The low-luminosity accretion flow of Sgr A* as seen by Chandra HETG

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in collaboration with

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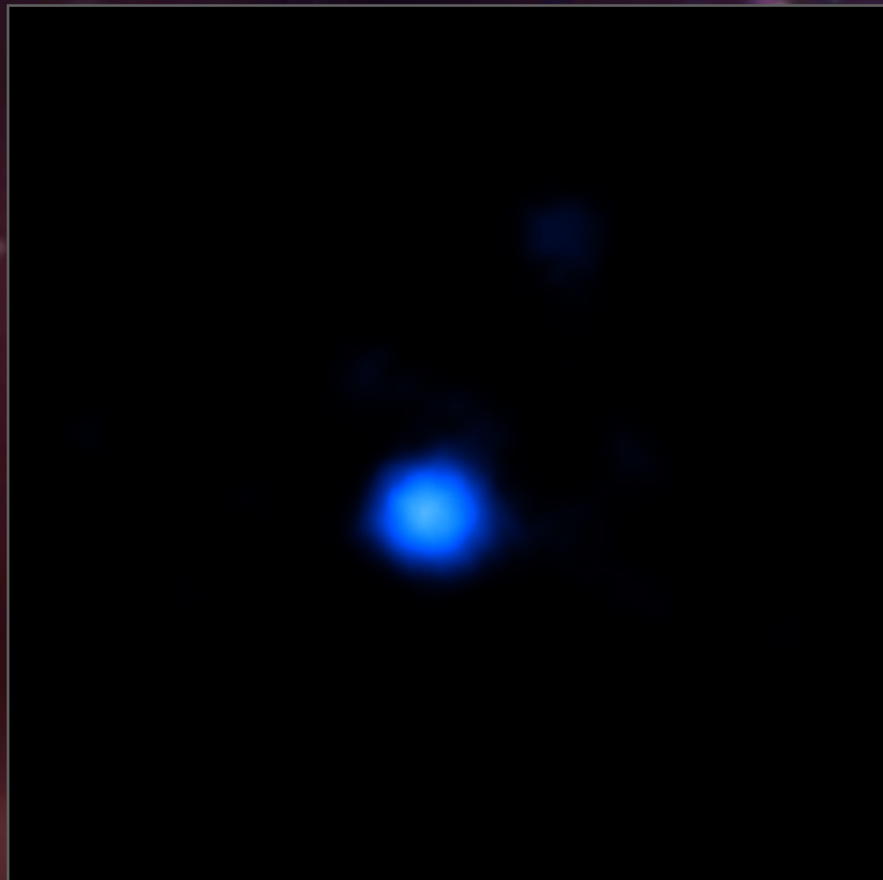
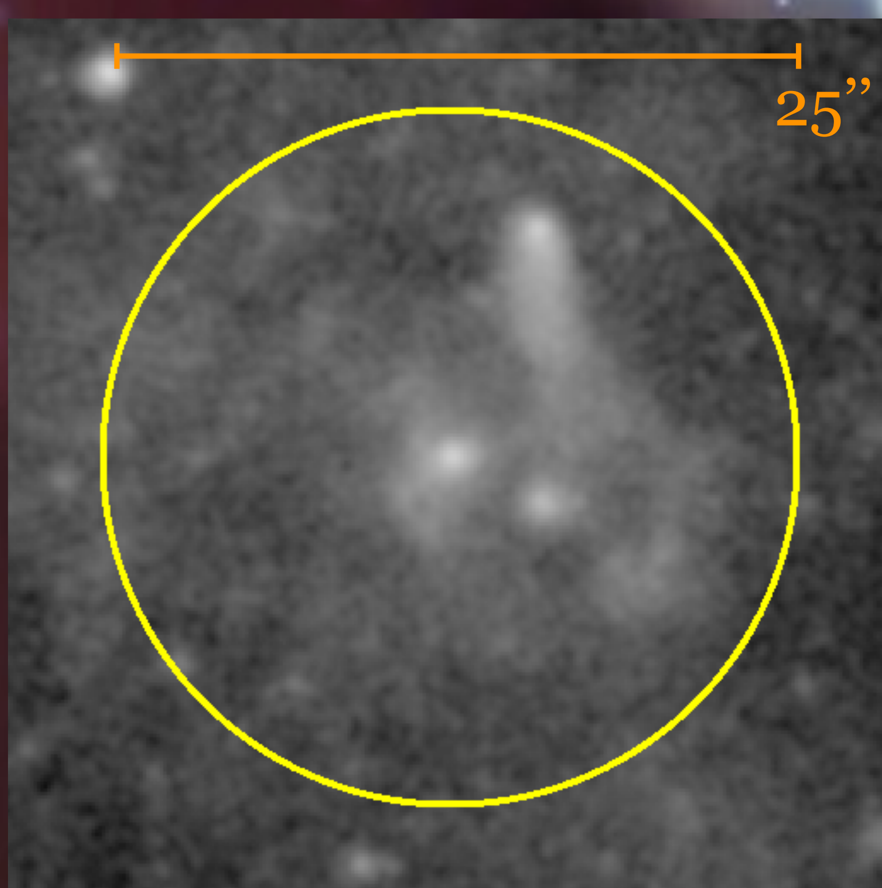
Image Credit: NASA/CXC/MIT/F.K.Baganoff

NASA/CXC/Amherst College/D.Haggard et al





central parsec

Sgr A* accretion

$L_X = 2.4 \times 10^{33}$ erg/s

implies ~ 10^{-10} Eddington

~ 10^5 x dimmer than standard accretion models for this environment

Baganoff+ 2003, Yang+ 2003, Wang+ 2013

Image Credit: NASA/CXC/MIT/F.K.Baganoff

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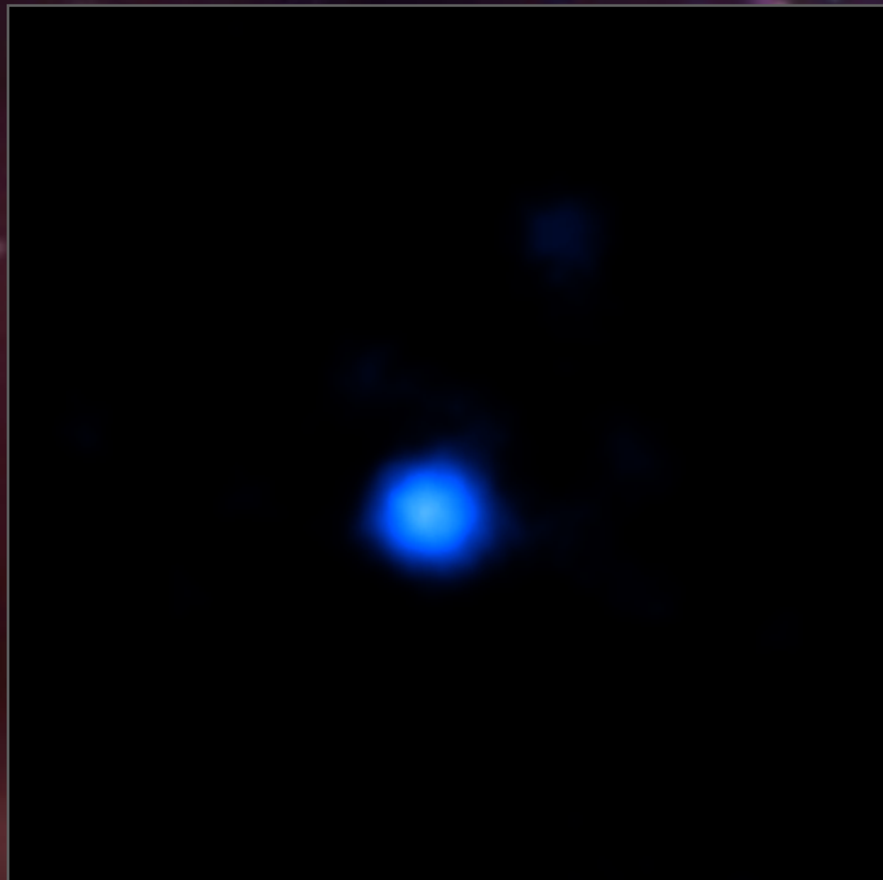
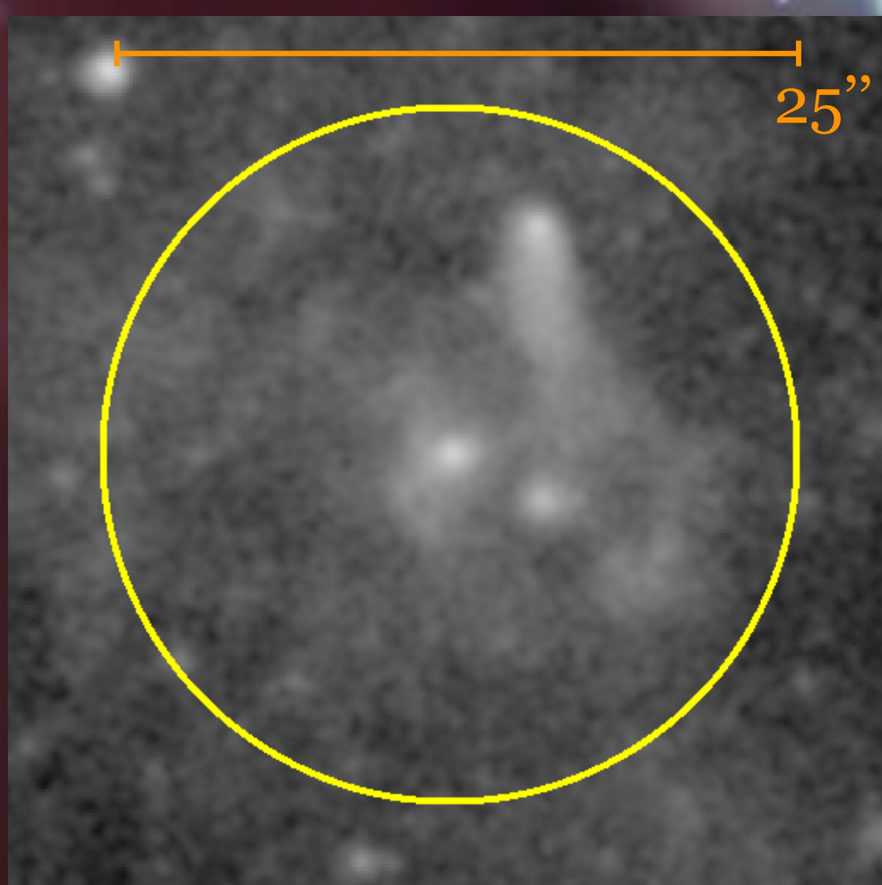
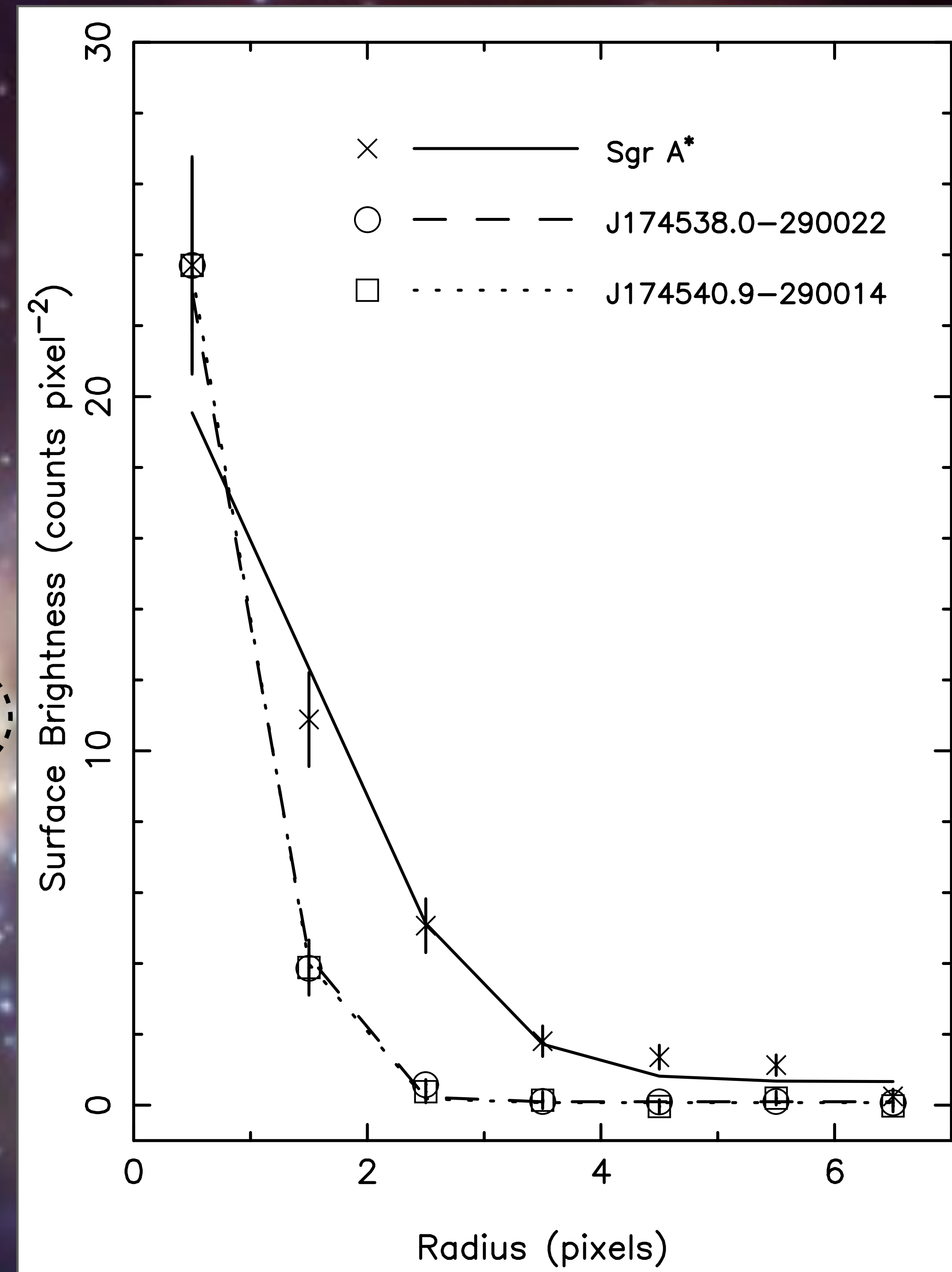




central parsec



Baganoff+ 2003

Image Credit: NASA/CXC/MIT/F.K.Baganoff

Radiatively Inefficient Accretion Flows

$$\dot{M} \propto \left(\frac{r}{r_0}\right)^{s} \qquad \rho \propto \left(\frac{r}{r_0}\right)^{-3/2+s} \qquad T \propto \left(\frac{r}{r_0}\right)^{-q}$$

