Iron Line Emission from NGC1068

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ABSTRACT. X-ray emission in the 2-10 keV energy range was observed with the Ginga satellite from the Seyfert 2 galaxy NGC1068. The continuum spectrum can be described by a power-law of photon index about 1.5. An intense iron line at 6.5 keV with an equivalent width of 1.3 keV was clearly noticed. The X-ray flux was about 6×10^{-12} erg/sec/cm^2 or 3×10^{41} erg/sec, assuming a distance of 22 Mpc. The observed spectrum is consistent with the scattering and reprocessing of X-rays by the gas surrounding the central engine. With this picture we estimate that the X-ray flux of the central engine is about 10^{43}- 10^{44} erg/sec, a typical value for a Seyfert 1 galaxy.

1. Observations and Data Analysis

The observations were made on 31 July-2 Aug., 1987 with the large area proportional counters (LAC) onboard the Ginga satellite. The effective area of LAC is 4000 cm^2 and the detector field of view is 1°x 2° (FWHM). The total observation time , after excluding high background data, was 3×10^4 sec. We determined the background spectrum by summing over pointed data from a large number of source-free regions of the sky, off the galactic palne. The excess X-ray flux in the 2-10 keV range above this background level was 2.3 counts/sec. The statistical error is negligible, while the ambiguity due to any non-X-ray background is estimated to be less than 0.1 count/sec in the relevant energy range. However, fluctuations in the diffuse sky X-ray emission introduce an

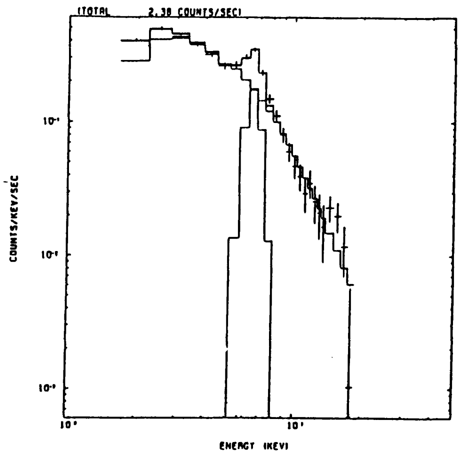

Fig.1 X-ray spectrum of NGC1068 together with the best-fit power-law continuum and iron emission line

D. E. Osterbrock and J. S. Miller (eds.), Active Galactic Nuclei, 167–172.

https://doi.org/10.1017/S0074180900140707 Published online by Cambridge University Press

additional error of about 0.7 count/sec. Therefore the overall error is estimate to be about 0.7 count/sec. Hereafter we will include this systematic error for the estimation of physical parameters.

The X-ray spectrum of NGC1068, after background subtraction, is given in figure 1. An intense line feature at about 6.5 keV, which is attributable to the iron K line, is clearly visible. The spectrum can be fitted by either a power-law or a thermal bremsstrahlung model adding an emission line and low energy absorption. The best-fit photon-index (or temperature),iron line energy and equivalent width are 1.5 ± 0.04 (17 ± 5 keV), 6.55 ± 0.1 keV and 1.3 ± 0.4 keV, respectively. The total flux in 2-10 keV energy band is estimated to be about (3 ± 1) x 10^{41} erg/s assuming a distance of 22 Mpc (Weedman 1977). This luminosity is nearly same as that observed previously (Elvis and Lawrence, 1988) and is one or two orders of magnitude smaller than that of a typical Seyfert 1 galaxy (e.g., Kriss et al. 1980). The low energy absorption was found to be less than 10^{22} H/cm^2. No apparent iron K-edge structure was found. The 90 % upper limit of N_{Fe} is equivalent to 7 x 10^{22} H/cm^2 of N_H assuming cosmic abundances.

2. Discussion

2-1 What does the iron line tell us ?

The observed spectral shape with a strong iron K emission line is unusual when compared to those of other AGNs. Such large equivalent widths as about 1.3 keV are usually observed from thermal plasma sources, typically supernova remnant. We show the Ginga spectrum of Cas A in figure 2, in which an intense iron line with equivalent width of about 1 keV is obvious. Is the iron line from NGC1068 also attributable to thin thermal emission? As shown above, a thin thermal bremsstrahlung model of 17 ± 5 keV gave an acceptable fit to the spectrum of NGC1068. In such a high temperature plasma, however,the iron line energy should be about 6.9 keV, corresponding to H-like iron. Furthermore the iron line intensity should be much smaller than observed. It is clear that a thermal origin for the X-ray emission from NGC1068 is unrealistic.

