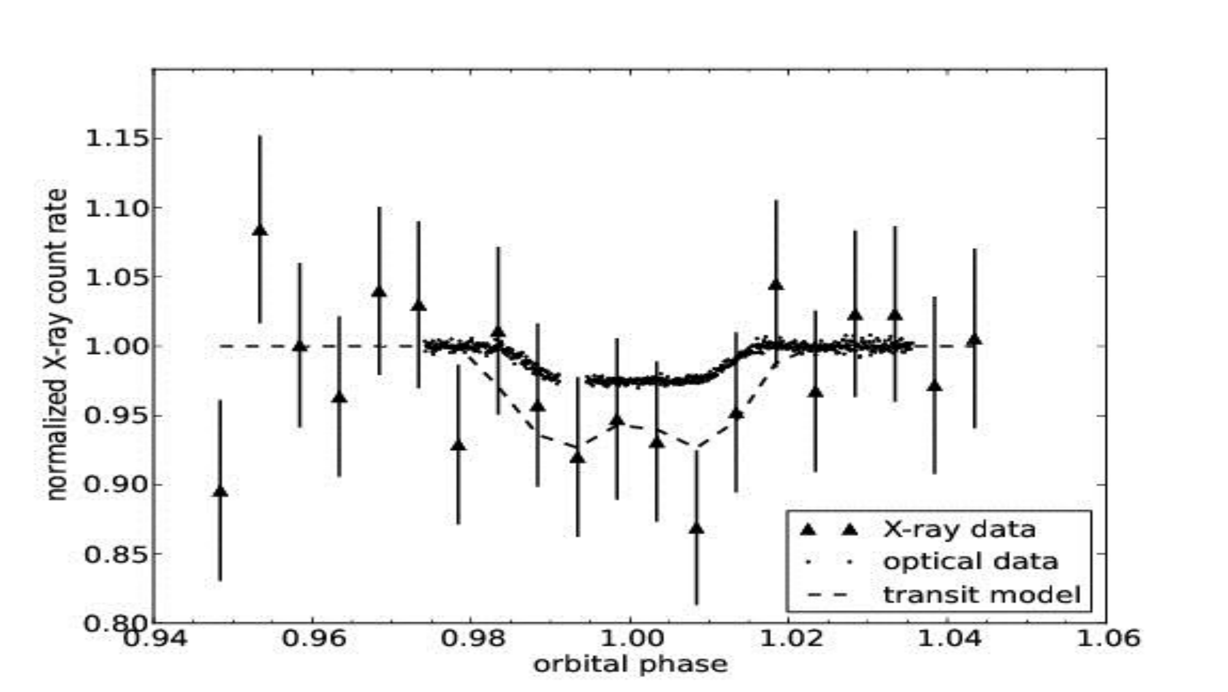
What can XMM-Newton do for the research on exoplanets?

Jorge Sanz-Forcada (CAB)

Transits in X-rays?

