Parametric imaging for STIX: global search methods

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The STIX forward-fit problem

The mathematical equation describing the image formation problem for STIX is:

$$\mathcal{F}\phi = \mathsf{V} \tag{1}$$

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the intensity of the X-ray photon flux emitted from (x, y) on the Sun

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$$\mathcal{F}\phi = \mathbf{V} \qquad (1)$$

the array containing the N_V complex values of the visibilities measured by STIX

The STIX forward-fit problem

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$$\mathcal{F}\phi = \mathsf{V} \tag{1}$$

the Fourier transform defined by

$$(\mathcal{F}\phi)_k = \iint \phi(x,y)\exp\left(2\pi i(xu_k + yv_k)\right)\, dx\, dy \quad k = 1,\ldots,N_v \tag{2}$$

The STIX forward-fit problem

Choose a parametric shape among:

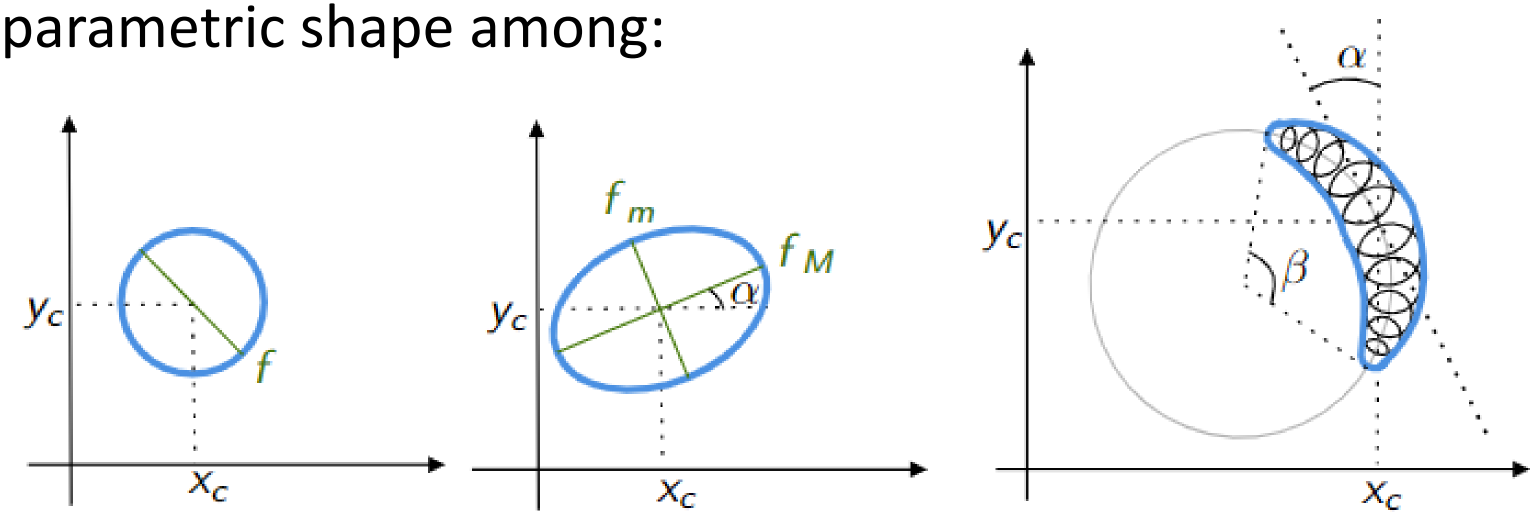

Figure: Gaussian shapes considered in the parametric imaging process.

and solve:

$$\underset{\theta \in \Theta}{\operatorname{argmin}} \; \frac{1}{N_v - N_\theta} \sum_{k=1}^{N_v} \frac{|V_k - (\mathcal{F}\phi_\theta)_k|^2}{\sigma_k^2} \tag{3}$$

