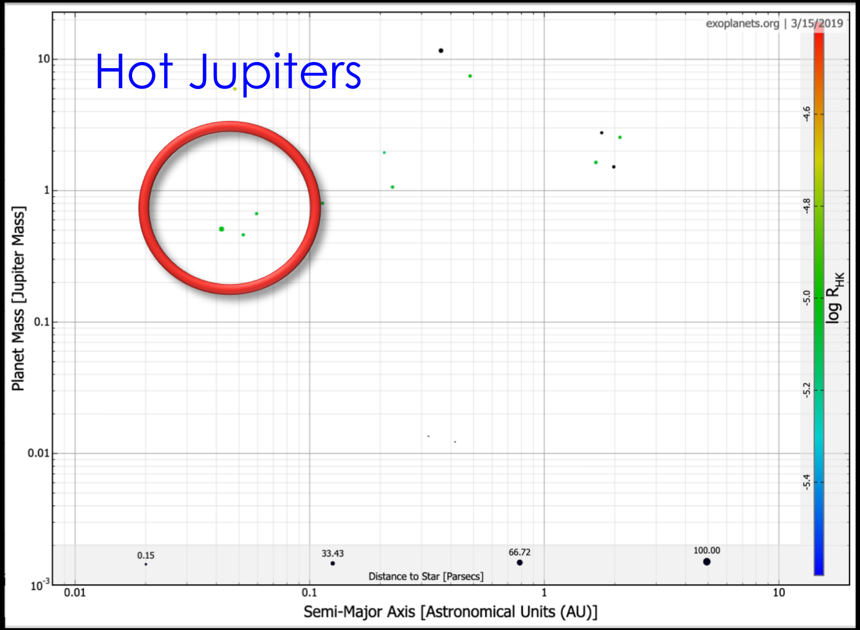
HIGH ENERGY AFFECTS OF EXOPLANET HOST STARS

Scott Wolk (SAO/CfA)

27 YEARS OF CHANDRA TIMELINE

The Exoplanet zoo

- 1992 Planets around pulsars
- 1995 51 Peg announced
- 1996 mirror assembly complete
- 1999 Chandra Launched
- 2006 CoRoT Launched
- 2009 Kepler Launched
- 2018 TESS Launched



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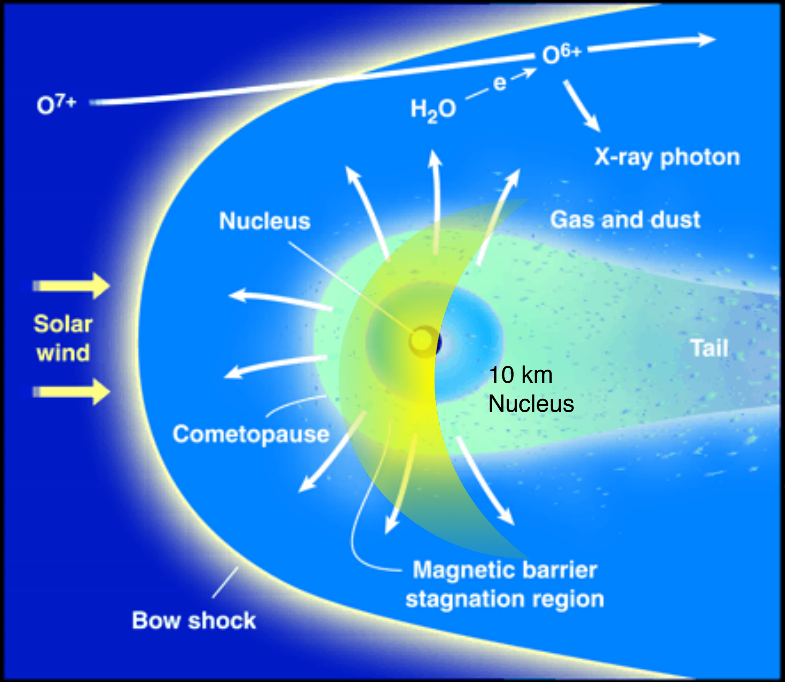
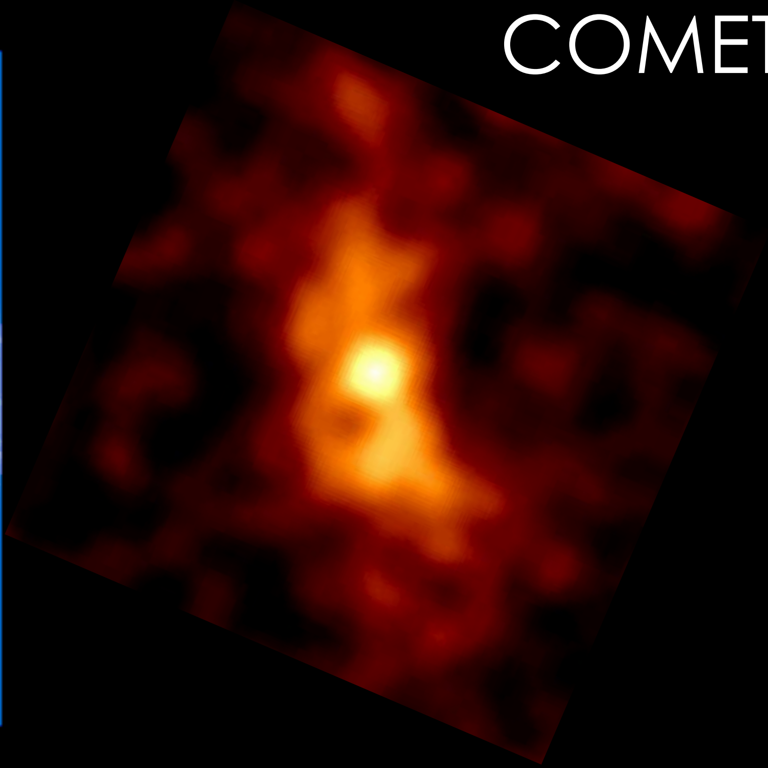
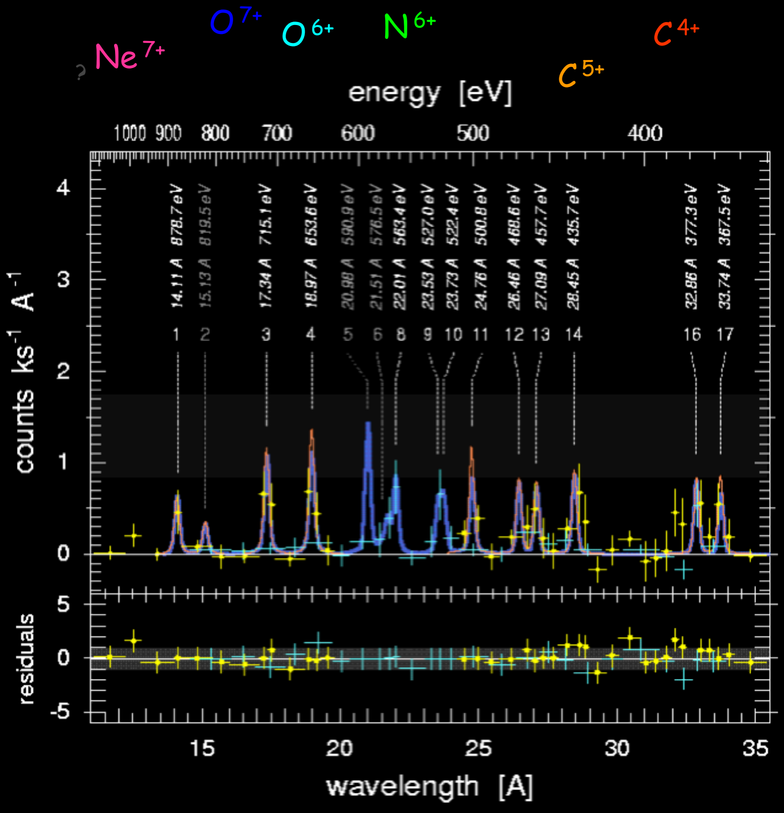
X-RAYS IN OUR OWN SOLAR SYSTEM: COMETS





