Study of the X-ray Emission of Stars with Hot Jupiters.

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Abstract. The number of exoplanets is to date higher than the number of participants to PPVI (850). The search of effects of star-planet interaction (SPI) on the host stars has given controversial results, with some systems showing variations of the activity phased with the planetary motion. We present the results of the search of SPI in X-ray band, focusing on 3 systems: HD 189733, HD 162020 and WASP-18. HD 189733 shows many signs of boosted X-ray activity due to SPI, HD 162020 has a variability phased with planet motion of marginal significance. WASP-18 (F6 V) is the most controversial system: it has a 10M$_{Jup}$ planet rotating at 3.5 stellar radii, it is completely dark in X-ray, at odds with an estimate of age of 600 Myr. In this case the massive planet could have a role in modifying or destroying the thin convective layer of the star.

HD 189733: signs of SPI in X-rays

- the hot Jupiter of HD 189733 has likely modified the evolution of the angular momentum of the parent star, resulting in a fast rotating > 2Gyr old star with enhanced X-ray and chromospheric activity.
- high X-ray resolution spectroscopy shows that the corona of this star is cold and dense, and similar to those of accreting active Pre Main Sequence stars.
- In X-rays, our observations at the secondary transit reveal enhanced X-ray time variability after the eclipse of the planet, perhaps phased with the planet motion.
- SPI can mimick a younger age in stars with hot Jupiters, this places a warning on using activity to date these stars.

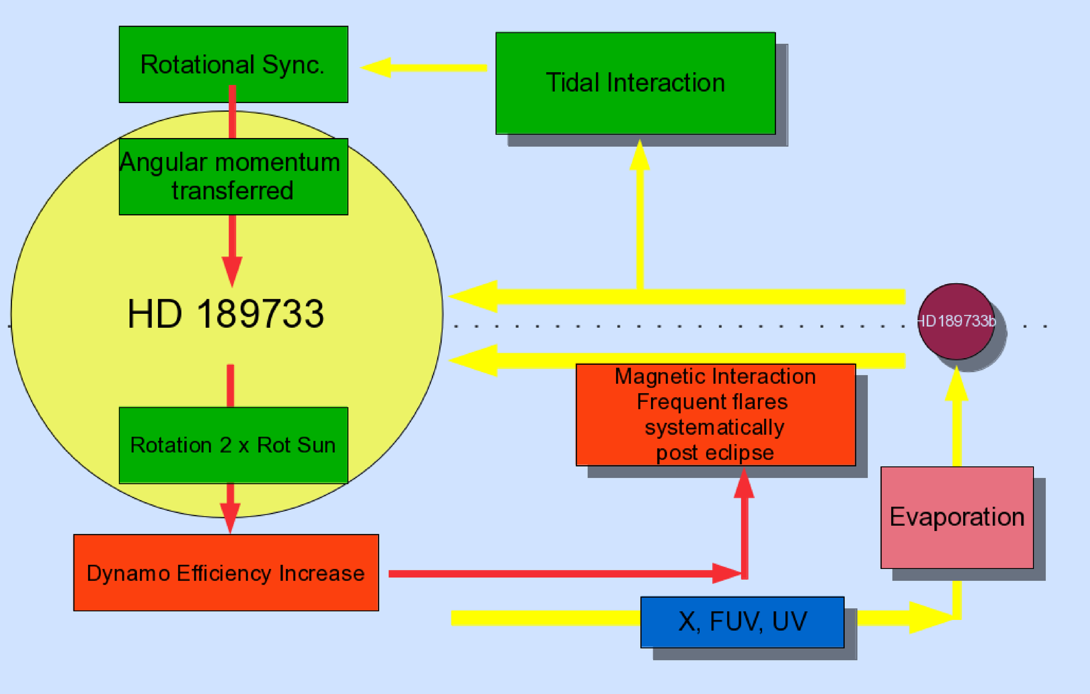
Table 1: Basic data of the HD 189733 system

	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	–	$2.219d$	$3200yr$
Mean orbital radius	–	0.003 AU	216 AU

Table 2: best fit results of EPIC spectra from 2007, 2009, 2011, and 2012 in the phases pre-flare, flare and post-flare.

