Short-term column density variability in the nearby changing-look CT-AGN NGC 1358: results from a multi-year NuSTAR-XMM-Newton monitoring to characterize the obscuring medium nearby accreting supermassive black holes

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Abstract

In Marchesi et al. (2022; ApJ, 935, 114) we presented the multi-epoch monitoring with *NuSTAR* and XMM-*Newton* of NGC 1358, a nearby Seyfert 2 galaxy whose properties made it a promising candidate X-ray changing-look active galactic nucleus (AGN), i.e., a source whose column density could transition from its 2017 Compton-thick (CT-, having line-of-sight Hydrogen column density $N_{H,los}>10^{24}$ cm^{-2}) state to a Compton-thin ($N_{H,los}<10^{24}$ cm^{-2}) one. The multi-epoch X-ray monitoring confirmed the presence of significant $N_{H,los}$ variability over time-scales from weeks to years, and allowed us to confirm the changing-look nature of NGC 1358, which has most recently been observed in a Compton-thin status.

Multi-epoch monitoring with *NuSTAR* and XMM-*Newton* is demonstrated to be highly effective in simultaneously constraining three otherwise highly degenerate parameters: the torus average column density and covering factor, and the inclination angle between the torus axis and the observer.

We find a tentative anti-correlation between column density and luminosity, which can be understood in the framework of Chaotic Cold Accretion clouds driving recursive AGN feedback. The monitoring campaign of NGC 1358 has proven the efficiency of our newly developed method to select candidate $N_{H,los}$-variable, heavily obscured AGN, which we plan to soon extend to a larger sample to better characterize the properties of the obscuring material surrounding accreting supermassive black holes, as well as constrain AGN feeding models. These targets would represent an ideal sample of sources to be studied with future-generation missions, such as the High Energy X-ray Probe (HEX-P).

Target selection

- The BAT 100-month catalog contains ~35 CT-AGN at z<0.05, all with NuSTAR coverage.
- Physically motivated models (MyTorus, borus02, UXClumpy…) allow one to measure average properties of the obscuring medium from the shape and intensity of the reprocessed emission ("Compton hump").
- We find a sample (red squares in Figure 1) of sources with small obscuring medium covering factor and l.o.s. column density significantly larger than the average column density of the medium.
- These sources (among which NGC 1358) are likely to have been observed through an over-dense region embedded in a significantly less dense environment. In such a scenario, the small covering factor would imply that the overall cloud volume filling factor is small, and the obscuring clouds occupy only a fractional part of the pc-scale region that surrounds the accreting SMBH where the obscuration is expected to take place.

