Solar flare measurements with STIX and MiSolFA

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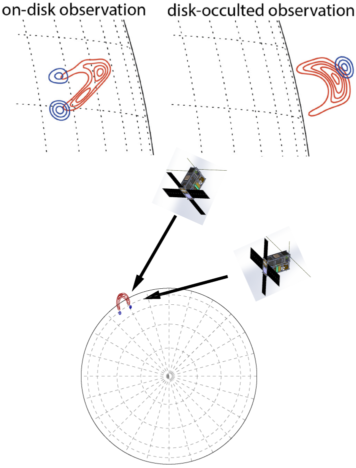
29 July 2016

15-th RHESSI Workshop

Contents

Stereo observations of solar flares

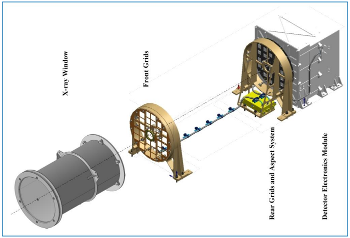
- Energy spectrum of footpoint and coronal sources
  - By looking at flares with occulted footpoints for one instrument
  - This overcomes an intrinsic limitation of indirect imaging
- Directivity of the same source as a function of the energy
  - This can be related to the electron anisotropy
- STIX and MiSolFA at next solar maximum
  - Good cross-calibration of the energy measurement is mandatory

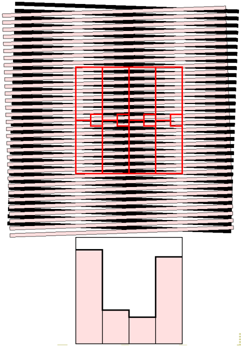


Simultaneous measurement of coronal and footpoint sources

STIX

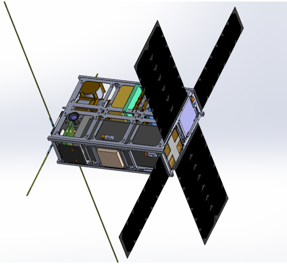
- Spectrometer Telescope for Imaging X-rays (STIX) is on the ESA/NASA Solar Orbiter mission
  - Orbiting close to the Sun ($\sim$ 0.3 au) with high inclination ($\sim 25^\circ$) during the next solar maximum
  - To be launched in Oct 2018
- Indirect imaging based on the moiré effect: 30 pairs of tungsten grids
  - 10 directions (20° steps)
  - 10 angular scales (7–180 arcsec)
- Photon detectors: Caliste-SO units developed by CEA Saclay
  - Better than 1 keV FWHM at 60 keV

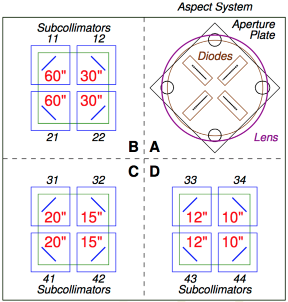




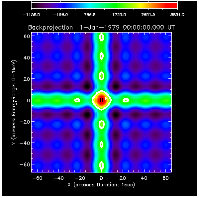
MiSolFA

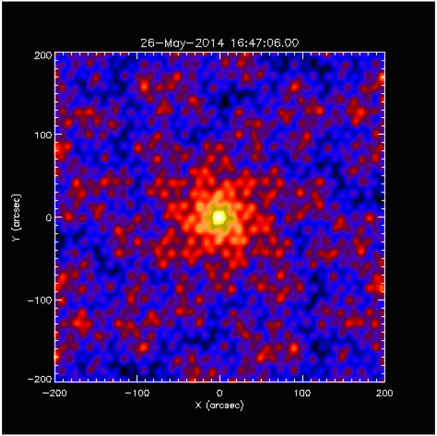
- Micro Solar-Flare Apparatus (MiSolFA) will complement STIX observations
  - Smallest moiré imager (financed by SNF)
  - Angular range: 10–60 arcsec
- 6U nanosatellite to be launched by the Italian Space Agency
  - Near-Earth polar orbit
  - 2–3 years overlap with STIX at solar max
  - Platform developed by IMT Rome
- Imaging spectroscopy with the same photon detectors used by STIX
  - Energy range: 10–150 keV
  - Special attention paid to energy cross-calibration





