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APS DPP
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Characterizing charge state distributions in photoionized plasma to test high density effects in astrophysical code XSTAR

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Summary: Independent charge state distribution (CSD) analysis for Si agrees with astrophysical model predictions

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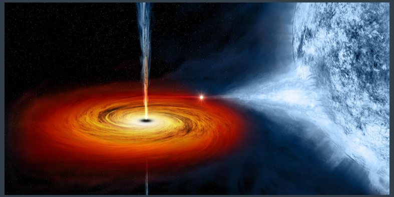

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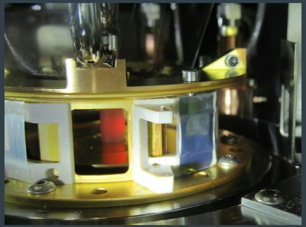

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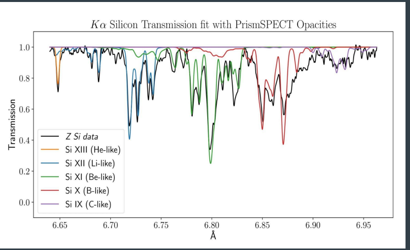
5. The Fe spectrum is much more complicated and work is ongoing.



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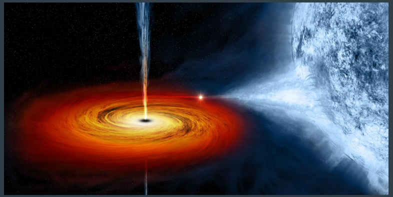

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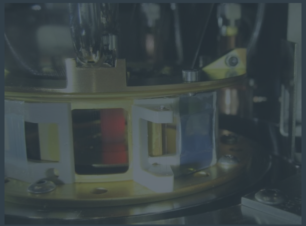

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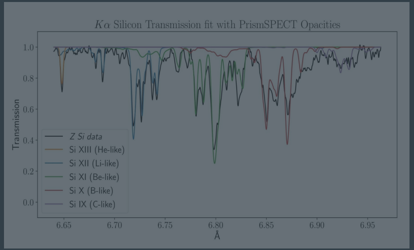

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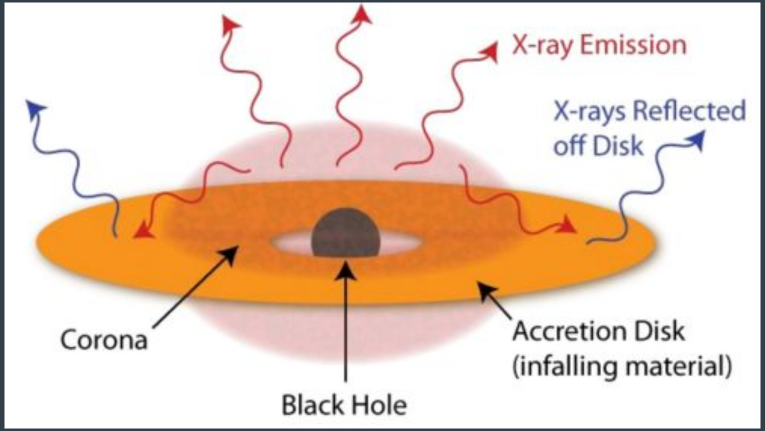
Fits to reflection spectra are used to determine properties of X-ray binaries and AGN

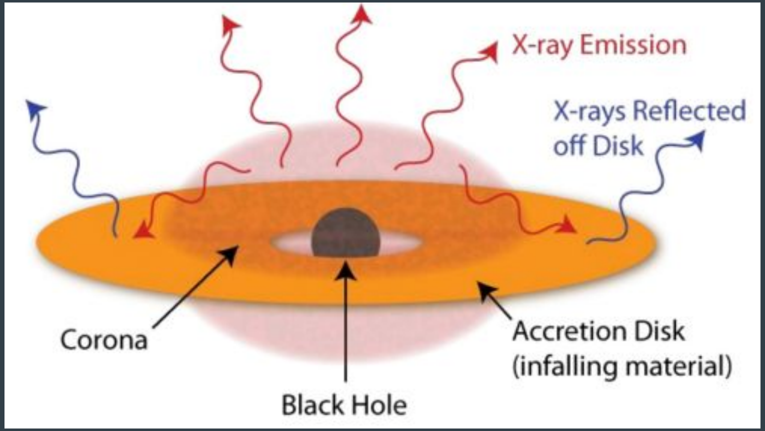
- Radiation emitted by the corona is “reflected” by the accretion disk.
- Fits to reflection spectra can be used to infer:
  - Composition
  - Density
  - BH spin
  - BH mass



