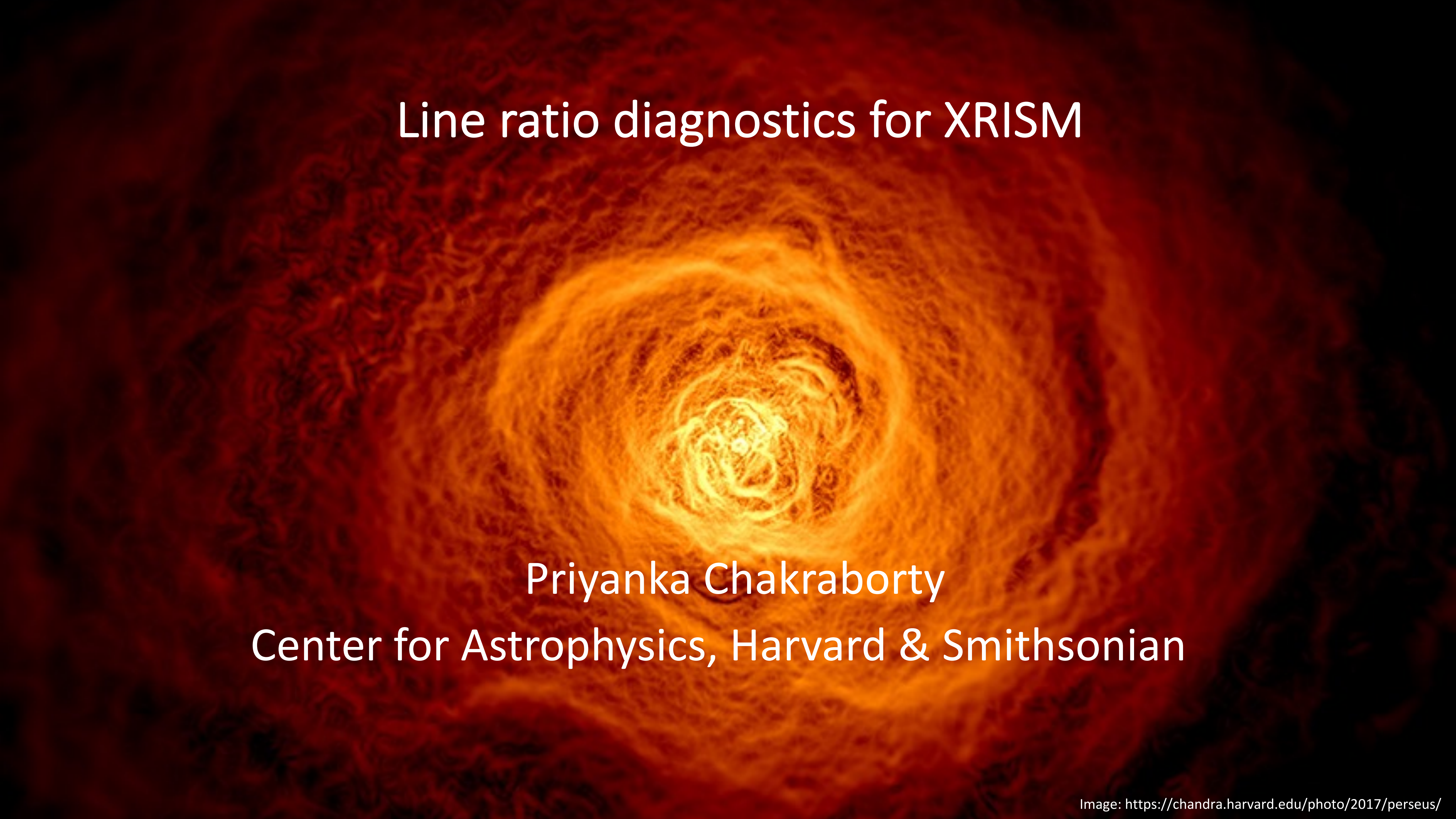

Line ratio diagnostics for XRISM

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Center for Astrophysics, Harvard & Smithsonian

Image: https://chandra.harvard.edu/photo/2017/perseus/

THE ASTROPHYSICAL JOURNAL, 901:68 (10pp), 2020 September 20 https://doi.org/10.3847/1538-4357/abaaab

X-Ray Spectroscopy in the Microcalorimeter Era. I. Effects of Fe XXIV Resonant Auger Destruction on Fe XXV Kα Spectra

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X-Ray Spectroscopy in the Microcalorimeter Era 4: Optical Depth Effects on the Soft X-Rays Studied with CLOUDY

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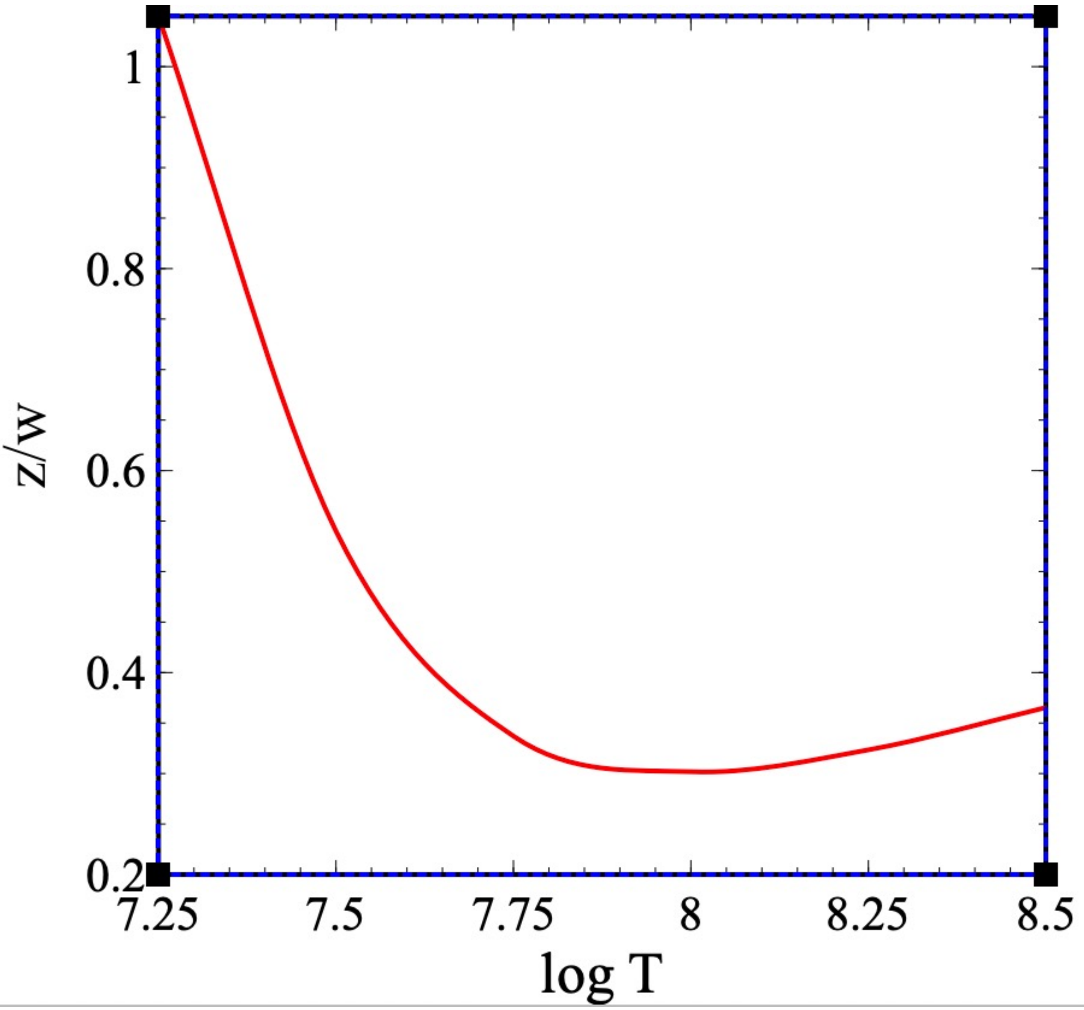
Why line ratio diagnostics

A technique used in astrophysics and spectroscopy to infer the physical conditions
(such as temperature, density, and ionization state)
of astronomical objects by analyzing the ratios of emission or absorption lines in their spectra.

