Deconvolution of ASCA Images of Galaxy Clusters and SNRs

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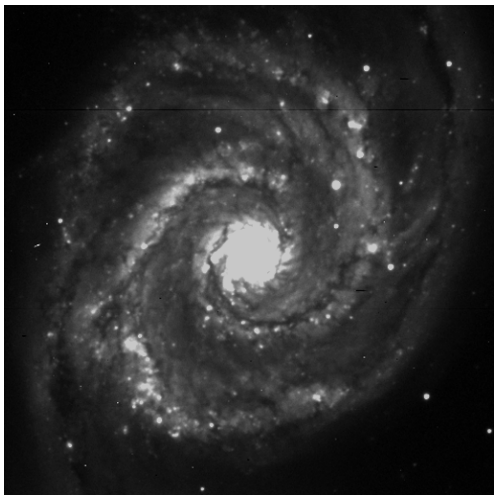
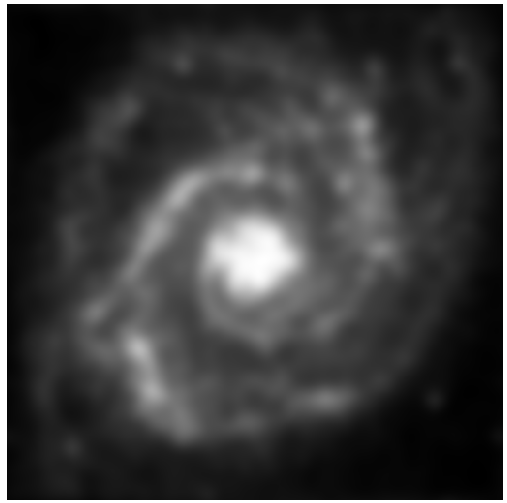
SLAC

Introduction – Inverse Problem



Response function,
Noise, Poisson error

Can it be restored?
Inverse problem



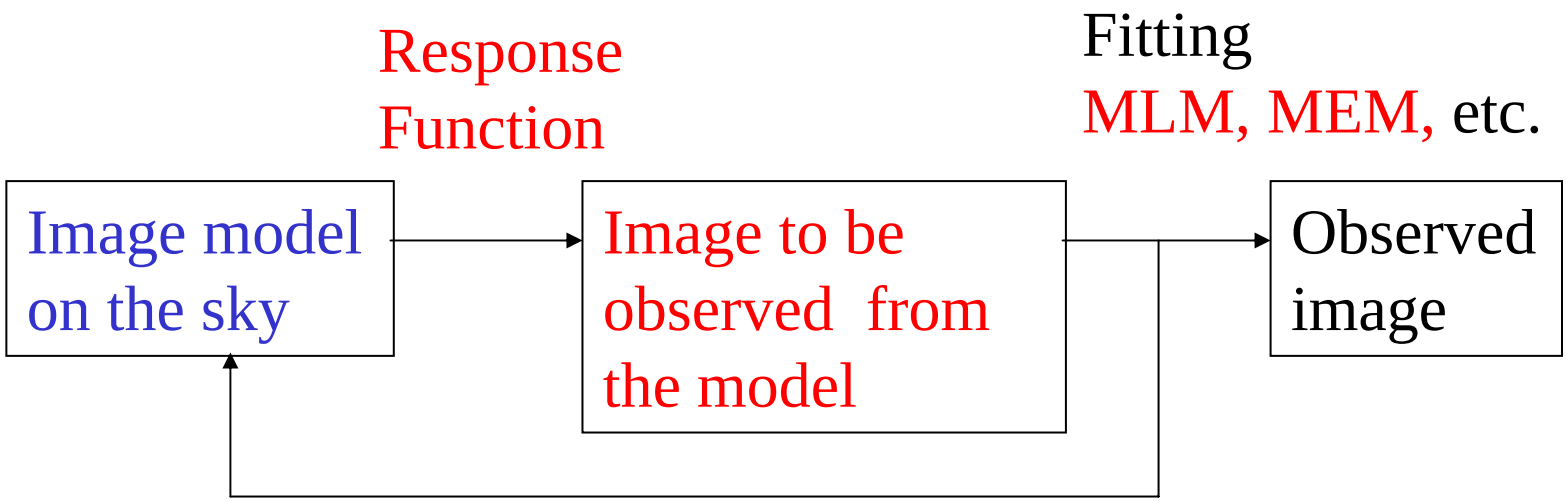
True Image

Observed Image

- How to obtain the best "true" image from the observed data?
- A classical and fundamental problem in observational astronomy

