Black Hole Accretion and X-Ray Variability in AGN

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ABSTRACT

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Active Galactic Nuclei (AGN) have very luminous centers which are so bright that the surrounding stars can not adequately account for the energy emission of AGN. One of the most accepted explanations for this energy release is black hole accretion. These black holes accrete near by gas and dust, and as a result gravitational potential is converted to energy which is released. In order to probe the accretion mechanism which lies close to the black hole, short time scale X-ray variability is analyzed. The very short time scale variability will increase understanding of the processes that occur in the heart of galaxies. Data from the ASCA X-ray telescope was reduced and analyzed using the programs FTOOLS, XSELCT, and ASCASCREEN. Light curves and event lists were generated for long term observations of different AGN which were sent to collaborators for further analysis using the event time arrivals. The analysis will compare accretion and jet dominated AGN and will provide use with an understanding of how short scale time variability can relate to the mechanism very close to black holes buried within AGN.

Introduction

Galaxies such as Active Galactic Nuclei (AGN) are characterized by a very bright core, where the total radiation flux greatly exceeds that which can be credited or explained by the total sum of stars in the galaxy [2]. The light from these very luminous objects can be observed in practically all bands of spectra. High Eddington Luminosity of AGN strongly suggests very massive cores within the heart of AGN with a mass greater than a million times more than of the sun. Eddington Luminosity is attributed to the Eddington Limit which sets a minimum mass M for the luminosity L of a celestial object [3]. This limit is due to the opposing forces that are attributed to the radiation pressure of Thomson Scattering and Gravity (fig. 1). Radiation pressure is given by $\frac{dp}{dtc} = \frac{\Phi}{c}$, where

c is the Thomson cross-sectional area and $\Phi = \frac{L}{4\pi R^2}$ is the radiation flux. The distance

R is determined as a function of red shift. The force due to the Thomson Scattering is

then $\frac{dp}{dt} = \frac{cL}{4\pi cR^2}$. Balancing the radiation force and the gravitational force $\frac{dp}{dt} = \frac{GMm_p}{R^2}$

and solving for luminosity, L gives the Eddington Limit $L \leq \frac{4\pi Gm_p cM}{\sigma} = 1.3 \times 10^{38} \frac{M}{M_\odot}$

where m_p is proton mass, c is speed of light in a vacuum, $M_\odot$ is solar mass, and G is the gravitational constant. Essentially this means that for a given source luminosity L the mass has to be at least M . The luminosities of these AGN are so intense that even the

case where $\frac{L}{L_E} = 1$ implies extremely large masses.

Along with very bright spectra, AGN spectra also have characteristic short time scale variability [4]. Variability refers to changing amounts of photon counts as a function of time. The variability of a source can be probed to determine a limit of geometrical size, because the event time interval Δt between two corresponding events on the light curve can be associated with the same cause for the event and therefore the same time signature (fig. 2). From this time scale in variability a limit for the distance across the source can be established, $D = c\Delta t$. Some AGN show time scale variability of approximately 1 hour, which is comparable to the size of the solar system. The relatively small size and very large masses of AGN suggests a source mass which has geometrical dimensions that lie within the Schwarzschild radius. This indicates nuclei that contain a source which is a black hole.

The energy that comes from the center of AGN is possibly converted from the gravitational energy of nearby gas that falls onto the black hole. This process of mass accretion of black holes is not completely understood, but probing this property of variability will possibly shed light on the physics that is responsible for the release of

gravitational potential by the matter falling onto the black holes in AGN and further our understanding of the subject. The most defined and rapid variability is from X-ray spectra from the source. These X-rays could also originate from relativistic electron jets were the jet is oriented in a way that the observer is looking down the jet. This analysis will identify and explain accretion and jet beaming of AGN.

The data that is used for this analysis is from the joint US and Japanese X-ray satellite mission, ASCA, which operated in the 1990s. The data used from the NASA ASCA archive was from long observations of several selected AGN by the two Gas Imaging Spectrometers (GIS) on board ASCA at high bit rate. Background signals from several constant sources were also taken for comparison. The primary computer resources used for creating event files for the analysis were computers running at SLAC on the Linux environment and using data analysis tools prepared by the NASA Archive Center. In particular, we used tools available in the software suite known as ftools: the programs were ascascreen and xselect. Time series from the data were extracted, and prepared for further time series analysis, which initially was going to be a variant of Fourier series. In particular, we were searching for the relationship between Fourier amplitudes and Fourier frequencies, which in turn should have characterized the means by which black holes accrete the material from their environment. Due to the high uncertainty and bad sampling data this Fourier method could not be used, therefore an alternative approach is used that uses photon arrival times to explain black hole accretion, formation, and powerful jet emission that are known to accompany AGN.

ASCA X-ray Satellite Mission

Data for analysis was taken from the NASA Heasarc website [1] which contains data archives from the ASCA satellite mission. ASCA was a Japanese cosmic X-ray telescope mission with heavy collaboration and joint observation from the US. After its launch on February 20, 1993 ASCA was operational for approximately 89 months. The satellite lost attitude control on July 14, 2000 ending its operation. The first ten months of operation after launch consisted of instrument calibrations and performance verification, and in December of 1993 ASCA started its scheduled observations. The first phases of the mission were dedicated to short term observation of sources, but the observations that were of most interest to this analysis were the long term observation conducted at the end of its mission.

