Gamma-ray emission from solar flares

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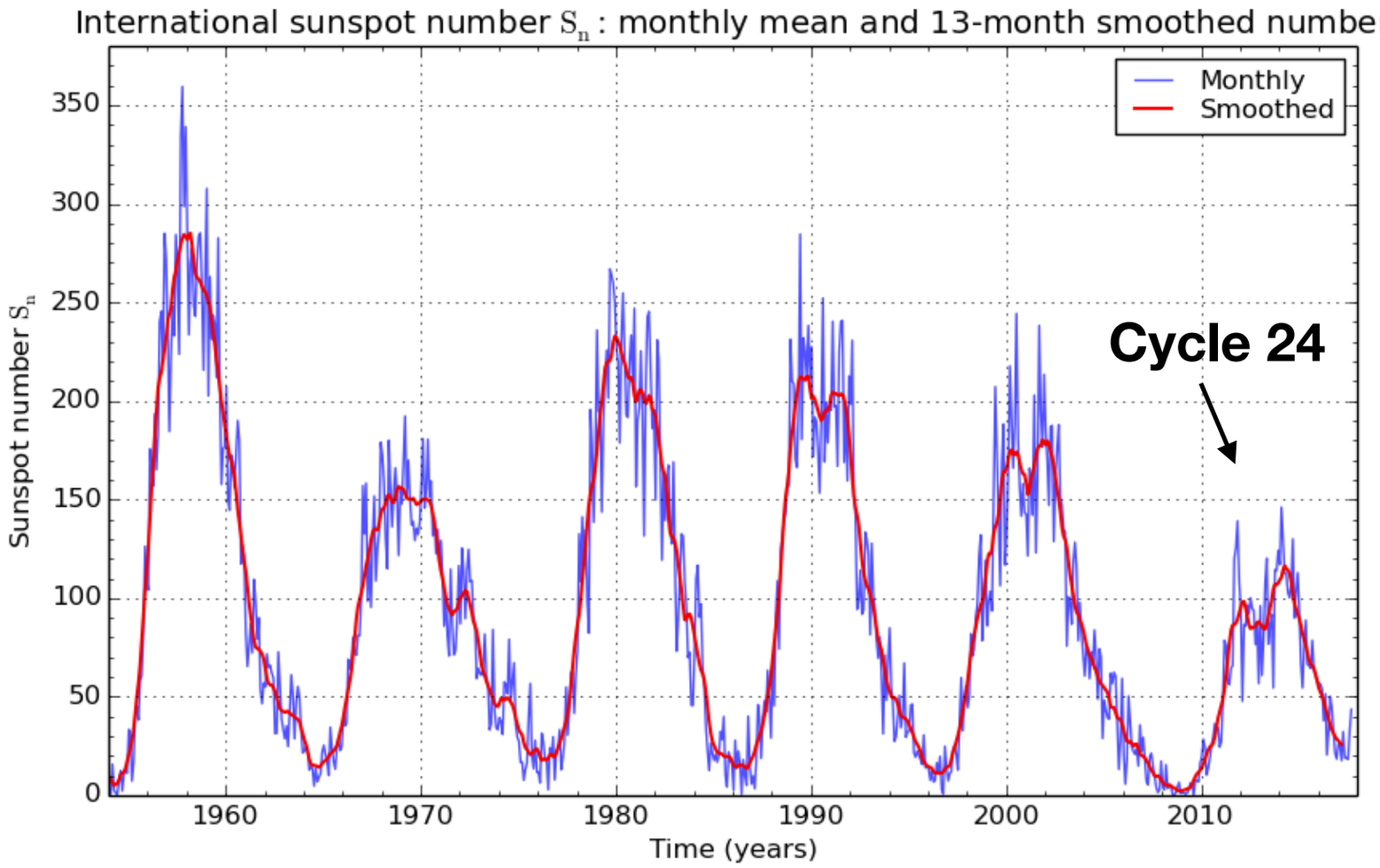
2nd e-ASTROGAM Workshop - Munich - October 13th 2017

