Electron maps: from photon to electron visibilities

MIDAgroup

Università di Genova
DIMA | Dipartimento di Matematica

STIX Co-Location

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From photon to electron visibilities

Photon visibilities:

$$V(u,v;\epsilon) = \mathcal{F}(I(x,y;\epsilon)) = \int\int I(x,y;\epsilon)e^{2\pi i(xu+yv)}\,dx\,dy \tag{1}$$

Bremsstralhung equation:

$$I(x,y;\epsilon) = \frac{a}{4\pi R^2}\int_\epsilon^\infty \boxed{N(x,y)}\boxed{\bar{F}(x,y,E)}Q(\epsilon,E)\,dE \tag{2}$$

$$\boxed{N(x,y) = \int_0^\ell n(x,y,z)\,dz}$$

$n(x,y,z)$is the local density of target particles along the line-of-sight depth $\ell(x,y)$

$$\boxed{\bar{F}(x,y;E) = \frac{1}{N(x,y)}\int_0^{\ell(x,y)} n(x,y,z)F(x,y,z;E)\,dz}$$

$F(x,y,z;E)$is the differential electron flux spectrum at the point (x,y,z) in the source

From photon to electron visibilities

Photon visibilities:

$$V(u,v;\epsilon) = \mathcal{F}(I(x,y;\epsilon)) = \int\int I(x,y;\epsilon) e^{2\pi i(xu+yv)}\,dx\,dy \qquad (1)$$

Bremsstralhung equation:

$$I(x,y;\epsilon) = \frac{a}{4\pi R^2}\int_\epsilon^\infty N(x,y)\bar{F}(x,y,E)Q(\epsilon,E)\,dE \qquad (2)$$

Electron visibilities:

$$W(u,v,E) = \frac{a}{4\pi R^2}\int\int N(x,y)\bar{F}(x,y;E)e^{2\pi i(xu+yv)}\,dx\,dy \qquad (3)$$

Bremsstralhung equation for visibilities:

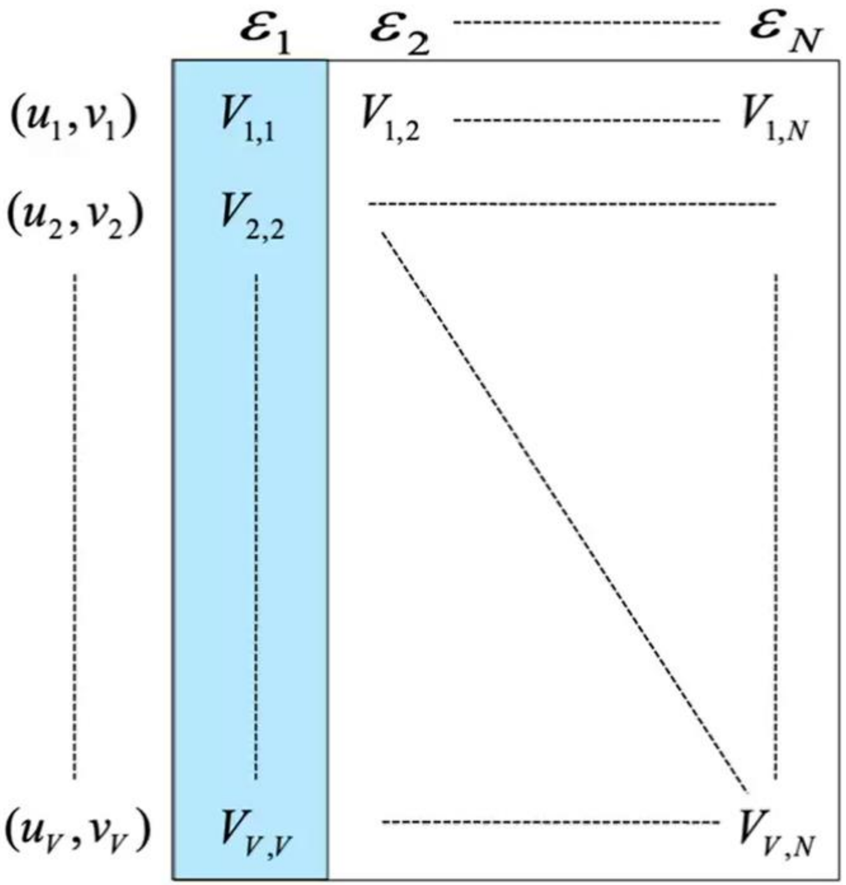
$$\boxed{V(u,v;\epsilon)} = \int_\epsilon^\infty \boxed{W(u,v;E)}\,Q(\epsilon,E)\,dE \qquad (4)$$

