First Statistical Tests for Clumpy-Torus Models: Constraints from RXTE monitoring of Seyfert AGN

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X-ray eclipse events in the RXTE archive

Survey of X-ray eclipse events in the RXTE archive using large samples of Type I & Compton-thin Type IIs, and probing $\Delta N_{\rm H}$ on timescales from days to years

Markowitz, Krumpe, & Nikutta 2014, MNRAS 439 1403:
Identify eclipse events due to transiting clouds
$\rightarrow$ locations; constraints on $N_{\rm H}$ or $\tau_{\rm V}$ of individual clouds; eclipse probabilities

Nikutta, Krumpe, & Markowitz, in prep.:
$\longrightarrow$ cloud sizes; cloud stability;
$\longrightarrow$ Bayesian methods to constrain Clumpy-model parameters q, N_0

MKN2014: sample selection

Used the vast archive of (dozens of) Seyferts monitored with RXTE. (many sources: 100s–1000s of visits)

HR light curves and TR spectroscopy to probe $\Delta N_{\rm H}$ on timescales from **0.3 d – 16 yr** in **37 type Is, 18 Compton-thin type IIs**

(lowly-ionized clouds, $N_{\rm H} \sim 10^{22.3-25}$ cm^{-2} only)

(complementary to short-term $<$ 1-d and/or ionized eclipses by Risaliti et al.)

Overview of Results

- Eight "secure" events in five Type I Seyferts

Four "secure" events in three Type IIs

Four weak, "candidate" events in three Type Is

- Durations span $\sim$ 12 hr to $\sim$ 550 d.

- $\Delta N_{\rm H}$ spans $4 - 26 \times 10^{22}$ cm^{-2}

No Compton-thick eclipse events!

($\rightarrow \tau_{\rm V} \sim 20 - 130$; agrees with models & IR SED fits)

- **Inferred Cloud Locations:** $\sim 0.3 - 140 \times 10^4 R_{\rm g}$

– 7/8 objects: Commensurate with outer BLR or inner dusty torus (IR-mapped structures)

– 8th object, NGC 5506: commensurate with inner BLR.

