Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

Exometeorology:
Weather on Worlds Beyond our Own

Dr Johanna Vos
Assistant Professor
Royal Society University Research Fellow

B. Biller, Y. Zhou, N. Whiteford, A. McCarthy, P. Muirhead, J. Faherty, J. Kestell, N. Cowan, C. Morley, C. Visscher, E. Nasedkin, X. Chen, B. Sutlieff, C. O'Toole, M. Limbach, M. Fabelo Ozcariz, E. Gonzales, E. Manjavacas, E. Calamari, G. Suarez, I. Crossfield, K. Cruz, M. Bonnefoy, N. Oliveros-Gomez, N. Crouzet, P. Molliere, P. Liu, T. Henning, G. Mace, T. Karalidi, P. Tremblin, T. Kataria


johannavos.github.io


johanna.vos@tcd.ie

Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

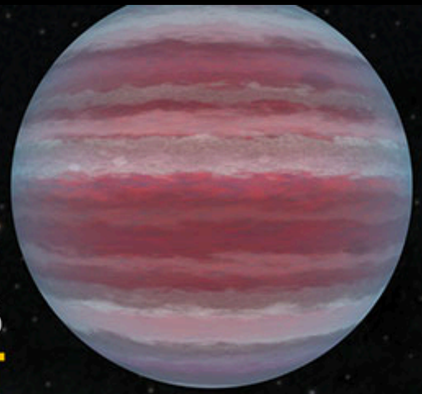
Exometeorology:
Weather on Worlds Beyond our Own

Dr Johanna Vos
Assistant Professor
Royal Society University Research Fellow

B. Biller, Y. Zhou, N. Whiteford, A. McCarthy, P. Muirhead, J. Faherty, J. Kestell, N. Cowan, C. Morley, C. Visscher, E. Nasedkin, X. Chen, B. Sutlieff, C. O'Toole, M. Limbach, M. Fabelo Ozcariz, E. Gonzales, E. Manjavacas, E. Calamari, G. Suarez, I. Crossfield, K. Cruz, M. Bonnefoy, N. Oliveros-Gomez, N. Crouzet, P. Molliere, P. Liu, T. Henning, G. Mace, T. Karalidi, P. Tremblin, T. Kataria


johannavos.github.io


johanna.vos@tcd.ie



30%

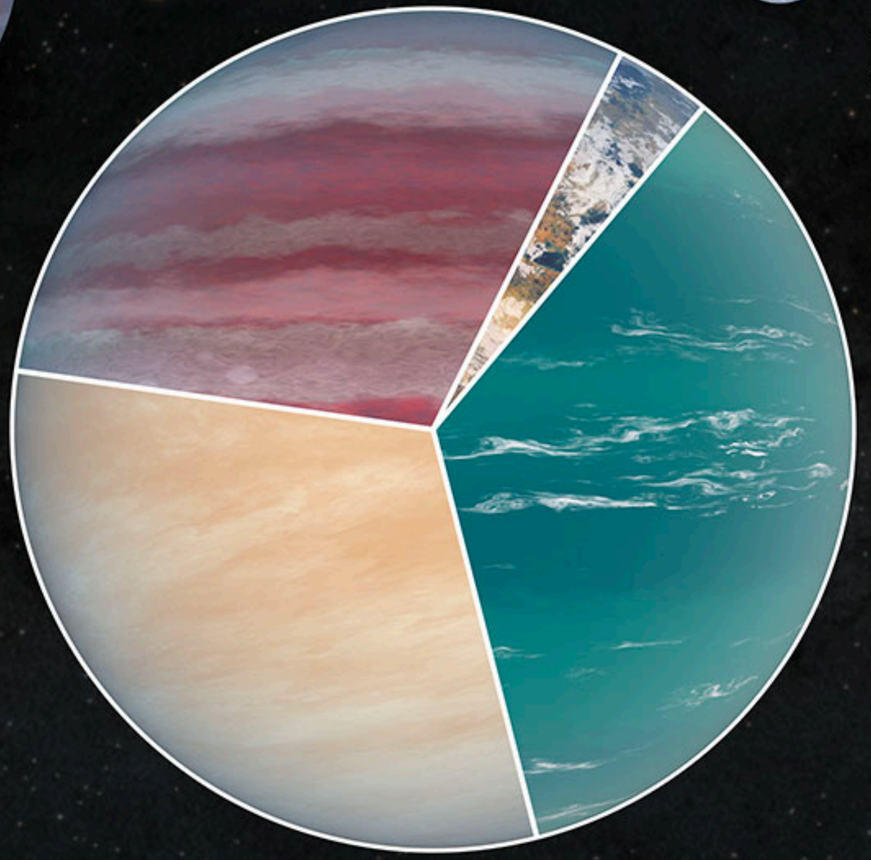
GAS GIANT

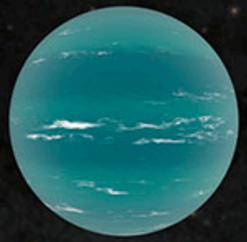
The size of Saturn or Jupiter (the largest planet in our solar system), or many times bigger. They can be hotter than some stars!

4%

TERRESTRIAL

Small, rocky planets. Around the size of our home planet, or a little smaller.





35%

NEPTUNE-LIKE

Similar in size to Neptune and Uranus. They can be ice giants, or much warmer. “Warm” Neptunes are more rare.

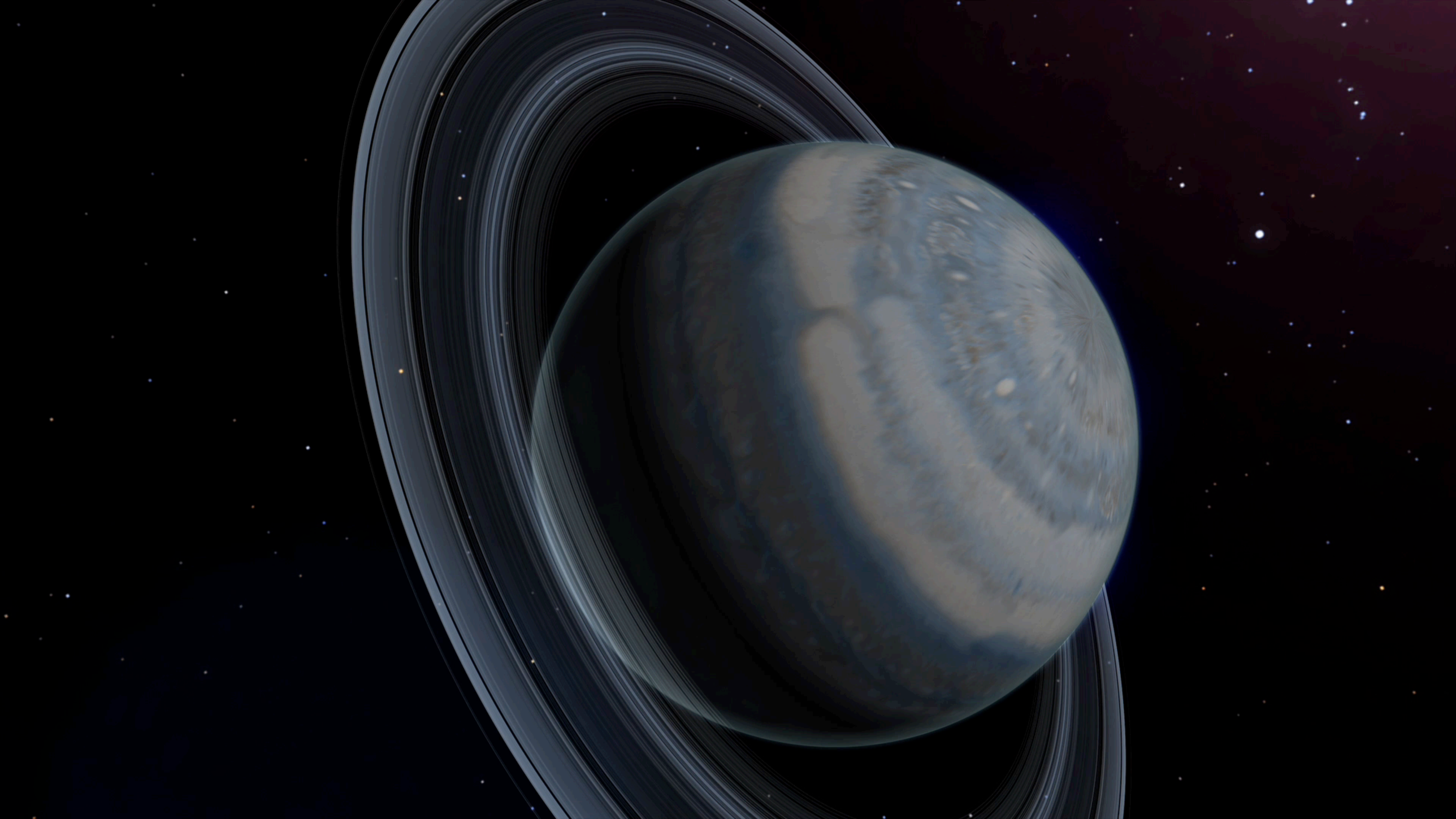
31%

SUPER-EARTH

Planets in this size range between Earth and Neptune don’t exist in our solar system. Super-Earths, a reference to larger size, might be rocky worlds like Earth, while mini-Neptunes are likely shrouded in puffy atmospheres.

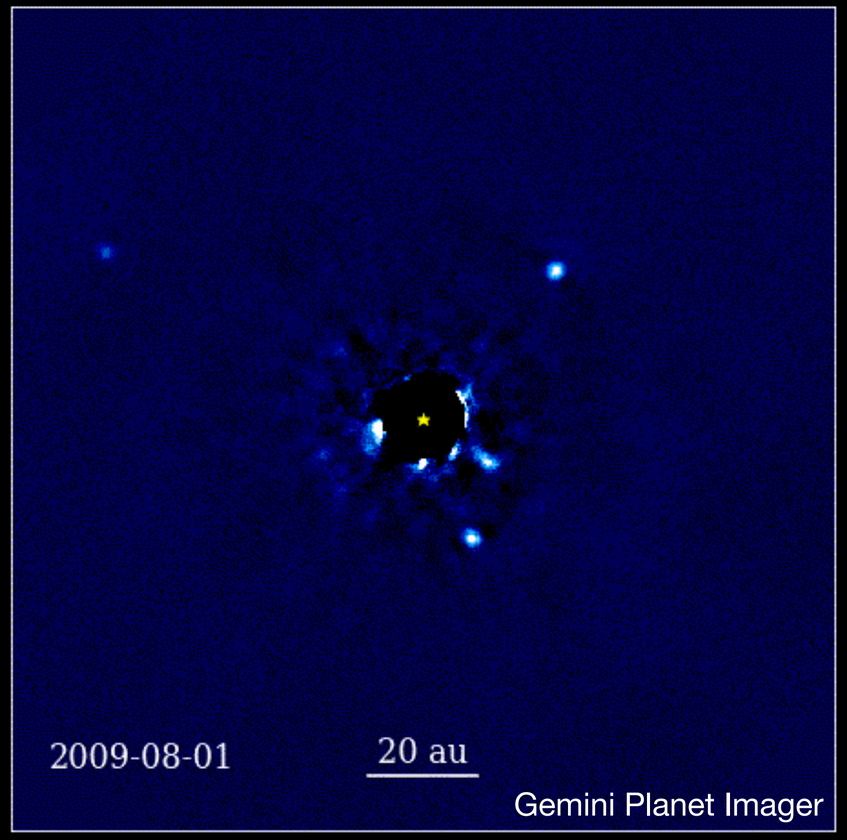
5000+

PLANETS FOUND



We have discovered ~30 directly imaged exoplanets

….. and >100 free-floating planets



HR8799 bcde

5-9 M_{Jup}

PSO J318.5-22

7 M_{Jup}

…and ~1000s of brown dwarfs

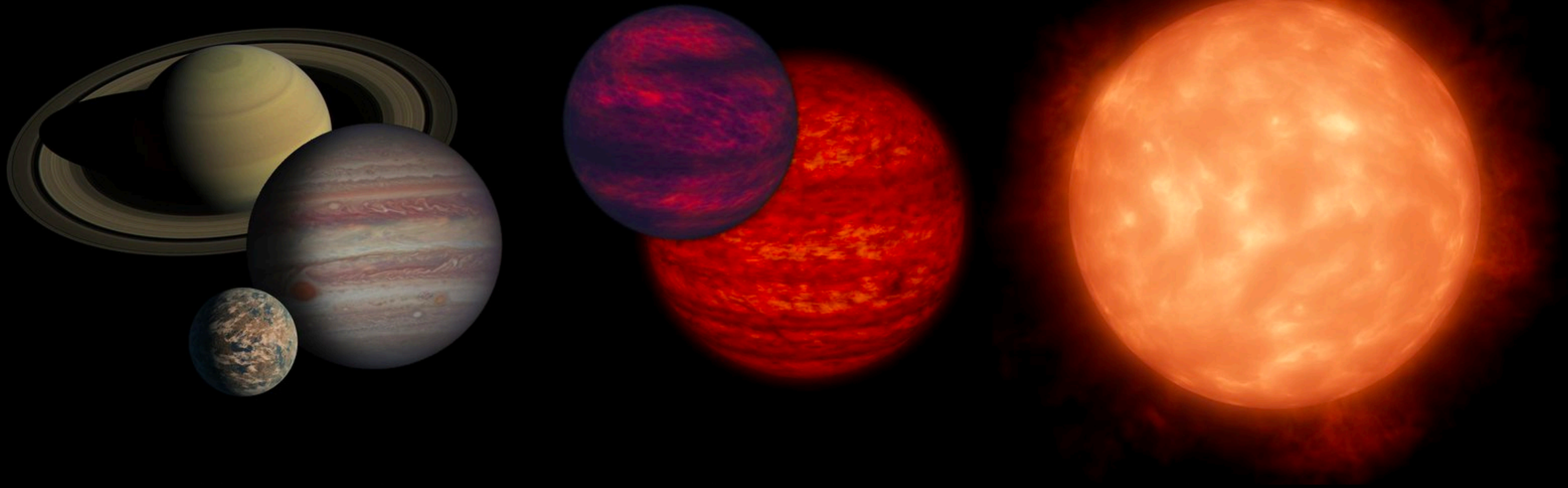
OpenSpace

Giant Extrasolar Worlds

Planets & Exoplanets

Brown Dwarfs

Stars
(Fueled by Nuclear Fusion)

