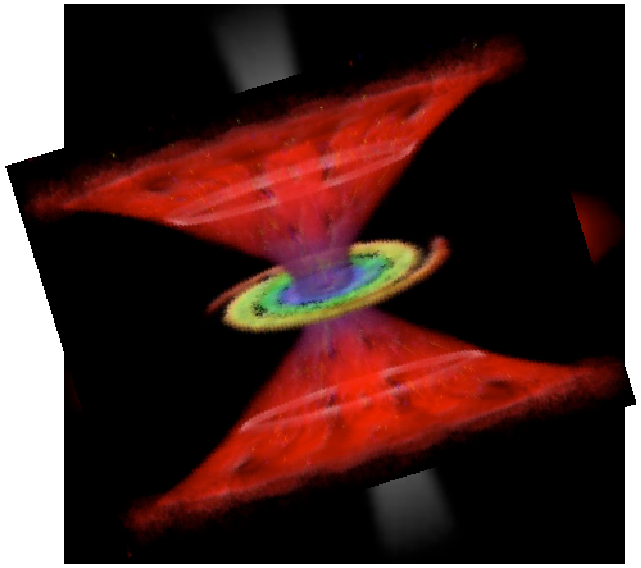
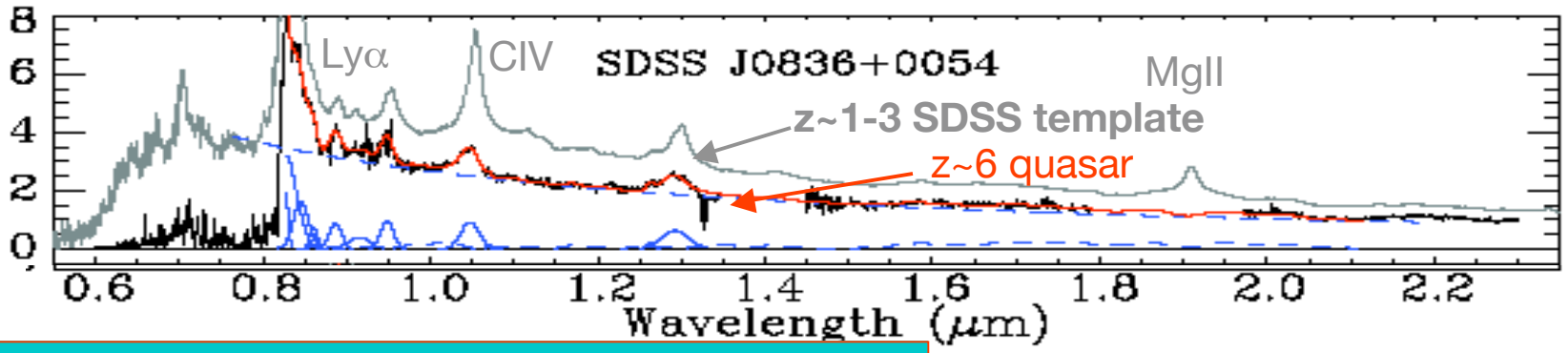
AGN Structure:
Clues from X-ray Spectral Variability

Martin Elvis
Harvard-Smithsonian Center for Astrophysics
with
Guido Risaliti, Yair Krongold, Fabrizio Nicastro
and many others…

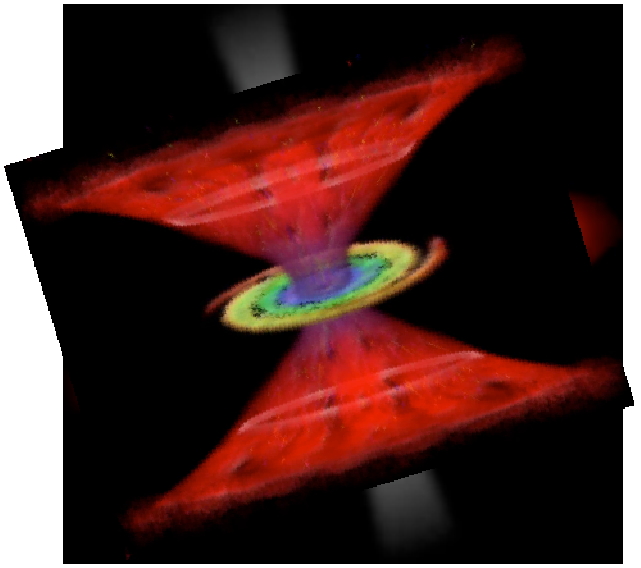


Structure of Quasars & AGNs

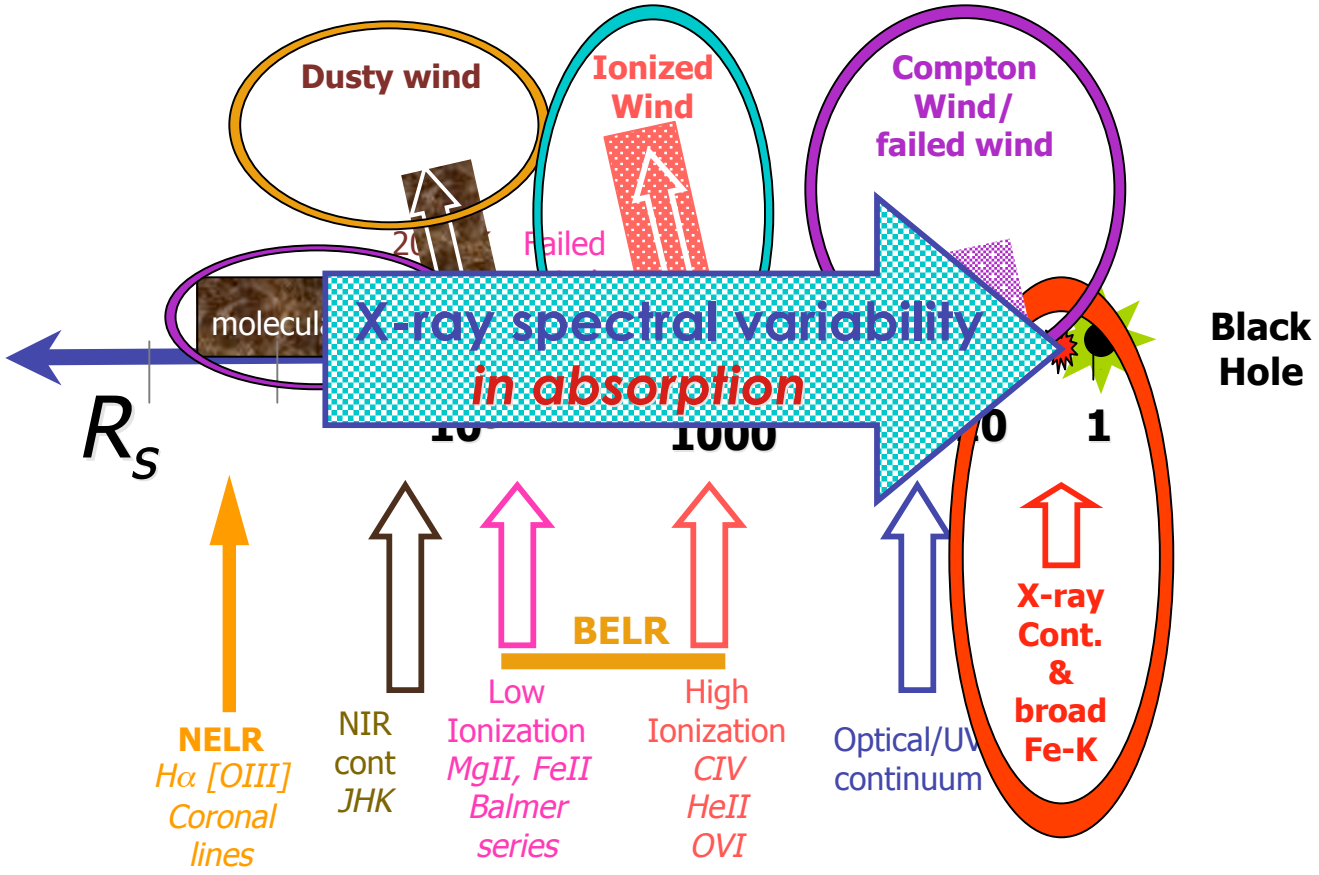
Jiang et al., 2007, ApJL, 666, L9, VanDen Berk et al., 2001,AJ,122, 549



- AGN SEDs, spectra same
  - Over 6 decades of Luminosity
  - Over 13 Gyr of cosmic time
- Unchanging structure
  - Determined within BH sphere of influence: "The Nucleus"
- Complex phenomenology
  - Non-trivial structure
- Answers affect cosmic feedback



