Observable Effects of Exoplanets on Stellar Hosts – Chandra in the Next Decade

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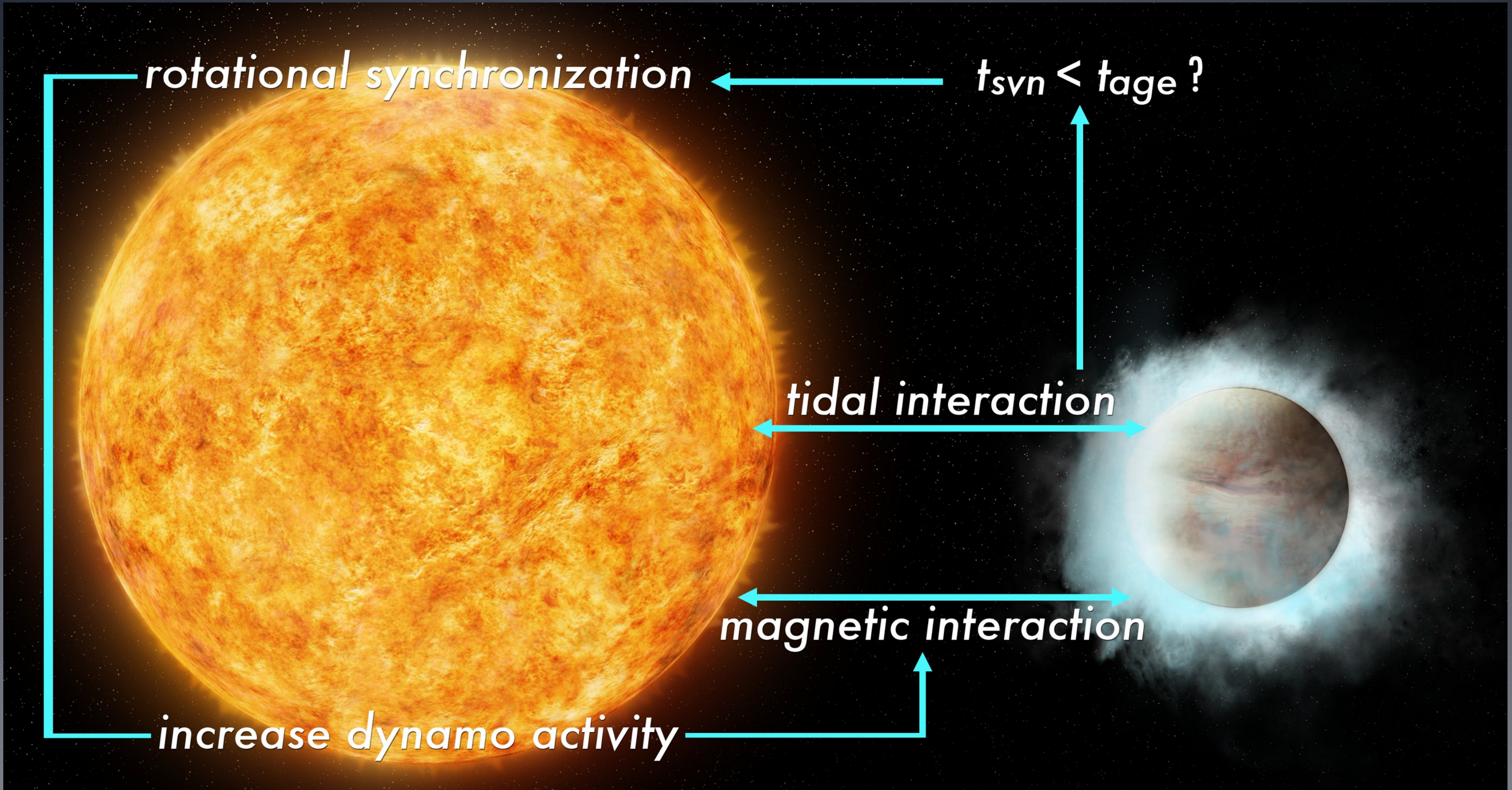
Star Planet Interaction



Cuntz et al. 2000

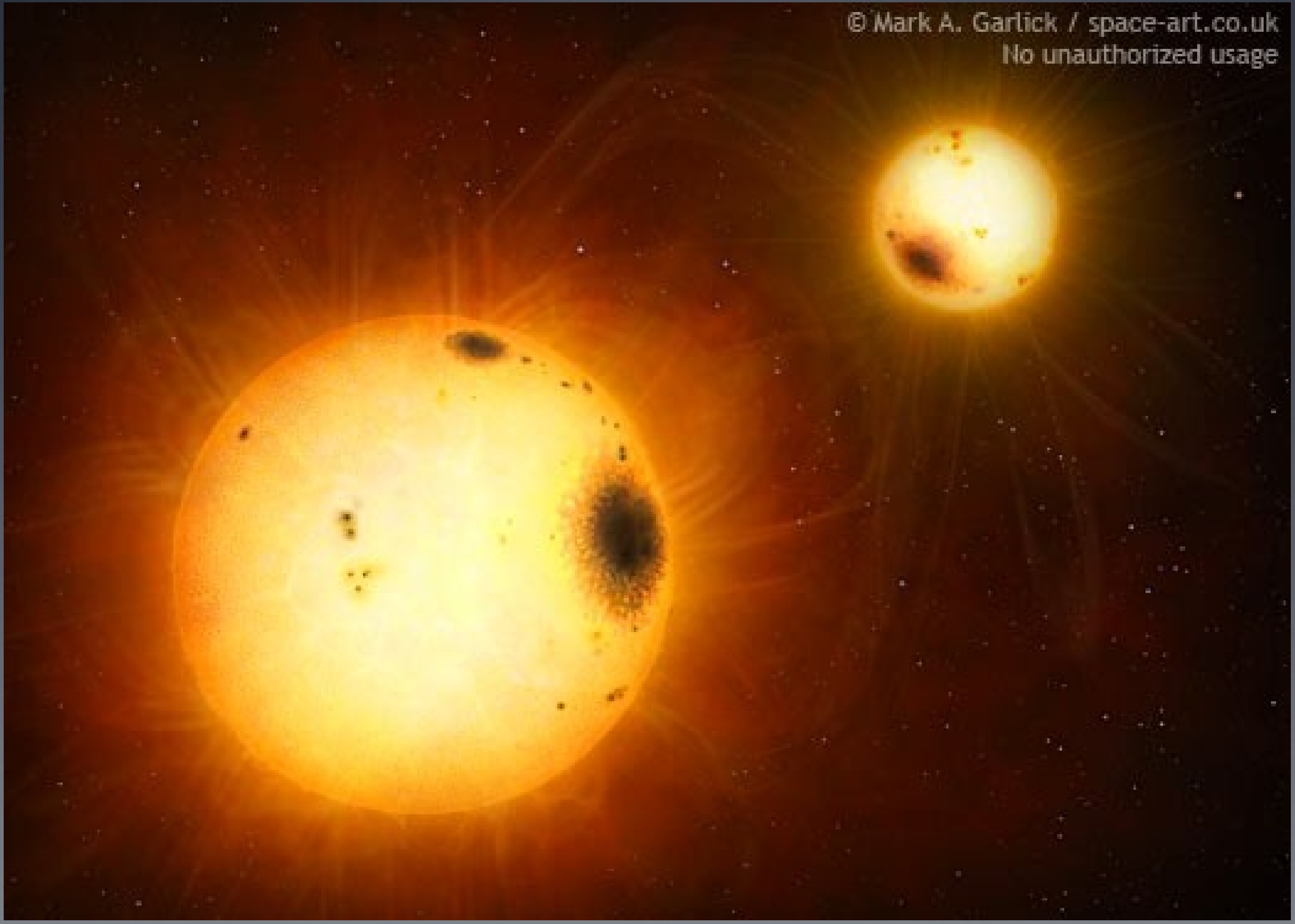
X-rays from stars effect exoplanets

- 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).

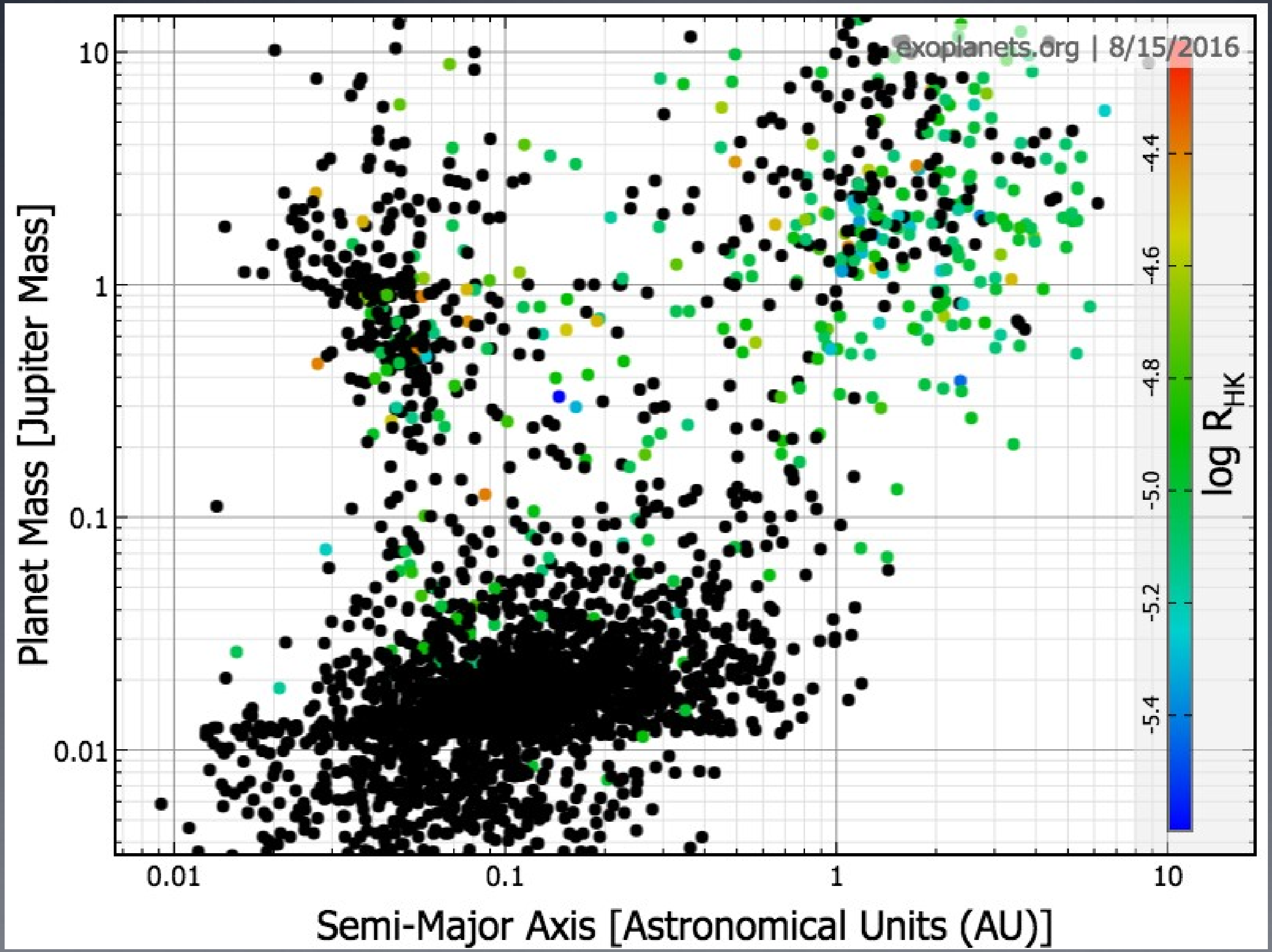
…Exoplanets may effect their host stars X-ray flux

- Analytic studies show □ $F_{recon} \propto a_p^{-3}$ (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.