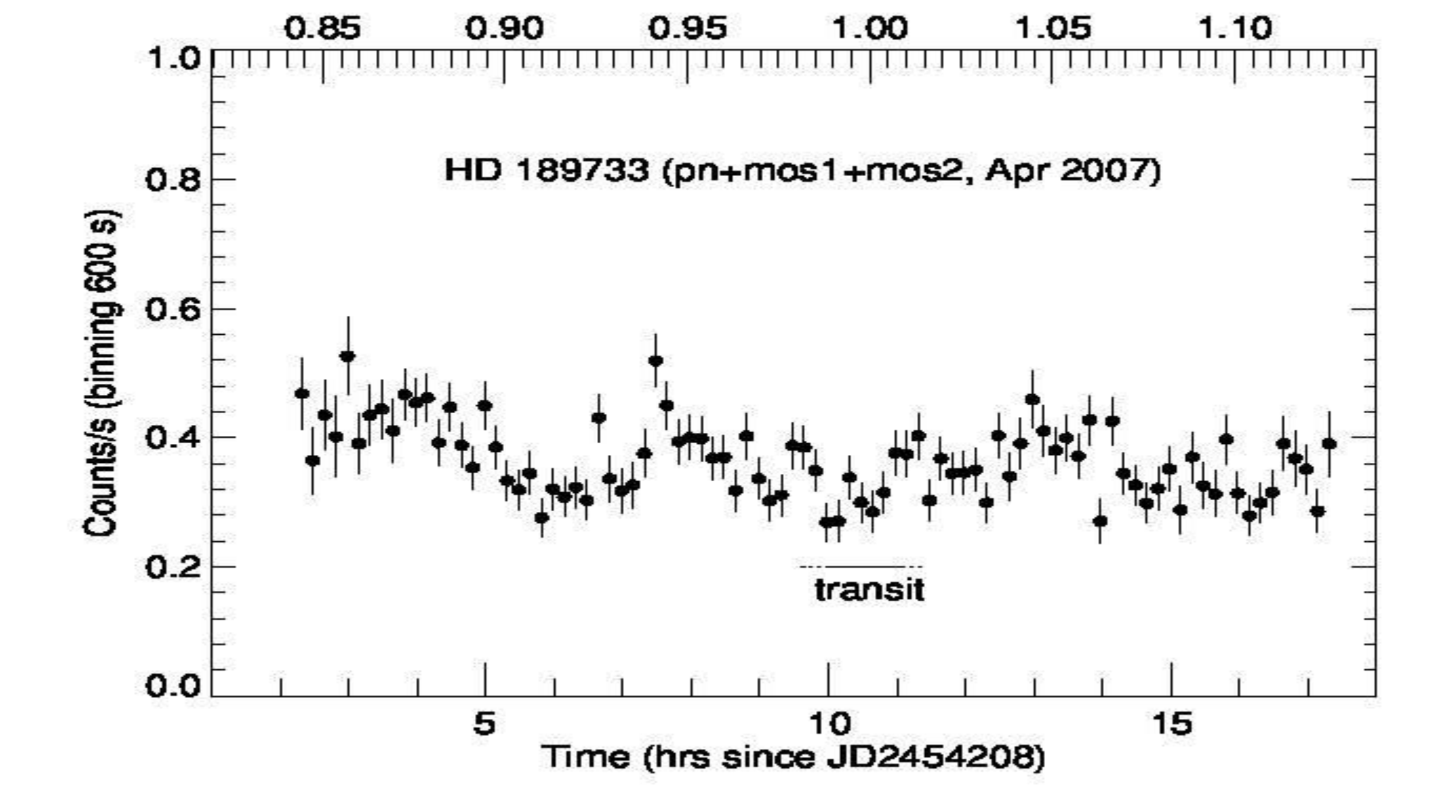


Chandra observations of 5 “transits” of HD 189733 b (Poppenhaeger, Schmitt & Wolk 2013)

Strong implications:

- Deeper transit (7% vs 2.4% in visible)
- Planet size bigger in X-rays (≈1.5 Rp)
- Exosphere of ionized hydrogen, transparent to visible

Transits in X-rays?



Sanz-Forcada et al. (2009, 2011)

Use of X-rays

- Star
  - Activity: Lx/Lbol
  - Variability: light curves, stellar cycles
  - Age: Age → rotation → Lx/Lbol
  - OM onboard XMM or SWIFT: UV or optical light curves
- Planet: XUV irradiation influences atmosphere
  - XUV < 912 Å ionizes H
  - XUV < 504 Å ionizes He (and C at ~516 A)
  - Mass loss rate likely due to XUV (main variable)
  - XUV models require X-rays (and UV if possible) to build a coronal model

XUV* ionizing radiation

First Ionization Potential of some elements (below Lyman α)

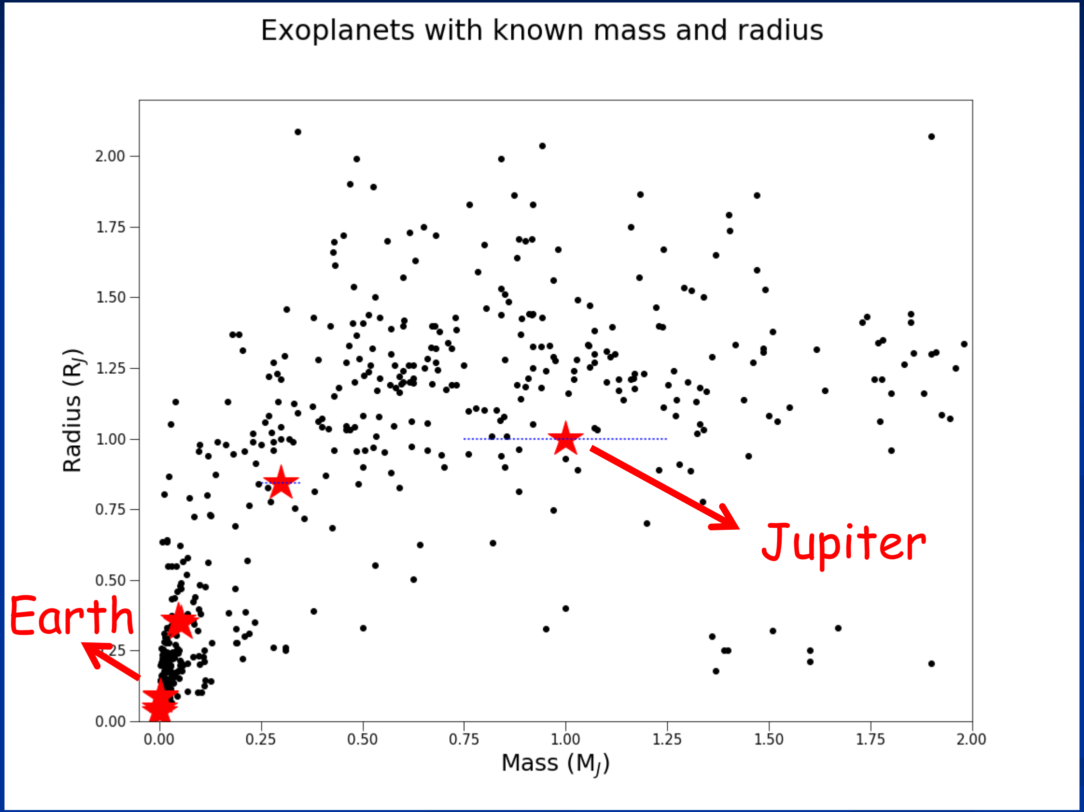
Element	FIP	λ (Å)
He	24.59	504.2
Ne	21.56	575.1
Ar	15.76	786.7
N	14.53	853.3
O	13.61	911.0
H	13.60	911.6
C	11.26	1101.1
S	10.36	1196.8

The XUV photons have some effects:

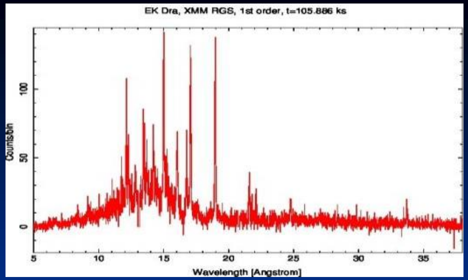
1. Ionize H (and He) in the ISM
2. Neutral atoms become vulnerable to stellar wind
3. Photochemistry in the planet atmosphere
4. Trigger some interesting lines (e.g. He I 10830 Å)

(*): X-rays: 1-100 Å, EUV: 100-920 Å

Transiting planets have short period orbits, thus they are very close to the star (bias)...



