

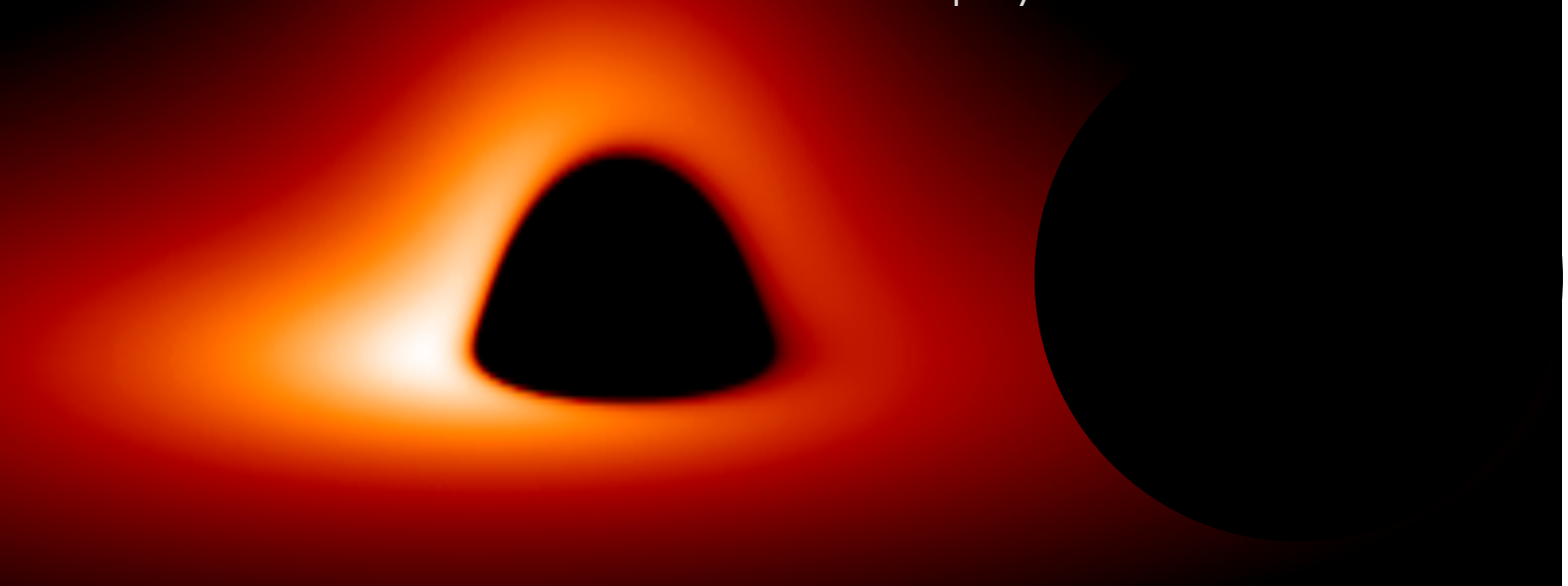


Quasar Eclipses

Revealing the Intimate Environment of Quasars

Martin Elvis

Harvard-Smithsonian Center for Astrophysics



Reynolds C.

with the collaboration of
Guido Risaliti, Roberto Maiolino, Marco Salvati, Yair Krongold,
Fabrizio Nicastro, Yuan Liu, Laura Brenneman
and others...



Martin Elvis, Wideband X-ray Astronomy, IUCAA, Pune India, 16 January 2011





Quasars have only a “High Theory”

i.e. conceptual, order of magnitude, estimates

massive black hole

Lynden-Bell 1969

accretion disk

Lynden-Bell 1969, Pri

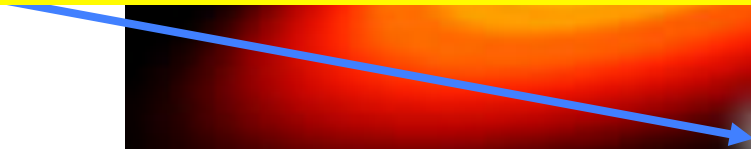
Shakura & Sunyaev 1

relativistic jet

Rees 1967 [PhD],

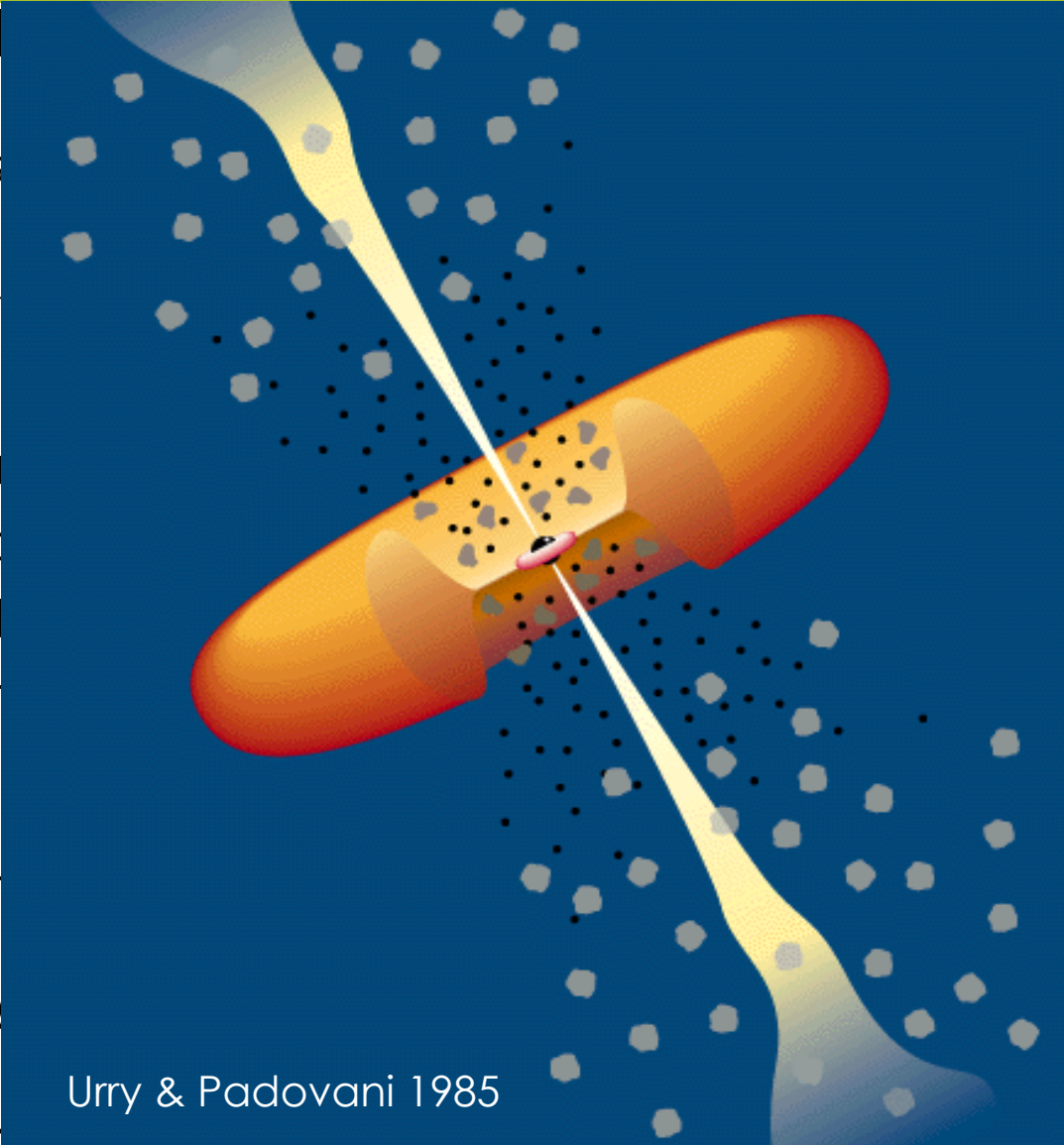
Blandford & Rees 1974

No prediction of:
X-rays,
Broad emission lines,
Broad & Narrow absorption lines,
Hot dust

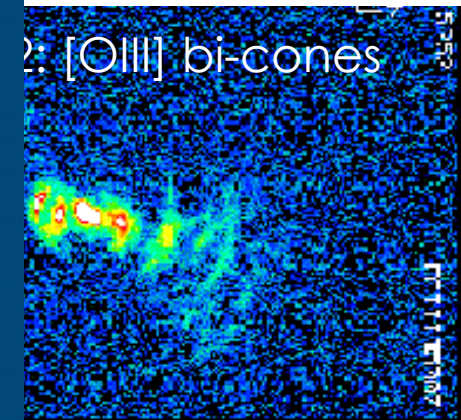
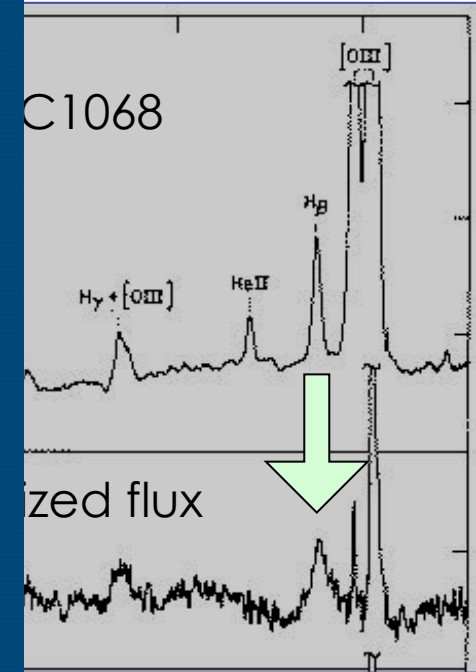


The Obscuring Torus

- Molecular torus (Krolik & Begelman 1988)
 - Large size
 - $r \sim 1 \text{ pc}$
 - $N_H \sim 10^{22}$
- Explains
 - Hidden AGN
 - Ratio of $H\alpha$ to $[OIII]$
 - Ionization
 - Maximum $H\alpha$ flux
- **But is it**
 - “Obscured AGN”
 - “Shrouded AGN”
 - May be obscured
 - Larger tori are known



Urry & Padovani 1985





Torus is a Myth

Multiple obscurers on multiple scales

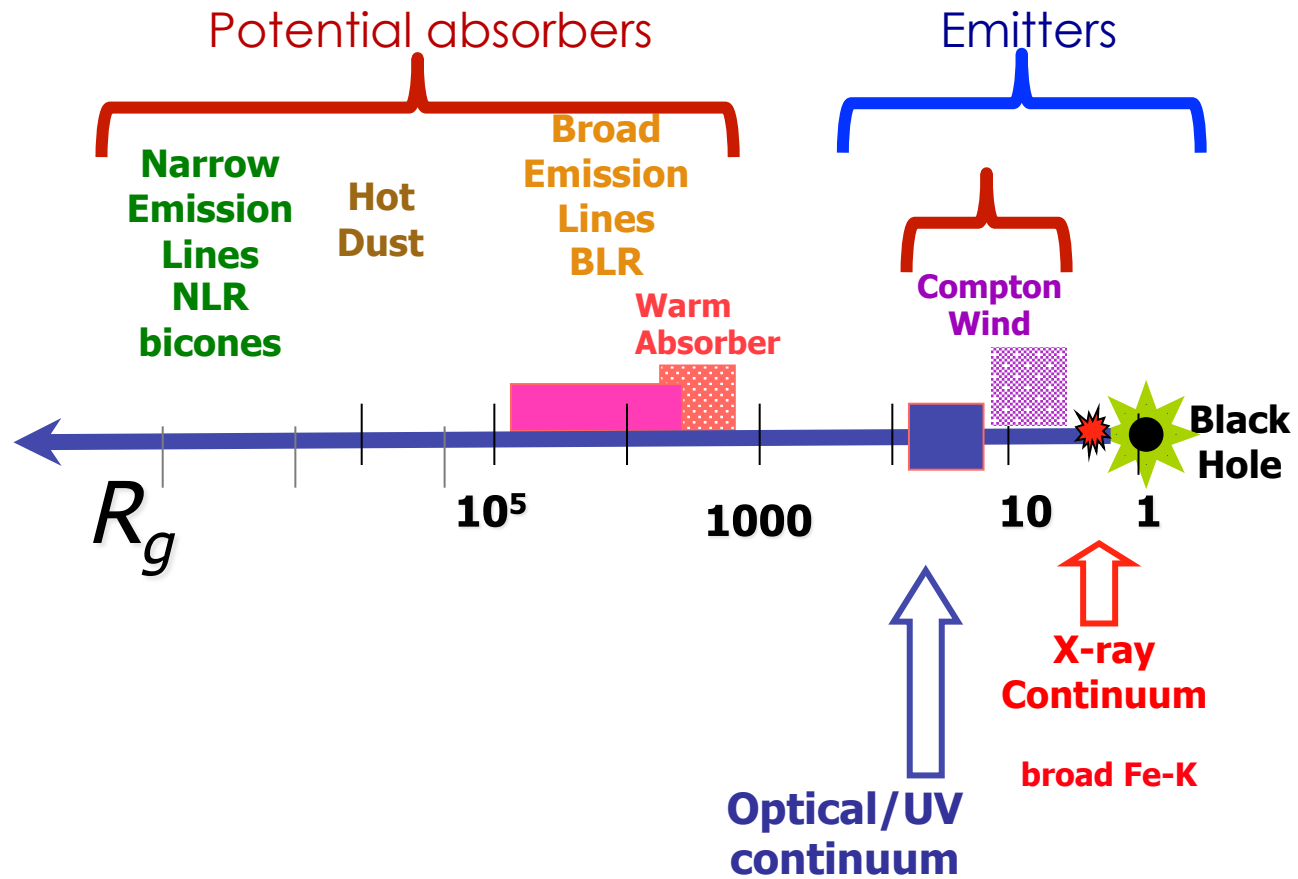
Need to look carefully at each obscurer: Where and What is it?