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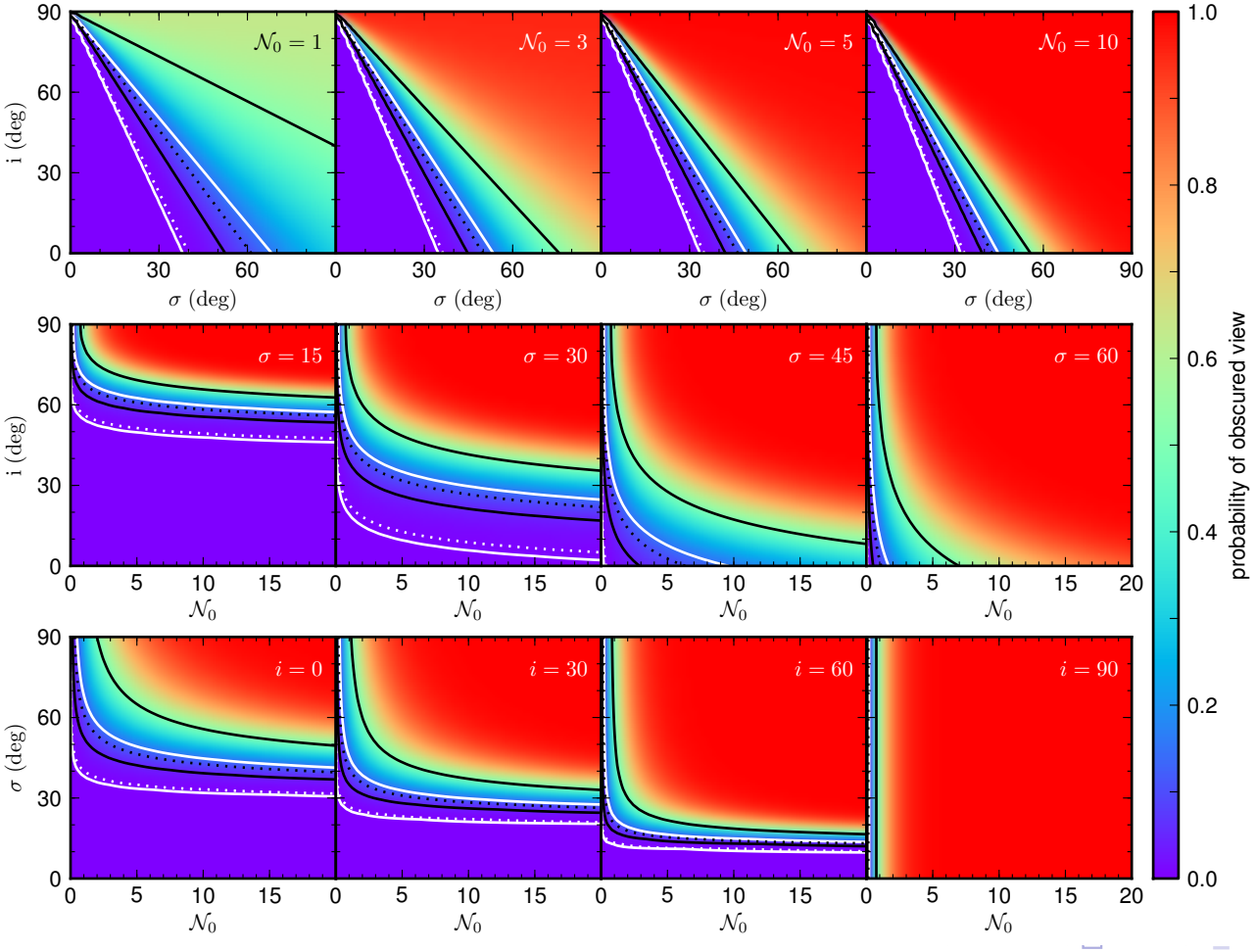
Probability of witnessing an eclipse

$\overline{P_{\rm ecl}}$ (type Is) = 0.007 (0.004–0.161)

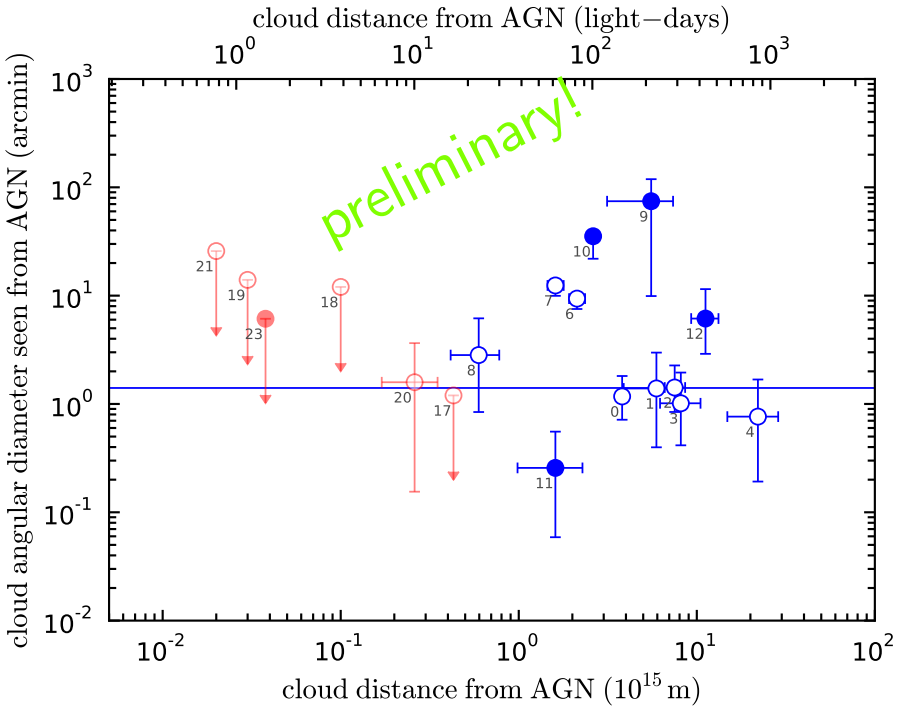
$\overline{P_{\rm ecl}}$ (type IIs) = 0.110 (0.052–0.520)

