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Forty Years of X-Raying Narrow-Line Seyfert 1 Galaxies

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Abstract

Forty years after the discovery of Narrow-Line Seyfert 1 Galaxies (NLS1s), and 20 years since the discovery of the remarkable ultrasoft soft X-ray emissions of NLS1s, strategic publications improved the understanding of the Seyfert phenomenon more generally. New theoretical models emerged from the observations and stimulated the discussions on the innermost regions of AGN. NLS1s are an amazing class of AGN for X-ray, optical and multiwavelength science.

Keywords: X-rays: Narrow-Line Seyfert 1 Galaxies.

1 Introduction

Type 1 AGN are divided into Broad Line Seyfert 1 Galaxies (BLS1s) and Narrow-Line Seyfert 1 Galaxies (NLS1s). BLS1s are associated with the name of Carl Seyfert (*11.2.1911, Cleveland, Ohio, USA+13.6.1960, Nesville, Tenneesee, USA). Seyfert (1943) discovered that the FWHM of the optical emission lines reaches values up to about 10000 km s^{-1}. Such high values were thought to originate from the Broad-Line Region in the gravitational potential of supermassive black hole. The FWHM values of BLS1s are much higher than the velocity dispersions found from the rotation curves of normal galaxies, which reach only a few 100 km s^{-1}. Observations of such high velocities in BLS1s suggested in addition that the observer has a direct view to the central regions of active galaxies.

In 1970, Fritz Zwicky (*14.2.1898, Bulgaria,+ 8.2.1974, Pasadena, Califormia, USA) made the fundamental discovery that type 1 AGN exhibit FWHM of the optical permitted lines much less than that what was observed in BLS1s, with FWHM values down to 500 km s^{-1} (Zwicky 1970). These objects were sometimes misclassified with normal galaxies, however the presence of very strong Fe II multiplet emission definitely revealed the type 1 AGN nature of these sources, as Fe II multiplet emission is only occurring in high density regions with densities larger than 10^9 cm^{-3}. Such densities are only present in the BLR clouds or the accretions disc in AGNs.

2 Historical Review

1970, Zwicky

The first note on a new class of type 1 AGN with unusually narrow permitted lines was made by Zwicky (1970).

1978, Davidson and Kinman

Davidson and Kinman (1978) investigated the optical spectrum of Mrk 359. They pointed out that the object has unusually narrow permitted optical lines and that 'this object merits further observations'.

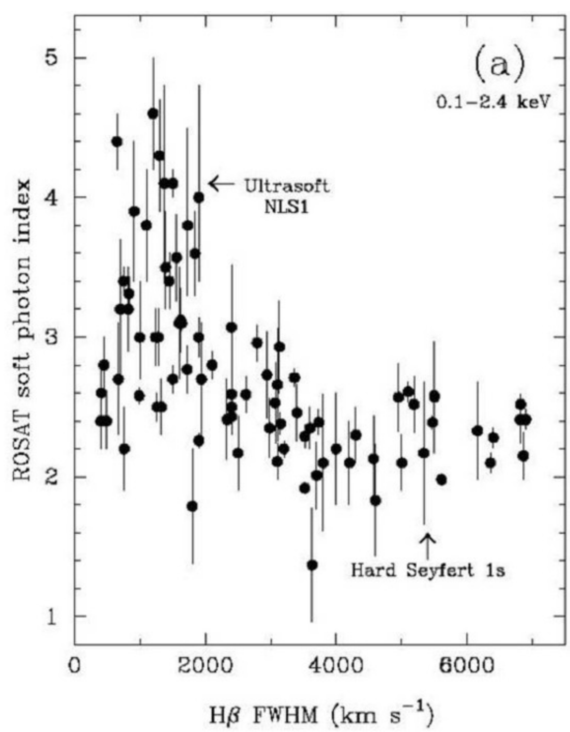

Figure 1: FWHM value of the Hβ line versus the ROSAT photon index for broad line Seyfert 1 galaxies and Narrow-line Seyfert 1 Galaxies. Below 2000 km s^{-1} the photon index reach values up to about 5.