Warning on VIS_FWDFIT in STIX framework

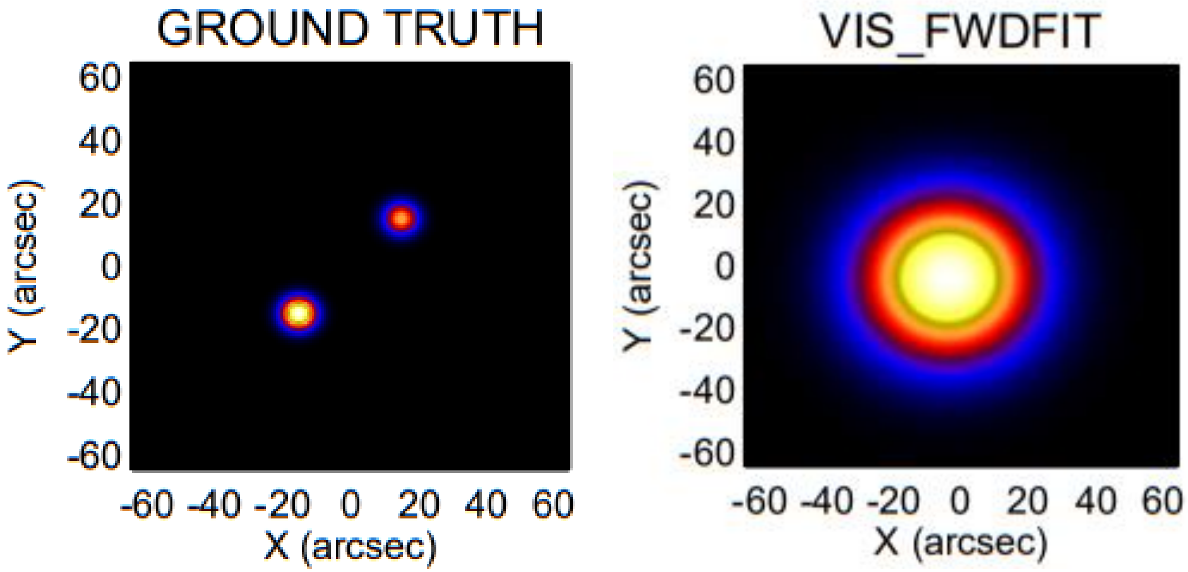

Figure: Left column: simulated configuration mimicking non-thermal emissions. Right column: example of the kind of reconstruction most frequently provided by VIS_FWDFIT.

