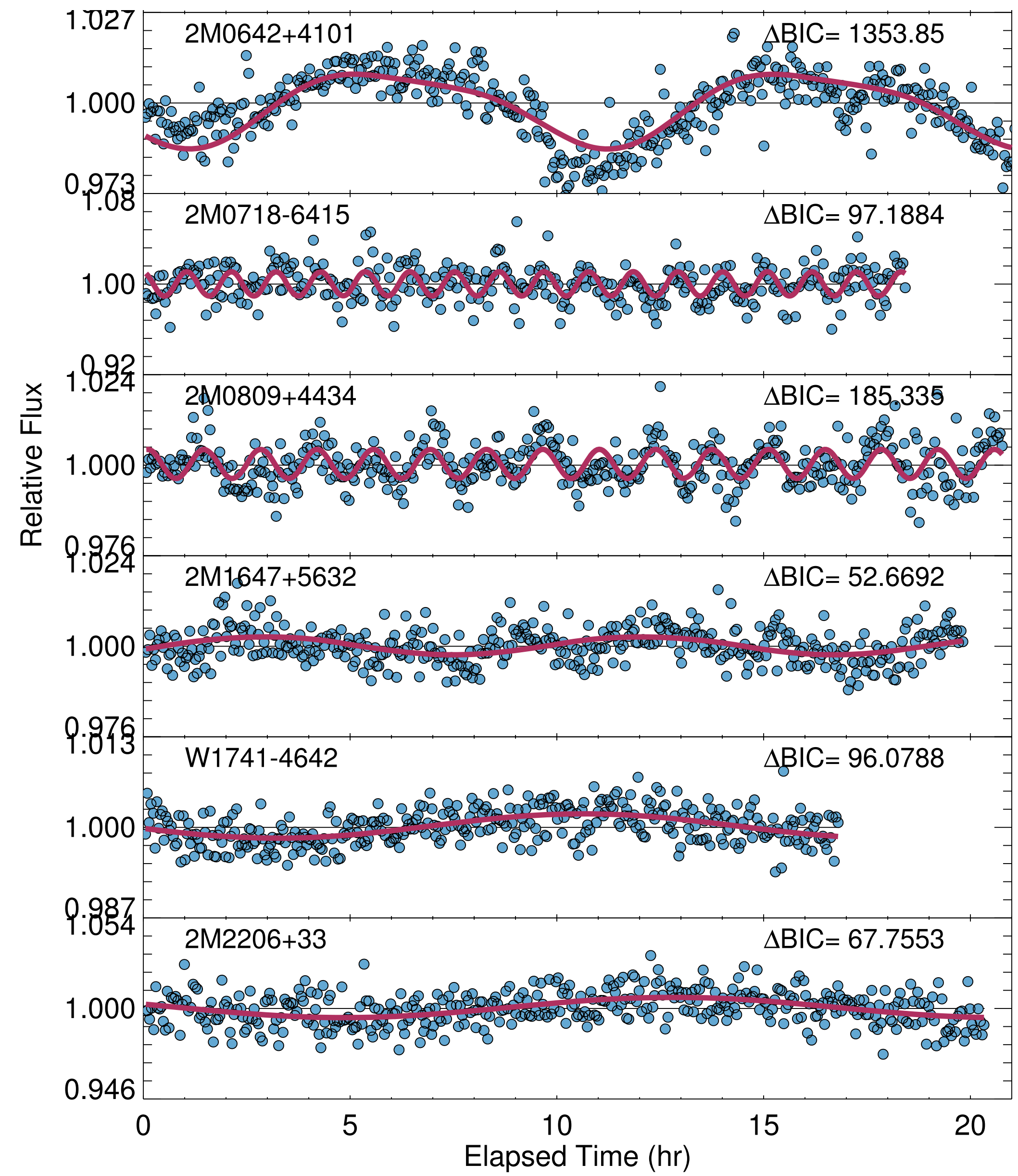


Apai et al. (2021)

Spitzer's Picture of Atmospheric Variability

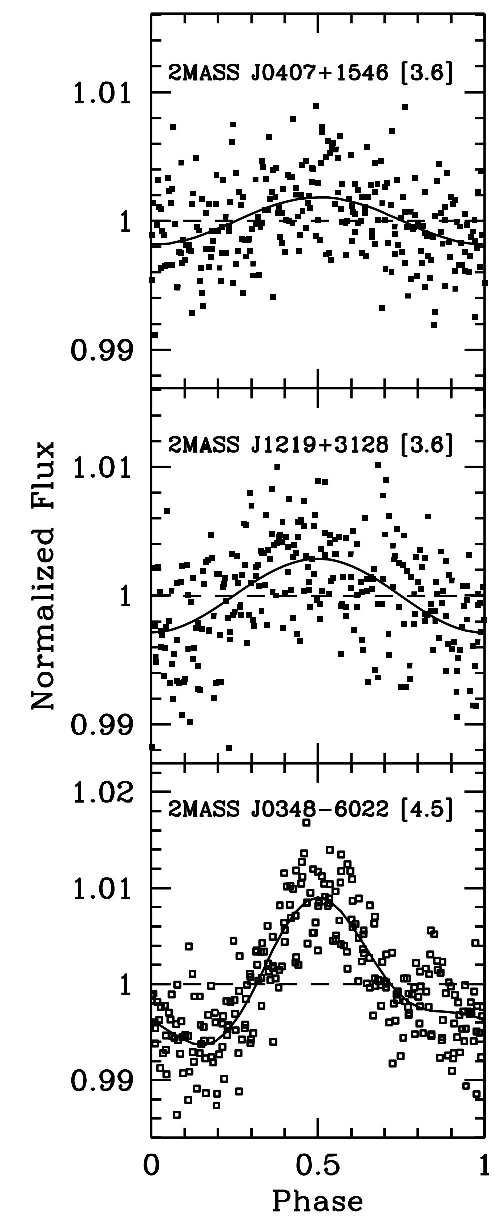


Metchev et al. (2015)

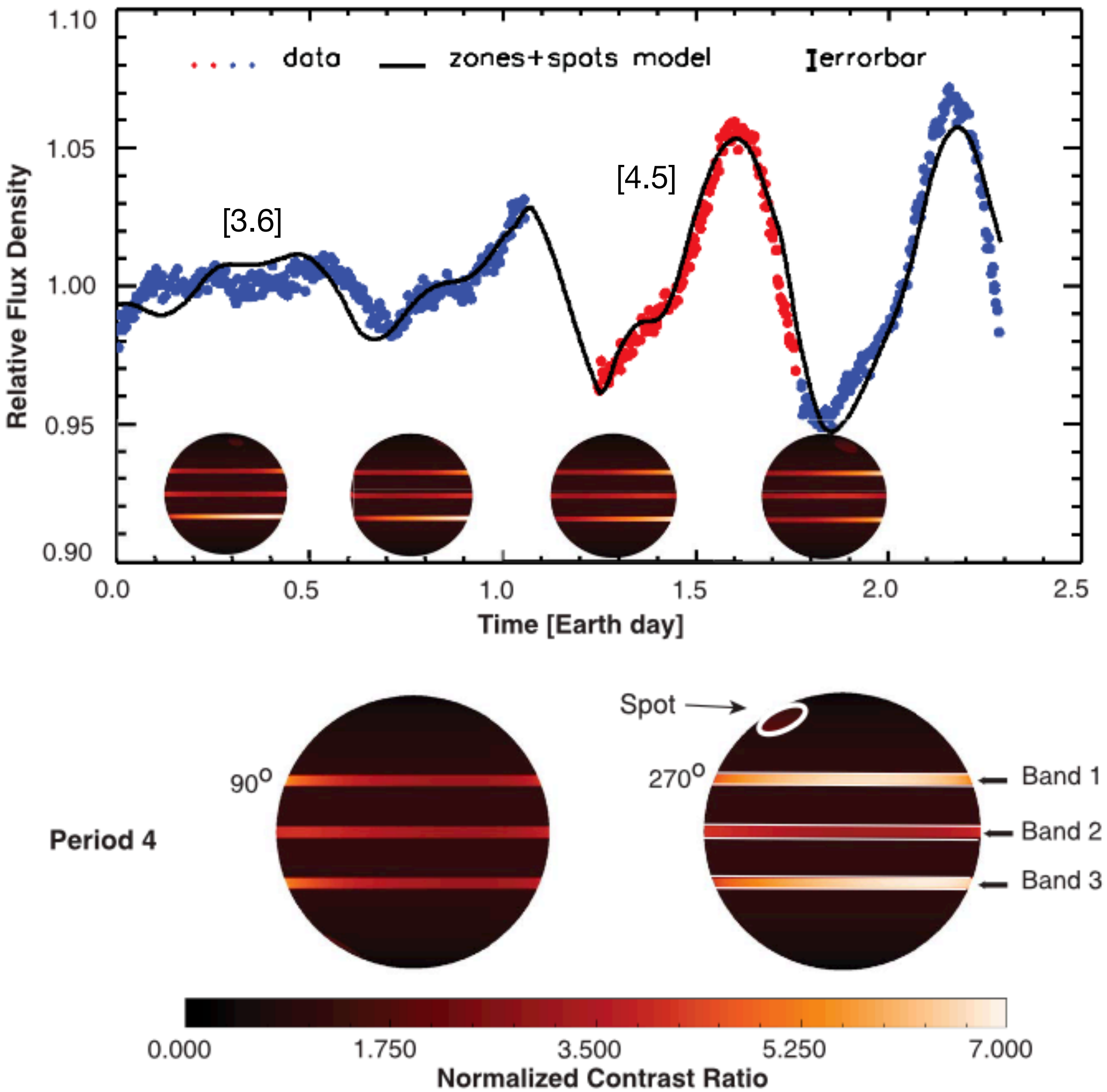


Vos et al. (2022)

