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HOT GAS IN ELLIPTICAL GALAXIES

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ABSTRACT

We review recent systematic investigation of the X-ray spectra of early type galaxies by using the Einstein data base and present new results by the ROSAT observations. The Einstein data suggested that the galaxies with low X-ray to optical luminosity ratio may have another very soft component. ROSAT observations confirm its presence and call for further study to understand the nature of this very soft emission. The X-ray bright galaxies have emission temperature of ~ 0.8 keV and show radial gradients in the sense that X-ray emission is softer and more absorbed in the inner region.

I. INTRODUCTION

One of the most outstanding achievement of the recent X-ray study by the Einstein Observatory is the discovery of hot gas in elliptical galaxies (see review by Fabbiano 1989). The presence of hot interstellar matter dramatically altered the traditional view that elliptical galaxies do not retain detectable amount of interstellar matter (for example Forman, Jone and Tucker 1985). It provides new tools to investigate elliptical galaxies, their formation and evolution and their ISM.

About 100 early type galaxies are now known to have X-ray emission of 10^{38} to 10^{40} erg sec^{-1}. The amount of hot gas is roughly 10^9 to 10^{10} g. The discovery of the hot gas in early type galaxies exclude the possibility that the galactic wind prevails from the early epoch. Instead, many cooling models have been suggested to explain the observational results. Strong observational constrains are very important in distinguishing various models and in understanding the origin and evolution of these galaxies.

In the first half of this paper, we present the results from the recent systematic study of the Einstein data base. In the second half we discuss the new results by the ROSAT observatory.

II. X-RAY EMISSION MECHANISMS

It is now quite clear that the X-ray emission in bright early type galaxies is due to the hot gas. There are several direct and indirect evidence for its presence. The most clear case is NGC 4406 where the displaced, asymmetric X-ray sources have been attributed by the ram pressure when this galaxy moves through the intercluster medium (White et al., 1991). In fact NGC 4406 has one of the highest peculiar velocity among the Virgo cluster galaxies. NGC 4472 also shows asymmetric distribution of X-ray rightness (Trinchieri and Fabbiano and Canizares 1986). X-ray bright galaxies have excess X-ray emission over that expected from the stellar sources as in spiral galaxies where the X-ray sources are mainly low-mass X-ray binaries (Fabbiano, Kim, Trinchieri 1992). This excess emission is naturally explained by the hot gas.

Recent spectral analyses of the Einstein data established the existence of the hot gas more firmly (Kim, Fabbiano and Trinchieri 1992a and 1992b). The X-ray spectra of early type galaxies, on the average, show lower emission temperature ($\sim$ 1 keV) than those of spiral galaxies ($\geq$ 3 keV). This spectral evidence definitely show that X-ray emission in early type galaxies are not from the X-ray binaries. Maybe the best evidence will be provided by the future detection of X- ray emission lines or optical coronal lines from the elliptical galaxies.

In order to understand the emission mechanisms in low luminosity elliptical galaxies which do not have extended X-ray emission and whose X-ray luminosity for a given optical luminosity is comparable to those from the stellar sources, we divided the early type galaxy sample according to the X-ray to optical luminosity ratio. The combined X-ray spectra of these groups are shown in Figure 1. The group 1 is assigned to those galaxies with the lowest ratio and group 4 to those with the highest ratio. In general, the emission temperature is order of 1 keV for the groups with a high X-ray to optical luminosity ratio and increases toward the group with a lower ratio. It indicates that contribution of gaseous emission decreases and stellar emission increases as the X-ray to optical luminosity ratio decreases. Interestingly, in the group with the lowest X-ray to optical ratio there appears another soft component in addition to the stellar emission. It needs further study and the ROSAT observations confirm its presence (see below).

