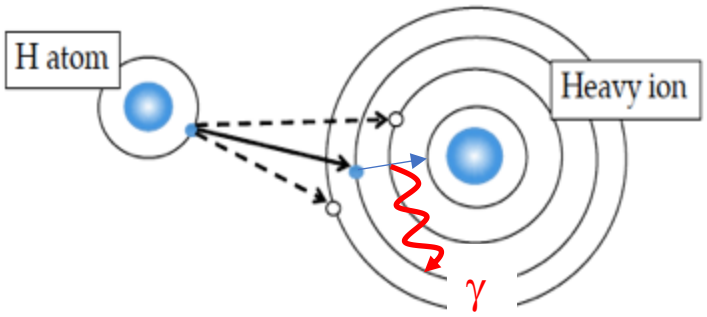
Establishing Charge Exchange X-Ray Emission from Supernova Remnants with Athena's X-IFU

Satoru Katsuda[1], Hiroshi Tsunemi[2], Koji Mori[3], Hiroyuki Uchida[4]
(1. Saitama U.; 2. Osaka U.; 3. U. Miyazaki; 4. Kyoto U.)

Charge Exchange vs. Collisional Excitation

Charge exchange

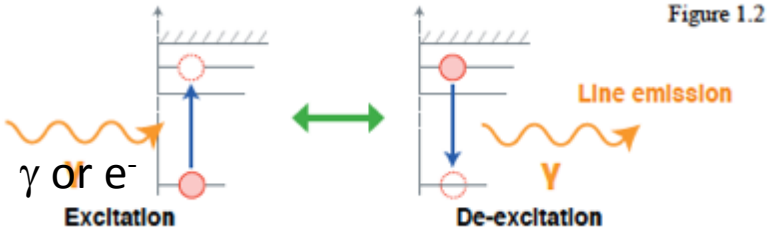


$\sigma_{CX} \sim 10^{-15}$ cm^{-2}

© Liyi Gu

>>

Collisional excitation

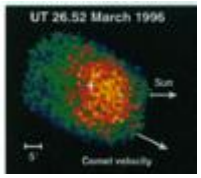


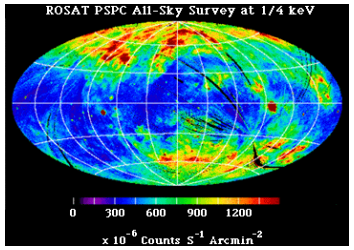
$\sigma_{CE} \sim 10^{-20}$ cm^{-2}

© ASTRO-H cook book

→ CX emission is non-negligible, if there are enough neutrals and ions.

Emerging Evidence for CX X-Ray Emission





- Comets (Lisse et al. 1996)
- Soft X-ray background (Snowden+ 1994; Robertson+ 2001)

Established

Debated

- Stellar winds and outflows from star forming region
- Supernova remnants
- Galaxies
- Galaxy clusters

CX X-Ray Emission in SNRs -1-

Wise & Sarazin (1989) performed a detailed calculation of the expected CX X-ray emission from SNRs.

They concluded that the contribution of CX X-ray emission is up to 1% of the total (thermal) emission.

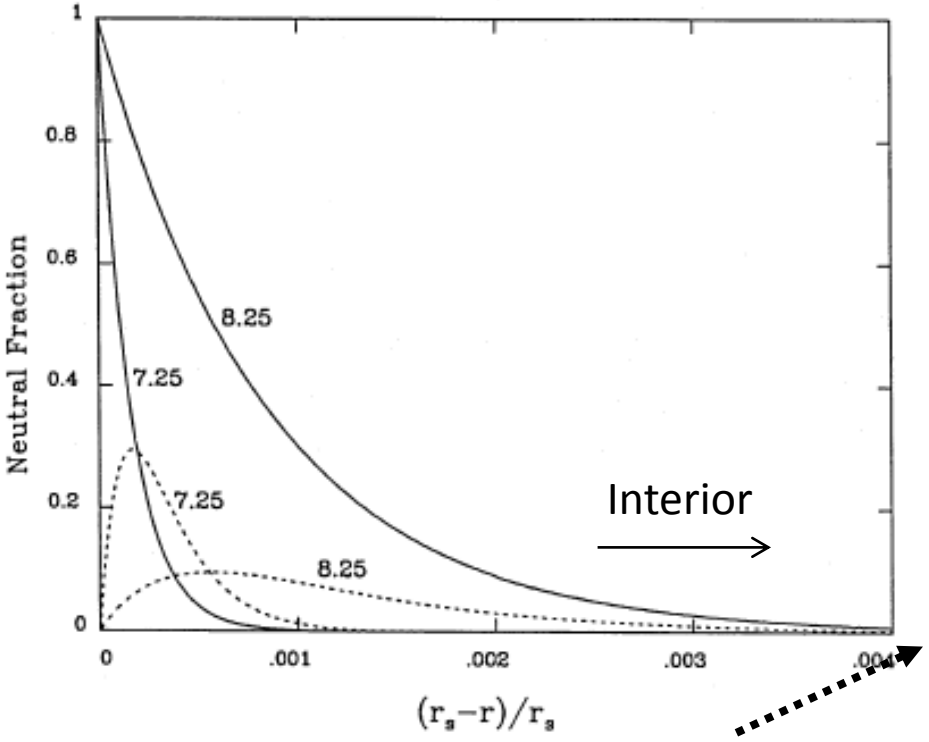
Why is the CX contribution so small?

→

Little amount of neutrals co-exist with highly ionized heavy elements.

