

Chandra

A photograph of the Chandra X-ray Observatory, showing its gold-coated mirror segments and solar panels against the dark void of space.

Hard Continuum & Fluorescent Fe K α beyond the Torus ESO 428-G014

G. Fabbiano

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Chandra

A blue-tinted image of the Chandra X-ray Observatory, showing its solar panels and instruments against a dark background.

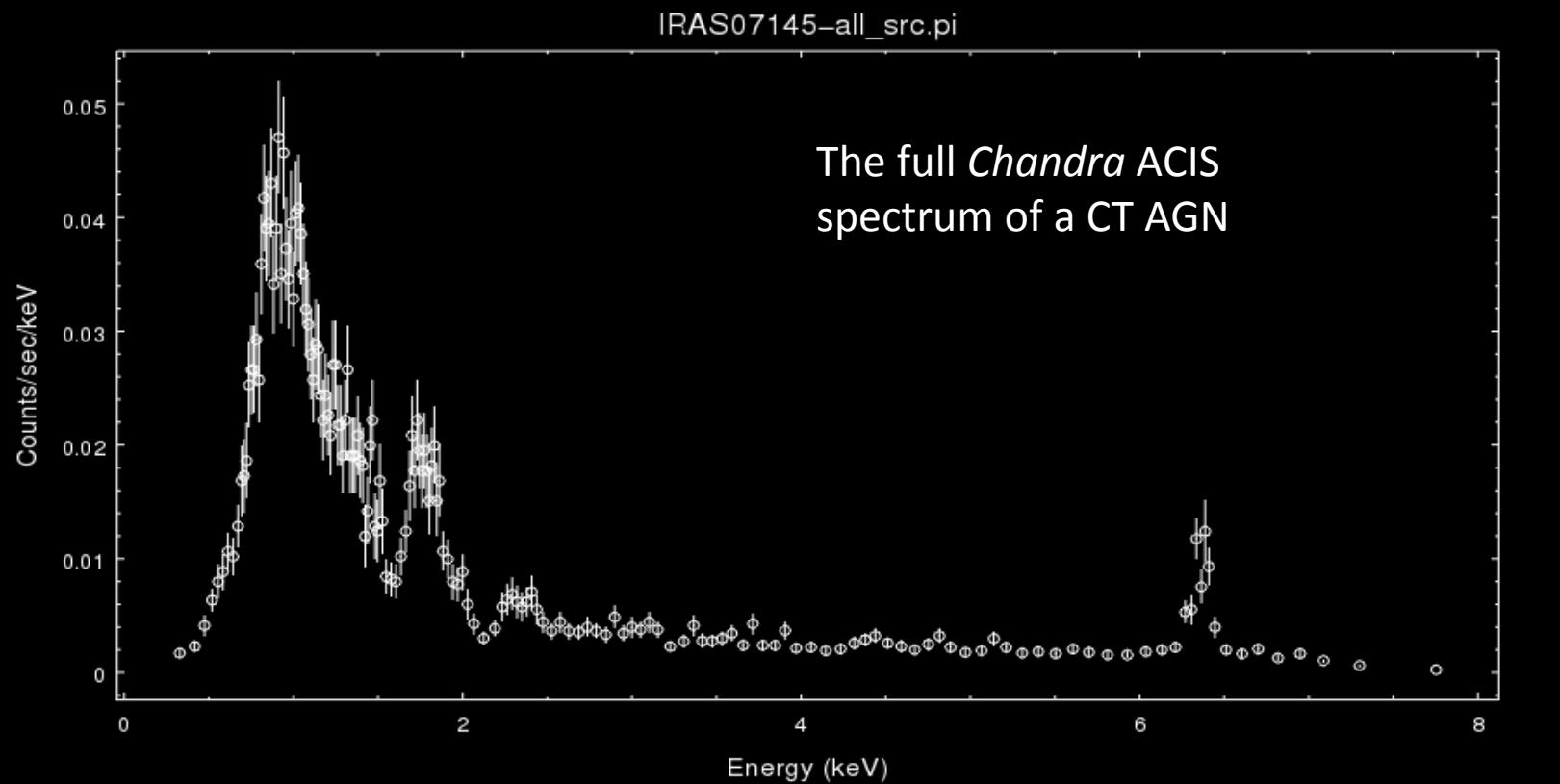
Hard Continuum & Fluorescent Fe K α beyond the Torus ESO 428-G014

Why Athena –Lynx synergy is important

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The Chandra X-ray Spectrum of the CT AGN ESO 428-G014



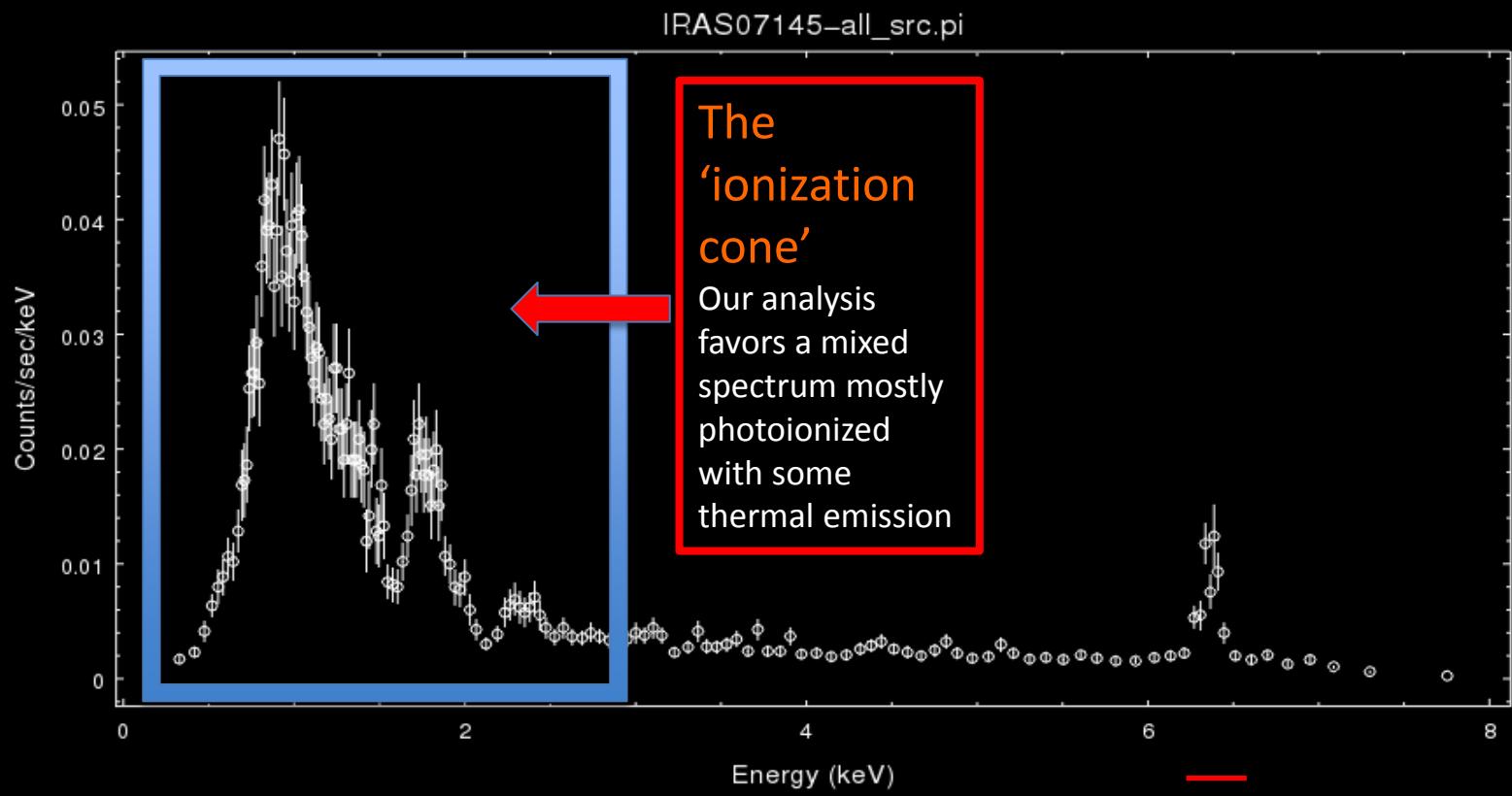
Soft line emission
O_{VII}, O_{VIII}, Ne_{IX},
Mg_{XI}, Si_{XIII}, etc.