III. VERY SOFT X-RAY EMISSIONS IN LOW LUMINOSITY ELLIPTICALS

We have observed NGC 4365 and NGC 4382 with the ROSAT PSPC (Position Sensitive Proportional Counter). These galaxies were selected because they are in the group with the lowest X-ray to optical luminosity ratio, for which the Einstein data suggest existence of a very soft X-ray component (Kim, Fabbiano and Trinchieri 1992b). The X-ray spectra of

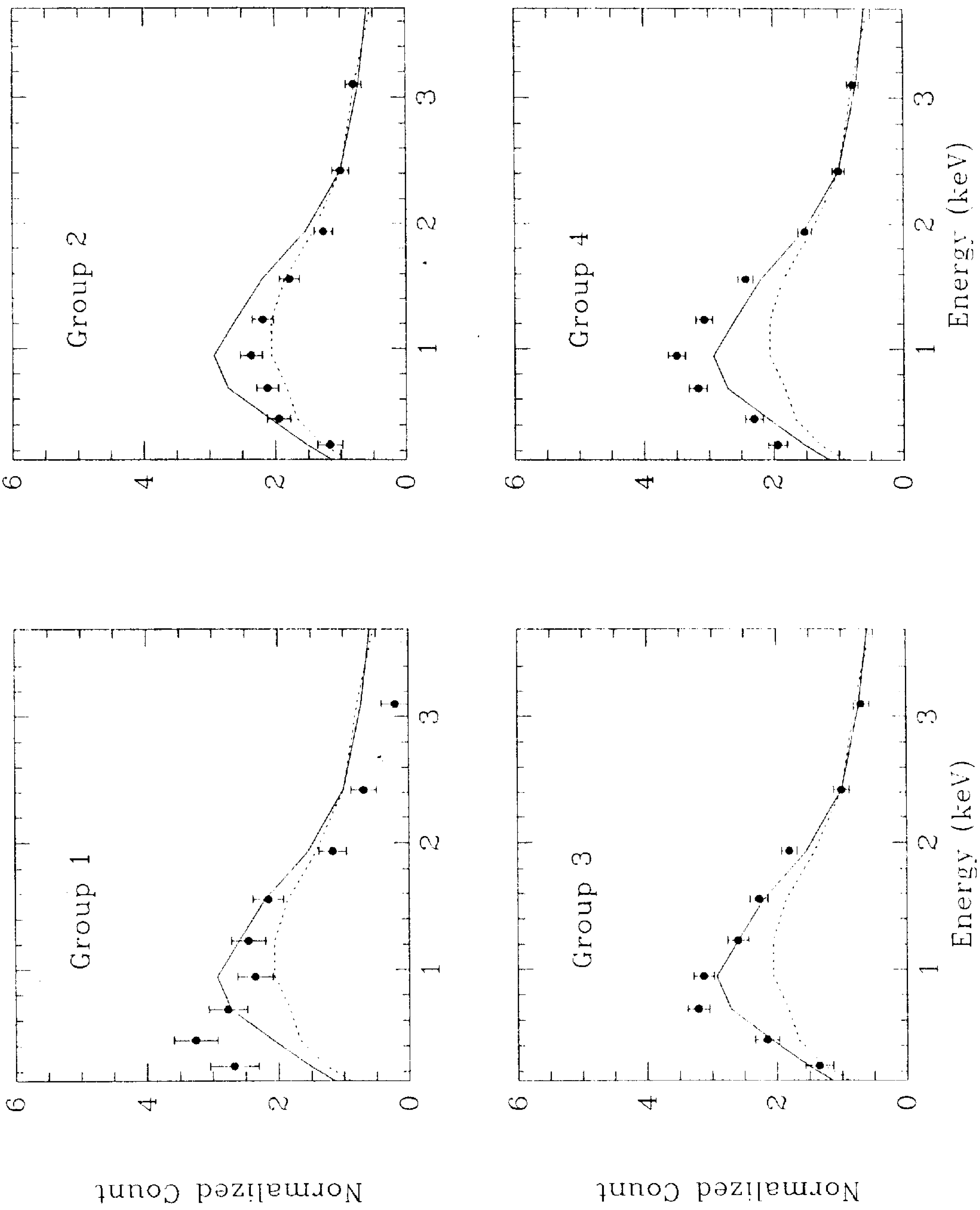

Fig. 1. Combined X-ray spectra of early type galaxies. The galaxies are grouped according to the X-ray to optical luminosity ratio. The group 1 has the lowest ratio and the group 4 has the highest ratio. The solid line is the average spectrum of early type galaxies and the dotted line is for that of spiral galaxies.