$O^{7+} + H \rightarrow O^{6+*} + p \rightarrow O^{6+} + p + h\nu$

Neutral fraction behind a shock

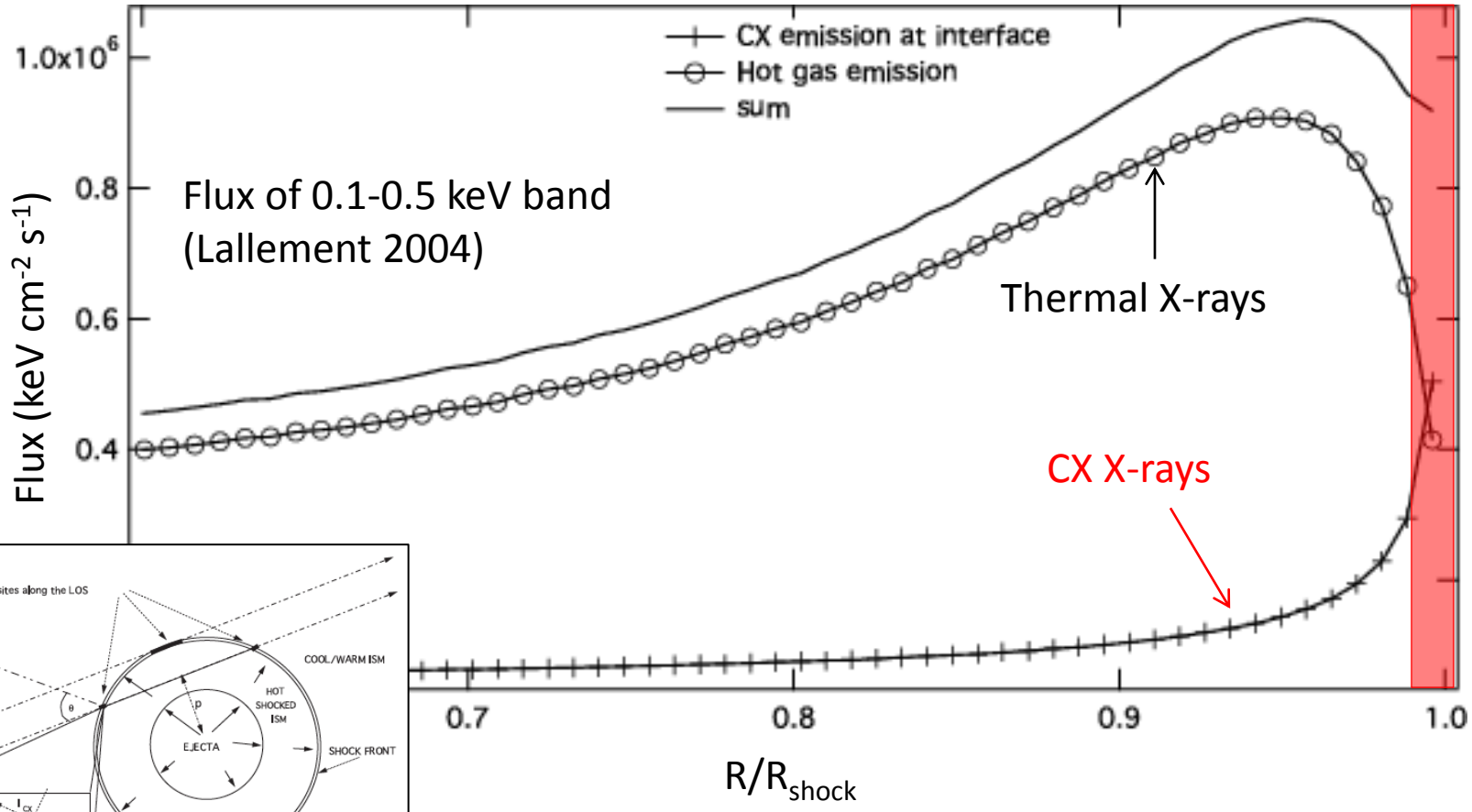


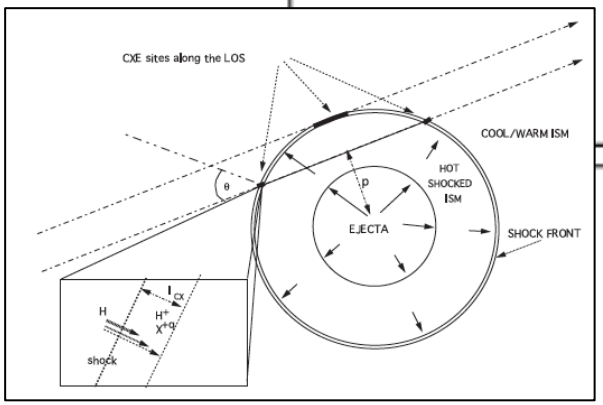
Almost no neutrals at 0.005 R_{SNR}.

CX X-Ray Emission in SNRs -2-

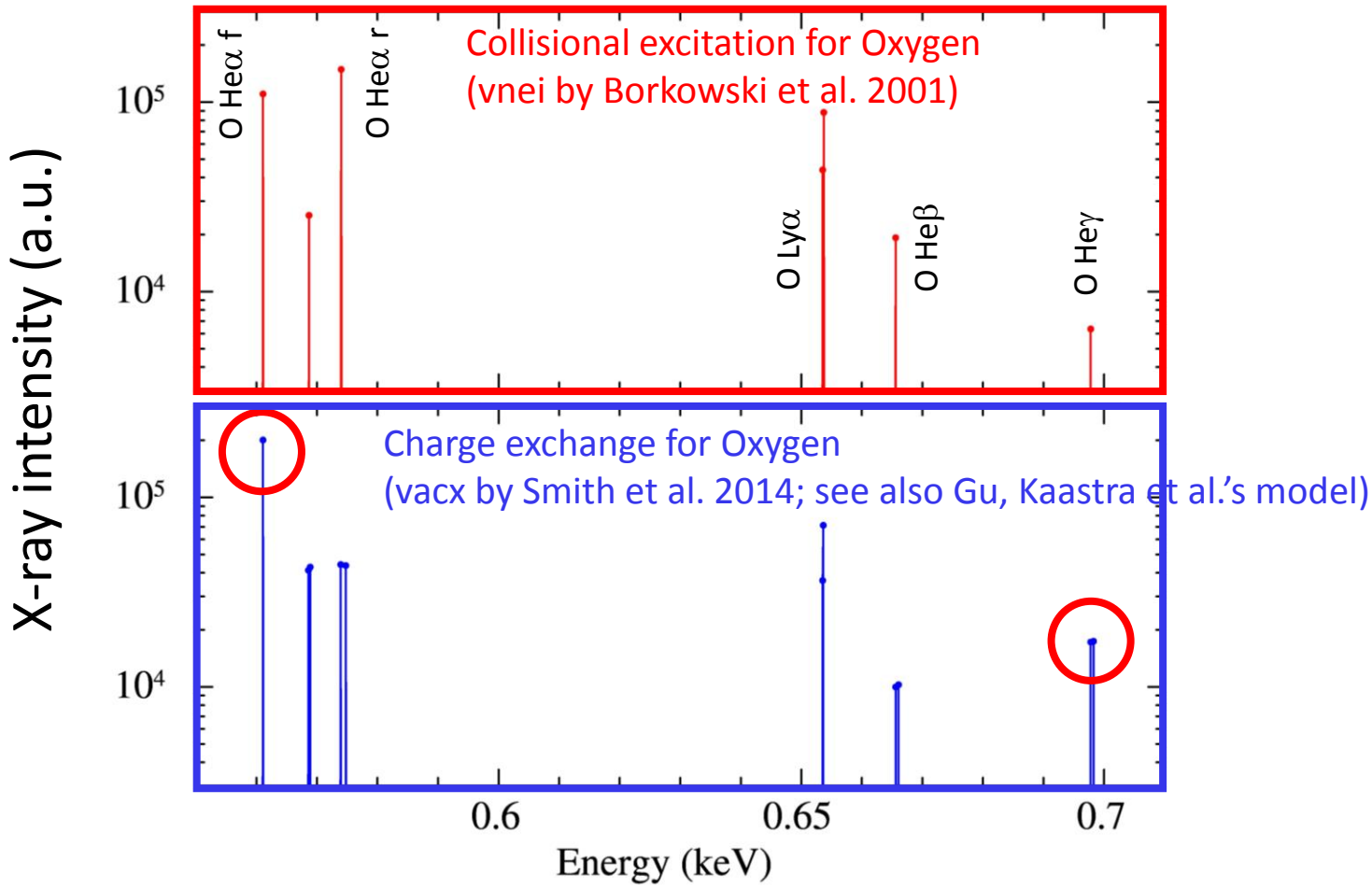
CX X-rays might be important at the edge of SNRs.

→ It's important to perform spatially resolved spectroscopy.





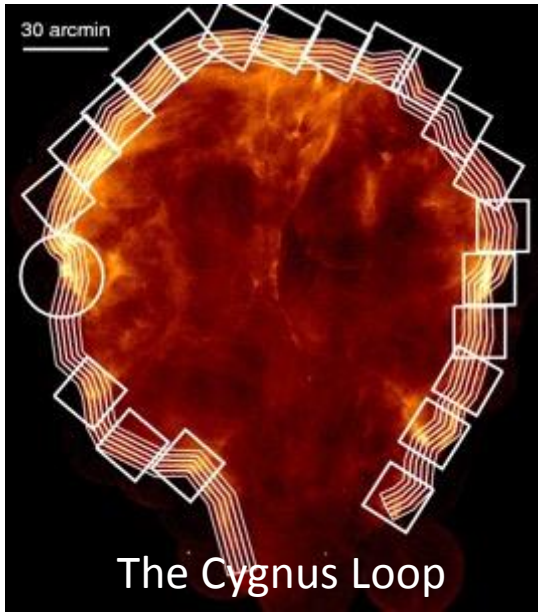
How Can We Identify CX X-Ray Emission?