$s = 0$

Bondi

Radiatively **I**nefficient **A**ccretion **F**lows

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$$s = 0$$

Advection **D**ominated **A**ccretion **F**low

energy transport through
advection >> radiation

Bondi, ADAF with no outflow

Narayan & Yi 1994, 1995

Radiatively Inefficient Accretion Flows

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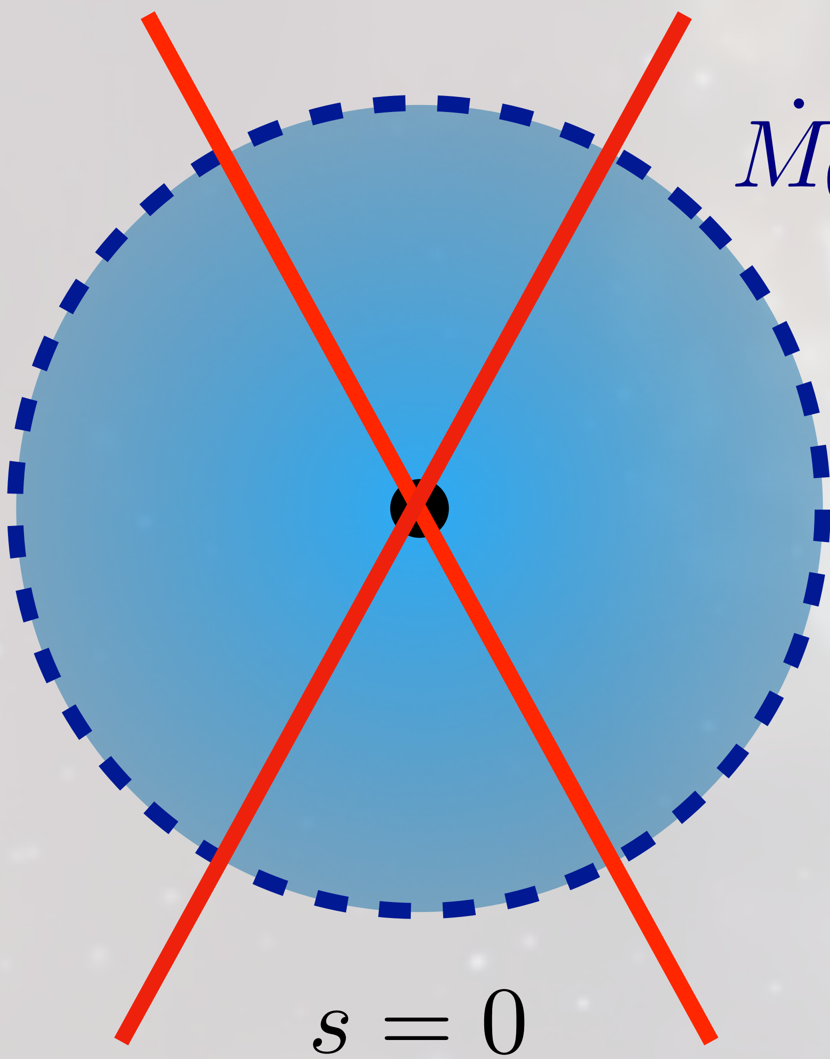

$s = 0$

$\dot{M}_0 \sim 10^{-5} M_\odot \ \mathrm{yr}^{-1}$

- Radio measurements show ~10% polarization at 100 GHz
- No polarization (<2%) at lower frequencies

$M_{\mathrm{BH}} \lesssim 10^{-8} M_\odot \ \mathrm{yr}^{-1}$

Aitken 2000, Bower+ 1999abc, Bower+ 2003, Quataert & Gruznov 2000b, Agol 2000, Özel+ 2000

Bondi, ADAF with no outflow

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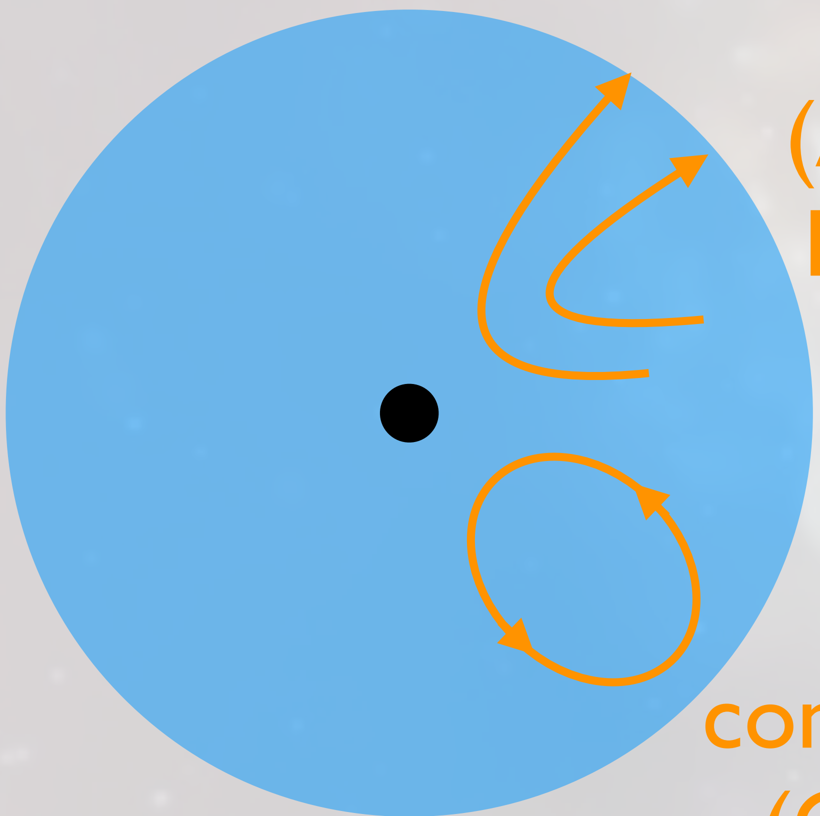

winds (ADIOS, RRIOS)

convection (CDAF)

$s > 0$ $\quad$ $s = 1$

ADAF with outflow

ADAF model has an outflow solution

None of these fit the multi-wavelength SED while preserving ADAF assumption

Narayan & Yi 1995b, Blandford & Begelman 1999, Quataert & Gruzinov 2000a, Narayan+ 2012

Radiatively Inefficient Accretion Flows

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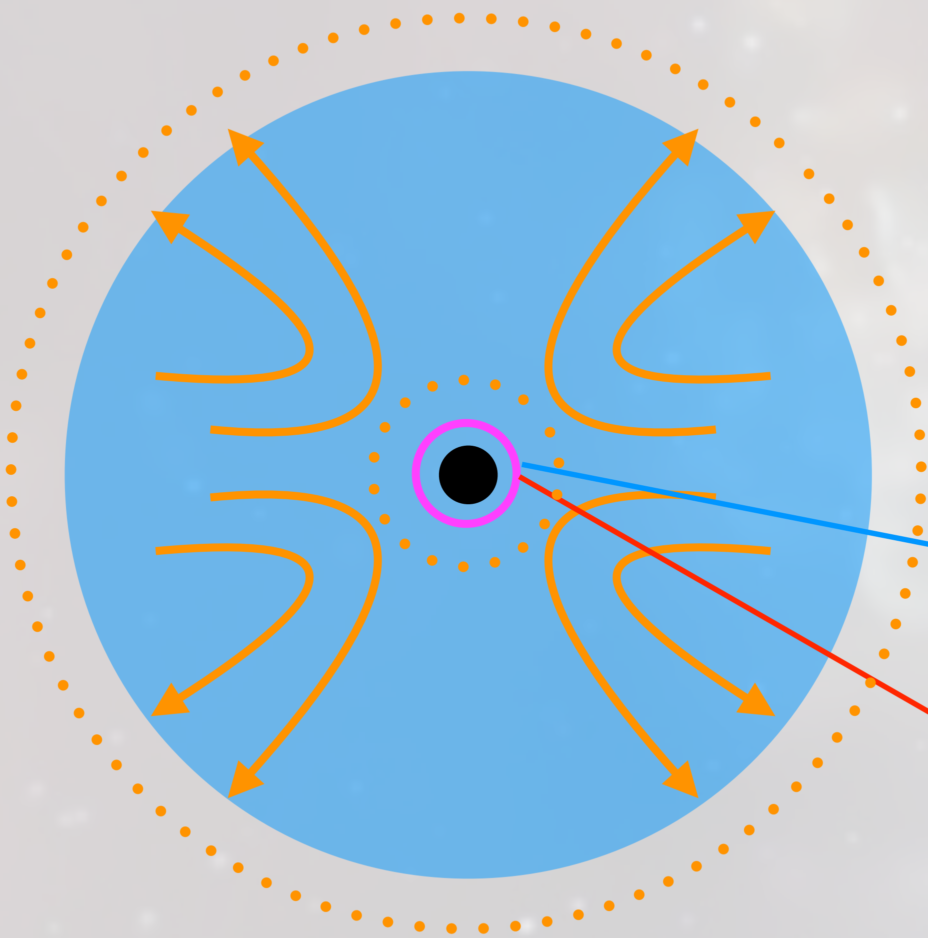
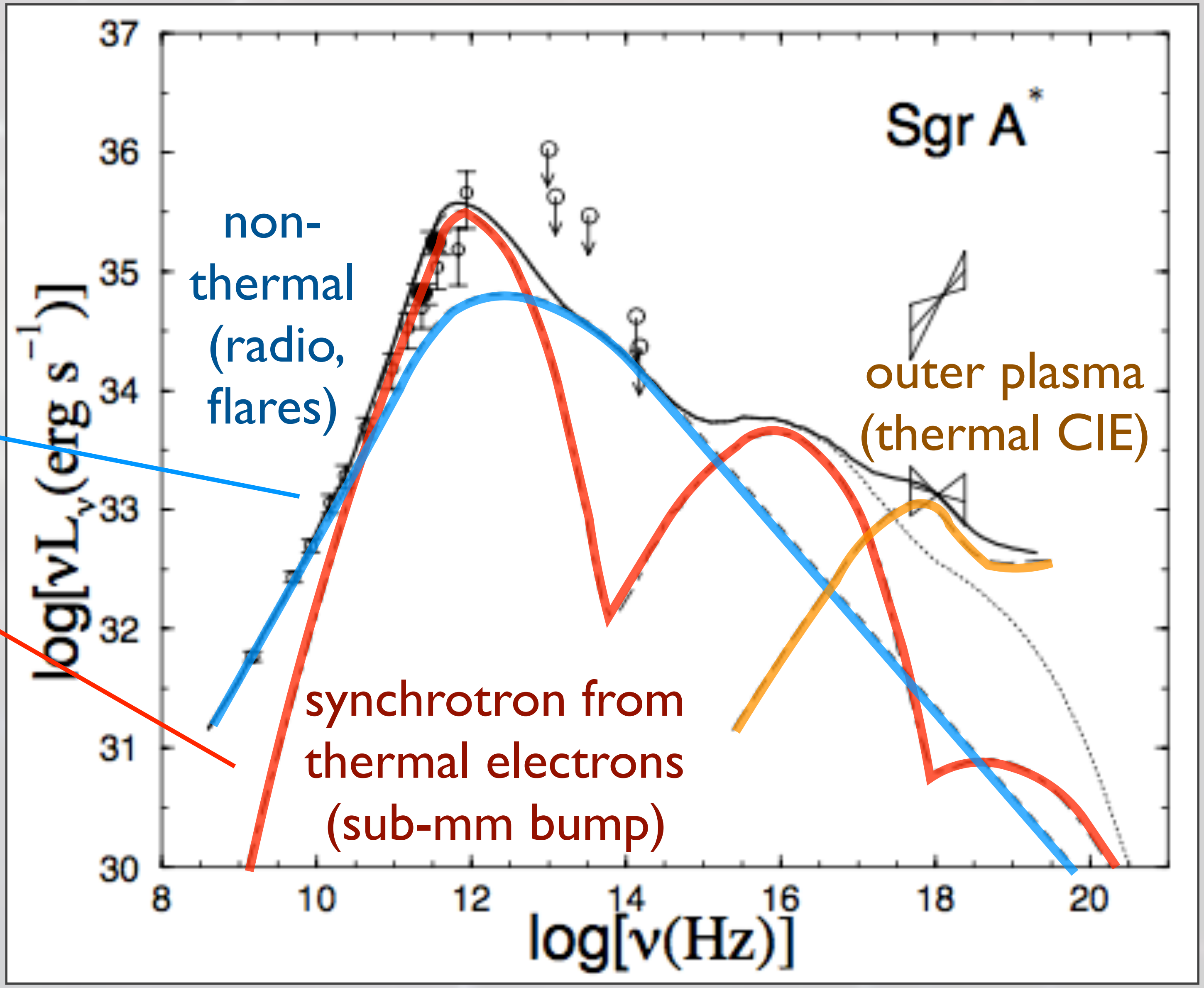