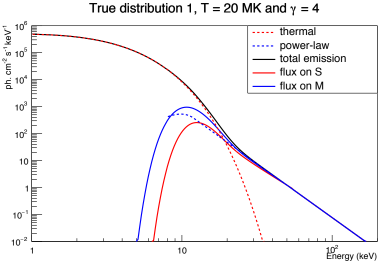
Quick comparison: imaging





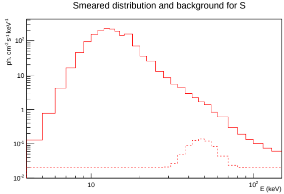
Backprojection reconstruction of a point-source for MiSolFA (left) and STIX (right)

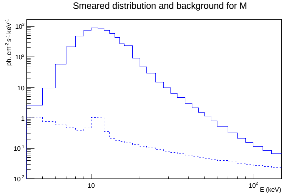
Quick comparison: spectroscopy

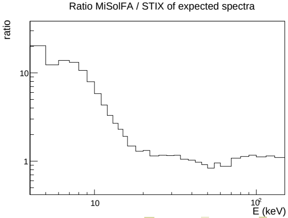


Same toy source viewed by STIX (S) and MiSolFA (M) with

- different attenuation
- different resolution
- different background
- same energy binning





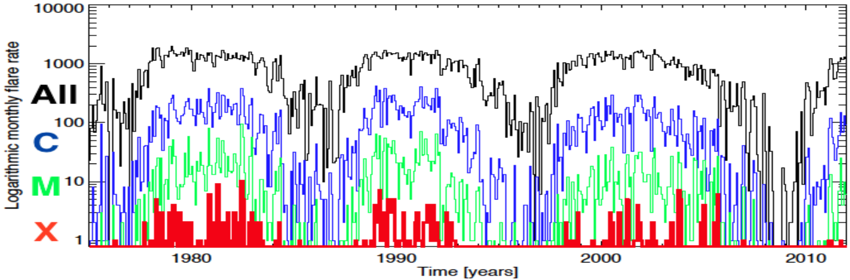


Expected non-thermal counts

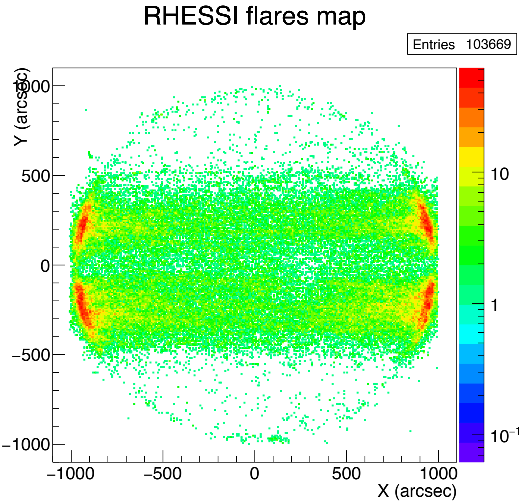
E bin	MiSolFA counts/min				Relative uncertainty			
(keV)	M1	M3	M5	X1	M1	M3	M5	X1
28–31	64				0.13			
31–34	43				0.15			
34–38	38	242			0.16	0.06		
38–42	25	159	402	1021	0.20	0.08	0.05	0.03
42–46	17	108	274	696	0.24	0.10	0.06	0.04
46–50	12	76	192	488	0.29	0.11	0.07	0.05
50–55	11	68	171	435	0.31	0.12	0.08	0.05
55–60	7	46	118	298	0.37	0.15	0.09	0.06
60–70	9	57	145	368	0.33	0.13	0.08	0.05
70–80	5	32	82	208	0.44	0.18	0.11	0.07
80–90	3	20	50	128	0.56	0.22	0.14	0.09
90–100	2	12	31	79	0.72	0.28	0.18	0.11
100–115	2	11	29	73	0.74	0.30	0.19	0.12
115–130	1	7	18	45	0.95	0.38	0.24	0.15
sums:	240	840	1512	3840				
STIX	6k	21k	38k	96k				

