Hot Jupiters and their Exoplanet hosts – an X-ray Perspective

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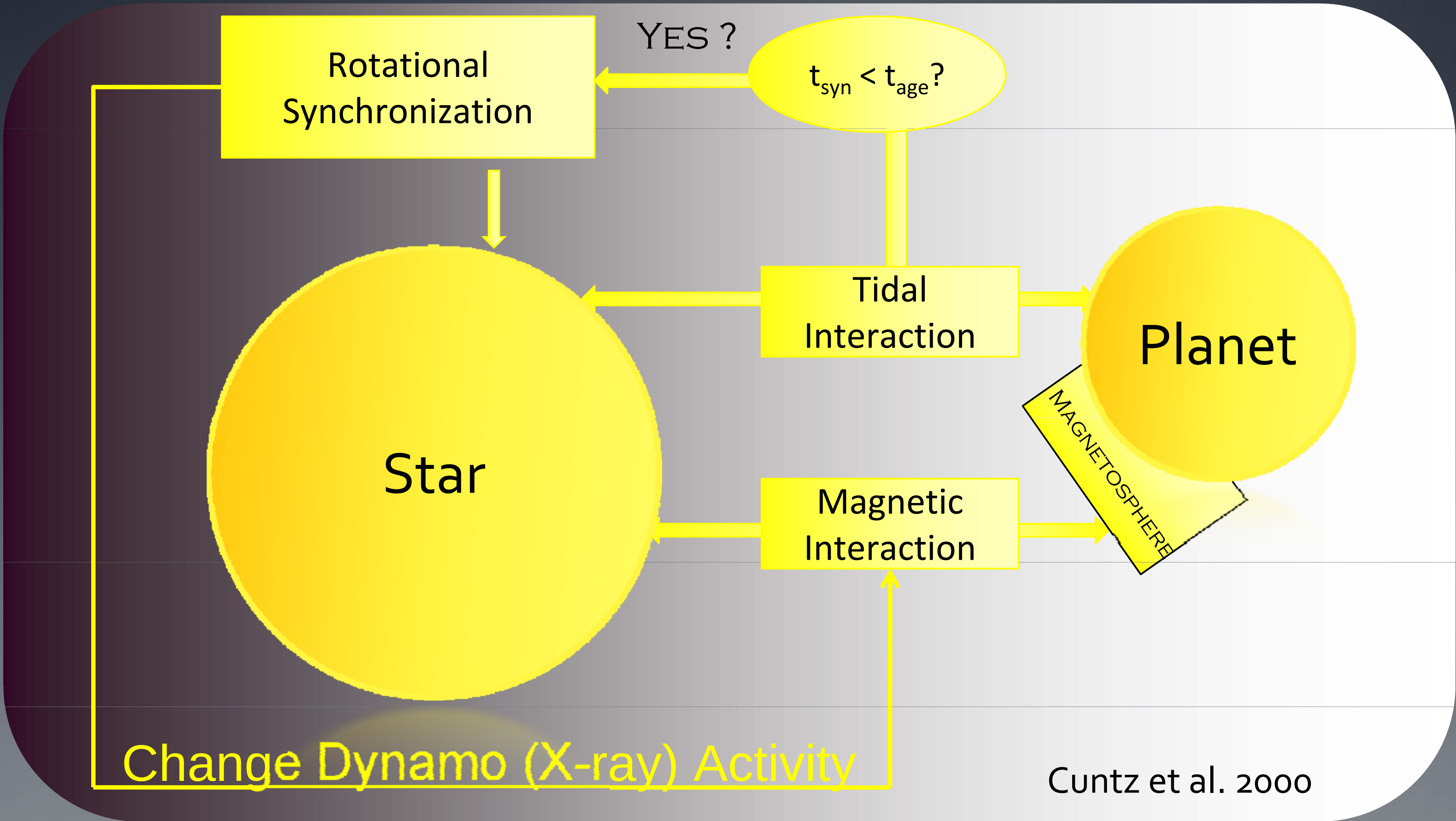
What is Star Planet Interaction?



Why do you care about X-rays?

- X-rays from stars affect exoplanets…
  - Some hot Jupiters appear inflated beyond what the bolometric luminosity would predict.
  - X-Ray/UV flux ➔ atmospheric expansion (Lammier et al. 2003).
  - X-Ray flux ➔ photochemistry changing the thermal budget (Laing et al. 2004; Burrows et al. 2008).
  - Coronal radiation produces rapid photoevaporation of the atmospheres of planets close to young late-type stars (Sanz-Forcada et al. 2011).

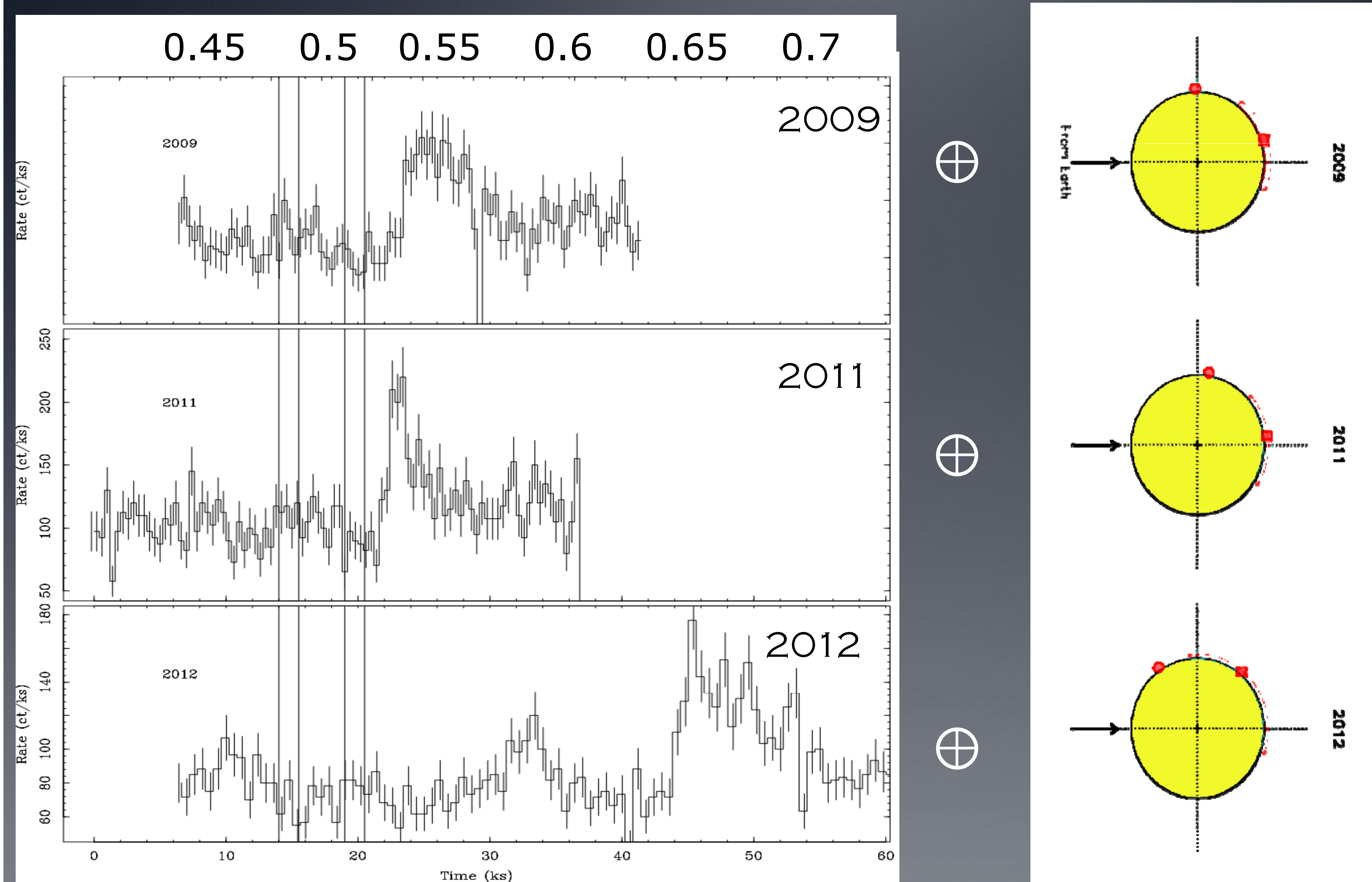
- …Exoplanets may affect their host stars.
  - Analytic Studies show ➔ $F_{recon} \alpha\ a_p^{-3}$ (Saar et al. 2004)
  - Analytic models indicate field lines can connect the star to the planet, ruptures of the lines could give rise to flare-like activity (Lanza 2008).
  - MHD simulations show strong feedback visible in X-rays (Cohen et al. 2011).
  - Tidal forces can work in two directions

Takeaways

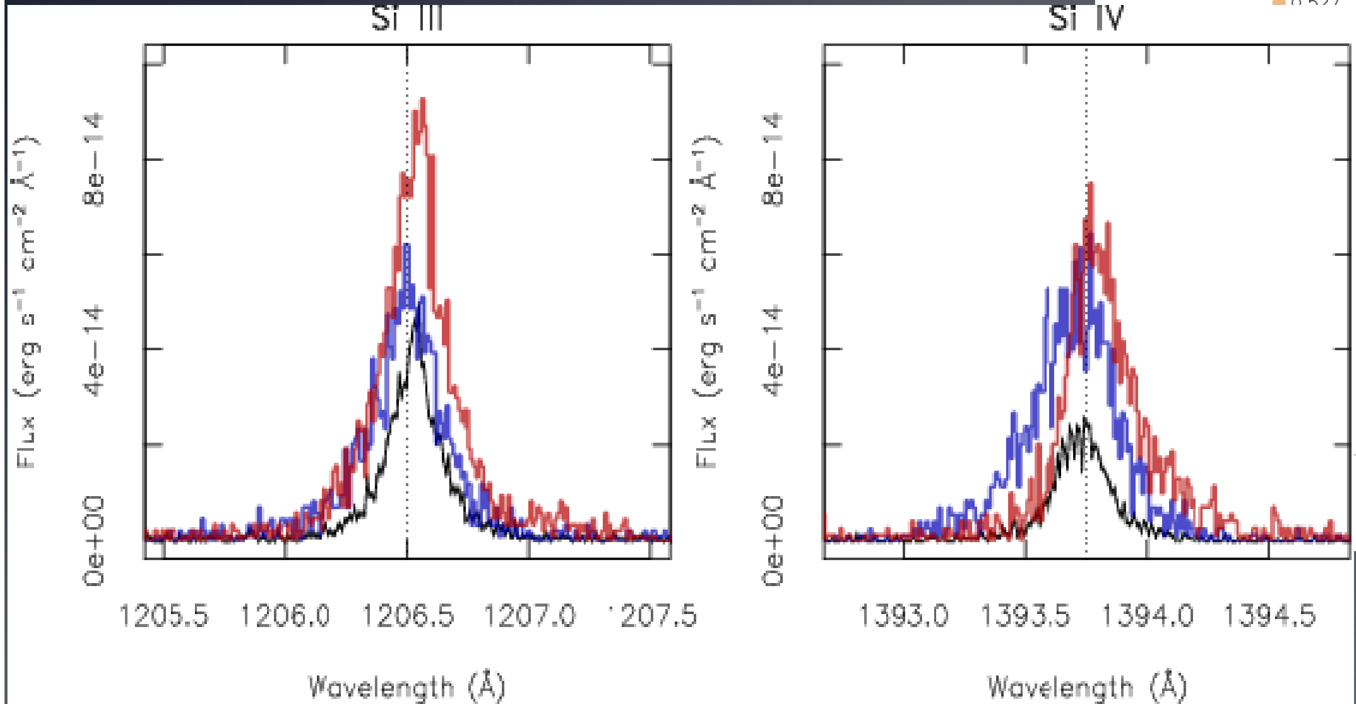
(in order of confidence)

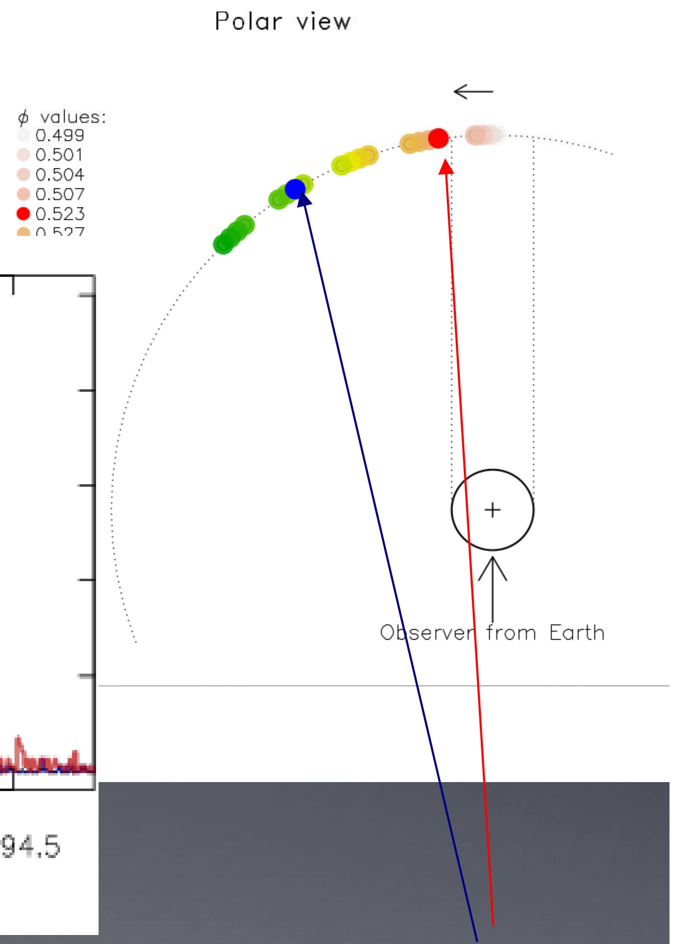
1. We have seen a planetary transit in X-rays and the planet is much "bigger" in X-rays than in any other wavelength.
2. Hot Jupiters can spin-up stars with large convective zones through tidal effects.
3. Planets can induce active spots on the stellar surface through magnetic effects.
4. Activity can include system scale stellar flares. (time permitting)

HD 189733 – Active spots?