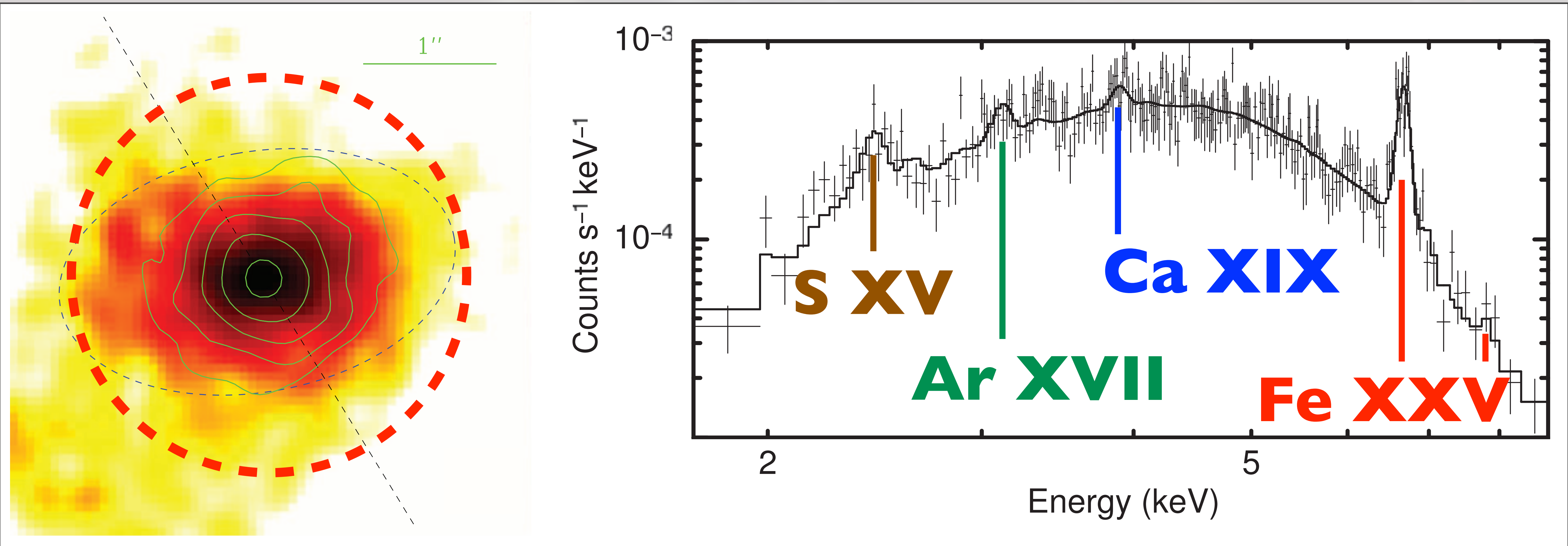
$s \approx 0.3$

Yuan+ 2003



Results of CCD resolution (~ 150 eV) data

Chandra Galactic Center X-ray Visionary Program (3 Ms)

