USING HIGH REDSHIFT LENSED QUASARS TO PROBE CORONAL EMISSIONS OF EARLY UNIVERSE SMBHs

1 Abstract

High redshift quasars offer a unique window into the formation of the earliest supermassive black holes (SMBHs). This makes them essential to understanding the innermost regions of early galaxies and the conditions present in the early universe. We propose a 100 ks Chandra observation of the recently discovered gravitationally lensed quasar FAK3 1234+567 at $z \approx 7.0$—the most distant known lensed quasar to date. Of the approximately 220 known gravitationally lensed quasars, the highest known redshift up until this point was $z = 6.52$ (Yang et al. 2022). Only a handful of quasars at $z > 6.5$ are currently known (Barnett et al. 2020), making this a rare opportunity to probe the X-ray emission of an Active Galactic Nuclei (AGNs) around 800 million years after the Big Bang. The presence of SMBHs at such early cosmic time poses a significant challenge to current models of black hole formation and growth (Wang et al. 2021). Beneficially, gravitational lensing amplifies the quasar's flux, which will enable Chandra to obtain higher signal to noise ratio data than would otherwise be attainable.

2 Scientific Rationale

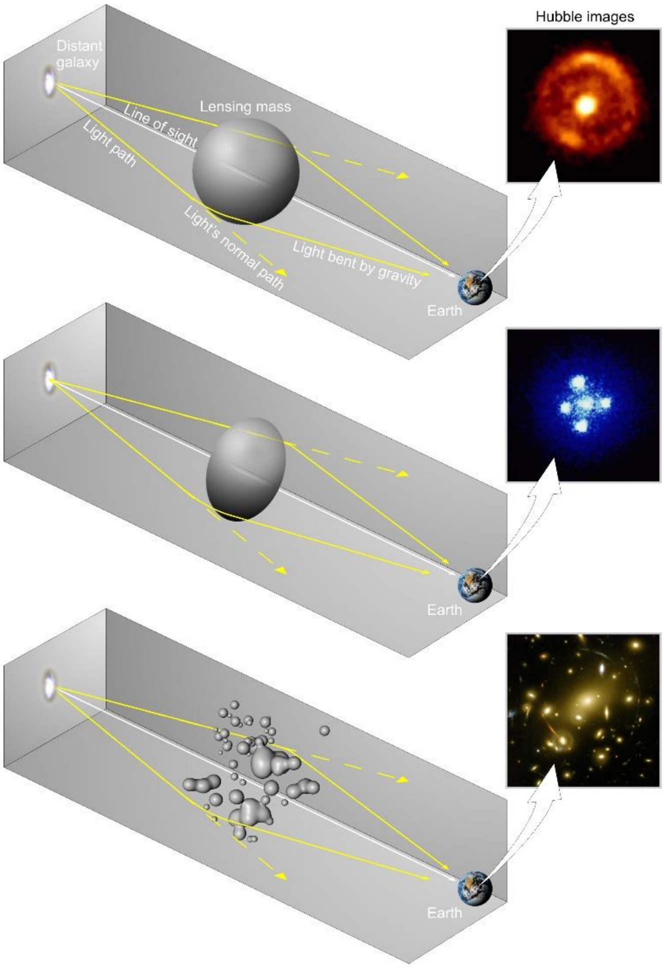
Quasar emissions provide a powerful tool for probing the structure of accretion discs and coronae, and measuring the growth rates of SMBHs. The discovery of a quasar at such high redshift enables us to gain insight into, and test, current theoretical models of SMBH formation in the universe less than 1 Gyr after the Big Bang. In order to reach the mass required to become supermassive, the rate of accretion is likely at or possibly exceeding the Eddington limit. This should provide the highest levels of emission from the quasar.

The corona exists in the region close to the BH and is made up of superheated (10^7 – 10^9 K) relativistic particles, driven by strong magnetic fields emanating from the inner region of the accretion disc. The corona's emissions radiate isotropically, with some of that emission Comptonized and reflected off the inner region of the accretion disc. The isotropic emissions can be modeled by a power-law, with the reflections appearing between 5 – 100+ keV. While accretion discs of SMBHs emit blackbody radiation peaking in the high ultraviolet, this radiation can be up-scattered into the soft X-ray band.

This high energy emission from the corona, combined with Compton reflection off the accretion disc, will be redshifted into Chandra's bandpass, allowing for observation of otherwise inaccessible higher energy emissions. For example; Fe kα emission around 6.4 keV will be shifted to around 0.78 keV, and energies up to ~99 keV will shift within Chandra's 10 keV limit.

Distant quasars are typically difficult to resolve due to their faintness and small angular size. However, gravitational lensing—caused by the chance alignment of a massive foreground object, such as a galaxy or galaxy cluster, with a more distant source—can magnify the background light and make these otherwise elusive objects observable. This lensing effect 'bends' the light's path toward the observer, effectively increasing the apparent brightness of the source.