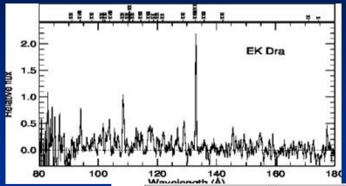
... they receive much XUV radiation, they are inflated

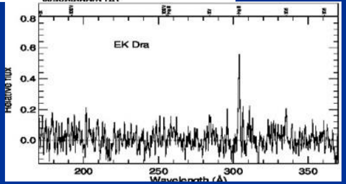


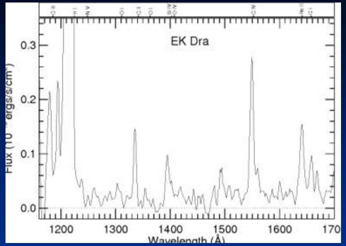
XMM
Chandra

1.5 - 175 Å

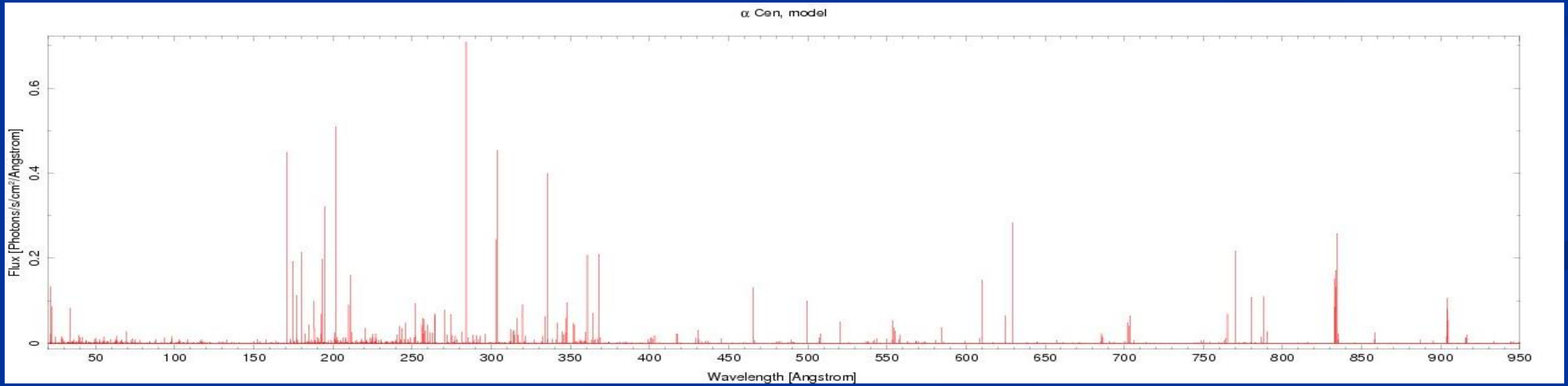
EUV: 90-400 Å
(ISM dependent)



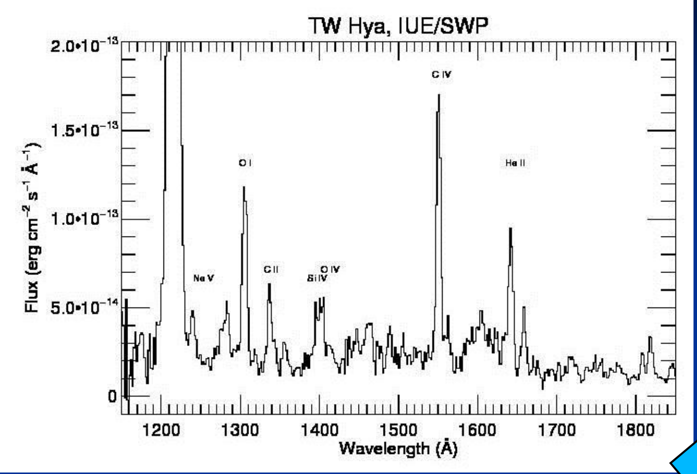




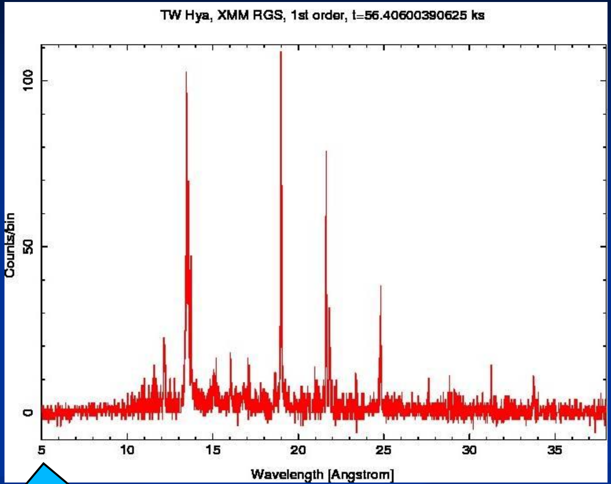
FUSE: 920-1180 Å
IUE: 1150-3000 Å
HST: 1200-3000 Å