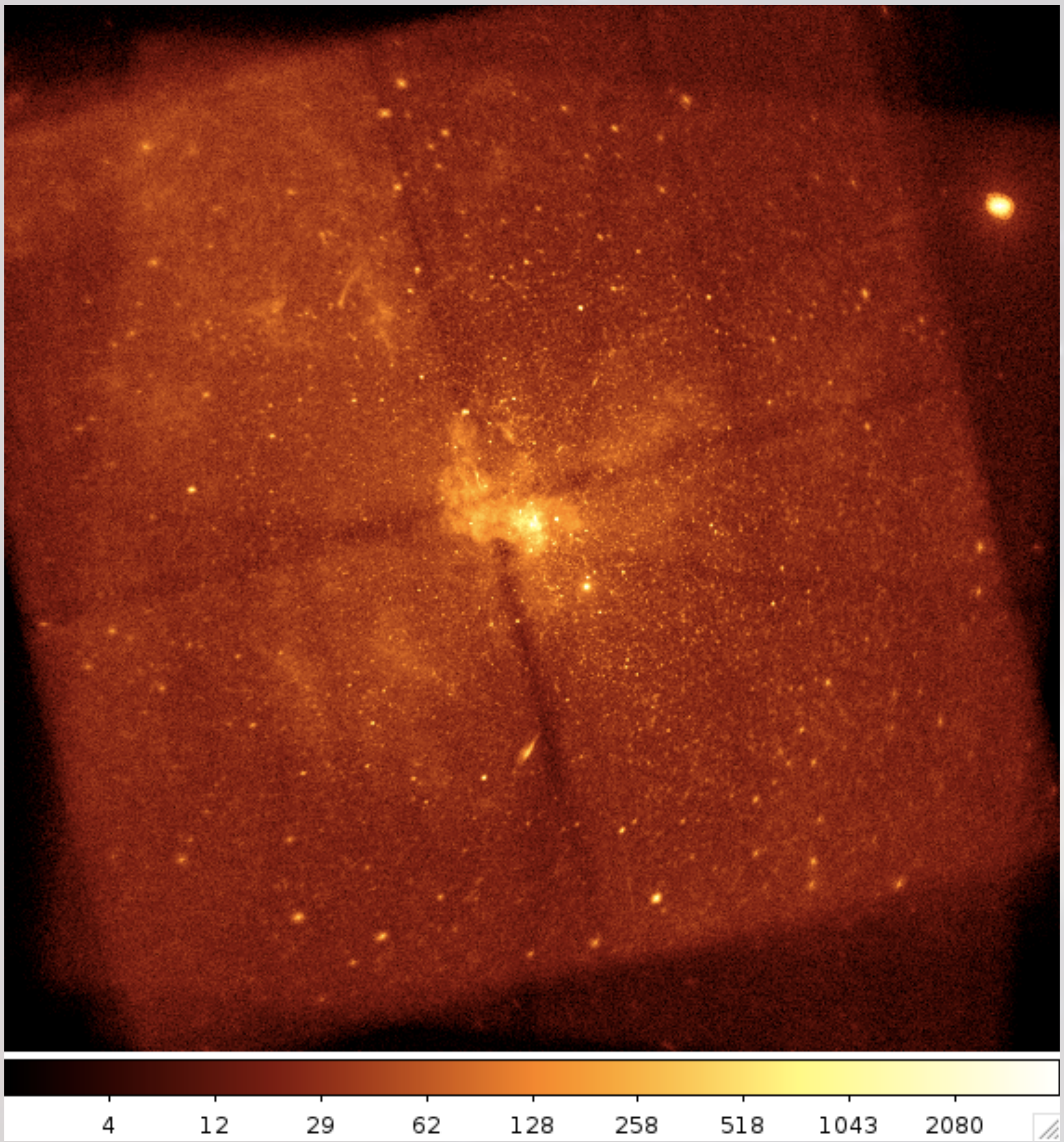


$s \sim 1$

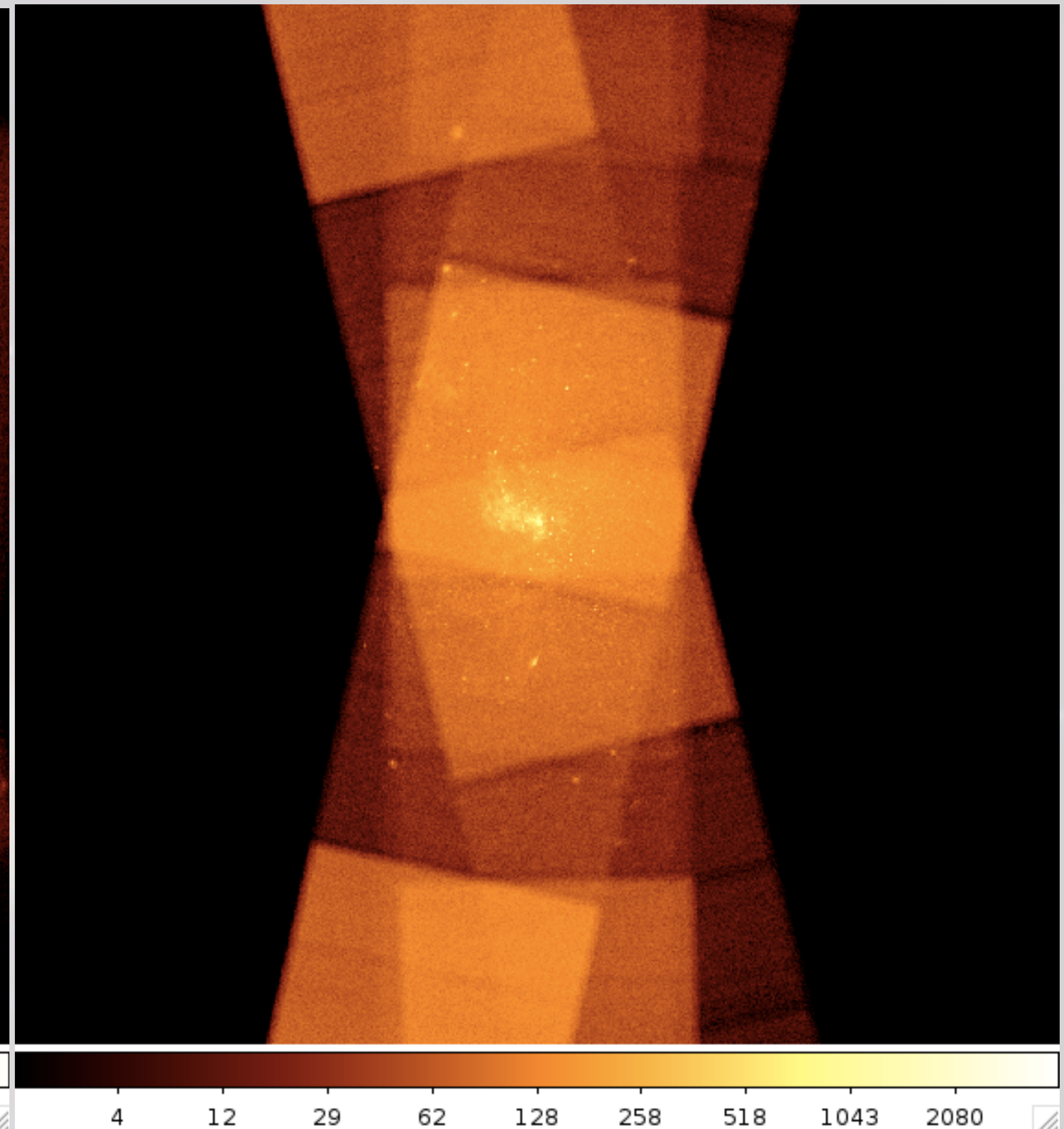
Wang+ 2013

Region chosen is ~1/2 Bondi radius

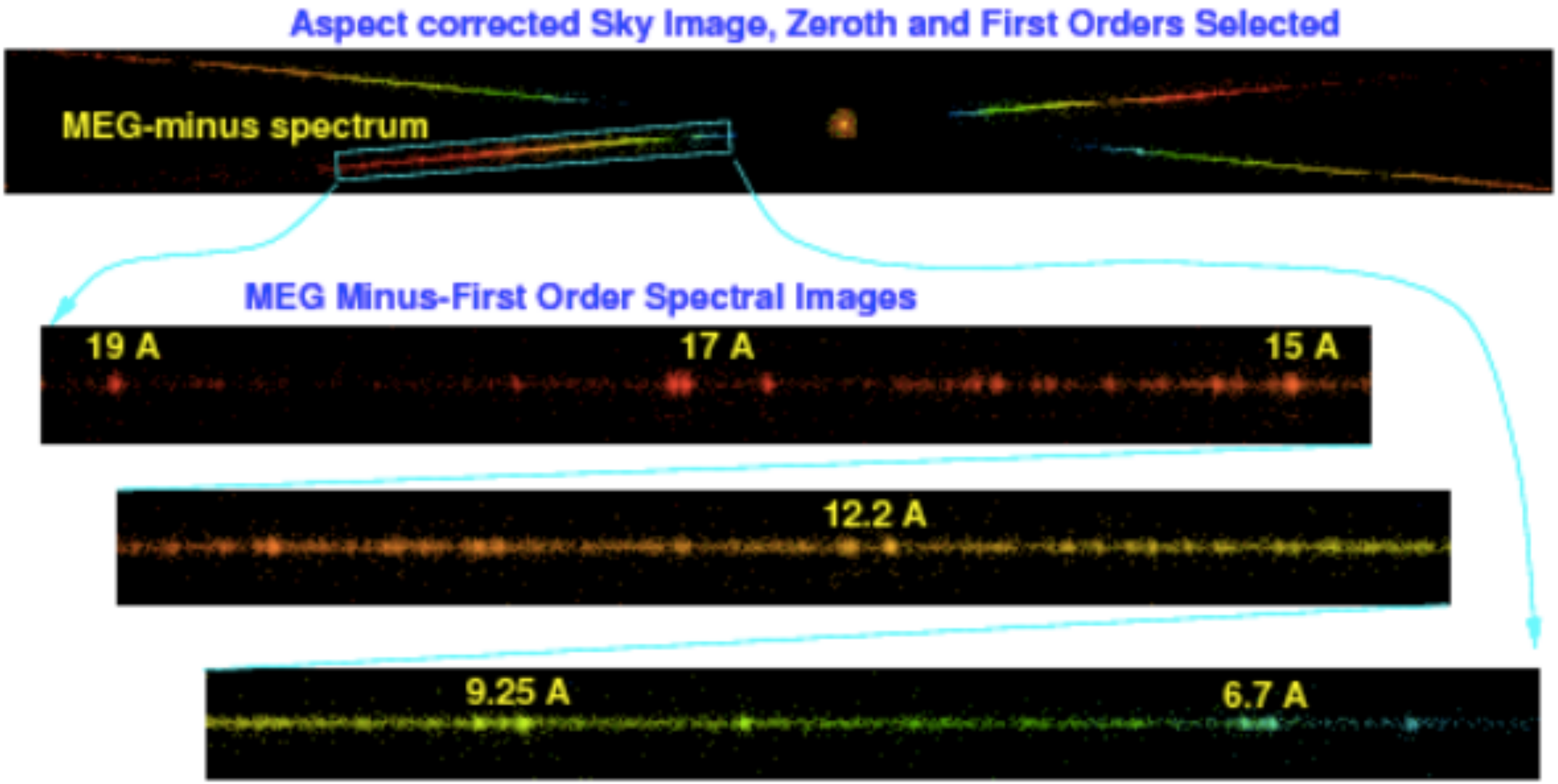
~1 Ms ACIS-I

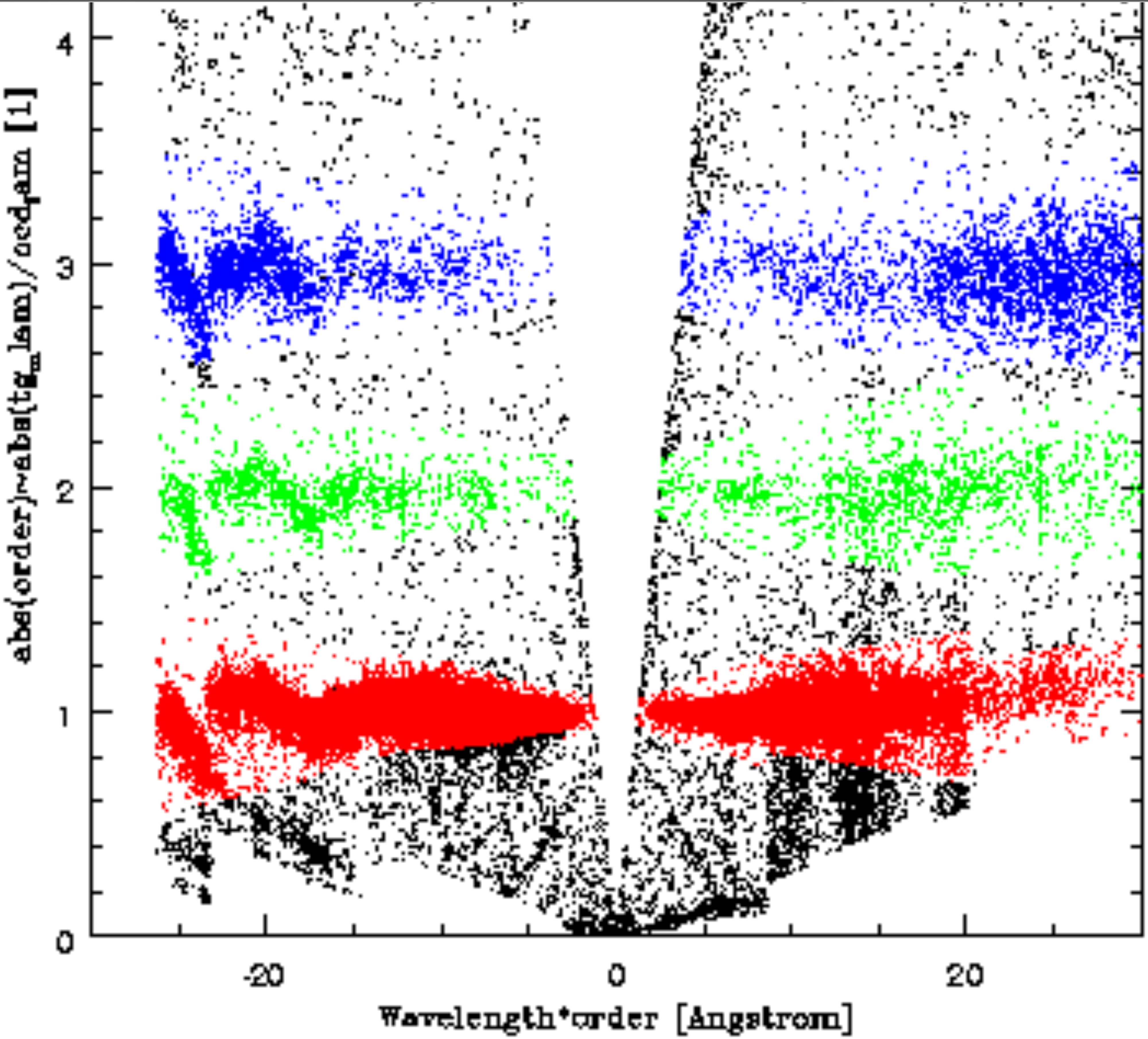


~3 Ms HETG (ACIS-S)



raw stacked images

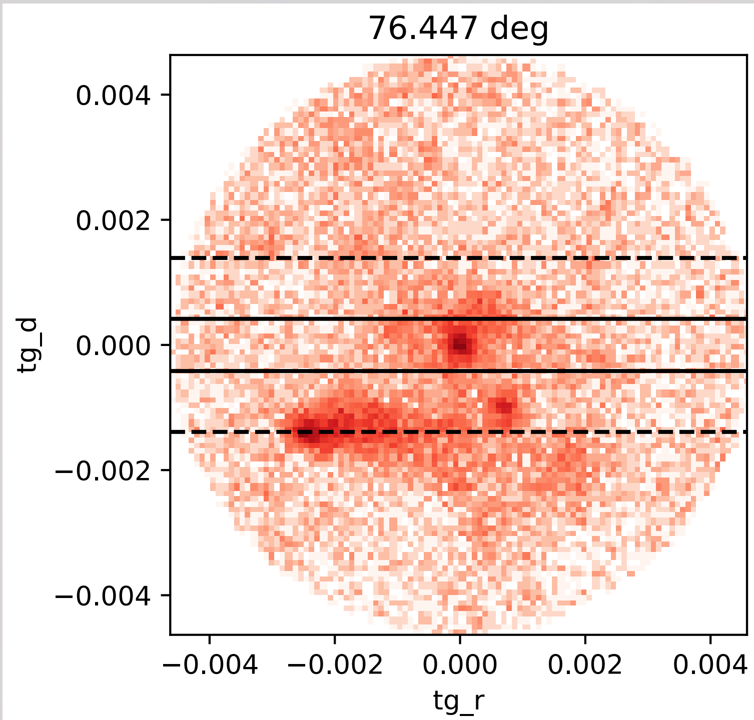

Aspect corrected Sky Image, Zeroth and First Orders Selected
MEG-minus spectrum
MEG Minus-First Order Spectral Images
19 A
17 A
15 A
12.2 A
9.25 A
6.7 A

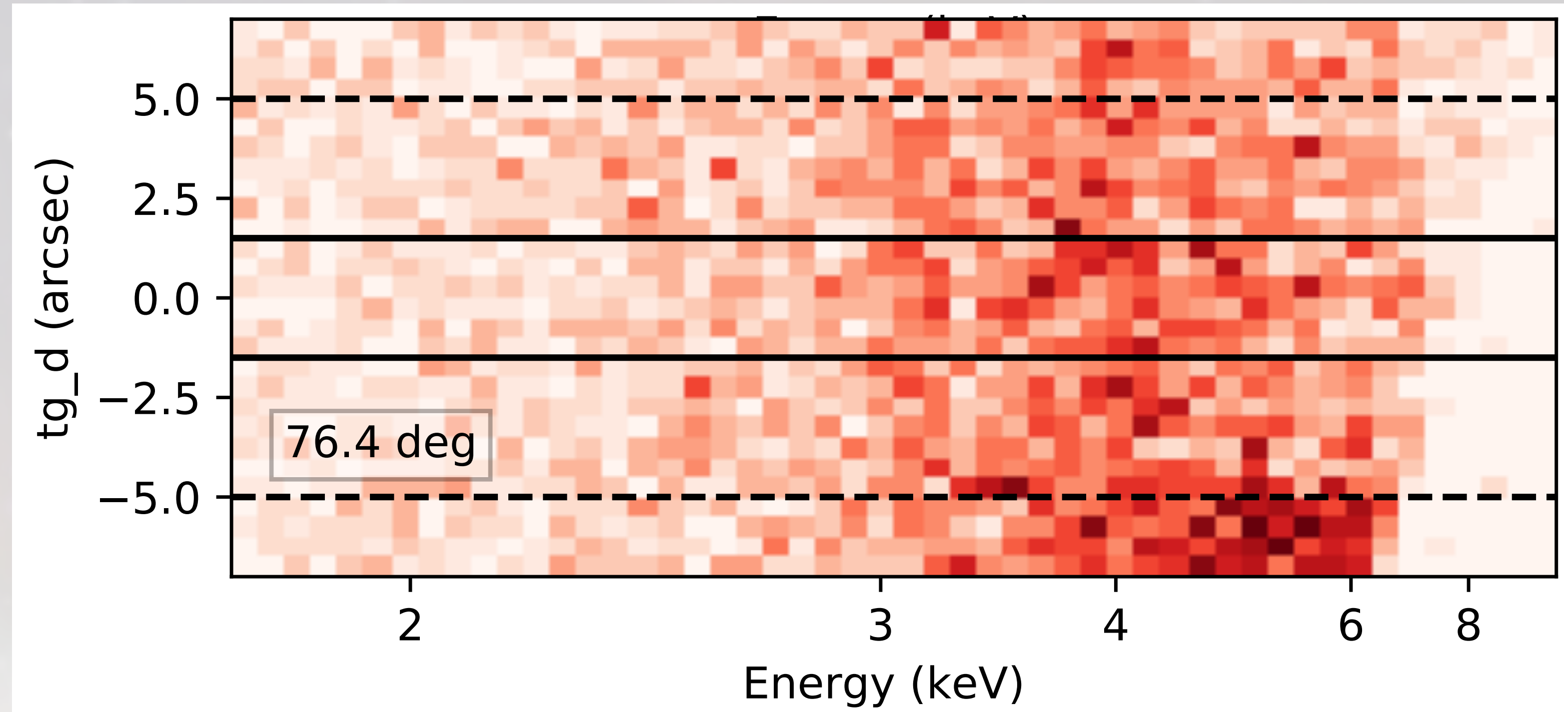


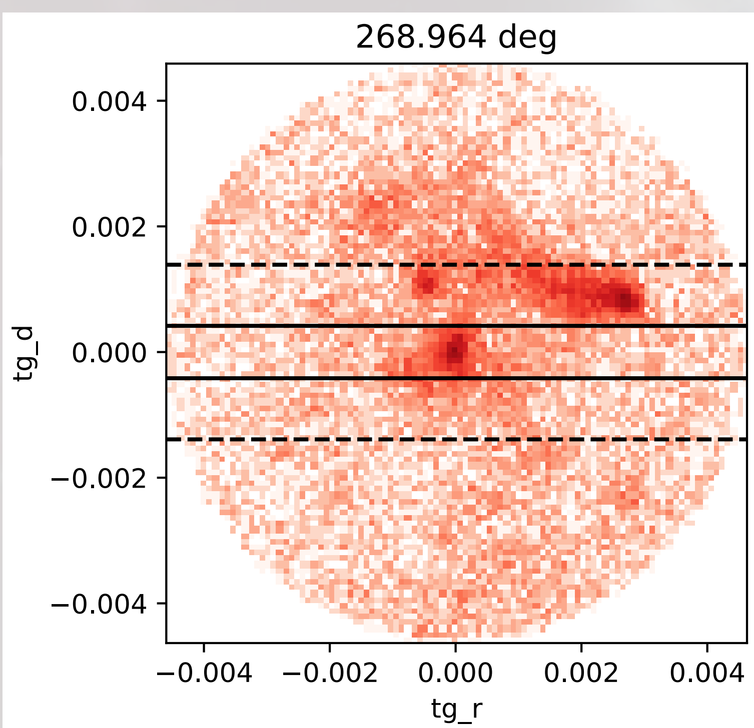
0
1
2
3
4
-20
0
20
Wavelength*order [Angstrom]

