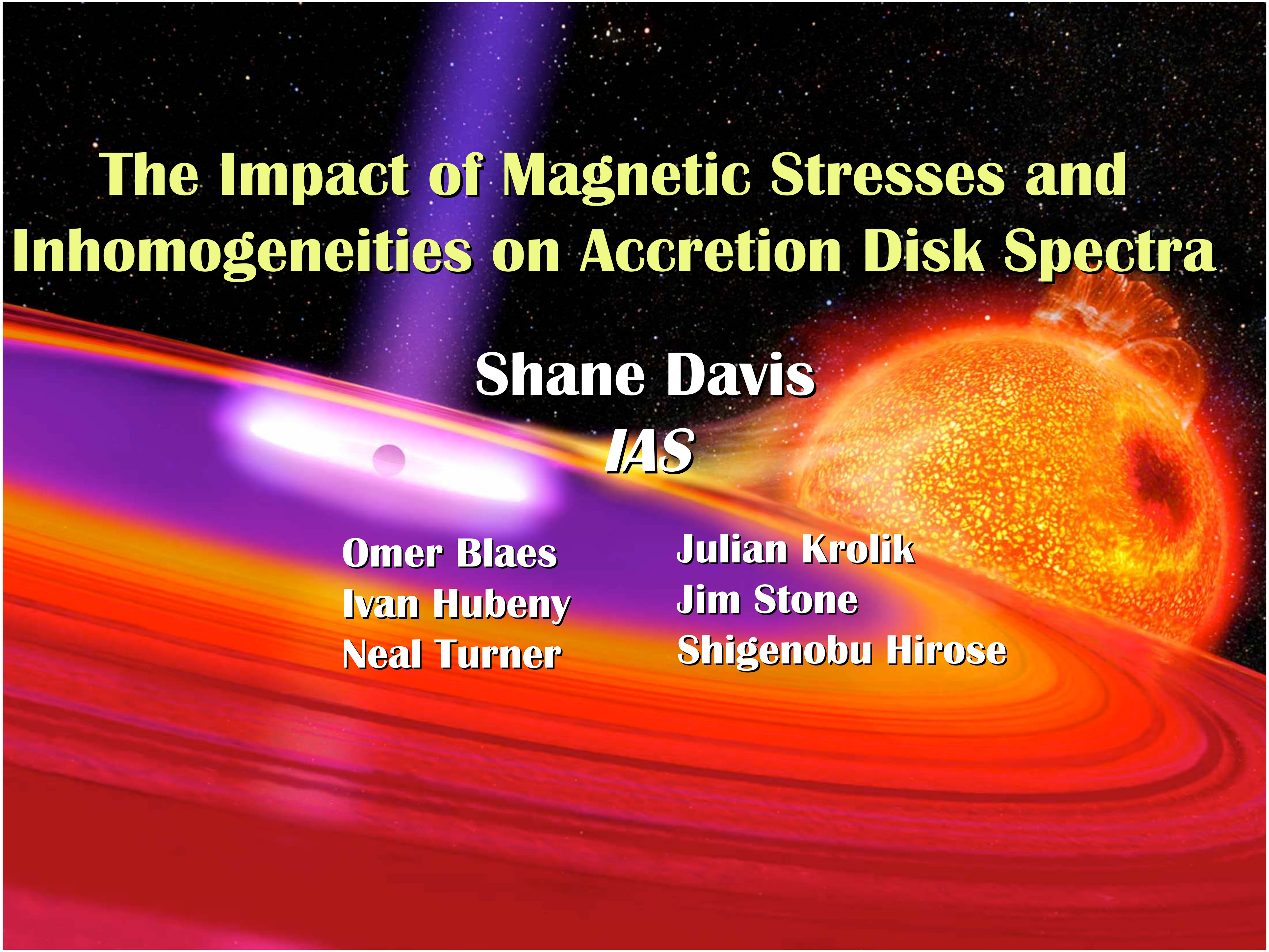

The Impact of Magnetic Stresses and Inhomogeneities on Accretion Disk Spectra

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Questions Addressed in This Talk

- How do magnetic fields and associated inhomogeneities affect disk spectra? (concentrate on local effects)
- What can we learn from (local) accretion disk simulations?
- What impact does this have on spin estimates?

