# Far-Ultraviolet Flares on M stars, Active and Inactive, Old and Young

*ExoPAG 18*

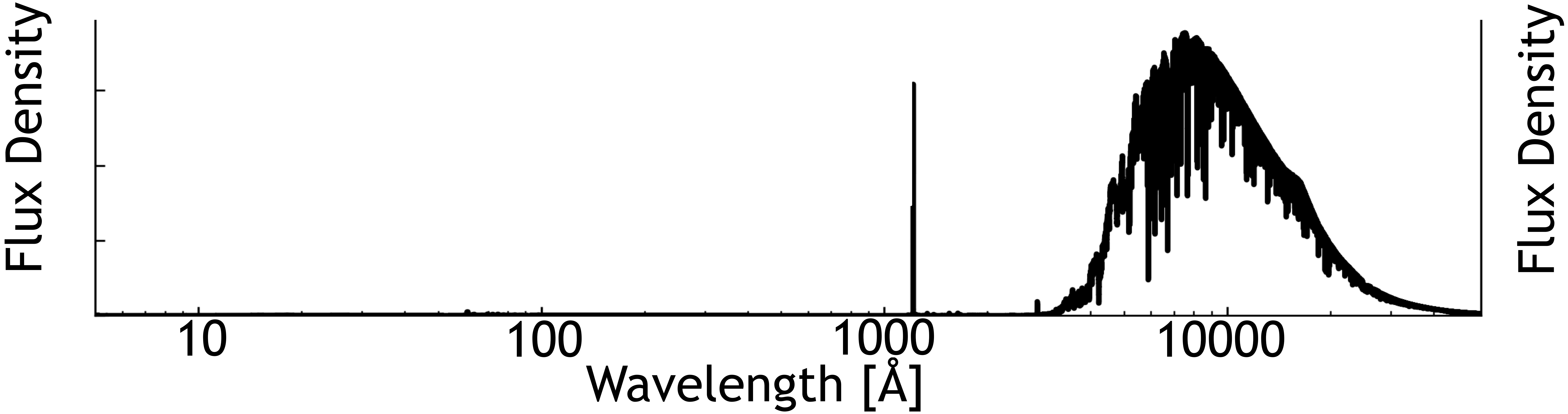
*R. O. Parke Loyd*

*2018 July 29*

# THE IMPORTANCE OF FAR ULTRAVIOLET FLARES ON M STARS

# The UV is Important

It drives photochemistry and thermal escape.



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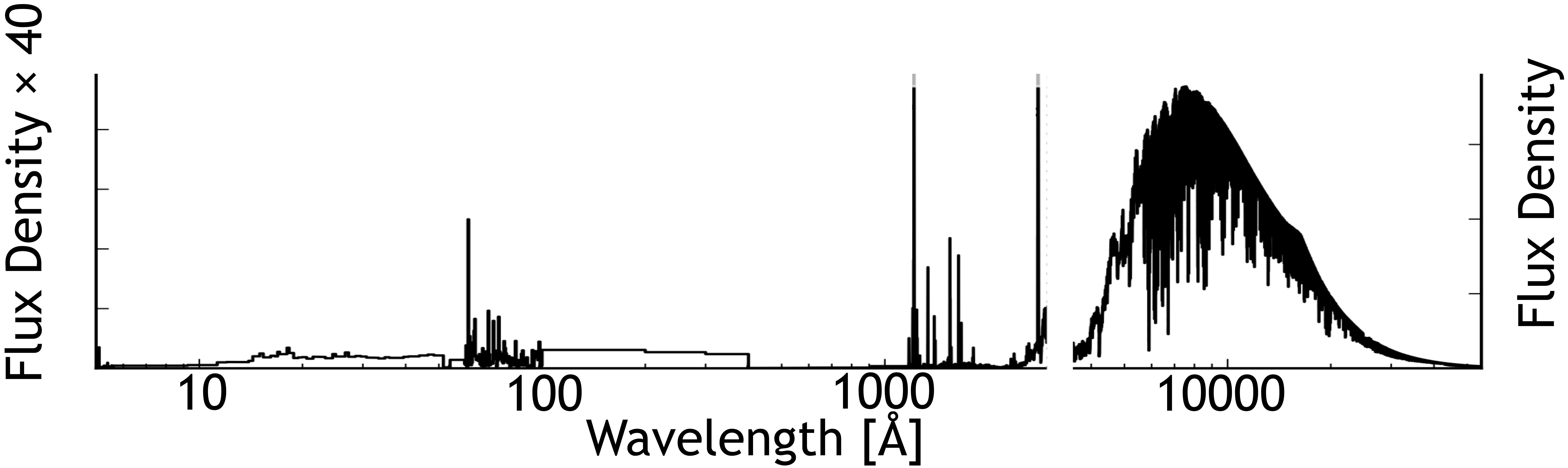

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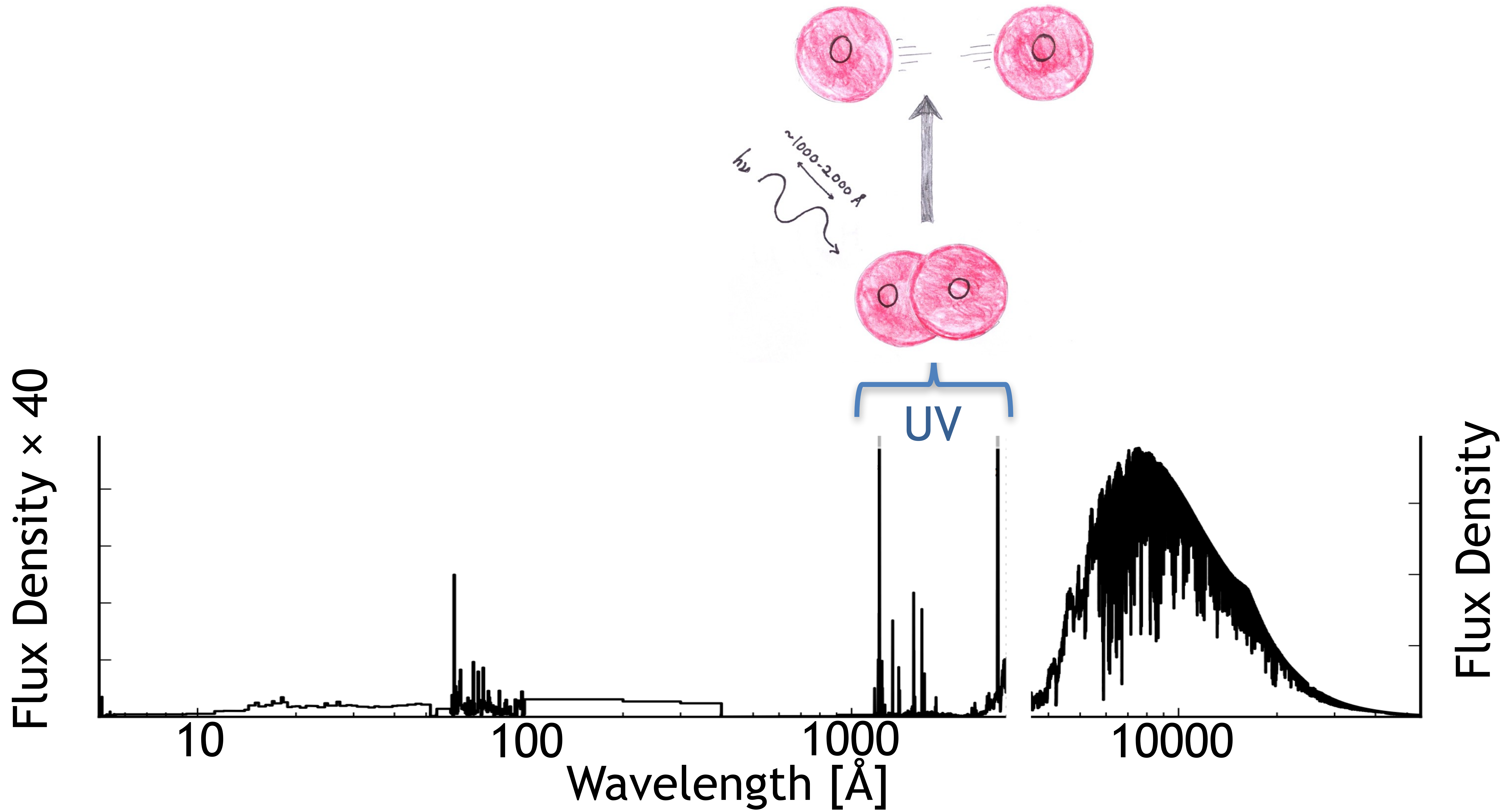

