Emission Line Variability, Soft Excess, and Obscuration in the Seyfert Galaxy NGC 2992

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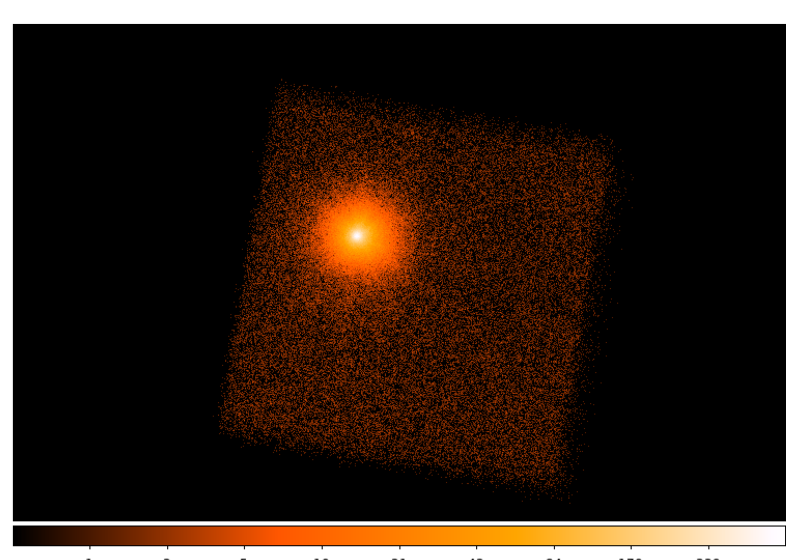
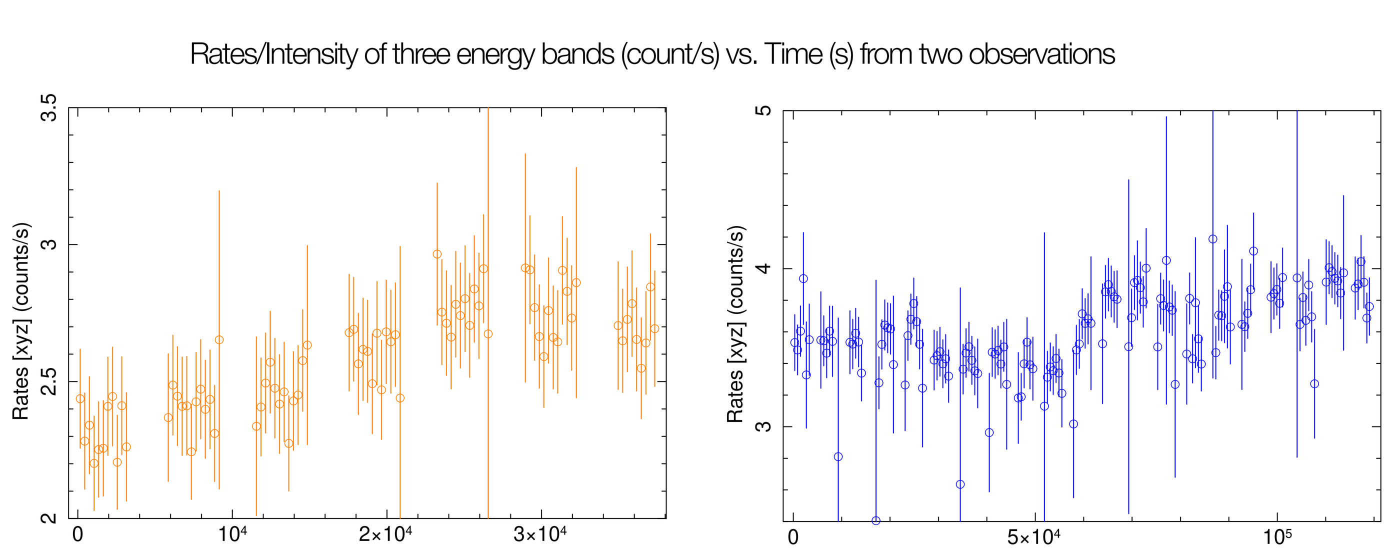
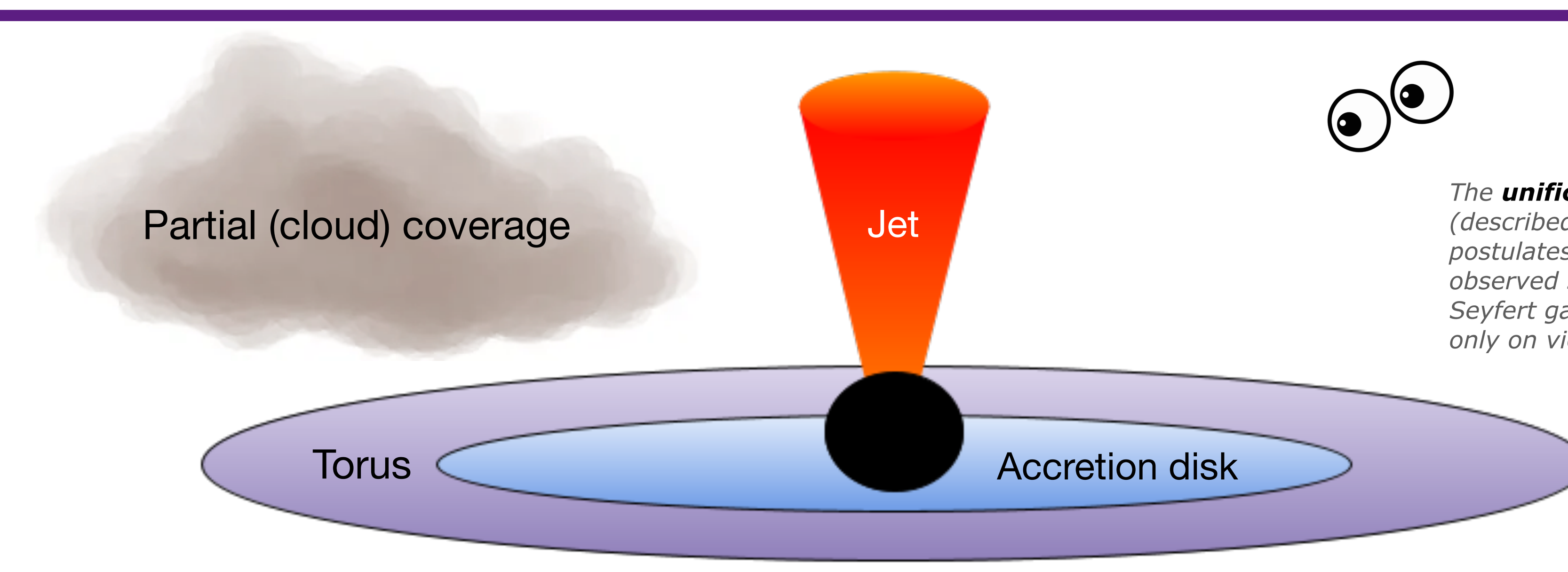
We investigated the X-ray emission characteristics of the active galactic nucleus (AGN) in the Seyfert galaxy NGC 2992, focusing on emission lines, variability, and obscuration. Four datasets—two each from the NuSTAR and XMM-Newton space telescopes—were utilized. Analysis of XMM-Newton RGS1 data in the 0.5–0.7 keV range revealed a soft X-ray excess. NuSTAR color-to-color diagrams in the 3–79 keV range allowed characterization of temporal variability, particularly of the Fe Ka emission line, providing insight as to its strength, and its location, relative to the black hole. We confirmed the presence of the Fe Ka line at ~6.4 keV, likely originating from a relatively distant torus, but were unable to validate three distinct iron emission lines reported by Marinucci et al. ("The lively accretion disc in NGC 2992 – I. Transient iron K emission lines in the high-flux state") without introducing statistical bias. An O VIII emission at ~0.65 keV was observed, potentially tracing hotter AGN structures relative to the torus, such as the corona or outflows. Partial obscuration by surrounding gas was modeled, showing significant improvements in fit statistics. Data suggest a possible Fe XXVI emission at ~6.97 keV, warranting further investigation. These findings support a model of NGC 2992 as a supermassive black hole with a jet along its rotational axis, a partially obscured accretion disk, and a distant torus. Future work includes refining the soft X-ray excess characterization, constraining obscuration fractions, and exploring relativistic effects in iron emission lines, contributing to a deeper understanding of AGN structure and the Seyfert unification model.