Hard continuum

Fe K lines
Neutral and Fe XXV

Fabbiano et al 2017, 2018a, 2018b, ApJ

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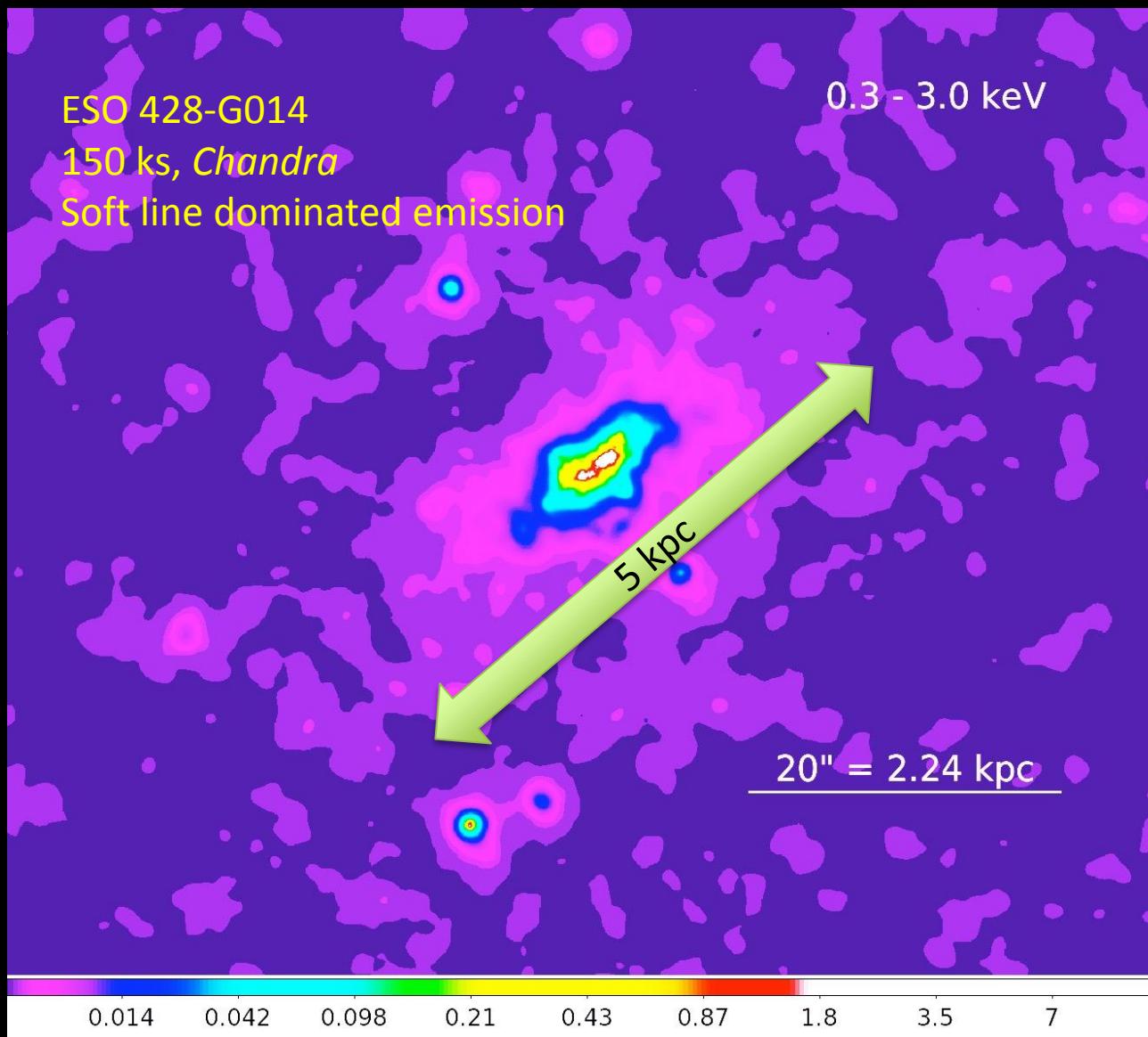
Soft line emission
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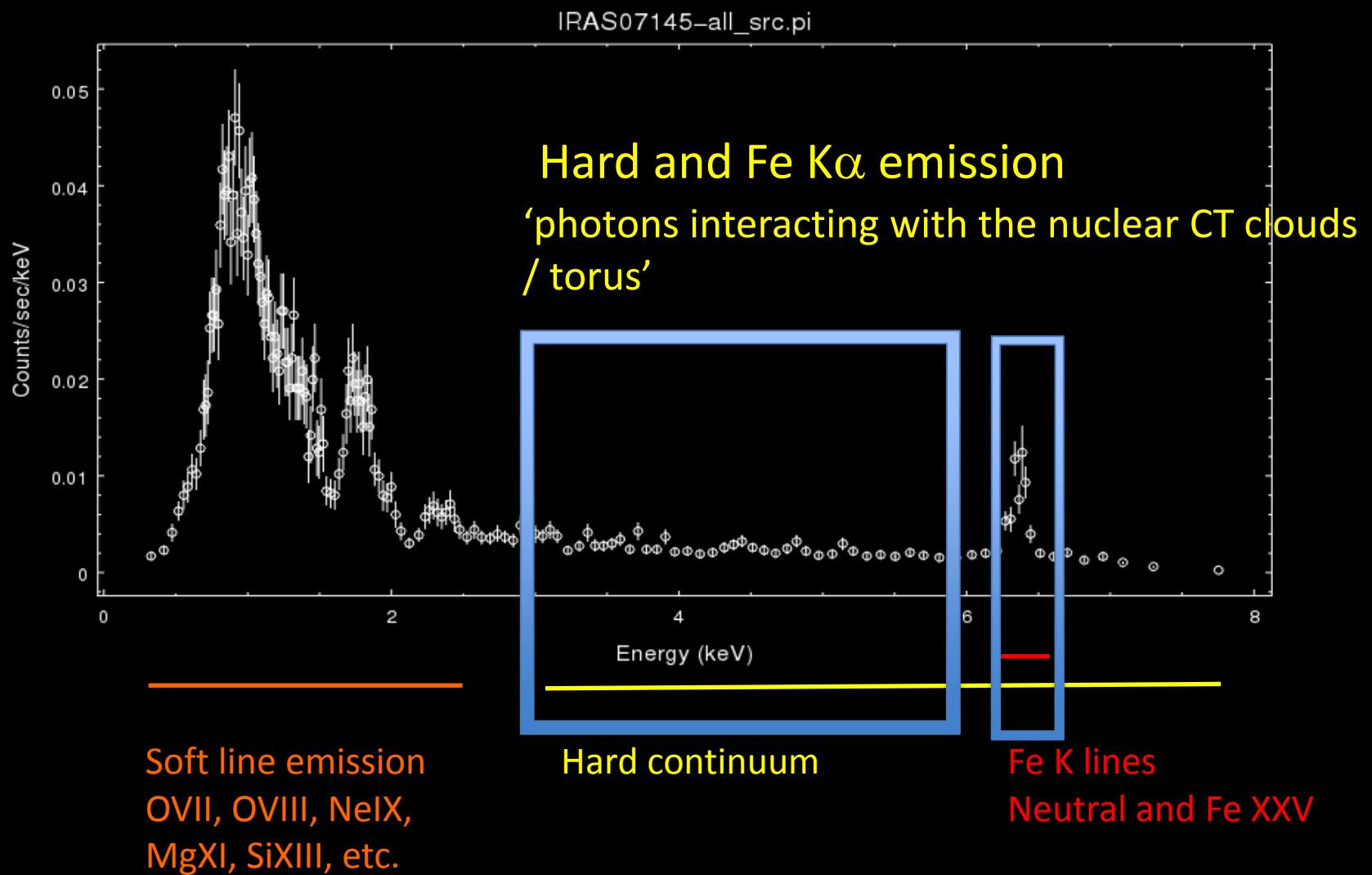
Fe K lines
Neutral and Fe XXV