Scales of Quasar/AGN Components

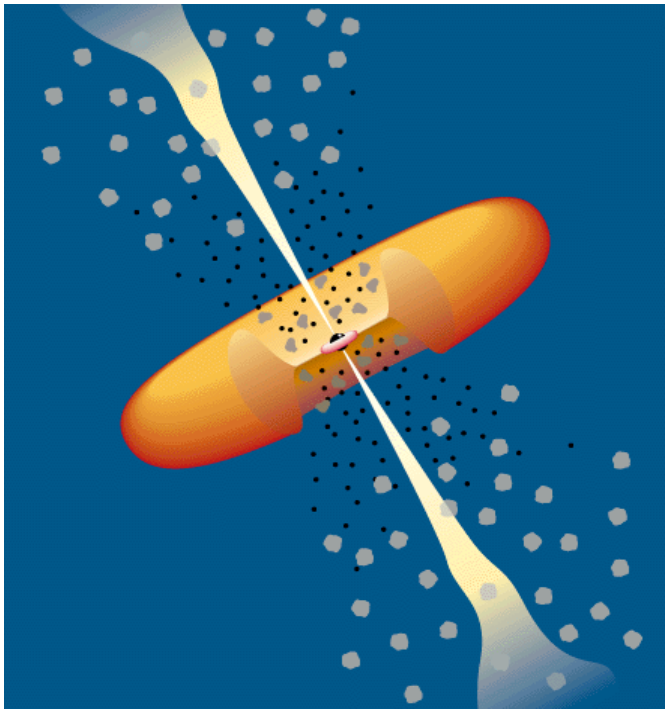


$10^5 R_S$ The Dusty Molecular Torus

- Flattened optical & X-ray obscuring region: type1➡type2 AGN = **'Unified Scheme'**
- $R_{sub} = 1.3\ L_{46}^{0.5}\ T_{1500}^{-2.8}$ pc
  $= \mathbf{1.3x10^5}\ L_{0.1}^{0.5}\ M_8^{0.5}\ T_{1500}^{-2.8}\ \mathbf{R_S}$
- $N_H \sim 10^{24} cm^{-2}$; H/R~1
- Puffed up by IR on dust?

Krolik 2007, Murray 2007

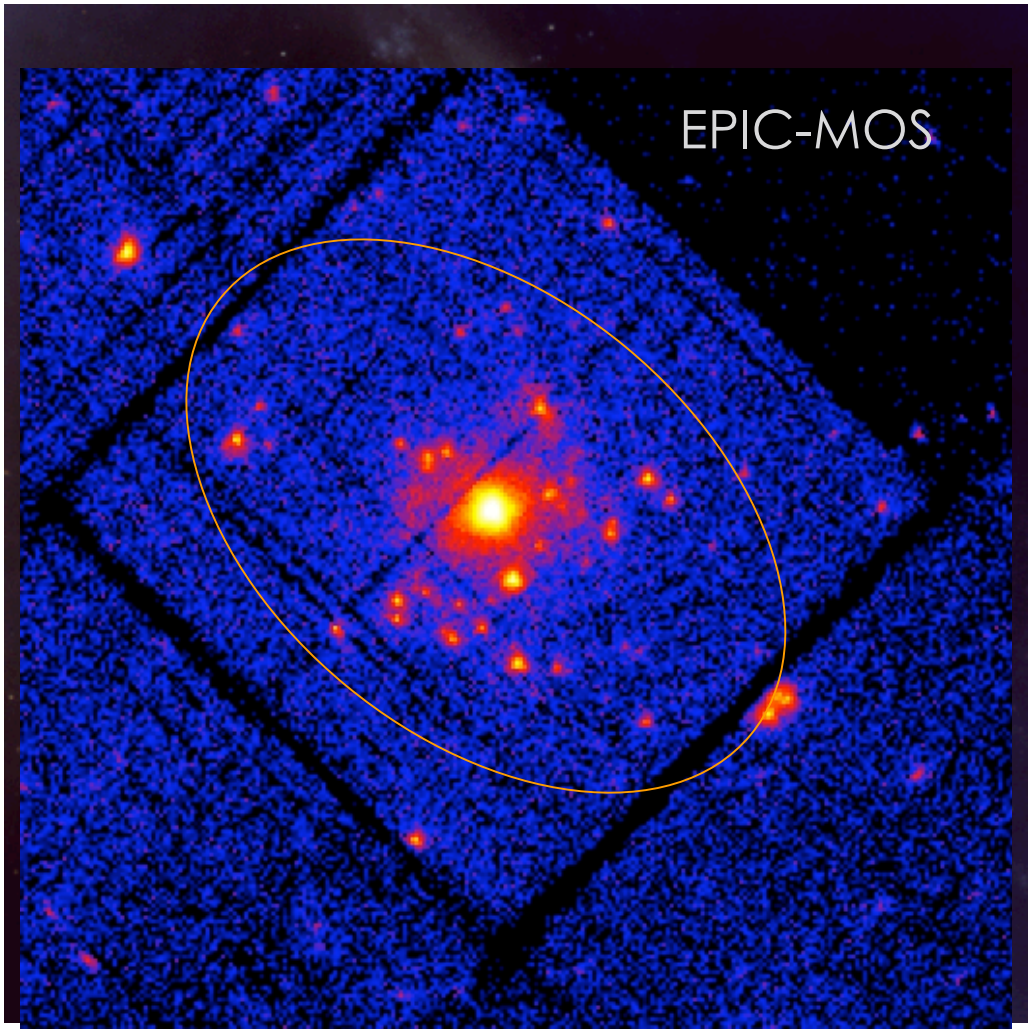
Is this the whole story?



NGC1365: an AGN Structure Laboratory

NGC1365:

- Face-on barred spiral D~25Mpc
- Bright X-ray source f_x~1mCrab, $log L_x$=42.2 Ward et al. **1978** MN 223, 788
- $L_{Bol} \sim 10^{43}$ erg/s$\sim 10^{-3}\ L_{edd}(M/M_8)^{-1}$
- $log M_{BH} \sim 7.3 - 7.8\ M_\odot$
  - M-σ_{bulge}, M-K
- Obscured: $N_H > 10^{22} cm^{-2}$
- Highly variable N_H:
  - *Key to study of structure*



NGC1365: Compton thick/Thin Transitions

Compton thick↔thin transitions are rare:

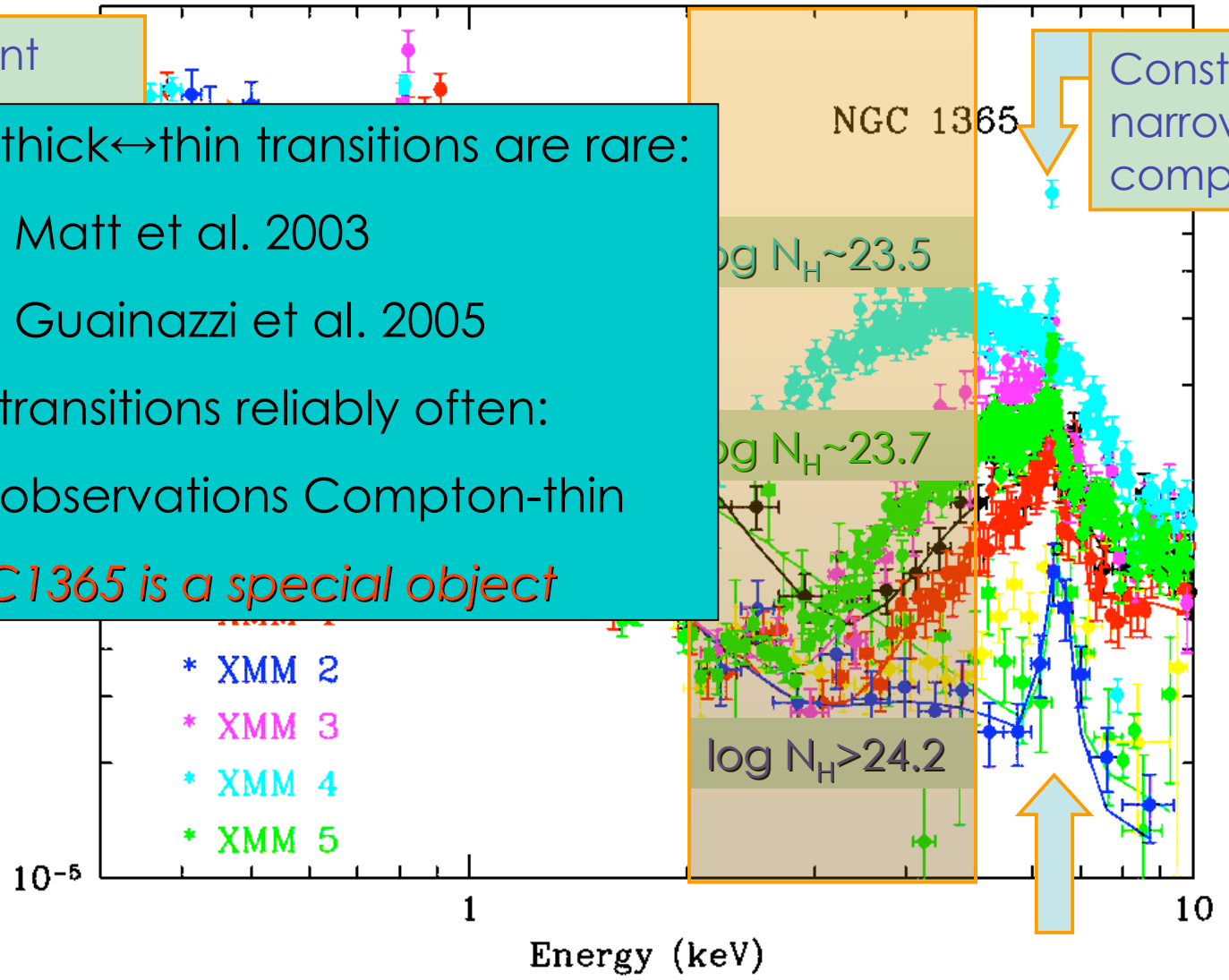
4/30 in Matt et al. 2003

1/11 in Guainazzi et al. 2005

NGC1365 transitions reliably often:

~7/13 observations Compton-thin

NGC1365 is a special object

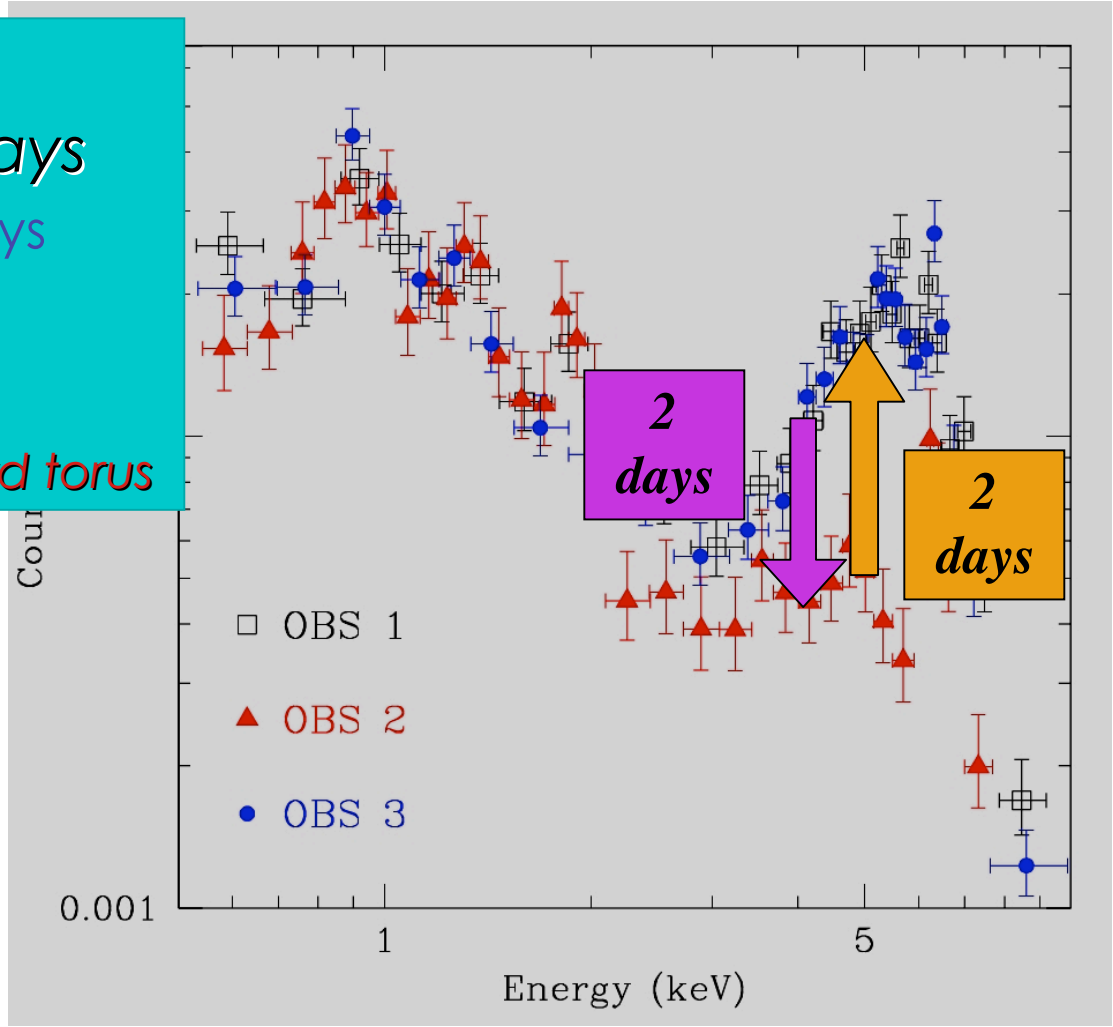


NGC1365: Really Rapid Compton thin/thick transitions

RISALITI ET AL., 2007, APJL, 659, L111

- *Chandra*: Compton *Thin→Thick→Thin in 4 days*
  - $\Delta N_H > \sim 10^{24} cm^{-2}$ in 2 days
  - $n_e > 10^9$ cm^{-3}
- R(NH) < *few* 1000 R_s

Hard to reconcile with standard torus



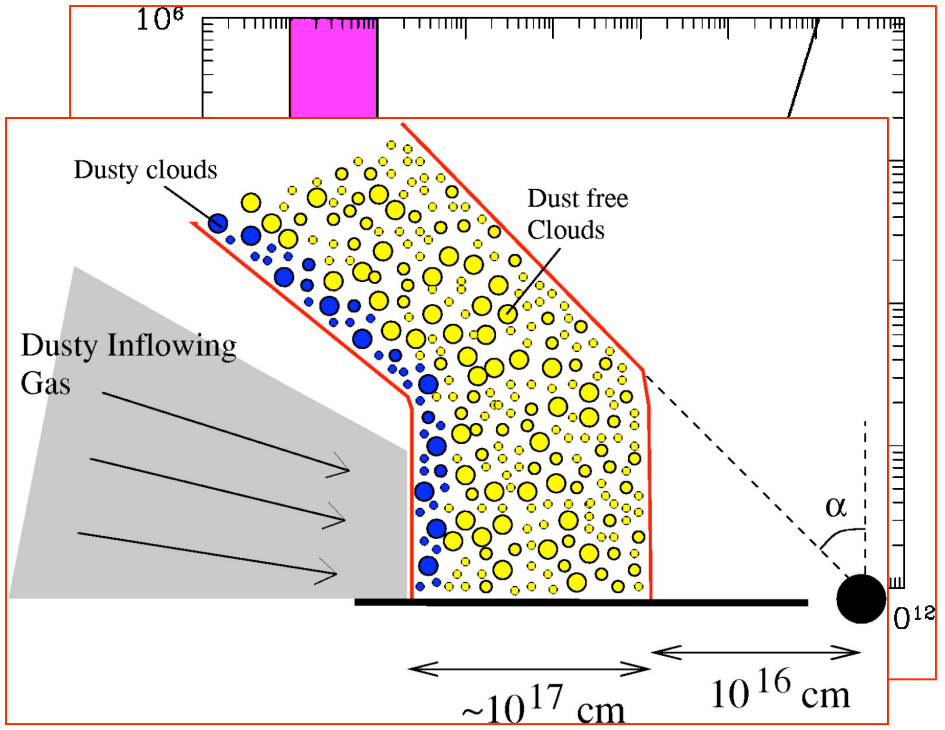
3000R_s A More Compact Torus

Risaliti et al., 2005a, ApJL, 623, L93

Elvis et al., 2004, ApJL, 615, L25

Need another 'torus' location:

- *Dust from an accretion disk wind*?
- Also toroidal
- T_{disk} <1000 K at R>~2000 R_s
  ⇨**dust survives in disk**
- Large H/R natural
- No support problem
- Magnetic support? Kartje & Konigl (



3000R_s

NGC5548: Where is the Fe-K core?

Suzaku Cycle 2: Elvis (PI) et al.

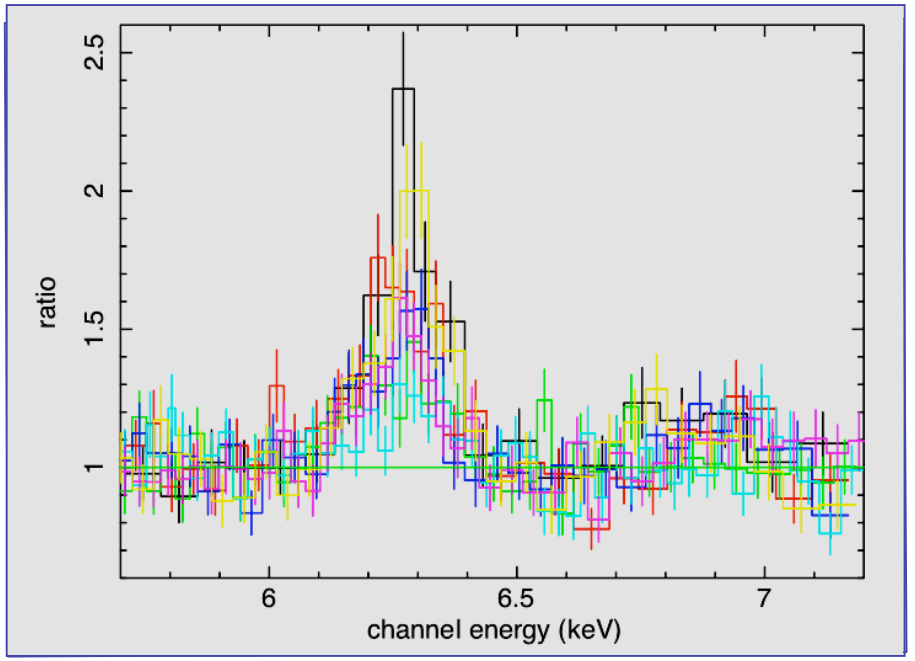
- Narrow Fe-K core: from the inner edge of obscuring torus?
- Suzaku 2-month monitoring of NGC5548 test of variability, line width. Lead: James Reeves

EARLY RESULTS!

