The X-ray reflector in NGC 4945: a time and space resolved portrait

A. Marinucci[1] , G. Risaliti[2,3], J. Wang[2], E. Nardini[2], M. Elvis[2], G. Fabbiano[2], S. Bianchi[1] ,G. Matt[1]

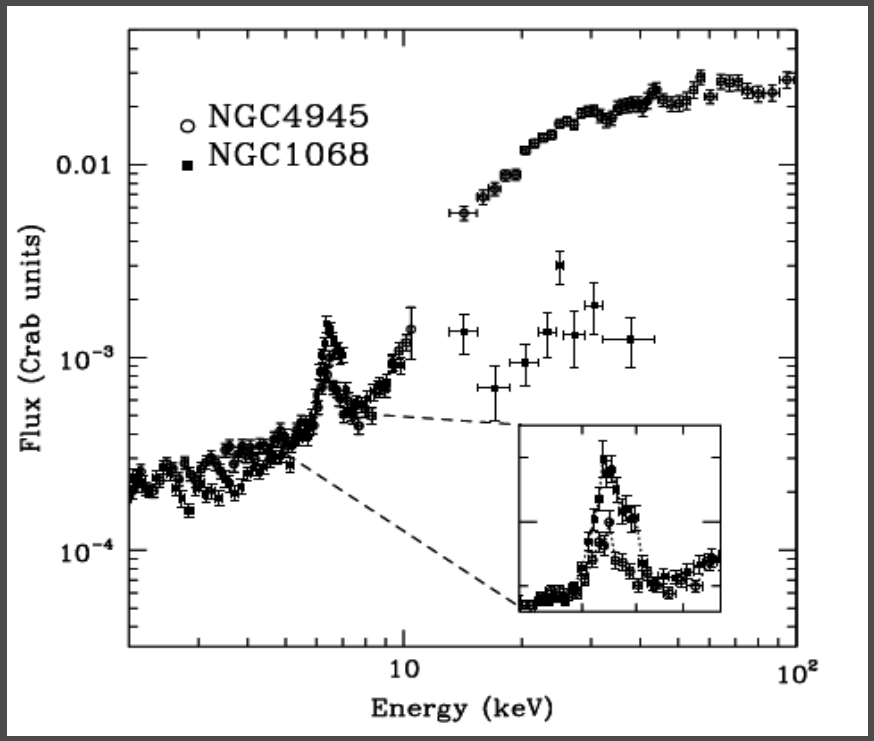
[1] Università degli Studi di Roma Tre, Rome, Italy

[2] Harvard-Smithsonian Center for Astrophysics, Cambridge MA, USA

[3] INAF - Osservatorio Astrofisico di Arcetri, Firenze, Italy

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 et al., 2000

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

NGC 4945 offers a unique possibility to perform a comparison between the variability of the intrinsic and the reflected X-ray emission, because it is the only know AGN with:

(a) Compton thickness τ_c>1 AND (b) a strong intrinsic variability above 10 keV

↓

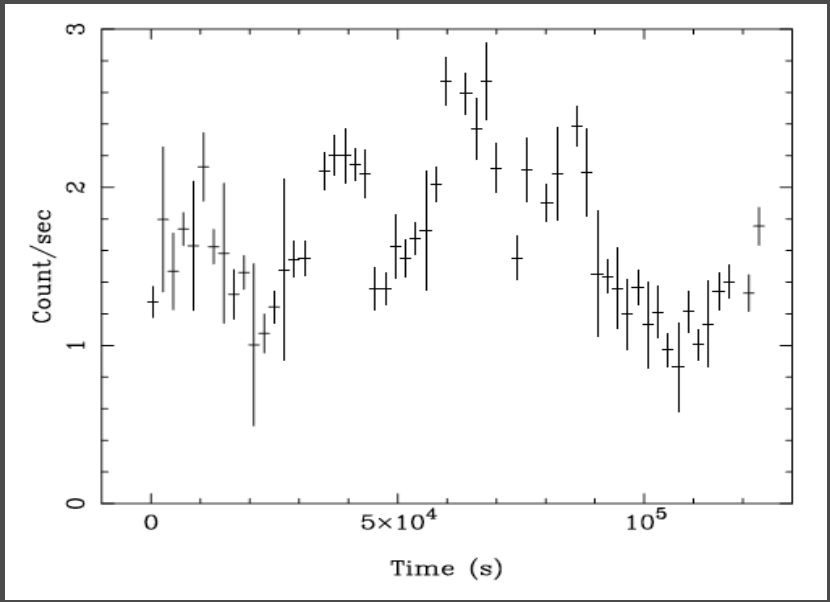
the Compton reflection component is diluted by the dominant direct component.

↓

NGC 1068 (N_H>10^{25} cm^{-2})
Circinus Galaxy (multiple Compton Scatterings)

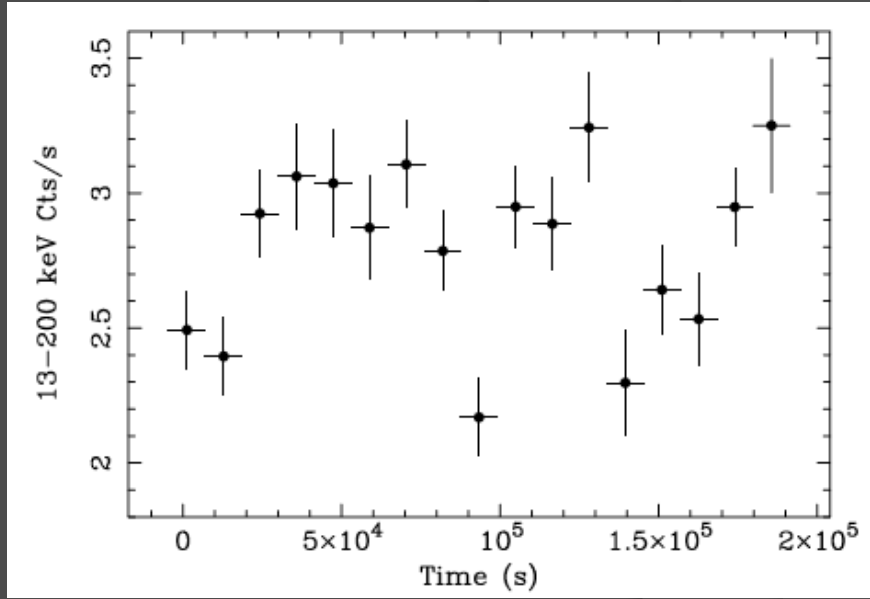
High energy variability

PCA 8–30 keV light curve (1 bin=4 ks)



