RHESSI X – Annapolis
August 1-6, 2010

Imaging with visibilities: uv_smooth

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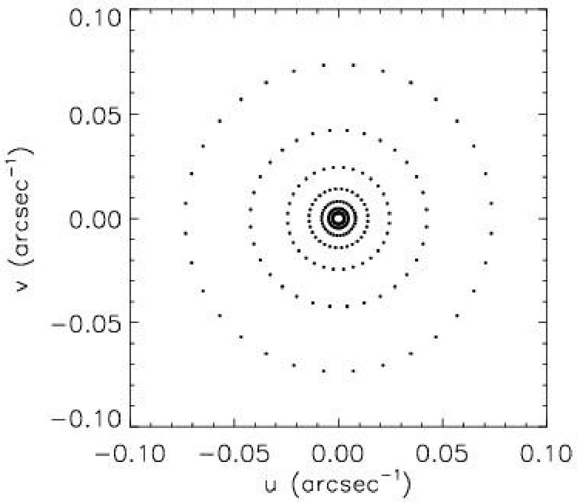
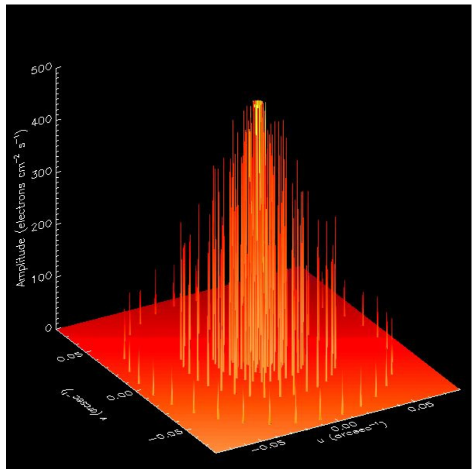
Imaging with RHESSI visibilities

The nine Rotating Modulation Collimators generate Fourier components (real and imaginary parts) in series of nine circles in Fourier space:

$$V(u,v;\varepsilon)=\iint I(x,y;\varepsilon)\,e^{2\pi i(ux+vy)}\,dxdy$$





how RHESSI samples the uv space

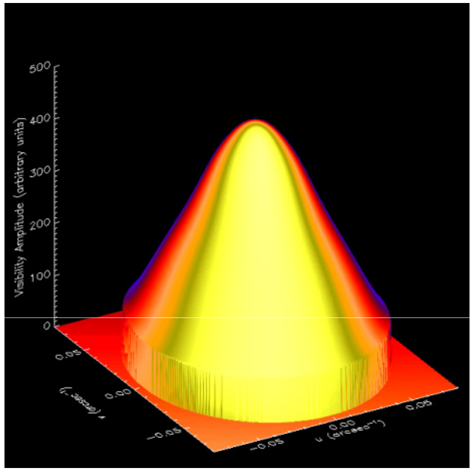
visibility amplitudes

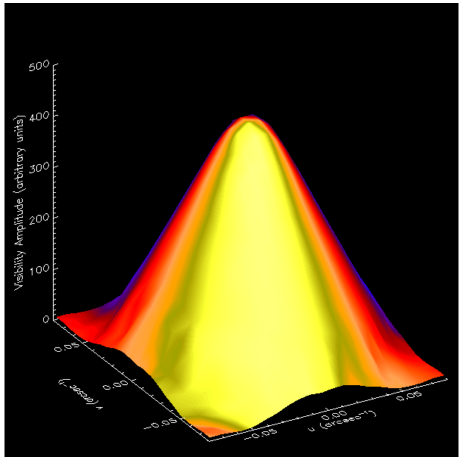
The idea of *uv_smooth*

uv_smooth is an imaging algorithm for hard X-ray imaging of solar flares using interpolated visibilities

(massone, emslie, hurford, prato, kontar and piana, *astrophys. j.* 2009)