Phase	kT$_1$ (keV)	kT$_2$ (keV)	kT$_3$ (keV)	E.M.$_1$ 10^{50} cm^{-3}	E.M.$_2$ 10^{50} cm^{-3}	E.M.$_3$ 10^{50} cm^{-3}	log f_X (erg s^{-1} cm^{-2})	log L_X (erg s^{-1})
2012 Pre	$0.19^{+0.03}_{-0.03}$	$0.7^{+0.03}_{-0.03}$	–	$10.7^{+1.3}_{-1.3}$	$8.9^{+1.3}_{-1.3}$	–	-12.6	28.07
Flare	(0.19)	(0.7)	$0.82^{+0.06}_{-.06}$	(10.7)	(8.9)	$7.60^{+0.7}_{-0.7}$	-12.37	28.27
Post	(0.19)	(0.7)	$0.72^{0.13}_{0.13}$	(10.7)	(8.9)	$1.3^{+0.8}_{-0.8}$	-12.54	28.11
2011 Pre	$0.24^{+0.02}_{-0.03}$	$0.73^{+0.08}_{-0.11}$	–	$5.8^{+1.0}_{-0.9}$	$3.6^{+0.9}_{-0.9}$	–	-12.5	28.17
Flare	(0.24)	(0.73)	$0.9^{+0.1}_{-.1}$	(5.8)	(3.6)	$3.0^{+0.5}_{-0.5}$	-12.36	28.29
Post	(0.24)	(0.73)	$0.62^{0.2}_{0.2}$	(5.8)	(3.6)	$1.35^{+0.03}_{-0.03}$	-12.41	28.24
2009 Pre	$0.18^{+0.08}_{-0.08}$	$0.47^{+0.08}_{0.08}$	–	$4.1^{+1.8}_{-1.8}$	$5.6^{+2.3}_{-2.2}$	–	-12.50	28.15
Flare	(0.18)	(0.47)	$0.99^{+0.08}_{-0.08}$	(4.1)	(5.6)	$3.2^{+0.4}_{-0.5}$	-12.37	28.29
Post	(0.18)	(0.47)	$0.75^{+0.17}_{-0.17}$	(4.1)	(5.6)	$1.3^{+0.3}_{-0.4}$	-12.4	28.22
2007	$0.24^{+0.01}_{-0.01}$	$0.71^{+0.04}_{0.03}$	–	$4.7^{+0.4}_{-0.3}$	$2.8^{+0.3}_{-0.3}$	–	-12.60	28.05

SPI at work in HD189733



A scenario for HD 189733A+b: the planet has migrated inward and the parent star has exchanged angular momentum with its hot Jupiter. Faster stellar rotation increases the efficiency of the stellar magnetic dynamo, and this has enhanced X-ray activity. The enhanced activity ($L_X \geq 10 \times L_{X\odot}$) implies stronger interaction with the magnetic field of the planet. It implies also vigorous evaporation of the planet's atmosphere because of the copious X-rays, FUV, and UV fluxes from the parent star.

