An XMM-Newton study of the hot gas in Early type galaxies

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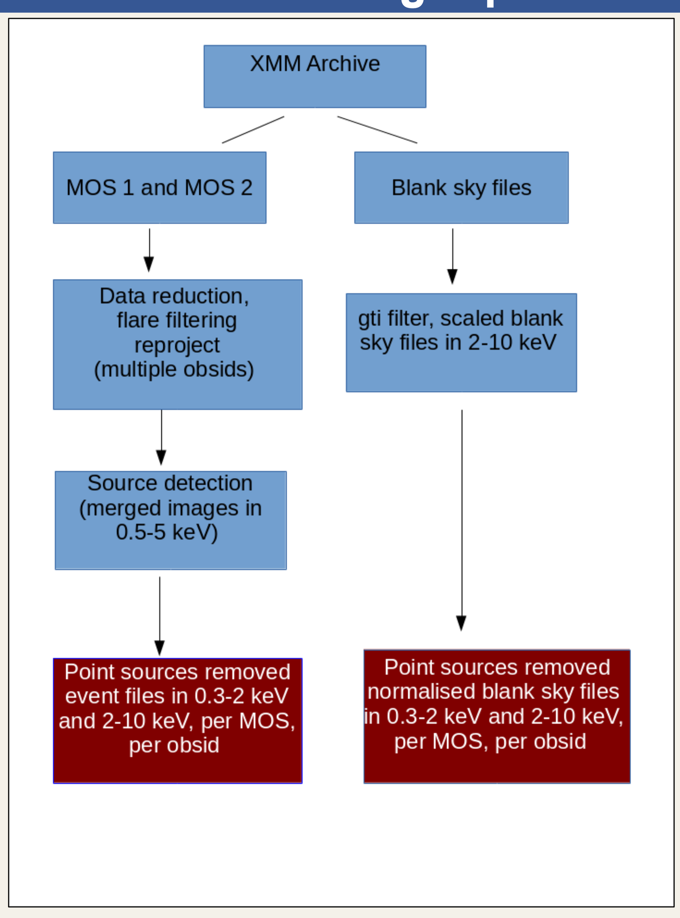
Objective

The distribution of hot ISM in early type galaxies (ETGs) bears the imprint of its formation and evolutionary history. The high sensitivity and large field of view of XMM-Newton has made it possible to investigate this diffuse emission in the galaxy outskirts, which is critical in understanding the interaction of this hot gas with the surrounding medium (e.g., by ram pressure stripping) and neighbouring galaxies (e.g., sloshing, merging), by measuring its spectral properties and mass profile on a larger scale.

This is an overview of the X-ray Galaxy Atlas project, where we systematically analysed the archival XMM-Newton observations of 50 ETGs and produced spatially resolved 2D spectral maps, with the aim of studying the distribution of the hot gas in these ETGs. These 2D spectral maps are more useful in revealing unique features in the distribution of hot gas, which may be not visible in 1D radial profiles or 2D surface brightness maps.

These results will be used complementary with the existing products from the archival Chandra observations (Kim et al 2019), to investigate both small scale and large scale structures in the distribution of the hot gas in ETGs.

Data Processing Pipeline



Flowchart showing an overview of the data reduction steps. For a galaxy, both source and blank sky MOS files are downloaded from the XMM-Archive. The source event files are filtered for high energy particle background and the same filters are also applied to the blank sky files. The 2-10 keV blank sky files are scaled to match the 2-10 keV source count-rates. The source detection algorithm is run to detect point X-ray sources and these are removed to create point source removed source and blank sky files.