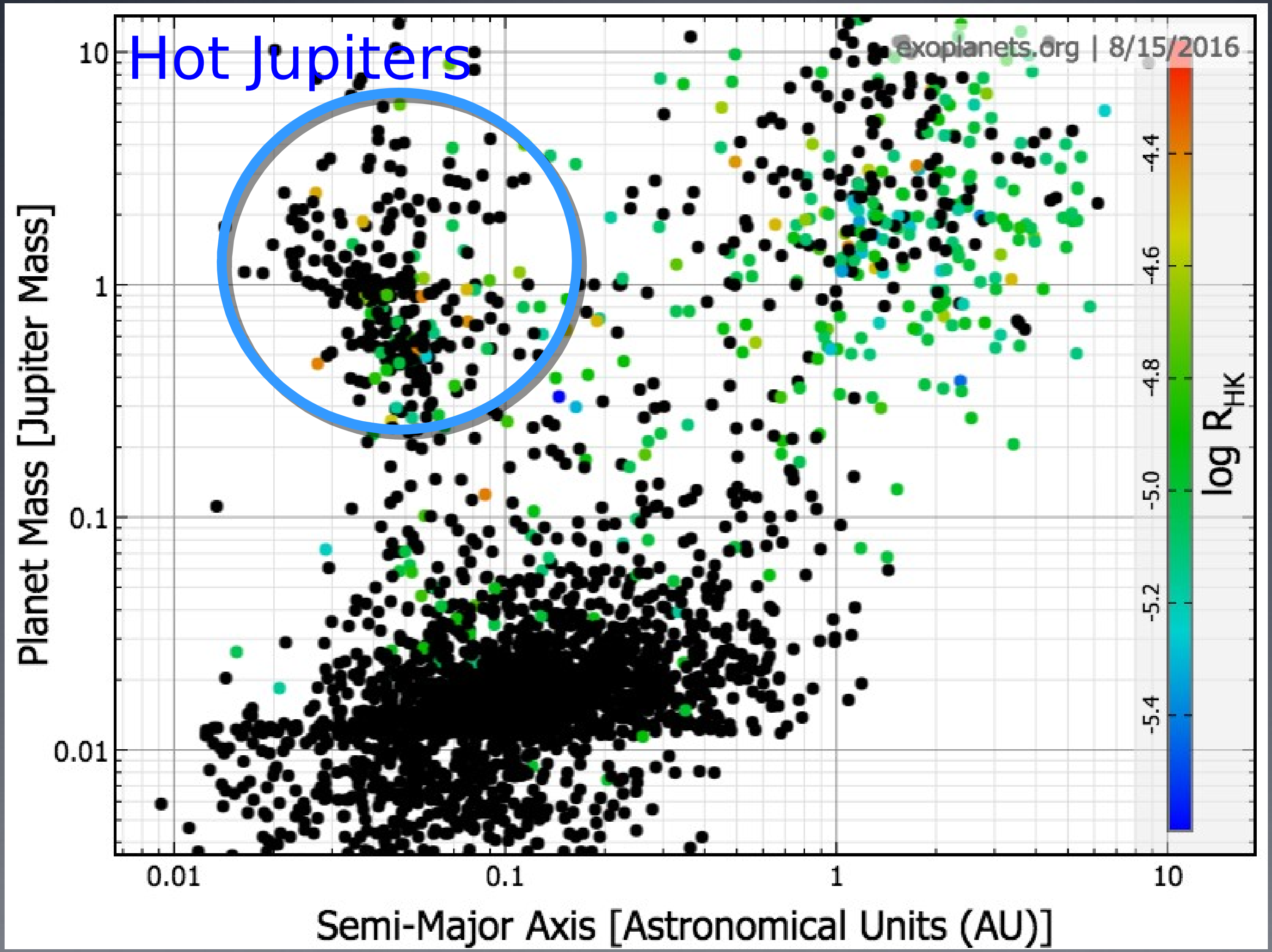
We know interactions happen



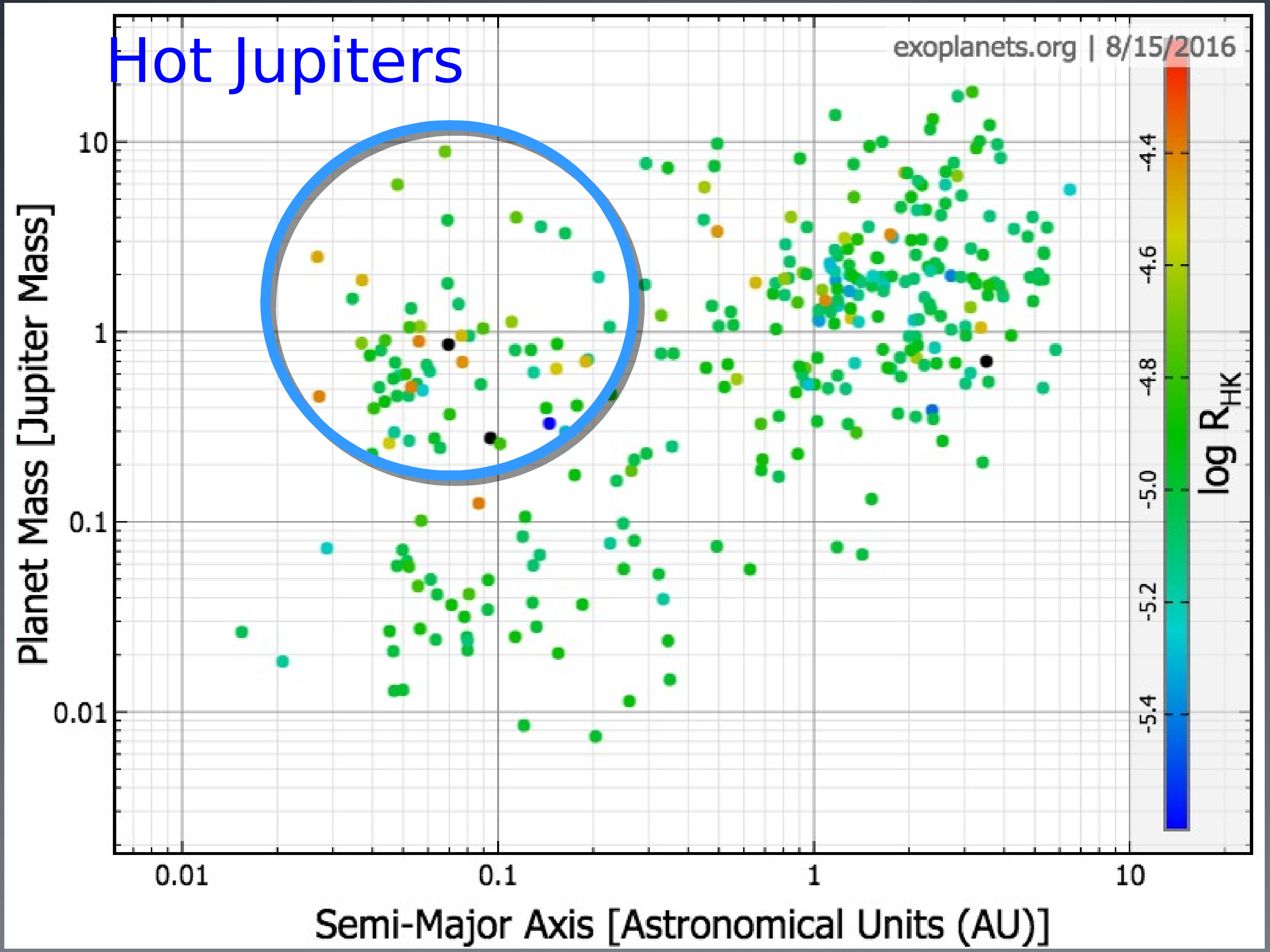
The Exoplanet zoo



The Exoplanet zoo



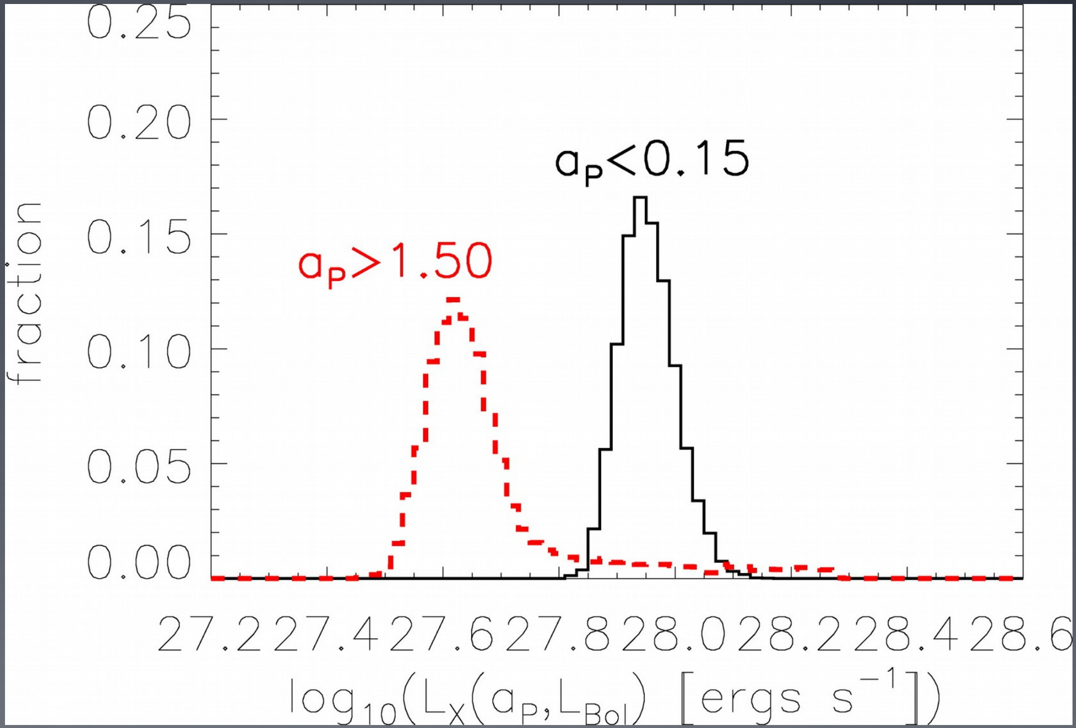
The Exoplanet zoo



Lies, Damn Lies, and Statistics

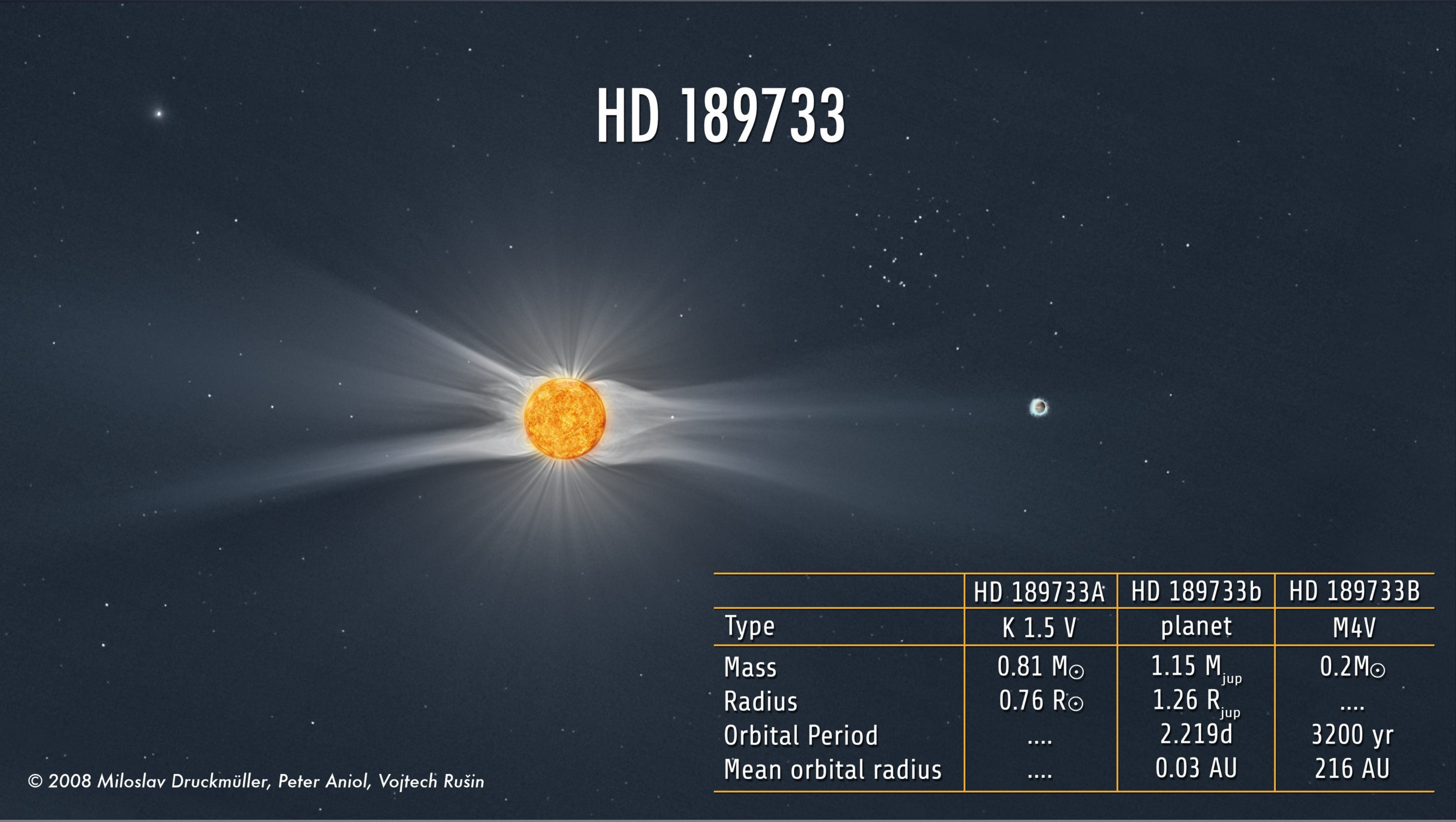
Complete statistical studies are complicated.

- Kashyap et al. (2008) found that stars with hot jupiters are statistically brighter in X-rays – even after accounting for statistical biases.
- Miller et al. (2015) used methods to combat biases and found a correlation between L_x and M_p/a^2, but concluded it was **driven by a handful of extreme systems.**