Subject to change without notice

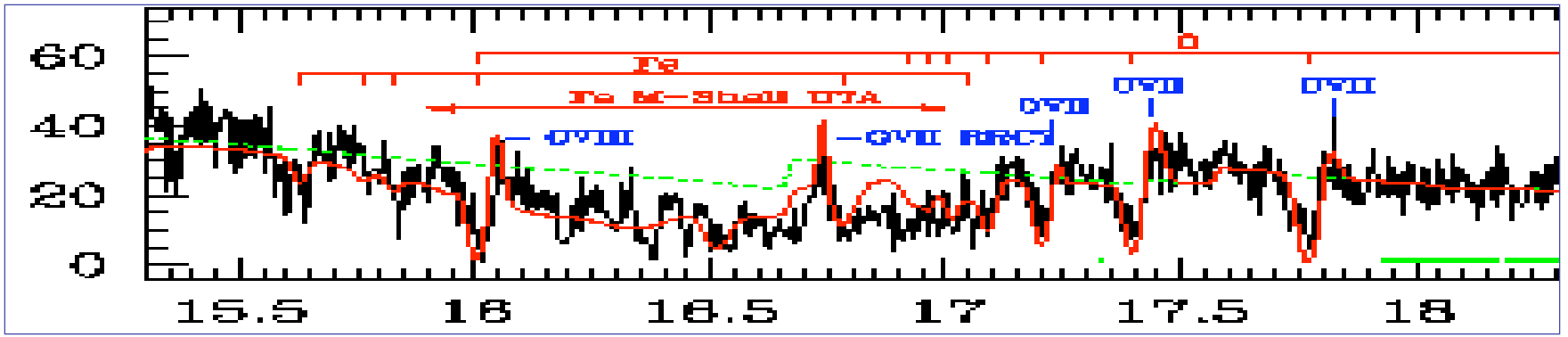
- High S/N 240 ksec spectrum
- Fe-K narrow core:
  - FWHM = 5500 km/s σ = 50+/-15eV
  - *R ~ 3000 = Obscuring material?*
  - R_s ~23 l-d $M_{BH} = 6.7 \times 10^7 M_\odot$
- Continuum changes factor ~4 in 30-60 days
- Fe-K core is constant
  - Larger than 3000 R_s?
  - Non-Keplerian motions?

Suzaku/NGC5548: Fe-K



3000R_s Where are the Warm Absorbers?

CHANDRA HETG: 900KSEC NGC3783, KASPI ET AL. 2002, APJ, 574, 643



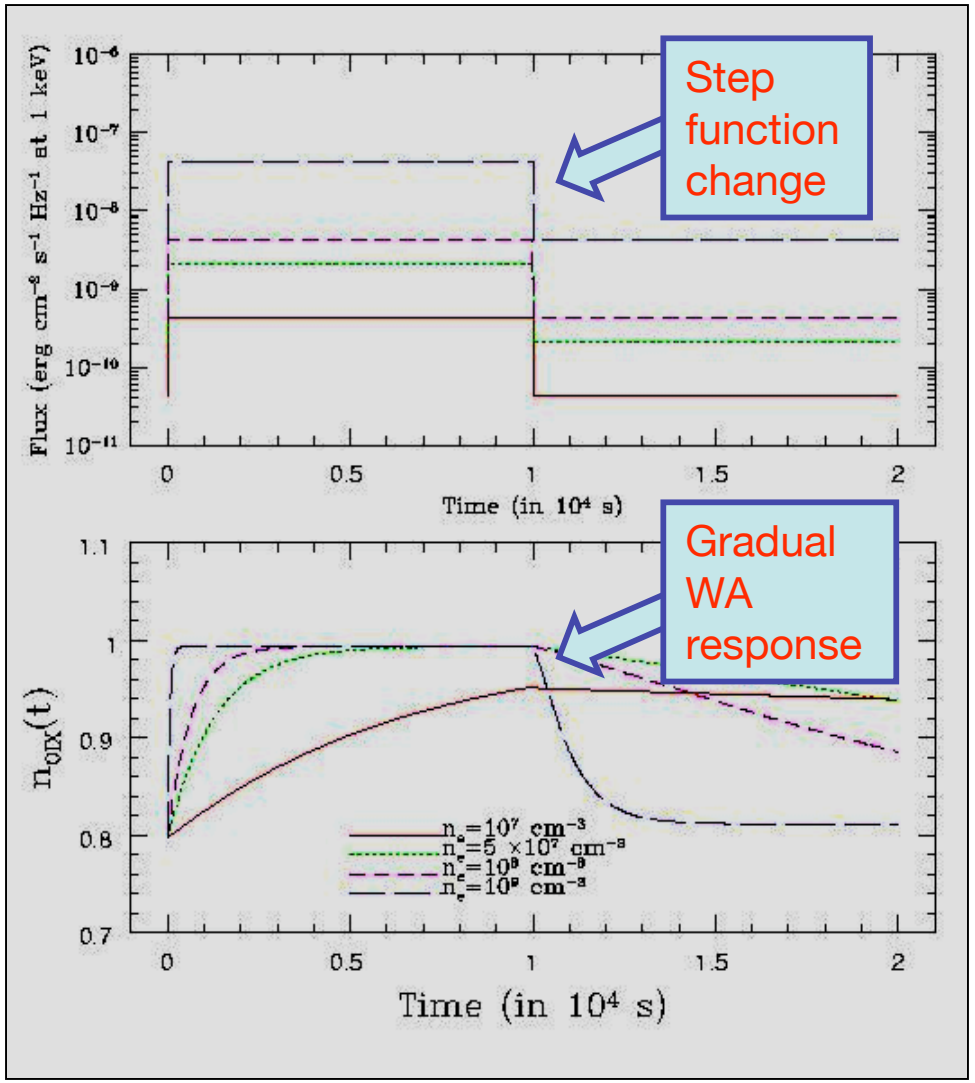
- Factor 10^6 in radius proposed: NELR to HiBELR
- Mass loss rate uncertain by factor 10^6
- Is AGN feedback important to galaxy evolution or not?

WA ionization/recombination times give WA Radius

NICASTRO ET AL., 1999, APJ, 512, 184

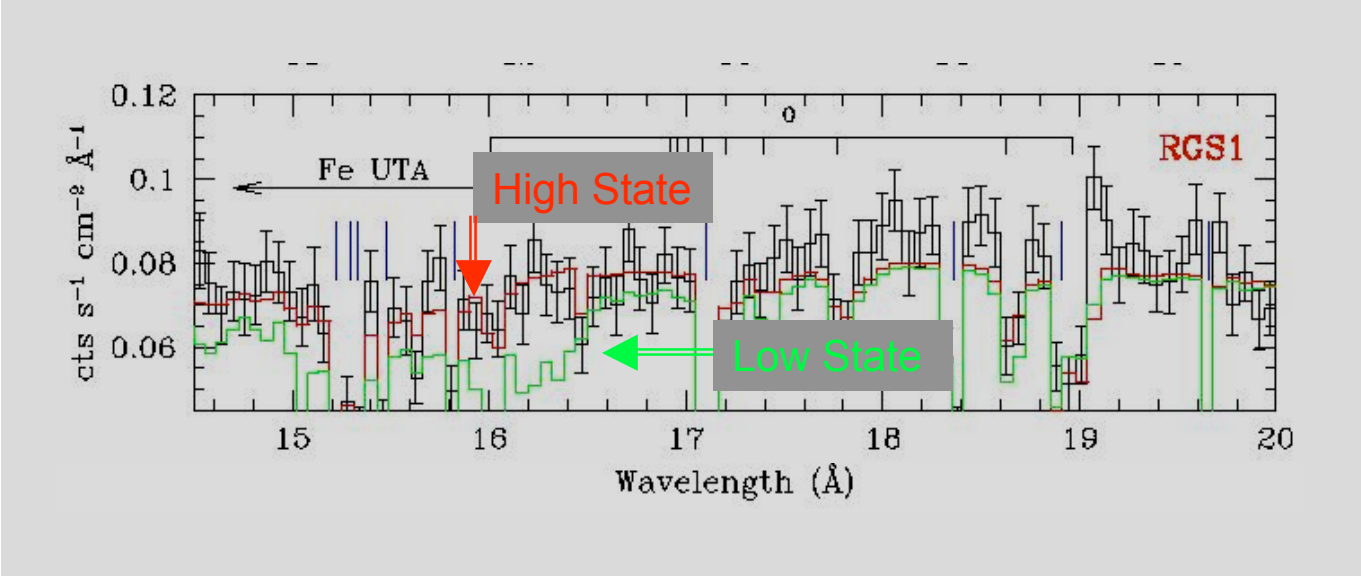
WA response to continuum is not instantaneous:

- 'Ionization time' and 'Recombination time'
  ➡**measure n_e**
- $U_X \sim 4\pi L_X/R^2$
- WA measures U_x
- hence ***R***



