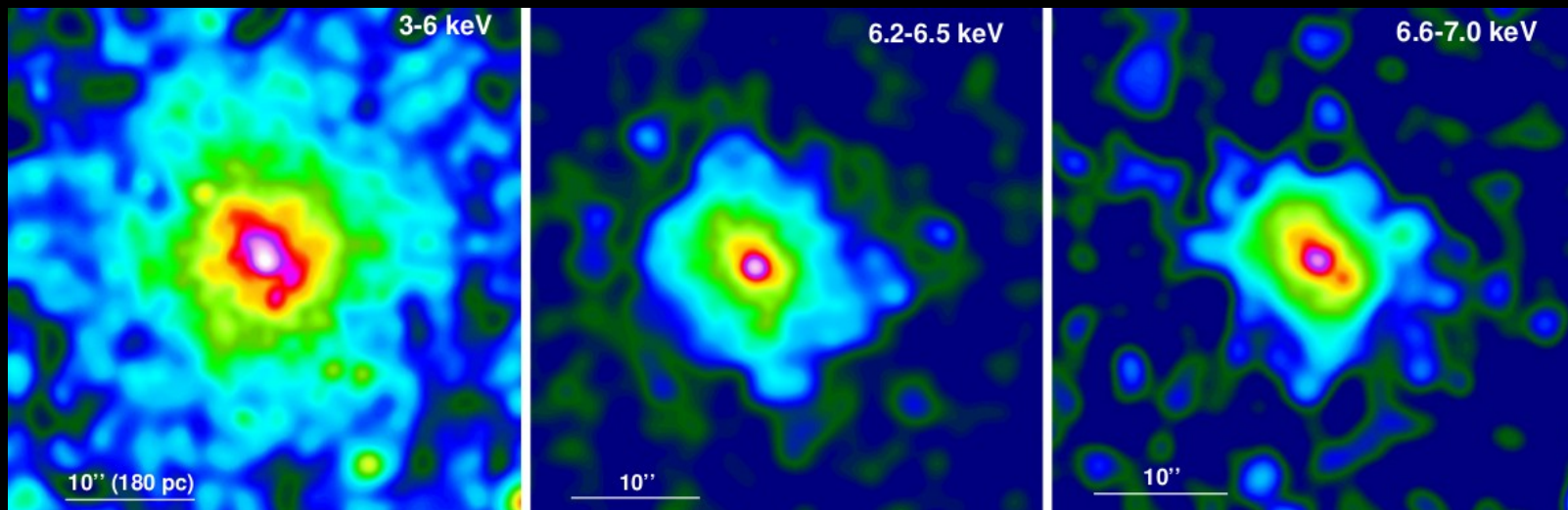# Spatially resolved spectroscopy of NGC 4945
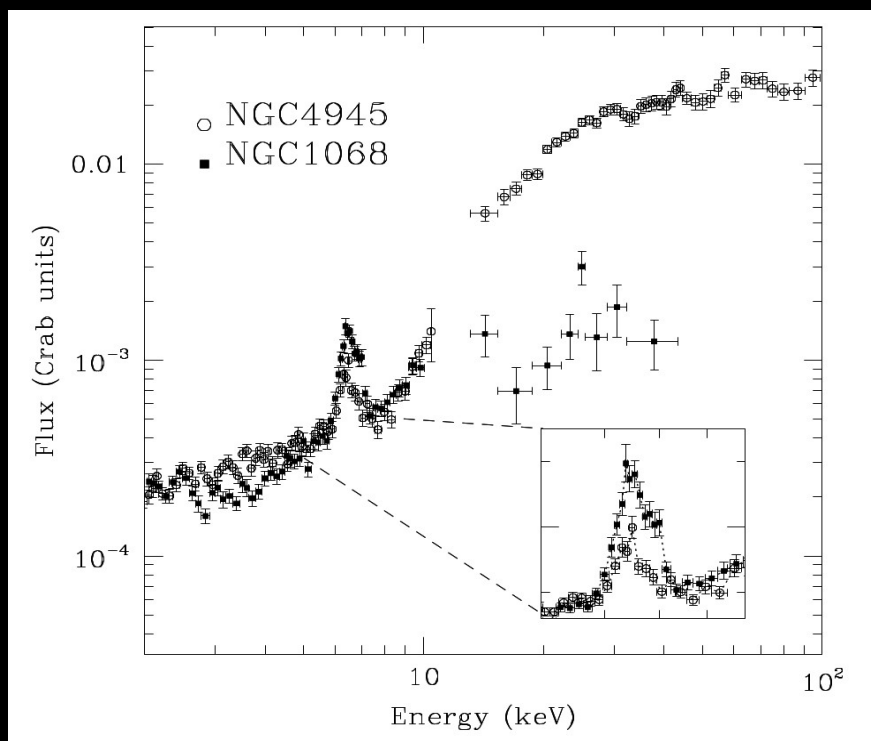

