Spatially Resolved Spectroscopy with EPIC

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OVERVIEW

- CAVEATS
- DATA PREPARATION
- EXTRACTION OF SPECTRA
- PREPARATION OF SPECTRA
- SPECTRAL ANALYSIS
- RESULTS: AN EXAMPLE

$\boxed{\text{CAVEATS}}$

- Relies heavily on calibrations: vignetting; rmf is position dependent.

- Low Surface Brightness emission: subtraction of intense instrumental background is an issue.

- Production of tens to hundreads of spectra.

NOT FOR WEAK HEARTS!

CAVEATS 2

- Vignetting measured in flight for off-axis angles smaller than $10'$. Further out you analyze at your own risk!

- A lot of effort is going into understanding the instrumental background, however for the time being: be very cautious in interpreting spectra from regions where the backgound intensity is comparable or larger than that of your source

DATA PREPARATION

- Flickering Pixels Cleaning (SAS cleaning algorithm is not always 100% effective, you may want to write your own S/W)

- Soft Proton Flares Rejection (Filter data on the basis of intensity in 10-12 keV band)

- Background

BACKGROUND

- Some objects fill the field of view
- Instrumental background varies with position and time

$$\Downarrow$$

- Use blank fields for background subtraction
- Background spectra accumulated from the same region of detector as source spectra
- Renormalize bkg spectra to account for variability
- If some pixels have been masked in the source image must be masked also in bkg and viceversa

SPECTRA ACCUMULATION

Use regions of adequte size to avoid under-sampling PSF.
(Innermost region: circle with radius $30''$)

Define grid over field, annuli, sectors, boxes and convert from sky to detector coordinates for MOS1, MOS2, PN.
(SAS does not provide tool for coordinate conversion)

For each region extract 6 spectra, 3 from Source and 3 from Bkg eventlists with evselect tool.
Note: backscal keyword is not a problem because extraction is from the same area of the detector

SPECTRA PREPARATION

Vignetting Correction

Applied to Spectra (both source and bkg) rather than to arfs.
Each photon is weighted by the inverse of its vignetting. Vignetting is function of off-axis angle and energy.

(Similar approach has been applied to ROSAT PSPC data).
Not formally correct however it does a good job in vast majority of cases.

SPECTRA PREPARATION 2

RMFs

Both MOS and PN RMFs are position dependent.
MOS low energy response (below 0.4-0.5 keV) can vary substantially.
Solution cut spectra off at 0.4-0.5 keV.
PN CTI has non negligible effects on spectral resolution. The further you go from read out the poorer the resoultion. (Similar to ACIS BI CCDs)
Solution: Different response matrices provided for differents parts of CCDs.

No RMF Summing routines available.
No ARF Summing routines available.

SPECTRA PREPARATION 3

Background Rescaling

Rescale intensity of background spectra so that in 10-12 keV band (where background is virtually all of instrumental origin) the source and bkg spectra for whole FOV match.

Sum MOS1 MOS2 spectra (optional)

Calibrations tell us instruments are similar

Associate RMFs to spectra

Remember to use poistion dependent PN RMF

Associate Bkg to Source Spectra

Remember to scale bkg for variability

Automatic reduction procedure recomended

SPECTRAL ANALYSIS

Question

How to analyze 100+ spectra and make sense of the results,
possibly not on geological timescales

This problem is not unique to XMM-Newton, it applies to Chandra as well and to a smaller extent to ASCA and BeppoSAX

Solution

Develop automatic analysis procedures.

