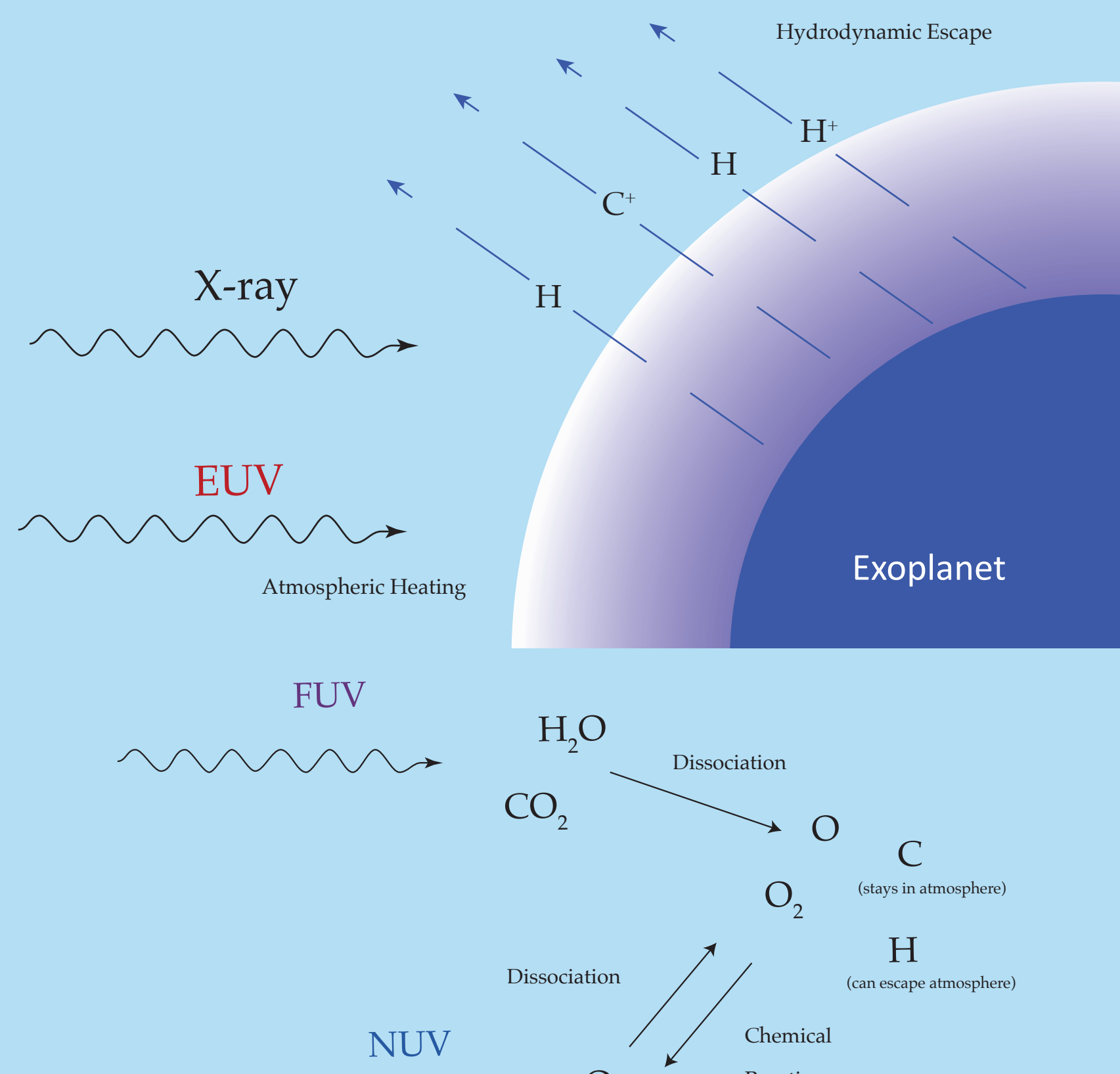


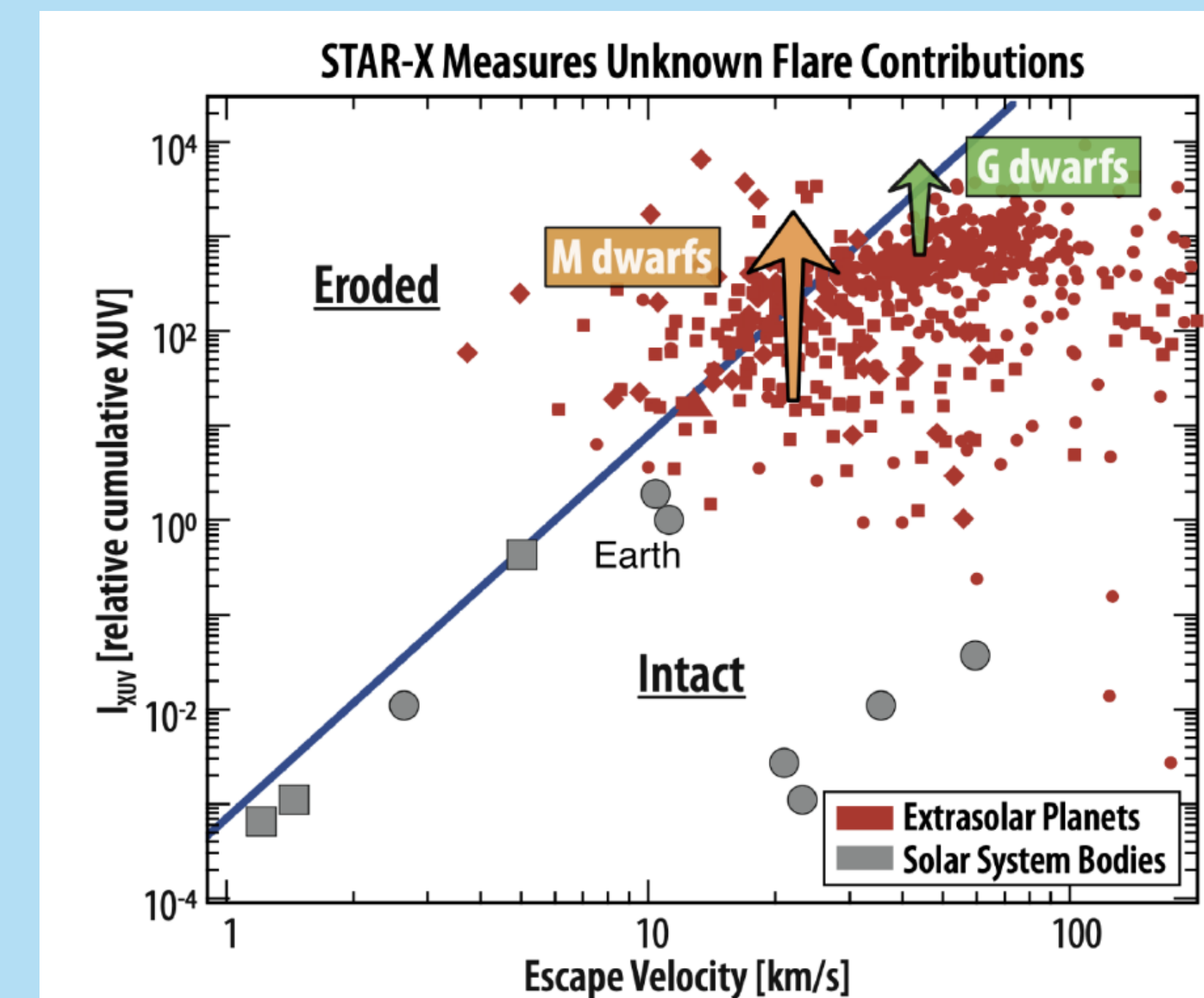
With sensitive X-ray & UV instruments, the *STAR-X* mission will answer outstanding questions fundamental to stellar astrophysics and exoplanet science. Unprecedented X-ray sensitivity enables short time cadence monitoring of nearby stars, which for the first time can separate low-level flaring from persistent emissions to directly measure unbiased quiescent fluxes. Numerous flare detections will enable the most precise measurement of the high-energy flare frequency distribution of nearby exoplanet hosts across a range of activity levels, and thus the total flaring contribution to the high-energy irradiation history of exoplanets. This history is a defining input to planet atmospheric modeling, and with simultaneous UV measurements, *STAR-X* will enable studies of exoplanet mass-loss, as well as prebiotic and photochemistry throughout planet evolution. Determining which planets are amenable to the development of life requires this stellar characterization: *STAR-X* will make this significant leap in understanding the pathways to habitable worlds.