these galaxies are shown in Figure 2. We first fitted the data to the isothermal gas model. χ^2 values are unacceptably high for both galaxies and there are definitely excess emission in lowenergy (0.1 - 0.8 keV) as seen in Figure 2. With two-temperature models, the data are well fitted and χ^2 values are acceptable (see Figure 3). The soft component has a temperature of 0.1-0.3 keV and the hard component has a temperature higher than ~ 1.5 keV (the temperature of the hard component cannot be well determined by the ROSAT observation).

While the spectra and the luminosity of the hard component are consistent with the stellar sources (X-ray binaries) seen in spiral galaxies, the origin of the soft component is not known. Possible explanations of the soft component are accumulation of M dwarf, unknown very soft sources like those found in M31 and warm interstellar gas (Pellegrini and Fabbiano 1993). More detailed analysis will be present in the future work (Fabbiano, Kim, Trinchieri and Canizares 1993).

Ⅳ. TEMPERATURE GRADIENT IN X-RAY LUMINOUS ELLIPTICALS

We observed two high X-ray luminosity elliptical galaxies, NGC 4636 and NGC 4649 with the ROSAT PSPC. These are in the group of highest X-ray to optical luminosity ratio among the Einstein sample (Trinchieri, Fabbiano and Canizares 1987; Kim, Fabbiano and Trinchieri 1992b). The X-ray spectra are fitted to the optically thin gas model with a single temperature. The best fit parameters are 0.7 keV and 0.8 keV for temperature and $\sim 10^{20}$ cm^{-2} for absorption column density. Although the temperature is not significantly different from the prediction of the gas models suggested by many authors, it is a little bit lower than the canonical value of 1 keV. Another important spectral information obtained by the ROSAT PSPC observations is that the spectra can be fitted only to the gas emission model with spectral lines.

In order to investigate the radial change in gas parameters, we make 3 radial bins and fit the spectra of each bin to the model. In both galaxies the temperature and column density varies in a sense that gas is cooler and X-rays are more absorbed in the inner region than in the outer region. The radial gradients found here are too small to have been detected by the previous X-ray missions. Qualitatively, the estimated gradient in temperature and column density is consistent with the prediction of the cooling flow model. Since the parameters are quite well defined, these observations will provide strong constraints to the model which should explain the observed gradient quantitatively. More detailed analysis will be present in the future work (Trinchieri, Fabbiano, Kim and Canizares 1993).