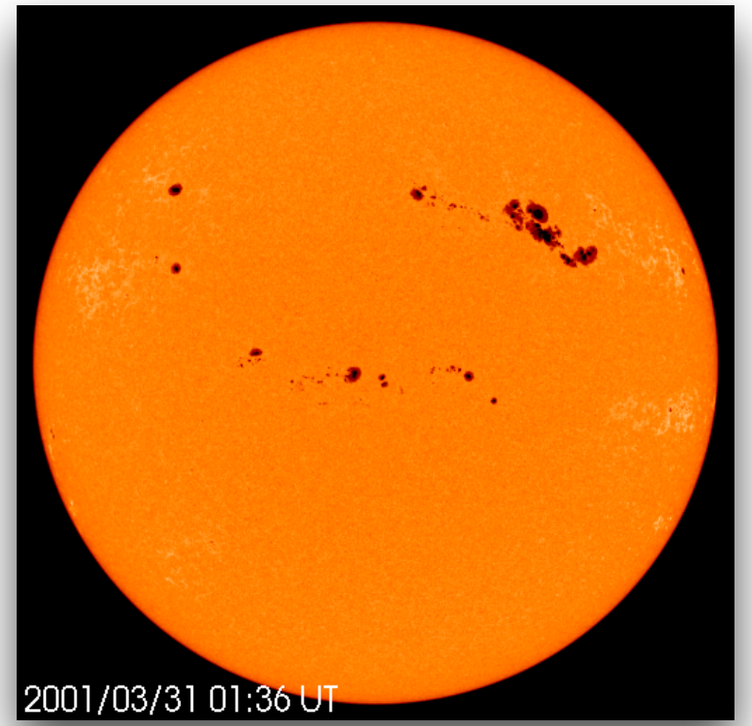
**Speaker*

Solar flares

flashes of light with time scales of minutes to hours,
releasing up to $10^{32\text{-}33}$ ergs.

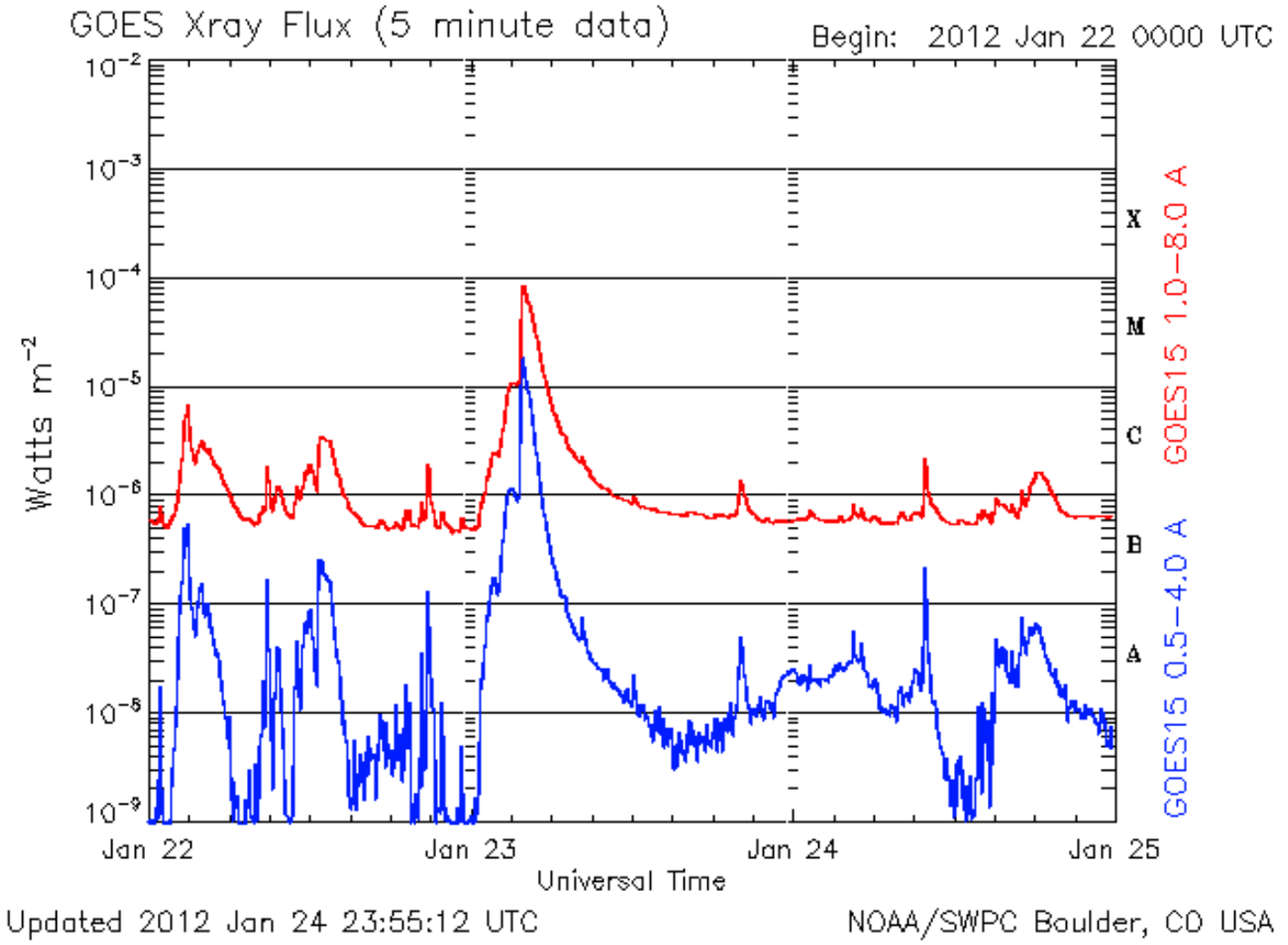
Their <u>frequency</u> is modulated by
the <u>11-year solar cycle</u>