SPECTRAL ANALYSIS 2

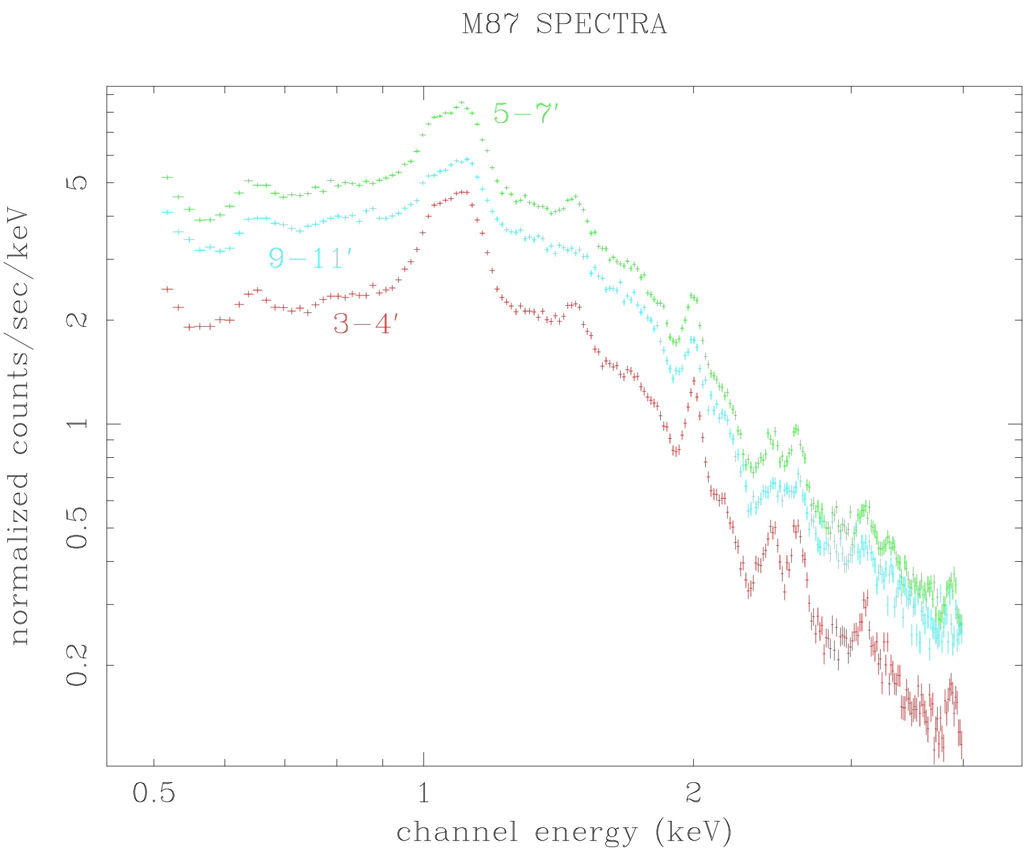
Develop procedures to analyze spectra

Relatively straightforward to develop shell scripts that fit spectral models to data within XSPEC

XSPEC allows to save to files best-fitting parameters plots, and other info needed for further analysis

An Example: M87

- Bright nearby object
- Emission out to edge of detector
- 100s of useful spectra
- low temperature, high metallicity, lots of emission lines, individual element abundances can be measured



An Example: M87

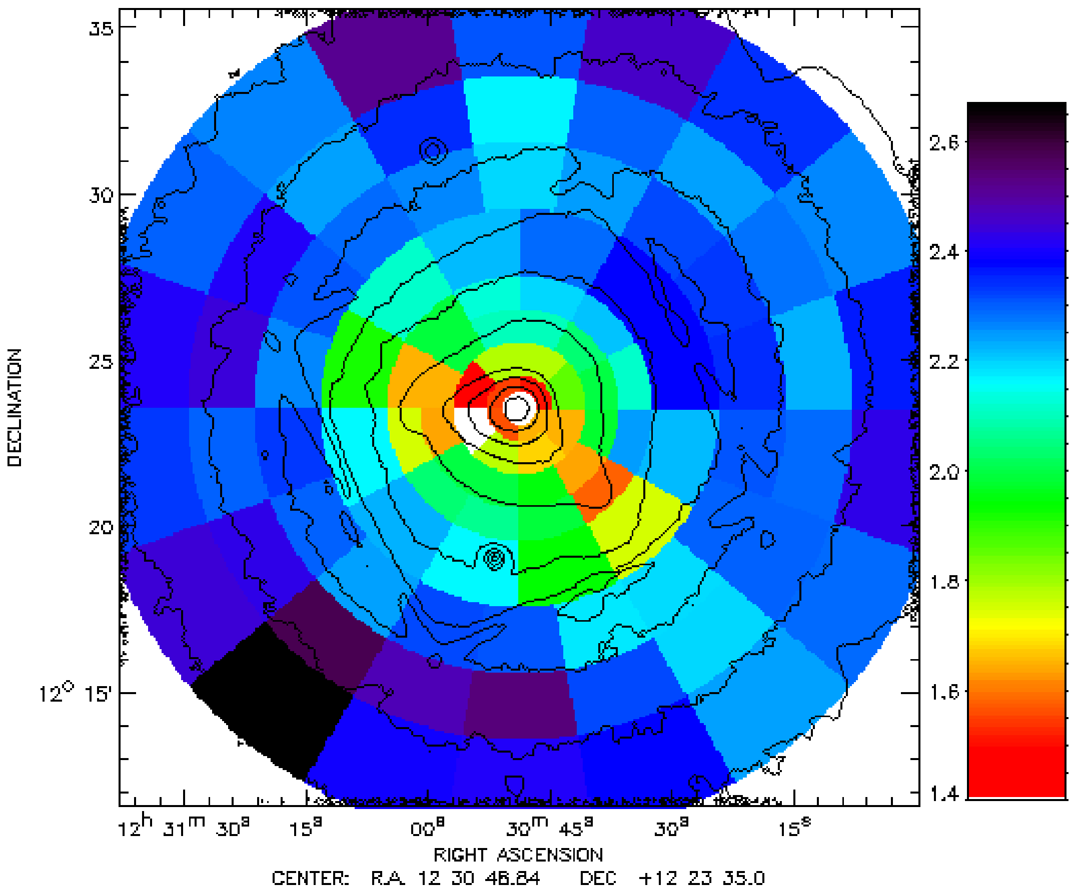
- Divide FOV in sectors
- Accumulate MOS1,MOS2 and PN spectra for each sector and for same regions of detector from bkg field
- Prepare MOS and PN Spectra