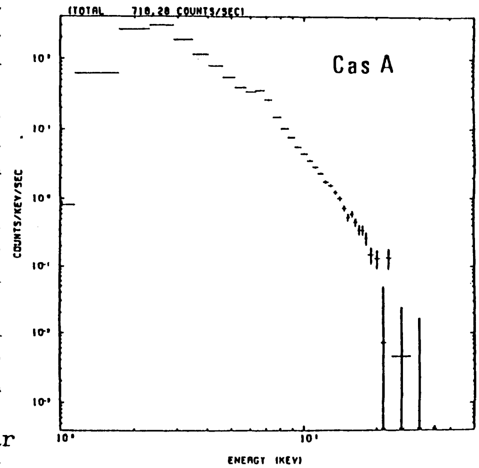

Fig.2 An example of thin thermal spectrum from Cas A. An intense iron line of equivalent width of 1 keV was observed.

Another possibility is that the

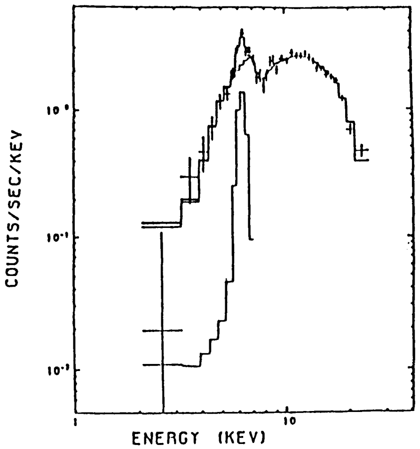

Fig.3 The spectrum of the X-ray pulsar GX301-2 (Leahy et al. 1988).

iron line emission is due to fluorescence. Some X-ray binary pulsars (such as GX301-2) exhibit a strong iron line by this mechanism. We can estimate the iron line equivalent width as a function of the column density of gas surrounding the X-ray emitter. If the column density is as large as 10^{24}H/cm^2, then we get an equivalent width of about 1 keV. This case is demonstrated in figure 3 for the X-ray pulsar GX301-2 (Leahy et al. 1988). In this case, the K-edge absorption structre is very prominant. On the other hand, the spectrum of NGC1068 shows no K-edge absorption. Thus,explaine the X-ray line emission through fluorescence by a large N_H is also unlikly for NGC1068.

The other case for intense iron line emission occurs during eclipse of X-ray binary pulsar. Figure 4 show the X-ray spectrum of Vela X-1 during eclipse (Sato et al. 1986). We see a strong iron line of equivalent width about 2 keV. What is the origin of this line ? A hot thin thermal plasma associated with the companion star is unlikely because the iron line energy is 6.4 keV , corresponding to emission from neutral iron. The geometry of this system during the eclipse is demonstrated in figure 5. A naive picture is that the observed X-rays are due to scattering in the circumsteller gas. In order to estimate the iron line intensity from the scattering gas, we did a numerical simulation assuming that the gas distribution and X-ray beam are spherically symmetric. Figure 6 shows the result of this simulation for cool gas with a cosmic abundance of iron (Inoue 1985). The iron line is due to fluorescence of the surrounding gas, while the continuum is due to Thomson scattering. Since the Thomson scattering cross section is almost energy independent, the spectrum of the scattered X-rays is similar to that of the direct spectrum. The equivalent width of the iron K-line is approximately

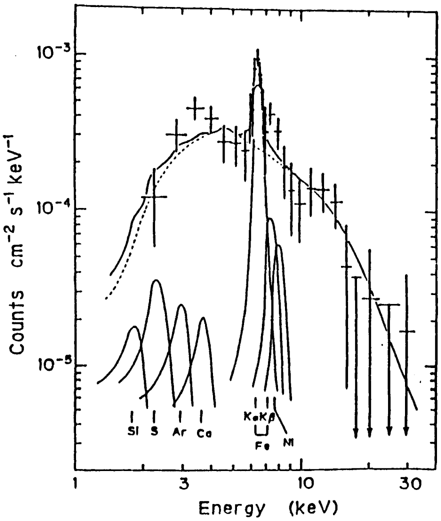

Fig.4 X-ray spectrum of Vela X-1 during the eclipse phase. The observed X-ray is due to the scattering of the surrounding gas around the binary system (Sato et al. 1986).

determined by the ratio of the Thomson cross section to the K shell absorption cross section. Then the equivalent width of iron for cosmic abundance can be large for a wide range of values for the column density of the surrounding gas (see also Krolik and Kallman 1987). If the column density is small enough, we see no significant K-edge absorption structure in the spectrum. In fact, the spectrum of Vela X-1 during the eclipse shows no K-edge structure. The spectrum can be fitted by the model of scattered X-rays with a column density about 10^{22}H/cm^2. We note here that this spectrum is very similar to that of NGC1068.

2-2 Model of Seyfert 2 Galaxy

Several models for the X-ray emission from Seyfert 2 galaxies have been proposed (e.g. Lawrence 1987). One attractive model is that Seyfert 2 galaxies have the same central engine as Seyfert 1 galaxies. The only difference for Seyfert 2 galaxies is that the central engine, as well as, the broad line region are obscured by dense matter, possibly an accretion torus (see Antonucci and Miller 1985). The present Ginga observations give strong support to this model. Indeed, an iron K line having exactly the observed properties was predicted on the basis of this model before these observation were made (Krolik and Kallman 1987). If the column density is less than a few 10^{22}H/cm^2, then this model spectrum gives almost the same continuum shape as that of the direct X-ray beam.