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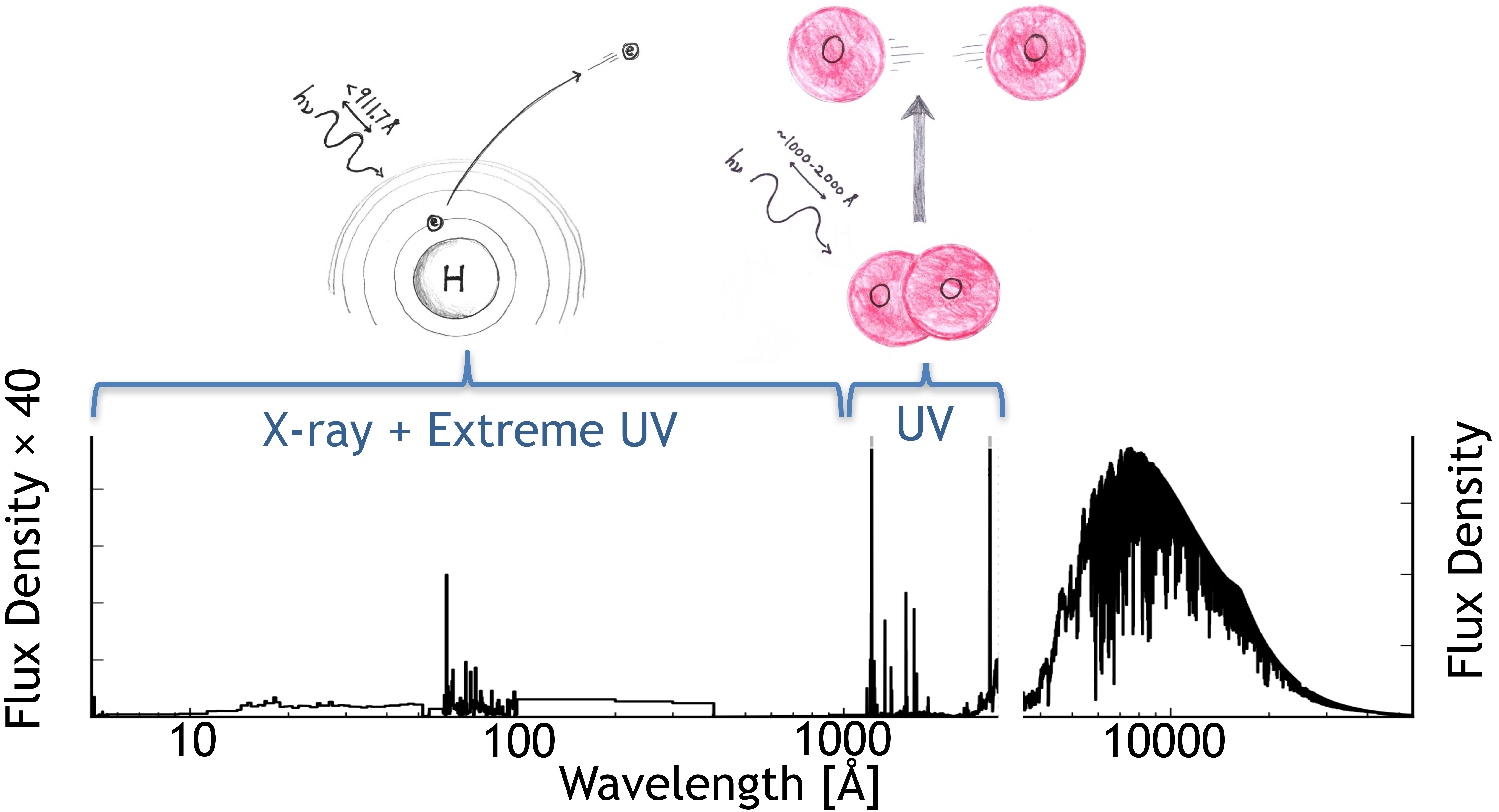
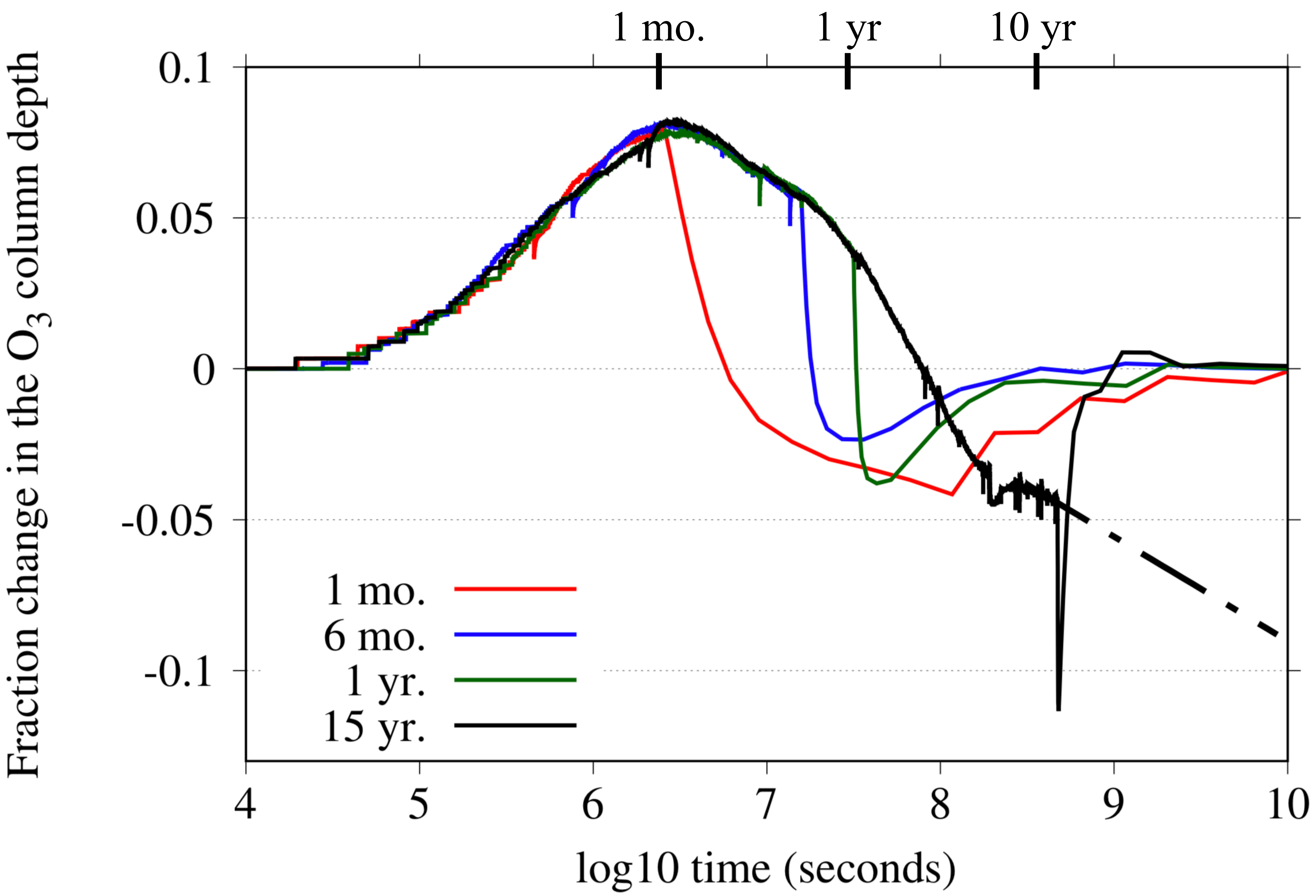


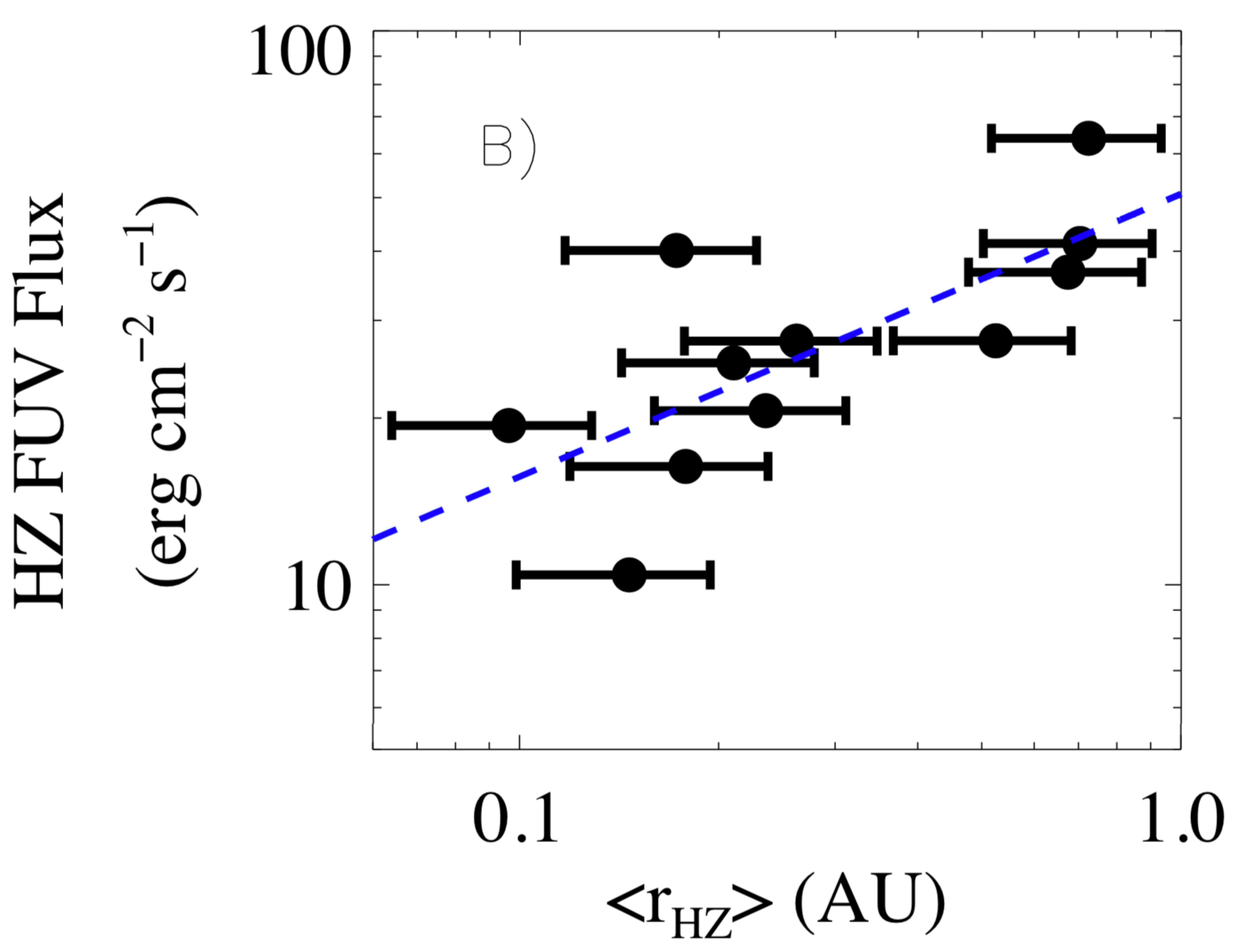
# UV flares will affect the composition of an Earth-like atmosphere

Work by Tilley et al. (2017 AsBio, in review) explores the influence of repeated M dwarf flares on atmospheric photochemistry. For example, applying ongoing flaring like that of the M Dwarf GJ 1243 for periods of 1 month up to 15 years suggests secular ozone loss.

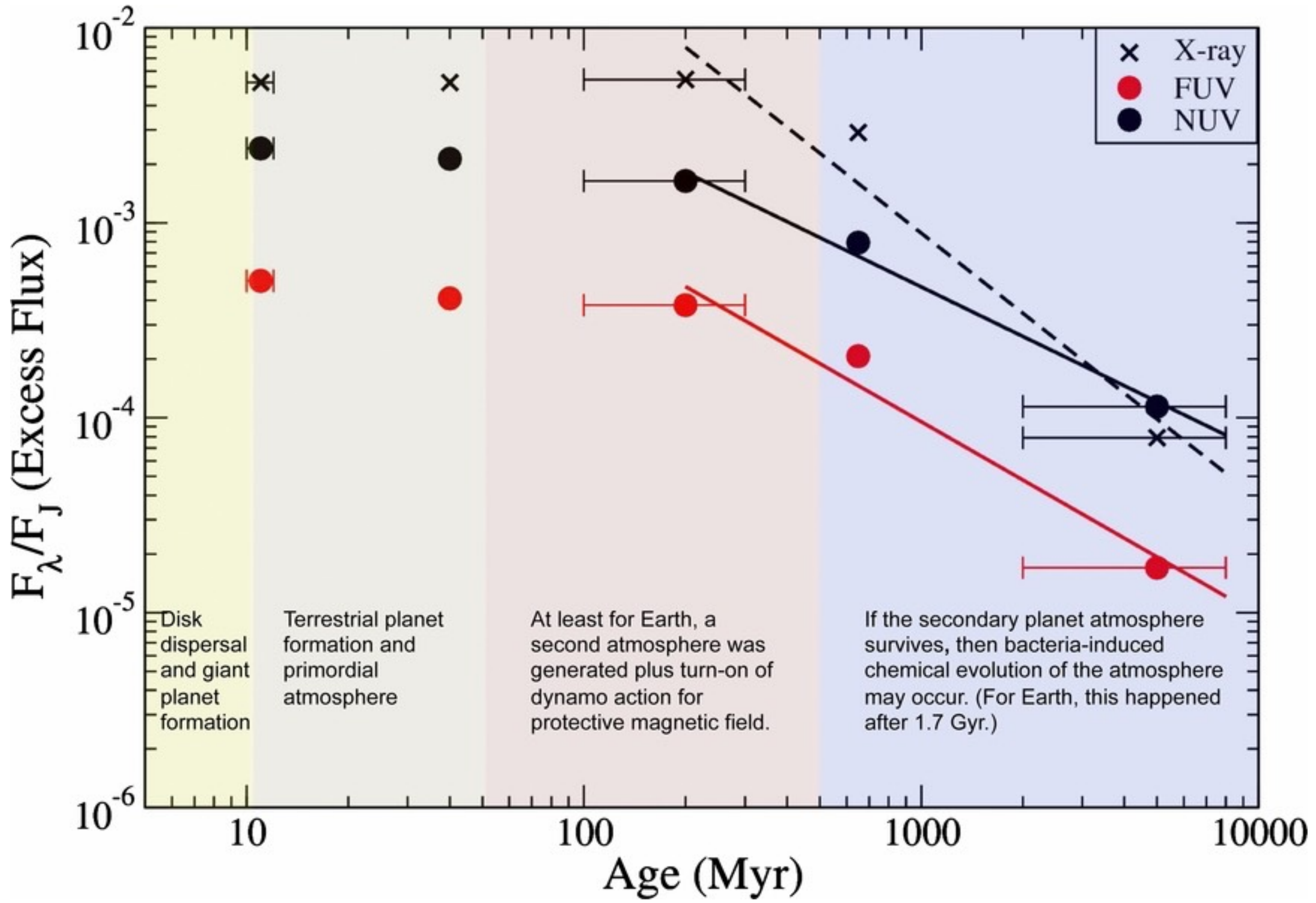


# RESULTS FROM *HST* SURVEYS

The **MUSCLES, Mega-MUSCLES,** and **HAZMAT** *HST* treasury surveys are gathering an unprecedented ~100 h each of ultraviolet observations of M stars




The MUSCLES program characterizes the harsh radiation of planet-hosting M dwarfs (France et al., 2016 ApJ).




