Active Galactic Nuclei are powered by accretion onto massive black holes. Although radio-quiet objects are not as spectacular sources of very high energy photons as radio-loud ones this class of objects also represents a challenge for modeling high energy processes close to a black hole. Both a hot optically thin plasma and a cooler optically thick accretion disk are usually thought to be present in the vicinity of a black hole although the details of the accretion flow are still under discussion. The role of the disk seems to decrease with a drop in the Eddington ratio: in sources like quasars and Narrow Line Seyfert 1 galaxies disk flow dominates while in Seyfert galaxies the disk retreats, and in sources like LINERS or Sgr A* a disk is most likely absent. Shocks and reconnections are possibly taking place in an inner hot flow and in the magnetic corona above the cold disk. Uncollimated outflow is also present and it may carry significant fraction of available mass and energy.

1 Introduction

Active Galactic Nuclei (hereafter AGN) are the most powerful persistent and compact sources of radiation in the Universe. As such, they are clearly of interest from the point of view of high energy processes. AGN activity is caused by accretion of material onto the massive black hole residing at the center of a host galaxy. Therefore, in those objects we can observe the behavior of the matter in a strong gravity field.

Although the basic engine is always the same — extraction of gravitational energy of the infalling material — AGN are quite an inhomogeneous class of objects. The most important differentiating property is perhaps the radio loudness. A small fraction of those sources are strong radio emitters and display spectacular jets and/or radio extended radio lobes. The majority, however, forms a population of radio quiet sources. The transition between the two populations is rather smooth, but nevertheless it is convenient to introduce two separate classes
of objects, with a focus on strong relativistic jets as the main property of radio-loud sources. The customary border is set at the 5 GHz radio to B band flux ratio \( \log F_{5\text{GHz}}/\log F_B = 10 \). The properties of the radio-loud objects are discussed by R. Moderski and A. Celotti (these proceedings). Here I will concentrate on the radio-quiet population and their relevance to high energy astrophysics.

2 Basic facts

AGN span a very broad range of luminosities. The brightest AGN (found among quasars) have bolometric luminosities almost up to \( \sim 10^{48} \text{ erg s}^{-1} \). They are mostly found among the high redshift objects. Nowadays, numerous quasars are found up to \( z \sim 6 \) as a result of massive surveys (e.g. SDSS). Nearby Seyfert galaxies are a few orders of magnitude fainter. The lower limit for a nuclear activity is unspecified since the determination of the weak nuclear activity is observationally difficult. However, it is now widely believed that all regular galaxies with bulges contain a supermassive black hole and must show some level of activity. In this sense we can also count SGR A* as an example of weak activity (see S. Nayakshin, these proceedings), with its occasional flares reaching up to the level of \( 10^{35} \text{ erg s}^{-1} \).

Black hole mass estimates indicate much narrower range, \( \sim 10^6 - 10^{10} M_\odot \), than the luminosity range which means that the Eddington ratio differs considerably between the sources.

2.1 Classification

Radio-quiet AGN are divided into several classes, with two parameters most plausibly underlying this classification scheme: inclination angle and the Eddington ratio.

Generally, all AGN are divided into type 1 and type 2 objects. Type 1 objects have very broad emission lines while type 2 objects show only narrow lines in their optical/UV spectra. It is generally accepted that class 2 is simply an obscured version of type 1 objects so we have no direct view of the nucleus in those sources. This obscuration is due to the material predominantly located in the equatorial plane, in a form of a dusty/molecular torus. It can be noted, however, that there may be intrinsic type 2 sources among low Eddington ratio AGN. It only means that classification based on the width of the hydrogen lines may not always represent well the characteristics of the central engine. In further text we will discuss only type 1 AGN.

Another classification, mostly historical, divides type 1 radio quiet AGN into quasars, Seyfert galaxies, Narrow Line Seyfert 1 galaxies and LINERS. The transition between these classes (connected mostly with the luminosity and the Eddington ratio) is smooth. Moreover, some quasars are also classified as NLS1 galaxies, and some LINERS perhaps are mostly starburst so the issue is confusing but we will preserve these subgroups to indicate the luminosity class of the discussed sources. Also for bright quasars the transition to the corresponding 'Narrow Line Type 1' class happens at much higher width (\( \sim 4000 \text{ km s}^{-1} \)) than for Seyfert galaxies (\( \sim 2000 \text{ km s}^{-1} \)). This can be easily understood if the transition happens at a fixed Eddington ratio and the difference in black hole mass is taken into account (see formulae in [7]).