Andrea Marinucci

S. Bianchi, G. Fabbiano, G. Matt, G. Risaliti, E. Nardini, J. Wang
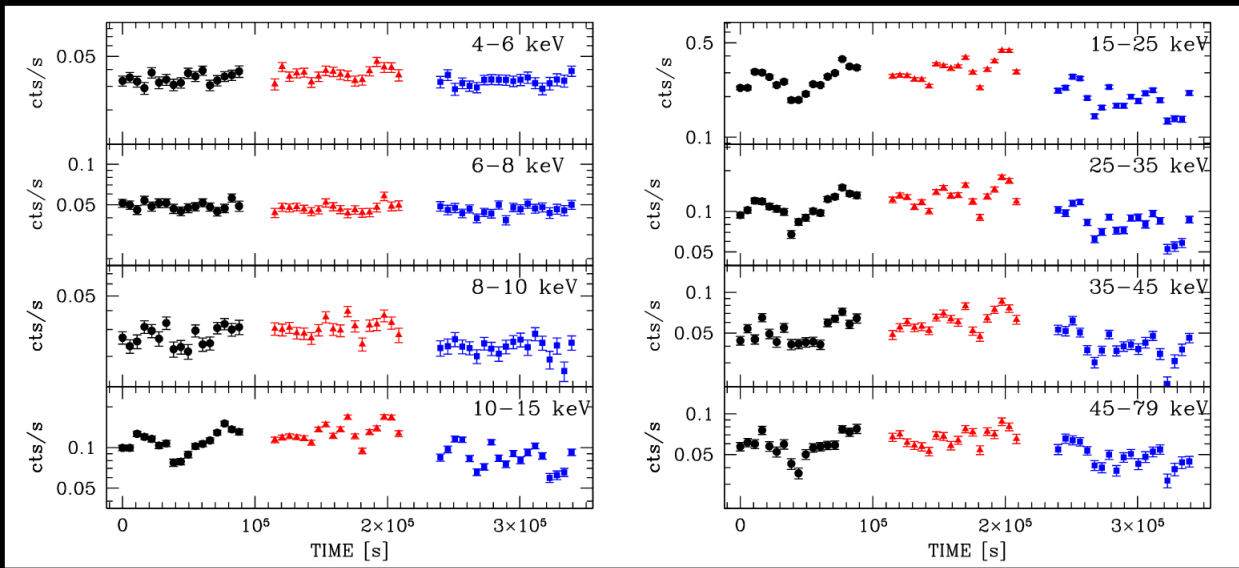
Introduction

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
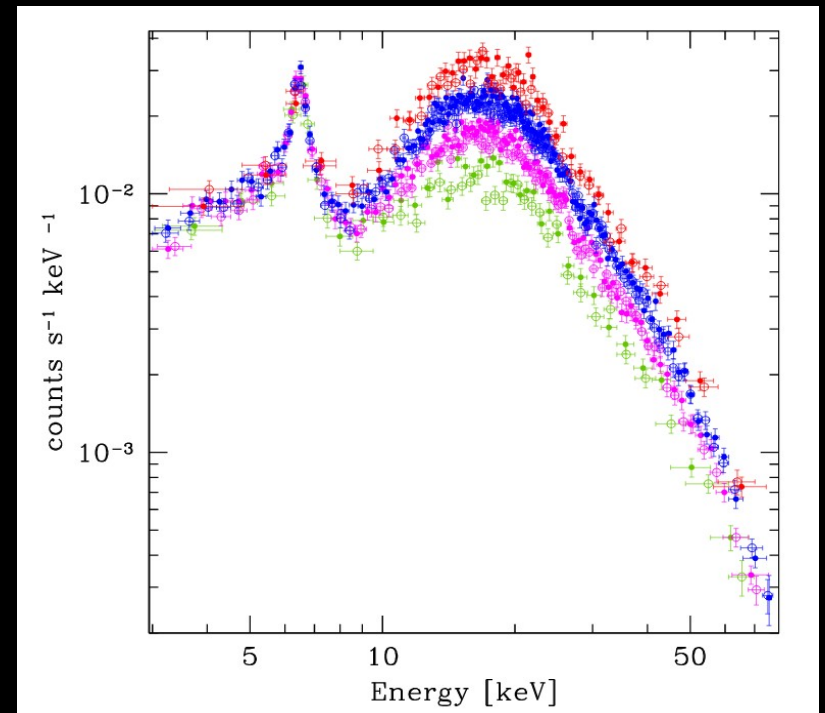of the 100 keV sky after NGC 4151 (Done et al, 1996)

Guainazzi+00