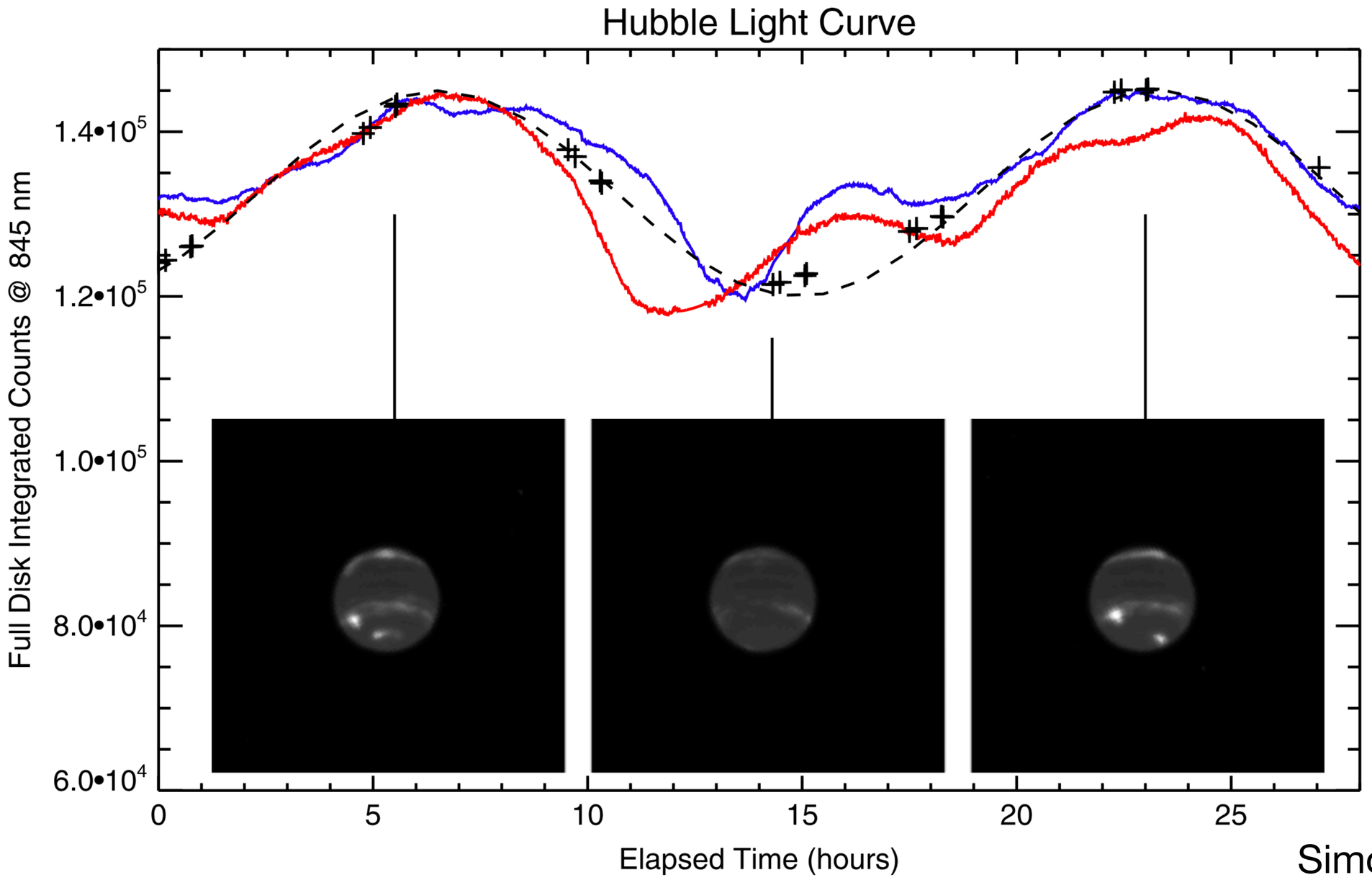


< 13 x Jupiter mass

< 80 x Jupiter mass

> 80 x Jupiter mass

Variability Monitoring Allows us to Probe “Weather” in Unresolved Worlds



Simon et al. 2016

First Splinter Session on Variability, Cool Stars 17

Clouds in brown dwarfs and giant planets

S. Metchev[1,⋆], **D. Apai**[2], **J. Radigan**[3], **É. Artigau**[4], **A. Heinze**[1], **C. Helling**[5], **D. Homeier**[6], **S. Littlefair**[7], **C. Morley**[8], **A. Skemer**[2], and **C. Stark**[5]

[1] Department of Physics & Astronomy, Stony Brook University, 100 Nicolls Rd, Stony Brook, NY 11794-3800, USA
[2] Steward Observatory, The University of Arizona, 933 N. Cherry Ave, Tucson, AZ 85712, USA
[3] Department of Astronomy & Astrophysics, The University of Toronto, 50 St. George St, Toronto, ON M5S 3H4, Canada
[4] Département de Physique, Université de Montréal, C.P. 6128, Succ. Centre-Ville, Montréal, QC, H3C 3J7, Canada
[5] School of Physics & Astronomy, University of St. Andrews, North Haugh, St. Andrews KY16 9SS, Scotland, UK
[6] Centre de Recherche Astrophysique de Lyon, ENS Lyon, 46 allée d'Italie, 69364 Lyon Cedex 07, France
[7] Department of Physics & Astronomy, University of Sheffield, Sheffield S3 7RH, UK
[8] Department of Astronomy & Astrophysics, University of California, 1156 High St, Santa Cruz, CA 95060, USA

Received 2012 Aug 19, accepted 2012 Dec 5
Published online 2013 Feb 1

Astronomical Notes
Astronomische Nachrichten
Founded by H. C. Schumacher in 1821

01–02
2013

Volume 334 · 2013 · Number 1–2 · February

www.an-journal.org

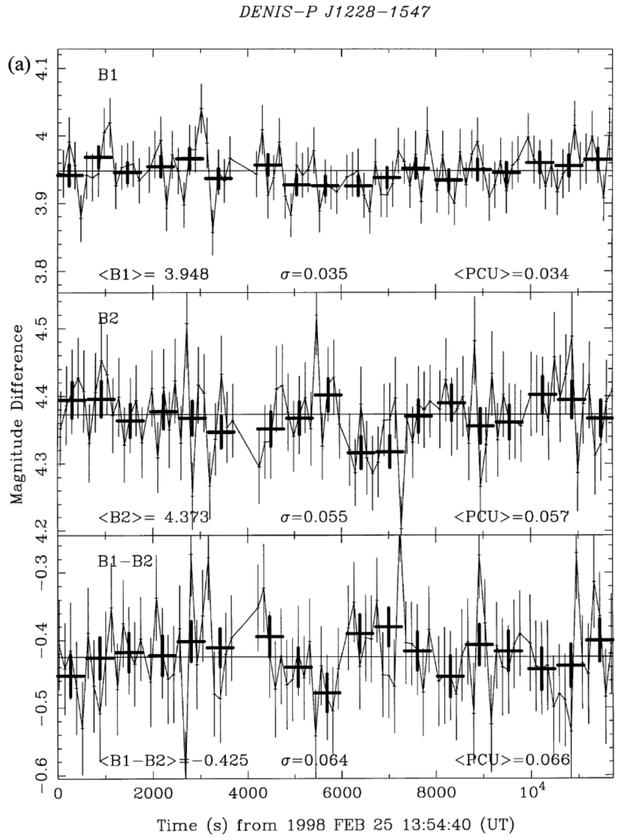
Special issue: Cool Stars 17
Guest Editors: Mercedes López-Morales and Klaus G. Strassmeier

Theoretical and Observational Evidence for Clouds Led to First Searches for Variability Monitoring

Searching for weather in brown dwarfs

C. G. Tinney[1⋆] and A. J. Tolley[1,2]
[1]*Anglo-Australian Observatory, PO Box 296, Epping, NSW 1710, Australia*
[2]*Jesus College, University of Oxford, Oxford OX1 3DW*

Accepted 1998 November 11. Received 1998 November 6; in original form 1998 September 18



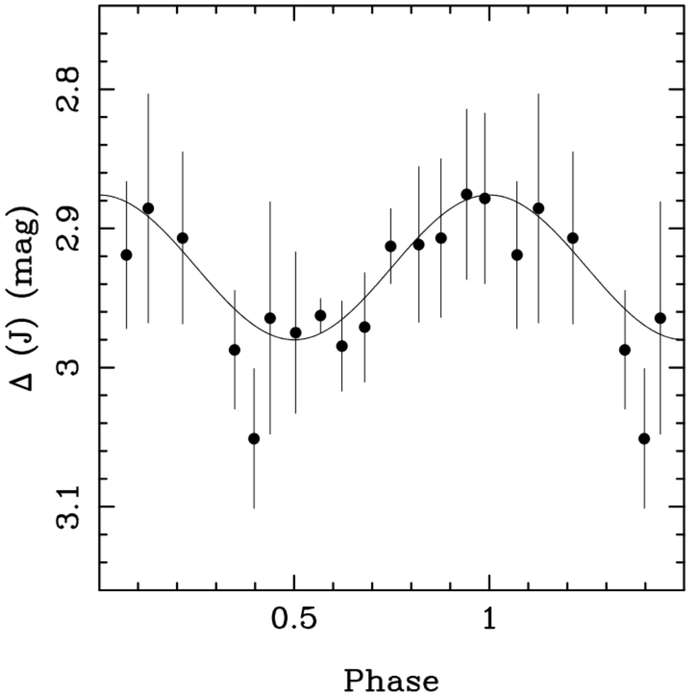
Tinney & Tolley 1999

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]

[1] LAEFF-INTA, PO Box 50727, 28080 Madrid, Spain
[2] Instituto de Astrofísica de Canarias, 38205 La Laguna, Tenerife, Spain
[3] Consejo Superior de Investigaciones Científicas, Spain

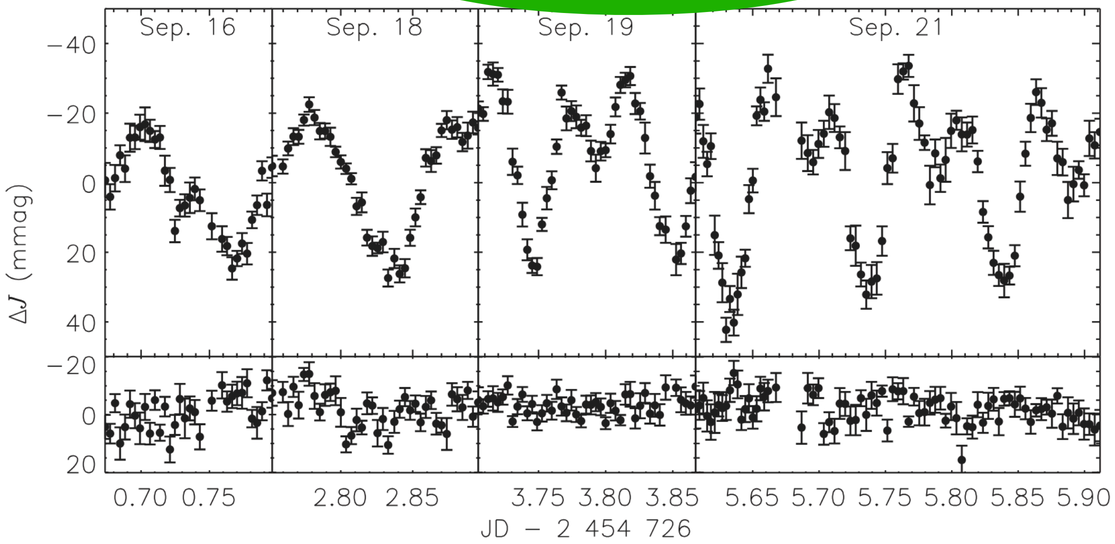
Received 7 March 2003 / Accepted 16 June 2003



Zapatero Osorio et al. 2003

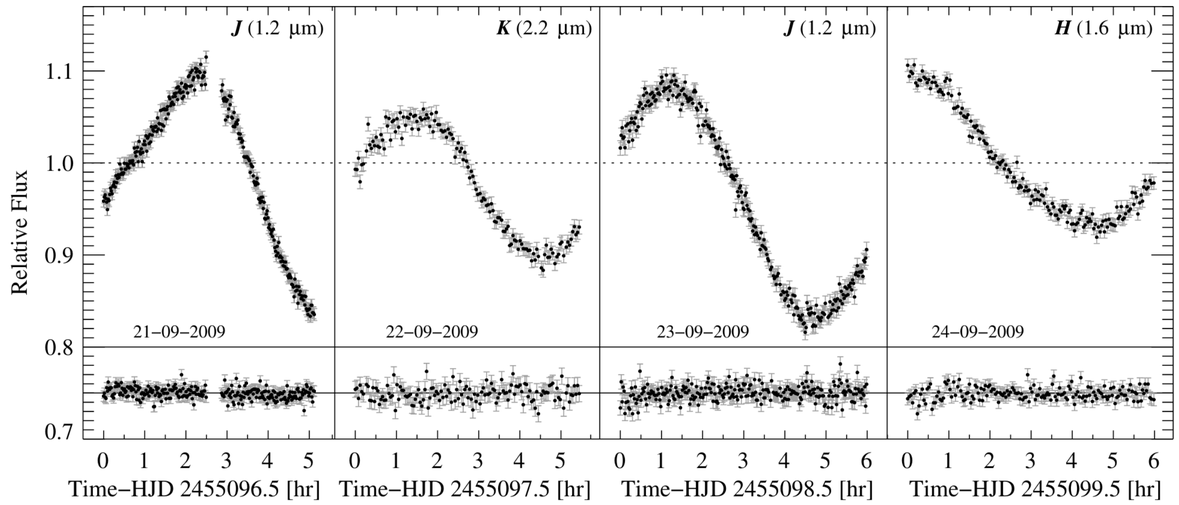
First Robust Detections of Variability in L/T Transition Brown Dwarfs

