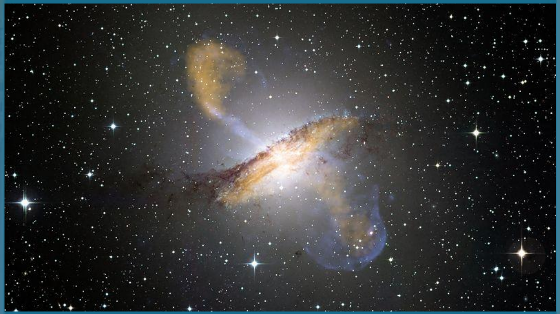
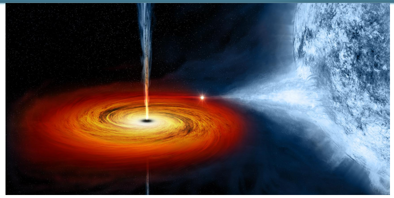
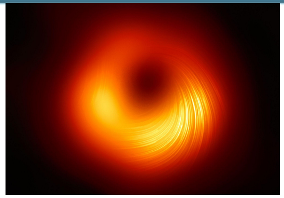
SAND2021-13915C

Sandia National Laboratories

Testing High Density Accretion Disk Models with Photoionized Iron Plasma Experiments







Los Alamos National Laboratory

NASA

California Institute of Technology 1891

Lawrence Livermore National Laboratory

Patricia Cho[1], Guillaume Loisel[2], Chris Fontes[3], Tim Kallman[4], Javier Garcia[5], Jim Bailey[2], Taisuke Nagayama[2], Duane Leidahl[6]

[1]University of Texas, Austin
[2]Sandia National Laboratories
[3]Los Alamos National Laboratories
[4]NASA Goddard
[5]Cal Tech
[6]Lawrence Livermore National Laboratories

LRGF Laboratory Residency Graduate Fellowship

TEXAS The University of Texas at Austin

WOOTTON CAPP

U.S. Department of Energy NNSA National Nuclear Security Administration

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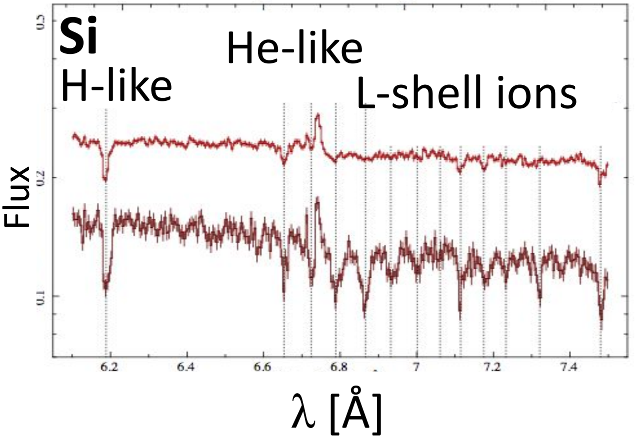
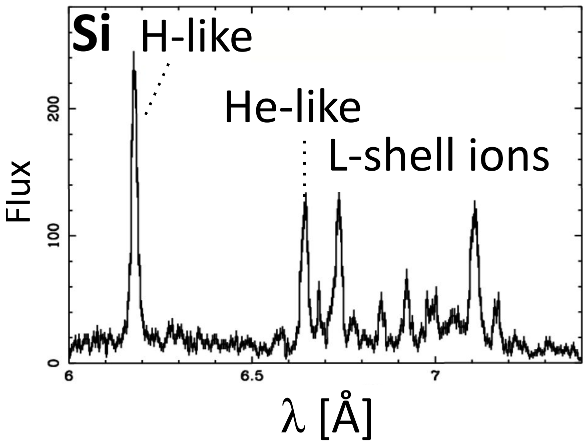
Astronomical X-ray spectra are used to access a wide variety of parameters related to black hole systems

Cygnus X-1 BH HMXB



Absorption spectra

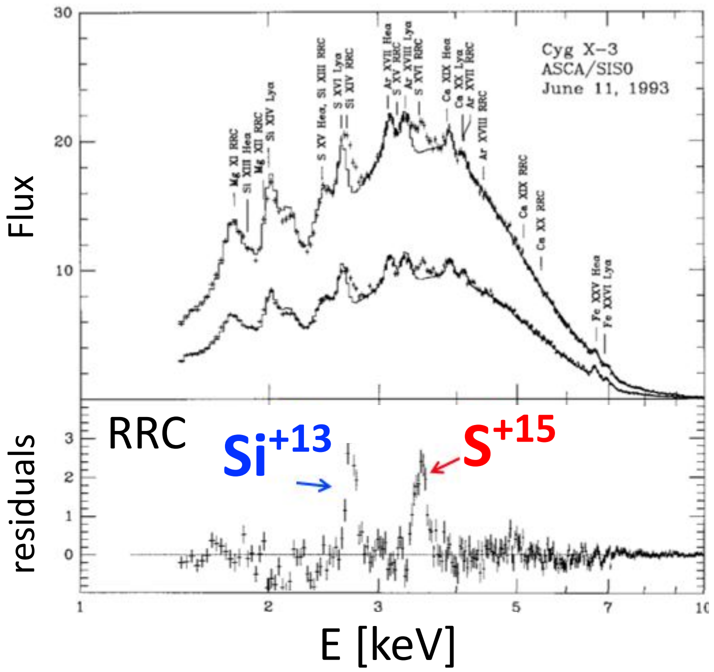
Vela X-1 NS HMXB



Emission spectra

- composition
- ionization parameter: ξ=4πflux/density
- Column density
- Accretion dynamics

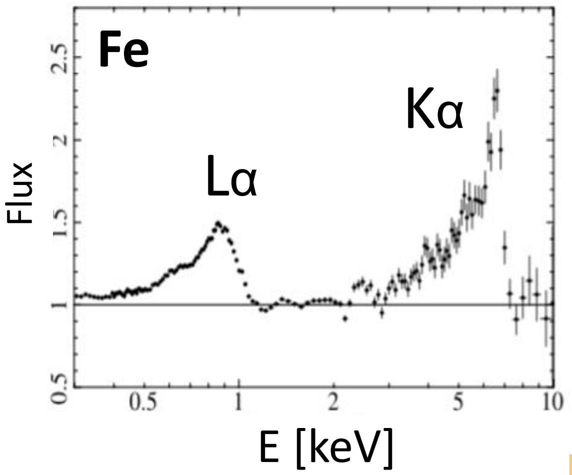
Cygnus X-3 HMXB



Radiative recombination continuum (RRC)

- T_e temperature

AGN 1H0707 SMBH

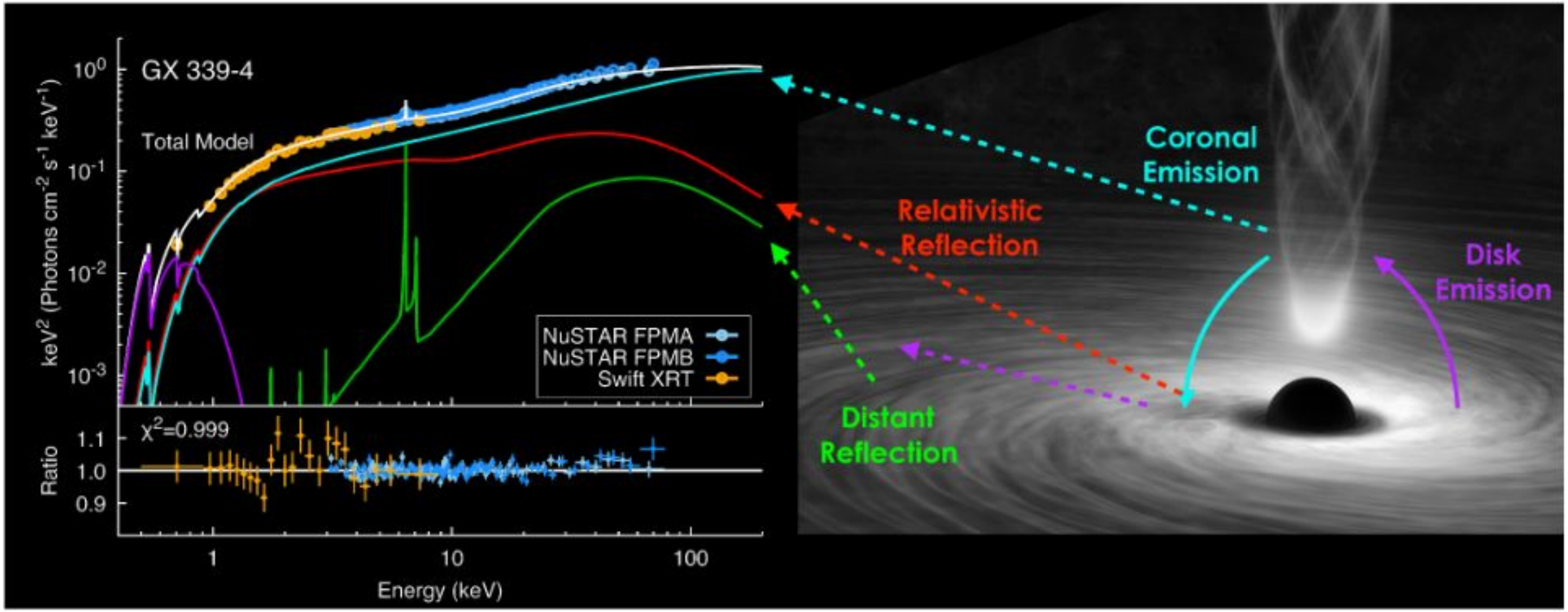


Broad Iron line

- Radiation transport effects
- Disk structure
- General relativity effects

Microphysics in the models used to interpret the observations are largely untested

An X-ray reflection spectrum is produced when hot coronal emission is reflected by an accretion disk in a black hole system