Small R_{WA} in NGC4051: XMM/RGS

KRONGOLD ET AL., 2007, APJ, 659, 1022



- 4X flux increase in ~30 ksec
- WA changes!
  - Not continuous U(r)
- WA is dense & compact
  - Not NELR

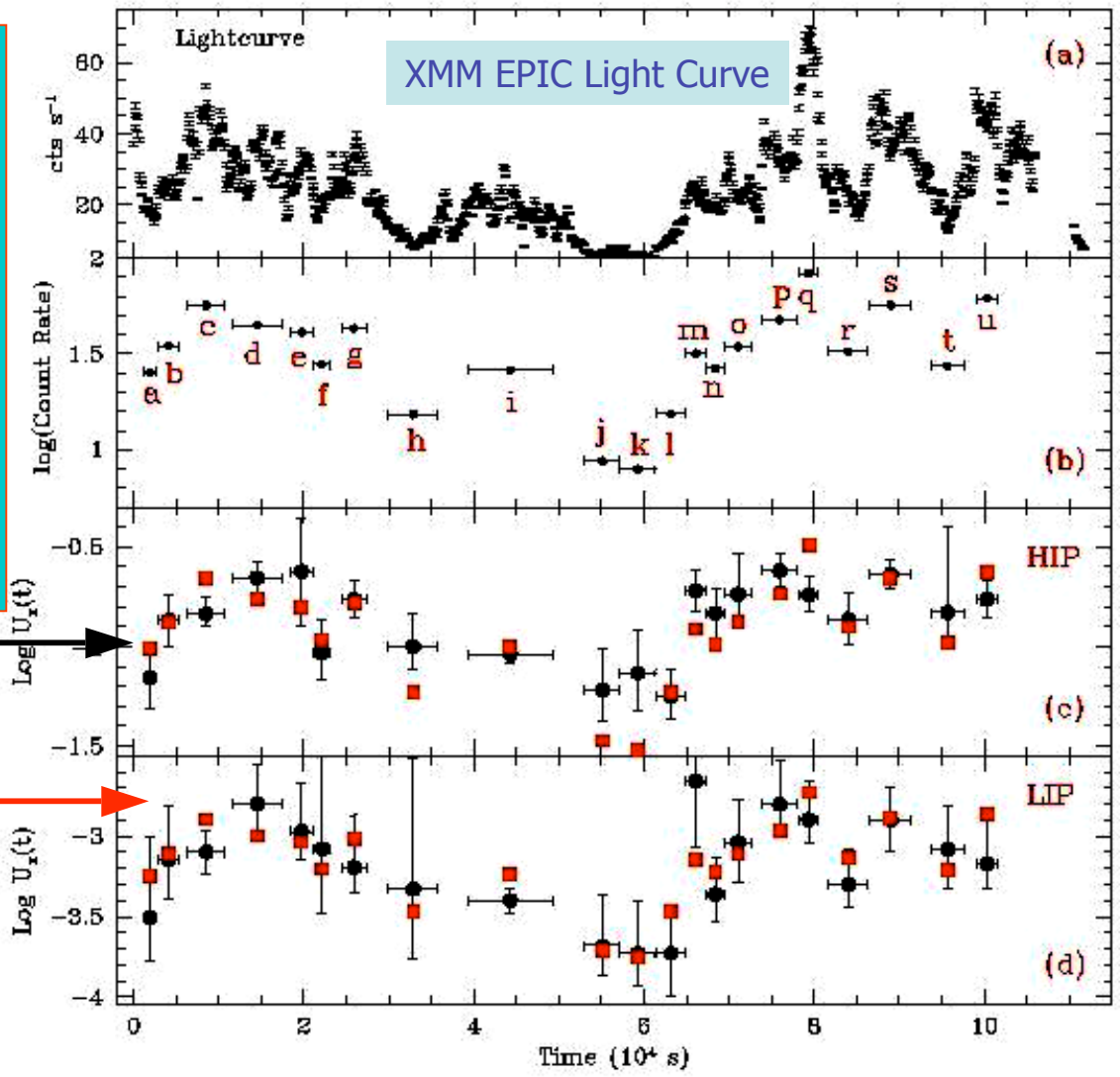
Small R_{WA} in NGC4051: XMM/EPIC

Krongold et al., 2007, ApJ, 659, 1022

- Two Warm Absorber components stay close to photoionization equilibrium
- Low Ionization (LIP)
  R<3.5 l-d
- High Ionization (HIP)
  R=0.5-1.0 l-d

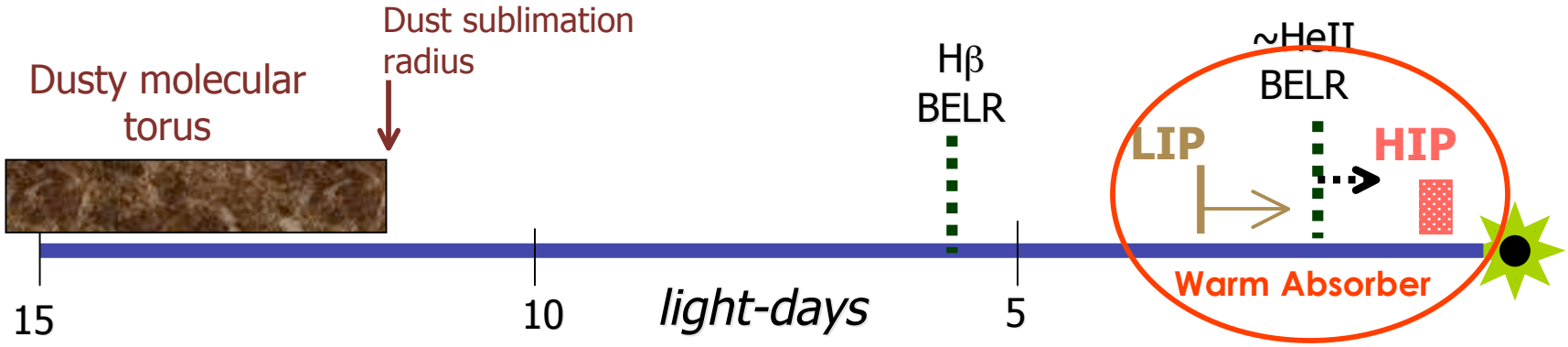
log $U_x(t)$, measured

log $U_x(t)$, predicted from photoionization equilibrium



NGC4051: An Accretion Disk Scale Warm Absorber

KRONGOLD ET AL., 2007, APJ, 659, 1022

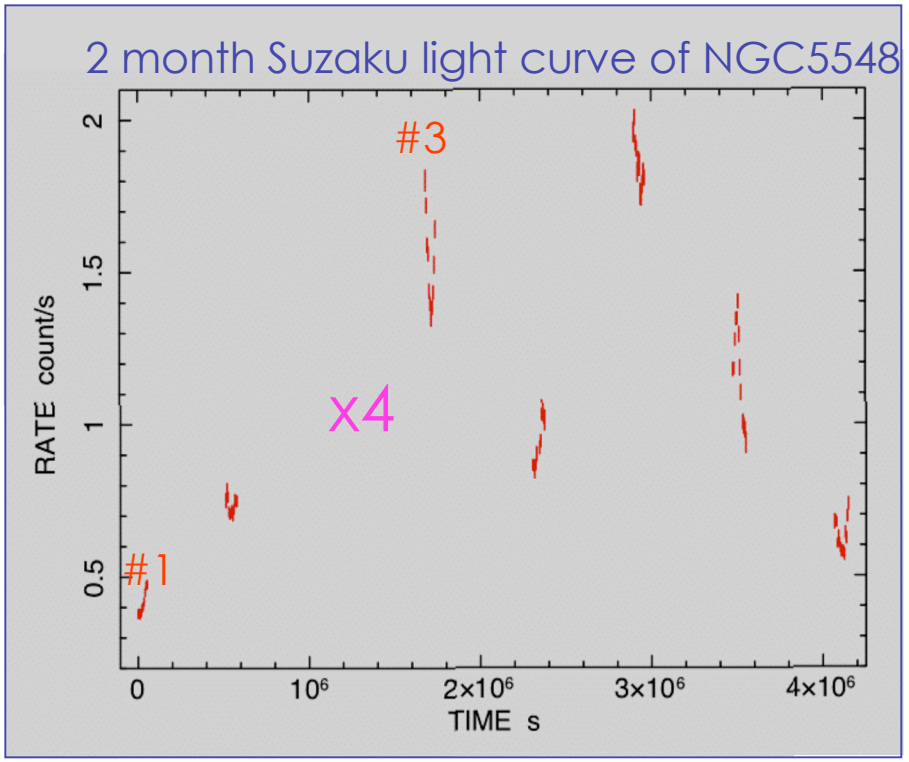


- ***Rules out*** *Narrow Emission Line Region* (kpc scale)
- ***Rules out*** *Obscuring molecular torus* (Krolik & Kriss, 2001)
  - Minimum dust radius, r_{subl}(NGC4051) ~ 12-170 light-days
- ***Rules out*** *Low Ionization (Hβ) broad emission line region* (BELR); R(Hβ) = 5.9 light-days (Peterson et al. 2000) **= disk?**
- Co-located with High Ionization BELR?: HeII **= wind?**
- **BUT:** *NGC4051 is pathological: a Narrow Line Seyfert 1*

NGC5548: R_{WA} in a normal Type 1 AGN

Suzaku Cycle 2: Elvis (PI) et al.