Observation time with two instruments

- All flares M1 or above can be well measured by MiSolFA
  - About 200 per year at solar maximum
- Overlapping time of STIX and MiSolFA
  - STIX in science mode for 20% of time
  - MiSolFA life time $\sim$ 50%
  - The same flare is viewed by both 50% of the time in which a flare is visible from Earth
  - 18 days per year, hence $\sim$ 10 (flares $\geq$ M1)/year



Flares distribution



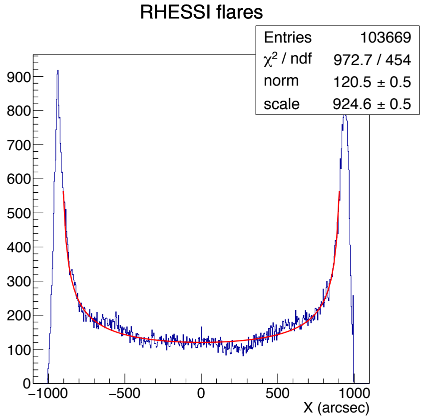
From HESSI Flare List generated on 2015-08-17 01:08

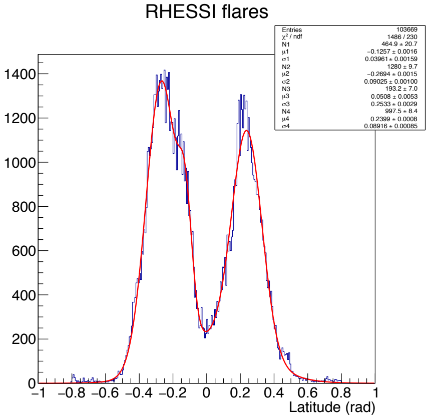
http://hesperia.gsfc.nasa.gov/hessidata/dbase/hessi_flare_list.txt

(Sometimes there is a problem with the roll angle)

Flares distribution

No correction applied for the distance to Sun ($\rightarrow$ smearing)



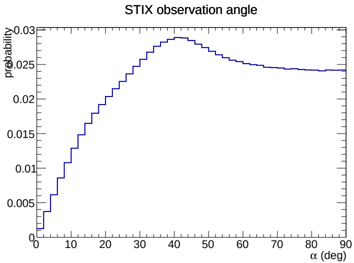


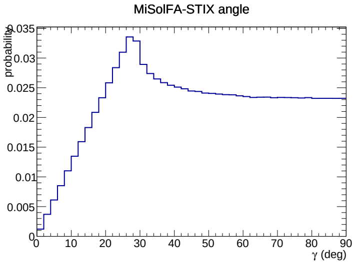
Uniform longitude distribution

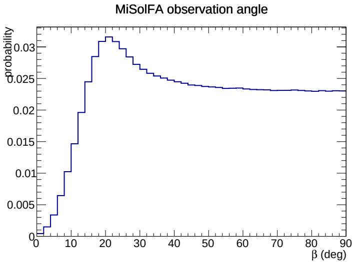
Latitude peaks at about $\pm 13.5^\circ$ with 6.3° std.dev.