The HAZMAT program tracks the changes in this radiation as M stars age. (Figure shows an analysis of *GALEX* data (Shkolnik and Barman 2014, ApJ)).

# The MUSCLES and HAZMAT observations are brimming over with far-ultraviolet (FUV) flares

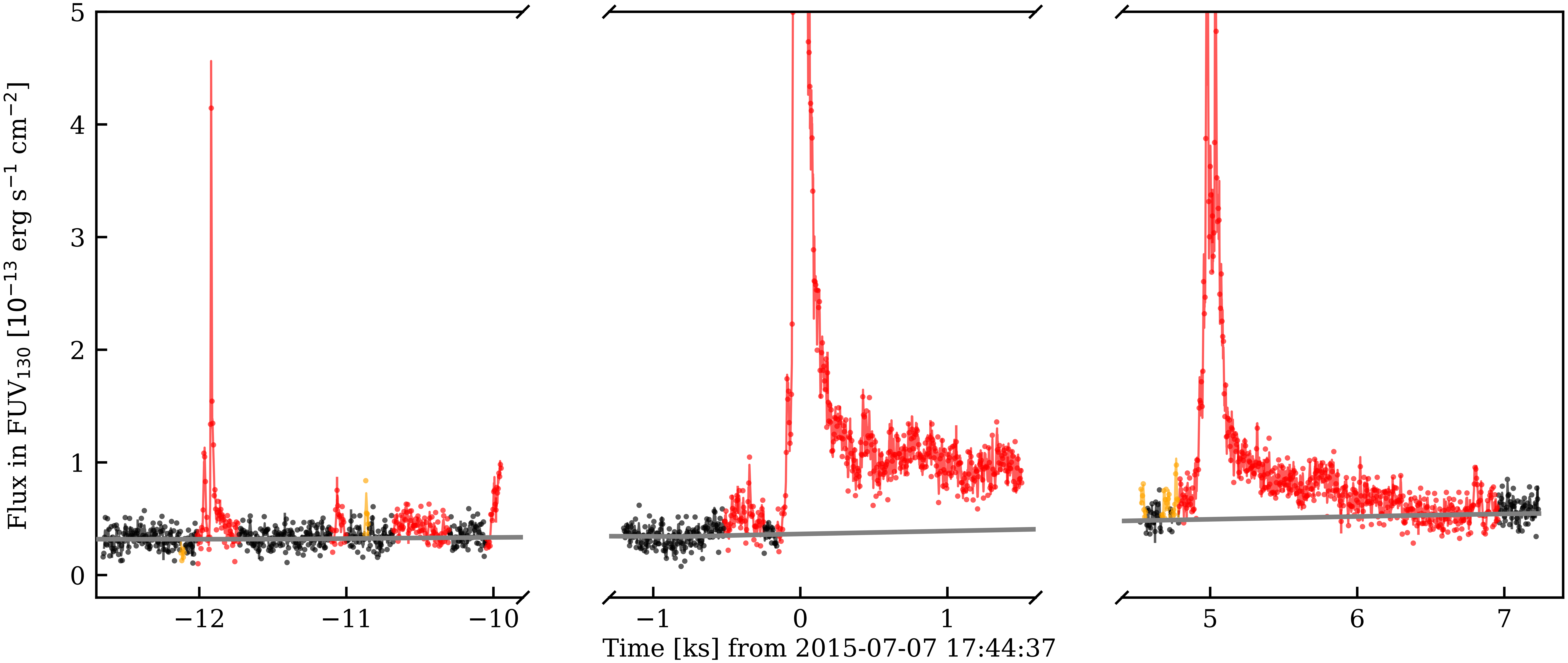
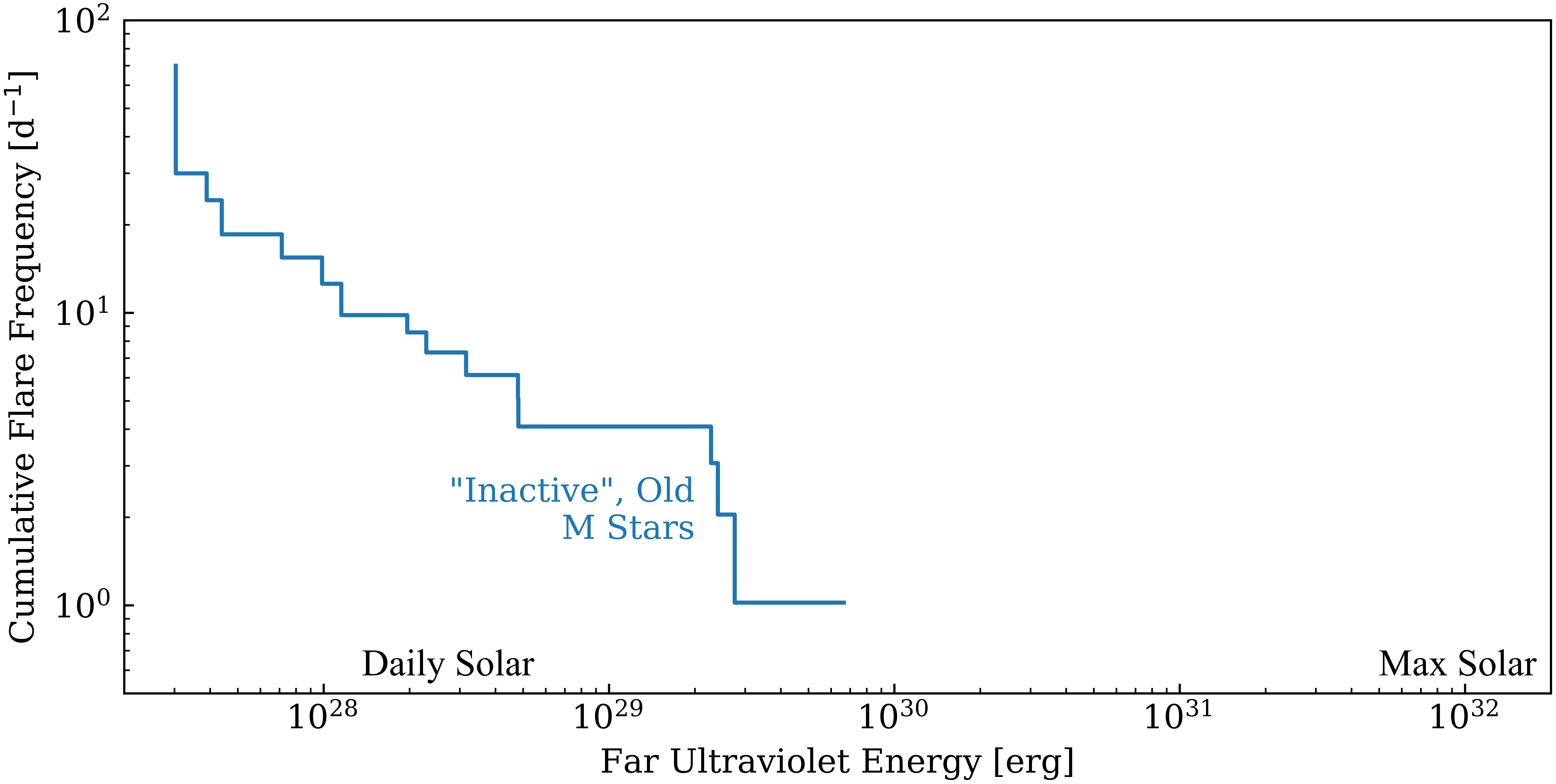
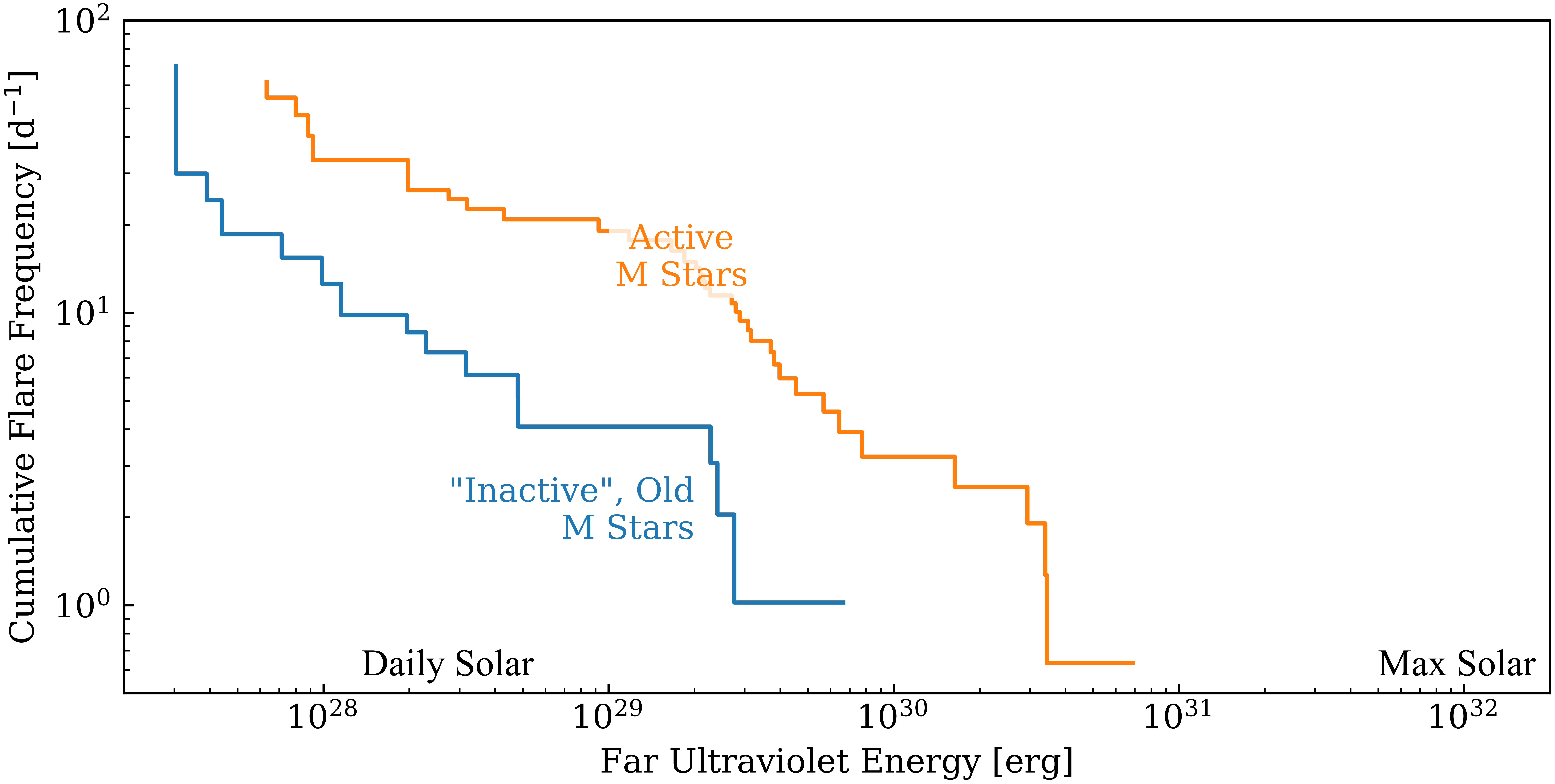