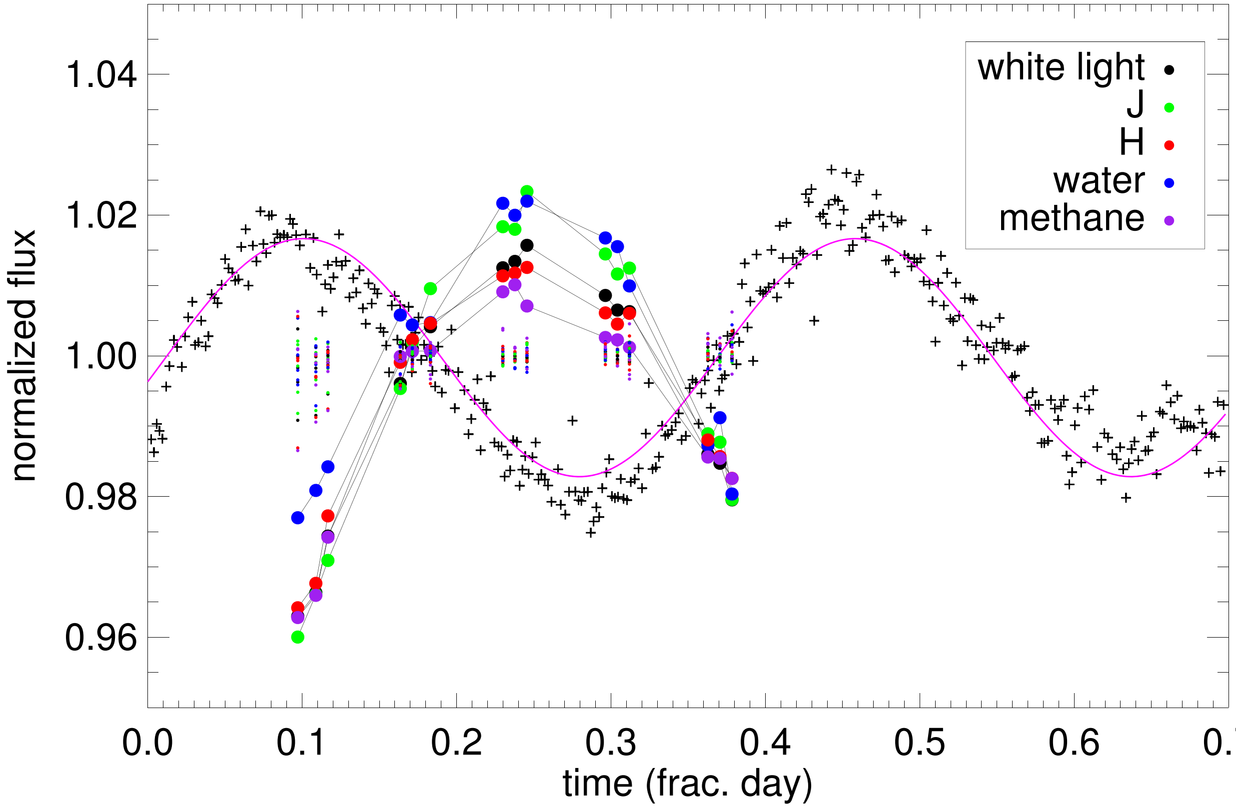
P_{rot} close to 1 hour!
(Tannock et al. 2021)



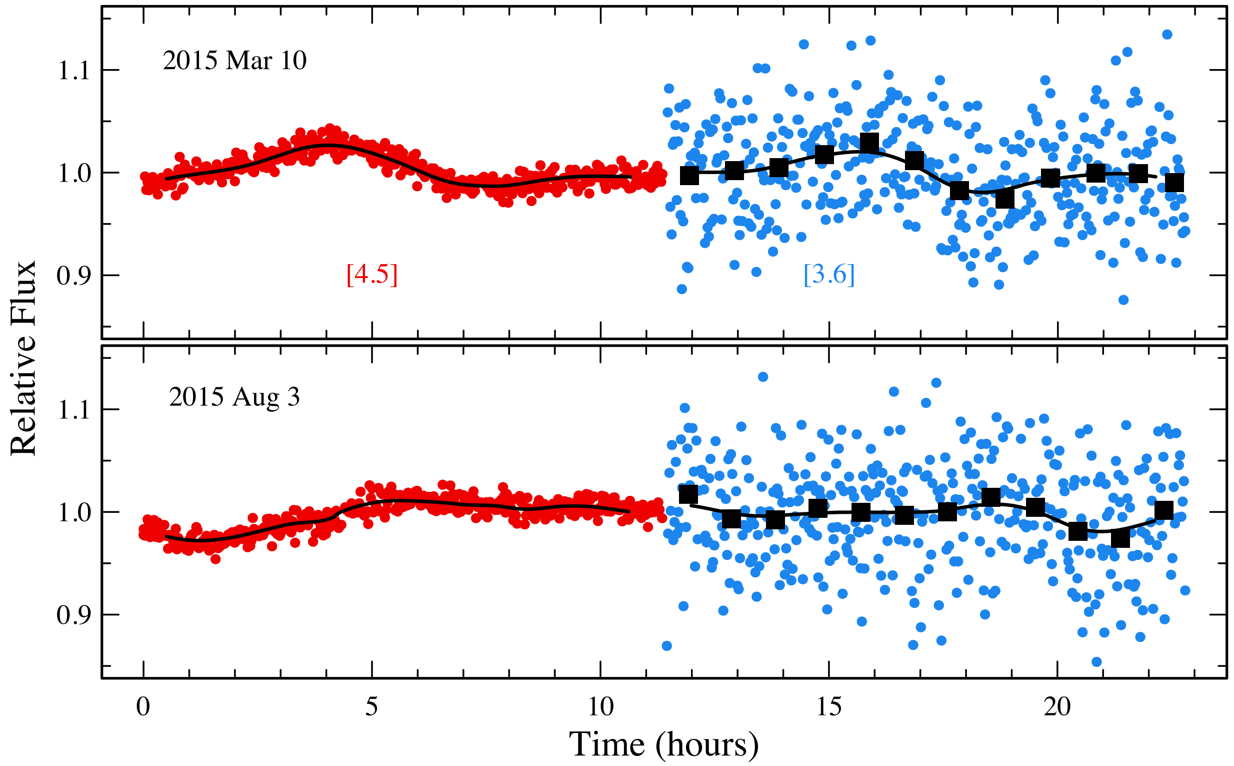
From Spots to Phase Shift



2MASS J13243553+6358281 (L8; Apai et al. 2017)

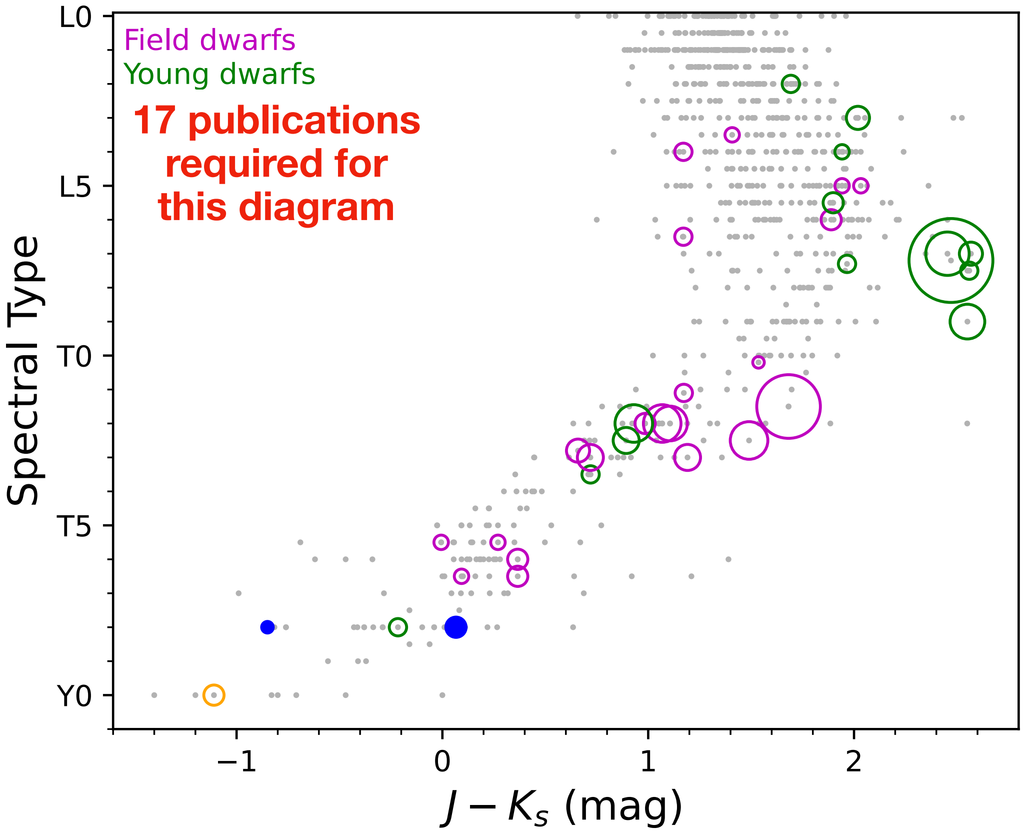


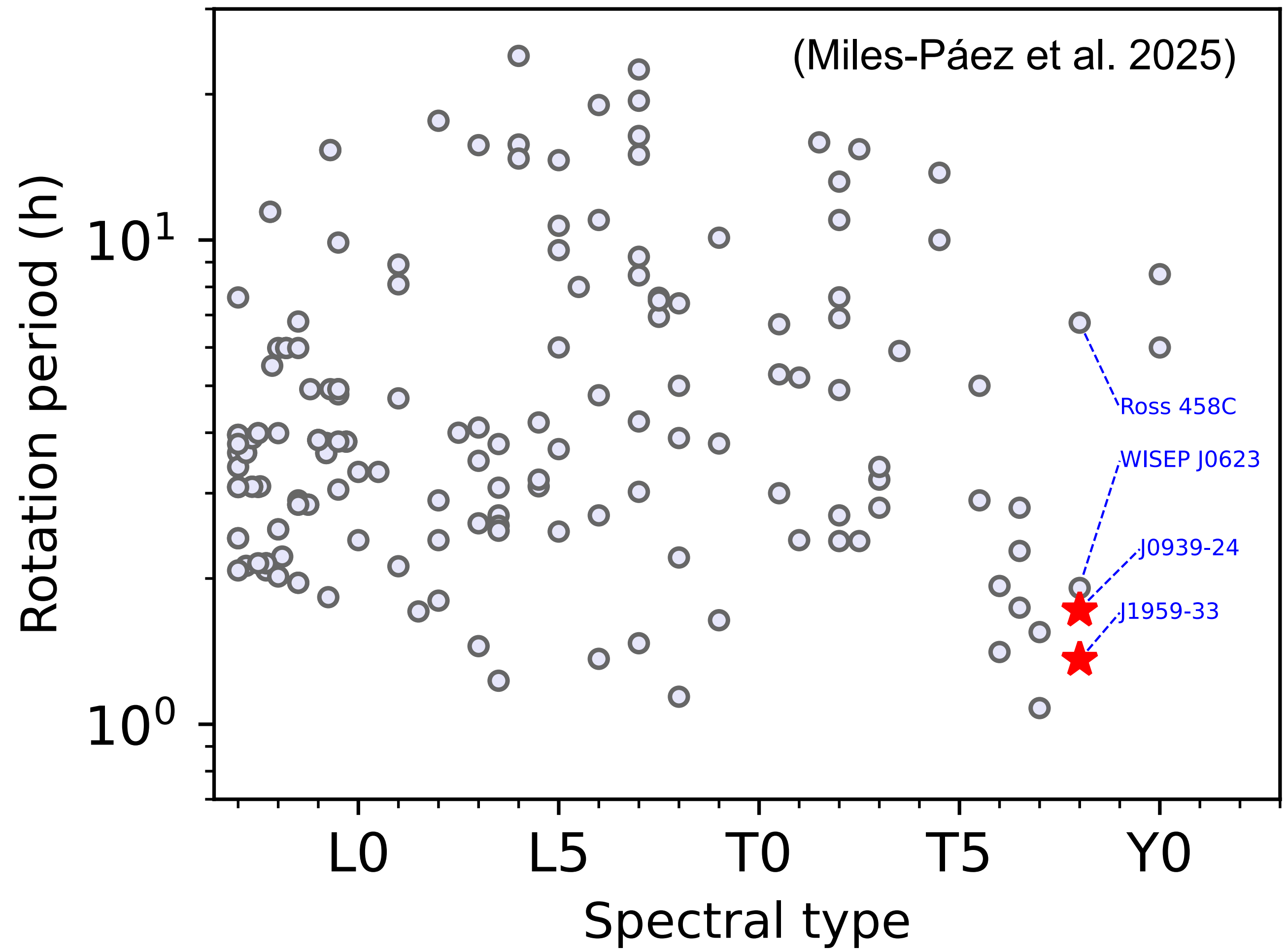
PSO J318.5-22 (L7.5; Biller et al. 2015)