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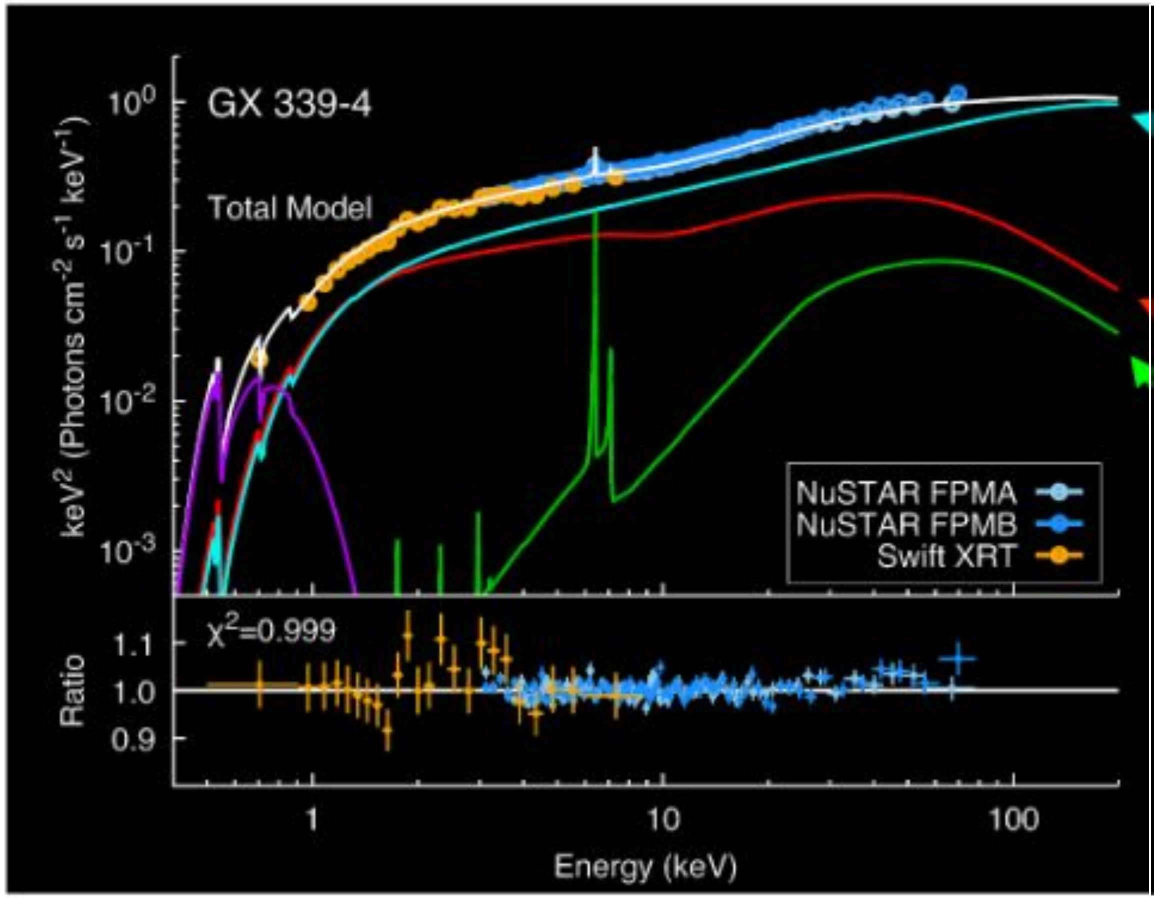
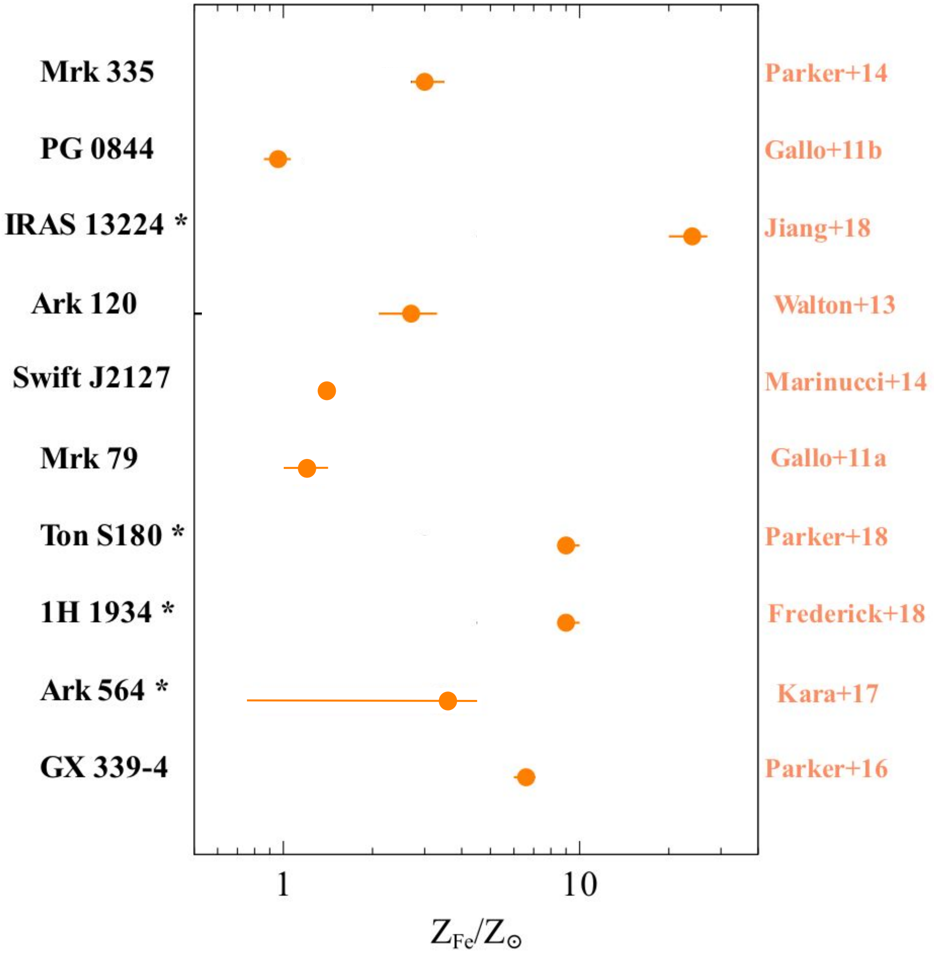


- Astrophysical models of black hole accretion disks suggest high Iron abundances in multiple systems that are often many times the Iron abundance in the sun.
- This phenomenon is known as the **Supersolar Iron Abundance Problem**.

The Supersolar Fe Abundance Problem has been informed by high density effects in accretion disk models

- Historically, models have imposed an upper bound ($n_e \leq 10^{15}$ cm^{-3}) on the plasma density in the accretion disk.
- This low density limit was suspected to be a large part of the reason for many of the supersolar Iron abundance determinations.

Jiang et al. (2019)



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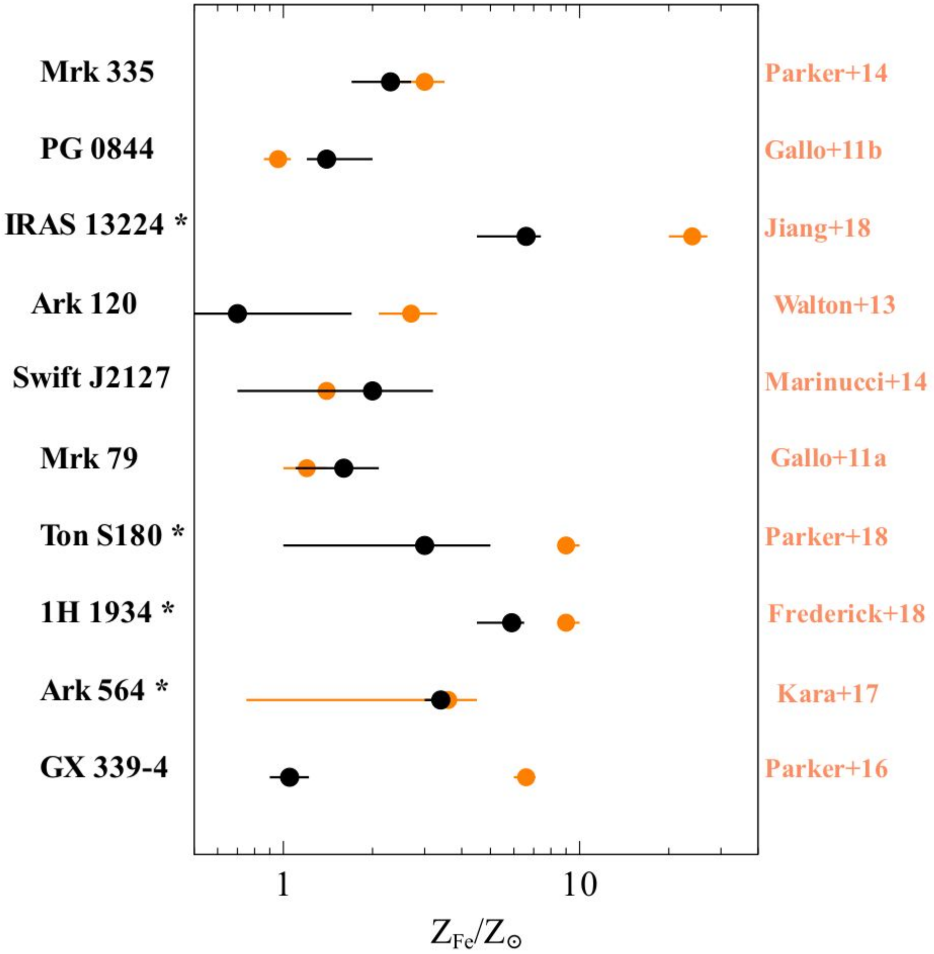
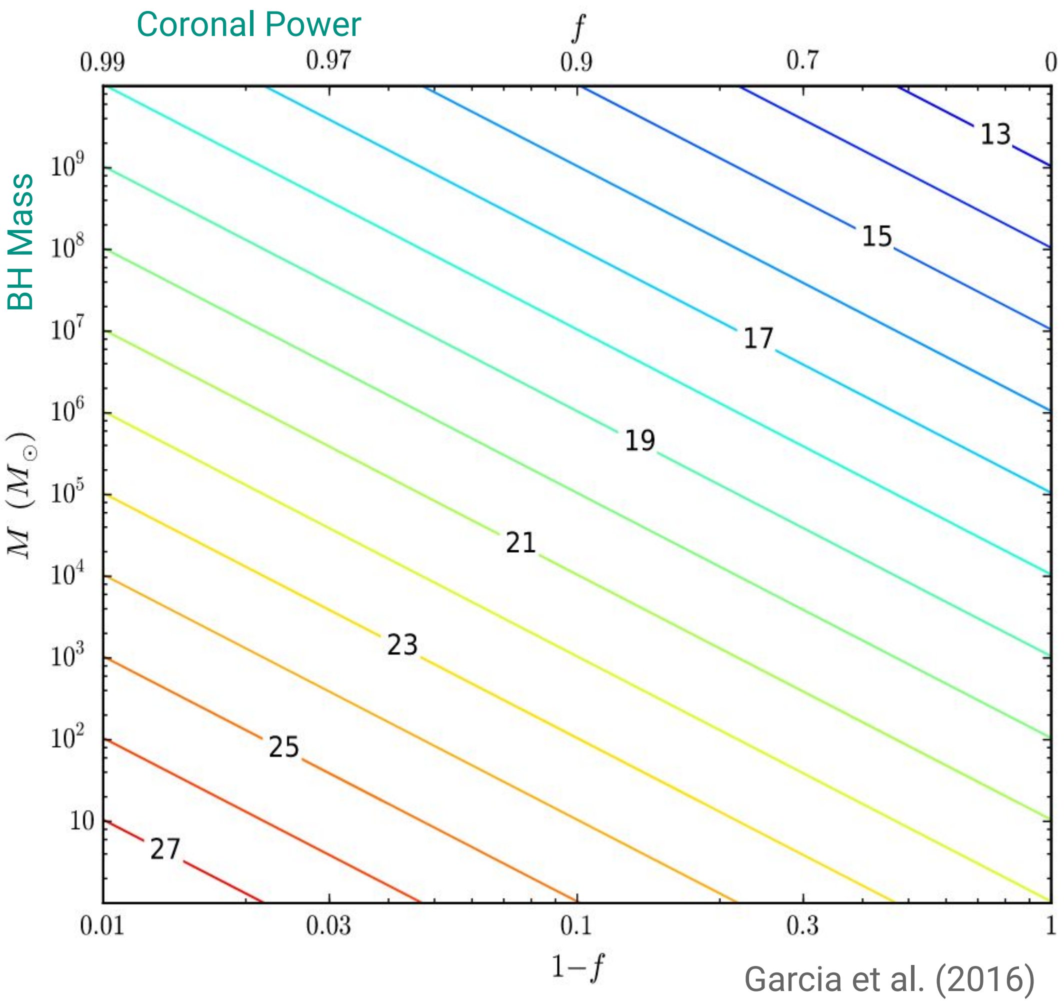
- This low density limit was suspected to be a large part of the reason for many of the supersolar Iron abundance determinations.
- Recently, high density effects have been incorporated in XSTAR.
- Iron abundances were revised to lower values for many systems.
- However, some abundance values are still quite high and the physical assumptions have not previously been tested against laboratory data.

