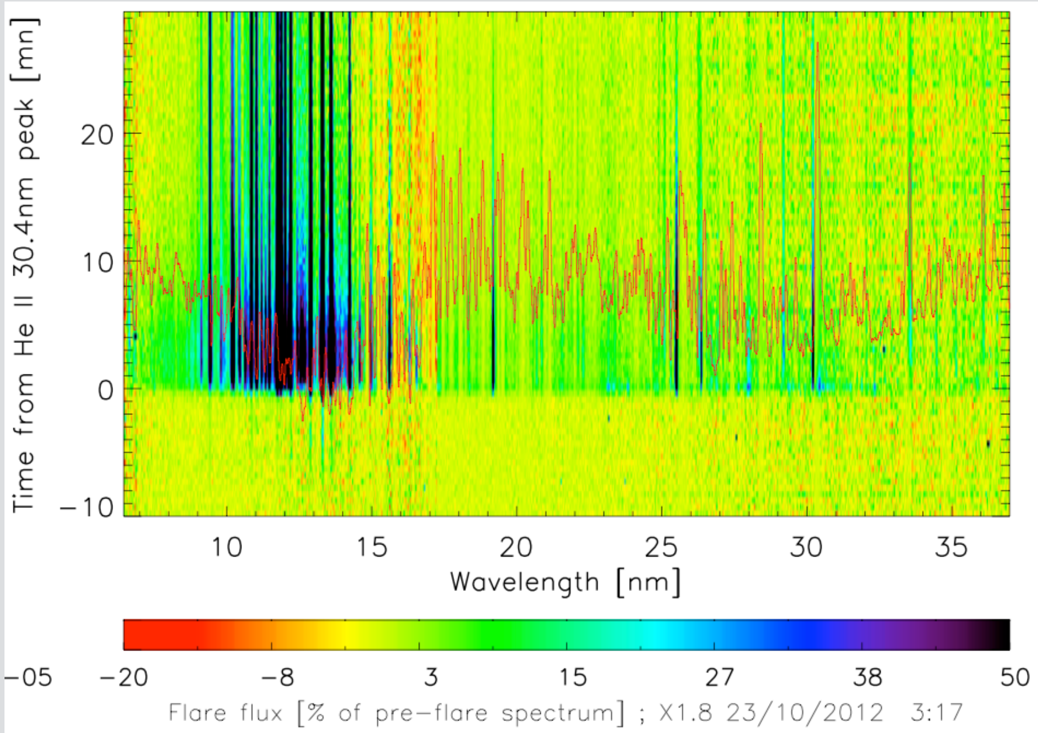
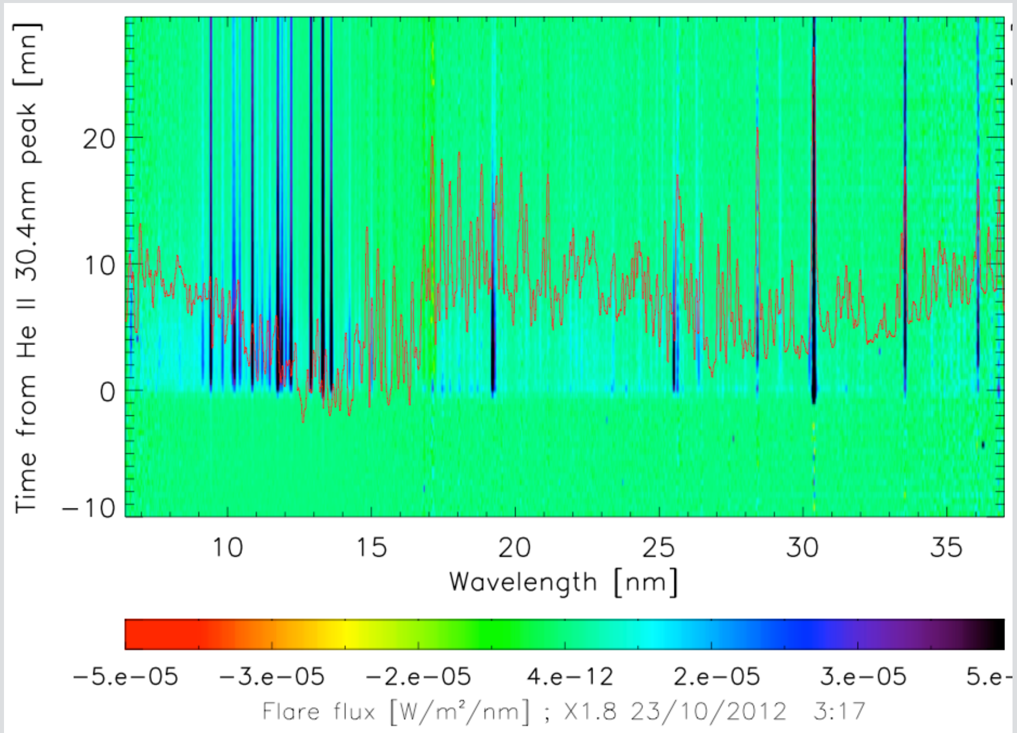
A Statistical Analysis of EUV Flares with SDO/EVE





Matthieu Kretzschmar (KRČMAŘ)
LPC2E, CNRS & University of Orléans, France

Spectral distribution of flare energy

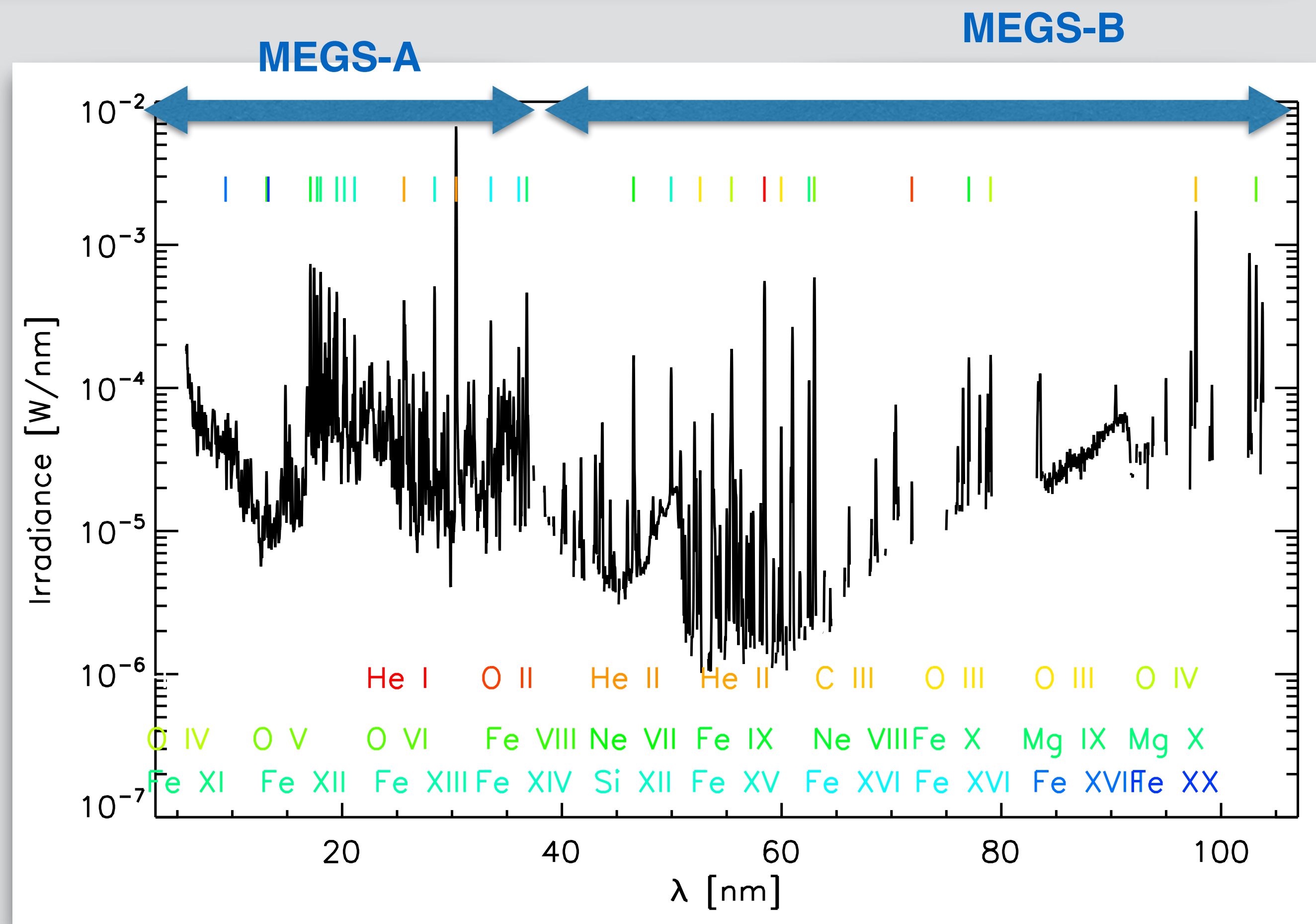
➡ How is the energy at each λ changing with the « flare size »?

➡ How much and where is the energy going in the X/EUV range ?

