ROMA TRE
UNIVERSITÀ DEGLI STUDI

SEVENTH FRAMEWORK PROGRAMME

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Obscured AGN studied with X-ray spectroscopy

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Plan of the talk

Introduction on obscured AGN spectra

Highlights from recent results

The promise of high resolution spectroscopy

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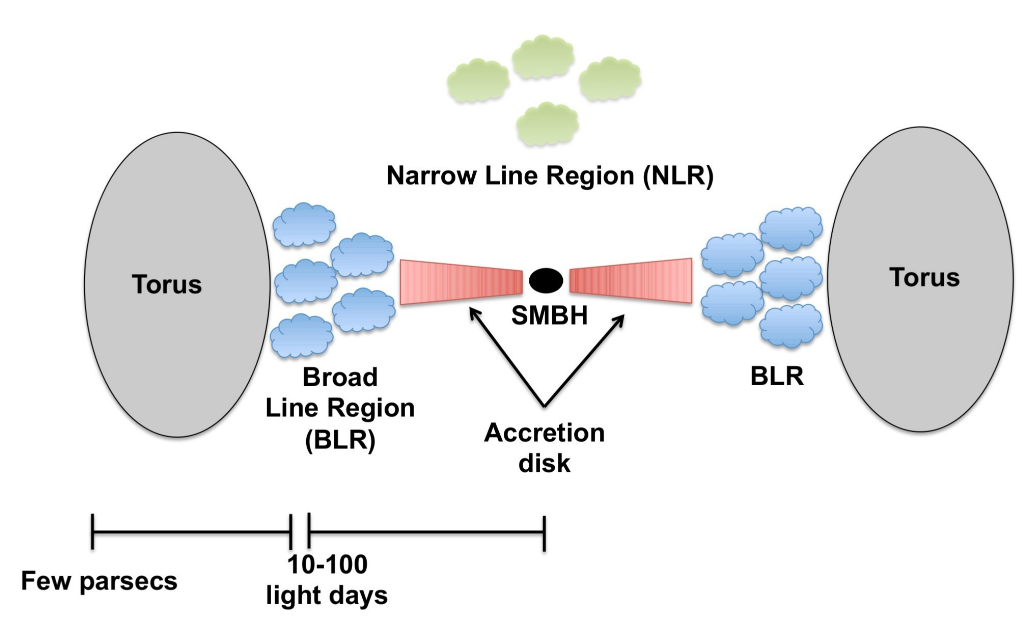
Obscured AGN spectra above 1 keV

Let us define as "Obscured AGN" those sources in which the primary, nuclear emission is hidden behind a screen of neutral matter.

Unless explicitely stated otherwise, we will refer to this matter as the 'torus', in deference to the Unification Model.

While of course in these sources the nuclear emission is difficult or impossible to study, its obscuration allows for other components to shine undiluted.



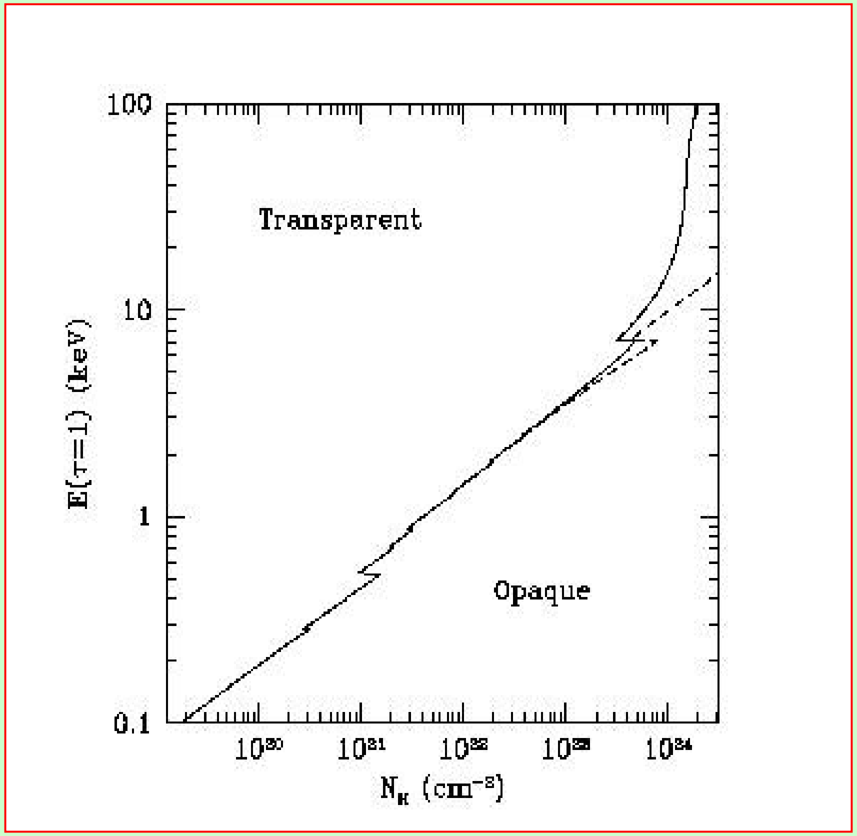
Obscured AGN are therefore the ideal sources to study circumnuclear matter.

Obscured AGN spectra above 1 keV

If the absorber is Compton-thin, i.e. NH < 1.5×10^{24} cm^{-2}, the spectrum has a low energy cutoff below 10 keV. The reflection component is also visible, with a relative flux depending on the covering factor of the absorbing material.

If the absorber is Compton-thick, i.e. NH ≥ 1.5×10^{24} cm^{-2}, the nuclear spectrum is completely obscured below 10 keV (where only the reflection component remains visible), and dimmed above 10 keV.

If NH > 10^{25} cm^{-2} or so, the transmitted radiation is completely suppressed, and the reflection component is the only visible one at all energies.



A reflection-dominated spectrum is usually assumed as a proxy for Compton-thick absorption.

Below 1 keV, a line-dominated spectrum from photoionized matter is almost invariably present (see Stefano Bianchi's talk).

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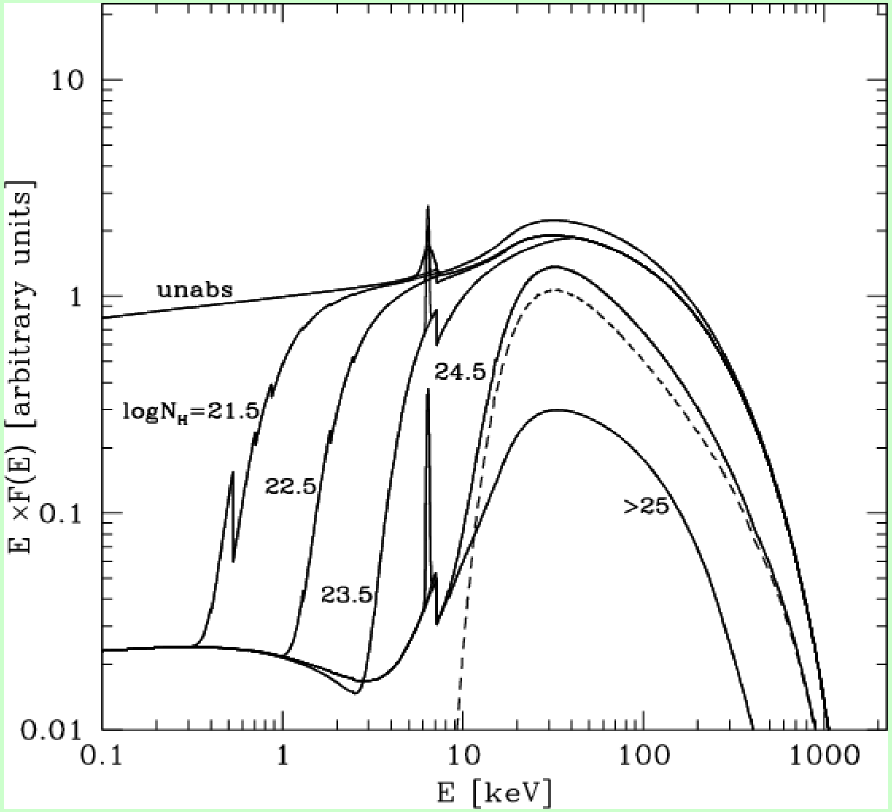

