Cyclotron Lines

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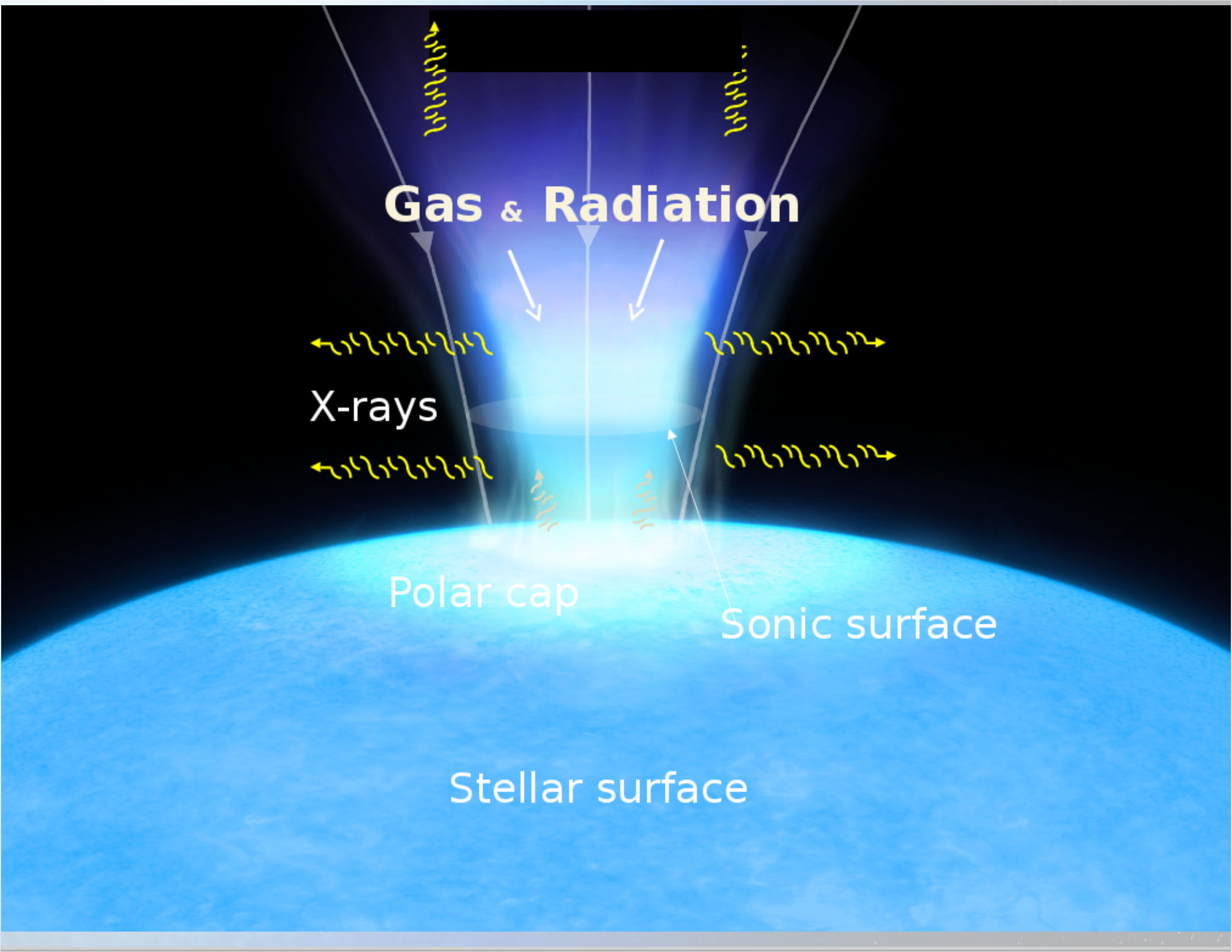
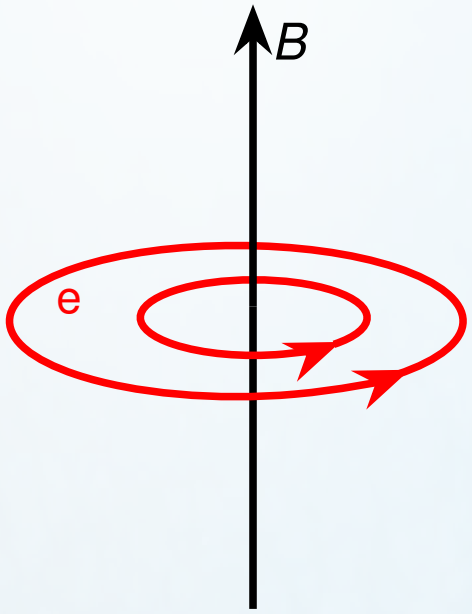