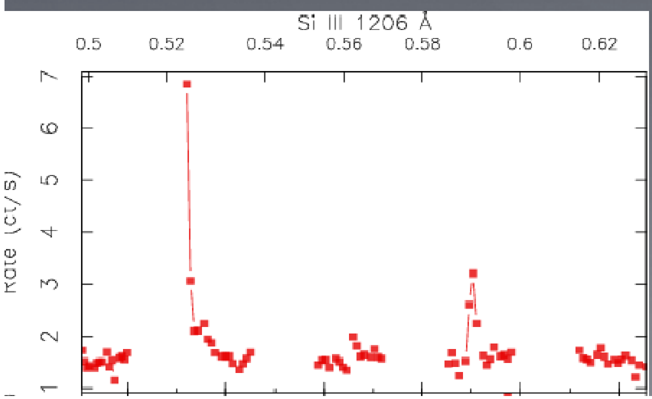


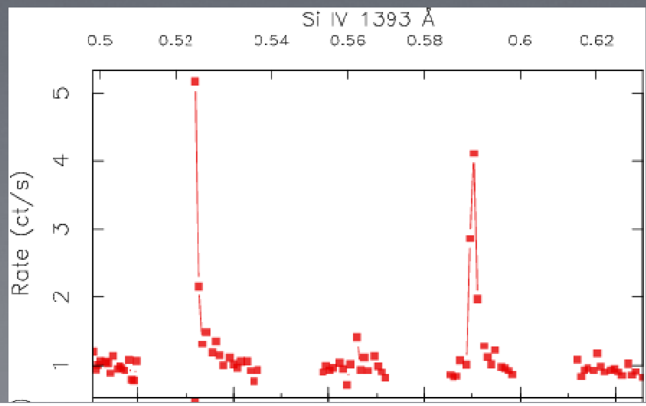
UV Variability at the same phases





Two flares





[see Pillitteri -poster]

Plausibility Argument: Accreting Streams and Tails

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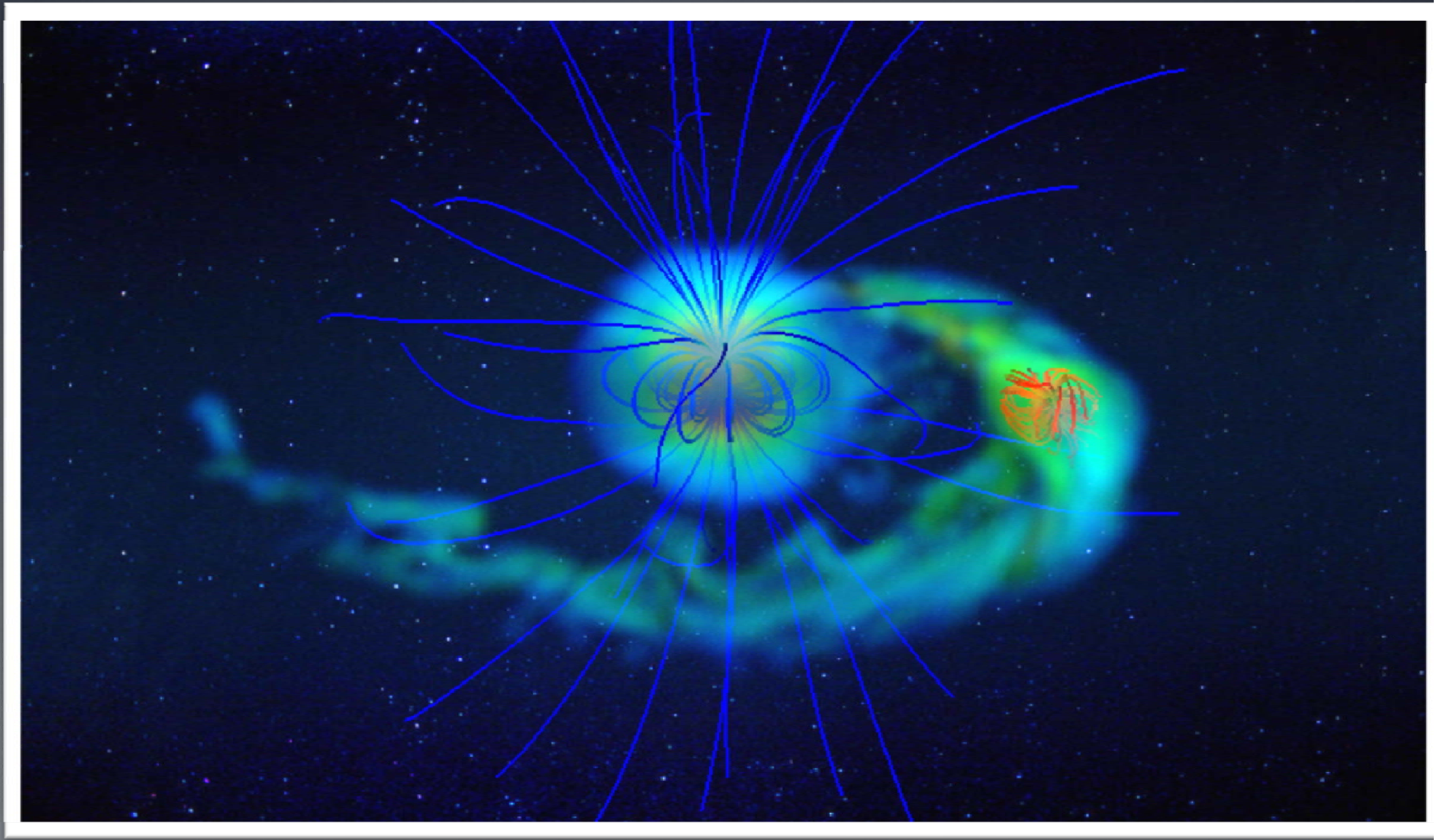
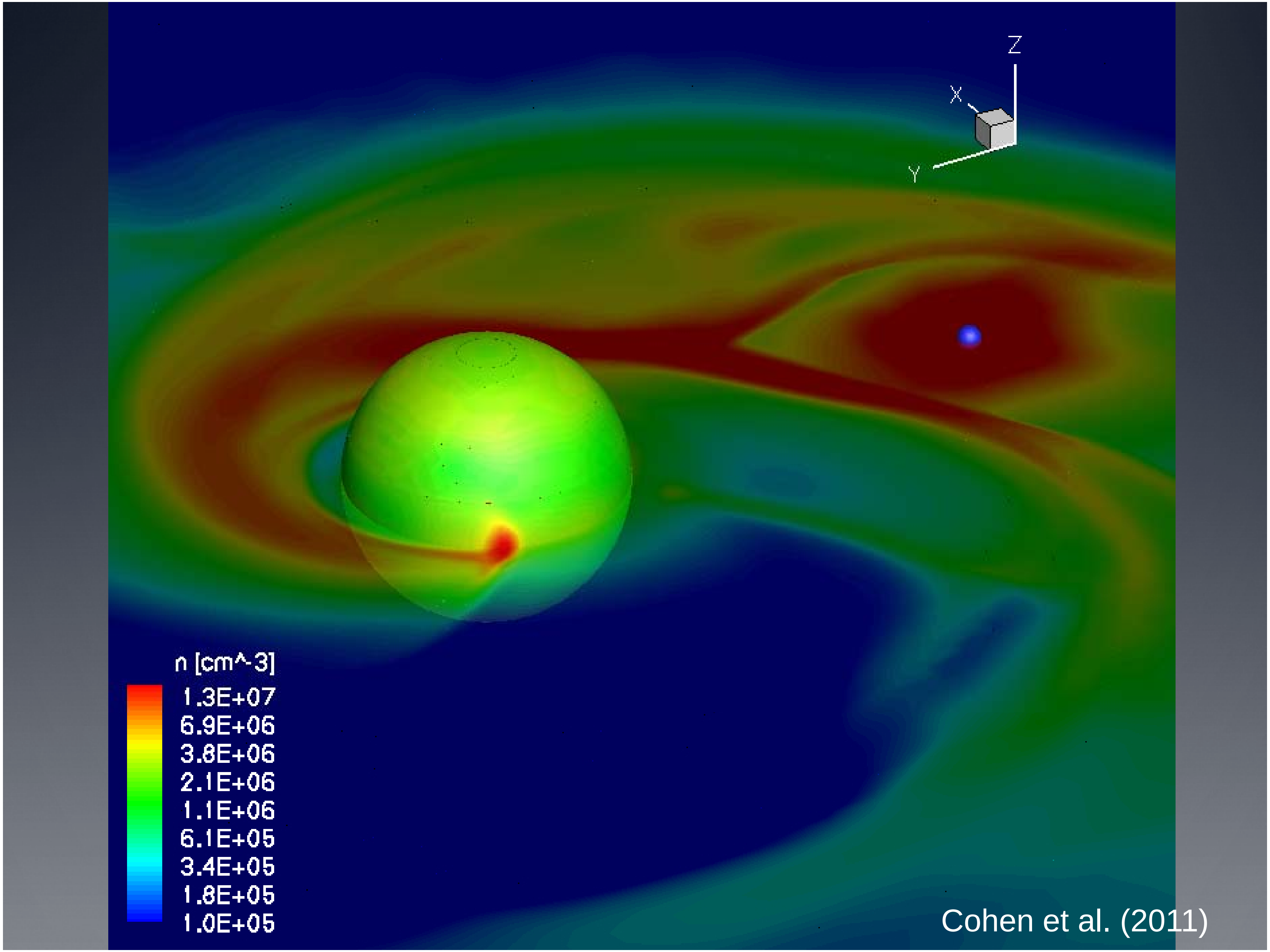
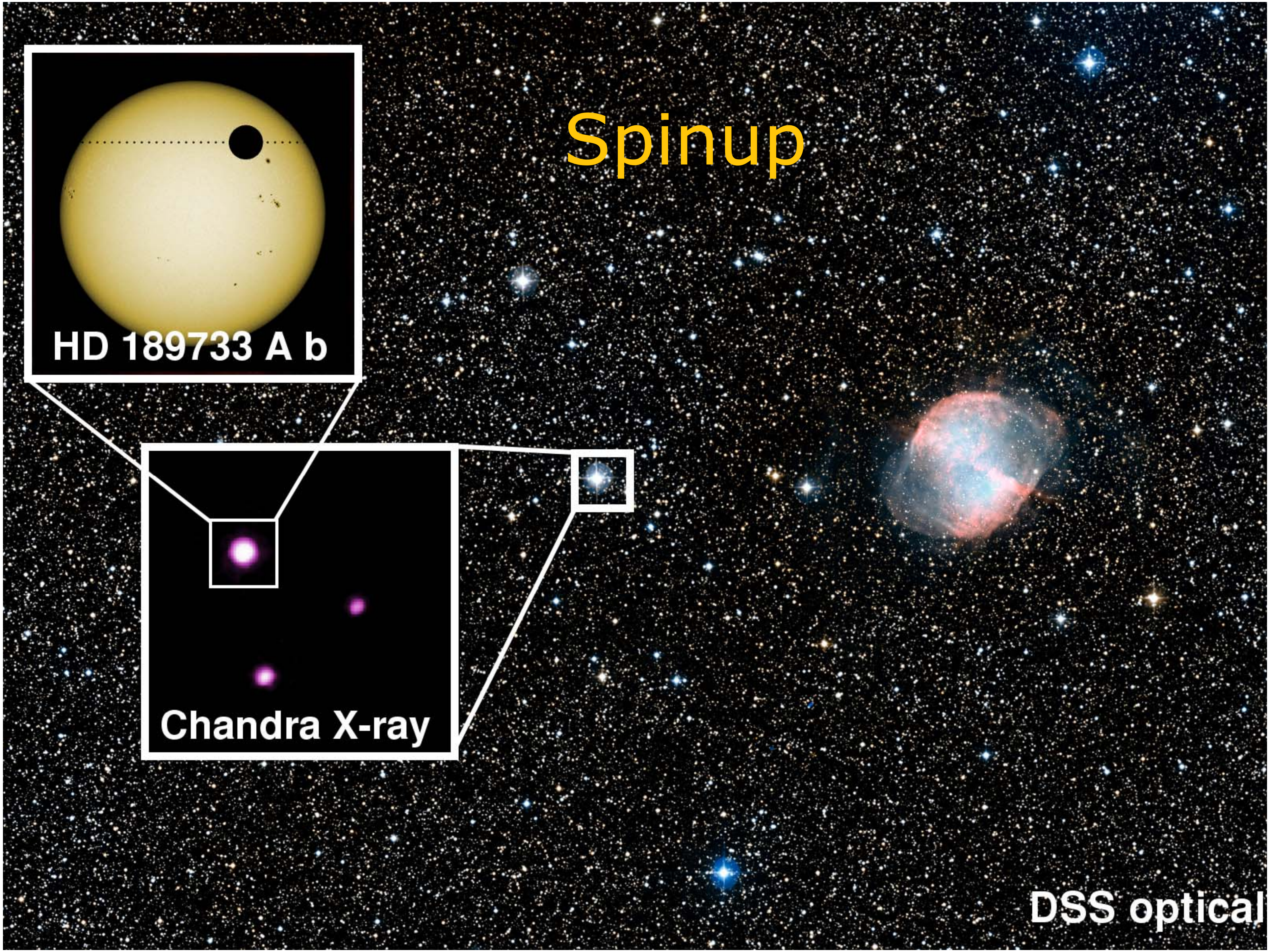
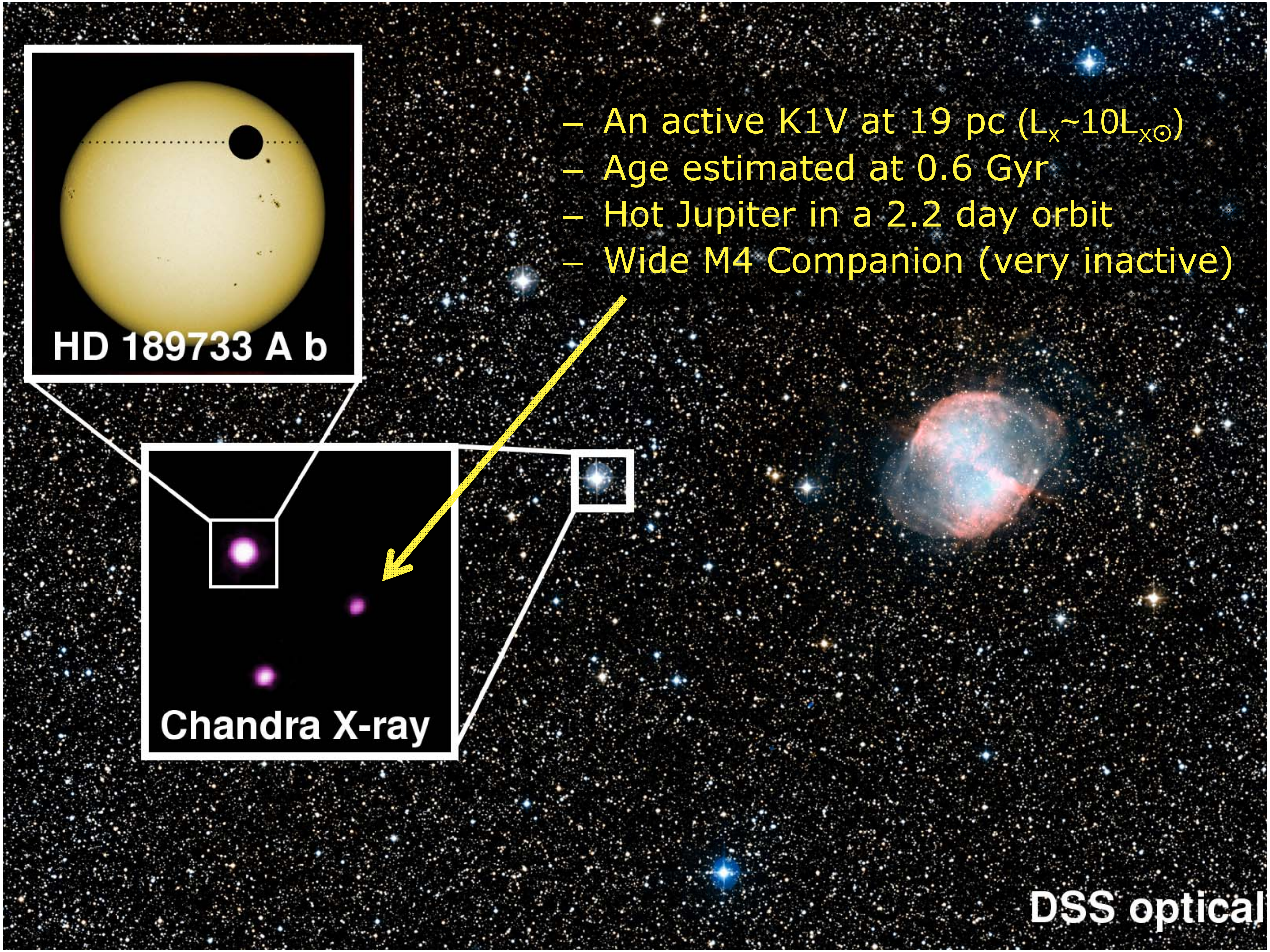
High UV,
~ M_{jup}



see Matsakos et al. (2014)