(Lisse, Wolk+ 2001)

MARS IS CURRENTLY LOSING ATMOSPHERE



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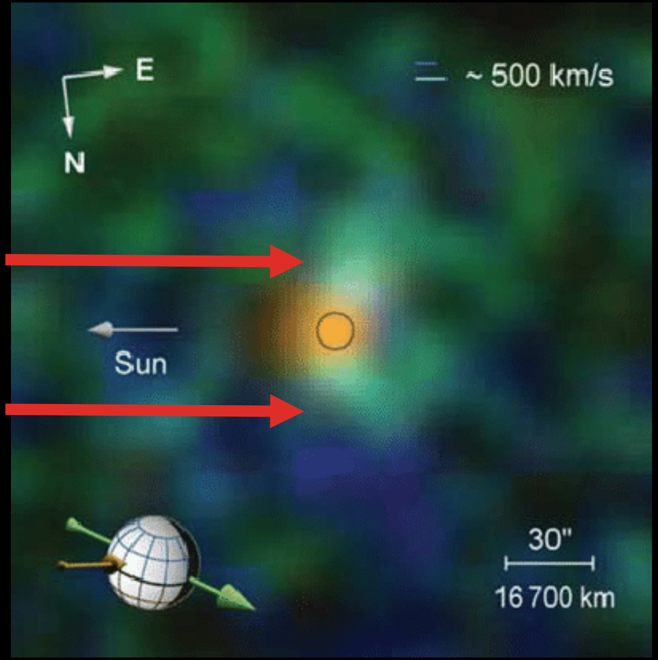
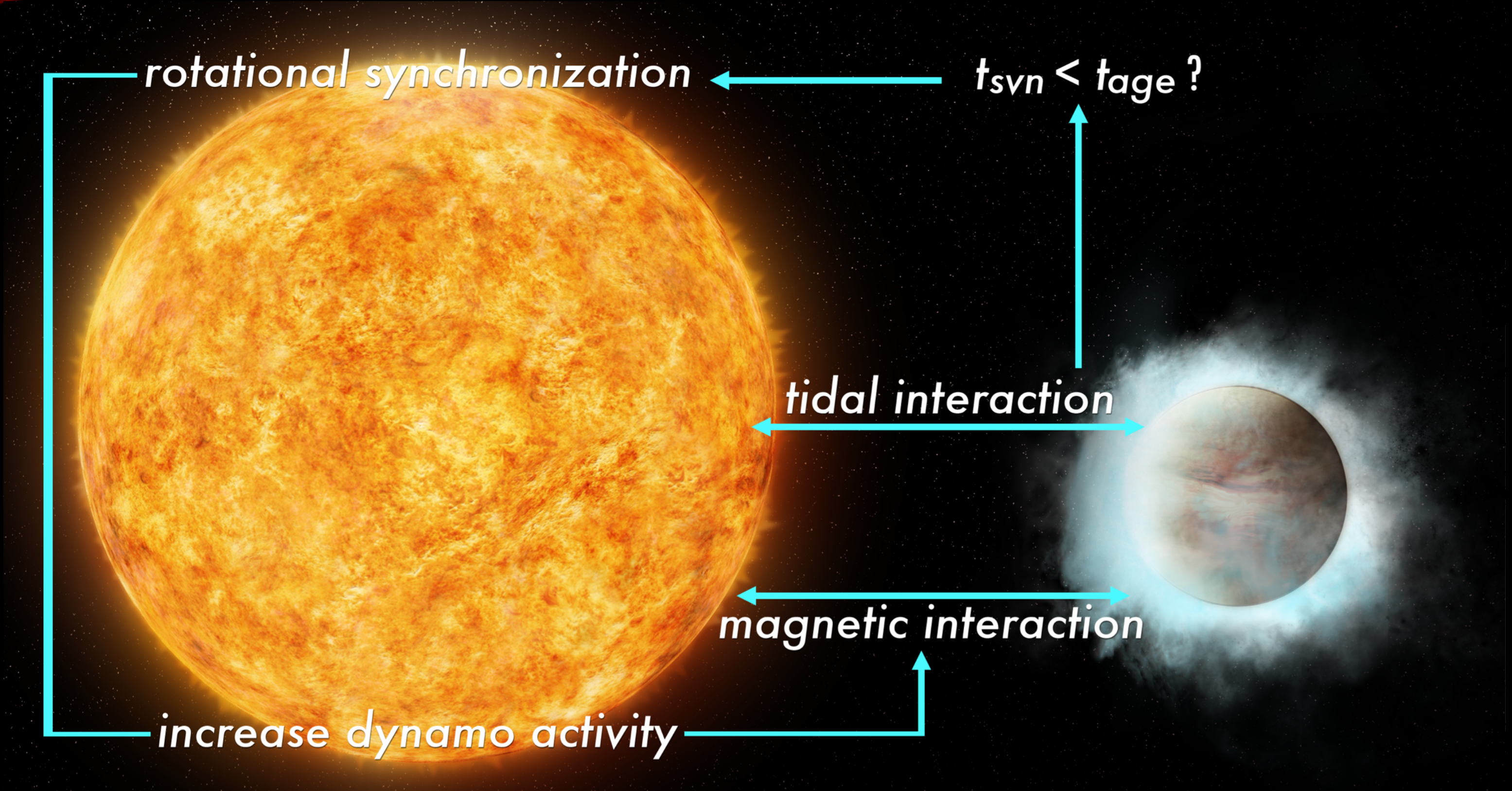


(Dennerl 2006)

Star Planet Interaction



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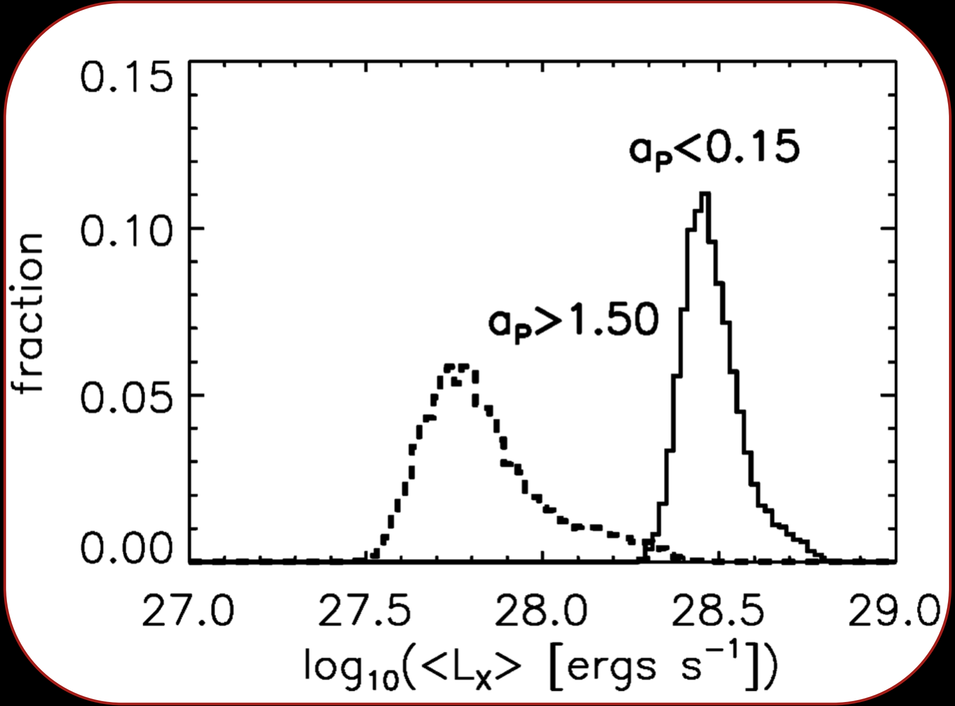
Cuntz et al. 2000

Evidence for Star-Planet Interaction?

