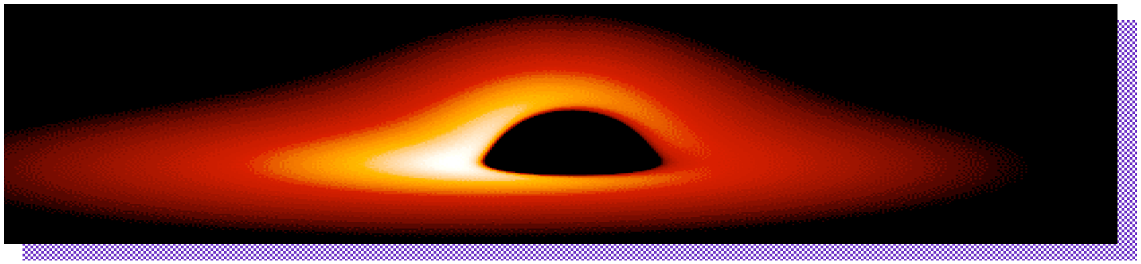
A Monte Carlo Treatment of Radiation Transfer in Black Hole Accretion Disks



Christopher Mauche

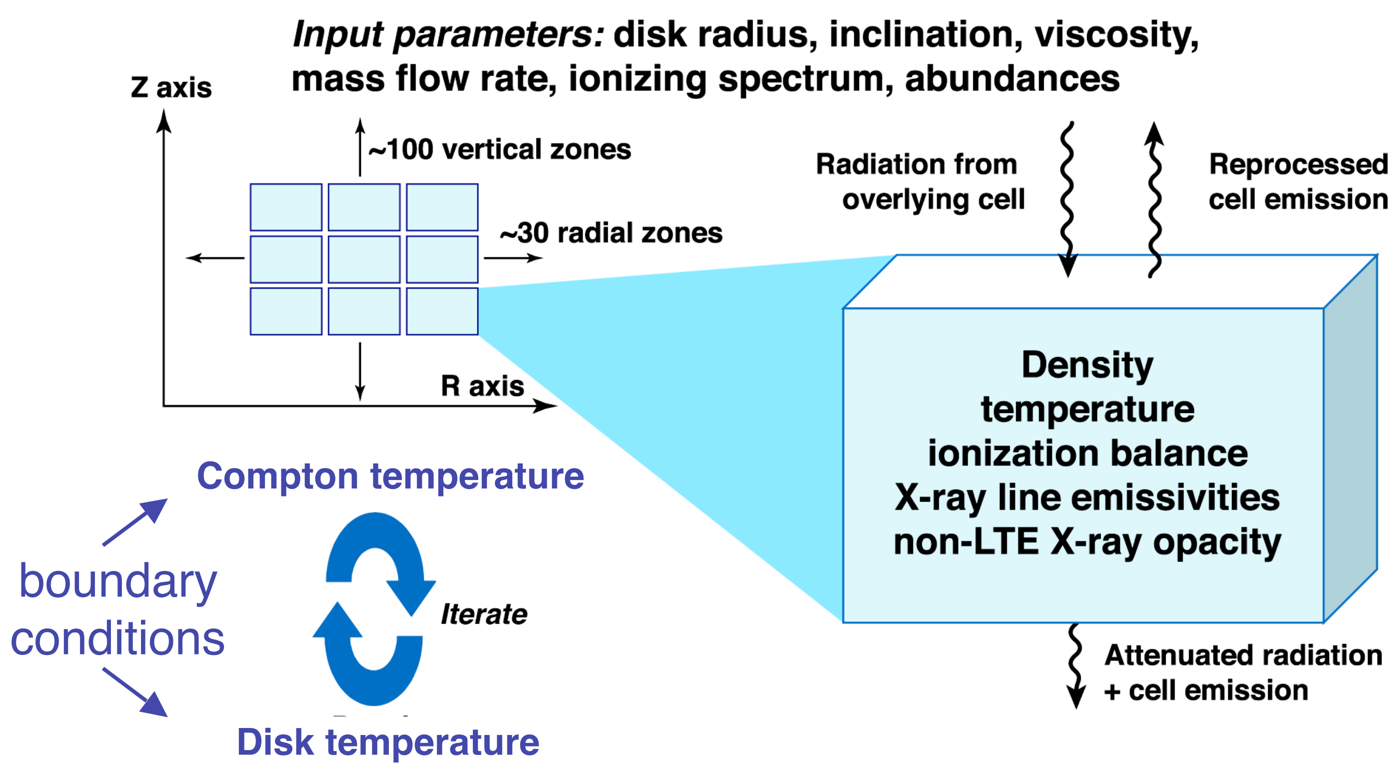
Duane Liedahl

Benjamin Mathiesen

Mario Jimenez-Garate