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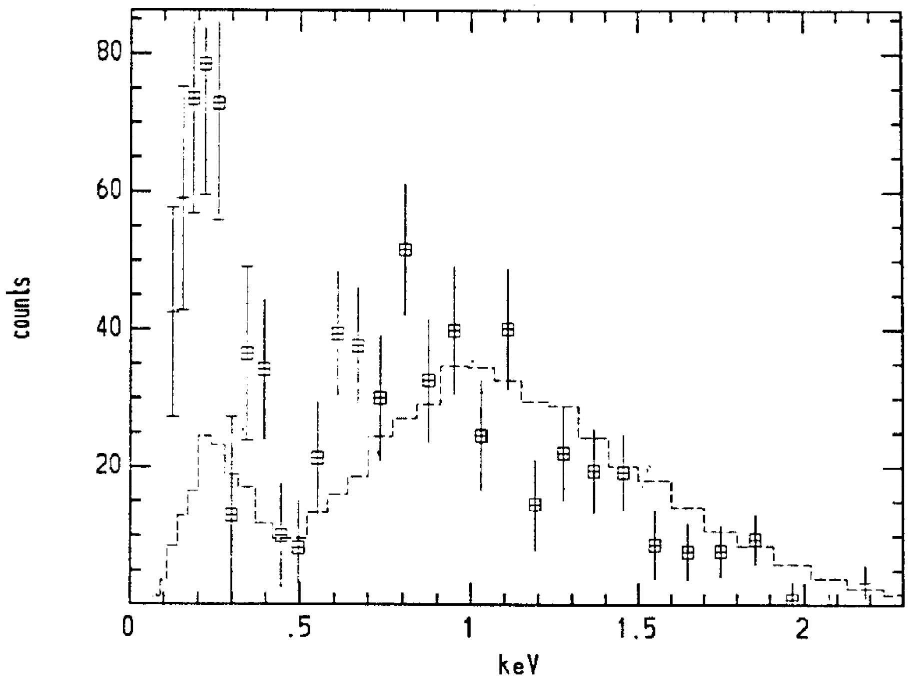
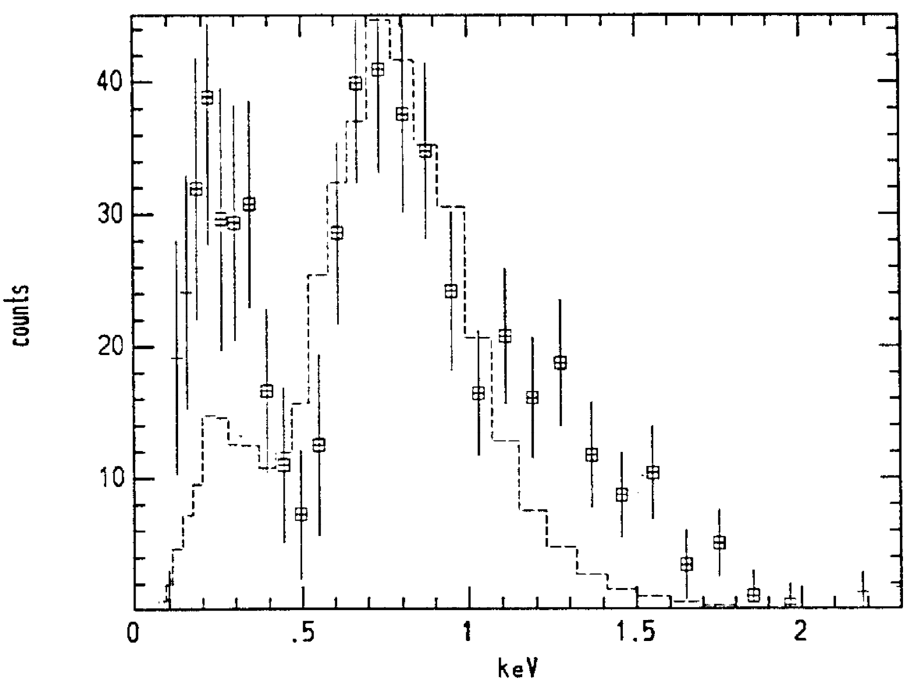


(a)



(b)

Fig. 2. X-ray spectra of (a) NGC 4365 and (b) NGC 4382. The dashed lines are the best fit model predictions using the one temperature gas model.