Structure Scales in AGNs

Martin Elvis, 18 October 2008



Martin Elvis, Wideband X-ray Astronomy, IUCAA, Pune India, 16 January 2011

Harvard-Smithsonian Center for Astrophysics

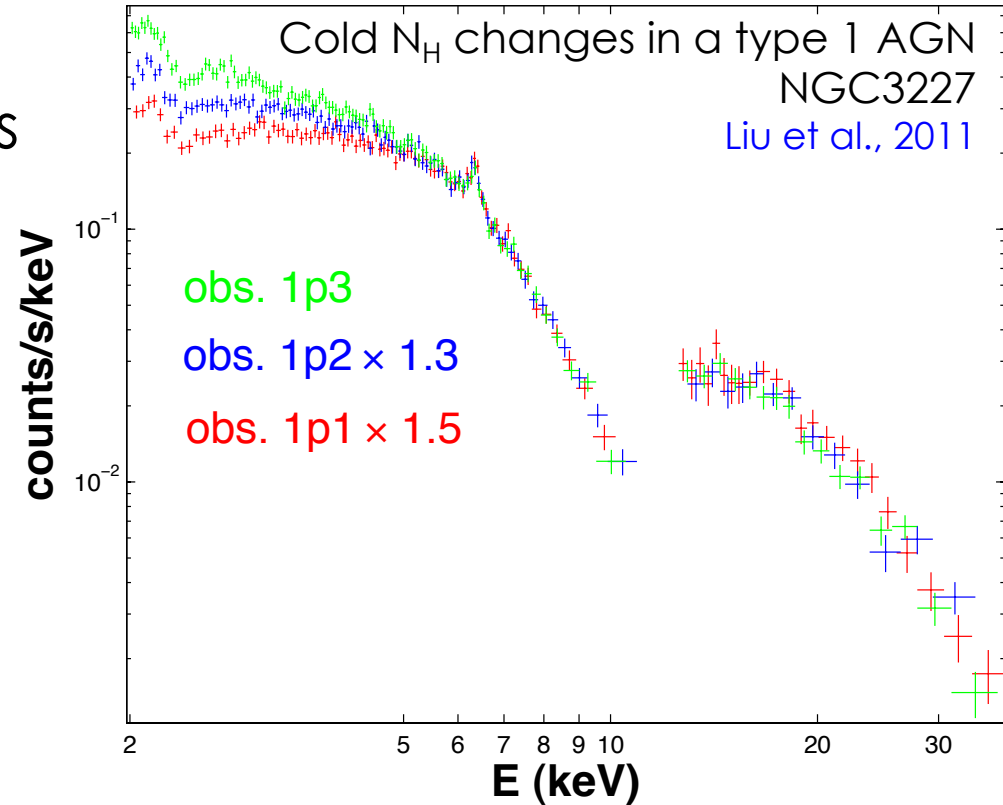




Eclipsing Material

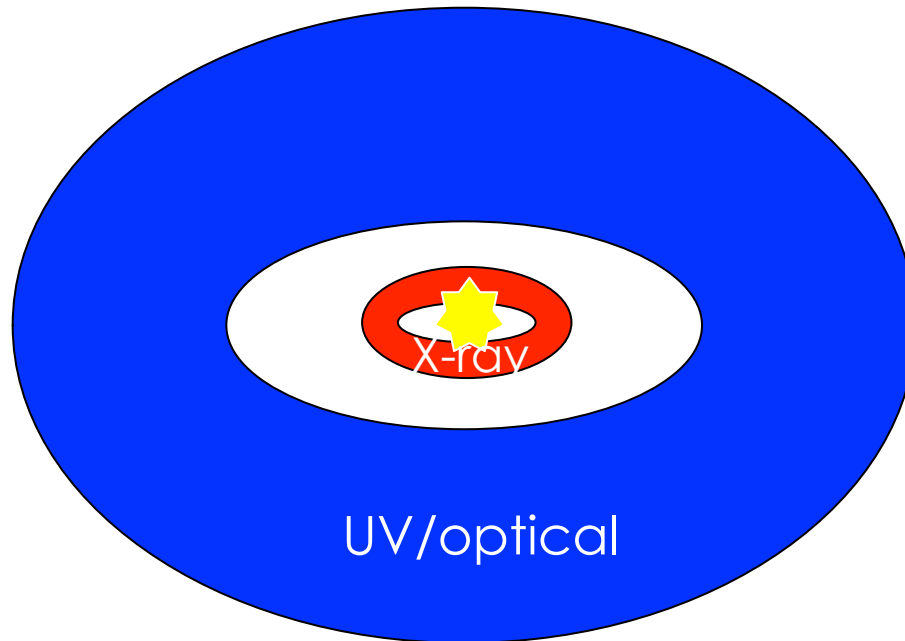
3 Types of absorber:
All possible ionization states

- Cold – mainly type 2
- Warm
- High Ionization





Eclipses are Easier in X-rays



$$A(\text{X-ray}) \sim 1\% A(\text{UV})$$

Timescales shorter for
Close-in absorbers

$$v_{\text{Kepler}} = r^{-1/2}$$



$$r(\text{X-ray}) \sim 3 R_g$$

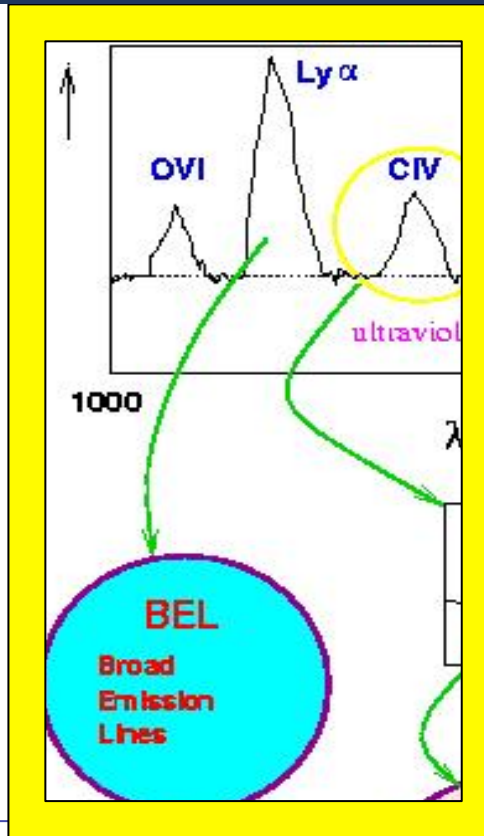


$$r(\text{UV}) \sim 30 R_g$$

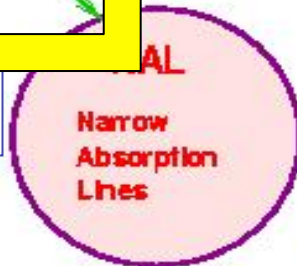
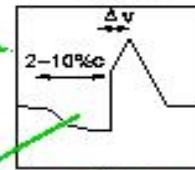
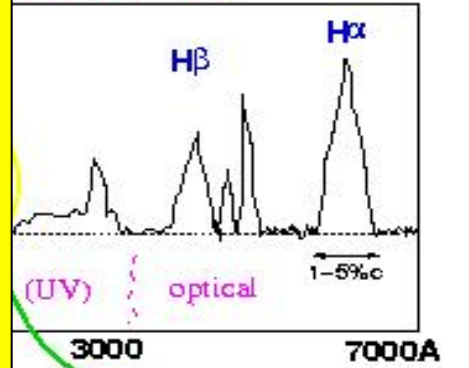


Broad Emission Lines

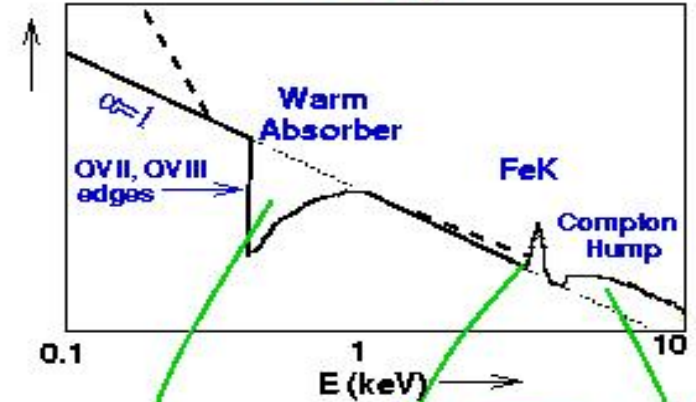
potential sources of eclipsing matter



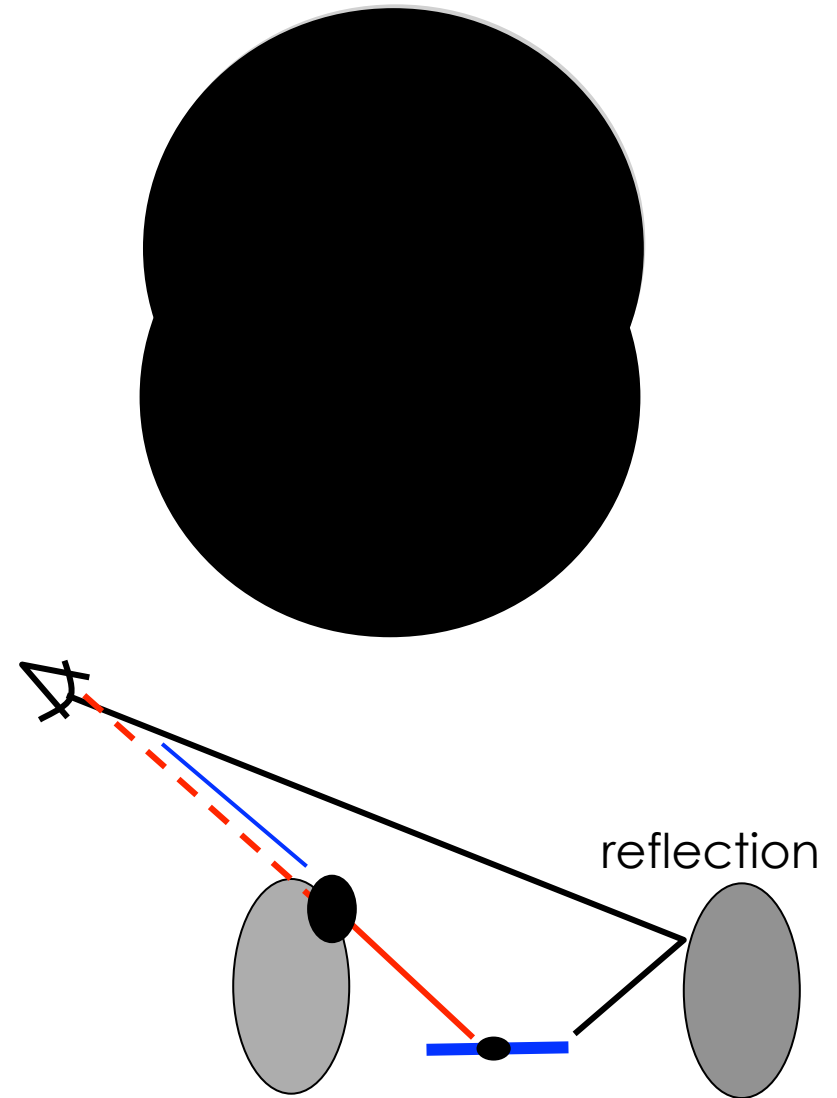
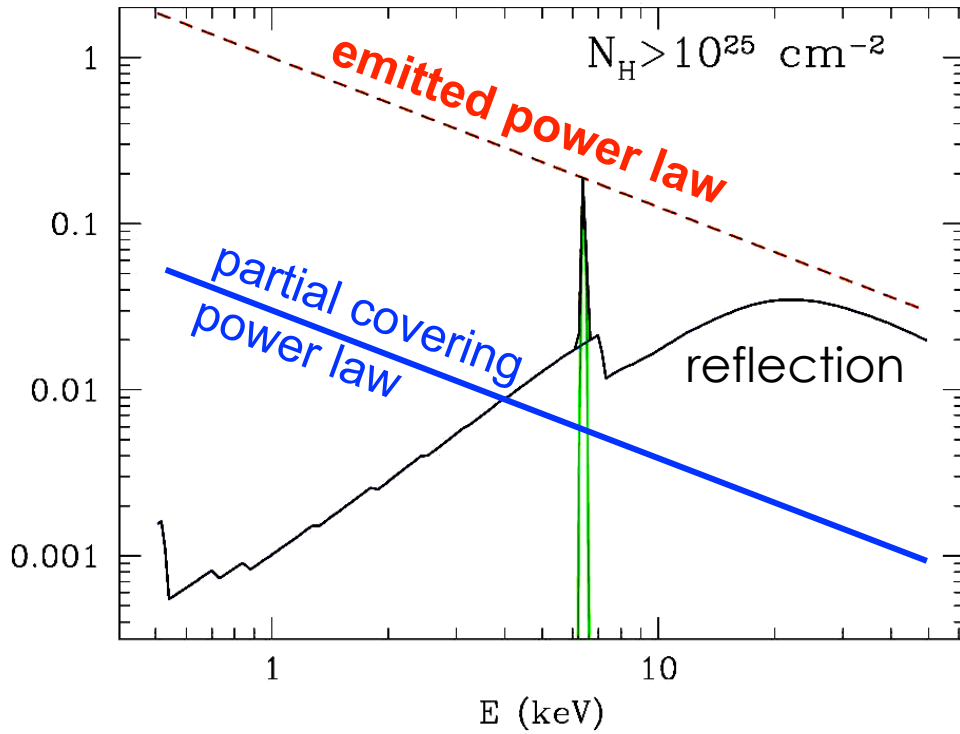
Ultraviolet



X-ray



High ionization: e.g. CIV, OVI
Low ionization: e.g. MgII, H β .

