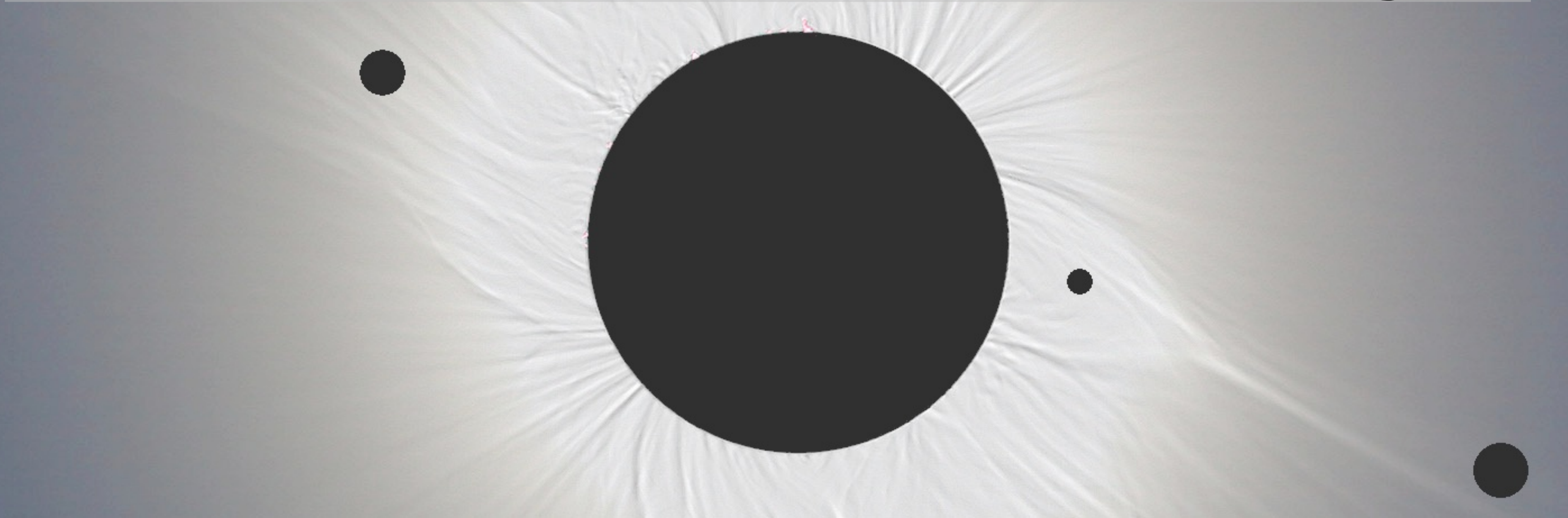
Stars and exoplanets: interaction, rotation, activity

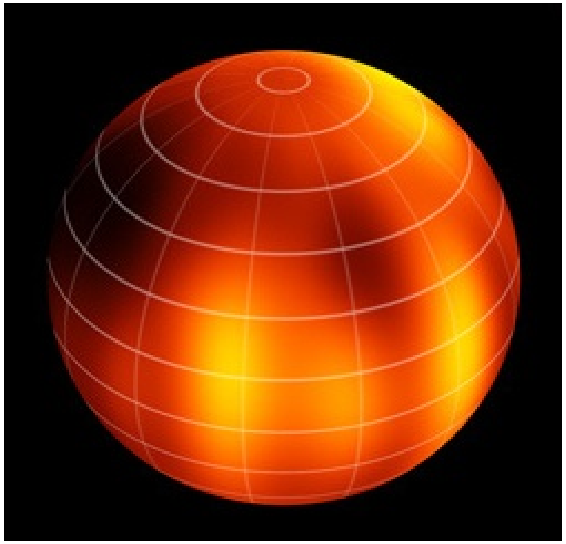


Katja Poppenhaeger

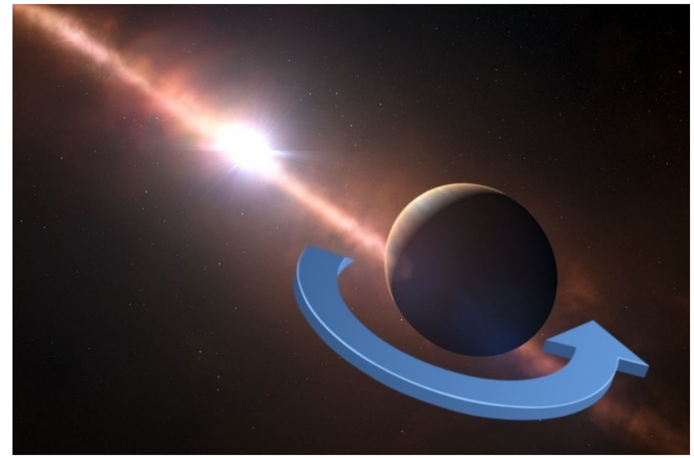
NASA Sagan Fellow
Harvard-Smithsonian Center for Astrophysics

→ Queen's University Belfast, UK

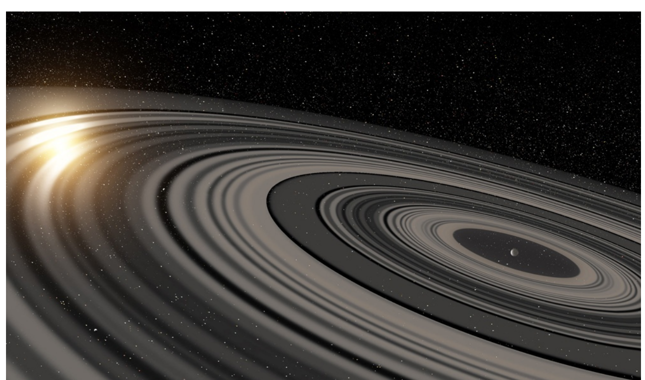
Exoplanets: exciting & newsworthy



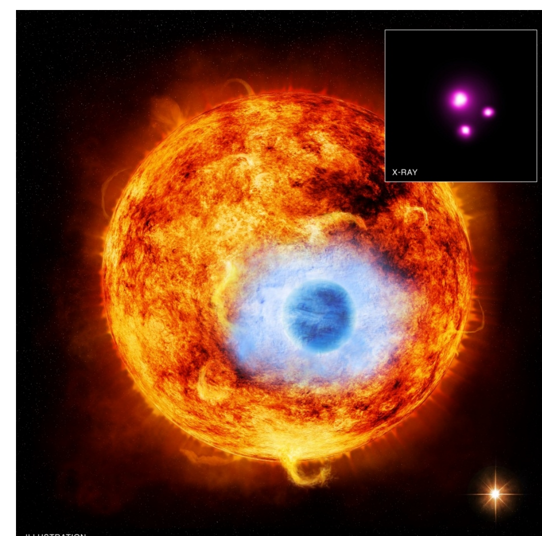
Temperature map of brown dwarf
(Crossfield et al. 2014)



Detection of exoplanet spin
(Snellen et al. 2014)



Transits of multi-ring system
(Kenworthy et al. 2015)



X-ray detection of extended atmosphere
(Poppenhaeger et al. 2013)

Exoplanets

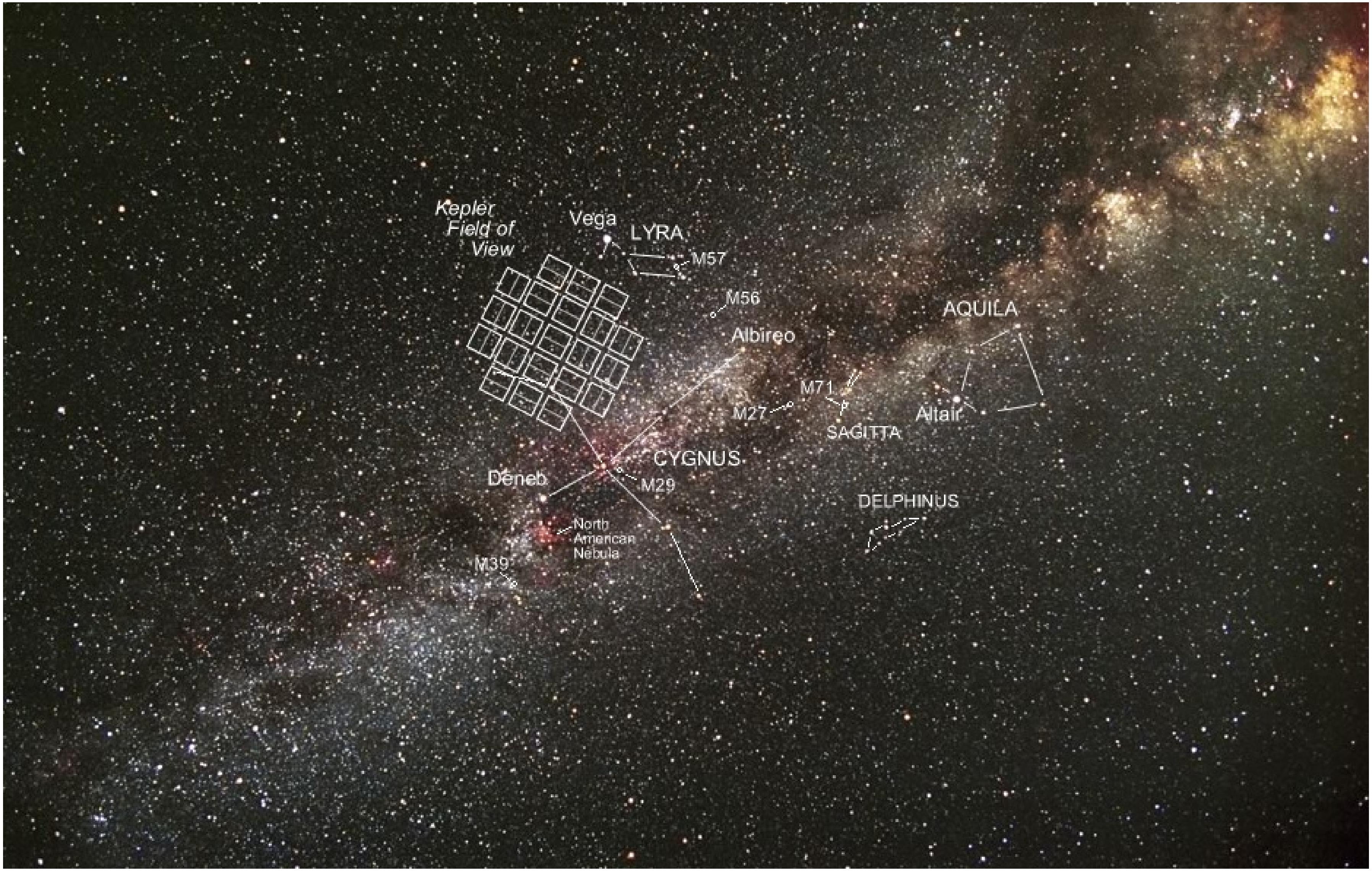


image credit: NASA/Kepler Team

Exoplanets

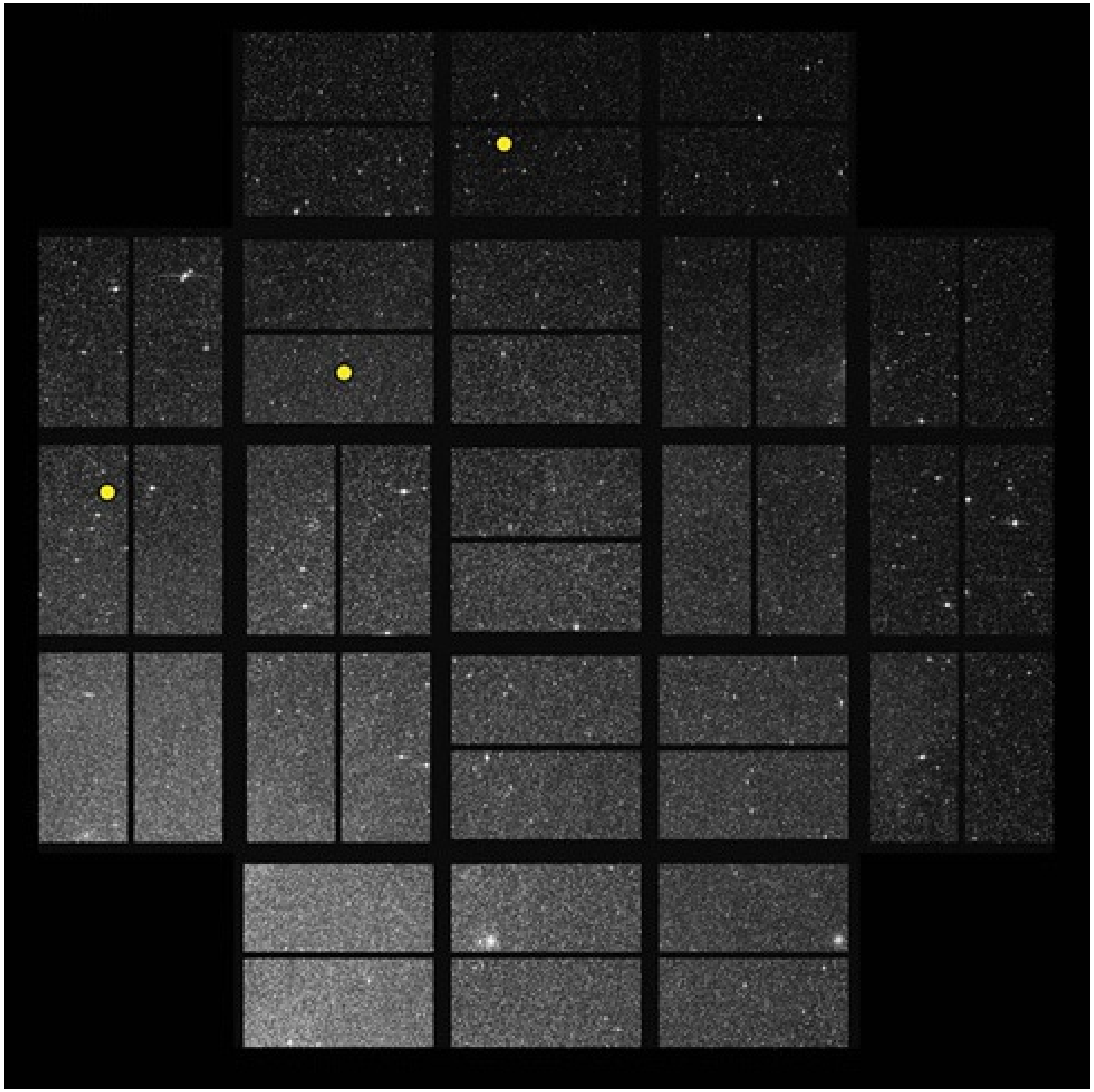


image credit:
NASA/Kepler Team

Exoplanets

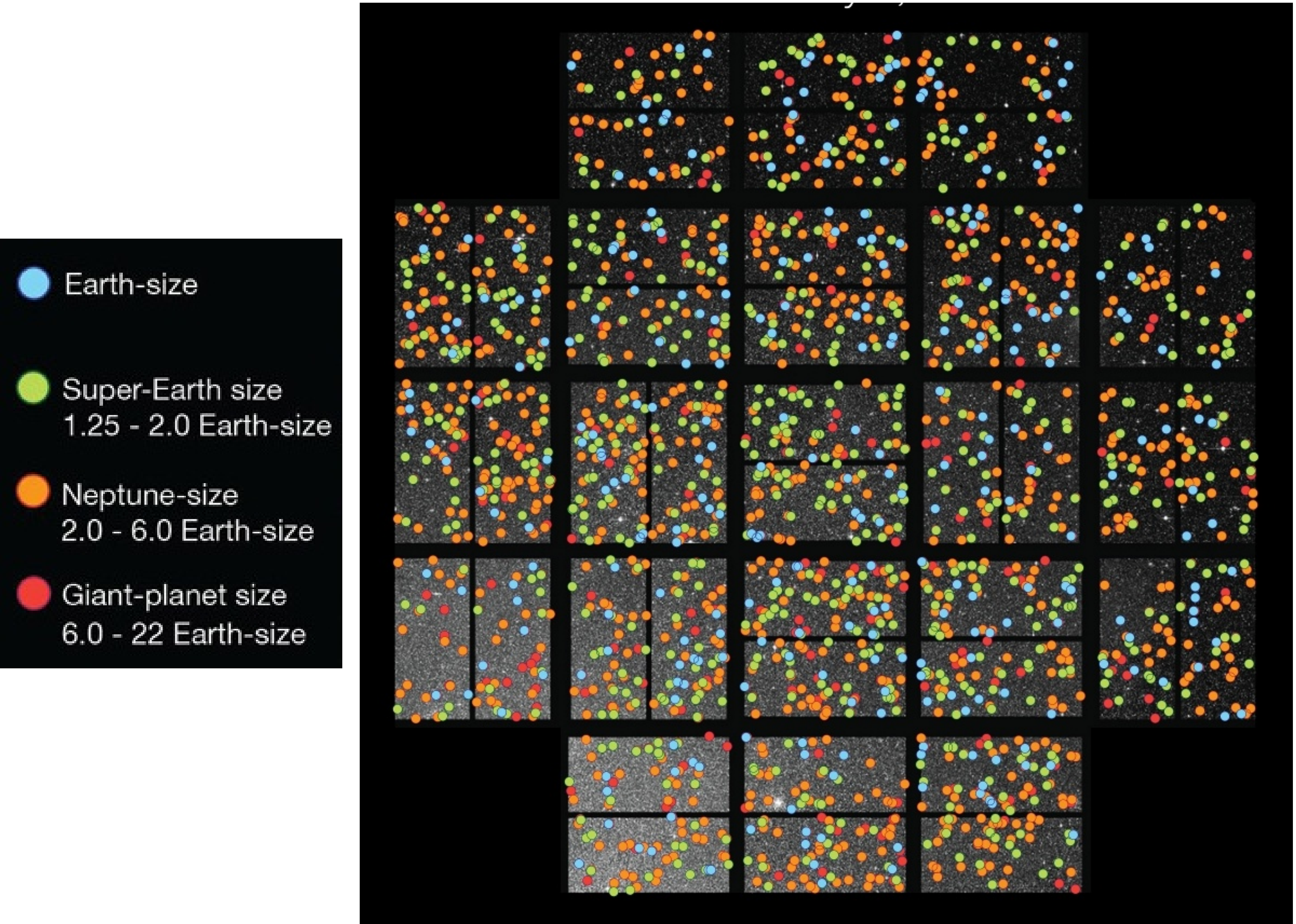
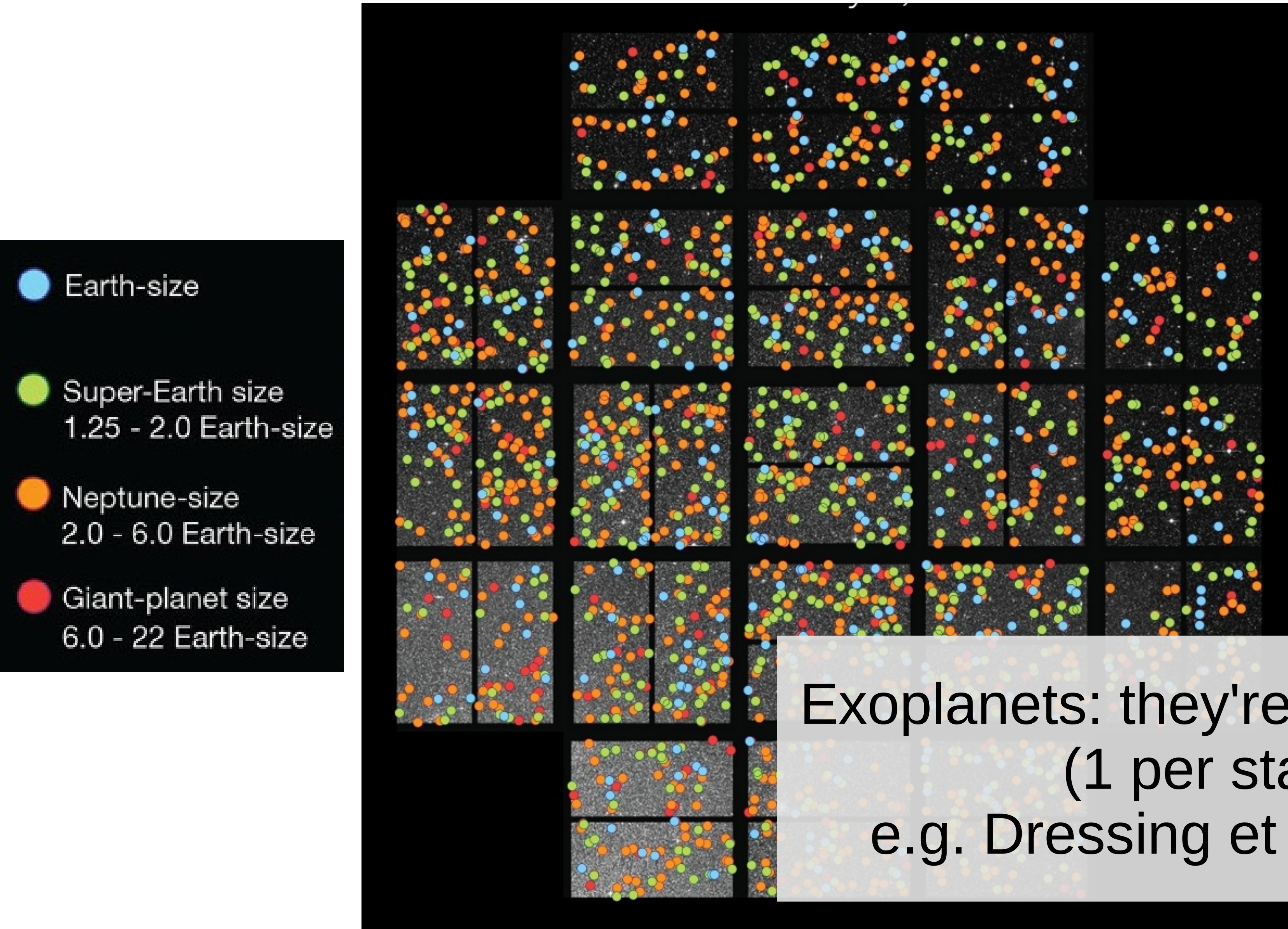


image credit:
NASA/Kepler Team

Exoplanets



Exoplanets: they're everywhere
(1 per star)
e.g. Dressing et al. (2013)

System architectures

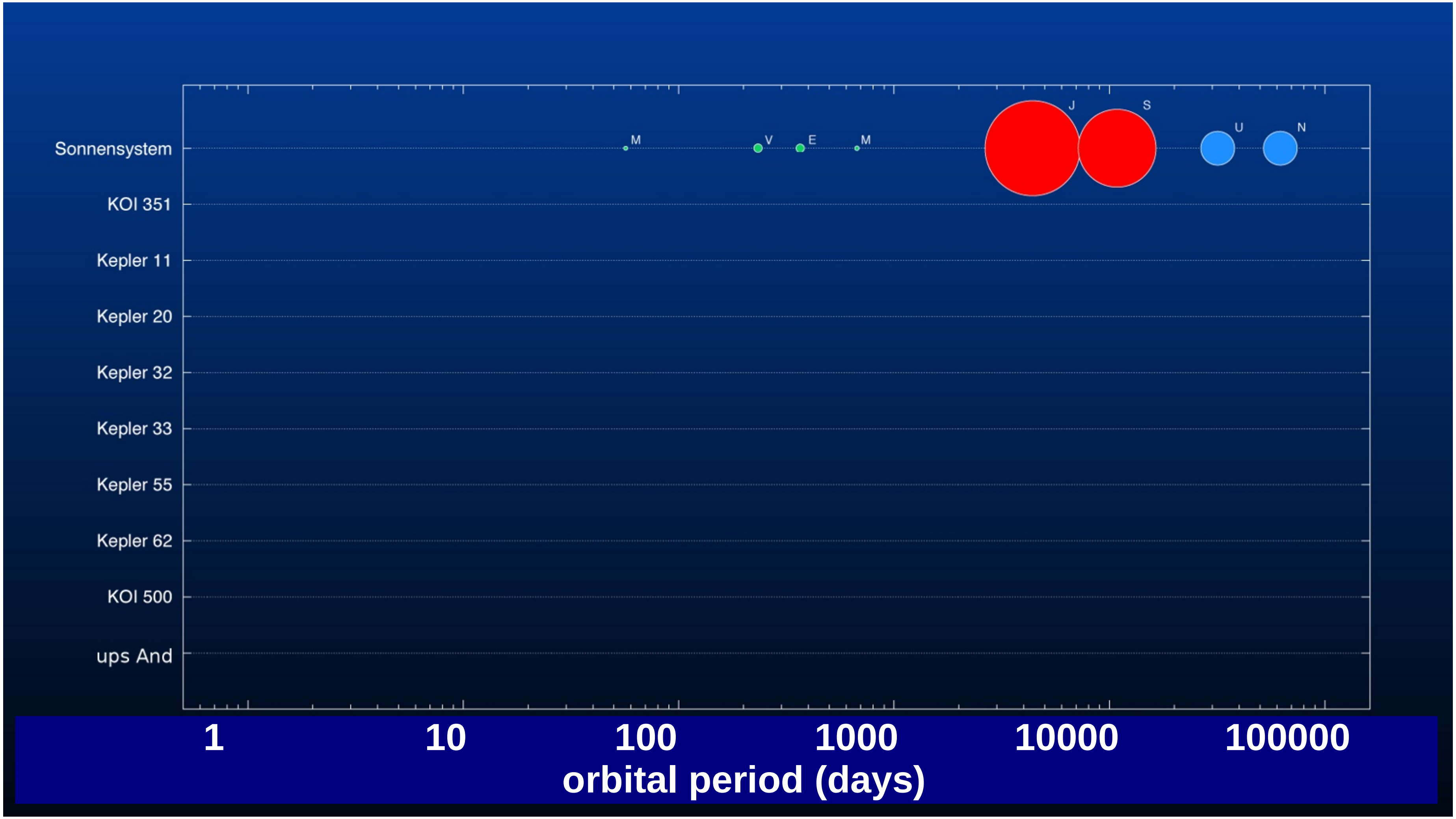


image credit:
German Air & Space Center (DLR)

