Suzaku observation of Markarian 359

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MRK 359 is one of the prototypical Narrow Line Seyfert 1 galaxies. I present the preliminary results of a new observation of MRK 359 taken by Suzaku, including a comparison to previous XMM-Newton data. The analysis is based on relativistic and non-relativistic emission models, including relativistically broadened accretion disc emission, absorption from a relativistic outflow, and a combination of the two scenarios.

The object

Markarian 359:

MRK 359 is an NLS1 AGN with an estimated black hole mass of 2 x 10^6 Solar masses (Wang & Lu 2001; Hao et al. 2005) at a redshift of 0.017385. Its optical properties place it at the edge of the parameter space of NLS1s, with unusually narrow forbidden and permitted lines. It is therefore a source which deserves investigation (Davidson \& Kinman 1978). It was previously observed by XMM-Newton a when it had a 0.2 – 10.0 keV luminosity of 1.7 x 10^{43} ergs/s (O'Brien et al. 2001). This observation revealed MRK 359 has relatively little short term variation for an NLS1 (15 per cent over time-scales of several kiloseconds). However, the source varies more significantly over longer time-scales, with a factor of 1.5 in two (~1 ks) ROSAT pointings separated by 35 ks, and a factor of 2 between the 1992 ROSAT observations and the 2000 XMM-Newton observation (ROSAT has a bandpass of 0.2 -- 2.4 keV).

Spectrally, the XMM-Newton observation revealed a power law, soft excess (an excess of emission below ~2 keV compared to an extrapolation of a power law fit at high energies) and a narrow iron line at 6.4 keV. The soft excess is well fit by two black body components and the line is fairly strong, with an equivalent with of ~200 eV. (O'Brien et al. 2001). The soft excess measured by Suzaku is shown in Figure 1.

The observation was re-analysed by Crummy et al. (2006) and Middleton et al. (2007) who found that the data could be reproduced reasonably well by reflection from a relativistic accretion disc and very well by relativistically smeared absorption of a power law plus disc reflection spectrum respectively.

Observation:

This observation is the highest quality X-ray dataset of MRK 359 to date. Unfortunately, the source was in a lower flux state than the XMM-Newton observation, and the Suzaku HXD (15 – 50 keV) signal is lower than uncertainties in the background modelling. It is not therefore not included in this initial analysis.

Results: non-relativistic

Non-relativistic fits:

I initially fit the hard X-ray 2 – 10 keV Suzaku data with a power law. This revealed a strong residual at ~6.4 keV in a spectrum otherwise well-represented by a power law; this residual can be easily identified as an iron line. Adding a narrow Gaussian at 6.4 keV improved the fit significantly (f-test probability > 0.999), and allowing the energy to vary did not, showing that the line is likely due to reflection from neutral material. Using a Gaussian with a free width was a further significant improvement (f-test probability > 0.999). A broadened line of this width (σ 0.17 keV) suggests motion in a rapidly-rotating accretion disc close to the central black hole, a motivation for attempting relativistic fits. Extrapolating the 2 – 10 keV power law over the entire XIS waveband reveals the presence of a soft excess, as in many type 1 AGN. In this observation the excess is weak, making up only 0.062 of the total 0.3 – 10.0 keV flux; in some AGN the soft excess can be the dominant component (e.g. Crummy et al 2005). Adding a black body provides a good fit (χ^2_ν 1.03).

Figure 2 shows a comparison between the Suzaku and XMM-Newton observations 2 – 10 keV spectra; it is unchanged (power law plus Gaussian fits confirm this), but the soft excess is much stronger in the XMM-Newton observation. The ROSAT observations which initially established the variability of the source measured only the soft band. A comparison of the black body plus power law fits for XMM-Newton and Suzaku shows that the black body temperature is higher and the power law harder in the Suzaku observation; although the 2 – 10 keV spectrum is identical the soft excess has changed shape as well as brightness. The lower temperature at higher luminosity behaviour is unexpected in classic accretion disc models, where brighter sources should have higher temperatures (Shakura & Sunyaev 1973). On the other hand the stable hard and and varying soft spectra do support treating the components separately, unlike some models where the whole spectrum is a product of one system.

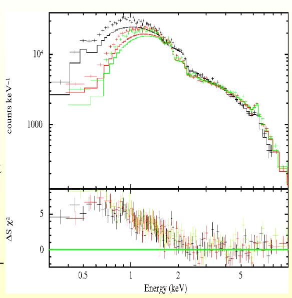

Fig.1 : The Suzaku data with the fit and residuals to a power law over 2 – 10 keV, the soft excess is clearly visible below 2 keV. The feature at 6.4 keV is an iron line, fit with a Gaussian.