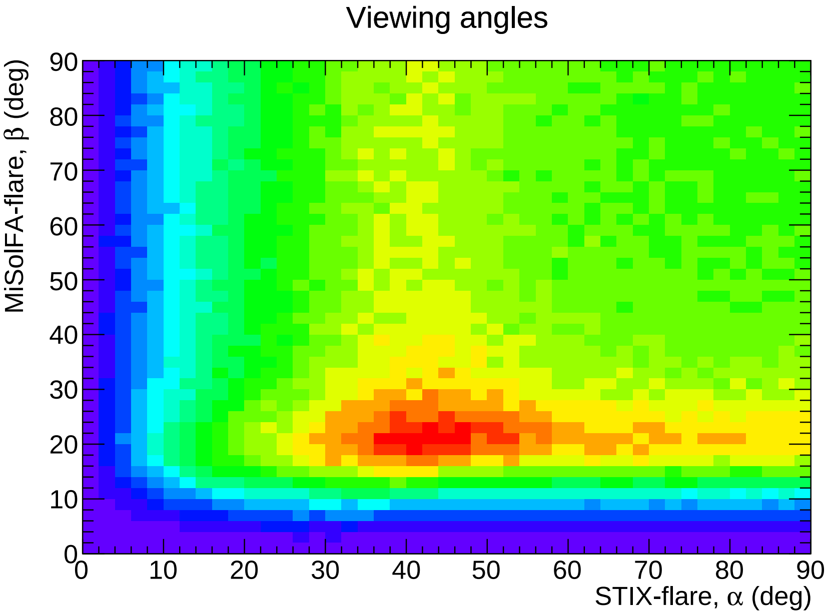
Viewing angles

- Flare directions from RHESSI
- STIX taken uniform in longitude $\pm\pi$ rad and latitude ± 0.5 rad
- MiSolFA taken at the Earth (lon $= 0$, lat $= 0$)








Viewing angles
MiSolFA-flare, β (deg)
0
10
20
30
40
50
60
70
80
90
STIX-flare, α (deg)

Limb flares

- 10–11% of all flares observed by each instrument fall beyond the limb by no more than 10°
  - About 20 (M1 or above) per year for each instrument
- The coronal emission will be measured for the flares with occulted footpoints for (only) one of the two instruments half of the time
- Accounting for the limited overlapping time, one expects to get a few good simultaneous observations of coronal and footpoint sources

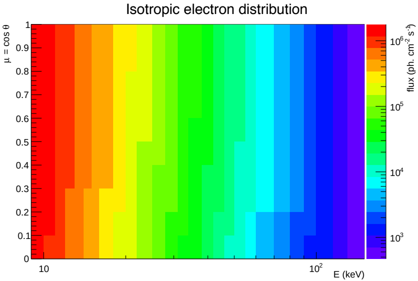
Directivity measurement

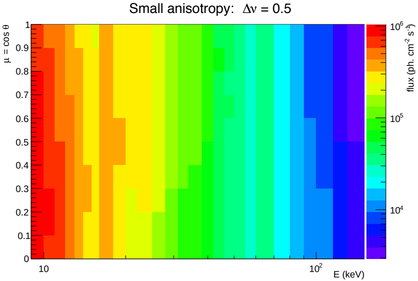
- Which degree of beaming for the accelerated electrons?
  - Intuitively one expects quite significant anisotropy
  - but so far no convincing direct proof
- STIX and MiSolFA will see the same source from different positions
  - Can compare X-ray intensity at different energies
  - Better constraints on electron anisotropy

Electron distribution

- N. Jeffrey & E. Kontar, A&A 536 (2011) A93
  - Electron distributions with different degrees of anisotropy
  - Photon emission and reflection (albedo)
  - Different flare locations, i.e. viewing angles
- Got total (direct + albedo) photon flux toward observer by Natasha (thanks!)
  - Photon spectrum in 10 bins uniform in $\mu \equiv \cos\theta$, where $\theta =$ heliocentric angle (viewed from Earth) $=$ viewing angle with respect to the local flare vertical direction
  - Parent electrons are isotropic, almost isotropic ($\Delta\nu = 4.0$), or beamed ($\Delta\nu = 0.5$)
  - Parent electrons have spectral index $\delta = 2$ and larger beaming for smaller $\Delta\nu$ ($\approx$ std.dev. of pitch angle distribution)