Solar flare classification

Class	Flux (peak) 0.1-0.8 nm [W/m²]
A	10^{-8}-10^{-7}
B	10^{-7}-10^{-6}
C	10^{-6}-10^{-5}
M	10^{-5}-10^{-4}
X	$>10^{-4}$



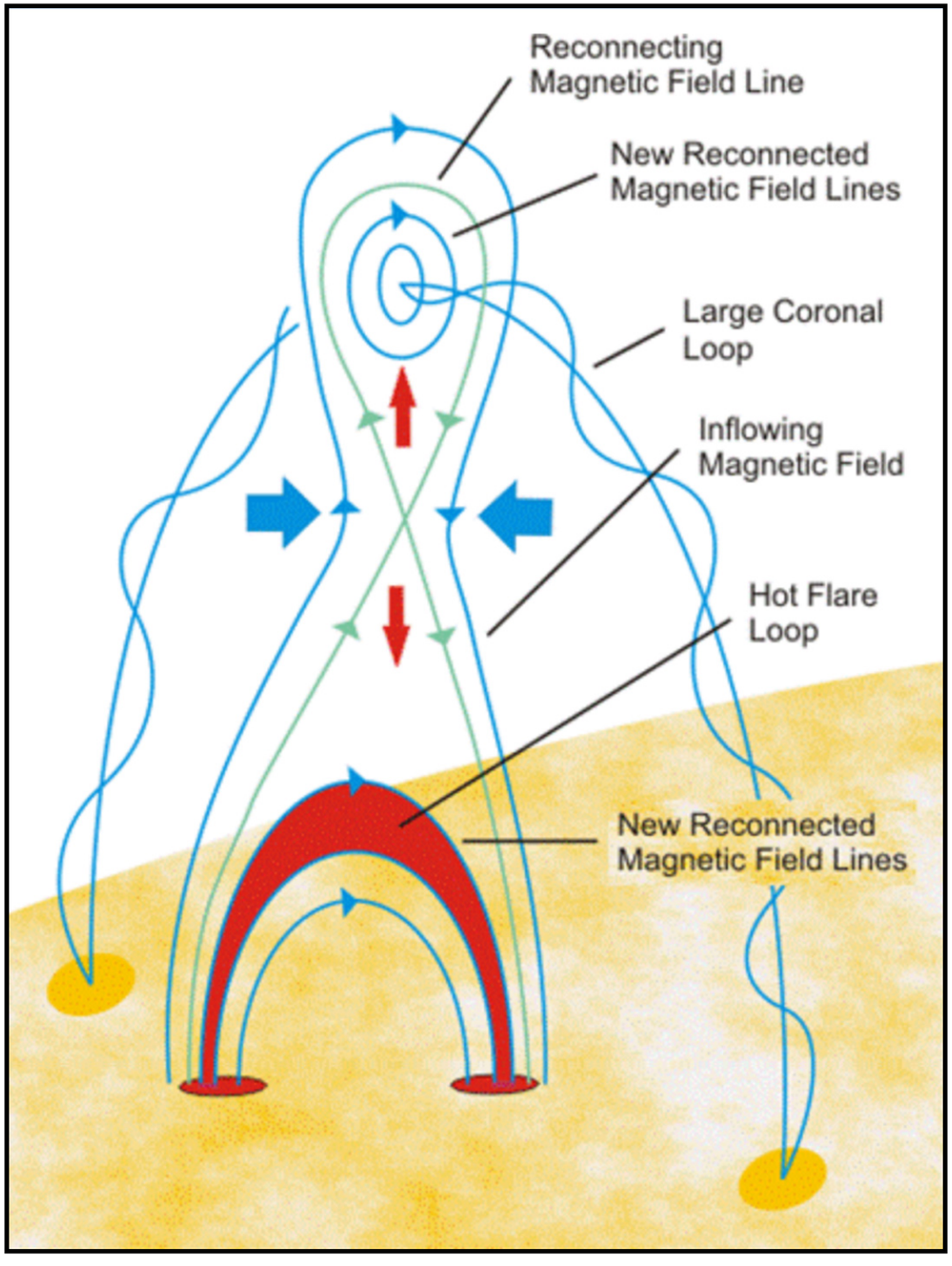