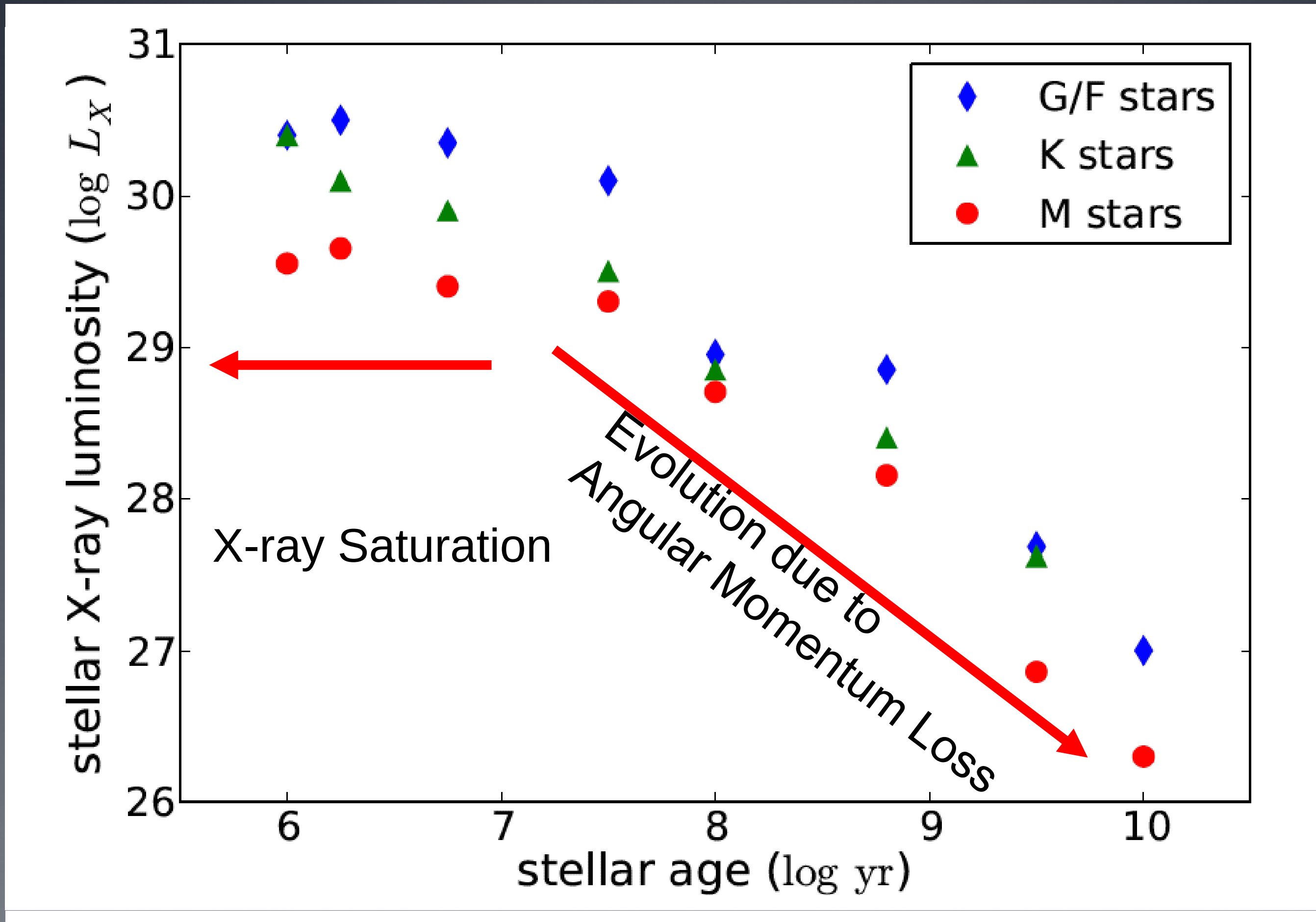

Z
X
Y
n [cm^-3]
1.3E+07
6.9E+06
3.8E+06
2.1E+06
1.1E+06
6.1E+05
3.4E+05
1.8E+05
1.0E+05
Cohen et al. (2011)


Spinup
HD 189733 A b
Chandra X-ray
DSS optical



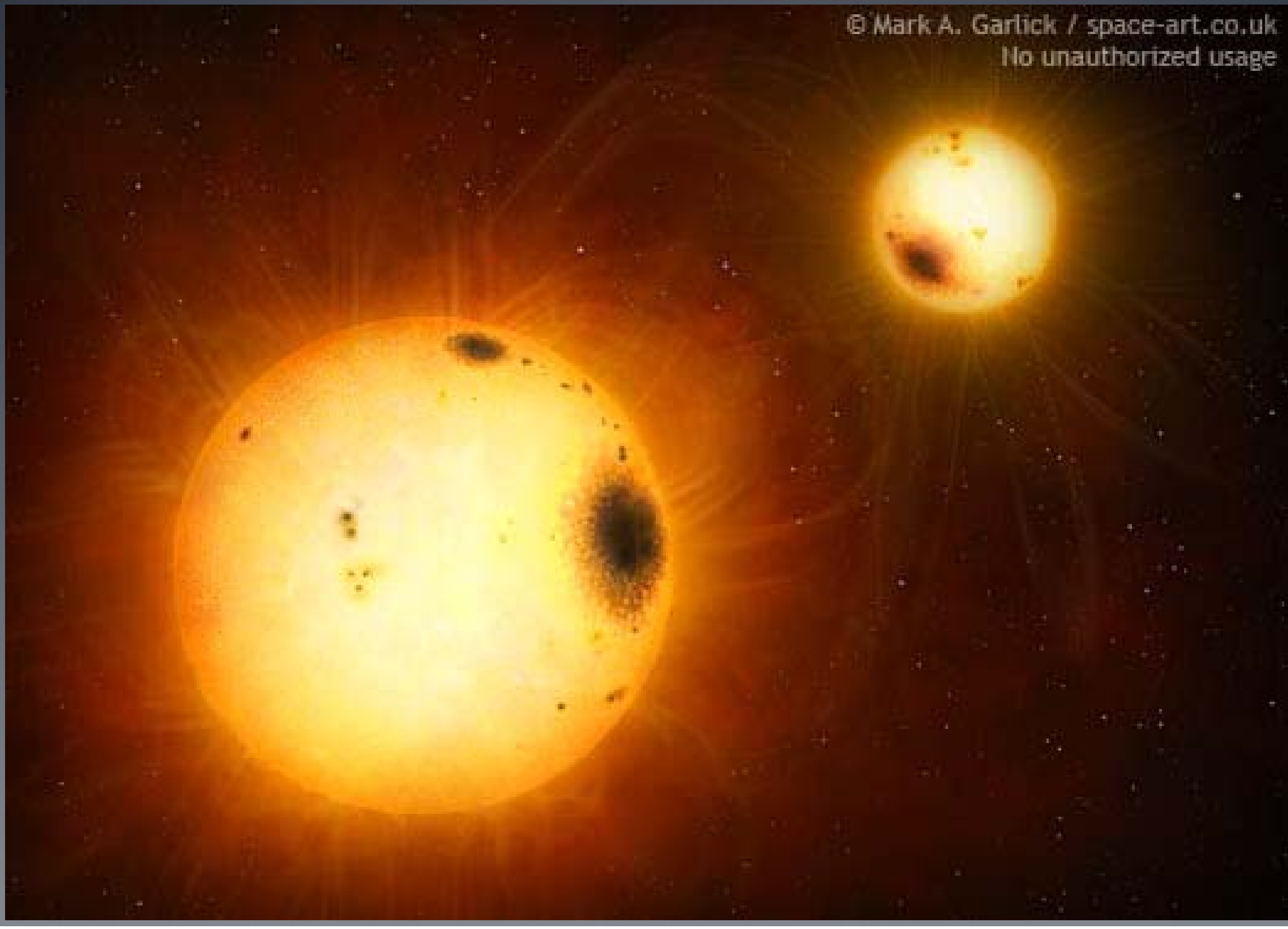
– An active K1V at 19 pc (L_x~$10L_{X\odot}$)
– Age estimated at 0.6 Gyr
– Hot Jupiter in a 2.2 day orbit
– Wide M4 Companion (very inactive)
HD 189733 A b
Chandra X-ray
DSS optical

Activity decline with stellar age

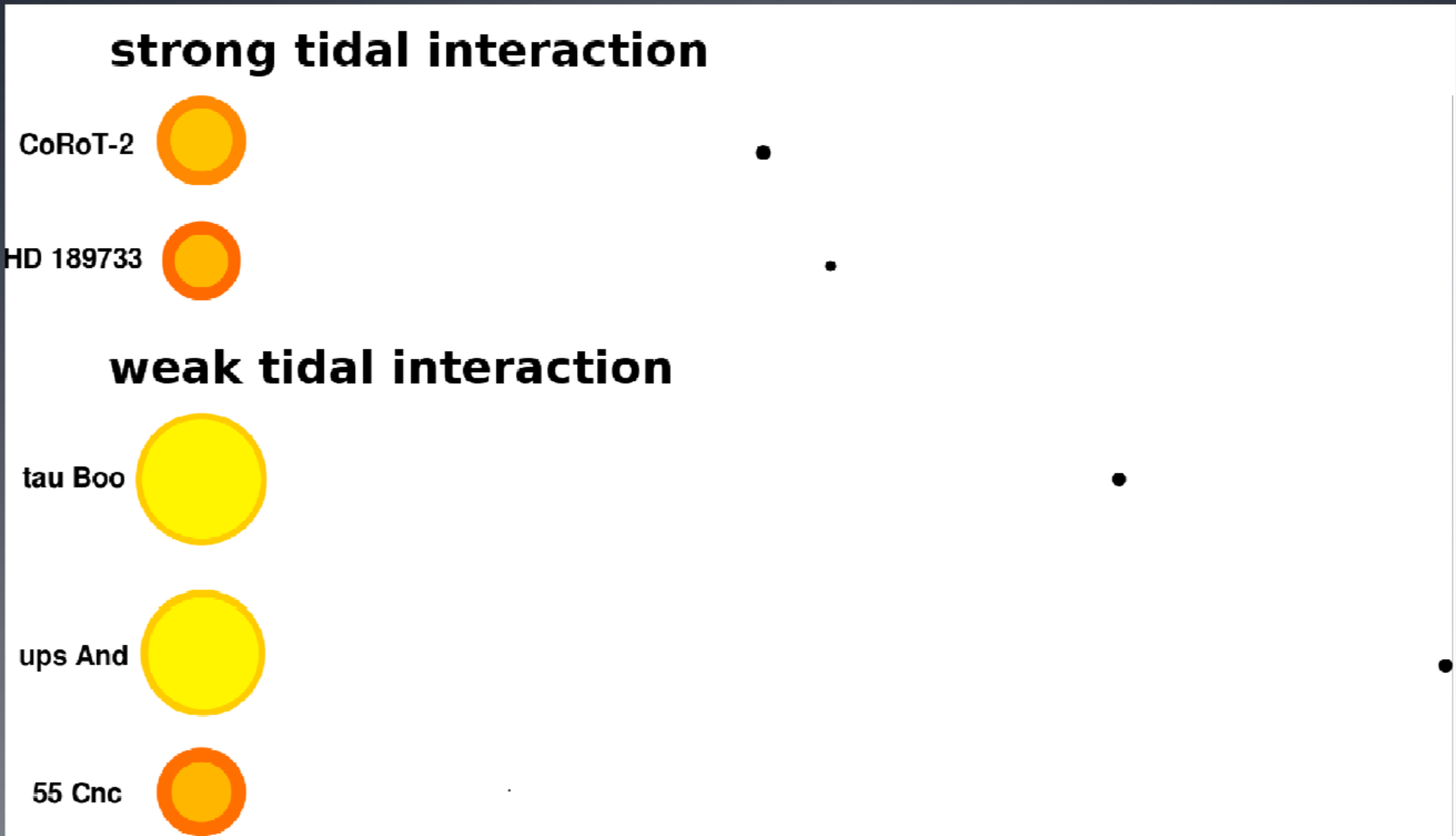


Data from Preibisch et al. 2005, Jeffries et al. 2006, Schmitt et al. 1995, Schmitt 1997, Maggio et al. 1987, Hawley et al. 1994