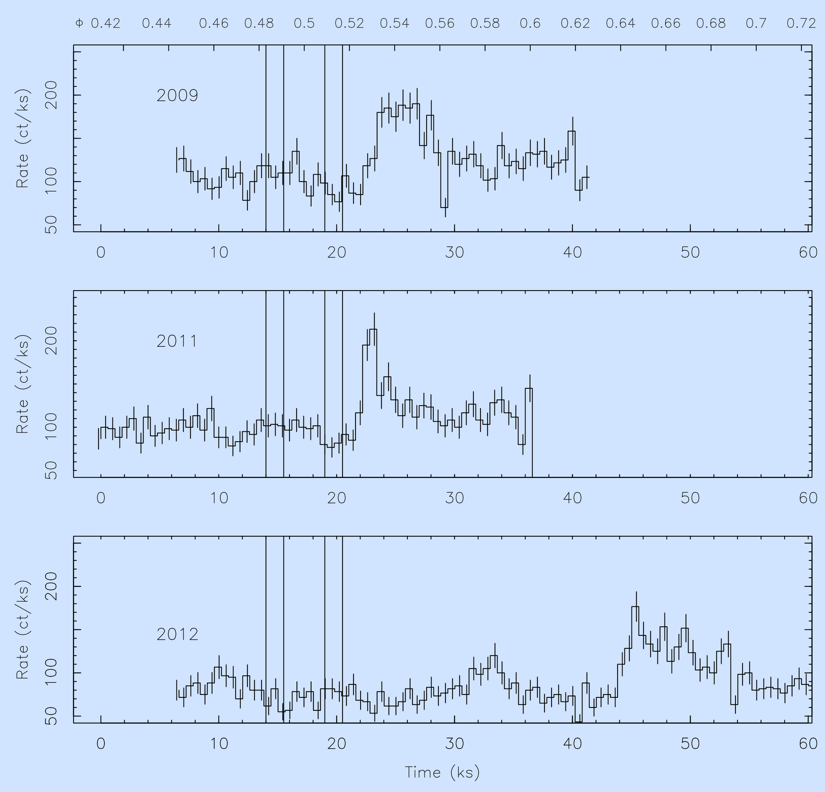


Fig. 1: PN light curves in 2009, 2011, 2012. Strong flaring activity is observed after the eclipse of the planet ($\phi = 0.5$, 1st, 2nd, 3rd, 4th contact marked with vertical lines). No similar flaring activity seen at the transit phase ($\phi = 0$). The planet could trigger flares on the stellar corona when crossing a region of space with stronger stellar magnetic field.

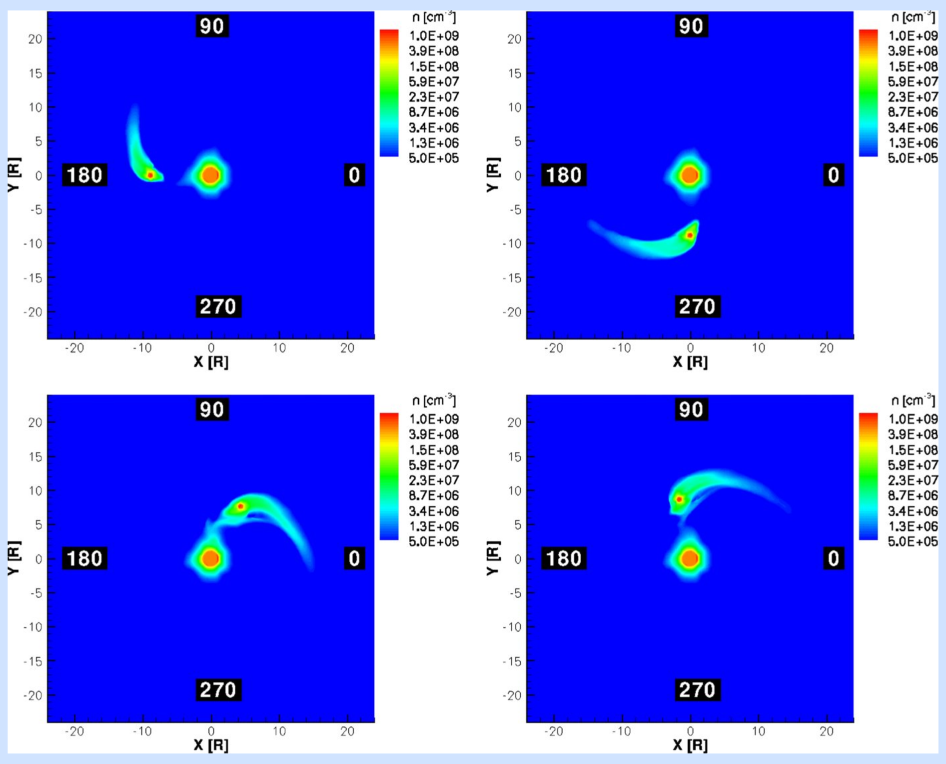


Fig. 2: MHD simulations with realistic maps of stellar magnetic field (Cohen et al., 2011). The planet can trigger reconnection events and plasma detachment from its cometary tail at particular phases, similarly to what we observed in X-rays after the secondary transit.

