WHERE IN AGN DOES THE NARROW FE Kα EMISSION LINE ORIGINATE?

1 Abstract

Determining the origin of the narrow Fe Kα emission in Active Galactic Nuclei (AGN) is difficult to determine. Challenges occur when distinguishing whether these emissions in AGN arise from the torus, parsecs of dense dust and gas surrounding its central structures, or from the broad line region (BLR), more central than the torus, comprised of high-velocity gas that produces broad emission lines. Both regions can show characteristic Fe Kα emission lines that are produced by emitting X-rays. We propose to observe Seyfert 1 galaxy NGC 3783, known for strong emission, with XRISM to further analyse the origin of its narrow Fe Kα emission line. XRISM's high spectral resolution at the 6 keV region will allow for detailed measurements of this emission.

2 Scientific Justification

Active Galactic Nuclei, referred to as AGN, are galaxies with active supermassive blackholes (SMBHs) found in their center. These blackholes emit dust and gas from X-rays to radio waves, contrasting the inactive ones who are undetected non-emitters (STSI 2025). AGN can refer to many different classifications such as quasars, blazars, and Seyfert galaxies, our focus is on the latter. These Seyfert galaxies are nearby and the easiest to study the surroundings of their blackholes. They are comprised of a Broad Line Region (BLR) that surrounds the central blackhole emitting broad emission lines, and a torus, a dense, dusty, donut-shaped structure that further surrounds the BLR (STSI 2025). Tori extend on a scale of parsecs.

X-ray emission is ubiquitous to the characteristics of AGN, and a key feature of their X-ray spectra is the narrow Fe Kα emission line that occurs around 6.4 keV. The origin of this line however is still a topic of much research. The main question being whether the origin comes from the Broad Line Region, with gas clouds moving at high velocities, or the torus that can obscure the BLR. Studying the narrow Fe Kα line is useful in providing information on the structure and dynamics of these regions (STSI 2025). To achieve our goal of finding the origin of narrow Fe Kα emission in AGN we propose to observe a galaxy using X-ray Imaging and Spectroscopy Mission's (XRISM's) high spectral resolution. This allows precise measurements of X-ray emission lines that will allow us to localize the emission. Spectral resolution will allow us to determine whether the line is narrow and symmetric, or if it shows velocity broadening, which correspond to the torus and BLR respectively. We can also use time-resolved spectroscopy observing the AGN over an extended period to observe the variability of the emission lines. A time lag in the primary X-ray continuum would indicate a torus origin due to X-rays being reflected off distant material. Further implying a torus origin would be reflection features such as a Compton hump seen in a spectral energy distribution (Laha S. & Ghosh R. 2021). This arises from Compton scattering where high-energy photons interact with cooler electrons changing direction and losing energy. A BLR origin would not have that lag as it is closer to the blackhole and would respond to changes in the X-ray flux faster. We propose to observe Seyfert 1 target NGC 3783 for its strong Fe Kα emission. Its spectral features have previous observations from other X-ray telescopes, and it seems an ideal candidate for observations using XRISM. Other similar AGN such as NGC 4151 have been observed using XRISM (XRISM Collaboration et al 2024 ApJL 973 L25) and have achieved results as seen in figure 1 that would be similar to expected observations of NGC

