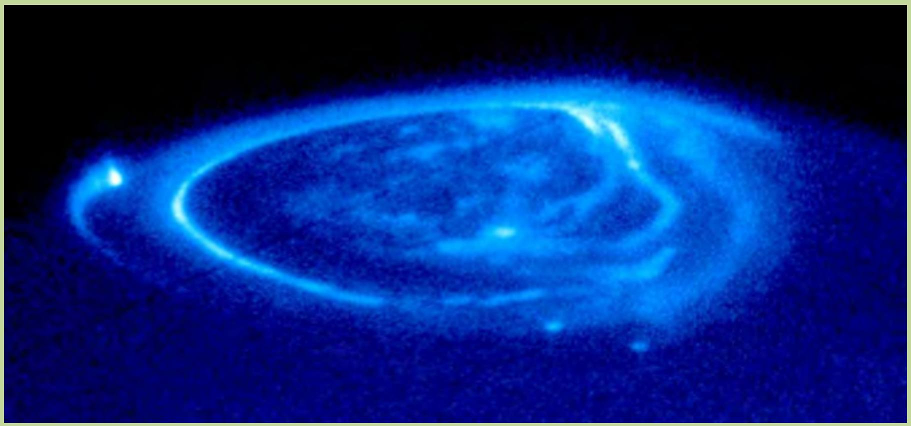
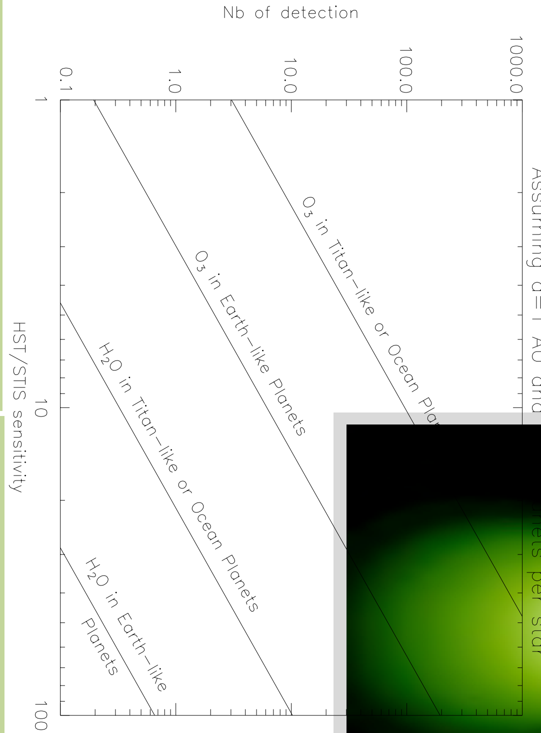
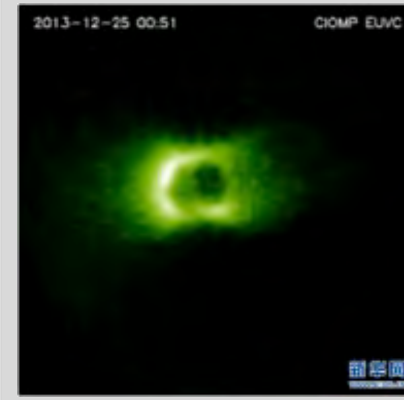
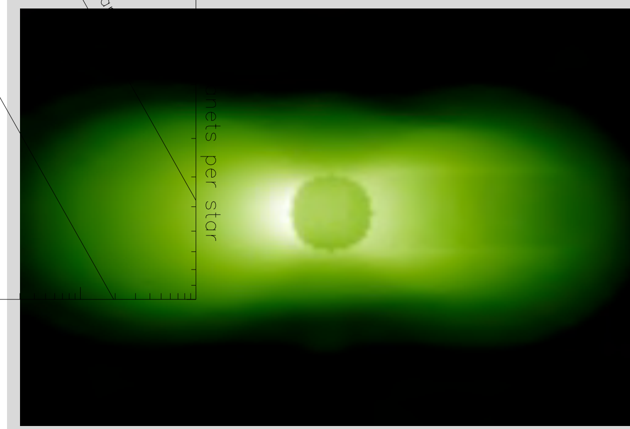








