X-ray Photoexcited Extranuclear Gas in Active Galaxies

Herman L. Marshall (MIT Kavli Institute)

Abstract

This is a summar of results from 16 years of high resolution X-ray spectroscopy o fgas in the neighborhood of Active Galactic Nuclei. Led by the prototypical Sy 2 galaxy NGC 1068, we now have many examples of circumnuclear gas that is excited by the central source. In galaxies with obscured nuclei, the gas is rich with emission lines from highly ionized species and radiative recombination continua. Outflows are apparent and several cases are resolved at the 1-5" level. The ionization models give velocity, density, and composition diagnostics. These outflows carry significant energy and momentum, affecting the energy budget of the local intergalactic medium. The X-ray Surveyor can examine the prevalence and impact of these ionization cones in the z < 1 universe.

Fig. 1 (left) The full resolution Chandra HETGS spectrum of the core of NGC 1068 (Kallman et al. 2014). The exposure was about 440 ks. Below 4 keV (3 Å), the spectrum is dominated by emission lines from a photoexcited plasma modeled with three ionization parameters from log(x) = 1-3.

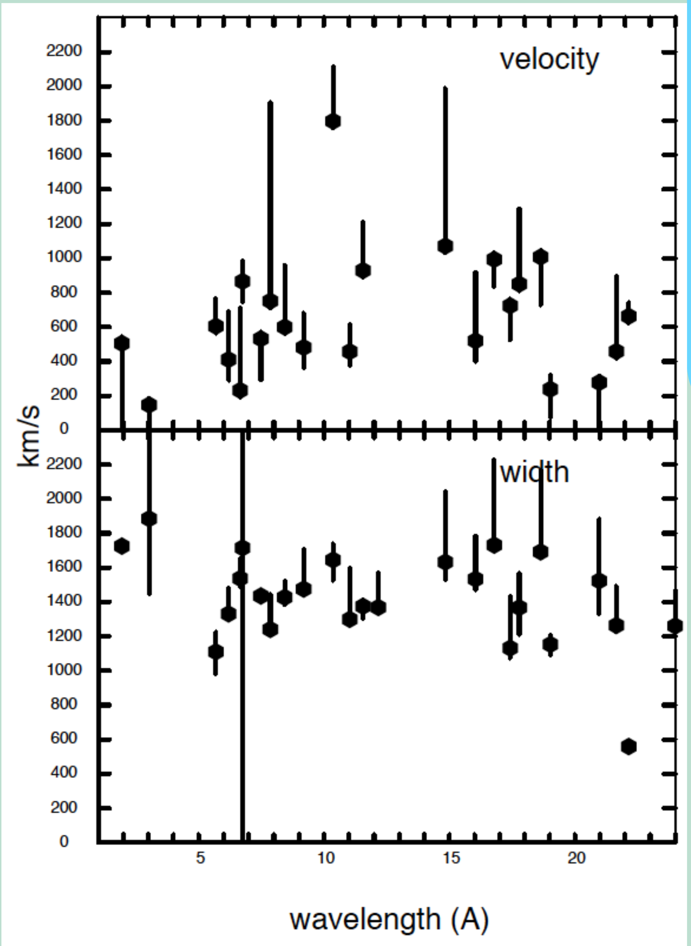


Fig. 2 Line widths and Doppler shifts, as measured for sufficiently strong lines in the HETGS observation of NGC 1068. Note that the gas is outflowing and the lines are significantly broadened.

NGC 1068: The Brightest Sy 2

Kallman et al. (2014) presented the deepest Chandra HETGS observation (440 ks) of this bright Sy 2 (see Fig. 1). Among the results included a detailed model of the ionization state of the gas, due to photoexcitation by X-rays from the obscured nucleus. The material is outflowing from the nucleus at 450 km/s and the lines are broadened by 1000-2000 km/s (Fig. 2). Abundances are generally above solar (Fig. 3) but well below solar for O for two gas components. In addition, Kallman et al. estimate the mass in the outflowing gas (Fig. 4) to be comparable to that in the narrow line region and the inferred outflow rate is 20x that needed to power the nucleus at 10% efficiency. The covering fraction is a few percent. Finally, there is extended ionized gas beyond 400 pc and the HETGS measures this gas independently of the nucleus (Fig. 5).