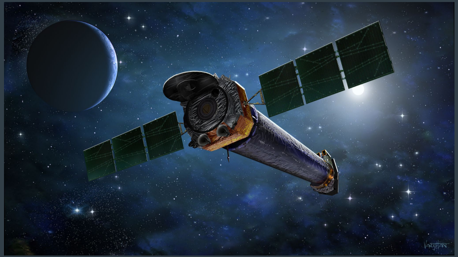
XSTAR is one widely used photoionized plasma model.

Model predictions for transmission spectra also need to be scrutinized

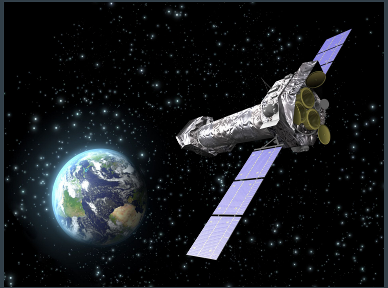
- Ion populations are established by photoionization.
- Ion populations are a key quantity predicted by photoionized plasma models.
- We see emission from these systems, but absorption is also occurring in the disk plasma.
- Both spectra are important to scrutinize.



The x-ray astrophysical community has called for independent measurements of CSDs



Chandra - NASA



XMM-Newton - ESA

"The two primary needs are precise and accurate determination of the wavelengths for common transitions as well as the [CSDs] of [L-shell ions of Mg, Si, Fe…] under a range of thermodynamic and radiative conditions."

- Smith et al., Laboratory Astrophysics Needs for X-ray Grating Spectrometers, Astro 2020 Decadal Review

Laboratory photoionized plasma data is sparse!

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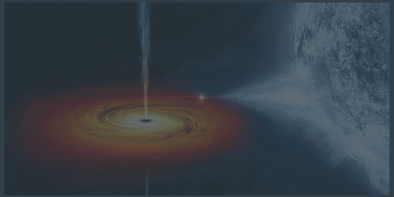

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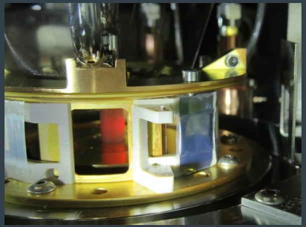

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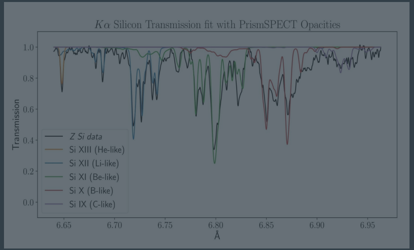
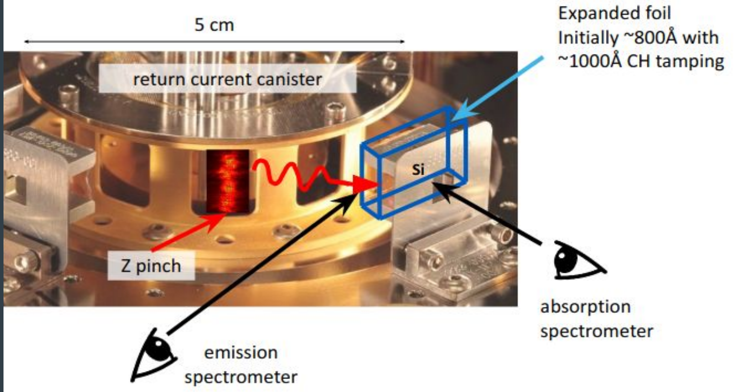


The foil photoionized plasma experiment on Z reaches regimes relevant to accreting systems

- A Si or Fe foil sample irradiated by the Z-pinch.
- We observe the plasma in both emission and absorption.