2.2 Broad band spectra

The radiation spectrum of radio quiet AGN is very broad and span from radio to gamma band. The spectrum is best studied for high luminosity sources. A schematic view, representative for sources with high Eddington ratio (quasars and Narrow Line Seyfert 1 galaxies; \( L/L_{Edd} \sim 1 \)) is shown in Fig. [8]. The spectrum usually peaks in the far UV/soft X-ray range, not accessible to the observations due to the Galactic extinction. However, the observational gap can be partially filled by combining low redshift and high redshift sources into a single composite spectrum [9].
The extension of the spectra beyond 100 keV is not well studied and we return to this point in Sect. 3.1.

The spectra of AGN with lower Eddington ratio like Seyfert 1 galaxies ($L/L_{Edd} \sim 0.01$) show less pronounced far UV peak and relatively stronger X-ray emission, and the X-ray spectrum is harder. The black holes accreting at the lowest rate ($L/L_{Edd} \sim 10^{-4}$) like those in LINERS or LLAGN do not show any strong UV emission while they are still relatively bright in X-rays. The broad band spectra of such objects are difficult to determine since the optical spectrum is in this case dominated by the host galaxy. Their X-ray spectra are as hard as in Seyfert 1 galaxies.

Practically all radio-quiet AGN are rather variable\textsuperscript{10,11}. The shortest variability timescales (hundreds of seconds) are seen in X-ray band, in Seyfert galaxies. Optical/UV emission varies in timescales of days in those sources while in quasars monitoring over years is needed to see significant changes in optical band\textsuperscript{12}.

3 Radio-quiet AGN as sources of high energy photons and particles

Radio-quiet AGN are not as obviously attractive from the point of view of the high energy physics as are radio-loud AGN. However, they also represent certain challenge for such studies. In order to show that we will discuss now the gamma-ray emission from these sources and the most plausible environment of its production.

3.1 Extension of the AGN spectra into high energies

The direct signature of the importance of high energy processes in a given object is the presence of the gamma-ray emission. Unfortunately, spectral measurements going beyond 100 keV were performed only for a few sources, and the results were uncertain. Fits to the OSSE composite spectrum\textsuperscript{13} gave the high energy cut-off $120_{-60}^{+220}$ keV for Seyfert 1 and $130_{-50}^{+220}$ keV for Seyfert 2 galaxies (at such high energies the obscuration by the torus is relatively unimportant). \textit{BeppoSAX} data, however, did not give such a strong constraints (cut-off energy $231_{-108}^{+\infty}$ keV for Seyfert 1 galaxies, no cut-off for Seyfert 2 galaxies\textsuperscript{14}). Comparison of the model to the observed X-ray background suggest that if the typical photon index is $\sim 1.9$ the spectrum extends up to $\sim 300$ keV\textsuperscript{15} while observations of high redshift quasars give results from 100 keV to 500 keV and more, depending on the object and the adopted geometry\textsuperscript{16,17}. 

Figure 1: Schematic view of the radiation spectrum of a bright radio quiet (continuous line) and radio-loud (dashed line) AGN.
Overall similarity of AGN and galactic black holes may suggest that sources with rather hard spectra (photon index 1.9 or less) are thermal (electron temperature of order of 100 keV). Such a spectrum is well explained as a result of the Comptonization of the soft photons by a predominantly thermal plasma with the electron temperature around $10^9$ K. Ions may have much higher temperature, or may not be fully thermalized, but we have no direct methods of estimating their properties. Efficient thermalization is supposed to be achieved through synchrotron self-absorption\cite{18}. Sources with steep spectra (photon index 2.0 and more) are likely to be significantly non-thermal, with a population of electrons having a power law distribution of energies, as expected in case of effective acceleration and ineffective thermalization.

Direct observation constraints should come from Astro-E2 and GLAST.