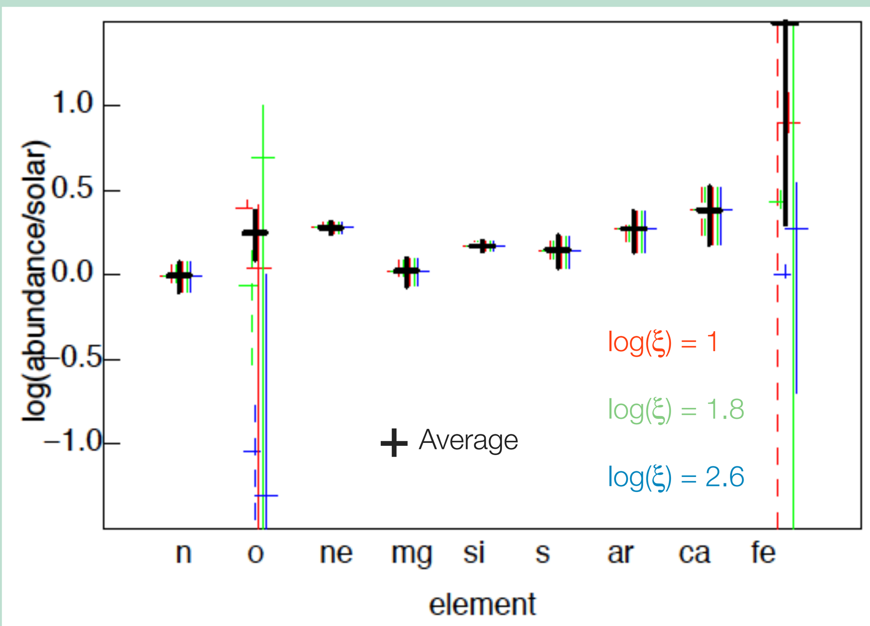


Fig. 3 Abundances were determined for each element for which several lines were measured. Ne and S are clearly overabundant relative to the solar value. Some ionization components were not well fit by the average value (black), so they are shown separately. Most components had $N_H = 3x10^{23}$ cm^{-2}, while dashed lines indicate components with x10 lower N_H. O is best fit with x10 underabundance for two ionization components.