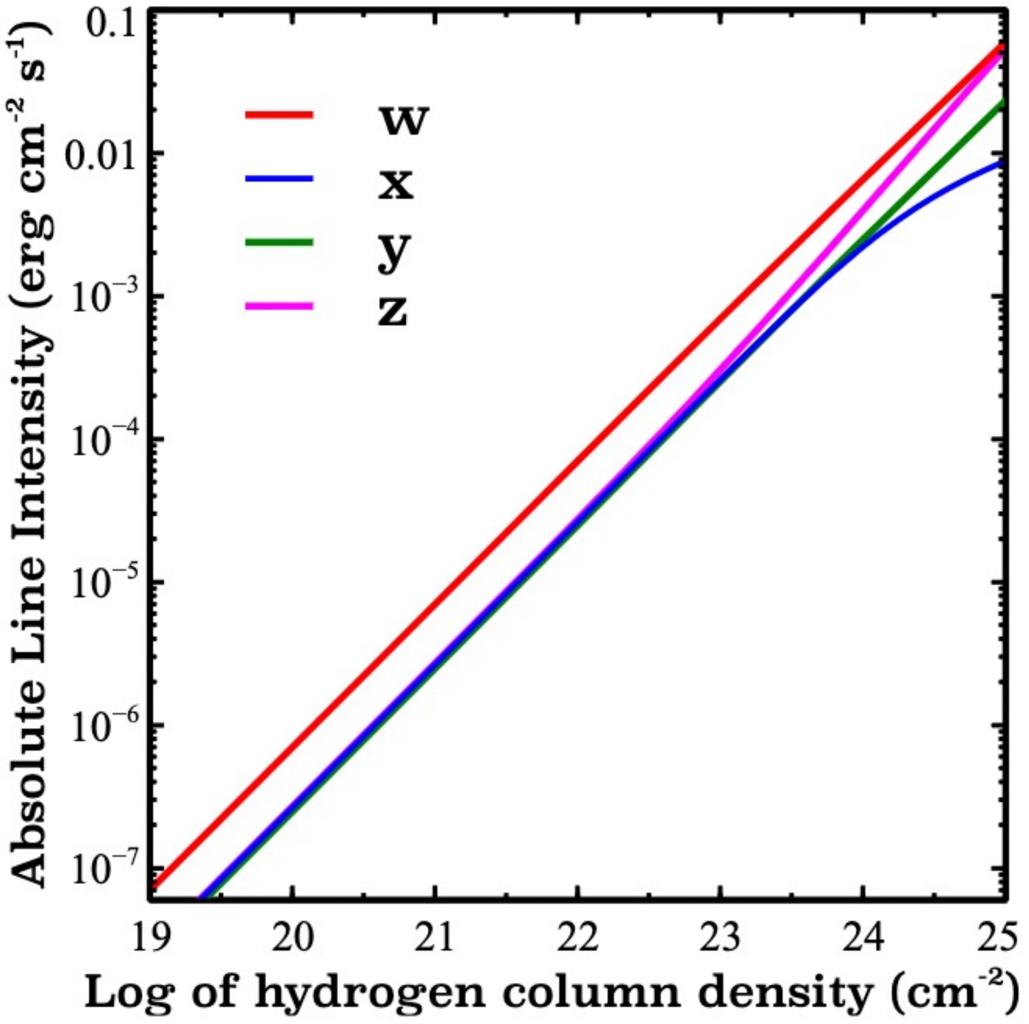


Line ratio diagnostics within Cloudy

```
hden 0
stop column density 21
constant temperature 6 log vary
grid 7.25 8.5 0.25
save linelist  ratio "output.txt" "LineList.dat" no hash
save grid "output.grd"
```

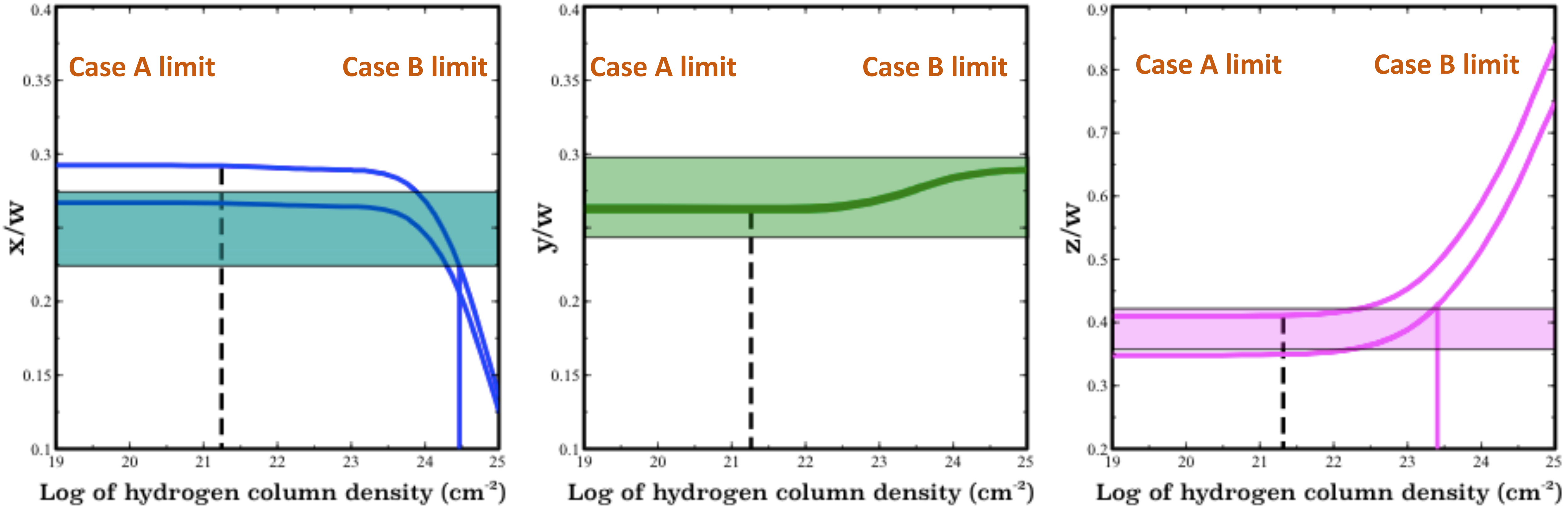
```
Fe25      1.86819A
Fe25      1.85040A
##
Fe25      1.85541A
Fe25      1.85040A
##
```

Why line ratio diagnostic is better than line intensity diagnostic



Collisionally ionized case:

Case A to B transition in Perseus
(novel method of measuring column density)



Chakraborty et al. (2020c)

Various atomic processes contributing to change in line intensity:

1) Case A to B transition → Collisionally ionized/ Photoionized cloud
   or
   Case C to D transition → Photoionized cloud

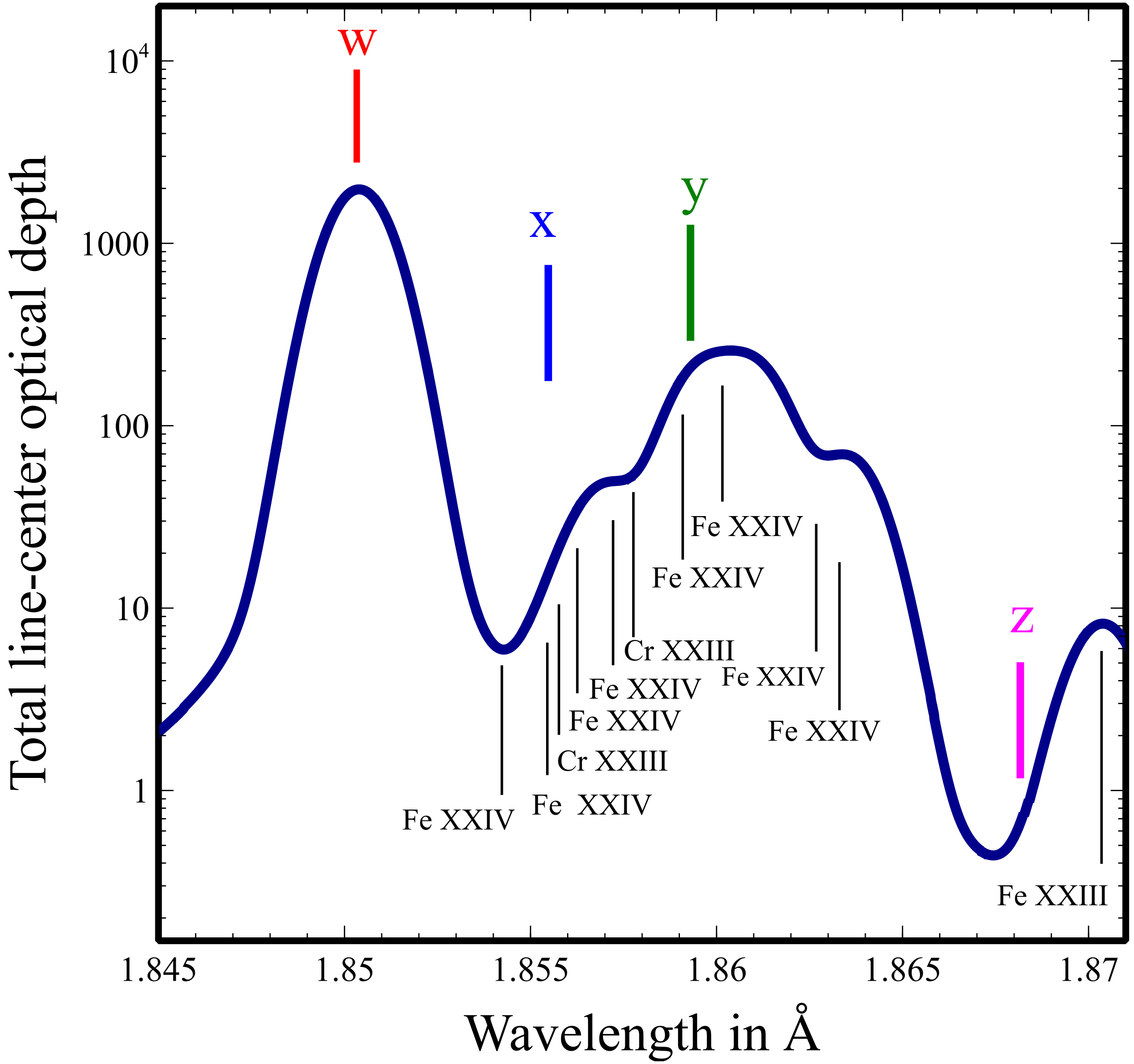
   Case A, Case B, Case C, Case D are different line formation conditions

2) Line interlocking and Resonant Auger Destruction (RAD)

3) Electron scattering escape (ESE)