Done et al., 2003

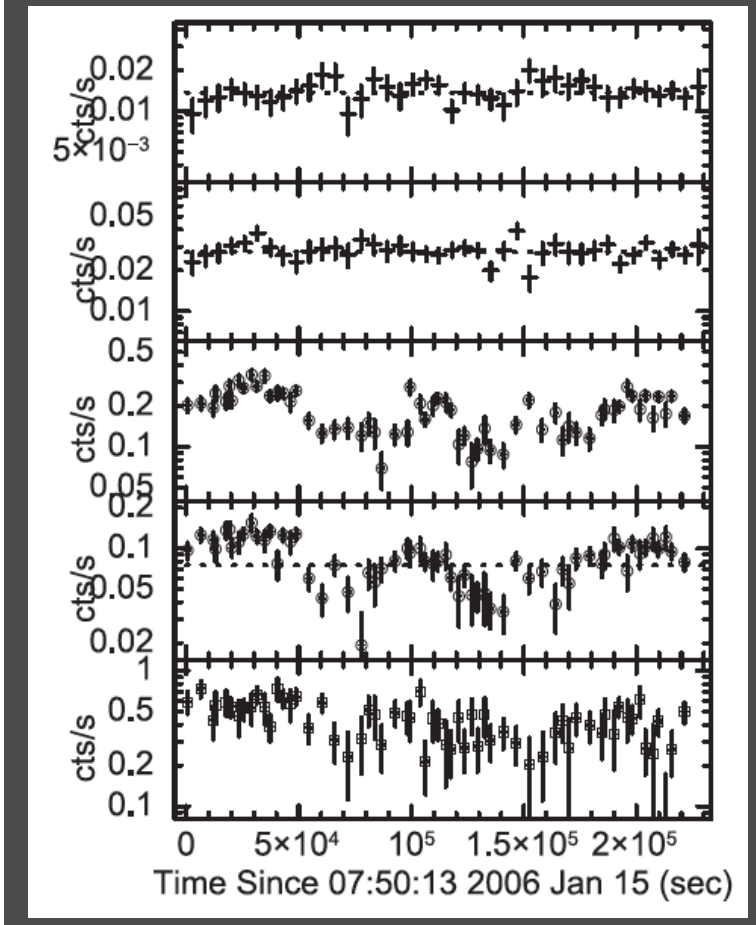
BeppoSAX light curve (1 bin=11 ks)



Guainazzi et al., 2000

The source shows a clear variation in the primary emission

First Suzaku observation in 2006



Itoh et al., 2008

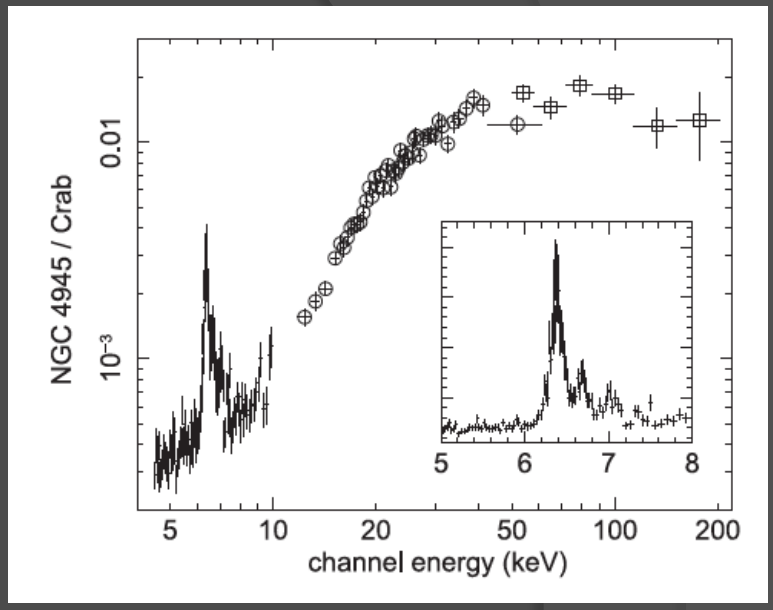
6.25–6.52 keV

6.50–9.00 keV

12–25 keV

25–50 keV

52–114 keV

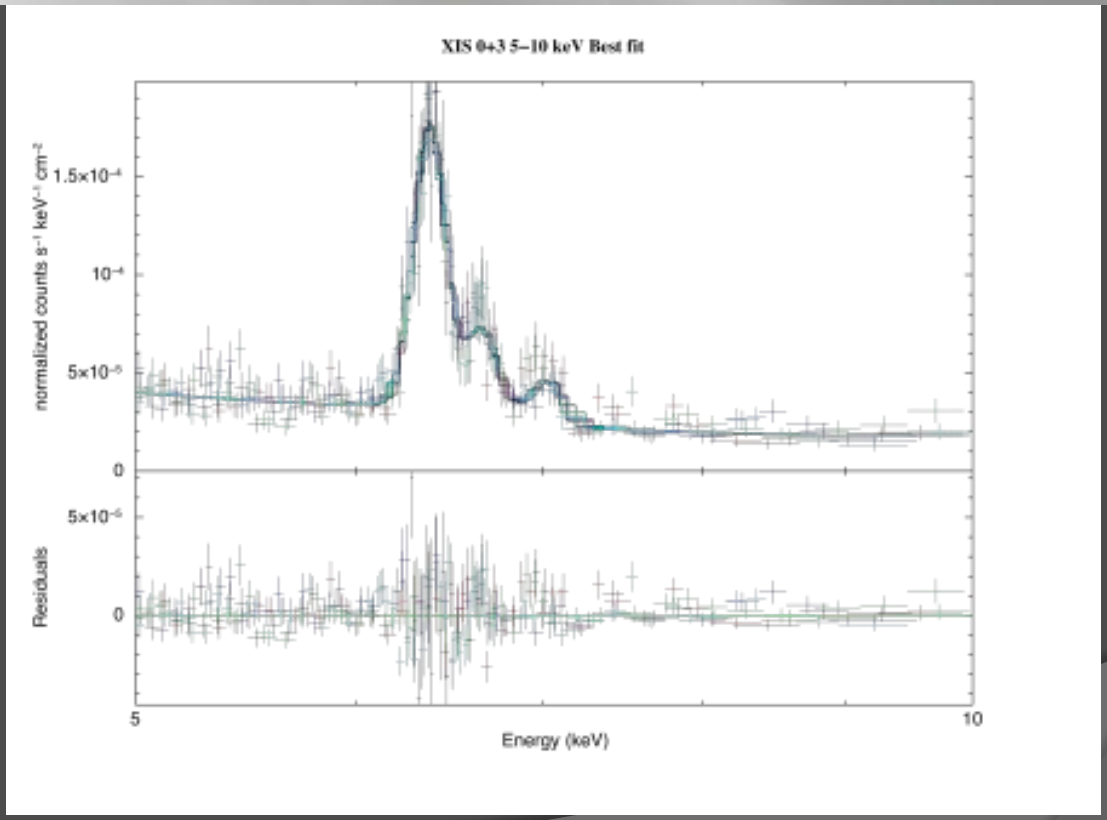


Itoh et al., 2008

230 ks observation
Excellent detection in the XIS, HXD-PIN, HXD-GSO
Variability in the high-energy spectrum was found

Our 2010-2011 Suzaku observational campaign

Five different 40 ks long snapshots to investigate variations
in the primary (>10keV, HXD-PIN, HXD-GSO) and
in the reflected continuum (< 10keV, XIS 0-1-3)