T_e: 20-40 eV

n_e: 10^{17} - 10^{18} cm^{-3}

ξ: 20-200 erg cm/s

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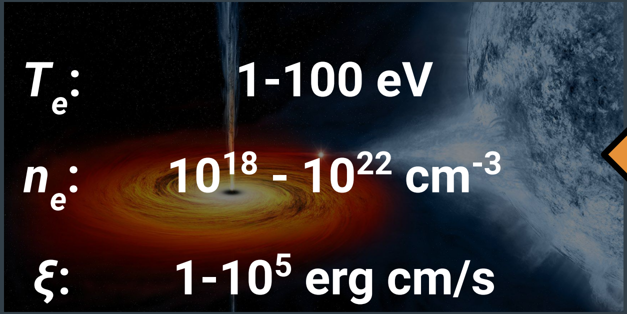
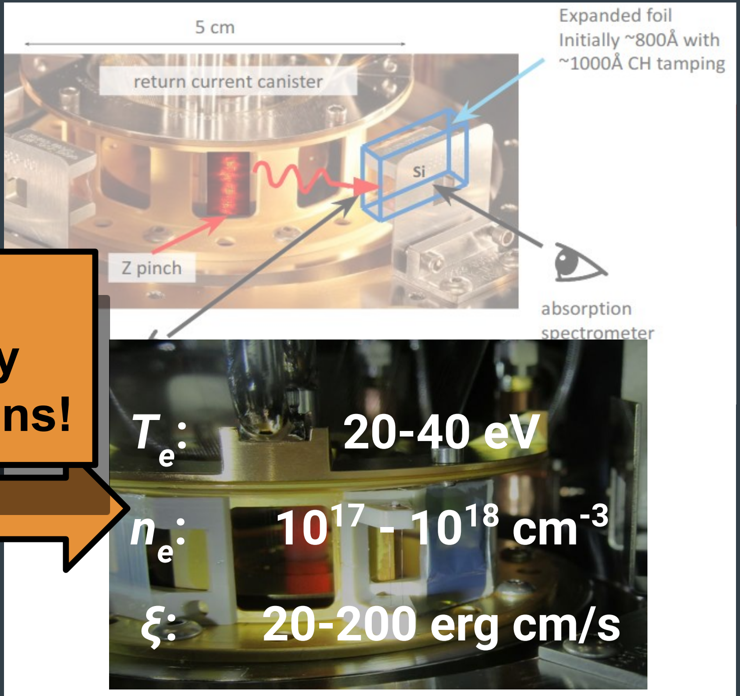


We reach astrophysically relevant conditions!



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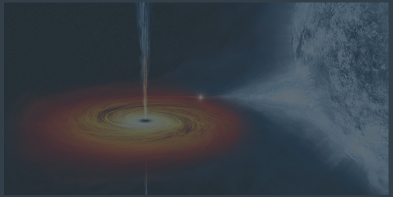

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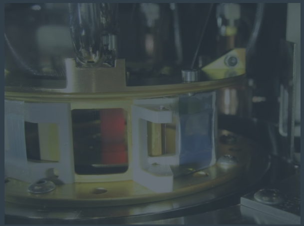

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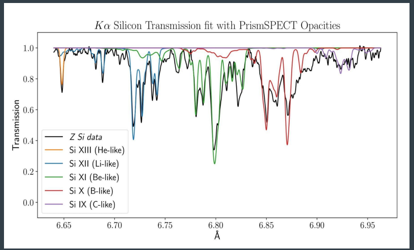