✓ Needed to
- ★ make the link between different observations (Sun/star, E_{bol}/E_{SXR}, ..)
- ★ know where and how much is the energy deposited
- ★ study the impact on planetary's atmosphere of solar and stellar flares

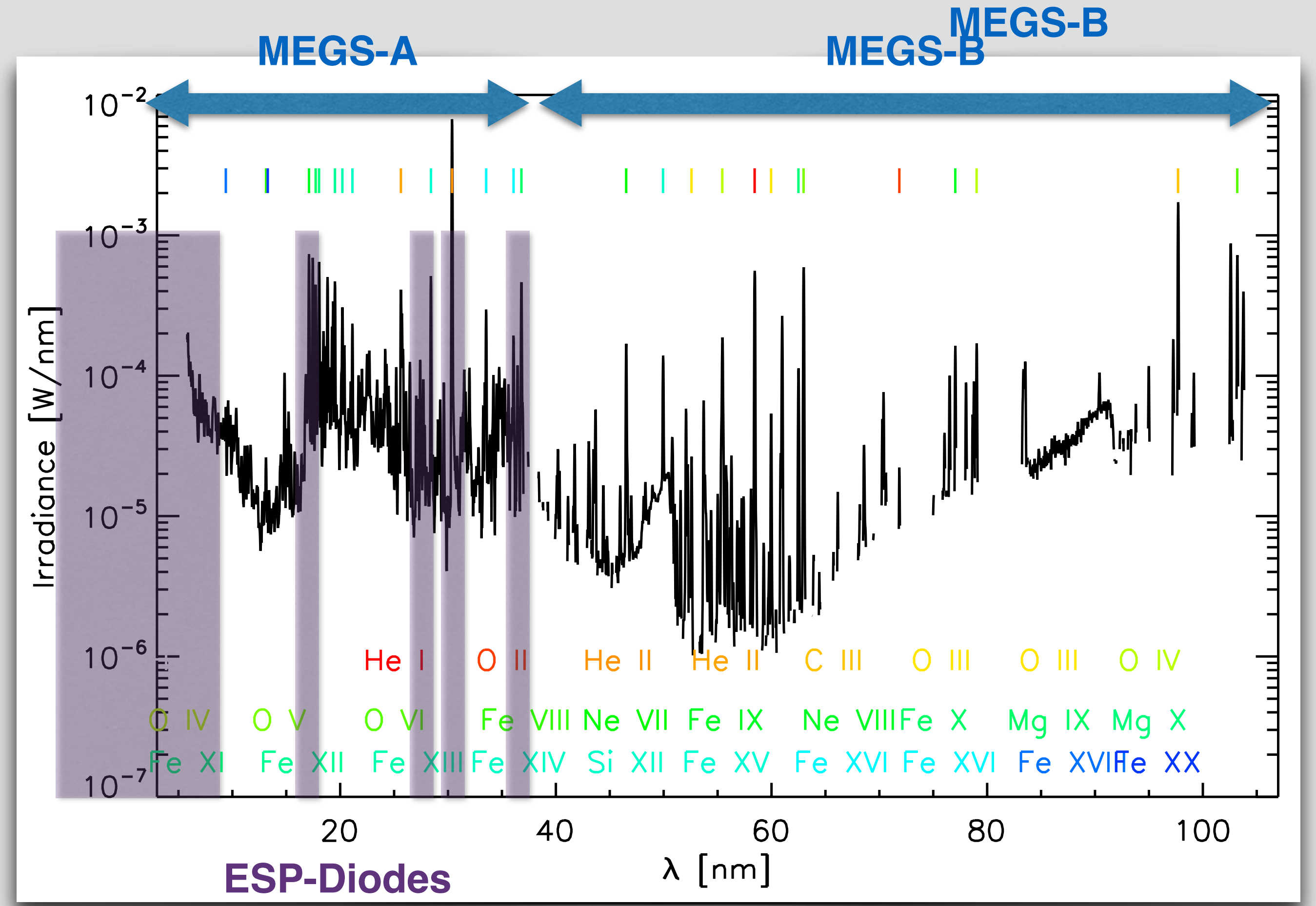
Retrieving Flare fluence from EVE

- ✓ Use GOES SXR to know about flares.
- ✓ Retrieve corresponding EVE data products
  - « Line » product: Fixed integration spectral width, continuum included
  - « Diodes » product: broad band measurements



Retrieving Flare fluence from EVE

- ✓ Use GOES SXR to know about flares.
- ✓ Retrieve corresponding EVE data products
  - « Line » product: Fixed integration spectral width, continuum included
  - « Diodes » product: broad band measurements

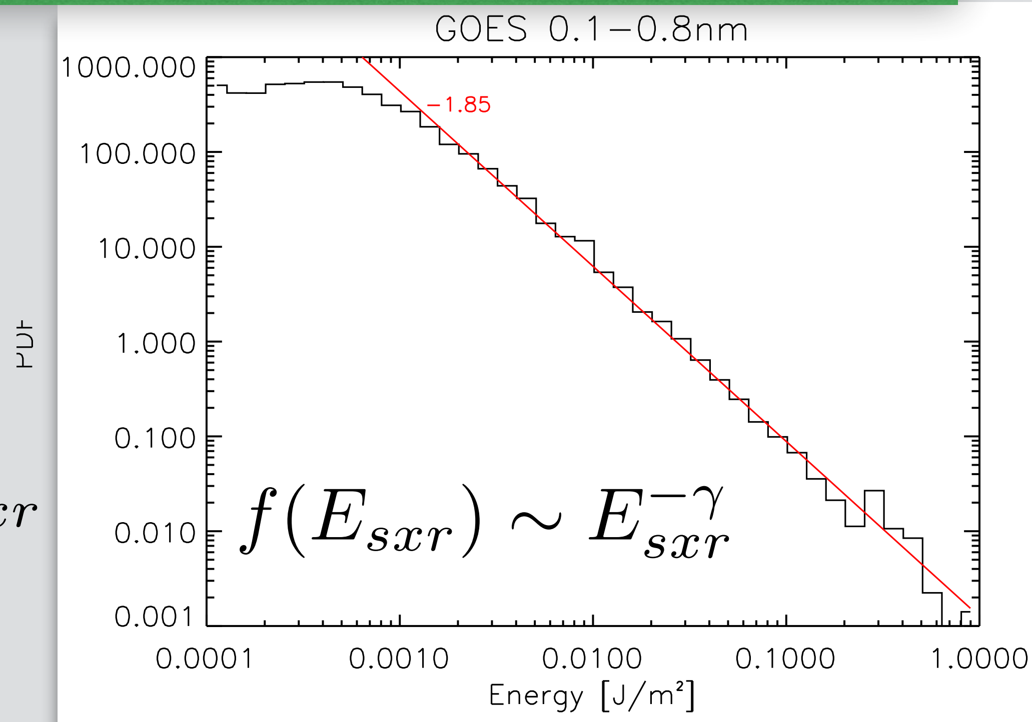


Energetics Scaling

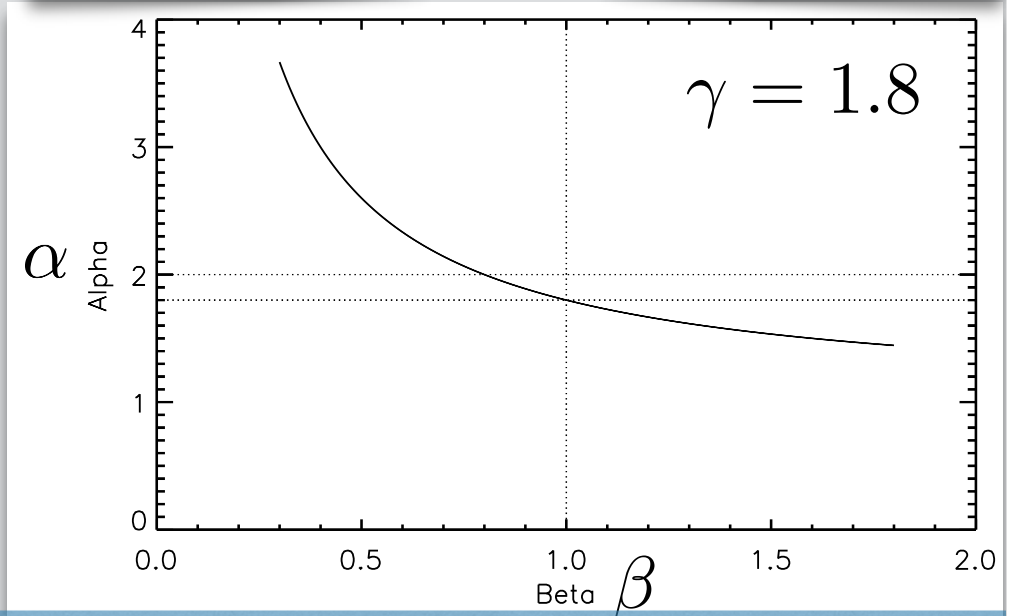
➡ How is the energy at each λ changing with the « flare size »?