Standard model of solar flares

Model proposed by
Kopp and Pneuman
(1976)

Fundamental ingredients
for energy release:

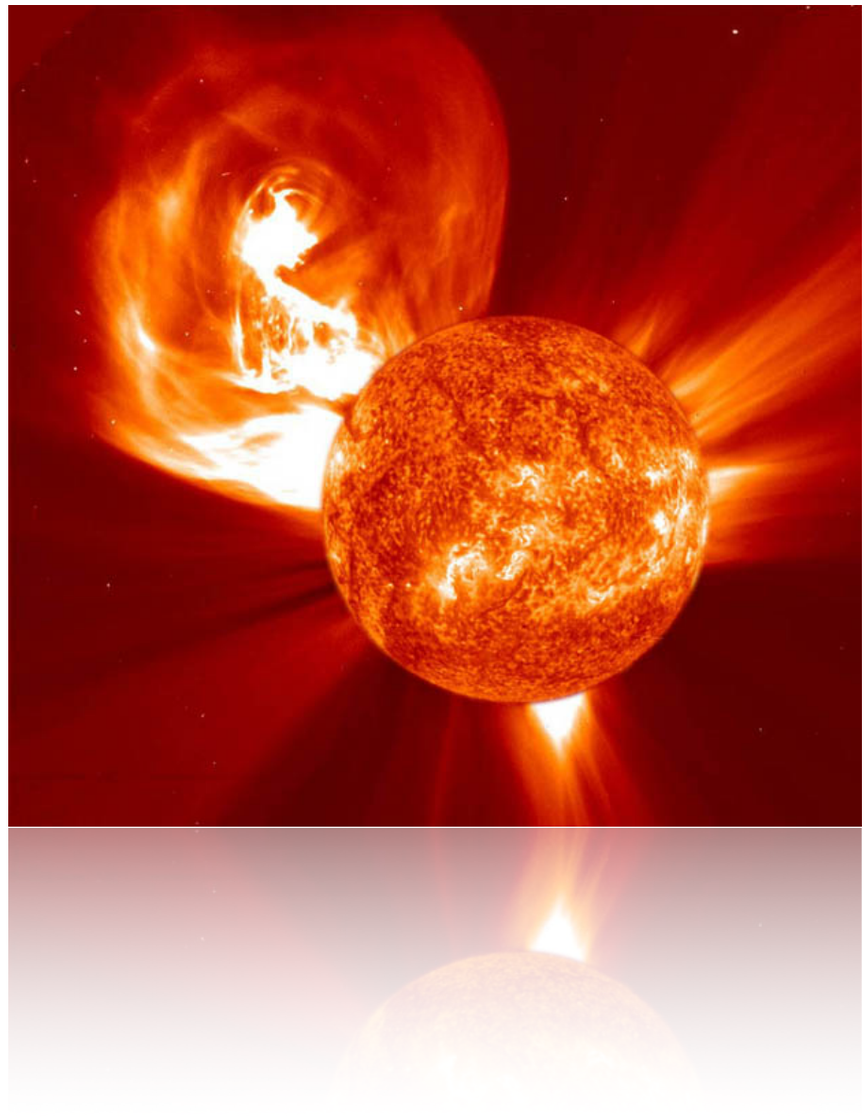
- reconnecting magnetic field lines
- accelerated particles