- ***Middle Right:*** Photon density map from the NGC 2992 AGN taken by NuSTAR's Focal Plane Module A (FPMA, ObID 90501623002).
- ***Bottom Left and Right:*** Average rate of energy versus time taken by both NuSTAR's focal plane modules (FPMA and FPMB, 60160371002 [Bottom Left], 90501623002 [Bottom Right]).

- NuSTAR, ObID 60160371002
- NuSTAR, ObID 90501623002
- XMM-Newton, ObID 0840920201
- XMM-Newton, ObID 0840920301

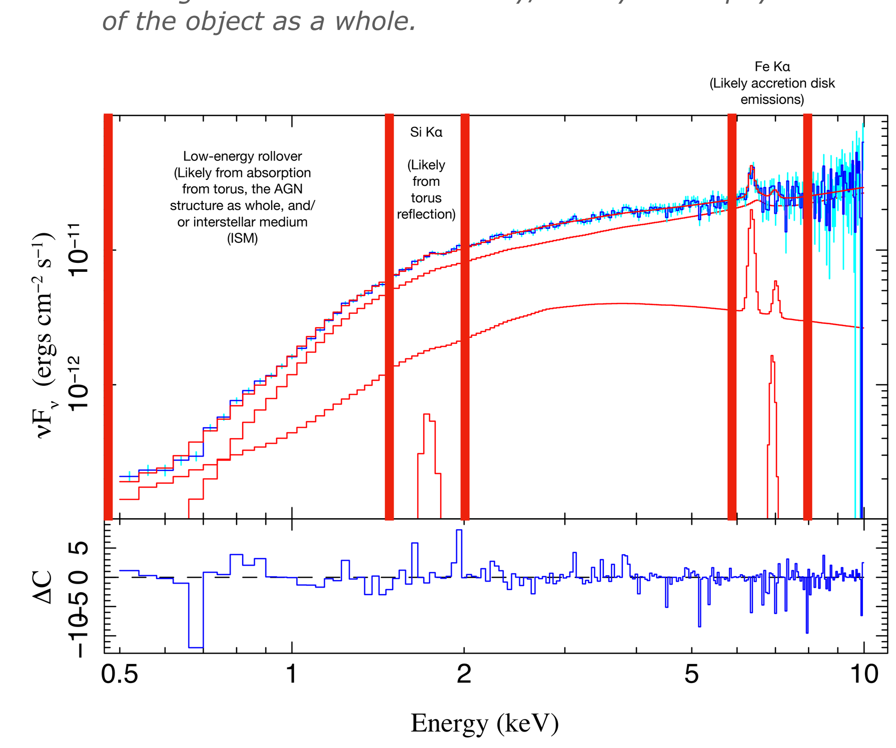






*The **unification model** (described below) postulates that the observed spectrum of a Seyfert galaxy depends only on viewing angle*

This figure does not scale linearly/exactly to the physical locations and sizes of the AGN structures, but rather provides a rough outline of the object as a whole.



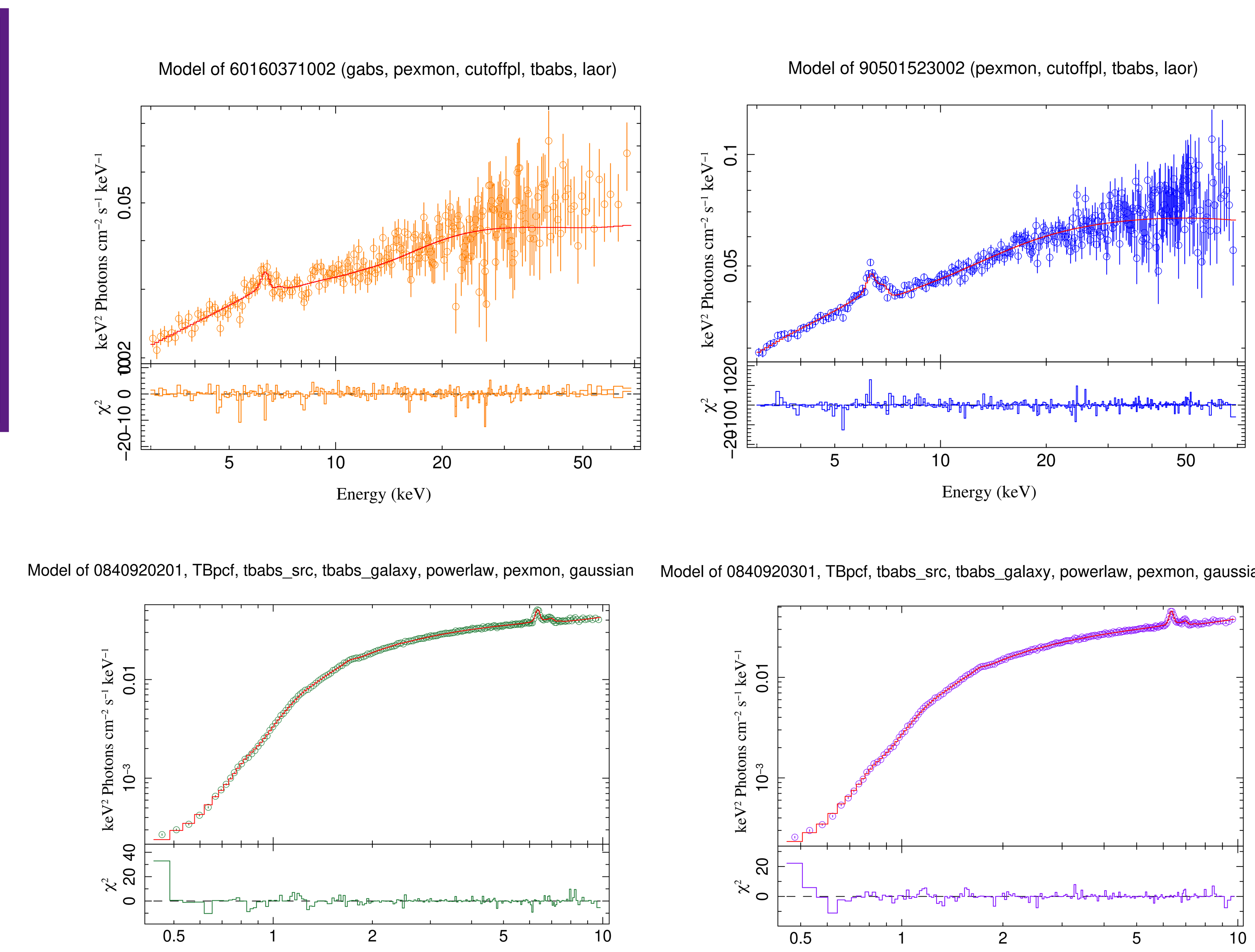
- ***Figure:*** Flux graph of NGC 2992 from prior *NICER* observations (Nowak, Murphy, Walters 2022).