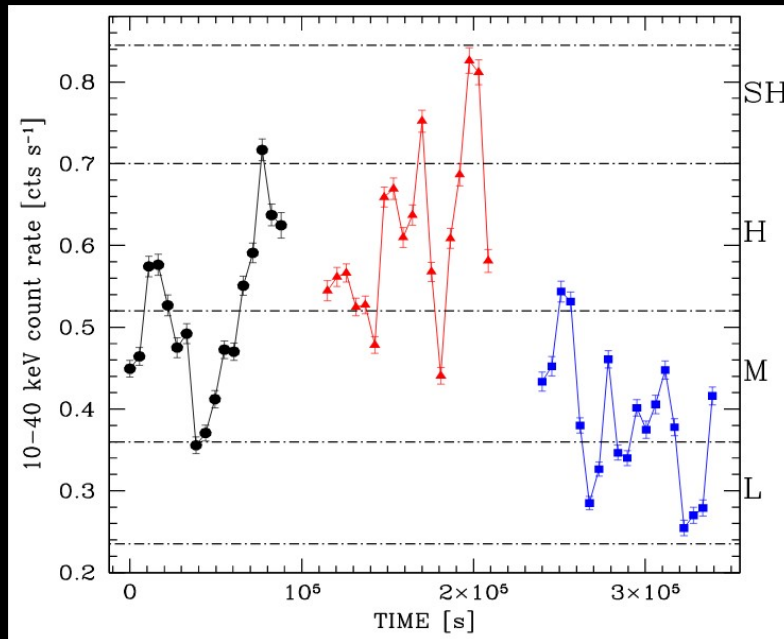Previous studies revealed the extreme absorbing column density of
$N_H \sim 4 \times 10^{24}$ cm^{-2} in the source.
It completely blocks the primary nuclear emission
below 8-10 keV and the nucleus can only be directly seen in higher
energy ranges (>10 keV).

