The SWIFT view of PKS0558-504: a highly accreting AGN with a jet

Mario Gliozzi (GMU), Dirk Grupe (PSU), Iossif Papadakis (U. Crete), Lucyna Kedziora-Chudczer (U. Sidney)

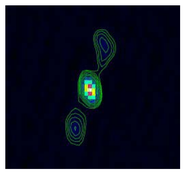
Motivation and Overview

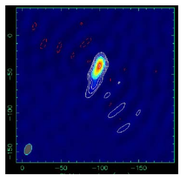
Our main goal is to shed light on the physical conditions (geometry and energetic of the accretion flow) around black holes and specifically on those leading to the formation of relativistic jets in active galactic nuclei (AGN).
To this end, we investigate in detail the multi-wavelength properties of the radio-loud Narrow line Seyfert 1 galaxy (NLS1) PKS 0558-504 (z=0.137), which, we argue, may play the role of an ideal laboratory. In this framework, an **ideal laboratory** should have: (1) a relativistic jet , whose emission does not dominate at higher energies, and (2) accretion properties directly observable (i.e., negligible absorption, not reflection-dominated, bright enough for time-resolved spectroscopy to break the spectral degeneracy).

PKS0558-504 before SWIFT

Radio Observations:

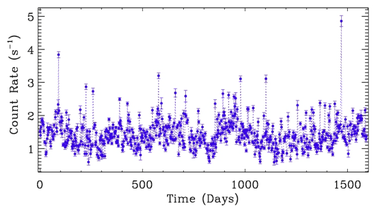
Despite being one of the first radio-loud NLS1 ever detected, the radio properties of PKS0558-504 are poorly known. For this reason, we started an observing program with the ATCA and VLBI. The preliminary main results can be summarized as follows:
(1) On scales of 10"-15" (20-30 kpc), PKS0558-504 shows 2 symmetric lobe-like structures
(left figure below: ATCA, f.o.v. 25"x25", 4.8 GHz).
(2) On milliarcsecond scales (~100 pc), a jet-like structure is resolved by the VLBI
(right figure: f.o.v. 200mas x 200mas, 2.3 GHz).
(3) The radio flux varies by a factor of 2-3 on timescales of several months (no short-term variability detected).

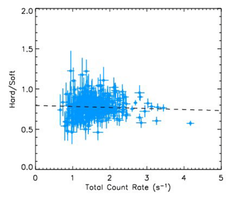




RXTE monitoring:

PKS0558-504 is the only radio-loud NLS1 bright enough to be monitored with RXTE. We have started a regular monitoring campaign (with 1ks observation every 2 days) since March 2005. The 2-15 keV light curve until July 2009 is shown in the left figure below. Interestingly, the frequent large-amplitude changes of flux appear to be achromatic, as revealed by the flat trend shown by the hardness ratio plotted versus the total count rate. This behavior is uncharacteristic for jet-dominated AGN and is reminiscent of GBHs in their intermediate state .



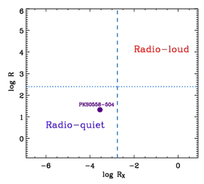


The SWIFT view of PKS0558-504

In September 2008 we started a SWIFT monitoring campaign with the XRT covering the 0.3-10 keV range and 5 UVOT filters probing the optical and UV bands . The first part of this monitoring was contemporaneous to a deep XMM-Newton observation (5 orbits; PI: Papadakis) as well as to a radio observation with ATCA.

Radio Loudness:

The simultaneous radio, optical, and X-ray coverage makes it possible to tightly constrain the radio loudness of the source using both the standard radio loudness parameter, $R=L_\nu(5GHz)/L_\nu(B)$, and the X-ray one, $R_x= \nu L_\nu(5GHz)/L_{2\text{-}10keV}$.
According to both criteria PKS 0558-504 appears to be fully consistent with radio-quiet Seyfert galaxies, as illustrated by the figure on the right, where the boundaries were determined using large samples of Seyfert galaxies and low-luminosity radio galaxies (Panessa et al. 2007).



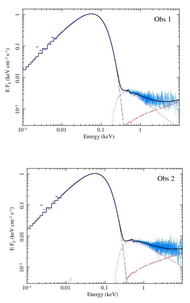
Black Hole Mass:

In order to investigate the energetic of a BH system, it is necessary to know its mass M_{BH}. Using the Kaspi et al. relationship based on the virial theorem, Papadakis et al. (2009) derive M_{BH} ~$6x10^7$ $M_{solar.}$. Assuming this value, the Eddington luminosity for PKS0558-504 is L_{Edd}~$8x10^{45}$ erg/s.