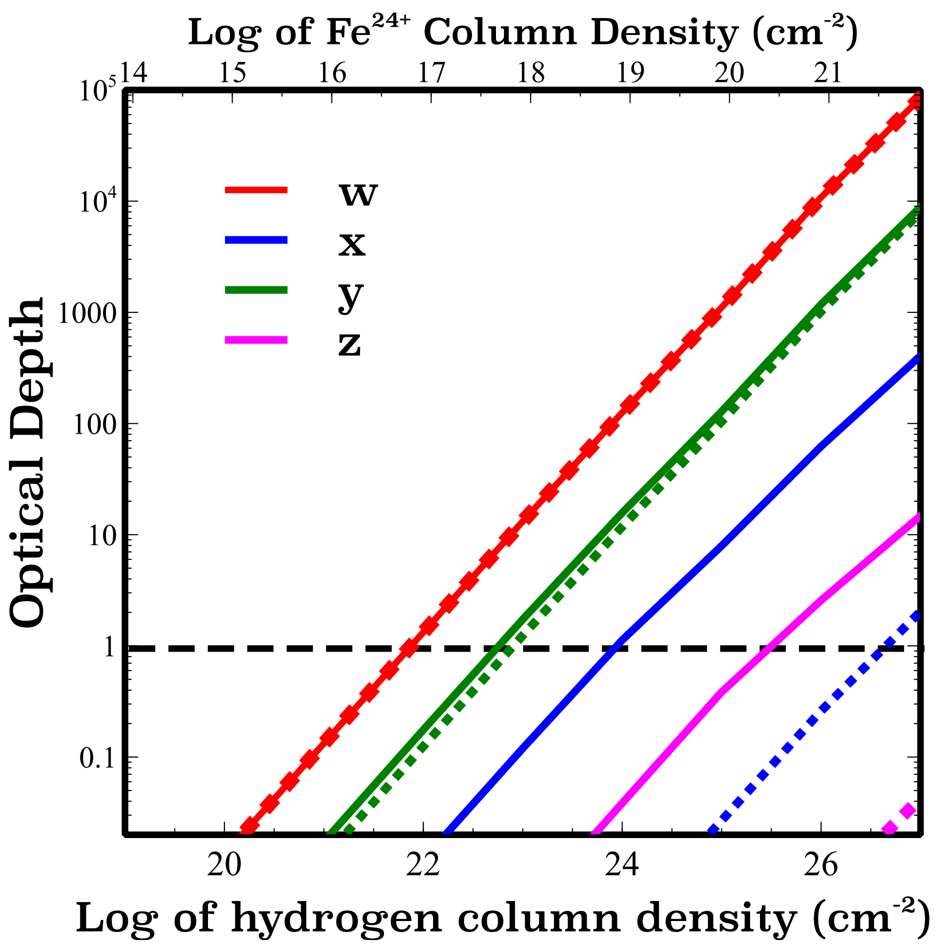
4) Photoelectric absorption

Loss of identity due to line interlocking



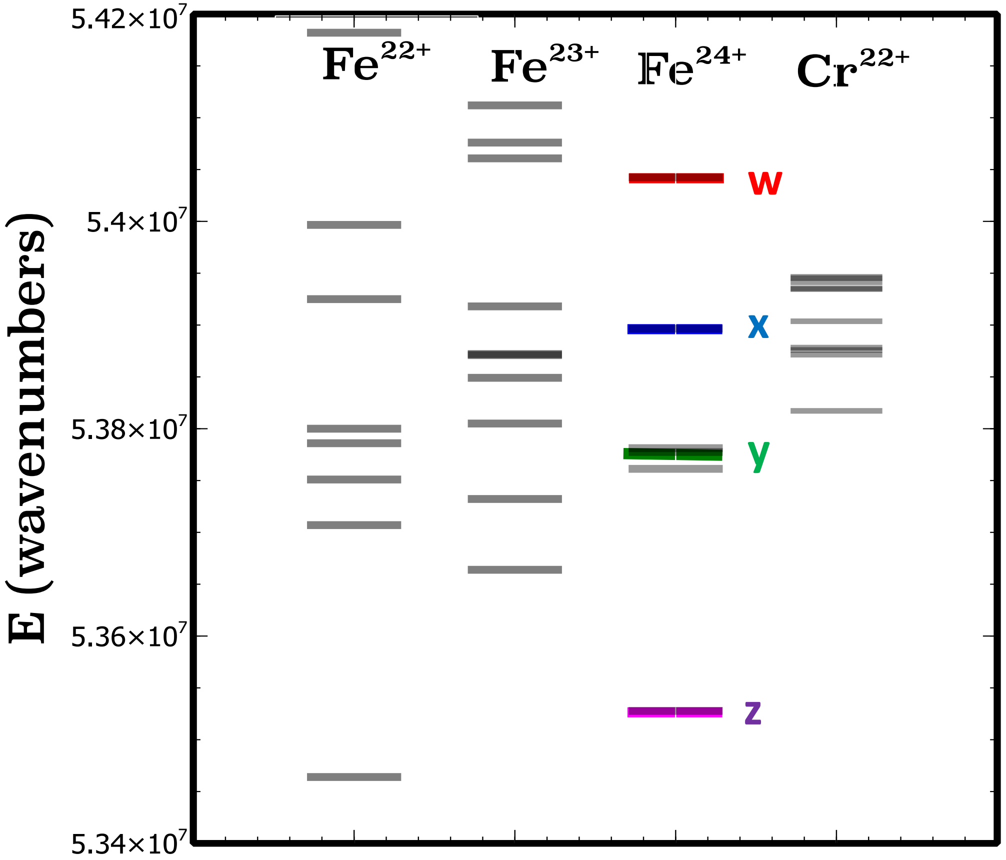
Loss of identity due to line interlocking

The total line optical depth (solid line) is greater than the optical depth of the Fe XXV lines when other lines overlap.



Are the energies similar?

Many satellite lines overlap



Greatly expanded energy level diagram

Chakraborty et al. (2020b)

What is Resonant Auger Destruction (RAD)?

Fe XXV line photons (mainly x) are absorbed by Fe^{23+} and Cr^{22+} due to line interlocking

↓

Absorbing ion autoionizes depending on its autoionizing rate

↓

The absorbed line photon is destroyed

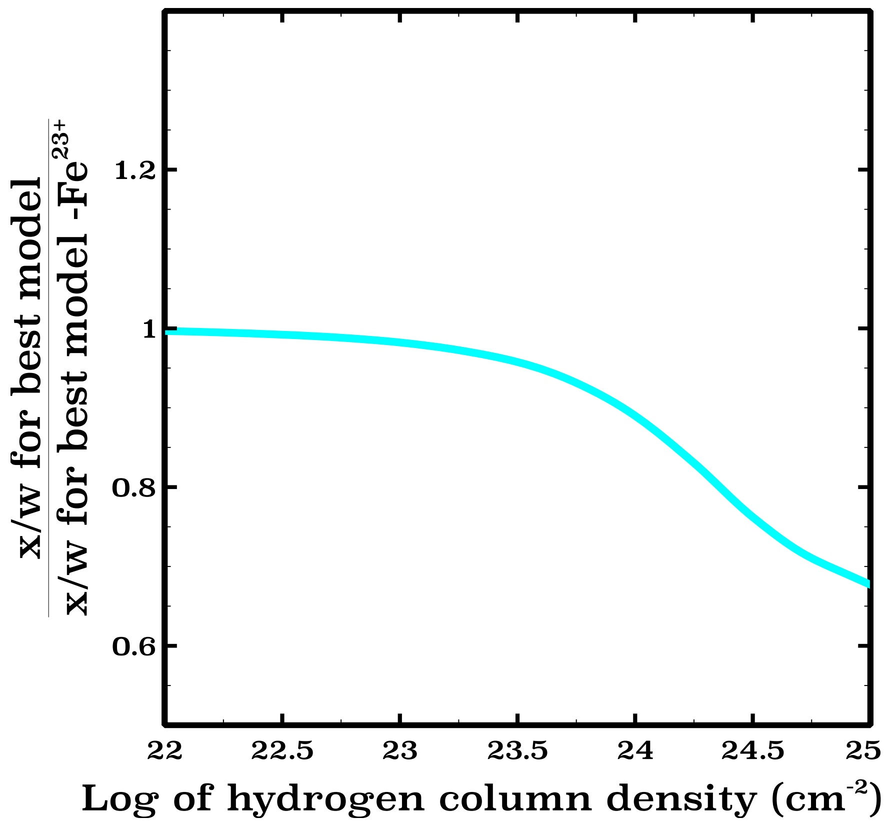
↓

Deficit in the absorbed line photon intensity

RAD: Ross et al. 1978; Band et al. 1990; Liedahl 2005

What role does the Fe XXIV satellite play?

Which Fe XXV Kα line is affected the most by RAD?



- RAD of x photons important for $N_H \geqslant 10^{23}$ cm^{-2}
- At $N_H=10^{25}$ cm^{-2}
  - ~32% of x photons are destroyed from our calculations with **CLOUDY**.
  - ~29% of x photons are destroyed according to analytical theory.

Chakraborty et al. (2020b)

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Electron Scattering Escape(ESE)

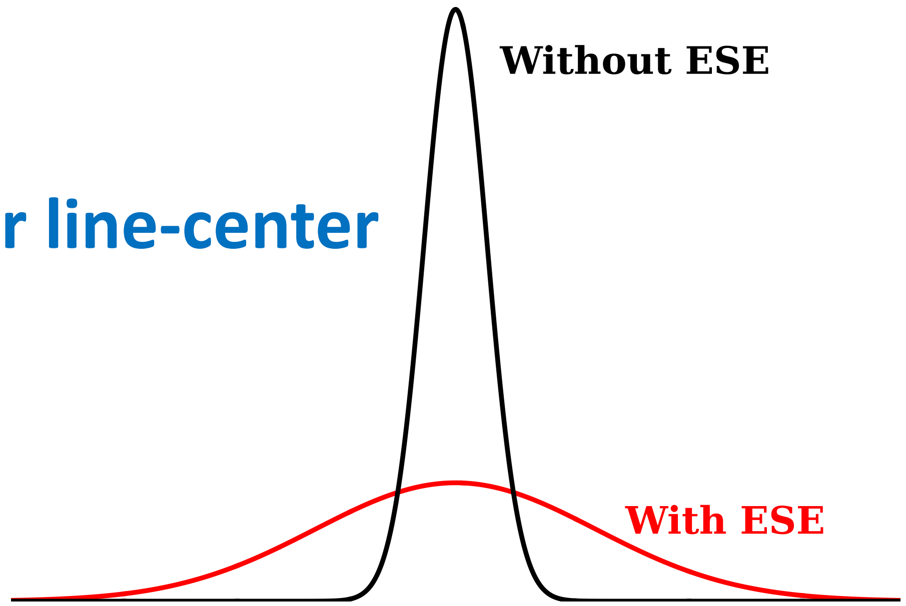
The presence of fast thermal electrons in the cloud may lead to one-scattering-escape in some fraction of the line photons.

