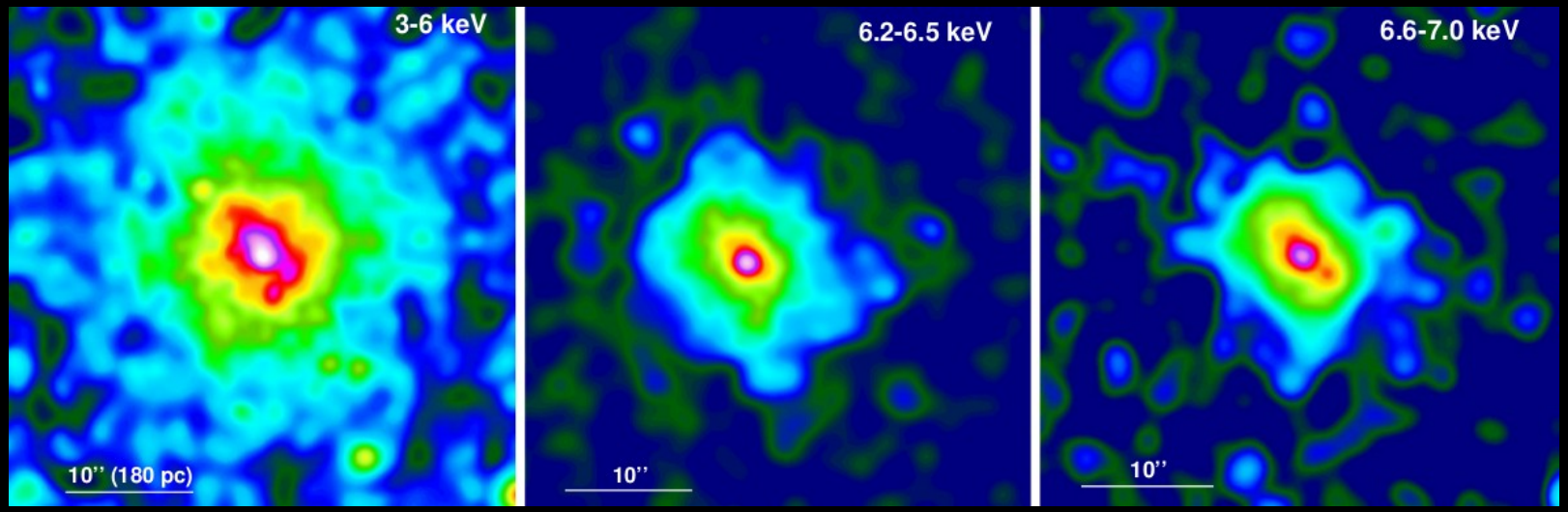
Spatially resolved spectroscopy of NGC 4945



Andrea Marinucci

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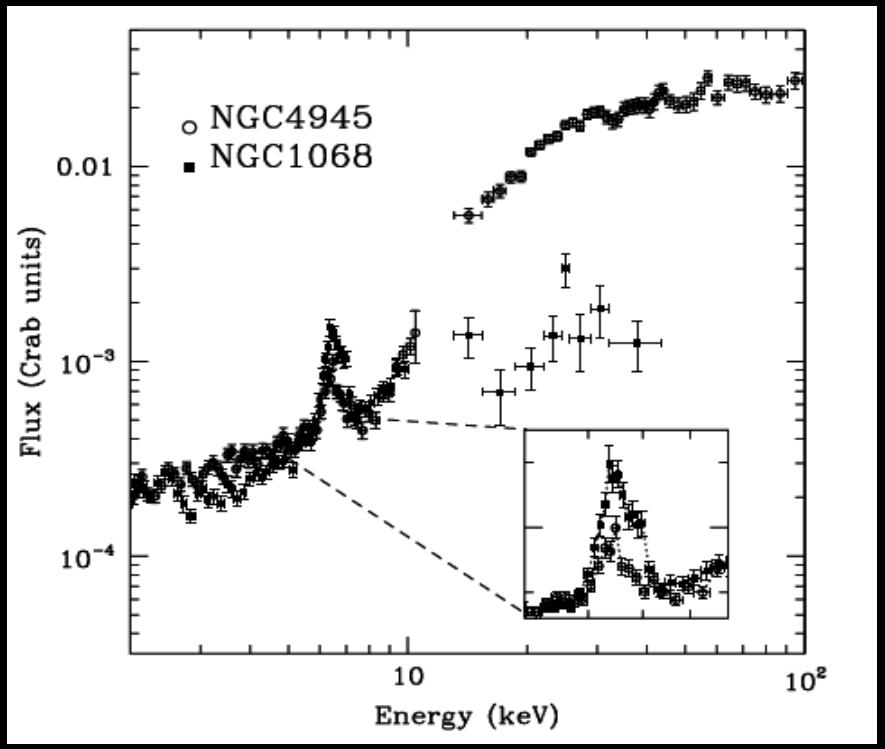
STRONGGRAVITY
EU FP7-SPACE research project 312789 2013 - 2017

Introduction

NGC 4945 is a nearby (3.7 Mpc), almost edge-on, spiral galaxy.
It is the brightest Sy 2 galaxy and the brightest radio-quiet AGN
of the 100 keV sky after NGC 4151 (Done et al, 1996)

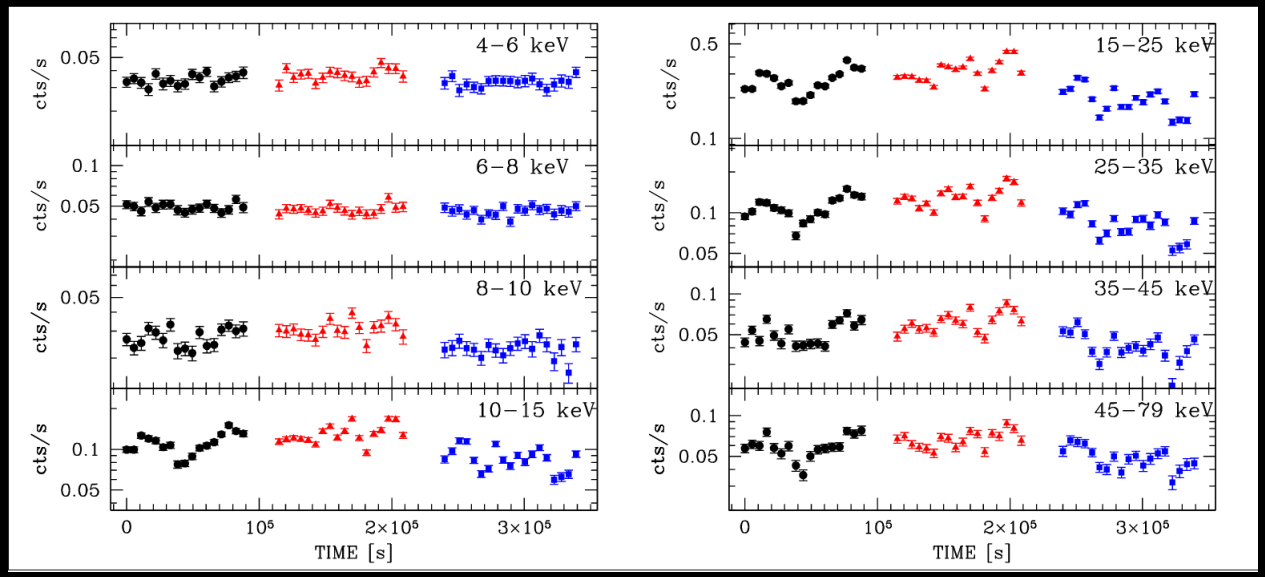


Guainazzi+00

Previous studies revealed the extreme absorbing column density of $N_H \sim 4 \times 10^{24}$ cm^{-2} in the source.