However, given that the optical data (H_β velocity dispersion and L_{510nm}) were not simultaneous and that the application of this secondary method to NLS1 has been questioned on different grounds by Marconi et al. (2008) and Decarli et al. (2009), it is important to constrain M_{BH} with alternative methods. Plugging our simultaneous measurements of L_{radio} and L_x in the equation of the fundamental plane for BH, L_{radio} - L_x - M_{BH} (Merloni et al. 2005), we derive M_{BH} ~$2.5x10^8$ $M_{solar.}$. A similar value is obtained using the GBH scaling relationship proposed by Shaposhnikov & Titarchuk (2009), which makes use of X-ray spectral results. With this second estimate of the BH mass, we obtain L_{Edd}~$3.3x10^{46}$ erg/s.

Energetics:

The simultaneous coverage of the optical and UV bands offered by 5 UVOT filters (range 212-545 nm) and of the X-ray energy band with the XRT allows not only the construction of reliable spectral energy distributions (SEDs) but also the investigation of the SED temporal evolution over different timescales. The overall SEDs are well fitted by a disk model (diskpn in XSPEC), which parameterizes the optical-UV emission and dominates the broadband emission, and by two Comptonization components (BMC in XSPEC) that characterize the 0.3-10 keV energy range. On timescales of days, despite large –amplitude changes of the X-ray flux, the disk component remains roughly constant, as shown by the figures on the right.
Assuming a conservative value of $2.5x10^8$ M_{solar} for M_{BH}, the total luminosity obtained by the integration of the best fit model between 0.001 and 100 keV is L_{bol}~$5.5x10^{46}$ erg/s= $1.7L_{Edd}$, which supports the hypothesis that this source is accreting at super-Eddington rate. More extreme values are obtained assuming $M_{BH}=6x10^7$ M_{solar} ; in that case $L_{bol}>20L_{Edd}$.
In the reasonable hypothesis that the bulk of the bolometric luminosity is associated with the accretion process, $L_{bol}=L_{accr}=\eta\dot{M}_{accr}c^2$ (where η is the radiative efficiency and $\dot{M}_{accr}$ the accretion rate), we derive an accretion rate of the order of 1 solar mass per year. In order to shed further light on the central engine of this powerful BH system, it is instructive to compare the accretion power with the kinetic power of the jet, $L_{kin}=(\Gamma\text{-}1)\dot{M}_{out}c^2$ (where Γ is the bulk Lorentz factor and $\dot{M}_{out}$ the outflow mass rate). An estimate of the kinetic power of the jet can be inferred from the radio core luminosity (Merloni & Heinz 2007). For any reasonable choice of η and Γ we derive $\dot{M}_{accr}>>\dot{M}_{out}$. Interestingly, this result is in full agreement with the findings of Ohsuga et al. (2009) obtained from radiation-MHD simulations of black hole systems in super-Eddington regime.



Conclusions and Future Work

Combining the main findings from our different monitoring programs with ATCA, VLBI, RXTE, XMM-Newton, and SWIFT, we can conclude that:
(1) PKS 0558-504 posses an active jet, whose emission appears to be negligible beyond the radio energy band. The latter conclusion, which is suggested by the radio structure, the low radio-loudness, and the long-term RXTE variability, is further supported by the X-ray spectral variability observed by XMM-Newton which is typical of Seyfert galaxies, and by the lack of detection of PKS0558-504 at γ-ray energies.
(2) The overall optical-UV-X-ray emission appears to be associated to the accretion flow, which is directly observable (XMM-Newton shows no evidence for local absorption nor for a strong reflection component).
(3) Based on the above results, PKS0558-504 fulfills the basic requirements for an ideal laboratory to study the link between accretion and ejection phenomena in BH systems.
(4) There is strong evidence that PKS0558-504 accretes at high (super-Eddington) rate and its long-term behavior and energetics are reminiscent of GBHs in their intermediate state.
(5) The ongoing long-term monitoring with SWIFT (see the figure on the right) will be of crucial importance to investigate the physical link between the fundamental components of the accretion flow.