Scaling exp. at different λ

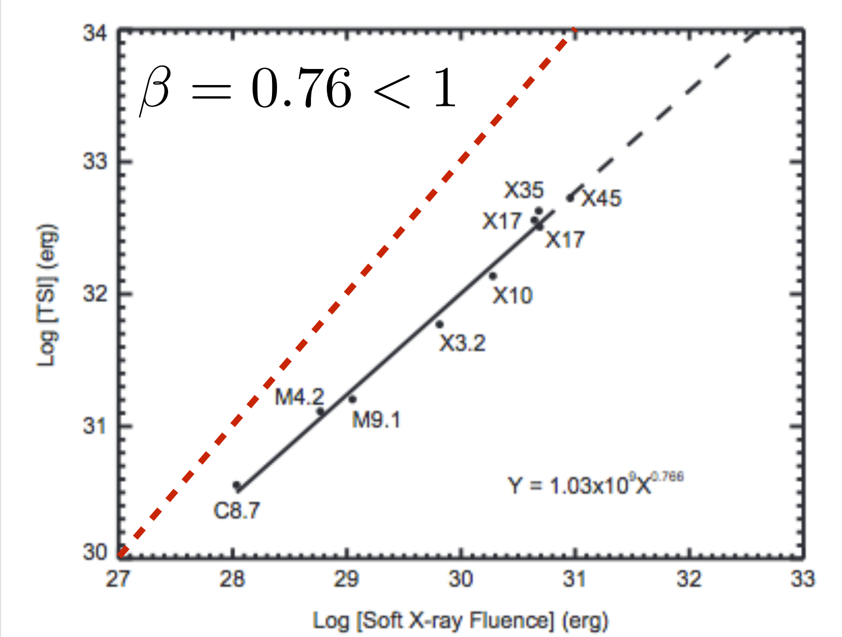
➡ If $f(E_{sxr}) \sim E_{sxr}^{-\gamma}$ and $E_\lambda \sim E_{sxr}^{\beta}$



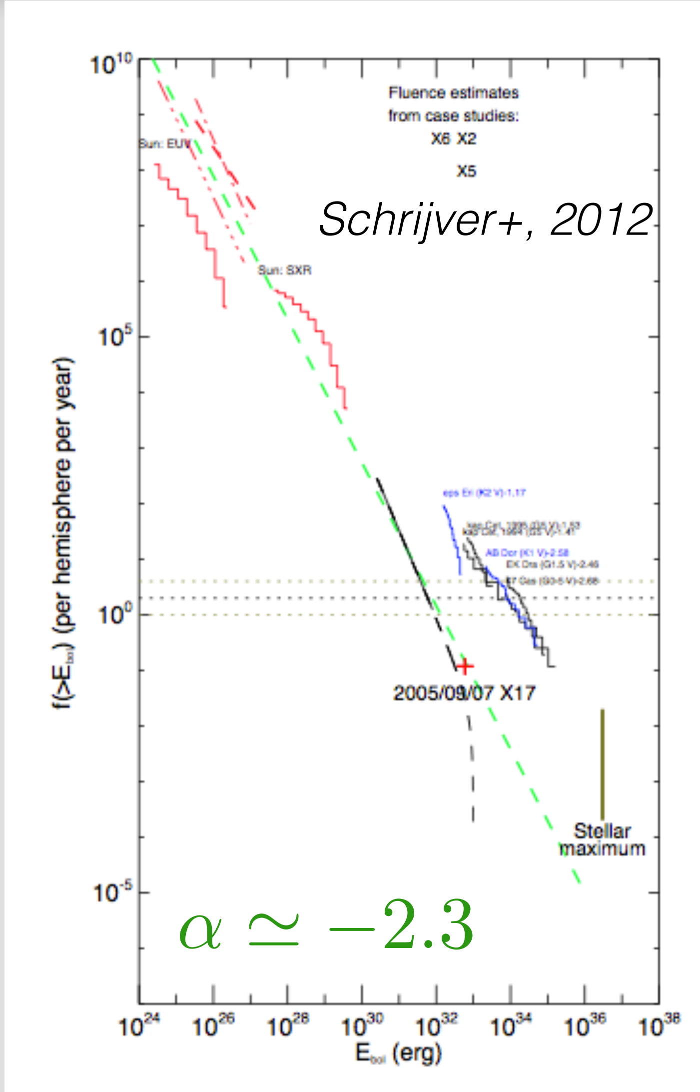
$$\Rightarrow \left| \begin{array}{l} f(E_\lambda) \sim E_\lambda^{-\alpha} \\ \alpha = \dfrac{\gamma - 1 + \beta}{\beta} \end{array} \right.$$



Ex: Bolometric vs SXR Energy



Cliver and Dietrich, 2013



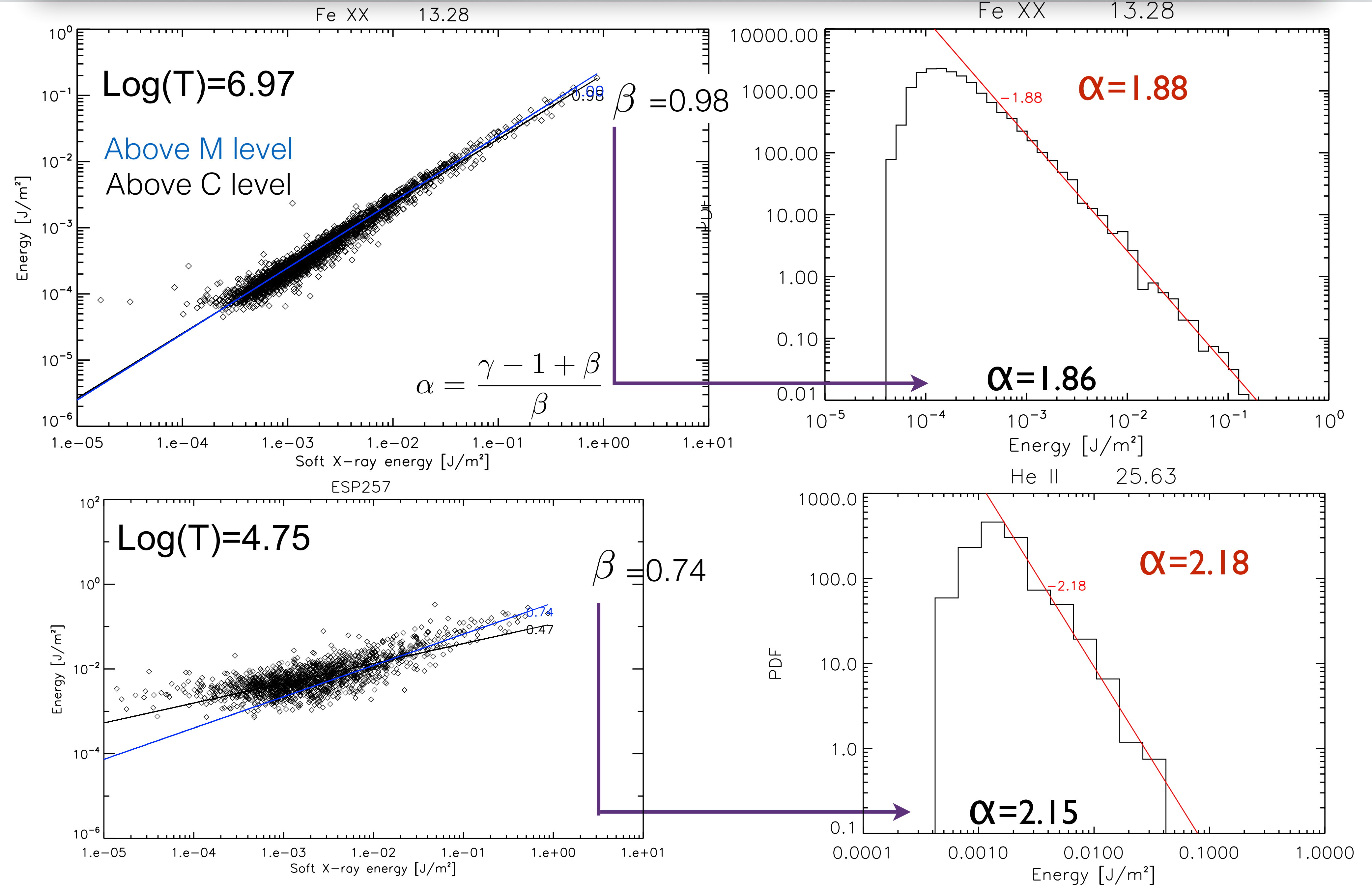
Schrijver+, 2012

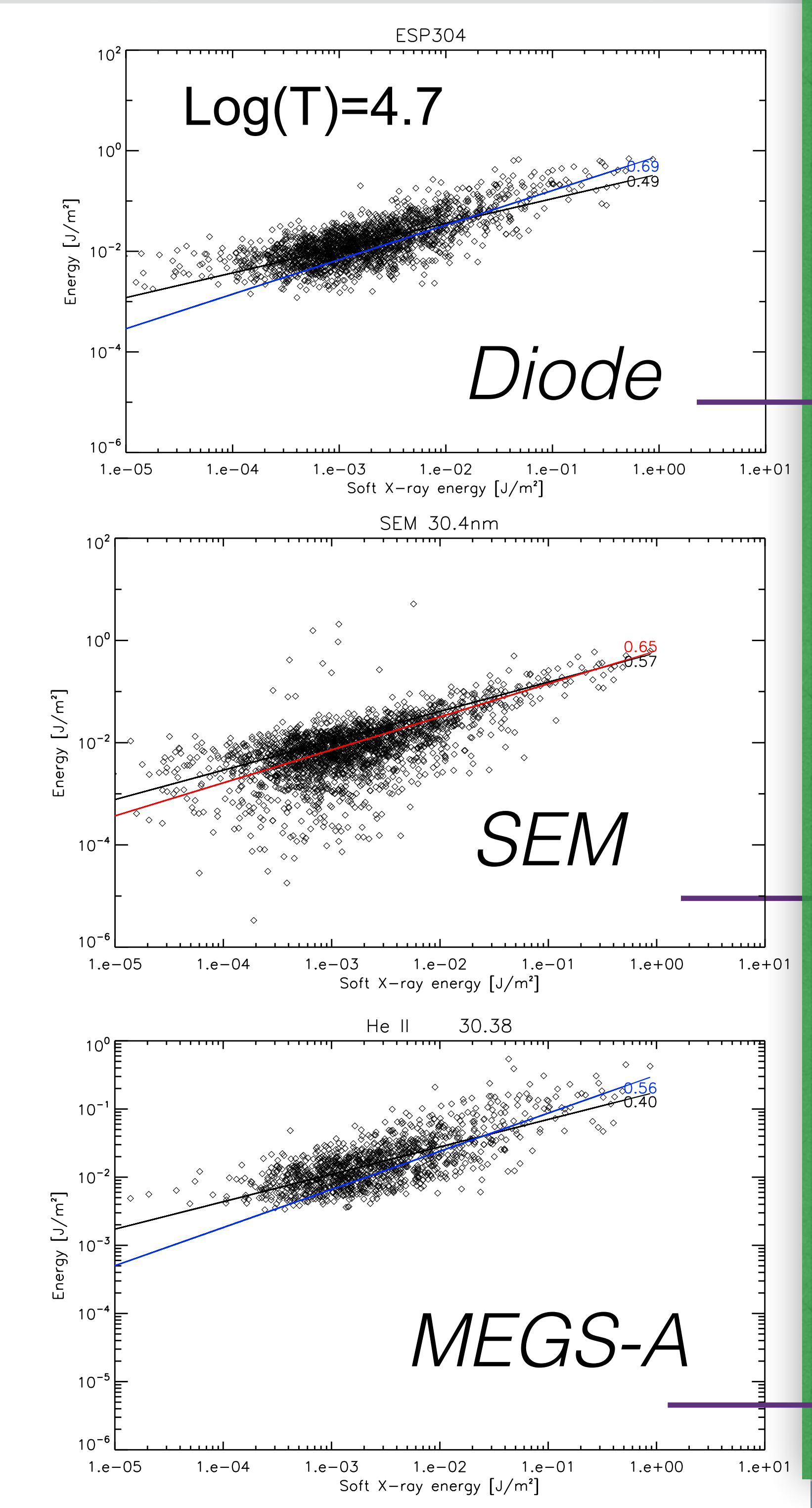
➡ A good scaling relationships between the fluence* at 2 wavelengths tells us the about the slope of the PDF

$$* \; F(\lambda) = \int_{T_f} [I(\lambda,t) - \mathrm{Backgnd}(\lambda,t)]\, dt$$

