Brian Punsly

Position: Research Scientist
Period covered: 10/2015-10/2016

I Scientific Work

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Black Holes and Quasars

1. Introduction

This report describes the research performed by Brian Punsly and collaborators in cooperation with ICRANet in 2015-2016. The research 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 relate directly to constraints on the initial state and boundary conditions on numerical models of black hole driven jets.

2. **The Relativistic Jet-Accretion Flow-Wind Connection in Mrk 231**

I led an international effort to study Mrk 231 during a radio flare with the highest resolution radio interformotry and in the X-ray band . This nearby quasar is in the process of transitioning from a radio quiet quasar to a radio loud quasar. A flare was detected during our Arc Minute MicroKelvin array monitoring at 17.6 GHz. This research is being done in collaboration with Cormac Reynolds and Natasha Hurley-Walker (Curtin University of Technology, Department of Imaging and Applied Physics), Christopher P. O'Dea (Department of Physics, Rochester Institute of Technology) and Giovanni Miniutti (Centro de Astrobiología (CSIC–INTA), Dep. de Astrofísica, European Space Astronomy Centre Madrid Spain). The paper has been very favorable reviewed by ApJ and is in the revision stage

ABSTRACT

Long term radio monitoring of the broad absorption line quasar, Mrk\,231, at 17.6 GHz detected a strong flare in 2015. This triggered four epochs of Very Long Baseline Array (VLBA) observations from 8.4 GHz to 43 GHz as well as three epochs of X-ray observations with NuSTAR and two with

XMM over a 15 week period. Two ejected components were detected by the VLBA observations. A conservative lower bound on the apparent speed of the first ejection is attained by assuming that it was ejected when the flare began, v_{app}>3.15c. Serendipitous far UV Hubble Space Telescope observations combined with our long term radio monitoring seem to indicate that episodes of relativistic ejections suppress flux that is emitted at wavelengths shortward of the peak of the far UV spectral energy distribution, similar to what has been observed in radio loud quasars. Episodes of strong jet production also seem to suppress the high ionization broad absorption line wind seen in weak jet states. We found a statistically significant increase (~24%) of the 3-12 keV flux during the radio flare relative to a quiescent radio state. This is explained by an ultra-fast (~0.06$) X-ray absorbing photo-ionized wind that is significantly detected only in the low radio state (similar to Galactic black holes). Mrk~231 is becoming more radio loud. We found that the putative parsec scale radio lobe doubled in brightness in 9 years. Furthermore, large flares are more frequent with 3 major flares occurring at ~2 year intervals..

3. Determining the Location of Relativistic Jet Launching in Quasars

The nature of the causative agent that makes some quasars radio loud (RLQs) has challenged astrophysicists for more than 50 years. It became clear early on that the optical/ultraviolet (UV) spectra of RLQs and radio quiet quasars (RQs) are very similar. Attempts to look for subtle differences involved statistical studies of optical and UV emission line strengths and widths. These emission regions are far from the central engine, many thousand times larger than the central black hole radius, so it is not clear what they tell us as a second order indicator of conditions in the jet launching region. Are they related to the fueling mechanism for radio loudness, the ionization continuum or jet propagation? Consequently, this research path has provided very little understanding of the jet launching mechanism. Seemingly more relevant to the physics of jet launching, the extreme ultraviolet (EUV) continuum, wavelength less than 1100 Angstroms, is created orders of magnitude closer to the central engine and RLQs display significant EUV continuum deficit relative to RQs. We have explored this in a series of new ApJ and MNRAS articles.

3A. The extreme ultraviolet spectra of low-redshift radio-loud quasars

This research was an attempt to see if the long term time averaged affect described above was evident in the time evolution of an individual radio loud quasar. The collaboration included the efforts from Cormac Reynolds (Curtin University of Technology, Department of Imaging and Applied Physics), Christopher P. O'Dea (Department of Physics and Astronomy, University of Manitoba, Winnipeg, MB R3T 2N2 Canada, Paola Marziani (INAF, Osservatorio Astronomico di Padova, Italia),

ABSTRACT:

This paper reports on the extreme ultraviolet (EUV) spectrum of three low redshift (z ~ 0.6) radio loud quasars, 3C 95, 3C 57 and PKS 0405-123. The spectra were obtained with the Cosmic Origins Spectrograph (COS) of the Hubble Space Telescope. These are all high Eddington ratio quasars. The bolometric thermal emission, L_{bol}, associated with the accretion flow is estimated to be at least the Eddington limit for PKS 0405-123 and just below the Eddington limit for 3C 57. 3C 95 also has a large Eddington ratio, ~40\% We estimate the long term time averaged jet power, Q, for the three

sources. Q/, L_{bol} is shown to lie along the correlation of Q/, L_{bol} and α_{EUV} found in previous studies of the EUV continuum of intermediate and high redshift quasars, where the EUV continuum flux density between 1100 Å and 700 Å is defined by $F_{\upsilon} \sim \upsilon^{-\alpha EUV}$. The high Eddington ratios of the three quasars extends the analysis into a wider parameter space. Selecting quasars with high Eddington ratios has accentuated the statistical significance of the partial correlation analysis of the data. Namely. the correlation of Q/, L_{bol} and α_{EUV} is fundamental and the correlation of Q/ and α_{EUV} is spurious at a very high statistical significance level (99.8\%). This supports the regulating role of ram pressure of the accretion flow in magnetically arrested accretion models of jet production. In the process of this study, we use multi-frequency and multi-resolution. Very Large Array radio observations to determine that one of the bipolar jets in 3C 57 is likely frustrated by galactic gas that keeps the jet from propagating outside the host galaxy

3B. The Extreme Ultraviolet Variability of Quasars

This research was an attempt to see if the long term time averaged affect described above was evident in the time evolution of an individual radio loud quasar. The collaboration included the efforts from Christopher P. O'Dea (Department of Physics and Astronomy, University of Manitoba, Winnipeg, MB R3T 2N2 Canada, Paola Marziani (INAF, Osservatorio Astronomico di Padova, Italia), Shaohua Zhang Antarctic Astronomy Division Polar Research Institute of China 451, Jinqiao Rd., Shanghai, China and Sowgat Muzahid The Pennsylvania State University, State College, PA 16802 , USA.

ABSTRACT:

We study the extreme ultraviolet (EUV) variability (rest frame wavelengths 500 - 920 Å) of high luminosity quasars using HST (low to intermediate redshift sample) and SDSS (high redshift sample) archives. The combined HST and SDSS data indicates a much more pronounced variability when the sampling time between observations in the quasar rest frame is 2×10^7 sec compared to $< 1.5 \times 10^7$ sec. Based on an excess variance analysis, for time intervals $< 2 \times 10^7$ sec in the quasar rest frame, 10\% of the quasars (4/40) show evidence of EUV variability. Similarly, for time intervals $>2 \times 10^7$ sec in the quasar rest frame, 55\% of the quasars (21/38) show evidence of EUV variability. The propensity for variability does not show any statistically significant change between 2.5×10^7 sec and 3.16×10^7 sec (1 yr). The temporal behavior is one of a threshold time interval for significant variability as opposed to a gradual increase on these time scales. A threshold time scale can indicate a characteristic spatial dimension of the EUV region. We explore this concept in the context of the slim disk models of accretion. We find that for rapidly spinning black holes, the radial infall time to the plunge region of the optically thin surface layer of the slim disk that is responsible for the preponderance of the EUV flux emission (primarily within 0 - 7 black hole radii from the inner edge of the disk) is consistent with the empirically determined variability time scale.

3C. The The Detection of Diffuse Extended Structure in 3C273: Implications for Jet Power.

This work was performed with Preeti Kharb (Indian Institute of Astrophysics, II Block, Koramangala, Bangalore).

