Black Holes and Quasars

1. Introduction

This report describes the research performed by Brian Punsly and collaborators in cooperation with ICRANet in 2011. There were three lines of research. The first was directed at finding environmental factors that are related to the switch-on of the general relativistic engine responsible for a few percent of quasars driving powerful relativistic jets. This is important since this will related directly to constraints on the initial state and boundary conditions on numerical models of black hole driven jets. The second line of research was the study of 3-D numerical simulations of black hole magnetospheres and how they relate to observations of astrophysical jets. The third area of research is based on using the jet in the Galactic black hole, GRS 1915+105, as a test case for black hole driven jets.

2. AGN Environments and the Launching of Jets

In 2011, the research was concentrated in two areas. Working with Shaohua Zhang, we mined the SDSS DR7 data base and FIRST database to study the relationship between accretion flow luminosity and jet power originally proposed by the classic paper of Rawlings and Sanders (1991). I am also leading collaborations to perform high frequency (high resolution), time resolved VLBA observations of broad absorption line quasars. Broad absorption line engines have weak or no central engine for powerful radio jets with the jets rarely strong enough to make it out of the host galaxy.

2a. Jet Power and Accretion Luminosity in AGN

The article, Punsly, Brian; Zhang, Shaohua, Calibrating Emission Lines as Quasar Bolometers was intended to see if line luminosity can be used to accurately estimate accretion flow luminosity**.**

2a.1 Abstract: Calibrating Emission Lines as Quasar Bolometers:
Historically, emission lines have been considered a valuable tool for estimating the bolometric thermal luminosity of the accretion flow in AGN, L_{bol}. We study the reliability of this method by comparing line strengths to the optical/UV continuum luminosity of SDSS DR7 radio quiet quasars with $0.4<z<0.8$. We find formulae for L_{bol} as a function of single line strengths for the broad components of Hβ and Mg II, as well as the narrow lines of [OIII] and [O II]. We determine the standard errors of the formulae that are fitted to the data. Our new estimators are shown to be more accurate than archival line strength estimations in the literature. It is demonstrated that the broad lines are superior estimators of the continuum luminosity (and L_{bol}) with $H\beta$ being the most reliable. The fidelity of the each of the estimators is determined in the context of the SDSS DR7 radio loud quasars as an illustrative application of our results. In general, individual researchers can use our results as a tool to help decide if a particular line strength provides an adequate estimate of L_{bol} for their purposes. Finally, it is shown that considering all four line strength, simultaneously, can yield information on both L_{bol} and the radio jet power.

The article Punsly, Brian; Zhang, Shaohua, The Jet Power and Emission-line Correlations of Radio-loud Optically Selected Quasars was intended to see if Rawlings and Sanders (1991) were right and use optically selected deep samples to see how strong most quasar jets really are.

2a.2 Abstract The Jet Power and Emission-line Correlations of Radio-loud Optically Selected Quasars:

In this Letter, the properties of the extended radio emission form SDSS DR7 quasars with $0.4<z<0.8$ is studied. This low redshift sample is useful since any corresponding FIRST radio observations are sensitive enough to detect extended flux in even the weakest FR II radio sources. In the sample, 2.7\% of the sources have detectable extended emission on larger than galactic scales ($>$ 20 - 30 kpc). The frequency of quasars with FR II level extended radio emission is $\approx 2.3\%$ and $>0.4\%$ of quasars have FR I level extended radio emission. The lower limit simply reflects the flux density limit of the survey. The distribution of the long term time averaged jet powers of these quasars, $\overline{Q}$, has a broad peak $\sim 3\times 10^{44}$ ergs/sec that turns over below 10^{44} ergs/sec and sources above 10^{45} ergs/sec are extremely rare. It is found that the correlation between the bolometric (total thermal) luminosity of the accretion flow, L_{bol}, and $\overline{Q}$ is not strong. The correlation of $\overline{Q}$ with narrow line luminosity is stronger than the correlation with broad line luminosity and the continuum luminosity. It is therefore concluded that previous interpretations of correlations of $\overline{Q}$ with narrow line strengths in radio galaxies as a direct correlation of jet power and accretion power have been overstated. It is explained why this interpretation mistakenly overlooks the sizeable fraction of sources with weak accretion luminosity and powerful jets discovered by Ogle et al (2006).