Fabbiano et al 2017, 2018a, 2018b, ApJ

ESO 428-G014 – The ‘ionization cone’ doesn’t look conical



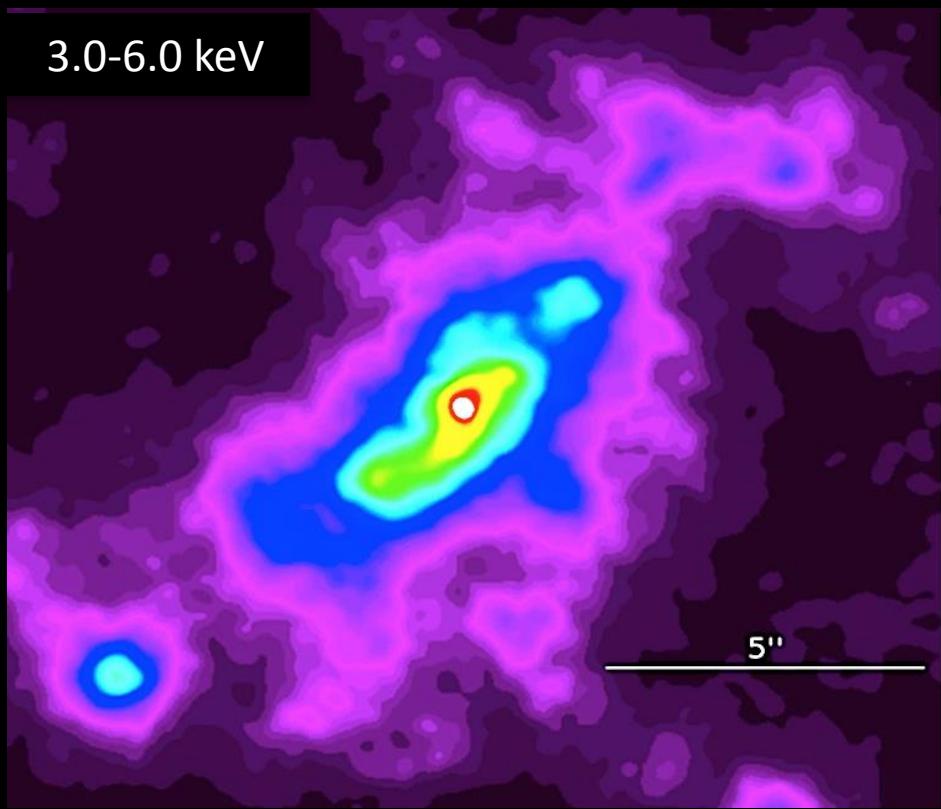
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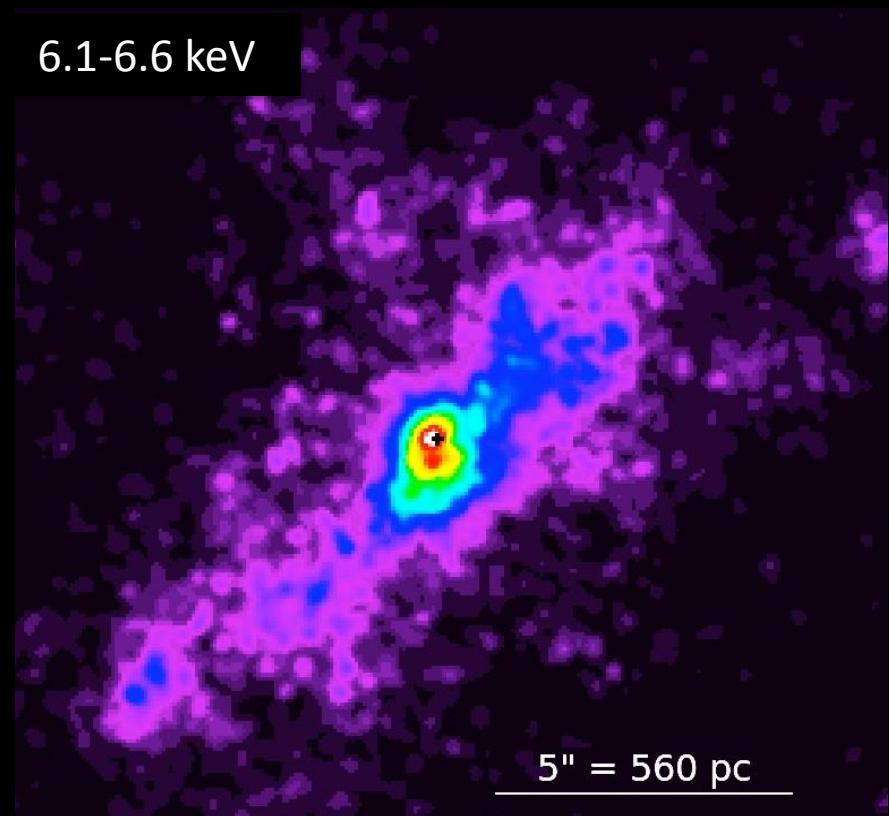
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ESO 428-G014 – ~2 kpc-scale hard continuum and Fe K α

Hard continuum

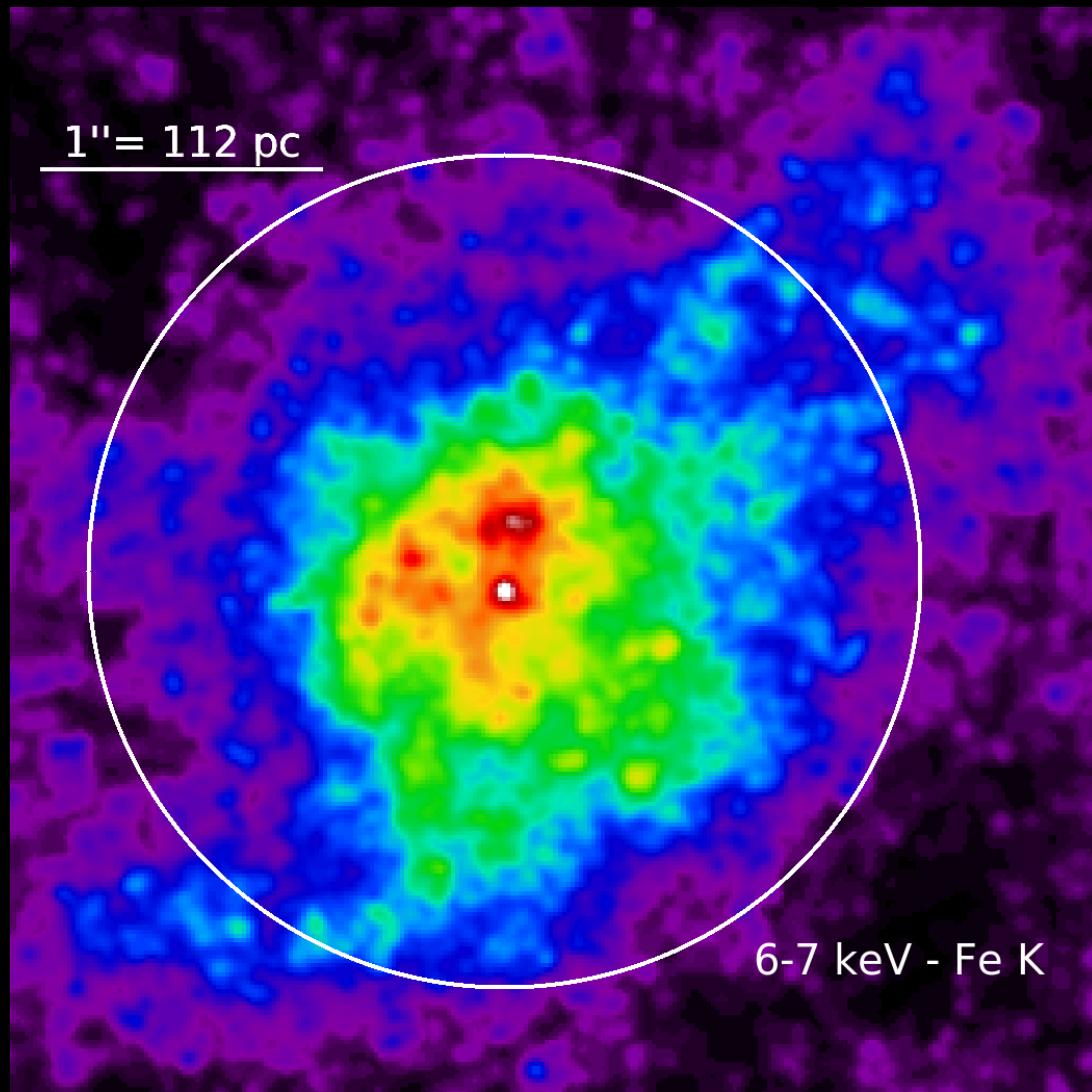


Fe K α line



counts in extended component ($1''.5 - 8''$ annulus)
are 30 % of counts in $r < 1''.5$

ESO 428-G014 – Fe K α in the inner circumnuclear region

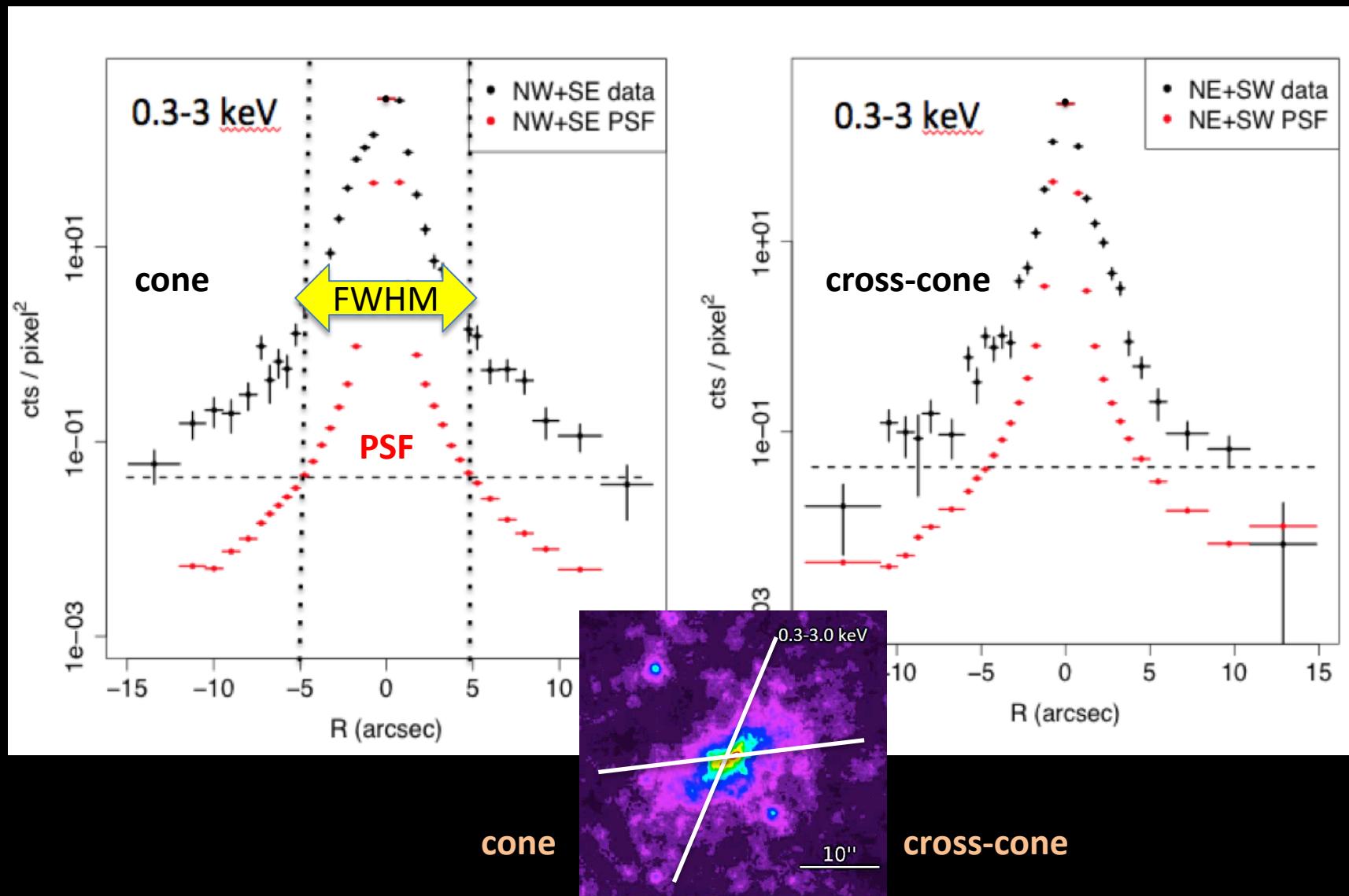


- $R < 1''.5$
C (extended) ~ 0.4 C (PSF)
- $R < 8''$
Total counts = 1.8 C (PSF)