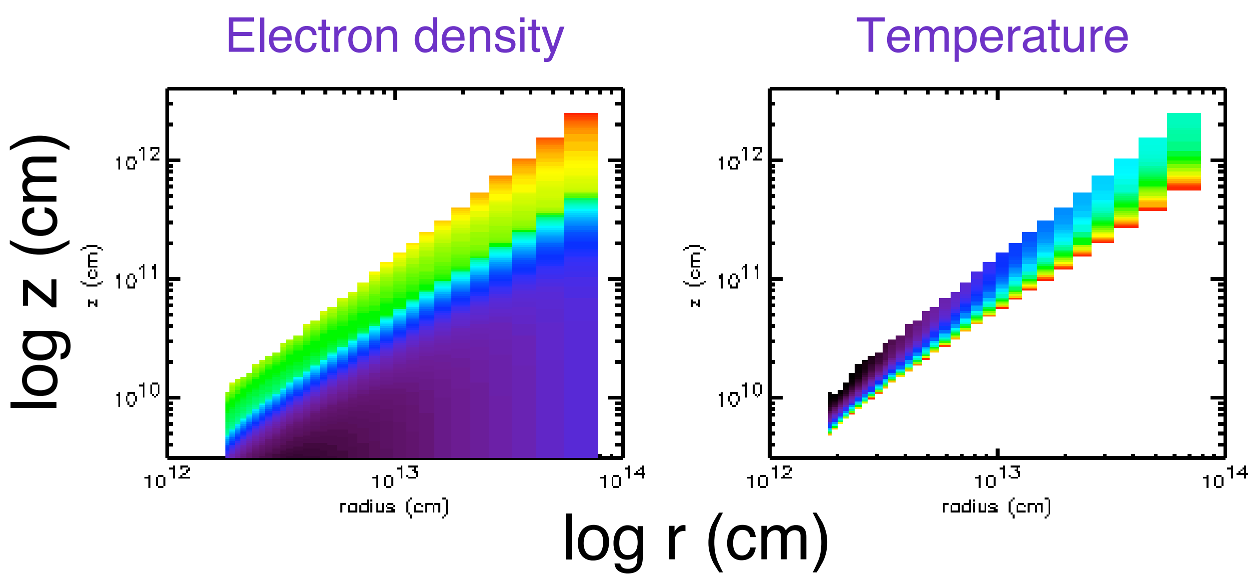
John Raymond

Calculation of 2-dimensional disk structure



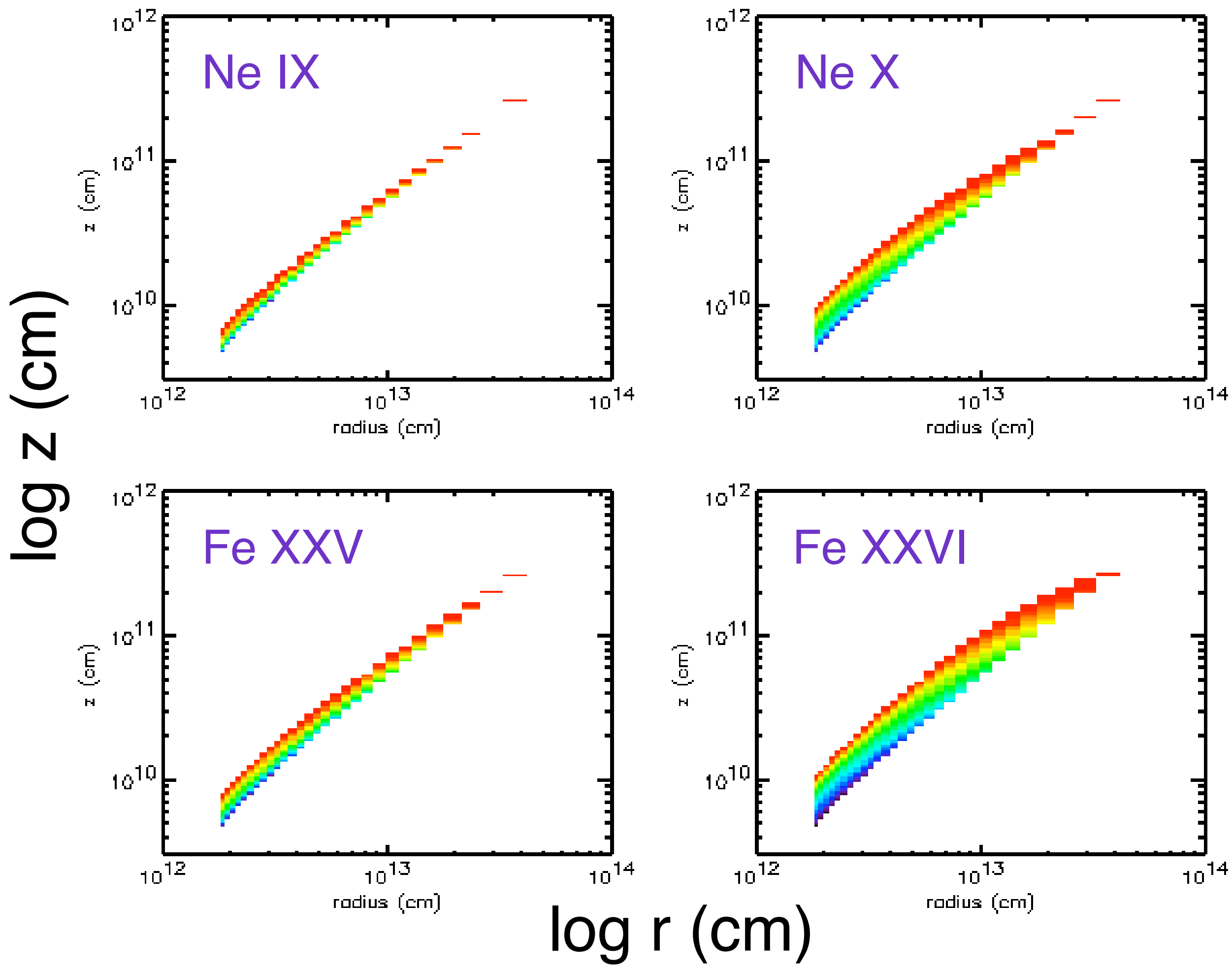
Jimenez-Garate, Raymond, Liedahl, & Hailey (2001, *ApJ*, 558, 448)
Jimenez-Garate, Raymond, & Liedahl (2002, *ApJ*, 581, 1297)