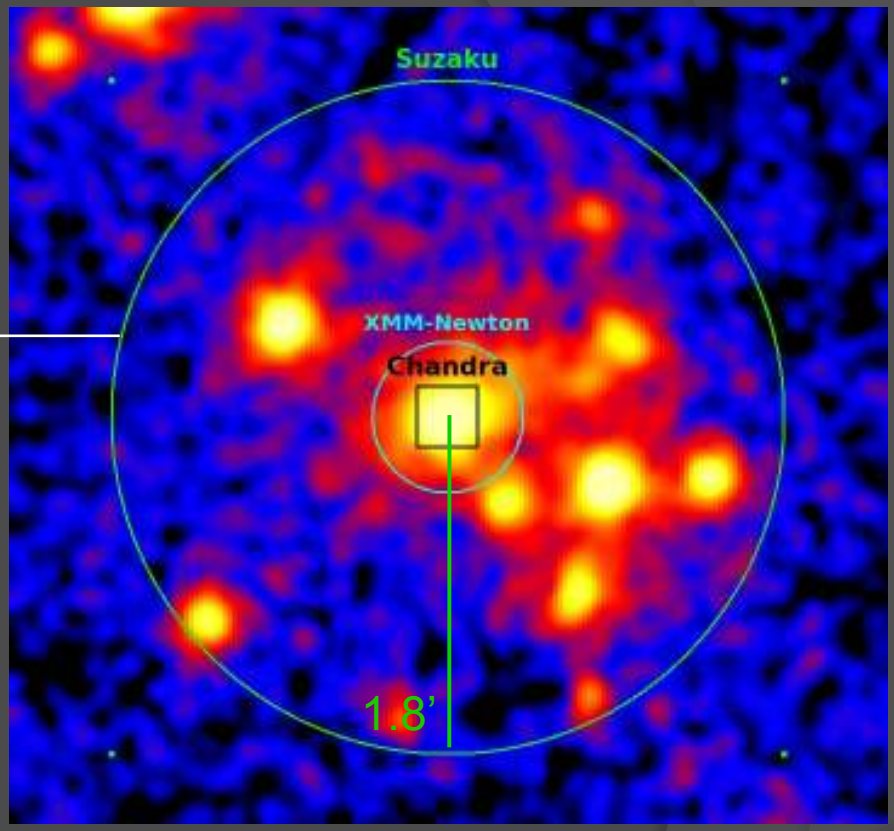


Our 2010-2011 Suzaku observational campaign

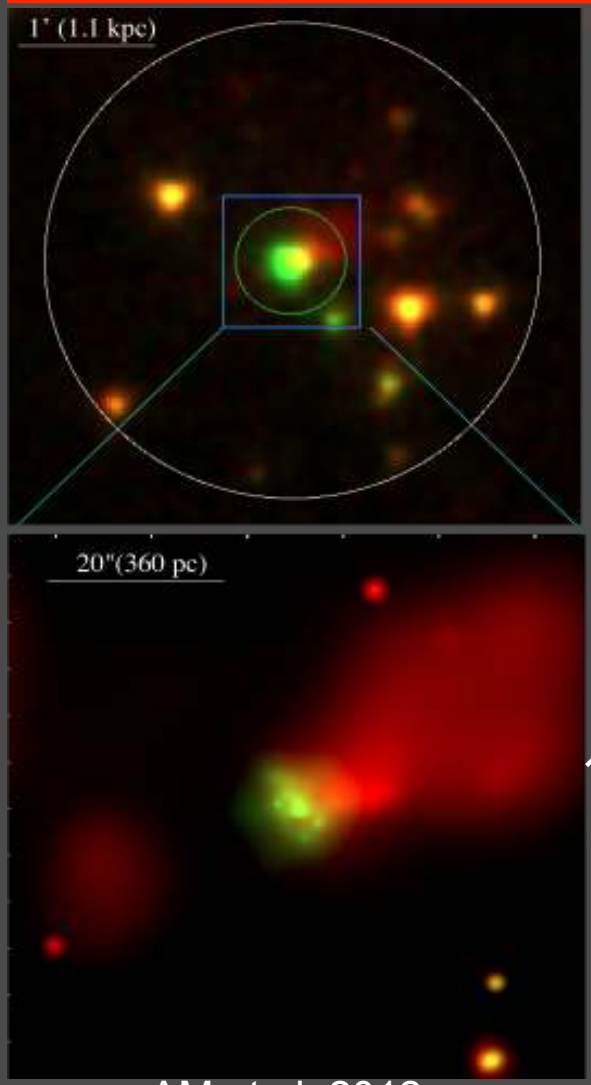
Unfortunately Suzaku alone is not enough to investigate the reflected emission accurately.

$L \sim 2 \times 10^{39}$ erg s^{-1} ←

We therefore used XMM-Newton and Chandra, performing a 10 years long study of the source in the 0.5-10.0 keV band.