Compare $\overline{P_{\rm ecl}}$ to predictions as a function of $\{N_{\rm eq}, \sigma, i\}$:



Cloud angular diameter as seen from central source

Nikutta, Krumpe, & Markowitz, in prep.:



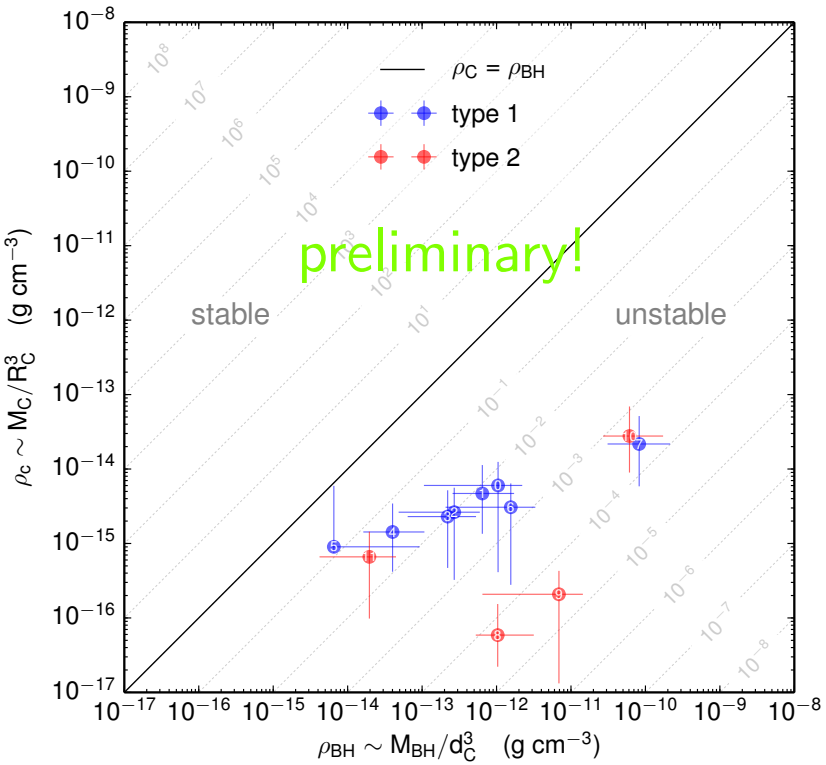
- Physical cloud size increases linearly with distance?

Disk fragmentation processes (Amaro-Seoane & Chen 2014)?

- $\sim 4 \times 10^7 / 8 \times 10^7$ **clouds (BLR + TOR)** needed for median covering factors for Is/IIs

Clouds are typically unstable against tidal shearing:

Nikutta, Krumpe, & Markowitz, in prep.:



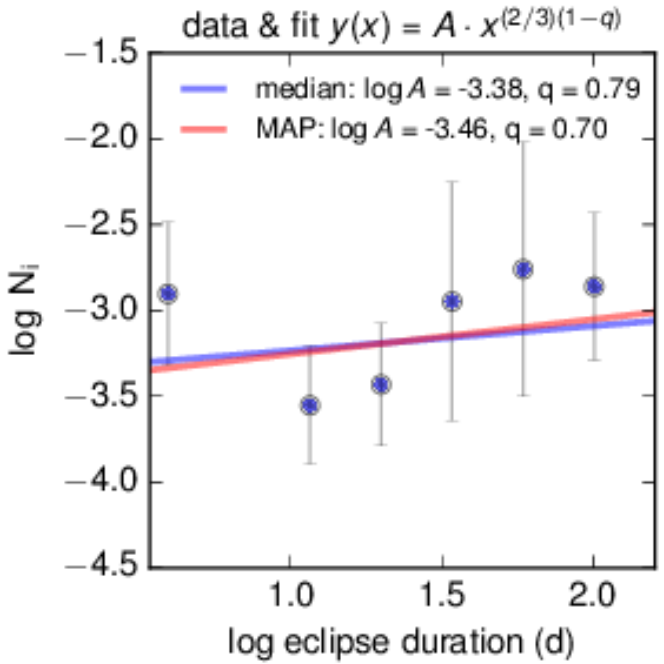
- Clouds underdense by 10^{1-3} to resist tidal disruption via self-gravity
- Suggests external confinement: ambient intercloud medium?

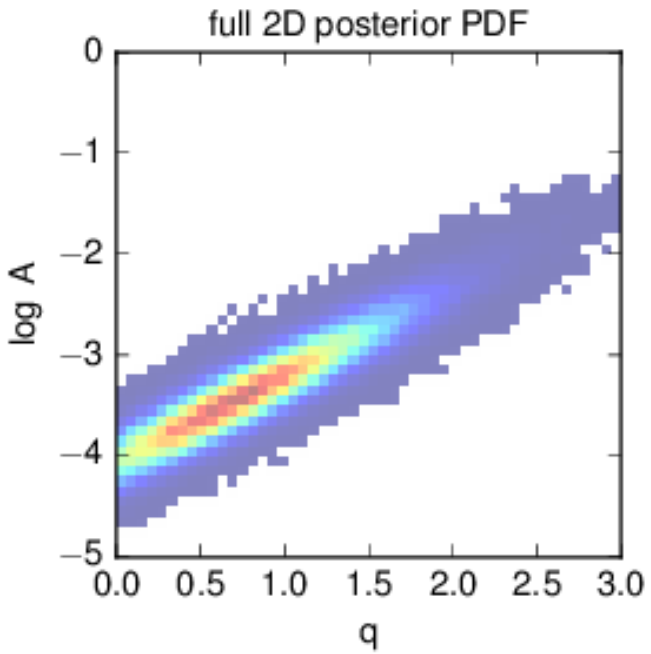
Magnetic fields? (e.g., Elitzur & Shlosman 2006) $B \sim$ **mG** sufficient

MCMC fitting & Bayesian parameter estimation: q

Considering all (secure) type-1 clouds as from a single source: $q = 0.79^{+0.55}_{-0.47}$, in agreement with Ramos Alemeida (2011) median value $q = 0.8 \pm 0.2$

Constraints on N_0, Y: still in progress....



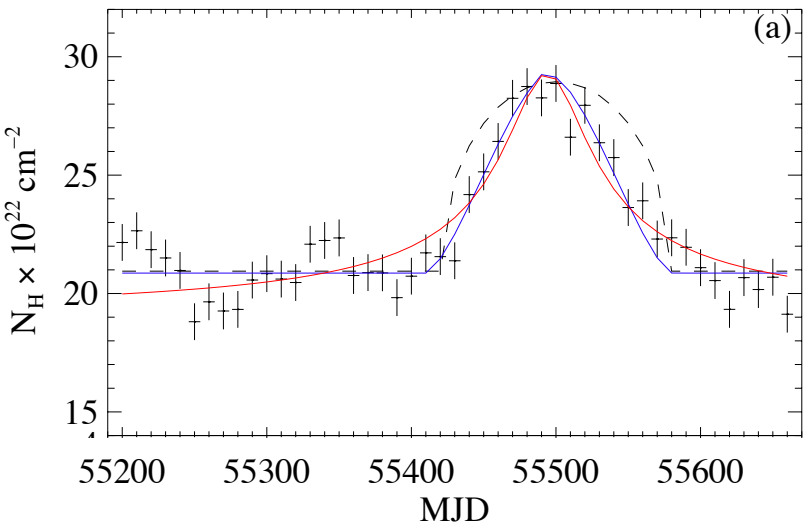


Range in profile shapes for individual clouds

Centaurus A
Rivers, Markowitz & Rothschild (2011, ApJ, 742, L29)