→ In a “typical” non-Chandra spectral extraction region the large Fe K component contributes almost as much as the nuclear source
i.e. *XMM-Newton*, *NuStar*, *Athena*

Fabbiano et al 2018c,
ApJ submitted

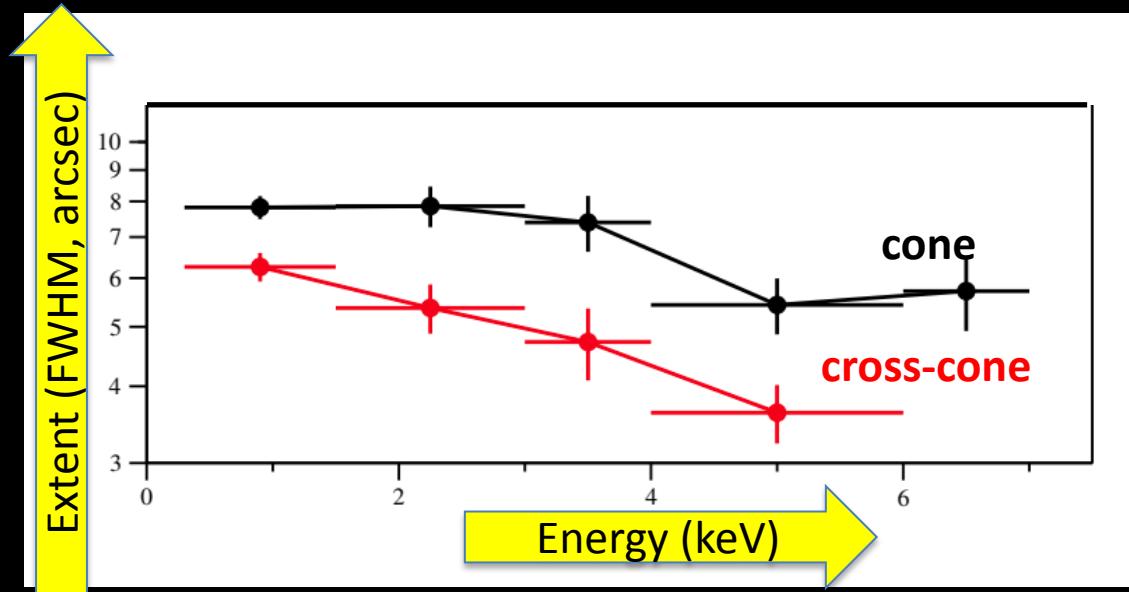
ESO 428-G014 –measuring the extent with radial profiles



ESO 428-G014 – Cross-cone extent

We have measured the extent (FWHM) of the emission in the ‘cone’ and ‘cross-cone’ directions as function of energy
Fabbiano et al, ApJ submitted

Significant extended emission
in the cross-cone direction up
to 6 keV

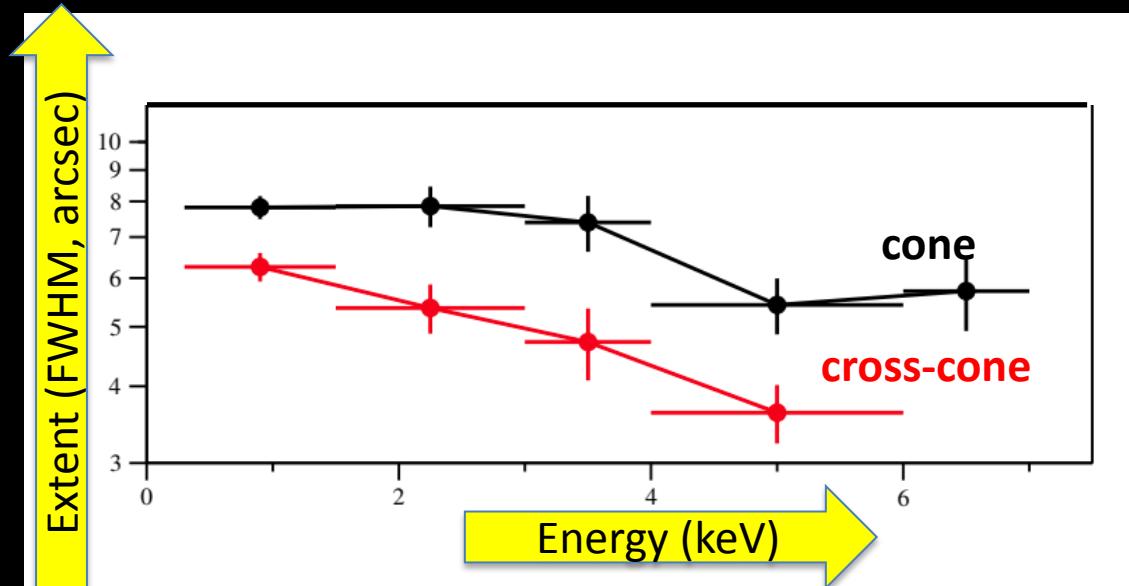
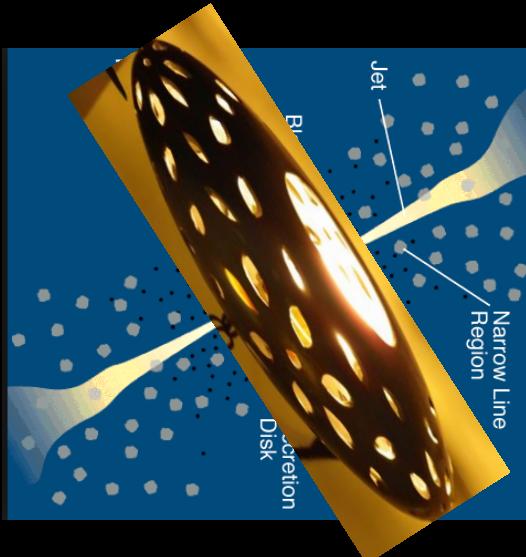


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- The torus is porous

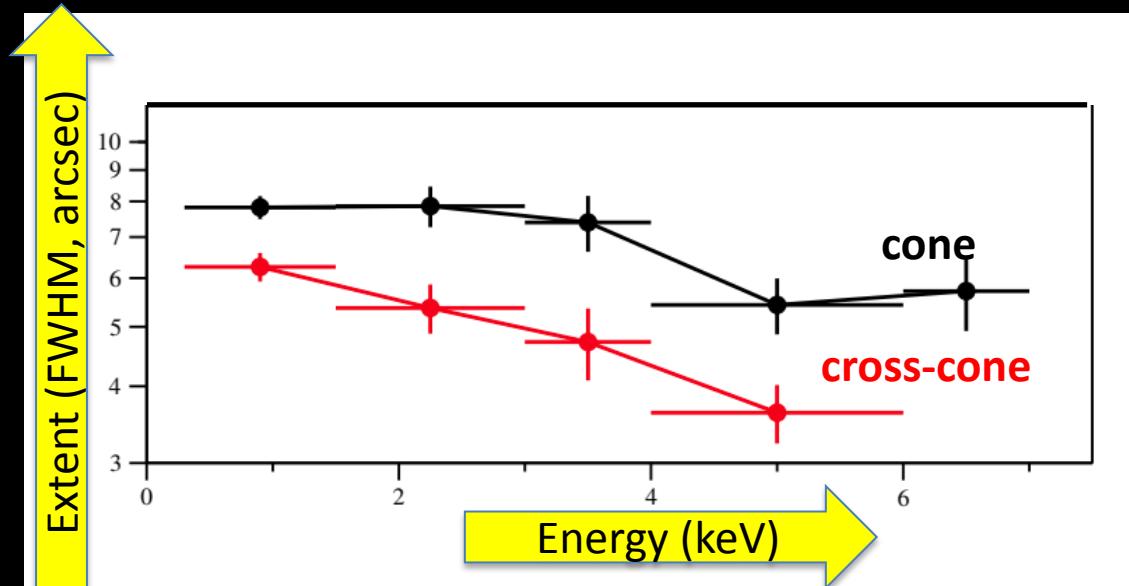
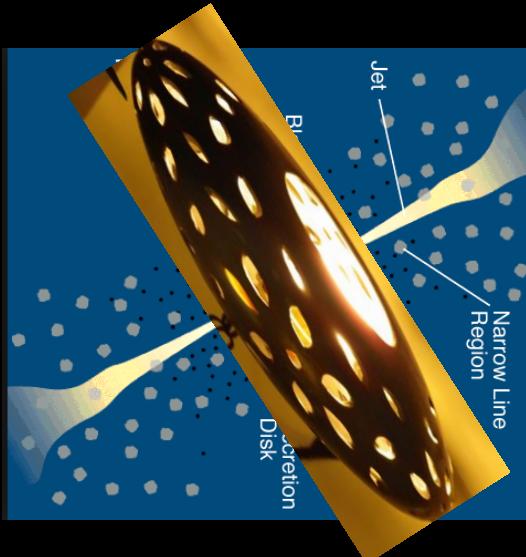