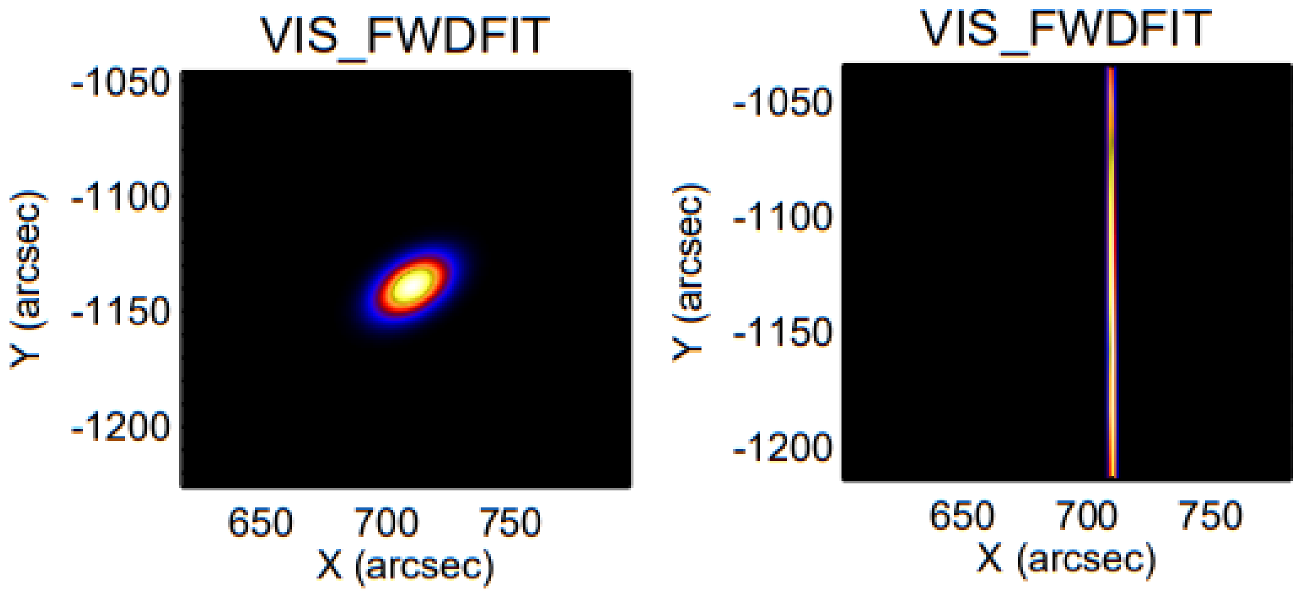

Figure: Parametric images of the thermal component of the August 26, 2021 event obtained by applying VIS_FWDFIT. Left column: parametric image with reference map-center. Right columns: parametric image with the map-center shifted of $|\Delta x| = |\Delta y| = 10$ arcsec.

Local and Global optimization

Local search algorithm

- VIS_FWDFIT (AMOEBA)

Global search algorithm

- Simulated Annealing
- Evolutionary Algorithm
- Particle Swarm Optimization (PSO)

