Evidence of energy cutoffs in flare-accelerated electrons

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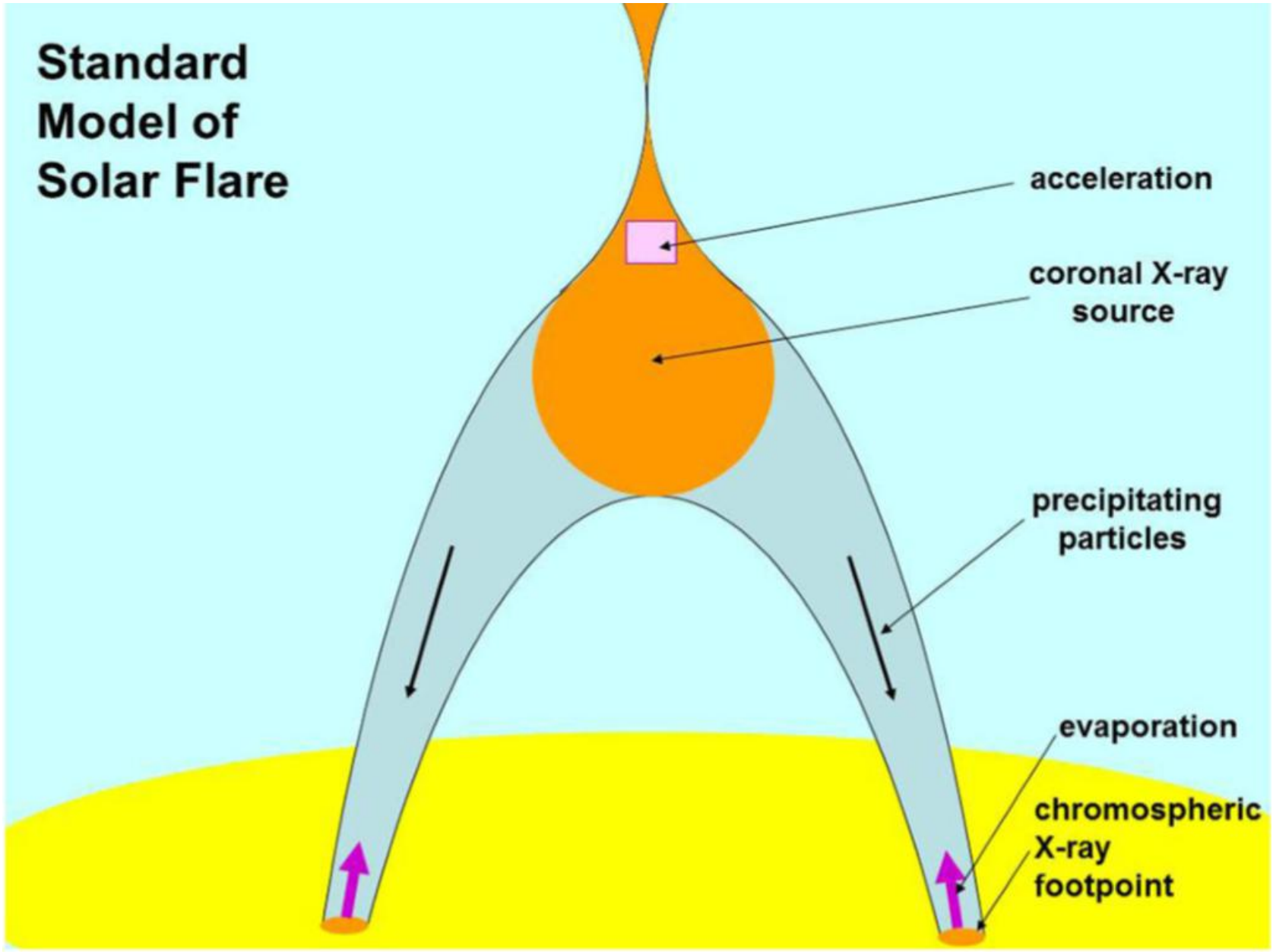
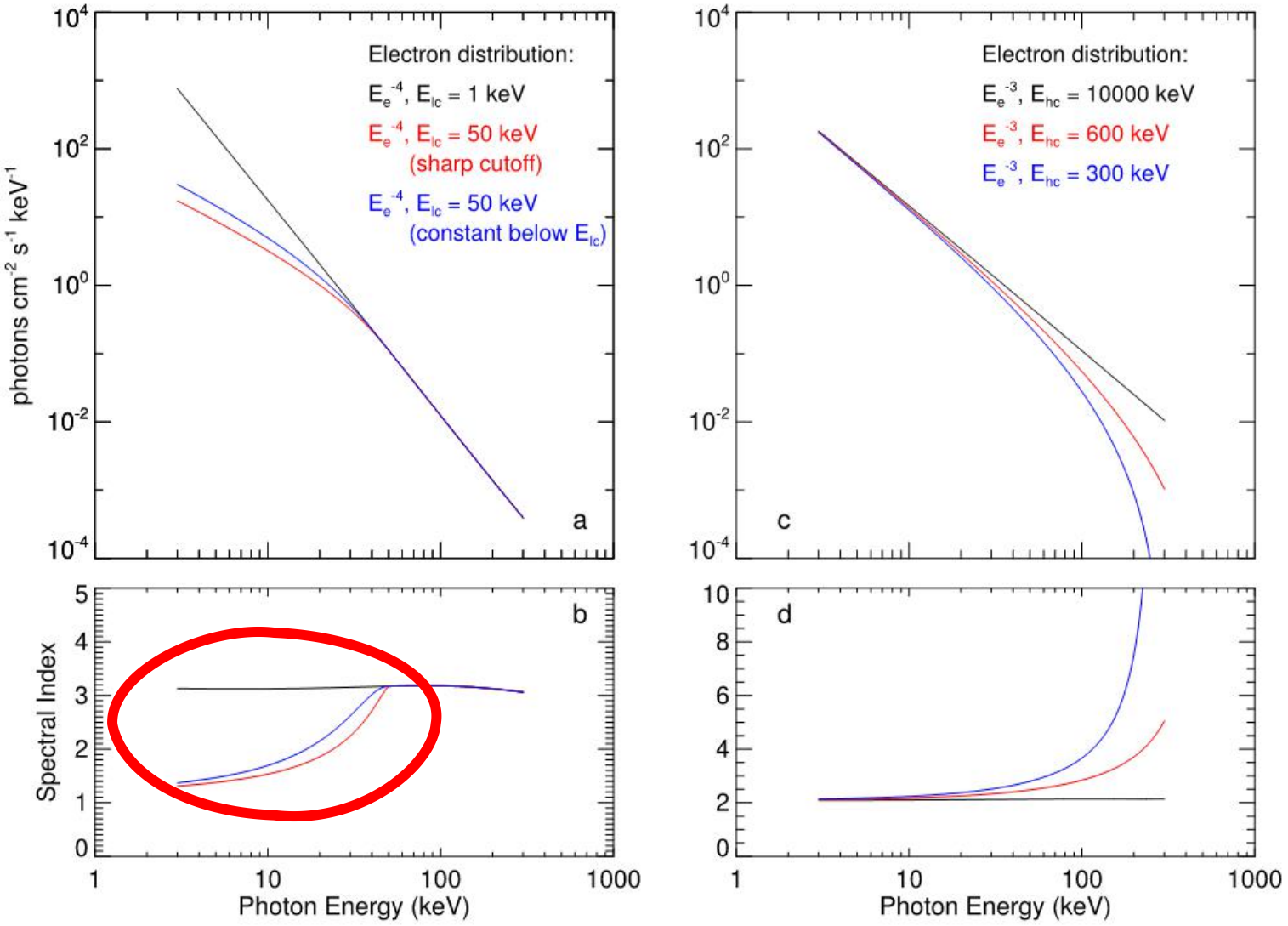
Xia et al. ApJ, 2021, 908(1): 111