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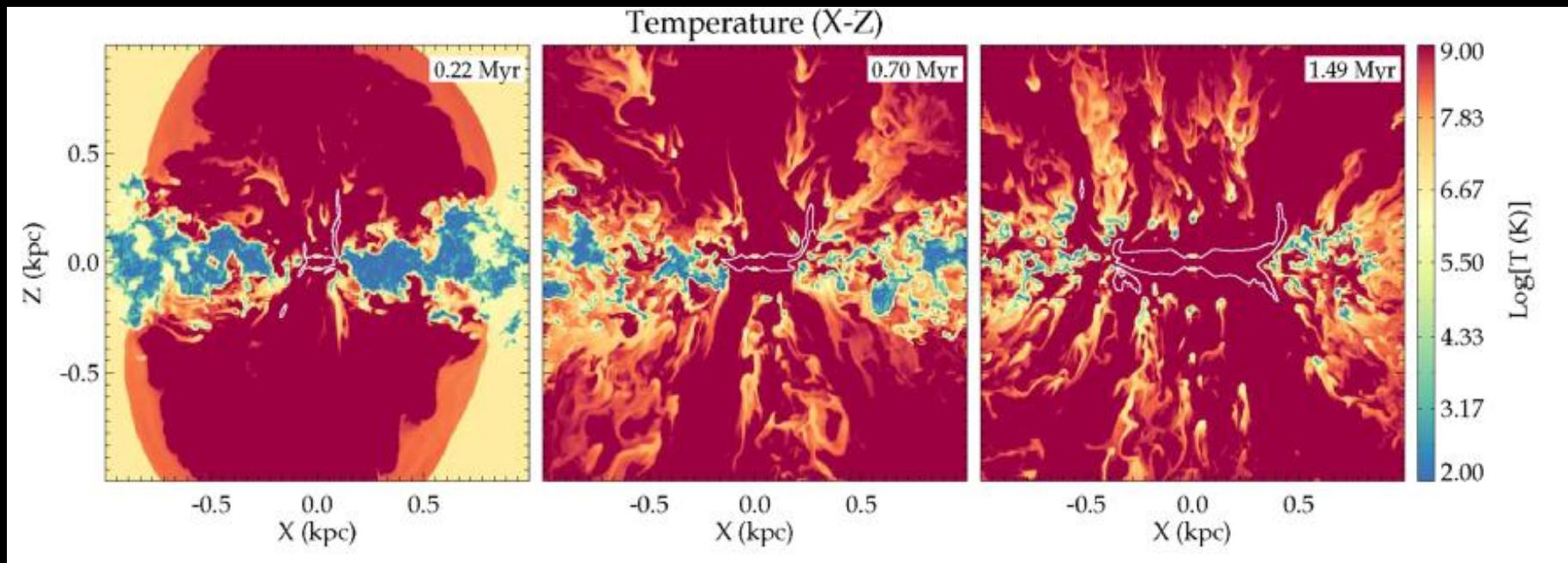
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Or.....

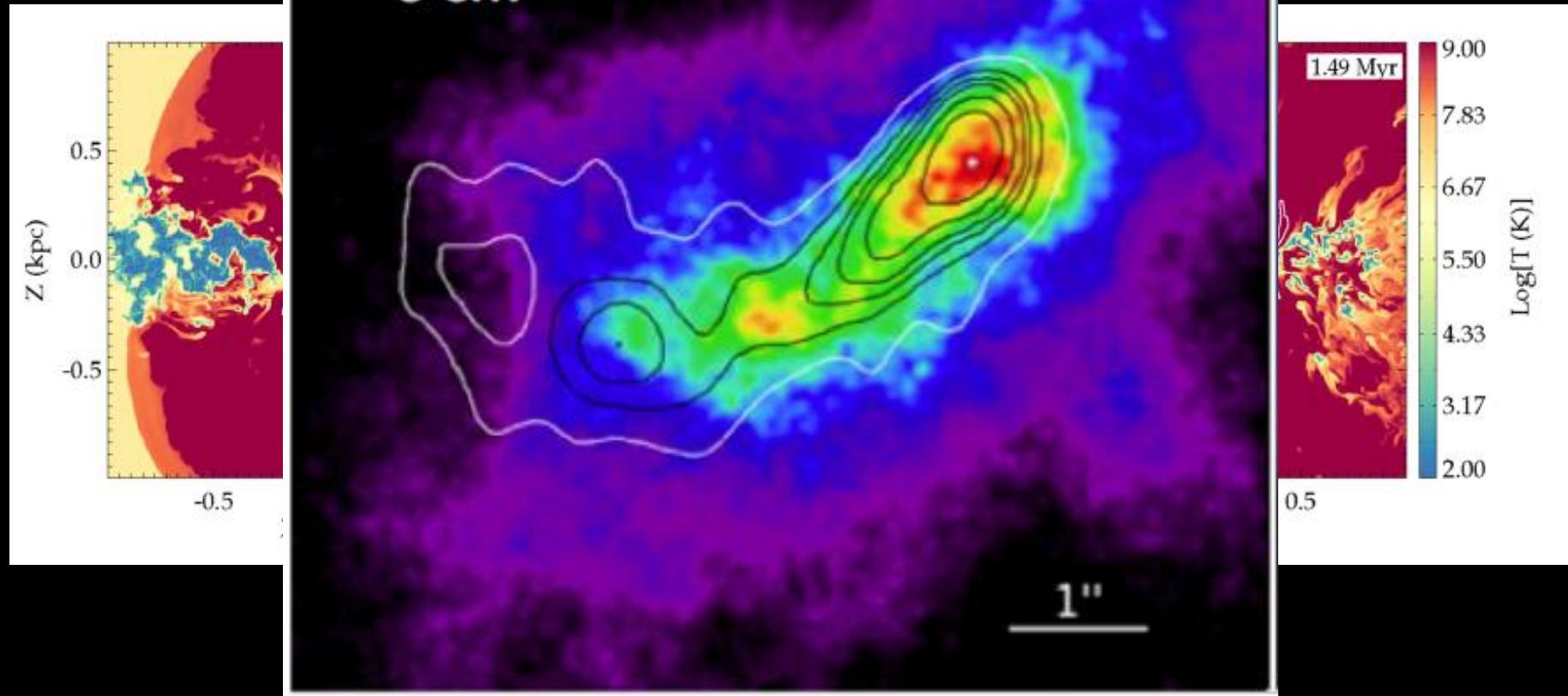
ESO 428-G014 – Cross-cone extent

- Hot cocoon from jet interaction with molecular clouds (e.g., simulations of Mukherjee et al 2018)



ESO 428-G014 – Cross-cone extent

- Hot cocoon from jet interaction with molecular clouds (Fabbiano et al 2018)



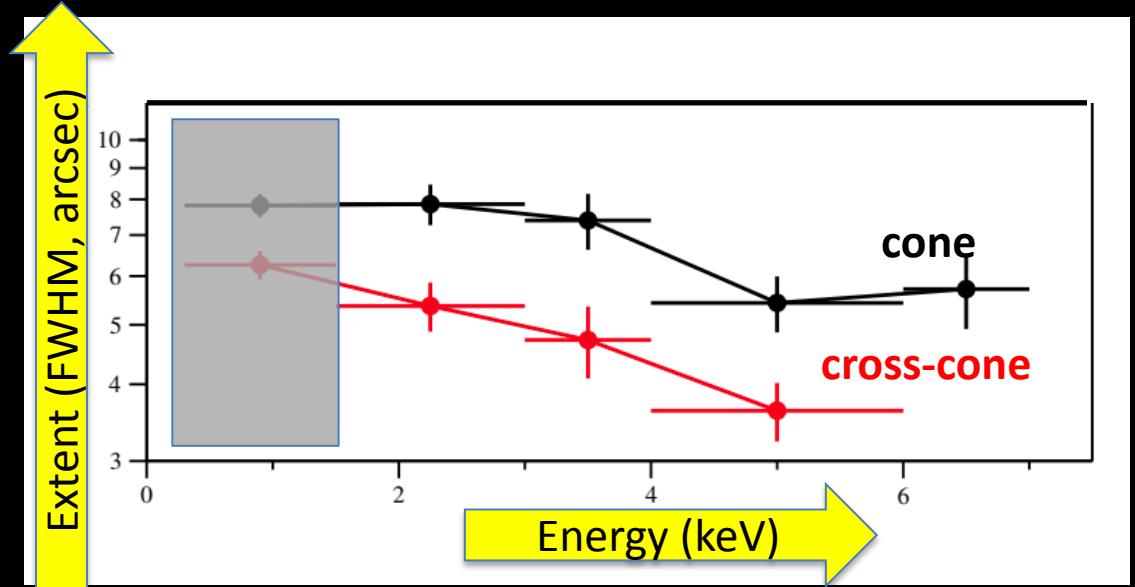
ESO 428-G014 – If Porous Torus, Cross-cone transmission

