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Flare onset evolution in solar active regions

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Solar flares are distributed as power laws

Lu & Hamilton 1991
ApJ 380, L89

SOLAR HARD X-RAY BURSTS 469

Dennis 1985, SolPhys 100, 465

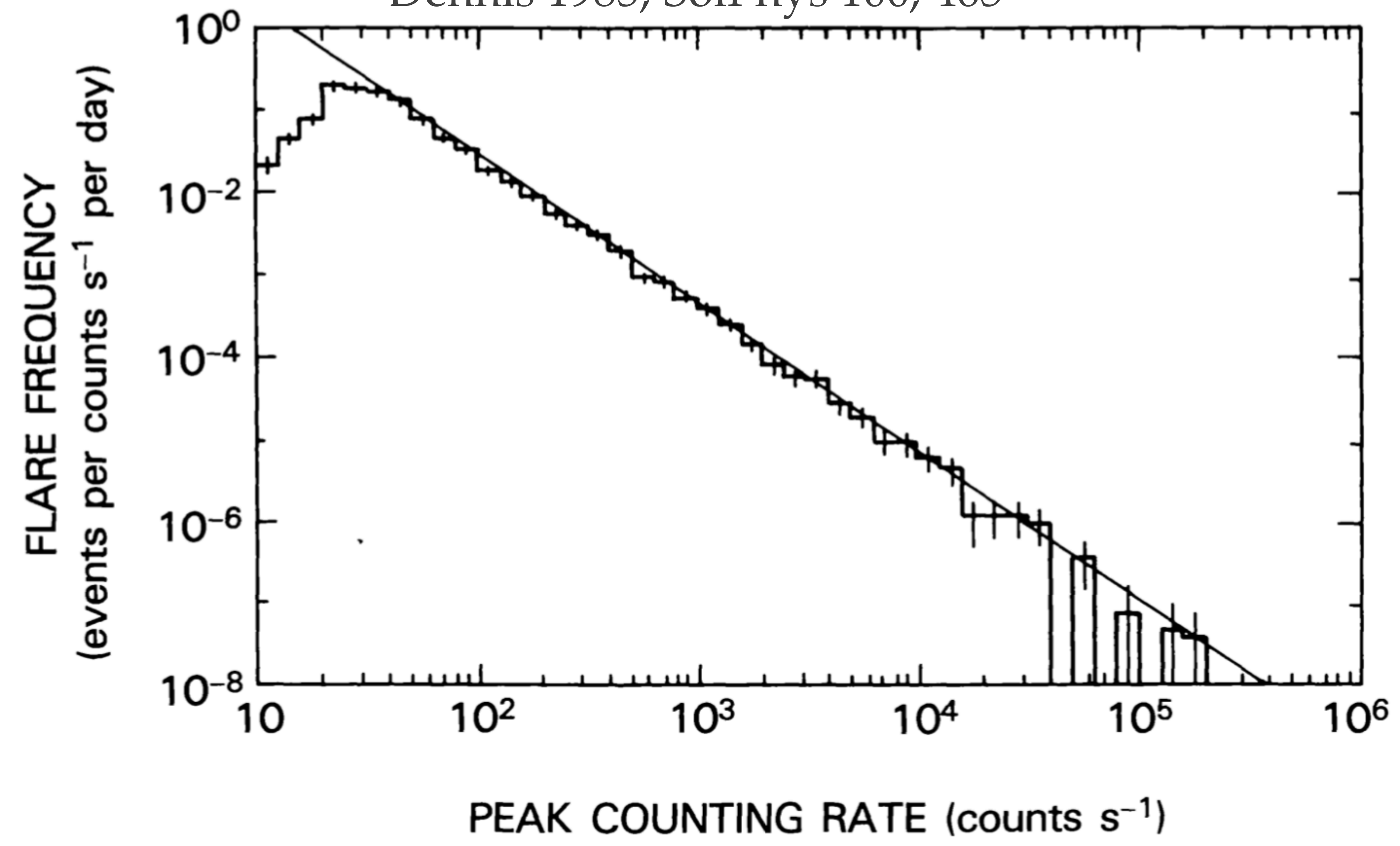


Fig. 3. Peak rate spectrum of all complete events detected with HXRBS from launch to February 1985. The straight line through the data corresponds to the power-law expression given in the text with a spectral index of − 1.8.

20 keV PHOT

FIG. 4.—The distribution of
peak 20 keV photon flux for the
balloon flight. Also shown for
hard X-ray bursts reported by Da

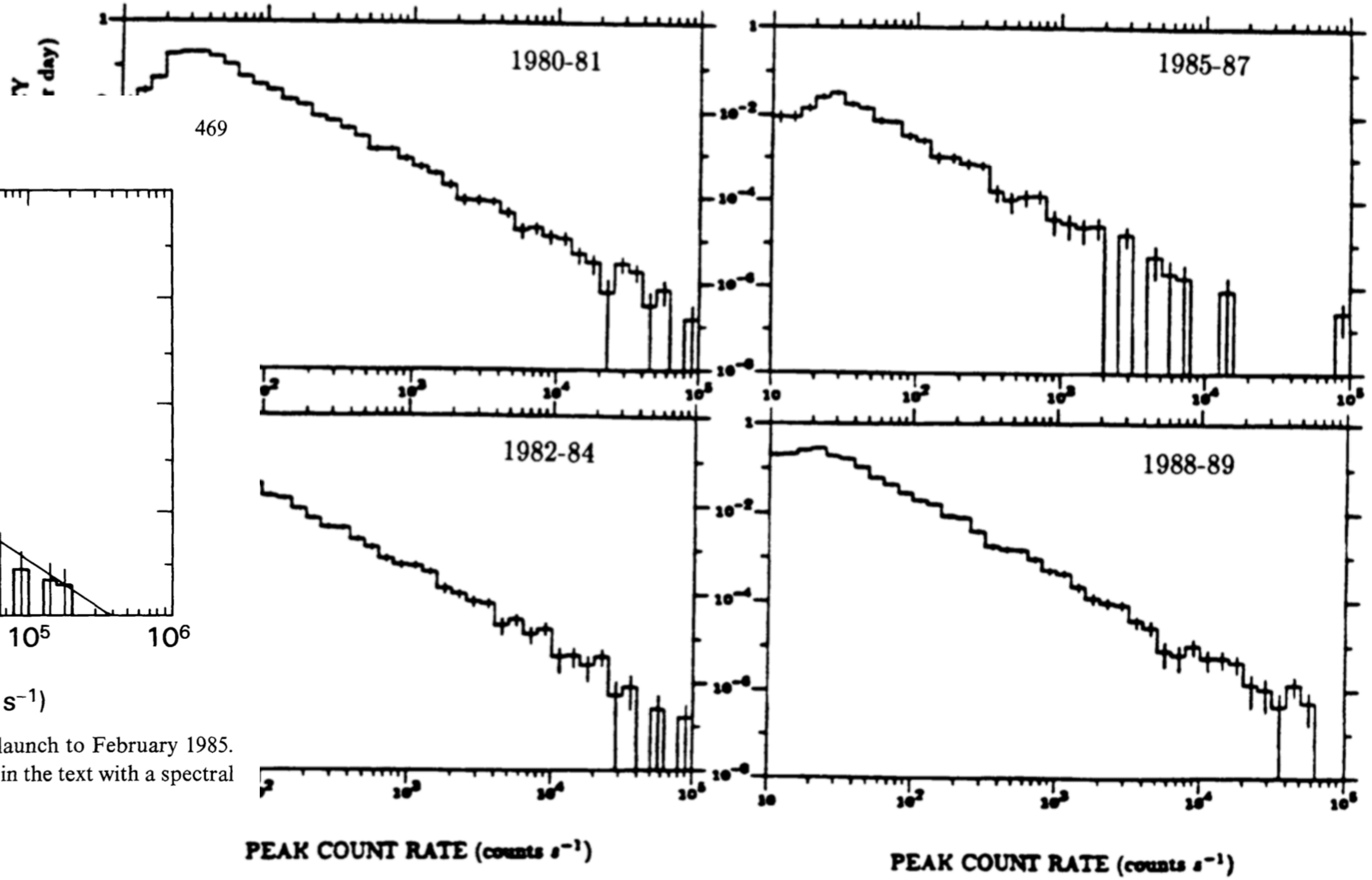


FIG. 2.—Same as Fig. 1, except that only flares detected during the years (*top left*) 1980–1981, (*bottom left*) 1982–1984, (*top right*) 1985–1987, (*bottom right*) 1988–1989 are included, showing the variation in the distribution over a solar cycle (figure provided by B. R. Dennis). The overall occurrence rate is seen to decrease then increase with the solar cycle, but all of the distributions are consistent with the same power law index of 1.8 found in Fig. 1 for all flares.