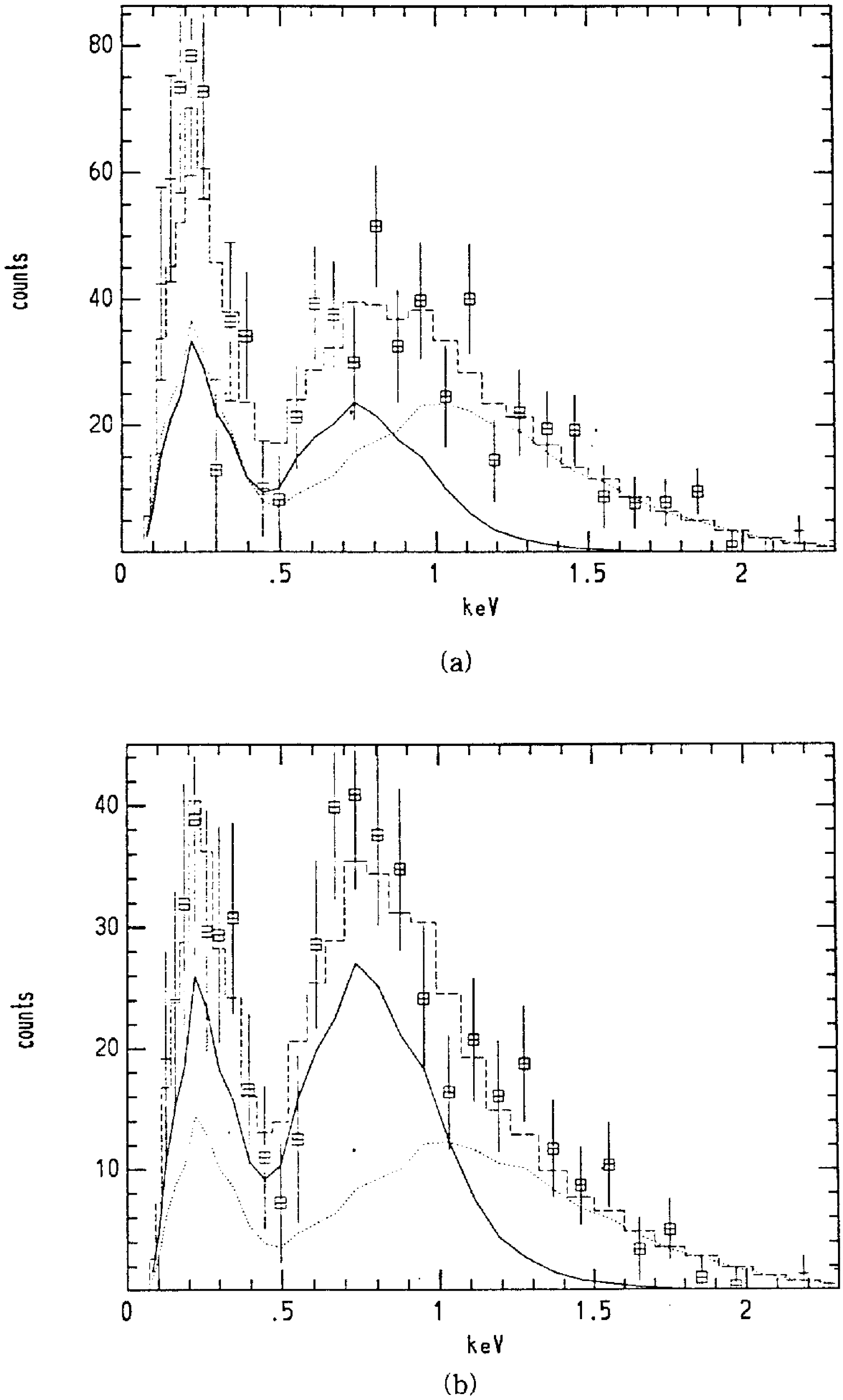
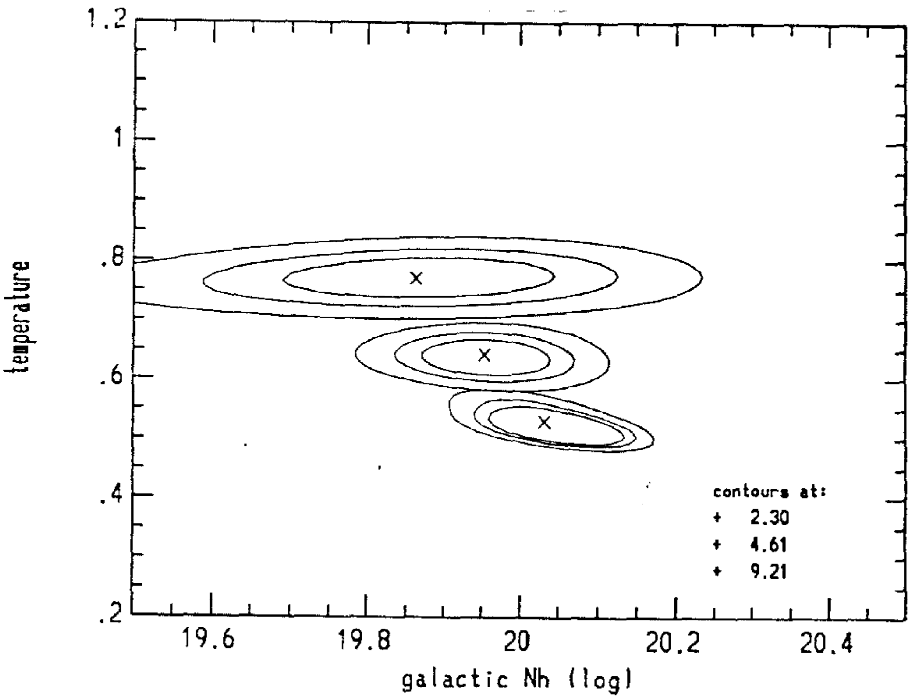
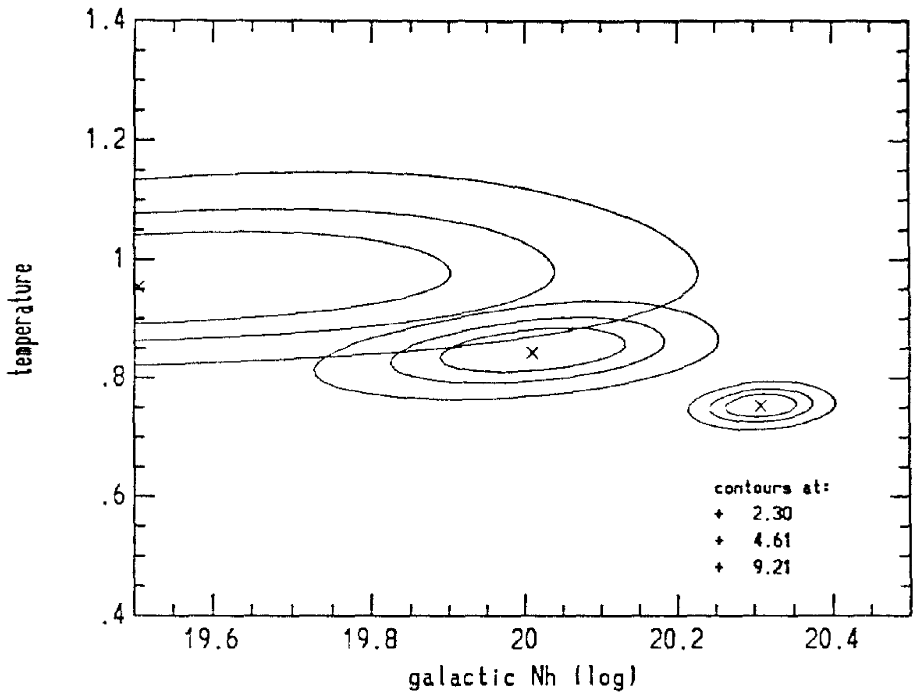


Fig. 3. Two temperature model fitting of the X-ray spectra of (a) NGC 4365 and (b) NGC 4382. The solid lines are for the soft component, the dotted lines are for hard component and the dashed lines are the combined emission.



(a)



(b)

Figure 4. χ^2 grid in kT and log(N_H) plane for (a) NGC 4636 and (b) NGC 4649. The best fit parameters are marked by x and the contours are for 68%, 90%, and 99% confidences. From lower right to upper left, the contours are for the regions of r<60'', r=60-120'' and r>120''.

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