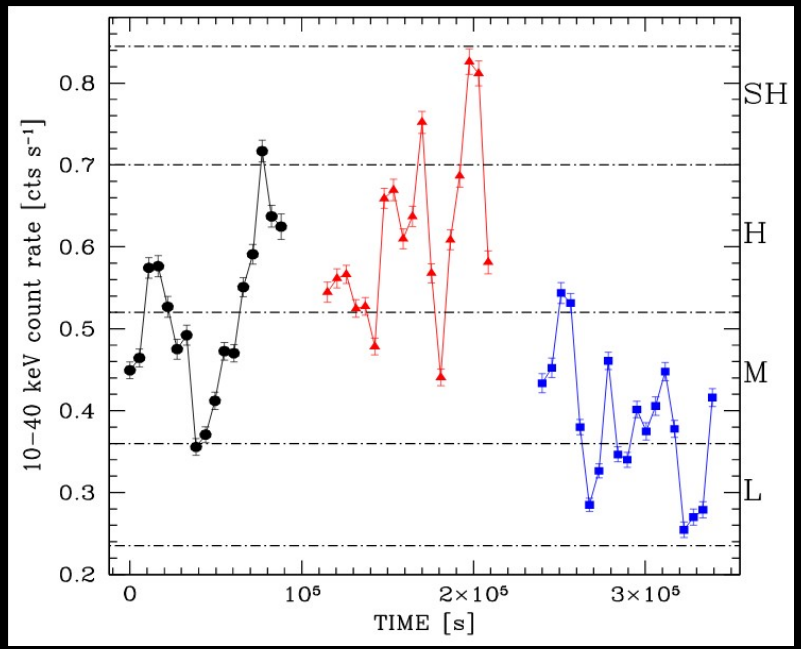
It completely blocks the primary nuclear emission
below 8-10 keV and the nucleus can only be directly seen in higher
energy ranges (>10 keV).

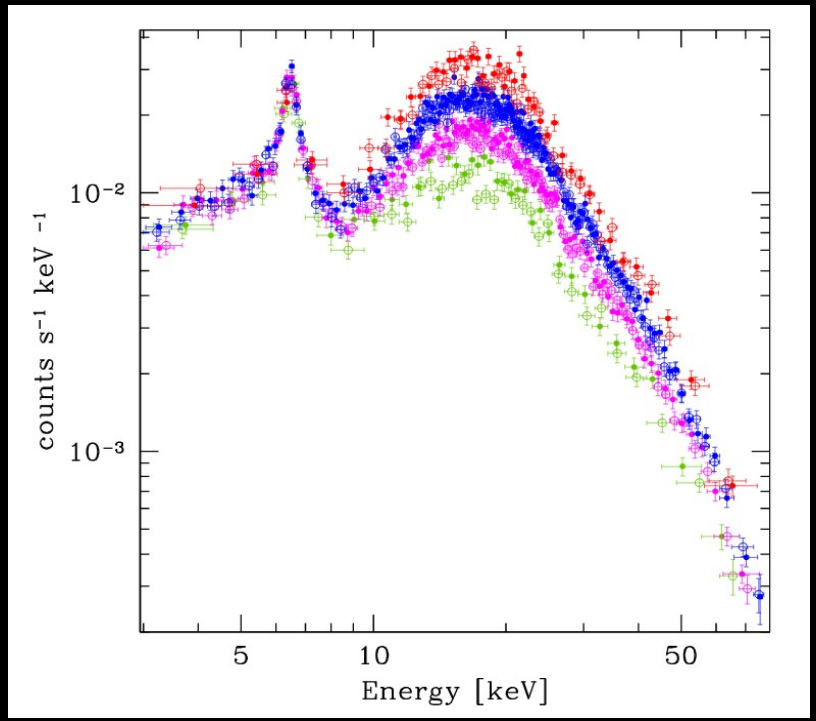
Introduction



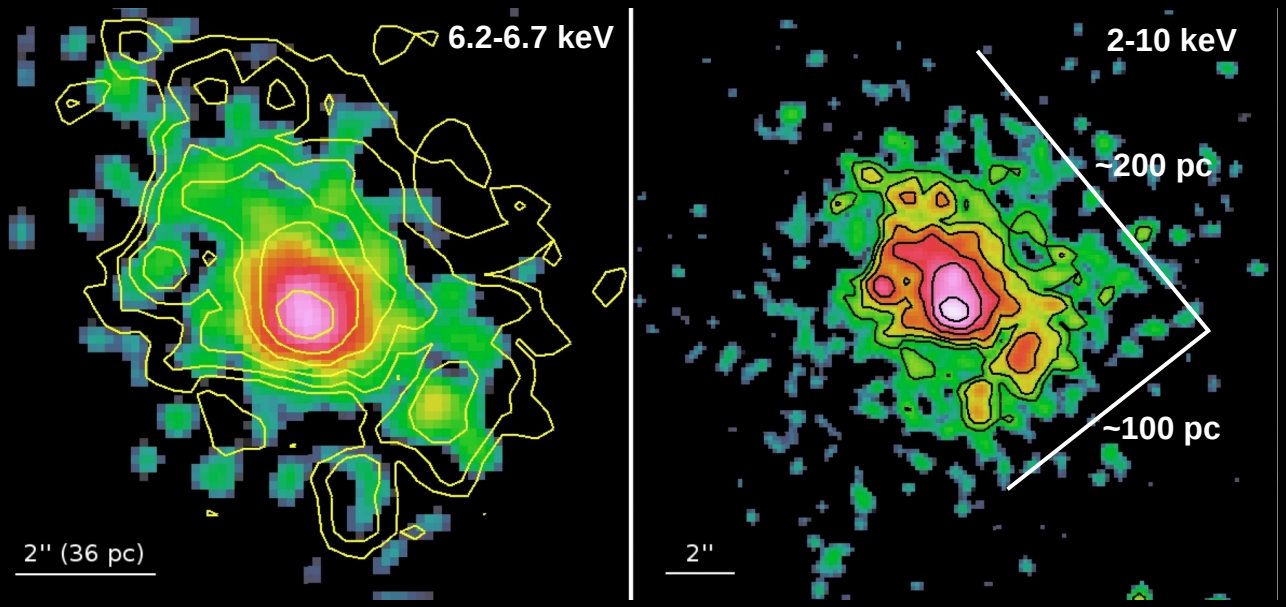
NuSTAR observations confirmed the very variable intrinsic continuum of the source and a constant emission below 10 keV.

Puccetti+14





Introduction

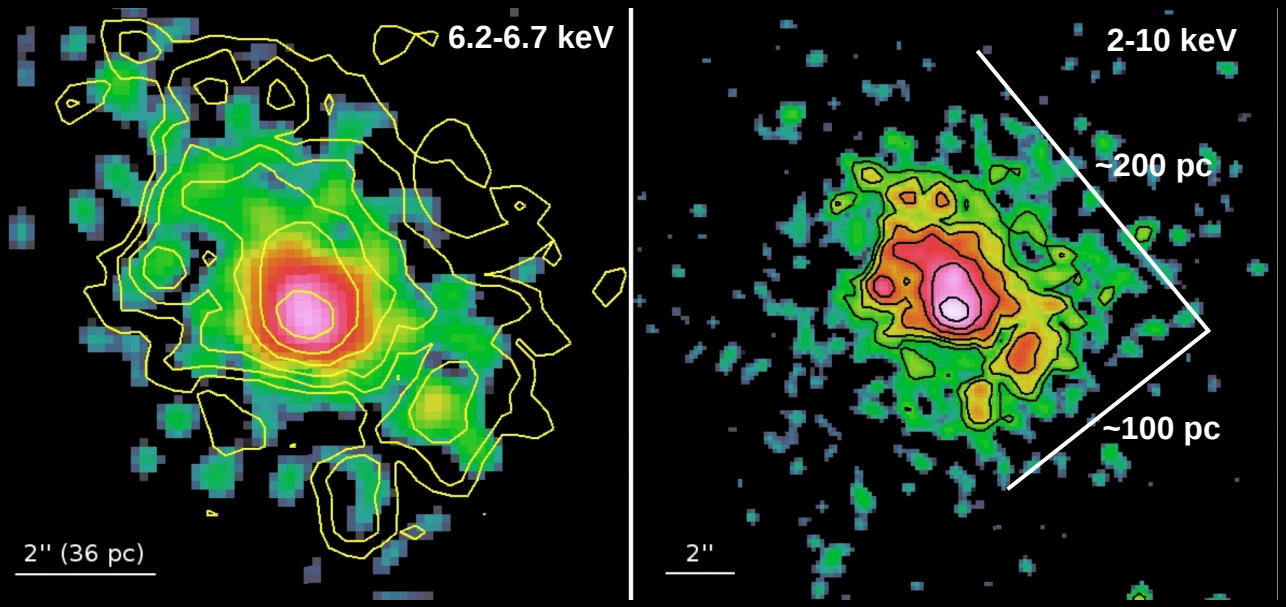


Marinucci+12

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

Comparing spectra taken with different instruments (and different extraction regions) on a time scale of ten years, the reprocessed emission is found constant within 4%.