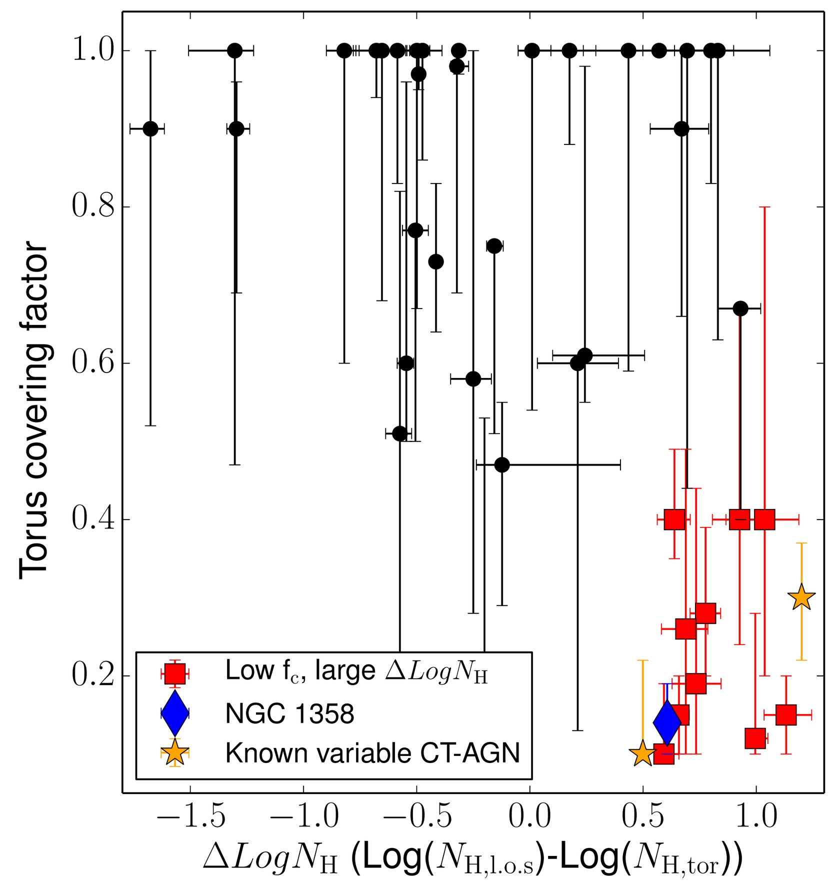

Figure 1 (left): Obscuring material covering factor as a function of the difference between the logarithms of the line-of-sight and torus average column density, for a sample of nearby CT-AGNs observed with NuSTAR and a 0.5-10 keV facility. Sources with f_c<0.4 and DeltaLogNH>0.5 are plotted as red squares. NGC 1358 is shown as a blue diamond: its large DeltaLogNH and low f_c make it an excellent candidate "clumpy environment" CT-AGN. MRK 3 and NGC 4945, both known variable CT-AGN also having large Delta NH} and low f_c, are plotted as orange stars.