Emission over a very wide range of energies: soft and hard X- rays, radio



Open questions and main motivations

-Trigger of the magnetic instability
-Acceleration mechanisms
-Association with Coronal Mass Ejections (CMEs) and Solar Energetic Particles (SEPs)



- Understanding the fundamental physics of the phenomenon
- Laboratory on smaller scale of phenomena like stellar flares
- Space weather

Gamma-ray emission

Accelerated electrons mainly responsible for X-ray (and radio) emission

Some gamma radiation mechanisms

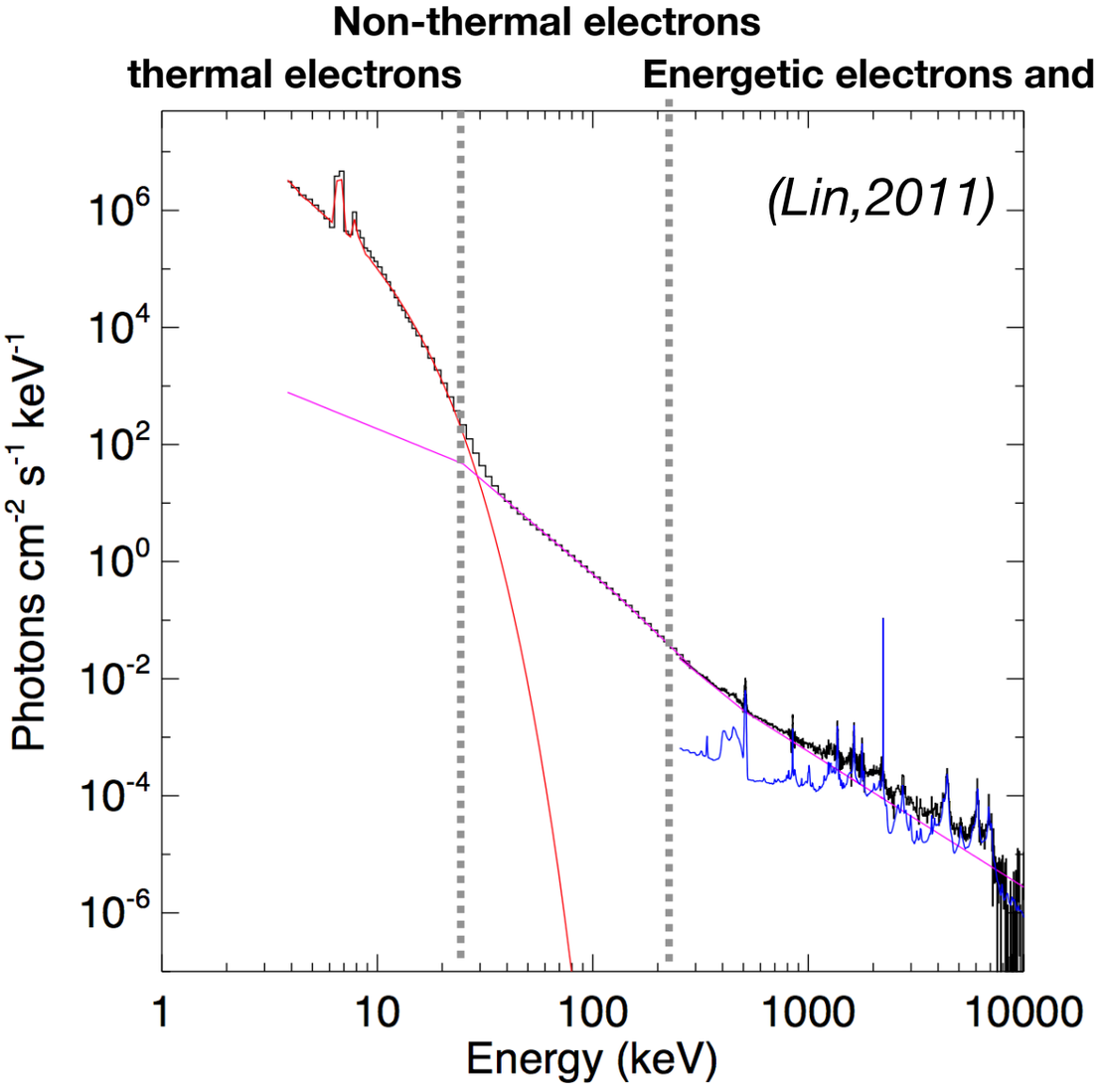
Nuclear de-excitation lines (e.g. 4.428 MeV, 6.129 MeV)