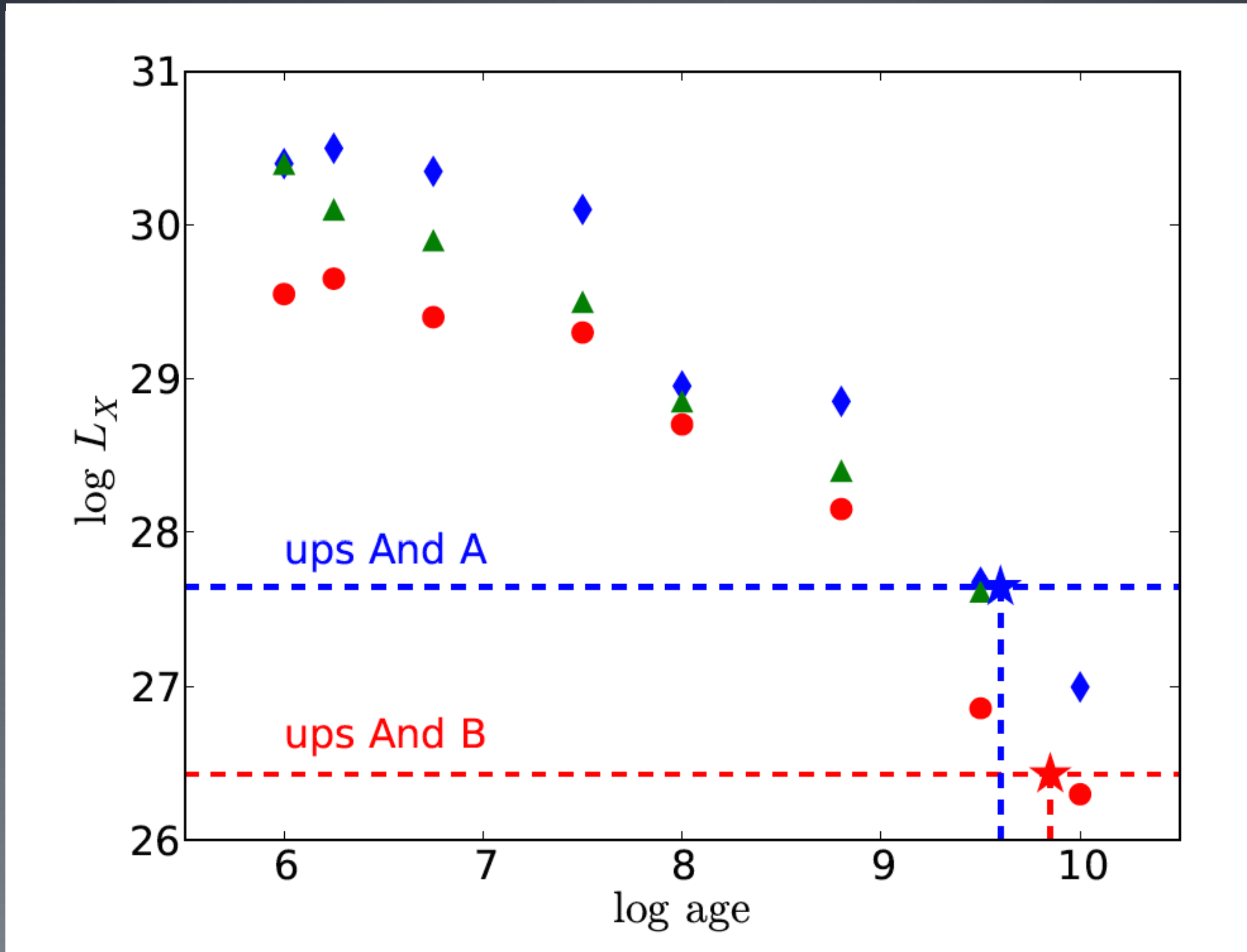
Tidal Evolution can effect gyrochronolgy – RS CVns



Planet Hosting Stars With Stellar Companions

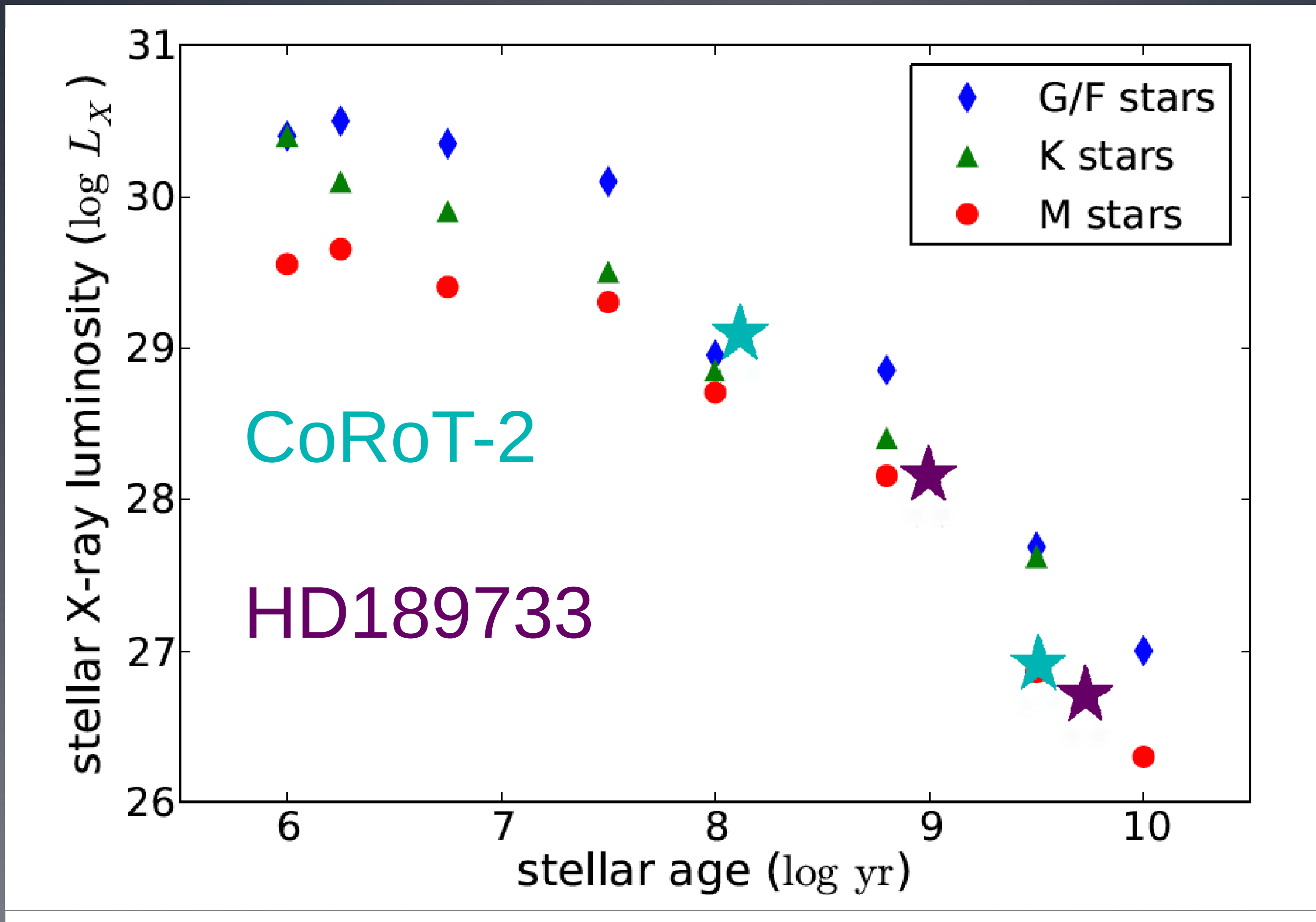


Age/activity in the weak tidal interaction case

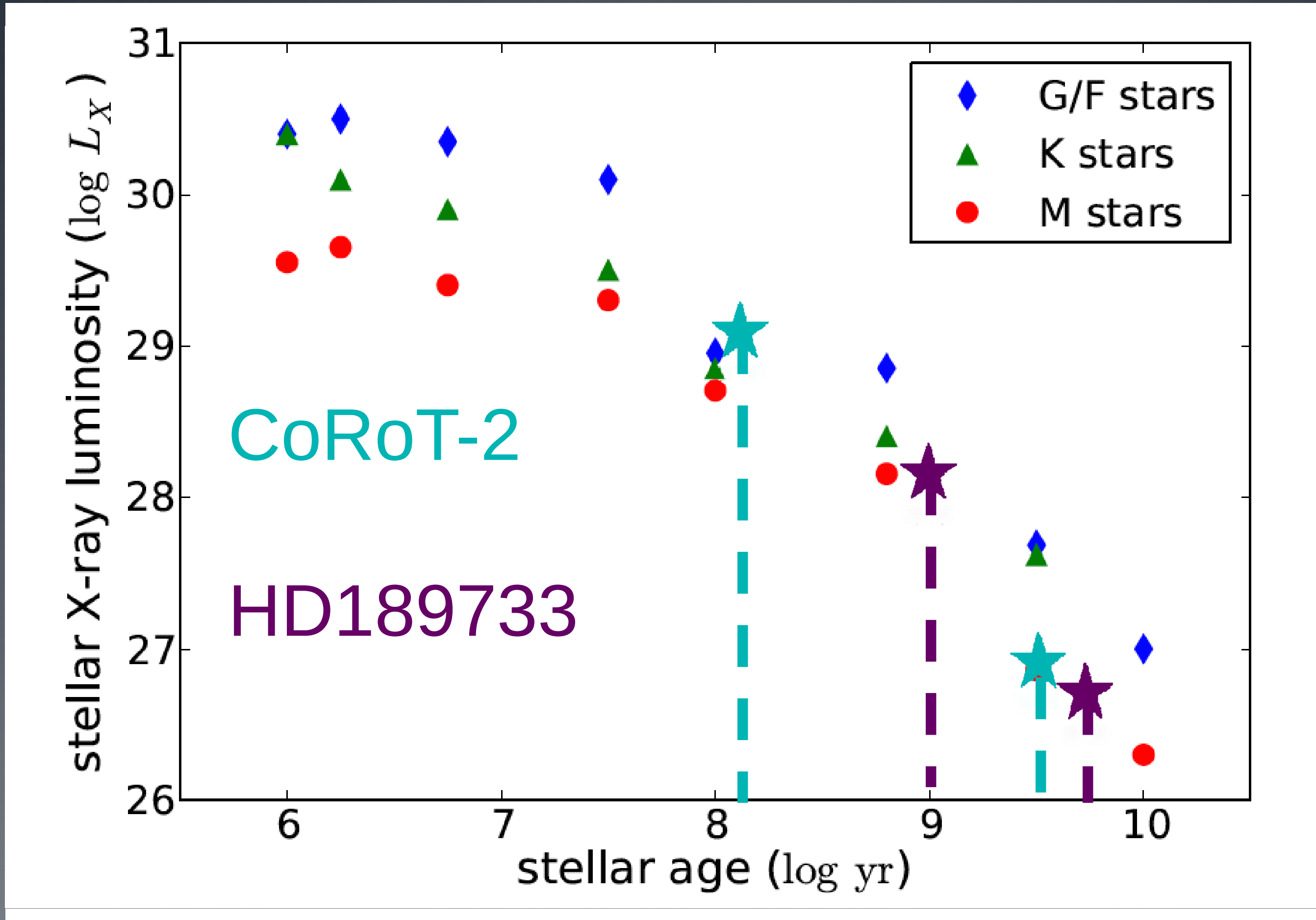


Poppenhaeger & Wolk (2014)

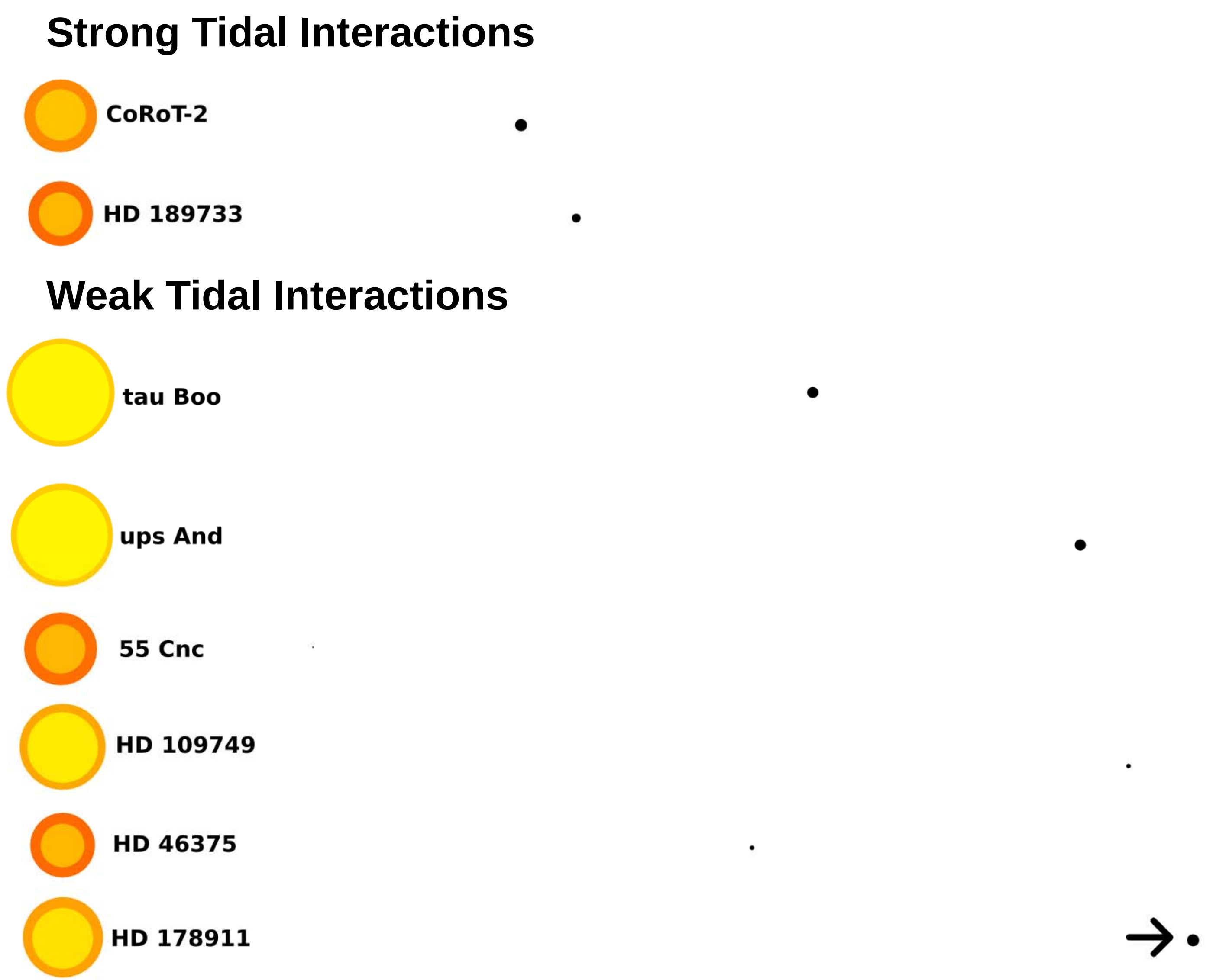
Age/activity in the strong tidal interaction case