Spectral Analysis

- Fit spectra with 1 Temperature model with free abundances (VMEKAL or VAPEC)

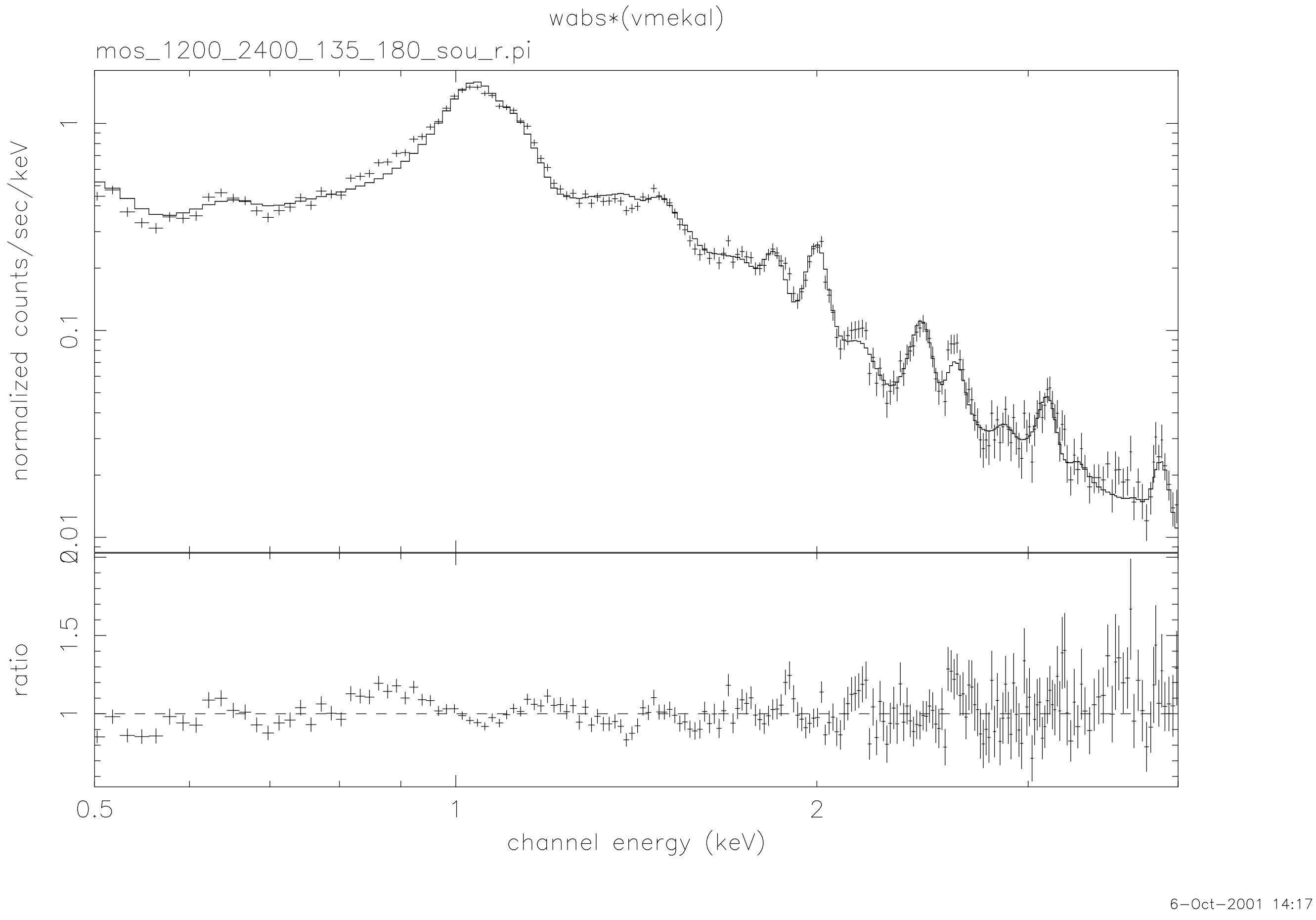
- Save best fitting models and plots for further inspection

