X-ray spectroscopy of obscured AGN: NuSTAR results and ASTRO-H perspectives

featuring: "The Markarian 3 case"

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ASTRO-H ESA Science Operation Center (SOC) - ESA/ESAC

Outline

Basic question of this talk: which quantitative constraints can we put on the circum-nuclear gas and dust in AGN?

1. Constraints from IR/optical
2. Constraints from X-ray spectroscopy and spectral variability
3. A showcase: a recent monitoring campaign on Markarian 3
4. What do we need to make a step forward: modelling and ASTRO-H

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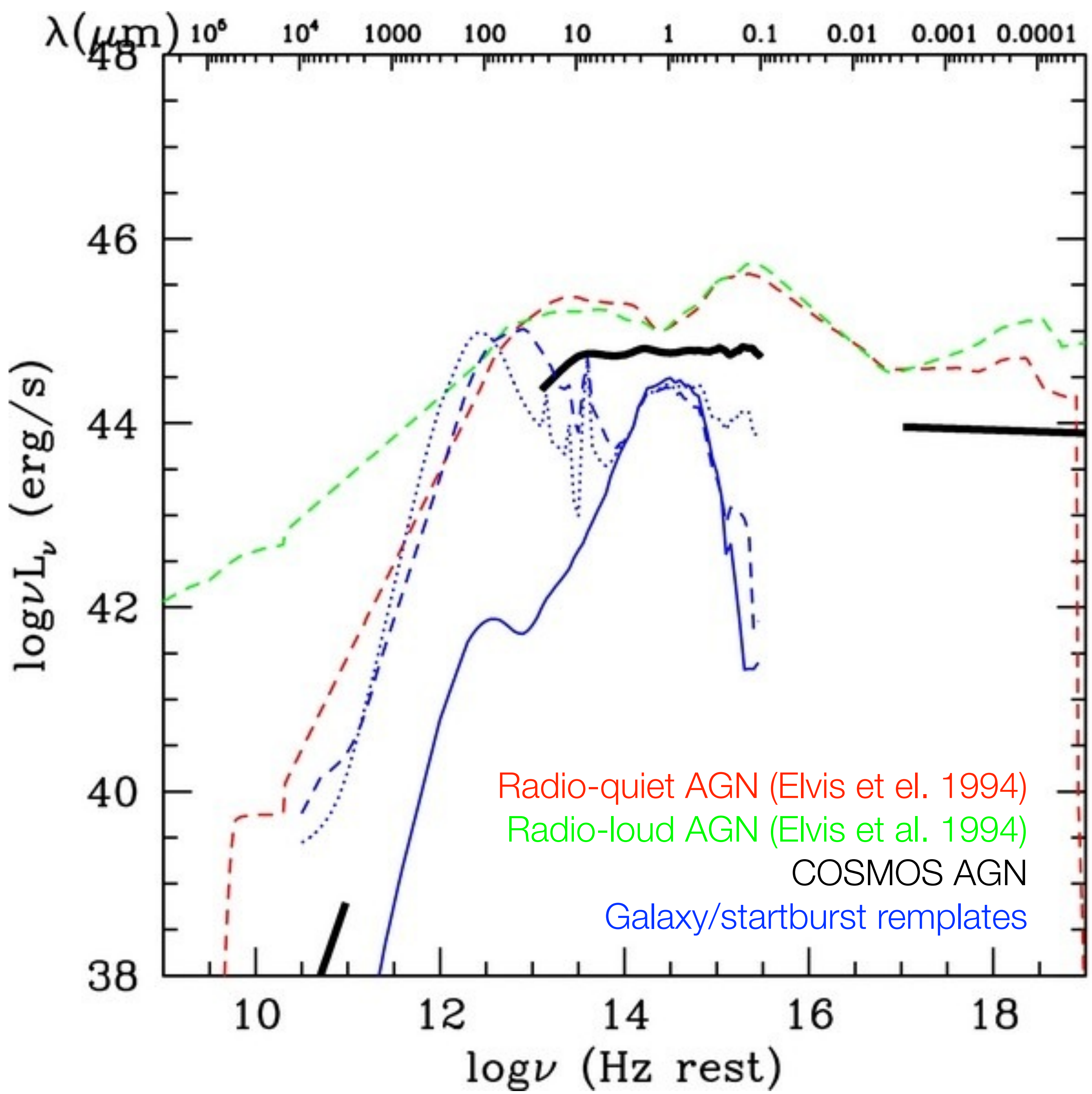
AGN Spectral Energy Distribution

Ho et al., 1995, ApJ

Elvis et al., 2012, ApJ, 759. 6; Detmers 2011, A&A, 534, A37



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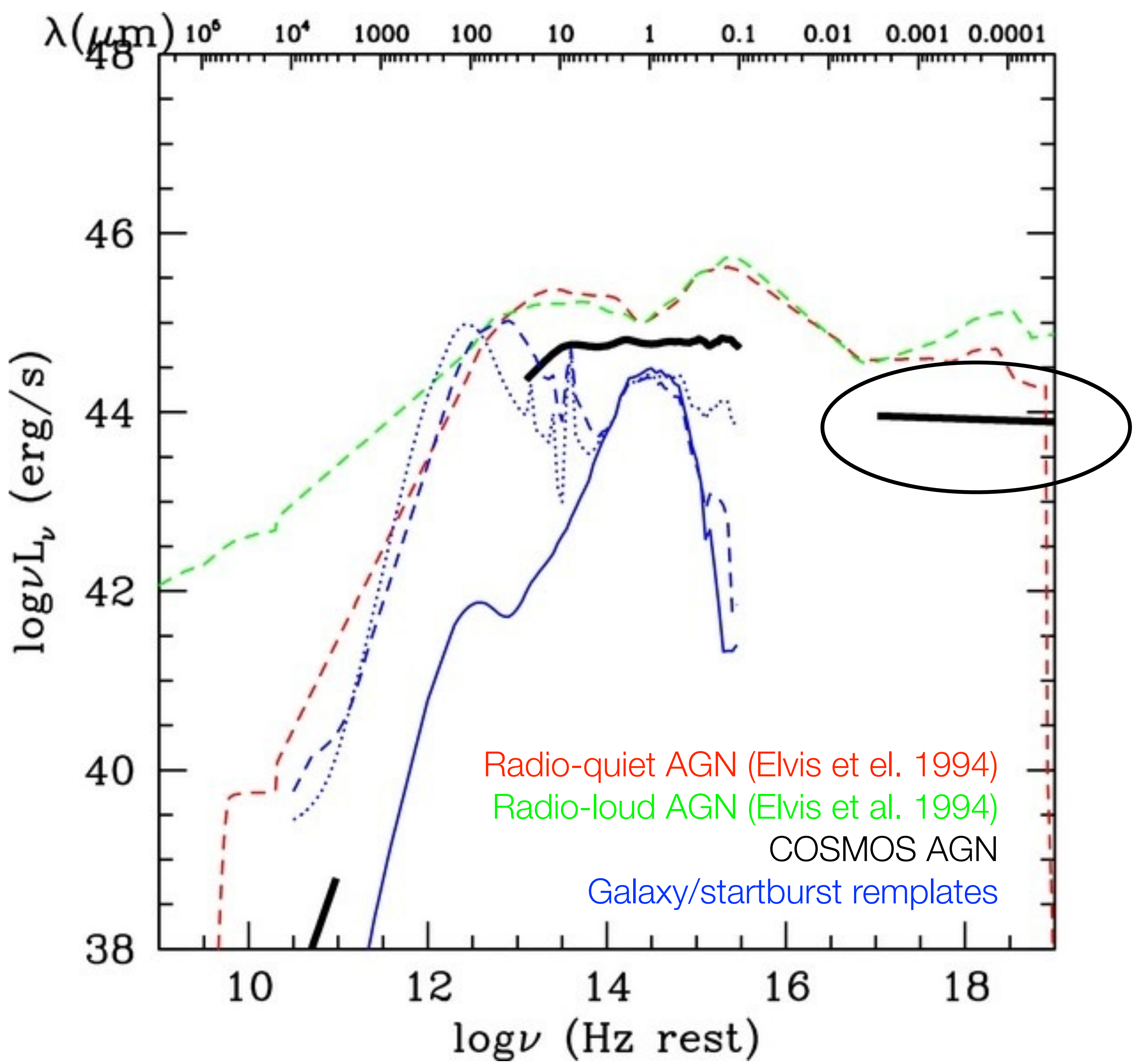