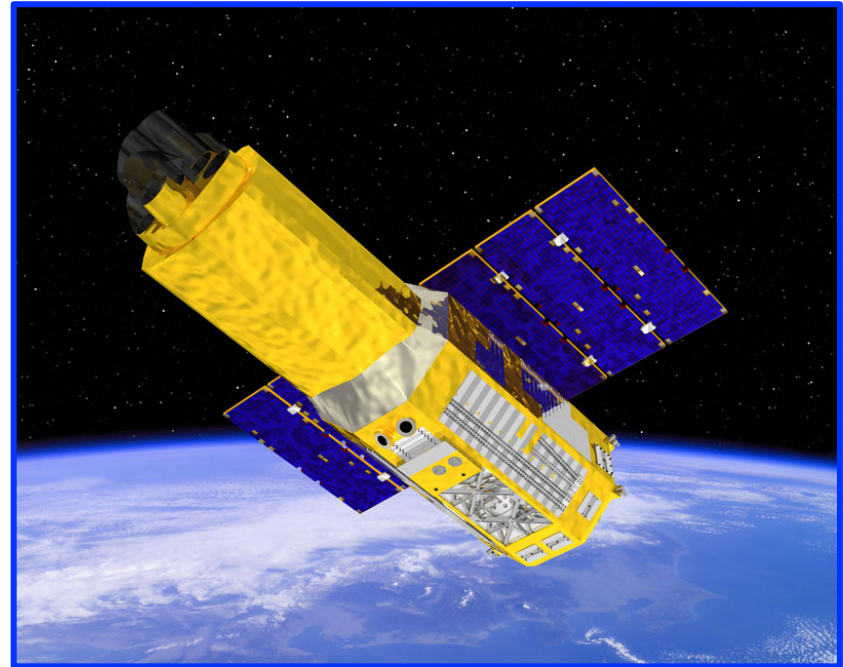




Three Large Area X-ray Satellites



XMM-Newton (ESA)
high effective area



Suzaku (Japan)
10-100 keV spectroscopy



Chandra (NASA)
high spatial resolution

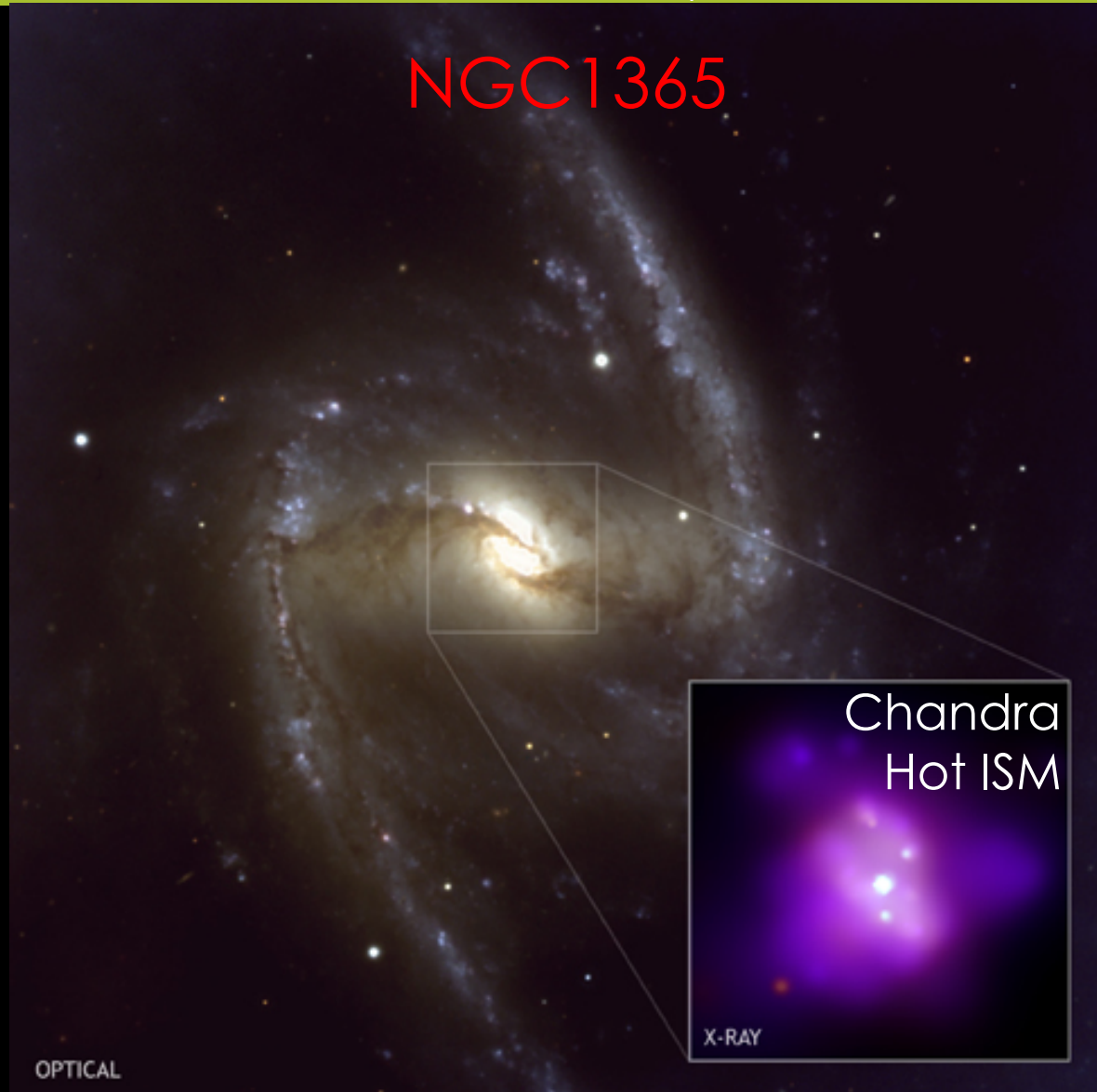




Rapid X-ray Continuum Eclipses

Risaliti et al., 2007, ApJL, 659, L111

NGC 1365



Martin Elvis, Wideband X-ray Astronomy, IUCAA, Pune India, 16 January 2011

Harvard-Smithsonian Center for Astrophysics

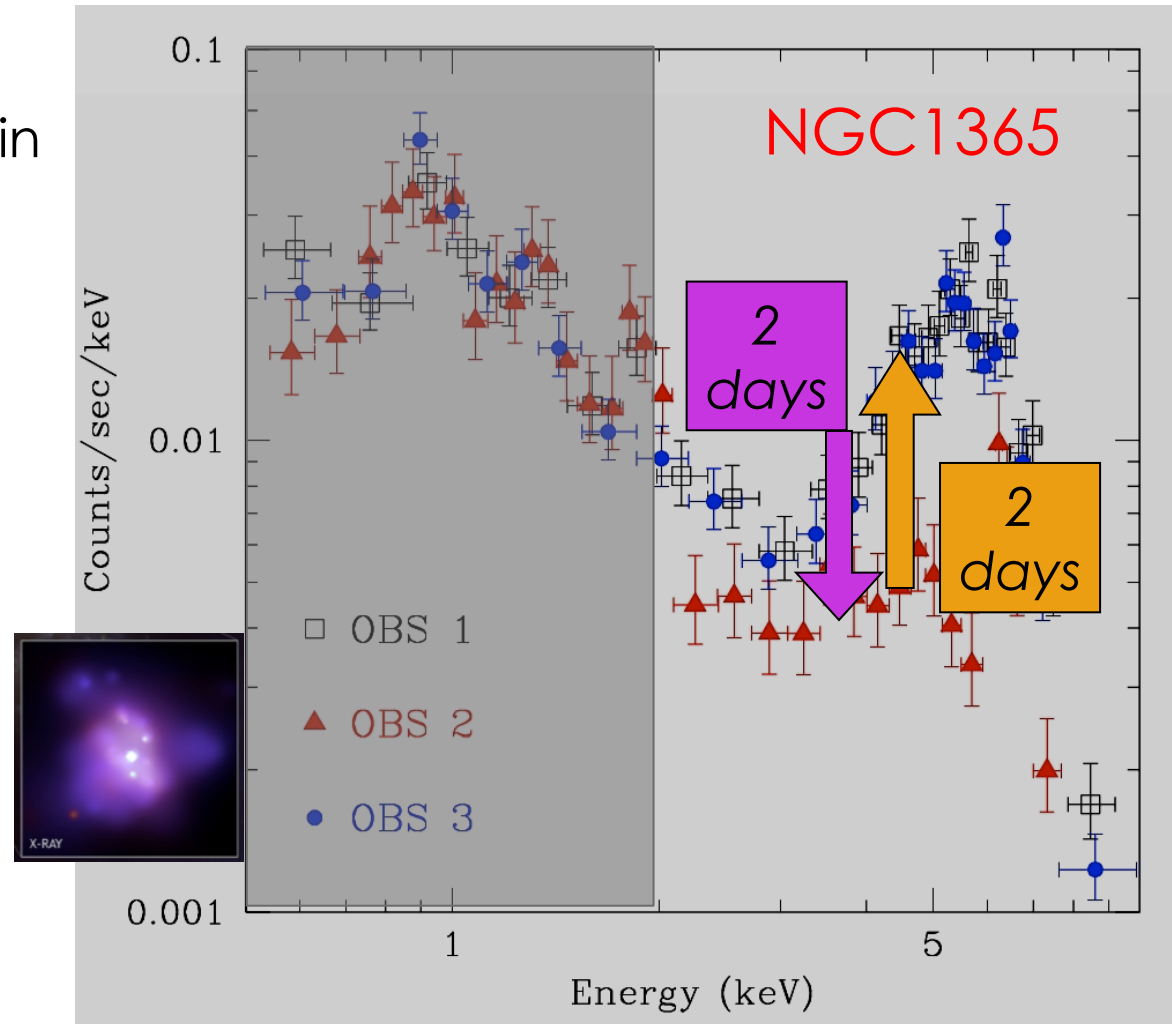




Rapid X-ray Continuum Eclipses

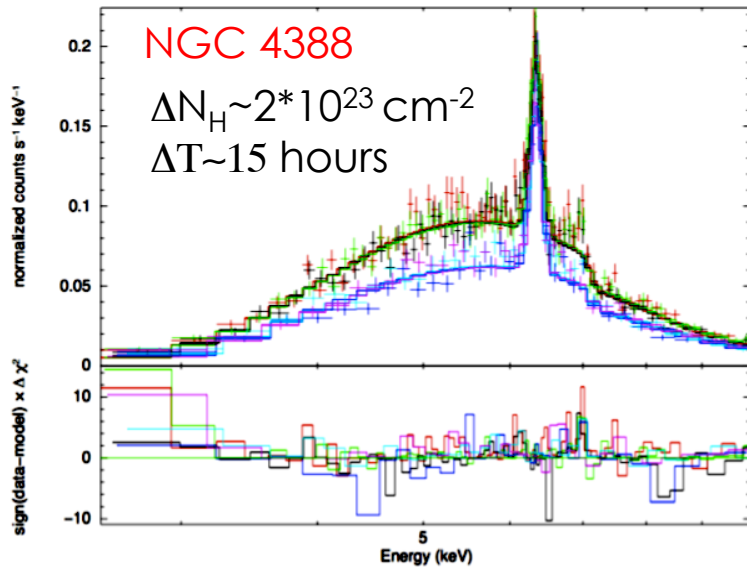
Risaliti et al., 2007, ApJL, 659, L111

Chandra monitoring:
Compton Thin \rightarrow Thick \rightarrow Thin
in 4 days

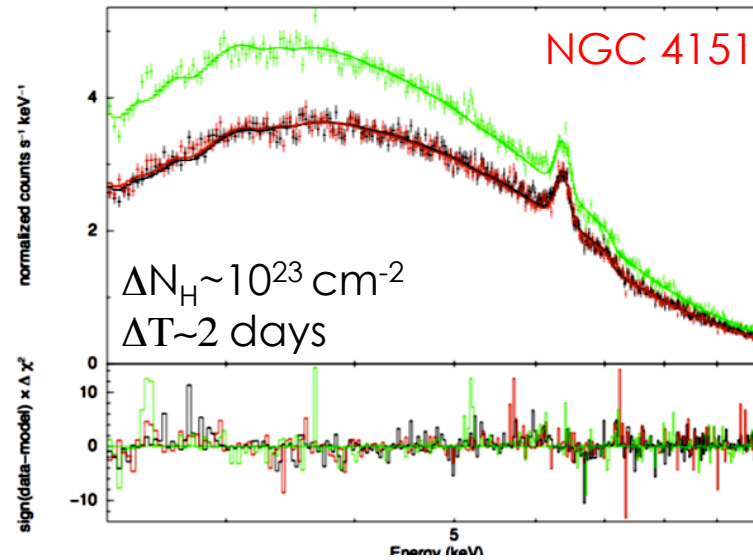




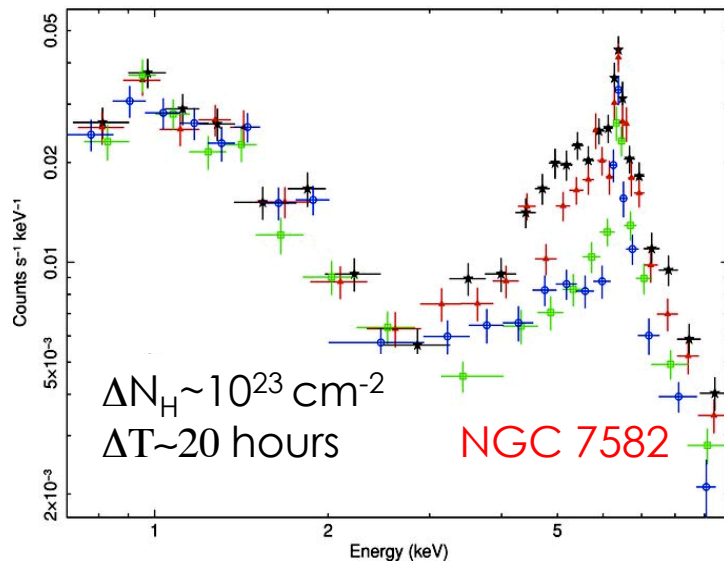
Cold N_H Eclipses in Hours–Days are Common



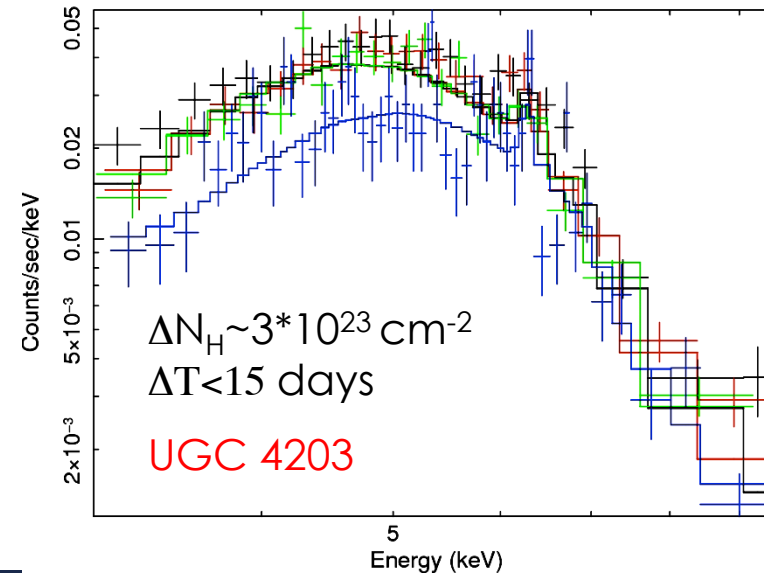
Elvis et al., 2004



Puccetti et al., 2007



Bianchi et al. 2009



Risaliti et al., 2010





Broad Line Region Clouds as Eclipsers

~100 microarcsecond structures

Eclipser velocity, density match BLR clouds:

$$V > \sim 10^3 \text{ km s}^{-1}$$

$$n \sim 10^{10} - 10^{11} \text{ cm}^{-3}$$

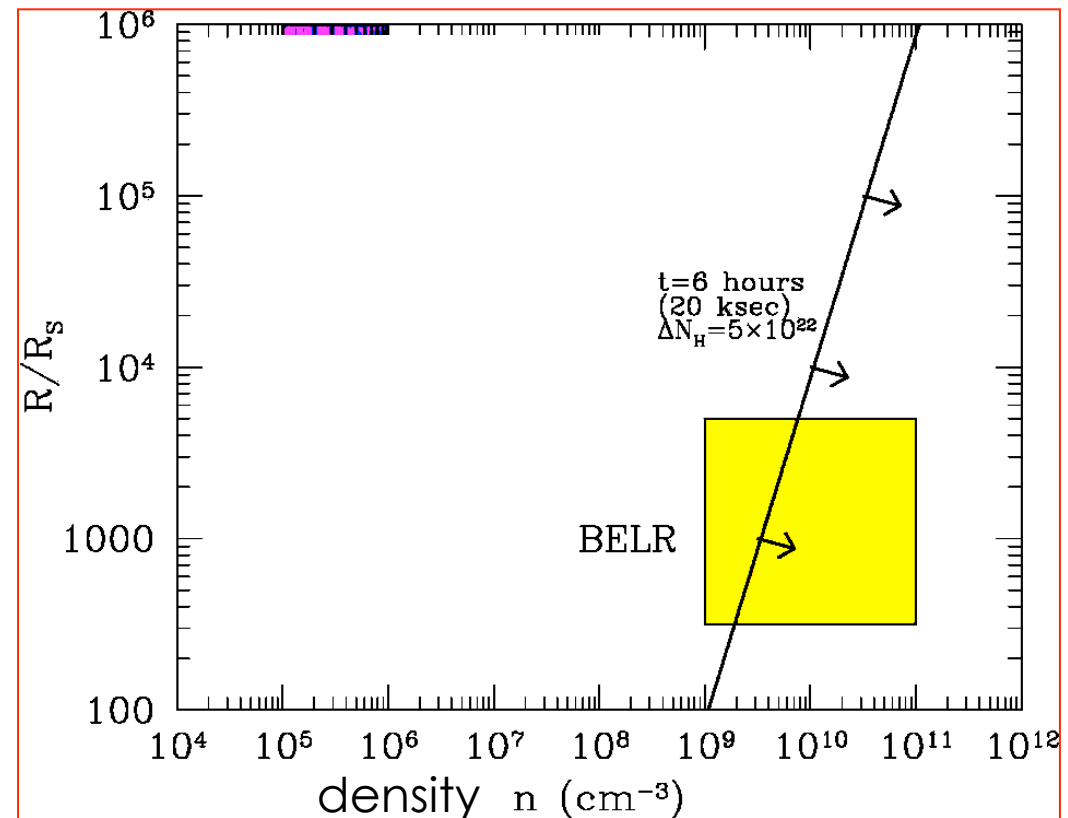
Ionization consistent

Gives new information:

$$\text{Sizes } D \sim 10^{13} \text{ cm.}$$

Blobs or sheets?