Introduction

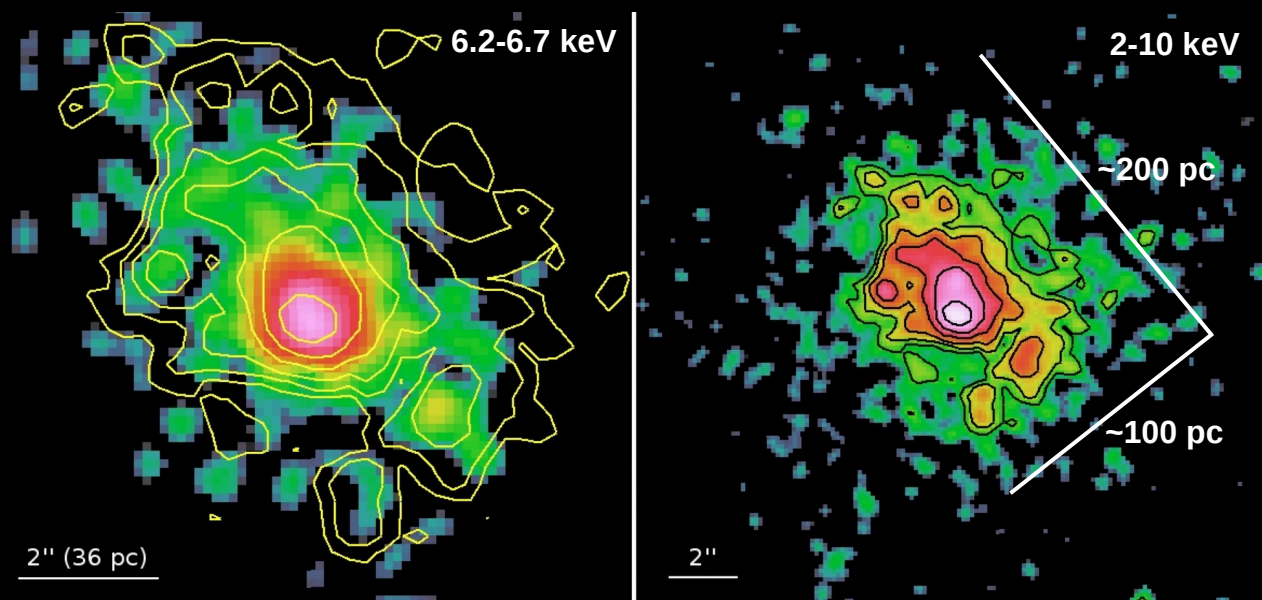Puccetti+14

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

Introduction

6.2-6.7 keV

2-10 keV

~200 pc
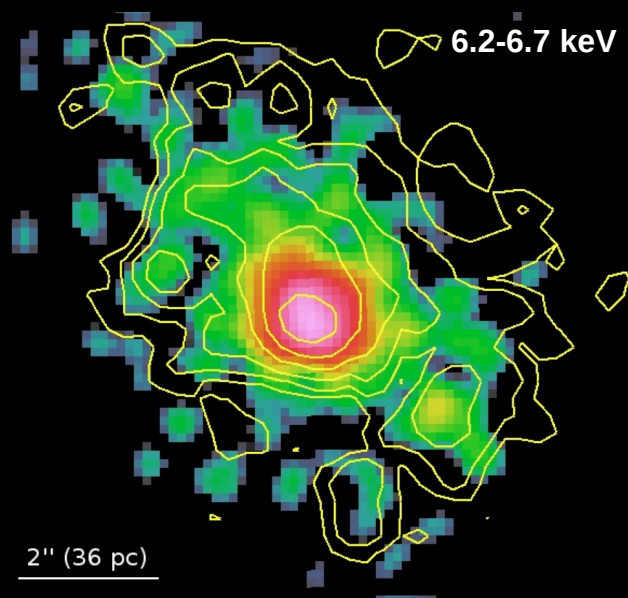
~100 pc

2'' (36 pc)

2''

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

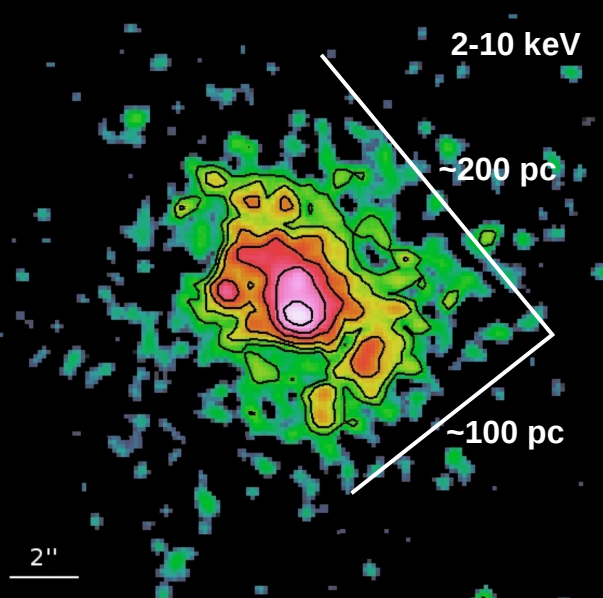6.2-6.7 keV

2-10 keV

~200 pc

~100 pc

2" (36 pc)