Introduction



Marinucci+12

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

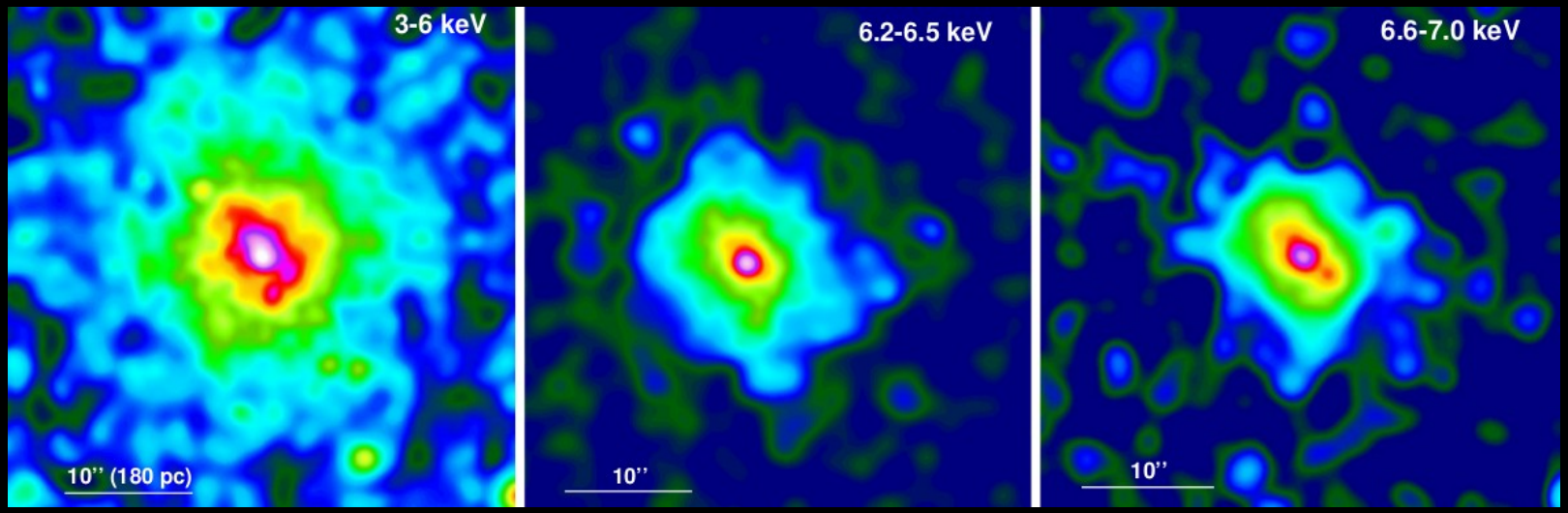
Comparing spectra taken with different instruments (and different extraction regions) on a time scale of ten years, the reprocessed emission is found constant within 4%.

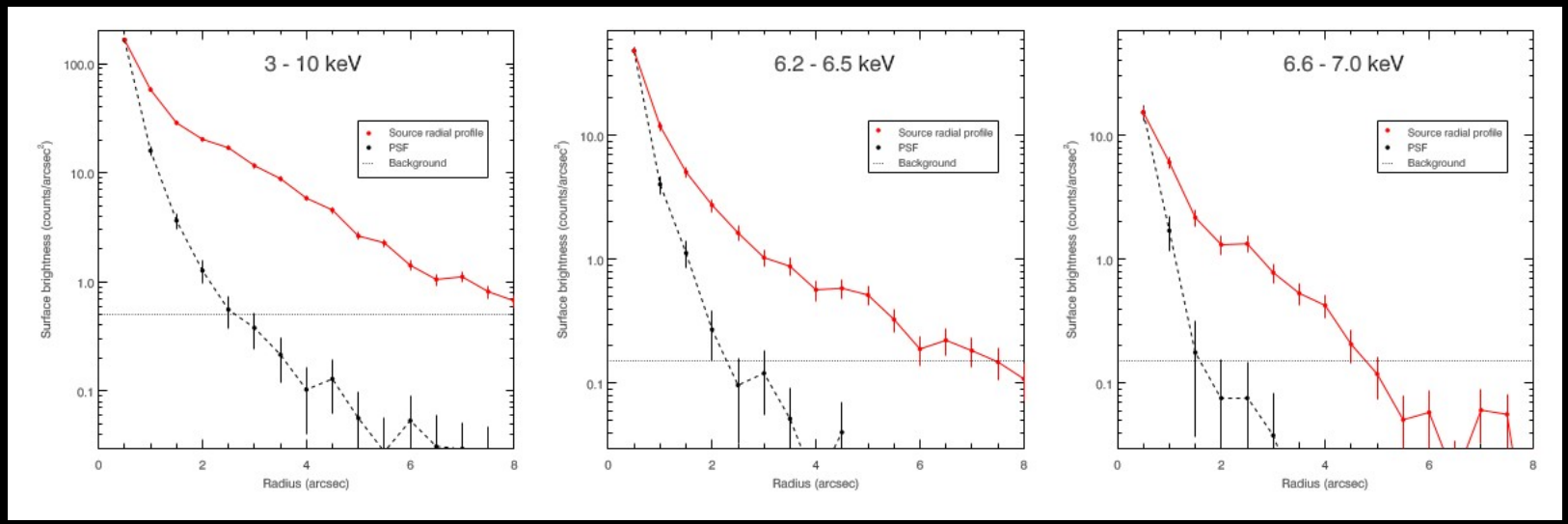
Obs. ID	Date	Exp. Time (ks)	HETG
864	2000-01-27	49.7	✗
4899	2004-05-28	78.6	✓
4900	2004-05-29	95.8	✓
14985	2013-04-20	68.7	✗
14984	2013-04-25	130.5	✗

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

Imaging analysis

When images in different energy bands are extracted from the combined event file, 420 ks long, a clump of ionized iron emerges on the south-west direction, 2.2" (~40 pc) from the nucleus.