Exhibit A: Part of an FUV lightcurve from the M 3.5 star GJ 876. (Loyd et al. 2018a, ApJ in review)

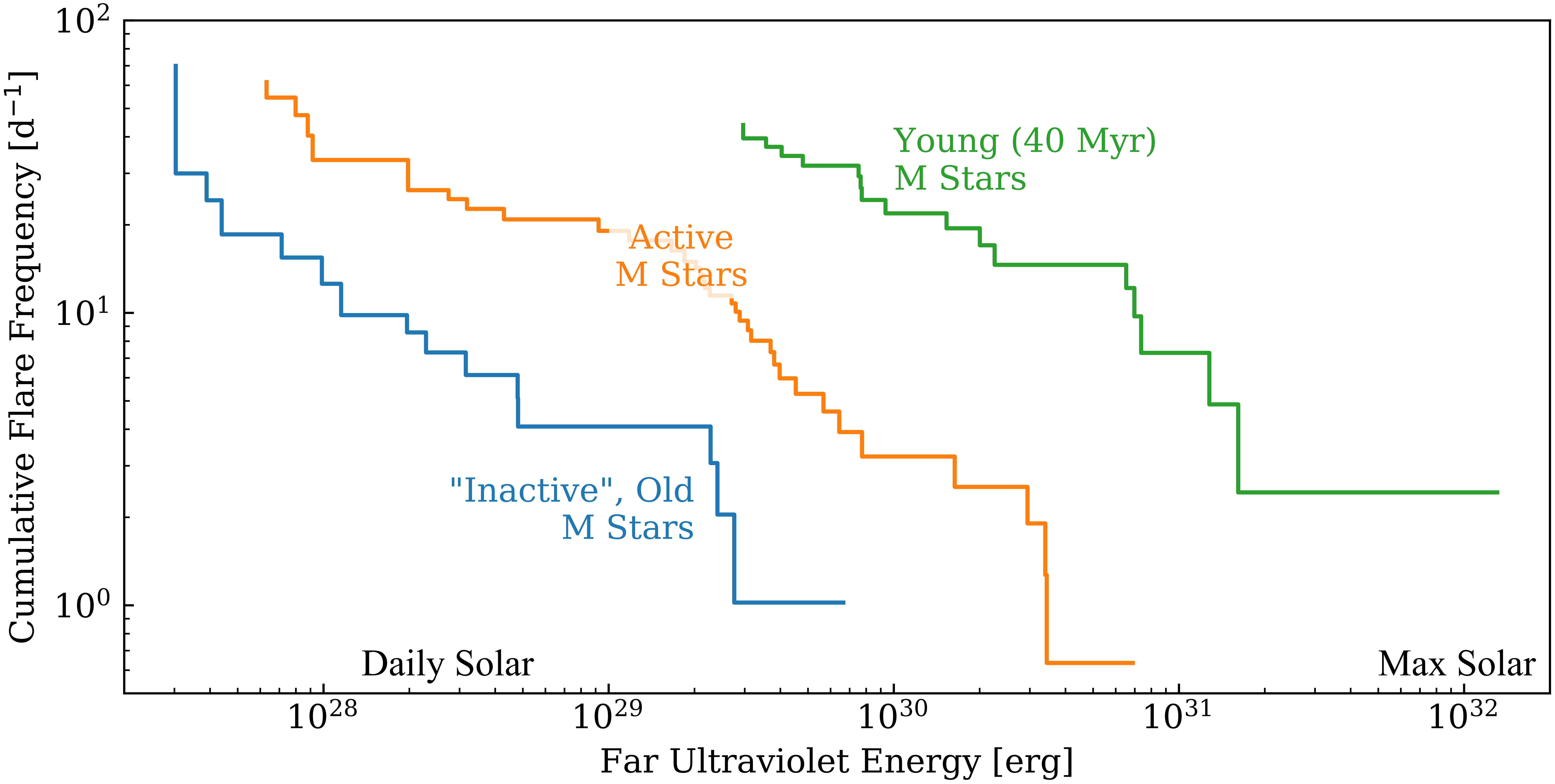
# Even "optically inactive" M dwarfs exhibit regular energetic flares in the FUV



# The FUV flares of active M stars (namely Prox Cen and AD Leo) are ~10x more energetic

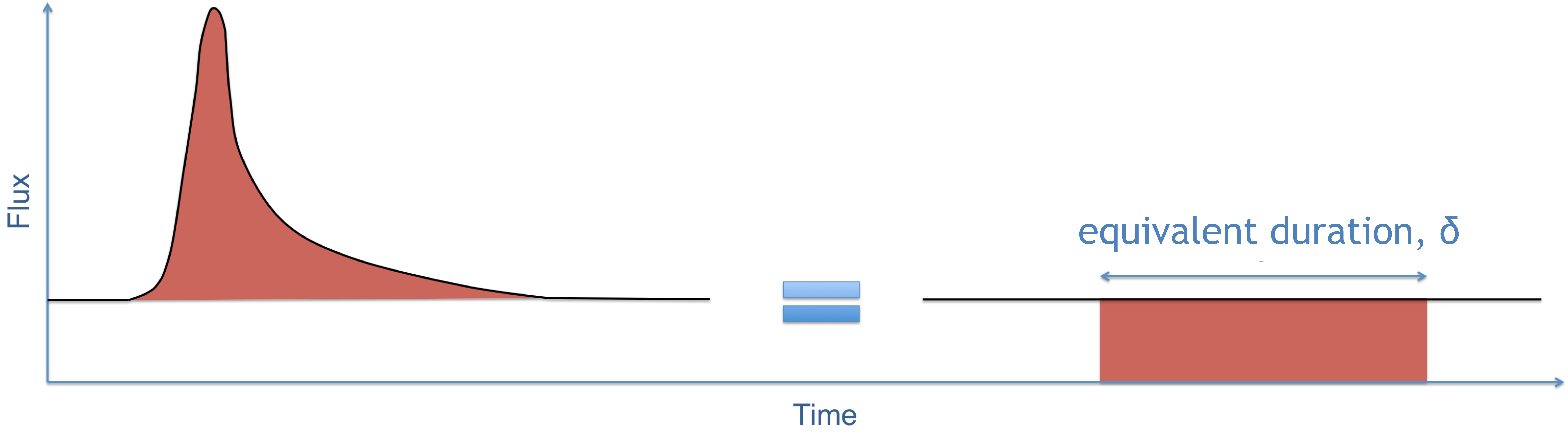


# The FUV flares of M stars in the Tuc-Hor moving group (40 Myr) are ~100x as energetic

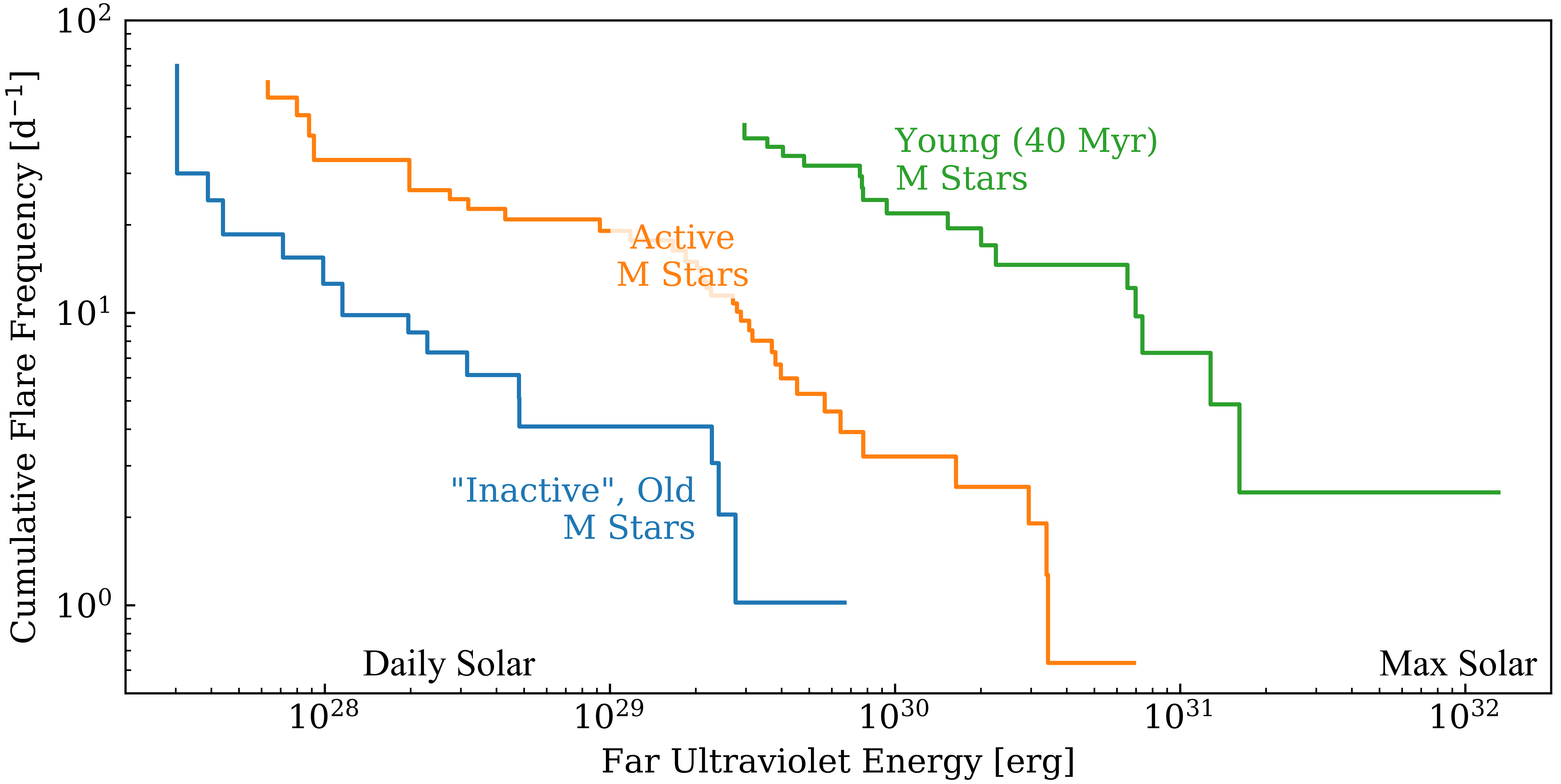


**These stars also have differing quiescent flux levels. What if we normalized by those levels?**

The natural way to do this is by measuring the "equivalent durations" of flares.