SOC

- $dN/dE \propto E^{-\alpha}$ ⇒ no controlling physical scale in regime we are observing
- Events occur as cascades (for flares, reconnections of magnetic field lines) ≡ Self-Organized Criticality
- Continuous version of sandpile avalanches is a Langevin process,

  $dx/dt = -\eta \cdot x^n + N(0,\sigma^2)$

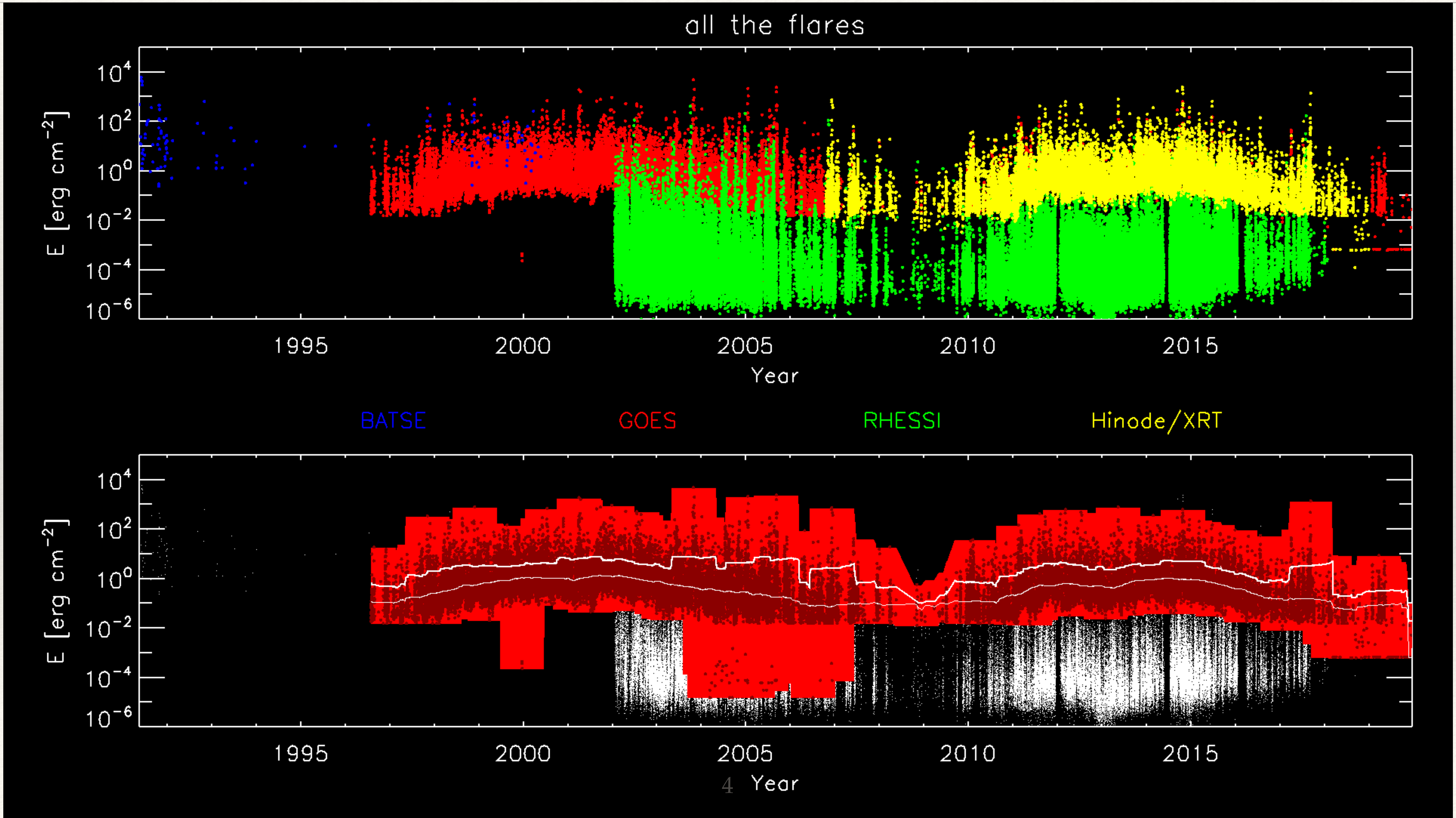
  and after some calculus (ask Eun-jin Kim), leads to a stationary distribution on x with controlling parameter $\beta \equiv \eta/\sigma^2$, which upon marginalizing over β using prior $p(\beta) = \gamma(x; m/2, \beta^*)$, yields

  $p(x) \propto [1/\beta^* + x^{n+1}/(n+1)]^{-m/2-1/(n+1)}$

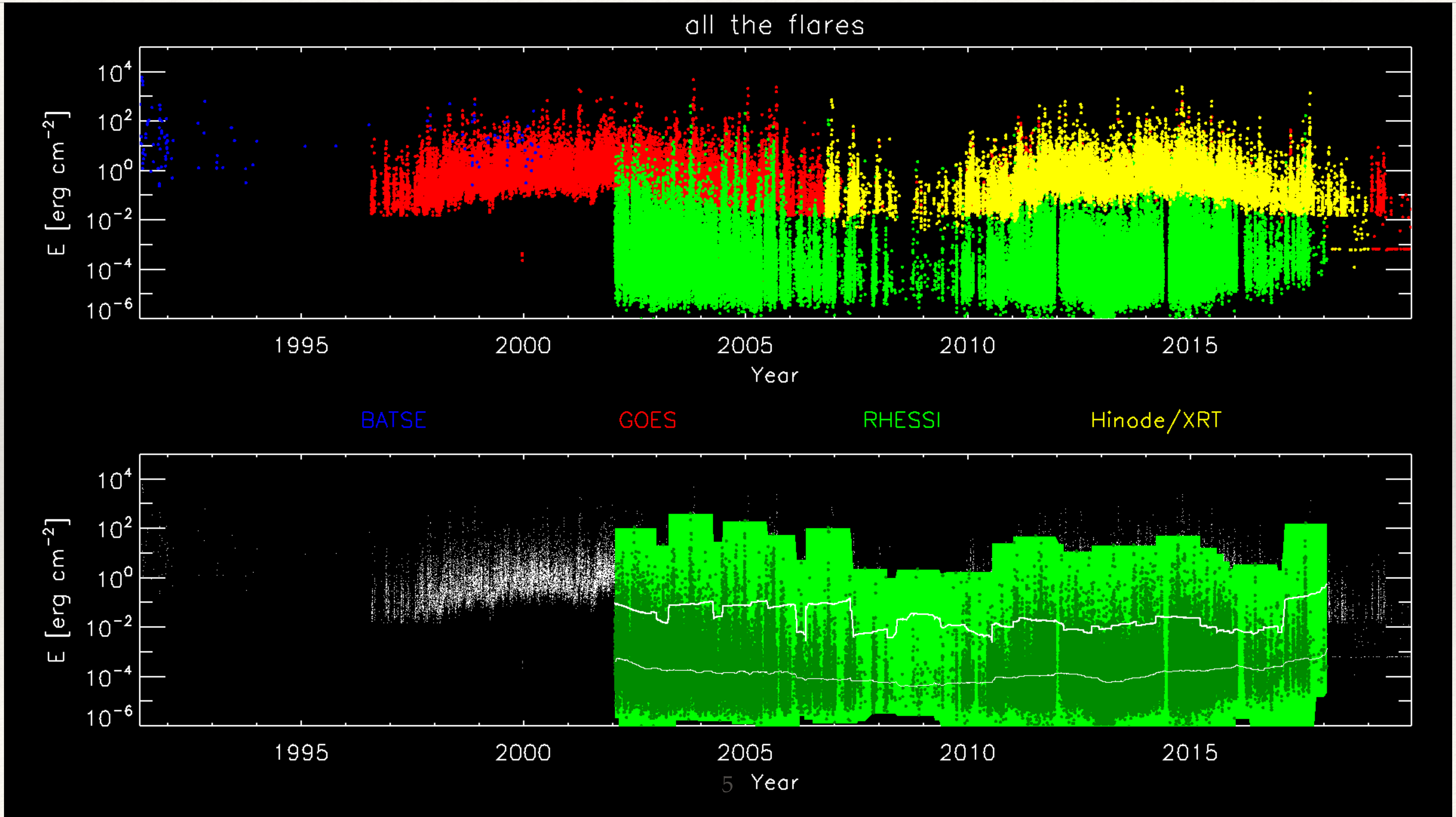
⇒ power-law at large x

⇒ reliable measurements of flare distribution slopes can place constraints on the underlying physics

