1.4.8 Variability

Finally, the radiation from active galaxies is known to vary in brightness over time, and this feature was key to the development of the theory of AGN structure as well as allowing for the detection of AGN activity in a given galaxy. AGN variability is one of the major features of AGN activity studied in this thesis and is expanded upon in the following section (Section 1.5).

1.5 Variability

A key feature of the broad-band emission from AGN is that it is not static, but varies in flux in every wavelength in which it has been observed (e.g., Fitch et al. 1967; Sánchez et al. 2017). This variability has been studied in detail since their discovery (e.g., Smith & Hoffleit 1963), and has been found to be aperiodic in nature. Hypotheses into the origin of variability point to stochastic processes within the AGN itself, with UV and optical variability originating from instabilities in the accretion disk, which has a knock on effect causing irregularities in the X-ray output of the corona as well as IR emission in the dusty torus. Variability in radio and gamma-rays however, likely arise from jet-related processes as well as uneven seed photons production from the accretion disk (Netzer 2013; Bianchi et al. 2022).

Despite the high power output and range of emission wavelengths AGN produce, the small physical size of an active galaxy's central engine means that accretion and emission occurs on scales many orders of magnitude smaller than that of the host galaxy. Consequently, resolving the central nucleus is simply not feasible for galaxies outside our local neighbourhood (e.g., Padovani et al. 2017) making AGN difficult to study. The difficulty in unpicking AGN emission from that of its host galaxy also poses a significant barrier in understanding the structures present within an AGN, and the impacts of the accretion process on the surrounding region (Grogin et al. 2005; Gabor et al. 2009; Pierce et al. 2010; Fan et al. 2014). As such, AGN variability is an important tool in the study of active galaxies, as variability observations are limited by light-travel times, allowing for small scales to be indirectly probed.

Since the speed of light in a vacuum is a known physical quantity, the timescale that AGN variability takes place on can be used to characterise the emitting region of the system. Such variability studies have produce key pieces of evidence for AGN emission theories, such as mass and radius estimates favouring black holes over other object as the nuclear body in the emission process (Green et al., 1993). Variability timescales have also been found to increase with wavelength, for example, emission at higher frequencies, such as X-rays, vary within hours, while UV and optical variations take days to weeks. The longer wavelengths, such as infrared (IR), typically vary on timescales of months or years (e.g., Berk et al. 2004). Since this variability is coupled to structures within the AGN itself, it allows for the study of AGN on the relatively tiny scales they span compared to the size of a galaxy.

Infrared variability is uniquely useful in the study of AGN, as IR measurements probe the dusty torus-like structure on the edges of the AGN system as material from it feeds the accretion disk as well as being able to probe dusty galaxies and rest-frame optical emission for galaxies at higher redshift. Unfortunately, the timescale of variability in the IR is several months to years, and this time cost has limited the research in this regime compared to variability in higher frequency wavebands. The Ultra Deep Survey (UDS, Chapter 2), however, provides a solution to the obstacles preventing IR variability studies, as it has 8 years of deep, near-IR imaging. The $\sim 1\text{deg}^2$ imaging has collected the time-intensive data required for significant IR variability to be observed and these deep observations provide the perfect dataset for the study of infrared variability in active galaxies.

AGN emission is invoked across many aspects of galaxy evolution to help explain observed phenomena, but this activity, and the underlying mechanisms that drive it, is still not fully understood. As a result, despite many theories within the literature, there is no firm consensus on the potential trigger (or triggers) that activates an AGN. Furthermore, we are currently unable to observe any given galaxy and know with certainty how and why it is, has been, or will become, active in its lifetime. In order to determine robust answers for these questions, a complete census of active galaxies in the Universe is necessary to allow for the study of the cosmic evolution of AGN and a complete understanding of the active galaxy system in of itself must be known.