- This is consistent with the Kashyap result



Kashyap et al. (2008)

One extreme system



	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

2D wavelet analysis of 2012 light curve

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

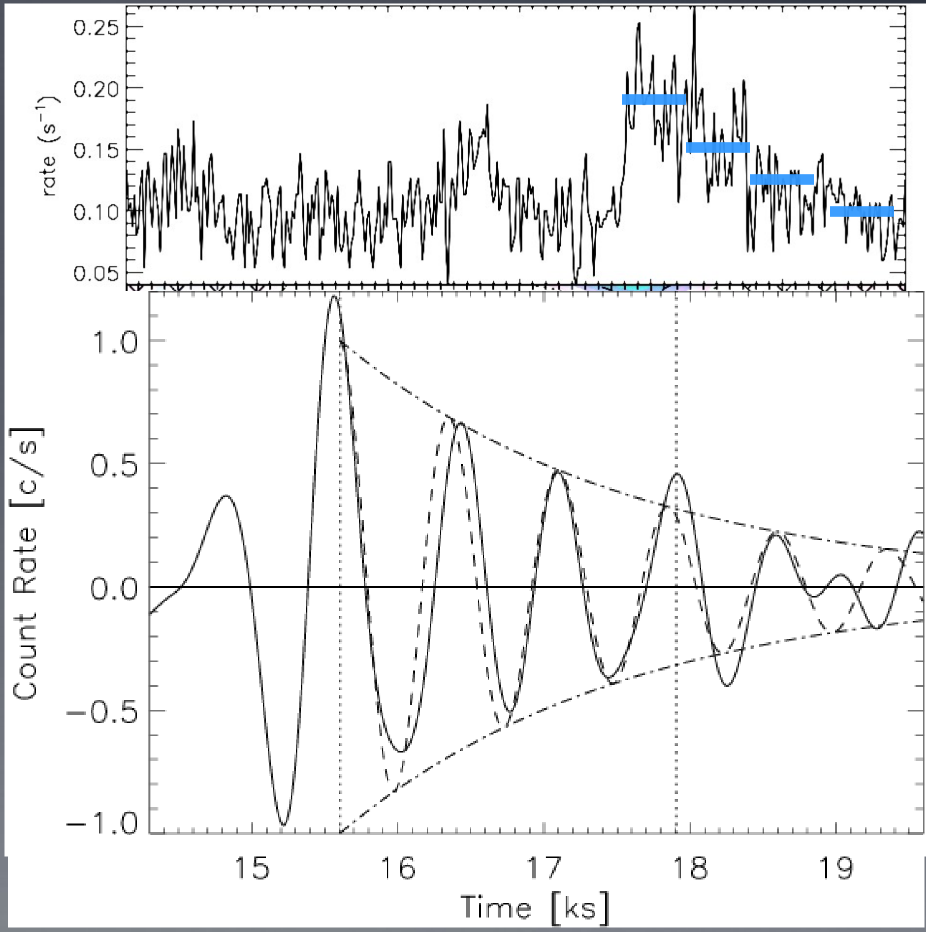
$\Delta I/I \sim 4\pi n k_B T/B^2$

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 $\tau_{osc} N T^{0.5}$

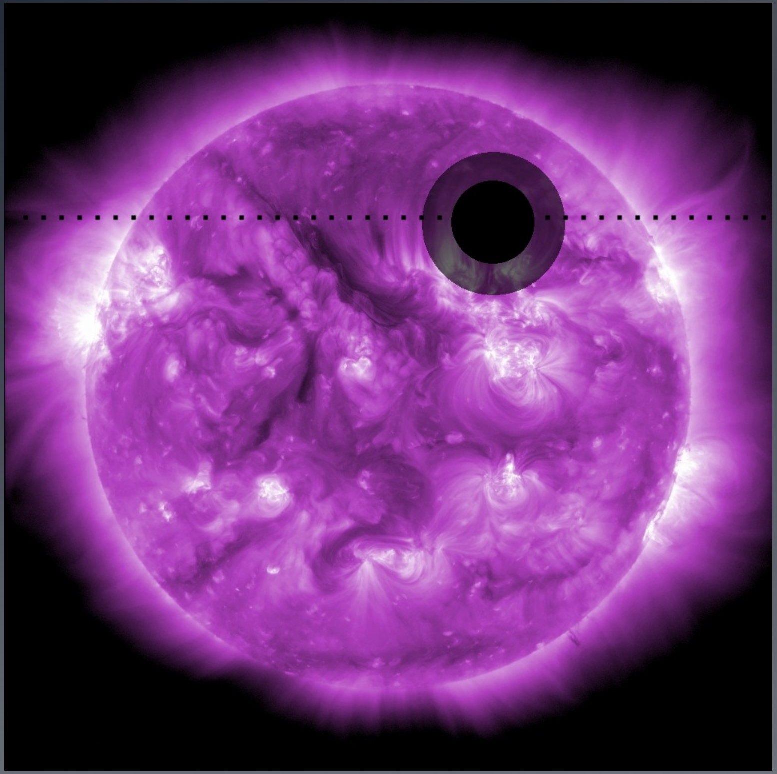
L~ 4 R_*

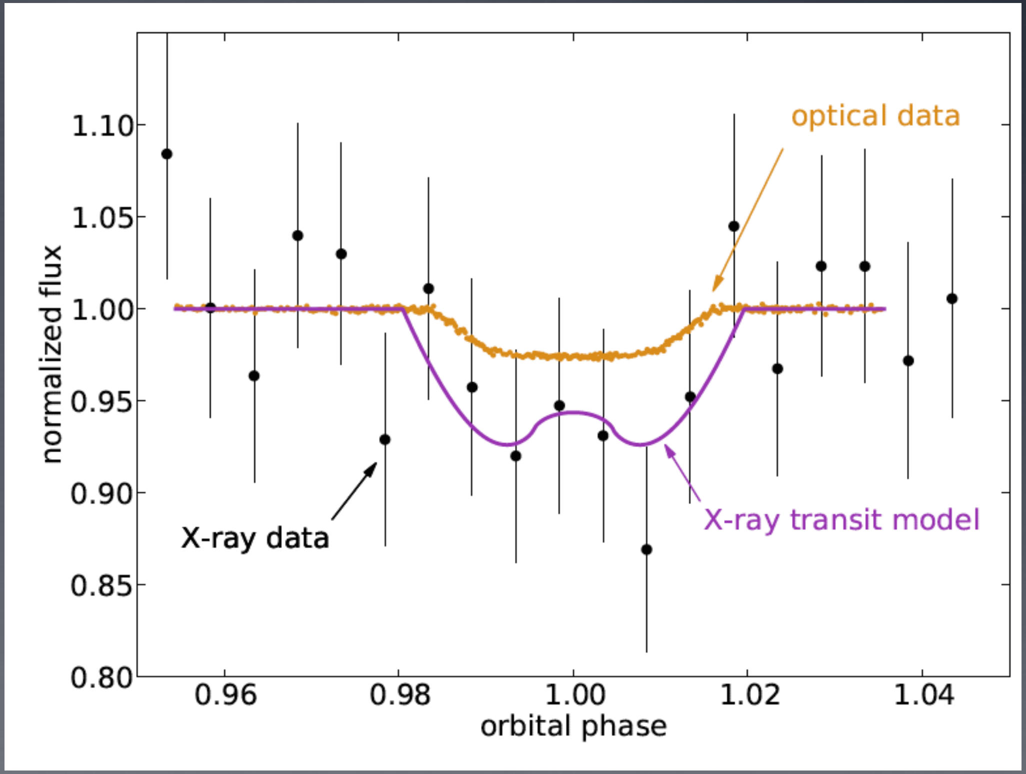


[see Mitra-Kraev et al. (2005)]

