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

Tobias Beuchert[1,2], A. Markowitz[1,3], T. Dauser[1,2], F. Krauss[1,2], J. Garcia[6], G. Miniutti[4], A. L. Longinotti[5], M. Guainazzi[5], I. de La Calle Pérez[5], J. Wilms[1], M. Kadler[2]

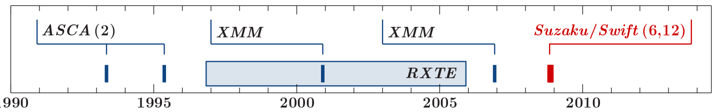
[1]Remeis Observatory/ECAP, Bamberg, Germany, [2]Lehrstuhl für Astronomie, Würzburg, Germany, [3]CASS, University of California, San Diego, USA; Alexander von Humboldt Fellow, [4]Centro de Astrobiología (CSIC-INTA), Madrid, Spain, [5]European Space Astronomy Centre of ESA, Madrid, Spain, [6]Harvard-Smithsonian Center for Astrophysics, Cambridge, USA

Email: tobias.beuchert@sternwarte.uni-erlangen.de

Abstract

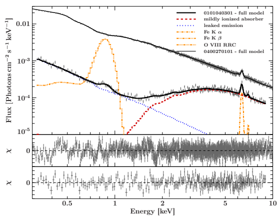
We present new time-resolved spectroscopy of an eclipse event in NGC 3227 from a *Swift* and *Suzaku* campaign over several weeks in 2008. Observations of variable X-ray absorption over the past decade support the paradigm of clumpy circumnuclear gas. Eclipse events across multiple Seyferts and timescales 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. 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



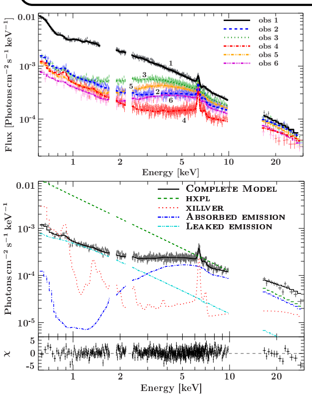
- **ASCA** (George et al., 1998): absorbed by intermediately ionized and neutral gas, N_H variability between 1995/1998, cloudy absorber proposed
- **XMM, 2000** (Lamer et al., 2003): absorbed by neutral gas
- **RXTE, 2000/1** (Uttley & McHardy, 2005; Lamer et al., 2003): weekly pointings; resolved eclipse 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)

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;** $\log\xi \sim -0.3, +1.5, +3.0$). The **spectral variability** is caused by **partial covering, mildly ionized/near-neutral gas**. We plot the model components of absorbed and leaked emission (dashed and dotted lines) plus three emission lines for the absorbed observation from 2000.

Variable intermediately-ionized absorber in 2008 – I

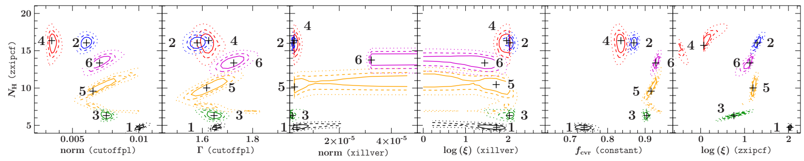


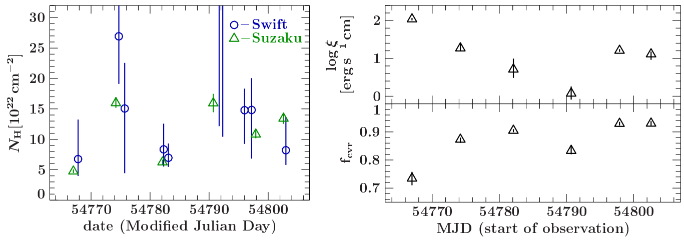
Top: Composit of all 6 *Suzaku* spectra with significant **spectral variability**. Per observation there are 2 simultaneous *Swift* observations. **Bottom:** Data and model components of obs. 2 (complete model, hard X-ray power-law, ionized reflection, absorbed emission, leaked emission).