Comastri, Gilli & Hasinger (2007)

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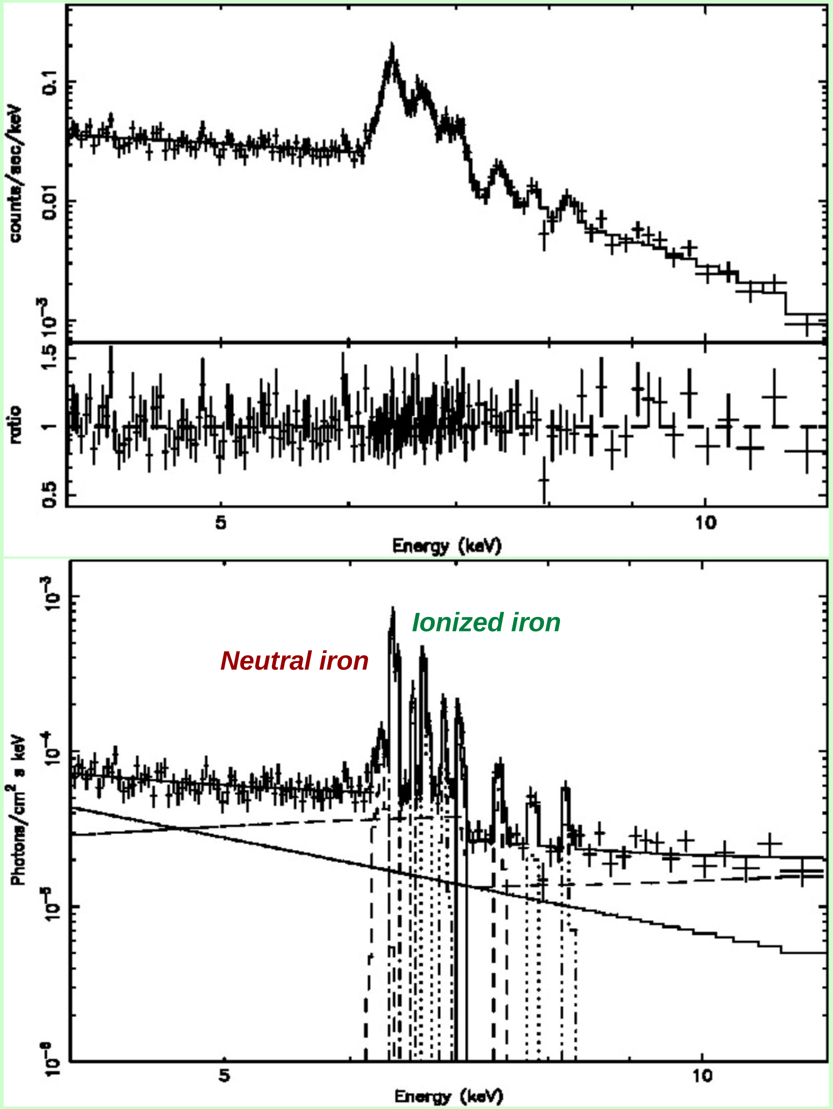
Obscured AGN spectra above 1 keV

NGC 1068, XMM-Newton (Matt et al. 2004)



In addition to the reflection from the absorbing material, other reflection components – neutral or ionized – can be present, as indicated by the iron line spectrum.

NGC 1068 is probably the best example. Evidence of Be-, He- and H-like iron ions (as well as of He-like nickel ions) are apparent in the XMM-Newton spectrum, implying the presence of a highly ionized reflector *(which is NOT the warm reflector responsible for the optical broad lines in polarized flux!)*

Physical (ionization state and nature), chemical (element abundances) and dynamical properties of the reflecting materials can be studied

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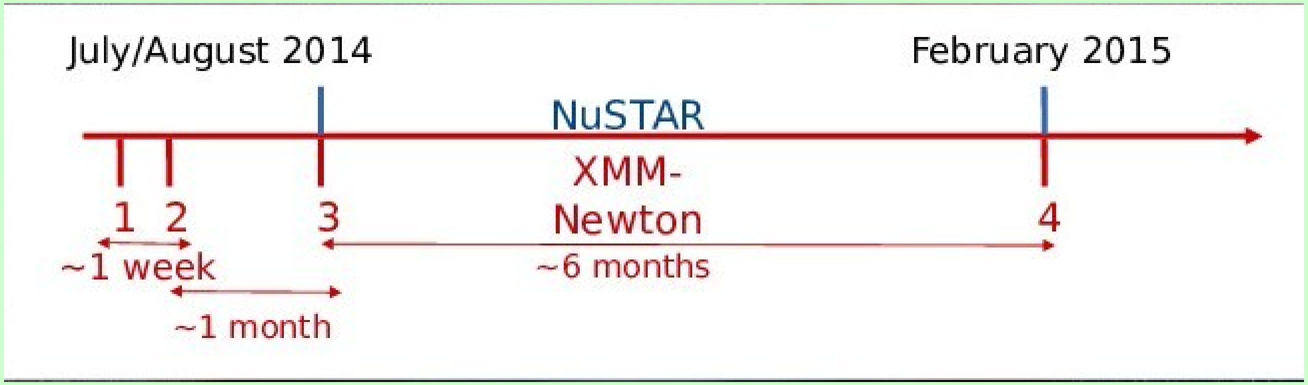
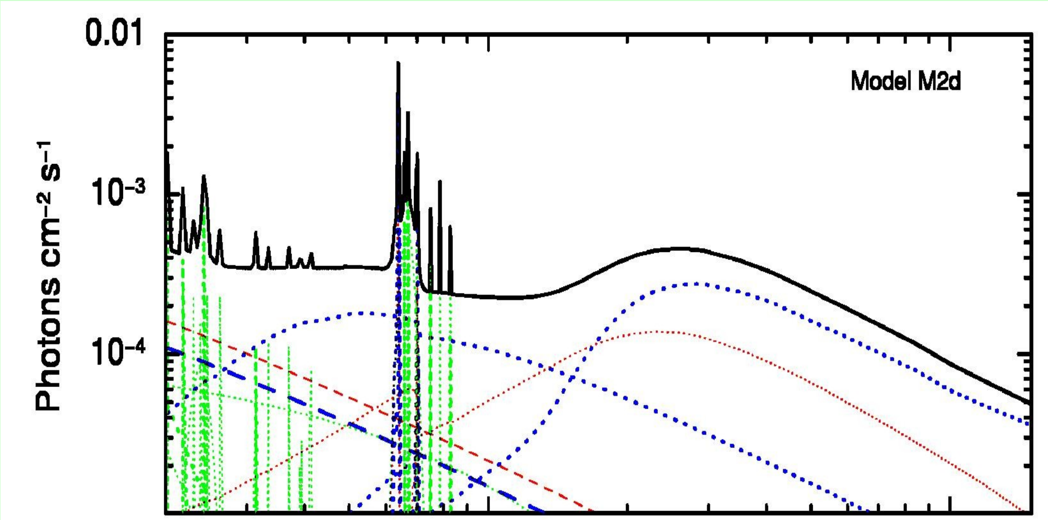
The clumpy torus of NGC 1068

NGC 1068, the archetypal Compton-thick Seyfert 2 galaxy, was observed four times by XMM-*Newton* from July 2014 to February 2015, NuSTAR joining the 3rd and 4th observations.