- Direct observation of phased emission from Ca II HK lines (Shkolnik et al. 2003, 2008)
- Stars with hot Jupiters are brighter in X-rays (Kashyap et al. 2009)
- But both results were disputed. (Poppenhager et al. 2010, 2011)



Kayshap et al. 2009

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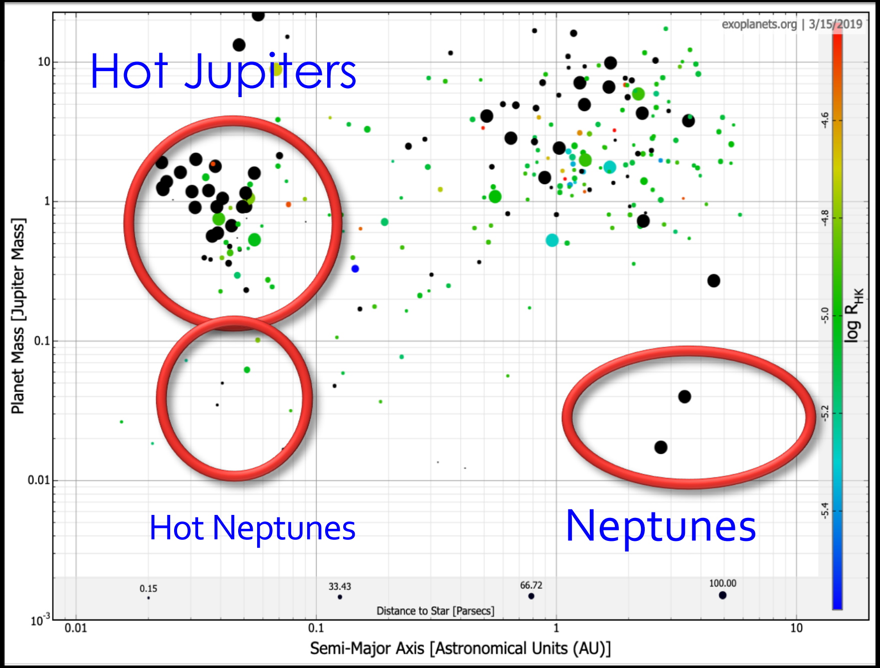

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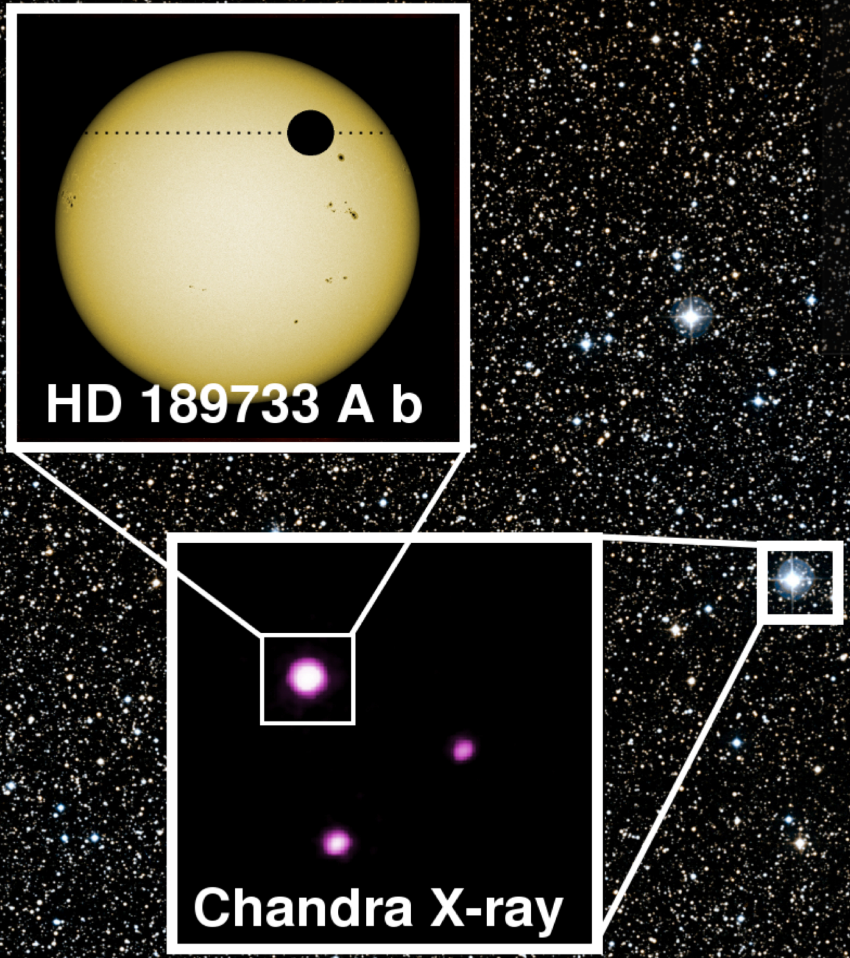
51 PEG (POPPENHAEGER+ 2009)

- **Weak** emission in the O VII triplet and emission around 200 eV which can be explained most likely by **cool** silicon emission lines.
- A coronal temperature of **1 MK** is consistent with the detected hardness ratios in different energy bands in both the XMM and the Chandra pointing as well as in the ROSAT observation carried out 16 years earlier.
- The constant and very low surface X-ray flux level together with a flat-activity behavior in chromospheric Ca II H and K line fluxes suggests **51 Peg to be a Hot Jupiter-bearing Maunder minimum candidate.**

THE GOLD STANDARD: HD 189733

- An active K1V at 19 pc ($L_x \sim 10 L_{x\odot}$)
- Age estimated at 0.6 Gyr



	HD 189733A	HD 189733b	HD 189733B
Type	K 1.5 V	planet	M4V
Mass	0.81 $M_\odot$	1.15 M_{jup}	0.2$M_\odot$
Radius	0.76 $R_\odot$	1.26 R_{jup}	....
Orbital Period	....	2.219d	3200 yr
Mean orbital radius	....	0.03 AU	216 AU