Flare-accelerated particles



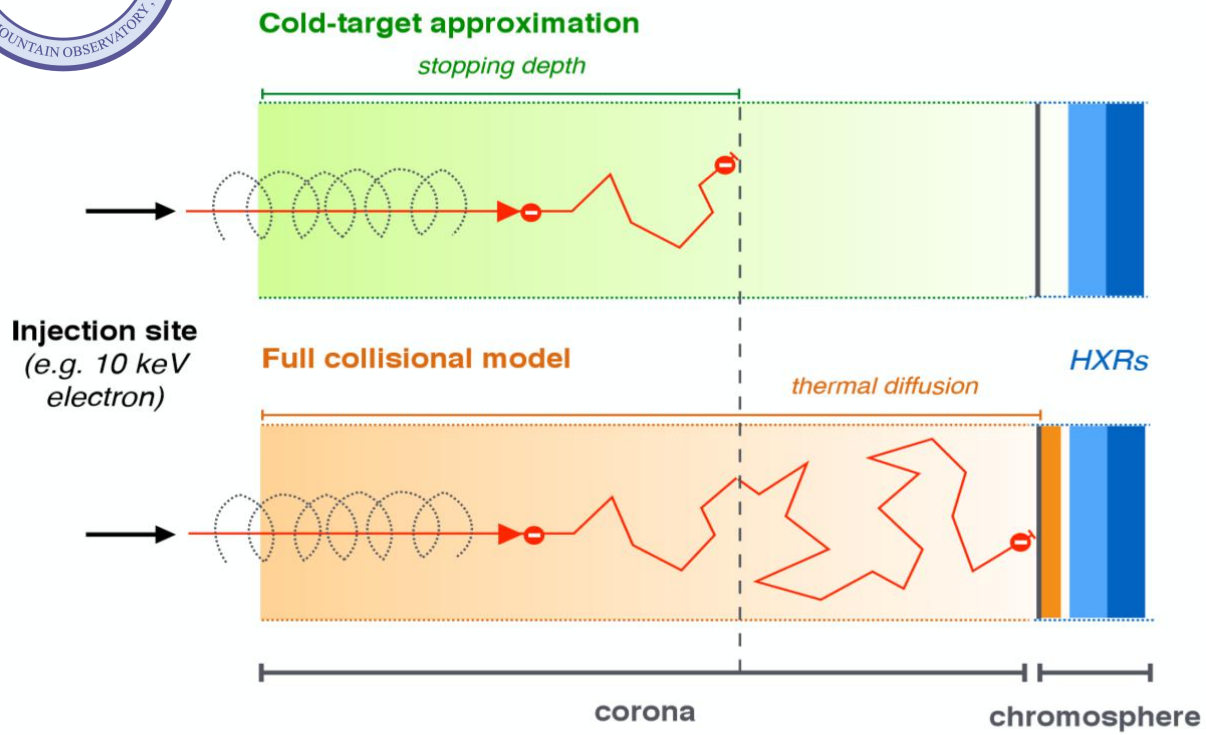
Effects of low- and high- energy cutoffs

Xia et al. 2021



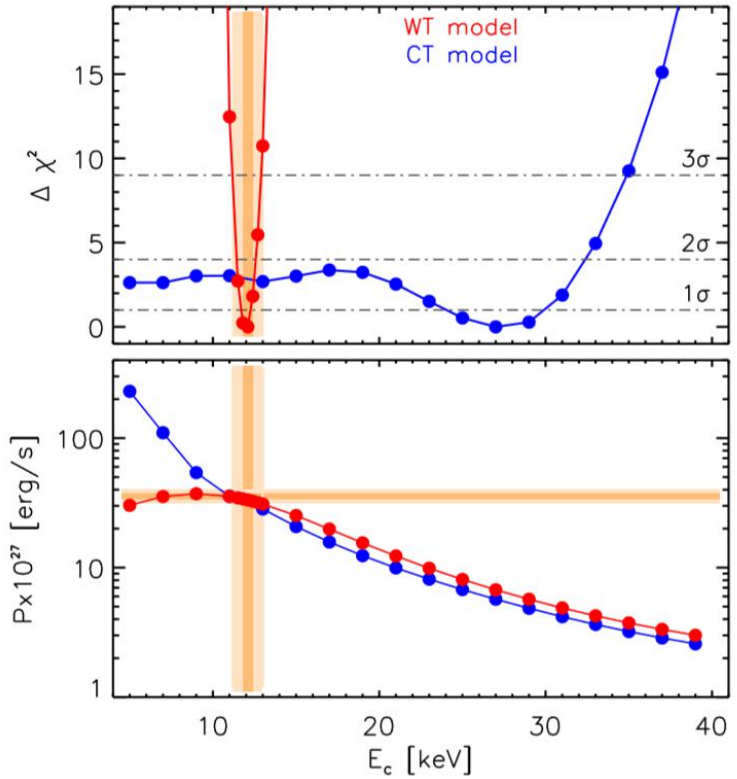
- Low-energy cutoff (Holman et al., 2003, 2011)
  - Important parameters for determining **electron number and energy**
  - Important for understanding **spectral shape**
- High-energy cutoff
  - important for **spectral shape** at high energies
  - important for understanding **polarization (Jeffrey et al. 2020)**

Do low-energy cutoffs really exist?