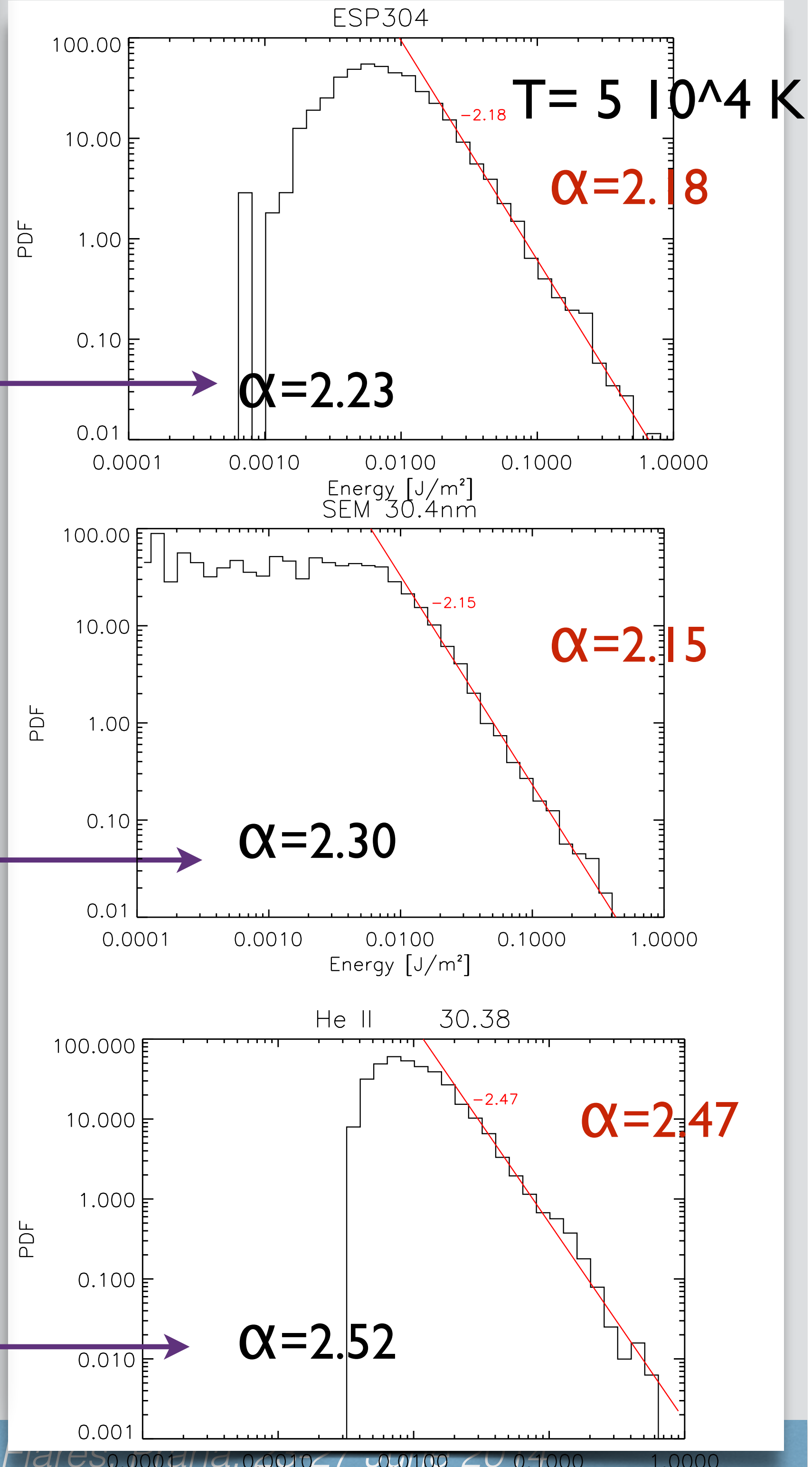
NB: $f(I_{bol}) \sim I_{bol}^{-\alpha}$ with α > 2 can be re-find independently

EVE directly integrated Lines



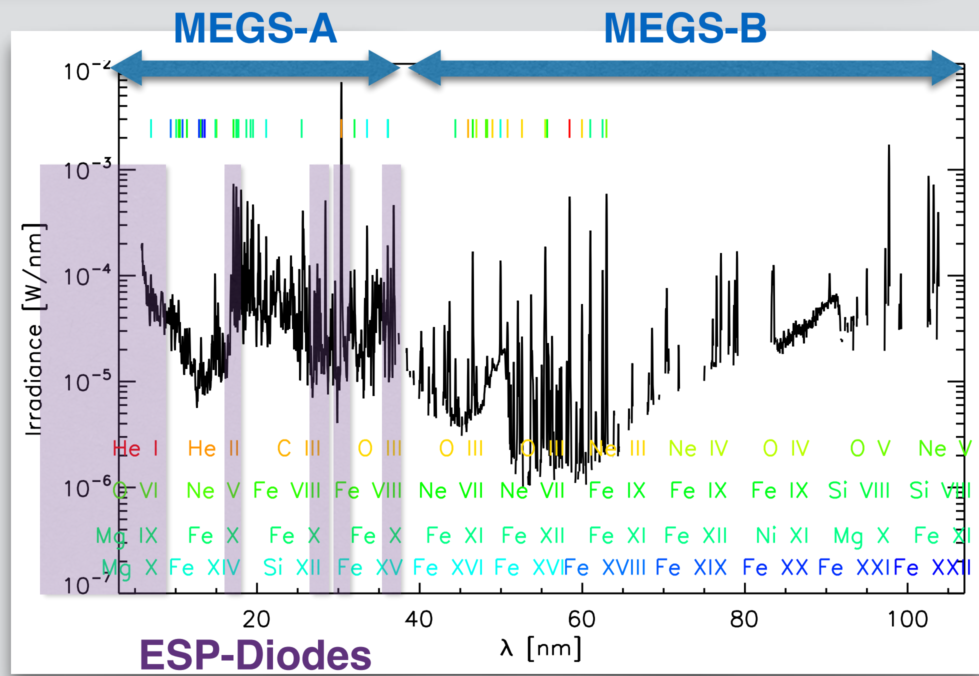

ESP304
Log(T)=4.7
Diode
0.69
0.49
Energy [J/m²]
Soft X-ray energy [J/m²]
SEM 30.4nm
SEM
0.65
0.57
He II 30.38
MEGS-A
0.56
0.40