Image Analysis Method - 1

- **Forward method: fitting analysis**



Examples of the image model
- Flat background+point source candidates
- King model (cluster of galaxies)

Merit:
Forward calculation
Demerit:
Need to assume model
Biased by the fitting algorithm

Image Analysis Method – 2

- **Inverse method**

$$I_{obs}(x) = \Sigma\ P(x,y)\ I_{sky}(y)$$

$$I_{sky}(y) = \Sigma\ R(x,y)\ I_{obs}(x)$$

  - Number of pixel (x) on the instrument = $M = n_x \times n_y$
  - Number of pixel (y) on the sky = $M = n_x \times n_y$
  - $P(x,y)$: response matrix, ($M \times M$)
  - $R(x,y)$: Inverse of response matrix , ($M \times M$)

The computer power to calculate inversion matrix is now not a problem!
If we know the response matrix function perfectly and the observation data with the infinite accuracy, the image on the sky should be perfectly inverted.

Issues of Inverse Method

- **Merits:**
  - Unbiased, no need to assume any model
  - Ideal case: improve of spatial resolution, S/N ratio

    PSF width = w

    Pixel size of inversed image = d

    S/N on inversed image become $\times(w/d)^2$

- **Demerits:**
  - Artifact
    - Imperfect knowledge of response function (PSF)
    - Poisson noise
    - Numerical error

The resolution (pixel size) higher, the problem of the demerits becomes severer

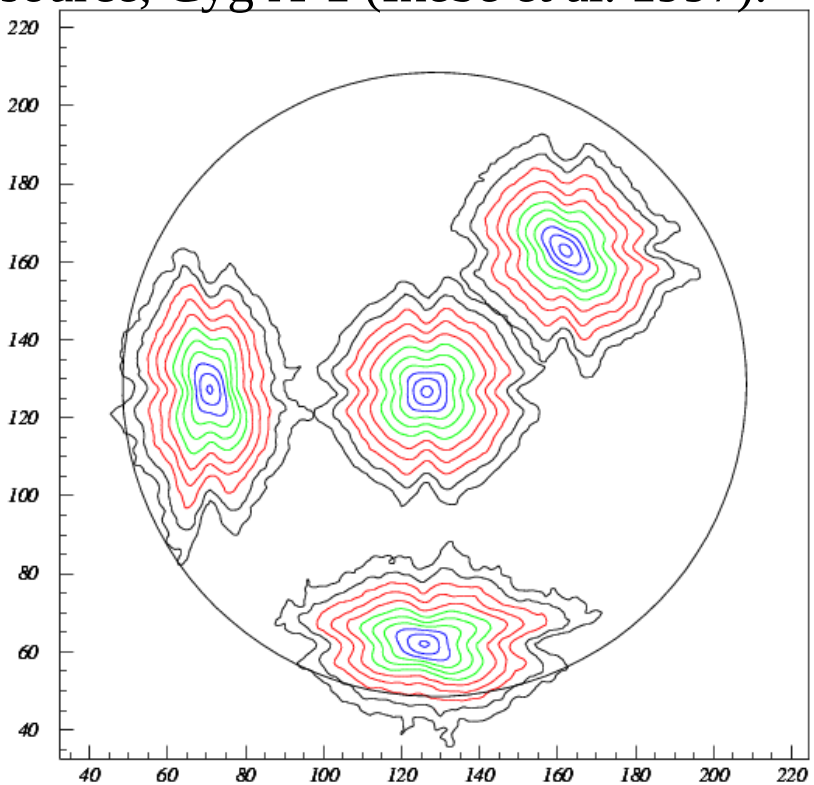
Issue: How to mitigate these artifact?