Gas & Radiation
X-rays
Polar cap
Sonic surface
Stellar surface

CRSF

Strong field at NS poles: Quantization of electron energies $\perp$ B-field lines (Landau levels):

$$E_n = m_e c^2 \frac{\sqrt{1 + 2n(B/B_{\rm crit}) \sin^2\theta} - 1}{\sin^2\theta}$$

$p_\parallel$: momentum of electron $\parallel$ B-field, n: major quantum number, $B_{\rm crit}$ is



$$B_{\rm crit} = \frac{m_e^2 c^3}{e\hbar} \sim 4.4 \times 10^{13}\,{\rm G}$$

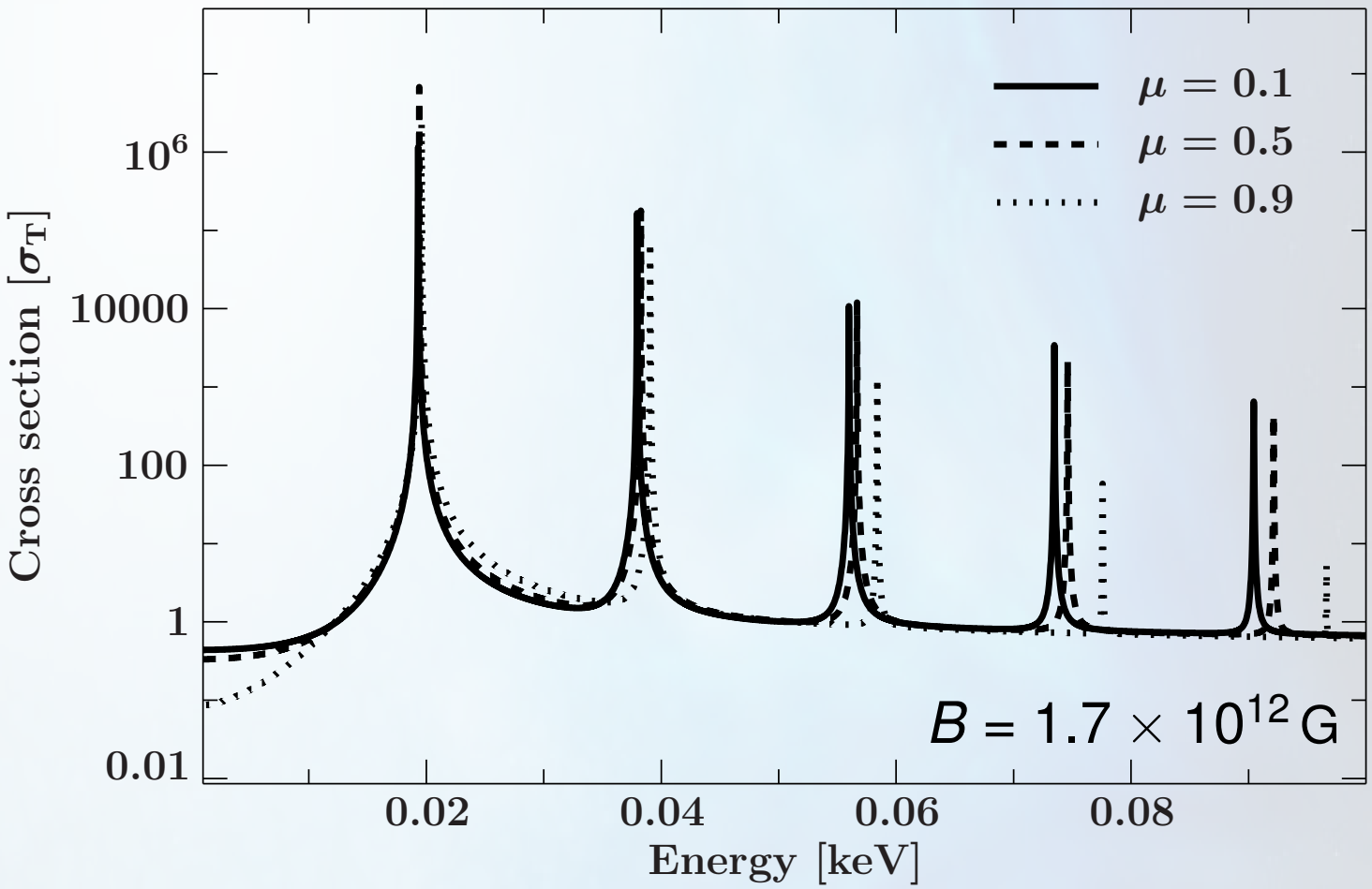
For $B \ll B_{\rm crit}$, distance between Landau levels:

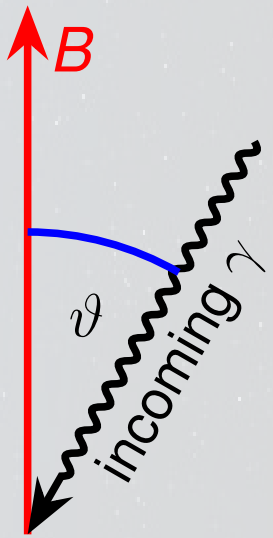
$$E_{\rm cyc} = \frac{\hbar e}{m_e c} B = 11.6\,{\rm keV} \left(\frac{B}{10^{12}\,{\rm G}}\right) \quad (\text{“}12\text{-}B_{12}\text{-rule”})$$

$\Longrightarrow$ Cyclotron Resonance Scattering Features (“Cyclotron lines”) at

$$E_n = nE_{\rm cyc} = (1 + z_{\rm grav}) E_{n,{\rm obs}}, \quad \text{where } 1 + z_{\rm grav} \sim 1.25 \ldots 1.4$$

Cross Sections





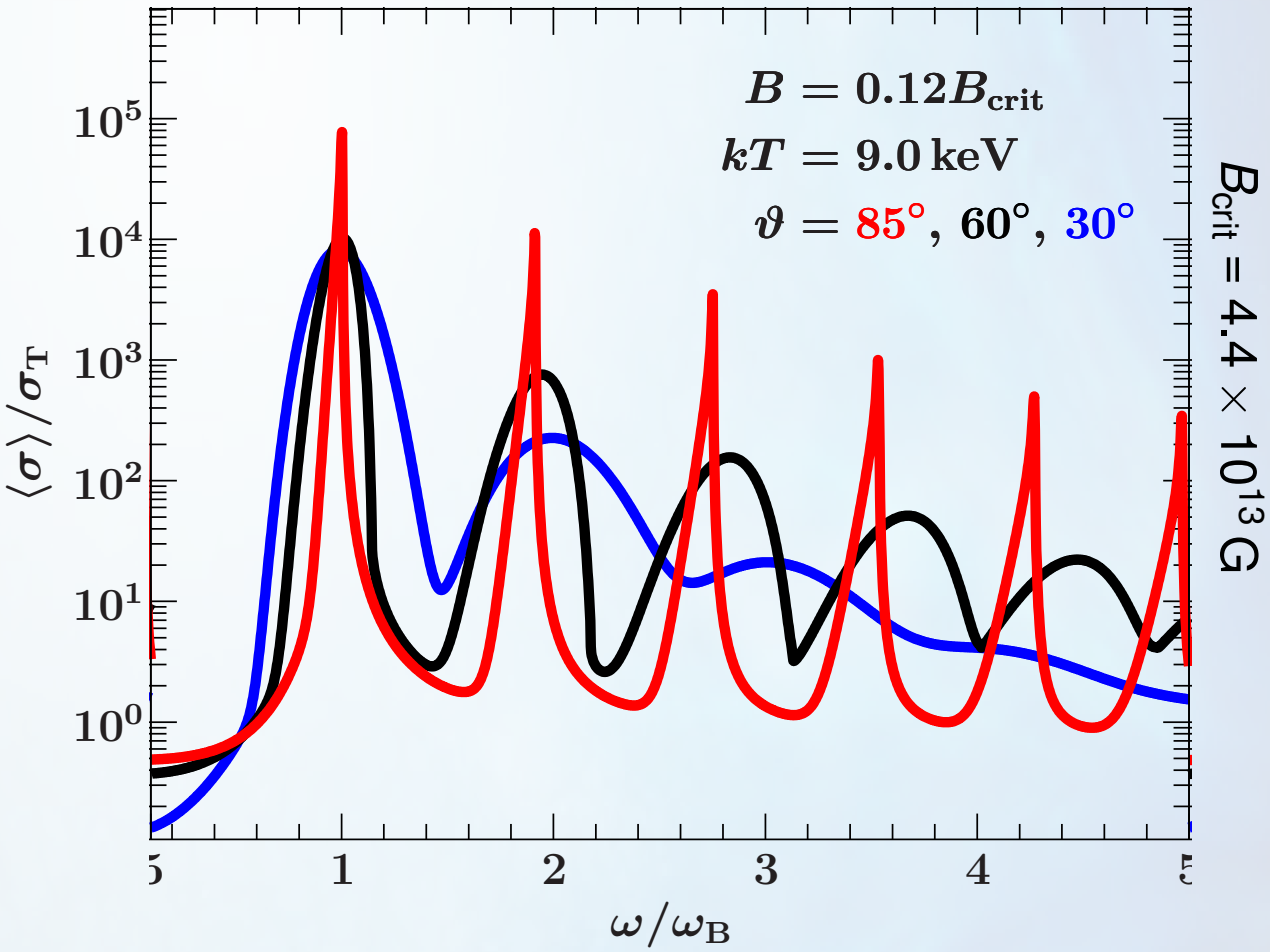
$\mu = \cos\vartheta$

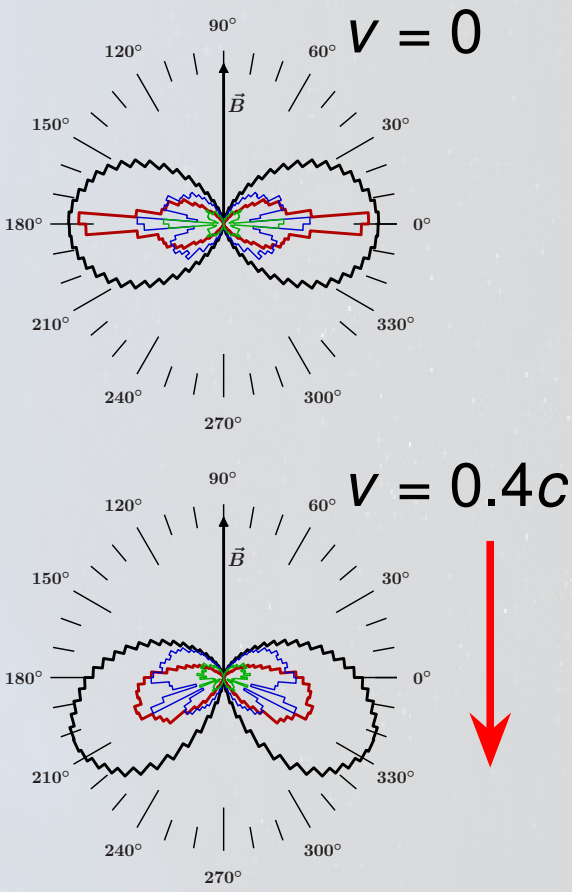
Schwarm et al. (2016, to be submitted): σ

