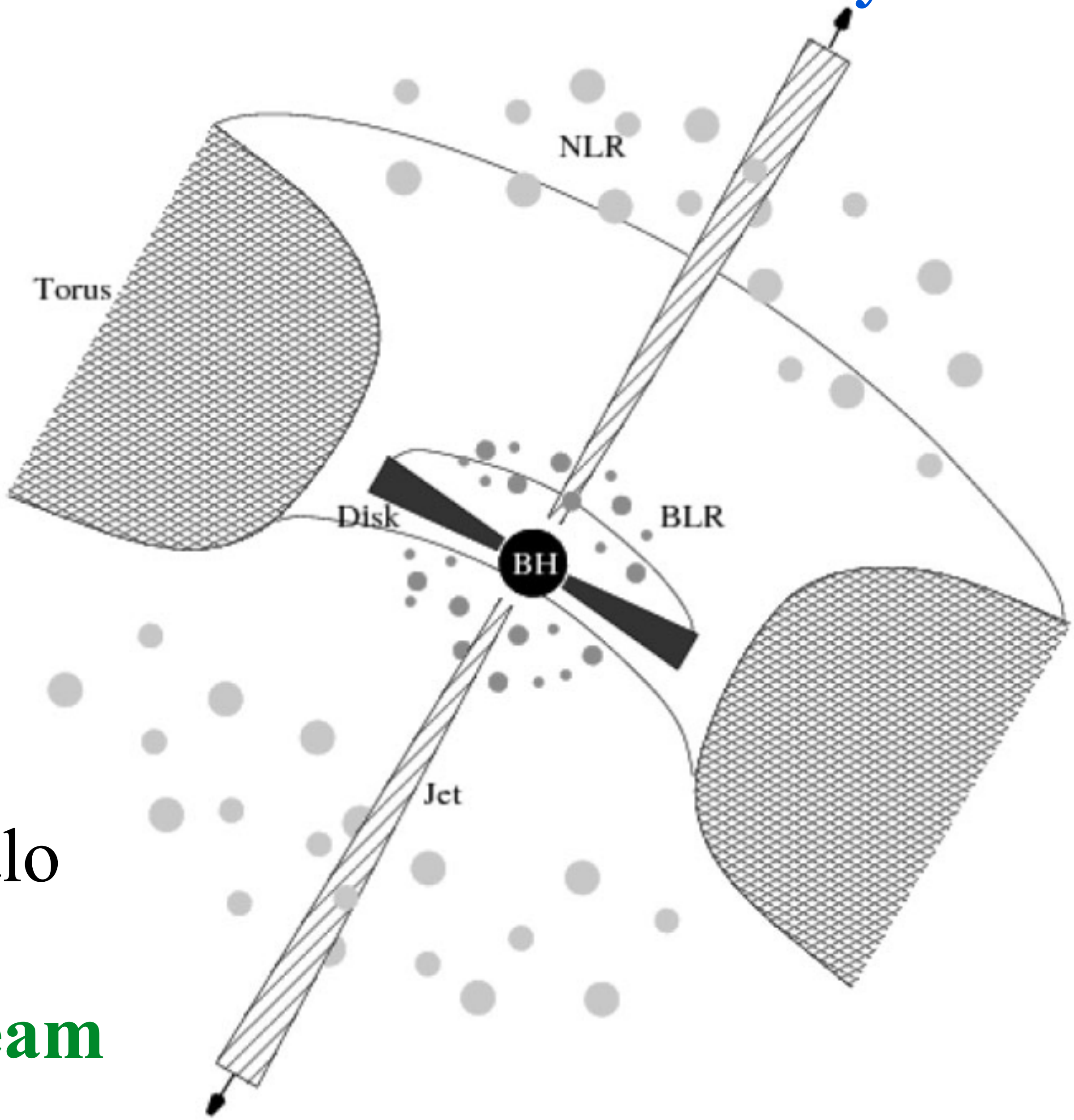
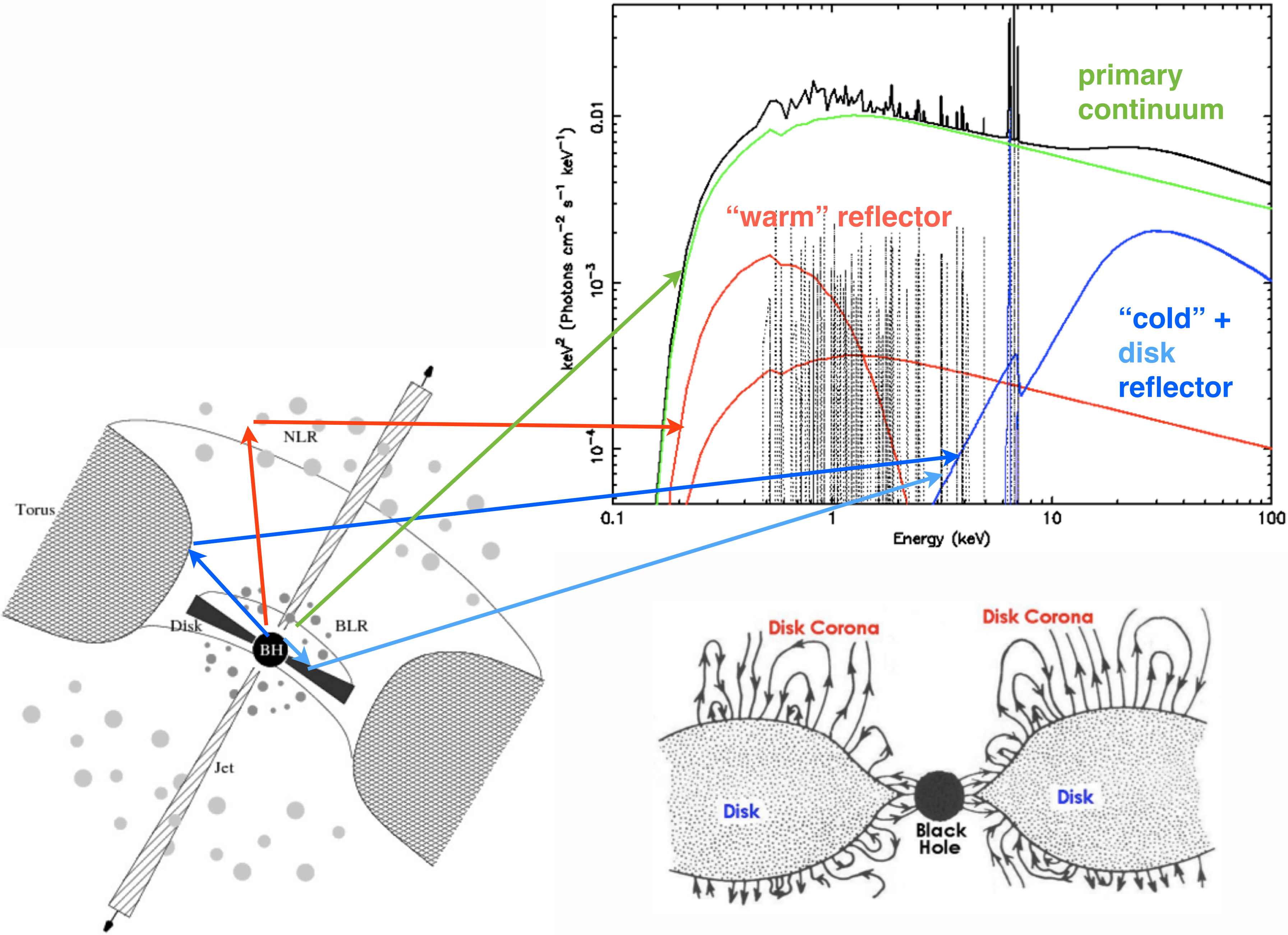
Probing the Torus Structure of Nearby AGN



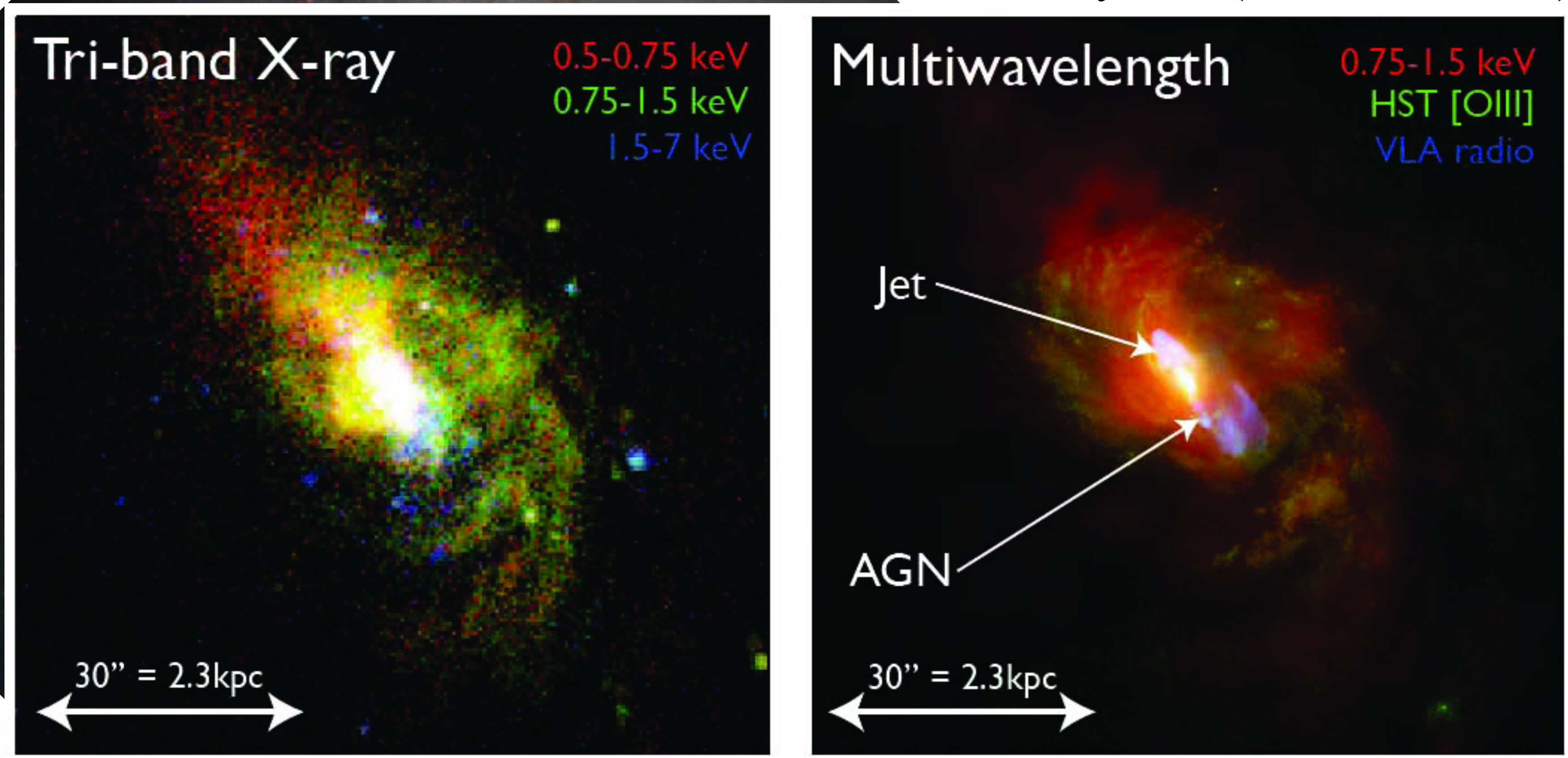
Franz Bauer
Patricia Arévalo
(PUC)
+ NuSTAR team


primary
continuum
"warm" reflector
"cold" +
disk
reflector
keV^2 (Photons cm^-2 s^-1 keV^-1)
0.01
10^-3
10^-4
0.1
1
10
100
Energy (keV)
NLR
Torus
Disk
BH
BLR
Jet
Disk Corona
Disk Corona
Disk
Disk
Black
Hole