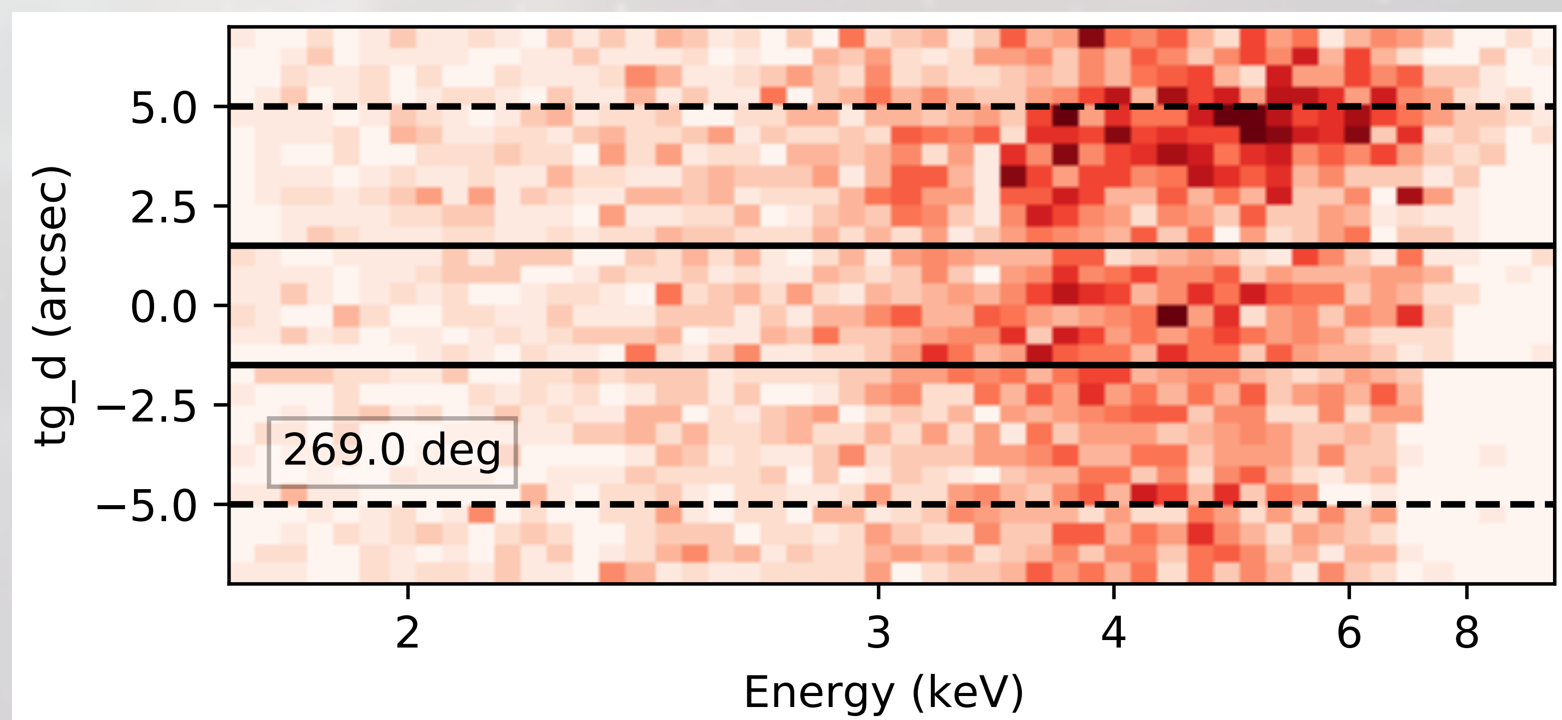
HEG coords

HEG -1



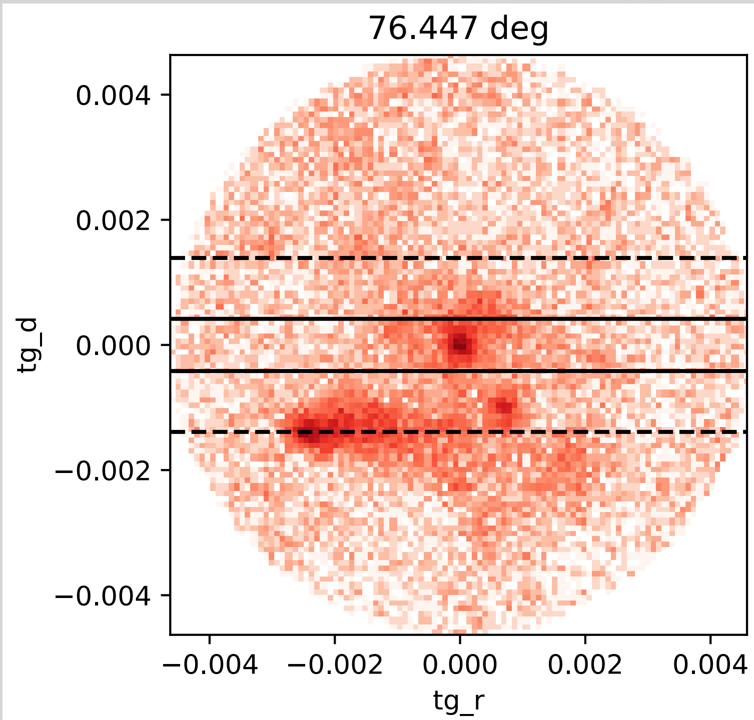


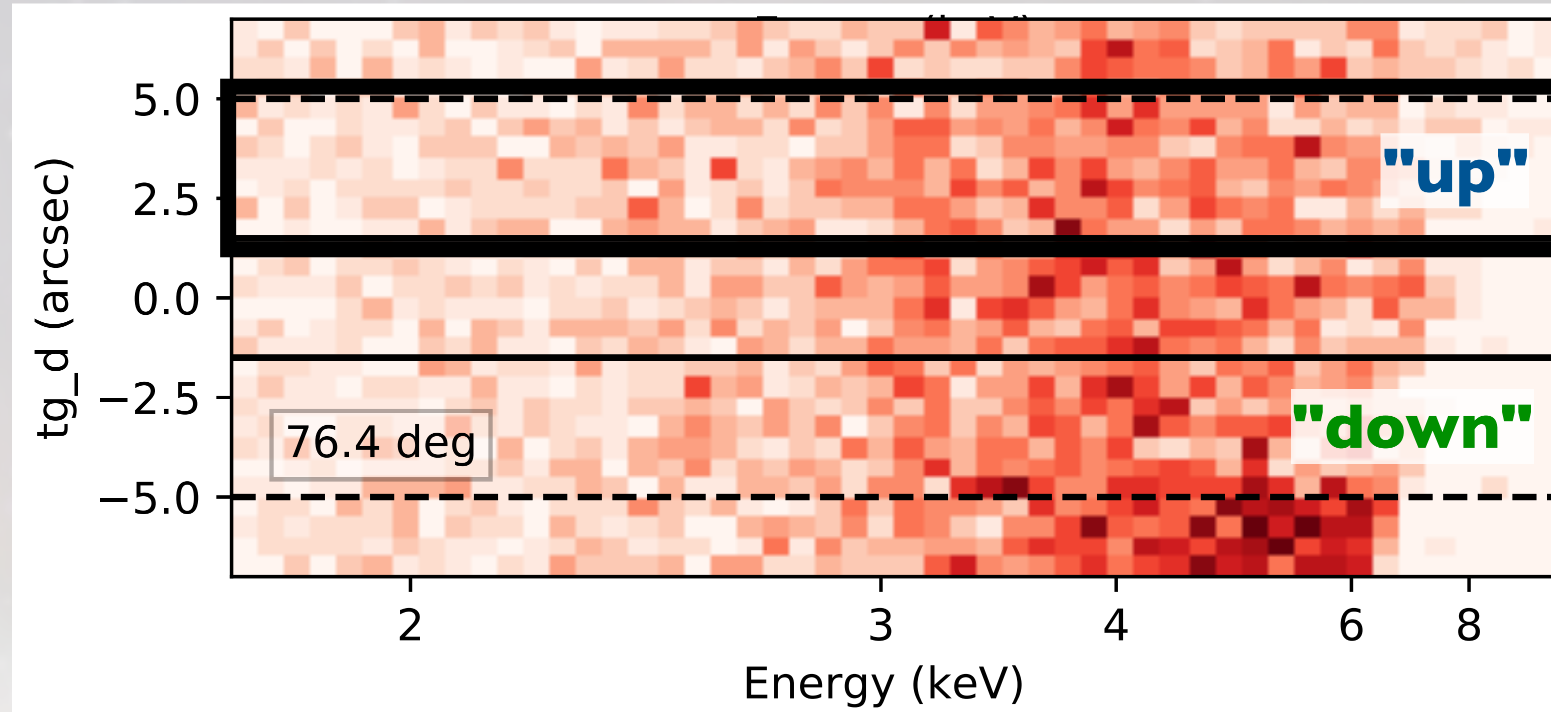


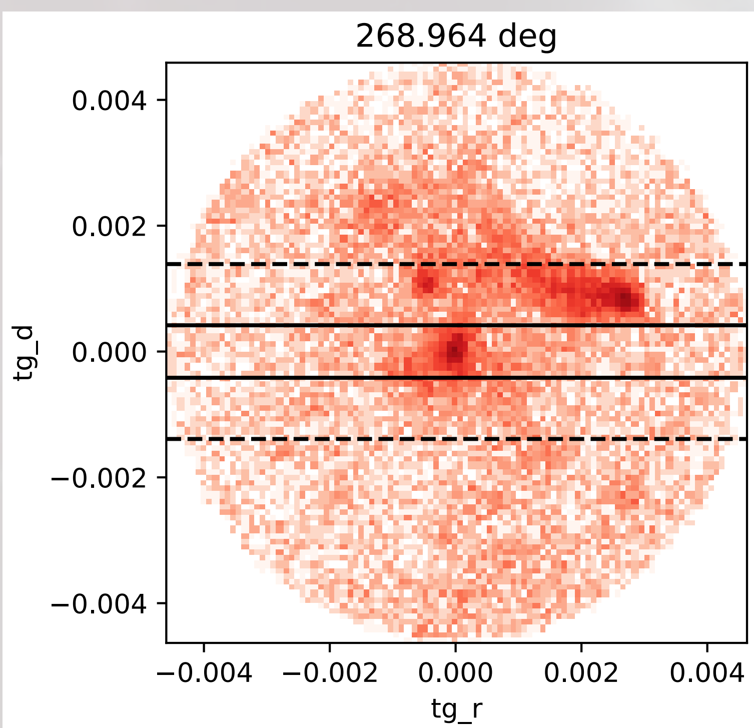


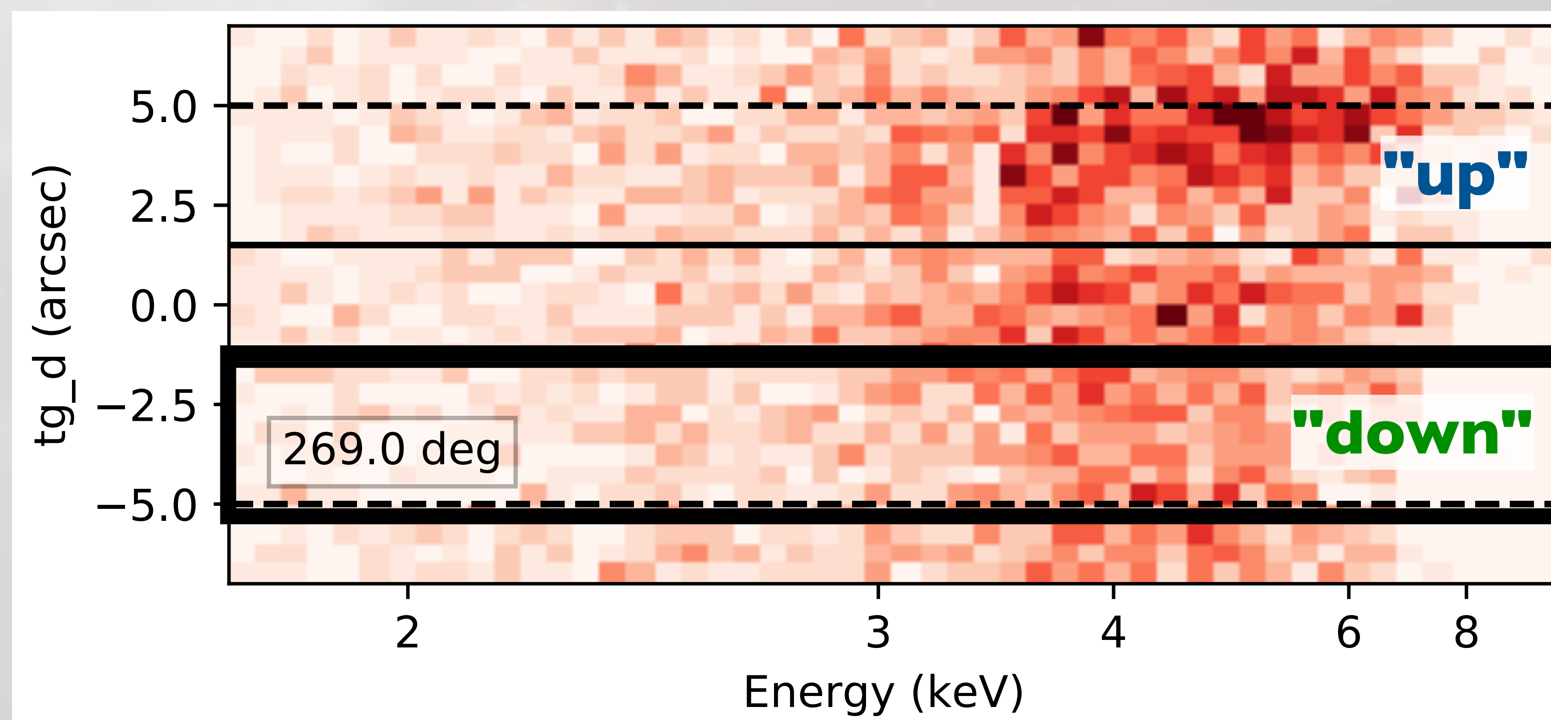
