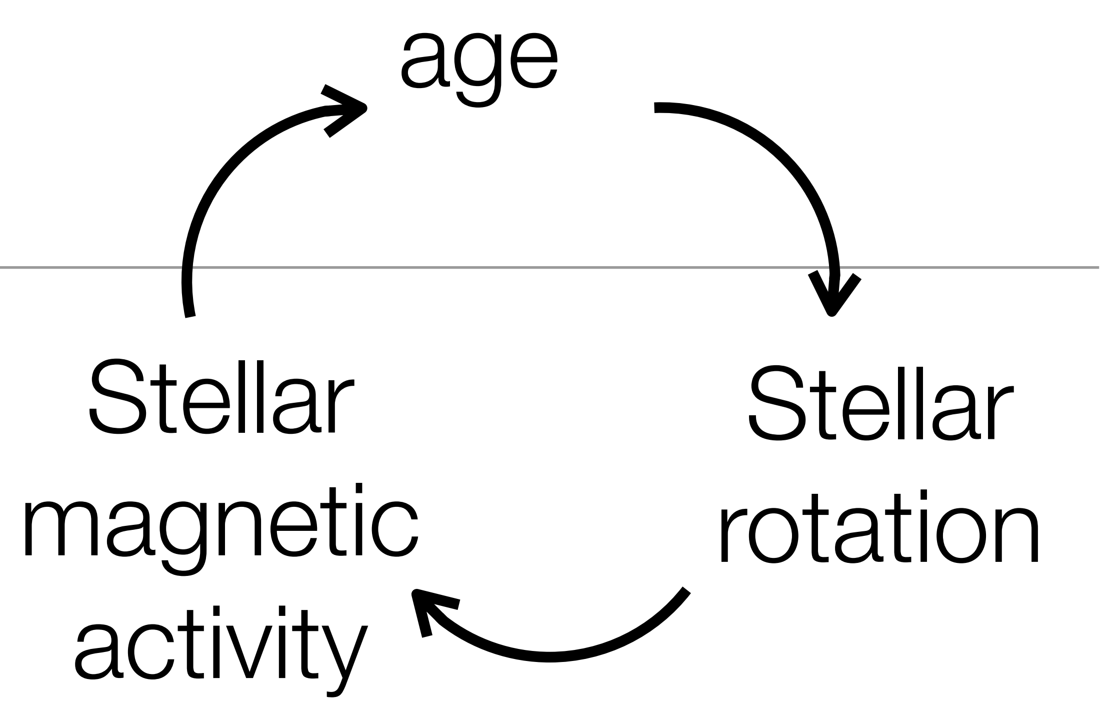
Star-planet interactions as a way to further characterise exoplanetary systems

Vidotto, A.

Star-planet interactions as a way to further characterise exoplanetary systems


particles: coronal mass ejections, stellar winds, etc
Stellar activity shape environment around planets
radiation: flares, coronal emission, etc
©KISS report on exoplanetary magnetism

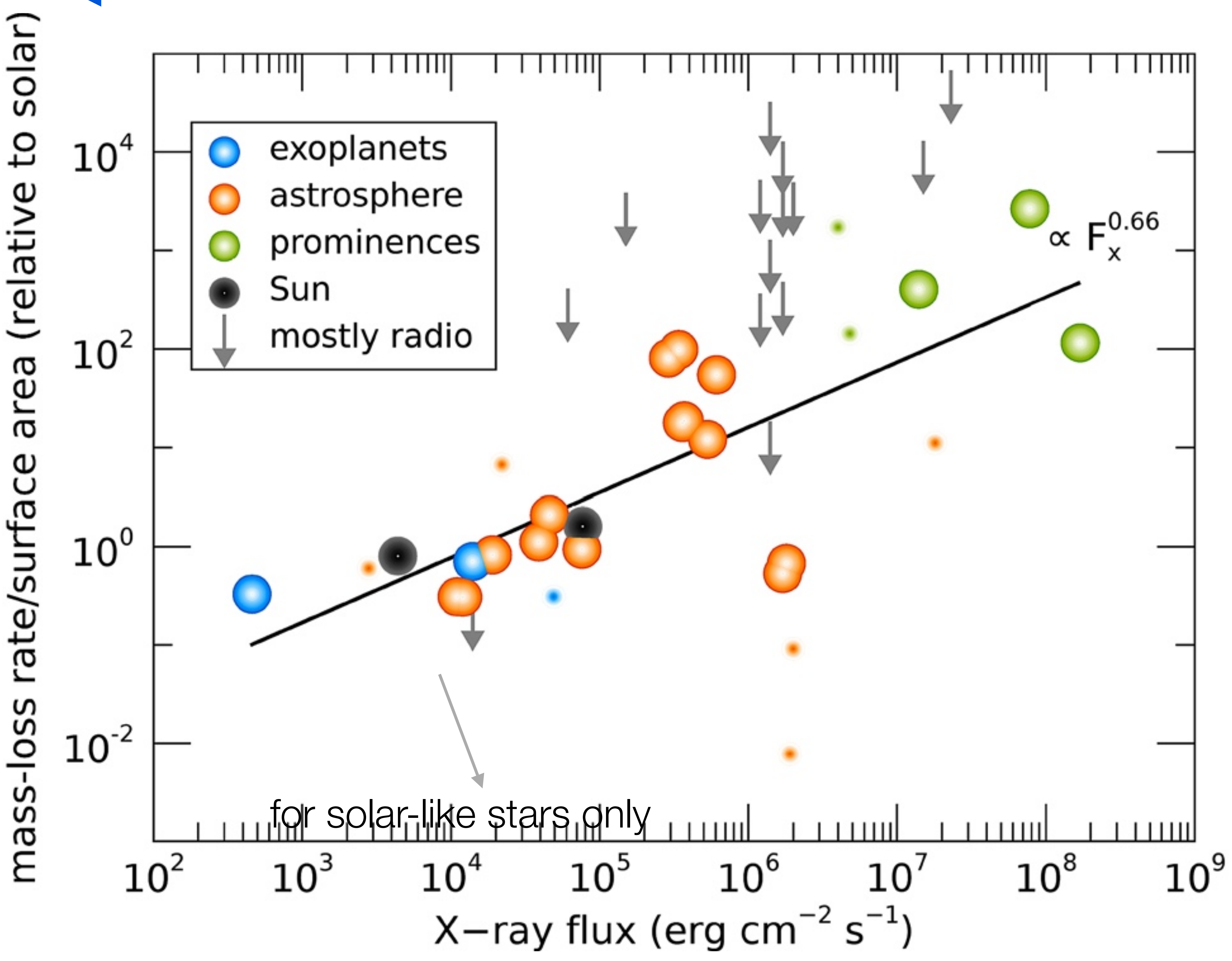
How do winds and high-E radiation evolve?



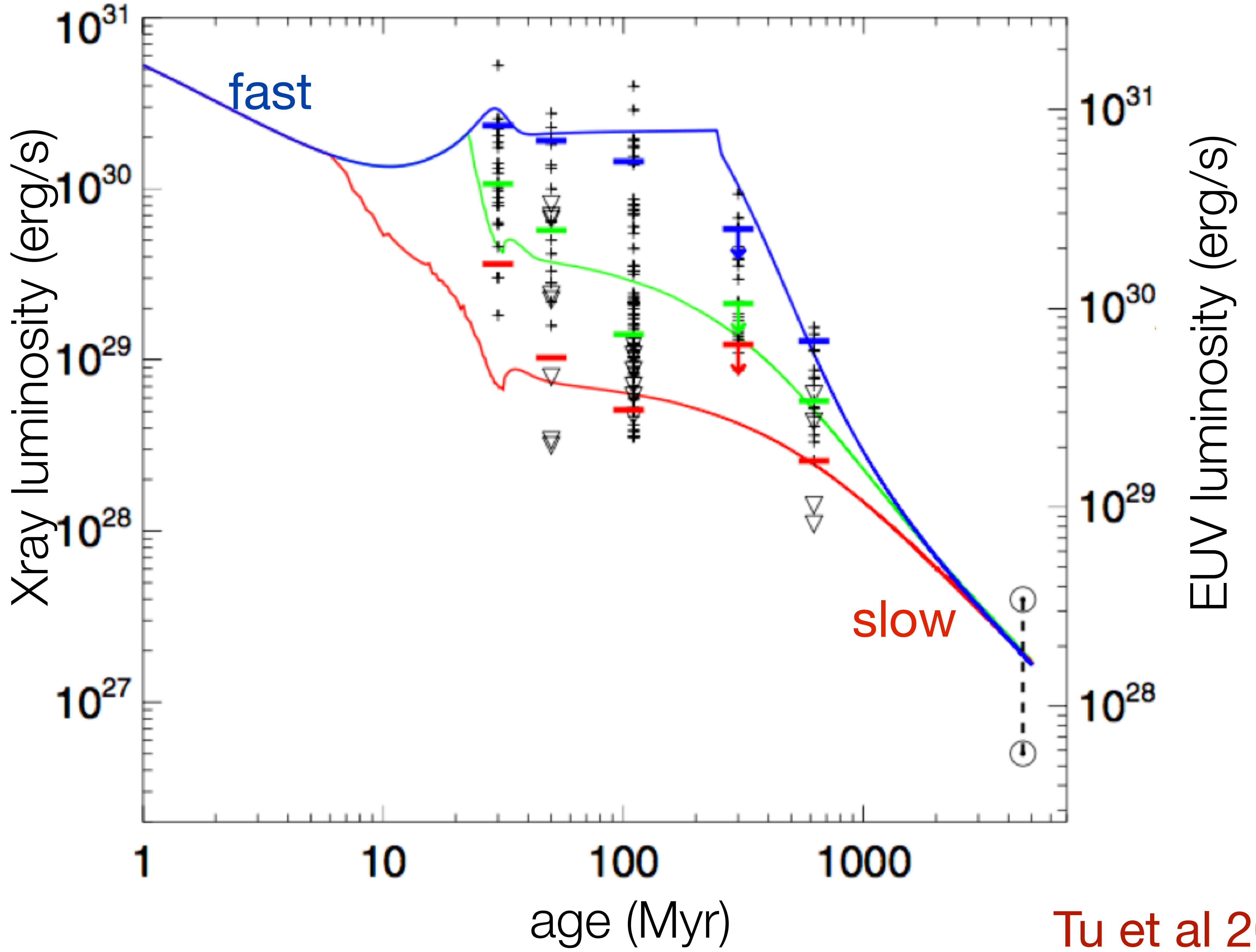
old stars (less active, slower rotation)

age

young stars (more active, faster rotation)