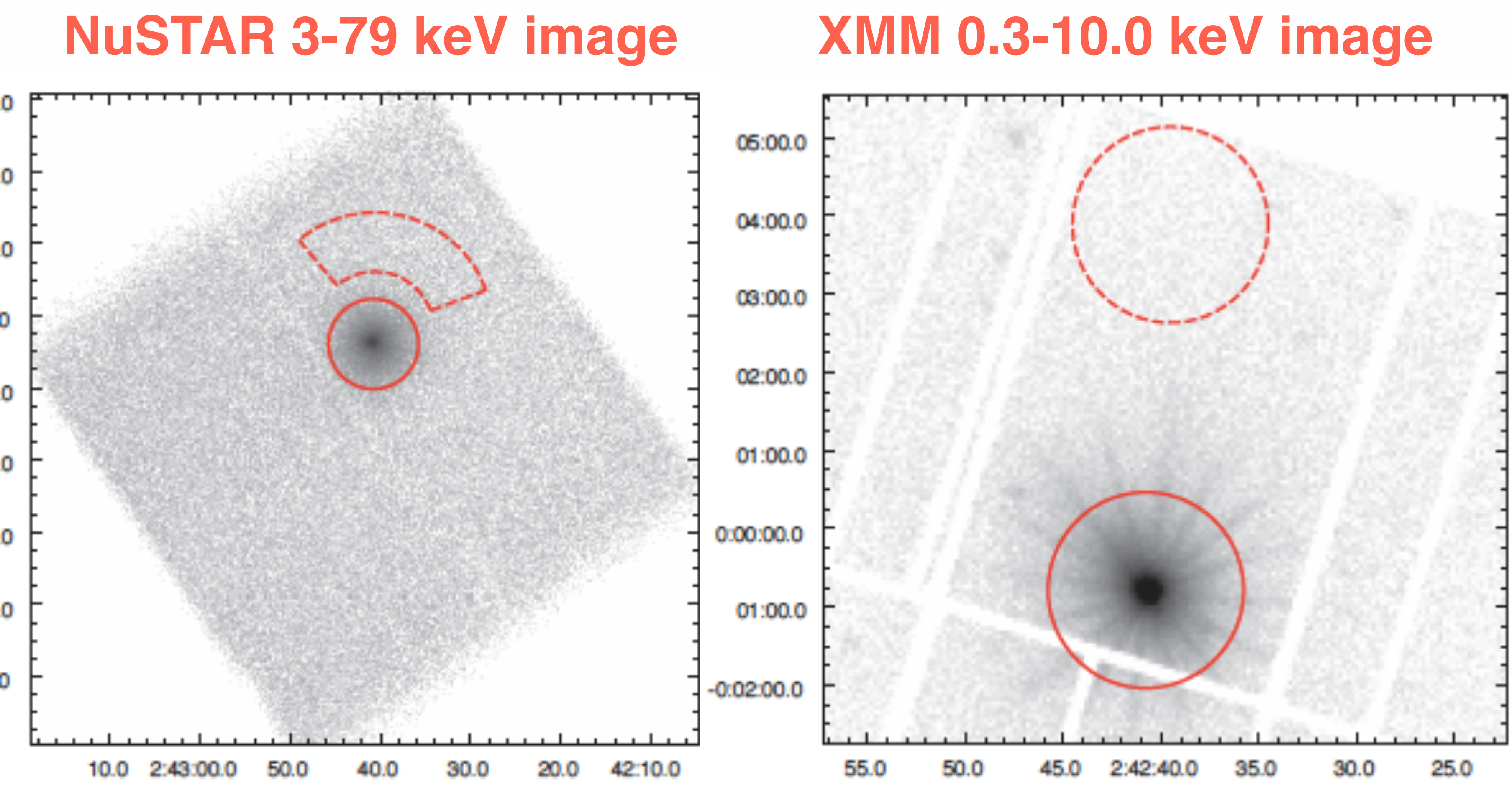
NGC 1068

~14.4 Mpc

Fully CT ($N_H > 10^{25}$ cm^{-2})

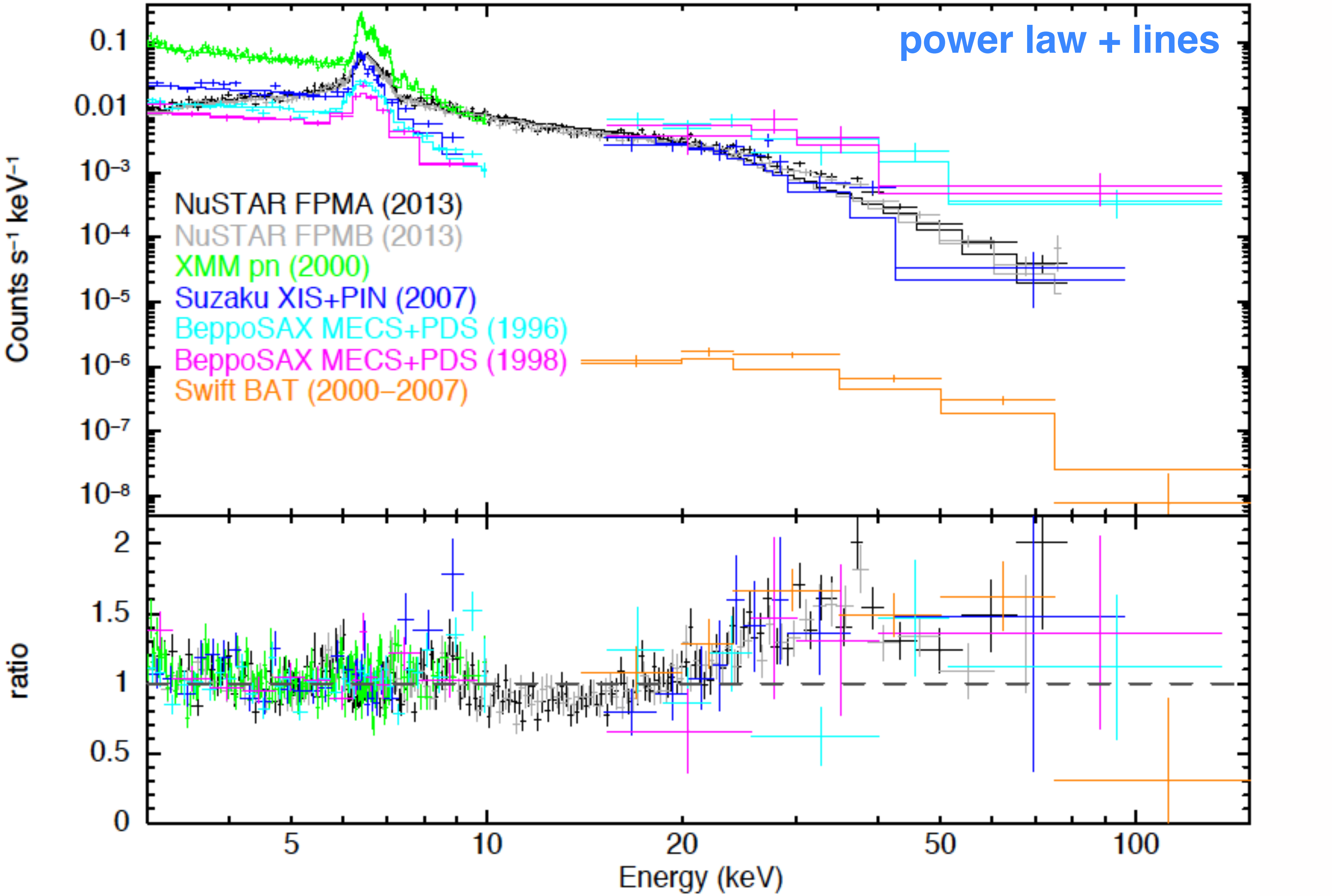


Ionization cone (aligned with radio jet)



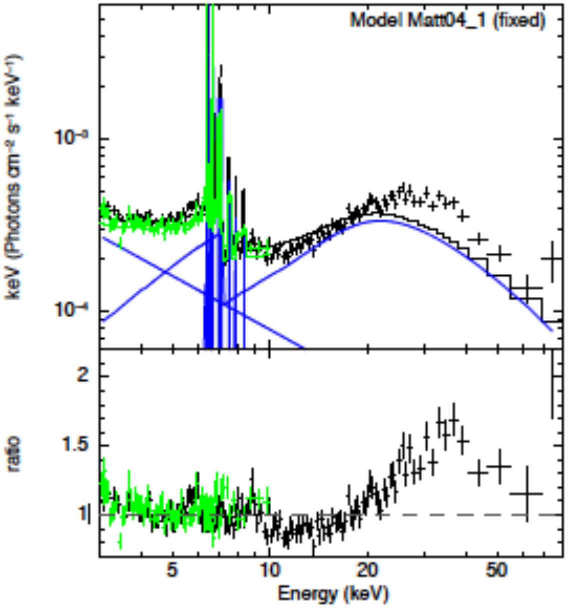
NuSTAR 3-79 keV image
XMM 0.3-10.0 keV image
10.0
2:43:00.0
50.0
40.0
30.0
20.0
42:10.0
05:00.0
04:00.0
03:00.0
02:00.0
01:00.0
0:00:00.0
01:00.0
-0:02:00.0
55.0
50.0
45.0
2:42:40.0
35.0
30.0
25.0