ABSTRACT: We present deep Very Large Array imaging of 3C 273 in order to determine the diffuse, large scale radio structure of this famous radio-loud quasar. Diffuse extended structure (radio lobes) is detected for the first time in these observations as a consequence of high dynamic range in the 327.5 and 1365 MHz images. This emission is used to estimate a time averaged jet power, 7.2 x 10^{43} ergs/s < Q < 3.7 x 10^{44} ergs/s. Brightness temperature arguments indicate consistent values of the time variability Doppler factor and the compactness Doppler factor for the inner jet, $\delta > 10$. Thus, the large apparent broadband bolometric luminosity of the jet, ~3 x 10^{46} ergs/s, corresponds to a modest intrinsic , ~3 x 10^{42} ergs/s or ~ 1\% of Q. In summary, we find that 3C 273 is actually a ``typical" radio loud quasar contrary to suggestions in the literature. The modest Q is near the peak of the luminosity distribution for radio loud quasars and it is consistent with the current rate of dissipation emitted from millimeter wavelengths to gamma rays. The extreme core-jet morphology is an illusion from a near pole-on line of sight to a highly relativistic jet that produces a Doppler enhanced glow that previously swamped the lobe emission. 3C 273 apparently has the intrinsic kpc scale morphology of a classical double radio source, but it is distorted by an extreme Doppler aberration.

4. Jets from Stellar Mass Black Holes

4A. A Temporal Analysis Indicates a Mildly Relativistic Compact Jet in GRS 1915+105

This continues a line of research with Jerome Rodriguez Laboratoire AIM, CEA/DRF-CNRS-Universit\'{e} Paris Diderot, IRFU SAp, F-91191 Gif-sur-Yvette, France

ABSTRACT:

Most of our knowledge of the radio morphology and kinematics of X-ray binary partially synchrotron self-absorbed compact jets (hereafter compact jets) is based on the observations of GRS~1915+105 which has the most prominent compact jet. Yet, the compact jet bulk velocity, v, is poorly constrained in the literature, 0.07 < v/c < 0.98. In spite of this uncertainty, compact jets are often unified with relativistic jets in active galactic nuclei. We have estimated v as part of a temporal analysis of GRS~1915+105 jets in ``high plateau states" (HPS). We define the HPS as a state showing a hard X-ray spectrum and low level of long-term (>10s) X-ray activity associated with 15 GHz flux density >70 mJy for >7 consecutive days. The radio emission is associated with compact jet emission. Two HPS were monitored at 15 GHz during their termination with e-folding times of 3.8 hrs and 8.6 hrs. We combine this time scale with the scale of spatial variation of the linear source of a VLBA image preceding the fade of one of these HPS in order to estimate the jet speed. Our assumption that the reduction in radio emissivity propagates as an approximate discontinuity down the HPS jet (leaving a weak jet in its wake) indicates 0.17 <v/c< 0.43. This agrees closely with the only other existing v estimates that are derived directly from radio images, jet asymmetry produced by Doppler enhancement.

4A. A Temporal Analysis Indicates a Mildly Relativistic Compact Jet in GRS 1915+105

This continues a line of research with Jerome Rodriguez Laboratoire AIM, CEA/DRF-CNRS-Universit\'{e} Paris Diderot, IRFU SAp, F-91191 Gif-sur-Yvette, France and Sergei A. Trushkin Special Astrophysical Observatory RAS, Nizhnij Arkhyz, 369167, Russia and Kazan FederalUniversity, Kazan, 420008 Russia

ABSTRACT:

The microquasar GRS~1915+105 is known for its spectacular discrete ejections. They occur unexpectedly, thus their inception escapes direct observation. It has been shown that the X-ray flux increases in the hours leading up to a major ejection. In this article, we consider the serendipitous interferometric monitoring of a modest version of a discrete ejection described in Reid et al. (2014) that would have otherwise escaped detection in daily radio light curves. The observation begins ~1 hour after the onset of the ejection, providing unprecedented accuracy on the estimate of the ejection time. The astrometric measurements allow us to determine the time of ejection as MJD $56436.274^{+0.016}_{-0.013}$ i.e., within a precision of 41 minutes (95 % confidence). Just like larger flares, we find that the X-ray luminosity increases in last 2 - 4 hours preceding ejection. Our finite temporal resolution indicates that this elevated X-ray flux persists within$21.8^{+22.6}_{-19.1}$ minutes of the ejection with 95% confidence, the highest temporal precision of the X-ray - superluminal ejection connection to date. This observation provides direct evidence that the physics that launches major flares occurs on smaller scales as well (lower radio flux and shorter ejection episodes). The observation of a X-ray spike prior to a discrete ejection, although of very modest amplitude suggests that the process linking accretion behavior to ejection is general from the smallest scales to high luminosity major superluminal flares.