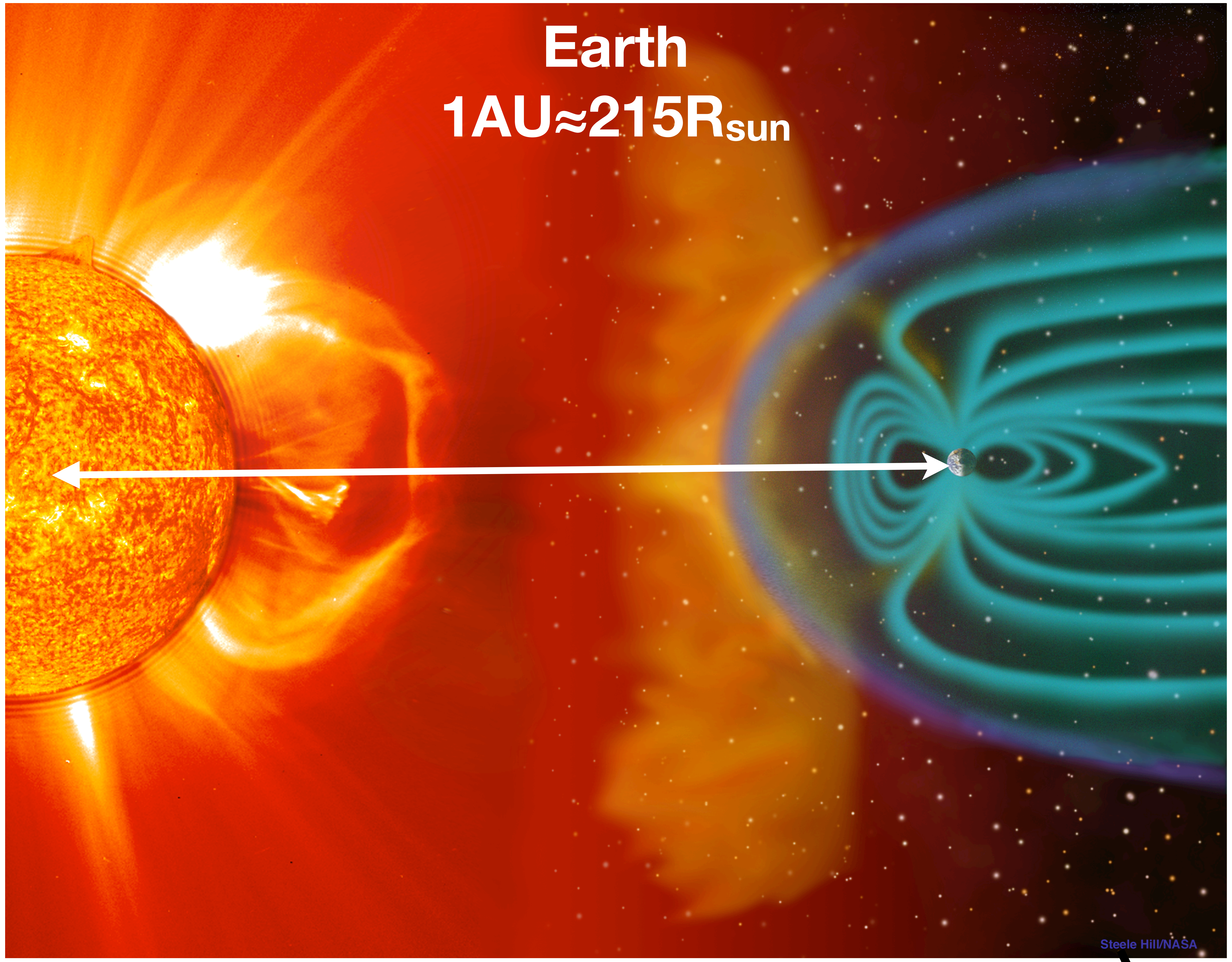


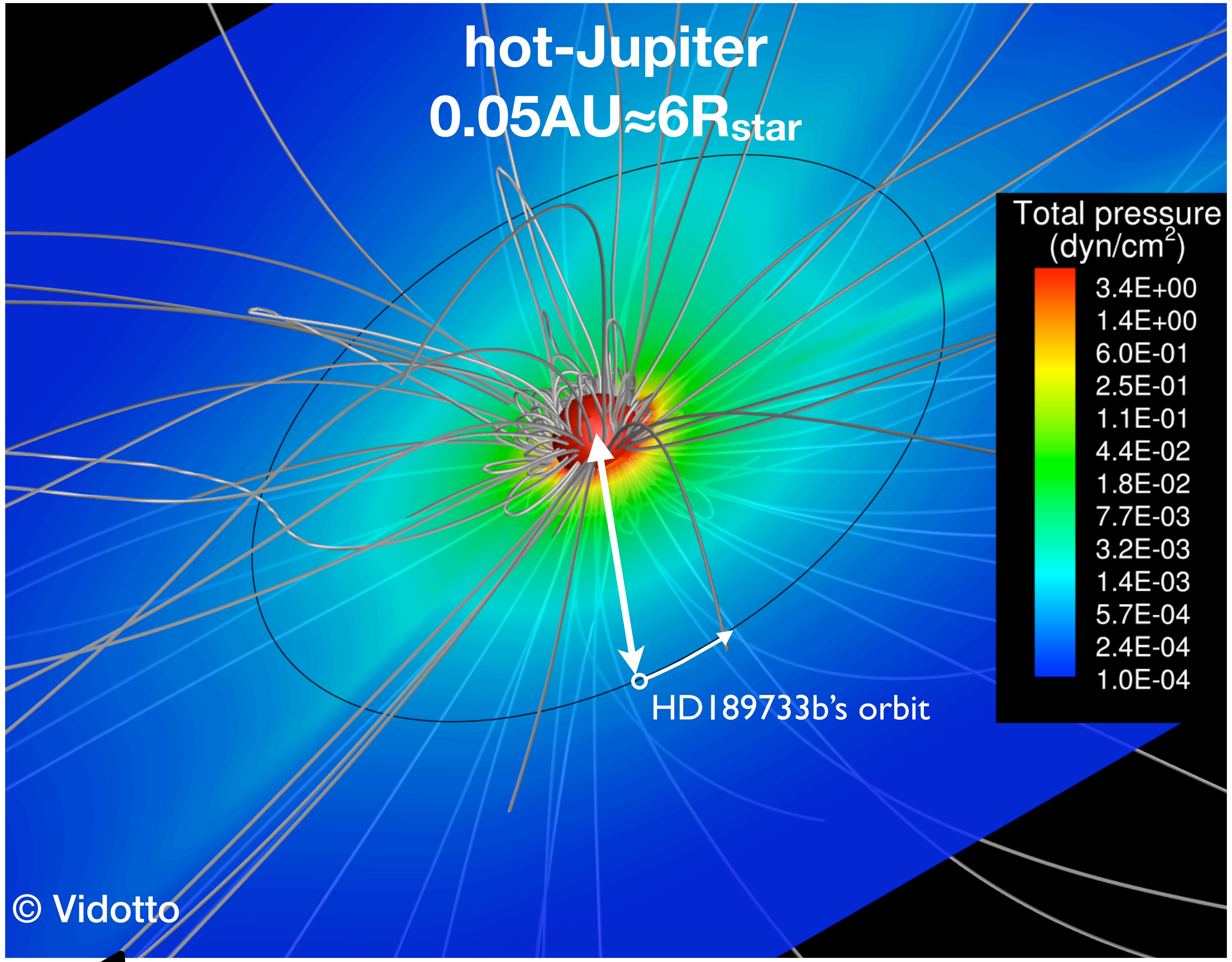
Vidotto 2021, Living Reviews in Solar Physics



Tu et al 2015

Interplanetary medium: stellar wind particles + magnetic fields





Close-in planets experience overall

- higher density external environment
- higher ambient magnetic fields
- higher radiative flux

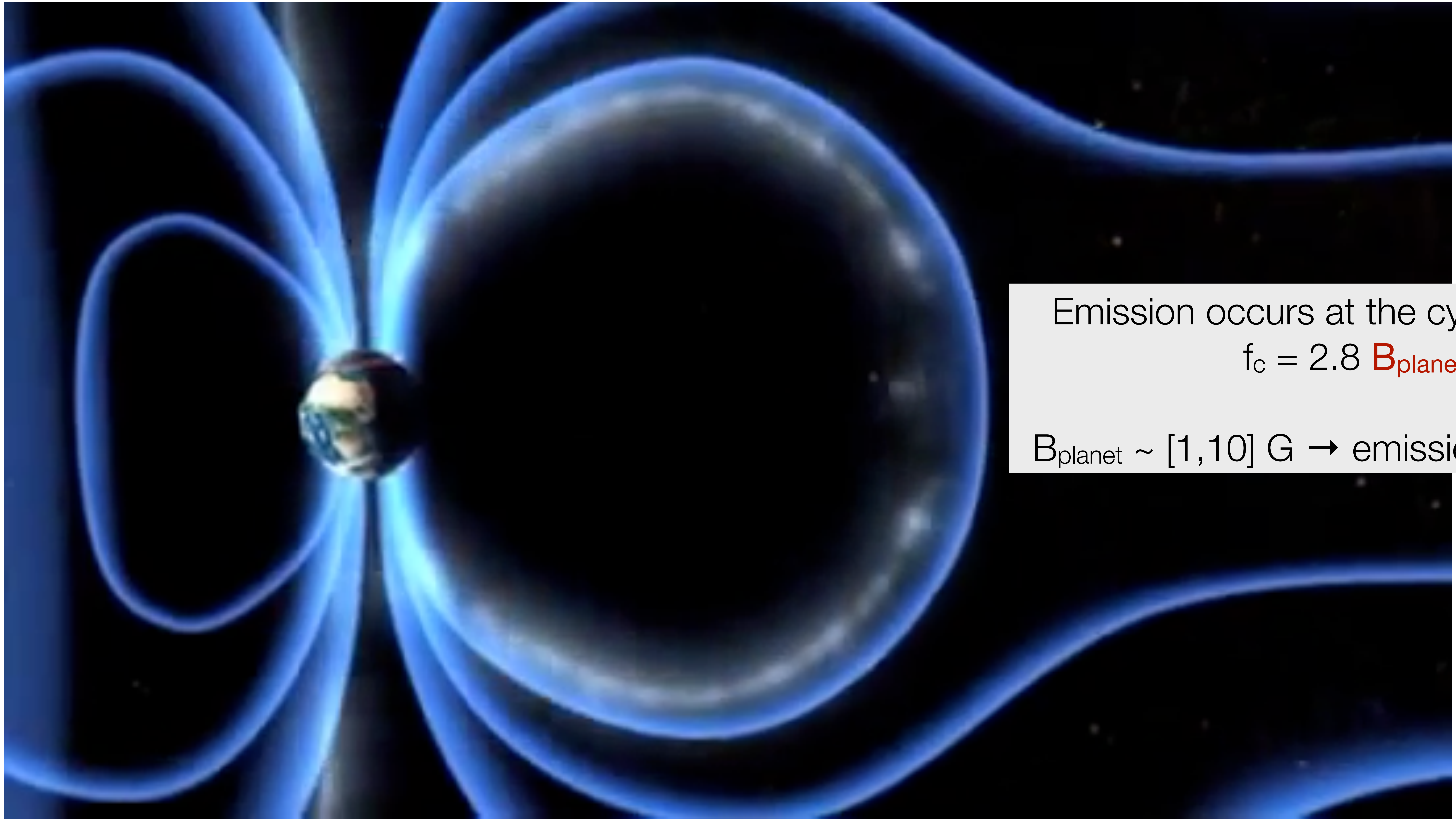
Outline

1 Planet-star interactions through stellar winds (particles & magnetic fields)

2 Planet-star interactions through radiation (plus winds)


Auroral emission from exoplanets
Planet-induced radio emission in stellar coronae
Radio emission from star-planet interactions