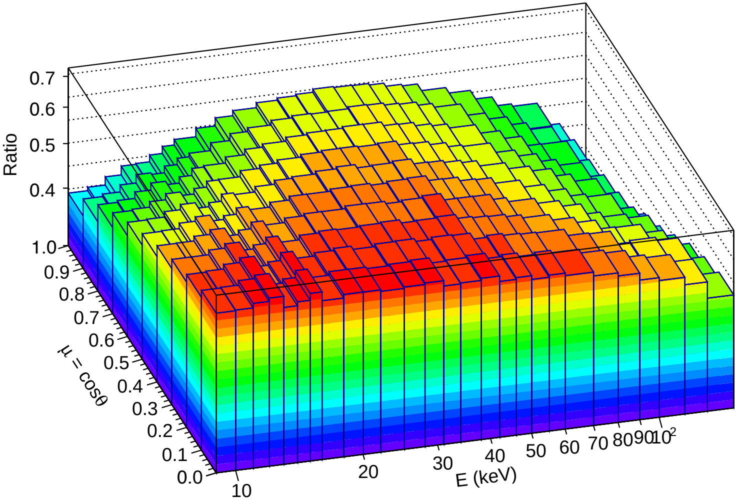
Photon distributions from Natasha Jeffrey





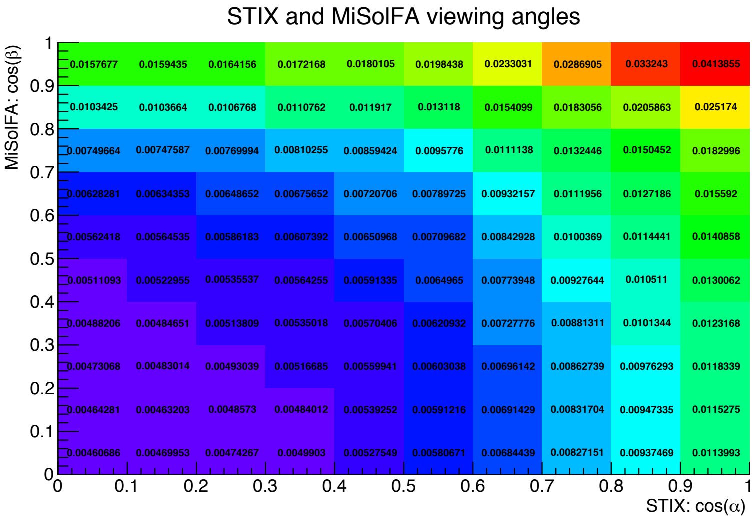
- $\mu = 1 \rightarrow$ head-on source
- $\mu = 0 \rightarrow$ source viewed from side