Structure calculation provides the conditions for the Monte Carlo calculation



- Monte Carlo code can be configured to track:
  - Photons coming in from above (external irradiation) ★
  - Photons coming up from below (from the accretion disk)
  - Thermal bremsstrahlung continuum photons
  - Recombination radiation lines and continua ★

Representative Lyman α line emissivities



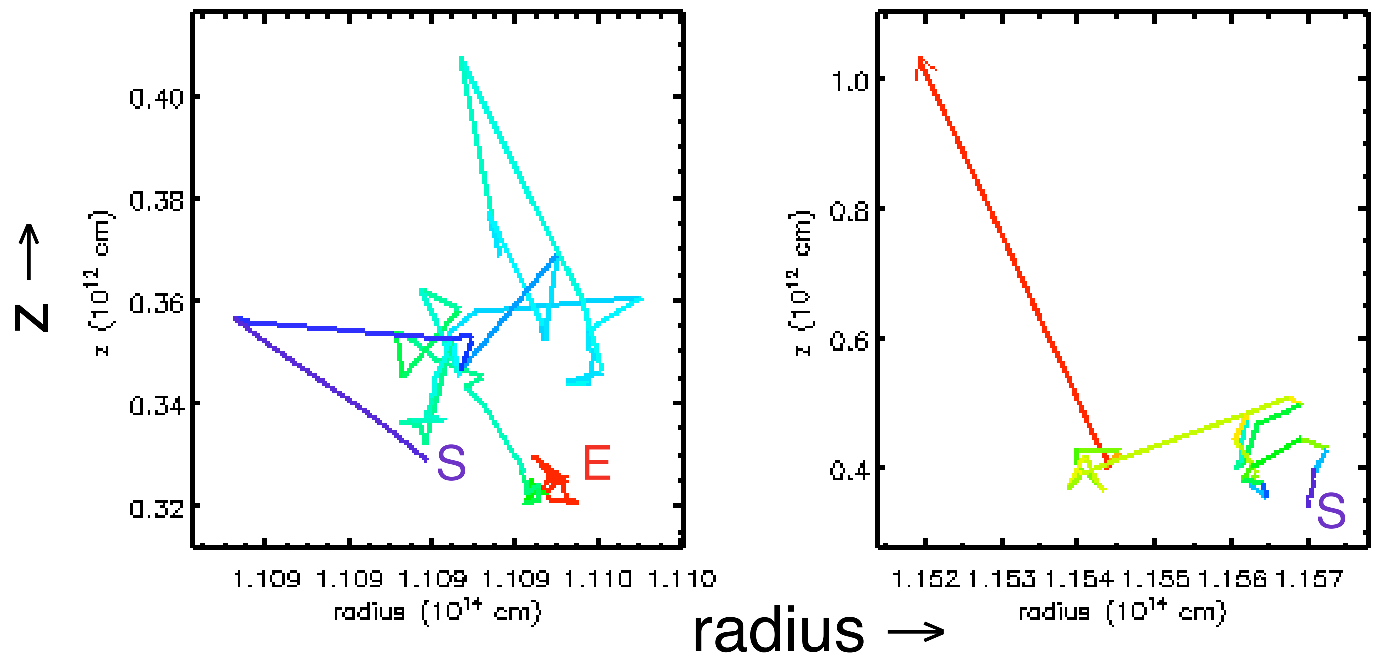
Code accounts for:

- Compton scattering by Maxwellian electrons:
  - $\Pi_{final} = Q\,(\Delta\theta, \Delta\phi) \bullet$
    $[R_{e\phi}^{-1}\, R_{e\theta}^{-1}\, \Lambda^{-1}\; R_{\nu\phi}^{-1}\, R_{\nu\theta}^{-1}\, R_{\Delta\phi}\, R_{\Delta\theta}\; R_{\nu\theta}\; R_{\nu\phi}\; \Lambda\; R_{e\theta}\;\; R_{e\phi}\,]\; \Pi_{initial}\,.$
- Photoionization:
  - Verner & Yakovlev (1995) photoionization cross sections:
    - 446 edges of 140 ions of 12 elements
- Recombination lines and continua:
  - following photoionization of K-shell ions.
- Fluorescence lines:
  - following inner-shell photoionization of M-shell ions
    - use a fixed energy and yield regardless of charge state.