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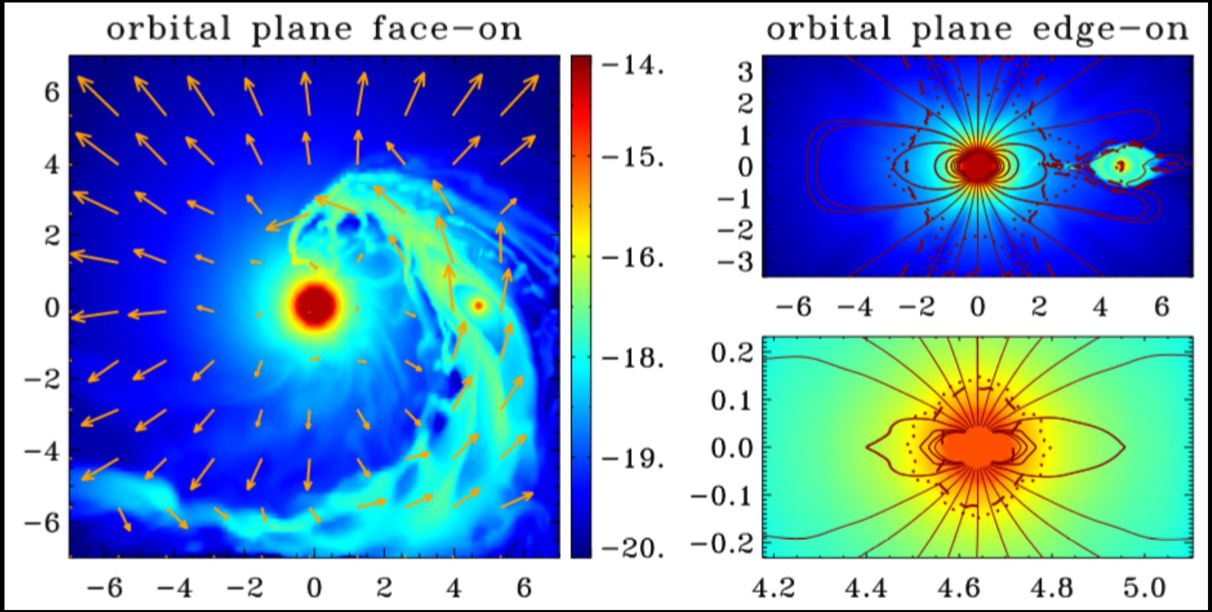
Plausibility Argument: Accreting Streams and Tails

⊕

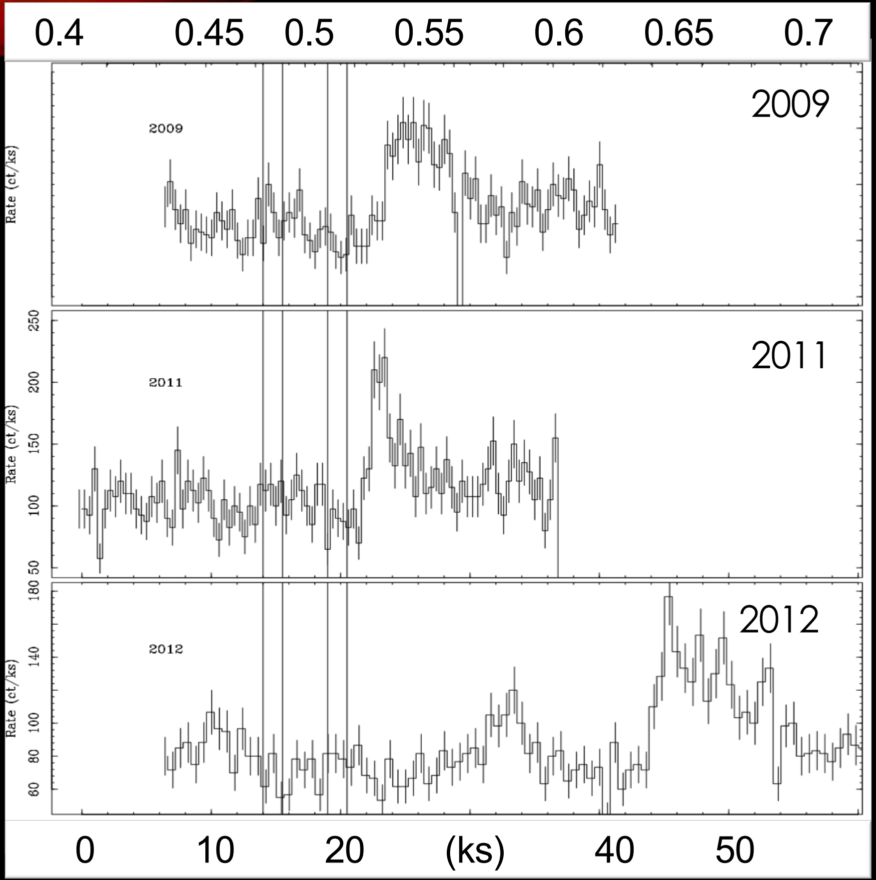
- High UV, ~ M_{jup}

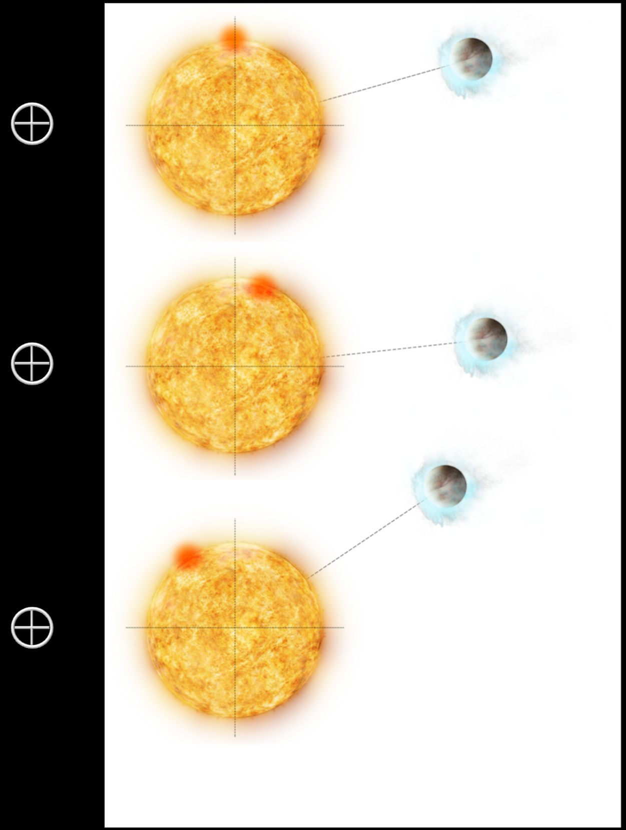


Matsakos et al. (2015)

Phased Time Variability?

Pillitteri et al. (2014)





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X-ray Flare of HD 189733

2D wavelet analysis of 2012 light curve

Description: A damped magneto acoustic oscillation in the flaring loop.

$\Delta I/I \sim 4\pi n k_B T/B^2$

T~ 12 MK

n: density=5×10^{10} cm^{-3}

(from RGS data)