> 1.5 keV

Cross-cone counts $\sim 50\%$
of cone counts at all energies

- Given a cross-cone volume
 ~ 5 -times larger than cone

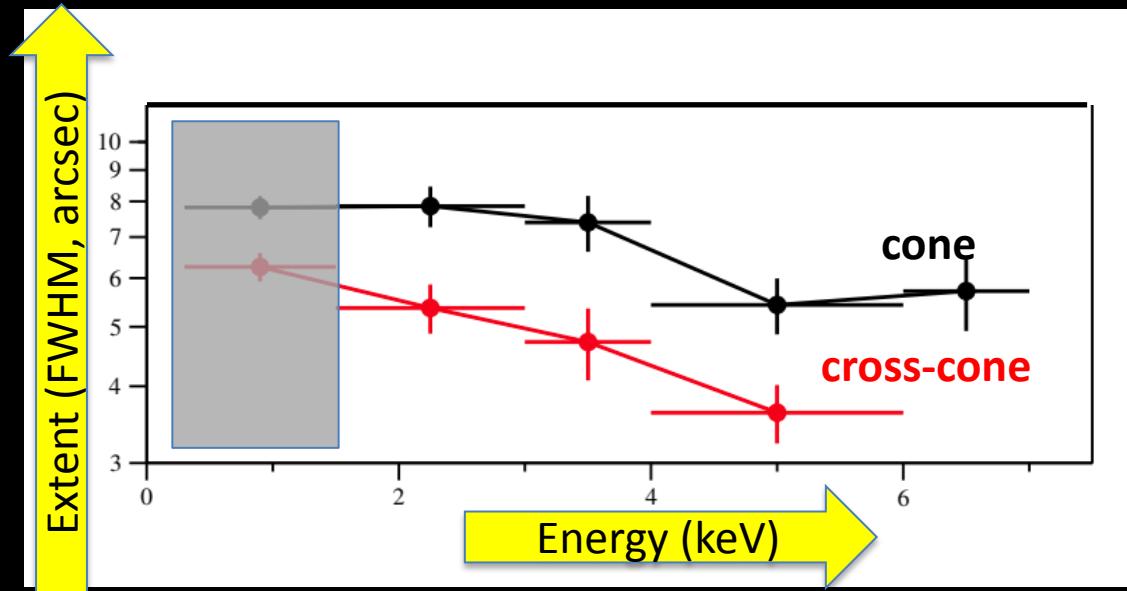

torus cross-cone
transmission $\sim 10\%$ of cone
transmission



ESO 428-G014 - AGN emission and cold ISM clouds

E>1.5 keV

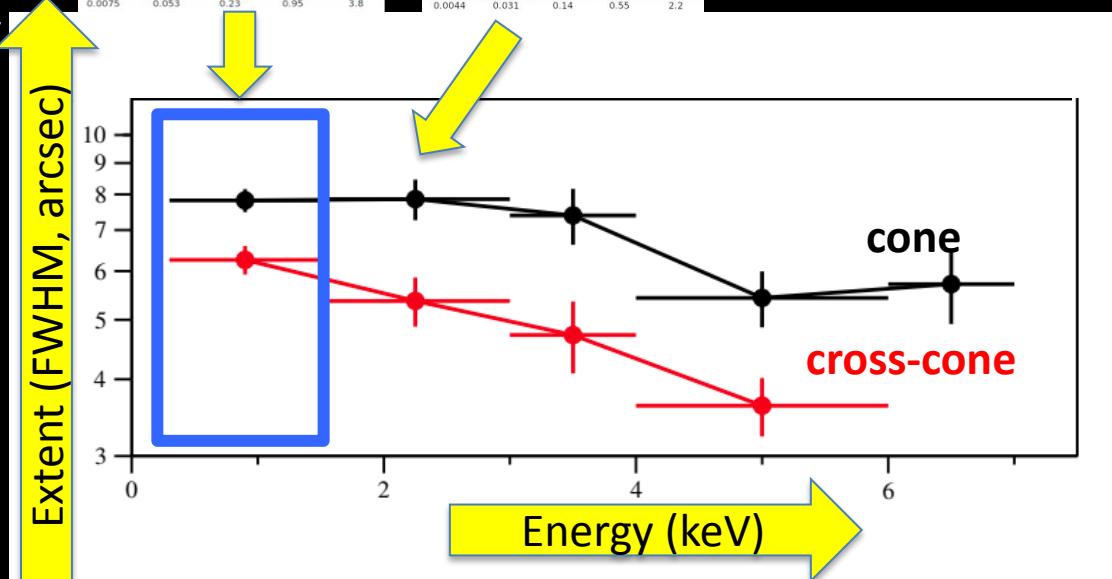
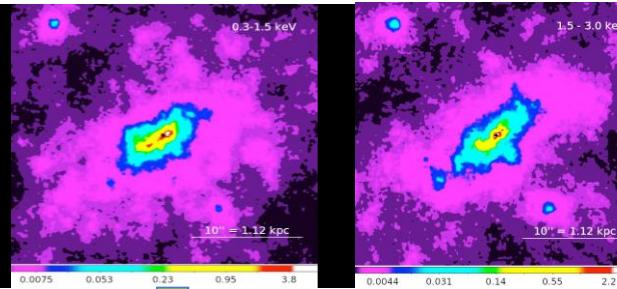
- Extent is smaller at higher energies
 - Optically thicker clouds ($N_H \sim 10^{24} \text{ cm}^{-2}$) nearer to galactic center?
 - MW analogy



ESO 428-G014 - Soft X-rays from hot ISM

0.3 - 1.5 keV

- FWHM cross-cone relatively larger
(image is ‘rounder’)
- cross-cone/cone count ratio increases: 84% (+/- 6%)
- New component?
 - Hot ISM of the galaxy
 - $L_x \sim 5 \times 10^{38} \text{ erg s}^{-1}$
 - $\tau_{\text{cooling}} \sim 10^9 \text{ yr}$
 - $E_{\text{tot}} \sim 10^{55} \text{ erg}$



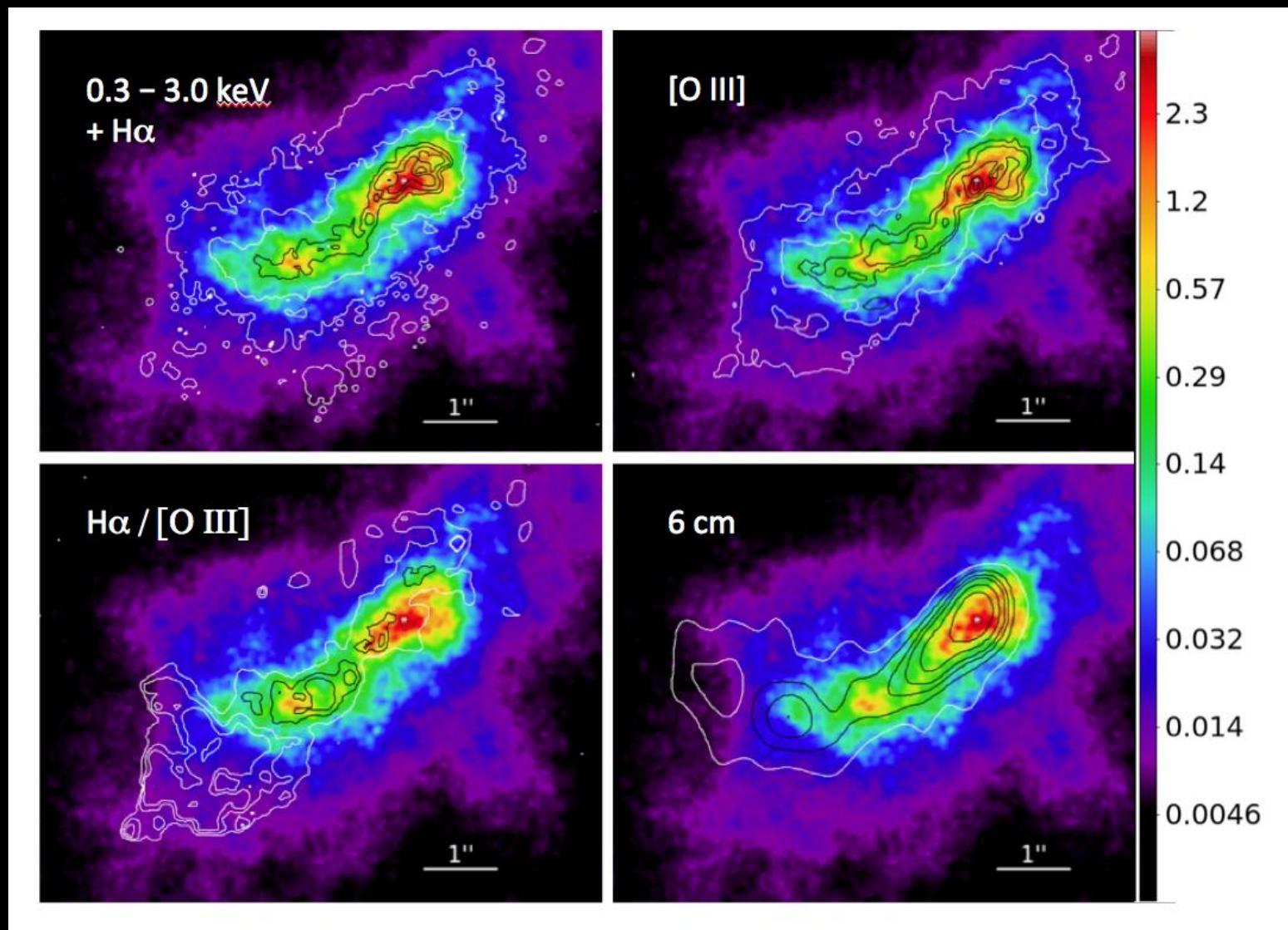
Summary: The CT AGN ESO 628-G014

1. Deep high-resolution spatial-spectral imaging with *Chandra* reveals complex extended kpc-size hard continuum and Fe K α
 - These extended components bias ‘torus’ spectral modeling
2. Cross-cone extent
 - The torus is porous, with 10% transmission cross-cone re. cone
 - Or, hot cocoon from radio jet / molecular disk interaction
3. X-ray Image of the absorbing/scattering molecular clouds in the galaxy disk
 - Denser ISM clouds at smaller galactocentric radii – as in MW
4. Synergy between *Lynx* and *Athena* is needed