Spectral analysis pipeline

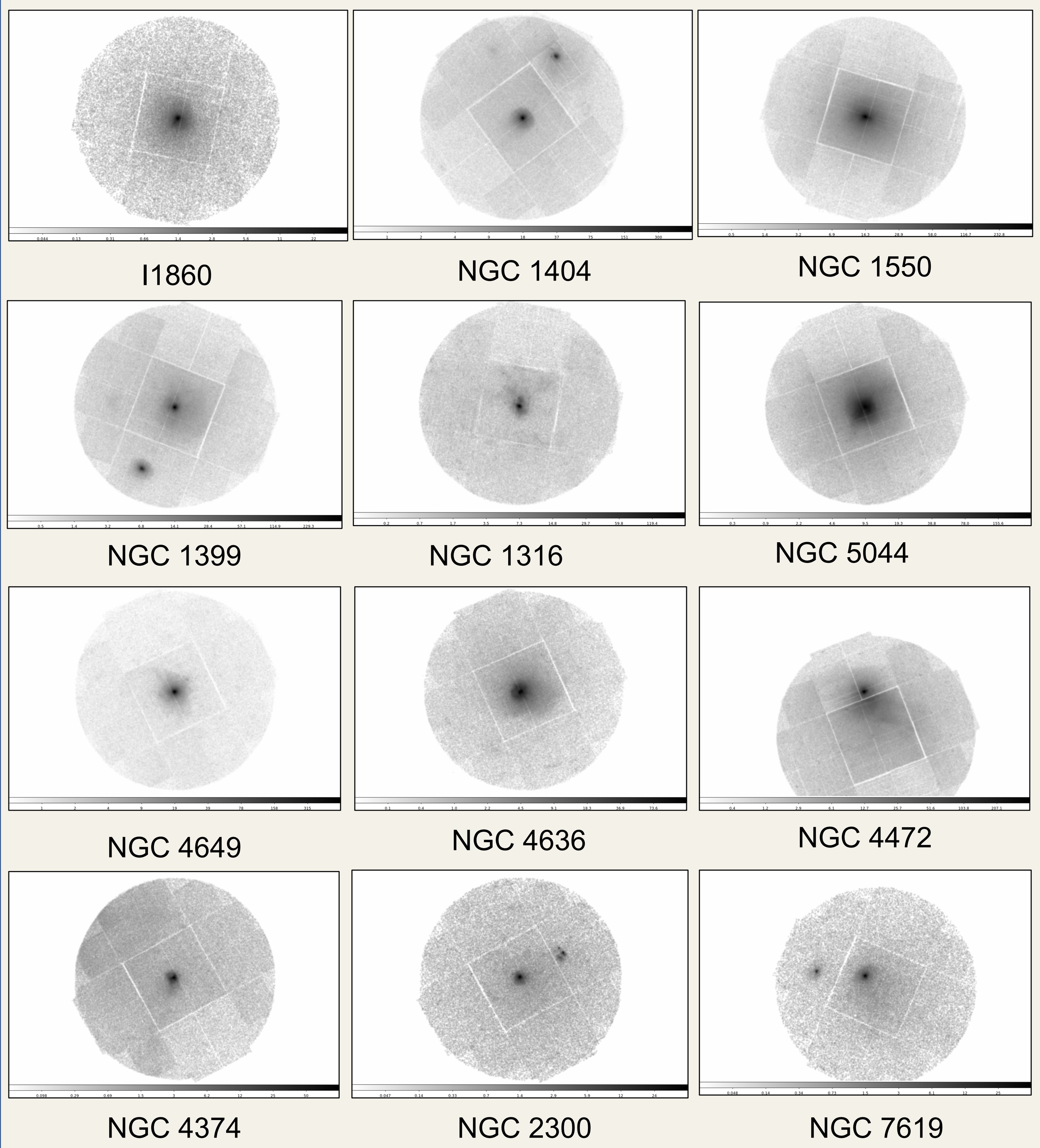
Adaptive binning: Four adaptive binning methods to effectively characterise the 2D gas information

1. Annulus Binning (AB): Circular annuli with adaptively determined inner and outer radii.
2. Weighted Voronoi Tessellation (WVT or WB) adaptive binning (Diehl & Statler 2006).
3. Contour Binning (CB): Groups the areas with similar surface brightness, since they have similar spectral properties (Sanders 2006).
4. Hybrid Binning (HB): Utilises grid-like binning method developed by O'Sullivan et al (2014). Maintains high S/N by extracting spectra from larger circular regions while keeping the spatial resolution in finer spatial grids.

Spectral Fitting:

- Spectral extraction (pi, rmf, arf) for each spatial bin per obsid per MOS.
- Combining spectra from each obsid into single spectra per MOS per bin.
- Background files are extracted from the corresponding scaled blank sky files.
- Simultaneous fitting of MOS 1 and MOS 2 files with two component VAPEC + power-law model.
- Spectral maps with various spectral parameters like gas temperature (kT), normalised emission measure, abundances, projected pseudo-entropy and pseudo-pressure maps etc.