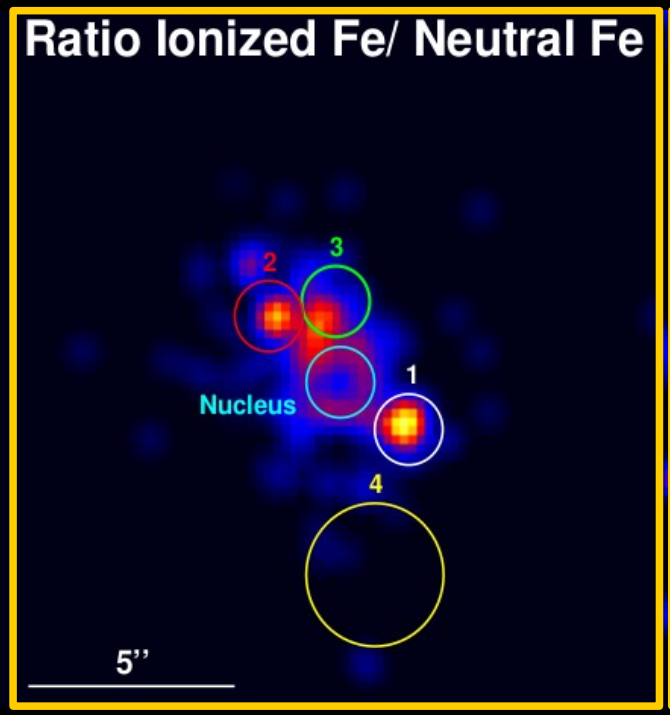


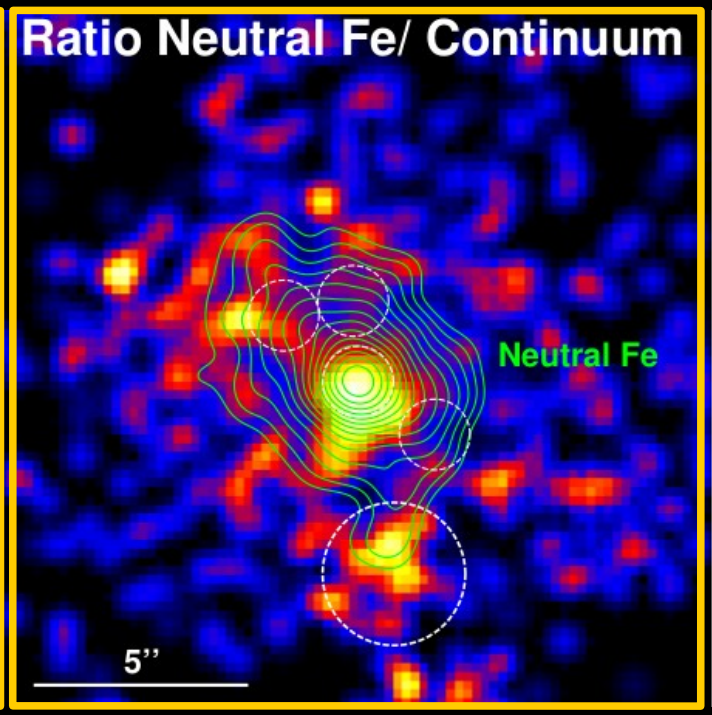


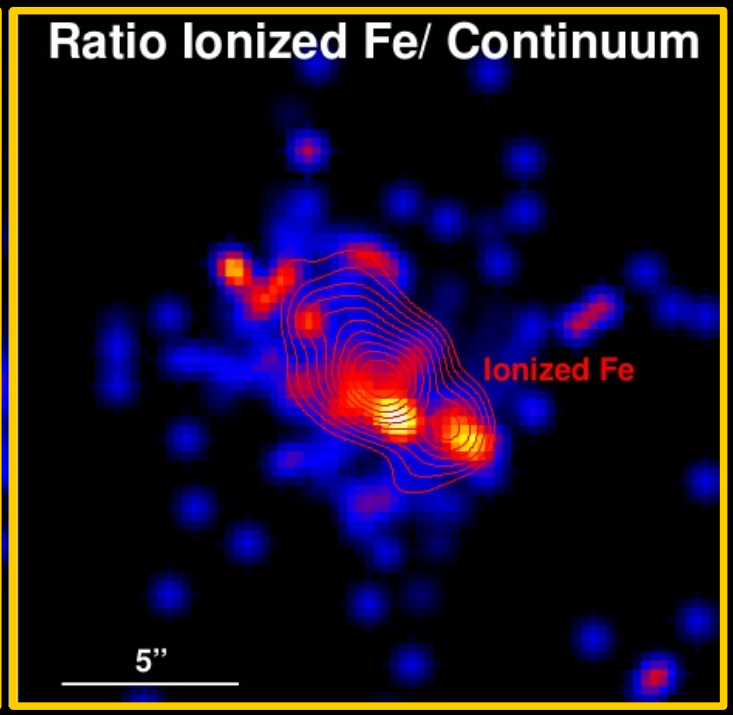
Marinucci et al., submitted

Imaging analysis

The ratios between the three images are proxies of the EW of the lines and can be helpful in choosing extraction regions.







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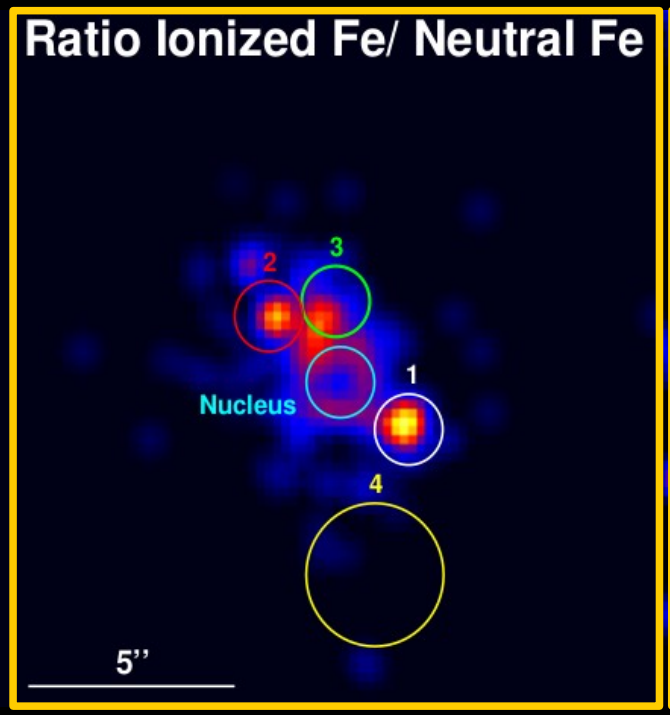
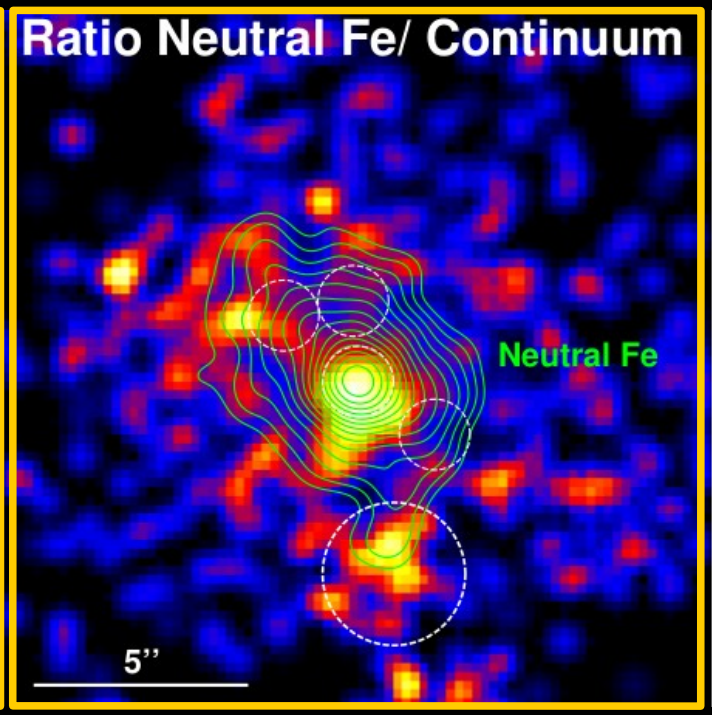
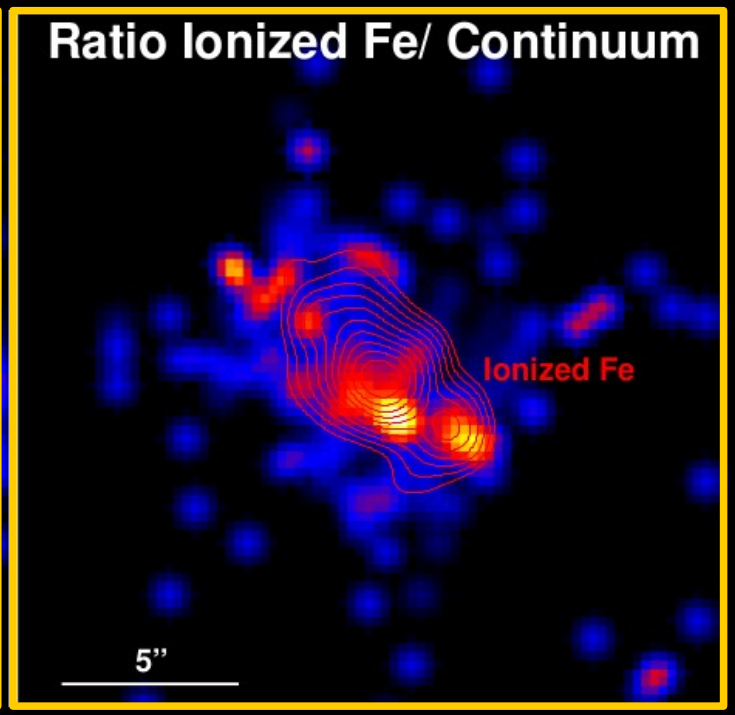