SIMP 0136 (T2.5)



Artigau et al. 2009

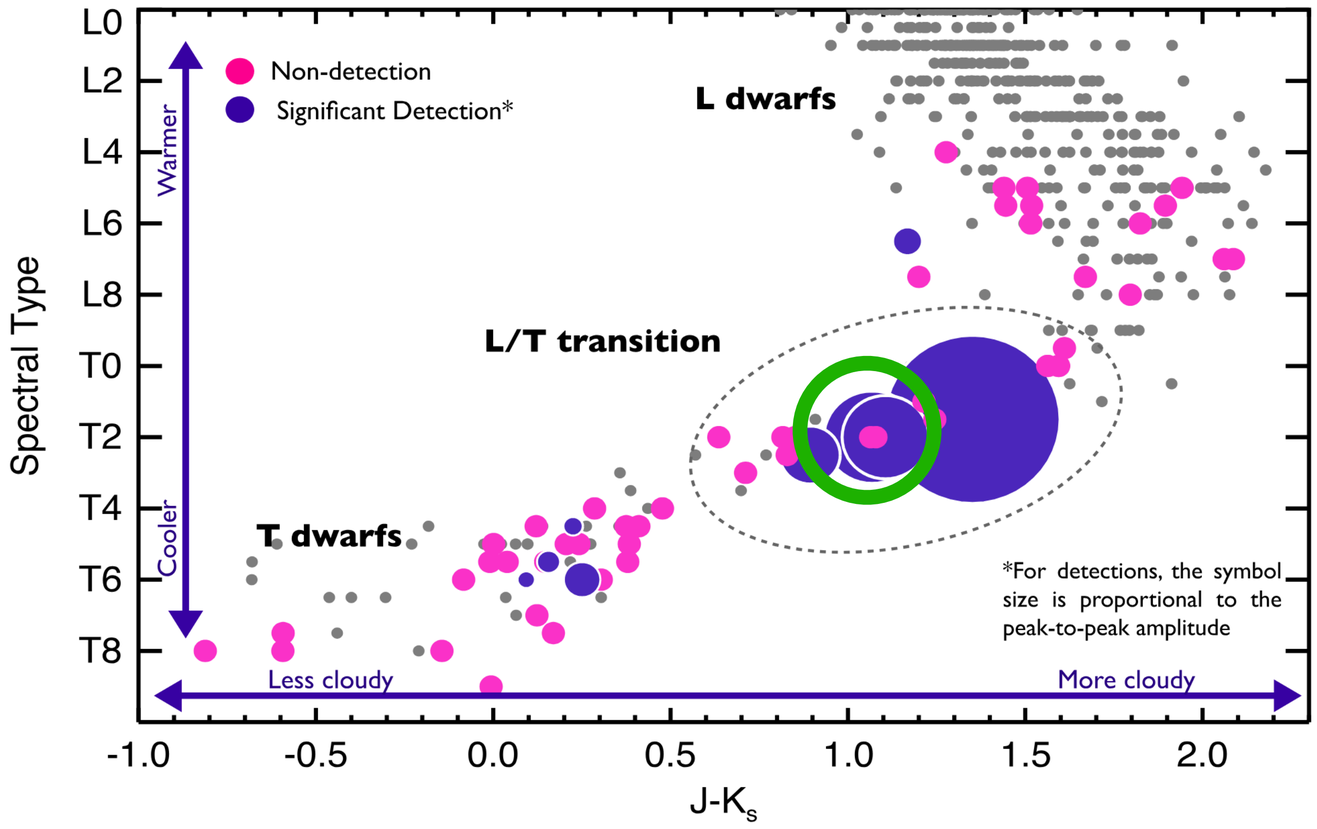
2MASS 2139 (T2.5)



Radigan et al. 2012

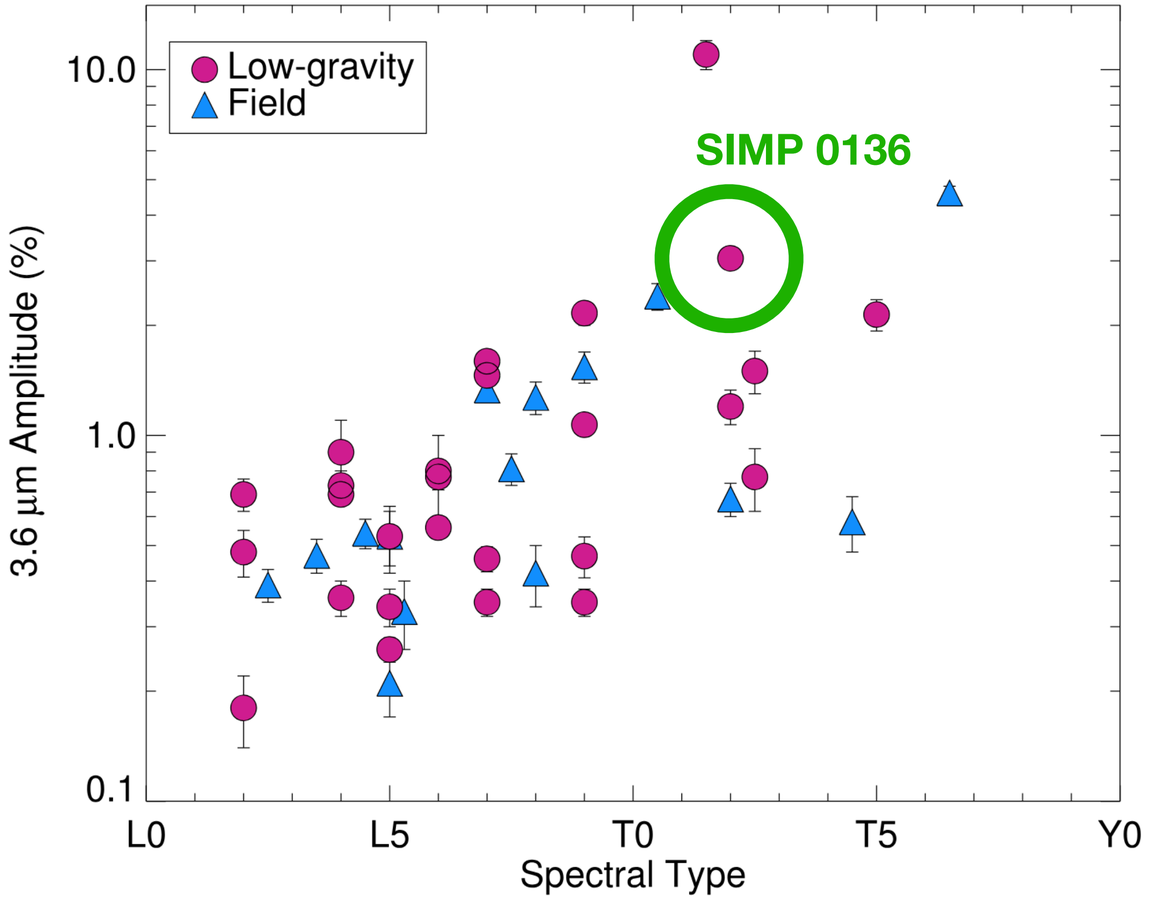
Large Surveys Show that Variability is Common at all Spectral Types