System architectures

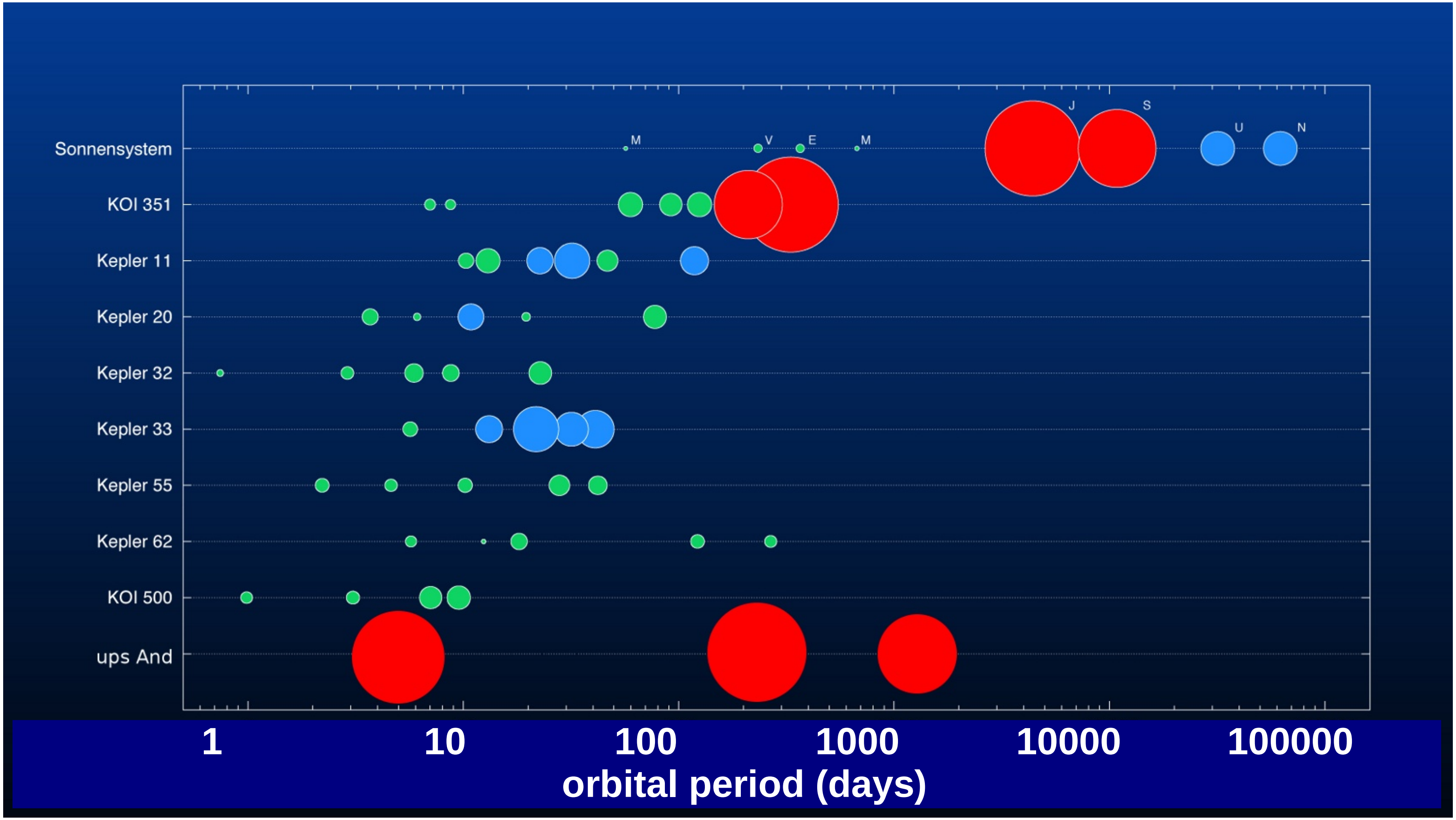
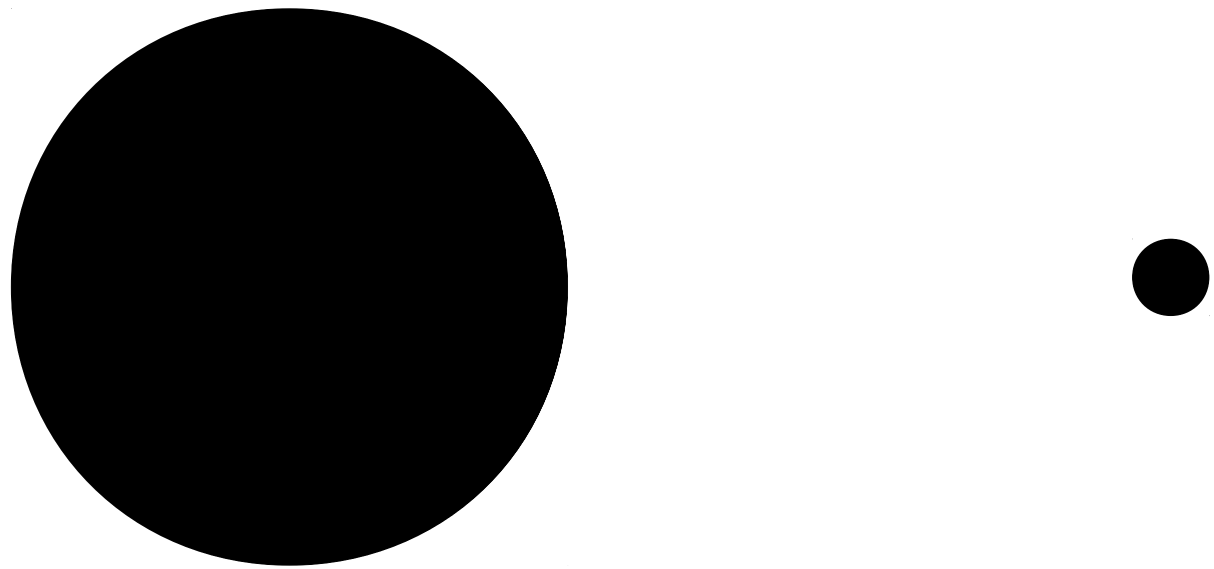
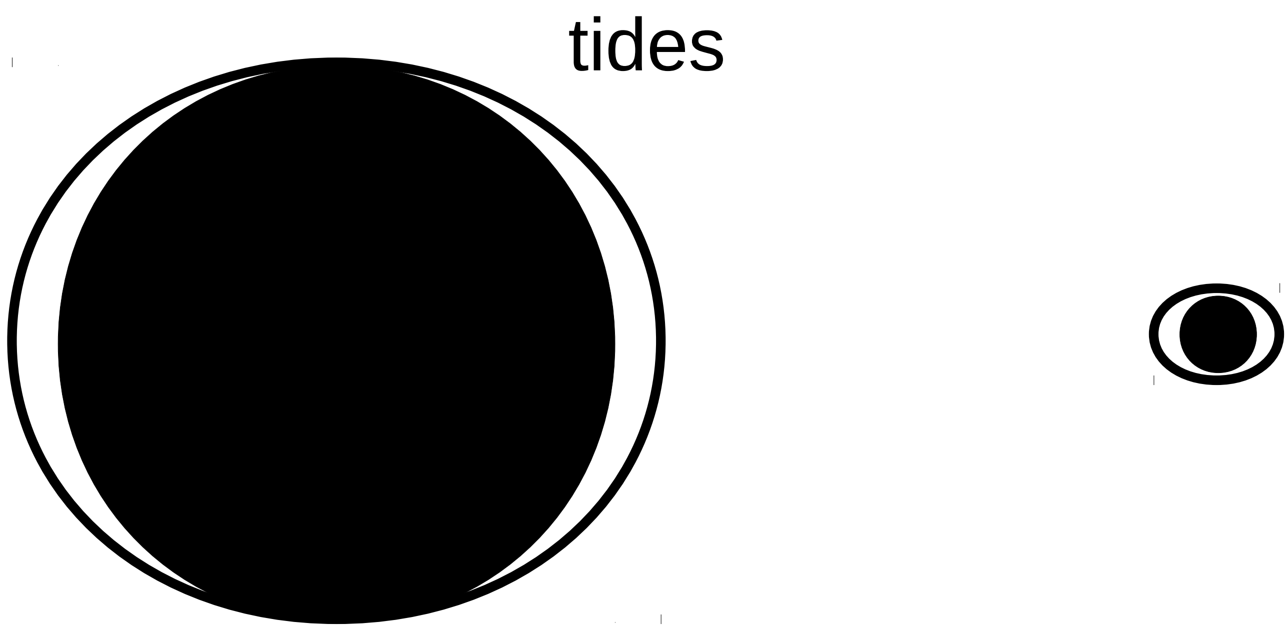


image credit:
German Air & Space Center (DLR)

Possible interaction types

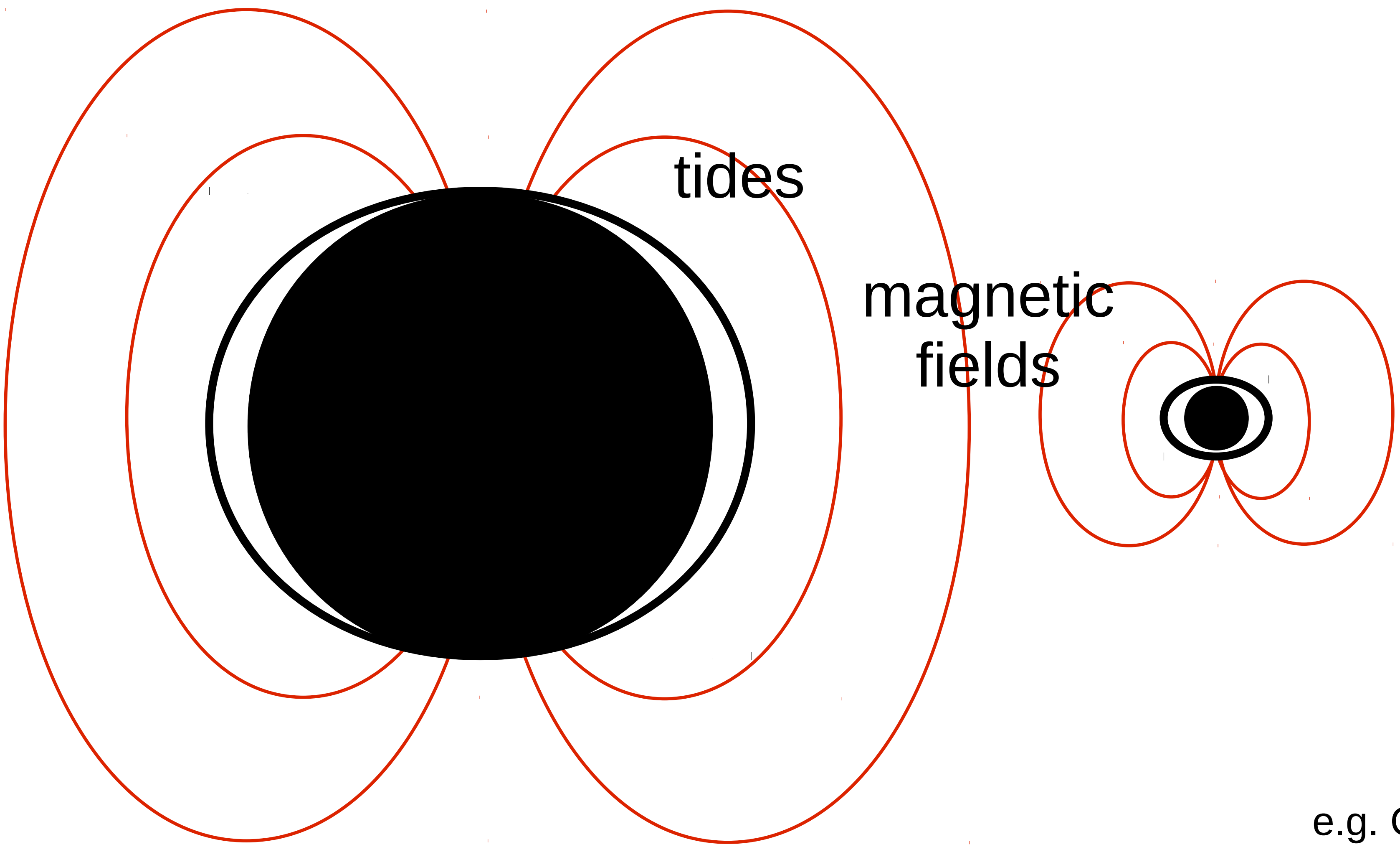


Possible interaction types



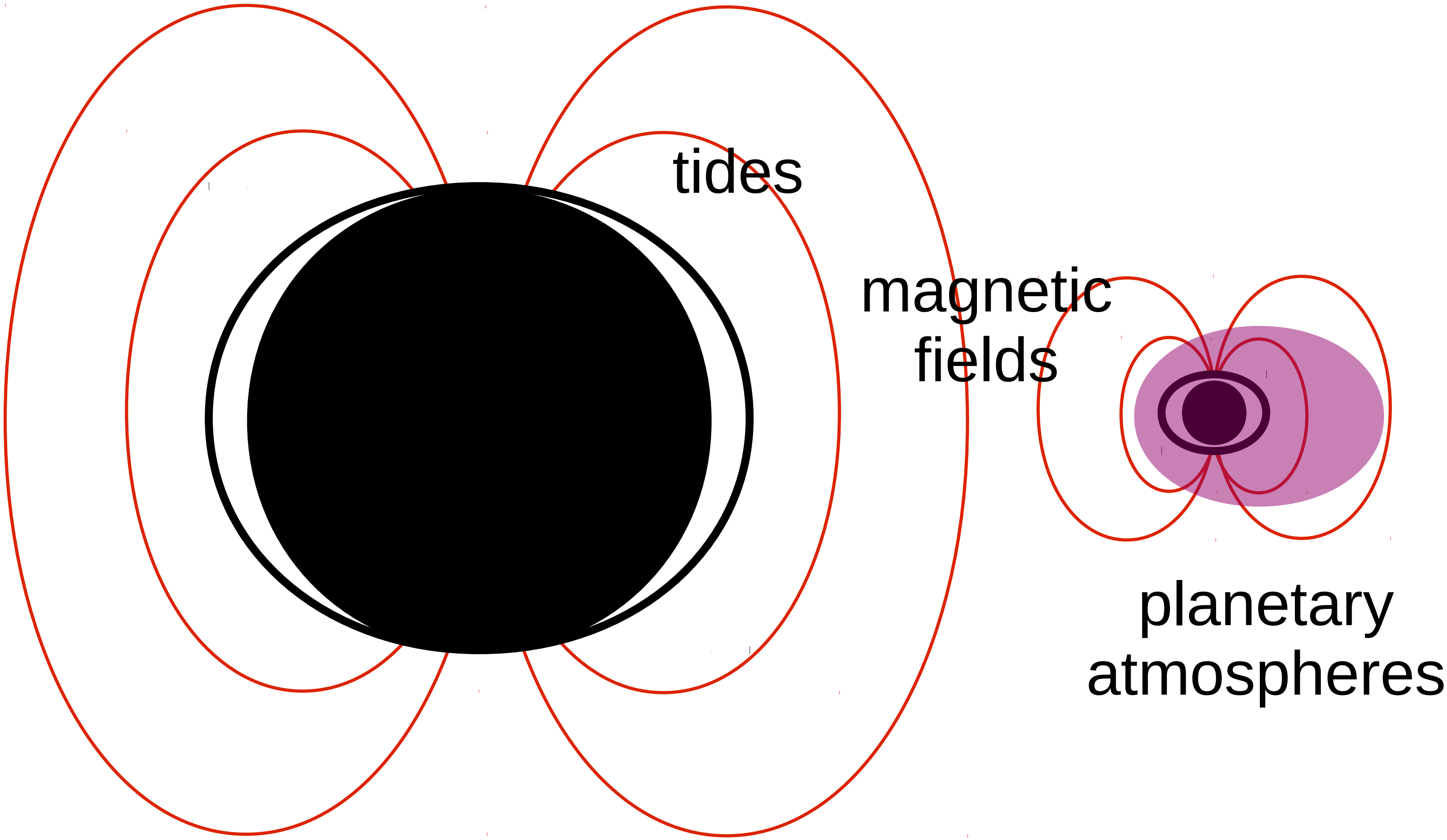
e.g. Cuntz et al. (2000)

Possible interaction types

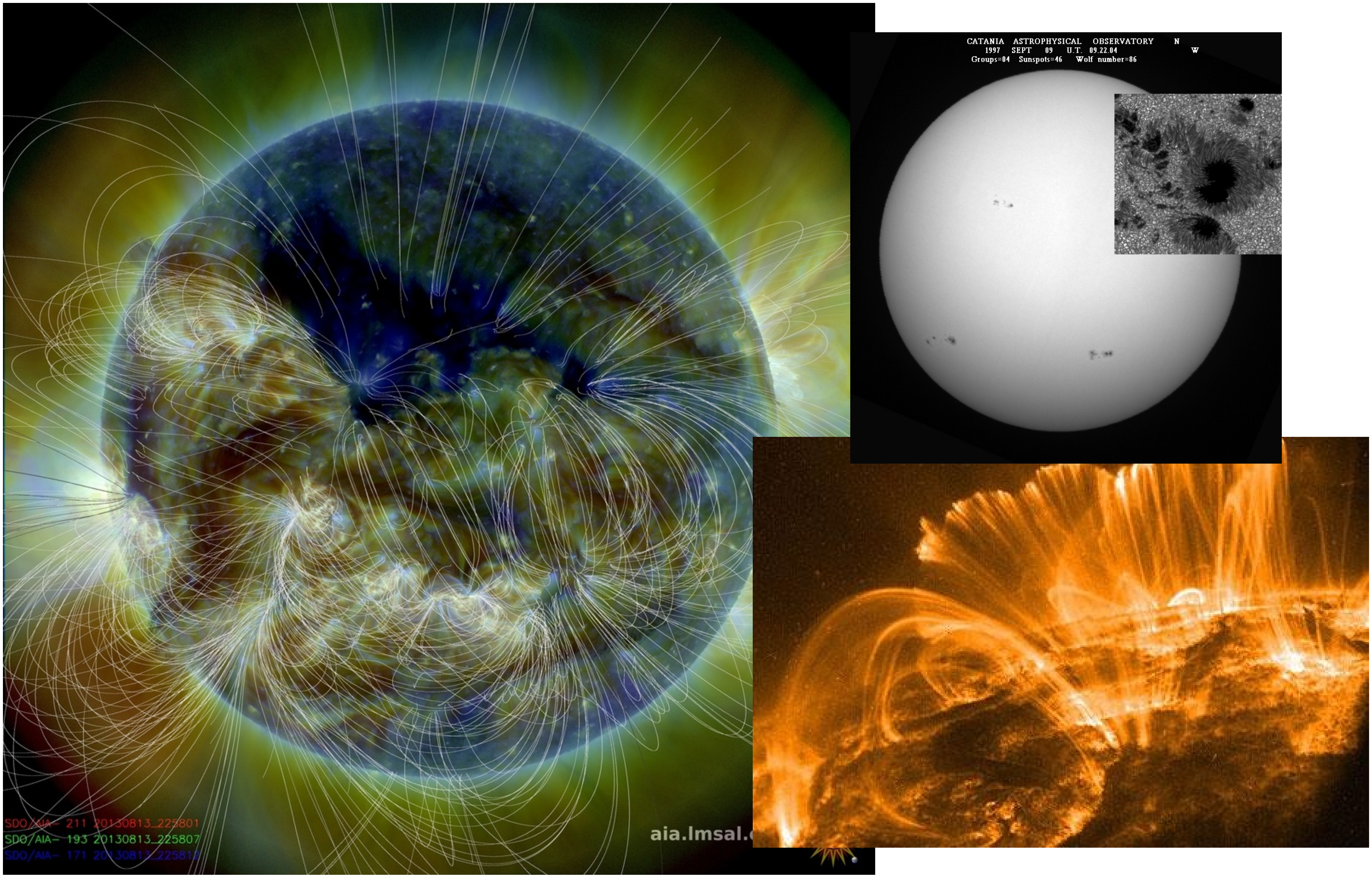


e.g. Cuntz et al. (2000)

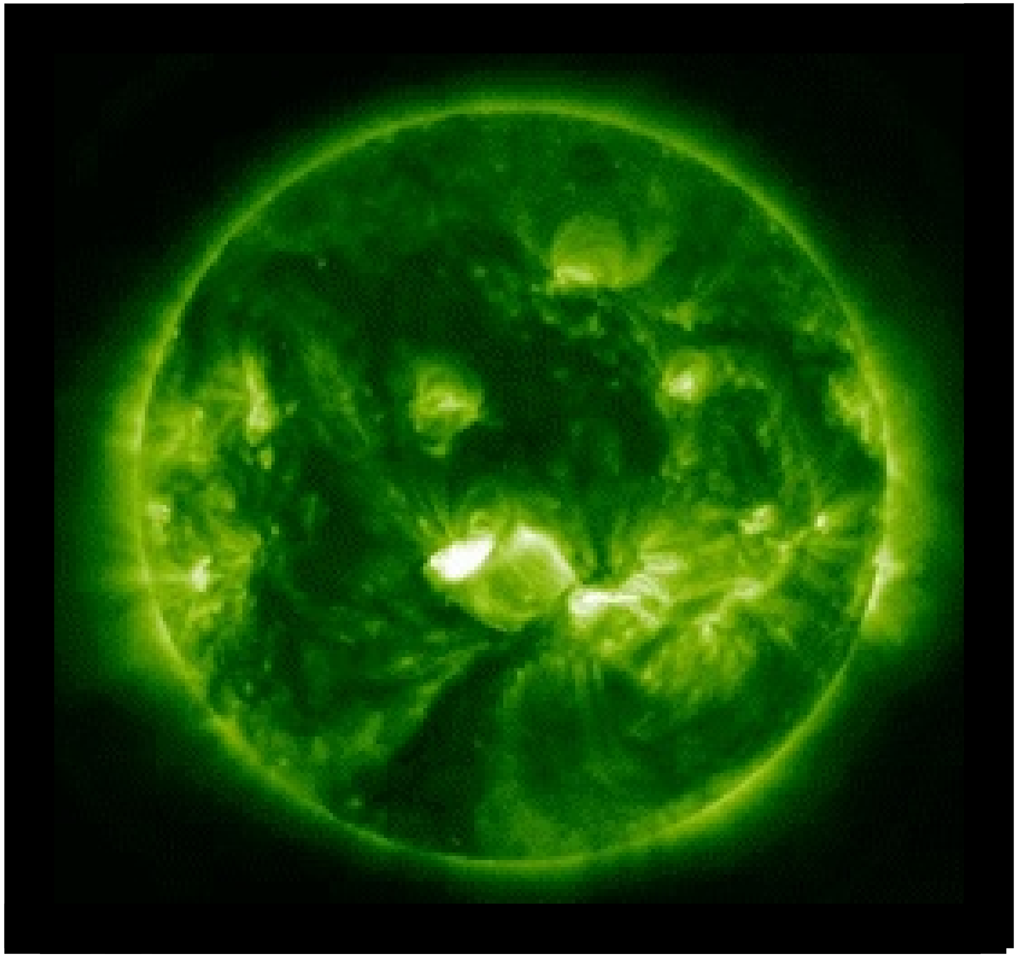
Possible interaction types



Exoplanet host stars



Magnetic activity



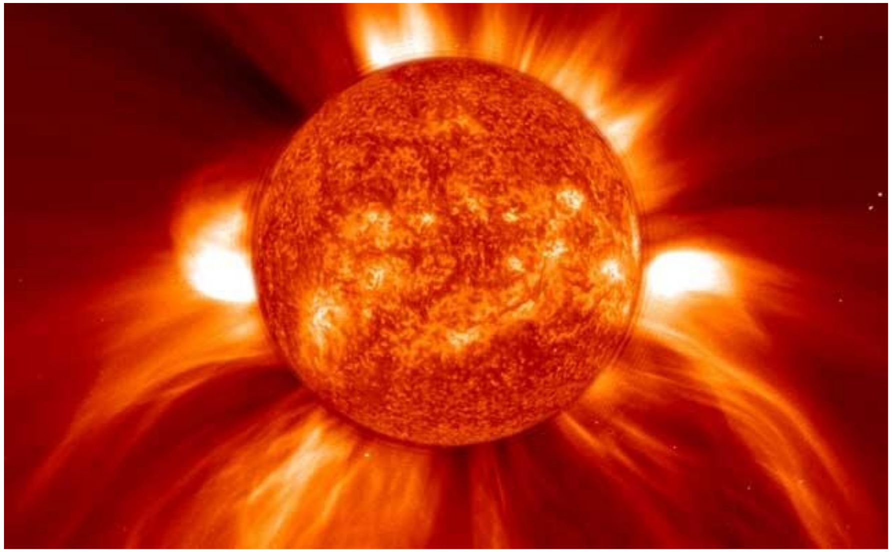
flares

X-ray emission

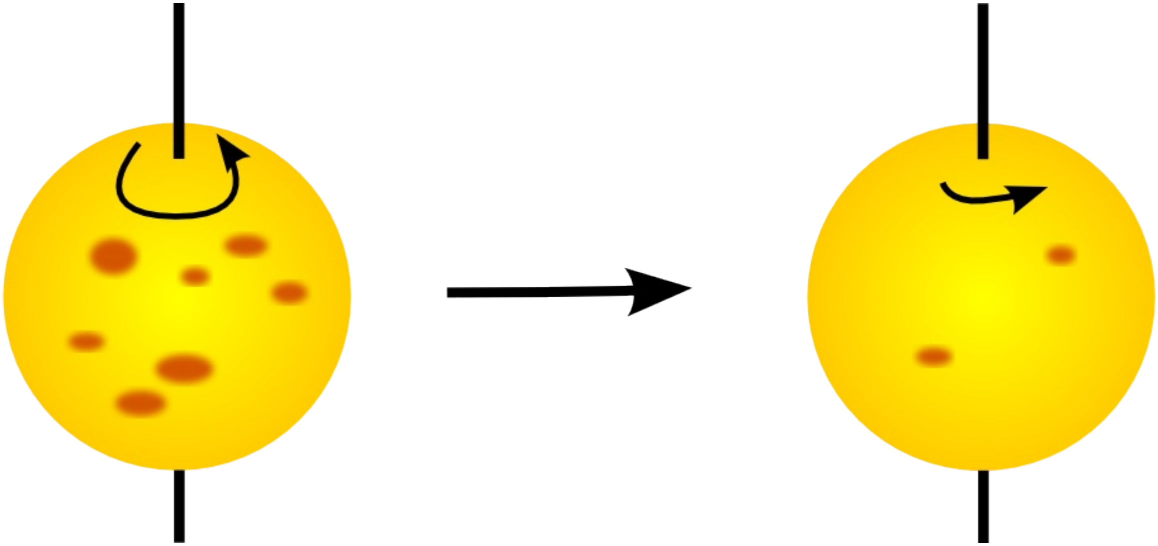
UV emission

image credit: SDO

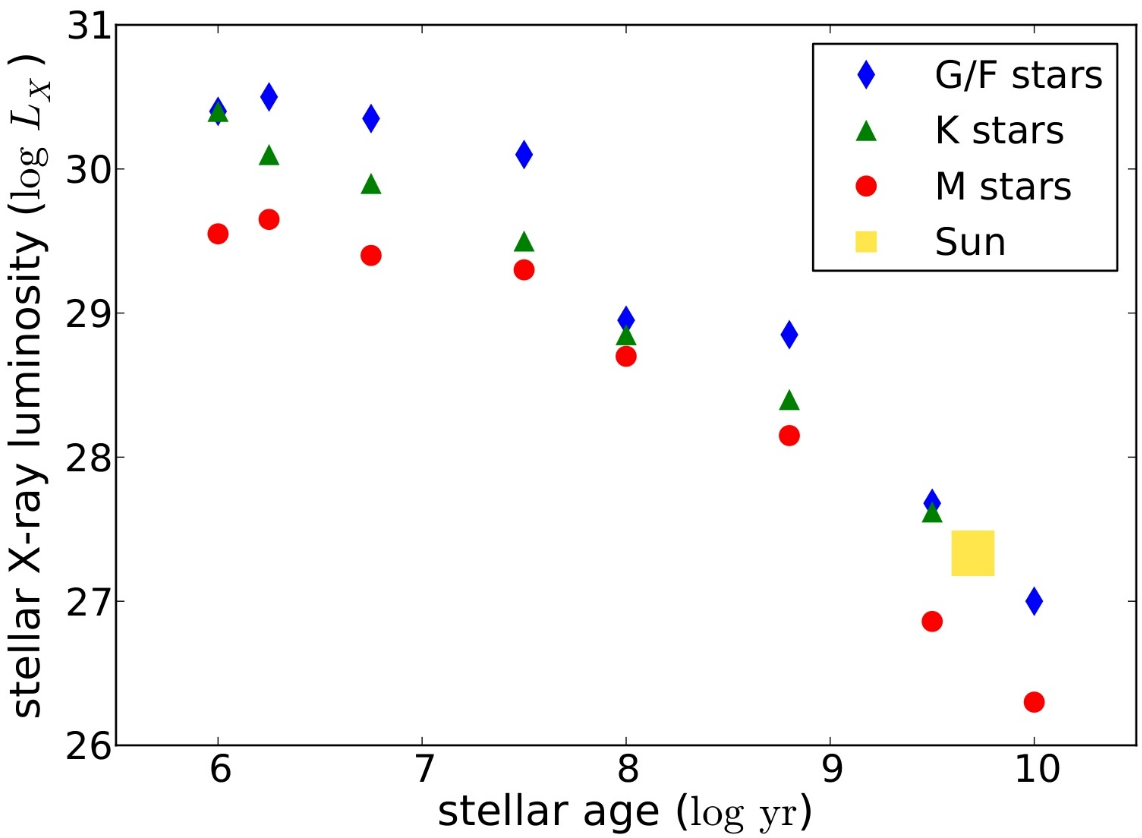
How stars age on the main sequence



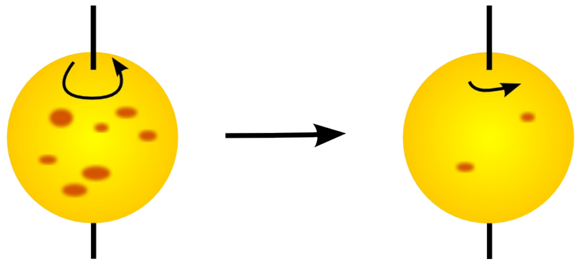
loss of angular momentum through stellar wind ("magnetic braking")