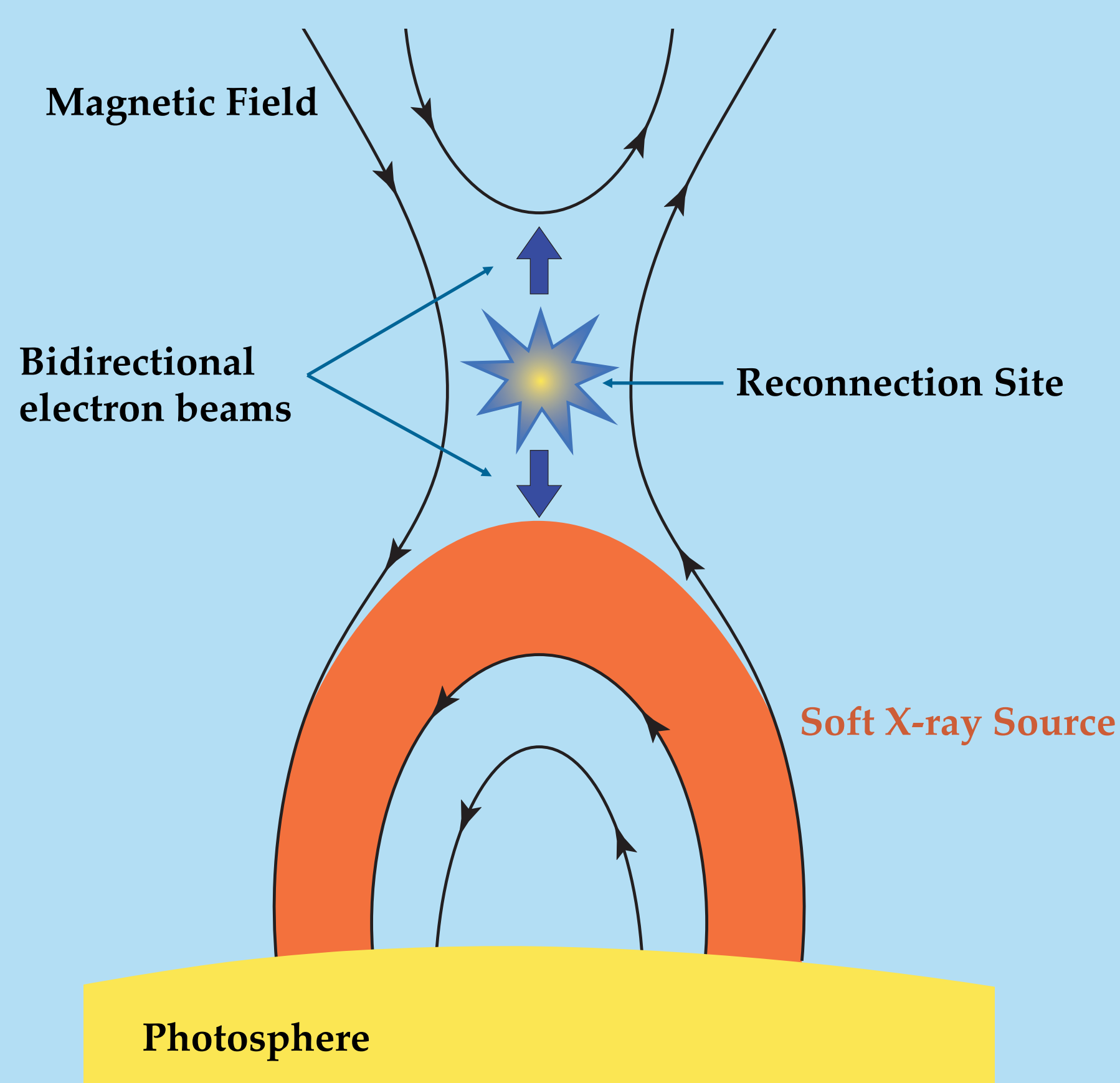
Above – Ultraviolet emissions drive planet photochemistry, determining levels of atmospheric oxygen, and are key to the creation of RNA precursors (Rimmer et al. 2018).