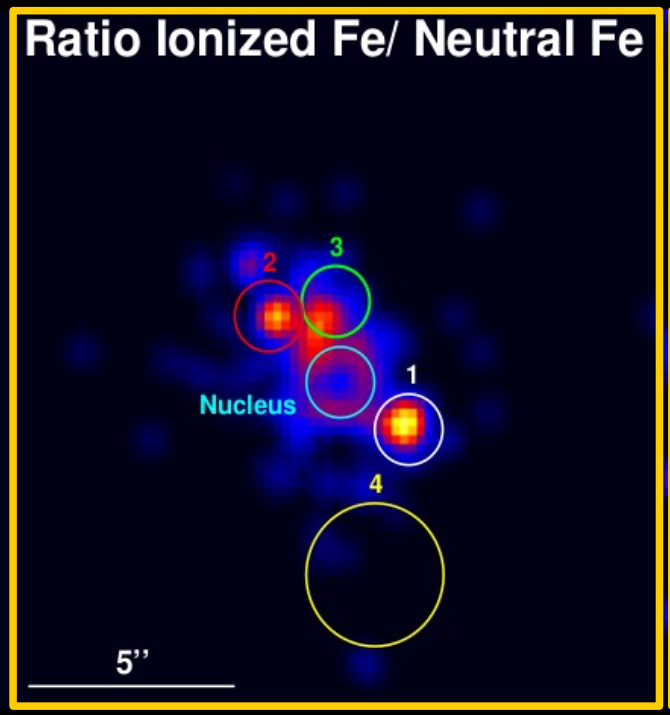


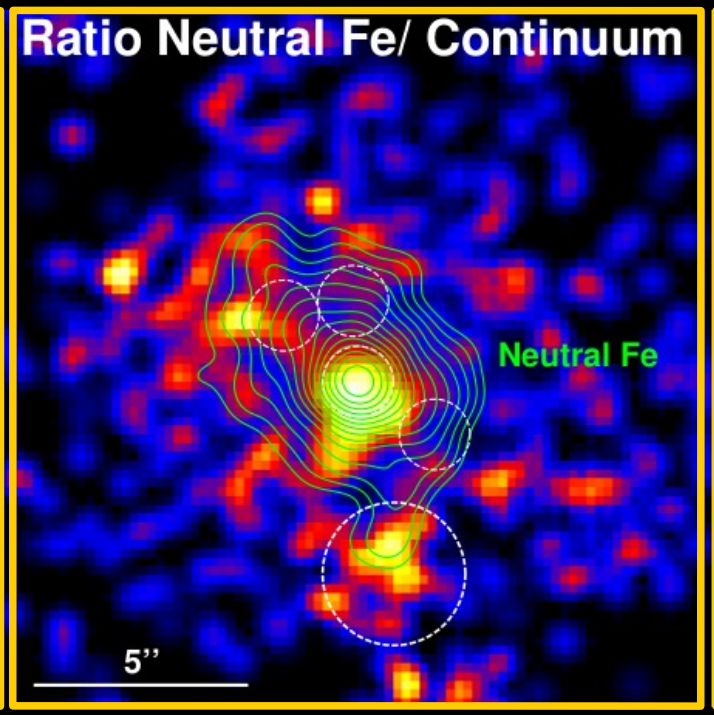


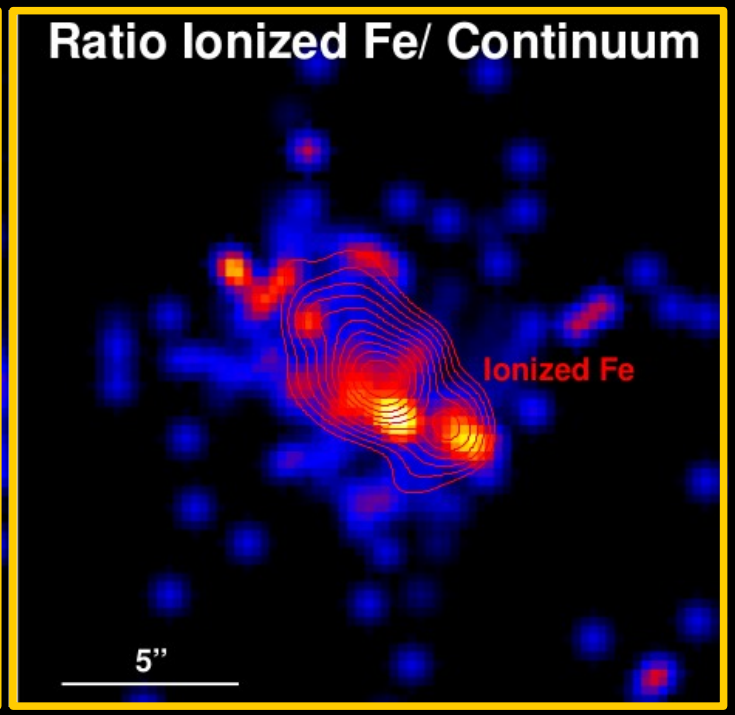
Obs. ID	3–10 keV Counts				
	Extraction region				
	1	2	3	4	Nucleus
864	361	303	460	148	359
14984					1029
14985					588
4899	116	138	163	46	370
4900					424

Imaging analysis

The ratios between the three images are proxies of the EW of the lines and can be helpful in choosing extraction regions.