He II @ 304nm

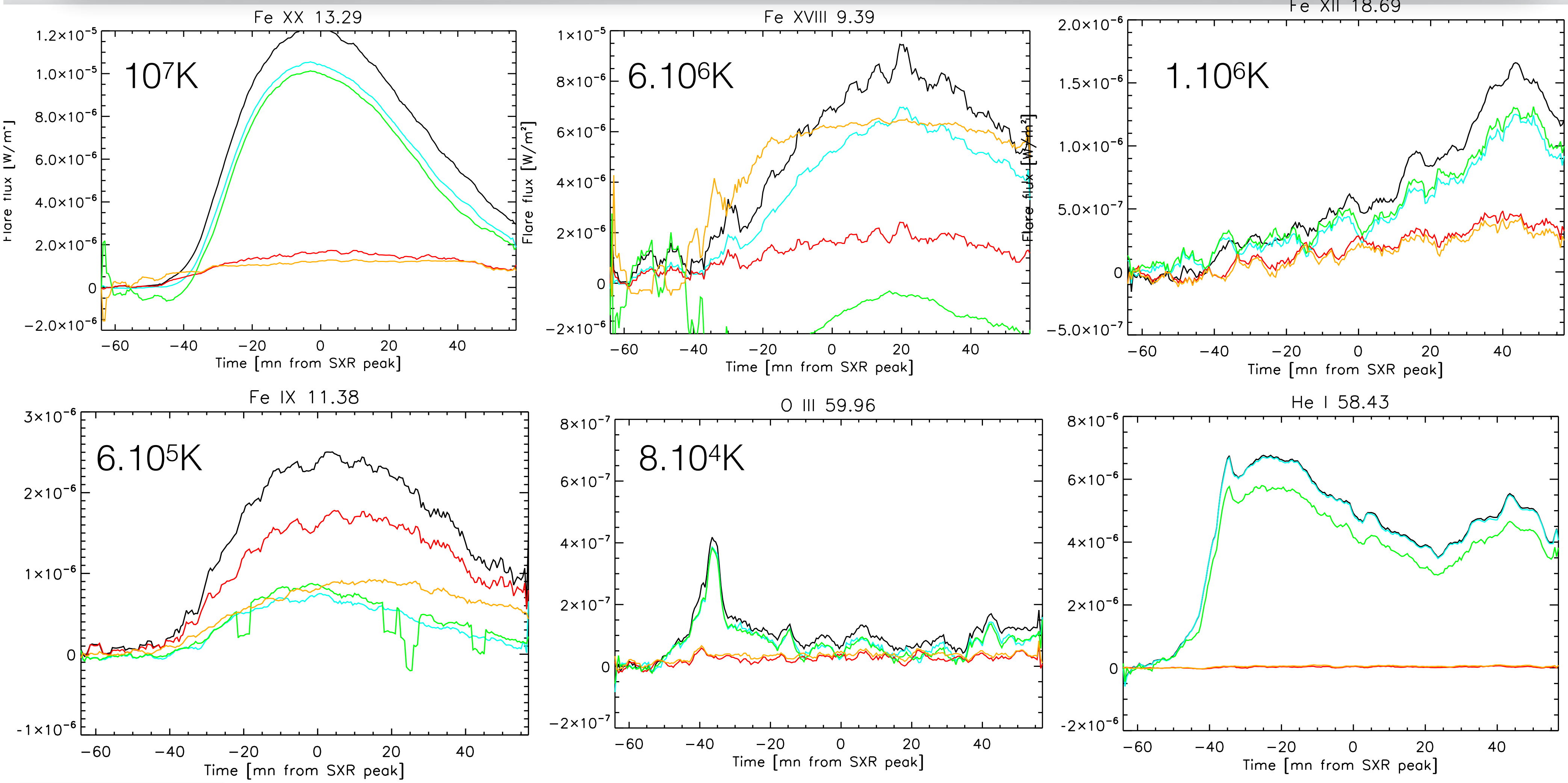

ESP304
T= 5 10^4 K
−2.18
α=2.18
α=2.23
PDF
Energy [J/m²]
SEM 30.4nm
−2.15
α=2.15
α=2.30
He II 30.38
−2.47
α=2.47
α=2.52

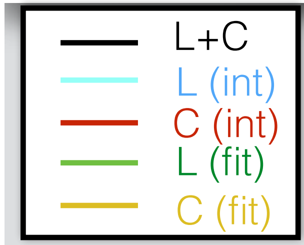
Retrieving Flare fluence from EVE

- ✓ Use GOES SXR to know about flares.
- ✓ Retrieve corresponding EVE data products
  - « Line » product: Fixed integration spectral width, continuum included
  - « Diodes » product: broad band measurements
  - « Spectrum » product (λ<35nm for most of the flare): 44 selected lines with good coverage in T and (hopefully) good contrast.
- ✓ Retrieve flare profiles for lines only:
  - remove background:
    - 1) pre-flare spectrum (av. over 8 minutes before flare starts, other flare removed)
    - 2) Remove the median for 4 minutes before flare.
  - Remove continuum:
    - 1) $I = a_0 + a_1 . \lambda + G(\lambda)$
    - 2) Remove min value over line profile.
    - 3) Ransac ?
- ✓ Compute fluence:
  - Use start - 5mn and end + 20mn time for GOES flare.



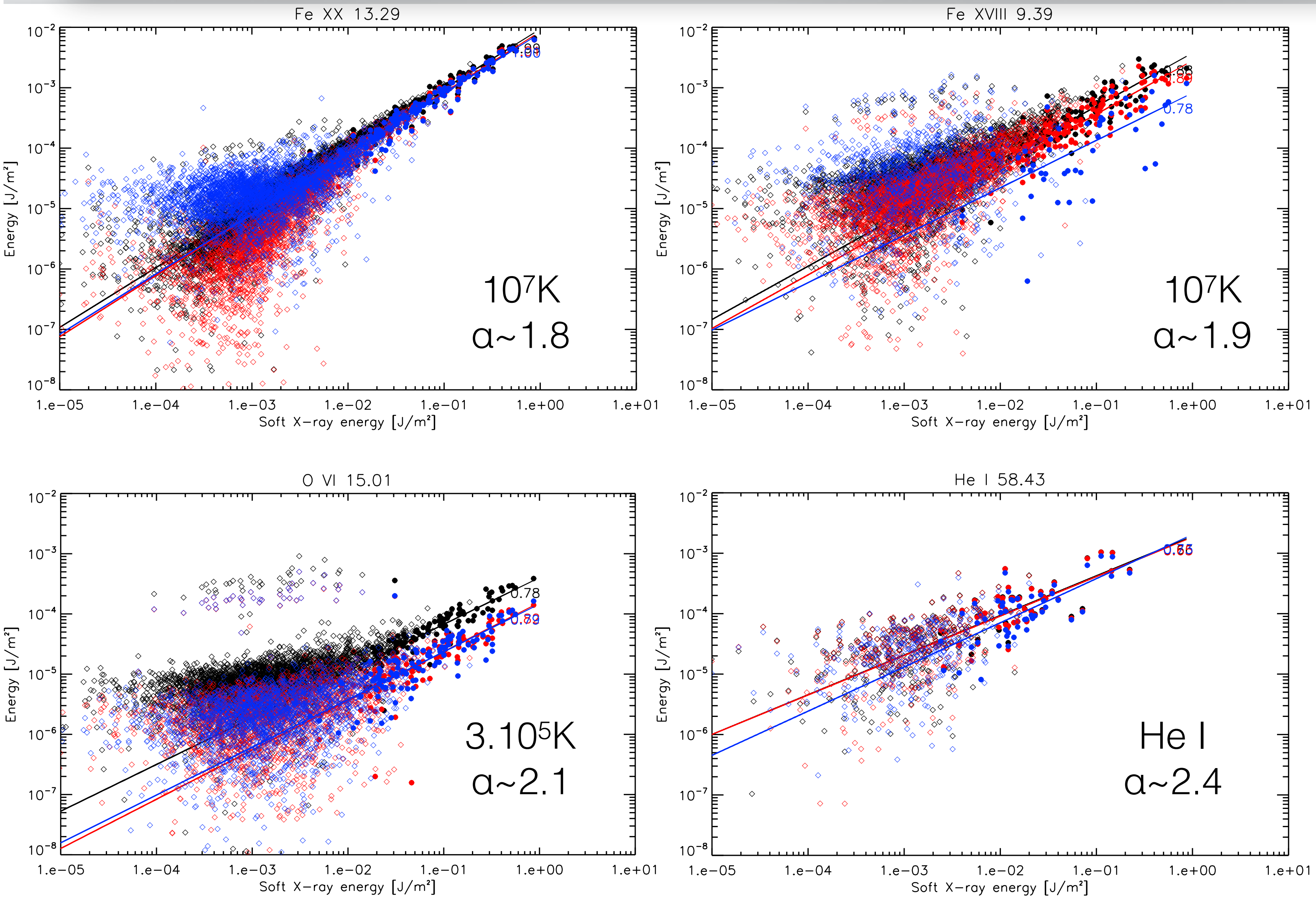
Flare Profiles for 20140104 M4





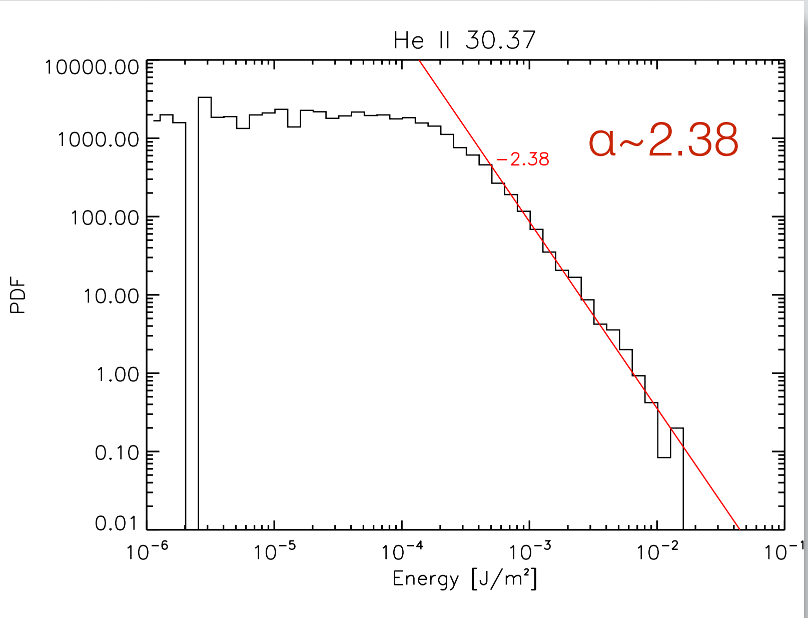
➡ Extremely different behaviors for different wavelengths.. and different flares !

