1. INTRODUCTION

In this review, rather than present and discuss in detail the first results obtained by BeppoSAX (see Boella et al. 1997 for an overall description of the mission) on Seyfert galaxies (these results are presented in detail elsewhere in this volume, see in particular the contributions by Perola, Comastri and Salvati), I will discuss current ideas on the X–ray emission of both type 1 and 2 objects, outlining topics in which BeppoSAX is expected to give, and is actually giving, important contributions. While results in the soft and medium X–rays will be soon extended and improved by missions like AXAF and XMM, in hard X–rays BeppoSAX results are likely to be rather lasting, and actually unrivalled for many years. This is the reason why, in this contribution, I will discuss more in details issues relative to the highest energy part of the spectrum, and more in general topics in which the unique broad band of BeppoSAX is particularly well suited.

2. SETTING THE SCENARIO. THE UNIFICATION MODEL

Let me start by describing the picture which is currently believed to describe Seyfert galaxies as a class. In this scenario, all Seyfert galaxies possess what can be called a type–1 nucleus: a supermassive ($10^6–9 \ M_\odot$) black hole accreting matter, probably via an accretion disc. The size of this region is determined by the black hole gravitational radius ($R_g = GM/c^2$, where $M$ is the black hole mass), which ranges from tenths of micro– to tenths of milli–parsecs. The nucleus (including also the Broad Lines Region, with a size of milli– to tenths– of pc) is surrounded by optically thick matter with a roughly cylindrical symmetry (hereinafter simply called “the torus”) on at least a pc–scale. In this unification model (see Antonucci 1993 for a review), the type–1 nucleus is visible only if the line–of–sight does not intercept the torus: the source is then classified as Seyfert 1. If, on the contrary, the line–of–sight does intercept the torus, the source is classified as Seyfert 2: the nucleus is hidden and its presence can be argued by indirect evidence in the optical to soft X–ray band, while it may turn out to be directly visible in hard X–rays, when the absorbing matter may become transparent (see sec. 4).

While the unification model in its strictest version (i.e. “the aspect angle is the only relevant parameter”) is likely to be incorrect (as it will be discussed in sec. 4.2), it is certainly valid in a broad sense. Therefore, unless explicitly stated, in the following it will be assumed as the basic scenario.

3. SEYFERT 1

3.1. The broad band spectrum

Seyfert 1 galaxies have been extensively studied by all X–ray missions, but only after GINGA it has become clear that the spectrum is complex, resulting from different components, both in emission and in absorption. After GINGA, ROSAT, ASCA and CGRO the most general picture is that of Fig. 1, even if not all components shown in the figure are always and simultaneously present.

The primary component is a power law (possibly cut–offed at high energies, see sec 1.3), which is likely produced by Inverse Compton between
relativistic electrons and UV/soft X-ray photons coming from the accretion disc. The details on the emission are not very well known, despite remarkable theoretical efforts (e.g. Haardt & Maraschi 1993; see e.g. Svensson 1996 for a recent review, and the references therein), as no clear-cut signature, able to unambiguously discriminate between alternative models, has been detected so far.

A significant fraction of the primary radiation is intercepted and then reflected by circumnuclear matter, either the accretion disc or the torus, or both. If the matter is neutral\footnote{From the hard X-rays point of view, matter is “neutral” as far as Carbon and heavier elements are not fully stripped. Ionization of lighter elements affects the spectrum only below \( \approx 0.3 \) keV.}, the shape of the reflected component is determined basically by the competition between photoelectric absorption (whose cross section depends on the energy, after each photoabsorption edge, as \( \approx E^{-3} \)) and Compton scattering (constant cross section, at least up to a few tens of keV; the two cross sections are equal at about 10 keV, if cosmic abundances are assumed) and by Compton downscattering. This so-called Compton reflection com-

Figure 1. The X–ray spectrum of Seyfert 1s: a cut–offed power law plus the fluorescent iron line from the relativistic disc with the associated reflection continuum, and a soft X–ray excess. The overall emission spectrum is partly absorbed by warm matter along the line–of–sight, which left its imprints in form of absorption edges. The figure has been produced by using models in the xspec code.
ponent has been studied in detail in several papers (see e.g. Lightman & White 1988; George & Fabian 1991; Matt, Perola & Piro 1991); its spectrum is a broad hump peaked around 30 keV. When added to the primary component, it hardens the total spectrum above a few keV and steepens it above a few tens of keV. Besides this Compton reflection continuum, the illumination of neutral matter by the primary radiation results also in a strong iron 6.4 keV fluorescent line, emitted by iron atoms after removal of a K electron by an X–ray photon.

