X-ray/EUV evaporation of hot Jupiter atmospheres

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Intense X-ray and extreme ultraviolet radiation (EUV) of host stars cause strong heating and expansion of the atmospheres of close-in extrasolar planets. This results in a planetary mass-loss. In the most extreme cases a complete evaporation of giant gas planets is possible. Expanded planetary atmospheres have been detected in three nearby systems. However, no commonly accepted model for the absorption signals exists. In an effort to understand planetary mass-loss, we composed a sample of eight systems, in which expanded atmospheres could be detectable by Lyα transit spectroscopy with the Hubble Space Telescope. For these targets we obtained *Chandra* and *XMM-Newton* X-ray observations to quantify the high energy irradiation of the planetary atmosphere and the expected mass-loss rates. Furthermore, the observations show that based on the relation between X-ray and Lyα luminosities our targets are suitable for HST Lyα transit observations.

1. Expanded atmosphere

Planetary mass-loss

Gaseous extrasolar planets with tight orbits (< 0.1 AU) experience strong X-ray/EUV irradiation.

- ➛ hot (~ 10000 K) and expanded (2-3 Rpl) atmospheres
- ➛ atmospheres overfill the Roche lobe or become unstable
- ➛ planetary mass-loss results, prop. to the XUV irradiation

EUV radiation is the main driver of mass-loss, but cannot be measured due to interstellar absorption.

- ➛ use X-ray emission as indicator for the EUV luminosity (see Fig. 2.)

energy limited escape: $\frac{dM}{dt} \leq \frac{\pi R_{XUV}^2 F_{XUV}}{\varphi_{grav}}$ (Watson et al., 1981)

➜ What mass-loss do existing planets experience?

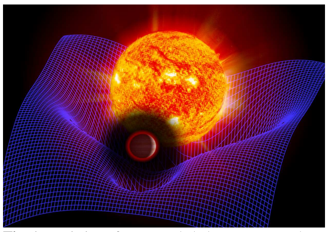

Fig. 1. Depiction of an expanded planetary atmosphere in transit, visualizing Lyα emission, and the effective gravitational potential. Comp. from SOHO and Cassini images, NASA, ESA)

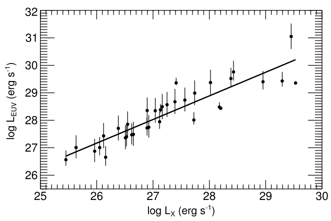

Fig. 2. X-rays are one of the best indicators for the EUV luminosity of stars (from Sanz-Forcada et al. 2011).

Detections of expanded atmospheres

- HD 209458 b:
  - 5.7% total absorption in H Lyα
  - blue + red shifted absorption
  - velocity offset ~ 100 km s^{-1}
  - other line absorption: O I, C II, Si III
- further detections in HD 189733 b & Wasp-12 b (indications: 55 Cnc b)
- competing theoretical models explain these absorption signals

➜ A systematic study of a larger number of hot Jupiters can destinguish between theo. models.

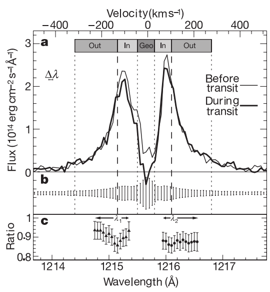

Fig. 3. Lyα transit signal of HD 209458 b from Vidal-Madjar et al. (2003).

2. Systematic study

Detections are most successfull by measuring Lyα absorption during transit.