- Plot temperature and abundance maps



Spectral Analysis 2

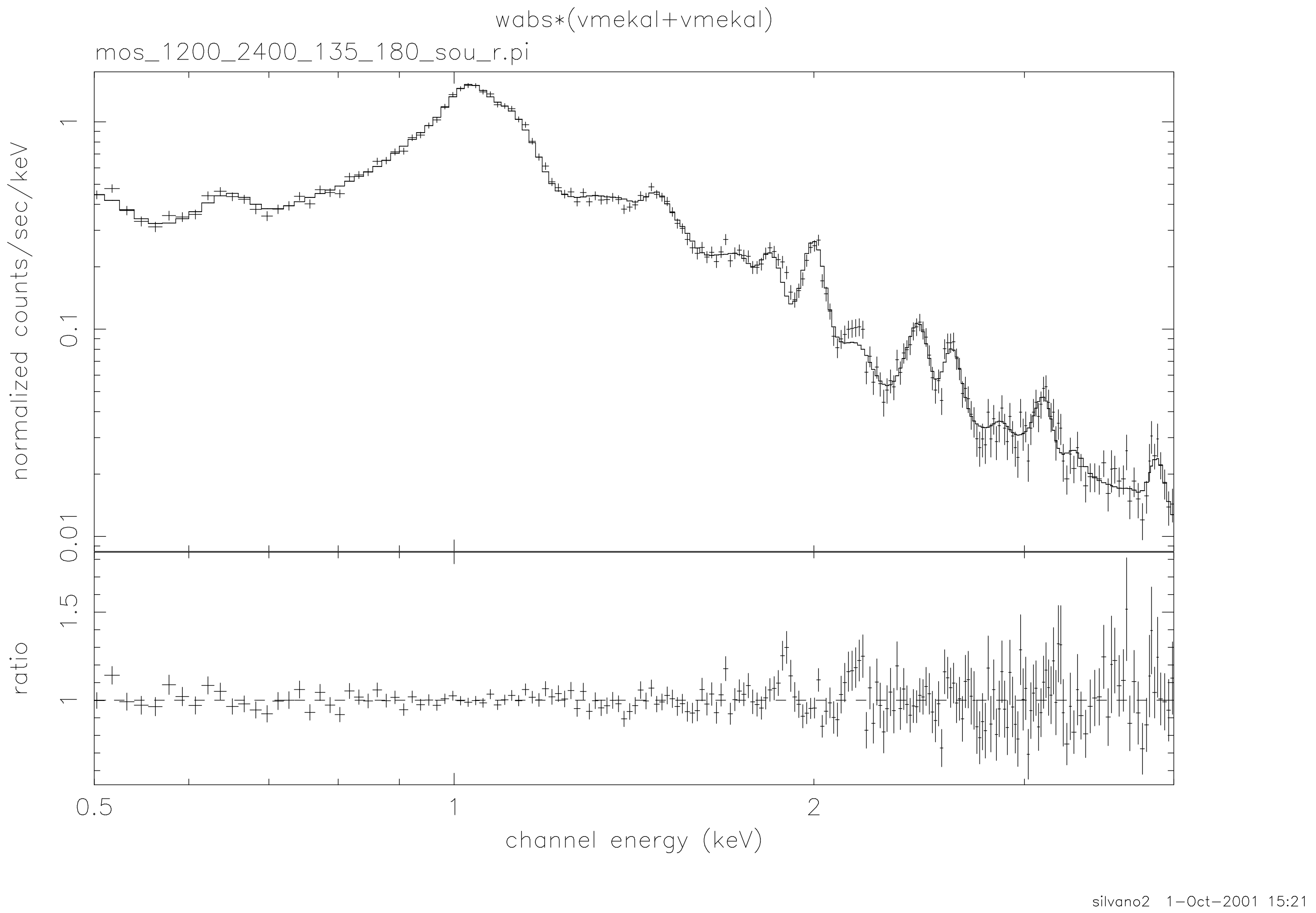
Some spectra require more complex model



Fit spectra with 2 Temperature model
with free abundances (VMEKAL + VMEKAL)

