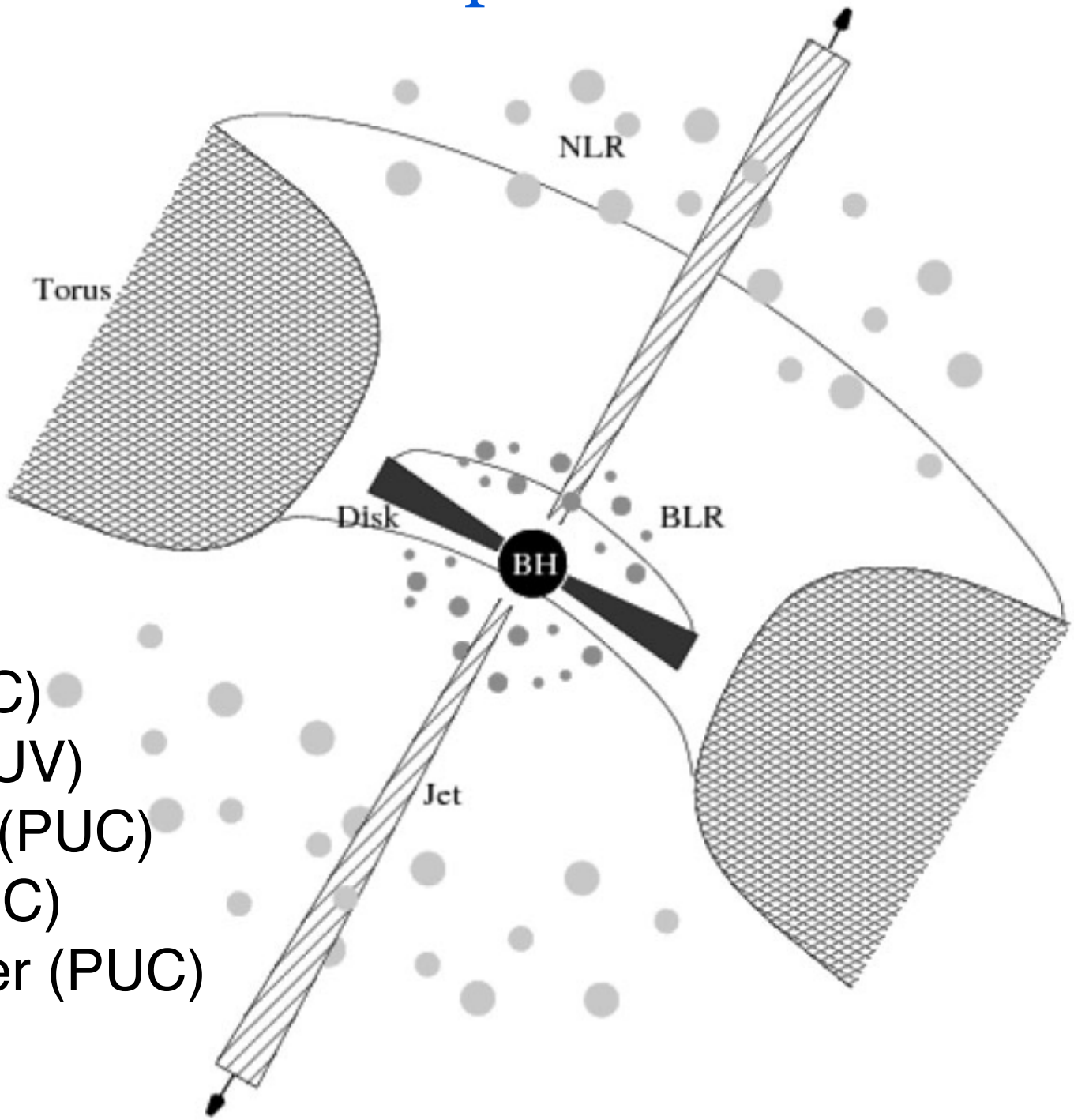
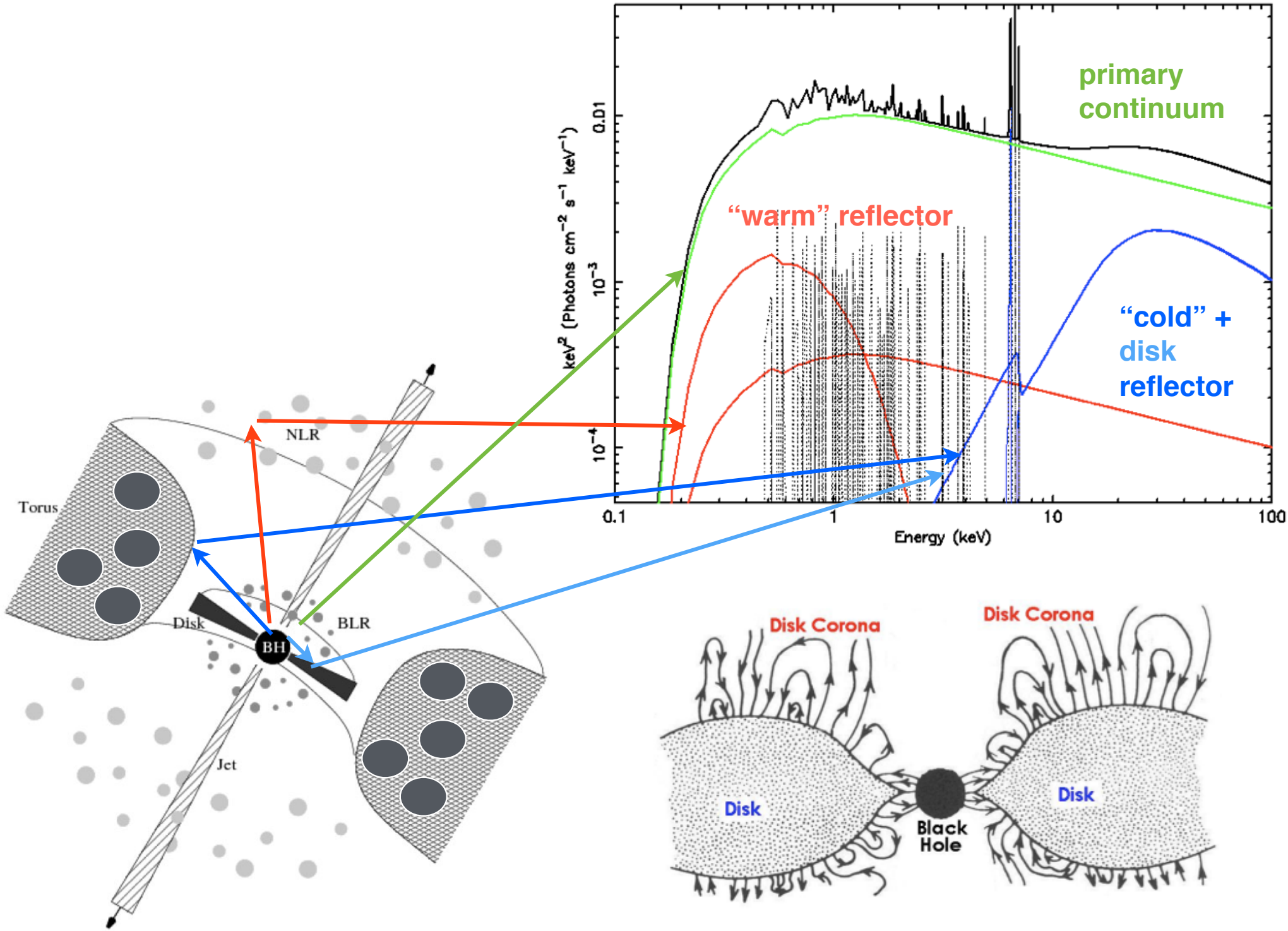
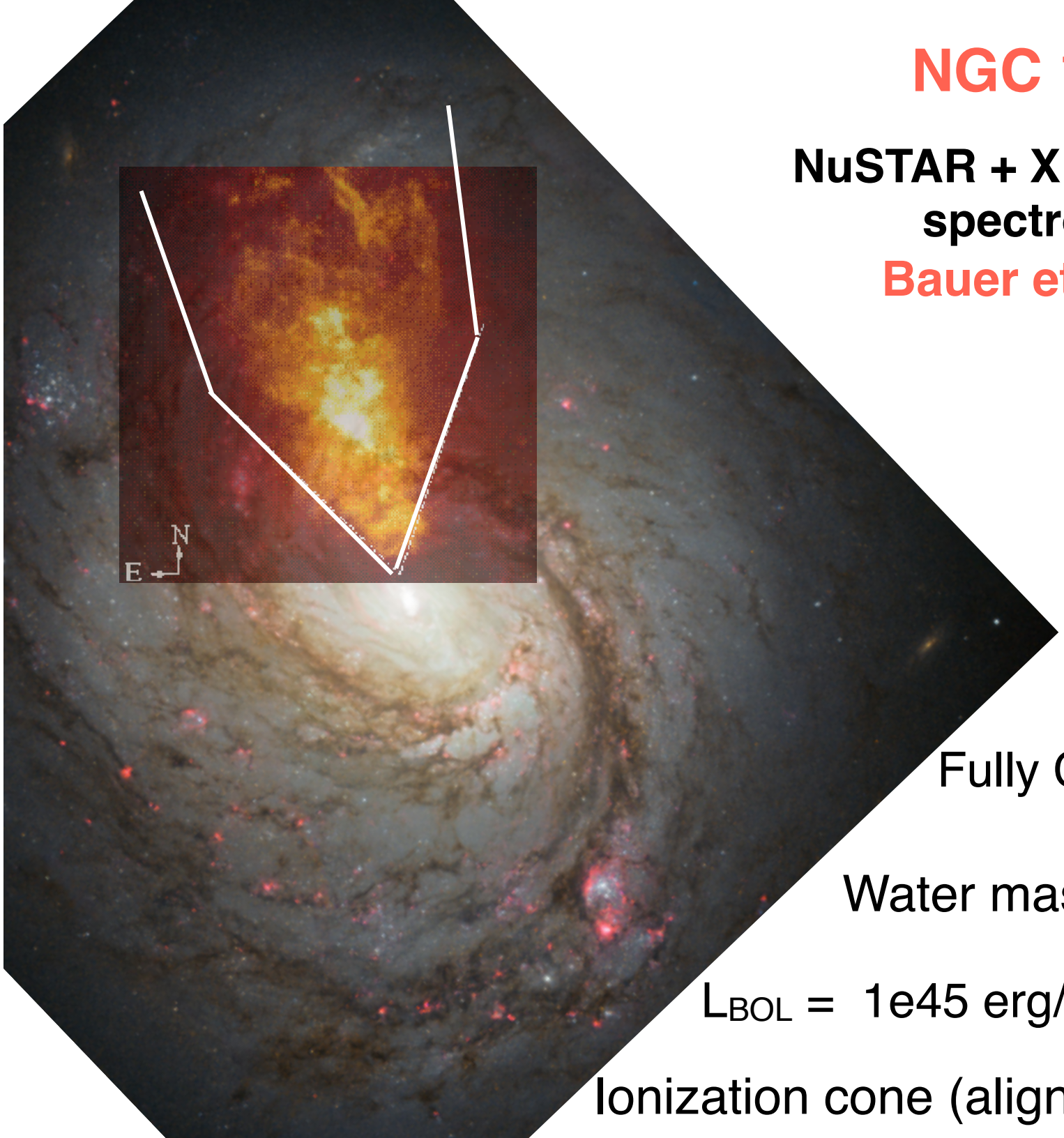
Ubiquitous Extended Fe K-alpha emission in AGN



Franz Bauer (PUC)
Patricia Arévalo (UV)
Ezequiel Treister (PUC)
Claudio Ricci (PUC)
Johannes Buchner (PUC)
+ others


primary
continuum
"warm" reflector
"cold" +
disk
reflector
keV² (Photons cm⁻² s⁻¹ keV⁻¹)
0.01
10⁻³
10⁻⁴
0.1
1
10
100
Energy (keV)
Torus
NLR
Disk
BLR
BH
Jet
Disk Corona
Disk Corona
Disk
Disk
Black
Hole



NGC 1068

NuSTAR + XMM+Chandra spectroscopy

Bauer et al. 2015

~14.4 Mpc

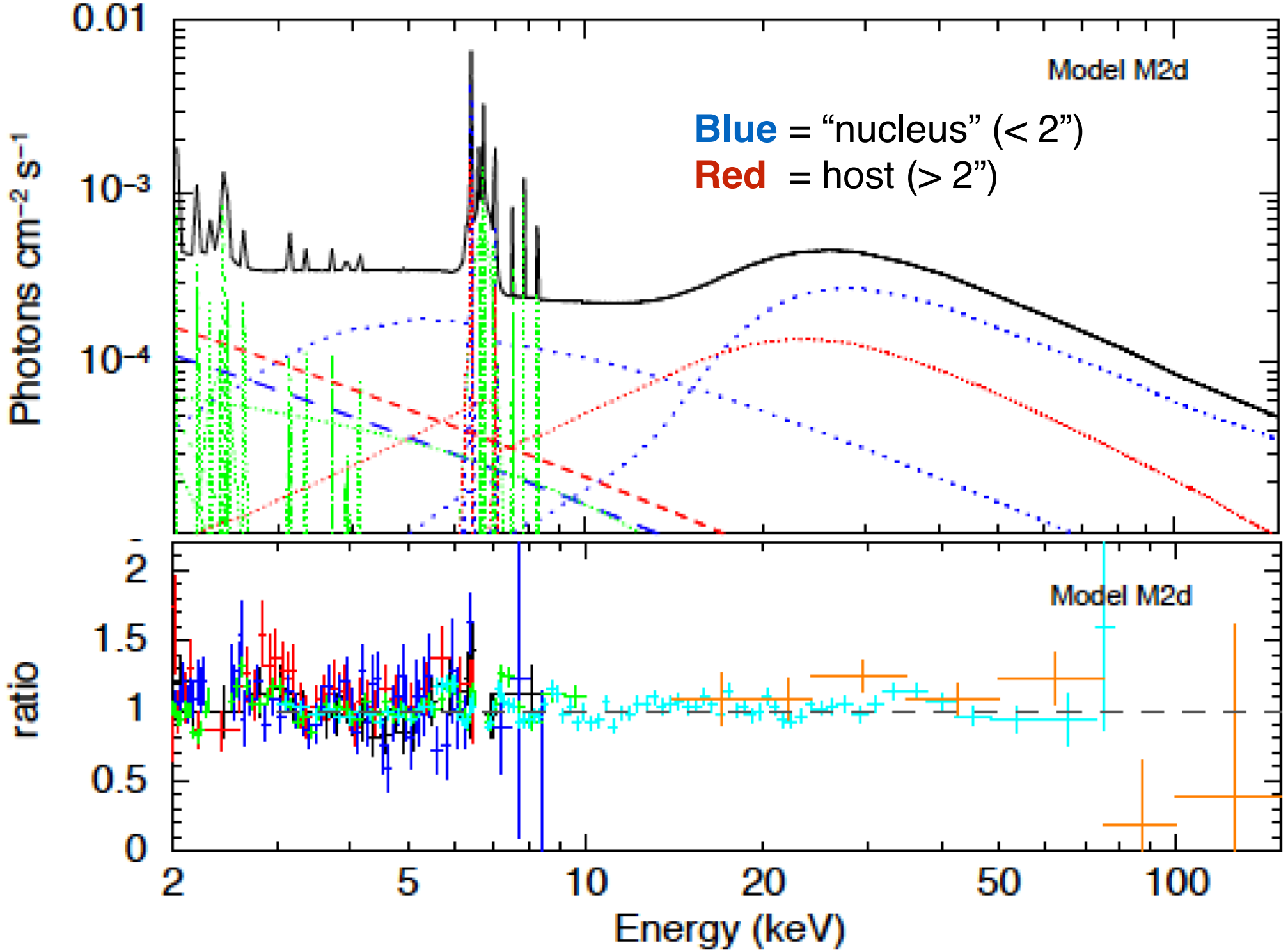
Fully CT (N_H>10^{25} cm^{-2})