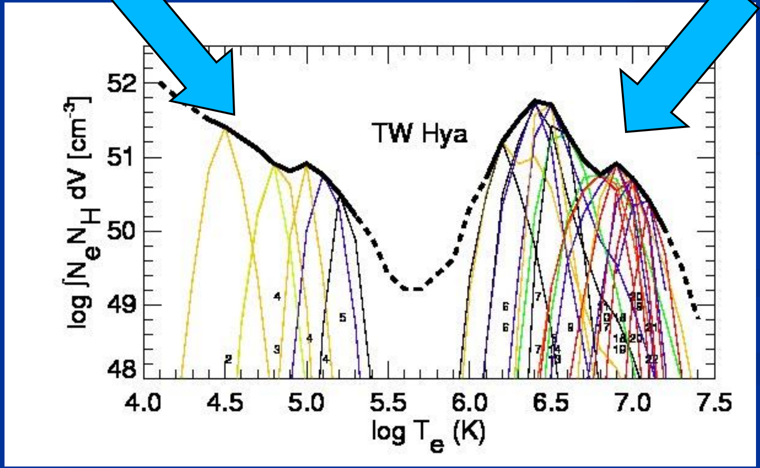
Coronal models



UV lines

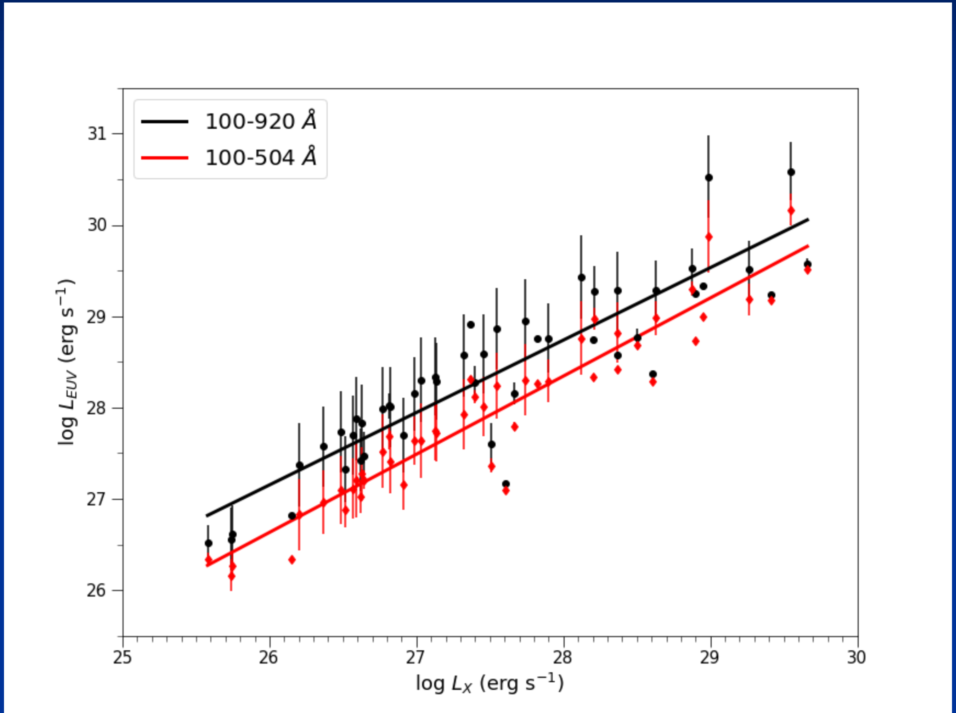


X-rays or EUV lines

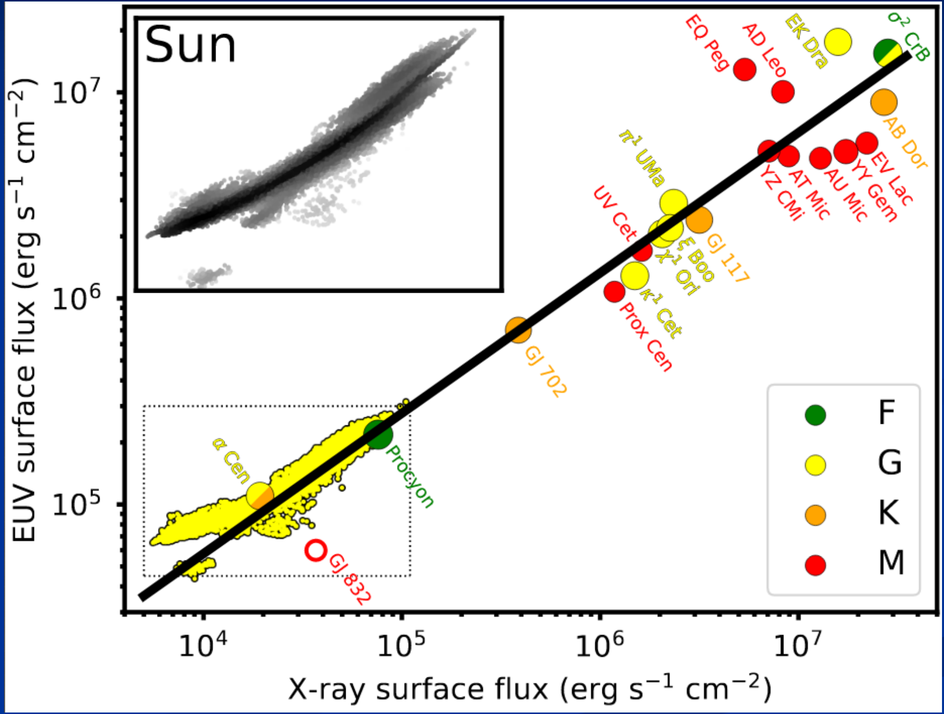


EMD (thermal structure)