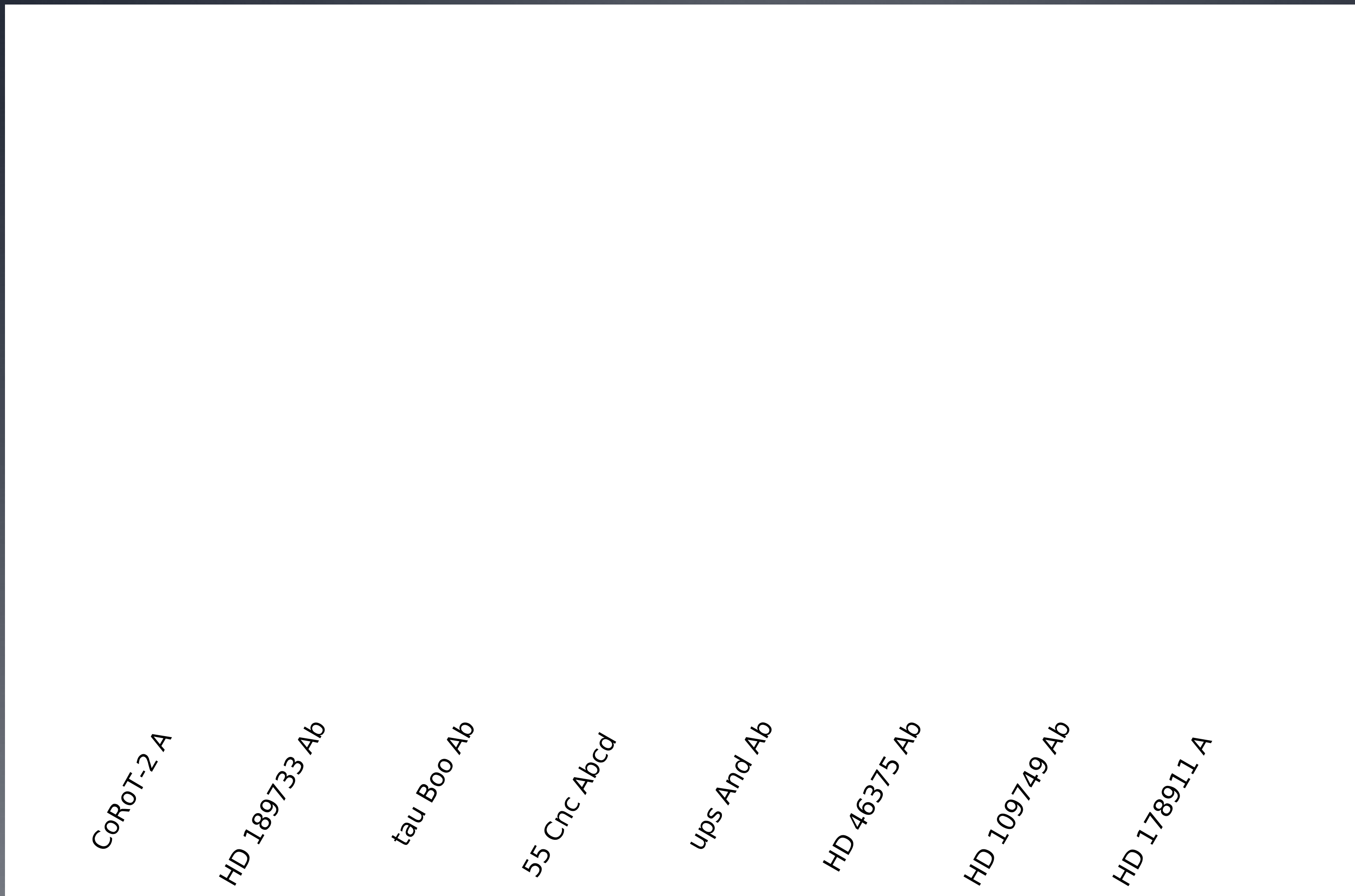
Age/activity in the strong tidal interaction case



Poppenhaeger & Wolk (2014)


Strong Tidal Interactions
CoRoT-2
HD 189733
Weak Tidal Interactions
tau Boo
ups And
55 Cnc
HD 109749
HD 46375
HD 178911

X-ray Activity for 8 Systems



Poppenhaeger & Wolk (in prep)

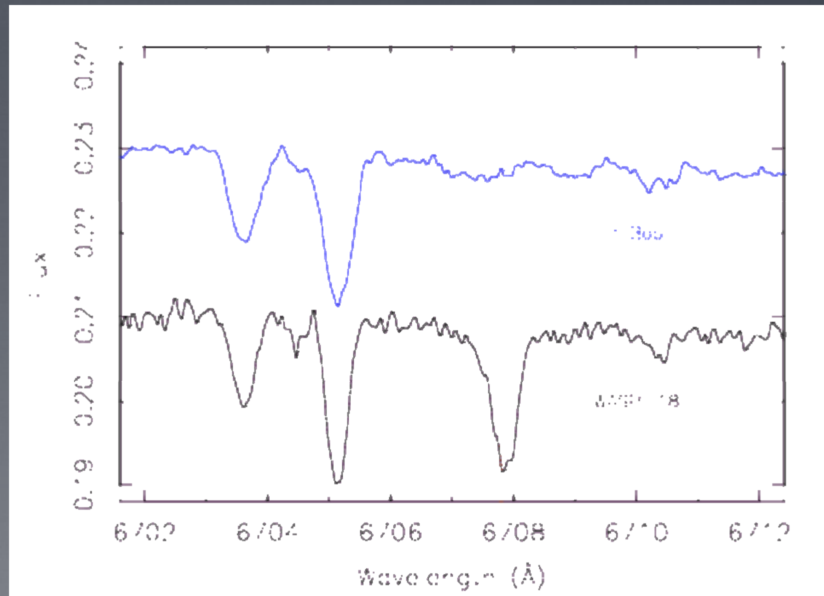
WASP-18

Single F6 star:
P~22.6 hours
M_{pl}~10.4M_{jup}

WASP-18 vs. other F stars

L_X WASP-18 < $10^{26.5}$ erg/s
L_X Tau Boo ~ 10^{28} erg/s
L_X Procyon ~ 10^{28} erg/s

WASP 18 is YOUNG ~0.6Gyr



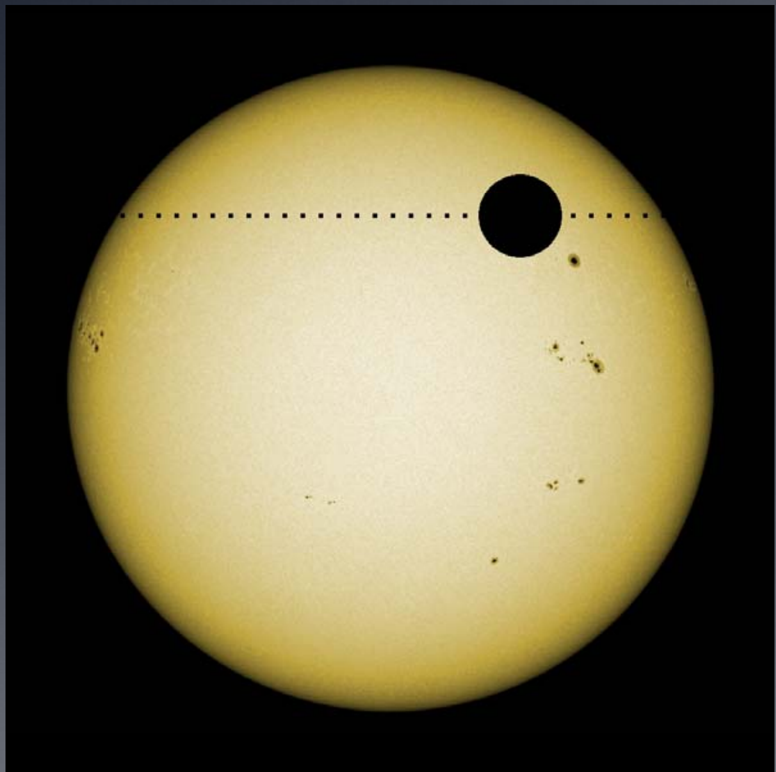
Pillitteri et al. (2014) See also Fossati et al. (2014)

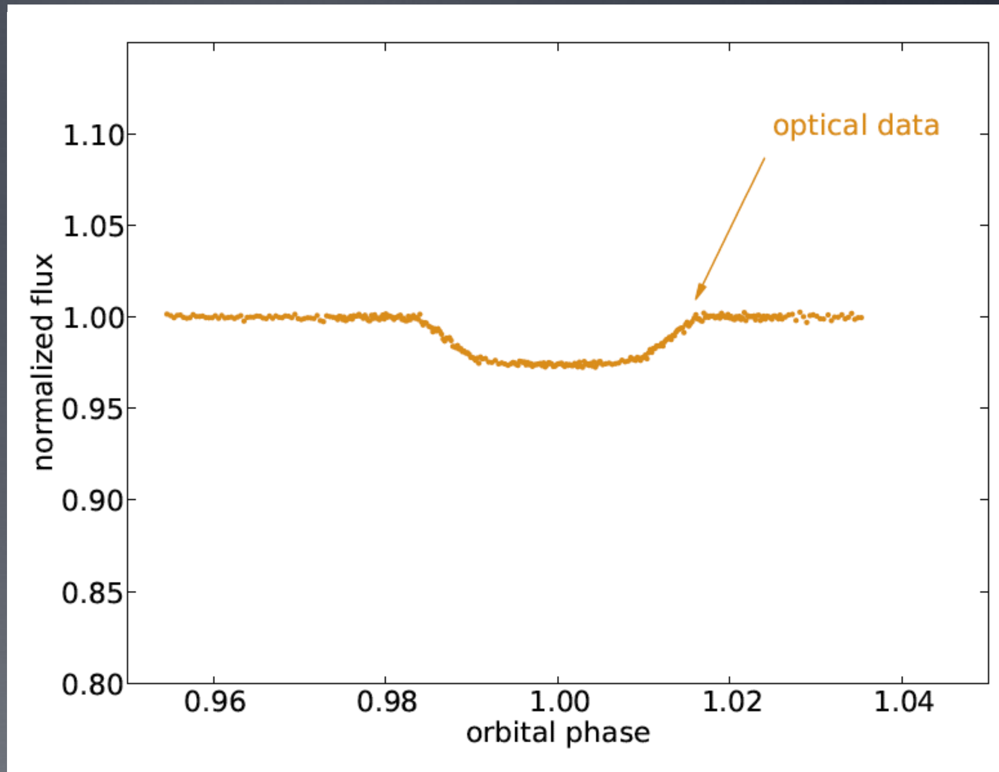
Star	T_{eff} K	R_{star} $R_\odot$	M_{star} $M_\odot$	M_{planet} M_{Jup}	Separation AU	$\log R'_{HK}$	H_P km	H_t km	H_t/H_P
WASP-18	6400	1.29	1.28	10.43	0.02047	-5.43	419	498.3	1.189
WASP-12	6300	1.599	1.35	1.404	0.02293	-5.5	600.1	122.3	0.204
WASP-14	6475	1.306	1.211	7.341	0.036	-4.923	458.7	44	0.096
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

[see Pillitteri -poster]

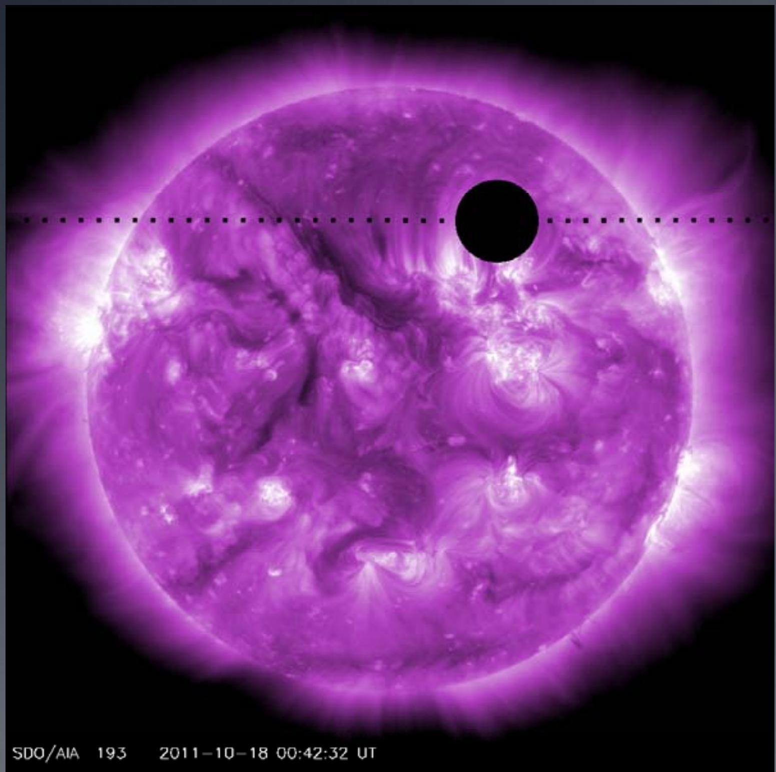
Pillitteri et al. (2014)