Types of radio emission: 1) Emission from the planet's magnetic field



Emission occurs at the cyclotron frequency

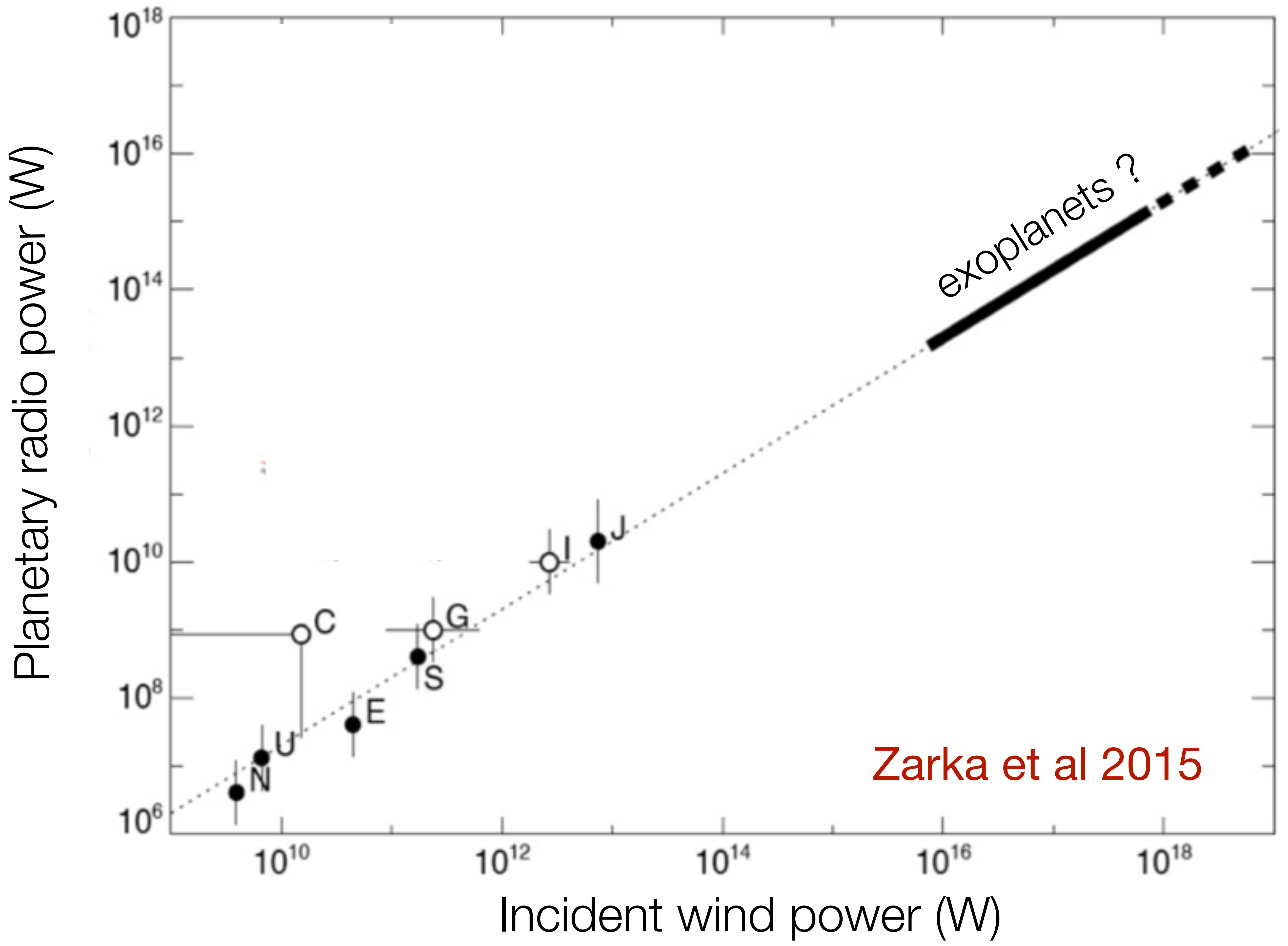
$f_c = 2.8\, B_{planet}$ MHz

$B_{planet} \sim [1,10]$ G → emission at [2.8, 28] MHz

Credit: NASA

Types of radio emission: 1) Emission from the planet's magnetic field

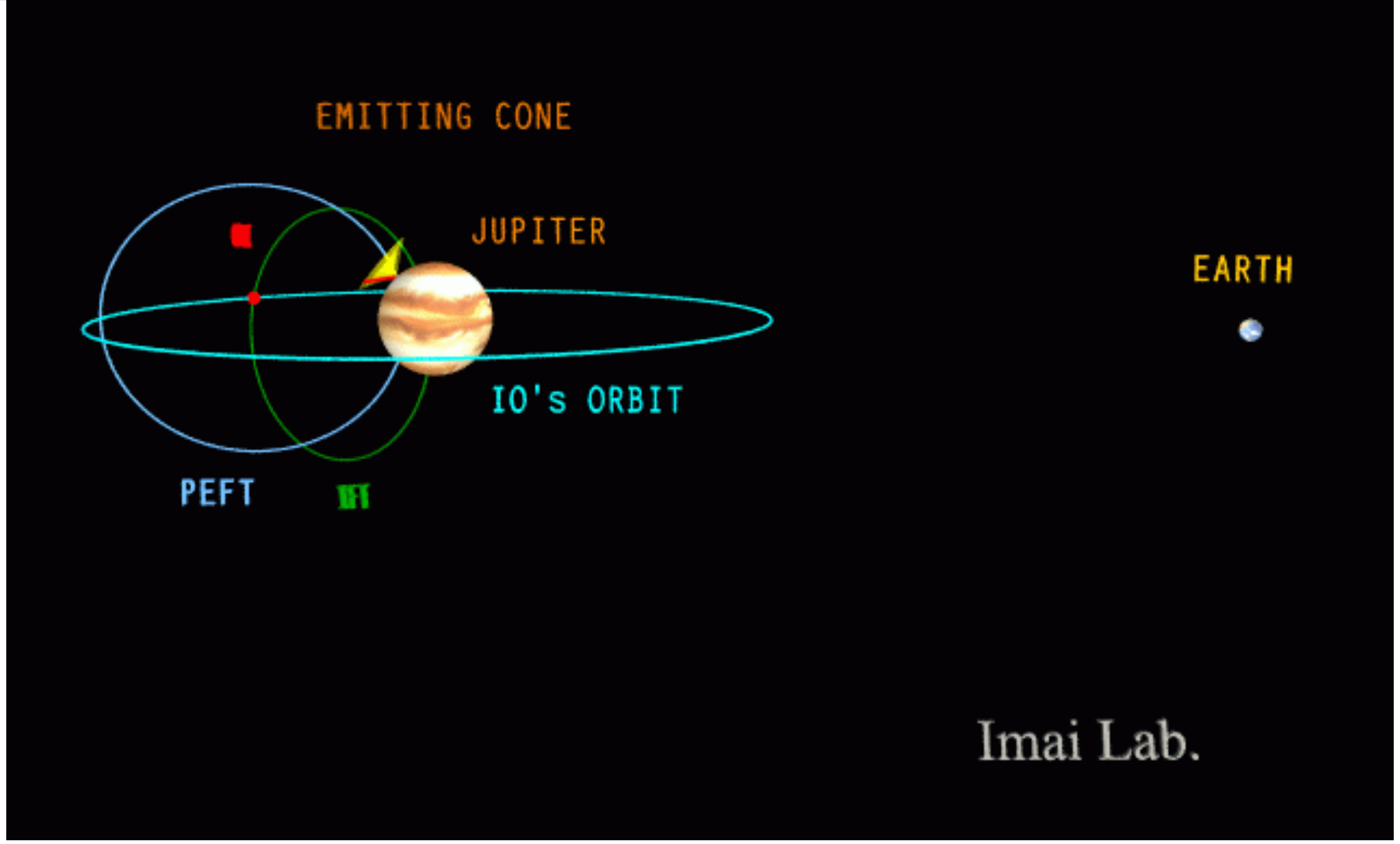
scaling law seems to apply more generally to any plasma flow-obstacle interaction



Why search for this emission?

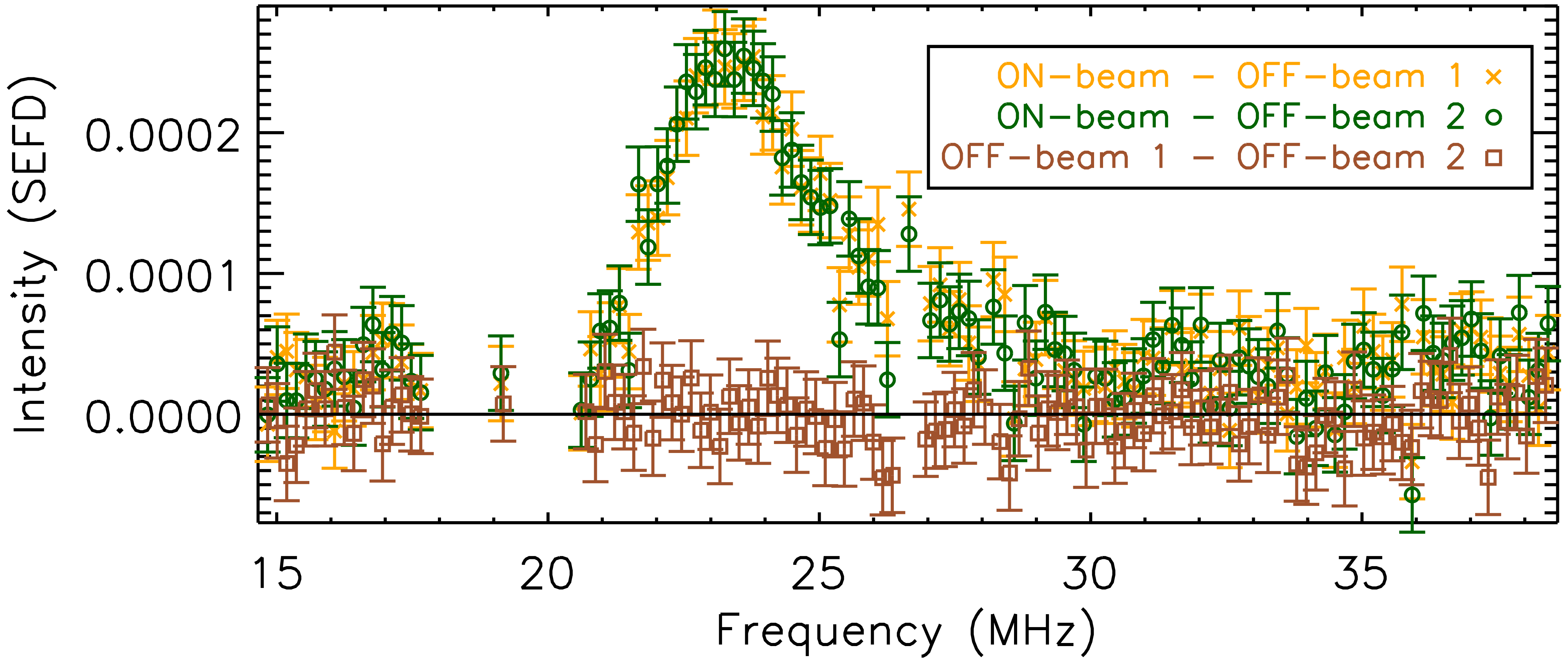
- direct detection of exoplanets
- detection would demonstrate that a planet is magnetised

Types of radio emission: 1) Emission from the planet's magnetic field



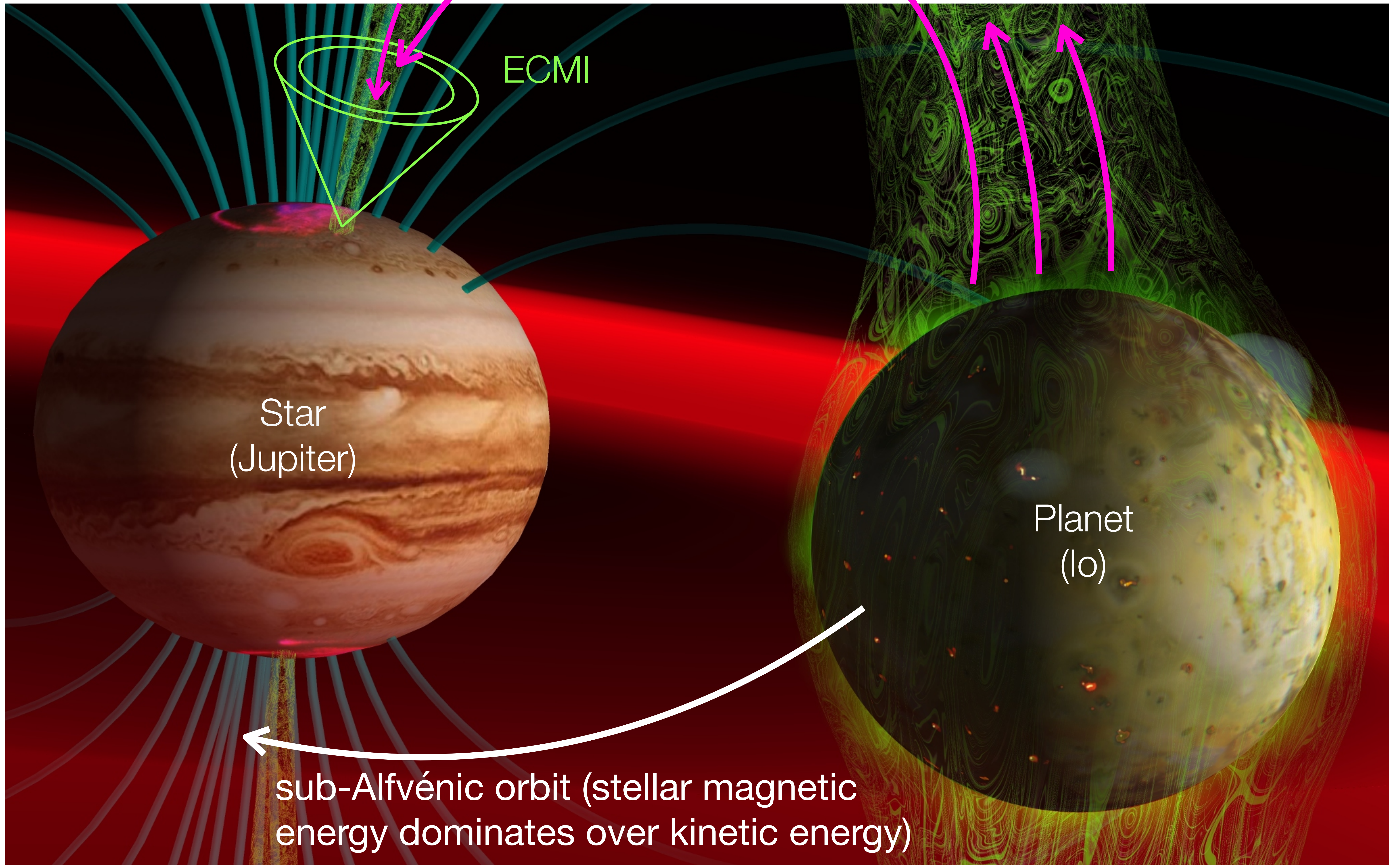
- Many searches have been unsuccessful
  - Observations not sensitive enough?
  - Low stellar wind power?
  - Small planetary field? Frequency mismatch.
  - Atmosphere of planet not allowing emission?
  - Emission beam not directed towards us?