Depending on the mass distribution and alignment of the lensing object, various lensing patterns can emerge (see Fig 1).



In the case of FAK3 1234+567, we observe a configuration resembling an Einstein Cross. Due to the differing lengths of the light paths, we expect measurable time delays between the images, with the possibility of ranging from seconds to months (Suyu et al. 2010). Quasars are known to have significant variability and these time delays may allow us to detect differences in the emissions, which may offer insight into the dynamics and structure of the corona and disc.

The magnification from lensing also increases the photon count rate, improving the signal-to-noise ratio in the spectral data. We aim to fit the observed spectrum with a power-law model to examine changes in slope and compare these with prior observations, with the goal of enhancing our understanding of quasar emission mechanisms in early cosmic time and refining current models.

Figure 1: Gravitational lenses produce different shaped images depending on the shape of the lensing body. If the lens is spherical then the image appears as an Einstein ring (in other words as a ring of light) (top); if the lens is elongated then the image is an Einstein cross (it appears split into four distinct images) (middle), and if the lens is a galaxy cluster, like Abell 2218, then arcs and arclets (banana-shaped images) of light are formed (bottom). Credit: European Space Agency

3 Technical Justification

Chandra's high spatial resolution of 0.5" should allow for precise measurement from each lobe of the Einstein cross allowing us to compare each beam of lensed light separately. Chandra also has an effective energy range in the correct band for our collection, based on the higher redshift. As seen in Yang et al 2022, a high redshifted lens quasar displays high rest frame energies in the 2-10 keV observation range (see Fig 2).

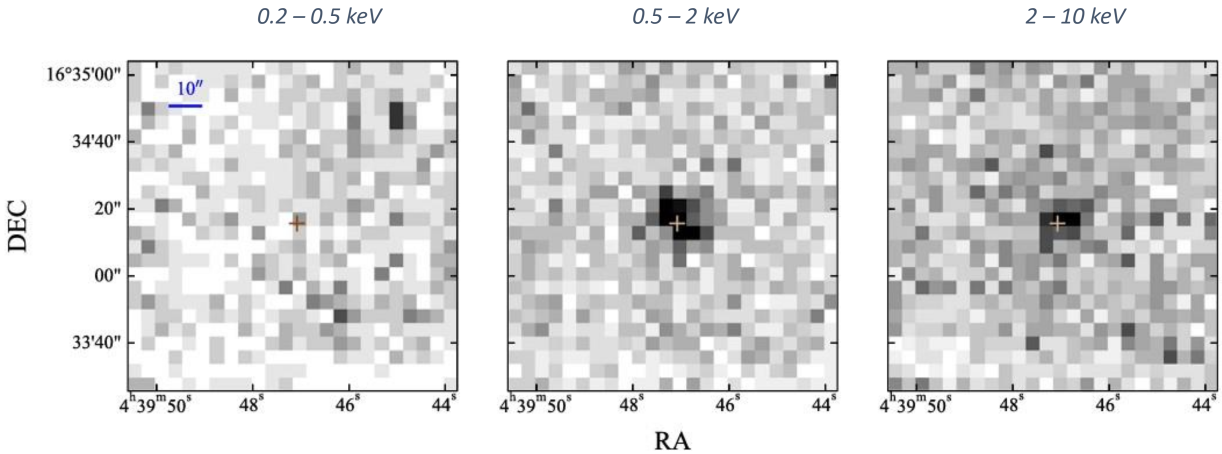


Figure 2: The XMM-Newton EPIC image (100″ × 100″) of J0439+1634, combined from the pn, MOS1, and MOS2 images, in the 0.2–0.5 keV (left), 0.5–2 keV (middle), and 2–10 keV (right) X-ray bands. The central crosses represent the optical coordinates of this quasar (i.e., J043947.08+163415.7, Fan et al. 2019). The quasar is detected in the 0.5–2 keV (rest-frame 3.8–15 keV) and 2–10 keV (rest-frame 15–75 keV) bands, but not in the 0.2–0.5 keV band (rest-frame 1.5–3.8 keV). Credit: Yang et al. 2022

With the z ≈ 7 of FAK3 1234+567 we expect rest frame energies between 1.6 – 99 keV to fall into Chandra's 0.2 - 10 keV High Energy Transmission Grating band pass.

When modelled in XSPEC (Arnaud 1996) using a tbabs zpower-law model we produced the following figure (see fig 3).