- Choose a normal type 1
  - Well characterized WA
  - Known M_{BH}
  - Known R(BELR), R(dust)
  - Reliable variable
  - Bright
- NGC5548 one of very few
- 7 x 35 ksec in 1 2-month Suzaku window
- Behaved perfectly!



NGC5548: R_{WA} in a normal Type 1 AGN

Suzaku Cycle 2: Elvis (PI) et al.

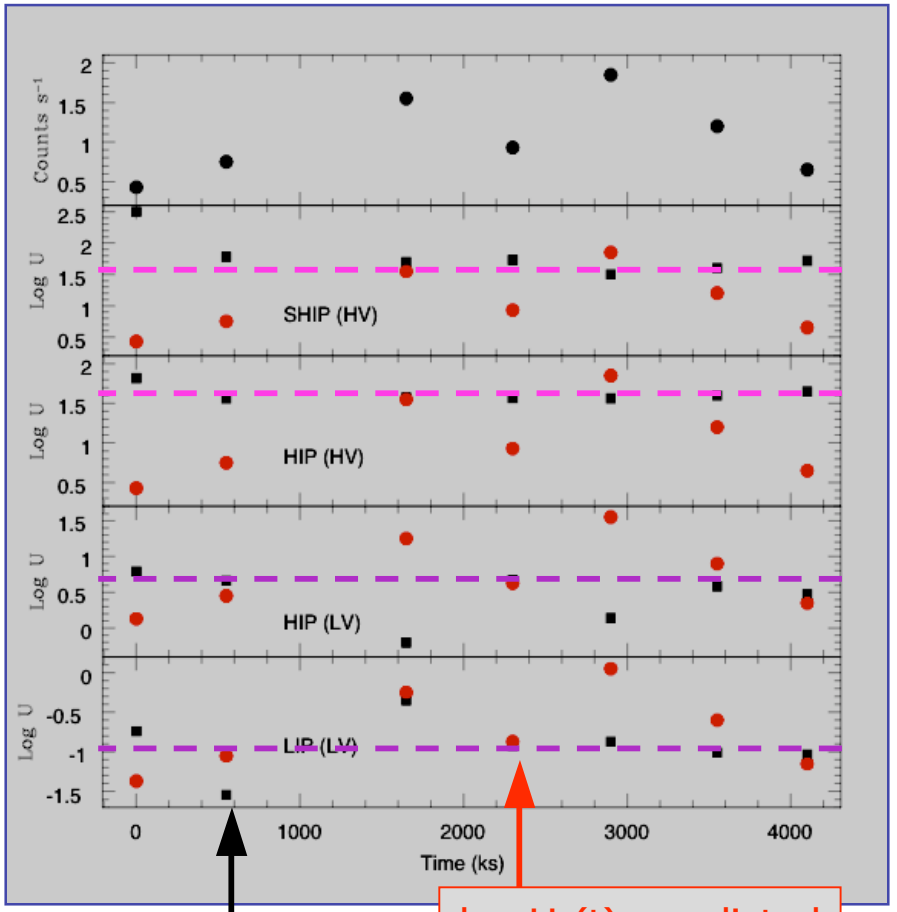
EARLY RESULTS!

Subject to change without notice

- WA *seems* to change in ~2 Msec (~1 month)

➔ Dense, compact

- 2 velocity systems *Chandra*
  - *HiVel*: no change in ξ
    - **Low density, large**
  - *LoVel*: ξ changes, but not in equilibrium
    - **Dense, compact**
  - WA acceleration?
- Need a sample: proposed NGC3227 in Cycle 3



log U_x(t), measured

log U_x(t), predicted from photoionization equilibrium

50R_s NGC1365: Compton Wind

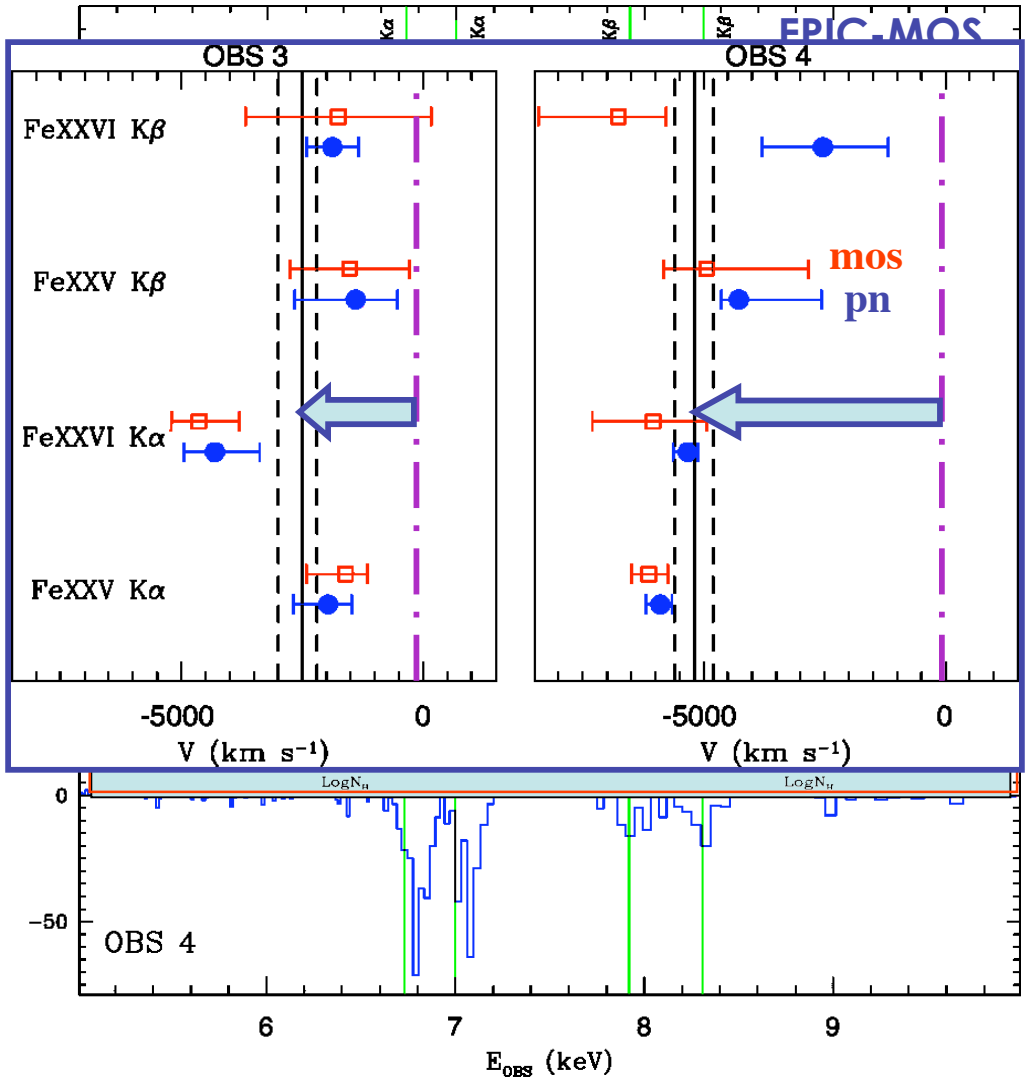
Risaliti et al., 2005, ApJL, 630, L129

- 4 strong absorption lines: FeXXV, FeXXVI K-α, K-β ~100eV
  - **Broad**: v_{turb}~500-1000 km/s
- 'Super-High' Ionization WA:
  - $logU_X$~0, **R ~ 50**$(M/M_8)^{-1}$ **R_s**
- Kα/Kβ small - saturated:
  - **High N_H**>$10^{23.5}$ Compton thick
- Blueshifted
- **1000 → 5000 km/s in 1.5 yr**:
  - acceleration?

  << V_{esc} ~50,000$(M/M_8)^{-1}$ km/s
  - failed or transverse wind'?

    Failed at high U, low L/L_{Edd}

= Murray & Chiang 'hitchhiking gas' ?

