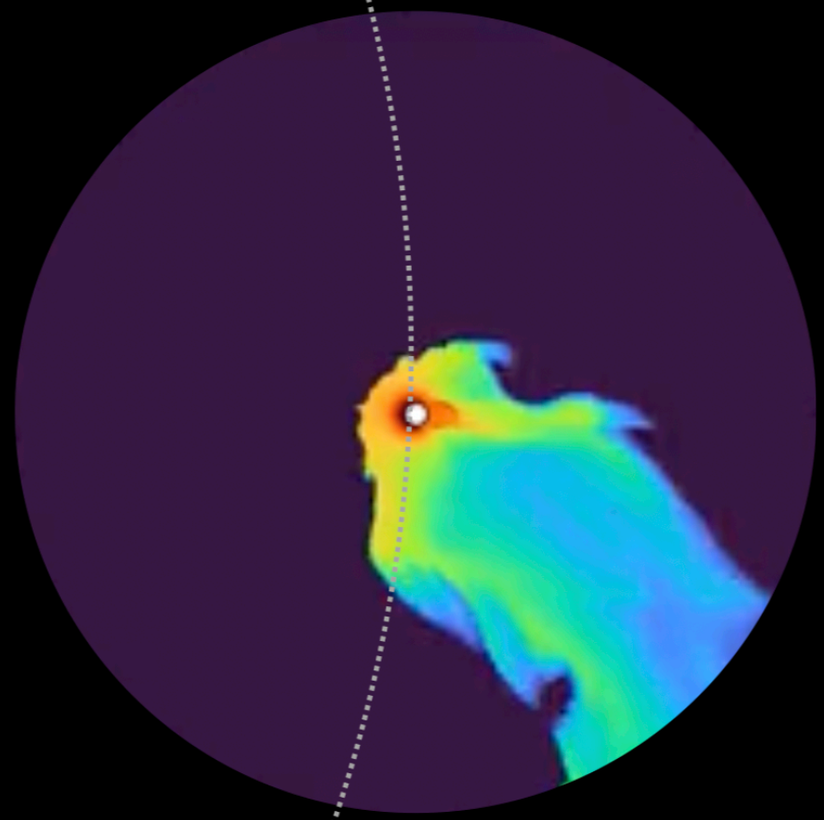
HD 209458b's Lyman-alpha double transit

Jessica Spake

E. Schreyer, P. Loyd, J. Owen, H. Knutson, L. Hillenbrand,
S. Vissapragada, M. Zhang



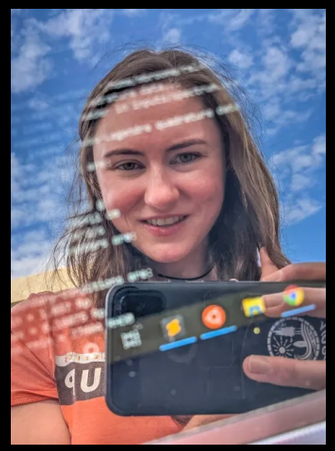
CARNEGIE SCIENCE

Collaborator Spotlight

Ethan Schreyer
UCSC

Parke Loyd
Eureka

James Owen
Imperial



Madelyn Broome
UCSC

Lynne Hillenbrand
Caltech

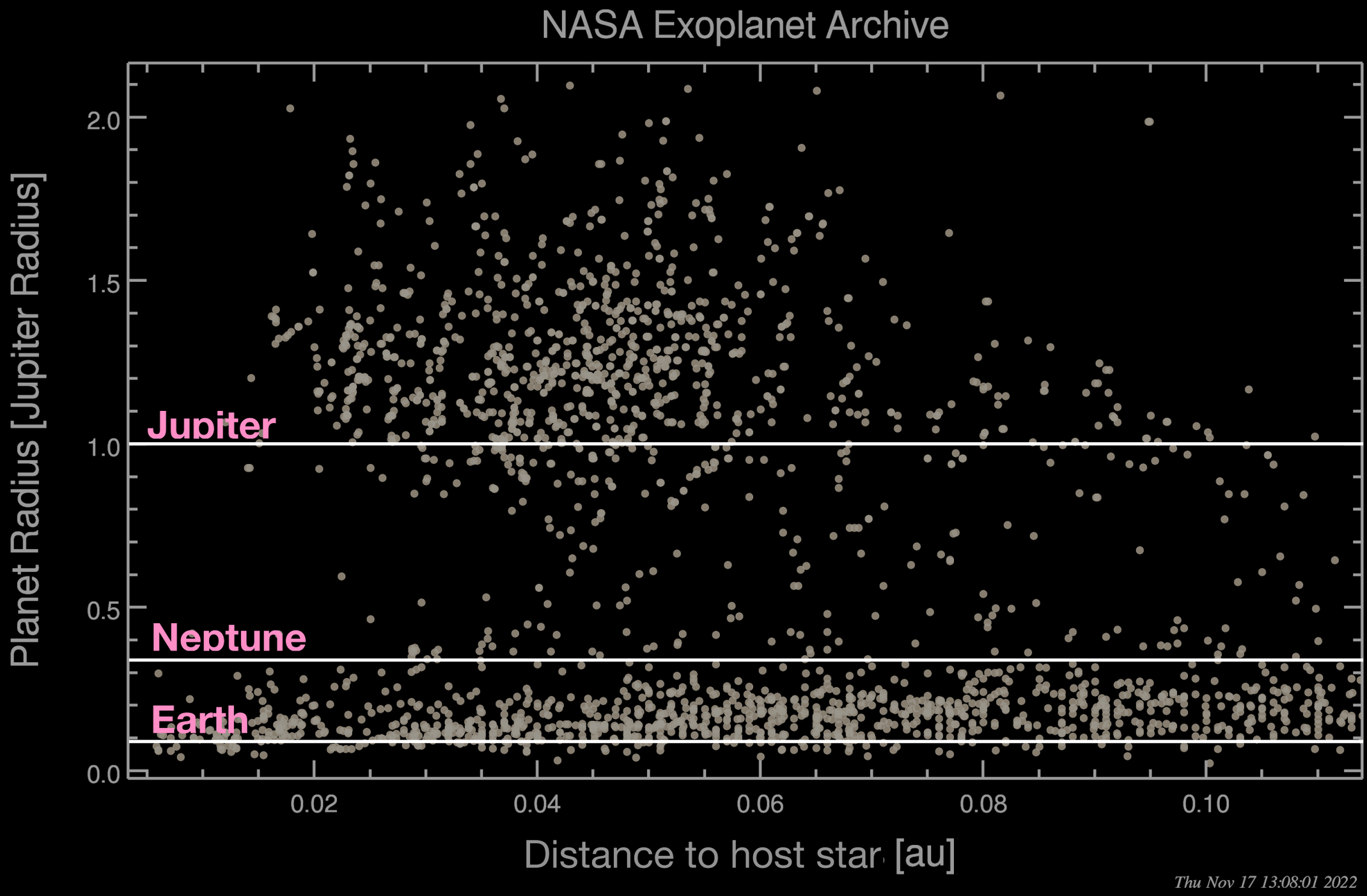
Shreyas Vissapragada
Carnegie

Heather Knutson
Caltech

Michael Zhang
Chicago

Solar Orbiter/ SOHO

Wang & Dai (2020)



See Owen & Wu (2013), Lopez & Fortney (2013), Mazeh et al. (2016), Fulton et al. (2017), Rogers et al. (2021)

It is still difficult to predict which exoplanets are undergoing ***measurable*** mass-loss

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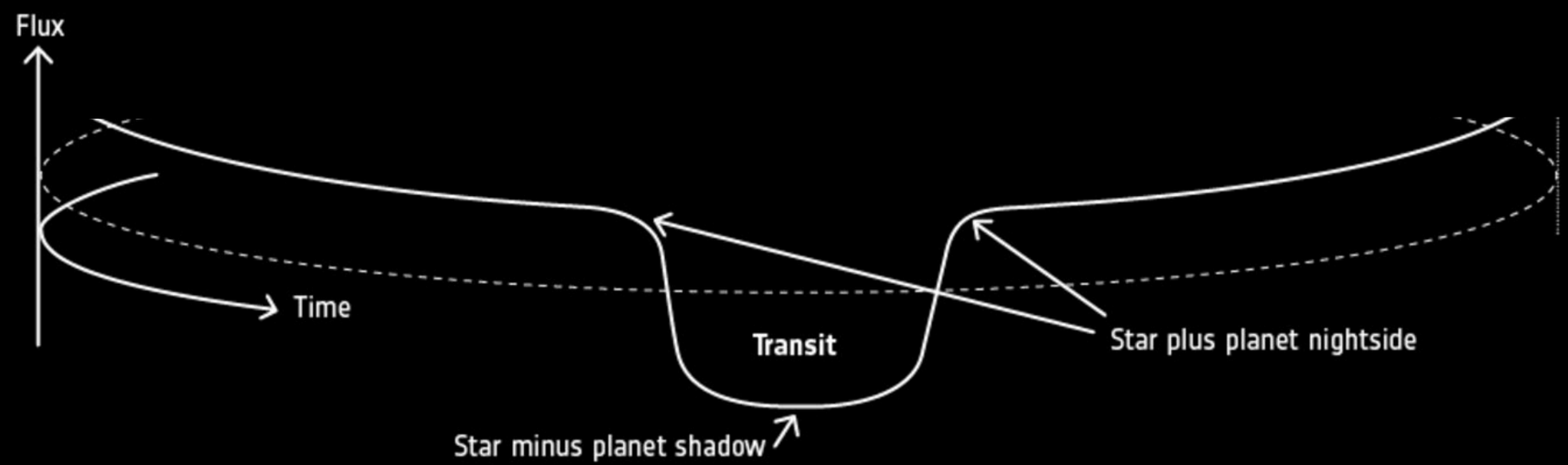
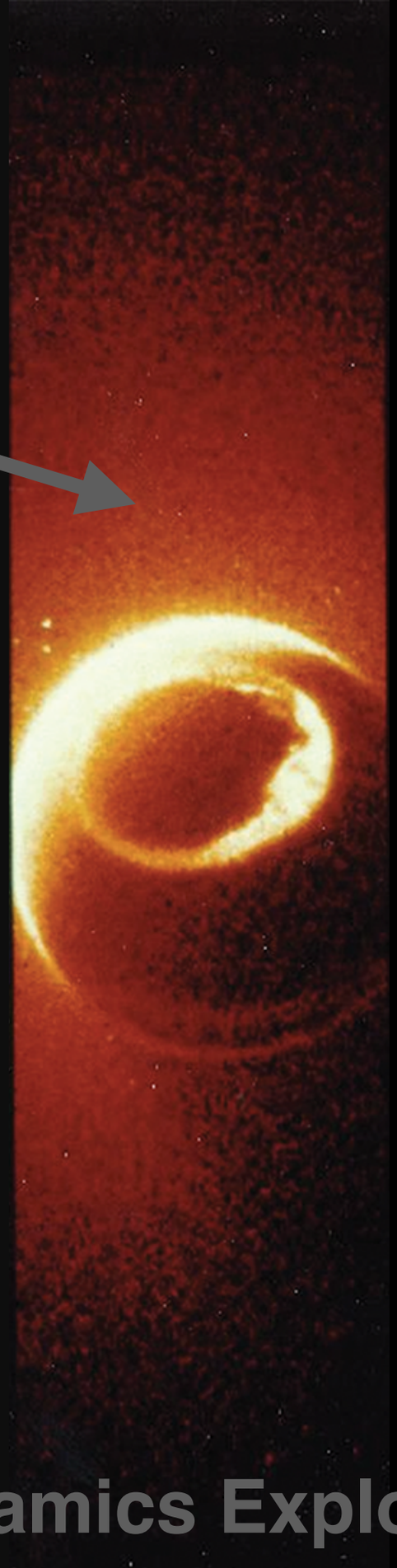
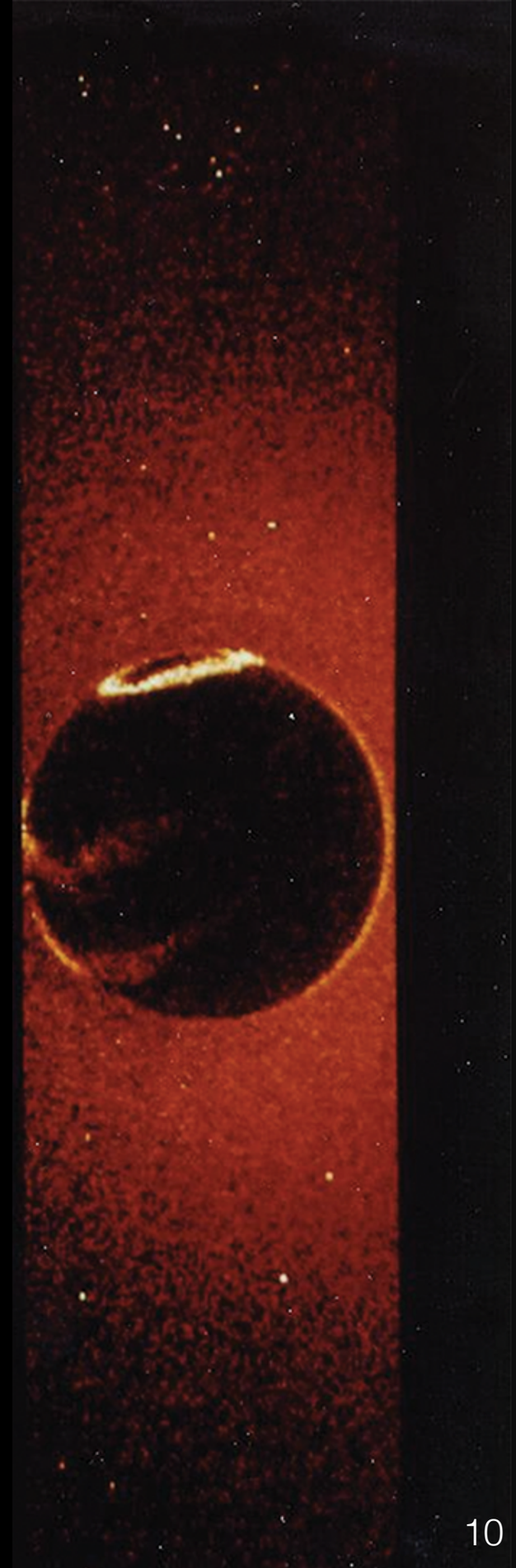
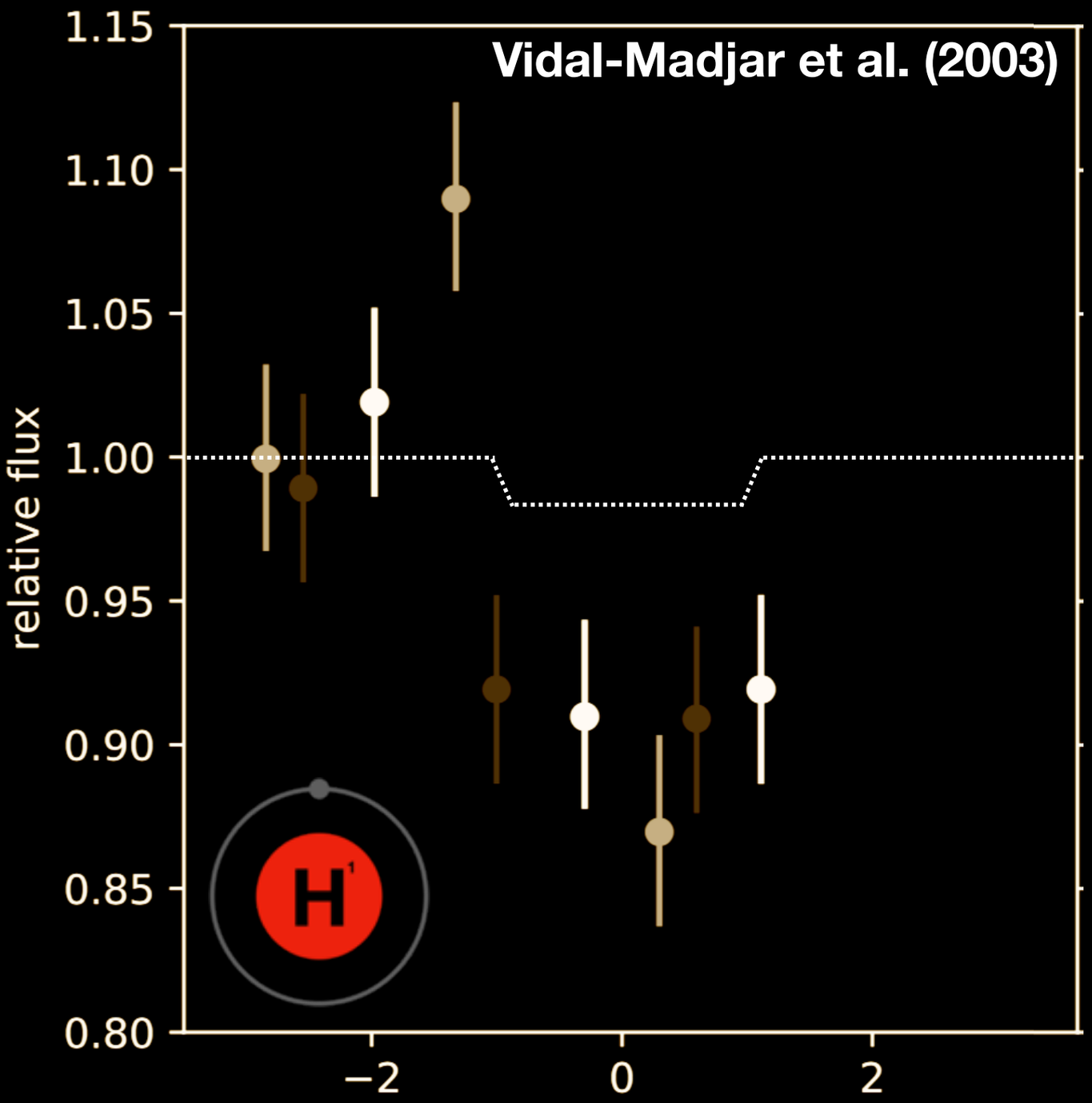
Abigail Tumborang