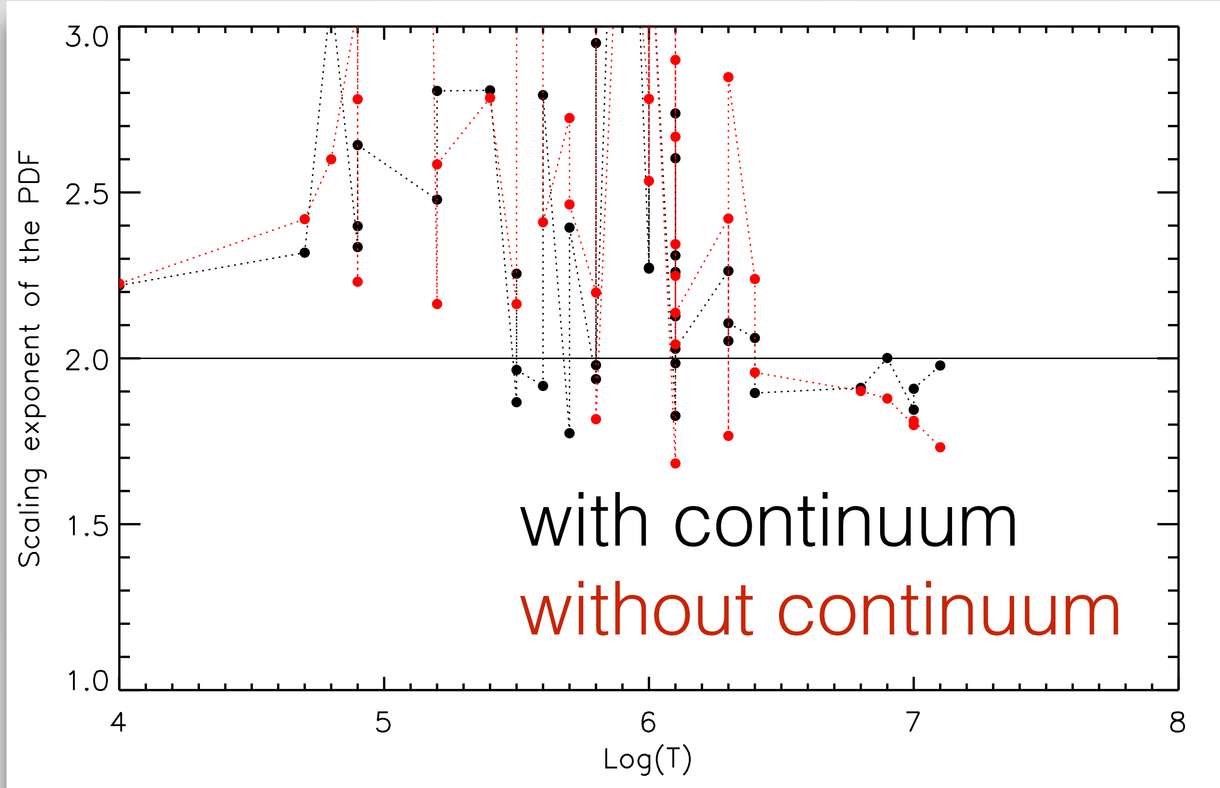
Line fluence vs SXR fluence



$$\alpha = \frac{\gamma - 1 + \beta}{\beta}$$

Scaling exp. vs Temperature



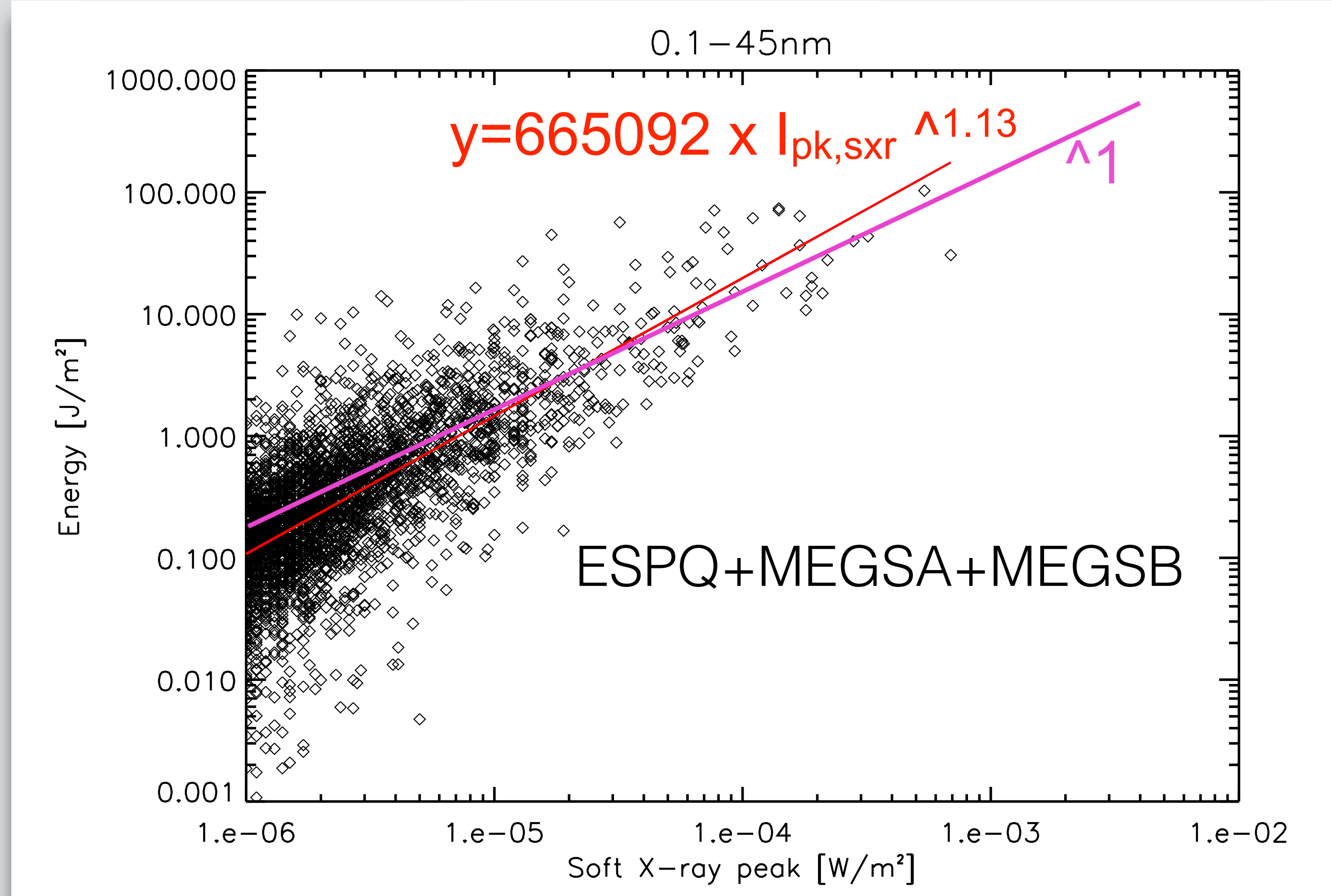


- ➡ Value of the exponent very dependent on many parameters.. However,
- ➡ Clear tendency for « chromospheric » emission to have α > 2

Energetics

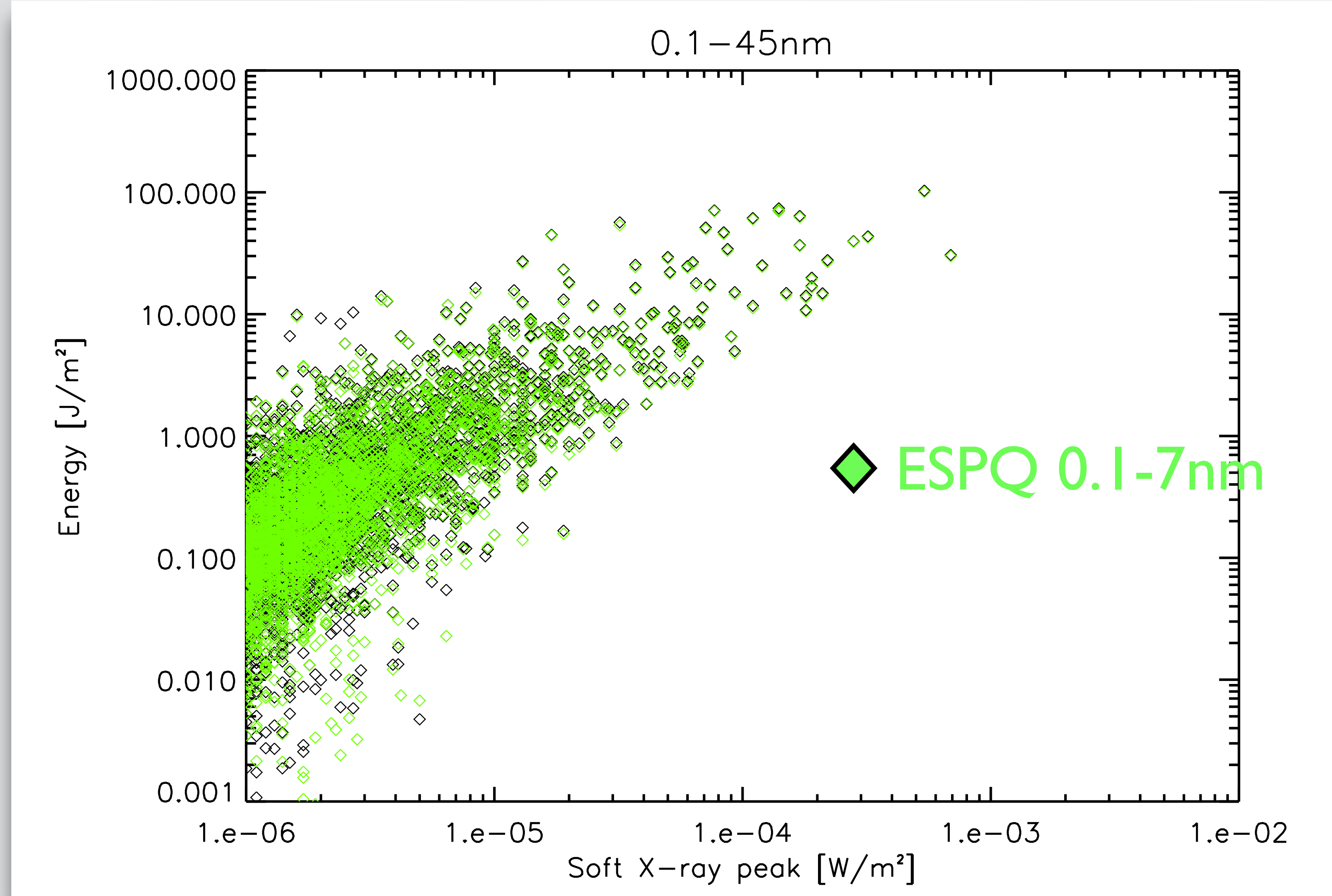
- How much and where is the energy going in the X/EUV range ?