HEG coords

HEG -1

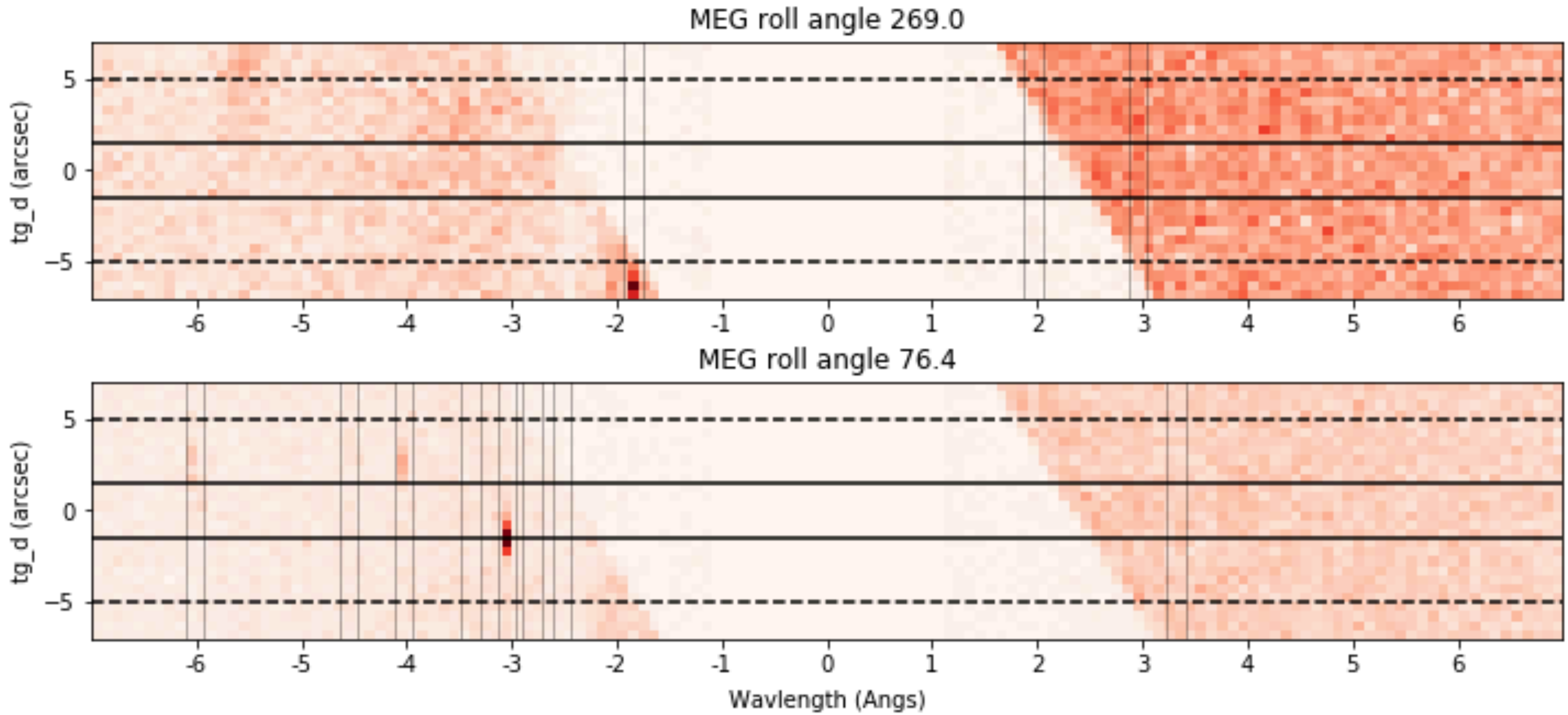




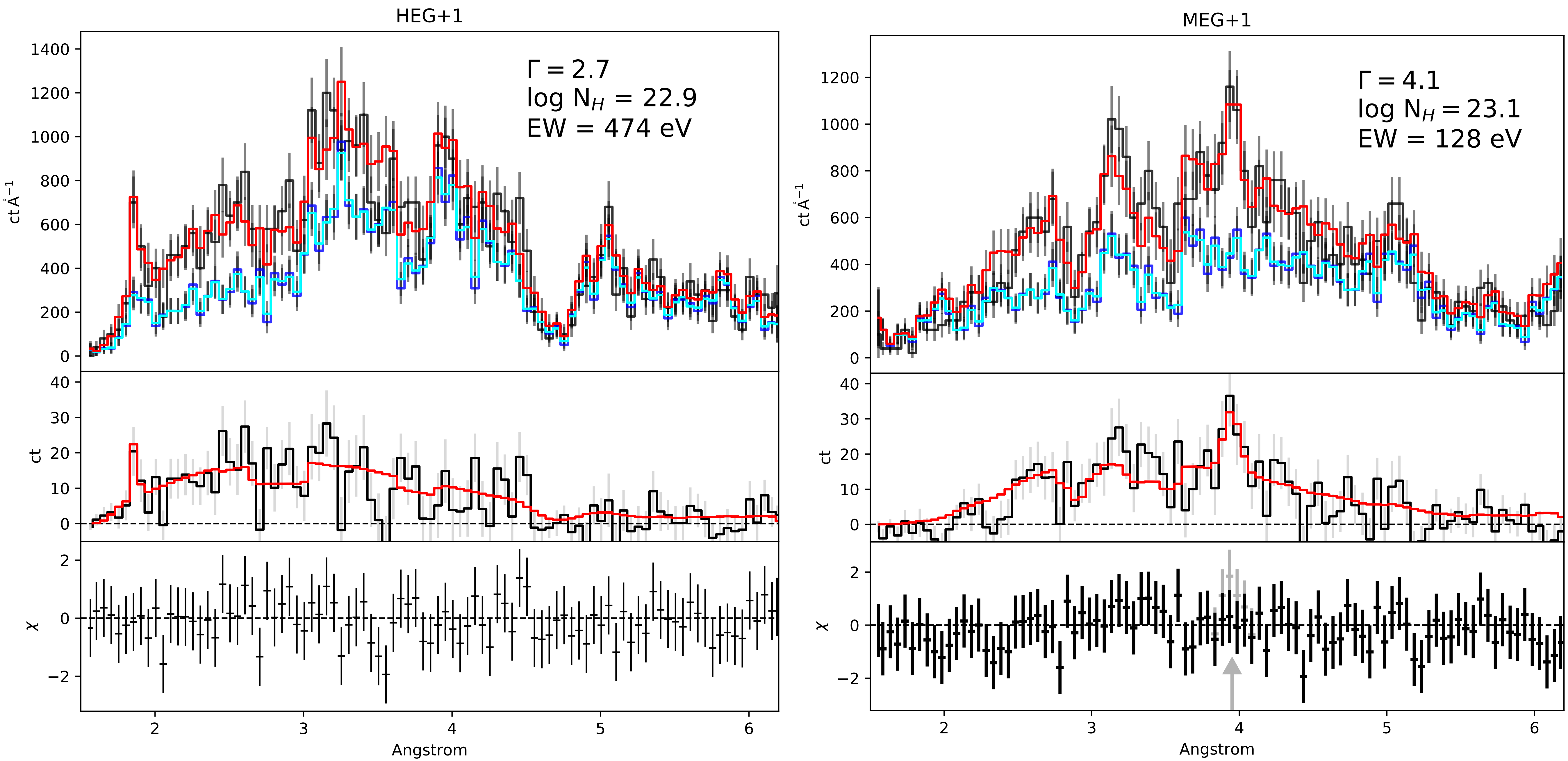




Overlapping point sources removed



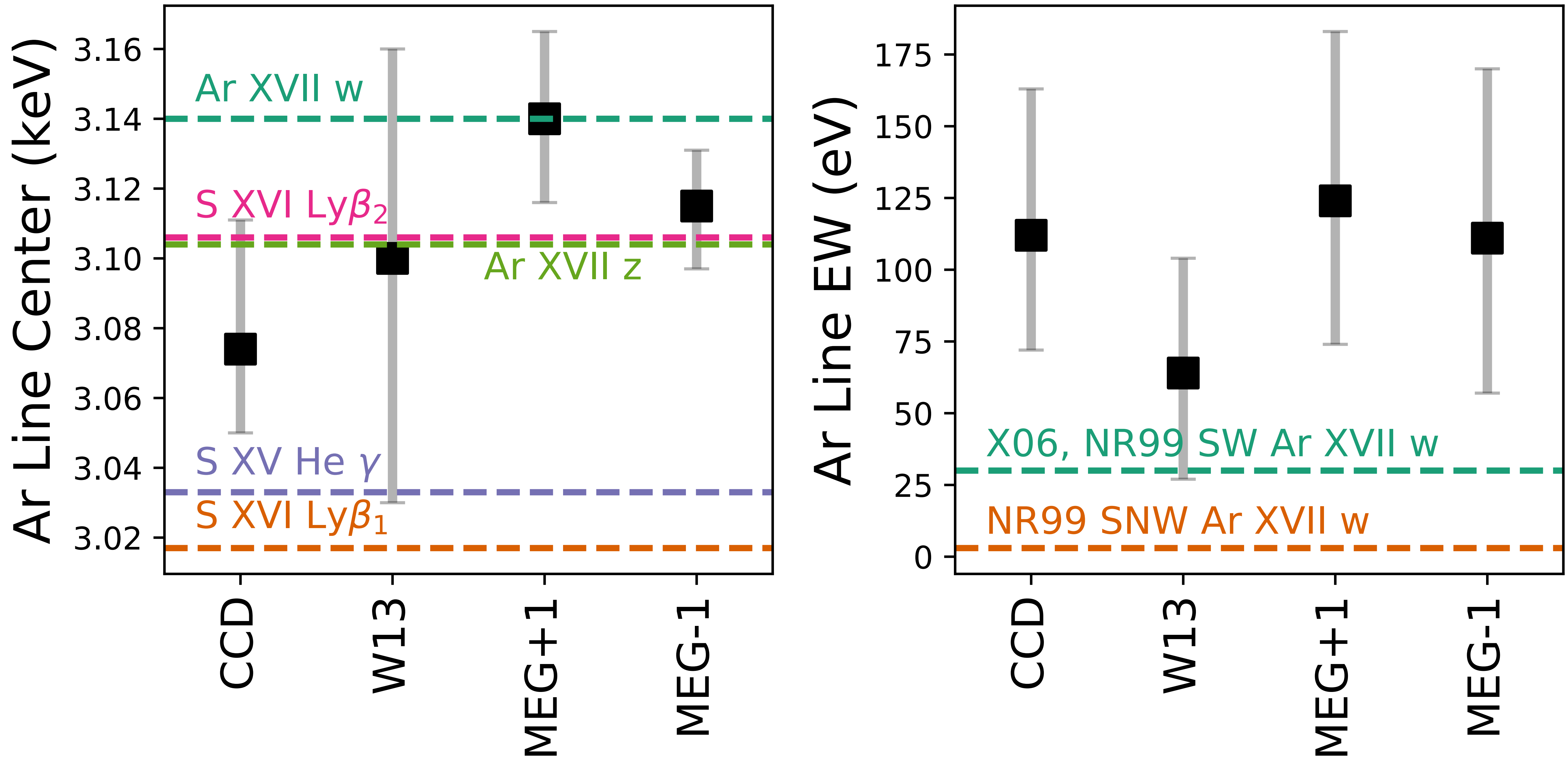
A simple Gaussian fit yields 6.7 and 3.1 keV lines