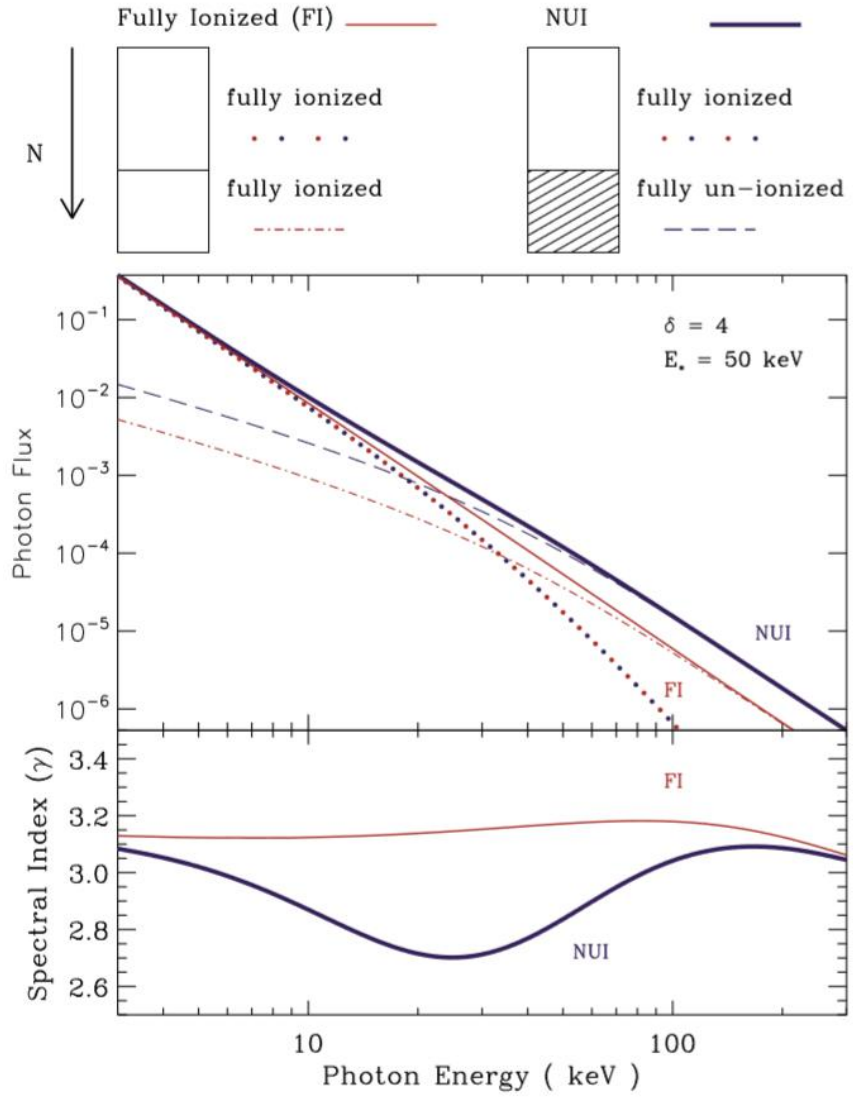
Emslie et al. 2003

Note: when the low-energy cutoff in the injected distribution Ec is larger than the energy $\sqrt{2KnL}$ that can be effectively stopped within the coronal part of the loop, the contribution ΔEM of the thermal component becomes negligible and the cold-target approximation is recovered.



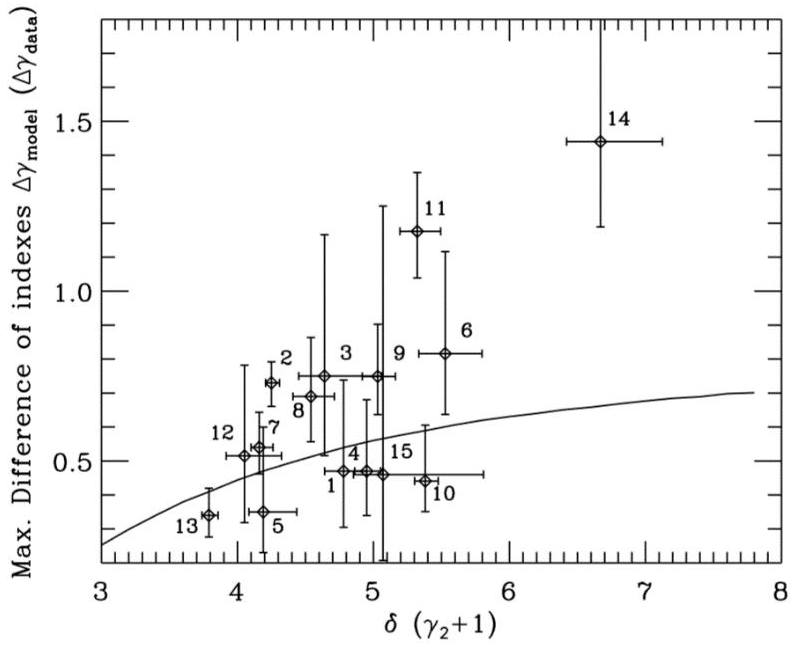
Kontar et al. 2019

The **warm-target model** can be used to obtain a lower estimate for the low-energy cutoff



Su. 2010

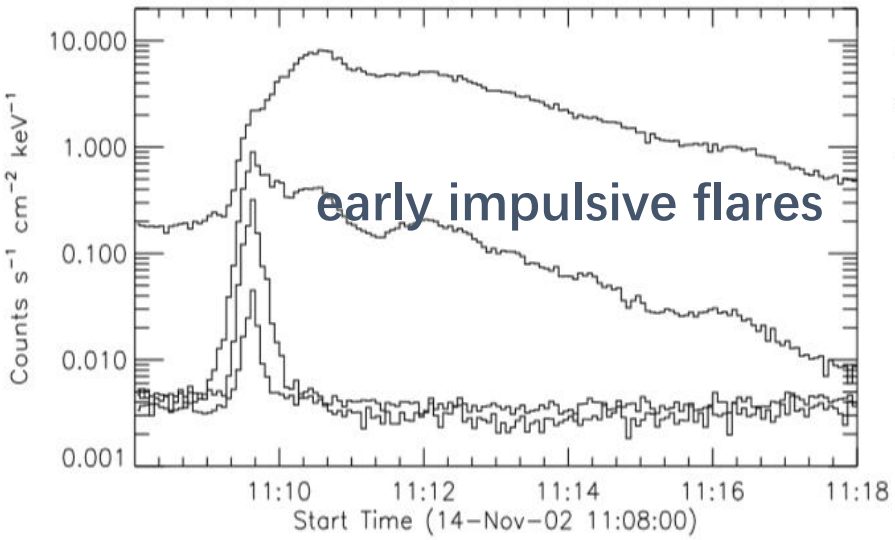
nonuniform target ionization:

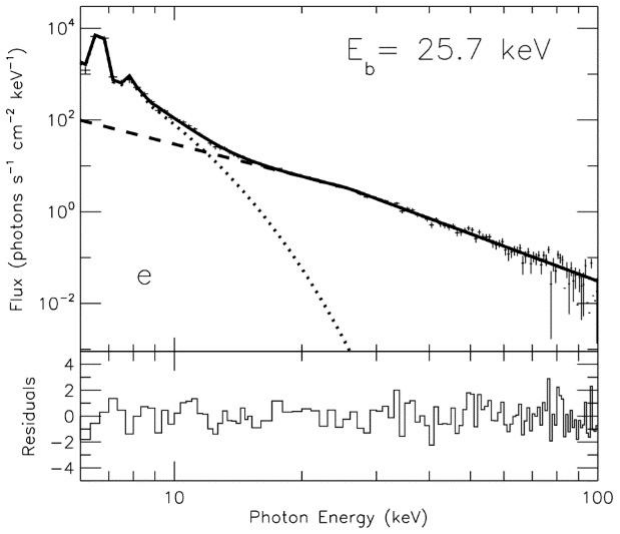


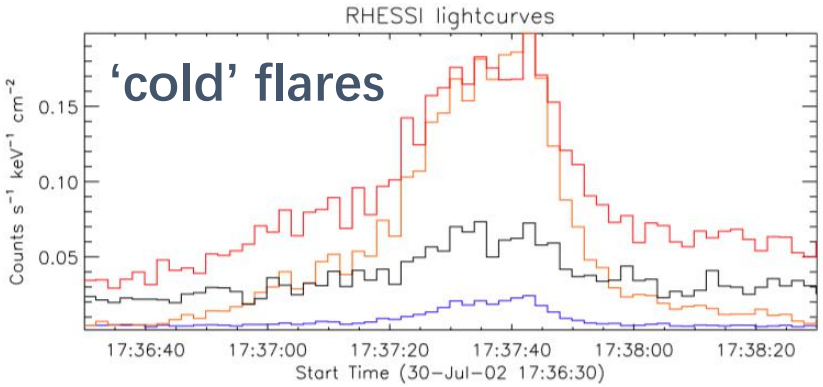
Su et al. 2009

15 flares with broken spectra, 6 have $\Delta\gamma$ over theoretical limits.

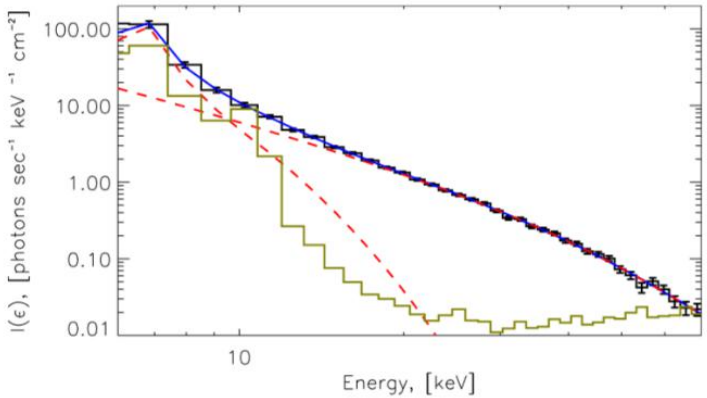
Evidence of low-energy cutoffs

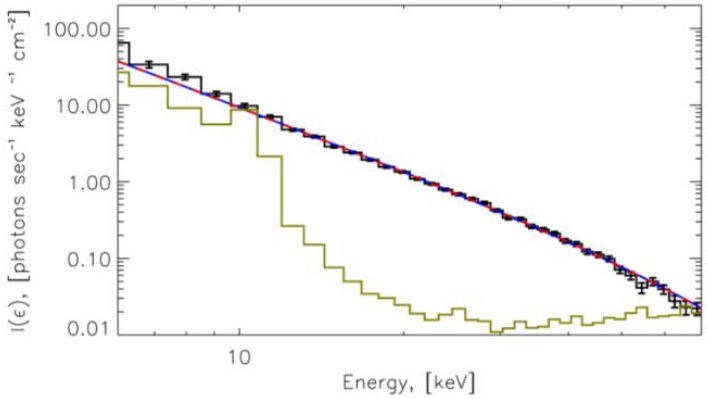


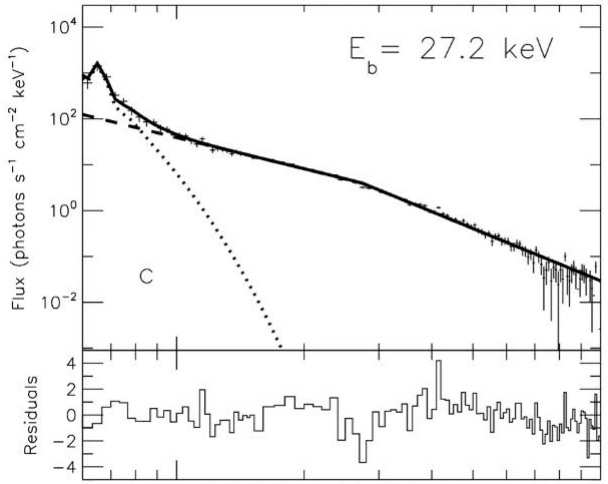




Fleishman et al. 2011







Sui et al. 2007

20-40kev

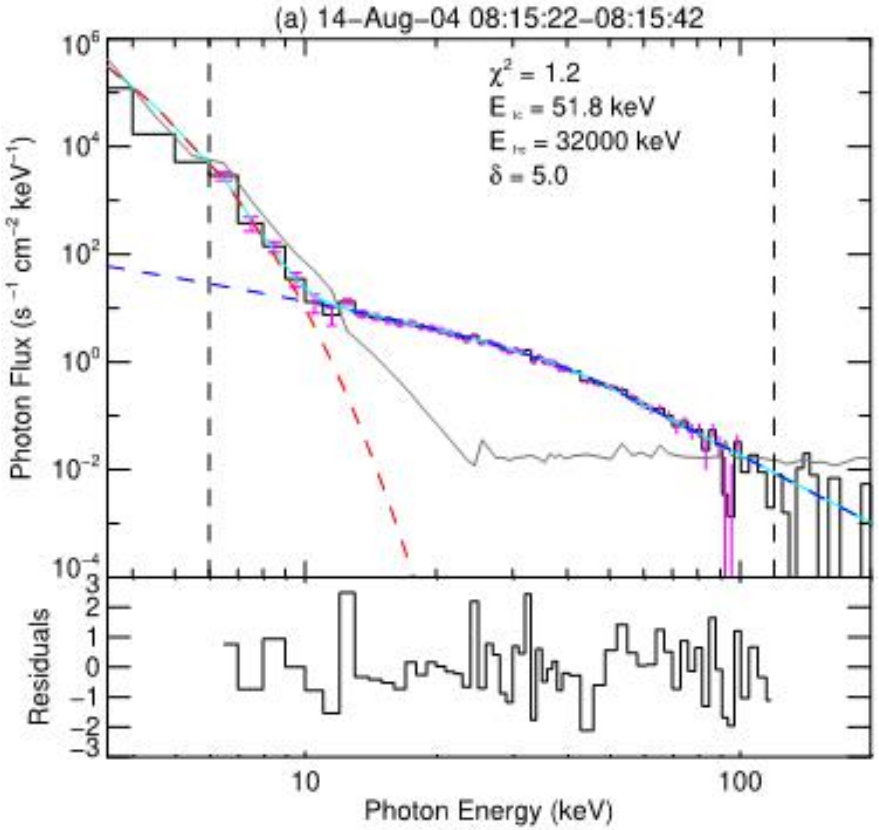
E_b without Albedo (keV)	E_b with Albedo (keV)	E_{Cutoff} (keV)	Albedo Causes Spectral Flattening
8–40	11–52	20–49	Unlikely
12–43	16–43	27–42	Unlikely
10–27	16–37	18–38	Unlikely
16–34	21–34	20–29	Unlikely
18–29	18–37	14–33	Unlikely
9–27	N/A	N/A	Likely
10–31	N/A	N/A	Likely
20–47	N/A	N/A	Likely
17–37	15–37	18–40	Unlikely