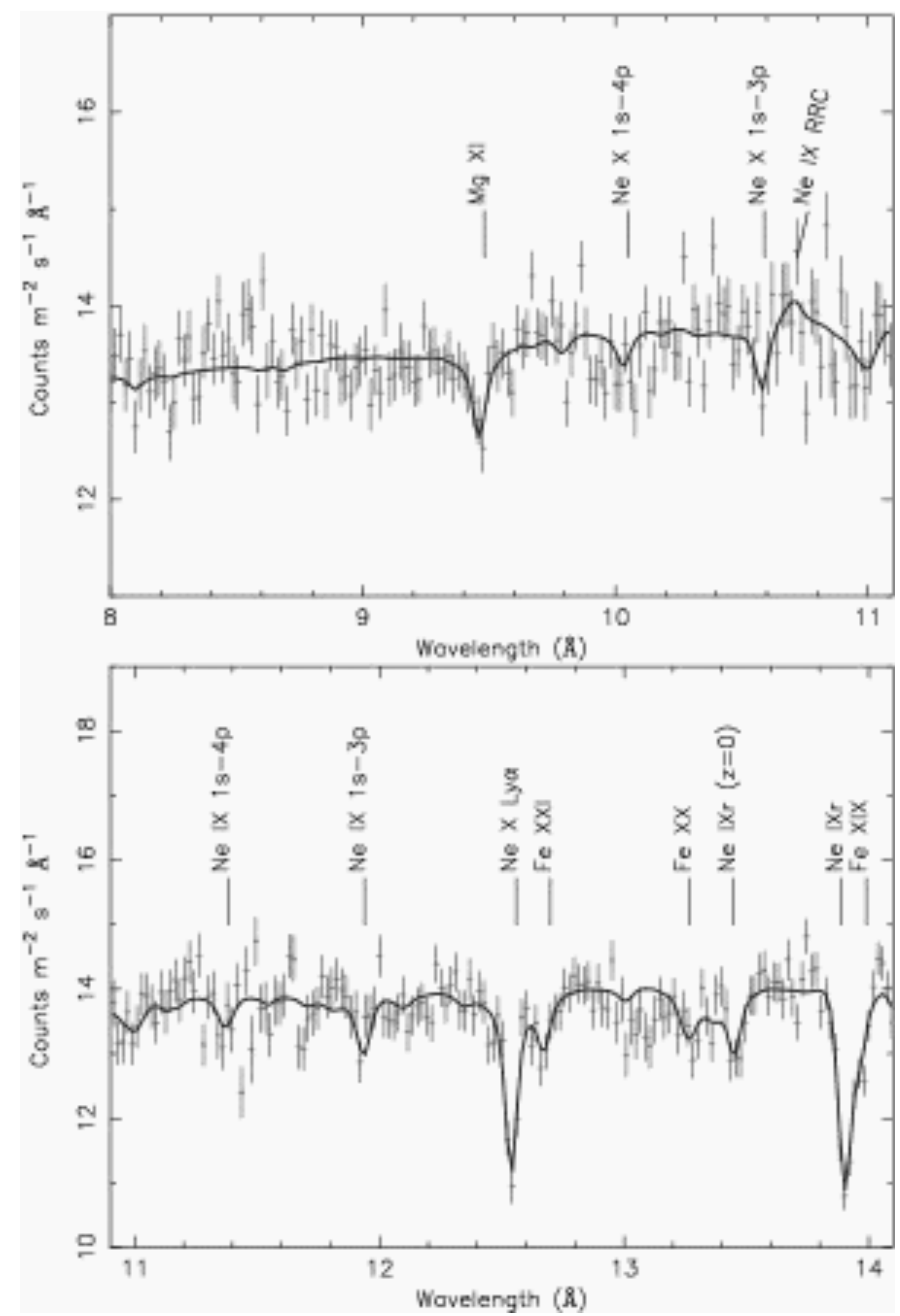

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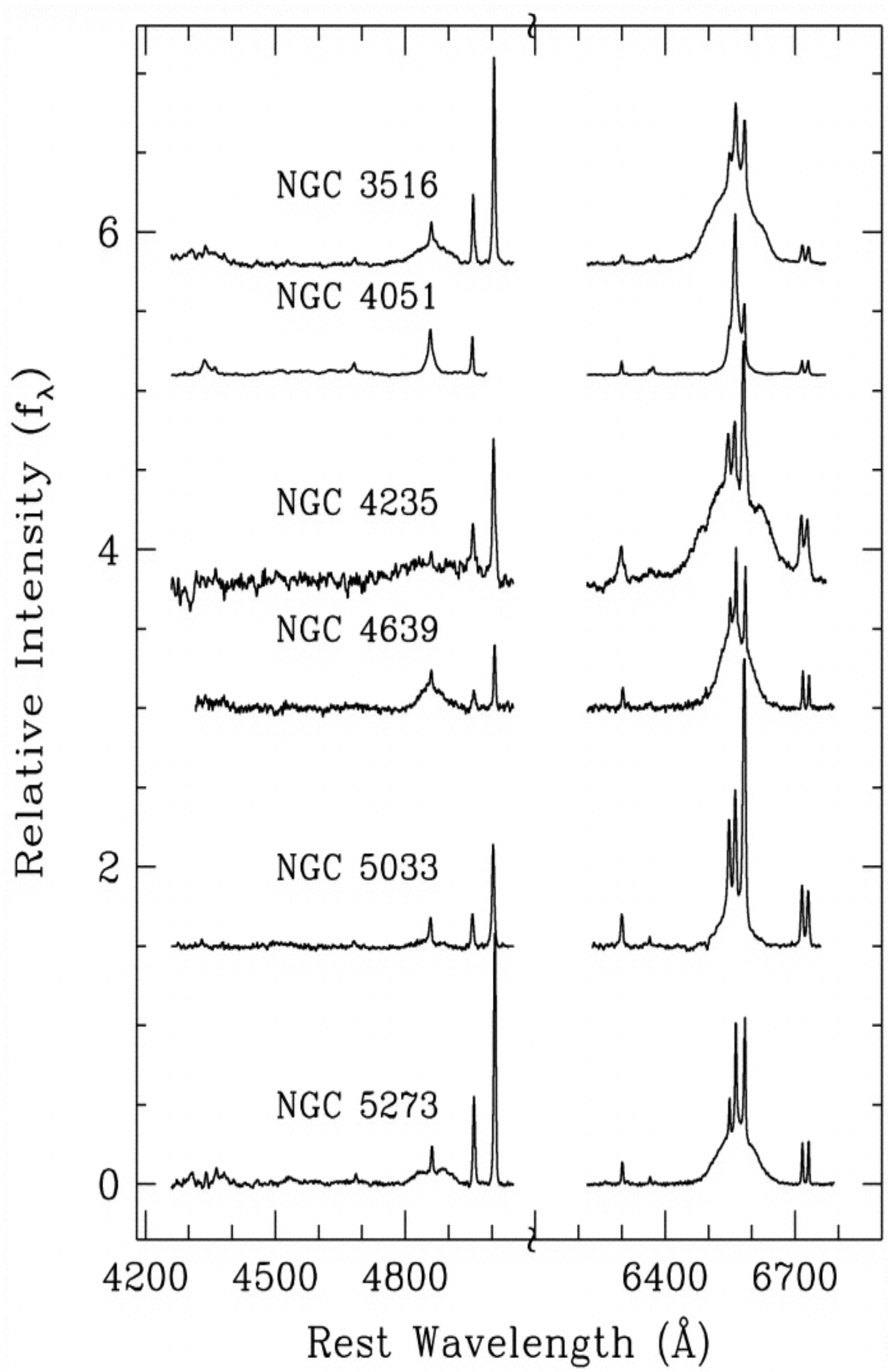
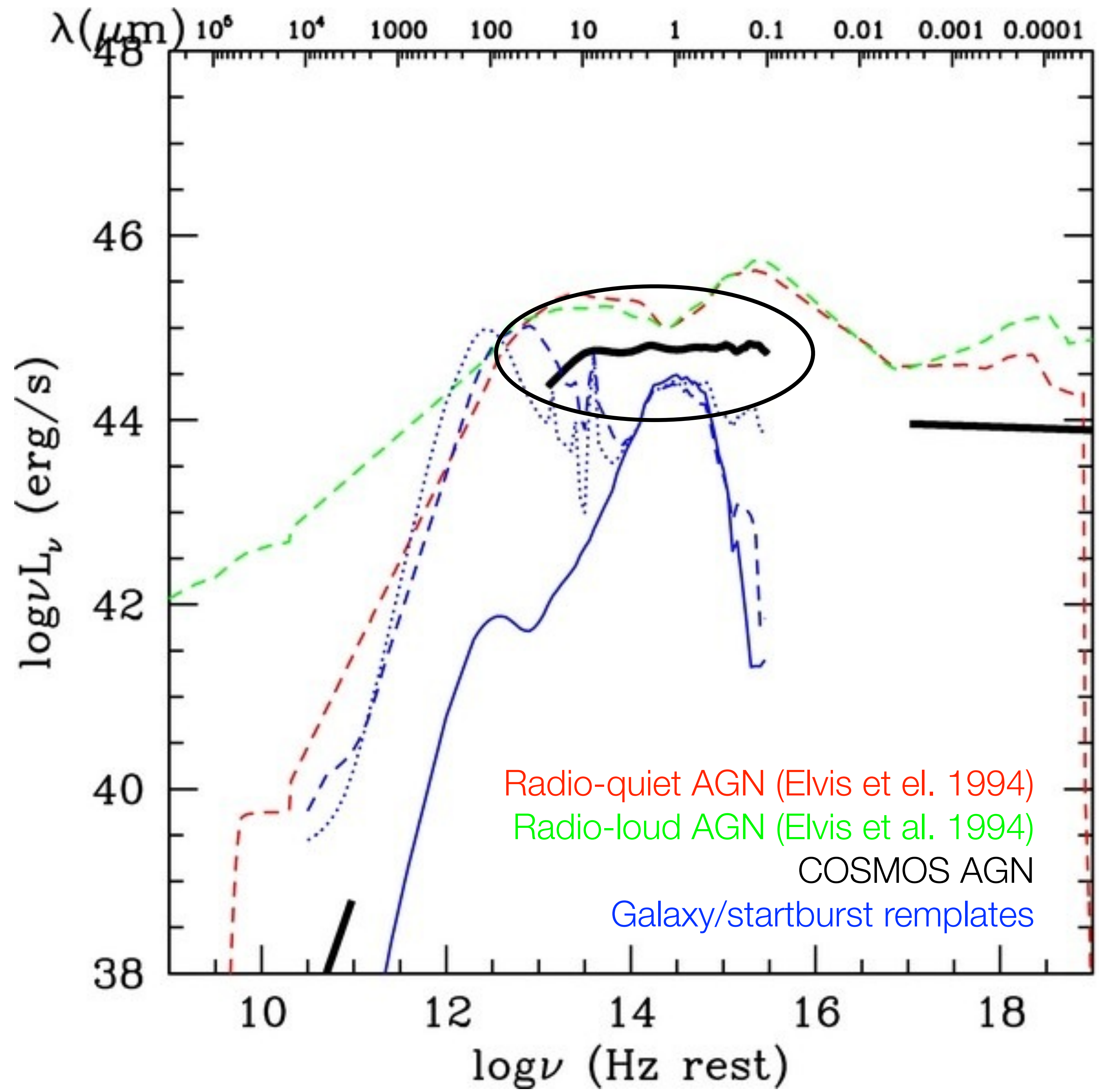
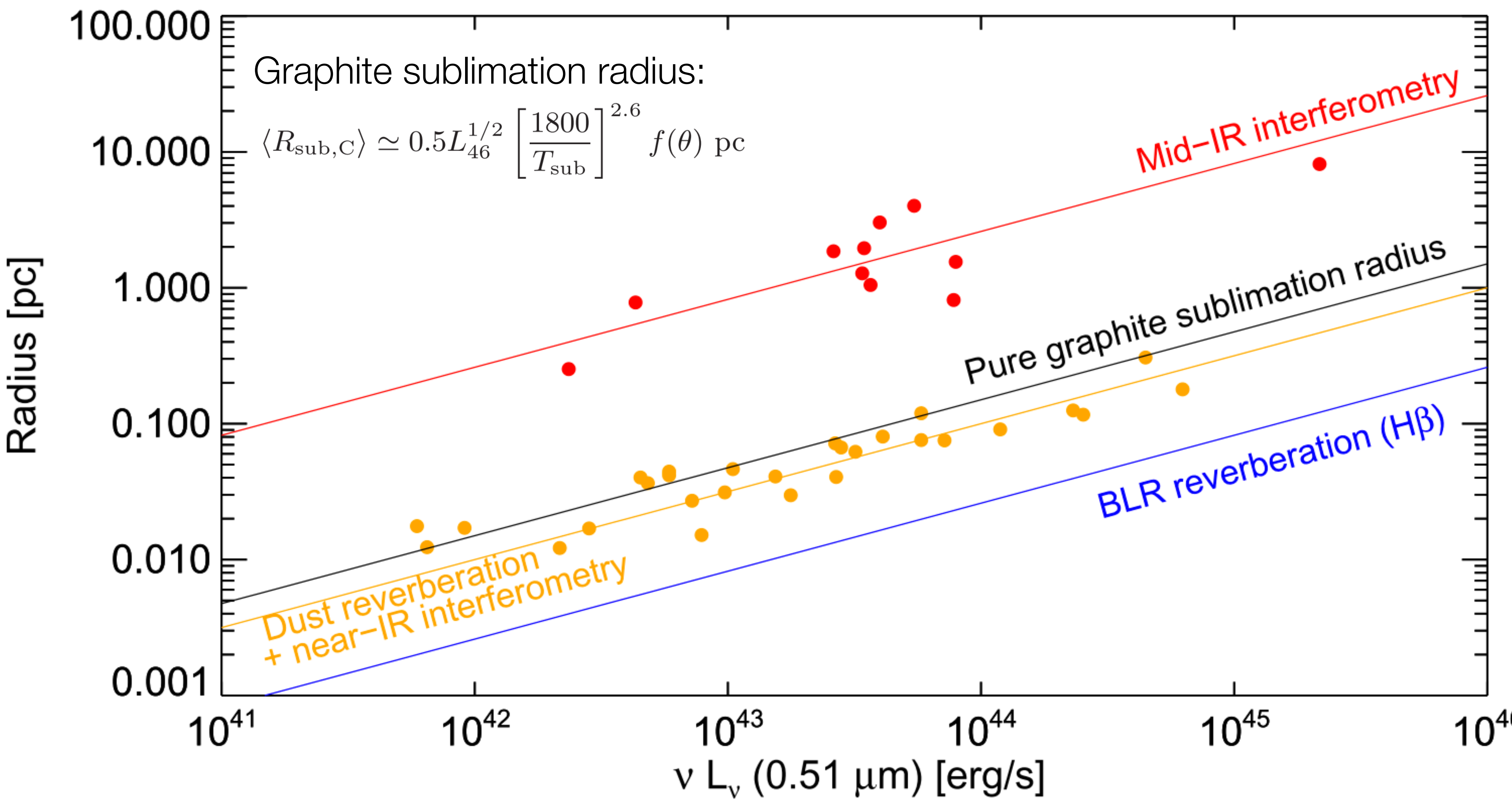




Reverberation+(IR) interferometry

Burtscher et al., 2015, A&A, 558, A8149



Why is this important? And why X-rays?

Tremaine et al., 2002, ApJ, 574, 740, Sazonov et al., 2007, A&A, 462, 57

However, most of the gas in the AGN environment in within the dust sublimation radius.

$$\langle R_{\rm sub,C} \rangle \simeq 0.5 L_{46}^{1/2} \left[\frac{1800}{T_{\rm sub}}\right]^{2.6} f(\theta)\ {\rm pc}$$

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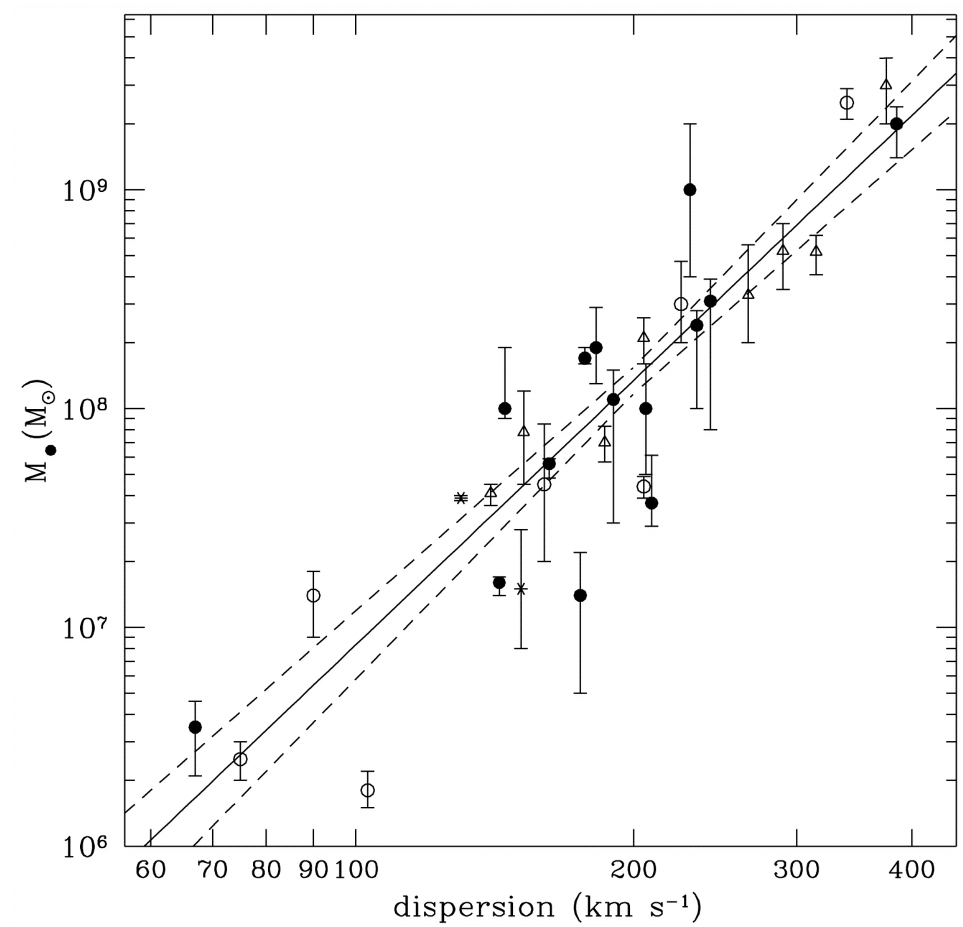

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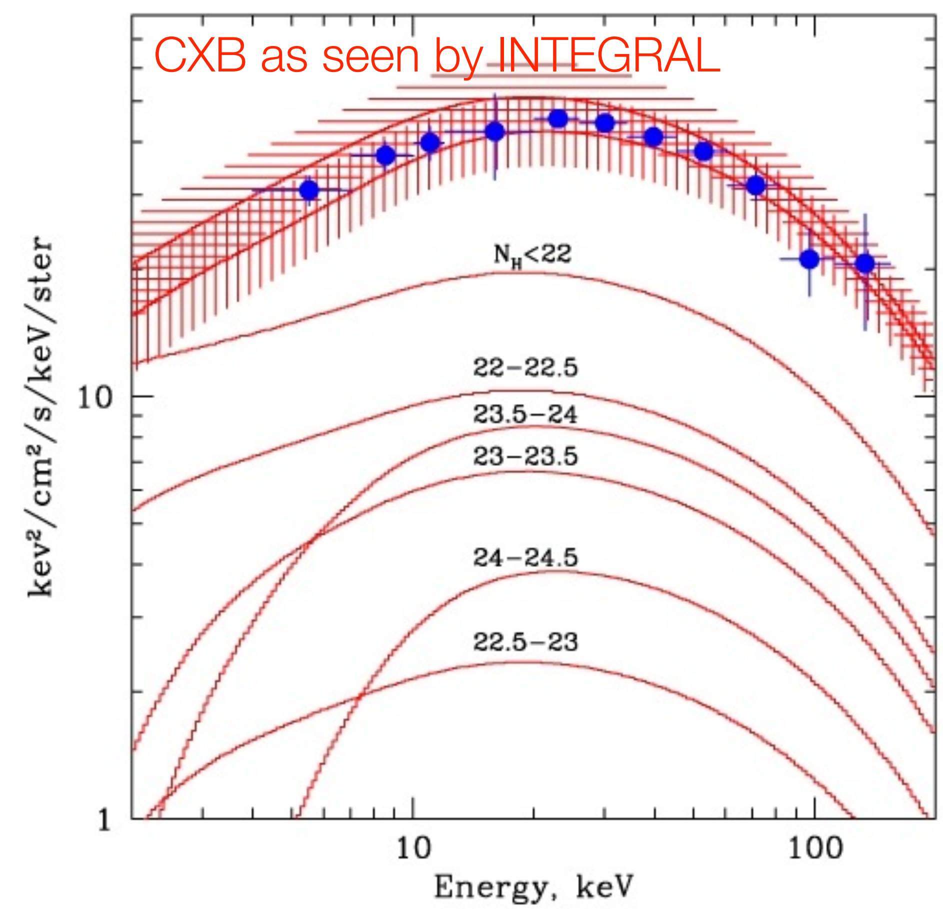
- AGN feeding from the host galaxy
- AGN feed-back to the host galaxy
- Synthesis models of the Cosmic X-ray Background



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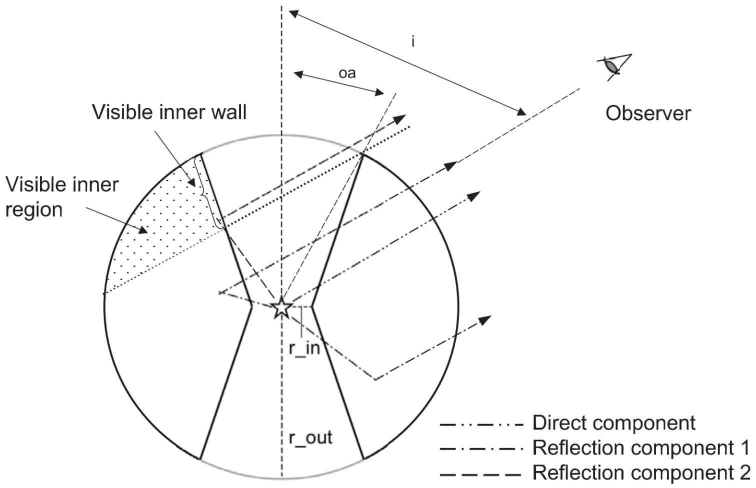
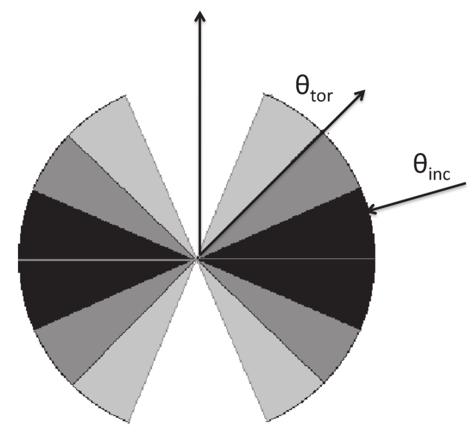
X-ray spectroscopy of obscured AGN: a primer