# When flares are normalized by quiescent flux, all groups flare at essentially the same rates



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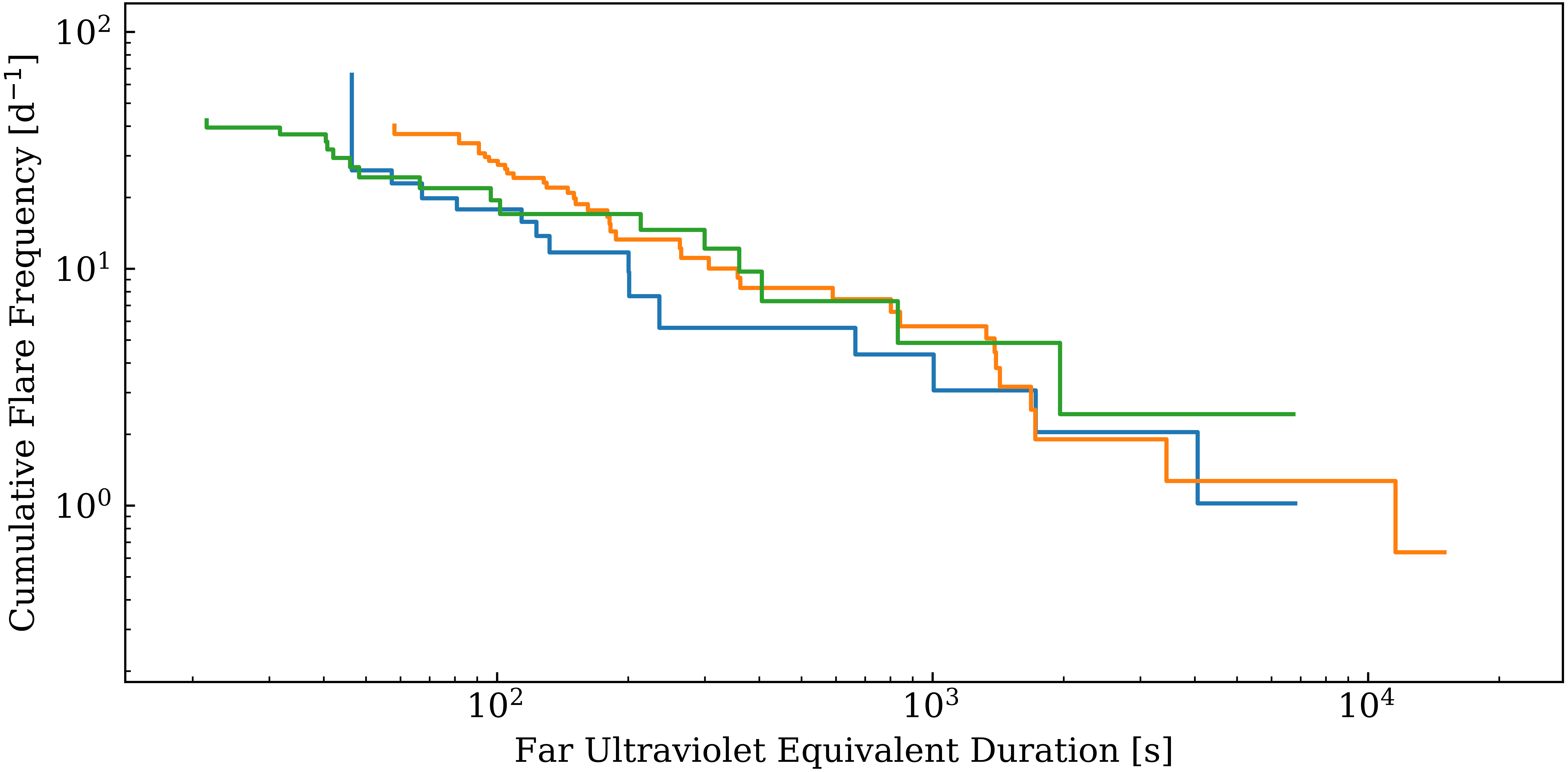

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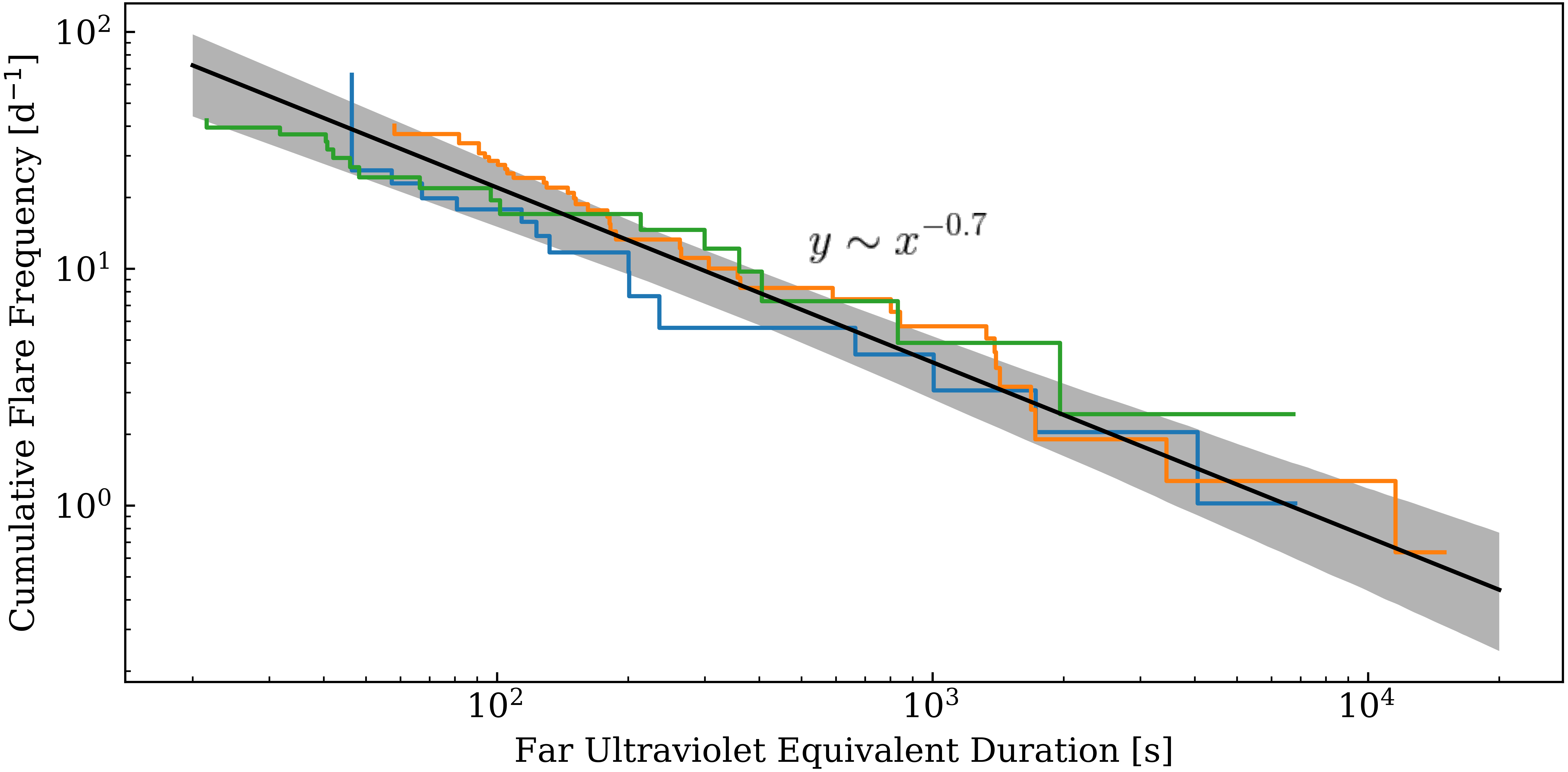
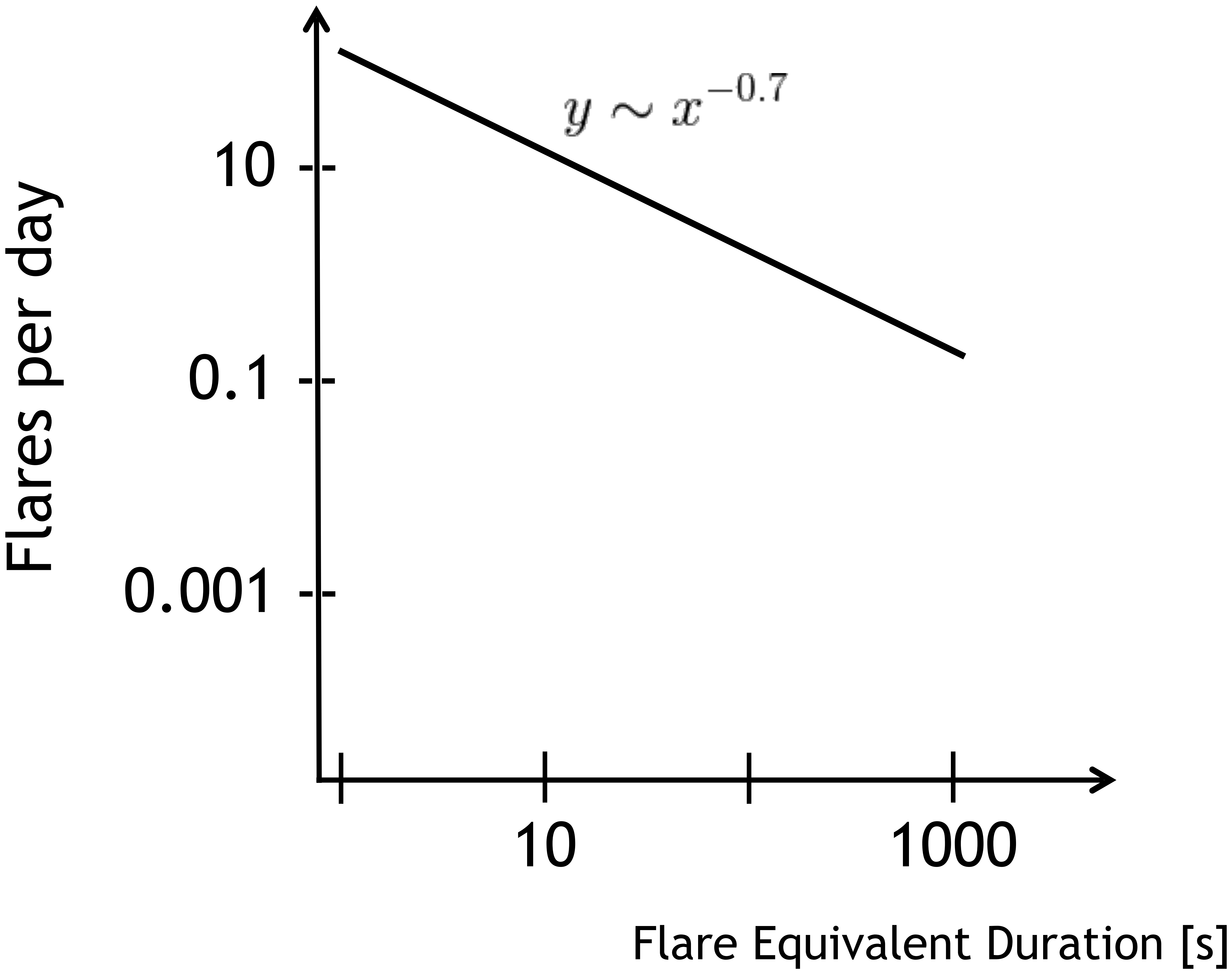