Measured photon visibilities

Electron visibilities

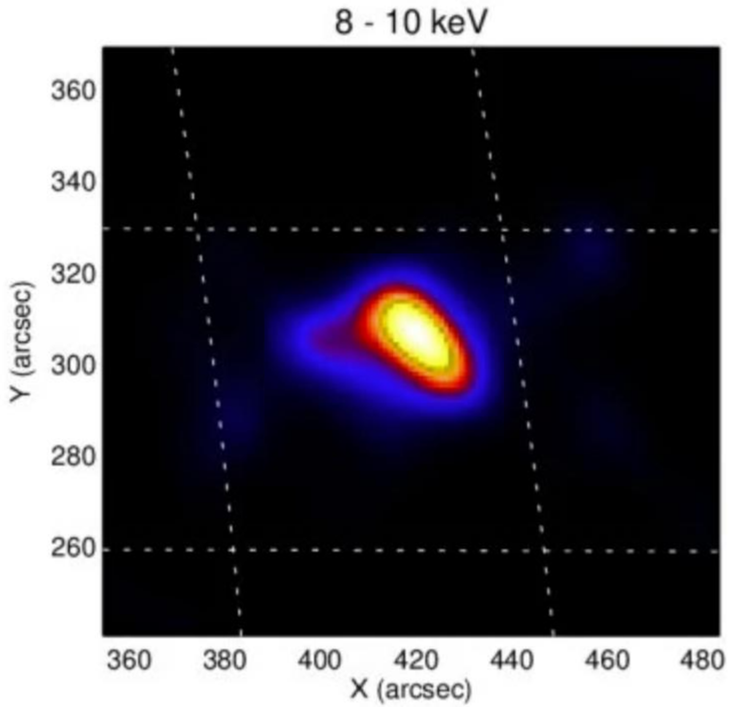
Photon visibilities

Photon visibilities



May 7, 2021

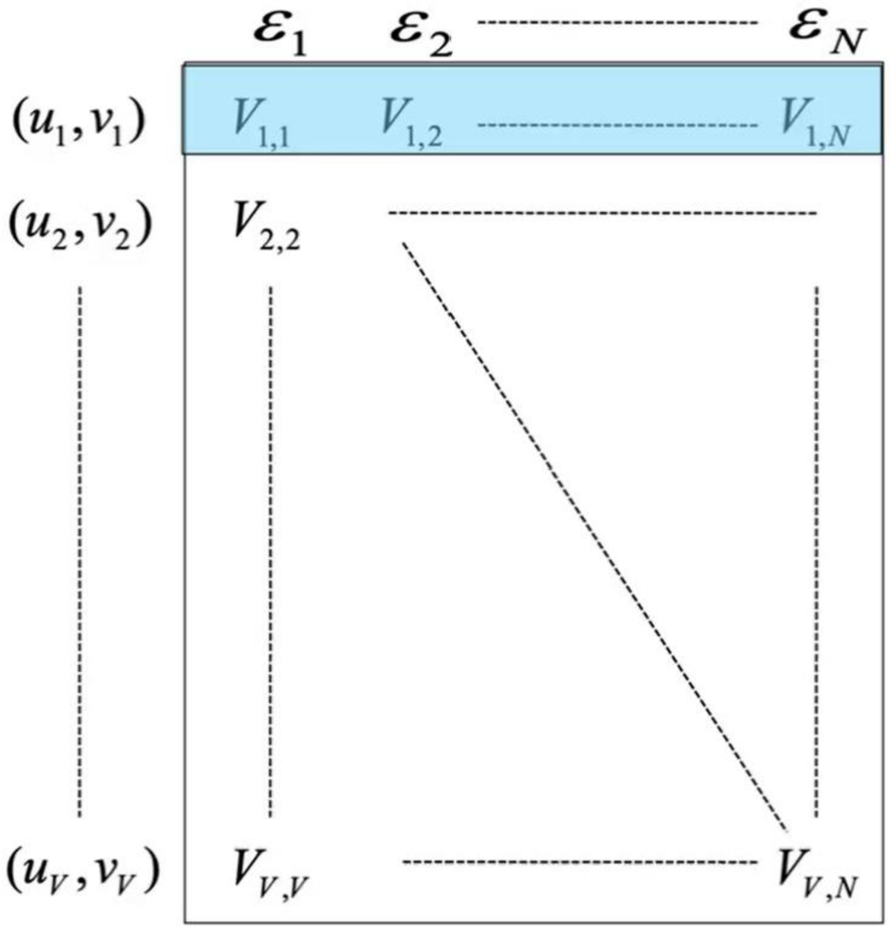
Time range = `18:51:00 – 18:53:40`



Reconstruction provided by MEM_GE, from photon visibilities.

Photon visibilities

Photon visibilities



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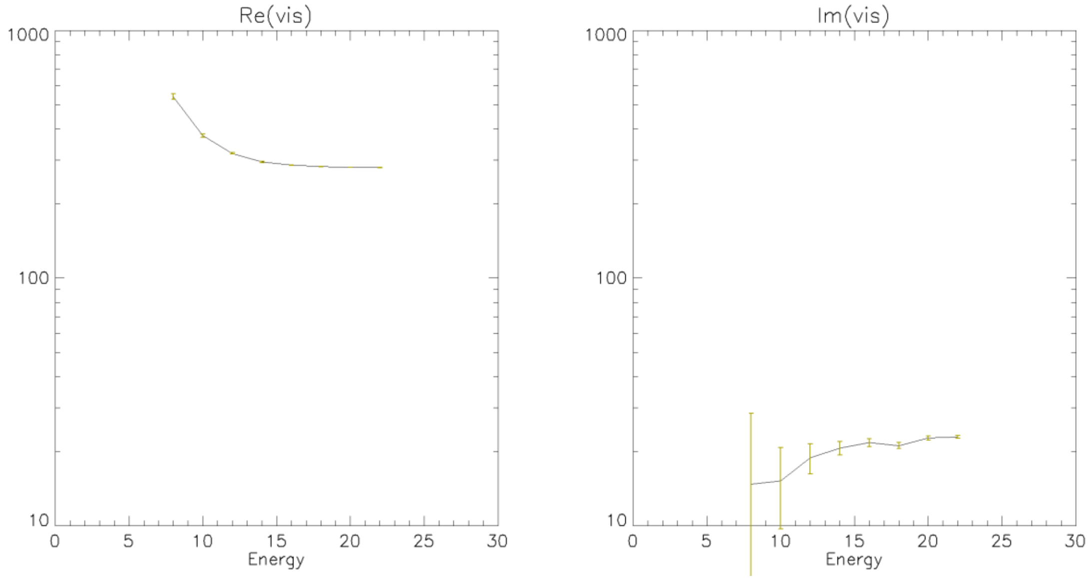
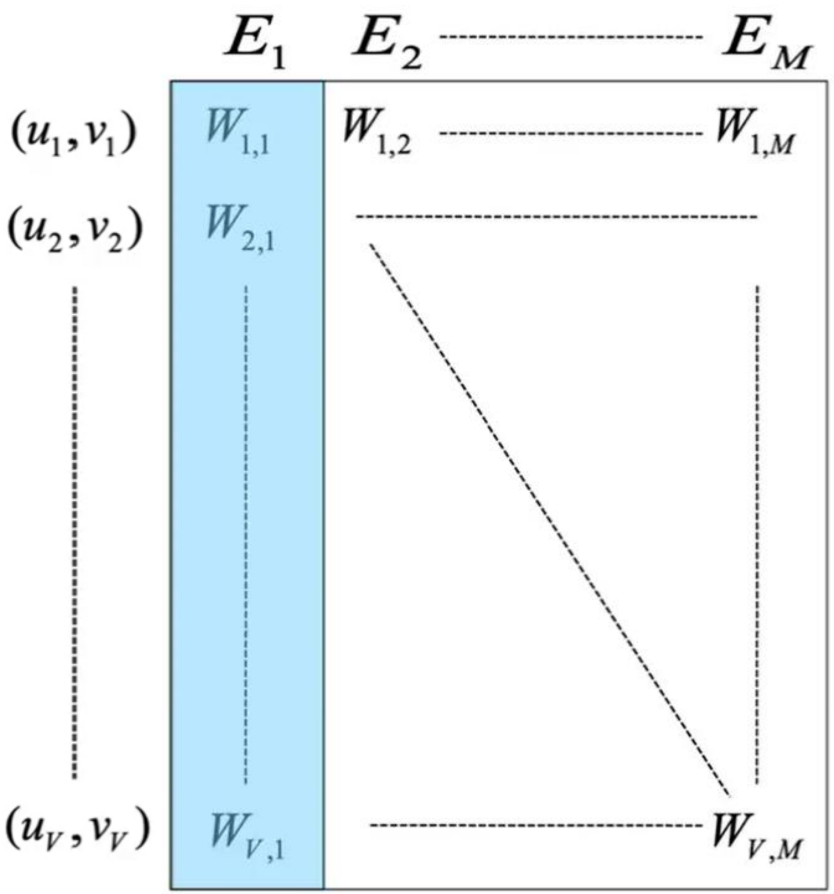


Real part (*on the left*) and imaginary part (*on the right*) of observed photon visibilities in $(u, v) = (0.002, -0.001)$ for eight energy bands.

