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RECENT *ASCA* RESULTS ON ACTIVE GALAXIES

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RESUMEN

El lanzamiento del satélite *ASCA* ha modificado radicalemnte la situación observacional en la astrofísica de altas energías. Comparado con instrumentos anteriores, tiene una resolución 6 veces mejor a $E > 2$ keV, $E/\Delta E \sim 50$ a 6 keV, un ancho de banda 0.4–10 keV, un incremento de 100 en la sensibilidad a $E > 2$ keV y capacidad para hacer imágenes espectrales en rayos X.

ABSTRACT

The launch of *ASCA* has radically changed the observational situation in high energy astrophysics. With an energy resolution 6 times better than previously available at $E > 2$ keV, $E/\Delta E \sim 50$ at 6 keV, a bandwidth from 0.4–10 keV, and an increase in sensitivity of a factor of 100 at $E > 2$ keV compared to previous missions, combined with true X-ray spectral imaging, *ASCA* has enabled a fundamentally new class of observations.
Key words: **GALAXIES: ACTIVE — GALAXIES: STARBURST — X-RAY: GALAXIES**

1. BROAD IRON K LINES

Well before the launch of *ASCA* (Tanaka, Holt, & Inoue 1994), in February 1993, it was realized (Lightman & White 1988) that, if the accretion onto the central object in active galaxies occurred primarily in a disk, or other "cold" optically thick medium, that several X-ray spectral features due the reprocessing of the continuum in this thick matter would be imprinted on the generalized power law continuum. Because the solid angle of the reprocessing matter was expected to be large near the event horizon of a Kerr or Schwarschild black hole it was considered possible that the strongest of such features, Fe K fluorescent emission at 6.40 keV, might be rather broad (Fabian et al. 1989) and carry the signature of relativistic motion. In a spectacular demonstration of this, the *ASCA* data have shown that a large fraction (at least 3/4) of Seyfert I galaxies show very broad (FWHM$>30 \times 103$ km s^{-1}) iron fluorescent line emission (Mushotzky et al. 1995; Tanaka et al. 1995; Nandra et al. 1996b). In the last 3 years over 250 active galaxies have been observed by *ASCA* resulting in more than 30 refereed papers (for a general review of the observational situation before the launch of *ASCA* see Mushotzky, Done, & Pounds (1993). It will not be possible to completely review the recent *ASCA* results and I have picked several highlights that I thought would be of interest for this meeting.

In addition to its large width, the line shape is skewed, in general, to lower energies requiring (Tanaka et al. 1995; Eraculous et al. 1996; Nandra et al. 1996b) both special and general relativistic effects to account for the line width and shape (Figure 1). This observation is the first demonstration of the need for relativistic effects in Seyfert I galaxies and provides very strong evidence for the existence of cold matter very near the central engine. As shown in detail in Nandra et al. (1996b) the Fe K line strength and shape are in good agreement with theoretical disk line models (cf., Fabian et al. 1989; Laor 1991). The observed range of inclination angles in the Schwarschild or Kerr disk-line fits, give a median value of 300, which requires a bias towards face-on objects. This bias is consistent with the so-called unified models (see Antonucci 1993) which hypothesize that Seyfert I and II galaxies are drawn from the same population and that Seyfert I galaxies are primarily face-on and Seyfert II's edge-on. There are indications that the line shape in two Seyfert galaxies MCG-6-30-15 (Iwasawa et al. 1996b) and NGC 7314 (Yaqoob et al. 1996) can change on timescales < 1 day, indicating an origin very close to the central engine. In MCG-6-30-15, when the continuum is weak, the line becomes extremely broad. If this is not due to some incorrect modeling of the continuum, the observed line width requires a Kerr metric for the central object. There is also a measurement of a change in the flux of the Fe K line on a one year timescale in NGC 3516 (Nandra et al. 1996d) which shows that most of the line flux in this object originates well within the central regions of the AGN. As stressed by A. Fabian, the X-ray data are probing within the central 30 Schwarschild radii, while all the other indications of a central massive black hole, such as the *HST* spectral data for M87 or the maser emission in NGC 4258 occur at 1 000's of Schwarschild radii. While the *ASCA* data