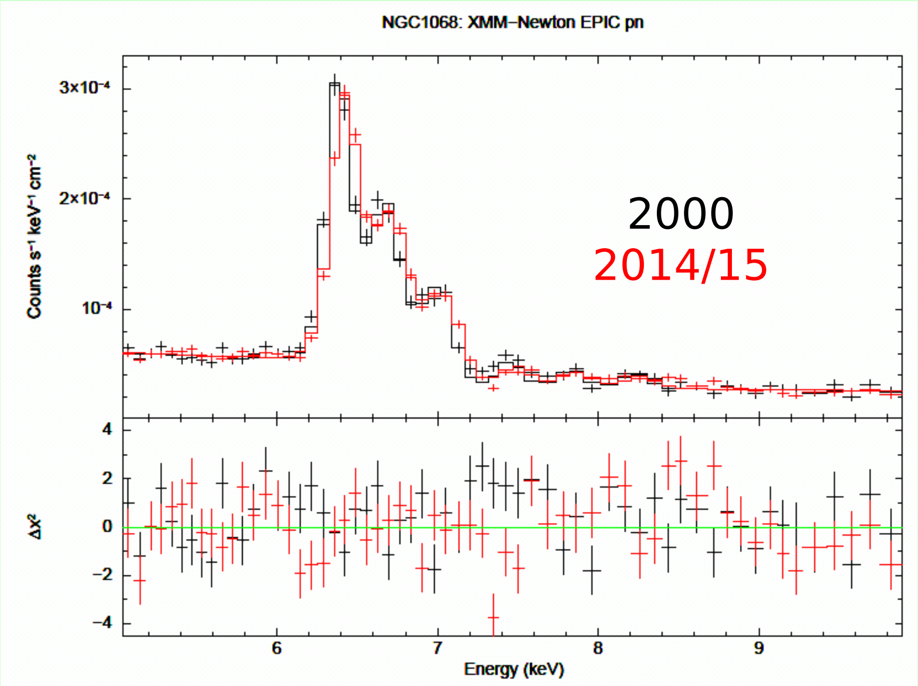


Bauer et al. 2015

Longer time-scales can be probed thanks to the two previous XMM-*Newton* observations performed in 2000 (Matt et al. 2004), and the NuSTAR observation performed in 2012 (Bauer et al, 2014), which found the nuclear emission to be fully suppressed by a material with NH ≥ 10^{25} cm^{-2}

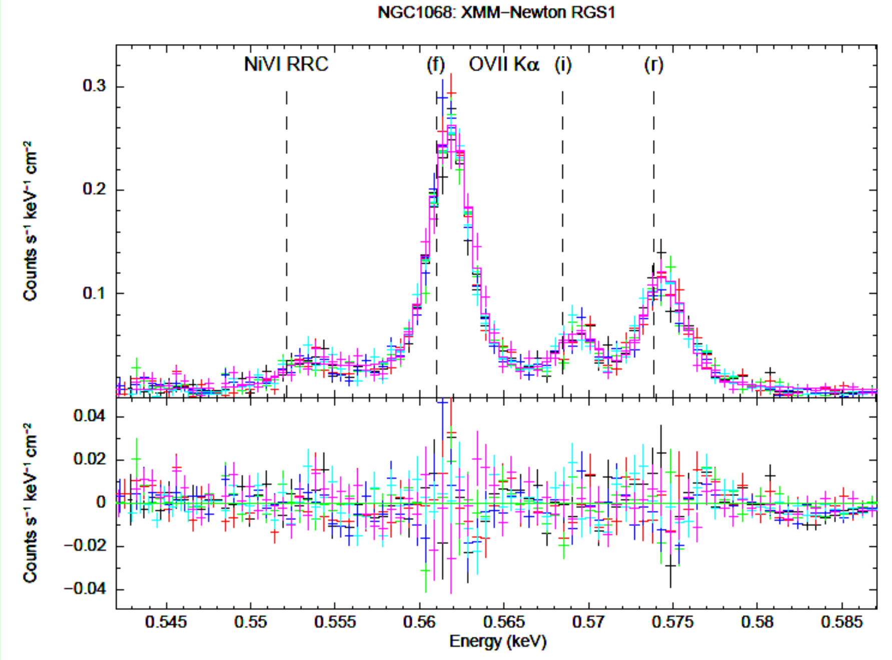


The clumpy torus of NGC 1068



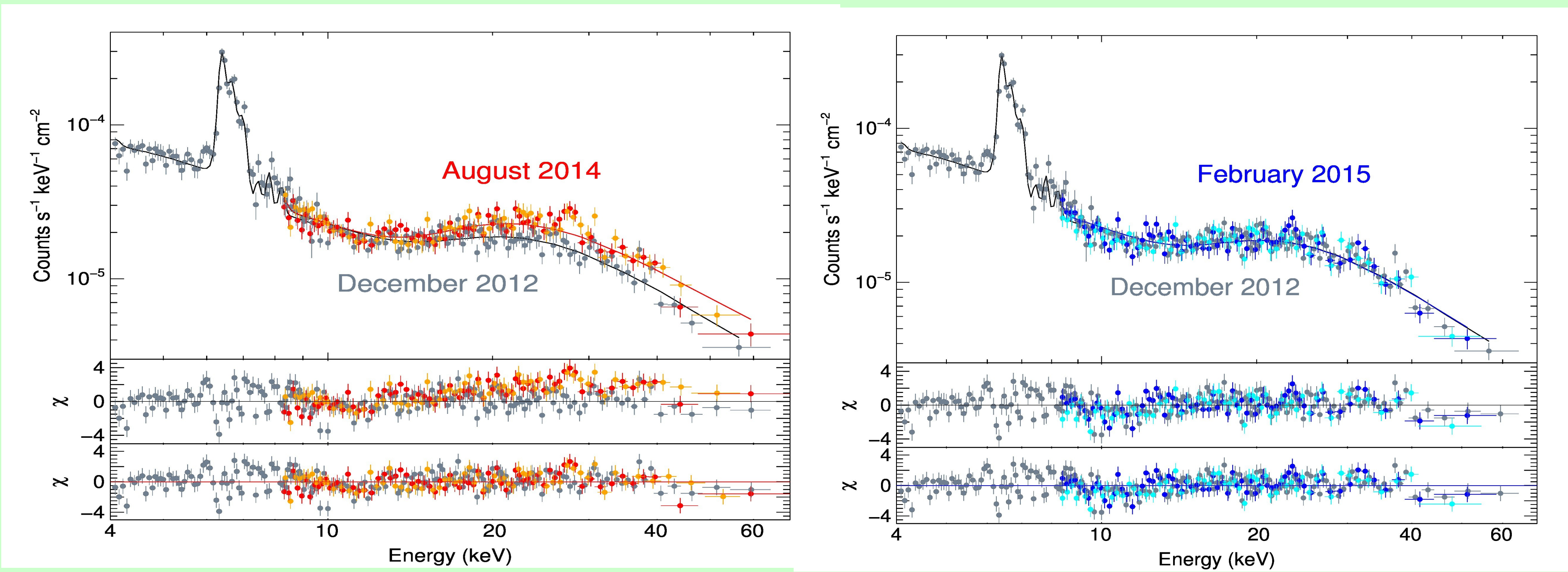
The neutral iron Kα line is constant within 5%

The forbidden component of the OVII Kα line triplet is constant within 1% (see S. Bianchi's talk)



The clumpy torus of NGC 1068

Marinucci et al. 2016



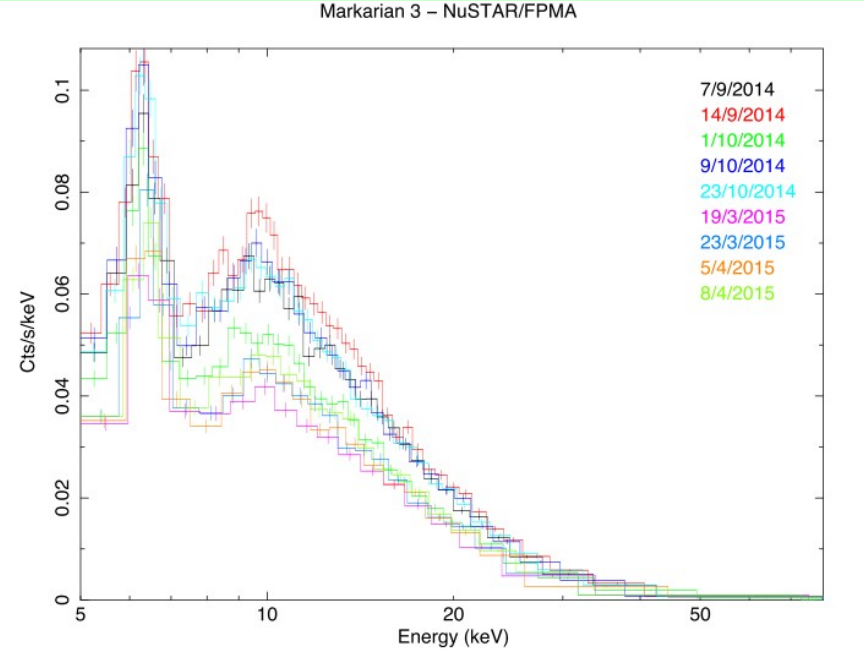
An excess is seen in the NuSTAR data of Aug 14 with respect to both Dec 12 and Feb 15.

