Origin of the narrow Fe Kα emission line in AGN

Abstract

AGN X-ray spectra commonly show a large narrow emission line around 6.4 keV, known as the Fe Kα line. This line appears in the reflection spectrum which is caused by X-rays that were created in the corona interacting with material. This emission feature can originate in two possible regions, the outer BLR or the inner torus. There have been several studies done to find the answer but there have been results supporting both sides. A recently found AGN will give the ability to solve this. To do this it requires a few short observations from the XMM-Newton observatory. With this, the data can be modelled to get properties of this iron line and the AGN itself. Certain values can be found such as velocity width, flux of the emission line, the line energy, and sublimation radius to decipher which region is fits in best.

Scientific Background

In active galactic nuclei (AGN), there is a supermassive black hole (SMBH), an accretion disc, a corona, a torus, and sometimes outflowing jets (Jones et al., 2015). There are two regions, the narrow line region (NLR) which spreads out far from the central engine, and the broad line region (BLR) that occupies the space within the torus, outside the accretion disc.

UV photons produced in the accretion disc come into contact with the corona and get up scattered to X-rays via Comptonization or inverse Compton scattering (Gallo, 2011). These X-rays get emitted isotropically so some are received on Earth creating the primary continuum, and others go back and hit the accretion disc. The X-rays that are now hitting the disc will ionize the top layer, causing heavier elements do get exited, and as they de-excite they emit photons through a process called fluorescence. This then creates a reflection spectrum where we can see emission lines. Some emission lines such as the narrow iron K alpha line can come from further outside the accretion disc, from the BLR or the torus. The neutral Fe Kα line is a common prominent feature in AGN spectra because it has a high fluorescent yield and is relatively abundant. This emission line could be due to a distant reflection where the X-rays from the corona make their way to the inner torus or outer BLR where cold, dense gas is located. The issue arises as it is currently unknown which of the two the narrow iron K alpha line originates from. As you move closer to the black hole the emission lines get broader, however there will not be a big difference when it comes to the outer BLR and inner torus especially as it is possible that these might not be such distinct regions (Gallo et al., 2023).

This transition occurs specifically as the X-rays interacts with the material. The photon has high enough energy during the photoelectric absorption process to liberate an electron in the K shell. With this, there is an absorption edge that is produced but is not often noticeable in AGN spectra.

Previous studies have shown conflicting results where some have claimed the origin lies in the inner torus (Nanda, 2006), while others have argued that it comes from the outer BLR. There have been a few that used Chandra HEG data that have tried to find the answer to this question (Gallo et al., 2023). One found the line to originate in the BLR by measuring the line energy and the corresponding FWHM. They would take this and compare to the Hβ line found in the BLR which were in agreement. Another acquired a spectrum that appeared to find the Compton shoulder to the iron line and also concluded the origin was located in the outer BLR. A competing study came out saying that it was actually in the torus. The next one then used a different method than finding FWHM and said that if the emission line comes from a radius less than the calculated radius of dust sublimation, it would be in the BLR. These projects all measured values from multiple Seyfert galaxies.

Every new piece of information involving AGN is important as there are still many unknowns. Finding the answer to this narrow iron line can help to uncover more details about the inner region, how it looks, if these regions are distinct, and how the components interact with one another. This project will give the ability to better constrain the BLR and the torus.

Observations and Data

This AGN is a good candidate as it is a bright, nearby Seyfert 1 galaxy. This means there will be an unobscured view and can see the central engine, BLR, and torus face on. It is believed to be able to provide the answer to the question at hand with these X-ray observations.

The proposed observations consist of 3 individual observations. The first one will be performed, then about three days later the second one can be taken, finally four days after the second one, the third can be taken. Each of these will have an exposure time of about 90 ks using the XMM-Newton observatory.

The XMM observatory is best suited for these observations with its large effective area and the high number of counts/s/keV around 6.4 keV that was found using NASA's WEBSPEC tool.[1] It will provide great data for this project as this is the energy band we're looking for.

The reason for three observations is to have a chance at detecting variability as AGN are highly variable X-ray sources (Gallo, 2011). If there is a change in flux of the emission line, it would help determine how far it is from the X-ray corona based on how long it would take the information to travel to the BLR or to the inner torus. If the flux of the line does not vary much but there are changes in the rest of the spectrum, it could be coming from a place very far from the X-ray emitting source.

From these observations three different spectra will be produced that can be analyzed using a spectral fitting package such as XSPEC. Each spectrum will show an emission line at about 6.4 keV, representing the narrow Fe Kα feature. The width of this line can lead to its location, if its broader it comes from the BLR, and if its very narrow it is produced in the torus. The velocity widths can be compared to those of Hβ to see if it is consistent with the BLR. On top of these, the radius of dust sublimation can be calculated, similar to the previous study, and whether the radius of the area Fe Kα is produced is greater than or less than that value, it will be deemed originating in the torus or BLR. With multiple different methods, it can be determined if they are consistent with one another to further reinforce the results. If lucky, this spectrum may show a Compton shoulder which can reassure that this emission line comes from optically thick material.