XMM+NuSTAR Spectral fit

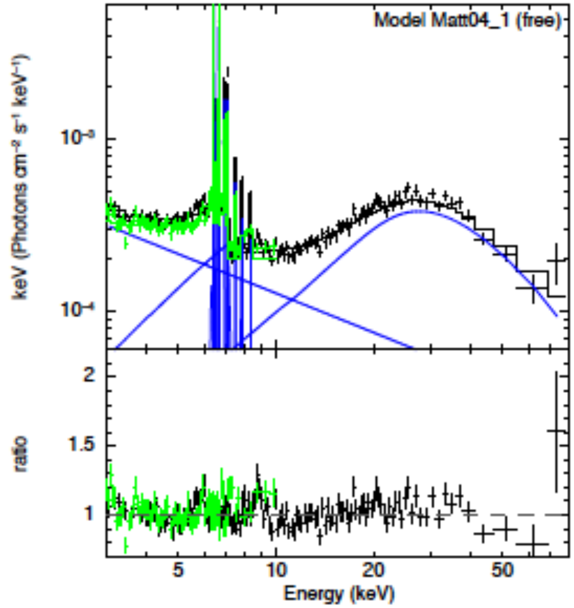


XMM+NuSTAR Spectral fit

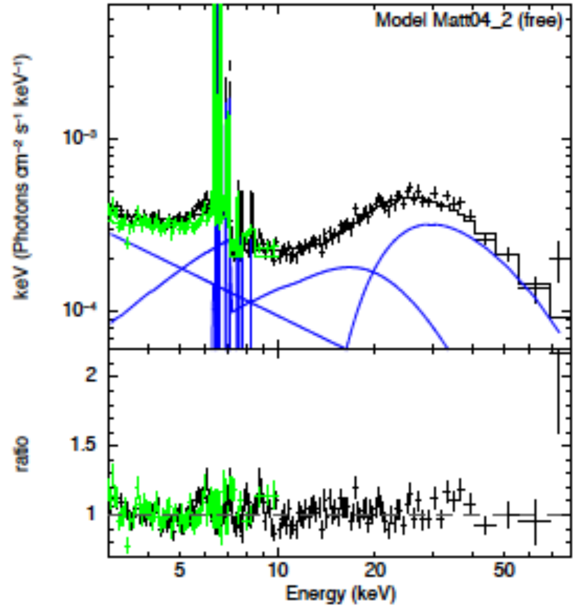
ϴ=88, Z=1



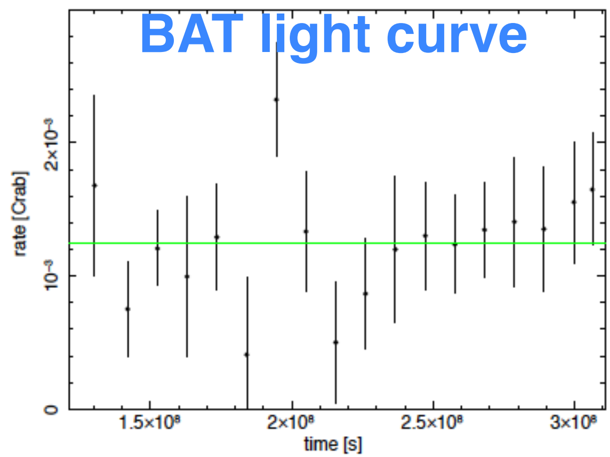
Z_Fe~7-8



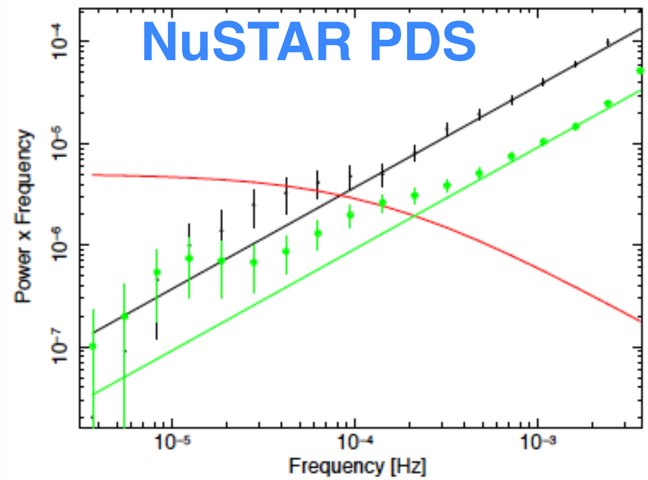
transmission?



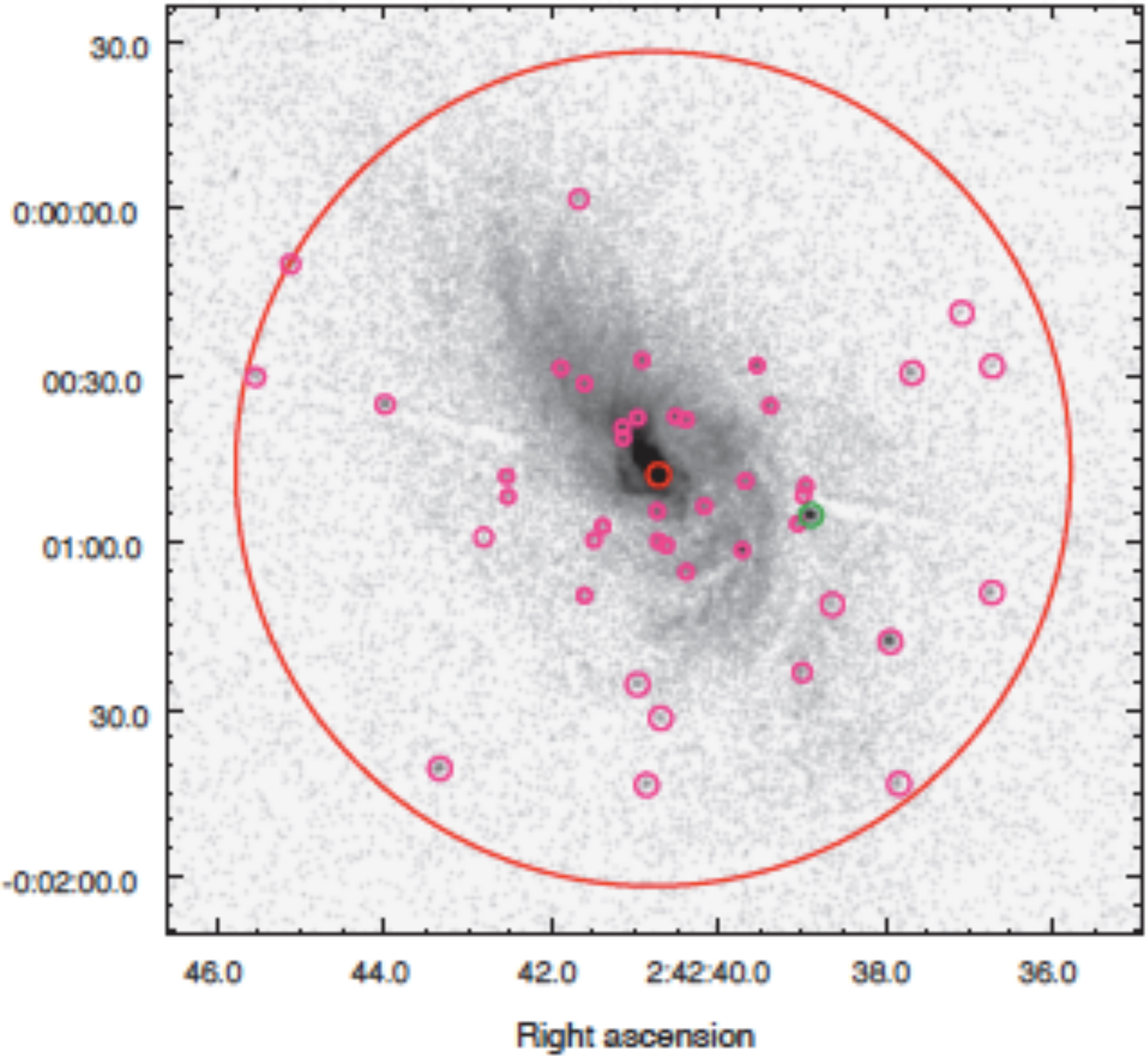
BAT light curve



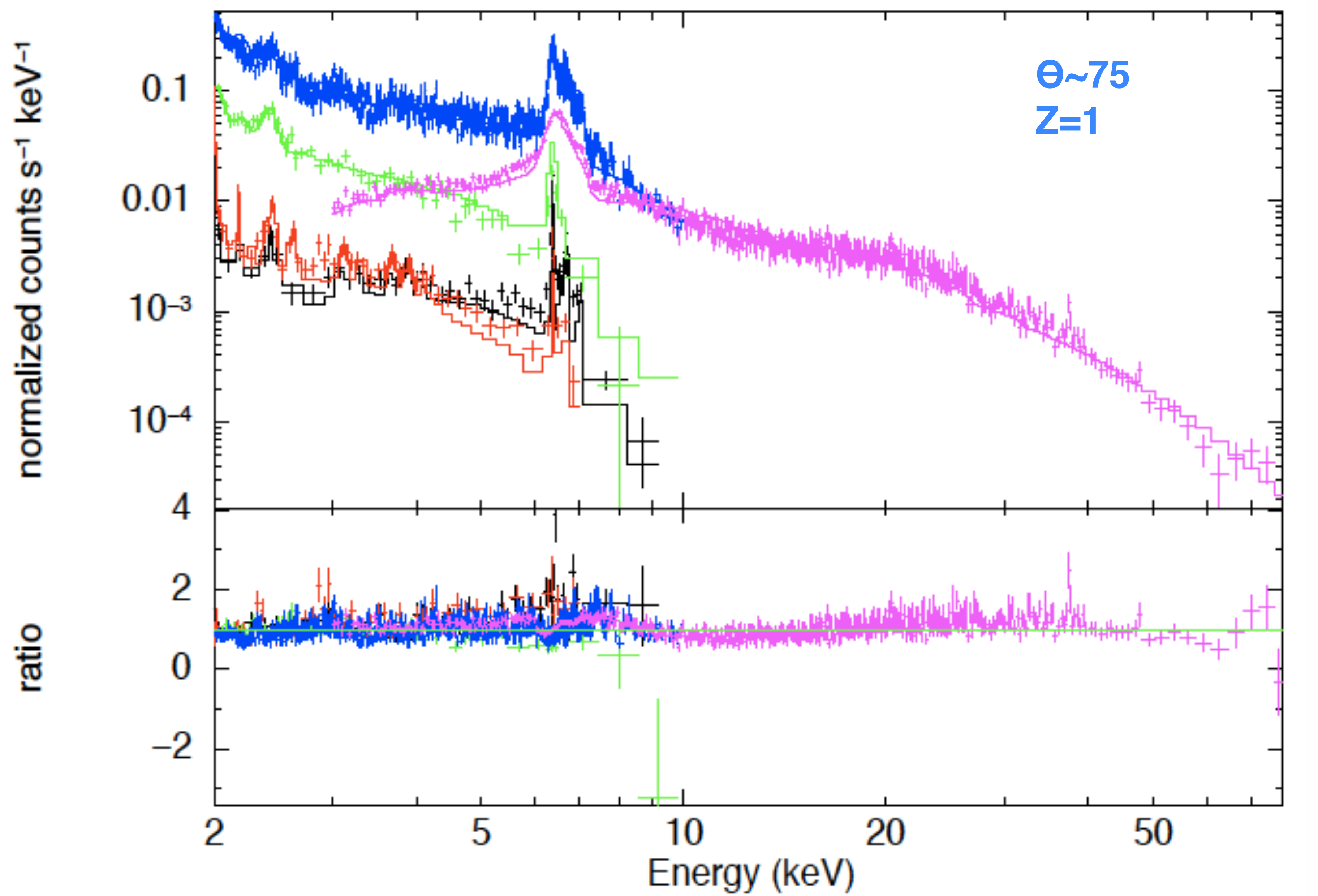
NuSTAR PDS



Chandra 0.3-8.0 keV image



XMM+NuSTAR+Chandra (Gal+Nuc) Spectral fit



XMM+NuSTAR+Chandra (Gal+Nuc) Spectral fit

TABLE 4
FLUX CONTRIBUTION FRACTION

Component	0.5-2.0 keV	2–5 keV	5–10 keV	10–40 keV
		<2″		
Warm Scattered AGN	0.52 (0.06)	0.55 (0.28)	0.49 (0.12)	0.68 (0.04)
Cold Scattered AGN	0.01 (0.00)	0.22 (0.11)	2.31 (0.55)	12.26 (0.72)
Other (brems + lines)	3.97 (0.42)	0.29 (0.15)	0.27 (0.06)	0.00 (0.00)
Total	4.50 (0.48)	1.06 (0.55)	3.17 (0.76)	12.94 (0.76)
		>2″		
Warm Scattered AGN	0.74 (0.08)	0.44 (0.23)	0.27 (0.06)	0.37 (0.02)
Cold Scattered AGN	0.01 (0.00)	0.11 (0.06)	0.52 (0.12)	3.25 (0.19)
Off-nuclear Pnt Src.	0.20 (0.02)	0.18 (0.09)	0.17 (0.04)	0.45 (0.03)
Other (brems + lines)	4.00 (0.42)	0.13 (0.07)	0.06 (0.01)	0.00 (0.00)
Total >2″	4.92 (0.52)	0.87 (0.45)	1.02 (0.24)	4.07 (0.24)

NOTE. — Columns 2-5 are in units of 10^{-12} erg s^{-1} cm^{-2}, with relative fractions of total flux within 75″ shown in ()s.