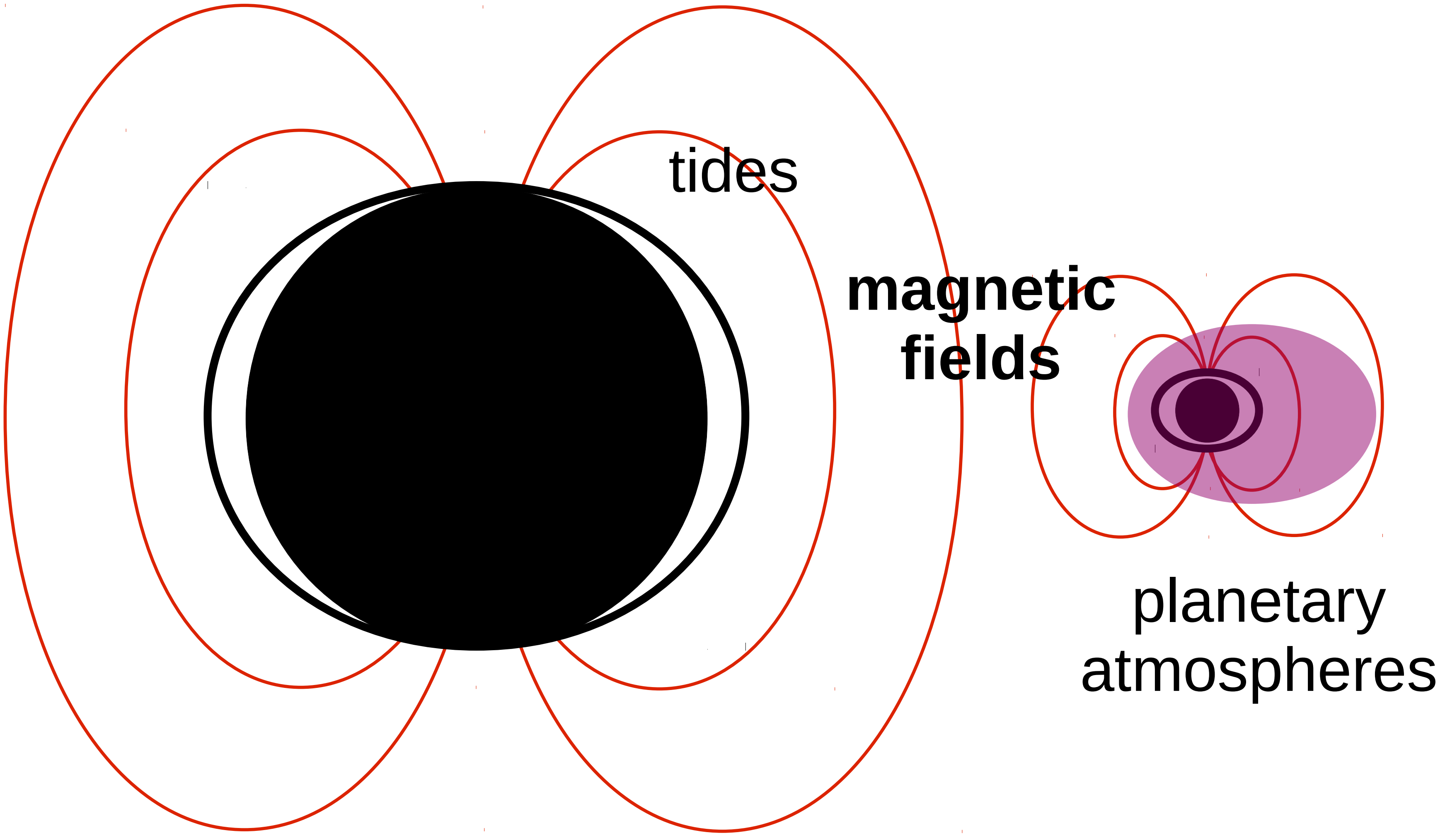
How stars age on the main sequence



loss of angular momentum through stellar wind ("magnetic braking")



Magnetic interaction



Template: stellar binaries

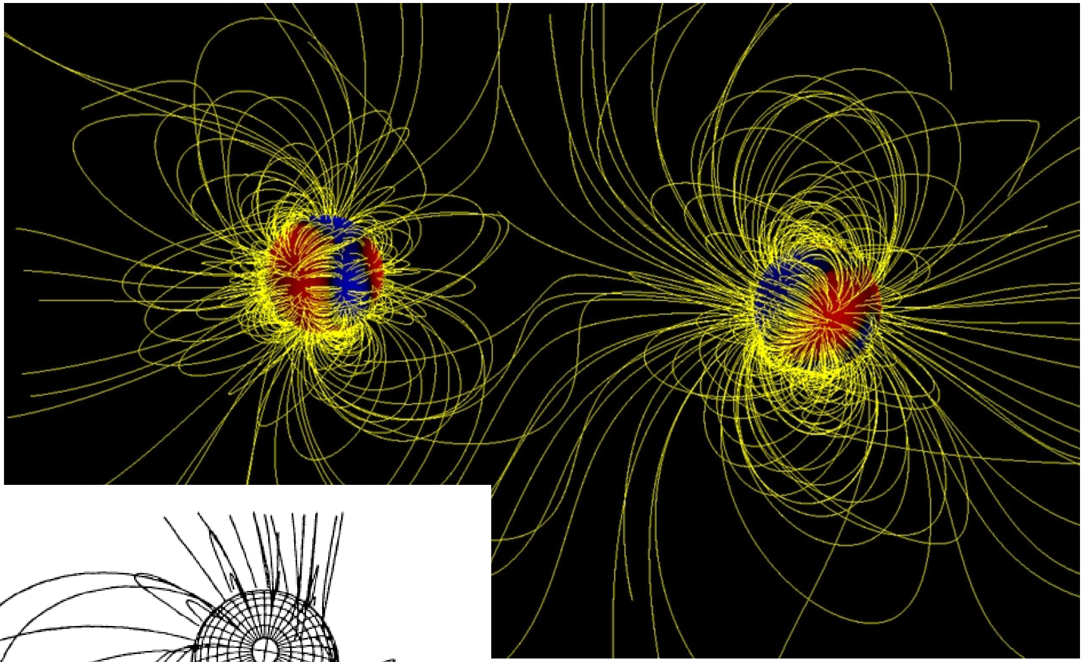


image credit:
V. Holzwarth, S.G. Gregory

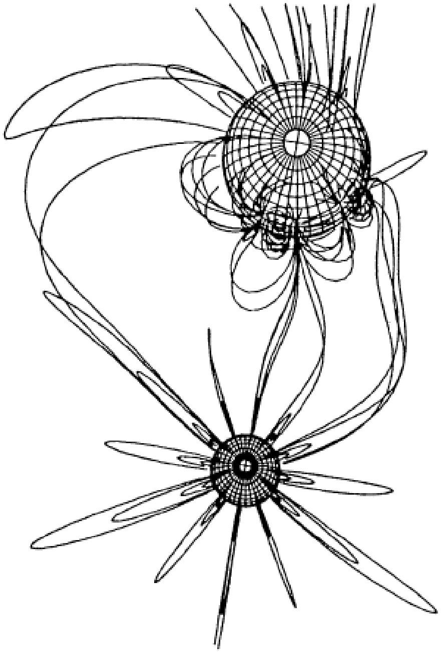
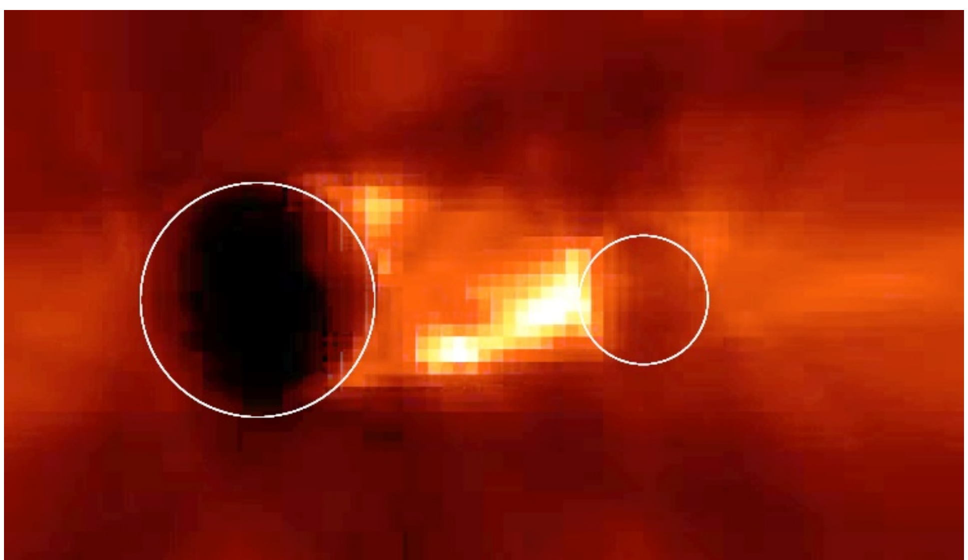


image credit:
Uchida & Sakurai (1985)

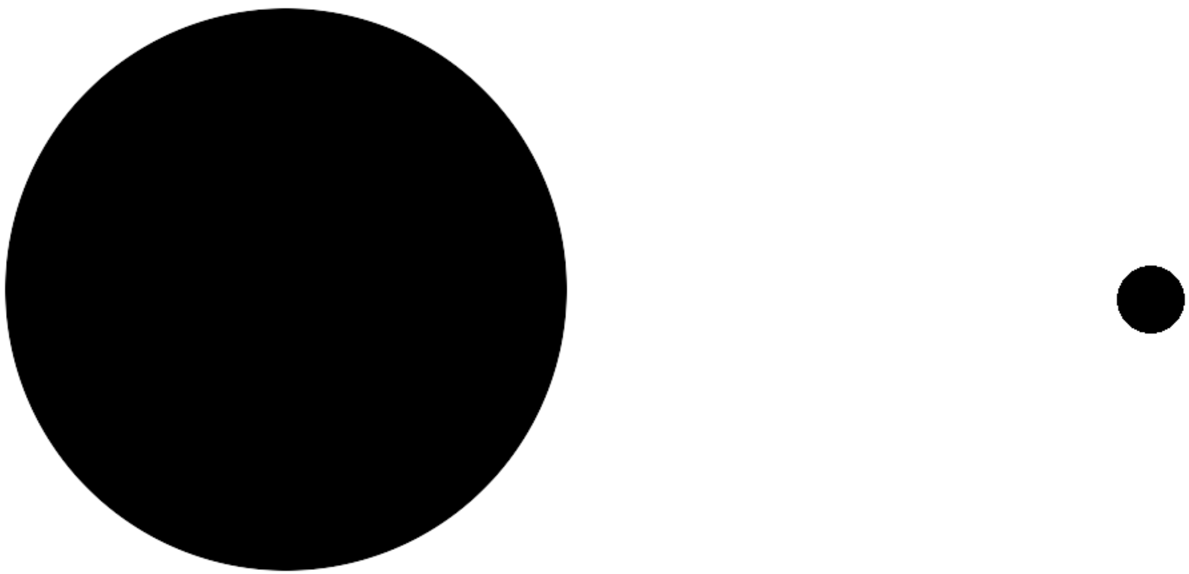
Template: stellar binaries

Binary YY Gem
Guedel et al. (2002)

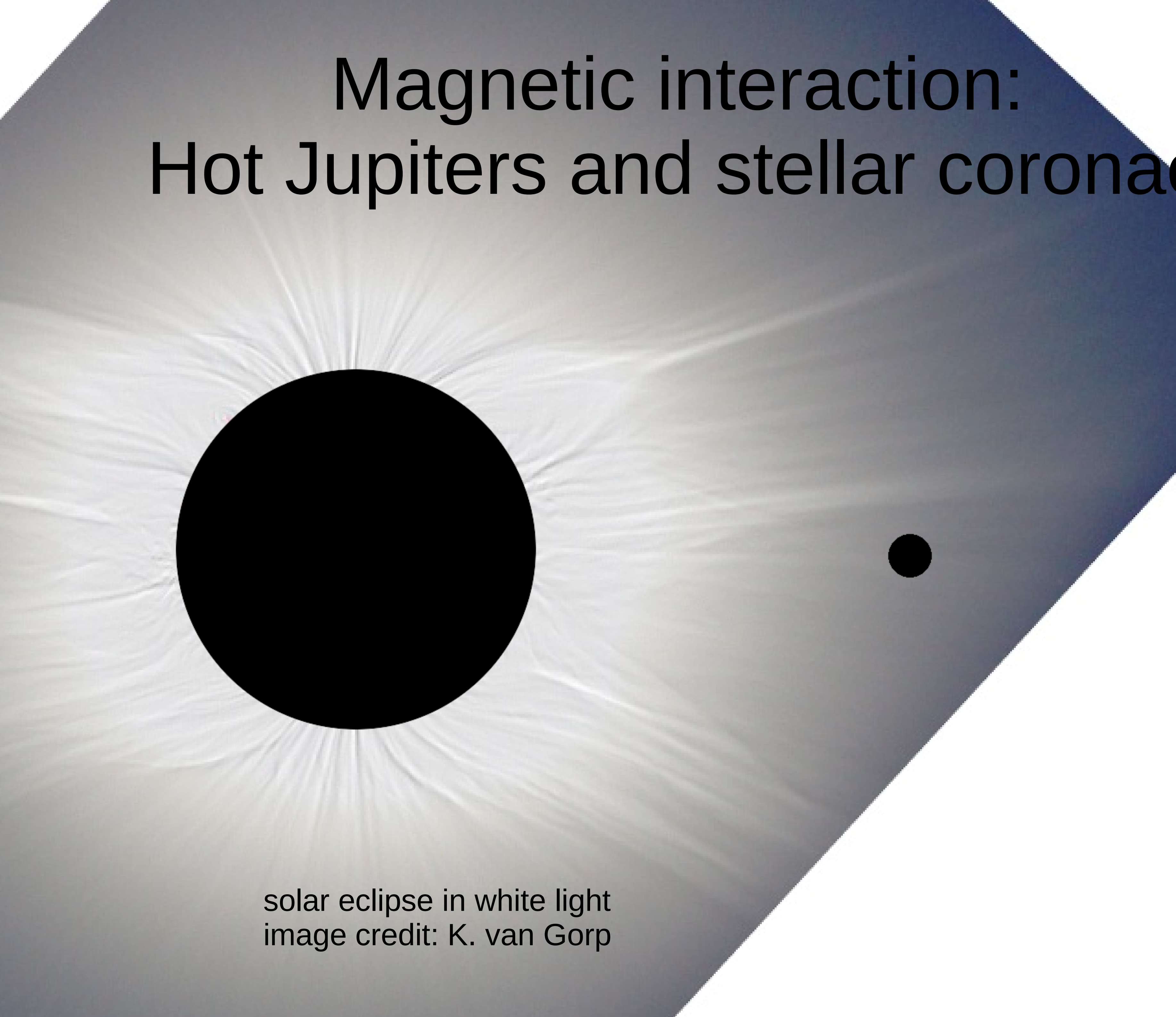


Binary AR Lac
Siarkowski et al. (1996)

Magnetic interaction:
Hot Jupiters and stellar coronae

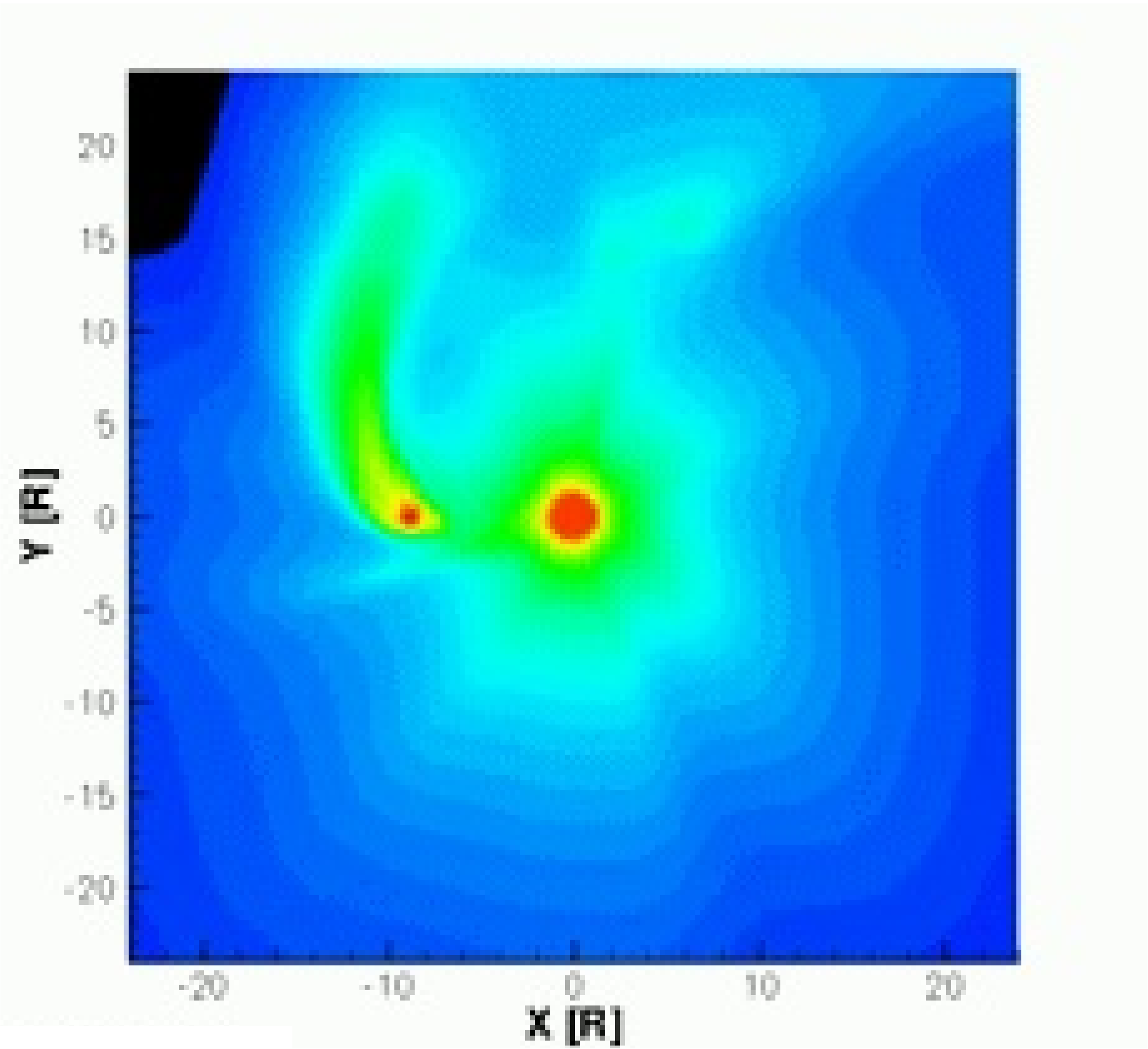


Magnetic interaction:
Hot Jupiters and stellar coronae



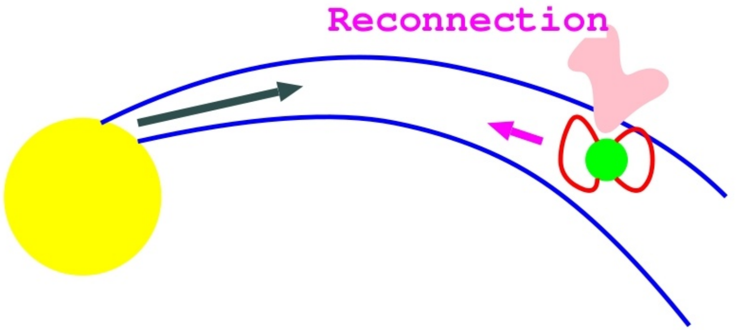
solar eclipse in white light
image credit: K. van Gorp

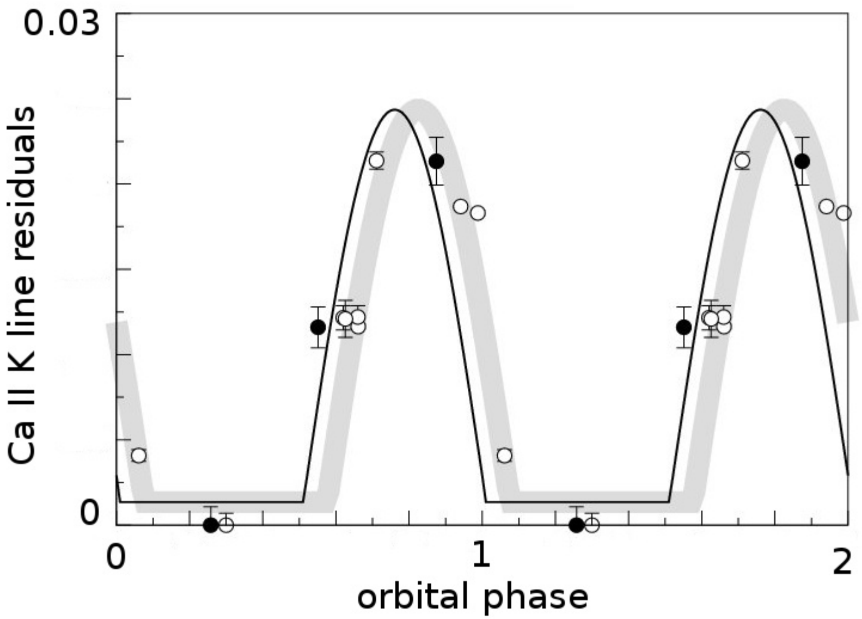
Planet-induced activity?



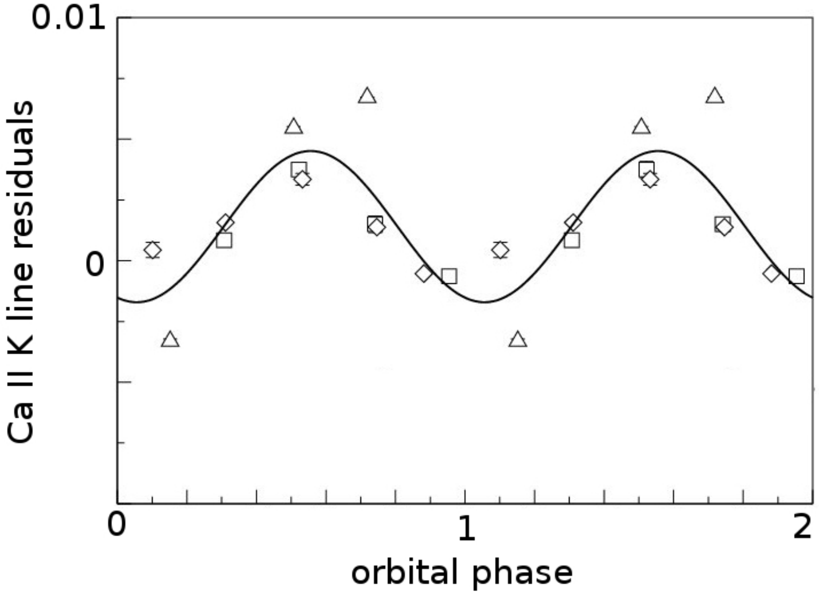
courtesy of O. Cohen

Planet-induced activity?





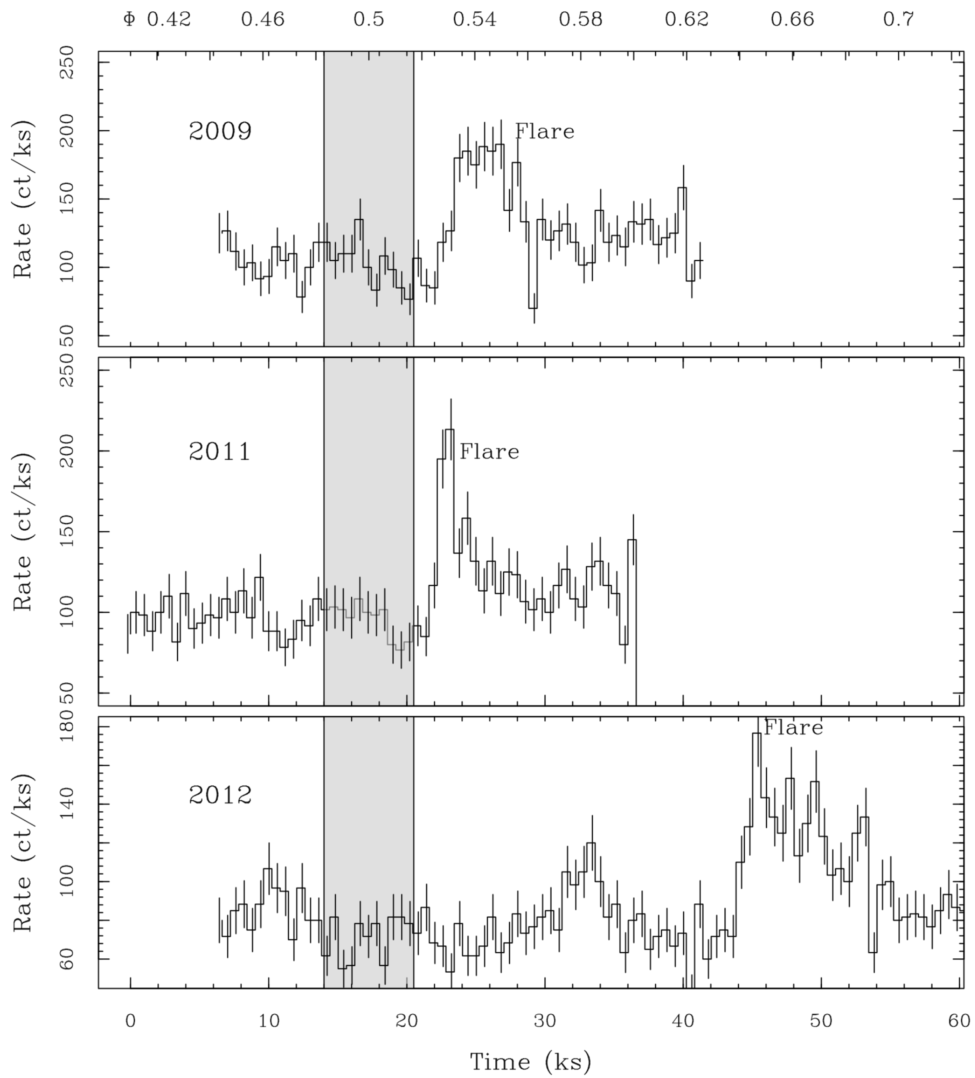
HD 179949
P_{orb} = 3.1 d
P_{rot} = 11 d



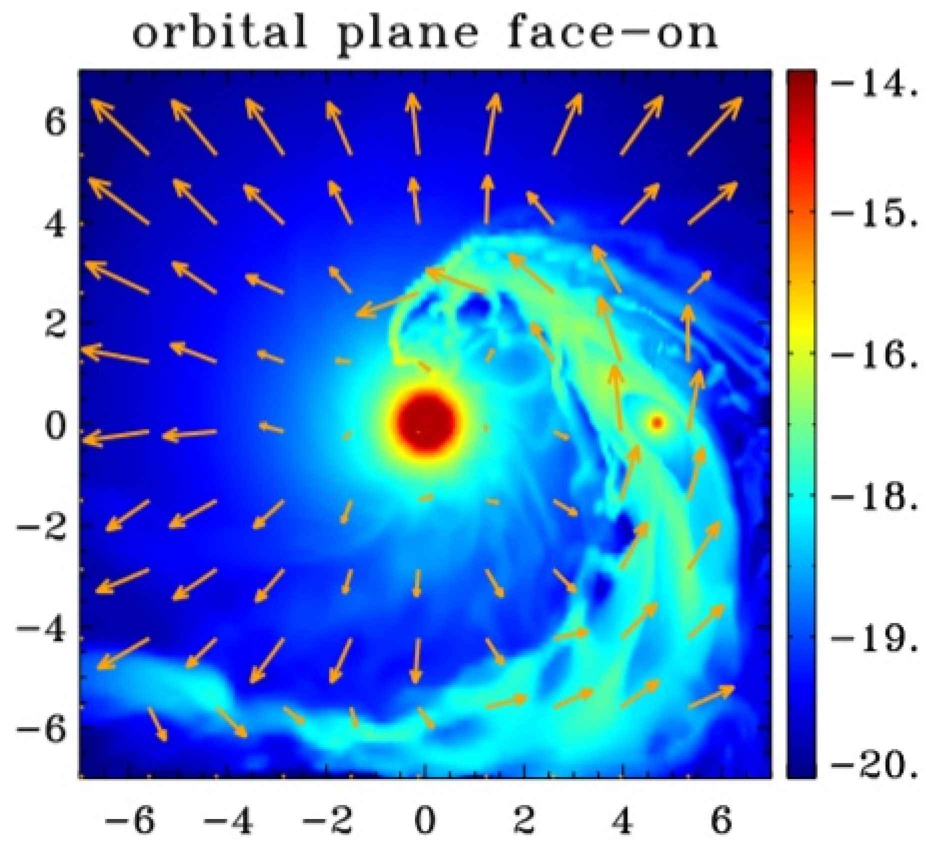
upsilon And
P_{orb} = 4.6 d
P_{rot} = 9.5 d

Shkolnik et al. (2005, 2008)

Magnetic flare triggering?