Effective cross section is strong function of E and angle

Derivation: e.g., Bussard et al. (1986), Sina (1996), using Breit-Wigner broadening approximation, electron wave functions from Sokolov et al. (1968)

Cross Sections

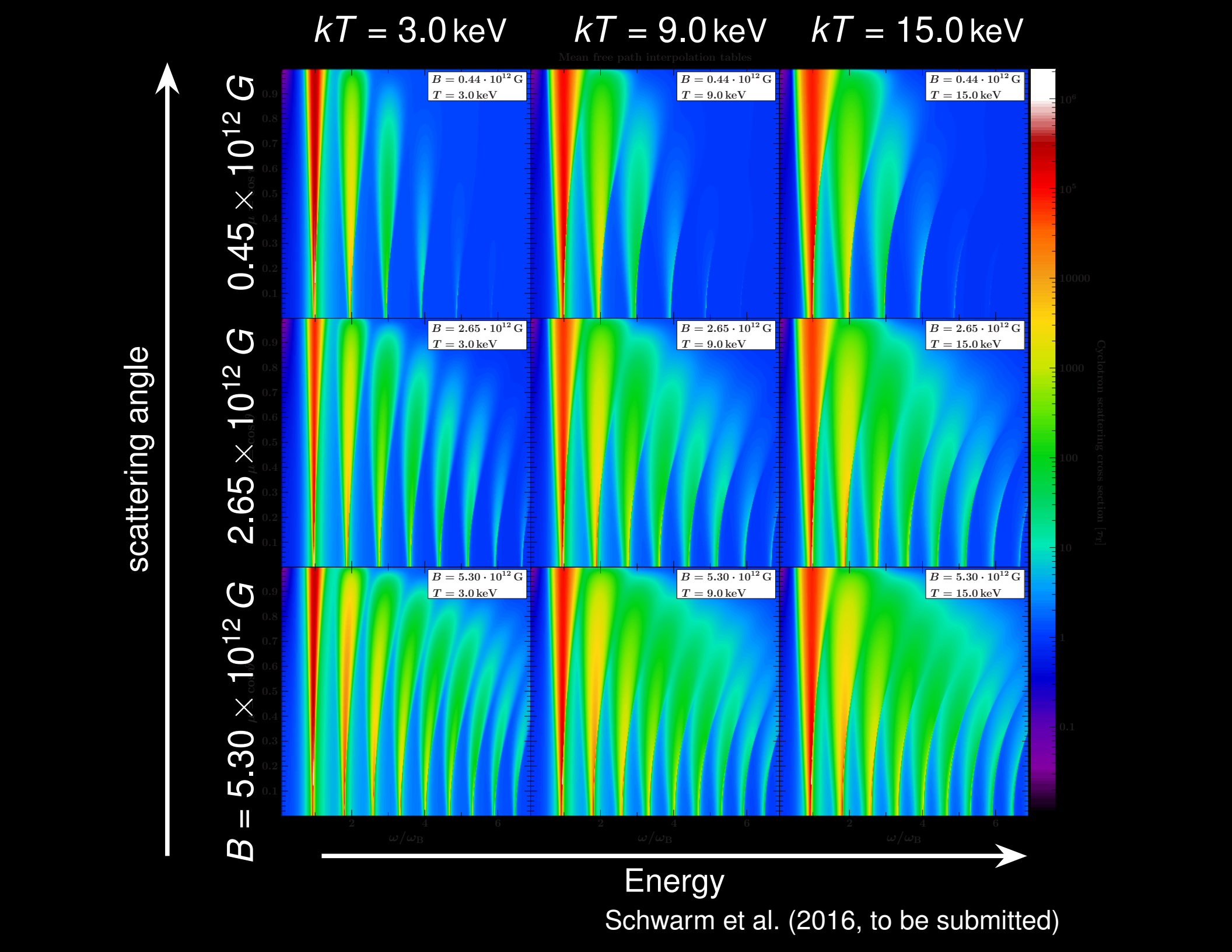




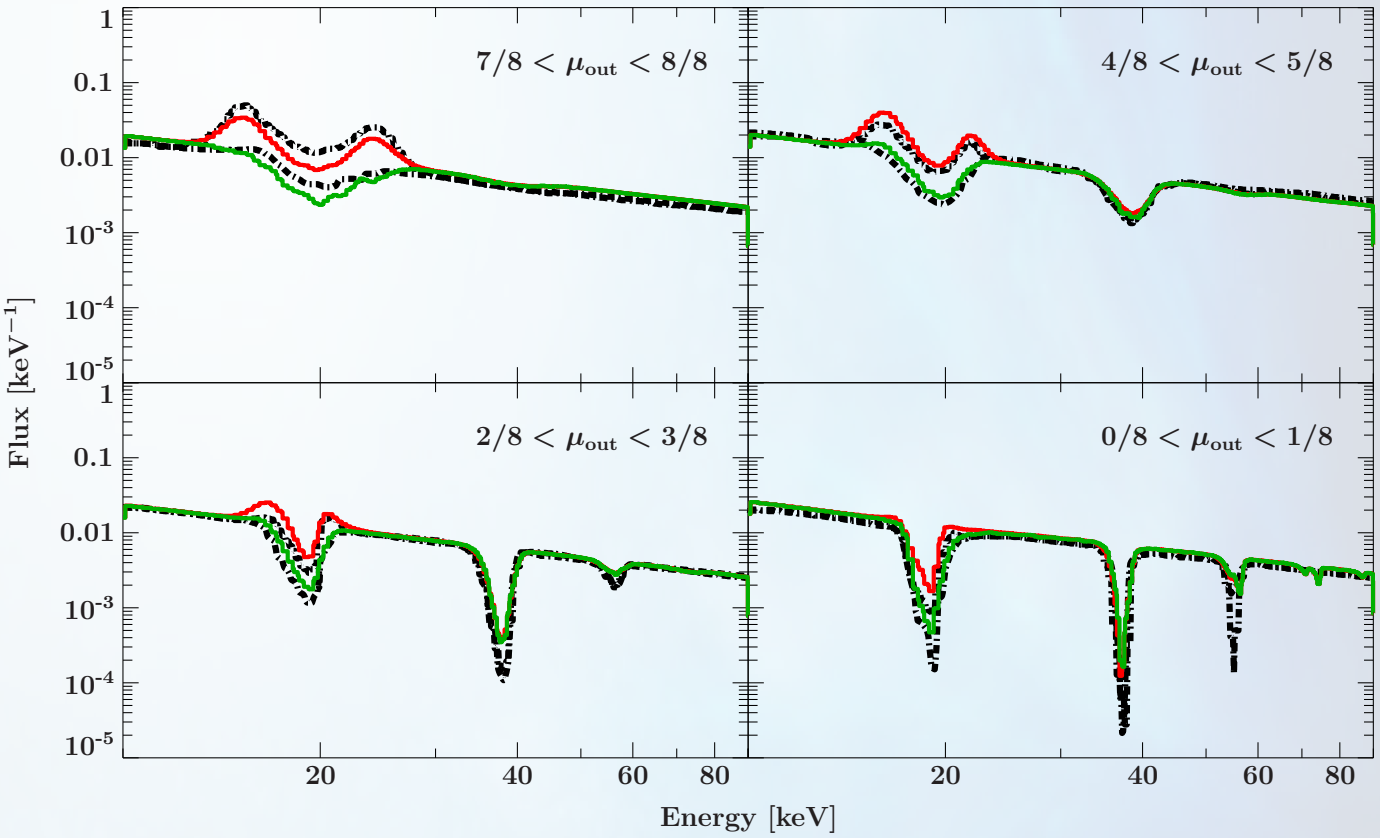
Schwarm et al. (2016, to be submitted): σ, convolved w/relativistic Maxwell

