Session 3: Diagnostics of High Gravity Objects with X- and Gamma Rays

3-3. AGNs

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EVIDENCE FOR STRONG GRAVITY IN THE AGN PLASMAS

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Abstract. X-ray spectroscopy of the broad iron line has revealed some relativistic effects caused by strong gravity about a black hole in active galactic nuclei (AGN). Recent results from ASCA observations of AGNs are reviewed.

1. Introduction

The impoved spectral resolution with the CCD X-ray spectrometer onboard ASCA has enabled the iron line profile in active galactic nuclei (AGN) to be resolved. The breadth and its skewed profiles found in Seyfert galaxies are in good agreement with those distorted by relativistic effects due to strong gravity about a black hole. They can therefore be used as a direct probe to the innermost part (e.g., $\leq 20r_g$) of the accretion disk in AGNs.

The detection of spectral features, a high energy hump above 10 keV and an iron K line at 6.4 keV, with Ginga in Seyfert 1 galaxies (Pounds et al 1990; Matsuoka et al 1990) is consistent with reflection from a cold disk irradiated by an X-ray source above it (e.g., George & Fabian 1991). Rapid X-ray variability commonly seen in AGNs suggests that the X-rays are produced in regions very close to a central massive black hole. X-ray irradiation of the disk occuring at such immediate neighbourhood of a black hole would lead considerable relativistic effects on line emission produced in the disk, as the speed of gas motion is approaching to the speed of light near the event horizon.

The line shape expected from such a relativistic disk have been computed for a stational (Schwartzschild) and a spinning black holes (Fabian et al 1989; Kojima 1991; Laor 1991; see also Chen, Halpern & Filippenko 1989 for emission line profiles from the outer disk). Major effects are Doppler boosting and gravitational redshift. Importance of those effects depends

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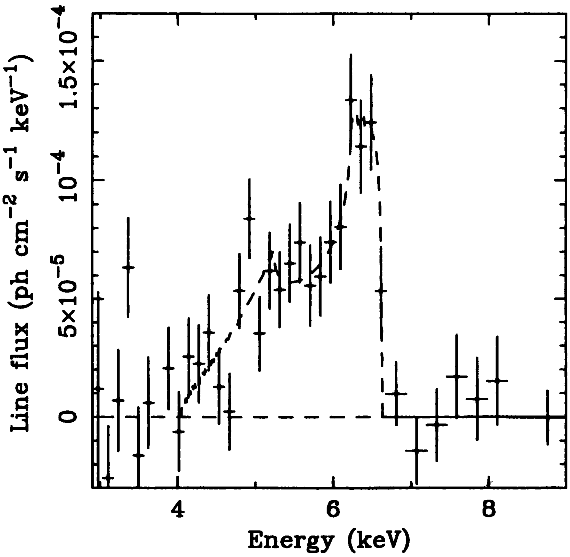

Figure 1. The iron K line profile of the Seyfert galaxy MCG–6-30-15 observed with the ASCA SIS (Tanaka et al 1995). The dashed-line shows the best-fit relativistic disk-line model.

on inclination angle of the disk. Since the iron line is the most prominent feature in the reflection spectrum, X-ray spectroscopy of the line can probe to strong gravity around a black hole in AGNs. Here ASCA studies of the broad iron line in AGNs are reviewed.

2. The ASCA results

The 4-day long observation of the bright Seyfert 1 galaxy MCG–6-30-15 provided high quality data for measuring the iron line profile (Fig. 1, Tanaka et al 1995). The line shape is clearly asymmetric and skewed to lower energy below 5 keV. The stronger blue (higher energy) peak is due to Doppler beaming originating in orbital motion of the disk. The sharp drop of the line emission around 6.6 keV constrains the inclination of the disk to be $\sim$ 30°. A fit with the diskline model suggests that the emission line is produced within 20 gravitational radii (r_g). Gravitational redshift plays the most important role to shift the emission to lower energies at such a small inclination angle. The relativistic diskline emission appears to be a currently most plausible interpretation for the broad iron lines (Fabian et al 1995).

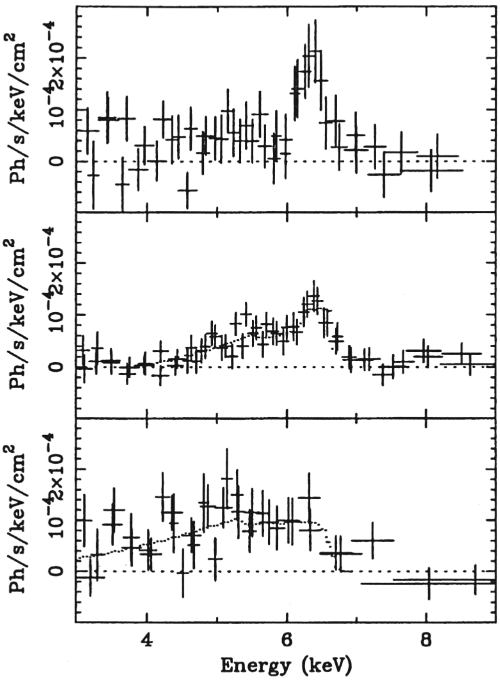

Figure 2. The iron K line profiles observed during the long-look at MCG–6-30-15. Top: bright flare; bottom: deep minimum; and middle: the others.

Variability of the iron line has also been found in several objects (MCG–6-30-15, Iwasawa et al 1996a; NGC7314, Yaqoob et al 1996; NGC3516, Nandra et al 1997a). A detailed study of the ASCA long-look data on MCG–6-30-15 revealed complicated behaviours of the line in response to the continuum changes (e.g., Fig. 2). Particularly, the line profile observed when the X-ray source is extremely faint indicates even more redshift than the others. In order to explain the enormous redshift, the line emission should be produced very close to a black hole (a few r_g) which is well within the last stable orbit of the disk in a stational black hole ($\sim 6r_g$). One possible way to account for this is having a black hole spinning. In a maximally spinning ($a/M = 0.998$) Kerr black hole, for instance, the accretion disk stretches down to $1.24r_g$. Dabrowski et al (1997) fitted the very broad profile of MCG–6-30-15 and demonstrated that the black hole is indeed rapidly spinning ($a/M > 0.9$). Reynolds & Begelman (1997) however proposed an alternative model with a Schwartzschild black hole, considering emission from gas within the stable orbit. In either case, the primary X-ray source must be located close to a central black hole, where strong gravity is operating.

Broad, skewed iron line profiles have been found in many other Seyfert galaxies (e.g., Mushotzky et la 1995; Yaqoob et al 1995; Iwasawa et al 1996; Weaver et al 1997; Nandra et al 1997b; Reynolds 1997). Quasars, however, appear to have different iron line properties from their lower luminosity counterparts. Nandra et al (1997c) investigated X-ray luminosity dependence of the line profile and intensity, using an ASCA data sample. The decreasing trend of equivalent width (EW) of the line towards higher luminosity AGNs (X-ray Baldwin effect, which was originally suggested by Iwasawa & Taniguchi 1993 based on Ginga data) is found, although there are a few counter-examples (e.g., 3C109, Allen et al 1997). The line emission is peaked at energies above 6.4 keV, suggesting an ionized disk in quasars. They interpret this as a consequence of a high accretion rate.

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