MEM Imaging for RHESSI

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RHESSI Imaging

The Ramaty High Energy Solar Spectroscopic Imager, or RHESSI, has been observing solar flares in the 3 keV - 17 MeV domain since February 2002. The instrument is a rotating modulation collimator with a set of 9 grid pairs, each with a corresponding pitch or wavenumber, and an HPGe detector behind each subcollimator. Incoming photons are modulated by the hardware and RHESSI software creates a modulation profile. Using the profiles, we can construct visibilities and then produce an image.

Visibilities

Visibilities, which are vectors with amplitudes and phases, form the basis of imaging with radio interferometers. The amplitudes and phases for the RHESSI modulation profiles create visibilities that are mathematically identical to the interferometer visibilities. Thus, each amplitude and phase from the modulation profiles forms a complex vector for each rotation angle and spatial frequency.

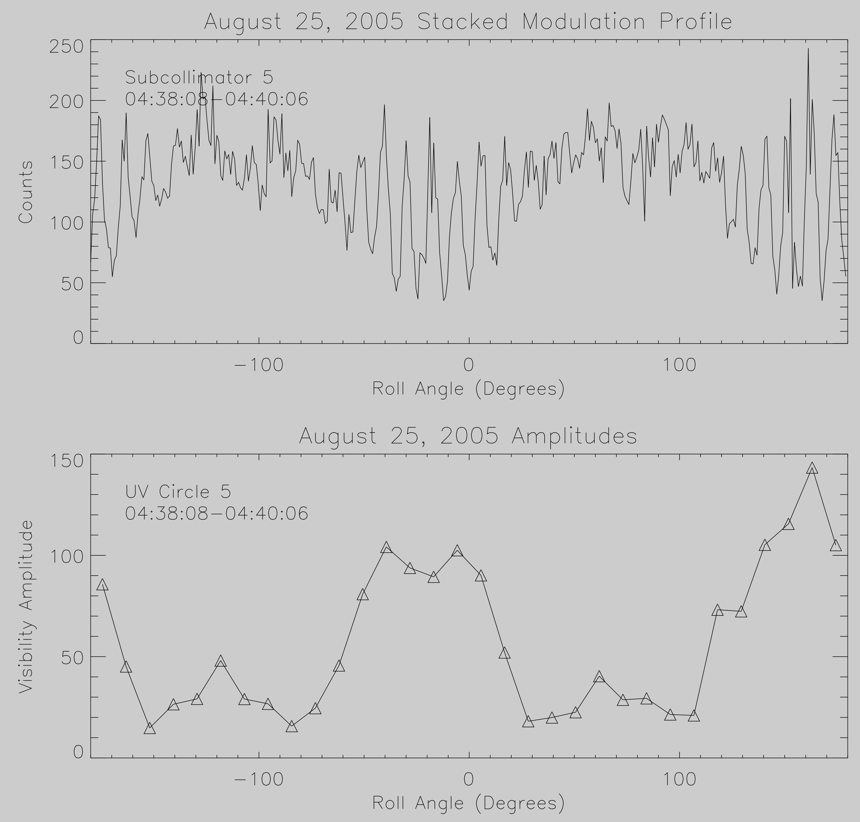

Figure 1

The rotating subcollimators provide samples of spatial frequencies $\vec{k} = (u_i, v_i)$ on 9 (u,v) circles whose radii ($|k_i| = \sqrt{u_i^2 + v_i^2}$) are inversely proportional to the angular resolution. The smallest (u,v) circle (k_9) corresponds to the coarsest subcollimator 9, and the largest (u,v) circle corresponds to the finest collimator, which has an angular resolution of $\sim 2.3''$ (FWHM). Some extended sources require that only the smaller circles are used to avoid over-resolution and reduce noise, while compact flares can only be resolved with the larger circles.

MEM_NJIT

MEM_NJIT is a part of Spatio-Spectral Maximum Entropy Method (SSMEM) that was originally developed as a 3-D MEM with x, y, and ν (frequency) coordinates (Bong et al. 2005,2006). Lee et al. at NJIT developed the 2-D version for RHESSI by turning off the frequency coordinates.

Traditionally, the Maximum Entropy Method minimizes an objective function. In the case of MEM_NJIT, the objective function introduced by Cornwell and Evans (1985) was used by Bong et al (2005,2006). Setting the function to zero after differentiating with respect to each pixel brightness F_{ij} yields:

$$\nabla J = \nabla H - \alpha \nabla \chi^2 - \beta = 0 \quad (1)$$

Here, H is the entropy term: $\Sigma F_{ij} log(F_{ij})$, where F_{ij} is the flux of a pixel at position (i,j) on a map. χ^2 is the customary goodness-of-fit measurement. α and β are Lagrange multipliers.

Image Comparison

We executed MEM_NJIT, Clean, and Pixon on 25 double footpoint flares. All flares have more than one well-resolved footpoint and $> 10^4$ counts in the Clean images from the RHESSI database. Energies above 25 keV were mapped to avoid imaging any thermal components. Figure 2 displays images produced by the three algorithms on a subset of our 25 flares.

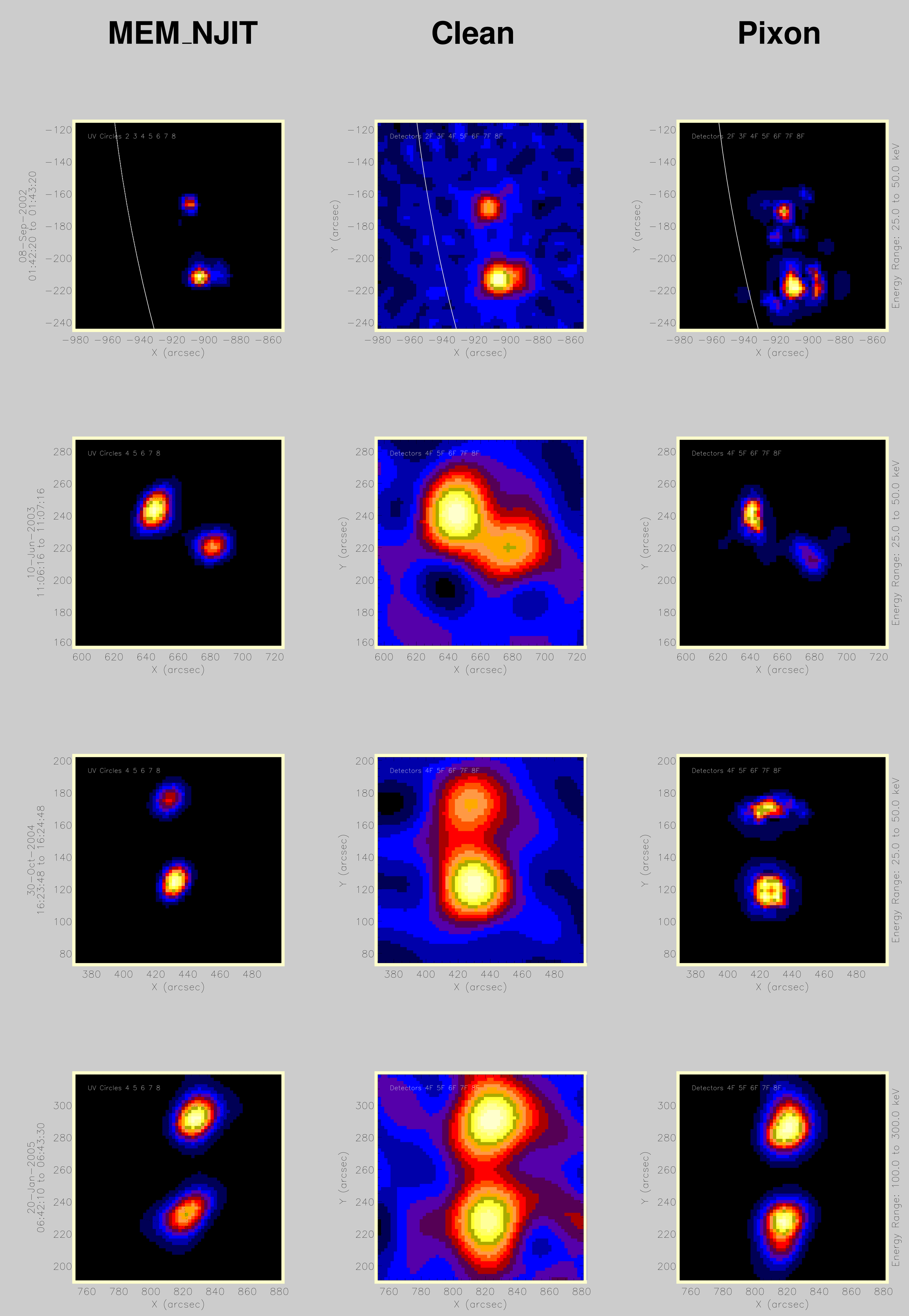

Figure 2

Statistical Comparison

Two measurements, flux and position, were made for each source in each image in order to validate the MEM_NJIT maps. "Position" here means the centroid of each footpoint. Both values were calculated using pre-selected regions in the images and were then compared to Clean and Pixon values. The results can be seen in Figure 3.

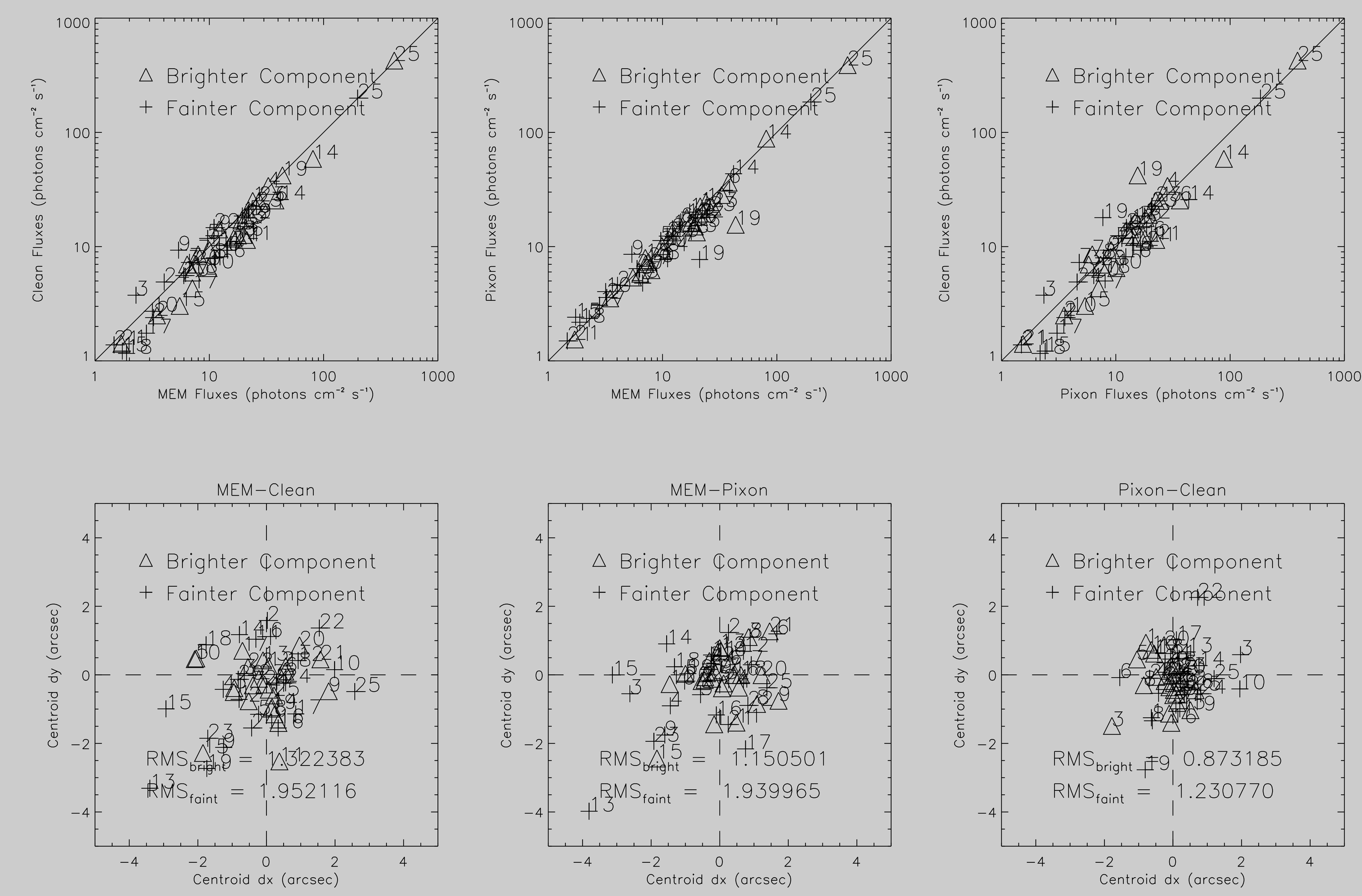

Figure 3

Weaknesses and Strengths

Weaknesses

- "Super-resolution" produces an unreliable source size estimate
- Positions have a larger dispersion than Clean and Pixon
- Visibilities have to be calculated before mapping
- The user must input a total flux before processing

Strengths

- MEM_NJIT isolates sources in flares that cannot be isolated in Clean (makes better use of the finer collimators)
- Qualitatively and quantitatively similar to Pixon
- More efficient than any current imaging algorithm (2-3 times faster than Clean and 2 orders of magnitude faster than Pixon)
- The program converges on the true flux even with errors of up to $\sim$ 30% in the input flux

After testing MEM_NJIT on approximately 30 flares, we do believe that its advantages, specifically its efficiency, outweigh its disadvantages.

REFERENCES

Bong, S.-C., Lee, J., Gary, D. E., Yun, H.S., & Chae, J.: 2005 '1' *JKAS*, **38**, 445.

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Cornwell, T. J., & Evans, K. F.: 1985, *A&A* **143**, 77.