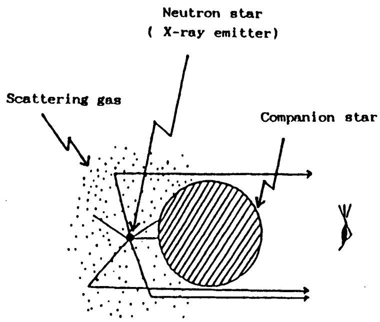

Fig.5 A schematic picture during the eclipse of Vela X-1.

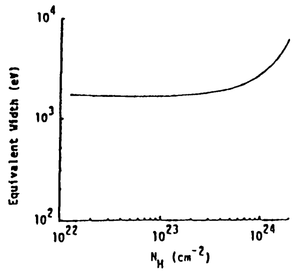

Fig.6 A Simulation of equivalent width of iron in the spectrum scattered by the surrounding gas (Inoue 1985).

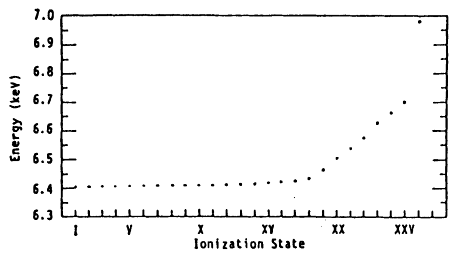

Fig.7 The energy of iron emission line as a function of the ionization states (Inoue et al. 1986).

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Therefore, based on the previous section, we conclude that the scattering model for NGC1068 can reasonably fit the observed spectrum.

From our best-fit parameter values, we will discuss the ionization condition of the scattering gas around NGC1068 under the following assumptions; the gas distribution is spherical of constant density n(/cc) and radius r(pc), the X-ray emission from the central engine is isotropic, the elemental abundance is cosmic, and the source distance is 22 Mpc.

The X-ray flux (scattered flux) is obserevd to be 3×10^{41} erg/sec. Thus the X-ray luminosity of the 'hidden' central engine is;

$$Lx = 5 \times 10^{41}(10^{24}/N_H) \qquad (1)$$

,where N_H = nr. The ionization parameter ξ at a distance r is;

$$\xi = Lx/nr^2 = 5 \times 10^{65}/N_H{}^2 r \quad (2).$$

The relation between ionization states and line energy is given in figure 7. (e.g. Inoue 1985). From the observed iron line energy, the ionization state of iron is between the Neon and Lithium-like. This condition is realized if $\log\xi$ is between 2.5 and 3 as given by Kallman and McCray (1982). From equation (2), we get the following relation;

$$N_H = (1-2) \times 10^{22} \; (1pc/r)^{0.5} \quad (3).$$

Since r is order of 1 pc (Krolik and Begelman 1986) , the N_H value should be about $(1-2) \times 10^{22}$ H cm^{-2}. Although this value is not in conflict with the observed N_{Fe} value ,it is inconsistent with the N_H values obtained from the low energy absorption. We note here that the EXOSAT observations set an upper limit for N_H at less than 10^{21} H/cm^2 (Elvis and Lawrence 1988). This constraint can be relaxed, however, by assuming partially ionized gas. If the oxygen K shell($\sim$ 0.6 keV) is fully ionized while the iron L shell($\sim$ 1keV) is not, then the present observation of small low energy absorption and the iron line energy of 6.55 keV can be reasonably explained. This ionization condition of the scattering gas is also realized near $\log\xi$ = 2.5-3.0.

The N_H value and intrinsic luminosity Lx are estimated to be about $(1-2) \times 10^{22}$ H/cm^2, and $(2-4) \times 10^{43}$ erg/sec, respectively. If we assume a reasonable covering factor, then the total luminosity can be much larger, possibly about 10^{44} erg/sec. These luminosities are typical for Seyfert 1 galaxies (Kriss et al. 1980).

3. Conclusion

We have observed a strong iron emission line from NGC1068. This result provides a clear picture of the structure of the central engine of NGC1068. The Seyfert 2 galaxy NGC1068 was found to have a similar central engine to a typical Seyfert 1 galaxy, with a luminosity about 10^{43} - 10^{44} erg/sec and photon index of about 1.5 . The direct X-rays from the central engine are blocked and X-rays we observe are scattered and repoceesed by a surrounding gas. The gas is partially ionized with the column density of about 10^{22}H/cm^2. Then only a few percent of the total X-ray flux is scattered into our line of sight.

The author wants to express his thanks to J. Krolik and J. Hughes for their valuable comments.

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