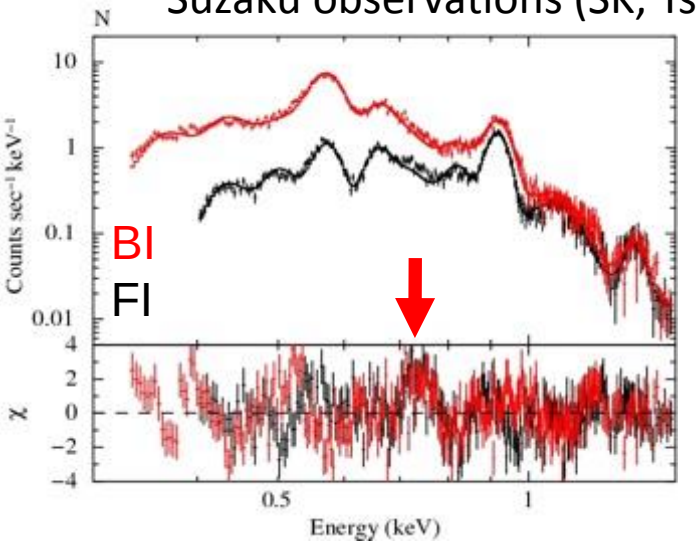
Important CX properties:

1) Heα forbidden > resonance
2) Strong Heγ line

The First Observational Implication for CX X-Rays in a SNR



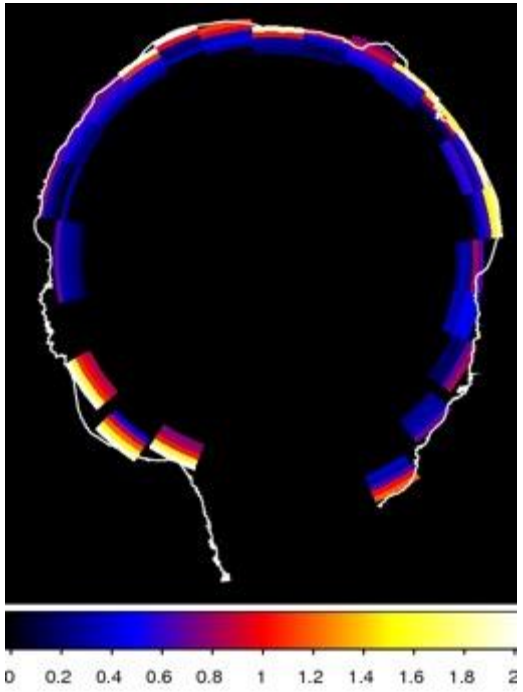
Suzaku observations (SK, Tsunemi, Mori, et al. 2011)



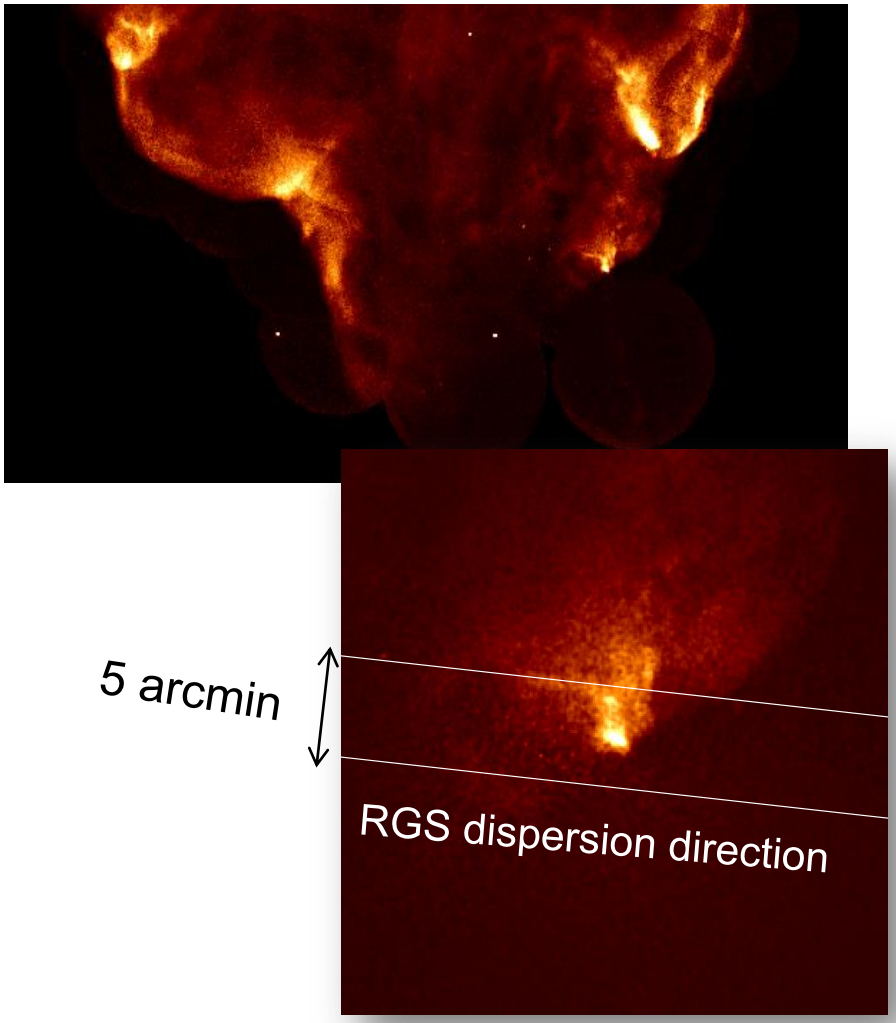
Excess emission at 0.7 keV
→ O Heγ δ etc. from CX
of H-like O + neutrals?

Spatial distribution of the 0.7 keV excess is consistent with the CX scenario.