At low energies (below \(\sim 1\) keV) a further component (“soft excess”) may arise. The origin of this component is rather unclear, and even ROSAT has not been able to conclusively settle this issue. It is likely that the soft excess is actually a mixture of different contributions which may or may not be present simultaneously in the same source (e.g. Piro, Matt & Ricci 1997): the tail of thermal emission from the accretion disc is one possibility, while reflection from ionized matter (Ross & Fabian 1993) is likely to occur in the accretion disc if the accretion rate is high enough (see sec. 3.2.3).

All these emission components, which are likely to originate in the vicinity of the black hole (apart from the possible reflection component from the torus) may pass throughout ionized matter (the “warm absorber”), whose main signatures are absorption edges of high ionization ions, mainly of oxygen atoms (Halpern 1984; Nandra & Pounds 1992; Fabian et al. 1994) In a large fraction of Seyfert 1s observed by ASCA absorption edges have been unambiguously detected (Reynolds 1997; George et al. 1997). Resonant absorption lines may also be important in warm absorbers (Matt 1994; Krolik & Kriss 1995; Nicastro, Matt & Fiore 1998), and detectable by the gratings onboard future missions (see Nicastro et al., this volume, for a possible ASCA detection of resonant absorption in NGC 985).

In the following I will discuss in some detail issues related to the high energy part of the X–ray spectrum, as it is in this band that BeppoSAX is expected to give its best contribution, thanks to the unprecedented (and unrivalled also in the next future, until Spectrum–X–Γ, INTEGRAL and ASTRO–E will be launched) sensitivity in hard X–rays of the PDS instrument (Frontera et al. 1996).

### 3.2. Probing the circumnuclear matter

The two main reflectors which are supposed to be present around the black hole in Seyfert galaxies are the accretion disc and the torus. Assuming that the matter is neutral in both cases (see sec. 3.2.3), the intensity of the reflected flux, and the iron line equivalent width are similar for the two reflectors (e.g. Matt et al. 1992 for the line equivalent widths from the accretion disc, and Ghisellini, Haardt & Matt 1994 and Krolik, Madau & Życki 1994 for the reflection form the torus). There are two ways in which the two components may be distinguished each other. The first is by variability studies: the reflection component from the accretion disc should respond to variations in the primary continuum on very short time scales (minutes or hours), while the torus component should lag the primary component by years. A second and perhaps better (at least for the impatient) possibility is to look at the iron line profile: while the line from the torus should be narrow (i.e. unresolved by present detectors), the line from the accretion disc is expected to be broad and skewed owing to kinematic and relativistic effects (Fabian et al. 1989; Laor 1991; Matt et al. 1992). Such a line has been actually detected by ASCA in the Seyfert 1 galaxy MCG–6-30-15 (Tanaka et al. 1995; see Molendi et al., this volume, for the BeppoSAX observation of the same object): it was the first time, to my knowledge, that a strong–field General Relativistic effect has been clearly observed. Studying a large sample of objects observed by ASCA, Nandra et al. (1997a) have shown that such a broad line is rather common in Seyfert 1s, even if in no other single source it has been so clearly detected, due to limited exposure times (a four days observation has been necessary to obtain the result on MCG–6-30-15 reported by Tanaka et al. 1995).

### 3.2.1. Static or rotating black holes?

Once the relativistic origin of the observed line broadening is established (and no satisfactory alternatives has been proposed yet: see Fabian et
al. 1995 for the discussion, and rejection, of most of them), in principle one may hope to determine the most important disc parameters: inclination angle, inner and outer radii.