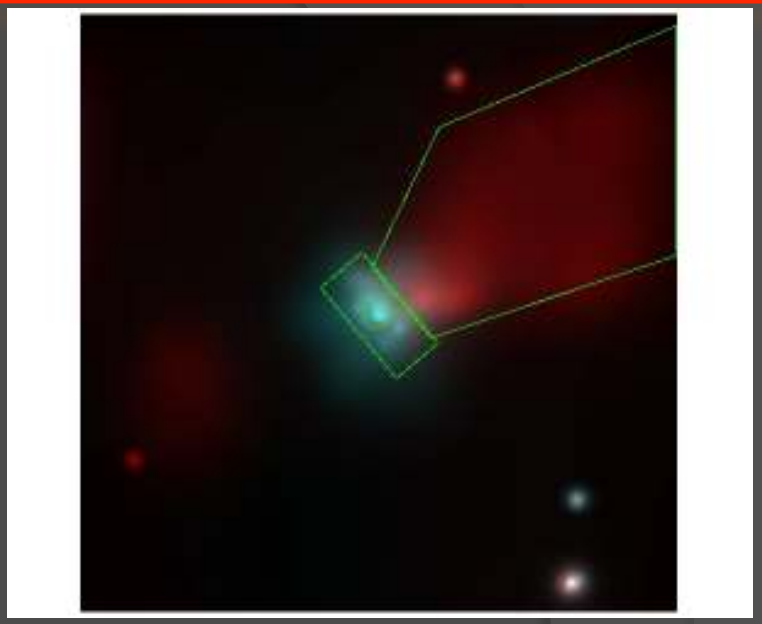


The geometry of the inner reflector: time and spectral variability



AM et al, 2012

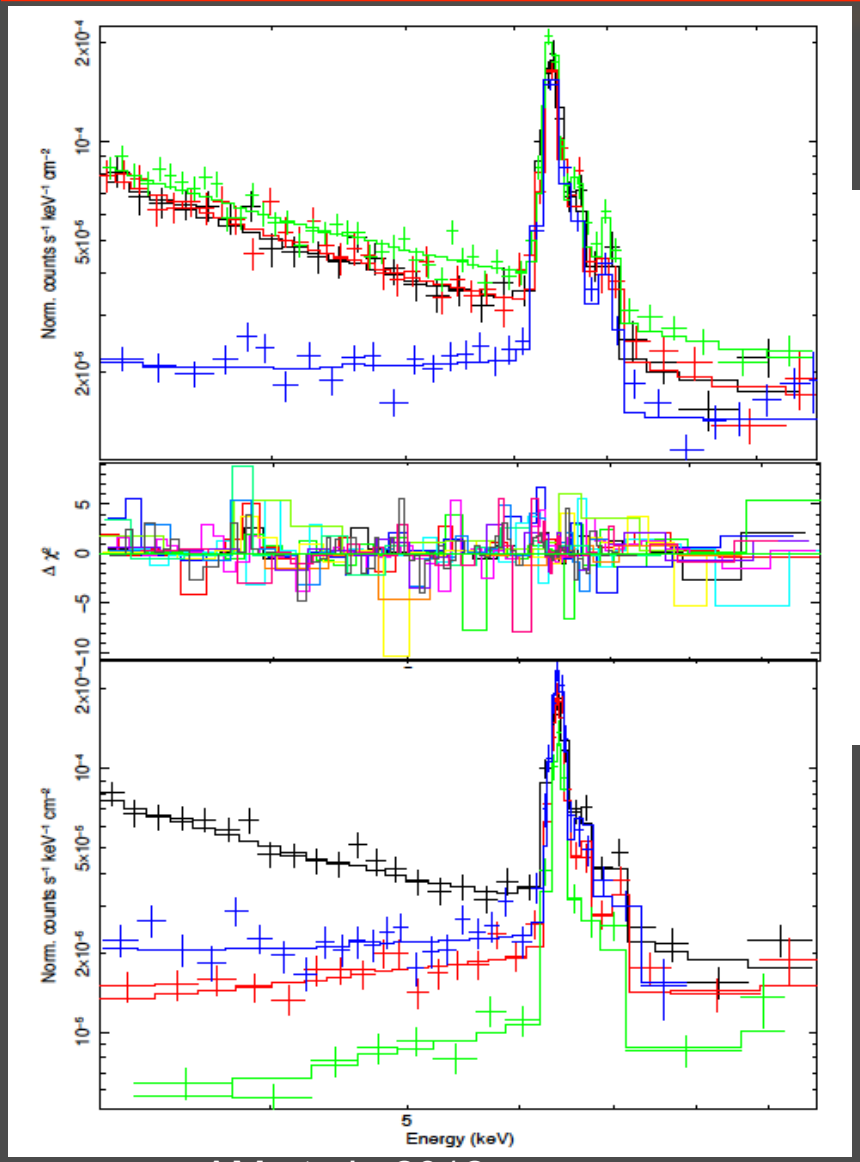
Red=0.3-2.0 keV
Green=2-10 keV



Extraction regions:

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

The geometry of the inner reflector: time and spectral variability



AM et al., 2012

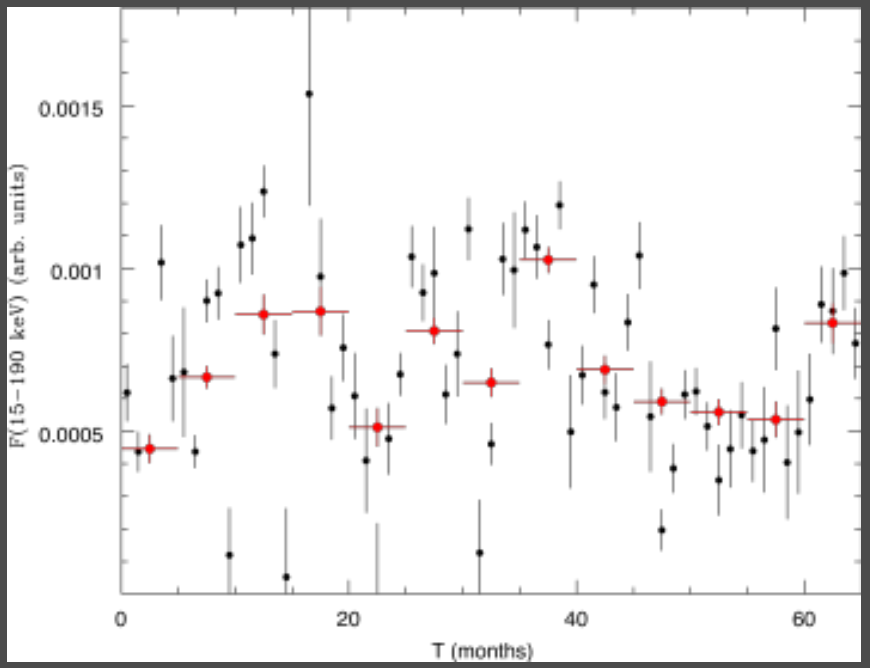
Suzaku in 2006
Suzaku in 2011
Suzaku in 2010
XMM-Newton in 2004 (25")

Param.	Value	OBS	Date	F[e]
Γ	1.6±0.1	Suzaku 1	01/06	1.00±0.06
E(1)[a]	6.39±0.01	Suzaku 2	07/10	1.00±0.08
EW(1)[b]	1020±100	Suzaku 3	07/10	0.99±0.08
E(2)[a]	6.66±0.01	Suzaku 4	07/10	0.97±0.08
EW(2)[b]	130±20	Suzaku 5	08/10	0.98±0.08
E(3)[a]	7.02±0.01	Suzaku 6	01/11	0.94±0.08
EW(3)[b]	140^{+20}_{-10}	XMM 1	01/00	0.97±0.05
N[c]	3.7±0.7	XMM 2	01/04	0.98±0.06
F^{d}_{2-10}	1.3×10^{-12}	Chandra 25"	05/04	1.08±0.11
L^{d}_{2-10}	2.2×10^{39}	Chandra BOX	05/04	0.86±0.07
χ^2/d.o.f.	1308/1205	Chandra 1.5"	05/04	0.58±0.06

Suzaku in 2010
Chandra in 2004 (25")
Chandra in 2004 (box)
Chandra in 2004 (nucleus)

If we assume a constant value of the relative flux F, we obtain <F>=0.98±0.02

The geometry of the inner reflector: time and spectral variability



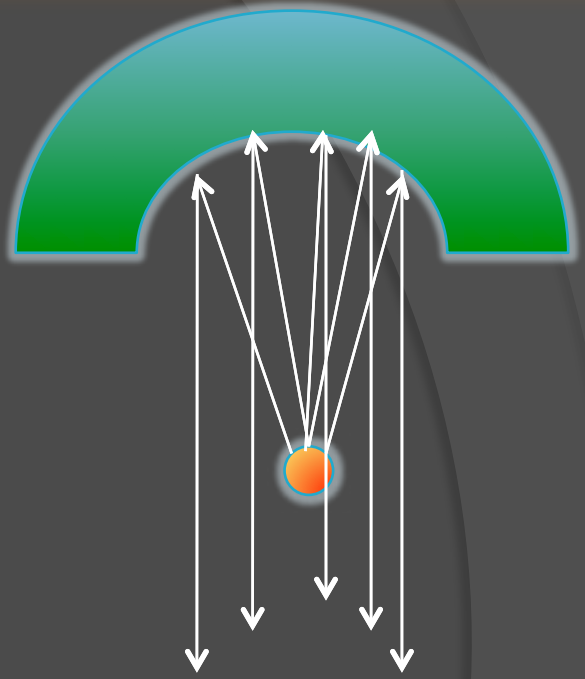
AM et al., 2012

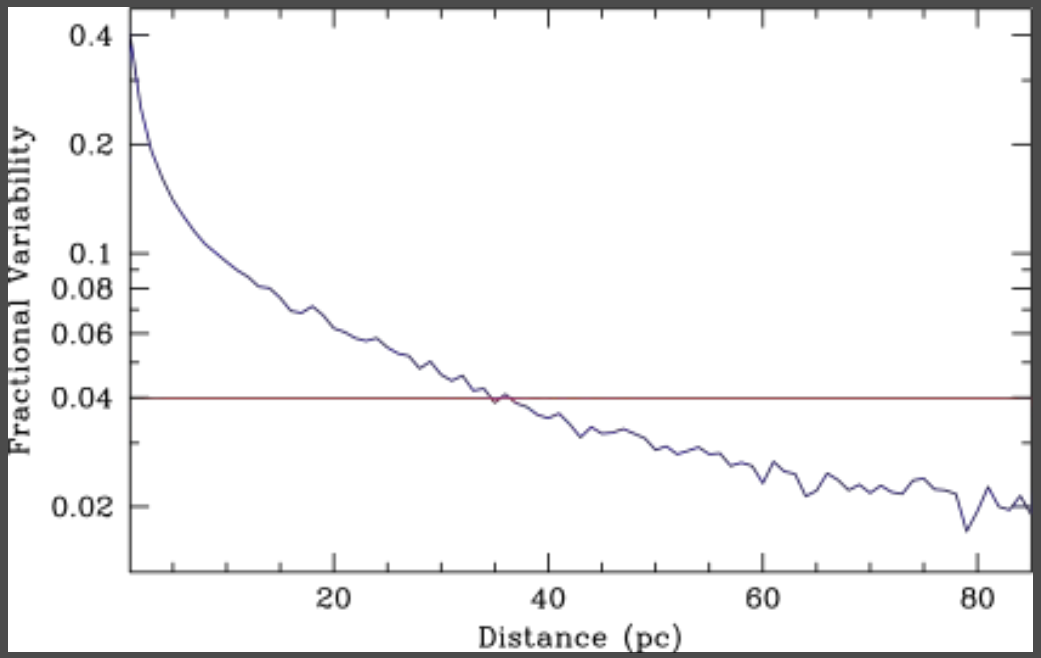
Swift/BAT light curve of the 15-195 keV emission of NGC 4945, grouped in time bins of 1 month (black) and 5 months (red).

