A Variable-Density Absorption Event in NGC 3227 mapped with *Suzaku* and *Swift*

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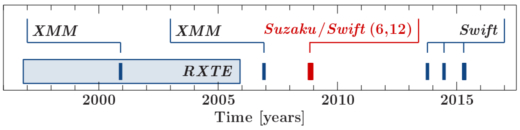
Abstract

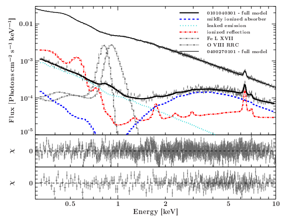
We present new time-resolved spectroscopy of an eclipse event in NGC 3227 from a *Swift* and *Suzaku* campaign over several weeks in 2008. Observations of variable X-ray absorption over the past decade support the paradigm of clumpy circumnuclear gas. Eclipse events across multiple Seyferts and timescales allow us to explore the properties of the clumps over a wide range of radial distances from BLR scales to beyond the dust sublimation radius. Time-resolved density profiles so far are rare, but suggest a range of shapes, including centrally-peaked, comet-shaped, or doubly-peaked ones. In the case of the 2008 event, we resolve the density profile to be highly irregular and variable, in contrast to a previous symmetric and centrally-peaked event mapped with RXTE in the same object. The data indicate a filamentary, moderately ionized cloud that covers 90% of the line of sight to the central engine. The UV data show significant reddening that is still unable to explain the measured X-ray column. We suggest a dust-free cloud. Our results for the first time show a variety of profile shapes within the same source and thus provide an excellent opportunity to further test models describing the formation and dynamics of individual clouds or filaments as well as their distances from the supermassive black hole (SMBH).

Archival observations



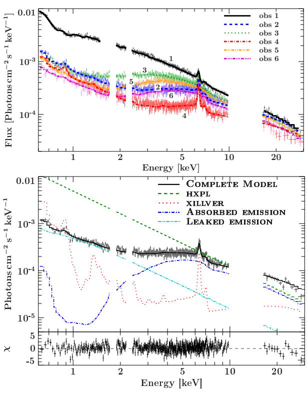
- **ASCA** (George et al., 1998): absorber is intermediately ionized and neutral, N_H variability between 1995/1998, cloudy absorber proposed
- ***XMM***, 2000 (Lamer et al., 2003): absorbed by neutral gas
- ***RXTE***, 2000/1 (Uttley & McHardy, 2005; Lamer et al., 2003): weekly pointings; resolved eclipse event, cloud passing through line of sight?
- ***XMM***, 2006 (Markowitz et al., 2009): less absorbed, high state, complex coexistence of 3 differently ionized absorbers (*XMM-Newton*/RGS)
- ***RXTE***, remainder of 1999-2005; ***Swift***, 2014/5: nearly unabsorbed

Variable cold absorber – historic *XMM* observations



Less absorbed (Markowitz et al., 2009) and heavily absorbed (Lamer et al., 2003) *XMM-Newton* spectra from 2006 and 2000. (Markowitz et al., 2009) identify **3 absorbers (mildly, intermediately, highly ionized;** WA$_1$, WA$_2$, WA$_3$; $\log \xi \sim -0.3, +1.5, +3.0$). The **spectral variability** is caused by **WA$_1$ (partial covering)**. We plot the model components of absorbed, leaked and reflected emission and two emission lines for the absorbed observation from 2000.

Variable intermed.-ionized absorber WA$_2$ in 2008 – I

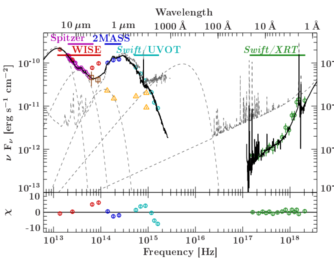


Top: Composite of all 6 *Suzaku* spectra with significant **spectral variability** of WA$_2$. Per observation there are 2 simultaneous *Swift* observations. **Bottom:** Data and model components of obs. 2 (complete model, hard X-ray power-law, ionized reflection, absorbed emission, leaked emission).

Simultaneous fit (**free**, **frozen**, **tied**) of all *Suzaku*/*Swift* observations with:

- Hard X-ray power-law (cutoffpl, norm, Γ) plus reprocessed power-law (xillver (García et al., 2013), norm, $\log \xi$, A_{Fe}) absorbed by
- partial covered intermediately (WA$_2$) ionized gas (zxipcf, f_{cvr}, N_H, $\log \xi$)
- fully covering mildly (WA$_1$) and highly (WA$_3$) ionized gas (zxipcf, N_H, $\log \xi$, $f_{cvr} = 1$)