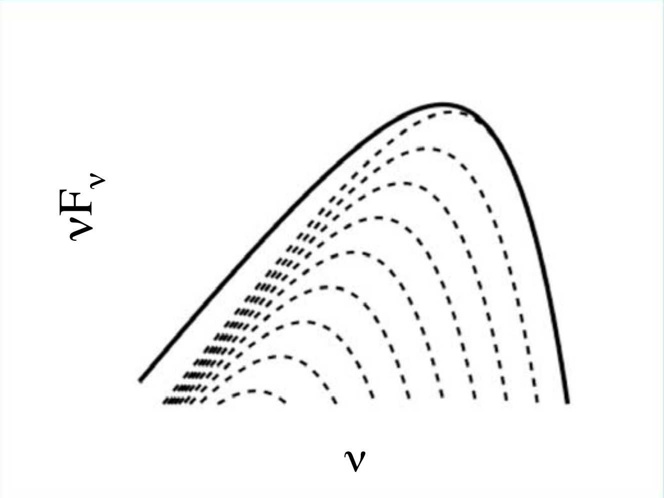
The Multicolor Disk Model

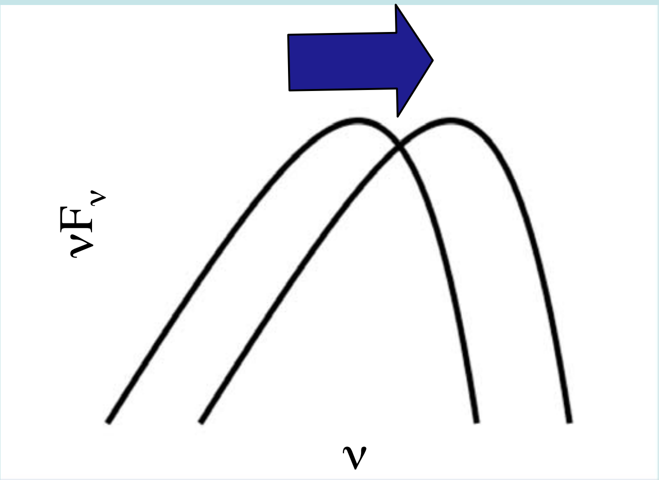
- **Assumes simple temperature distribution:**

$$T_{\rm eff} \propto R^{-3/4}$$

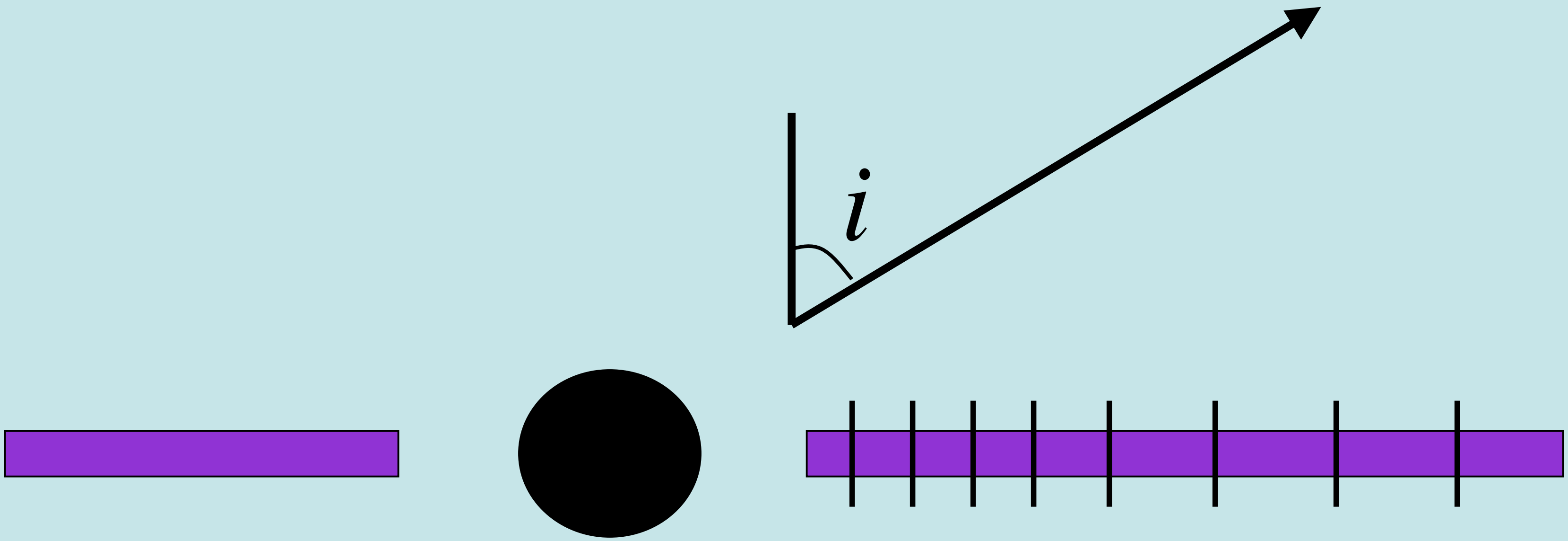
- **Spectrum assumed to be color-corrected blackbody:**