1) rank all hosts of hot gas giants in order of predicted Lyα lum. [1]
2) measure X-ray luminosity
   → derive irradiation level (Fig. 2.) and mass-loss
   → estimate Lyα lum. [1]
3) HST/STIS short exposures to measure the Lyα strength
4) for suitable targets:
   Lyα transit study to detect expanded atmospheres

1. Linsky, J. L., France, K., & Ayres, T. 2013, ApJ, 766, 69
2. Pizzolato, N., Maggio, A., Micela, G., Sciortino, S., & Ventura, P. 2003, A&A, 397, 147
3. Sanz-Forcada, J., Micela, G., Ribas, I., et al. 2011, A&A, 532, A6+
4. Vidal-Madjar, A., Lecavelier des Etangs, A., Desert, J.-M., et al. 2003, Nature, 422, 143
5. Watson, A. J., Donahue, T. M., & Walker, J. C. G. 1981, Icarus, 48, 150

3. *Chandra*/*XMM-Newton* observations

- 6 host stars observed with *Chandra*, 2 with *XMM-Newton*
  - ➛ 7 clear detections, one non-detection
- spectral X-ray model for each target (e.g., see Fig. 4.)
  - ➛ X-ray luminosity
  - ➛ estimates for XUV luminosity
  - ➛ determine the mass-loss (see Table 1.)
  - ➛ improved estimates for Lyα luminosity

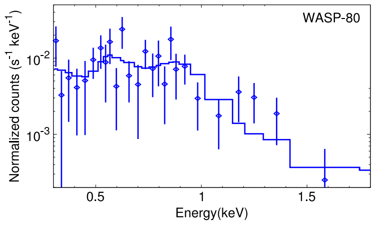

Fig. 4. X-ray spectra of WASP-80, shown with a two temperature plasma emission models (APEC).

4. Conclusions

- ➜ for the first time mass-loss rates based on observations
- ➜ **7 out of 8 targets show strong activity, now HST Lyα observations are required to measure the atmospheres**
- ➜ targets are less active than predicted (see Fig. 5), could be a bias of the planet searches
  - ➜ no indication for star planet interaction enhancement
- ➜ measured irradiation is used as input for simulations

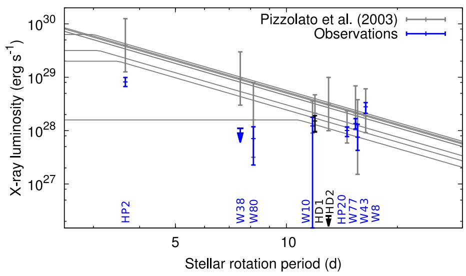

Fig. 5. We compare the X-ray luminosities of our targets (plus HD 209458 and HD 189733) with the rotation based predictions (5-100 Å).

Table 1. Results from the X-ray analysis and mass-loss estimates.

System	Sp. type	Dist. (pc)	P_{rot} (d)	L_X (erg s^{-1})	$L_{EUV}{}^c$ (erg s^{-1})	$L_{Ly\alpha}{}^d$ (erg s^{-1})	$\dot{M}^e$ (g s^{-1})
HAT-P-2	F8V	114	3.7	$8.2^{+1.7}_{-1.5} \times 10^{28}$	4.6×10^{29}	1.0×10^{29}	9.7×10^{09}
WASP-38	F8V	110	7.5	$< 1.1 \times 10^{28}$	$< 8 \times 10^{28}$	$< 5 \times 10^{28}$	$< 5 \times 10^{09}$
WASP-77	G8V	93	15.4	$1.4^{+0.3}_{-0.3} \times 10^{28}$	9.9×10^{28}	5.7×10^{28}	8.8×10^{10}
WASP-10	K5V	90	11.9	$1.2^{+0.6}_{-1.2} \times 10^{28}$	9.0×10^{28}	5.6×10^{28}	1.3×10^{10}
HAT-P-20	K3V	70	14.6	$1.0^{+0.2}_{-0.2} \times 10^{28}$	7.6×10^{28}	5.2×10^{28}	2.9×10^{09}
WASP-8	G8V	87	16.4	$2.8^{+0.6}_{-0.7} \times 10^{28}$	1.8×10^{29}	7.2×10^{28}	7.6×10^{09}
WASP-80	K7-M0V	60	8.1	$7.1^{+4.7}_{-4.8} \times 10^{27}$	5.6×10^{28}	4.7×10^{28}	4.4×10^{10}
WASP-43	K7V	80	15.6	$7.5^{+5.7}_{-3.2} \times 10^{27}$	5.9×10^{28}	4.7×10^{28}	6.7×10^{10}