Implication of the wavelet analysis

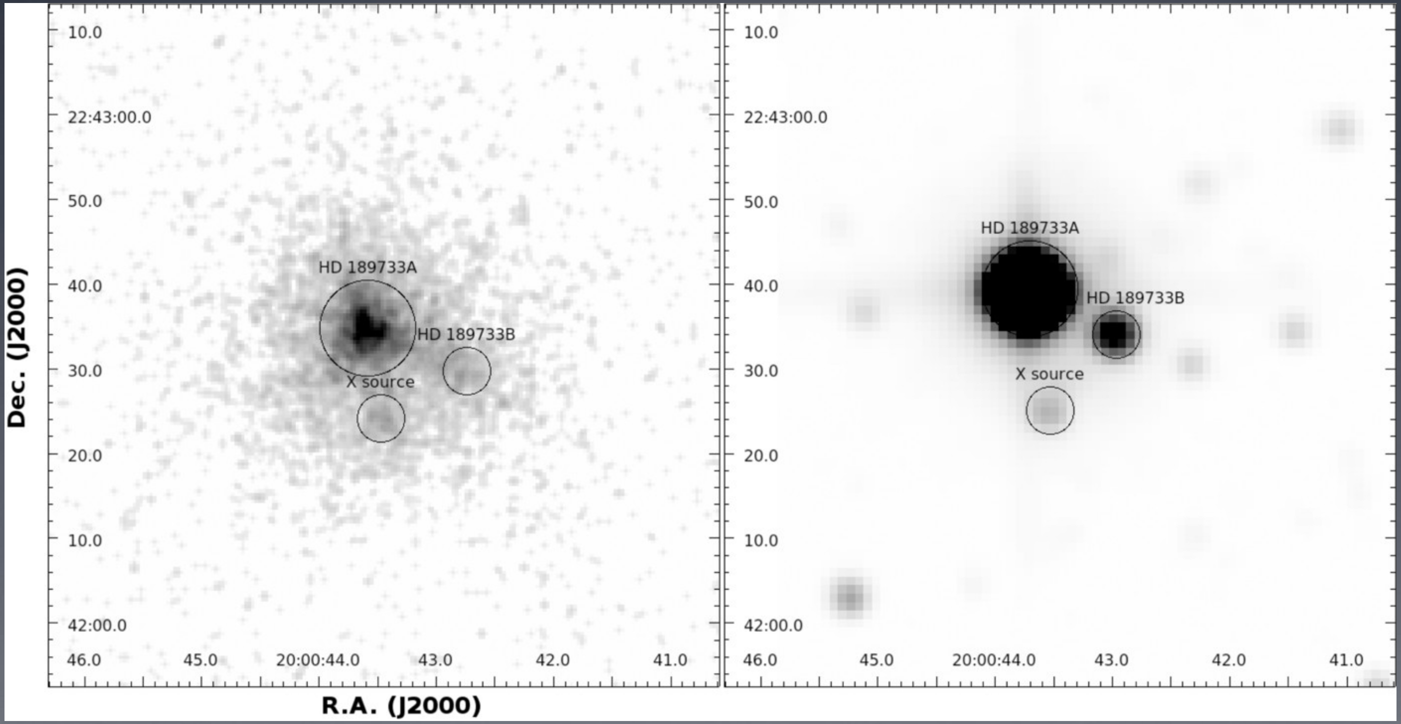
Transit of HD 189733 – 7 CXO observations co-added





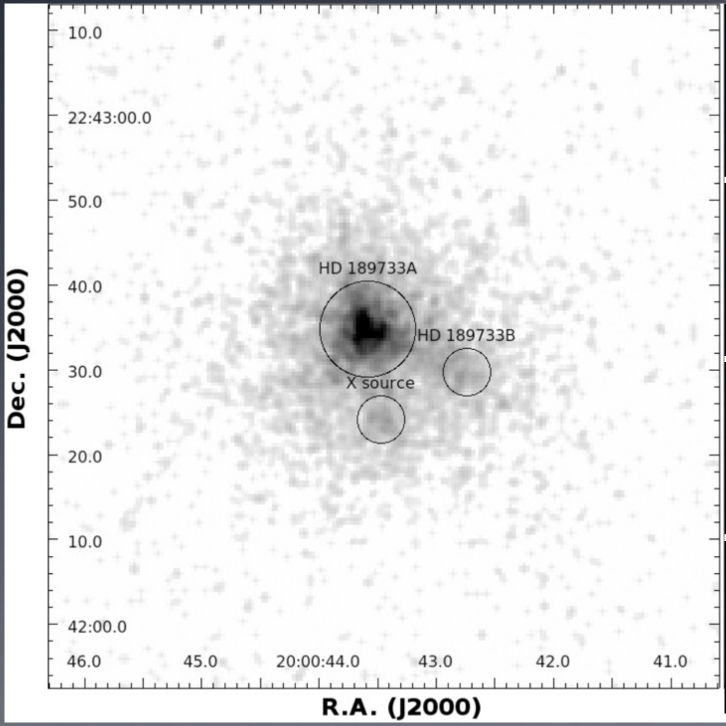
Poppenhaeger, Schmidt & Wolk (2013)

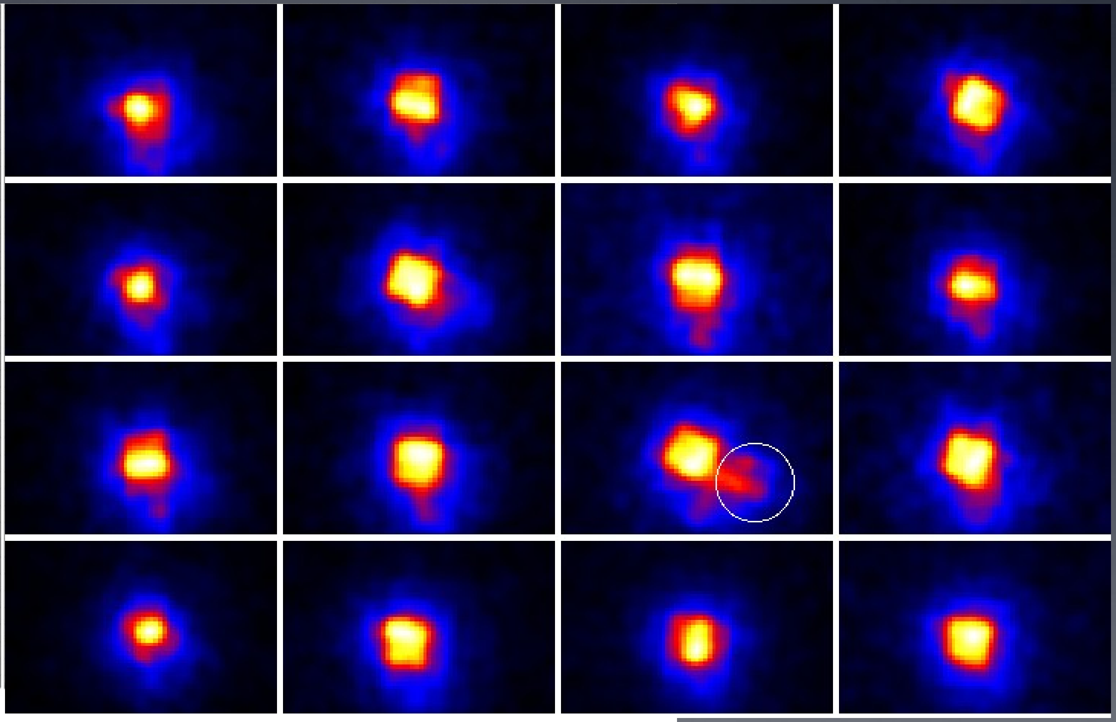
XMM Large Project



[Wheatley PI]

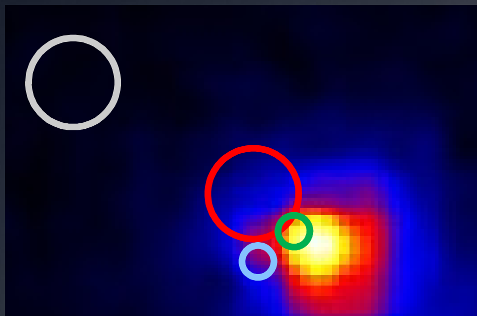
XMM Large Project

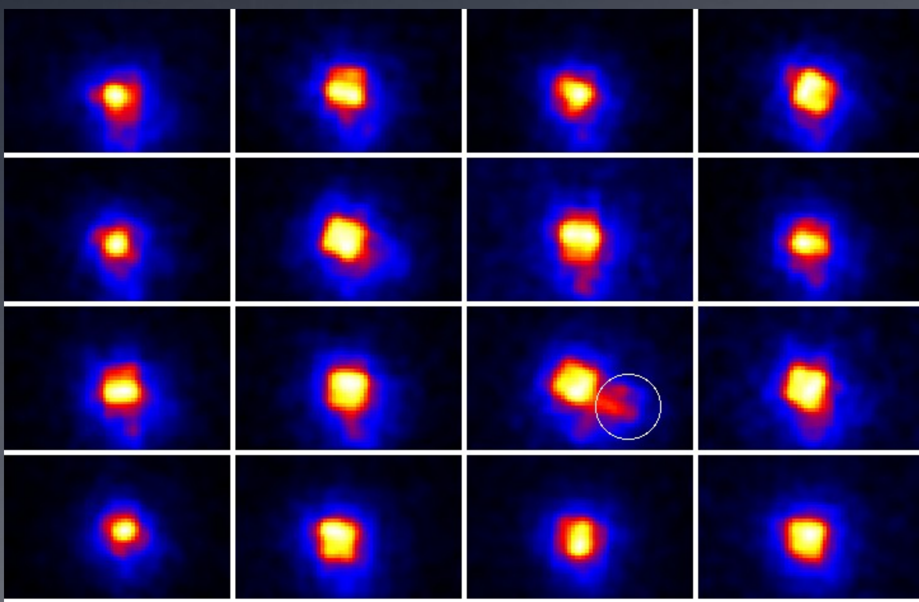


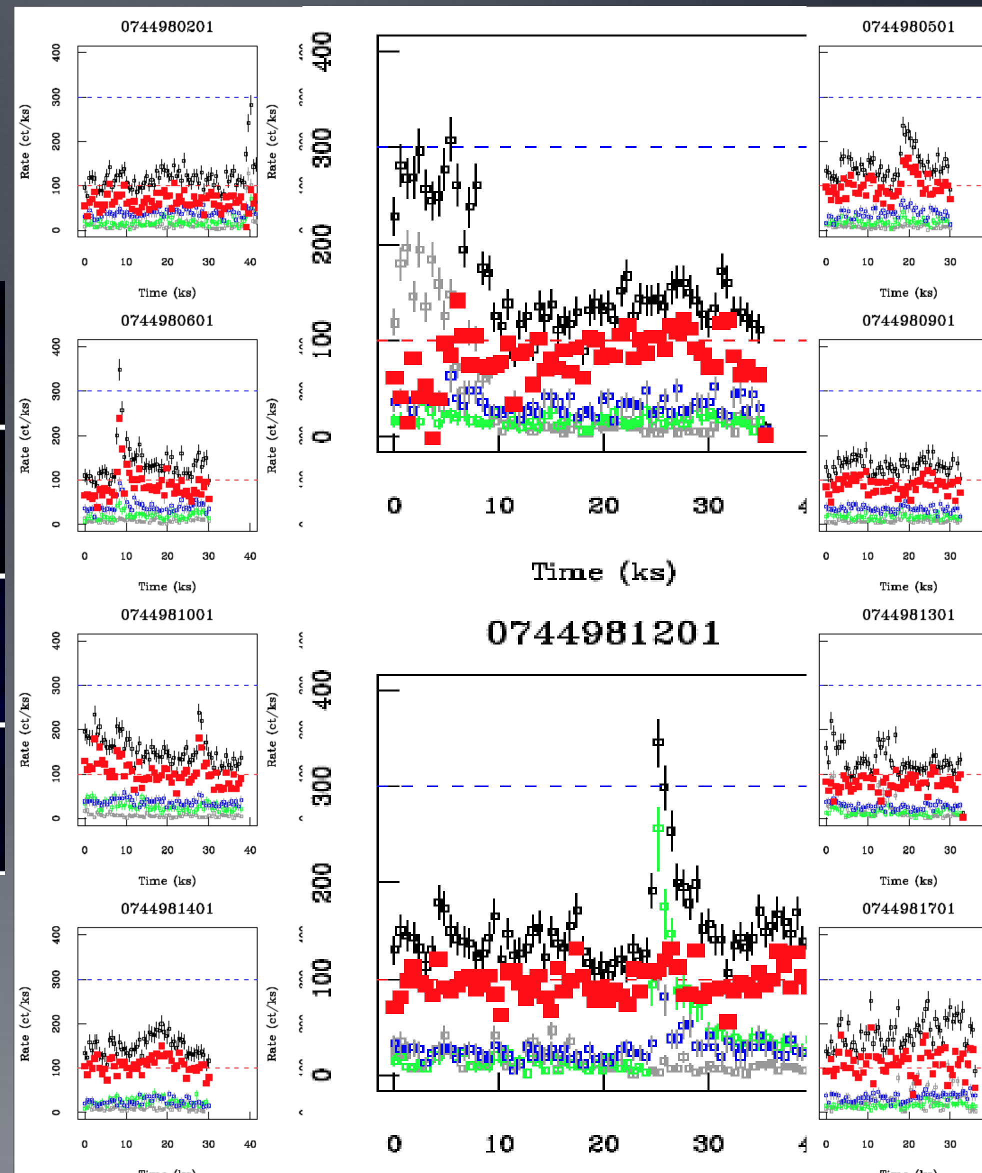


[Wheatley PI]