6-month long eclipse, 2010–1

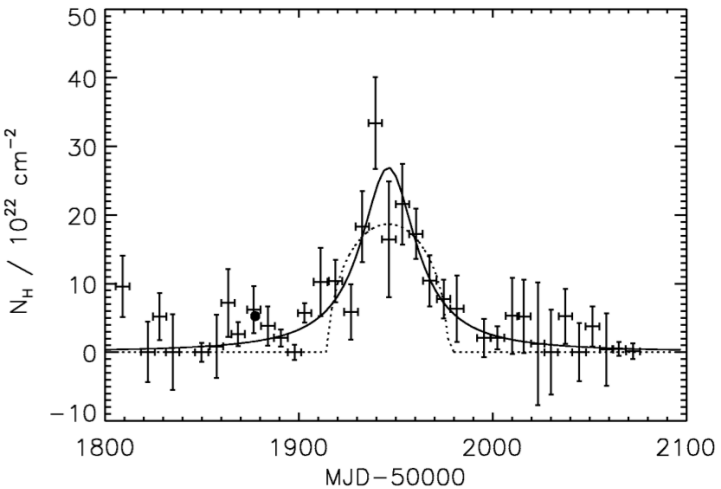
$\Delta N_{\rm H} = 8 \times 10^{22}$ cm^{-2}



NGC 3227
Lamer et al. (2003)

~80 day eclipse, 2000–1

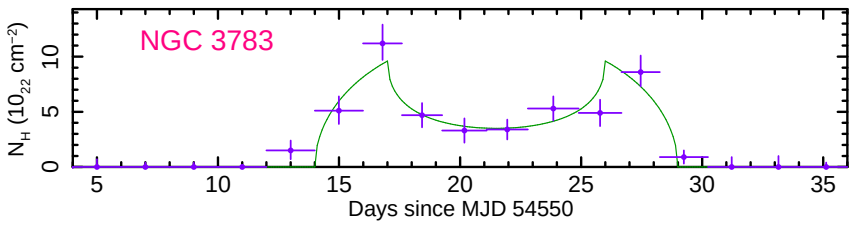
$\Delta N_{\rm H} = 2.6 \times 10^{23}$ cm^{-2}

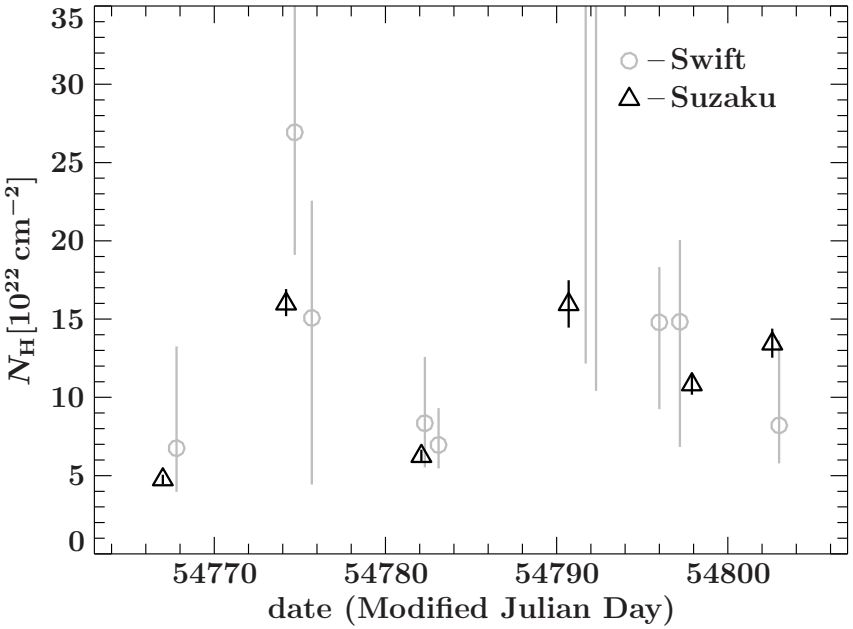


See also: Sanfrutos et al. (2013), SWIFT J2127.4+5654

Range in profile shapes for individual clouds

(Markowitz+14)