3.2 accretion flow geometry

The broad band spectrum clearly shows that the accretion flow is (at least) a two-phase medium. The profound optical/UV/soft X-ray bump (Big Blue Bump) so characteristic for high $L/L_{Edd}$ sources is well modeled as a thermal emission of a Keplerian, optically thick and geometrically thin disk (see Fig. 2). The hard X-ray emission must come from a hot optically thin plasma in the vicinity of the disk. The IR emission is due to reprocessing of a part of the radiation by circumnuclear dust, usually referred to as a dusty-molecular torus. The presence of this torus is responsible for shielding the central parts for highly inclined observers, as is the case for type 2 objects. The torus is most probably clumpy, and quite possibly it is rather a kind of outflowing dusty wind instead of a structure in the hydrostatic equilibrium.

The location and geometry of the hot plasma is uncertain. A plausible possibility is shown in Fig. 2. The disk is covered by magnetic loops emerging from its interior\cite{19}. The mechanism behind this is the magneto-rotational instability (MRI) operating in the disk interior. This instability is responsible for the disk viscosity, and the corresponding Shakura-Sunyaev parameter $\alpha$ is $\sim 0.01$, according to numerical simulations. Occasionally, large loops emerge high above the disk surface\cite{20}, and the magnetic field reconnection results in formation of a flare (hard X-ray flash). Therefore, a corona similar to the solar corona forms above the disk. In the innermost part the cold disk can be evaporated due to the interaction with such an active corona\cite{21}. A flow towards the black hole proceeds through a hot plasma phase,\cite{22,23,24} and a (perhaps significant) fraction of the plasma can be expelled out in the process. In strongly radio-loud objects this
outflow takes a form of a relativistic well-collimated jet but in radio-quiet objects the outflow is slower and uncollimated. The mechanism of the outflow is unknown.

Within this picture, we would expect the formation of non-thermal plasma in the coronal loops above the disk while in the hot phase the electrons would be predominantly thermal. The relative role of the two media is determined by the disk truncation radius which in turn is determined by $L/L_{Edd}$. At $L/L_{Edd} \sim 0.1 - 0.5$ or more the disk is supposed to extend down to the marginally stable orbit.

The geometry shown in Fig. 2 is not a unique possibility. Other accretion flow models include (i) the lamp-post model in which the disk always extends up to the marginally stable orbit and the high energy emission comes from a shock formed in the outflowing plasma and localized on the symmetry axis 25,26 (ii) disk always extending down to the marginally stable orbit with magnetic flares above it 19 (iii) accretion in the form of clumps of cold material embedded in a hot plasma 27. In those models the spectral differences between high Eddington and low Eddington sources are less naturally explained.

4 X-ray spectroscopy as a tool to study the plasma motion

Given the lack of sufficient spatial resolution the key to the flow geometry lies in X-ray spectroscopy. First extremely useful results came from Ginga 28 and ASCA 29 data, now Chandra and XMM-Newton offer still higher quality data. A number of blueshifted absorption lines was identified which allowed to measure the outflow velocity of the material, and measured a number of emission line profiles, including the famous iron $K\alpha$ line.

4.1 outflow

Chandra and XMM-Newton observations confirmed the earlier findings that a partially ionized warm absorber exists in many Seyfert 1 and NLS1 galaxies 30. Outflow velocities range from hundreds km s$^{-1}$ in Seyfert 1 31,32 galaxies to a fraction of light speed in NLS1 33,34. The distance of this outflowing material from the black hole is difficult to assign. Simple arguments based on the assumption of a roughly Keplerian velocity suggest that the slow outflow originates somewhere between the Broad Line Region and a Narrow Line Region, i.e. at a few parsecs from the nucleus, and the fast outflow originates closer in, at distances of order of hundreds of Schwarzschild radii. The amount of outflowing material may be quite large - fast outflows may actually carry out considerable fraction of the inflowing material 35. The estimates are difficult since a fraction of the material may be completely ionized and leave no direct signature in the soft X-ray spectrum. However, this material will scatter a fraction of the nuclear emission and may lead to modification of the optical spectrum of an AGN through the irradiation of the outer disk 36,37.

4.2 quasi-Keplerian motion

Chandra and XMM-Newton confirmed that in some objects the very broad emission lines (iron line and soft X-ray lines) are seen, with the shape well represented as the effect of the relativistic smearing due to the Keplerian motion of the emitting material located very close to the black hole 38. Some observations indicate that the inner radius of the disk increases when the source becomes fainter 39.

However, the observed variability of the iron line is not well understood and remains a major puzzle 40,41. Models require some fine tuning in order to reproduce the observed trends.