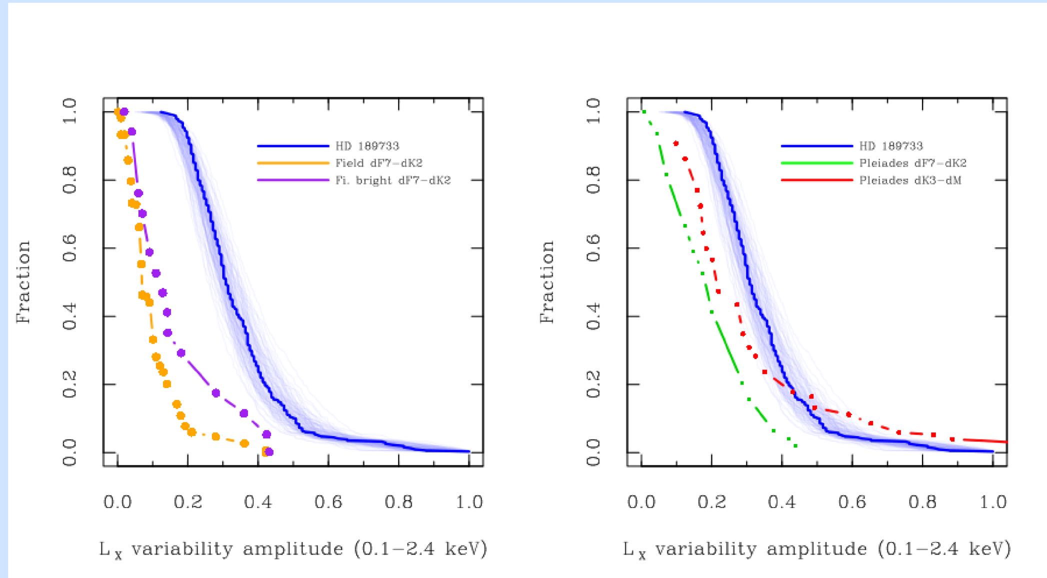


Fig 3: HD189733 shows larger variability amplitudes of X-ray luminosity with respect to field stars (left panel), and different from that of young Pleiades (right panel). Pleiades and field stars data from Marino et al. (2003).

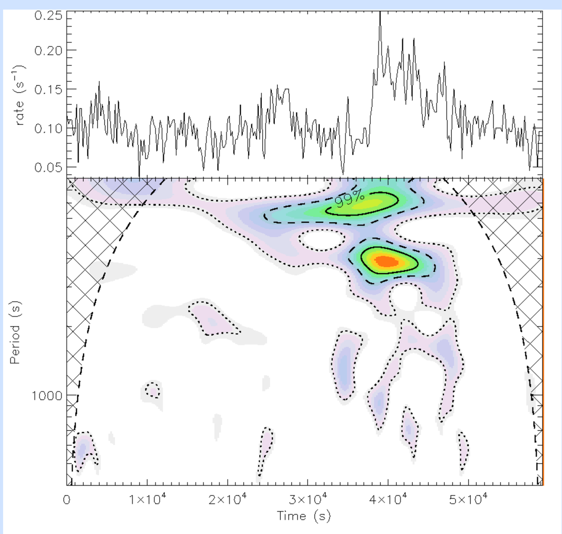


Fig 4a: wavelet deconvolution of the light curve (see Gómes de Castro et al. 2013, Mitra-Kraev et al. 2005). A damped oscillation in the main flare with period of 4ks is detected. Combined with density from RGS data $n_e = 3 - 11 \times 10^{10}$, we obtain a measure of magnetic $B = 40 - 110$ G and a loop length estimate of $2 - 4R_*$. The large size of the loop suggests a magnetic SPI origin for the flare.