Since the reflected spectra are extremely constant (4%) on a 10 years time scale, at what distance should the reflector be in order to smooth out all the variations observed?

The geometry of the inner reflector: time and spectral variability

We modeled the circumnuclear gas as a cylinder with the axis on the plane of the sky, with radius R and height H, such that H/R<0.1, as derived by the analysis of Done et al. 2003.

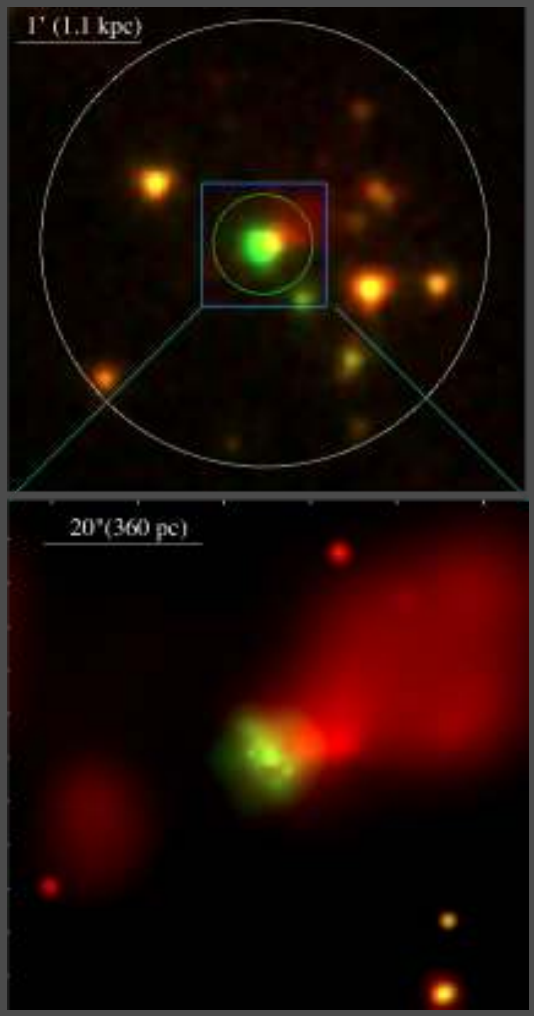




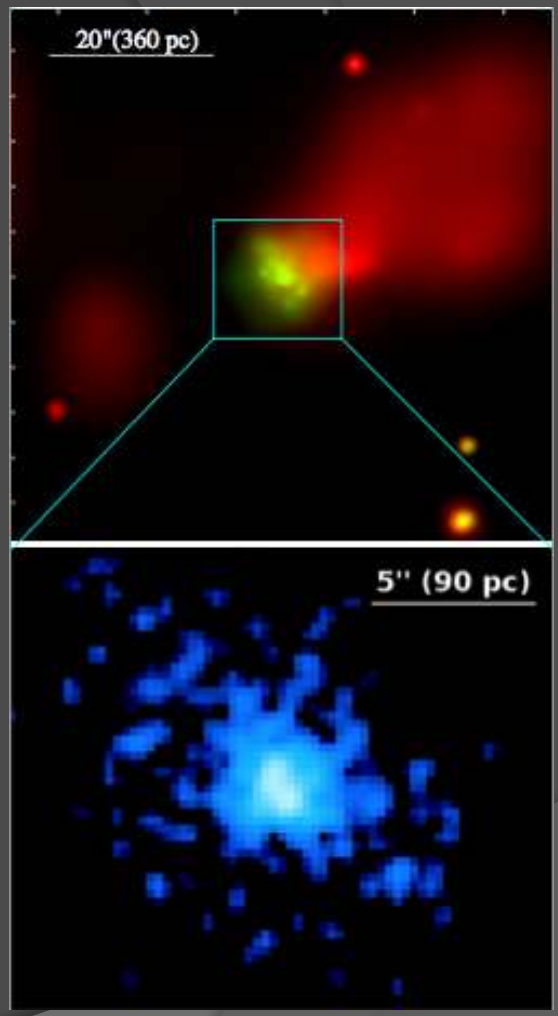
AM et al., 2012

In order to observe a variation not larger than 4% (<F>=0.96-1.00), the reflector must be at a distance larger than 35 pc.

The geometry of the inner reflector: imaging

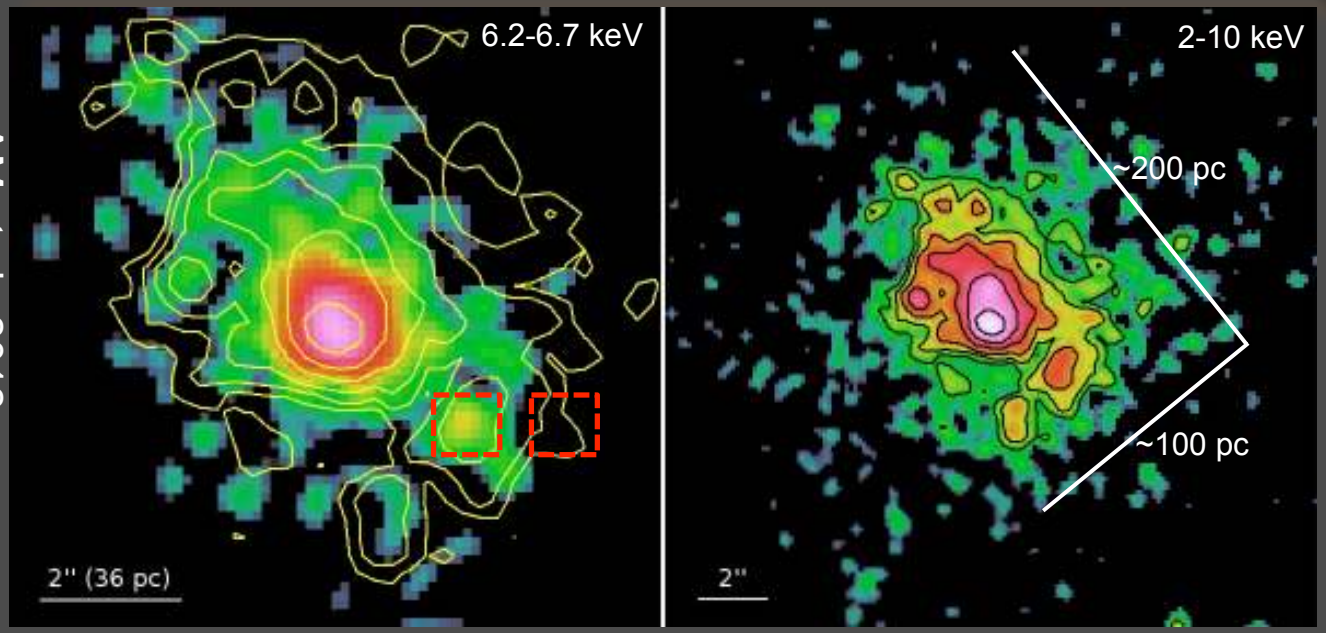


If the reflector is at a distance greater than 35 pc (~2") we expect to resolve it with Chandra.