Image Gallery showing diffuse hot gas emission

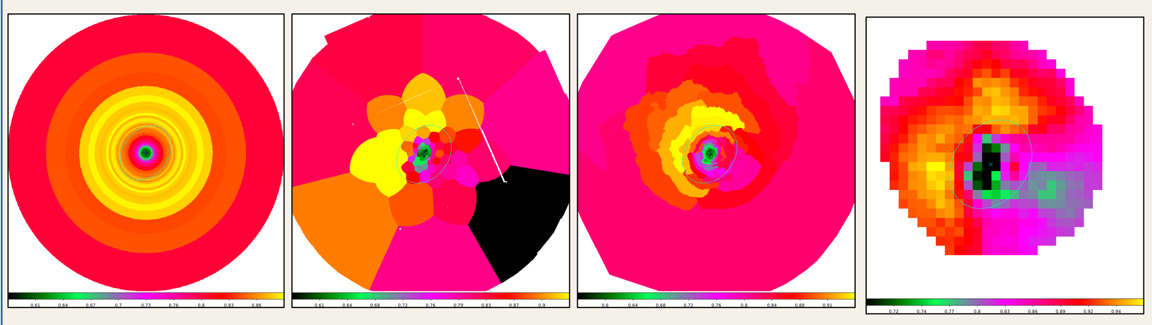


The images show the diffuse hot gas emission in each galaxy in energy band 0.3-2.0 keV. The images are constructed after excluding the point sources detected by source detection and refilling the values extrapolated from the surrounding pixels. The various patterns seen in these distribution of hot gas are related to AGN feedback, environment and its interaction (sloshing, ram pressure stripping) etc. In NGC 1399, NGC 1404, NGC 7619, NGC 2300, the XMM FOV allows us to see interaction of hot gas with neighbouring galaxies.

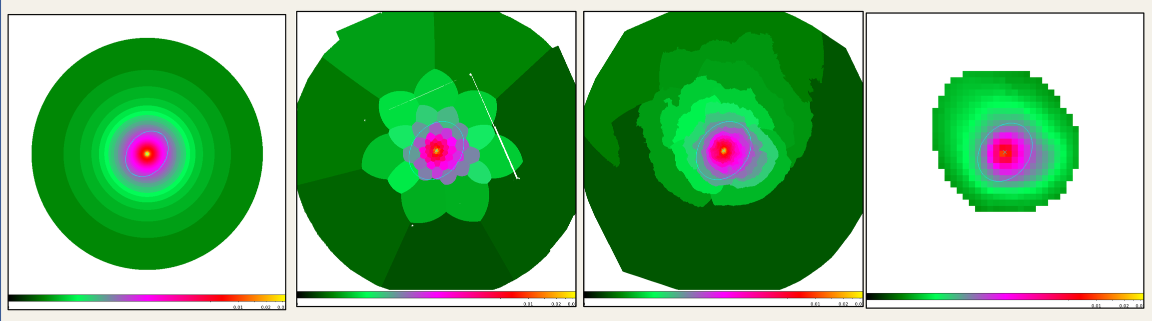
Spectral maps of hot gas in NGC 4636

Annulus Binning | WVT binning | Contour binning | Hybrid Binning

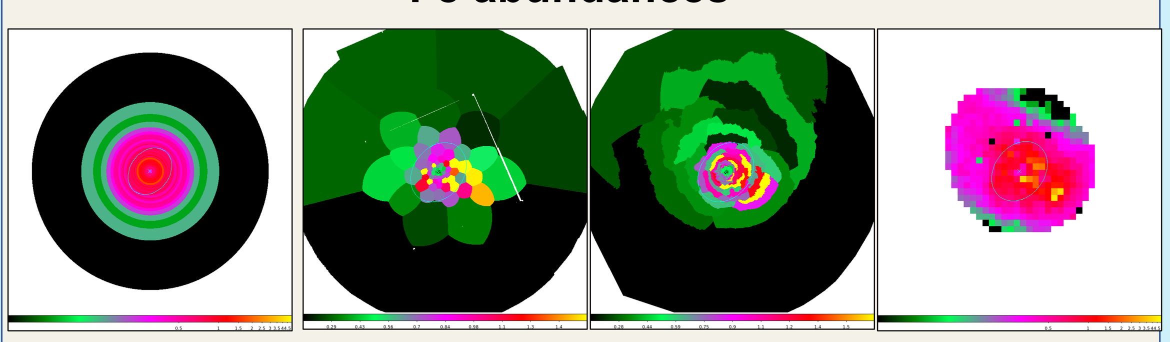
Temperature (kT)