Challenges

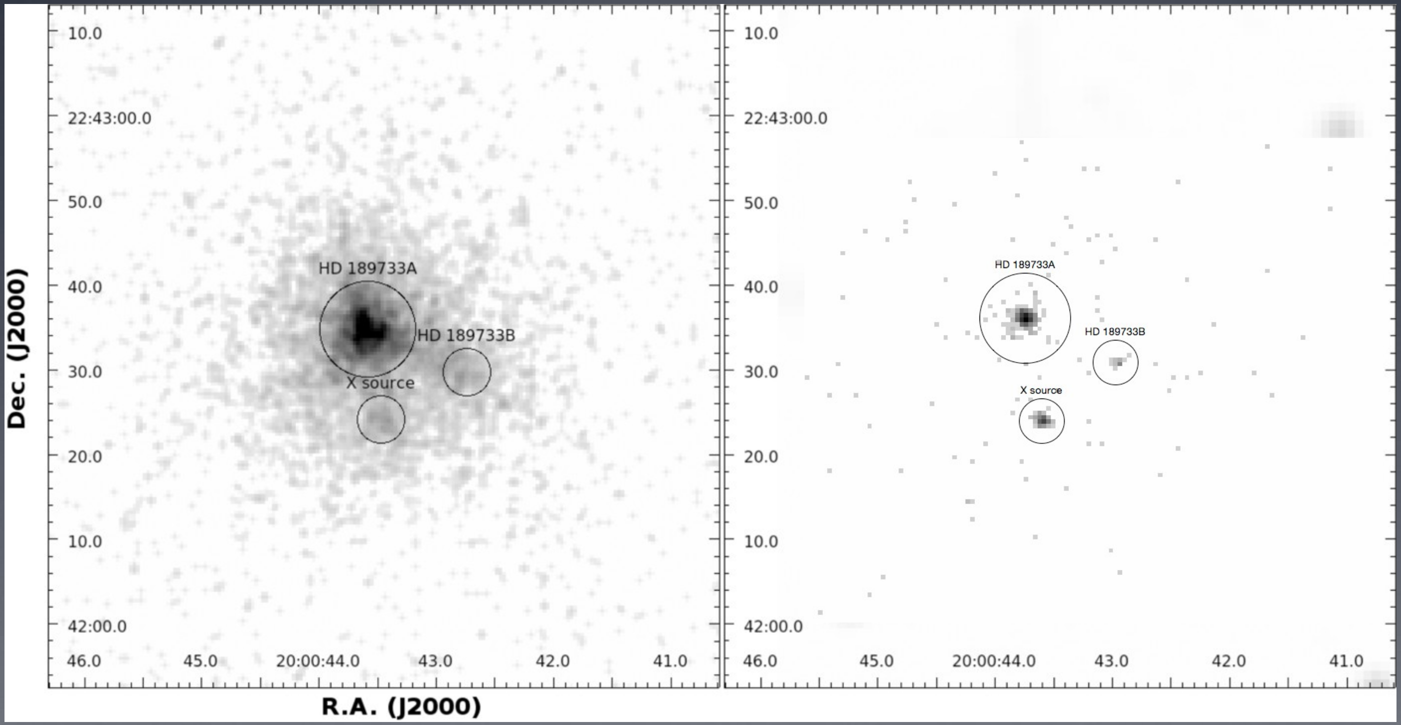





0744980201
0744980601
0744981001
0744981401
0744980501
0744980901
0744981301
0744981701
0744981201
Rate (ct/ks)
Time (ks)

Much stronger Chandra project

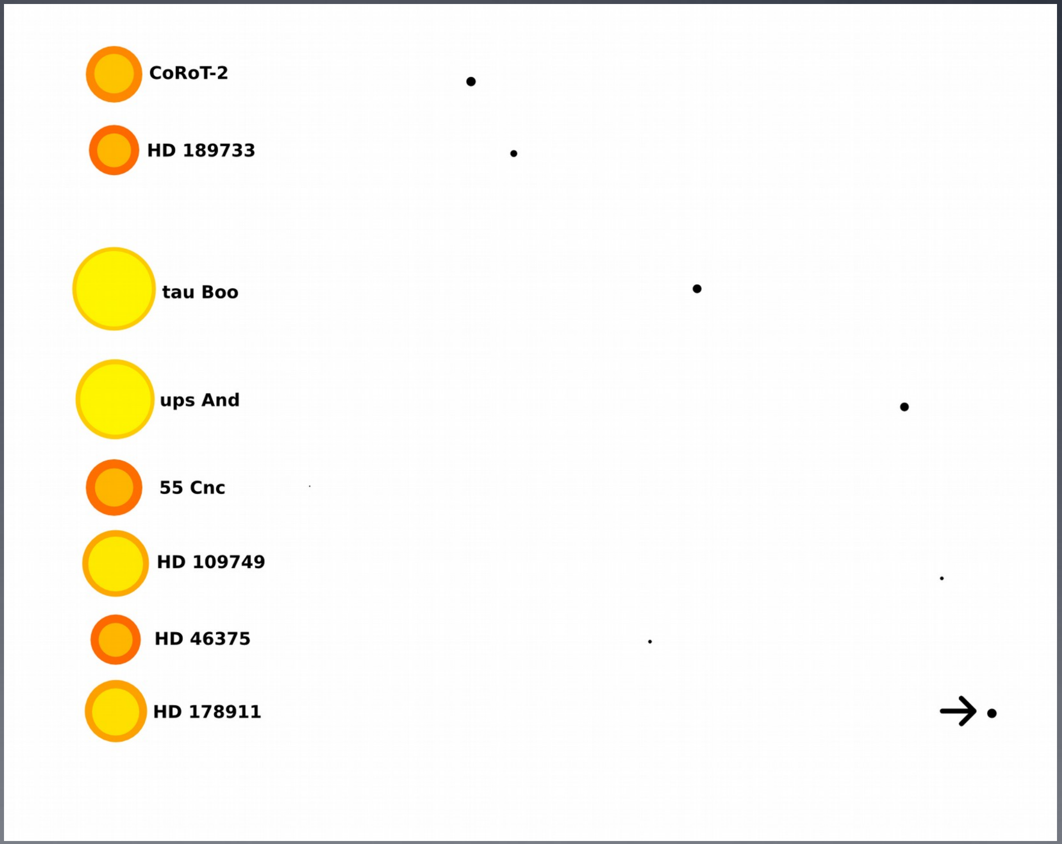
- With XMM PN   S:N 40 per ks with large background flares
- Sources of astrophysical noise include variability of variability of HD 189733A HD 189733B and the `X' source for XMM



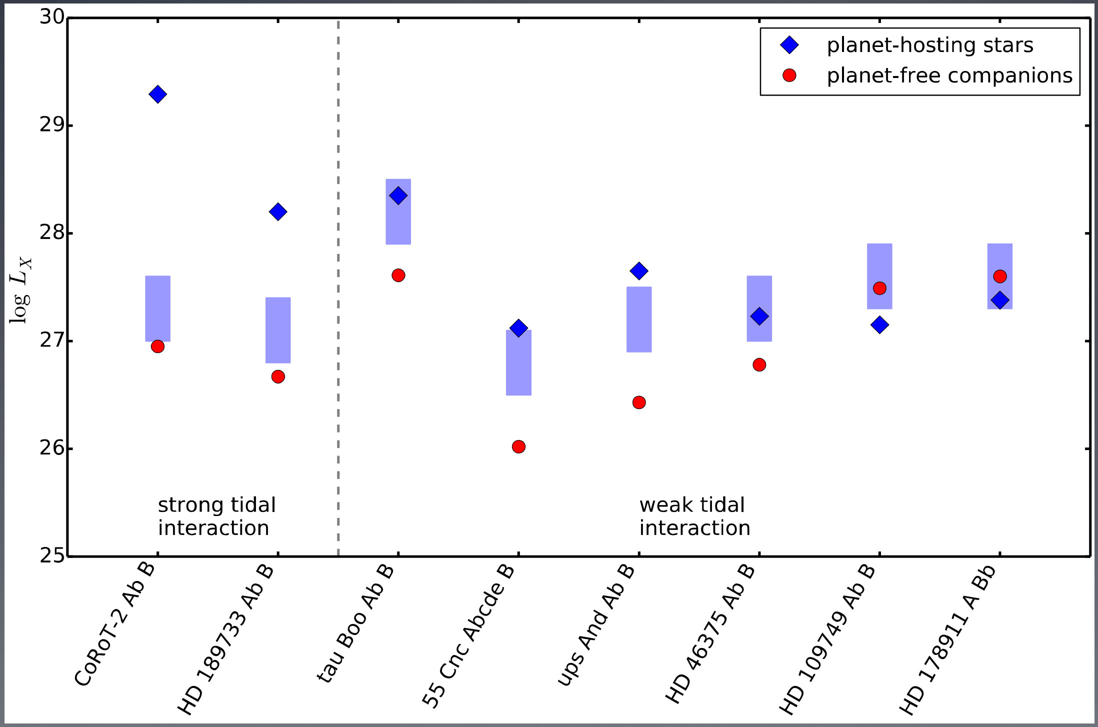
- With Chandra, non- astrophysical noise is about 1 count per PSF per 100 ks.
- Signal is 60 per ks
- With no contamination – but low energy effective area maybe an issue.

Binaries as probes of spin-up

Since global statistics maybe diluted, we have been observing binary pairs wherein one star hosts a close in planet. In the figure, the planet free companion is used to predict the X-ray flux of the hot jupiter host (blue region), The actual observations are shown as blue points. The two cases with the most massive and close-in planets and convective hosts show the strongest excesses.