..and that variability is enhanced for low-gravity objects



Radigan et al. 2014

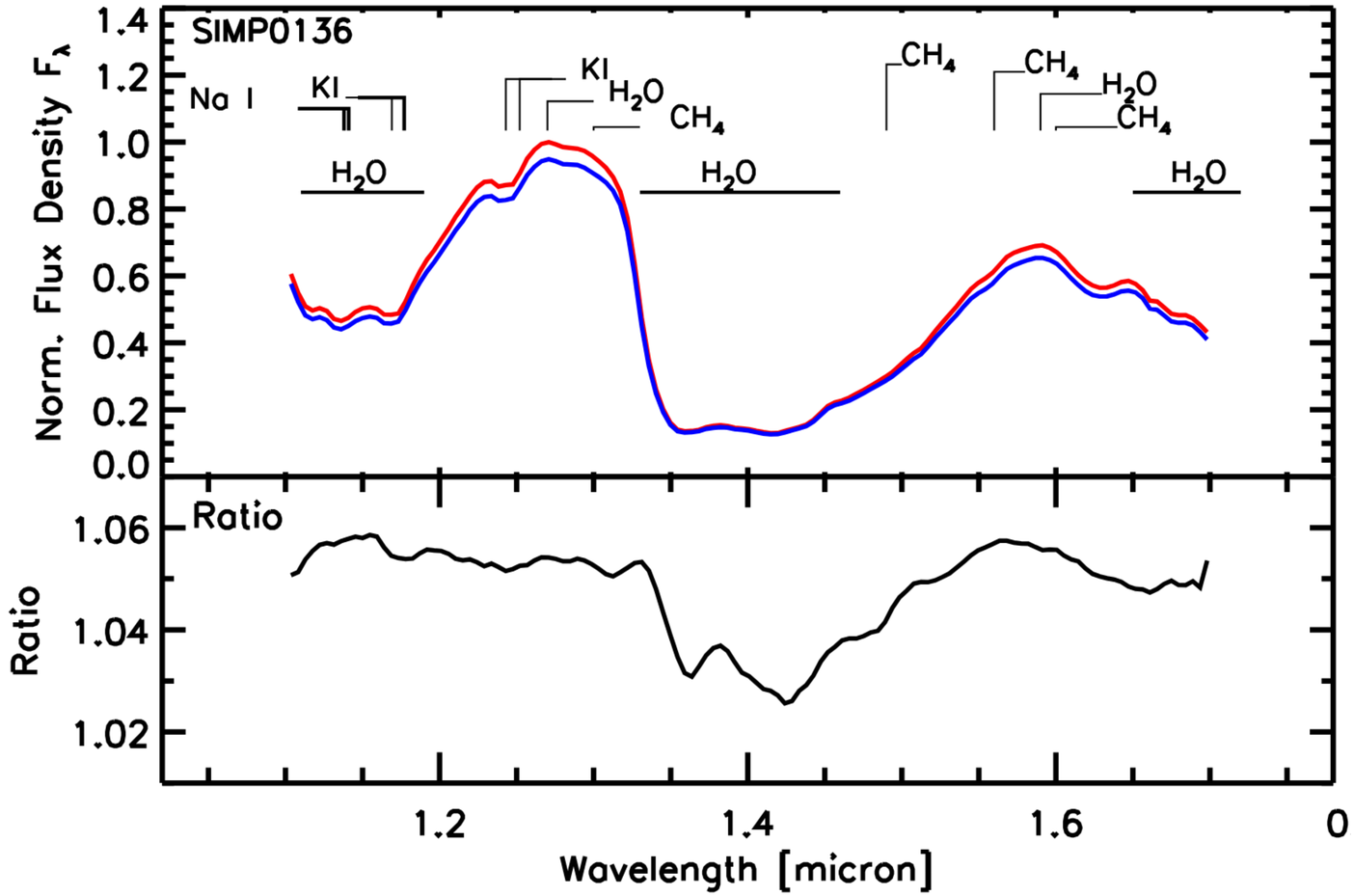
See also: Metchev et al. 2015

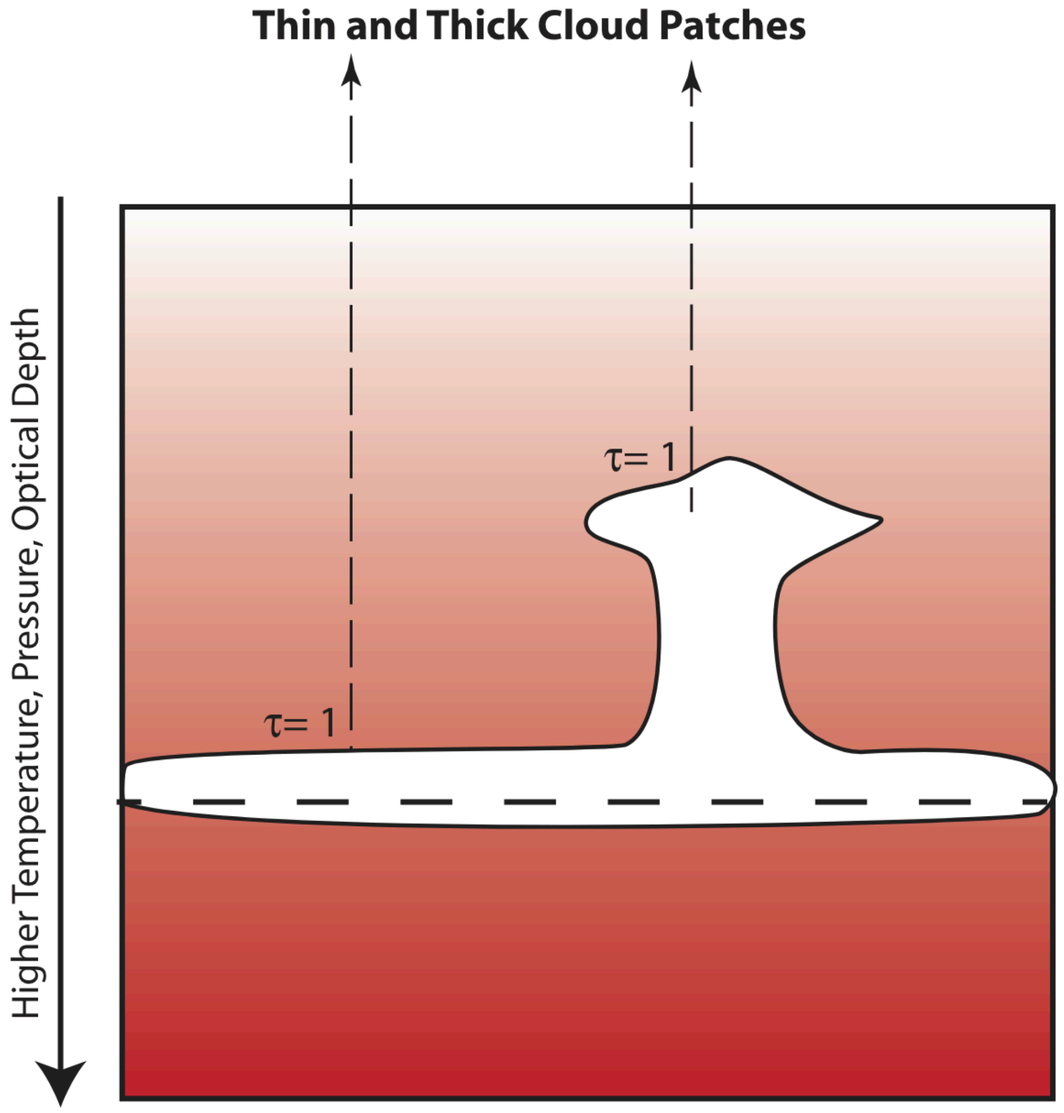


Vos et al. 2022

See also: Liu et al. 2024

Spectroscopic Variability Reveals Vertical Atmospheric Structure





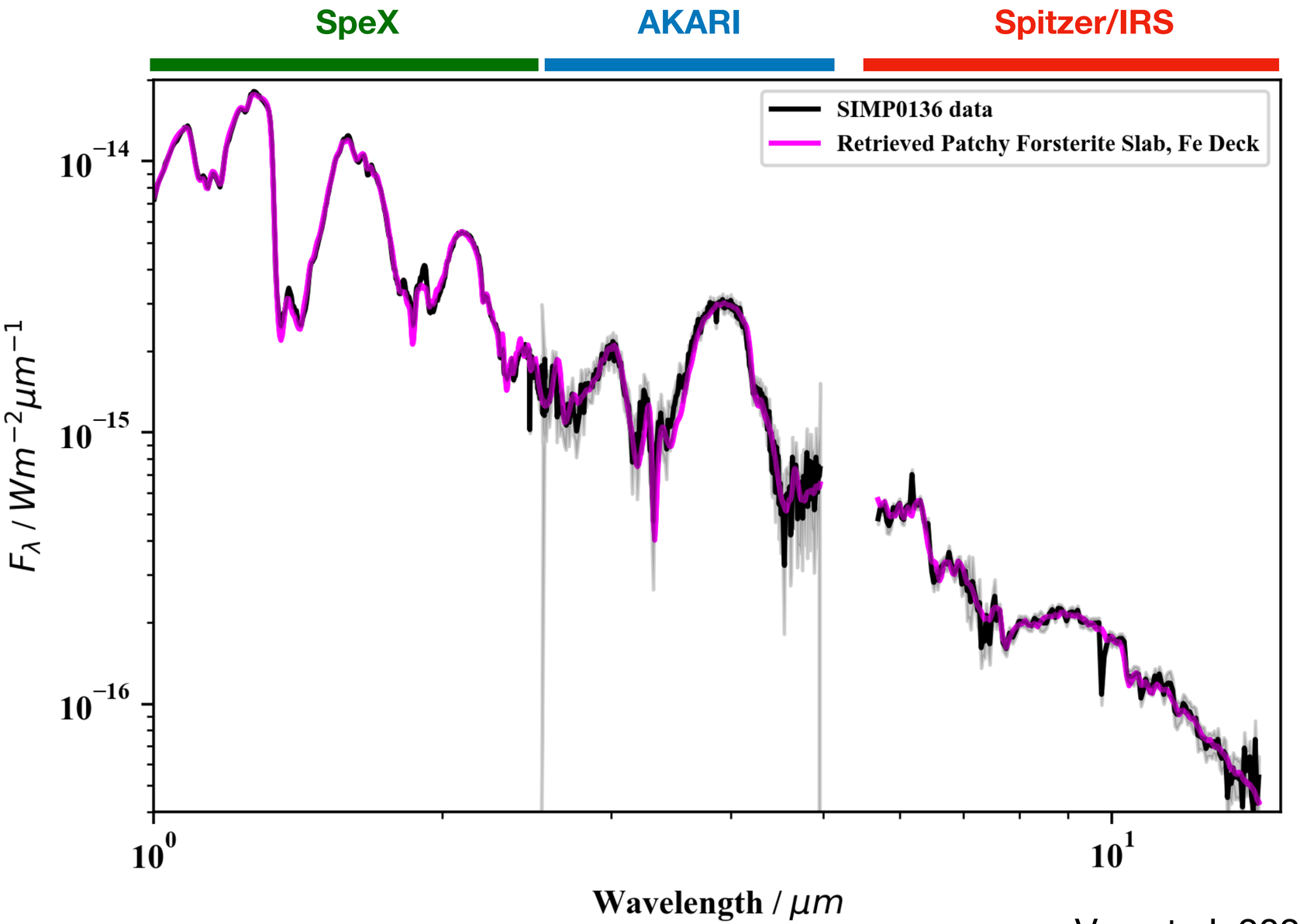
Apai et al. 2013

The Isolated Giant Planet Analog SIMP 0136

- ~1100 K
- 200 Myr old
- 11-14 M_{Jup}
- Variable (5%)
- 2.4 hr period
- 90° inclination
- Auroral emitter

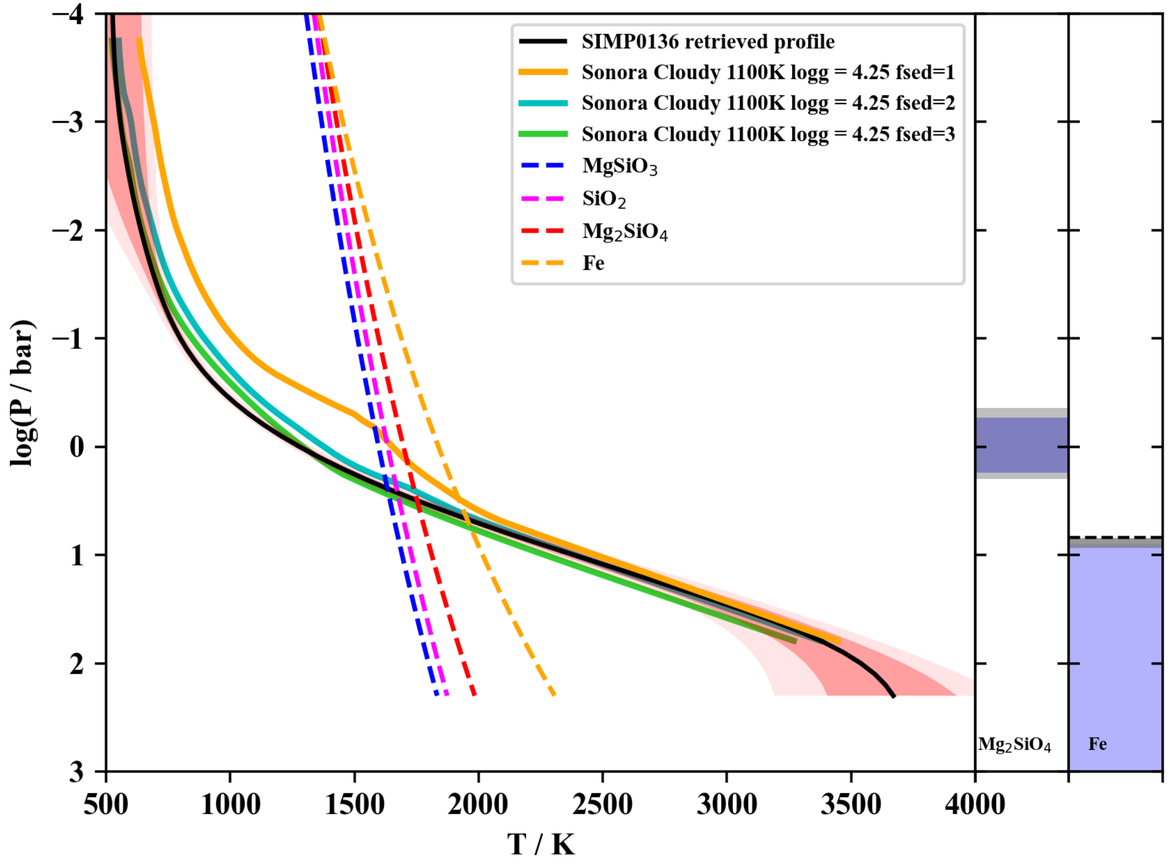
The Isolated Giant Planet Analog SIMP 0136

- ~1100 K
- 200 Myr old
- 11-14 M_{Jup}
- Variable (5%)
- 2.4 hr period
- 90° inclination
- Auroral emitter