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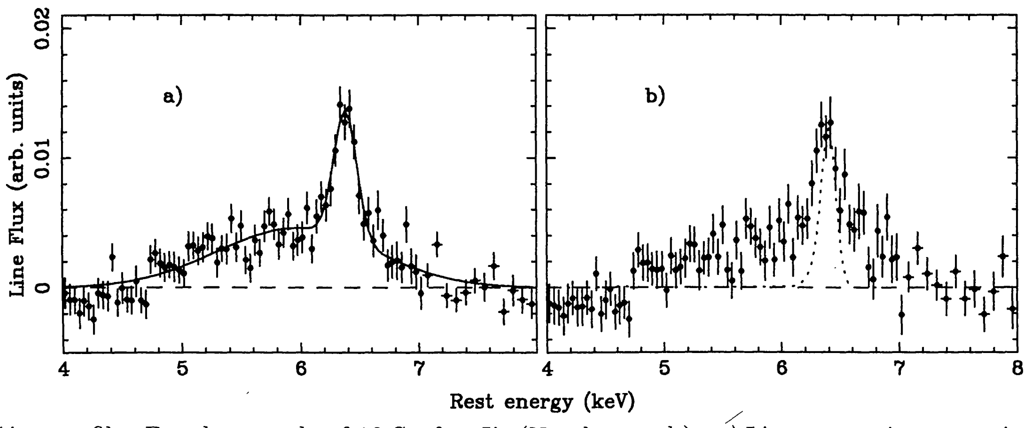

Fig. 1. Line profiles For the sample of 18 Seyfert I's (Nandra et al.). *a)* Line to continuum ratio for the entire sample. *b)* Same ratio with the two brightest objects removed. The detector energy resolution is shown by the dotted line. The data points have been redshifted into the rest frame for each source. The full width of the line profile is about 2 keV which, corresponding to a velocity spread of 100 000 km s^{-1}.

are strongly indicative of relativistic effects, determination of the mass of the central object requires a detailed reverberation mapping which requires increased sensitivity. The Fe K line profile in Seyfert II/narrow emission line galaxies, shows a much wider range of behavior with some objects (e.g., NGC 2992 Weaver et al. 1997, NGC 1068 Ueno et al. 1994) showing only a narrow Fe K fluorescent line while others (e.g., NGC 2110, Hayashi et al. 1996; MCG-5-23-16, Weaver et al. 1996; IRAS 1832-5906, Iwasawa et al. 1996a) showing a broad line which is shifted more towards the blue than in Seyfert Is, consistent with a model in which the disk is seen at a angle greater than 40 degrees, as expected in the unified model for these objects. The very large number of unpublished observations of line profiles leads me to expect a qualitative improvement in the observational situation in the next 2 years.