Water maser => 1e7 M_{BH}

L_{BOL} = 1e45 erg/s => 0.5-0.8 L_{EDD}

Ionization cone (aligned with radio jet)

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



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

TABLE 4
FE AND NI LINE FLUXES (M04 MODEL)

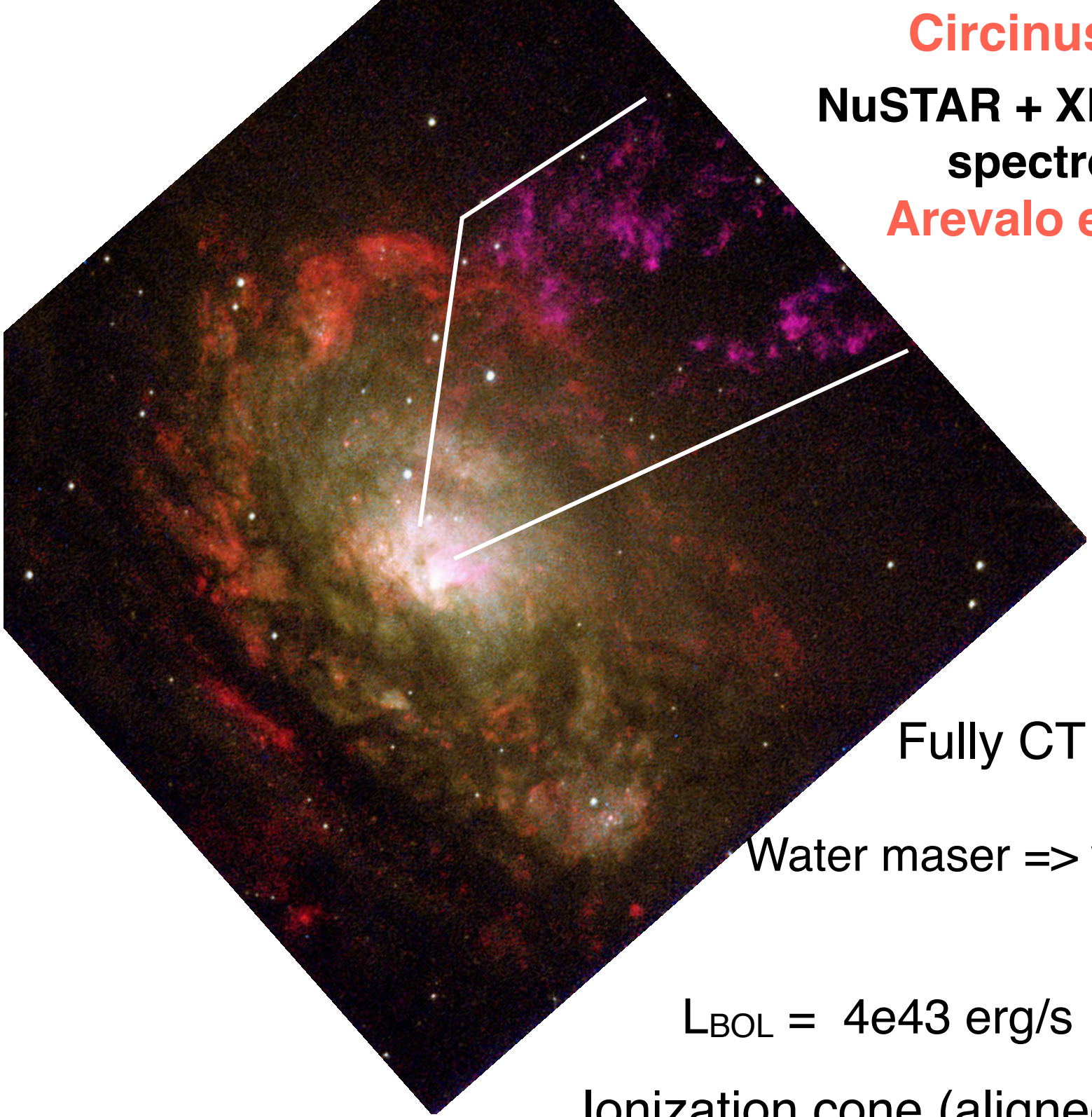
Line	*XMM-Newton* M04 <40″	*XMM-Newton* this work <75″	*Chandra* HETG <2″	*Chandra* ACIS-S 2″-75″
Fe Kα	44.3	$47.4^{+1.9}_{-2.2}$	$38.9^{+3.8}_{-3.8}$	$17.5^{+3.3}_{-3.3}$
Fe Kα CS	8.7	$3.8^{+1.5}_{-2.2}$	$4.2^{+3.6}_{-2.2}$	< 1.5
Fe Kβ	9.1	$8.9^{+1.1}_{-1.5}$	$4.3^{+3.1}_{-1.9}$	< 5.2
Ni Kα	5.6	$5.8^{+1.8}_{-0.9}$	< 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 (+ 5-10 keV cont.) from lower N_H reflection.

Bulk of 30 keV hump coming from high N_H reflection

~30-35% of Fe reflection from > 2” (i.e., >140pc!!)

Encountering signs of very complex multi-phase environments near AGN



Circinus Galaxy

NuSTAR + XMM+Chandra spectroscopy

Arevalo et al. 2014

~4 Mpc

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

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

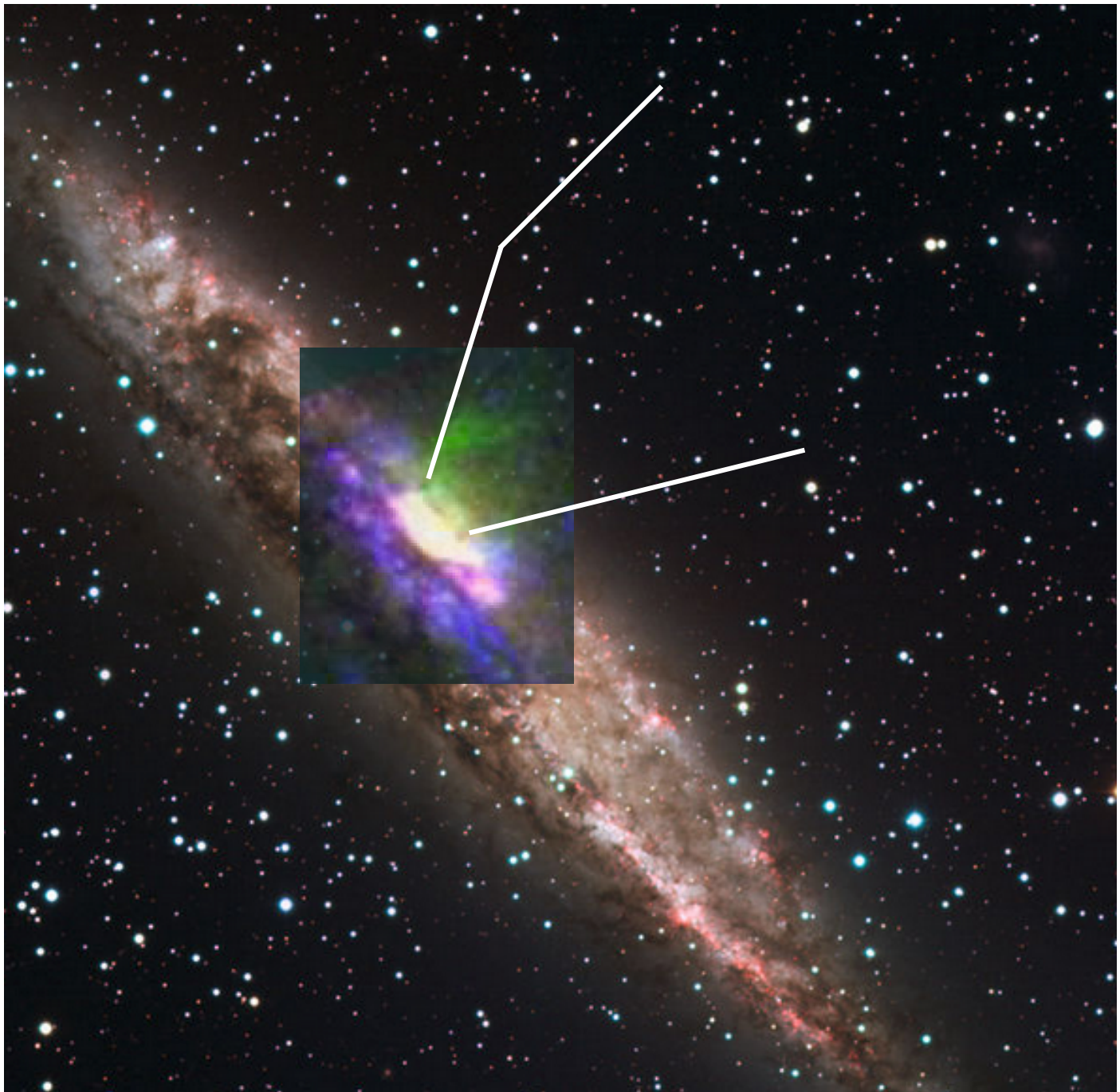
L_{BOL} = 4e43 erg/s => 0.2 L_{EDD}

Ionization cone (aligned with radio jet)

NGC 4945

NuSTAR + XMM+Chandra spectroscopy

Puccetti et al. 2014



~4 Mpc

Moderate CT
(N_H~4x10^{24} cm^{-2})

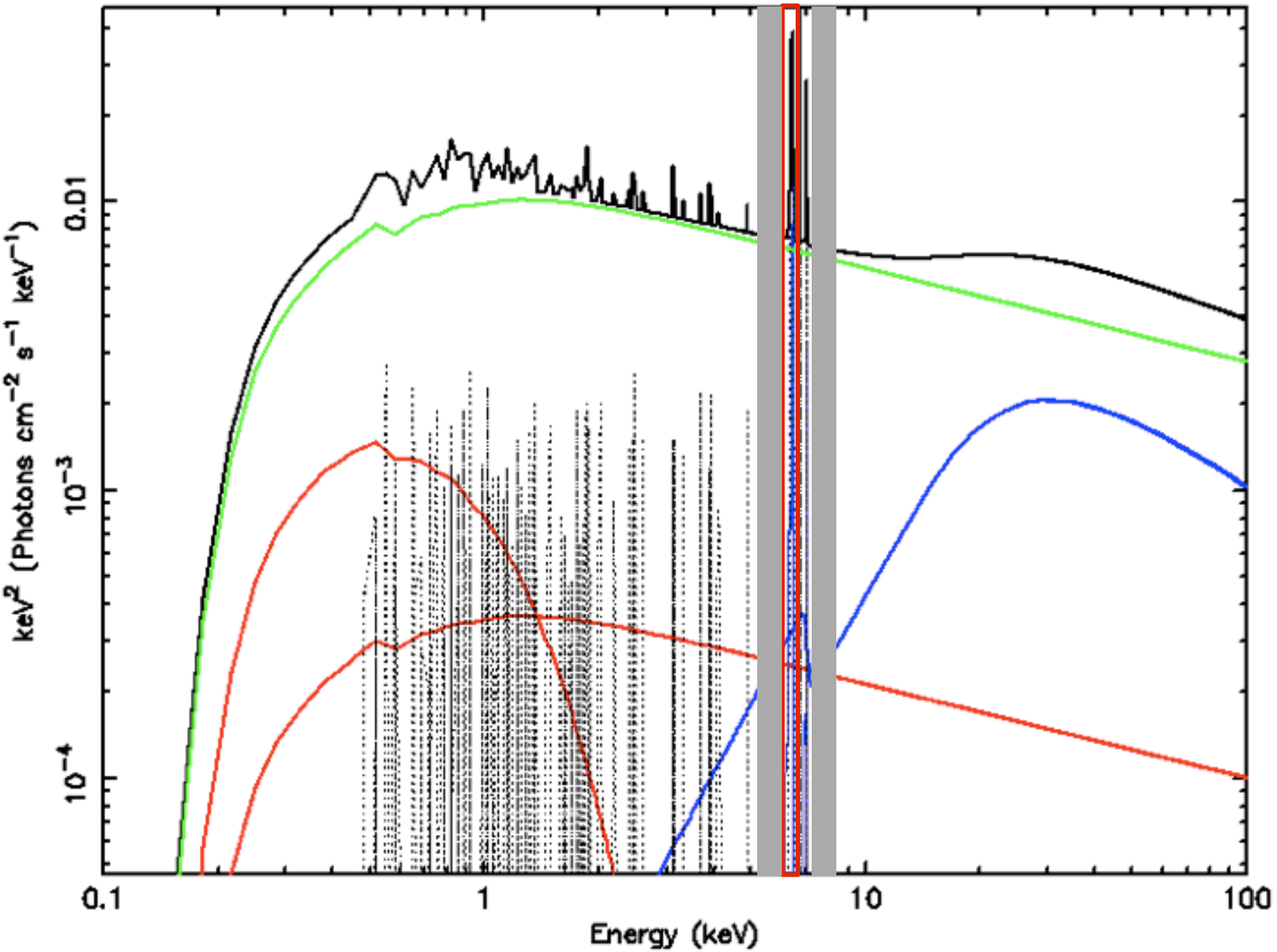
Water maser
=> 1.4e6 M_{BH}

L_{BOL} = 4e43 erg/s
=> 0.1-0.3 L_{EDD}

Ionization cone
(aligned w/ radio jet)

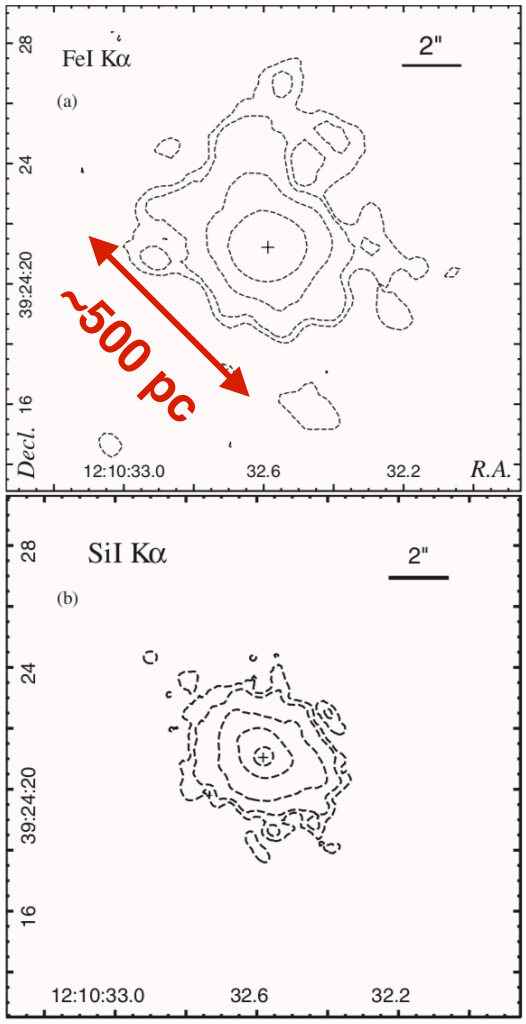
What about spatial distribution of Reflection?

