

HESPE - high energy solar physics data in europe

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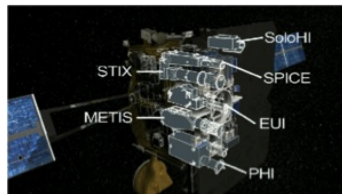
10th european space weather week
antwerp november 19 2013

hard X-ray telescopes

rhessi (2002)



stix (2017)

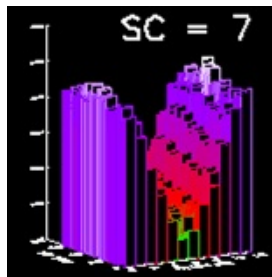


hard x-ray telescopes

- do not focus radiation
- modulate radiation
- record very indirect information on the observed physics
- need math to work

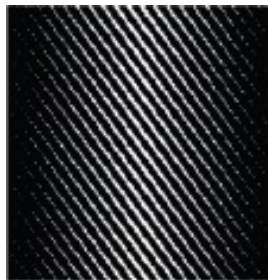
modulation

rhessi (2002)



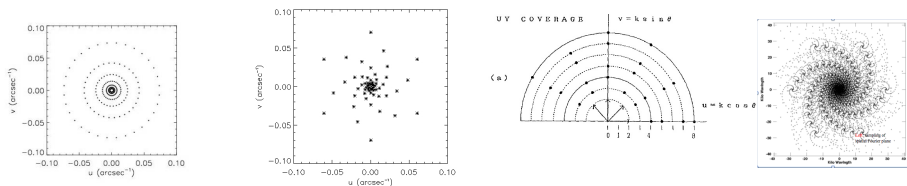
- rotation: yes
- hardware: grids (uniform)
- processing: data stacking

stix (2017)



- rotation: no
- hardware: grids (moire patterns)
- processing: numerical integration

visibilities



visibilities:

$$V(u_j, v_j; \epsilon) = \iint I(x, y; \epsilon) e^{2\pi i(u_j x + v_j y)} dx dy \quad j = 1, \dots, M$$

imaging from visibilities

difficult issues:

- visibility generation from measured counts (as a function of time and energy)
- image reconstruction
- image interpretation: electron maps

FP7 cooperation project 'high energy solar physics data in europe (HESPE)'



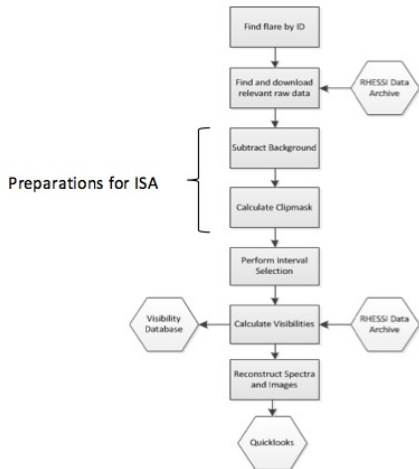
HESPE crew:

- DIMA-UNIGE (coordinator)
- fachhochschule nordwestschweiz
- university of glasgow
- universitaet graz
- observatoire de paris
- SSL berkeley
- NASA GSFC
- CNR - SPIN

HESPE goals:

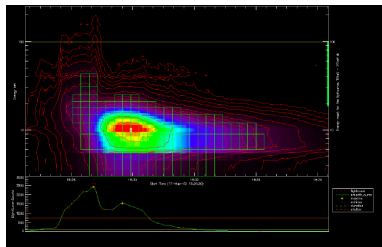
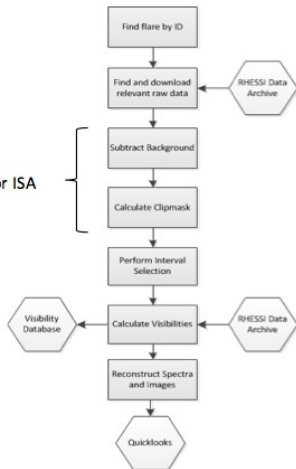
- automatic generation of optimized visibilities
- computational corpus of spectroscopy, imaging and imaging spectroscopy methods
- interpretation in the framework of advanced flare models