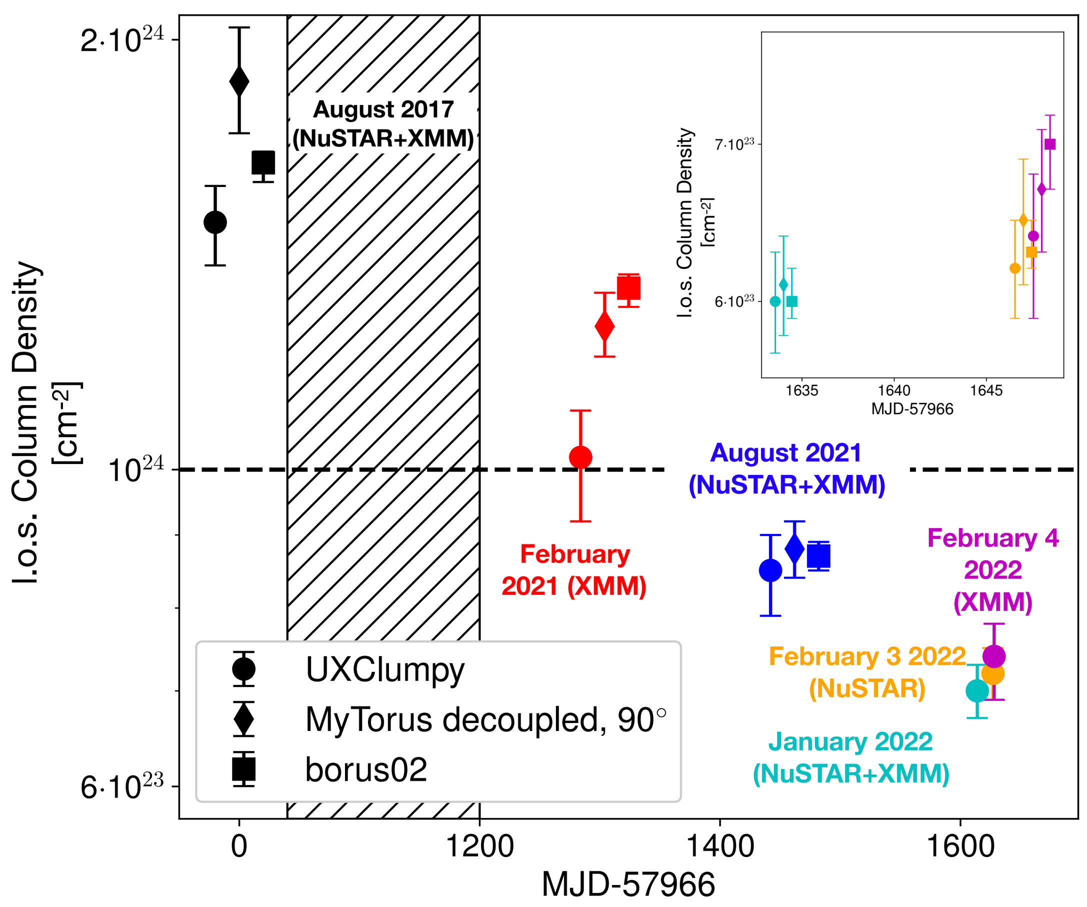

Figure 2: l.o.s. column density of NGC 1358 as a function of time, as obtained using three different models. In the inset we show a zoom-in of the 2022 observations, with potential evidence of a new increase in NH. The UXClumpy and borus data-points are shifted by 20 days (0.5 days in the inset) for visualization purposes. To further increase the plot clarity, the first 1200 days (hatched area) are not in scale.

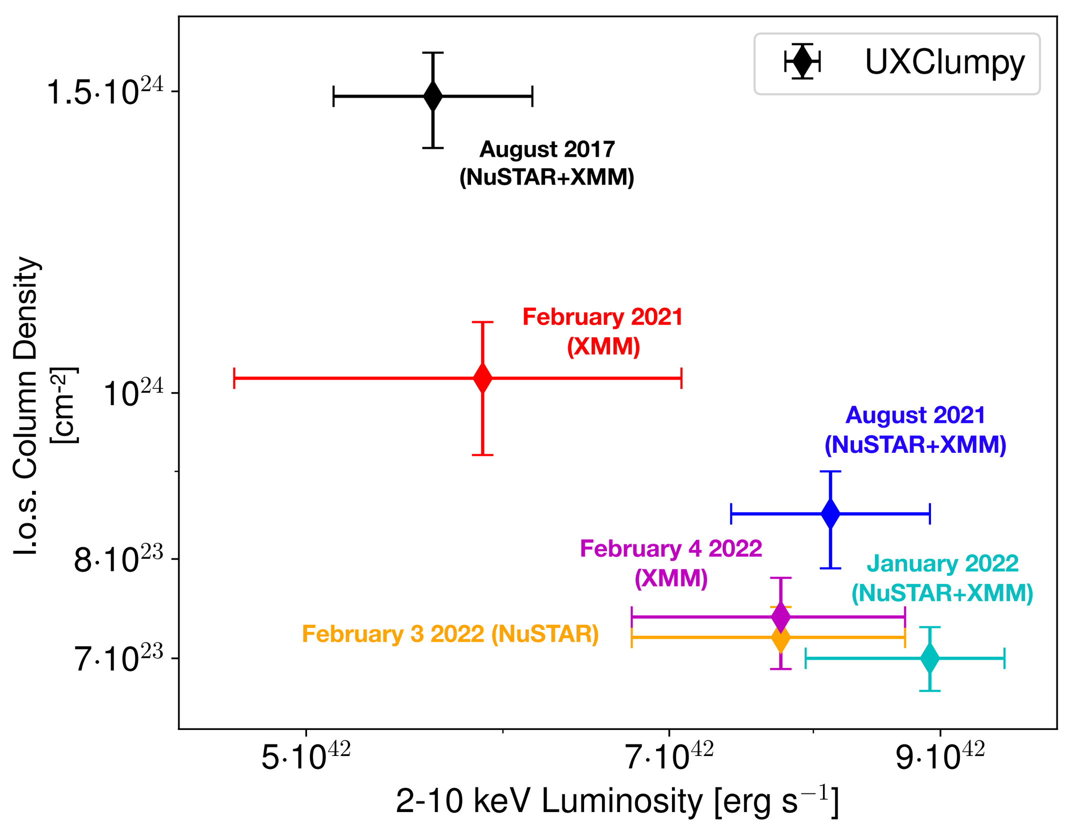

Figure 3: Line-of-sight column density as computed with the UXClumpy model as a function of the 2-10 keV intrinsic luminosity in NGC 1358. We observe tentative evidence of anti-correlation, consistent with a self-regulated feeding/feedback scenario.