To investigate further, look at narrow Chandra images

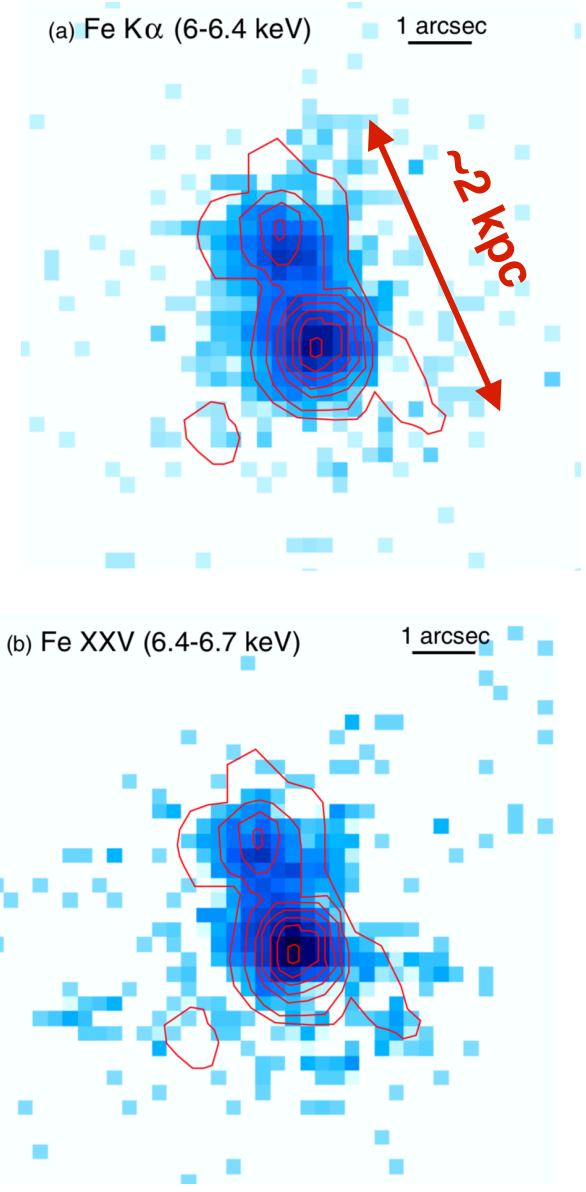


A number of previous AGN studies have highlighted extended Fe Ka emission:

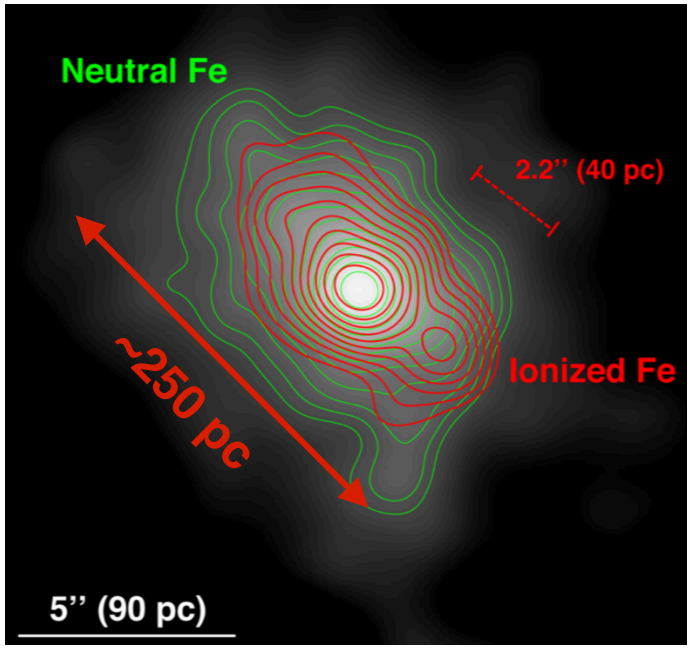
NGC 4151: Wang+11



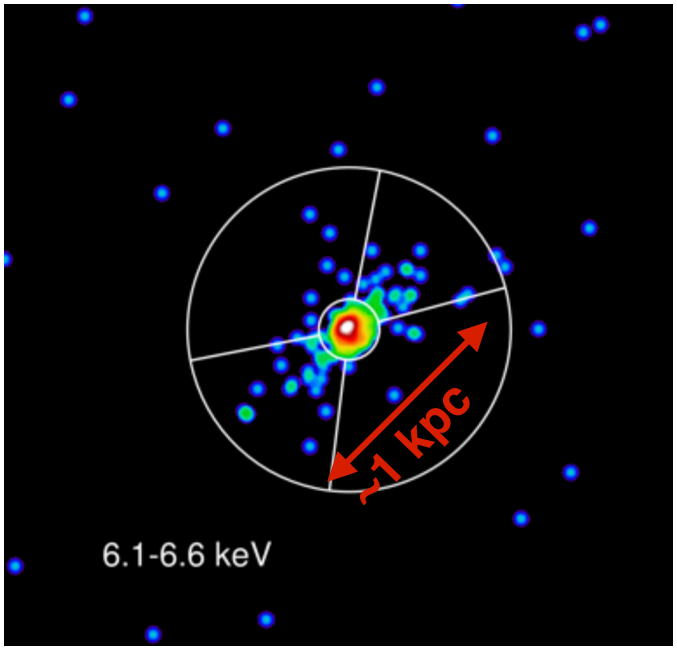
NGC 6240: Wang+14



NGC 4945: Marinucci+17

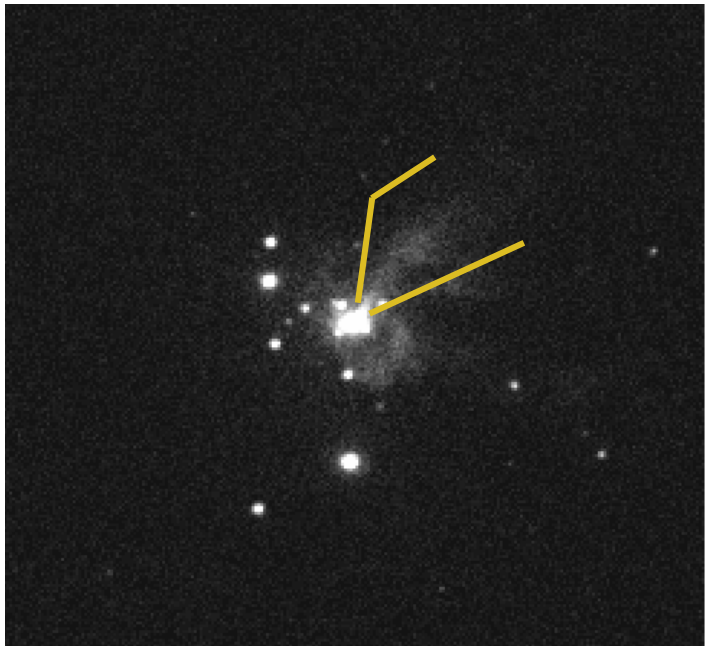


ESO428–G014: Fabbiano+17

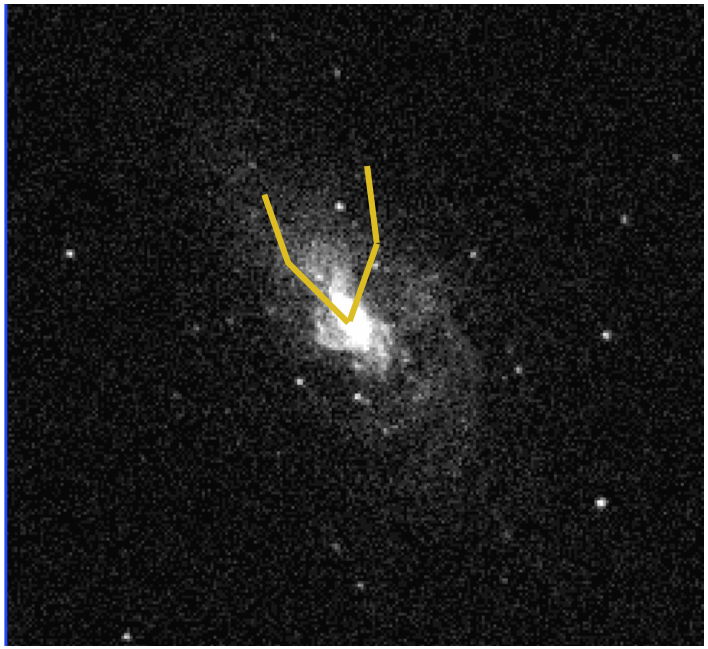


Compare 3 famous, nearby CTAGN

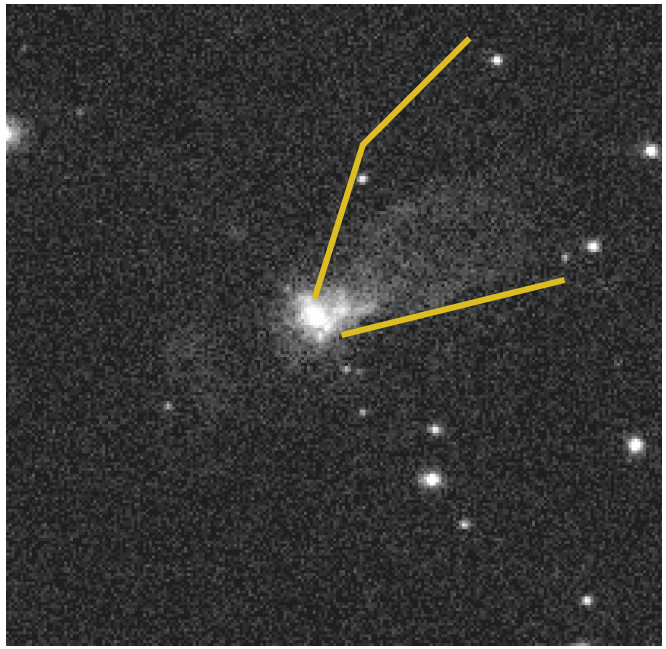
Circinus Galaxy



NGC 1068

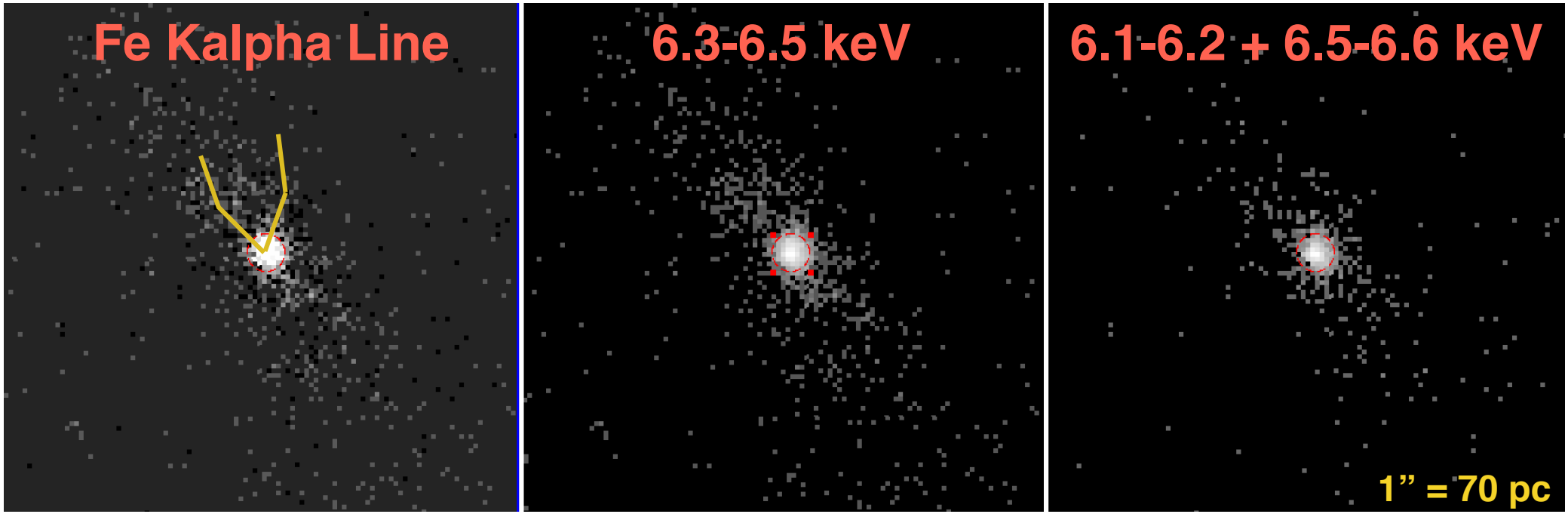


NGC 4945

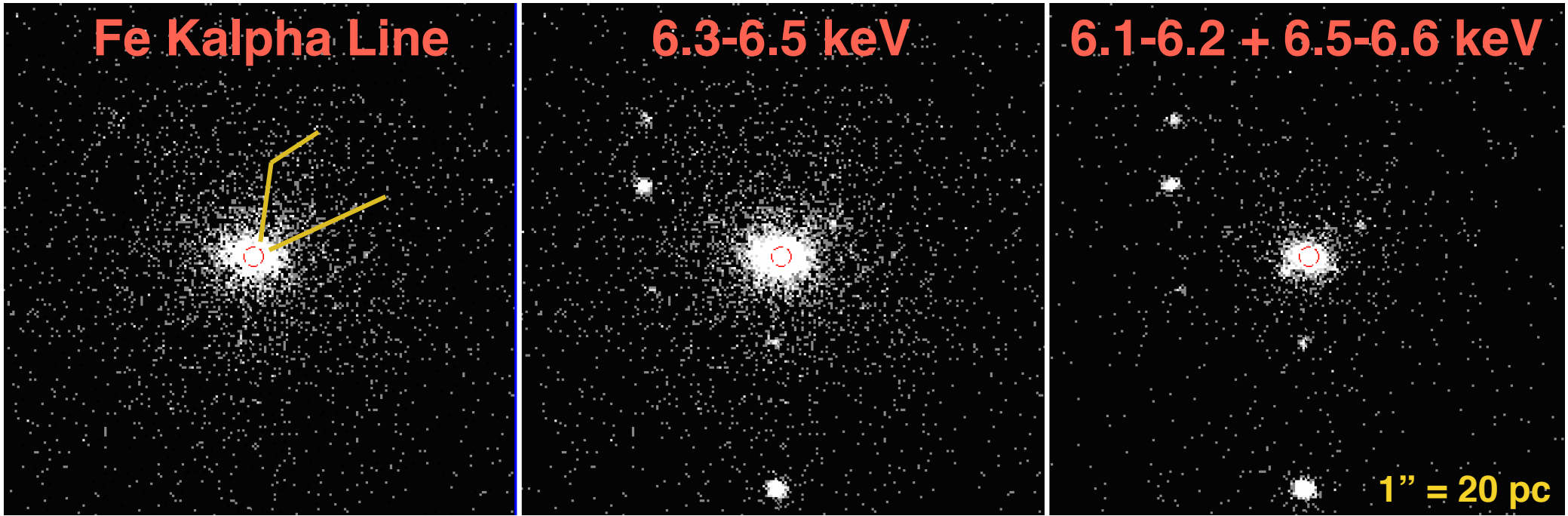


0.3-8.0 keV images

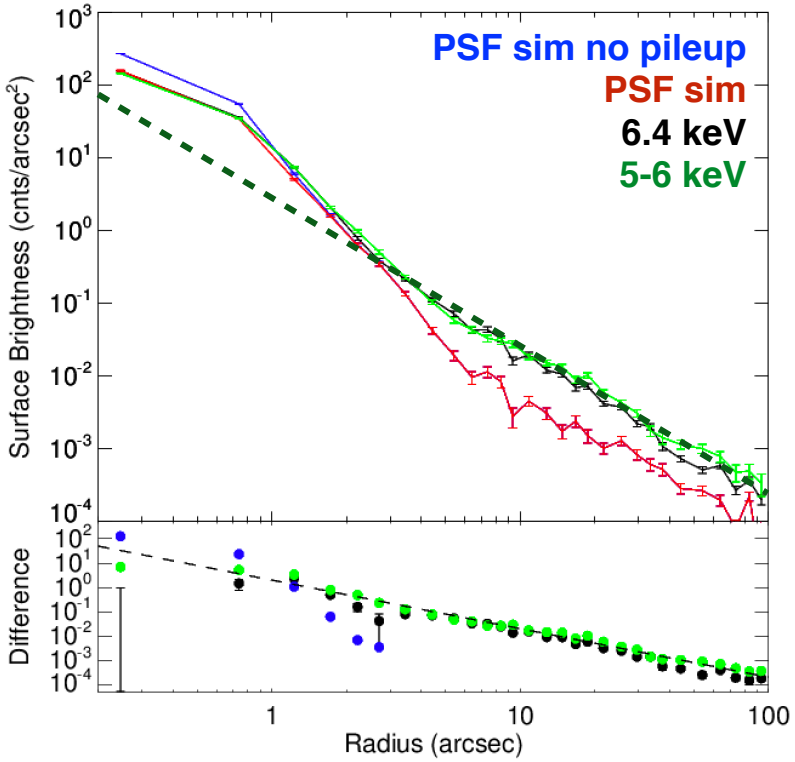
NGC 1068



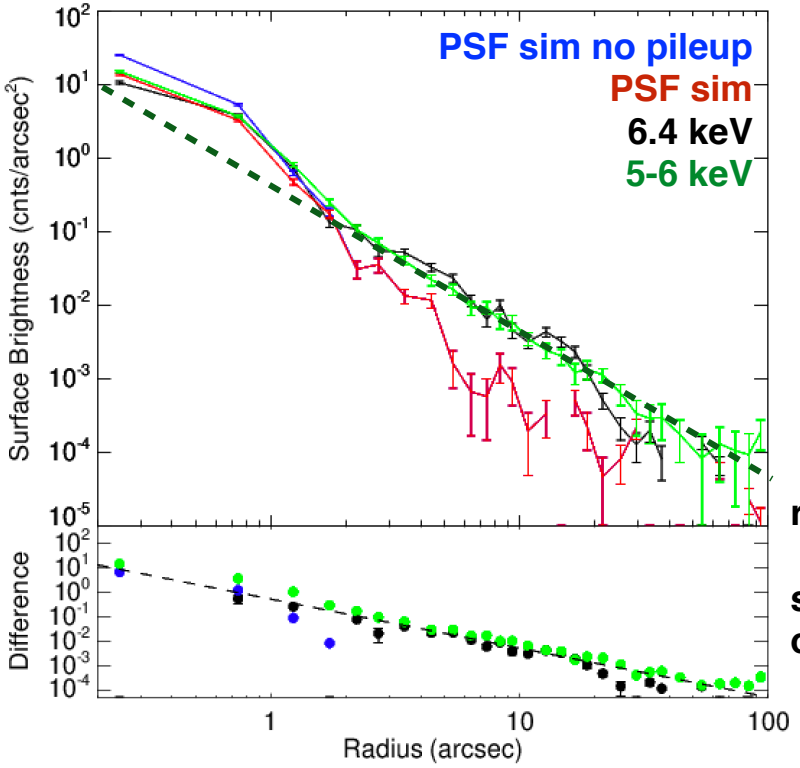
CIRCINUS



Circinus Galaxy

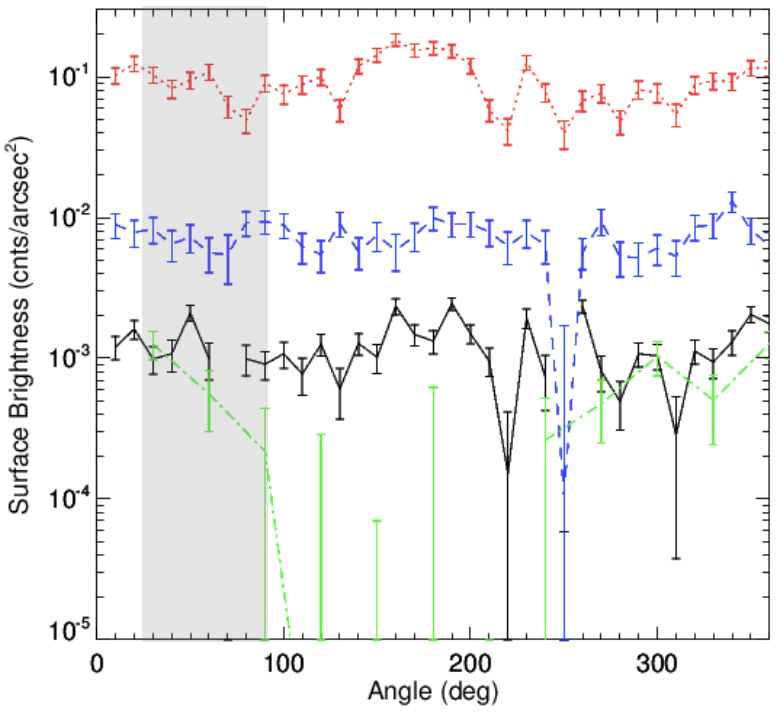


NGC 1068



r^{-2} profile

signif. % outside nuc.

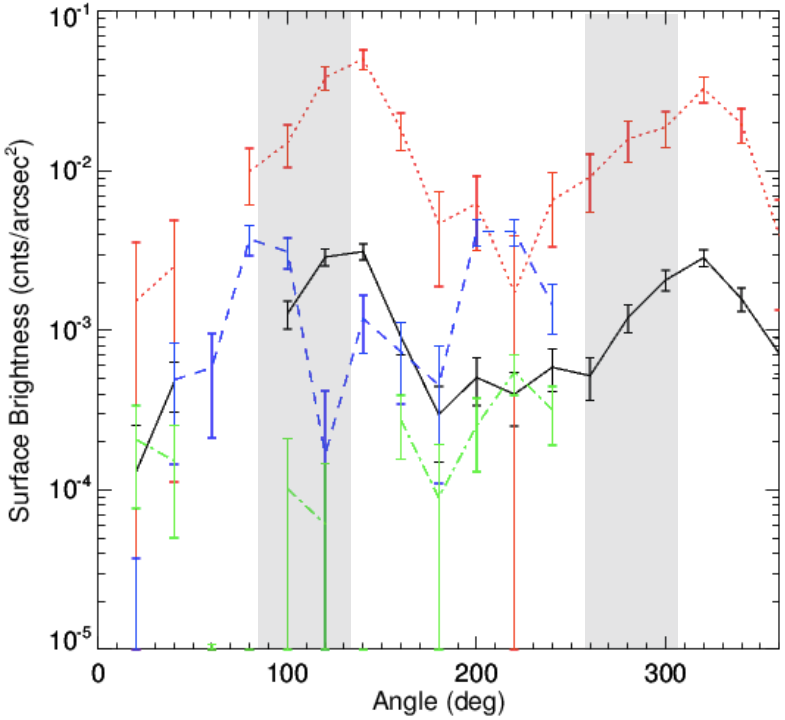


2-5”

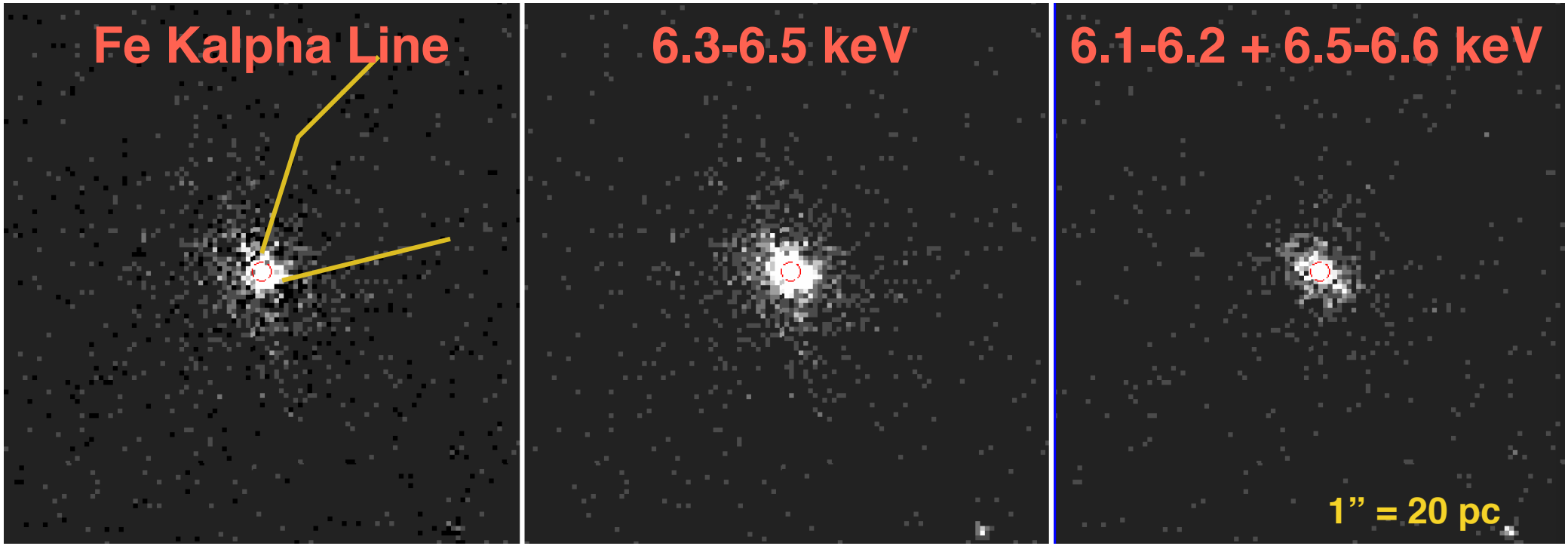
5-12”

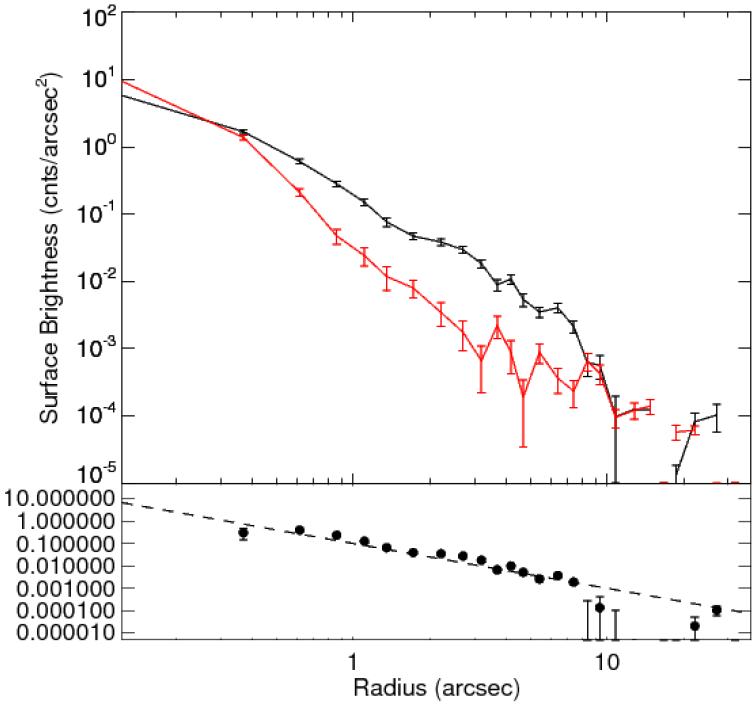
2-25”

12-25”



NGC 4945





Data
PSF sim

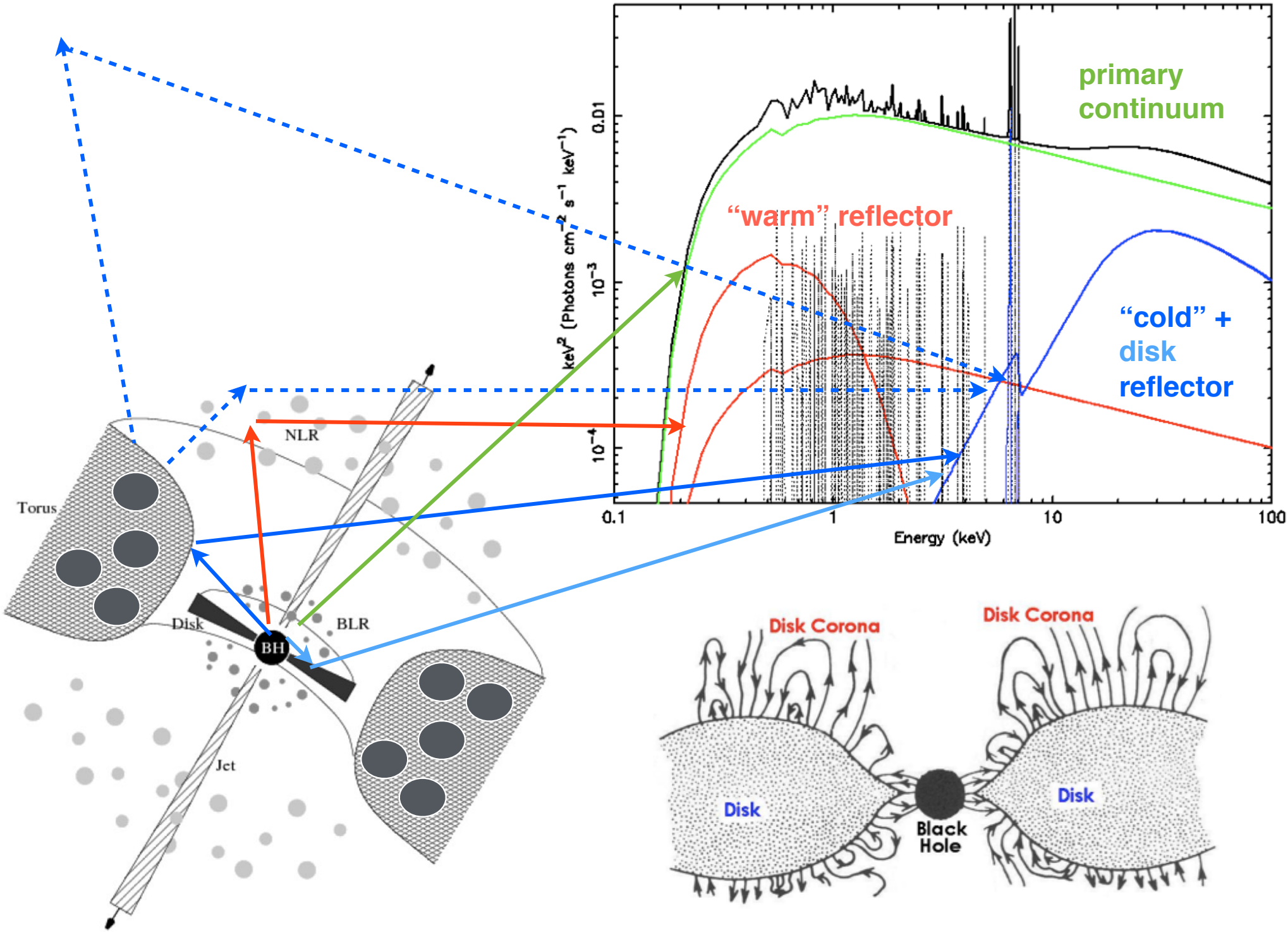
r^{-2} profile

signif. % outside nuc.