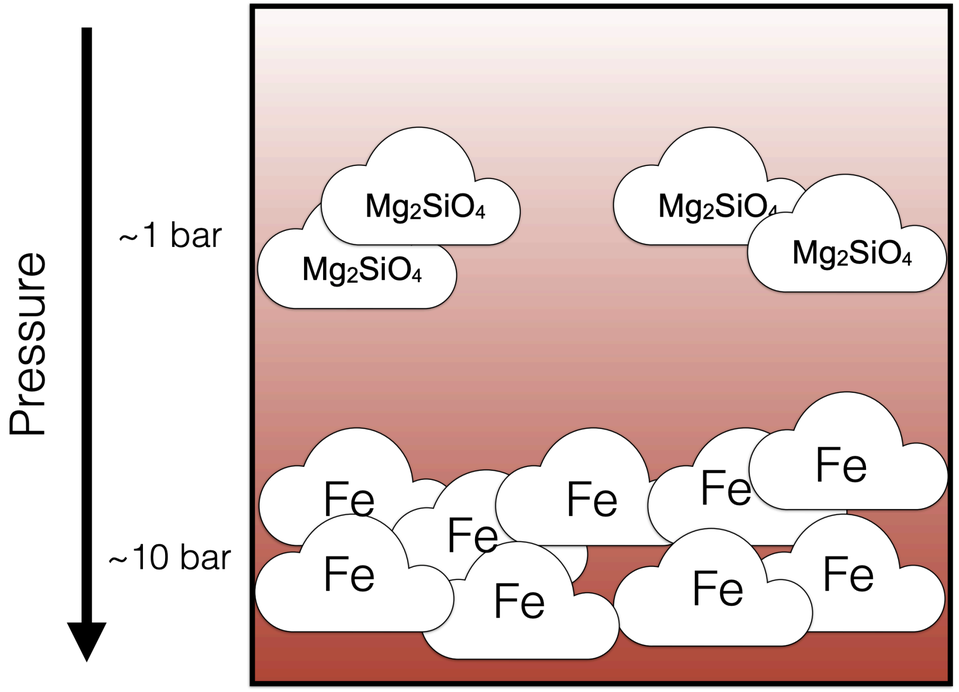


Vos et al. 2023

The Isolated Giant Planet Analog SIMP 0136



Patchy forsterite clouds above an iron deck

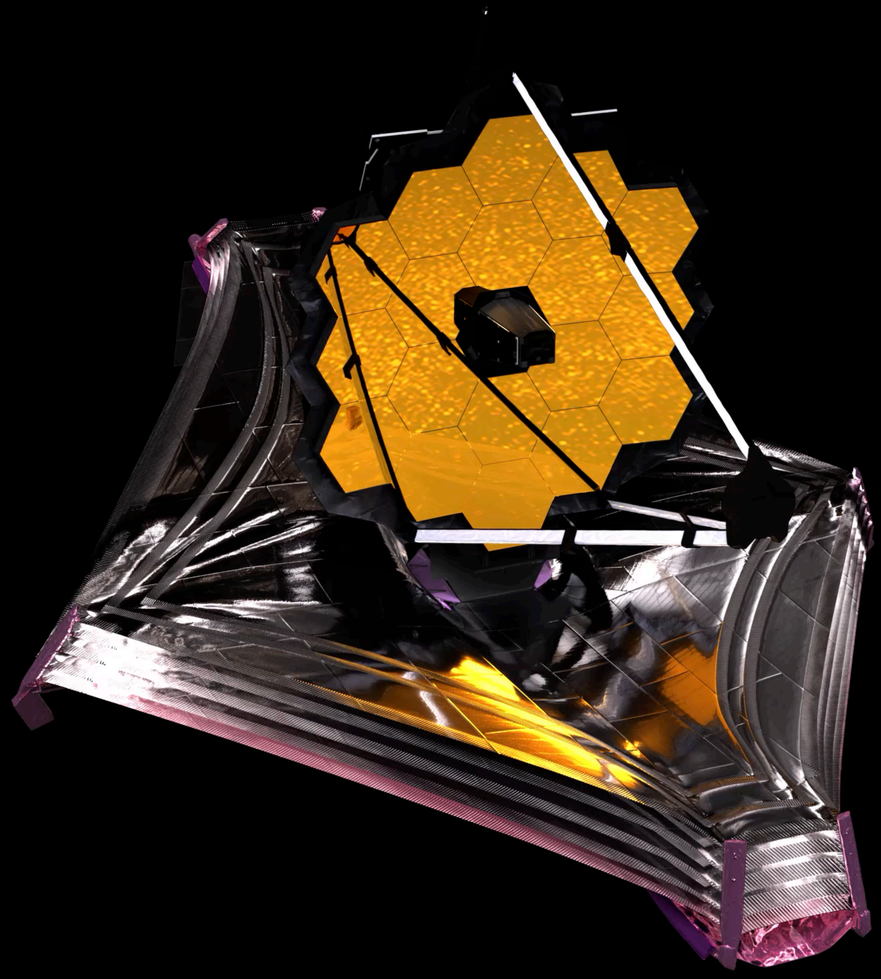


Mg_2SiO_4

Fe

Vos et al. 2023

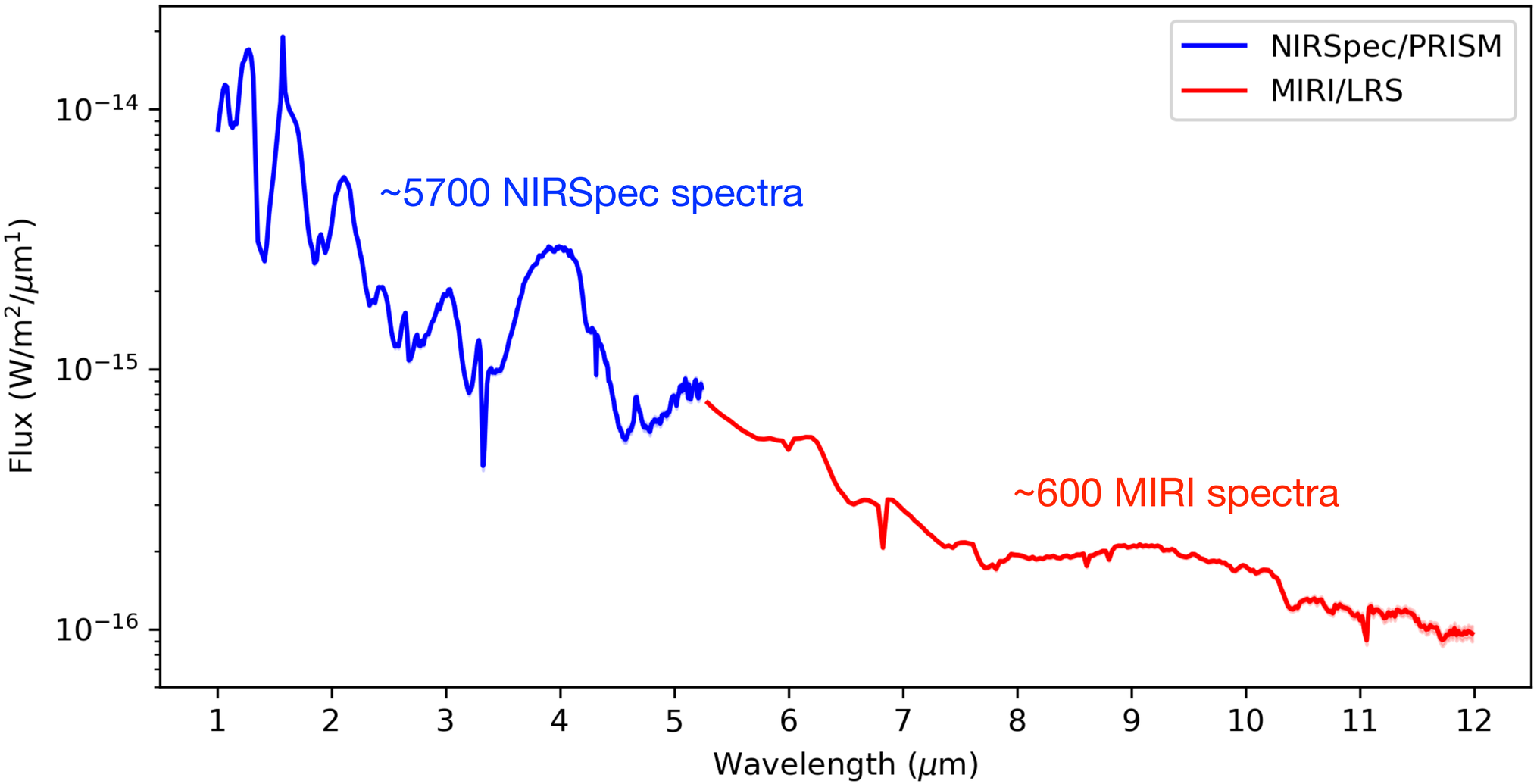
JWST is revolutionising the field of exometeorology



Complementary JWST Programs Probe Extrasolar Weather

3375	Dancing 1 - 14 micron spectra to solve the cloudy and chemical puzzle of brown dwarf variability	PI: Niall Whiteford Co-PI: Yifan Zhou
3548	Exometeorology: Weather on an Isolated World Beyond Our Own	PI: Johanna Vos
2965	Clouds or Chemistry?: Pinpointing the drivers of variability across the L/T transition via the benchmark L/T binary WISE 1049AB	PI: Beth Biller
3181	Monitor a variable planetary mass companion with NIRSpec IFU	PI: Yifan Zhou

JWST NIRSpec + MIRI Spectra of an Isolated World: SIMP 0136

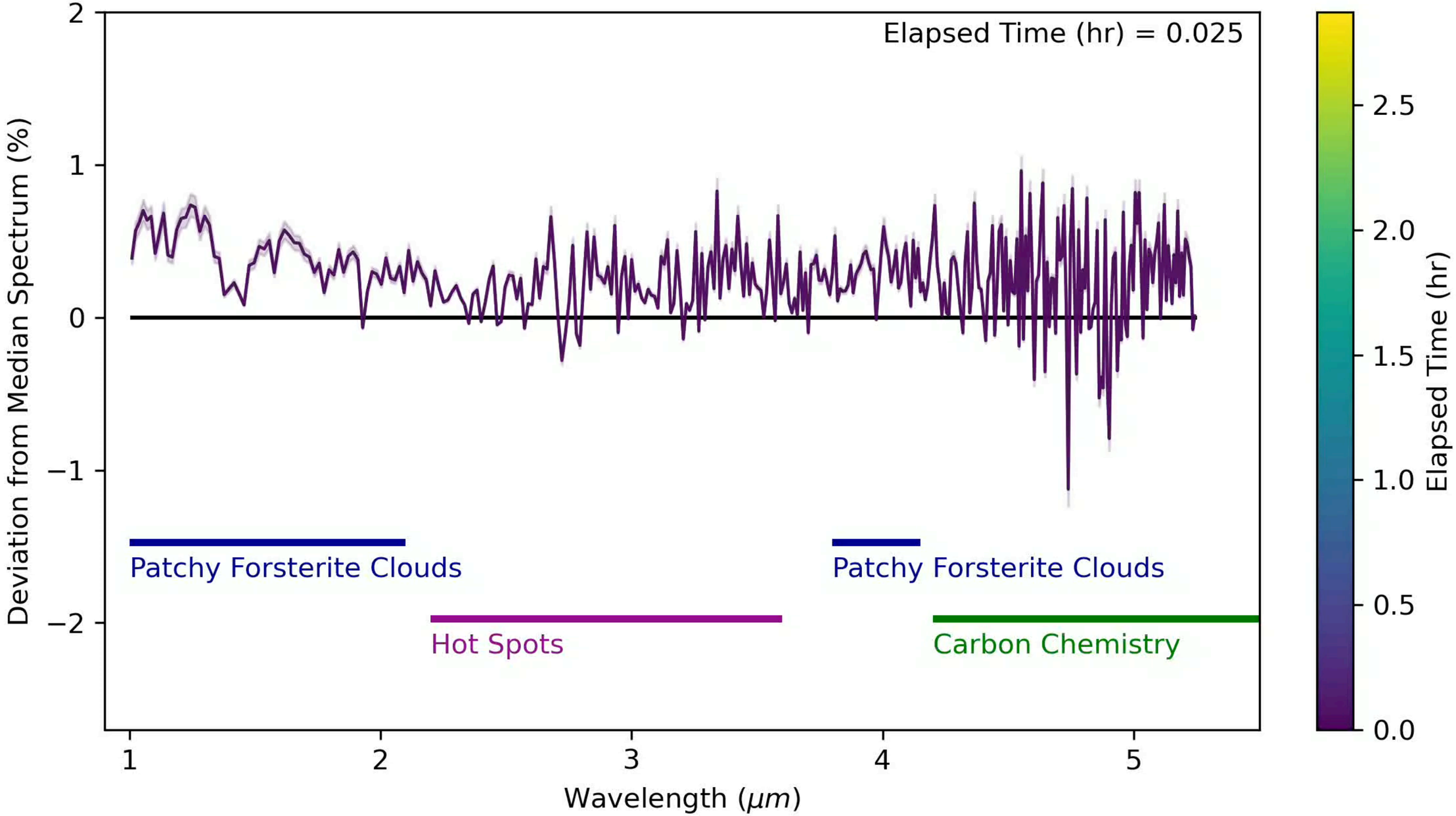


Allie McCarthy
Boston University
Monday Splinter

Look out for Program #1209 for NIRISS monitoring (PI: Artigau)