Our approach

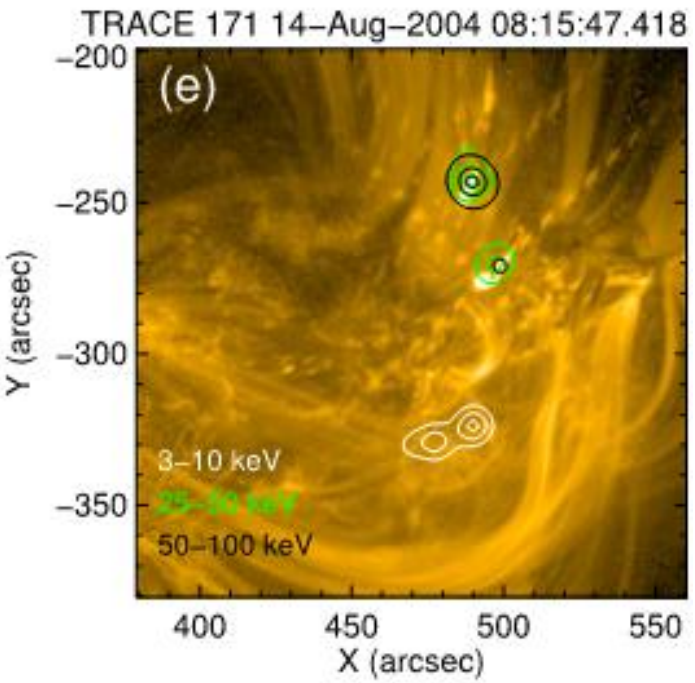
- Try to avoid effect of thermal emission
- We search for **full spectral signature** (spectral flattening can be caused by many other processes.)
- We search for **acceleration-related cutoffs**
- Try to avoid CME-related eruptive events (focus on **flare-related acceleration**)
- Search for consistent evidence in SEP electron data
  - **X-ray photon spectra**: downward injected energetic electrons
  - **SEP electron distribution**: escaped energetic electrons

The results: Late Impulsive Bursts

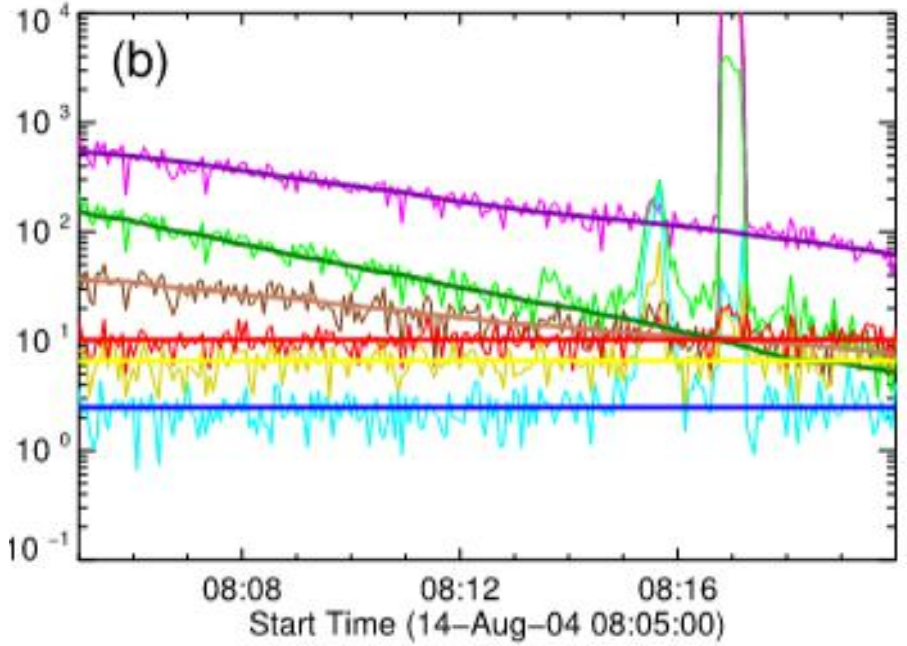
OSPEX fit results:



imaging:



light curves and background selection (important):