ON THE POTENTIAL OF LYMAN-α MONITORINGS FOR EXOPLANETS STUDIES

Ana I. Gómez de Castro

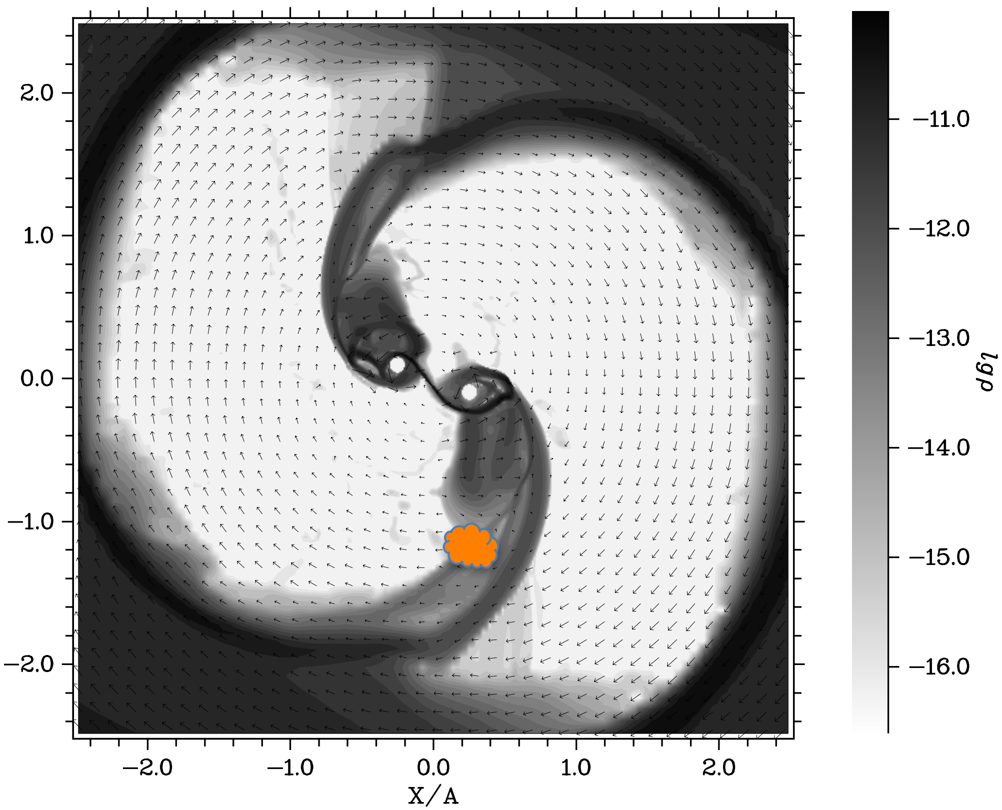
THE RELEVANCE OF LYMAN ALPHA

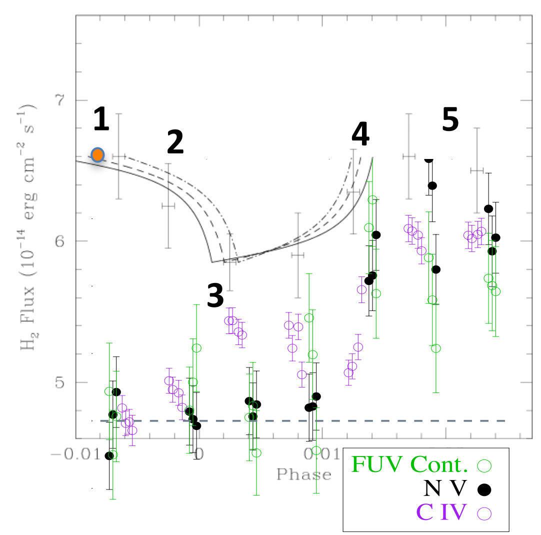
Lyα is the most sensitive (the optically thickest) **line of the Universe**

1. Hydrogen is the most abundant element (80% of matter is Hydrogen)
2. $\boldsymbol{\sigma} = 5.9\ 10^{-12} \cdot 1050^{-1/2}$ (K) cm^2 *(Bishop, 1999)*

$N_H > 5\ 10^{17}$cm^{-2} suffices to block Lyα radiation …

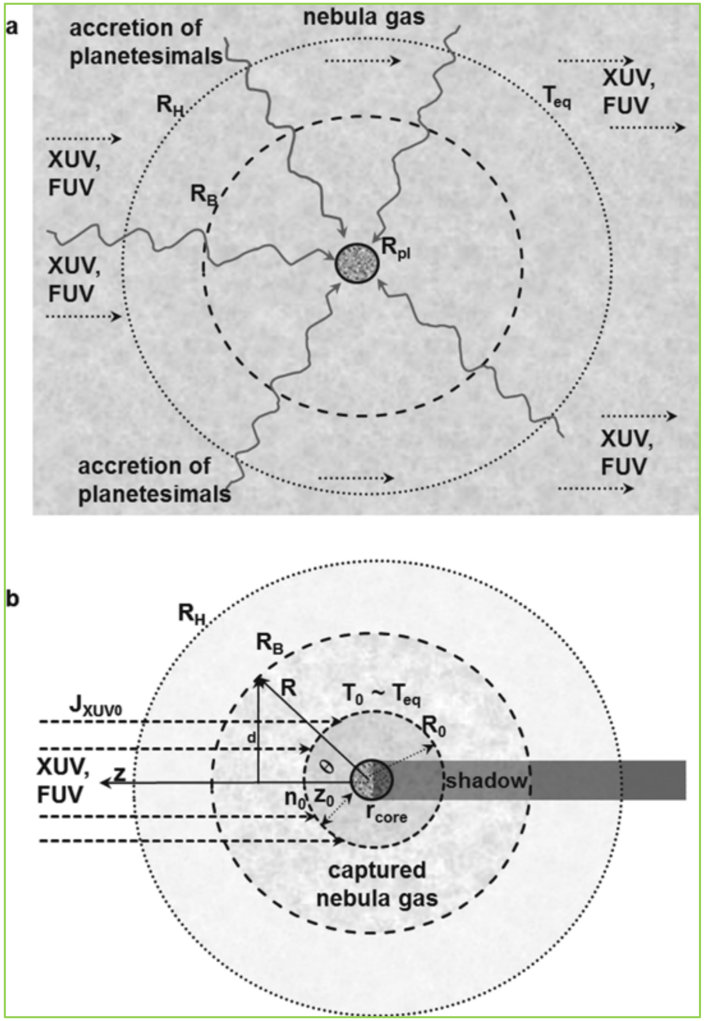
(*without producing noticeable effects in the rest of the stellar spectral tracers*)





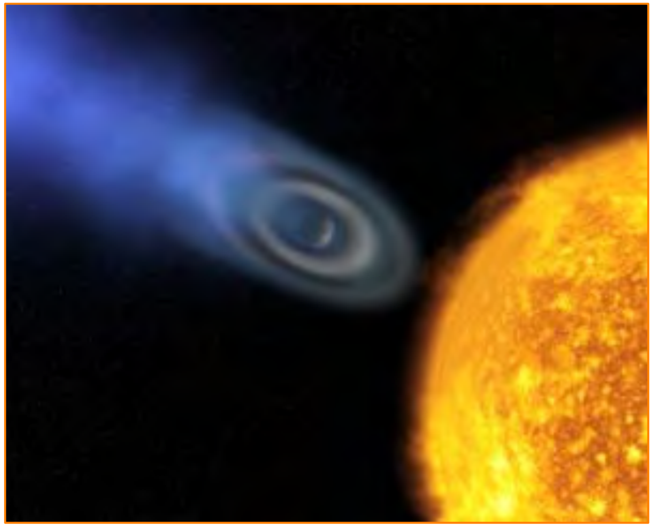
Hydrogen is abundant in planetary exospheres….