10/1/2018

G. Fabbiano

ESO 428-G014 – The inner ~500 pc



Extended % within $r < 1''.5$ and $r < 5''$

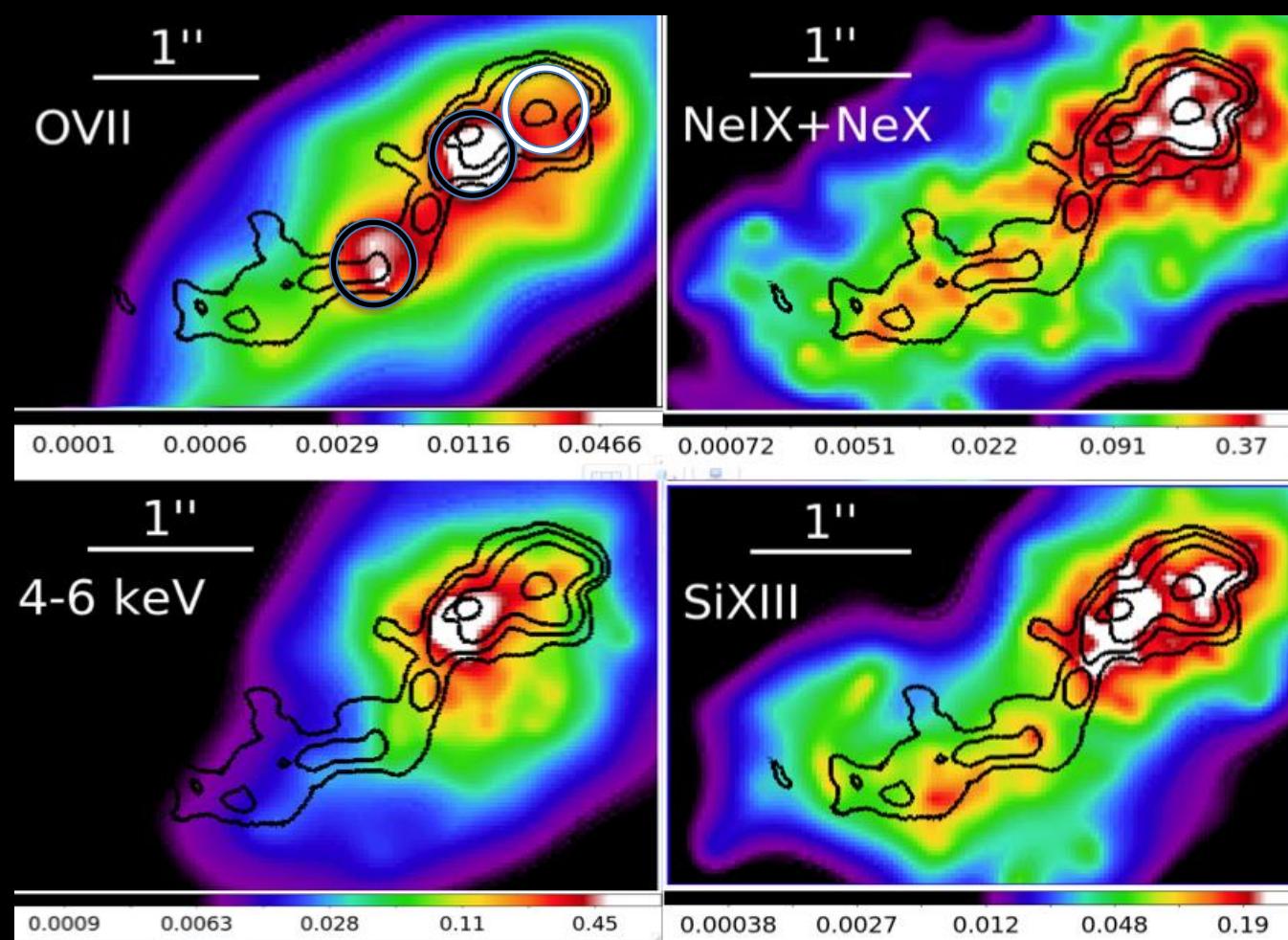
Table 2. Extended Counts within a Radius and as Fraction of Point Source (PS)

Band (keV)	Counts $R < 0''.5$	Counts ^{a,b} $R < 1''.5$	Counts ^{a,b} $R < 5''$	$\Delta^{b,c}$ $< 1''.5$	$\Delta^{b,c}$ $< 5''$	% Ext. ^{b,d} $< 1''.5$	% Ext. ^{b,d} $< 5''$
3-4	128	297 (171 [184])	430 (183 [195])	126 [113] ± 18	237 [235] ± 22	73 [61]	120 [120]
4-5	123	260 (164 [177])	322 (176 [187])	96 [83] ± 17	146 [135] ± 19	58 [47]	83 [72]
5-6	134	236 (179 [193])	275 (192 [204])	57 [43] ± 16	83 [71] ± 18	32 [22]	43 [35]
6-7	200	374 (267 [288])	437 (286 [304])	107 [86] ± 21	151 [133] ± 23	40 [37]	53 [44]

Fe K

- a) Image counts within the indicated radius. The values in parenthesis are the estimated PSF counts.
- b) Values in square brackets are from the simulated PSF, which contains aspect blur.
- c) Difference between image counts and PSF count within indicated radius.
- d) Fraction of counts in the extended component relative to the PSF counts.

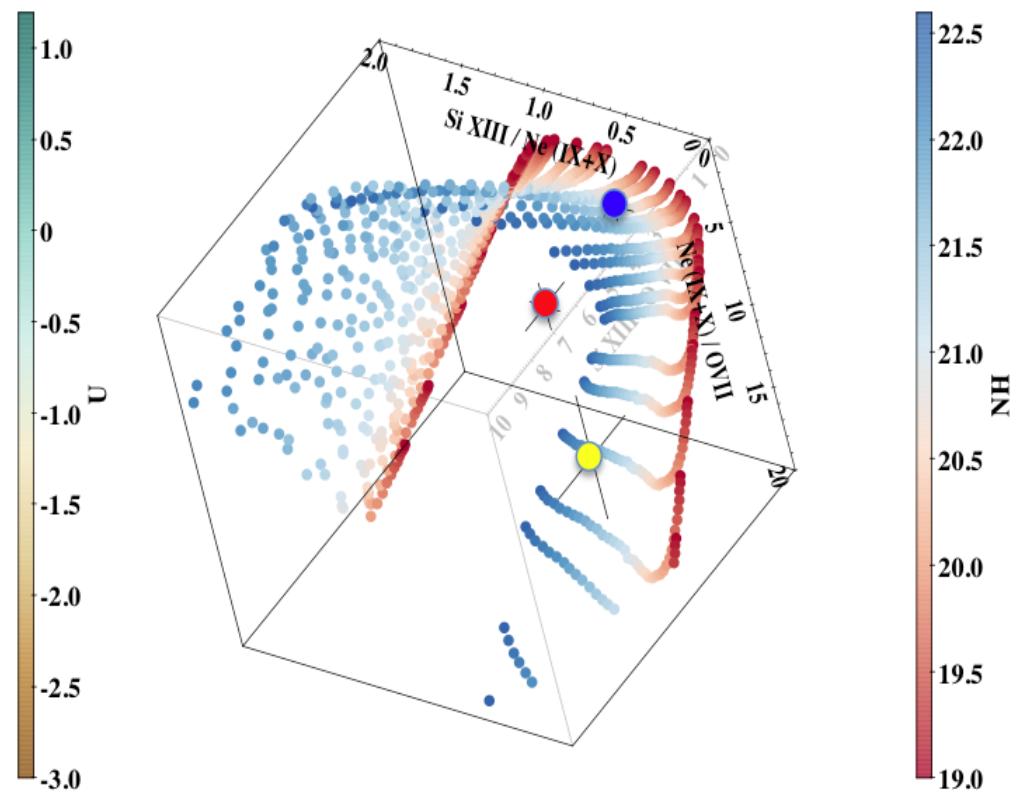
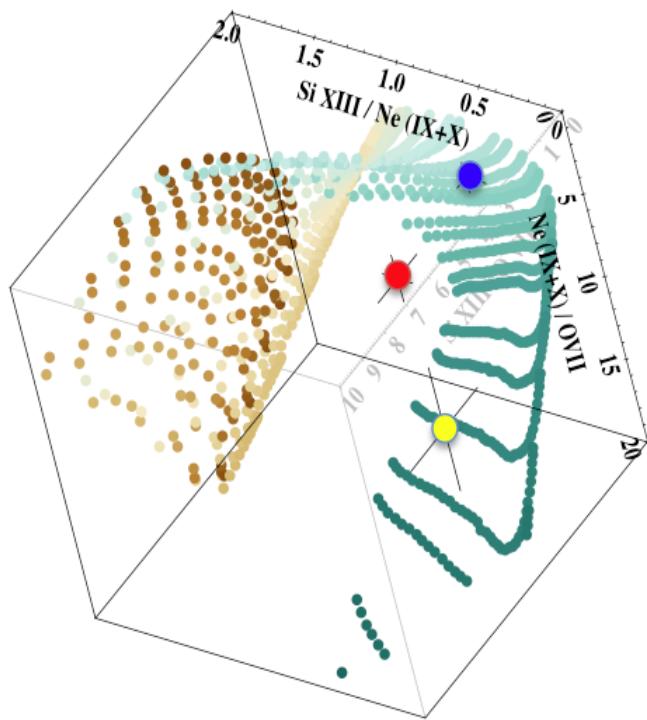
ESO 428-G014 – The inner ~500 pc – X-ray emission lines