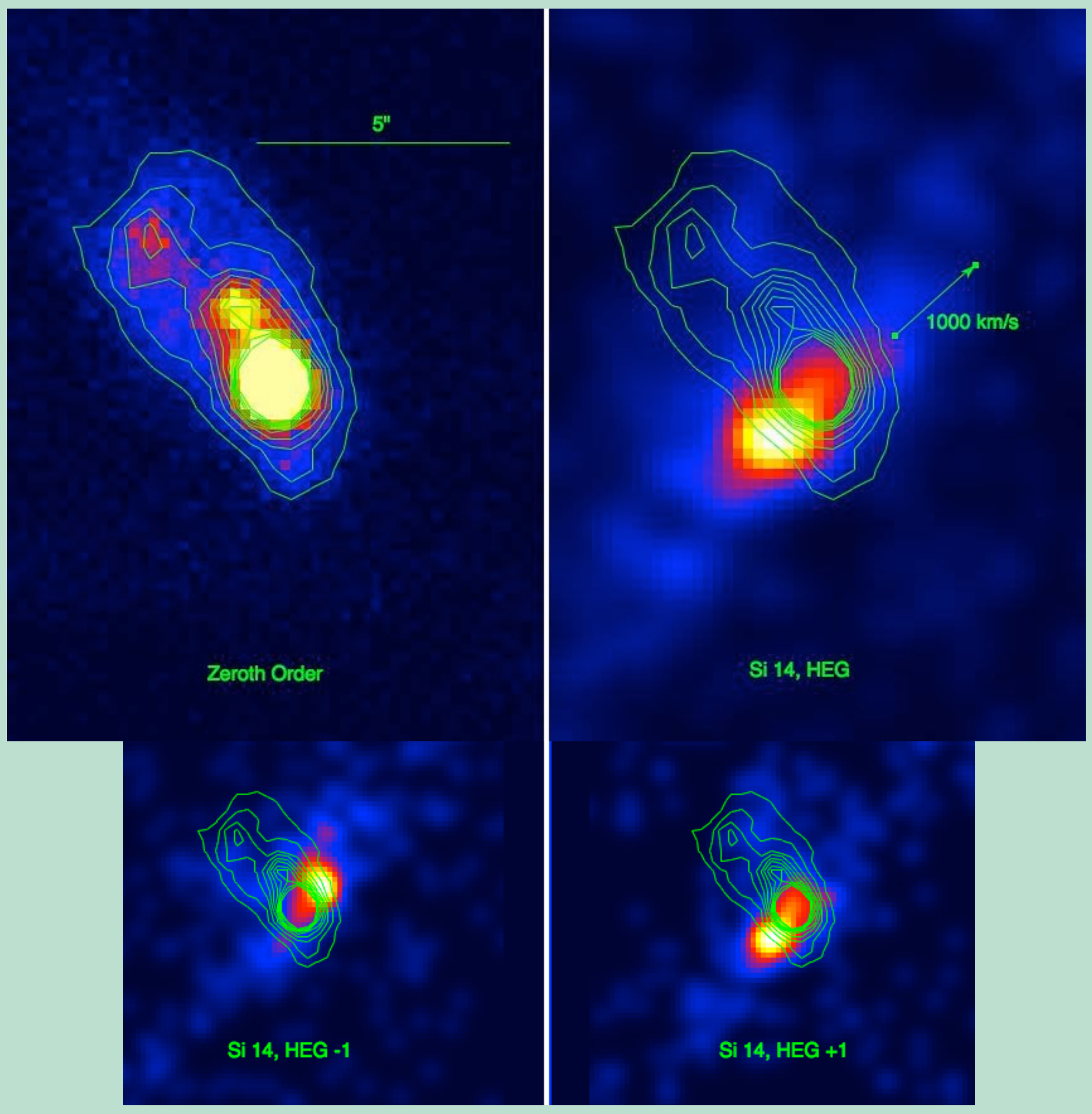


Fig. 5 The Chandra HETGS images of NGC 1068. The upper left shows 0th order, which sets the contours. The bottom pair of images shows the dispersed HEG spectra in sky coordinates for the Si xiv line, with spectral dispersion (increasing wavelength) running to the upper right for +1 order and to the lower left in -1. Given the mirror symmetry of the two images, they can be flipped and to form the upper right image, which shows 1) that the nuclear emission is blue-shifted mostly, 2) the nuclear emission is considerably Doppler broadened, and 3) that the off-nuclear emission is slightly redshifted.