Comparison of global strategies

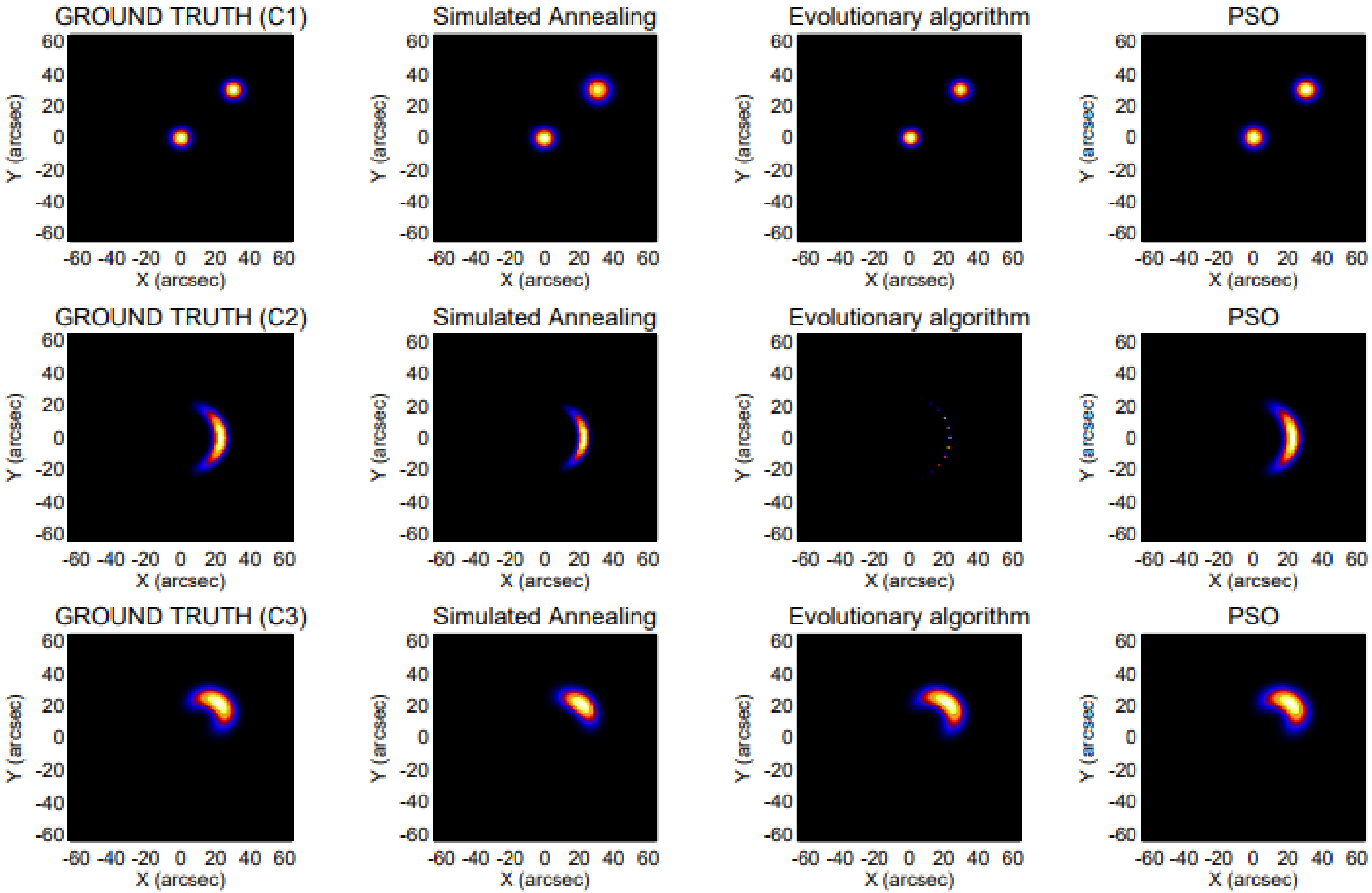

Figure: First column: simulated configurations mimicking one non-thermal and two thermal emissions. The second, third and fourth columns show the kind of reconstruction most frequently provided by Simulated Annealing, Evolutionary algorithm and Particle Swarm Optimization, respectively.

Particle Swarm Optimization

Particle Swarm Optimization is a **biology-inspired technique** based on the model of **intelligent cooperative behaviour** of some animals such as flocks of birds or schools of fish.

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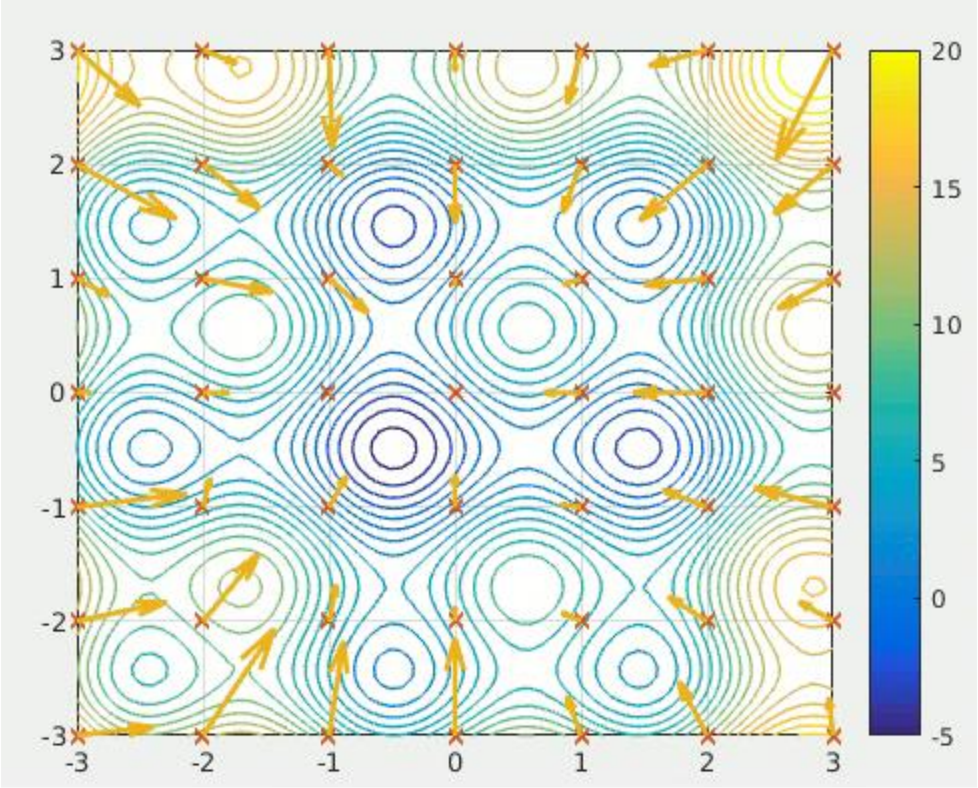