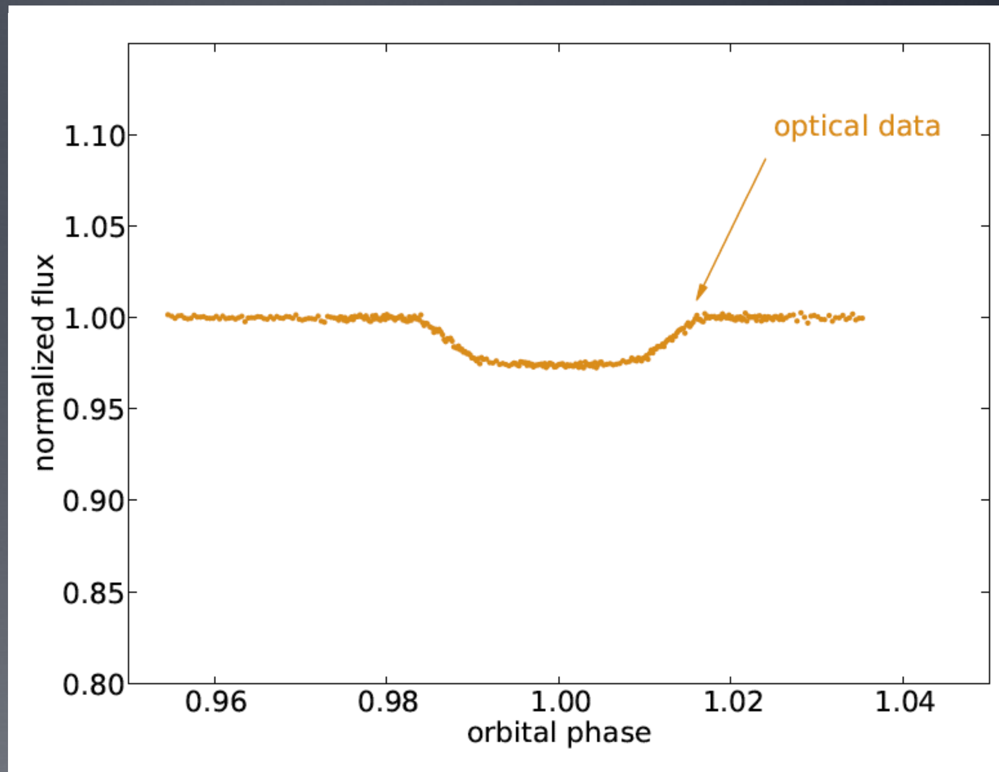
Transit of HD 189733





Transit of HD 189733





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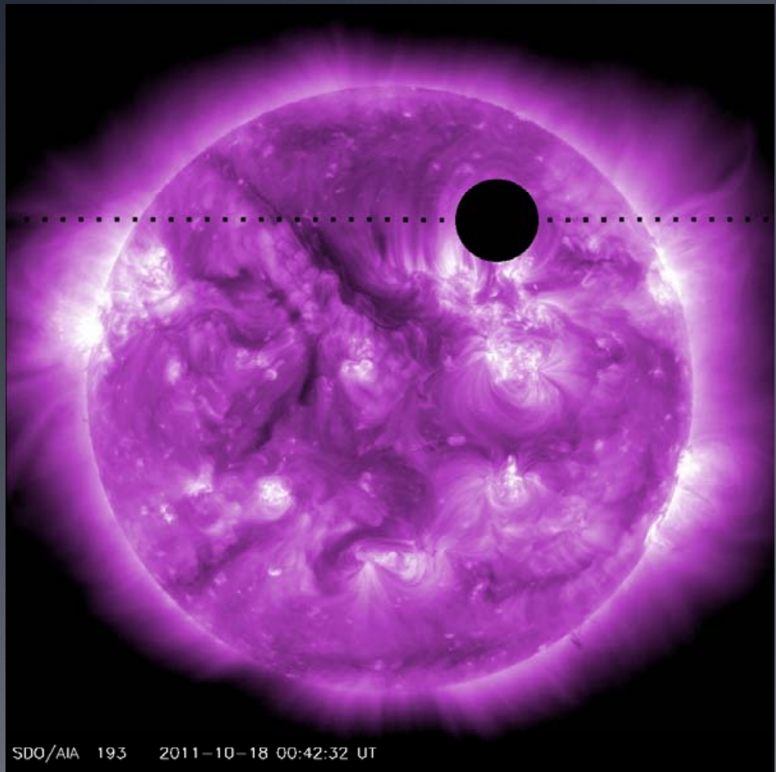
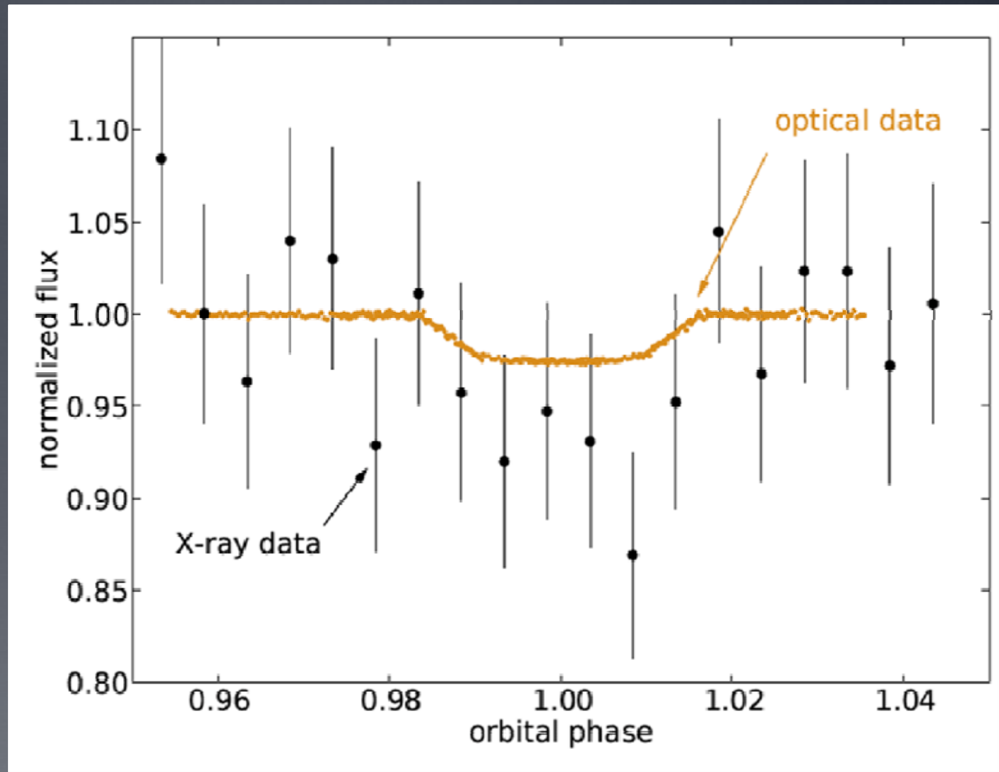
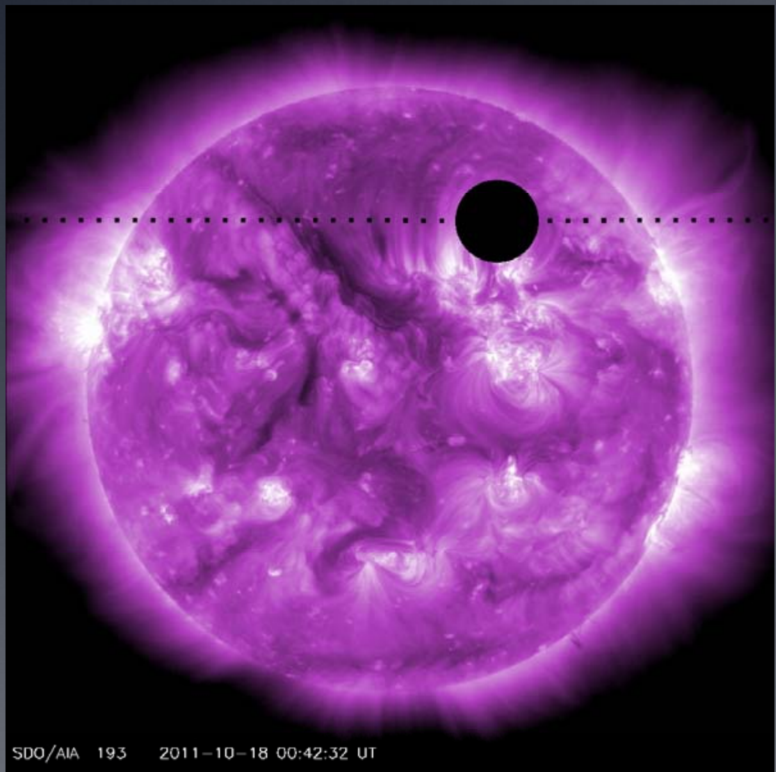
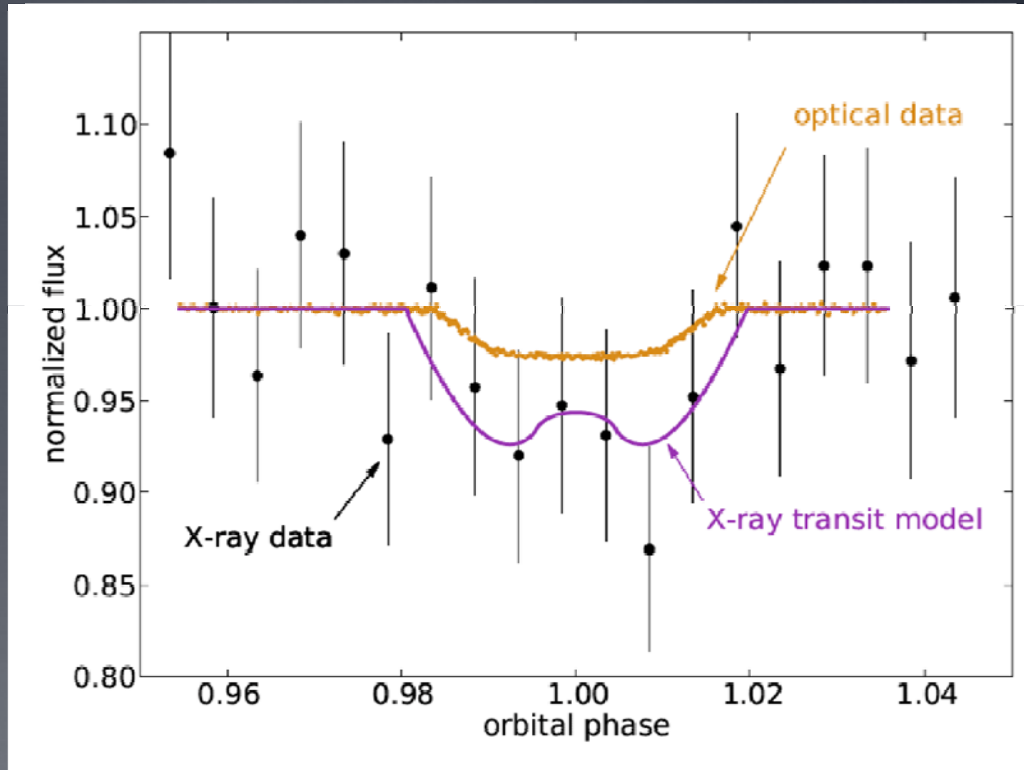




Transit of HD 189733





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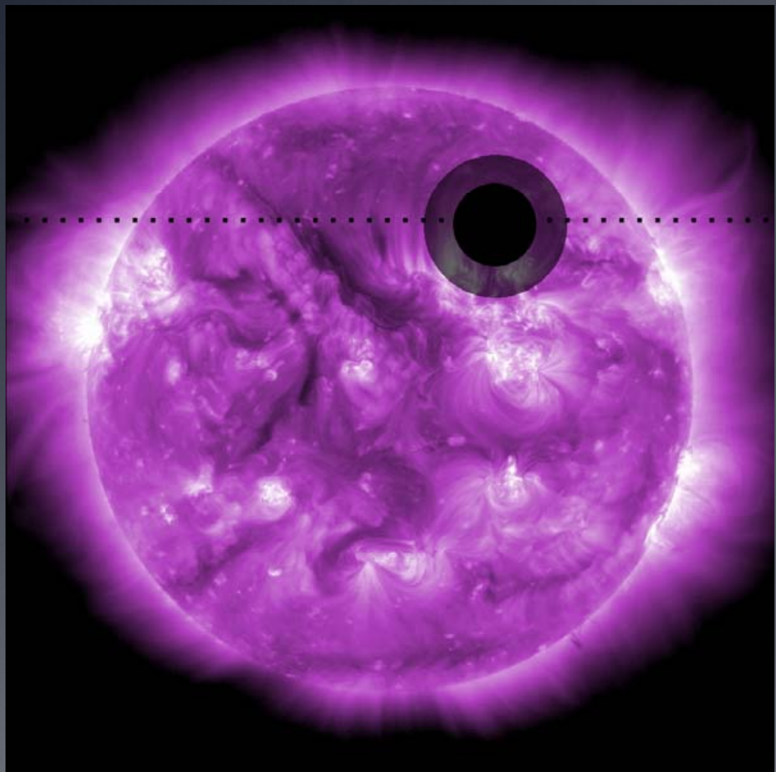
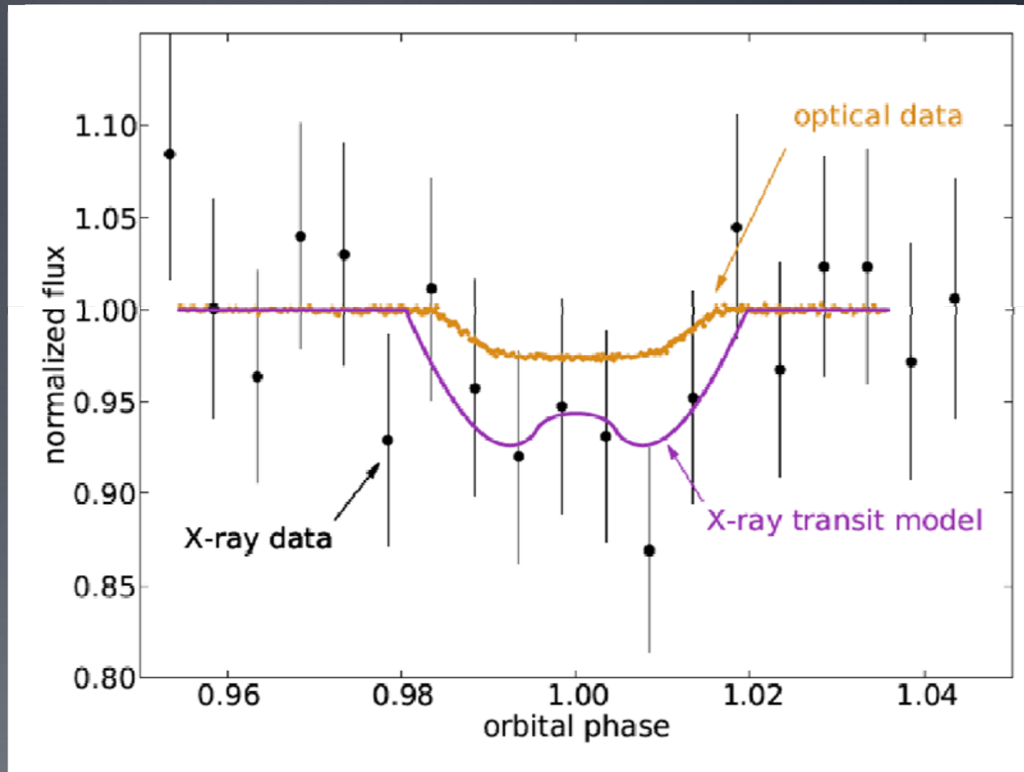
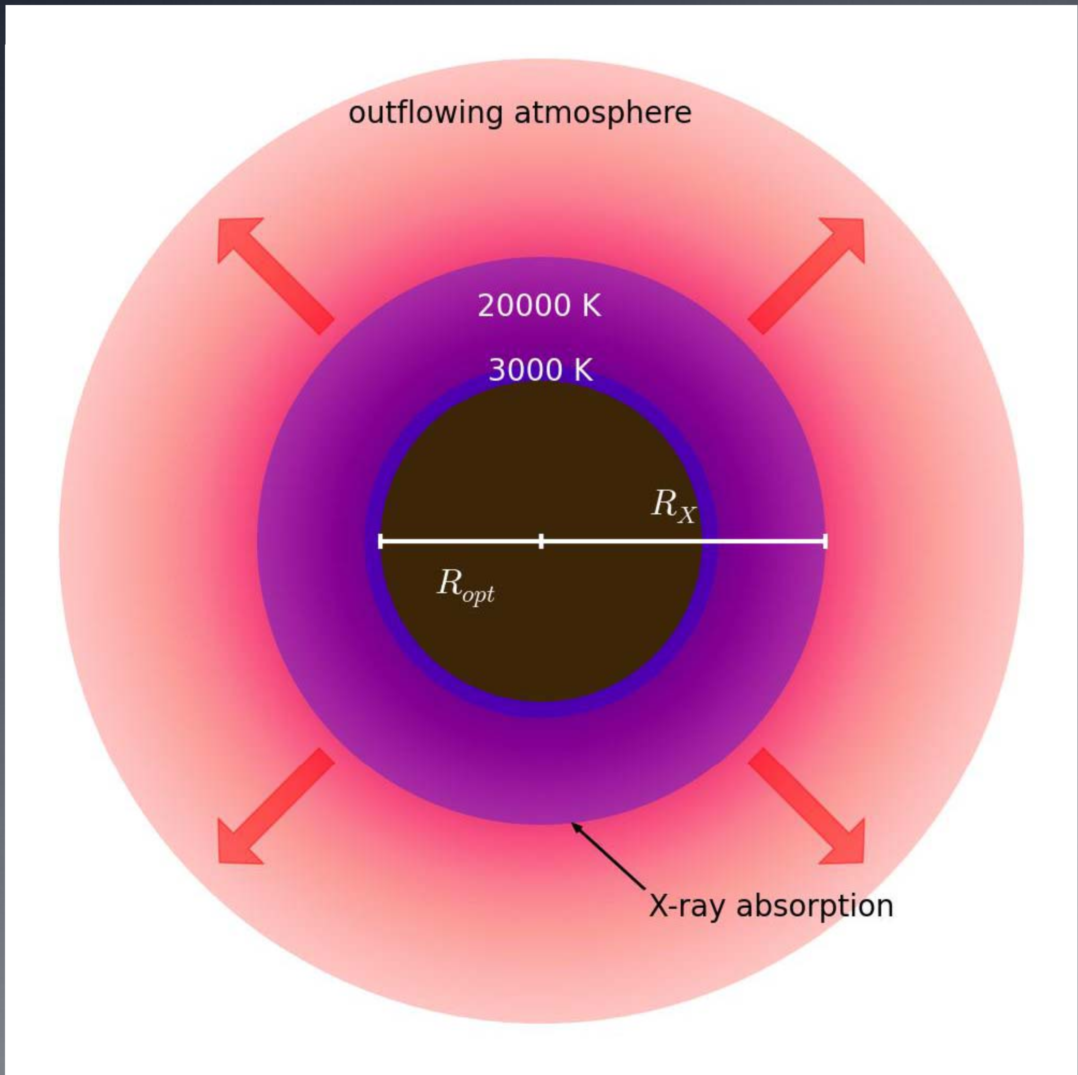




Poppenhaeger, Schmidt & Wolk (2013)

Planetary Atmosphere: Toy Model



$H=kT/\mu_m g$

$\Delta D \sim HR_{Pl}/R_*$

Miller-Ricci & Fortney (2010)

To be X_ray opaque density at $1.75R_{Pl}$: 10^{11} cm^{-3}

high-altitude temperature: ~ 20,000K

Poppenhaeger, Schmitt & Wolk (2013)

ARCUS

- ARCUS is a SMEX proposal for a 100-1500eV dispersive spectrograph.