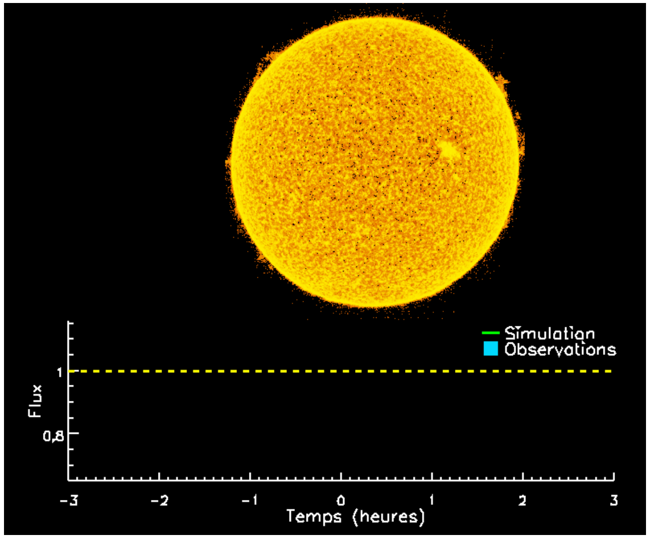
Hydrogen during planet growth



Lammer et al. 2014

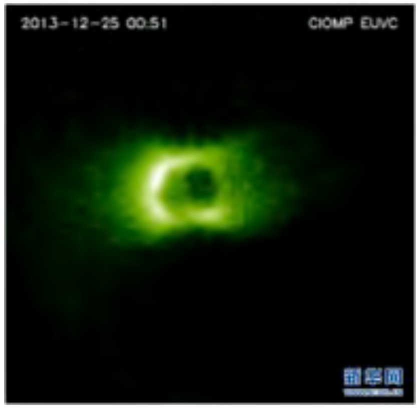
Hot Jupiters & Neptunes





....even in the Earth

OBSERVATION



THEORY

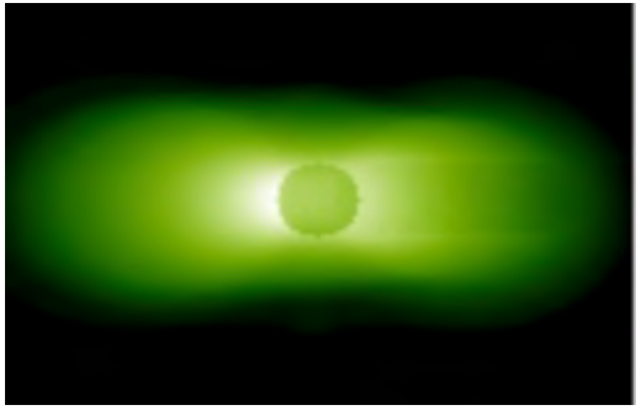
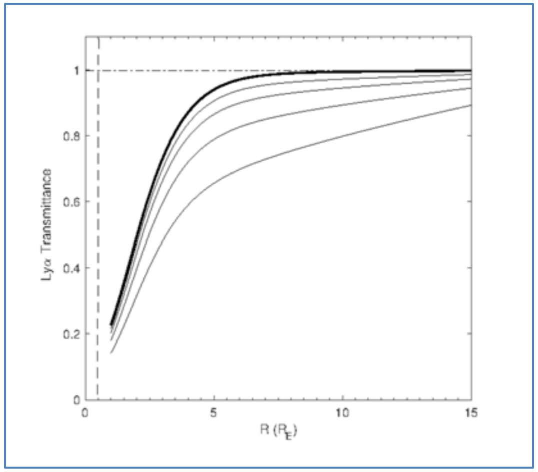
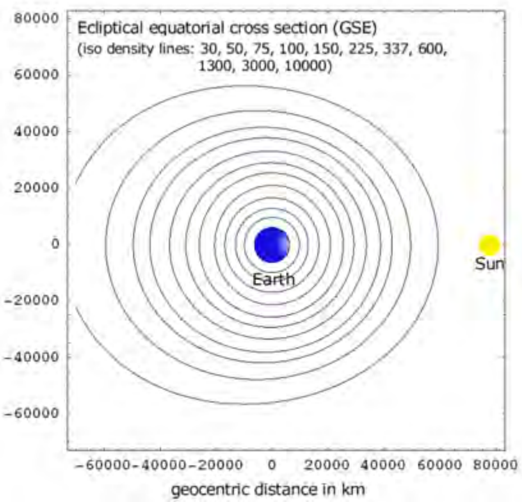


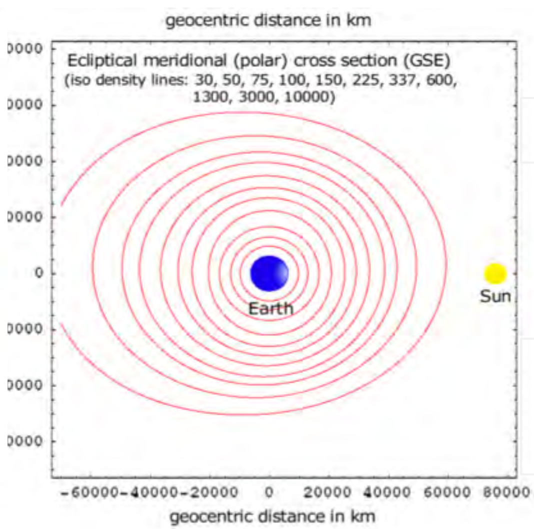
Image of the Earth magnetosphere at 30.4 nm (He II) obtained with the EUV camera on Chang'e 3 [Source: Chinese Academy of Sciences].