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864	361	303	460	148	359
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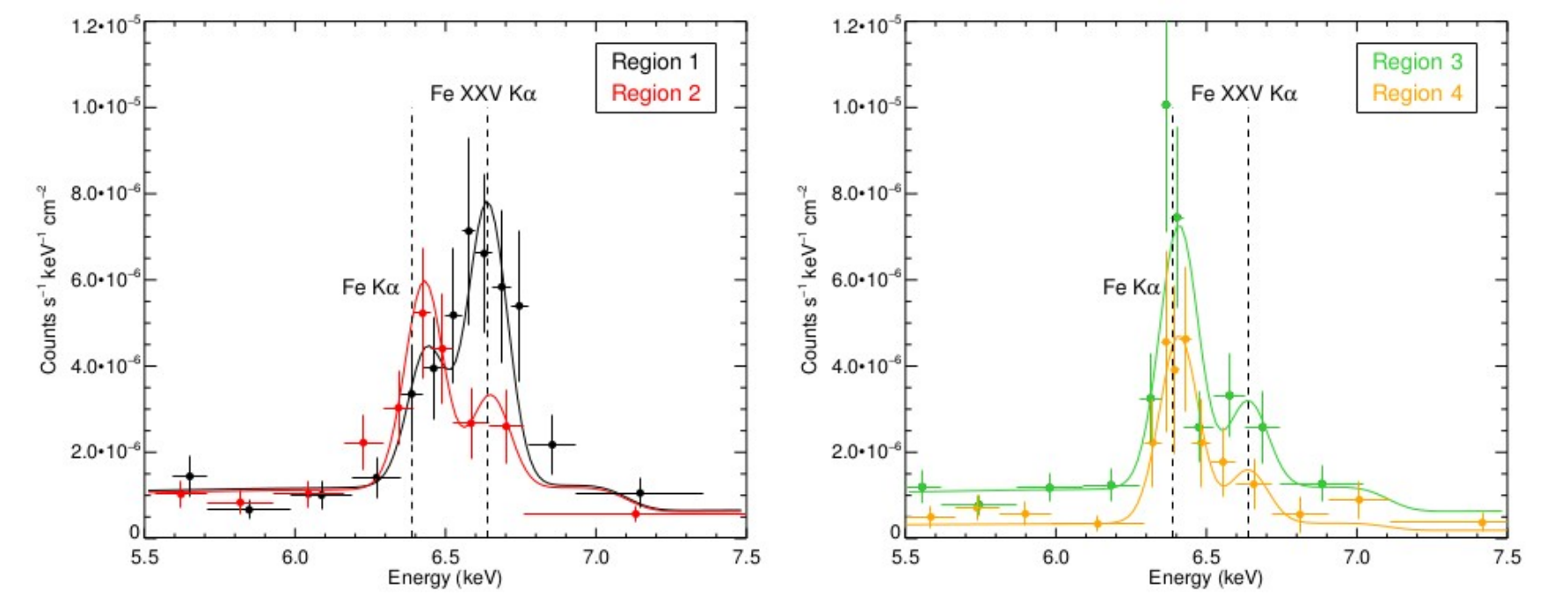
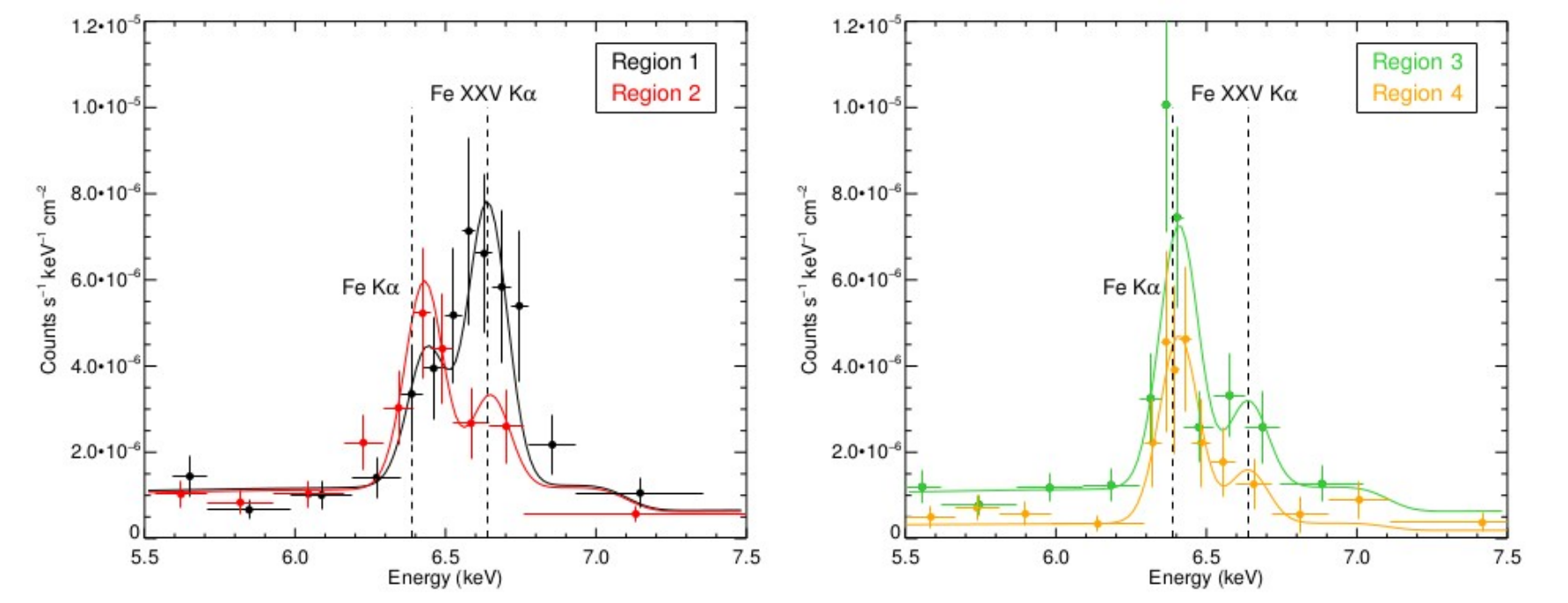
The unresolved, nuclear emission confirms to remain constant throughout the 13 years of monitoring.
The Equivalent Width of the neutral Fe Kα emission line is 2.7±0.5 keV.

Spectral analysis



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

Spectral analysis



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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

The variable Fe Kα EW

The Fe Kα EW, depends on the Fe abundance (Matt et al, 1997), on the angle θ i between the polar direction and the line of sight (Matt et al., 1991; George & Fabian, 1991) and on the column density of the illuminated material (Yaqoob et al. 2010, Matt 2002).

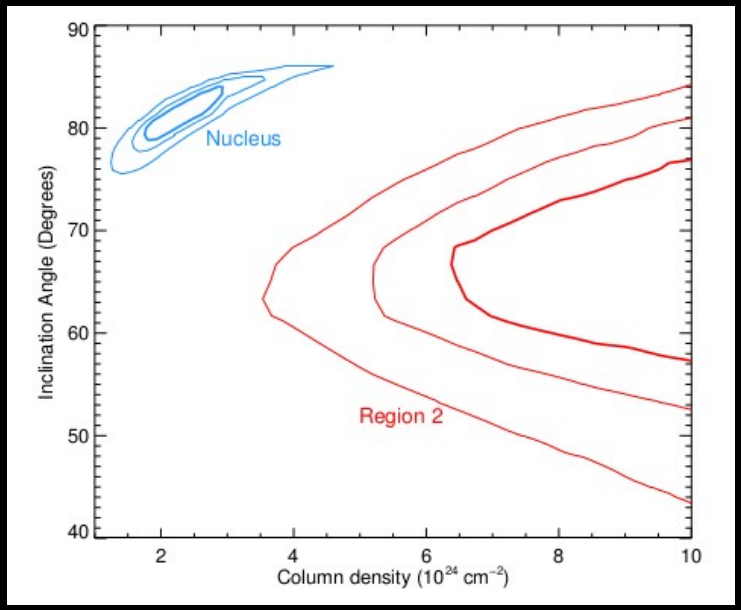
We therefore used different models to retrieve the observed EWs of the Fe Ka in the nuclear region (2.7±0.5 keV) and in region 2 (0.65±0.30 keV).

Pexmon

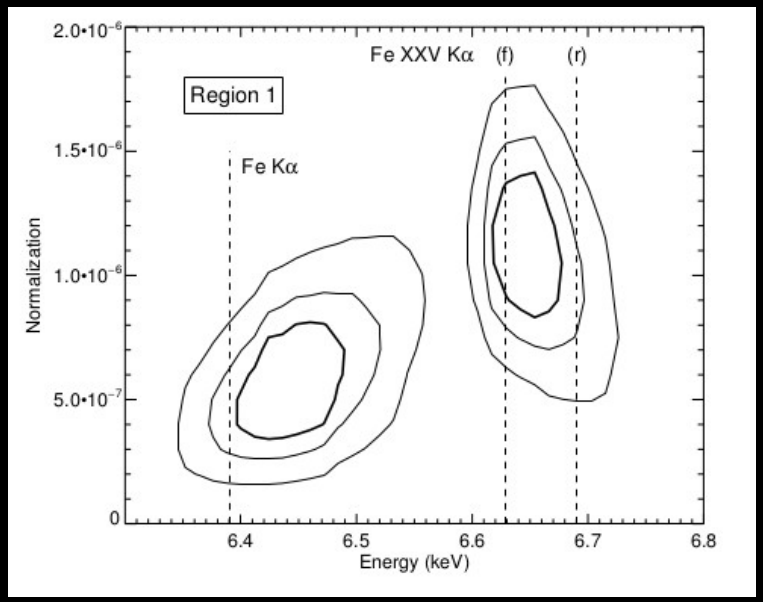
A_{fe}(Nucleus)=3.2±0.4

A_{fe}(Region 2)=0.8±0.5

MYtorus



The Fe XXV Kα clump (a.k.a. region 1)



The energy centroid of the Fe xxv Kα, even though consistent with the resonant line at the 90% confidence level, suggests the predominance of the forbidden line within the triplet.

We can use these results to provide estimates on the gas parameters, such as its column density, the Fe abundance and the ionization state.

With the CLOUDY code we are able to model the spectrum from region 1 in terms of a self-consistent photoionization model and retrieve the best-fit parameters :

$\log U = 2.2 \pm 0.3$

$\log N_H > 23.5$

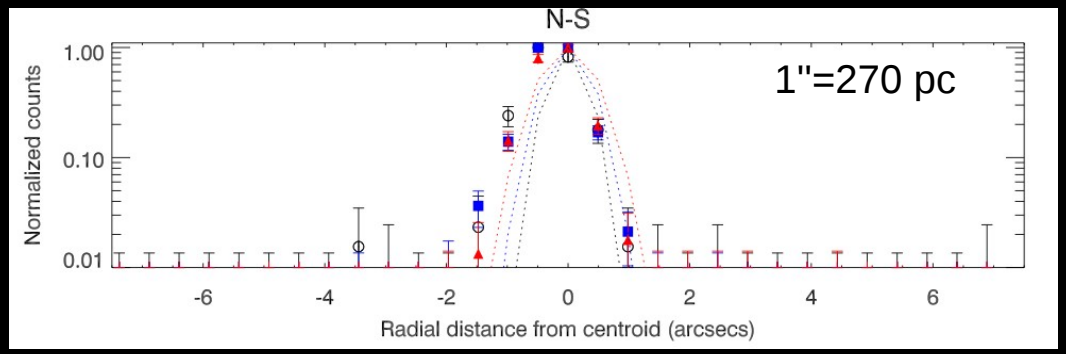
$A_{fe} > 3$

Using the inferred ionization parameter, the SED and L_{2-10} of NGC 4945, at a distance d=40 pc the clump has a density $n_{cl} = 10^2$ cm^{-3}.