B ⟶ 40-100 G

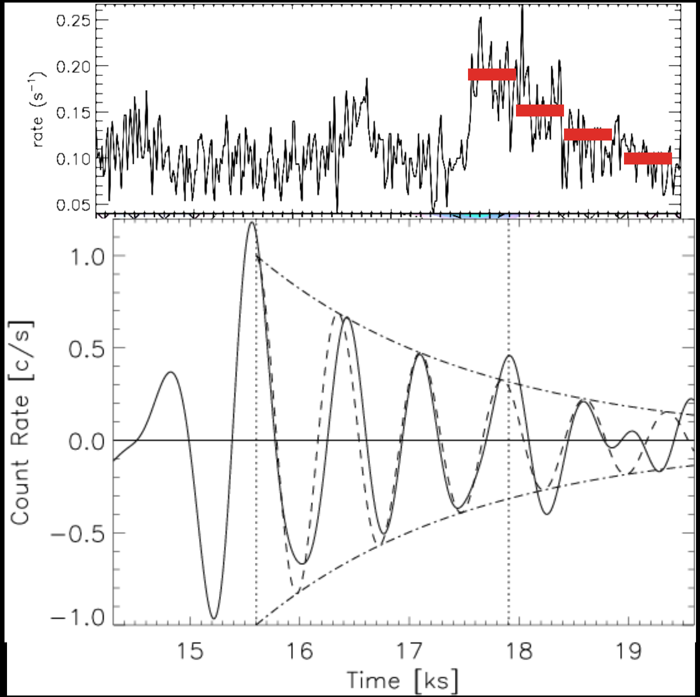
$\tau \sim L/c_s$

$c_s = \sim T^{0.5}$

τ= oscillation period ~ 4 ks

L=Const. X $\tau_{osc} N T^{0.5}$

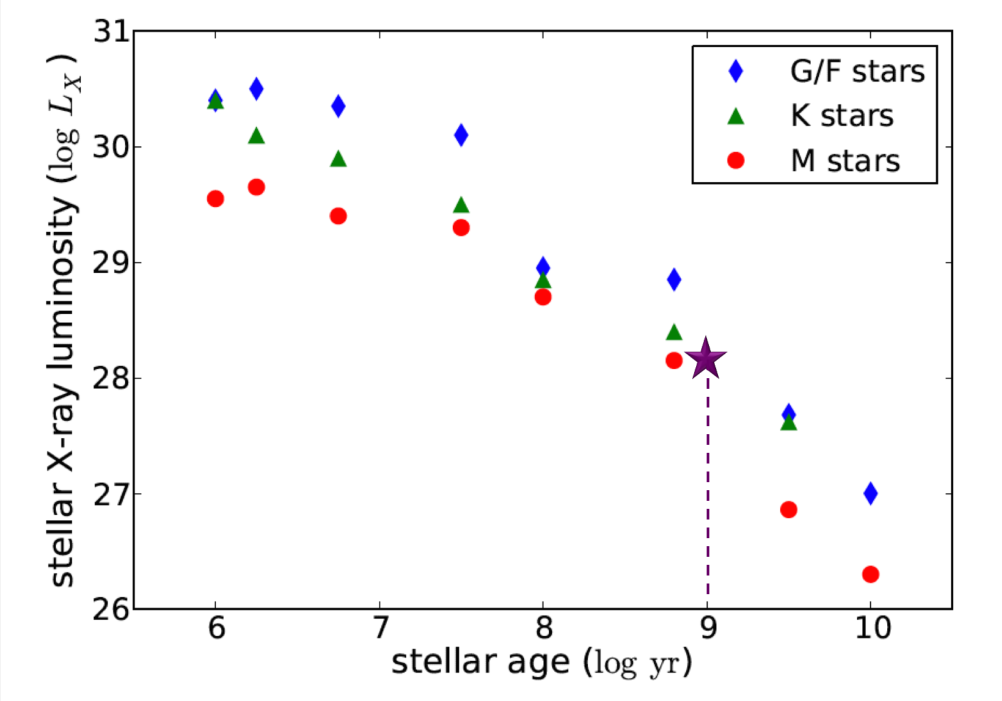
L~5 R_*



Pillitteri et al. (2014)

Implication of the wavelet analysis

THE AGE OF HD 189733A



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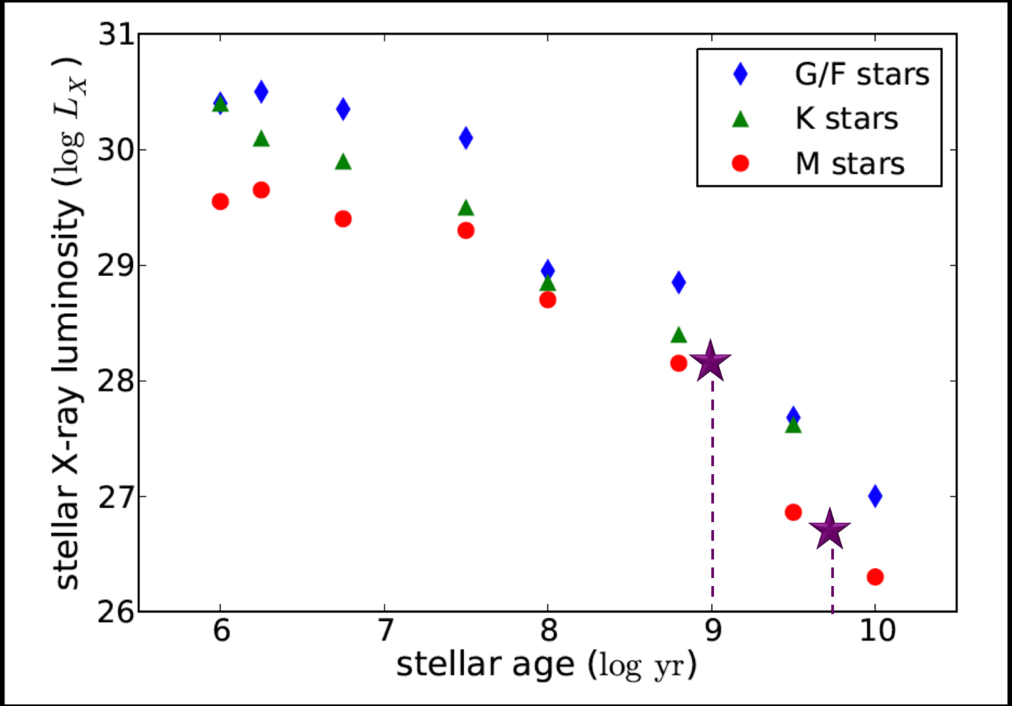
Poppenhaeger & Wolk (2014)

THE AGE OF HD 189733A&B



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Poppenhaeger & Wolk (2014)

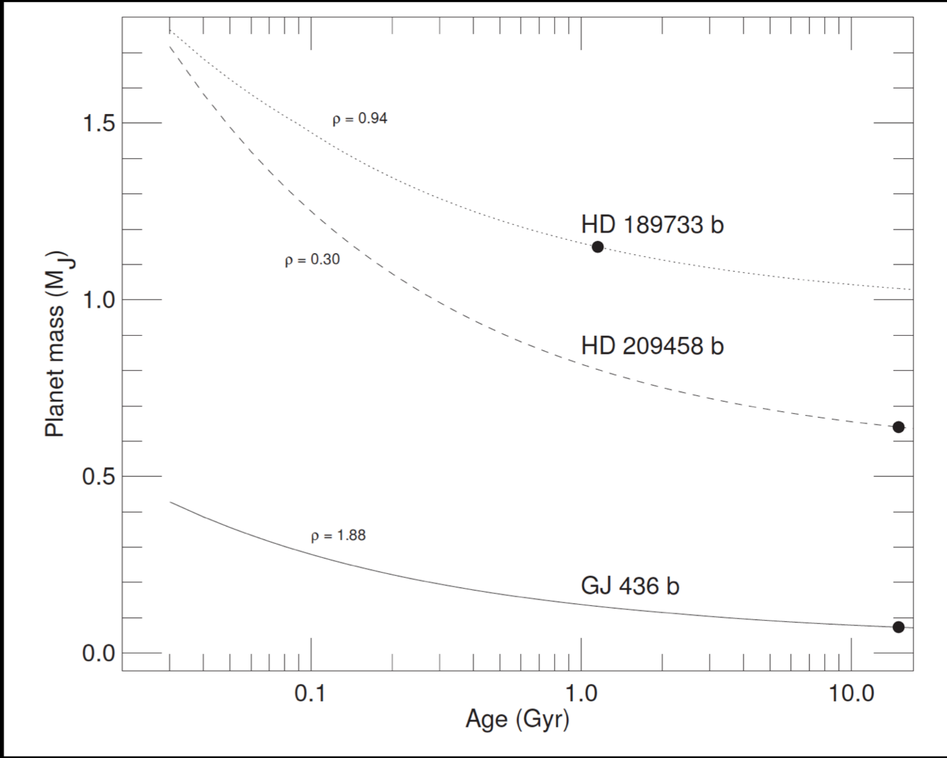
WHAT DOES THIS MEAN FOR THE PLANETS?

