A variable-density absorption event in NGC 3227 mapped with *Suzaku* and *Swift*

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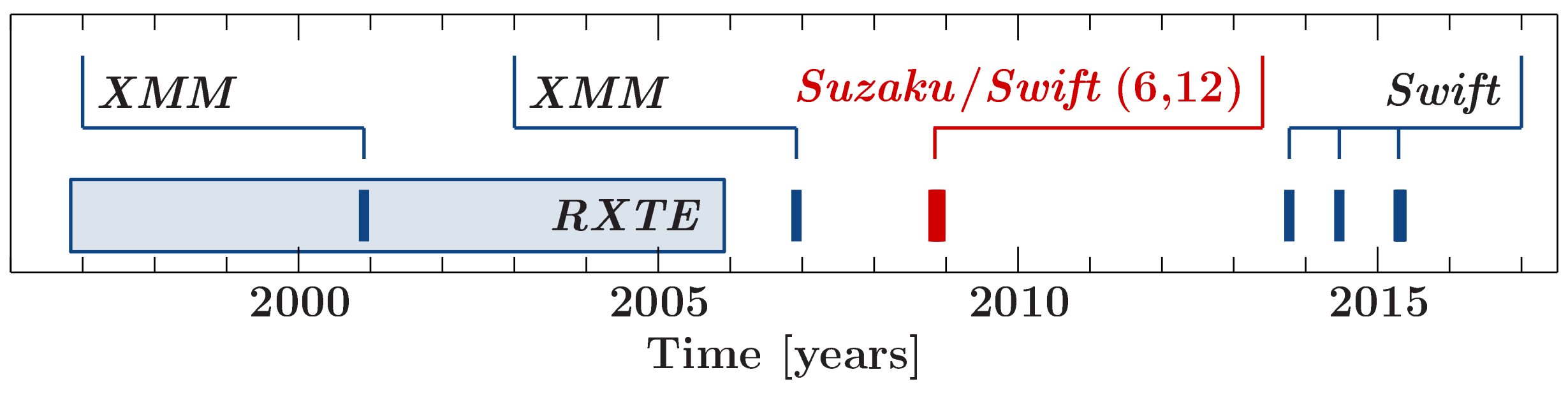
Abstract

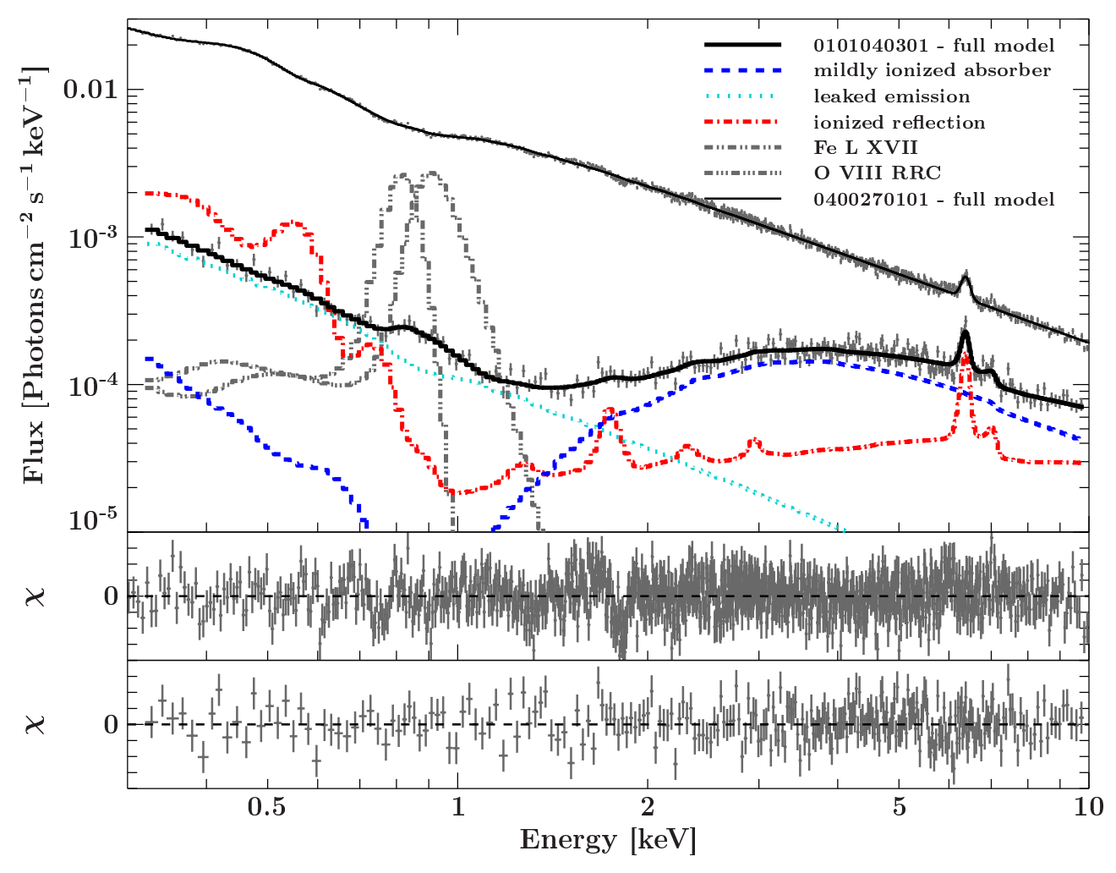
We present new time-resolved spectroscopy of an eclipse event in NGC 3227 from a *Swift* and *Suzaku* campaign over several weeks in 2008. Observations of variable X-ray absorption over the past decade support the paradigm of clumpy circumnuclear gas. Eclipse events across multiple Seyferts and timescales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