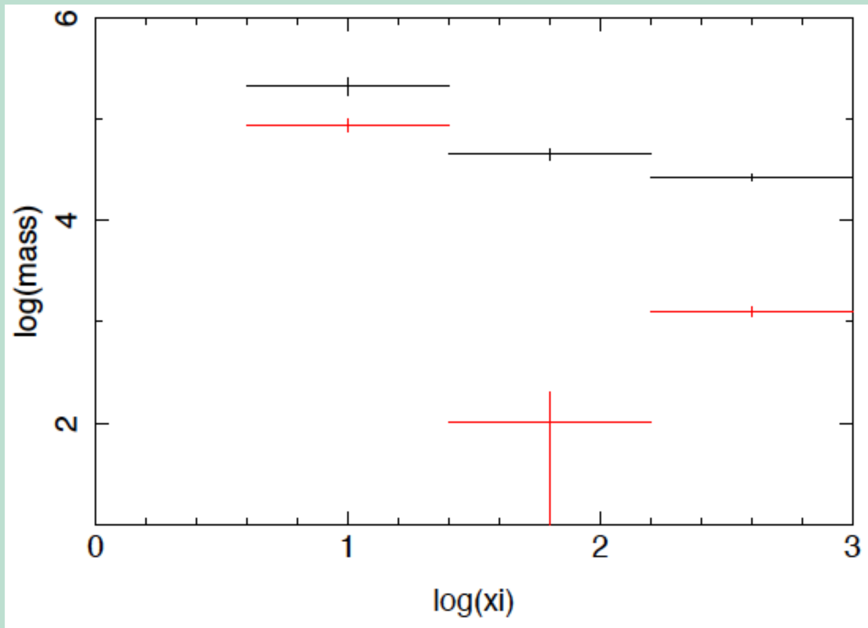
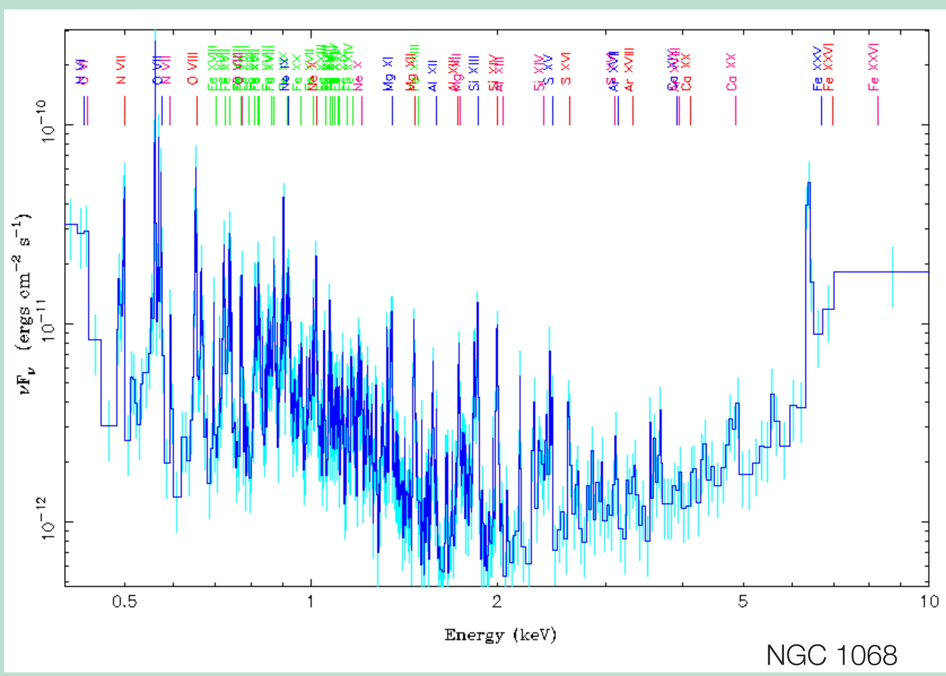