Monte Carlo code tracks the complex interactions and trajectories of individual photons

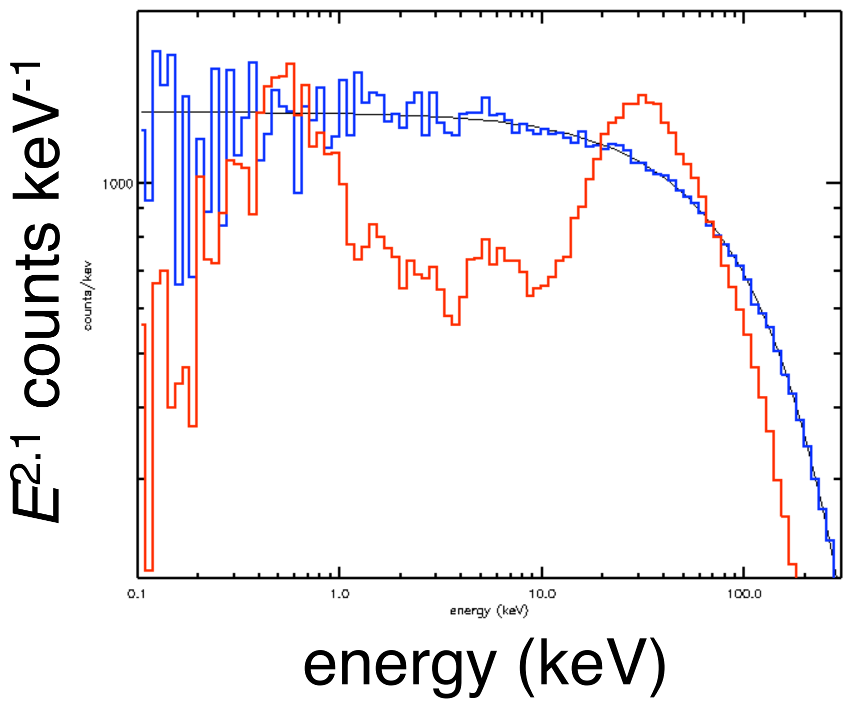
Photon destroyed

Photon escapes



Colors encode the relative energy of the photon, starting (S) with purple and ending (E) with red.

Case of external illumination



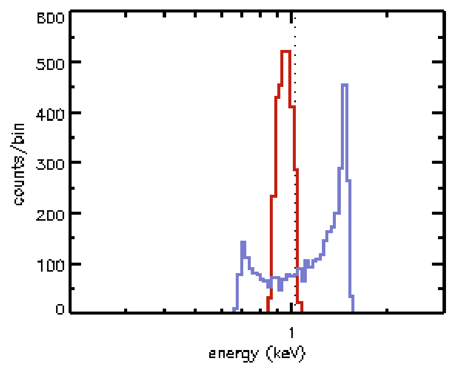
blue:
incident spectrum:
cut-off power law:
$dN/dE = E^{-2.1}\exp(-E/150)$

red:
reflected spectrum

Reflected spectrum shows the characteristic Compton bump at ~ 30 keV and a complex pattern at low energies due to recombination emission and photoionized bound-free opacities.

Case of recombination emission: Ne X Ly α ...