Best explanation: a decrease of NH (from >10^{25} to about 7×10^{24} cm^{-2}).

One less single cloud on the line of sight?

⇒ Clumpy Torus

Yet another clumpy torus? Mrk 3

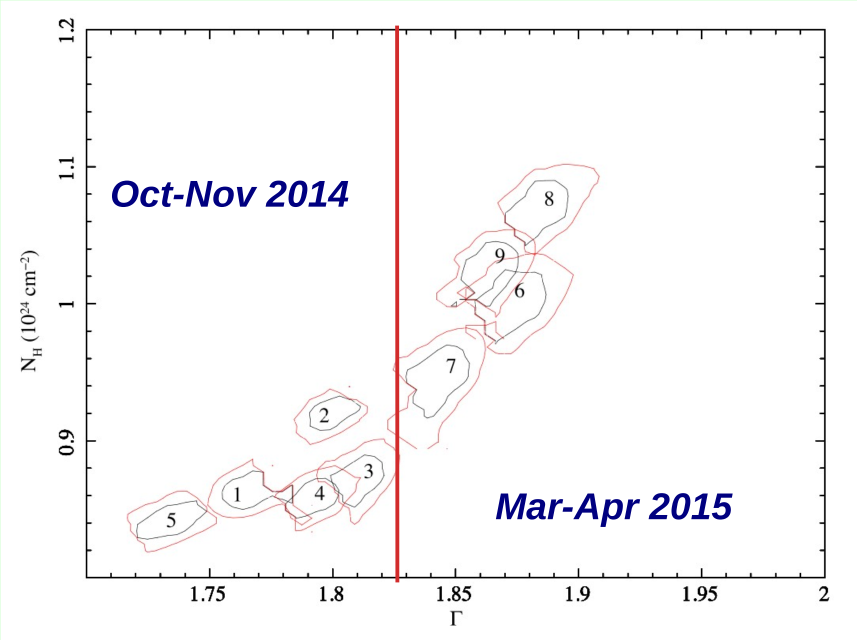


Guainazzi et al. 2016

Mrk 3 is a Seyfert 2 just short of being Compton-Thick (NH ~ 10^{24} cm^{-2})

Observed by NuStar in Oct-Nov 2014 and then in Mar-Apr 2015

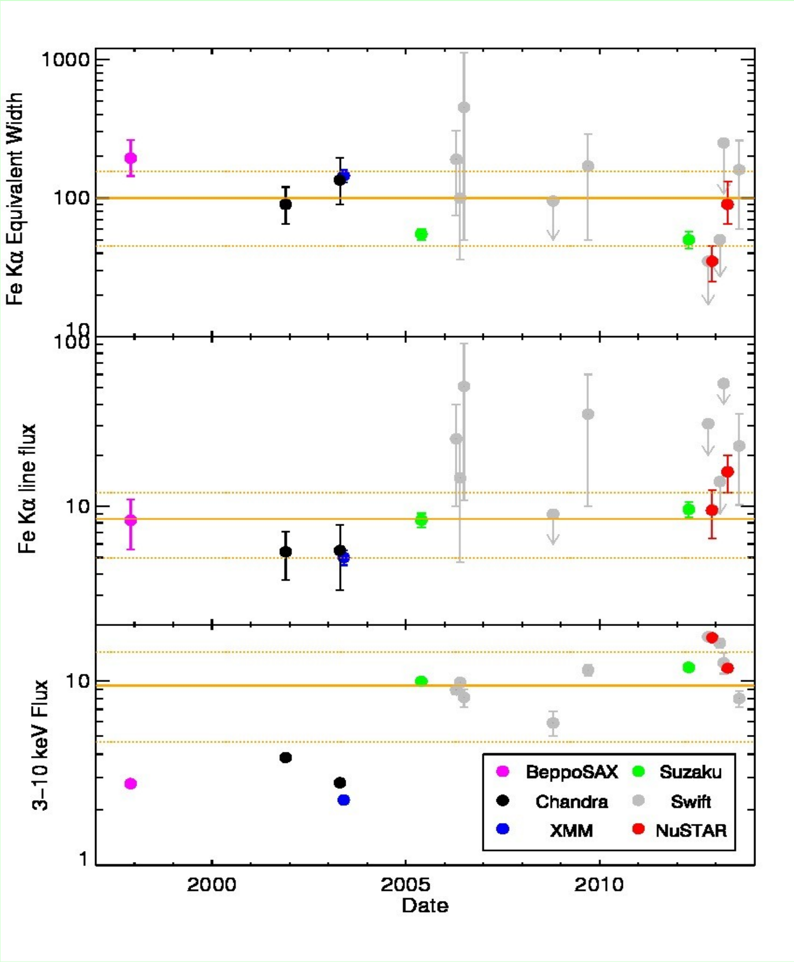
Variable in photon index



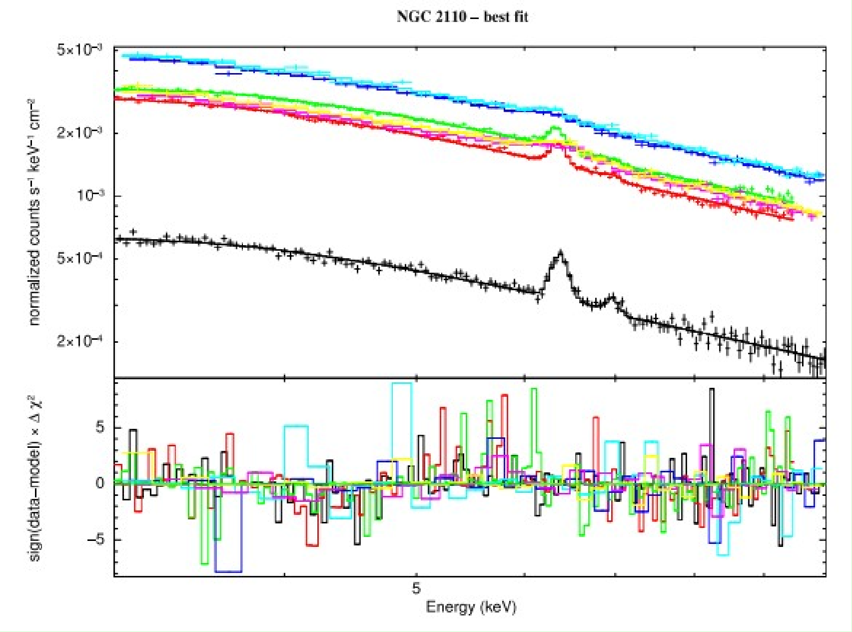
During the Oct-Nov 2014 campaign, NH is constant but for an occulation event with ΔNH ~ 5×10^{22} cm^{-2} (*__note that the NH of the cloud is about 2 orders of magnitude smaller than in NGC 1068!!__*). If due to a single cloud, this implies N_{cloud}~20