- 20 transit observation of 30 ks each are required for this S/N, assuming that the optical transit lasts 10 ks. Typical transit durations for Hot Jupiters range from 5 ks to 20 ks

- Model assuming an X-ray flux of 10^{-12} erg s^{-1} cm^{-2}, an optical exoplanetary transit depth of 3% and a maximum extent of the outer atmosphere of twice the optical radius

- We expect TESS to provide at least 5 such targets.

energy (keV)

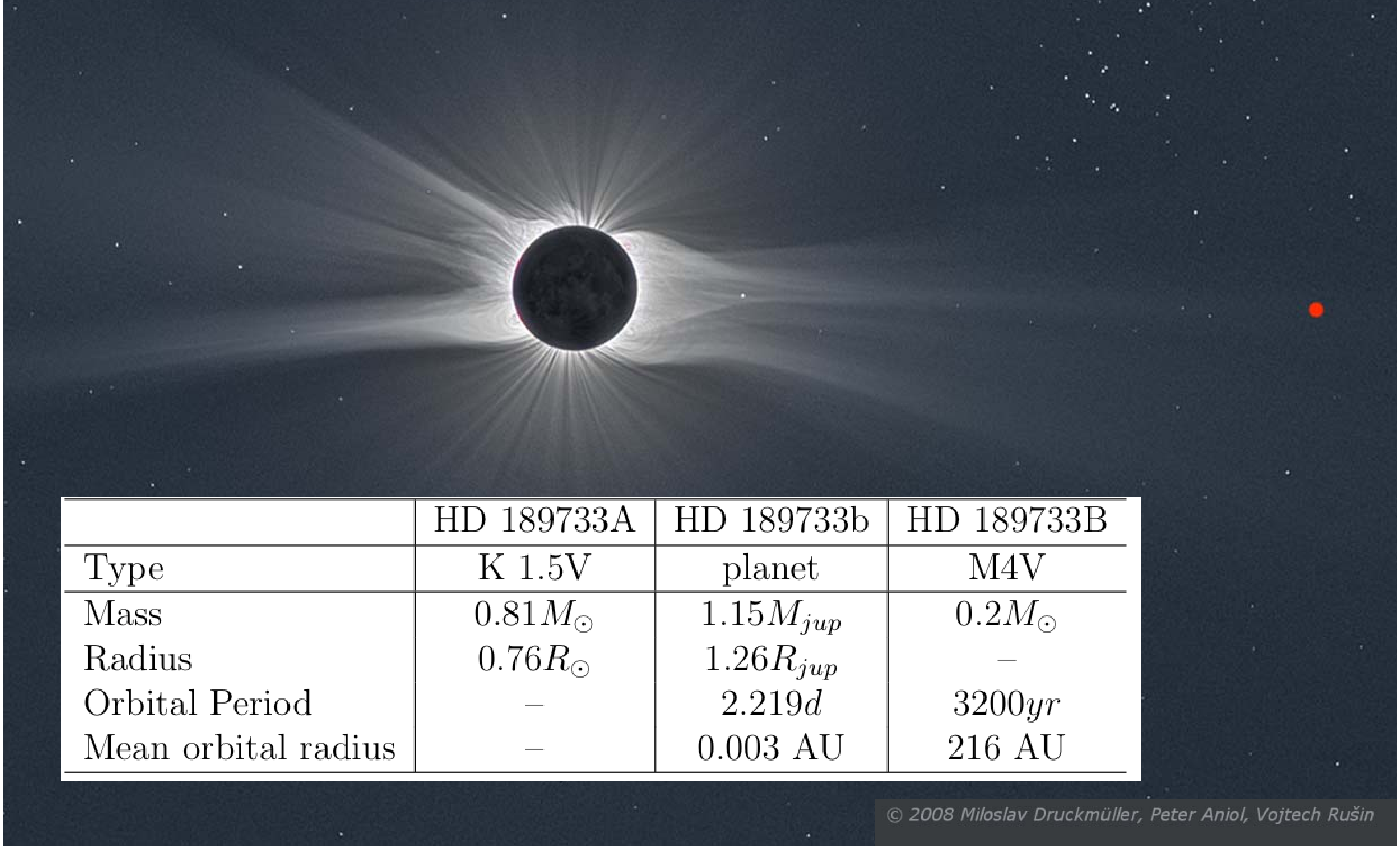
K. Poppenhaeger

X-Rays and exoplanets: Status 2014

- Extended planetary atmospheres can lead to deep X-ray transits.
  - These can be used along with UV and optical data to model atmospheres.
- When a hot Jupiter and its host's *convective zone* have strong tidal coupling, stellar secondaries appear too faint.
  - Hot Jupiter's keep their host planets looking young.
  - Corollary: **You cannot use activity to date stars with close in planets.**

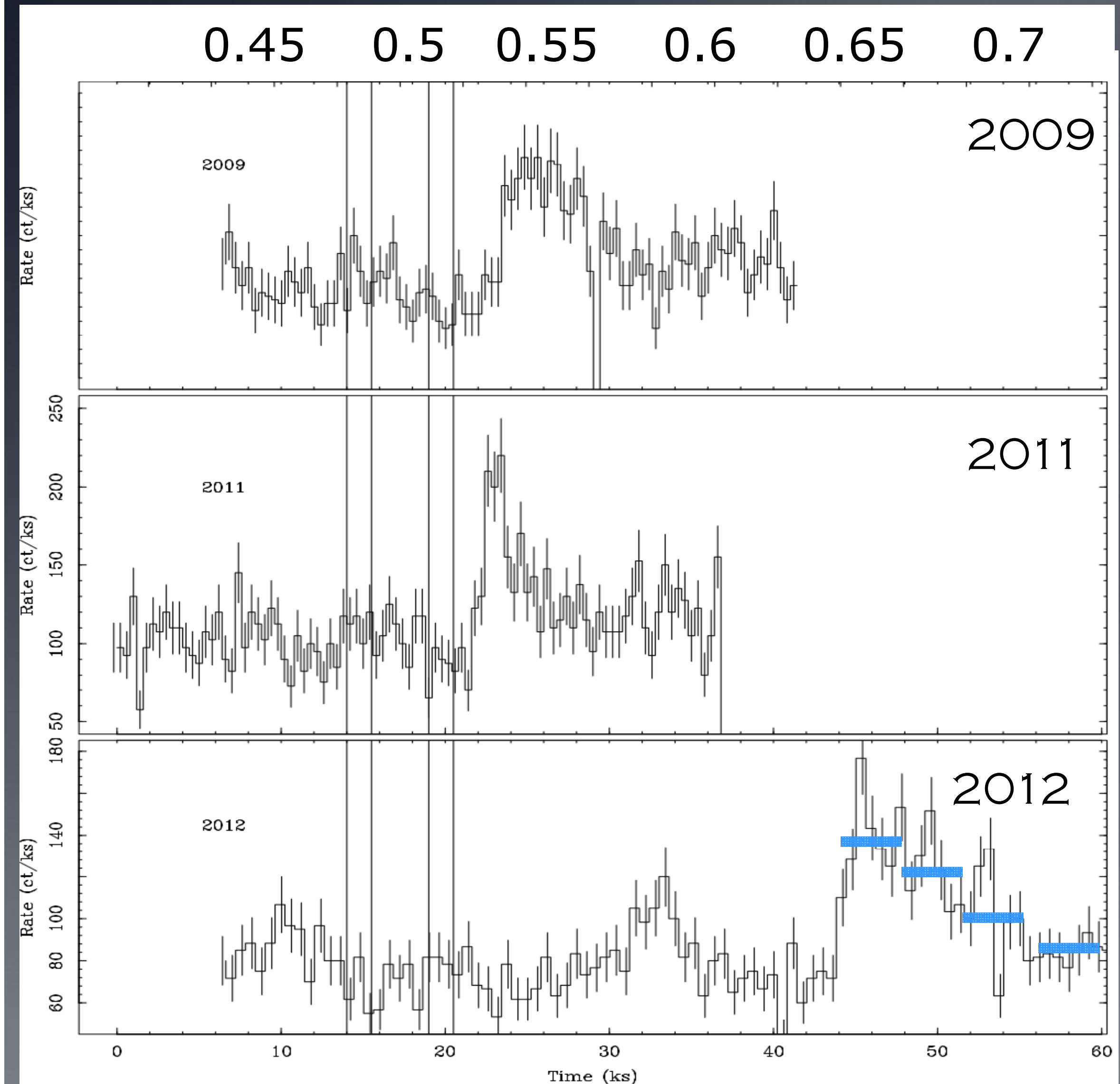
- *On all three occasions an X-ray flare was observed between phases 0.50-0.65. (& 2 UV flares in the same range)*
  - *But how does the flare "know" where the Earth is?*
    - *MHD models predict a foot point 70-90º forward of the sub-planetary point.*
- *We were able to measure the loop length of one flare.*
  - *It is a large fraction of the star-planet distance*

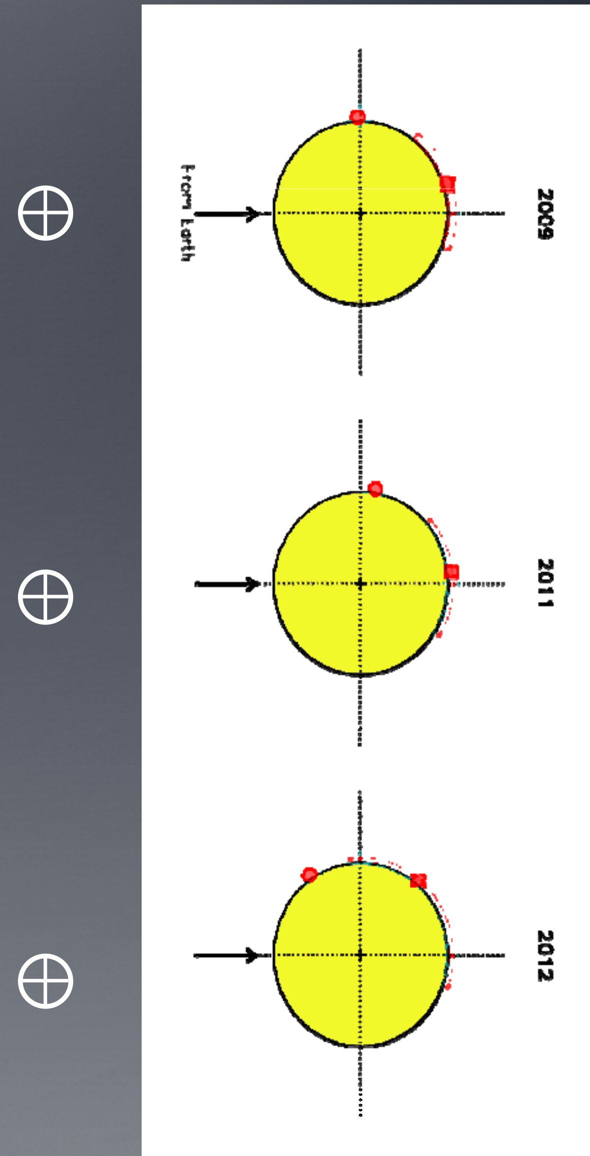
HD 189733



	HD 189733A	HD 189733b	HD 189733B
Type	K 1.5V	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	–	$2.219 d$	$3200 yr$
Mean orbital radius	–	0.003 AU	216 AU

Phased Time Variability?