Jiang et al. (2019)



Models assume **low density (≲ 1e15 cm^{-3})** and **constant density** for the accretion disk atmosphere



Garcia et al. (2016)

Density for standard α-disk

- high accretion rates
- Radiation pressure-dominated inner region

$$n_e = \frac{1}{\sigma_T R_S} \frac{256\sqrt{2}}{27} \alpha^{-1} r^{3/2} \dot{m}^{-2} [1 - (3/r)]^{-1} (1 - f)^{-3}$$

Svensson & Zdziarski (1994)

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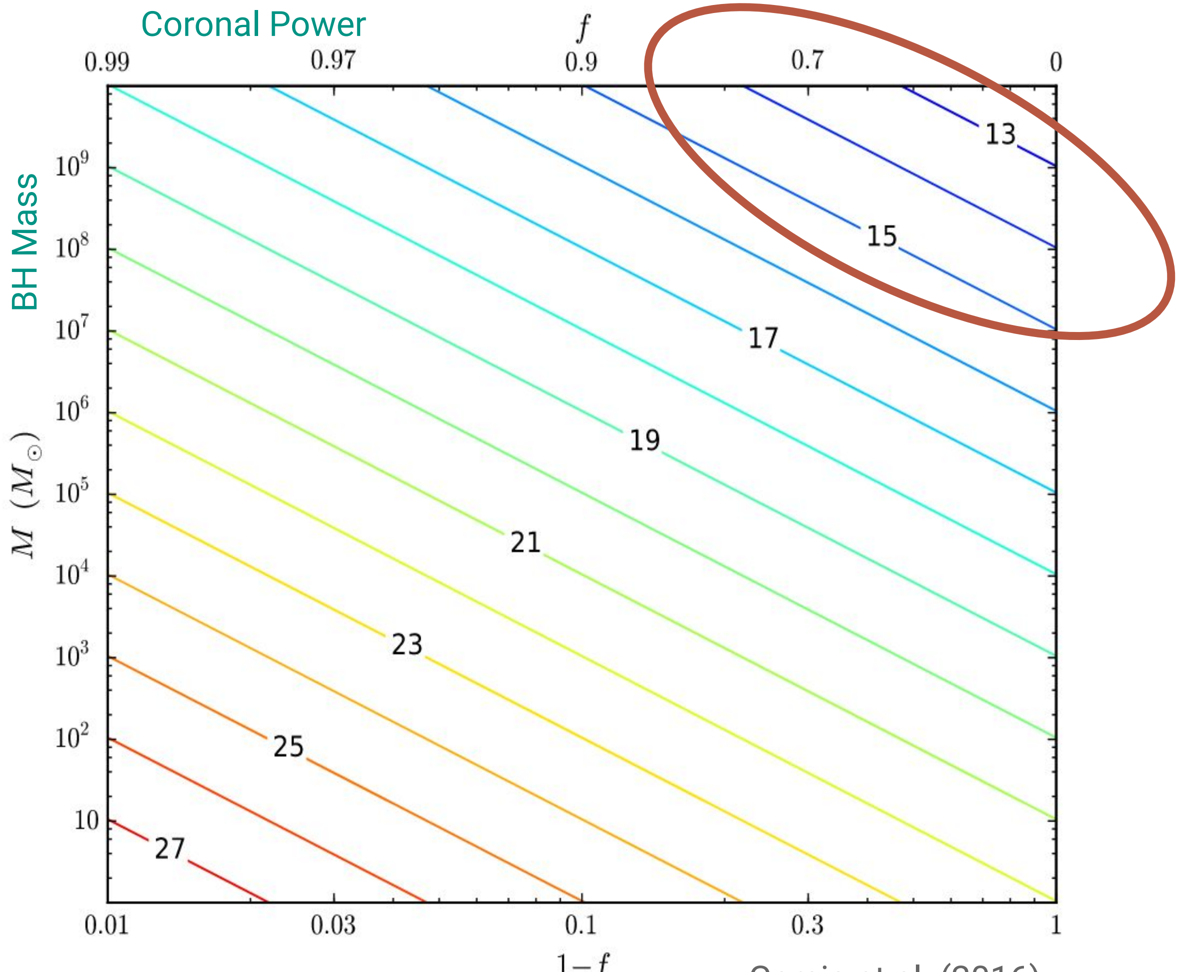

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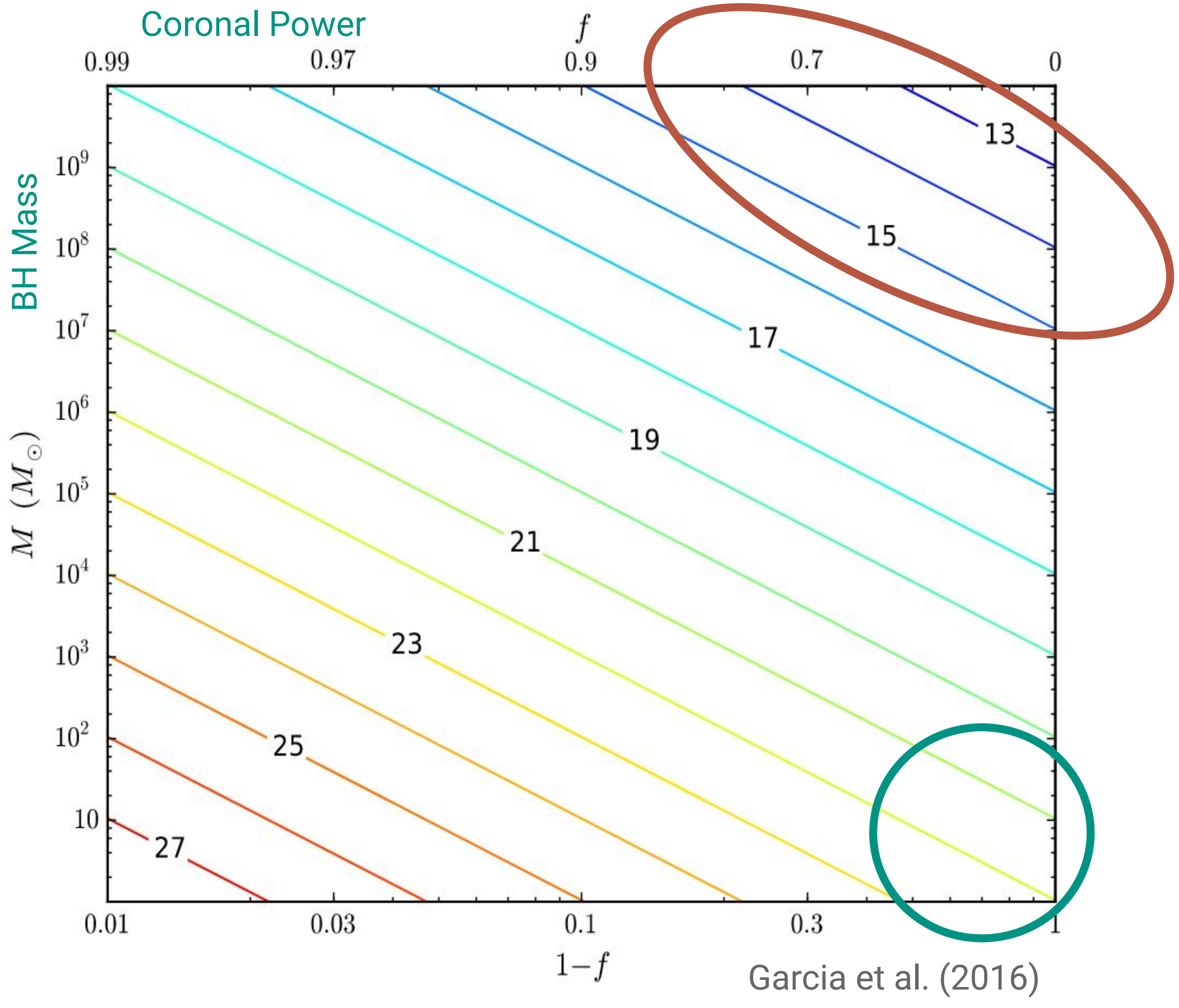
Low density models (n_e ≤ 10^{15} cm^{-3}) are only valid for high mass and low coronal power.