X-rays vs EUV relations

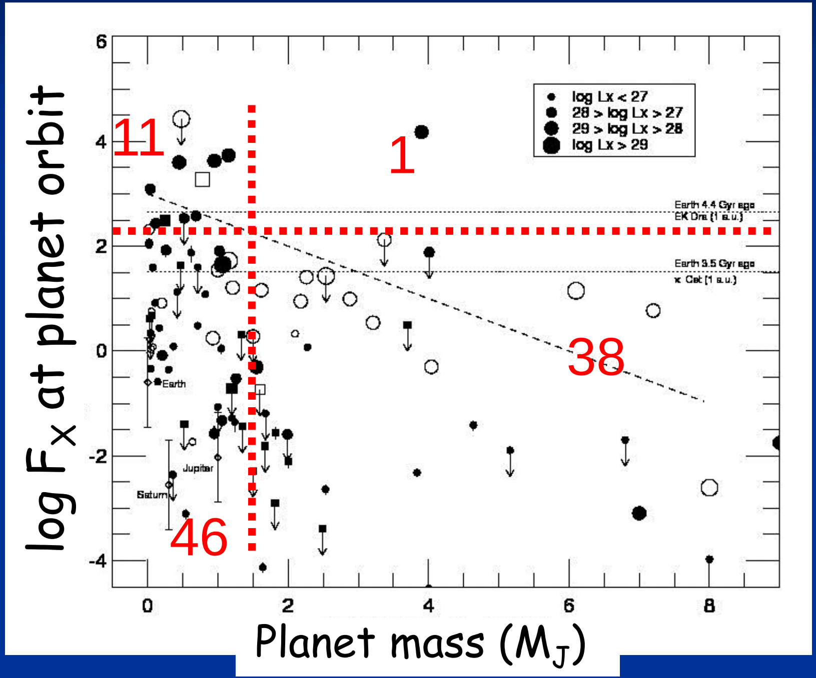


Sanz-Forcada+ (2011, updated 2022) using coronal models for EUV



Johnstone+ (2021) using solar spectrum for EUV above 400 Å

X-ray flux vs planet mass



Sanz-Forcada et al. (2010, 2011)

● Dwarfs ○ ROSAT ◊ Solar System

■ Subgiants ● XMM/Chandra

Energy-limited mass loss rate:

$$\dot{M} \geq \frac{3F_{XUV}}{4G\rho}$$

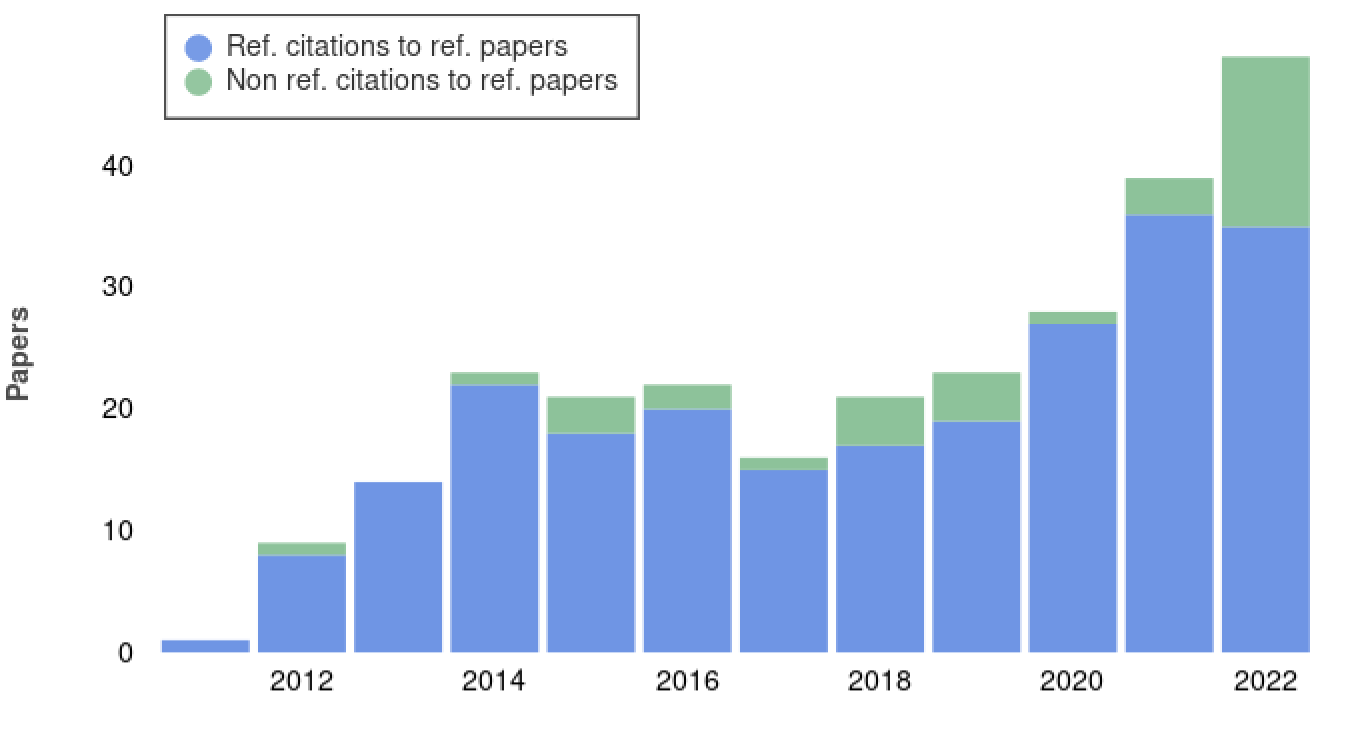
Coronal flux (EUV+X)

Planet density

Lack of massive planets being irradiated (X-exoplanets results). Possible explanations:

- Rapid mass loss during first Gyr
- Effects of planet formation
- A combination of both