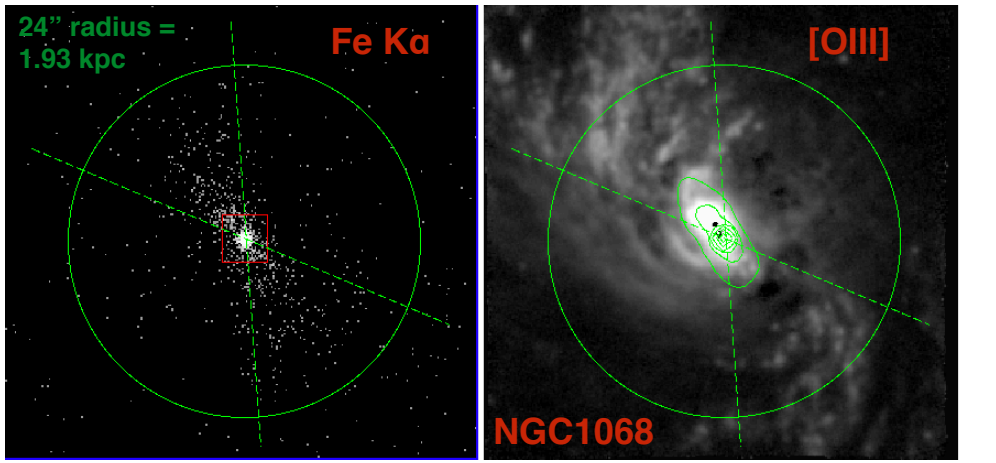
Similar extent to what Marinucci+17 found.

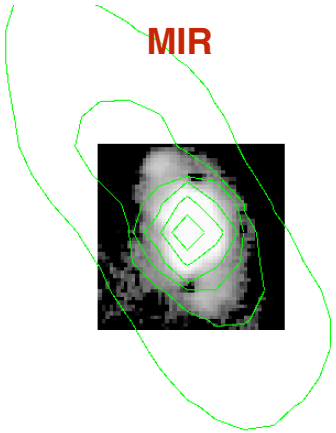
What are we seeing?

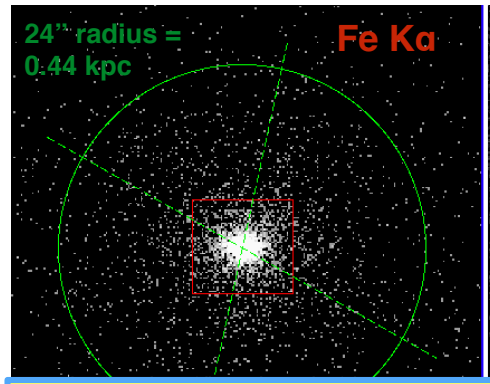
- **Bulk of Fe reflection likely (last) emitted at > 1pc out to > kpc scales**
  - ➡ **NOT from 0.4-1pc torus wall, as often (always?) assumed!**
  - ➡ **Extended Fe Kα produced in the central pc, but scattered at large radii due to neutral / ionised ISM mirror (*Thomson scattering*)?**
  - ➡ **OR Extended Fe Kα emission produce at large radii due to "dense" clouds or lines-of-sight (*Compton scattering*).**
- **Morphologies differ!**
  - ➡ **Fe Kα emission comes from variety of sight lines. Must depend on "internal" torus cloud geometry/structure & "external" structure of the ISM and ionisation cone scattering mirror.**
  - ➡ **Total spectra will give angle averaged X-ray reflection. Reflection fraction is at least in part based on ISM. Torus models will need to account for this.**
- **The spatially resolved morphology of the Fe Kα gives insight into structure of torus and/or mirror.**
  - ➡ **Fe Ka tomography can provide novel constraints on cloud density, number, and position.**

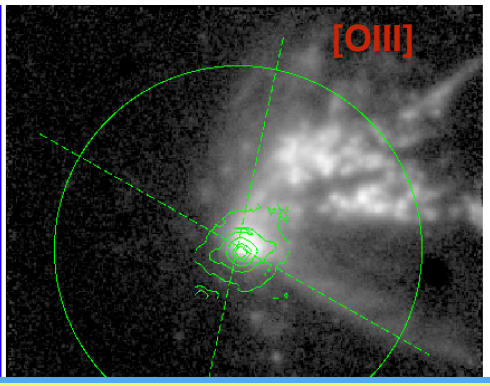

primary
continuum
"warm" reflector
"cold" +
disk
reflector
keV² (Photons cm⁻² s⁻¹ keV⁻¹)
0.01
10⁻³
10⁻⁴
0.1
1
10
100
Energy (keV)
Torus
NLR
Disk
BLR
BH
Jet
Disk Corona
Disk Corona
Disk
Black
Hole
Disk

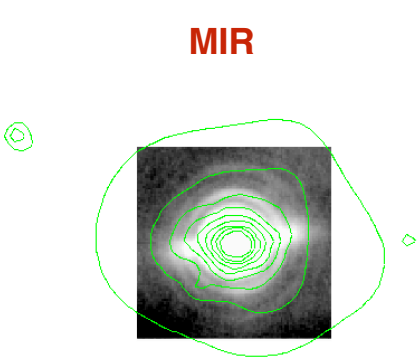
morphology of various torus "tracers"

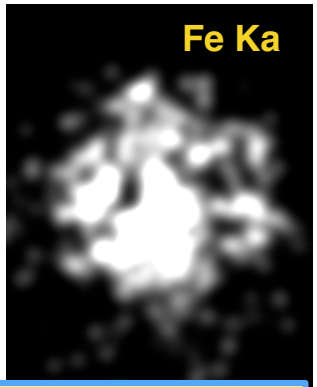












Correspondence between tracers is poor

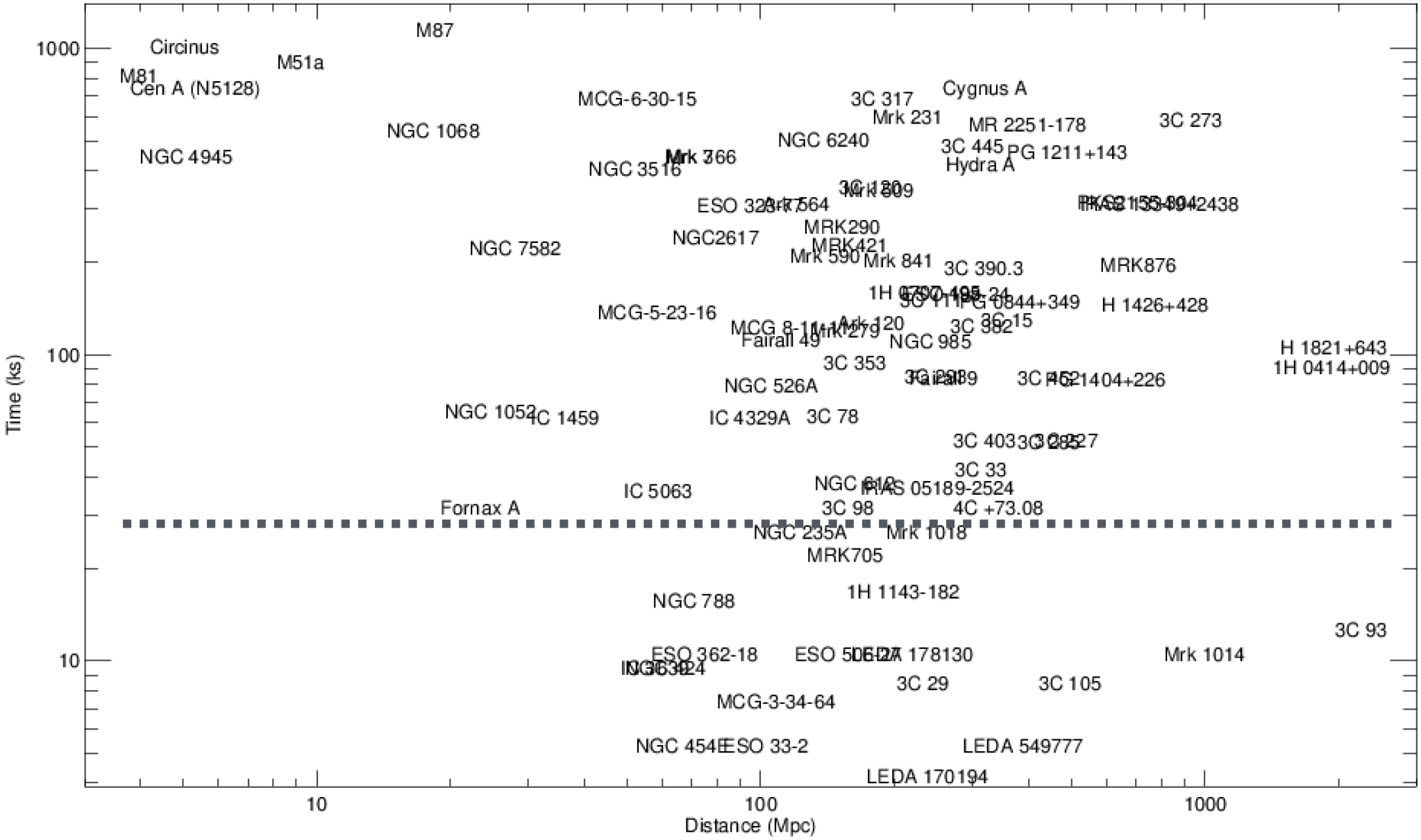
morphology of Fe Kα an imprint of 10^{24} cm^2 torus

" of [OIII] an imprint of much lower N_H torus

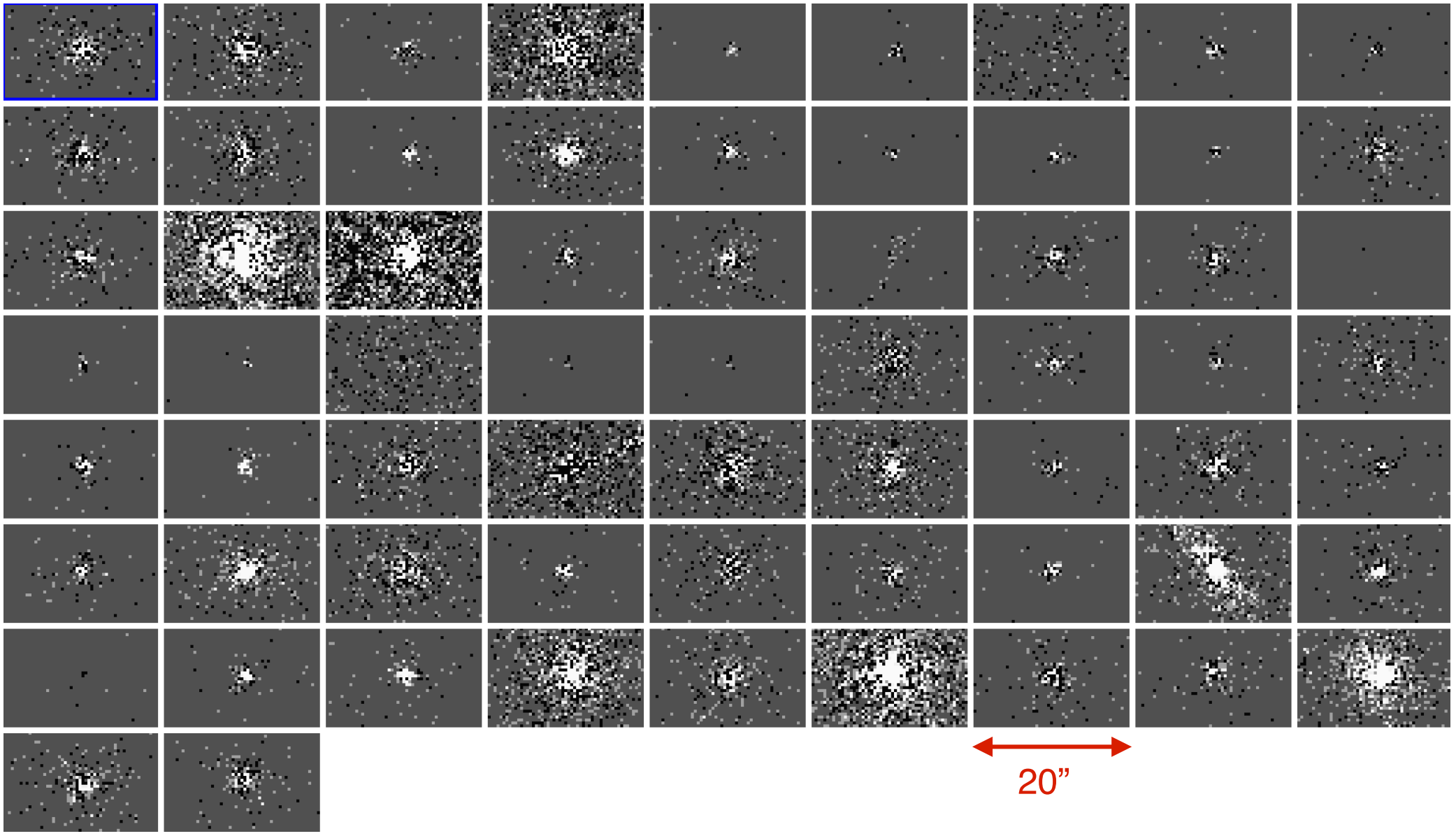
" of mid-IR an imprint of hot dust

What about other well-known AGN? Start with Asmus et al. 2015 sample ("representative") of 152 nearby AGN with IR and X-ray constraints + 28 others => 99 objects considered, although only fraction useful.