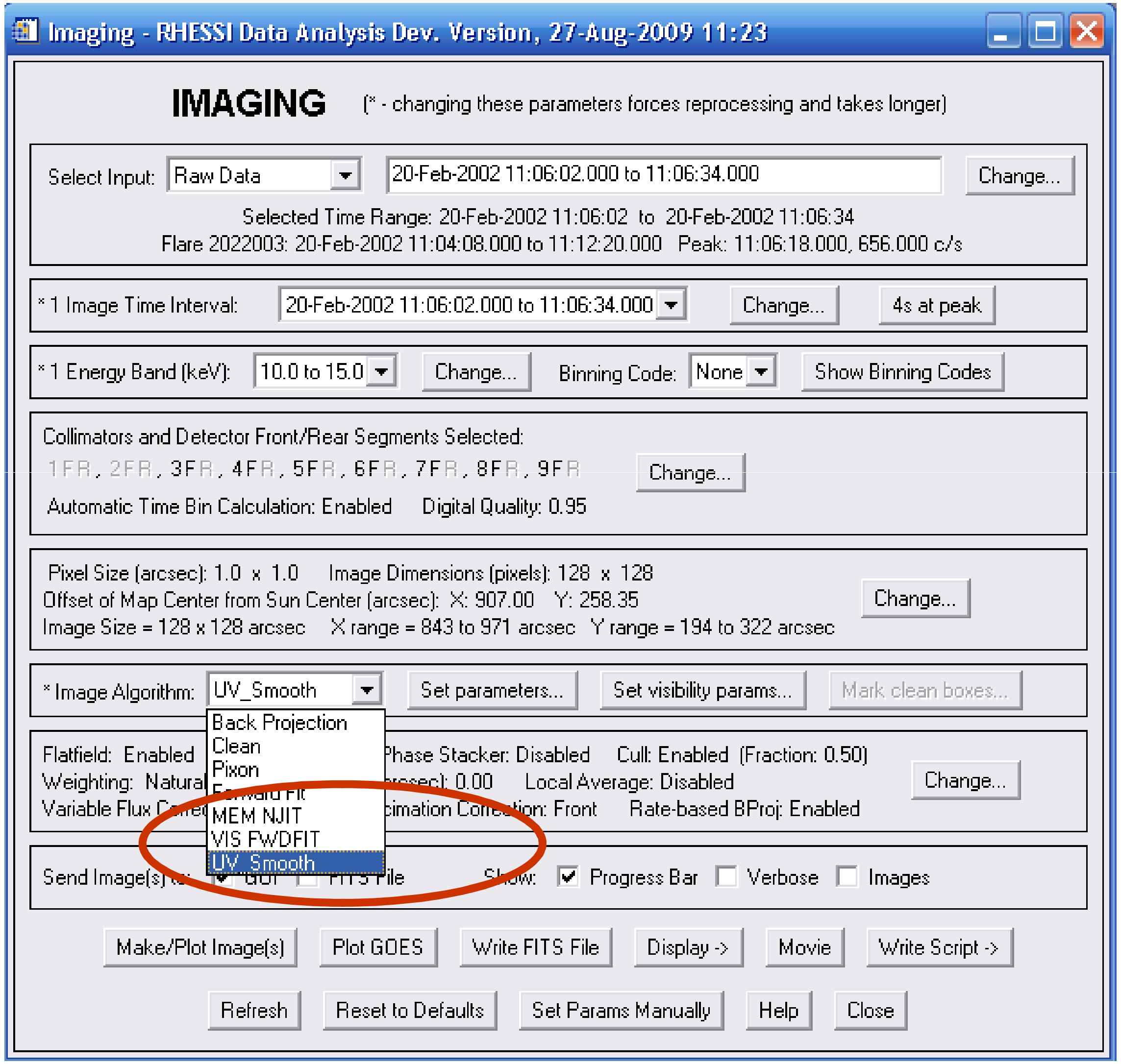
1. if R is the biggest collimator radius in the uv-plane, estimate the visibilities inside the circle of radius R by means of an interpolation routine





2. using these uniformly-spaced visibility values in a **FFT**-image reconstruction algorithm AND the imposition of a **positivity constraint** on the image produces images in which many of the undesirable sidelobes associated with sparse ($u; v$) sampling are suppressed → extrapolation effects

uv_smooth in the SSW gui



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Electron visibilities and electron maps

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From photon to electron visibilities

- Photon visibility definition:

$$V(u,v;\varepsilon) = \iint I(x,y;\varepsilon)\, e^{2\pi i(ux+vy)}\, dxdy$$

- Bremsstrahlung equation:

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

- Electron visibility definition:

$$W(u,v;E) := \frac{a^2}{4\pi R^2} \iint \overline{F}(x,y;E)\, e^{2\pi i(ux+vy)}\, dxdy$$

- Bremsstrahlung equation for visibilities

$$V(u,v;\varepsilon) = \int_{\varepsilon}^{\infty} W(u,v;E)\, Q(\varepsilon,E)\, dE$$

From photon to electron visibilities

$$V(u,v;\varepsilon) = \int_{\varepsilon}^{\infty} W(u,v;E)Q(\varepsilon,E)dE$$

The relation between the **measured photon visibilities** and the **electron visibilities** is described by a Volterra integral equation of the first kind

Visibility inversion problem: determine the electron visibilities, *W(u,v;E)*, from the observed count visibilities *V(u,v;ε)*

Visibility information in photon space may, through a (regularized) spectral inversion technique, be converted to visibility information in the *electron* domain.

Electron maps

Algorithm for electron image reconstruction:

1. for each (u,v) pair solve

$$V(u,v;\varepsilon) = \int_{\varepsilon}^{\infty} W(u,v;E)\,Q(\varepsilon,E)\,dE$$

   by means of Tikhonov regularization algorithm (which smoothes along the energy direction)