2b. VLBA Observations of Sub-Parsec Structure in Mrk 231: Interaction between a Relativistic Jet and a BAL Wind

I am leading an effort to study Mrk 231 at the highest resolution. It is the nearest broad absorption line quasar and we have proven that it conforms with the idea of a polar broad absorption line outflow (instead of the popular notion of an equatorial outflow) that was developed in Punsly (1999a,b). This research and proposal is being done in collaboration with Cormac Reynolds (Curtin University of Technology, Department of Imaging and Applied Physics), Christopher P. O'Dea (Department of Physics, Rochester Institute of Technology) and Joan Wrobel (NRAO, Socorro).

2b.1. Large VLBA Proposal Approved

We have already received re-approval for 2011 for a very aggressive observation this object.

Abstract

We propose VLBA monitoring at 8.4, 15, 22 and 43 GHz of a high frequency flare in the nearby quasar MRK231. The “target of opportunity" observation (ToO) would be triggered by a flare detected by VLA monitoring at 22 and 43 GHz (see related proposal). The primary goals would be to detect a superluminal motion, estimate the internal energy of the flare from the spectrum and component sizes, and monitor the temporal evolution in order to understand the energy injection mechanism (rise) and the cooling mechanism (decay).

Background

From previous VLBA studies of MRK231 in Reynolds et al (2009) and other RQ (radio quiet) quasar studies, we have seen that RQ AGN can have relativistic outflows with significant kinetic luminosities (but maybe for short periods of time). So this raises the question what is it that makes some sources RQ and others radio loud (RL)? At a redshift of 0.042, MRK231 is one of the nearest radio quiet quasars to earth. The radio core is perhaps the brightest of any radio quiet quasar at high frequency (22 and 43 GHz). The combination of significant 43 GHz flux density and its proximity to earth makes MRK231 the optimal radio quiet quasar for study with VLBA. No other radio quiet quasar central engine can be explored with such high resolution, so it is ideal for studying the high kinetic luminosity relativistic ejecta in radio quiet quasars. 43 GHz VLBA observations can fully resolve nuclear structure to within 3.5 x 10^{17} cm. We propose to use sensitive high resolution observations to study the temporal evolution of the size and spectrum of a strong flare in MRK231 in order to shed light on why such strong flares cool off and never link to large scale powerful radio lobes.

2b2. VLBA Observations of Parsec Scale Structure of the "Radio Loud" BALQSO FIRST J1556+3517

I am also leading an effort to study FIRST J1556+3517at the high resolution. It is one of the nearest broad absorption line quasar and we have proven (Ghosh and Punsly 2007) that it conforms with the idea of a polar broad absorption line outflow (instead of the popular notion of an equatorial outflow) that was developed in Punsly (1999a,b). The first epoch observations are complete the second epoch observations are stil in the proposal review cycle..This proposal was done in collaboration with Cormac Reynolds (Curtin University of Technology, Department of Imaging and Applied Physics), and Christopher P. O'Dea (Department of Physics, Rochester Institute of Technology).

ABSTRACT FROM ACCEPTED PROPOSAL: We propose VLBA observations at 1.8, 5, 8.4 and 15 GHz of the Broad Absorption Line Quasar FIRST J1556+3517 ("the first radio loud BALQSO"). The primary goal would be to resolve the flat spectrum radio core for the first time. Determination of the radio jet direction, in consort with the knowledge that the jet is relativistic and viewed in a pole-on orientation and the known PA of the optical continuum polarization tightly restrict the quasar geometry. This will allow us to directly constrain the relative orientations of the "dusty torus" (scattering surface), accretion disk and the broad absorption line outflow. We also propose multiple frequency observations to look for free-free absorption that might arise from the local environment of the accretion disk or the BAL wind gas itself. If the jet is resolved by the VLBA, this observation would be the first data point in a search for component motion. If the jet is not resolved, the incredibly compact nature of the relativistic outflow indicates a severe kinematical environment.

3. 3-D Numerical Simulations of Black Hole Magnetospheres

There were two efforts in this regard. The first showed that simulations of Blandford-Znajek jets were not efficient enough to drive powerful AGN. This initiated a flurry of activity by the

Blandford-Znajek school to rerun simulations with new boundary conditions and initial states to drive up the power. The grandiose claims of needed to evolve the system from a physically plausible initial state needed to be dropped in light of this emergency. The second showed how the results (whether there is an ergospheric disk jet or Blandford-Znajek jet) of all simulations depend on numerical artifacts derived from numerical diffusion induced reconnection.

3a.1. Numerical Simulations and Large Jet Powers.