Yaqoob et al., 2015, arXiv:1508.07685

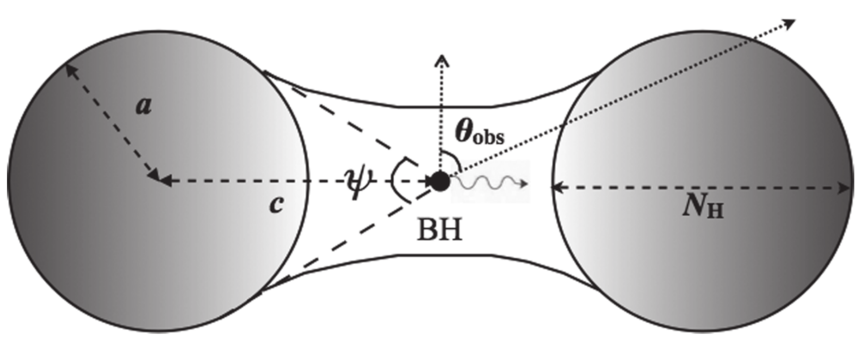
Ikeda, PASJ, 2009, 692, 608

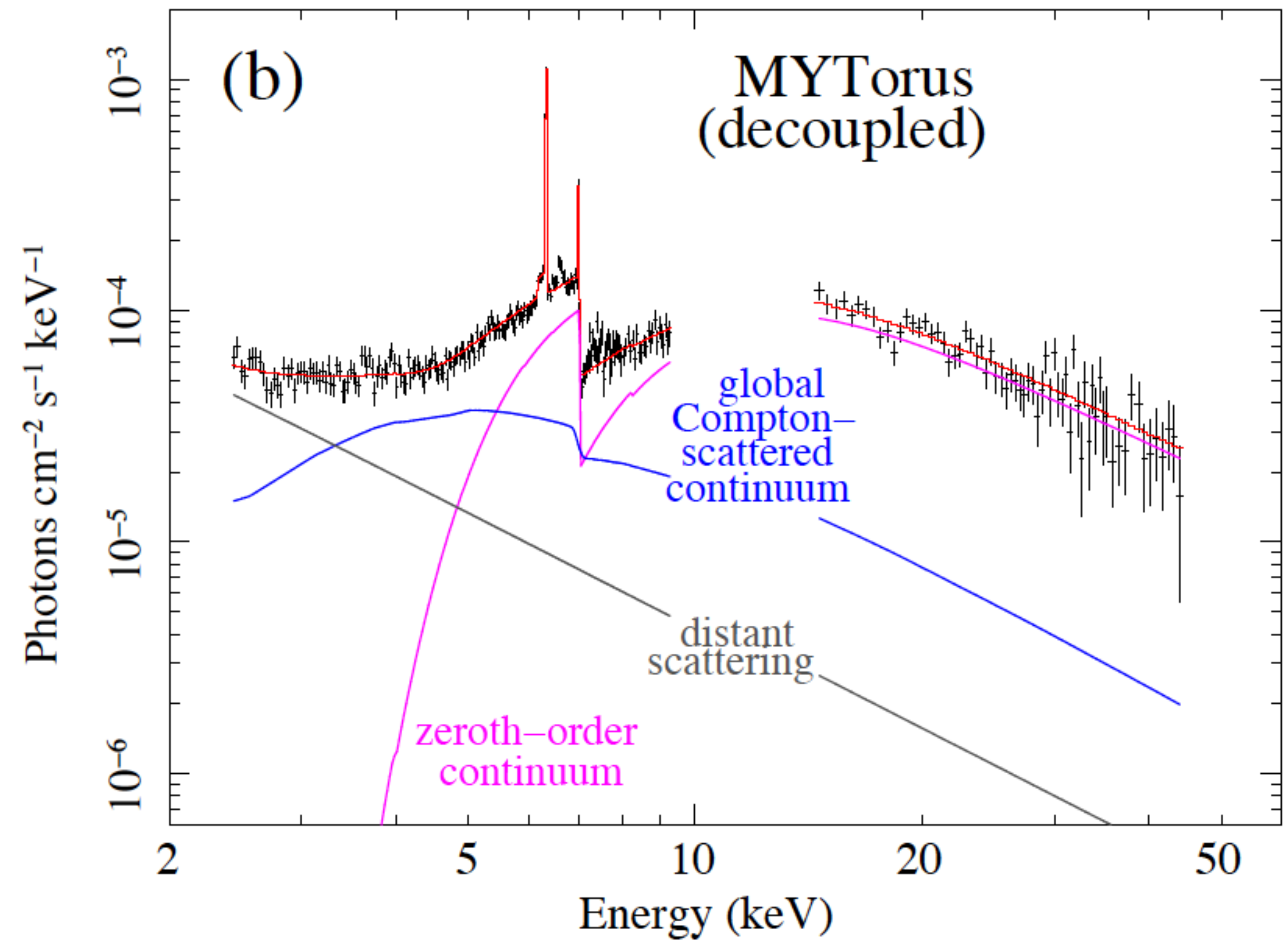


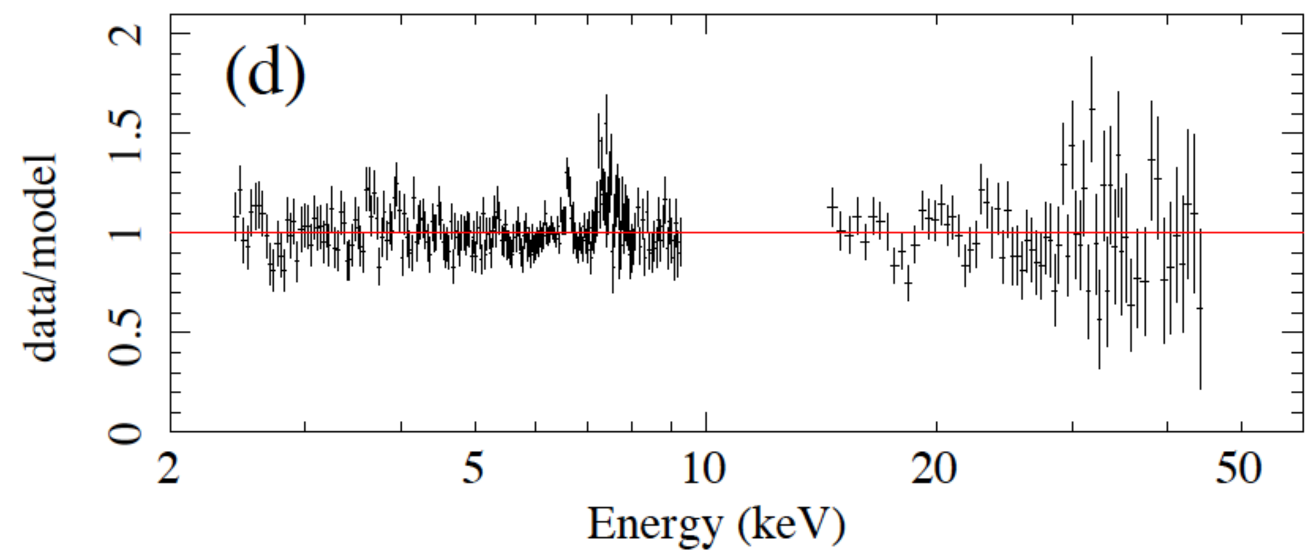
`torus`, Brightman & Nandra 2011, MNRAS, 413, 1206



`mytorus`, Murphy & Yaqoob, 2009, MNRAS, 397, 1549



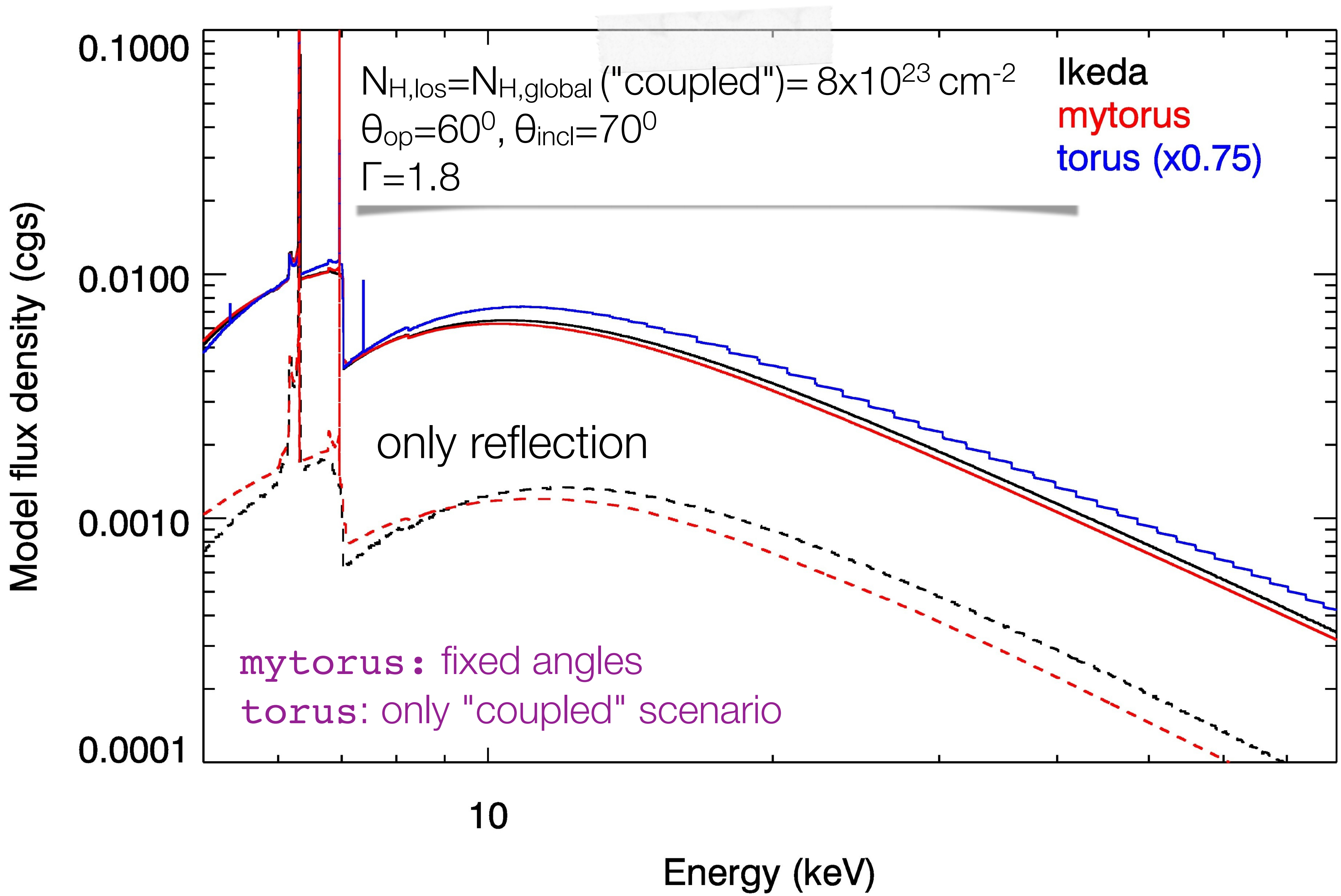




Fitting for:

- line-of-sight column density ($N_{H,abs}$)
- global column density ($N_{H,global}$)
- inclination angle (θ_{incl})
- half-opening angle (θ_{op})