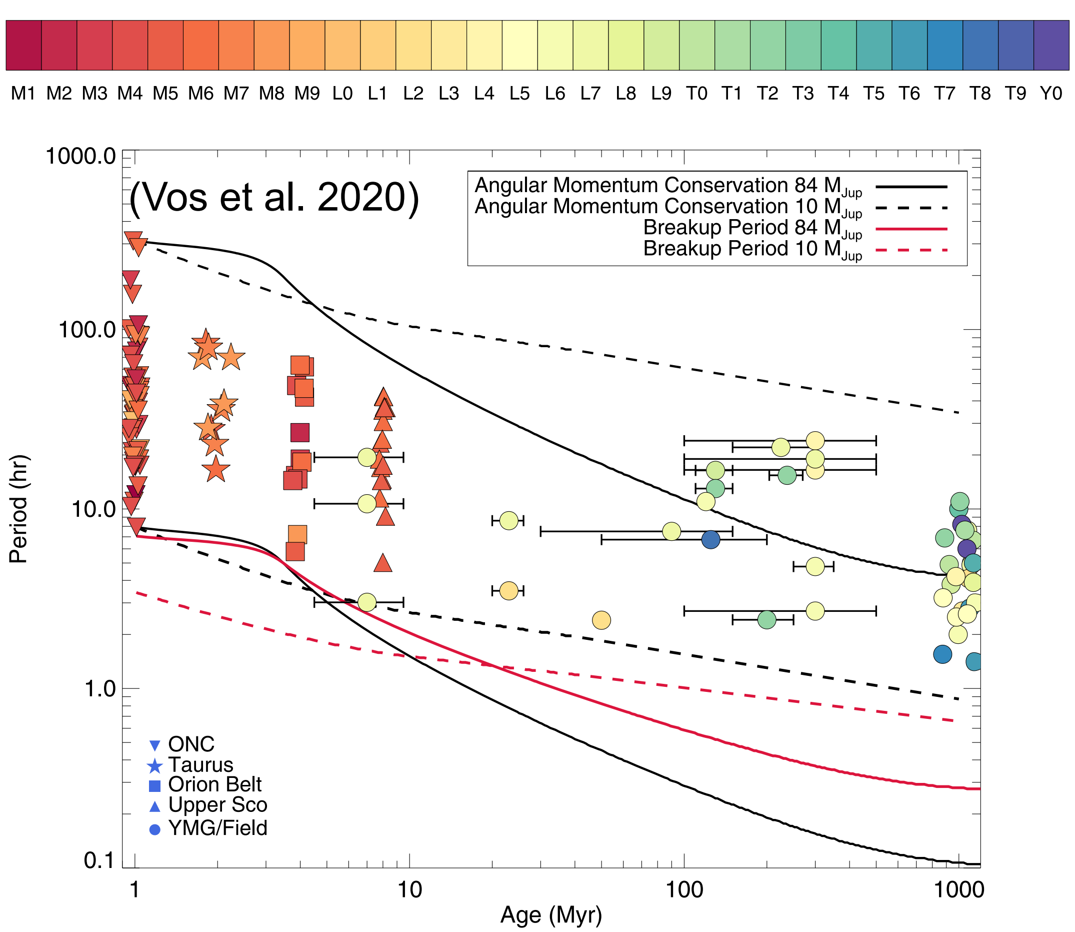


WISE J085510.83-071442.5 (Teff ~250 K; Esplin et al. 2016)

What We Learned from Surveys

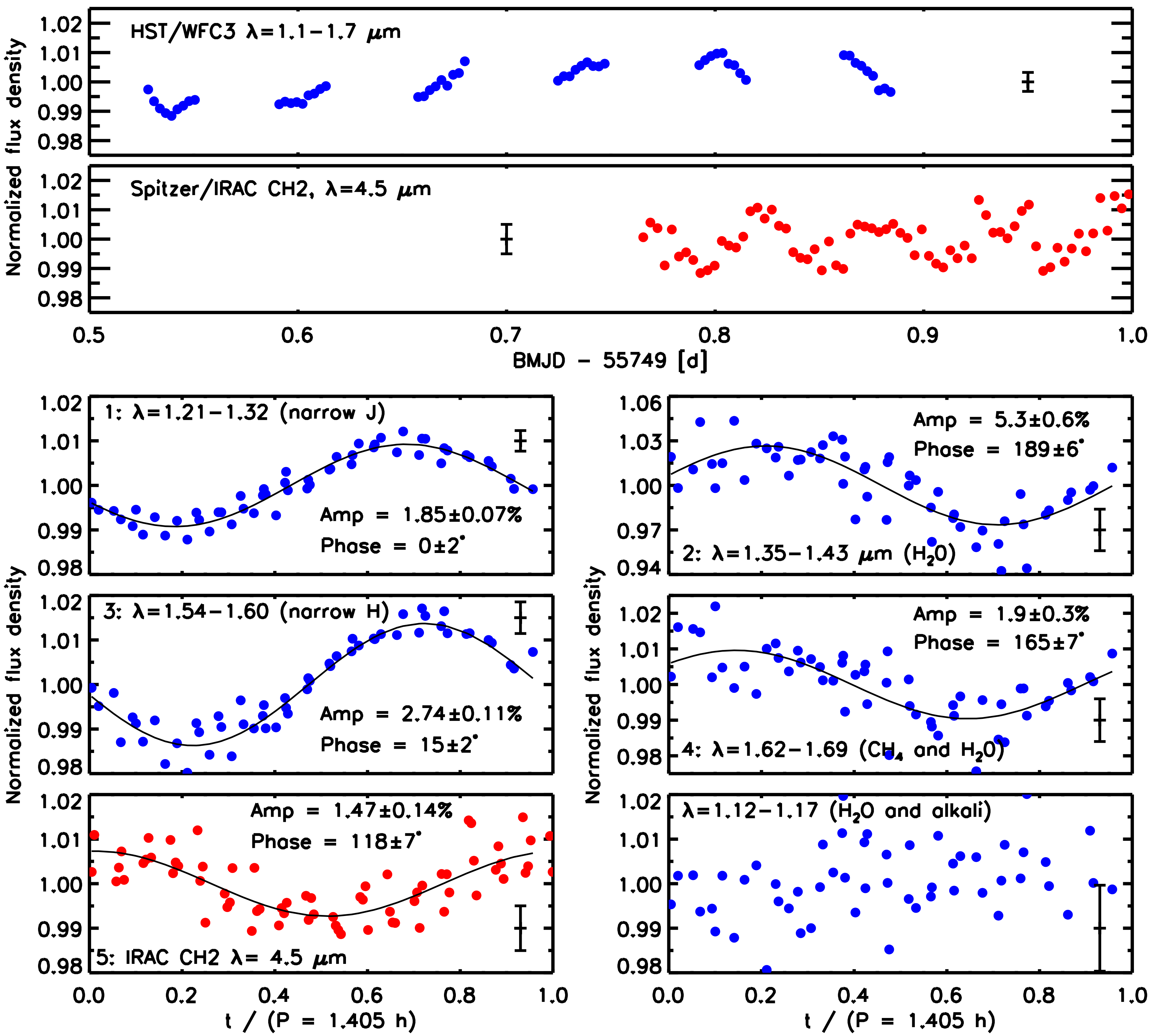






- Surface heterogeneities are common in late-M, L and T dwarfs.
- P_{rot} ~ 1-20 h for field dwarfs.
- Largest variability occurs at the L/T transition, where cloud settling is patchy.
- Young objects show higher amplitudes, likely from lower gravity and thicker clouds.
- Brown dwarfs spin up with age, losing far less angular momentum than Sun-like stars.