Most important, one could in principle also determine whether the black hole is spinning or not. This is a key point, as one of the most popular explanation for the radio–loud/radio–quiet dichotomy in AGN is in term of black hole rotation, black holes in radio–quiet sources being static or slowly rotating, while those in radio–loud objects being rapidly rotating (e.g. Wilson & Colbert 1995). Seyfert galaxies would then have static black holes, and the appropriate metric would be the Schwarzschild one (while the Kerr metric must be used for spinning black holes, and then for radio–loud objects). Kerr and Schwarzschild metrics may be distinguished by the iron line profile. The principal difference in the profile arises from the fact that, while in the Schwarzschild metric the innermost stable orbit is at $6r_g$, for a Kerr black hole it can be as small as $1.23r_g$ (Bardeen, Press & Teukolsky 1972; Thorne 1974).

In Fig. 2 the normalized line profiles from the accretion disc around both static (solid curve) and maximally rotating (dashed curve) black holes are shown. The inclination angle and the outer radius are the same for the two profiles ($45^\circ$ and $20r_g$), while the inner radius is set to the innermost stable orbit, i.e. $6r_g$ and $1.23r_g$, respectively. For the spinning black hole the profile is redder than for the static black hole, the difference being essentially due to the increased importance of the gravitational redshift in the former case, as photons can originate from very close to the black hole. The line emission in the two cases differs not only in shape, but also in intensity: “returning radiation” due to gravitational bending (Dabrowski et al. 1997), light focusing and gravitational blueshift of the primary radiation illuminating the disc as well as gravitational redshift of the primary radiation escaping to the observer (Martocchia & Matt 1996) may increase significantly (and even dramatically, in the Martocchia & Matt geometry) the line intensity.

An iron line well fitted by a Kerr profile has been possibly observed in MCG–6-30-15 during a deep minimum phase (Iwasawa et al. 1996; see also Fabian 1997. This result does not contradict the Tanaka et al. time–averaged result, as it is possible that in the source normal state line emission arises from radii greater than $6r_g$, as Tanaka et al. have found, where differences between Schwarzschild and Kerr metrics are negligible). This result would rule out the spin of the black hole as the key parameter for the radio–quiet/radio–loud dichotomy. However, it is important to stress that the main difference in the line emission between the static and spinning black hole cases lies in the different radius of the last stable orbit. As pointed out by Reynolds & Begelman (1997) the difference would be much smaller if efficient line emission is allowed from matter inside the last stable orbit in the static case. This is possible if the accretion rate is high enough to make the free–falling matter optically thick. In practice, only moderate accretion rates (of the order of hundredths of the Eddington value) are required. Therefore, in such conditions Schwarzschild and Kerr black holes are indistinguishable, at least at the first order (effects on the line profile due only to the different photons’ geodesics are probably too subtle to be testable by present and near future missions), and the Iwasawa et al. result would still be explainable with a static black hole. A possible way to distinguish between the two cases is by studying the ionization of the matter (see sec. 3.2.3; in fact, Reynolds & Begelman (1997) also showed that the free–falling matter is likely to be significantly ionized, independently of the accretion rate, while matter in a true accretion disc, may remain almost neutral provided that the accretion rate is small enough. This point, however, has not been fully explored yet for a Kerr black hole, and so quantitative predictions are still lacking.

### 3.2.2. Iron abundance

Element abundances, in particular of iron, strongly affect the reprocessed emission (see e.g. Basko 1978; George & Fabian 1991; Matt, Fabian & Reynolds 1997). This occurs in two ways: by changing the intensity of the iron line, and by altering the shape of the reflected continuum. The intensity of the iron line depends linearly on the iron abundance only in a small interval around
Figure 2. Line profiles from accretion discs orbiting around static (solid curve) and extremely rotating (dashed curve, provided by A. Martocchia) black holes. The inclination angle is 45°, the outer radius is 20$r_g$. A power law emissivity with index -2 is assumed. The inner radius is set to the last stable orbit in both cases, i.e. 6$r_g$ for the static black hole and 1.23$r_g$ for the rotating one.