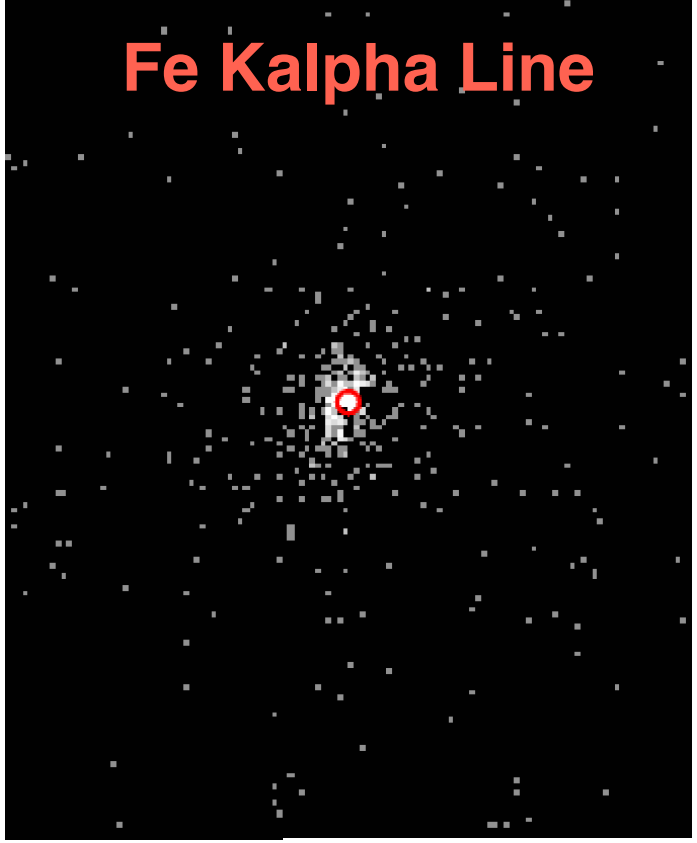
Simple statistic: estimate % of Fe Ka > 1" (corrected for PSF, 15%)