Spectral distribution in the EUV/SXR



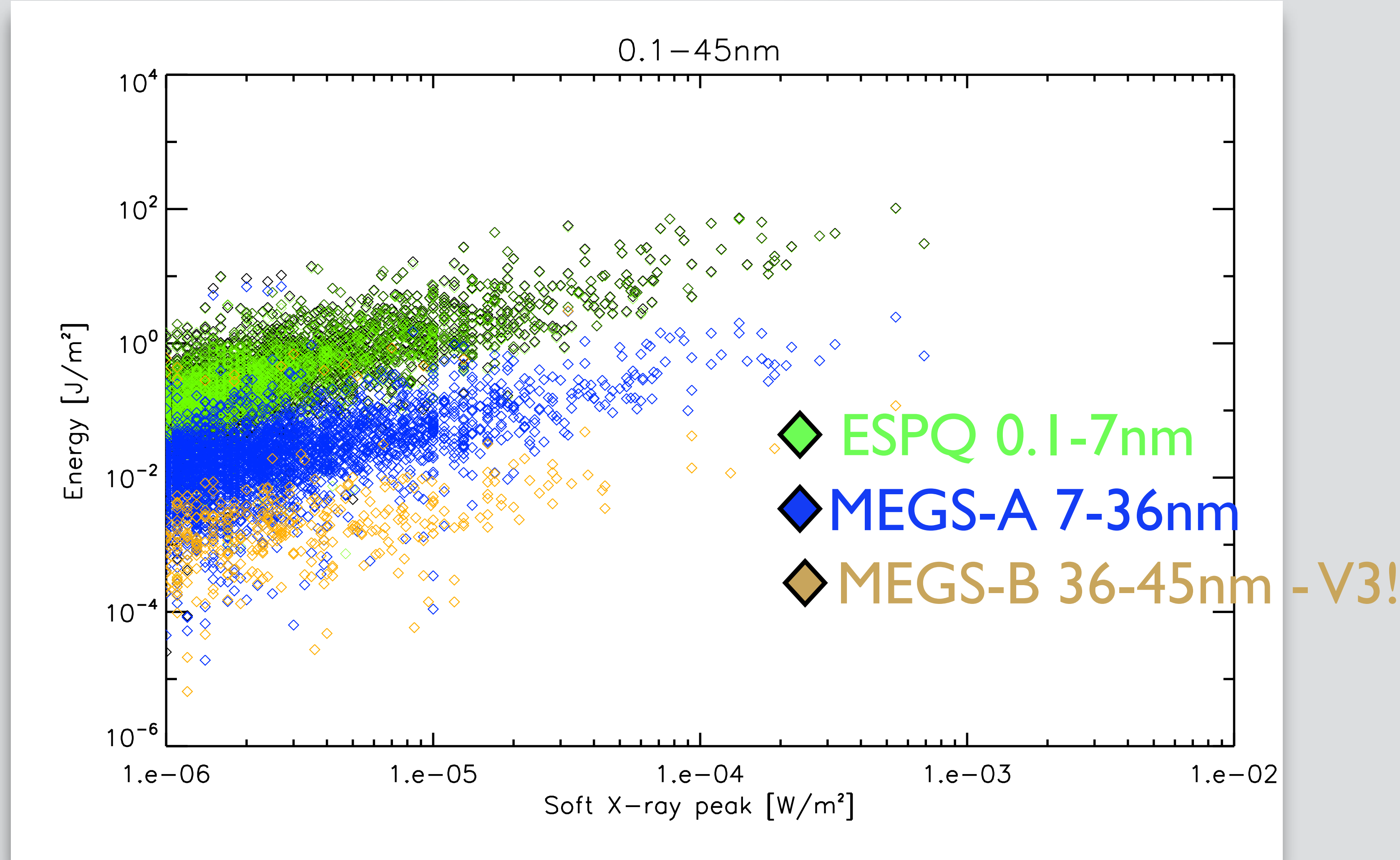
➡ Good correlation over all. More than tens of Joule/m^2 for X-class flares !

Spectral distribution in the EUV/SXR



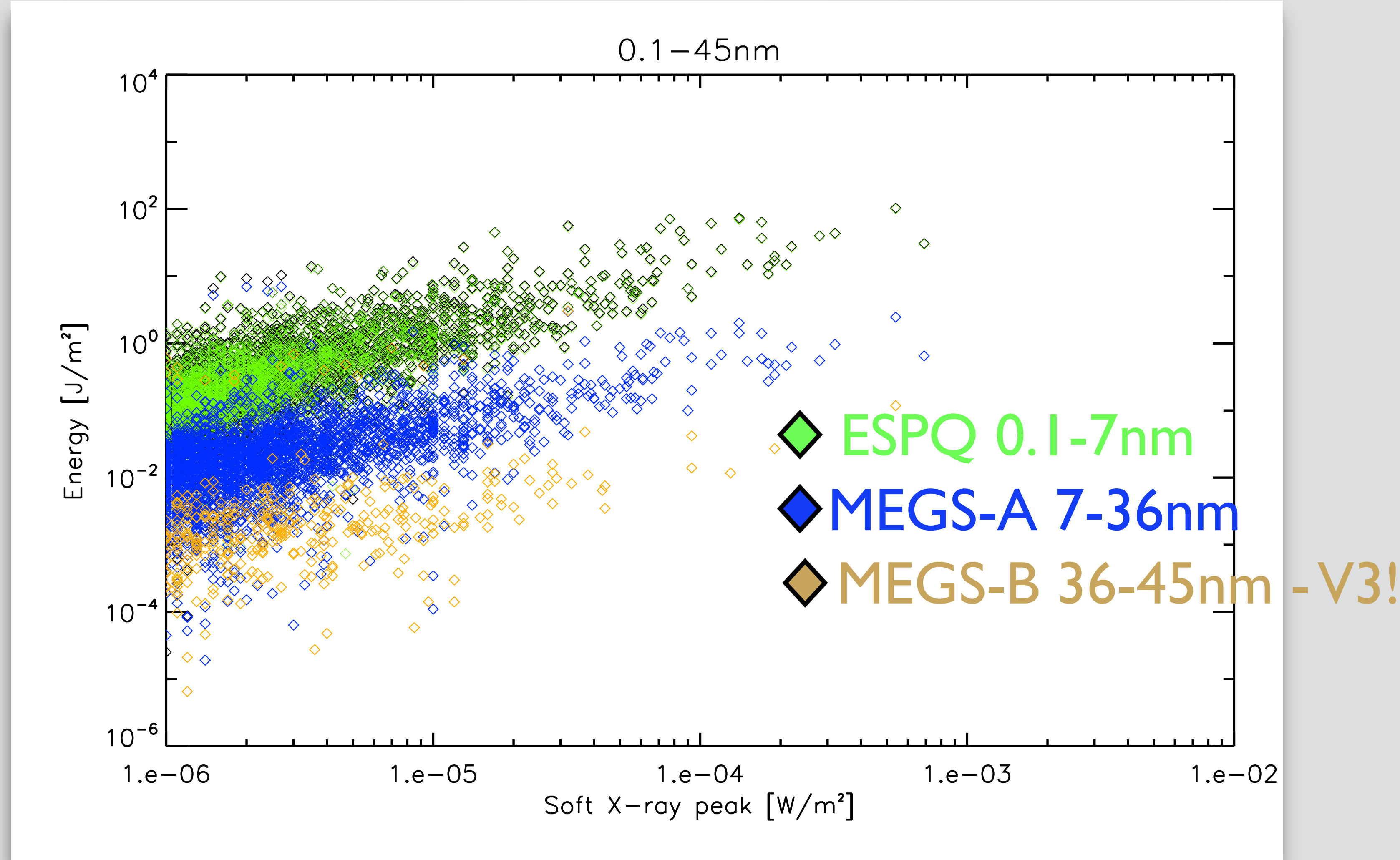
➡ Everything below 7nm ??