Left – High energy X-ray and extreme ultraviolet emissions power planet hydrodynamic escape.

Below – Adapted from Zahnle & Catling (2017), XUV is key measurable possibly dictating survivability of exoplanet atmospheres, with the contributions from flares currently poorly characterized: *STAR-X* will address this problem.



Below – Standard model diagram of stellar flaring driven by magnetic reconnection in stellar upper atmosphere. Energy release manifests as multi-wavelength impulsive emissions.



Measuring the cumulative irradiation of exoplanet systems requires both unbiased quiescent measurements and an assessment of the contribution from frequent high-energy flares. The flaring luminosity is determined by the flare frequency distribution for flares of a given energy,  $E$ , with power-law slope  $\alpha > 0$ :

Differential flare frequency distribution (flare rate/erg):

$$\frac{dN}{dE} = kE^{-\alpha}$$

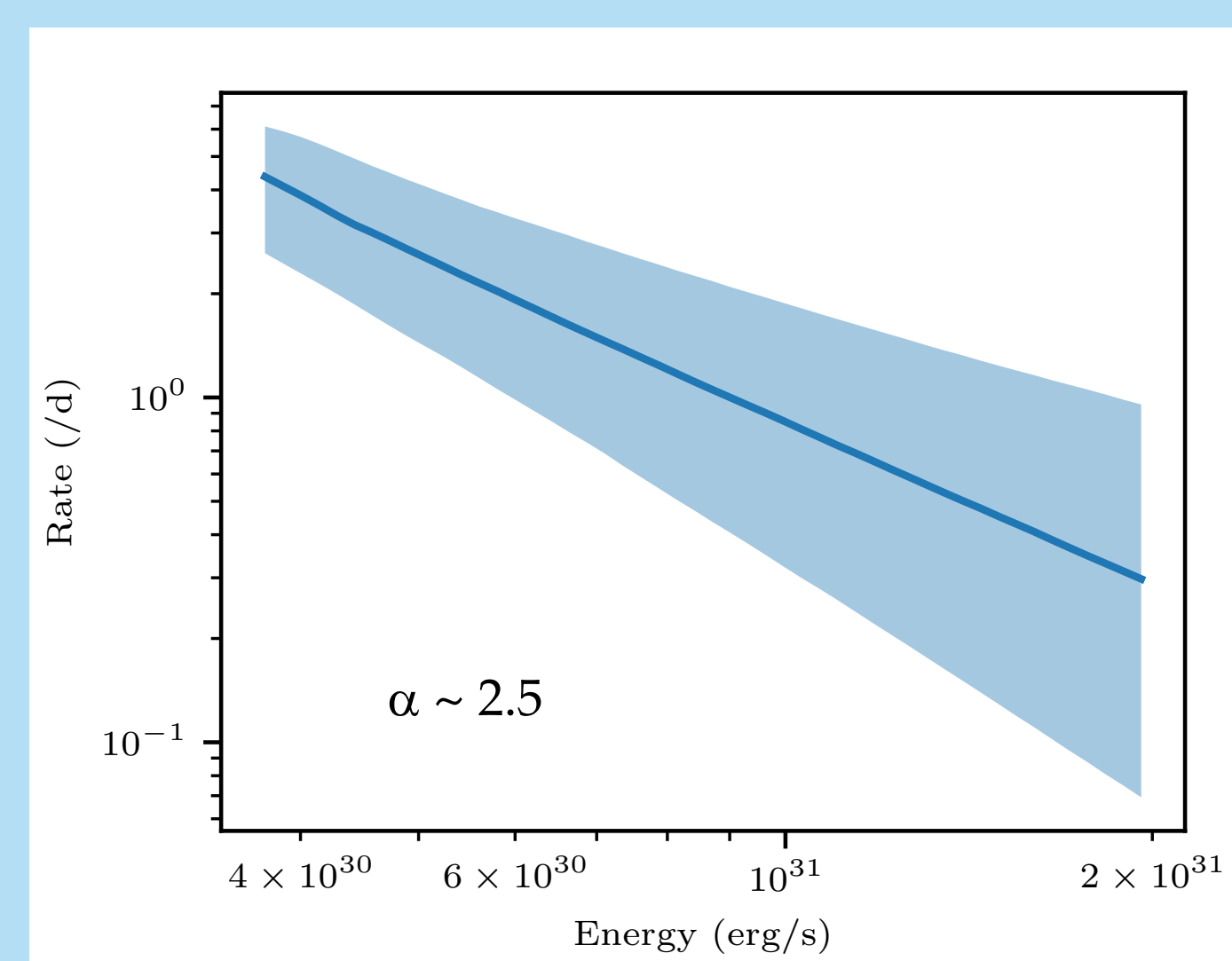
Cumulative flare frequency distribution (total rate for flares of at least energy,  $E$ ):

