Probing accretion/ejection flows in AGN via Fe K emission/absorption lines variability

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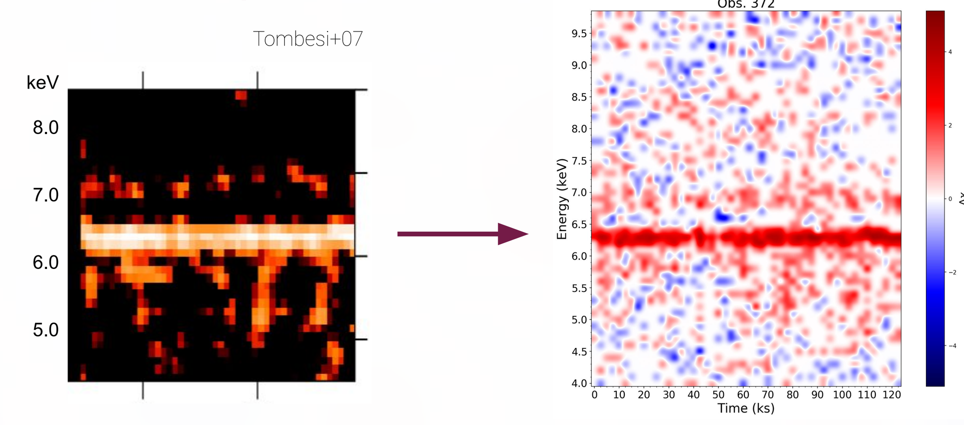
Abstract

The dynamics and geometry of the material close to the SMBH in AGN are still largely uncertain, both as regards the inflows via accretion disk and the outflows. The latter phenomena may have a fundamental role in the AGN feedback on the host galaxy, so it is important to understand their properties and extent.
The 4.0-10.0 keV energy band is the most suitable to study the innermost regions,, because it includes the Fe Kα fluorescence emission line at 6.4 keV, a fundamental proxy of the motions around the SMBH, and possibly Fe resonant absorption lines, features that indicate the presence of massive, relativistic (<v>~0.1c) disk winds (Ultra Fast Outflows, Tombesi et al. 2010), observed in about 50% of local AGN for which good quality data exist.
Both emission and absorption features show variability on a wide range of time scales (hours → years), probing phenomena at different distances from the central engine.
A simultaneous investigation of inflows and outflows may highlight some kind of correlation, that shall help to unravel the driving mechanisms of massive winds from the disk, still an open issue. Time-resolved spectral analysis is a key tool to investigate these phenomena.

Goals

- Search for variability patterns, to help understand why a particular feature is changing and the physics behind this.
- Find correlations and/or anticorrelations among patterns of different features, to indicate links among the phenomena producing them.

Residual Maps



Excess Map
only positive residuals
(Iwasawa+ 04, Turner+ 06, Tombesi+ 07, De Marco+ 09, Nardini+ 16, ...)

Residual Map
positive + negative residuals simultaneously
(Costanzo+ in prep.)

- Time resolved spectral analysis technique
- Useful to study short time scale variability on bright sources (few ks ↔ few Rg)
- How to produce the maps:
  1. Observation is sliced in time
  2. For each time-bin a simple continuum is fitted on the extracted spectrum and then subtracted
  3. Residuals of all time-bins are put together in the time-energy plane
- Positive and negative residuals are used together, in order to map the evolution of both emission and absorption features

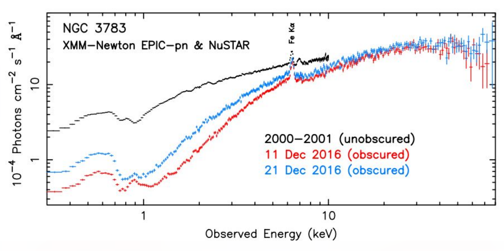
To confirm the reliability of the maps we searched for:

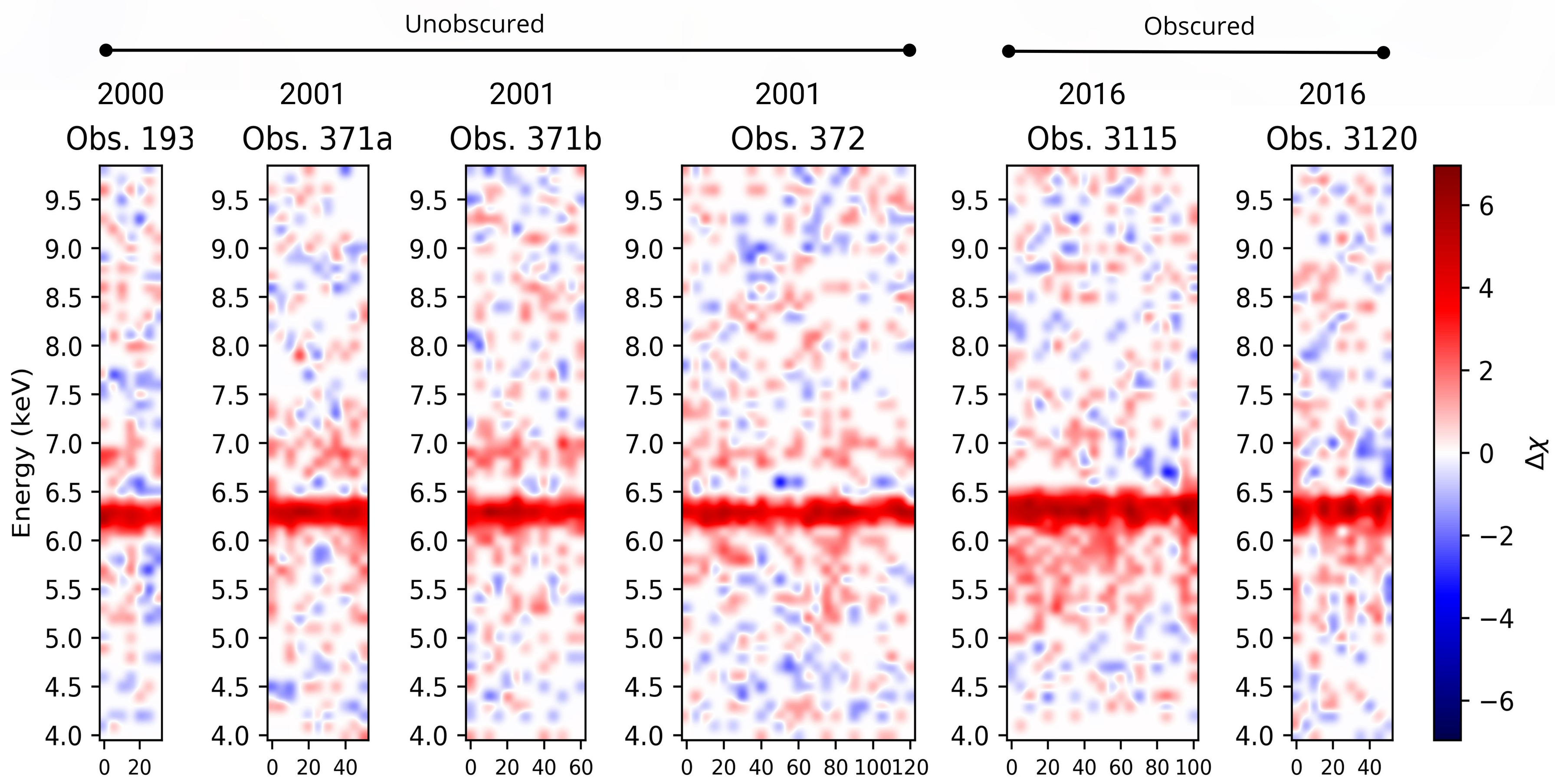
- Systematics: check for the balance between positive and negative pixels in the fitting bands on all residual maps → good balance in 4-5 keV band, slight predominance of positive residuals in the 7.5-10 keV band (~57%)
- Model-dependencies: search for possible correlation between the photon index of the power law and intensity of the narrow Fe Kα line intensity of the red wing (both measured by summing the residuals in the corresponding energy channels for each spectrum of each observation) →no strong correlation present: Narrow line vs Γ: ϱ = -0.036; Red wing vs Γ: ϱ =-0.006 (ϱ being the Spearman correlation coefficient)