More complex variability in Mar-Apr 2015. With similar assumptions, N_{cloud}~30

The origin of the iron line in NGC 2110



Marinucci et al. 2015

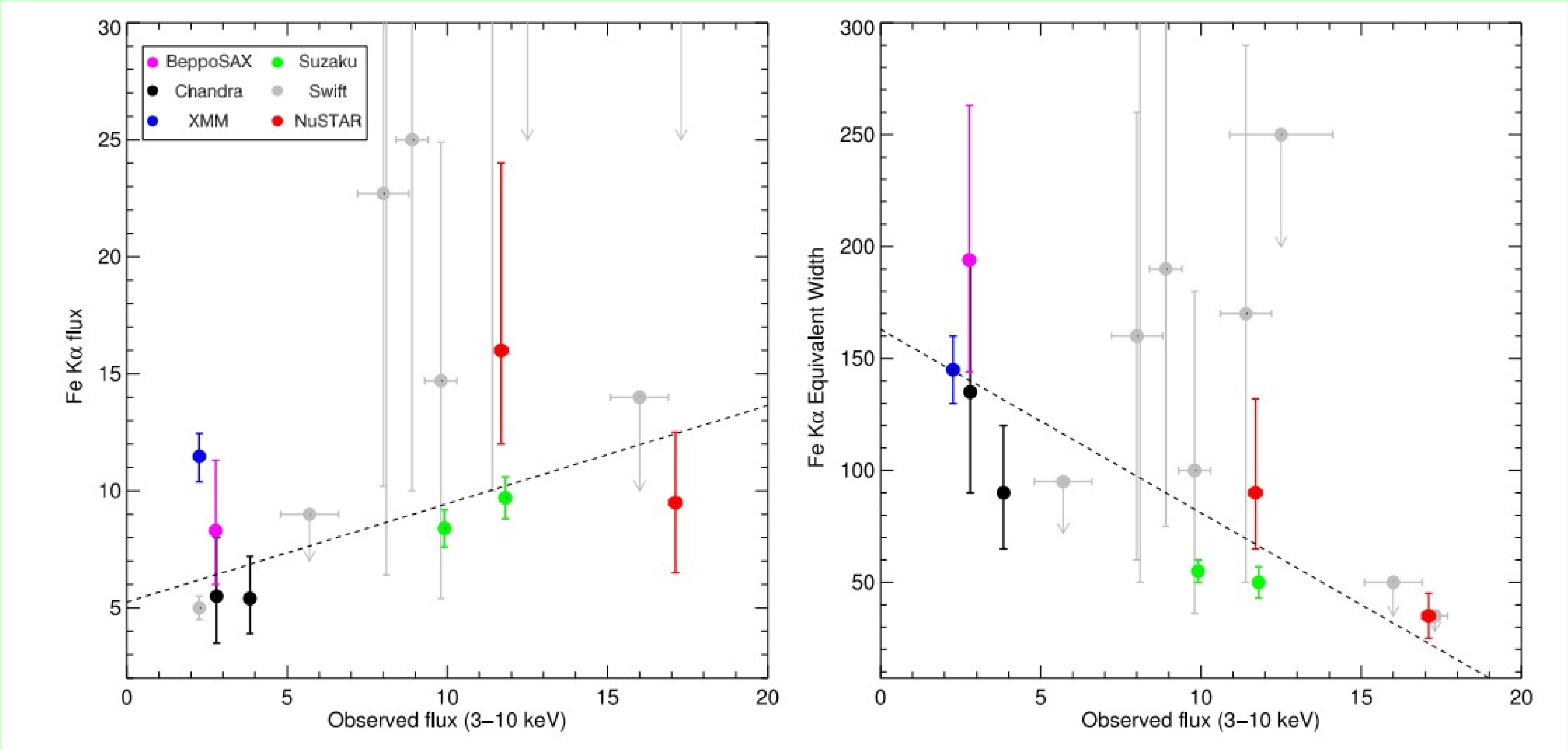


A moderately absorbed Seyfert 2 galaxy (NH~ 4×10^{22} cm^{-2}).

Intense iron line, highly variable continuum

The origin of the iron line in NGC 2110

Marinucci et al. 2015



Fe Kα line produced by distant matter ⇨
constant line flux and EW linearly anticorrelated with continuum flux.

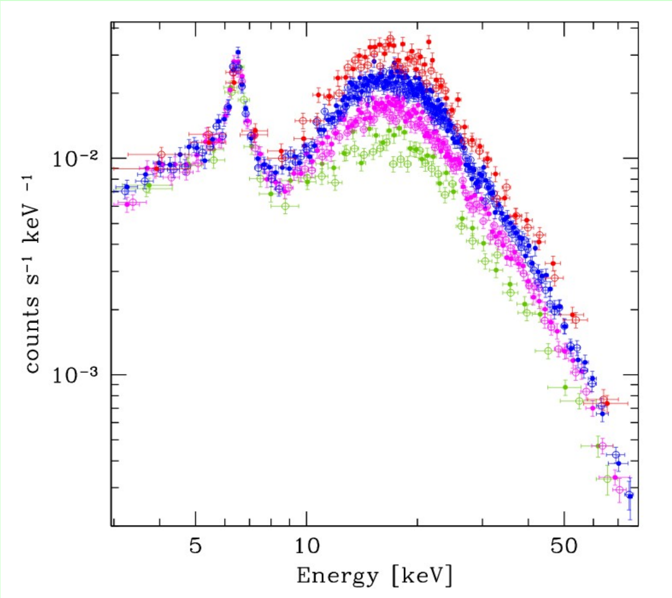
Fe Kα line emitting material closer than cΔt ⇨
constant EW and line flux linearly correlated with continuum flux

The situation is intermediate: 2 components! (BLR and torus)

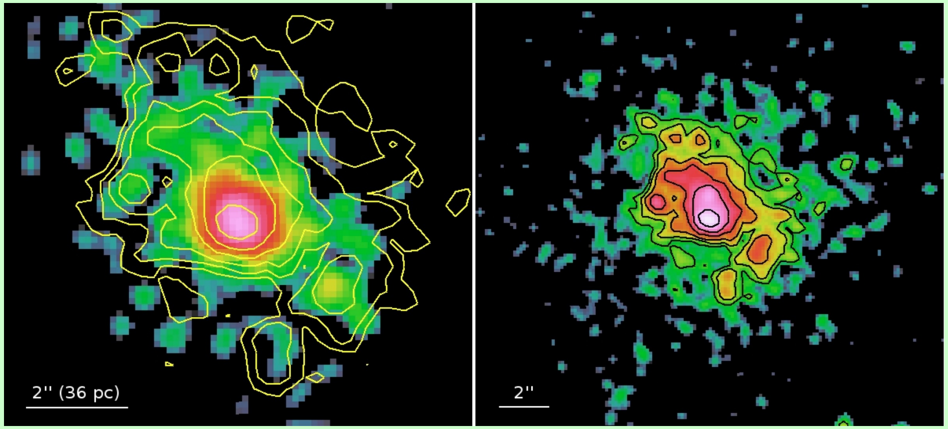
Spatially resolved iron line spectroscopy in NGC4945

NGC 4945 is a nearby (3.7 Mpc), almost edge-on, spiral galaxy. It is the brightest obscured, and the second brightest radio-quiet, AGN in the 100 keV sky (Done et al, 1996).

Very variable, but only above 10 keV.



Puccetti et al. 2014



Marinucci et al. 2012

Past imaging analysis with Chandra (~ 230 ks) revealed that the Iron Ka and the associated Compton reflection continuum are spatially extended on scales of hundreds of parsecs.

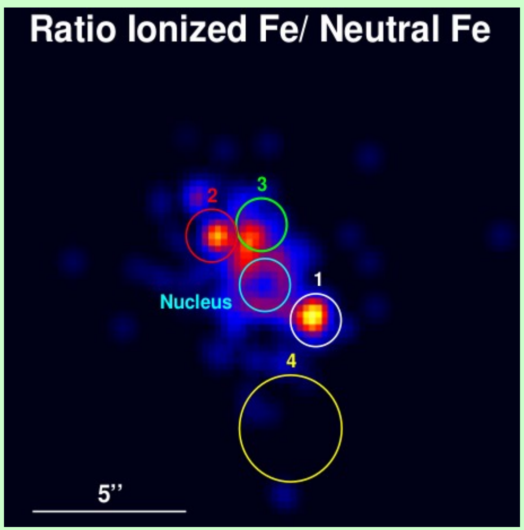
Spatially resolved iron line spectroscopy in NGC4945