- Great news!
  - Turner et al 2021: Bursty emissions from Tau Boo at ≈15-30 MHz (LOFAR) → planetary radio emission?
    - ➡ needs follow up
  - Planetary magnetic field ≈ 5-11G



Turner et al 2021

Types of radio emission: 2) Planet-induced radio emission

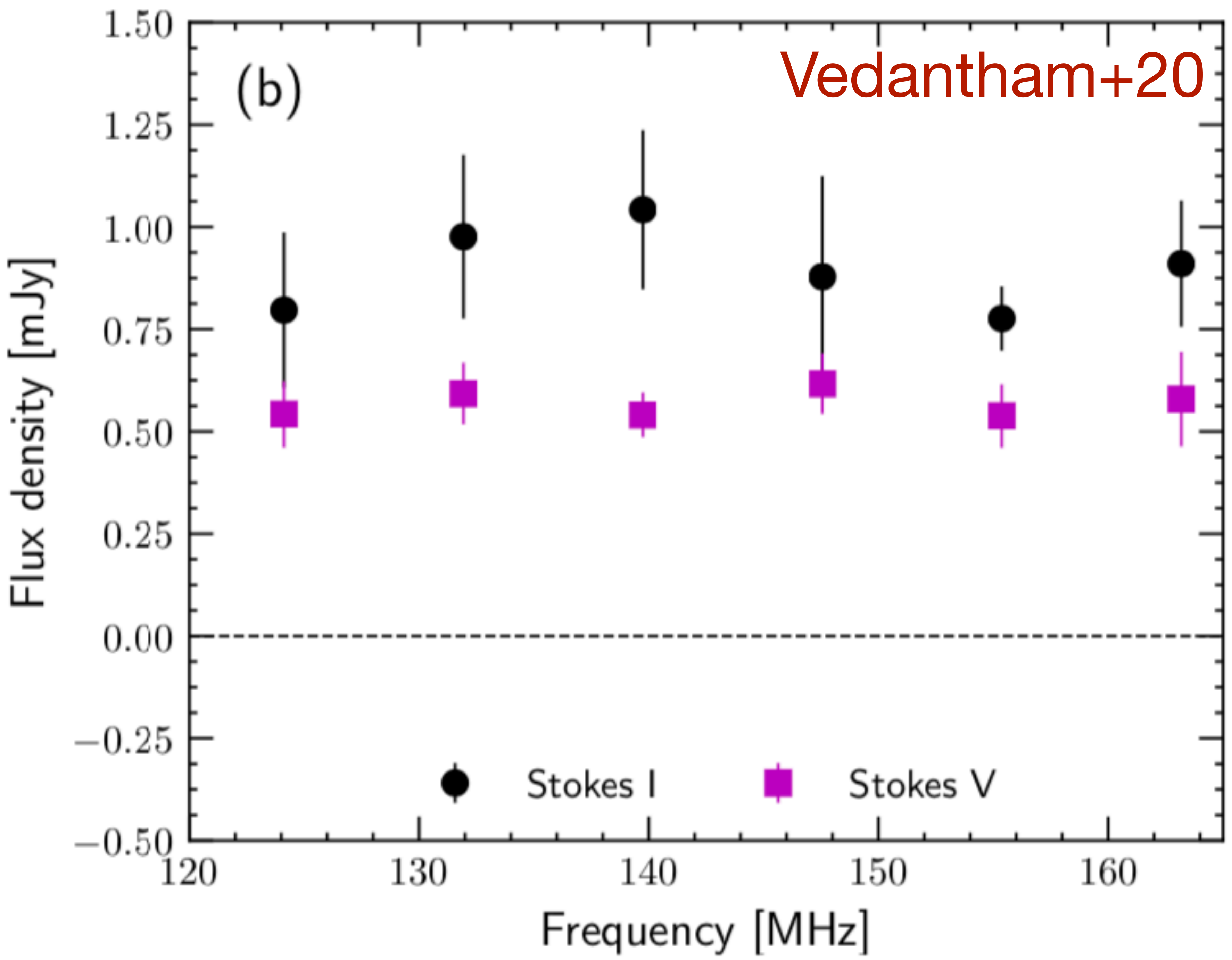


Emission occurs at the cyclotron frequency

$f_c = 2.8\ B_{star}$ MHz

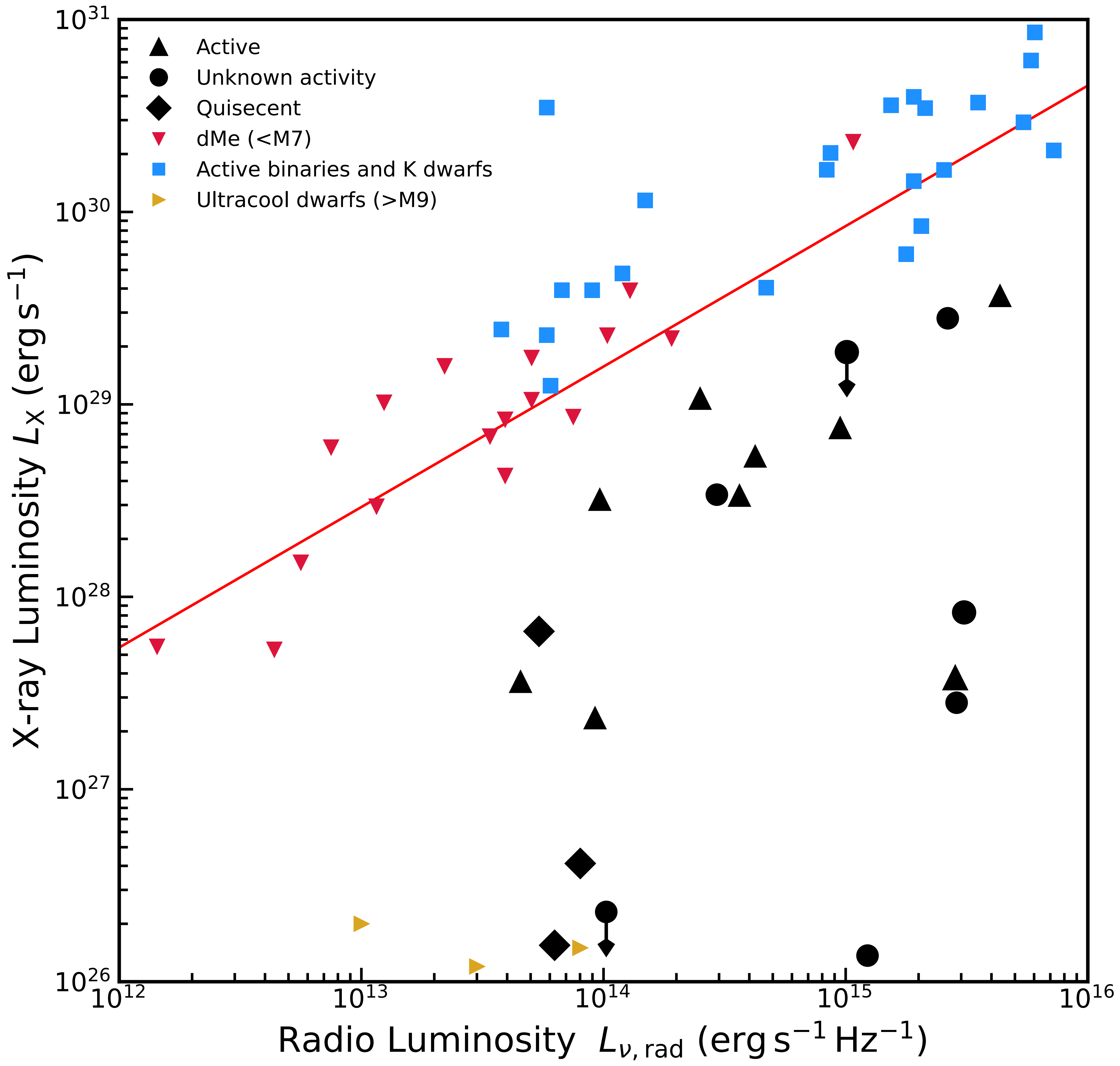
Observations at [120,160] MHz → B_{star} ~ [40, 60] G

Highly-polarised emission from the M dwarf GJ 1151 at 120 – 160 MHz



Consistent with cyclotron maser emission induced by a planet with P_{orb} ~1 to 5 days

Types of radio emission: 2) Planet-induced radio emission



Callingham et al 2021

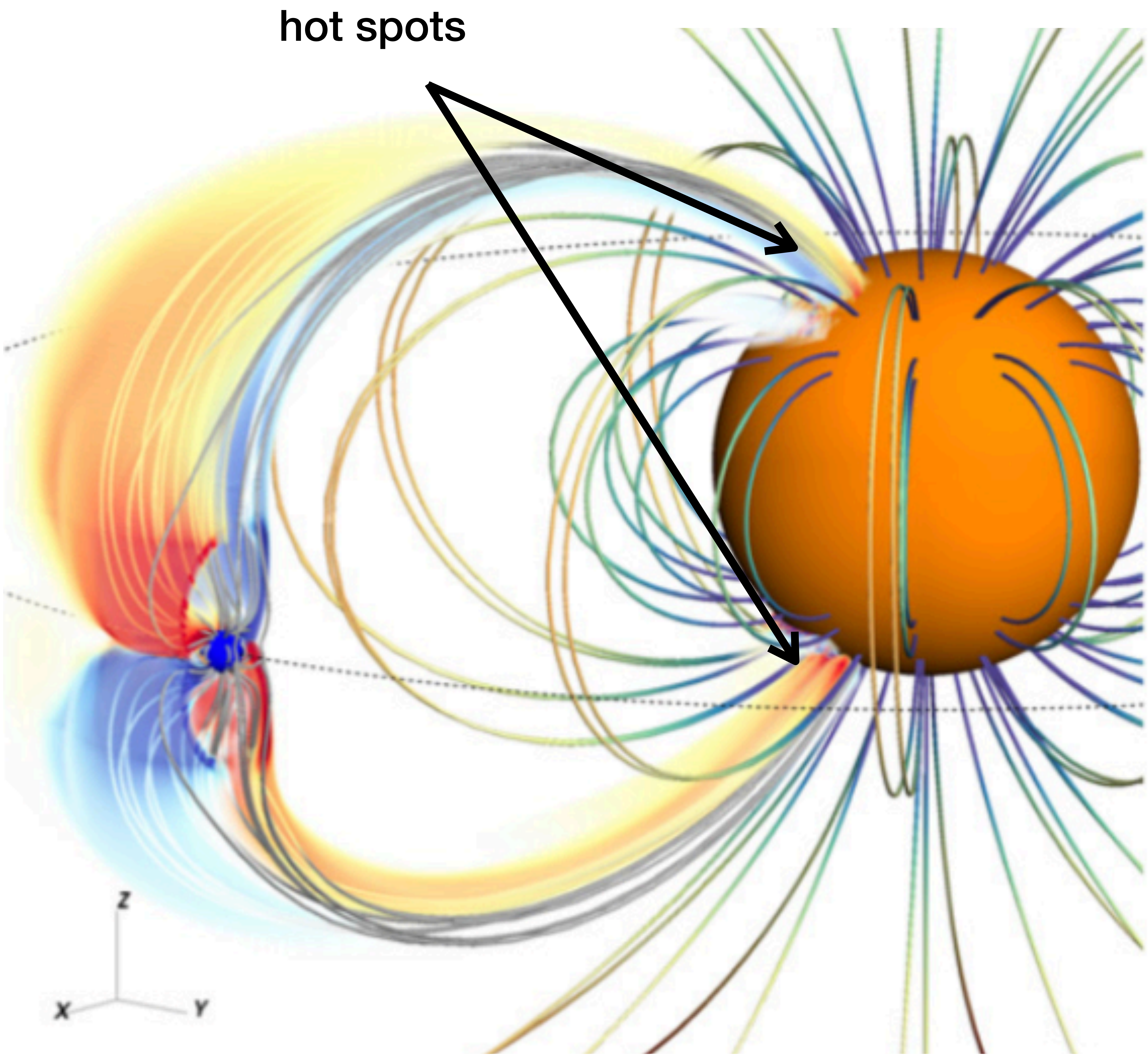
- More apparently inactive M dwarfs showing highly-polarised radio emission at 120 – 160 MHz
- most quiescent sources: emission could be planet-induced emission