↓

Line photons receive large Doppler shift from their line-center upon scattering off high-speed electrons.

↓

Line profiles are broadened.



High-resolution telescopes will ONLY detect the narrow line component

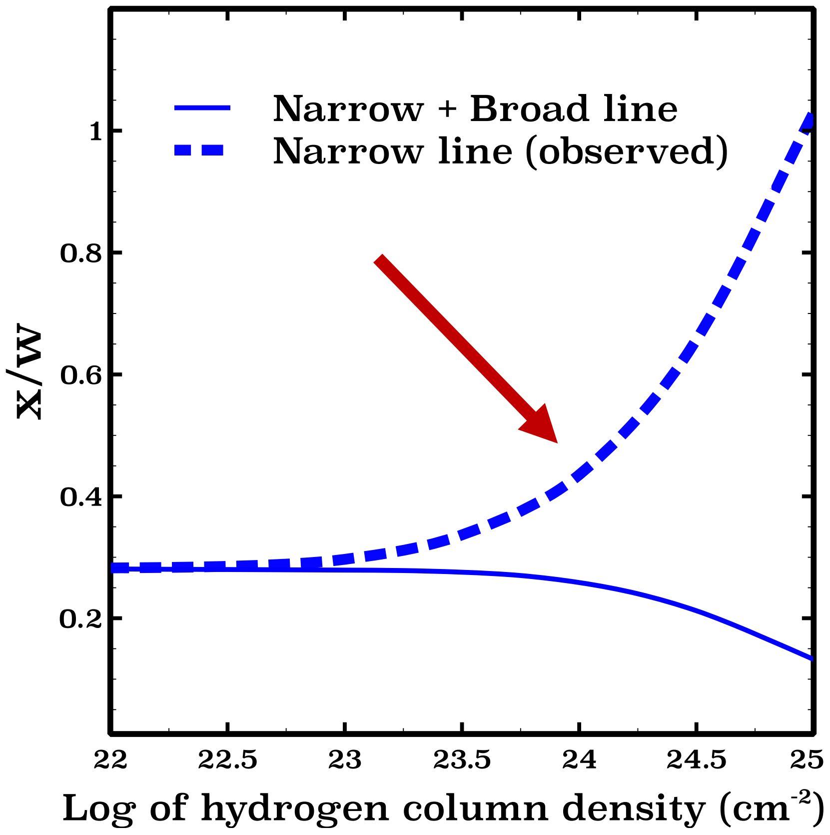
$$\frac{\Delta\ E^{\rm broad}_{\rm FWHM}}{\Delta\ E^{\rm sharp}_{\rm FWHM}} = \sqrt{m_{\rm Fe}/m_{\rm e}} \sim 300$$

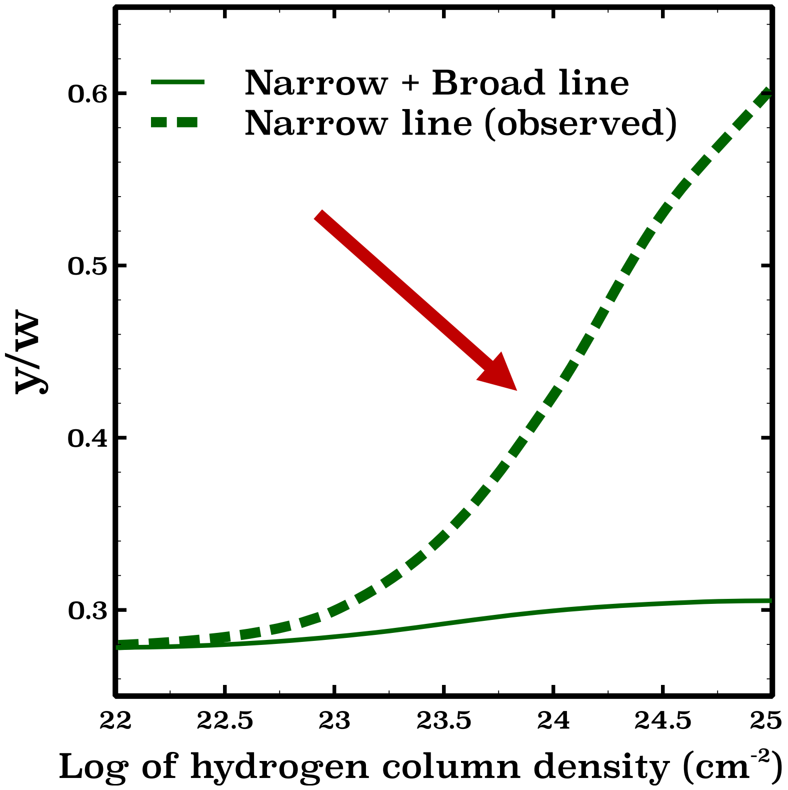
$\Delta\ E^{\rm sharp}_{\rm FWHM}$ ~ 0.004 keV

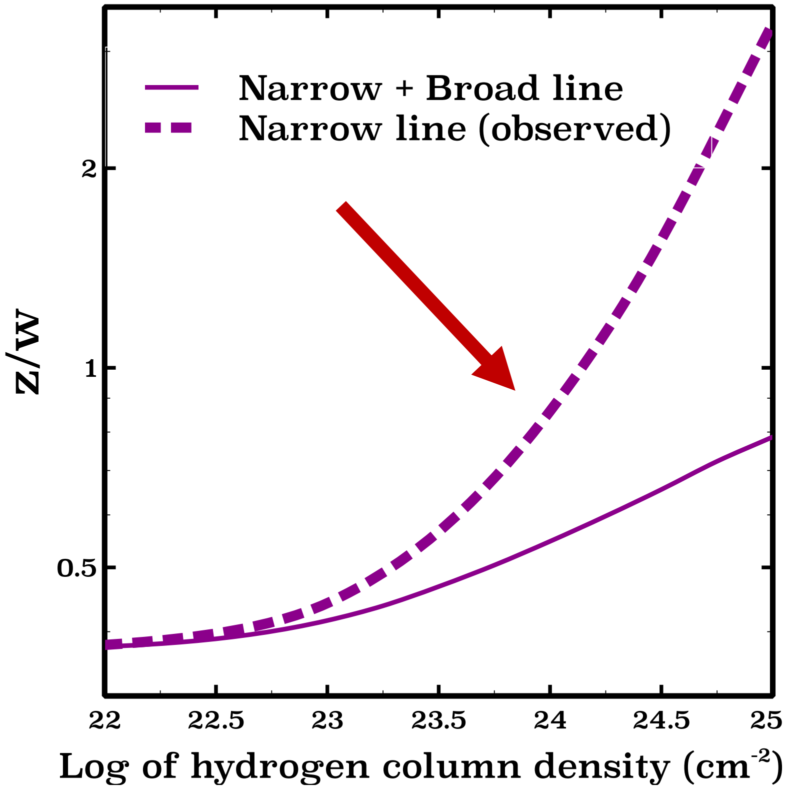
$\Delta\ E^{\rm broad}_{\rm FWHM}$ ~ 1 keV

What will a high-resolution telescope see?