The source

We analyzed **NGC 3783:**

- Seyfert 1
- >450 ks XMM-Newton exposures, taken in 2000, 2001, 2016
- z = 0.00973 (Theureau+ 98)
- $F_{4.5\text{-}12\ keV} \approx 3.3\ 10^{-11}$ erg /cm²/ s
- Temporary obscuration event due to clumpy medium with NH~10^{23} cm⁻² outflowing at few 1000 km/s in the BLR, lasting for a month (Mehdipour+ 17)

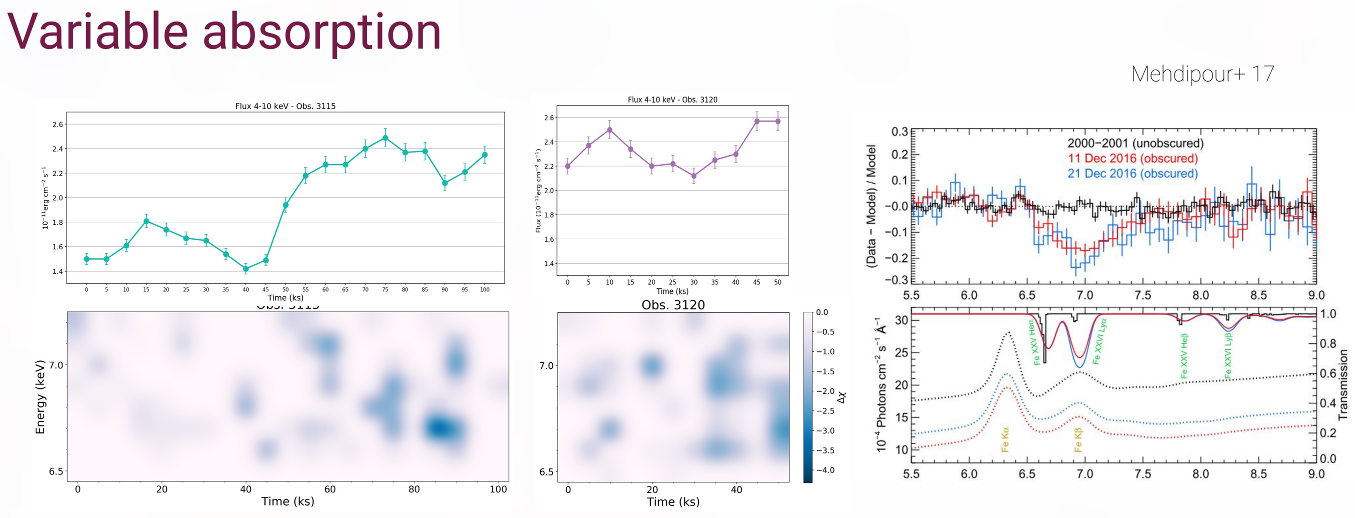




In the residual maps we find:

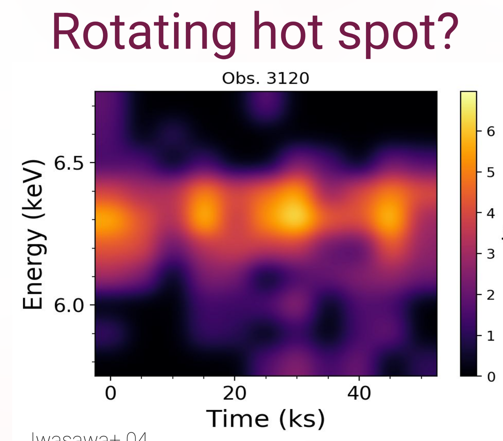
- Persistent Fe Kα line, with variable normalization
- Variable blend of Fe Kβ and ionized Kα, mostly present in 2000/2001 observations (Reeves+ 04)
- Variable excess from ~5.0 to 6.4 keV, stronger in 2016 data (due to complex absorption or relativistic deformation of the Fe Kα)
- Recurrent absorptions in 6.7-7.0 keV range

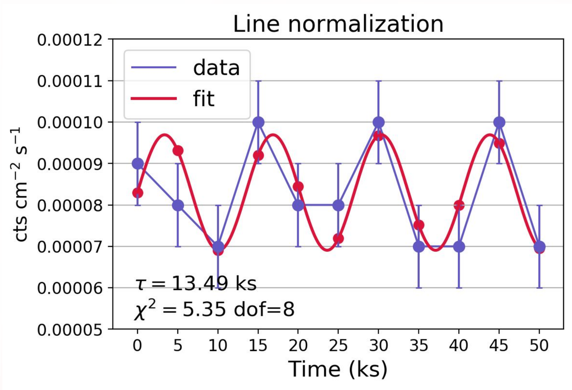
Variable absorption



The medium causing the ~ 6.6 - 7.0 keV absorption features in the 2016 observations seems to respond to flux variations in a time shorter than 5 ks (residual maps time-bin size).
Fe XXVI Lyα and Fe XXV Heα absorption lines appear resolved in the residual maps. Results are in good agreement with Mehdipour+ 17.

Rotating hot spot?



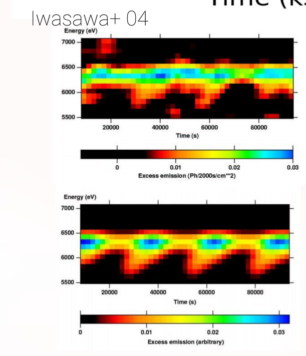


Bardeen+ 72

$$T_{orb} = 310 \left[a + \left(\frac{r}{r_g}\right)^{3/2} \right] M_7 \ s$$

13.5 ks ↔ 6 Rg

Iwasawa+ 04

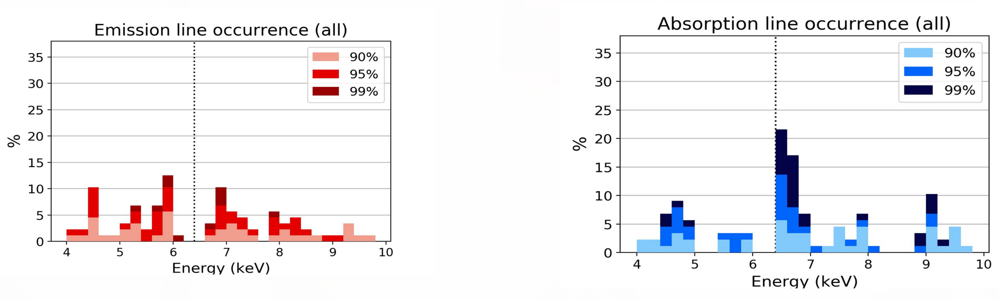


Last 2016 observation shows hints of modulated signal for the Fe Kα, similar to what was detected in NGC 3516 and explained as a rotating hot spot in the corona by Iwasawa+ 04. The period corresponds to Keplerian orbits at 6 Rg for a maximally rotating BH of 3 10^7 M⊙ (Peterson+ 04), but too few point to asses actual periodicity.