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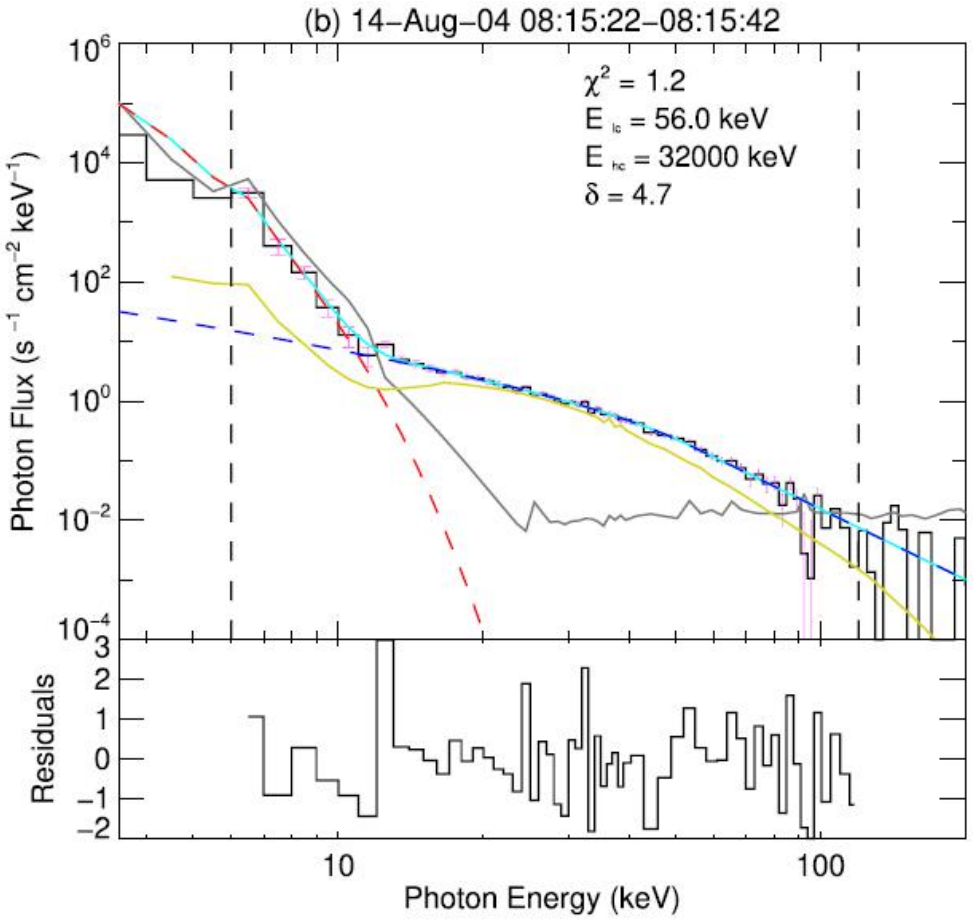
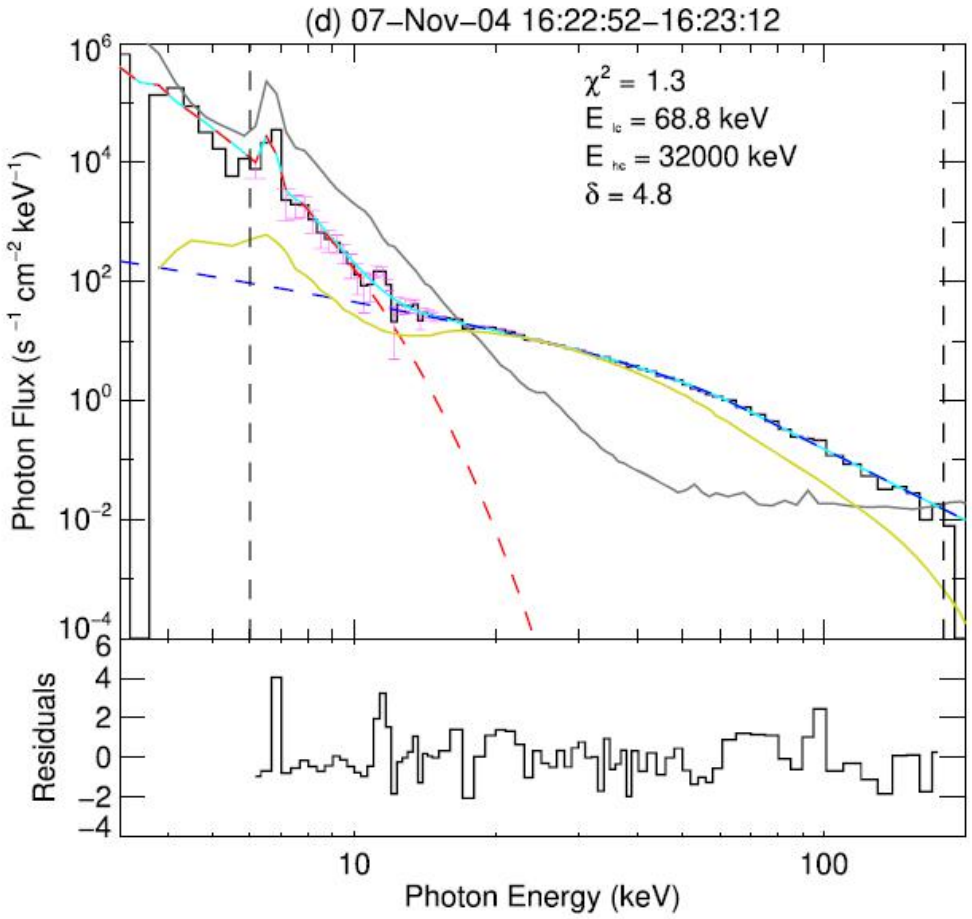
We observed the full spectral signature of low-energy cutoff that cannot be easily explained by other processes rather than the acceleration itself.

The results: Late Impulsive Bursts

with albedo correction





The results: Late Impulsive Bursts

Flare index	Date	GOES Class	Peak Time (UT)	Late Peak Time (UT)	E_{lc1} (keV)	E_{lc2} (keV)	E_{lc3} (keV)	Lower E_{hc} (keV)	δ_2	δ_3	Nonthermal Energy (erg)
1	2002 Aug 20	M5.0	01:40	02:08	49.0(±2.6)	53.9(±3.8)	11.6(±20.5)	197.7(±22.4)	4.50	2.67	$>2.76 \times 10^{30}$
2	2002 Sep 8	M1.5	01:43	01:46	38.6(±3.3)	35.3(±3.4)	18.8(±21.0)	371.2(±91.2)	3.71	3.14	2.99×10^{29}
3	2003 Oct 24	M7.6	02:54	06:05	31.6(±1.6)	32.8(±2.4)	29.0(±3.4)	234.8(±61.9)	4.62	4.24	3.29×10^{29}
4	2004 Aug 14	M7.4	05:44	06:32	36.6(±4.8)	37.7(±6.4)	24.8(±14.5)	117.5(±43.1)	5.07	3.30	8.55×10^{27}
5	2004 Aug 14	M2.3	07:56	08:15	51.8(±2.7)	56.0(±4.1)	45.1(±7.4)	195.8(±44.4)	4.73	3.23	2.99×10^{28}
6	2004 Nov 7	X2.0	16:06	16:21	58.1(±1.1)	68.8(±2.0)	60.5(±2.7)	334.6(±57.3)	4.76	3.95	$>1.02 \times 10^{29}$
7	2005 Jan 20	X7.1	07:01	15:19	42.0(±4.3)	42.2(±4.4)	…	…	4.96	…	2.08×10^{28}
8	2005 Nov 19	C1.5	20:19	20:35	40.6(±4.0)	34.3(±4.9)	29.3(±6.3)	173.4(±107.9)	4.48	3.67	8.48×10^{27}
9	2006 Dec 6	X6.5	18:47	19:18	89.0(±4.4)	107.1(±7.1)	41.1(±24.8)	623.5(±163.7)	3.78	2.28	1.25×10^{29}
10	2011 Feb 15	X2.2	01:56	03:19	31.1(±4.4)	27.7(±6.0)	…	…	3.89	…	2.20×10^{28}
11	2011 Feb 24	M3.5	07:35	07:52	53.8(±15.7)	54.5(±16.1)	52.7(±20.0)	360.4(±2125)	4.11	3.70	$>1.49 \times 10^{28}$
12	2015 Apr 16	C5.7	09:07	09:17	34.2(±6.2)	35.0(±8.9)	…	…	4.06	…	4.12×10^{29}
1	2003 Oct 23	M2.4	02:41	…	27.2(±1.5)	25.9(±2.2)	23.4(±3.2)	264.0(±71.4)	4.58	4.35	$>3.05 \times 10^{30}$
2	2012 Nov 18	C5.7	04:07	…	46.3(±5.5)	46.8(±7.0)	43.2(±9.8)	220.8(±91.6)	4.48	3.74	7.54×10^{28}