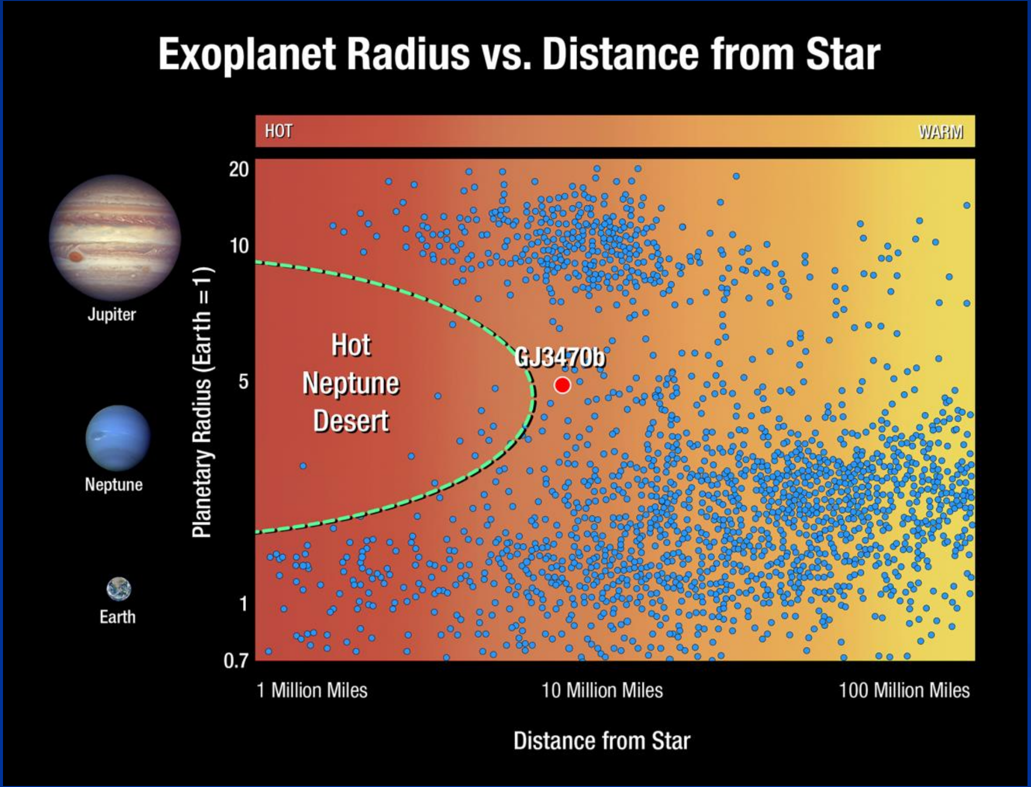
Not just a theoretical exercise: X-rays are needed to interpret exoplanet atmospheres

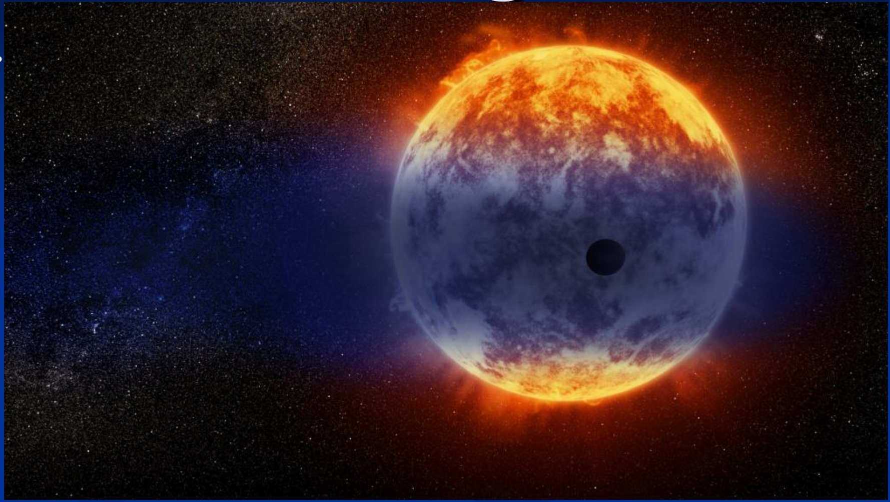


Number of citations to Sanz-Forcada et al. (2011)