Blind search for features

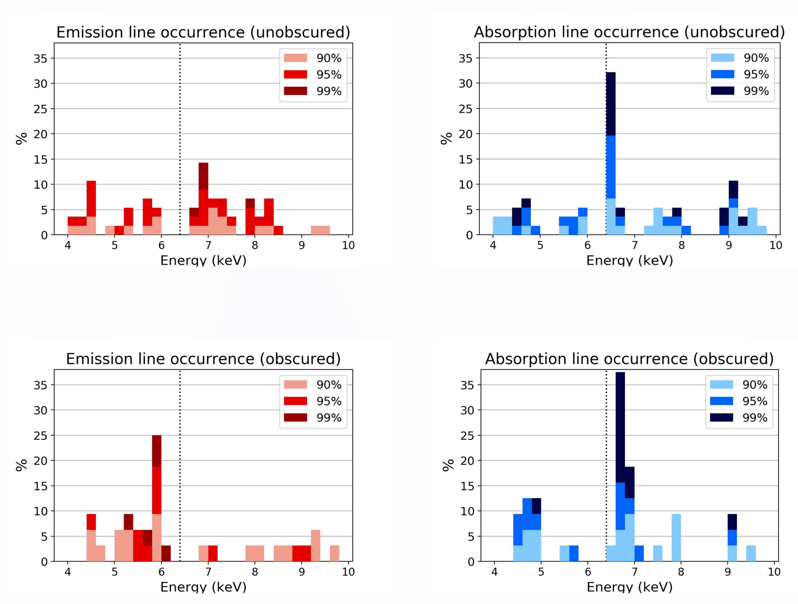
Assessing features significance from residual maps is not trivial, so we run an independent blind search for emission/absorption lines on the same time-bins.

- For each 5 ks spectrum a fit is performed with using a power law and a partial covering cold absorber, to account for the (eventually absorbed) continuum, and a narrow Gaussian, to account fo the Fe Kα (which we assume to be always present)
- A Gaussian line is added to the best fit, its significance is evaluated for all possible combinations of energy (4→10 keV) and normalization (-6.5 → +6.5 10^{-5} cts/cm²/s).The line width can vary between 10 and 500 eV, in order to consider both narrow and broader features.
- The features are counted to check how frequent they are and their distribution in energy, as shown below.



If the distributions are plotted separately for the unobscured and obscured observations, some differences appear evident:

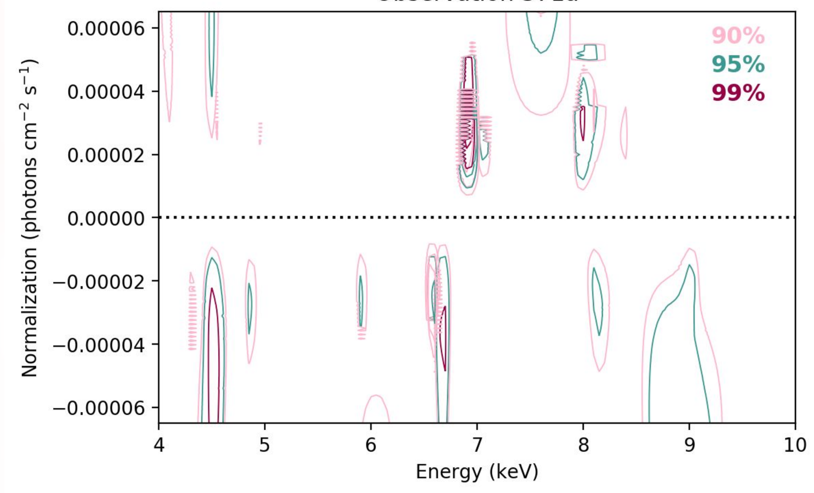
- In the 2000+2001 observations there is a peak in the emission line distribution around 7 keV, that is not present in 2016 data.
- The incidence of emission lines at energies between 5 and 6.4 keV is higher in the 2016 observations.
- The peak of absorption line distribution in 2016 observations is shifted to higher energies and broader.