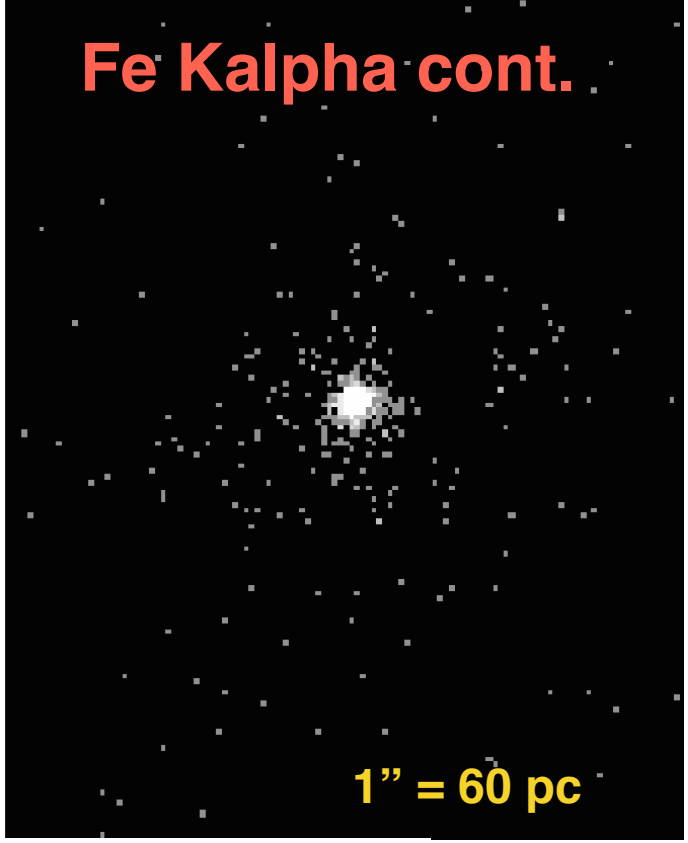


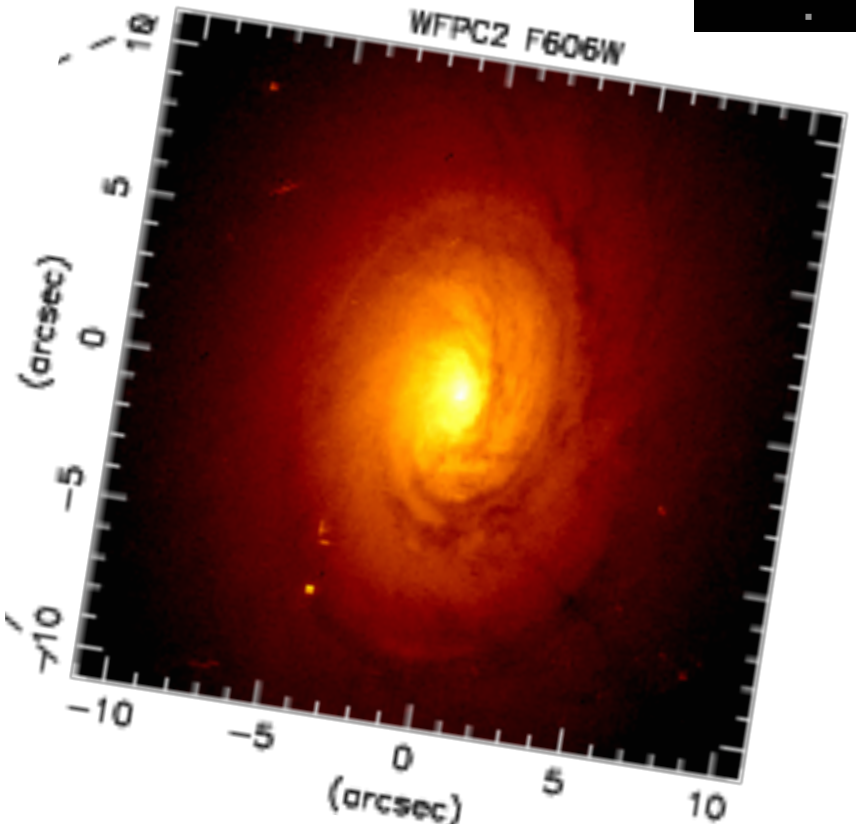
Kα EW images for 65 AGN so far…

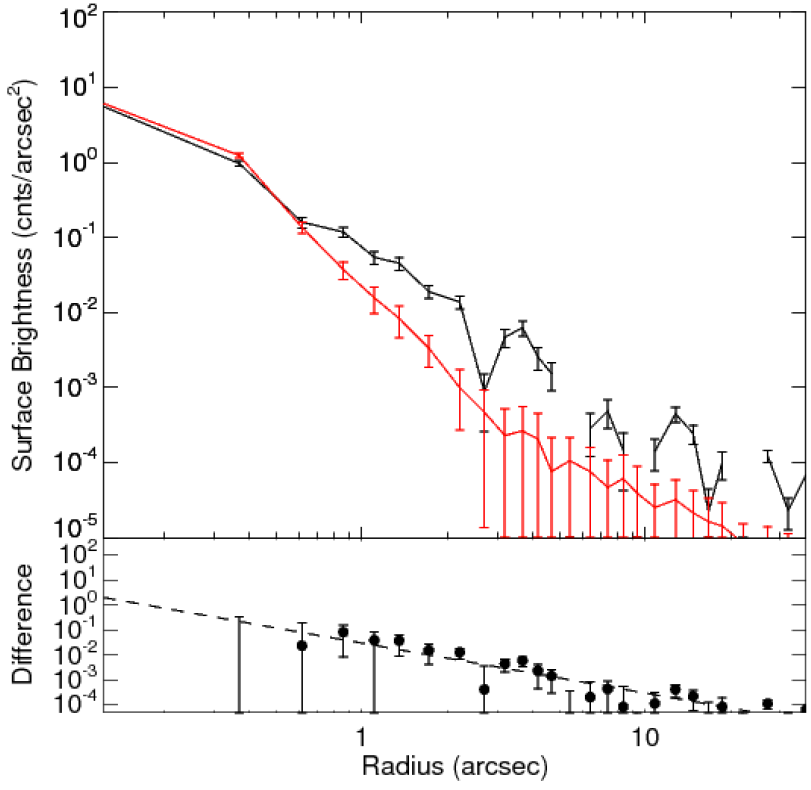


NGC 2110
Sy 1

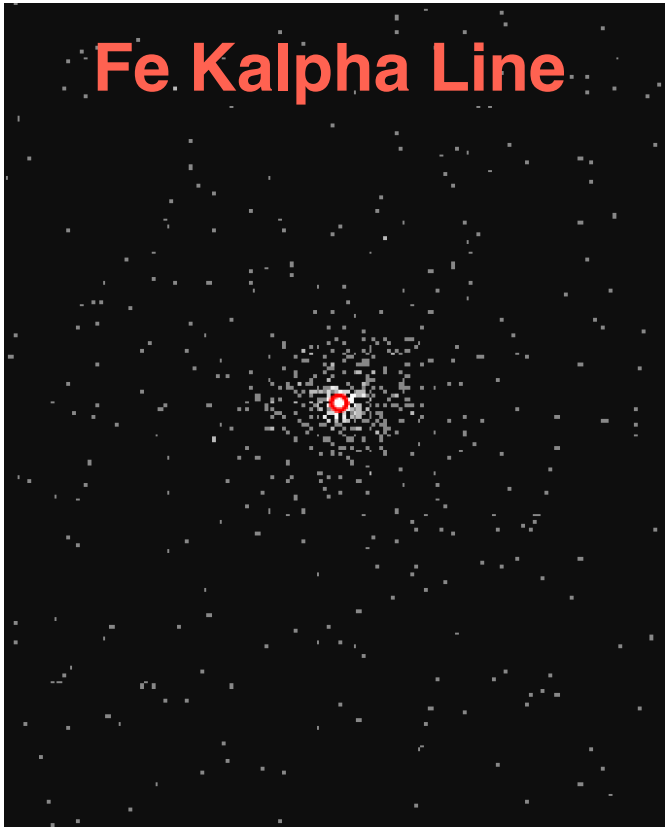

Fe Kalpha Line

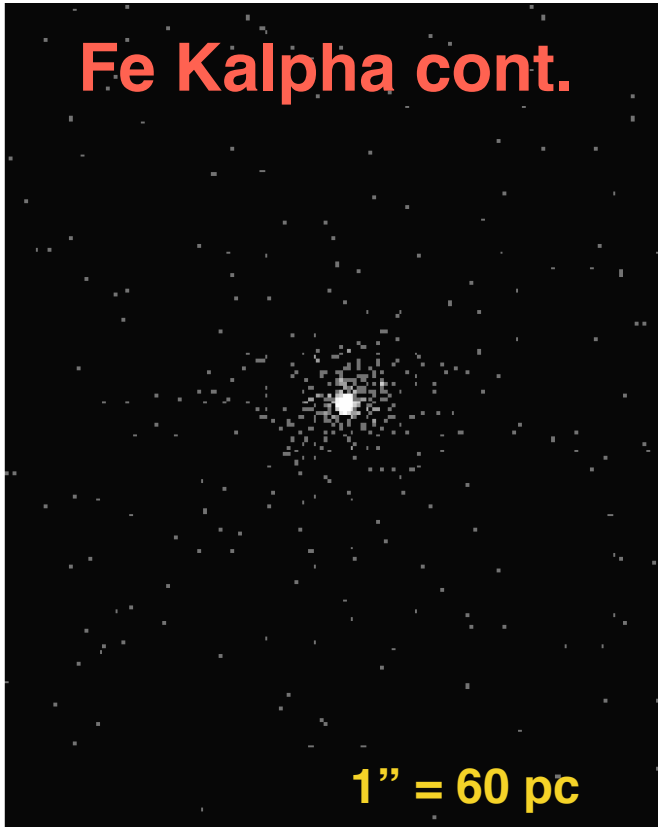

Fe Kalpha cont.
1” = 60 pc

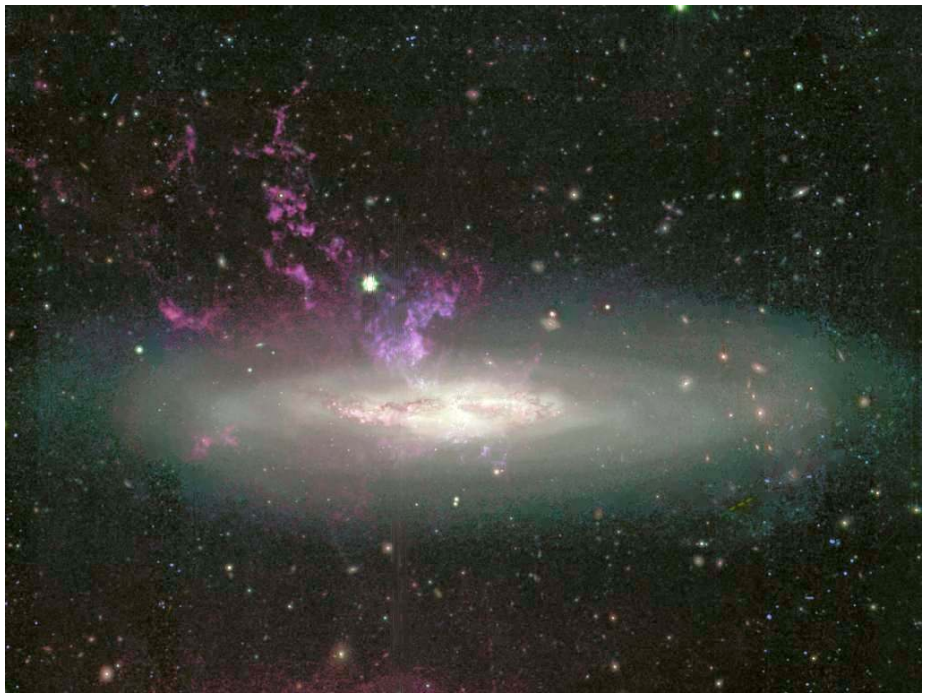

WFPC2 F606W
(arcsec)
(arcsec)
10
5
0
−5
−10

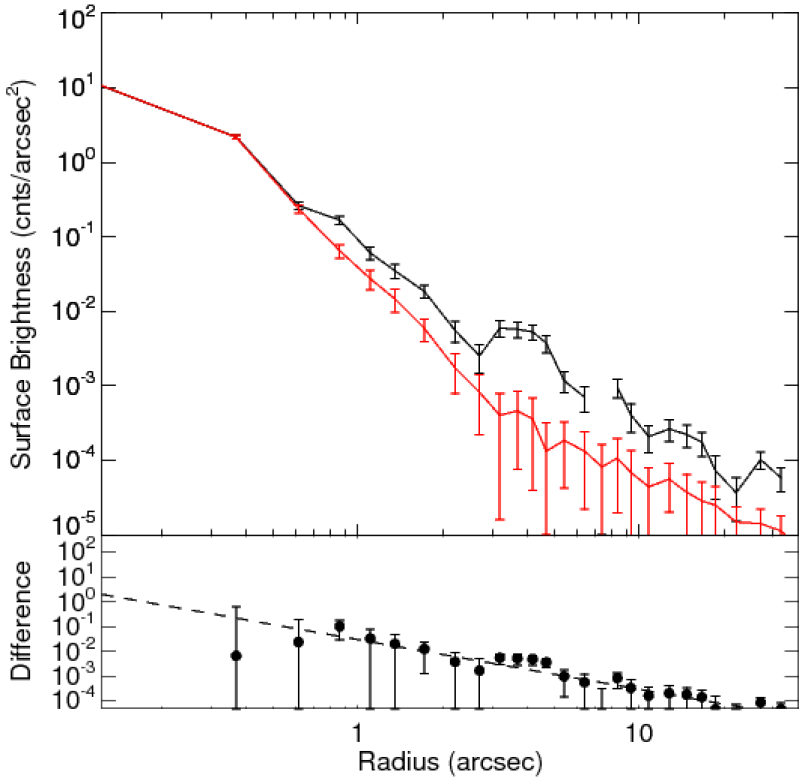

Surface Brightness (cnts/arcsec²)
Difference
Radius (arcsec)
1
10

NGC 4388
Sy 1.9

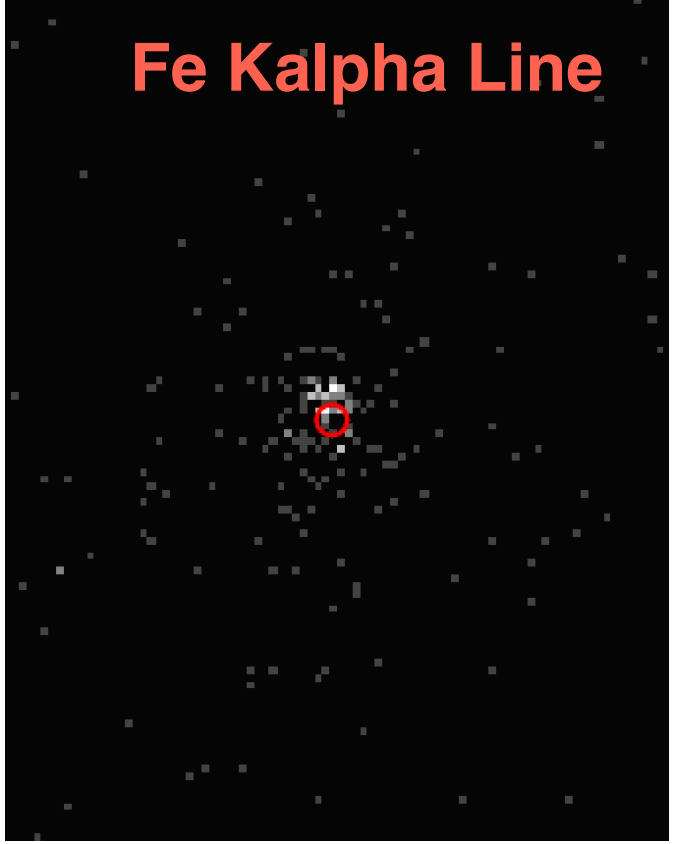


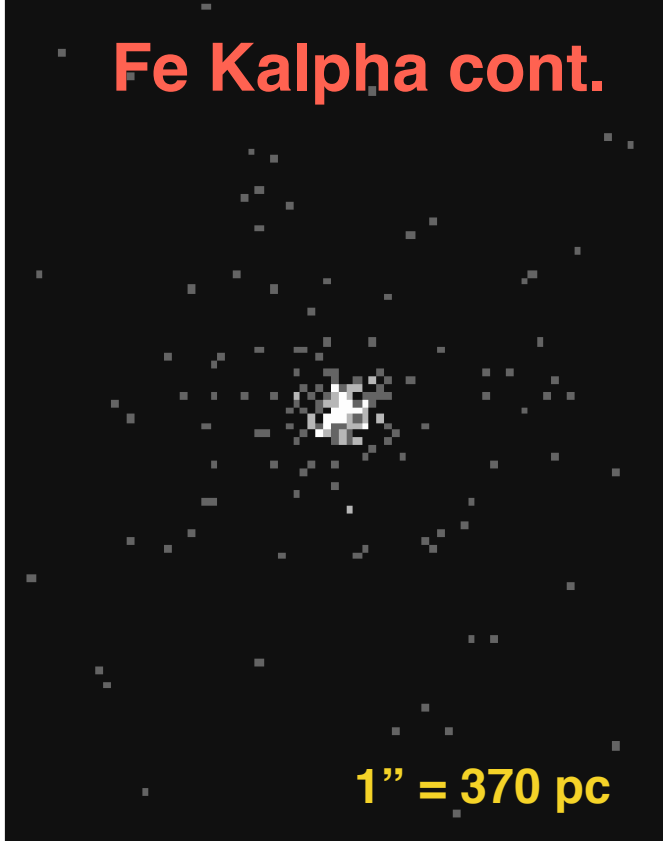


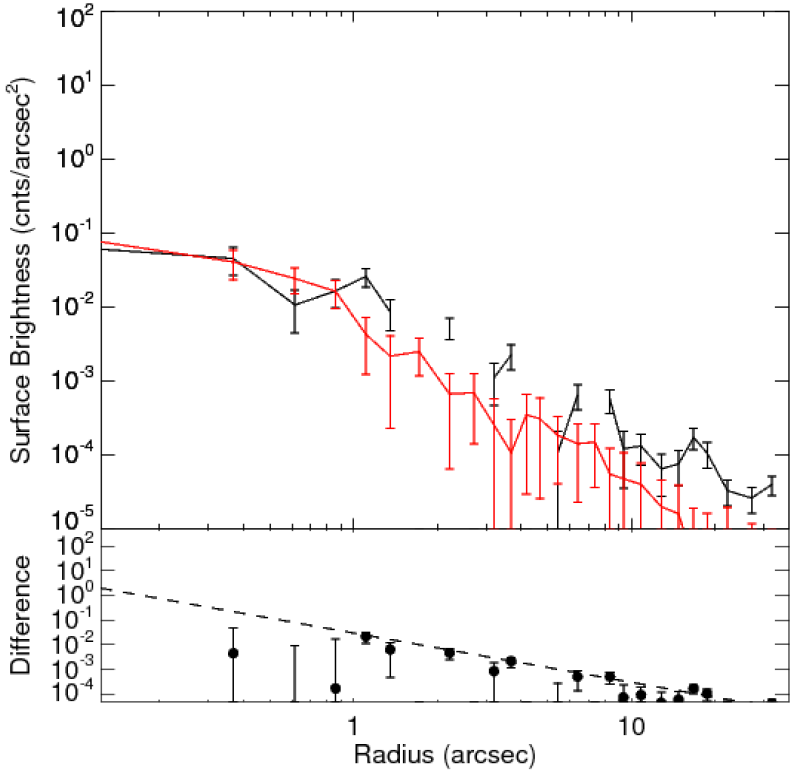




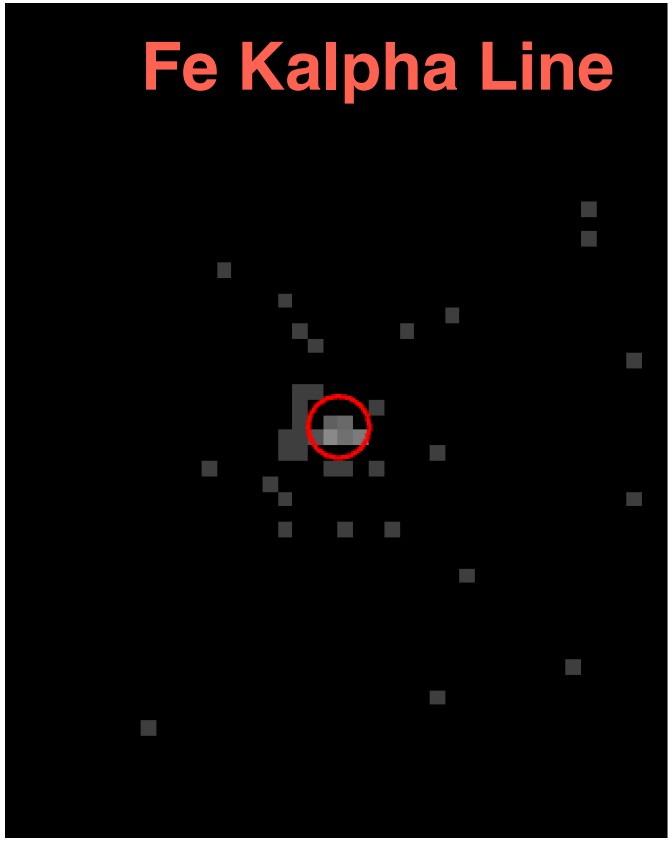
IC4329A
Sy 1.2

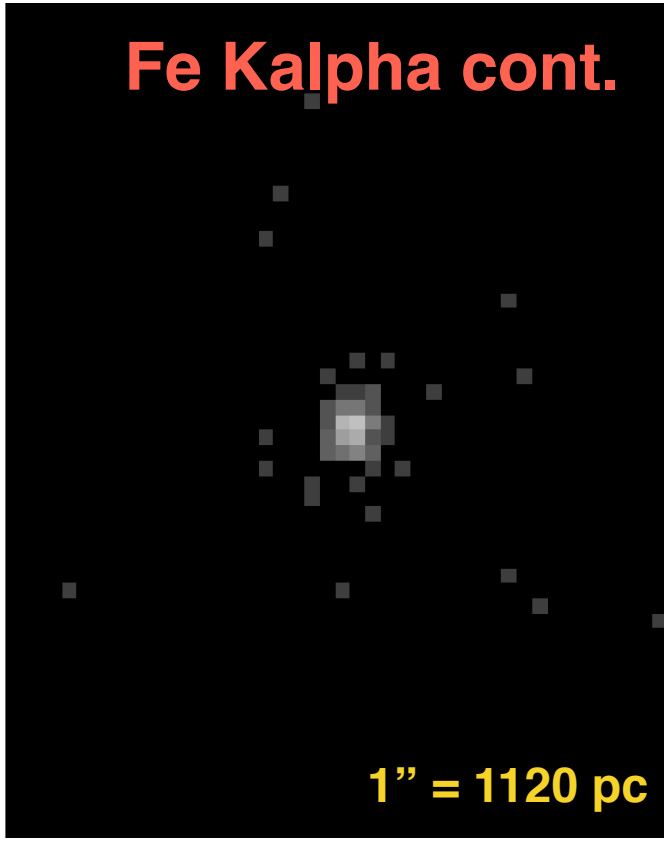


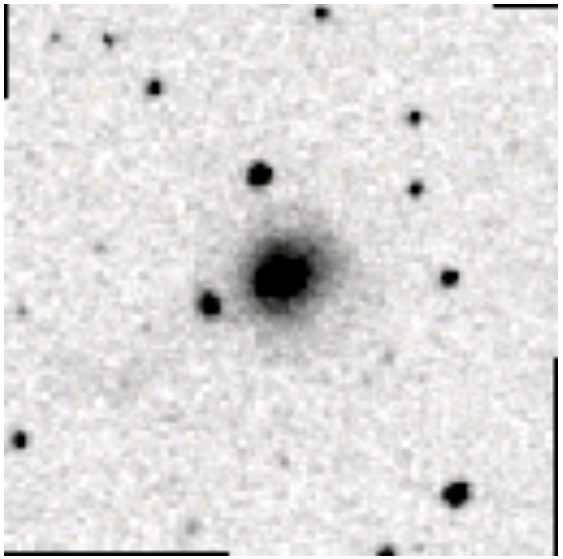


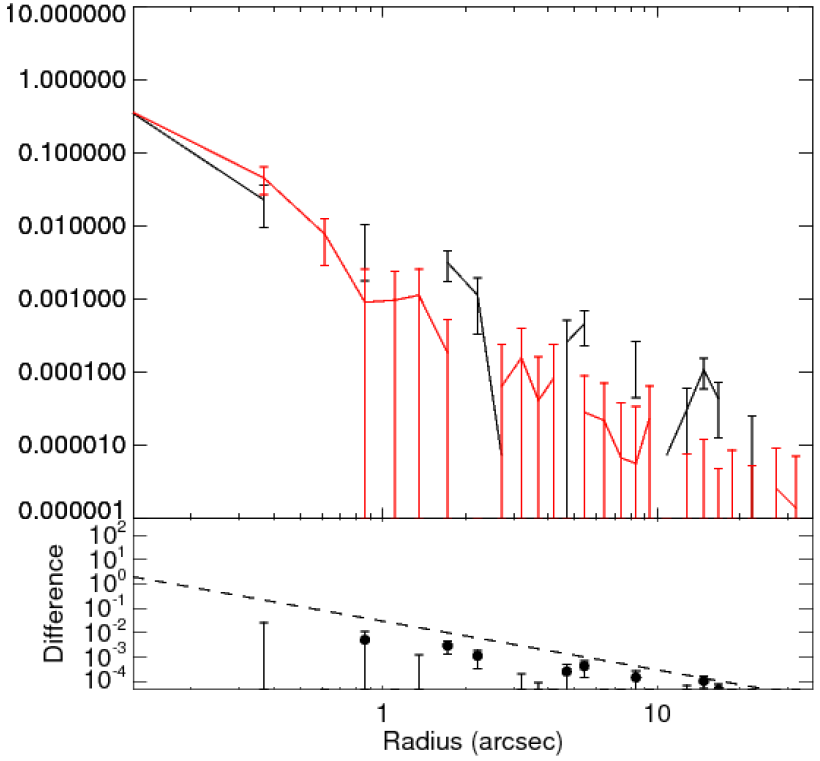


Fairall 9
Sy 1

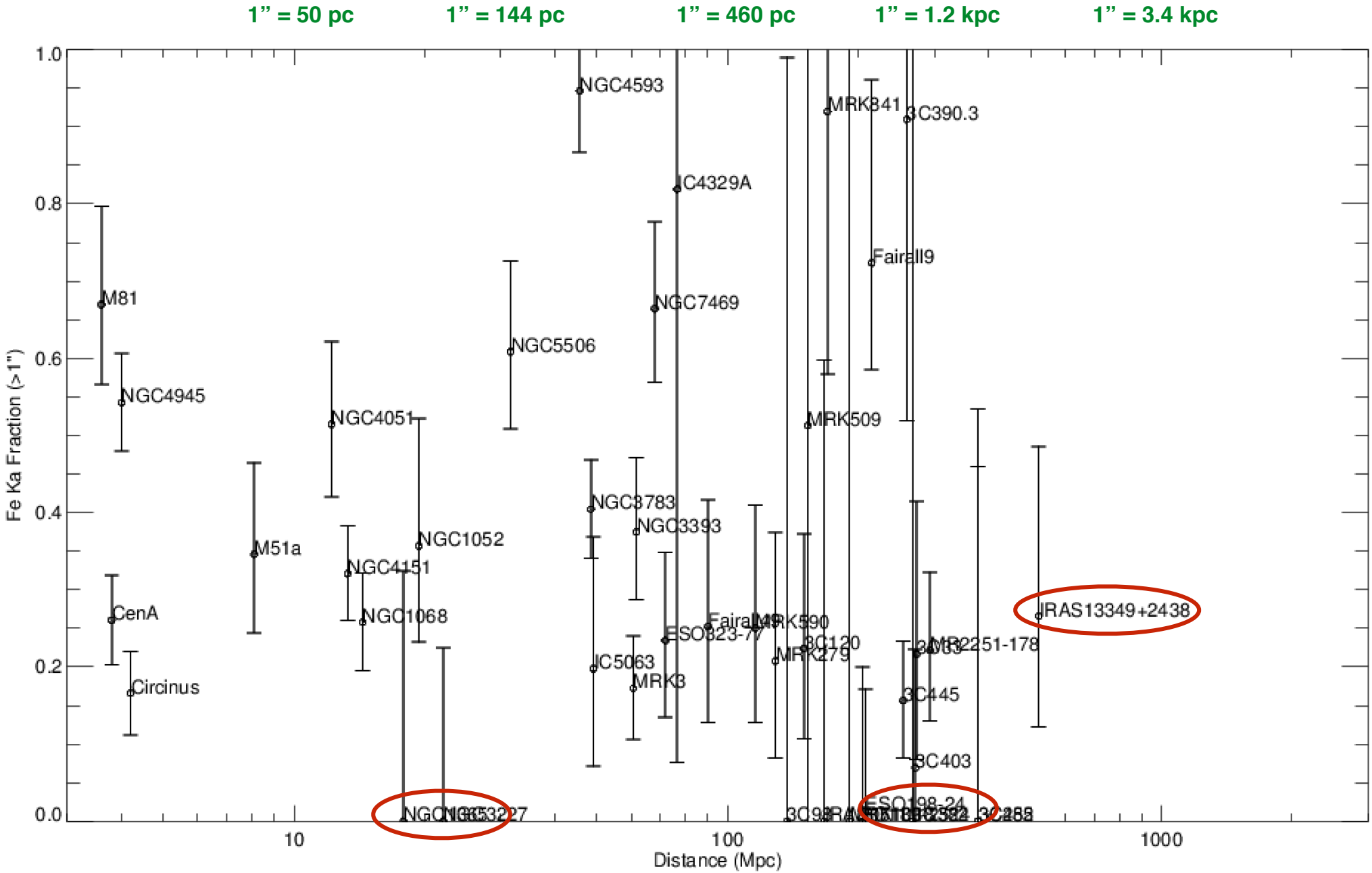




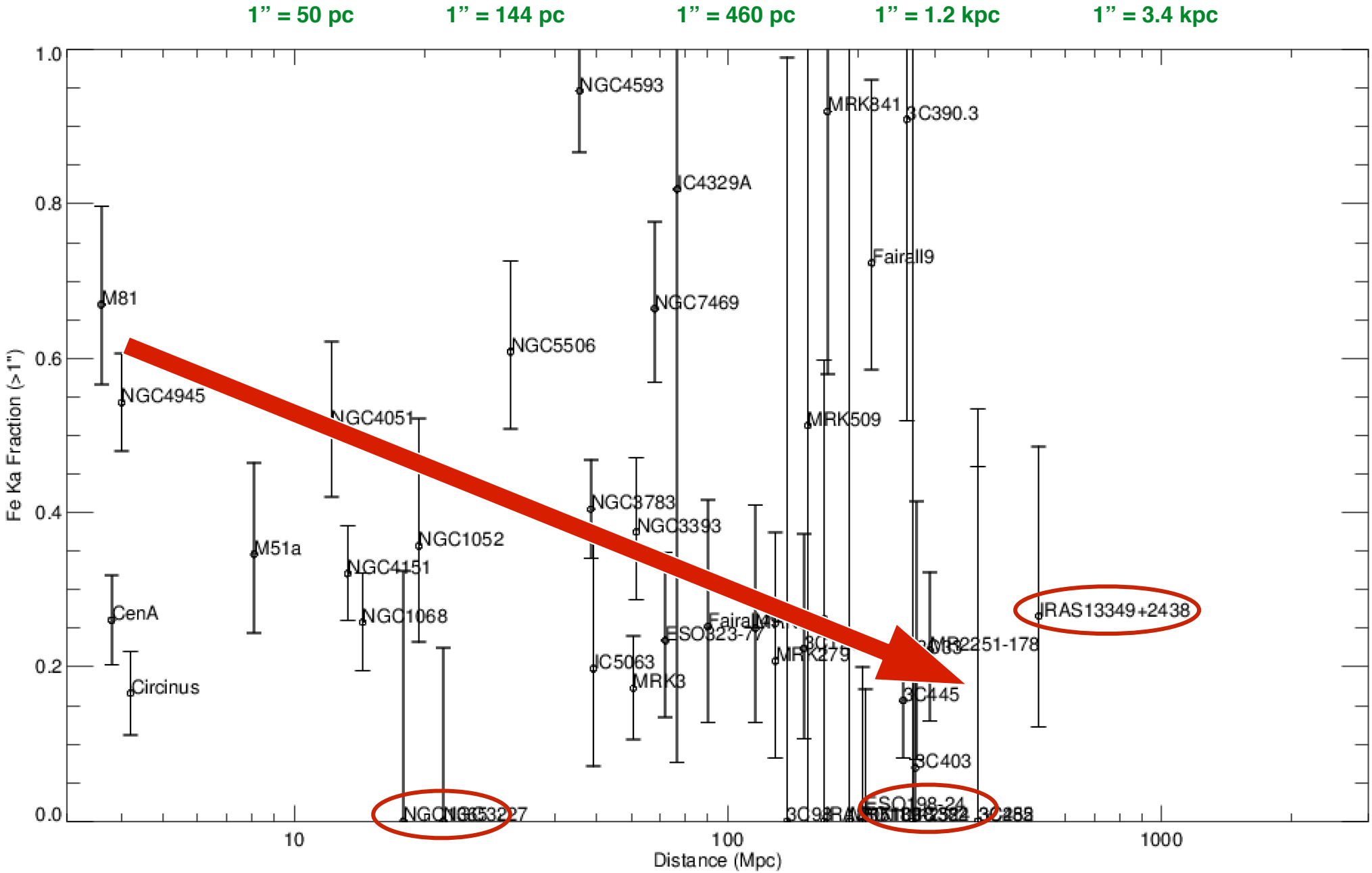




Fe Kα EW fractions for 43 AGN… (removed some weak Fe Kα sources)



Fe Kα extended in many AGN

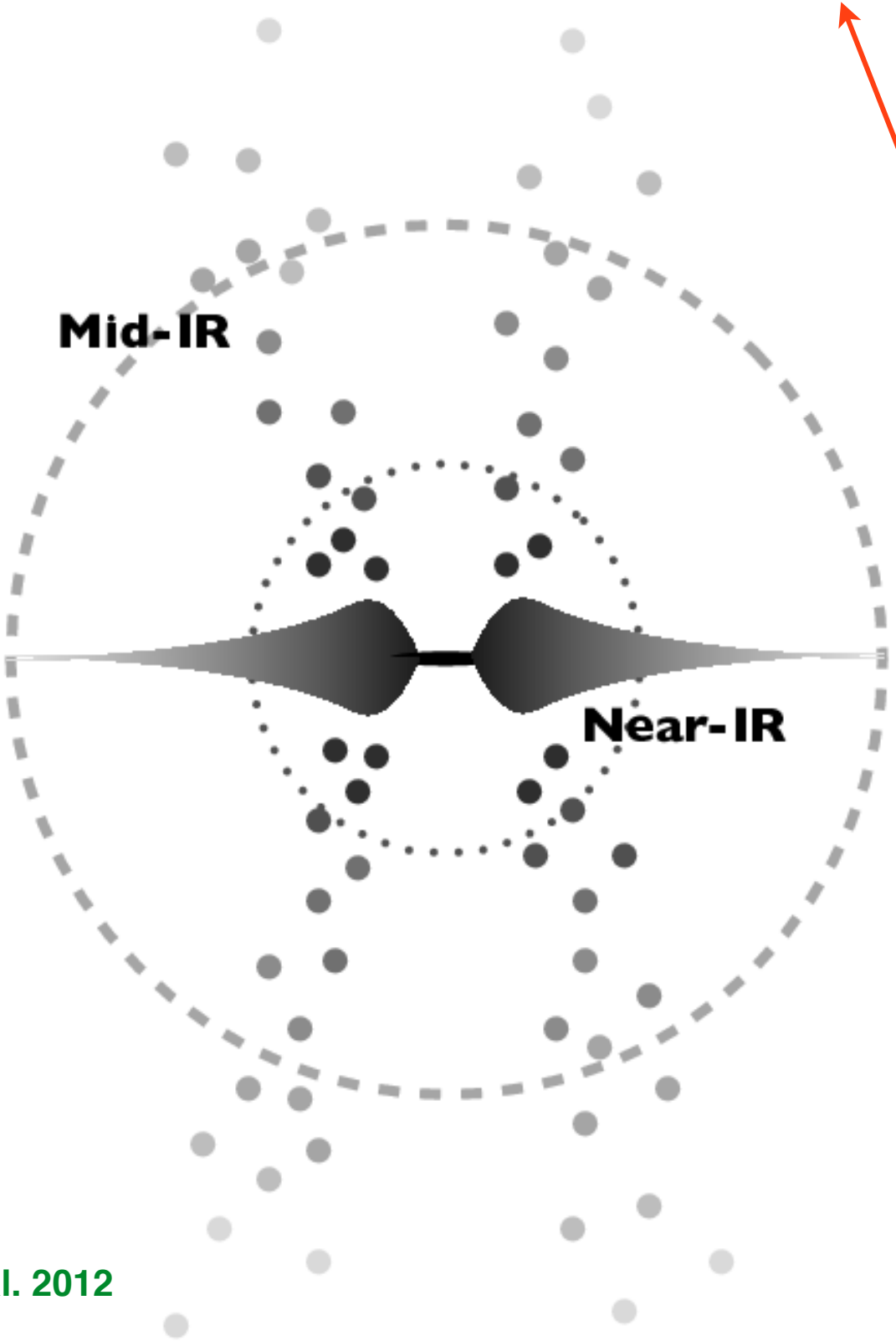


Conclusions

- **STILL WORK IN PROGRESS (refine statistics, model pile-up better, line variability, comparison with other parameters)**
