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ASCA OBSERVATIONS OF THE STARBURST GALAXY M82

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RESUMEN

El espectro obtenido por *ASCA* de M82 necesita tres componentes: una blanda (0.32 keV), una intermedia (0.95 keV) y una dura (13.8 keV). Las líneas de emisión indican que las componentes blanda e intermedia son originadas en un gas caliente, por el brote de formación estelar. Las abundancias de O, Ne, Mg, Si y S son menores a las solares y sus cocientes no pueden ser obtenidos con mezclas de SN I y II. La componente dura es puntual, pero la blanda y la intermedia son extendidas. Los datos desde *Uhuru* hasta *ASCA* muestran que la componente dura ha variado por un factor entre 2 y 4. Además, su temperatura obtenida con *ASCA* es de 13.8 keV, mayor al valor 5.75 keV obtenido por *Ginga*. Esto indica la posibilidad de un núcleo activo en M82.

ABSTRACT

The *ASCA* spectrum of M82 is fit by three components: a soft component (0.32 keV), a medium one (0.95 keV), and a hard one (13.8 keV). The presence of line emission indicates that the soft and the medium components are due to gas heated by the starburst activity. The abundances of O, Ne, Mg, Si and S are lower than the solar values and the abundance ratios cannot be reproduced by a combination of SN Ia and II. Imaging analysis shows the hard component is point-like, but the soft and medium components are extended. Long term variability from *Uhuru* to *ASCA* by a factor of 2 $\sim$ 4 is detected in the hard component. Additionally, the temperature of the hard component obtained with *ASCA* is 13.8 keV, significantly higher than the *Ginga* value of 5.75 keV. These results suggest that M82 may contain a nuclear activity similar to that seen in AGN.

Key words: **GALAXIES: ACTIVE — GALAXIES: STARBURST — X-RAY: GALAXIES**

1. INTRODUCTION

Starburst galaxies are thought to be undergoing a burst of star formation in their nuclear regions. Their X-ray emission is believed to result from hot plasma associated with SN remnants and compact objects produced by SN explosions following the starburst. Starburst galaxies are important because they are thought to be prototypes of early phases of galaxy evolution. Some astronomers suggest that a link may exist between AGN activity and starburst activity. M82 is the most famous and the nearest starburst galaxy and has been investigated at many wavelengths including the X-ray band (Watson et al. 1984; Fabbiano 1988; Schaaf et al. 1989; Tsuru 1992; Petre 1993; Tsuru et al. 1994; Watson et al. 1994; Collura et al. 1994; Bregman et al. 1995).

2. SPECTRAL ANALYSIS

Figure 1 shows the SIS spectrum of M82 with the best fit model spectrum (described below). Prominent Mg, Si and S emission lines are seen in the spectrum, implying the presence of a hot plasma. However, the continuum above 2 or 3 keV can only be explained by a temperature greater than 10 keV. At such a high temperature, Mg, Si and S are fully ionized. Thus the presence of the lines and the continuum demand at least two components. The observed line strength ratio of H-like Kα to He-like Kα for each element is a measure of the temperature of the material containing the element. The upper limit allowed by the Mg lines

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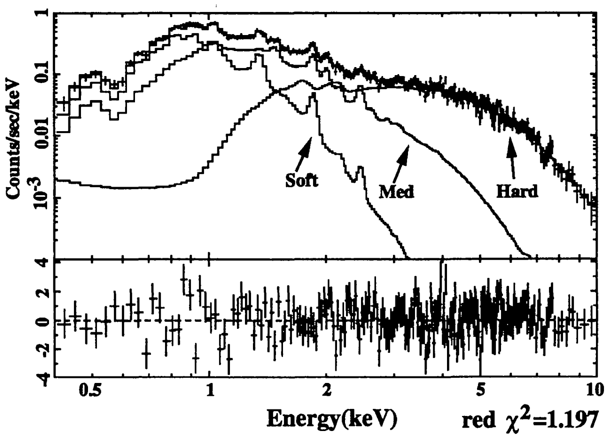

Fig. 1. The SIS spectrum of M82 is shown with the best fit model spectrum. The best fit is obtained from simultaneous spectral fitting to the SIS and GIS data, although only the SIS spectrum is plotted here.

is 0.68 keV, while the Si lines imply a temperature of about 1.2 keV. As the temperature ranges consistent with the observations of the Mg and Si lines have no overlap, the line-emitting component itself must be composed of at least two components. Thus a total of three components, two line emitting and one hard, are needed. We carried out spectral fitting using the following three component model, and found acceptable results: $(\mathrm{Abs_{Whole}})(\mathrm{RS_{Soft}} + \mathrm{RS_{Med}} + \mathrm{Abs_{Hard}} \times \mathrm{RS_{Hard}})$. RS means the Raymond-Smith thermal model emission from the Soft, Med and Hard components. The absorption covering the entire spectrum is $\mathrm{Abs_{Whole}}$, and is about $3.0 \times 10^{21}\mathrm{cm}^{-2}$, higher than the Galactic 21-cm column densities. The temperatures of the soft and the medium components are 0.32 and 0.95 keV respectively. The temperature of the hard component is 13.8 keV and with an extra absorption, $\mathrm{Abs_{Hard}}$, on only this component alone of $1.9 \times 10^{22}\mathrm{cm}^{-2}$.