Collisionally ionized cloud



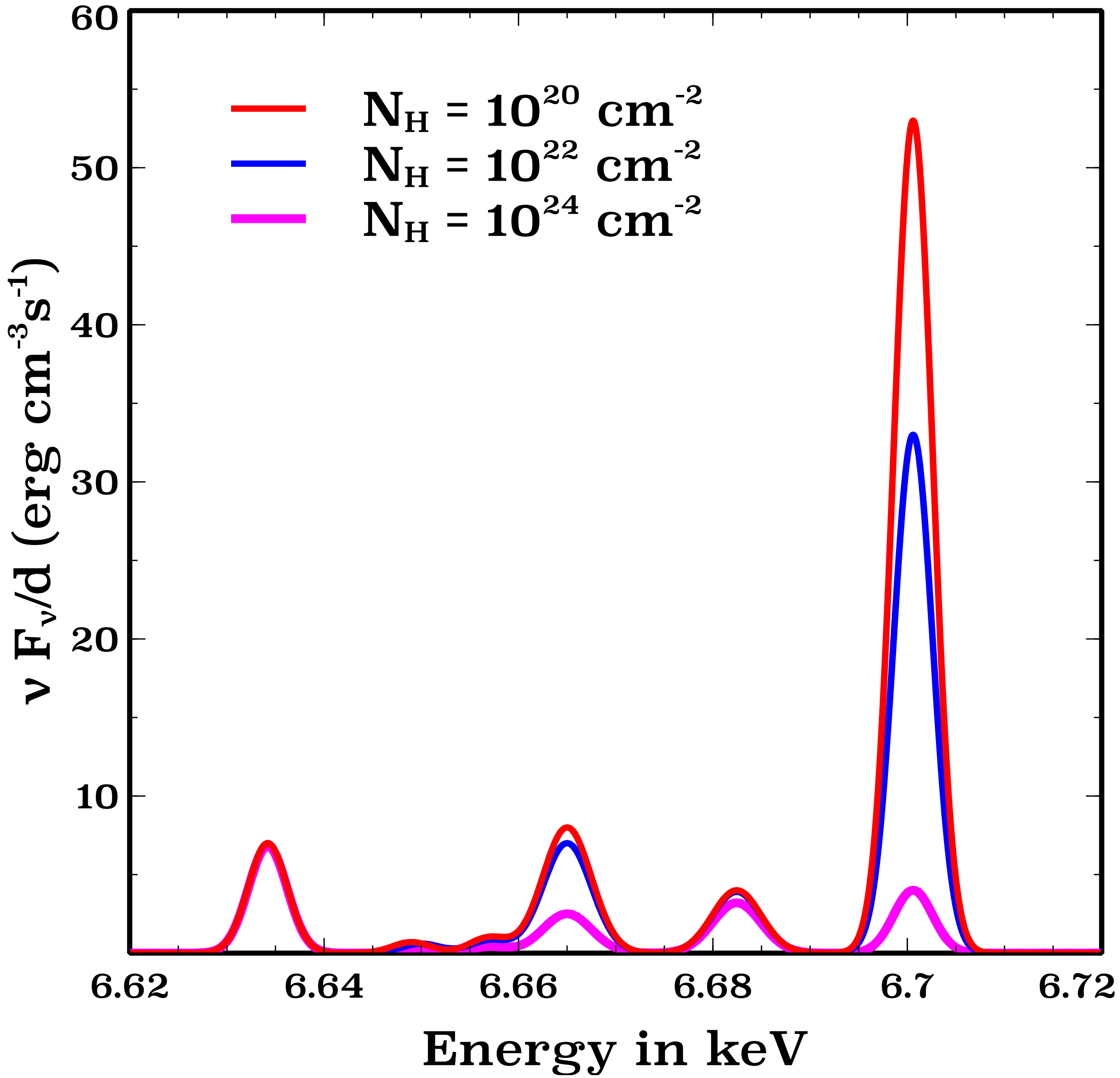




Chakraborty et al. (2020b)

What will a high-resolution telescope see?

Photoionized Cloud



Chakraborty et al. (2021)

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https://doi.org/10.3847/1538-4357/abed4a

X-Ray Spectroscopy in the Microcalorimeter Era. III. Line Formation under Case A, Case B, Case C, and Case D in H- and He-like Iron for a Photoionized Cloud

P Chakraborty[1], G. J. Ferland[1], M. Chatzikos[1], F. Guzmán[2], and Y. Su[1]
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Received 2021 February 5; revised 2021 March 6; accepted 2021 March 8; published 2021 April 30

In Cloudy, these broad Gaussian profiles can be excluded with the following Cloudy command:

no scattering intensity

This will report only the intensities of the sharp line profiles, which you will need for XRISM

Chakraborty et al, 2021

Various atomic processes contributing to change in line intensity:

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   or

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2) Line interlocking and Resonant Auger Destruction (RAD)

3) Electron scattering escape (ESE)

4) Photoelectric absorption

Photoelectric absorption

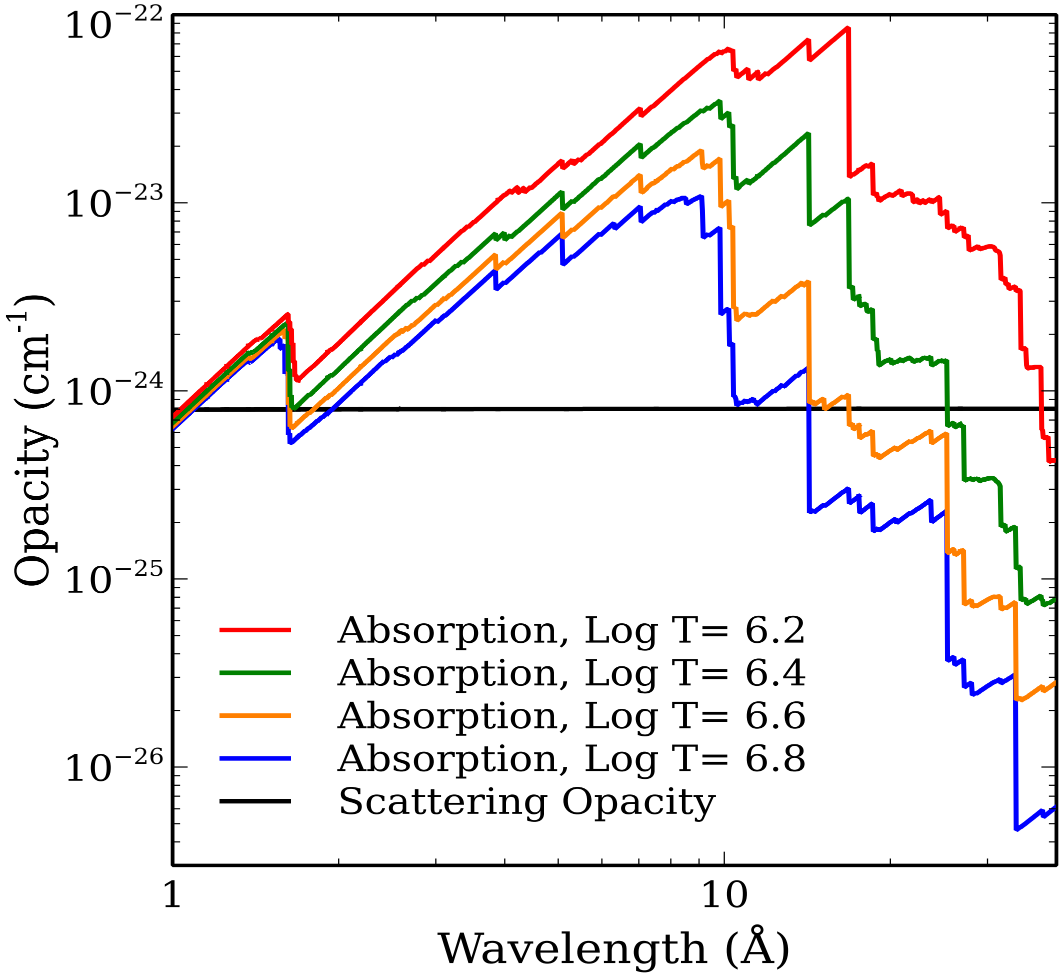
Photoelectric absorption of line photons can significantly decay the line intensities.

Strongly varies with temperature

$$N = \frac{1.11\tau^{1.071}}{1+(\log\tau/5.5)^5} \quad , \text{ if } \tau \geq 1$$

(Ferland & Netzer, 1979)

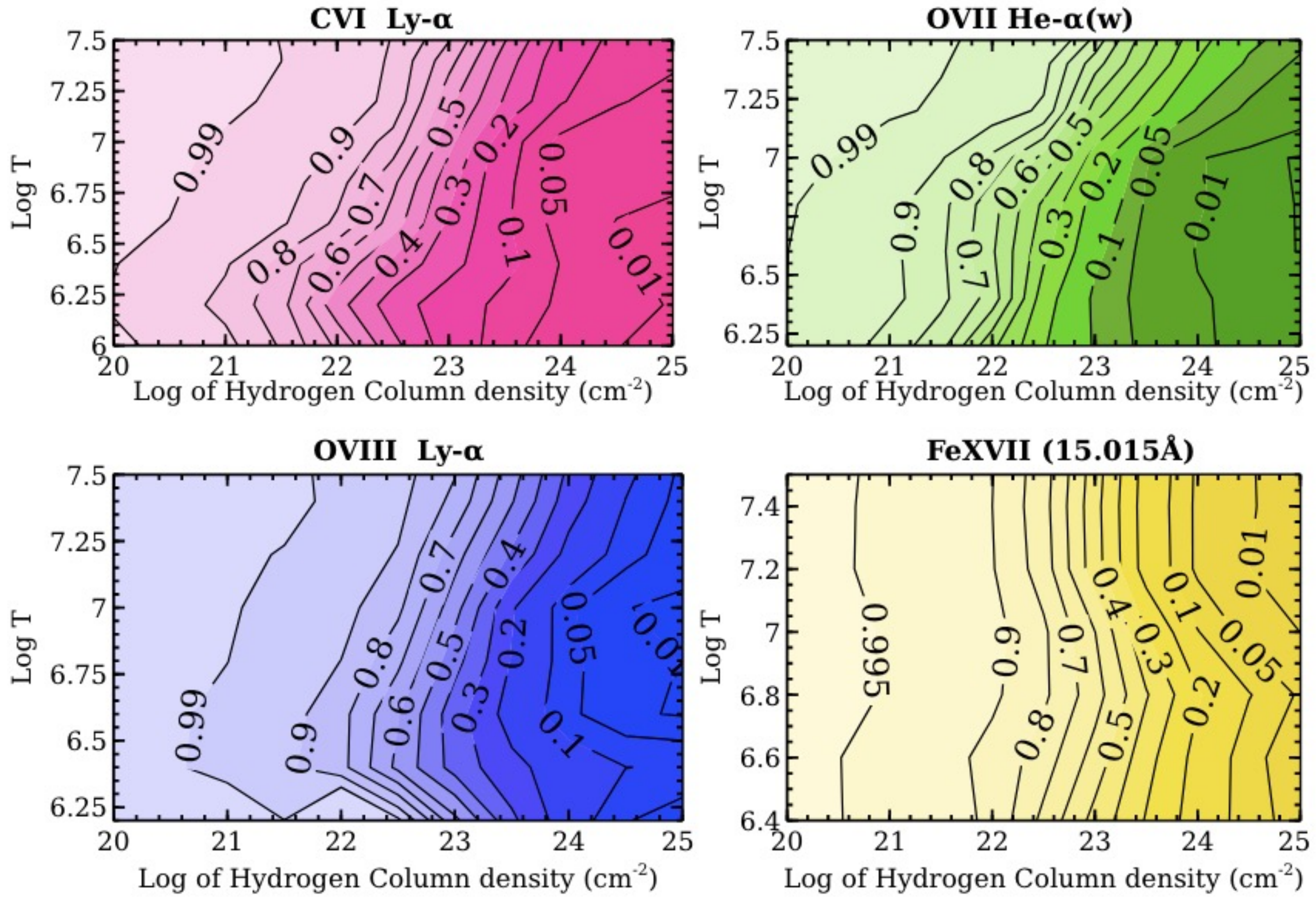
$$P_{\text{photoelectric}} = \frac{\kappa_{\text{photoelectric}}}{\kappa_{\text{total}}} \qquad P_{\text{scattering}} = \frac{\kappa_{\text{scattering}}}{\kappa_{\text{total}}}$$



$$f_{\text{modification}} = (1 - P_{\text{photoelectric}} - P_{\text{scattering}})^N$$