Spectral Analysis 3

Clearly, for many spectra 2T models provide a much better description of the data

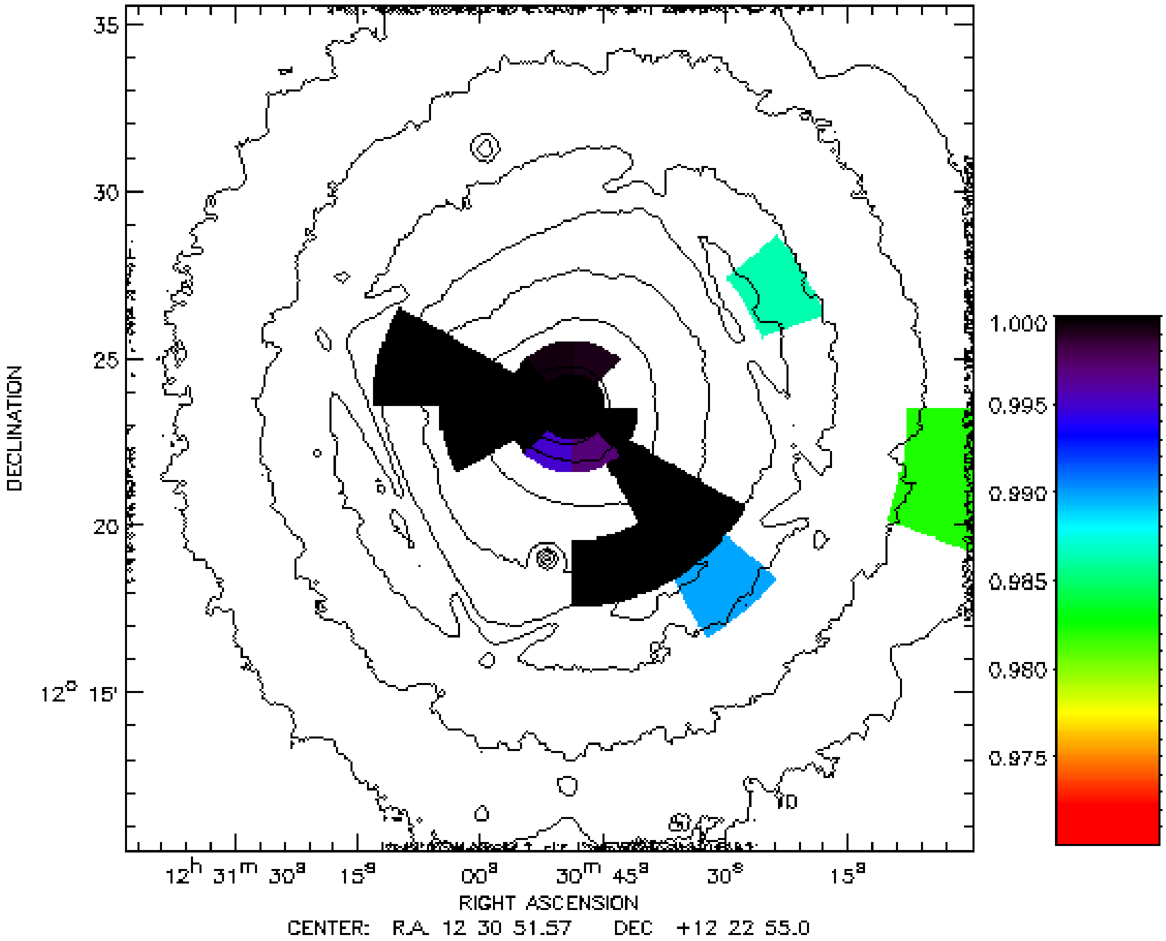


An F-test can be performed to test exactly where 2T fit do better than 1T fits

Spectral Analysis 4

F-tests → P Map

P indicates the probabilty that the improvement when going from the 1T model to 2T model is not due to an increase of free parameters