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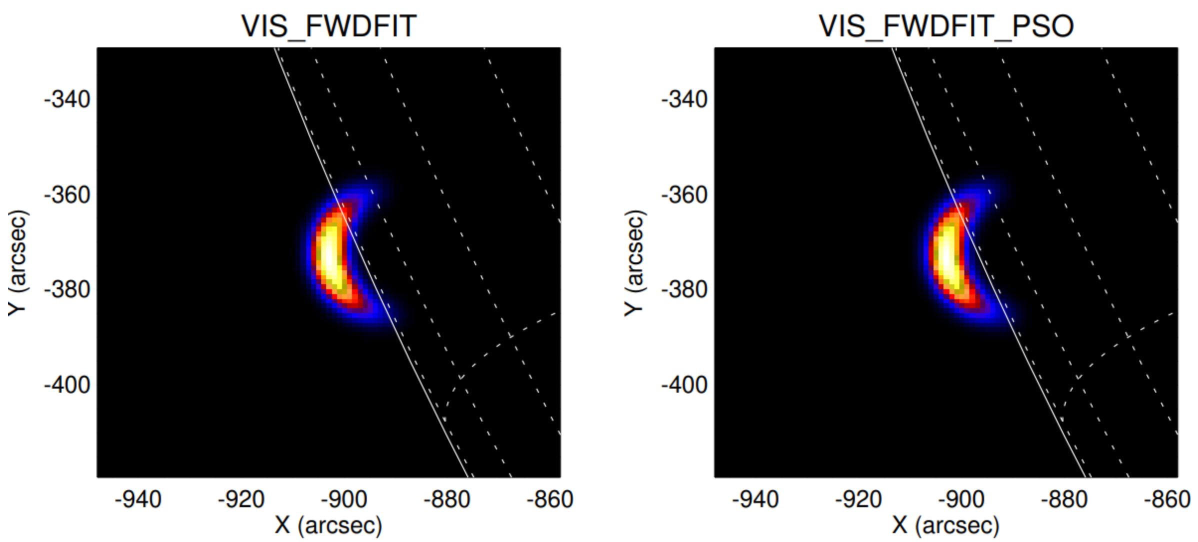
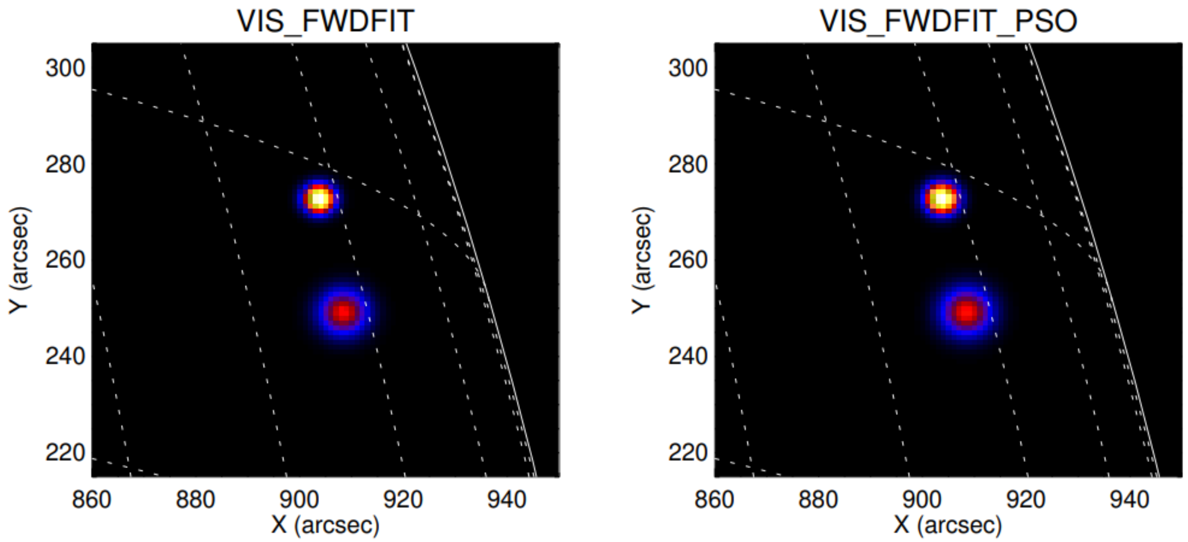
Given a swarm of **candidate solutions**, a position vector and a velocity vector are computed, at each iteration, for each one of the particles. These vectors are then updated taking into account:

- Inertia: velocity at the previous iteration
- Individual cognition: Best position visited since the beginning of the iterative process
- Social learning: Global best position visited by the whole storm

PSO and AMOEBA for RHESSI visibilities



(a) reconstructions of the thermal component (6 -- 12 keV) of the February 13, 2002 event 12:29:40 -- 12:31:22 UT.