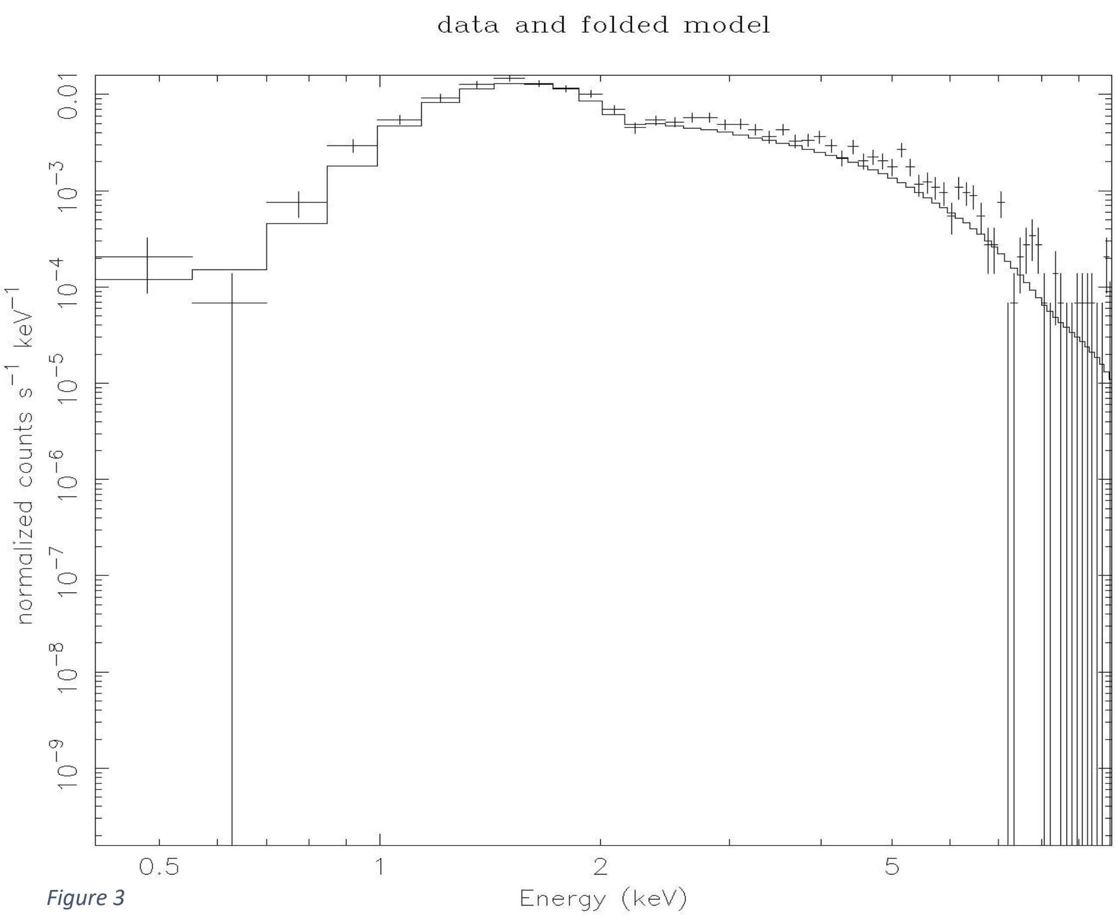


Figure 3

Using HEASARC tools, based on the RA and Dec of FAK3 1234+567, we estimated an average column density (N_H) of 2.84 x 10^{20} cm^{-2}. Using an estimated photon index of 1.9 PIMMS produced a normalization of 1.267 x 10^{-4}. Based on a 100 ks exposure, this resulted in a count rate of 46 at 4.6 x $10^{-4}s^{-1}$ and an energy flux of 1.289 x 10^{-14} erg/cm^2/s. While quite low, this flux is an order of magnitude higher than Chandra's Advanced Charged Couple Imaging Spectrometer (ACIS) sensitivity limit over the same exposure time.

With Chandra's 0.5" resolution we should be able to collect similar counts for each of the lobes of the Einstein cross providing us with 4 observations simultaneously.

4 Conclusion

This proposal is a rare and timely opportunity to investigate the physics of SMBH growth in the early universe. The high redshift brings the hard X-ray emissions of AGNs into the bandwidths of our current telescopes, while the gravitational lensing makes these undetectable objects visible to our instruments. By leveraging Chandra's high spatial resolution and sensitivity in the X-ray band, we can analyze the coronal and accretion disc emissions from multiple lensed images simultaneously—offering a rare, time-resolved glimpse into the heart of a quasar 800 million years after the Big Bang. This proposal will not only test the limits of our current technology, but also push the frontier of high-redshift AGN physics.

5 References

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6 Inspiration

The inspiration for FAK3 1234+567 originates with QSO 0957+561 A/B, the first discovered gravitationally lenses double quasar (Walsh et al. 1979), and J0439+1634, the current highest redshift lensed quasar (Yang et al. 2022).

The RA and Dec used in HEASARC to estimate N_H comes from J0439+1634. The photon index used in XSPEC was drawn from J0439+1634.