X-RAY SPECTROSCOPY OF COOLING FLOWS

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Introduction

Cooling flows in clusters of galaxies occur when the cooling time of the gas is shorter than the age of the cluster; material cools and falls to the center of the cluster potential. Evidence for short X-ray cooling times comes from imaging studies of clusters (e.g. Forman and Jones 1982; Fabian 1994) and X-ray spectroscopy of a few bright clusters. Because the mass accretion rate can be high (a few $100 \; M_\odot \; \text{year}^{-1}$) the mass of material accumulated over the lifetime of a cluster can be as $10^{12} M_\odot$. However, there is little evidence for this material at other wavelengths, and the final fate of the accretion material is unknown. X-ray spectra obtained with the Einstein SSS show evidence for absorption; if confirmed this result would imply that the accretion material is in the form of cool dense clouds. However ice on the SSS make these data difficult to interpret.

We obtained ASCA spectra of the cooling flow cluster Abell 85. Our primary goals were to

- Search for multi-temperature components that may be indicative of cool gas
- Search for temperature gradients across the cluster
- Look for excess absorption in the cooling region
We fit a two-temperature (Raymond thermal plasma) model to the inner 210 kpc of the SIS0 spectrum of Abell 85 (the exposure time was 35,000s). The models are summarized in Table 1 below. The second model, with $N_H$ in excess of galactic, is a better fit. There are residuals at 1-2 keV which may be due to uncertainties in the atomic data.

<table>
<thead>
<tr>
<th>Model</th>
<th>$\chi^2$/DOF</th>
<th>Reduced $\chi^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$kT=6.7$ (fixed)</td>
<td>347/229</td>
<td>1.54</td>
</tr>
<tr>
<td>$kT=2.1$ (fit)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$N_H = 3 \times 10^{20}$ (fixed, galactic)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two temperature</td>
<td>276/229</td>
<td>1.23</td>
</tr>
<tr>
<td>$kT=6.7$ (fixed)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$kT=1.8$ (fit)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$N_H = 8 \times 10^{20}$ (fit)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

We also evaluated the $N_H$ as a function of radius. The central bin encompassing the cooling region shows clear evidence for excess absorption, indicative of cool gas. There is a slight rise in absorption in the outer bin, probably an artifact of mirror scattering.
Summary of Results

- Spectra extracted outside of the cooling flow region are fit by a single temperature plus galactic absorption.
- The central bin requires a two temperature fit, showing the presence of cool gas.
- The central bin shows clear evidence for excess absorption.
  - The excess absorption $N_H \sim 5 \times 10^{20}$, less than that reported by Fabian et al., 1994 for other clusters. Because of uncertainties in the early ASCA response matrices, the absorption reported by Fabian et al. may be overestimated.
  - The gas mass implied by this $N_H$ is $\sim 2 \times 10^{11} M_\odot$. This is approximately a factor of 10 below that expected if the current cooling rate ($230 M_\odot \text{ year}^{-1}$) has been constant over the age of the cluster ($10^{10}$ years).