C.f. Ives, Sanford & Penston 1976





Population Properties of Cold Eclipsers

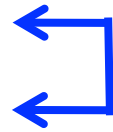
Maiolino et al. 2010

Frequency of NGC1365 eclipses:

$$N_{\text{clouds}} \sim 3 \times 10^7$$

$$\Sigma M_{\text{clouds}} \sim 0.004 M_{\odot}$$

$$\text{c.f. } M_{\text{BLR}} \sim 0.7 M_{\odot}$$



Why are Cold Absorbers <1% of BLR?

- X-ray eclipses pick out small clouds?
- Local heating, not just central photoionization?

$$\Sigma(\text{mass loss}) \sim 0.01 M_{\odot}/\text{year.}$$

Where does it go?

Makes hot WA/intercloud medium
by photo-heating at low densities?

*There is something fascinating
about science. One gets such
wholesale returns of **conjecture** out
of such a trifling investment of fact.*

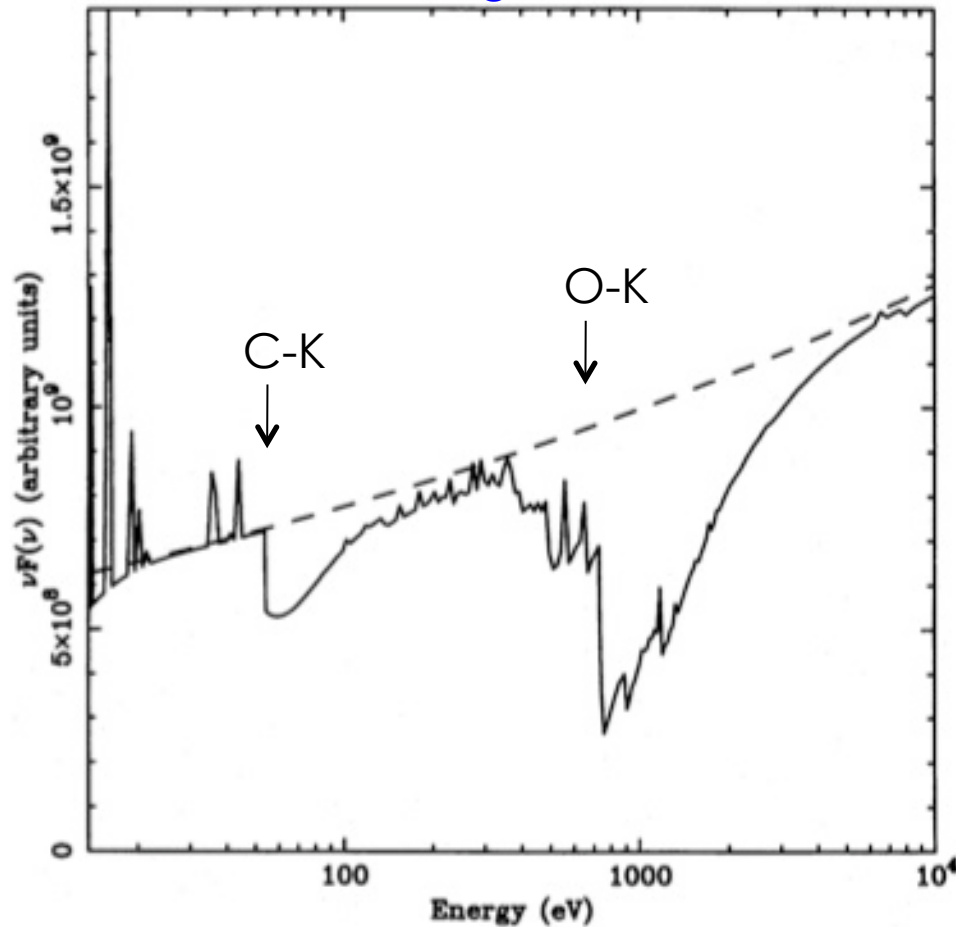
*Mark Twain.
Life on the Mississippi*



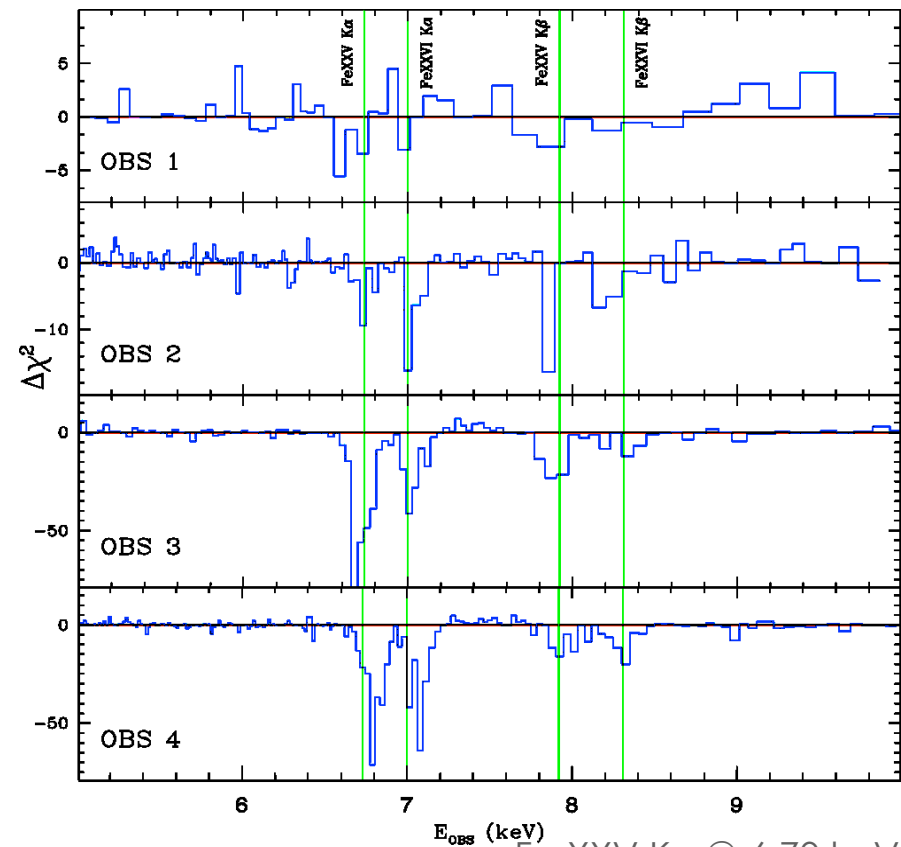


Ionized Absorbers

“Warm”: Moderate ionization
Line driving dominates



“Hot”: High ionization
Compton scattering dominates



Fe XXV K α @ 6.70 keV
Fe XXVI K α @ 6.97 keV
Fe XXV K β @ 7.88 keV
Fe XXVI K β @ 8.27 keV





Warm Absorber Winds

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

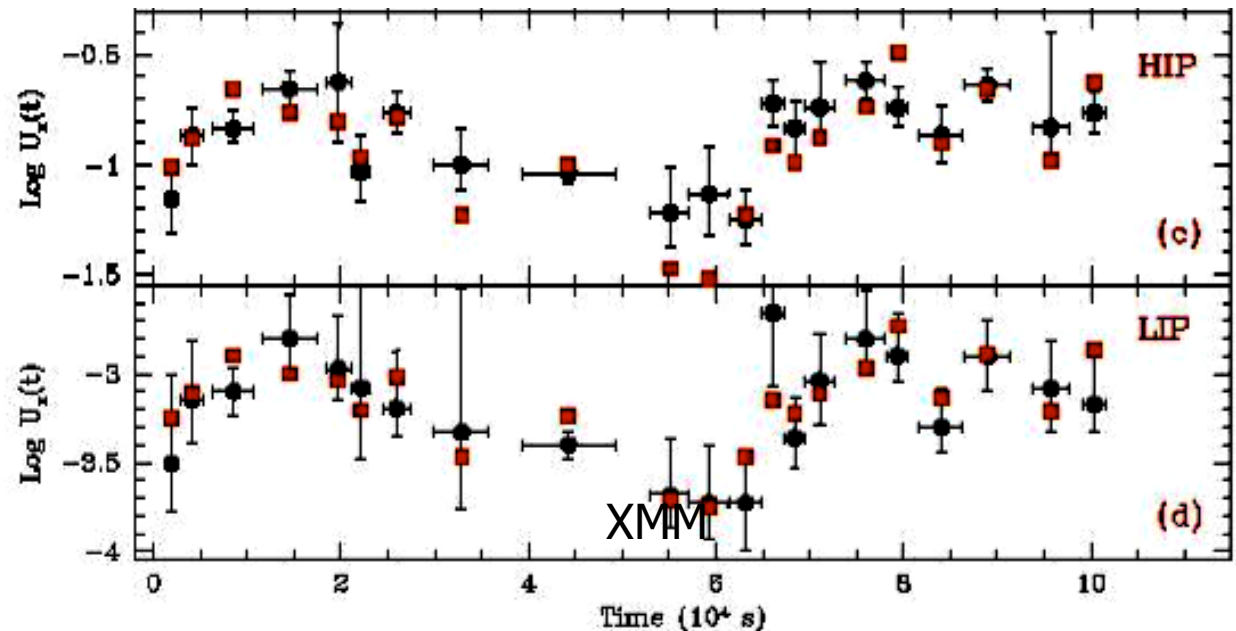
Warm Absorber ionization (U_x) closely follows continuum.

- high density
- small radius
- ~High Ionization BLR

WAs vary in U_x
Always present:
→ “Curtain”

Blueshifted
→ Wind

NGC4051 Chandra



log $U_x(t)$, measured

log $U_x(t)$, predicted



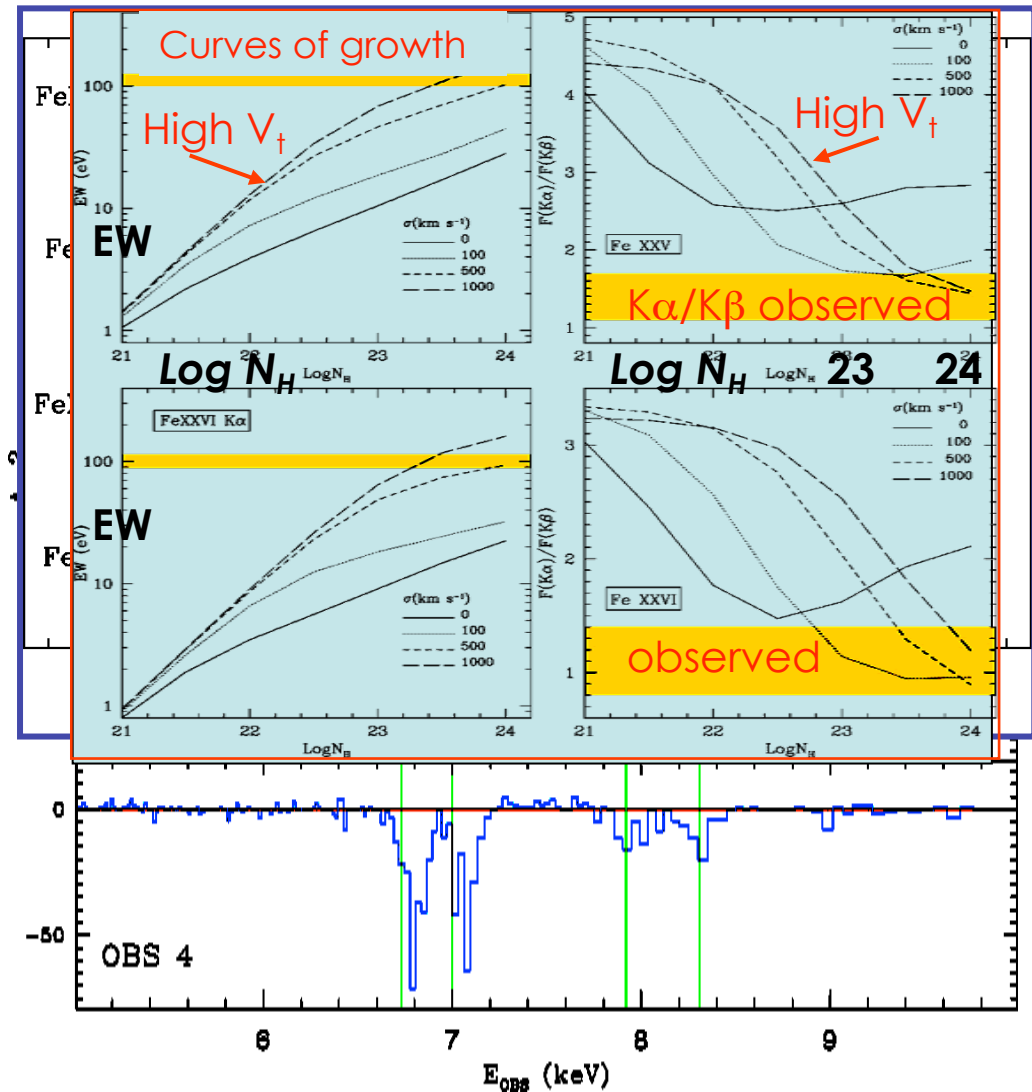


High Ionization Winds

NGC1365 Risaliti et al., 2005, ApJL, 630, L129

- Variable velocity outflow
 - 2500 → 5000 km/s in 1.5 years
- Broadened
 - $v_{\text{turb}} \sim 500\text{-}1000\text{ km/s}$
- Compton \sim thick
 - $N_{\text{H}} > 10^{23.5} \text{ cm}^{-2}$
- Super-High Ionization WA:
 - $\log U_{\text{X}} \sim 0$
 - Compton scattering
 - $R \sim 50 (M/M_8)^{-1} R_s$
- Not Eddington limited