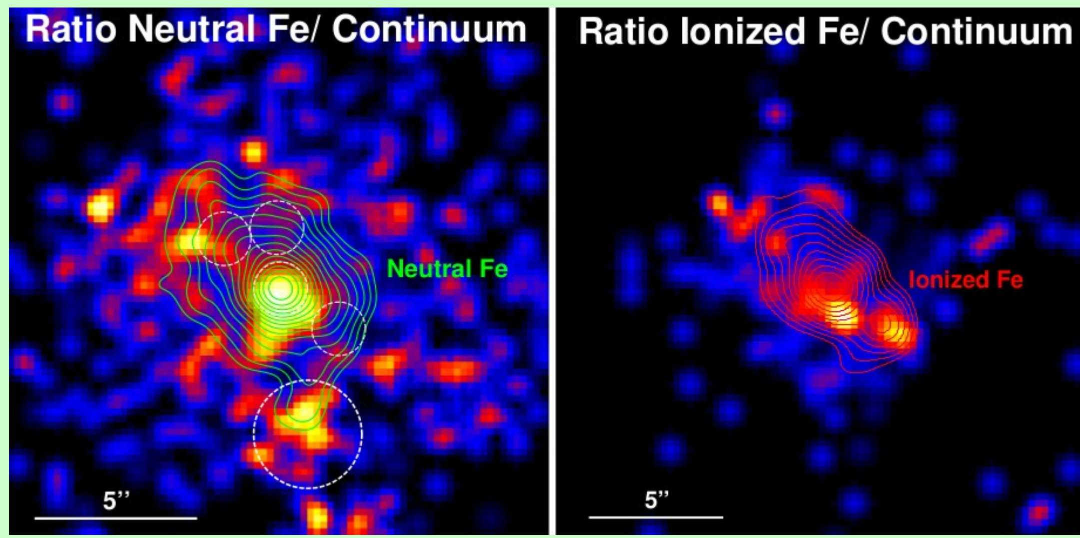
Obs. ID	Date	Exp. Time (ks)	HETG
864	2000-01-27	49.7	✗
4899	2004-05-28	78.6	✓
4900	2004-05-29	95.8	✓
14985	2013-04-20	68.7	✗
14984	2013-04-25	130.5	✗

Table 1. Observation log for the *Chandra* ACIS-S observations of NGC 4945.

Observed by Chandra for a total observing time of about 450 ks

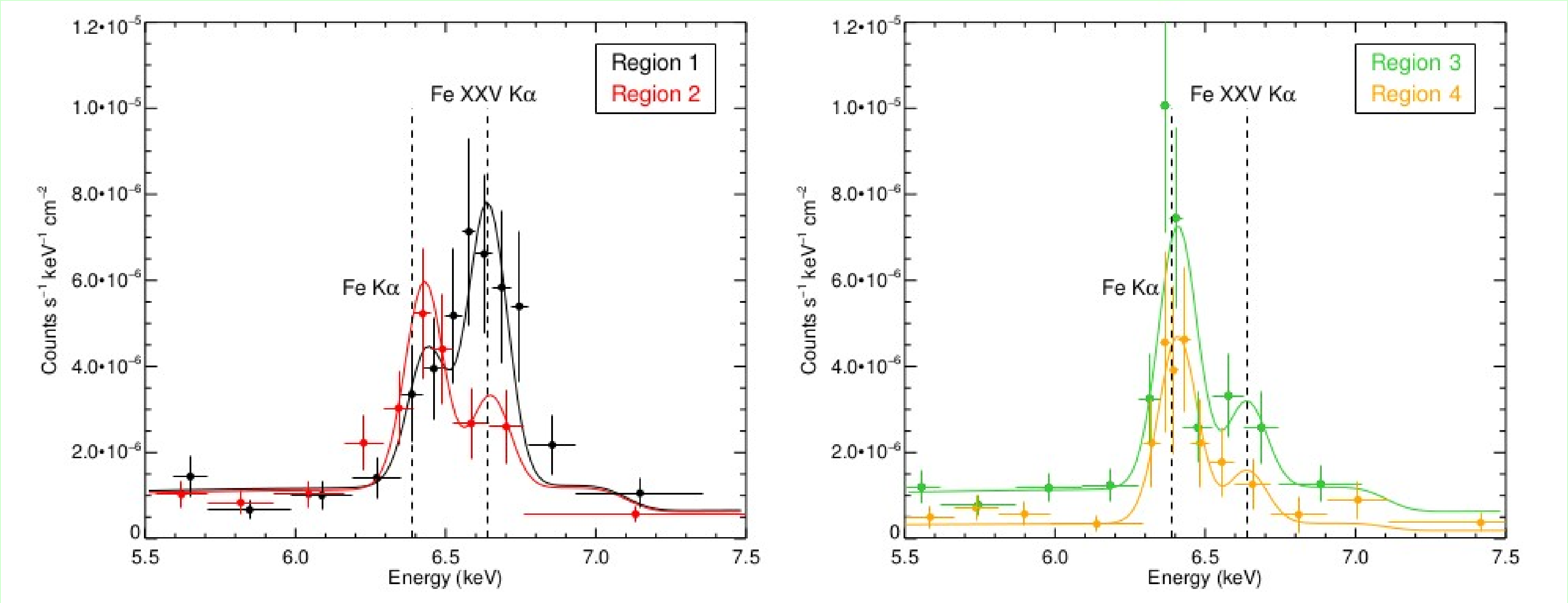
The distributions of neutral and ionized iron are very structured.





Marinucci et al. 2017

Spatially resolved iron line spectroscopy in NGC4945



Marinucci et al. 2017

Parameter	Reg. 1	Reg. 2	Reg. 3	Reg. 4
N_{pexrav}	0.40 ± 0.03	0.39 ± 0.03	0.37 ± 0.08	0.12 ± 0.02
Fe Kα				
Energy	6.44 ± 0.05	6.43 ± 0.03	6.40 ± 0.03	$6.40^{+0.02}_{-0.03}$
Flux	0.05 ± 0.02	0.08 ± 0.02	0.09 ± 0.03	0.07 ± 0.02
EW	$0.45^{+0.30}_{-0.20}$	$0.65^{+0.30}_{-0.25}$	$0.75^{+0.40}_{-0.25}$	$2.15^{+1.30}_{-0.85}$
Fe XXV Kα				
Energy	$6.65^{+0.03}_{-0.04}$	6.66 ± 0.07	6.65 ± 0.06	6.60 ± 0.10
Flux	0.11 ± 0.03	0.04 ± 0.02	0.03 ± 0.02	0.02 ± 0.01
EW	0.90 ± 0.30	0.30 ± 0.25	0.35 ± 0.30	$0.60^{+0.70}_{-0.45}$
$F_{3-10\ keV}$	0.80 ± 0.07	0.75 ± 0.08	0.85 ± 0.08	0.28 ± 0.05
C/d.o.f.	37/51	65/40	28/38	26/31

To be noted:

A very large neutral iron EW in region 4, either due to a large iron abundance and/or column density/inclination of the reflecting material

A clump of Fe XXV (region 1). Photoionized, optically thick gas

Not quite obscured. I. "True" Seyfert 2s

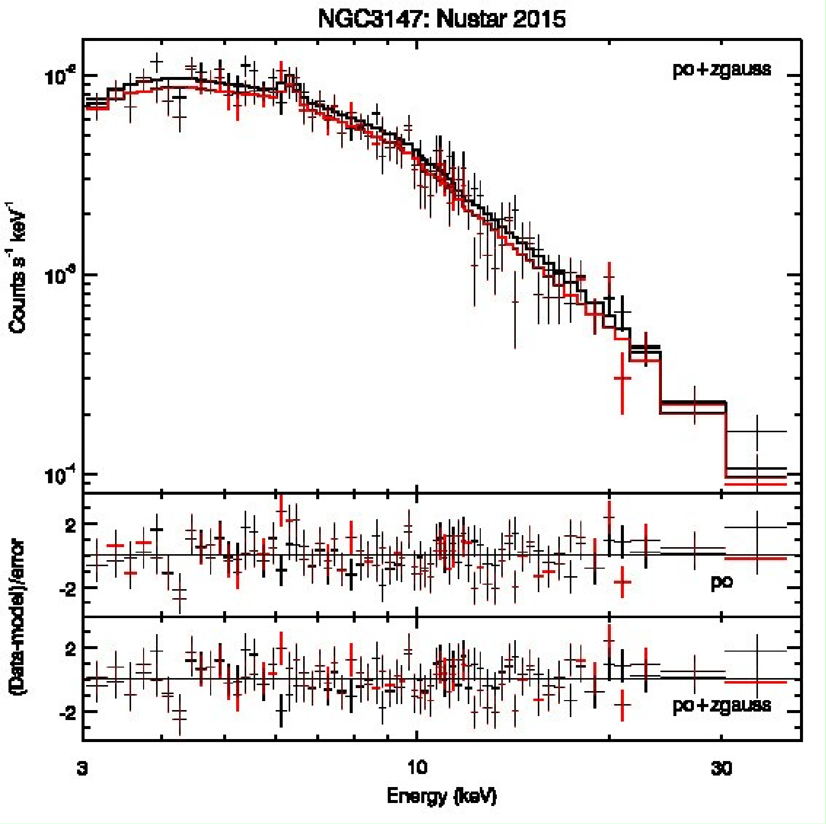
Seyfert 2 galaxies are almost always obscured in X-rays, as expected in the Unification Model. There are, however, a few exceptions. Some Seyfert 2s are not obscured in X-rays, suggesting that thery are lacking the BLR (possibly due to their low accretion rate, Nicastro 2000). The best studied case is NGC 3147, a Seyfert 2 with a Seyfert 1 X-ray spectrum (an unabsorbed power law spectrum and a relatively low EW iron line).