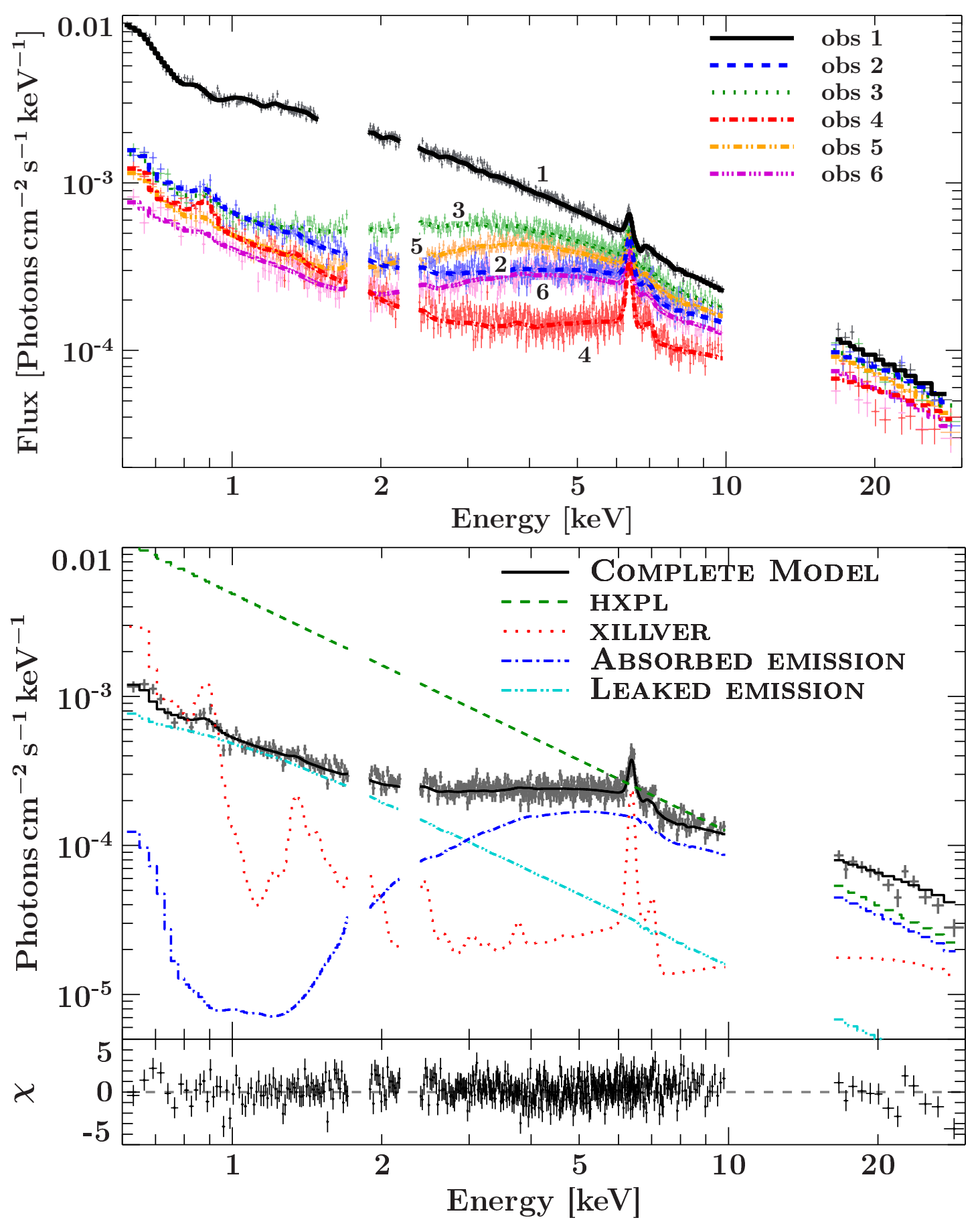
- **ASCA** (George et al., 1998): absorber is intermediately ionized and neutral, N_H variability between 1995/1998, cloudy absorber proposed
- ***XMM***, 2000 (Lamer et al., 2003): absorbed by neutral gas
- ***RXTE***, 2000/1 (Uttley & McHardy, 2005; Lamer et al., 2003): weekly pointings; resolved eclipse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