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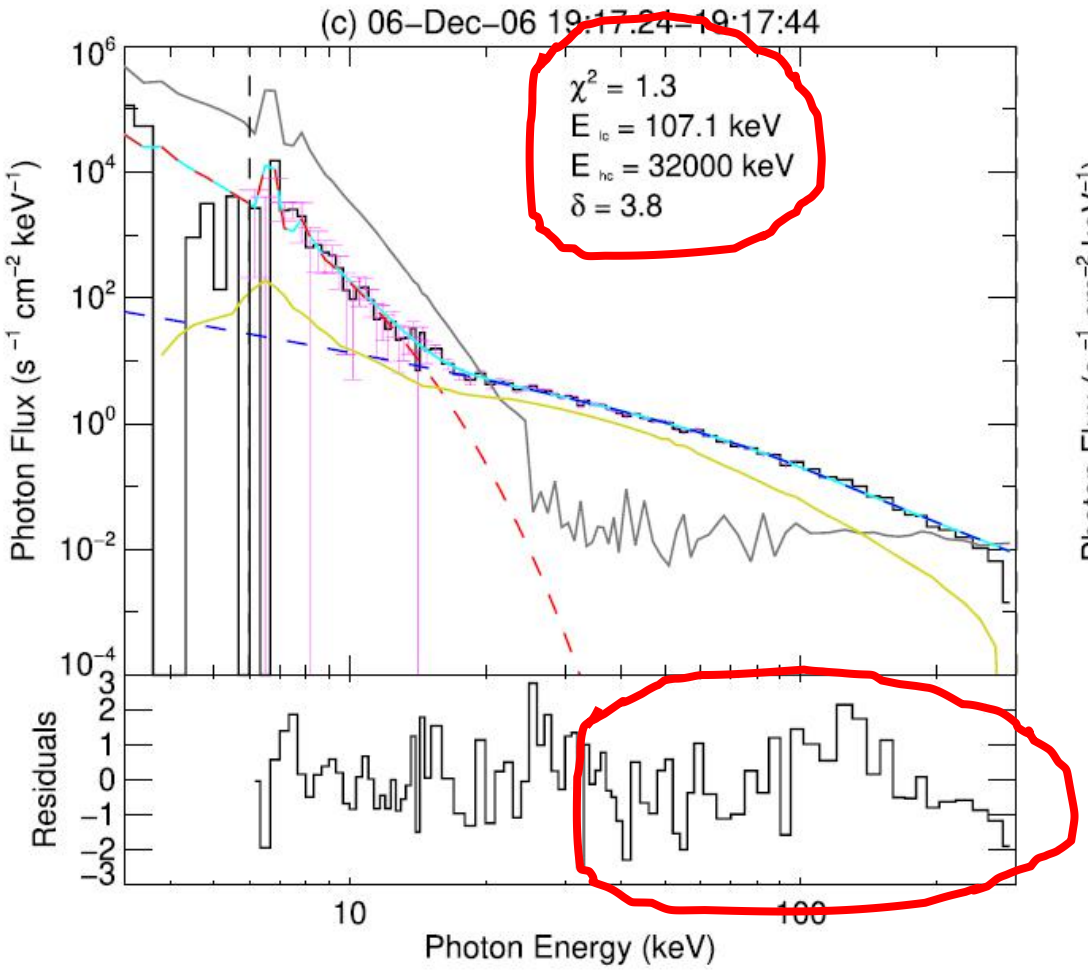
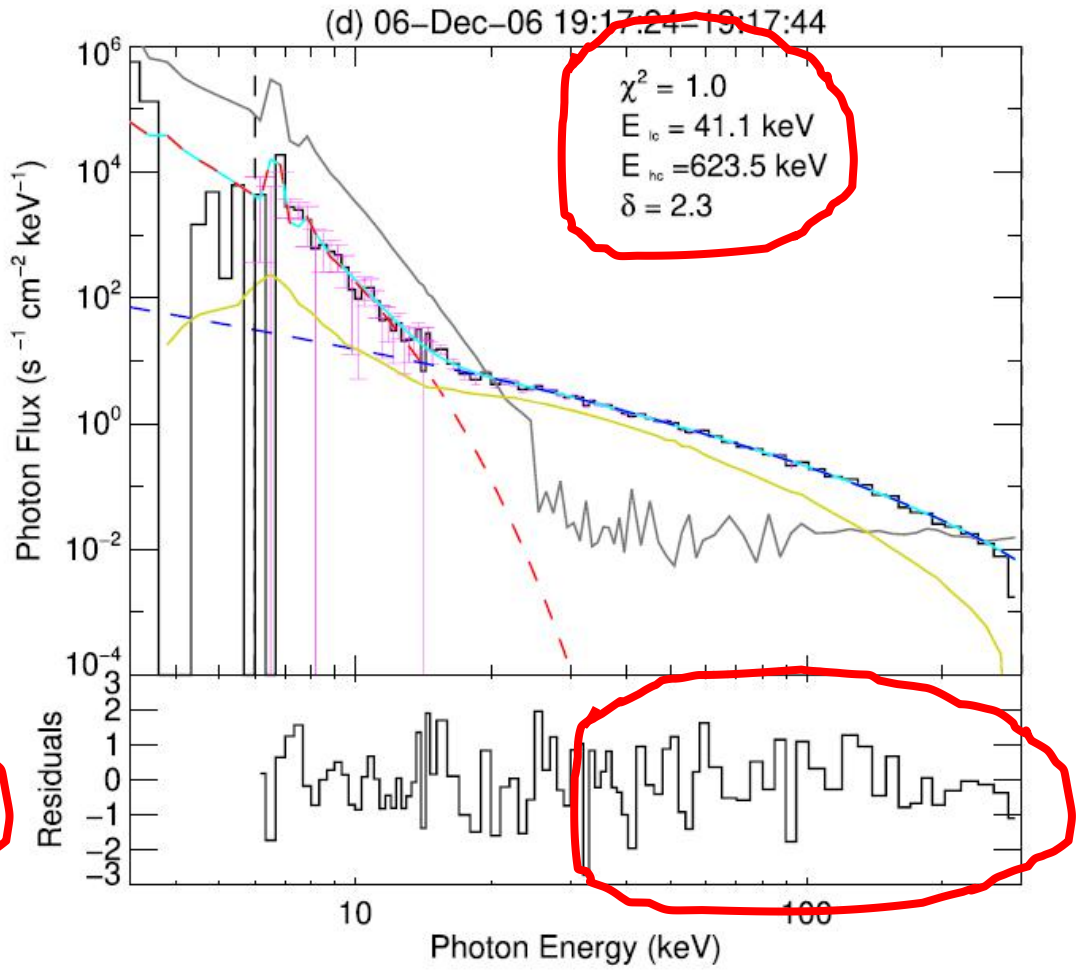
The albedo effects have small impacts on these low-energy cutoffs

The high-energy cutoff is also important (but rarely studied)