3783. There have also been observations of NGC 3783 using XMM-Newton.

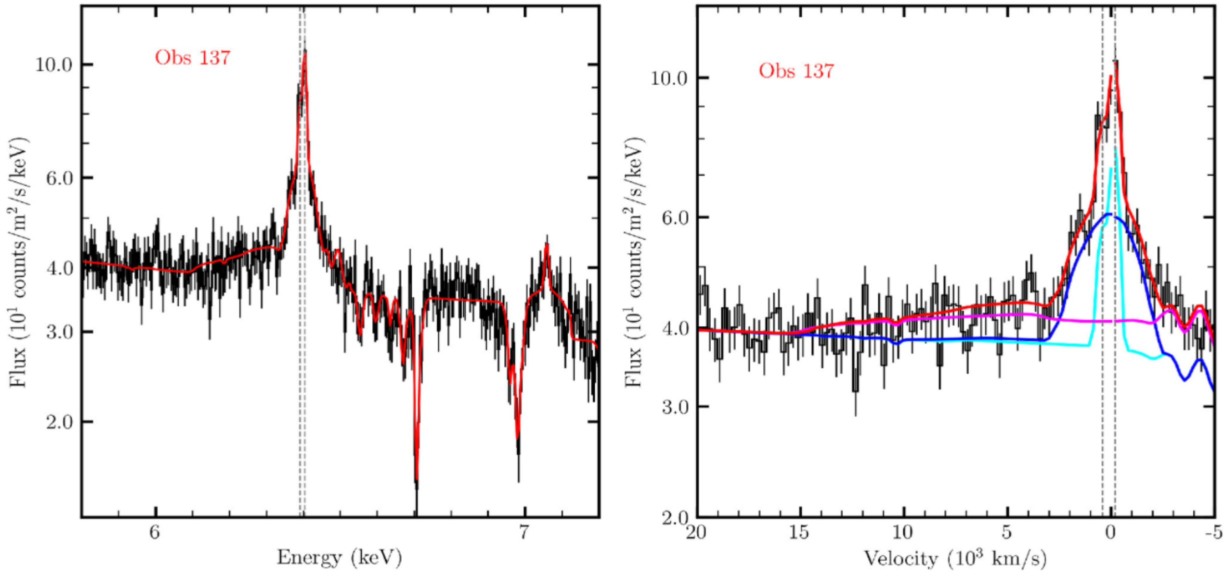

Figure 1: An example of data that can be received to disect Fe Kα lines, NGC 4151 observed by XRISM Collaboration et al. (2024) while assuming a weighted centroid energy of 6.40 keV. Figure on the left showing the energy space and the right showing the velocity space. They are indicititative of strong Fe Kα emission and velocity broadening likely from the outer BLR (XRISM Collaboration et al 2024 ApJL 973 L25).

3 Technical Justification

Studies done to determine the origin of the narrow Fe Kα emission line in AGN have previously used *Chandra* and *XMM-Newton*. Our proposal is best suited for *XRISM*. While *Chandra* has high spatial resolution, 0.5 arcseconds in the X-ray band (Chandra 2012), and *XMM-Newton* has broad X-ray coverage, able to detect X-ray features at 0.2-12 keV and even 20-30 keV (ESA 2010), XRISM has very high spectral resolution. This allows identification of very small shifts in the Fe Kα line like kinematic effects such as broadening or any shifts (NASA 2023). The primary instrument aboard XRISM is its X-ray spectrometer. It is designed to measure X-ray spectra from 0.3-12 keV which can show chemical compositions, physical conditions and velocities of its observed sources (NASA 2023). It has a high spectral resolution of about 7 eV (full width half max, FWHM) at 6 keV making it incredibly useful at distinguishing details in the Fe Kα line and identifying any shifts it experiences.

This X-ray spectrometer uses a microcalorimeter array, a solid-state detector, to measure X-ray photons. Photon energies get measured individually allowing detailed emission lines of fine structures within the X-ray spectrum. While its spatial resolution is not that of *Chandra and XMM-Newton*, it has an angular resolution of about 1 arcminute (NASA 2023) which still allows for precise measurements of nearby AGN.

Along with XRISM's X-ray spectrometer, it has a complementary X-ray Imaging Camera. It does not have the high spectral resolution as the X-ray spectrometer but is designed for broad-band imaging. This is useful for determine the special extent of X-ray emissions like the broad region of an AGN (NASA 2023). It has an angular resolution of about 1.5 arcminutes.

The X-ray spectrometer and the X-ray Imaging Camera are accompanied by an advanced onboard data processing system that records individual photon events from the detectors and relays their energy, time, and position.