The **low density (≲ 1e15 cm^{-3})** assumption for accretion disk atmospheres is likely incorrect



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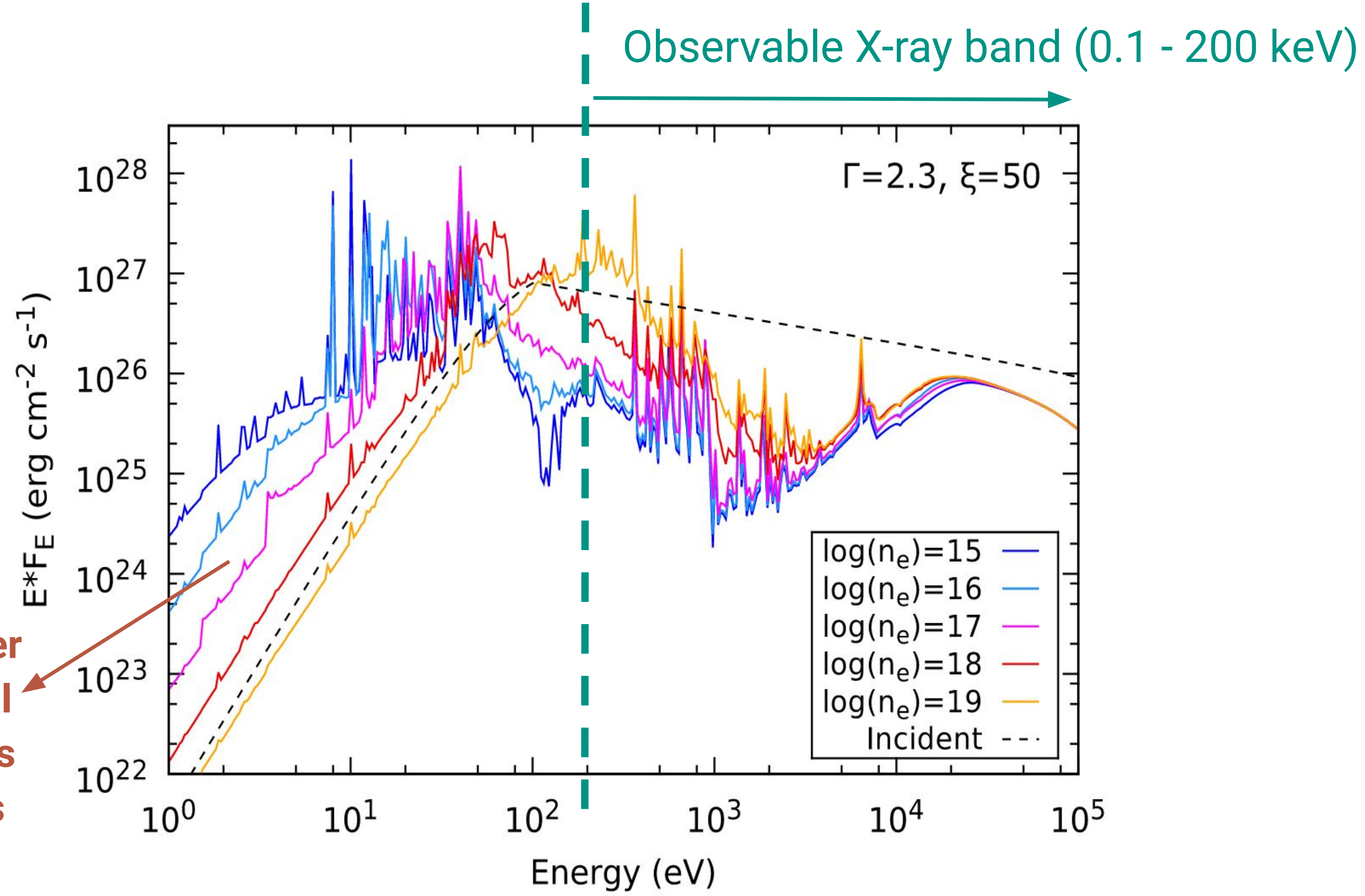
Low density models (n_e ≤ 10^{15} cm^{-3}) are only valid for high mass and low coronal power.

For a 10 solar mass BH, at the minimum f, the density is still near n_e ~ 10^{22} cm^{-3}.

All Spectra are similar at high energies (≳ 5 keV), and show increasing divergence at low energies

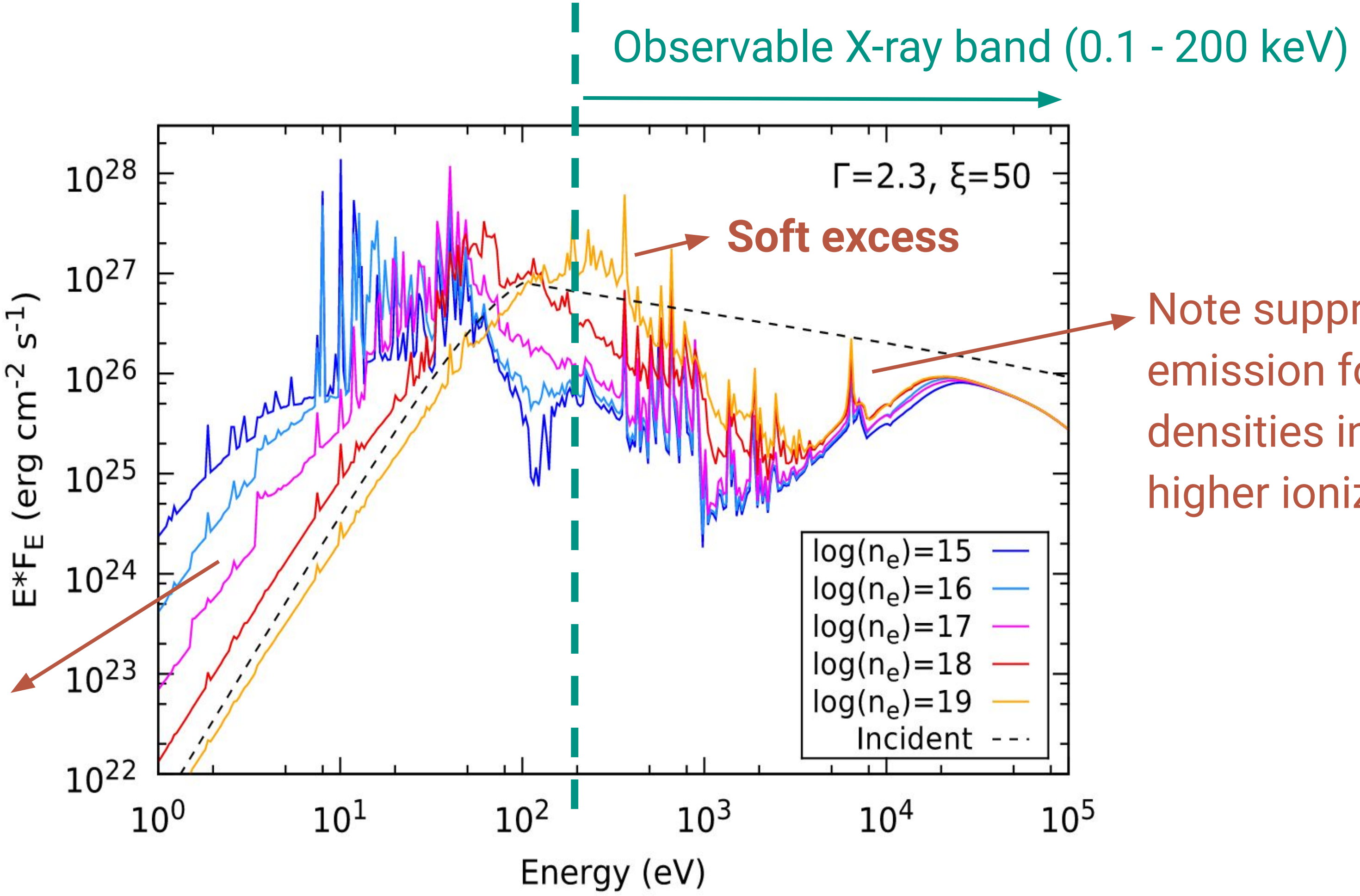


higher density → higher temperature → thermal part of spectrum skews toward higher energies

The most notable change in the reflected spectrum with higher densities is the increase in soft emission

Shape of soft excess is roughly similar to blackbody emission because the dominant source is free-free (Bremmstrahlung) emission.

higher density → higher temperature → thermal part of spectrum skews toward higher energies

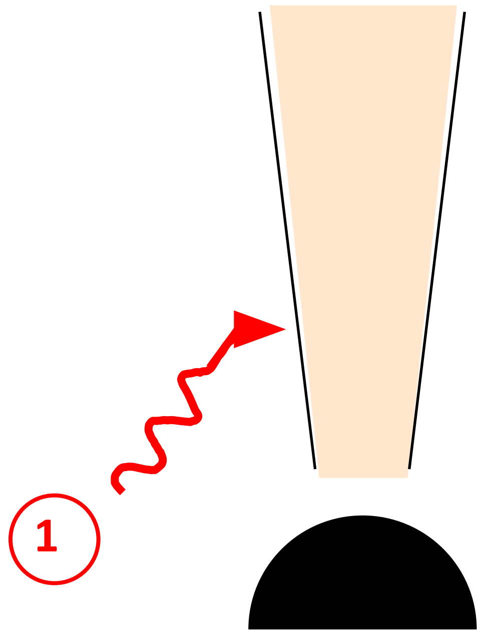


Note suppressed Kβ emission for highest densities indicating higher ionization state.