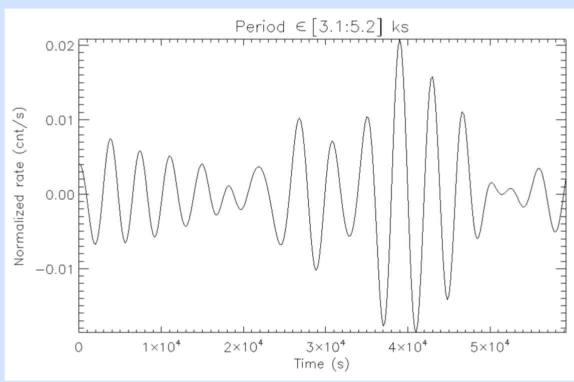


Fig 4b: reconstructed light curve using the periods between 3.1 and 5 ks.

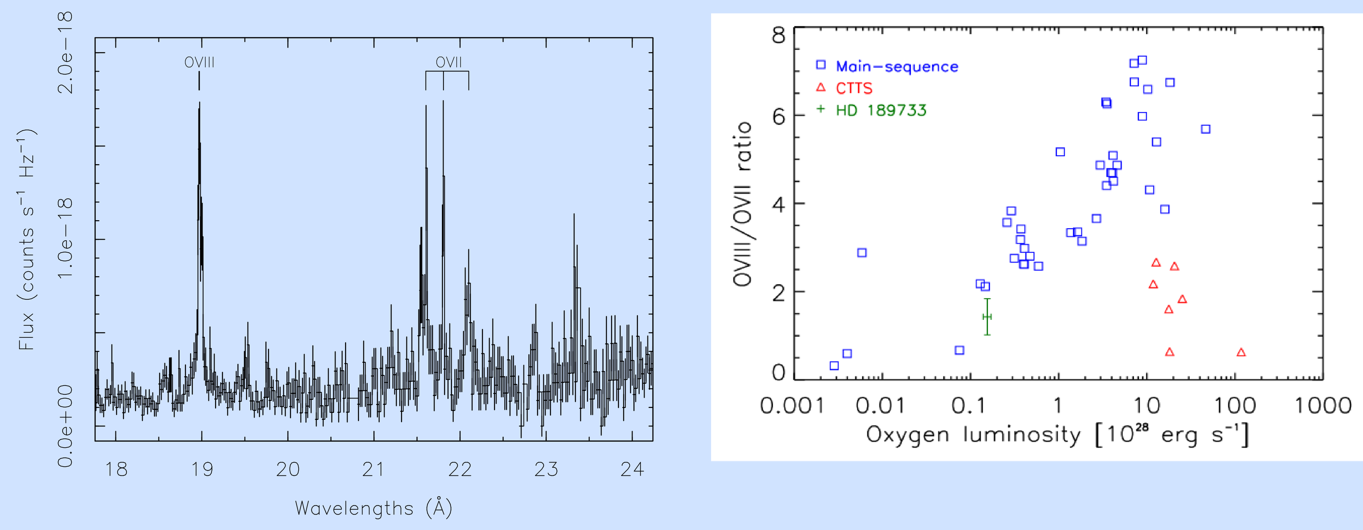


Fig. 5. Left: sum of RGS spectra collected in 2007, 2009, and 2011, portion around OVII/OVIII lines. The corona appears denser than stellar coronae of field stars, and more similar to young active coronae (right panel, other data from Robrade et al. 2007).

HD 162020b: an eccentric orbit.