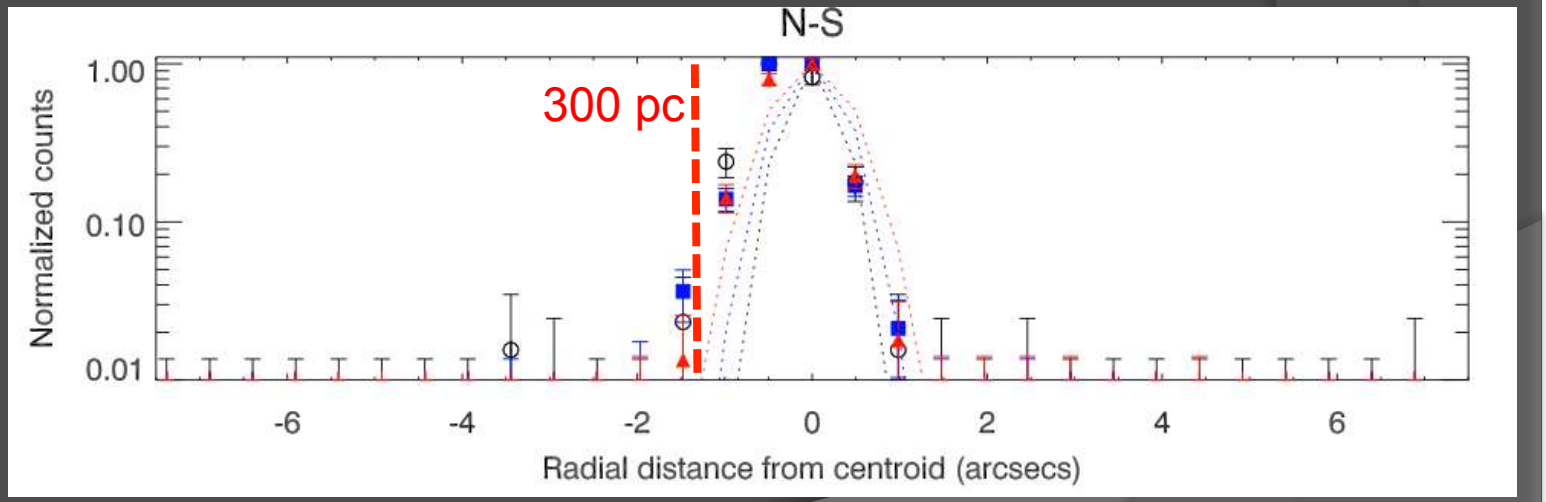
The geometry of the inner reflector: imaging