Multi-epoch monitoring results/1

- If the source is indeed surrounded by a clumpy medium, l.o.s. NH should vary with time.
- Multi-epoch monitoring with NuSTAR and XMM-Newton aimed at confirming this scenario.
- Different time-scales between two consecutive observations (days to months) allow one to probe different cloud-SMBH distances (assuming a certain coronal size), varying from mpc to tens of pc.
- As shown in Figure 2, **NGC 1358 is found to be highly variable in NH,** thus proving the effficency of the selection criteria, and even transitioning from CT to Compton thin from 2017 to 2021-2022.
- Figure 2, inset: potential new increase taking place in February 2022
- Figure 3: tentative evidence for anti-correlation between l.o.s. NH and 2-10 keV luminosity: consistent with a self-regulated AGN feeding and feedback cycle driven via CCA raining clouds.

Results (2) and future developments

- Broad-band, multi-epoch monitoring is key, as shown in Fig. 4, to break degeneracies between parameters and measure with unprecedented accuracy the average properties of the obscuring medium.
- Other works by our group (Torres-Albà+23; Pizzetti+22; Sengupta+ in prep.) are analyzing larger samples of sources with multi-epoch X-ray archival data over >20 years time-span(see Fig. 5). See also A. Pizzetti poster!

- We will propose for a NuSTAR+XMM monitoring of all targets in Fig. 1 sharing the same properties of NGC 1358.
- Future missions, such as the High Energy X-ray probe (HEX-P) could extend this analysis to 1 dex lower luminosities or to higher redshifts.

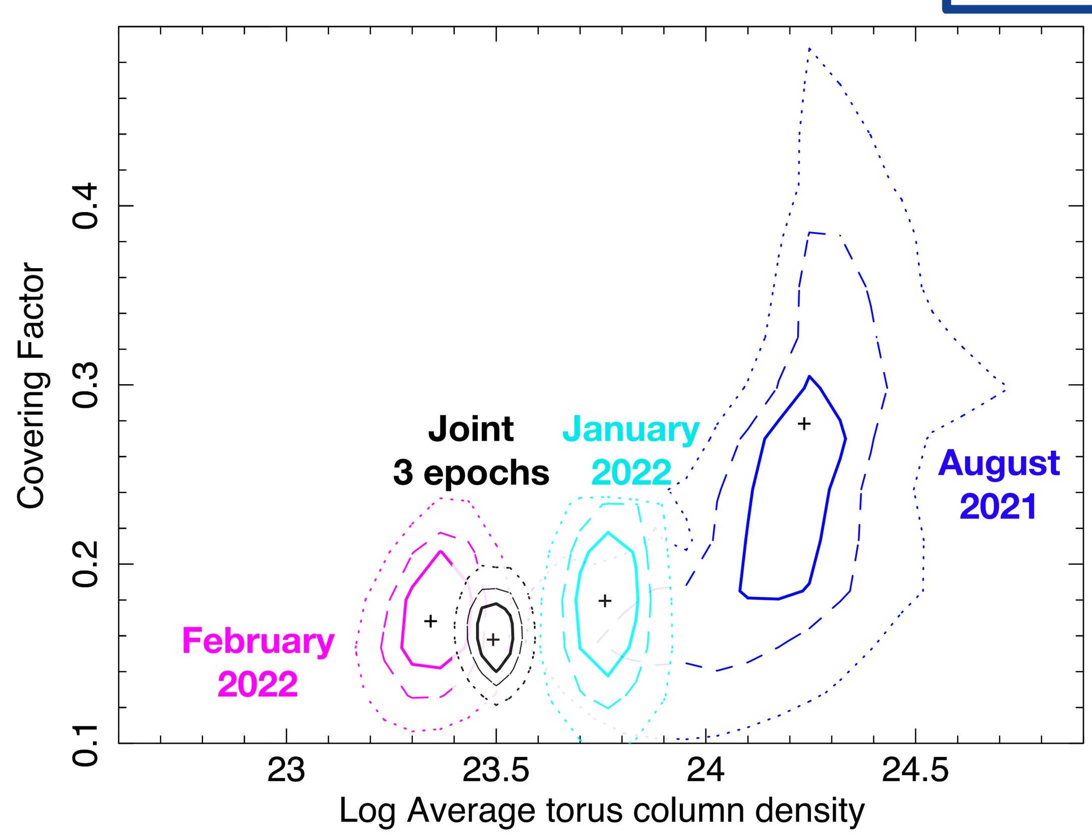

Figure 4: 68, 90 and 99\,\% confidence contours of the covering factor as a function of the average torus column density, computed using the borus02 model. The contours obtained from the multi-epoch joint fit are plotted in black. These parameters are not expected to vary on short time scales: single-epoch measurements are affected by multi-parameter degeneracies that can be solved only by multi-epoch monitoring.