Detection of this emission can tell us about the stellar wind mass-loss rate

See Rob Kavanagh's talk

Enhanced “Anomalous” stellar activity

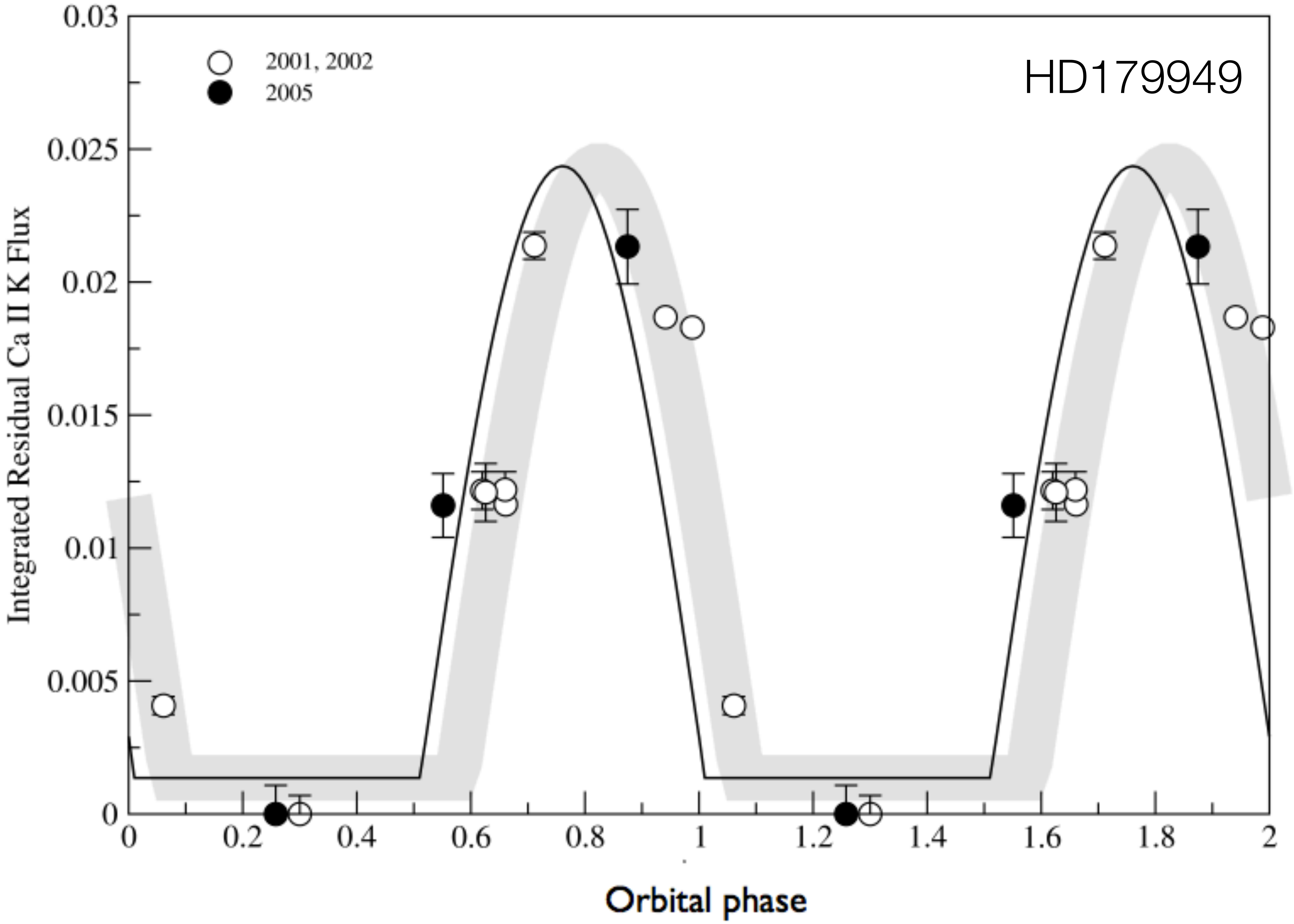
- Star and planet connected to each other through magnetic field lines
- Formation of “hot spots” which could enhance chromospheric activity



Strugarek et al 2015

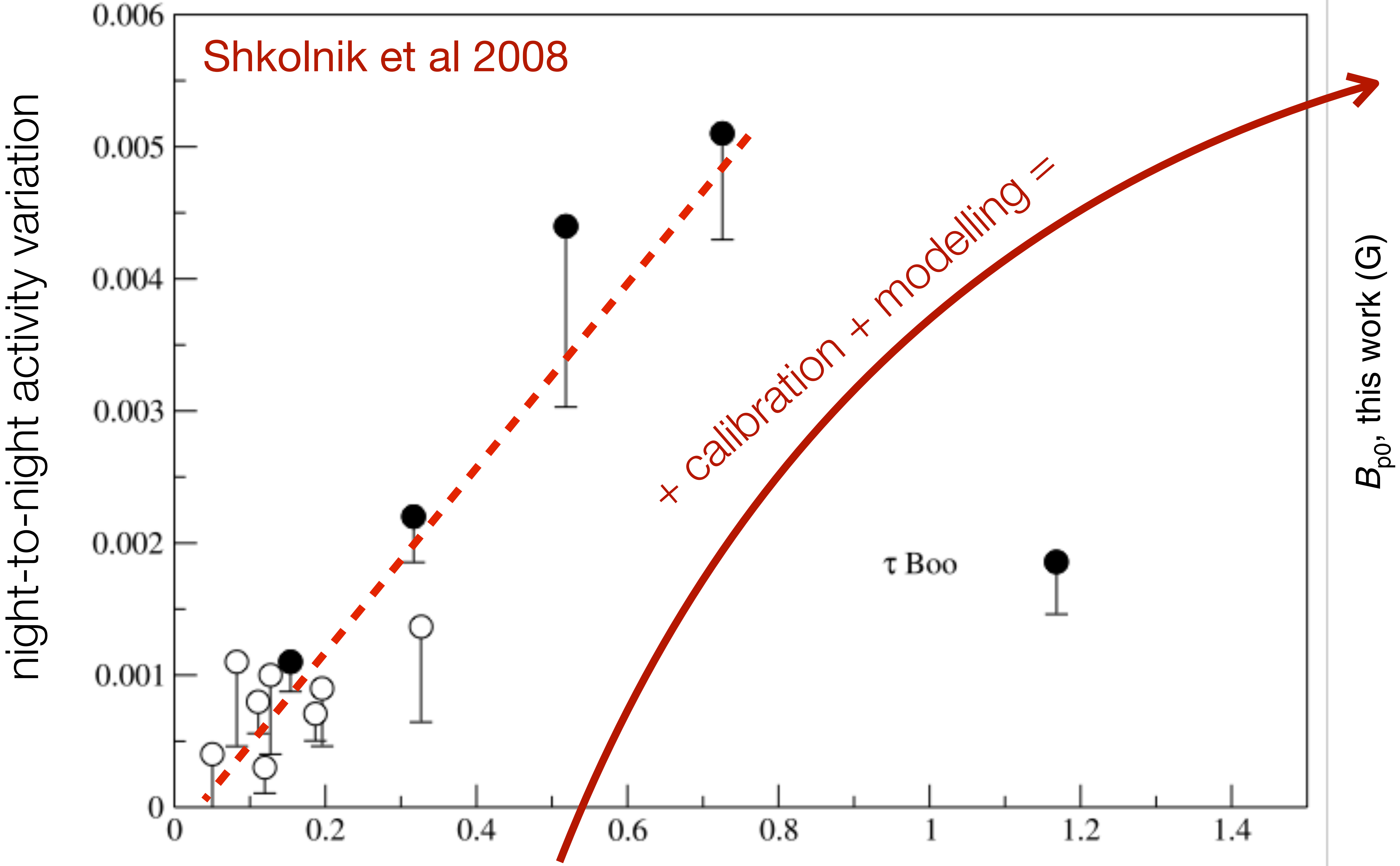
Planet causing enhanced activity on the star: HD179949