AM et al., 2012



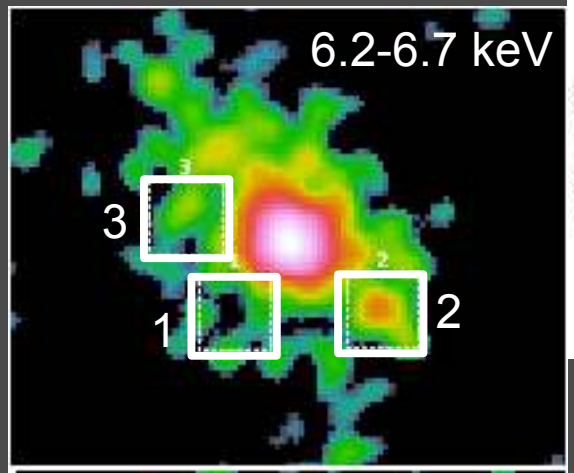
Mrk 3

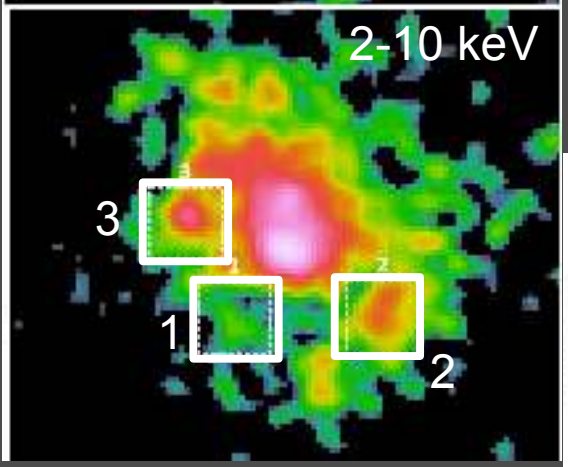
Guainazzi et al., 2012

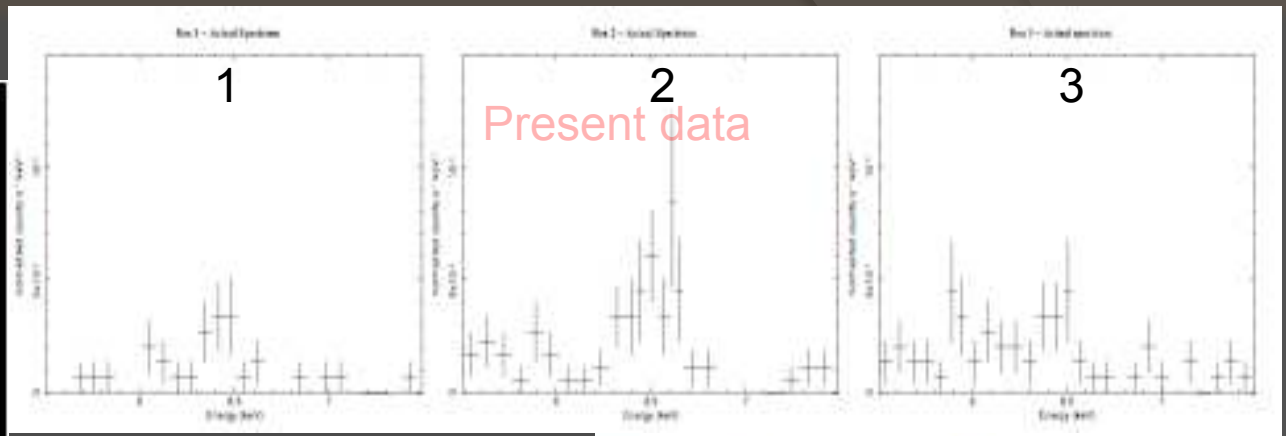


(Not so) Future Results & Perspectives

More exposure time = more statistics



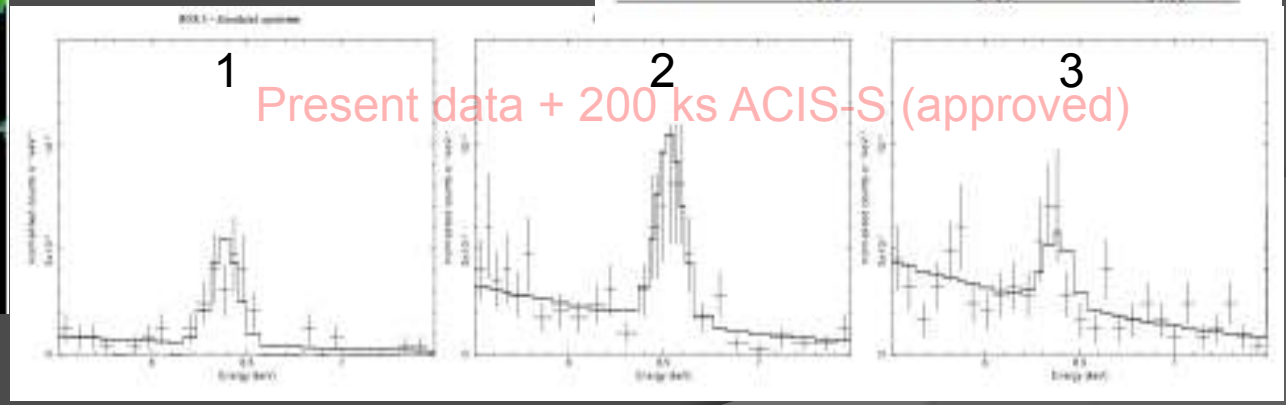




Present data

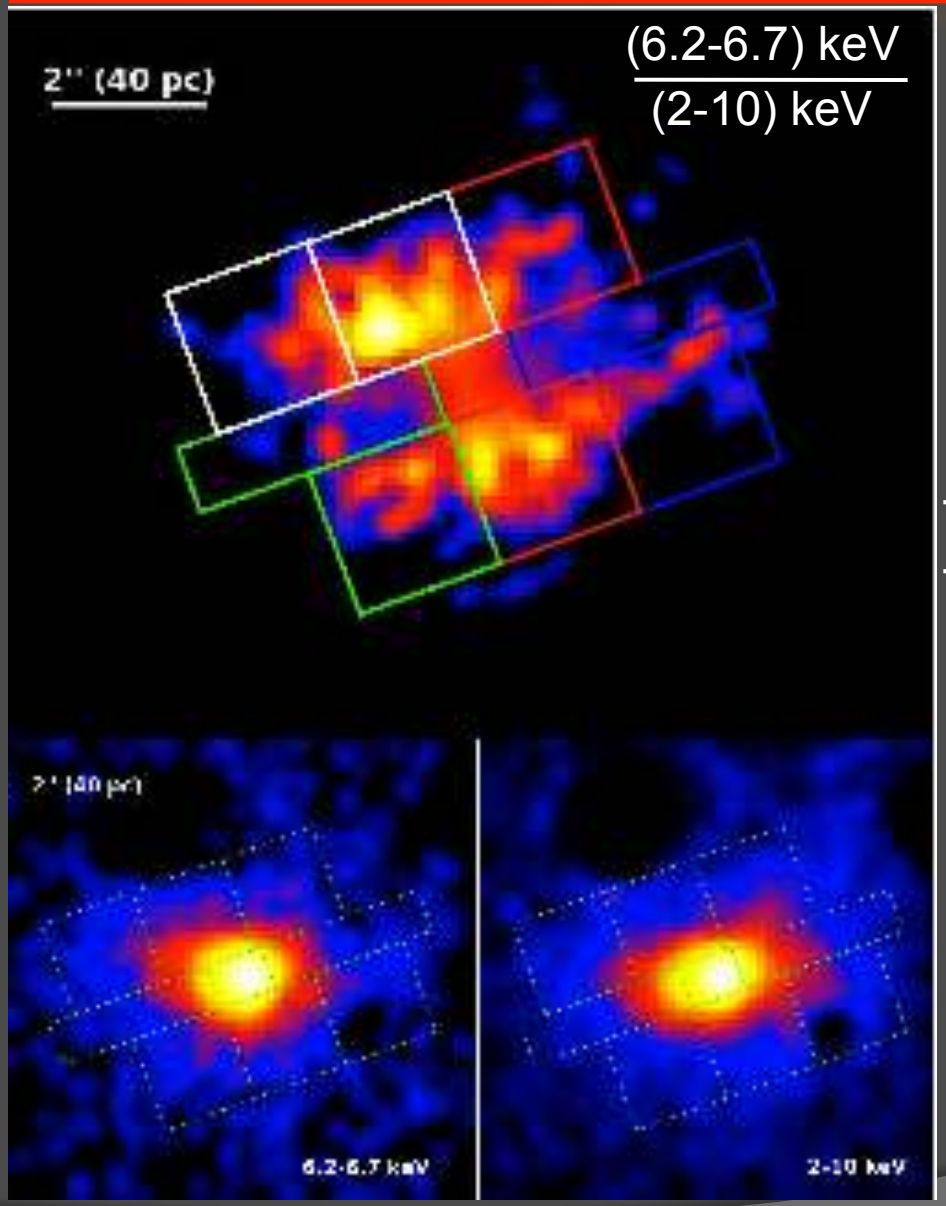
Table 1: fluxes are in 10^{-6} ph cm^{-2} s^{-1}, EW in keV, errors are at 1σ confidence level.

Region	Flux	Line Energy	EW
Box 1	$0.8^{+0.3}_{-0.2}$	$6.44^{+0.02}_{-0.03}$	$1.5^{+0.5}_{-0.5}$
Box 2	$1.4^{+0.4}_{-0.4}$	$6.57^{+0.02}_{-0.04}$	$1.0^{+0.3}_{-0.1}$
Box 3	$0.7^{+0.3}_{-0.3}$	$6.46^{+0.04}_{-0.01}$	$0.37^{+0.15}_{-0.15}$



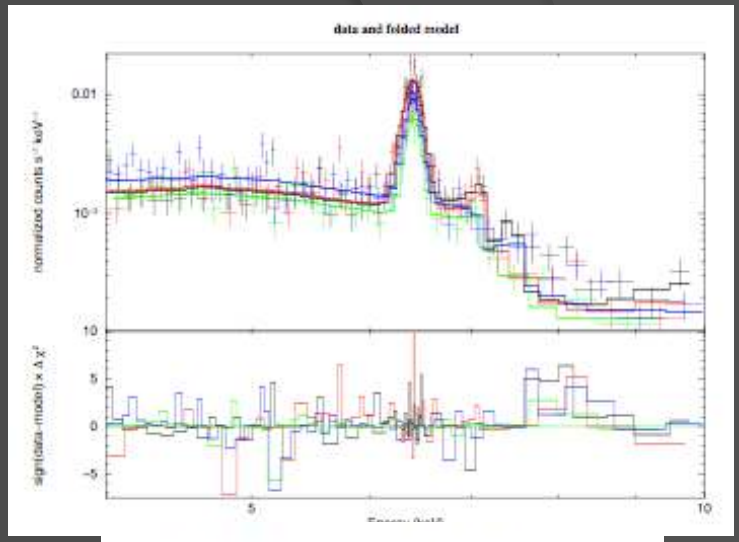
Present data + 200 ks ACIS-S (approved)

The Circinus Galaxy



AM et al, in prep.