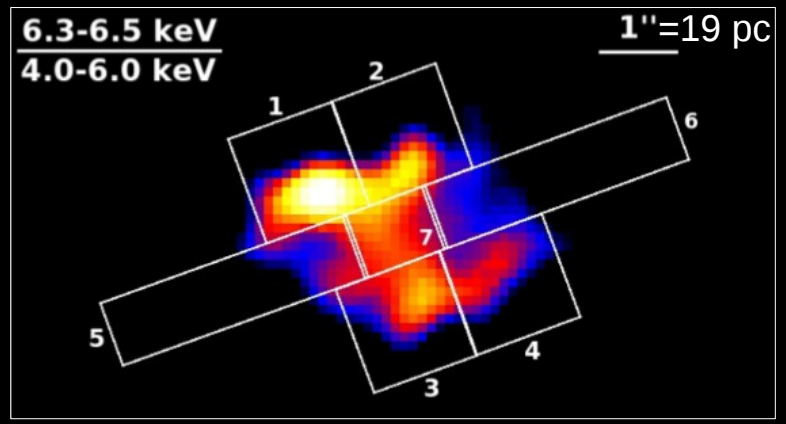
The Chandra view of nearby CT sources

Guainazzi+12

Mrk 3

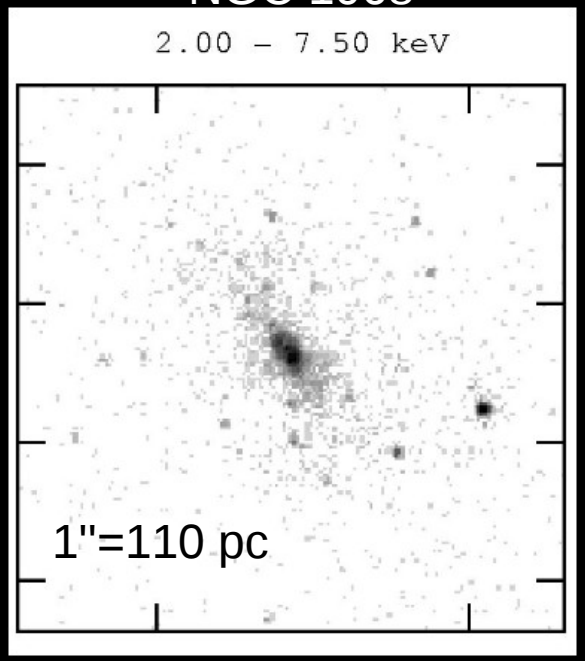


Circinus



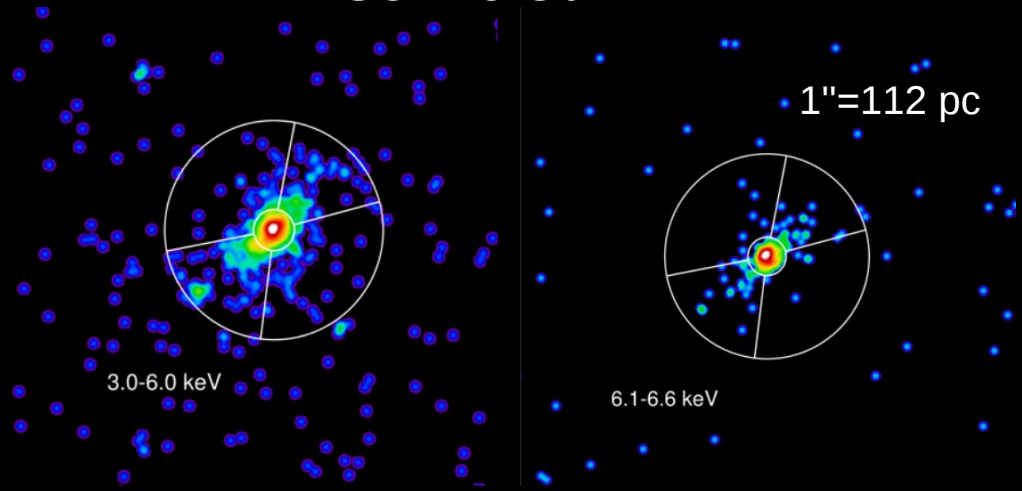
Marinucci+13

NGC 1068



Young+01

ESO 428-G014



Fabbiano+17

Conclusions

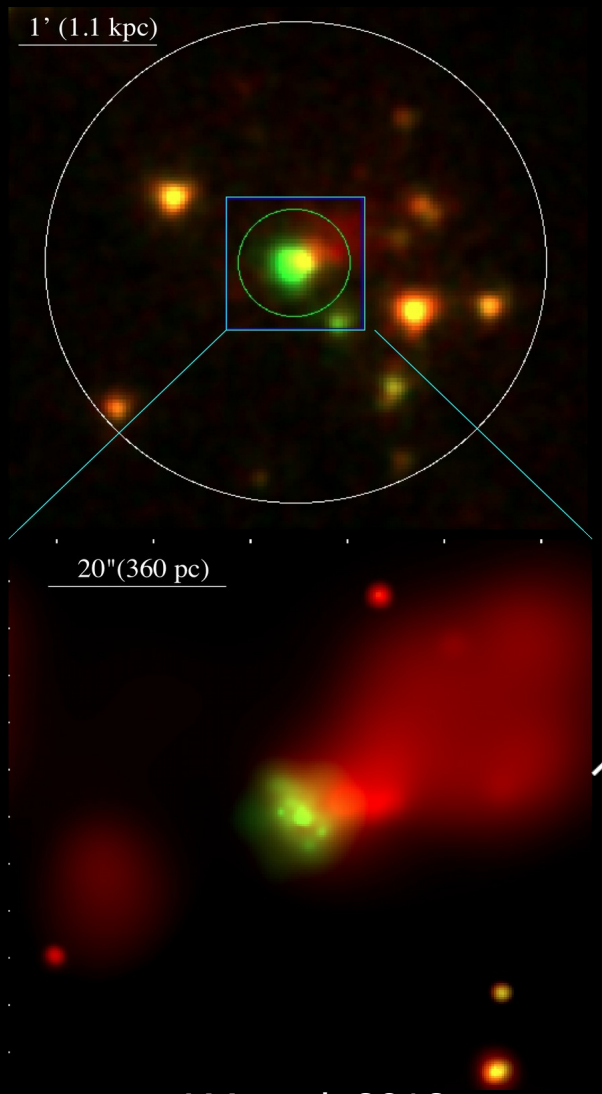
The additional 200 ks of data on NGC 4945 allowed us to study the extended Iron Kα emission and associated reflection continuum with much greater detail:

- the equivalent width of the Iron Kα line is found to be spatially variable

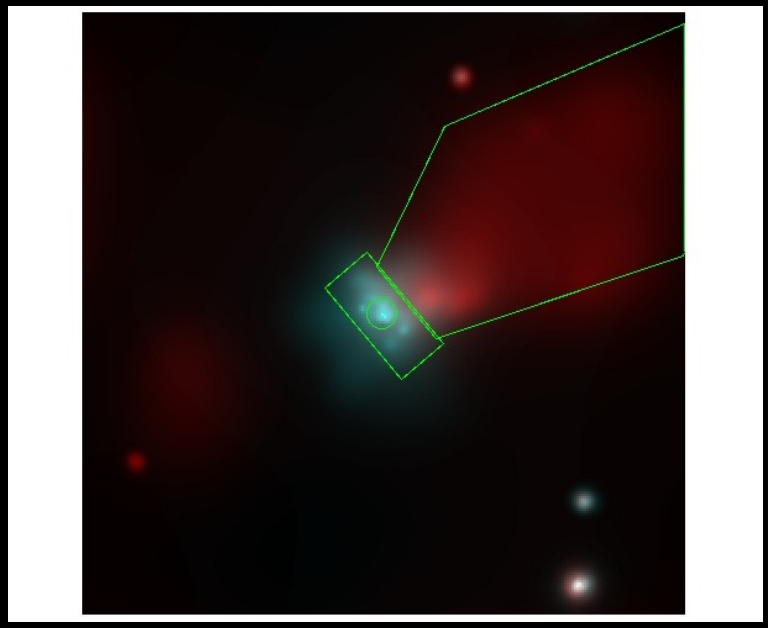
- a highly ionized Iron emission in a very confined region, about 40 pc distant from the nucleus, has been detected and spectrally characterised

Our findings support a physical environment around the nucleus which is not homogeneously distributed: the gas responsible for the reprocessing of the nuclear radiation is clumpy and extended around the central region, on scales of hundreds of parsecs.