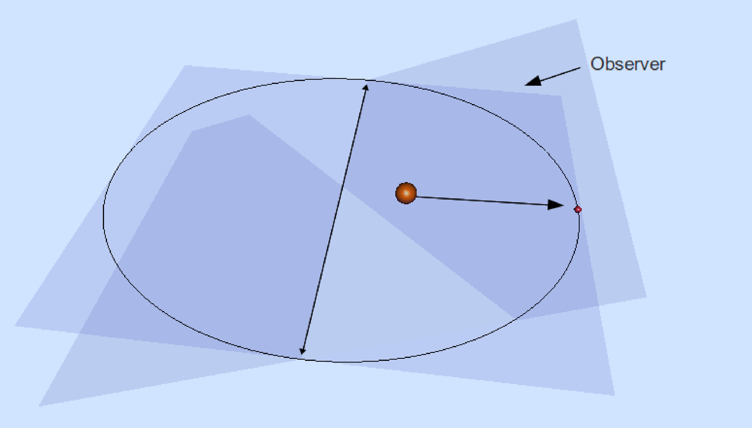


Fig 6: the cartoon represents the orbit, the relative sizes of the star and the planet, and the inclination with respect to the observer. We obtained a series of XIS-*Suzaku* observations to probe changes of X-ray emission at apoastron and periastron phases.

Basic facts:

- HD 162020 has a massive hot Jupiter in an eccentric orbit.
- The star-planet separation varies between 16 and 28 stellar radii.
- In a system with varying planet-star separation we expect systematic evidence of SPI.

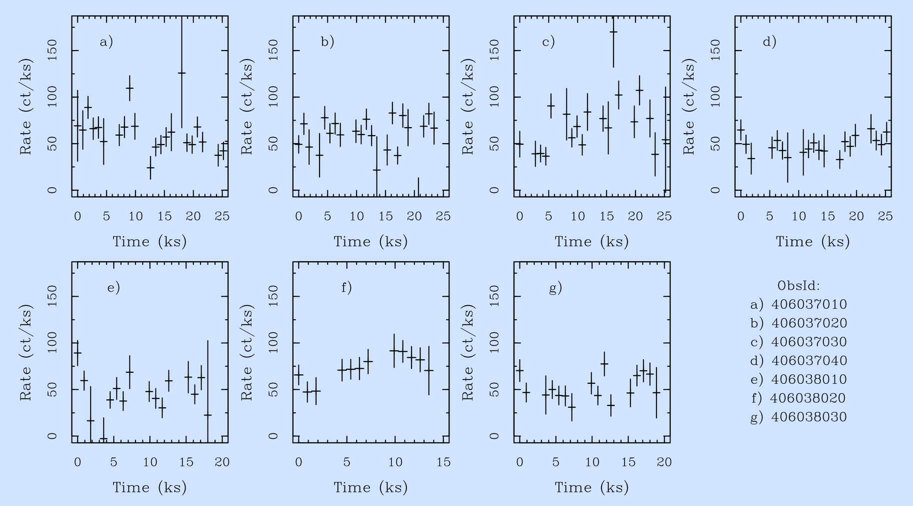


Fig. 7: Light curves of HD 162020 during Suzaku observations. Top row phase: periastron, bottom row phase: apastron. Some enhanced variability is seen (at 1σ significance level) when the hot Jupiter is close to the periastron (top row observations)

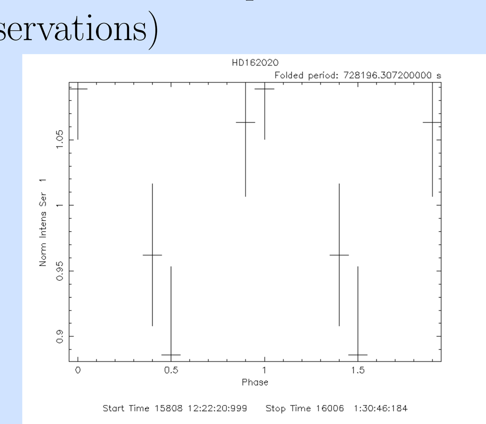


Fig. 8: phase folded light curve. The e-fold time is the orbital period of the planet (8.42 days). Some hint of modulated emission at the periastron ($\phi = 0.0$) is visible at 1σ significance level.