Electron visibilities

Electron visibilities



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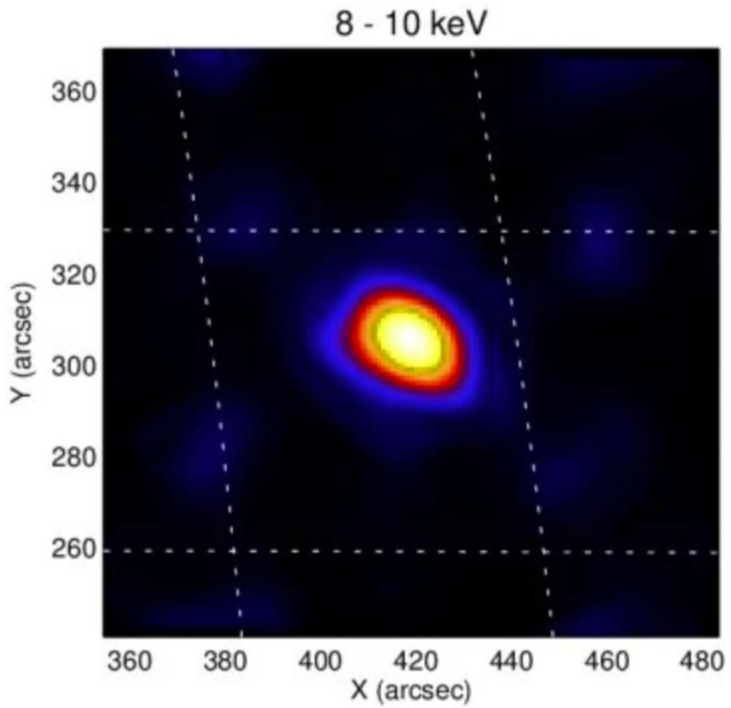
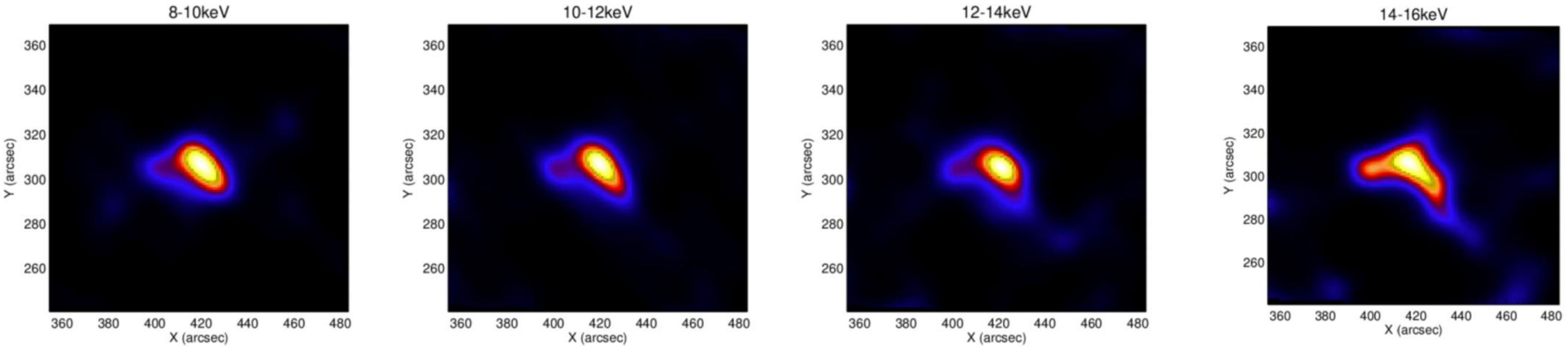


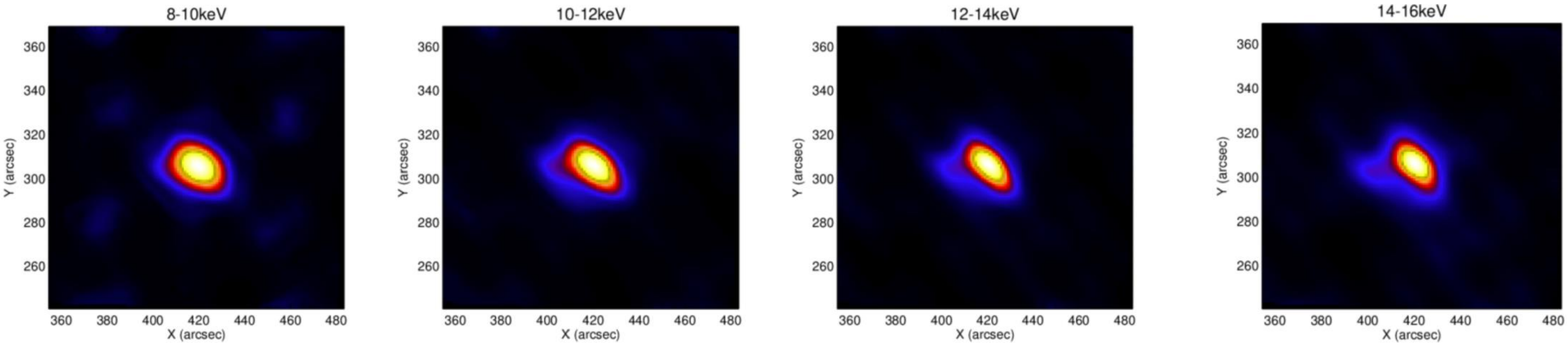
Reconstruction provided by MEM_GE, from electron visibilities.

Results – May 7, 2021

PHOTON VISIBILITIES



REGULARIZED ELECTRON VISIBILITIES



Results – May 7, 2021

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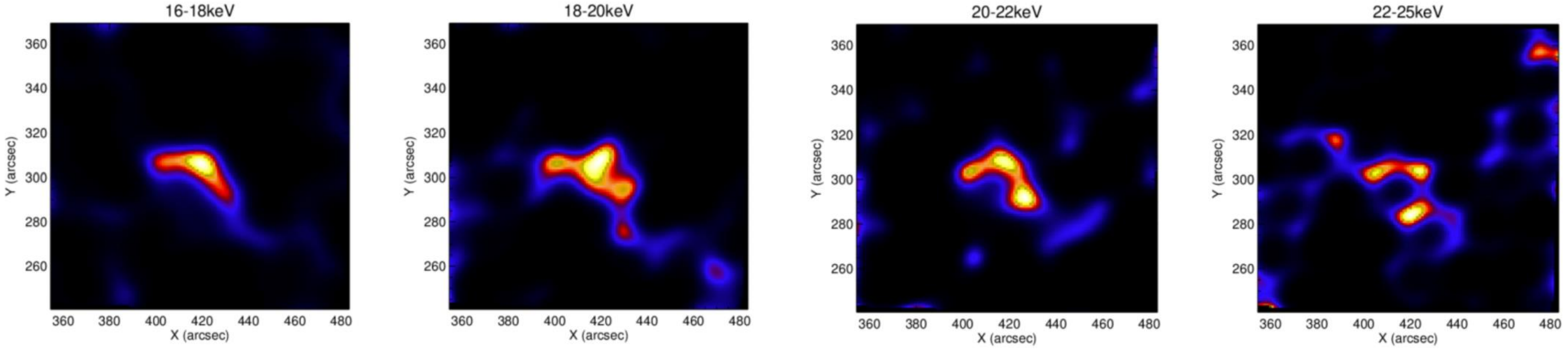