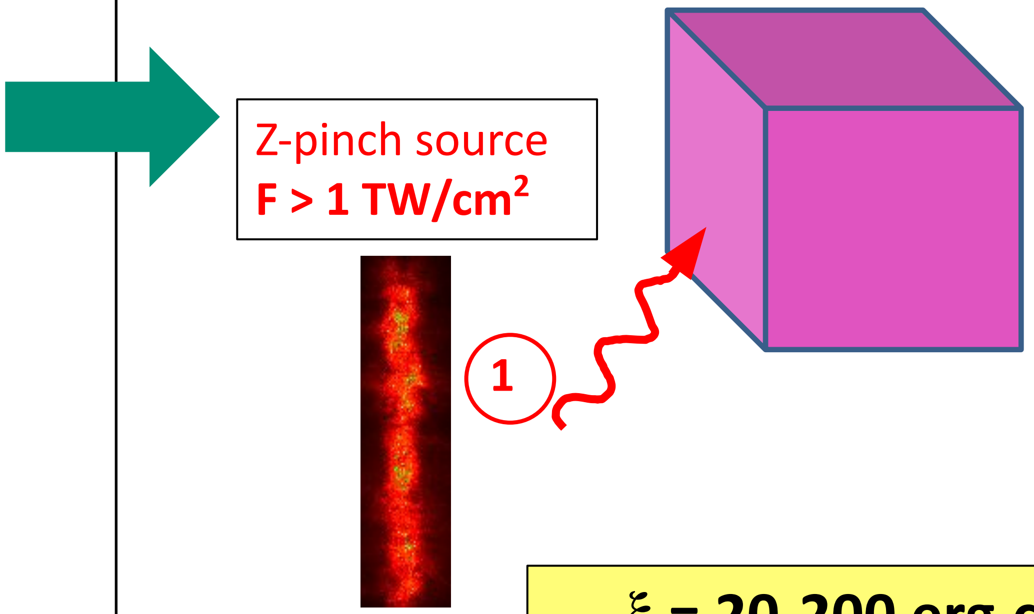
We built a laboratory analog for accretion disk X-ray emission and absorption

accretion disk

(1) X-ray illumination



laboratory



ξ = 20-200 erg.cm/s

We built a laboratory analog for accretion disk X-ray emission and absorption

accretion disk

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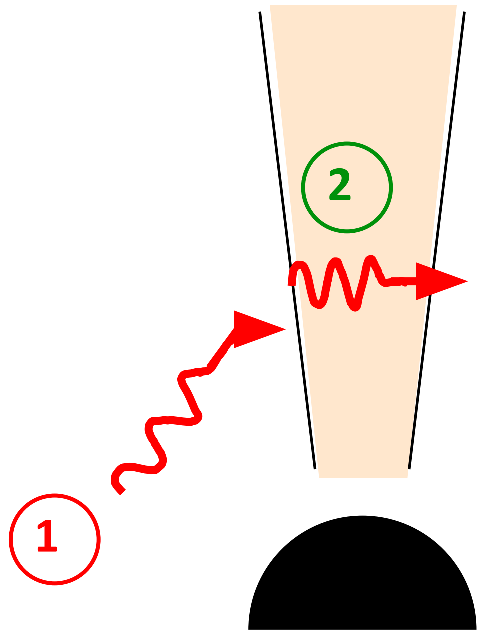
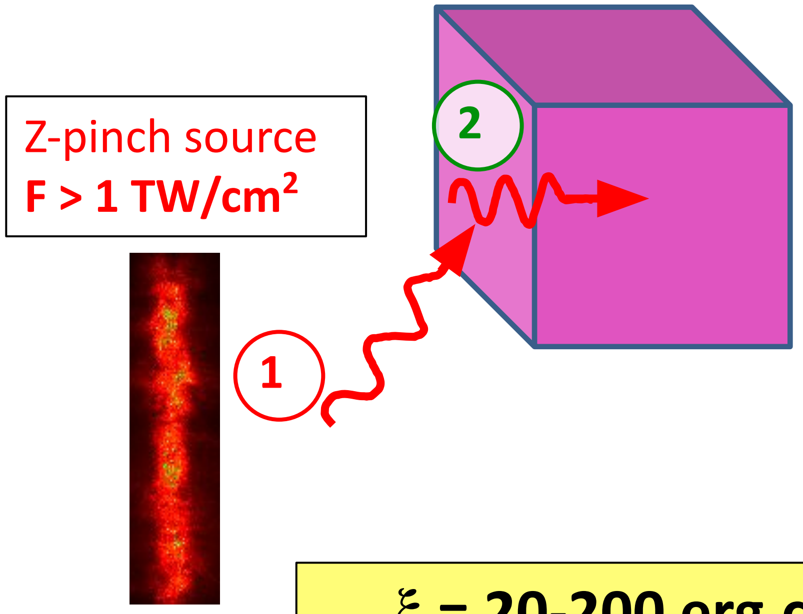
2 Photon ionization and atomic kinetics



laboratory

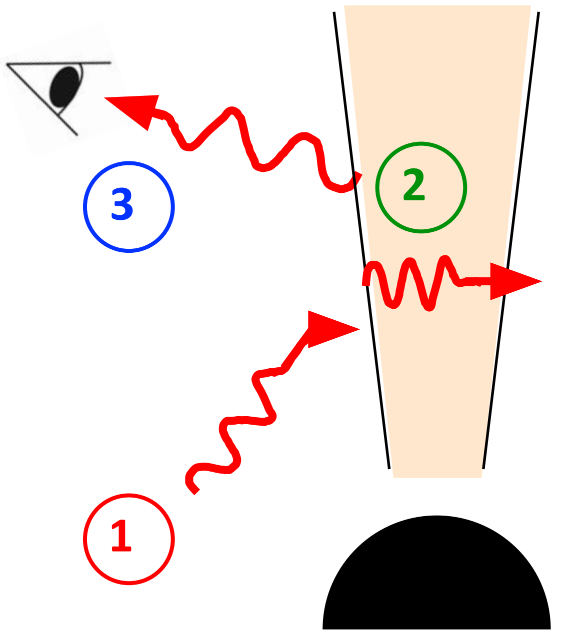


ξ **= 20-200 erg.cm/s**

We built a laboratory analog for accretion disk X-ray emission and absorption

accretion disk

1. X-ray illumination
2. Photon ionization and atomic kinetics
3. Plasma emission



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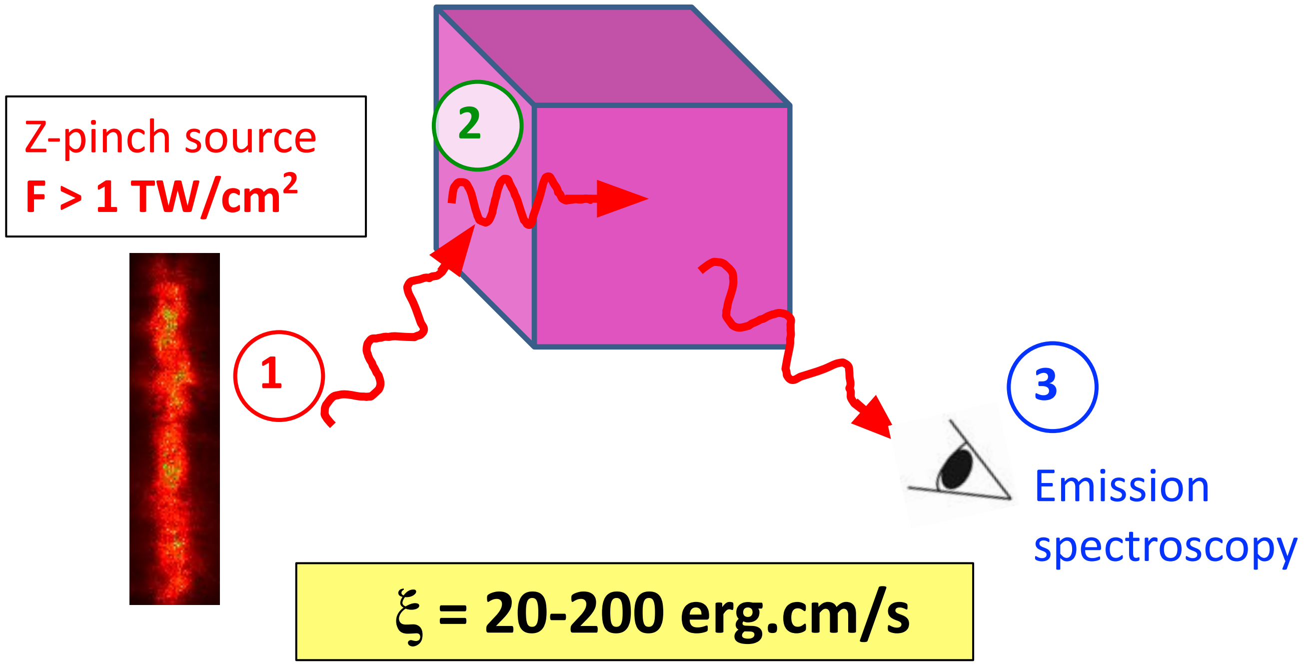