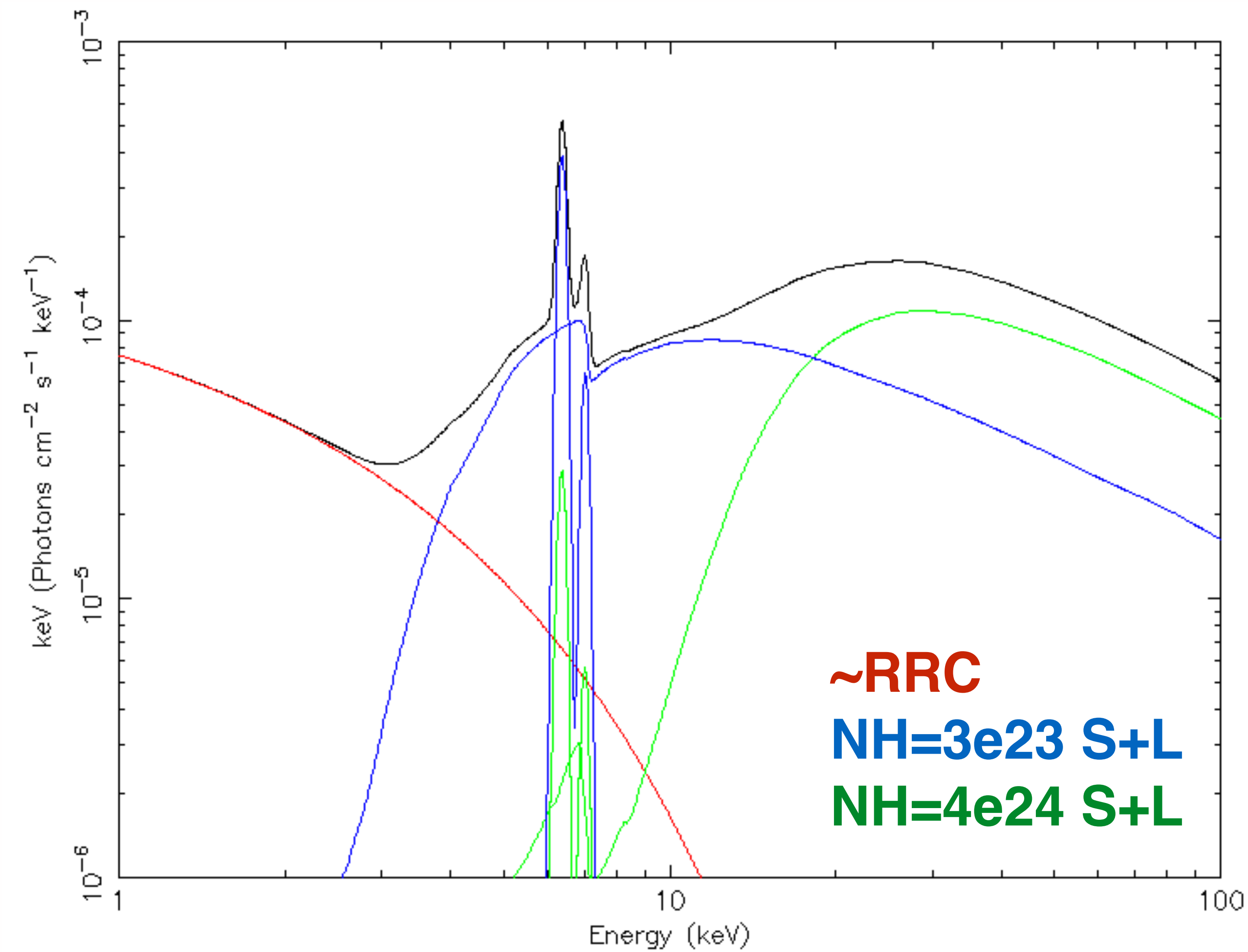
TABLE 4
FE AND NI LINE FLUXES (M04 MODEL)

Line	*XMM-Newton*		*Chandra*	
	M04 <40″	this work <75″	HETG <2″	ACIS-S 2″-75″
Fe Kα	44.3	$47.4^{+1.9}_{-2.2}$	$38.9^{+3.8}_{-3.8}$	$17.5^{+3.3}_{-3.3}$
Fe Kα CS	8.7	$3.8^{+1.5}_{-2.2}$	$4.2^{+3.6}_{-2.2}$	< 1.5
Fe Kβ	9.1	$8.9^{+1.1}_{-1.5}$	$4.3^{+3.1}_{-1.9}$	< 5.2
Ni Kα	5.6	$5.8^{+1.8}_{-0.9}$	< 7.3	< 8.8
Ni Kβ	3.2	$3.1^{+0.9}_{-1.3}$	<19.8	<16.8
Fe Be-like 6.57 keV	**7.6***	$8.0^{+1.5}_{-2.1}$	$6.3^{+2.1}_{-2.5}$	$3.9^{+2.9}_{-2.9}$
Fe He-like 6.69 keV	**22.8***	$27.8^{+1.0}_{-2.9}$	$12.8^{+3.9}_{-2.3}$	$6.1^{+2.4}_{-2.4}$
Fe H-like 6.97 keV	**7.1***	$8.2^{+0.8}_{-2.5}$	$7.7^{+1.5}_{-5.8}$	< 6.1
Ni He-like 7.83 keV	**2.7***	$3.9^{+1.1}_{-1.1}$	<10.2	<10.4

Bulk of Fe reflection coming from LARGE scales (i.e. > 1pc)

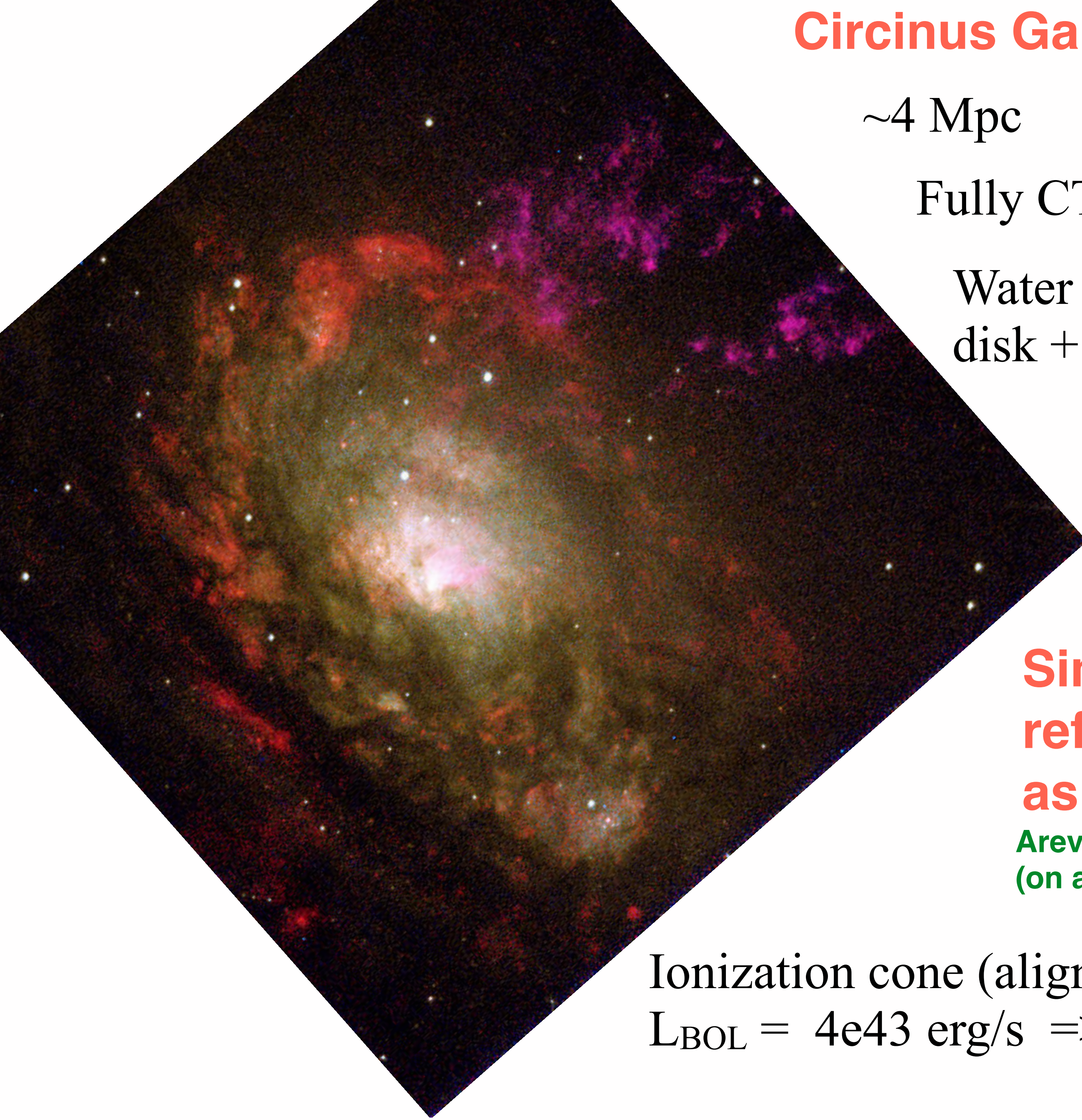
NOT from 0.4-1pc torus wall, as usually (always?) assumed!

MYTorus example. Do we have a problem?



Bulk of Fe coming from lower NH reflection.

Bulk of 30 keV hump coming from high NH reflection



Circinus Galaxy

~4 Mpc

Fully CT (N_H>10^{25} cm^{-2})

Water maser => warped disk + 1.5e6 M_{BH}

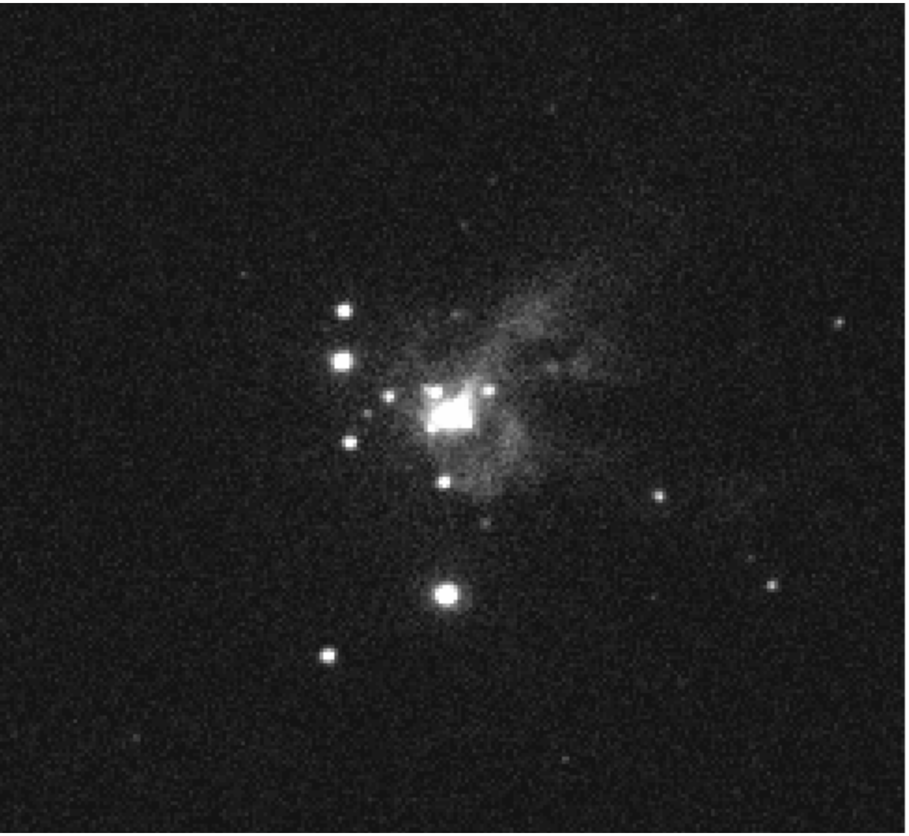
Similar global reflection props as NGC 1068