1985, Osterbrock and Pogge

Osterbrock and Pogge (1985) came up with the first definition for NLS1s. They defined NLS1s as follows: (i) the permitted optical lines are only slightly broader than the forbidden lines; (ii) strong Fe II multiplet emission, centered between 4400 and 4500 Å; (iii) a ratio of the O III line to Hβ line with less than 3; (iv) having FWHM of the Hβ line between 500 and 2000 km s^{-1} (added by Goodrich 1989).

1992, Puchnarewicz

Based on Einstein IPC data (Puchnarewicz 1992) reported for the first time on remarkable ultra-soft X-ray spectra of NLS1s. The sample size of NLS1 with steep soft X-ray spectra reached a number of 53.

1996, Boller, Brandt, Fink

In 1996, we (Boller, Brandt, Fink, 1996) published a relation between the FWHM value of the Hβ line and the ROSAT 0.1-2.4 keV photon index (c.f. Fig. 1).

While BLS1 have their photon indices confined to a fairly narrow range around about 2.3, the ROSAT photon index rises steeply below FWHM values of 2000 km s^{-1}. This plot demonstrates that the emission within a few R_G around the black hole determines the velocity distribution at much larger scales in the BLR. The main reasons for the steep X-ray spectra of NLS1s are the low masses of the black hole and the very high accretion rates (Boller et al. 1996). There appears also a zone of avoidance (FWHM values larger than 2000 km s^{-1} and photon indices larger than 3), where so Seyfert galaxies have been observed so far.

1997, Boller, Brandt, Fabian, Fink

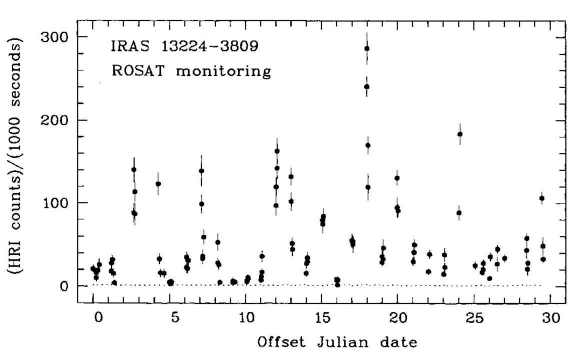

Figure 2: 30 day ROSAT monitoring of the NLS1 galaxy IRAS 13224-3809 taken in 1997. Persistent, giant and rapid amplitude variations have been detected with the maximum amplitude variation with a factor of about 57.

In 1997 we have performed a 30 day ROSAT monitoring observation of the NLS1 galaxy IRAS 13224-3809 (Boller et al. 1997). Giant, persistent and rapid amplitude variations have been discovered with a maximum amplitude variation with a factor of 57 within about 1200 seconds. The peak in luminosity corresponds to about 10^{44} erg s^{-1} within that time scale. The most plausible explanation for these extreme X-ray variability is flux boosting of hot spots orbiting the central black hole. As the flux boosting factor scales with the Doppler-factor to the power of 3+Γ, and as the photon index of the object is very steep with 4.4, such extreme variability is a natural consequence of flux boosting in steep spectrum NLS1s (Fig. 2).

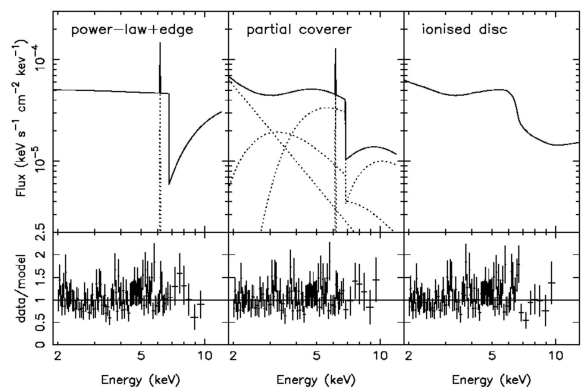

Figure 3: Sharp spectral cut-off detected in 1H0707-495. A power-law plus absorption edge model, a partial covering model and an ionized reflection disk model are shown with their corresponding residua.