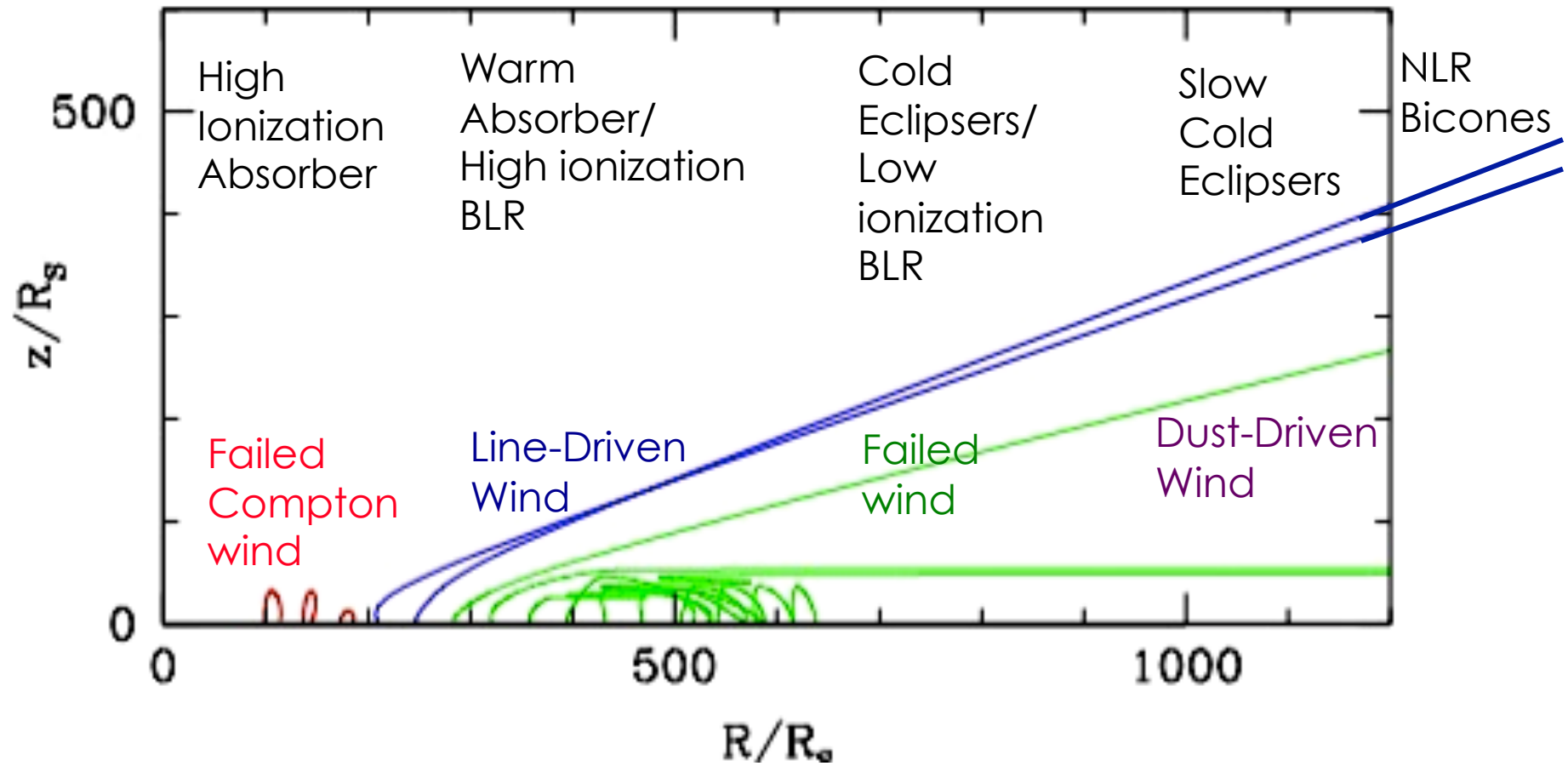
→ “Failed wind”





A Simple Wind Model

Risaliti & Elvis, 2010, A&A 516, A 89



Does all this absorbing/emitting gas come from the disk?

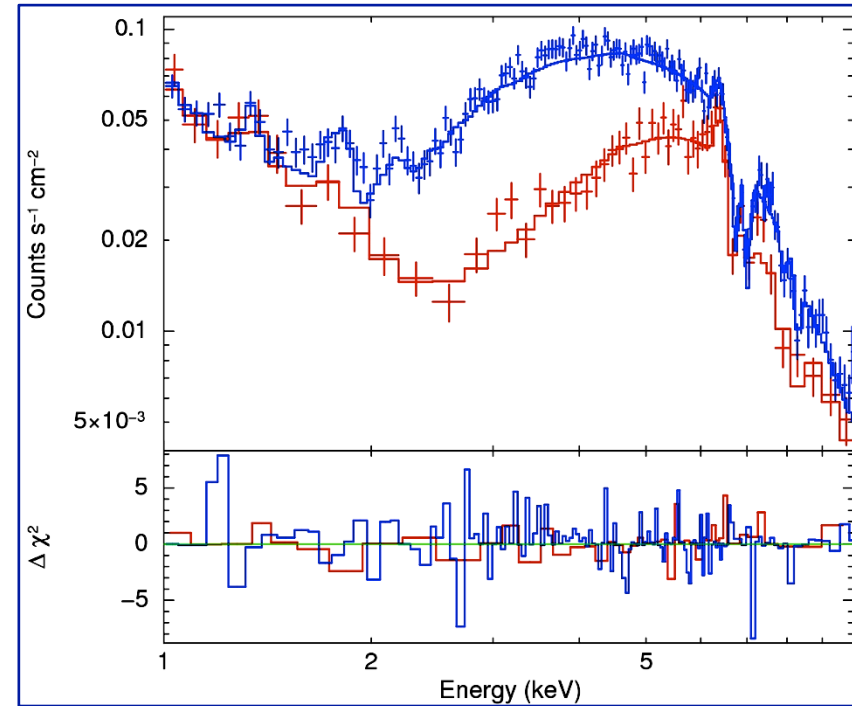
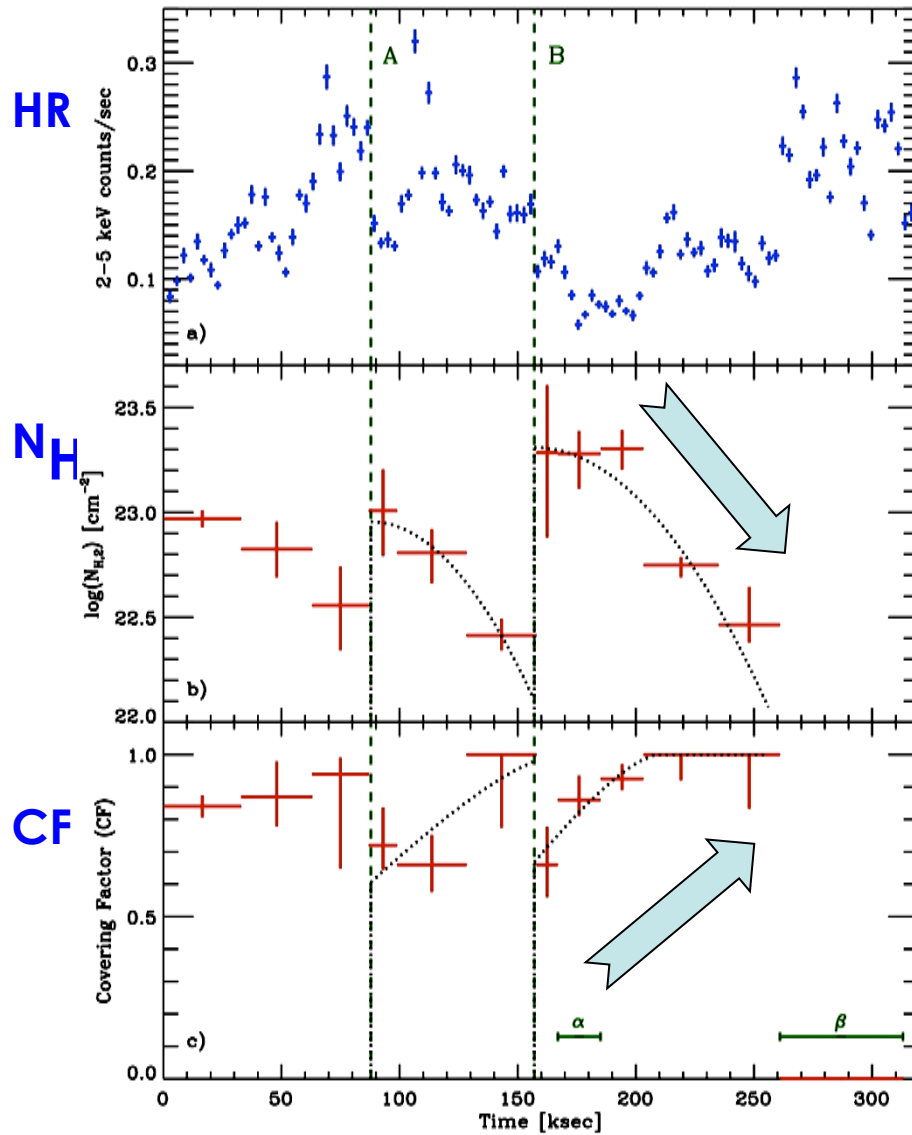




Fine Structure in the Eclipser

NGC 1365 Suzaku

Maiolino et al. 2010



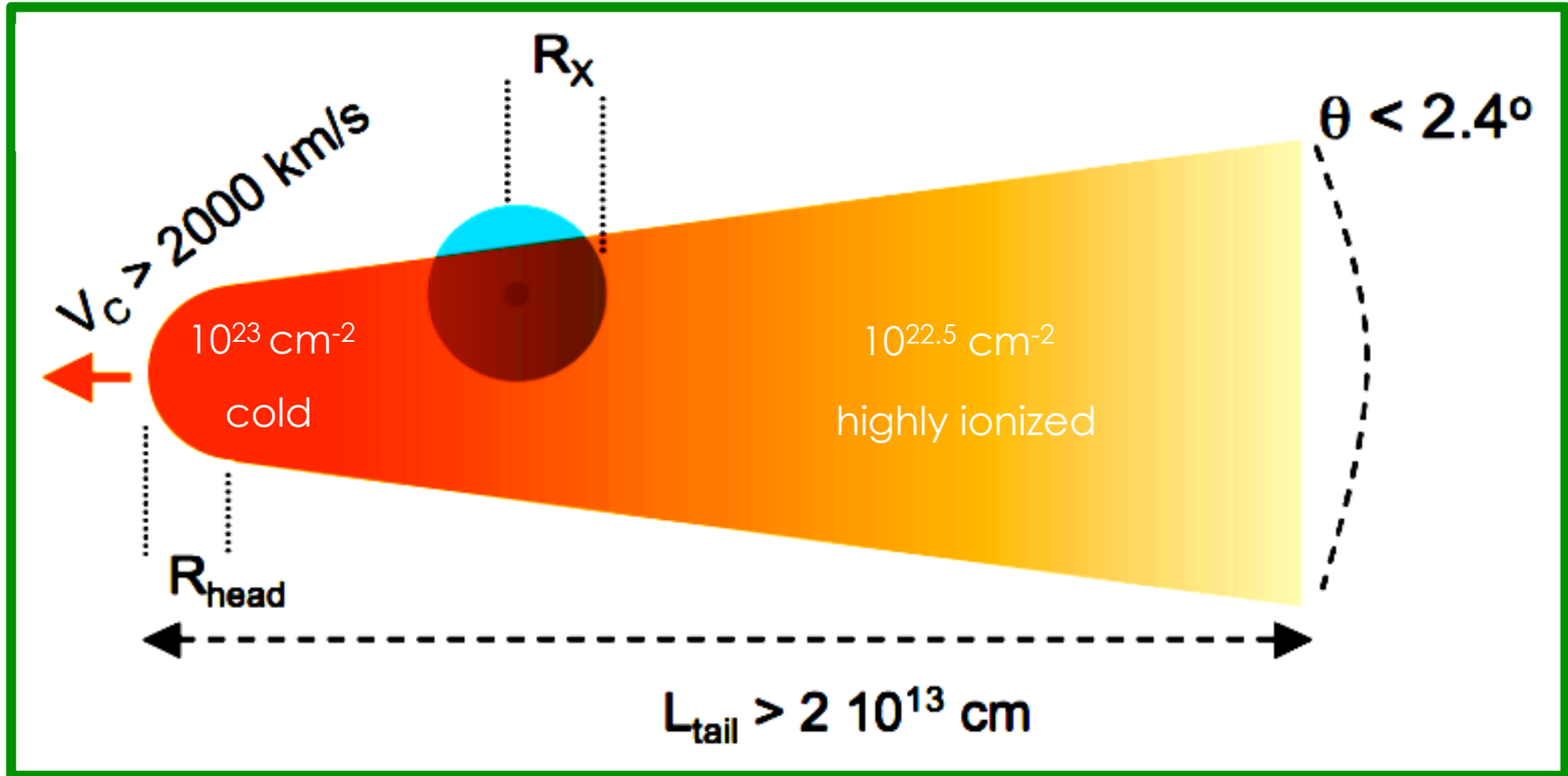


“Cometary” Eclipsers

~1 microarcsecond structures

NGC 1365 Suzaku

Maiolino et al. 2010





Cometary Eclipser Properties

Maiolino et al. 2010

Asymmetric: not radial, unlike solar system comets

Tail from motion through hot ($\sim 10^7\text{K}$) medium?

Mach cones?

$M > 20$ opening angles 1.5-4deg

Mass Flow:

$M(\text{head}) \sim 4 \times 10^{-11} M_{\odot}$ (if 100% filling factor) [c.f. $M_{\text{Earth}} \sim 3 \times 10^{-6} M_{\odot}$]

Mass loss rate $\sim 3 \times 10^{-10} M_{\odot}/\text{year}$ (via tail)

→ Head Lifetime ~ 2 months $< P_{\text{orbital}} \sim 1$ year (c.f. Mathews & Ferland 1987)

→ **clouds constantly renewed**

Never see the same gas twice

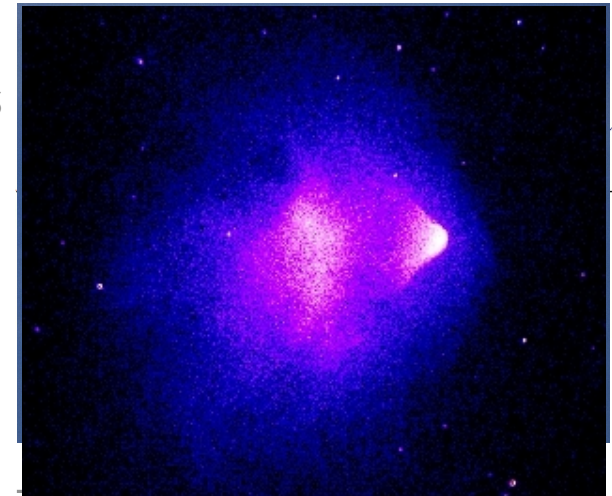
at small radii ($< 10^{16}$ cm)

→ **clouds come from accretion disk**

What launches the wind?