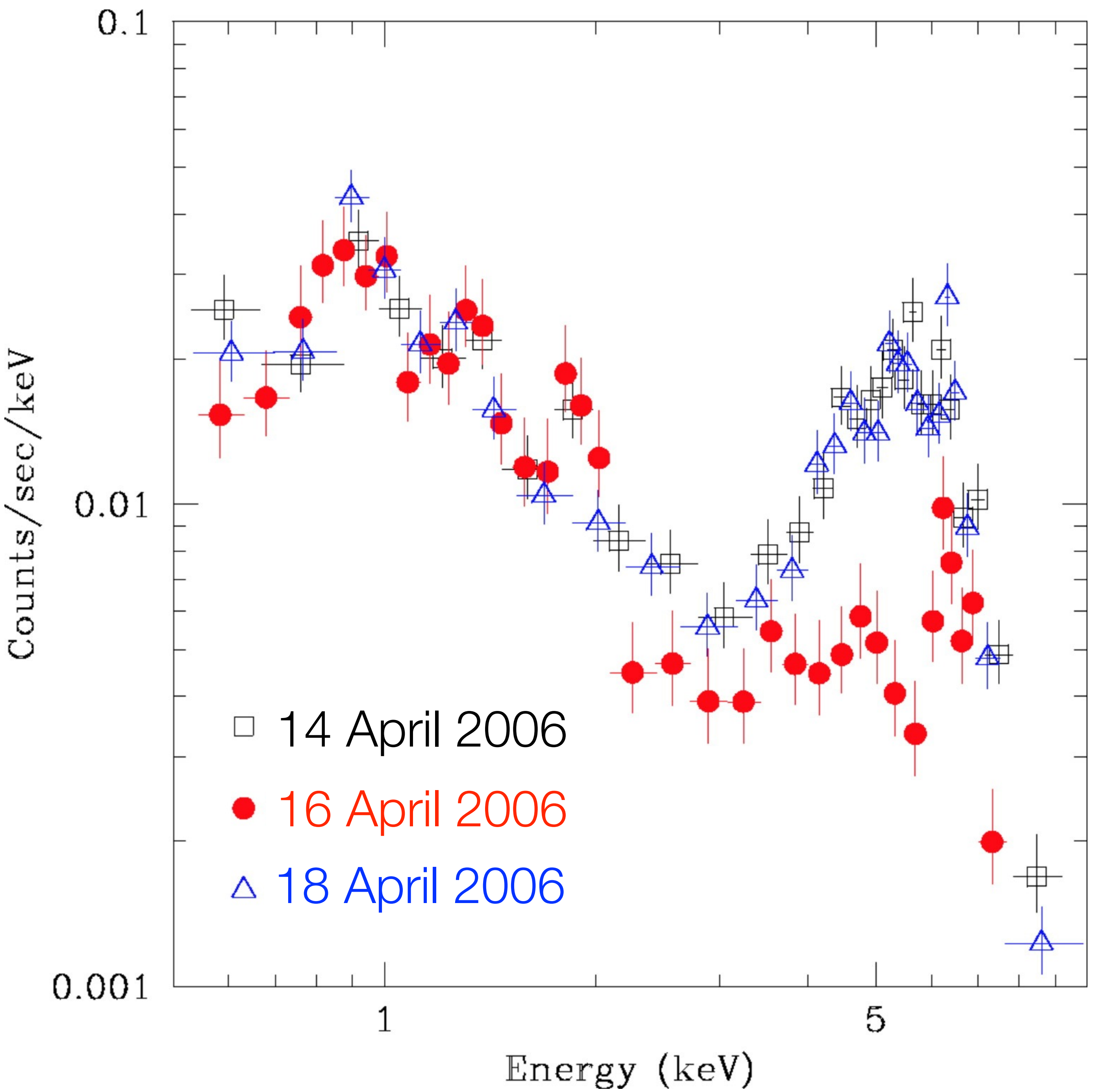
Geometry matters



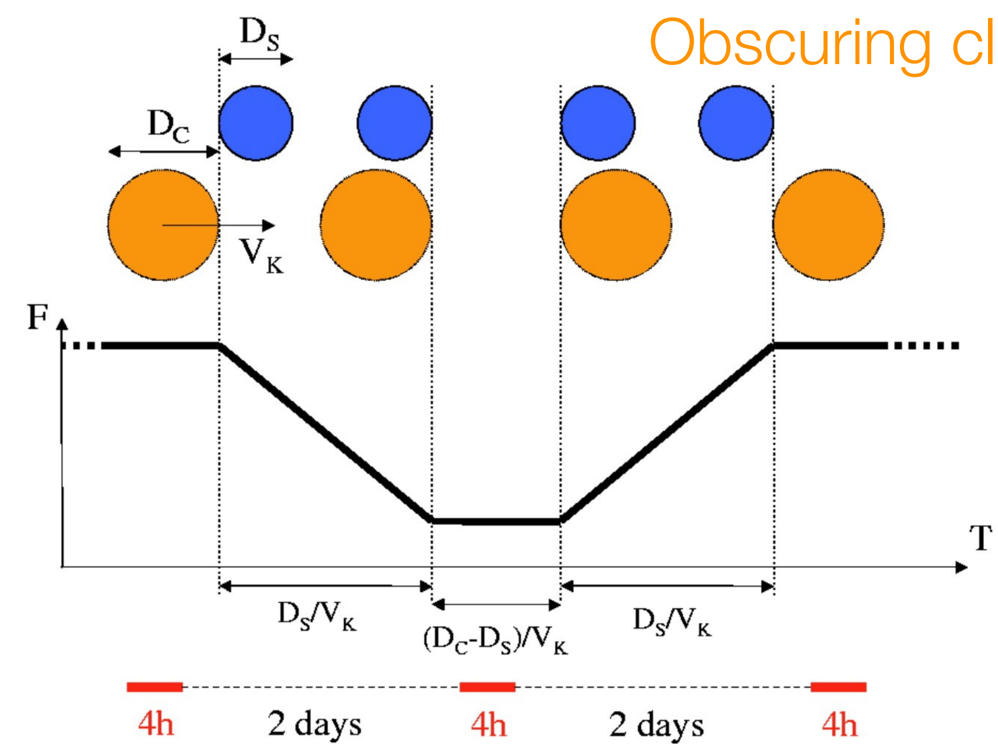
Occultation by "cold" clouds

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

NGC1365/Chandra



X-ray source
Obscuring cloud



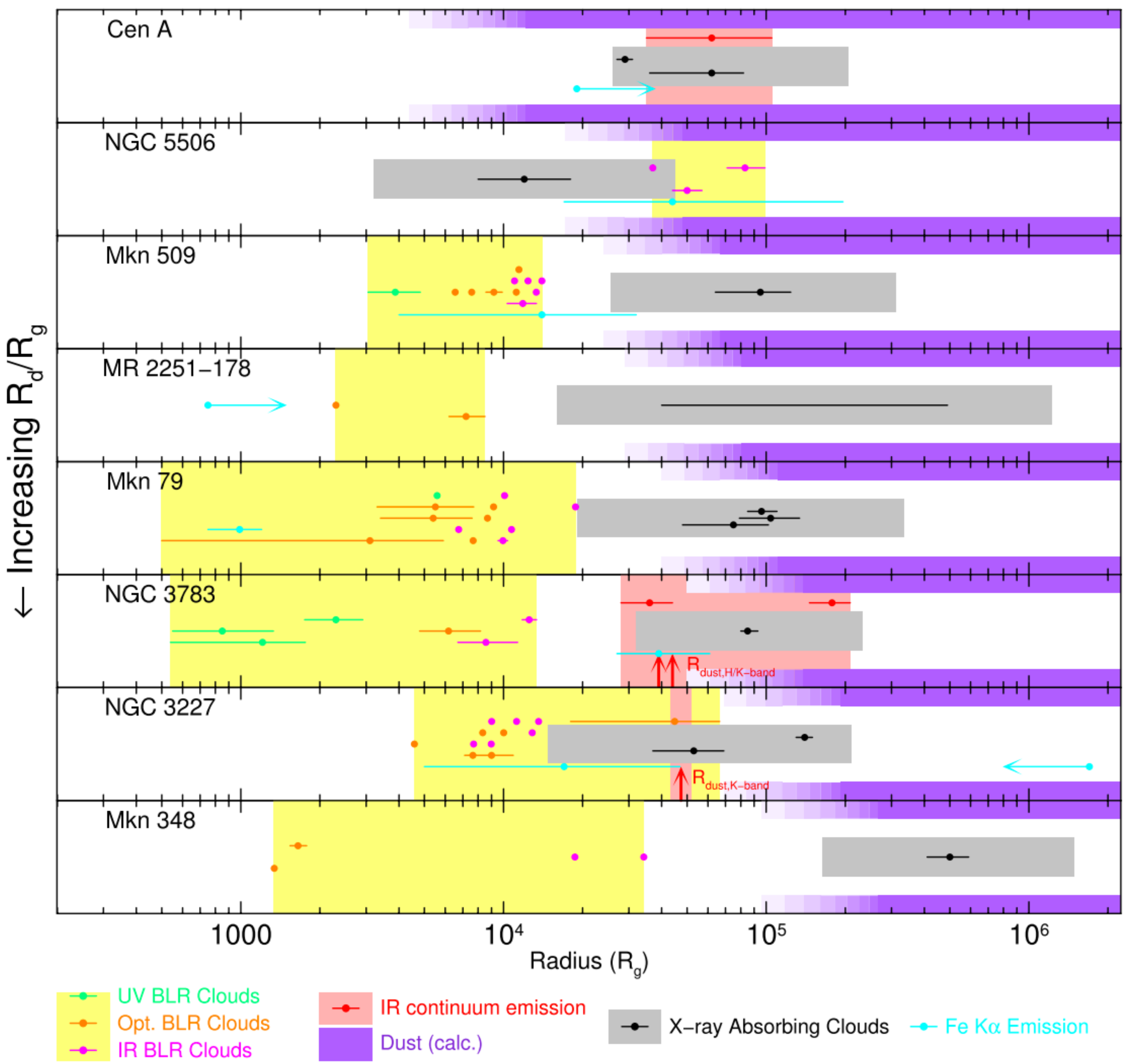
$$v_{circular} = \sqrt{\frac{GM}{r}}$$

Assuming a cloud in: a) Keplerian motion; b) virial turbulent motion; c) ionization equilibrium with the AGN:

- Source Linear size D~10^{13-14} cm
- Distance from the AGN d~10^{-1} pc

Occultation event statistics

Markowitz et al,. 2014, MNRAS, 439, 1403



8 AGN with occultation events in the RXTE archive (~270 years in the AGN life)

BLR clouds

IR continuum

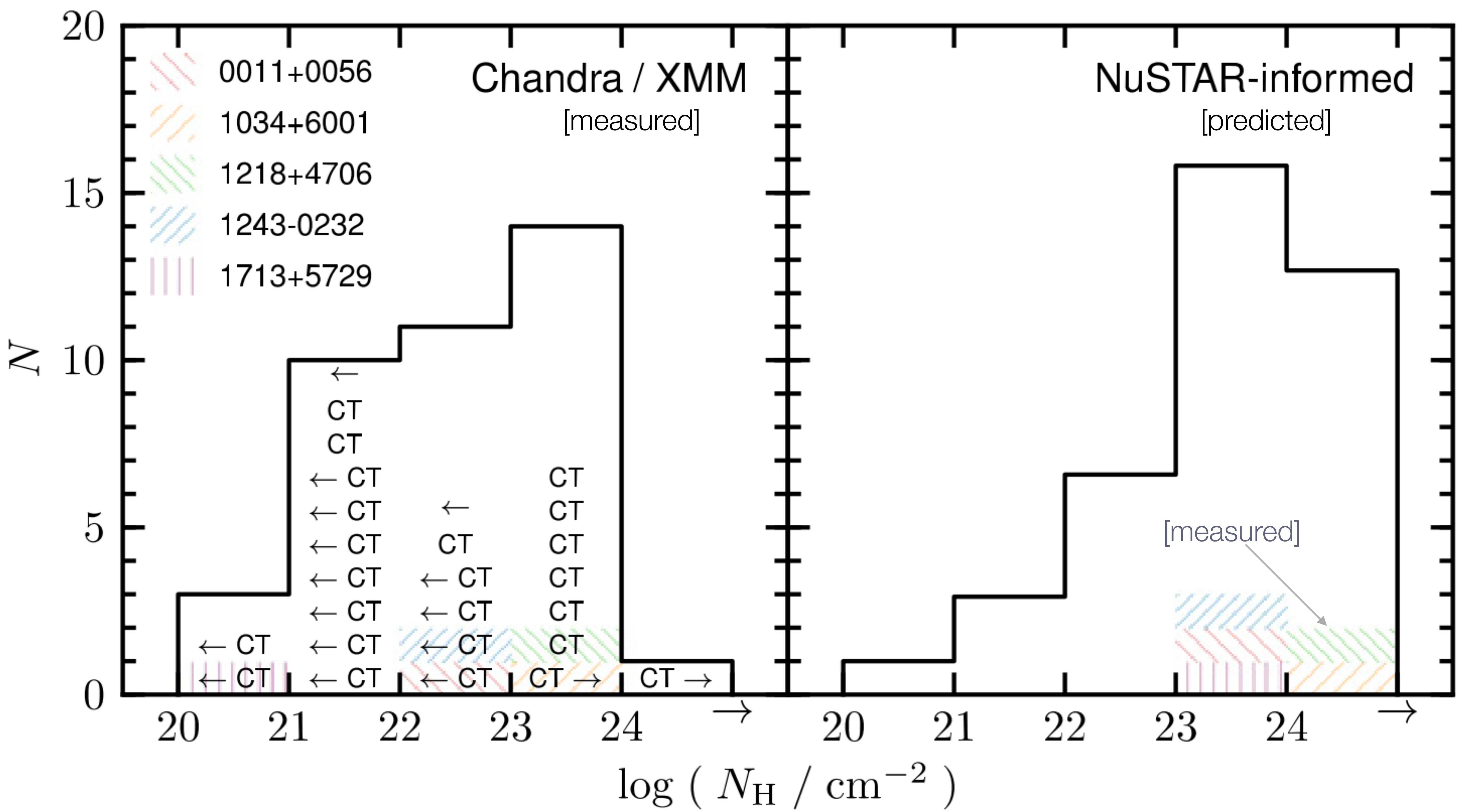
Dust (0.4-1 x sublimation radius, R_d)

X-ray clouds

Bonus: the “true” column density distribution

Lansbury et al., 2015, ApJ, 809, 115; Civano et al., 2015, ApJ, 808, 185

Sample of a z<0.5 SDSS-selected QSOs



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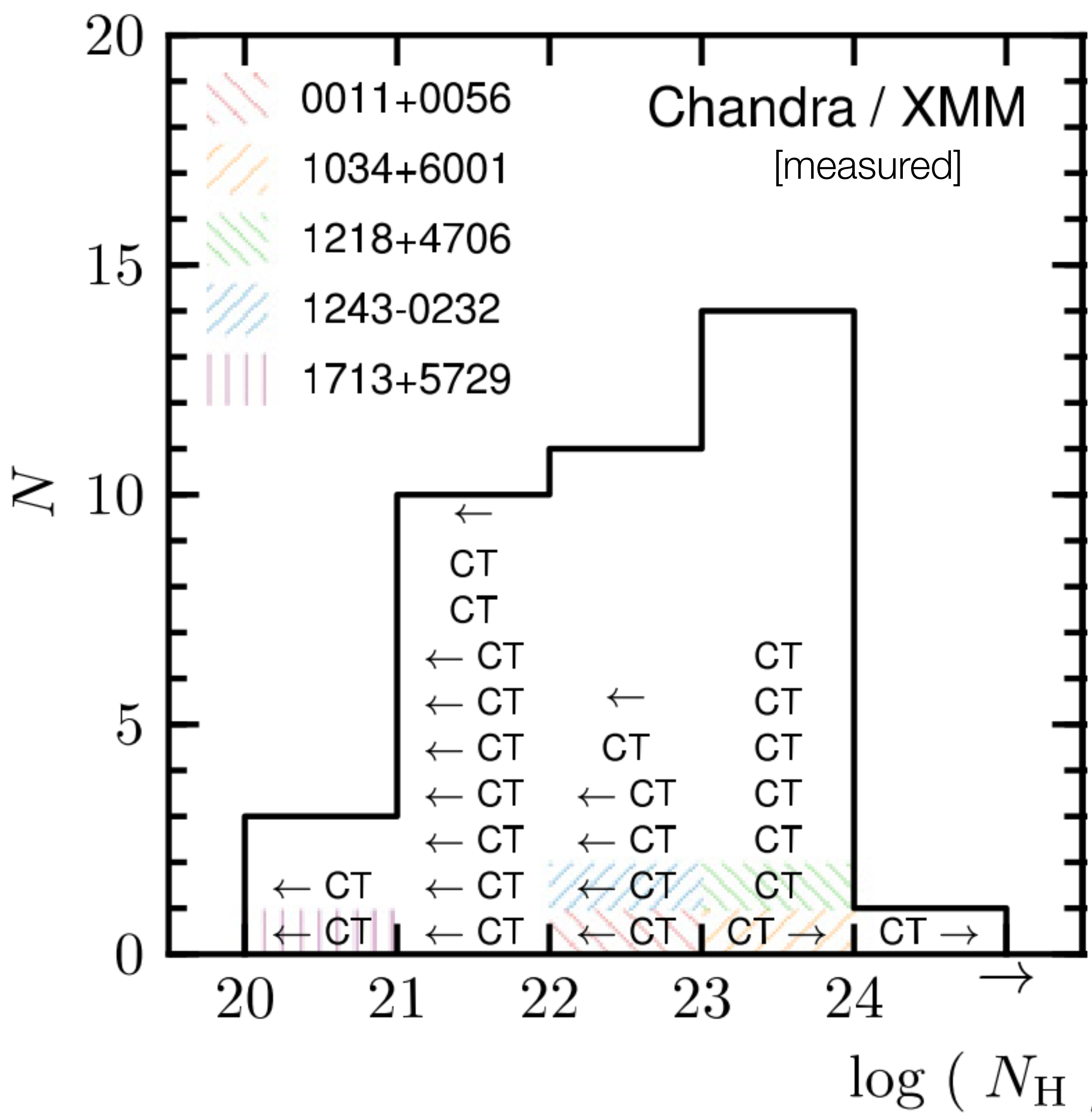
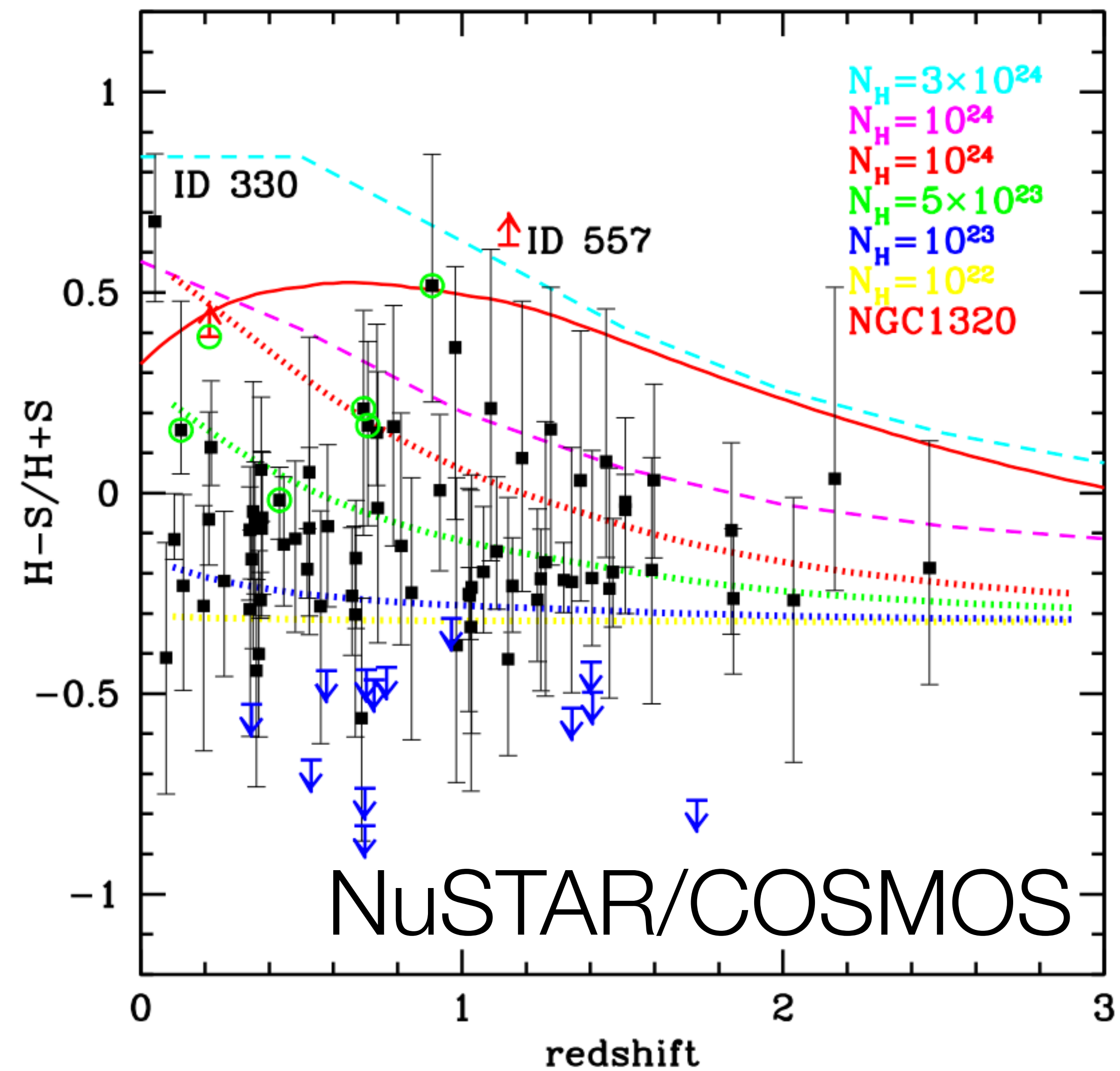
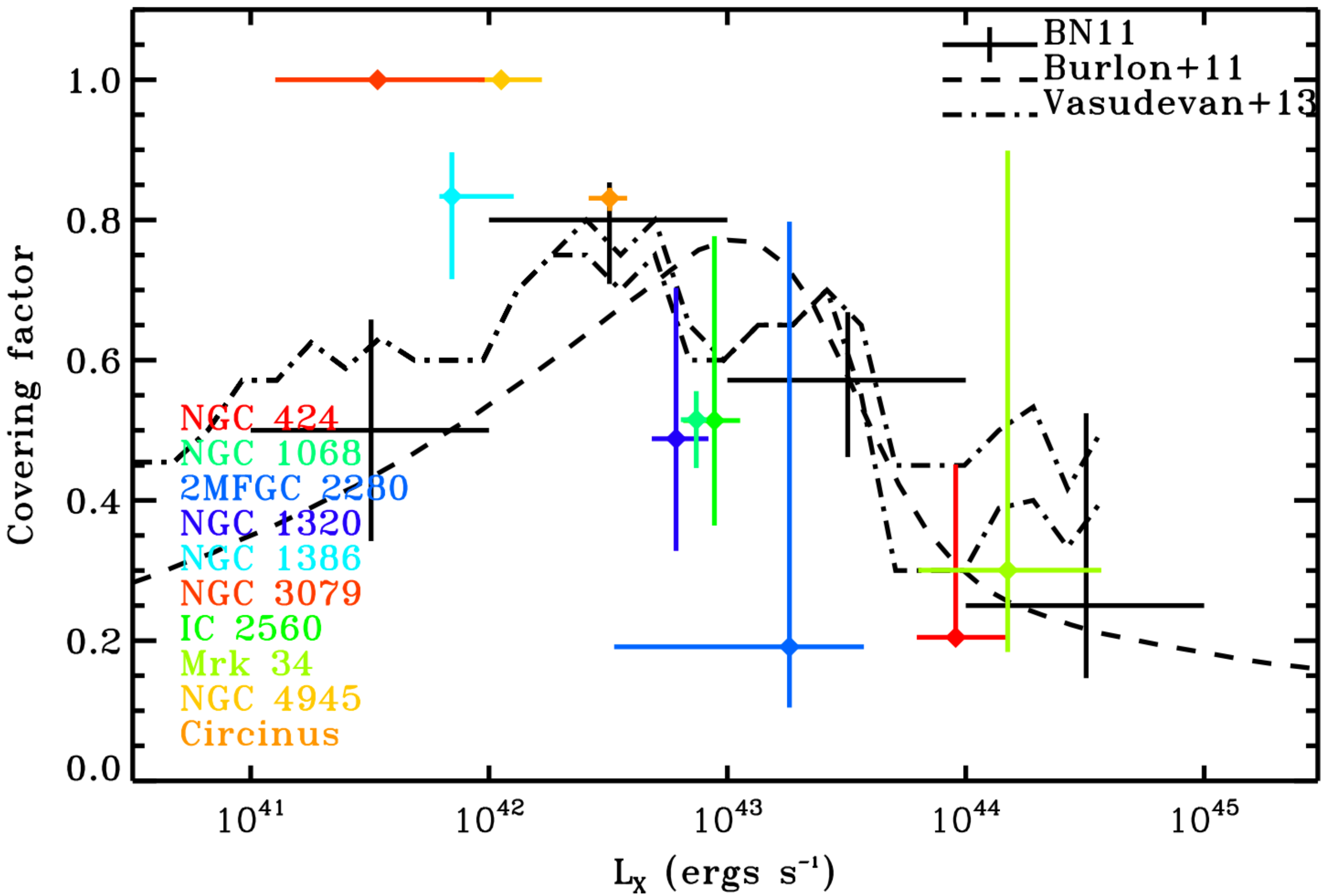