2002, Boller, Fabian, Sunyaev, Trümper

In 2002 we (Boller et al., 2002) have discovered the first sharp spectral drop at around 7 keV without any noticeable Fe K emission. The spectral drop is of the order of about 2. Two explanations have been discussed in this paper, (i) a partial covering scenario, and (ii) a reflection dominated spectrum. While the partial covering model appears to be ruled out in subsequent analysis, the reflection model of Ross and Fabian (2005) might explain this type of new spectral cut-offs, now also discovered in other NLS1s.

2003, Pounds

High velocity outflows with substantial fractions of the speed of light have been detected by (Pounds et al. 2003). In the NLS1 galaxy PG 1211+143 outflow velocities up to 0.2 c have been seen. This discovery fits into the general scheme of understanding NLS1 as super-Eddington accreting sources, which naturally leads to substantial mass outflows.

2004, Miniutti, Fabian
Triggered by the detection of sharp spectral drops in the high energy spectra of NLS1s, a new spectral model has been developed, named as the 'light bending model' by Miniutti and Fabian (2004). In this model a hot and compact region, emitting a power law spectrum, is located very close to the central black hole and changes its scale height above the black hole. The compact source illuminates the accretion disc and gives rise to reflection spectrum. When the scale height of the compact object is small (2 R_G) then most of the power law photons from the compact object are bent towards the black hole and the power law contribution for the external observer is small. The spectrum is in this case reflection dominated and especially the strongest X-ray emission lines, the Fe K and Fe L lines become visible (Fabian et al. 2009). When the source height is increasing, a smaller amount of photons is lost into the black hole and the powerlaw component increases in strength for the external observer. While the power law component varies by a factor of about 70, the reflection component is less variable with a factor of about 4. This model can explain the missing relation between the illumination strength of the disc and the strength of the Fe K line as well as most of the spectral and timing properties we have observed from the innermost regions of AGNs.

2007, Komossa
In 2006, Komossa (2006) carried out a systematic search for radio-loud NLS1s. The analysis confirmed that most NLS1s are radio-quiet objects and that only 2 per cent can be considered as radio-loud with an R value greater than 100. The physical reasons for the radio-loudness of some NLS1s are still under discussions.

2008, Foschini; Malizia
Foschini (2008) and Malizia (2008) first reported on the detection of NLS1s at hard (2-20 keV) X-rays. This was something unexpected given the steep X-ray spectra of these objects.

2009, Fabian
A very important discovery, strongly supporting the light bending model from Miniutti and Fabian (2004), was the detection of a 30 second reverberation lag between the direct hard power-law emission and the soft Fe L line reflection component, with the power-law emission leading the soft X-ray emission (Fabian et al. 2009). The light bending model predicted that the external observer first sees the direct power-law emission from a compact and hot region sitting very close to the central black hole and after that the reflection component, which has a longer light travel time. In addition, both the Fe K and the Fe L line were seen for the first time in a AGN. The lines are strongly relativistic and the intensity of the lines are in the ratio of 20 to 1, in excellent agreement with atomic physics.

2012, Foschini
The first detection of gamma-ray emission from a NLS1 galaxy was reported by Foschini et al. (2012, and references therein). A more than three years monitoring programme ranging from the radio to gamma-rays on the NLS1s PMN J0948+0022 revealed the detection of emission above 100 MeV. The observations revealed the presence of a powerful relativistic jet with isotropic emission of about 10^{48}erg s^{-1}. A complete understanding of the radio and gamma-ray emission has still not emerged from the few available data.