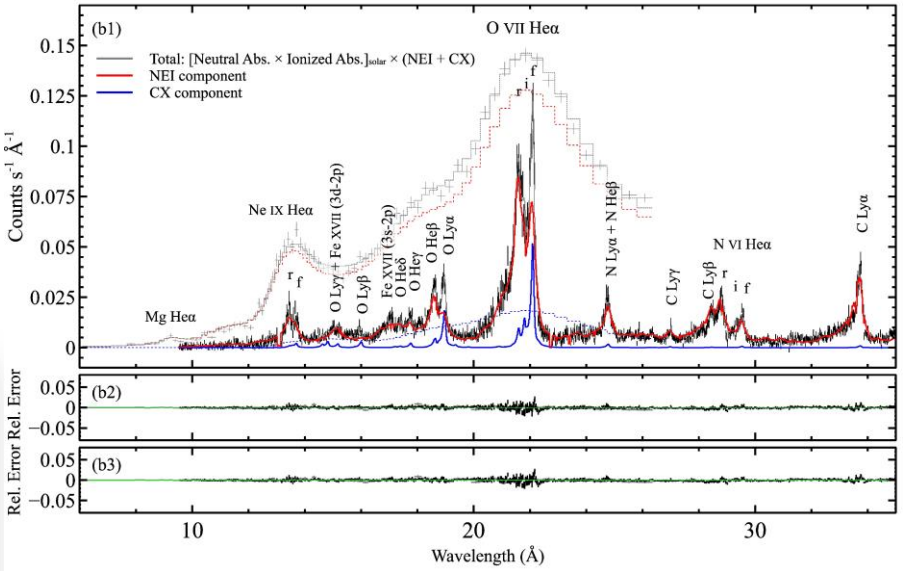
Distribution of the 0.7 keV excess



Further Support by High-Res. Spectroscopy



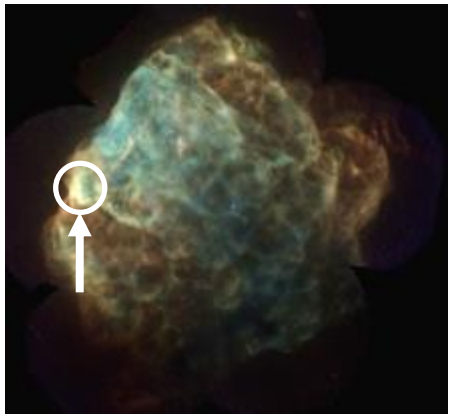
XMM-Newton's RGS observations
(Uchida, SK, Tsunemi, et al. 2018 to be subm.)



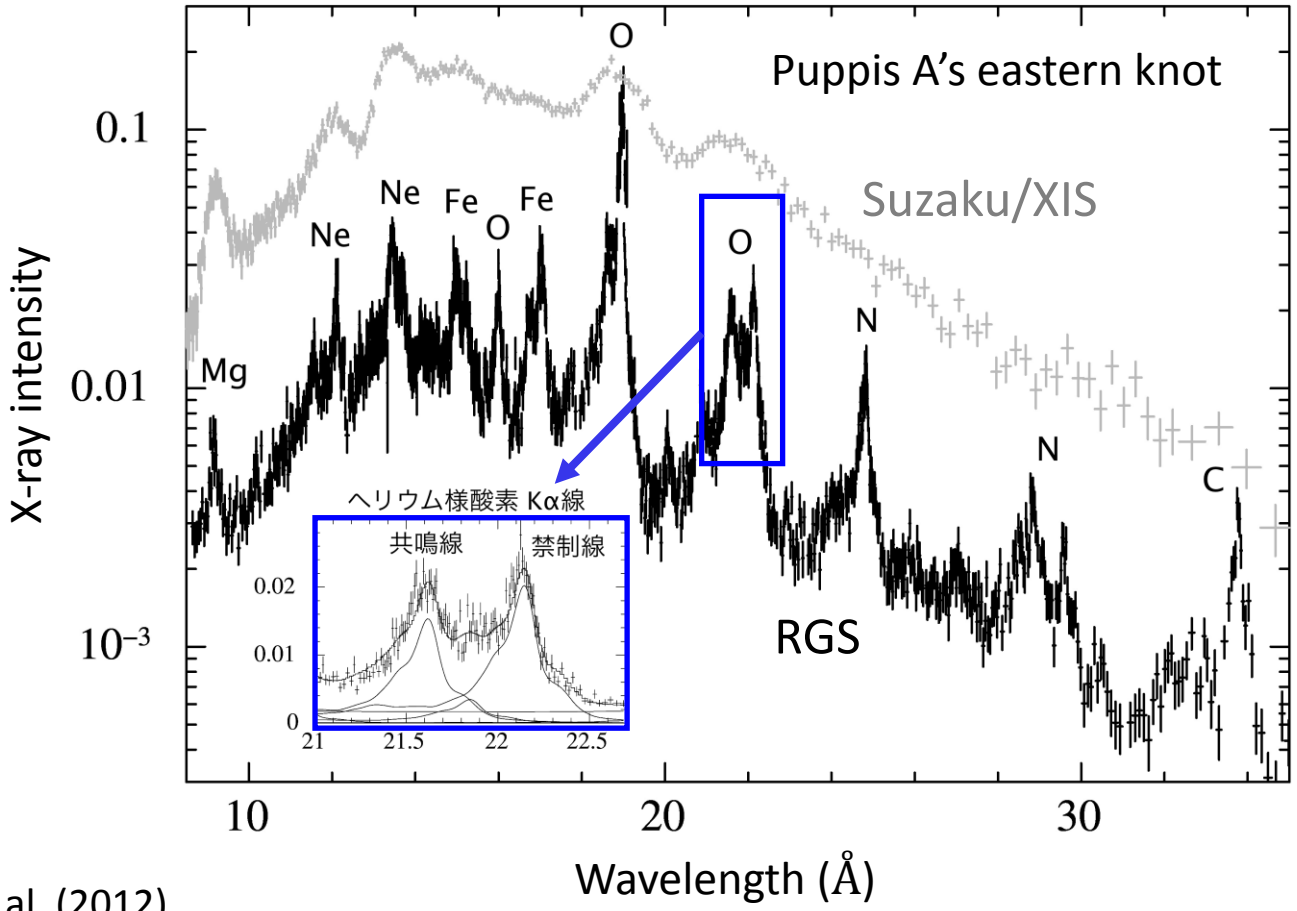
"Forbidden > Resonance"
supports the significant
contribution of CX emission!

(See also Roberts & Wang 2015)

Another f/r Ratio Anomaly in Puppis A



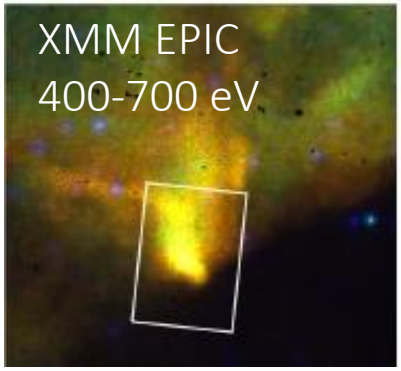
Forbidden > Resonance! → suggests CX contribution

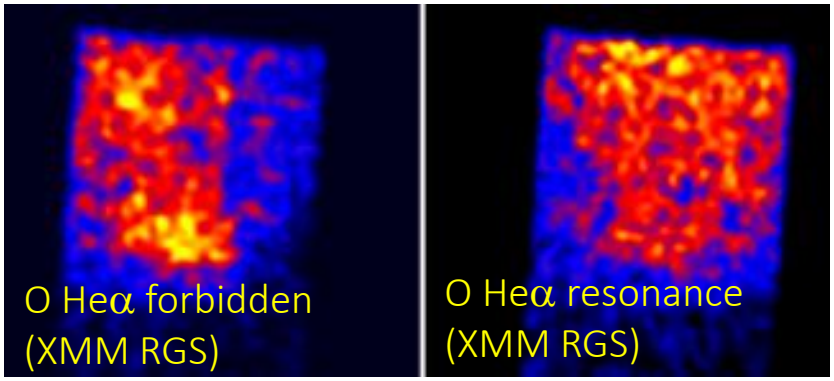


SK, Tsunemi, Mori, et al. (2012)