(b) reconstructions of the non-thermal component (22 -- 50 keV) of the February 20, 2002 event 11:06:05 -- 11:07:42 UT.

Figure: Forward fitting RHESSI visibilities with AMOEBA and PSO.

PSO and AMOEBA for STIX synthetic visibilities

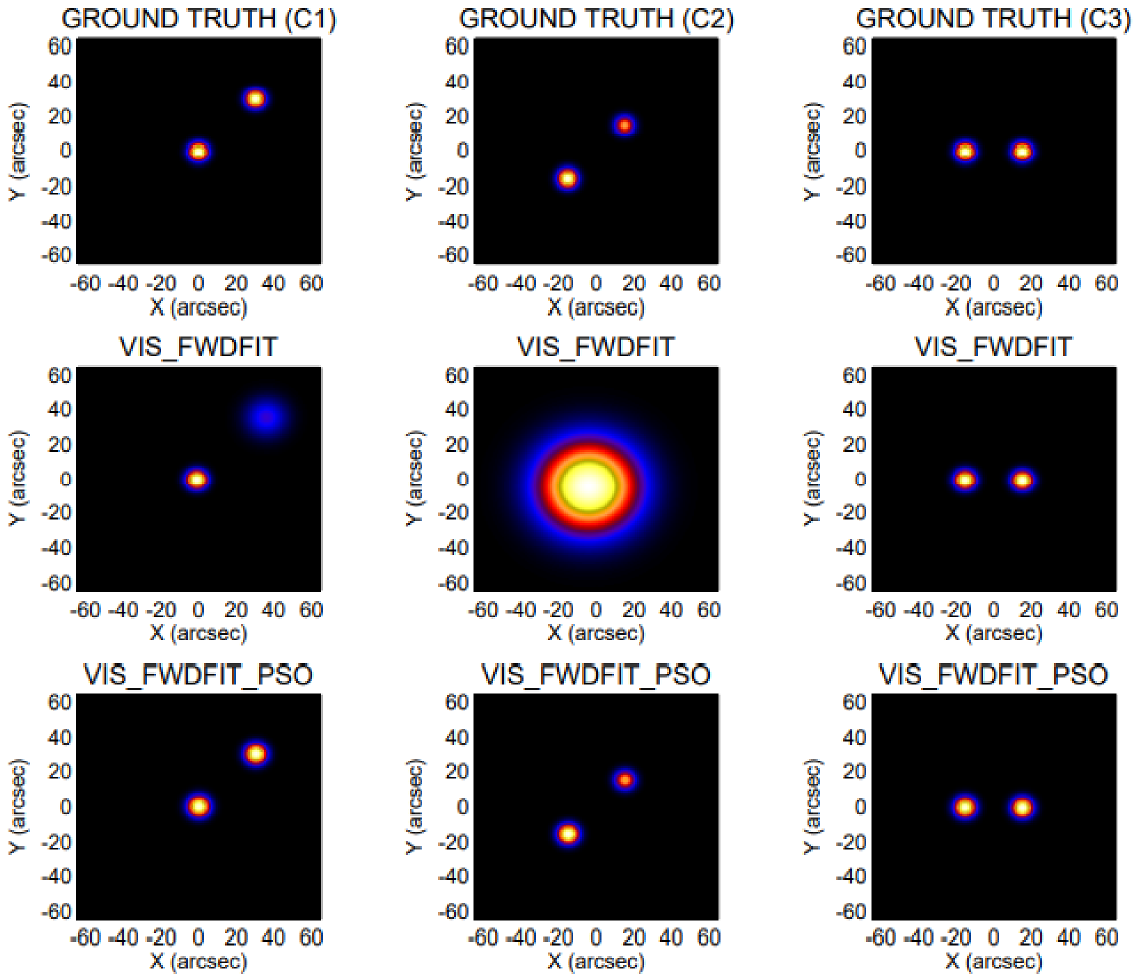
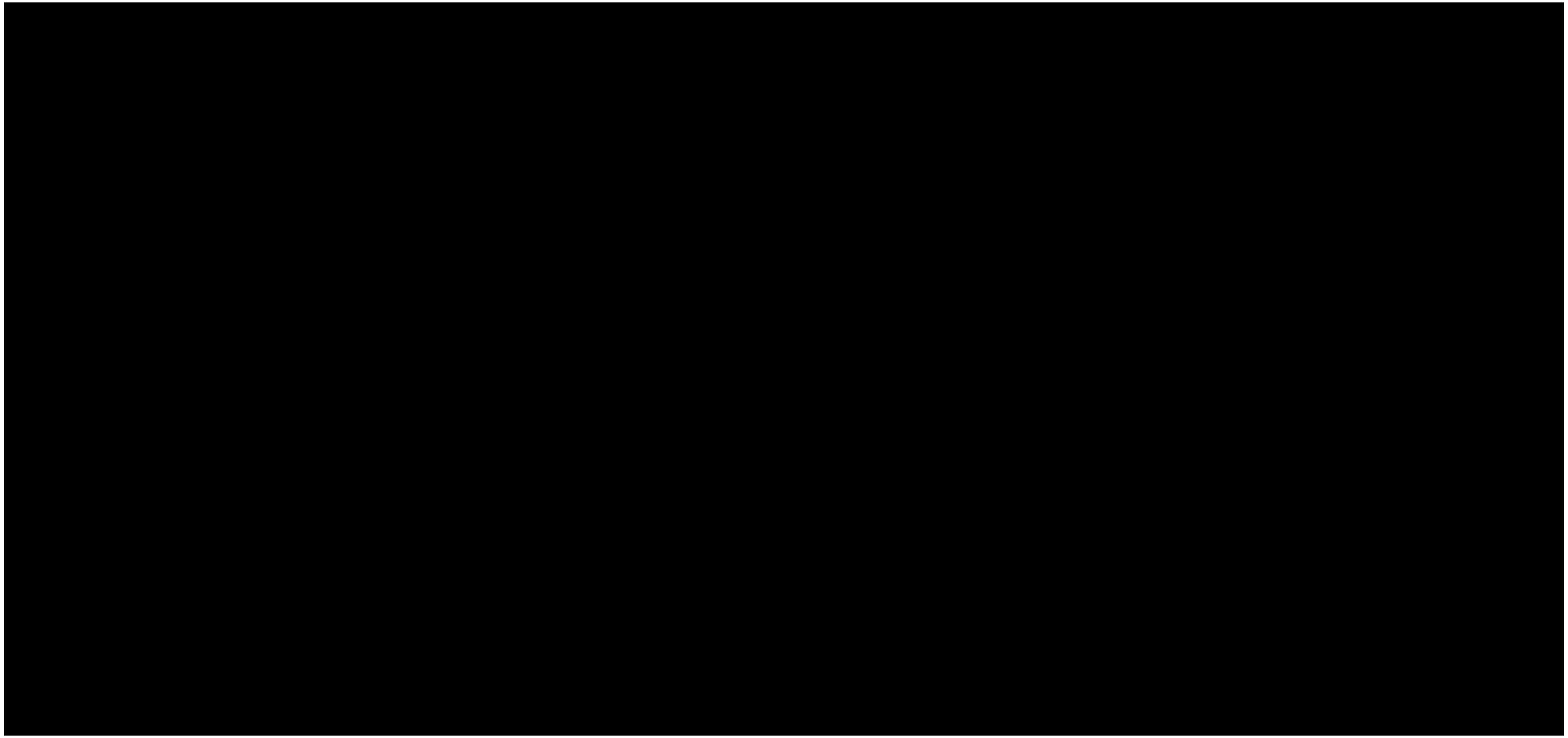