interval selection algorithm



interval selection algorithm

Preparations for ISA



imaging methods

- uv_smooth: interpolation in the frequency plane + extrapolation based on soft-thresholding and positivity (massone a m, emslie a g, hurford g j, prato m, kontar e p and piana m, *astrophysical journal*, 2009)
- back projection (non-uniform weights, tapering) (giordano s, massone a m and emslie a g, *astronomy and astrophysics*, in preparation)
- visibility-based CLEAN: standard CLEAN + polar/tapered back-projection (giordano s, massone a m and emslie a g, *astronomy and astrophysics*, in preparation)
- bayesian filtering of visibilities: particle filter with smoothing along the time/energy direction (sorrentino a, massone a m and schwartz r, *astronomy and astrophysics*, in preparation)
- sequential monte carlo algorithm: regularized convergence to the posterior distribution at a fixed time/energy interval (sorrentino a, massone a m and schwartz r, *astronomy and astrophysics*, in preparation)

HESPE database - 1

Quick Navigation

- Event Selection
- Spectrogram
- Preview
- Download

[Edit...](#)

Event Selection ▲

GOES Curve List

Flare ID	GOES Class	Total Counts	Start Time	End Time	Lower Energy	Upper Energy
40813105	X1.0				3	31
2080327	X1.0				3	49
4022686	X1.1				3	49
12030505	X1.1*				3	46
2021423					3	11
2021423					3	11

Event Filter

Time/Date: 2002/1/12 — 2013/9/5

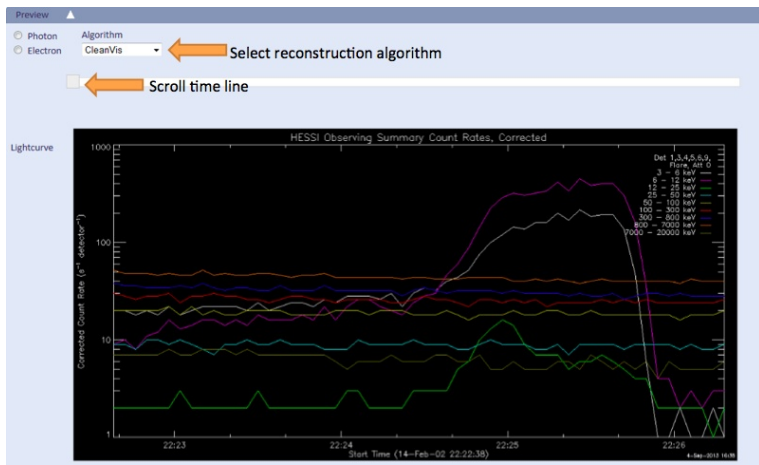
GOES Class: A1.0 — >X9.9

Duration: 1 — 1000

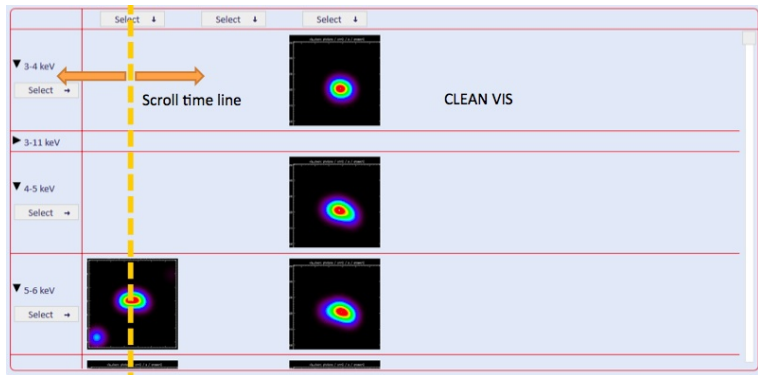
Flare ID:

Navigation icons: back, forward, search, etc.