Planet mass loss in low mass regime

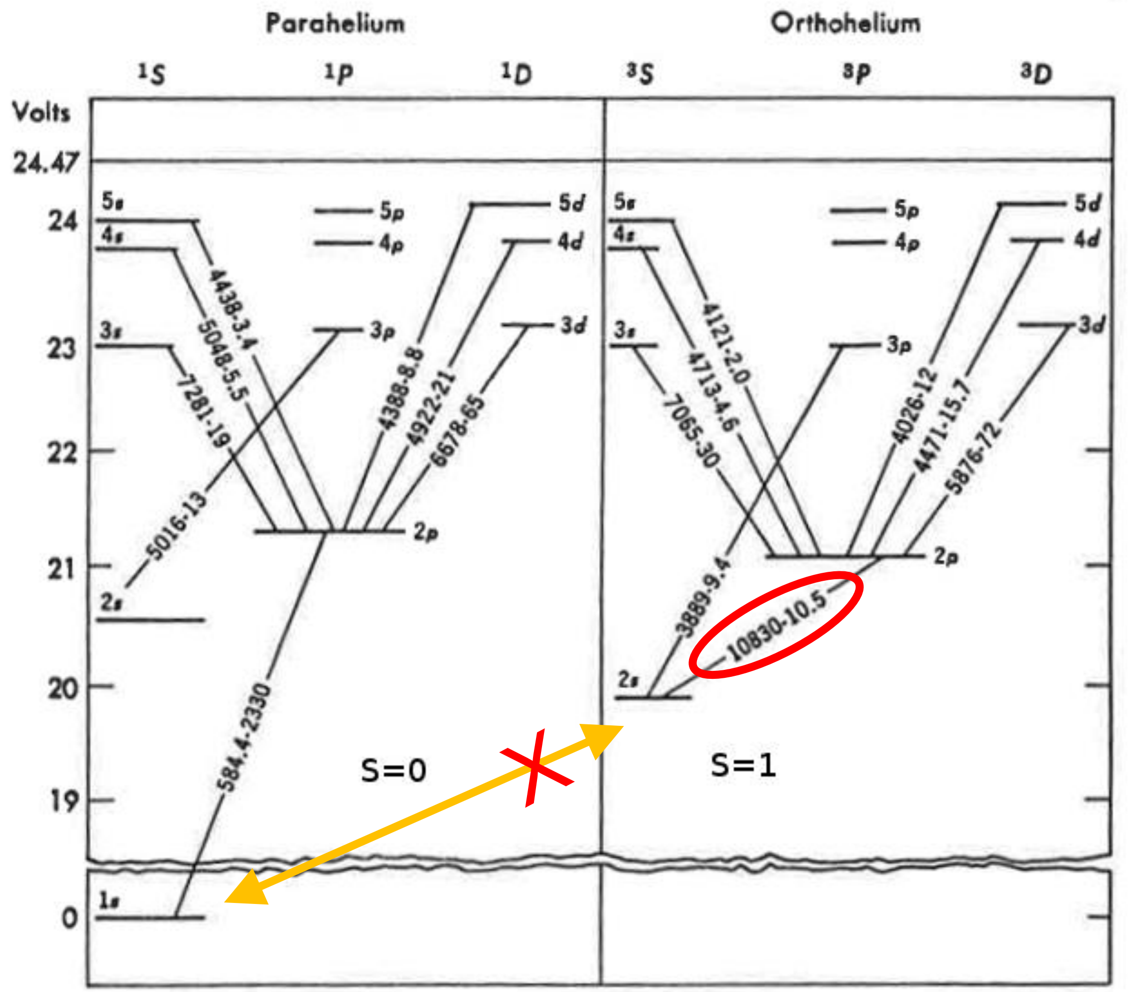
Bourrier, ..., Sanz-Forcada, et al. (A&A 2018).
35% absorption in Lyman α (HST)





Low mass planets lose atmosphere quickly to leave just the rocky core.

H Lyman α studies limited by ISM absorption.



Zirin (1988)

The He I 10830 line triplet

1s → 2s radiatively forbidden

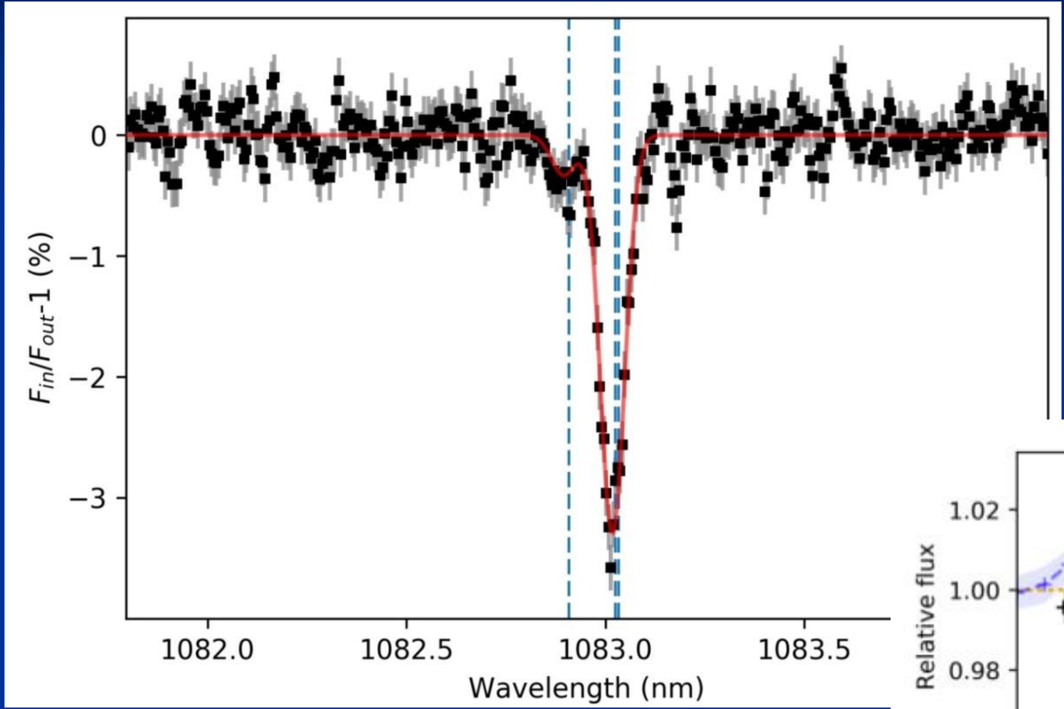
To populate the 2s:

- Collisional excitation (> 20,000 K)

- P-R mechanism: Photoionization (λ < 504 Å, E> 24.6 eV) followed by recombination.