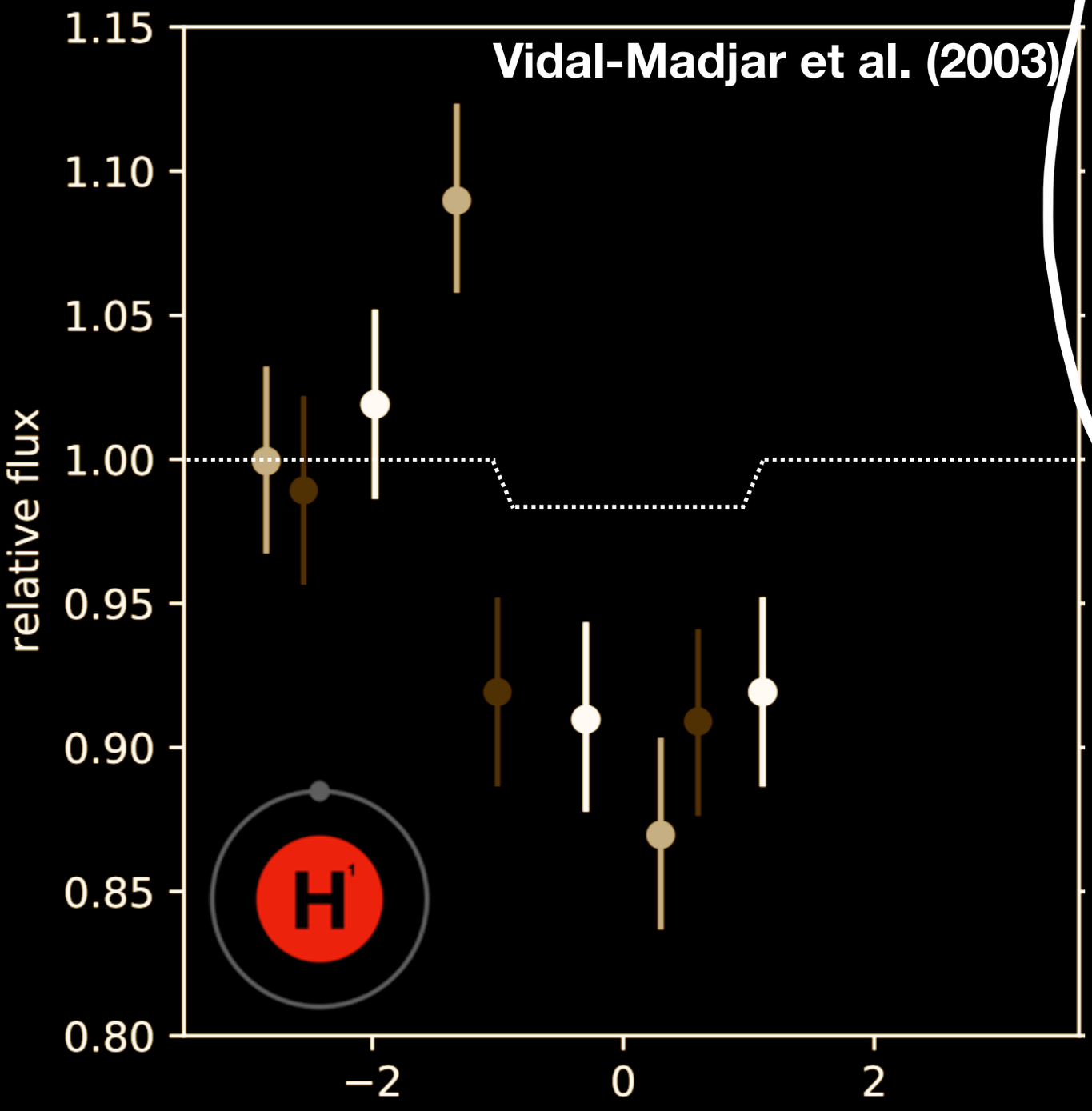




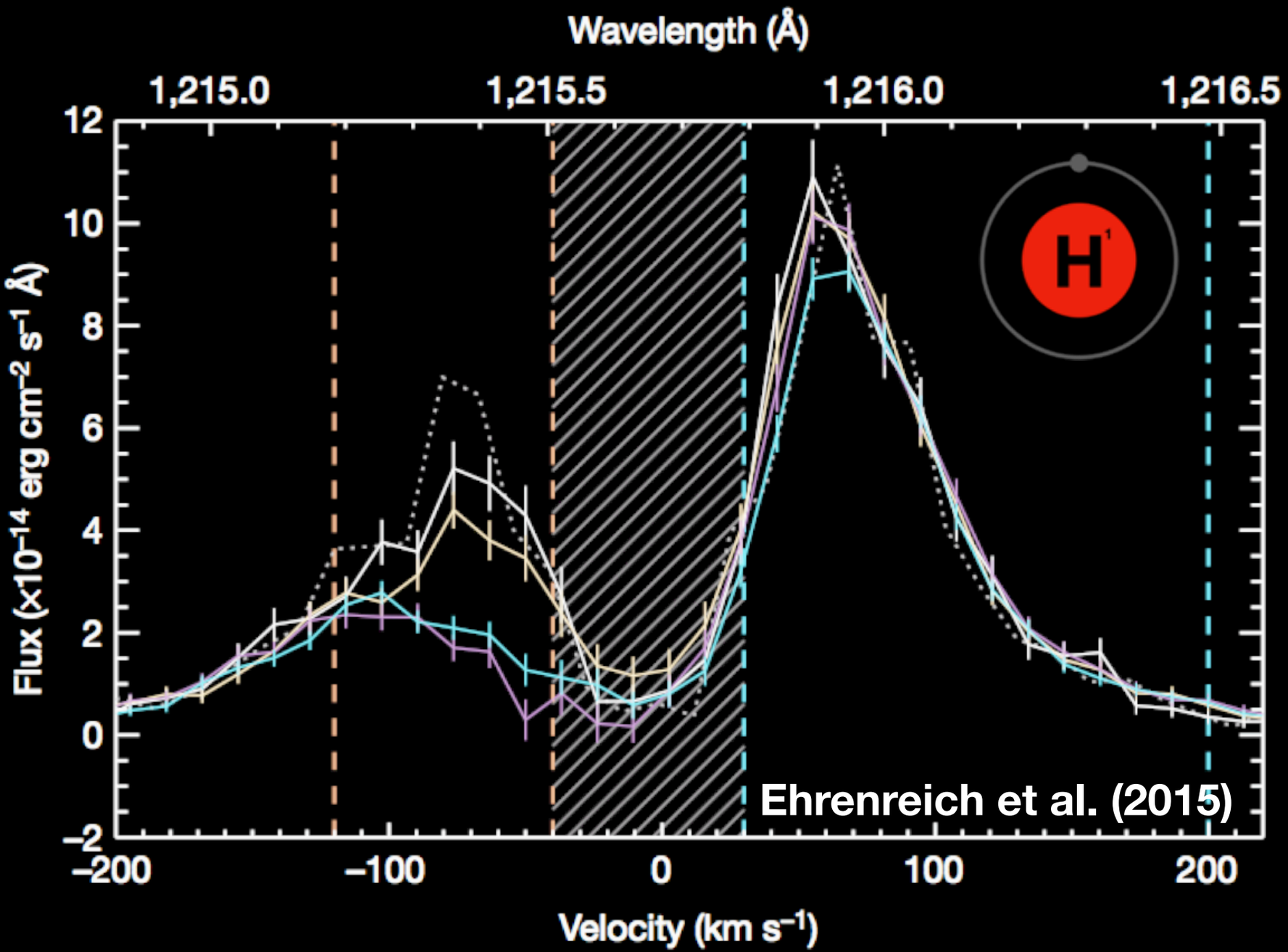
From NASA’s Solar Dynamics Explorer

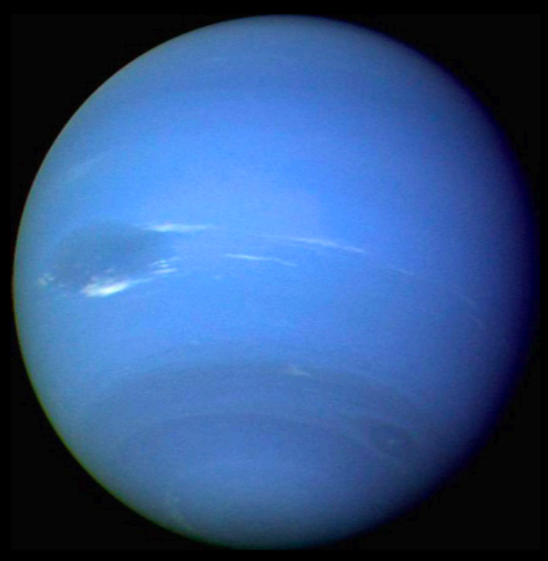

Vidal-Madjar et al. (2003)
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
relative flux
−2
0
2
hours from mid-transit
H1

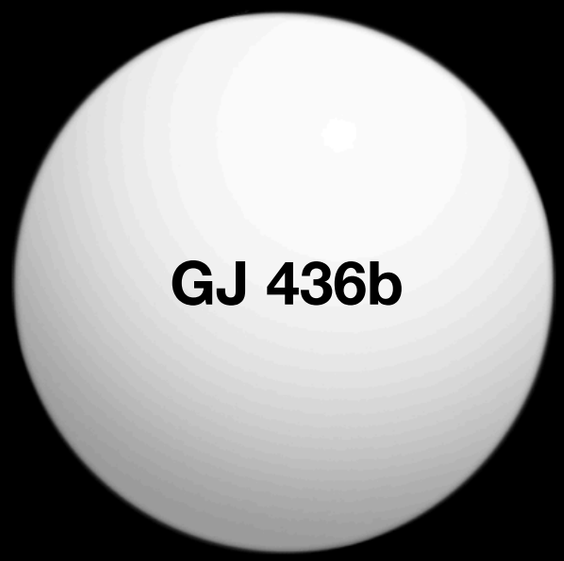
HD 209458b


Vidal-Madjar et al. (2003)
relative flux
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
−2
0
2
H1

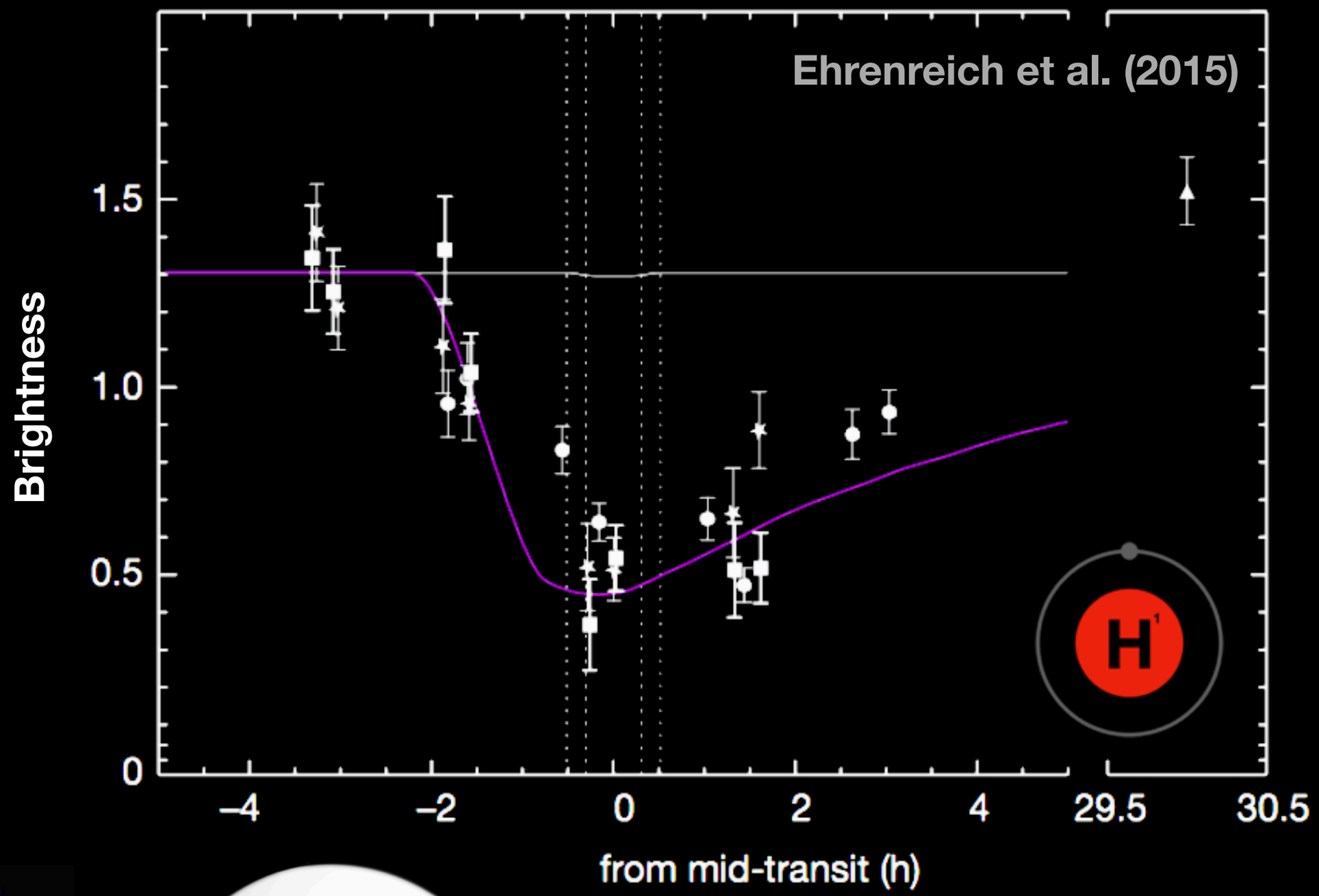
HD 209458b

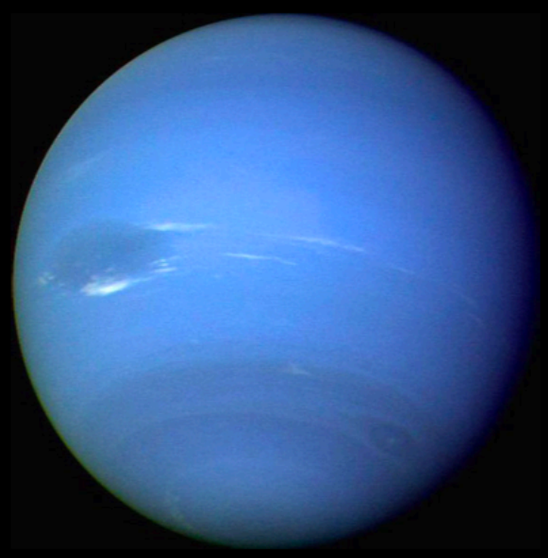

Wavelength (Å)
1,215.0
1,215.5
1,216.0
1,216.5
Flux (×10⁻¹⁴ erg cm⁻² s⁻¹ Å)
12
10
8
6
4
2
0
−2
−200
−100
0
100
200
Velocity (km s⁻¹)
H¹
Ehrenreich et al. (2015)

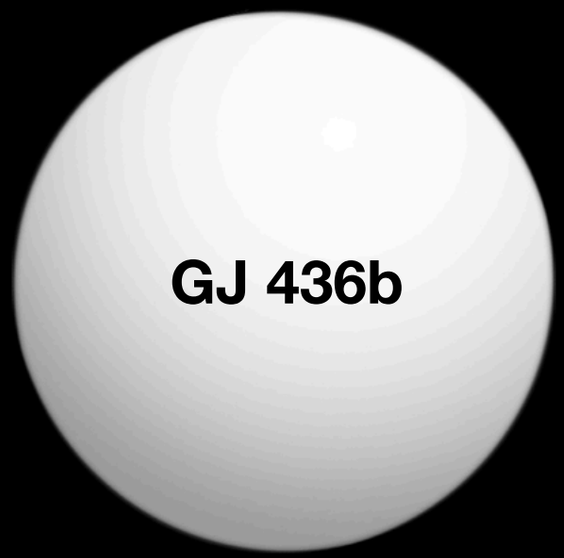



GJ 436b

Ehrenreich et al. (2015)

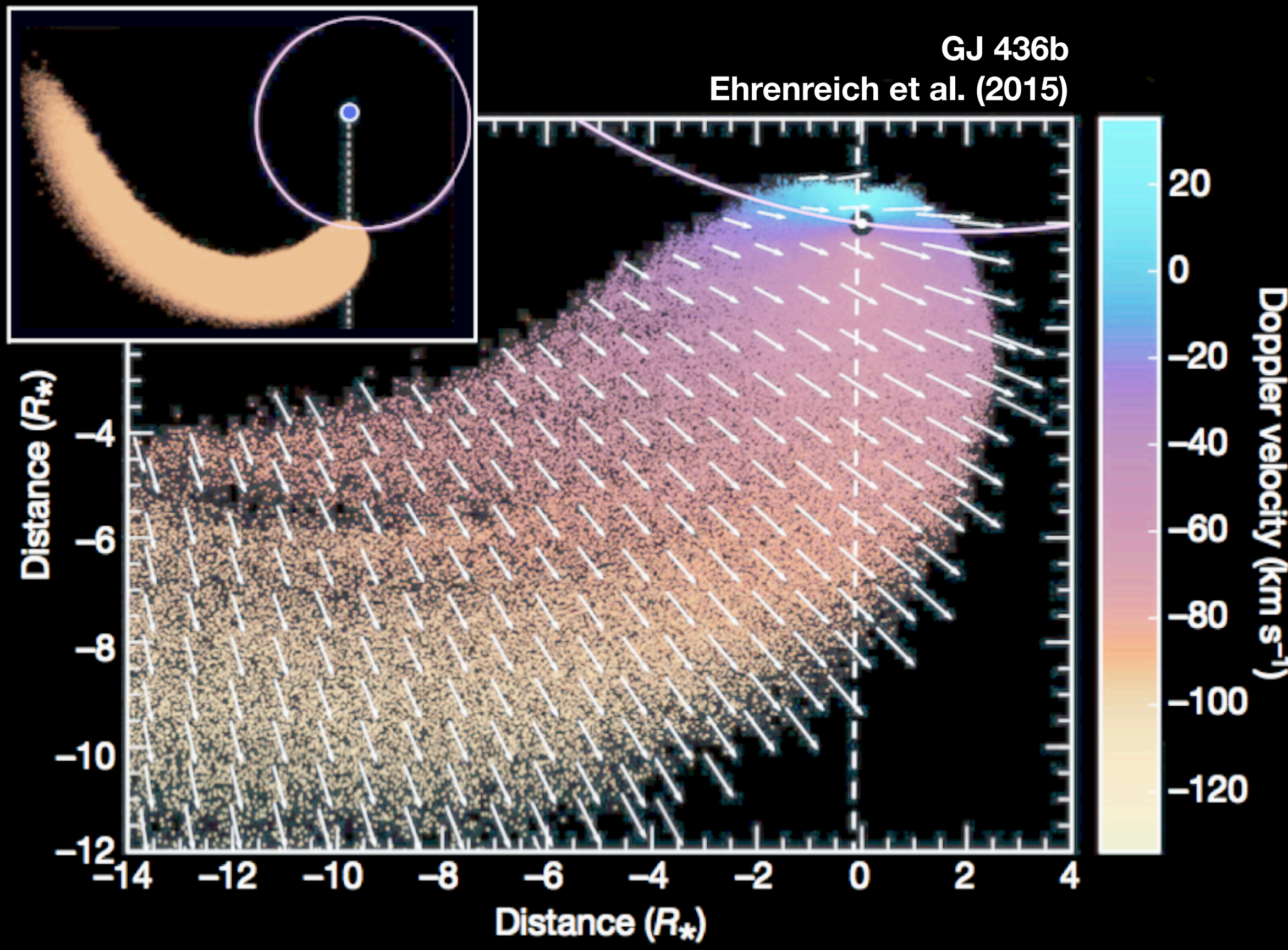


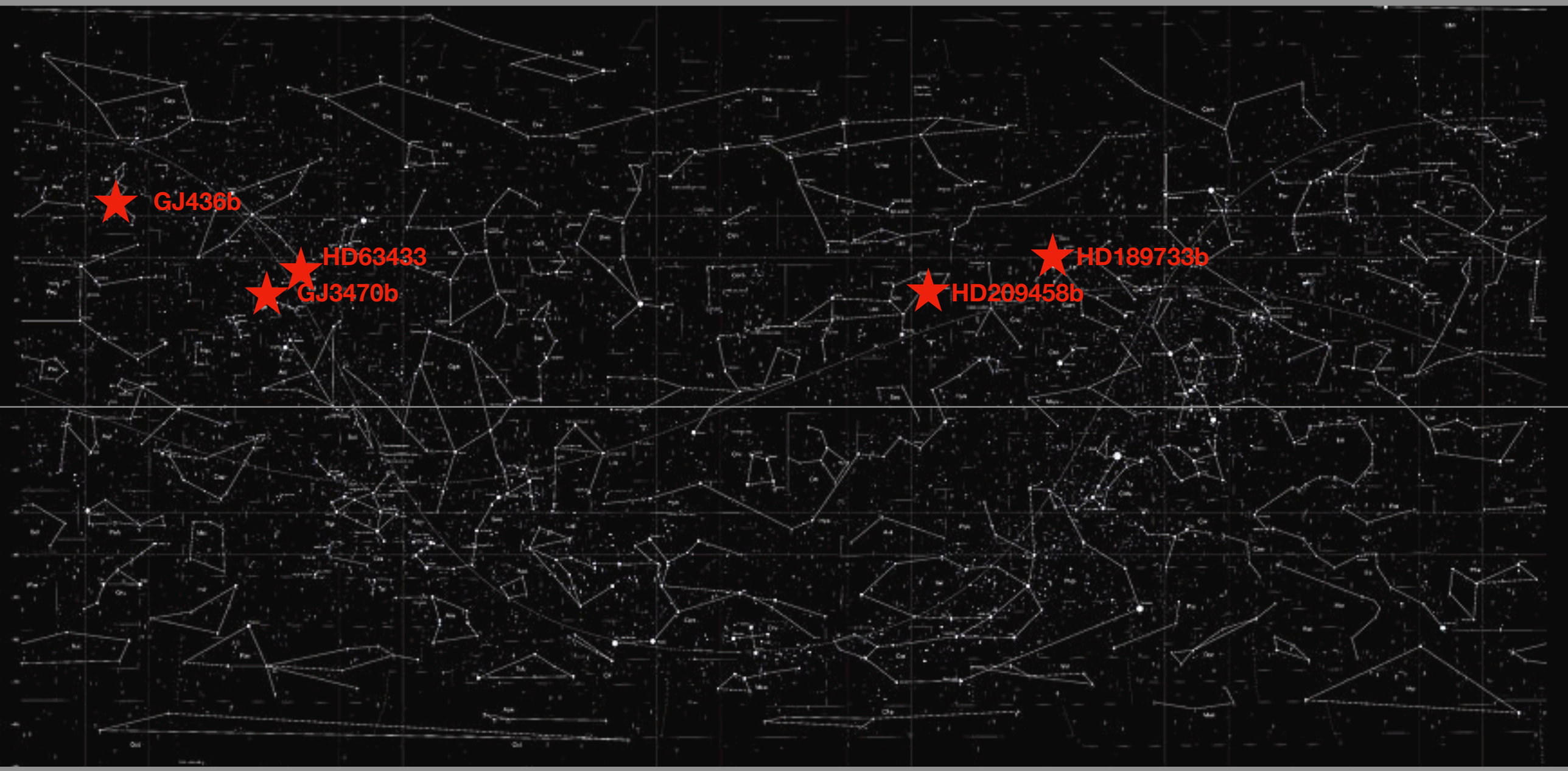




GJ 436b

GJ 436b
Ehrenreich et al. (2015)