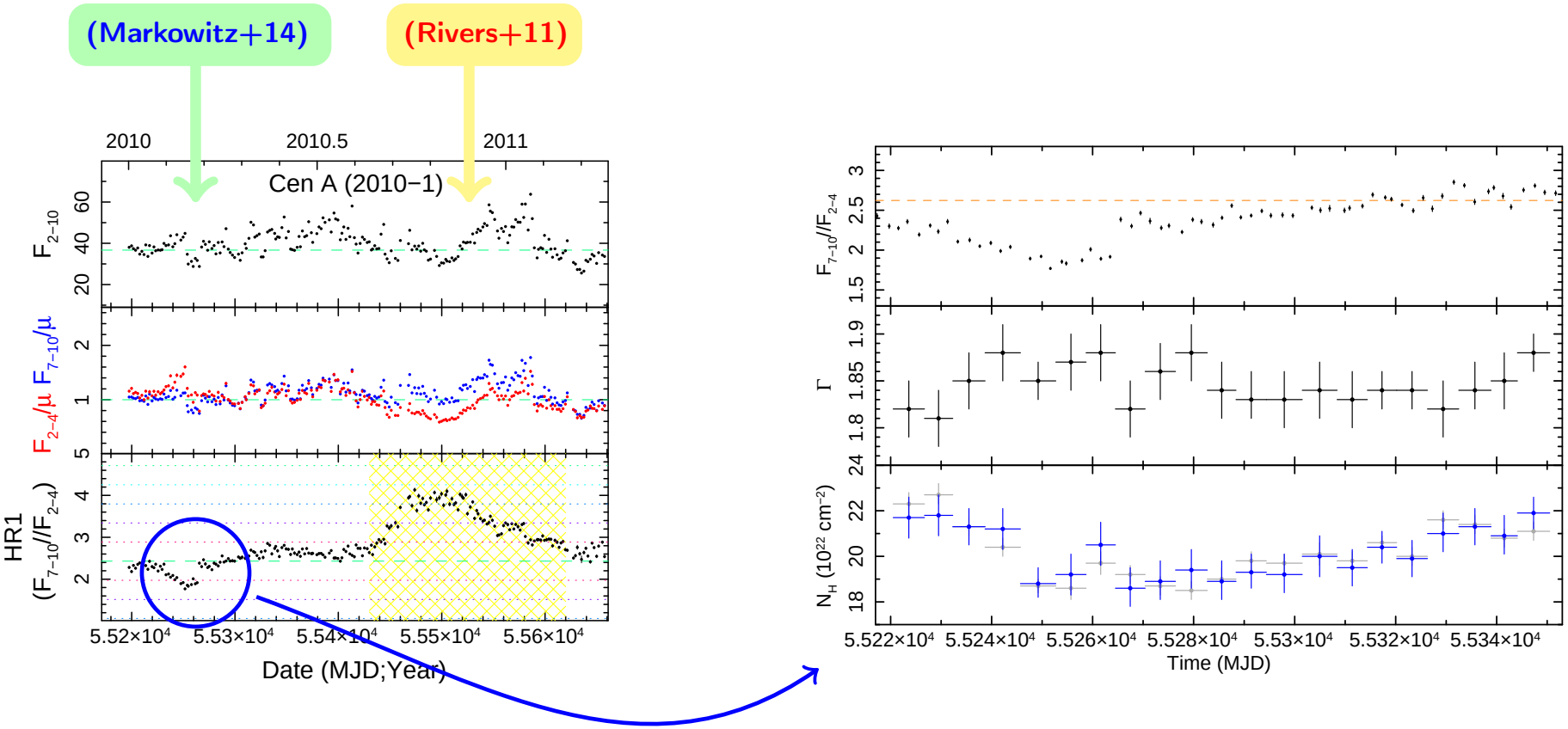


Beuchert+15, NGC 3227: SEE POSTER!