Spectroscopic variability

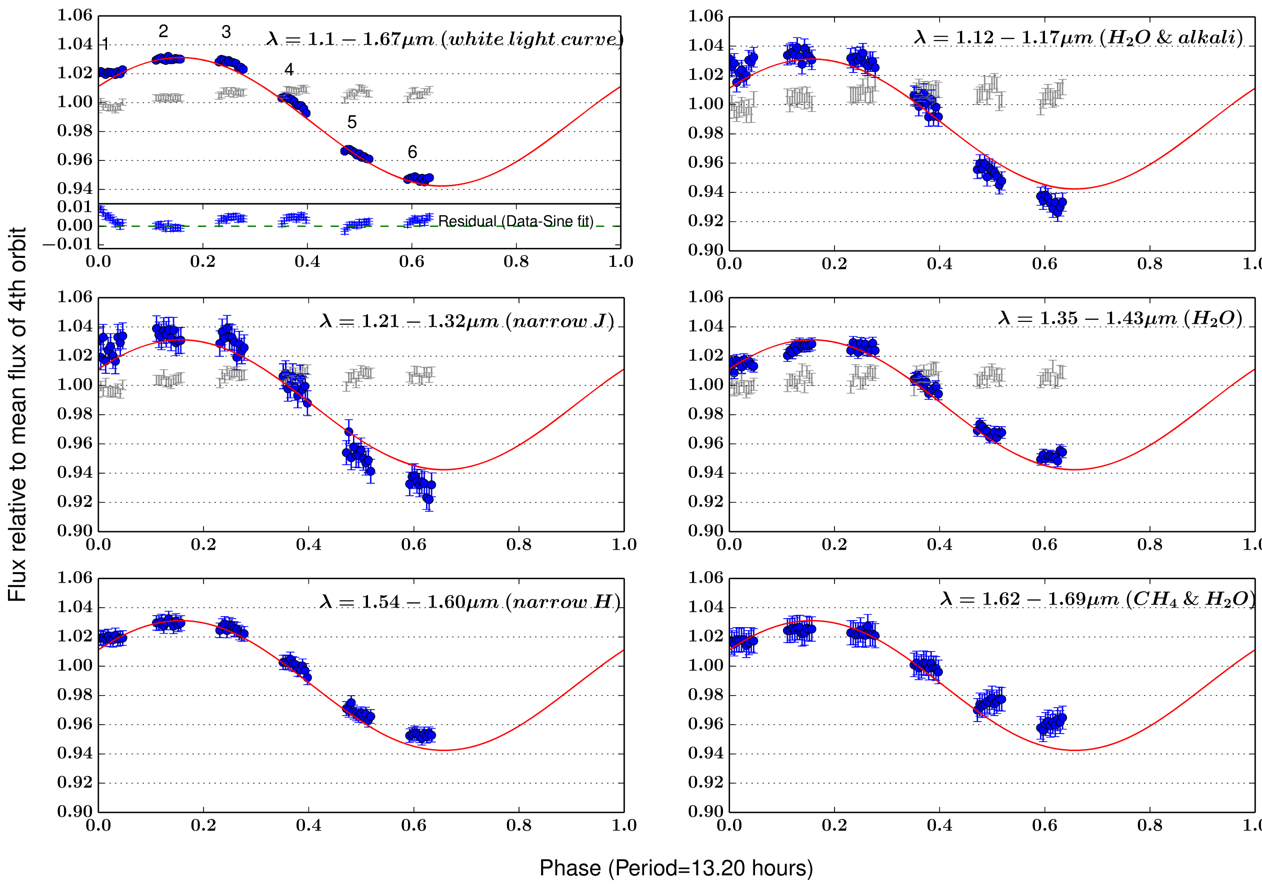


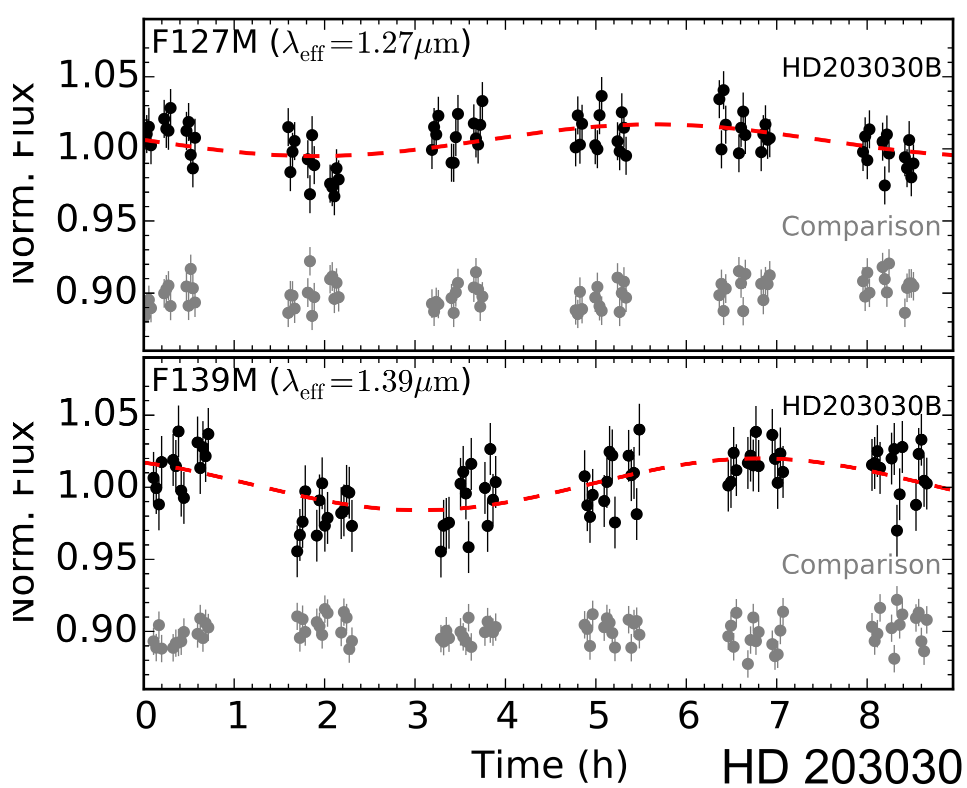
2MASS J22282889−431026
(T6.5; Buenzli et al. 2012)

- Infrared variability, ~1.4 hr period.
- Amplitudes 1.5–5.3% of mean flux.
- Similar shapes across wavelengths, but phase offsets.
- Lag increases with altitude.
- First probe of horizontal & vertical heterogeneity.

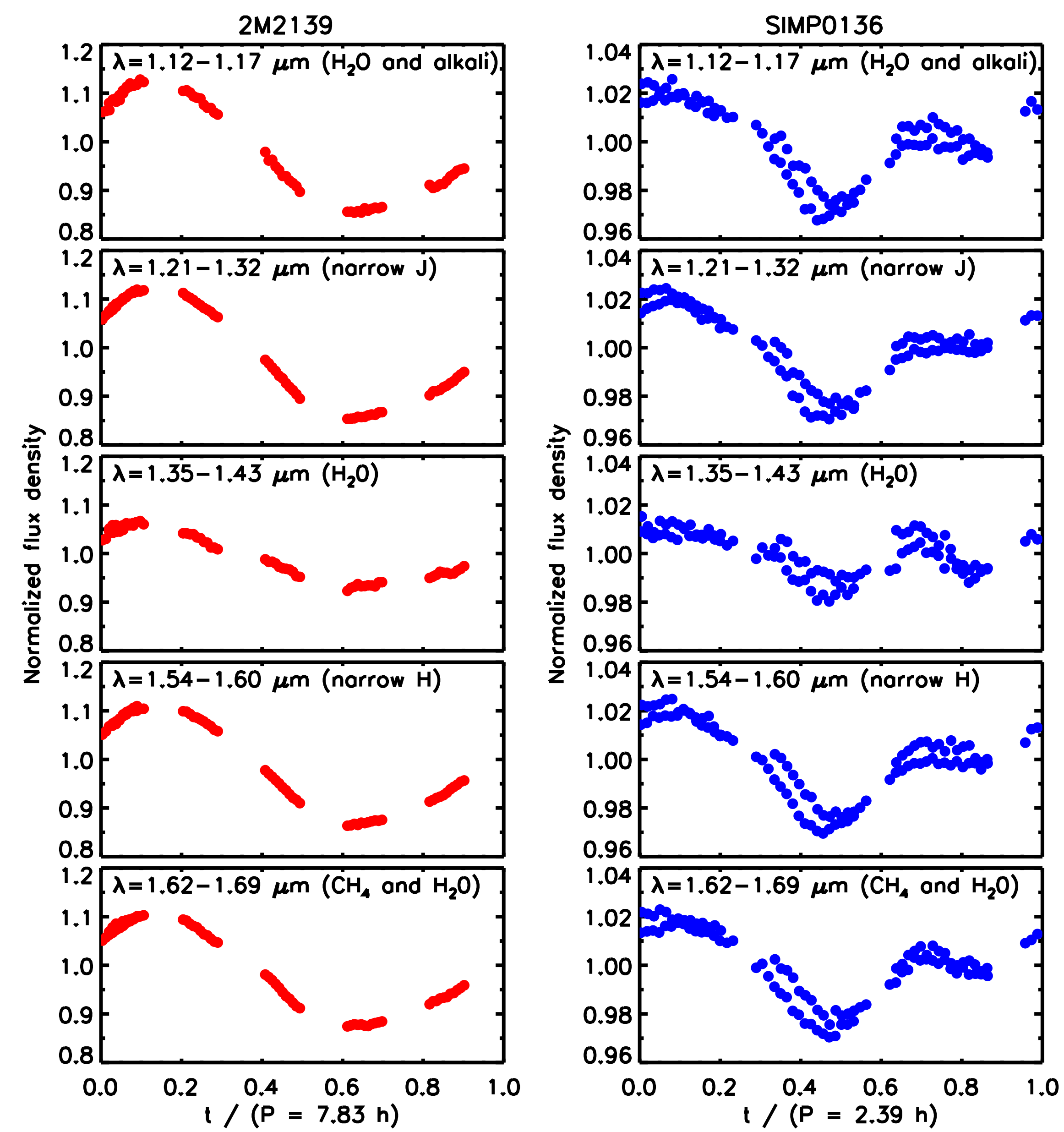
Diversity in Spectroscopic Variability

WISEP J004701.06+680352.1 (L6; Lew et al. 2016)