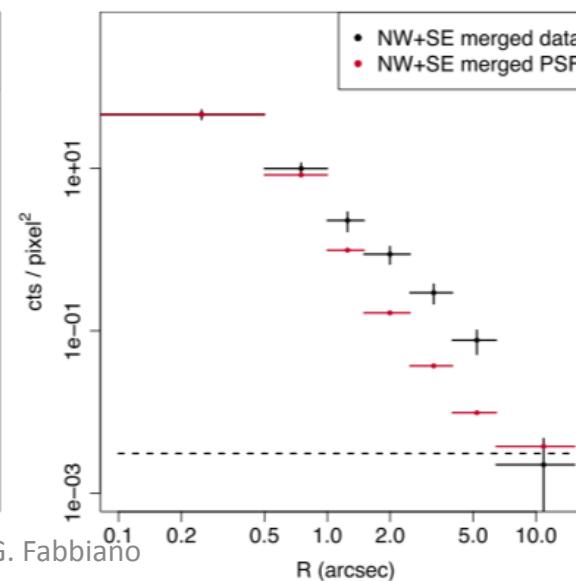
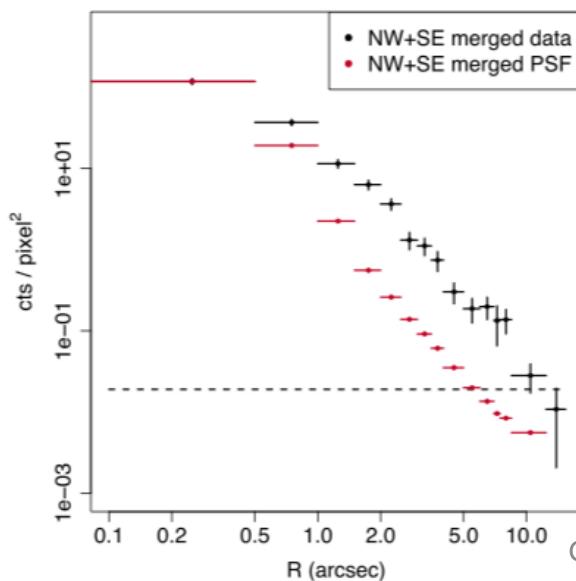
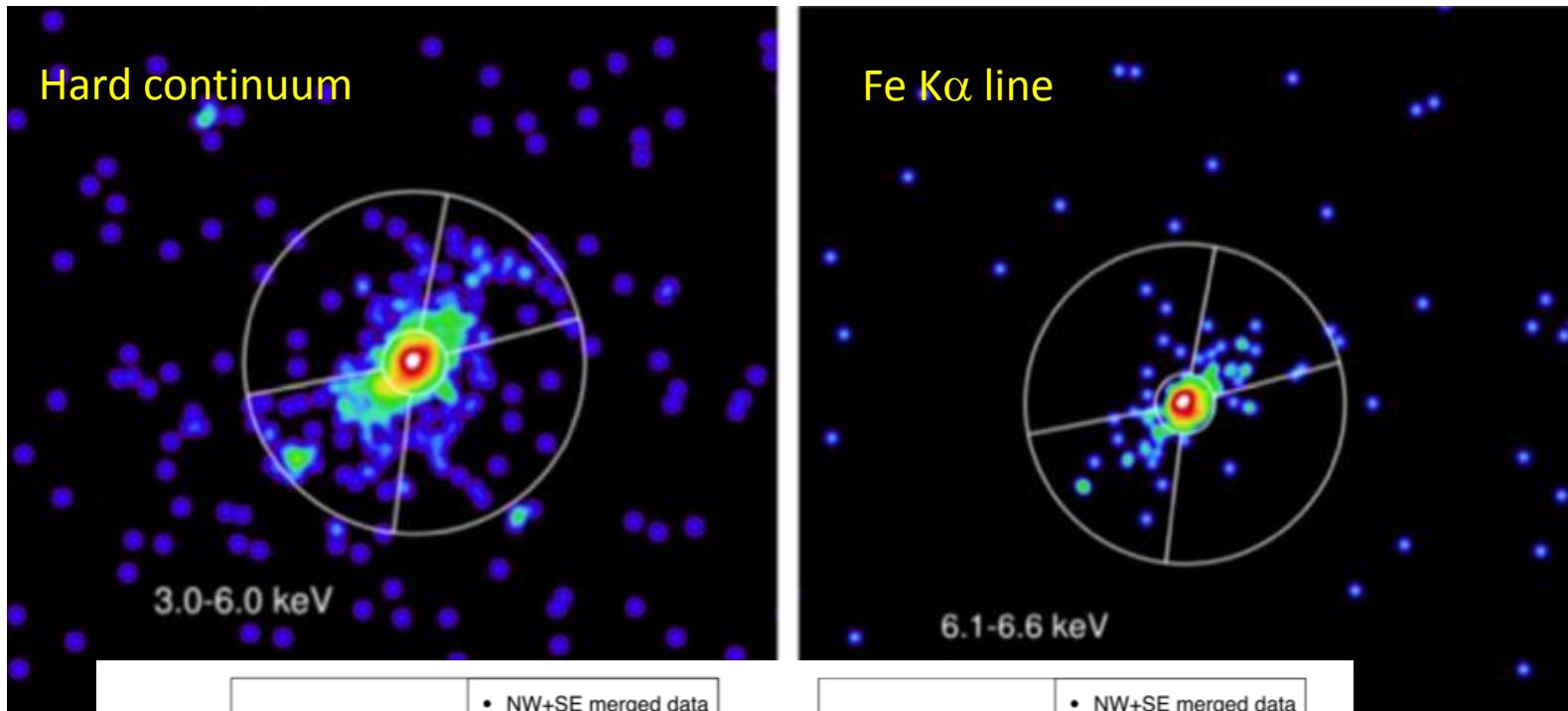
Contours are $\text{H}\alpha$

ESO 428-G014 –X-ray emission line ratios and models

- Nucleus
- SE knot
- NW knot

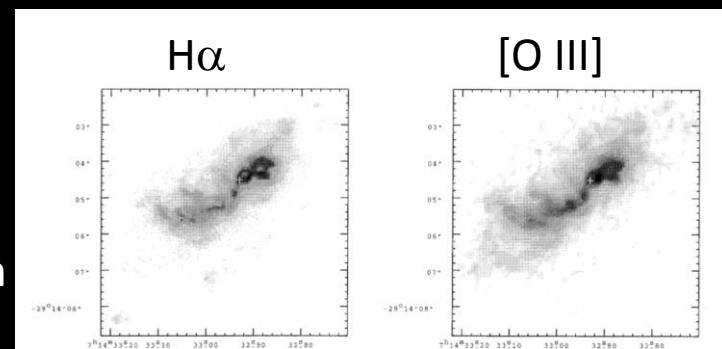
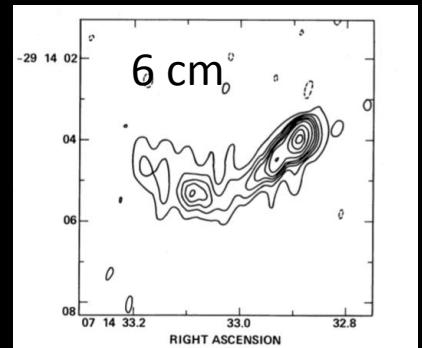


ESO 428-G014 – raw data Fabbiano et al 2017



Case study: ESO 428-G014

- Southern barred galaxy [SAB(r)] - J2000 RA = $7^h16^m31.2^s$, Dec = $-29^\circ19'28.6''$
- D \sim 23.3Mpc (scale = 112pc/arcsec)
- Highly obscured Seyfert 2 nucleus (CT, $N_H > 10^{25} \text{ cm}^{-2}$)
Maiolino et al. 1998
- One-sided, curved, 5"-long, 6 and 20 cm radio jet
Ulvestad & Wilson 1989
- Extended H α and [O III] optical line emission
Falcke et al. 1996, 1998
- Extended soft X-ray component detected with 30 ks Chandra exposure
 - David et al (2006) suggest thermal emission
 - Levenson et al (2006) advocate photoionization



- We have obtained a cumulative exposure of 150 ks with *Chandra* ACIS
Each photon individually detected and tagged with position, energy and time of arrival

ESO 428-G014 – *Chandra* hard band images – Fabbiano et al 2018