See also: "Comet" and "anti-comet" shaped profiles in NGC 1365 (E. Rivers+15, Maiolino+10)

MHD- or IR-driven dusty winds relevant? (Fukumura+10, Moscibrodzka+13, etc.)

Cen A: Small variation in "baseline" $N_{\rm H}$ (indep. of clumps)



$\sim$ 80-d transit by an underdense region.

$N_{\rm H,baseline}$ originates in not-completely-homogeneous medium close to the BH?

Summary

Multi-timescale (days–years), sustained, X-ray spectral monitoring of 55 Seyferts with RXTE → First systematic X-ray constraints on a new generation of *clumpy*-absorber models.

- Markowitz, Krumpe, & Nikutta (2014):

⊙ triple the number of eclipse events observed with RXTE: 12 secure events in 8 Seyferts; durations span $\lesssim$ 1d to $\gtrsim$ 1 yr.

⊙ No Compton-thick eclipses; $N_{\rm H,X}$ ($4 - 26 \times 10^{22}$ cm^{-2}) agrees with $\tau_{\rm V}$ values used in CLUMPY.

⊙ X-ray absorbing clouds commensurate with inner TOR torus or outer BLR in 7/8 sources

⊙ Probabilities to observe sources in eclipse → constraints for type Is/IIs in { $N_{\rm eq}$, σ, i } parameter space

Summary, cont'd:

Multi-timescale (days–years), sustained, X-ray spectral monitoring of 55 Seyferts with RXTE $\rightarrow$ First systematic X-ray constraints on a new generation of *clumpy*-absorber models for AGN.