Technical stuffs to mitigate artifact

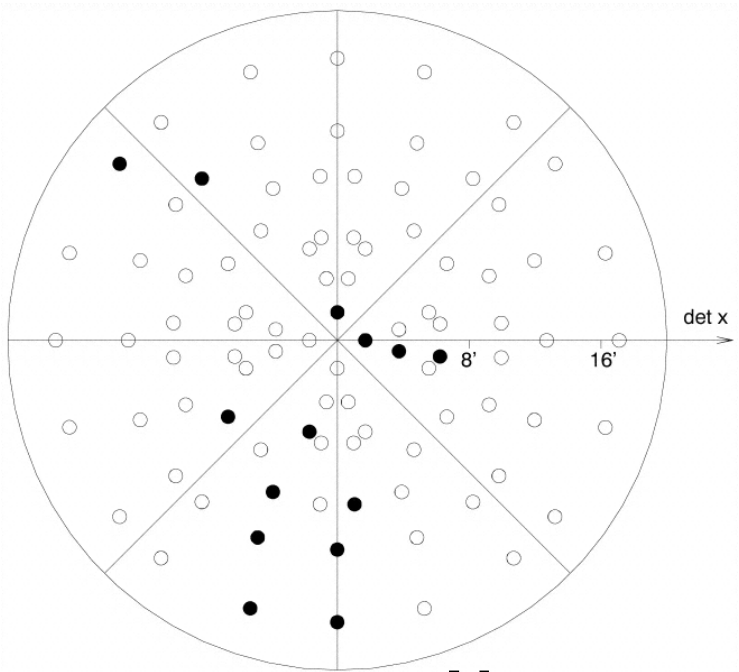
- **Incomplete knowledge of PSF:**
  - Use the very approved ASCA XRT-GIS point-spread function here.
- **Poisson error:**
  - Smoothing to mitigate the artifact fluctuation before/after inversion process if necessary
  - Use gaussian function here and tune the width to keep the optimal resolution.
- **Numerical error:**
  - Program for matrix inversion: numarray module in python
  - Calculation in double(64-bit) precision: we confirmed it is good enough for the 64×64 pixel image (the response-matrix size is 4096×4096).

Study with ASCA-GIS X-ray image

- **ASCA:** previous Japanese X-ray satellite (1993-2000)
  - XRT-GIS energy band: 0.8-10 keV
  - FOV: diameter 40 arcmin, PSF: HPD ~ 4 arcmin (typical).
- Calibration of PSF was done with a series of observation of a bright point source, Cyg X-1 (Ikebe et al. 1997).



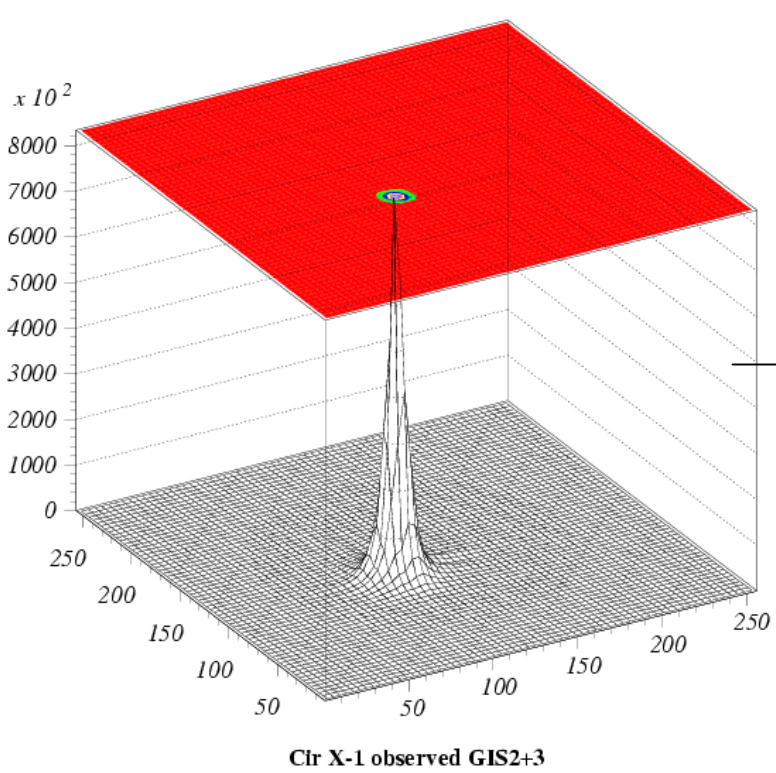
ASCA-GIS PSF images (log scale, scale range=20)

