Image Deconvolution of XMM-Newton Data

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The on-axis point-spread function (PSF) of each XMM-Newton mirror is around 5" FWHM at 1.5 keV. The shape of the PSF is complicated by shadowing caused by the support structure that holds the mirror shells and the electron deflector within each telescope, and distortions due to circular asymmetry. Recent advances in modelling the shape of the PSF by the EPIC Instrument Calibration Team have offered the possibility of improved results from image deconvolution techniques. We present examples of how spatial structure not visible in objects in raw XMM-Newton images can be recovered using image deconvolution with this model PSF. For this study we have used EPIC-MOS data because of the higher spatial resolution of the detectors (1.1" pixels on the sky, c.f. 4.1" for EPIC-pn).

Introduction

The image on the right is a typical example of an EPIC-MOS1 observation of a point source on the optical boresight of the telescope. It shows the characteristics of the on-axis point spread function of the telescope due to the mirror and support structure that holds the mirror shells and the electron deflector within each telescope. The structure of the PSF changes significantly as a function of off-axis and azimuthal angle.

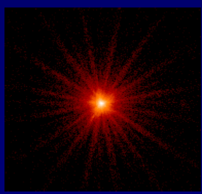
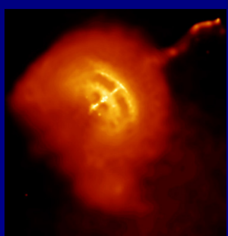
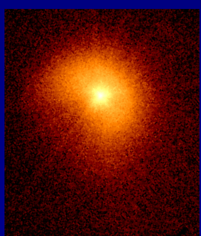


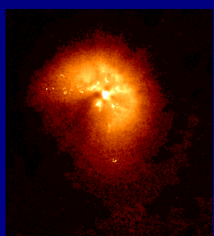
Image deconvolution is a useful technique to recover the original scene from the observed degraded data. With recent advances in modelling the point-spread function of the instrument, we are now able to apply the Richardson-Lucy Deconvolution method [1] to XMM-Newton data. For example, after deconvolving the EPIC-MOS Vela Pulsar Wind Nebula (PWN) data, we can see similar structure as is seen in a Chandra high-spatial resolution image, which was hardly visible in the raw MOS data.



Chandra Image



Observed MOS Image



Deconvolved MOS Image

Deconvolution Algorithm

The Richardson-Lucy deconvolution algorithm is an iterative procedure which can be described by the two formulae beneath:

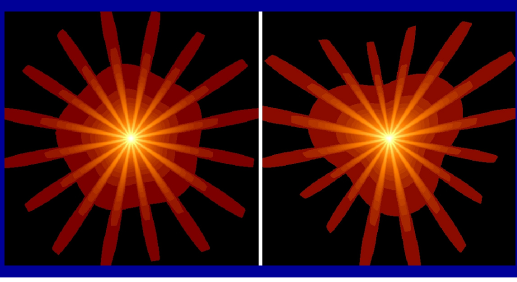
$$\phi^r(x) = \int \Psi^r(\xi) P(x \mid \xi) d\xi$$

$$\Psi^{r+1}(\xi) = \Psi^r \int \frac{\phi(x)}{\phi^r(x)} P(x \mid \xi) dx$$

where $P(x|\zeta)$ and $\phi(x)$ are the PSF of the instrument and the observed data respectively. $\Psi^r(x)$ is the rth prediction of the original scene from the given observed data and PSF.

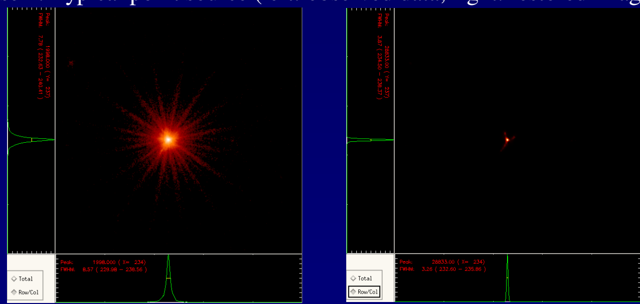
PSF Modelling

On-axis model PSFs of the EPIC-MOS detectors used in the deconvolutions are shown below (left: MOS1; right: MOS2).



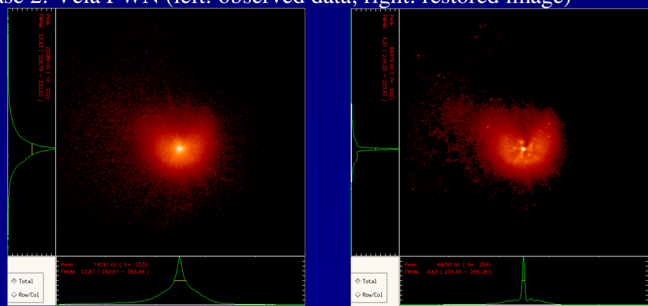
Examples

Case 1: Typical point source (left: observed data; right: restored image)



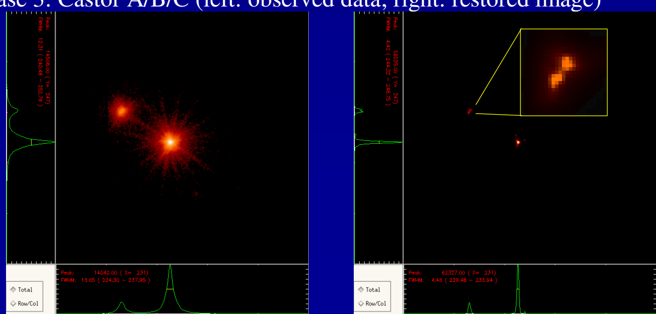
(The point source is restored with the FWHM reduced from about 9" to about 4".)

Case 2: Vela PWN (left: observed data; right: restored image)



(The shock structure is more visible and the histogram shows the Vela pulsar surrounded by the pulsar wind nebula.)

Case 3: Castor A/B/C (left: observed data; right: restored image)



(The twin stars, Castor A and B, to the upper-left area, are separated and visually distinguishable [see inset]. The histogram of the twin stars also shows a gap between the two stars. Castor C in the centre is restored with the FWHM reduced from about 14" to about 5".)

Conclusions & Future Work

- Richardson-Lucy deconvolution has been applied to EPIC-MOS data
- Fine structure within the sources can be resolved after deconvolution
- Unwanted structure is still seen in the deconvolved images, indicating that improvements are needed w.r.t. the PSFs and the algorithms
- Future application of method to off-axis sources using appropriate model PSFs

References: [1] Lucy L. B., 1976, The Astronomical Journal, 79, 6, 745-754