Questions are:

Is NGC 3147 really unobscured and not Compton-thick?
Yes, with high confidence

Not (cold) reflection-dominated
Variable on yearly time scales
X-ray/OIII flux ratio as for Seyfert 1s
Not absorbed up to N_H~ several x 10^{24} cm^{-2}

Is NGC 3147 really a Seyfert 2?
A HST observation to search for faint, very broad lines has been granted. Stay tuned...

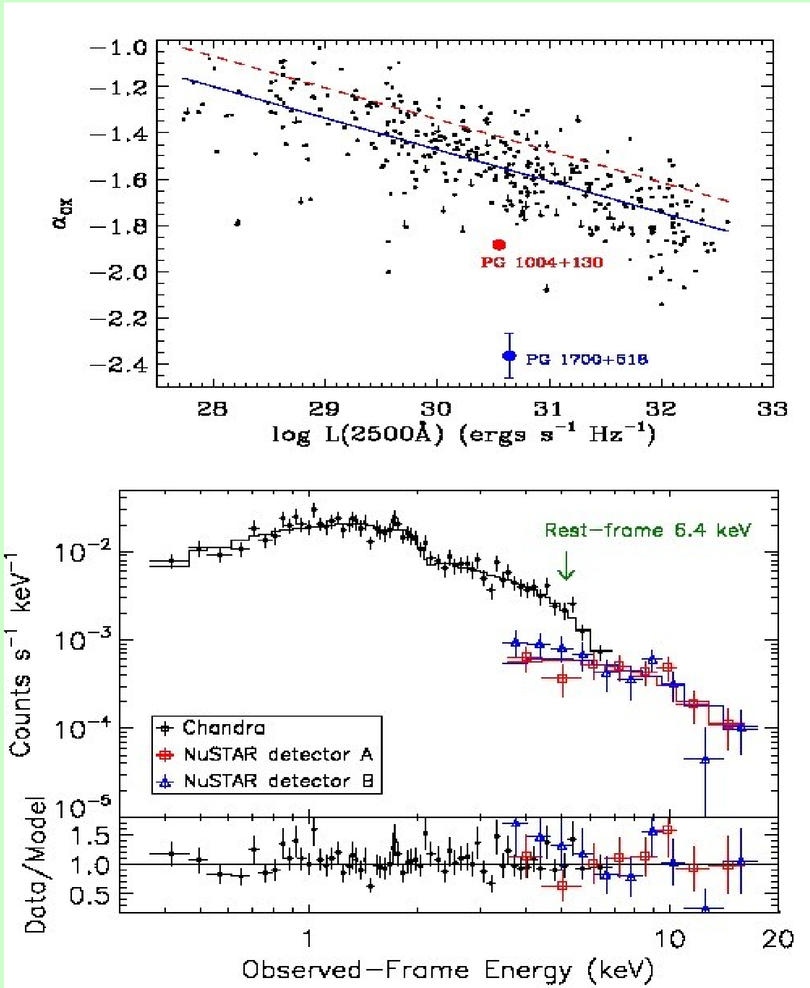


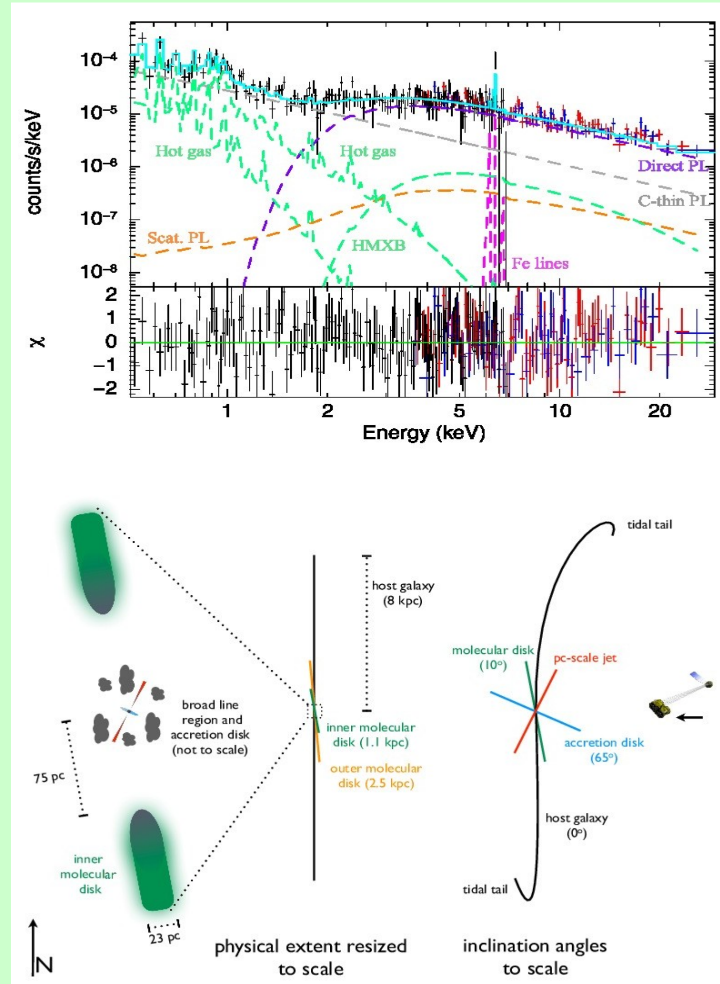
Bianchi et al. 2017

Not quite obscured. II. BAL QSOs

Broad Absorption line quasars have a low X-ray-to-optical flux ratio

→ Absorption or intrinsic X-ray weakness?





PG 1004+130 Chandra+NuSTAR
(Luo et al. 2013)

Mrk 271 Chandra+NuSTAR
(Teng et al. 2014)

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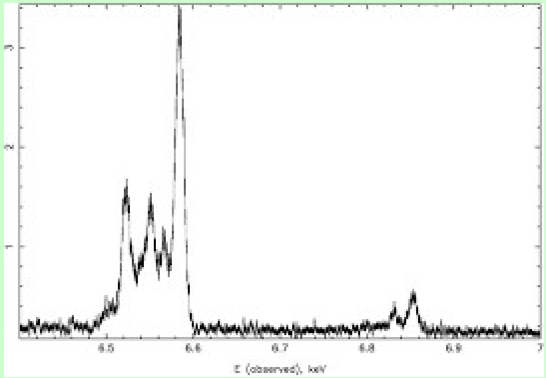
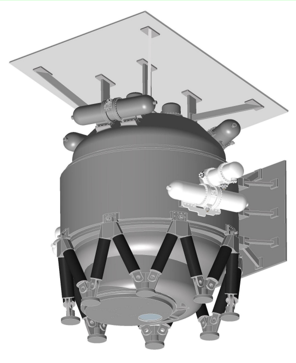
Future high spectral resolution X-ray missions



Perseus Cluster

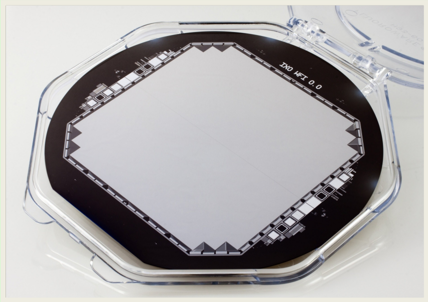
XARM (X-ray Astronomy Recovery Mission).
A simplied version of Astro-H (Hitomi).
Approved by JAXA with important contribution by NASA and participation by ESA.
Launch in 2021+

ATHENA (Advanced Telescope for High ENergy Astrophysics).
The next major X-ray observatory. Selected by ESA as the second Large mission in the Cosmic Vision program, with NASA and JAXA partecipation.
Launch in 2028+ (more on ATHENA this afternoon).