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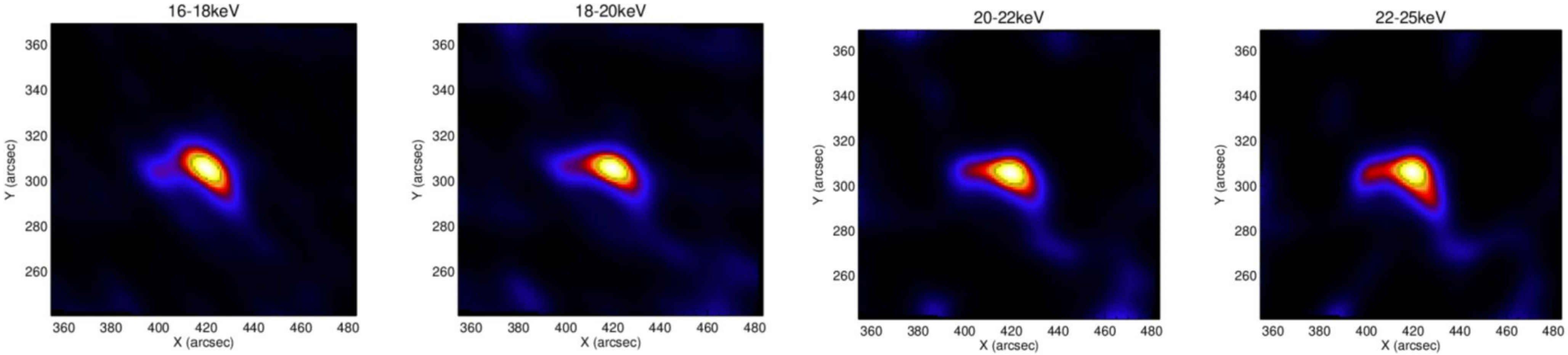

Results – May 7, 2021

PHOTON VISIBILITIES

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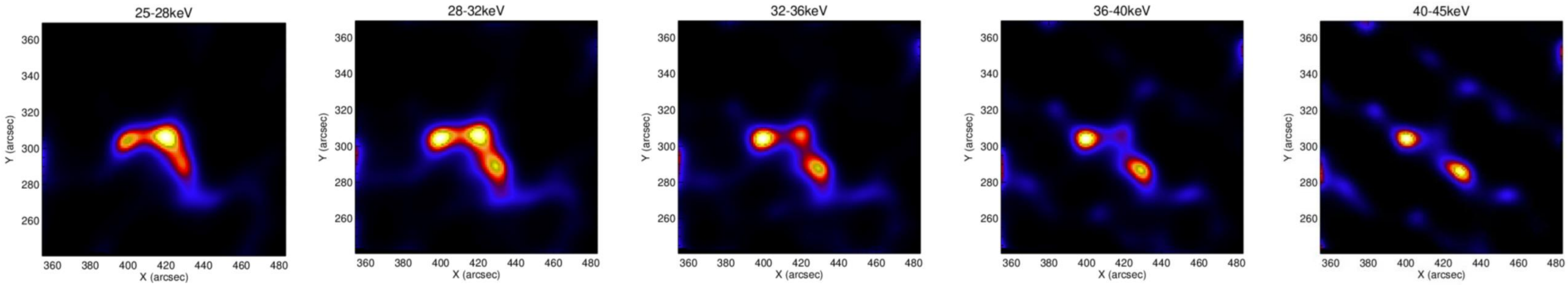

Results – May 7, 2021

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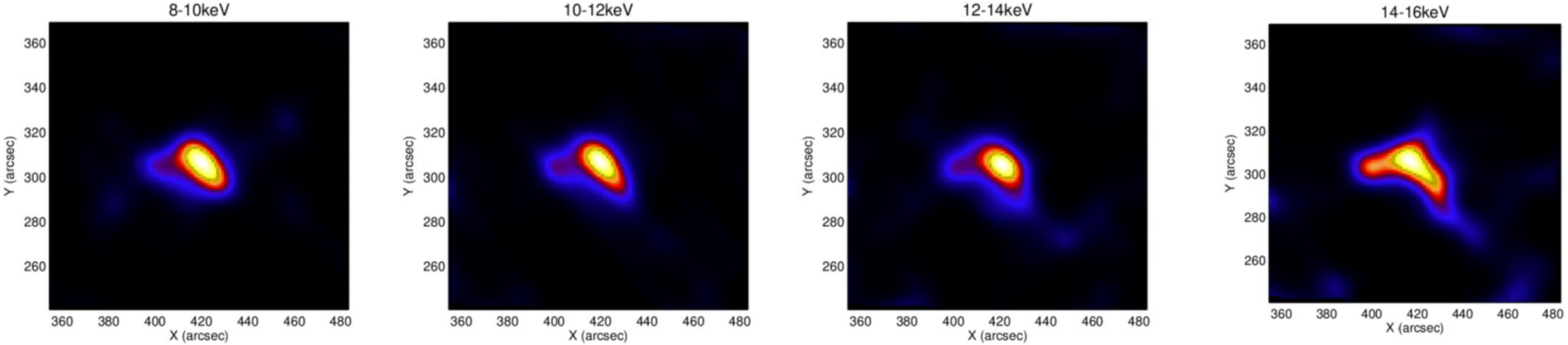

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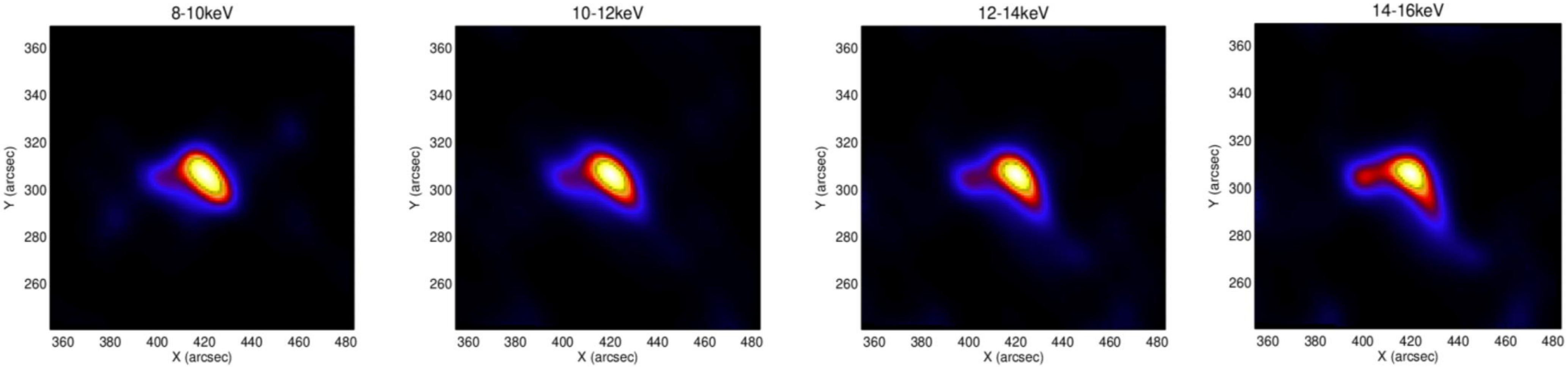