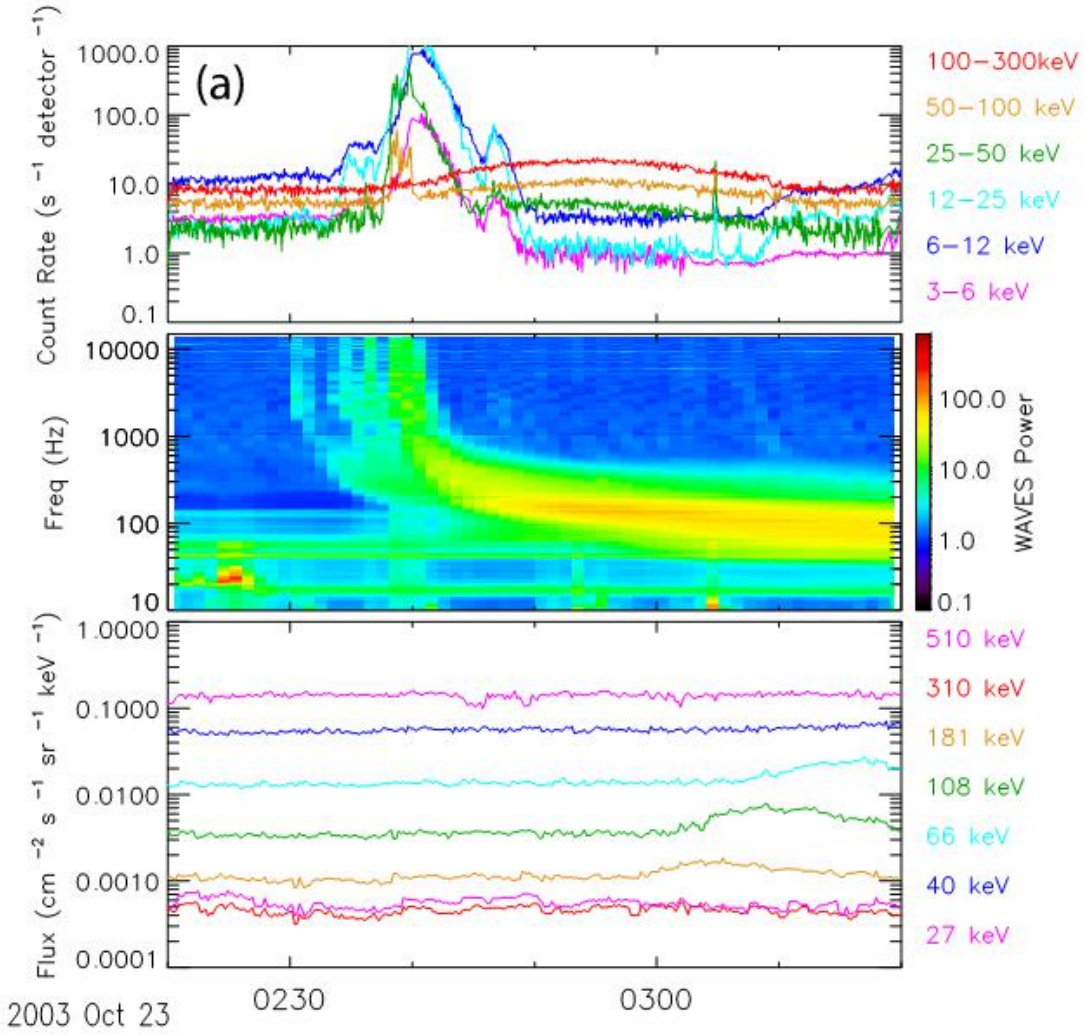
Without effect of high-energy cutoff



With effect of high-energy cutoff



The results: SEP events



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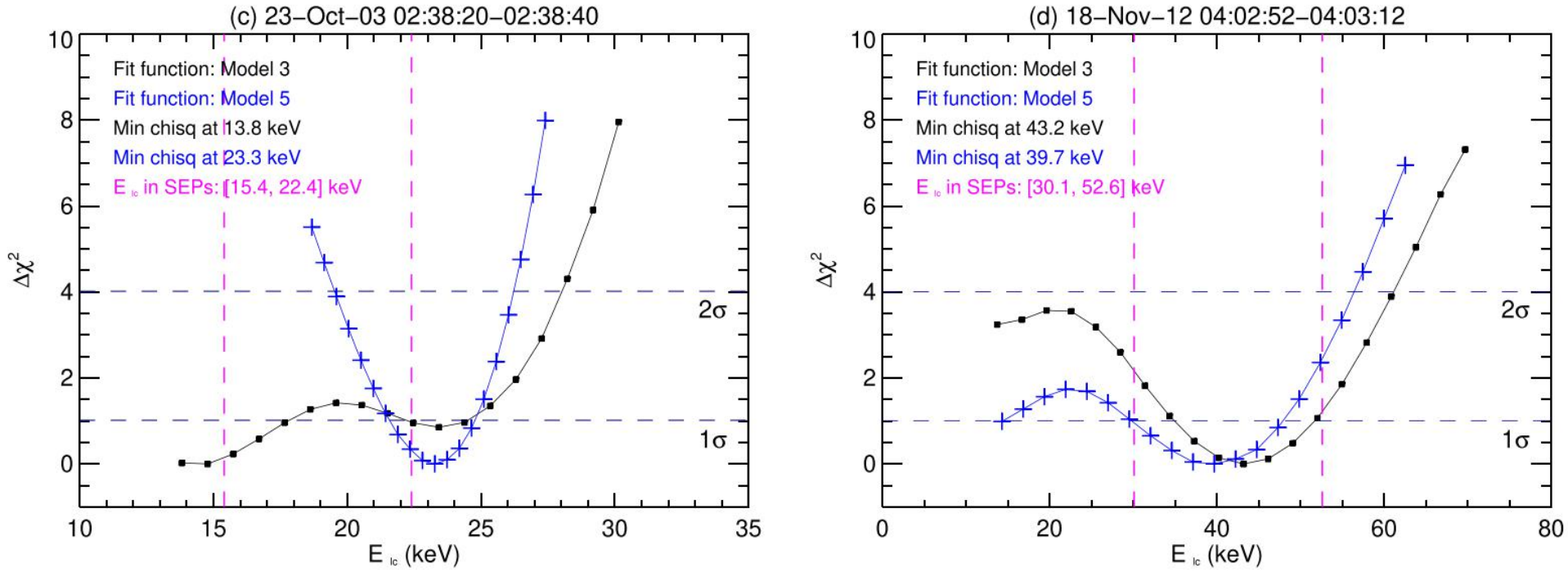
The two events we selected:

- Show nearly no enhancement in electron flux below 27 keV.
- Accompanied by flares that have flattened HXR spectra.

The results: SEP events



We found that the lower and upper cutoff energies of these two electron populations (injected and escaped from the same acceleration process) are consistent.

Thank you!