2"

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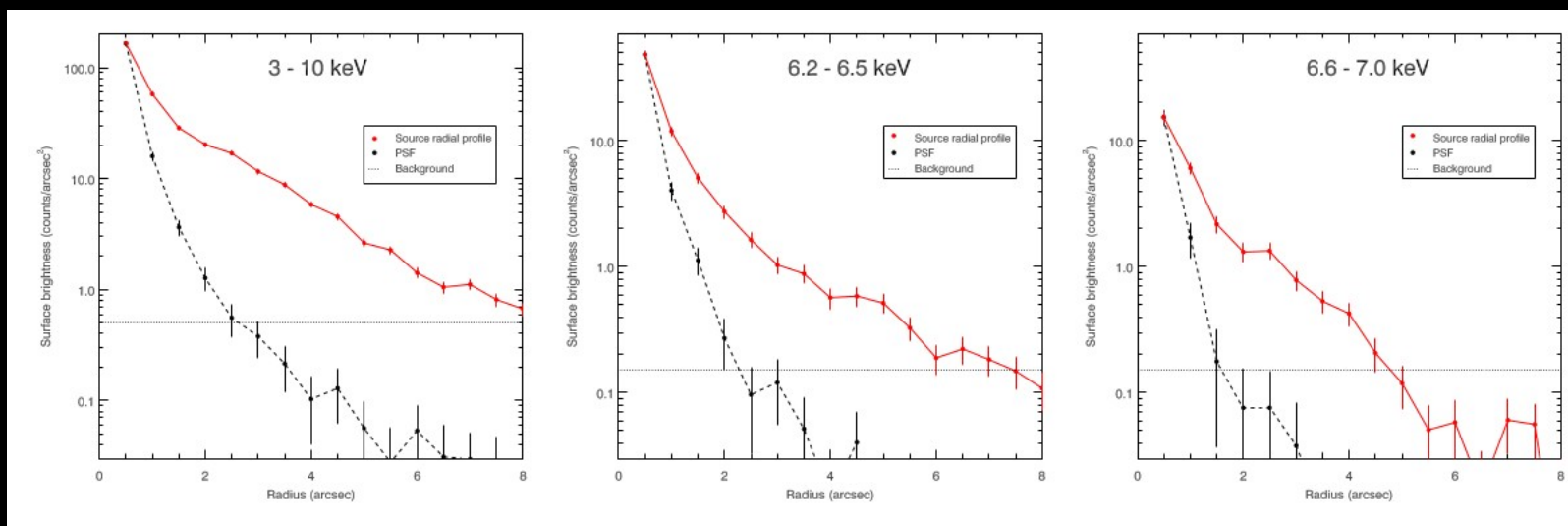
Comparing spectra taken with different instruments (and different extraction regions) on a time scale of ten years, the reprocessed emission is found constant within 4%.

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-east direction, 2.2" (~40 pc) from the nucleus.
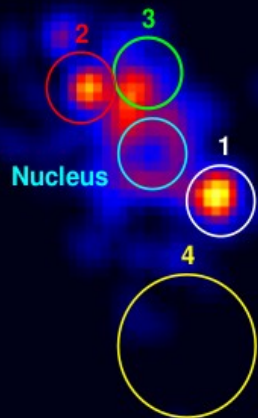
Imaging analysis

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

Imaging analysis

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and can be helpful in choosing extraction regions.