Results – May 7, 2021

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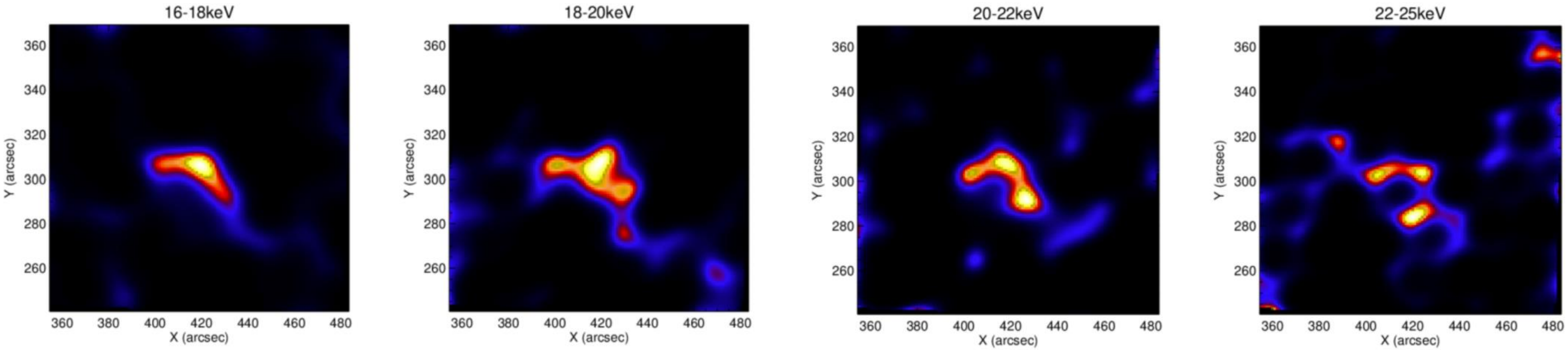
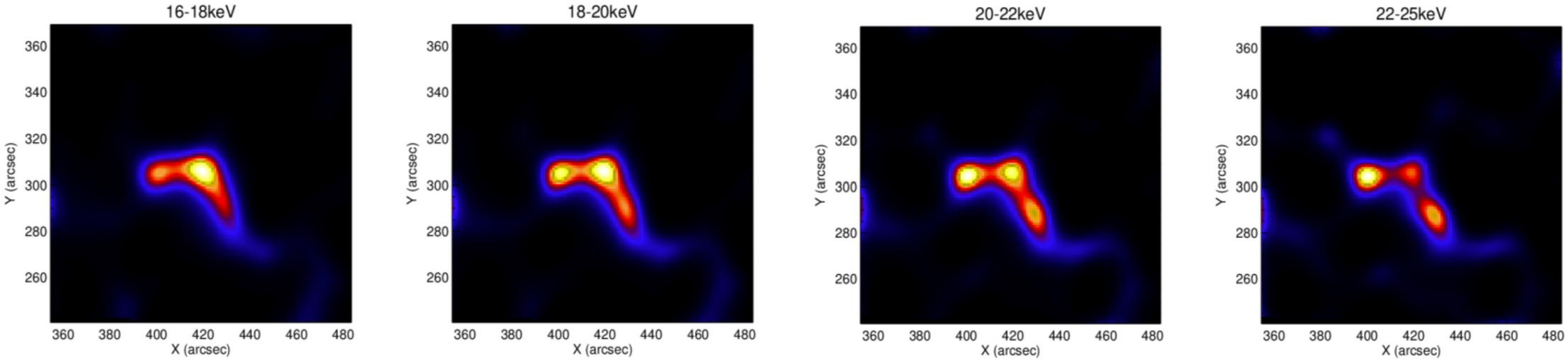
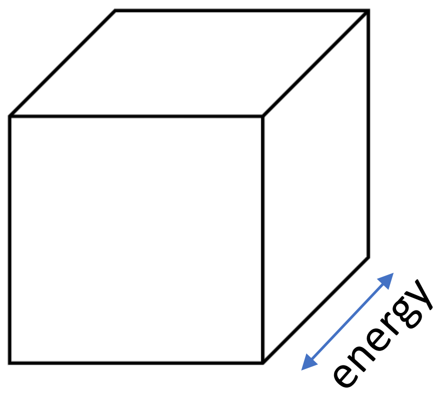


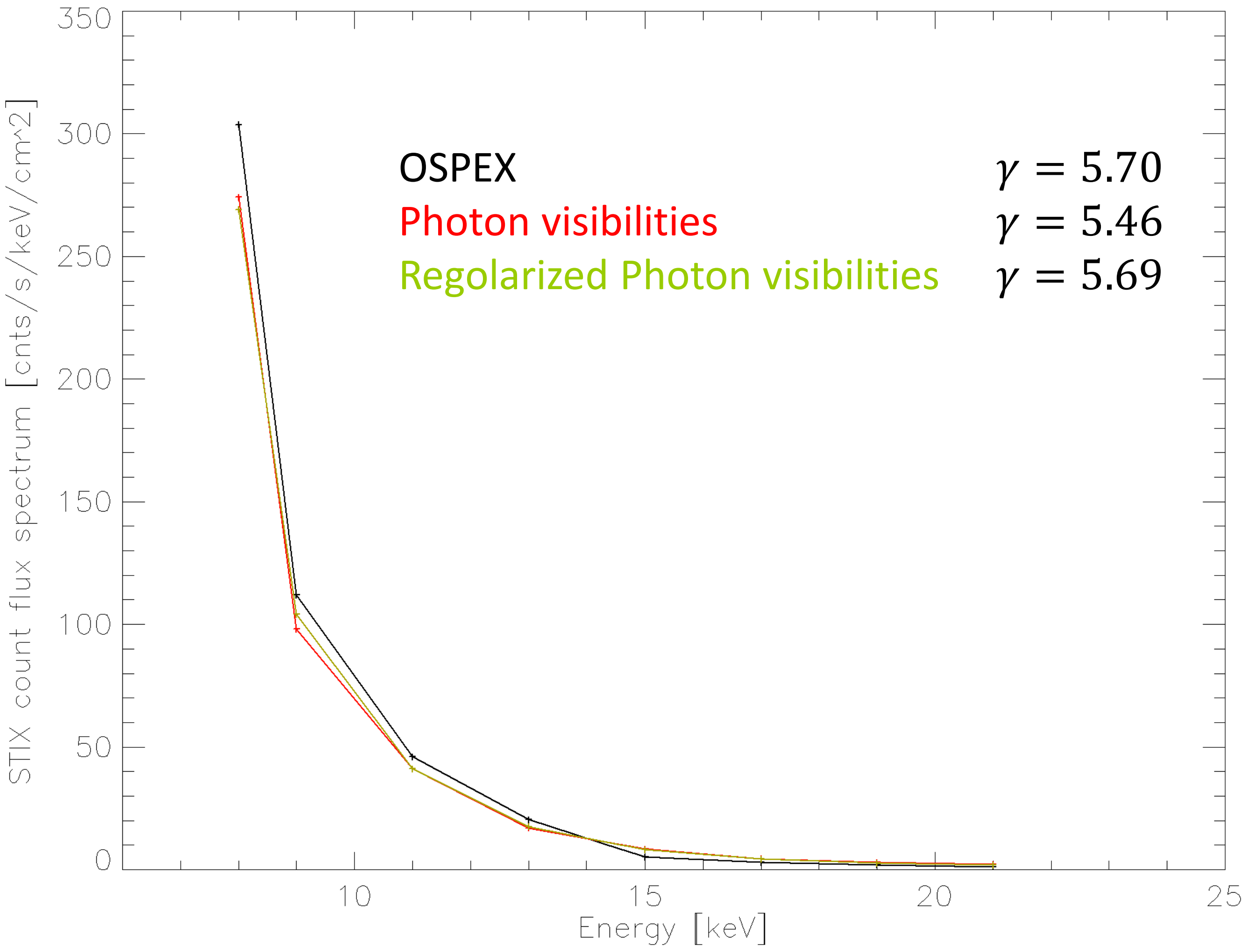
REGULARIZED PHOTON VISIBILITIES



Photon spectrum



1. For each energy bin consider the total flux in the recovered map;
2. Consider the total flux as a function of the energy and fit with a power law
$$A\epsilon^{\gamma}$$
3. Consider the flux spectrum provided by OSPEX and fit it with a power law.