Ratio of photon flux: smally anisotropy/isotropic

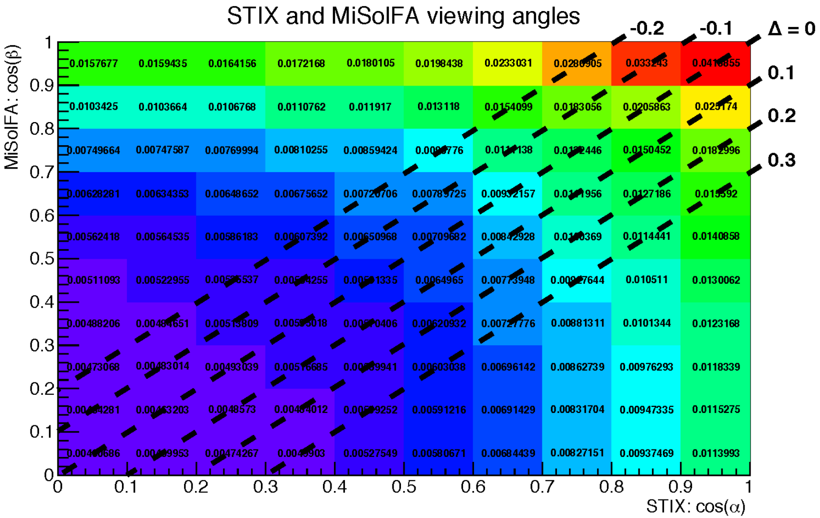


Sizable spectral difference vs. energy and viewing angle

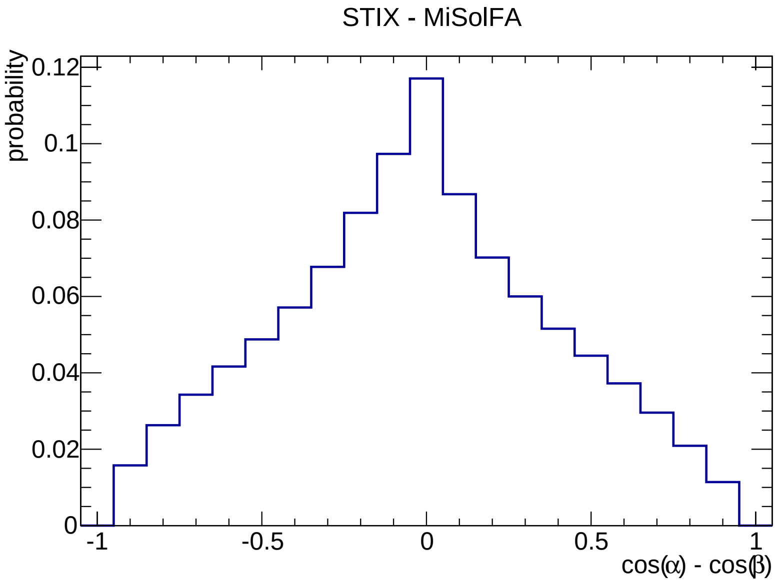
Viewing angles



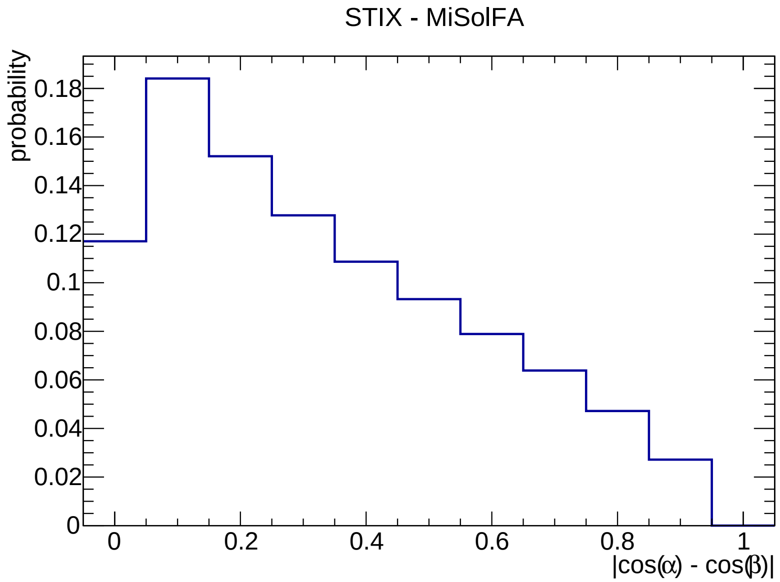
Viewing angles



Viewing angles

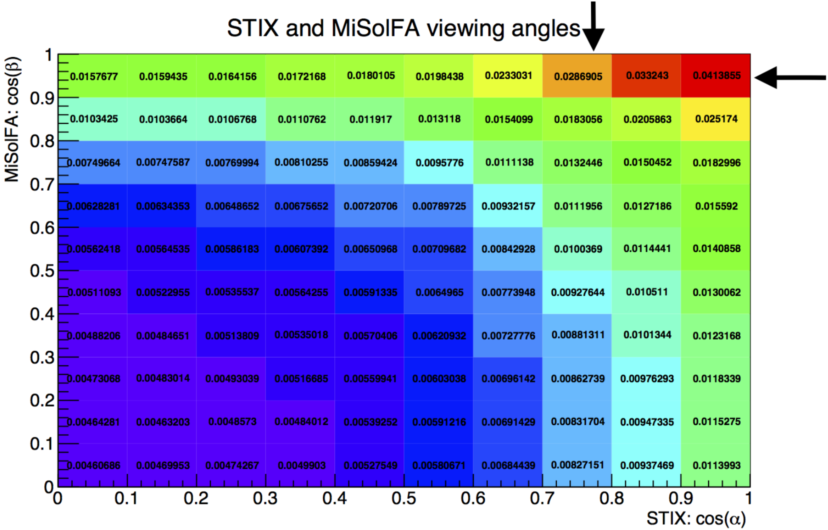


Viewing angles



Use case: $\cos(\alpha) = 0.7\text{–}0.8$

$\cos(\beta) = 0.9\text{–}1.0$

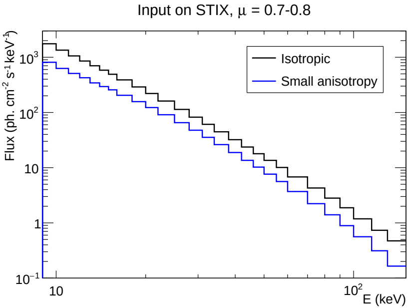


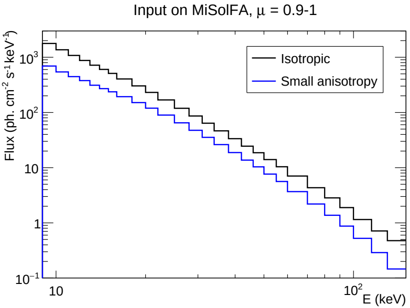
Simulation of detector measurement