$$N(> E) = \frac{k}{\alpha - 1} E^{1-\alpha}$$

Flaring luminosity:

$$L_{X,f} = \int_{E_{\min}}^{E_{\max}} kE'^{1-\alpha} dE'$$

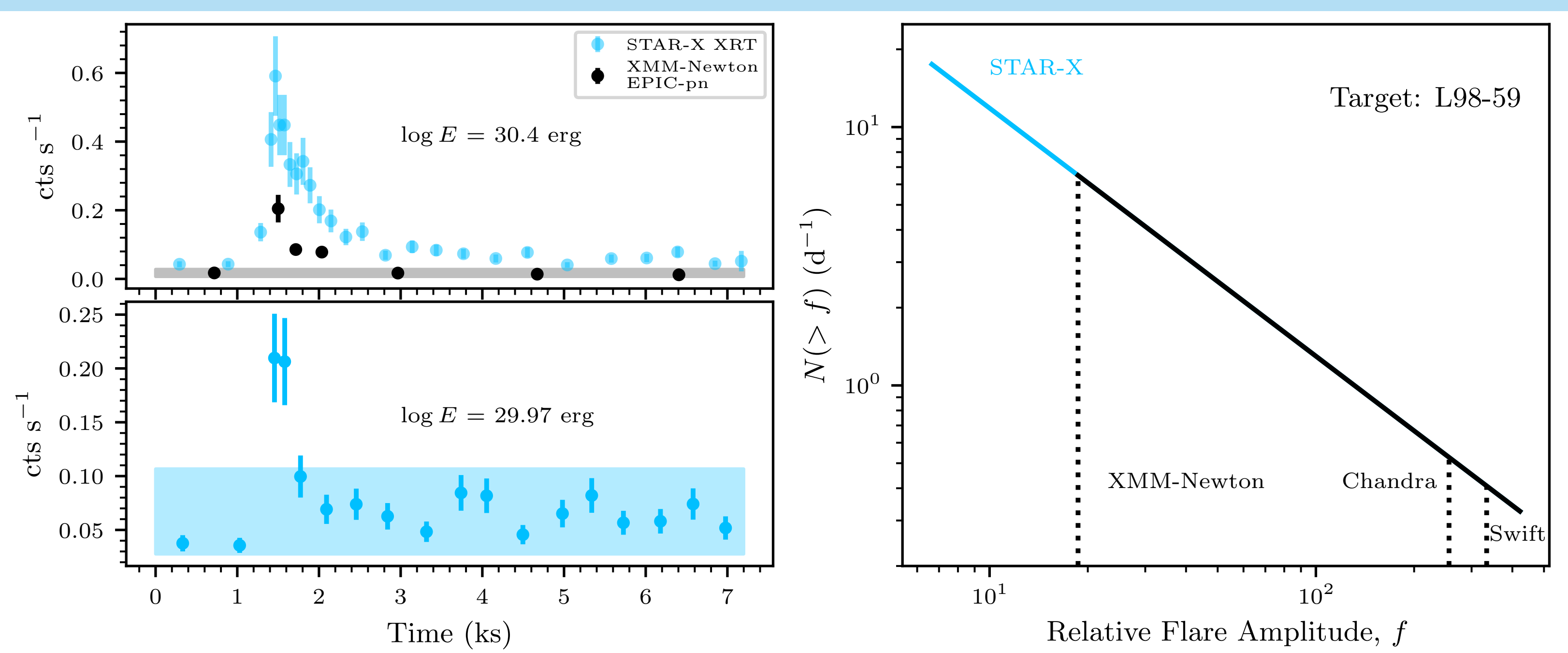
Below – Example FFD power-law fit of 5 flares observed with *Chandra* on Proxima Centauri from Fuhrmeister et al. (2022), with  $1\sigma$  shaded bands.