Individual Line Images with XMM's RGS

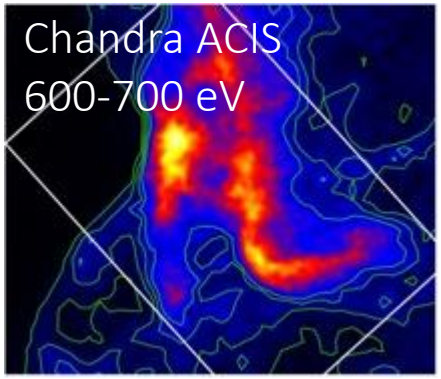
Cygnus Loop's Southwestern Knot

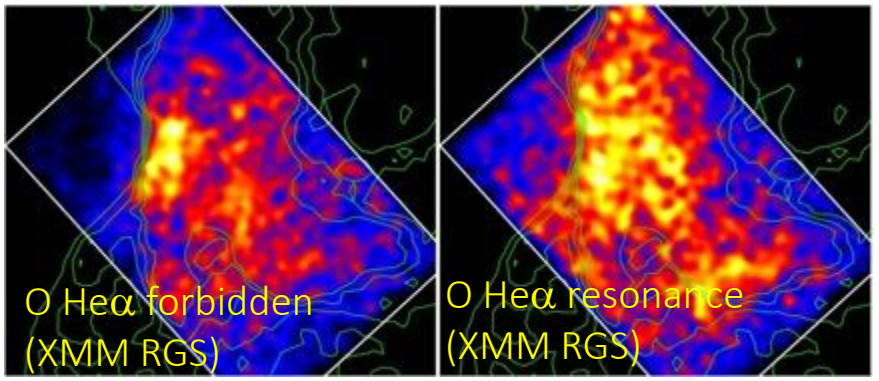




Uchida, SK, Tsunemi, et al. (2018)

Puppis A's Eastern Knot





Cf., SK, Tsunemi, Mori, et al. (2012)

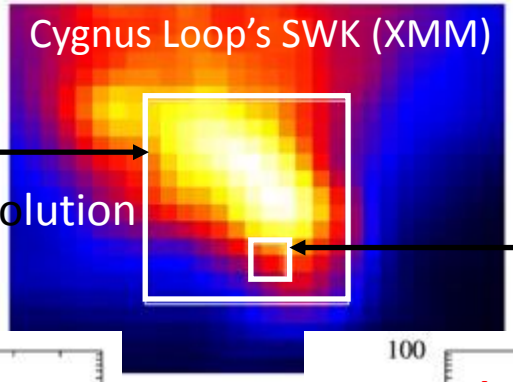
Forbidden lines seem to arise from a more compact region than resonance lines.
But, the resonance maps are contaminated by intercombination lines to some extent.
→ Need for clean line images with calorimeters!

The Power of Athena's X-IFU

- High spectral resolution
  → Resolve individual lines
- High spatial resolution + Large throughput
  → Map individual lines with sufficient resolution and statistics.

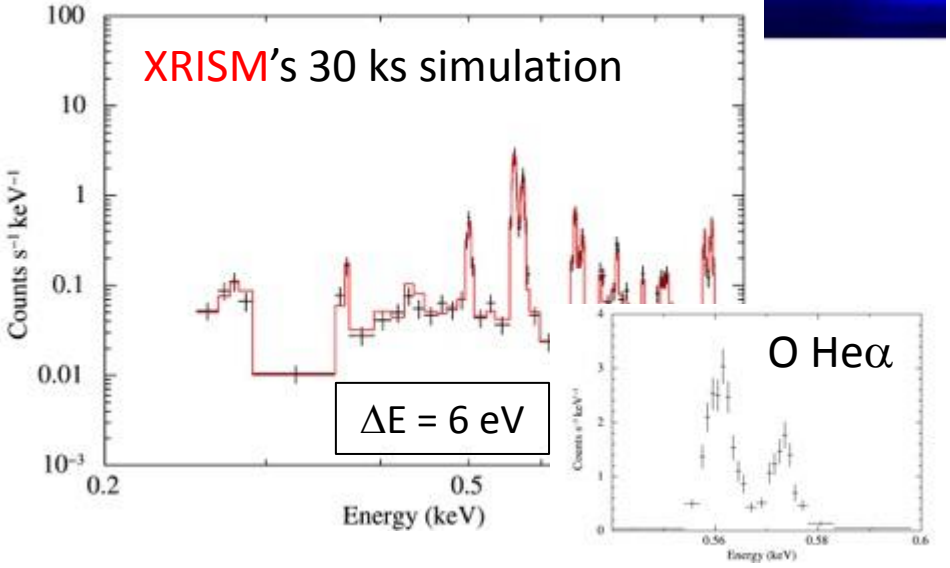
← XRISM can do this, but Athena can do better.

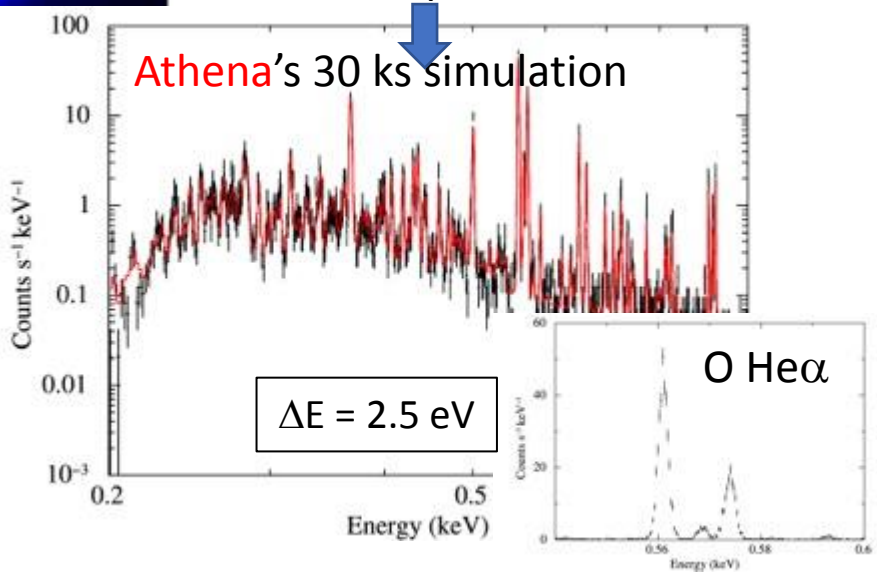
← Only Athena can do this.