Luminosity-dependent covering fraction

Brightman et al., 2015, ApJ, 805, 41



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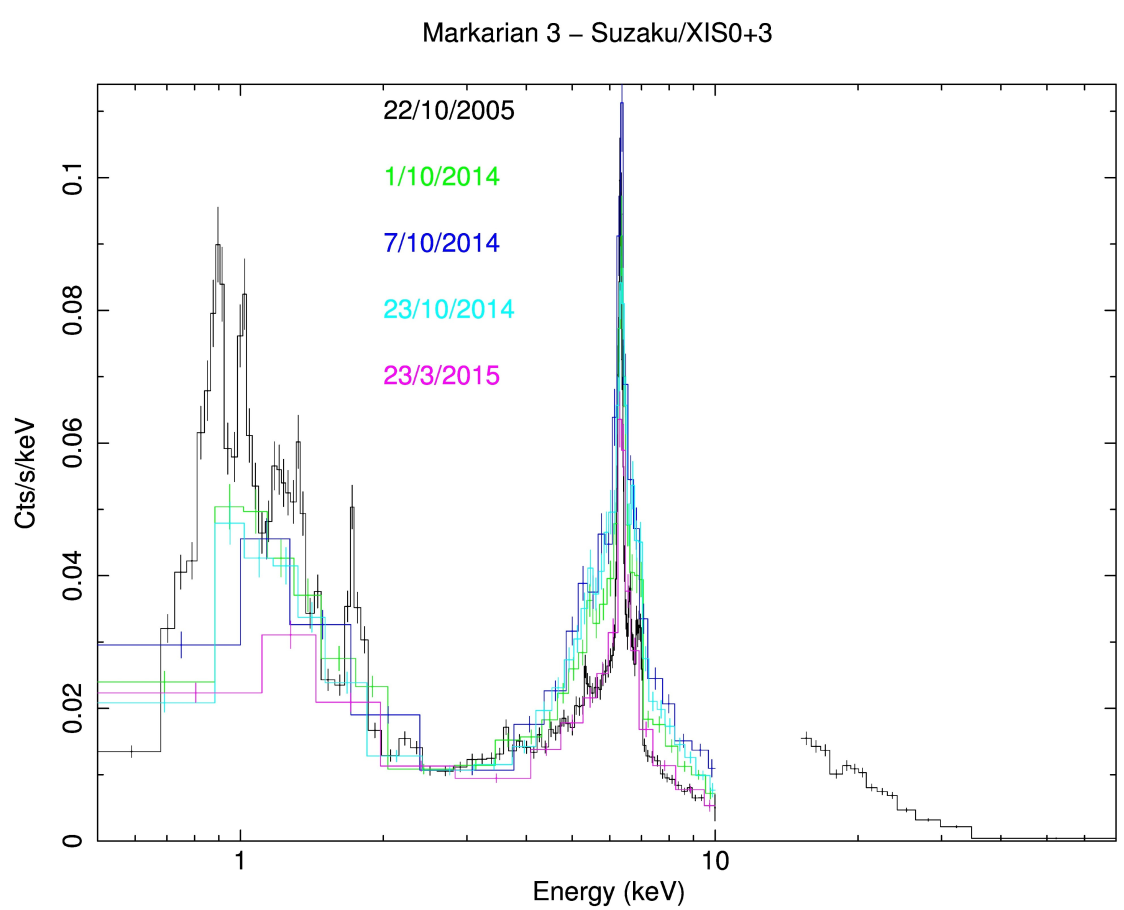
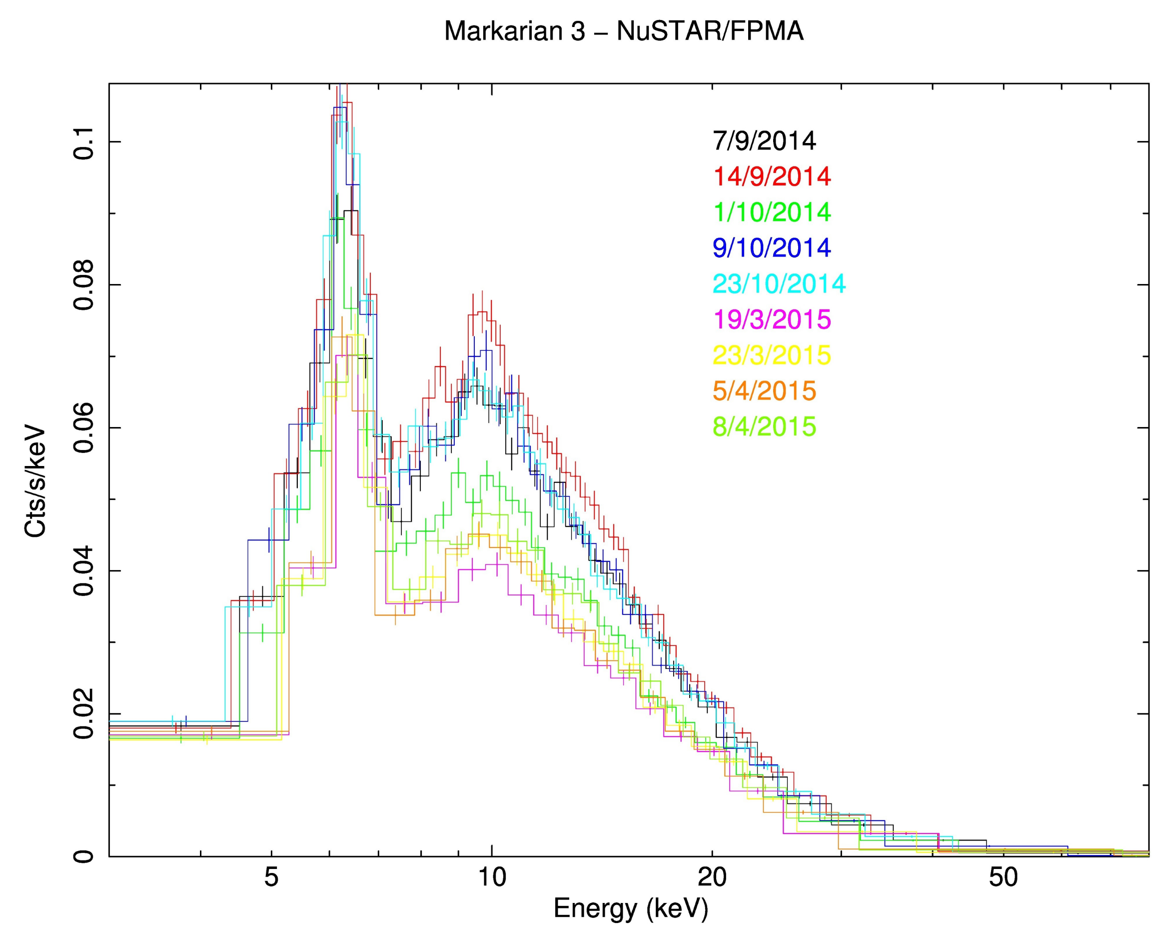
Mkn3 2014-2015 NuSTAR campaign

Guainazzi et al., in preparation

9 observations: 5 in autumn 2014 (7, 14 Sep, 1, 9, 23 Oct), 4 in spring 2015 (19, 22 Mar, 5, 8 Apr). NuSTAR + Suzaku or XMM-Newton

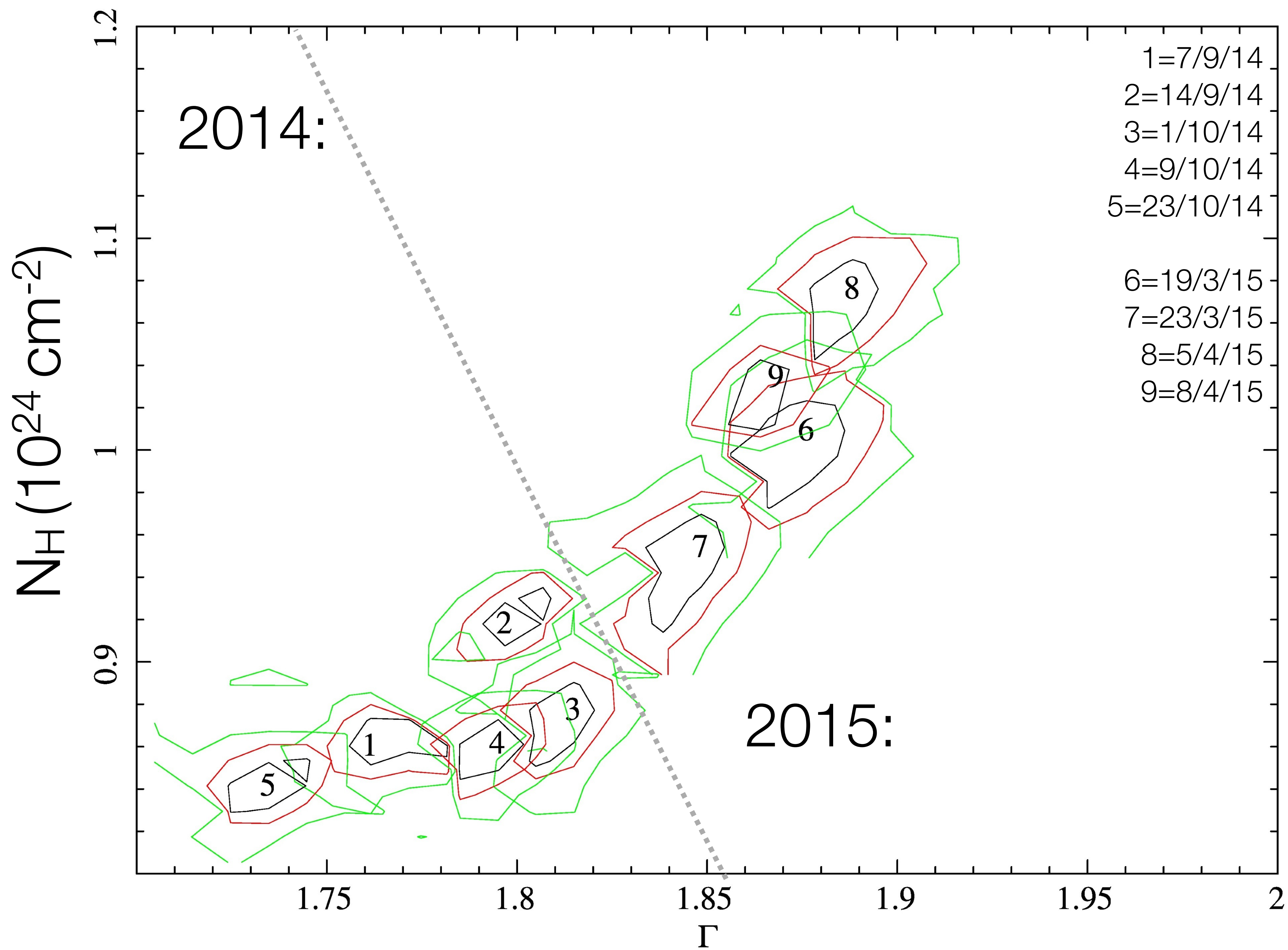




The spectra of Markarian 3 above ~3 keV show variability on all time-scales down to ~2 days

Absorber column density variability

Guainazzi et al., in preparation



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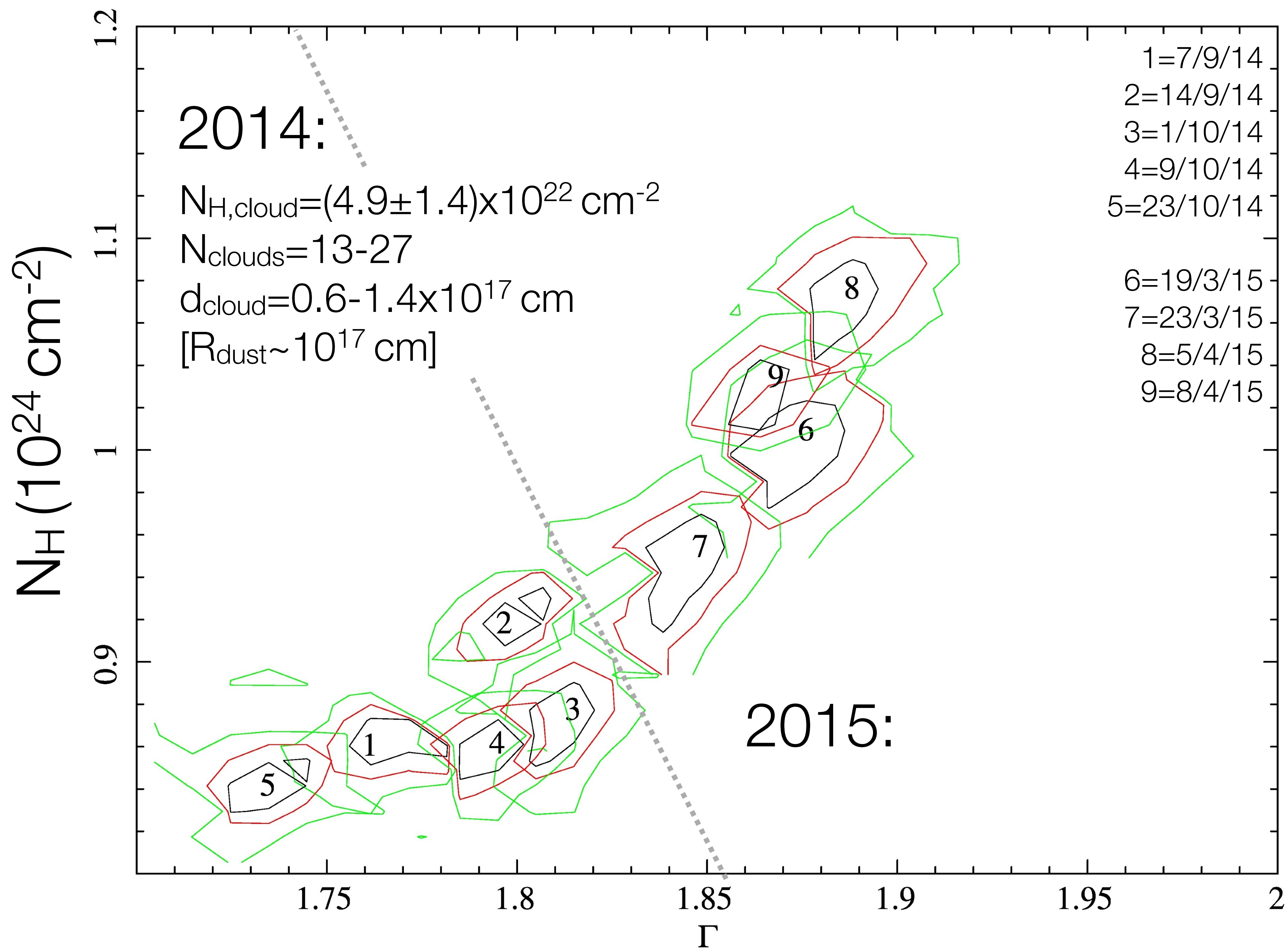