Models which explore full observational information have even more difficulties. We attempted to reproduce both the fractional variability amplitude and point-to-point fractional variability amplitude for MCG-6-15-30. The model assumed that magnetic flares are randomly
distributed above the disk surface. The flare flux, flare duration and the probability of a flare at a given radius were assumed to have a power law dependence on the radius. Black hole was assumed to rotate, disk was assumed to extend down to the marginally stable orbit appropriate for an adopted Kerr parameter. Each flare created a hot spot on the disk surface by irradiation and the reflection (including iron line and other soft lines) was calculated using the code TITAN/NOAR\textsuperscript{12} and taking into account that the incident flux depends on the distance from the flare center. Flare was assumed to be short-lasting so the vertical structure of the disk was taken from an unilluminated model and the disk expansion was neglected. Predicted spectrum was integrated in specific time bins, as in the data, all relativistic effects were included using the code KY\textsuperscript{13}.

Within this scenario, we could not find a parameter range which would reproduce the shape of both fractional variability functions. Either still the model is too simple (we did not consider the dependence of the shape of the reprocessed radiation on the radius) or an important element is still missing. There is some evidence that variations in the outflowing warm absorber can contribute significantly. It was even suggested that warm absorber is mostly responsible for the observed shape of the spectrum in soft X-ray band\textsuperscript{14}, and the broad iron line is partially an artefact\textsuperscript{15}.

5 Shocks and magnetic field reconnections as a heating mechanism of the hot plasma

Although the geometry of the hot material is still under discussion, some mechanisms of plasma heating are needed to explain the observed X-ray emission.

Models that can apply to magnetic flares above the disk surface were discussed in numerous
In ADAF type solutions most of the gravitational energy is used to heat ions, and subsequently directed towards electrons through Coulomb interaction\cite{22,18}. However, a fraction of energy will be inevitably used to heat electrons directly\cite{49} thus limiting the low radiative efficiency of the flow.

Several other aspects were also discussed, like disk-corona coupling\cite{50}, disk evaporation and the ion irradiation of the disk\cite{51} but the picture is far from being complete.

Observationally, very interesting results were obtained in the context of a galactic source (microquasar) GRS 1915+105\cite{52} and they may apply to AGN when timescales are corrected by the black hole mass ratio. Methods, like Fourier-resolved spectroscopy, successfully applied to galactic sources\cite{53} may be also helpful although the AGN data at present are hardly of the appropriate quality.

Therefore, observational determination of the gamma-ray emission from radio-quiet objects