Arevalo et al. 2014
(on arXiv a few weeks ago)

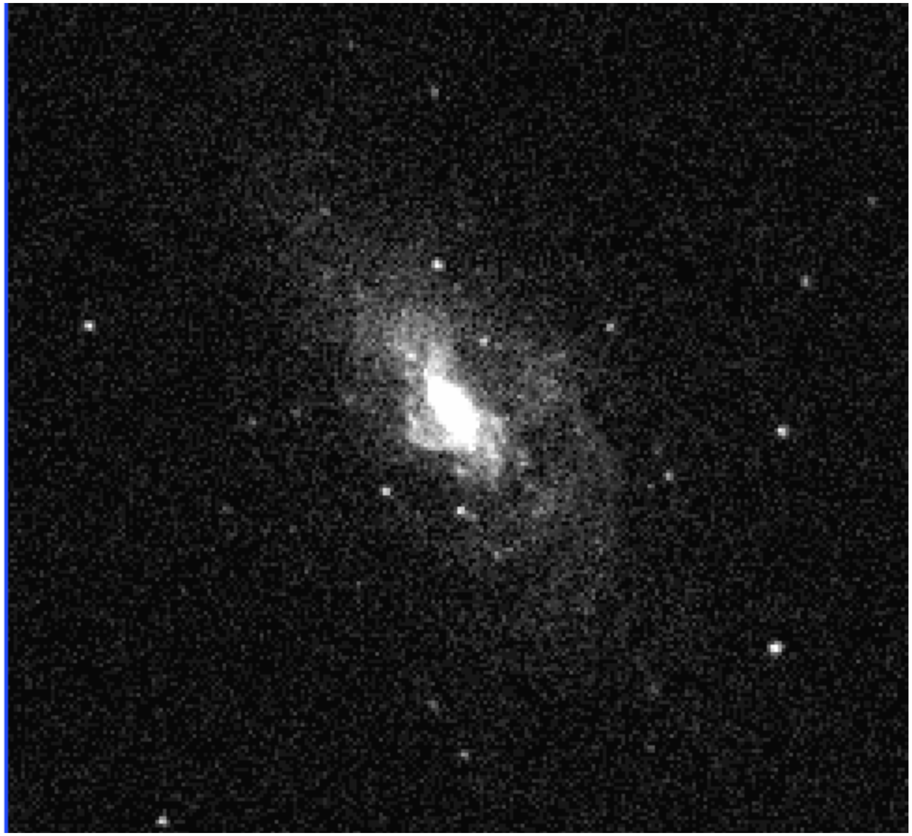
Ionization cone (aligned with radio jet)
L_{BOL} = 4e43 erg/s => 0.2 L_{EDD}

What about spatial distribution of Reflection?