Earth transmittance to Lyα



Gómez de Castro et al. 2017



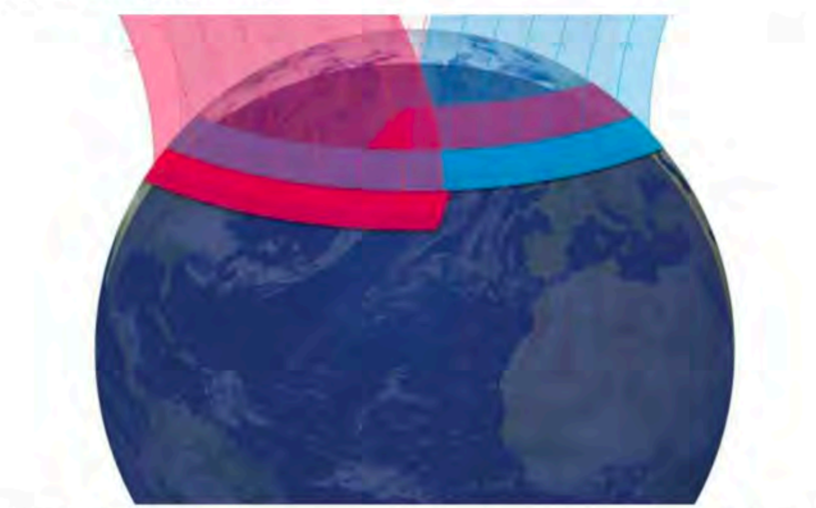


$$n(H)(cm^{-3}) = 10^4 e^{-Re/1.02Re} + 70 e^{-Re/8.2Re}$$

H I DISTRIBUTION IN THE EARTH EXOSPHERE OBTAINED BY THE TWINS MISSION (NASA)
Zoennchen et al. 2011

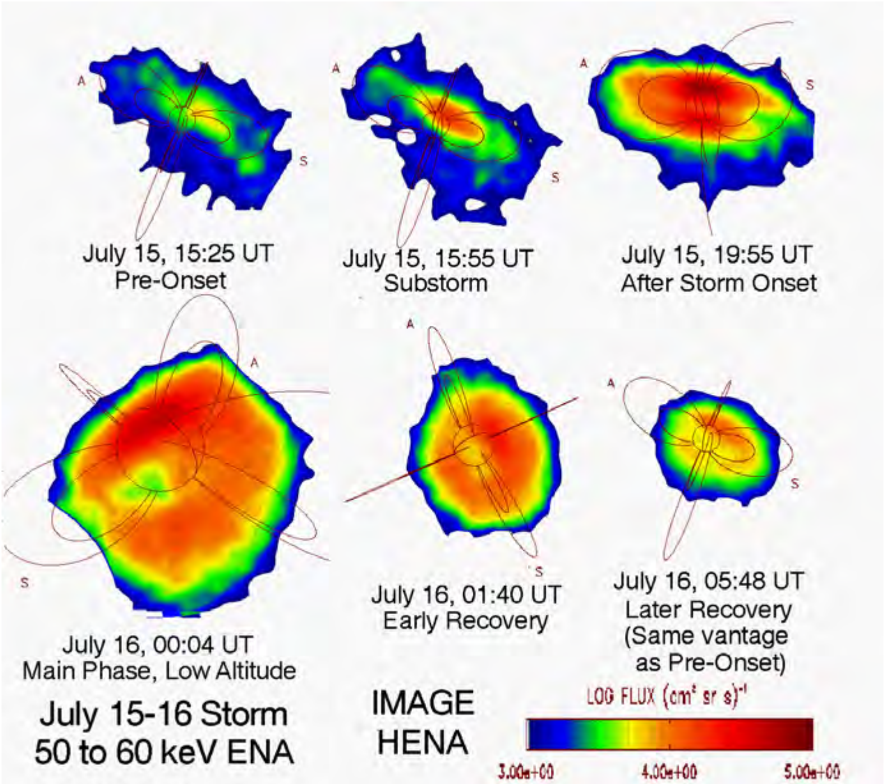
… and more

- Simultaneous Lyα and broad band monitoring inform about HI distribution.
- Part of HI population are Energetic Neutral Atoms (ENA) sensitive to magnetospheres.
- Tracking the spatial distribution of the stellar Lyα emission.
- Study of planetary winds and atmospheric stability.



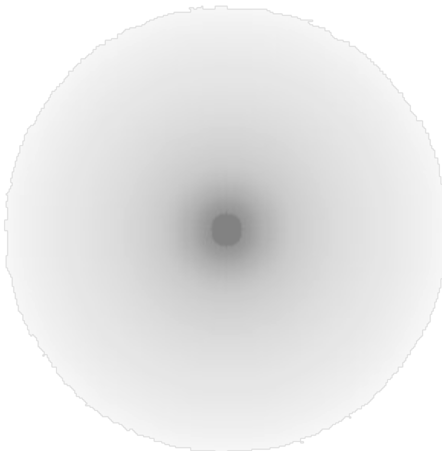
Birkeland currents carry up to 1 TW of electric power to the upper atmosphere – about 30 times the energy consumed in New York during a heatwave. They are also responsible for 'aurora arcs', the familiar, slow-moving green curtains of light … more

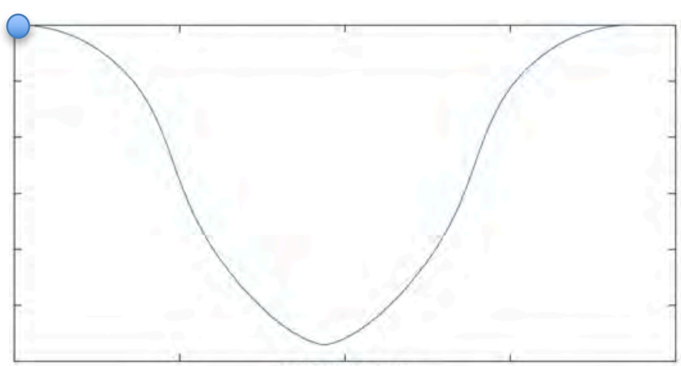
Birkeland currents are driving jets and carry about 1 TW of power into the upper atmosphere



TRACKING PLANETARY TRANSITS IN LYMAN ALPHA

an image worths a thousand words
(parameters for M5 V star)





VWS are best detected through integral flux monitoring (provided that the signal is not rapidly variable…)

Very Weak Signals

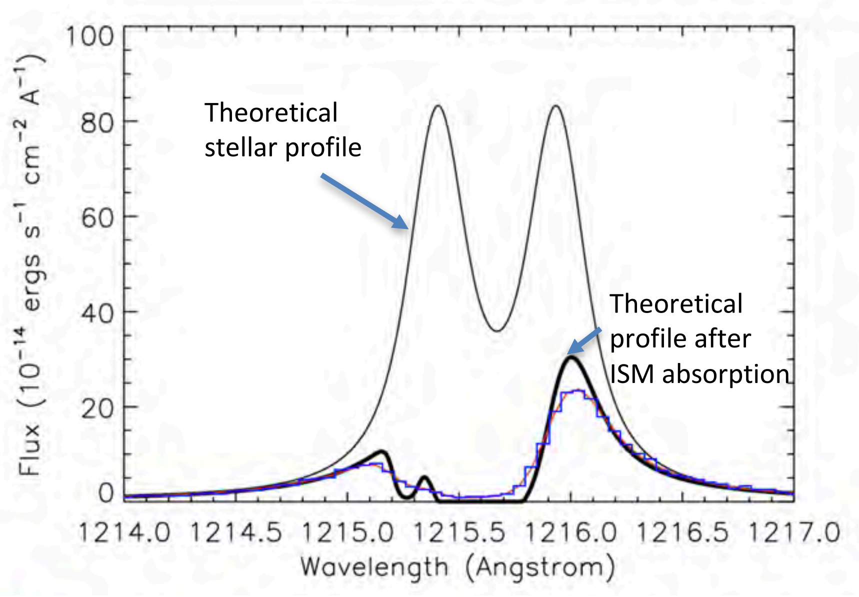
PARAMETER	PROXIMA CENTAURI	AU MIC	ALPHA CENTAURI/SUN
Spectral Type	M5 V	M0 V	G2 V
Radius (R_{sun})	0.14	0.5	1
Mass (M_{sun})	0.12	0.6	1
Semimajor axis of planet orbit in the habitable zone (AU)	0.032	0.3	1
$\log N_H$ (cm^{-2})	18.36	17.6	18.36/0
Dista ce (pc)	1.3	9.9	1.3