We extract areal densities from a transmission spectrum by fitting opacities

- X_ν [cm2] is an opacity "cross-section": it is *almost* independent of plasma parameters except for the line shape ϕ_ν.
- PrismSPECT + ATBASE to get X_ν per ion.
- The product of areal density and opacity cross section across all wavelengths gives a transmission spectrum.
- We can fit areal densities for several ions to a transmission spectrum, giving a CSD measurement.

$$T_\nu = \exp\left[-\sum_i X_{\nu,i}^{\text{prism}} \times \underline{nl_i}\right]$$

We extract areal densities from a transmission spectrum by fitting opacities

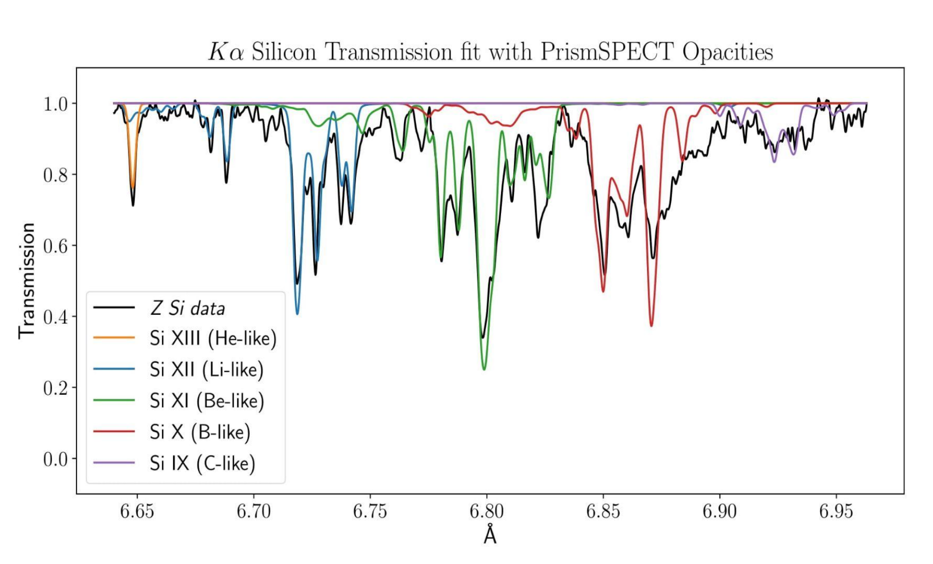
Steps:

- Get $X_{v,i}$.
- Convert to transmission.
- Convolve with instrumental resolution.
- Levenberg-Marquardt minimization to get best fit nl_i.

$$T_\nu = \exp\left[-\sum_i X_{\nu,i}^{\text{prism}} \times \underline{nl_i}\right]$$

Results with Si show the method is effective

- Spectrum from Loisel et al. (2017) was obtained by averaging several Si transmission spectra collected across multiple shots.
- Fits to the ion areal densities return a total areal density that agrees with independent Rutherford back-scattering measurements.