All the flares

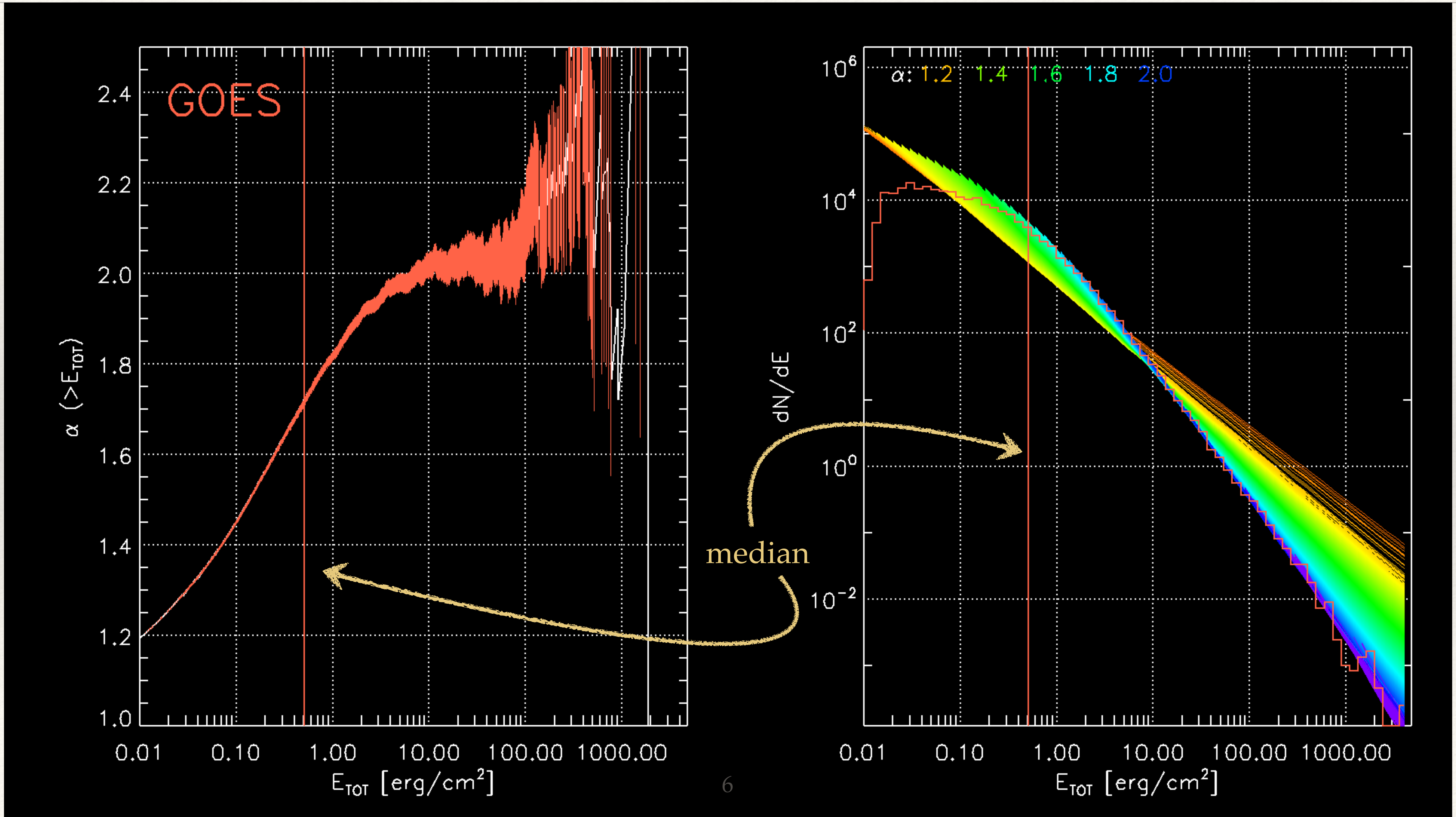


All the flares



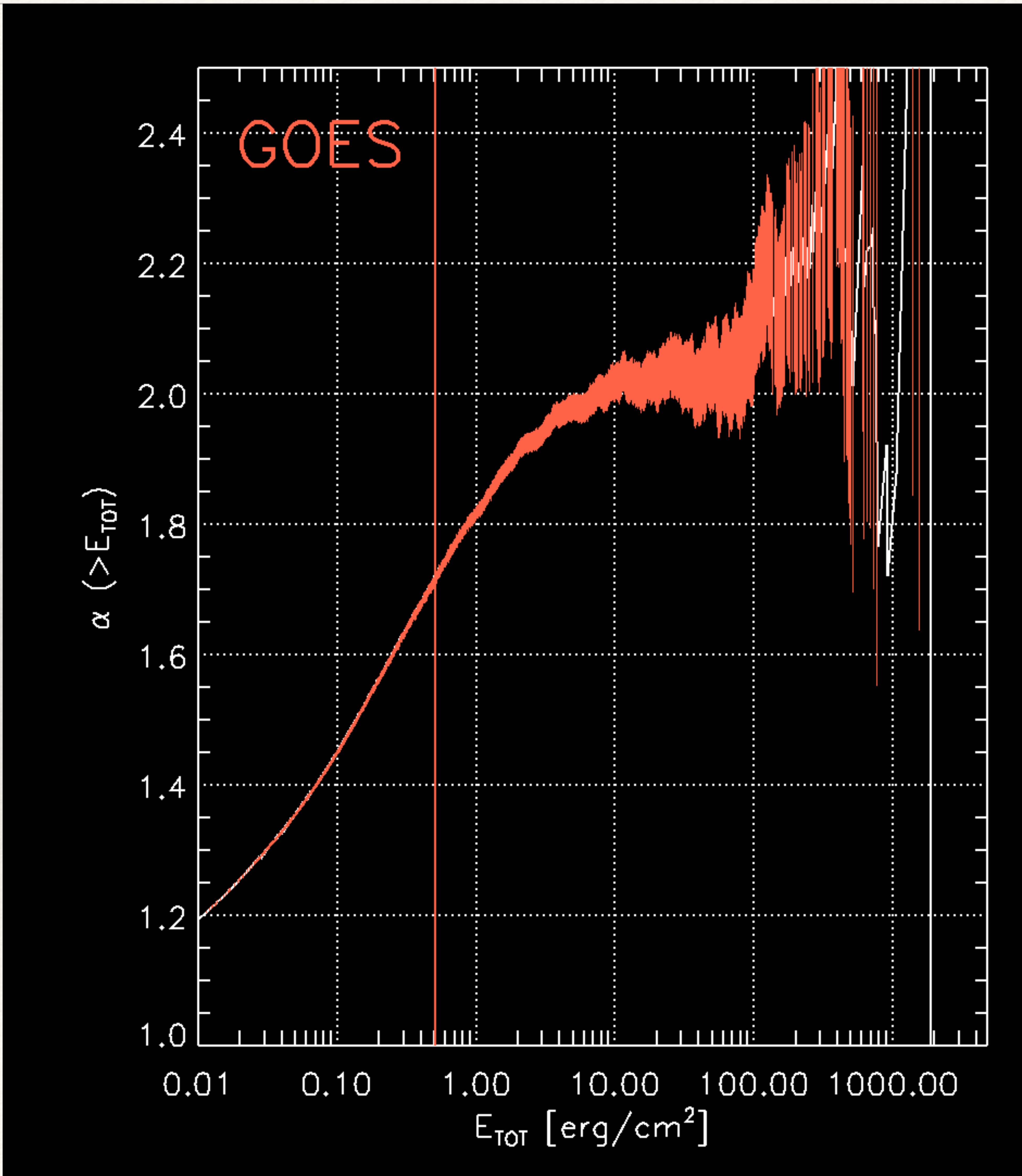
Compute $\alpha(>E_{TOT})$ for all $E \in [E_{TOT},\infty)$ using MLE method of Crawford et al (1970, ApJ 162, 405)