$$\dot{M} = \frac{4\pi\beta^3 R_p F_{XUV}}{GKM_p}$$

β Atmospheric inflation
K: Roche lobe overflow

$$\dot{M} = \frac{3F_{XUV}}{G\rho}$$

Sanz-Forcada et al. (2011)



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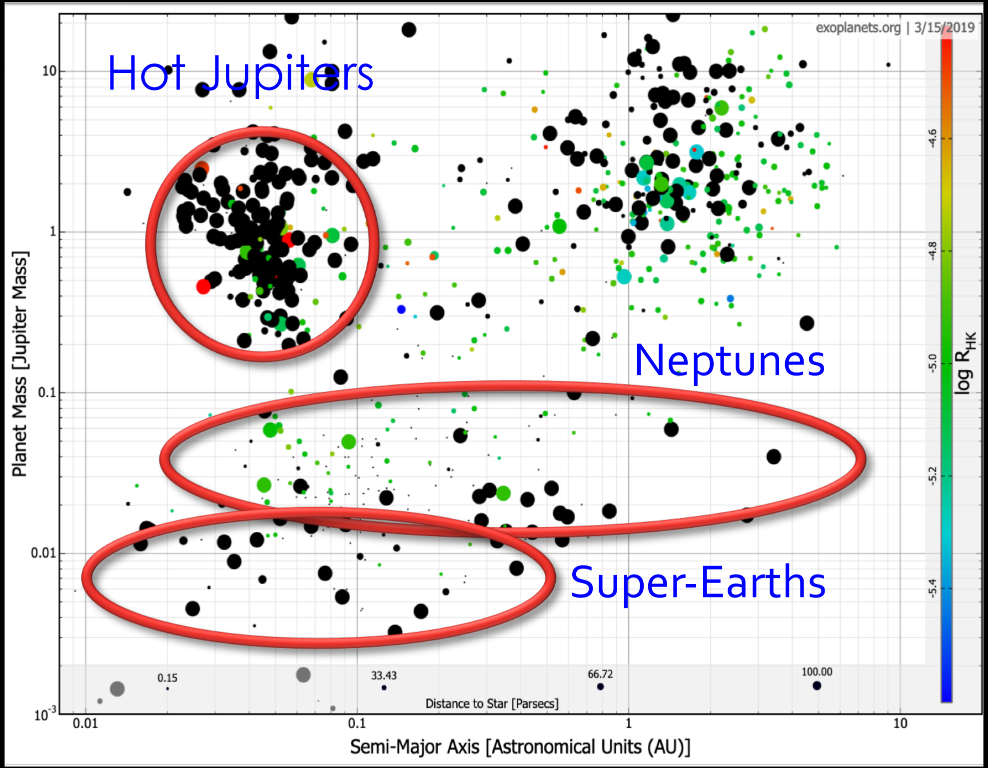

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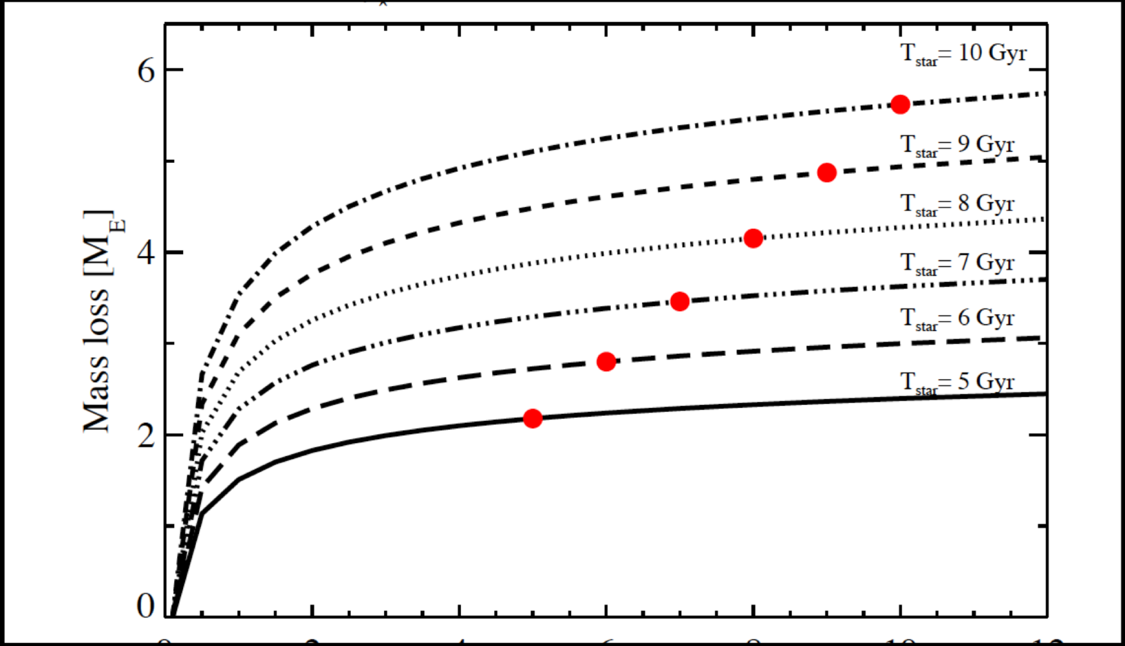
GJ 1214b: SUPER-EARTH

- M4
- 1.6 day period.
- Planet is about 6 Earth masses…

- …but has lost several Earth masses of atmosphere



(Lalitha et al. 2014)

WASP-18 another kind of interaction

Single star:

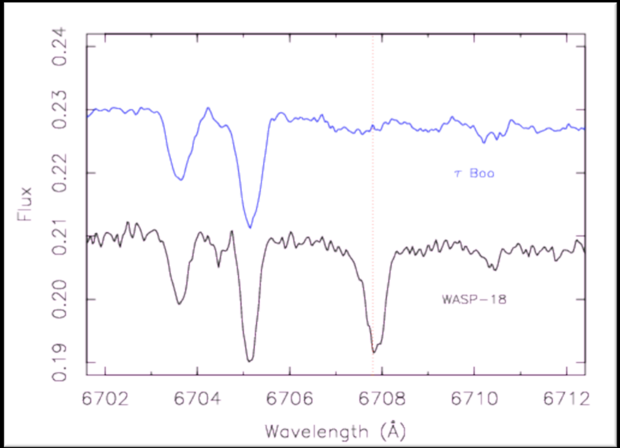
Young F6

WASP-18b 10.4 M_{Jup},

a~0.02 AU; = 3.5 $R_{\star}$

P_{rot} =22.6h

WASP 18 is YOUNG



L_x WASP-18 < $10^{26.5}$ erg/s

L_x Tau Boo ~ 10^{28} erg/s

L_x Procyon ~ 10^{28} erg/s

Pillitteri, Wolk et al. (2014)