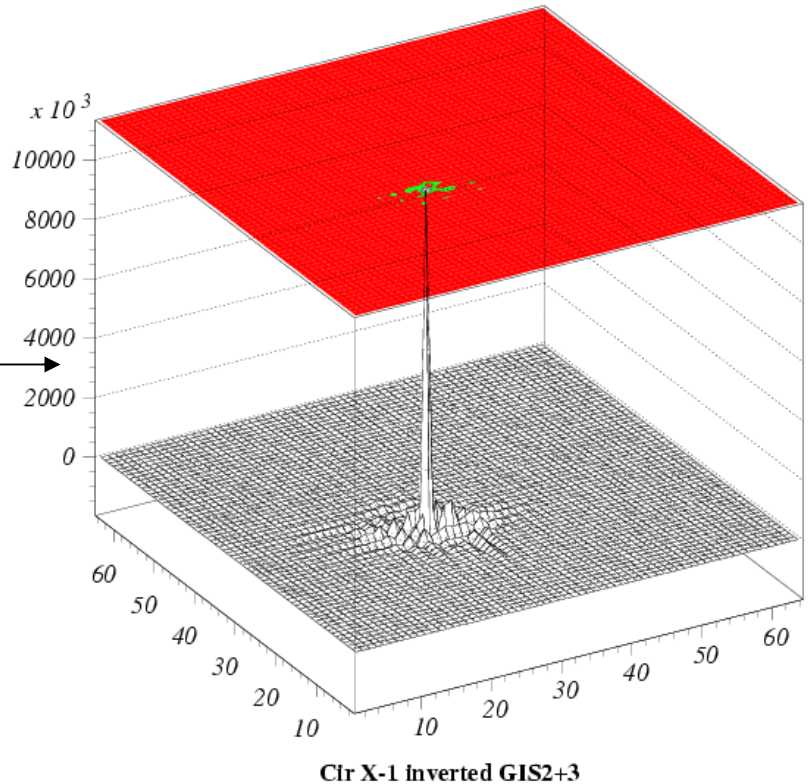


Points covered by PSF calibration

An ideal case: a bright point source

- Cir-X1

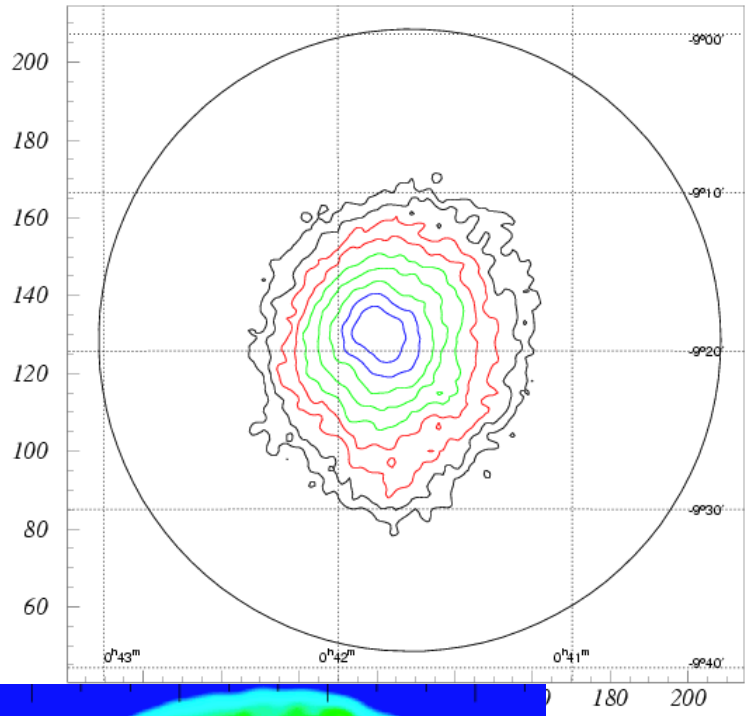