2. WARM ABSORBERS

Before the launch of *ASCA* there were indications (Halpern 1984; Nandra & Pounds 1992; Turner et al. 1993) that the low energy continuum of some Seyfert galaxies was modified by absorption due to highly ionized material. The *ASCA* data have revolutionized this field showing that ~ 50 % of Seyfert I galaxies have absorption due to ionized oxygen with optical depths > 0.2. The typical features seen are absorption edges due to O VI, O VII and/or O VIII. If the gas is photoionized by the central continuum these features are expected to be the strongest in the *ASCA* bandpass given the relative abundance of oxygen. The inferred ionization state of the gas is rather high (Netzer 1993) and the implied column densities (assuming a solar abundance of oxygen) is $N(H) \sim 10^{22}$ atms/cm^2, similar to that of the optical broad line clouds. The high occurrence rate of this ionized absorber indicates a large covering factor for the gas . With the high covering fraction and the high column density this ionized gas can be the major mass component in the central regions of Seyfert I galaxies. So far, time variability studies have indicated that the strengths of these features do not always respond to changes in the continuum as expected in a one zone photoionization model (Reynolds & Fabian 1995; Otani et al. 1996) indicating that either the gas distribution is more complex than a one zone model or that the ionization mechanism is not totally due to the radiation seen by the observer. In at least two objects MCG-6-30-15 and NGC 3516 (Otani et al. 1996; Kriss et al. 1996ab), a two zone model is required to explain the X-ray data. However, detailed analysis of a large sample of objects by George et al. (1996), shows that many can be well fit by a one zone model. At present it is not clear if this is due to lower signal to noise or a true variation from object to object. In some objects (Mathur, Elvis,& Wilkes 1995) the same ionization conditions responsible for the "x-ray warm absorber" can account for the C IV and N V UV resonance absorption lines but this is not always the case (Kriss et al. 1996a,b). In a few cases (George et al. 1996) the combination of the oxygen edges observed by *ASCA* and the ionized Fe edge observed by Ginga require a high ionization region which must have a very high effective column density ($> 10^{23}$ atms/cm^2). In general one also expects significant features due to carbon and (perhaps) nitrogen and Fe L (Reynolds & Fabian 1995) which will be observable with AXAF. While the *ASCA* data do not have the spectral resolution to resolve the observed features it is clear that there must exist absorption due to both ionized edges and resonance absorption lines (Kriss et al. 1996a) as well as superimposed emission features (George, Turner, & Netzer 1995). Future observations with the much higher spectral resolution possible with the next generation of X-ray satellites should reveal such features.

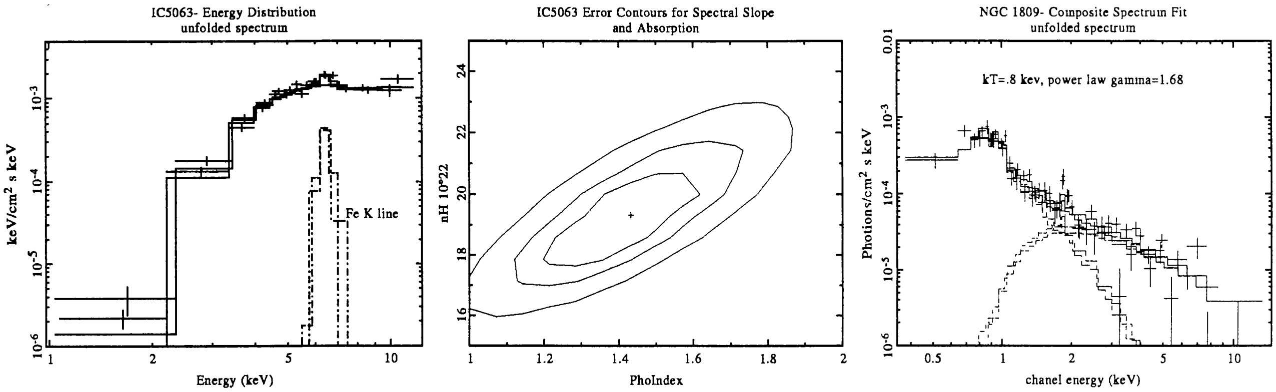

Fig. 2. *a)* Energy distribution, 0.4-10 keV for IC5063. Luminosity increases with energy in this high column density source. *b)* Probability map for the uncertainty in column density and intrinsic spectral slope for IC5063, the contours correspond to 68,90 and 99confidence. Column density in units of 10^{22} atms./cm2. Best fit of $\sim 2x10^{23}$ atms/cm2 corresponding to a $A(V) \sim 90$ for a Milky Way dust to gas ratio. This makes the central source invisible in the UV, optical and near IR bands. *c) ASCA* spectrum for NGC 1808. The source is very small in the Rosat HRI image. The hard component dominates at E > 2 keV, while the thermal component, presumably due to hot gas generated by the starburst dominates at E < 2 keV. Each component has roughly equal luminosity.