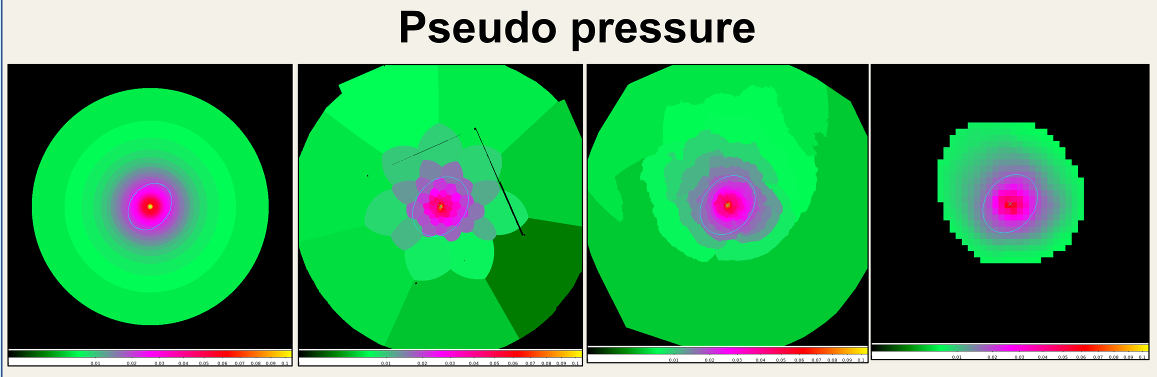
Emissivities



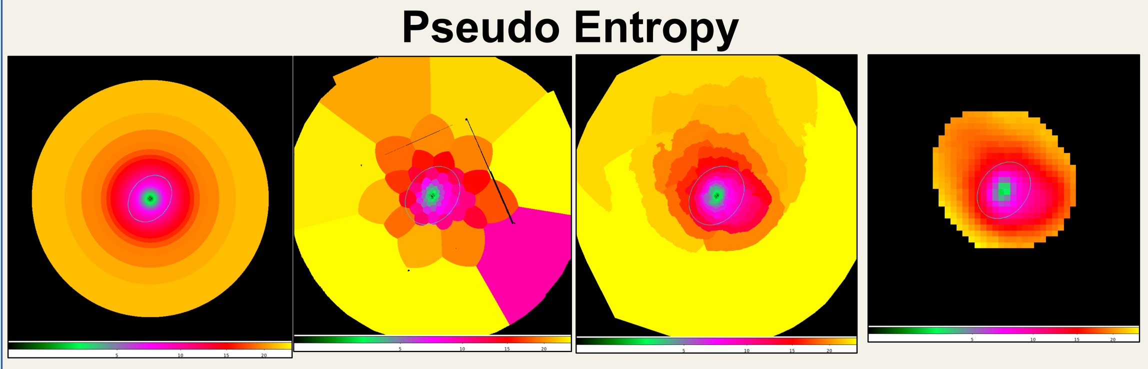
Fe abundances



Pseudo pressure



Pseudo Entropy



The temperature profile of NGC 4636 in WB, CB and SB binning methods, shows an asymmetric distribution of the hotter gas of ~1 keV along N-W, outside the D_{25} ellipse of the galaxy having a cooler temperature of ~0.6 keV. From the Fe abundance map, we see an increasing super-solar metallicity, extending along S-E direction. Both indicates either presence of sloshing or AGN feedback in NGC 4636.