2D wavelet analysis of 2012 light curve

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

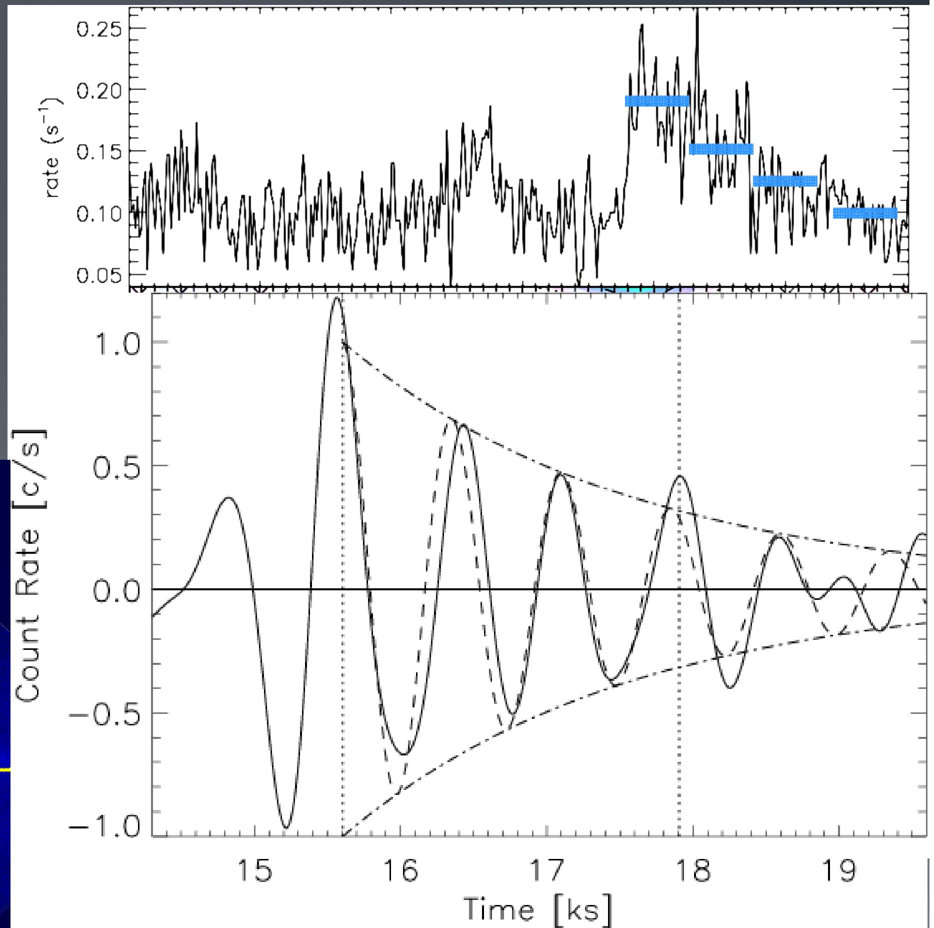
$\Delta I/I \sim 4$□$n k_B T/B^2$

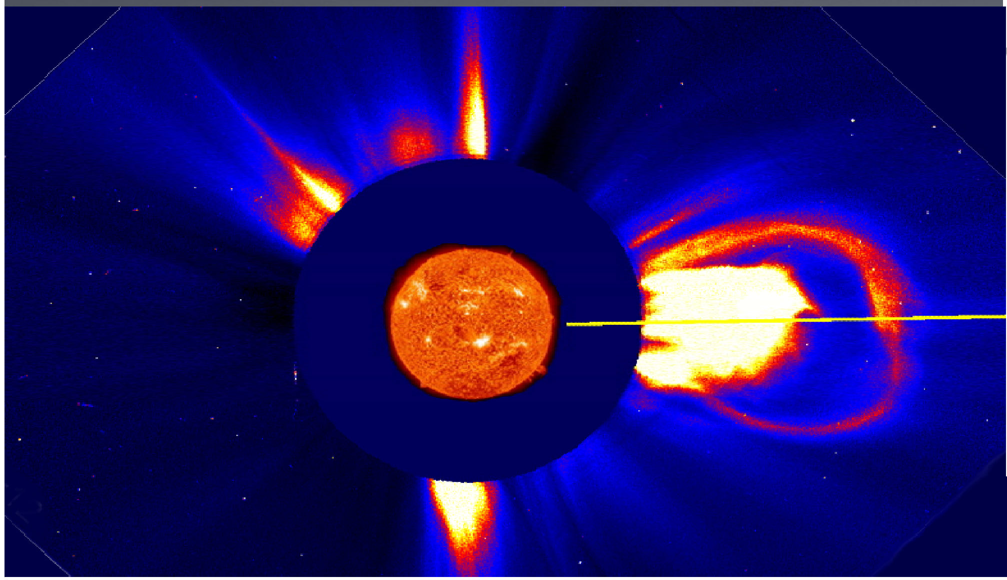
T~ 12 MK

n: density=5×10^{10} cm^{-3}

(from RGS data)

B ⟶ 40-100 G





[see Mitra-Kraev et al. (2005)]

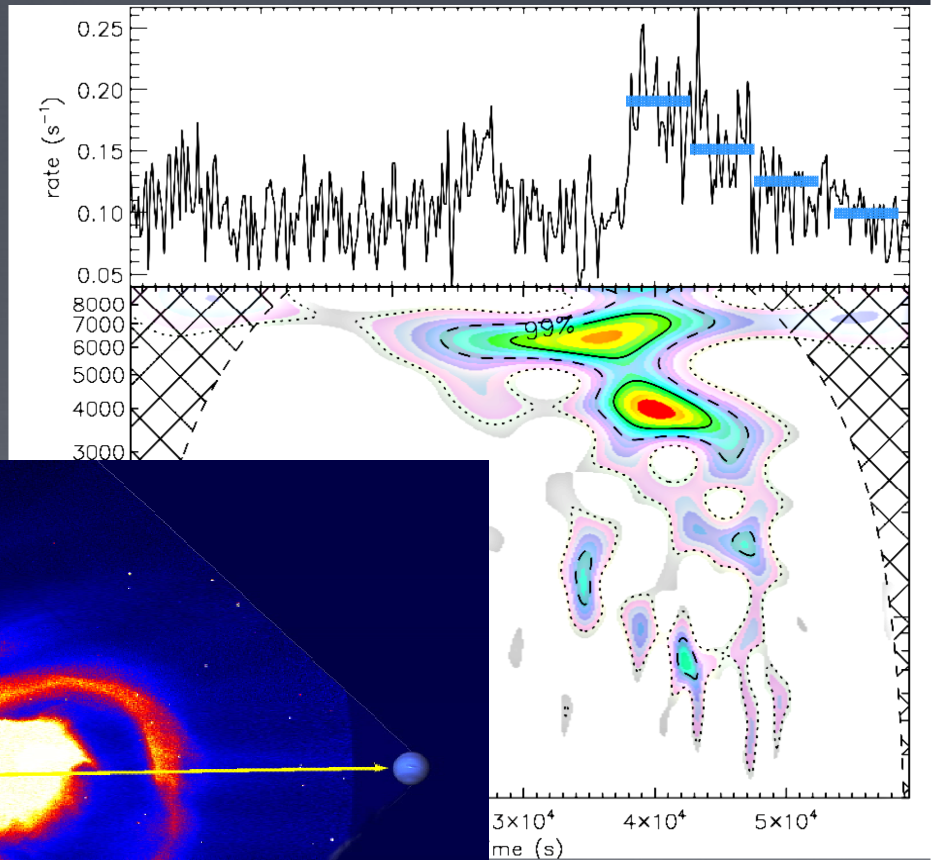
2D wavelet analysis of 2012 light curve

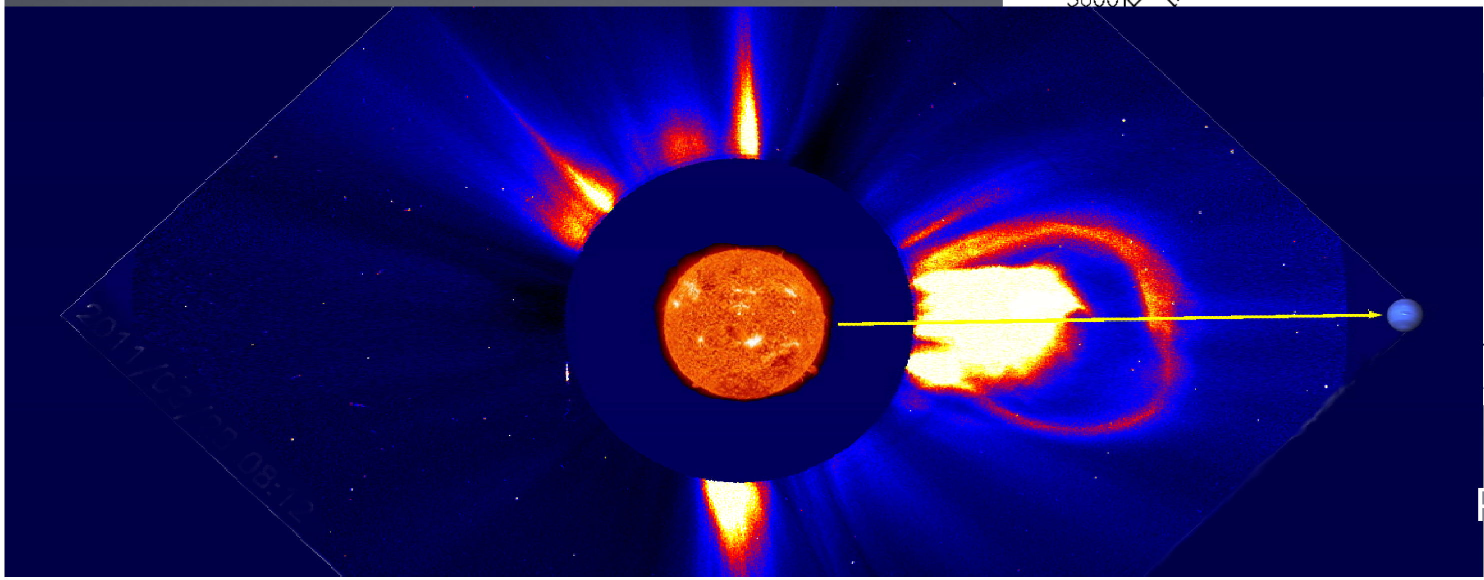
Description: If a single loop it travels a fair fraction of the distance to the planet.

$\tau \sim L/c_s$
$c_s = \sim T^{0.5}$
$\tau =$ oscillation period $\sim$ 4 ks
$L = \text{Const.} \times \tau_{osc} N T^{0.5}$

assuming N=1

L $\longrightarrow$ 2-4 R_*





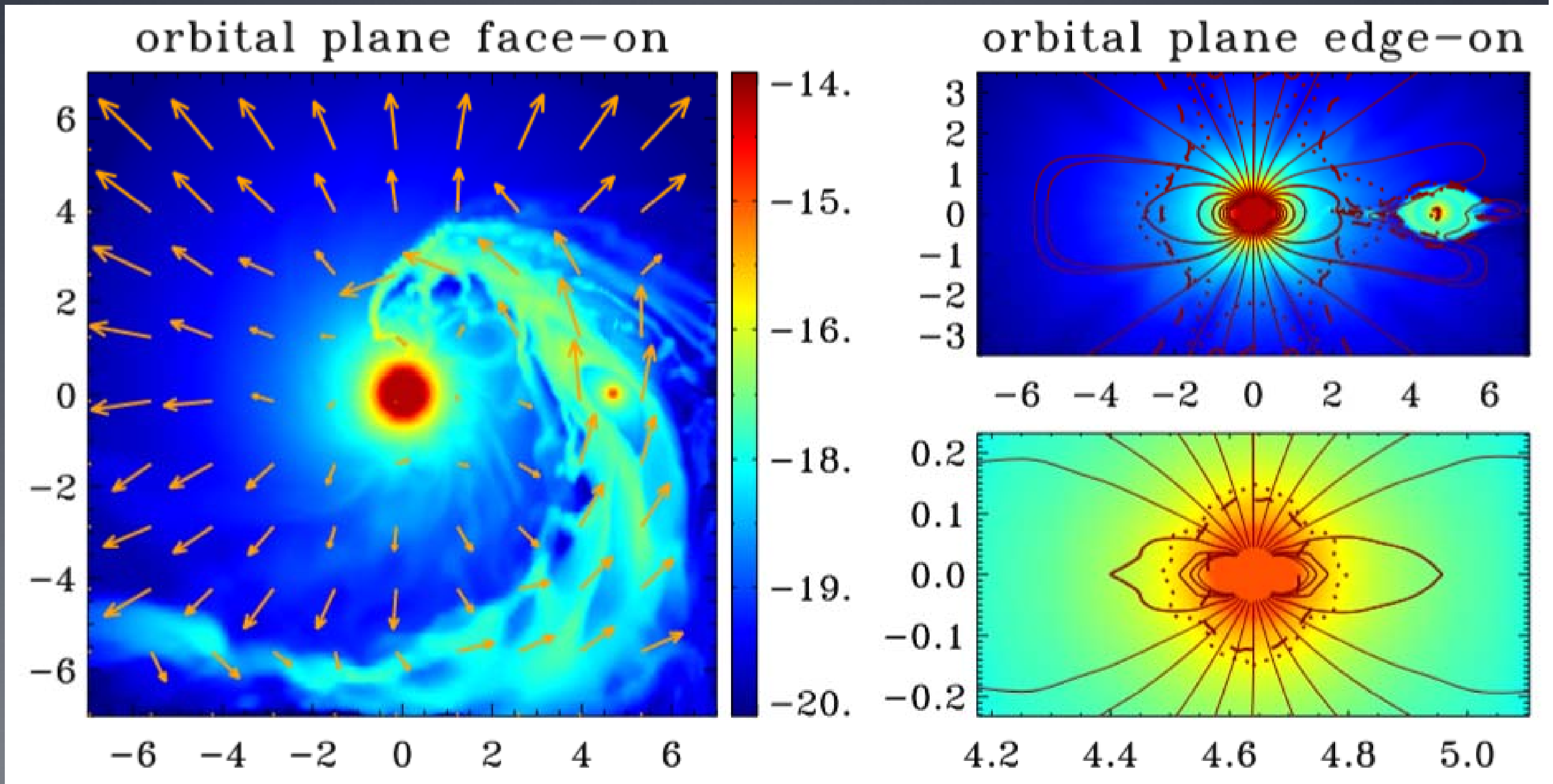
Pillitteri et al. (2014)

Plausibility Argument: Accreting Streams and Tails

⊕

High UV,

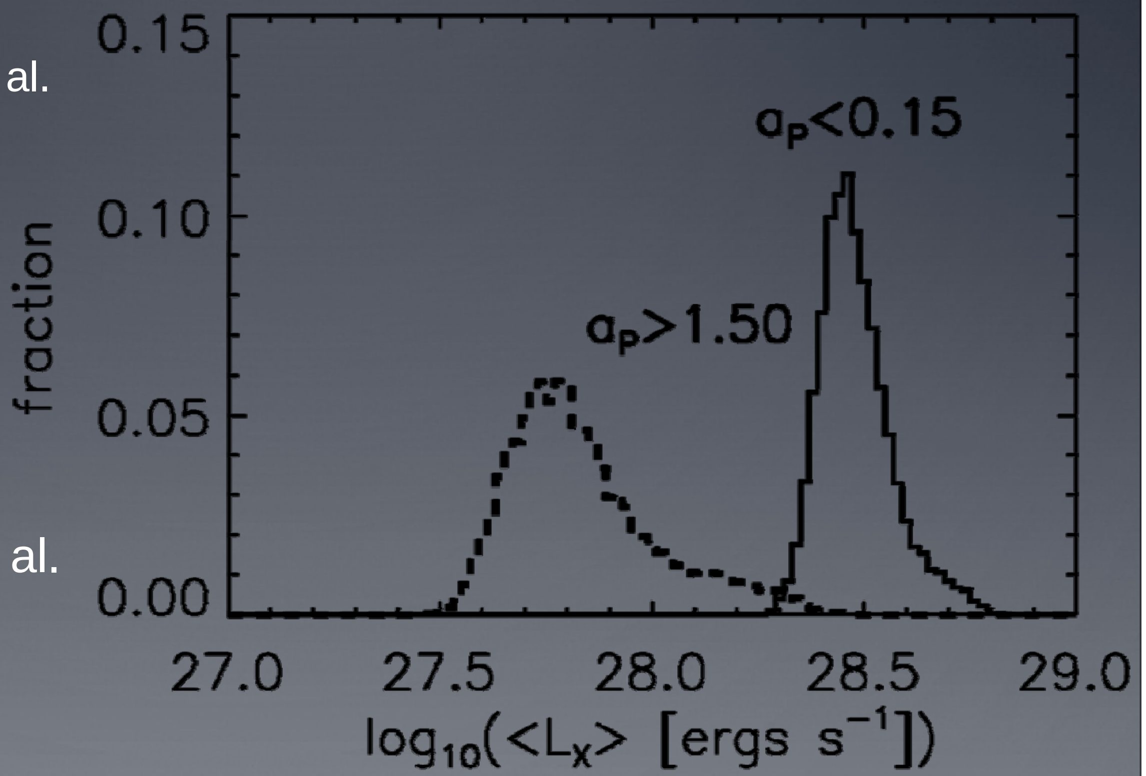
~ M_{jup}



see Matsakos et al. (2014)

What is the evidence exists 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 are disputed. (Poppenhager et al. 2010, 2011)



Kayshap et al. 2009