Source spectrum | Powerlaw + Gaussian
Background spectrum | Background model

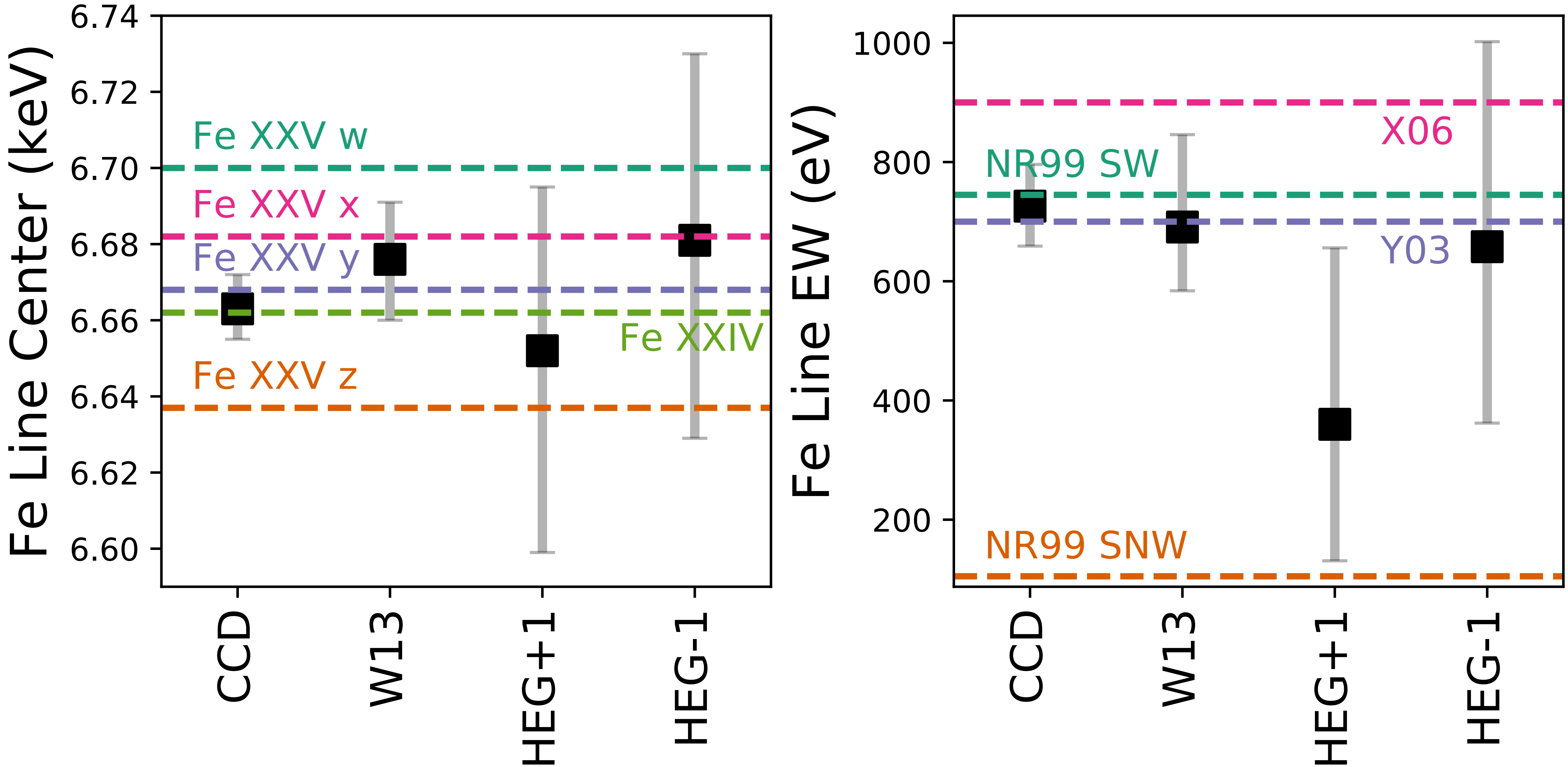
Corrales+ 2019, in review

Better constraint on 3.1 keV line centroid, most likely He-like Argon

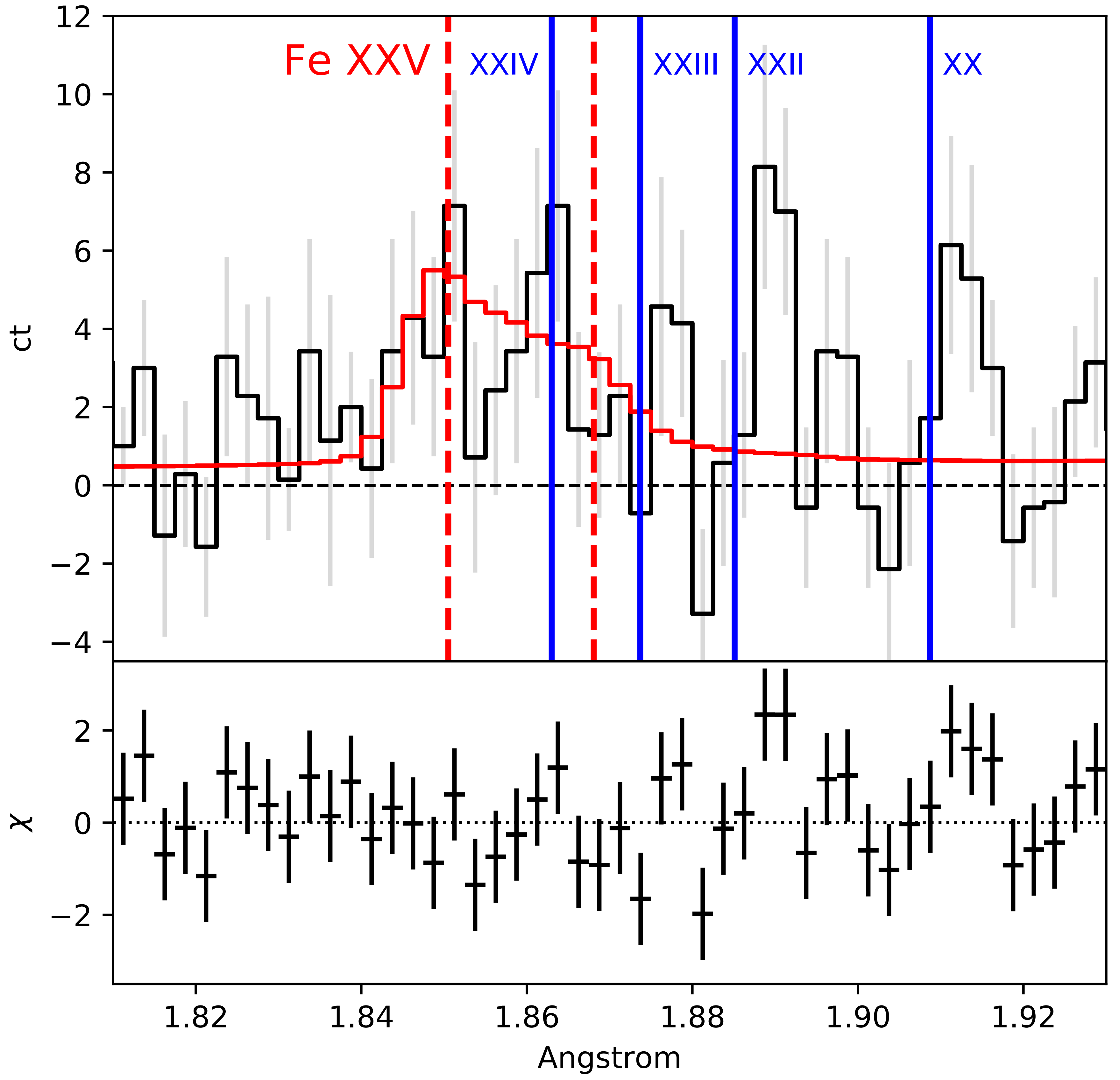


Corrales+ 2019, in review

Single Gaussian fit to Fe XXV lines consistent with but no better than CCD fits

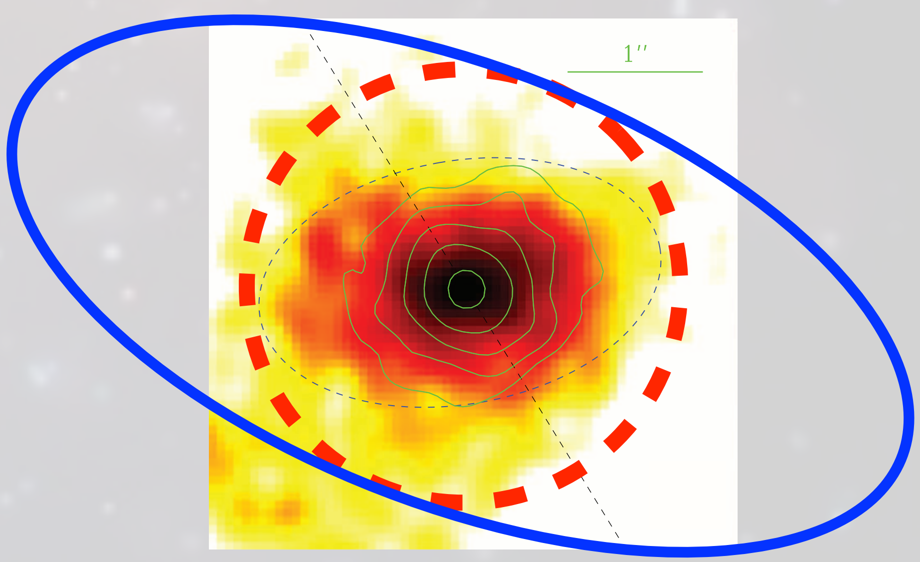


Corrales+ 2019, in review



Corrales+ 2019, in review

Examination of the unbinned spectrum reveals more of the Fe line complex and potential velocity shifts



for illustrative purposes only

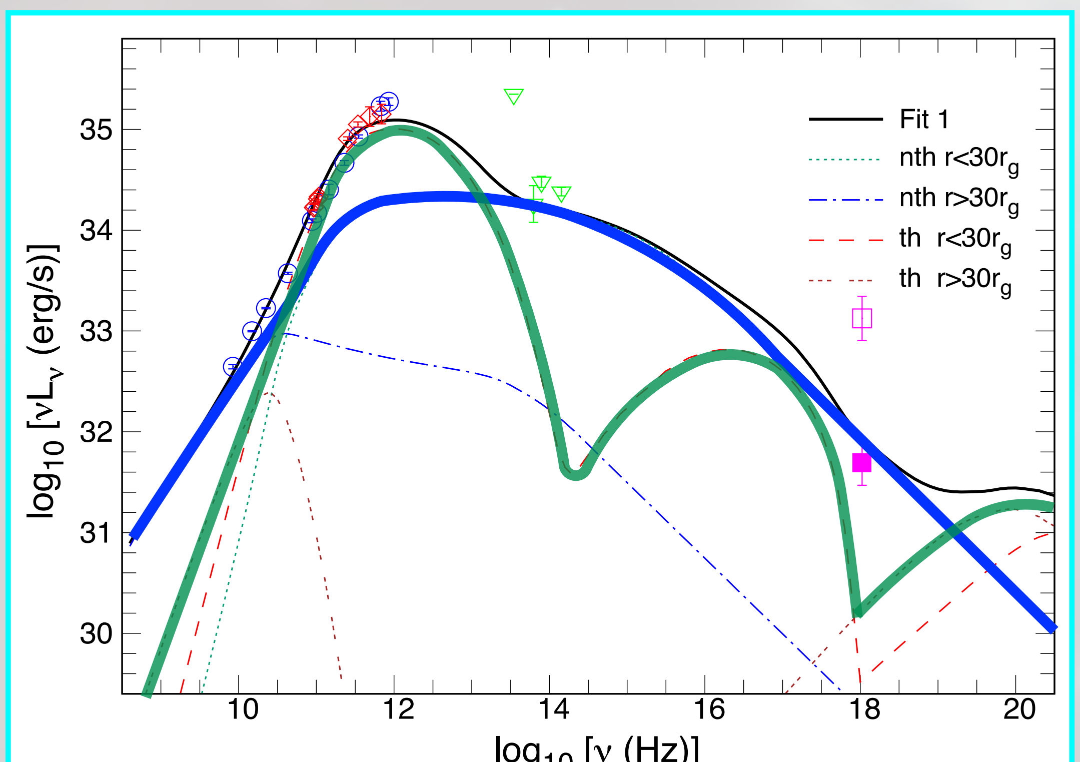
Outflow models with variable density gradient

Point source component of Sgr A*:

- Inner 10^3 r_g (< 0.5")
- 4% of quiescent X-rays

Ma, Roberts et al. (2019)

non-thermal component **thermal component**

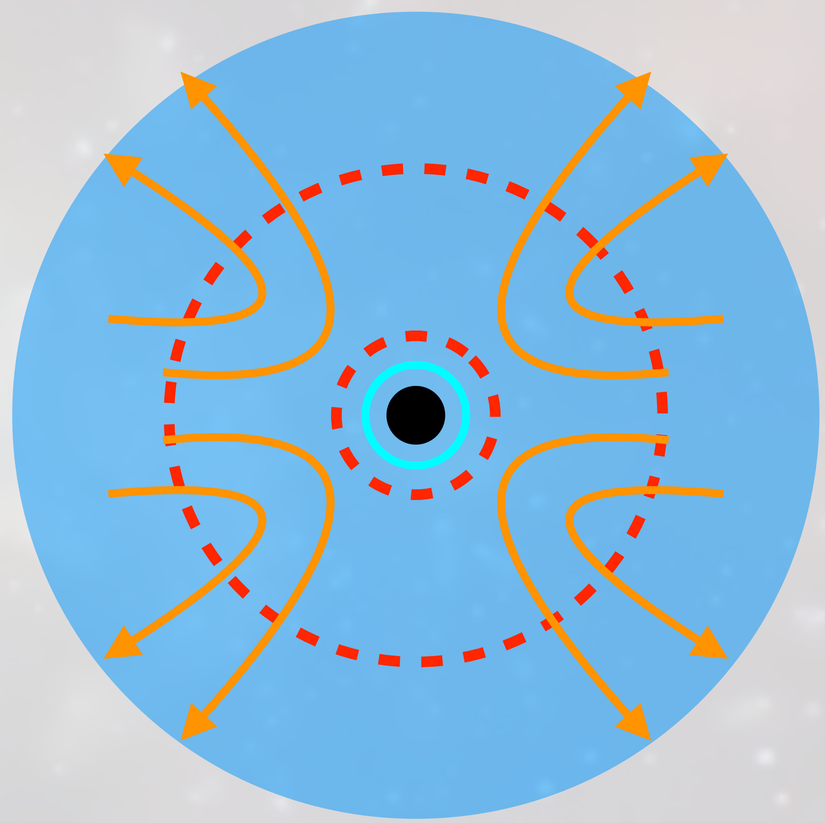


Wang et al. (2013)

lines from < 12 keV gas

$s \sim 1$

quiescent X-ray (plasma)



$s = 0.37$

Same physics as Yuan+ 2003

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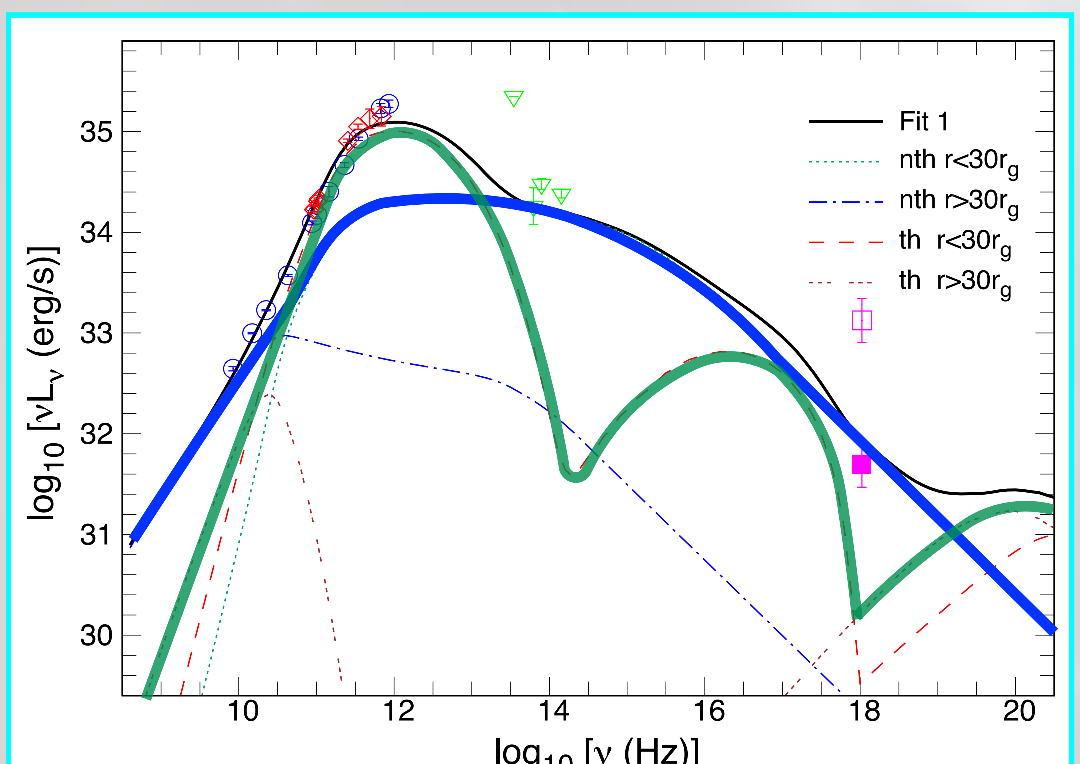

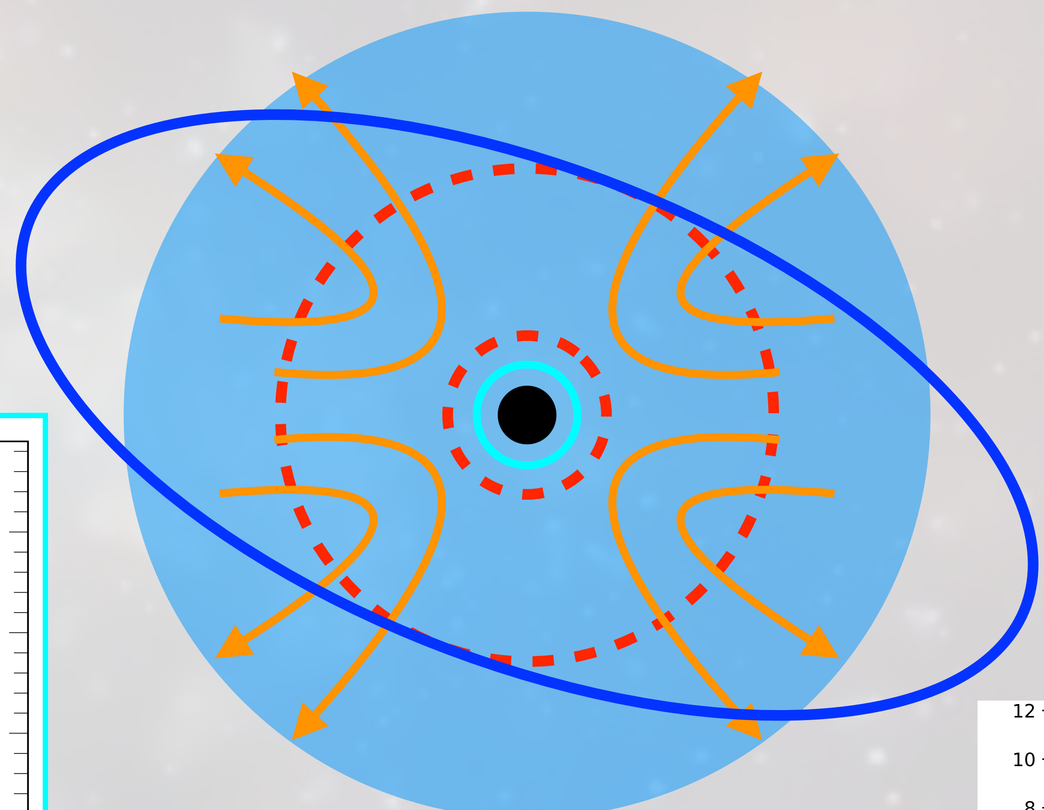

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Wang et al. (2013)