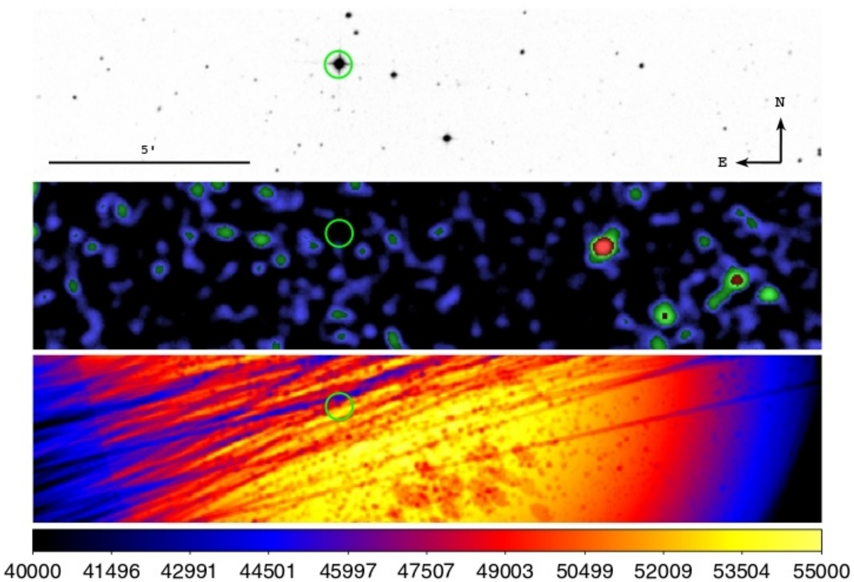


Pillitteri et al. (2015 submitted)



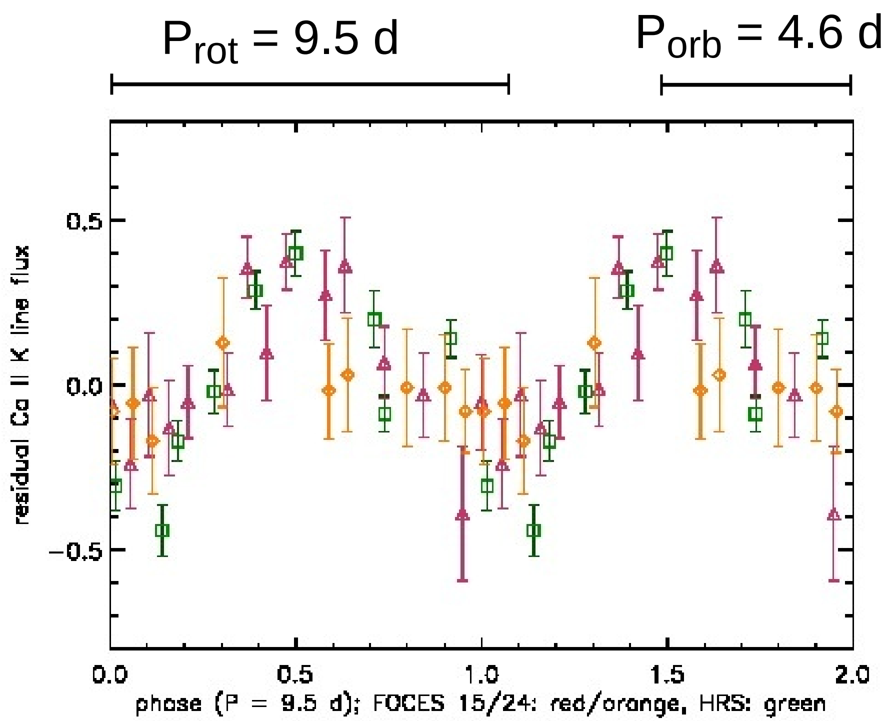
other works:
Lanza (2013)
Scandariato et al. (2013)
Strugarek et al. (2014)

Absence of magnetic effects



WASP-18 (1.2 M_{Sun}):
completely X-ray dark!

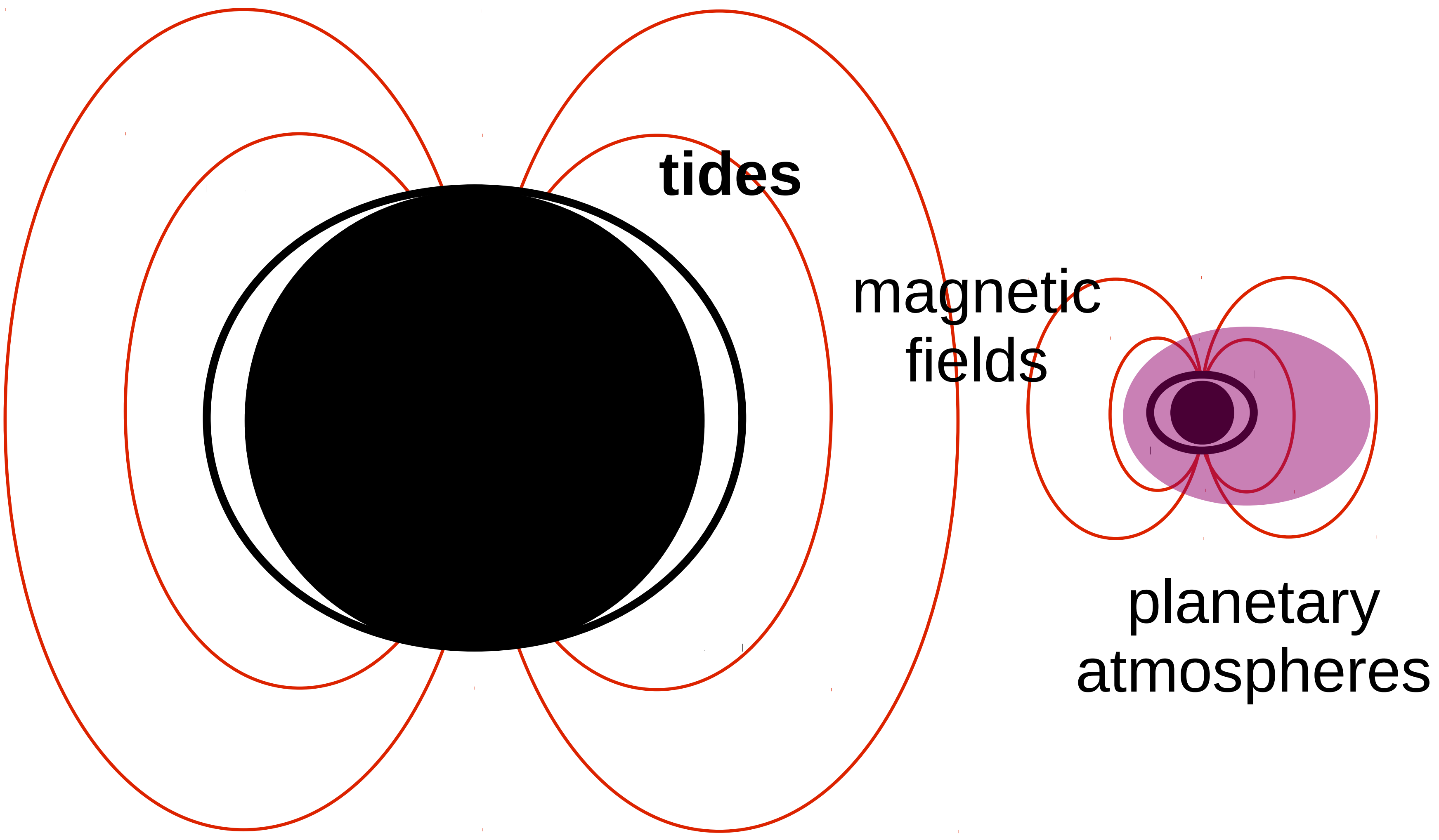
Miller et al. (2012),
Pillitteri et al. (2014)



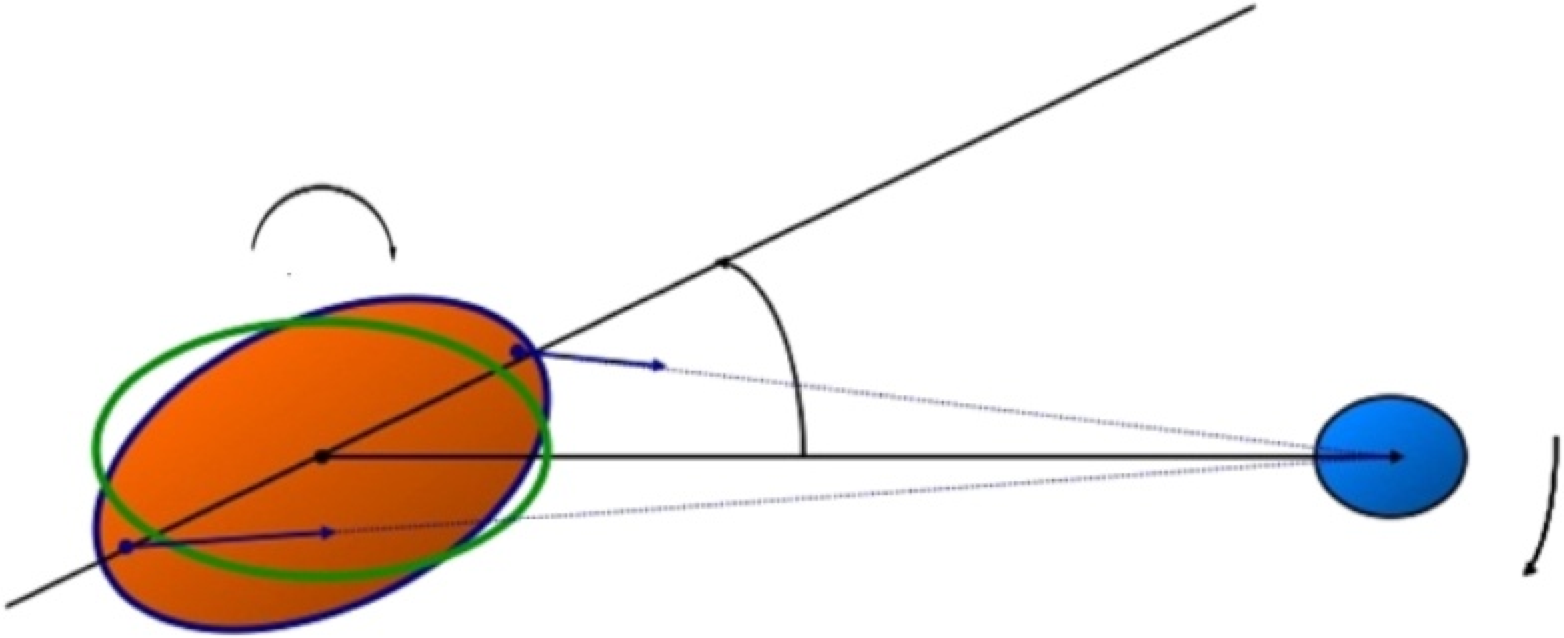
upsilon And (1.3 M_{Sun}):
varies with stellar rotation, not
with Hot Jupiter orbit

Poppenhaeger et al. (2010)

Tidal interaction

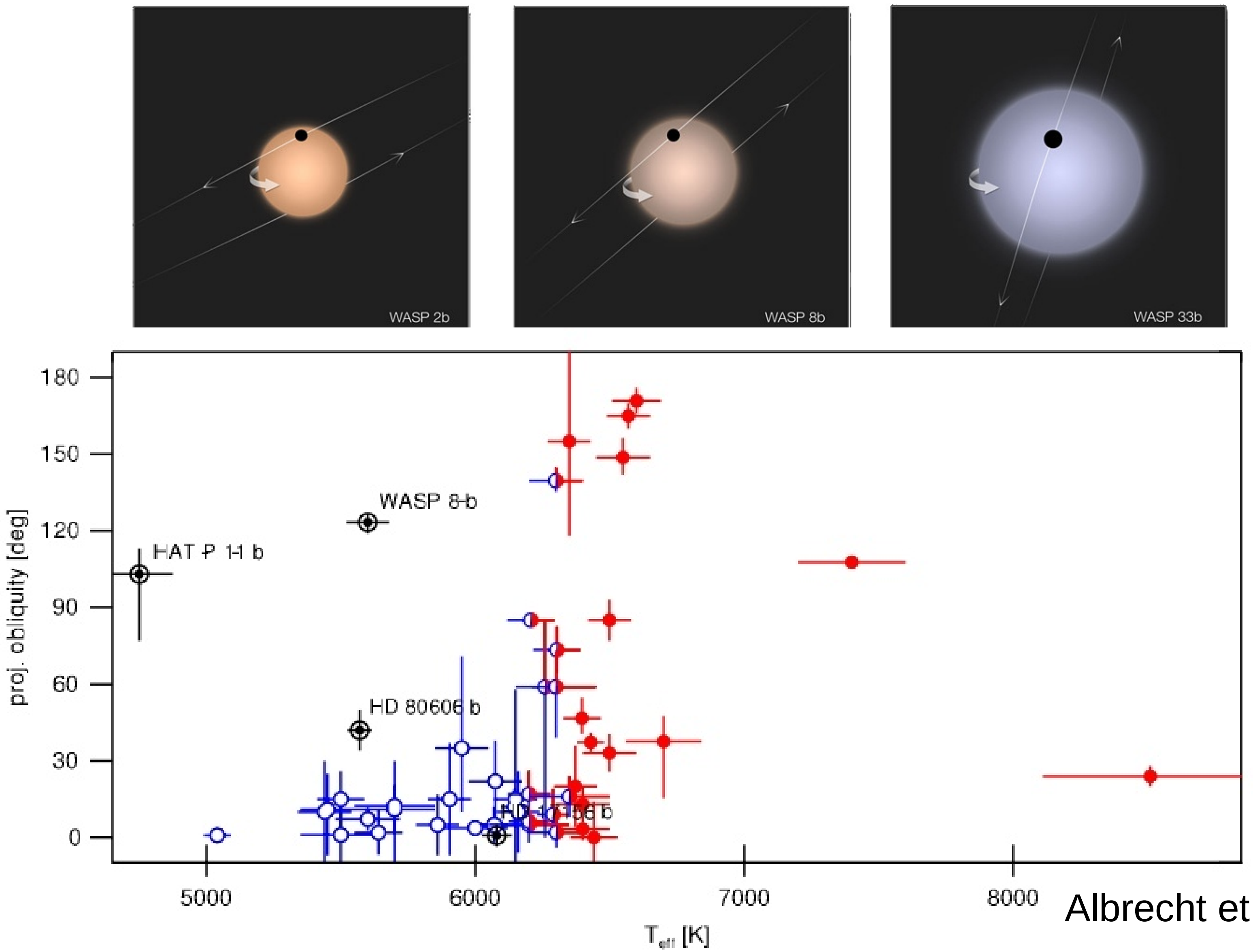


Tidal interaction



Mathis & Remus (2013)

Tidal interaction and orbital obliquities

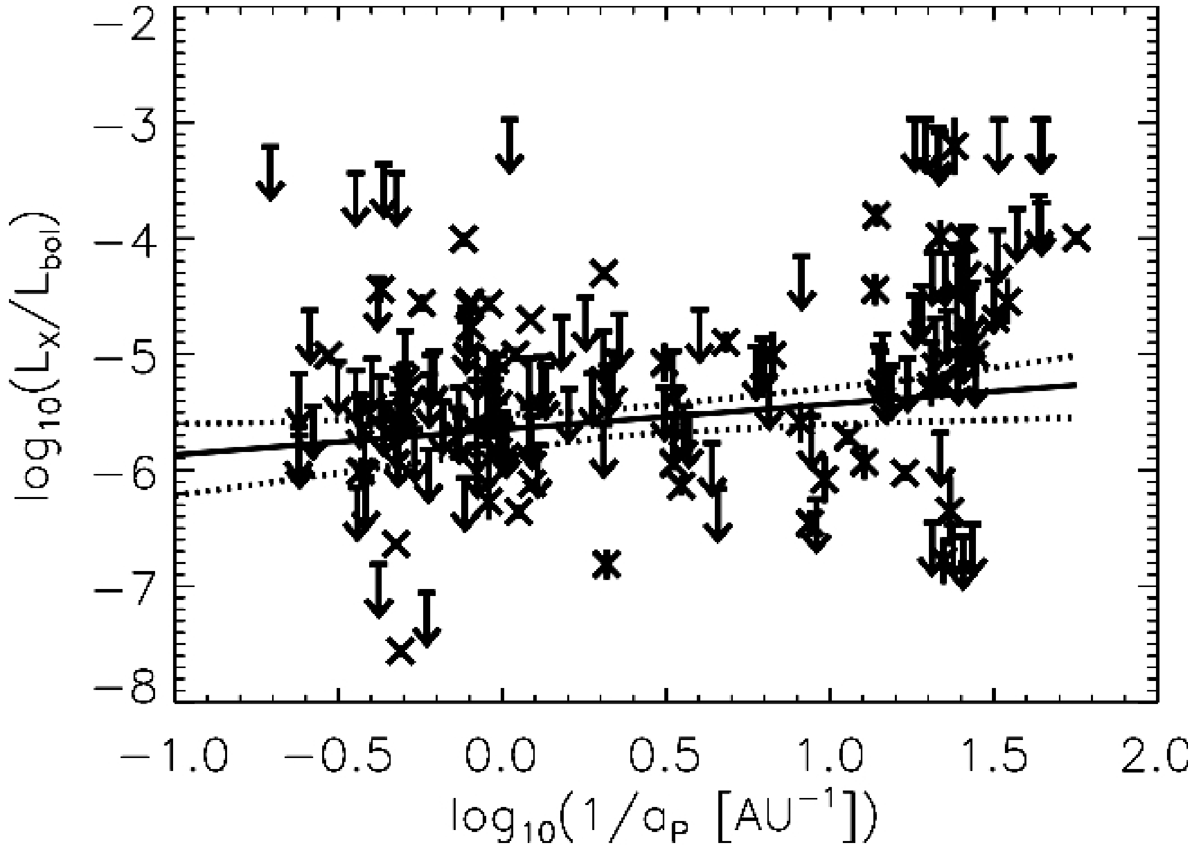


Albrecht et al. (2012)

Test for planet-induced activity

Test for planet-induced activity

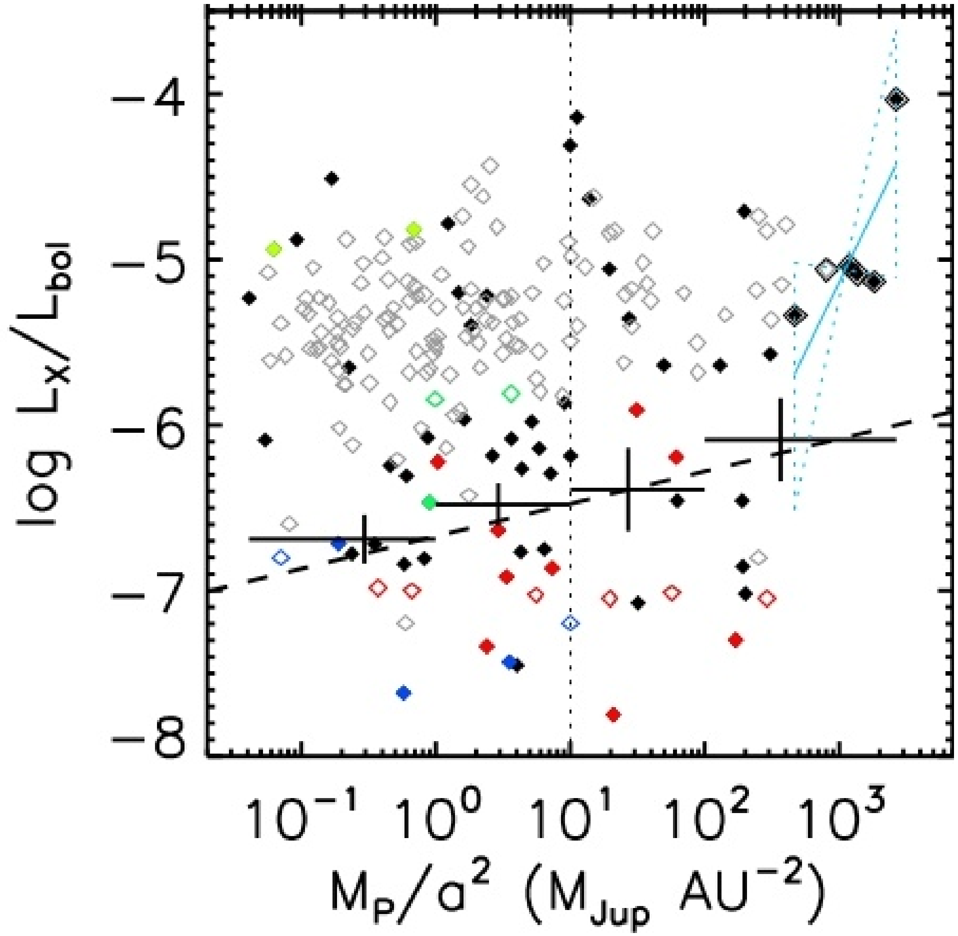
more active



Kashyap et al. (2008)

more Hot Jupiter-like

Test for planet-induced activity



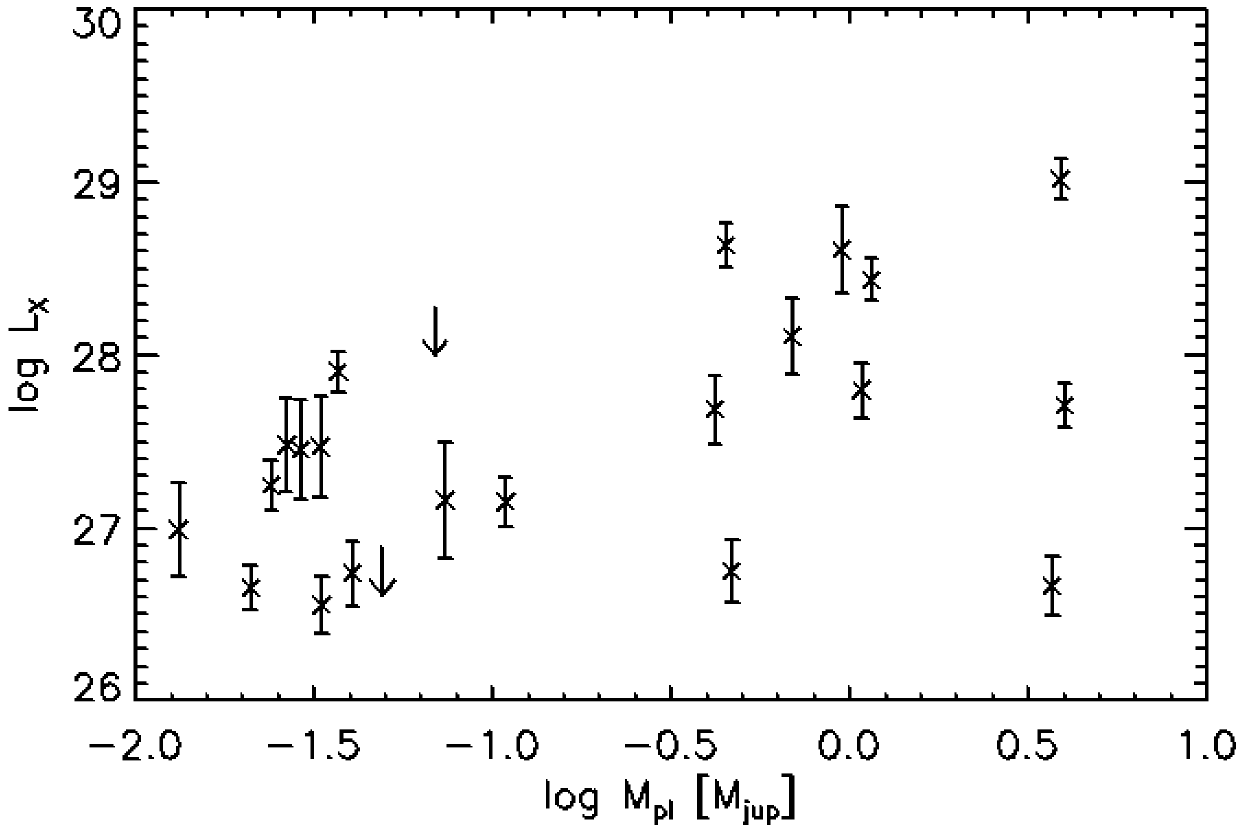
Miller et al. (2014)

more active

more Hot Jupiter-like

Test for planet-induced activity

more active



Poppenhaeger et al. (2011)

other works:

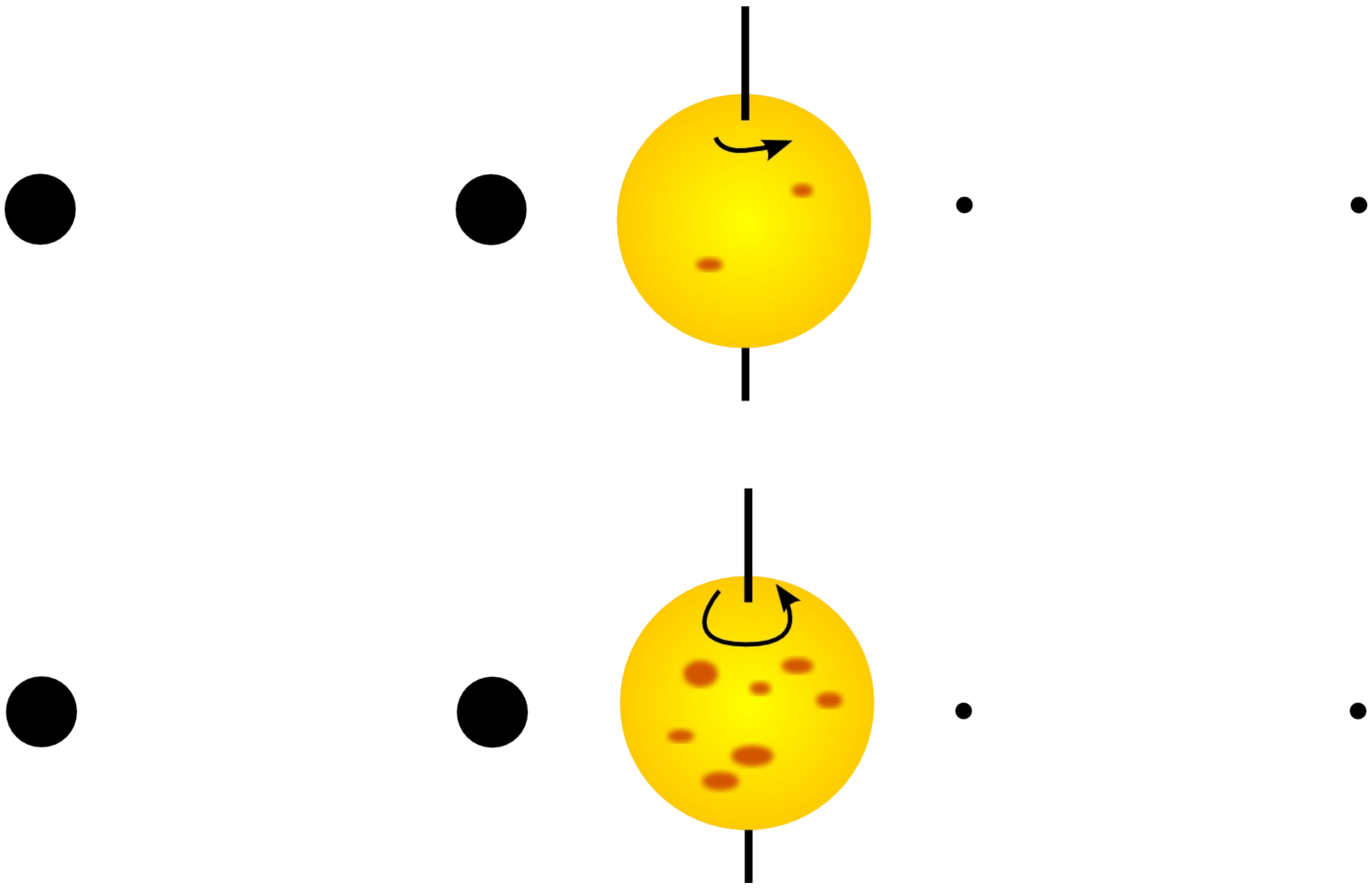
Alves et al. (2010)

Canto Martins et al. (2011)

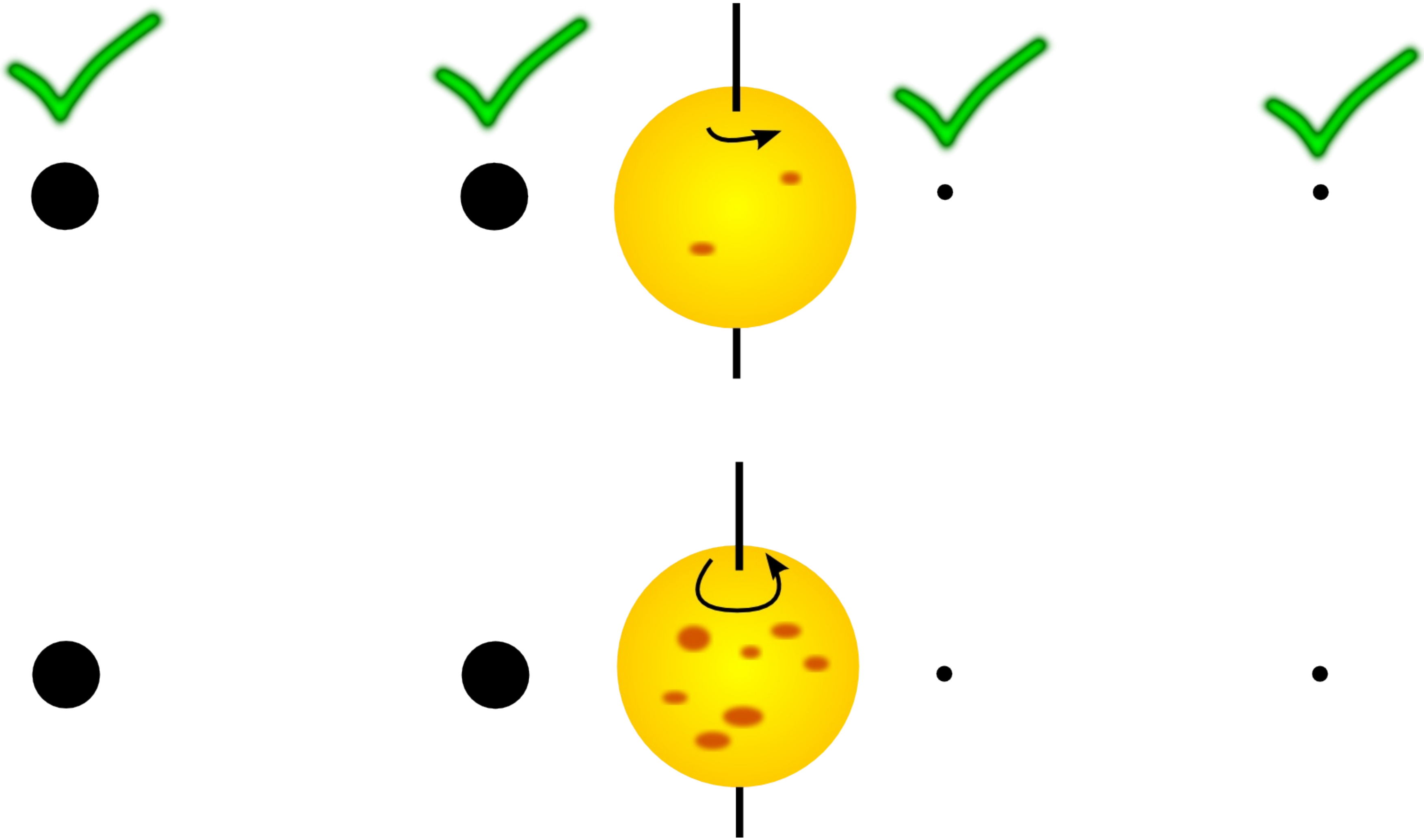
Shkolnik (2013)

more Hot Jupiter-like

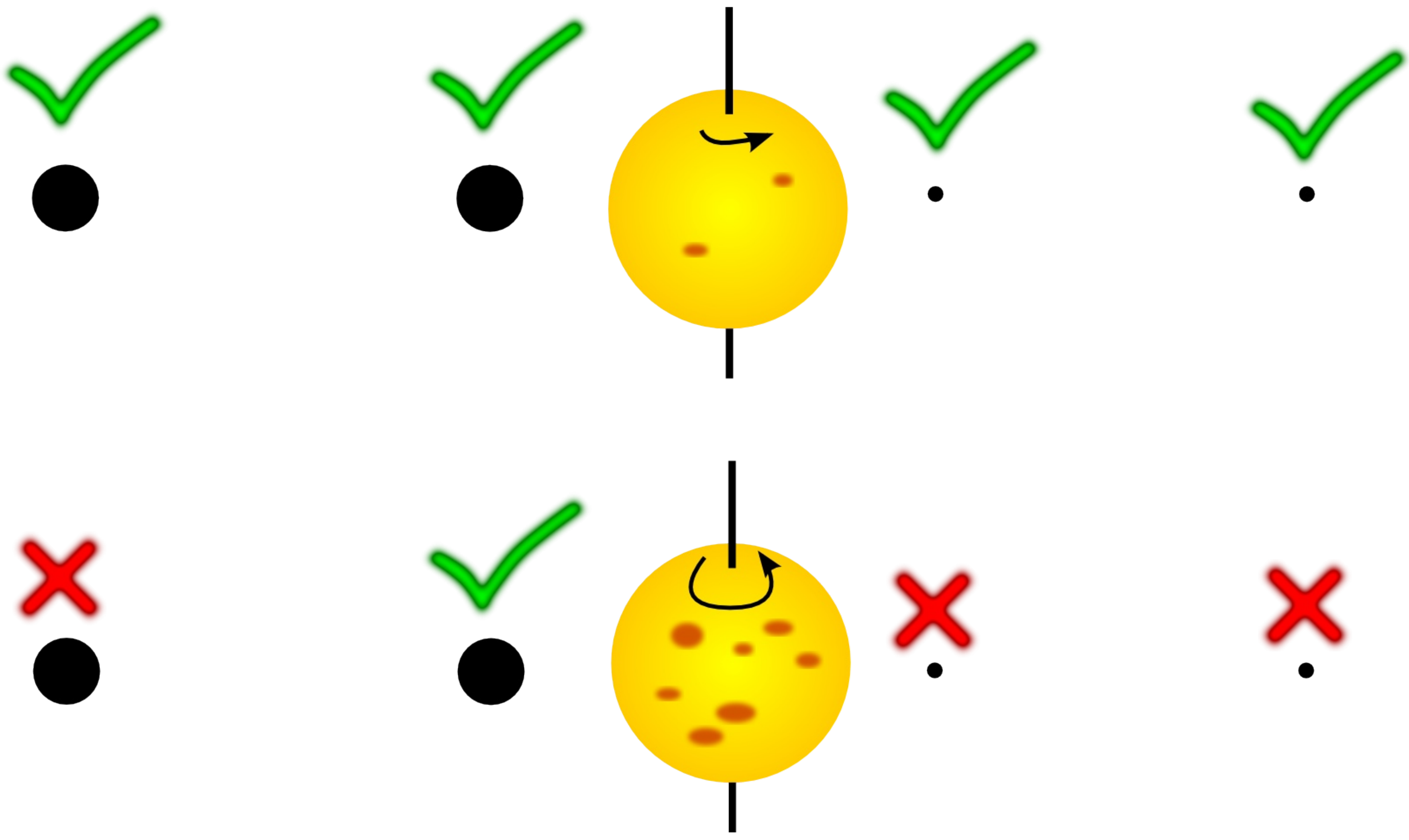
What do we see?



What do we see?

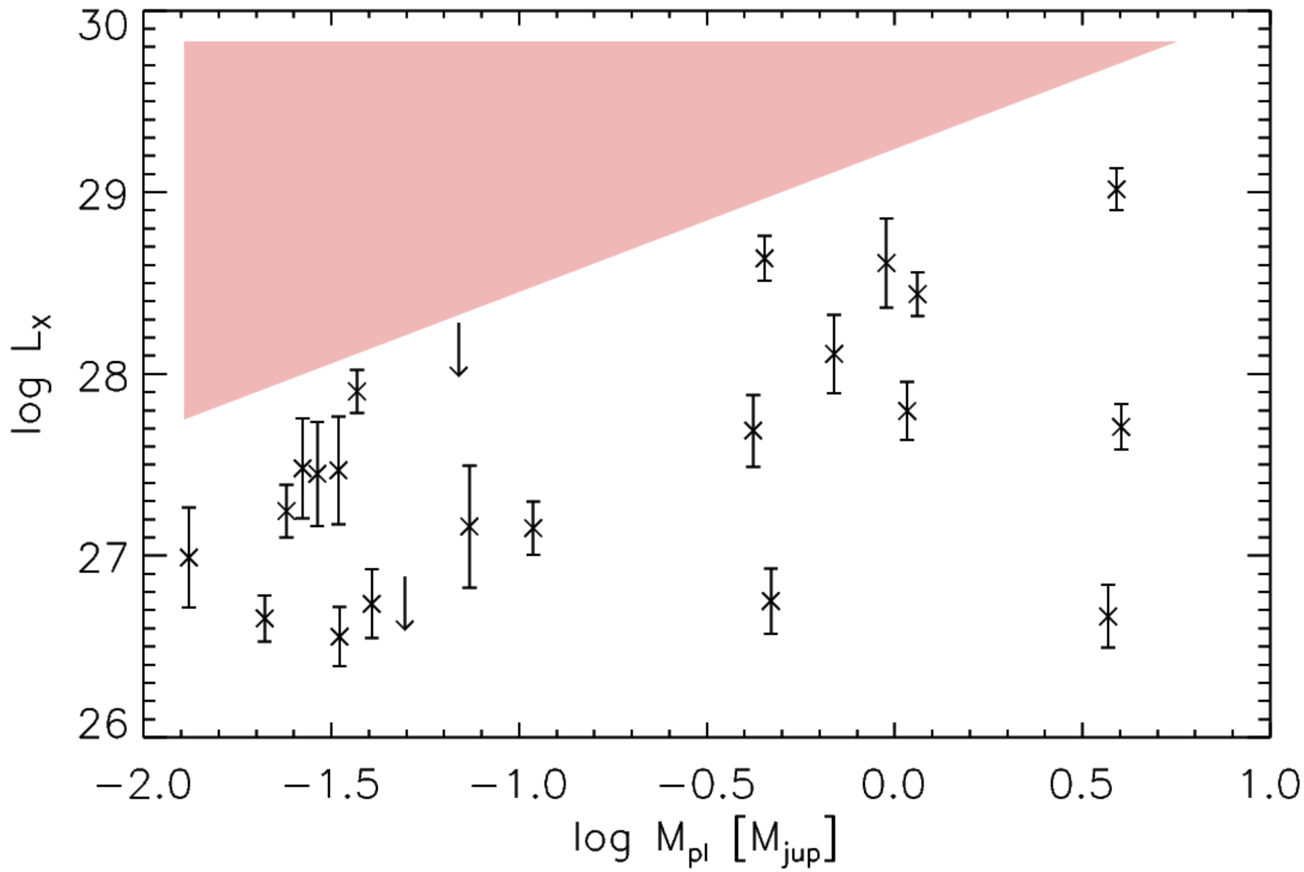


What do we see?



What do we see?

more active



more Hot Jupiter-like

Poppenhaeger et al. (2011)

Bias-controlled sample: planet-hosting wide binaries

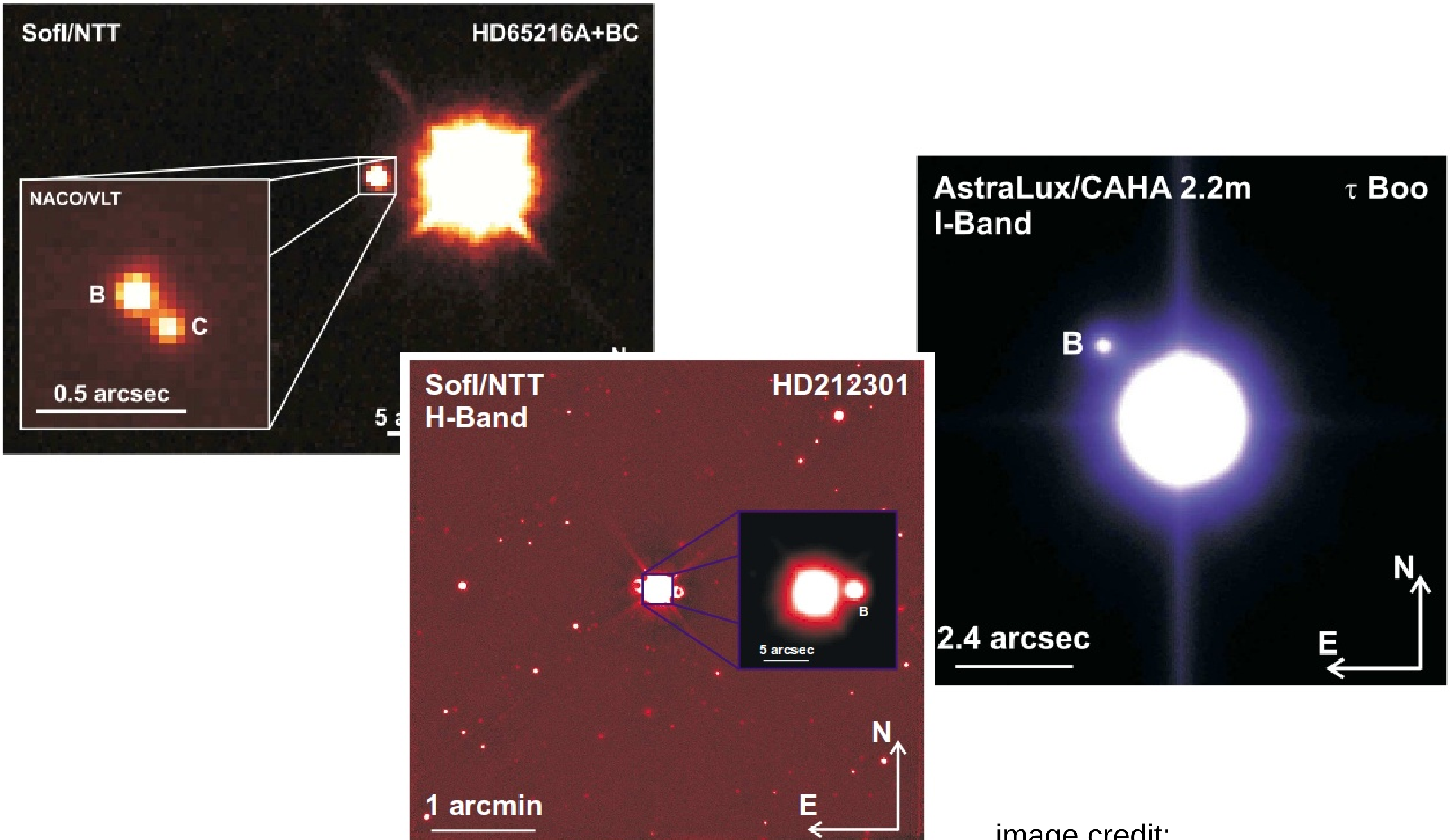
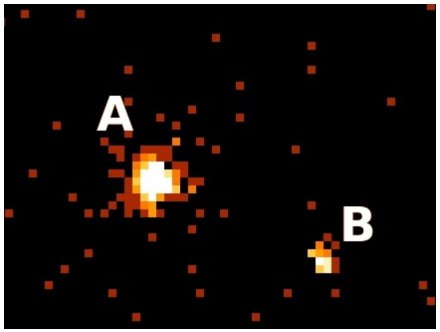
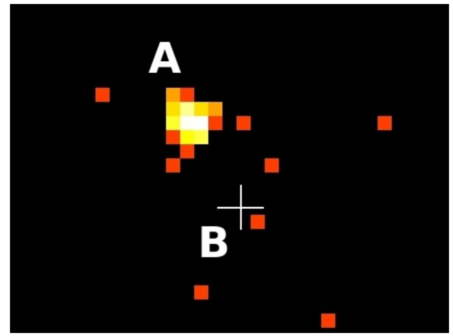


image credit:
Mugrauer et al. (2007);
see also Raghavan (2006)

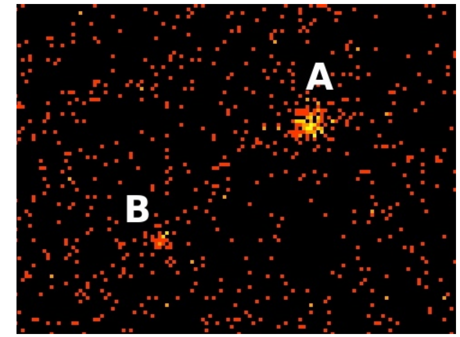
Planet-hosting wide binaries



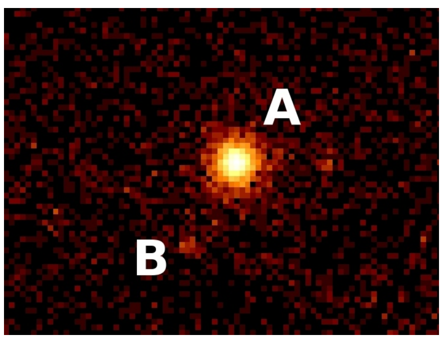
HD 189733 Ab B



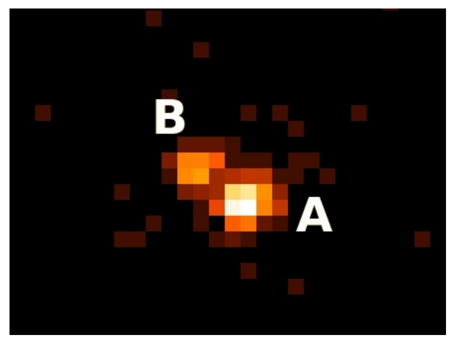
CoRoT-2 Ab B



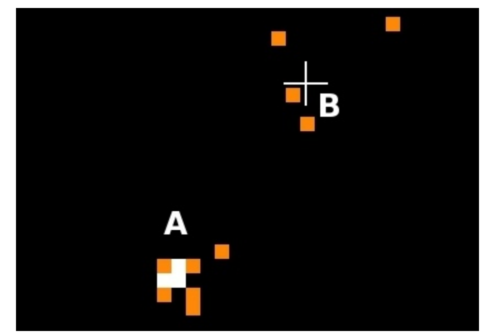
55 Cnc Abcde B



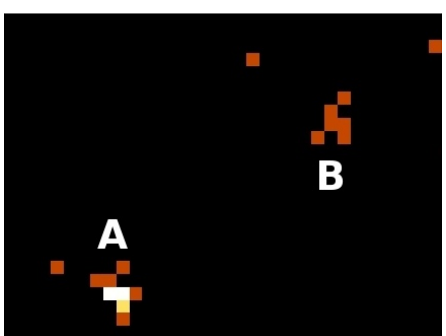
upsilon And Ab B



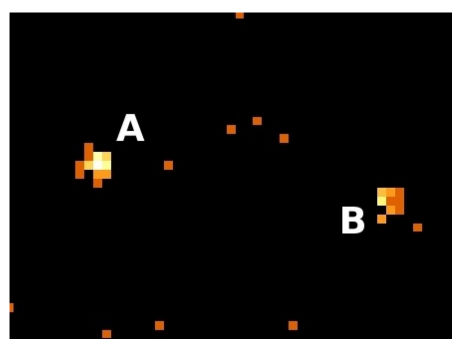
tau Boo Ab B



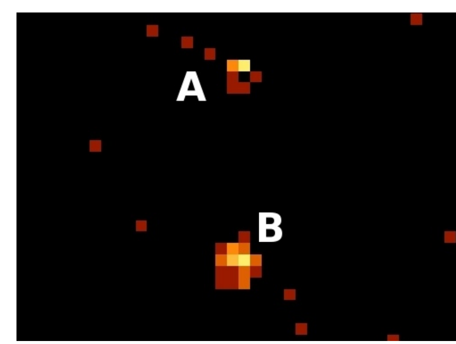
HAT-P-20 Ab B



HD 46375 Ab B



HD 178911 A Bb

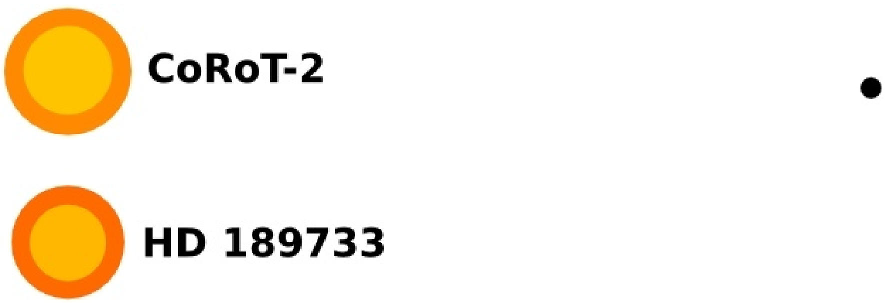


HD 109749 Ab B

Poppenhaeger et al. (2014),
Poppenhaeger et al. in prep.