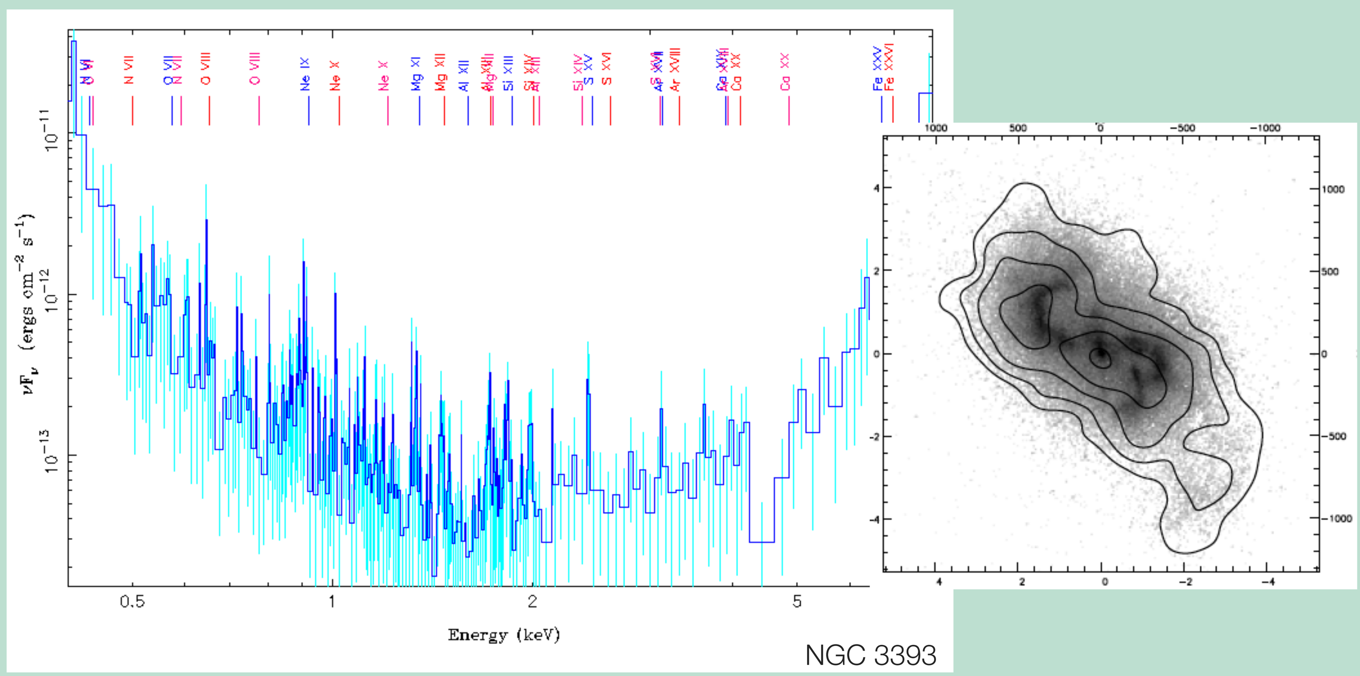
Fig. 4 Mass estimates for the six components of the spectral model fit to the data in Fig. 1 (Kallman et al. 2014). Black indicates the higher NH component (see Fig. 3). The total mass is about 4 x10^5 Msun. When combined with the outflow speed of 450 km/s and region size, the outflowing mass rate is 20x that due to accretion.

A Gallery of Chandra HETGS Observations

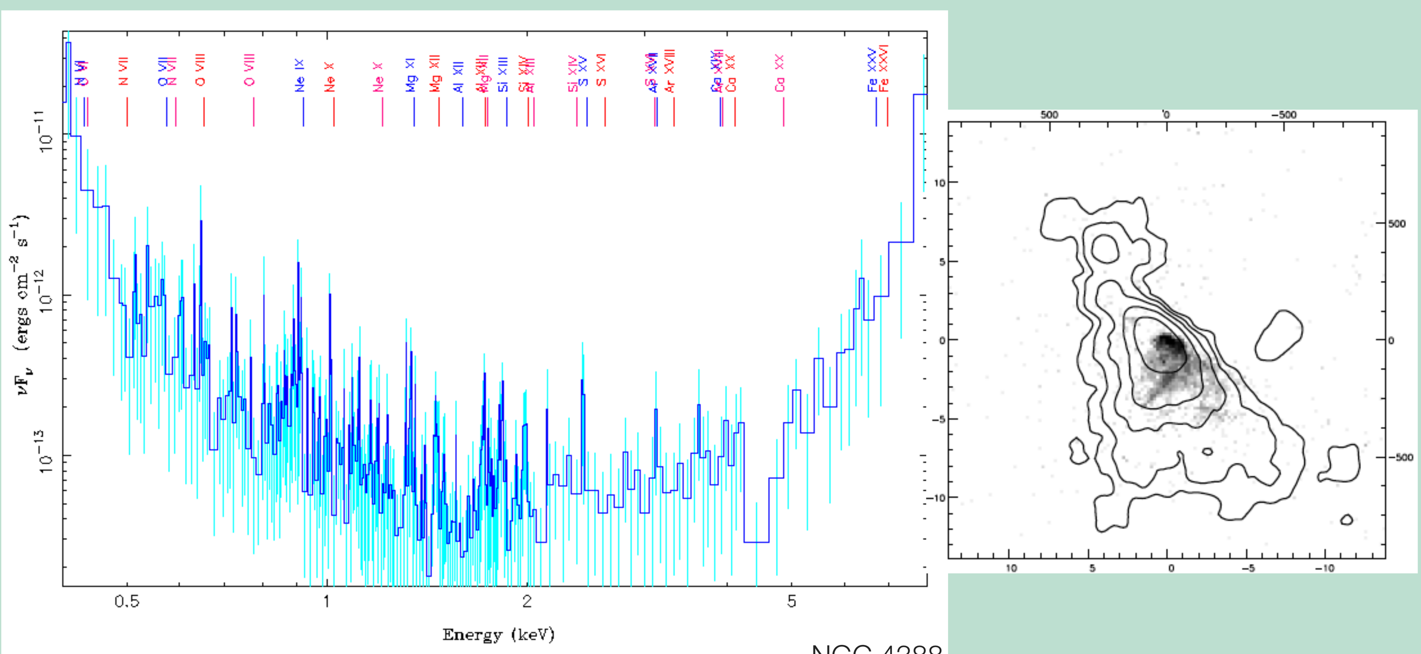
Shown here are six νF_ν plots of HETGS spectra obtained from the Chandra archive using the TGCat interface and plotting tool. These are all obscured AGN, giving one an impression of the complexity of the soft spectra. One observation of NGC 1068 (30 ks) is shown for comparison. Most of these sources also show extended emission over 5-10", so only a telescope with high spatial resolution like Chandra or the X-ray Surveyor can provide the means to separate nuclear and off-nuclear gas. Next to the spectra are grayscale images in O III overlaid by X-ray contours from Bianchi et al. 2006. The left and bottom scales are in arcsec and the right and top scales are in pc.