the solar value, deviating strongly from a linear law at very low and very high values (see Matt, Fabian & Reynolds 1997 for simple, approximated laws). The reflection continuum is affected mainly at the iron edge, which of course deepens with increasing iron abundance (see Magdziarz & Zdziarski 1995 and relative xspec codes): between 7.1 and, say, 20 keV the reflection continuum is then smaller for higher abundances. Therefore, the ratio between iron line and reflection continuum intensity is in principle a powerful diagnostic tool for studying the iron abundance in AGN. The combination of GINGA (Nandra & Pounds 1994) and ASCA (Nandra et al. 1997a) results suggests that this abundance is usually oversolar, a result which seems confirmed by first BeppoSAX results (see Perola, this volume); note that BeppoSAX is the first mission able, thanks to its unprecedented broad band, to determine by itself this ratio with sufficient precision.

3.2.3. Neutral or ionized matter?

For high enough accretion rates (i.e. more than a few tenths of the critical value) the innermost accretion disc should be significantly photoionized (see e.g. Ross & Fabian 1993; Matt, Fabian & Ross 1993): the ionization parameter $\xi$, i.e. the ratio between the flux of ionizing radiation and the matter density, depends in fact strongly on the accretion rate. The iron line intensity depends strongly on the ionization parameter: the fluorescent yield (i.e. the probability that a photoionization is followed by a radiative instead than an Auger deexcitation) increases with the ionization state of iron, and the transparency of the matter at the iron line energy is also greater for ionized matter. However, for intermediate ionization states, when the L shell has at least one vacancy but is still not fully stripped, so-called Auger destruction occurs: the K\alpha line photon is resonant, and is very likely absorbed by another atom of the next ionization state (resonant absorption cross sections are usually order of magnitudes greater than any other relevant cross section). Auger deexcitation occurs 2/3 of the times, and the photon is quickly destroyed. This mechanism does not work when iron atoms have the L shell completely filled, as resonant re–absorption is obviously impossible, and when the L shell is completely stripped, as there are no longer available electrons for Auger deexcitation (and photons may eventually escape, even if after many resonant scatterings). The dependence of the line intensity (divided by the illuminating flux) on the ionization parameter is shown in Fig. 3 (from Matt, Fabian & Ross 1996): the decrease in the intensity at very high values of the ionization parameter is due to the fact that most iron atoms are then completely stripped. It is worth noticing that at high ionizations most photons are Compton scattered before escaping from the matter (see Fig. 3): this part of the line is very broadened and it is probably not easy to separate
it from the underlying continuum.

As said above, iron lines from ionized matter (which are recognizable from their highest centroid energy) are expected in sources with high accretion rates. ASCA observations of iron lines in Seyfert 1s (Nandra et al. 1997) indicate that the emitting matter is generally neutral and then that the accretion rate does not exceed about 0.1–0.2 the critical value (according to the model of Matt, Fabian & Ross 1993). On the other hand, high accretion rates have been suggested by (Laor et al. 1997) to be the basic explanation for the the Narrow Line Seyfert 1s phenomenon (Boller, Brandt & Fink 1996). In TON S 180 BeppoSAX has actually detected such an ionized line (Comastri et al. 1998 and this volume), lending support to this hypothesis. High accretion rates and then high ionization parameters (actually so high to have most iron atoms completely stripped) have also been invoked by Nandra et al. (1997b) to explain their findings, based on ASCA results, of an anti–correlation between iron line EW and luminosity (so–called “X–ray Baldwin effect”, originally proposed by Iwasawa & Taniguchi 1993).

### 3.3. Studying the emission mechanism

The primary emission mechanism in Seyfert 1s is not well known at present. While Inverse Compton appears to be the basic emission process, details are still very uncertain, and even the thermal or non–thermal nature of the electron population is an open issue, even if the thermal hypothesis is now more popular, after the seminal work of Haardt & Maraschi (1991) and the SIGMA/GRANAT discovery of a thermal–like cut–off in the spectrum of NGC 4151 (Jourdain et al. 1994). Due to the limited sensitivity of hard X–ray instruments before BeppoSAX, NGC 4151 has remained for many years the only single source in which such a cut–off has been unambiguously detected. BeppoSAX, thanks to the excellent performances of the PDS, has already added one more source, namely NGC 5548 (see Piro, this volume) to the class of the $\lesssim 100$ keV (e–folding energy) cut–offed sources, while for other two sources, NGC 5506 and Fairall 9, it has been able to put lower limits to the e–folding energy definitely inconsistent with the NGC 4151 and NGC 5548 values (see Perola, this volume). Therefore, a first result is that there is not a universal cut–off energy (temperature?) in Seyfert galaxies.