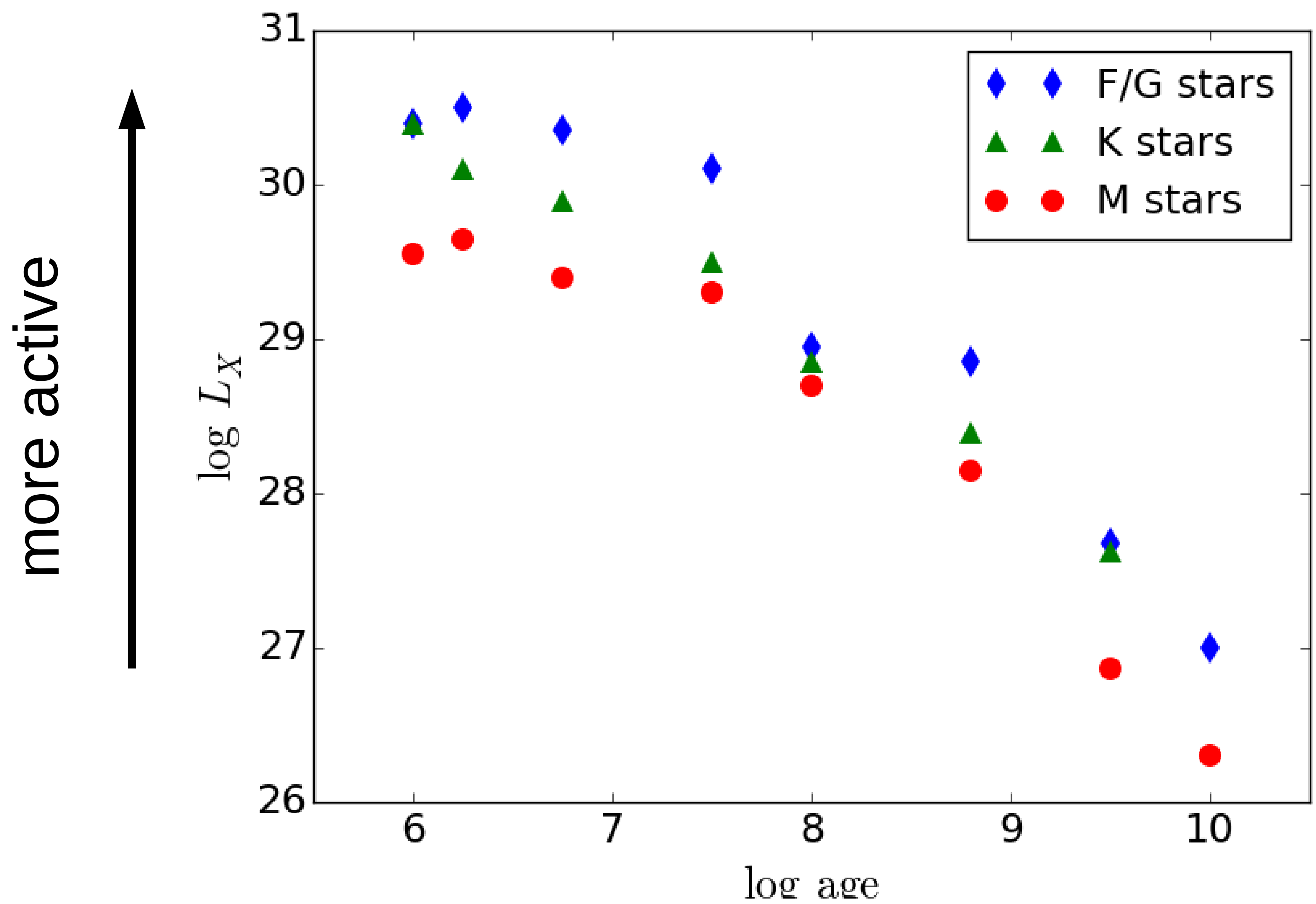
Planet-hosting wide binaries

strong tidal interaction

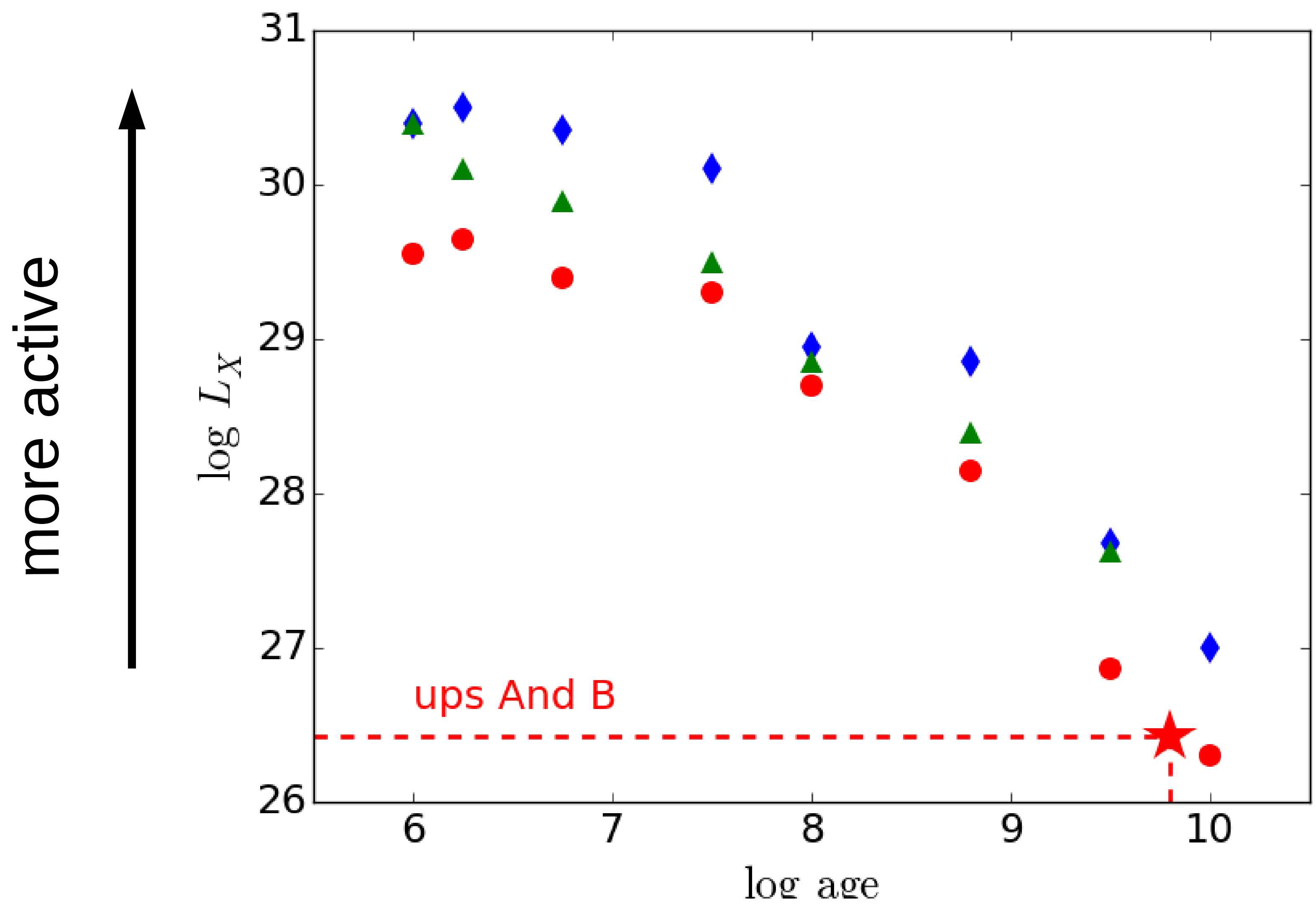


weak tidal interaction

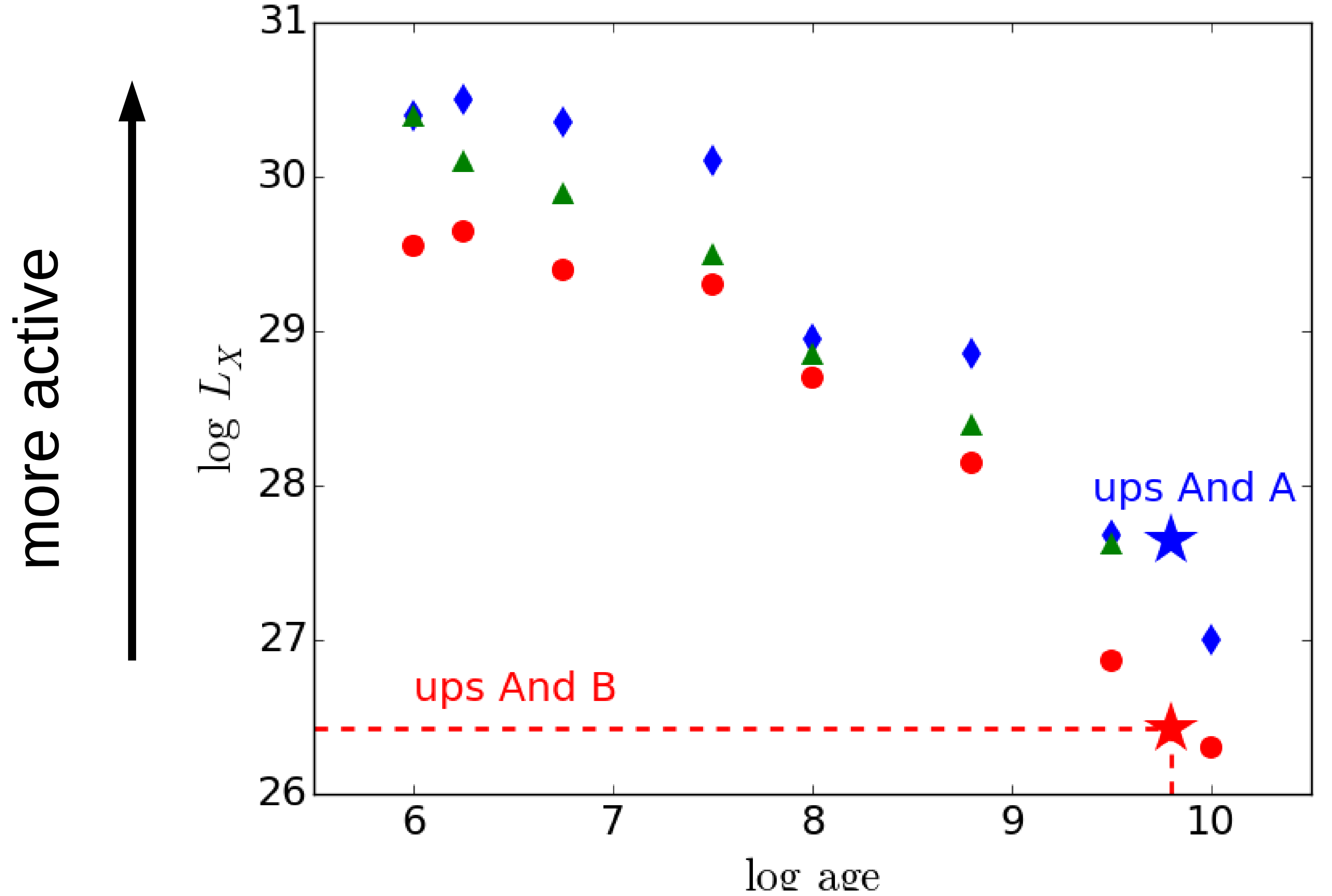
Planet-hosting wide binaries



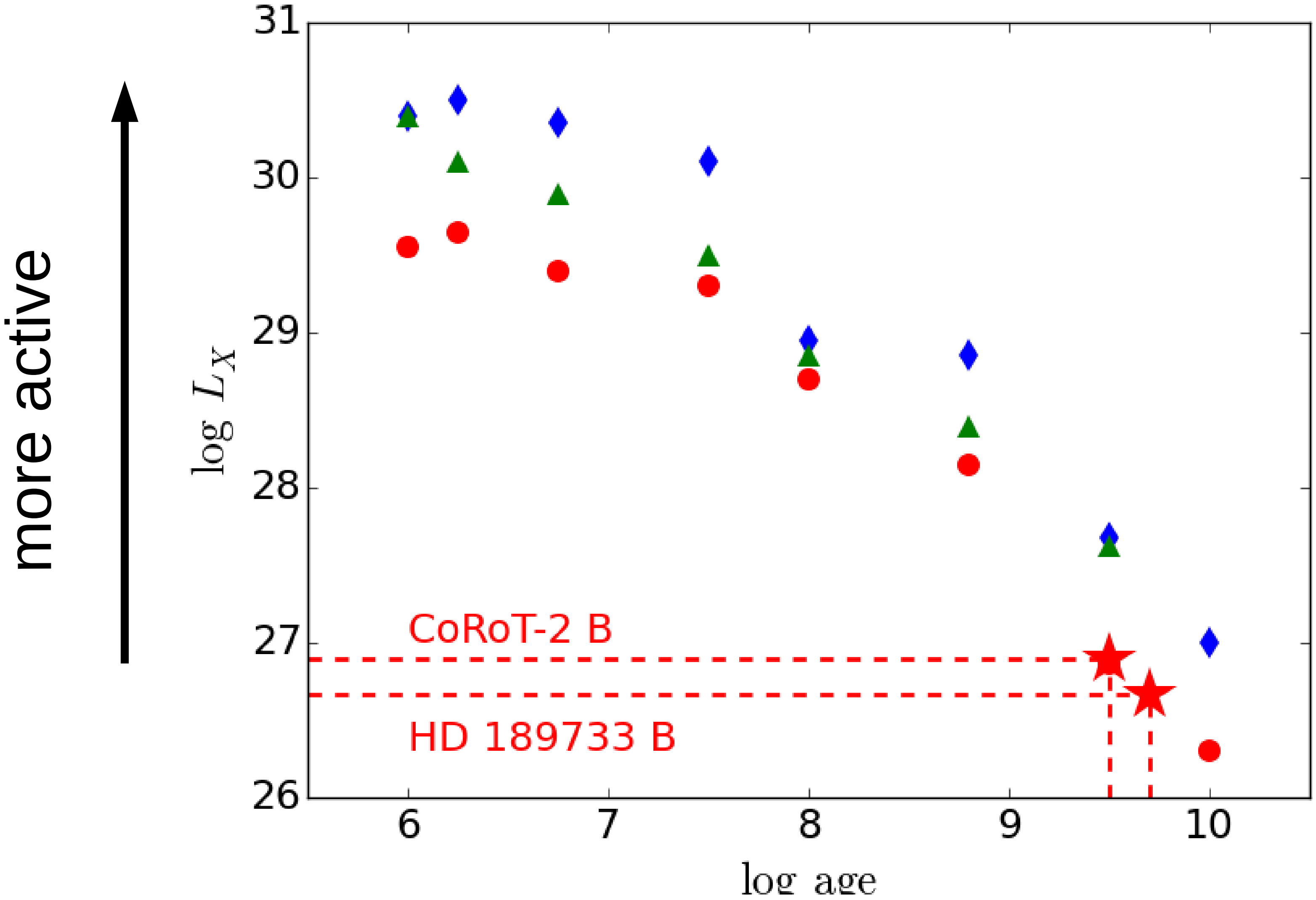
Planet-hosting wide binaries



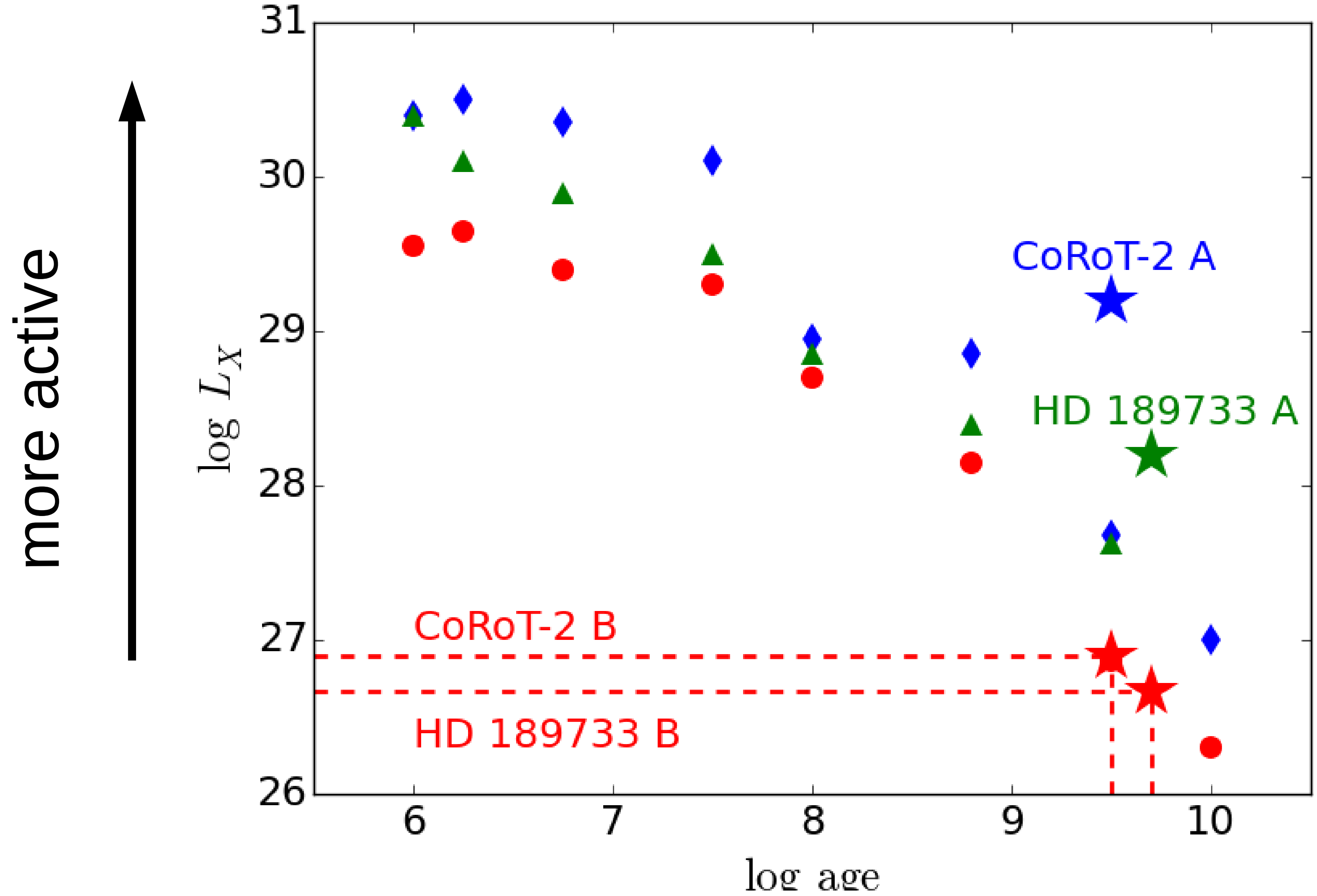
Planet-hosting wide binaries



Planet-hosting wide binaries

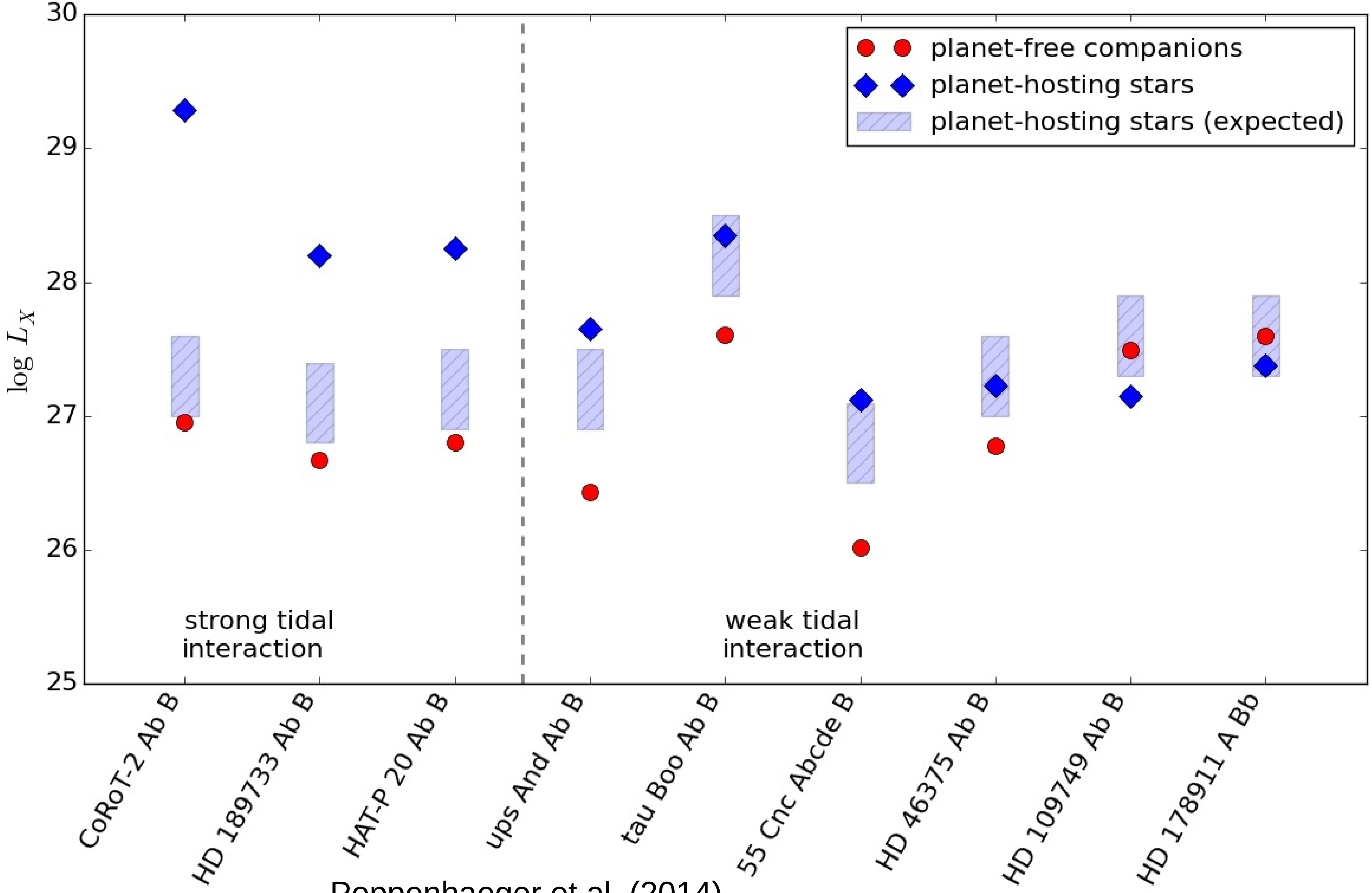


Planet-hosting wide binaries



Several over-active systems

more active



Poppenhaeger et al. (2014),
Poppenhaeger et al. in prep.

Tidal effect in very close systems

planet-induced enhanced activity
(and rotation):

- massive exoplanet (at least 1 M_{Jup})

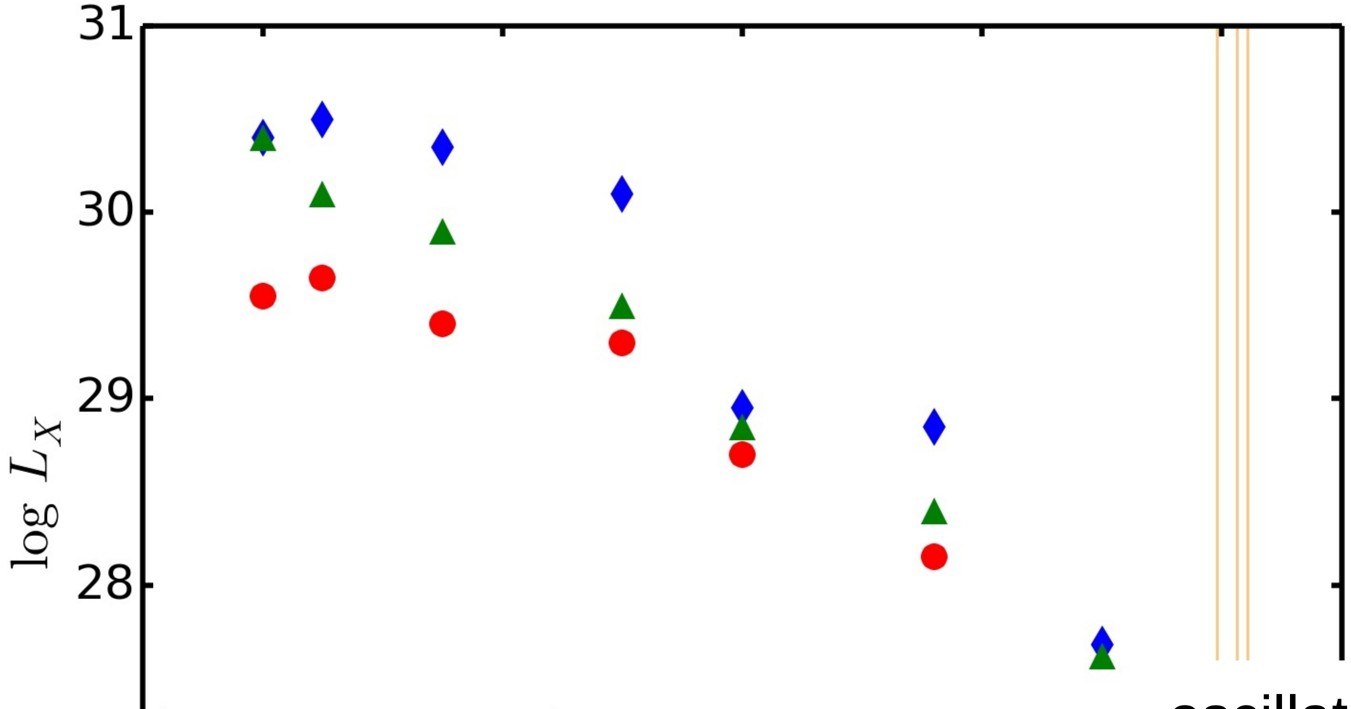
- very close orbit (3 days or less)

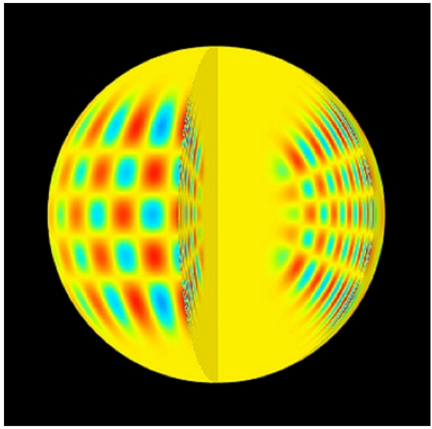
- low-mass host star, i.e. thick convection zone (less than 1 M_{Sun})

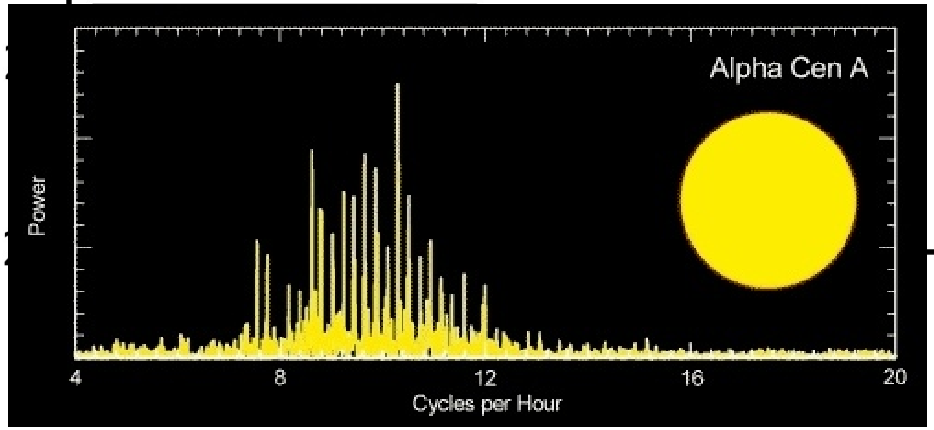
→ activity enhancement of 1-2 orders of magnitude possible

Improving stars as clocks

more active





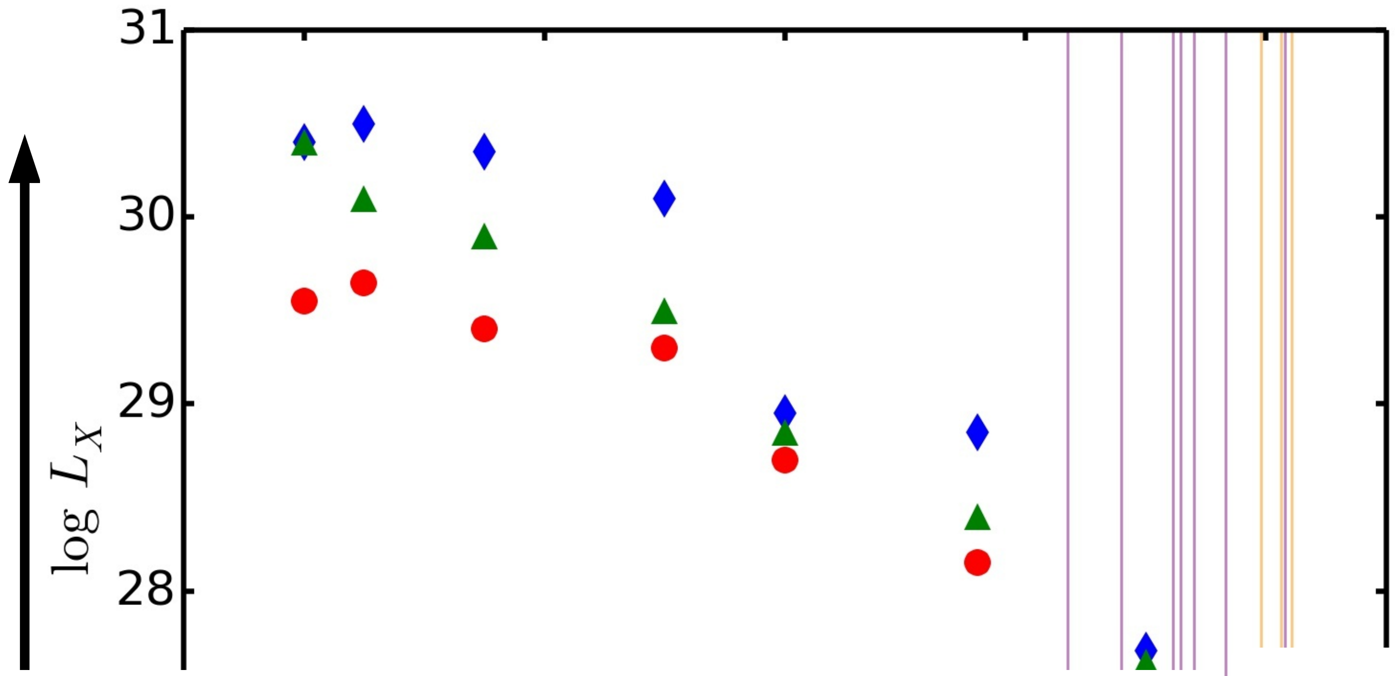


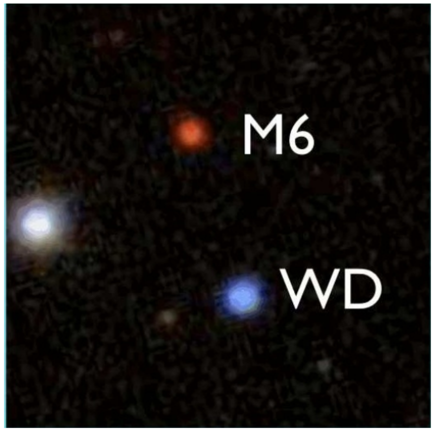
oscillation frequency spectrum:

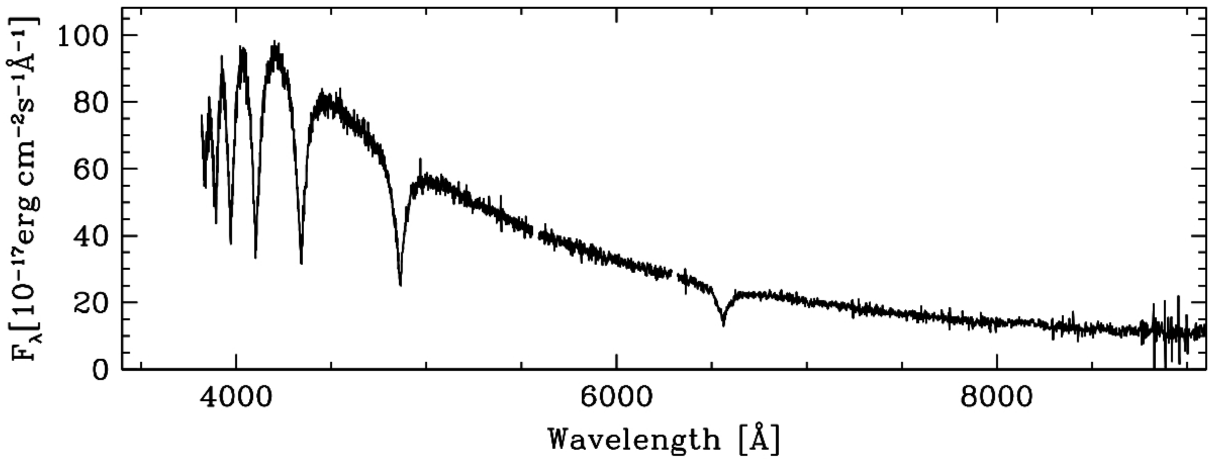
$\Delta\nu$ → mean density
$\delta\nu$ → density in core
+ evolution models
= stellar age

Improving stars as clocks

more active



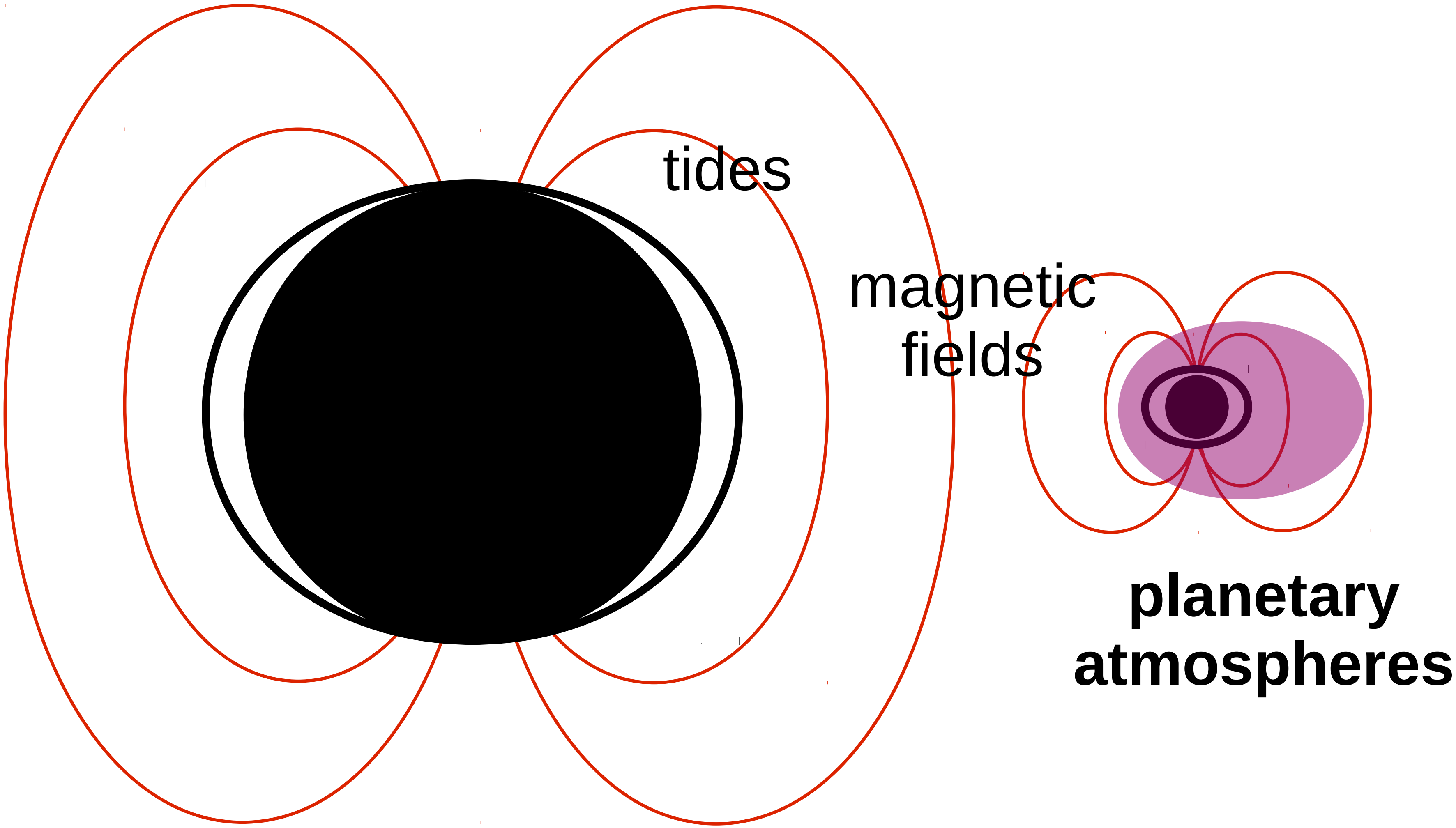




WD spectrum:

T_{eff}, log(g) →
mass, cooling time
+ progenitor lifetime
= stellar age

Exoplanetary atmospheres



Atmospheres and high-energy photons

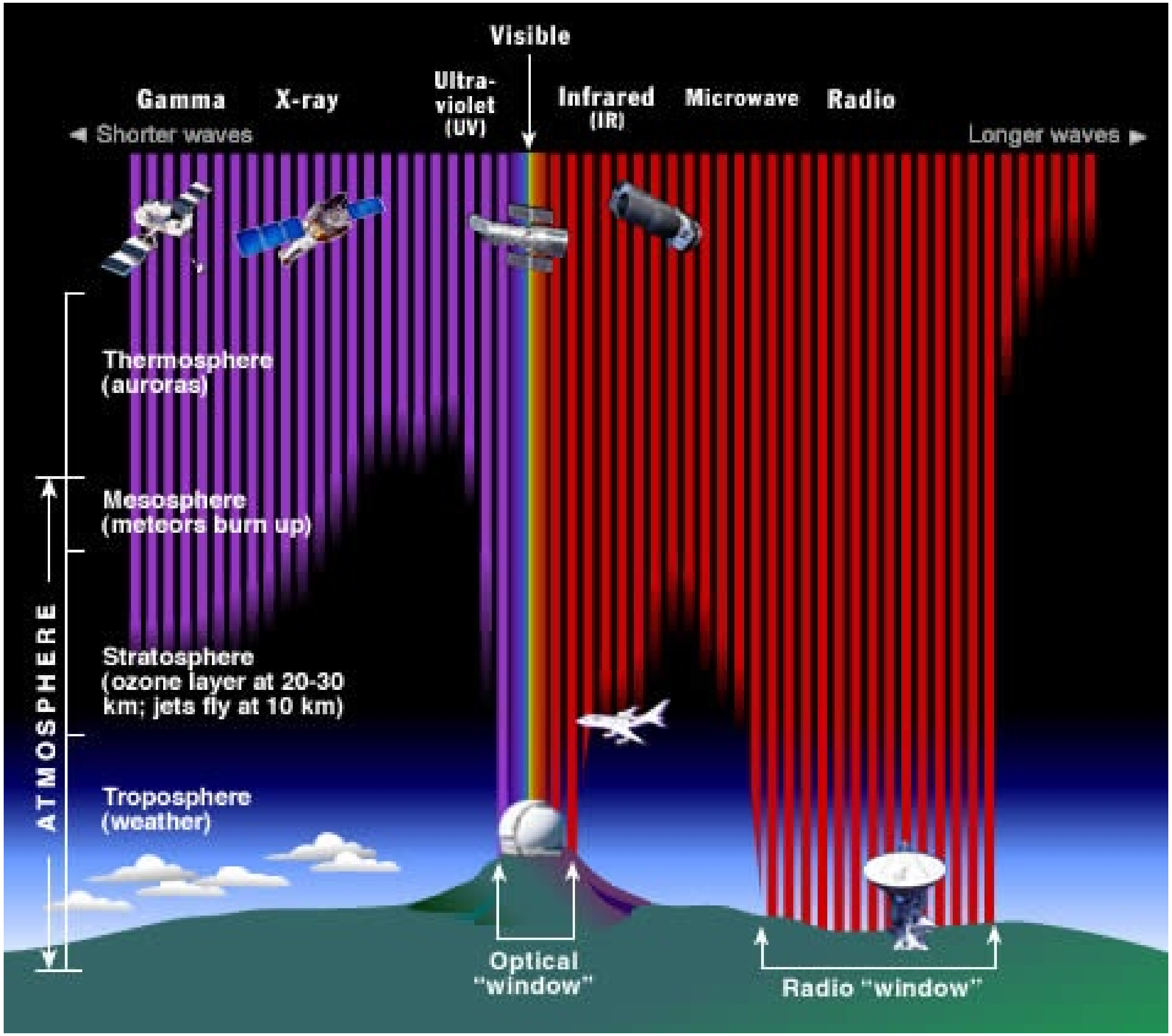


image credit: NASA

Atmospheres and high-energy photons

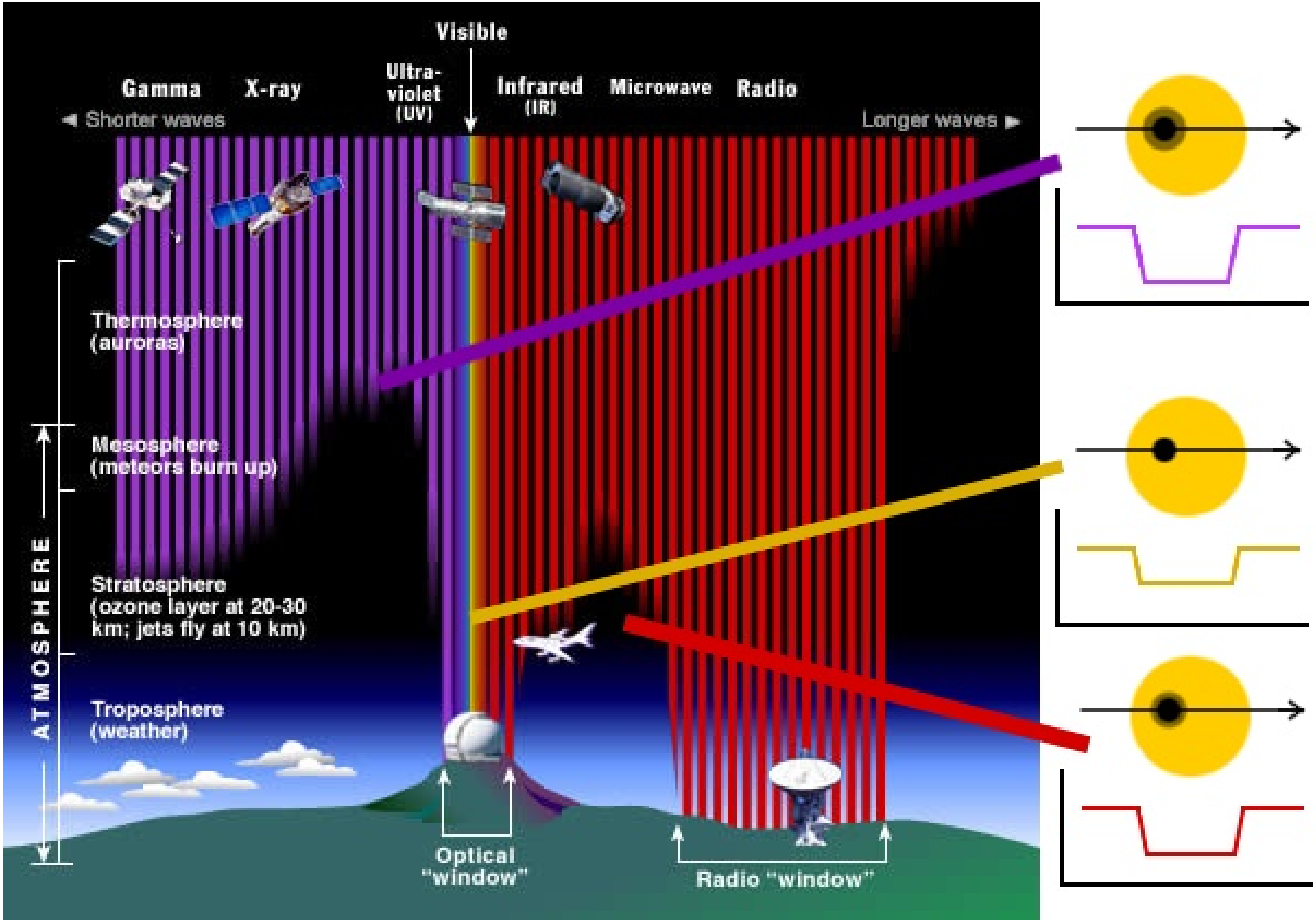
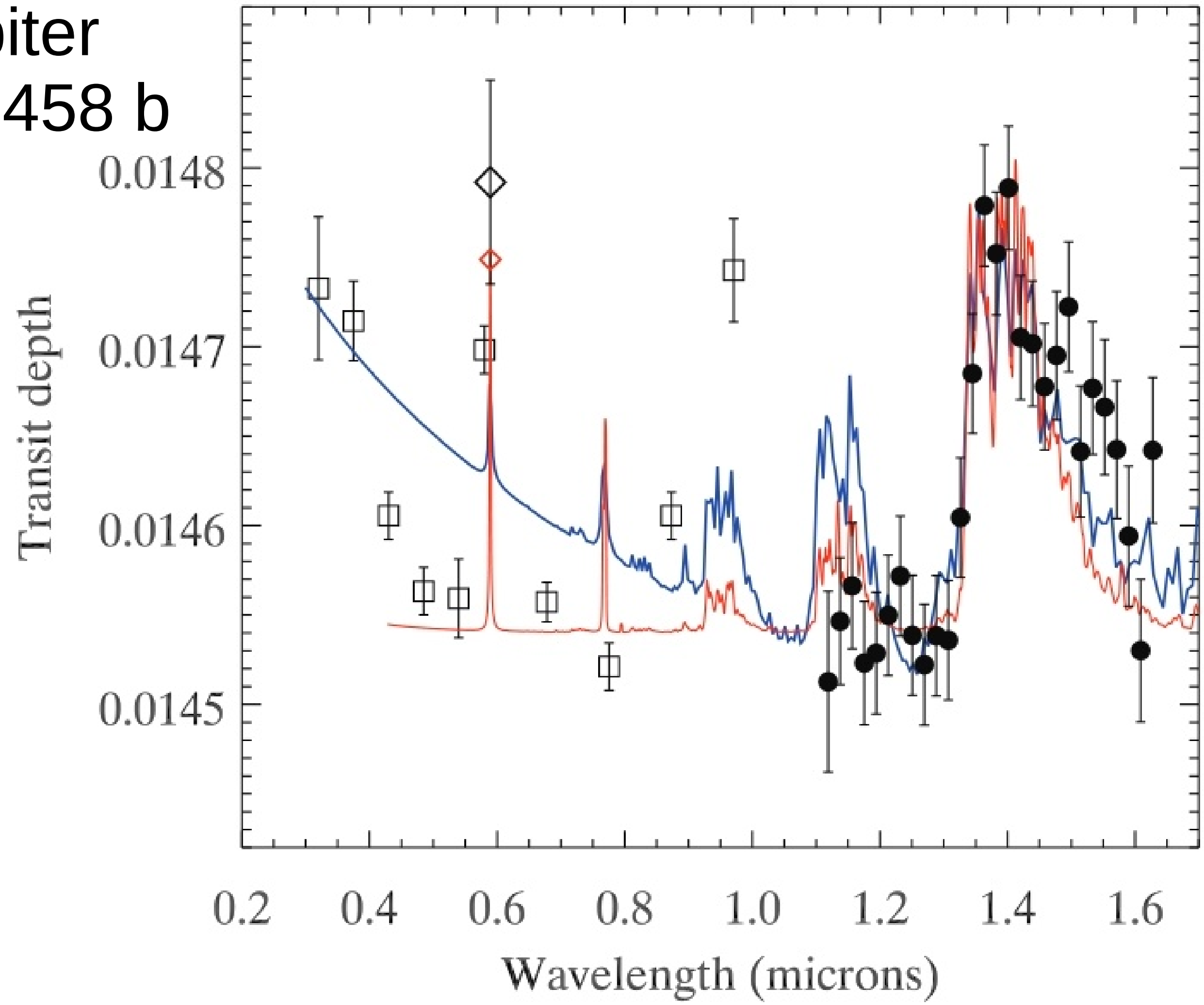


image credit: NASA

Spectra of atmospheres

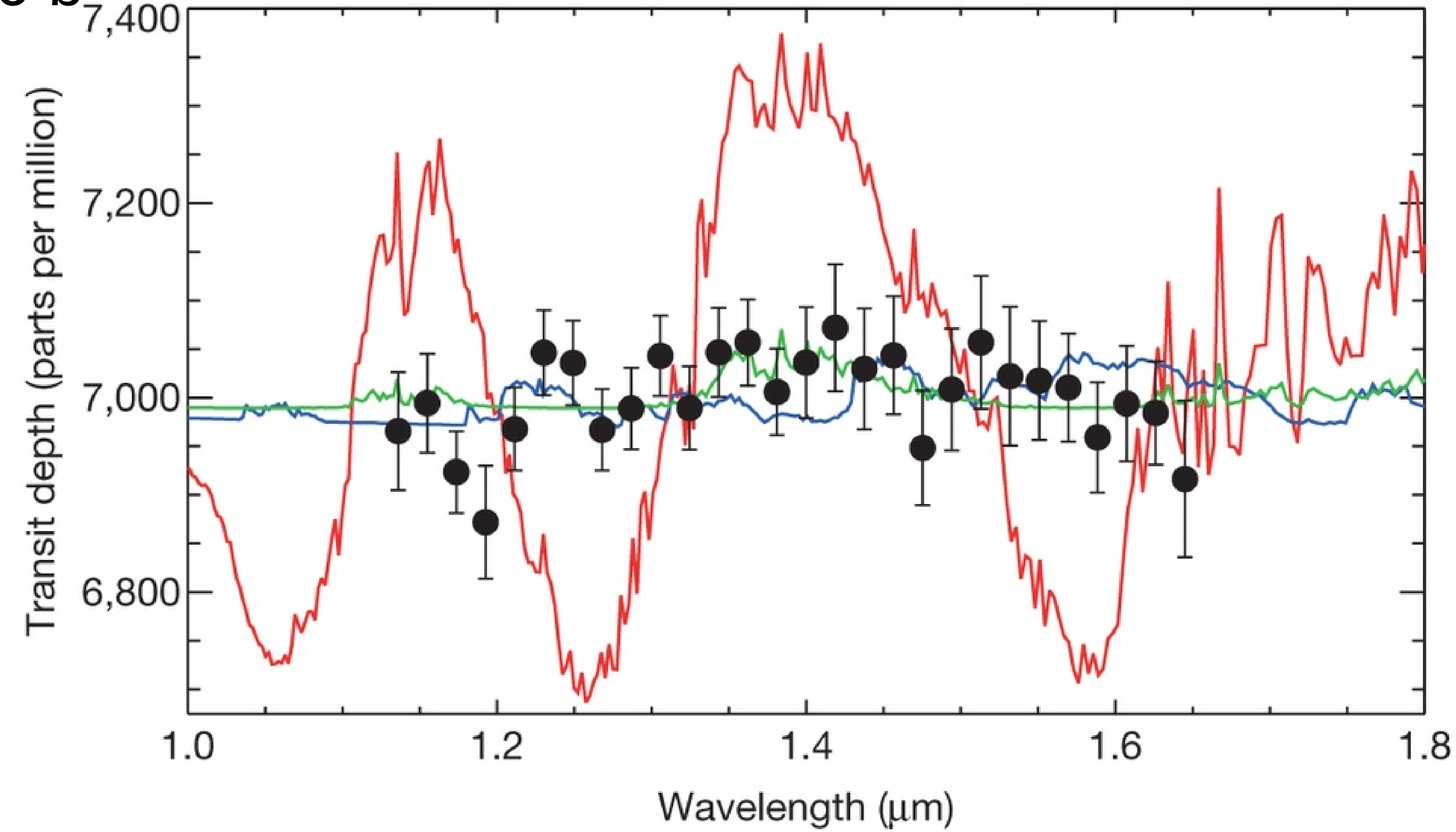
Hot Jupiter
HD 209458 b



Deming et al. (2013)

Spectra of atmospheres

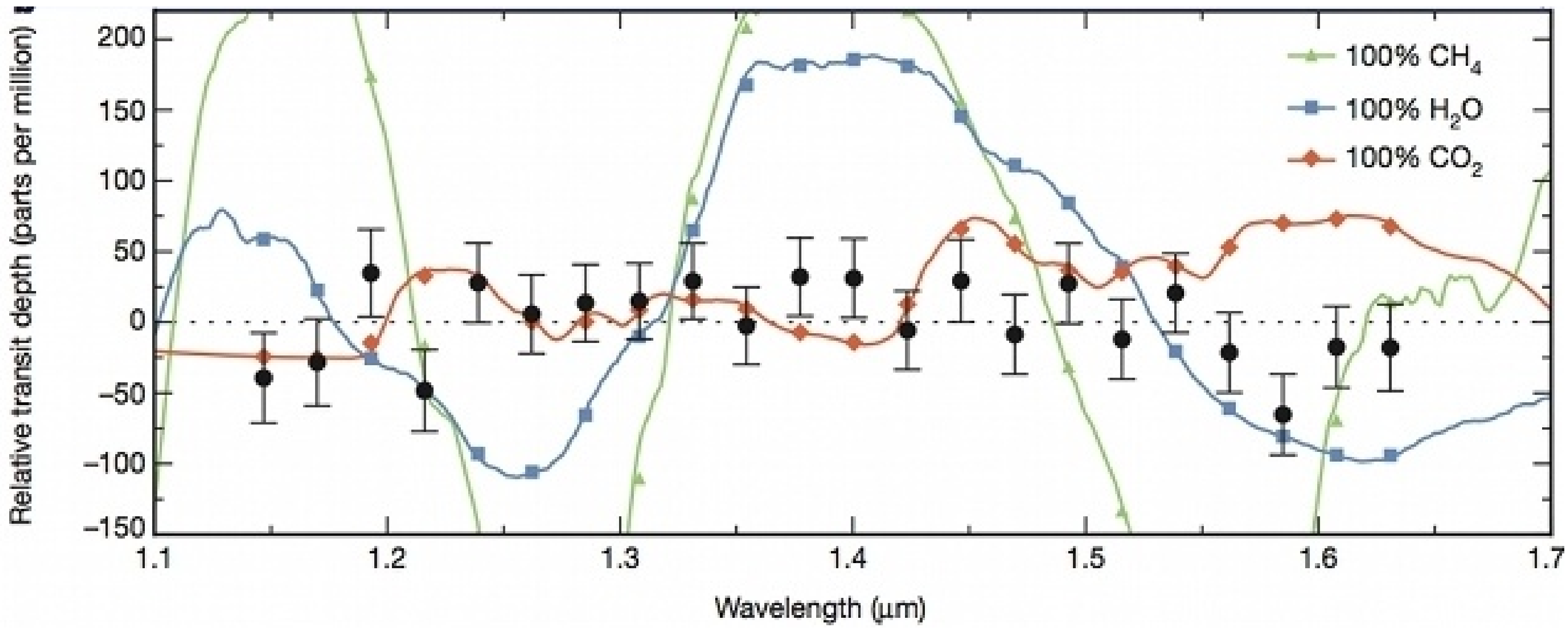
Hot Neptune
GJ 436 b



Knutson et al. (2013)

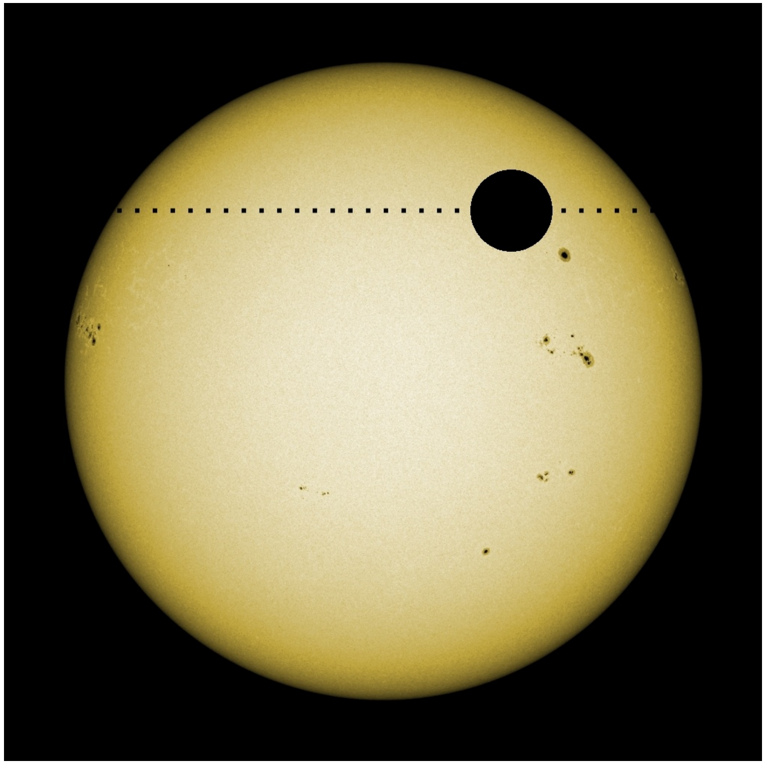
Spectra of atmospheres

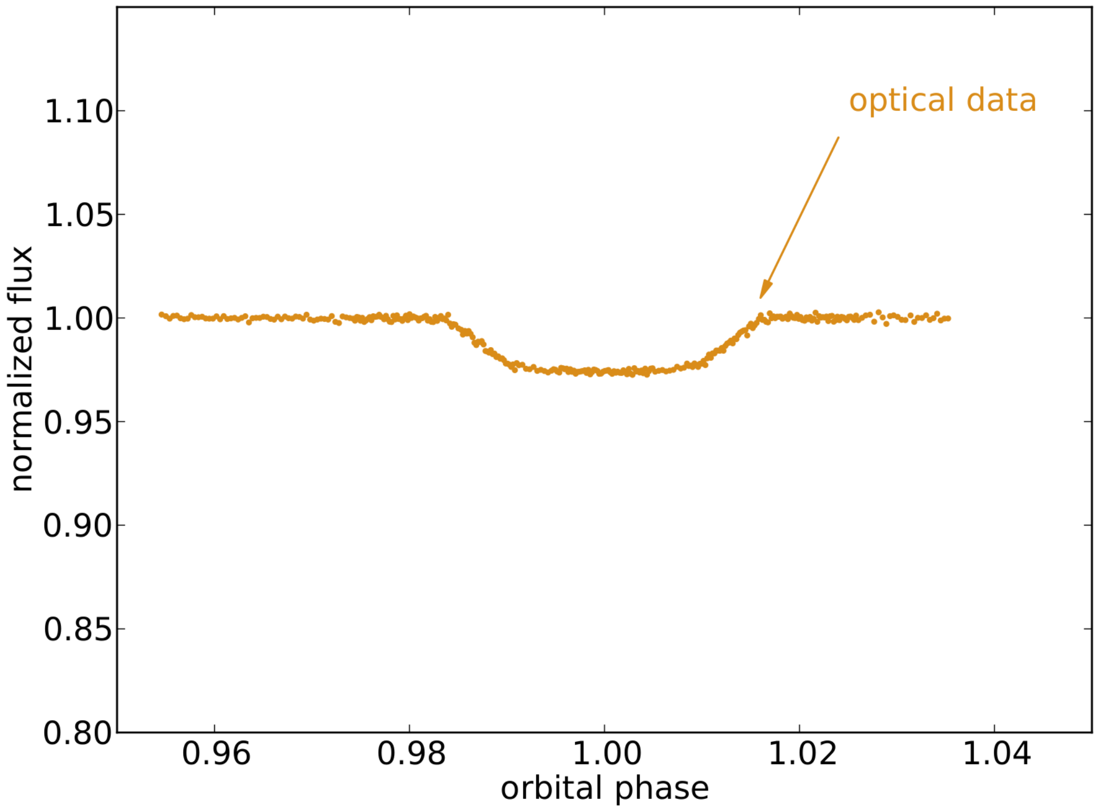
Super-earth
GJ 1214 b



Kreidberg et al. (2014)