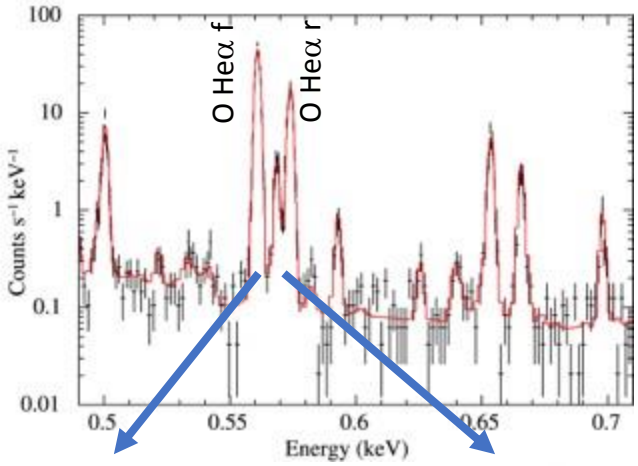
1' x 1' box
~XRISM's spatial resolution

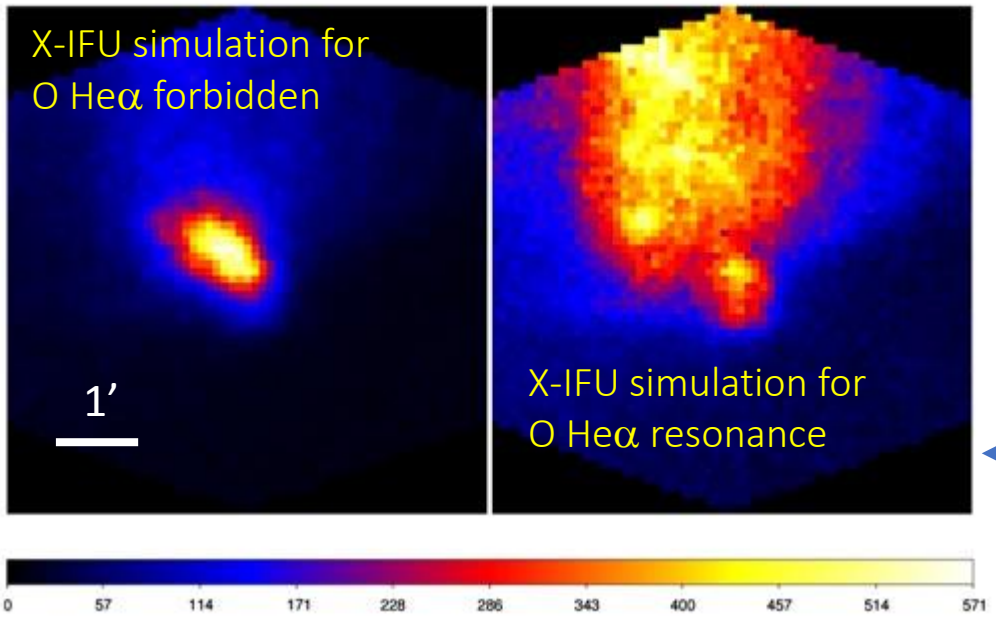
10" x 10" box
~Athena's spatial resolution





Athena X-IFU's Line Images of the Cygnus Loop's Southwestern Knot





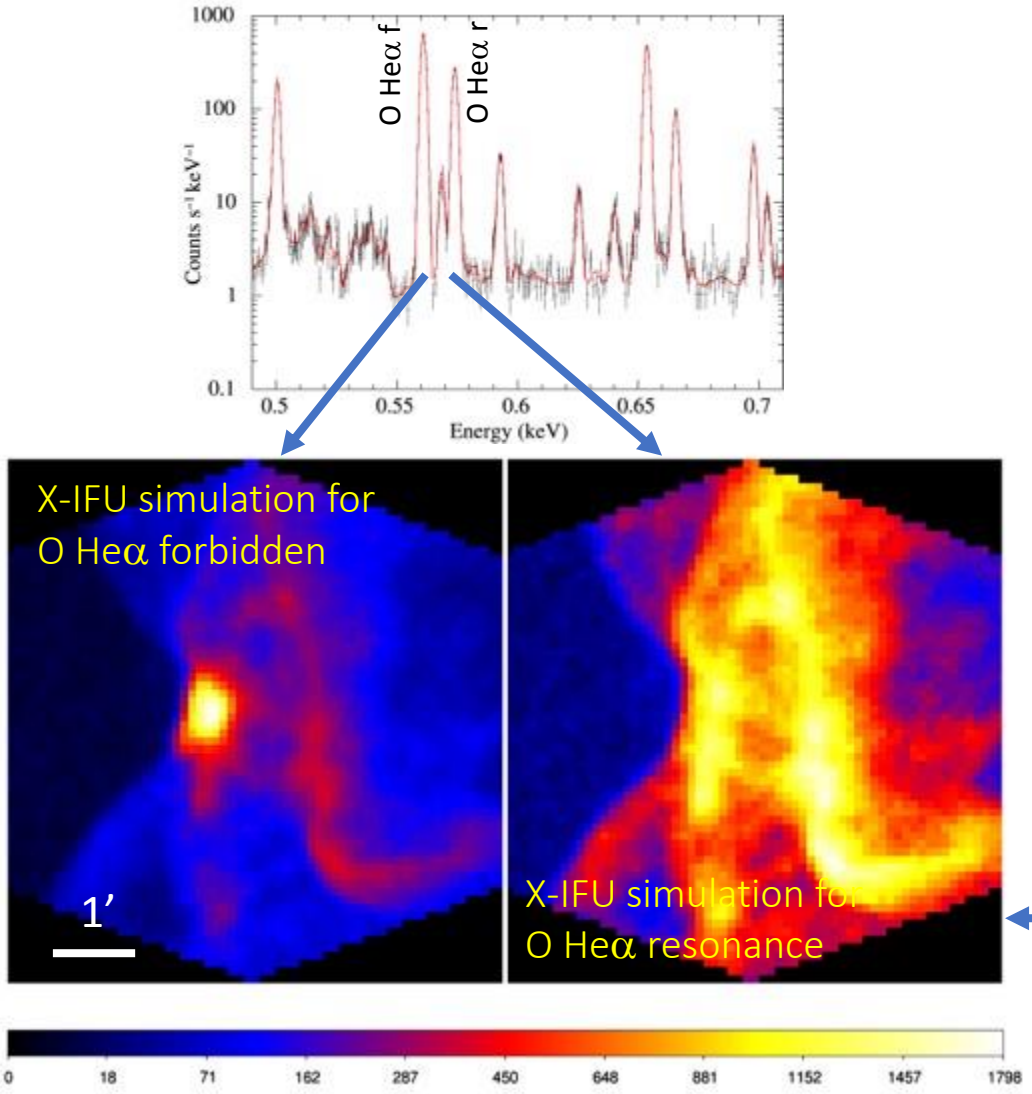
With an exposure time of 30 ks, we can obtain detailed images for individual lines.

We will be able to clarify if the forbidden and resonance lines show different distributions.

The detailed spatial distribution, combined with images in different wavelengths, will help support/reject the CX scenario.

At least a few 100 counts per pixel (10"x10")

Athena X-IFU's Line Images of Puppis A



An exposure time of only 10 ks will provide us with good data.

At least a few 100 counts per pixel (10"x10")

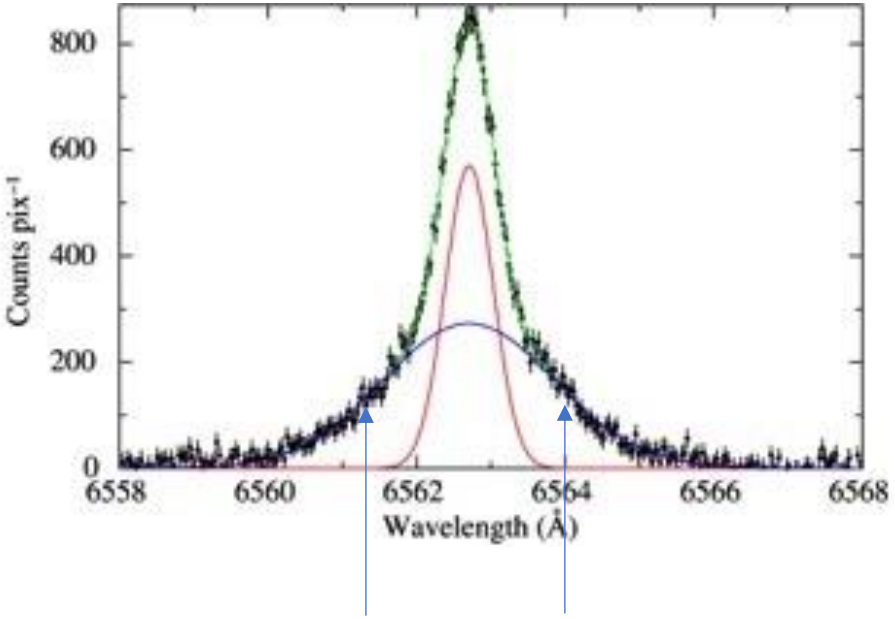
Summary

- There is emerging evidence for charge exchange X-ray emission in various astrophysical sites.
- We have found a few pieces of possible evidence for CX X-rays in two supernova remnants, the Cygnus Loop and Puppis A, based on Suzaku and XMM-Newton observations.
- To establish the presence of the CX X-ray emission, detailed spatial spectral variations will be the key.
- XRISM will provide us with interesting information, but its angular resolution of ~1’ is larger than the size of typical X-ray structures, and hence won’t be sufficient.
- Athena is the most promising satellite that will establish (or reject) the CX hypothesis.

CX Hα Emission in Supernova Remnants

Balmer-dominated filaments

Hα line profile: narrow + broad

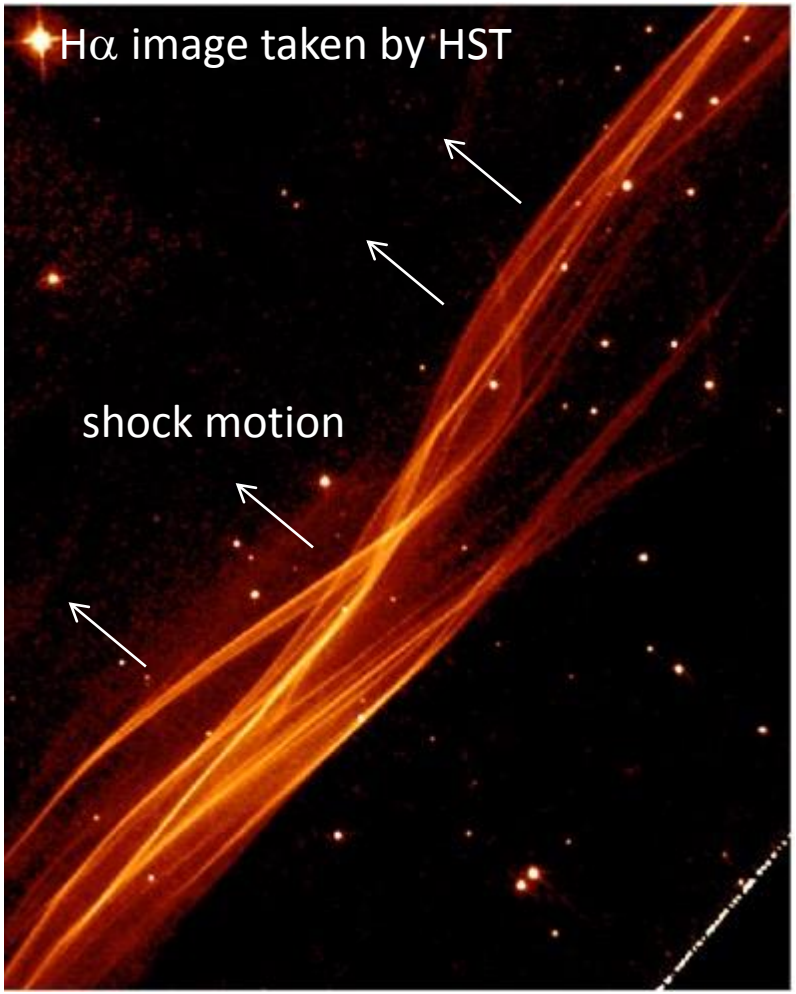


The broad component originates from CX:

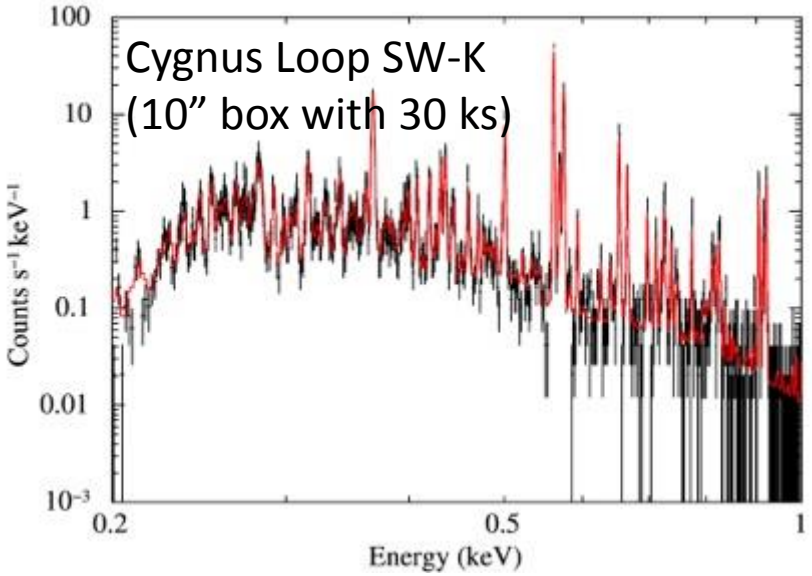
$H + p \rightarrow p + H^* \rightarrow p + H + h\nu$

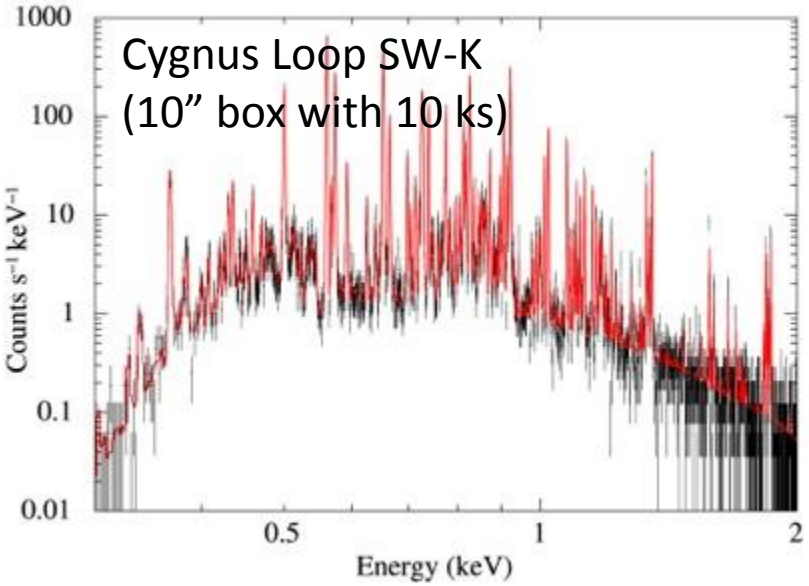
(e.g., Chevalier, Kirshner, & Raymond 1980)