Anomalous stellar activity modulated by P_orb

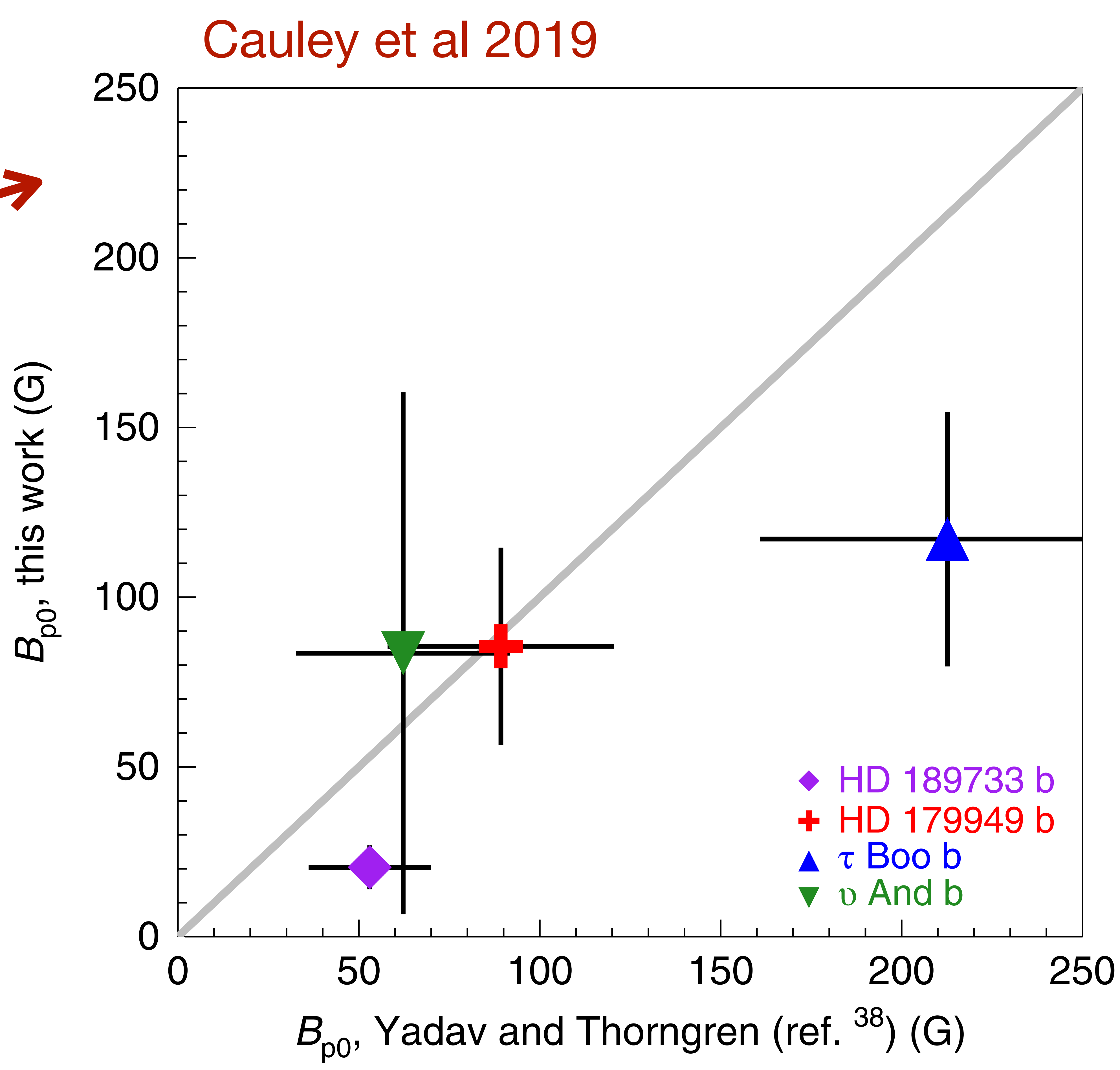


Shkolnik et al 2008

Anomalous activity can constrain planetary magnetic field



$M_p\sin(i)/P_{orb} \propto$ planet's magnetic moment



surface magnetic field values for these hot Jupiters: ≈ **20 G to 120 G**

2 Planet-star interactions through radiation (plus winds)

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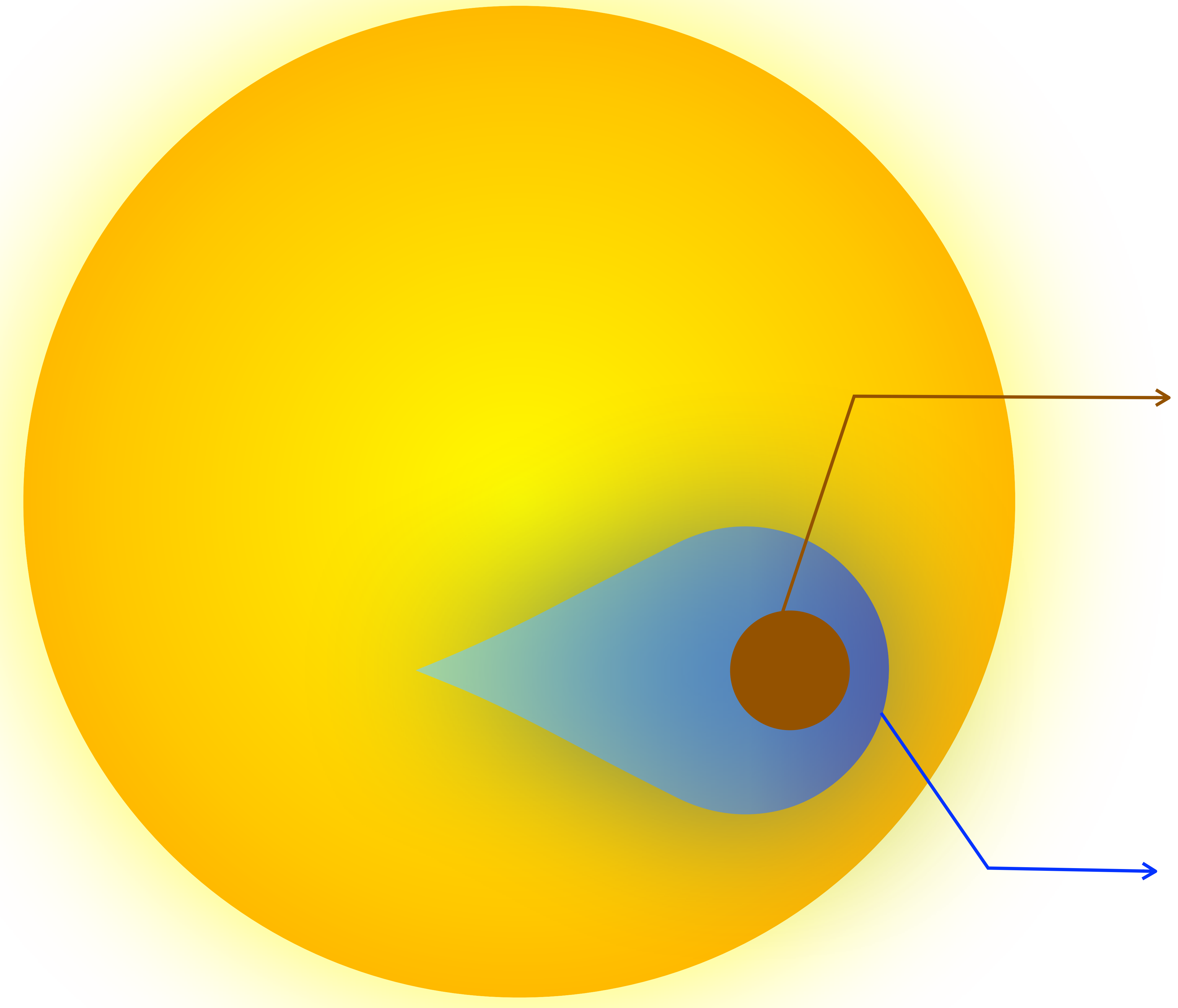
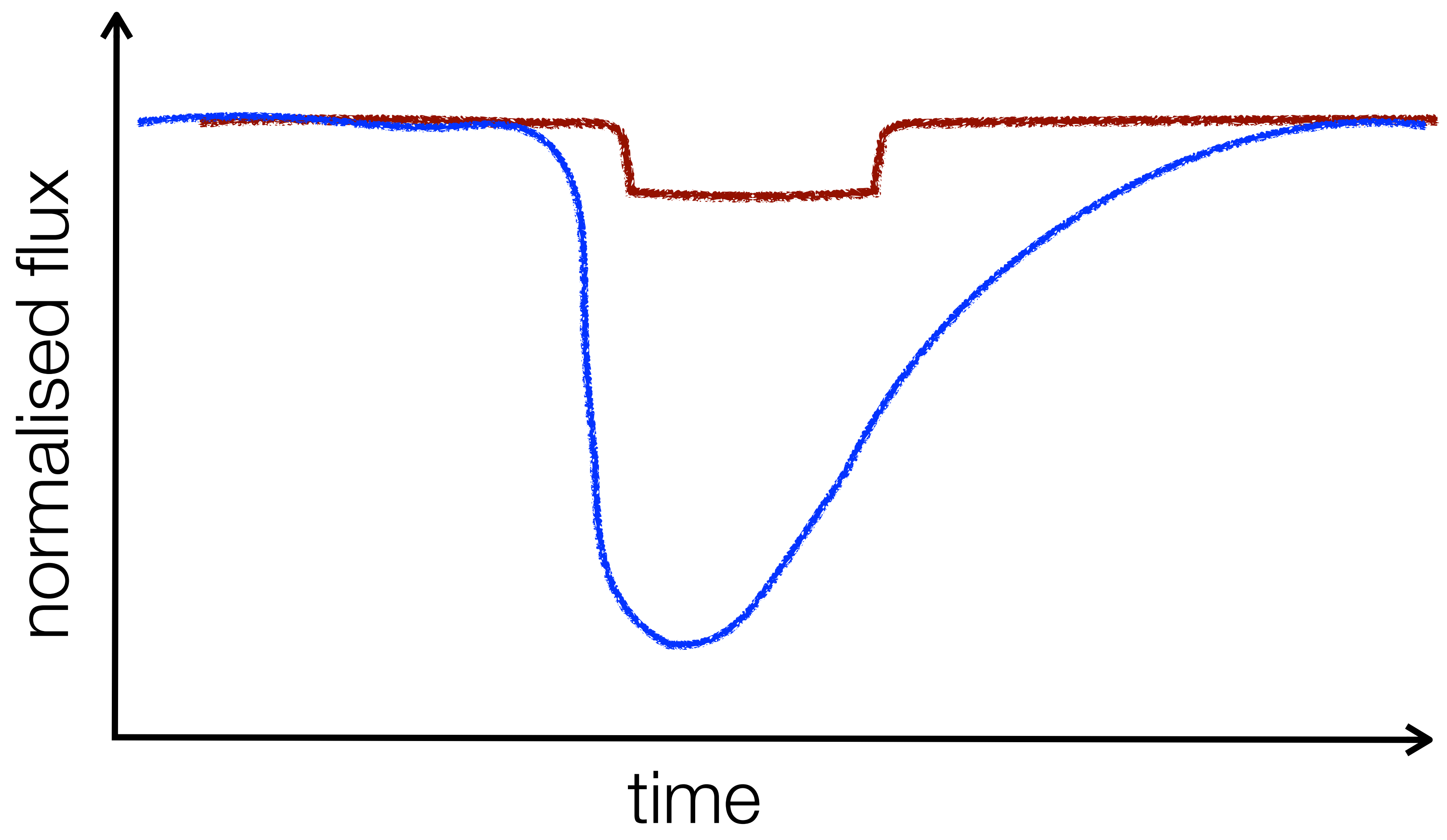
Using spectroscopic transits to probe atmospheric escape



Transmission spectroscopy

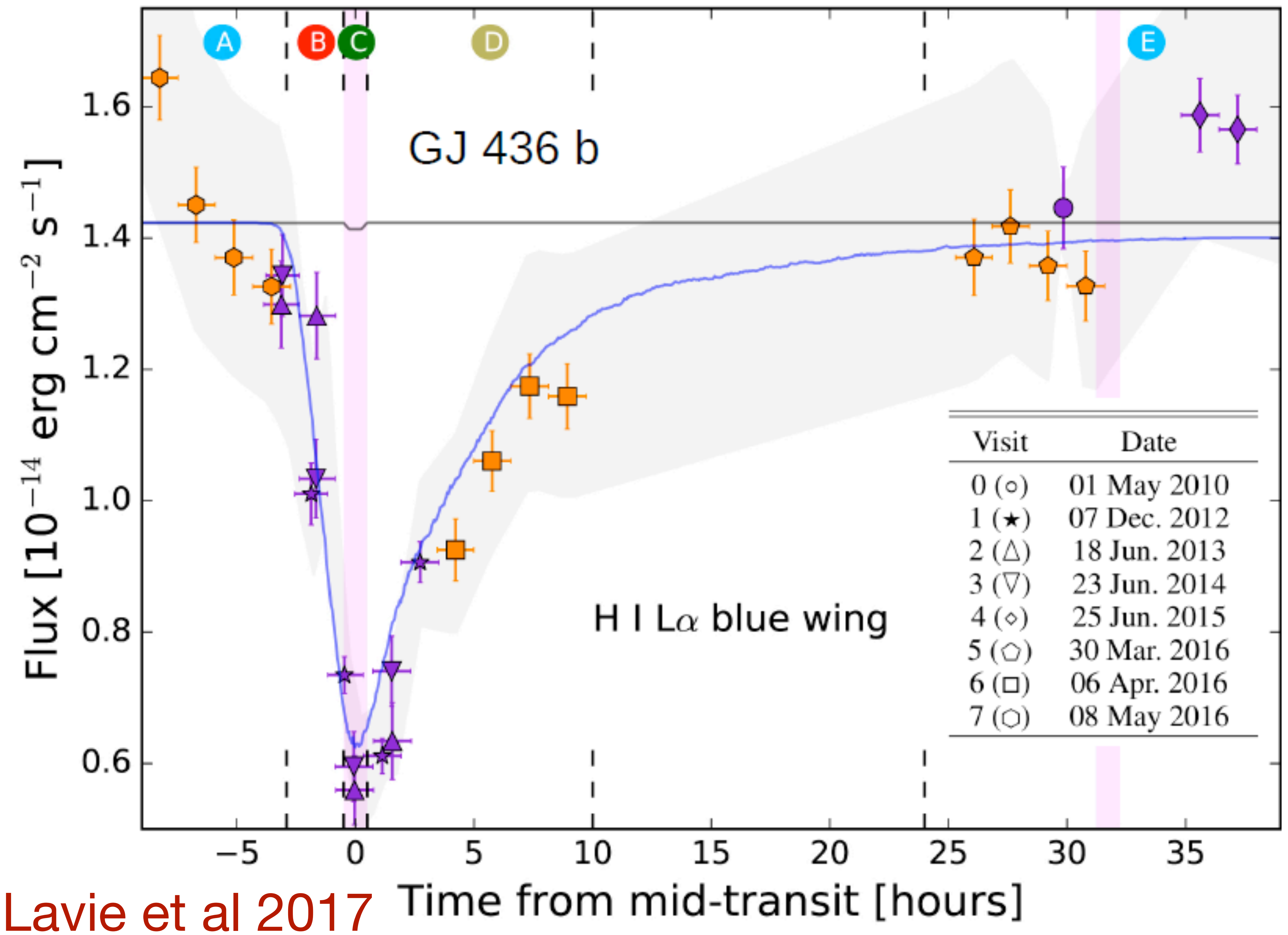
During transit, stellar radiation is transmitted through the exoplanet's atmosphere