Neutron capture line (2.223 MeV)

Positron annihilation (0.511 MeV)

Neutral meson decay (peak at 67.5 MeV)

Electron bremmsstrahlung



Experimental results
from different experiments:
SMM and EGRET, (in the past)
RHESSI, Fermi

Some events from Fermi

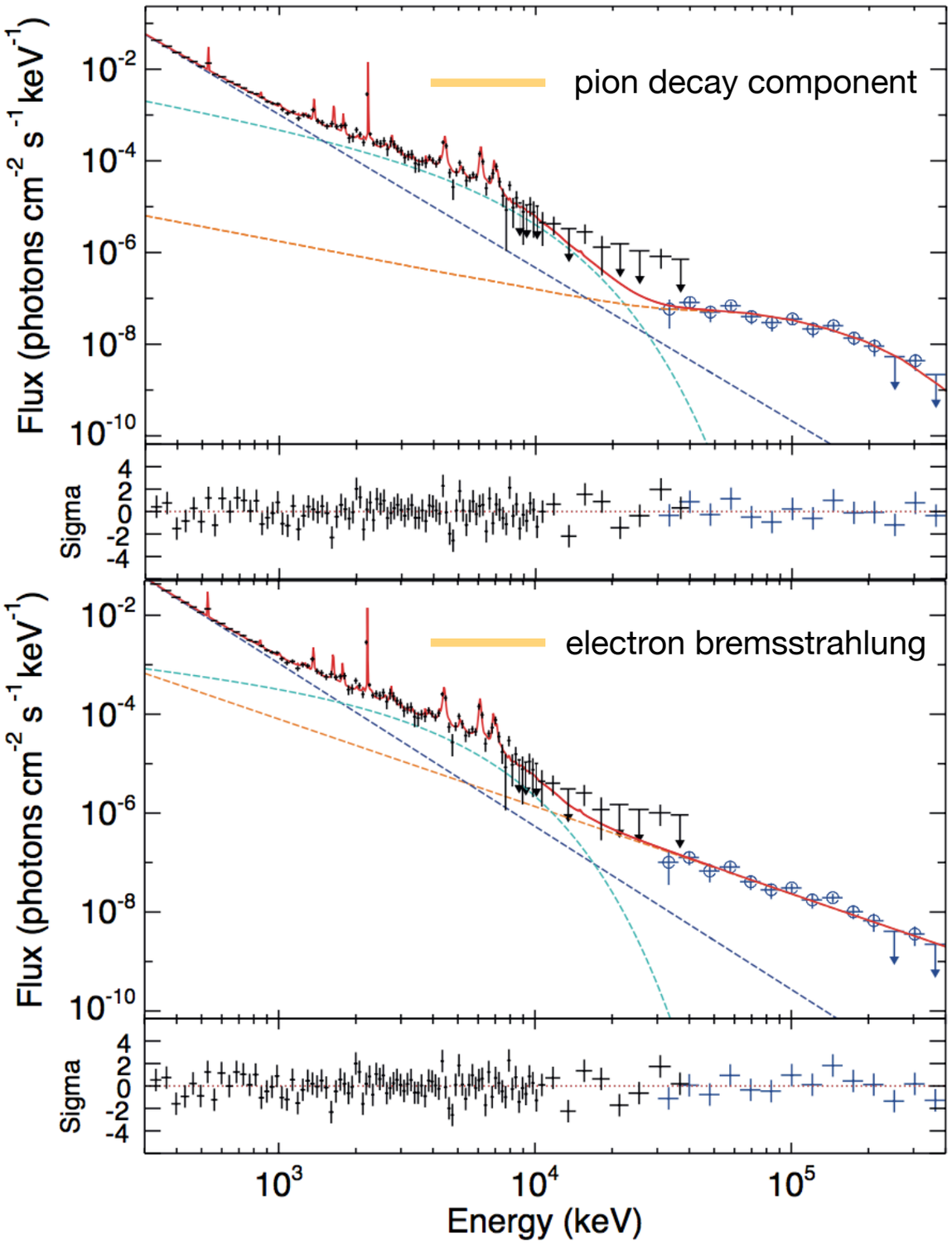
TABLE 1
SOLAR FLARES DETECTED BY *Fermi* LAT FROM 2008 AUGUST TO 2012 AUGUST.