Rotation only



Ne X Lyman α
1.02 keV

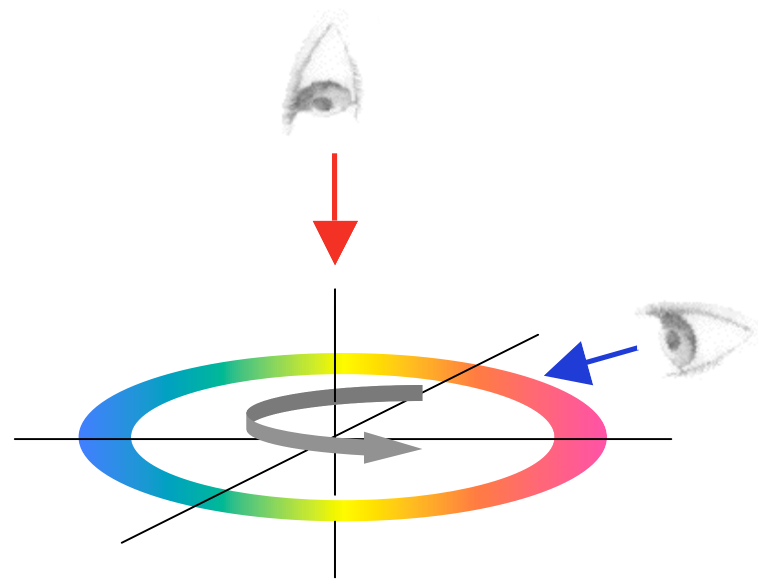
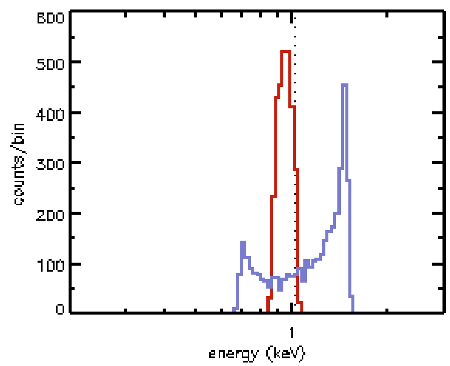
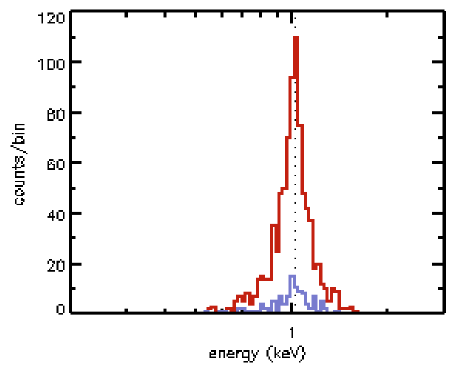


Figure shows Ne X Lyman α line profiles for observers at $i = 0^o$ (red) and $i = 75^o$ (blue). The rotation velocity $\beta = 0.37$.

Case of recombination emission: Ne X Ly α ...

Rotation only



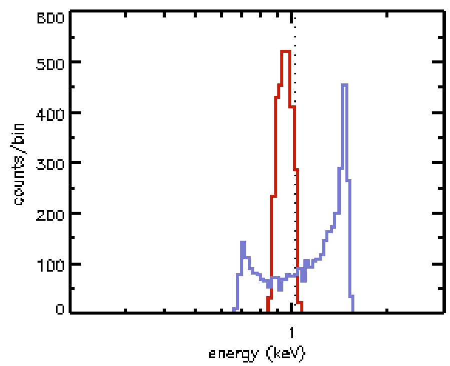


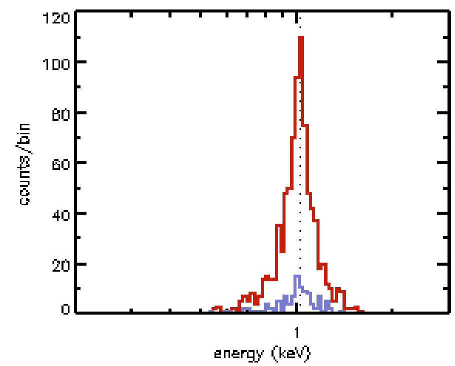
Compton scattering

Compton scattering broadens the profiles.

Case of recombination emission: Ne X Ly α ...

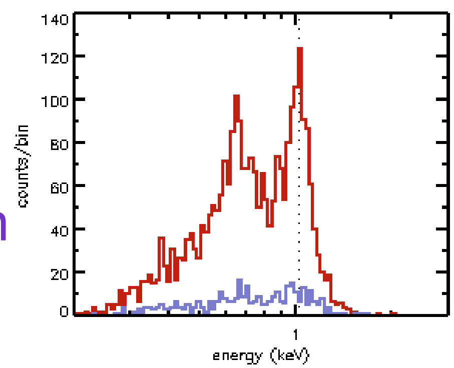
Rotation only





Compton scattering

Compton scattering + Recombination



Recombination emission transforms Ne X Lyman α photons into O VIII Lyman α, β, and recombination continua photons.

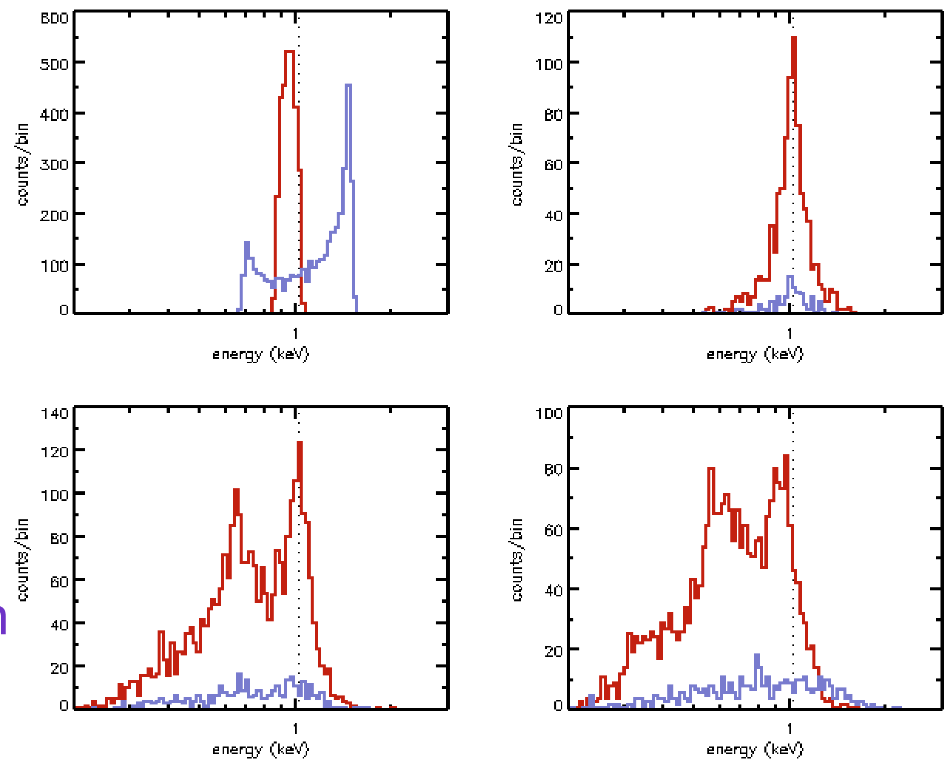
Case of recombination emission: Ne X Ly α