The ASCA satellite contained four X-ray sensors: two Gas Imaging Spectrometers (GIS) and two Solid-state Imaging Spectrometers (SIS). Data in this analysis was only taken from the GIS sensors, because of the superior time resolution over the SIS. This lack of time resolution is contributed from the SIS use of CCD which gives the SIS exceptional intensity and positioning accuracy. On the other hand gas scintillation method of GIS has very accurate timing measurements. Of course event arrival time information is more important when doing arrival time analysis. The GIS housing is composed of a magnesium alloy and contains the gas chamber, position sensitive phototube (PSPT), electronics and the detector power supply. The housing is 580 mm with a diameter of 140 mm. Photon detection occurs in the gas chamber, which is divided into two separate sub chambers (fig. 3). At the front of the gas chamber is a focusing mirror that refines the incoming signal into a more concentrated beam of X-rays.

The cosmic rays enter the gas chamber through a thin 10 μm Beryllium window with a -8000 V electrical potential. The first section which is the drift chamber contains a 90% Xenon 10% Helium gas mixture. Photons passing through the drift chamber are incident on the Xenon particles causing ionization of the Xenon. The photoelectrons produced by this ionization drifts into the scintillation chamber which is separated from the drift chamber by an electrode mesh that has a voltage of -7,000V. The scintillation chamber contains a strong electric field that is parallel to the Beryllium entrance window. The photoelectrons are accelerated by this potential enough to excite the xenon but not enough to ionize it. When the excited Xenon relaxes UV rays are emitted and pass through the ground mesh and then pass through a quartz window into the chamber that houses the Position Sensitive Photo Tube (PSPT). The PSPT measures the UV ray positions and the energies which are proportional to the initial corresponding X-rays. The PSPT contains 10 parallel dynodes which consist of triangular mesh layers; each successive dynode is rotated 90° to insure a straight electron trajectory to the anode. The anode is made of 32 wires for position detection 16 for each the X and Y direction.

Fig. 3

A large amount of background radiation is a problem that vexes all experiments that venture outside of the earth's protective atmosphere. To reduce solar background the detection unit is shielded by a hood that is located around the entrance area of the detector. During unusually high peaks of radiation the Radiation Burst Monitor temporarily shuts down the high voltage supply of the GIS until the radiation levels subside. The rejection for more nominal radiation background is done by the CPU in the GIS. Upper and Lower discriminators are set from the radiation monitoring system. The CPU will reject events that are outside of the radiation limits, therefore removing most of the background. Other factors to consider that contribute to the background radiation are the South Atlantic Anomaly (SAA) and Geomagnetic Rigidity. There is a high level of electro magnetic background during the passage over the SAA region; GIS passes through the SAA during 9 of its 15 orbits a day. To avoid high levels of background from SAA the GIS turns off until after passage and all the background radiation levels diminish; GIS is inoperable for 15-30 minutes per orbit due to SAA. Background can also escalate when Geomagnetic Cut off Rigidity is low. During low Cut off Rigidity the GIS remains operable. In the event of extremely low Cut off Rigidity data taken from GIS should not be used for analysis. Observations at small angle elevations will be contaminated by interference of the earth's atmosphere; this effect can be eliminated by avoiding elevation in $0-5^\circ$. Most observation will also be inhibited by earth occultation or shadowing; this will cause gaps in the observation data. Earth occultations will not occur for observation done at declination $\pm 58.5^\circ$ every 56.5 days for a 10 day period.

Data Analysis

Data for variability analysis and background calibration were downloaded via FTP from the Heasarc website. The variable AGN observed are the accretion dominated AGN NGC 4151 and the jet dominated AGN MKN 421, and MKN 501. Constant background sources analyzed were Abell 2199, 496, and 665. The event files were downloaded in TAR files that were contained in ZIP files. Using the UNIX machines on the Noric cluster at SLAC the downloaded source files were un-tarred and un-zipped. The event files for both GIS1 and GIS2 detectors were extracted from the resulting files using ftools with ascascreen and were processed at high bit rate. These files include time stamps and energies for each event. The events files occasionally have gaps in them due to SAA and Earth Occultation; these gaps can be seen on the histograms of X-ray emission of the sources (fig. 4). Using ftools the event lists were made into text files and sent to collaborators for further analysis. This analysis will provide information on how jet driven short scale variability compares with the short time scale variability of accretion dominated AGN.

Data

Constant Source Abell 2199, GIS_1

Constant Source Abell 2199, GIS_2

Constant Source Abell 496, GIS_1

Constant Source Abell 496, GIS_2

Constant Source Abell 665, GIS_1

vollrath 9-Aug-2004 15:29

Constant Source Abell 665, GIS_2

vollrath 9-Aug-2004 14:19

Variable Source MKN 421, GIS_1

vollrath 1-Jul-2004 11:10

Variable Source MKN 421, GIS_3

vollrath 9-Aug-2004 14:24

Variable Source MKN 501, GIS_1

vollrath 9-Aug-2004 14:25

Variable Source MKN 501, GIS_2

vollrath 9-Aug-2004 13:56

Variable Source NGC 4151, GIS_1

vollrath 9-Aug-2004 14:00

Variable Source NGC 4151, GIS_2

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Reference:

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