Date (UT)	Duration min.	GOES X-ray Class, Start–End	CME† Speed, km s^{-1}	TS	Type	Flux (>100 MeV $\times 10^{-5}$ ph cm^{-2} s
2010-06-12 00:55	∼1	M2.0, 00:30–01:02	486	LLE*	I	(–)
2011-03-07 20:15	25	M3.7, 19:43–20:58	2125	230	I/S	(1.9± 0.3)
23:26	36			520	S	(3.5± 0.3)
2011-03-08 02:38	35			450	S	(3.5± 0.3)
05:49	35			200	S	(1.9± 0.3)
2011-06-02 09:43	45	C2.7,9:42–9:50	976	35	I/S	(0.4±0.2)
2011-06-07 07:47	53	M2.5, 06:16–06:59	1255	570	S	(3.6 ± 0.3)
2011-08-04 04:59	34	M9.3, 03:41–04:04	1315	390	S	(2.5 ± 0.3)
2011-08-09 08:01	$\lesssim 1$	X6.9, 07:48–08:08	1610	LLE*	I	(–)
2011-09-06 22:17	$\lesssim 1$	X2.1, 22:12–22:24	575	LLE*	I	(–)
2011-09-06 22:13	35			2600	I/S	‡
2011-09-07 23:36	63	X1.8, 22:32–22:44	792	350	S	(1.0 ± 0.1)
2011-09-24 09:35	∼1	X1.9, 09:21-09:48	1936	LLE*	I	(–)
2012-01-23 04:07	51	M8.7, 03:38–04:34	1953	180	I/S	(0.8 ± 0.1)
05:25	69			650	S	(2.1±0.2)
07:26	16			69	S	(3.7±0.9)
08:47	35			97	S	(2.6±0.5)
2012-01-27 19:45	11	X1.7, 17:37–18:56	1930	78	D	(3.2±0.8)
21:13	24			47	S	(1.0±0.3)
2012-03-05 04:12	49	X1.1, 02:30–04:43	1602	69	I/S	(0.5±0.1)
05:26	71			250	S	(0.9±0.1)
07:23	28			39	S	(0.8±0.2)
2012-03-07 00:46	31	X5.4, 00:02–00:40	1785	22000	S	‡
		X1.3, 01:05–01:23			I/S	
2012-03-07 03:56	32			16000	S	(113.1±2.0)
07:07	32			8900	S	(71.9±1.6)
10:18	32			1900	S	(30.1±1.5)
13:29	32			120	S	(8.9±1.9)
19:51	25			50	S	(0.4±0.1)
2012-03-09 05:17	34	M6.3, 03:22–04:18	844	51	D	(0.6±0.2)
06:52	35			100	S	(0.9±0.2)
08:28	34			159	S	(1.4±0.2)
2012-03-10 21:05	30	M8.4, 17:15–18:30	1379	43	D	(0.4±0.1)
2012-05-17 02:18	22	M5.1, 01:25–02:14	1582	45	I/S	(1.0±0.3)
2012-06-03 17:52:33	∼1	M3.3, 17:48–17:57	605	LLE*	I	(–)
17:40	23			300	I/S	(3.2±0.4)
2012-06-14 14:48	49	M1.9,12:52–15:56	987	49	I/S	(1.1±0.3)
2012-07-06 23:19	52	X1.1,23:15–23:49	892	930	I/S	(3.5±0.2)

† CME data are available at the following url: http://cdaw.gsfc.nasa.gov/CME_list/
‡ The flux estimate is unreliable because of X-ray pile-up in the ACD.
⋆ LLE detections are >30 MeV while TS values are calculated for >100 MeV.

(The Astrophysical Journal, 787:15 (13pp), 2014)

ArXiv1111.7026



Measurements with e-ASTROGAM

Solar flares in the MeV-GeV domain!

-Temporal evolution	Distinguishing between short and long duration events, comparison with emission in different wavelengths
-Energy spectrum	Optimal sensitivity and energy resolution to detect the de-excitations lines, distinguish between leptonic and hadronic origin of the emission.
-Polarization	Possibility of a detailed study. New! In the past: gamma-ray polarimetry studied by RHESSI, but only for two solar flares.
-Source localization	Not in details, but interesting to see for constraining emission and acceleration processes (0.2° at 1 GeV, a factor 4 better than Fermi)

Interesting to complement information from dedicated experiments!

Interesting multiwavelength and multimessenger observations!