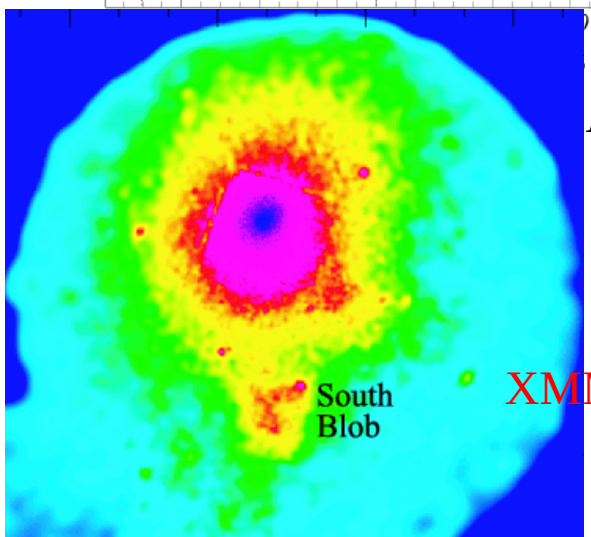


Observed image

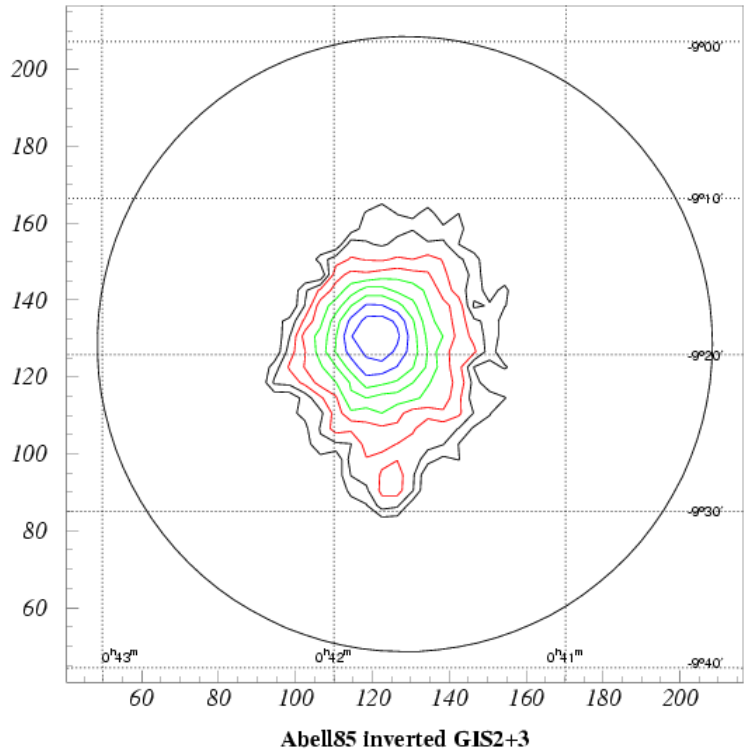
Deconvolved image

Example of Cluster of Galaxy: Abell 85





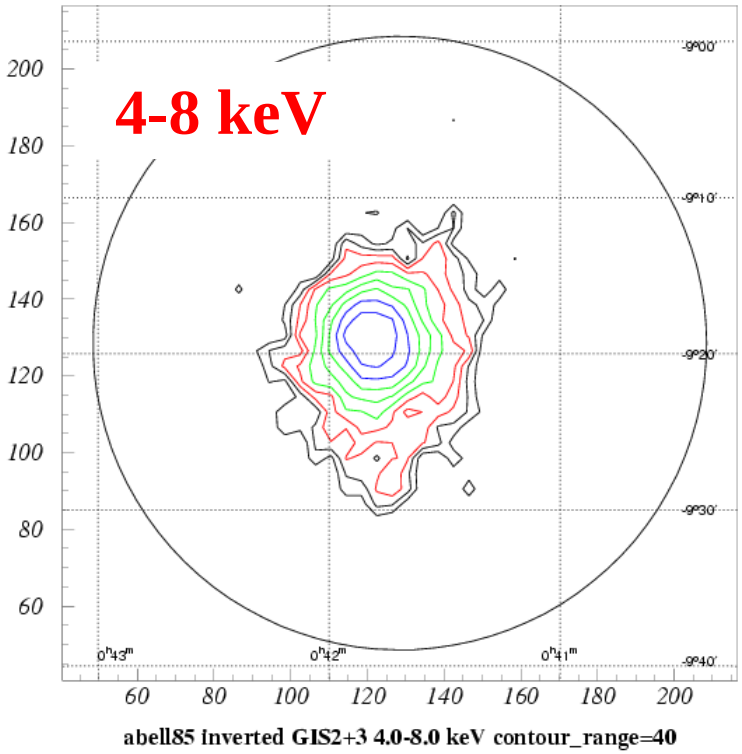
ASCA

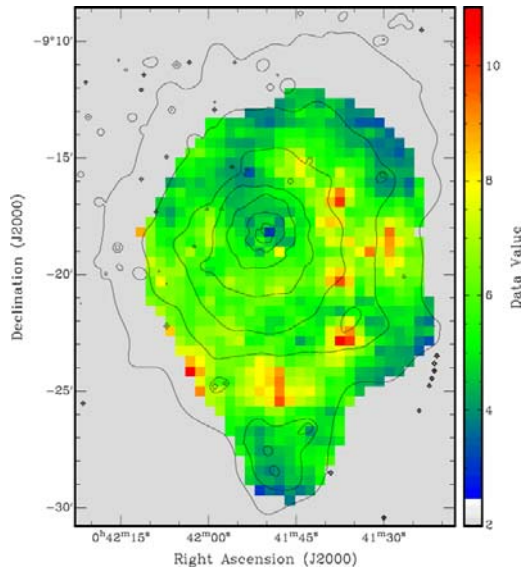


Inverted image
(smoothed with a gaussian kernel with σ=0.7 arcmin before/after inversion)

XMM image (Durret et al. 2003)