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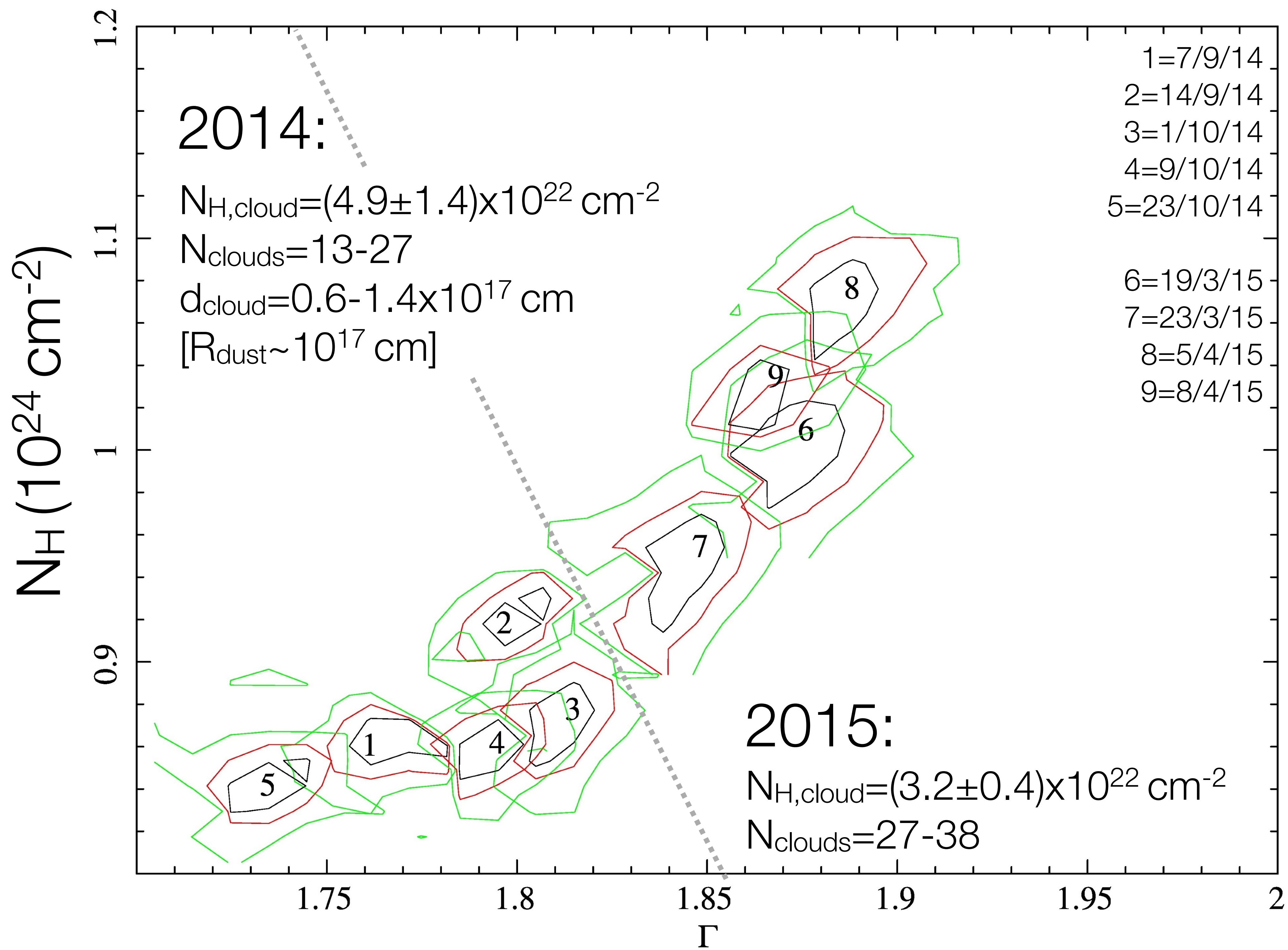


Mkn3: X-ray vs. IR absorber/reprocessor

Guainazzi et al., in preparation; IR results from Sales et al., 2014. A&A, 441. 630

	X-rays (gas+dust)	IR (dust)
N (10	2.2±0.9	0.5±0.3
N	13-38	9±3
θ	66.0	50
θ	68.9	61

Still poorly known:

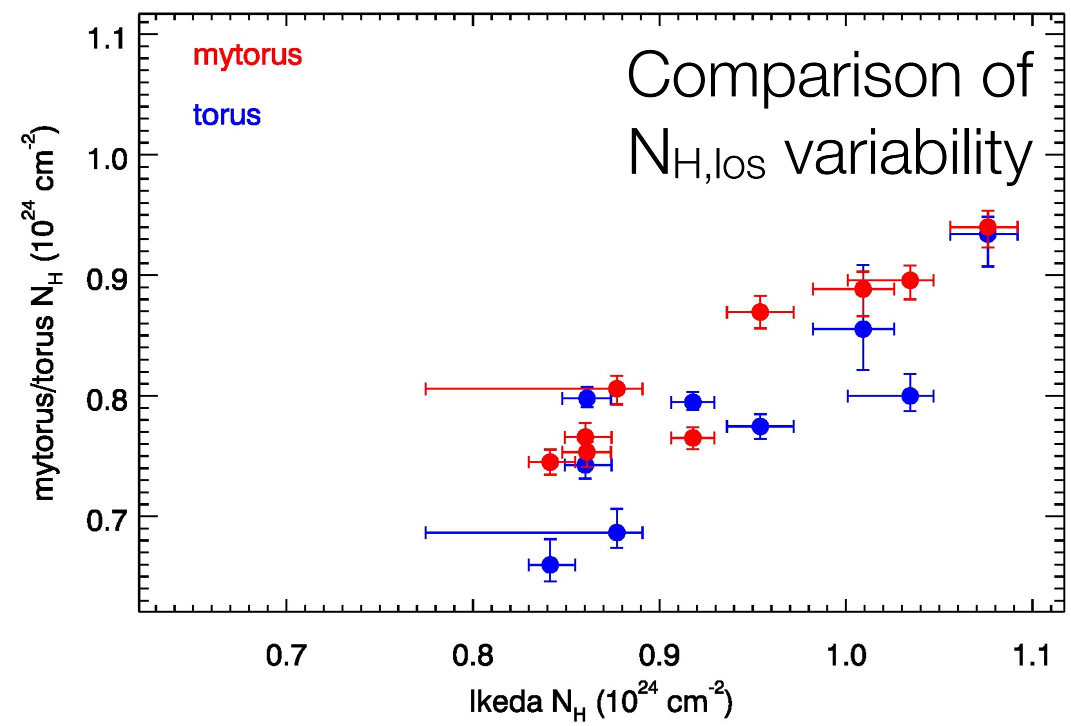
- X-ray cloud size/volume filling factor ($R_{cloud} \lesssim 2000\ R_S/R^2_{corona,10Rs}$)
- X-ray cloud density [$n \gtrsim 10^5\ cm^{-3}\ (R^2_{corona,10Rs})$]
- radial profile of gas and dust (no idea)

IR analysis suggests that the torus extends up to ~7-8 pc

Comparison of Compton-scattering results

Guainazzi et al., in preparation

	Ikeda ("decoupled")	mytorus ("decoupled")	torus ("coupled")
N (10	2.2±0.9	0.12±0.01	N
N (10	0.86-1.08	0.74-0.93	0.65-0.93
θ	66.0±0.4	60 (fixed)	58.3±1.8
θ	68.0±1.5	N/A	>83

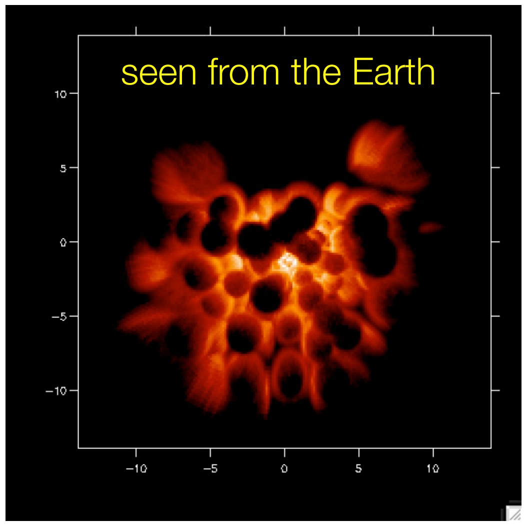


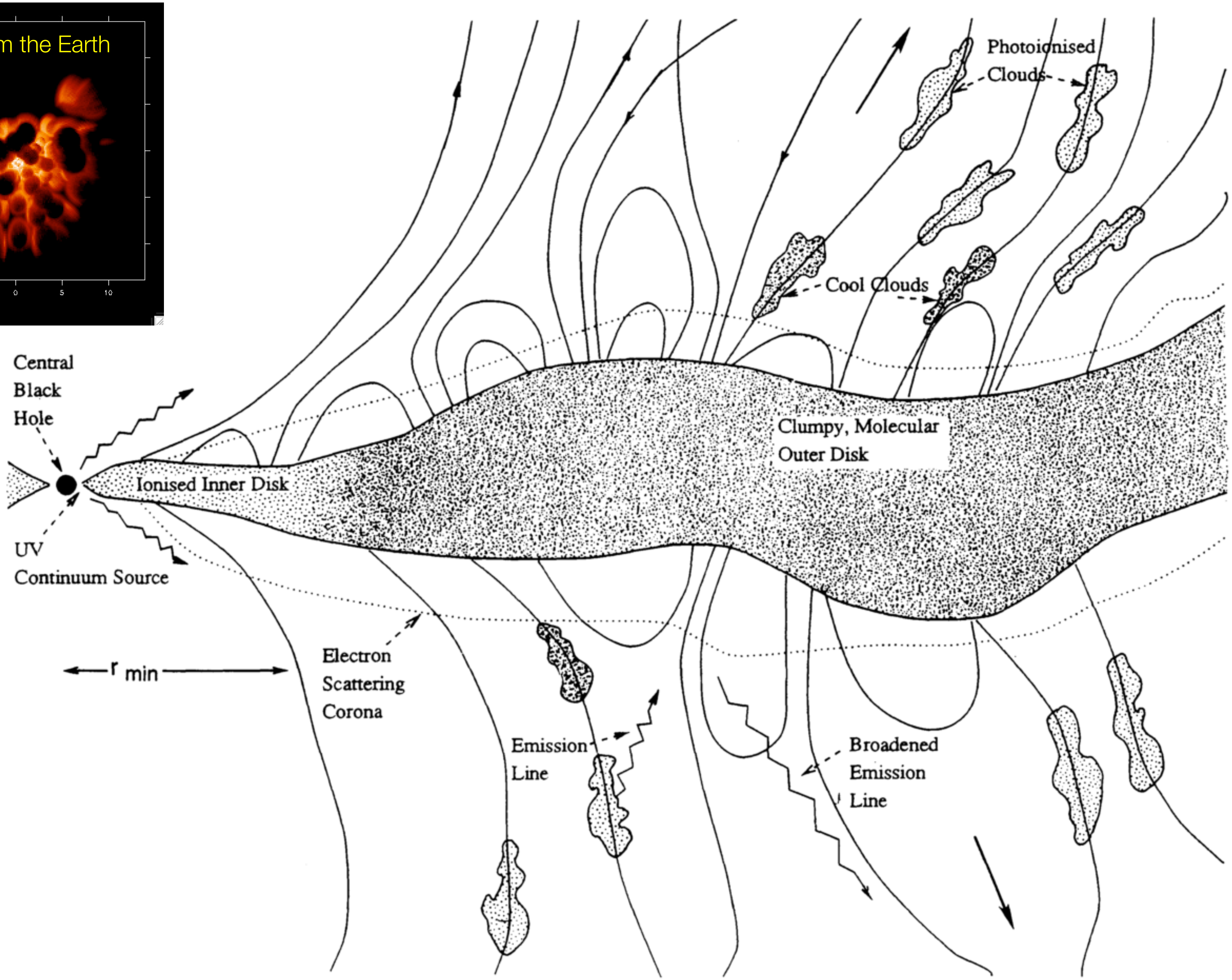
<u>Good news</u>: $N_{H,los}$ (*i.e.* Γ, L_X) does not strongly depend on the details of the torus model

<u>Bad news</u>: comparison of torus models is difficult due to the incongruent assumptions