Spin Up by Hot Jupiters



This is now 15 systems:
Poppenhaeger & Wolk (2016) - Submitted

X-rays and exoplanets: Status 2016

1. In extreme cases… through tidal effects, Hot Jupiter's can spin-up stars with large convective zones.

2. We have seen a planetary transit in X-rays and the planet is much "bigger" in X-rays than in any other wavelength.

3. Through magnetic effects planets appear to induce active regions on the stellar surface.

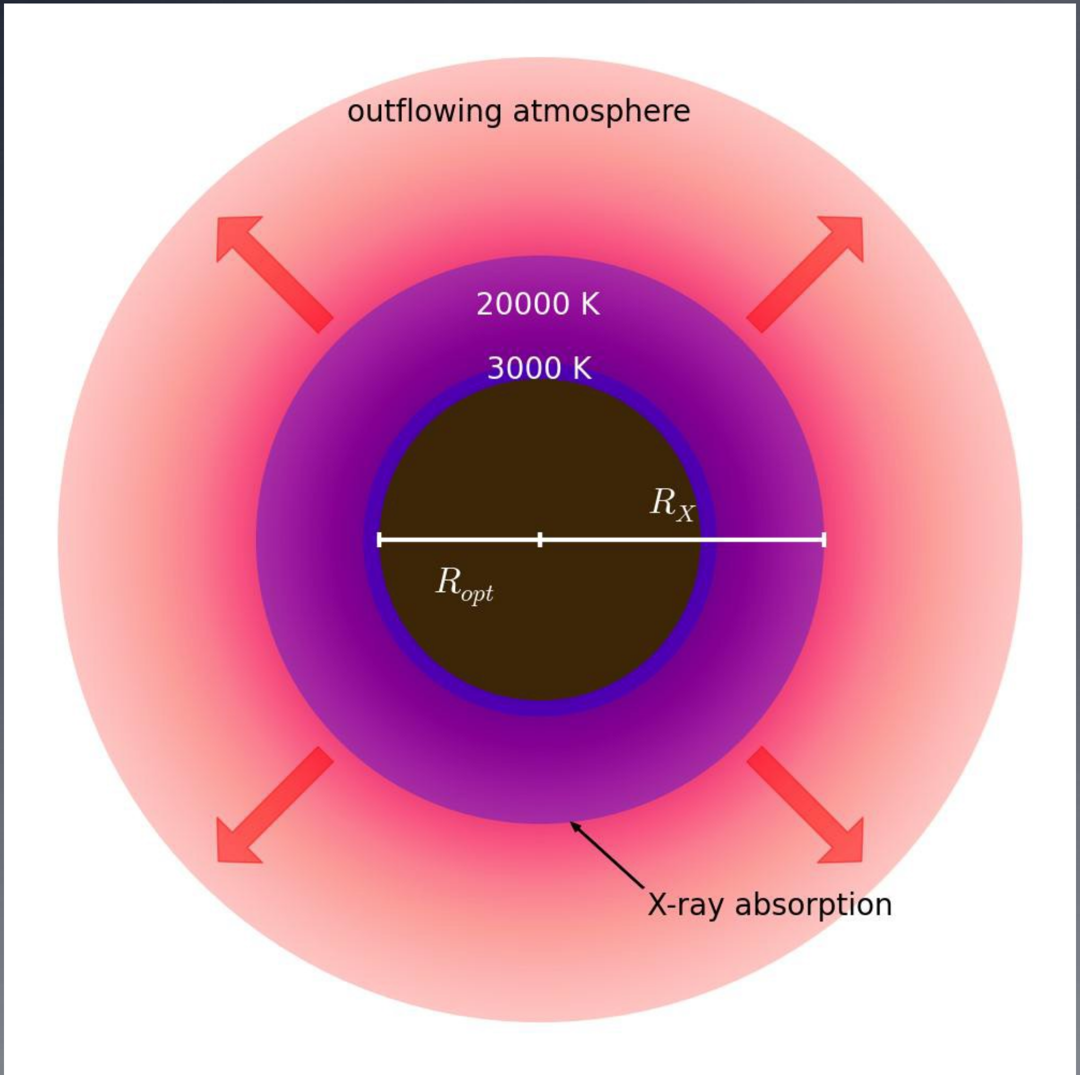
4. This activity can include system scale stellar flares.

The Future is Bright…

…X-ray sources with transiting hot jupiters

- There are about 50,000 stars in the RASS.
  - These have Chandra count rates > 0.014 cps.
- About 14,000 RASS sources at in the Tycho catalog with V> 11.5 – within the TESS survey.
- Somewhere between 0.3 and 1.3 percent of all stars host a hot Jupiter (cf. Wright 2012).
  - 150-650 RASS sources are Hot Jupiter hosts.
    - Assume 250 (0.5%)
  - Probability of a transit of a hot system is ~ 15%
  - More than 35 X-ray bright transiting sources.

Planetary Atmosphere : Toy Model



$H = kT/\mu_m g$

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

Miller-Ricci & Fortney (2010)

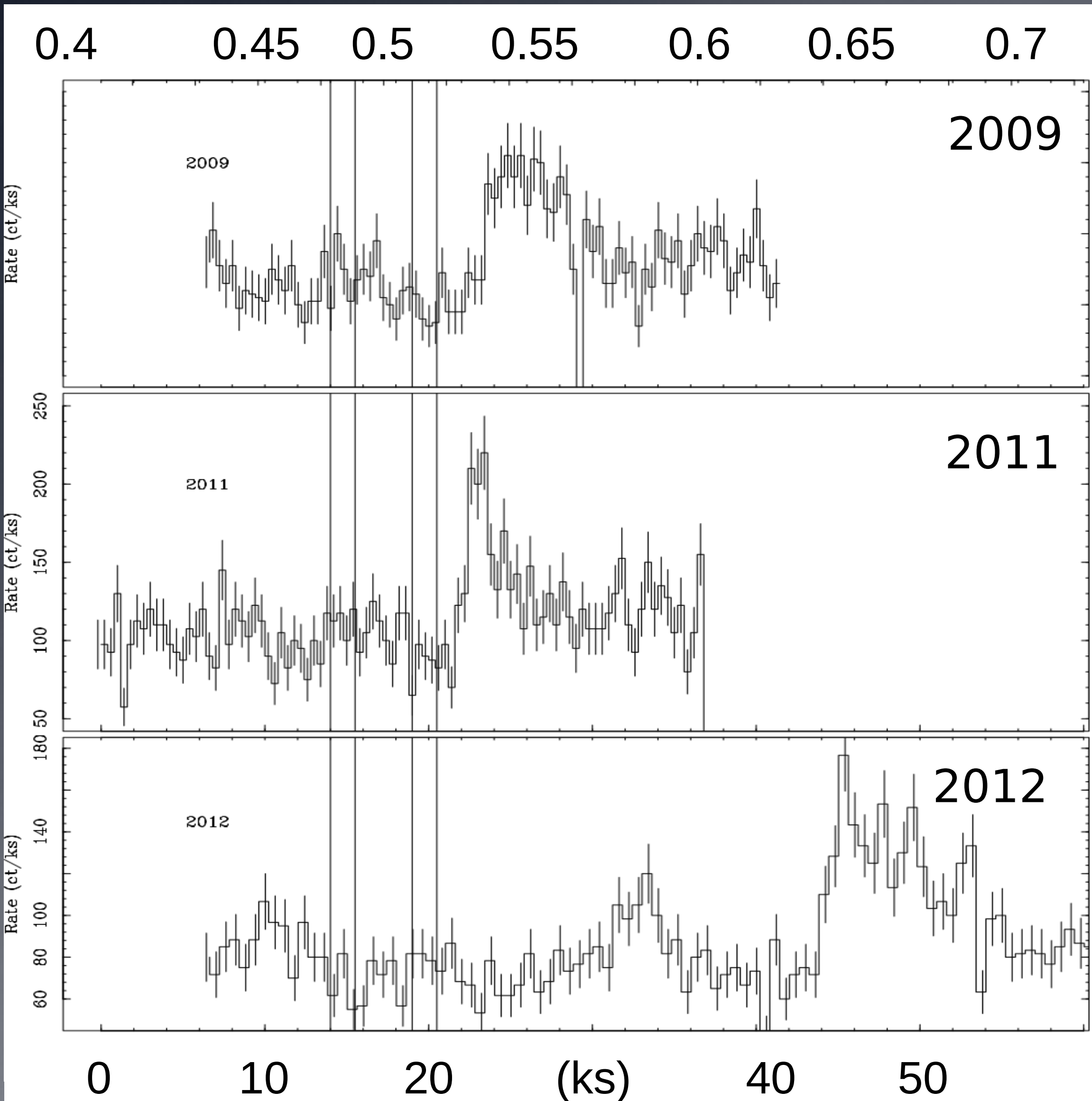
To be X-ray opaque
density at $1.75R_{Pl}$: 10^{11} cm^{-3}

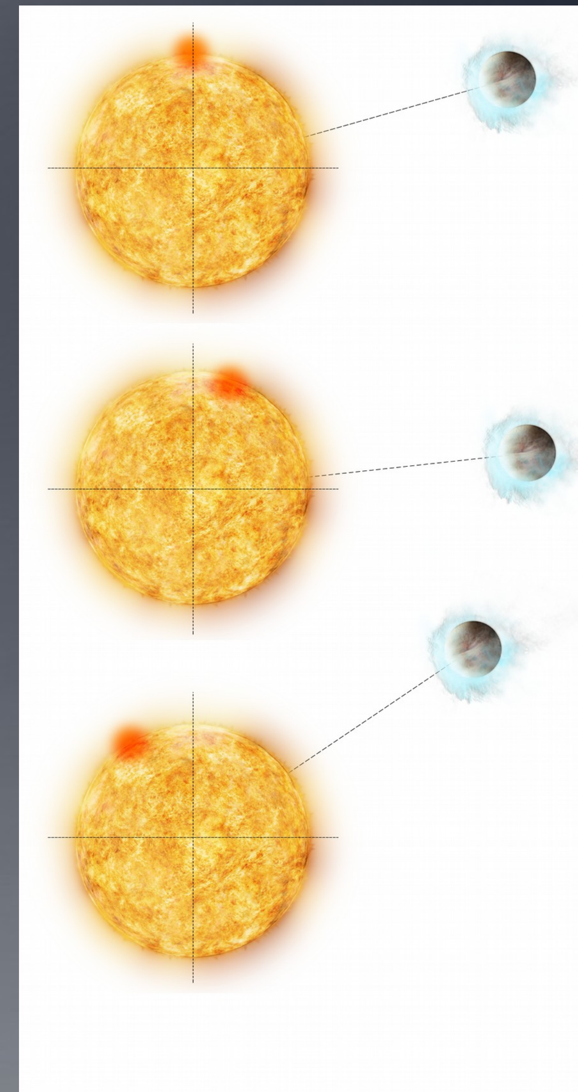
high-altitude temperature:
~ 20,000K

Poppenhaeger, Schmitt & Wolk (2013)

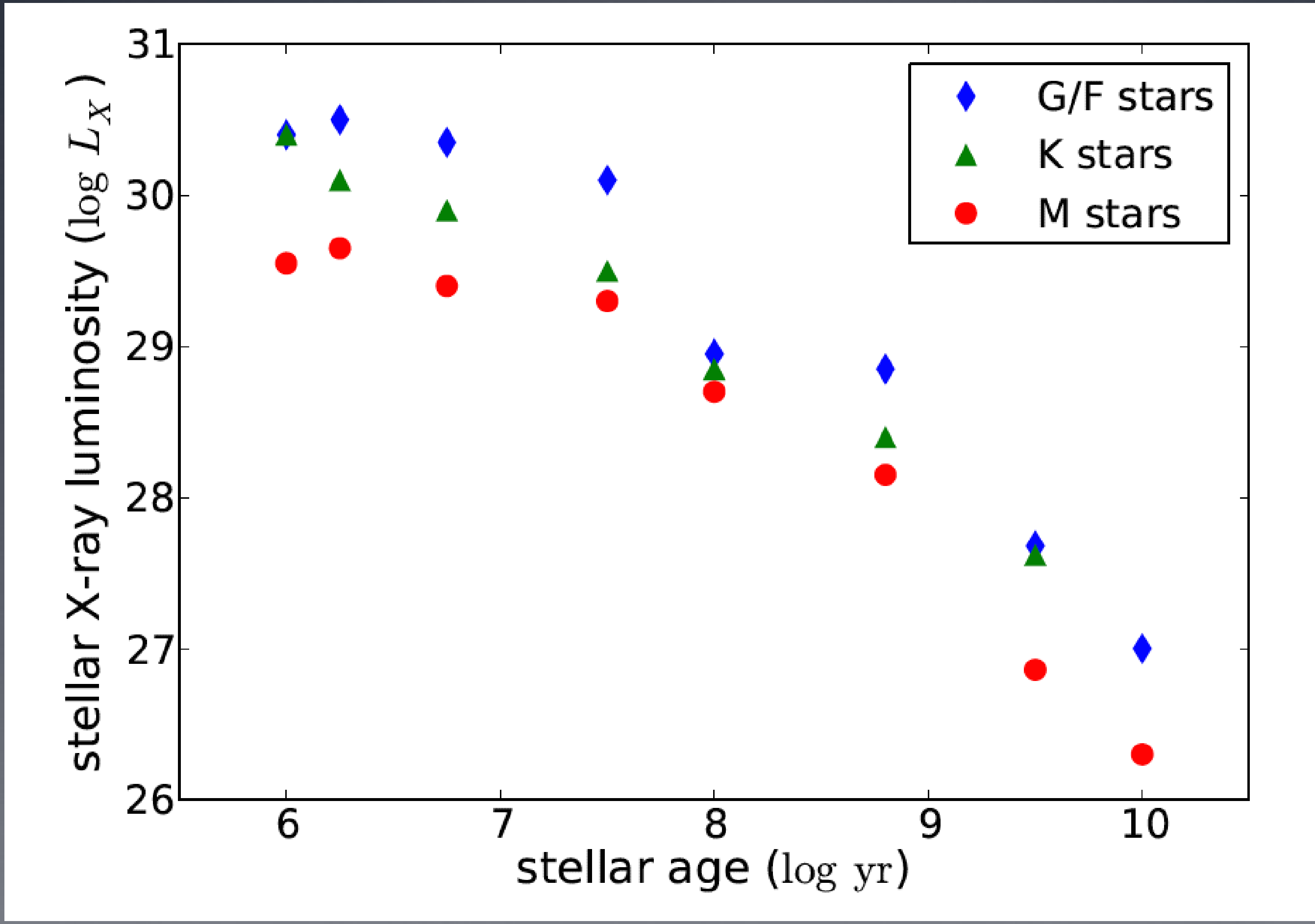
Phased Time Variability?