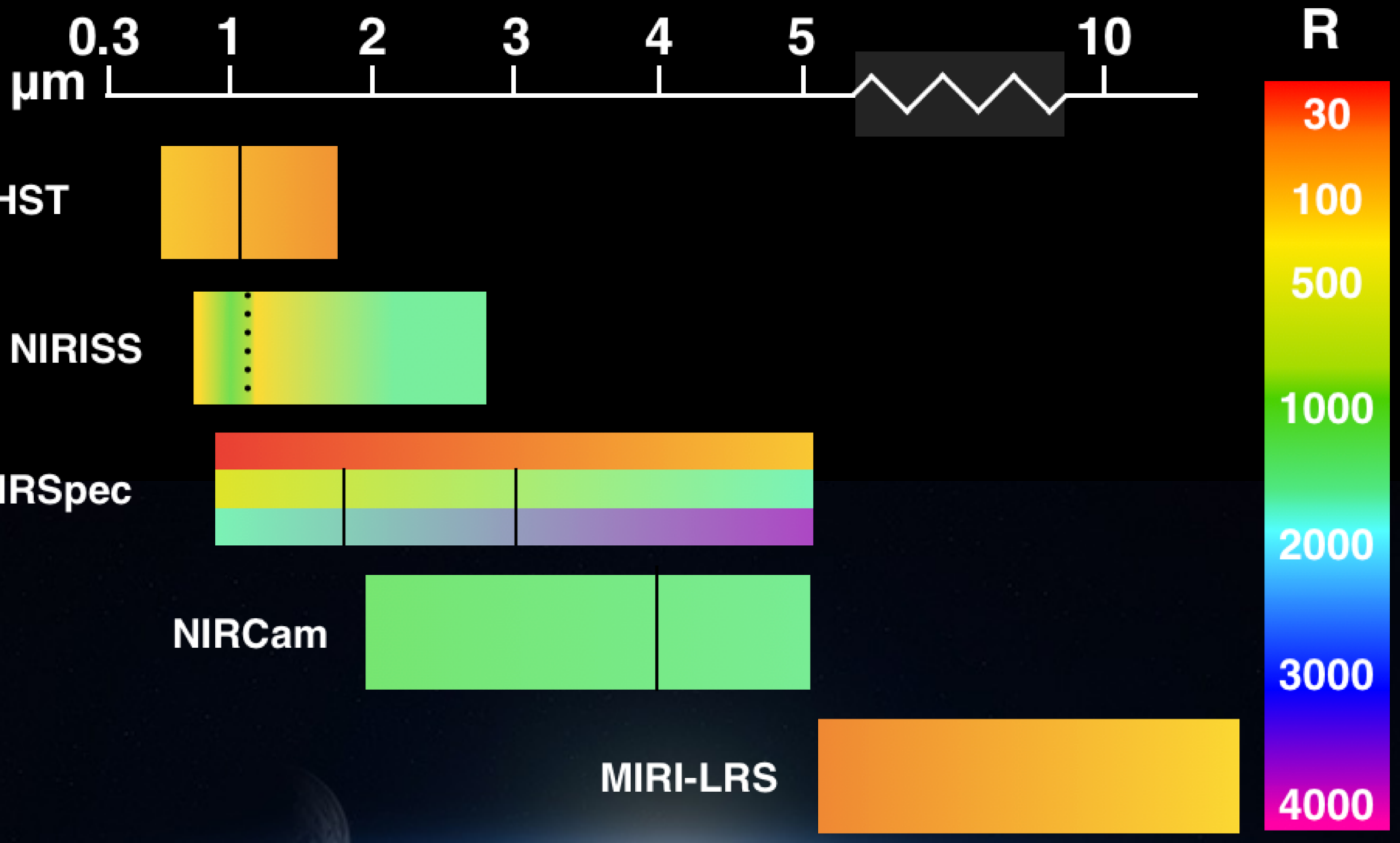


HD 203030B (L8; Miles-Páez et al. 2019)



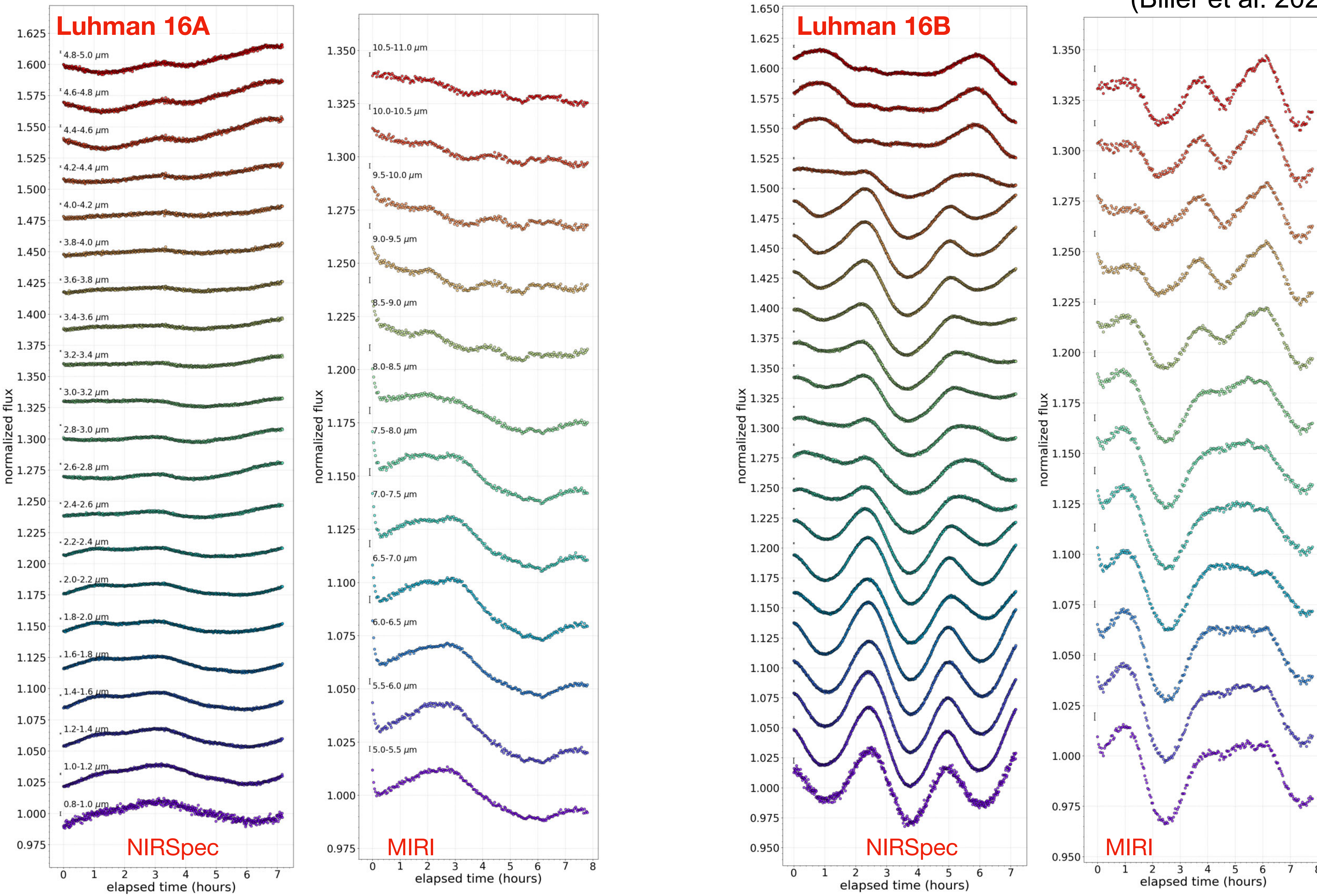
T2 dwarfs (Apai et al. 2013)

Diversity of Observing Modes



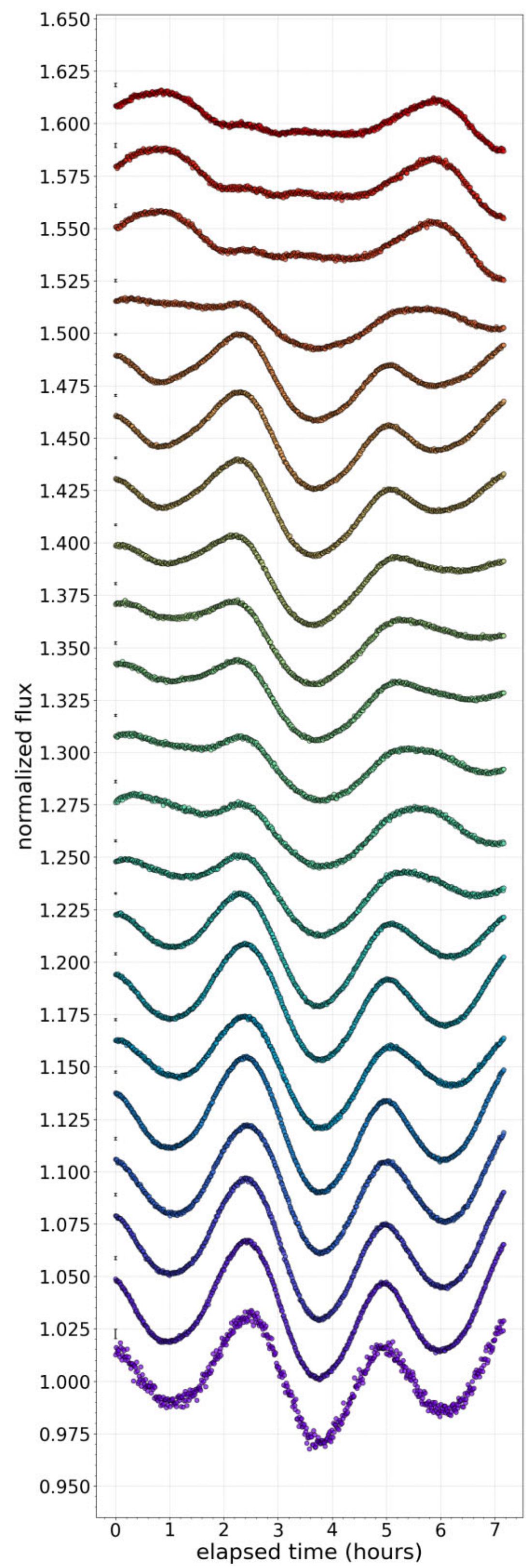
Luhman 16A and B: No Two Wavelengths Alike

(Biller et al. 2024)