# Flares could dominate the FUV emission budget of the average M star



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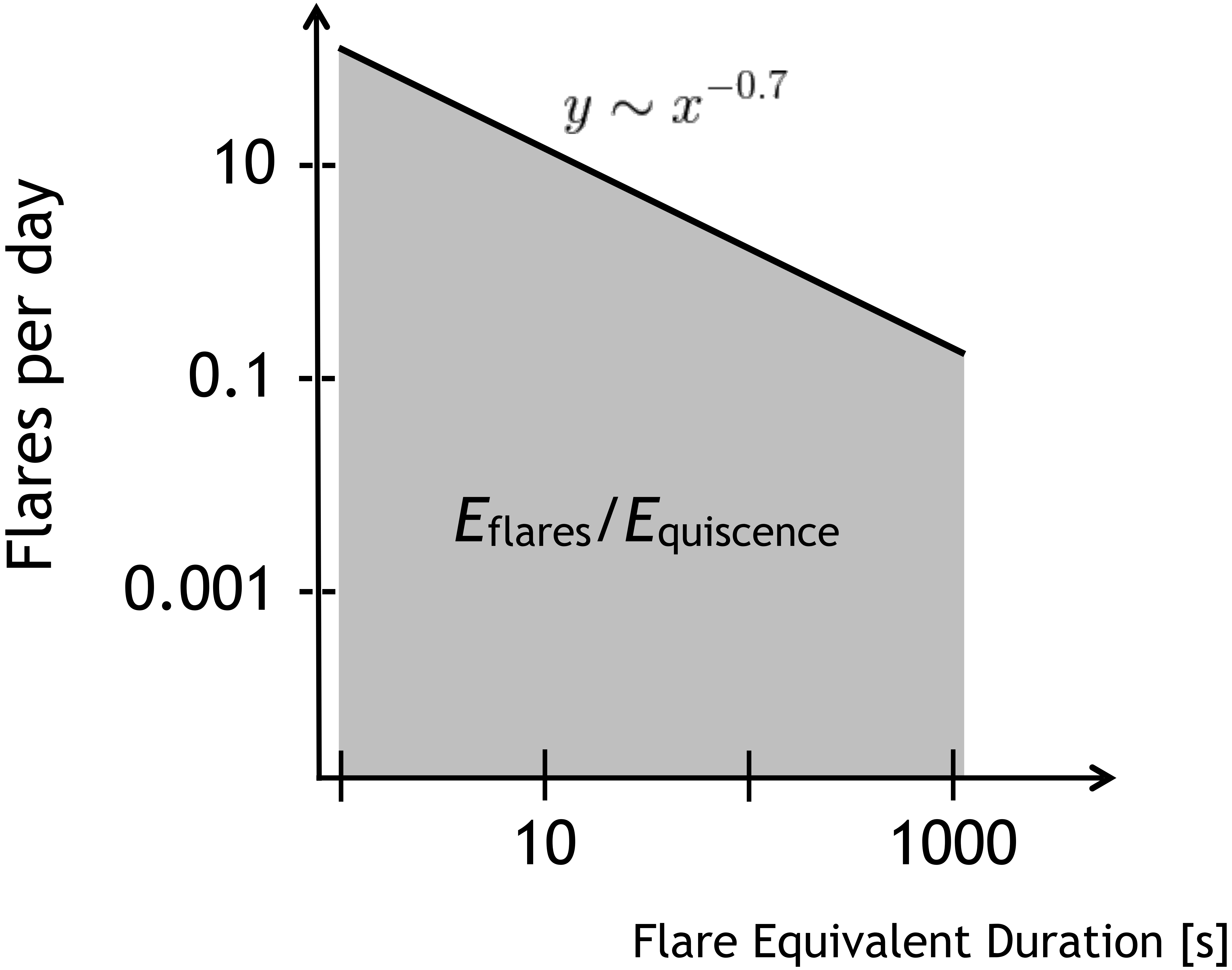

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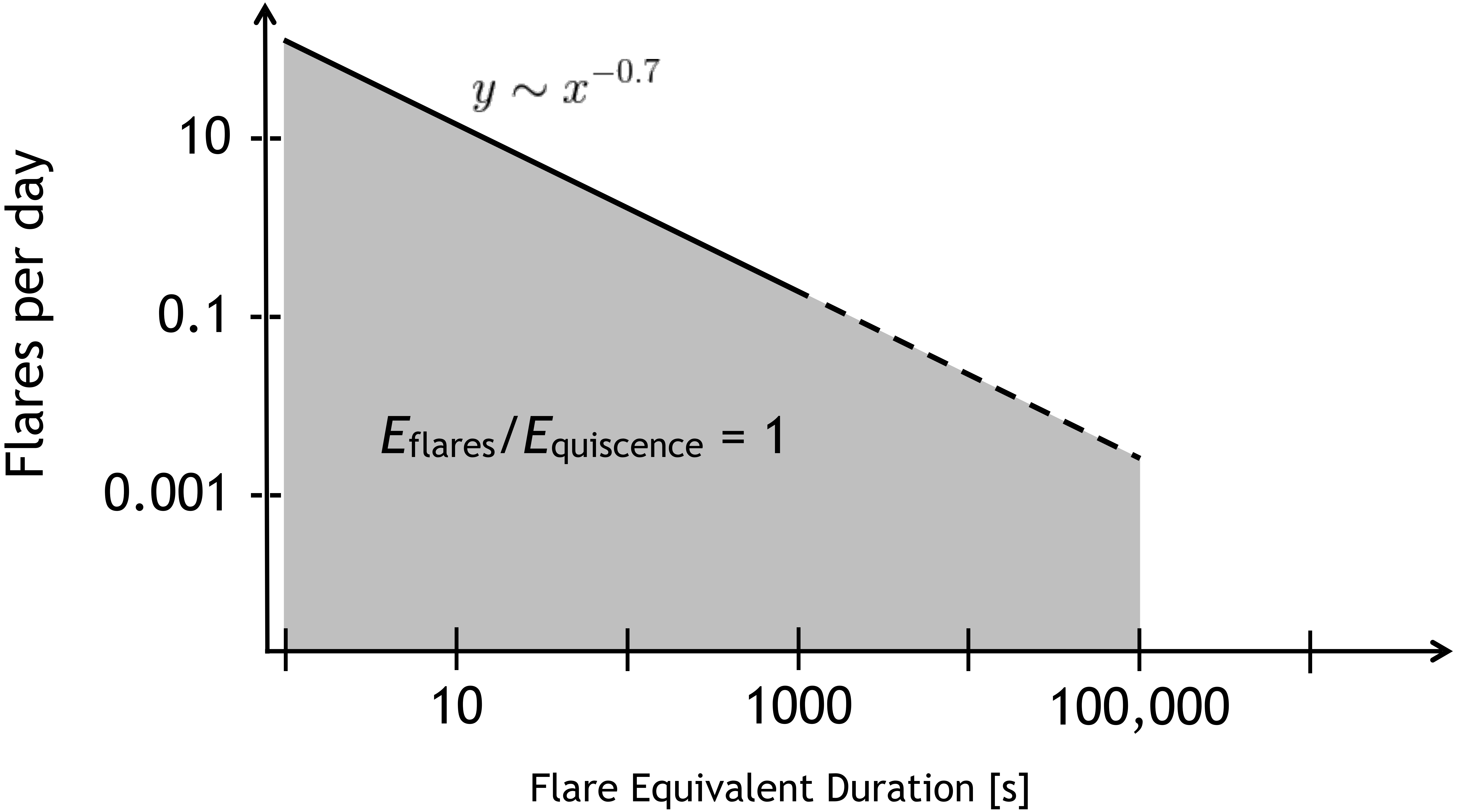

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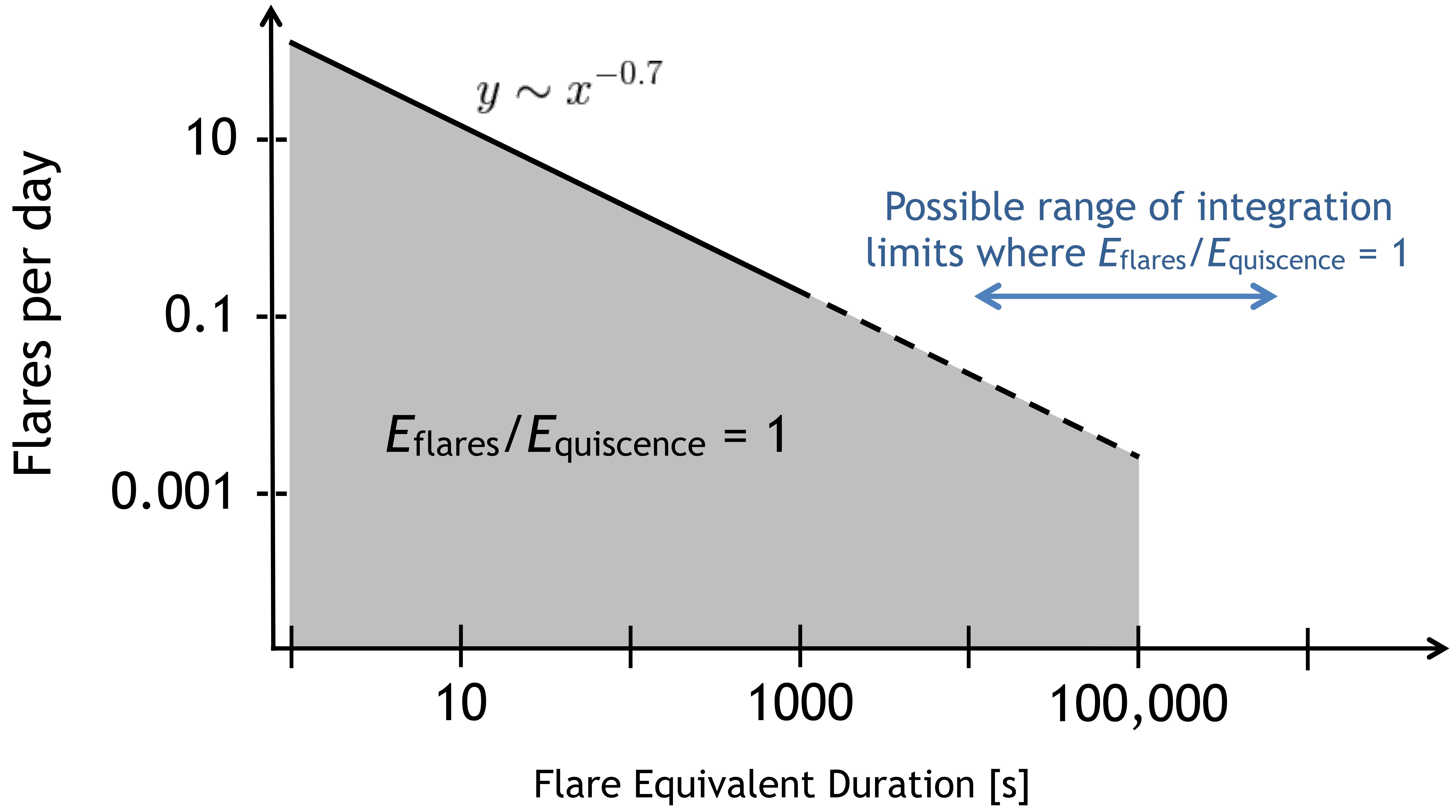
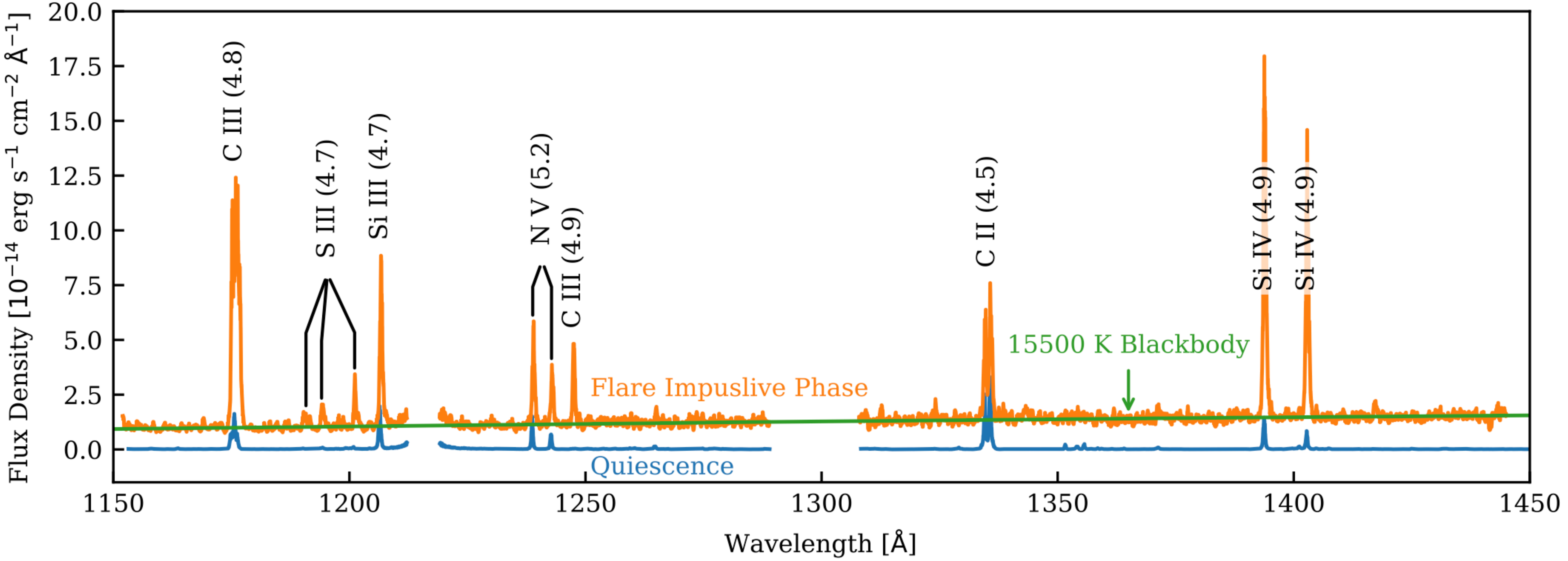