Pillitteri et al. (2014)





Base Plot


31
30
29
28
27
26
6
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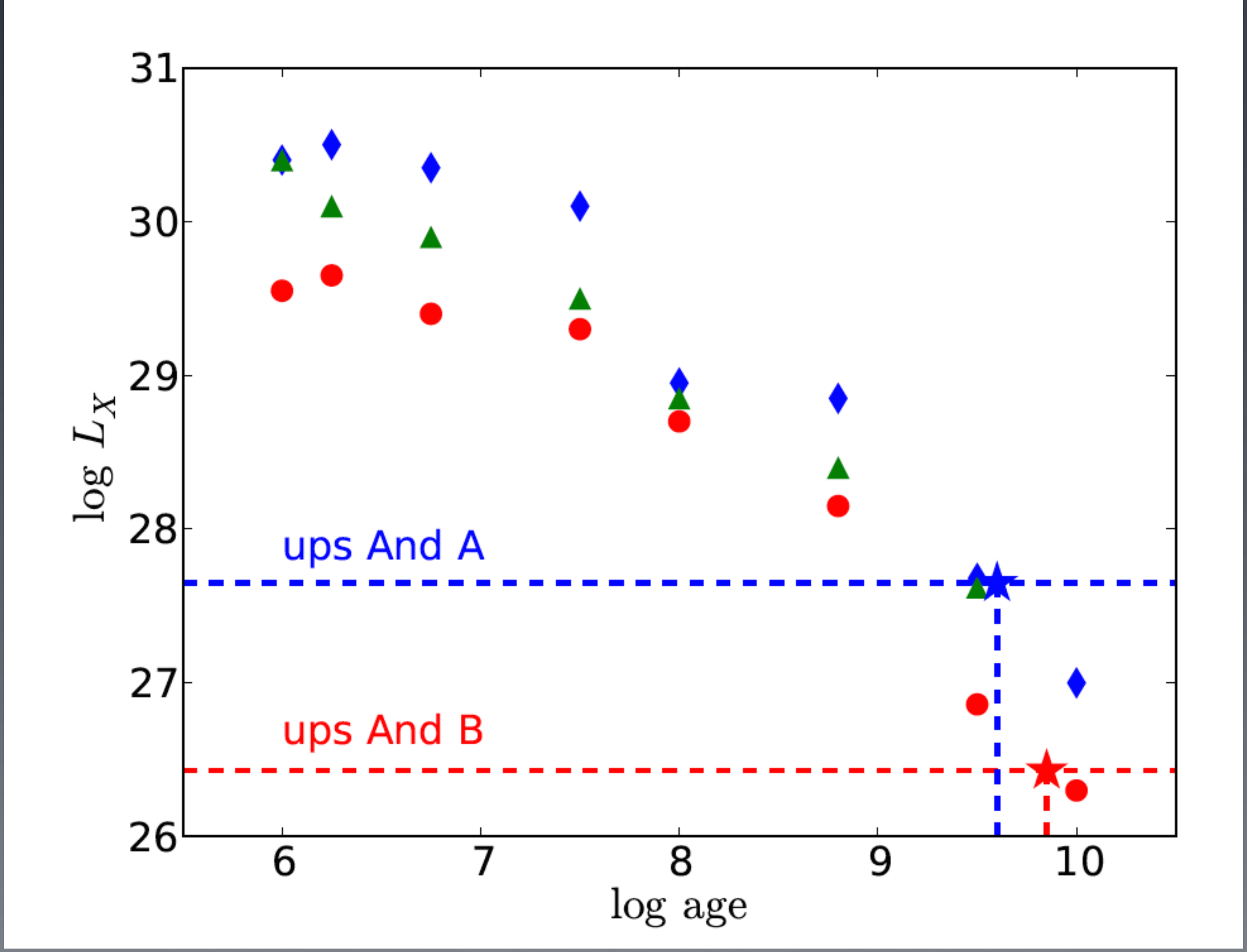
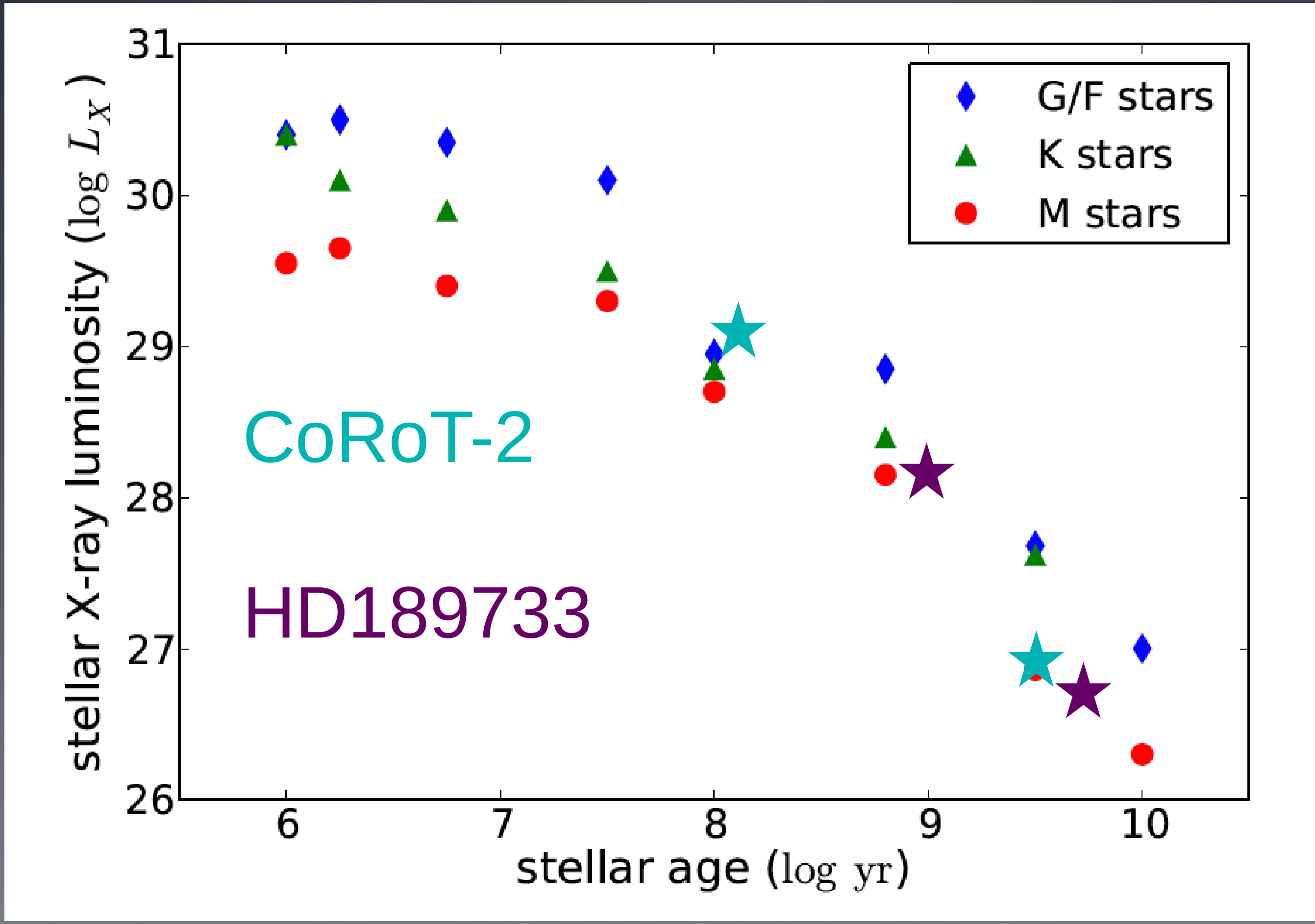
9
10
stellar X-ray luminosity ($\log L_X$)
stellar age ($\log$ yr)
G/F stars
K stars
M stars

Age/activity in the weak tidal interaction case



Poppenhaeger & Wolk (2014)