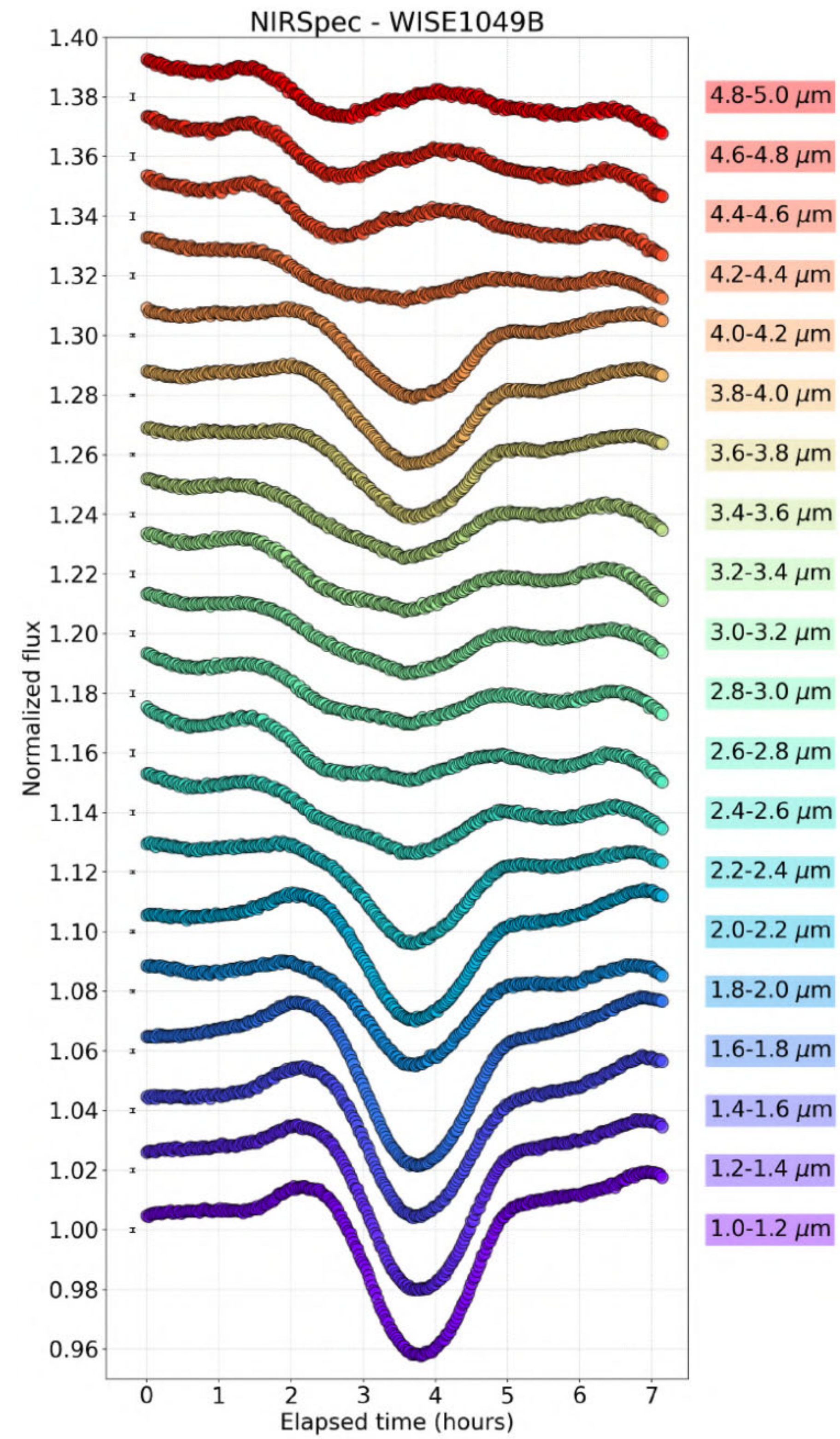


Luhman 16A and B: No Two Epochs Alike

Modeling suggests that, at the same wavelength chunk, light-curve shapes evolve across epochs but arise from the same mechanism.

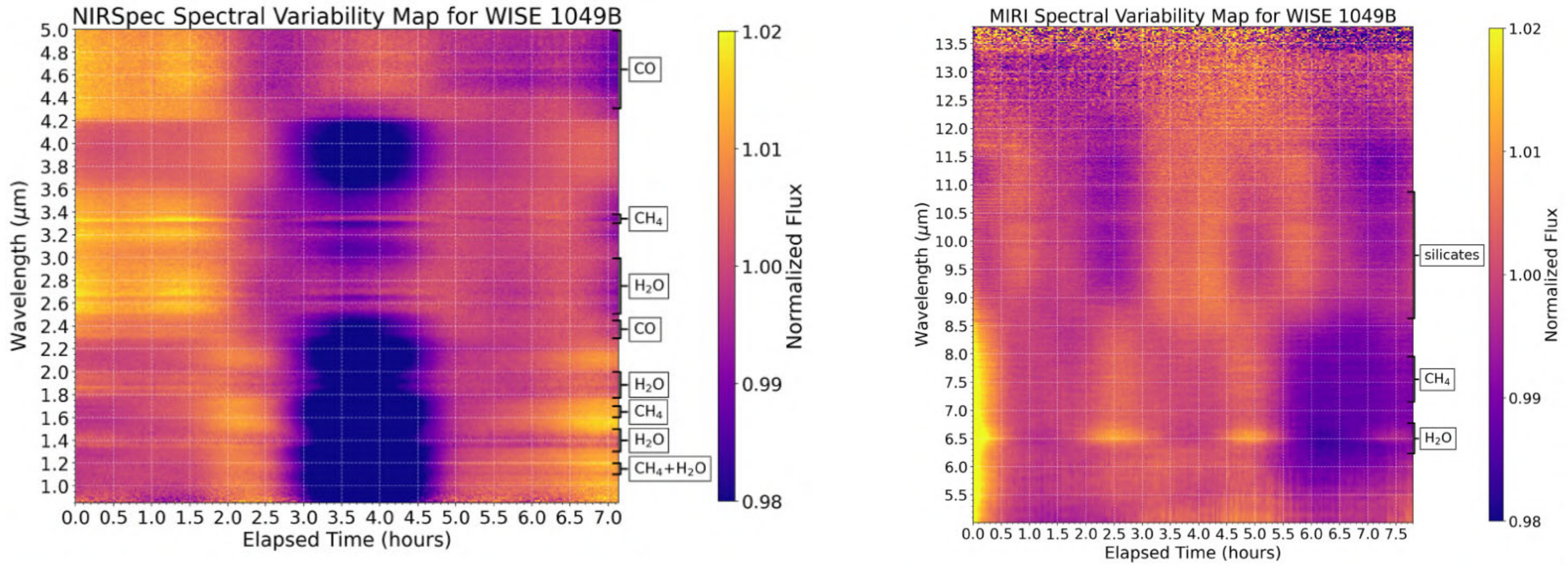


(Biller et al. 2024)

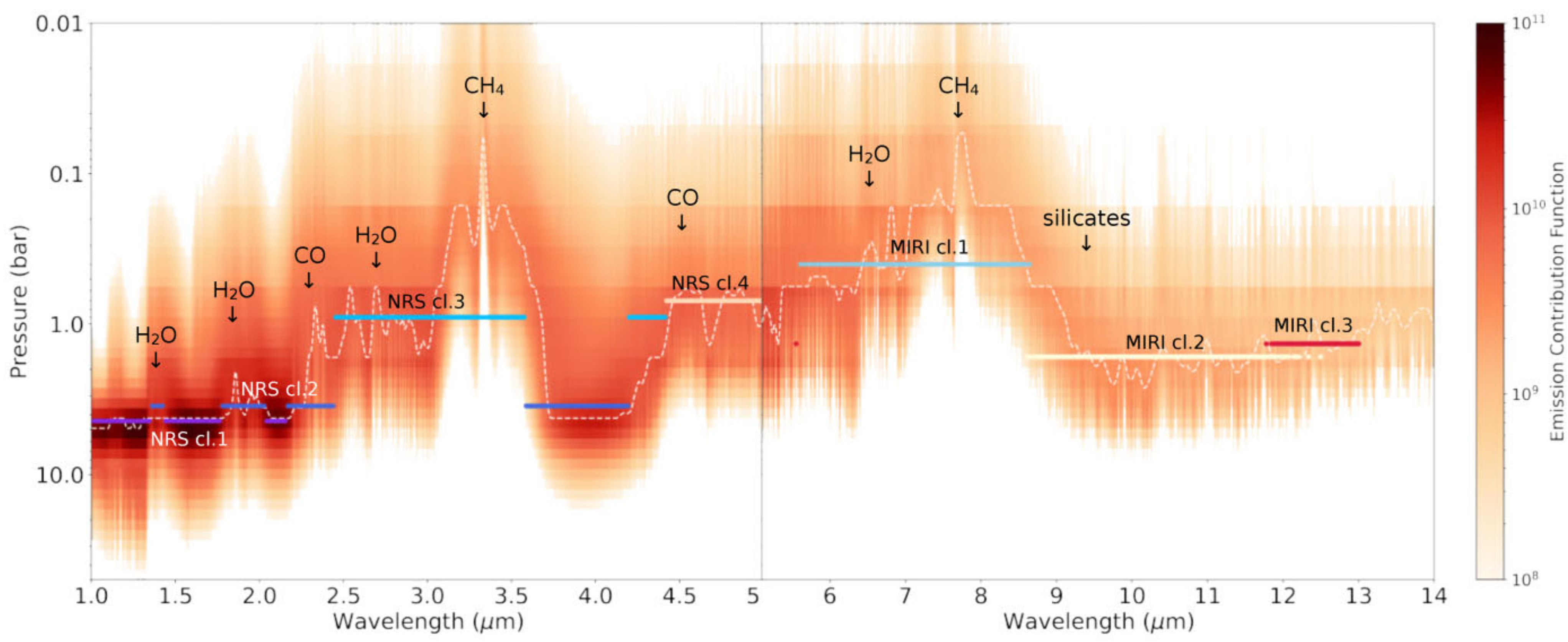


(Chen et al. 2025)