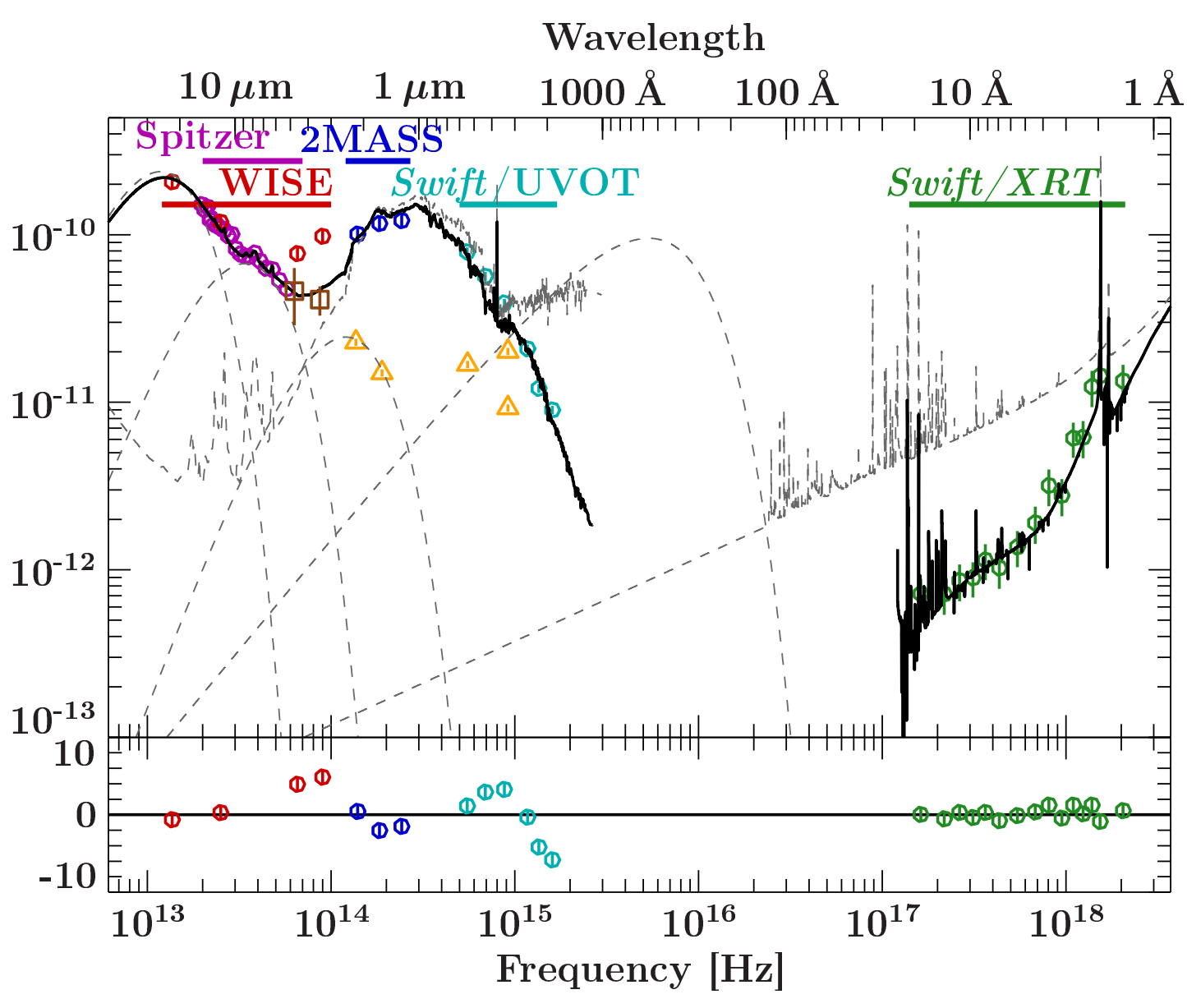


TOP: Composite of all 6 *Suzaku* spectra with significant **spectral variability of** WA$_2$. Per observation there are 2 simultaneous *Swift* observations. **BOTTOM:** Data and model components of obs. 2 (complete model, hard X-ray power-law, ionized reflection, absorbed emission, leaked emission).