3. LOW LUMINOSITY "AGN"

ASCA imaging and spectroscopy of many nearby galaxies often show the presence of low luminosity, $L(x) < 10^{41}$ erg/s, point-like sources with flat power-law spectra very similar to that of Seyfert I galaxies. The most reasonable interpretation is that these objects are low luminosity AGN (LLAGN) and that they are extremely common in nearby galaxies (Serlemitsos et al. 1994) and can also occur in elliptical galaxies (Loewenstein 1995). While many of these objects, have been characterized as LINERs, some show no evidence of optical line emission (e.g., NGC 1313, Petre et al. 1994). While similar to Seyfert I galaxies they often show significant differences. In particular, they do not show soft excesses ($\sim$ 50 % of all Seyfert I galaxies show a rather sharp rise in their spectra at E < 1 keV while very few of these low luminosity objects show such an excess (cf., M81, Ishisaki et al. 1996). While almost all low luminosity Seyfert I galaxies show high amplitude rapid variability (cf., Leighly et al. 1996; Nandra et al. 1996b) none of the LLAGN have shown this type of behavior. However, most of them show large amplitude variability on timescales of months. In addition, almost all of the objects have a much higher $L(x)/L(opt)$ than Seyfert I galaxies or quasars (cf., NGC 4594, Barth et al. 1996; M81, Ho, Filippenko, & Sargent 1996). Because these objects are much weaker, in general, than the Seyferts, the Fe K line data from *ASCA* is of lower quality. However, in the case of M81 it is clear that the Fe K line is either complex (e.g., multiple components due to cold and hot Fe) or broad. (Ishisaki et al. 1996). The *ASCA* data strongly favor a "mini-AGN" model for these objects and their very common occurrence is a strong argument for the pervasive presence of massive black holes in nuclei of "normal" galaxies. The ability of *ASCA* to detect "AGN-like" sources even when there are no emission lines visible from the ground is a powerful tool for conducting a true census of AGN activity. However, there is also evidence that some of these objects (e.g., M33, Mitsuda et al. 1996) may be massive, stellar black holes, like Cygnus X-1.

4. STARBURSTS/SEYFERT IIS

ASCA has now observed a large number of "narrow line-IR bright objects" including hyperluminous FIR galaxies, "Seyfert IIs", and "starbursts" (Ueno 1996; Awaki, Tsuru, & Koyama 1995). Many, but not all, of the optically classified "Seyfert II galaxies" show large X-ray column densities ($< N(H) >\sim 10^{22.5} - 10^{24}$) (Figure 2). There is a wide range of Fe K line equivalent widths ($EW \sim 1$ keV for NGC 1068, but only 85 eV for IC5063) and the lines tend to be narrow. Objects that show spectra similar to the prototypical Seyfert II NGC 1068 (Ueno et al. 1994), are rare. While most of the Seyfert IIs have not shown a broad Fe K line there is a strong exception in the case of IRAS 1832-589 (Iwasawa et al. 1996a). Some of the Seyfert "IIs" have varied at $E > 2$ keV (Mkn3 IRAS 1832, Iwasawa et al. 1994), but none of them have been observed to vary at $E < 1$ keV, indicating that the hard X-ray emission is often seen directly through the obscuring region but that the soft X-rays, like the optical and UV radiation is scattered into the line of sight. There is an indication in