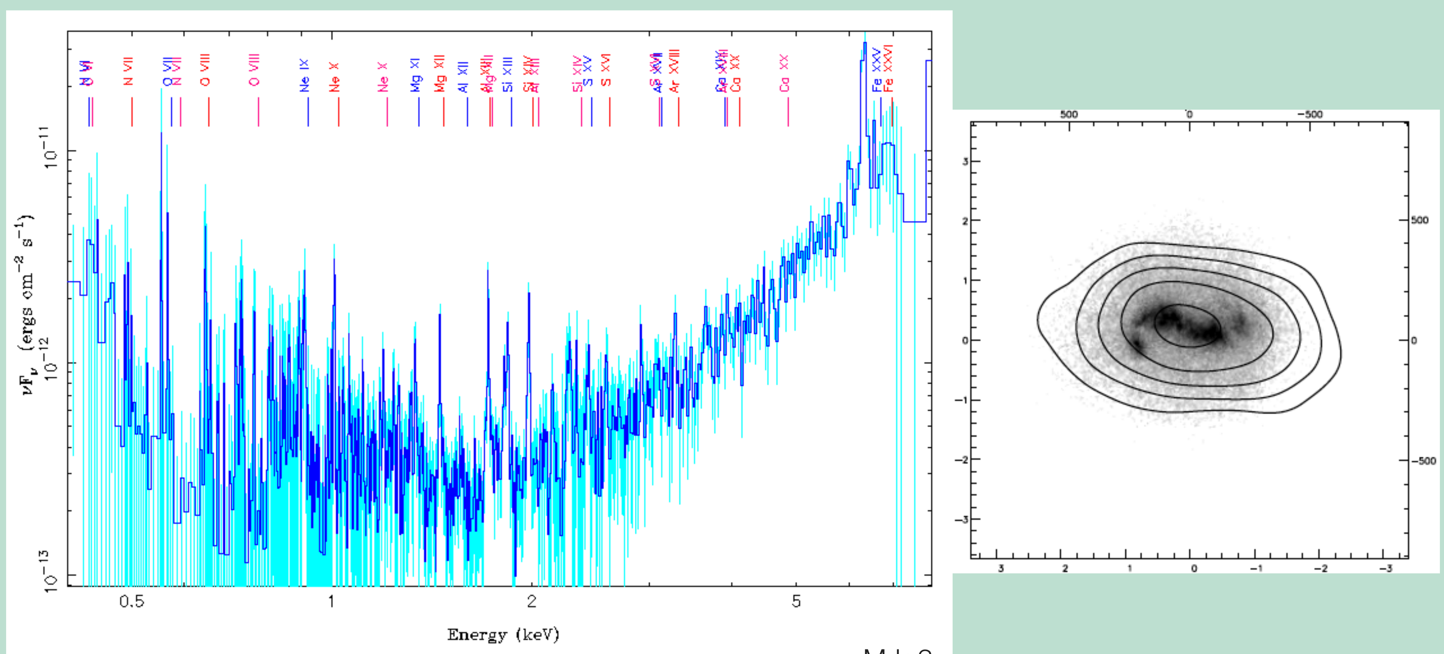
NGC 1068



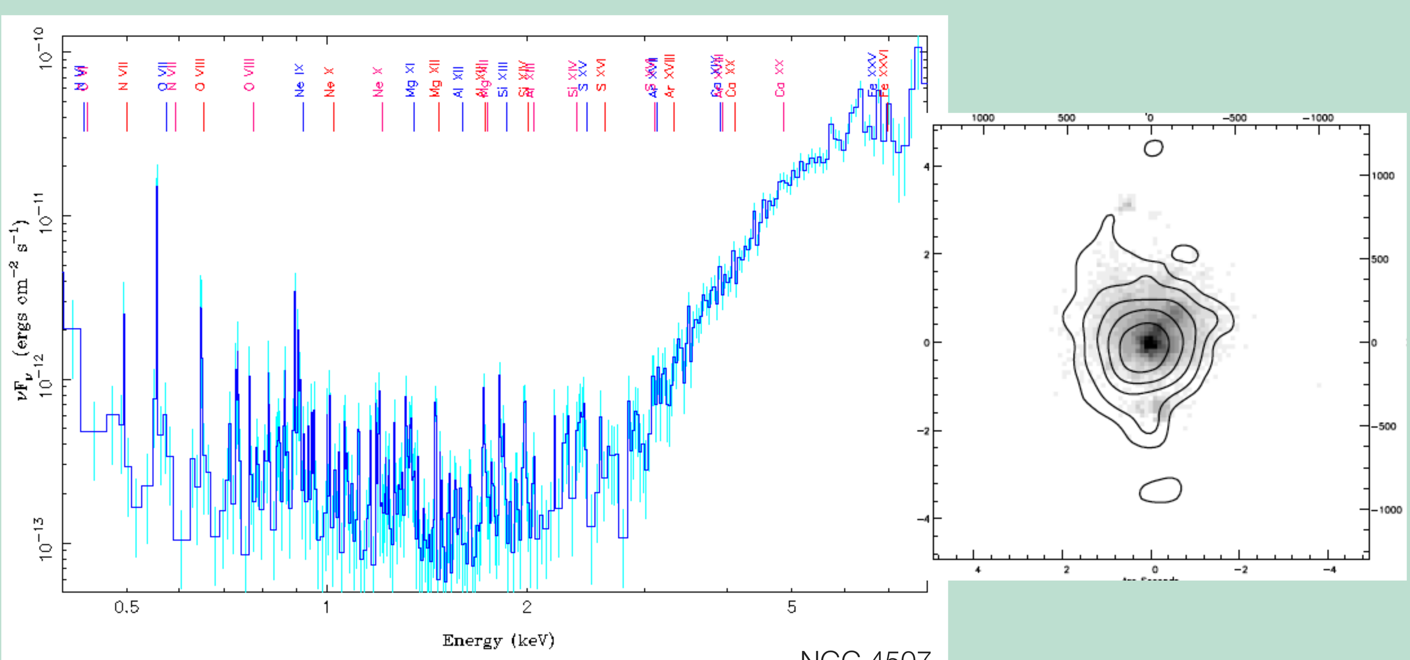
NGC 3393



NGC 4388



Mrk 3



NGC 4507

Surveyor Prospects

Fig. 6 (right) shows the distribution of O VII fluxes for obscured AGN observed by XMM. At x1000 more area at 0.5 keV, Surveyor's grating spectra would be comparable to Chandra's best (NGC 1068) in only 40 ks for any one of these targets. Clearly, much fainter sources could be observed.