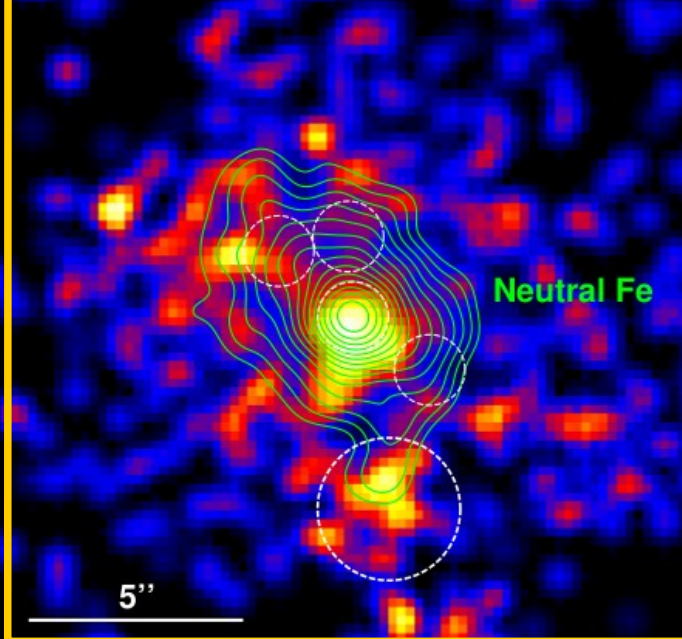| Obs. ID	3–10 keV Counts				
	Extraction region				
	1	2	3	4	Nucleus
864					359
14984	361	303	460	148	1029
14985					588
4899	116	138	163	46	370
4900					424

Imaging analysis

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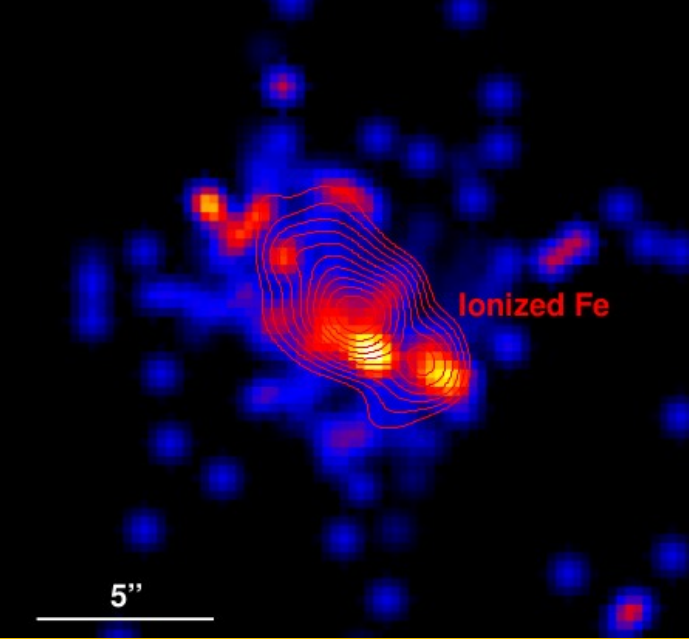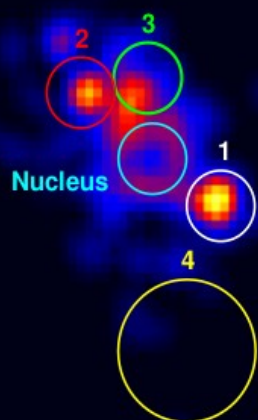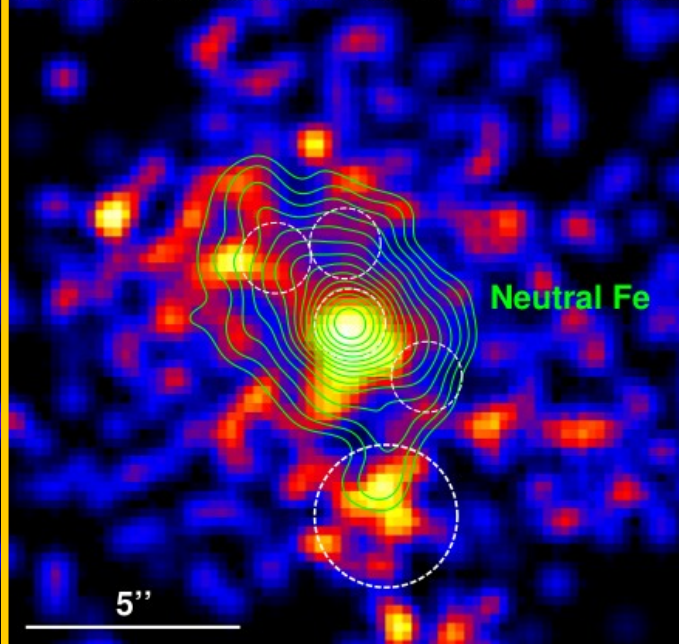and can be helpful in choosing extraction regions.