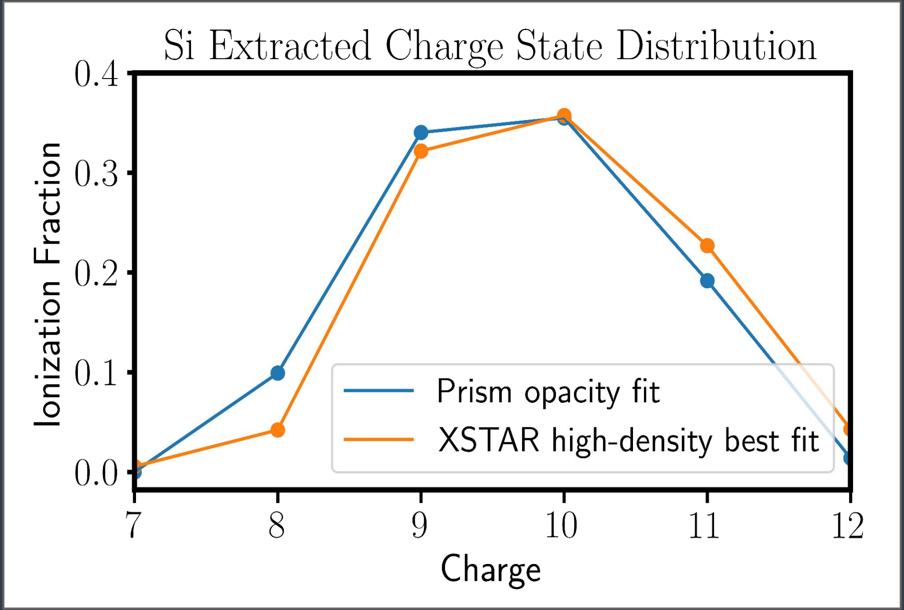


RBS Areal Density: 3.10×10^{17} Si/cm^2 ± 5%
Fitted Areal Density: 2.97×10^{17} Si/cm^2

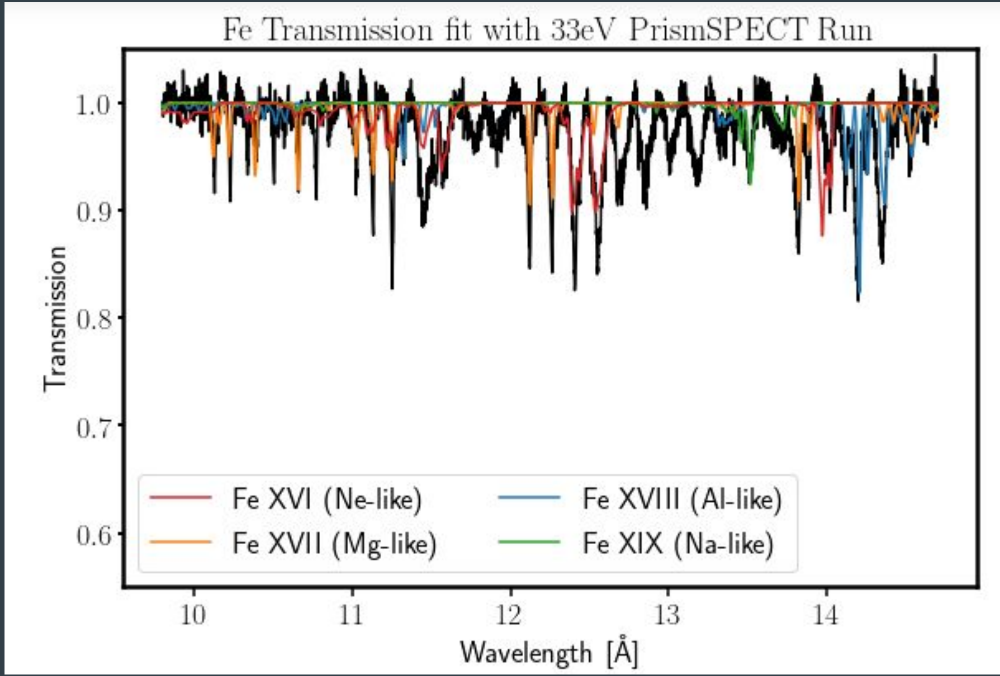
XSTAR predicts similar CSD to our measurements

Next steps:

- Robust error analysis
- Investigate T_e differences



CSD analysis for Fe is in progress



Next Steps:

- Apply wavelength-dependent instrumental resolution
- Re-evaluate continuum in absorption spectrum

Thanks!

More on opacity cross sections and fitting routine

$$\frac{\kappa_\nu}{\rho} = \frac{\pi e^2}{mc}\frac{N_A}{M} f_l f_{l\to u}\phi_\nu \to X_\nu \equiv \frac{M}{N_A f_l}\left(\frac{\kappa_\nu}{\rho}\right) = \frac{\pi e^2}{mc} f_{l\to u}\phi_\nu$$

$$T_\nu = \exp\left[-\sum_i X_{\nu,i}^{\text{prism}} \times \underline{nl_i}\right] \qquad \frac{\lambda}{\delta\lambda} \sim 2400$$

Instrumental resolution for Si data