CAREFUL ! THE INTERSTELLAR MEDIUM CAN SATURATE THE CORE OF THE LINE

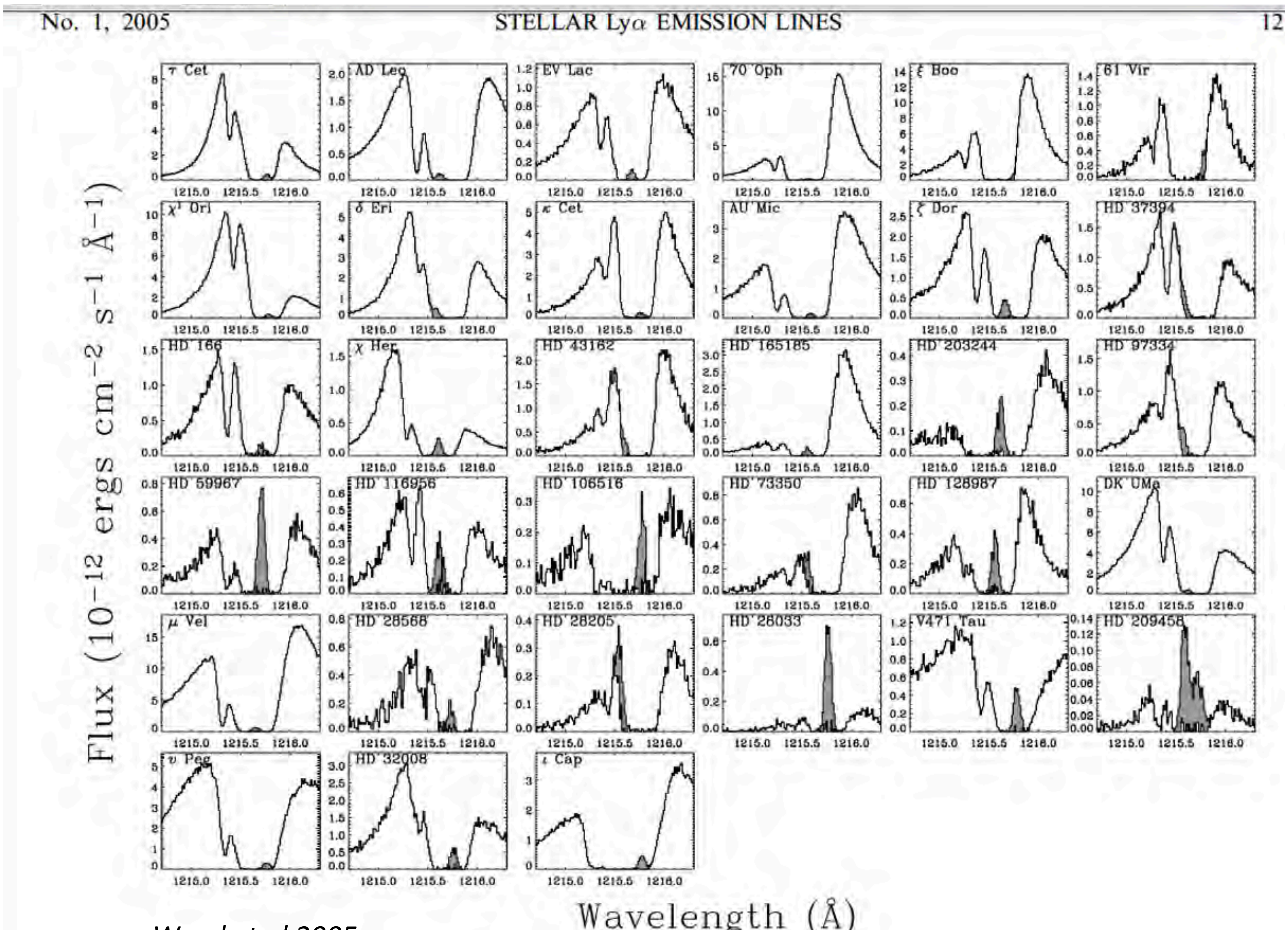
Plot of the theoretical profile of **HD189733** Lyα line.

BY Dra star: K1-K2V
d= 19.3 ($\pm$ 0.2) pc
V=7.67

Planet mass: 1.142 ($_{-0.02515}^{+0.02516}$) M_J
a= 0.03142 ($\pm$ 0.00052) AU



There are clouds of atomic hydrogen along many lines of sight

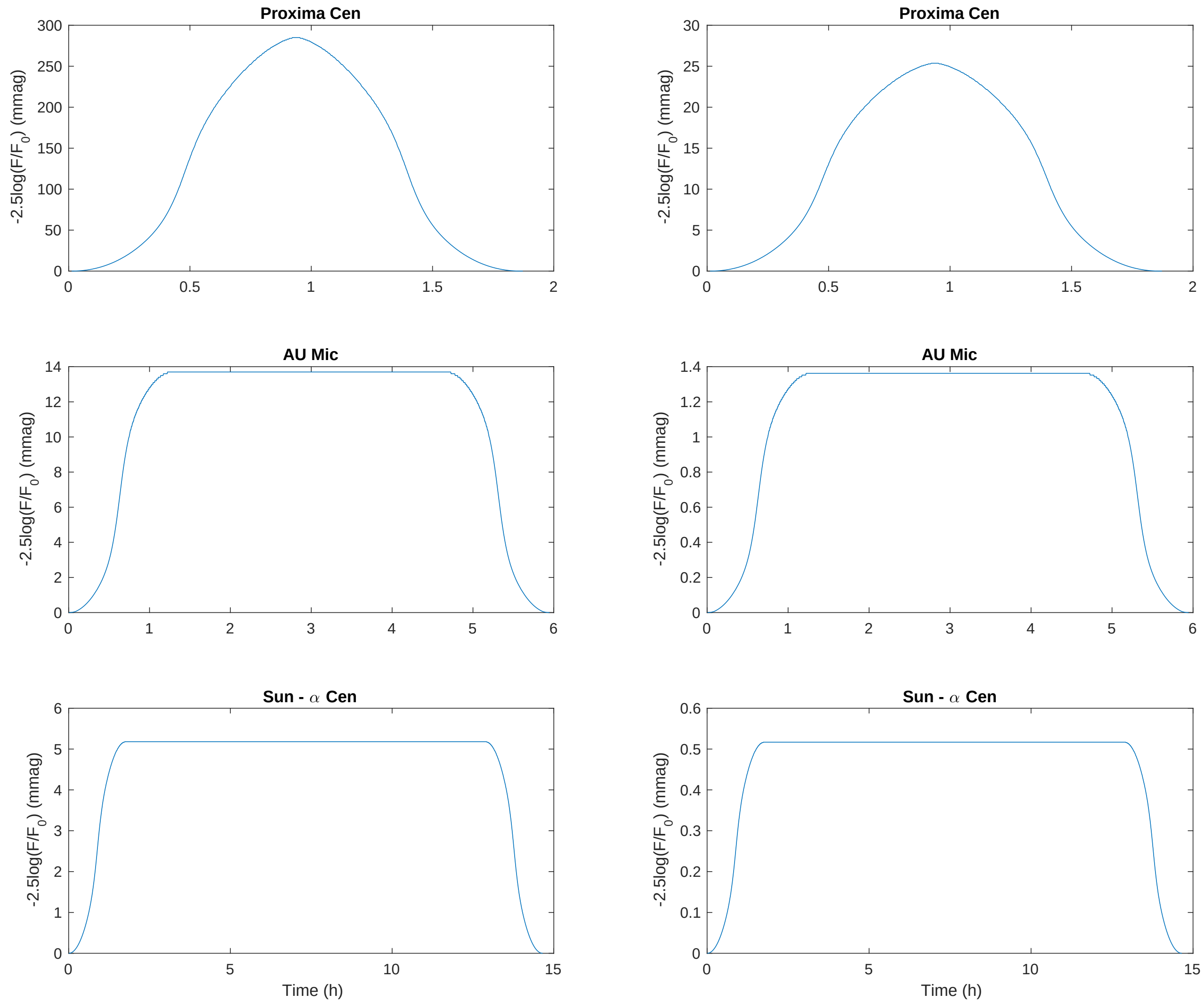


Wood et al 2005

Light curves for various saturation levels of Lyα.

no saturation

10% of the transit depth is observed



BUT THERE IS ANY ABSORPTION OUTSIDE THE CORE OF THE LINE?