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.

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

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.	$37/51$	$65/40$	$28/38$	$26/31$

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	$6.40^{+0.02}_{-0.03}$
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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.	$37/51$	$65/40$	$28/38$	$26/31$

The variable Fe Kα EW

The Fe Kα EW, depends on the Fe abundance (Matt et al, 1997),
on the angle θ 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
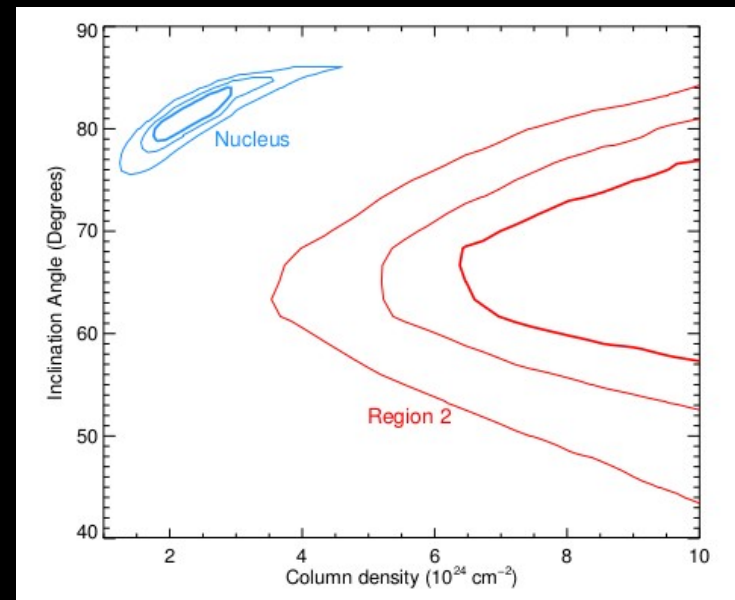(Yaqoob et al. 2010, Matt 2002).

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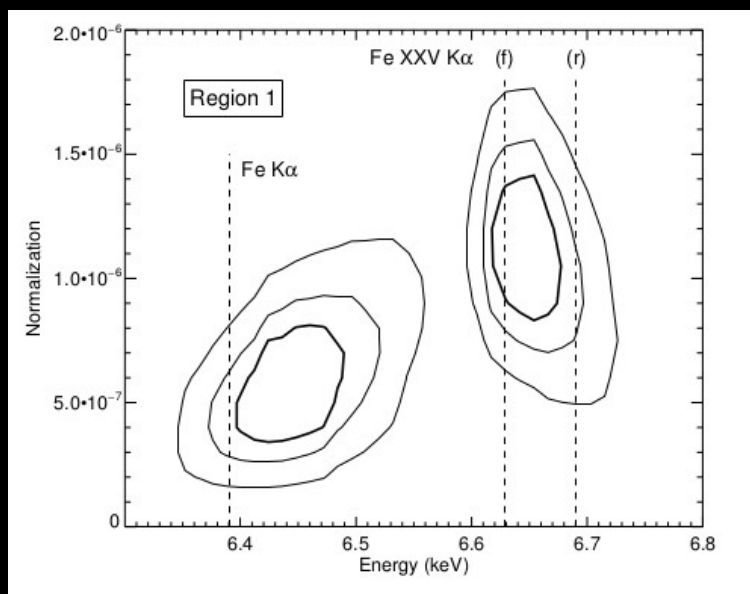nuclear region (2.7±0.5 keV) and in region 2 (0.65±0.30 keV).