Age/activity in the strong tidal interaction case



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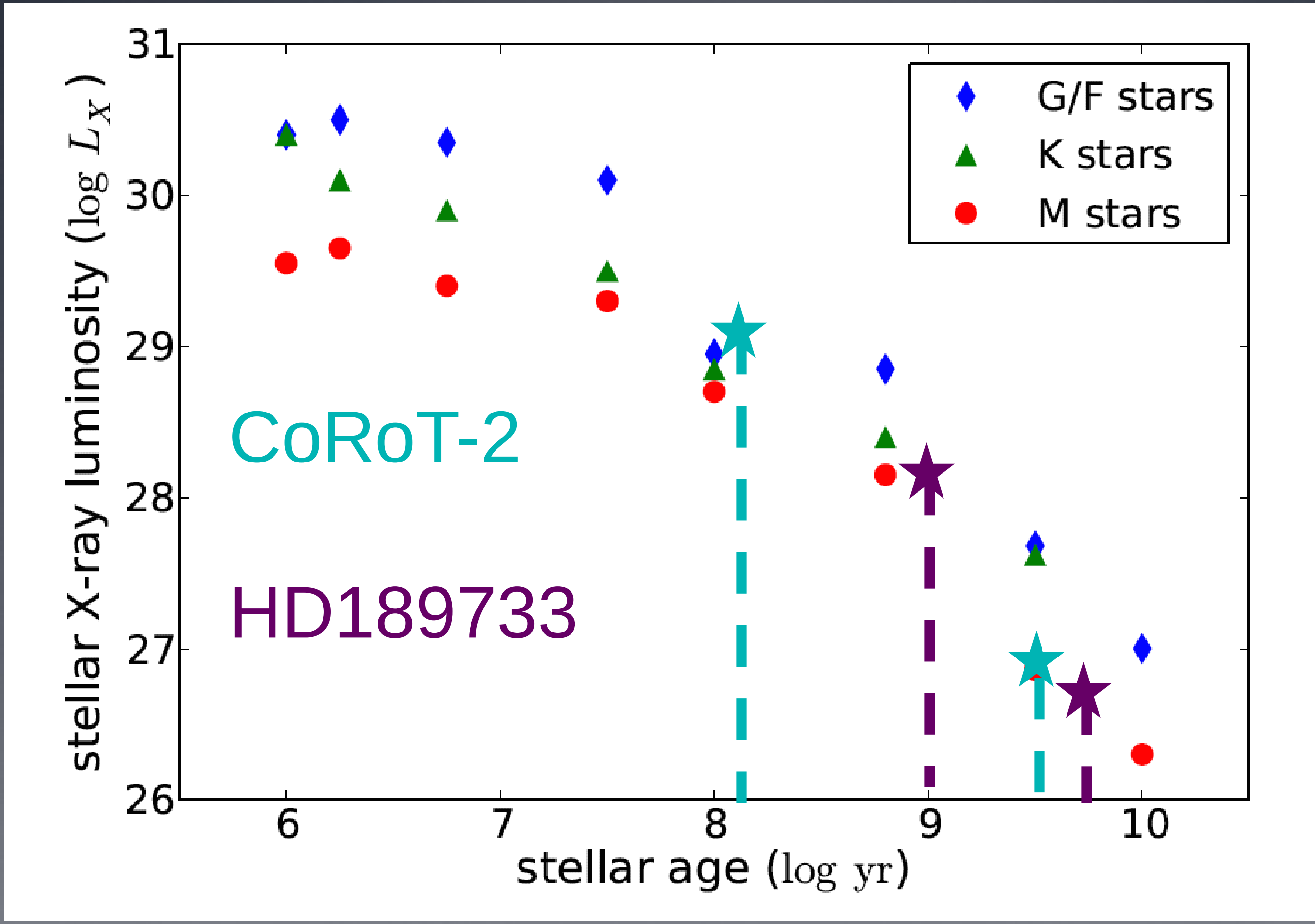
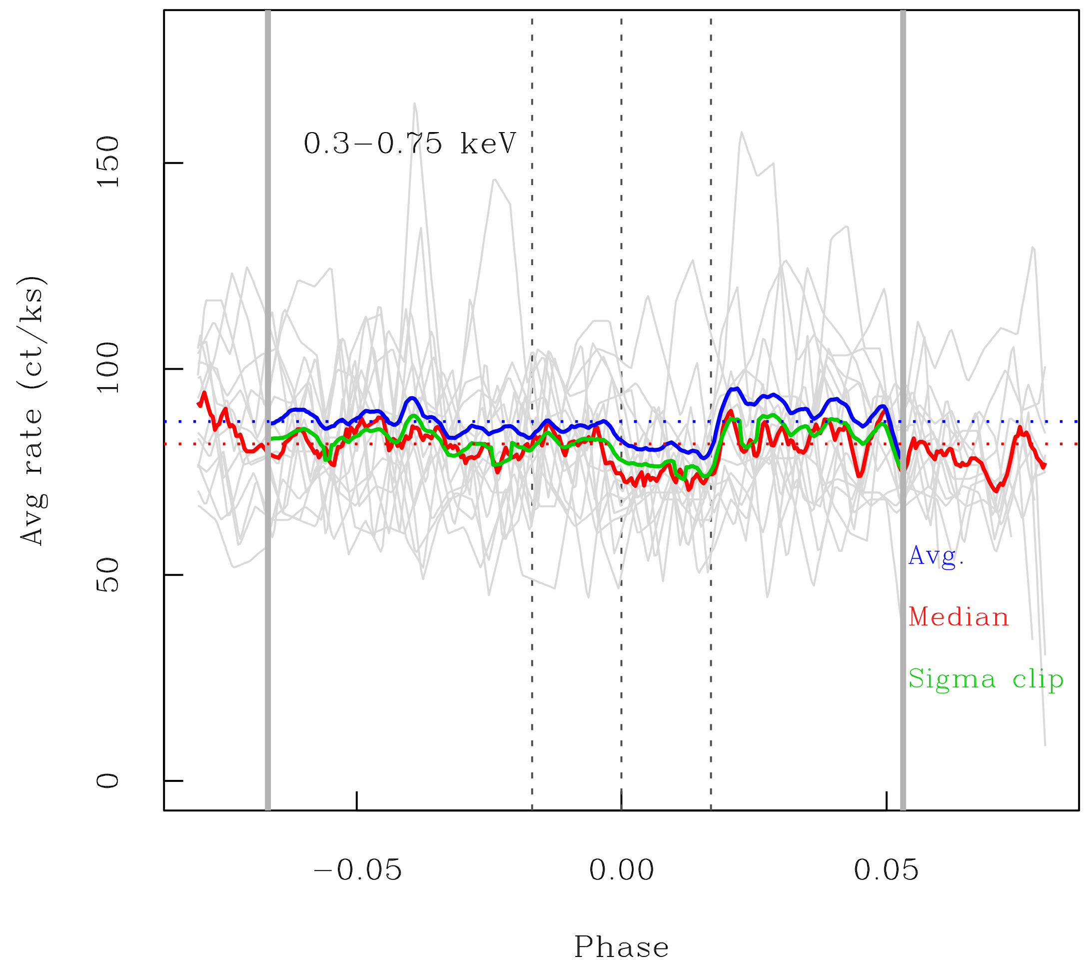


Poppenhaeger & Wolk (2014)

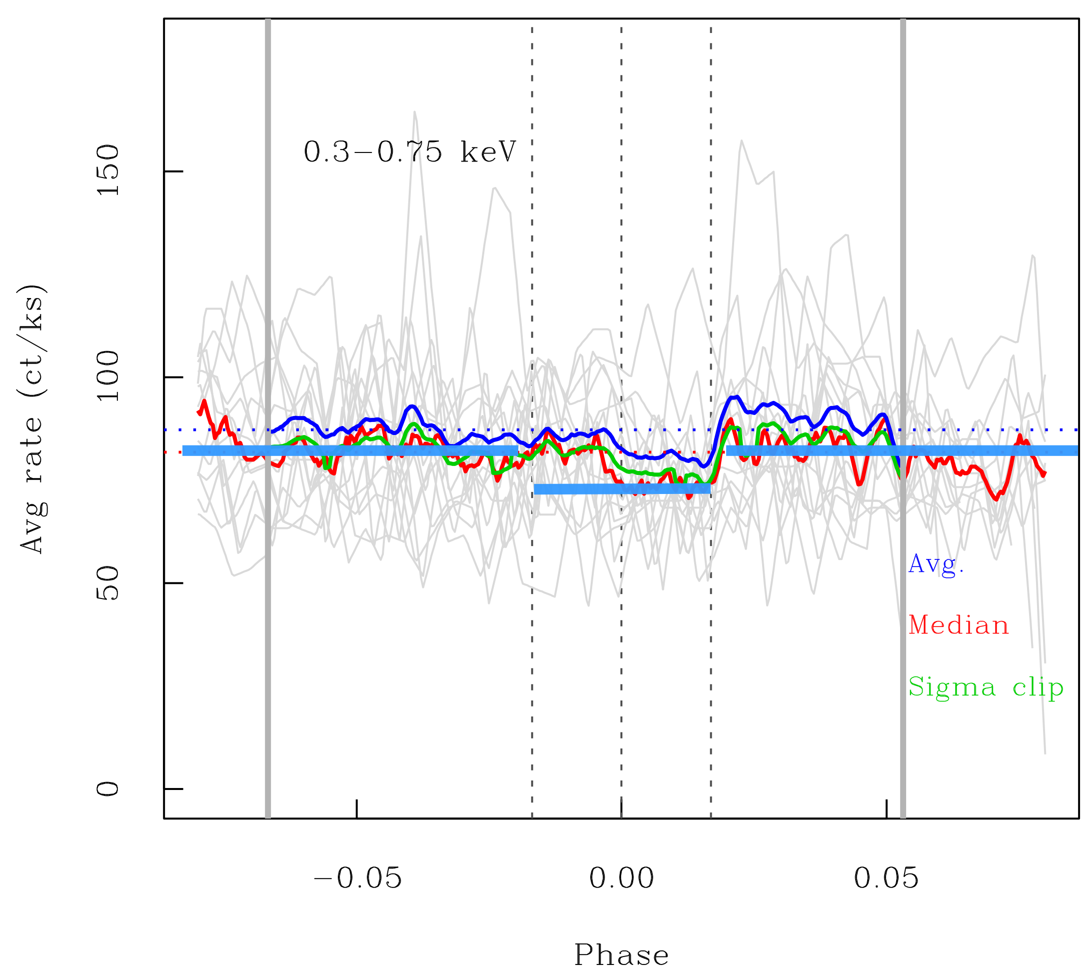
WASP-18 another kind of extreme

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 et al. (2014)



0.3−0.75 keV
Avg rate (ct/ks)
0
50
100
150
−0.05
0.00
0.05
Phase
Avg.
Median
Sigma clip



0.3−0.75 keV
Avg rate (ct/ks)
0
50
100
150
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Phase
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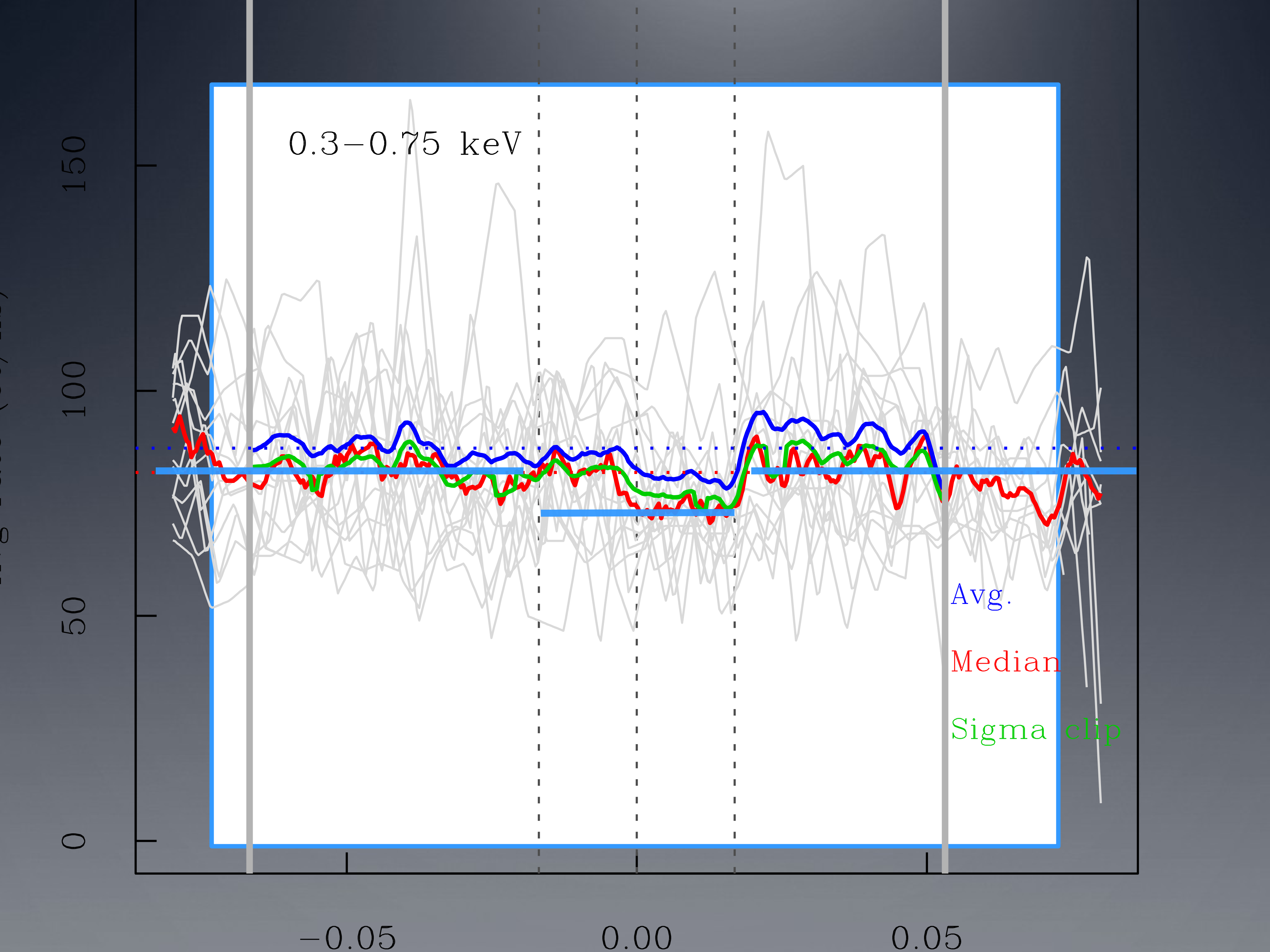
Median
Sigma clip


0.3–0.75 keV
Avg.
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Sigma clip
0
50
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150
−0.05
0.00
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