200 ks Chandra



Parameter	EW (keV)
Top-left	$1.6^{+0.3}_{-0.3}$
Top-central	$2.0^{+0.2}_{-0.2}$
Top-right	$1.8^{+0.2}_{-0.3}$
Central-left	$0.9^{+0.1}_{-0.1}$
Central-right	$1.0^{+0.1}_{-0.1}$
Bottom-left	$2.4^{+0.4}_{-0.4}$
Bottom-central	$1.9^{+0.2}_{-0.2}$
Bottom-right	$1.3^{+0.3}_{-0.4}$

Conclusions

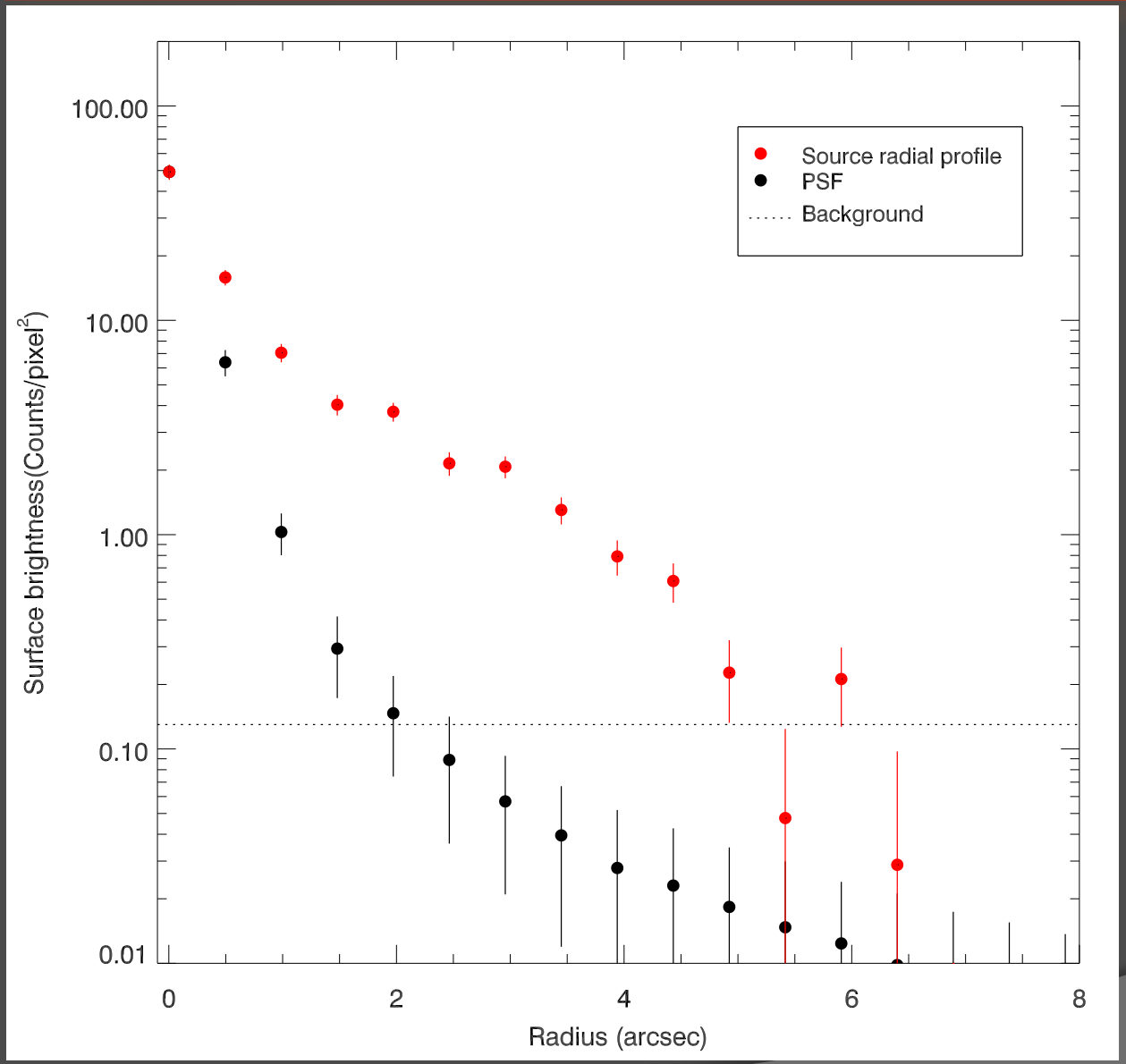
1) The comparison between the strong intrinsic variability measured by Swift/BAT and the constant reflection spectra from XMM-Newton and Suzaku observations implies a distance of the reflector in NGC 4945 D>35 pc.

2) The Chandra image reveals an extended hard emission on projected scales of 200x100 pc.
The spectrum of this emission is entirely reproduced by a cold reflection model.
The central 30 pc account for about 50% of the whole emission.

3) We present the first X-ray image of the inner reflector of an AGN.
The large scale structure of the emission region is clumpy and asymmetric, and the central region is resolved by Chandra.

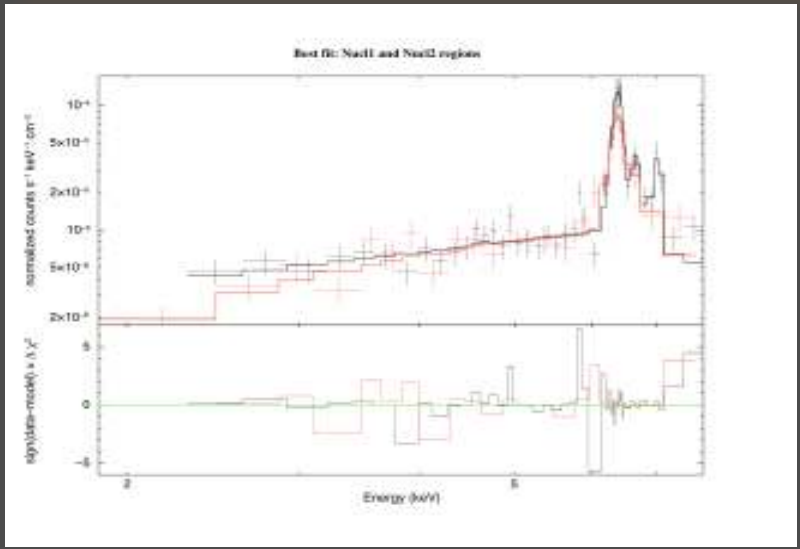
4) Preliminary results on different sources are very encouraging.

Backup slides (1)

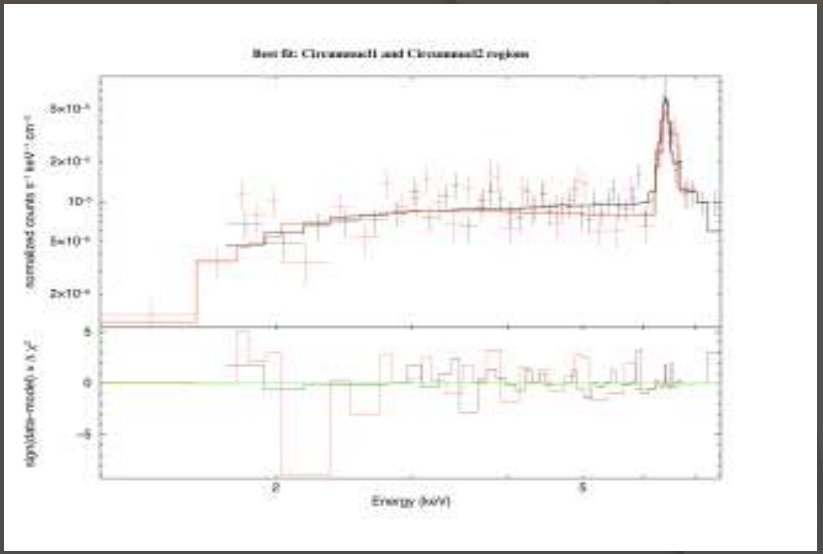


NGC 4945
2-10 keV
Radial profile

Backup slides (2)



1.5” Nucleus



Circumnuclear region

12”x 6” Box