Structure of the absorber

Ennering et al., 1992, ApJ, 385, 460





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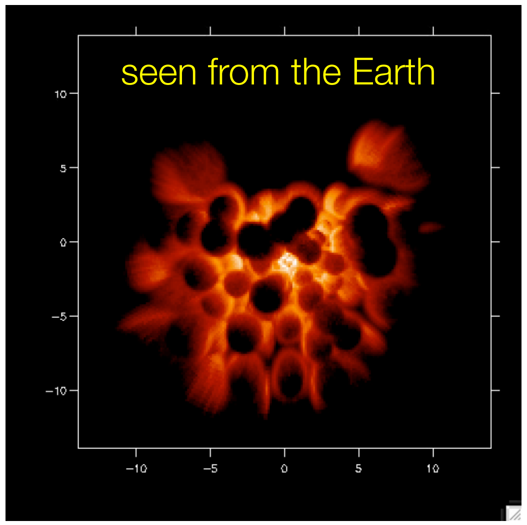
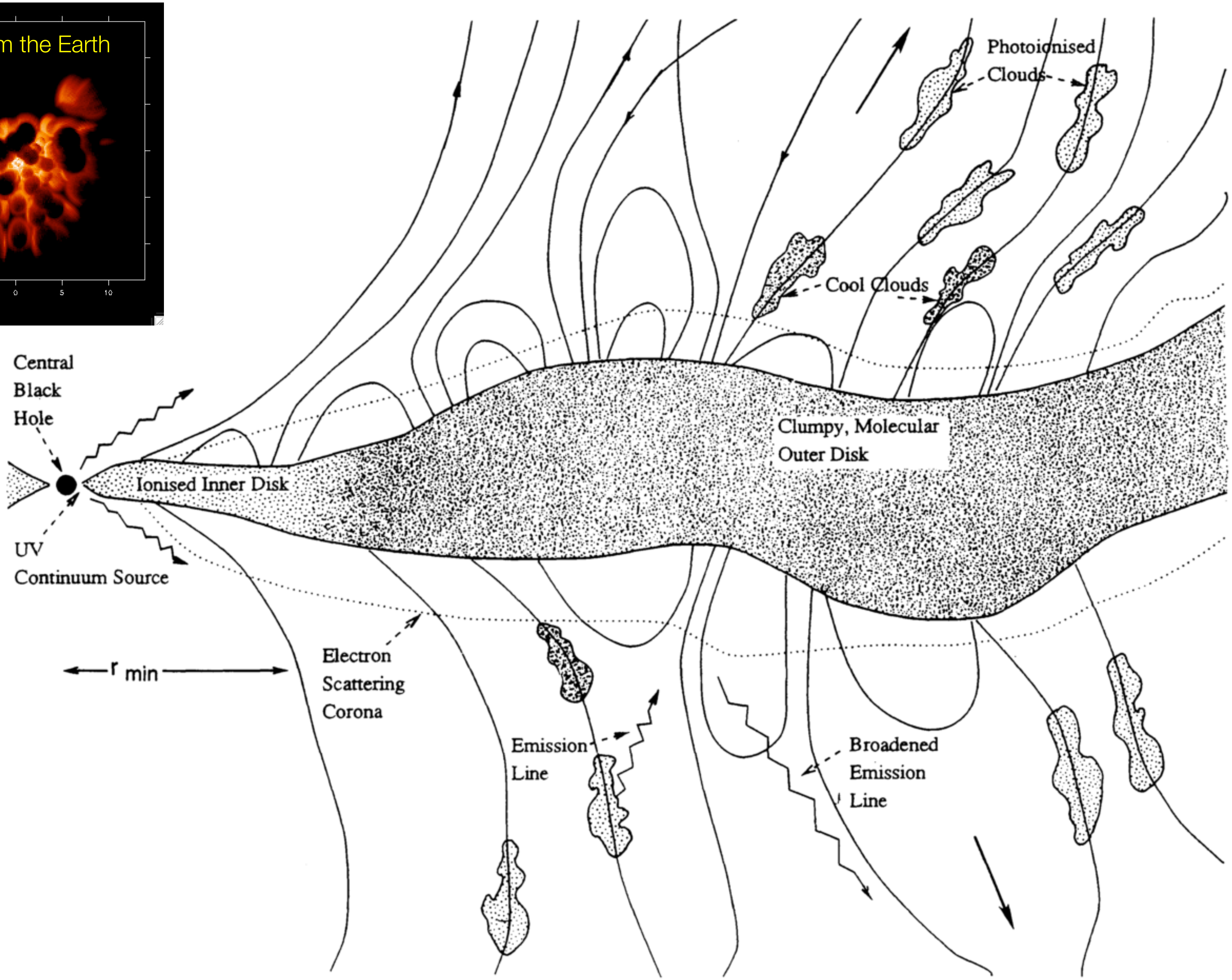
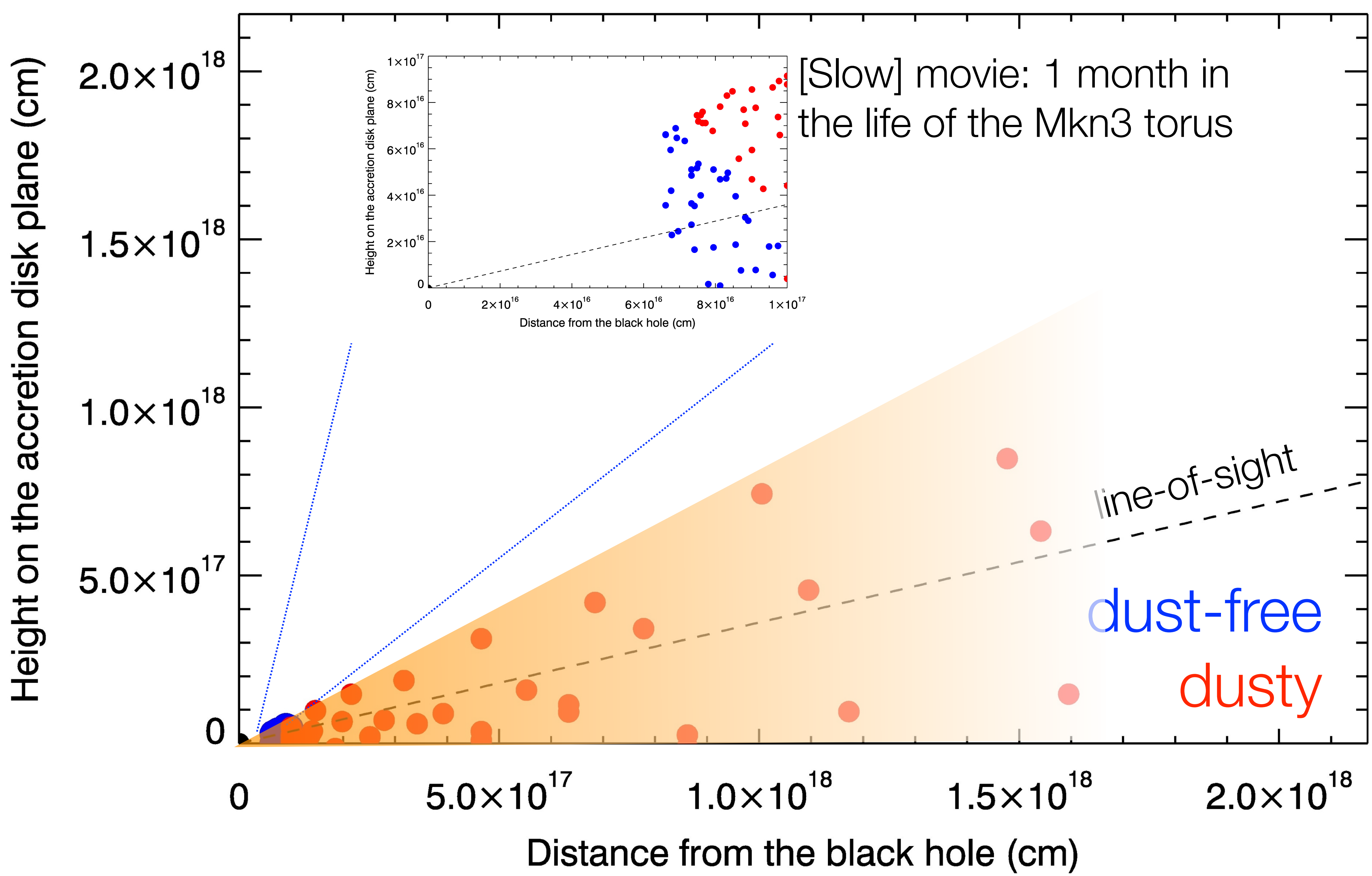




A possible structure of the torus in Mkn3

Guainazzi et al., in preparation



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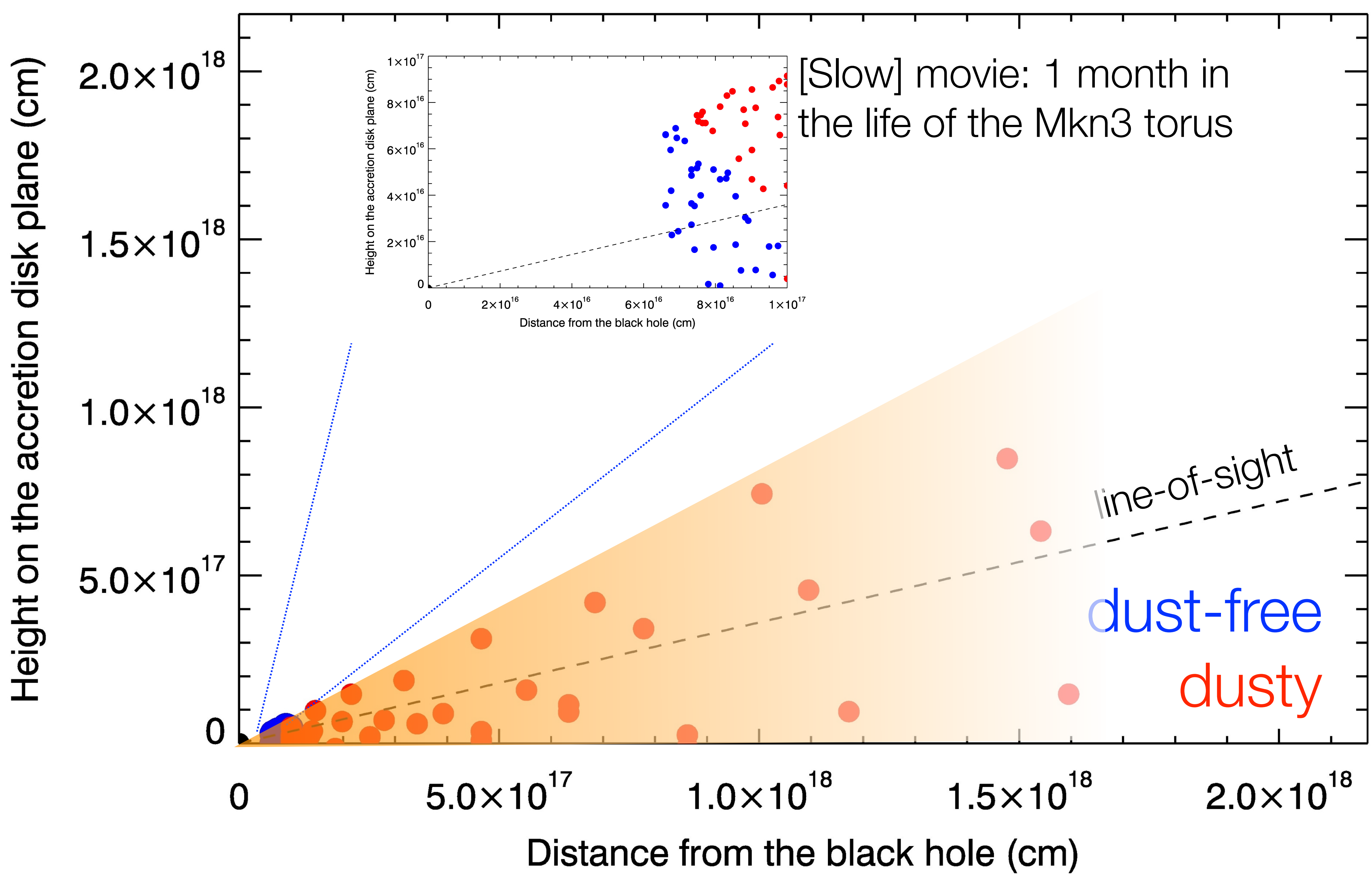
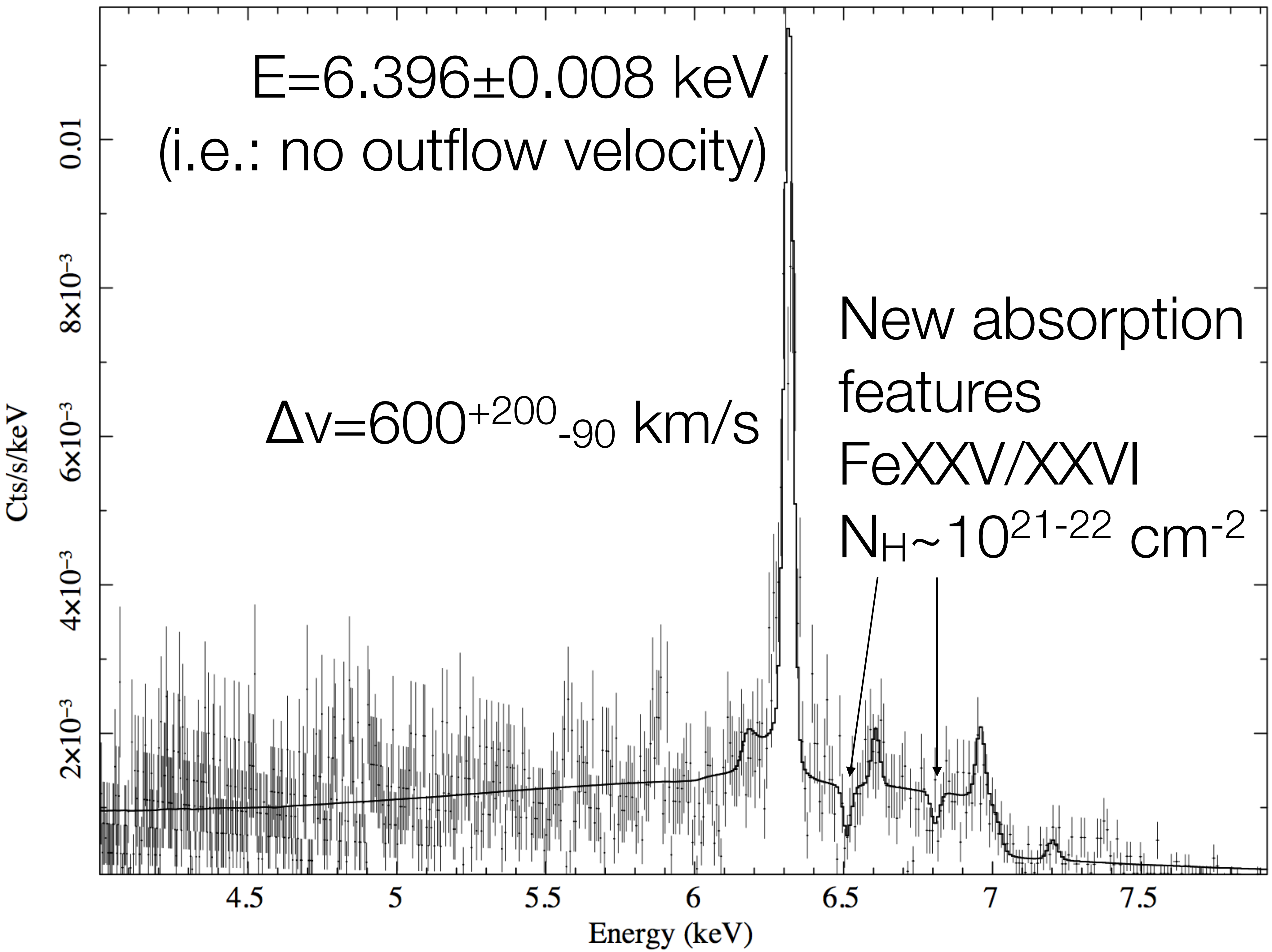


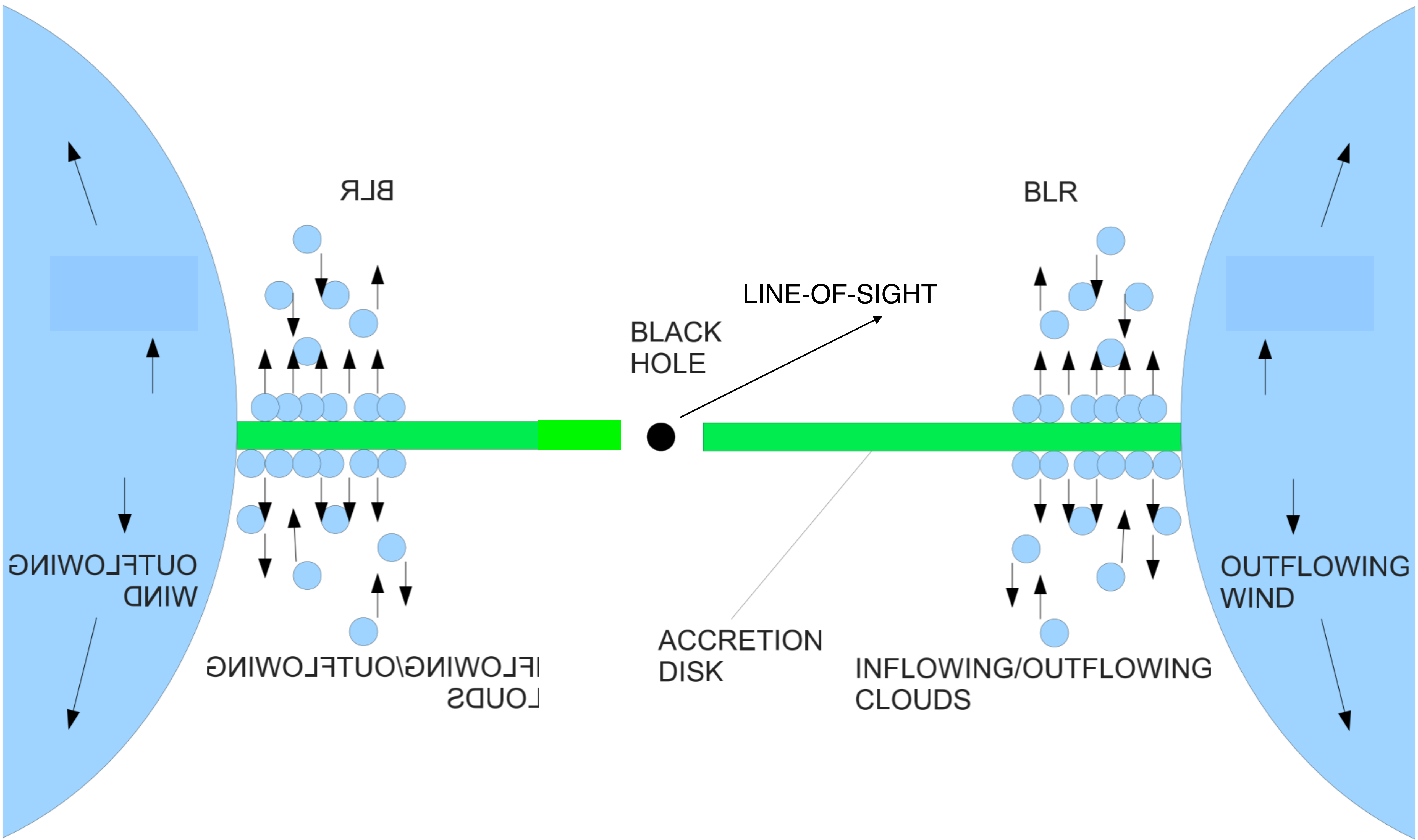
Markarian 3 HETG spectrum (770 ks)