NGC 1068 and the Circinus galaxy (Matt et al. 1996) that even the hard continuum in these objects is seen vi scattering. As in other wavelength bands it is clear that some of the Seyfert IIs (e.g., NGC 1068, NGC 5005 have composite spectra very similar to "starburst galaxies" (Ueno 1996) and, in fact, distinguishing the AGN component of these galaxies is rather difficult. These "composite" Seyfert IIs have low X-ray luminosities in the 2–10 keV band and 0.5–2 keV luminosities consistent with that expected from their IR luminosity (which i presumably due mostly to the starburst). Their low ratios of hard X-rays to FIR luminosity is also consisten with this hypothesis. As in the IR, the X-ray images of the "narrow line IR luminous galaxies" are often ver compact with most of the soft X-ray luminosity arising in regions of size <40″ (Armus et al 1995). From a X-ray point of view the difference between some "starbursts" and some Seyfert IIs is very subtle indeed an relies mainly on a) the absence of a strong Fe K line (M82, NGC 253) b) the relative weakness of the 2–10 keV continuum c) the relative strength of the 0.5–2 vs. 2–10 keV continuum . However the X-ray spectra of all th starburst galaxies shows both a soft and a hard component, similar to that of some classical Seyfert IIs. Whil the nature of the hard component is not entirely clear, it may be due to very luminous X-ray binaries, youn supernova remnants or micro-AGN. In some objects it is clear that the X-rays are due to a highly embedde AGN even if there is no sign in the IR band of such an object. However, in others the situation is rathe ambiguous. The column densities in some of these objects (e.g., NGC 4945, Done, Madejski, & Smith 1996) ar very high, $N(H) > 10^{24}$ cm^{-2}, which effectively blocks even 10 micron radiation and makes them visible onl at $E > 10$ keV.

5. WATER MASERS AND LUMINOUS QUASARS

So far all the detected "mega" water masers have that have been observed by *ASCA* either have highl absorbed X-ray AGN at their centers (NGC 4258, ESO103, NGC 5506, MKN1210 etc.) or apparently have a column density so high (e.g., Circinus, NGC 1068, NGC 3097) that all the observed X-ray flux is scattere into the line of sight. This strong connection is not entirely unexpected (Neufeld, Maloney, & Conger 1994 if the masers are driven by X-ray heating. This connection offers the potential for comparing mass model using the X-ray line profiles and the maser maps. In the case of Circinus (Matt et. al 1996) the high qualit *ASCA* data allow a direct modeling of the absorbing medium. The results indicate that the observed X-ra spectrum is completely consistent with reflection-that is the direct view to the central engine is complete obscured and even the hard x-ray flux is due to scattering. At $L(x) > 10^{46}$ erg/s *ASCA* data have shown tha most objects have a relatively featureless spectrum with weak or absent Fe K emission and weak or absen "reflection" continuum. Some of the objects, in particular the radio loud quasars, can have rather flat spectr (energy indices of $\sim 1/2$) out to rest frame energies of 30 keV (Elvis et al. 1994; Nandra et al. 1995; Sieber et al. 1996). In the luminosity range $L(x) \sim 10^{45} - 10^{46}$ erg/s (PG1211, Yaqoob et al. 1994; PG1116, Nandr et al. 1996c; E1821+643, Yamashita et al. 1994) the Fe K line appears to be ionized compared to the "cold Seyfert I values (e.g., the line appears at 6.7 keV in the rest frame). If this trend holds it may be that th absence of a Fe K line in the higher luminosity objects is due to ionization effects, that is the gas responsibl for reprocessing the X-rays is too hot to emit Fe K radiation.

6. FUTURE PROSPECTS

The future for X-ray spectroscopy of AGN and starburst galaxies is extremely bright. AXAF (a U.S. missio to be launched in the fall of 1998) with its 1/4″ angular resolution will provide high signal to noise images c compact star forming regions and be able to spatially resolve the AGN from the star forming regions in th composite objects. XMM (a ESA program to be launched in the summer of 1999) with its large collecting are (6 times that of AXAF) and 15″ angular resolution will be able to obtain much higher signal to noise spectr than *ASCA* and have a much larger number of objects available for study. Astro-E (A joint Japanese-U.S satellite to be launched in February 2000) will have a high throughput spectrometer with a resolution of 50 at 6 keV capable of measuring detailed dynamics of the Fe K line and the warm absorber. Both XMM an AXAF also have high resolution spectrometers with somewhat smaller collecting areas. This suite of powerfu new X-ray missions will vastly enhance our knowledge of AGN and starbursts. However, even before then w can expect that publication of the 100's of *ASCA* spectra of these objects will open new windows on thes fascinating objects.

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