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

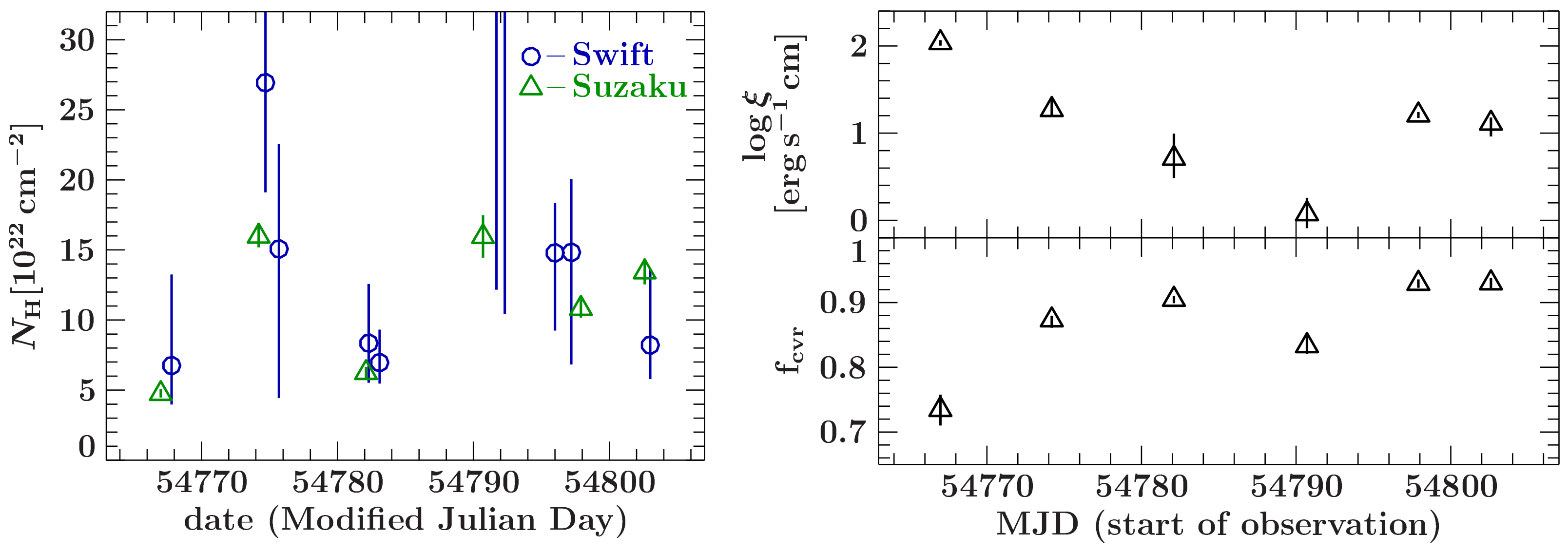


SED from the **MIR/NIR** over the **optical** to the **NUV** and **X-ray** band. The data are taken with varying apertures: **sub-arcsec scales**, sensitive to the AGN only (●: *Spitzer*; ▲ *HST*; ■: ground-based telescopes) and **arcsec scales**, including the host galaxy (WISE, 2MASS and *Swift*/UVOT).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

- data suggest: **X-ray absorber mainly non-dusty**, distinct from the **dusty UV absorber** due to strong variability and 100× Galactic gas-to-dust ratio
- **UV absorber** responsible for the reddening ($N_H = 0.12 \times 10^{22}$ cm^{-2} for N_H/A_V Galactic), consistent with the **distant, lukewarm absorber**, 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; **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$_2$