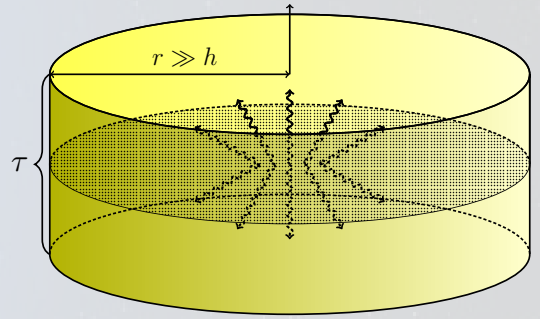
Effective cross section is strong function of E and angle

Derivation: e.g., Bussard et al. (1986), Sina (1996), using Breit-Wigner broadening approximation, electron wave functions from Sokolov et al. (1968)

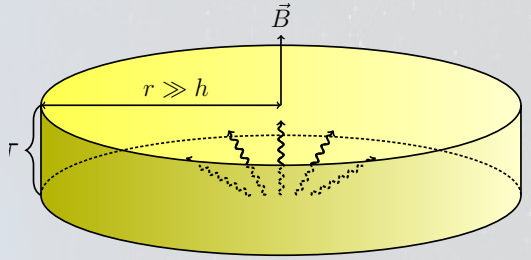

kT = 3.0 keV
kT = 9.0 keV
kT = 15.0 keV
Mean free path interpolation tables
$B = 0.44 \cdot 10^{12}$ G
$T = 3.0$ keV
$B = 0.44 \cdot 10^{12}$ G
$T = 9.0$ keV
$B = 0.44 \cdot 10^{12}$ G
$T = 15.0$ keV
$B = 2.65 \cdot 10^{12}$ G
$T = 3.0$ keV
$B = 2.65 \cdot 10^{12}$ G
$T = 9.0$ keV
$B = 2.65 \cdot 10^{12}$ G
$T = 15.0$ keV
$B = 5.30 \cdot 10^{12}$ G
$T = 3.0$ keV
$B = 5.30 \cdot 10^{12}$ G
$T = 9.0$ keV
$B = 5.30 \cdot 10^{12}$ G
$T = 15.0$ keV
$B = 0.45 \times 10^{12}$ G
$B = 2.65 \times 10^{12}$ G
$B = 5.30 \times 10^{12}$ G
μ_{cos}
ω/ω_B
Cyclotron scattering cross section [πr_e^2]
scattering angle
Energy
Schwarm et al. (2016, to be submitted)