A potentially powerful tool for studying the emission mechanism is broad–band spectral variability (Haardt, Maraschi & Ghisellini 1997), even if it usually requires long and well sampled observations, not easily granted by Time Allocation Committees always dealing with heavy overbookings. Of course, BeppoSAX is the best suited satellite for this purpose, and we can be confident that in the long run it will be able to do a good job in this respect.

![Figure 3. The iron intensity (divided by the illuminating flux and normalized to the neutral matter value) as a function of the ionization parameter $\xi$. The filled circles are the full emission, the crosses the unscattered emission (see text). Figure adapted from Matt, Fabian & Ross (1996).](image-url)
4. SEYFERT 2

In the unification model, Seyfert 2 galaxies are simply Seyfert 1’s observed throughout absorbing matter (which from now on is assumed to be the molecular torus). The energy at which matter becomes transparent, and then the appearance of the X–ray spectrum, depends on the column density (see Fig. 4). In particular, for \( N_H \) exceeding \( \sim 10^{24} \text{ cm}^{-2} \), matter is optically thick at all energies (up to the Klein–Nishina decline) owing to Compton scattering: the source is therefore called “Compton–thick”. In this case, the nucleus can be observed only in scattered light, either from optically thin, ionized matter\(^2\) or from the inner surface of the torus, or both (Ghisellini, Haardt & Matt 1994; Matt, Brandt & Fabian 1996; Matt 1996 and references therein). The reflection from the inner surface of the torus has the shape discussed in sec. 3. One of the signatures of the reflection from the torus is the 6.4 keV fluorescent iron line, with a characteristic equivalent width (with respect to the reflected continuum) of about 1 keV: the Circinus Galaxy is perhaps the most spectacular example of such a line (Matt et al. 1996). Reflection from highly ionized matter, on the other hand, maintains approximately the shape of the illuminating continuum, with superimposed fluorescent/recombination and resonant scattering lines with equivalent widths (with respect to the continuum reflected by the same matter) ranging from hundreds of eV (if the matter is optically thick to resonant absorption) up to several keV (if optically thin to resonant absorption: Matt, Brandt & Fabian 1996).

4.1. Mirroring the nucleus. The case of NGC 1068

NGC 1068 is the best known and most studied among Compton–thick Seyfert 2s, and the best example of how circumnuclear matter can be probed in these sources. BBXRT (Marshall et al. 1993) and ASCA (Ueno et al. 1994; Iwasawa, Fabian & Matt 1997) have already shown, based on the presence of both neutral and ionized iron lines, that both reflectors are at work in this source. To disentangle the two continua, however, hard X–rays observations are necessary. We observed NGC 1068 with BeppoSAX for about 100 ksec, detecting it for the first time above 10 keV (Matt et al. 1997; see Fig. 5). The spectrum above 4 keV (below this energy a thermal–like component dominates) is well fitted by a two–reflector model (one reflector being neutral\(^3\) the other highly ionized) plus a broad iron line (actually a blend of different lines). The fluxes from the two reflectors are comparable in the MECS range, but the neutral one, being much harder, dominates in the PDS band. It is important to note that, assuming an X–ray luminosity of about

\(^2\)In Seyfert 1s, this matter may be observed in transmission rather than in reflection: i.e. the warm reflector becomes the warm absorber discussed above.

\(^3\)In the sense explained in footnote 1: hydrogen may well be largely ionized, as observed in the inner region of NGC 1068, see Gallimore, Baum & O’Dea 1997, without affecting significantly the X–ray reflection.
10^{44} \text{erg s}^{-1} \text{ (see discussion in Iwasawa, Fabian \\ Matt 1997)}, the amount of neutral reflection (if this component is attributed, as it seems natural, to the inner torus surface), implies a very thick torus (more than 10^{25} \text{cm}^{-2}) viewed almost edge–on in agreement with water maser findings (Gallimore et al. 1997). Note that attributing the neutral reflection component to a rather ad hoc optically thin material (Netzer & Turner 1997) would rise the problem of explaining why reflection from the torus is not observed.