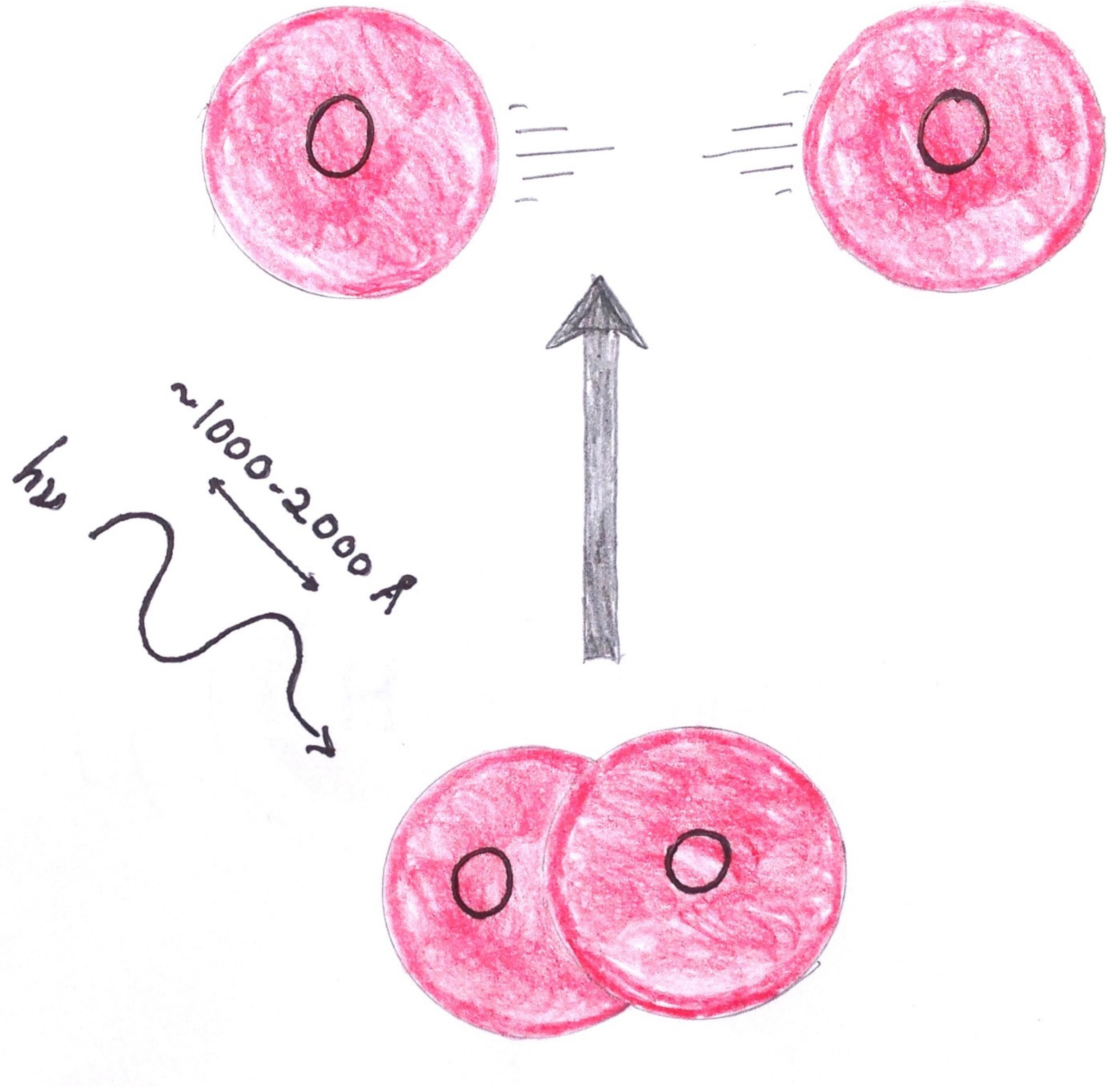
## *HAZMAT* captured a superflare ($E_{bolo}$ > $10^{33}$ erg), the "Hazflare", providing exquisite spectra of an energetic flare with blackbody emission at 15500 K.




Spectrum of the Hazflare superflare observed by the HAZMAT program (Loyd et al. 2018b, ApJ in review). The blackbody emission is hotter than any previously recorded from ground-based observations.

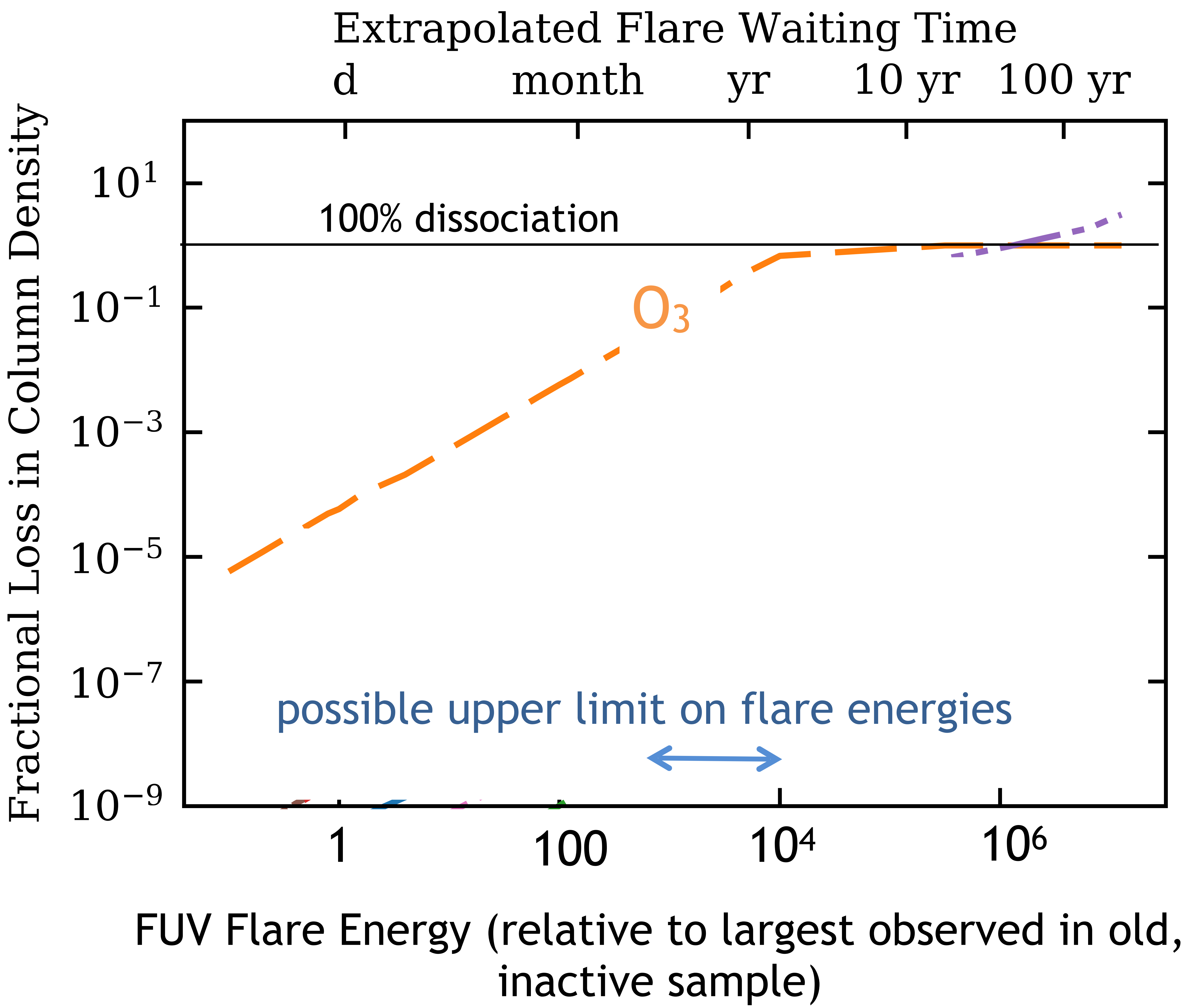
# PLANETARY IMPLICATIONS

*Remember that FUV photons photolyze molecules?*



“Average” (i.e. occurring daily) flares on old, inactive M stars don’t significantly impact column densities of ozone in isolation. Those on young M stars are significant (0.1-1%), and more energetic, rare flares could have a major effect.*