3 Upcoming NLS1 eROSITA Science

3.1 Survey science

eROSITA will carry out a 4 years all-sky survey in the 0.3 to 10 keV band. The expected number of new NLS1s which will be detected is 100000, exceeding the presently known number of NLS1s by orders of magnitude. These objects CAN easily disentangled from other objects, via their distribution in the FWHM - Photon index plane (c.f. Fig. 1). As most of the source will have only moderate count rate statistics during the survey observations, the survey science will be restricted to statistical analysis on different science cases discussed below.

- Eigenvector 1 analysis

  Brandt and Boller (1999) have carried out an Eigenvector 1 analysis of broad and narrow-line Seyfert 1 galaxies. We found that NLS1s lie towards one extreme of the primary Eigenvector, and that steep X-ray spectra, narrow optical permitted lines, extreme X-ray variability, week [O III] emission, strong Fe II multiplet emission are correlated. These type of analysis will be applied to the eROSITA NLS1s with much higher data statistics, probing the physical mechanism lying behind these correlations with much better statistics.

- Super-Eddington accretion and Comptonization

  Most NLS1 galaxies are accreeting above the Eddington limit. The relation between Super-Eddington accretion, outflows, steepness of the X-ray spectra and Comptonization has been summarized by Boller (2011). The basic idea is that super-Eddington accretion results into a strong UV luminosity and a stronger and to higher energies shifted Planck-emission from the accretion disc. The stronger the UV disc luminosity is and the larger the solid angle subtended by the reflector is, the greater is the cooling by the seed photons incident on the plasma, the lower is the plasma electron temperature, and the steeper are the X-ray photon indices, consistent with the observations. Again, with the much larger number of new NLS1s detected in the eROSITA survey observations, a better physical understanding of the relation between all these properties will emerge.

Other science cases which will be addressed during the eROSITA survey observations will be, (i) search for extreme X-ray variability and nonlinear X-ray variability, (ii) $\alpha_{\rm ox}$ science and the global X-ray Baldwin effect, and (iii) multiwavelength source population properties.

3.2 eROSITA science with pointed observations

After the 4-years period of survey observations, pointed observations will be carried out with eROSITA, allowing for much higher count rate statistics. Some of the basic science drivers for the NLS1 research will be:

- Relativistic iron K and L lines and reverberation lag physics

  eROSITA will offer a unique possibility to further study the behavior of matter under strong gravity on a much larger sample as presently known.

- eROSITA black hole growth studies

  NLS1 galaxies with their proven high accretion rates are the objects with the highest black hole growth rates and are therefore ideally suited for such studies.

- Accretion disc physics and NLS1 science

  eROSITA will open a new window on the study of relativistic disc reflection. Strong X-ray reflection is a natural consequence for the existence of a compact corona close to the central black hole system.

eROSITA will offer much more NLS1 and AGN science. Among them are: (i) high velocity outflows and feedback processes, (ii) strong gravity in the high-curvature regime and GR tests (Boller and Müller, 2013), (iii) intensive starbursts, super-solar metallicities, and relation to AGN accretion, (iv) extending the luminosity function of NLS1s to higher redshifts, (v) models for the black hole regions of NLS1s, (vi) the origin of the extreme soft x-ray excesses, (vii) thin and thick accretion discs in NLS1s, (viii) the accretion disc coronae of NLS1s, (ix) the origin of the extreme X-ray variability in NLS1, (x) interpretation of line and continuum correlations, and (xi) models for the Broad Line Region and the X-ray and UV absorption.

Acknowledgement

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DISCUSSION

MATTEO GUAINAZZI's Comment: Do you believe that measurements of black hole masses in NLS1s are nowadays robust?

Thomas Boller: After the discovery of the extreme X-ray properties of NLS1s all reverberation measurements have shown that NLS1s lie at the lower mass end of the mass distribution in AGN. Especially the papers by B. Peterson are extremely helpful in that matter.