$$I_\nu = f_{\rm col}^{-4} B_\nu(f_{\rm col} T_{\rm eff})$$

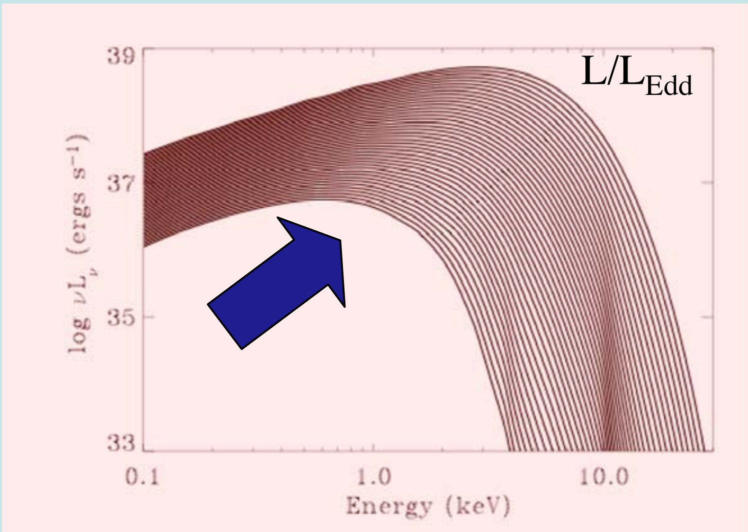


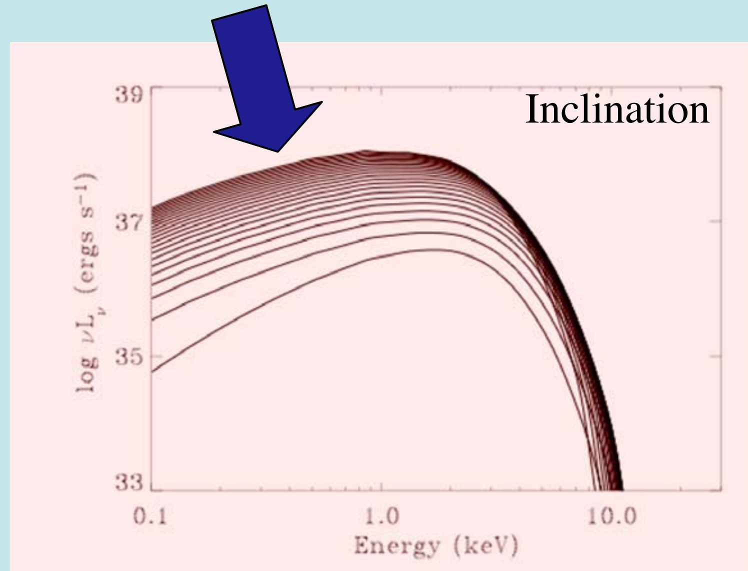


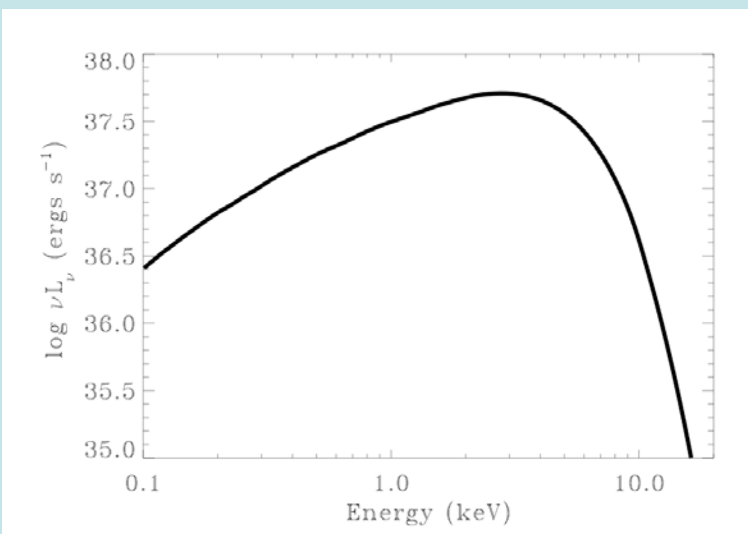
BHSPEC

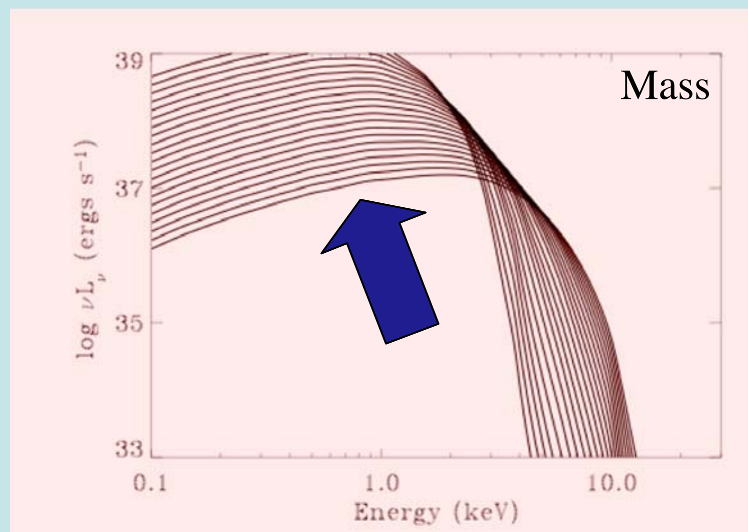


Model Parameters









Spectral Formation