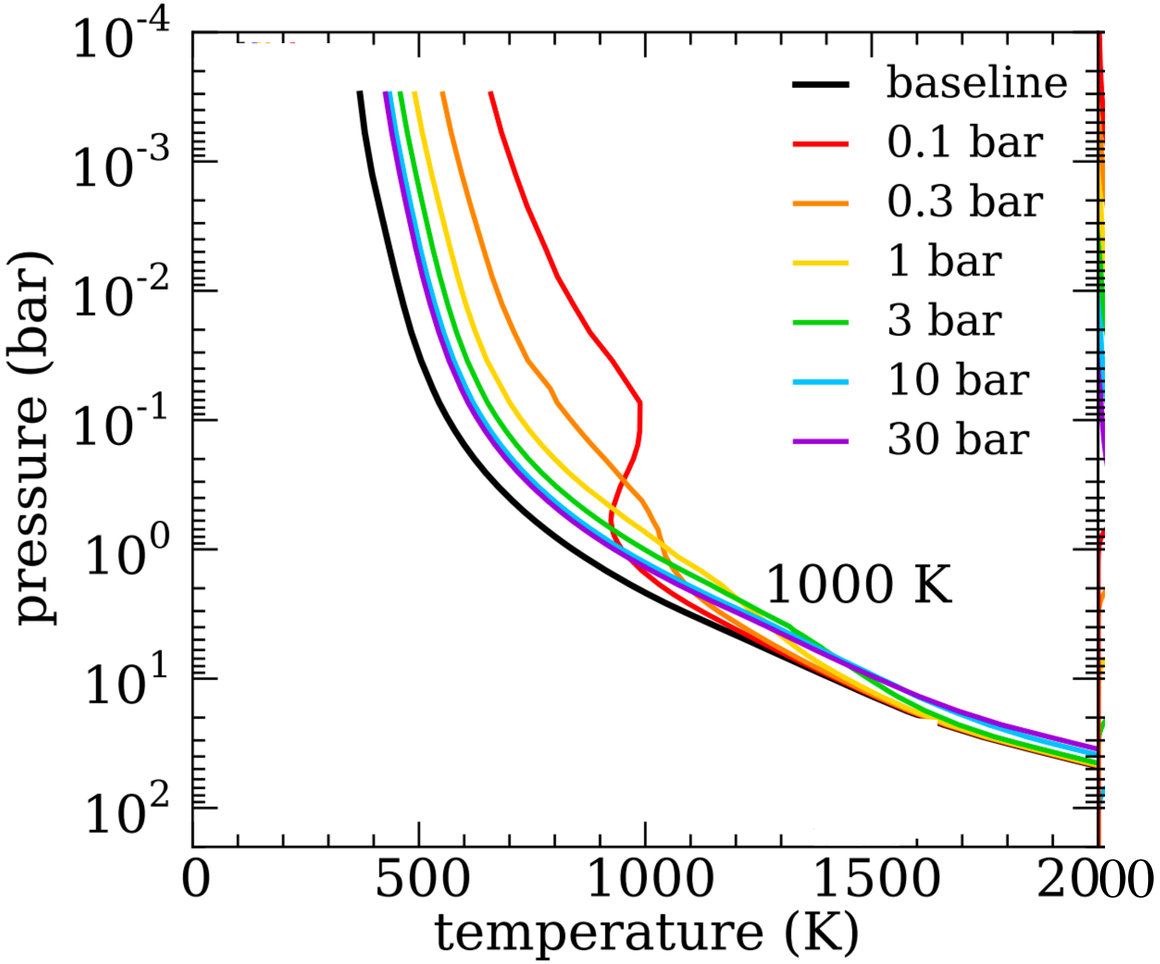
McCarthy, Vos et al. in prep

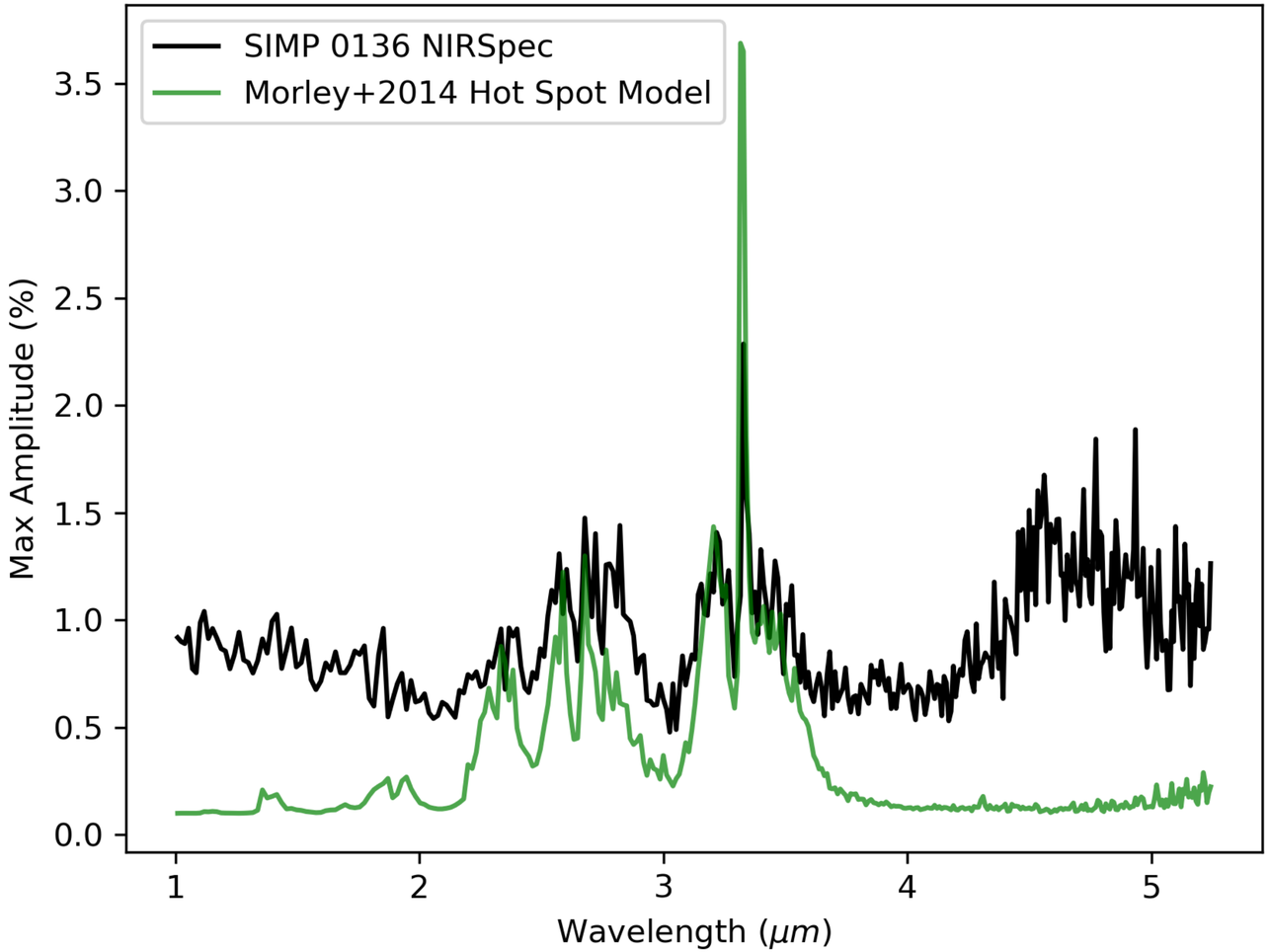
JWST NIRSpec/Prism Monitoring Reveals Highly Complex Weather



McCarthy, Vos et al. in prep

Evidence for Variability Driven by Upper Atmospheric Heating

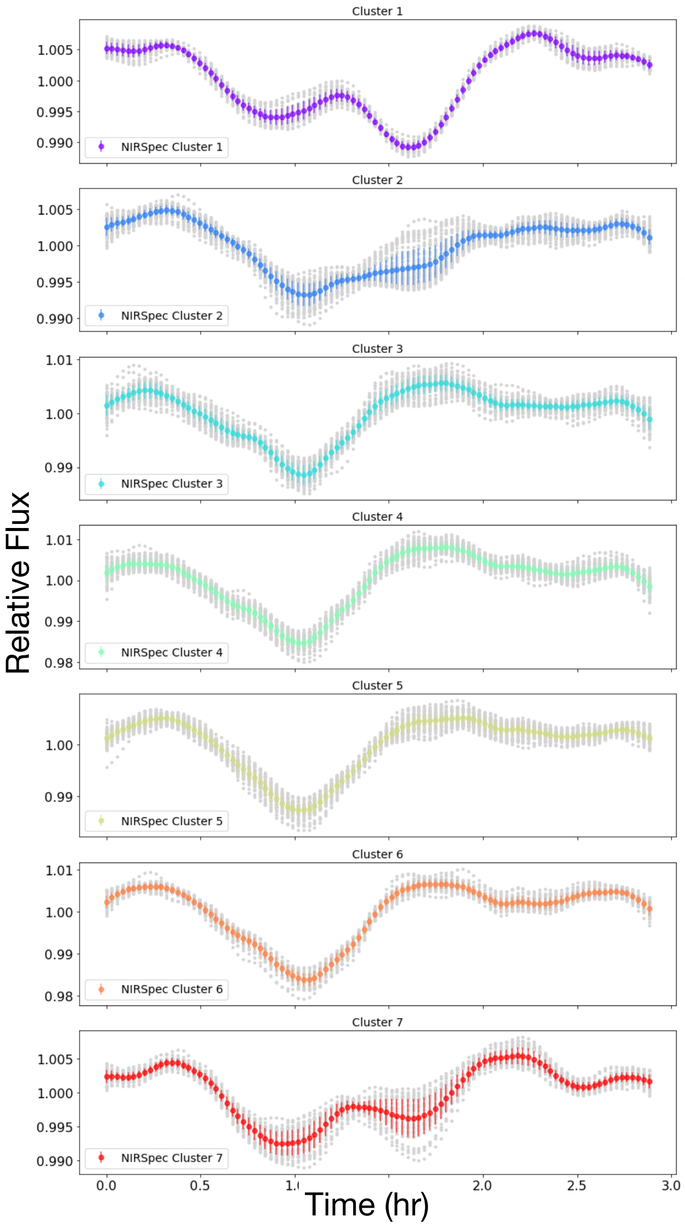




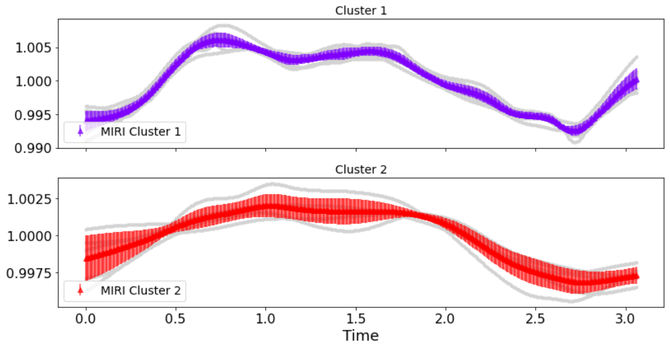
Morley et al. 2014

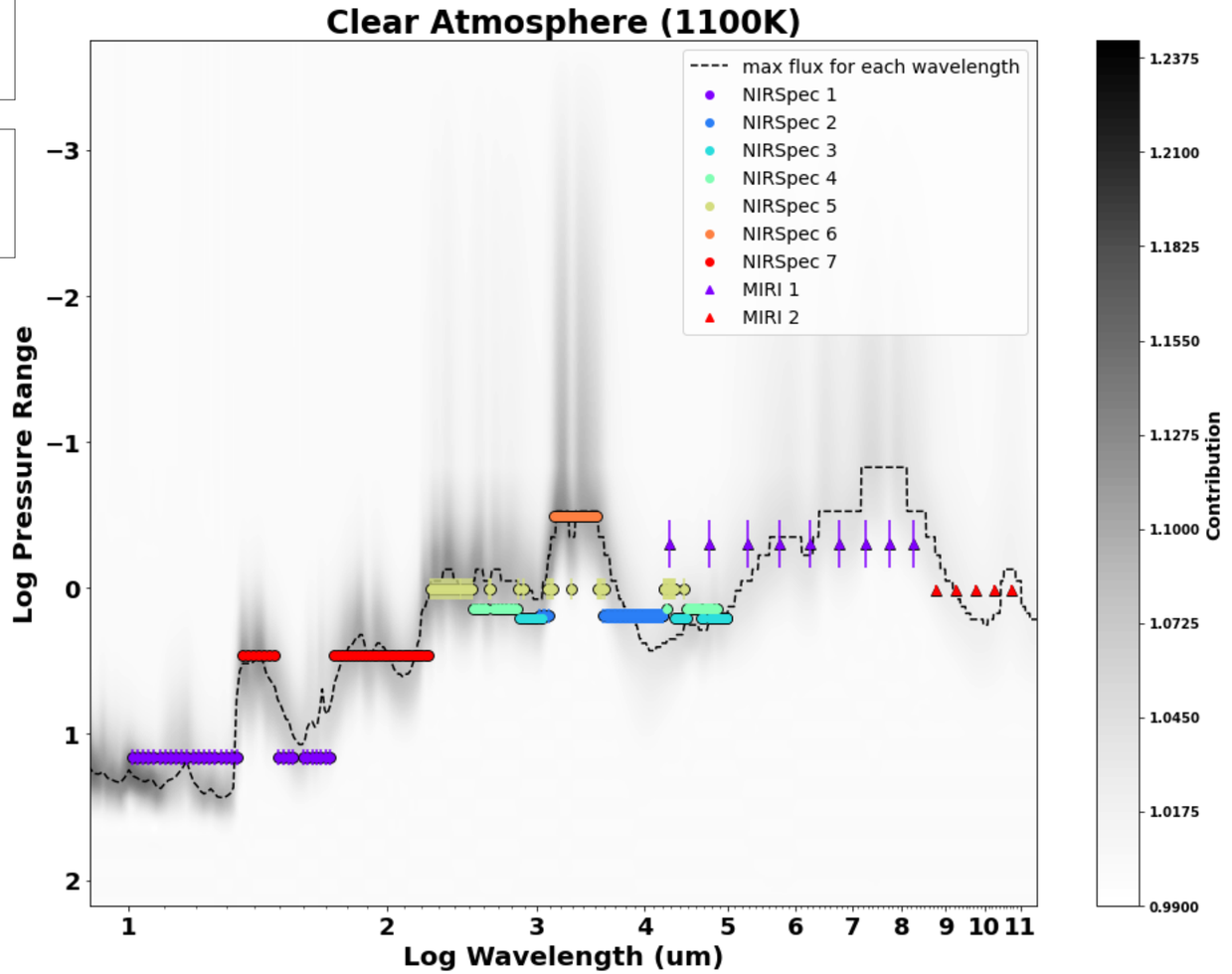
Light Curve Behaviours Correlate with Pressure

7 NIRSpec Clusters



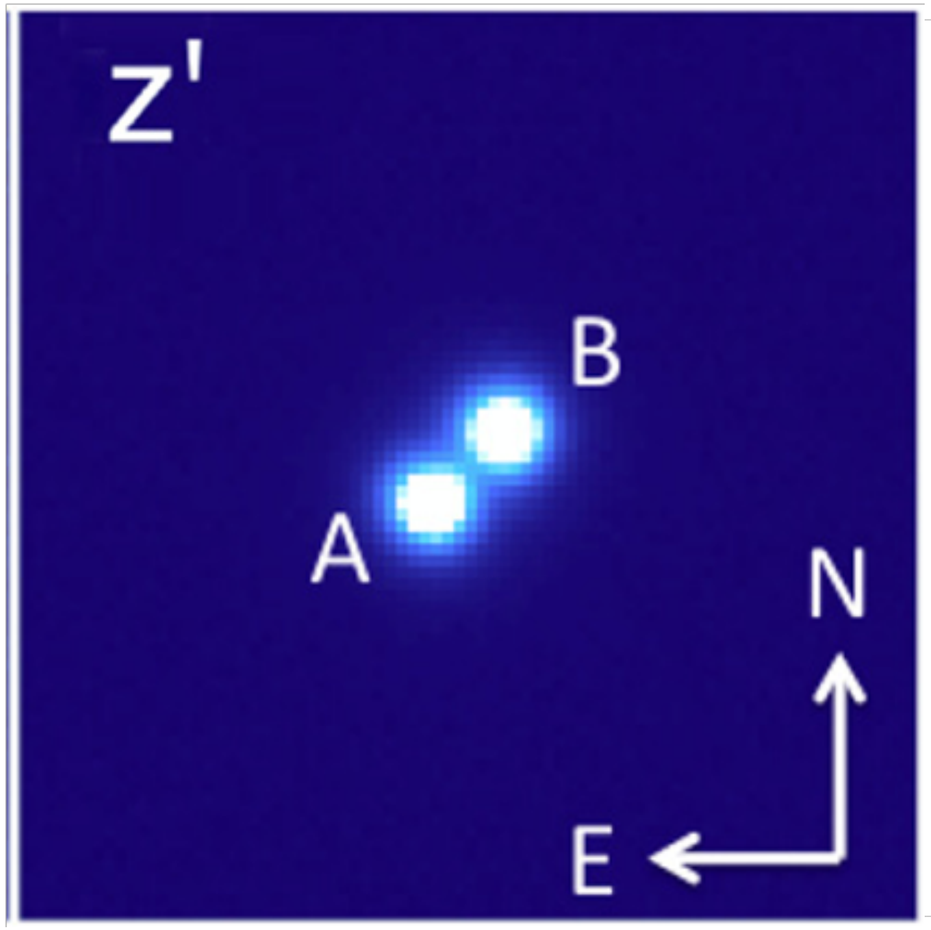
2 MIRI Clusters



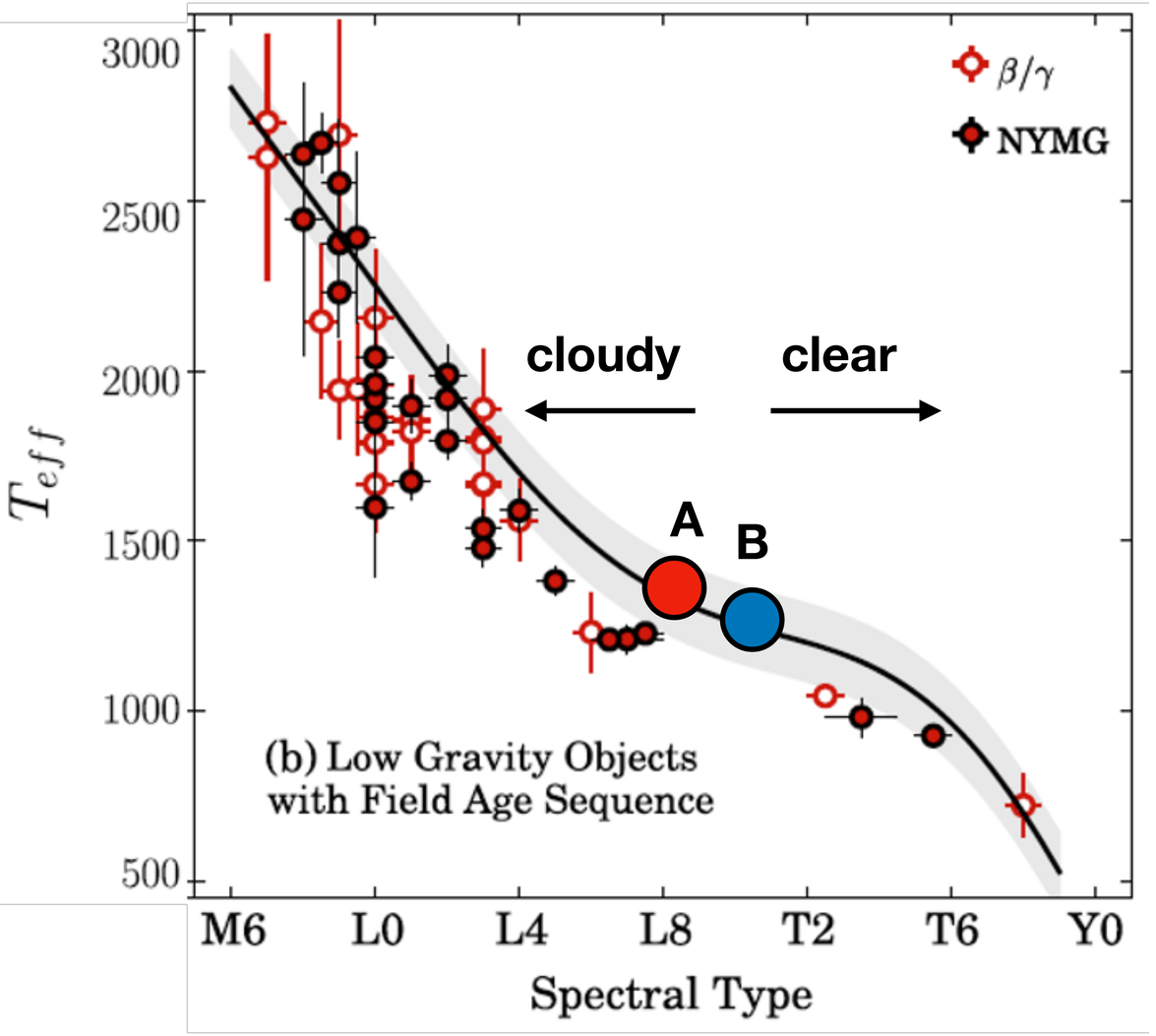


McCarthy, Vos et al. in prep

Closest Brown Dwarfs WISE 1049AB Straddle the L/T Transition

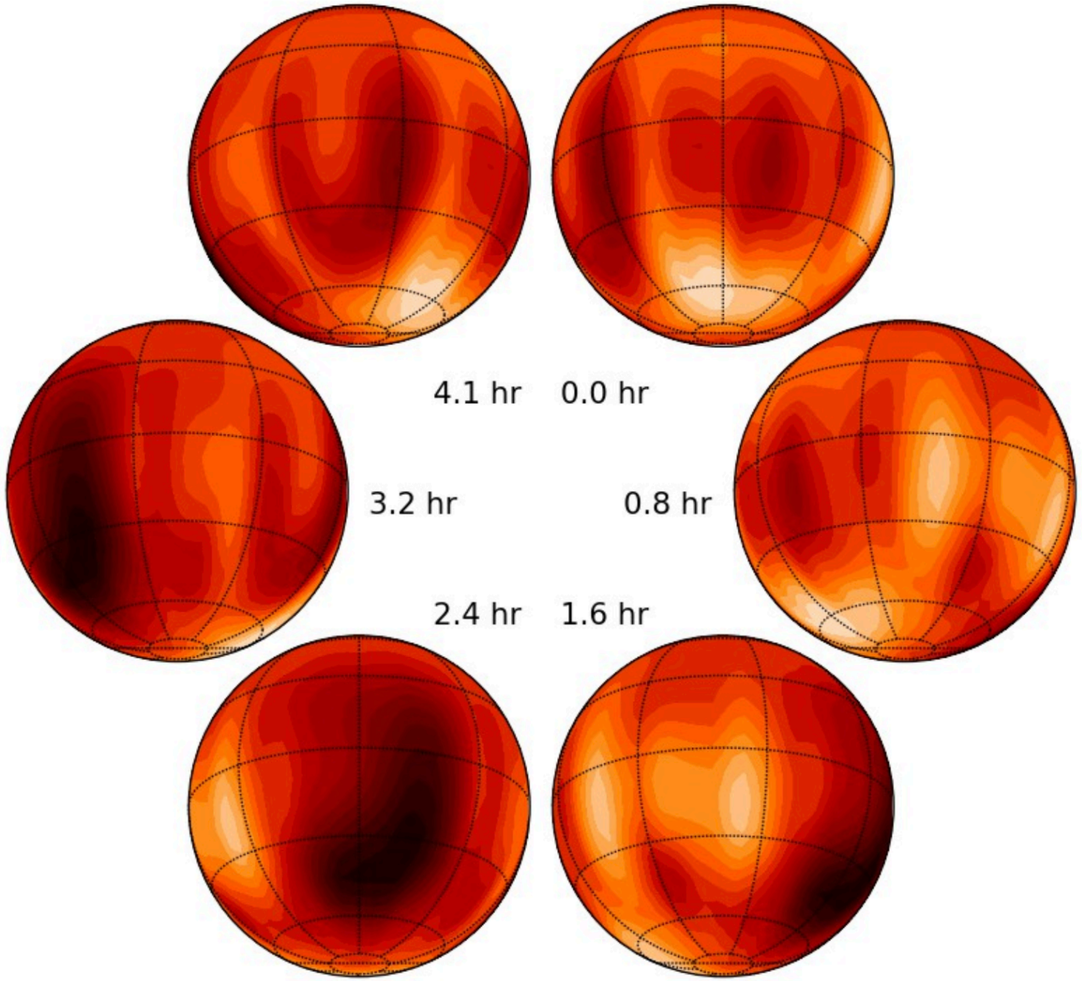


Biller et al. 2013



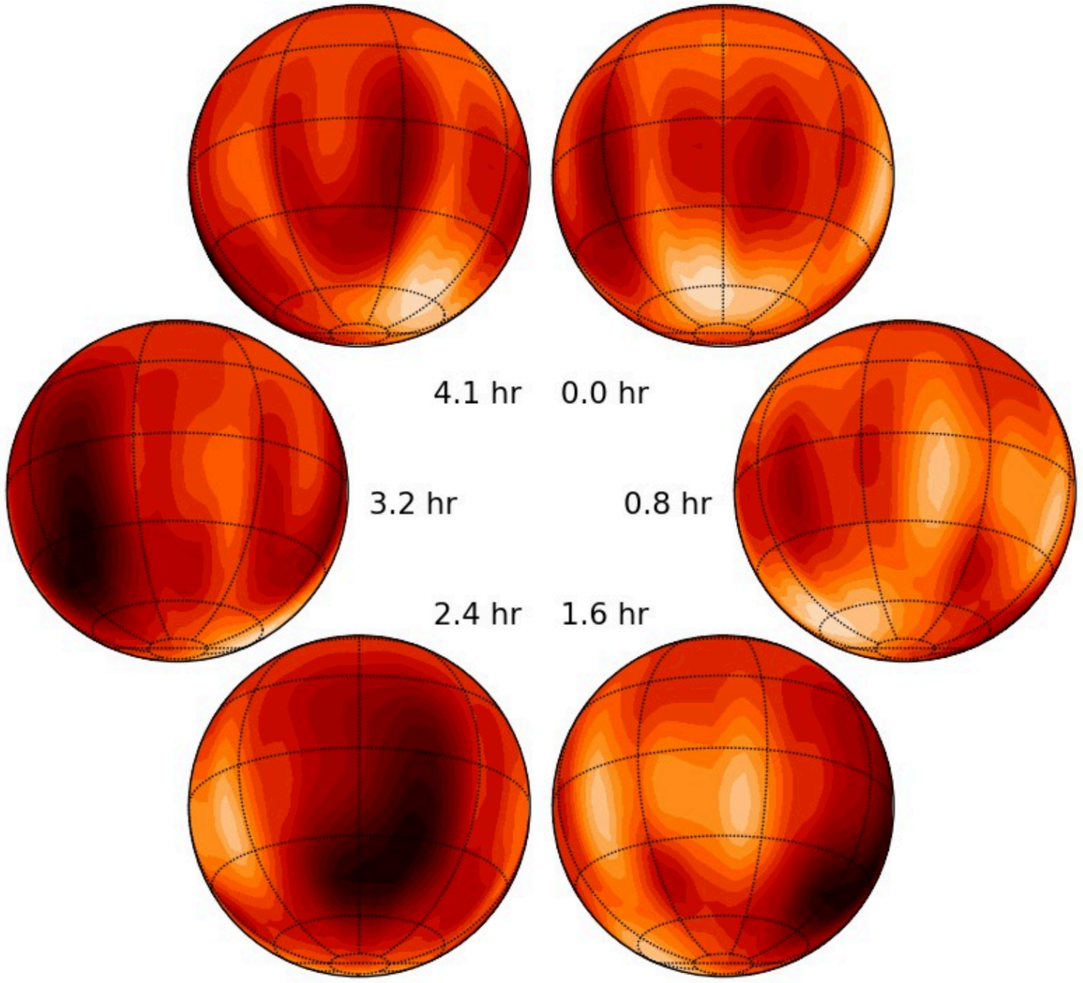
Filipazzo et al. 2015

Global Weather Cloud Map of WISE 1049B



Crossfield et al. 2014

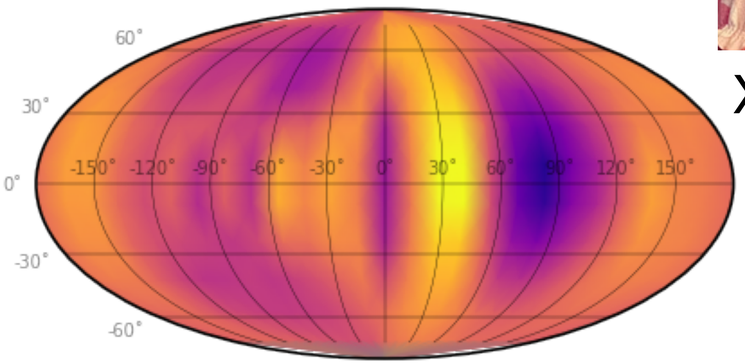
Global Weather Cloud Map of WISE 1049B



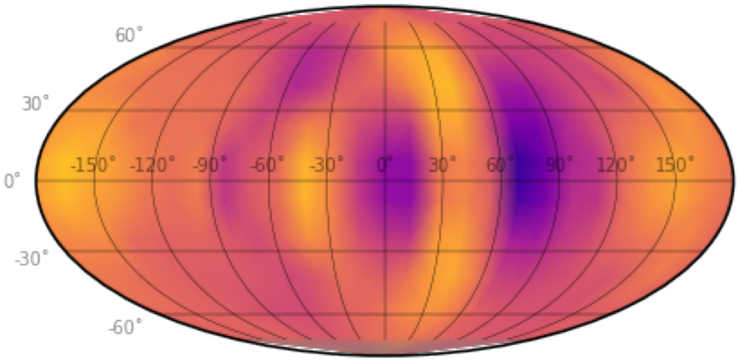
Crossfield et al. 2014

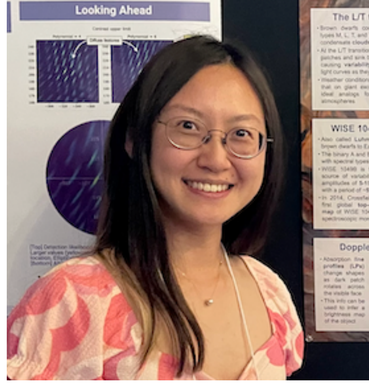
WISE 1049B Feb 11

H-band



K-band



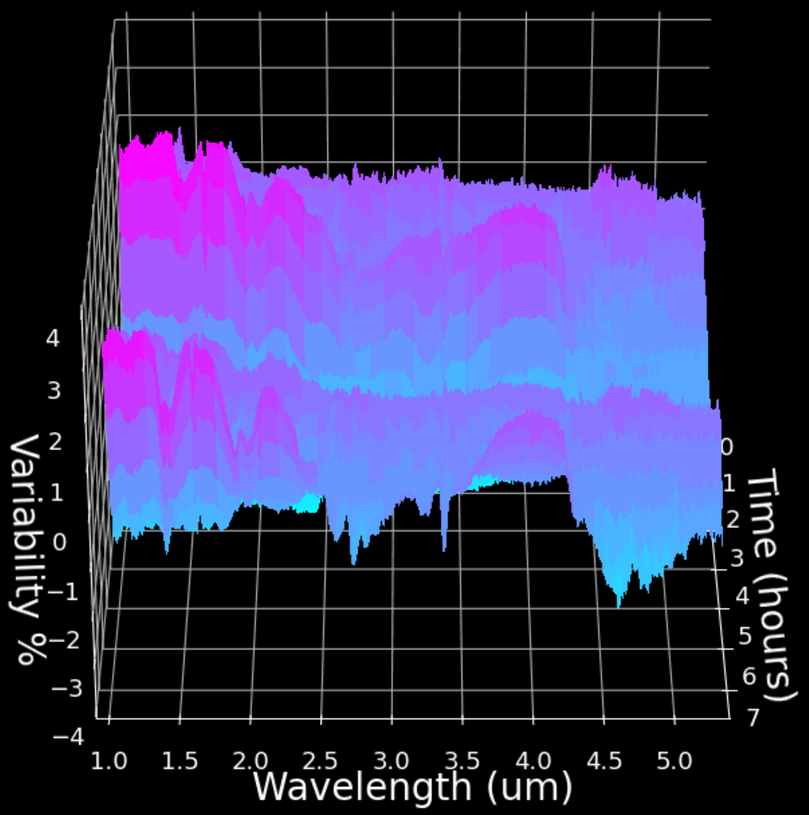


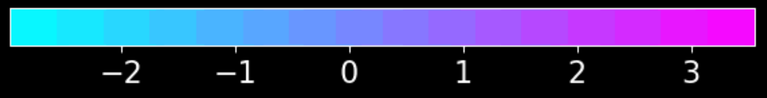
Xueqing Chen
U Edinburgh

Chen et al. under review

WISE 1049B Shows Highly Complex Variability from 1-14 micron

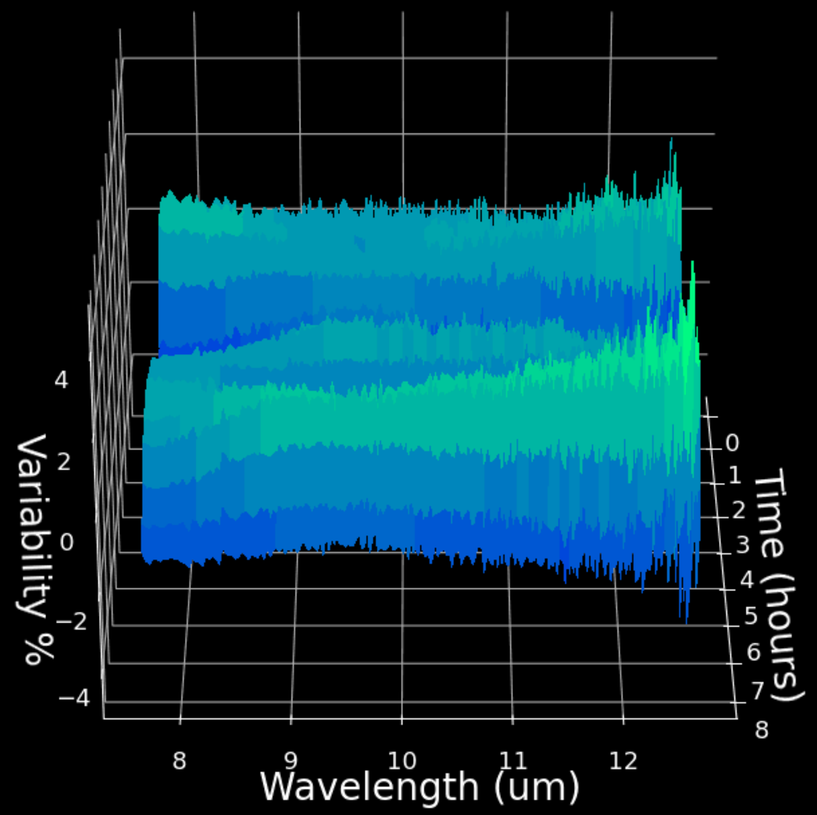
NIRSpec

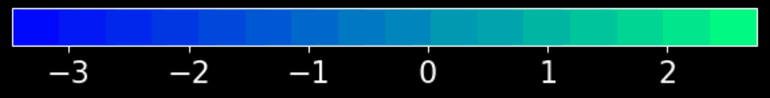




Variability (%)

MIRI



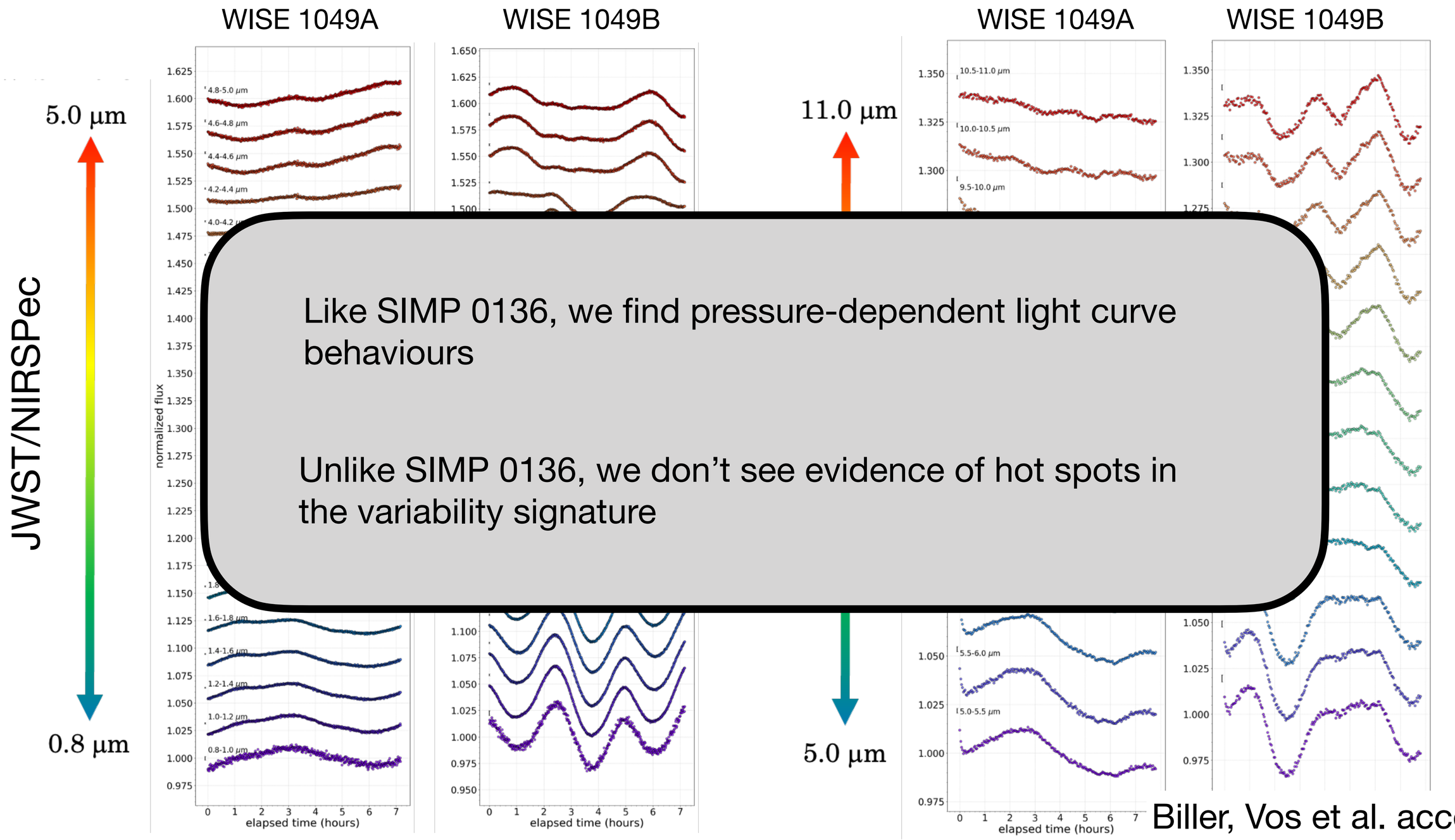


Variability (%)

PI: Biller, Animations by N. Whiteford

Biller, Vos et al. accepted

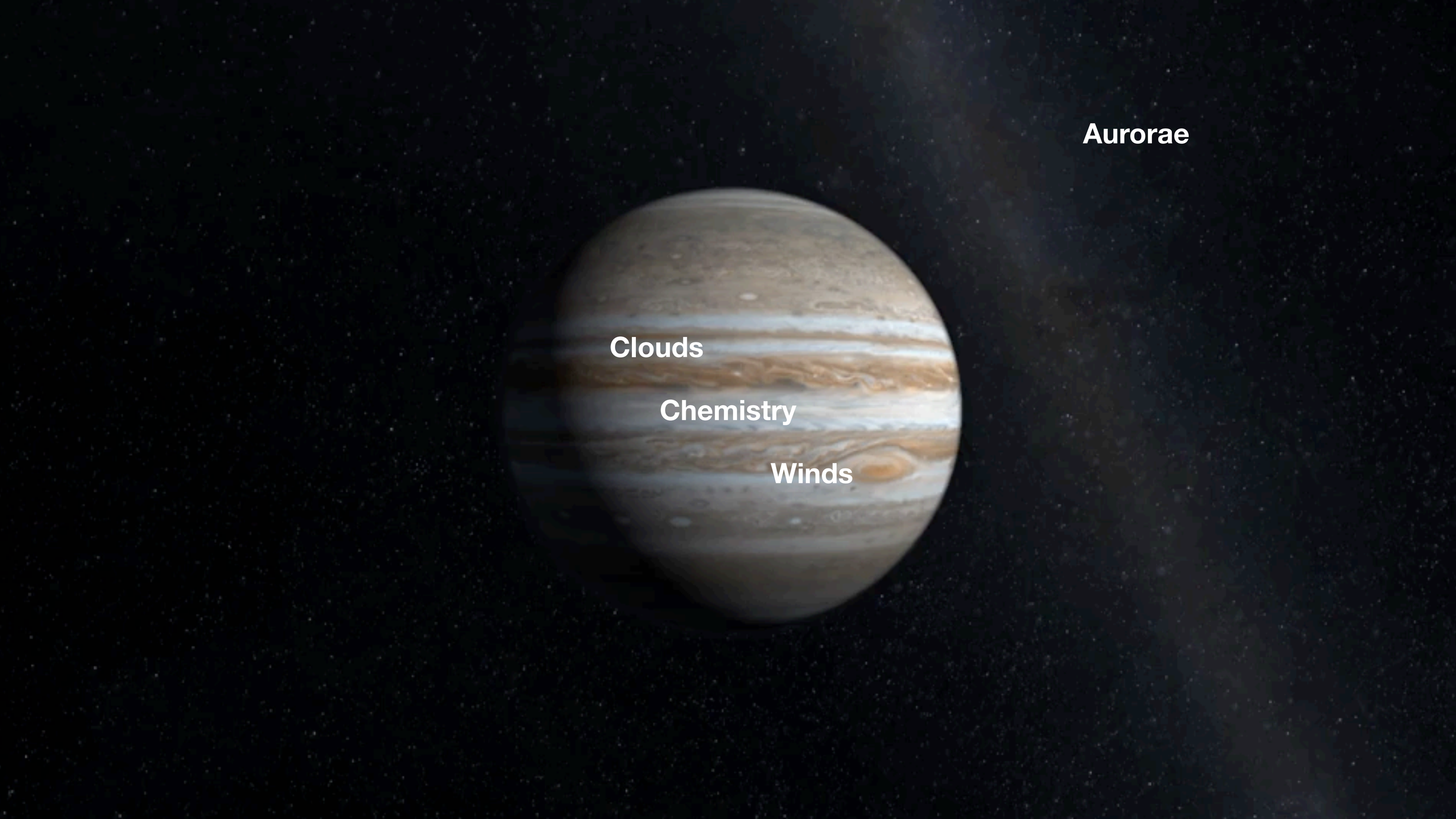
Light Curves Highlight Wavelength Dependent Behaviour



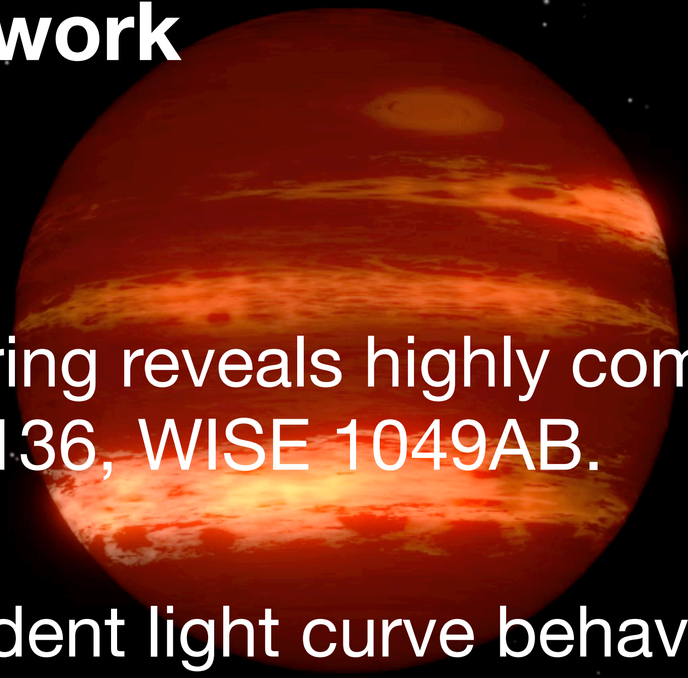
Like SIMP 0136, we find pressure-dependent light curve behaviours

Unlike SIMP 0136, we don't see evidence of hot spots in the variability signature

Biller, Vos et al. accepted


Aurorae
Clouds
Chemistry
Winds

Summary & Future work



JWST variability monitoring reveals highly complex weather in the atmospheres of SIMP 0136, WISE 1049AB.

We find pressure dependent light curve behaviours in all three targets.

We find variability driven by upper atmospheric heating in our auroral target SIMP 0136.

Look out for future papers applying forward modelling, retrieval and mapping techniques to these data.