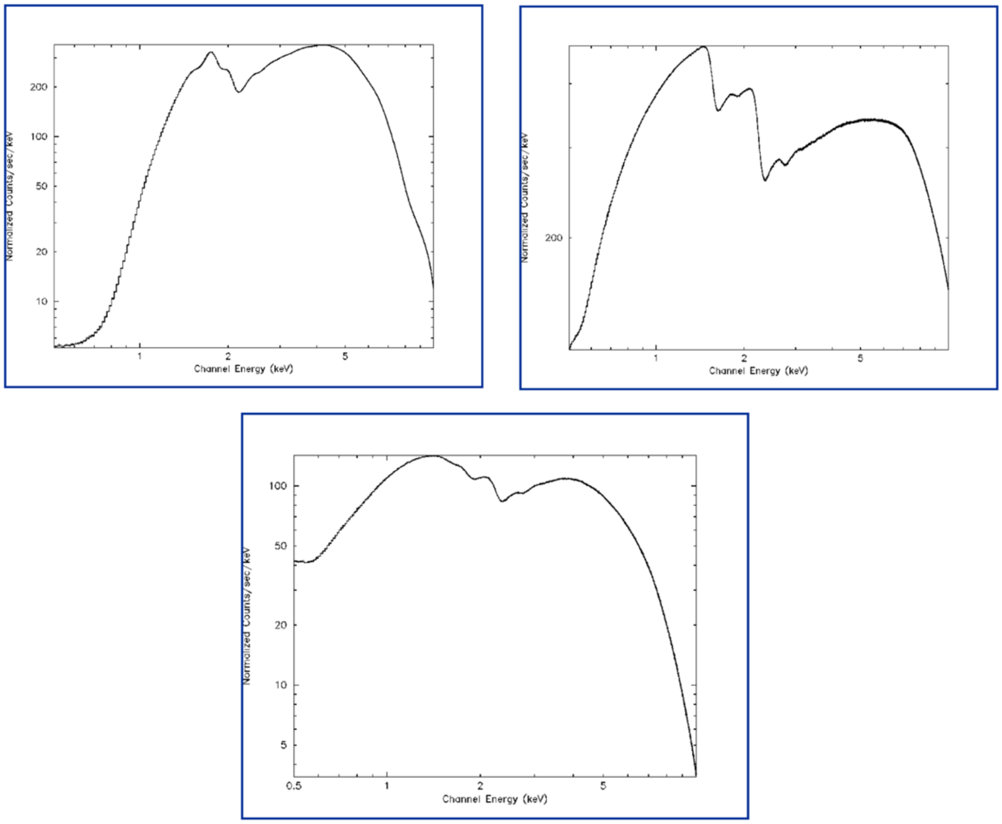

Figure 2: Using WebSpec (HEASARC), a simulation tool from NASA, and modelling an X-ray source as a power law, we estimated the best count rate/collecting area we would get at around 6 keV using *Chandra, XMM-Newton* and *XRISM.* The most effective collecting area at around 6 keV, useful to observe narrow Fe Kα lines was found using *XRISM*. **Top Left:** Using *Chandra,* this shows the collecting area at around 6 keV would be just above 200 normalized counts/sec/keV. **Top Right:** Using *XRISM,* this shows the collecting area at around 6 keV would be well above 200 normalized counts/sec/keV, the highest of the three. **Bottom:** Using *XMM-Newton,* this shows the collecting area at around 6 keV would be just above 100 normalized counts/sec/keV.

4 Feasibility

We request an exposure of 72 ks with XRISM for this observation. NGC 3783 is located 130 Mlys away, has RA = 11h 39m 1.97s and Dec = -37º 44’ 30.06” (ESA/Hubble et al 2024), and are in XRISM’s field of view. Due to XRISM’s X-ray Spectrometer and X-ray Imaging Camera’s previously mentioned angular resolutions, NGC 3783 can be accurately pin-pointed and detected. It has a flux of about 10^{-5} erg/cm^2/s in the 6.4 keV band (Reeves et al 2004) and like NGC 4151 (XRISM Collaboration et al 2024 ApJL 973 L25), it is bright enough that background will pose little interference. XRISM’s X-ray spectrometer has an effective area of about 150 cm^2 at the 6 keV range (XRISM Collaboration et al 2024).

To determine the count rate, we can do as follows, Count rate = Flux × Effective area = 10^{-5} erg/cm^2/s × 150 cm^2 = 1.5 × 10^{-3} counts/sec in the 6.4 keV band. We also need to take into account the signal to noise ratio, which should be 10 times the background noise, but ideally greater, and an estimate for bright sources in XRISM have a background noise of about 0.1 counts/sec. This leads to counts of about 1 count/sec for the Fe Kα line. To get the required exposure time to view the Fe Kα line, we take Exposure time = Required counts ÷ count rate (CXS 2017). Therefore, we get Exposure time = 1 count/sec ÷ 1.5 × 10^{-3} counts/sec = 666.7 sec. This is the minimum exposure time to view the Fe Kα line as a single spectrum, and longer times would enhance the signal-to-noise ratio. NGC 3783 however, varies intensity on timescales of up to 10 hours (De Marco 2020) so longer exposure times are still necessary. This is why 72 ks are proposed, to view the variance twice and account for any errors that may occur.

Once the observations are complete, the data will be processed and interpreted using the XRISM Quick Reference guide (Ota et al 2022), which aids to distinguish strong lines, velocity, and broadening of those lines. According to previous studies of similar AGN such as XRISM Collaboration et al. (2024), and Adonie et al. (2022), we expect to find velocity broadening at the 6 keV range, and lack of a Compton hump at a larger range, both of which point to an outer BLR origin for the narrow Fe Kα emission line in AGN.

5 Conclusion

By utilizing XRISM's high resolution X-ray spectroscopy and X-ray Imaging Camera, we can distinguish the origin of the narrow Fe Kα emission from the BLR or torus of an AGN. Focusing on bright NGC 3783 and studying its strong Fe Kα emission lines will further aid in this distinction. Following previous AGN studies using XRISM and other instrumentation, broadening and other features point to a likely origin in the outer BLR region, different than previous thoughts of these emissions having a sole torus origin.

6 References

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