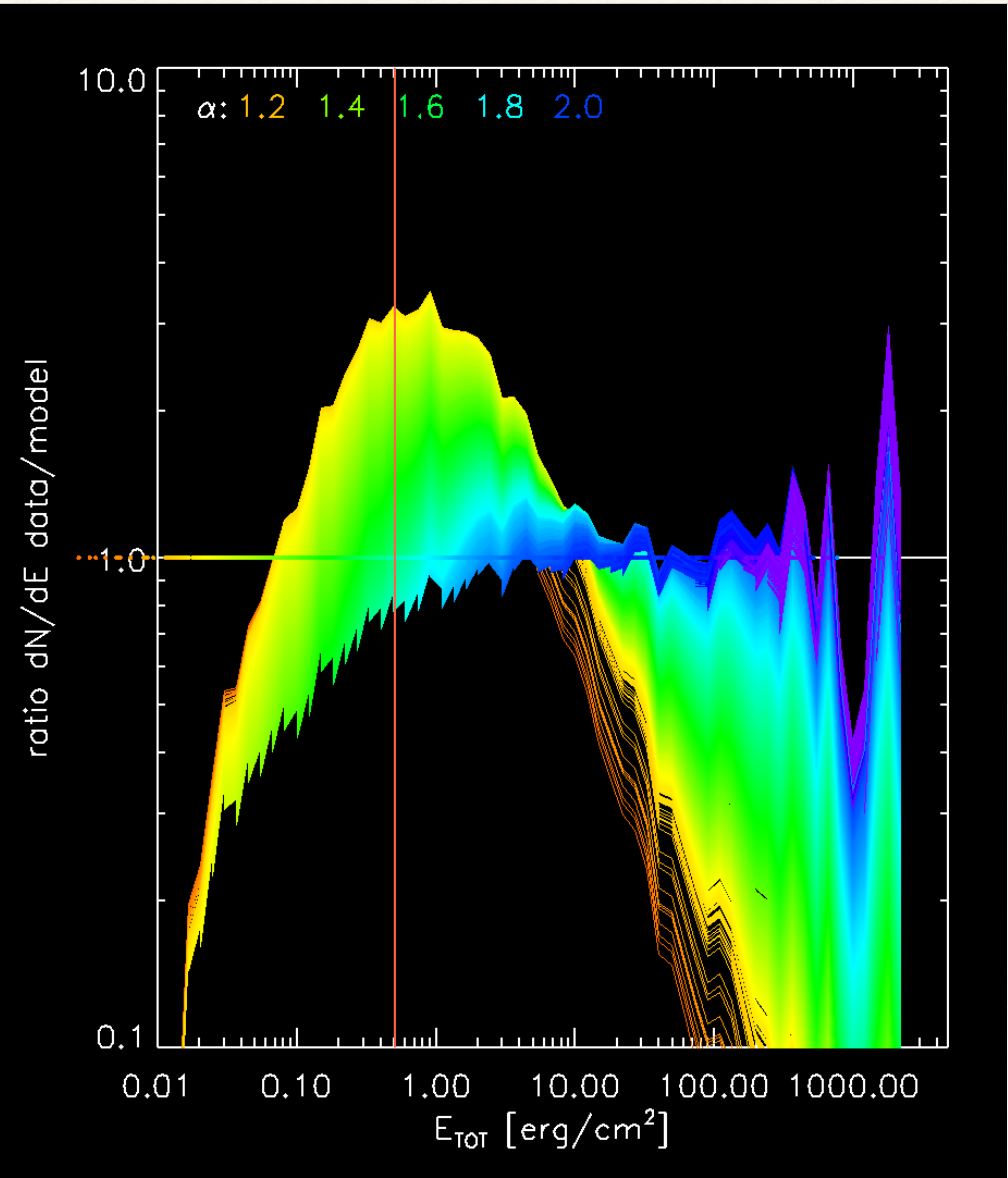
α(E)



Compute $\alpha(>E_{TOT})$ for all $E \in [E_{TOT},\infty)$ using MLE method of Crawford et al (1970, ApJ 162, 405)