Abstract from Punsly, B., High Jet Efficiency and Simulations of Black Hole Magnetospheres:

This article reports on a growing body of observational evidence that many powerful lobe dominated (FR II) radio sources likely have jets with high efficiency. This study extends the maximum efficiency line (jet power $\approx$ 25 times the thermal luminosity) defined in Fernandes et (2010) so as to span four decades of jet power. The fact that this line extends over the full span of FR II radio power is a strong indication that this is a fundamental property of jet production that is independent of accretion power. This is a valuable constraint for theorists. For example, the currently popular "no net flux" numerical models of black hole accretion produce jets that are 2 to 3 orders of magnitude too weak to be consistent with sources near maximum efficiency.

3b.1. Numerical Simulations and Reconnection

.Abstract from Punsly, B. Evidence on the Origin of Ergospheric Disk Field Line Topology in Simulations of Black Hole Accretion:

This Letter investigates the origin of the asymmetric magnetic field line geometry in the ergospheric disk (and the corresponding asymmetric powerful jet) in 3-D perfect magnetohydrodynamic (MHD) numerical simulations of a rapidly rotating black hole accretion system reported in \citet{pun10}. Understanding, why and how these unexpected asymmetric structures form is of practical interest because an ergospheric disk jet can boost the black hole driven jet power many-fold possibly resolving a fundamental disconnect between the energy flux estimates of powerful quasar jets and simulated jet power \citep{pun11}. The new 3-D simulations of \citet{bec09} that were run with basically the same code that was used in the simulation discussed in \citet{pun10} describe the "coronal mechanism" of accreting poliodal magnetic flux towards the event horizon. It was determined that reconnection in the inner accretion disk is a "necessary" component for this process. The coronal mechanism seems to naturally explain the asymmetric ergospheric disk field lines that were seen in the simulations. Using examples from the literature, it is discussed how apparently small changes in the reconnection geometry and rates can make enormous changes in the magnetospheric flux distribution and the resultant black hole driven jet power in a numerical simulation. Unfortunately, reconnection is a consequence of numerical diffusion and not a detailed (yet to be fully understood) physical mechanism in the existing suite of perfect MHD based numerical simulations. The implication is that there is presently great uncertainty in the flux distribution of astrophysical black hole magnetospheres and the resultant jet power.

4. GRS 1915+105 as a Laboratory for Studying Black Hole Driven Jets

I am currently embarked on a research program to study the Galactic black hole jet in GRS 1915+105. There is much confusion in this field because it is led by scientist not familiar with the history of astrophysical jets or the theory of black holes. There are three large projects that were developed in 2011 and I glad to report that one is in production.

Abstract from Punsly, B. Models of the compact jet in GRS 1915+105;

In this article, models are constructed of the compact jet in GRS 1915+105 during an epoch of optimal data capture. On April 02, 2003, the object was observed in the hard X-ray/soft gamma ray band (INTEGRAL), hard X-ray band (RXTE), near IR (ESO/New Technology Telescope) and the VLBA (8.3 GHz and 15 GHz). The source was in a so-called "high plateau state." The large radio flux provides high signal to noise ratios in the radio images. Thus, one can image the jet out to large distances ($ > 10^{15}$ cm). This combined with the broadband coverage make this epoch the best suited for modeling the jet. The parametric method developed in the papers \cite{ghi85,ghi89,ghi96,sam97} that has been successfully utilized in the realm of extragalactic radio jets is implemented. The basic model is one where external inverse Compton (EIC) scattering of accretion disk photons by jet plasma provides the hard X-ray powerlaw. Unlike AGN jets, it is found that the radio jet must be highly stratified in the transverse direction in order to produce the observed surface brightness distribution in the radio images. Various jet models are considered. The jet power is $Q \approx 3-4 \times 10^{38}$ ergs/sec if the hard X-ray powerlaw luminosity is from EIC in the jet and $Q \approx 2 - 9 \times 10^{37}$ ergs/sec if the X-rays are emitted from the accretion disk corona. These estimates indicate that the jet power can be as high as 60\% of the total X-ray luminosity.

2011 List of Publication

Punsly, B. High Jet Efficiency and Simulations of Black Hole Magnetospheres, The Astrophysical Journal Letters, Volume 728, L17 (2011).

Punsly, Brian; Zhang, Shaohua Calibrating emission lines as quasar bolometers, Monthly Notices of the Royal Astronomical Society: Letters, Volume 412, pp. L123-L127

Punsly, Brian; Zhang, Shaohua The Jet Power and Emission-line Correlations of Radio-loud Optically Selected Quasars, The Astrophysical Journal Letters, Volume 735, L3 (2011).

Punsly, B. Models of the compact jet in GRS 1915+105 MNRAS in press

Punsly, B. Evidence on the Origin of Ergospheric Disk Field Line Topology in Simulations of Black Hole Accretion MNRAS Letters in press