Using as input the functions $n(r)$, $T(r)$ and $V_e(r)$ from Erkaev et al. 2012, we have computed the optical depth of the exospheric absorption of Lyα photons as a function of R, the cylindrical distance to the center of the Earth-like planet and the velocity of the exospheric gas v, as,

$$\tau(R,v) = \sigma \int_{-z_l}^{+z_l} n(r) f(r,v) dz \tag{5}$$

with $f(v,z)$ the normalized velocity profile of the gas at a distance r obtained by the convolution of the thermal broadening (assuming T(r) as in Erkaev et al. 2012) and the natural broadening profile ($\phi(v)$). Hence,

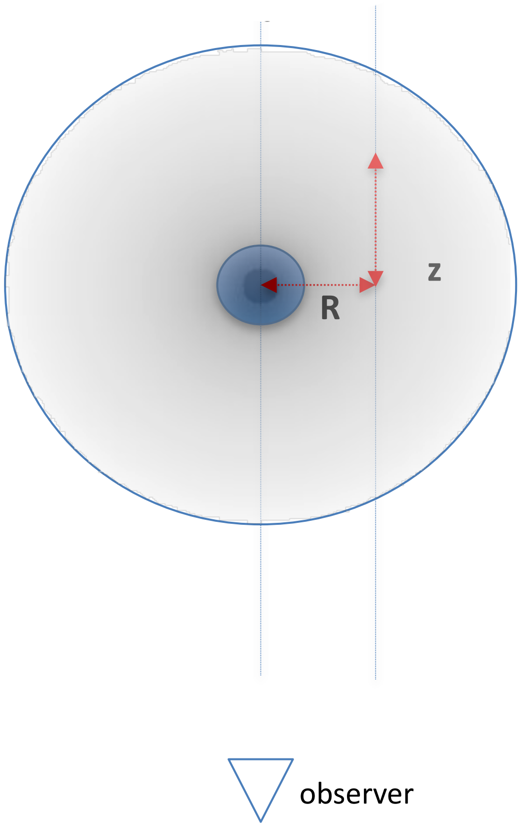
$$f(r,v) = \frac{\exp(-U(r,v))}{2k\pi T(r)/m_H} * \phi(v) \tag{6}$$

and,

$$U(r,v) = \frac{(v - V_e(r))^2}{2kT(r)/m_H} \tag{7}$$

Note that m_H is the mass of a hydrogen atom, k is the Boltzmann constant and

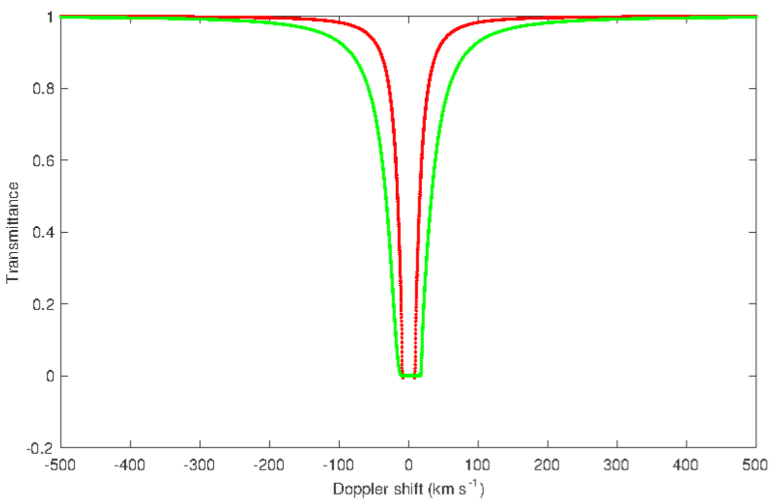
$$r = \sqrt{(R^2 + z^2)} \tag{8}$$

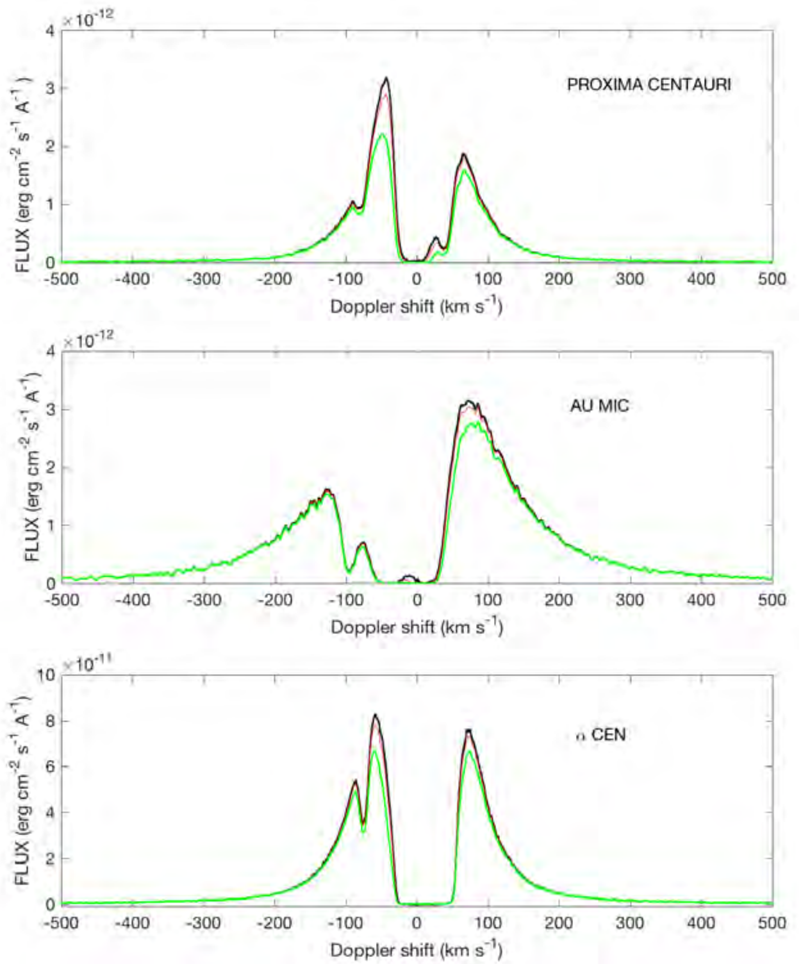


Lyα absorption profiles produced by the exosphere.