$\boxed{\text{Spectral Analysis 5}}$

Merge 1T and 2T results

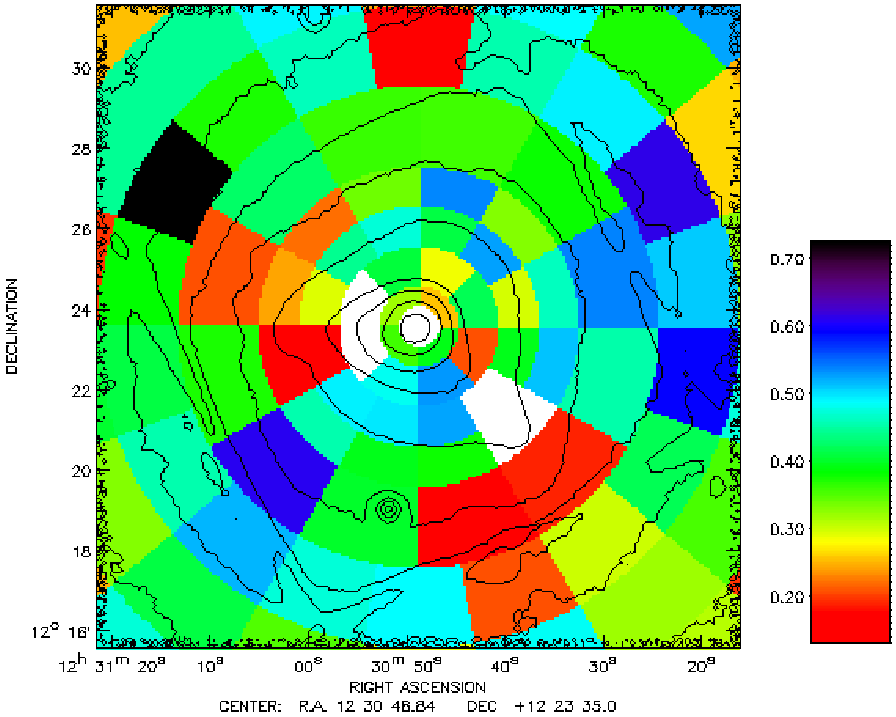
IF P< Thr. THEN

1T results

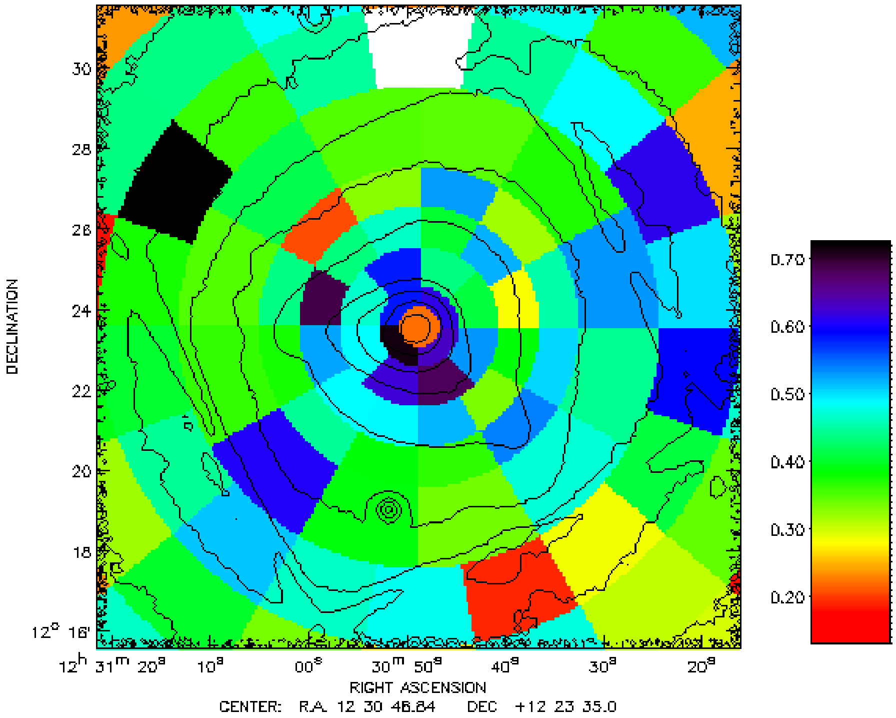
ELSE

2T results

1T O Map



Merged O Map



$\boxed{\text{SUMMARY}}$

- Spatially Resolved spectroscopy of extended sources with EPIC can be very rewarding

- A lot of the calibration work necessary for this kind of analysis has been done

- Major difficulties:

  – Require a detailed understanding of background for analysis of low-surface brightness sources

  – a few taks necessary for the analysis are not available within SAS