3. IMAGE ANALYSIS

We investigate the spatial distribution of the these components from images made at 0.5 – 0.8 keV (soft component), 1.2 – 1.8 keV (medium component) and 3 – 10 keV (hard component). The soft component shows a clear extension, along the direction of the minor axis of the optical image of M82. The radial profile of the image of the hard component is indistinguishable from the *ASCA* Point Spread Function. The image of the medium component does not show the obvious extension of the soft component, but the radial profile of the medium component is inconsistent with the *ASCA* Point Spread Function at radii around 1 arc-min, demonstrating that the medium component is slightly extended. The peaks of the emission from the hard and medium components are identical within the *ASCA* resolution. The soft component image shows multiple peaks, none of which correspond to the peak of the hard and medium components. We interpret the image of the hard component as a point-like source associated with the nucleus of M82, while the soft component is a thermal, diffuse emission. The multiple peaks seen in the soft image may be due to patchy absorption in the source.

4. ABUNDANCES AND TIME VARIABILITY

Figure 2a shows the inferred abundances from spectral fits to the soft and medium components of M82. All abundances are below the solar values. The maximum abundance is found for Si and S, while those of O and Fe are very low. Comparing these abundances with the abundance ratios synthesized by SN Ia and II (Tsujimoto et al. 1995), we find a strong disagreement. SN contribute much more O and Fe than Si and S. Thus no combination of SN Ia and II abundance enhancement can explain the observed M82 abundance ratios.

No apparent short time variability in the 2 – 10 keV band is detected from either the SIS or GIS during the *ASCA* observation. Figure 2b shows the long term light curves from *Uhuru* to *ASCA*. The crosses mark the luminosity in the 2 – 10 keV band, which corresponds to the hard component emission. The circles mark the luminosity in the 0.2 – 4 keV band, which corresponds to the soft and the medium components. The luminosity at 0.2 – 4 keV obtained with *ASCA* and the ones with *Einstein* HRI and IPC are almost the same, but there seems to be time variability in the 2 – 10 keV band by a factor of 2 to 4.

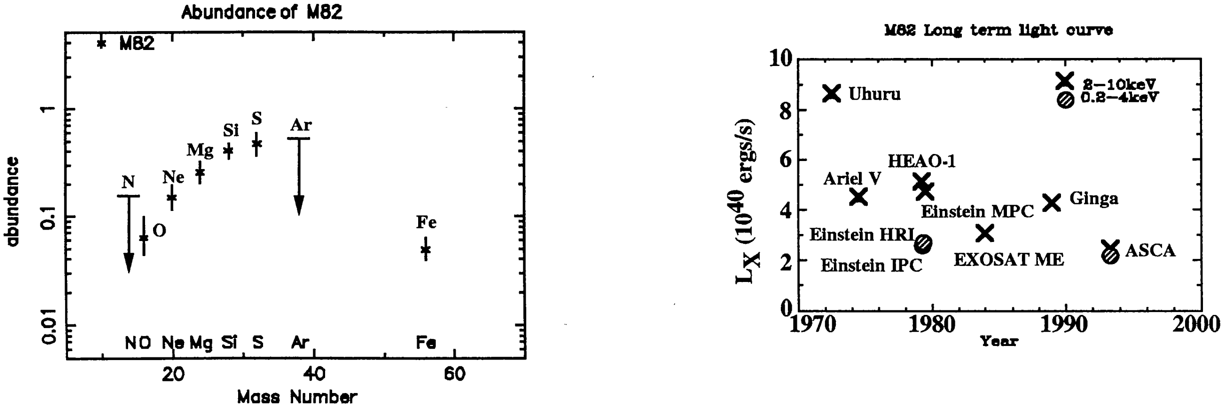

Fig. 2. *a)* The metal abundances derived from the soft and medium components. *b)* Light curves, in the $2-10$ and $0.2-4$ keV bands, from *Uhuru* to *ASCA*.

5. ORIGIN OF THE HARD COMPONENT

Based on our observations, what can we say about possible origins of the hard component? A first possibility is a simple sum of X-ray binary sources such as seen in our Galaxy. In this case, 100 or 1000 binary sources are needed to explain the luminosity of 10^{40} to 10^{41} ergs s^{-1}. However, it would be extremely unlikely for such a large number of sources to change their luminosities simultaneously to produce the time variability we observe. Thus we reject this hypothesis. A second idea is a very young SNR like SN1993J in M81 (Kohmura et al. 1994). The initial X-ray luminosity of SN1993J obtained with *ASCA* was about 10^{40} ergs s^{-1}, which is rather comparable to M82's luminosity. However, the luminosity of M82 has decreased from *Ginga* to *ASCA* by a factor of 2, while the temperature has increased from 5.75 keV to 13.8 keV. SNRs typically cool as they expand, not heat up. Additionally, the strong Fe-K line detected in SN1993J is not observed in M82. So this hypothesis is not acceptable either. A third possibility is a so-called super-Eddington source. *ASCA* detected several point sources outside the nuclear regions in some spiral galaxies whose X-ray luminosities are in the range of 10^{39} to 10^{40} ergs s^{-1}(Okada et al. , 1994). In the M82 case, the hard component is very close to the nucleus. Additionally, the luminosity of the hard component reaches 9×10^{40} ergs s^{-1}, which is rather bright for a super-Eddington source. However, the possibility cannot be ruled out as the nature of super-Eddington sources has not been completely understood. The last possibility we call the hidden Low Luminosity AGN (LLAGN). *ASCA* observations show that some spirals are hosts of LLAGN whose luminosity is 10^{40} to 10^{41} ergs s^{-1}(Ishisaki et al. 1996). In M82, no AGN activity has yet been reported but the large absorption column and complicated starburst activity might be disguising the LLAGN activity at other wavelengths. We conclude, therefore, the LLAGN possibility is the most plausible.

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