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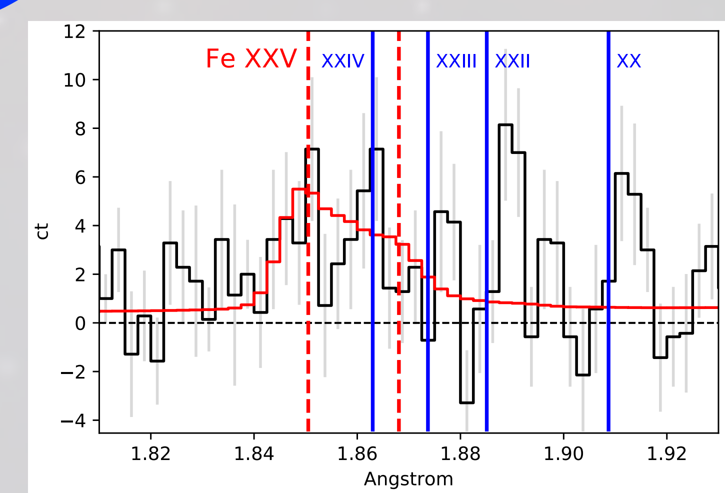
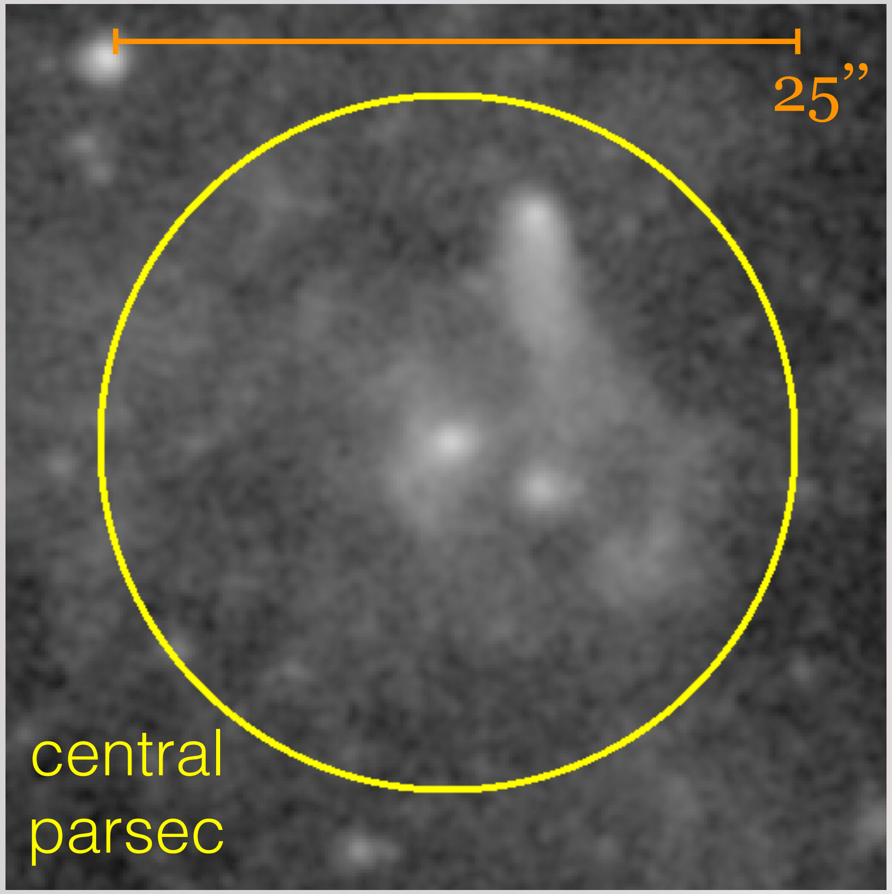
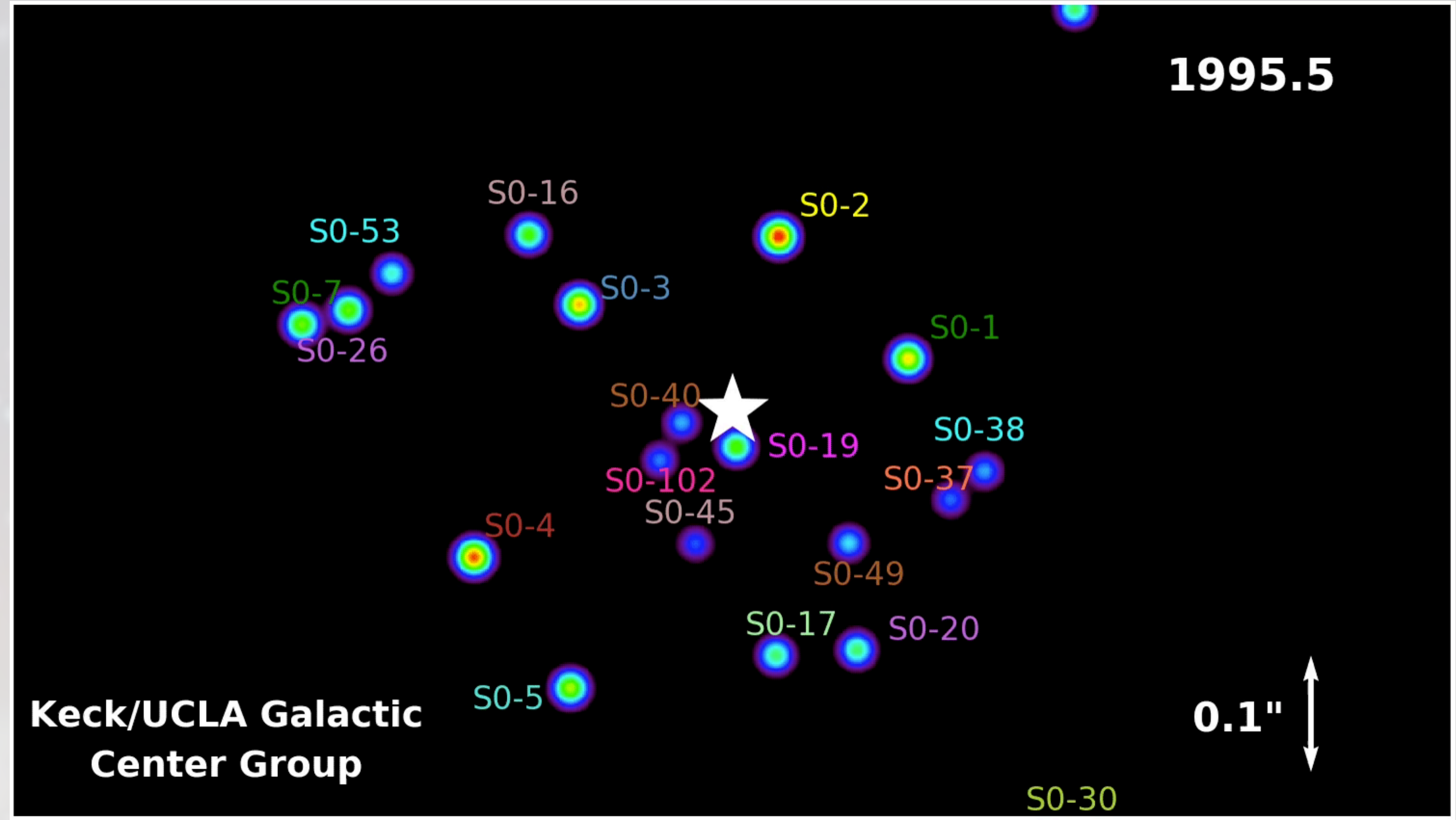
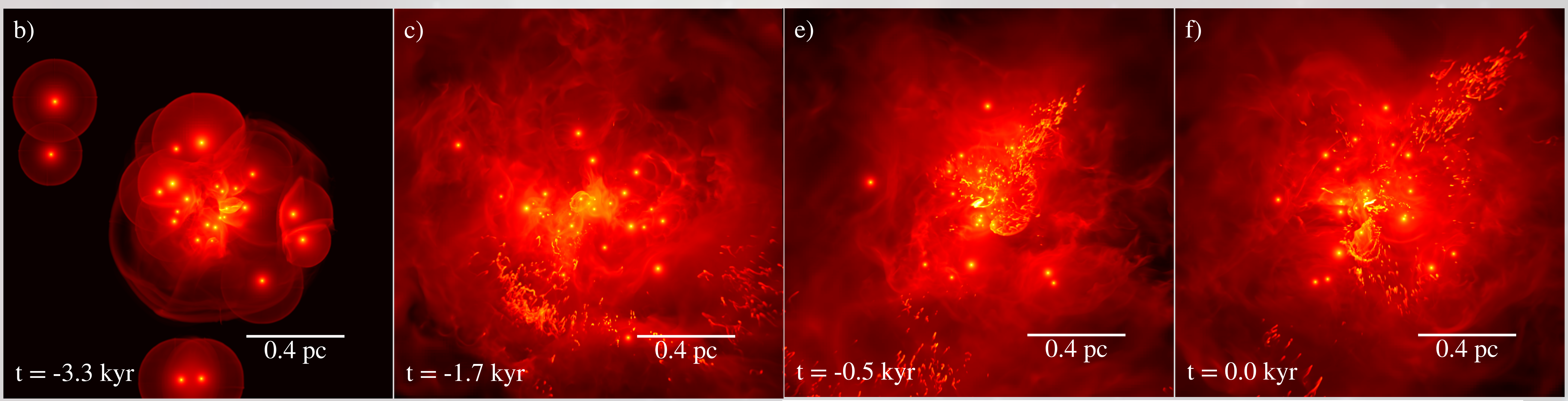
More to come!





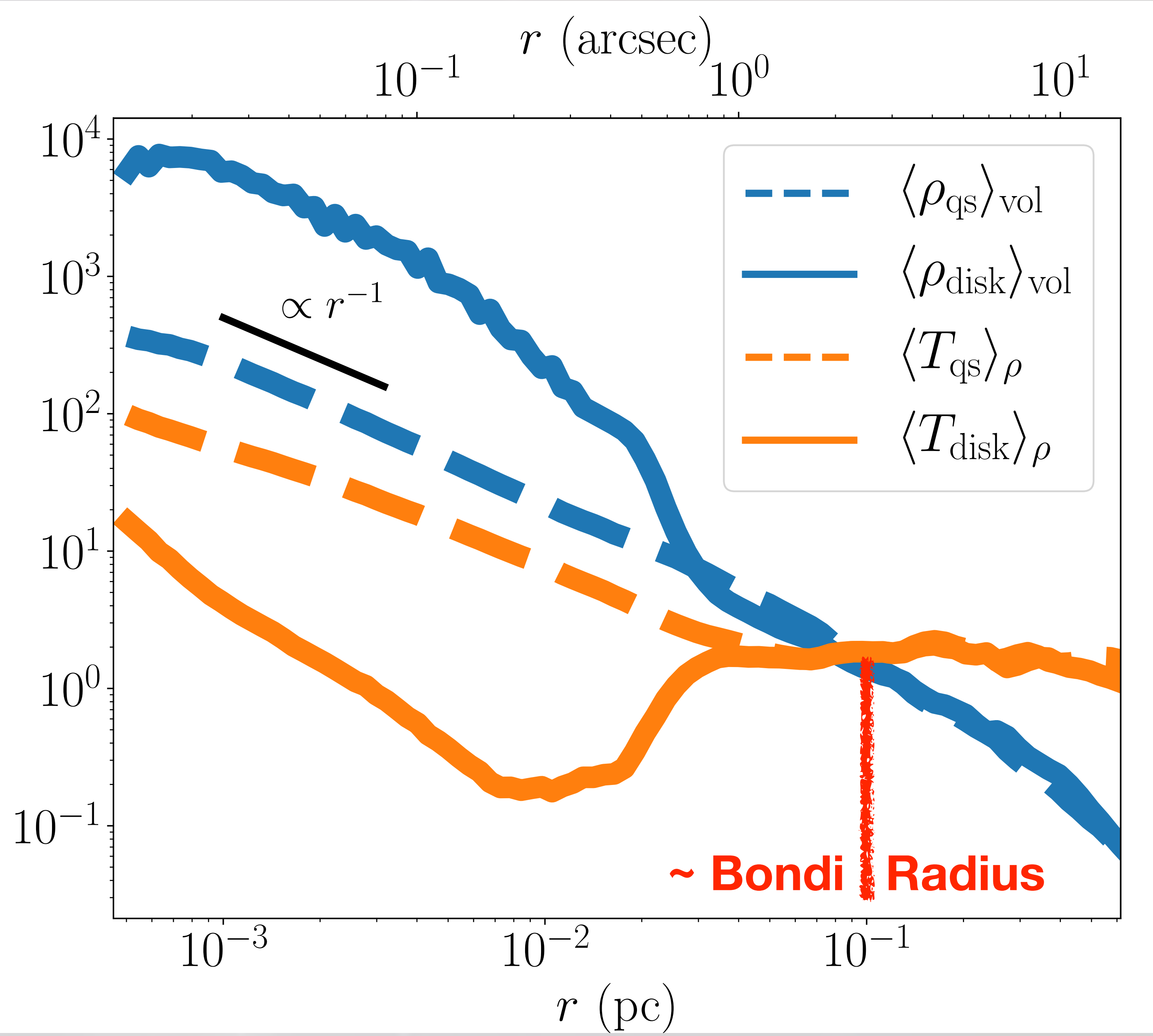




Calderón et al. 2019

Outflow models with variable density gradient

Take a **holistic** view of the Galactic Center environment – what plasma profile arises from **surrounding stars**?



Calderón et al. 2019

Sgr A* is an **extreme low-luminosity** black hole that **challenges** our fundamental understanding of **accretion**

Chandra's combined capabilities of **high resolution imaging** and **spectroscopy** is uniquely capable of capturing Sgr A* in quiescence

Until Lynx, no other telescope can do this

The Chandra HETG spectrum of Sgr A* reveals a **combined hot and cool plasma** environment from $\sim 10^3$–10^5 r_g (out to and just beyond the Bondi radius), and **potential velocity structure**.