- The Fe Kα line originates from the torus of the black hole, as these are the colder regions of the AGN structure.
- The emissions indicate that the X-ray continuum is reflecting off dense material, consistent with the presence of an obscuring torus and/or other locally distant materials.
- The O VIII emissions at ~0.65 keV can explain the closer, hotter structures of the AGN, such as the black hole corona and any potential AGN winds.
- The identified cloud coverage is likely between the source emissions (the jet and accretion disk of the supermassive black hole) and the torus, modeled through the *TBpcf* model. Its exact coverage fraction is currently unknown.

- We verified the existence of a Fe Kα emission line at ~6.4 keV, but proved that the proposed three emissions, allegedly correlated to Fe XXV (He-α-like emission), Fe XXVI (Ly-α), and Fe Kβ, cannot be proven by the NuSTAR data without uncertainty due to statistical noise.
- Nearby energy emissions correlating to Fe Kβ, Ni Kα, and a Fe Kα Compton shoulder are also modeled by *pexmon,* as shown in the figures to the right. However, the exact energy values, sigma values, and locations of these emissions have not been fully resolved.
- Whether or not these emissions are relativistic is still uncertain, but we found it to be a possibility. If these emissions are relativistic, they could be useful in determining the inclination of the AGN in the future.
- Additionally, we verified the existence of an O VIII emission at ~0.65 keV (XMM-Newton RGS1 and RGS2, both observations).
- Furthermore, we have identified a partial cloud coverage.
- NuSTAR data suggest the presence of an emission at ~6.97 keV, corresponding to an emission of Fe XXVI, but this requires further study.
- The two figures above also demonstrate NGC 2992's emission variability over time through two observations.

- ***Top Left and Right:*** Spectra of NuSTAR FPMA and FPMB data combined, including models.
- ***Bottom Left and Right:*** XMM-Newton EPIC-pn spectra, including models.

- Understanding Seyfert galaxies like NGC 2992 could provide insight into the validity of the **unification model**, the theory that Seyfert type I and type II galaxies differ only by viewing angle but are intrinsically the same object.
- Efforts to constrain the unification model drive technological and methodological advances, such as the development of high-resolution infrared and X-ray instruments to probe obscured regions, improved spectral modeling and image reconstruction algorithms, and better machine learning classifications for survey data. These innovations often transfer to other fields, such as medical imaging and data science.



References

Marinucci, A., Bianchi, S., Braito, V., De Marco, B., Matt, G., Middei, R., Nardini, E., & Reeves, J. N. (2020). *The lively accretion disc in NGC 2992 – I. Transient iron K emission lines in the high-flux state.* Monthly Notices of the Royal Astronomical Society, 496(3), 3412–3423. https://doi.org/10.1093/mnras/staa1683

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