Multi-scale CLEAN

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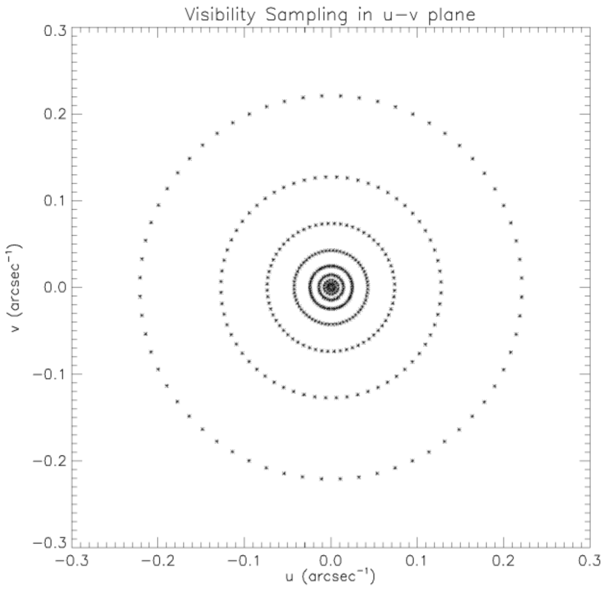
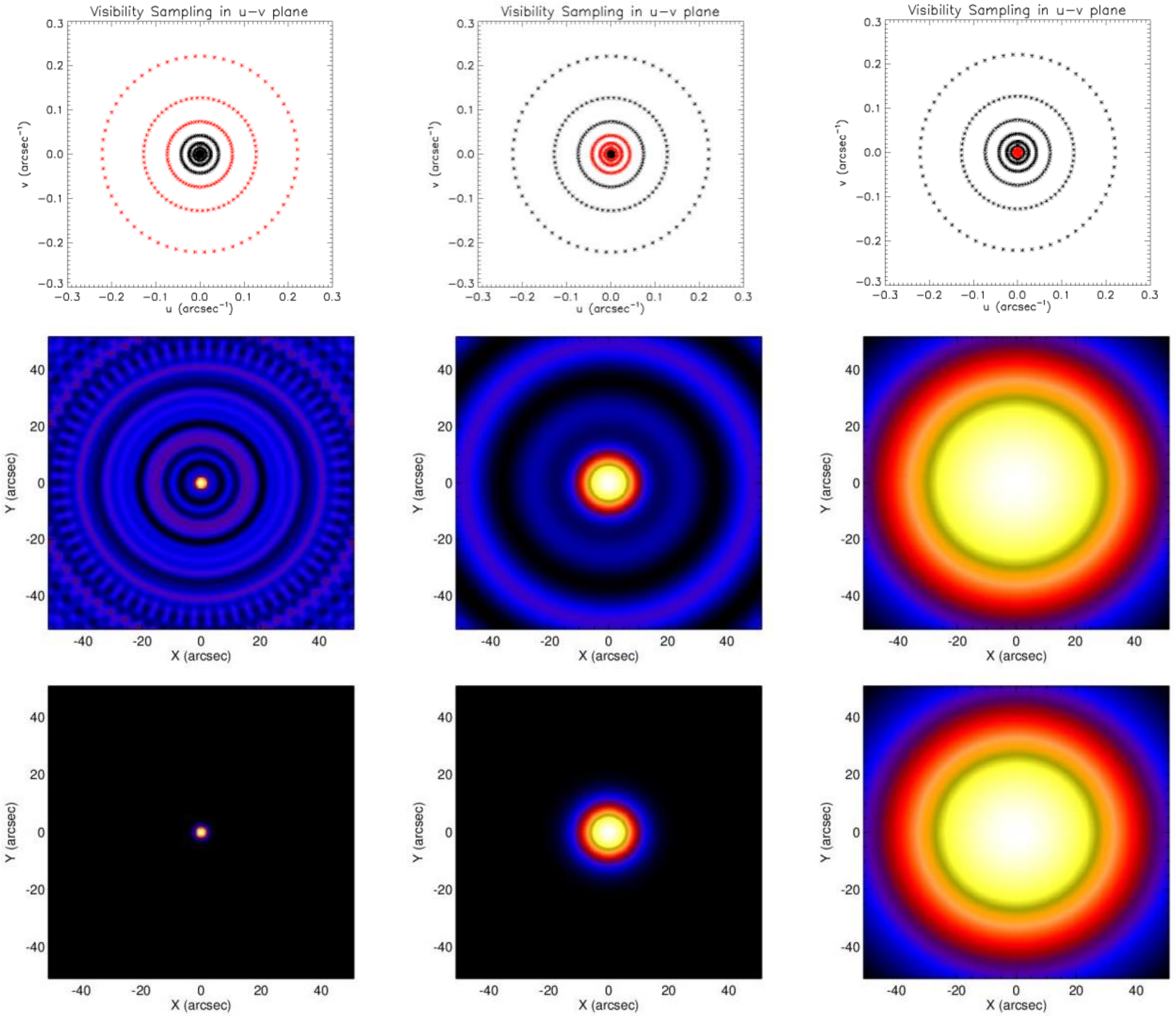
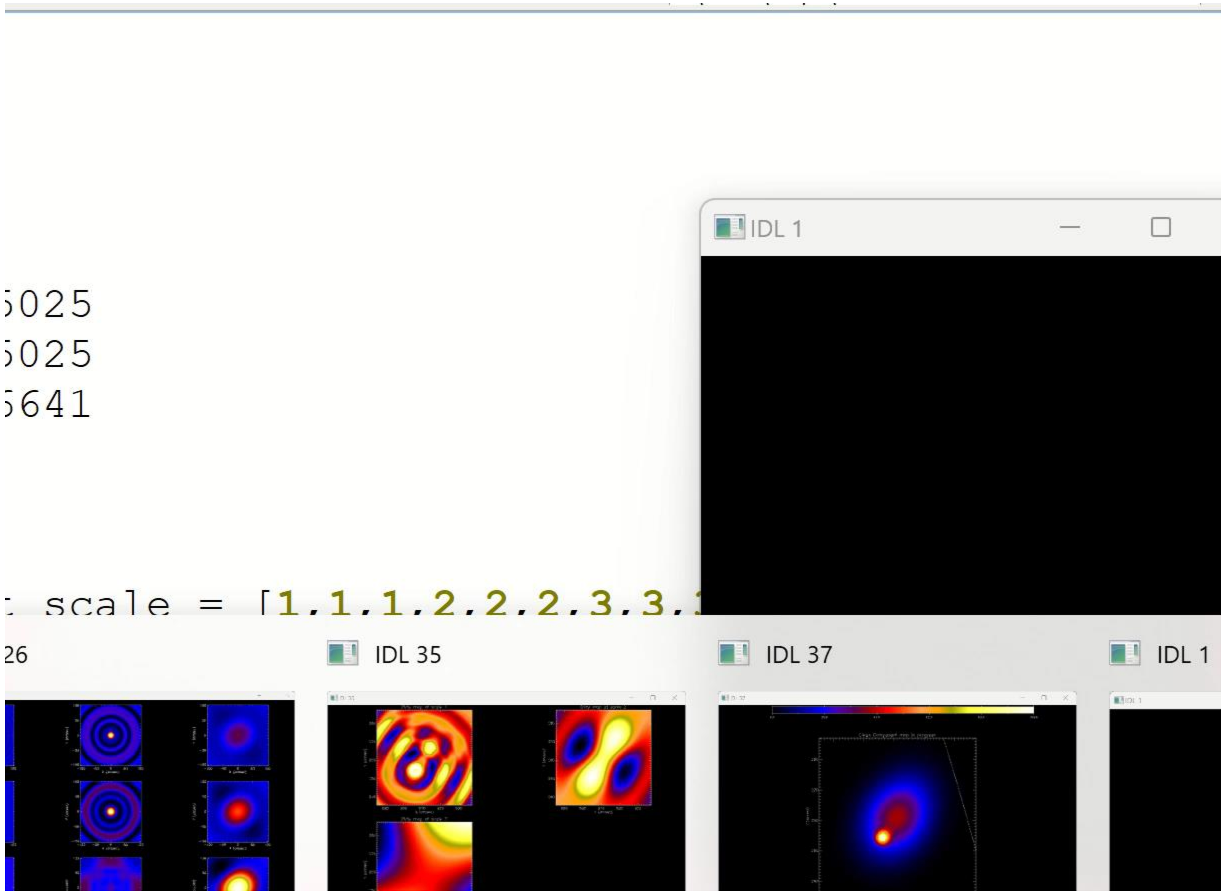
Multi-scale CLEAN algorithm