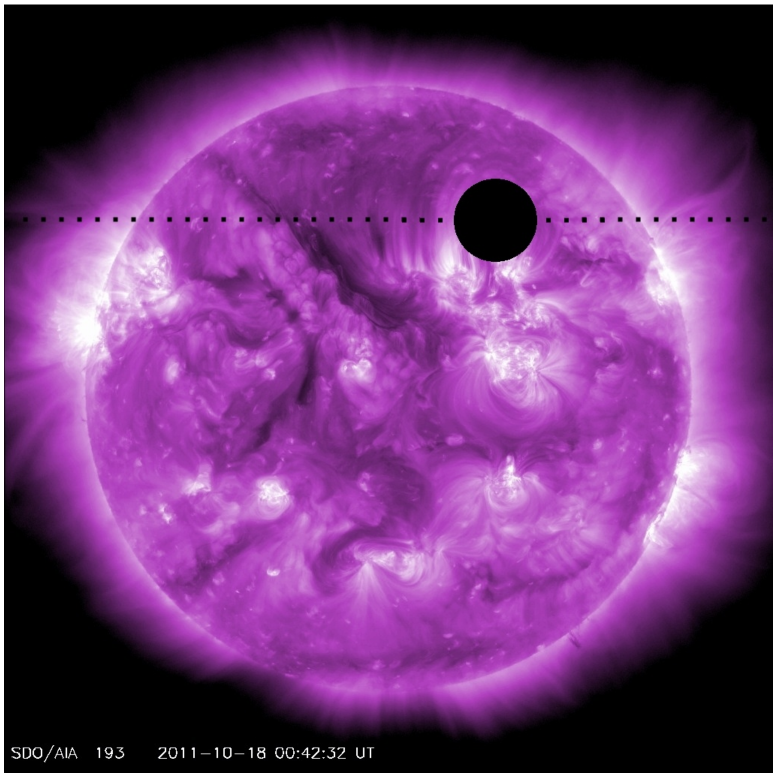
X-ray transits: extended atmospheres

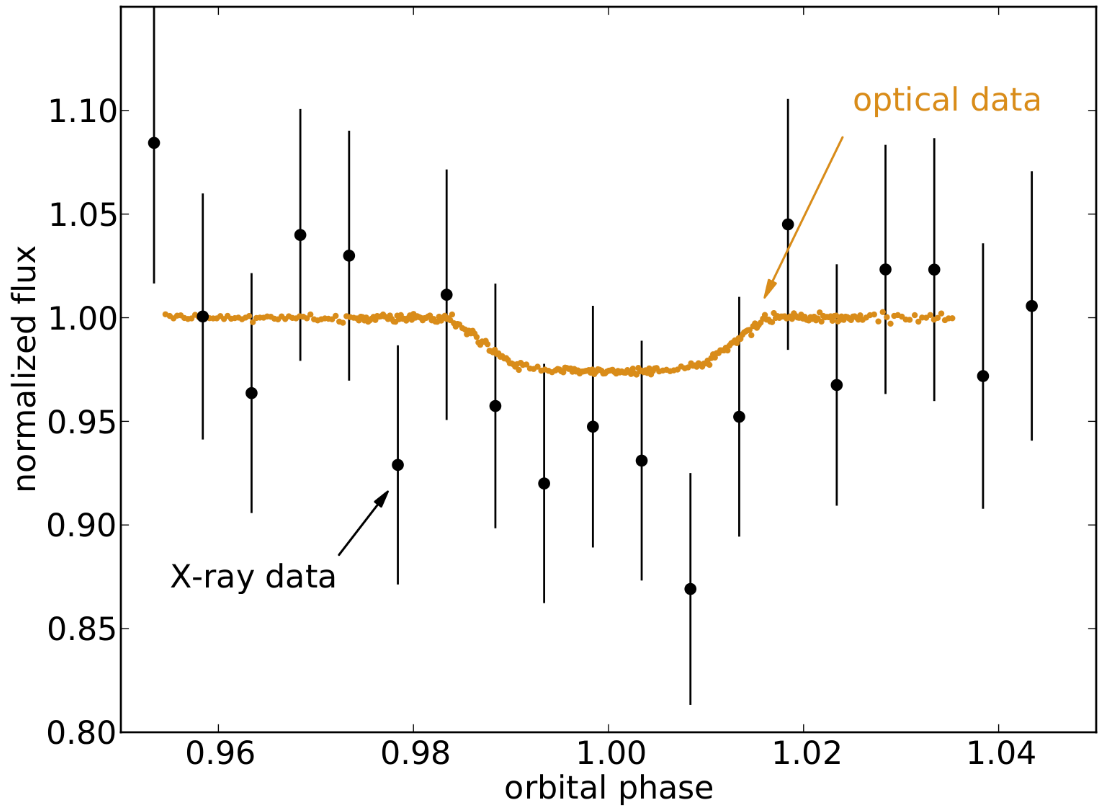




Poppenhaeger et al. (2013)

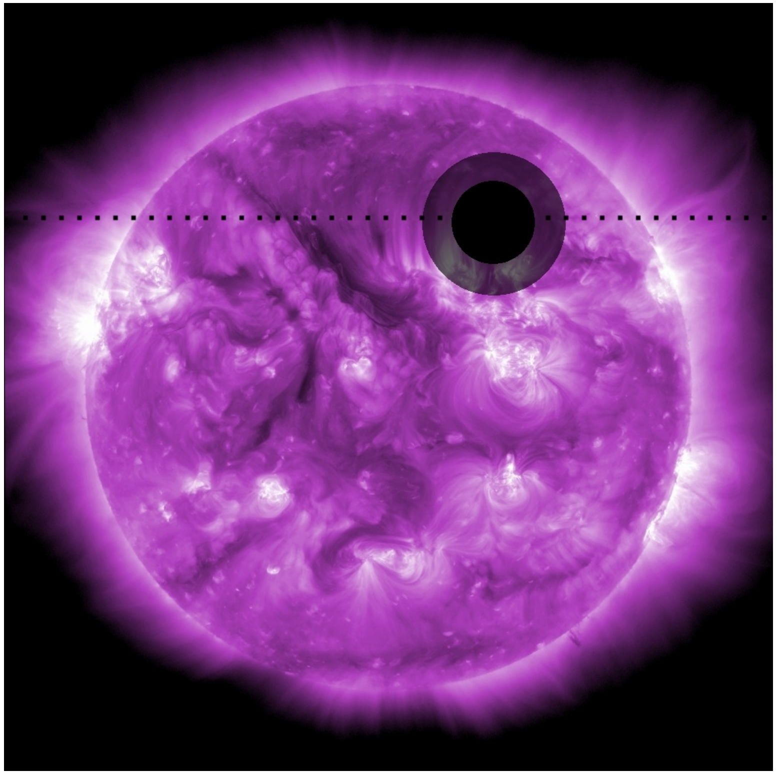
X-ray transits: extended atmospheres

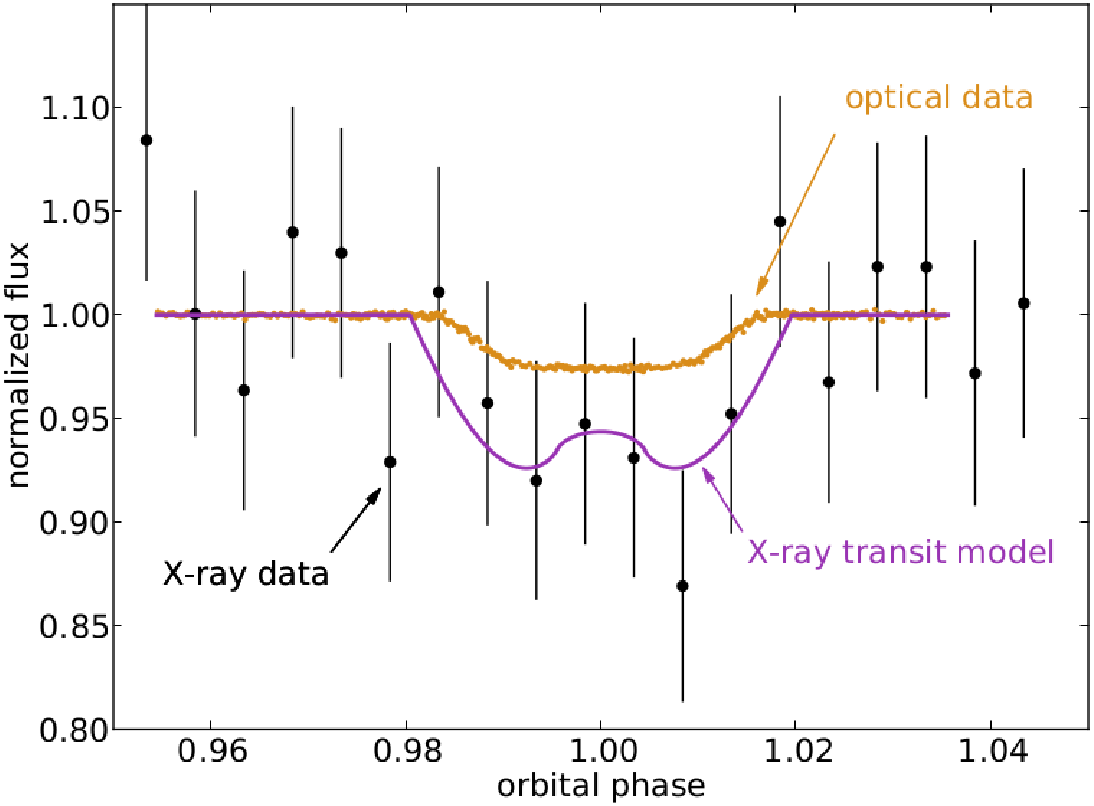




Poppenhaeger et al. (2013)

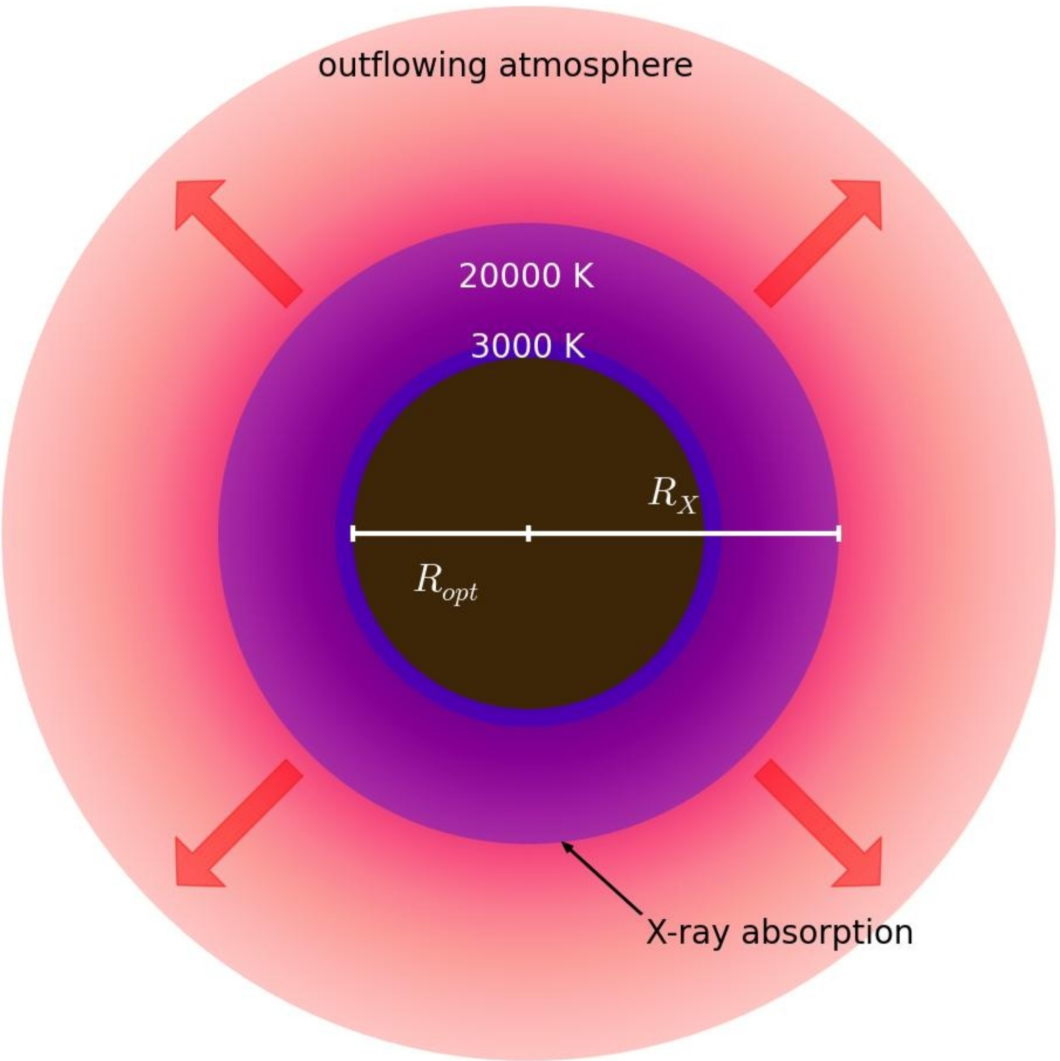
X-ray transits: extended atmospheres





Poppenhaeger et al. (2013)

Extended atmospheres

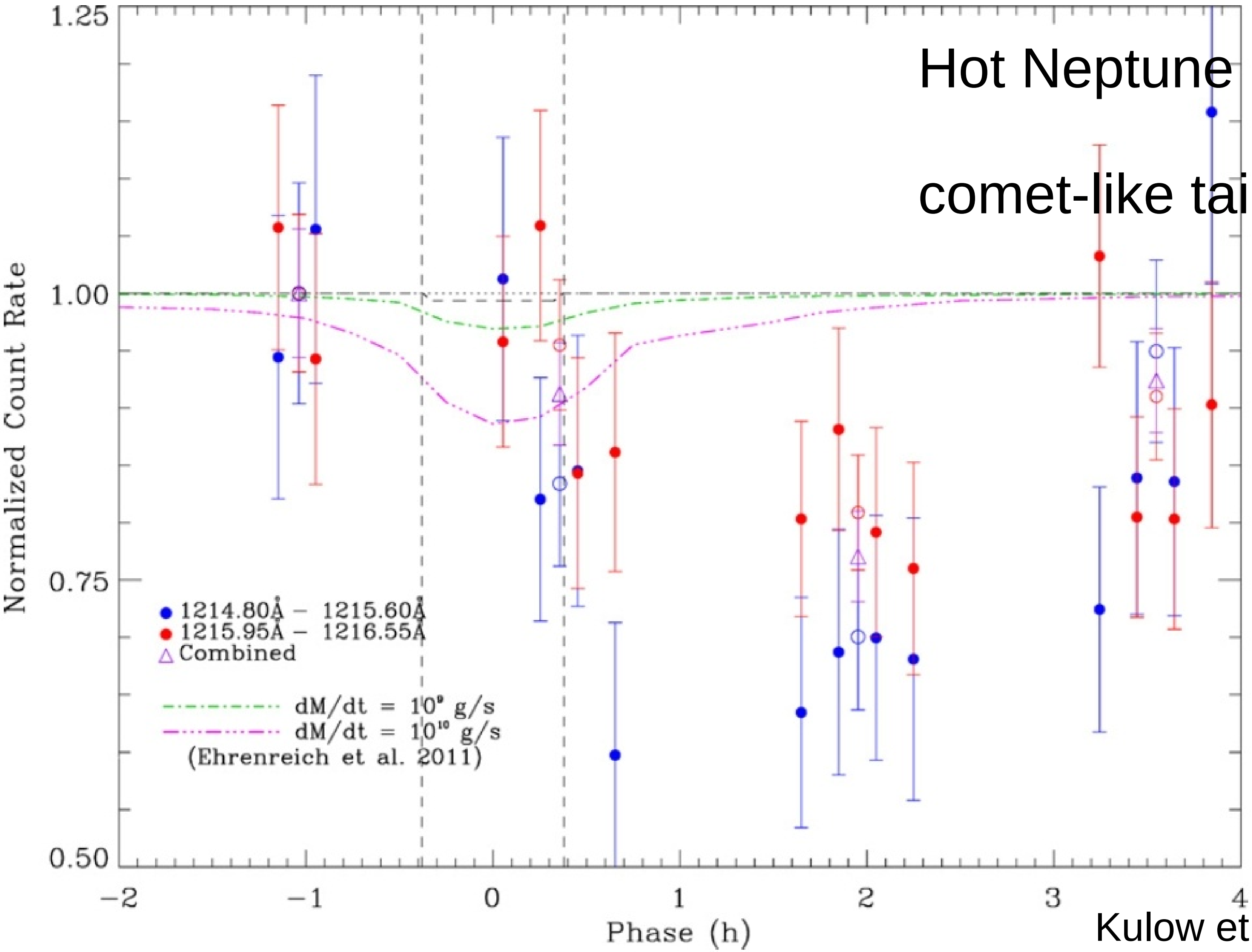


X-ray absorption at 1.7 R_{opt}

Density at X-ray absorbing altitude: ca. 10^{11} cm^{-3}

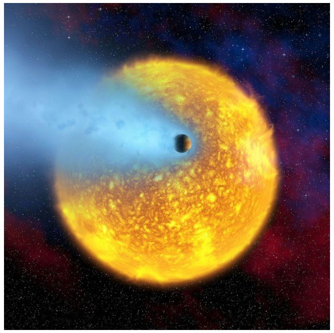
Temperature ca. 20000 K

Extended atmospheres in UV/X-ray



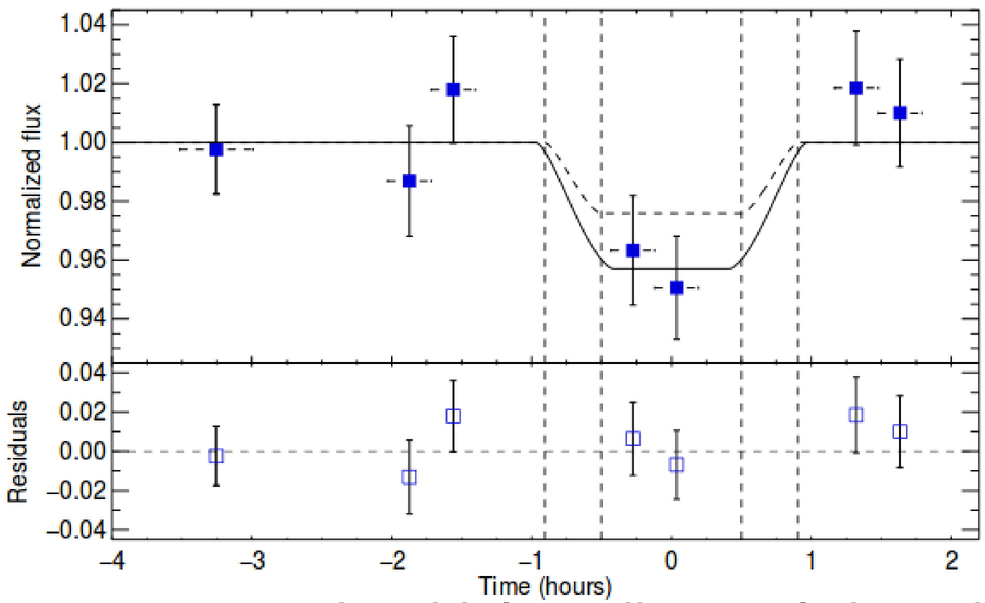
Hot Neptune GJ 436 b:

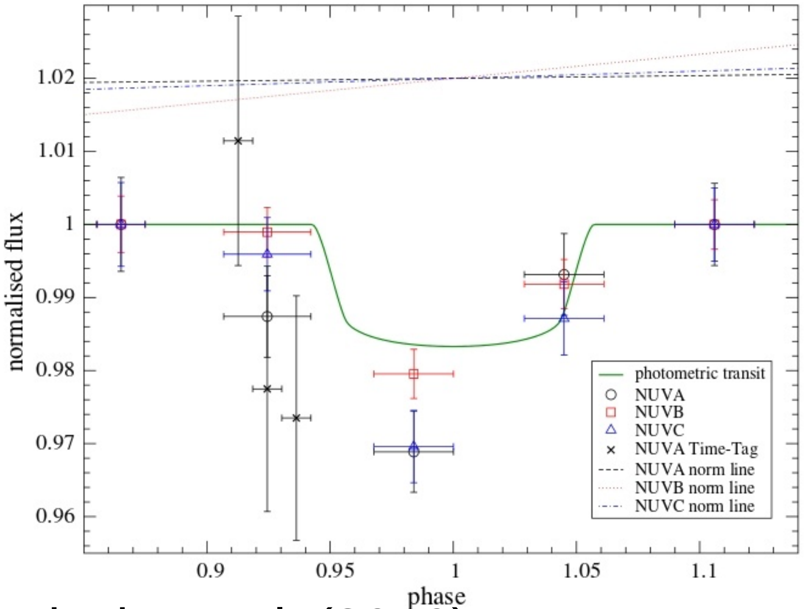
comet-like tail



Kulow et al. (2014)

Extended atmospheres in UV/X-ray





HD 209458 b: Vidal-Madjar et al. (2003), Linsky et al. (2010)

HD 189733 b: Lecavelier des Etangs et al. (2010), Bourrier et al. (2013), Ben-Jaffel & Ballester (2013)

55 Cnc b: Ehrenreich et al. (2012)

WASP-12 b: Haswell et al. (2012), Fossati et al. (2013)

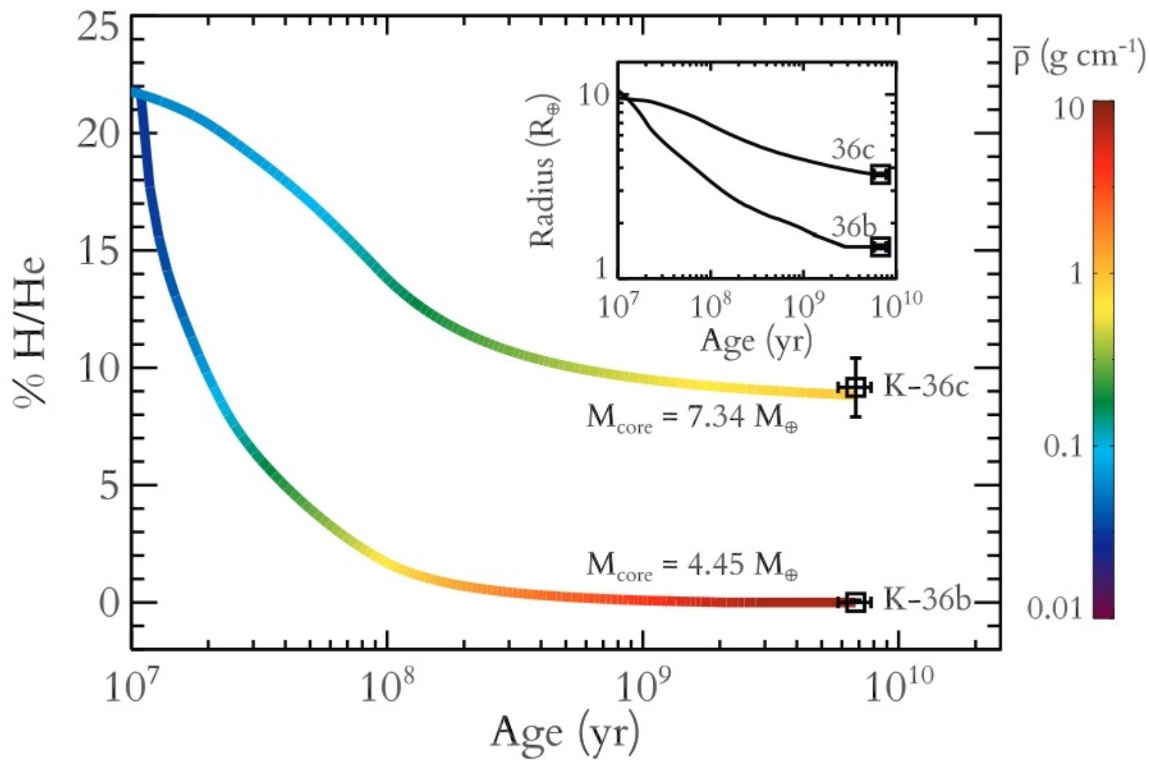
CoRoT-2 b: Czesla et al. (in prep.)

Atmospheric evaporation

driven by X-ray and extreme UV photons

e.g. Murray-Clay et al. (2009), Lecavelier des Etangs (2004)

total estimated mass loss: small for Jupiters (few %), substantial for small (Neptune-like) exoplanets

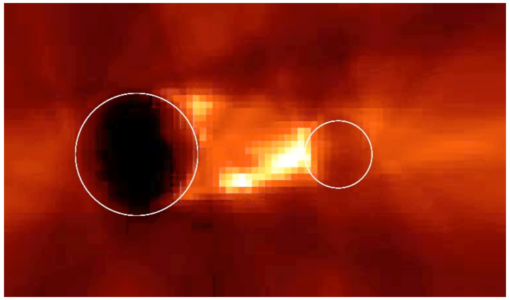


Lopez et al. (2013)

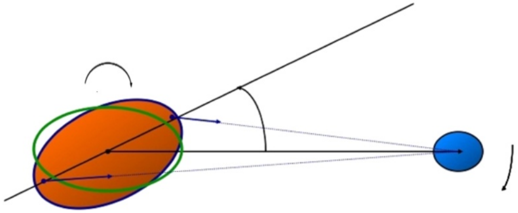
see also
Lecavelier des Etangs (2004)
Sanz-Forcada et al. (2011)

Interaction between stars and exoplanets

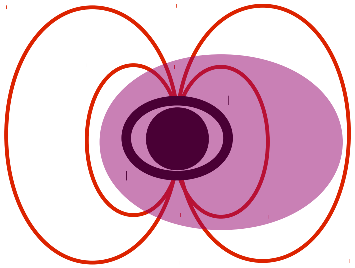
Interaction possible through tides or magnetic fields



Magnetic interaction
- difficult to observe due to intrinsic variability of stellar magnetic structure



Tidal interaction
- orbital obliquities; activity enhancements for very close systems

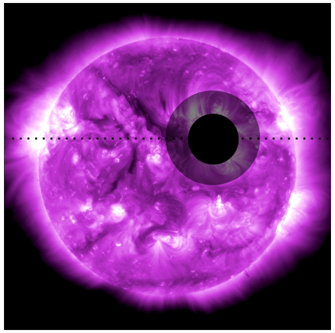


Effect on exoplanet atmospheres and habitability
- X-ray/UV driven evaporation, flares

Moving forward

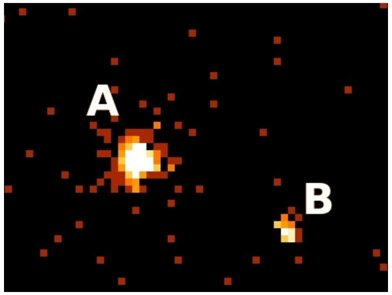
Exoplanet atmospheres

- high-energy transit observations of exoplanets (ASTRO-H, eROSITA)



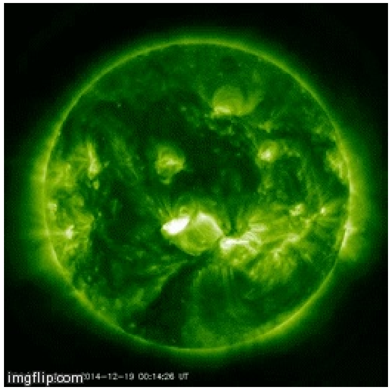
Tidal interaction

- constrain theoretical tidal quality factors of stars from exoplanet lifetimes from systems with known interaction



Fundamental properties of exoplanet host stars

- independent ages (seismology, white dwarf companions) and activity in the presence of planets



Interactions of exoplanets and their host stars

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Hans-Moritz Günther

Ofer Cohen

Ignazio Pillitteri