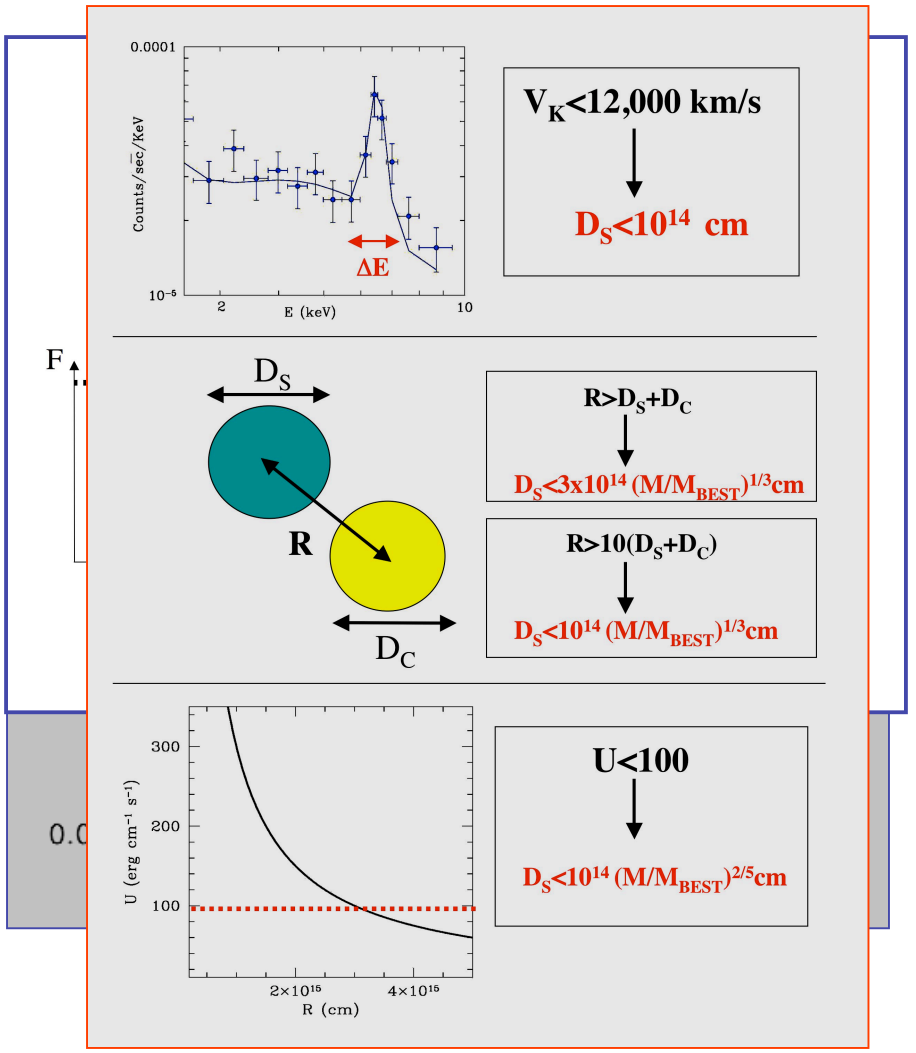


X-ray Continuum Eclipses

RISALITI ET AL., 2007, APJL, 659, L111

NGC1365

- *Chandra* campaign 2006
  - 6x15 ksec obs over 10 days
- 4 days to go Compton thin ➡thick ➡ thin
- Eclipse of X-ray continuum
  - $D_S < 10^{14}$ cm
- $D_S < 33\ (M_{bh}/M_{est})^{-2/3}\ R_S$

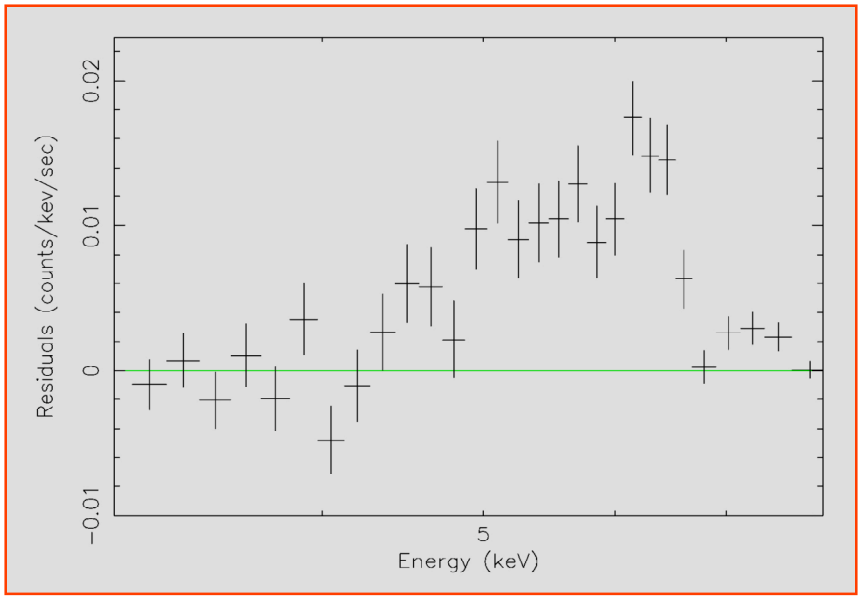


<30 R_S Broad Fe-K Eclipses

RISALITI ET AL., 2007, APJL, 659, L111

NGC1365

- Strong broad Fe-K
  - & strong Fe-K absorption lines
  - High Fe abundance?
- Gone in Compton-thick spectrum.
- $D_{Fe\text{-}K} < 10^{14}$ cm, <33 R_S
- Resolved eclipse will measure size.
  - 'anti-eclipse' in XMM long look suggests ingress ~ 10hours ~7R_S
- Goal of Suzaku Cycle 3 proposal

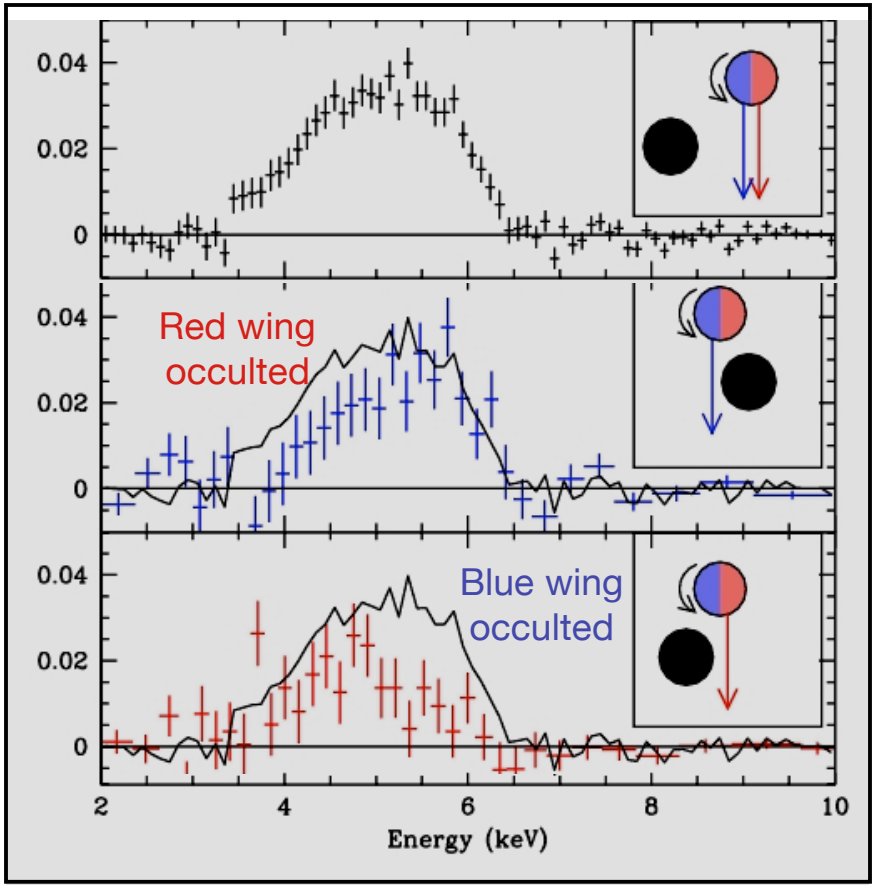


<30 R_S Tomography of Fe-K, Continuum

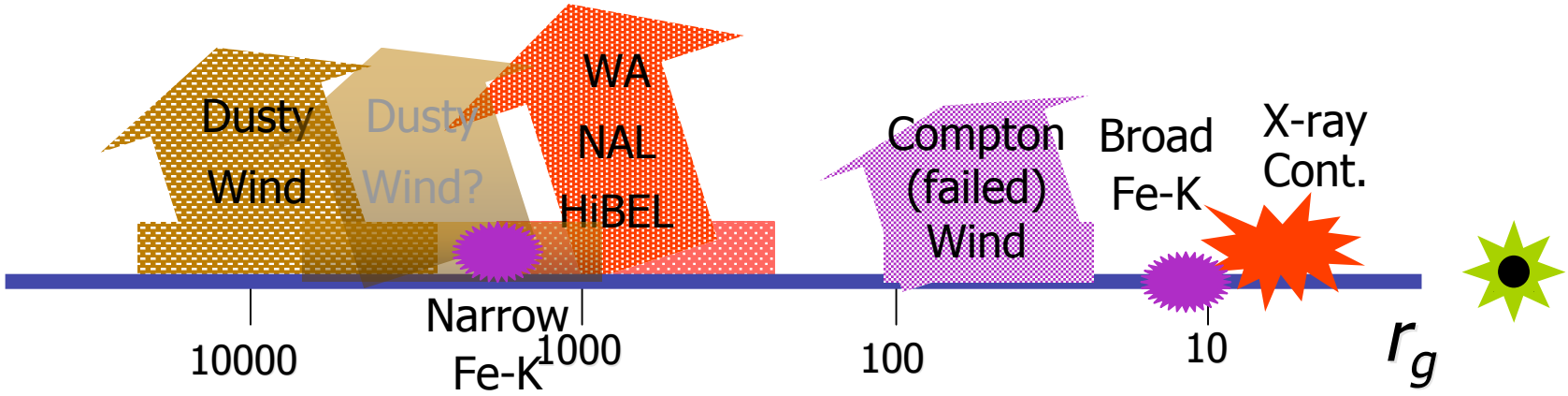
REYNOLDS, RISALITI, ELVIS, ...