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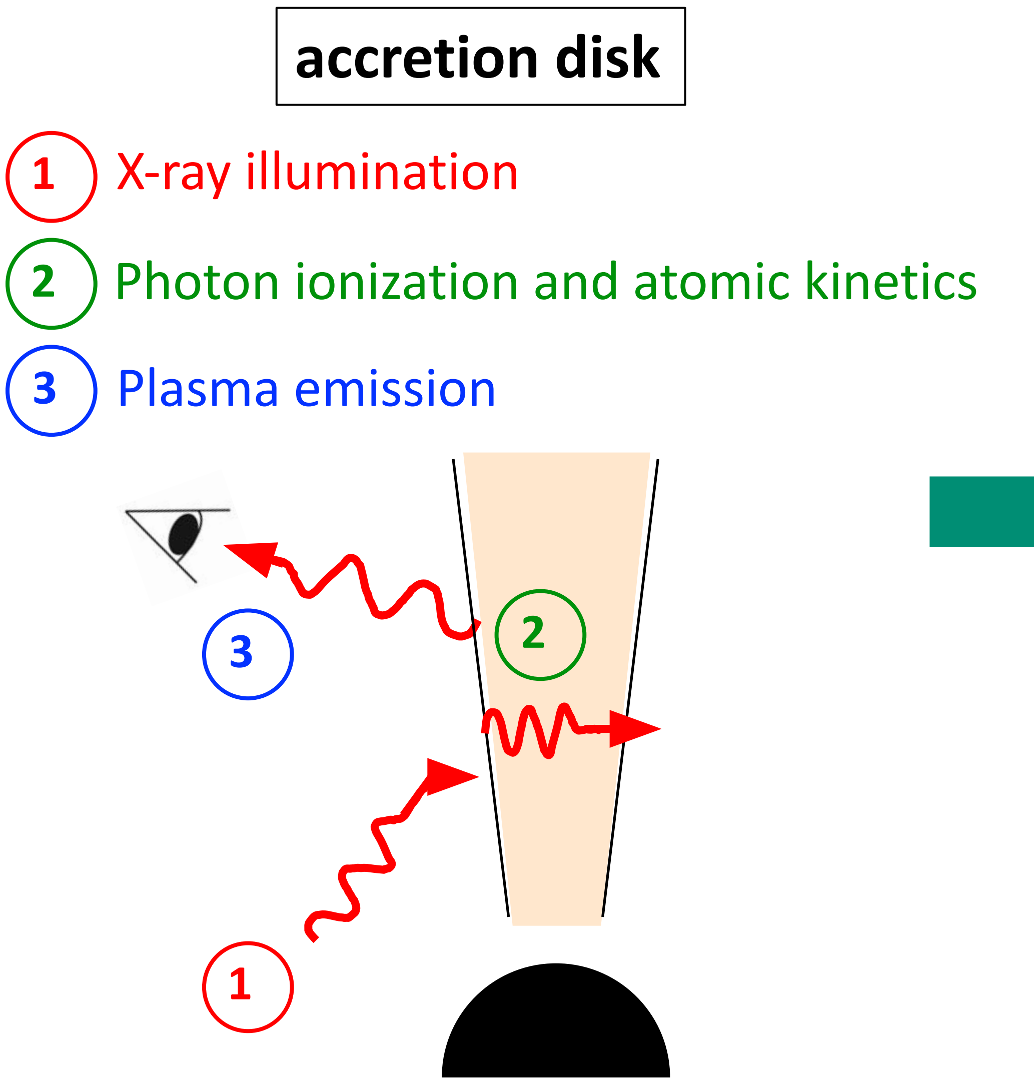
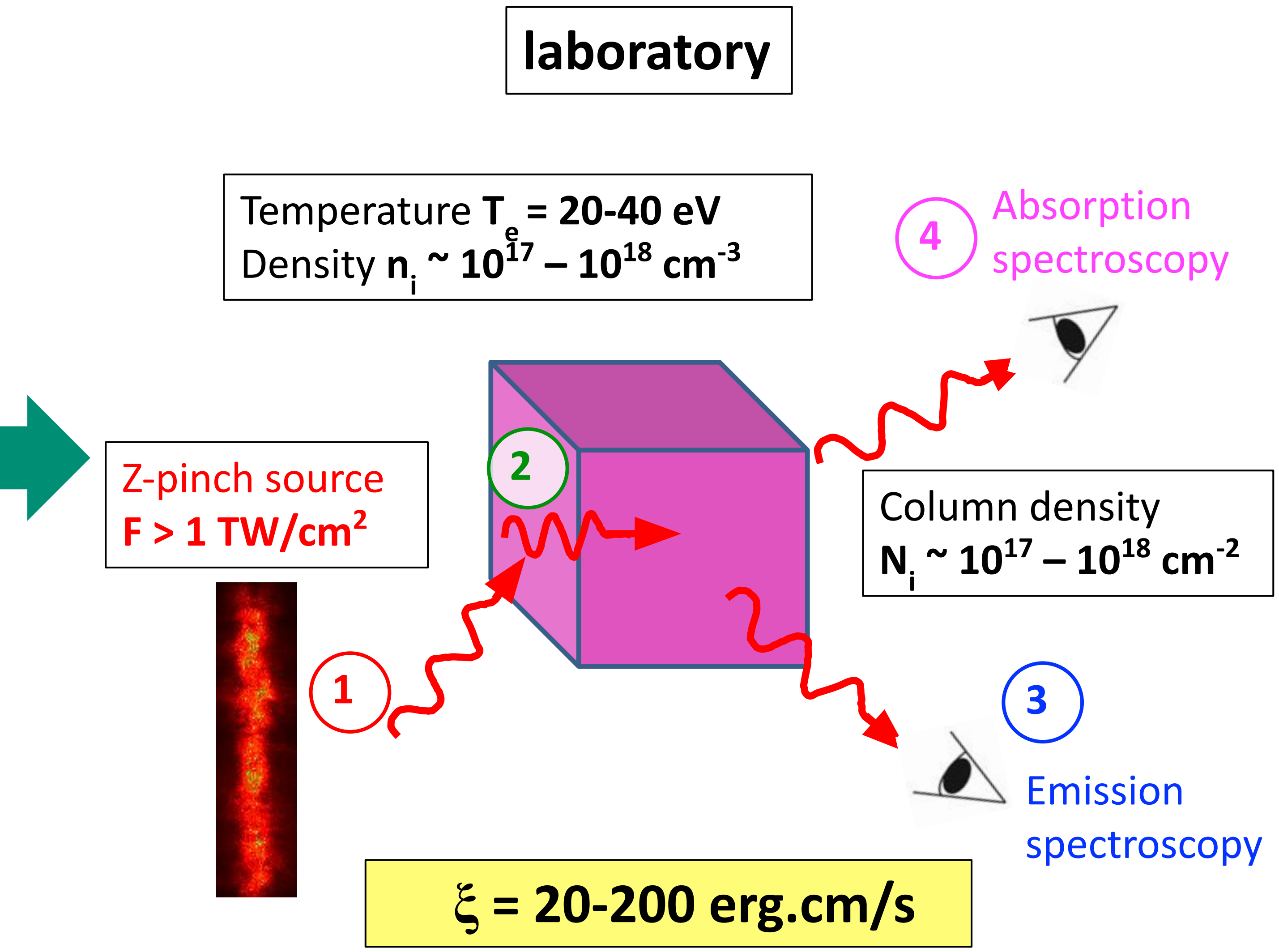