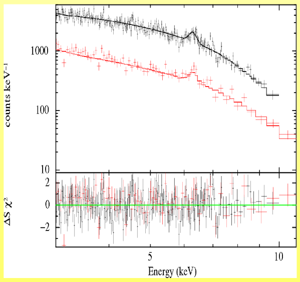

Fig.2 : The Suzaku (black) and XMM-Newton (red) 2 – 10 keV data with the fit and residuals to a power law plus Gaussian model. Both observations are fit with an identical model, showing the hard X-rays have not varied. Only one Suzaku detector and the EPIC pn are shown for clarity.

Results: relativistic

Relativistic models:

This work makes use of two different relativistic models. The first is a model of power law emission plus the photoionized reflection of that emission from a cool accretion disc that is relativistically blurred by the motion of the disc and the gravitational effects of the central black hole. These models have been applied to many sources (e.g. Ross & Fabian 1993). The specific model used here is described in Crummy et al. (2006); it uses reflected and reprocessed emission from a slab of gas calculated by the model of Ross & Fabian 2005 convolved with a Laor (1991) relativistic line profile.

The second is the model of Gierliński & Done (2004), where an intrinsic spectrum (due to the disc and/or corona) is modified by the effect of an absorbing wind moving at relativistic speeds. The absorption spectrum is calculated by XSTAR and convolved with a broad Gaussian (the assumed velocity distribution of the wind). The intrinsic spectrum can be anything, such as simple power law, or a power law and a truncated disc (Middleton et al. 2007). In this work I introduce a model where the intrinsic spectrum is the relativistic reflection model described above; this can represent a truncated disc or one which extends down to the last stable orbit.

Relativistic models are important because they provide the possibility of learning more about accreting AGN systems, e.g. the reflection model allows measuring the inclination, iron abundance and inner disc radius of AGN accretion discs; previously it has been shown using this model that AGN black holes must strongly rotate, with the caveat that alternative models exist. Further research should enable us to find the correct model.

Relativistic fits:

The relativistic reflection model described above is a reasonable fit to the XMM-Newton observation of MRK 359. For that data set the illuminating power law component of the model is not required, possibly indicating extreme gravitational effects on the illuminating source. A similar model without a power law is a good fit to the Suzaku data, and has some consistent parameters with the XMM-Newton fit, although the iron abundance of the accretion disc is significantly lower. Furthermore, adding a power law to the Suzaku model provides a significantly better fit (χ^2_ν 1.03). In this model the measured inclination of the disc is almost 90º and the majority of the flux comes from the power law. This inconsistency argues against relativistic reflection, as the 2 – 10 keV spectrum remains identical despite being primarily made up of difference components in the two observations. Simultaneously fitting both data sets with the inclinations and iron abundances constrained to be the same shows that the variability can be accounted for by changes in the power law and the illumination of the disc, as well as the Suzaku hard spectrum being power law dominated and the XMM-Newton hard spectrum being principally reflection. Doing the same for the model without a power law (Figure 3) shows that in this scenario similar changes in the illuminator can explain the variability.

The relativistically blurred absorption model was also applied to the data. Fits using the simplest possible intrinsic spectrum, a power law, are good (χ^2_ν 1.04). However, both the absorption column and the width of the blurring Gaussian are pegged at their maximum values. The width of the Gaussian implies a wind moving at 0.5c. The model is a reasonable fit to the XMM-Newton data (χ^2_ν 1.14), which likewise has a 0.5c wind; trying to fit both with the same intrinsic spectrum fails.

Finally, the relativistic disc with relativistic absorption model was tried, first using a truncated accretion disc with an inner edge at 30 gravitational radii (following Middleton et al. 2007). This is a better fit to the Suzaku data than the intrinsic power law model (f-test probability 0.998), and is the best-fitting of all the models tried (χ^2_ν 1.01). Allowing the inner radius to very does not significantly improve the fit. The absorber velocity profile is again extremely high and the absorbing column is pegged at the maximum tabulated value. Using the same model on the XMM-Newton data gives a reasonable fit (χ^2_ν 1.16; n.b. Middleton et al. 2007 use a different reflection code and get a much better fit), trying to fit the XMM-Newton and Suzaku data with consistent disc parameters gives an unrealistically low power law index.

None of the four models tried provide consistently good fits to the Suzaku and XMM-Newton data, and all of them have other problems: black body temperature decreasing with increasing luminosity, changes in strength of components but a constant overall spectrum, or extreme velocities in the absorber and an intrinsic spectrum that is difficult to constrain.

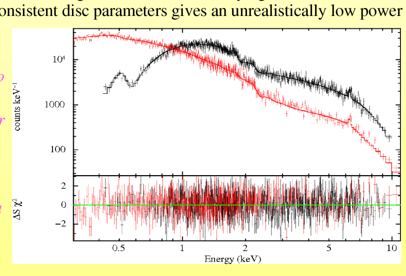

Fig.3: A simultaneous pure reflection fit to the Suzaku (black) and XMM-Newton (red) data. All parameters except the disc illumination profile power law index and the ionization parameter of the disc are the same between the two models.

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