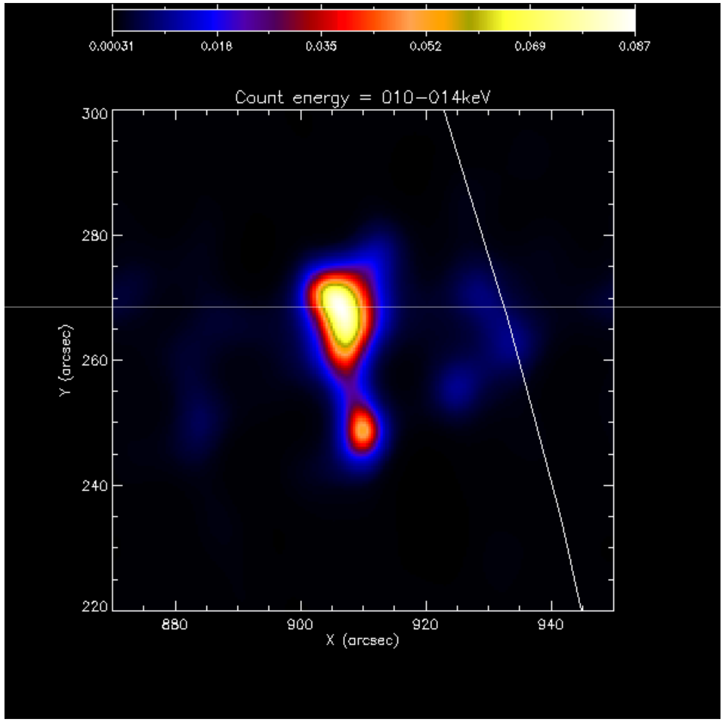
2. for each E solve

$$W(u,v;E) = \frac{a^2}{4\pi R^2} \iint \overline{F}(x,y;E)\,e^{2\pi i(ux+vy)}\,dx\,dy$$

   by means of a Fourier-based imaging algorithm (which reduces ringing effects by imposing appropriate constraints)

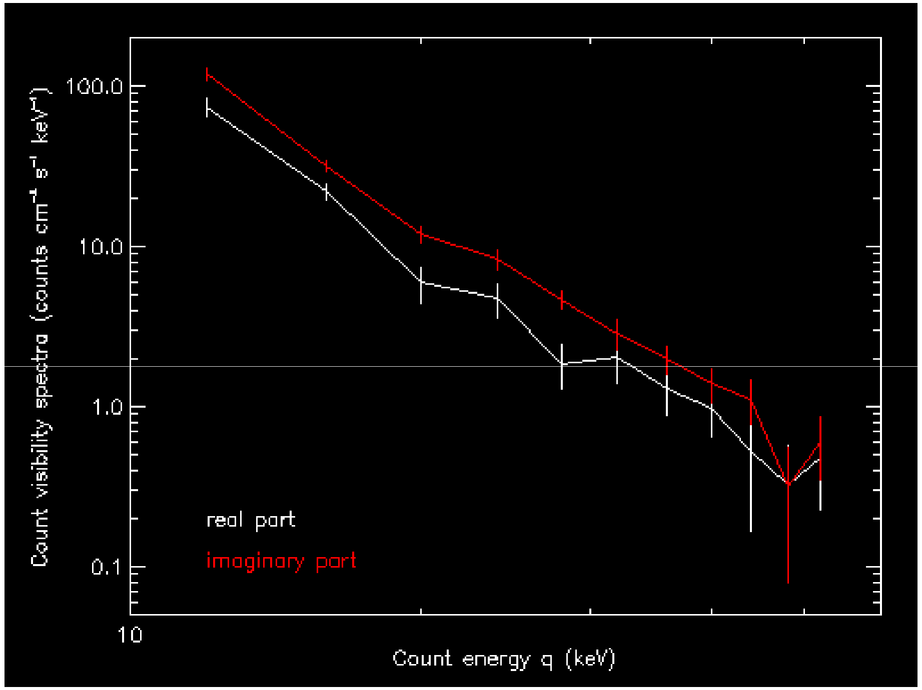
Visibility inversion algorithm: implementation

$$
\begin{array}{c|cccc|}
 & \varepsilon_1 & \varepsilon_2 & \cdots & \varepsilon_N \\
\hline
(u_1, v_1) & V_{1,1} & V_{1,2} & \cdots & V_{1,N} \\
(u_2, v_2) & V_{2,2} & \cdots & \cdots & \cdots \\
\vdots & \vdots & \ddots & & \vdots \\
(u_V, v_V) & V_{V,V} & \cdots & \cdots & V_{V,N} \\
\hline
\end{array}
$$