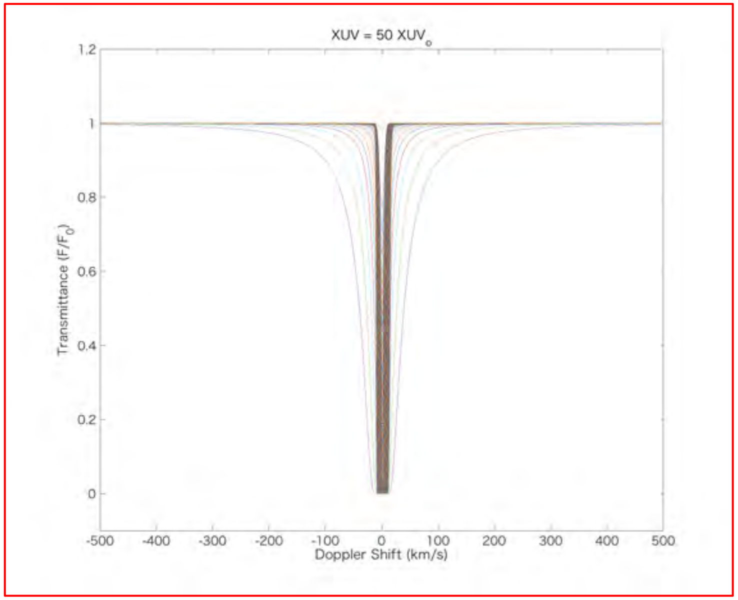
Models by Erkaev et al 2012 give detailed predictions for V(r), n(r), T(r) for the exospheres of Earth-like planets submitted to various XUV fluxes: from solar-like (red) to 100 times this value.

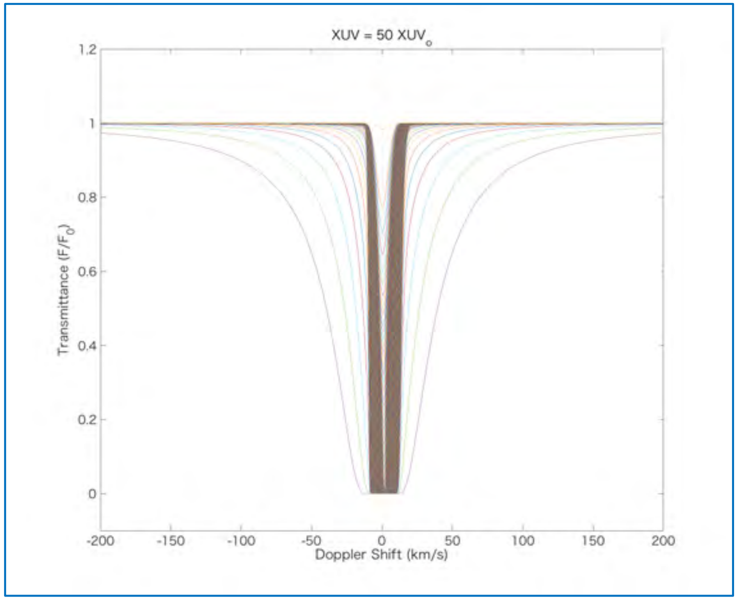
Green curves correspond to 50 XUV_{sun} (smaller than typical values in M stars)





The exospheric absorption by depth





DETECTABILITY

Instrument impact on observed light curves

$$SNR = \frac{\Delta SCR \times T_{\mathrm{exp}}}{\sqrt{SCR \times T_{\mathrm{exp}} + N_{pix} \times BCR \times T_{\mathrm{exp}}}} \quad (10)$$

with

- SCR, the stellar Lyα count rate.
- BCR, the Lyα background count rate.
- ΔSCR measures the depth of transit: the out of transit SCR minus the SCR at maximum depth during transit.
- N_{pix} the number of pixels used to integrate the signal. For this calculation, $N_{pix} = 4$ is assumed.

The count rate is derived from the Lyα flux, $F_{Ly\alpha}$, from the usual expression:

$$SCR = \left(\frac{D}{4m}\right)^2 A_{eff} \frac{F_{\mathrm{Ly}\alpha}}{h\nu_{\mathrm{Ly}\alpha}} \quad (11)$$

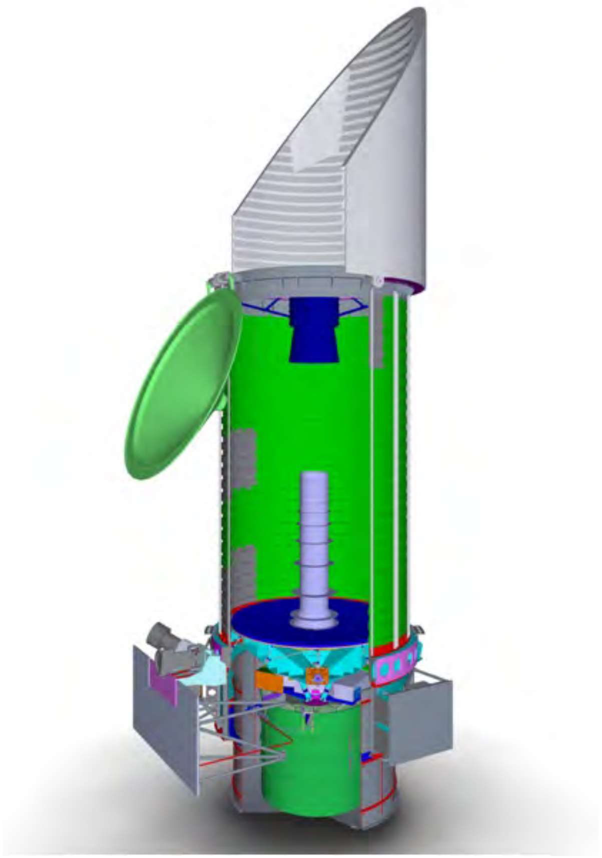
Default instrument configuration for SNR calculation

Mirrors (3): primary+secondary+pick-off (0.8 reflectivity)