Rotation only

Compton scattering

Compton scattering + Recombination

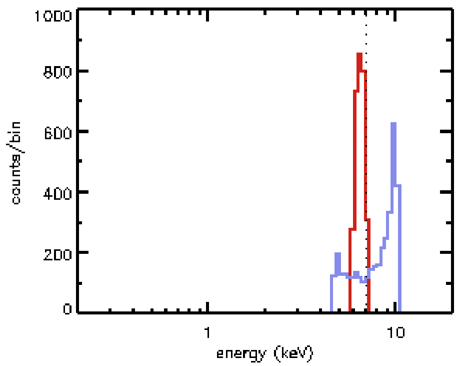
Compton scattering + Recombination + Rotation



Rotation broadens the profiles, shifts the peaks to lower (higher) energies for small (large) disk inclinations.

Case of recombination emission: Fe XXVI Ly α ...

Rotation only



Fe XXVI Lyman α
6.97 keV

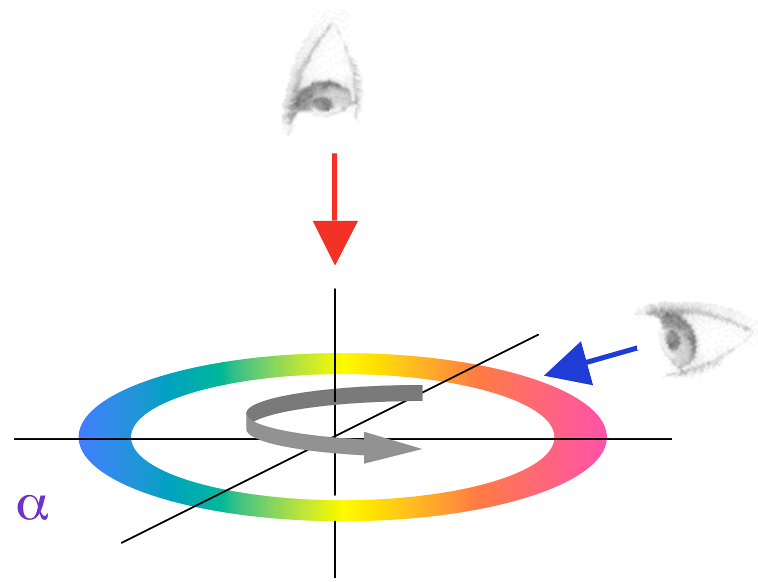
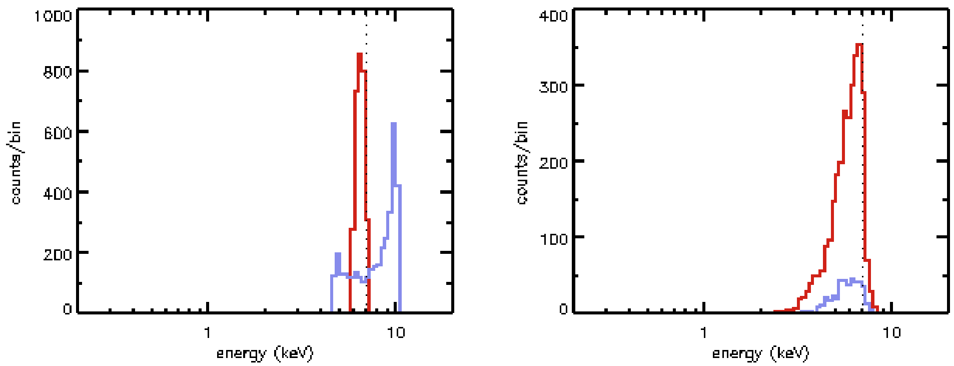


Figure shows Fe XXVI Lyman α line profiles for observers at $i = 0^{o}$ (red) and $i = 75^{o}$ (blue). The rotation velocity $\beta = 0.37$.