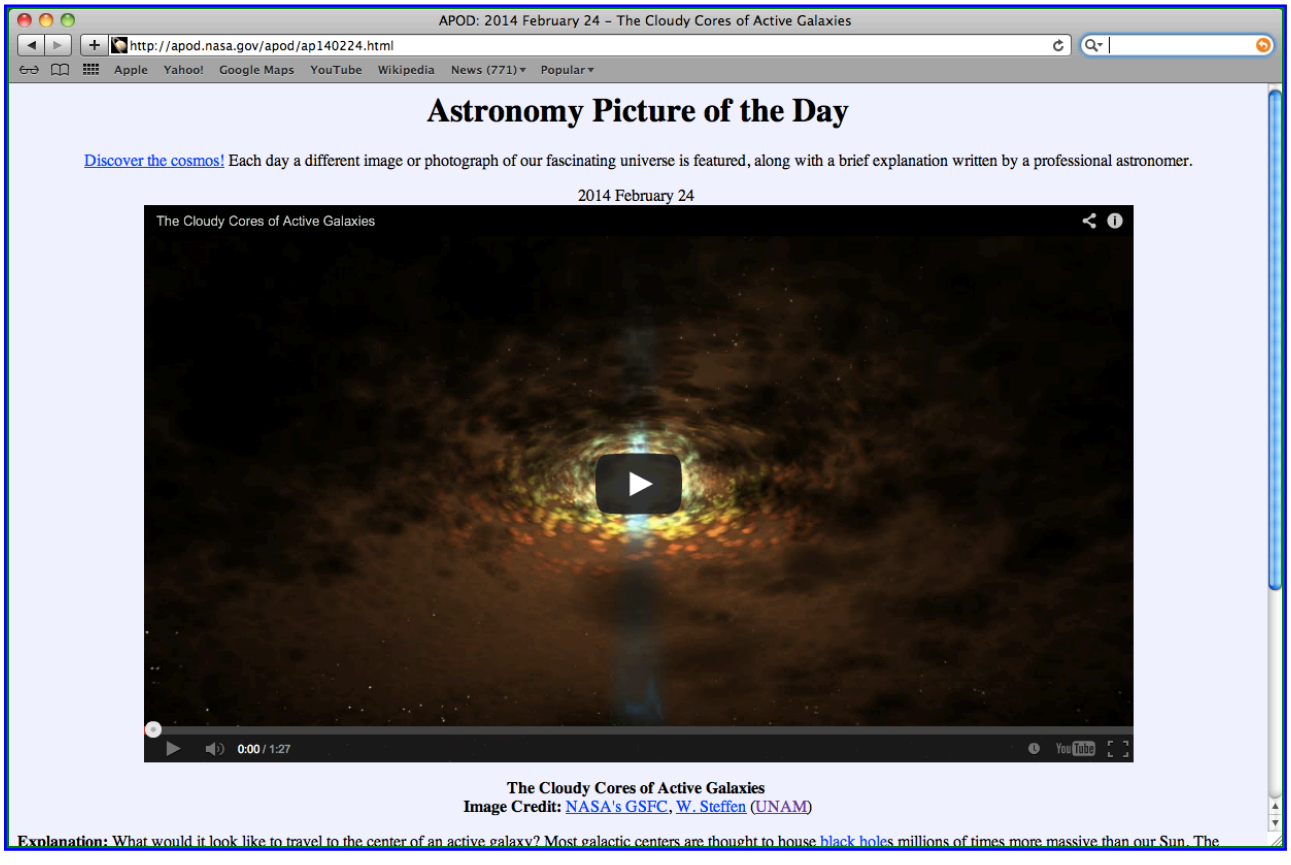
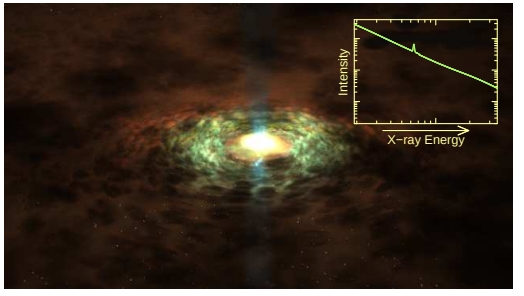
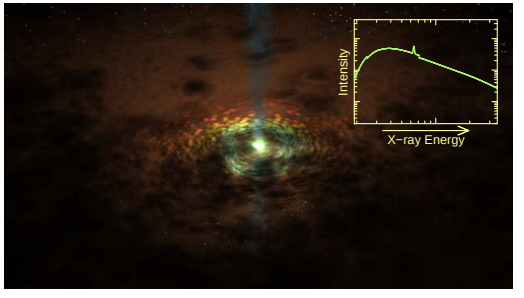
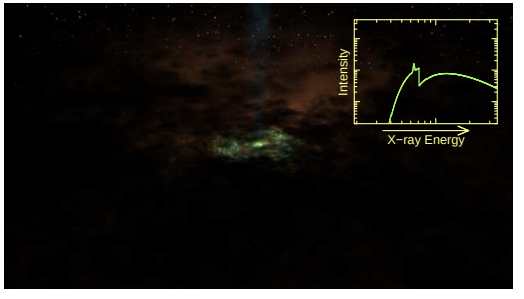
- Nikutta, Krumpe, & Markowitz, in prep.:

$\odot$ Clouds likely confined by external pressure ($B \sim$ few mGauss)

$\odot$ Constraints on cloud sizes; implications for cloud formation?

$\odot$ Bayesian fits to constrain q, N_0

- We're seeing a wide range of time-resolved $N_{\rm H}(t)$ profiles: Irregular profiles – filamentary/turbulent winds?

Press Release, Febr. 2014:

Video Animation by Wolfgang Steffen, UNAM, Ensenada, Mexico: