Charge exchange X-ray emission in Spiral galaxies

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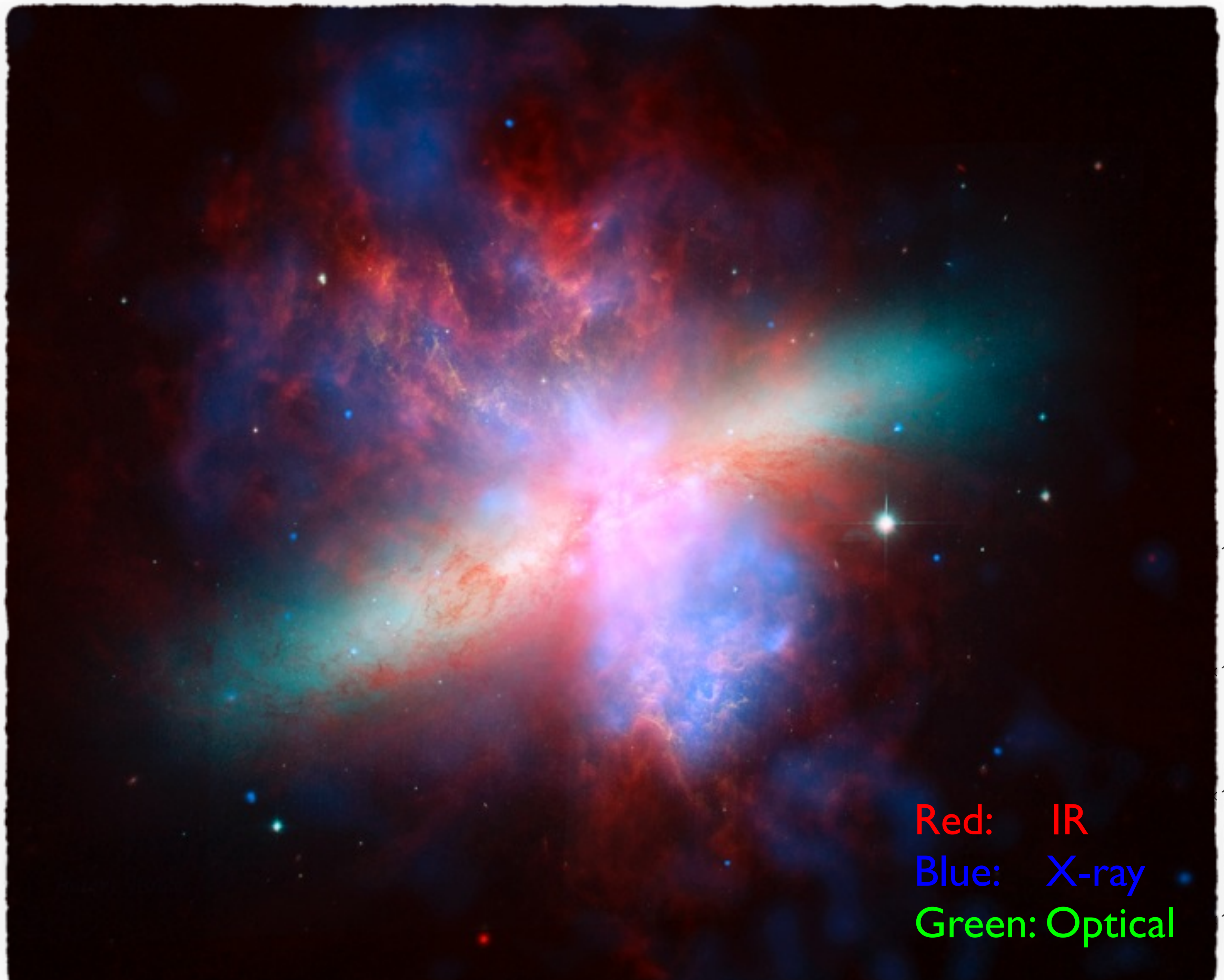
Charge exchange X–ray Universe
20 June 2024, Volos, Greece

Trace the interplay between Hot and cold gas

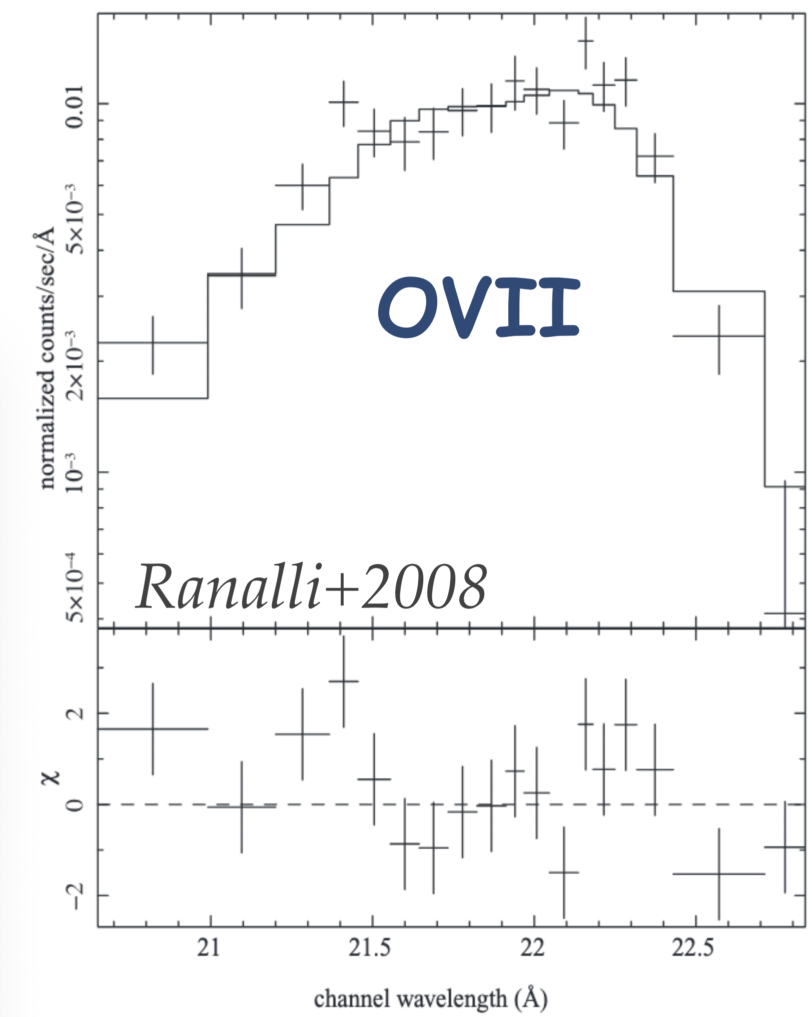
—> An important coolant

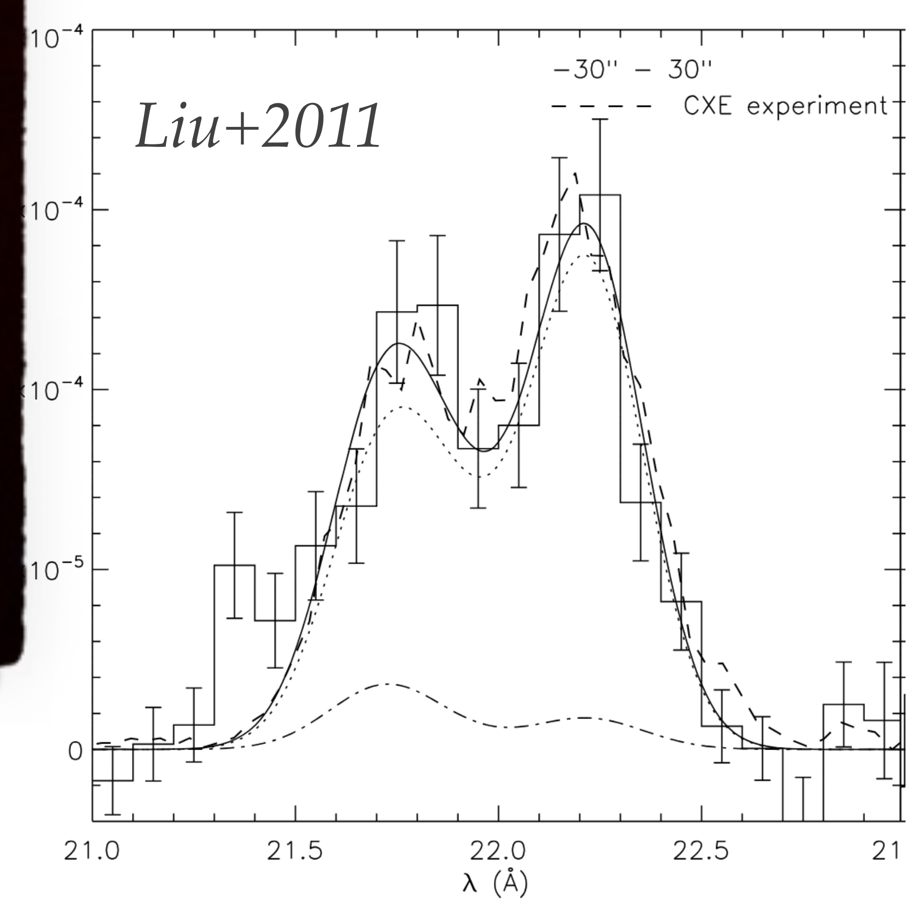
—> Correct hot gas properties

Galactic superwind

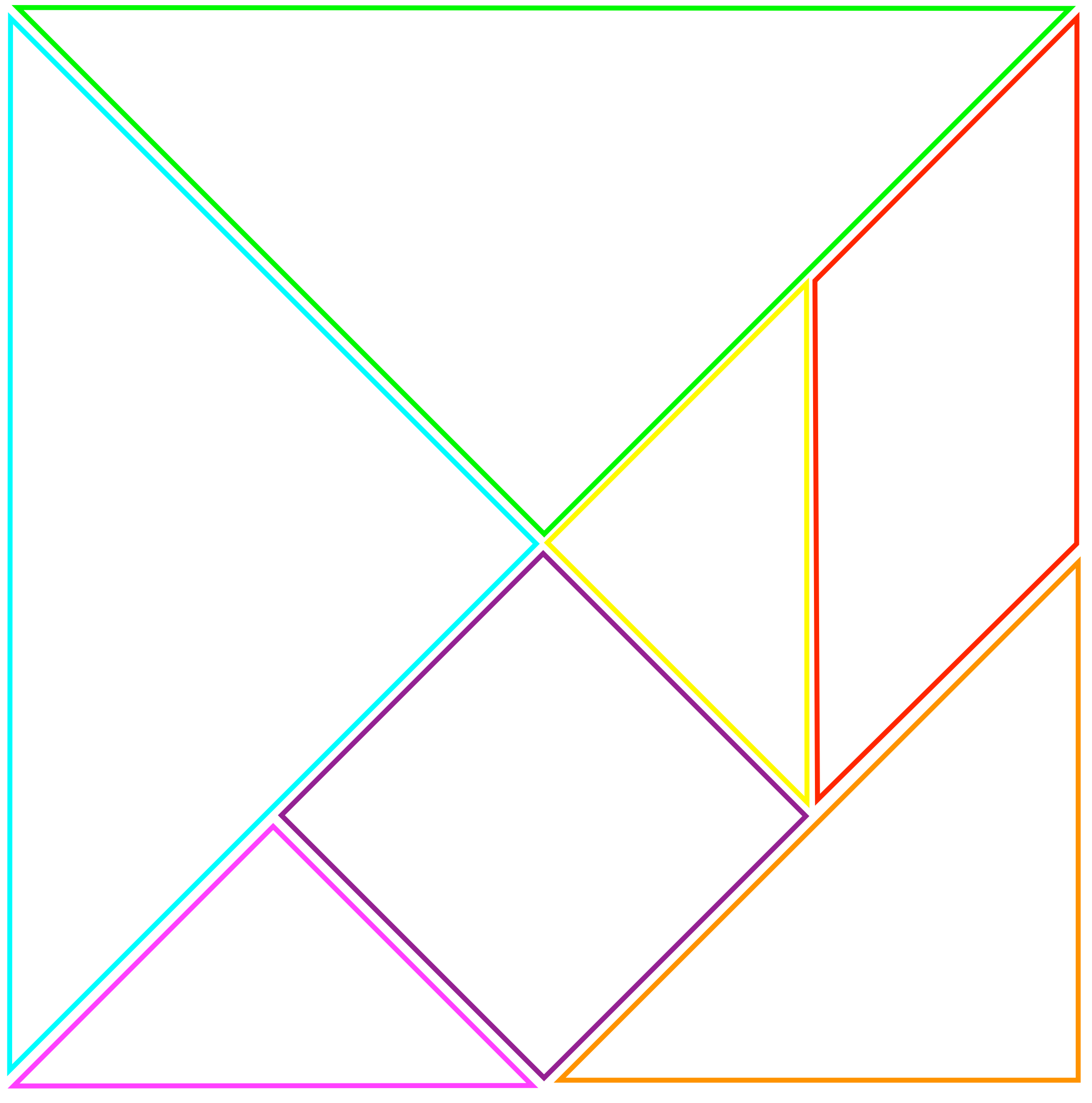


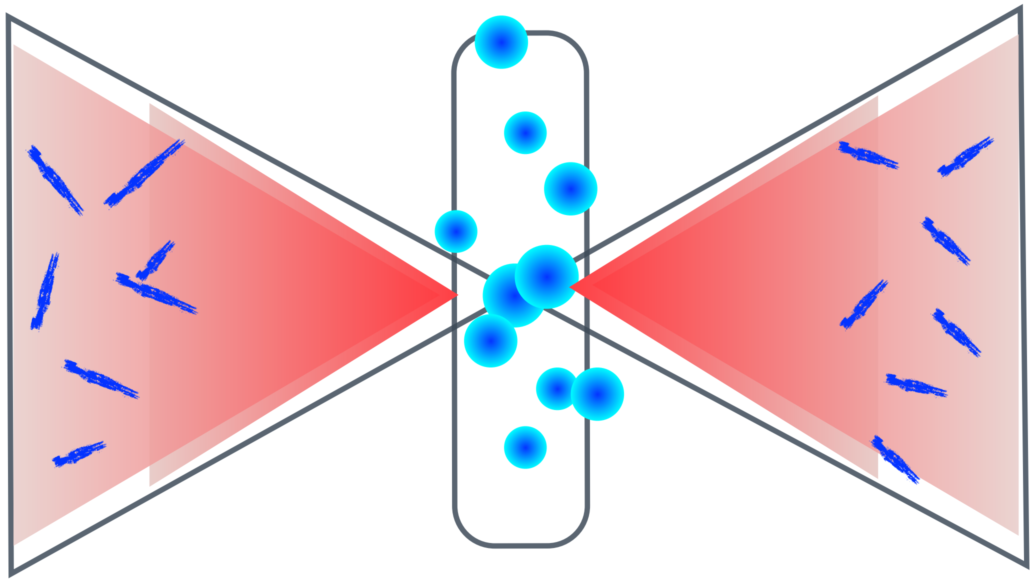
Credit: X-ray: D.Strickland; Optical: The Hubble Heritage Team; IR: C. Engelbracht





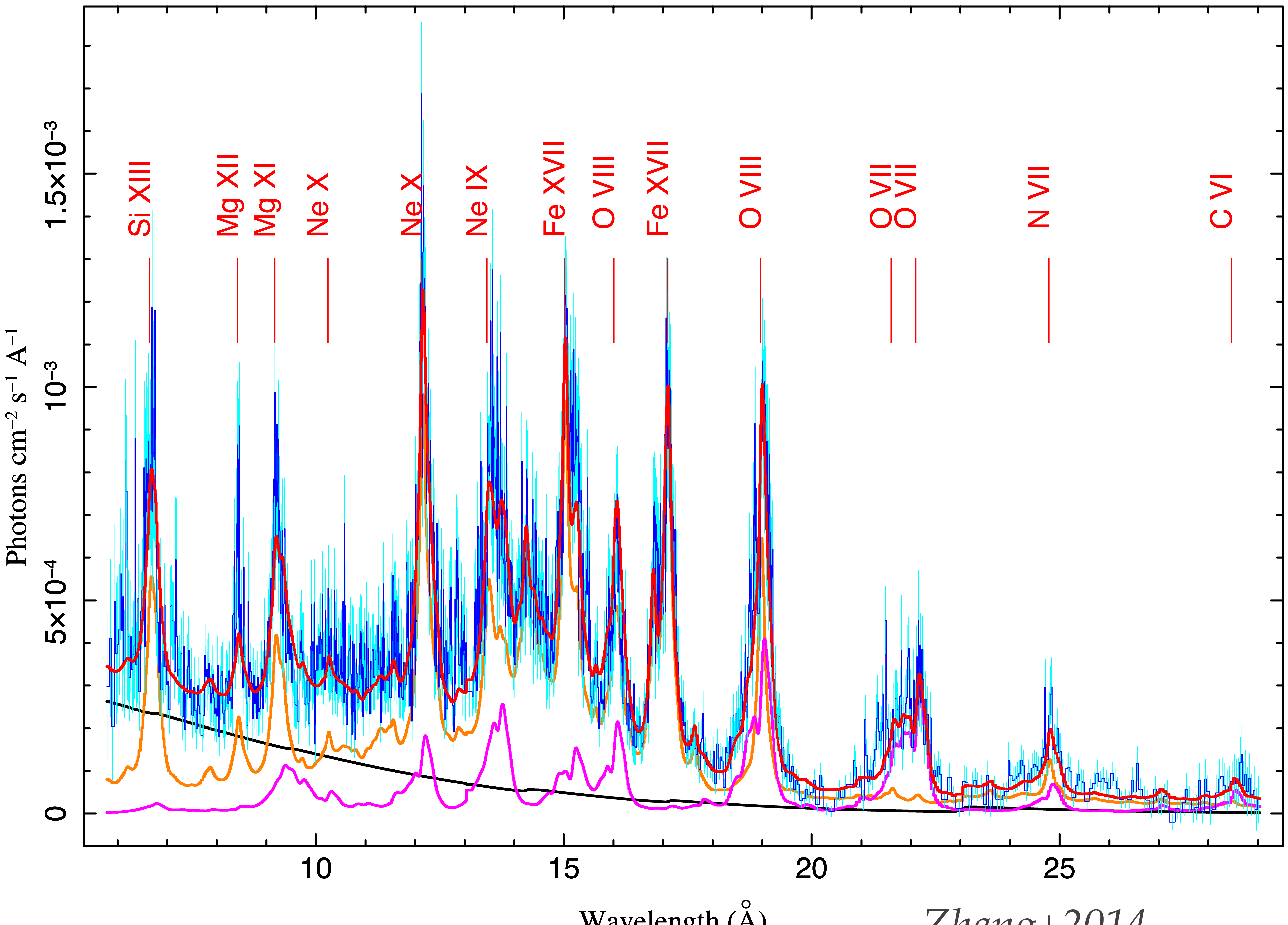
Tangram





abs1*pow

+abs2*(thermal+CX)

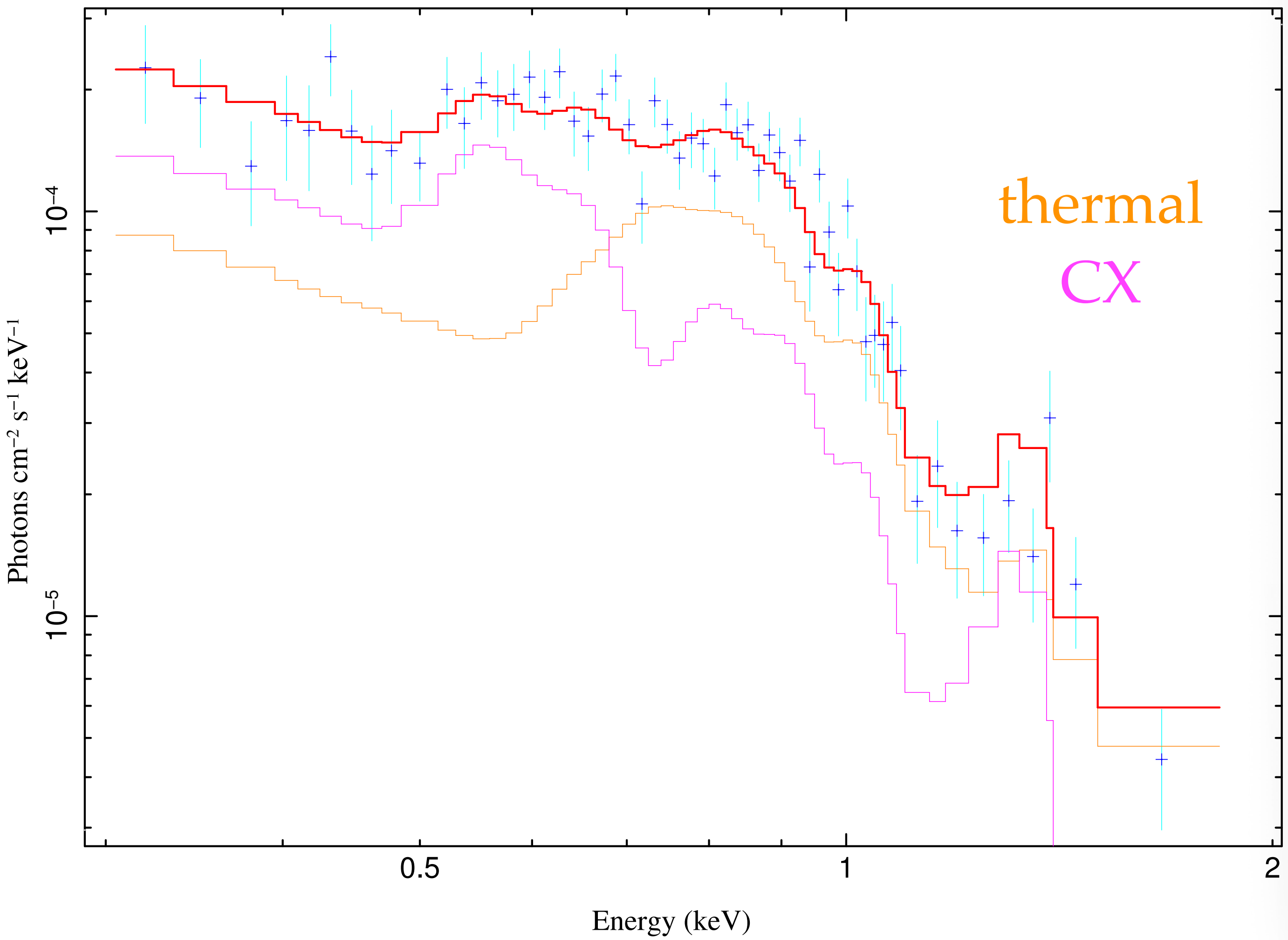


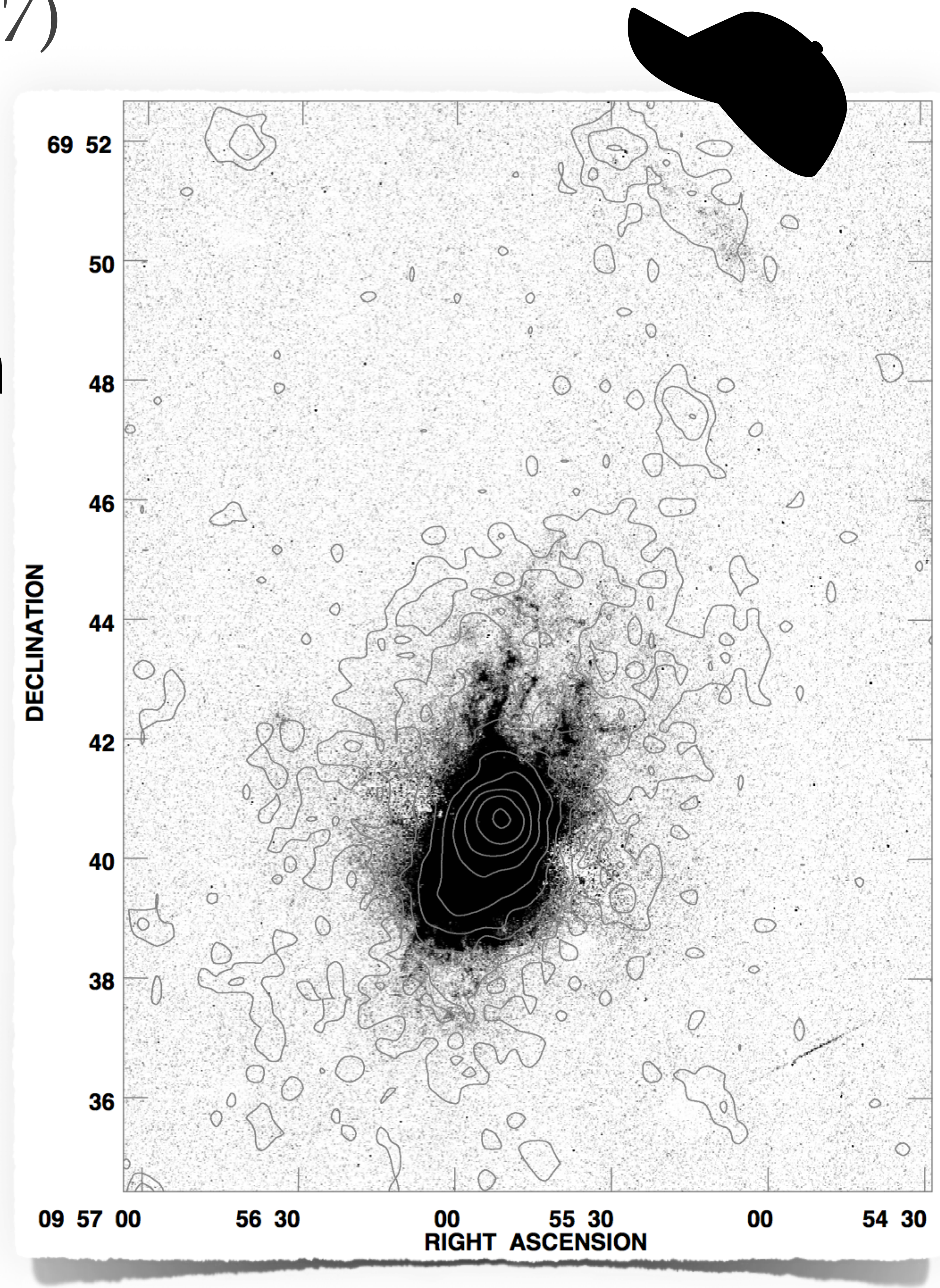
Zhang+2014

☐ 0.6 keV + 0.2 keV (Tsuru+2007)

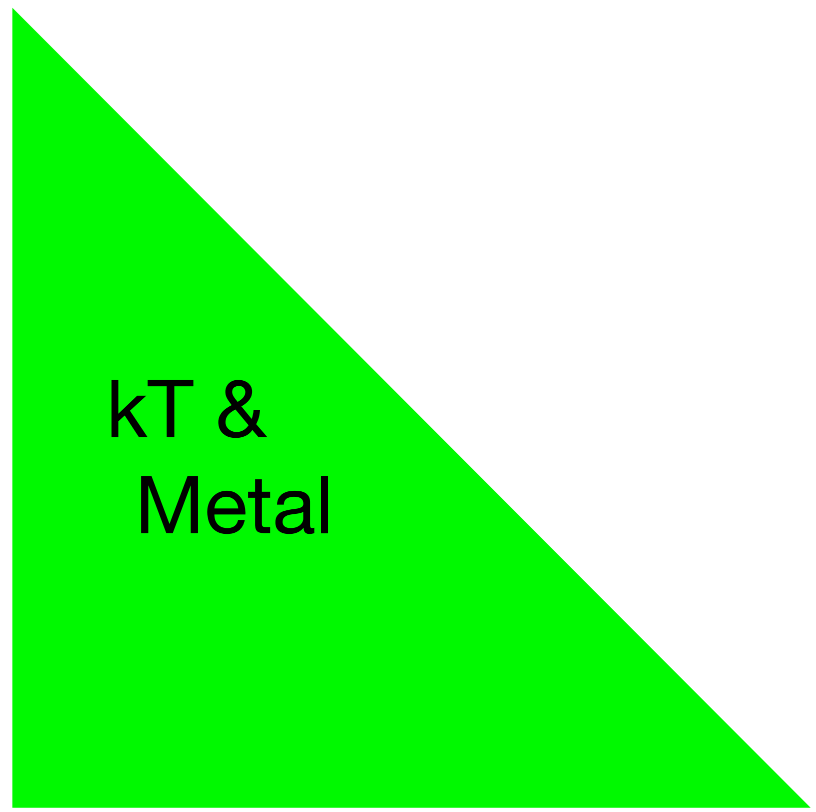
☑ 0.6 keV (50%) + CX (50%)

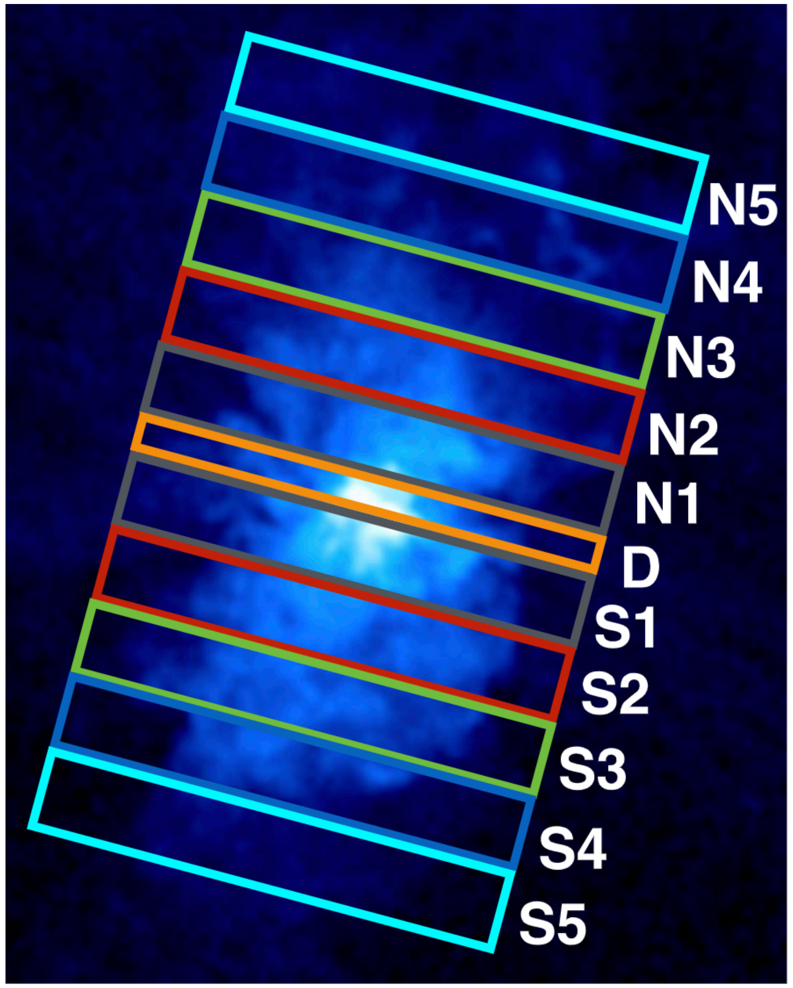
Wind went into Cap region

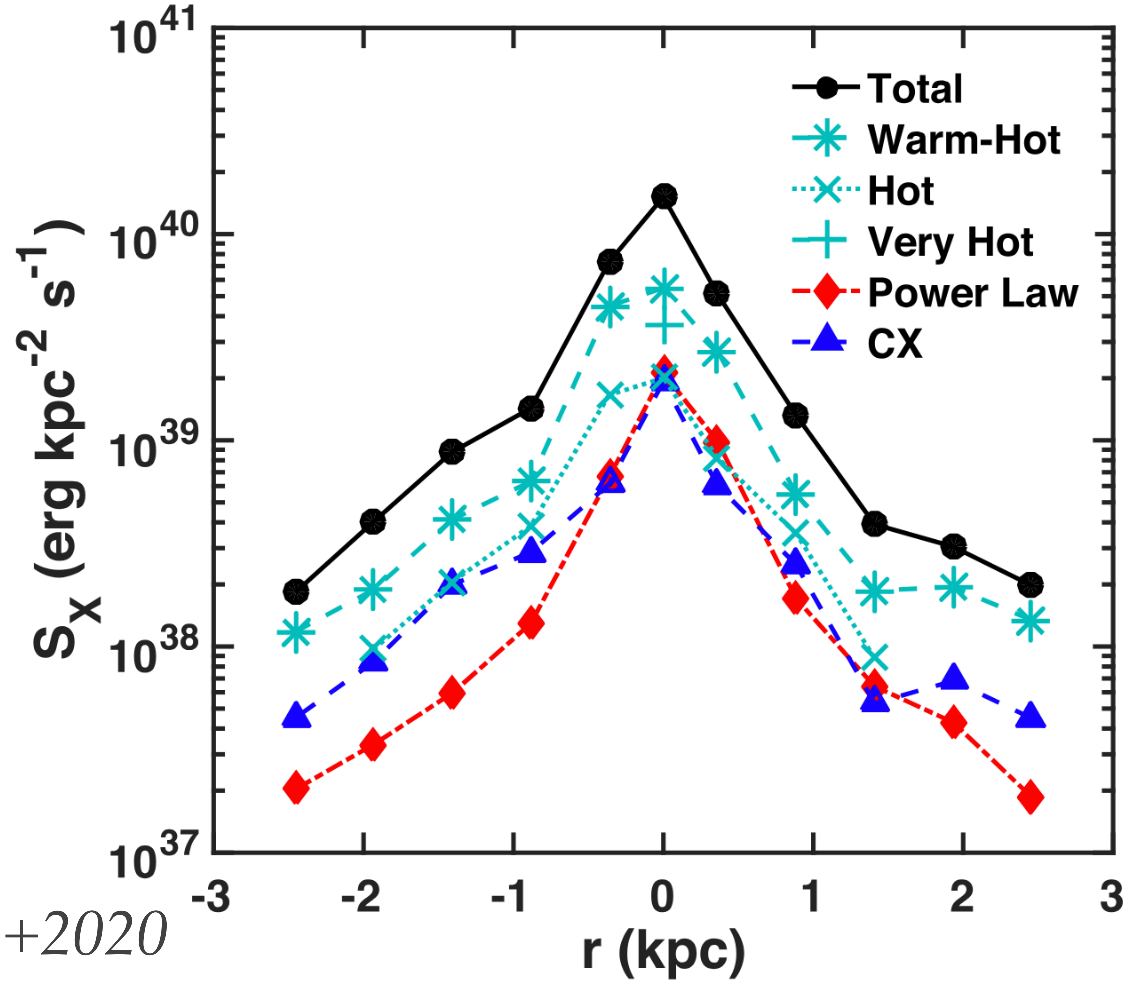




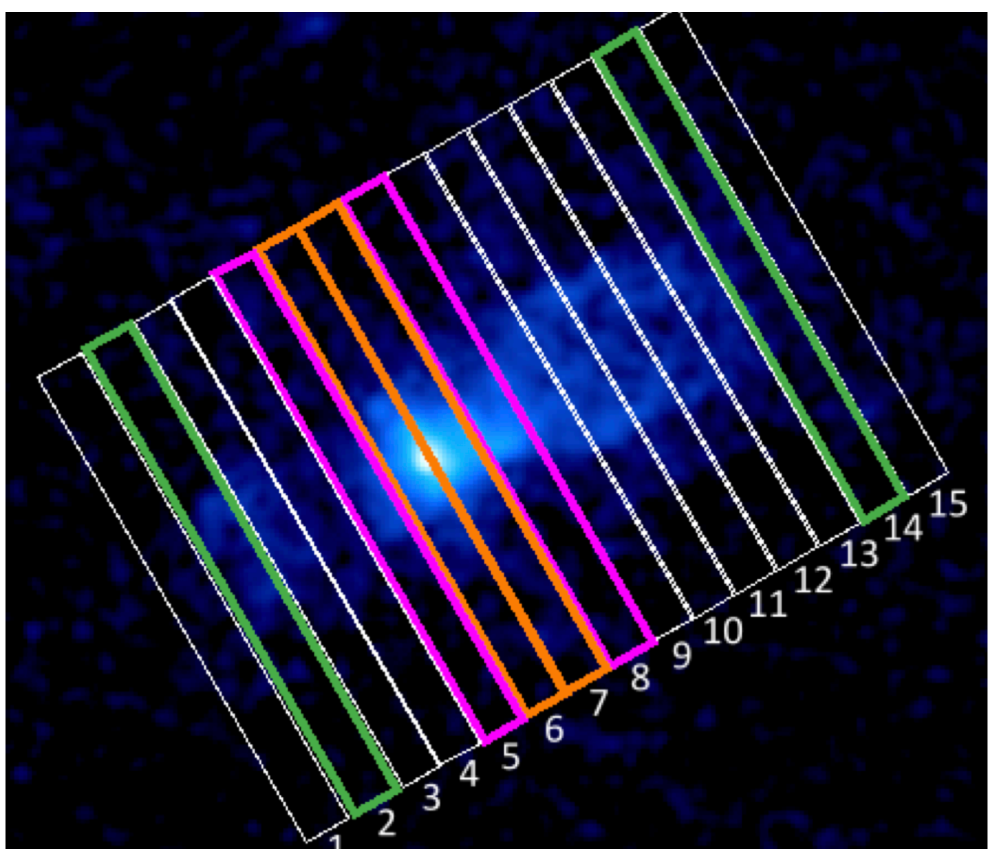
Lehnert+2009


kT &
Metal

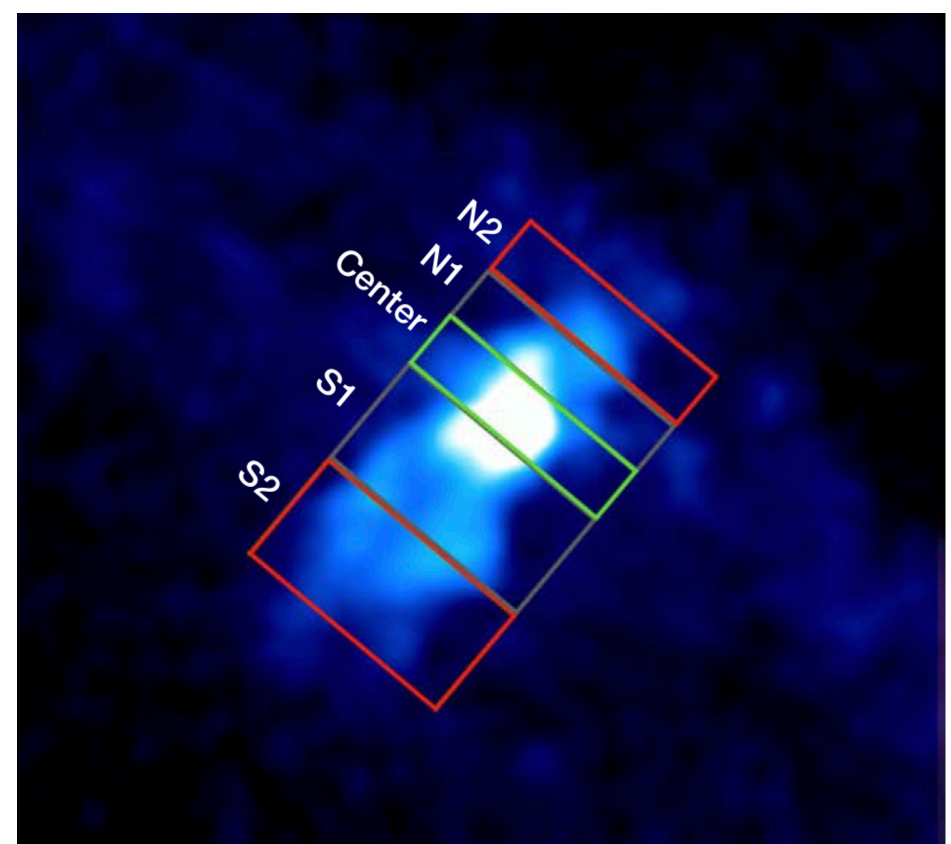




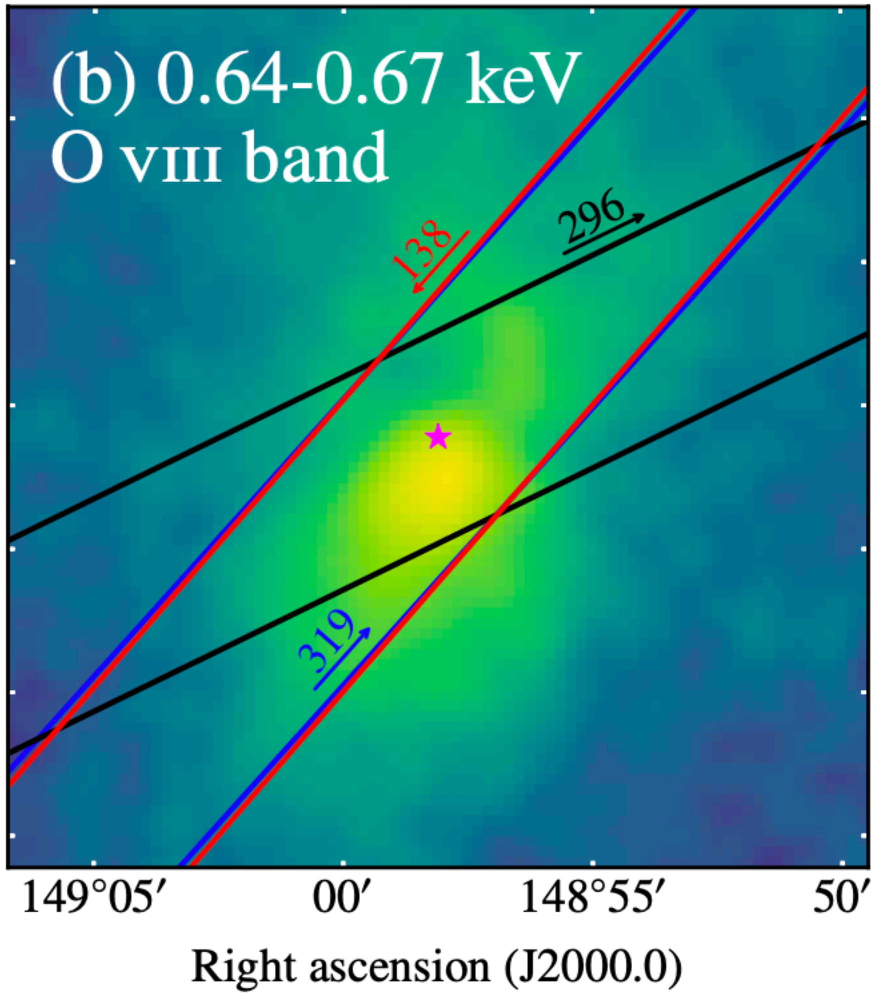
Lopez+2020



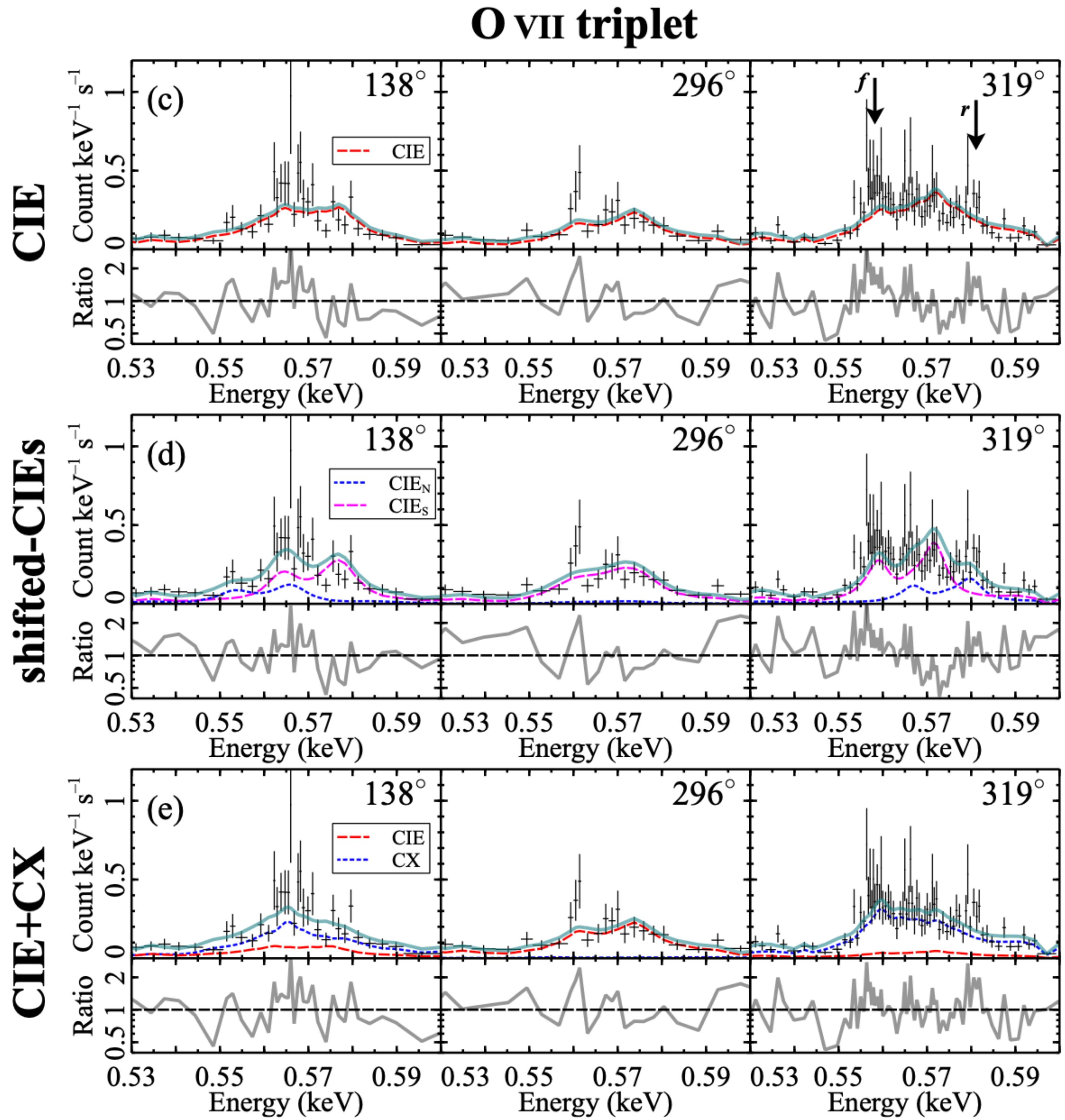
Barrera+2024; NGC4945 CX 12%



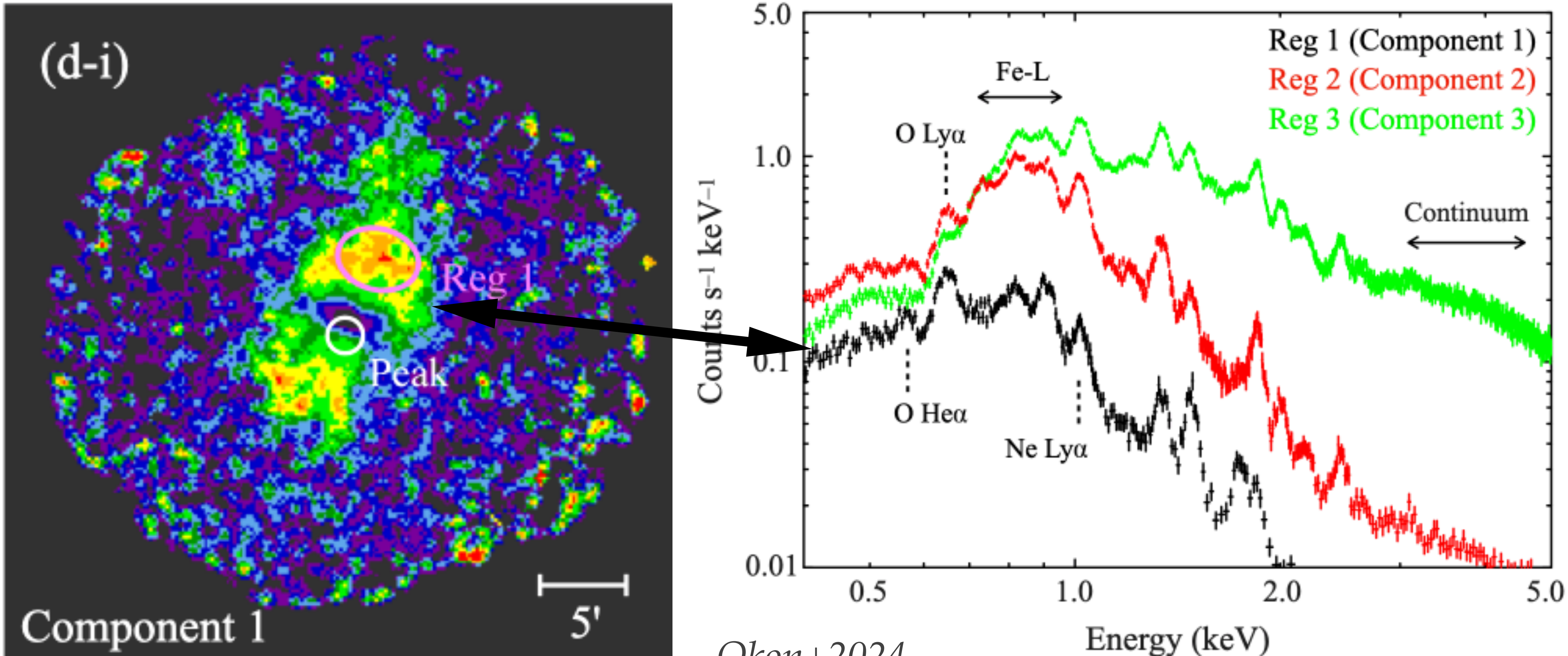
Lopez+2023; NGC253 20%–42%



- Hard to see where is the CX
- The CX may be not true

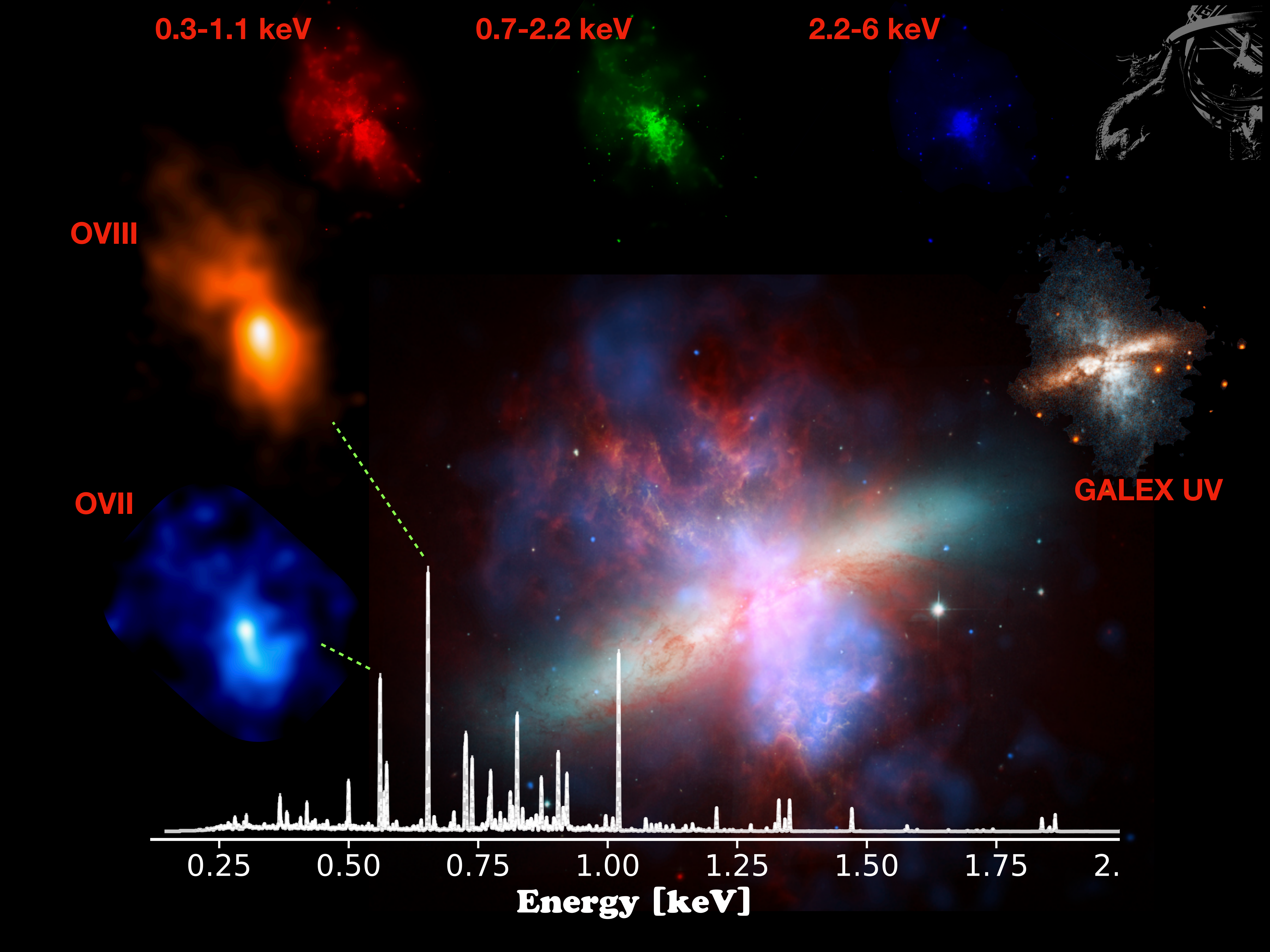


Fukushima+2024



Okon+2024

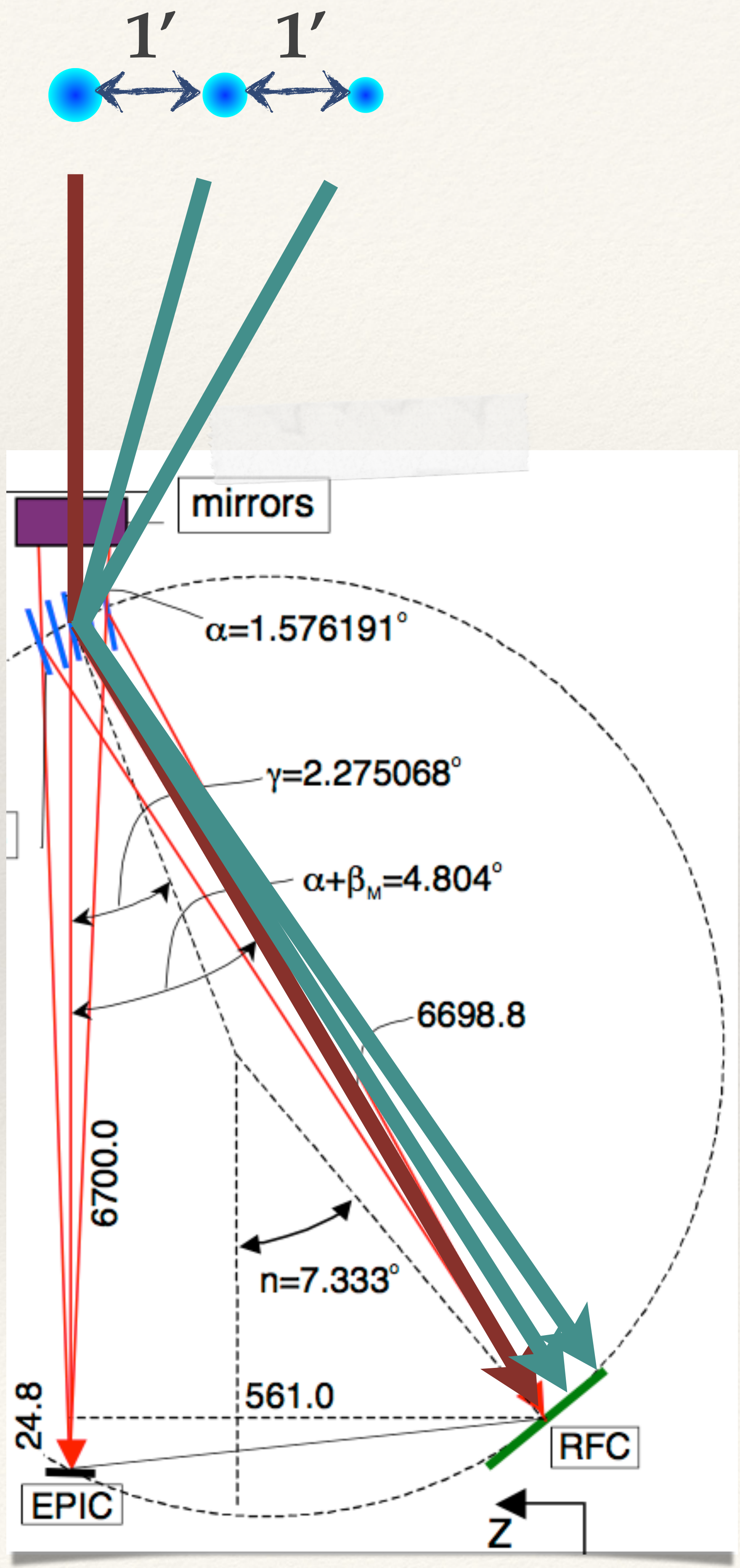
- CX occurs in an extremely limited region near the interface zone.
- CX process mainly occurs in the layer whose temperature rapidly decreases due to thermal conduction (~0.2 keV).

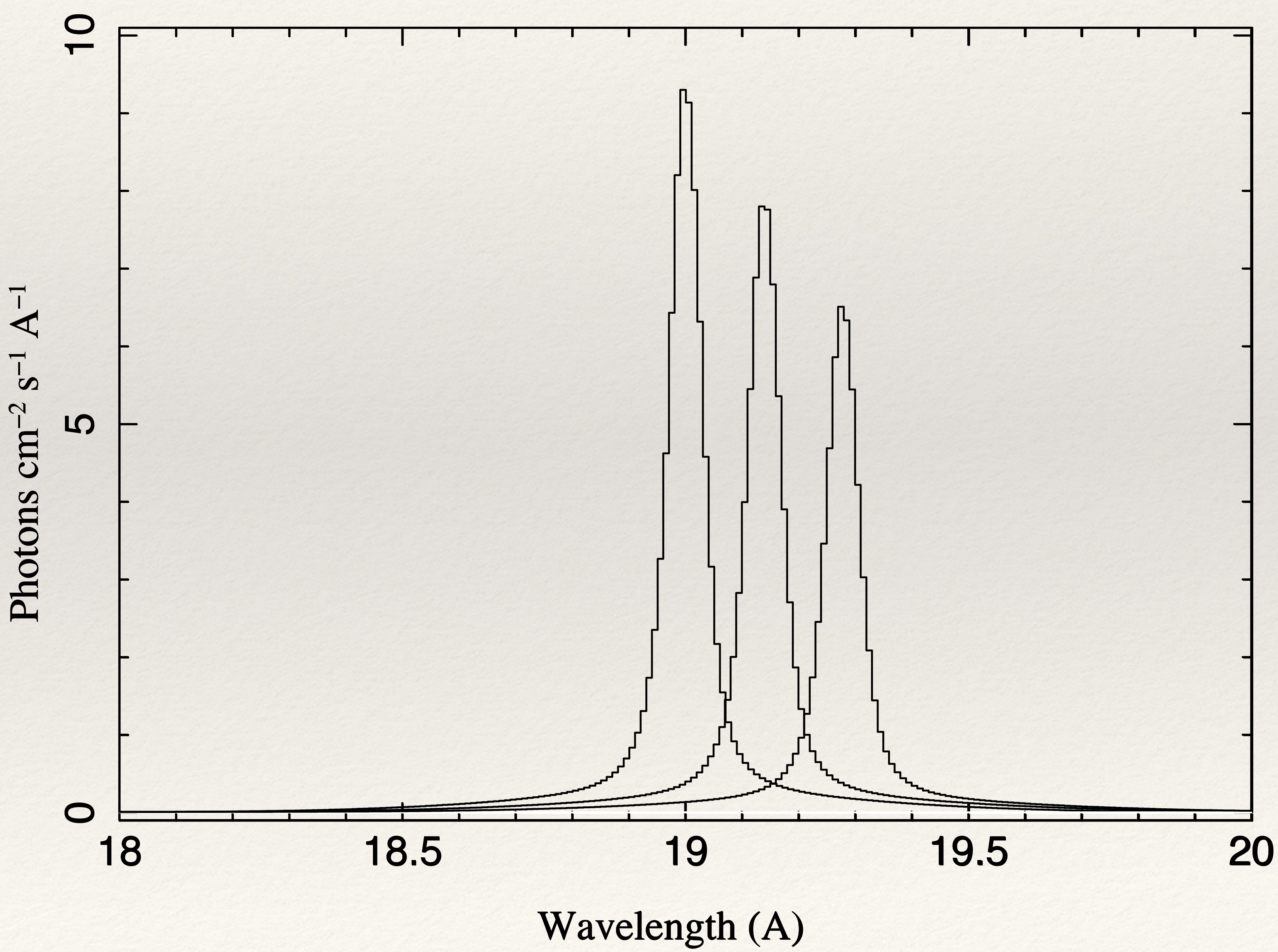

0.3-1.1 keV
0.7-2.2 keV
2.2-6 keV
OVIII
OVII
GALEX UV
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.
Energy [keV]

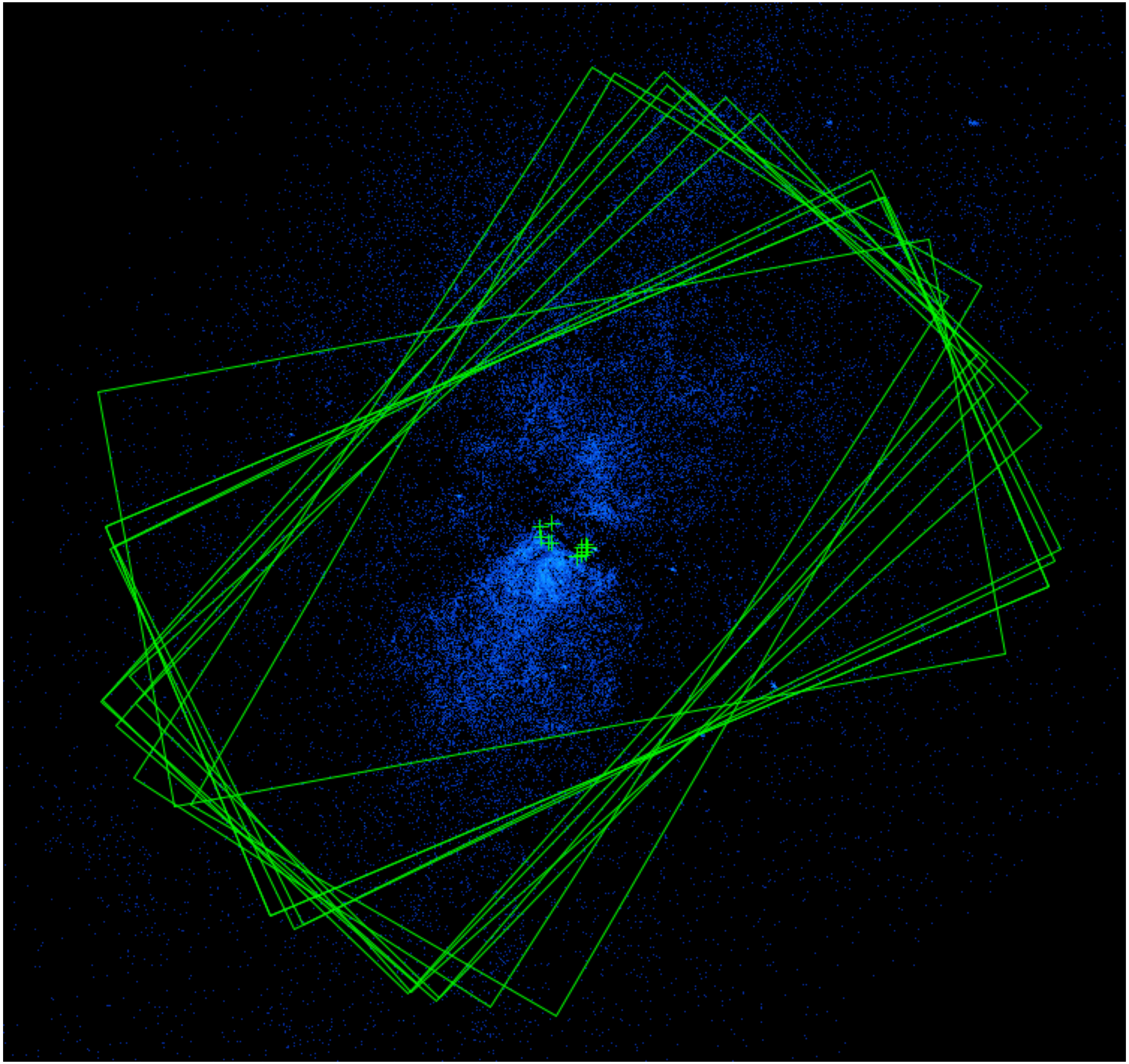
Slit-less Grating records Spatial Info

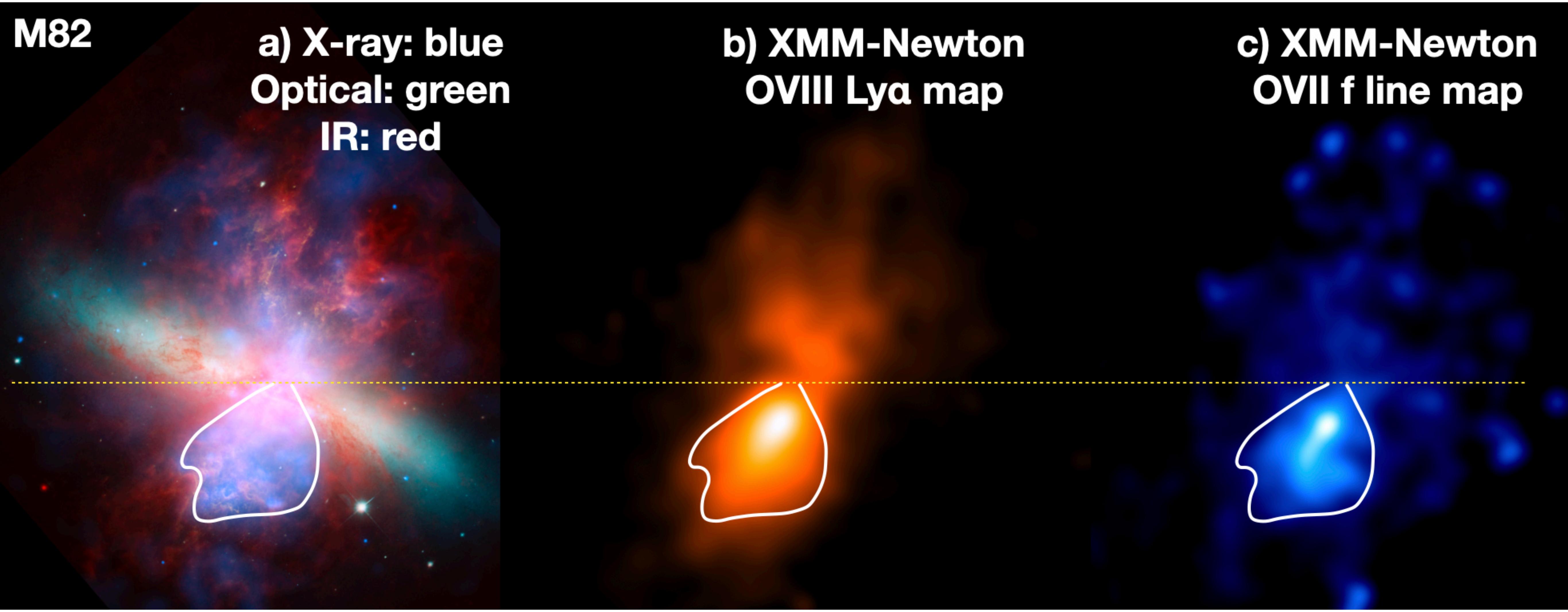
1 arcmin ~ 0.138 Å

Single Energy Photons





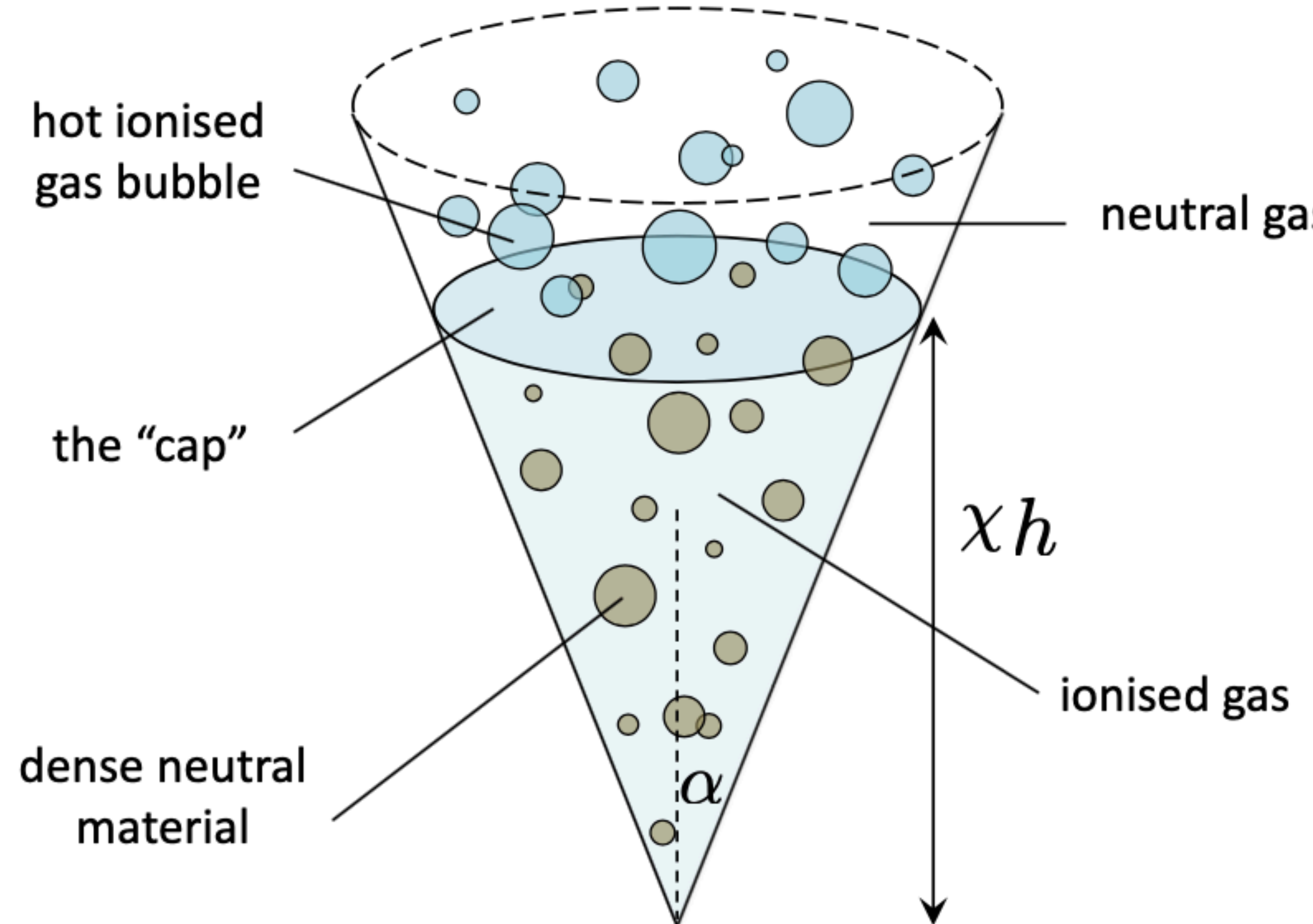




- Only data.
- OVII f is mainly in the southern wind, along the outflow axis.
- OVII f —> CX distribution.

Where
CX

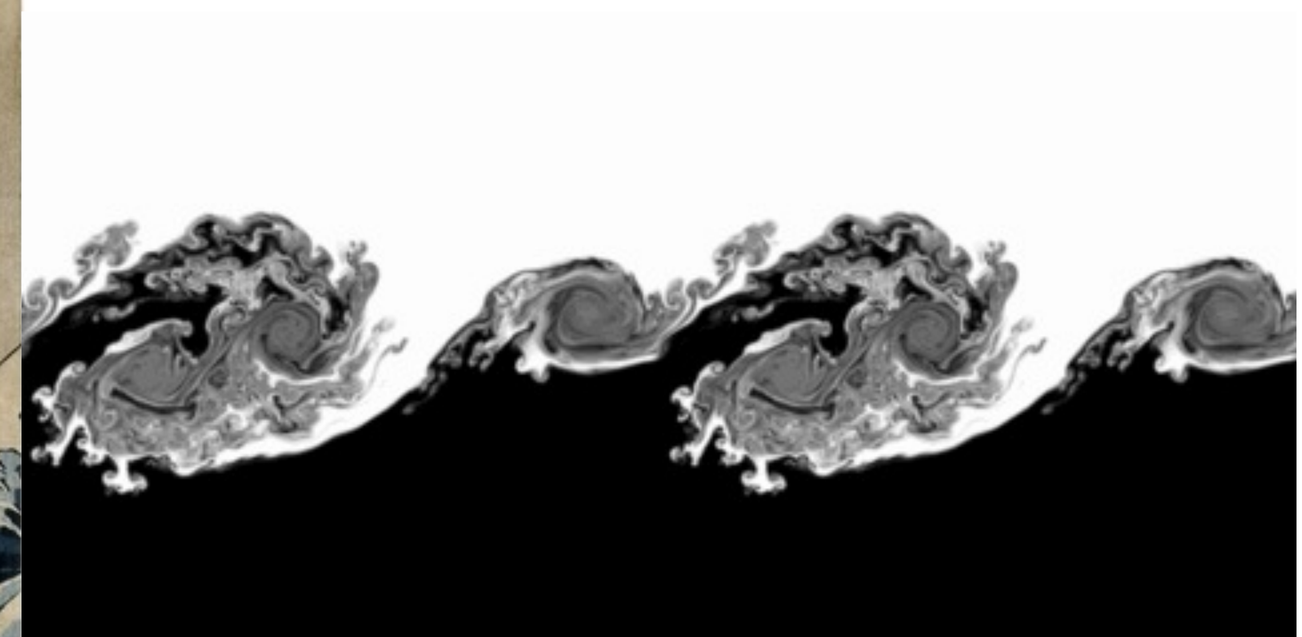
Schneider+2020



Wu+2020

- CX simply occurs at the surfaces of the cold clumps entrained and the cold shell.

Turbulences at the interface



for 10^{15} cm scale

Ionization:

10^8 s

Recombination:

10^{12} s

CX:

a half year

Conduction:

a half year

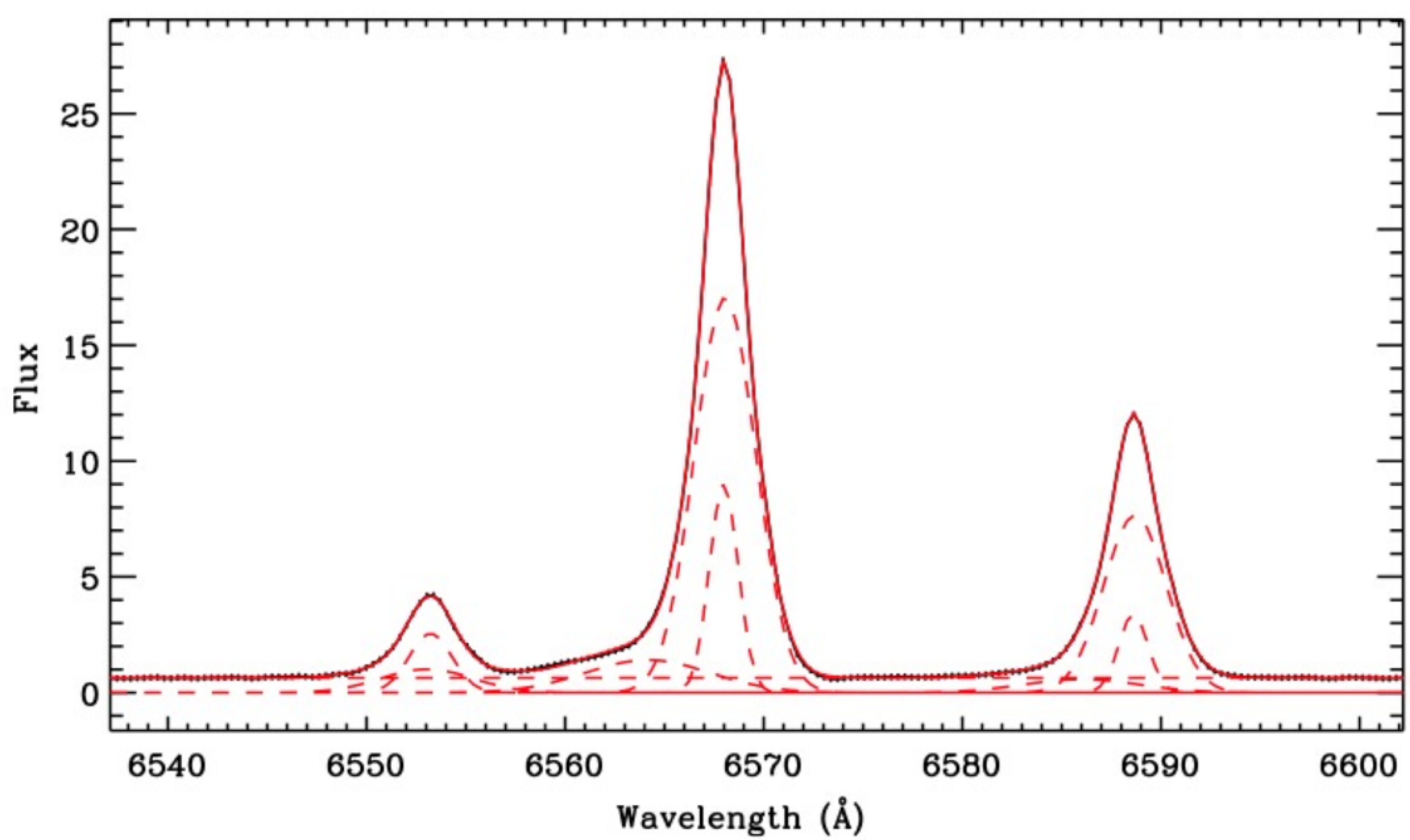
How

Broad Hα component

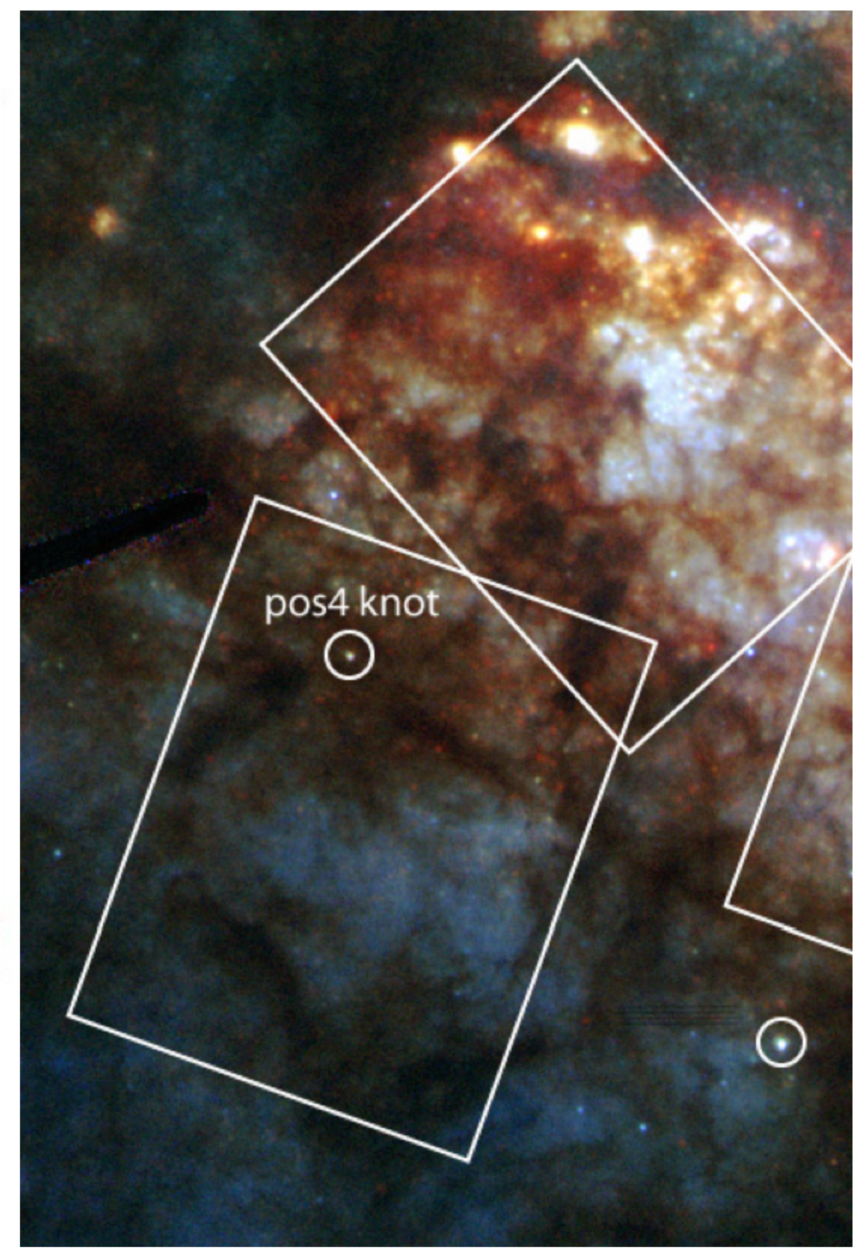
Component	Hα FWHM (km s^{-1})	Hα Radial Velocity (km s^{-1})
C1	156	40
C2	333	−138
C3	53	37

CX contributes **3%** Hα

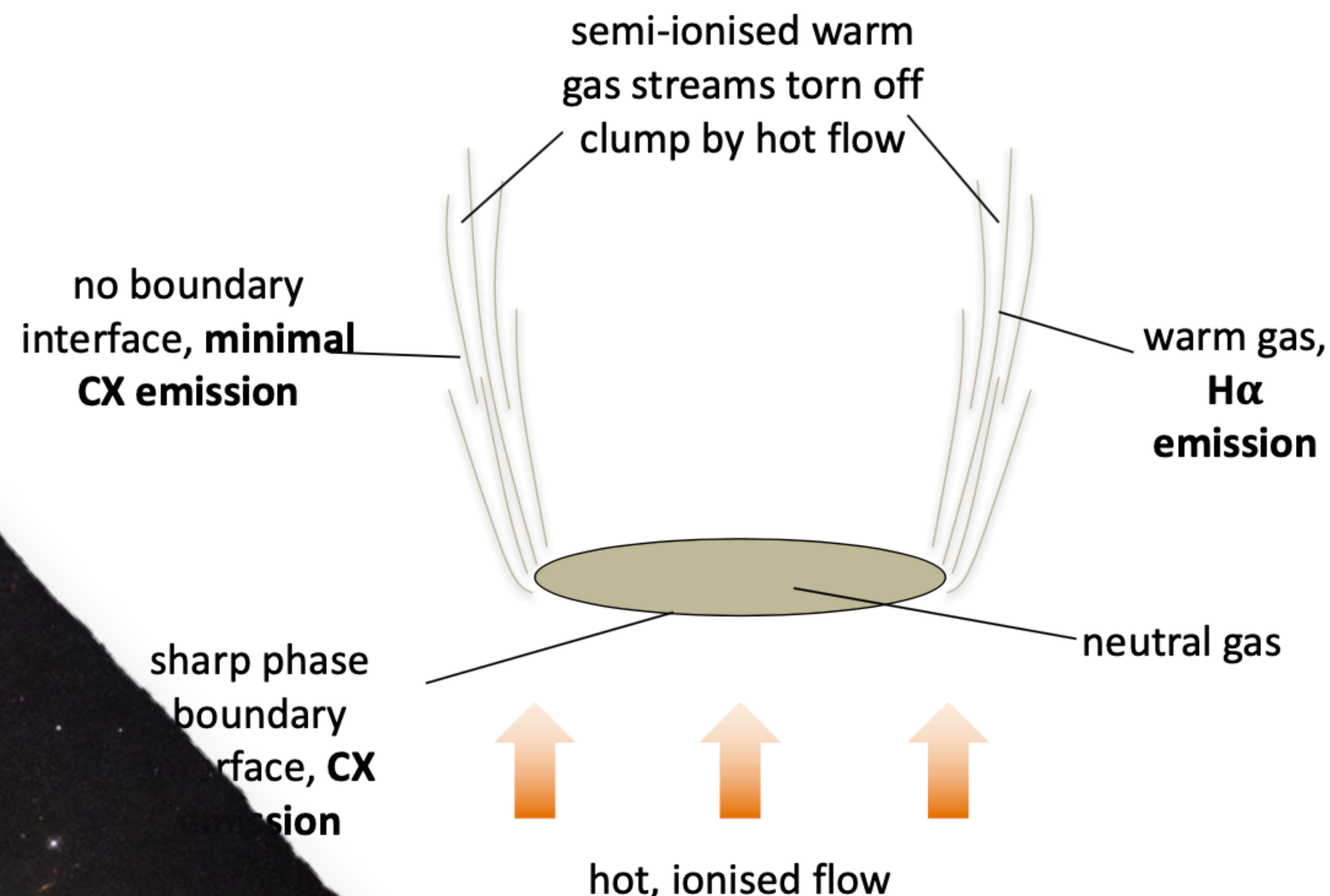
Southern wind



Westmoquette et al. 2009: Gemini GMOS-IFU

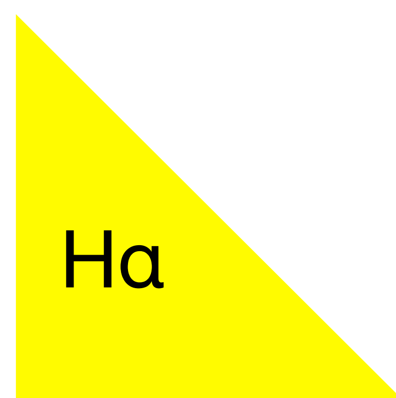


Hα Not related to CX directly



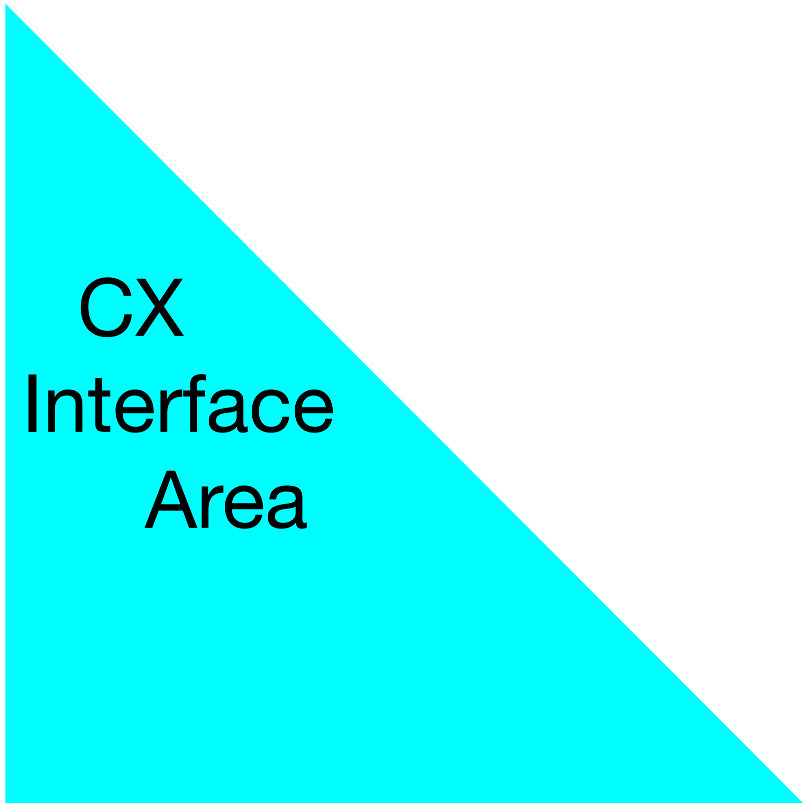
Wu+2020

Credit: NASA & ESA

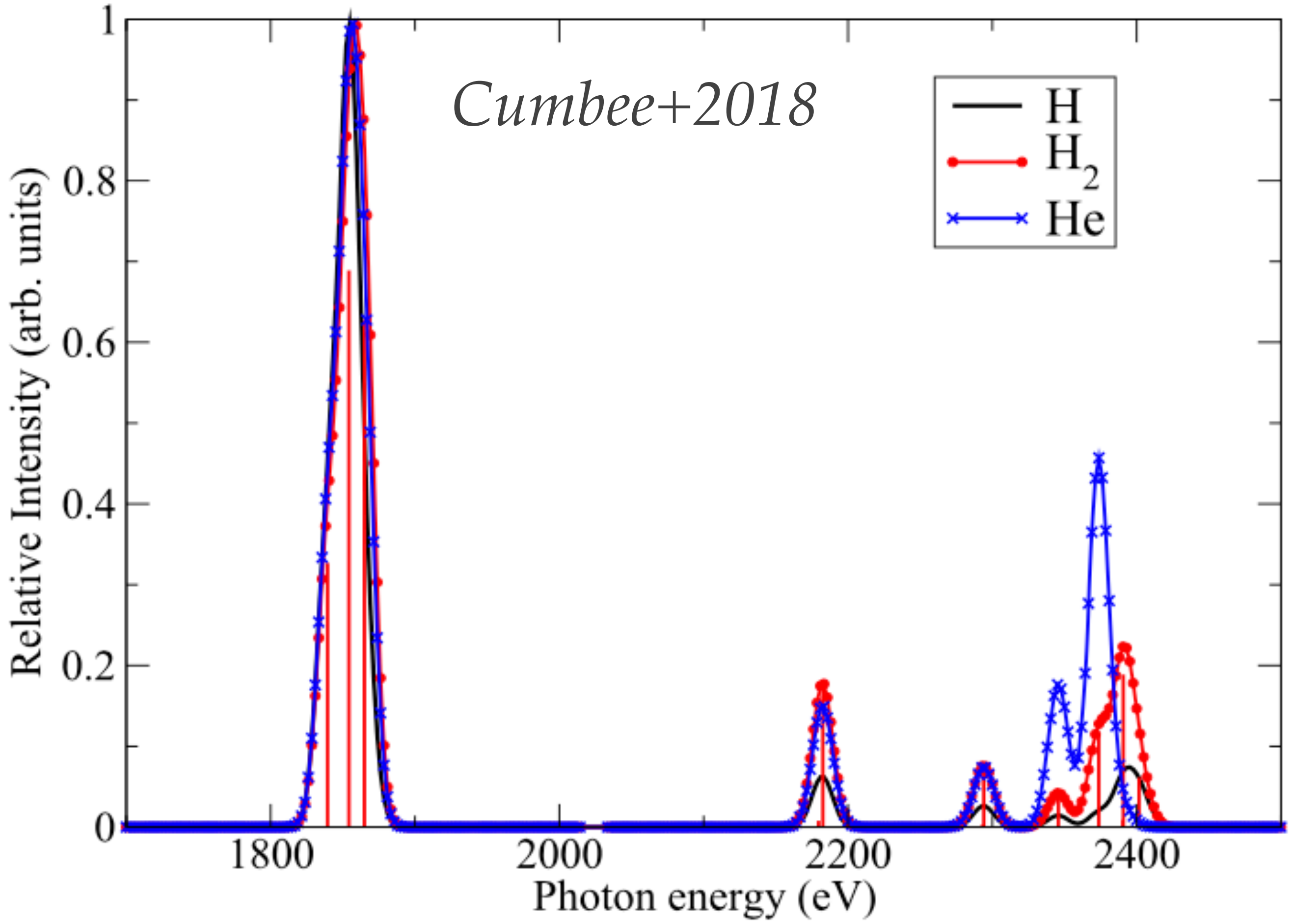

Ha

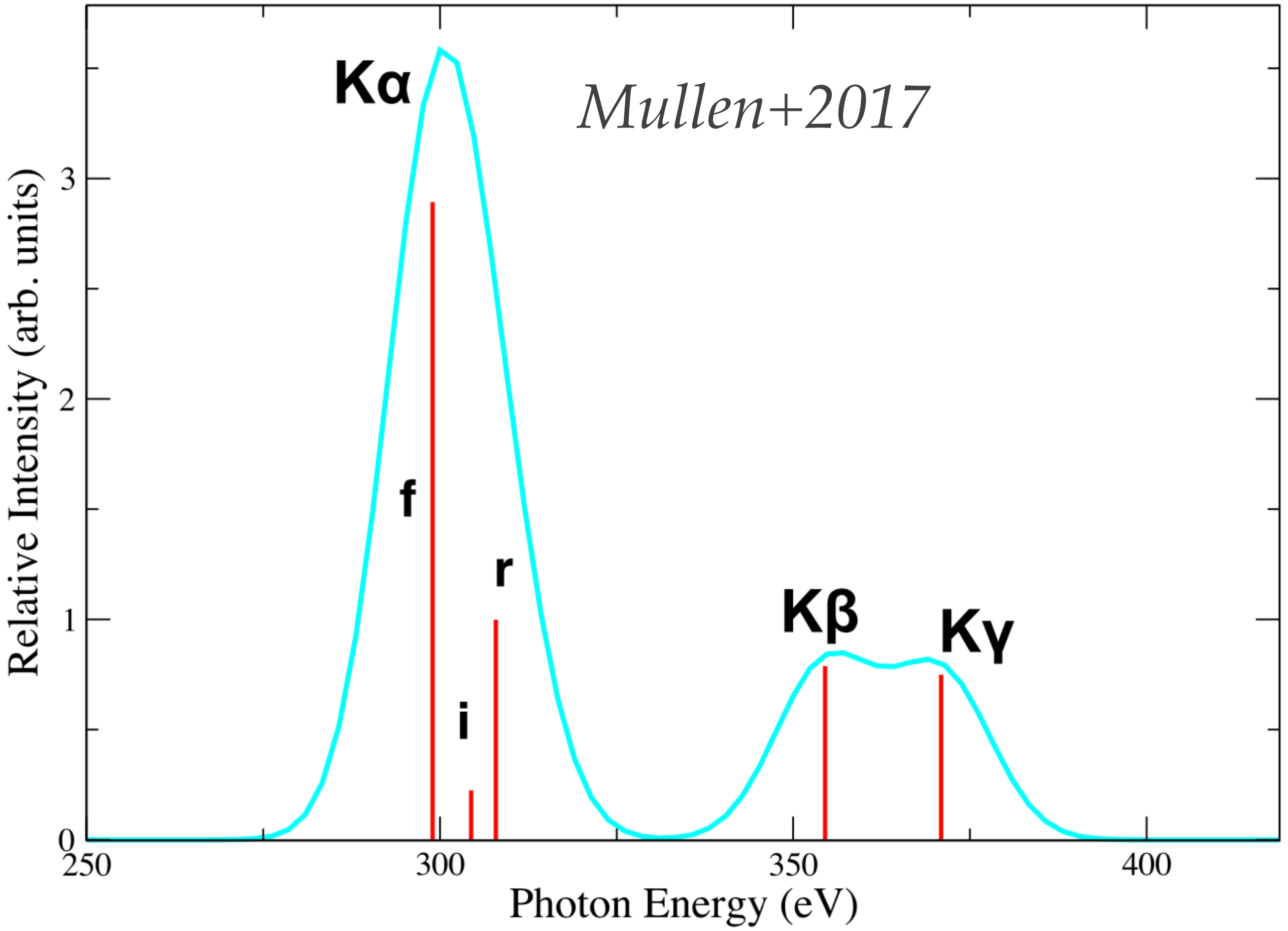
Assuming interacting velocity: 500 km/s

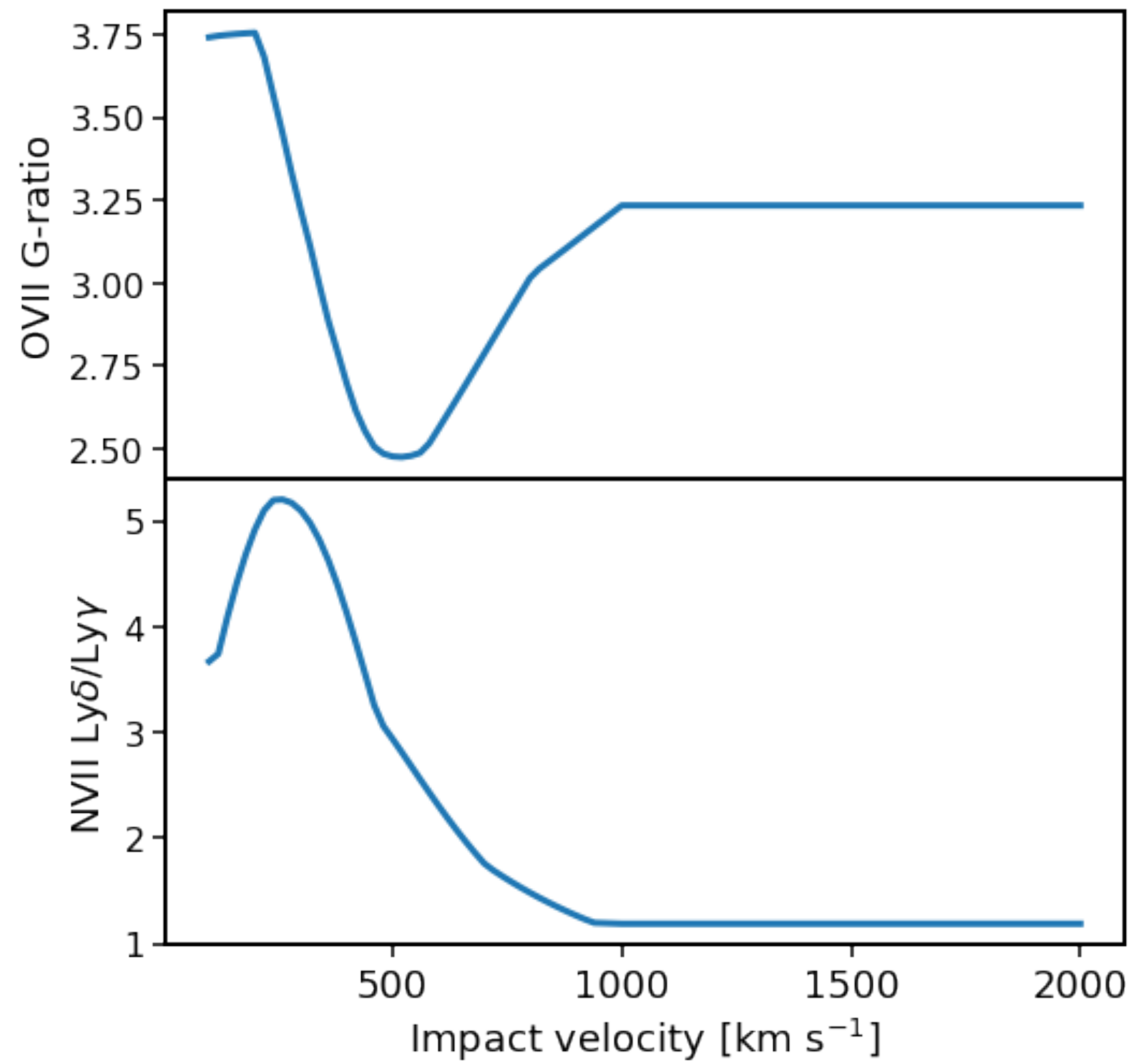
The interface area of hot & cold gas ($\sim 10^{45}$ cm^2)
is one order of magnitude larger than
the superwind geometric area ($\sim 10^{44}$ cm^2)



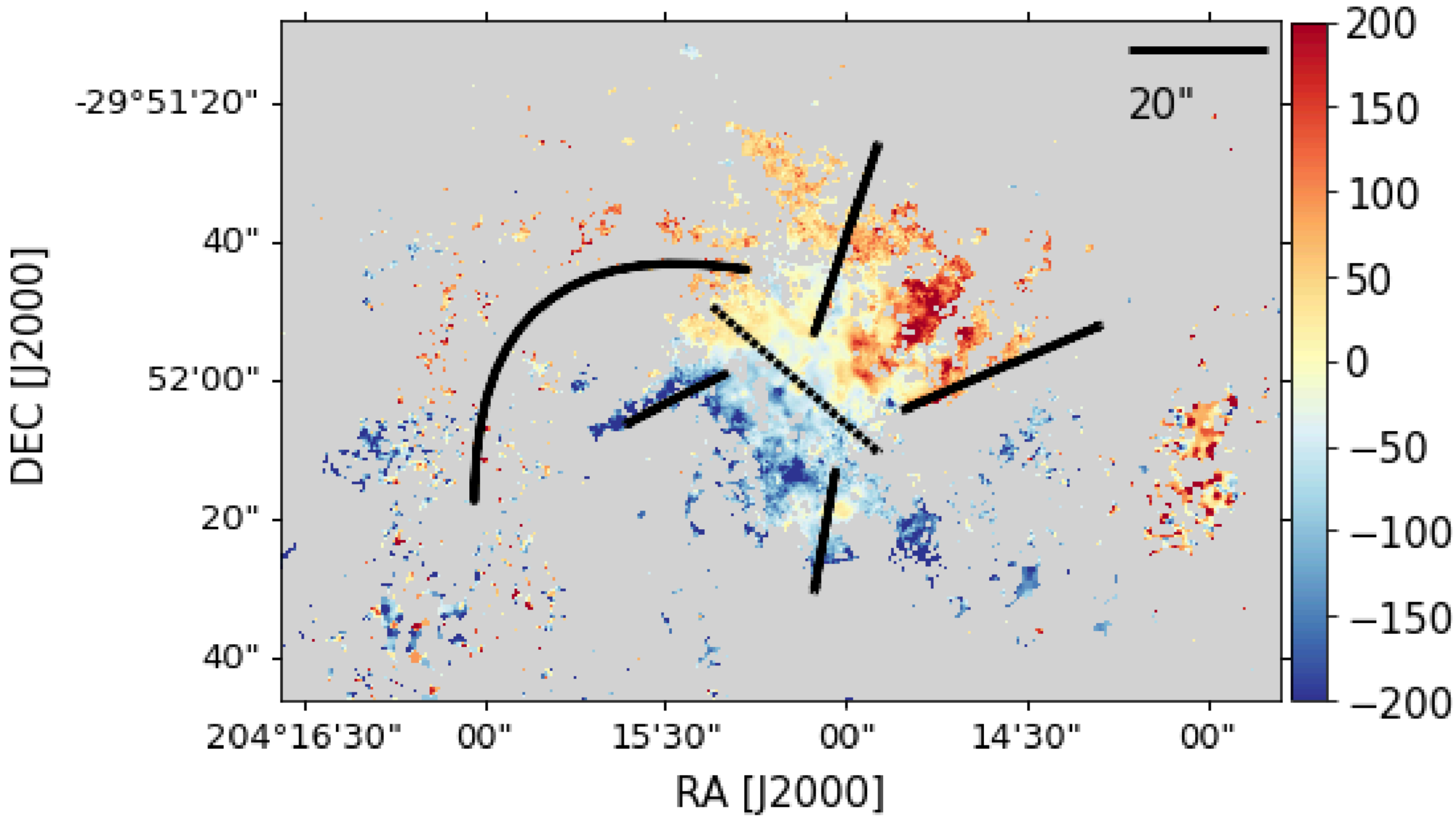
Constrain velocity using CX



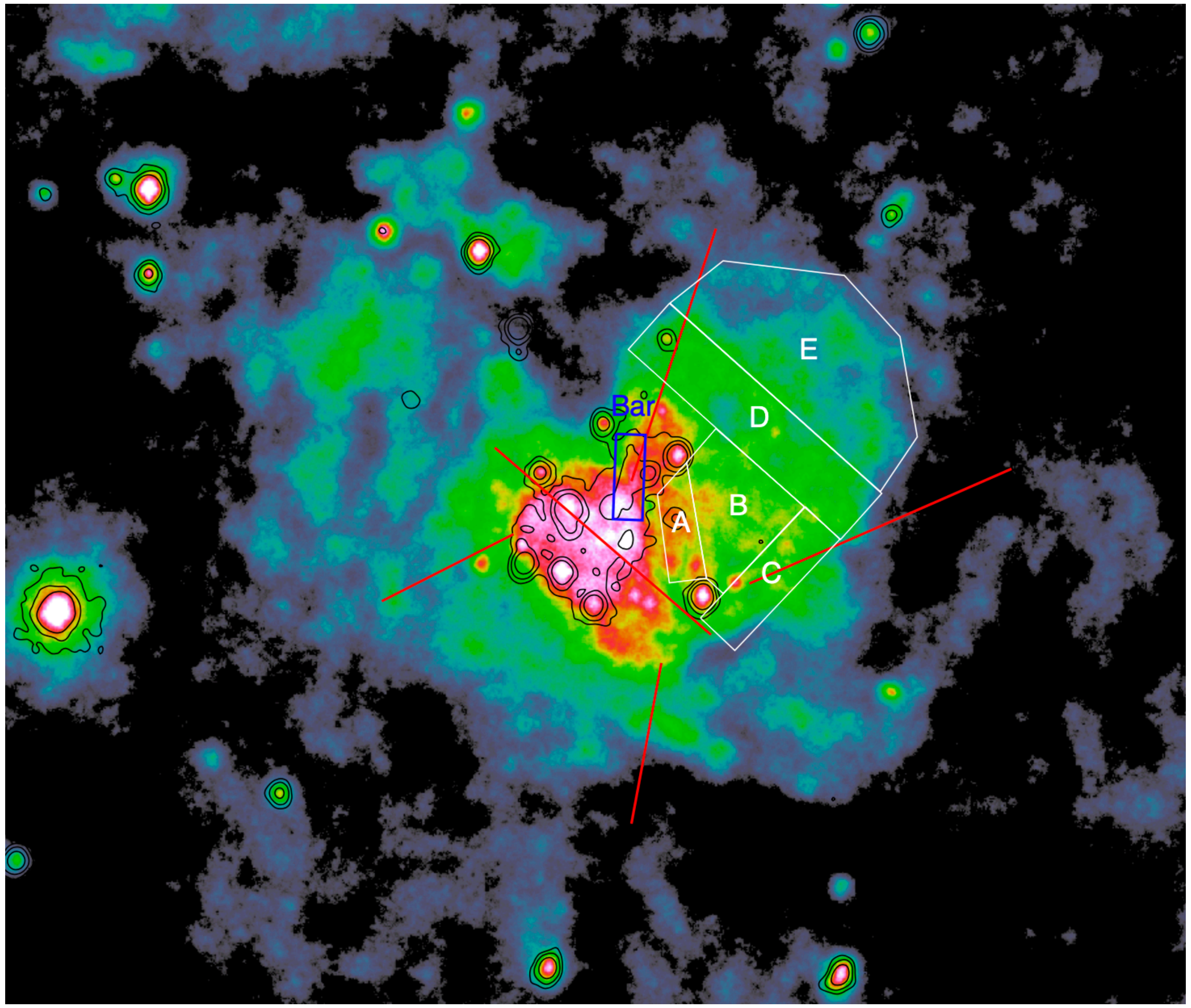




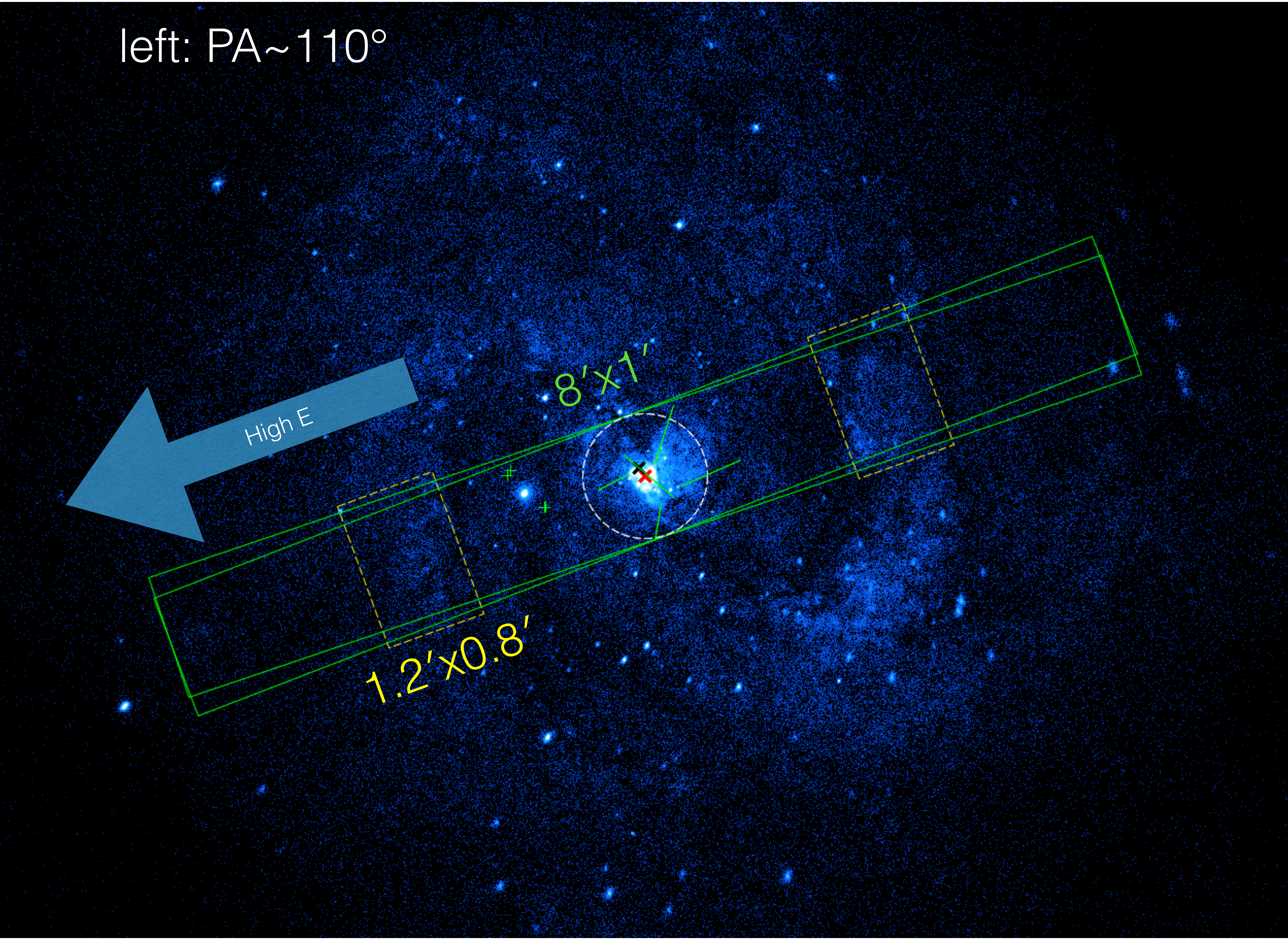
Credit for above images: NASA/CXC/U.Leicester/U.London/R.Soria & K.Wu

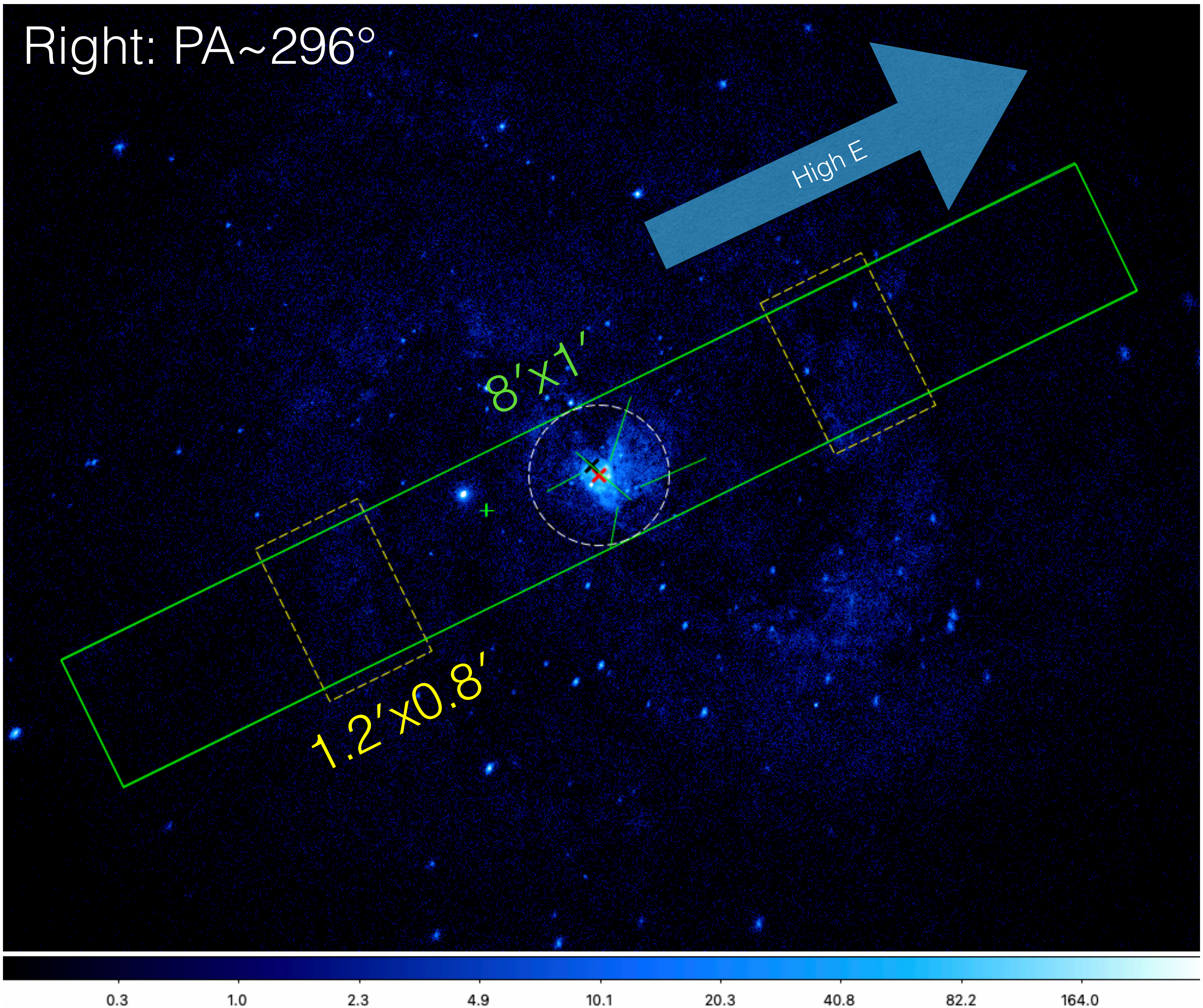


Bruna+2022; MUSE

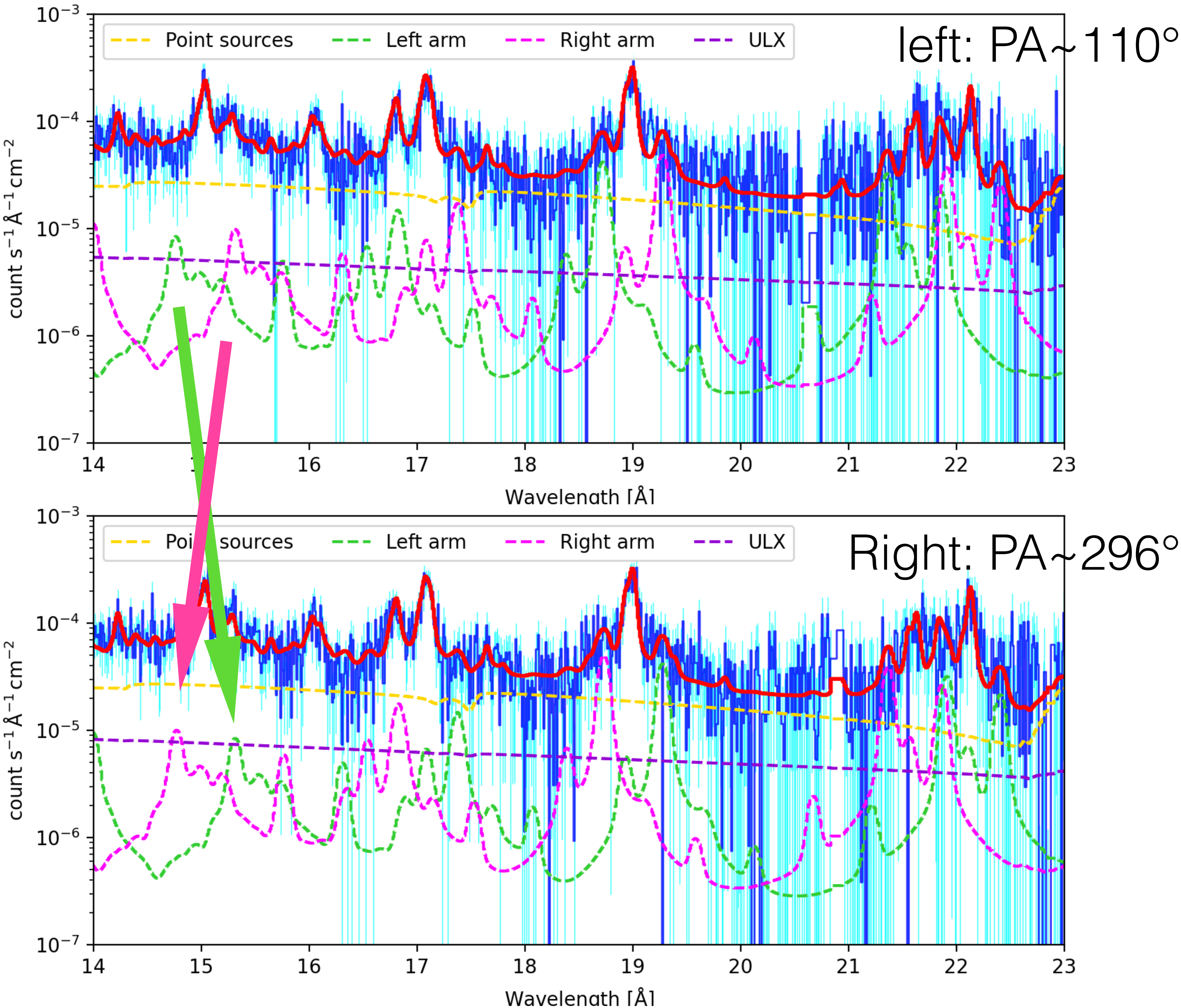


Chi et al. in preparation; Chandra

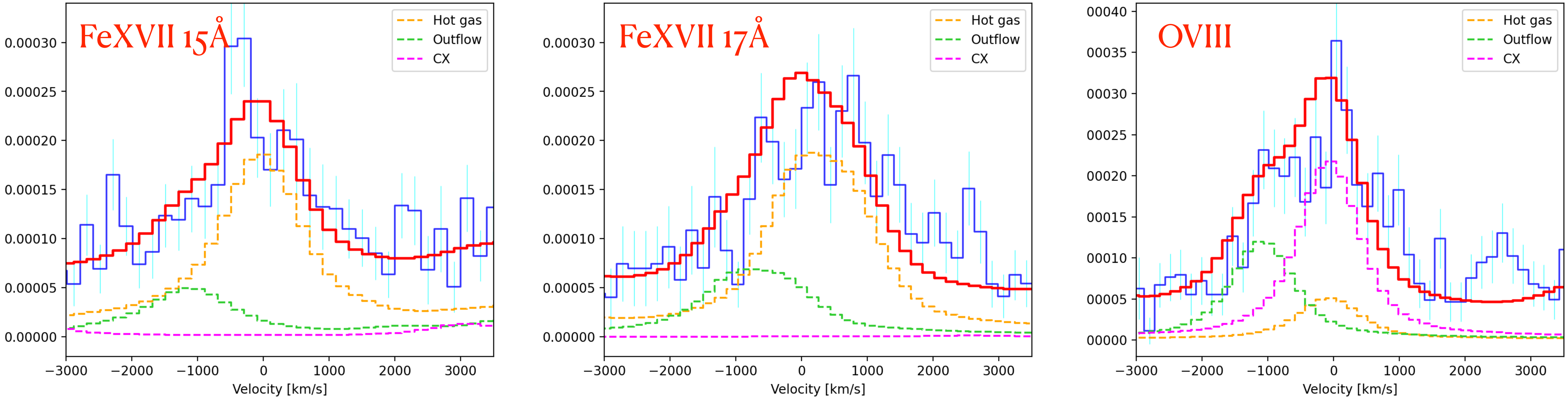

left: PA~110°
High E
8′x1′
1.2′x0.8′



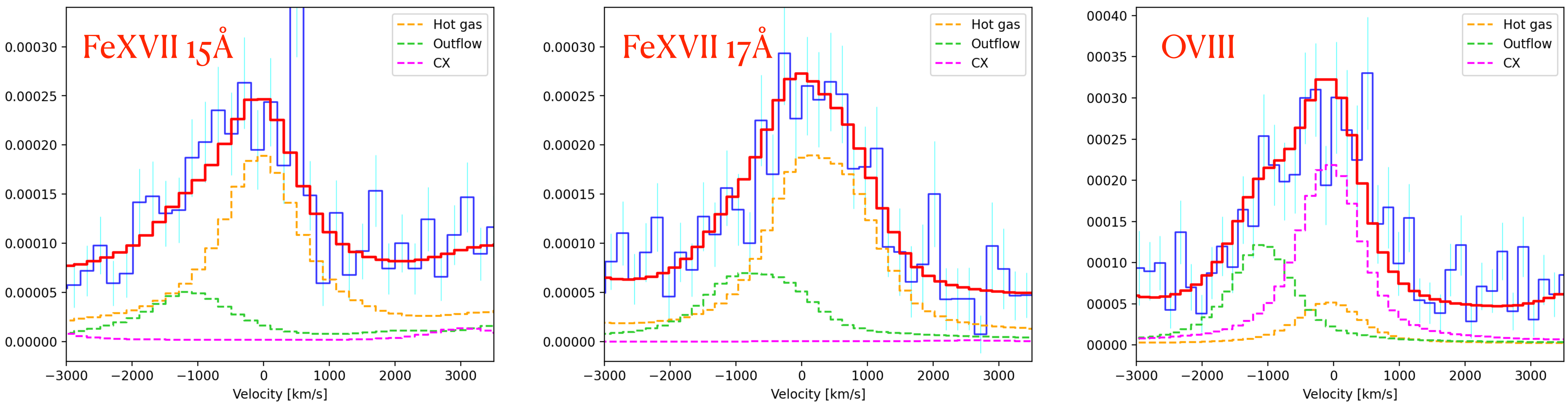
Right: PA~296°
High E
8′x1′
1.2′x0.8′
0.3
1.0
2.3
4.9
10.1
20.3
40.8
82.2
164.0


Point sources
Left arm
Right arm
ULX
left: PA~110°
Right: PA~296°
count s^{-1} Å^{-1} cm^{-2}
Wavelength [Å]
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
14
15
16
17
18
19
20
21
22
23

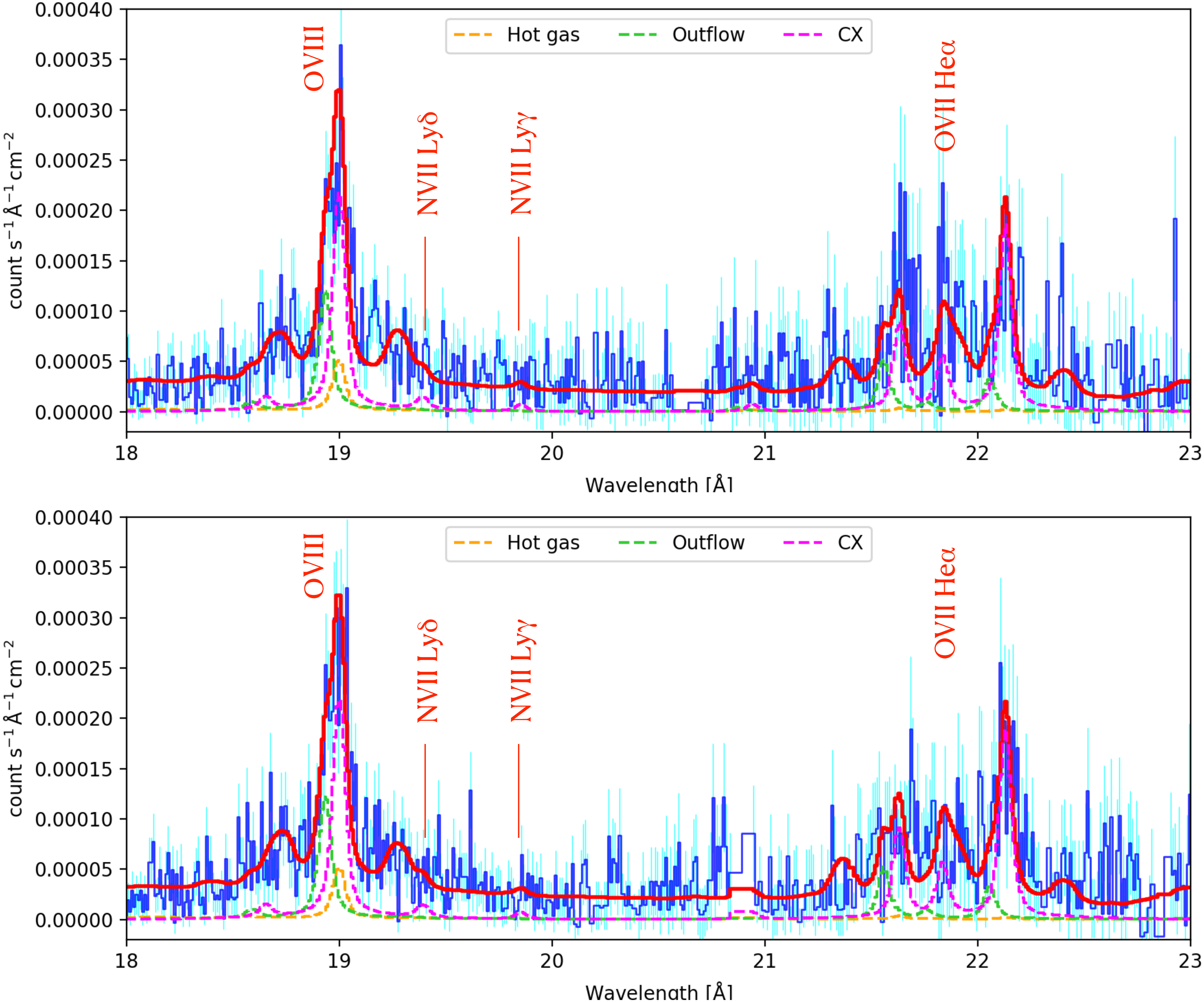
left: PA~110°



Right: PA~296°



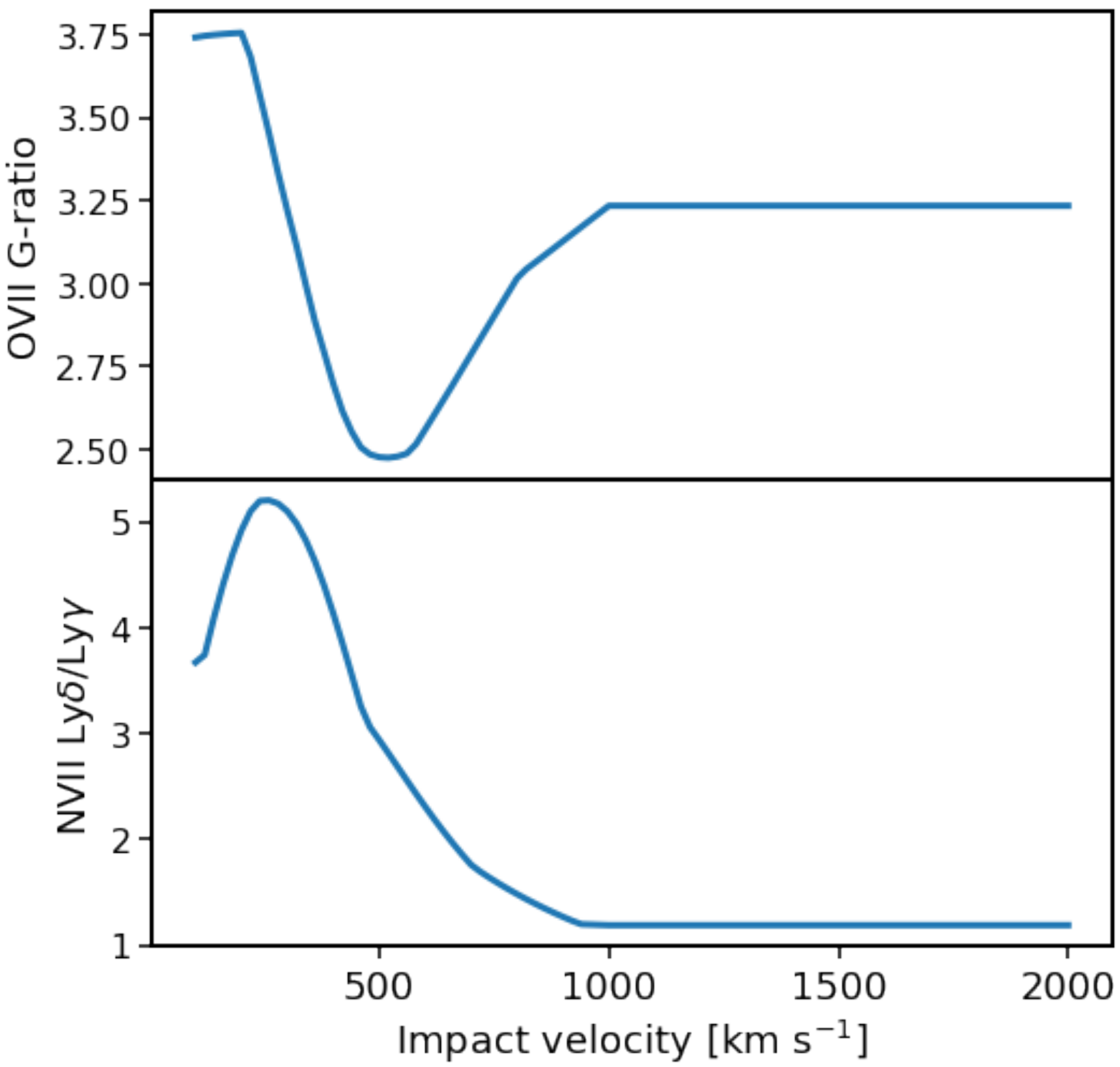
- **Outflowing velocity ~ -1000 km/s.**
- **Soft X-ray emission is from the outflowing hot gas.**



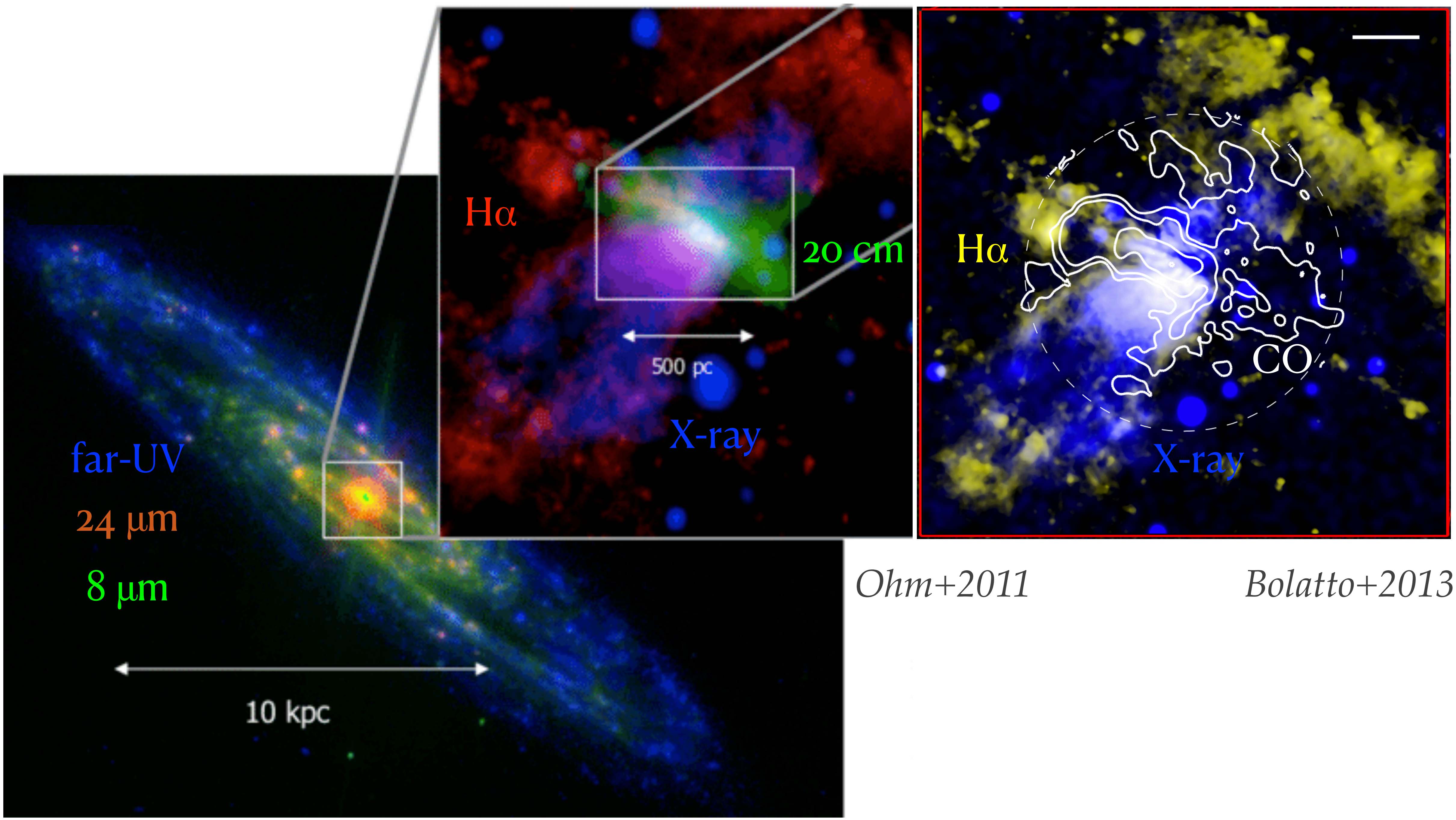
Hot gas
Outflow
CX
OVIII
NVII Lyδ
NVII Lyγ
OVII Heα
count s^{-1} Å^{-1} cm^{-2}
Wavelength [Å]

Wait~

Interplay
Velocity



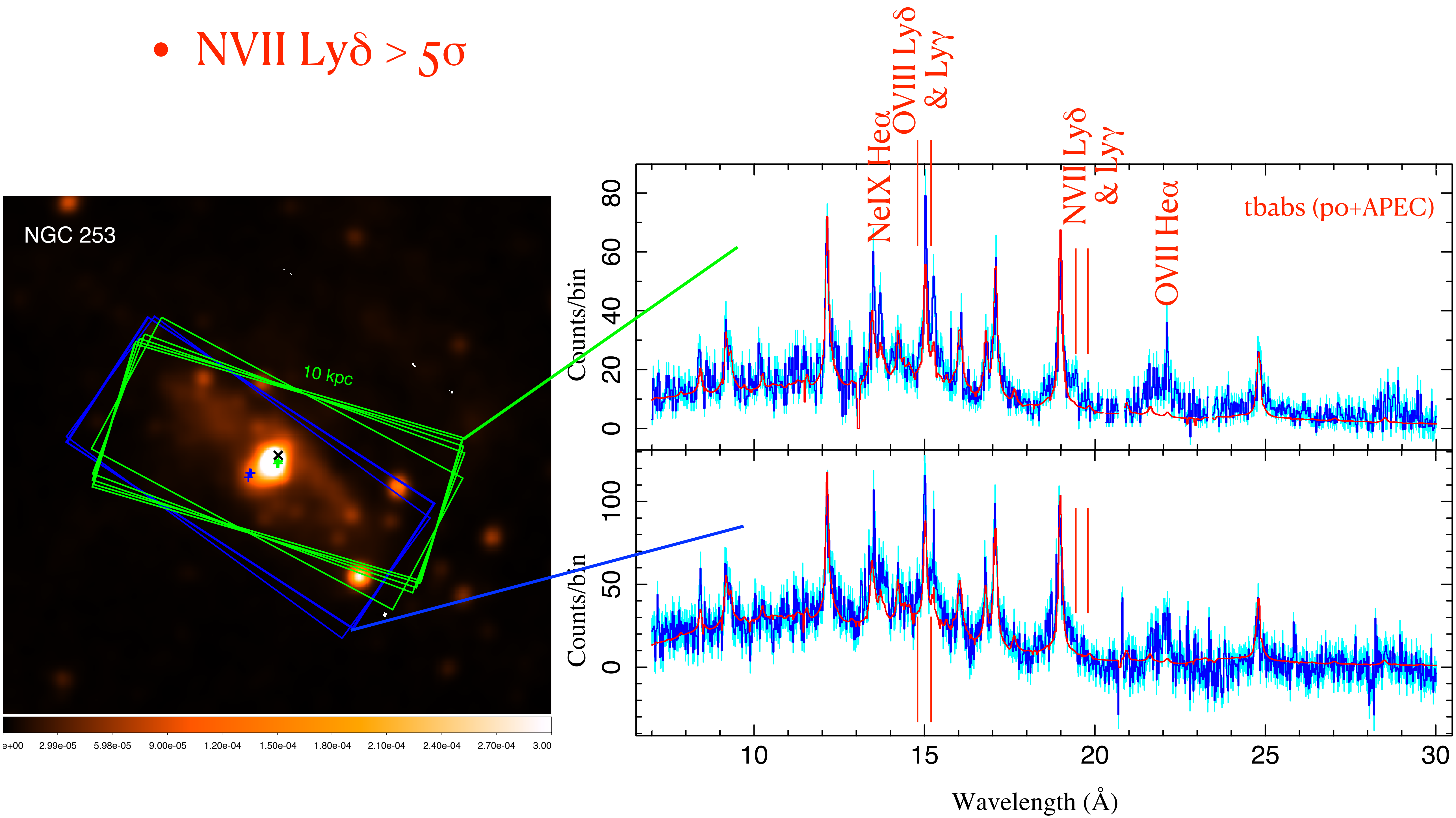
NGC253



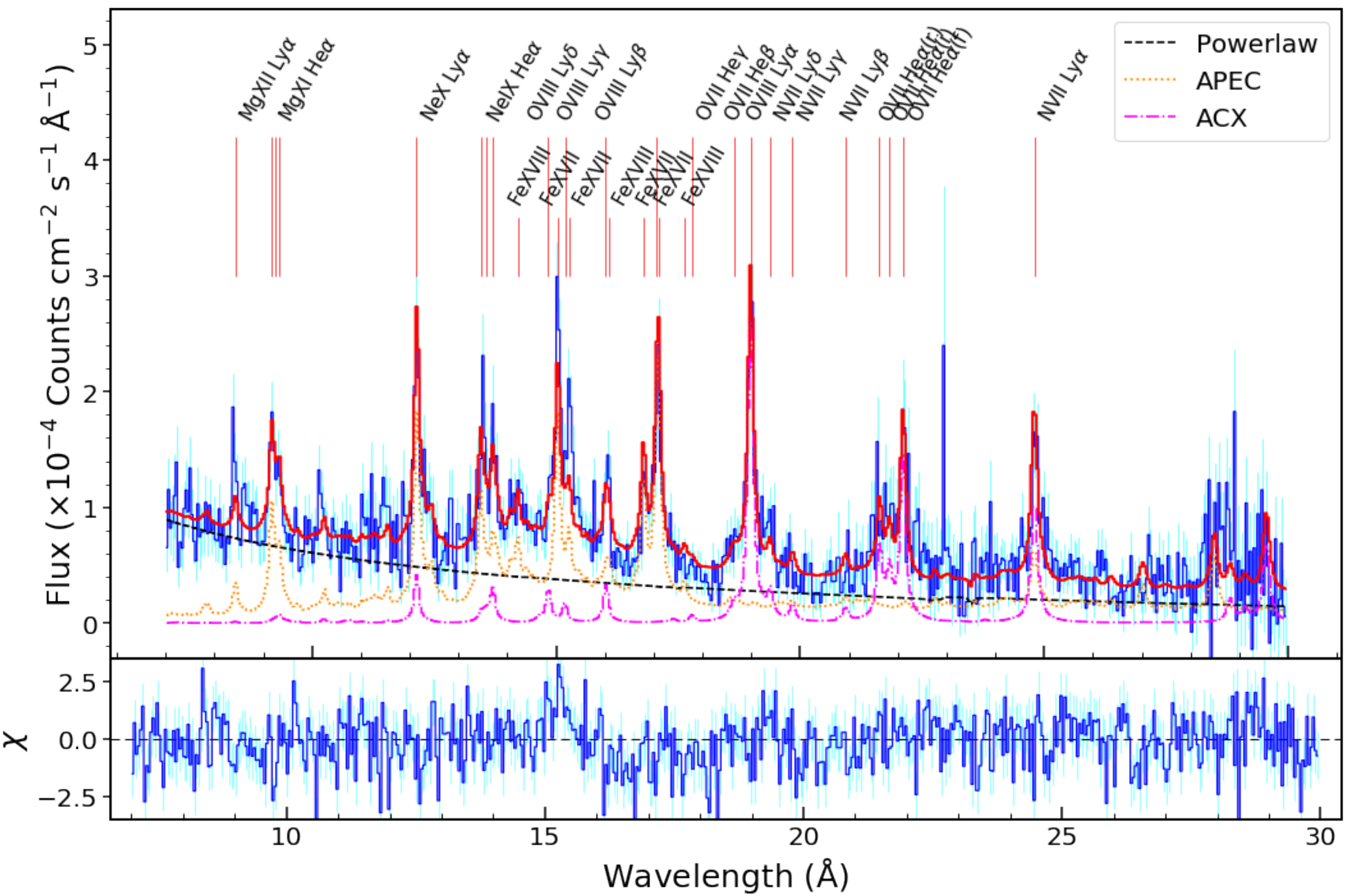
Ohm+2011 *Bolatto+2013*

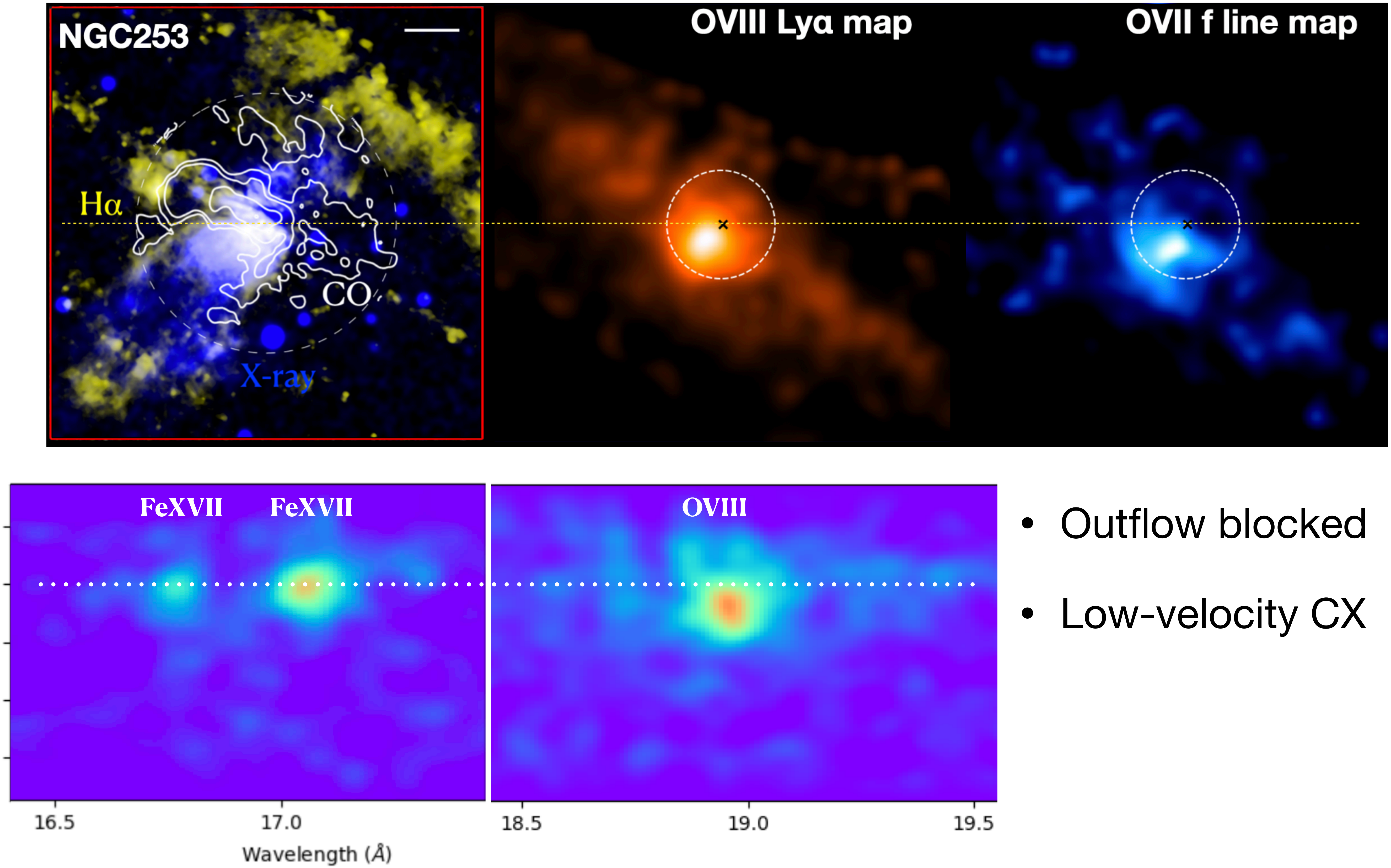
Opposite dispersion directions

- Blue & Green
- NVII Lyδ > 5σ



preliminary

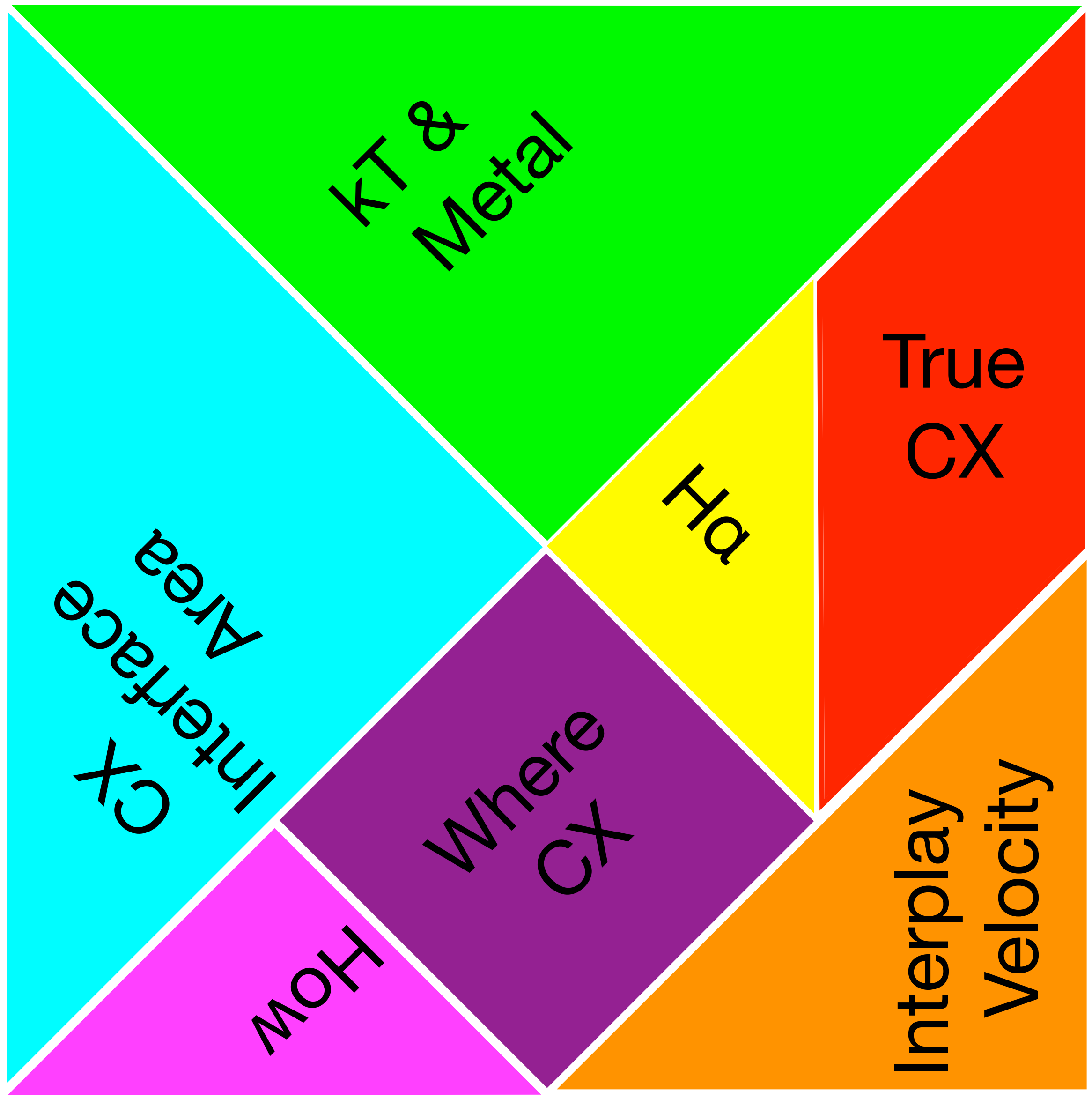


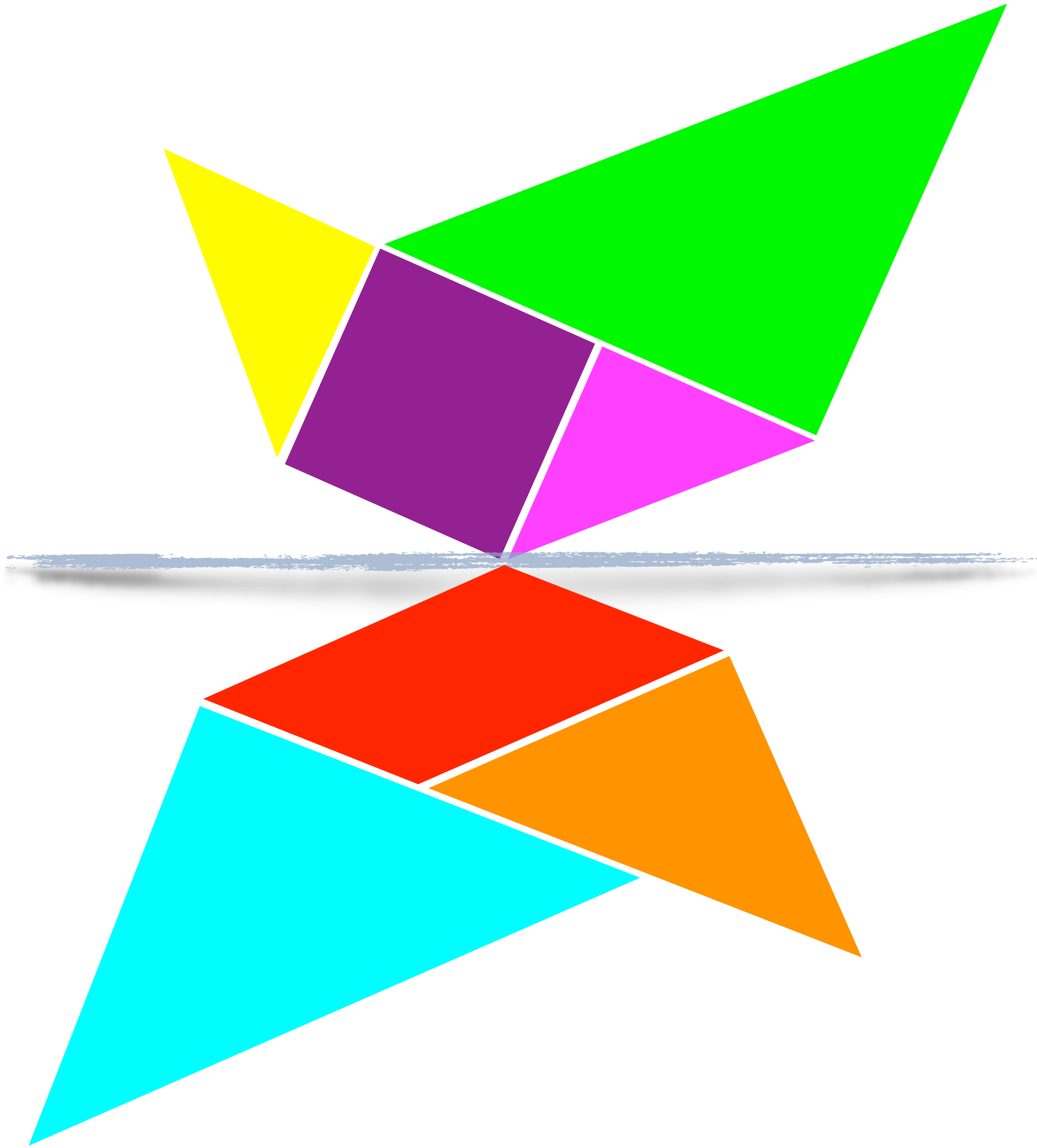


- Outflow blocked
- Low-velocity CX

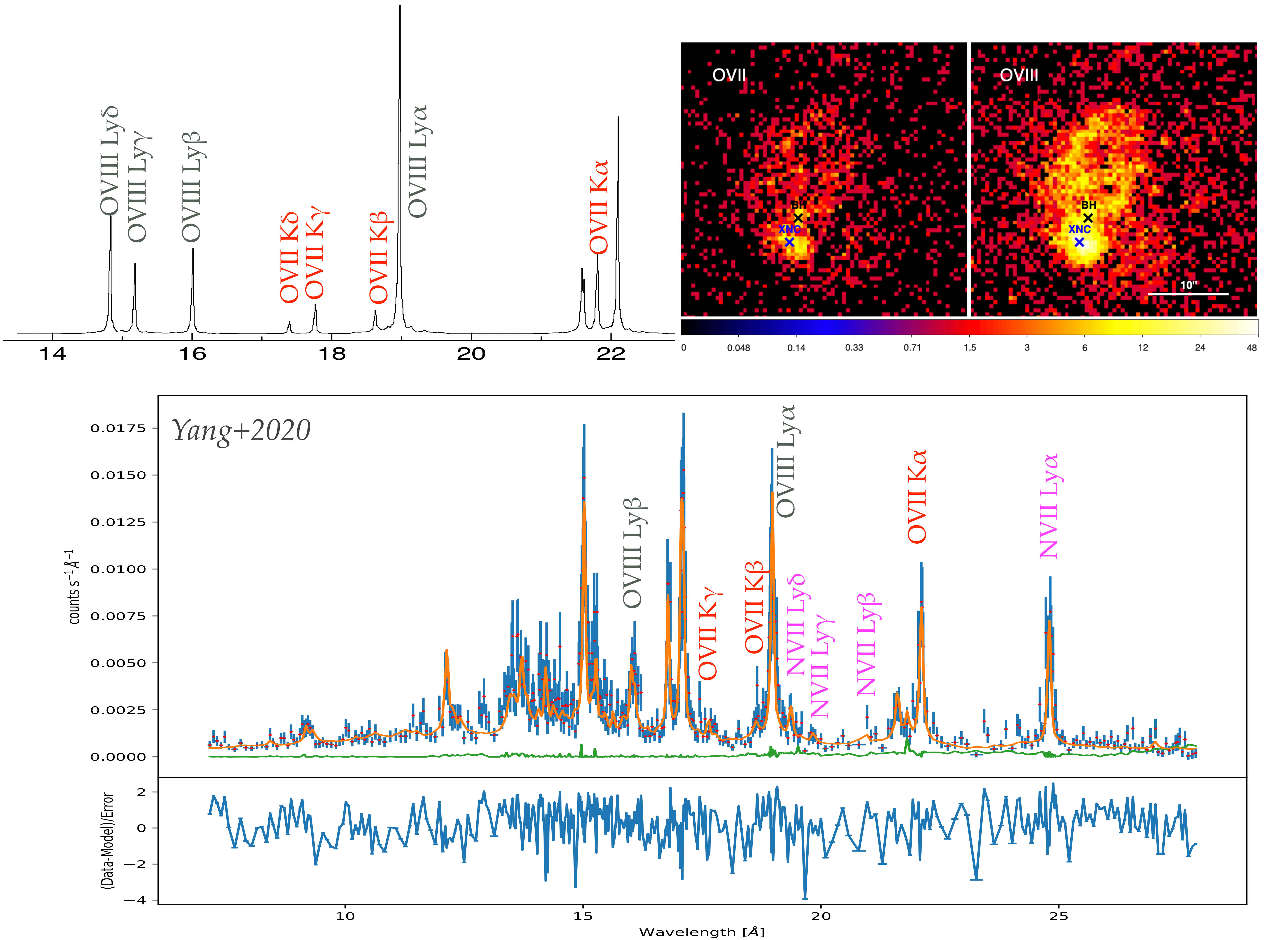

True
CX

Tangram


kT &
Metal
True
CX
Hα
Interface
Area
CX
Where
CX
How
Interplay
Velocity

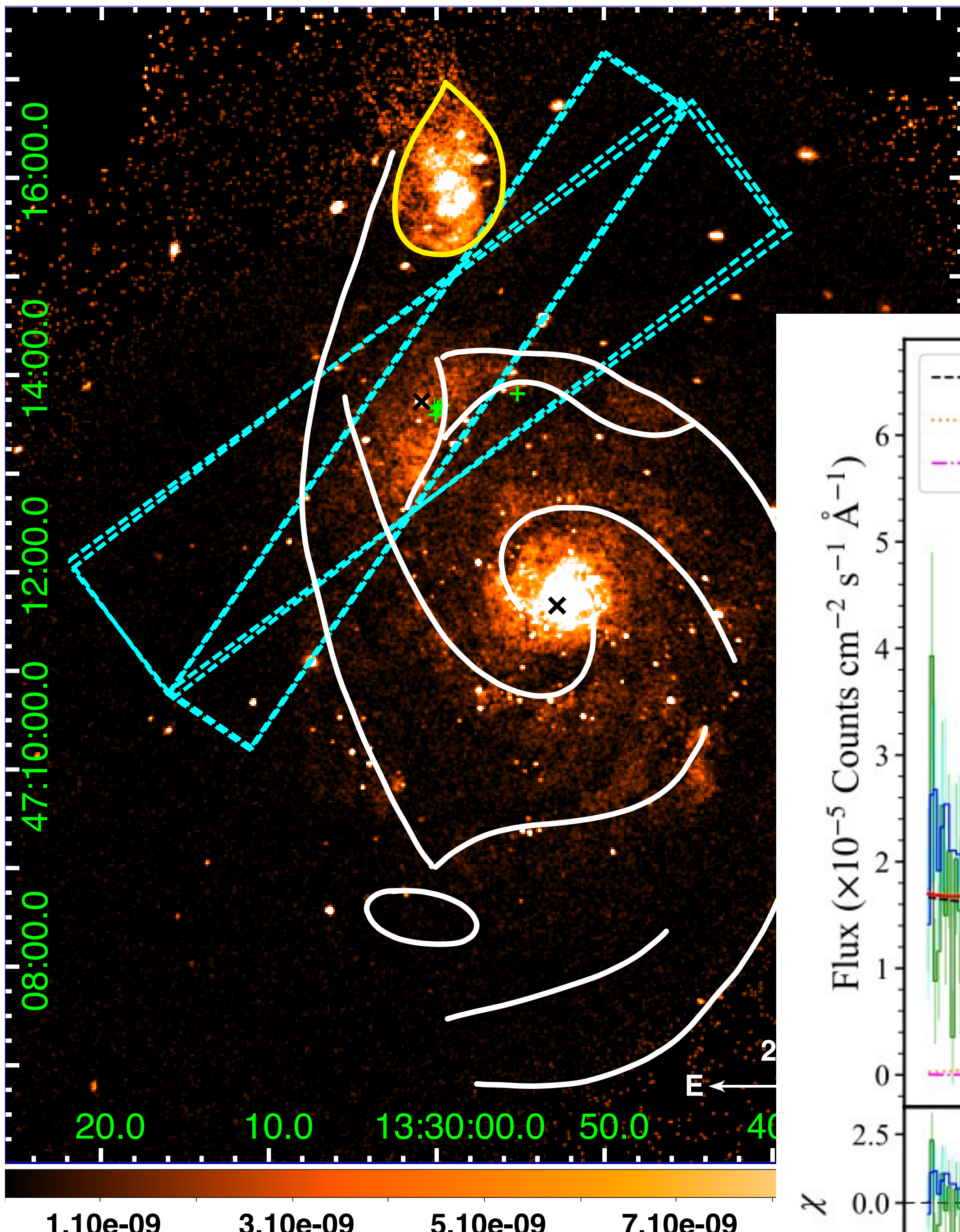



Credit: NASA & ESA



OVIII Lyδ
OVIII Lyγ
OVIII Lyβ
OVII Kδ
OVII Kγ
OVII Kβ
OVIII Lyα
OVII Kα
14
16
18
20
22
OVII
OVIII
BH
XNC
10"
0
0.048
0.14
0.33
0.71
1.5
3
6
12
24
48
Yang+2020
counts s^{-1} Å^{-1}
(Data-Model)/Error
Wavelength [Å]
NVII Lyδ
NVII Lyγ
NVII Lyβ
NVII Lyα

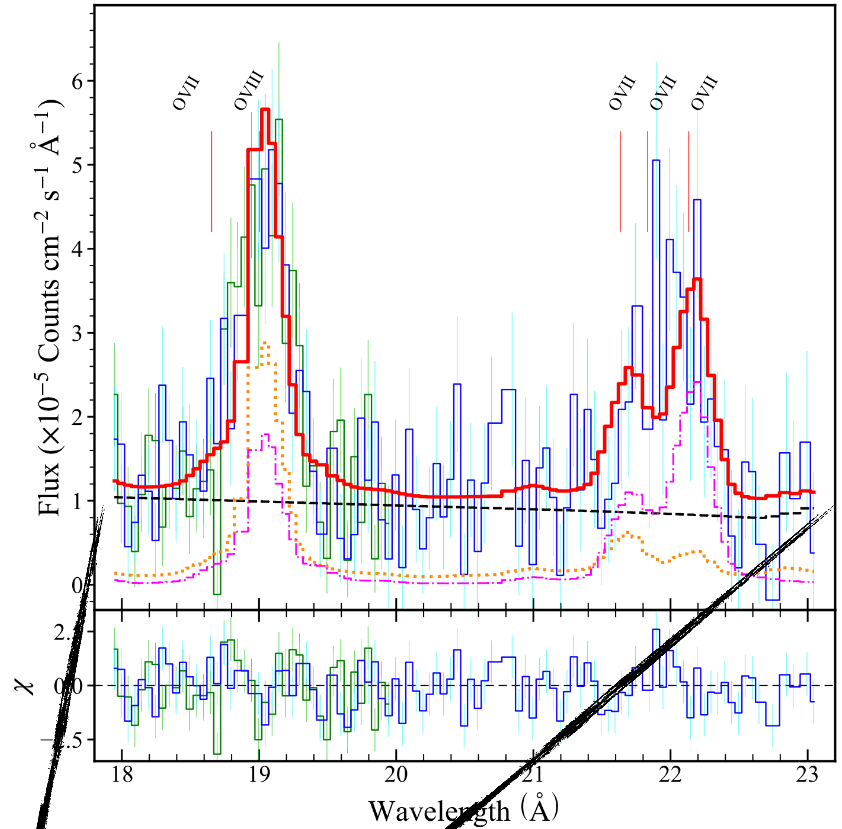
CX on the disk

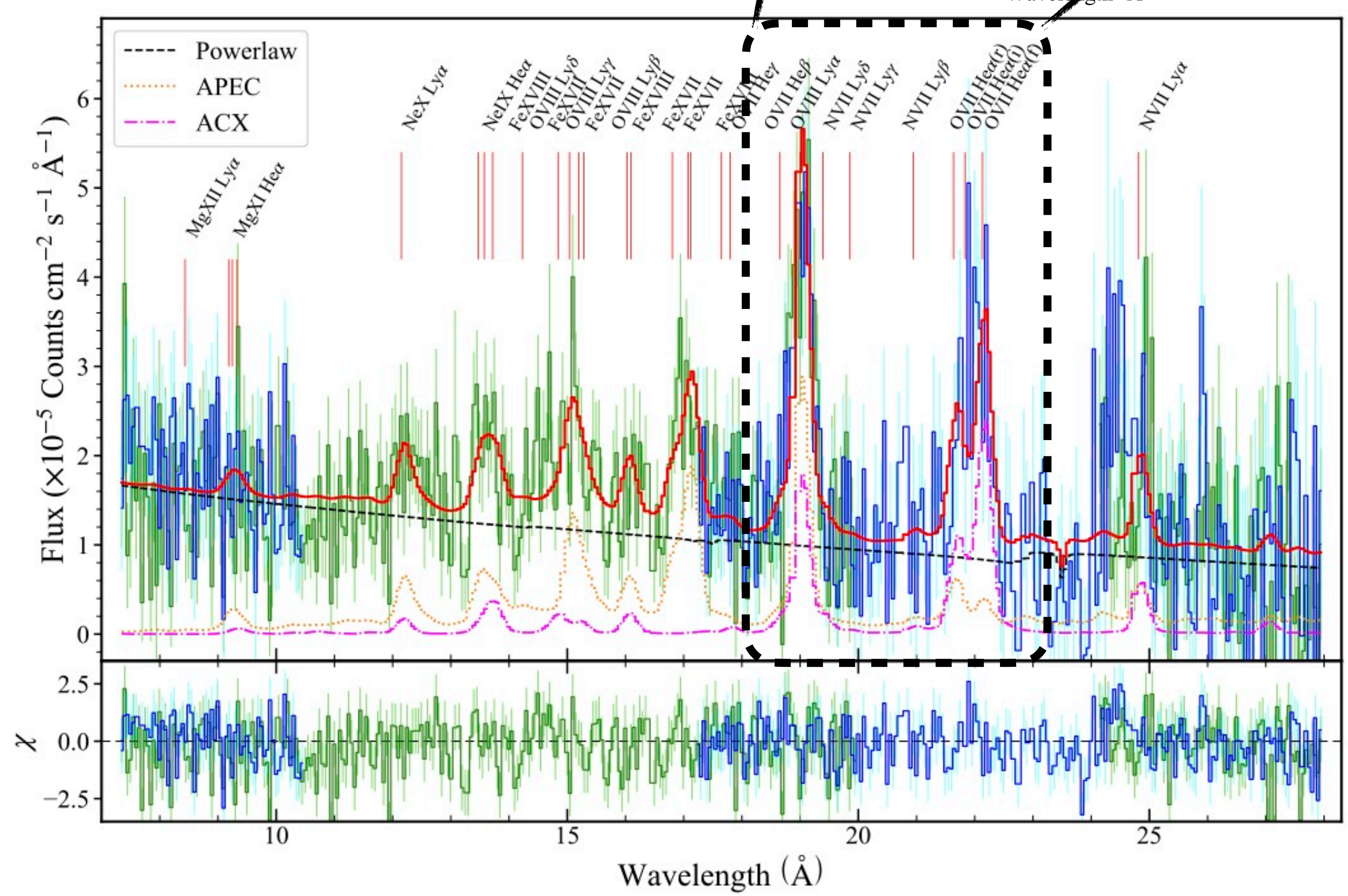


Zhang+2022

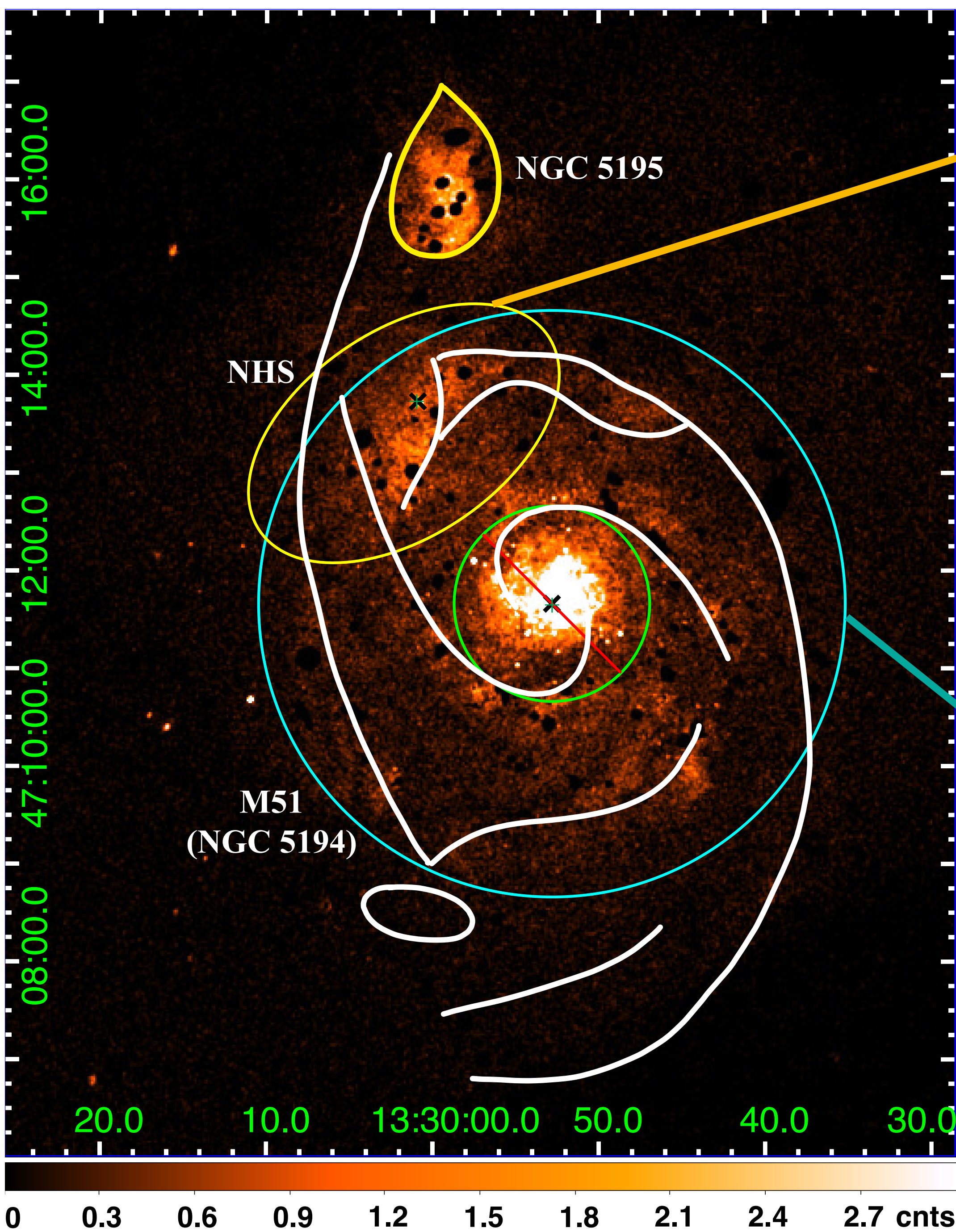
OVII G-ratio:
(f+i)/r
~ $3.2^{+6.9}_{-1.5}$

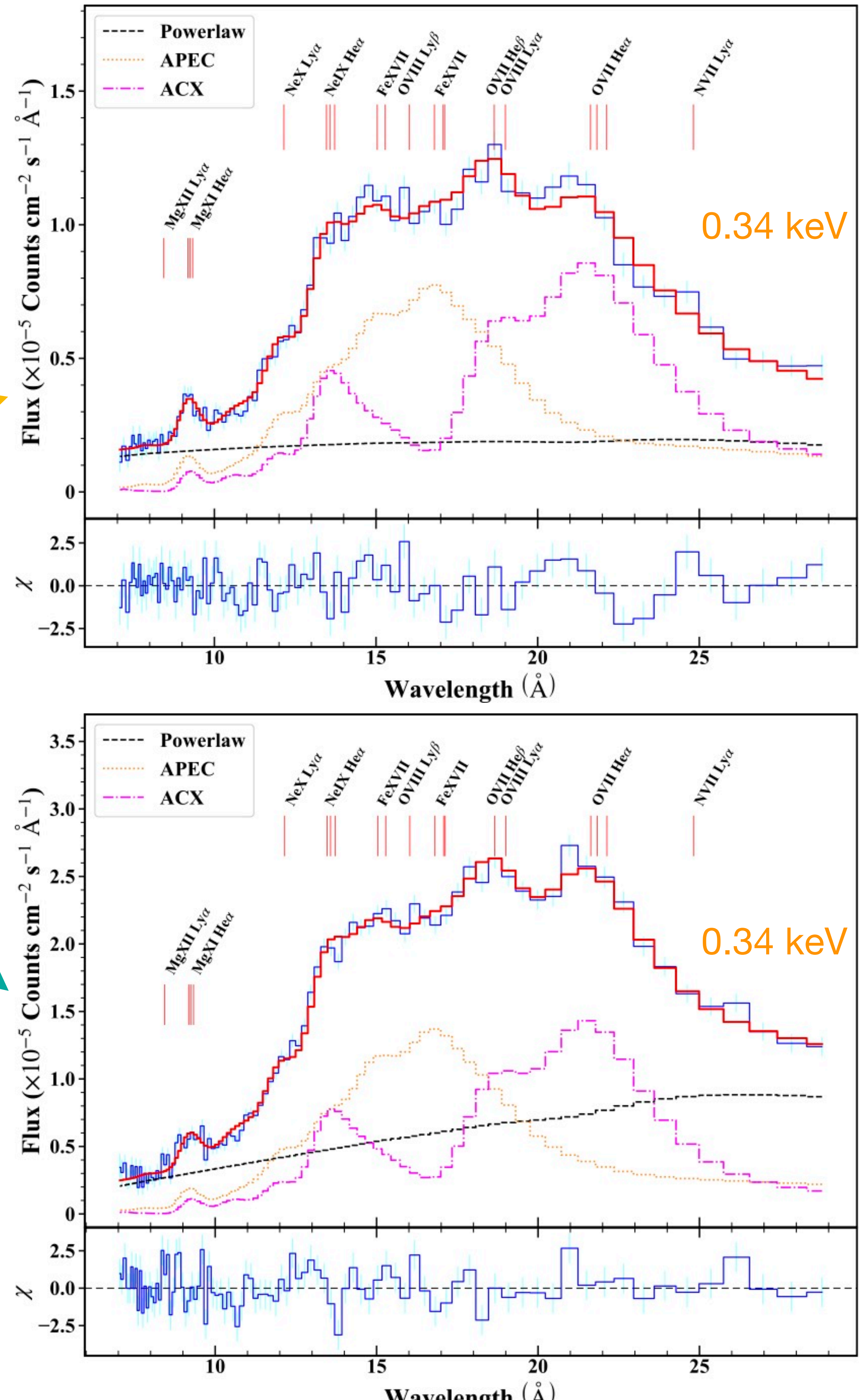
Not Photoionization, not NEI, not RS

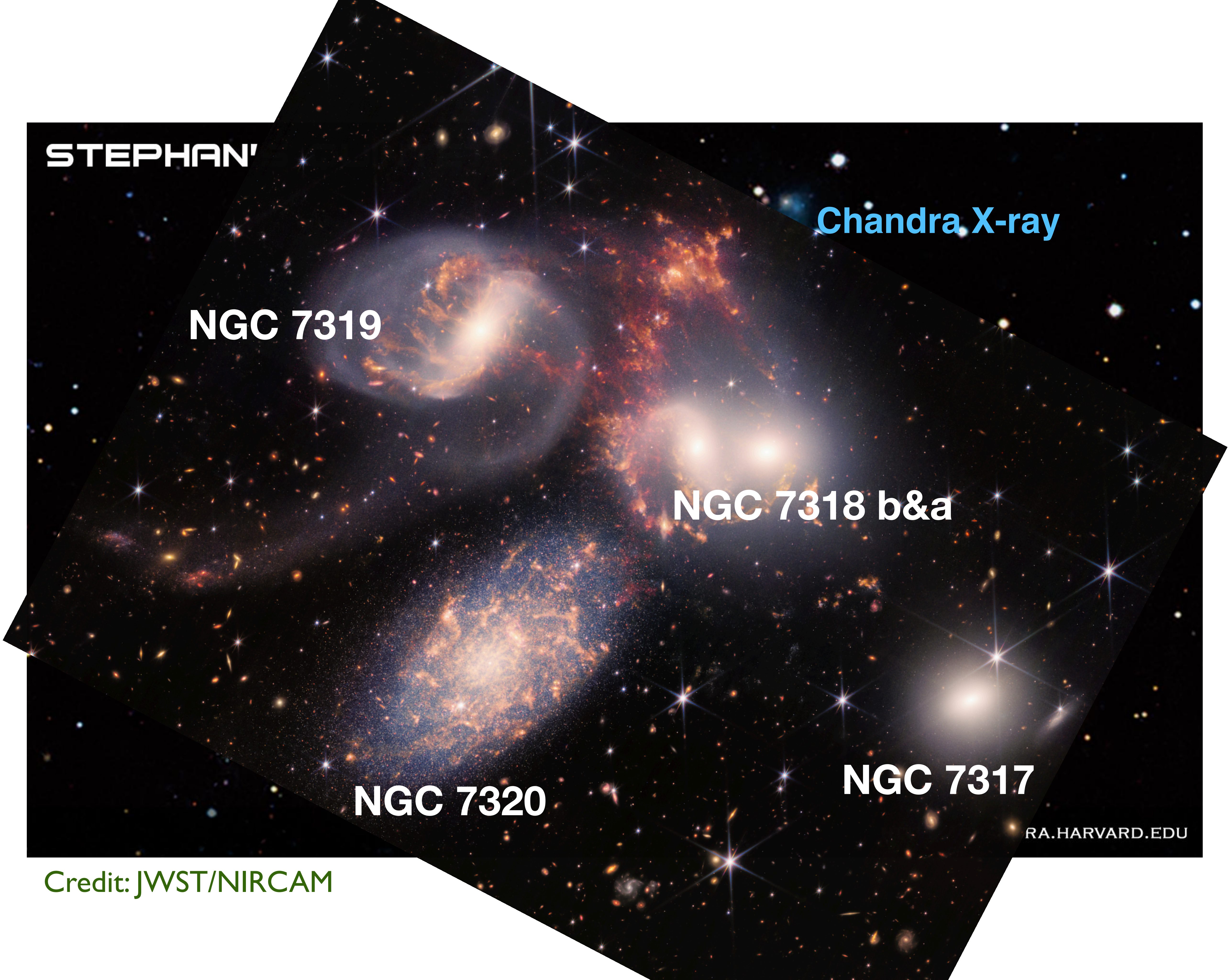




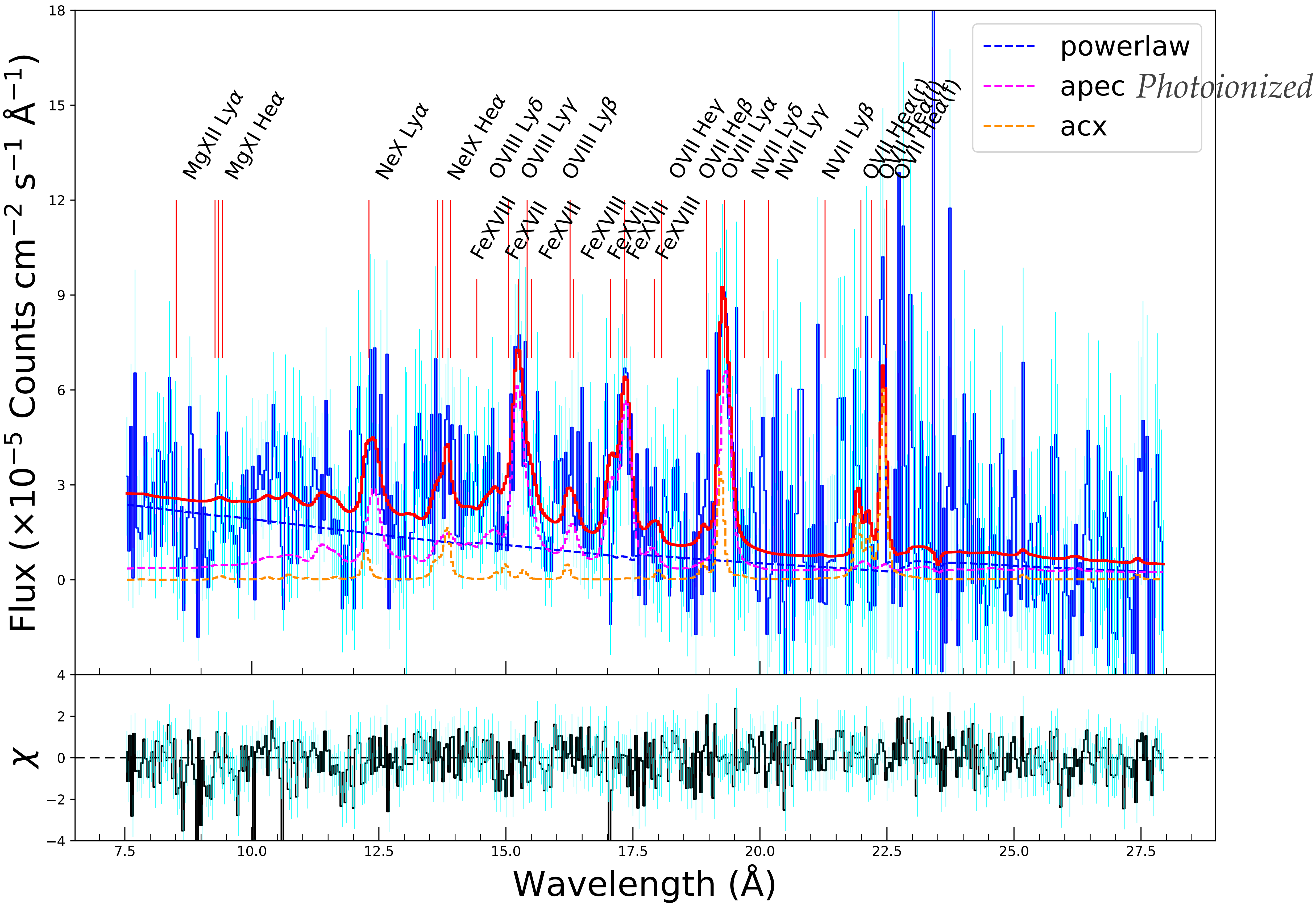
Chandra/ACIS spectra for the entire disk



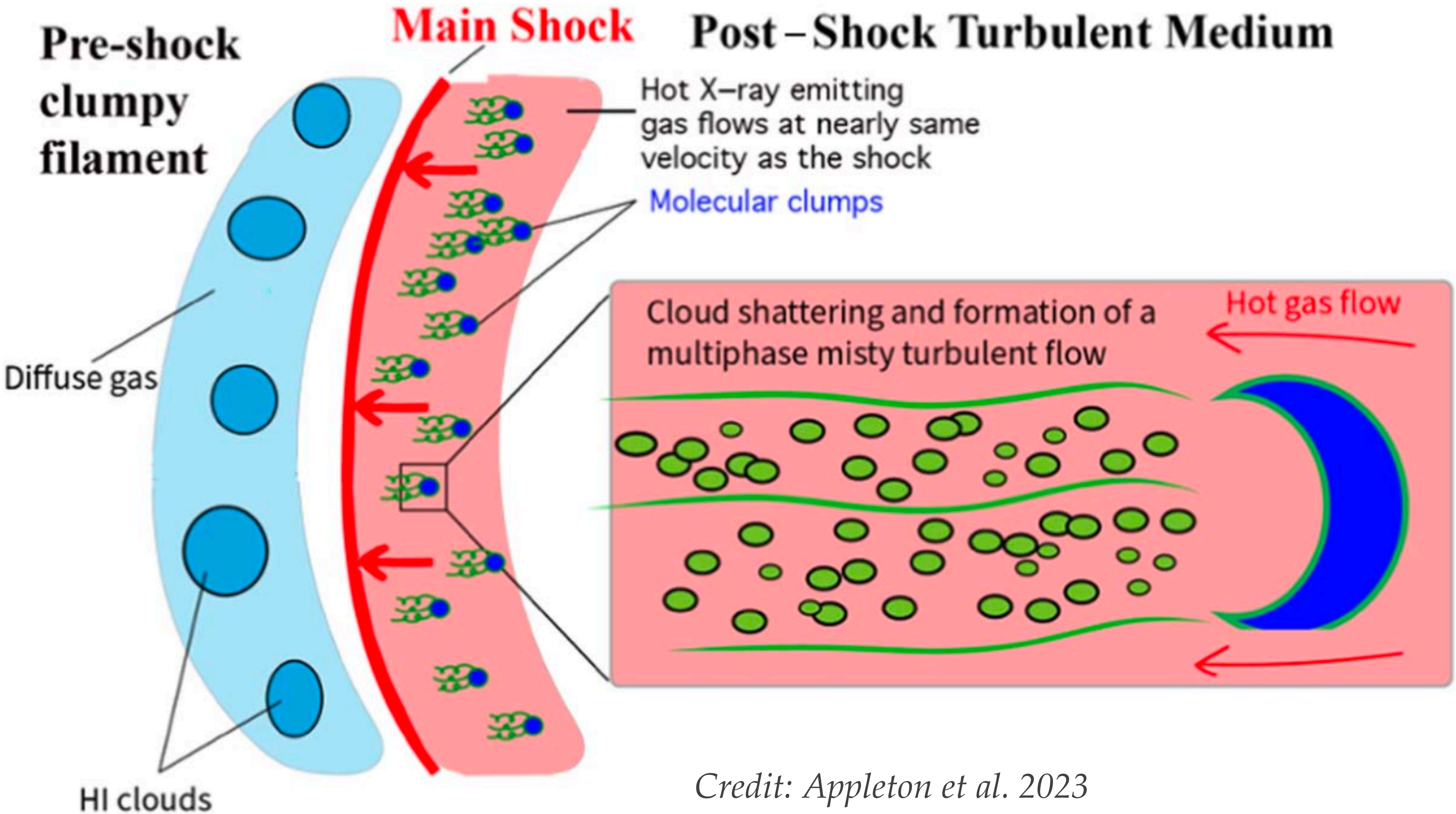




Credit: JWST/NIRCAM



Mao et al. in preparation



Credit: Appleton et al. 2023

Summary

- CX may everywhere in the galaxy: center, disk, superwind, outside.
- CX helps constrain properties of both the hot and the cold gas.
- Sometimes, the hot gas interacts with the cold ISM severely, which consumes the hot gas quickly.