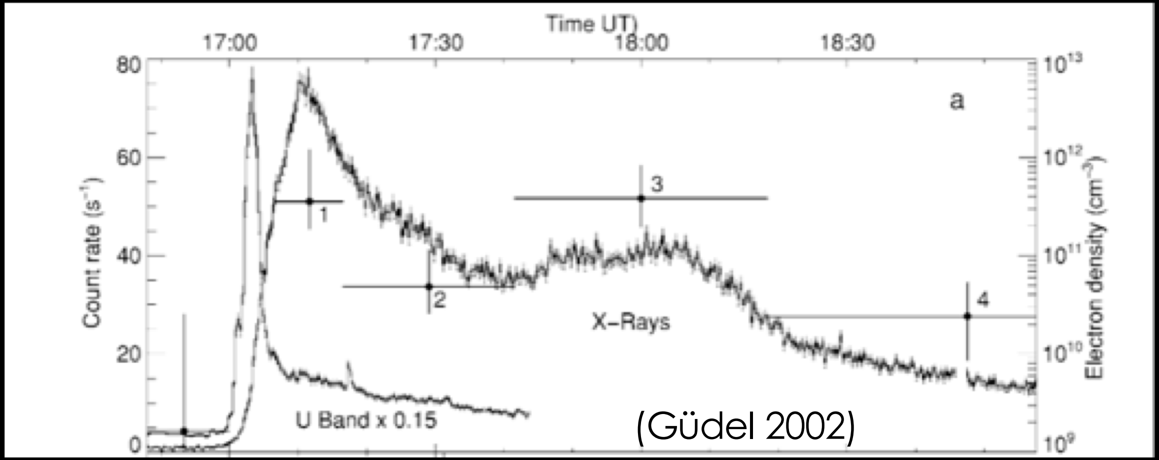
WASP-18 another kind of interaction

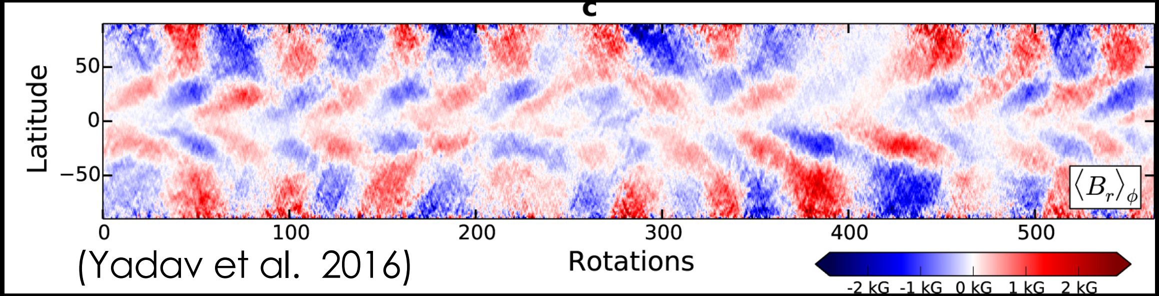
Star	T_{eff} K	R_{star} $R_\odot$	M_{star} $M_\odot$	M_{planet} M_{Jup}	Separation AU	$\log R'_{HK}$	H_P km	H_t km	H_t/H_P
WASP-18	6400	1.29	1.28	10.43	0.02047	-5.43	419	498.3	1.189
WASP-12	6300	1.599	1.35	1.404	0.02293	-5.5	600.1	122.3	0.204
WASP-14	6475	1.306	1.211	7.341	0.036	-4.923	458.7	44	0.096
XO-3	6429	1.377	1.213	11.79	0.0454	-4.595	505.5	39.4	0.078
HAT-P-7	6350	1.84	1.47	1.8	0.0379	-5.018	735.5	37.2	0.051
HAT-P-2	6290	1.64	1.36	8.74	0.0674	-4.78	625.6	14.6	0.023
Kepler-5	6297	1.793	1.374	2.114	0.05064	-5.037	740.9	14.1	0.019
HAT-P-14	6600	1.468	1.386	2.2	0.0594	-4.855	516	3.4	0.007
HAT-P-6	6570	1.46	1.29	1.057	0.05235	-4.799	545.9	2.6	0.005
Kepler-8	6213	1.486	1.213	0.603	0.0483	-5.05	568.8	2.3	0.004
WASP-17	6650	1.38	1.2	0.486	0.0515	-5.331	530.7	1.1	0.002
HAT-P-9	6350	1.32	1.28	0.67	0.053	-5.092	434.7	1	0.002
WASP-19	5500	1.004	0.904	1.114	0.01616	-4.66	308.5	55.2	0.179

Pillitteri, Wolk et al. (2014)

PROXIMA CEN

- M5.5
- ~5Gyr
- But a young star!
- 1.3 Earth mass
- In HZ
- 11 day period
- 11 $R_\star$

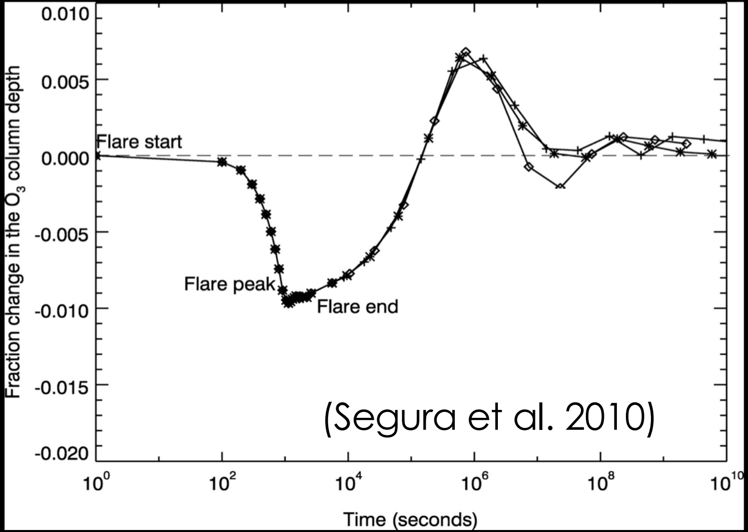




Exoplanet Impacts

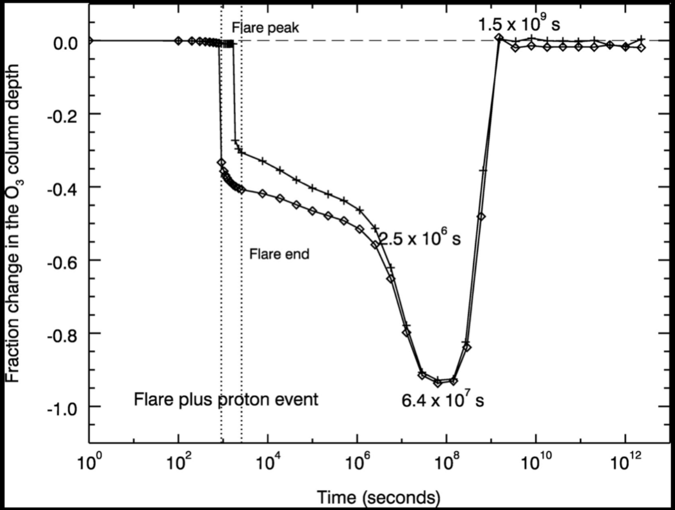
How do the characteristics of flares change with time and what impact does this have on exoplanet conditions?
Given an M star with an Earth mass planet in the habitable zone…

Flare Alone



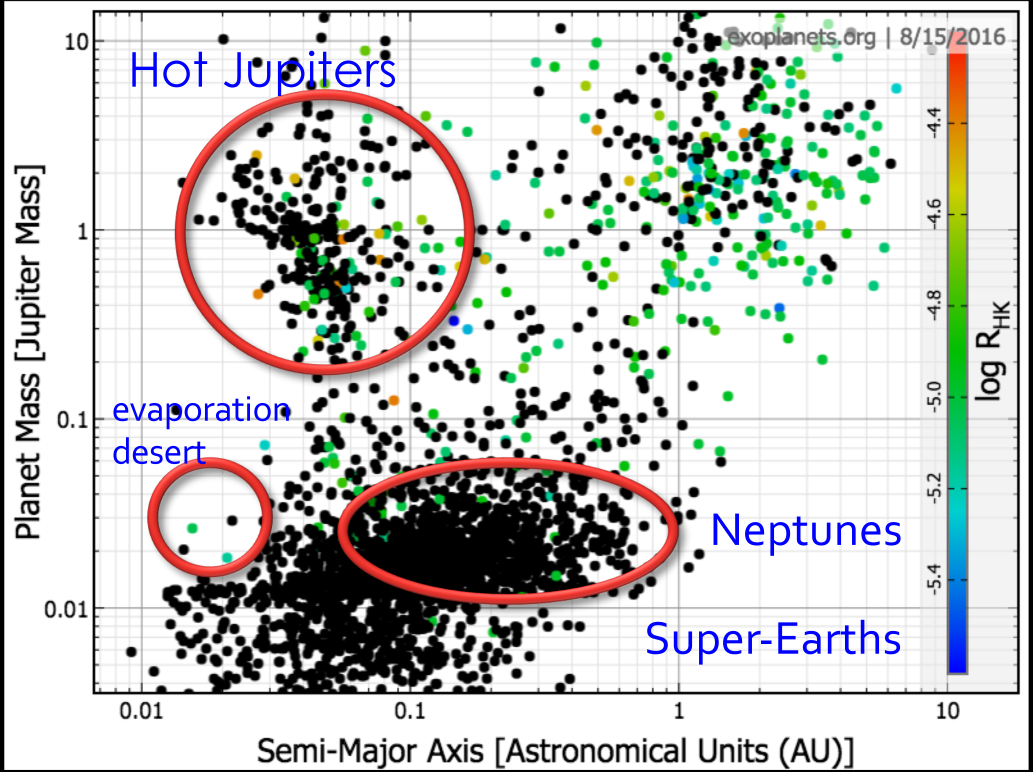
A strong flare depletes 1% of the ozone. This recovers in ~11 days.

Flare + Coronal Mass Ejection



A strong flare combined with a CME depletes nearly all of the ozone…for 50 years!

THE EXOPLANET ZOO

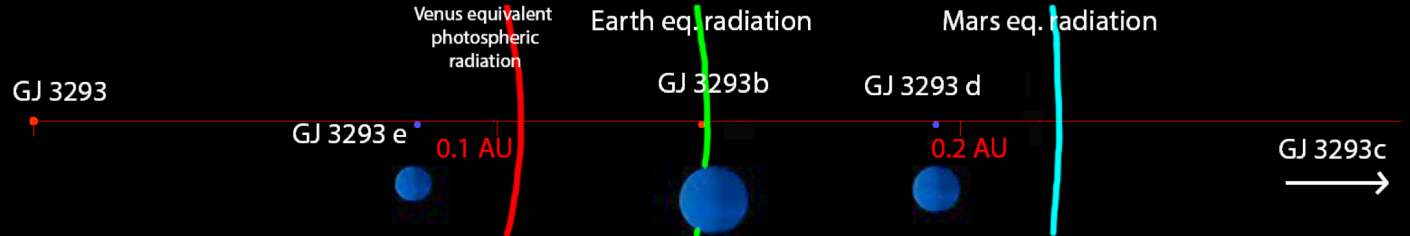


X-RAYS AND (EXO)PLANETS: STATUS 2019

1. High energy flux is important to the evolution of a planet's atmosphere and is very individual experience for each planet.
    1. XUV flux can remove significant amounts of atmosphere.
    2. XUV flux can add additional energy.
2. Planets affect their host stars…through tidal effects, Hot Jupiter's can spin-up stars with large convective zones.
3. Planetary feedback leads to enhanced activity
    1. This activity can include system scale stellar flares.
    2. Through magnetic effects planets appear to induce active regions on the stellar surface.
    3. This can make the inferred age deviate from the actual age.
4. We have seen a planetary transit in X-rays and the planet is much "bigger" in X-rays than in any other wavelength.

Future Exoplanet Stellar Studies

- Searching for habitability
- Focused on low mass M dwarfs
  - Habitable zones are closer to star
  - Maybe not such a good idea
- Issues include destruction of atmosphere by:
  - Stellar flares and concurrent CME’s
    - Planets can recover from massive flare/proton flux …but it takes time (Segura+ 2010)
  - Stellar UV to X-ray radiation
    - But UV is promising for catalyzing prebiotic chemistry (Ranjan & Sasselov 2016)
    - EUV will not be directly observable for most planets and so must infer from X-ray

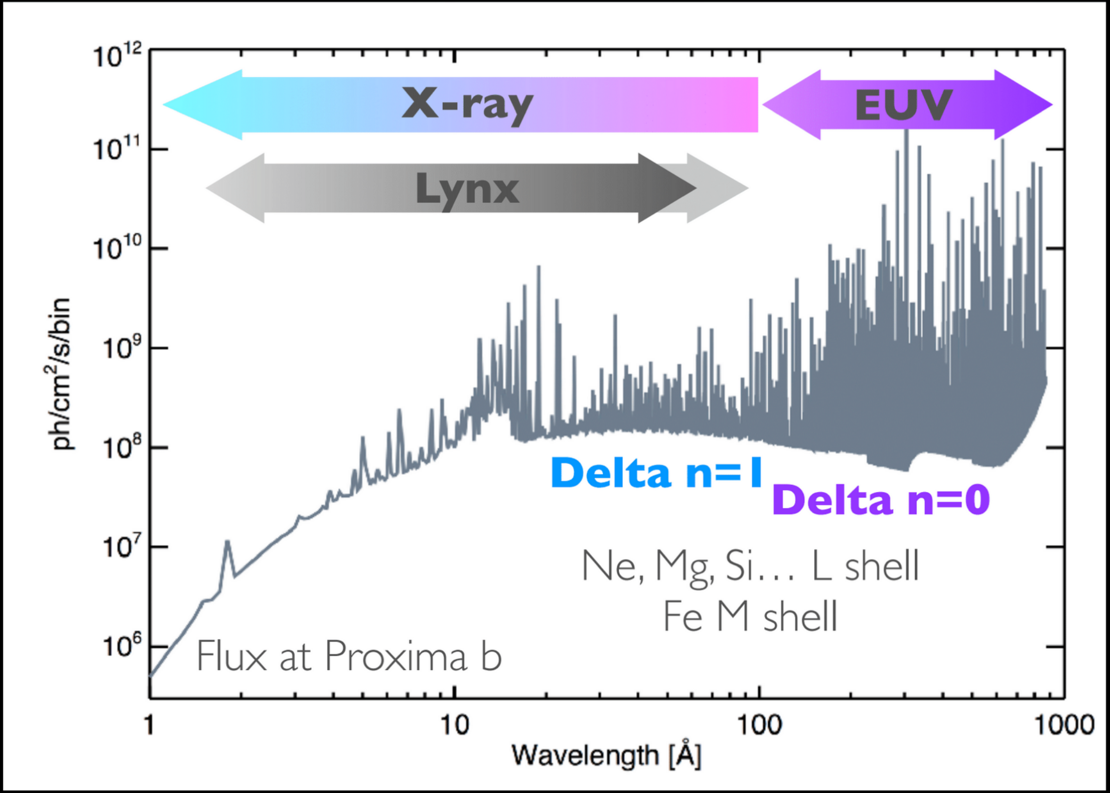


X-RAY OBSERVATORY LYNX

ATHENA

The coronal emission of stars affect exoplanets.

- Planetary atmospheric evolution is fundamentally linked to XEUV emission
- X-rays trace magnetic structure directly



SOME MORE EXOPLANET SYSTEMS LEFT TO EXPLORE