- **Not surprisingly, "torus" complex multi-phase environments near AGN, with structural components on many scales. Variety of filling factors, covering factors, N_H?**
- **Most AGN have substantial extended Fe Kα emission, and when well-resolved, present potential variety of extended structures. => *Fe Kα Tomography* can allow constraints on individual tori.**
- **Kα fraction could capture AGN variability (echoes), as well as Galactic ISM morphology, in addition to standard covering factor.**

Next generation X-ray telescopes could routinely make such observations, broadening sample to 100s-1000s of objects at least with good statistics (=> Ni, Fe, S, Si Kα?). With such samples, perhaps can address…

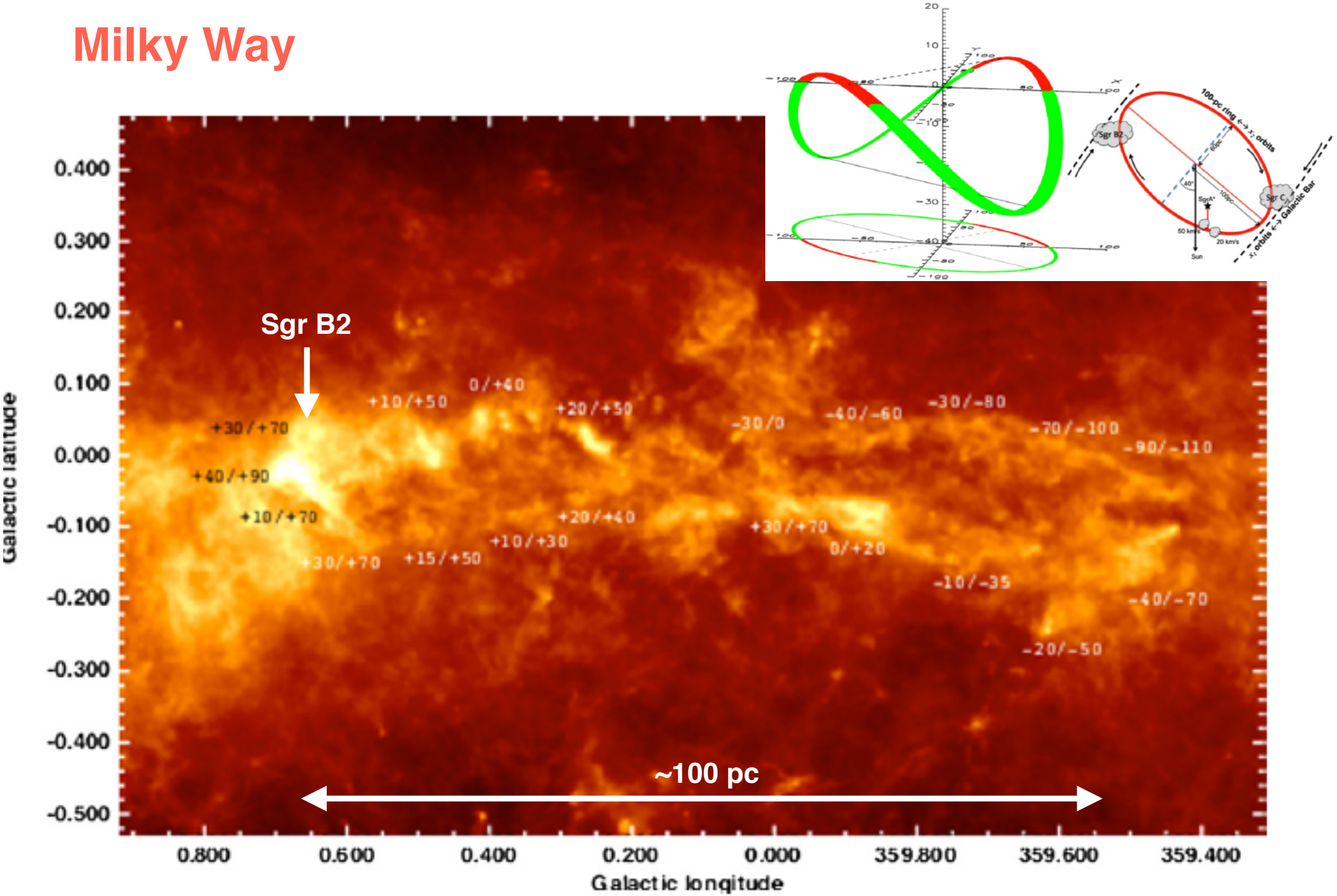
- **How does larger scale structure tie into the AGN feeding process?**
- **How does structure change as a function of AGN luminosity (e.g., receding torus)?**
- **How does larger structure affect/relate to our classification schemes?**



Many Fe Ka photons coming off material WAY out there?

Hoenig et al. 2012

Milky Way



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

Molinari et al. 2011