1. Take a spectrum of the star at out-of-transit time
2. Take a spectrum of the star during transit
3. Divide the two to find % of absorption by the planetary atmosphere

Escaping atmosphere of close-in gas giants

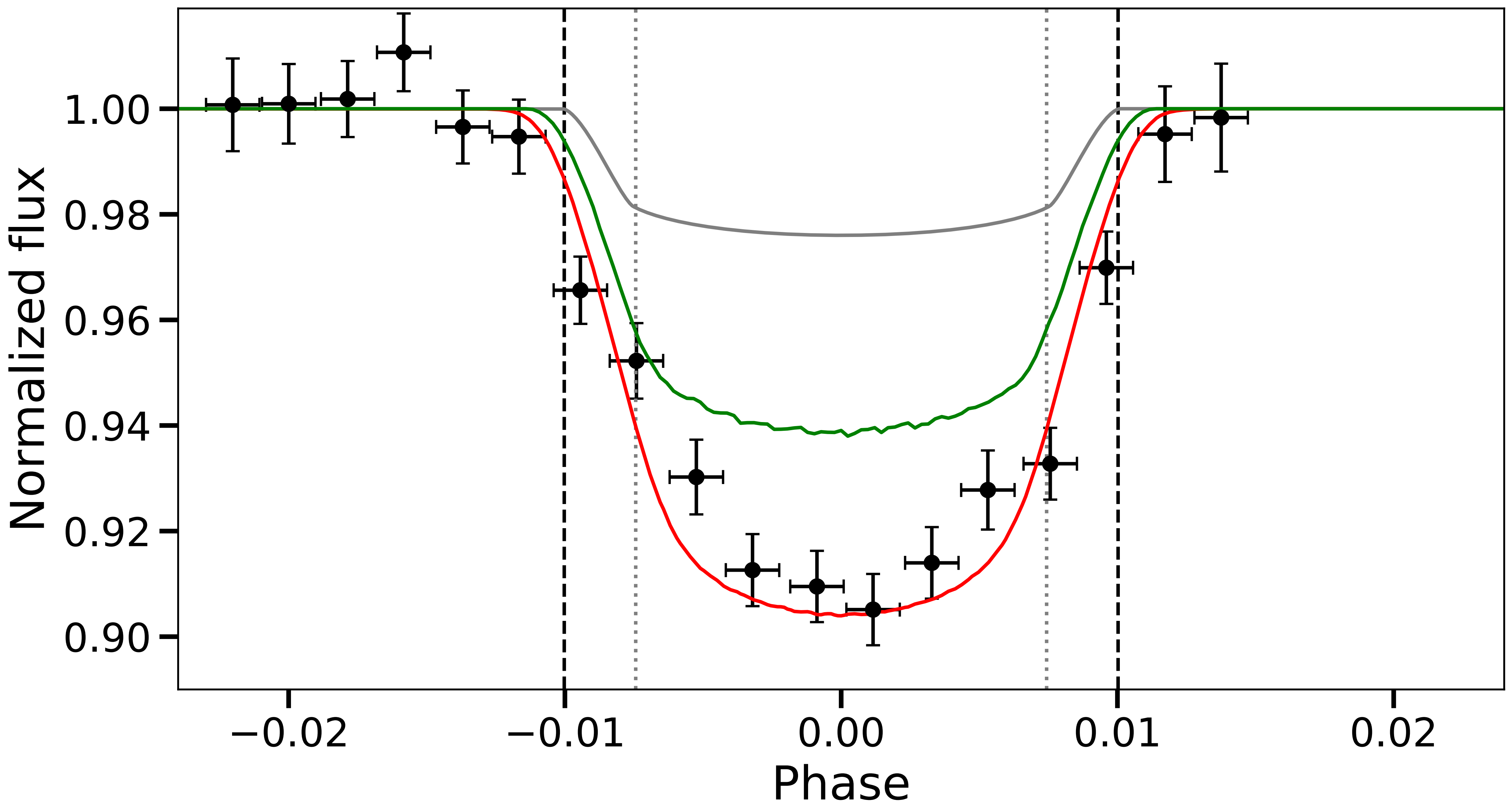
Ly-alpha: GJ436b



Lavie et al 2017

transit depth ~ 60% (!)

HeI triplet: WASP-107b



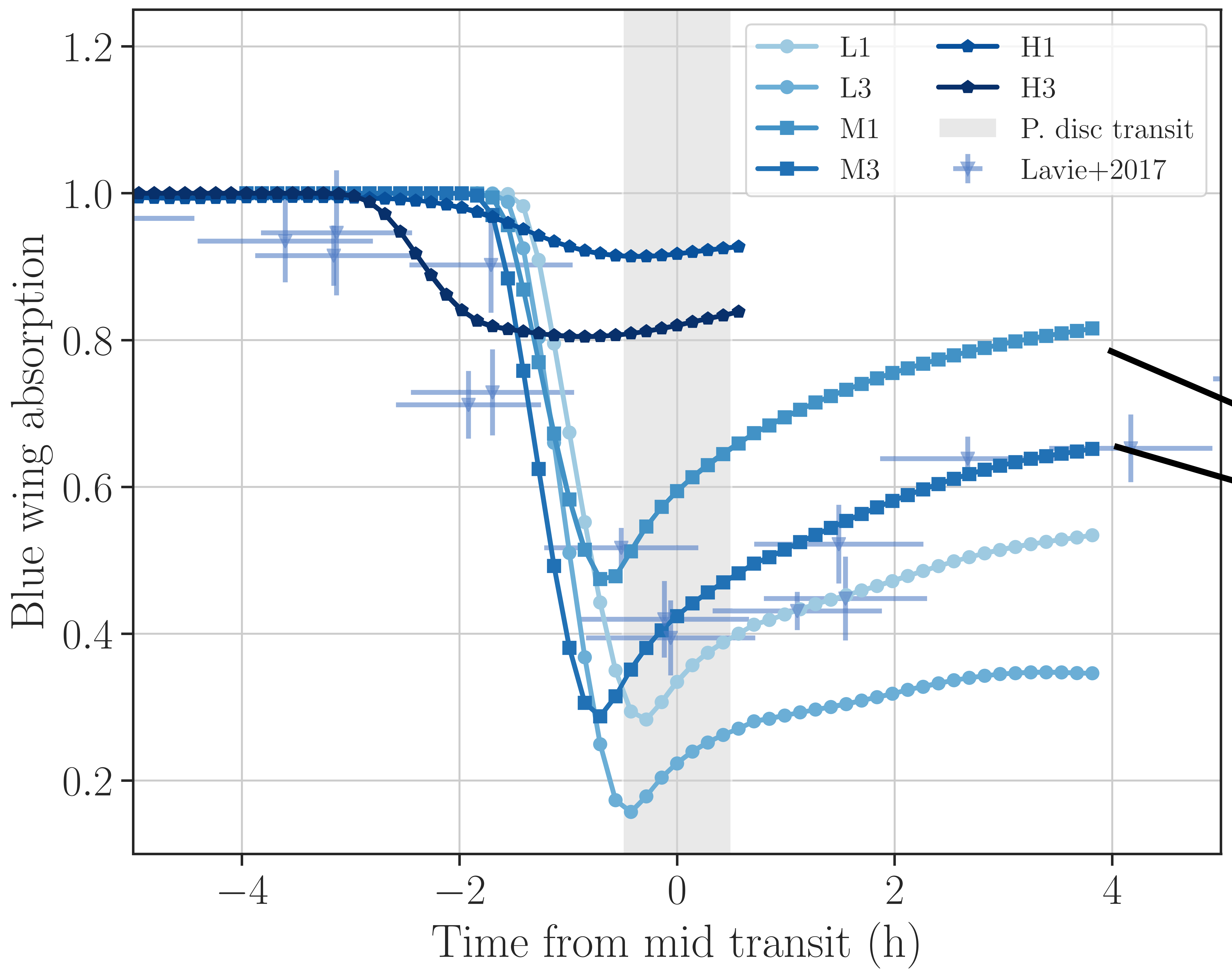
Allard et al 2018
see also Spake et al 2018

transit depth ~ 10%

Stellar irradiation **and** stellar wind erosion
shape atmospheric evaporation


stellar wind
star
density (g/cc)
1E-15
1E-16
1E-17
1E-18
1E-19
1E-20
orbital motion
bow shock
planet’s
shadow
(nightside)
tail shaped by the
stellar wind interaction
+ orbital motion
Stellar irradiation and stellar wind
shape atmospheric evaporation
erc
simulations
from the
ASTROFLOW
project

What do we learn from observations of escape?



Villarreal D'Angelo et al 2021

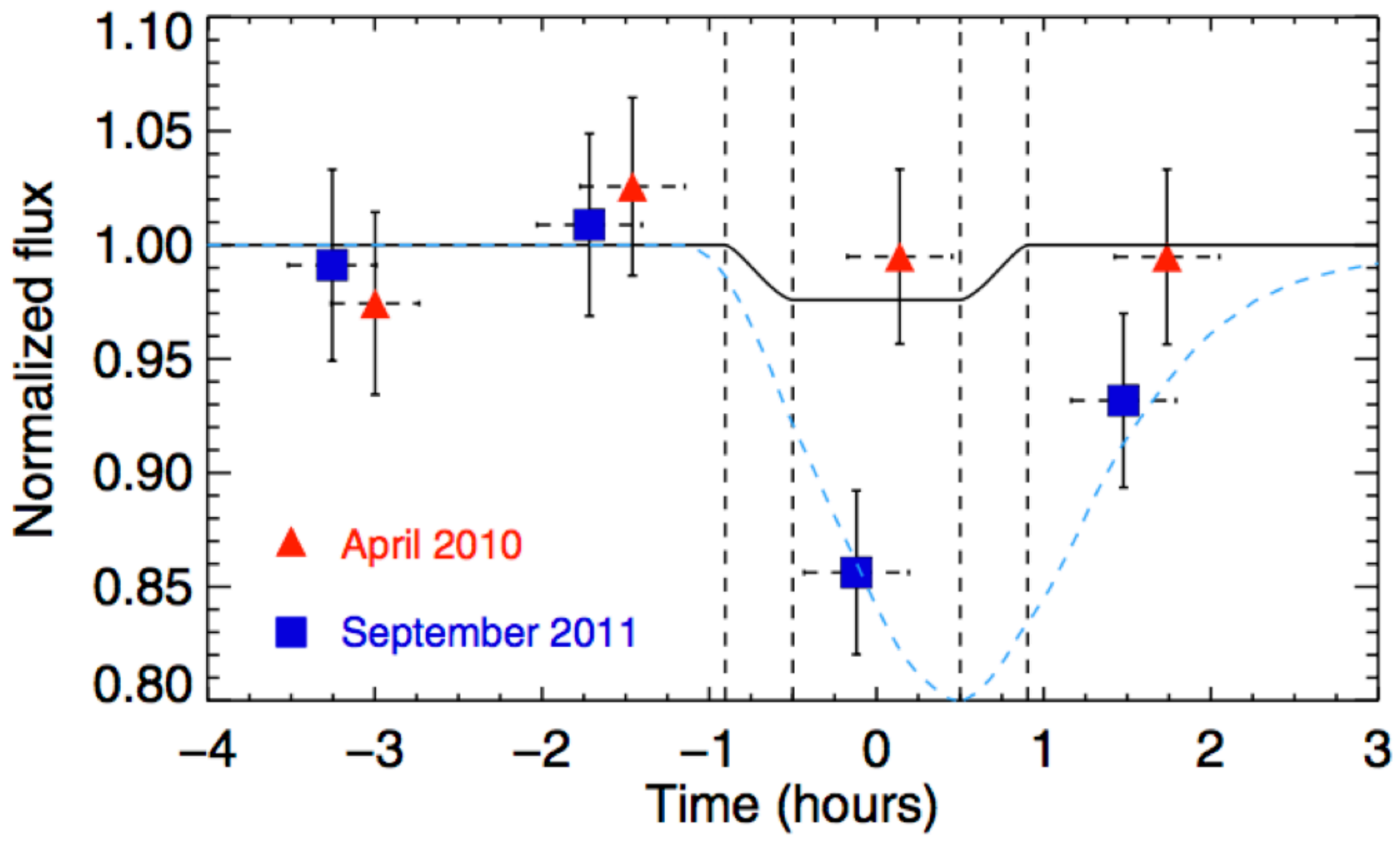
Observations + Modelling	=	atmospheric escape rate + local stellar wind properties