Line Profiles





slab 1-0



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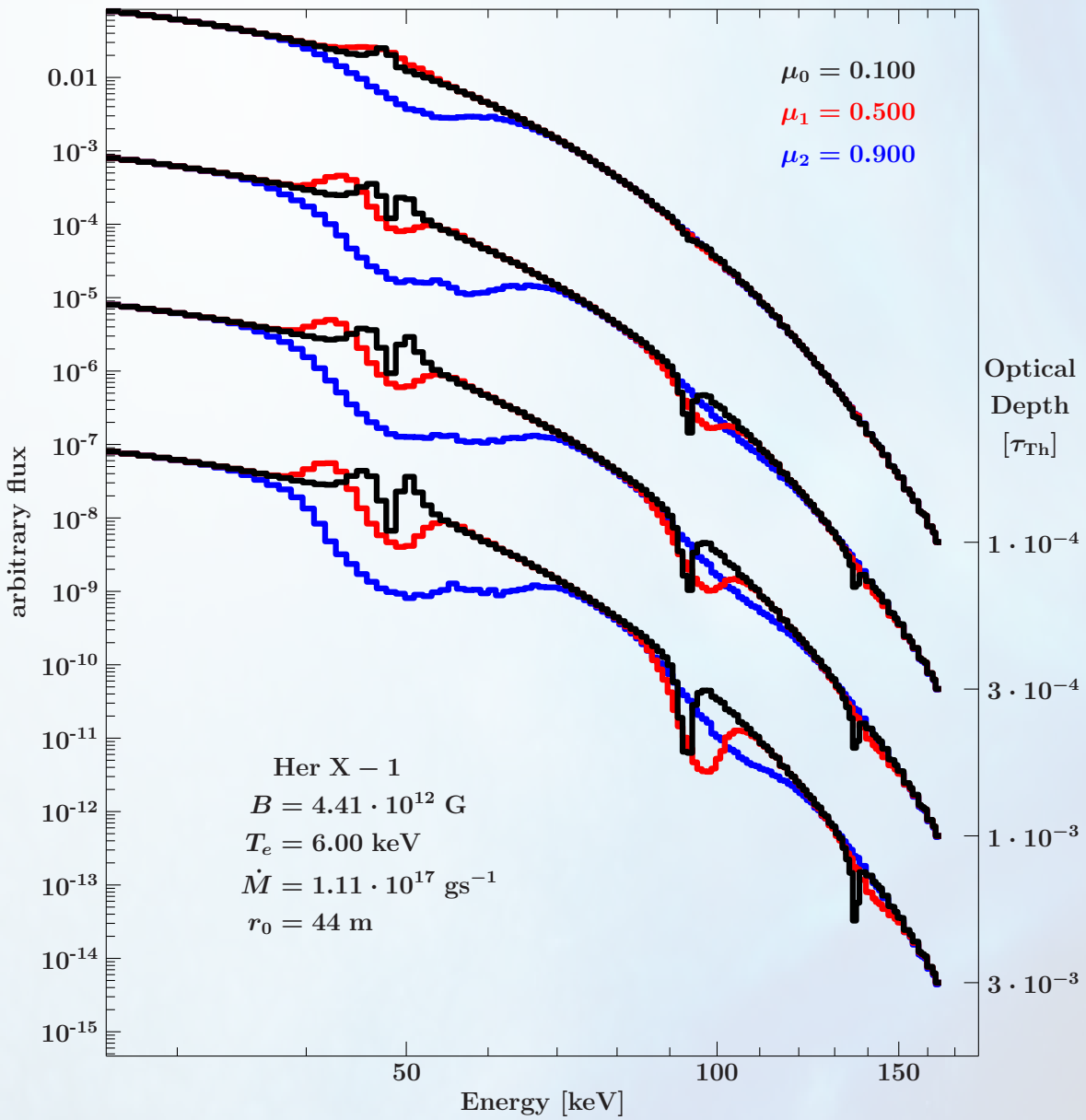
Monte Carlo simulations: complex, geometry dependent line shapes:

- asymmetry due to relativistic Maxwell
- wings from “photon spawning”

  photons emitted by excited electron cascading to ground state

earlier works, e.g., Nagel (1980), Isenberg et al. (1998), Araya & Harding (1999), Araya-Góchez & Harding (2000),. . .

Summary



- Cyclotron lines: allow *direct* measurement of *B*-field in line formation region *and* obtain further clues on geometry of accretion column
- Calculation of lines very challenging due to strong angle and energy dependency of the cross section
- Solution of radiative transfer problem with Monte Carlo approach
- Large grid of Green's functions for different scattering geometries is about to be released.

see Schönherr et al. (2007)

References

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