Goal: estimate directivity vs. energy with $\cos(\alpha) = 0.7$–0.8 (STIX) and $\cos(\beta) = 0.9$–1.0 (MiSolFA)

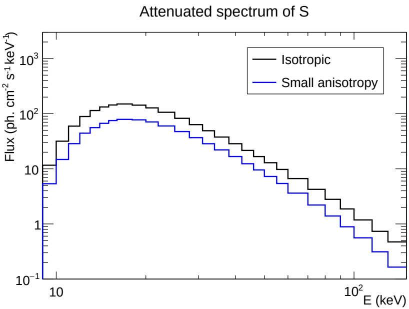
1. Take photon flux by Jeffrey & Kontar .... DONE
2. Account for different attenuation .... DONE
3. Account for different energy resolution .... DONE
4. Account for different background .... DONE
5. Account for different (effective) collecting areas .... DONE
6. Simulate experiment (Poisson in each bin) .... DONE
7. Infer back about “true” input .... TO BE DONE

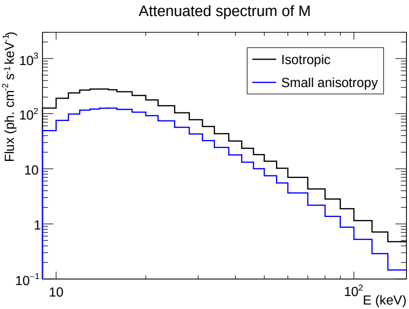
Incoming photon flux (scaled by 1e-3)