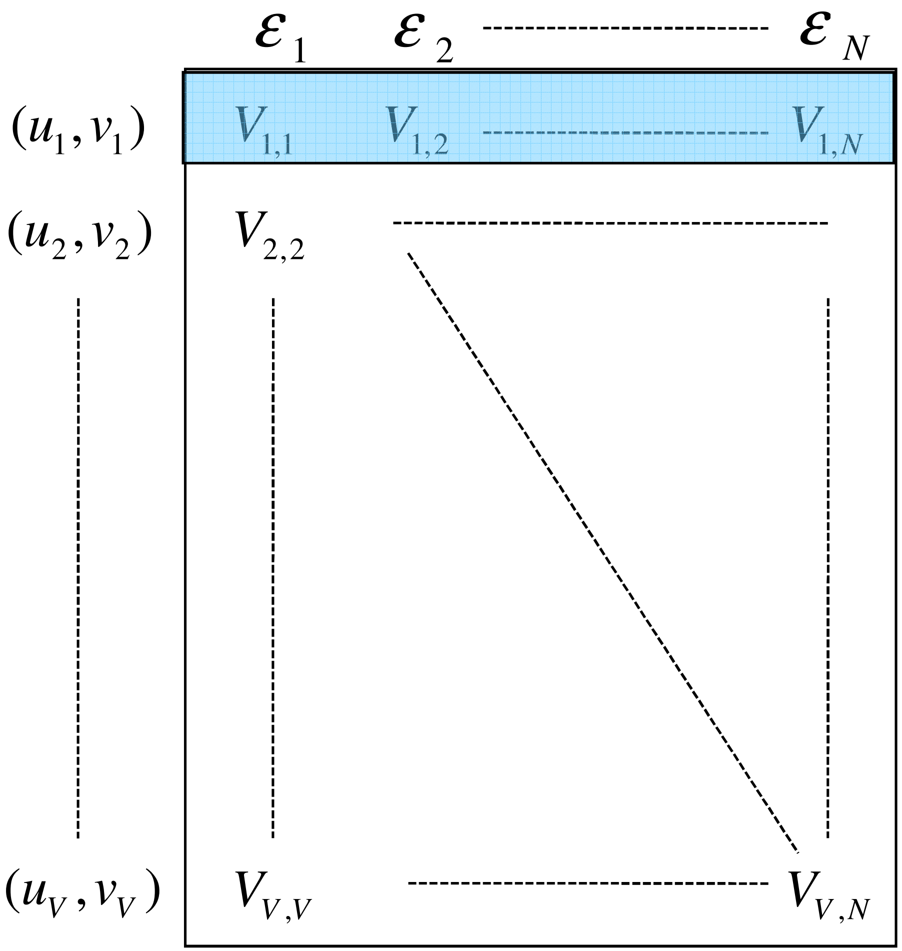
Visibility inversion algorithm: implementation

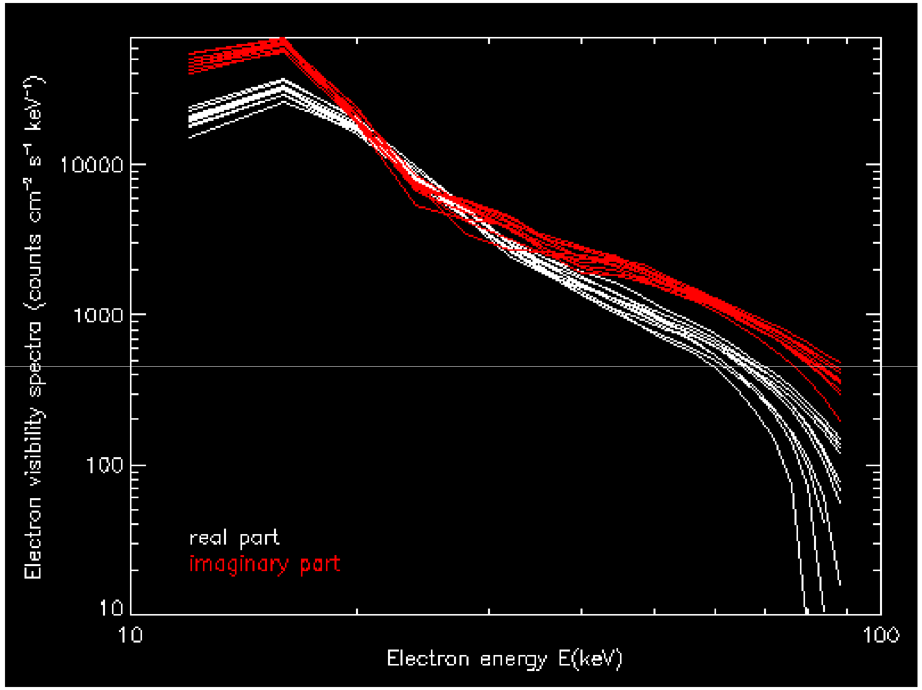
$$\begin{array}{c|cccc} & \varepsilon_1 & \varepsilon_2 & \cdots & \varepsilon_N \\ \hline (u_1,v_1) & V_{1,1} & V_{1,2} & \cdots & V_{1,N} \\ (u_2,v_2) & V_{2,2} & \cdots & \cdots & \cdots \\ \vdots & \vdots & & \ddots & \vdots \\ (u_V,v_V) & V_{V,V} & \cdots & \cdots & V_{V,N} \end{array}$$