HESPE database - 2



HESPE database - 3



HESPE database - 4

	Select ▾	Select ▾	Deselect ▾	
▼ 3-11 keV Select →				
▼ 4-5 keV Select →				
▼ 5-6 keV Select →				Select entire time and energy intervals or single maps
▼ 6-7 keV				

HESPE database - 5

Download

Download Options

Data Volume

- Current Selection
- Entire Event

Data Products

Photon

- Visibilities
- Maps
- UV Smooth
- MEM_NUIT
- CleanVis
- Bayes

Electron

- Visibilities
- Maps
- UV Smooth
- MEM_NUIT
- CleanVis
- Bayes

Misc

- Scripts

Download data products

Download

electron maps - 1

(piana m, massone a m, hurford g j, prato m, emslie a g, kontar e p and schwartz r a
astrophysical journal, 2007)

two nested inverse problems:

- 1 instrumental: from visibilities to photon flux (fourier inversion problem from limited data)
- 2 physical: from local photon flux to electron flux (solution of the bremsstrahlung equation)

electron maps - 1

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$$F(x, y; E) \rightarrow \mathcal{A}(F(x, y; E)) = I(x, y; \epsilon) \rightarrow \mathcal{B}(I(x, y; \epsilon)) = V(u, v; \epsilon)$$

$$V(u, v; \epsilon) = \mathcal{B}(\mathcal{A}(F(x, y; E)))$$

electron maps - 1

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$$V(u, v; \epsilon) = \mathcal{B}(\mathcal{A}(F(x, y; E)))$$

theorem:

$$[\mathcal{B}, \mathcal{A}] = 0$$

proof (hint): apply fubini's theorem

electron maps -2

(piana and massone, *solar physics*, 2013)

reconstruction algorithm for electron maps

part 1:

- 1 fix a (u, v) point
- 2 construct the photon visibility spectrum $V(u, v; \epsilon)$
- 3 define the electron visibility spectrum $W(u, v; E) = \int \int F(x, y; E) e^{2\pi i(ux+vy)} dx dy$
- 4 solve the spectral problem $V = \mathcal{A}W$
- 5 back to 1.

electron maps -2

(piana and massone, *solar physics*, 2013)

reconstruction algorithm for electron maps

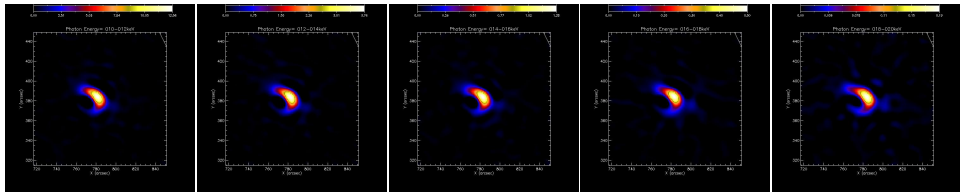
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- 3 define the electron visibility spectrum $W(u, v; E) = \int \int F(x, y; E) e^{2\pi i(ux+vy)} dx dy$
- 4 solve the spectral problem $V = \mathcal{A}W$
- 5 back to 1.

part 2:

- 1 fix an electron energy E
- 2 construct the set $W(u, v; E)$ for all (u, v) points
- 3 solve the image reconstruction problem $W = \mathcal{B}F$
- 4 back to 1.