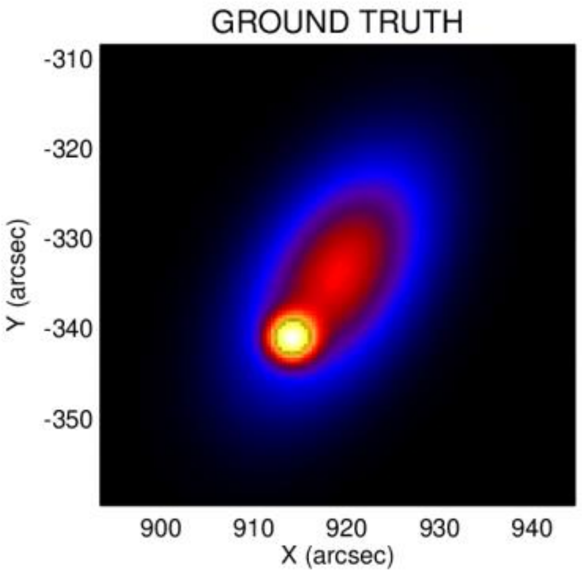


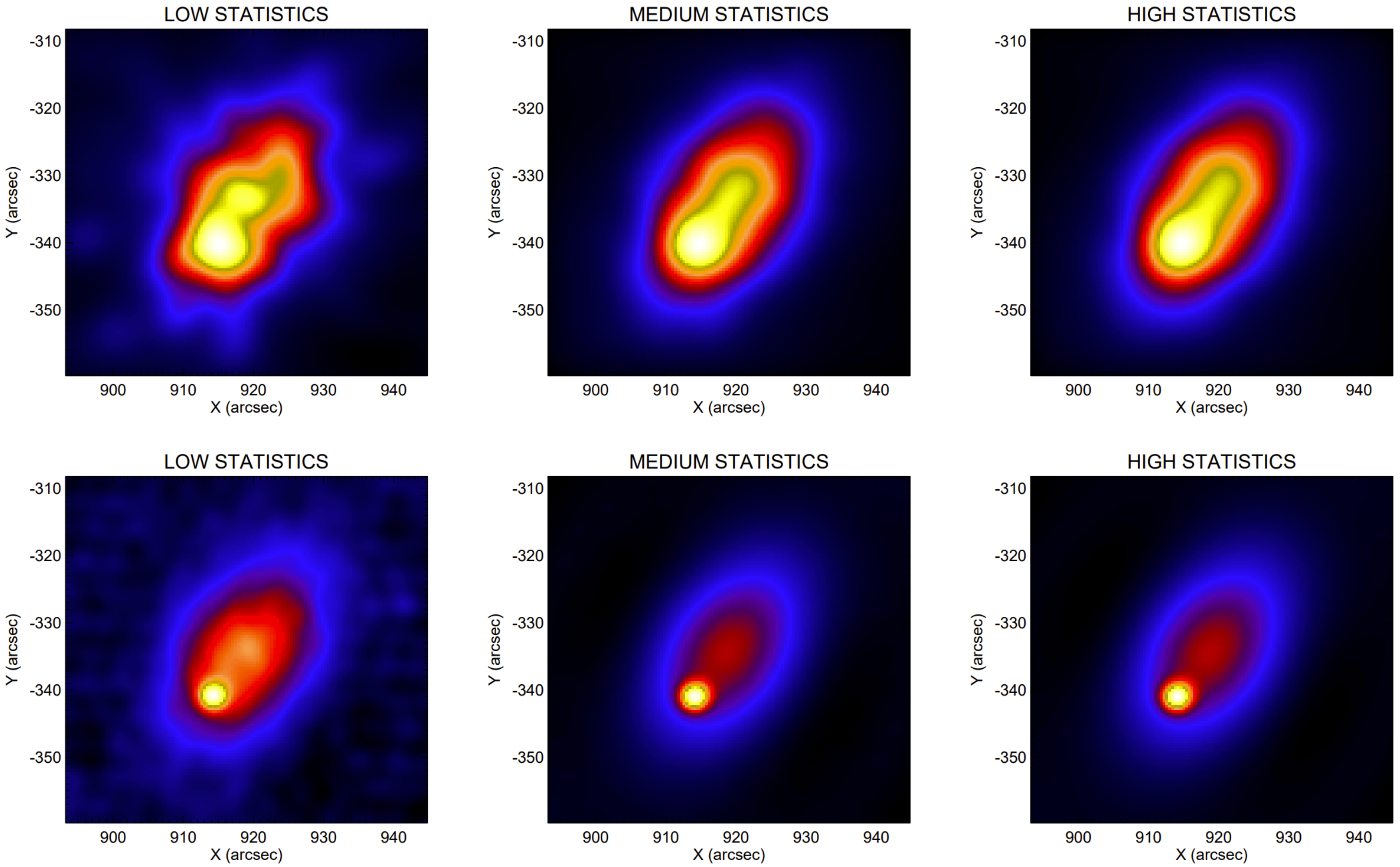
Top row: visibilities grouped in the same scale. *Middle row*: the three PSF components using 3 scales: det. 1-2-3, det. 4-5-6, det. 7-8-9. *Bottom row*: the three corresponding basis functions.