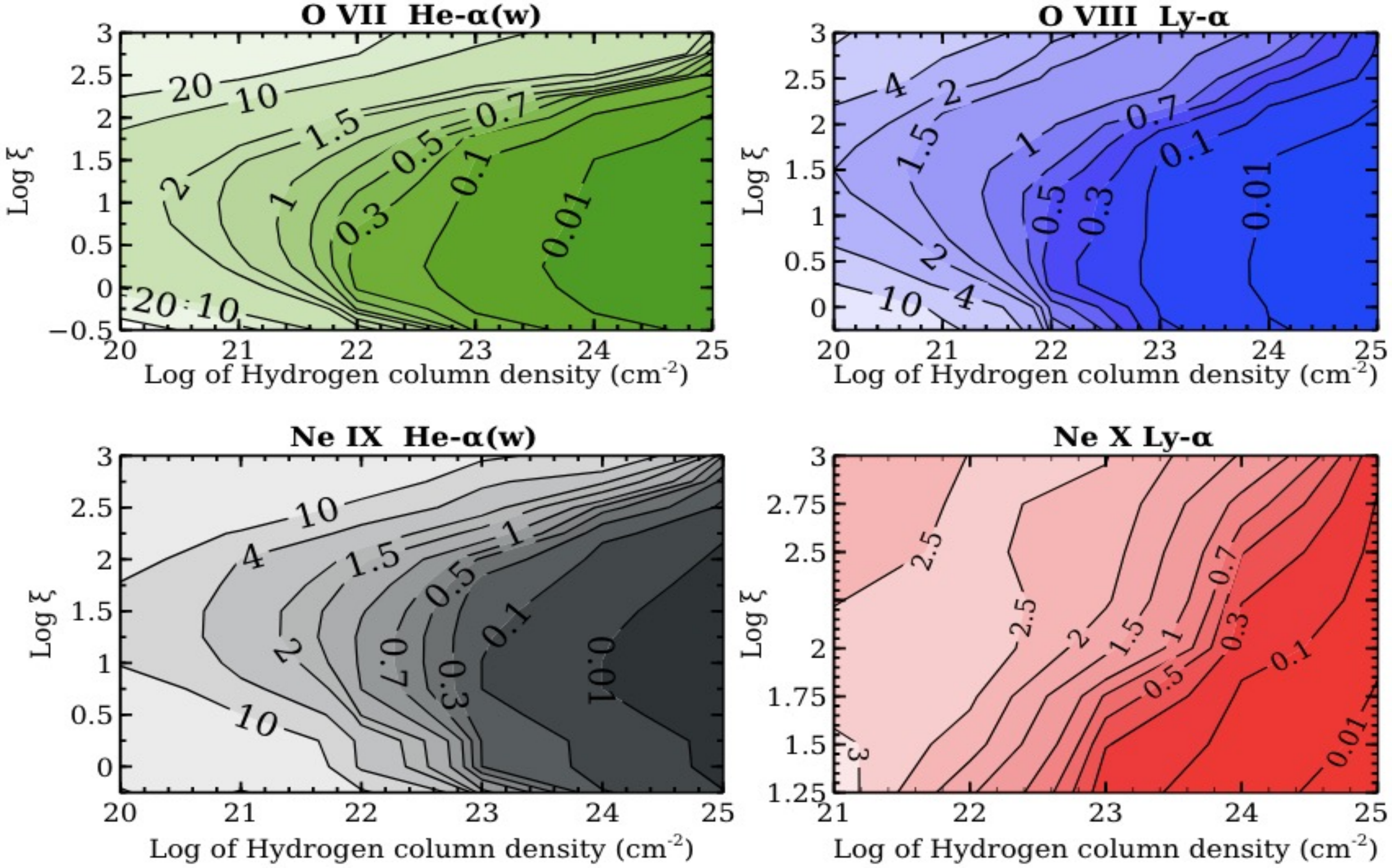
Line modification factor- Collisionally-ionized plasma

$$0 \le f_{\mathrm{modification}} \le 1$$

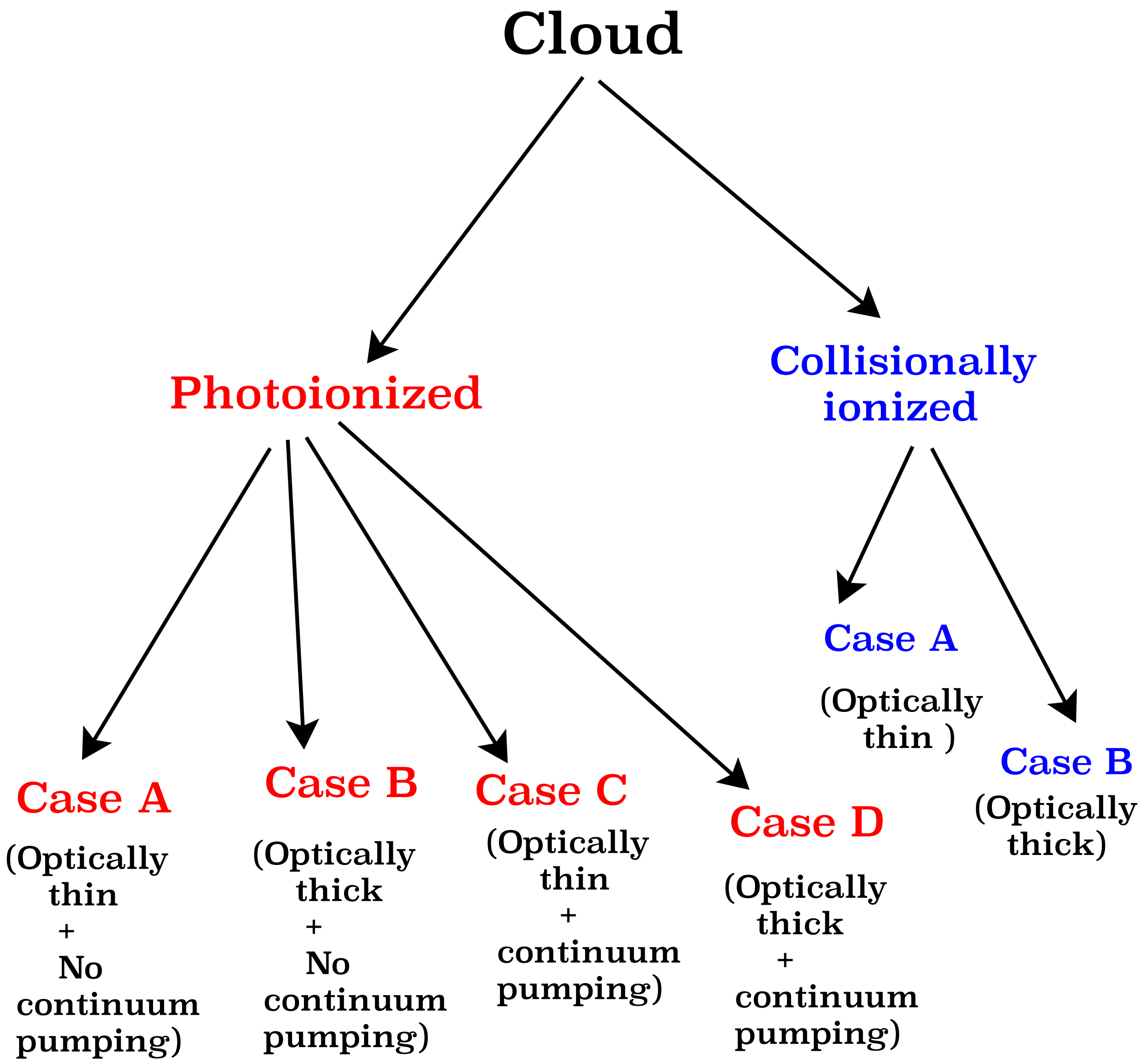


Line modification factor- Photoionized plasma

$0 \leq f_{\mathrm{modification}} \leq 1$ or $f_{\mathrm{modification}} \geq 1$



Various line formation conditions in a cloud



Chakraborty et al. (2021)

Real astronomical systems can be hybrid (collisionally-ionized + photoionized)