We built a laboratory analog for accretion disk X-ray emission and absorption

(1) X-ray illumination

(2) Photon ionization and atomic kinetics

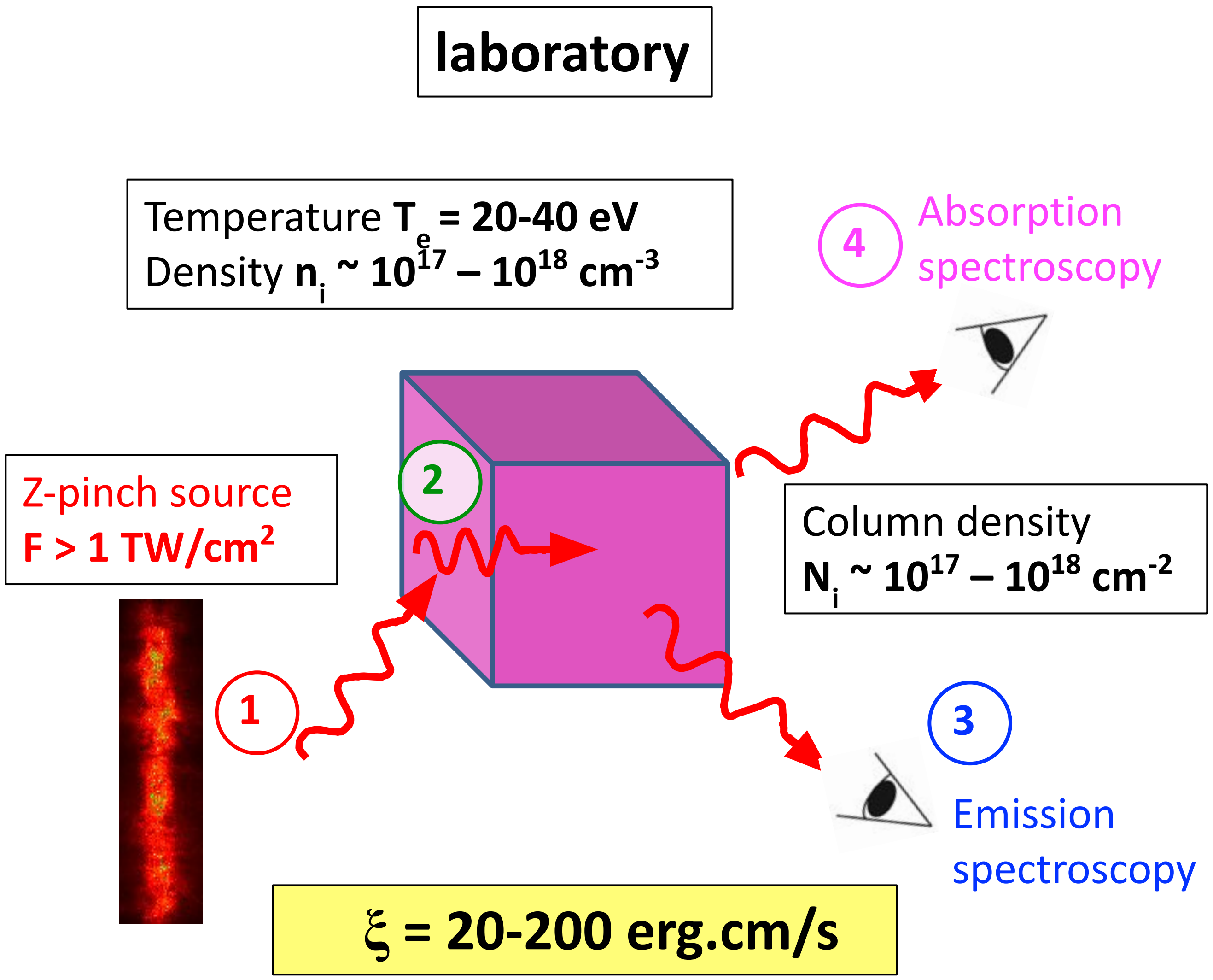
(3) Plasma emission

Advantages

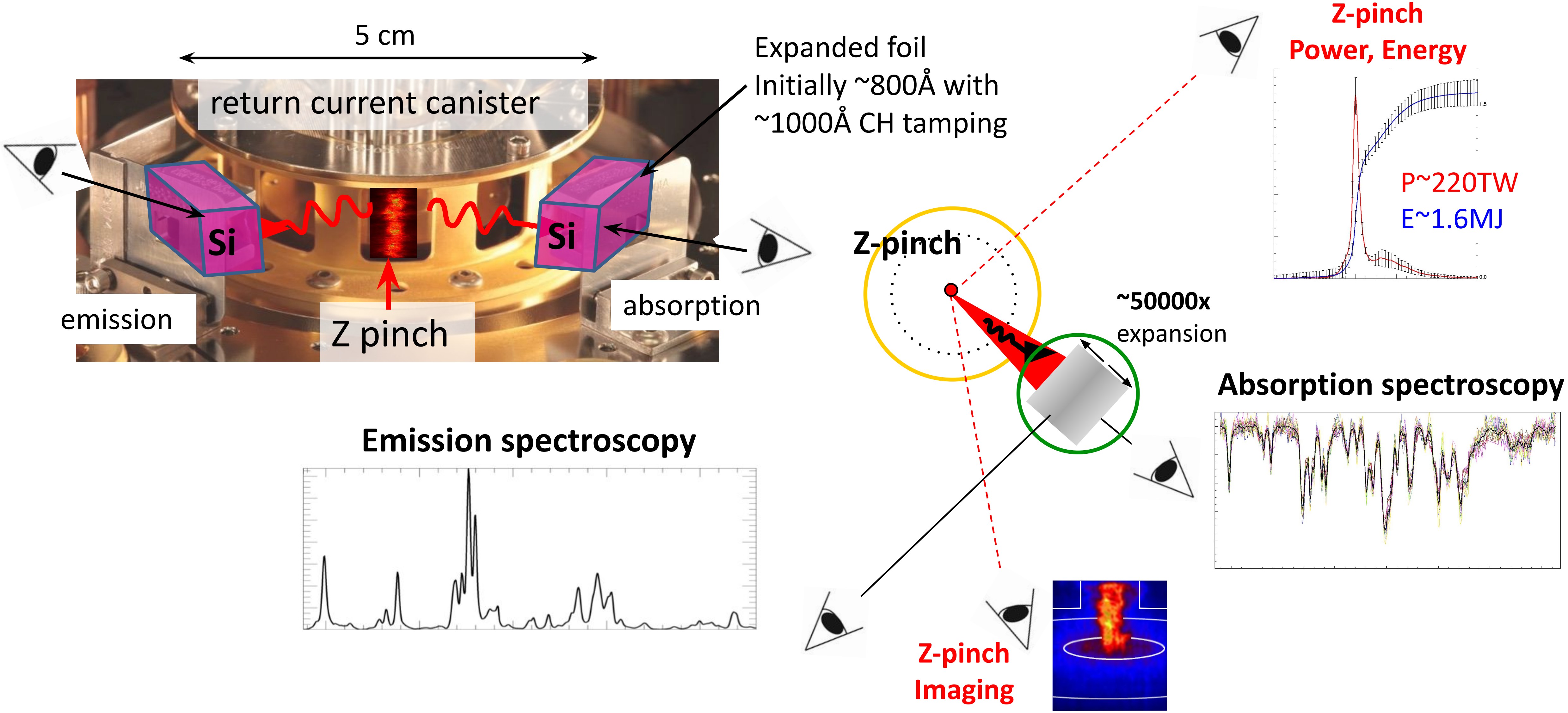
- study individual process (1) (2) (3)
- single element
- known drive
- controlled uniform plasma size
- higher spectral resolution
- higher signal to noise

Challenges

- dynamic evolution
- ensure higher density doesn't impact results
- measurement accuracy
- residual non-uniformities

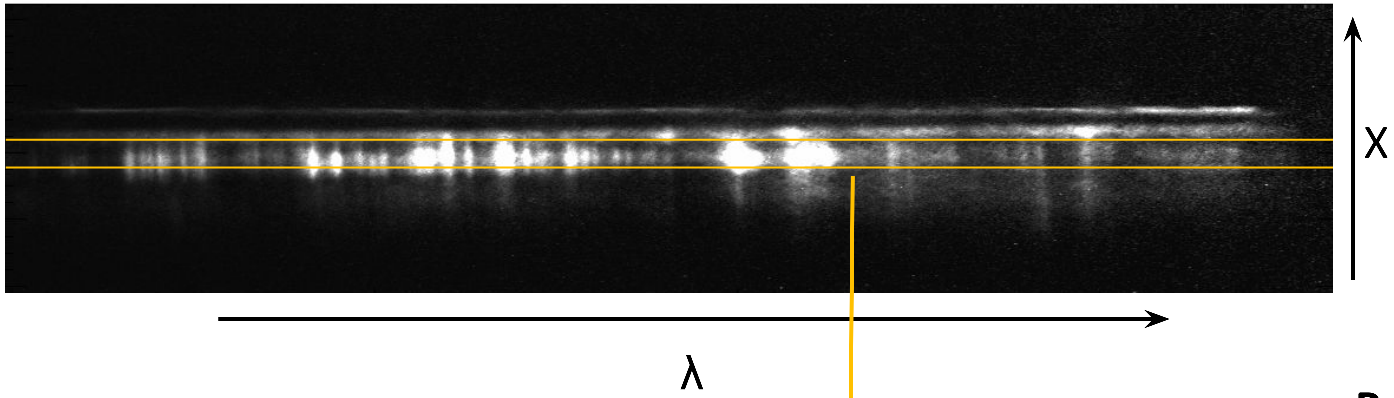


All required inputs are obtained on a single Z shot, confirm the plasma is photoionized and in relevant regime

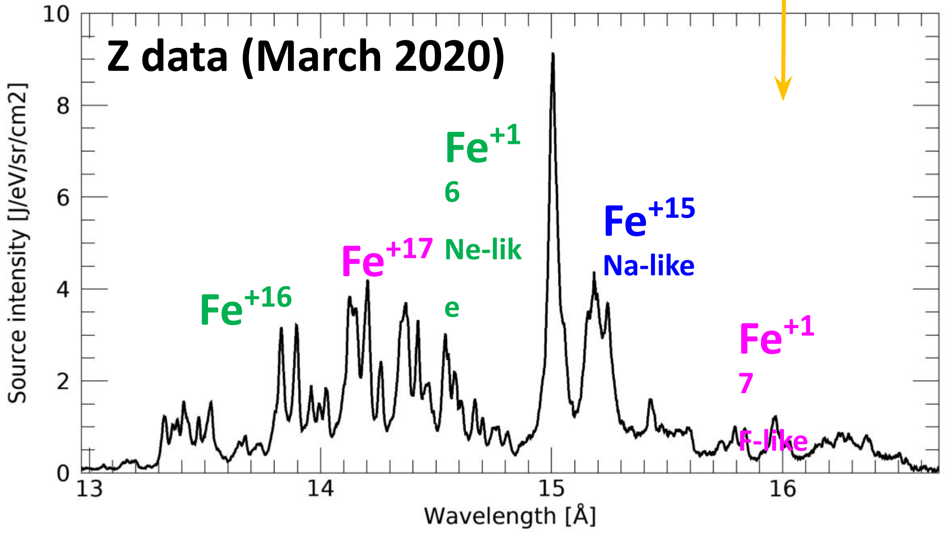


Photoionized Iron and Calcium emission data can be used to test the physical assumptions of high density effects in XSTAR

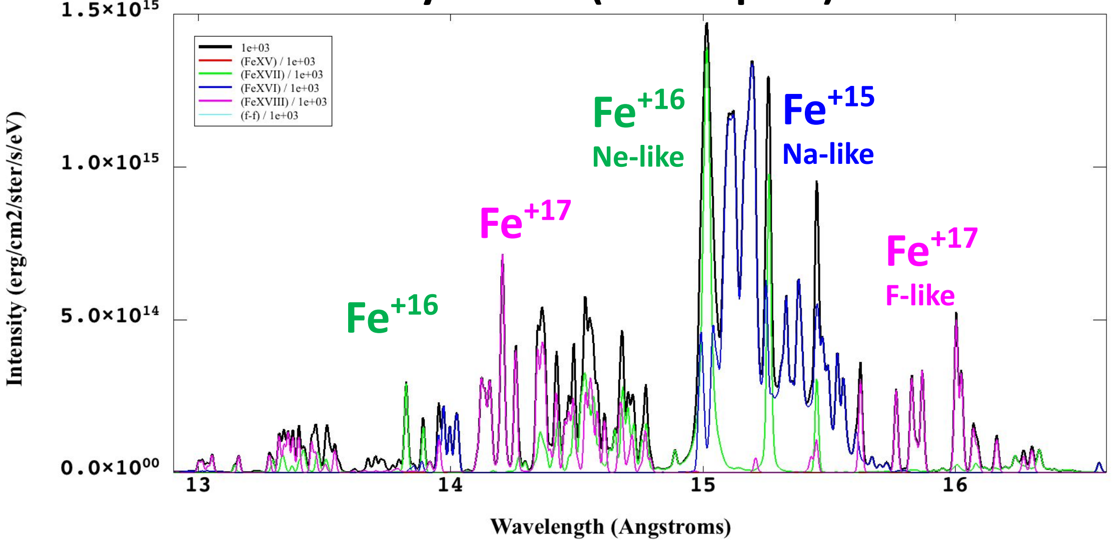
Fe L-shell emission image on Z (XRS[3])



Photoionized Iron L-shell and Calcium K-shell ions are created **when sample is located closer to the z-pinch (~3cm).** **<u>Observed charge state distributions can be compared against model predictions.</u>**

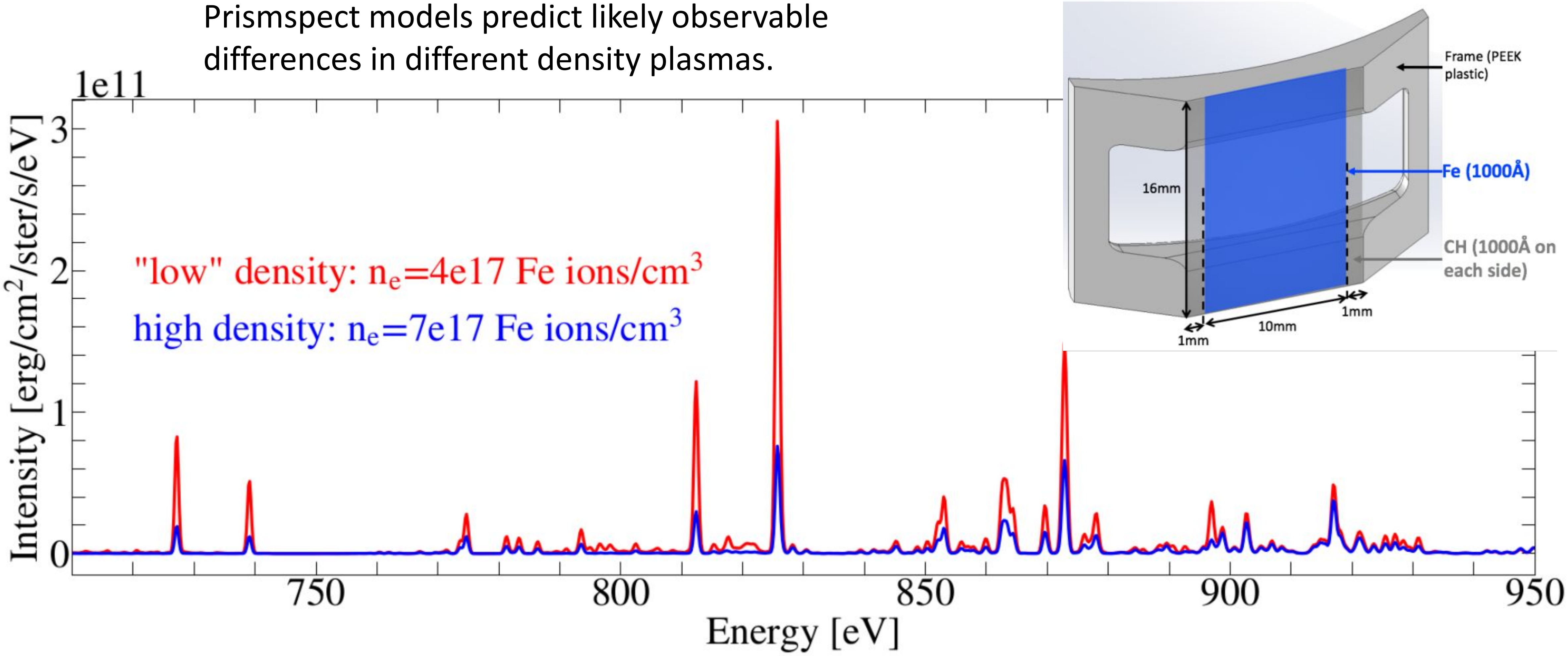


Preliminary model (Prismspect)