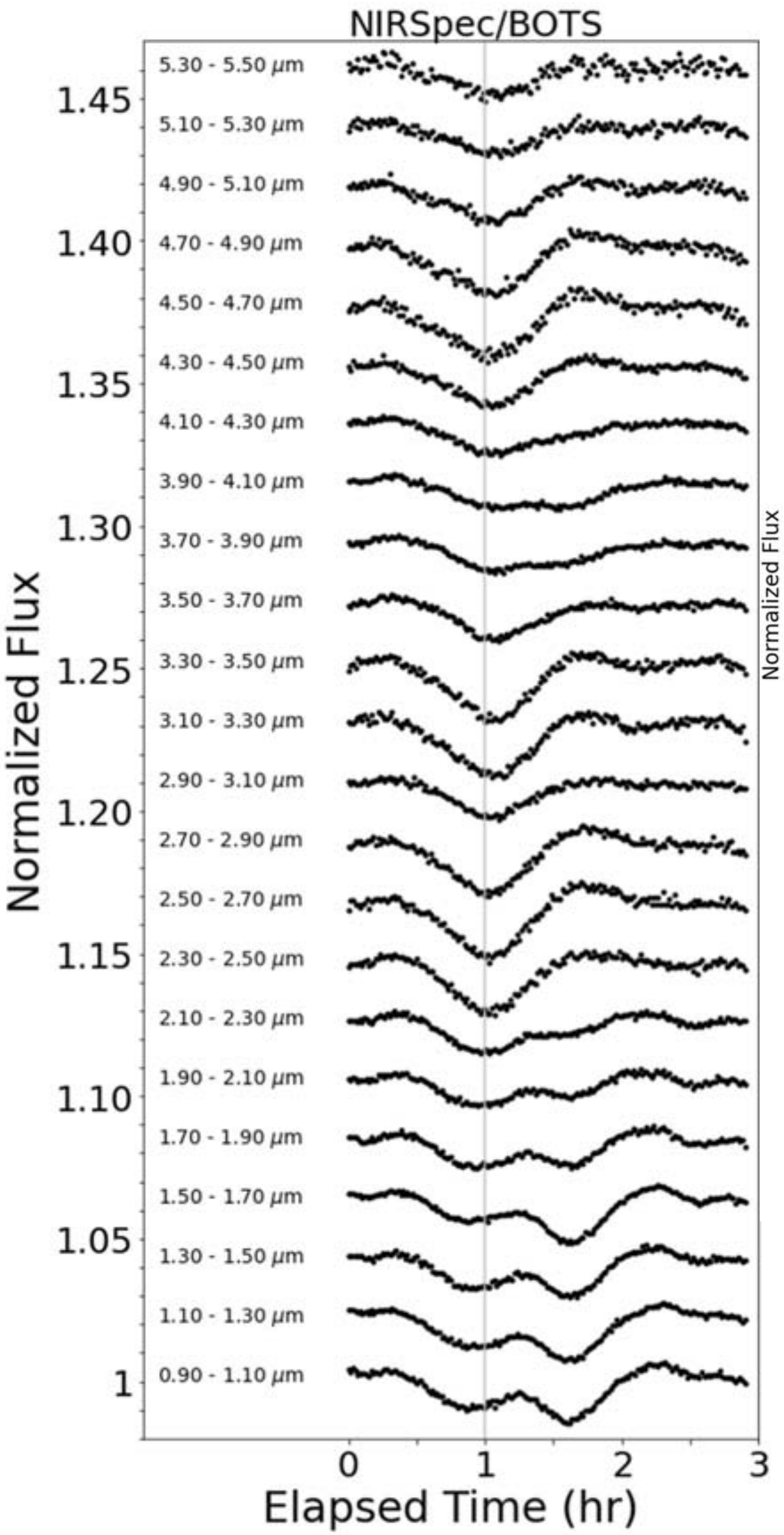
From Light Curves to Weather Maps

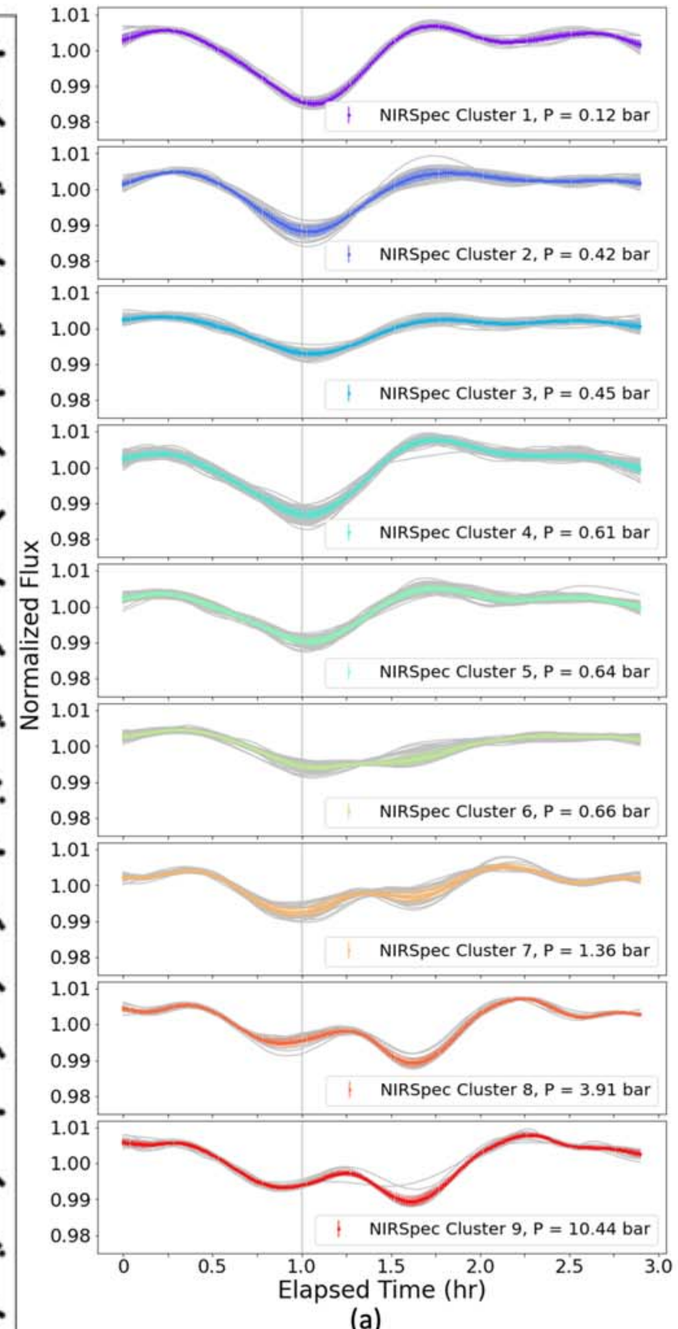


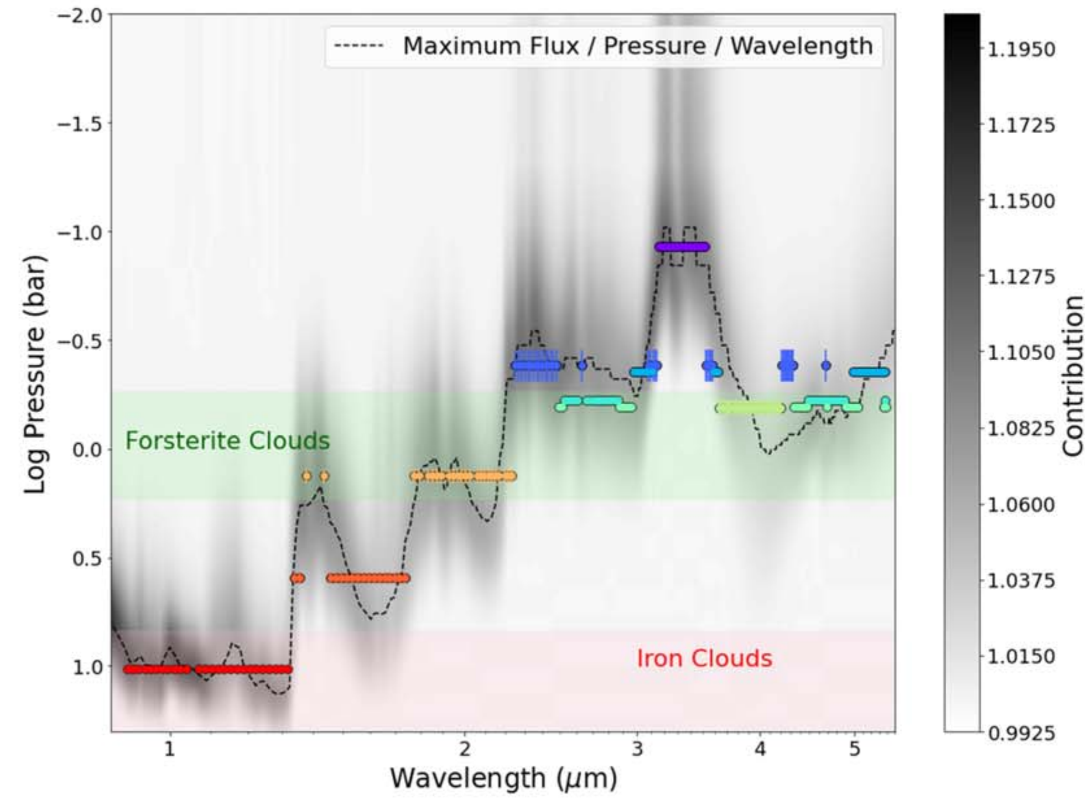
(Chen et al. 2025)