Multi-scale CLEAN algorithm



Results – simulated visibilities





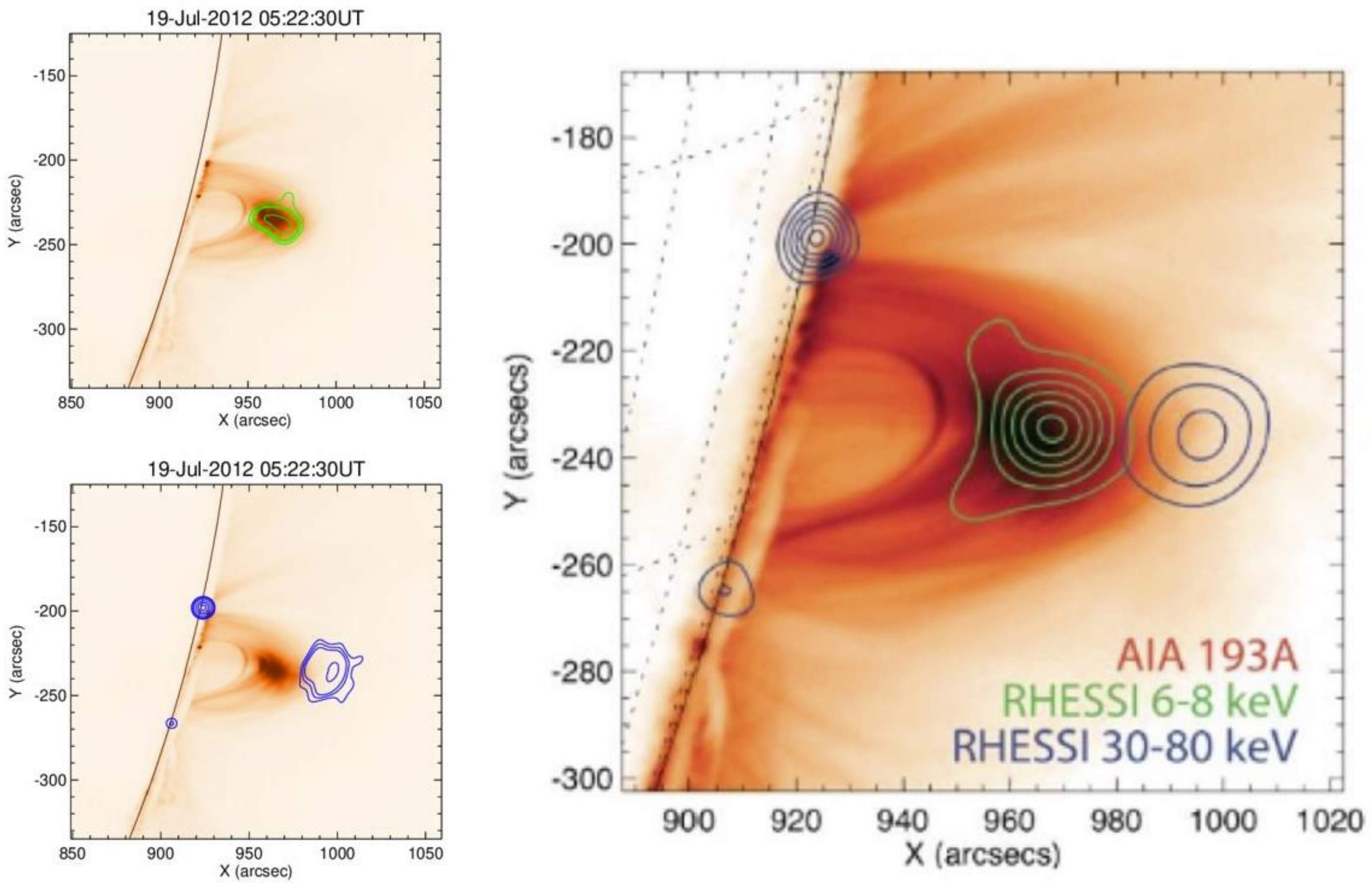
CLEAN vs multi-scale CLEAN for the reconstruction of the synthetic hard X-ray source. Reconstructions obtained by standard CLEAN (*top row*) and multi-scale CLEAN (*bottom row*) in the case of low, medium and high statistics.

Results – experimental visibilities

Energy range: 6 – 8 keV
3 scales: det. 3-4, det. 5-6, det. 7-8-9
Contour levels: 55, 65, 70, and 90%

Energy range: 30 – 80 keV
3 scales: det. 3-4, det. 5-6-7, det. 8-9
Contour levels:

Footpoints: 15, 20, 30, 50, 70,and 90%
Coronal source: 2, 2.5, 3, and 5%



Left panel: Multi-scale CLEAN reconstructions superimposed to the 193 $\dot{A}$ extreme ultra-violet map recorded by SDO/AIA. *Right panel*: the EUV emission provided by AIA with superimposed the level curves provided by the two-step CLEAN algorithm.

Multi-scale CLEAN algorithm

We exploit the fact that hard X-ray telescopes are characterized by a PSF that can be written as the sum of a finite number of PSF components, each one filtering a specific portion of the (u, v) plane

We group the circles in the (u, v) plane in *N* disjoint sets, we can define a number *N* of experimental PSF components, i.e. of dirty beams $\{K_j(x, y)\}_{j=1,..,N}$ such that

$$K(x,y) = \sum_{j=1}^{N} K_j(x,y) \qquad K_j(x,y) = \sum_{l=1}^{N_j} \exp[-2\pi i(xu_l^{(j)} + yv_l^{(j)})]\delta u \delta v \qquad j = 1, \ldots, N.$$

where N_j and $\{u_l^j, v_l^j\}_{\mathrm{l=1,..N_j}}$ are the number and the set of visibilities belonging to the $j-th$ subset of sampled circles in the (u, v) plane.

Using the same approach, we can define a set of *N* dirty maps

$$I^D(x,y) = \sum_{j=1}^{N} I_j^D(x,y) \qquad I_j^D(x,y) = \sum_{l=1}^{N_j} V(u_l^{(j)}, v_l^{(j)}) \exp[-2\pi i(xu_l^{(j)} + yv_l^{(j)})]\delta u \delta v \qquad j = 1, \ldots, N$$

Multi-scale CLEAN algorithm

The source image $I(x, y)$ can be modeled as the superposition of the basis functions

$$I(x,y) = \sum_{i=1}^{N} \sum_{q_i=1}^{Q_i} I_{q_i} m_i(x - x_{q_i}, y - y_{q_i}) + B(x,y).$$

at scale *i*, for $i = 1, \dots, N$, there are Q_i sources, each one placed at (x_{q_i}, y_{q_i}) and with peak intensity I_{q_i} for $q_i = 1, \dots, Q_i$

$$I^D(x,y) = \sum_{j=1}^{N} I_j^D(x,y) = \sum_{j=1}^{N} \left(\sum_{i=1}^{N} \sum_{q_i=1}^{Q_i} I_{q_i} (m_i * K_j)(x - x_{q_i}, y - y_{q_i}) + (K_j * B)(x,y) \right) \tag{5}$$