$$V(u_1, v_1; \varepsilon)$$

Visibility inversion algorithm: implementation



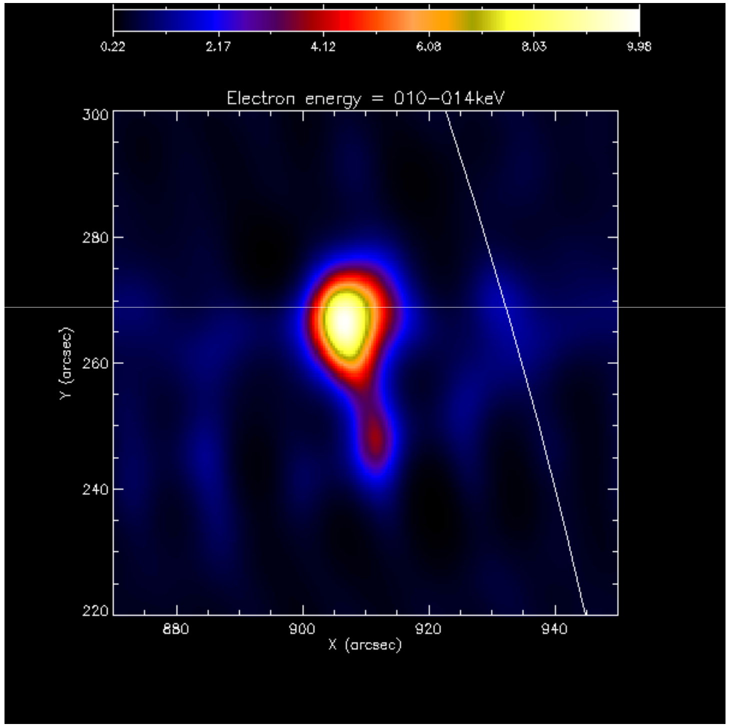


$$W(u_1, v_1; E)$$

Visibility inversion algorithm: implementation

$$
\begin{array}{c|cccc|}
 & \varepsilon_1 & \varepsilon_2 & \cdots & \varepsilon_N \\
\hline
(u_1, v_1) & V_{1,1} & V_{1,2} & \cdots & V_{1,N} \\
(u_2, v_2) & V_{2,1} & \cdots & \cdots & \cdots \\
\vdots & \vdots & & \ddots & \vdots \\
(u_V, v_V) & V_{V,1} & \cdots & \cdots & V_{V,N} \\
\hline
\end{array}
\qquad
\begin{array}{|cccc|}
E_1 & E_2 & \cdots & E_M \\
\hline
W_{1,1} & W_{1,2} & \cdots & W_{1,M} \\
 & & & \\
 & & & \\
 & & & \\
\hline
\end{array}
$$

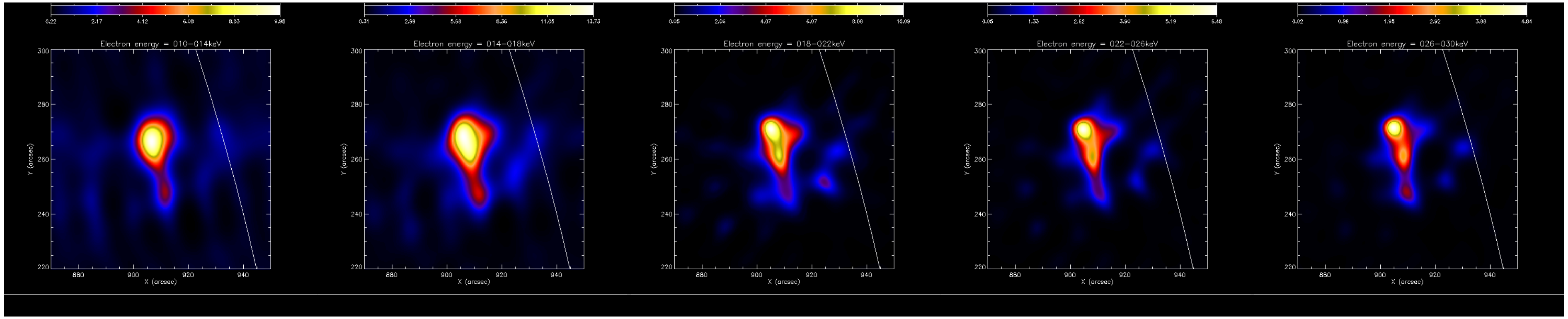
From electron visibilities to electron maps



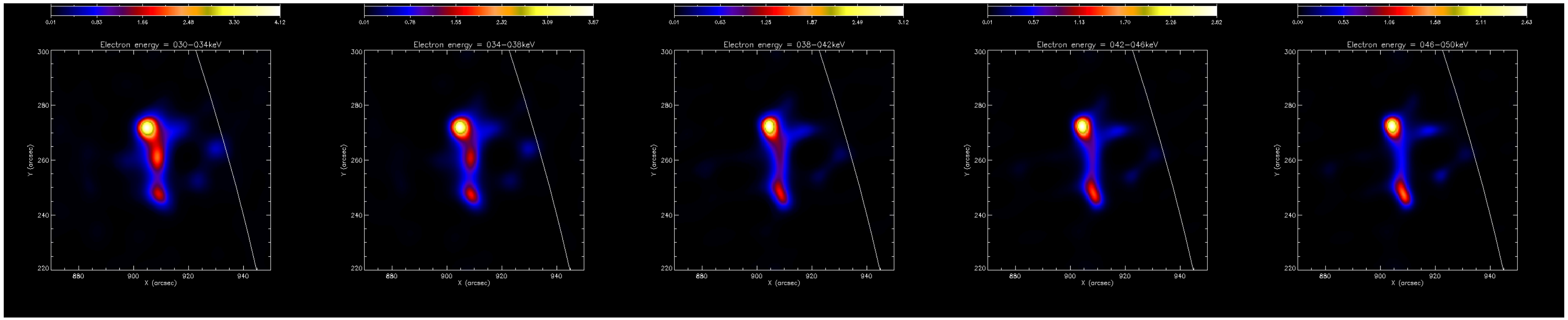
$$
\begin{array}{cccc}
E_1 & E_2 & \cdots & E_M \\
\hline
W_{1,1} & W_{1,2} & \cdots & W_{1,M} \\
W_{2,1} & \cdots & \cdots & \cdots \\
\vdots & & \ddots & \vdots \\
W_{V,1} & \cdots & \cdots & W_{V,M}
\end{array}
$$