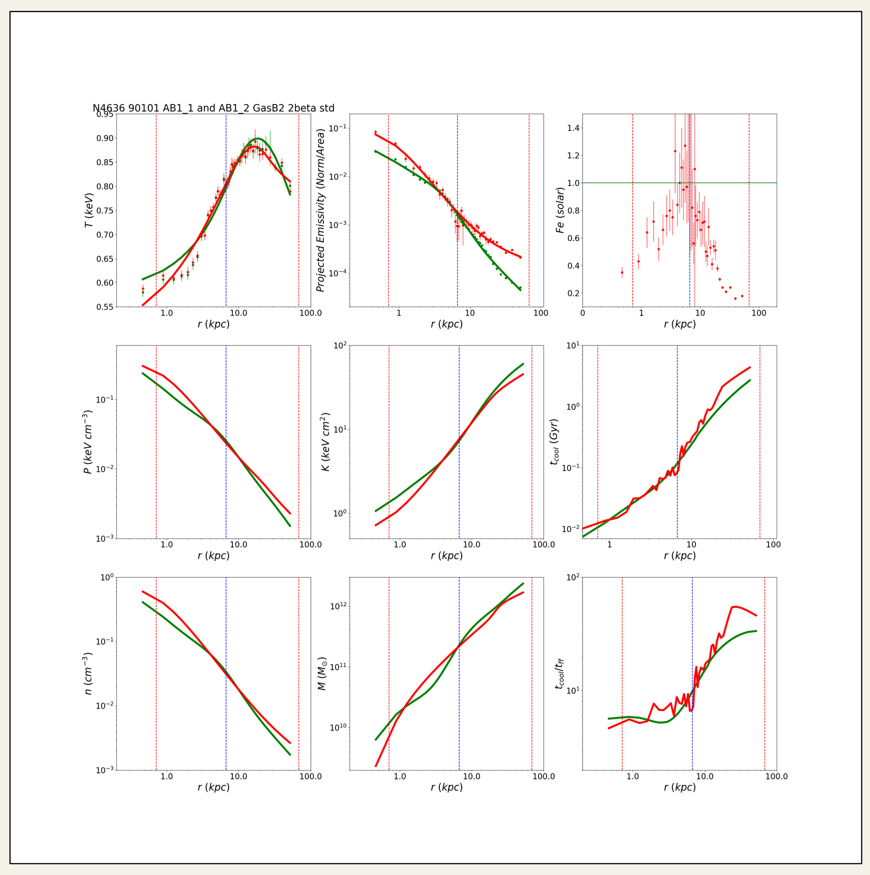
Science Goals

1. **Gas Morphology**: Due to the higher effective area and larger FOV of XMM-Newton, the observations of ETGs will allow us to trace the full extent of the gas halos and study the faint emission from outskirts of galaxies. This would be crucial in studying the interaction of hot gas with its surroundings. Combining the products from Chandra observations of these galaxies would be important in studying both smaller scale asymmetries in the gas distribution and hot gas properties on larger scales.
2. **Metal abundances**: Higher S/N with larger effective area of XMM-Newton has made it possible to investigate the metal abundances, especially Fe abundances, in ETGs. These abundances hold clues to star formation rate and supernovae rate in ETGs, which are important in studying the formation and chemical evolution of these galaxies.
3. **X-ray based mass profiles**: X-ray observations of the hot ISM can be used to measure the total mass, assuming hydrostatic equilibrium. With XMM-Newton observations of these galaxies, we can estimate the mass profiles to larger extent than that possible with only Chandra observations.
4. **Scaling relations**: The global quantities like gas luminosity, mass, temperature, metal abundances etc will be used in studying the correlations with properties measured in other wavelengths, to get insights into the physical properties of the hot ISM and evolution of ETGs.

Data Products

Data products generated from this project will be available to the astronomical community

1. X-ray images of diffuse emission: Raw and exposure corrected and smoothed images in multiple energy band, of the hot gas after removing the point sources and refilled with values from surrounding pixels.
2. 2D maps for gas temperature, emissivities, elemental abundances, pseudo-entropy and pseudo-pressure
3. 1D radial profiles



Radial profiles for NGC 4636 from AB binning method. Top left to bottom right: Radial profiles of temperature (in keV), projected emissivity (Norm/Area), iron abundance (in solar units), pressure (keV/cm^3), entropy (keV cm^2), cooling time (in Gyr), density, mass and ratio of cooling time to free fall (t_{cool}/t_{ff}). The green lines are for fixed abundances fit and red lines are for variable abundances fit.

References

1. Kim et al. 2019, ApJS, 241, 36 http://cxc.cfa.harvard.edu/GalaxyAtlas/v1/
2. Diehl S., Statler T. S., 2006, MNRAS, 368, 497
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