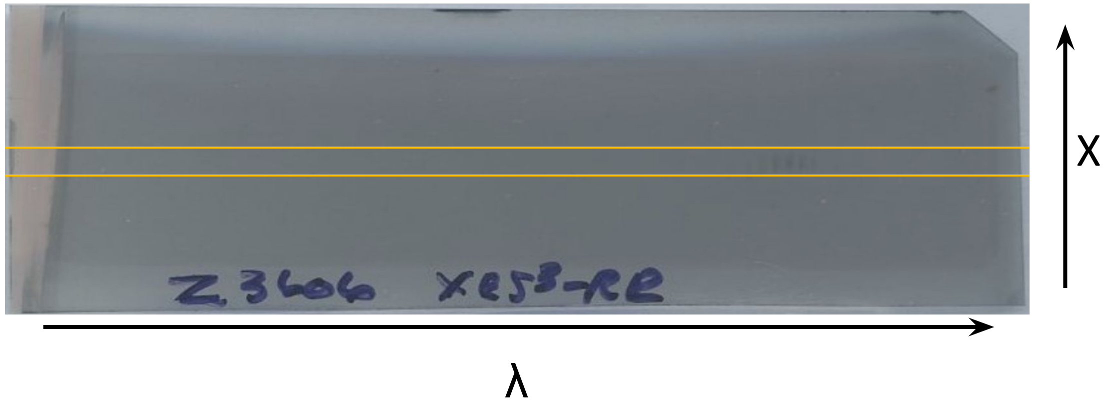
Thicker tamper material will be used to achieve different densities and interrogate relative density effects in XSTAR

Prismspect models predict likely observable differences in different density plasmas.



Potential future line of inquiry: Calcium can be used as a surrogate to examine K-shell behavior instead of Iron

Ca K-shell emission image on Z (XRS[3])



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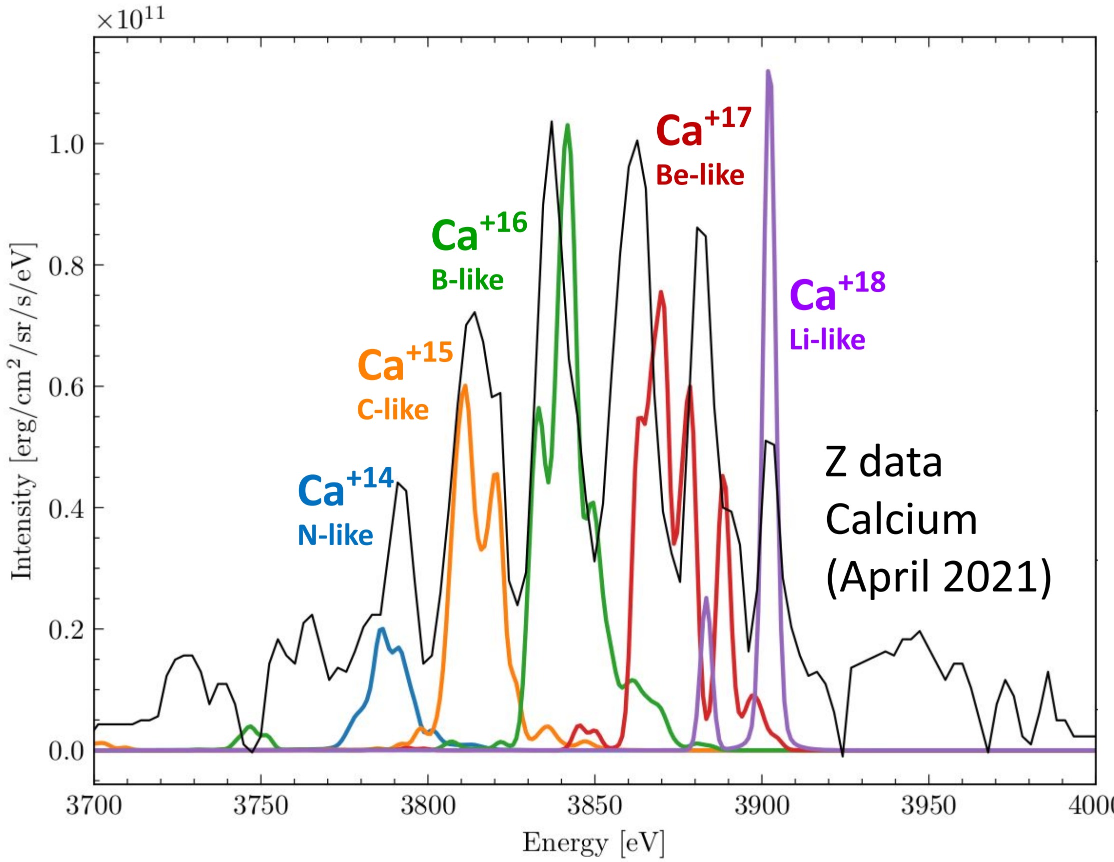
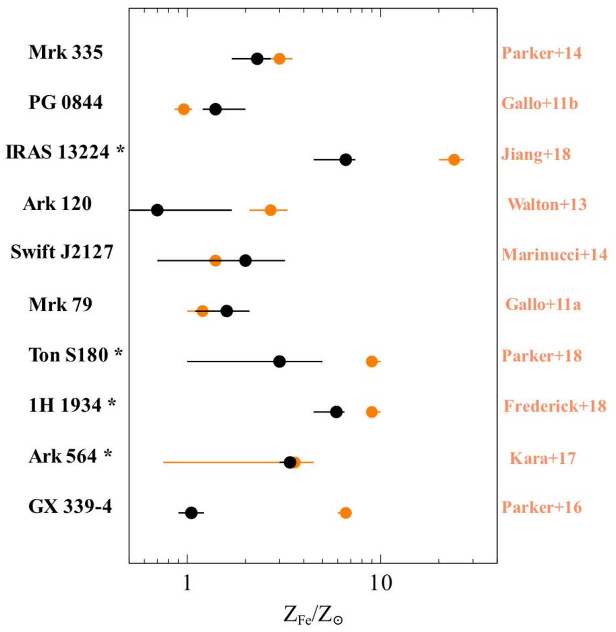
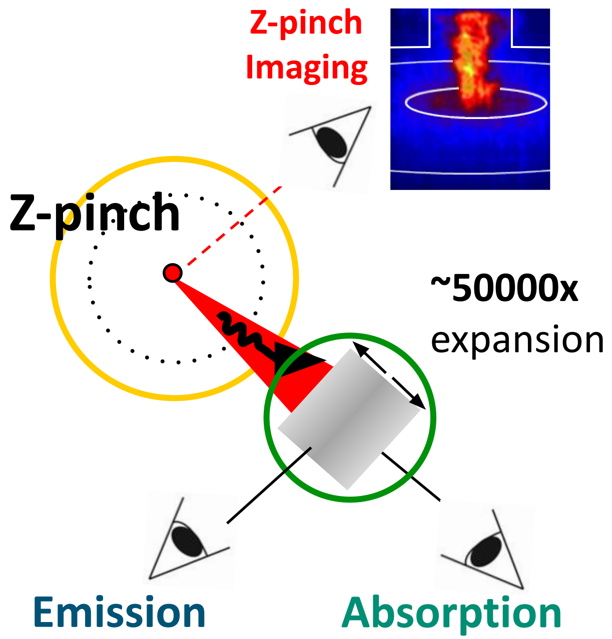


Summary: the new high density version of astrophysical code XSTAR shows promise but requires validation from the laboratory

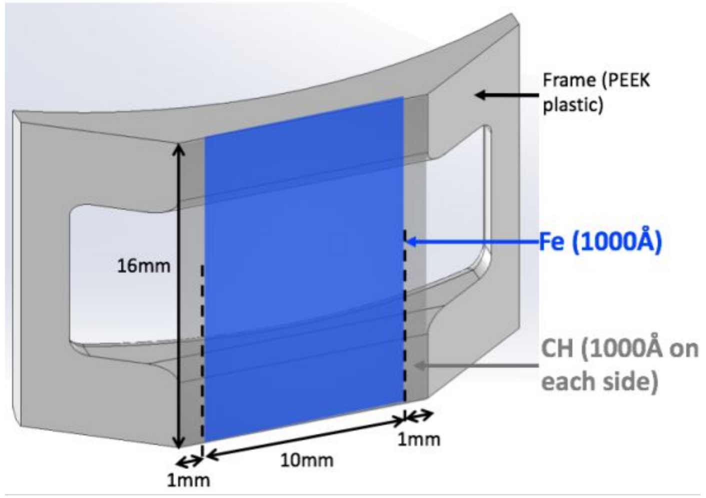
New high density plasma effects in XSTAR have informed the supersolar Fe abundance problem



We have built a laboratory analog for black hole accretion disks that we can use to test the microphysics



We collected Fe L-shell and Ca K-shell data. Variable density Fe plasma data will help validate the models.



Remaining Challenge: Properly characterize the X-ray drive for a valid input to the models.