Grating (1): 20% reflectivity

MCP detector: QE(Lya) = 20%

Aeff (cm^2) = $\boldsymbol{\pi}(400)^2 0.8^3 0.2^2$

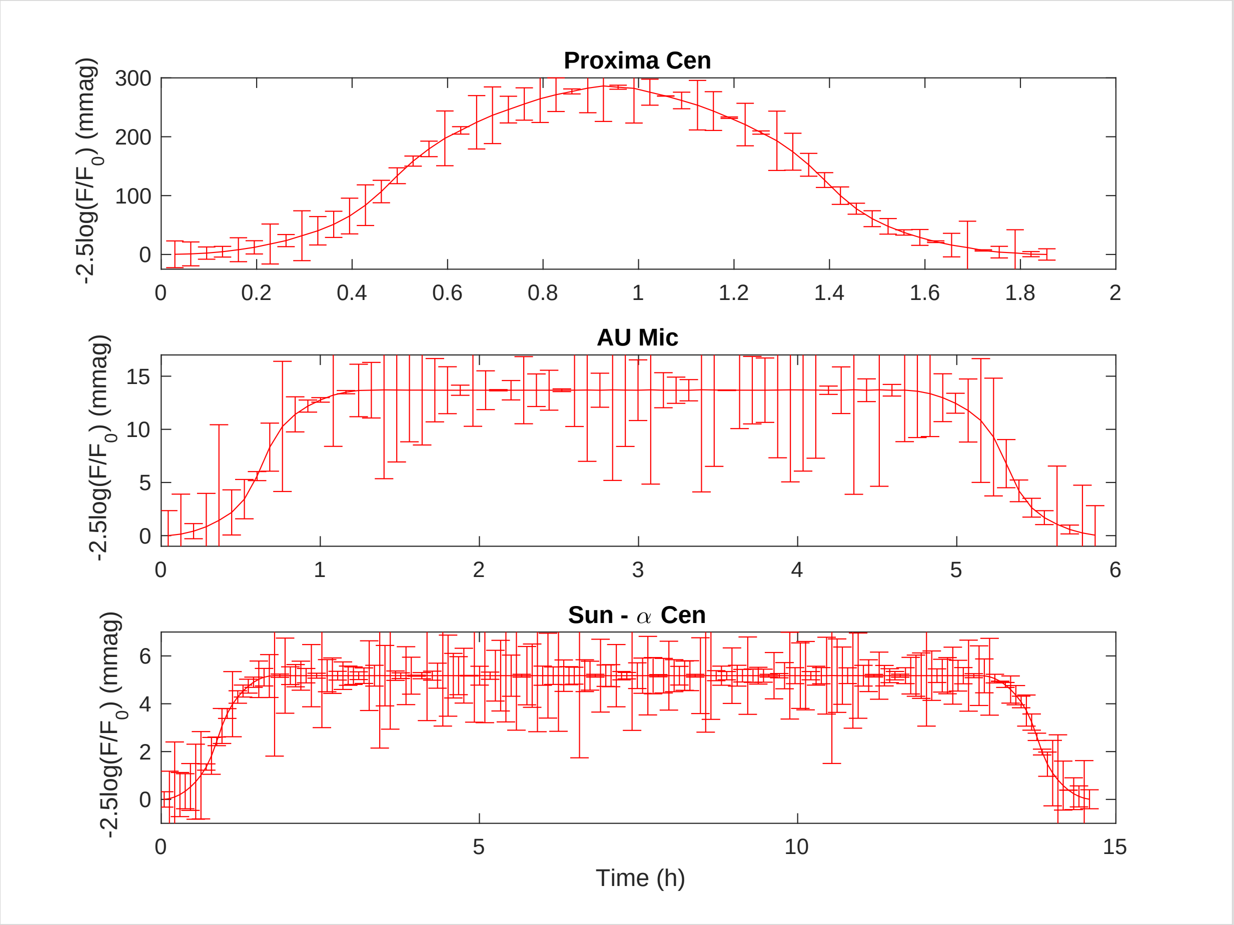


Detectabilidad

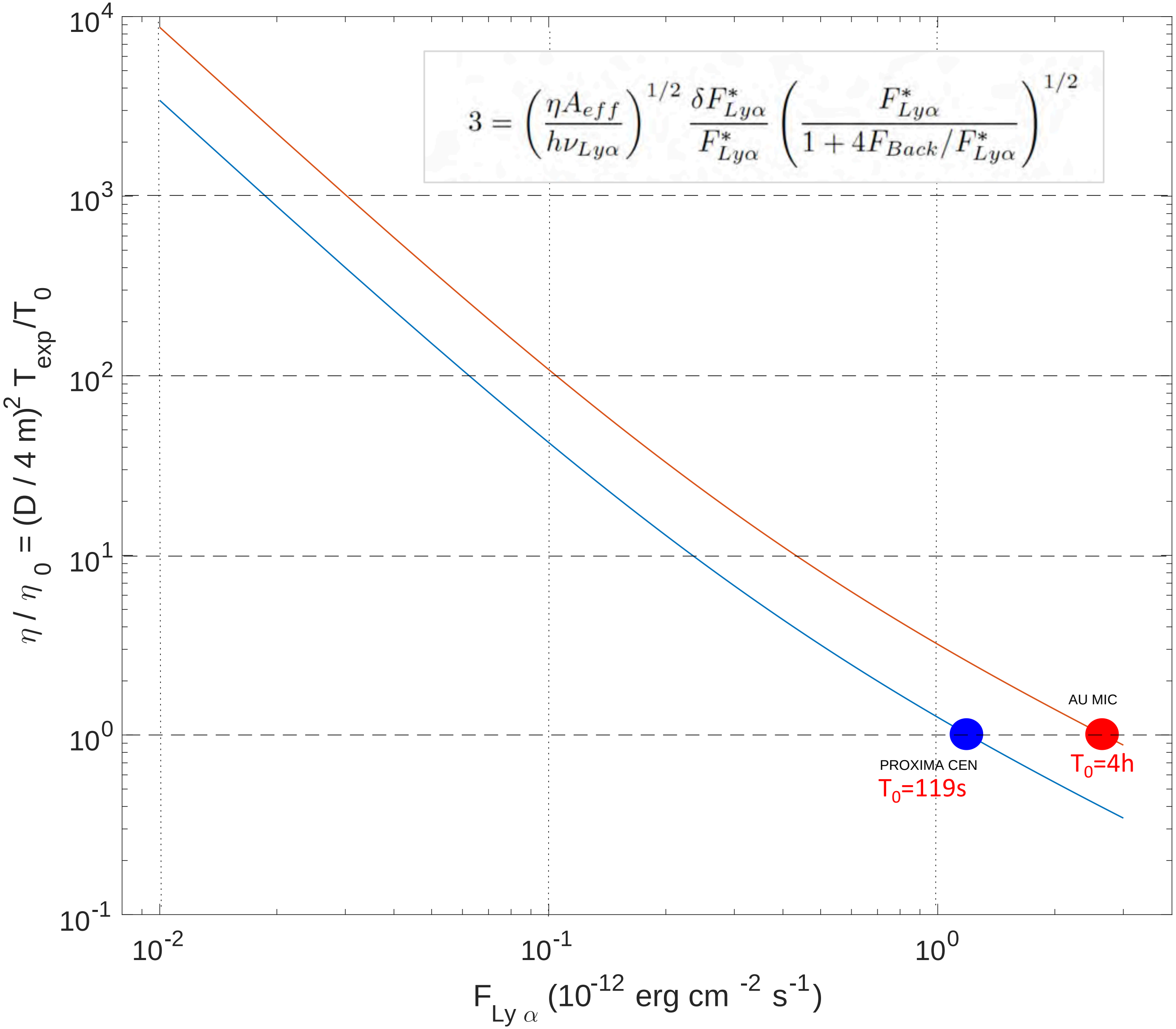
Time bin= 2 min
4m telescope
SNR=11

Time bin= 4 min
12m telescope
SNR=3.5

Time bin= 10 min
12m telescope
SNR=4.4



DETECTABILITY OF A TRANSITING EARTH-LIKE PLANET IN Lyα



CONCLUSIONS

- Studying exoplanets in the UV (and in Lyα) is feasible and provides unvaluable information on the planet atmosphere interaction with the interplanetary medium
- As exoplanets are everywhere, the line of sight to search for them must be selected carefully to allow follow-up UV studies.
- High XUV flux favours high exospheric flows and increase the chances of detectability.

The three body problem and exoplanets: the case of Prox. Cen