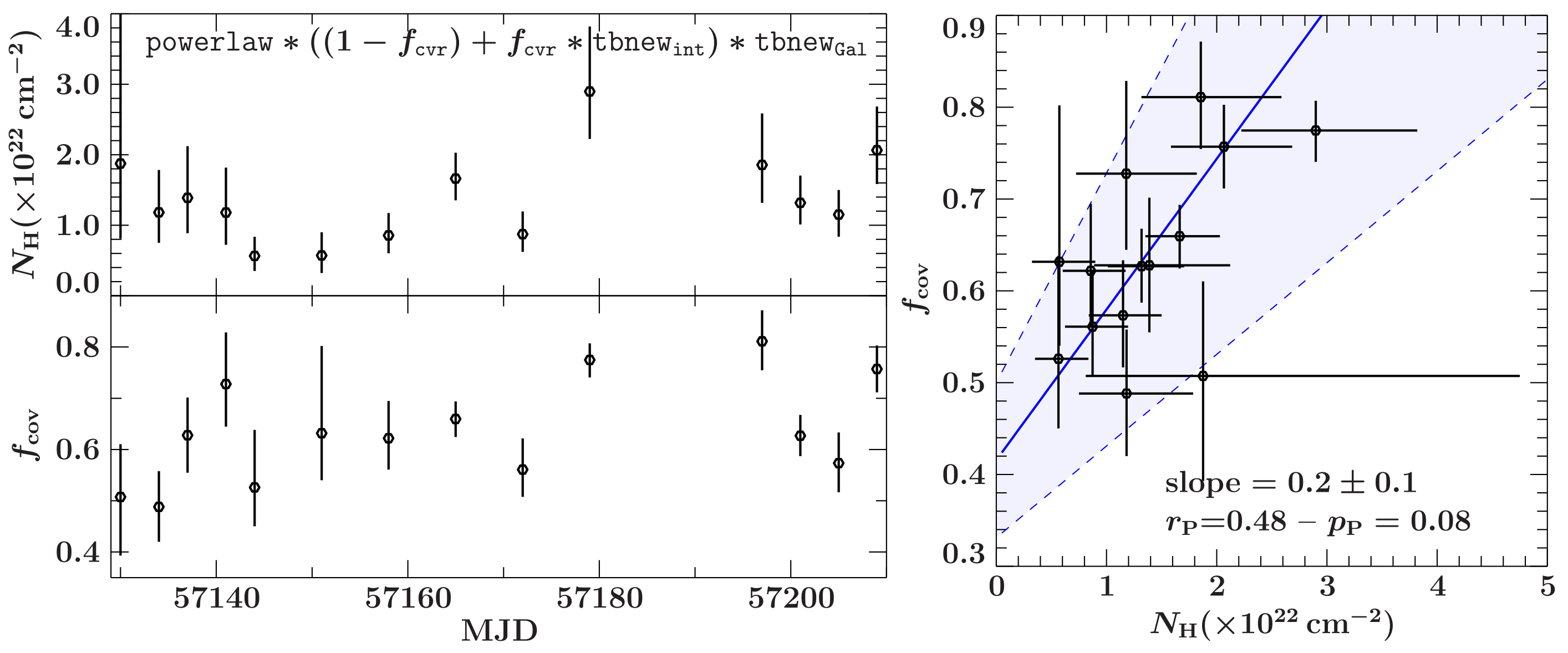
$\lesssim$ 2.2 pc for gas with a certain ionization by a central source: $R \leq L_{ion}/\xi N_H$ with $\xi = L_{ion}/n_e R^2$
$\lesssim$ 0.65 pc from

- $\Delta R < N_H/n_e$ 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
- $\Delta R = N_H R^2 \xi / L_{ion}$

$\gtrsim$ 0.1 pc for an orbiting spherical cloud on Keplerian orbits after, e.g., Lohfink et al. (2012).
We use the entire width of the N_H profile (≥ 35 d) for the cloud-passing-time Δt.
$\gtrsim$ 0.017 pc from radial constraints (ionization) and constraints due to orbital motion ($\Delta t \gtrsim 35$ d) using the N_H profile.

- origin of the absorber: likely the **BLR** below the dust sublimation region (0.018–0.046 pc)
- hypothetical spherical cloud ~four orders larger than the limit for the tidal shearing (Elitzur & Shlosman, 2006)
- 2008 event explainable by a **filamentary cloud with variable internal density** passing the line of sight at $\gtrsim$ 0.017 pc from the SMBH
- absorber also consistent with the **clumpy-torus model** (Nenkova et al., 2008a,b) extended to below the dust sublimation region.

Recent Swift monitoring in 2015



The figures show data that we obtained from a recent *Swift* monitoring. **LEFT:** Evolution of N_H and covering fraction f_{cvr} with time. The coronal power-law slope is tied between all observations, with a value of 1.63. **RIGHT:** Tentative evidence (92% conf. level) for a correlation between N_H and f_{cvr}, which is qualitatively consistent with a clumpy torus model.

- again consistent with the **distant, lukewarm absorber** as baseline column, e.g., Crenshaw et al. (2001)
- correlation of N_H and f_{cvr} consistent with "clumpy torus" model, while $\gtrsim$ 50% of the line of sight is always covered
- possible "anti-eclipse" around MJD 57150 due to a transiting under-dense region, see also Markowitz et al. (2014)

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/.