Circinus Galaxy

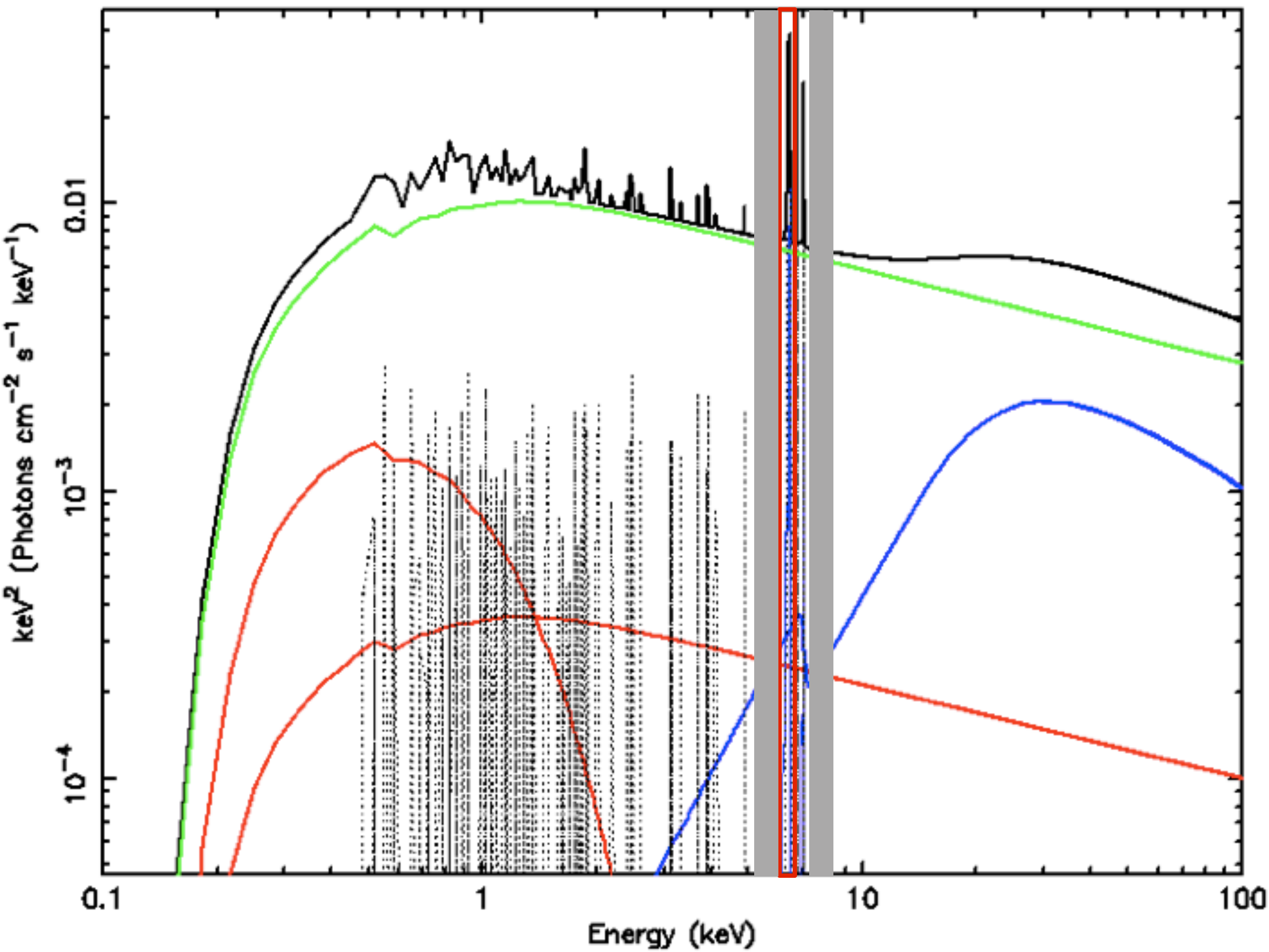


NGC 1068

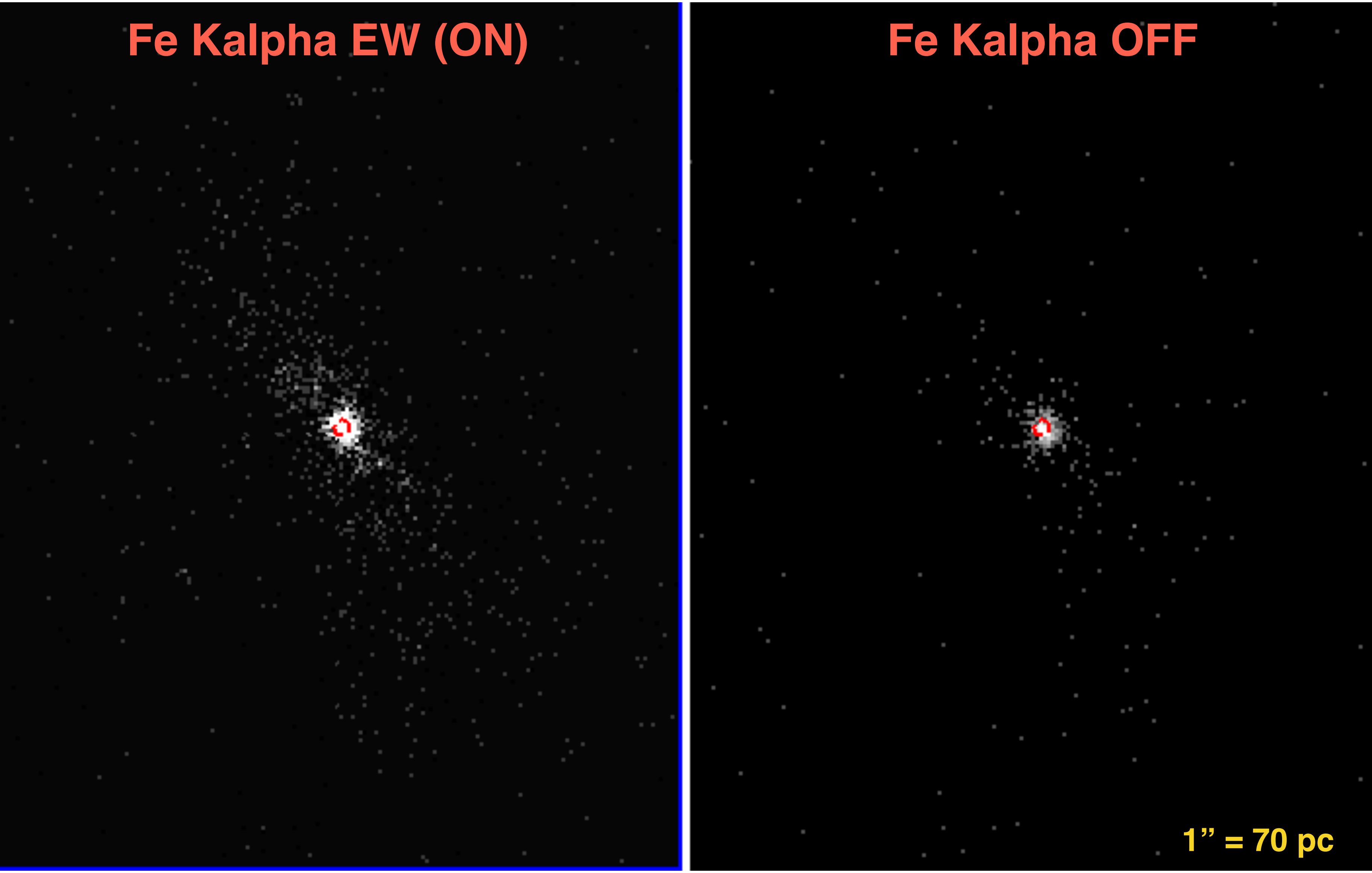


0.3-8.0 keV images

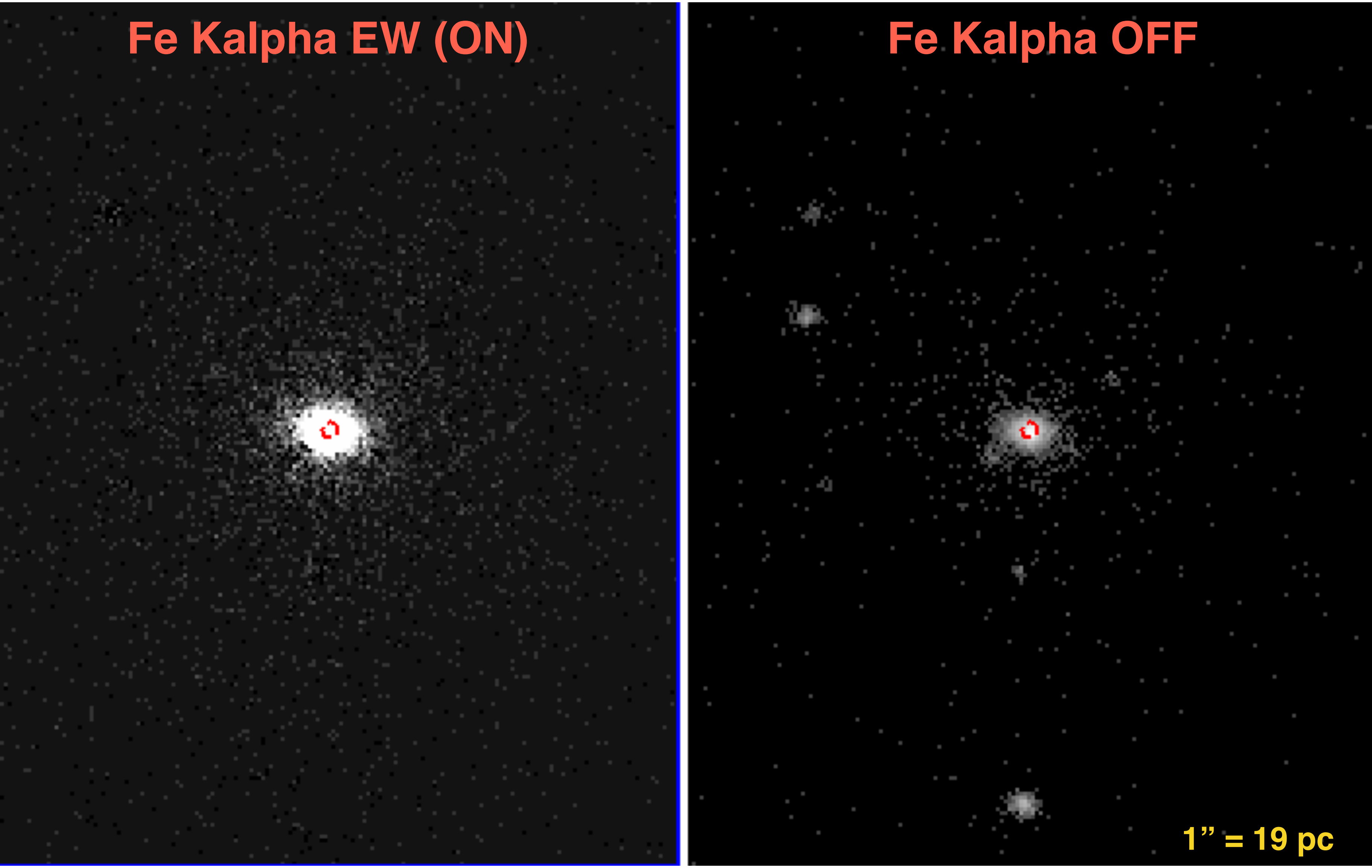
0.3-8.0 keV images



NGC 1068

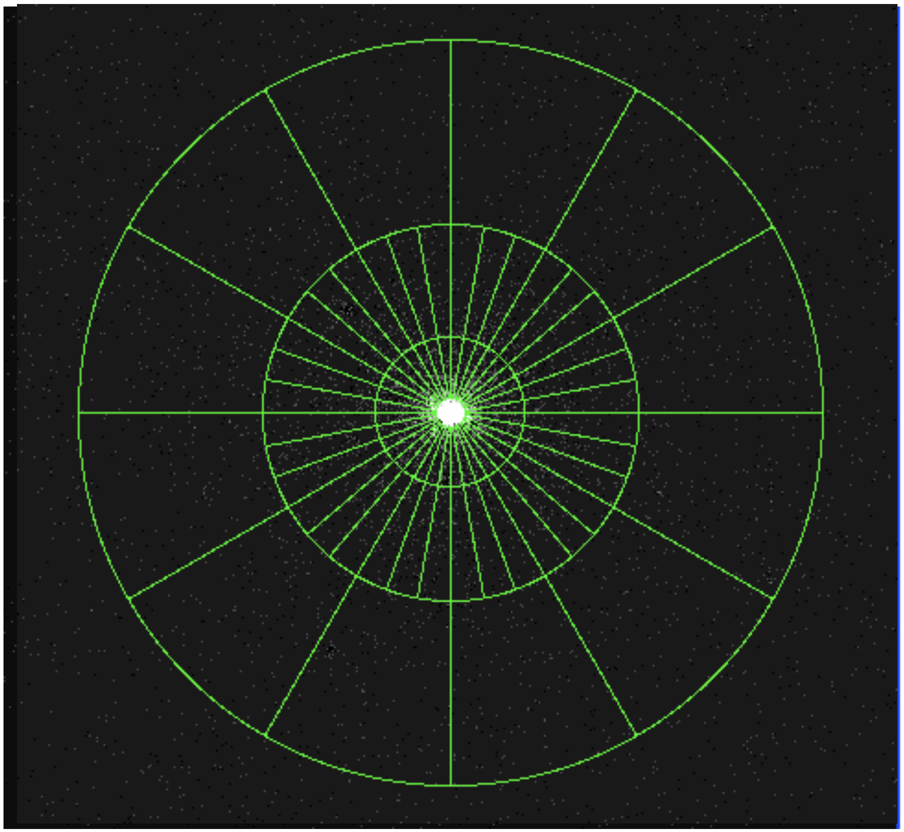


CIRCINUS

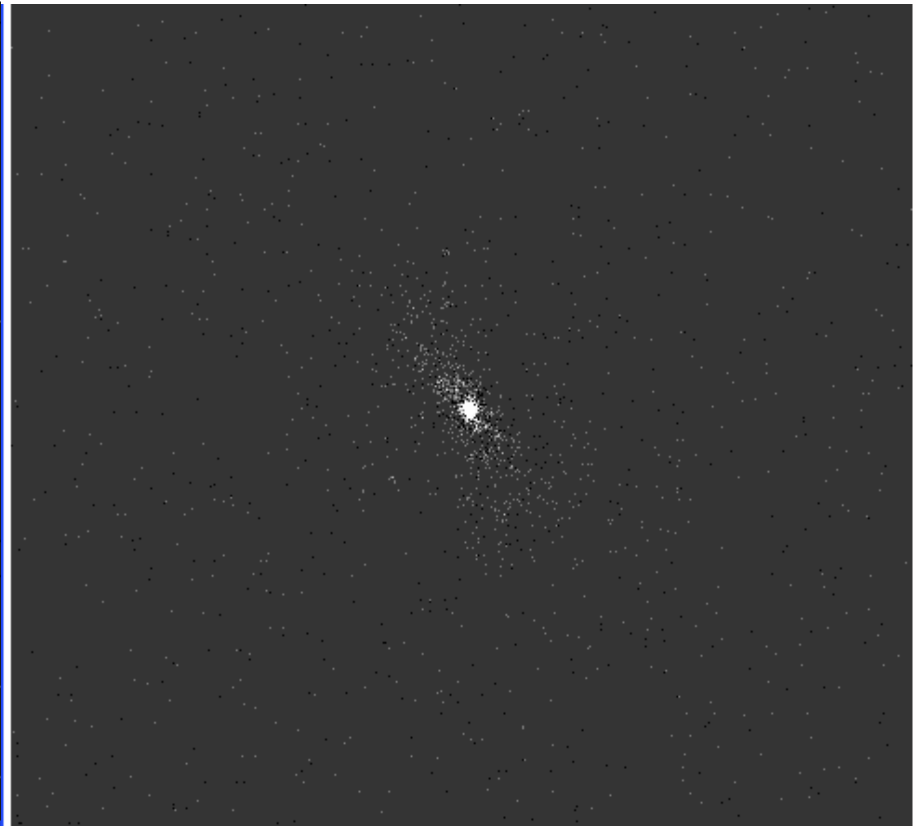


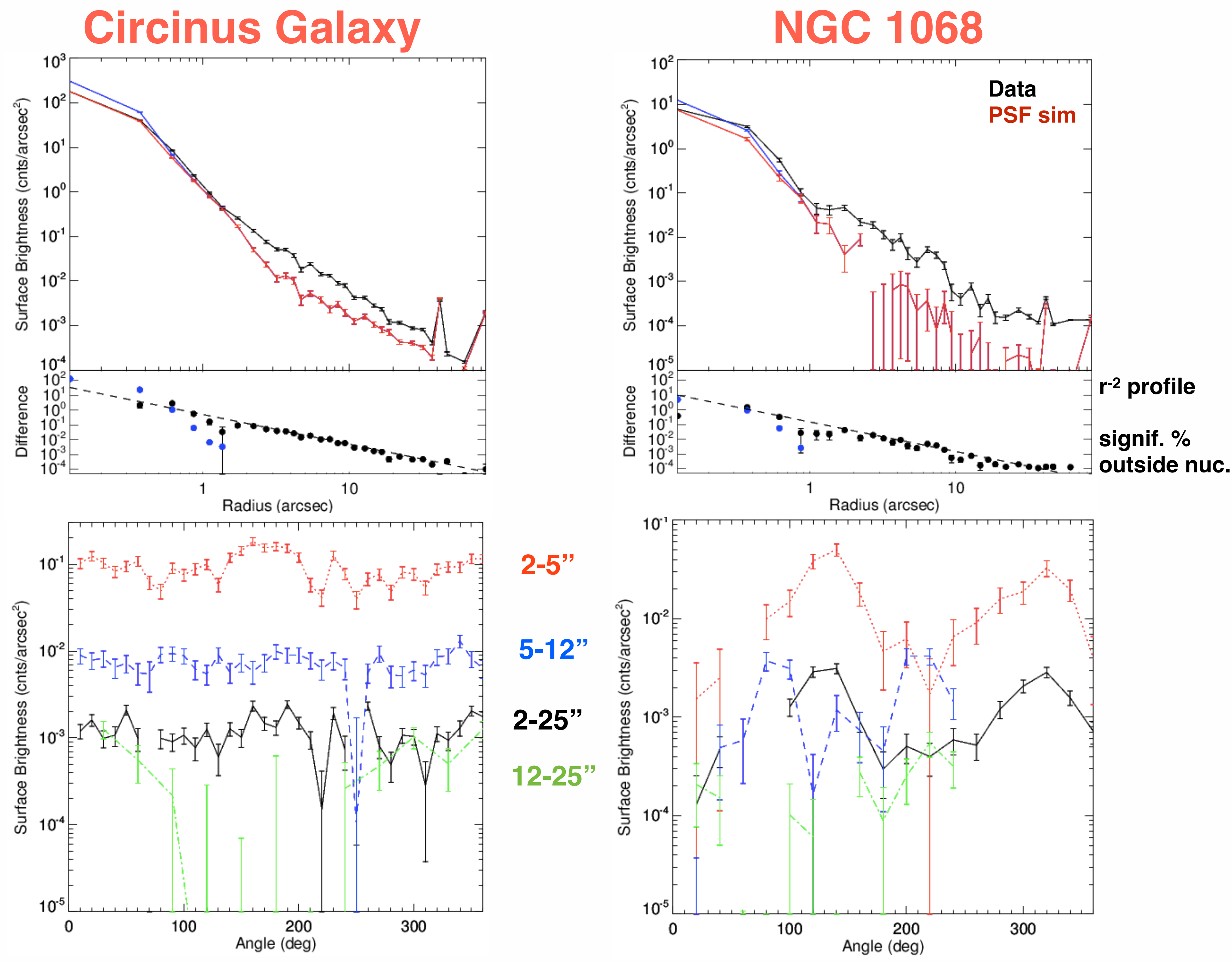