SIMP J0136+0933: Different Layers, Different Stories





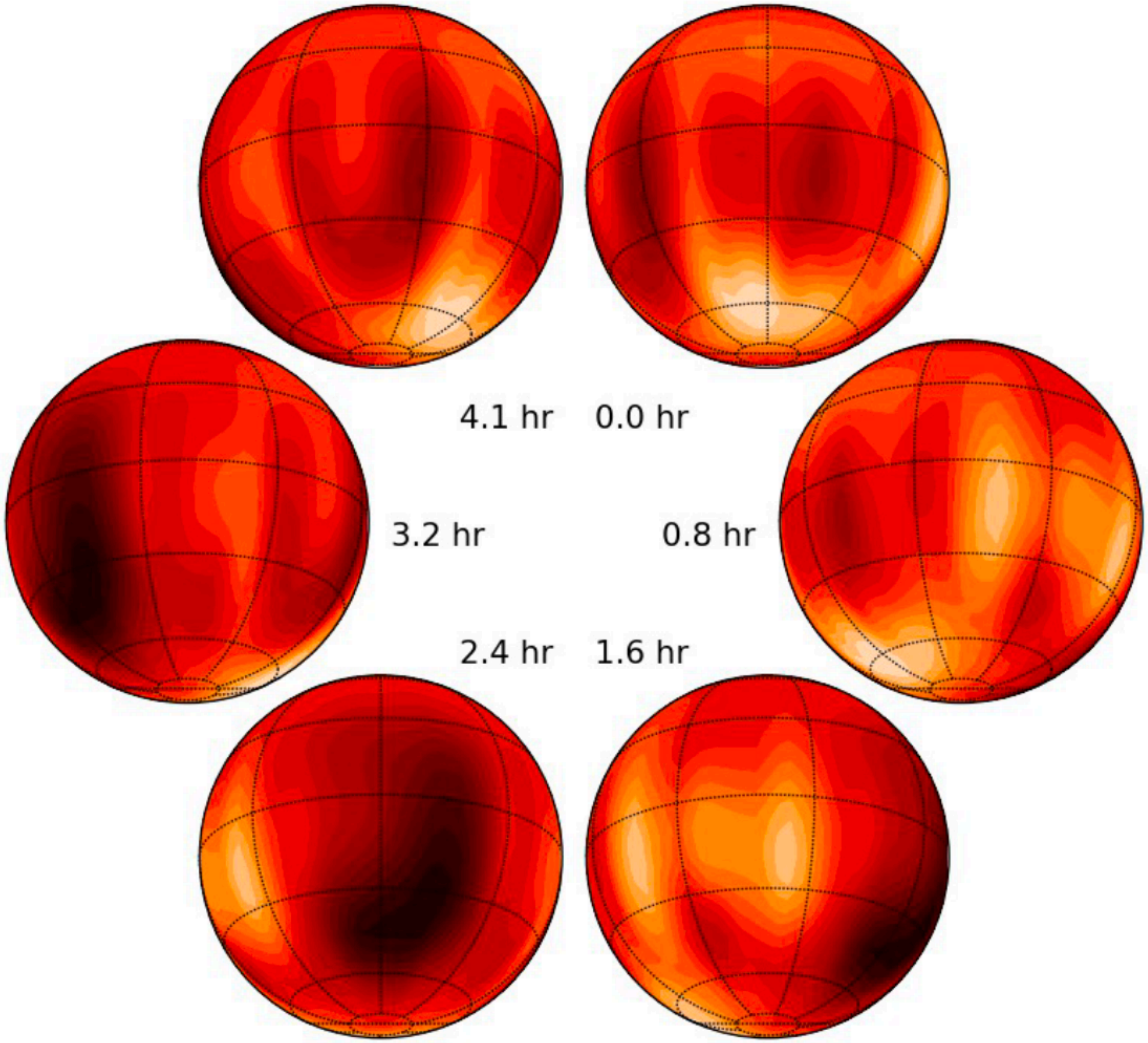


(McCarthy et al. 2025)

Also, time-resolved atmospheric retrievals in Nasedkin et al. (2025)

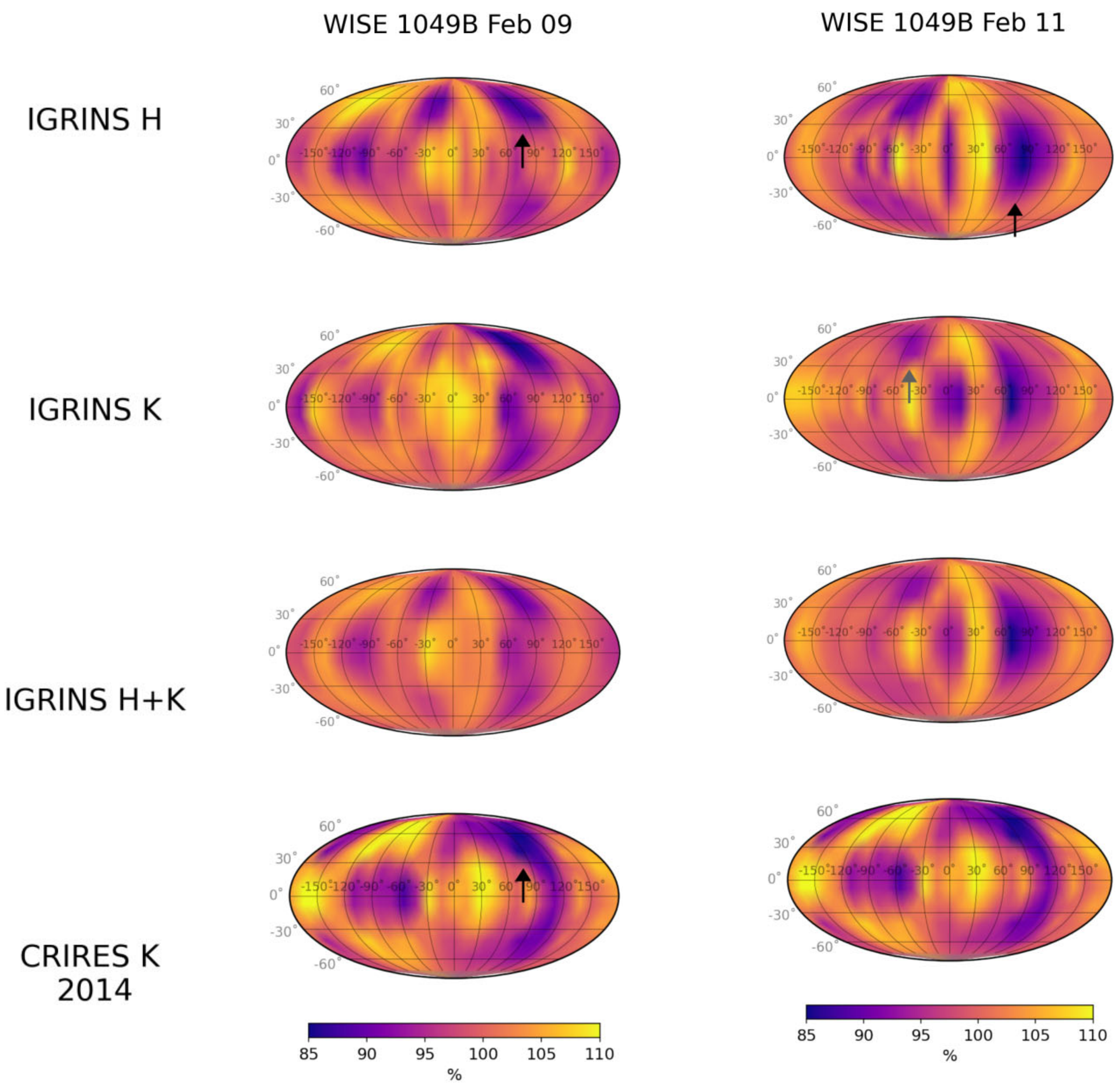
More on JWST results in the talks by Jared Bull and Natalia Oliveros Gómez!

Doppler imaging: When Variability Becomes a Map



Crossfield et al. (2014)

Doppler imaging: When Variability Becomes a Map

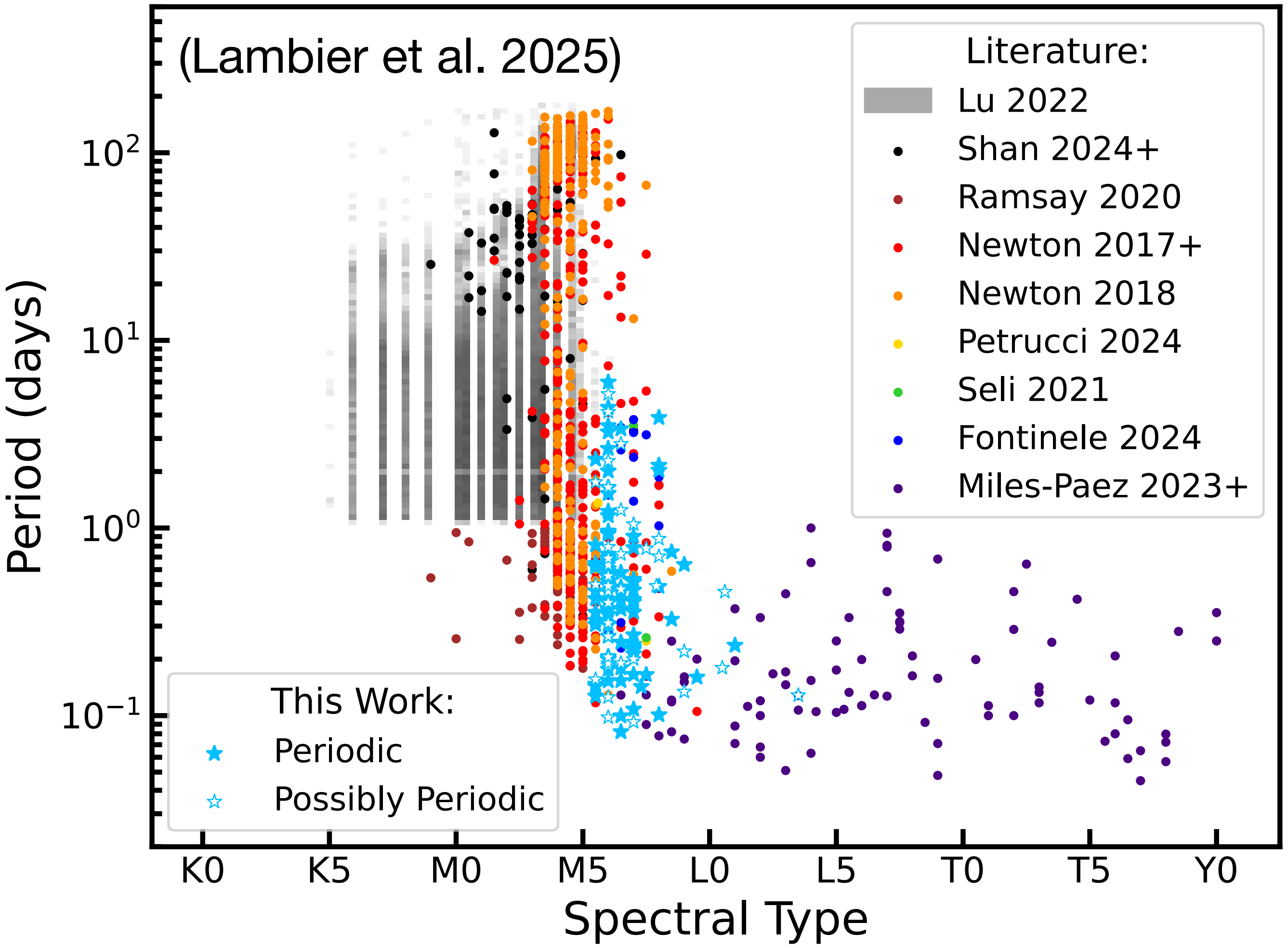


Chen et al. (2024)

Take-home messages

Studying brown dwarf variability has been a mix of careful technique and serendipitous discovery. Sometimes we know what we are looking for, sometimes the objects surprise us.

- Variability is ubiquitous in brown dwarfs.
- Rotation reveals how brown dwarfs spin up with age, losing angular momentum only moderately compared to stars.
- Multi-wavelength variability probes clouds, temperature gradients, chemistry, and magnetism in 3D.
- Brown dwarfs as exoplanet analogs — with JWST and ELTs turning light curves into weather maps.



What's Missing?

- More Y dwarf rotation periods! Is there a Y-dwarf analogue to the L/T transition peak in variability?
- How slowly/fast can field brown dwarfs rotate? Pulsations?
- Variability studies in subdwarfs.
- Potential correlations between radio and optical/IR variability.
- Sun-like magnetic cycle analogues?