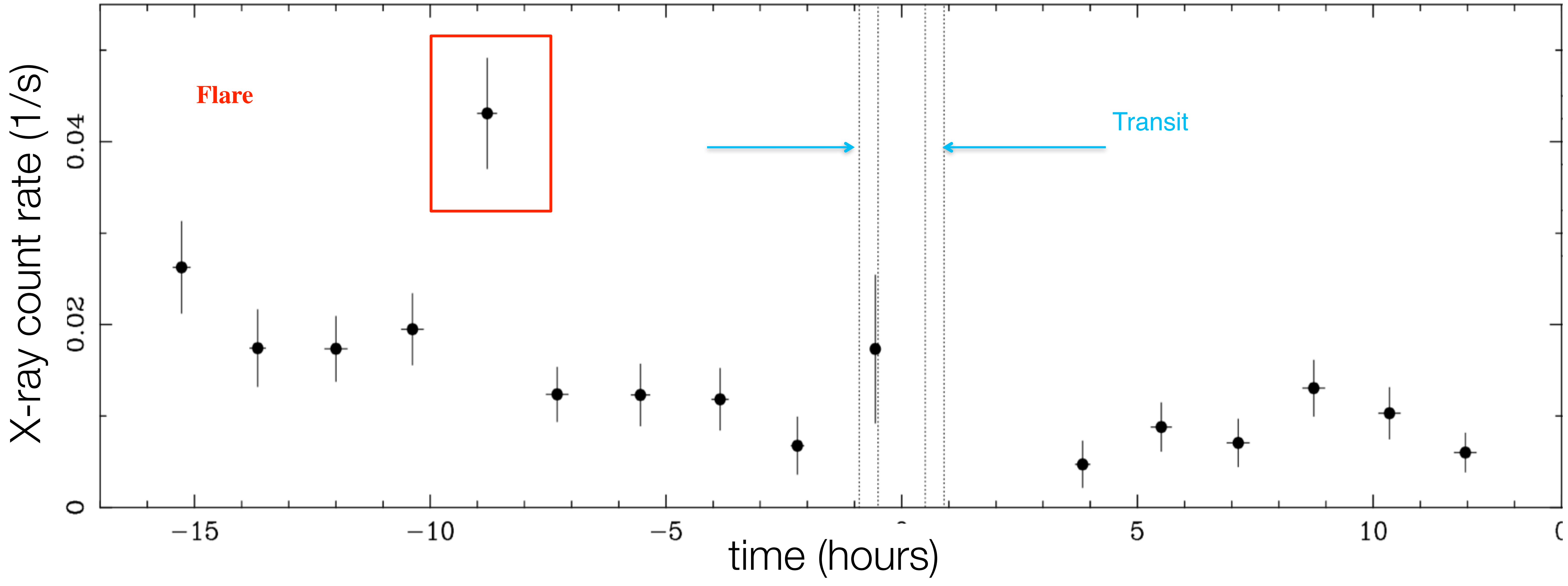
different stellar wind properties

Exoplanet can be used to probe stellar winds
(Vidotto & Bourrier 2017)

Effects of stellar activity on planetary escape

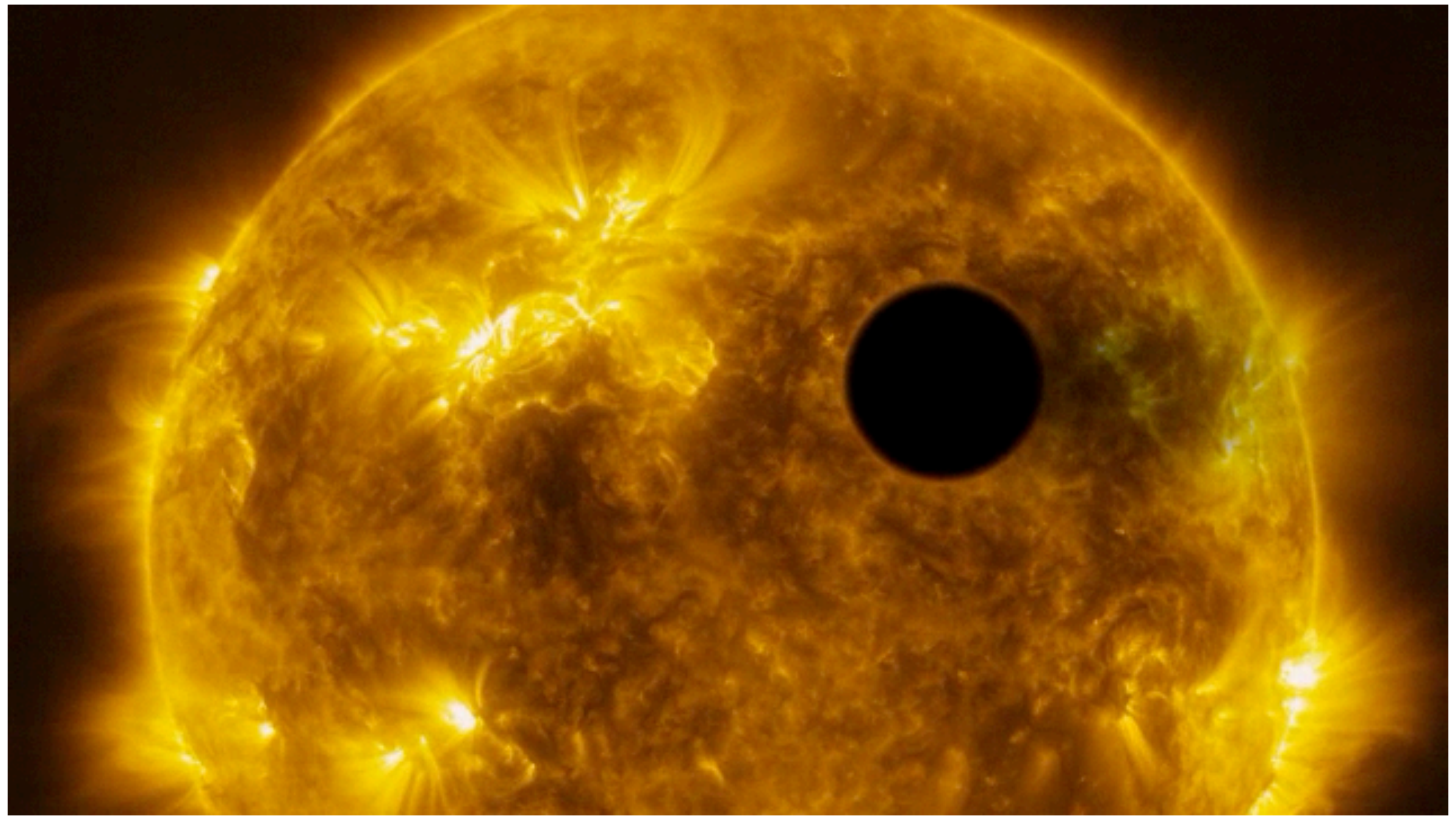
Temporal variations in the exosphere of HD189733b





Lecavelier et al 2012
Bourrier et al 2013

Credit: NASA, ESA, L. Calçada, SDO



Possible scenarios:

1. Change of stellar wind properties (passing of a Coronal Mass Ejection)
2. Increase of stellar energy input into the planet's upper atmosphere

Effects of stellar activity (flares & CMEs) on planetary escape

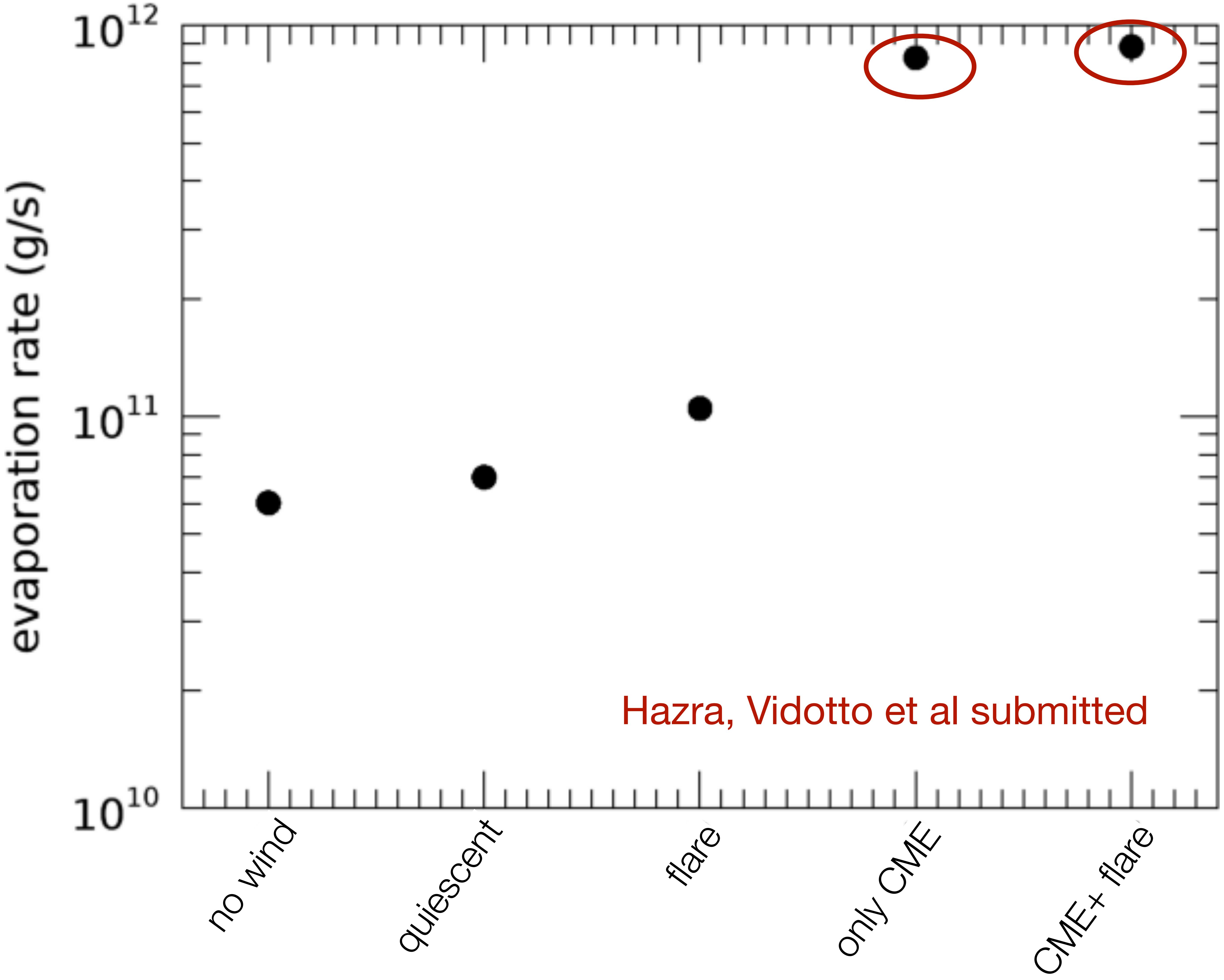
Scenarios simulated in 3D: Hazra, Vidotto et al submitted

Quiescent: XUV flux + stellar wind

Active: flare (XUV↑) + CME (particles↑)

Density profiles (cut at the orbital plane)

Does stellar activity (flares & CMEs) affect planetary escape?



- Yes, but..
  - Flare alone does not change evaporation significantly
  - CMEs are more effective at removing planetary material momentarily
- CMEs are expected to be more frequent at younger age → include them in evaporation models at younger ages

Conclusions

Several types of star-planet interactions

- Magnetic interaction
- Tidal interaction
- Stellar wind interaction
- Radiative interaction

Observing interactions between stars and exoplanets allow us to further characterise planetary systems

- planet magnetic field
- stellar wind properties
- evaporation rates

@AlineVidotto

IAU Symposium 370: “Winds of Stars and Exoplanets”

8-11 August 2022

https://local.strw.leidenuniv.nl/iaus370

Abstract submission (from 1 Jan 2022):
https://www.iauga2021.org/