---

[1] https://heasarc.gsfc.nasa.gov/cgi-bin/webspec/xspec_sim.pl

Observing Instrument and Feasibility

XMM-Newton has a large effective area with 58 mirrors per module, coated in gold.[2] These mirrors follow the Wolter 1 design where the first mirror is shaped as a paraboloid and the second a hyperboloid to get large grazing angles. WEBSPEC showed this telescope to have the highest count rate at an energy of about 6.4 keV. EPIC-pn is the best choice as EPIC is sensitive in the range of 0.3-12 keV and pn has a quicker readout than the MOS detectors.[3][4] However the combined pn and MOS spectra will be useful to analyze. Chandra HEG does have better resolution in this energy band, though observations have previously been taken with this with the goal of finding the origin of this line (Gallo et al., 2023). They had good resolution but were limited in effective area as Chandra has an effective area less than that of XMM. It is useful to see what another telescope such as XMM–Newton will provide as it is also good in this energy band. Other observatories were either better at higher and lower energies or had a smaller effective area in this band.

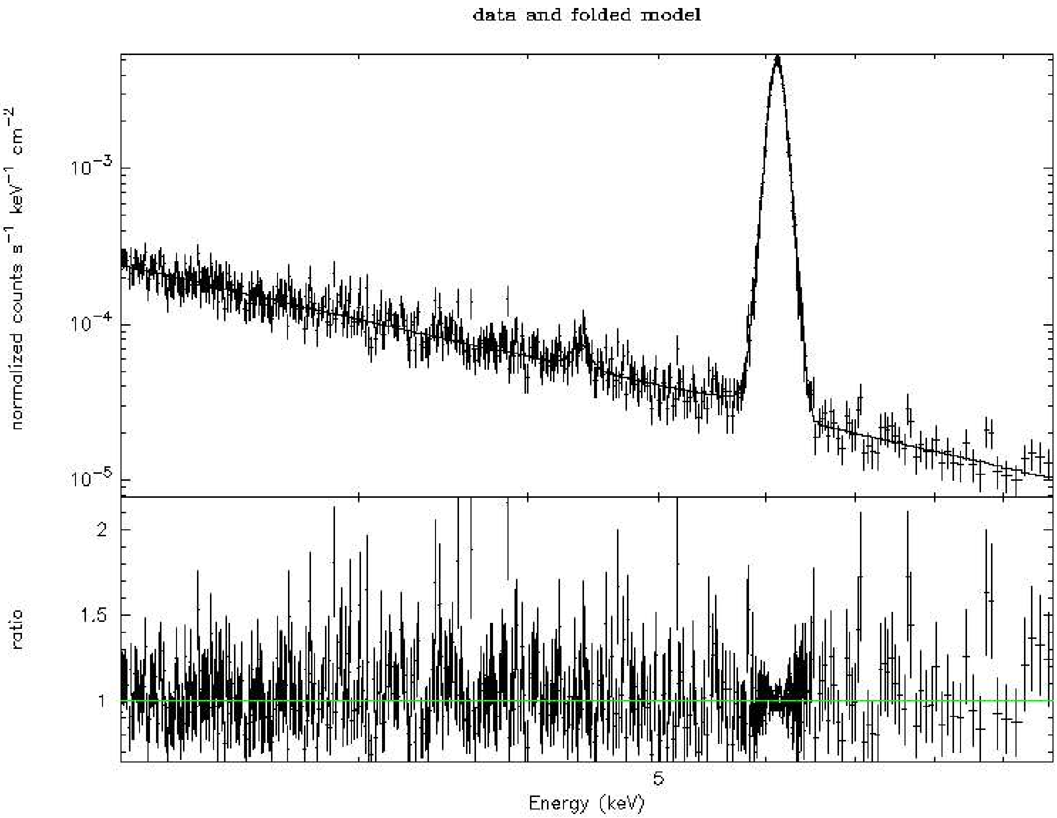
With this bright source, the flux is about $10^{-11} erg/cm^2/s$ and a predicted photon index at about 2.0. It is relatively nearby and has a redshift of 0.0457. This source was only recently found so there is not much data on this specific AGN yet, but it is anticipated to be a good source for problem. These observations can be carried out at any time within the year, no major changes are expected at any point.

To meet precision of prior results, an error on the line energy would be to about the second decimal point or lower, which is achievable with XMM. Simulations came out with a higher uncertainty than desired, though the simulation consisted of simply a power law and a narrow Gaussian feature. The actual data will be modelled more vigorously and with more complicated models.

Figure 1 shows the simulated spectrum given 90 ks with the XMM EPIC-pn instrument. It only includes a simple model consisting of a power law for the primary continuum and a Gaussian profile for the iron line. More complicated models will be added with the real spectrum, but this was a good check to see if the exposure time of 90 ks will be sufficient and the uncertainty will reach the desired precision.

[2] https://www.cosmos.esa.int/web/xmm-newton/technical-details-mirrors
[3] https://heasarc.gsfc.nasa.gov/docs/xmm/xmmhp_inst.html
[4] https://xmm-tools.cosmos.esa.int/external/xmm_user_support/documentation/uhb/mos_pn.html

Figure 1: Simulated spectrum of XMM EPIC-pn data between 2-10 keV for a flux on the order of $10^{-11} erg/cm^2/s$. Including a power law for the primary continuum and a narrow Gaussian profile at 6.4 keV.



References

Gallo, L., 2011, JRASC, 104, 4, 143

Gallo, L. C., Miller, J., Costantini, E., 2023, arXiv, page arXiv :2302.10930

Ricci, C., Ueda, Y., Ichikawa, K., Paltani, S., Boissay, R., Gandhi, P., Stalevski, M., Awaki, H., 2014, A&A, 567, A142

Nandra, K., 2006, MNRAS, 368, 1, L62-L66

Jones, M., Lambourne, R., Serjeant, S., 2015, Cambridge University Press, 111-152