X-ray Integral Field Unit:

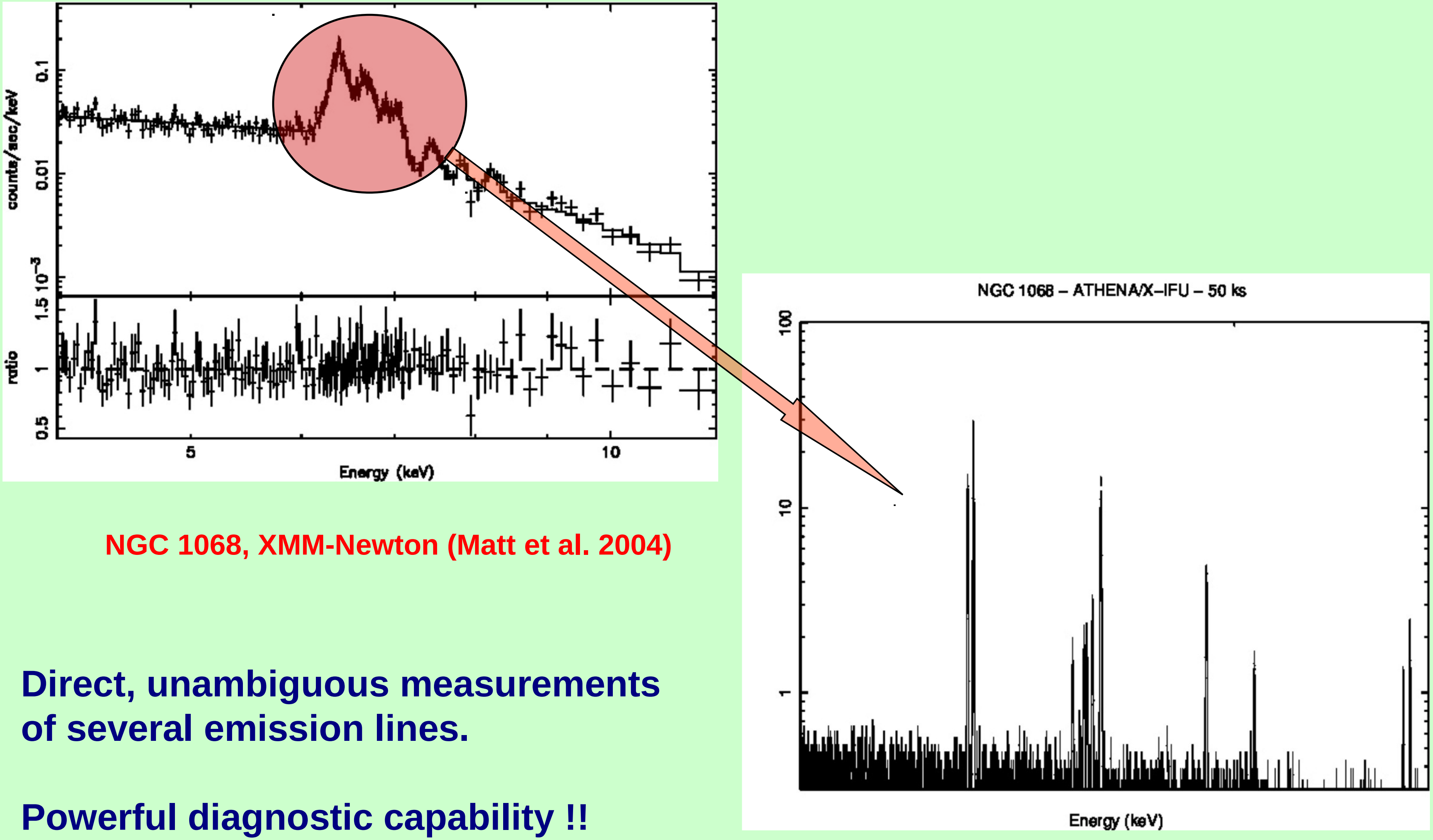
ΔE: 2.5 eV



Wide Field Imager:

ΔE: 125 eV

ATHENA

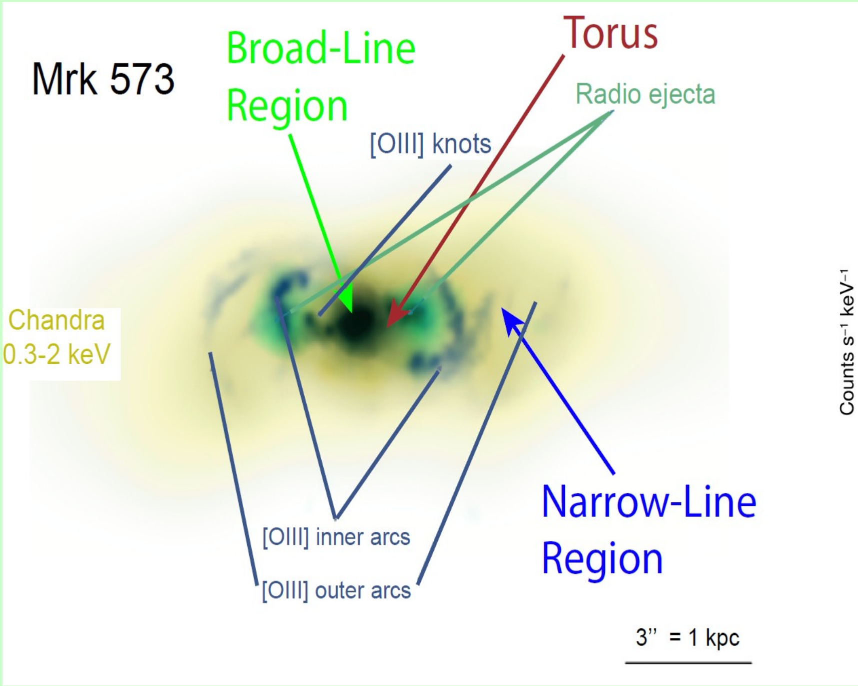


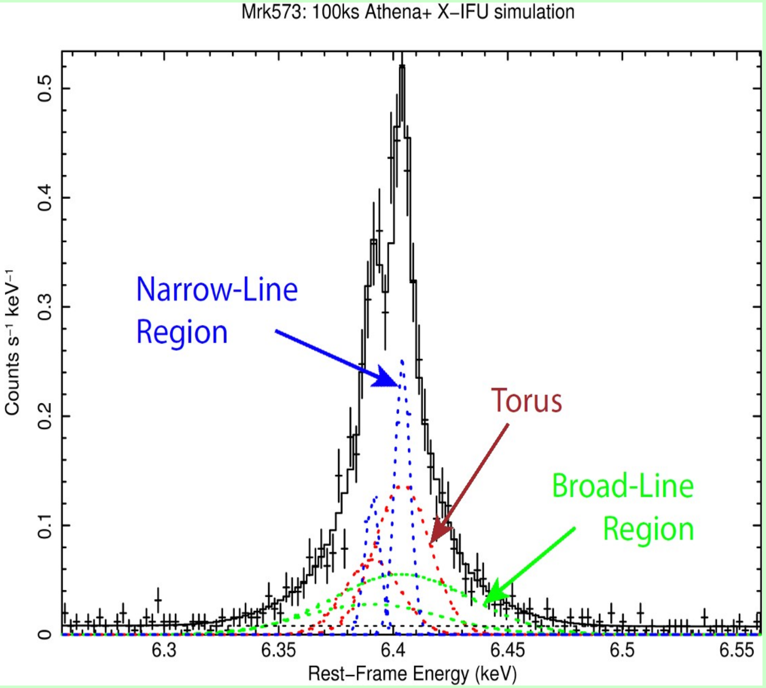
NGC 1068, XMM-Newton (Matt et al. 2004)

Direct, unambiguous measurements of several emission lines.

Powerful diagnostic capability !!

ATHENA





ATHENA/X-IFU high resolution will allow us to separate the various components of the iron Kα line (BLR, torus, NLR) and measure their widths (and therefore the distance of the emitting regions, assuming Keplerian motion)

A fundamental progress in our understanding of the torus

Conclusions

X-ray (continuum and line) spectroscopy is fundamental for our understanding of obscured AGN and their environments

Next great leap forward expected from high spectral resolution spectroscopy provided by XARM and especially ATHENA