Example shown

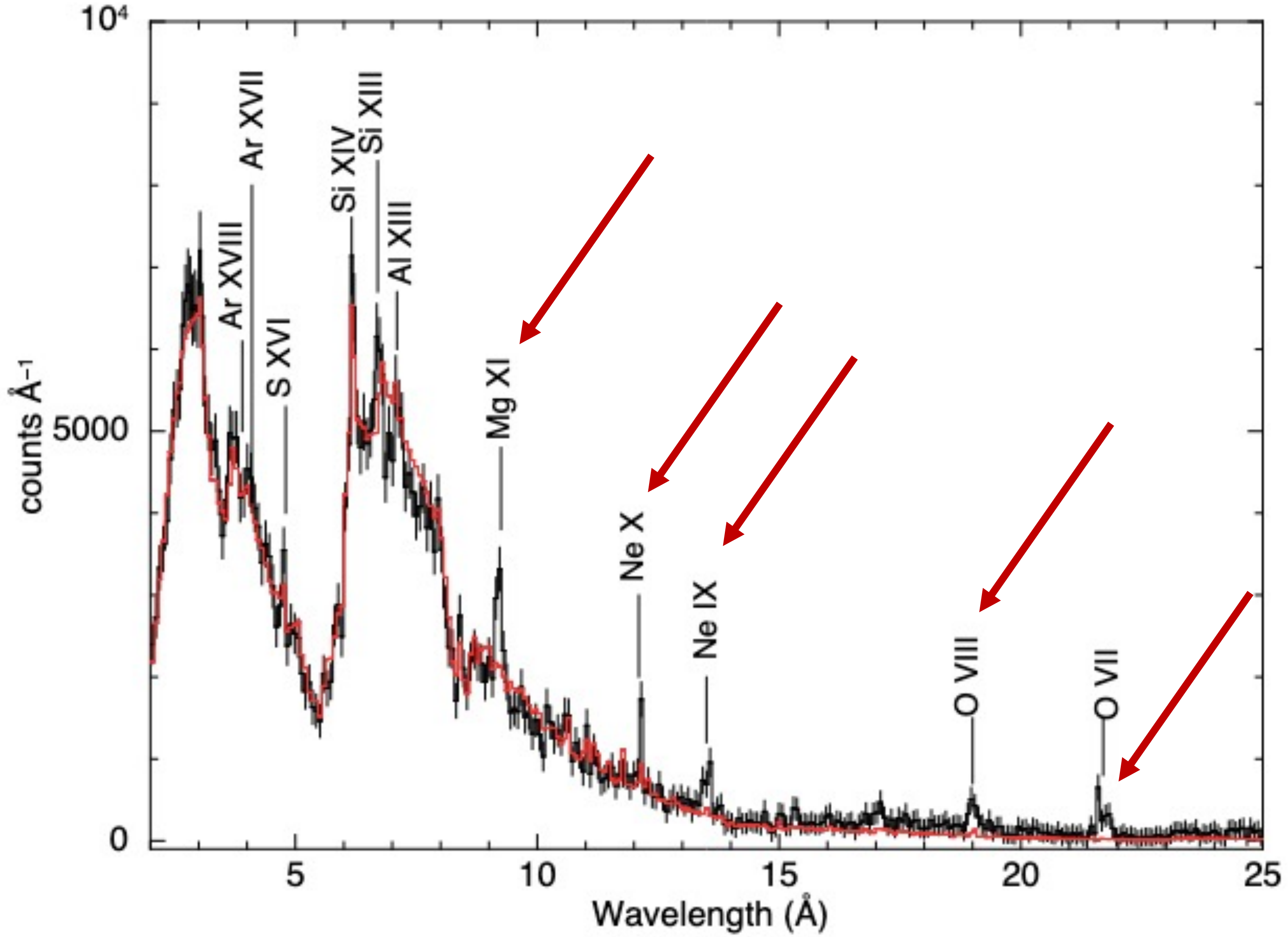
↓

V1223 Sgr, an X-ray emitting binary star system

↓

Chandra HETG spectrum of V1223 Sgr is fitted with Cloudy models

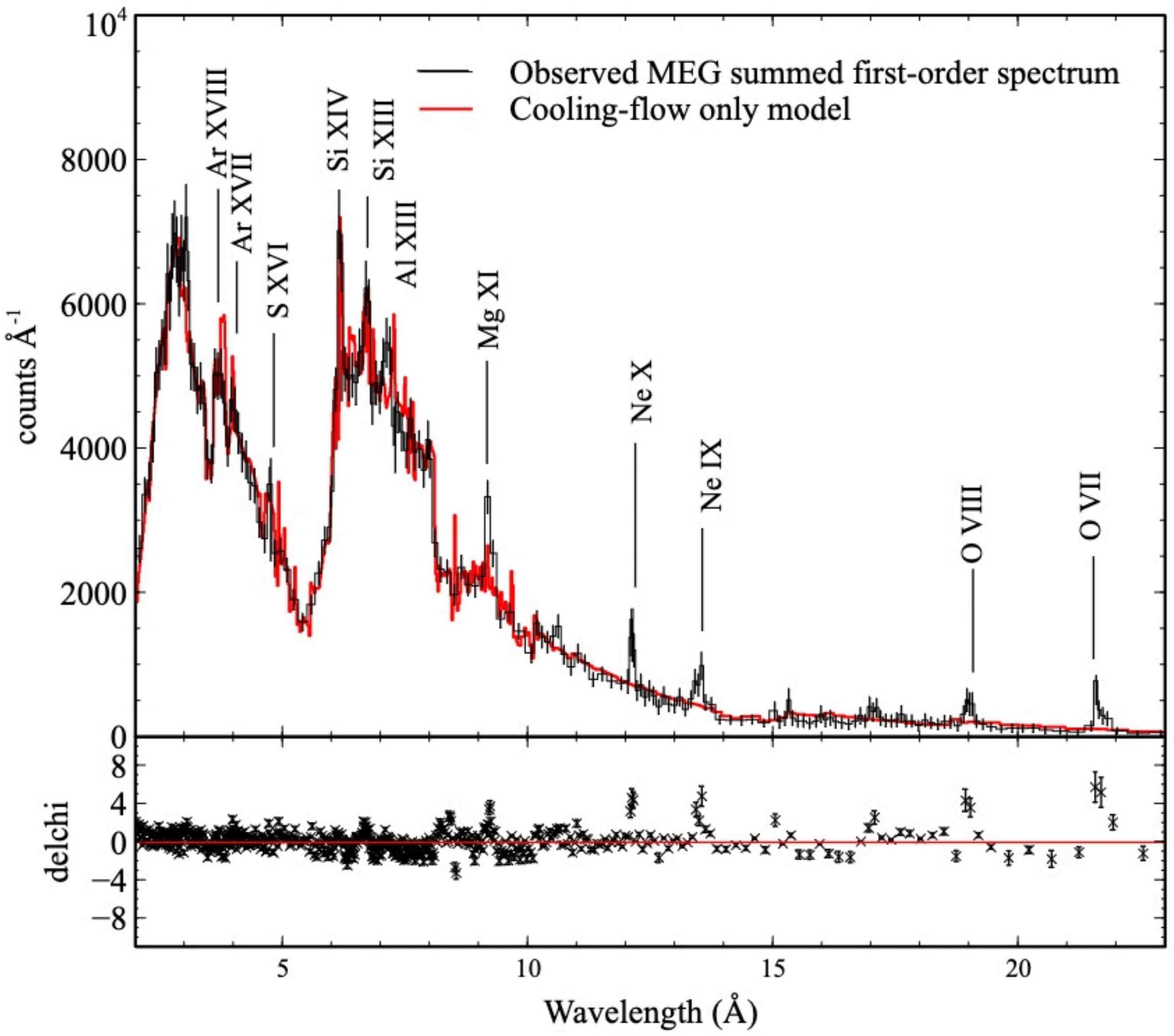
Recent studies did not fit the spectrum of V1223 Sgr well



Chandra HETG spectrum of V1223 Sgr overplotted with an absorbed cooling flow model

Islam & Mukai (2021)

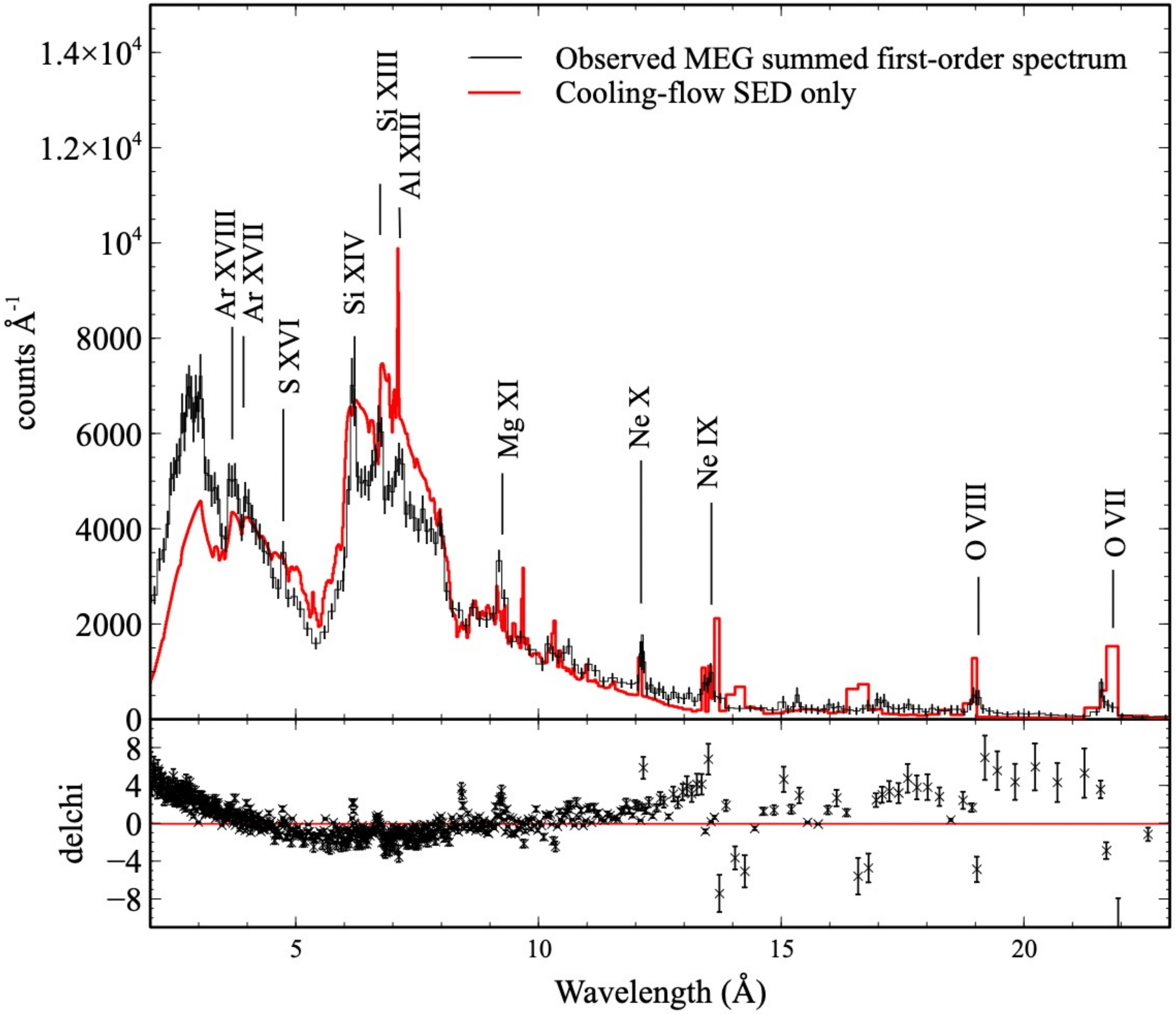
Cooling flow model with Cloudy - poor fit to the lines