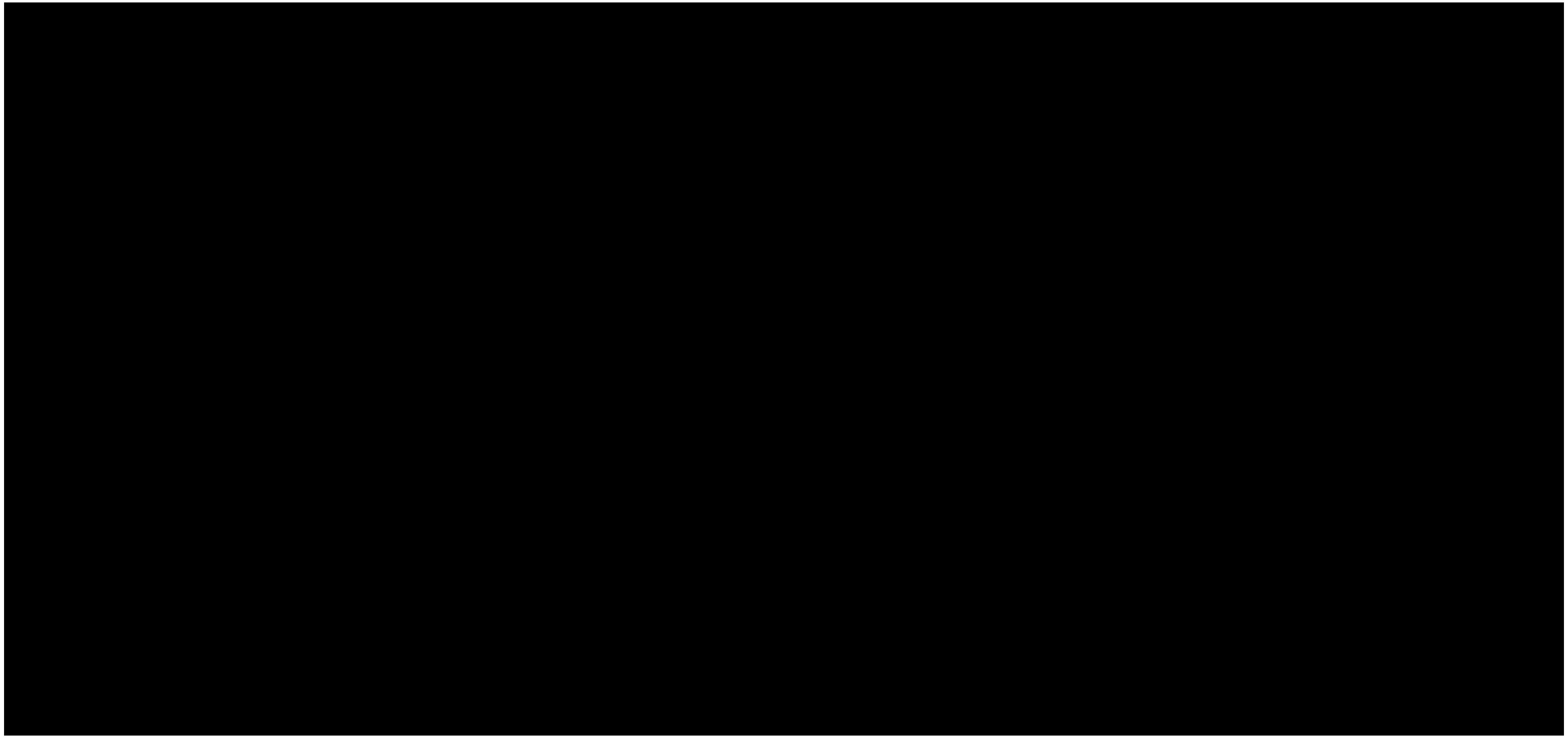
Figure: First row: simulated configurations mimicking three non-thermal emissions. Second and third row: examples of the kind of reconstruction most frequently provided by VIS_FWDFIT and VIS _FWDFIT_PSO, respectively.

PSO and AMOEBA for STIX visibilities



Parametric images of the thermal component of the March 2, 2022 event obtained by applying VIS_FWDFIT (left column) and VIS_FWDFIT_PSO (right columns) on STIX observations with the map-center iteratively shifted of $|\Delta x| = |\Delta y| = 5$ arcsec.

PSO and AMOEBA for STIX visibilities



Parametric images of the non-thermal component of the March 2, 2022 event obtained by applying VIS_FWDFIT (left column) and VIS_FWDFIT_PSO (right columns) on STIX observations with the map-center iteratively shifted of $|\Delta x| = |\Delta y| = 5$ arcsec.

Conclusions

- VIS_FWDFIT routine is significantly less effective in the STIX framework;
- New forward-fitting method has been implemented
  - same good performances with respect to VIS_FWDFIT in the case of RHESSI data;
  - more robust with respect to even slight modifications of the map center;
  - the price to pay is a heavier computational burden.

More details available in:
Volpara et al., Forward-fitting STIX visibilities, submitted to A&A

THANK YOU FOR THE ATTENTION!