4.2. Is the unification model correct?

The BeppoSAX results on NGC 1068, as well as on other Seyfert 2 galaxies (see contributions to this volume by Malaguti et al., Salvati et al., Ueno et al.), are brilliant confirmations of theoretical models based on the unification scenario. However, in recent years many observations pointed against type 1 and 2 Seyfert being different only for the aspect angle: enhanced star formation, on average, in Seyfert 2 galaxies (Maiolino et al. 1997); different morphologies between galaxies hosting type 1 and 2 nuclei, those hosting type 2 being on average more irregular (Maiolino et al. 1997, Malkan et al. 1997); a greater dust content in Seyfert 2s (Malkan et al. 1997); evidence for face–on relativistic iron lines in Seyfert 2s (Turner et al. 1997 and this volume). Clearly, aspect angle cannot be the only relevant parameter: there must be an intrinsic difference between average properties of Seyfert 1 and 2. Of course, the first thing one needs to verify is whether there is a difference in nuclear properties. To do so, the best way is to observe in X–rays (where nuclear activity dominates the emission) a sample of optically selected sources. Salvati et al. (1997 and this volume) have selected an OIII flux–limited sample of Seyfert 2’s to be observed with BeppoSAX, in the assumption that the OIII flux is a good isotropic indicator of Seyfert activity (this is not completely true, but OIII flux is nevertheless probably the best one). The main result of this program is that all sources observed so far have been detected (8 out of 8), with typical X–ray luminosities exceeding those of normal galaxies. Even if not conclusive, this is nonetheless a very strong indication that all Seyfert 2 have a type 1 nucleus, and then that any difference between the two classes should be searched for in the nuclear environment. A tentative solution is as follows: all Seyfert have a type 1 nucleus plus circumnuclear, optically thin (to Compton scattering) dust lanes (see Malkan et al. 1997); only a fraction of them, however, have also the (Compton–thick) molecular torus, which possibly forms preferentially in irregular, disturbed galaxies (which have also, probably for the same reason, an enhanced star formation activity as well as an overall greater dust content). If the nucleus is freely observed, the source is a Seyfert 1. If the line–of–sight intercepts matter other than the torus (i.e. a dust lane, or even the galactic disc for highly inclined galaxies) the source falls in the big cauldron comprising different subclasses like Compton–thin Seyfert 2’s, intermediate Seyfert and NELG. If, finally, the line–of–sight intercepts the torus, the source is a Compton–thick Seyfert 2 galaxy. Note that one of the new results from BeppoSAX is that Compton–thick sources are a large fraction (see e.g. the contributions to this volume by Malaguti et al., Salvati et al. and by Ueno et al.). Therefore, in our proposed scenario the presence of a molecular torus, even if no longer ubiquitous, is still rather common.

4.3. A new population of hard sources

One of the most important results obtained so far by BeppoSAX is the discovery, with the MECS, of many serendipitous hard sources, sometimes observed only above a few keV. This topic is extensively discussed elsewhere in this volume (see contributions by Giommi and by Fiore et al.), and therefore I will not enter into details here. A follow–up optical identification program is currently in progress, and we do not yet know for certain the nature of these sources. One can, however, guess that these sources will turn out to be highly obscured AGN. What we already know is that they have usually high X–to–optical ratios, higher than, for instance, the sources in the Salvati et al. sample mentioned above. It is then possible that they are the moderate–z cousins of local Seyfert 2s; in fact, if one suppose that the discovered sources have nuclear (and then X–ray) luminosities larger than those...
of local AGN, their X–to–optical ratio (the latter band being dominated by the host galaxy light for obscured sources) can be explained. What is important to remark is that these hard sources, whatever they are, are needed to explain the Cosmic hard X–ray Background (e.g. Comastri et al. 1995; Matt 1995 and references therein), and actually this BeppoSAX discovery may represent the first step towards resolving the X–ray Background at these energies.

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