IR–X-ray SED

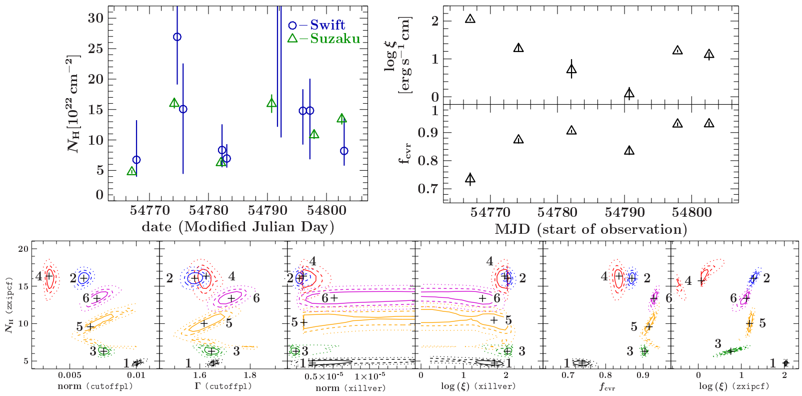


SED from the **MIR/NIR** over the **optical** to the **NUV** and **X-ray** band. The data are taken with varying apertures: **sub-arcsec scales**, sensitive to the AGN only (●: *Spitzer*; ▲ *HST*; ■: ground-based telescopes) and **arcsec scales**, including the host galaxy (WISE, 2MASS and *Swift*/UVOT). We describe the IR–UV spectrum made of composite model consisting of:

- three black-bodies in the IR → **dusty torus**
- stellar (Sa, SWIRE) + starburst template (Kinney et al., 1996) in the UV → **host galaxy**
- disk-blackbody ($T_{max} \sim 1 \times 10^5$ K at $r_{in} = 6\,r_g$) → **accretion disc**

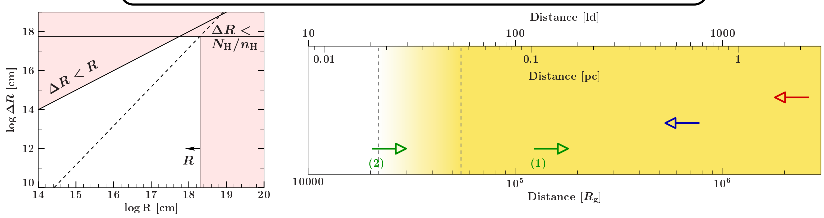
The data suggest that the **X-ray absorber is mainly non-dusty** and distinct from the **dusty UV absorber** due to its strong variability and high gas-to-dust ratio (100× Galactic). The latter is responsible for the reddening ($N_H = 0.12 \times 10^{22}$ cm^{-2} for N_H/A_V Galactic) and consistent with a **distant, lukewarm absorber** claimed by multiple authors, e.g., Crenshaw et al. (2001).

Variable intermediately-ionized absorber WA$_2$ in 2008 – II



Top, left: Complex, irregular and outstanding N_H–profile; **Top, right:** variability of ionization and covering fraction; **Bottom:** N_H–related contours for *Suzaku* data confirm strong variability; **Unique opportunities**: probing the nature and properties of the absorbing gas in the vicinity of the SMBH. Long (> 80 d), resolved and centrally peaked absorption events have been found for, e.g., Cen A (Rivers et al., 2011a) and NGC 3227 (Lamer et al., 2003) opposed to short (≲ 1 d) events of, e.g., NGC 1365 (Maiolino et al., 2010) or Mrk 766 (Risaliti et al., 2011). Suitable models to explore include, e.g., a **clumpy/cloudy BLR/torus** (Nenkova et al., 2008a,b) explored by Markowitz et al. (2014) using archival *RXTE* data but also MHD– or IR–driven accretion **disc winds** (Fukumura et al., 2010; Dorodnitsyn & Kallman, 2012).

Properties and distance of the variable absorber WA$_2$



Left: After Reynolds & Fabian (1994). **Right:** 2D sketch showing upper and lower distance constraints (arrows) for a putative cloud around the dust sublimation zone ($[0.4 - 1]R_d$, dashed lines). The distance constraints are derived from measured properties of the variable ionized absorber WA$_2$.

Upper distance for gas with a certain ionization by a central source: $R \leq L_{ion}/\xi N_H$ with $\xi = L_{ion}/n_e R^2$

Upper distance from the figure on the **left**. The $\log R - \log \Delta R$ space allows to derive better limits on R with:

- $\Delta R < N_H/n_e$ requiring the recombination time $t_{rec} \sim (n_e \alpha_{rec})^{-1}$ to be lower than the variability time scale (7 days)
- $\Delta R < R$ per definition

The intersection of the relation $\Delta R = N_H R^2 \xi / L_{ion}$ (dashed) with the horizontal limiting line for ΔR gives the limit on R.

(1) Lower distance for an orbiting spherical cloud on Keplerian orbits after, e.g., Lohfink et al. (2012). Here we use the width of the N_H profile (≳ 35 d) for the cloud-passing-time Δt.

(2) Combination of radial constraints (ionization) and constraints due to orbital motion ($\Delta t \gtrsim 35$ d) using the N_H profile.

Result: The absorber likely originates in the BLR with sublimated dust. A hypothetical spherical cloud in that region must be four orders larger than the limit for tidal shearing (Elitzur & Shlosman, 2006). The 2008 absorption event can be explained by a **filamentary cloud with variable internal density** passing the line of sight at ≳ 0.017 pc from the SMBH. The absorber is also consistent with the **clumpy-torus model** (Nenkova et al., 2008a,b) extended to below the dust sublimation region.

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