Visibility-based electron maps

Imaging from visibilities: MEM



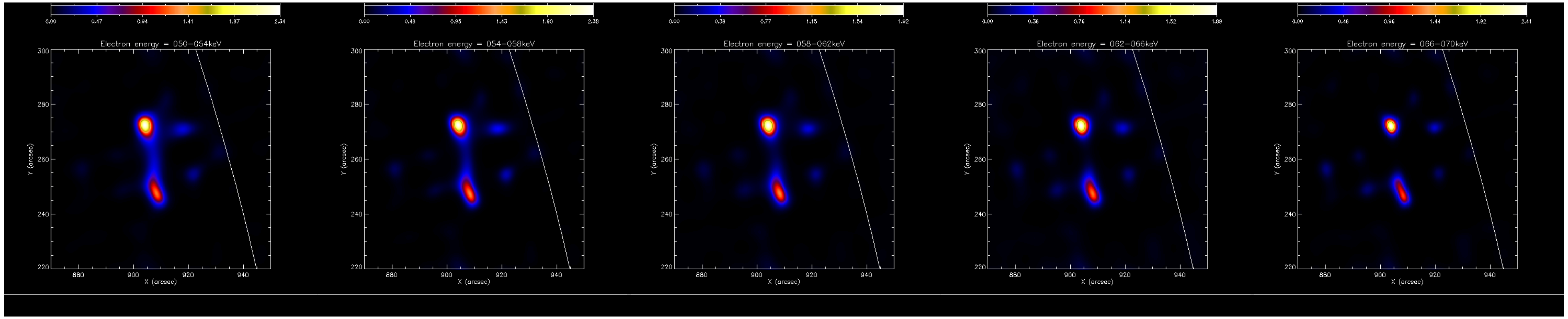
10-14 keV   14-18 keV   18-22 keV   22-26 keV   26-30 keV



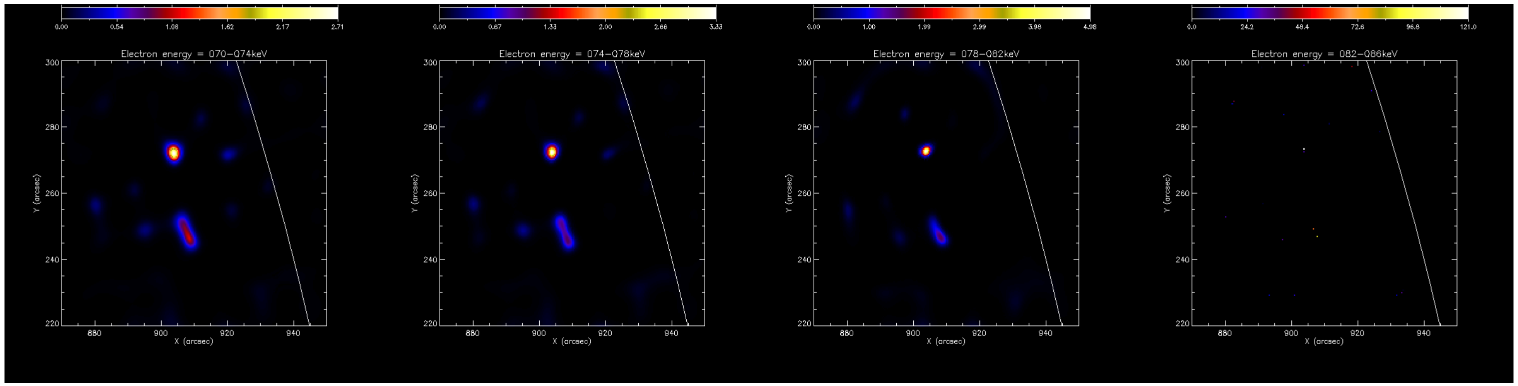
30-34 keV   34-38 keV   38-42 keV   42-46 keV   46-50 keV