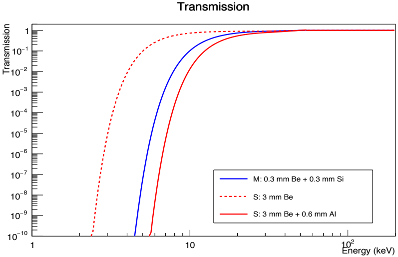




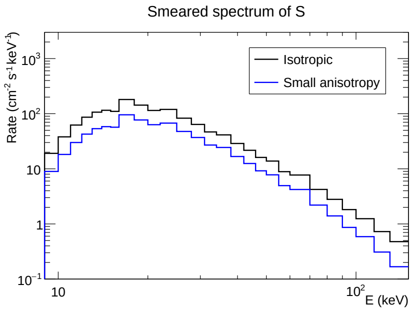
Flus attenuated by passive materials

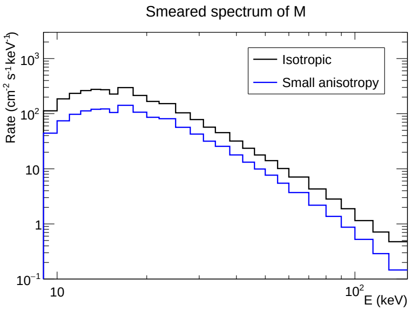


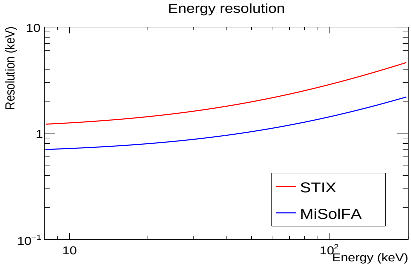




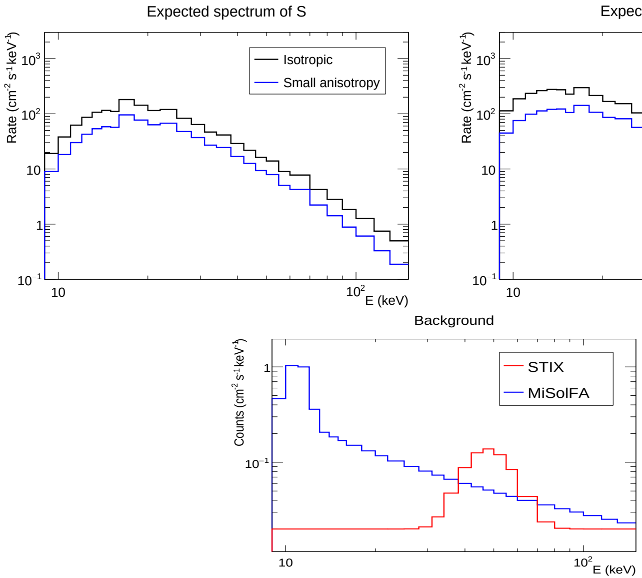
Energy resolution → bin-to-bin migration



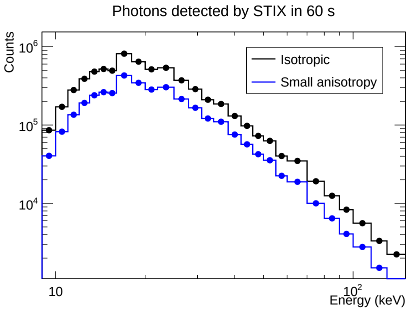


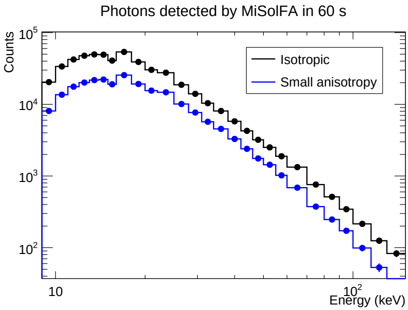


Add background counts

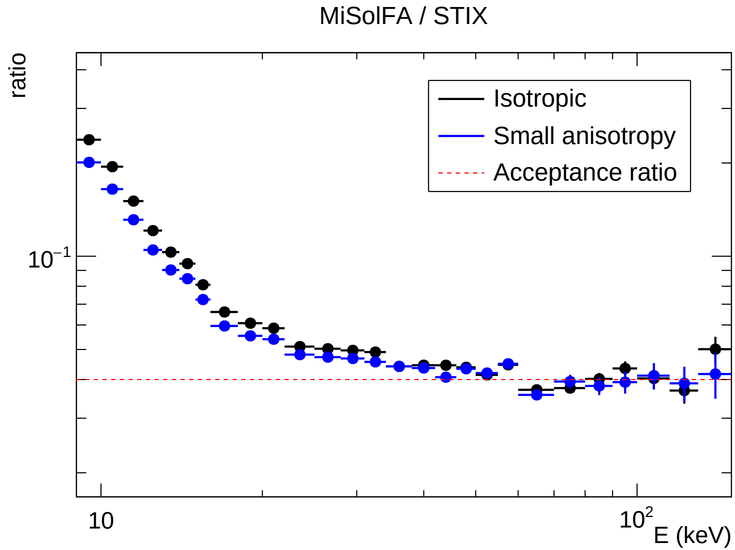


Pseudo-experiment: counts in 1 minute





Quick (and dirty) comparison



Summary

- STIX and MiSolFA will provide stereo measurements
  - Simultaneous observation of footpoint and coronal sources
  - Directivity of the same source as a function of the energy
- Assuming an overlapping time of 5% (18 days/year) there will be several good flares per year
- Angular separation of 20°–30°, or more
  - Can observe energy-dependent directivity
  - Better constraints on electron anisotropy