The 10830 line is the most intense (apart from resonance lines)

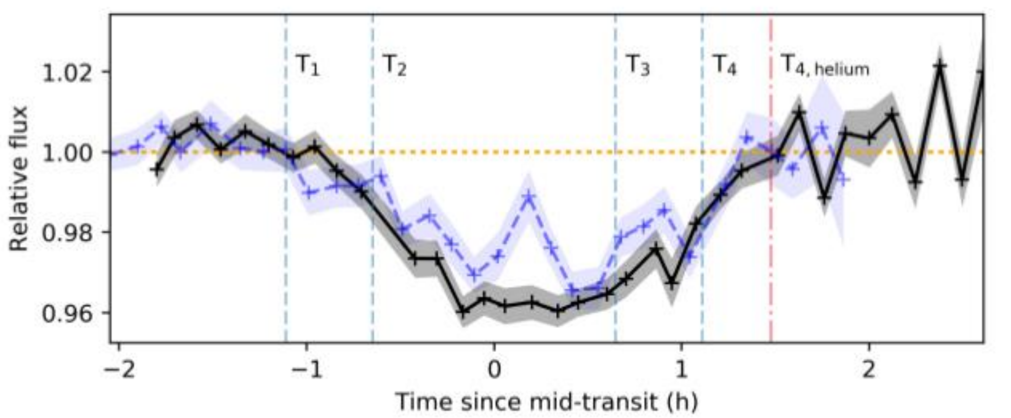
He I 10830: WASP-69 b + others



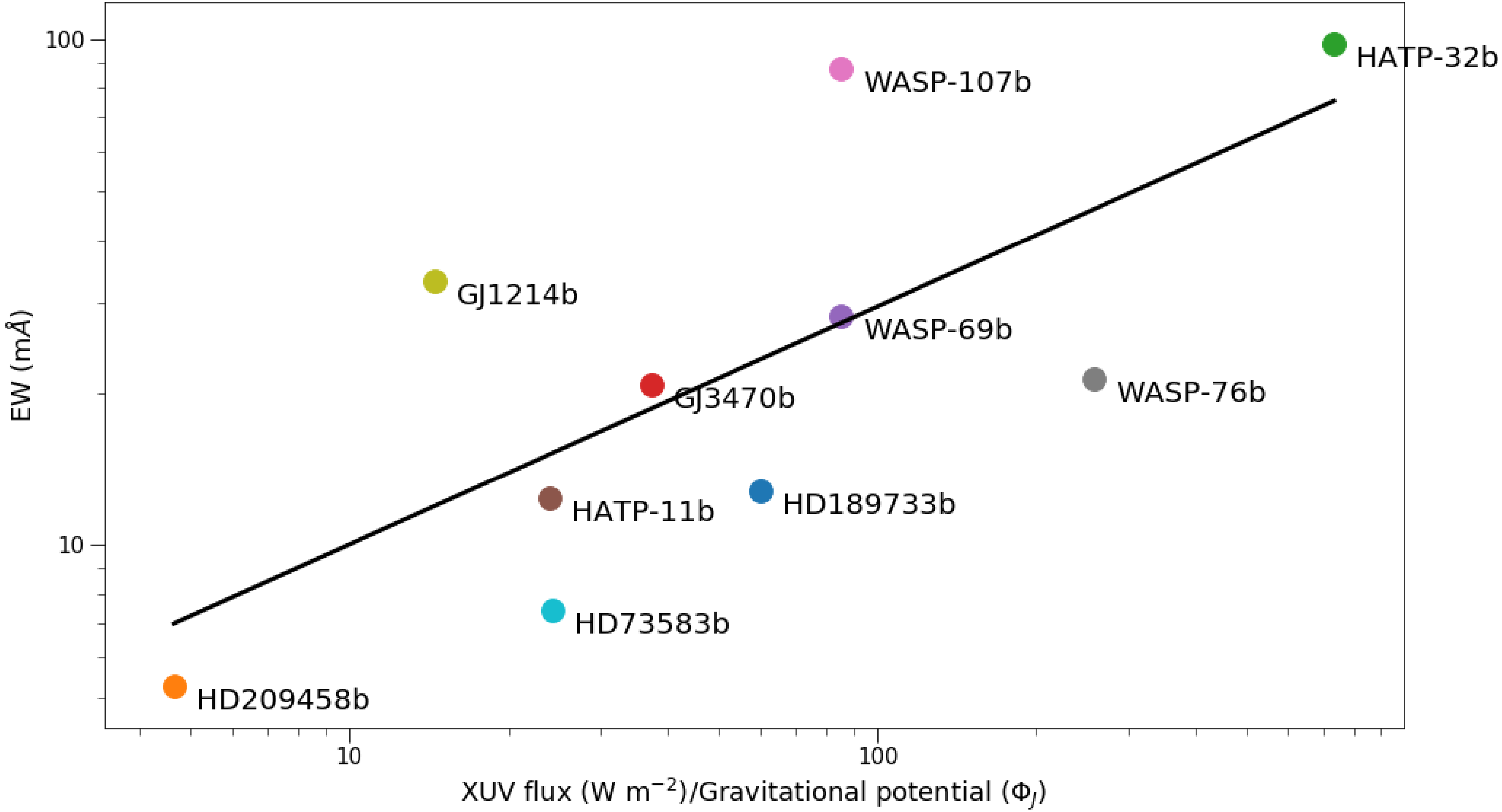
Net absorption of 3.86 ± 0.25% and 3.00 ± 0.31% (1st and 2nd transit)

Wind velocity 3.58 ± 0.23 km/s (day -> night)

Nortmann+ (2018), using CARMENES



He I 10830 triplet in exoplanets is triggered by XUV stellar irradiation



Sanz-Forcada et al. (2022, Cool Stars Meeting; also A&A in prep.)

Conclusions

- X-rays (and UV) are needed to model planet atmospheres
- Planet photoevaporation is likely produced by stellar XUV irradiation
- XUV also triggers the production of He I 10830 Å in exoplanets
- Correct interpretation requires the best X-ray spectra possible