Spectral distribution in the EUV/SXR



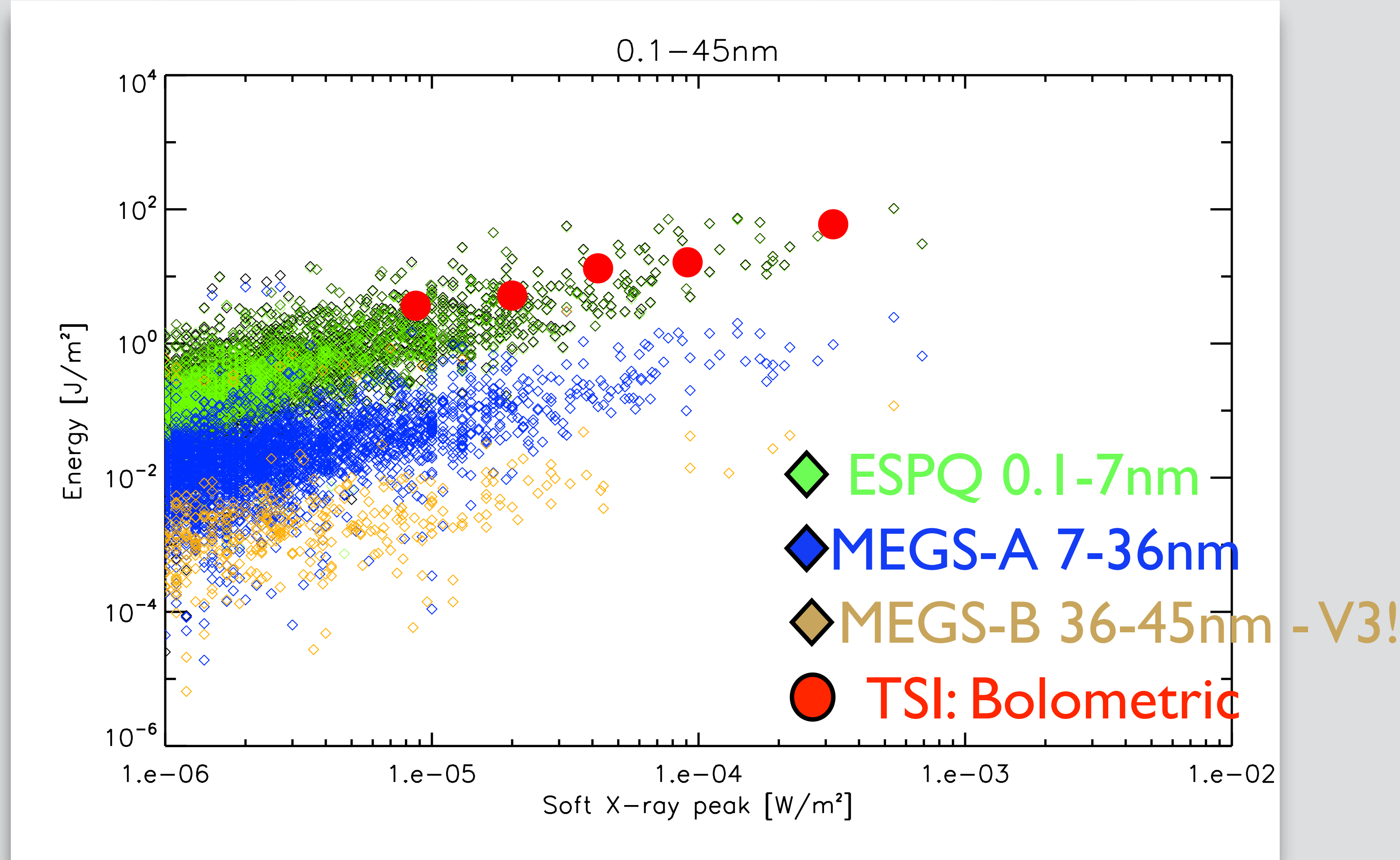
➡ Indeed: much less above 7nm..

Spectral distribution in the EUV/SXR



➡ Indeed: much less above 7nm..

Spectral distribution in the EUV/SXR



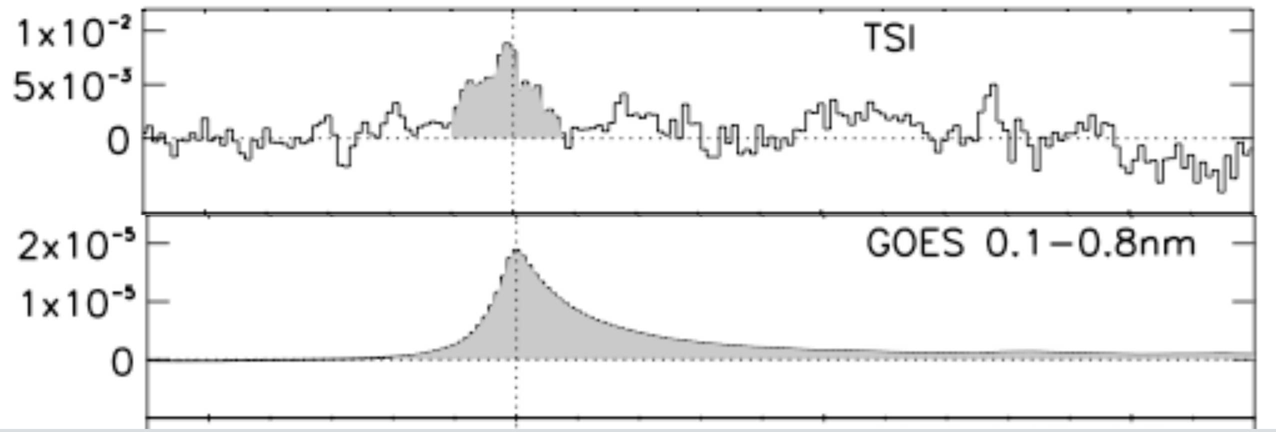
➡ E below 7nm equivalent to Etot ??

Discussion

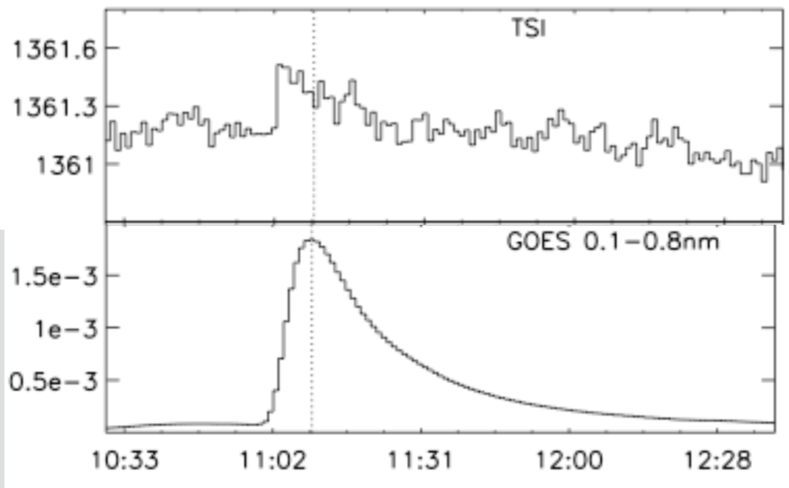
➡ The calibration of ESP-Q relies on both modeled spectral response and modeled spectrum. Necessity to observe the spectrum at these wavelength. Energy between 0.1nm and 7nm overestimated ?

➡ In the flare energy estimates, most of E_{tot} comes from impulsive phase. Gradual phase hardly detectable. Total energy underestimated ?

Average flare light curve



28 Oct. 2003



Conclusion

Rodgers et al., 2006

- ✓ A large part of the energy seems to be release below 7(2)nm.

- ✓ Chromospheric wavelengths look to scale differently than coronal ones (α>2)

GOES-8 Class	XPS 0–2 nm Irradiance, mW/m^2	XPS 0–7 nm Irradiance, mW/m^2
M2.3	0.282	0.424
M1.4	0.161	0.232
C7.8	0.083	0.120
C7.0	0.095	0.138
C9.7	0.092	0.204
C3.5	0.042	0.068
M1.3	0.291	0.387
C3.3	0.064	0.104
C8.0	0.146	0.204
M8.0	0.290	0.414
M4.0	0.246	0.372
X1.5	1.97	2.29
C4.0	0.067	0.087
M1.3	0.101	0.149
C6.1	0.116	0.183
M1.4	0.128	0.211
C9.4	0.118	0.164
M2.0	0.163	0.261
C3.4	0.070	0.110
M1.6	0.244	0.315
C1.9	0.046	0.095
M1.4	0.146	0.202
M4.3	0.373	0.524
M1.8	0.148	0.184
M1.0	0.191	0.247
M5.9	0.396	0.552
M8.5	0.298	0.354
M6.9	0.686	0.957
X4.8	1.62	1.87

Conclusion

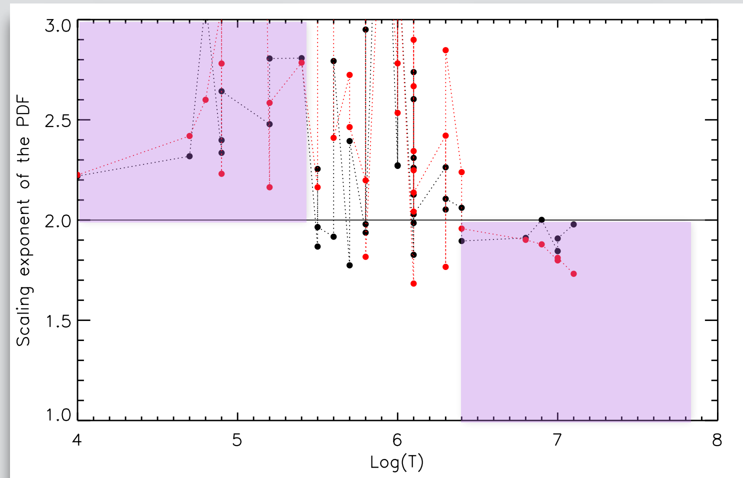
Rodgers et al., 2006

✓ A large part of the energy seems to be release below 7(2)nm.

✓ Chromospheric wavelengths look to scale differently than coronal ones (α>2)

GOES-8 Class	XPS 0–2 nm Irradiance, mW/m^2	XPS 0–7 nm Irradiance, mW/m^2
M2.3	0.282	0.424
M1.4	0.161	0.232
C7.8	0.083	0.120
C7.0	0.095	0.138
C9.7	0.092	0.204
C3.5	0.042	0.068
M1.3	0.291	0.387
C3.3	0.064	0.104
C8.0	0.146	0.204
M8.0	0.290	0.414
M4.0	0.246	0.372
X1.5	1.97	2.29
C4.0	0.067	0.087
M1.3	0.101	0.149
C6.1	[illegible]	[illegible]
M1.4	[illegible]	[illegible]
C9.4	[illegible]	[illegible]
M2.0	[illegible]	[illegible]
C3.4	0.070	0.110
M1.6	0.244	0.315
C1.9	0.046	0.095
M1.4	0.146	0.202
M4.3	0.373	0.524
M1.8	0.148	0.184
M1.0	0.191	0.247
M5.9	0.396	0.552
M8.5	0.298	0.354
M6.9	0.686	0.957
X4.8	1.62	1.87

3.2 10^{30} ergs/s



THE END

THANK YOU !