Backup slides - 1



- Red=0.3-2.0 keV
  Green=2-10 keV

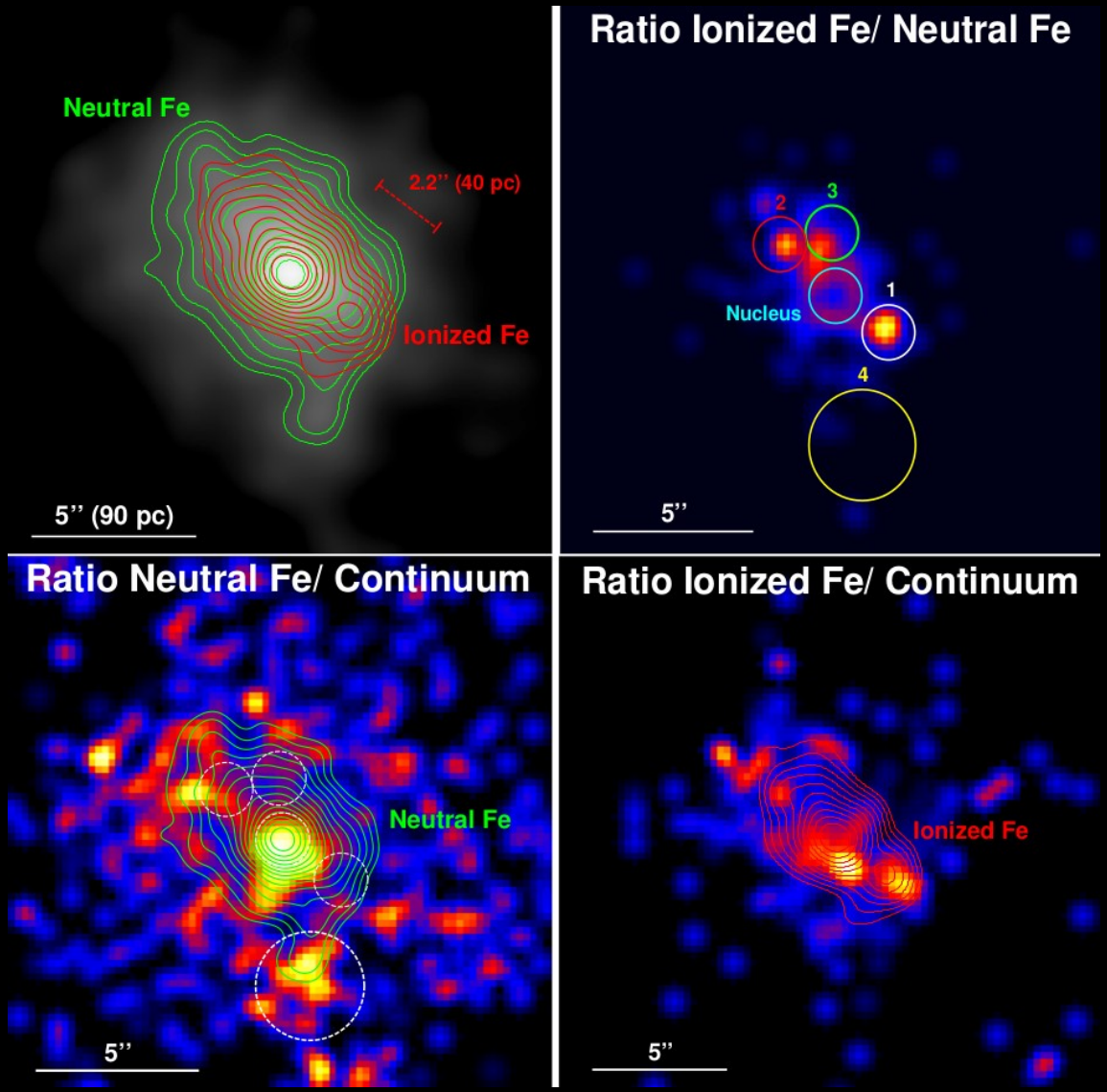


- AM et al, 2012

Extraction regions:

1)
2) 1.5" Nucleus
3) 12"x 6" Box
4) 2) – 1)
5) Soft emission cone
6)

Backup slides - 2



Backup slides - 3

Parameter	All-tied	Obs. 1	Obs. 2	Obs. 3	Obs. 4	Obs. 5
N_{pexrav}	1.55 ± 0.10	1.80 ± 0.20	1.90 ± 0.30	1.60 ± 0.20	1.40 ± 0.10	1.55 ± 0.15
Fe Kα						
Energy	6.414 ± 0.007	-	-	-	-	-
Flux	1.25 ± 0.10	$1.00^{+0.15}_{-0.25}$	1.20 ± 0.30	1.40 ± 0.30	$1.35^{+0.20}_{-0.15}$	1.40 ± 0.20
EW	2.7 ± 0.5	$1.9^{+0.5}_{-0.7}$	2.0 ± 0.6	3.0 ± 0.8	$3.2^{+0.6}_{-0.5}$	3.1 ± 0.7
Fe Kβ						
Energy	$7.09^{+0.03}_{-0.04}$	-	-	-	-	-
Flux	0.43 ± 0.07	0.20 ± 0.15	0.50 ± 0.20	0.40 ± 0.15	0.45 ± 0.10	0.50 ± 0.15
EW	1.1 ± 0.4	0.4 ± 0.3	1.1 ± 0.5	1.1 ± 0.5	1.3 ± 0.4	1.3 ± 0.5
Fe XXV Kα						
Energy	$6.68^{+0.01}_{-0.03}$	-	-		-	-
Flux	0.32 ± 0.05	0.20 ± 0.15	0.30 ± 0.20	< 0.40	0.30 ± 0.10	0.50 ± 0.15
EW	0.6 ± 0.3	0.4 ± 0.3	0.5 ± 0.3	< 0.8	0.6 ± 0.3	1.1 ± 0.3
Fe XXVI Kα						
Energy	6.966	-	-	-	-	-
Flux	0.12 ± 0.07	< 0.15	0.25 ± 0.15	< 0.30	0.20 ± 0.10	< 0.30
EW	0.3 ± 0.2	< 0.2	0.3 ± 0.2	< 0.7	0.4 ± 0.2	< 0.7
Compton Shoulder	$20 \pm 10\%$	$35^{+35}_{-20}\%$	$40^{+30}_{-20}\%$	$25 \pm 15\%$	$20 \pm 15\%$	$15^{+15}_{-10}\%$
$F_{3-10\ keV}$	-	4.7 ± 0.5	5.6 ± 0.6	5.0 ± 0.5	4.8 ± 0.5	5.1 ± 0.5

Table 3. Best fit parameters. A model composed of pure reflection and five emission lines is applied to the spectra extracted from the central regions, dashes indicate fixed parameters. The PEXRAV normalization is in 10^{-3} photons/keV/cm^2/s at 1 keV, fluxes are in 10^{-5} photons/cm^2/s, equivalent widhts in keV and the Compton shoulder is calculated with respect to the narrow iron Kα core flux. Fluxes in the 3–10 keV band are in 10^{-13} erg/cm^2/s.