Guainazzi et al., in preparation



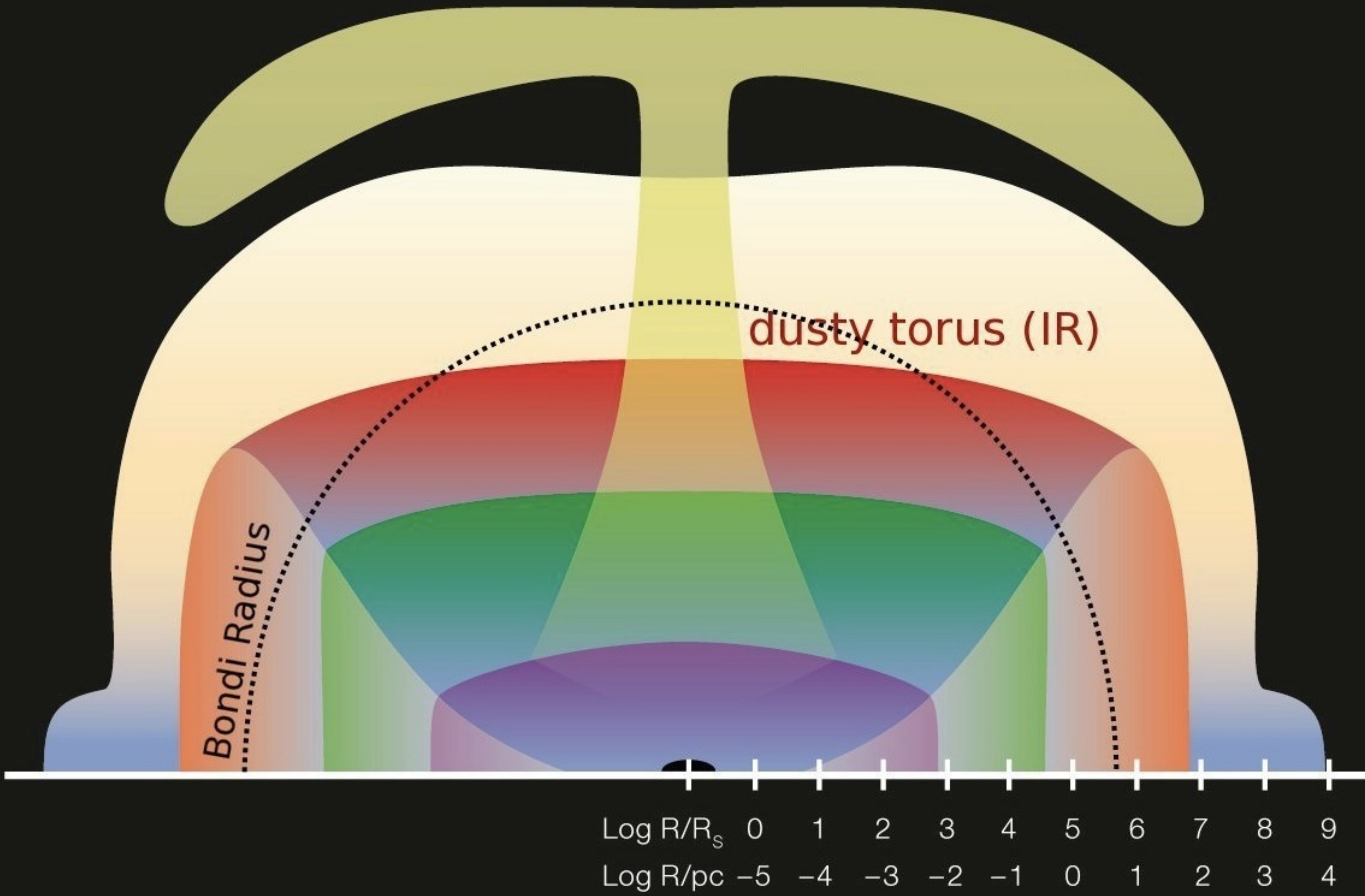
Failed winds and the origin of BLRs

Czerny & Hryniewicz, 2011, A&A, 525, L8



Conclusions

Courtesy A.Merloni & S.Bonoli, MPE



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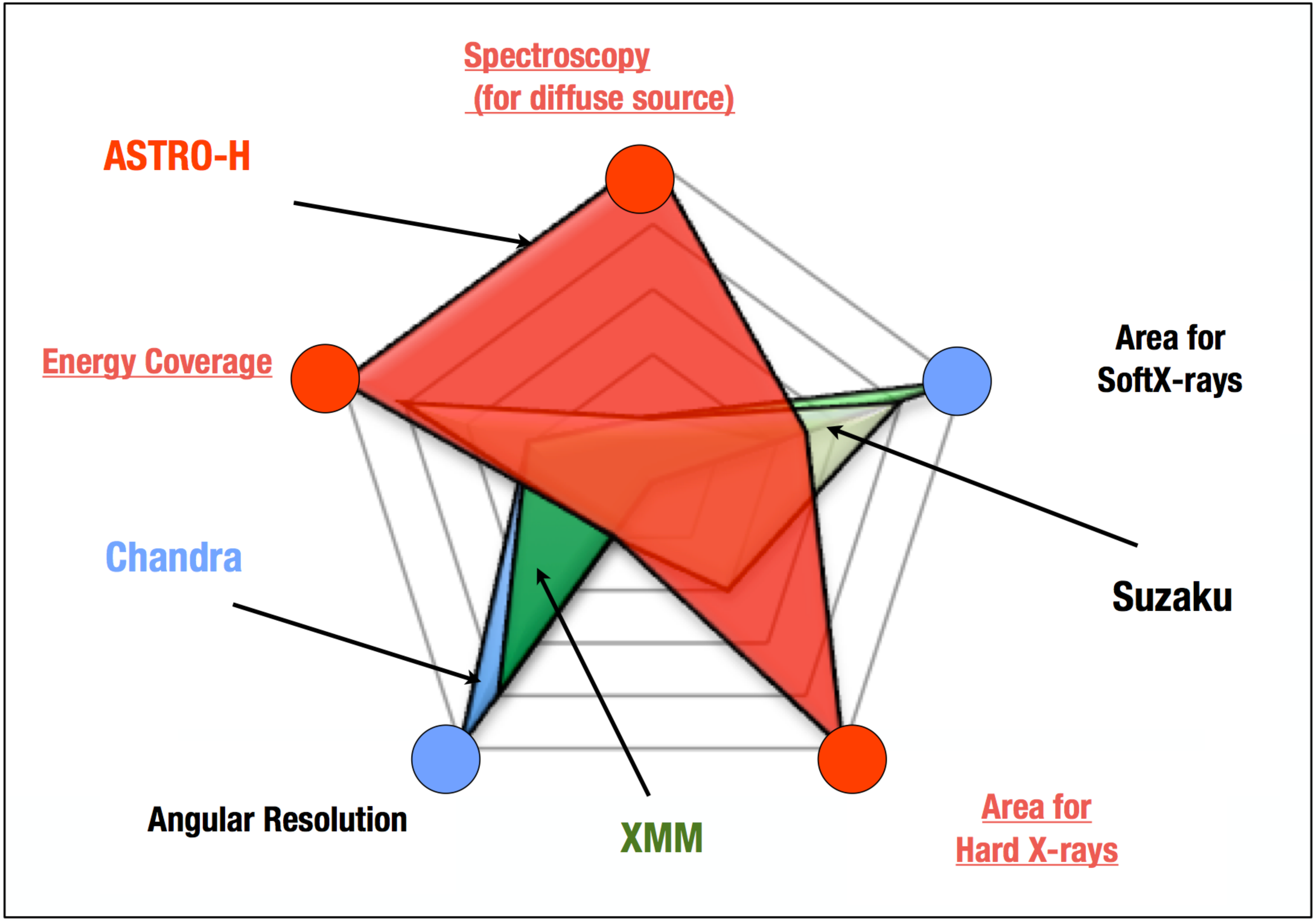
Uniqueness of ASTRO-H

Courtesy T.Takahashi, JAXA



Instruments’ synopsis

(Takahashi, 2013, MmSAI, 84, 776)

Parameter	Hard X-ray Imager (HXI)	Soft X-ray Spectrometer (SXS)	Soft X-ray Imager (SXI)	Soft γ-ray Detector (SGD)
Detector technology	Si/CdTe cross-strips	micro calorimeter	X-ray CCD	Si/CdTe Compton Camera
Focal length	12 m	5.6 m	5.6 m	–
Effective area	300 cm^2@30 keV	210 cm^2@6 keV 160 cm^2 @ 1 keV	360 cm^2@6 keV	>20 cm^2@100 keV Compton Mode
Energy range	5 –80 keV	0.3 – 12 keV	0.5 – 12 keV	40 – 600 keV
Energy resolution (FWHM)	2 keV (@60 keV)	$<$ 7 eV	150 eV (@6 keV)	4 keV (@40 keV)
Angular resolution	<1.7 arcmin	<1.3 arcmin	<1.3 arcmin	–
Effective Field of View	$\sim 9 \times 9$ $arcmin^2$	$\sim 3 \times 3$ $arcmin^2$	$\sim 35 \times 35$ $arcmin^2$	0.6×0.6 deg^2 ($<$ 150 keV)
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High-resolution spectroscopy

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High-resolution spectroscopy **Imaging up to 80 keV**

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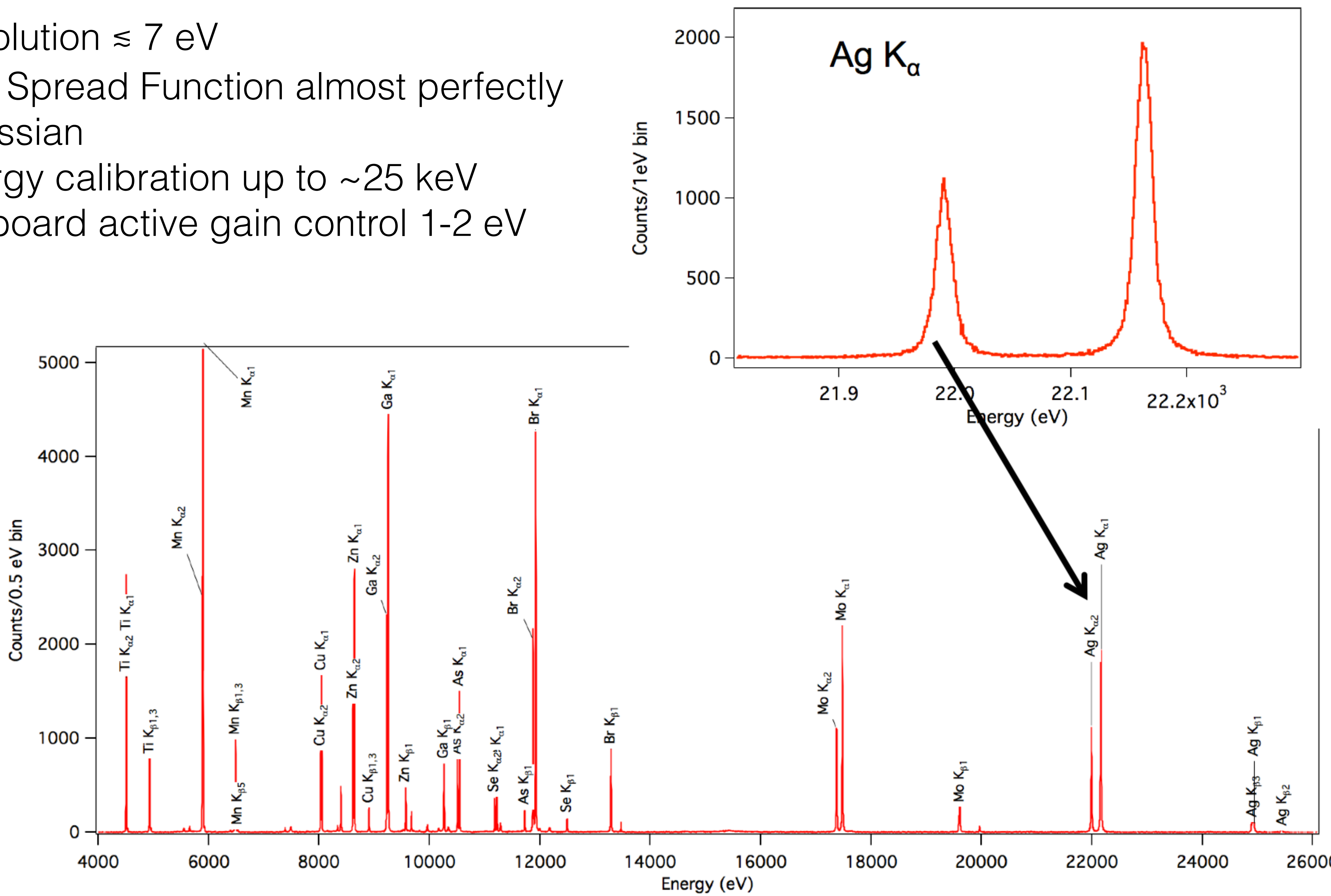
High-resolution spectroscopy **Imaging up to 80 keV** **Wide band, high sensitivity**

SXS performance energy performance

Courtesy S.Porter and SXS Team

- Resolution ≲ 7 eV
- Line Spread Function almost perfectly Gaussian
- Energy calibration up to ~25 keV
- On-board active gain control 1-2 eV

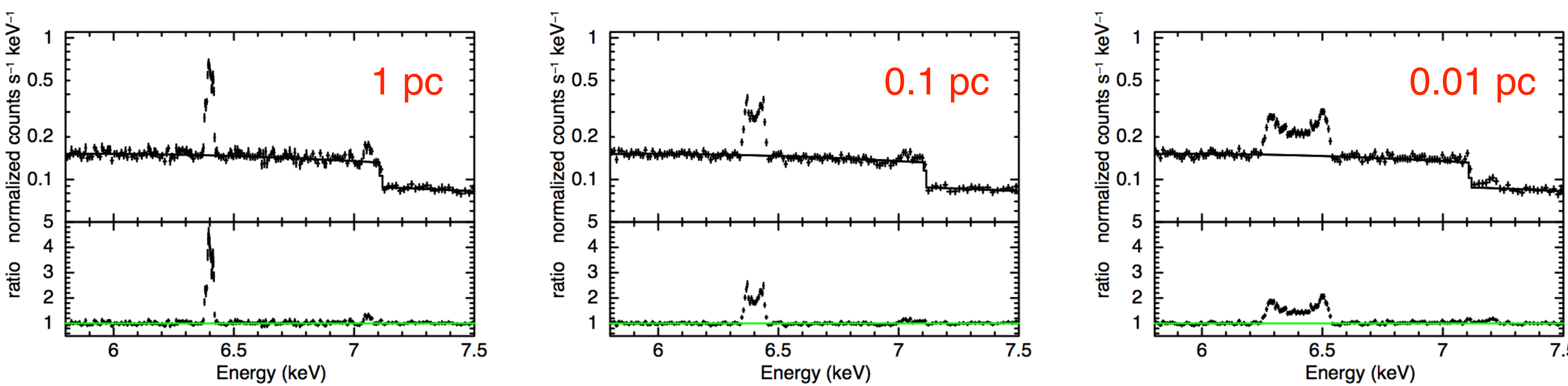


Spectroscopy of optically thick nuclear gas

Reynolds et al., 2014, arXiv:1412.1177

One of the missing observables is the radial the velocity field radial profile of the Compton-scattering gas.

Measurements of the profile of the K_α iron line with the SXS!



simulation of 100 ks on NGC4388 (very similar AGN to Markarian 3)