Inner: Line-driven radiation pressure (Proga)

outer: Dust opacity (Czerny et al. 2010)





A More Complete Quasar Model

Broad, Narrow Absorption Lines, High Ionization Emission Lines, hot dust

massive black hole

Lynden-Bell 1969

accretion disk

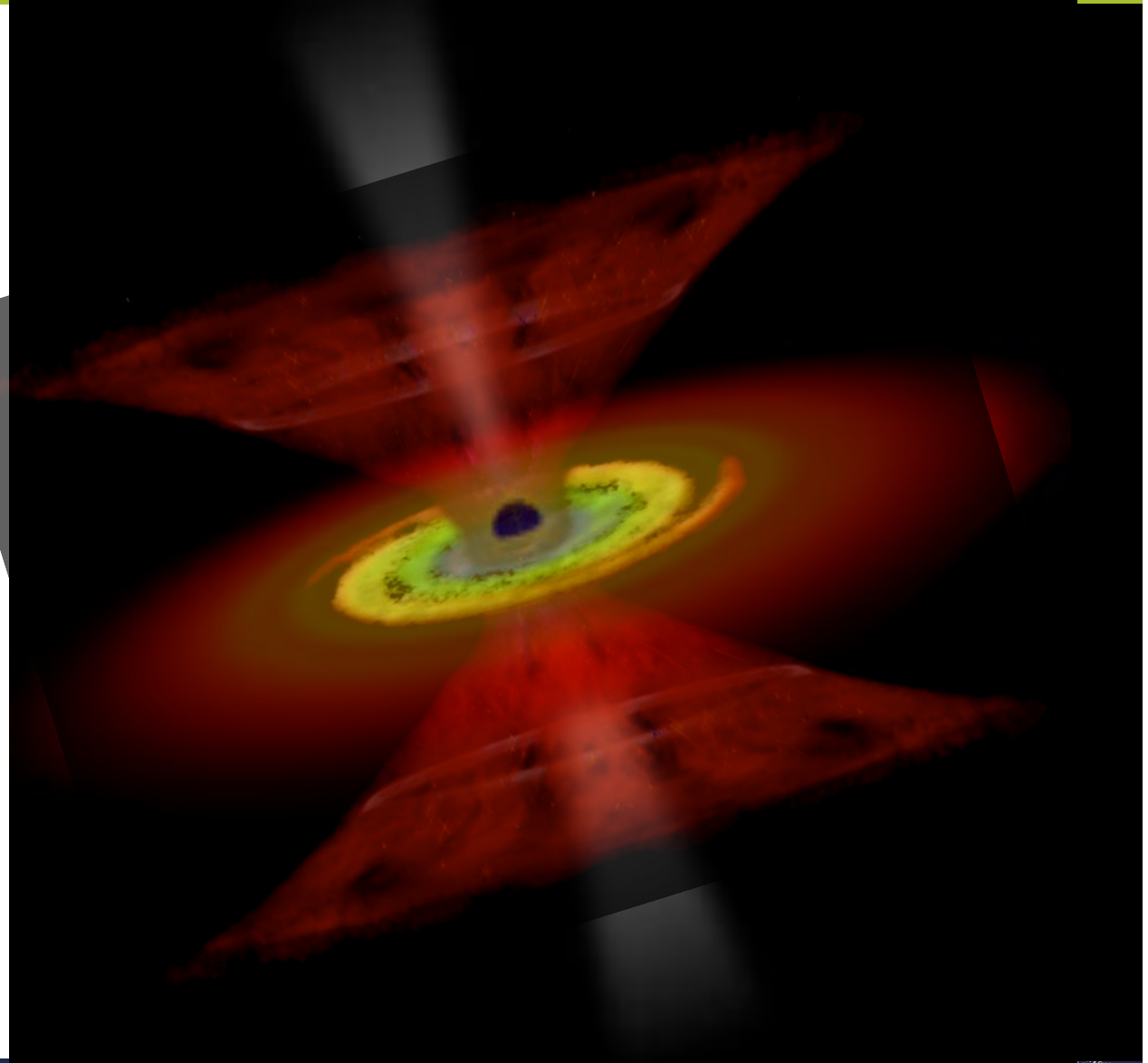
Lynden-Bell 1969, Pringle & Rees 1972,
Shakura & Sunyaev 1972

relativistic jet

Rees 1967 [PhD],
Blandford & Rees 1974

disk winds

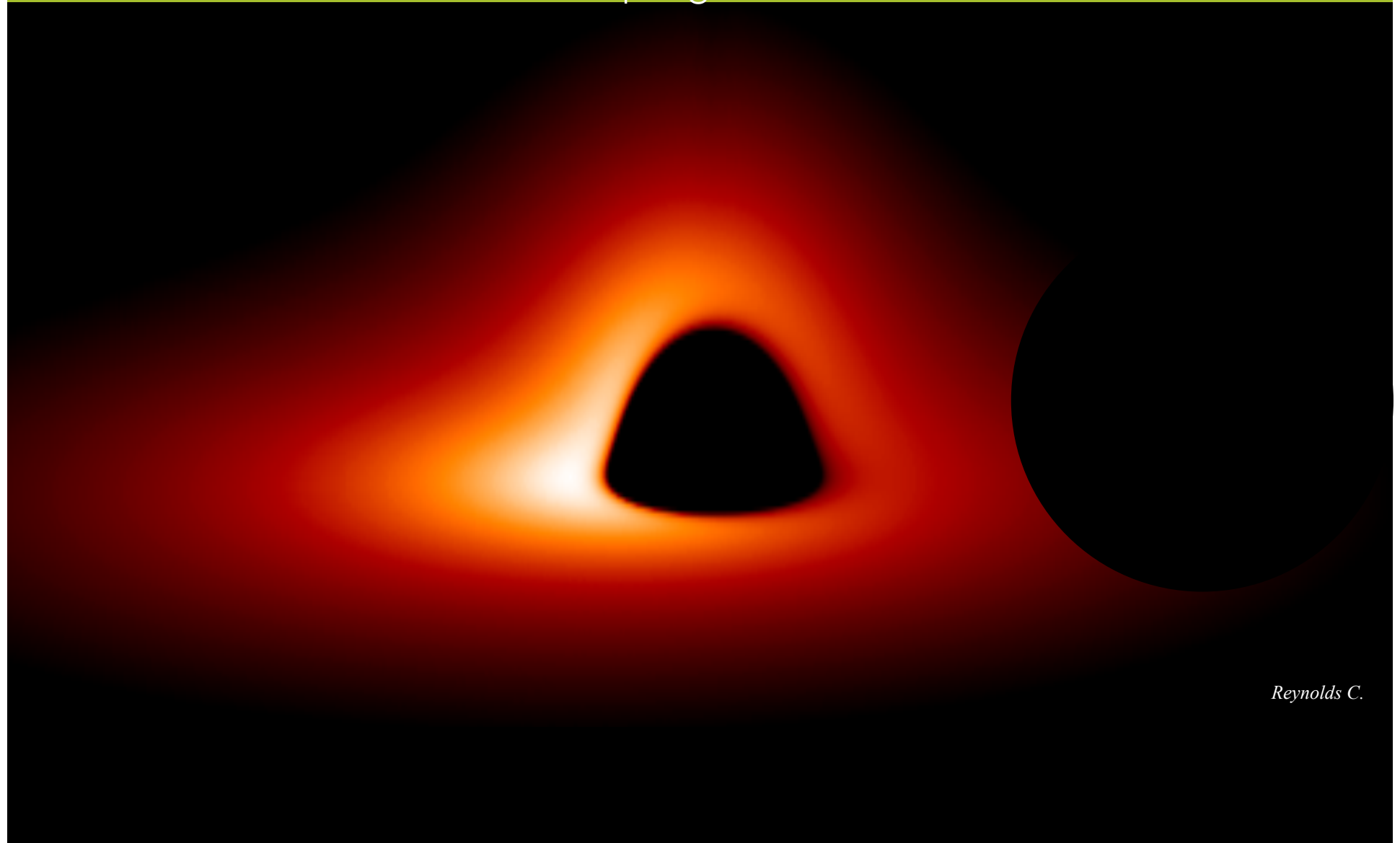
Murray et al., 1995
Elvis 2000
Eliitzur 200x





The X-ray Continuum Source

Eclipsing the Source



Reynolds C.



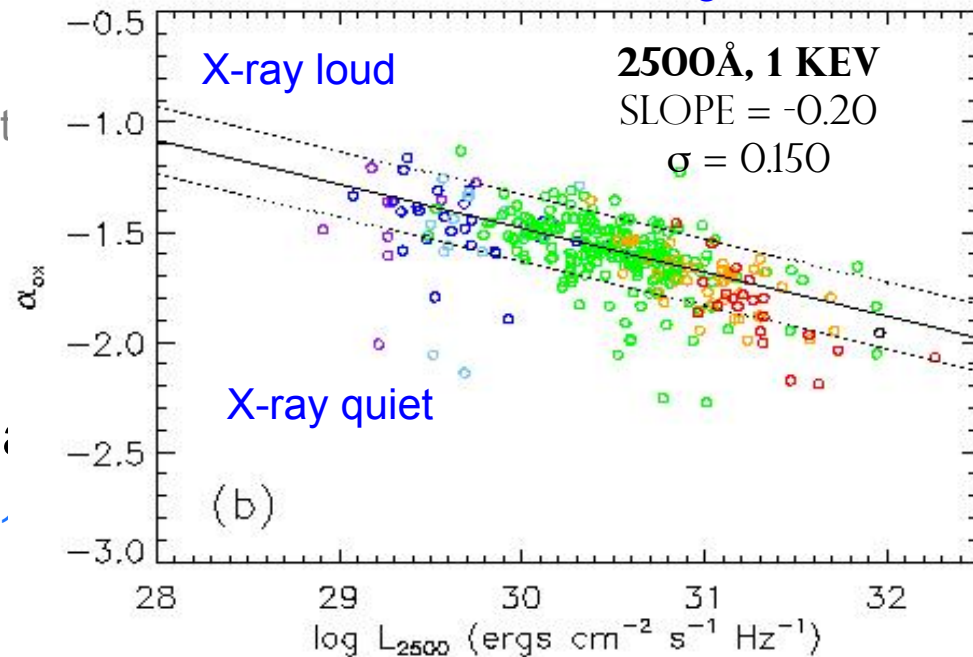
Martin Elvis, Wideband X-ray Astronomy, IUCAA, Pune India, 16 January 2011



Harvard-Smithsonian Center for Astrophysics

- Know a lot about behavior, little about origin
- Options, as in binaries: (see Malzac 1999)
 - Inefficient cooling?
 - Reconnection?
 - Jet?
- Less efficient corona production at high L ($\alpha_{\text{ox}} - L_{\text{UV}}$ relation) [Tananbaum et al. 2001](#), [Steffen et al. 2006](#), [Strateva et al. 2006](#), [Young et al., 2006](#)
 - L_{UV} *NOT* L/L_{Edd}
- Different accretion modes?
 - But continuous, large scatter
- Knowing geometry would help

Monica Young, BU PhD, 2010



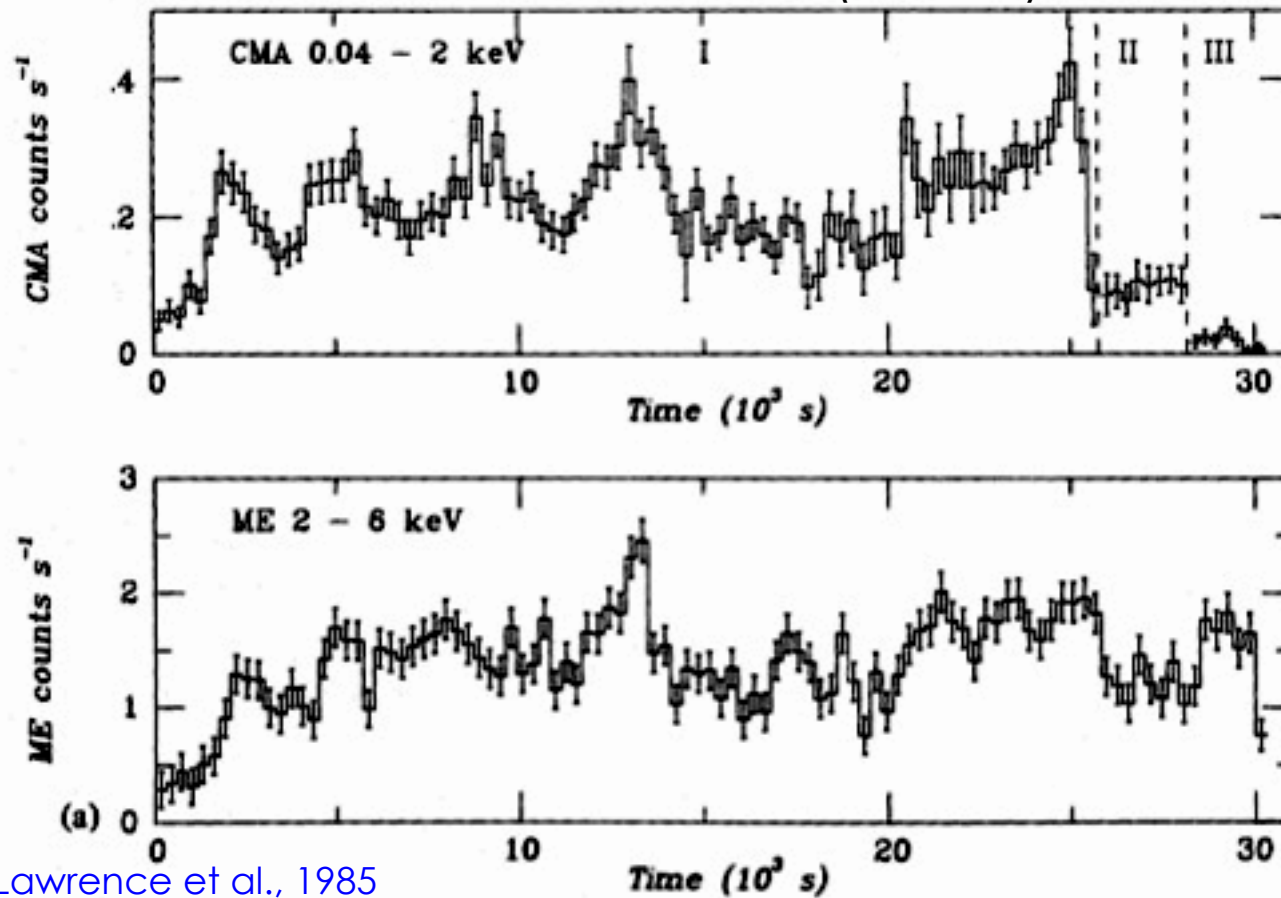


The X-ray Continuum Size

Light travel time size = $200 \text{ lt-sec} = 10R_g$

$$M_{\text{bh}} = 1.7 \times 10^6 M_{\odot} \text{ (Denney et al, 2009)}$$

NGC4051: 300s time bins (EXOSAT)