photon maps



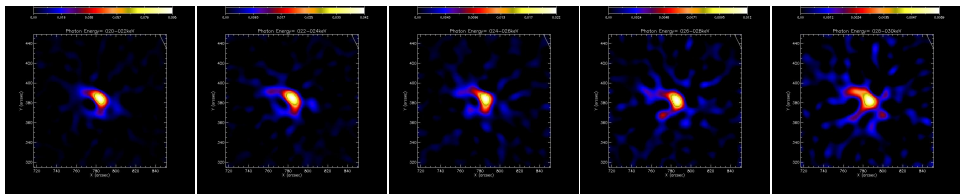
10-12 keV

12-14 keV

14-16 keV

16-18 keV

18-20 keV



20-22 keV

22-24 keV

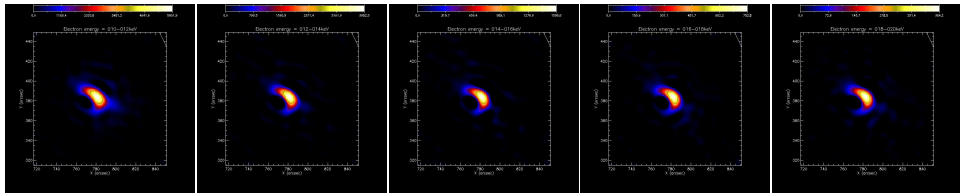
24-26 keV

26-28 keV

28-30 keV



electron maps



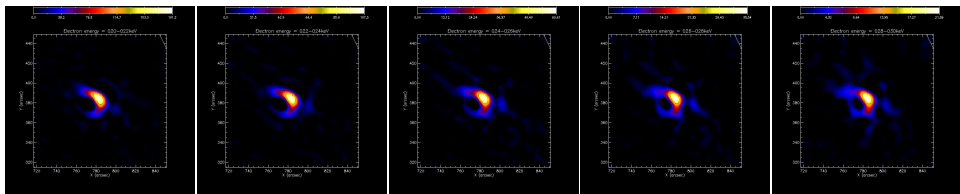
10-12 keV

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18-20 keV



20-22 keV

22-24 keV

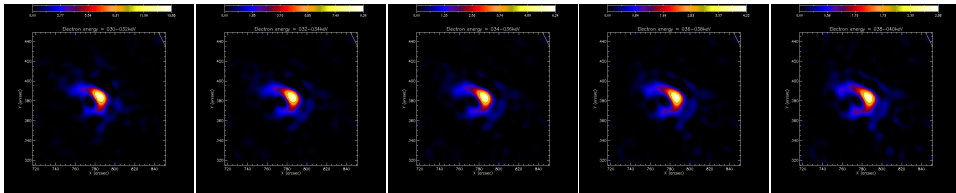
24-26 keV

26-28 keV

28-30 keV



electron maps (continued)



30-32 keV

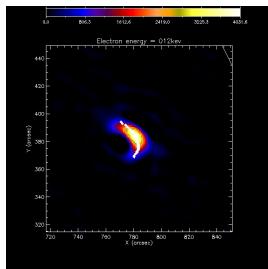
32-34 keV

34-36 keV

36-38 keV

38-40 keV

continuity equation - 1



$$F(s, E) = F_+(s, E) + F_-(s, E)$$
$$\pm \frac{\partial}{\partial s} F_{\pm}(s, E) - \frac{\partial}{\partial E} \left(-\frac{dE}{ds} F_{\pm}(s, E) \right) = S(s, E)$$

the physics is in:

- the energy loss rate $\frac{dE}{ds}(n, T)$
- the injection term $S(s, E)$

continuity equation - 2

the electron continuity equation hides a hyperbolic nature: (pinamonti, torre, codispoti, massone and piana, *astrophysical journal*, in preparation)

some definitions:

$$\Phi_{\pm}(s, E) := -\frac{dE}{ds} F_{\pm}(s, E) \quad A(s, E) := -\frac{dE}{ds} \frac{S(s, E)}{\sqrt{2mE}}$$

$$x(E) := x_0 - \int_{E_0}^E \frac{1}{\frac{dE}{ds}} dE' \quad \Phi(s, E) = \Phi_+(s, E) + \Phi_-(s, E)$$

wave equation for the electron maps:

$$-\frac{\partial^2}{\partial x^2} \Phi(s, E(x)) + \frac{\partial^2}{\partial s^2} \Phi(s, E(x)) = 2 \frac{\partial}{\partial x} A(s, E(x))$$

initial conditions:

$$\lim_{x \rightarrow \infty} \Phi(x, s \pm x) = 0 \quad \lim_{x \rightarrow \infty} \partial_x \Phi(x, s \pm x) = 0 \quad \forall s$$

green function

$$\square G(s, s'; x, x') = -\partial_x \delta(s, s'; x, x')$$

two solutions:

$$G(s, s'; x, x') = \delta_{\pm}(x - x' \mp |s - s'|)$$

but just one (δ_-) is coherent with the initial conditions. therefore:

$$\Phi(s, E(x)) = (\delta_- * 2A)(x, s)$$

$$F(s, E(x)) = \sqrt{\frac{2}{m}} \frac{1}{\frac{dE}{ds}} \int \delta(x - x' + |s - s'|) \frac{dE}{ds} \frac{S(s', E(x'))}{\sqrt{E(x')}} dx' ds'$$

lhs: measurements

rhs: models (for the energy loss rate and for the injection term)

model selection

example 1 (torre, pinamonti, emslie, guo, massone and piana, *astrophysical journal*, 2012):
how hot and dense is the flaring target?

- spitzer's model for the energy loss term
- box function for the injection term
- density: $n = (2.0 \pm 0.1) \times 10^{11} \text{ cm}^{-3}$
- temperature: $T = (1.61 \pm 0.05) \text{ keV}$

model selection

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- temperature: $T = (1.61 \pm 0.05) \text{ keV}$

example 2 (codispoti, torre, piana and pinamonti, *astrophysical journal*, 2013): are there return currents balancing the charge equilibrium violation?

- the energy loss rate accounts for return currents
- box function for the injection term

15-Apr-2002

Time[UT]	Mod	$E_0[\text{keV}]$	$n[\text{cm}^{-3}]$	$h_s[\text{cm}^{-5}\text{keV}^{-1}\text{s}^{-1}]$	χ^2
00:03:00-00:06:00	Mod 1	7.7 ± 0.2	$(8.0 \pm 0.8) \times 10^{10}$	$(1.6 \pm 0.3) \times 10^{30}$	0.80
	Mod 2	2.5 ± 0.1	$(1.81 \pm 0.16) \times 10^{11}$	$(4.7 \pm 0.8) \times 10^{30}$	1.04
	Mod 3	7.9 ± 1.9	$(7.86 \pm 0.12) \times 10^9$	$(4.2 \pm 0.5) \times 10^{30}$	0.82
	Mod 4	0	$(3.4 \pm 0.3) \times 10^{10}$	$(9.52 \pm 1.19) \times 10^{30}$	3.58
00:06:00-00:09:00	Mod 1	8.2 ± 0.3	$(6.3 \pm 0.6) \times 10^{10}$	$(1.04 \pm 0.21) \times 10^{30}$	0.33
	Mod 2	3.2 ± 0.1	$(1.42 \pm 0.11) \times 10^{11}$	$(3.3 \pm 0.5) \times 10^{30}$	0.55
	Mod 3	3.5 ± 0.8	$(6.99 \pm 0.12) \times 10^9$	$(3.5 \pm 0.4) \times 10^{30}$	0.43
	Mod 4	0	$(2.30 \pm 0.19) \times 10^{10}$	$(7.2 \pm 0.8) \times 10^{30}$	2.45
00:09:00-00:12:00	Mod 1	4.9 ± 1.2	$(1.6 \pm 0.3) \times 10^{10}$	$(5.1 \pm 2.3) \times 10^{28}$	0.65
	Mod 2	3.2 ± 0.6	$(4.5 \pm 0.7) \times 10^{10}$	$(3.45 \pm 1.11) \times 10^{29}$	0.70
	Mod 3	0.2 ± 0.1	$(4.47 \pm 0.11) \times 10^9$	$(1.00 \pm 0.24) \times 10^{30}$	0.79
	Mod 4	0	$(6.2 \pm 0.5) \times 10^9$	$(1.4 \pm 0.3) \times 10^{30}$	1.21