Visibility-based electron maps

Imaging from visibilities: MEM

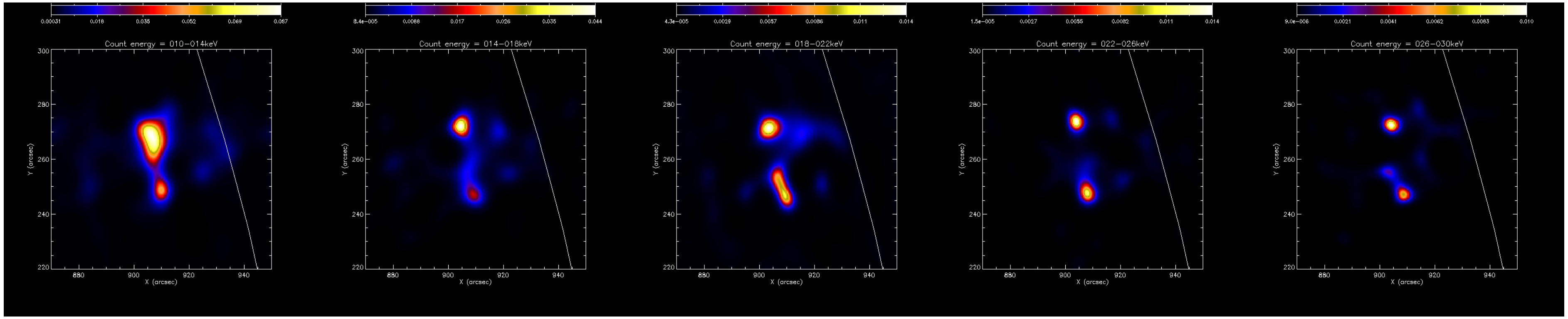


50-54 keV | 54-58 keV | 58-62 keV | 62-66 keV | 66-70 keV

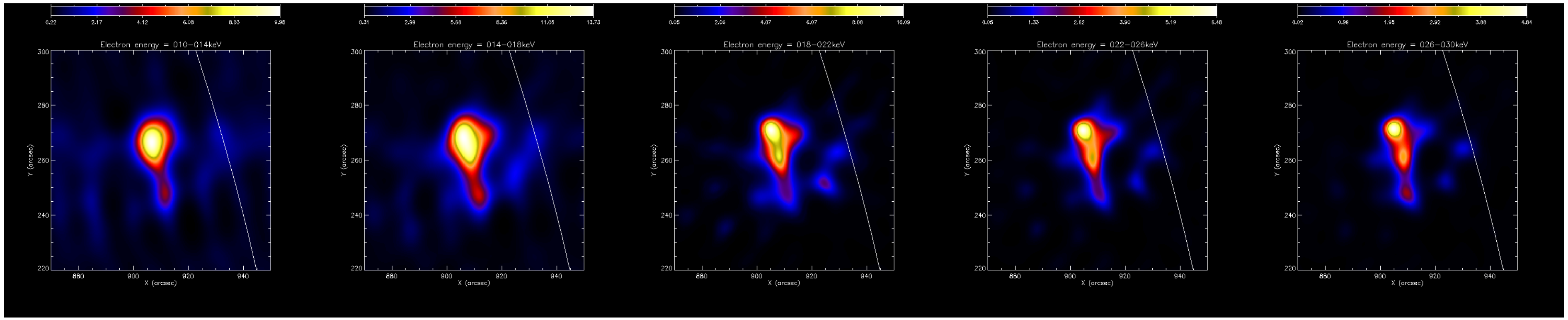


70-74 keV | 74-78 keV | 78-82 keV | 82-86 keV | 86-90 keV

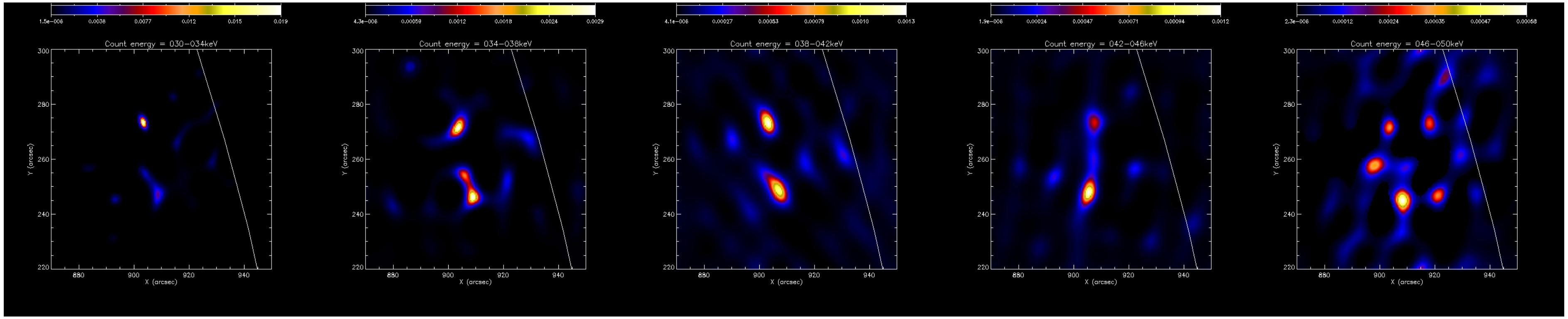
Photon maps vs electron maps



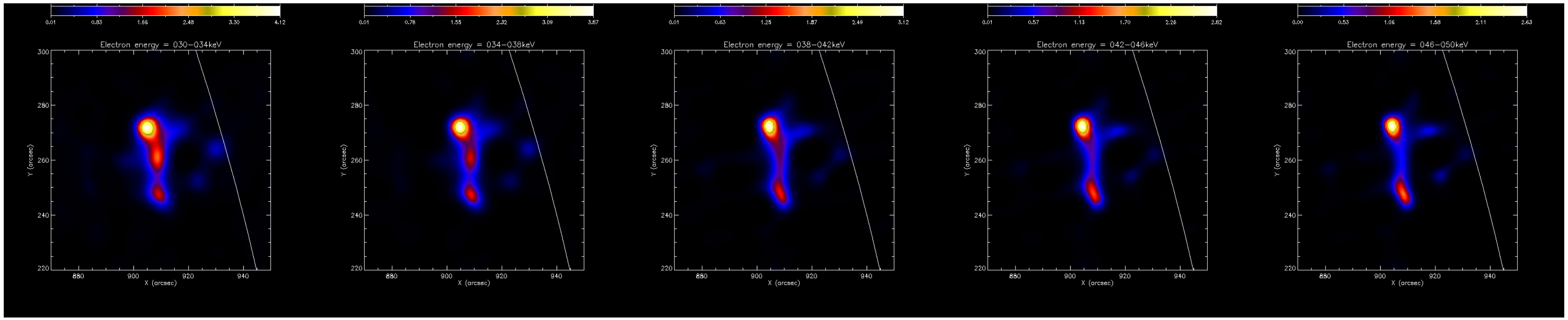
10-14 keV 14-18 keV 18-22 keV 22-26 keV 26-30 keV