4C. General Relativistic Considerations of the Field Shedding Model of Fast Radio Bursts

Performed with ICRANet colleague Donato Bini.

ABSTRACT:

Popular models of fast radio bursts (FRBs) involve the gravitational collapse of neutron star progenitors to black holes. It has been proposed that the shedding of the strong neutron star magnetic field (B) during the collapse is the power source for the radio emission. Previously, these models have utilized the simplicity of the Schwarzschild metric which has the restriction that the magnetic flux is magnetic ``hair'' that must be shed before final collapse. But, neutron stars have angular momentum and charge and a fully relativistic Kerr Newman solution exists in which B has its source inside of the event horizon. In this letter, we consider the magnetic flux to be shed as a consequence of the electric discharge of a metastable collapsed state of a Kerr Newman black hole. It has also been argued that the shedding model will not operate due to pair creation. By considering the pulsar death line, we find that for a neutron star with $B = 10^{11}$ - 10^{13} G and a long rotation period, >1 s this is not a concern. We also discuss the observational evidence supporting the plausibility of magnetic flux shedding models of FRBs that are spawned from rapidly rotating progenitors.

5. Numerical Simulations of Black Hole Magnetosphere.

This line of research is designed to help reform the current numerical movement in numerical work. It was performed with the Notre Dame University numerical team, Dinshaw Balsara, Jinho Kimand Sudip Garain

5A**. Riemann solvers and Alfven waves in black hole magnetospheres**.

ABSTRACT:

In the magnetosphere of a rotating black hole, an inner Alfven critical surface (IACS) must be crossed by inflowing plasma. Inside the IACS, Alfven waves are inward directed toward the black hole. The majority of the proper volume of the active region of spacetime (the ergosphere) is inside of the IACS. The charge and the totally transverse momentum flux (the momentum flux transverse to both the wave normal and the unperturbed magnetic field) are both determined exclusively by the Alfven polarization. Thus, it is important for numerical simulations of black hole magnetospheres to minimize the dissipation of Alfven waves. Elements of the dissipated wave emerge in adjacent cells regardless of the IACS, there is no mechanism to prevent Alfvenic information from crossing outward. Thus, numerical dissipation can affect how simulated magnetospheres attain the substantial Goldreich-Julian charge density associated with the rotating magnetic field. In order to help minimize dissipation of Alfven waves in relativistic numerical simulations we have formulated a one-dimensional Riemann solver, called HLLI, which incorporates the Alfven discontinuity and the contact discontinuity. We have also formulated a multidimensional Riemann solver, called MuSIC, that enables low dissipation propagation of Alfven waves in multiple dimensions. The importance of higher order schemes in lowering the numerical dissipation of Alfven waves is also catalogued.

2016 List of Publication

Punsly, Brian; Rodriguez, Jérôme A Temporal Analysis Indicates a Mildly Relativistic Compact Jet in GRS 1915+105 2016 ApJ 833 54

Punsly, Brian; Bini, Donato, General relativistic considerations of the field shedding model of fast radio bursts 2016 MNRAS Lett. 41

Punsly, Brian; Rodriguez, Jérôme; Trushkin, Sergei A.., The Accretion Flow-Discrete Ejection Connection in GRS 1915+105 2016 ApJ 826 5

Punsly, Brian; Reynolds, Cormac; Marziani, Paola; O'Dea, Christopher P., The extreme ultraviolet spectra of low-redshift radio-loud quasars 2016 MNRAS 459 4233

Punsly, Brian; Marziani, Paola; Zhang, Shaohua; Muzahid, Sowgat; O'Dea, Christopher P., The Extreme Ultraviolet Variability of Quasars 2016 ApJ http://dx.doi.org/10.3847/0004-637X/830/2/104

Punsly, Brian; Balsara, Dinshaw; Kim, Jinho; Garain, Sudip, Riemann solvers and Alfven waves in black hole magnetospheres. 2016 Computational Astrophysics and Cosmology, 3, 5

Punsly, Brian; Kharb, Preeti.. The Detection of Diffuse Extended Structure in 3C~273: Implications for Jet Power 2016 ApJ in press