Chakraborty et al. 2022

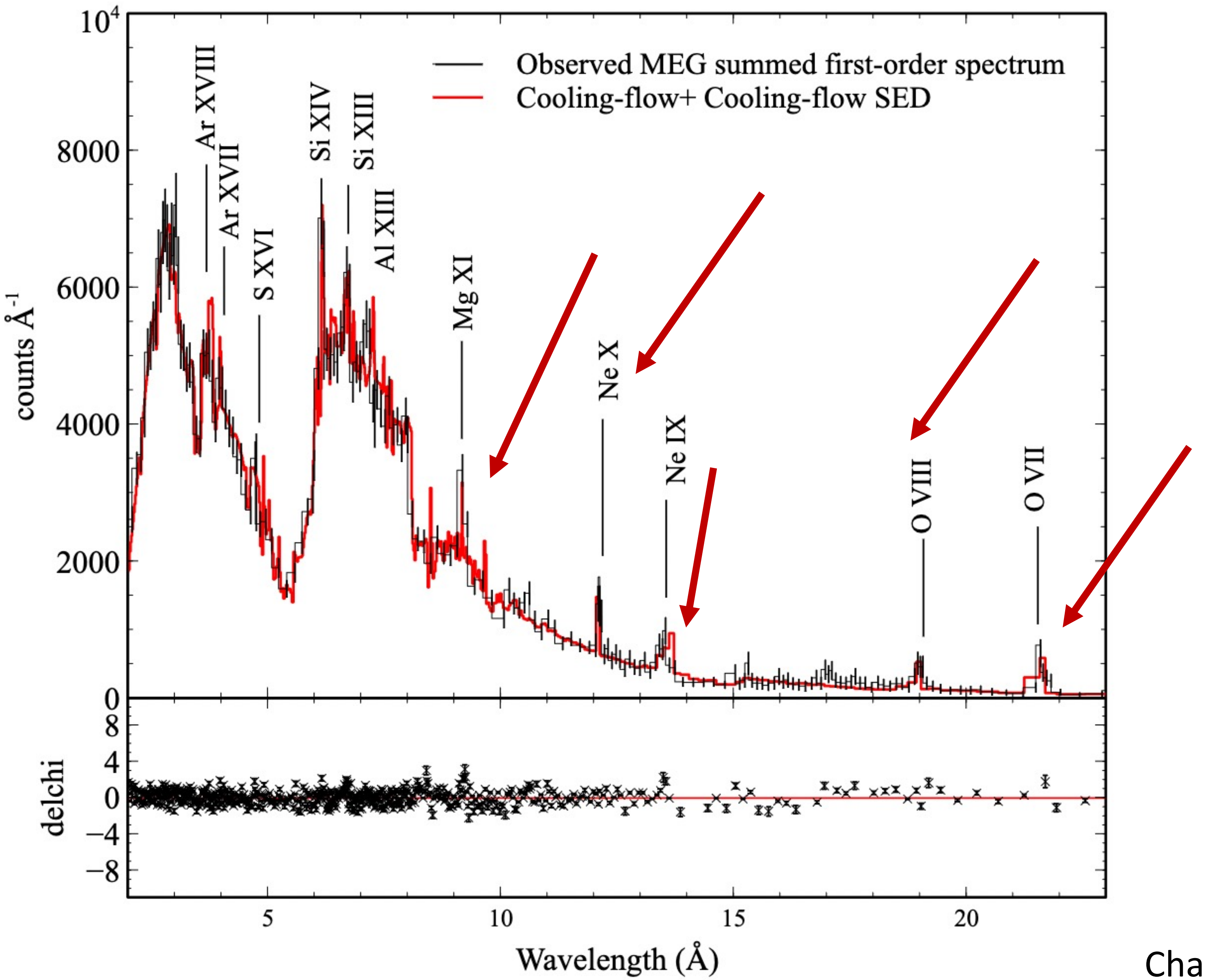
What is producing the excess emission lines?

Using cooling flow SED for modeling- poor fit to the spectrum



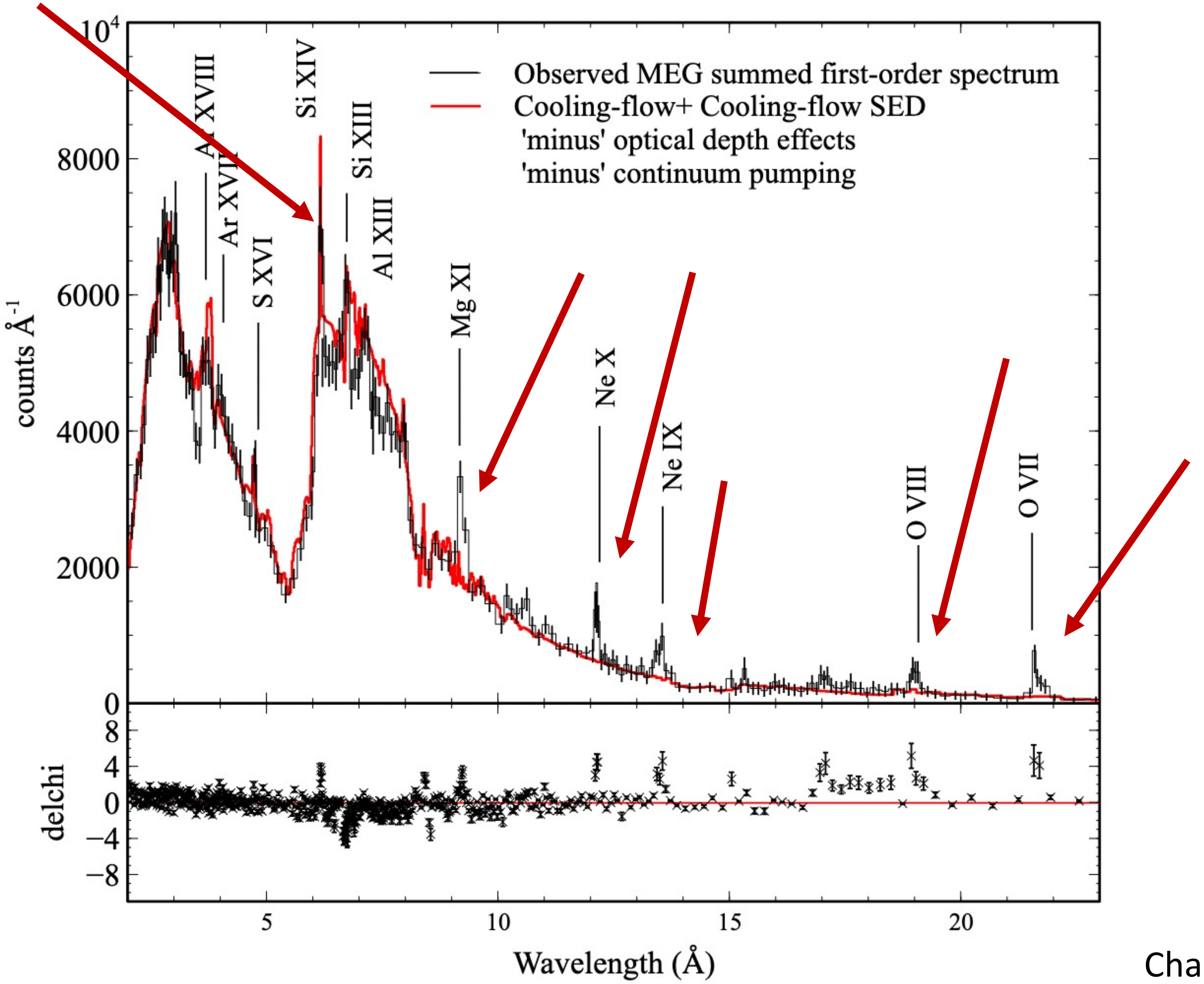
Chakraborty et al. 2022

Best-fit model : cooling-flow+ cooling-flow SED



Chakraborty et al. 2022

What happens the atomic processes are not correctly accounted for?



Chakraborty et al. 2022

Summary

- Understanding atomic processes in collisionally-ionized and photoionized cloud is important to interpret spectra from XRISM and Athena.

- The physics of Resonant Auger Destruction (RAD) and Electron Scattering escape (ESE) was discussed for a range of column densities (Chakraborty et al. 2020b, c, Chakraborty et al. 2021).

- Photoelectric absorption opacity and other optical depth effects on the soft X-rays was discussed. The best-fit Cloudy model was used to successfully fit the Chandra HETG spectrum of V1223 Sgr (Chakraborty et al. 2022).