Case of recombination emission: Fe XXVI Ly α ...

Rotation only

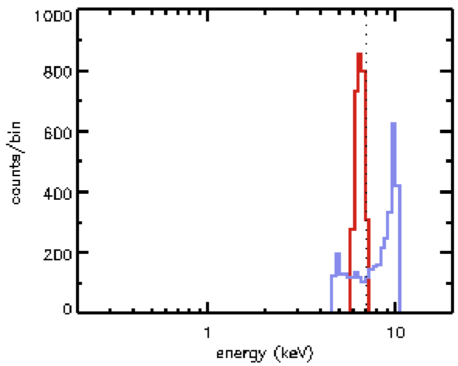


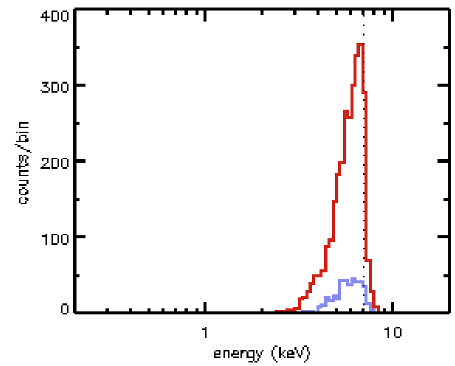
Compton scattering

Compton scattering broadens the profiles and skews them to the red.

Case of recombination emission: Fe XXVI Ly α ...

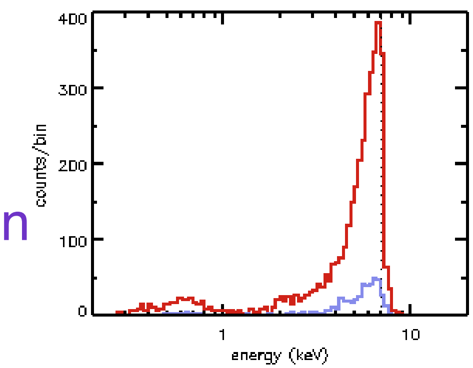
Rotation only





Compton scattering

Compton scattering + Recombination



Recombination emission transforms Fe XXVI Lyman α photons into various Lyman α, β, and recombination continua photons.

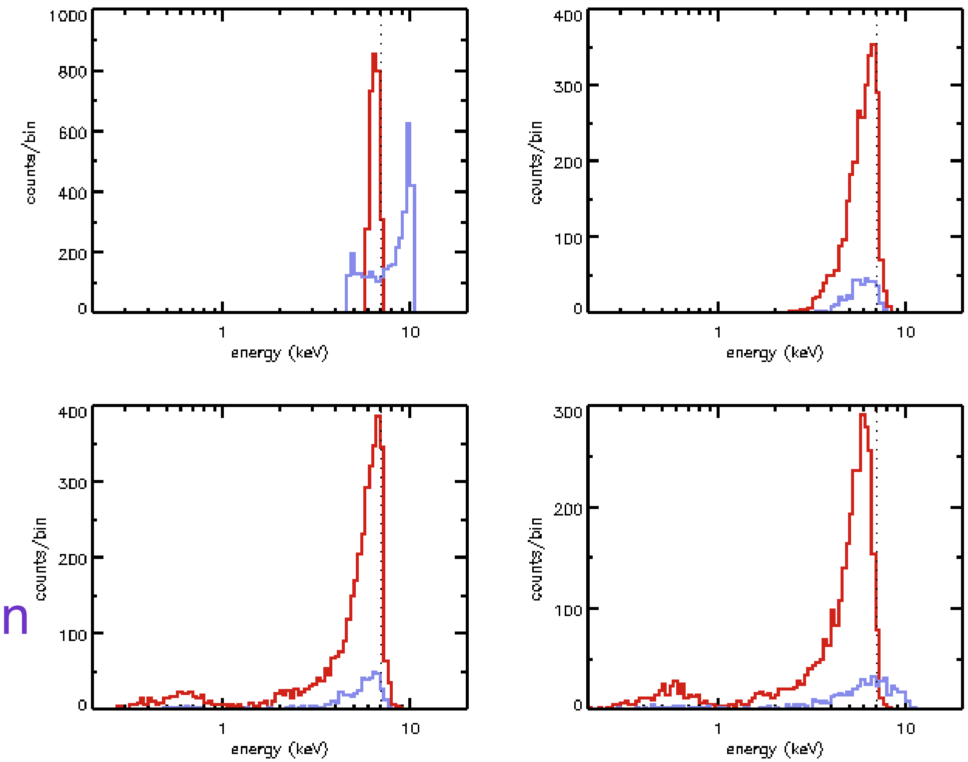
Case of recombination emission: Fe XXVI Ly α