Photon maps vs electron maps



30-34 keV 34-38 keV 38-42 keV 42-46 keV 46-50 keV



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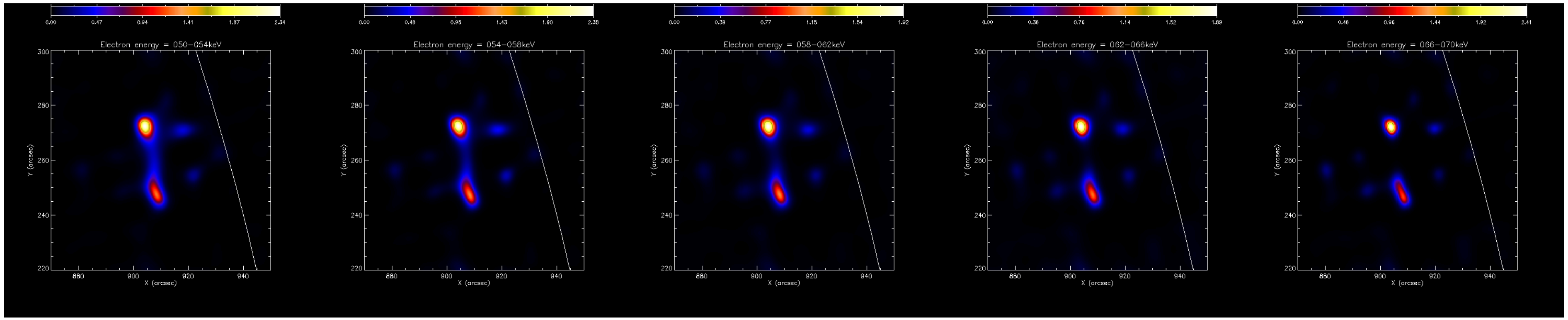
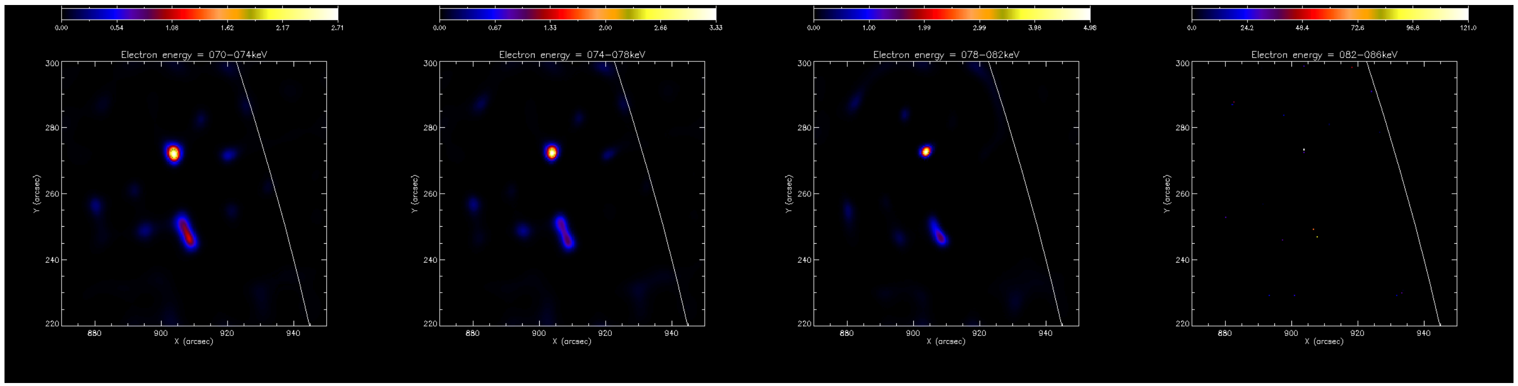


Photon maps vs electron maps

70-74 keV 74-78 keV 78-82 keV 82-86 keV



APPLICABILITY CONDITIONS

This software is an effective imaging spectroscopy procedure, i.e. it provides electron visibility cubes from photon visibility cubes. Therefore:

- you need count visibilities at many count energies
- you need uniform sampling of the count energies (optimal energy bins 2-4 keV)
- the output electron energies are uniformly sampled with the same bin (but you can resample by combining visibilities)
- you will have more output electron energies than input count energies
- the count visibilities are combined before inversion, then the electron visibility are combined too (i.e. $u>0$)
- the visibility spectral inversion procedure may fail for some u,v points

  → you may have less electron visibility spectra than count visibility spectra