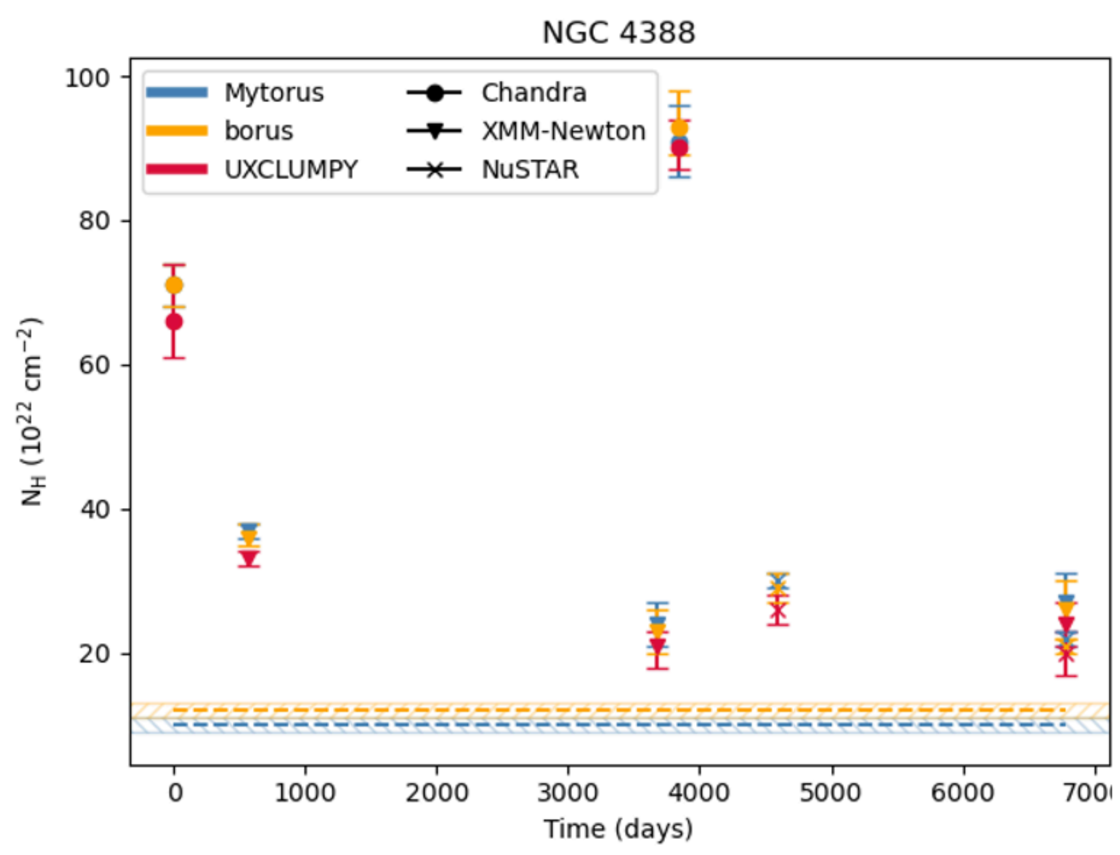

Figure 5: Variability of l.o.s. column density for a source in the sample of Torres-Albà+23, a 12-source sample of Compton thin BAT sources with NuSTAR coverage. The dashed, horizontal line is the best fit value for the average column density of the obscuring medium, while the shaded area represents the error range. The values of l.o.s. obscuring column density do not match the average column density of the torus, suggesting a decoupling between the material causing the obscuration and the one causing the reprocessed emission.

References: Marchesi+22 (ApJ, 935, 114); Pizzetti+22 (ApJ 936, 149); Torres-Albà+23 (arXiv: 2301.07138); Cox+23 (arXiv:2301.07142); Gaspari+20 (NatAs, 4, 10)

Need more details? Check the Clemson-INAF CT-AGN webpage!