Lawrence et al., 1985

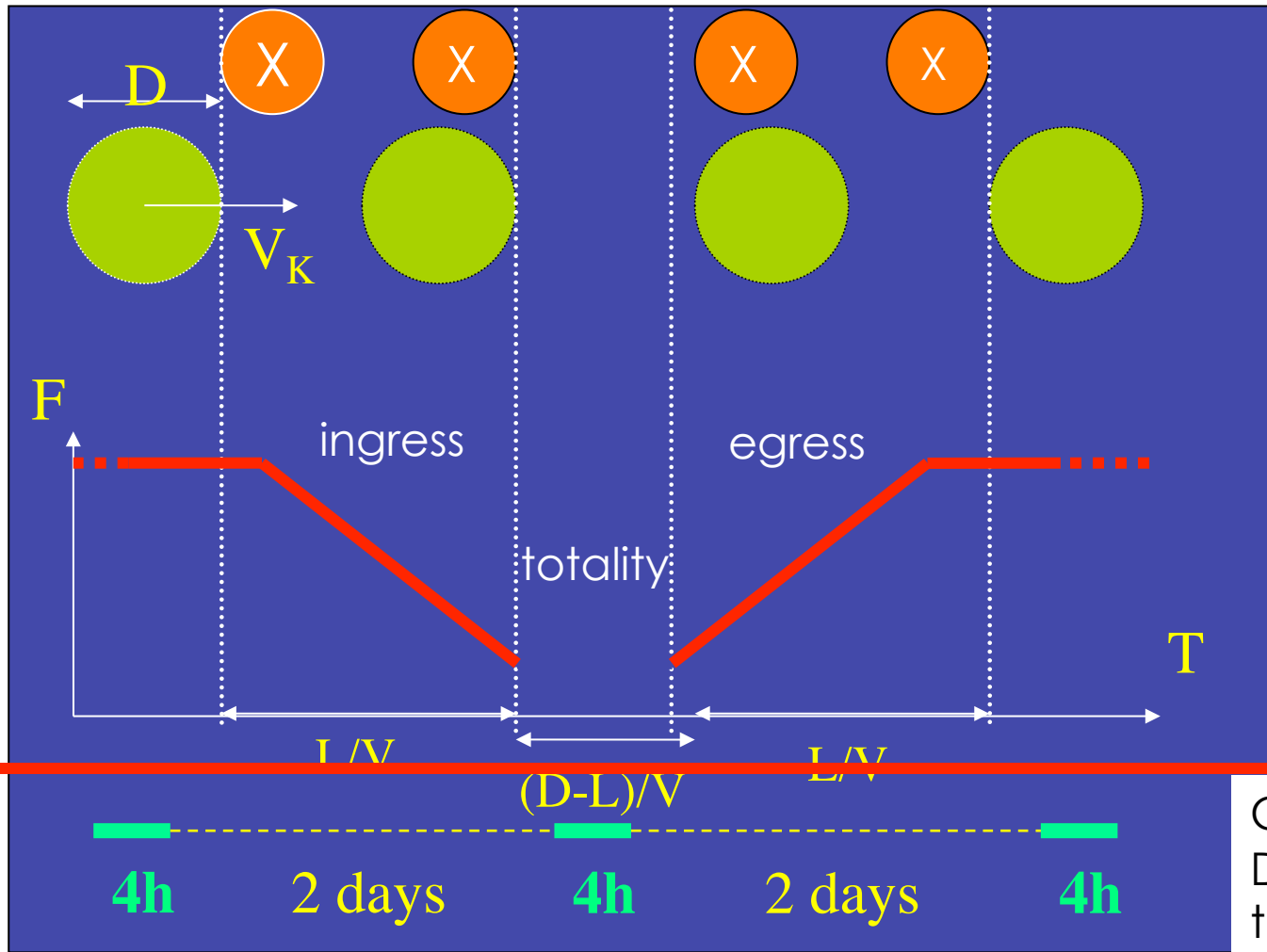




Eclipse Size of the X-ray source

NGC1365 Chandra Risaliti et al. 2007, astro-ph/0703173

$D_X = V_K T \sim 10^{14} \text{ cm}$ ($v \sim 10^4 \text{ km s}^{-1}$) $\sim 10 M_7 R_G$ Almost resolved



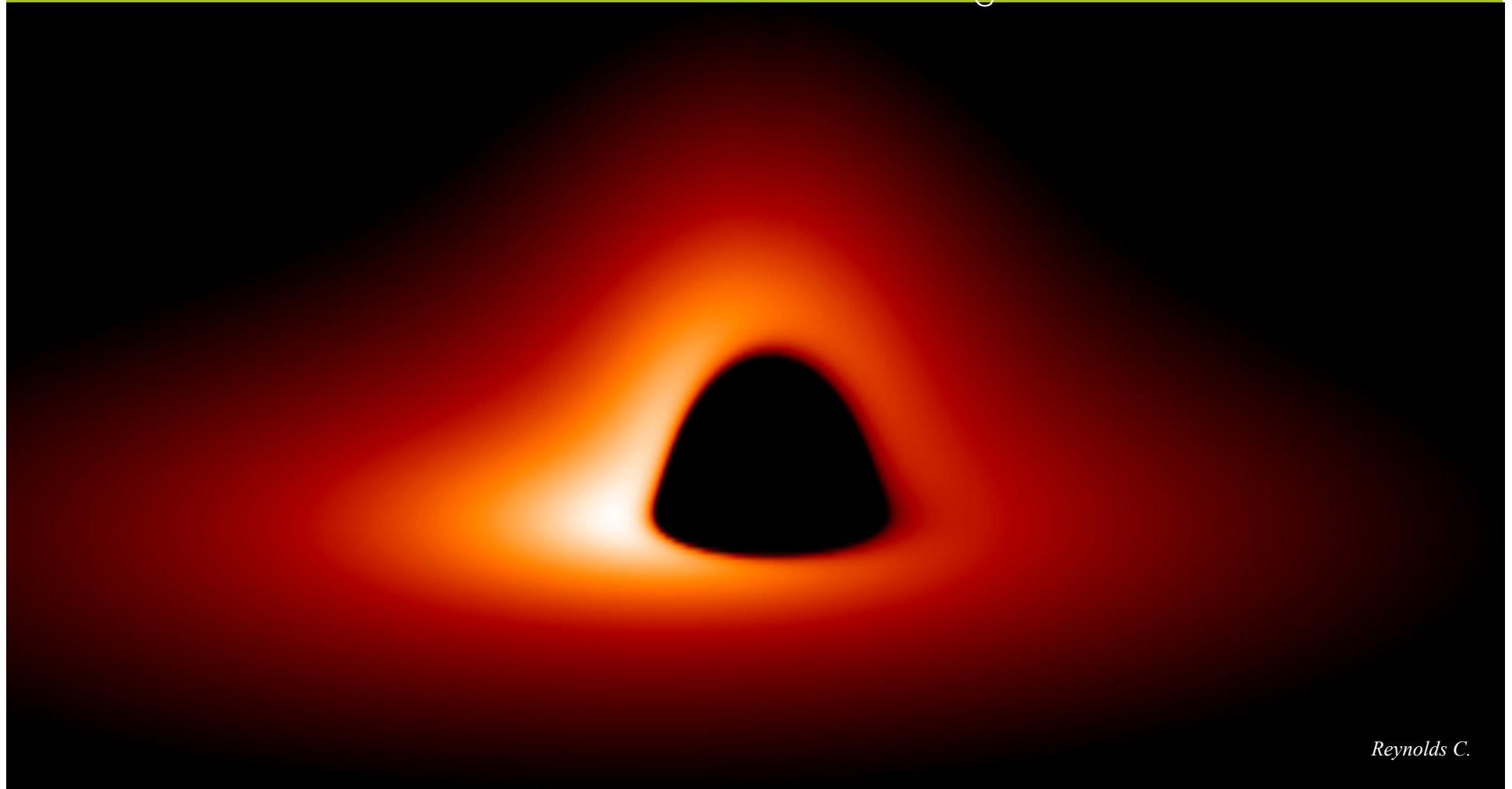
Sparse Data	4h	2 days	4h	2 days	4h	Complete Data → tomography
	(D-L)/V					



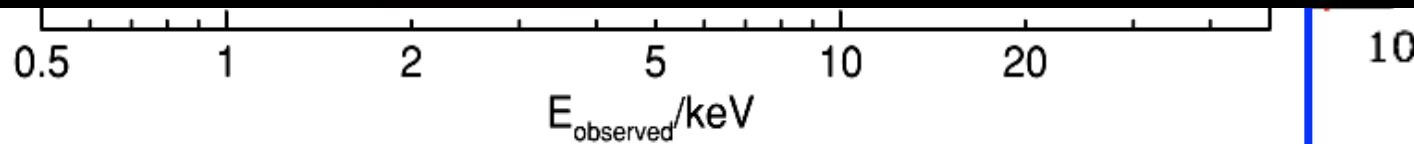


The Relativistic Iron Line Puzzle

GR broadened lines from a few R_G in Quasars?



Reynolds C.



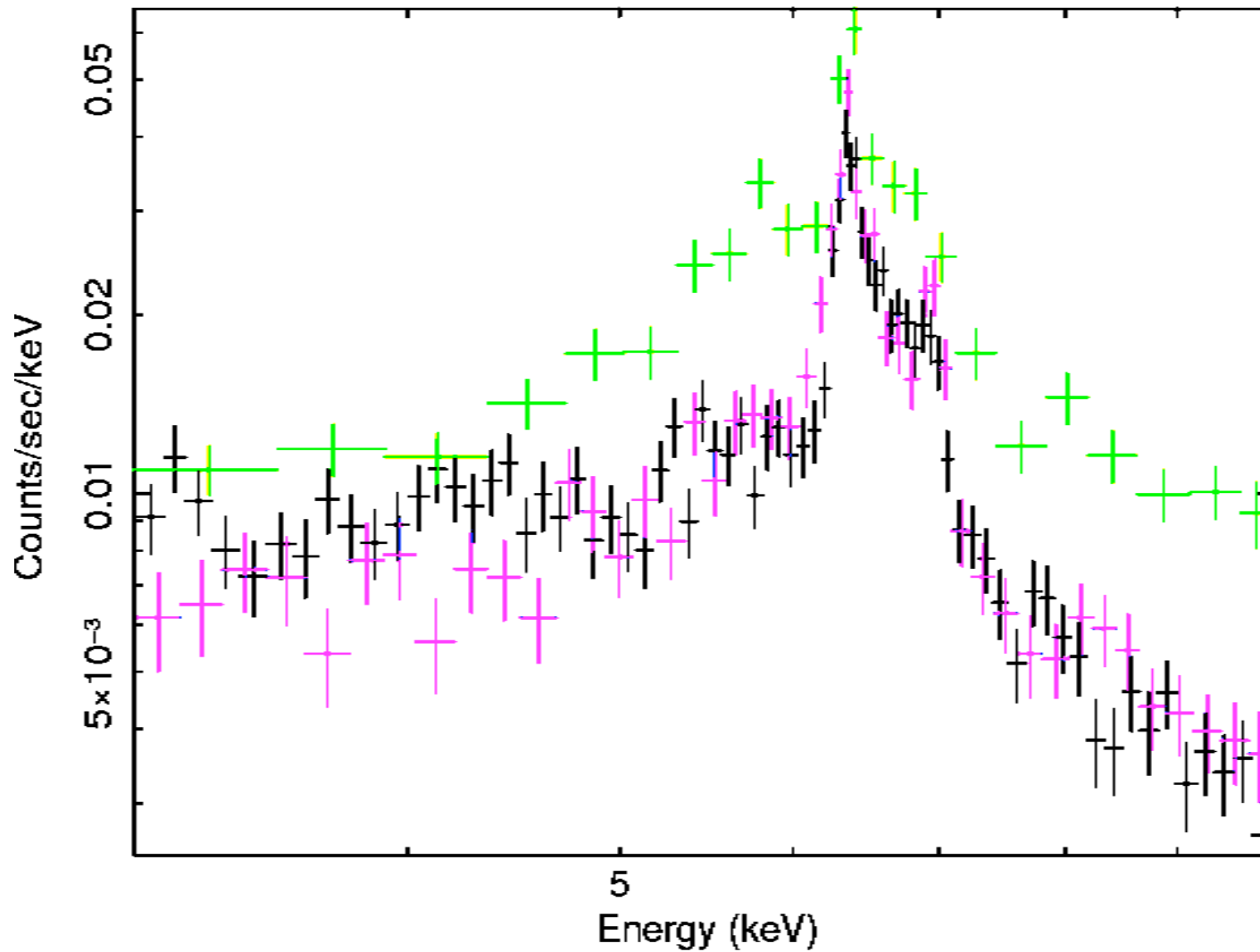
Martin Elvis, Wideband X-ray Astronomy, IUCAA, Pune India, 16 January 2011





“Fe-K” Profile changes in Eclipse

NGC1365 XMM Long Look

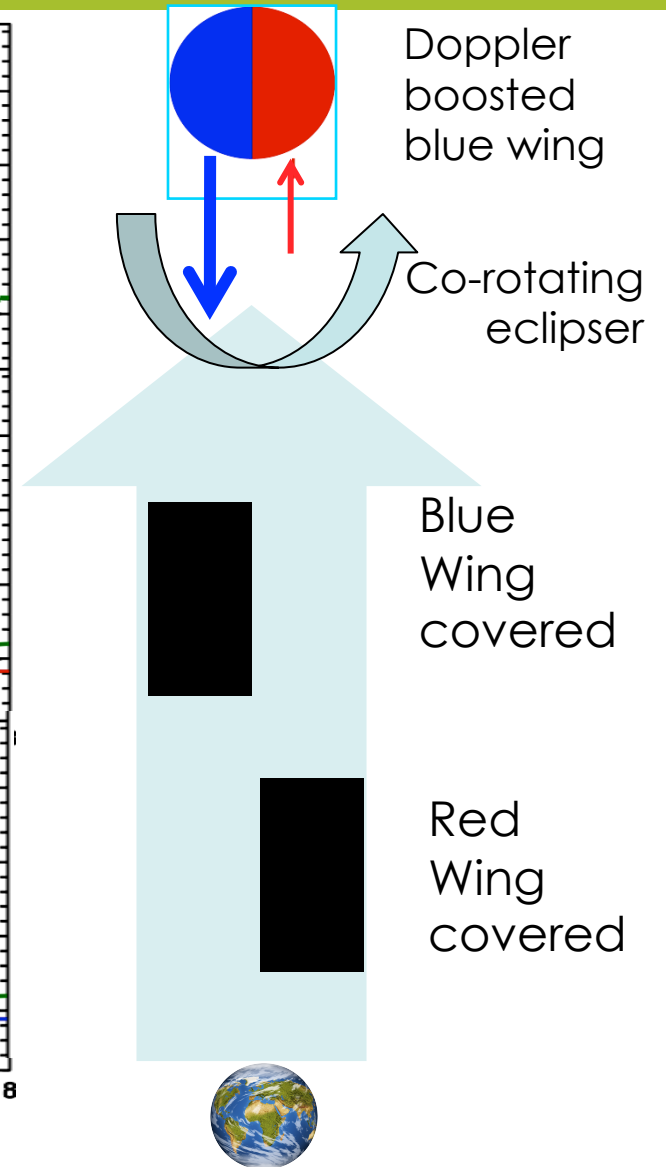
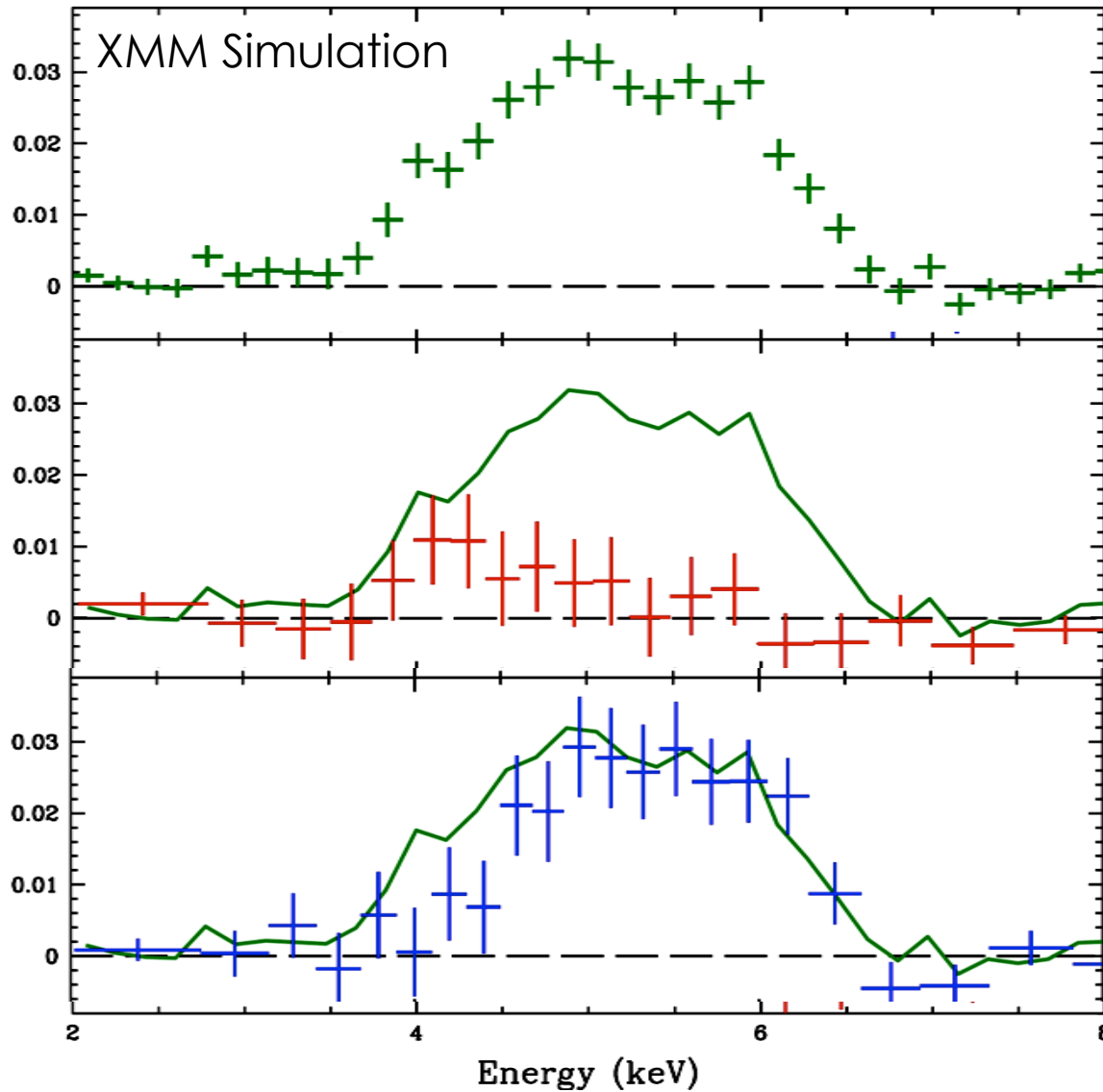