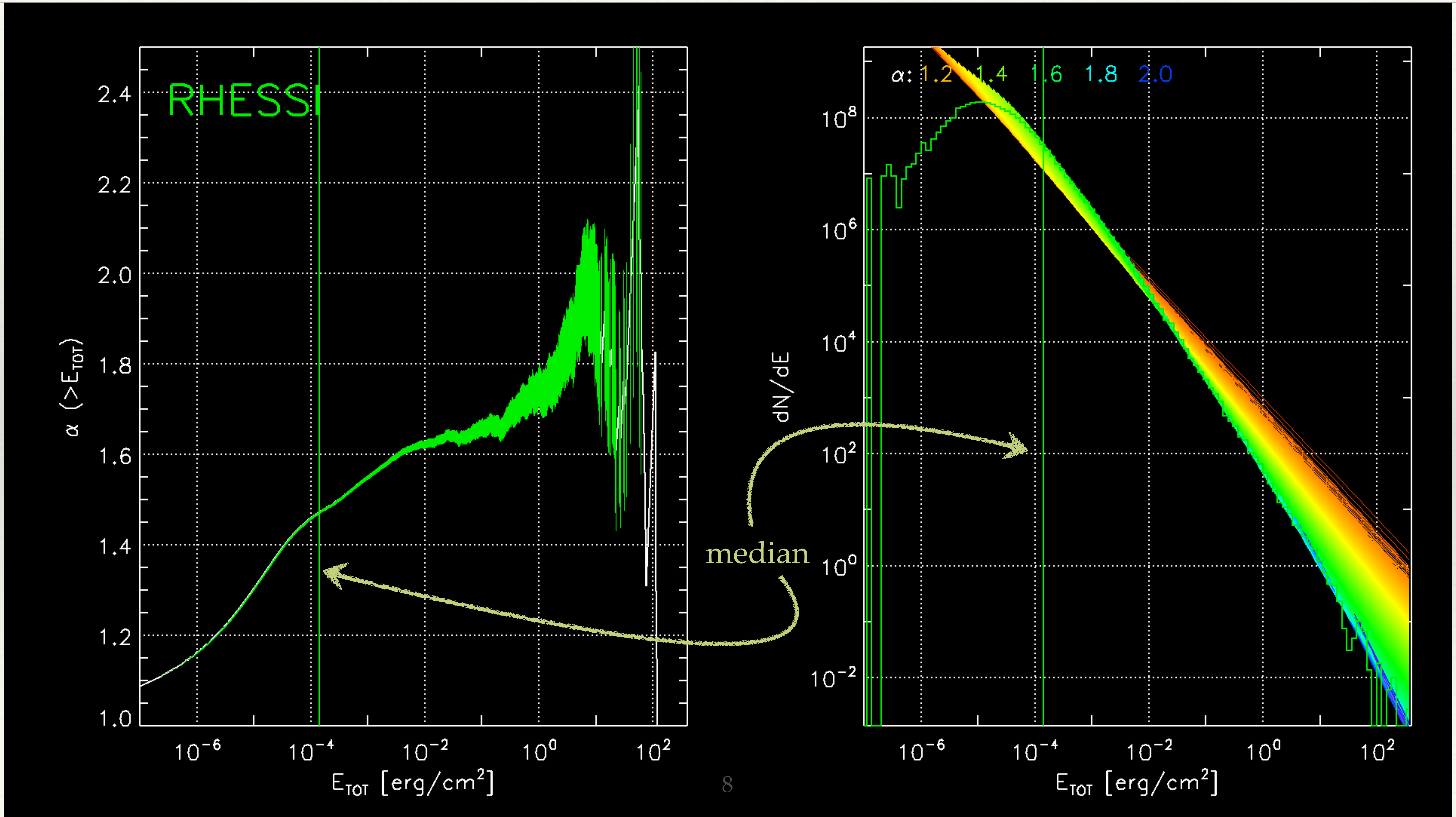
$\alpha(E)$





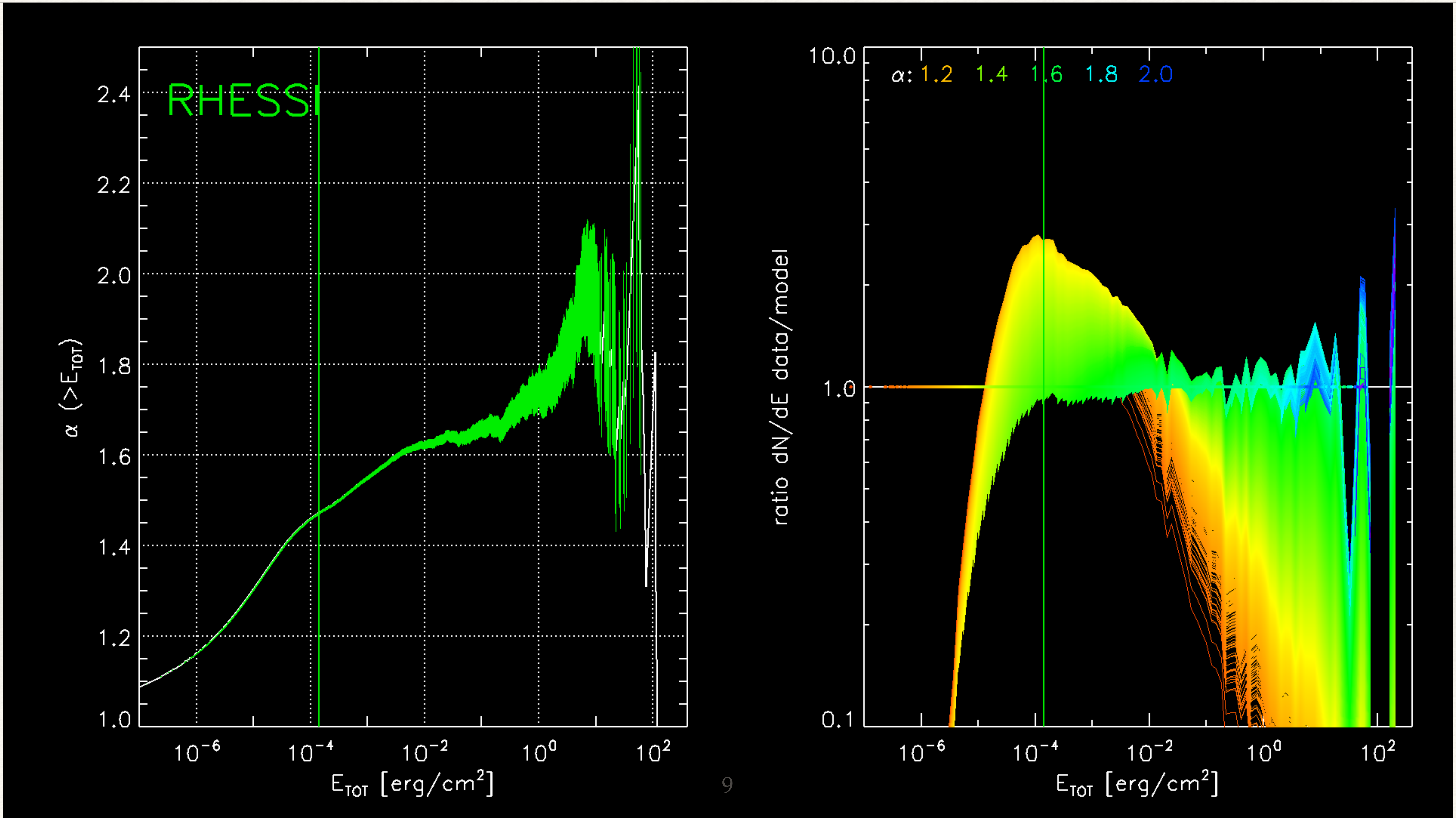
Compute α(>ETOT) for all E ∈ [ETOT,∞) using MLE method of Crawford et al (1970, ApJ 162, 405)

α(E)



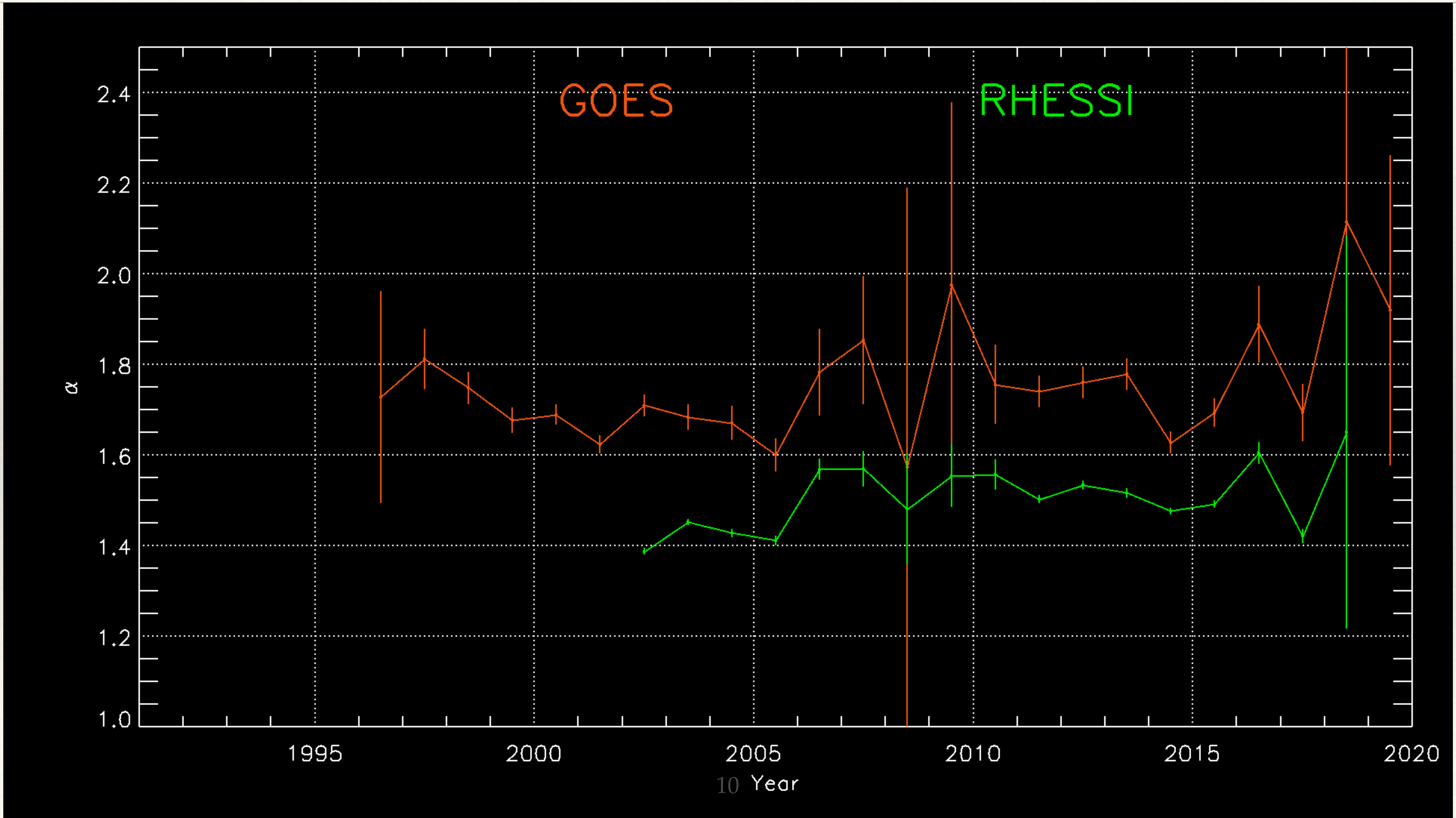
Compute α(>E_{TOT}) for all E ∈ [E_{TOT},∞) using MLE method of Crawford et al (1970, ApJ 162, 405)

α(E)



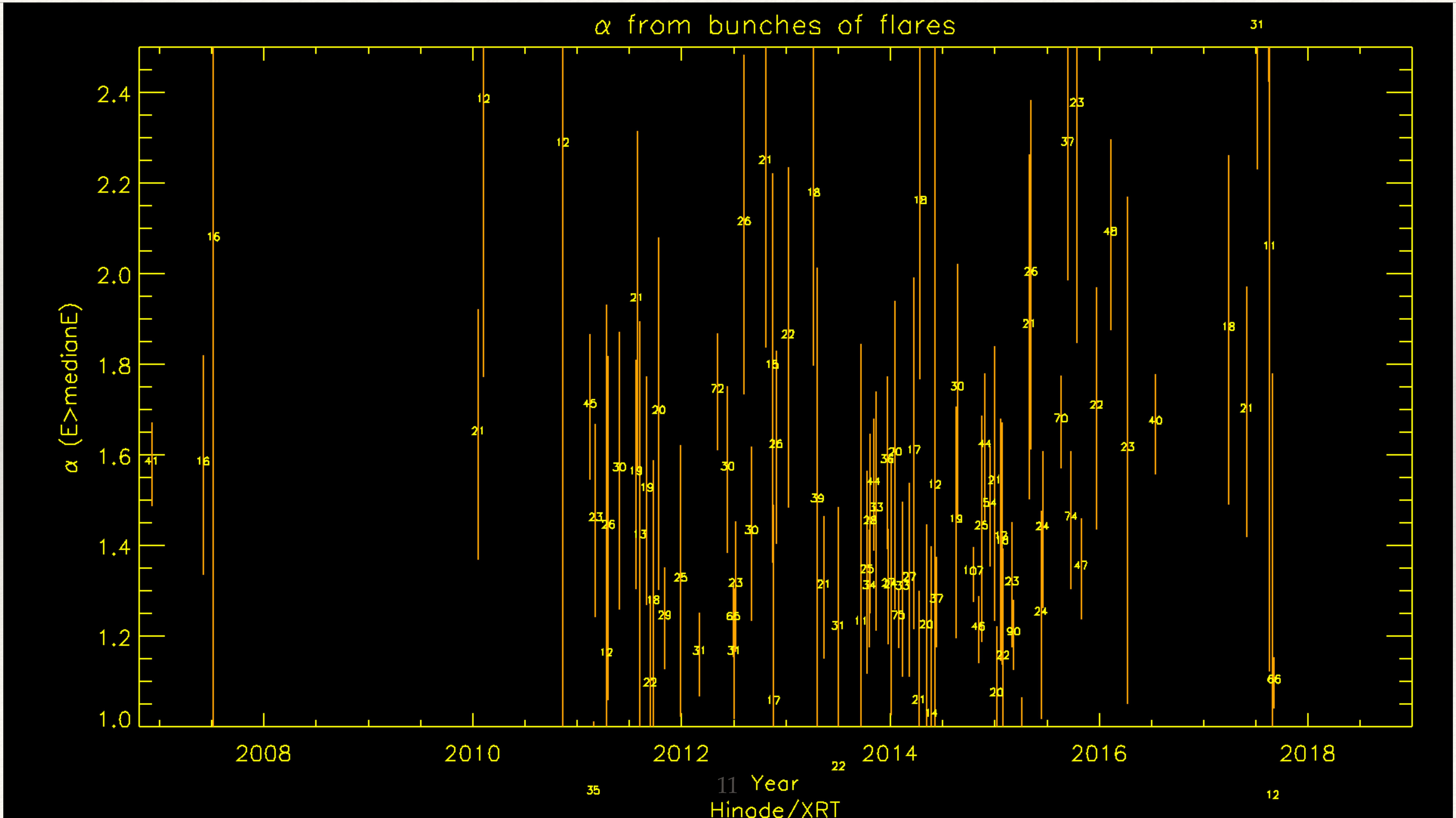
Note: no evidence for cycle phase dependence; possible offset between cycles; RHESSI consistently lower, but correlated with GOES

Variation of α(>E$_{MEDIAN}$) with solar cycle



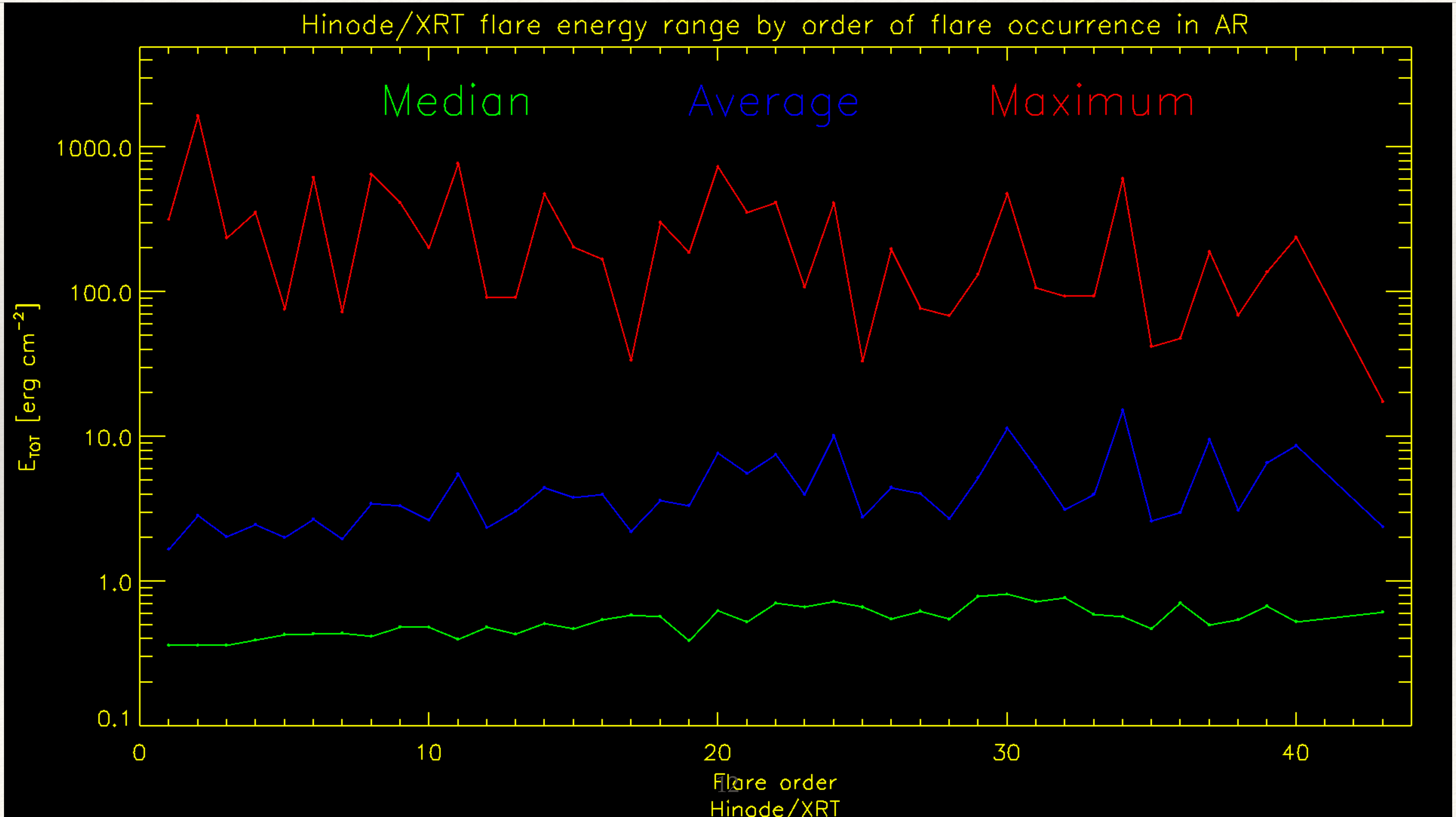
We can assign each flare to an active region, and compute α(>E_{MEDIAN}); no obvious correlation with cycle phase or longevity

How do individual active regions behave?



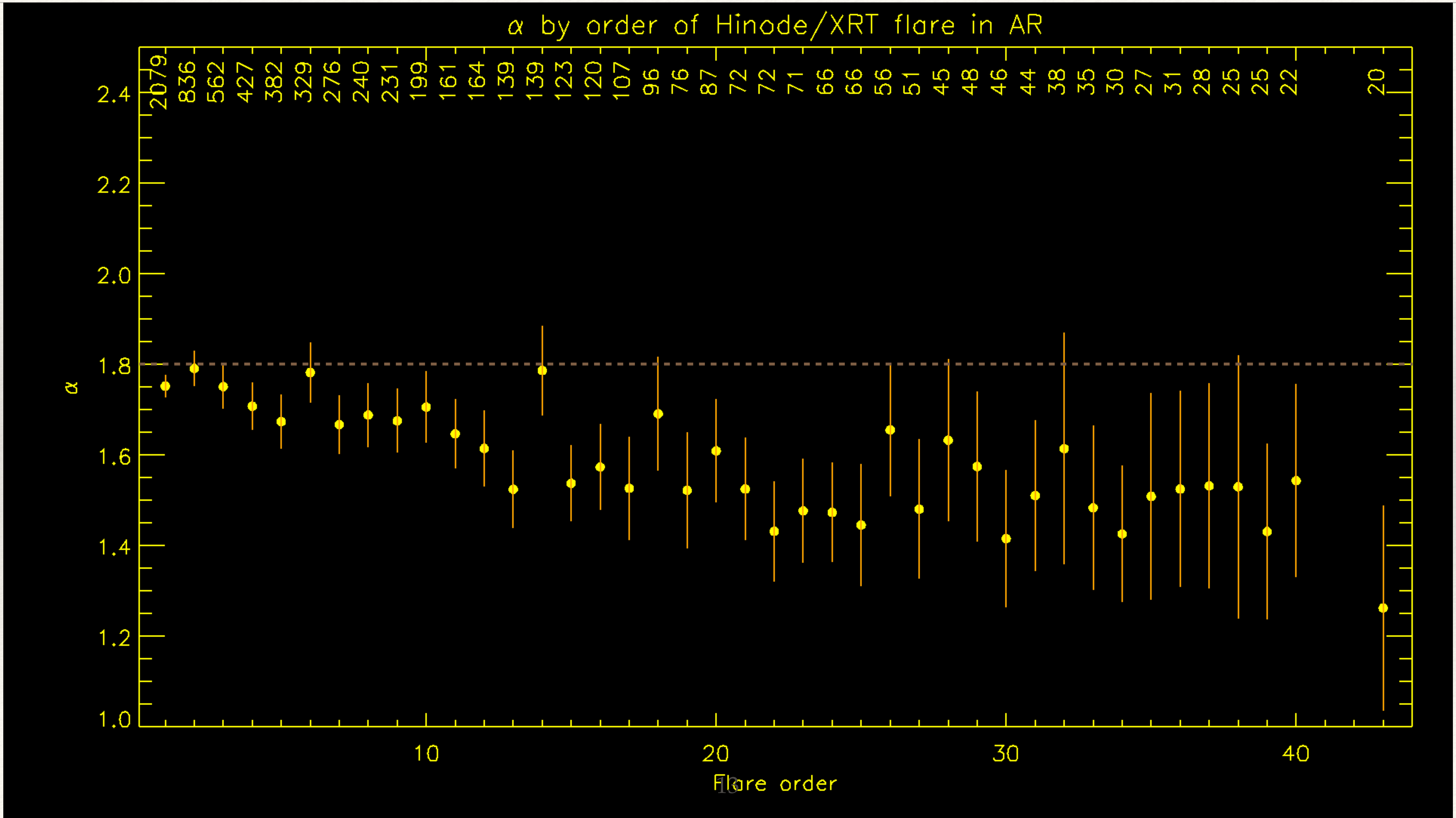
There appears to be a trend towards larger flares when we look at flares that occur later in an active region

The nth flare of an active region



There appears to be a trend towards smaller α(>EMEDIAN) (flatter distributions) for flares that occur later in an active region

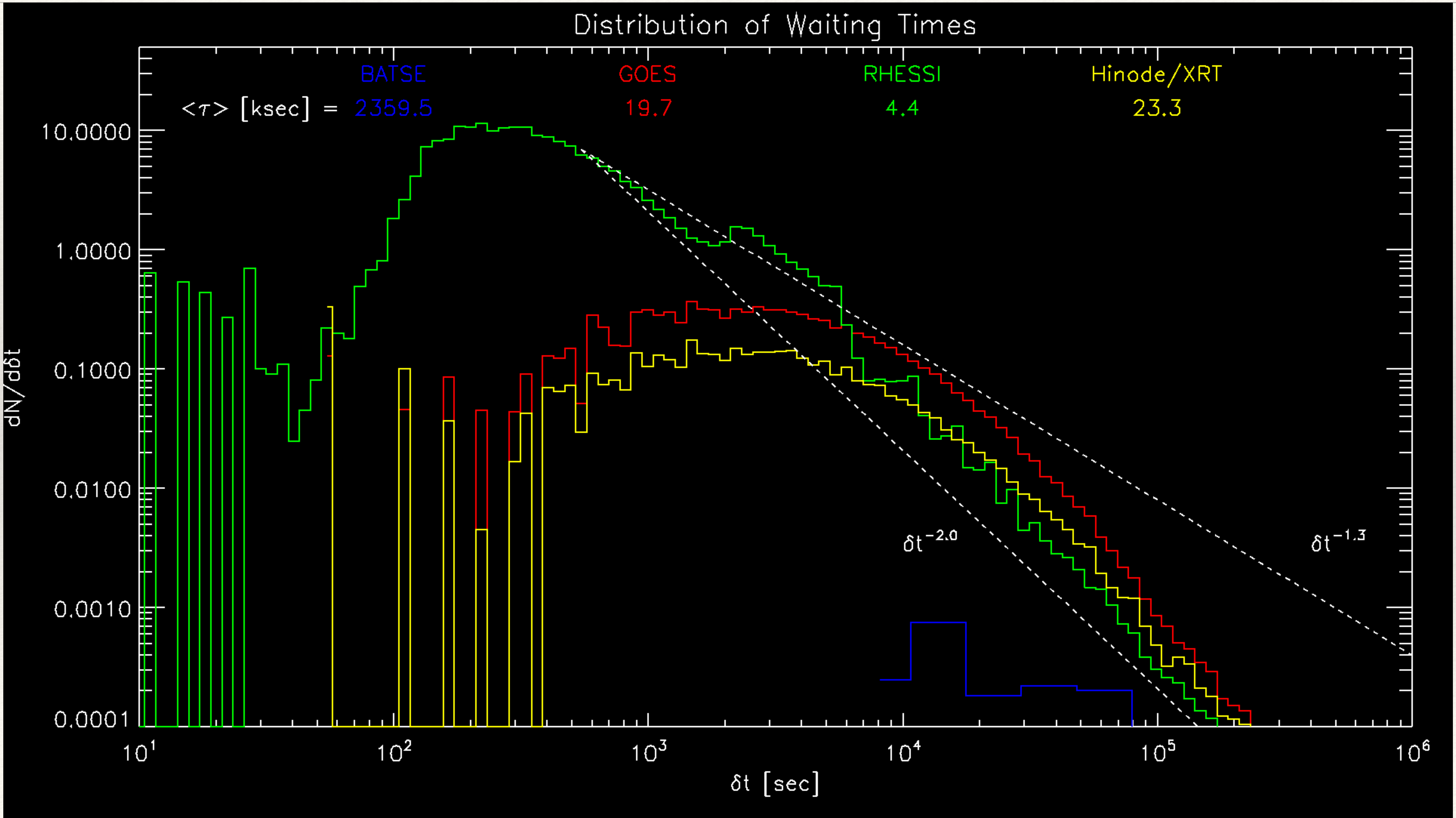
The n^{th} flare of an active region



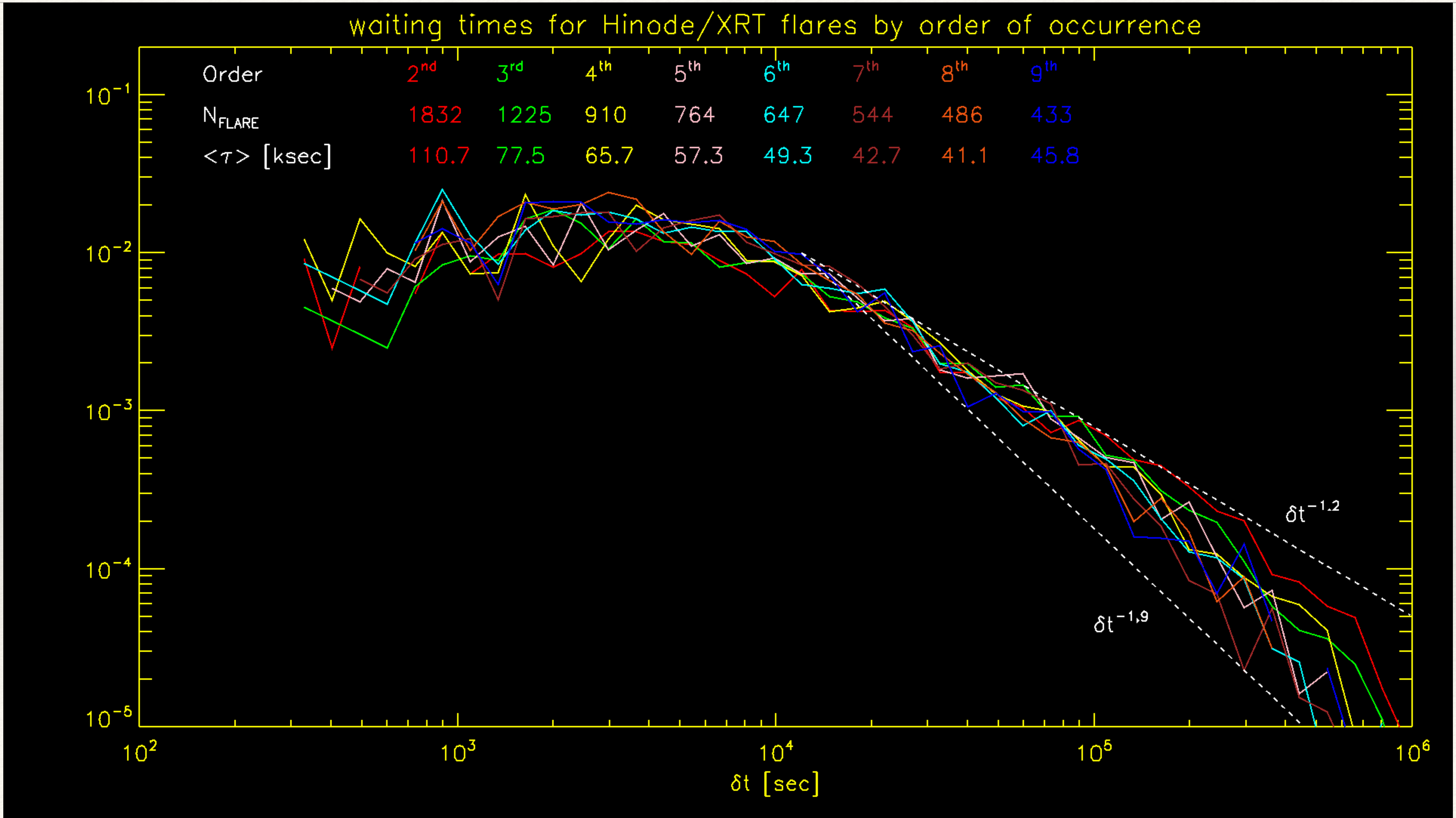
Takeaways

- Slope is not robust — Xufei will have more to say on this
- No apparent dependence on cycle phase
- Slope gets flatter (more energetic flares) as active regions age

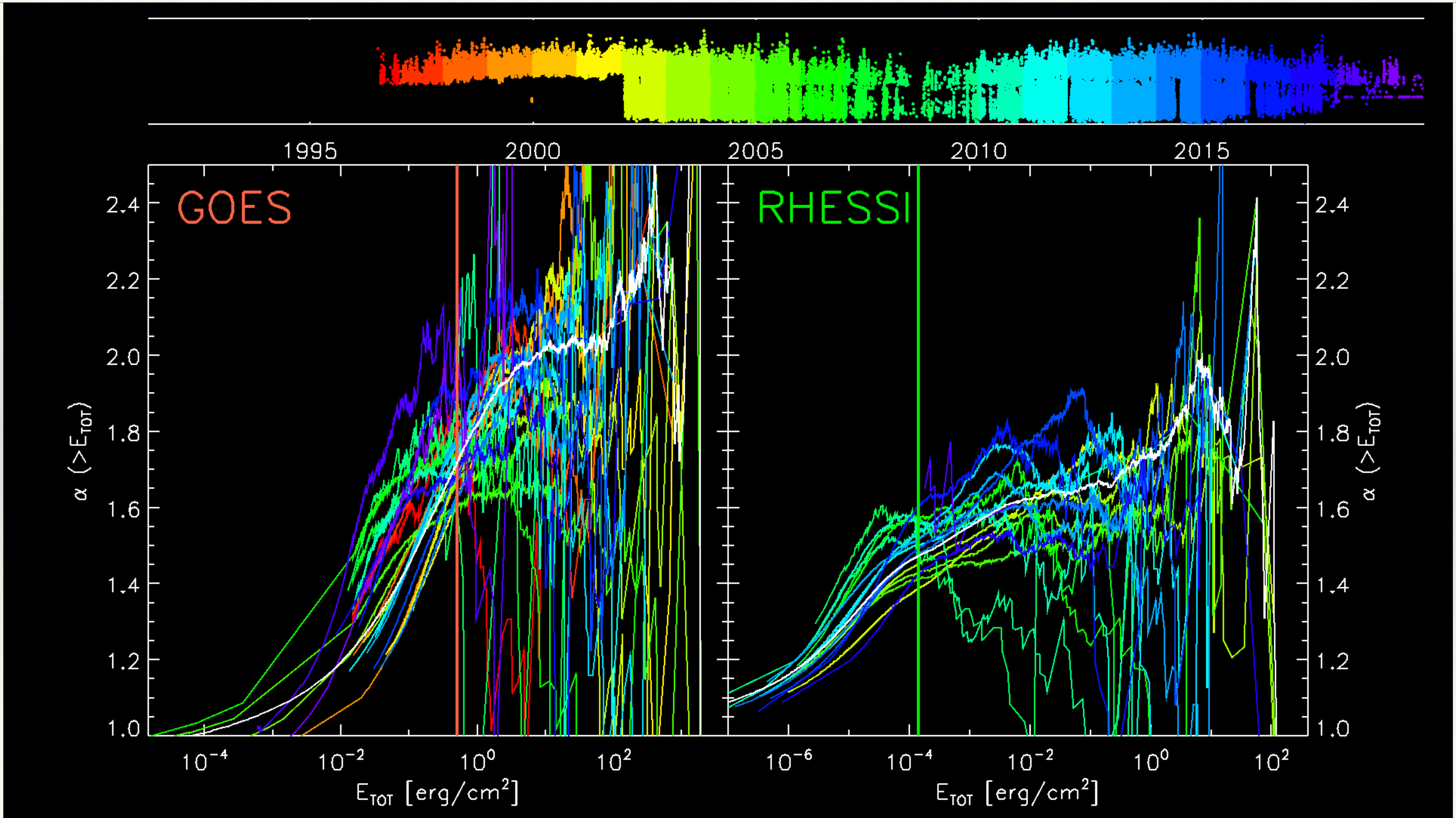
Waiting time distribution (all flares)



Waiting time distribution (flare order)



α(>E|year)



1995
2000
2005
2010
2015
GOES
RHESSI
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
$\alpha\ (>E_{TOT})$
10^{-4}
10^{-2}
10^{0}
10^{2}
10^{-6}
E_{TOT} [erg/cm^2]