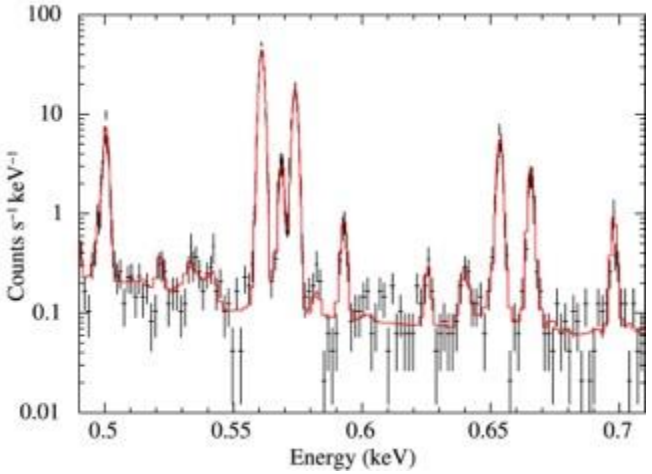
The Cygnus Loop's NE limb

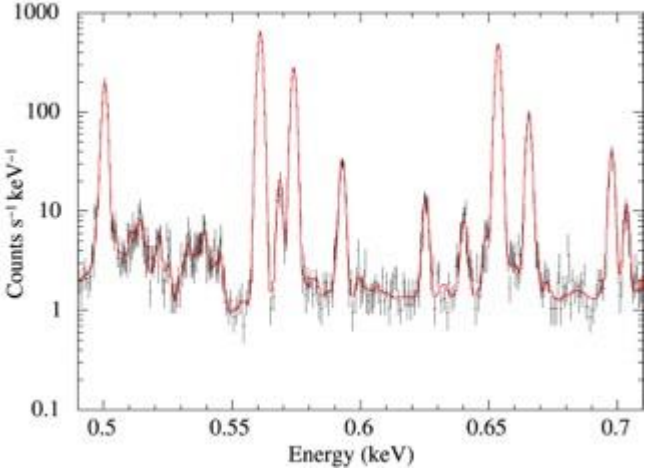


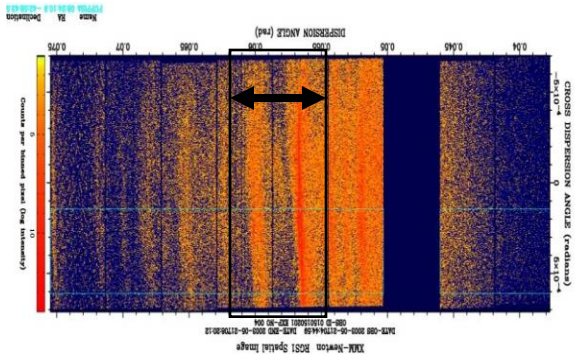
X-IFU Spectra Simulated for the Cygnus Loop and Puppis A



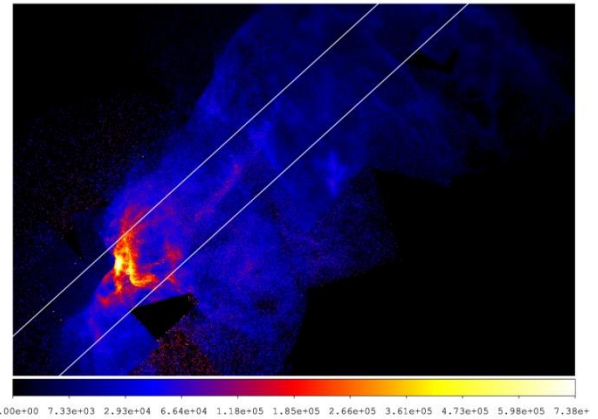


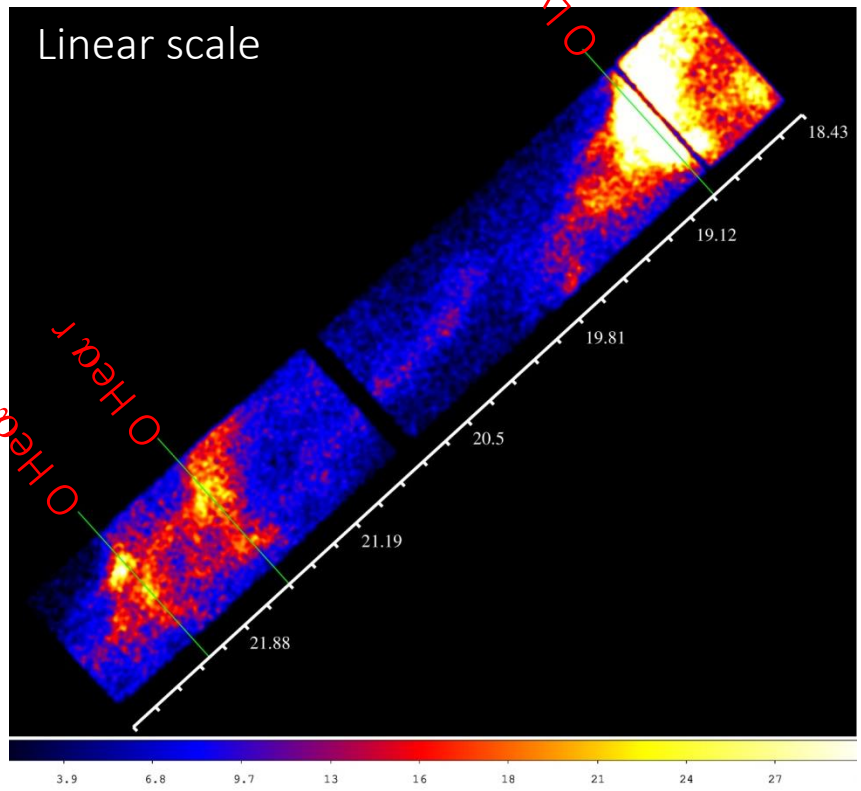


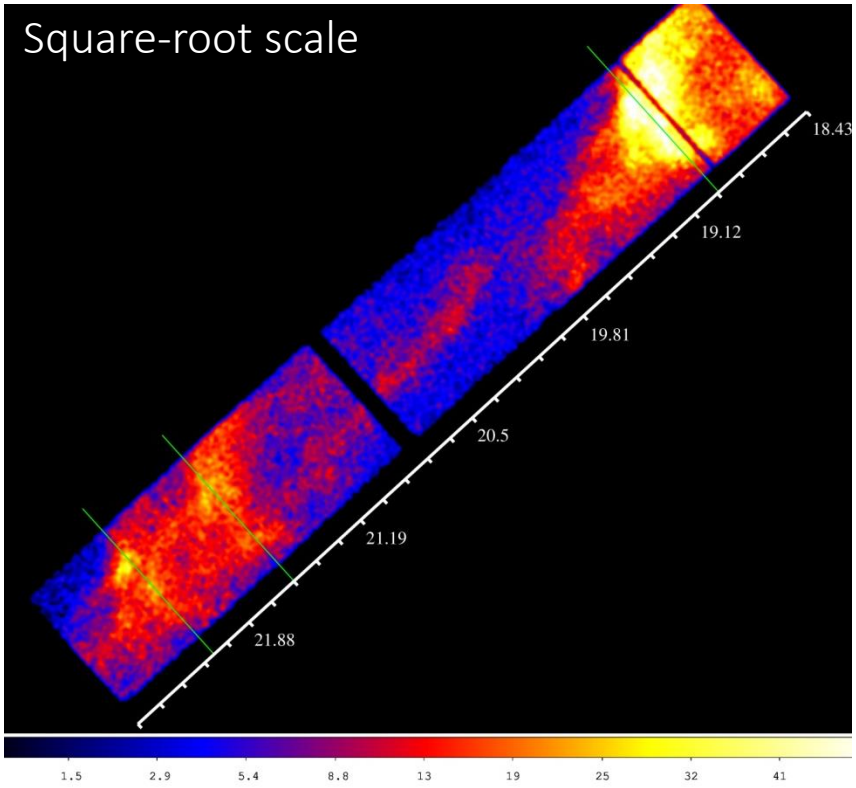




RGS Image


.00e+00 7.33e+03 2.93e+04 6.64e+04 1.18e+05 1.85e+05 2.66e+05 3.61e+05 4.73e+05 5.98e+05 7.38e+


Linear scale
O Lyα
O Heα r
O Heα f
18.43
19.12
19.81
20.5
21.19
21.88
3.9
6.8
9.7
13
16
18
21
24
27


Square-root scale
18.43
19.12
19.81
20.5
21.19
21.88
1.5
2.9
5.4
8.8
13
19
25
32
41