Pexmon   MYtorus

A_{fe}(Nucleus)=3.2±0.4

A_{fe}(Region 2)=0.8±0.5

The Fe XXV Kα clump

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 :
$$logU=2.2±0.3$$
$$logN_H>23.5$$
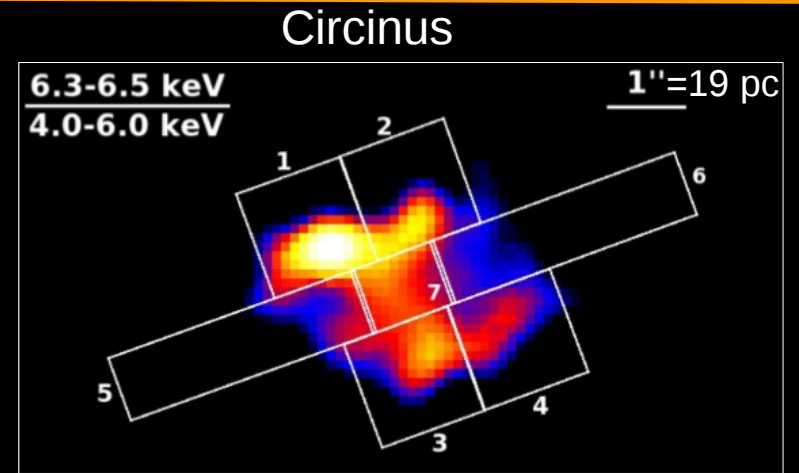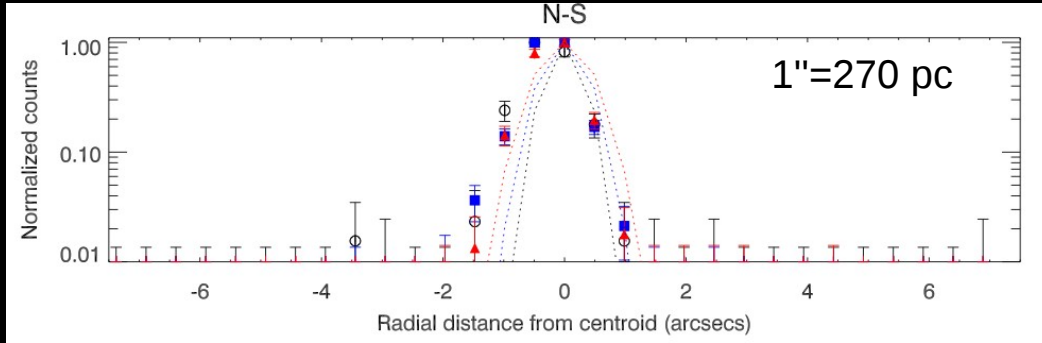$$A_{fe}>3$$
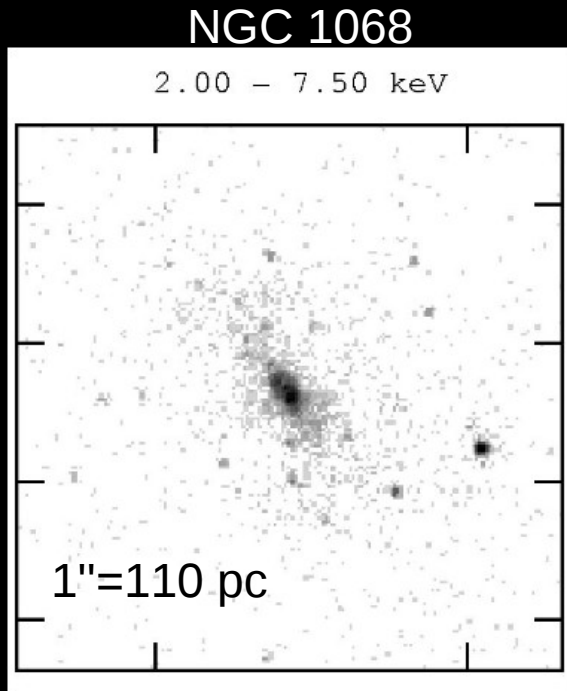Using the inferred ionization parameter, the SED and L_{2-10} of NGC 4945, at a distance
d=40 pc the clump has a density $n_{cl}=10^2$ cm^{-3}.

Guainazzi+12

Mrk 3

1"=270 pc

Circinus

Marinucci+13

NGC 1068

1"=110 pc

Young+01

ESO 428-G014

1"=112 pc

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.