WASP-18: a controversial system.

Characteristics of the system:

	WASP18 A	WASP 18b
Type	F6VI-V	planet
Mass	$1.23 M_\odot$	$10.4 M_{jup}$
Radius	$1.24 R_\odot$	$1.16 R_{jup}$
Period	Rotation: $11.9d$	Orbital: $0.94d$
Orbital radius	–	0.0205 AU = 3.5 R$_*$
Distance	100±10 pc	–

This is one of the stars with the closest, massive and fast hot Jupiter. The estimate of the age for this system is about 600 Myrs, similar to Hyades and M67, based on isochrone fitting.

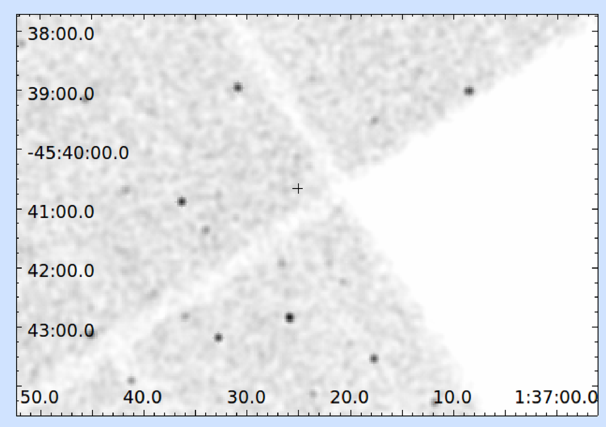


Fig. 9: Chandra-ACIS image toward WASP-18 (cross marks the optical position). After 87 ks of exposure the star is undetected.

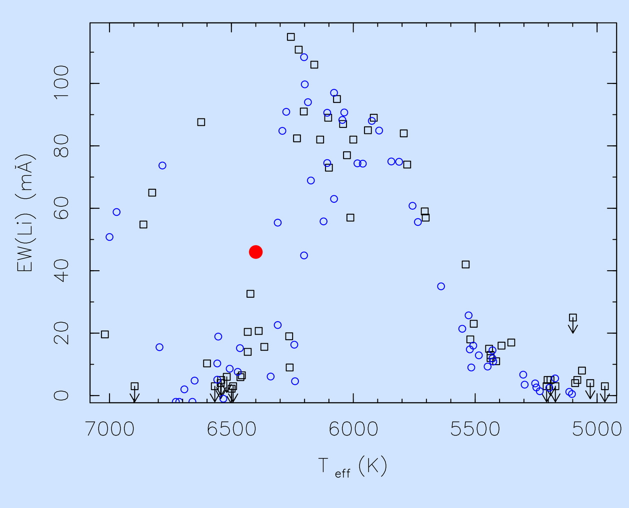


Fig. 10: Lithium in WASP-18 (46±2 Å, red dot), in Hyades and M67 (from Pace et al. 2012; Takeda et al. 2012). The strong Li absorption conflicts with the X-ray darkness of the star.

Conflicting facts about WASP-18:

- $L_X < 4.3 \times 10^{26}$ erg/s
- Hyades F late stars at $L_X = 10^{29}$ erg/s
- null chromospheric activity (from Hα, Ca lines etc.)
- Strong Li absorption
- Low activity implies an old age of the star
- The close orbit suggests a short life left to the planet
- Why WASP-18 is so dark in X-rays?
- Does the planet destroy/modify the *thin* convective layer and any dynamo?

Bibliography: Cohen et al. 2011, ApJ 733 67 • Gómez, et al. 2013, MNRAS, 429, L1 • Günther et al. 2011, AN 332, 448 • Marino et al. 2003, A&A 406, 629 • Marino et al. 2006, A&A, 456, 977 • Mitra-Kraev et al. 2005, A&A, 436, 1041 • Pillitteri et al. 2010, ApJ 722, 1216 • Pillitteri et al. 2011, ApJL 741, 18 • Robrade & Schmitt 2007, A&A 473, 229

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