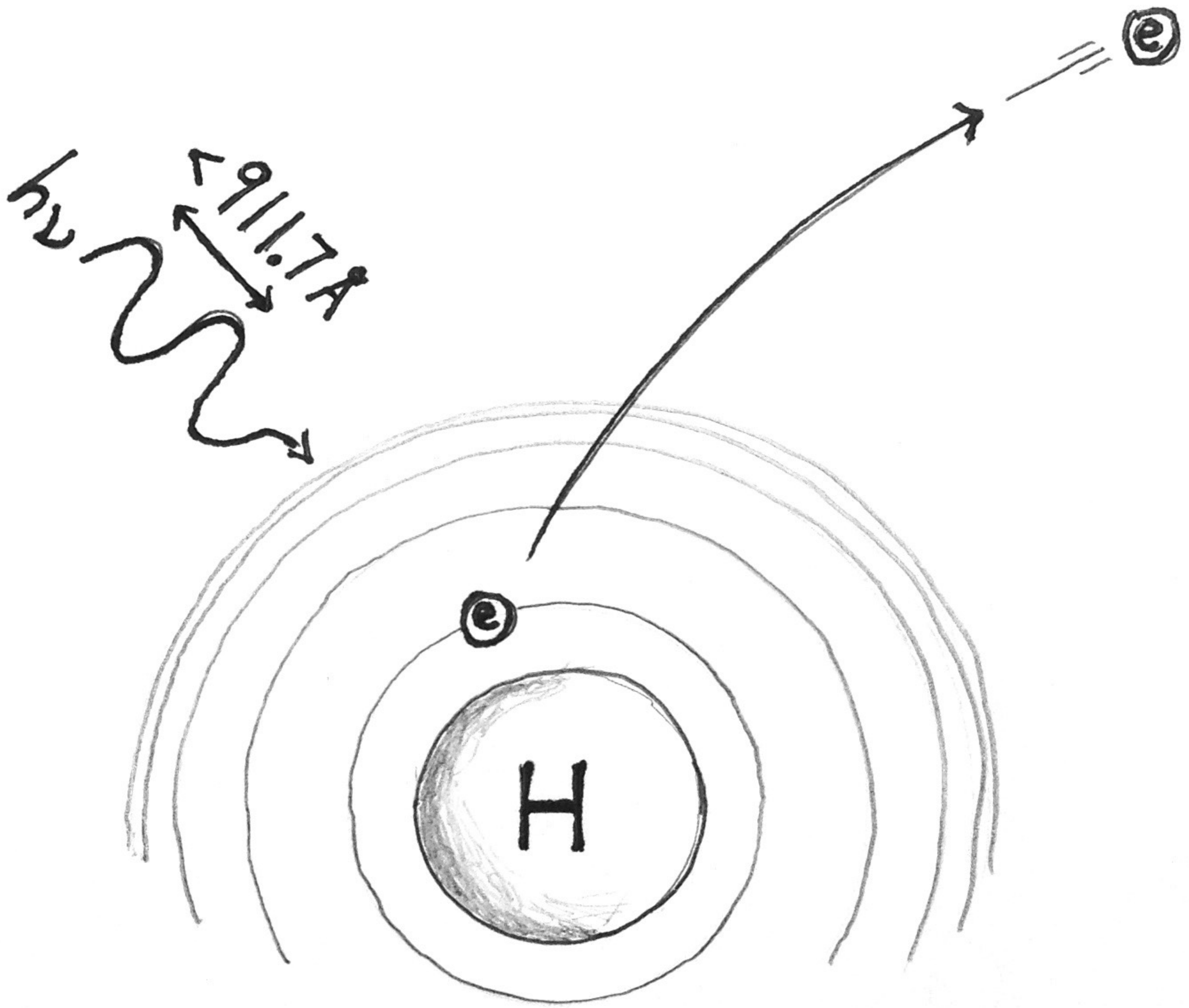
(*However, ozone always recovers quickly from a single flare unless the flare includes a particle shower.)




(Loyd et al. 2018a, ApJ in review)

*Remember that EUV photons (closely linked to the FUV) drive ionization heating and thus escape of planetary atmospheres?*

Basic energy arguments suggest that just the EM from flares like the Hazflare could play a significant role in eroding nascent atmospheres.



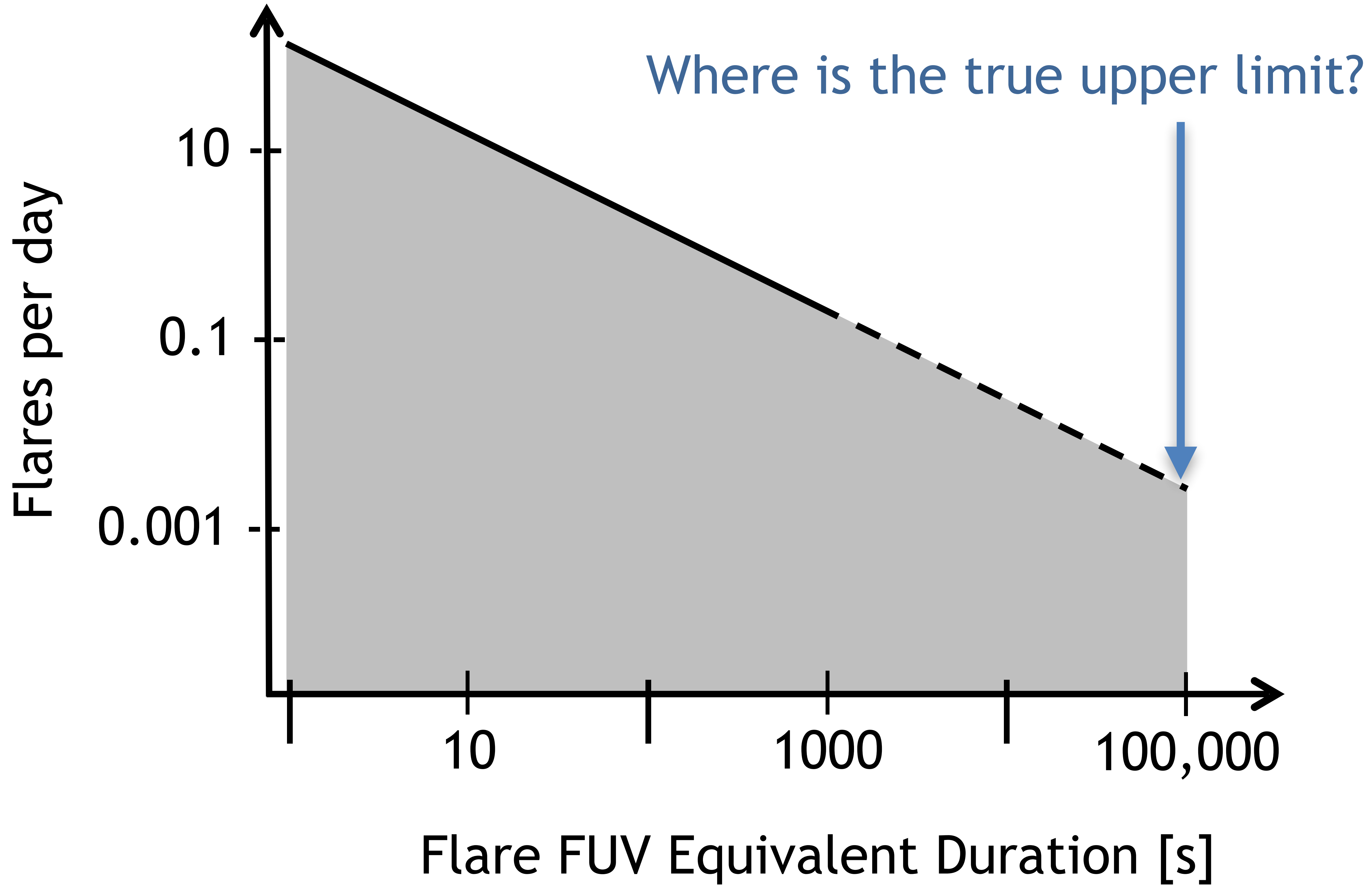
Notable gaps in our knowledge of stellar flares and their planetary impacts

# LOOKING AHEAD

**Question:** How much do flares really contribute to the long-term energy budget of FUV and EUV emission?

**Needed:** UV observations that stare long enough to catch rare, energetic flares.

**Prospects:** The *SPARCS* (FUV and NUV) and possibly *CUTE* (NUV) cubesat missions will address this.

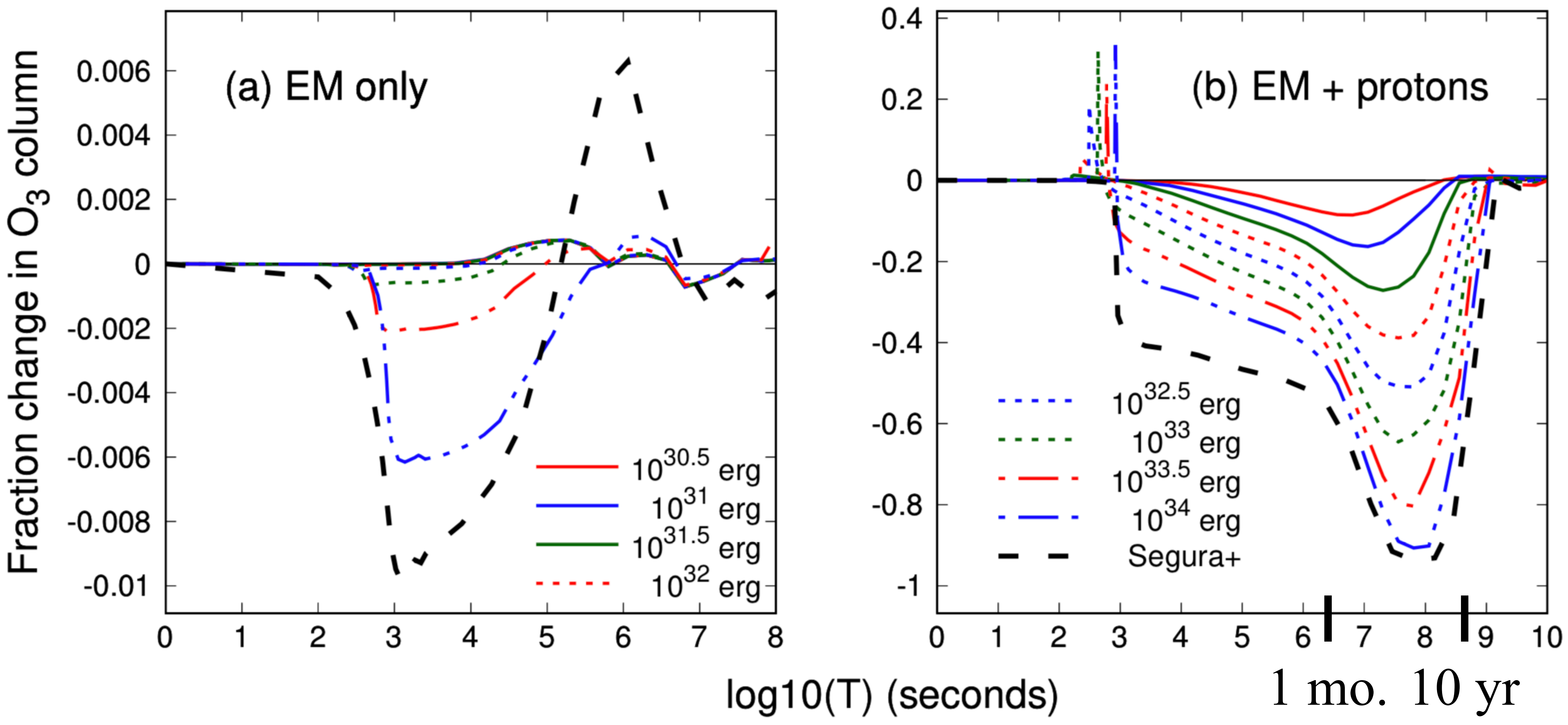


**Question**: Do energetic particles accompany M-star flares like they accompany the most energetic solar flares?

**Needed**: Some means of directly detecting and massing the coronal mass ejections that would generate these particles.

**Prospects:** Detections of of type II radio bursts, stellar coronal dimming, or methods yet to be thought of.

(Tilley et al. 201, AsBio in review)



# Summary

- **What's new:**
  - The *MUSCLES* and *HAZMAT* surveys have given us a wealth of spectrophotometric FUV data on M stars.
  - All (including optically inactive) M stars flare regularly in the FUV. Active M star flares are ~10x more energetic than inactive, old M stars. Young (40 Myr) M star flares are ~100x more energetic.
  - Flares are an important, possibly dominant contributor of FUV photons to the environment surrounding M stars.
  - The *HAZMAT* program discovered that the blackbody-like emission of a flare can reach (15500 K), as it did during the Hazflare superflare.
- **What it means to planets:**
  - As expected, M dwarf flares will play a significant role in the chemistry and retention of planetary atmospheres, especially in the early stages of planetary development.
- **What's left:**
  - We need stare in the FUV to pin down the frequency of the rarest, most energetic flares.
  - We need to figure out how to observe stellar coronal mass ejections (CMEs).

# Thanks to the MUSCLES team!

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