Similar changes in long Suzaku monitoring – Brenneman et al., in prep.





Eclipse of the Iron Line: Unique Signature

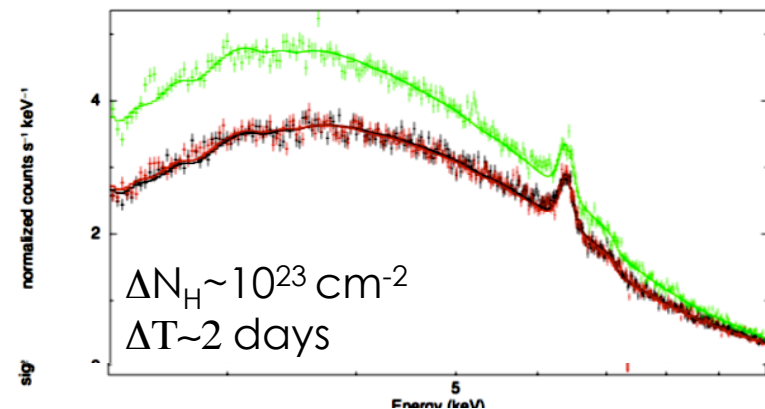
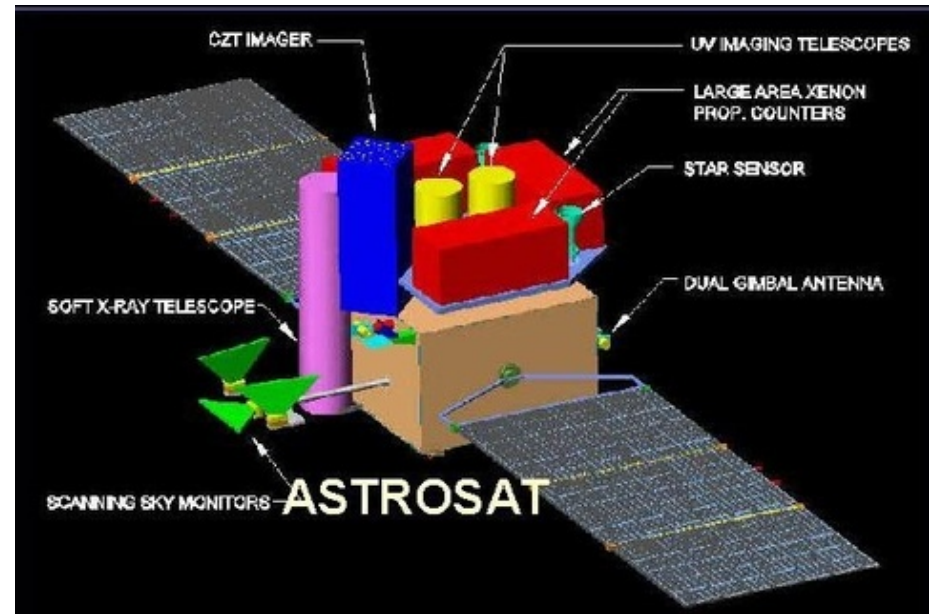




ASTROSAT and Quasar Eclipses

Obscuration Monitoring

- Not subtle effects
 - No need for CCDs
 - But need wide band
- Obscured Sample monitoring
 - Statistics
- Unobscured AGN:
 - WA variations?
 - Cold N_H events
- Intensive studies of Best AGNs
 - Structure of BELR clouds
 - Structure of X-ray source
- Dusty Absorbers?
 - UVIT monitoring



Puccetti et al., 2007

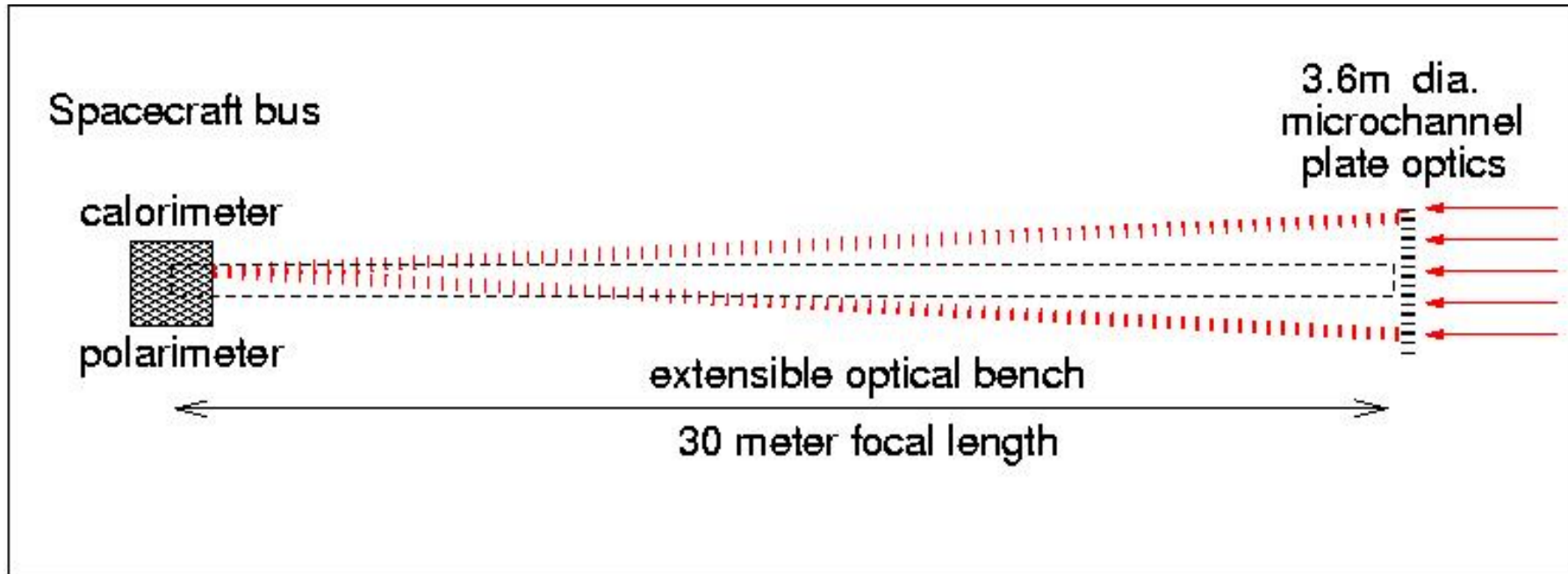




Extreme Physics Explorer

GR broadened lines at IXO quality with an Explorer class mission

GR Fe-K line tests, tomography needs: Big Area, Good Spectral Resolution



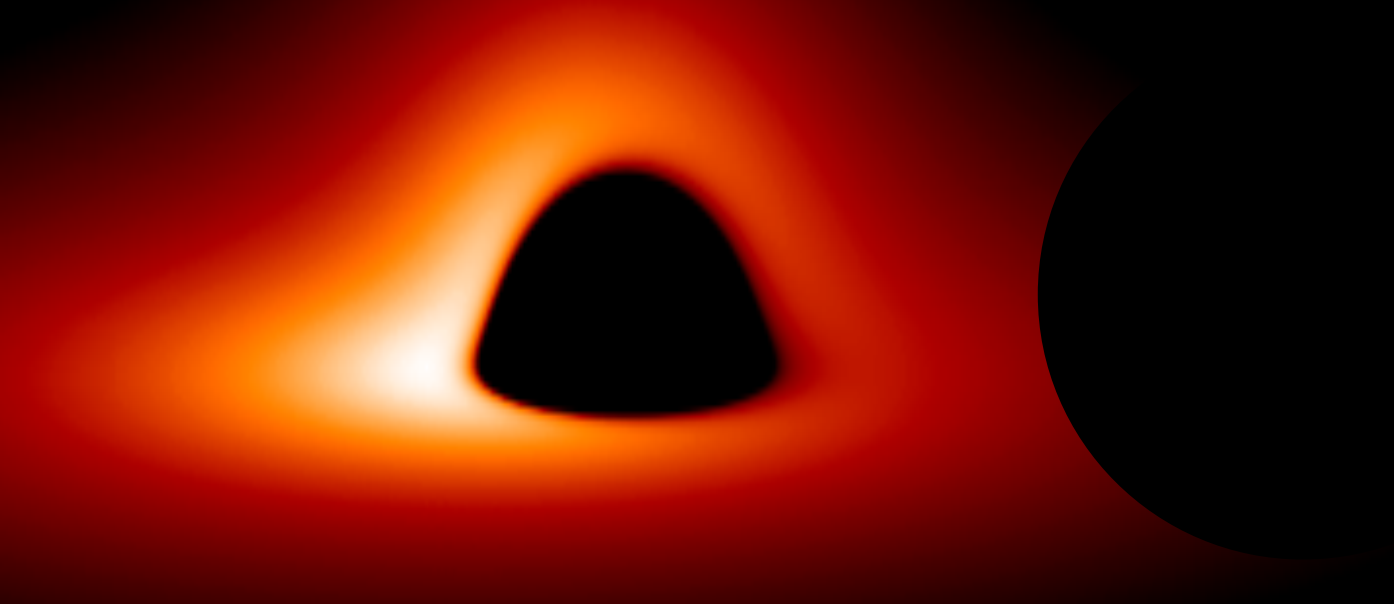
Sq. meters A_{eff}
Sub-msec timing
Arcmin imaging - to reach bright AGNs
2eV resolution
Polarimeter?





Quasar X-ray Eclipses

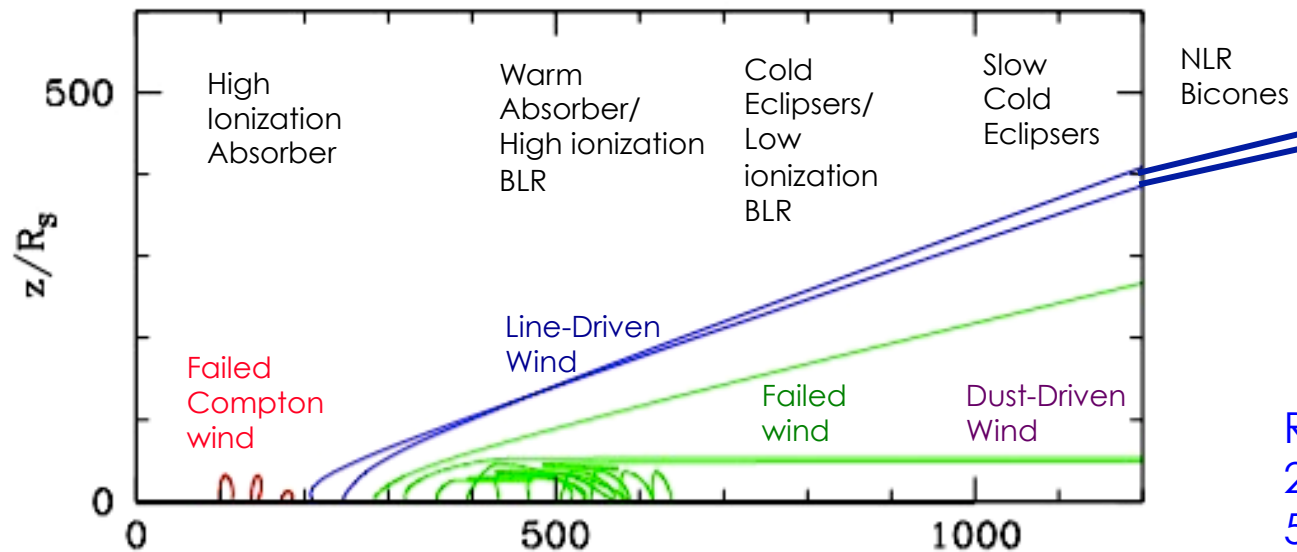
...give a new, unified, view of the innermost structure of quasars



Reynolds C.



1. Donut Torus is too simple: larger and smaller scale absorbers
2. Unified by accretion disk winds
3. Cometary Broad Line Region clouds
4. Close to resolving X-ray continuum source
- 5. *ASTROSAT will be great!***
6. Definitive test and properties of GR Fe-K line
7. *Extreme Physics Explorer*



Risaliti & Elvis,
2010, A&A
516, A 89



Discussion

1. Top 3 recommendations for key science programmes with Astrosat
2. Top 3 requirements for Astrosat operations strategy:
e.g. TOO fraction, multiwavelength operation, calibrations etc.
3. Top 3 desired mechanisms for idea exchange and follow-up of this conference:
e.g. conferences,
smaller workshops,
schools,
web-based discussion forum etc.