5 published Lyman-alpha detections

It is still difficult to predict which exoplanets are undergoing ***measurable*** mass-loss

Because it is ***difficult*** to observe directly

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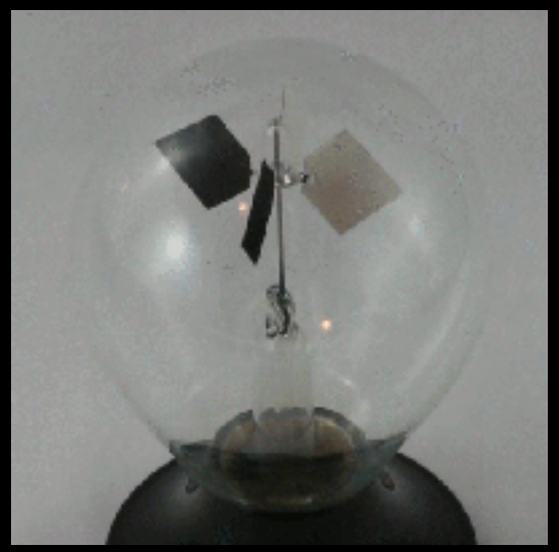
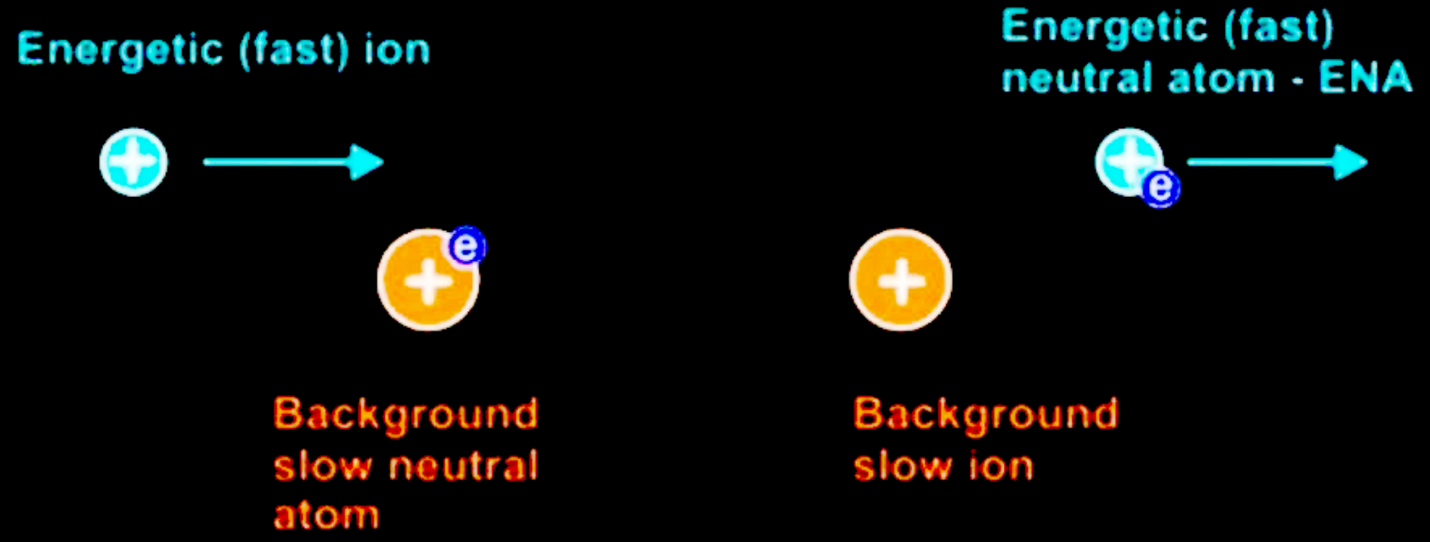
What accelerates the neutral hydrogen?

Radiation pressure



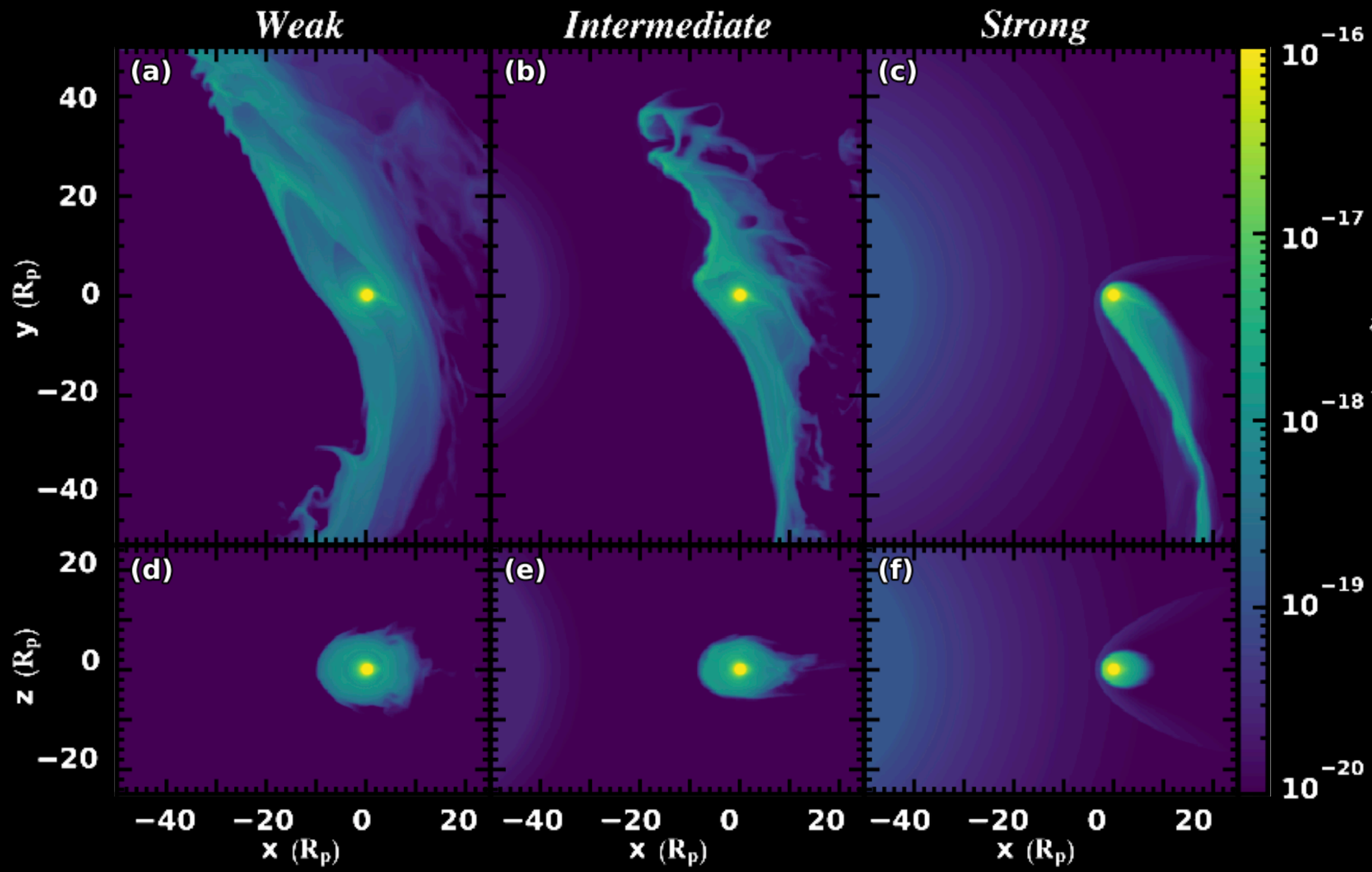
Stellar wind ram pressure

Energetic Neutral Atoms (ENAs)

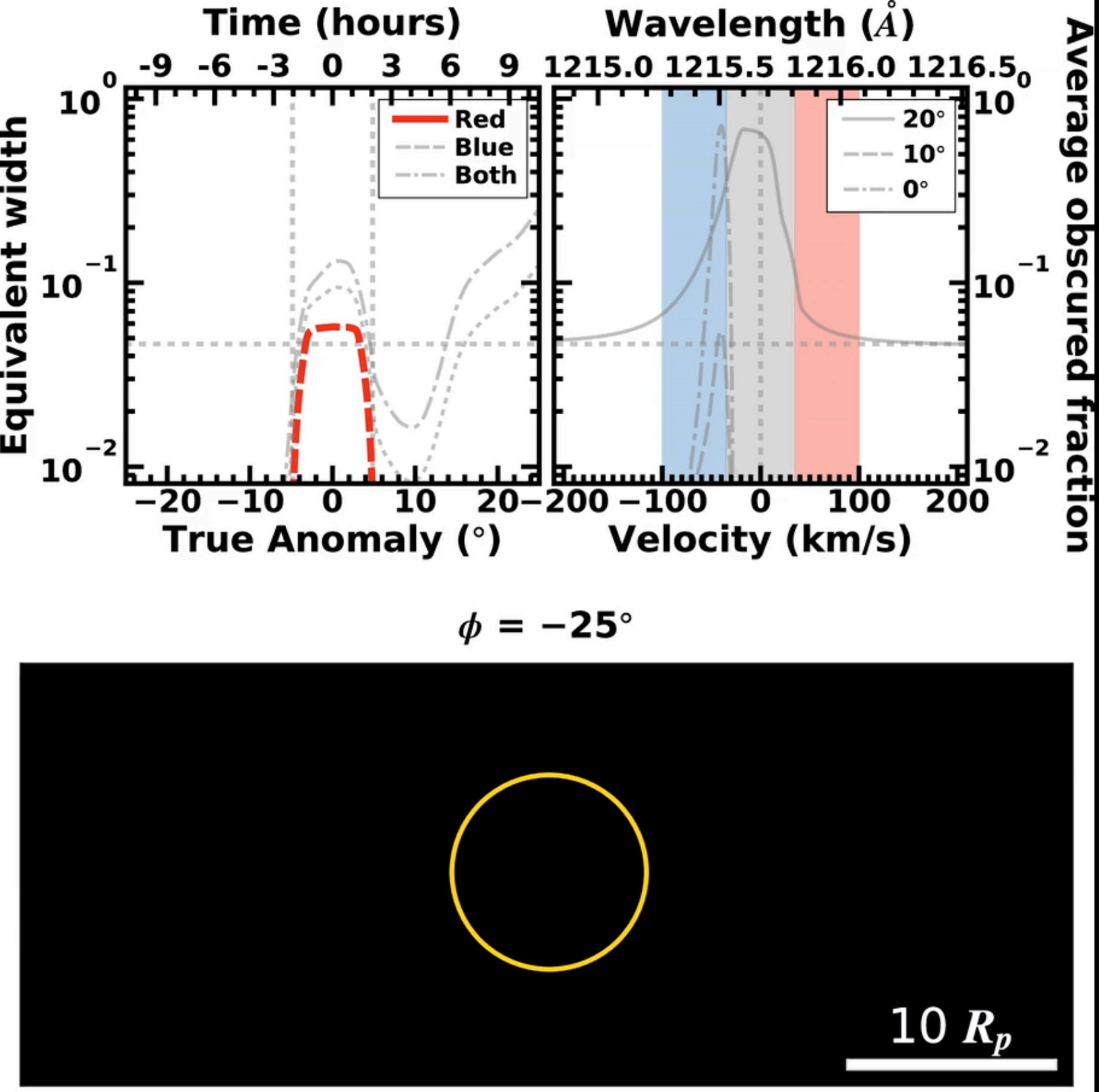


Stellar wind sculpting post-transit tails

McCann et al. (2019)

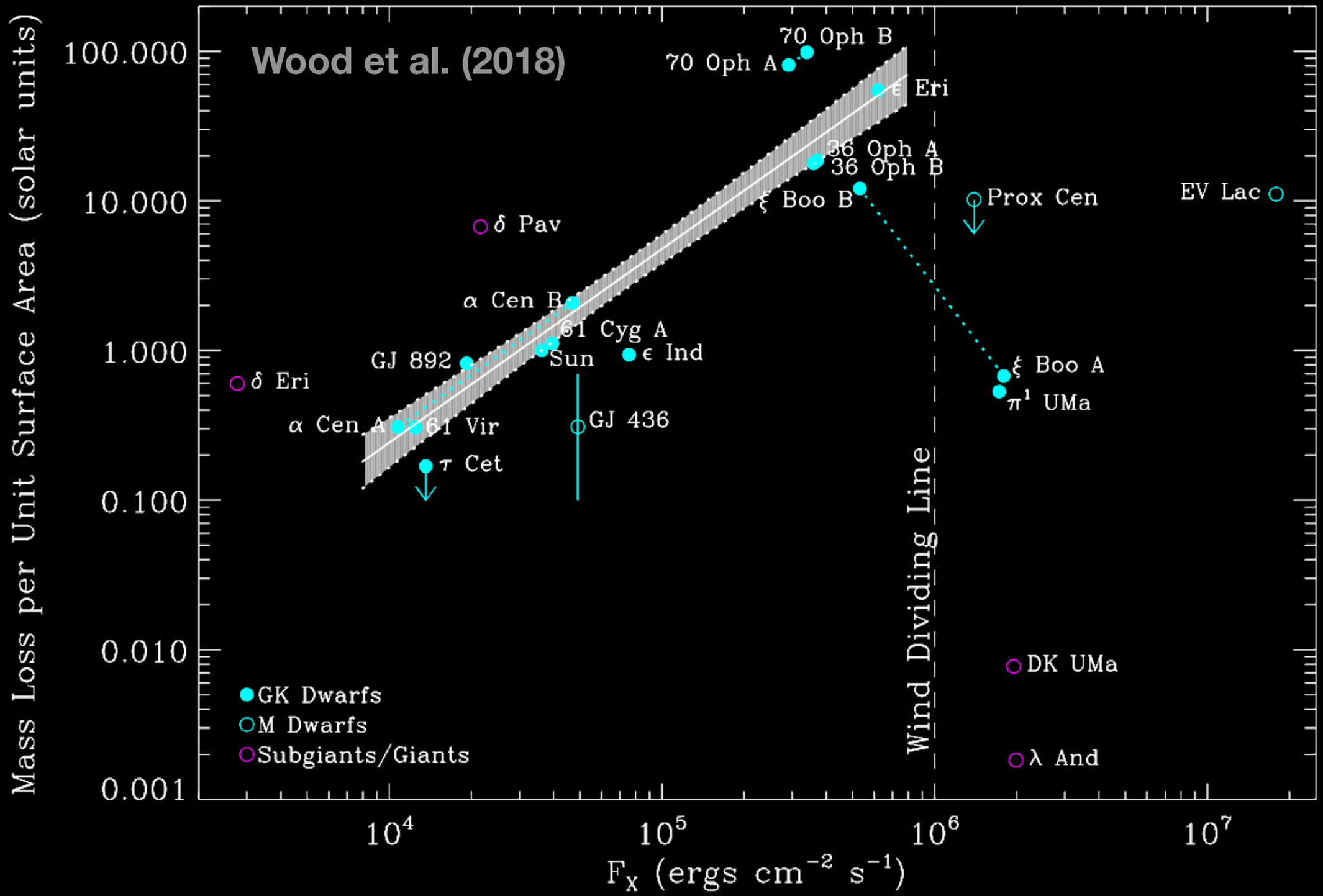


see also MacLeod & Oklopčić (2021)



McCann et al. (2019)

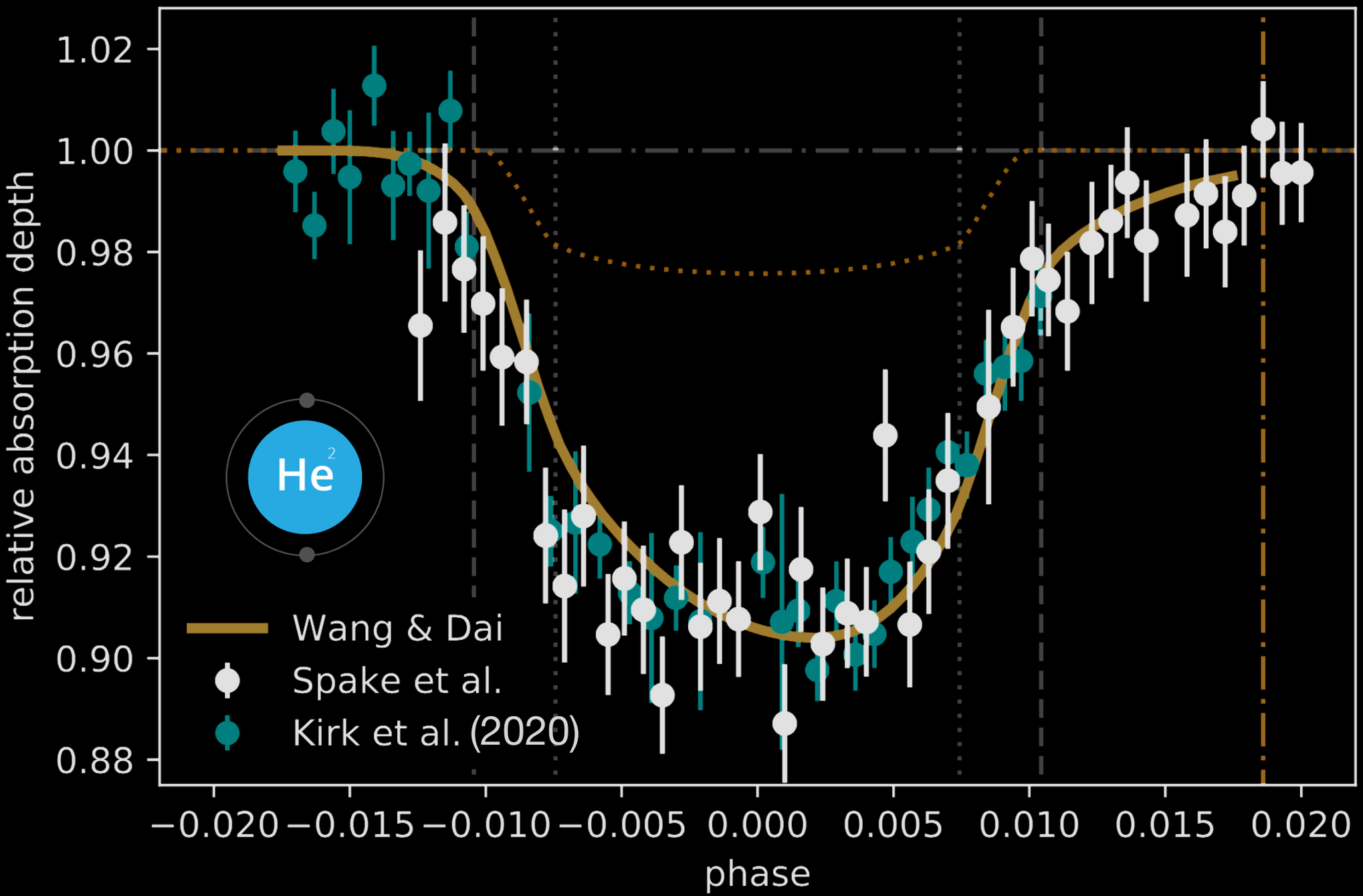
stronger stellar winds



increasingly active stars

WASP-107b's tail observed at 10830 A with Keck/NIRSPEC

Spake, Oklopčić & Hillenbrand (2021)

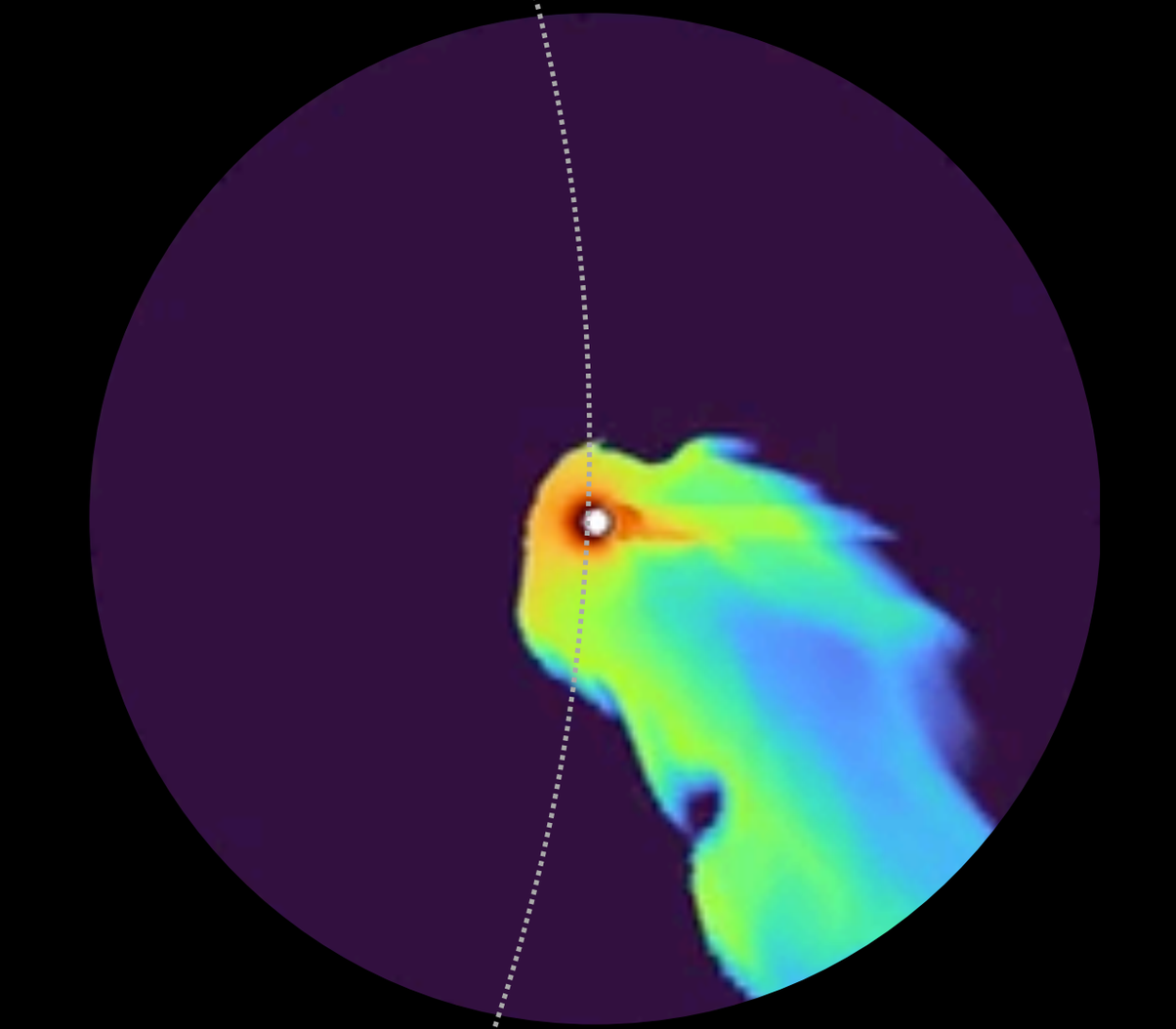


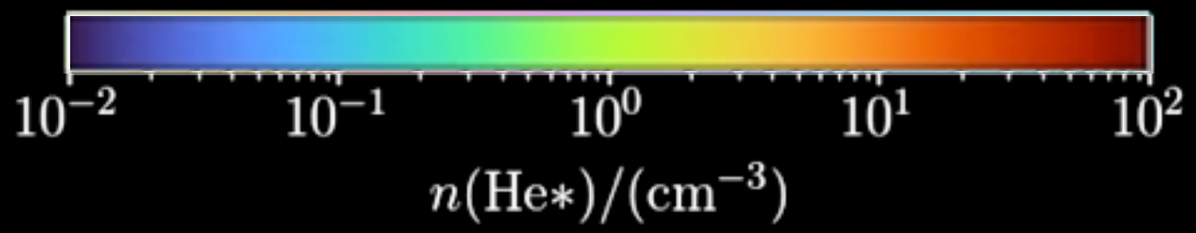
See also Kirk et al. (2020), Z.J. Zhang+(2023)

Wang & Dai (2020)
10 x Solar wind strength

orbit

to star





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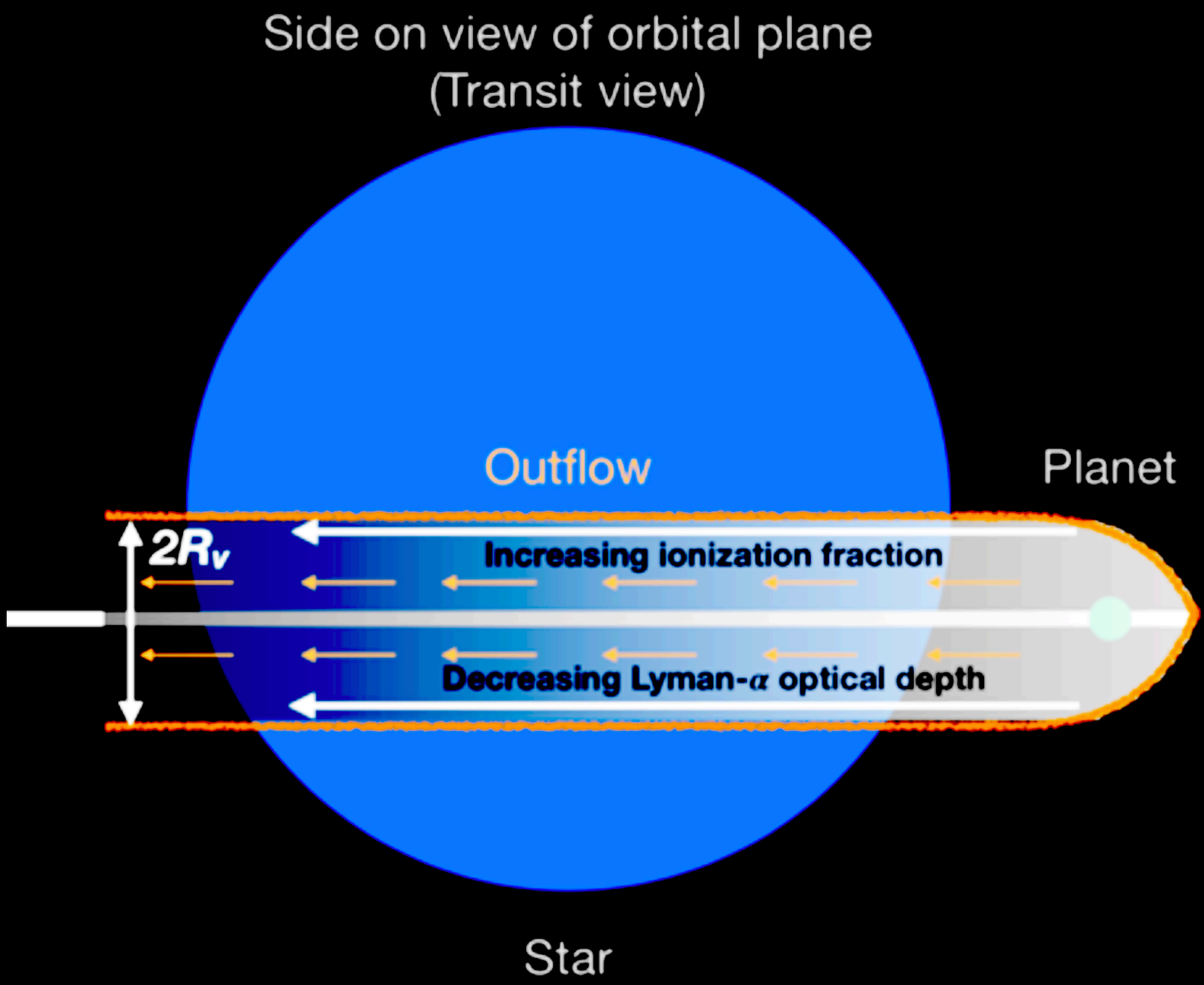
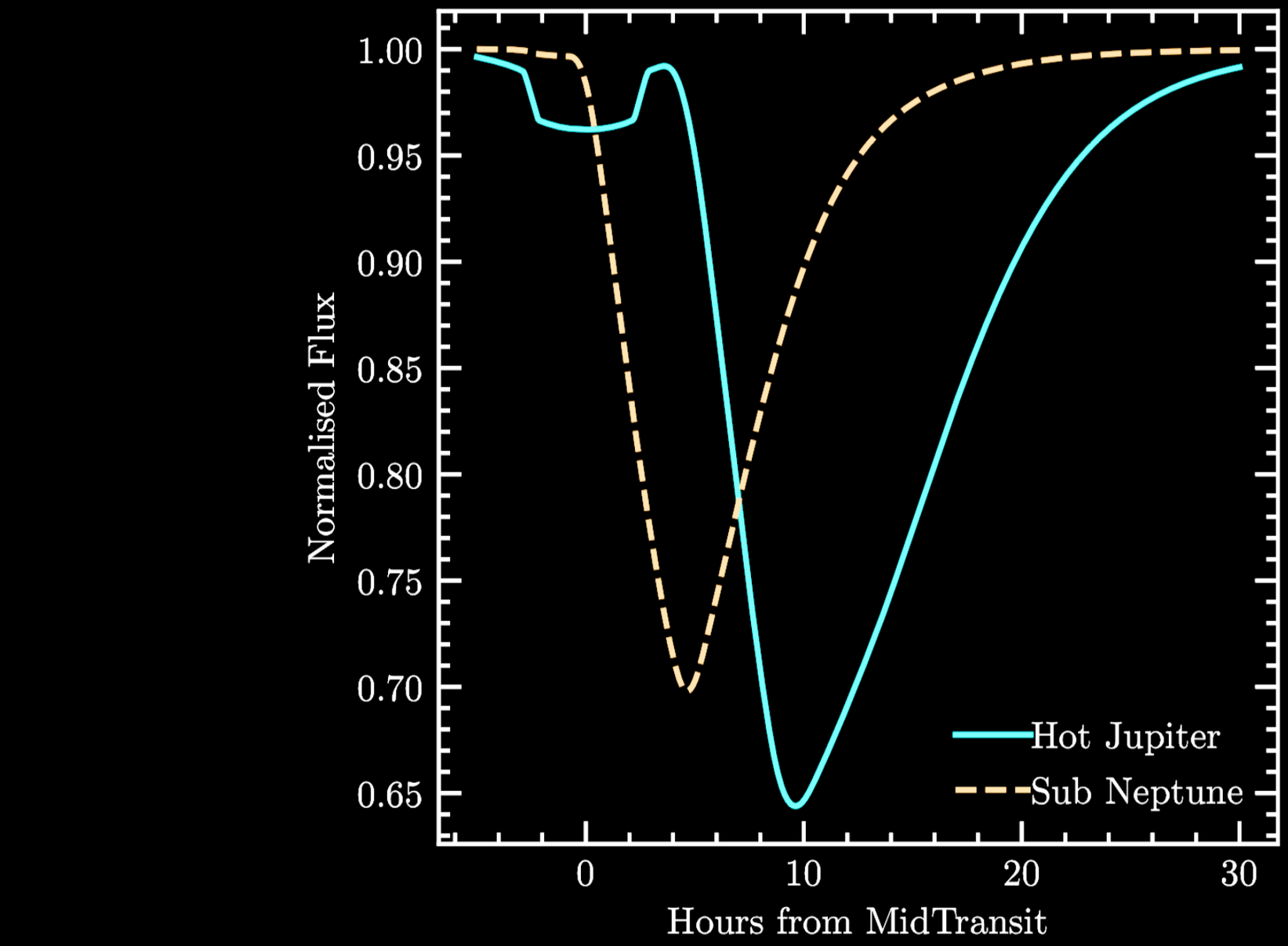
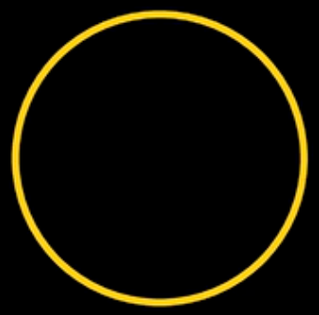


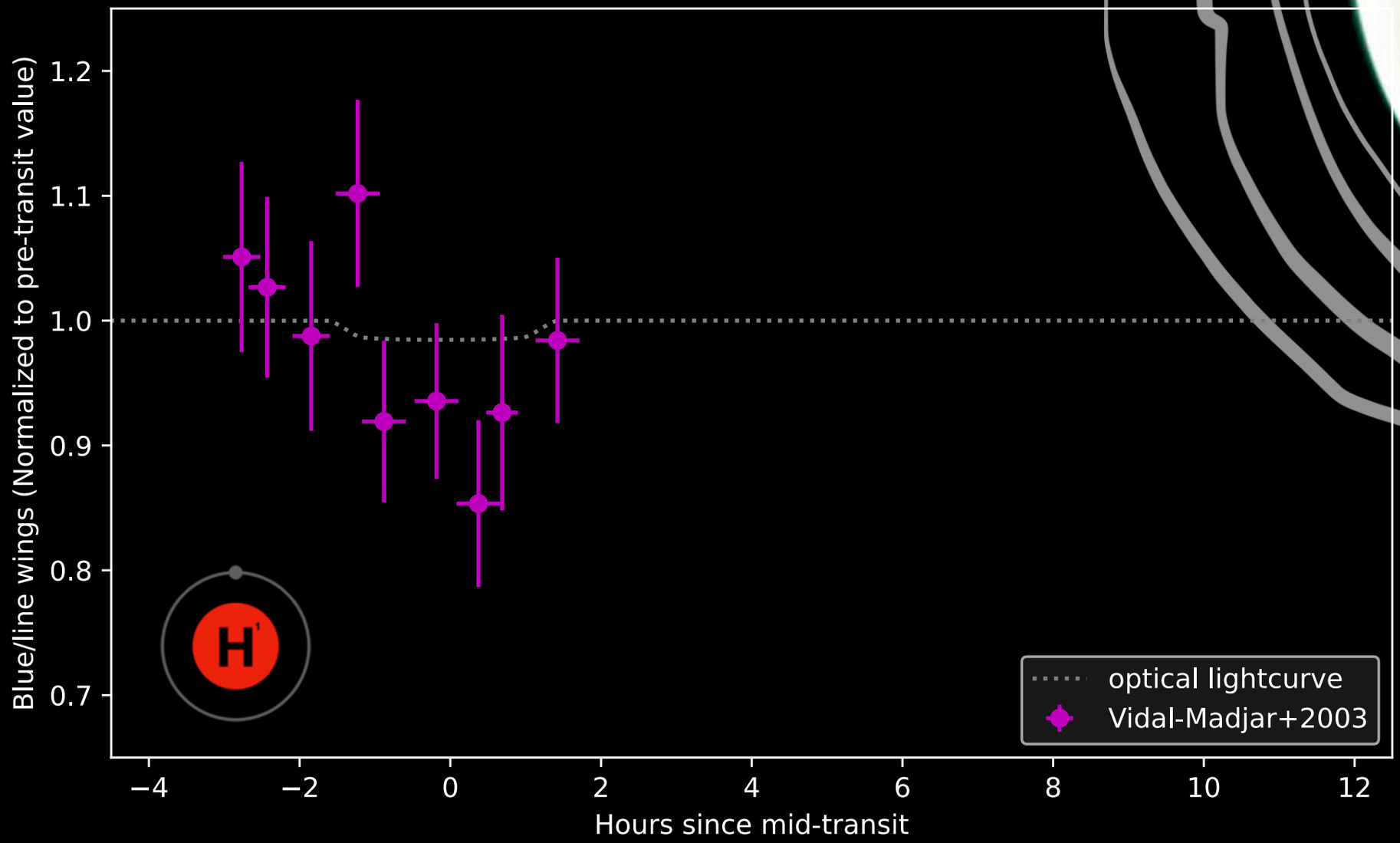
Owen et al. (2022)

Owen et al. (2022)



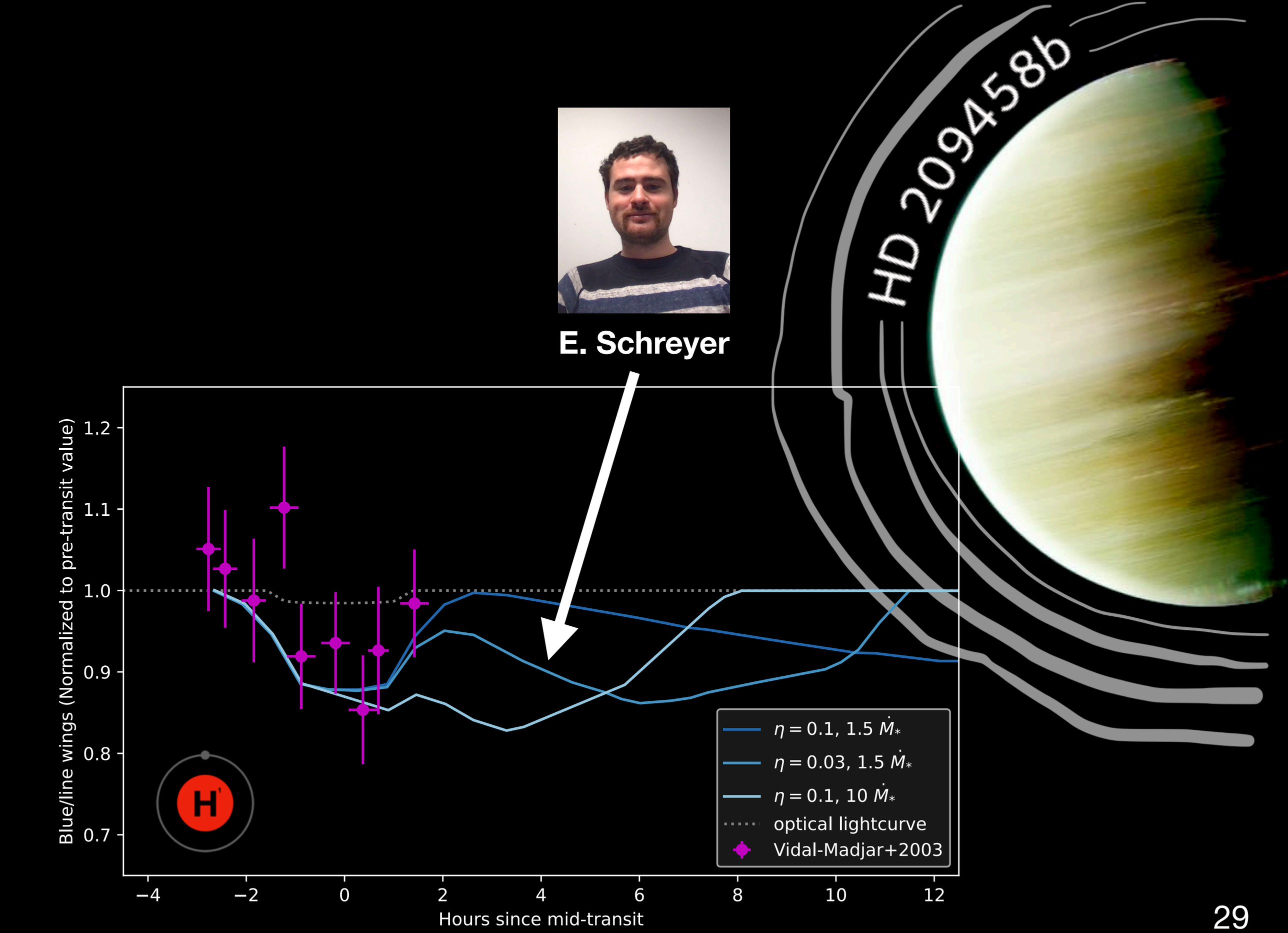
McCann et al. (2019)



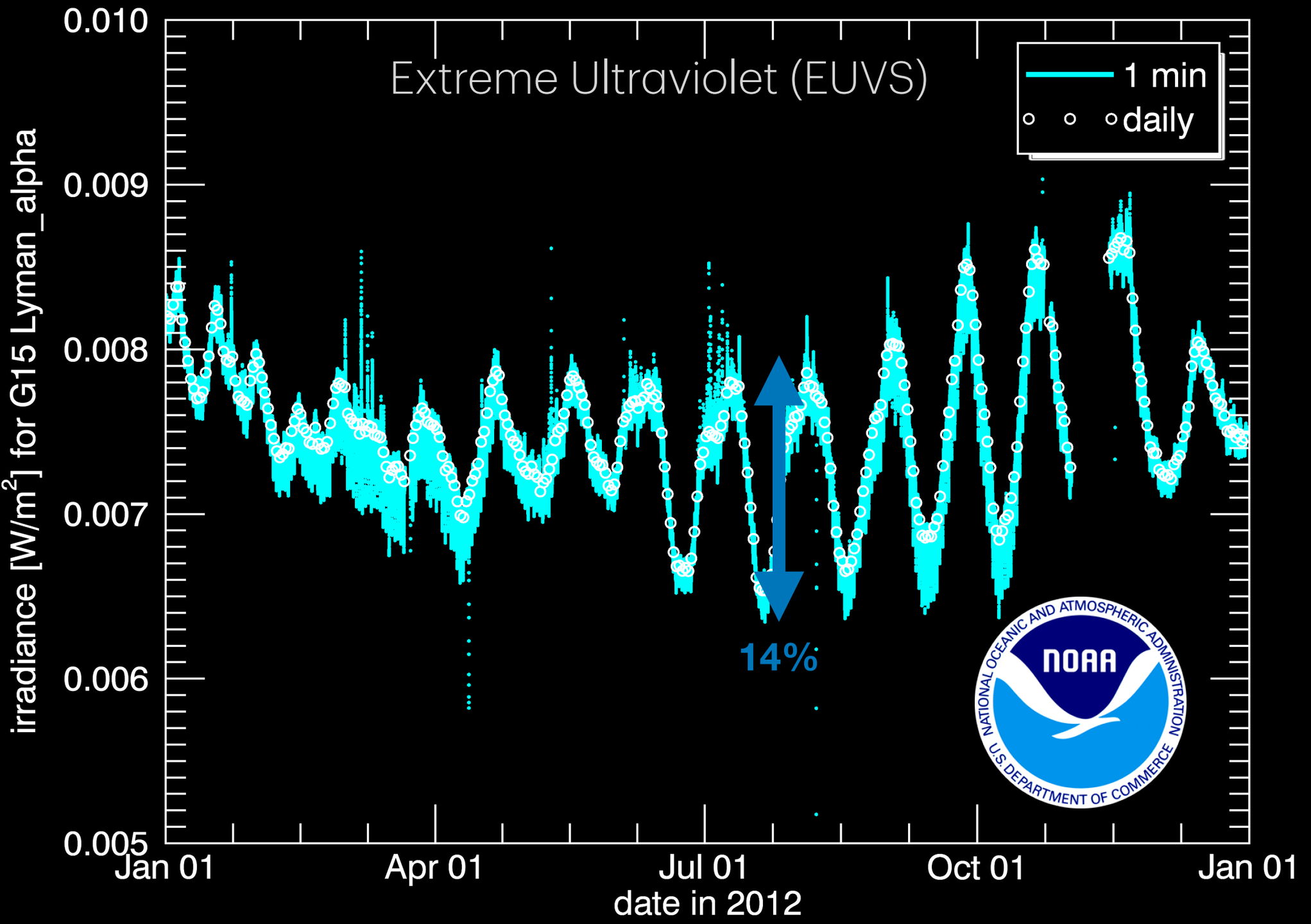

Blue/line wings (Normalized to pre-transit value)
1.2
1.1
1.0
0.9
0.8
0.7
−4
−2
0
2
4
6
8
10
12
Hours since mid-transit
H1
optical lightcurve
Vidal-Madjar+2003

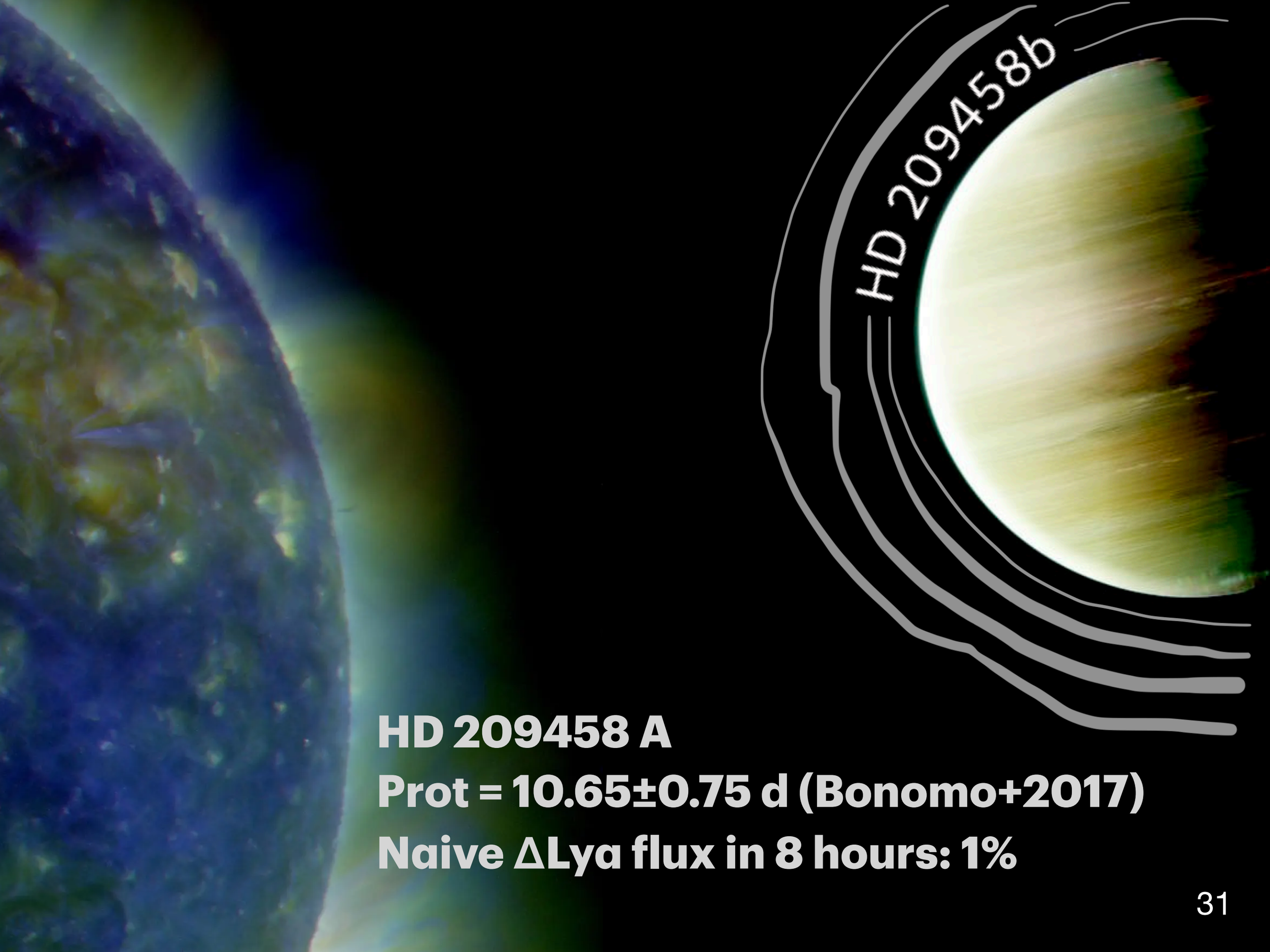
HD 209458b

E. Schreyer


HD 209458b
Blue/line wings (Normalized to pre-transit value)
1.2
1.1
1.0
0.9
0.8
0.7
−4
−2
0
2
4
6
8
10
12
Hours since mid-transit
H¹
$\eta = 0.1$, 1.5 $\dot{M}_*$
$\eta = 0.03$, 1.5 $\dot{M}_*$
$\eta = 0.1$, 10 $\dot{M}_*$
optical lightcurve
Vidal-Madjar+2003

Geostationary Operational Environmental Satellites (GOES) 1–15

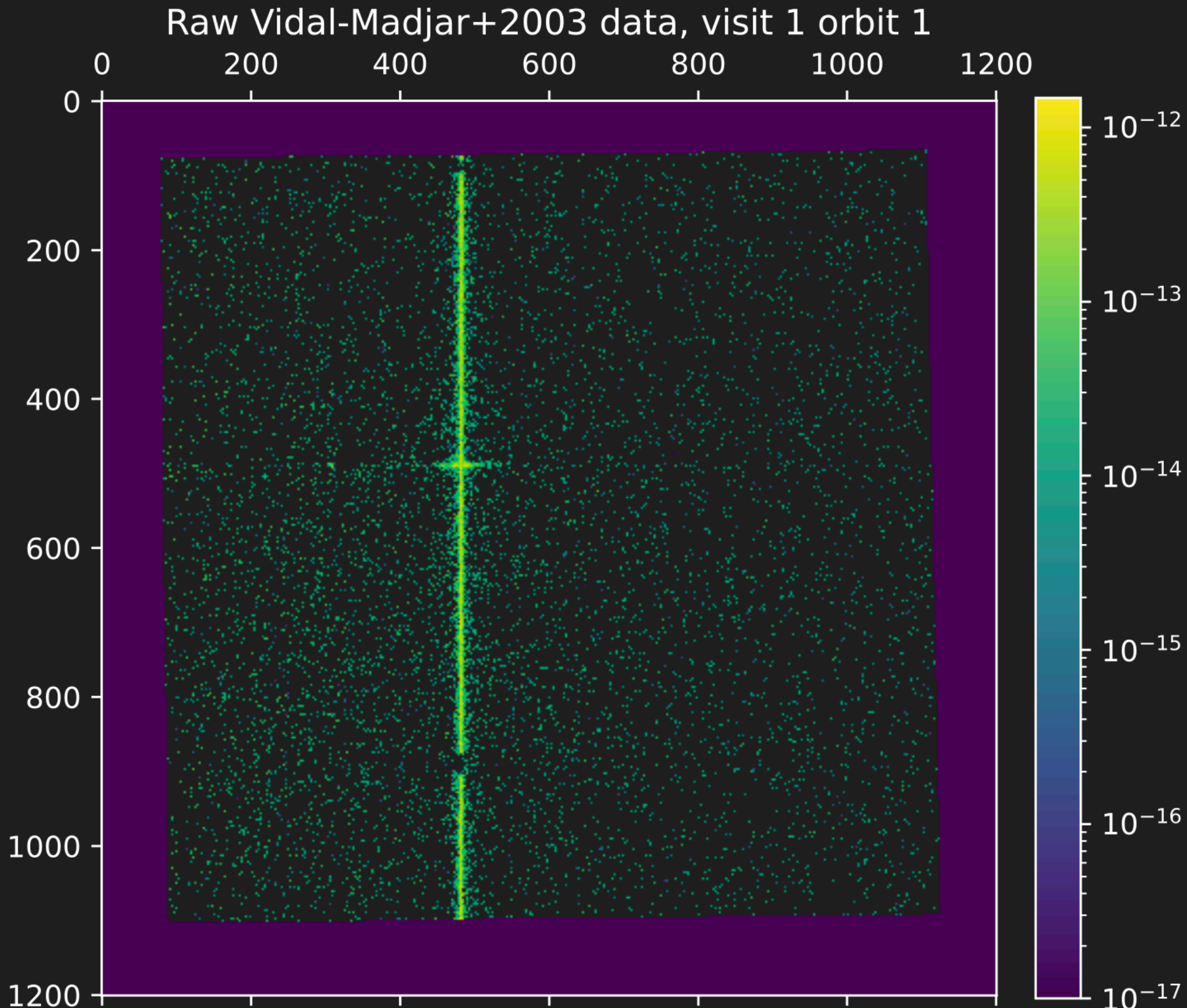


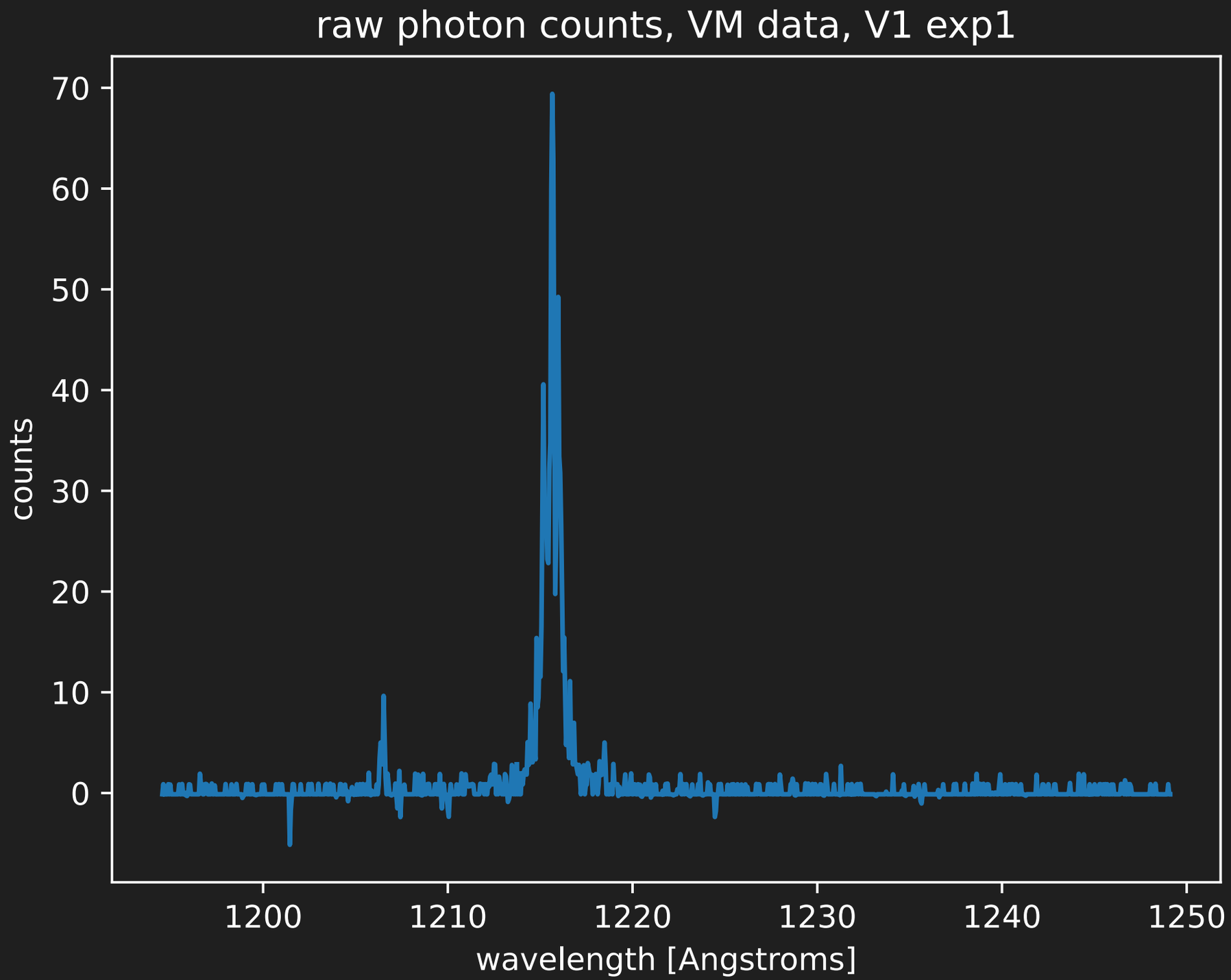


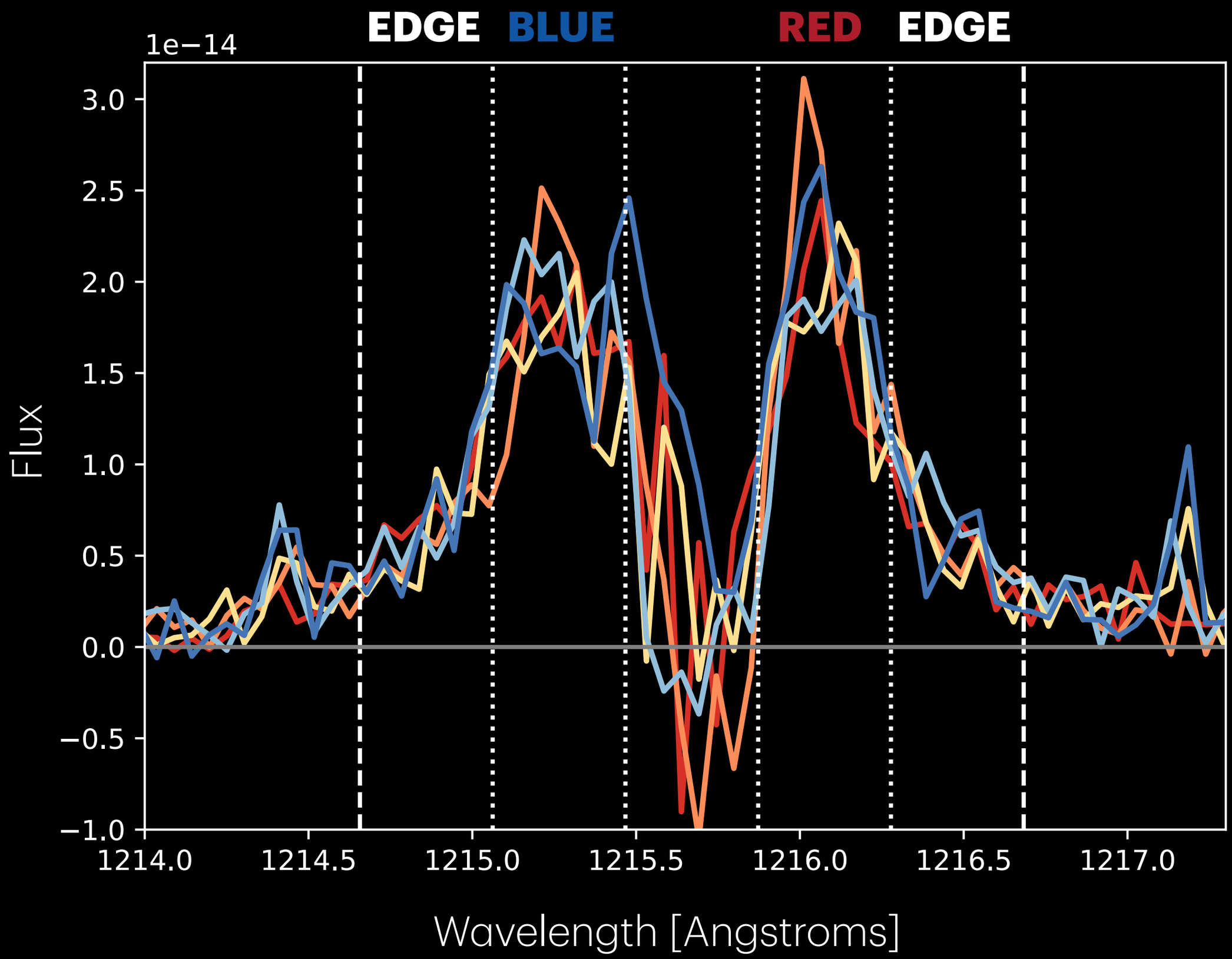
HD 209458 A

Prot = 10.65±0.75 d (Bonomo+2017)

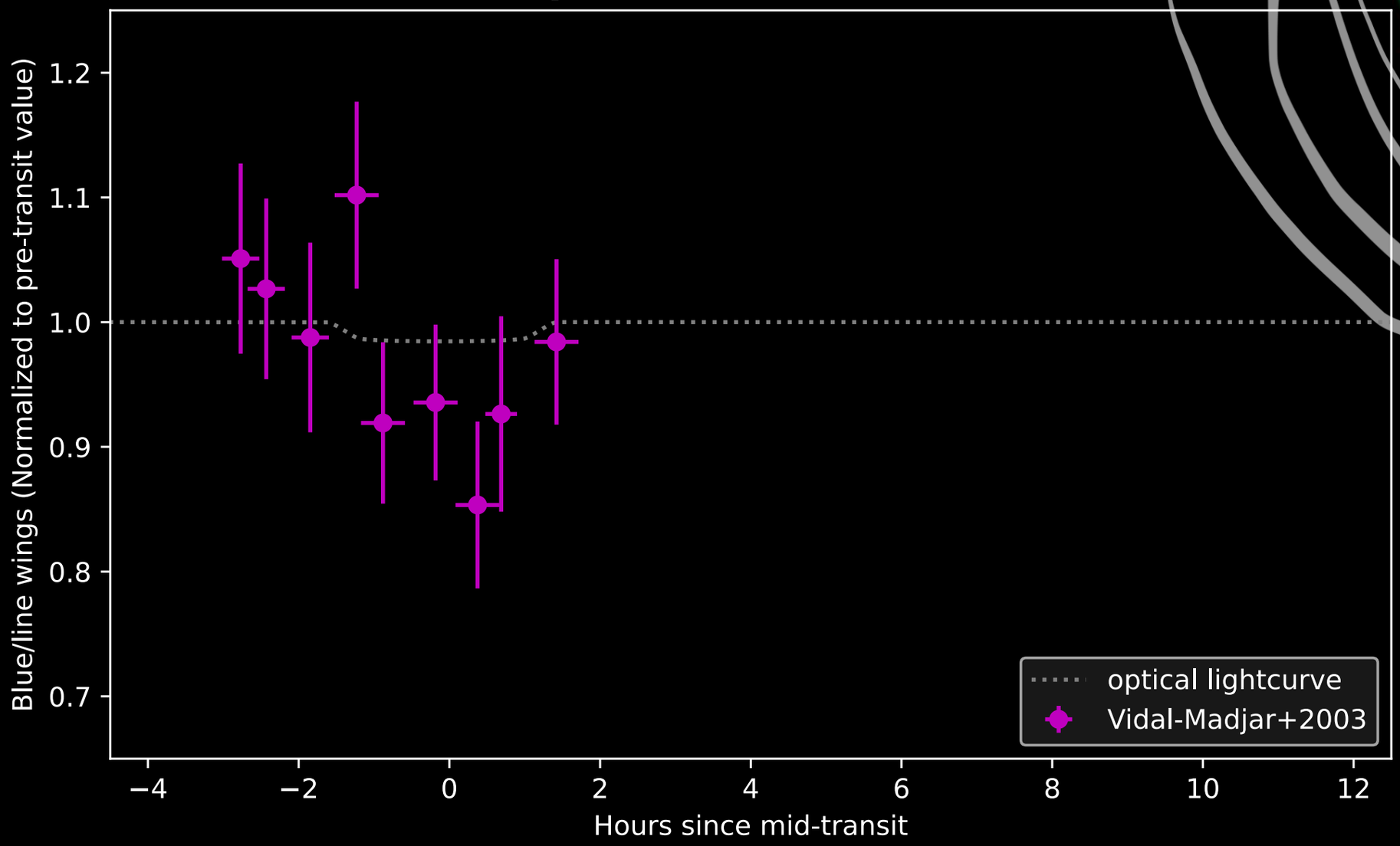
Naive ΔLya flux in 8 hours: 1%


Raw Vidal-Madjar+2003 data, visit 1 orbit 1
0
200
400
600
800
1000
1200
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-17}

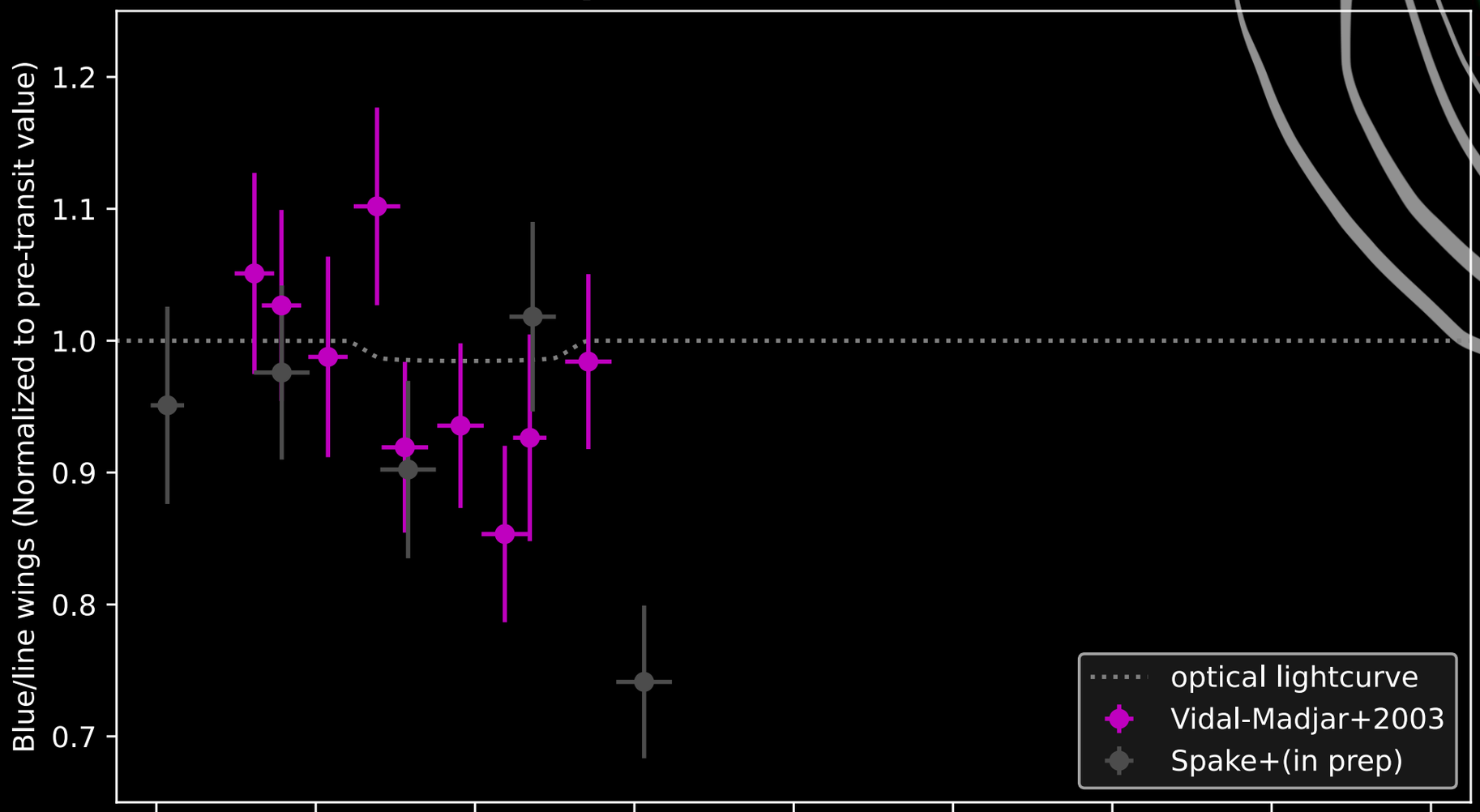

raw photon counts, VM data, V1 exp1
counts
70
60
50
40
30
20
10
0
1200
1210
1220
1230
1240
1250
wavelength [Angstroms]

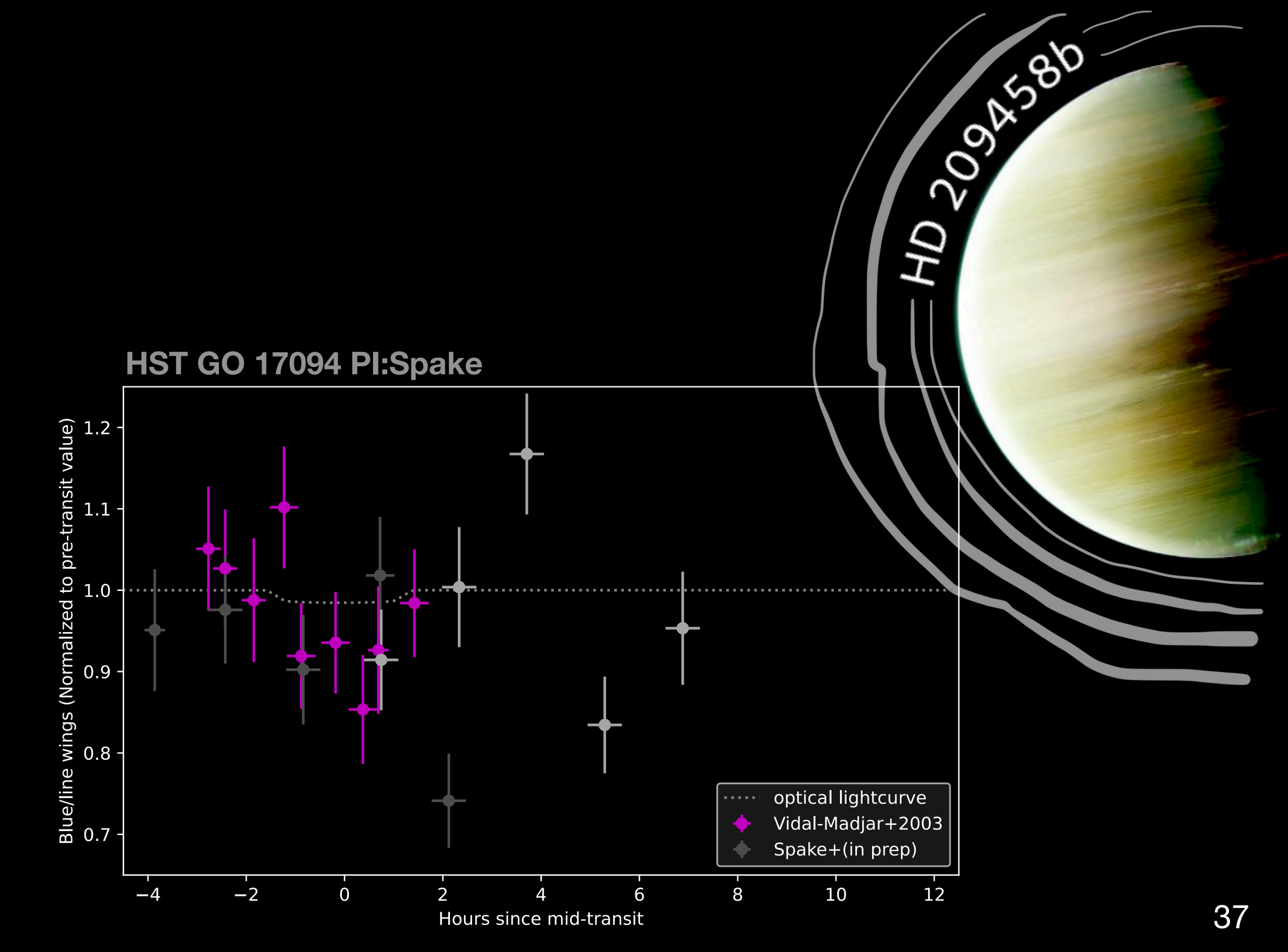

EDGE
BLUE
RED
EDGE
1e−14
3.0
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
Flux
1214.0
1214.5
1215.0
1215.5
1216.0
1216.5
1217.0
Wavelength [Angstroms]

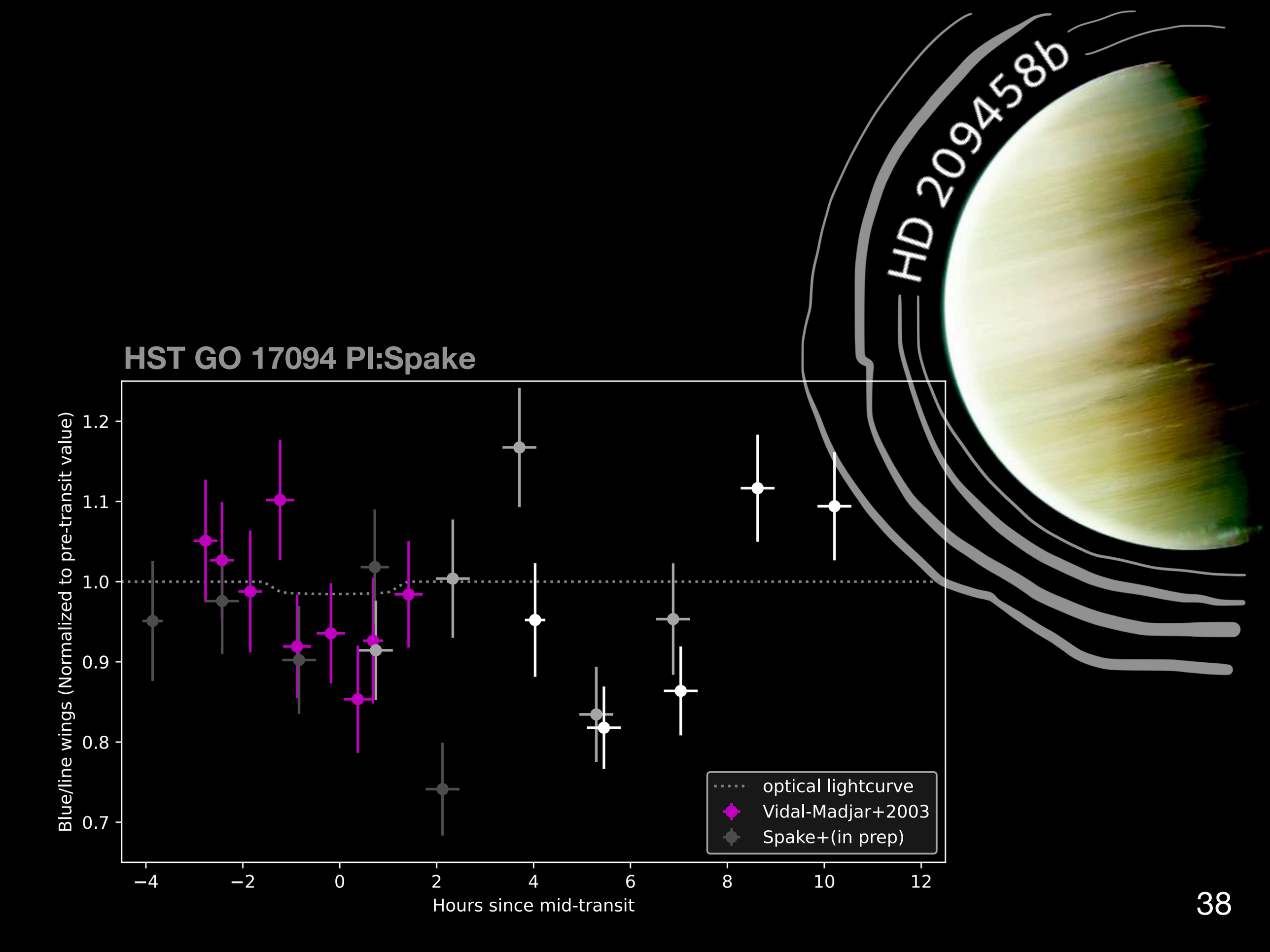
HST GO 17094 PI:Spake



HST GO 17094 PI:Spake




HD 209458b
HST GO 17094 PI:Spake
Blue/line wings (Normalized to pre-transit value)
1.2
1.1
1.0
0.9
0.8
0.7
−4
−2
0
2
4
6
8
10
12
Hours since mid-transit
optical lightcurve
Vidal-Madjar+2003
Spake+(in prep)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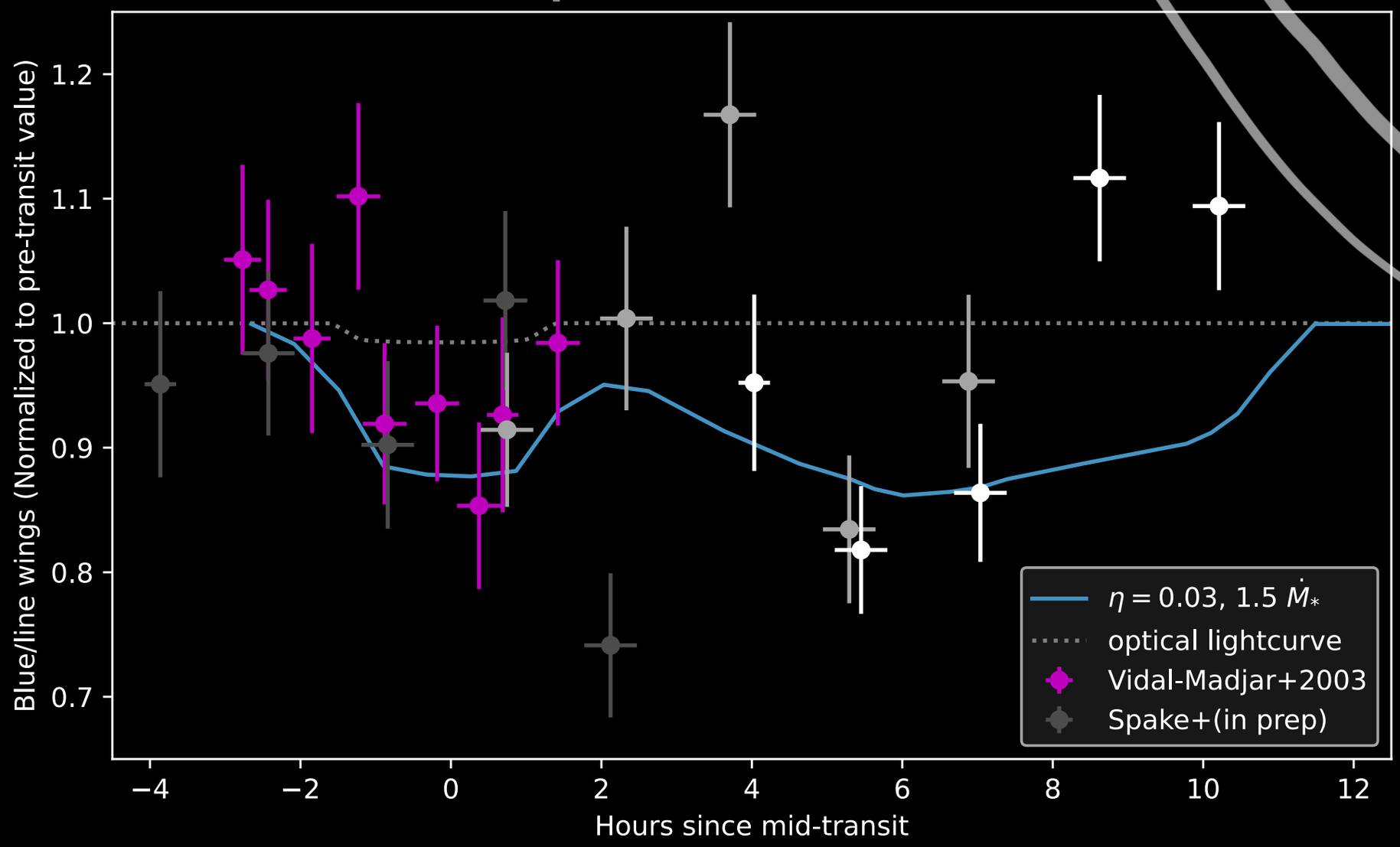
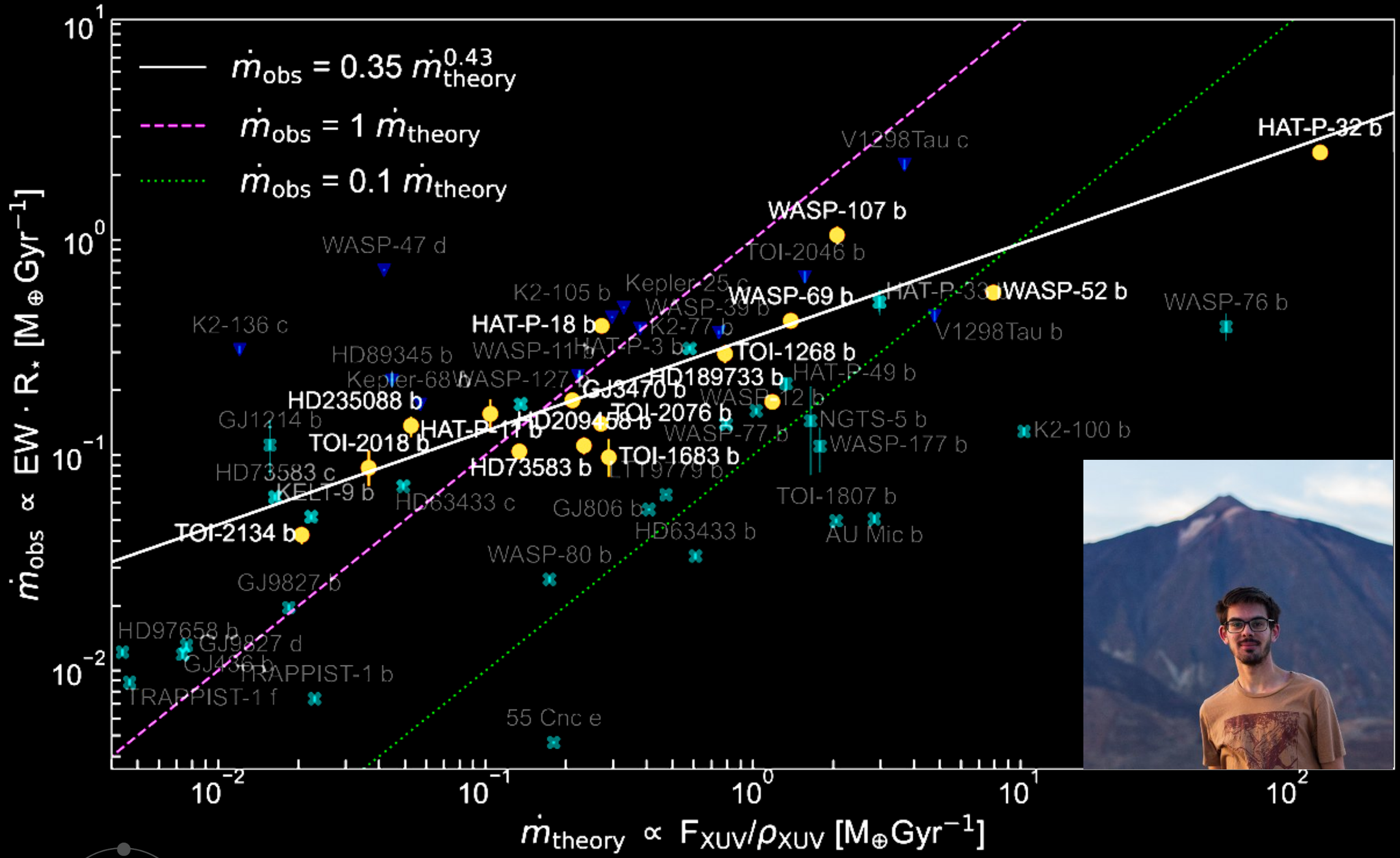


Evidence for HD209458b's ***double Lyman-alpha tail***

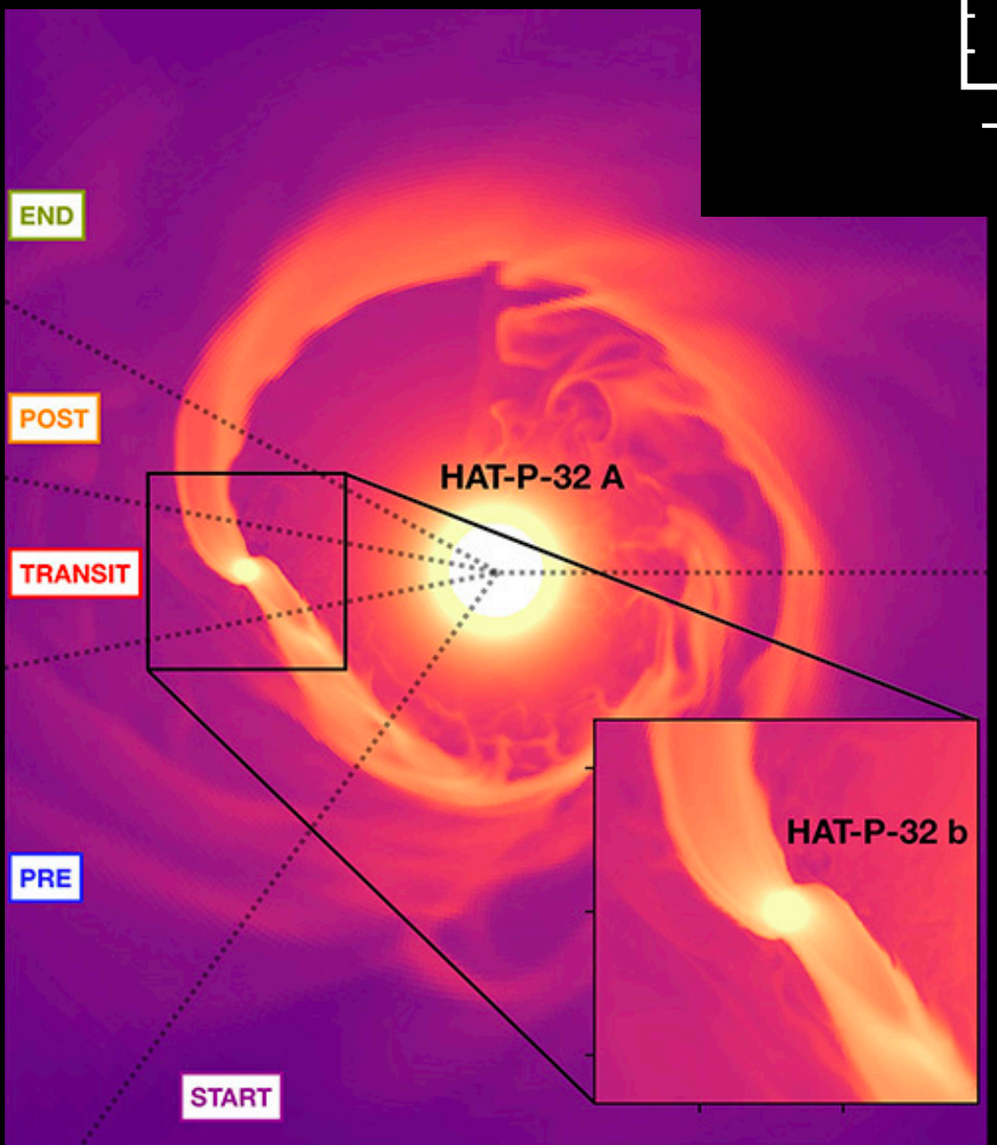
Validates 3D star-planet mass-loss models

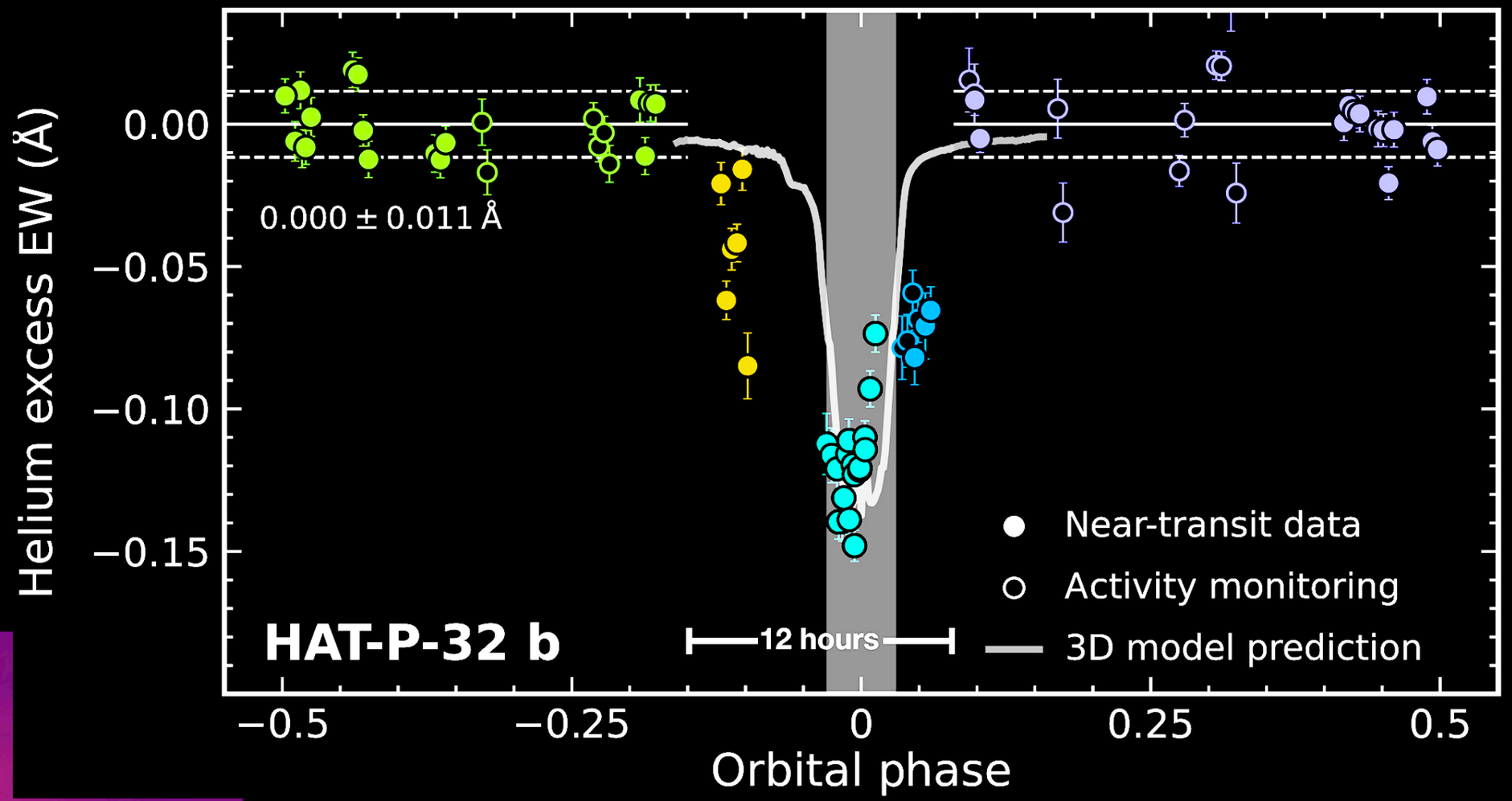
Which we can now use for ***better star+planet mass-loss measurements***

Orell-Miquel et al. (2024)

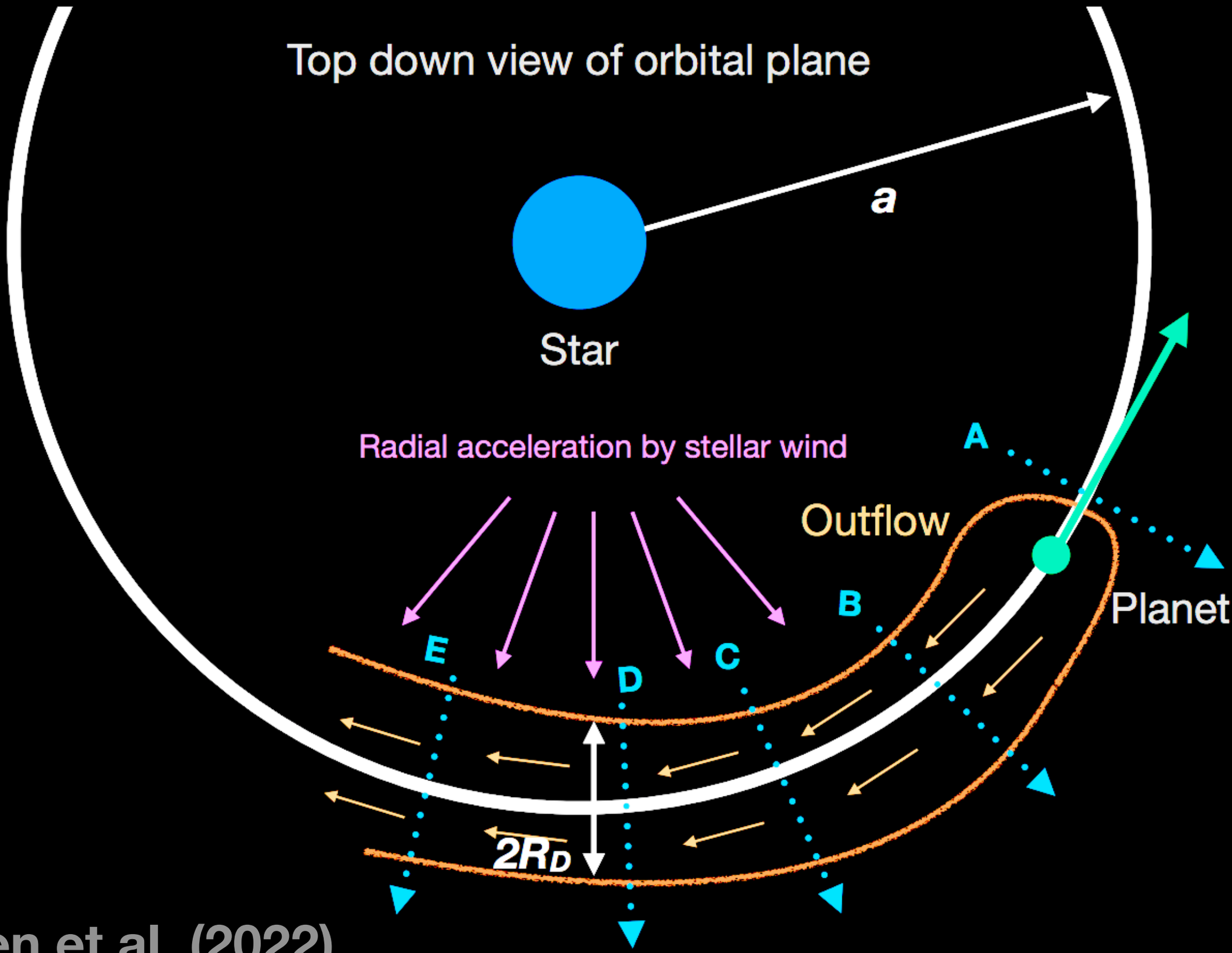


19 helium detections

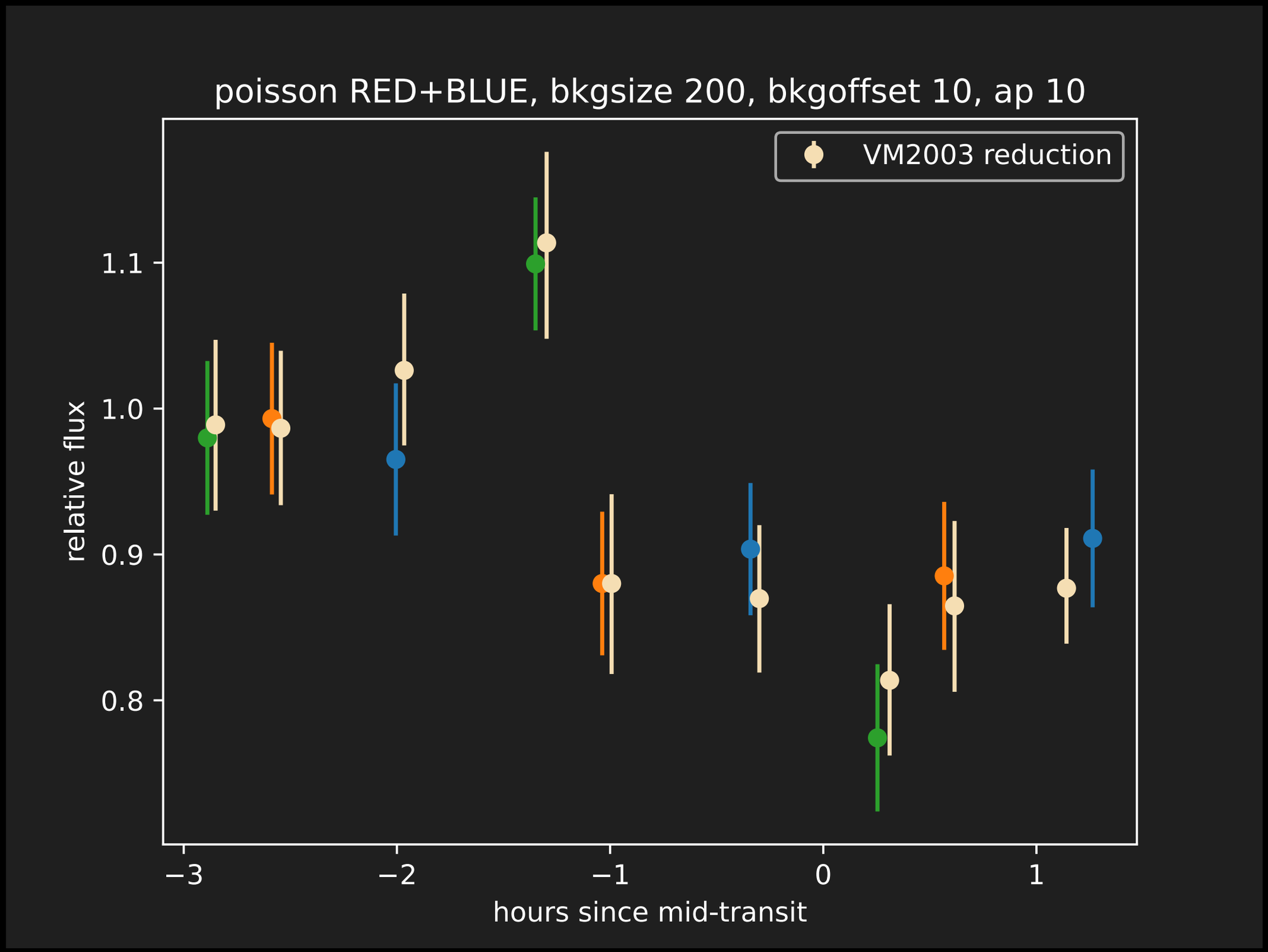


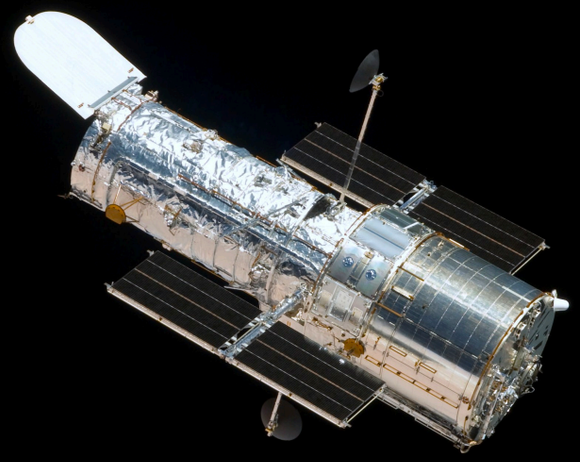


Zhang et al. (2023)

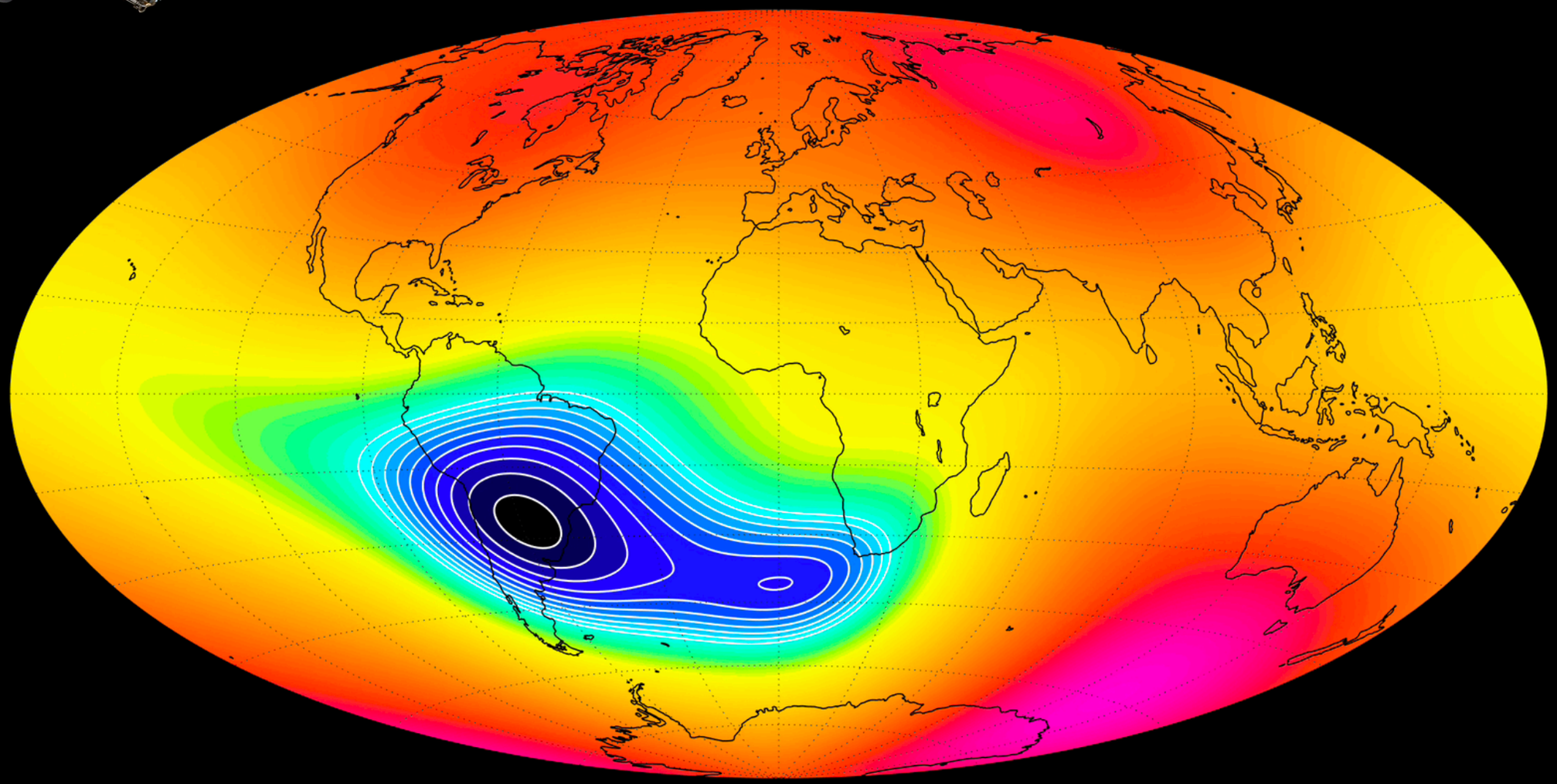


Owen et al. (2022)


poisson RED+BLUE, bkgsize 200, bkgoffset 10, ap 10
VM2003 reduction
1.1
1.0
0.9
0.8
relative flux
−3
−2
−1
0
1
hours since mid-transit

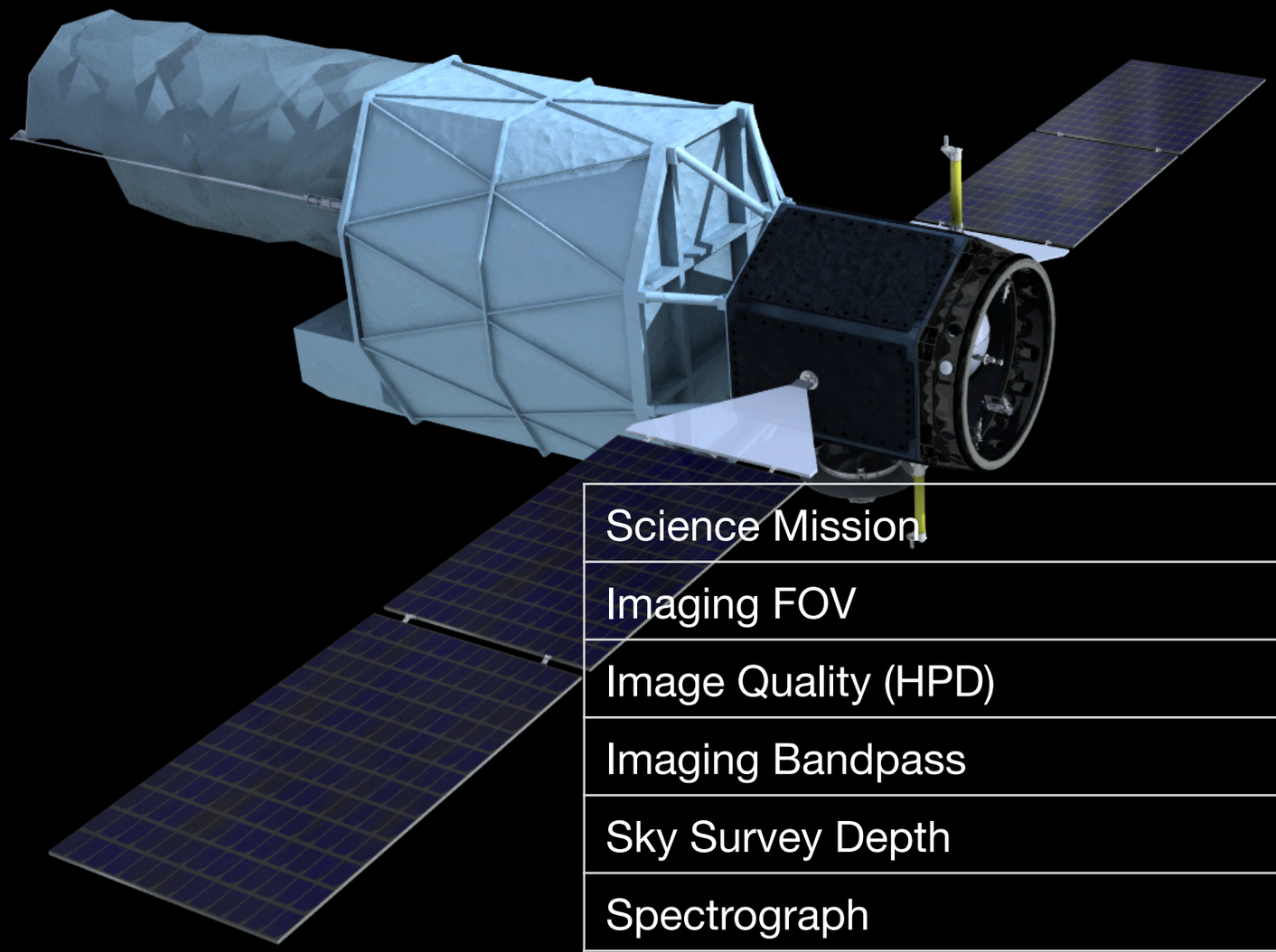


No Hubble Ly-α observations during SAA crossings



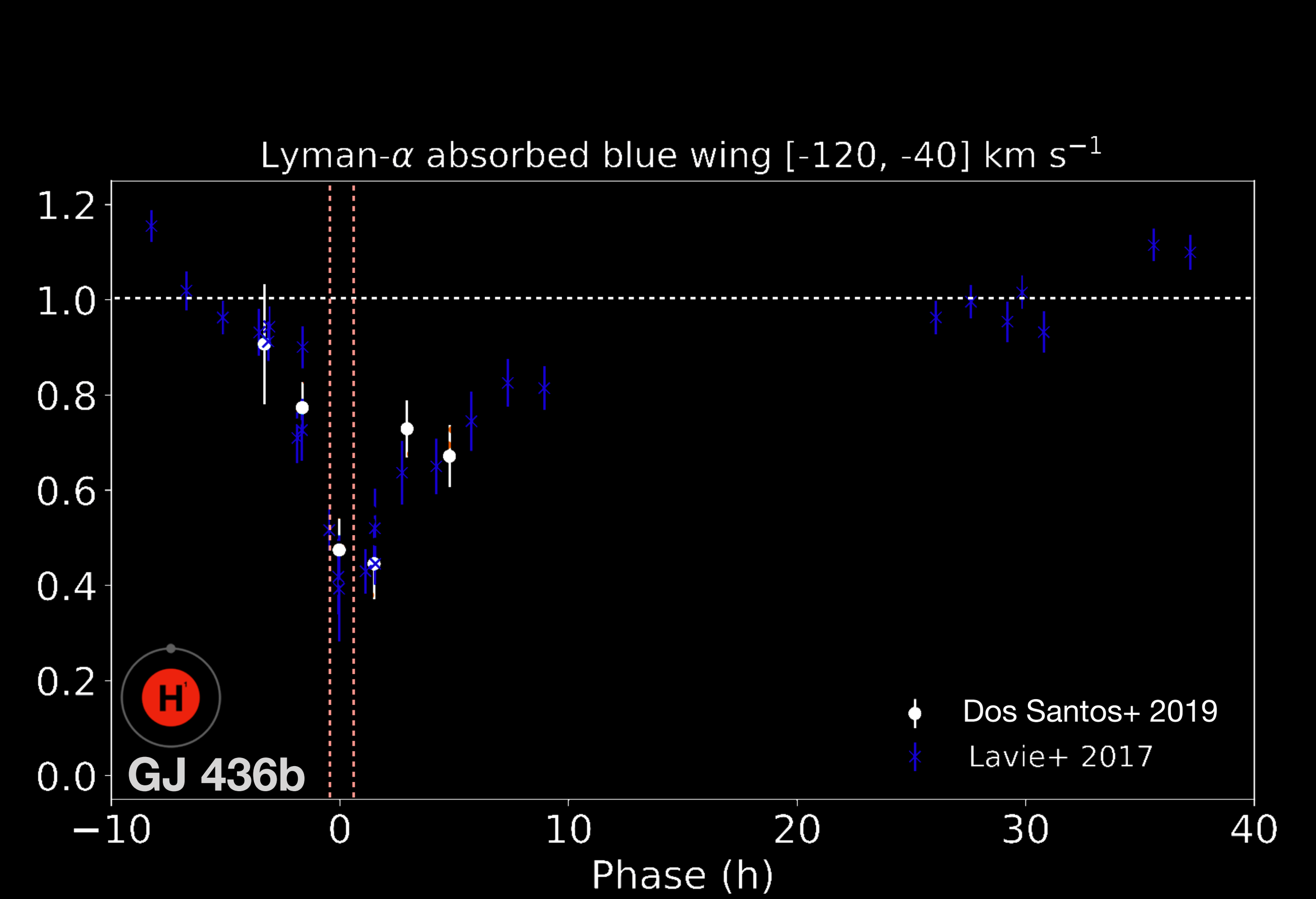
22000 32000 42000 52000 62000 nT

ESA

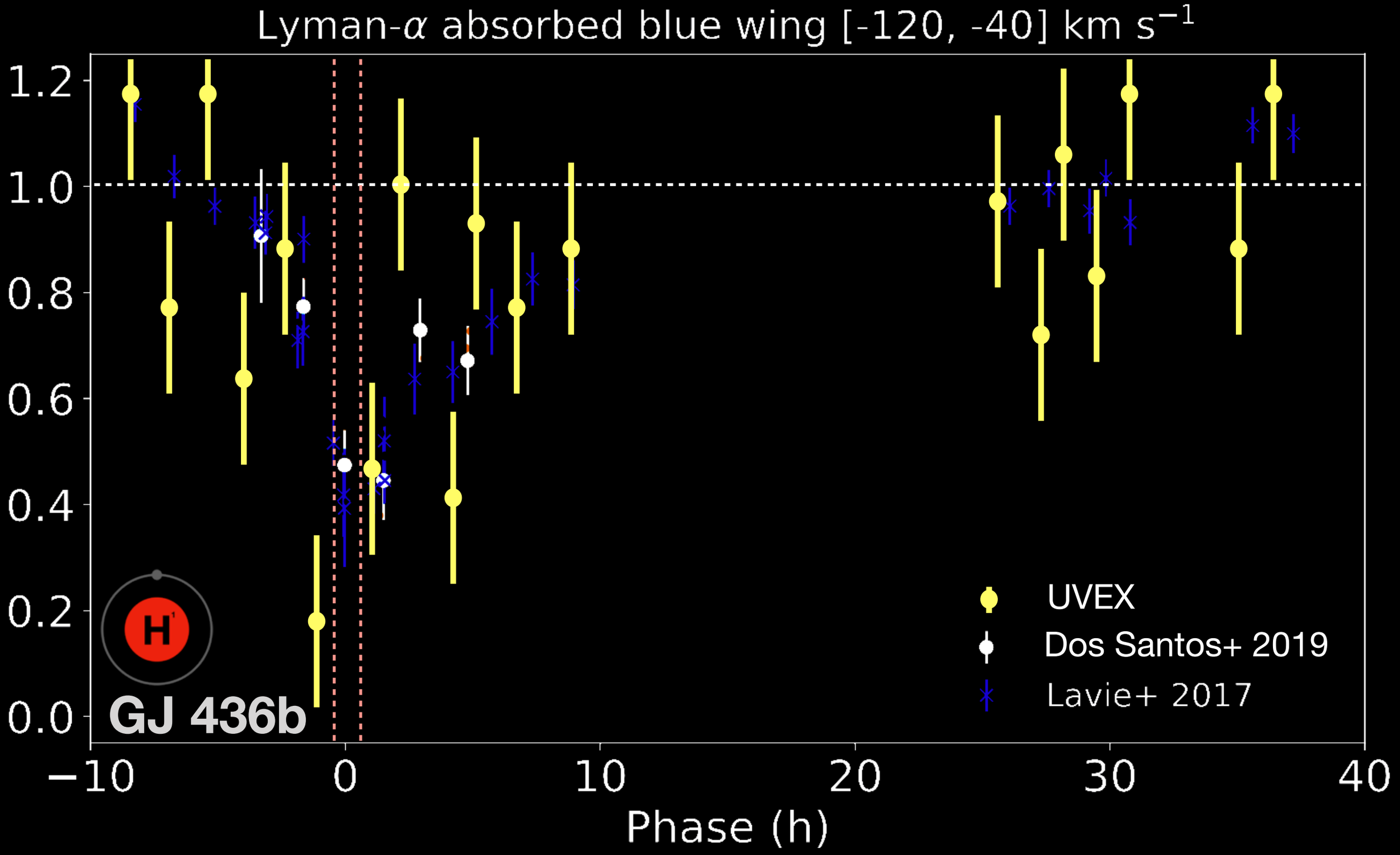


UVEX

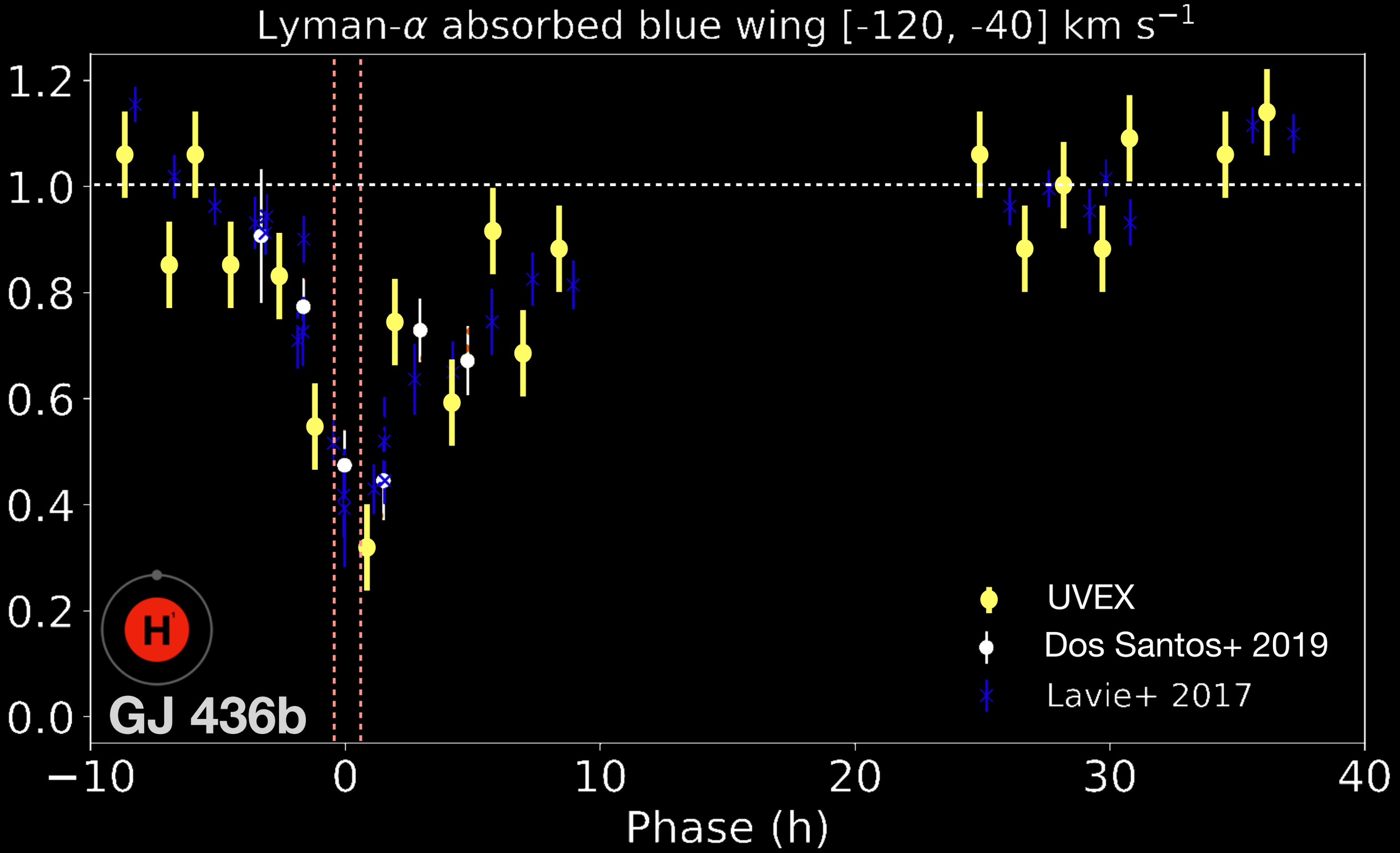
Science Mission	Launch: 2028, duration 2 years
Imaging FOV	3.5° x 3.5°
Image Quality (HPD)	< 2.25″
Imaging Bandpass	FUV: 1390–1900 Å
Sky Survey Depth	> 25.8 mag (FUV and NUV)
Spectrograph	2°-long slit, multiple widths
Spectrograph Bandpass	1150–2650 Å
Spectrograph Resolution	R > 1000
Orbit	Elliptical 17 R_E x 59 R_E, 13.7 days
Instantaneous Sky Accessibility	> 70%
Average ToO Response	< 3 hours


Lyman-α absorbed blue wing [-120, -40] km s^{-1}
1.2
1.0
0.8
0.6
0.4
0.2
0.0
H
GJ 436b
Dos Santos+ 2019
Lavie+ 2017
−10
0
10
20
30
40
Phase (h)

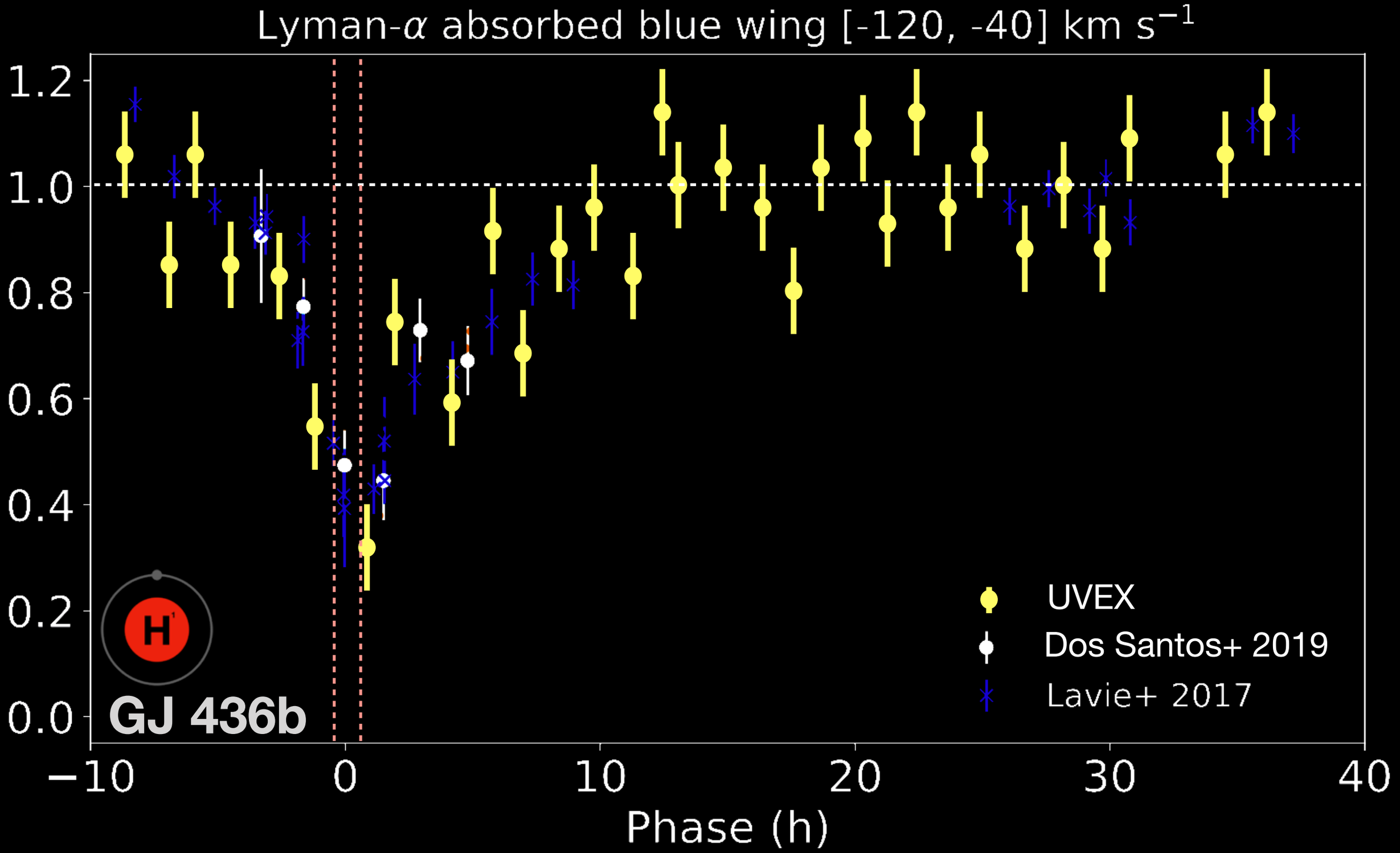
1 UVEX VISIT


Lyman-α absorbed blue wing [-120, -40] km s^{-1}
1.2
1.0
0.8
0.6
0.4
0.2
0.0
H
GJ 436b
UVEX
Dos Santos+ 2019
Lavie+ 2017
−10
0
10
20
30
40
Phase (h)

4 UVEX VISITS



4 UVEX VISITS



4 UVEX VISITS