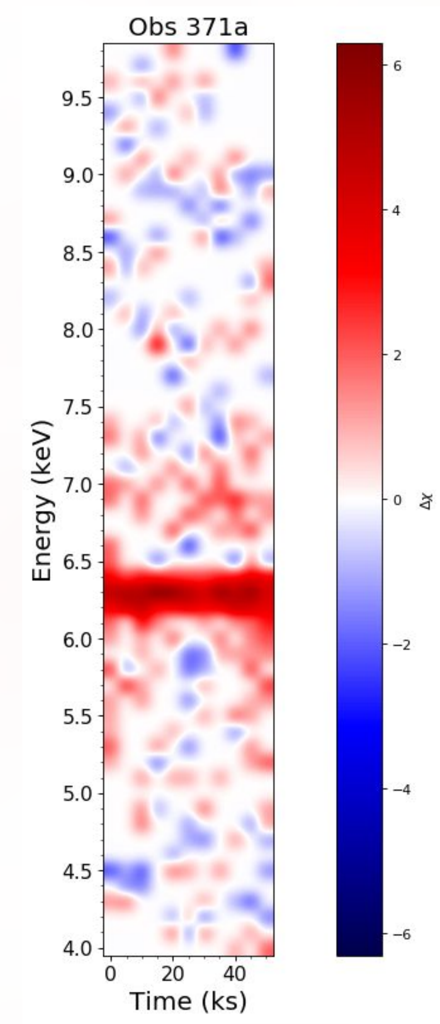


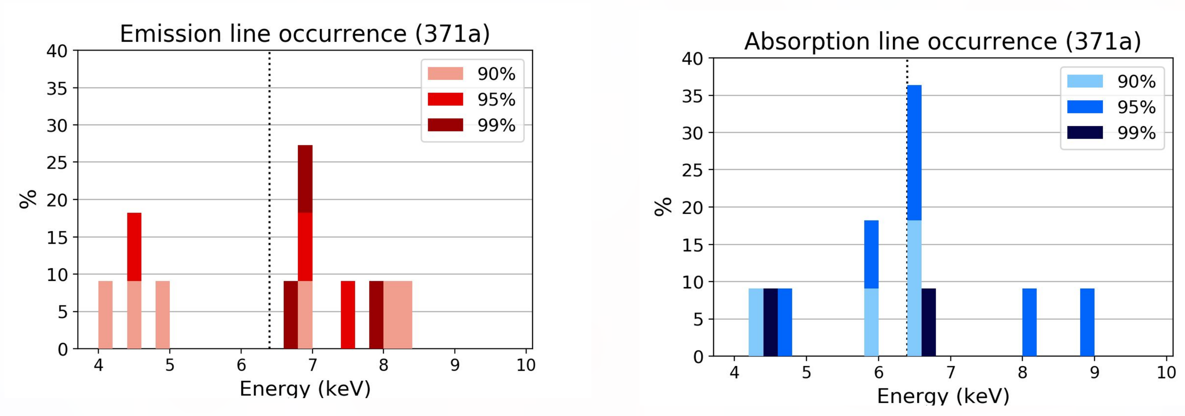
Combined search

Example of the combined method used on Observation 371a (2001).

Below we see the stacked contours of the 11 5ks slices of the observation and their distributions in energy. All of the features found via blind search are also present in the map, on the right. Visualizing them in the time-energy plane allows to (easily) look for evolution/patterns.







References: • Bardeen et al. 1972, ApJ 178, 347–370 • Theureau et al. 1998, A&AS, 130, 333 • Iwasawa et al. 2004, MNRAS 355, 1073–1079 • Peterson, et al. 2004, ApJ, 613, 682 • Turner et al. 2006, A&A 445, 59–67 • Tombesi et al. 2007, A&A 467, 1057–1063 • De Marco et al. 2009, A&A 507, 159–169 • Tombesi et al. 2010 A&A 521, A57 • Nardini et al. 2016, ApJ, 832, 45 • Mehdipour,et al. 2017, A&A, 607, A28