$\alpha \sim 2.5$  for Prox. Cen. is a steep power-law, implying more frequent low-energy flares dominate the flaring luminosity. Measured flares suggest at least as much flaring X-ray luminosity as quiescent X-ray emission, extrapolating to lower flare energies undetected with *Chandra* sensitivity.

FFD measurements are needed across stellar angular momentum evolution to determine the influence of flaring luminosity on exoplanet atmospheric evolution.

***STAR-X* will target 20 exoplanet host stars monitoring them for a total of 3 Ms, measuring quiescent fluxes and flare frequency distributions.**



Left – Flare light curve simulations demonstrate that *STAR-X* probes to much weaker flare energies than is possible with current facilities. The limiting flare energy detectable with *XMM-Newton* (top) is factors of several greater than what is possible with *STAR-X* (bottom). The limits are based on typical flare detection algorithms requiring 3 consecutive  $3\sigma$  deviations from median curve.

Right – Cast as a relative flare amplitude, the nominal sensitivity of *STAR-X* pushes beyond current capabilities, as demonstrated in this FFD for example target L98-59, using short duration (5 min FWHM) canonical flare profiles (Veronig et al. 2002, Mendoza et al. 2022). The detection of frequent low-energy flares will provide precise measurements of the overall FFD for each target.

### Target Selection

- 7 mass bins across 0.1 – 1.0 solar masses
- 3 stars per mass bins (except Sun as representative of inactive 1.0 solar mass object) – 20 total targets
- Each mass bin includes early, intermediate, and old age benchmarks for evolution of X-ray and flaring emissions.
- Stars chosen to be exoplanet hosts of considerable interest, for example, *JWST* targets.

	Active	Intermediate	Inactive
$L_X / L_{\text{bol}}$	$\sim 10^{-3}$	$\sim 10^{-4}$	$\sim 10^{-5}$

### Key Science Outcomes:

- Quiescent X-ray luminosity measurements of individual stars
- Flare frequency measurements for sample across activity evolution
- Joint X-ray and UV flare response
- Benchmarks for total high-energy irradiation of exoplanets across time

### Additional Science:

- Importance of microflares for stellar atmospheric heating
- Coronal abundances for exoplanet host stars
- Precision high-energy irradiance of individual exoplanets
- Detailed flare physics, for example,
  - Quasi-periodic oscillations
  - Flare differential emission measures
  - Multi-wavelength monitoring opportunities