Fe Kalpha EW images

Circinus Galaxy



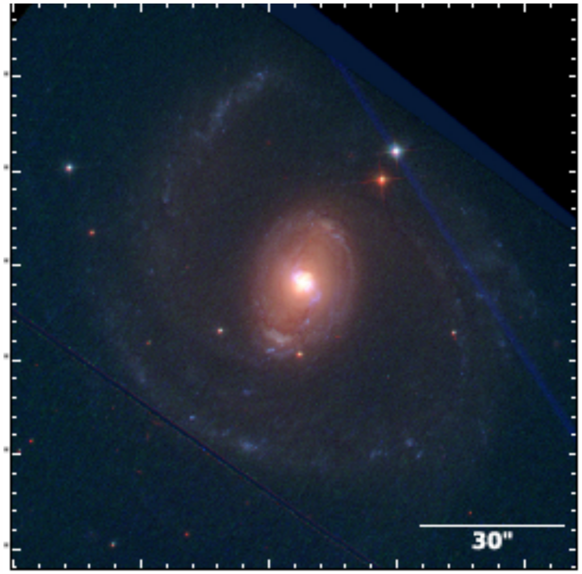
NGC 1068

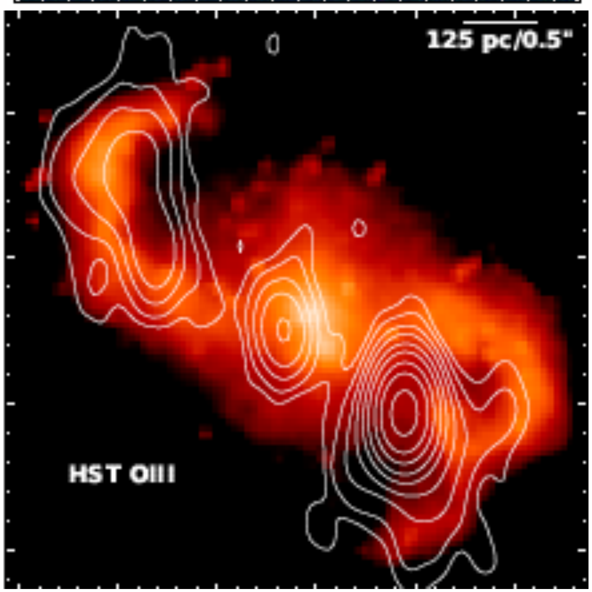




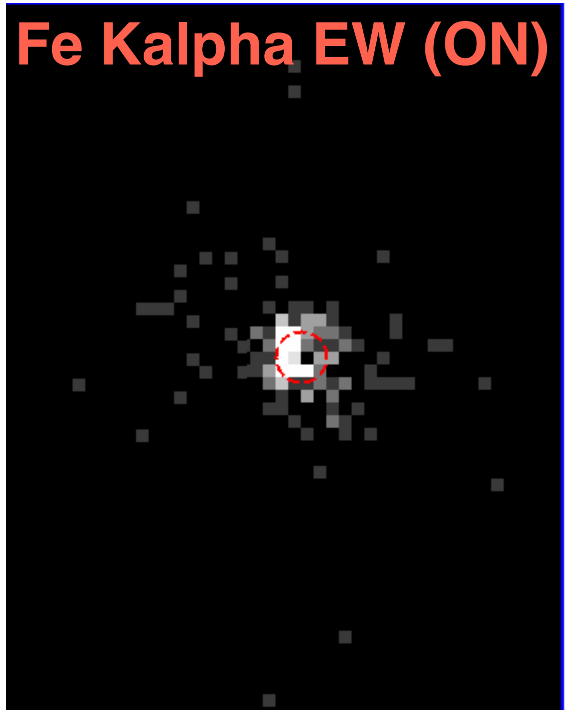
Circinus Galaxy
NGC 1068
Data
PSF sim
r-2 profile
signif. %
outside nuc.
2-5”
5-12”
2-25”
12-25”
Surface Brightness (cnts/arcsec2)
Difference
Radius (arcsec)
Angle (deg)