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References

1. J.-H. Woo and C.M. Urry, \textit{ApJ} \textbf{579}, 530 (2002)
2. X. Fan et al., \textit{AJ} \textbf{128}, 515 (2004)
3. \url{http://www.sdss.org/}
4. A. Wandel, Proc. of IAU Symp. 222, Black Holes, Stars and ISM in Galactic Nuclei, astro-ph/0407399 (2004)
5. H.D. Tran, \textit{ApJ} \textbf{583}, 632 (2000)
6. R. Bachev et al., \textit{ApJ} \textbf{617}, 171 (2004)
7. B. Czerny, A. Różańska and J. Kuraszkiewicz, \textit{A&A} \textbf{428}, 39 (2004)
8. M. Elvis et al., \textit{ApJS} \textbf{95}, 413 (1994)
9. A. Laor et al., \textit{ApJ} \textbf{477}, 93 (1997)
10. A. Markowitz et al, \textit{ApJ} \textbf{593}, 96 (2003)
11. T. Totani et al., \textit{ApJ} \textbf{621}, L9 (2005)
12. U. Giveon et al., \textit{MNRAS} \textbf{306}, 637 (1999)
13. A.A. Zdziarski, J. Poutanen and W.N. Johnson, \textit{ApJ} \textbf{542}, 703 (2000)
14. S. Deluit and T.J.-L. Courvoisier, \textit{A&A} \textbf{399}, 77 (2003)
15. N. Menci, F. Fiore, G.C. Perola, and A. Cavaliere, \textit{ApJ} \textbf{606}, 58 (2004)
16. M. Sobolewska, A. Siemiginowska and P.T. Życki, \textit{ApJ} \textbf{608}, 80 (2004)
17. M. Sobolewska, A. Siemiginowska and P.T. Życki, \textit{ApJ} \textbf{617}, 102 (2004)
18. G. Ghisellini, R. Svensson, Proceedings of the NATO Advanced Research Workshop Physical Processes in Hot Cosmic Plasmas, held in Vulcano, Sicily, Italy, May 29-June 2, 1989. Eds, Wolfgang Brinkmann, Andrew C. Fabian, Franco Giovannelli; Publisher, Kluwer Academic Publishers, Dordrecht, The Netherlands, Boston, MA, (1990)
19. A.A. Galeev, R. Rosner and G.S. Vayana, \textit{ApJ} \textbf{229}, 318 (1979)
20. K.A. Miller and J.M. Stone, \textit{ApJ} \textbf{534}, 398 (2000)
21. A. Różańska and B. Czerny, \textit{A&A} \textbf{360}, 1170 (2000)
22. S.L. Shapiro, A.P. Lightman and D.M. Eardley, \textit{ApJ} \textbf{204}, 187 (1976)
23. S. Ichimaru, \textit{ApJ} \textbf{214}, 840 (1977)
24. R. Narayan and I. Yi, \textit{ApJ} \textbf{428}, L13 (1994)
25. G. Henri and G. Pelletier, *ApJ* **383**, L7 (1991)
26. G. Miniutti and A.C. Fabian, *MNRAS* **349**, 1435 (2004)
27. S. Collin-Souffrin, B. Czerny, A.-M. Dumont, P.T. Życki, *A&A* **314**, 393 (1996)
28. K.A. Pounds, K. Nandra, G.C. Stewart, I.M. George, A.C. Fabian, *Nature* **344**, 132 (1990)
29. Y. Tanaka et al., *Nature* **375**, 659 (1995)
30. A.J. Blustin, M.J. Page, S.V. Fuerst, G. Branduardi-Raymont and C.E. Ashton, *A&A* **431**, 111 (2005)
31. S. Kaspi et al., *ApJ* **554**, 216 (2001)
32. J.S. Kastra et al., *A&A* **386**, 427 (2002)
33. G. Chartas, W.N. Brandt, S.C. Gallagher, and G.P. Garmire, *ApJ* **279**, 169 (2002)
34. K.A. Pounds, A.R. King, K.L. Page and P.T. O’Brien, *MNRAS* **346**, 102 (2003)
35. A.R. King and K.A. Pounds, *MNRAS* **345**, 657 (2003)
36. B. Czerny et al., *A&A* **412**, 317 (2003)
37. Z. Loska, B. Czerny and R. Szczerba, *MNRAS* **355**, 1080 (2004)
38. C.S. Reynolds and M.A. Nowak, *Physics Reports* **377**, 389 (2003)
39. G. Matt et al., astro-ph/0502323 (2005)
40. A.L. Longinotti, K. Nandra, P.O. Petrucci, P.M. O’Neil, *MNRAS* **355**, 929 (2004)
41. S. Bianchi et al., *A&A* **422**, 65 (2004)
42. A.-M. Dumont, A. Abrassart and S. Collin, *A&A* **357**, 823 (2000)
43. M. Dovciak, V. Karas and T. Yaqoob, *ApJS* **153**, 205 (2004)
44. M. Gierliński and C. Done, *MNRAS* **349**, L7 (2004)
45. K.A. Pounds, astro-ph/0505447 (2005)
46. D.A. Larrabee, R.V.E. Lovelace and M.M. Romanova, *ApJ* **586**, 72 (2003)
47. B.F. Liu, S. Mineshige, and K. Ohsuga, *ApJ* **587**, 571 (2003)
48. R. Narayan, R. Mahadevan and E. Quataert, E. 1999, in The Theory of Black Hole Accretion Discs, ed. M. A. Abramowicz, G. Bjorsson, and J. E. Pringle (Cambridge: Cambridge Univ. Press)
49. G.S. Bisnovatyi-Kogan and R.V.E. Lovelace, *ApJ* **529**, 978 (2000)
50. Z. Kuncic and G.V. Bicknell, *ApJ* **616**, 669 (2004)
51. C. P. Dullemond and H.C. Spruit, *A&A* **434**, 415 (2005)
52. R. Fender and T. Belloni, *Ann. Rev. Astron. Astrophys.* **42**, 317 (2004)
53. P.T. Życki, *MNRAS* **340**, 639 (2003)