Rotation only

Compton scattering

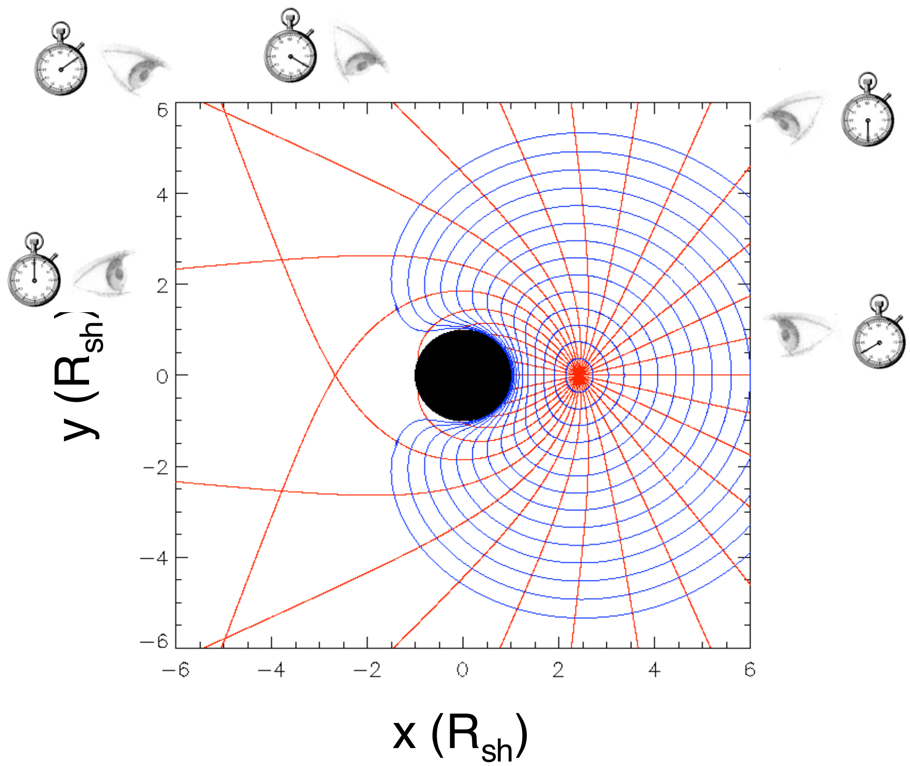
Compton scattering + Recombination

Compton scattering + Recombination + Rotation



Rotation broadens the profiles, shifts the peaks to lower (higher) energies for small (large) disk inclinations.

Planned improvements to the code: 1



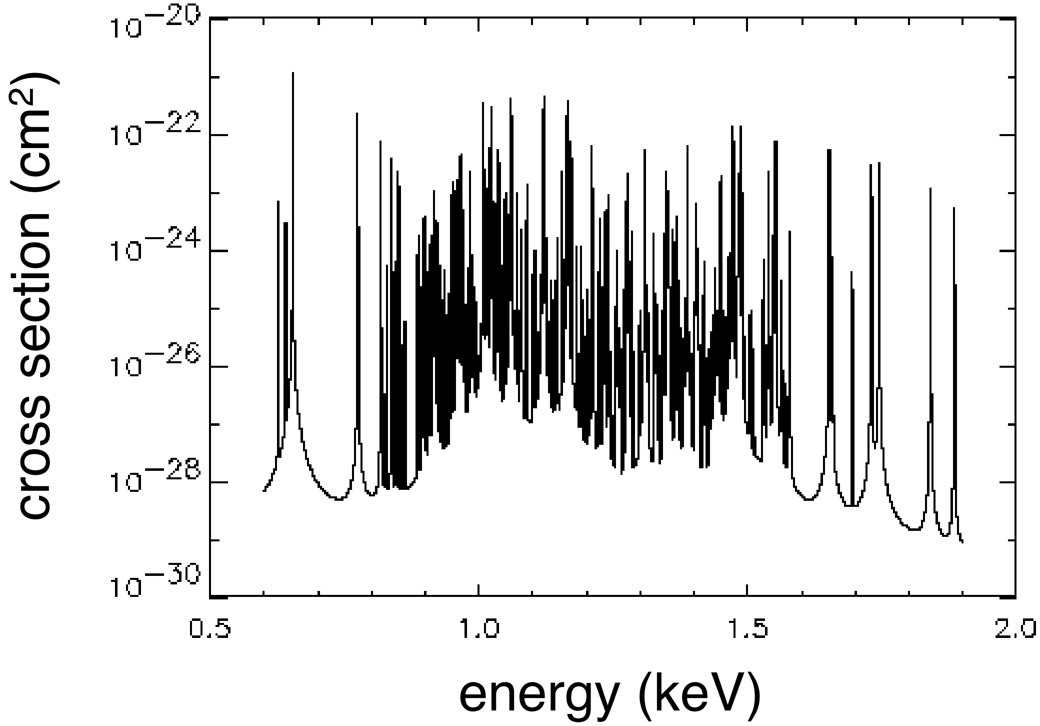
red:
photon geodesics

blue:
isochrones

Add geodesic solver to account for light bending

for both Schwarzschild and Kerr black holes

Planned improvements to the code: 2



Add line opacity using LLNL atomic models

Planned improvements to the code: 3

Port to LLNL ASCI supercomputer

Auspices statement

This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.