Prospects:

- apply Binary physics
- Ingress, egress successively cover/uncover red-/blue-shifted Fe-K
- *Establish rotation, z(R)*
- Goal of Suzaku Cycle 3 proposal

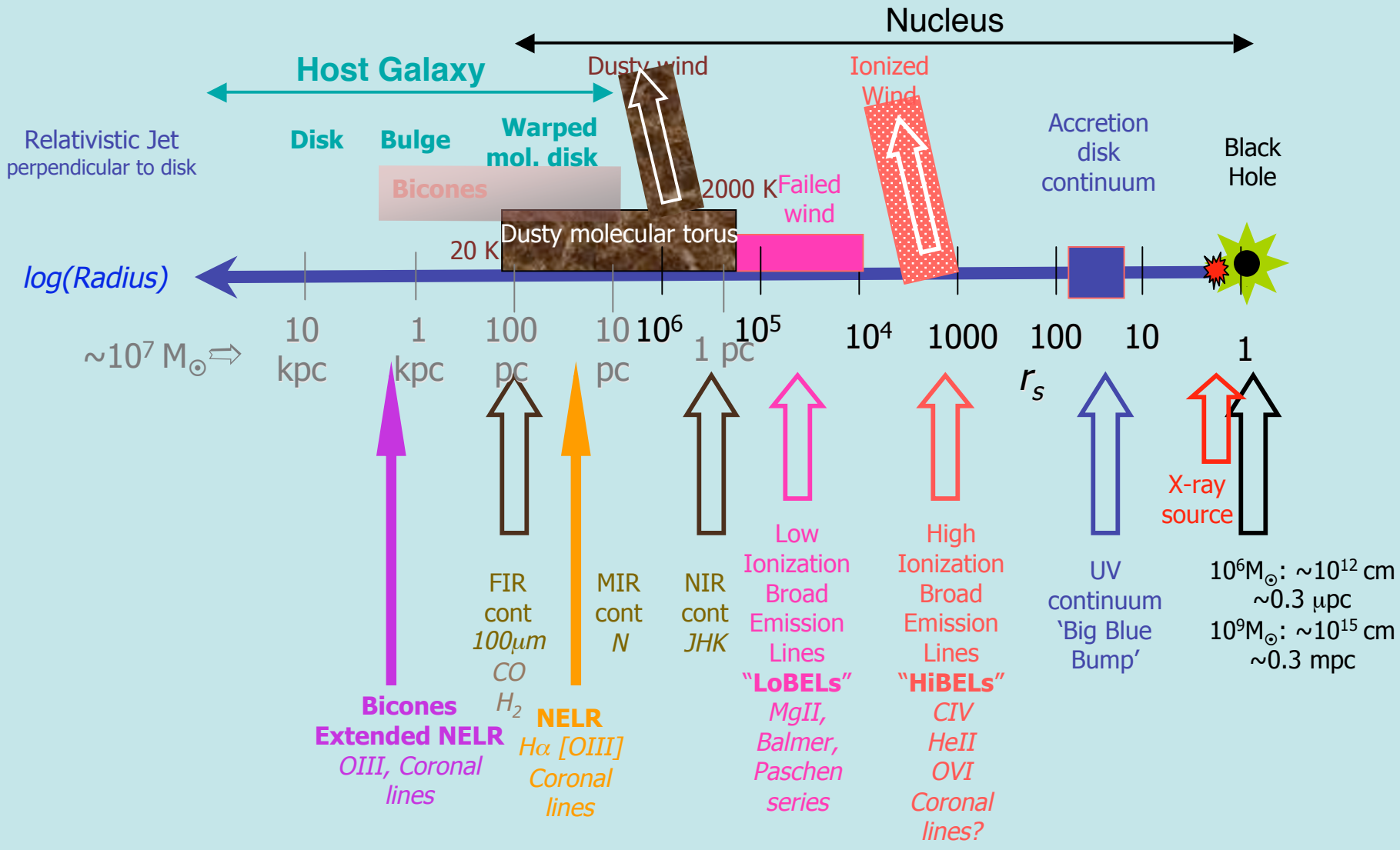


AGN Structure from X-ray Spectral Variability



- Probe scales from 10^5- 10 R_s
  - Obscuring torus
  - Dusty wind
  - Warm Absorber/HiBELR
  - Compton (failed) Wind
  - X-ray continuum
  - Broad Fe-K
- Suzaku has a big role to play

Scales of Quasar/AGN Components

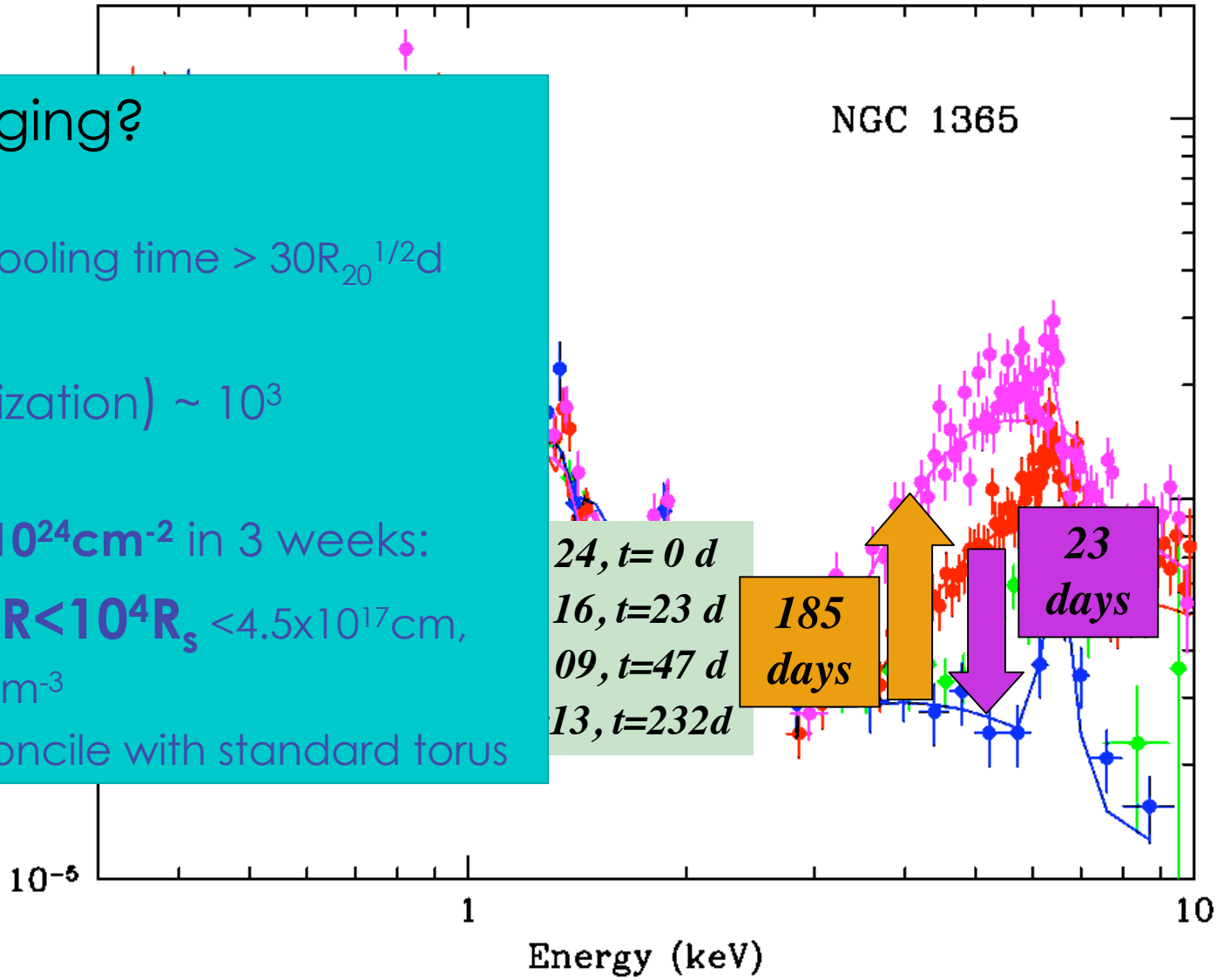


NGC1365: Fairly Rapid Compton thin/thick transitions

RISALITI ET AL., 2005A, APJL, 623, L93

What is changing?

- f_x(intrinsic)?
  - cf disk cooling time > $30R_{20}^{1/2}$d
- ionization?
  - $\Delta\xi$ (ionization) ~ 10^3
- **N_H✓**
  - **ΔN_H>~10^{24}cm^{-2}** in 3 weeks:
  - requires **R<10^4R_s** <4.5x10^{17}cm,
  - n_e>10^9 cm^{-3}
- Hard to reconcile with standard torus



Small R_{WA} in NGC4051: XMM/EPIC

Krongold et al., 2007, ApJ, 659, 1022

- Two Warm Absorber components stay close to photoionization equilibrium
- Low Ionization (LIP)
  R<3.5 l-d
- High Ionization (HIP)
  R=0.5-1.0 l-d

log $U_x(t)$, measured

log $U_x(t)$, predicted from photoionization equilibrium