Energy-sorted Image Inversion: Abell 85

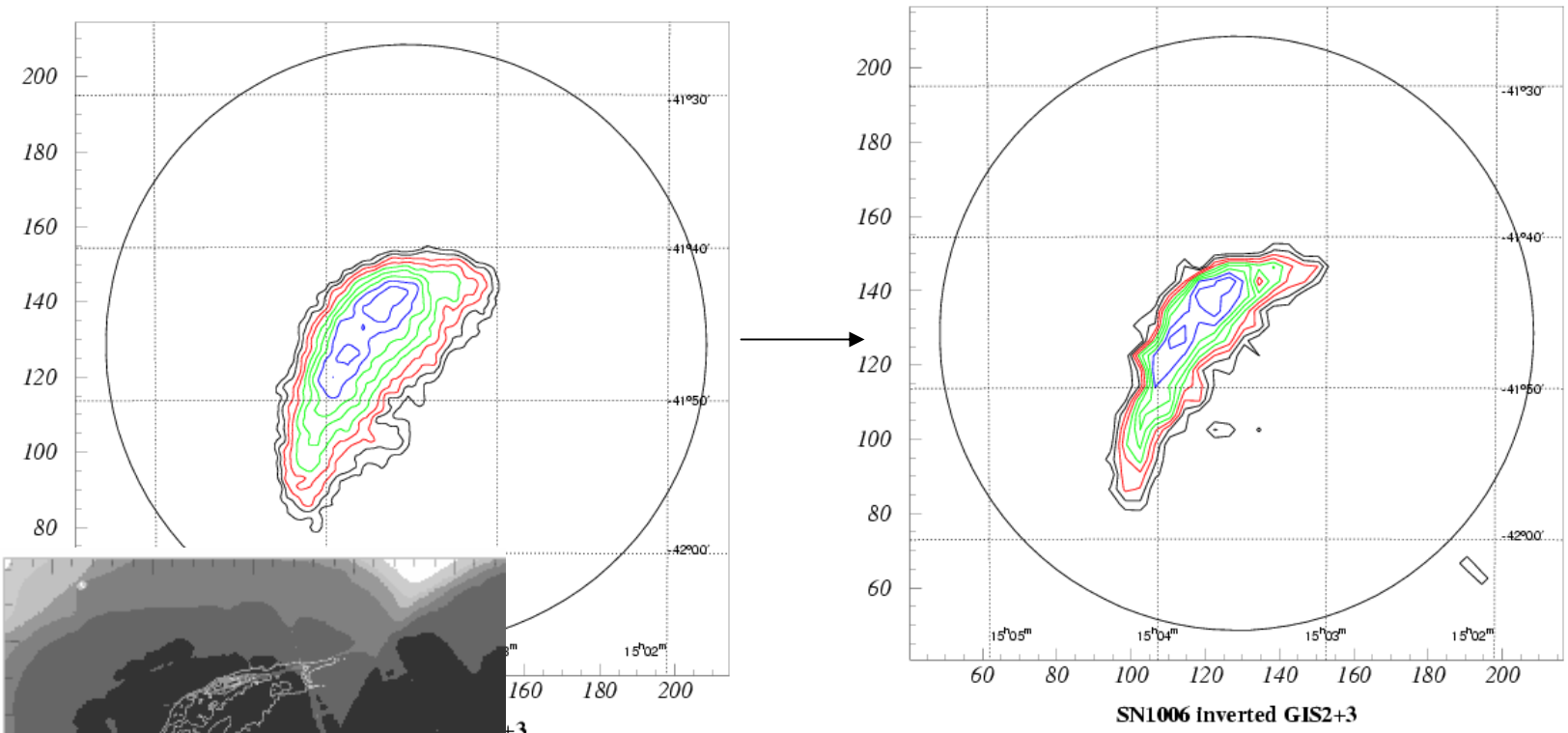




Temperature map by XMM

Example of SNR 1: SN1006

- SN1006 NE rim



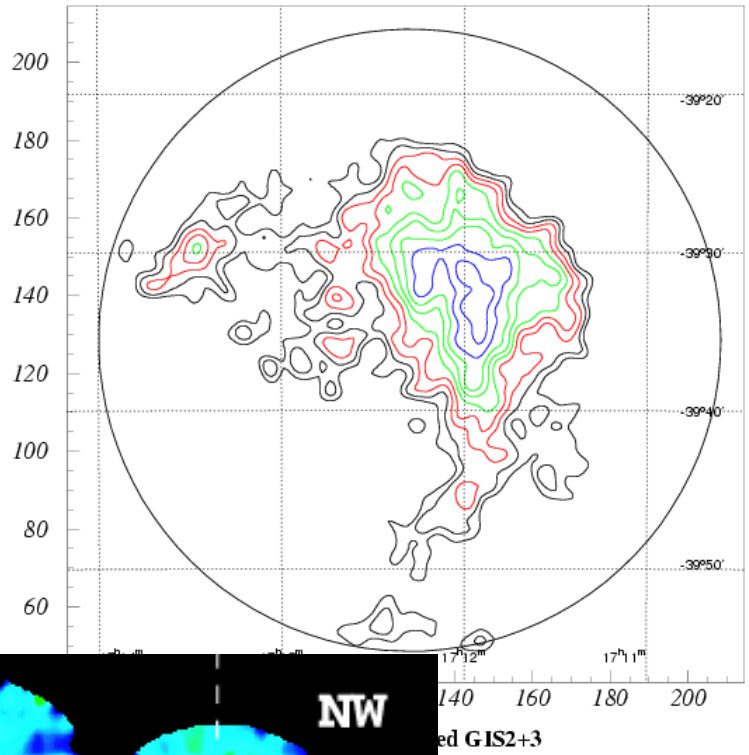
ASCA

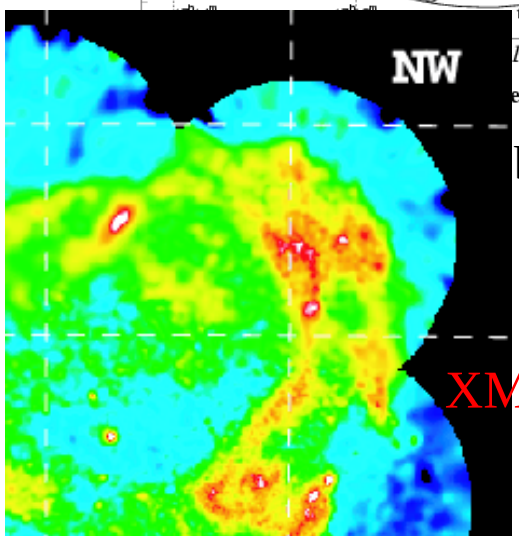
Inverted image
(smoothed with a gaussian kernel with σ=0.6 arcmin before/after inversion)

Contour:
XMM image
(Rothenflug et al. 2004)

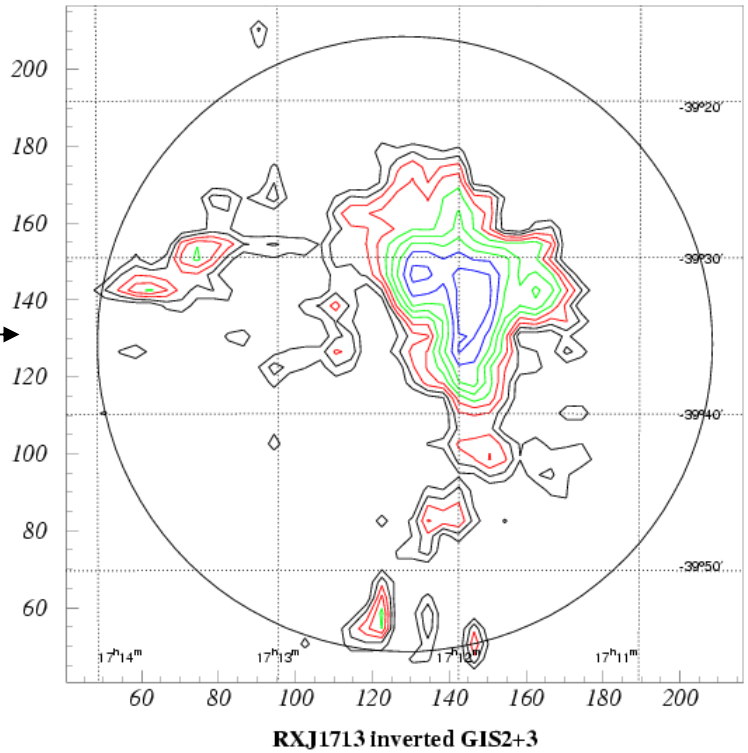
Example of SNR 2: RX J1713.7-3946

- NW rim





by ASCA



Inverted image
(smoothed with a gaussian kernel with σ=0.8 arcmin before/after inversion)

XMM image (Cassam-Chenai et al. 2004)

Conclusion and Future Plan

- This inversion method is working good !
- Application to the Astro-E2 (SUZAKU) data
  - The PSF HPD of the Astro-E2 X-ray telescope = ~1'. (Chandra:<0.01', XMM: 0.15')
  - Astro-E2 (SUZAKU) has an advantage in effective area against Chandra and in background against XMM.
- Study for the GLAST data
  - Study of this inversion method was begun for application to the EGRET data by Tune.
  - It would be worthwhile especially for the lower energy band where the spatial resolution is bad but the photon statistics is good.