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 ionized gas (`zxipcf`, f_cvr, N_H, $\log\xi$)
- fully covering mildly and highly ionized gas (`zxipcf`, N_H, $\log\xi$, $f_\mathrm{cvr}=1$)

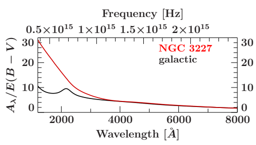
Variable intermediately-ionized absorber in 2008 – II

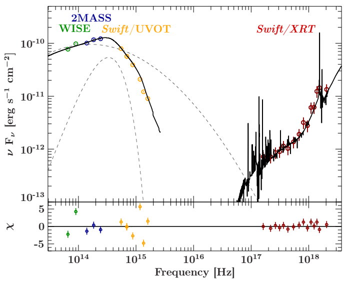




Top: Mostly inconsistent N_H–related contours of the simultaneously fitted model for *Suzaku* data. **Bottom:** Variability of the intermediately-ionized absorber. **Complex, irregular and outstanding** N_H**–profile** (left) and variability of ionization and covering fraction (right). Unique opportunities: 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 ($\lesssim$ 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).

IR–X-ray SED

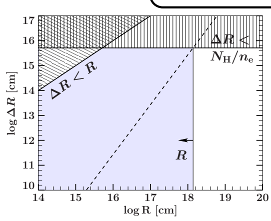


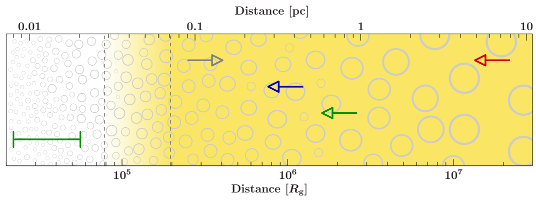


Left: Applied reddening curve for NGC 3227 (Crenshaw et al., 2001) (red) compared to the standard Galactic curve. **Right:** SED from the MIR/NIR (WISE) over the optical (2MASS, *Swift*/UVOT) to the NUV (*Swift*/UVOT) and X-ray band up to 10 keV (*Swift*/XRT).

We fit the IR–UV spectrum with a reddened phenomenological log-parabola and a black-body with $T \sim 4100\,K$ (dashed lines). The fitted extinction A_V corresponds to an X-ray absorbing column of $N_\mathrm{H} = 0.07 \times 10^{22}\,\mathrm{cm}^{-2}$, assuming the Galactic dust/gas ratio (Nowak et al., 2012). The X-ray column from the simultaneous *Swift*/*Suzaku* fit is at least 70 times larger. In contrast to the X-rays, we lack absorption variability in the UV. We propose the **X-ray absorber** to mainly consist of **non-dusty gas** below the dust sublimation region while the **UV absorber** that reddens the UV spectrum is mainly of a **dusty** nature (Crenshaw et al., 2001).

Properties and distance of the variable absorber





Left: After Reynolds & Fabian (1994). **Right:** 2D sketch showing the radial distribution of clumps that can potentially exist below and beyond the dust sublimation zone ($[0.4-1]R_\mathrm{d}$, dashed lines). Distance constraints from measured properties of the variable ionized absorber are marked by arrows.

- $v_\mathrm{outflow} > v_\mathrm{escape} = \sqrt{2GM_\mathrm{BH}/R}$ with $v_\mathrm{escape}^\mathrm{max}$ from the 2006 *XMM-Newton* obs. (Markowitz et al., 2009)
- Upper distance for gas with a certain ionization by a central source: $R \le L_\mathrm{ion}/\xi N_\mathrm{H}$ with $\xi = L_\mathrm{ion}/n_\mathrm{e}R^2$
- Upper distance from the figure on the **left**. The $\log R - \log \Delta R$ space allows to derive better limits on R with:
  - $\Delta R < N_\mathrm{H}/n_\mathrm{e}$ requiring the recombination time $t_\mathrm{rec} \sim (n_\mathrm{e}\alpha_\mathrm{rec})^{-1}$ to be lower than the variability time scale (7 days)
  - $\Delta R < R$ per definition

  The intersection of the relation $\Delta R = N_\mathrm{H}R^2\xi/L_\mathrm{ion}$ (dashed) with the horizontal limiting line for ΔR gives the limit on R.
- Upper distance for an orbiting spherical cloud on Keplerian orbits after Lohfink et al. (2012). We use the width of one hump of the N_H profile ($\sim$ 14 d) for the cloud-passing-time.
- Combination of radial constraints (ionization) and constraints due to orbital motion using the N_H profile.

Result: The absorber likely originates in the BLR with sublimated dust. Hypothetical spherical clouds 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 0.01–0.02 pc from the SMBH.**

Acknowledgments & References

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This research has made use of a collection of ISIS (Houck & Denicola, 2000) scripts provided by the Dr. Karl Remeis observatory, Bamberg, Germany at http://www.sternwarte.uni-erlangen.de/isis/.