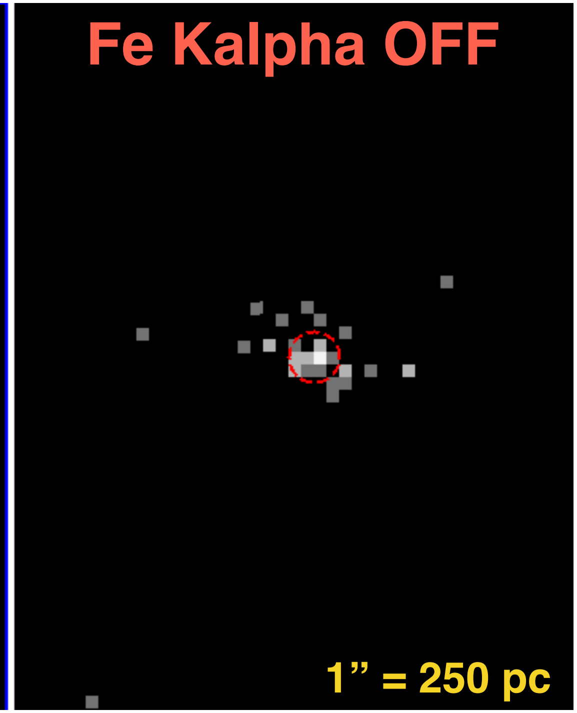
NGC 3393

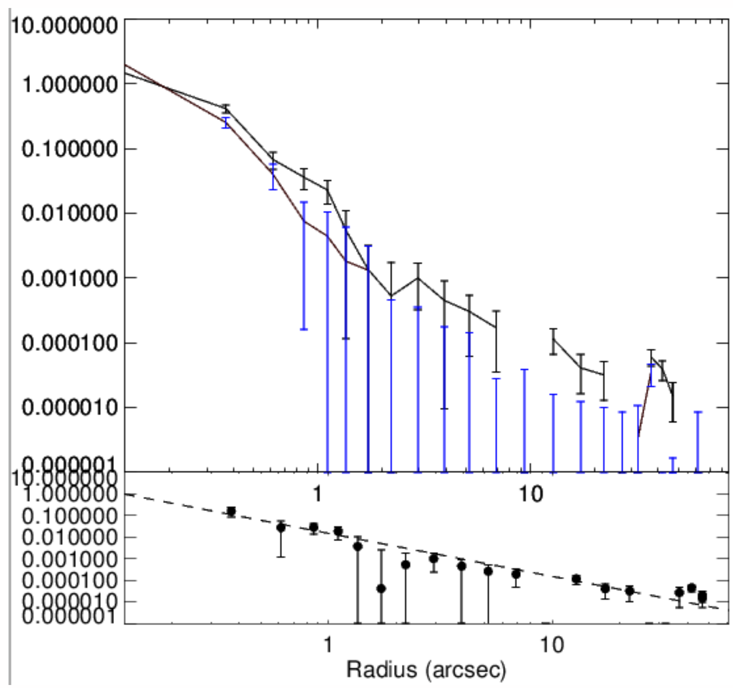




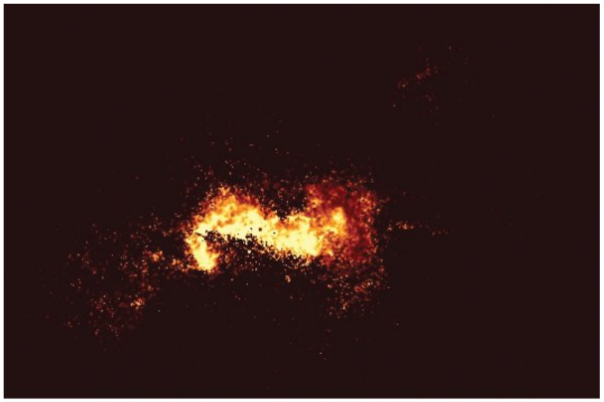
Koss et al. 2014

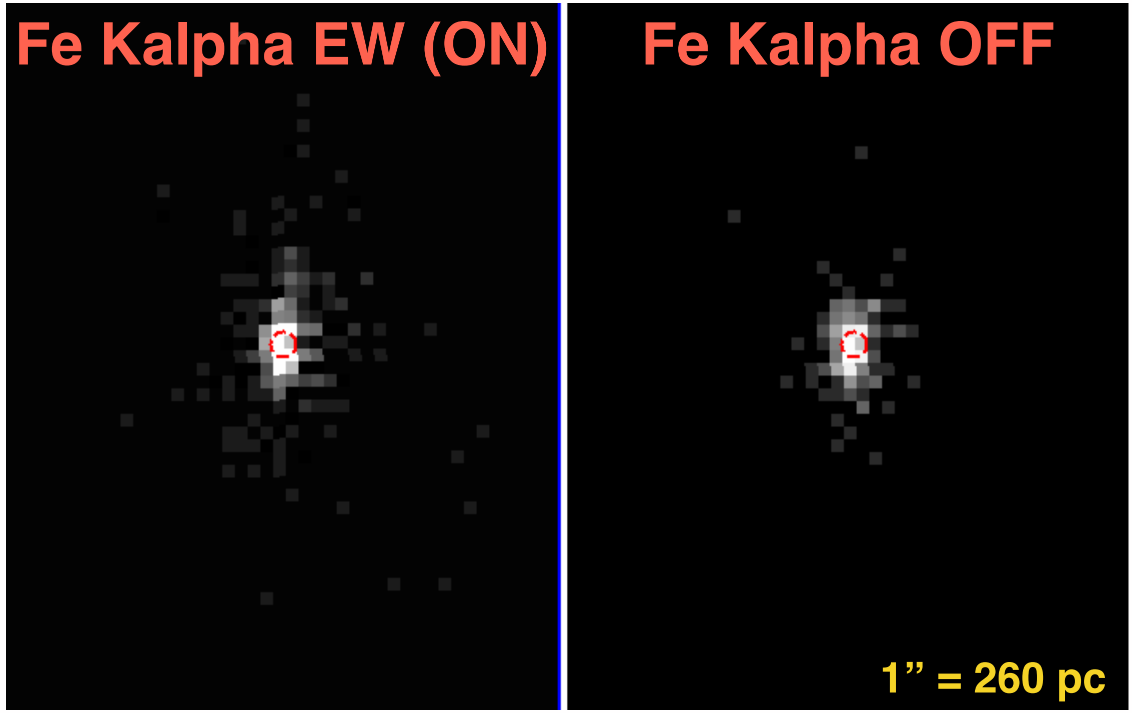


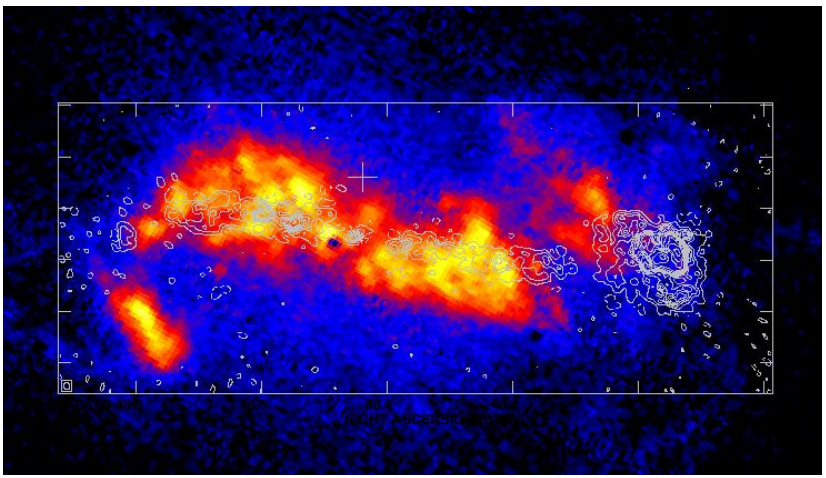


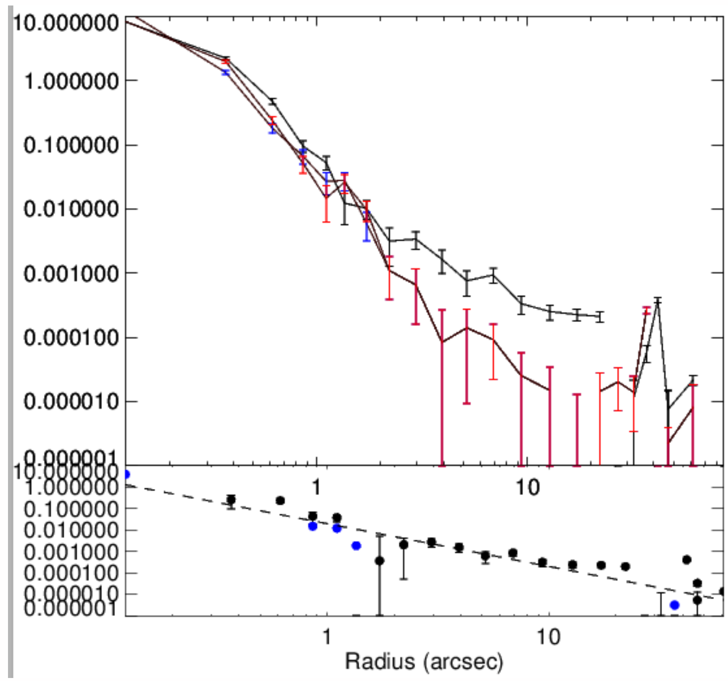


MRK 3





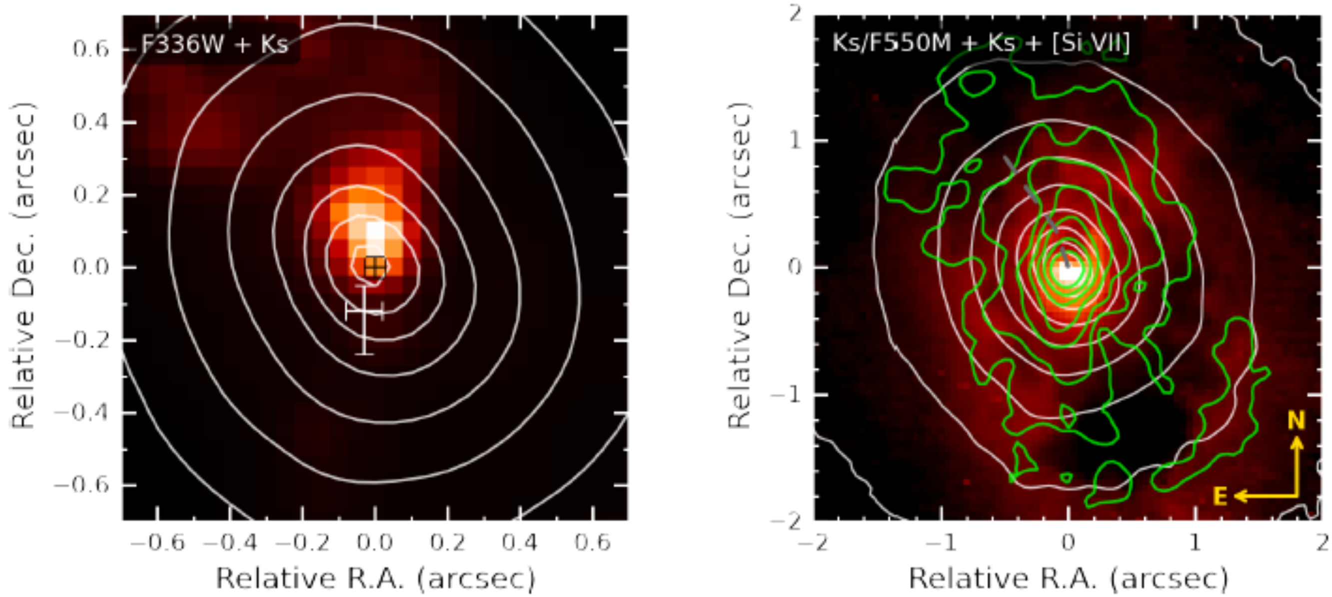




Kukula et al. 1999
Crenshaw et al. 2010

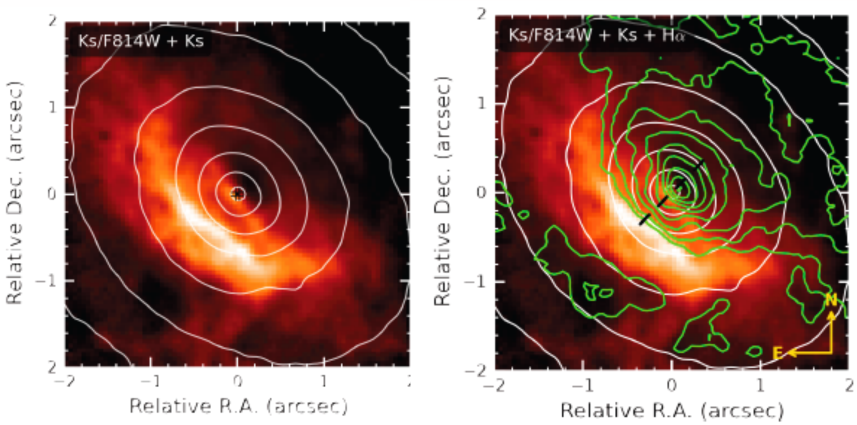
INTERESTING TO COMPARE TO HOST DUST

NGC 1068



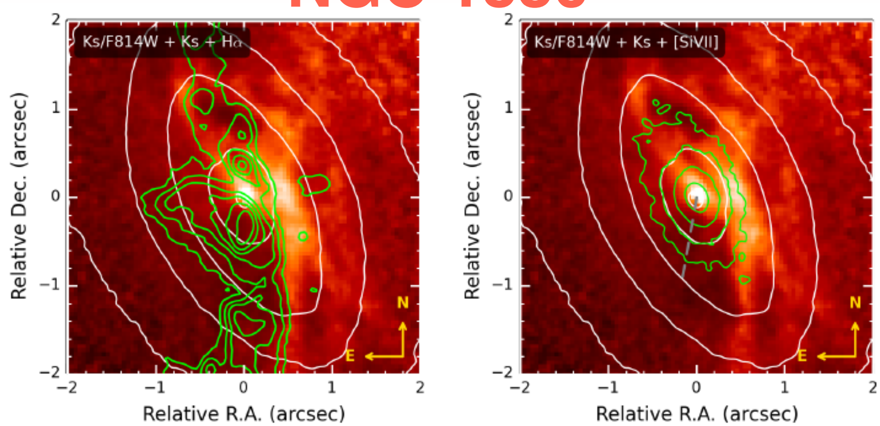
1”=70pc

NGC 3169



1”=120pc

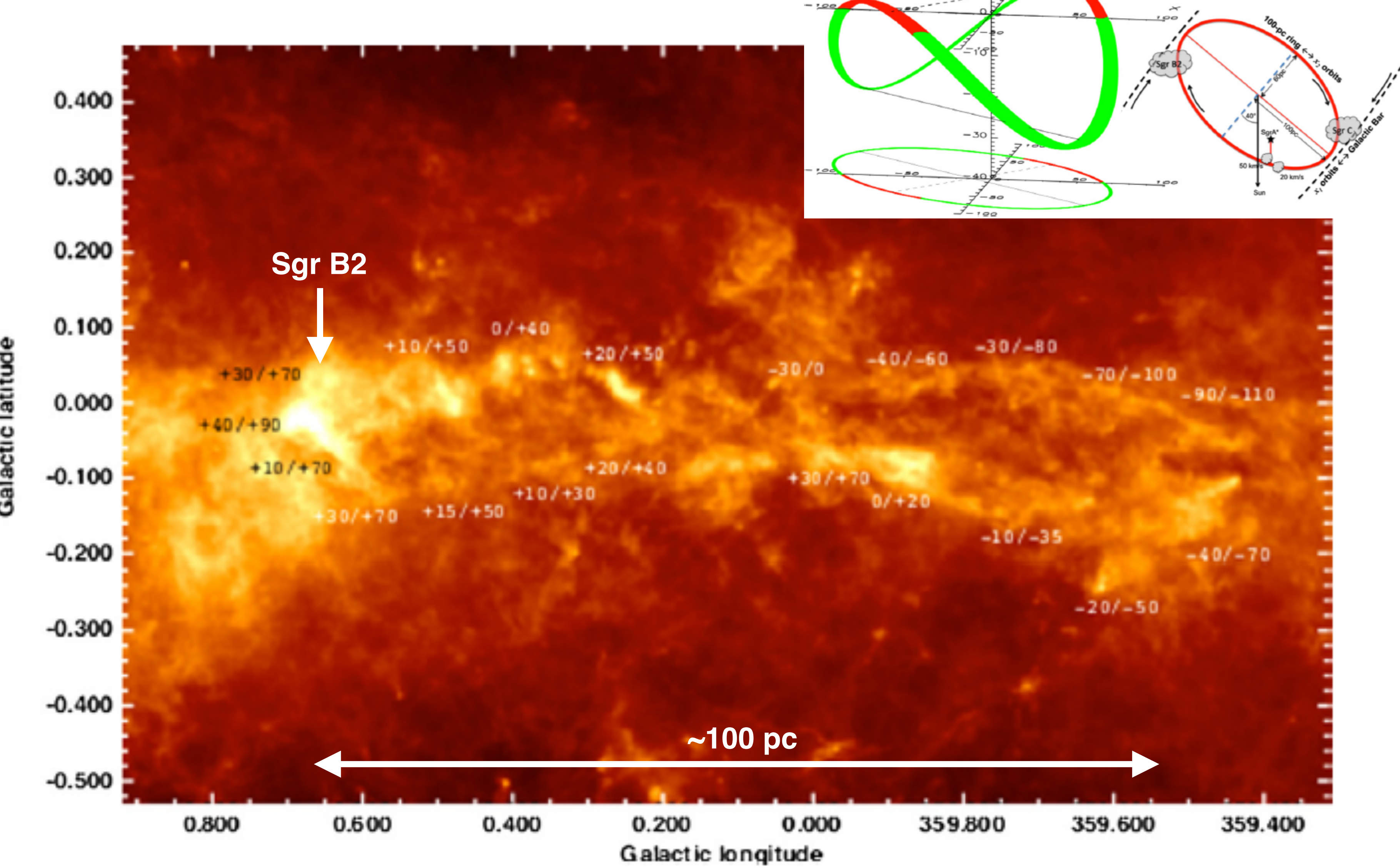
NGC 1386



1”=74pc

Prieto et al. 2014 (arXiv:1405.5653)

Milky Way



Atomic hydrogen column density map (4e22 to 4e25 cm-2)

Molinari et al. 2011

Conclusions

- Picture shaping up to be that molecular clouds on many scales likely contribute to **clumpy** obscuration.
- Likely a variety of filling factors; probably variety of covering factors too
- Start thinking of the torus as **clumpy** and comprised of multiple structural components (MIR people already do this, but others need to as well).
- Classical "torus" is not necessarily needed to produce Compton-Thick AGN

- How does this larger scale structure tie into the AGN feeding process?
- How does this structure change as a function of AGN luminosity (e.g., receding torus)?
- How does this larger structure affect our classification schemes?