Studies on Long Term Variability of Active Galactic Nuclei and O VI Absorption in the Interstellar Medium

Abstract

Active Galactic Nuclei (AGN) are among the most fascinating objects in the universe. Nowadays it is strongly believed that a Supermassive Black Hole (SMBH) exists at the centre of every galaxy. If the accumulation of matter by the SMBH, a process termed as accretion, is large enough that the emitted radiation dominates the luminosity output of the entire galaxy, then these objects are referred to as active galactic nuclei. AGNs emit enormous luminosities ranging from $\sim 10^{42}$ to $\sim 10^{48}$ erg s^{-1} from extremely compact volumes.

In terms of luminosity, AGNs are very high and steady sources in the Universe. It is found that the nuclei of some nearby galaxies emit about 10^{40} erg s^{-1} (1 erg = 0.1μ J) whereas distant quasars emit more than 10^{47} erg s^{-1}. The emission is spread widely across the electromagnetic spectrum, often peaking in the UV, but with significant luminosity in the X-ray and the infrared bands. The power output of AGN is often variable on the time scales of years and sometimes on time scales of days, hours or even minutes.

AGNs have been classified in many ways. Two important classes are the Seyfert Galaxies, which have modest luminosities and the Quasars, which are more luminous than the host galaxy.

X-ray emission is a common property of active galaxies. X-ray spectra of a typical AGN in the 2-10 keV range show primarily the signature of a power-law continuum and an iron line. At energies < 2 keV there is often a soft excess over the power-law emission. The power-law emission is widely considered as the outcome of inverse Compton scattering of thermally produced accretion disk seed photons (optical/UV) by a corona of hot electrons close to the disc.

The origin of X-rays from close to the central black hole means that X-ray data offer a chance to study the immediate environs of SMBH and the poorly understood accretion process that fuels them. Since the X-ray emission region is too small to image with current instrumentation, X-ray variability studies, timing

and spectral analysis offer best ways to probe these regions indirectly.

AGNs are variable in all the wavelengths and time-scales. We can observe the variability in two dimensions — amplitude variability and time-scale variability. The amplitude of variability can be considered as a tool to know the relative importance of variability. Amplitude of variability suggests how much the emission from the varying region varies and/or what fraction of the output is contributed by the varying region. The timescale of variability gives information about the rate at which the region varies. X-ray variability is one of the most promising techniques used to derive the properties of the core and to provide constraints on physical models.

To study the nature of AGN, X-ray spectral and temporal data are found to be most important tools. The X-ray spectra bear signatures thought to arise from close to the central object.

It is clear that high-resolution X-ray spectroscopy provides an important workbench for the study of the AGN. The current and past X-ray satellites provide accurate estimates of spectral variability, Fe k line, time lag, soft excess emission etc., which are useful to determine the physics near the SMBH of an AGN. However, a systematic and long term spectral variability study for individual AGN is limited in number. Keeping these issues into consideration, this thesis aims to focus on the properties of AGN in the X-ray regime with the help of variability studies to probe the innermost regions of the black hole and to understand the physical processes that modulate the emission of X-rays.

This thesis aims to study the variability of AGN particularly long term variability of highly variable Narrow Line Seyfert 1 (NLS1) galaxy.

It is known that interstellar gas is the building material for stars. This interstellar gas is also the storehouse of the energy and mass ejected by the stars. In the star formation process, magnetic field plays an important role. Dust is another important component of interstellar medium (ISM) which acts as catalyst for the formation of hydrogen molecules and also for other chemical reactions. All these activities make the ISM a very complex system.

Highly ionized gas spanning the temperature range 10^5 to 10^7 K are important constituents of Interstellar Medium (ISM). In UV, the ions Si IV, C IV, N V and O VI show strong transitions from their ground states. The absorption features caused by these highly ionized atom in the spectra of background stars, is an important tools to study the hot gas of the ISM.

O VI ion is very useful in studying the warm-hot interface gas in the ISM. O VI which is five times ionized oxygen has two strong resonance absorption lines at (1032 Å, and 1038 Å) with oscillator strengths of 0.133 and 0.066 respectively. As the energy needed to ionize O V is 113.9 eV, it is likely that collisional ionization is the main source of O VI. The degree of ionization together with the measured line width of this ion imply a temperature of a few 10^5 K. This temperature is found at the interface of hot (T> 10^6 K) and warm (T $\sim 10^4$ K) ionized gas in the ISM. Again high abundance of oxygen makes this ion special for the study of hot gas of the Milky Way and other nearby galaxies.

In this thesis along with the variability study of AGN I also study the hot ISM of the Milky Way. We present measurements of the distribution of hot gas in the local interstellar medium as a result of a search for O VI absorption in the UV spectra of 70 stars.

In Chapter 1, we present a general introduction to active galactic nuclei and the Interstellar Medium. It includes different classes, unified model, accretion process of AGN. A description of different phases and composition of ISM is also given in this chapter. Review of literature along with contemporary research has been included here.

Chapter 2 describes the two telescopes from which the data are used in this work. For AGN study, I have used *XMM-Newton* observatory. I discuss features of instruments and detectors used in *XMM-Newton* in this chapter. I have also used Far Ultraviolet Spectroscopic Explorer (*FUSE*) data for the study O VI in the Milky Way. *FUSE* provides high-resolution spectra in the wavelength regime between 905 Å and 1187 Å which is the first instrument with sufficient sensitivity and spectral resolution to observe O VI absorption using large numbers of extragalactic objects as background targets. A description of this is also included in the chapter.

A description of X-ray variability studies is given in Chapter 3. In this studies I have considered two NLS1 galaxies - MRK 335 and Ark 564. I describe the observations and data reduction process in this chapter. I have studied the X-ray power law photon index and luminosity relation of the two NLS1 galaxies using flux-resolved spectroscopy. I discuss the phenomenological model and flux-resolved spectroscopy of the two sources in this chapter. I find important results from this study which is discussed here.

Chapter 4 describes the study of absorption spectra of some extragalactic stars observed by *FUSE*. I have considered 70 different lines of sight for stars in the Large Magellanic Cloud (LMC) for this study. These stars are mostly early O and B type stars with several Wolf-Rayets. I have used the apparent optical depth technique to measure the equivalent width and column density of the O VI absorption. I have derived O VI equivalent width and column density for all line of sight stars which are included here. I have also studied the distribution of O VI from the Galactic plane by measuring scale height. I have studied O VI column density variation with respect to the angular scale. Doppler parameter have also been derived in this chapter.

I present the conclusions in the Chapter 5. In the variability study, I confirmed that for both objects the power law index correlates with the X-ray luminosity. I have found that the accretion geometry of MRK 335 may be changing during the time of observation. I also found that the O VI column density variation in the Milky Way is higher but scale height is comparable to the earlier reported value. I have measured O VI column density variation in a much smaller scale than earlier reports. These interesting results of this studies definitely motivate us to extend this work in future. Specially a lot of work is possible to explore the the hot ionizing gas using both UV and X-ray data.

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