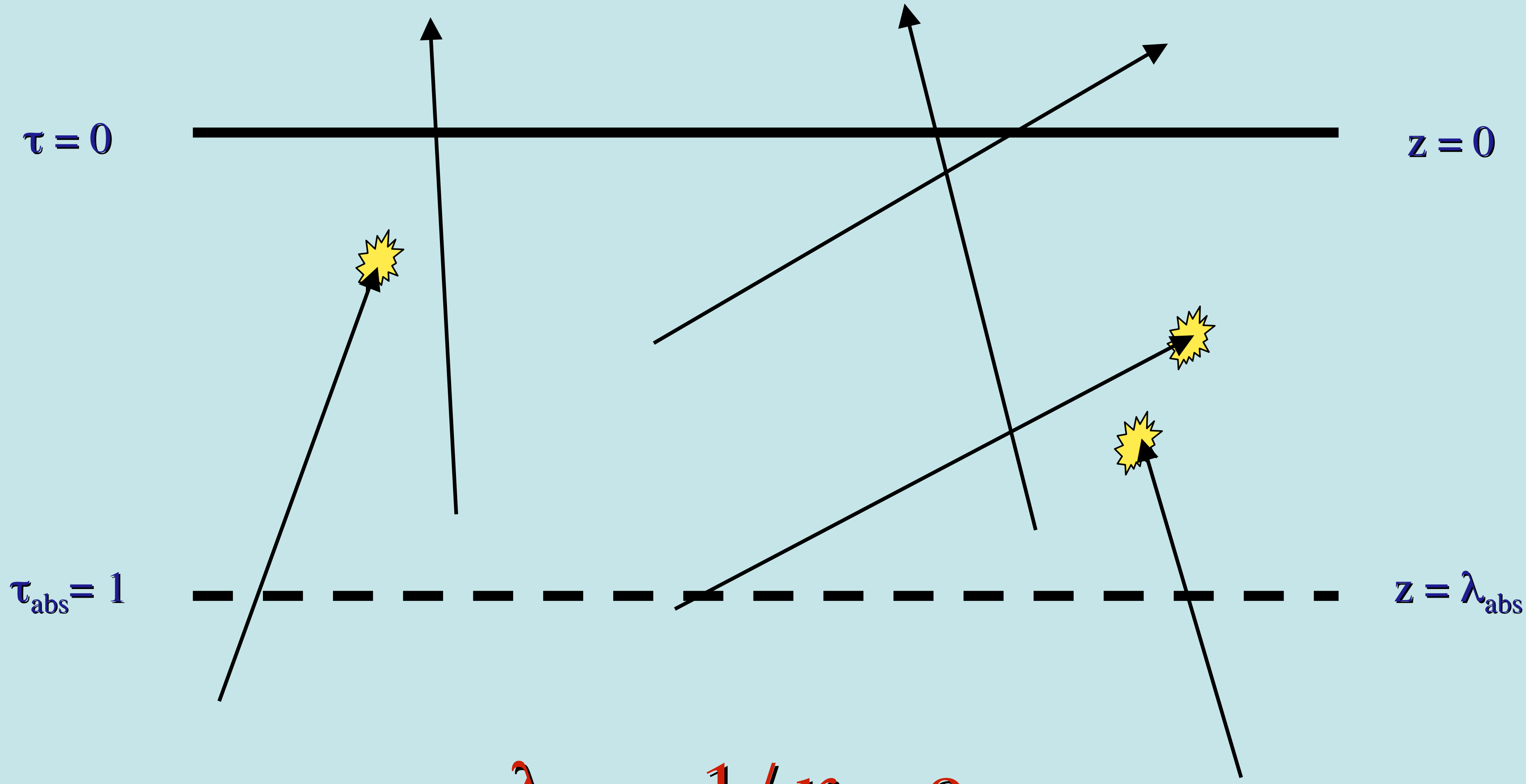
$\tau = 0$ $\qquad$ $z = 0$

$\tau_{abs} = 1$ $\qquad$ $z = \lambda_{abs}$

$$\lambda_{abs} = 1 / \kappa_{abs}\, \rho$$

η_ν : emissivity; λ_{abs} = mean free path to absorption

Spectral Formation



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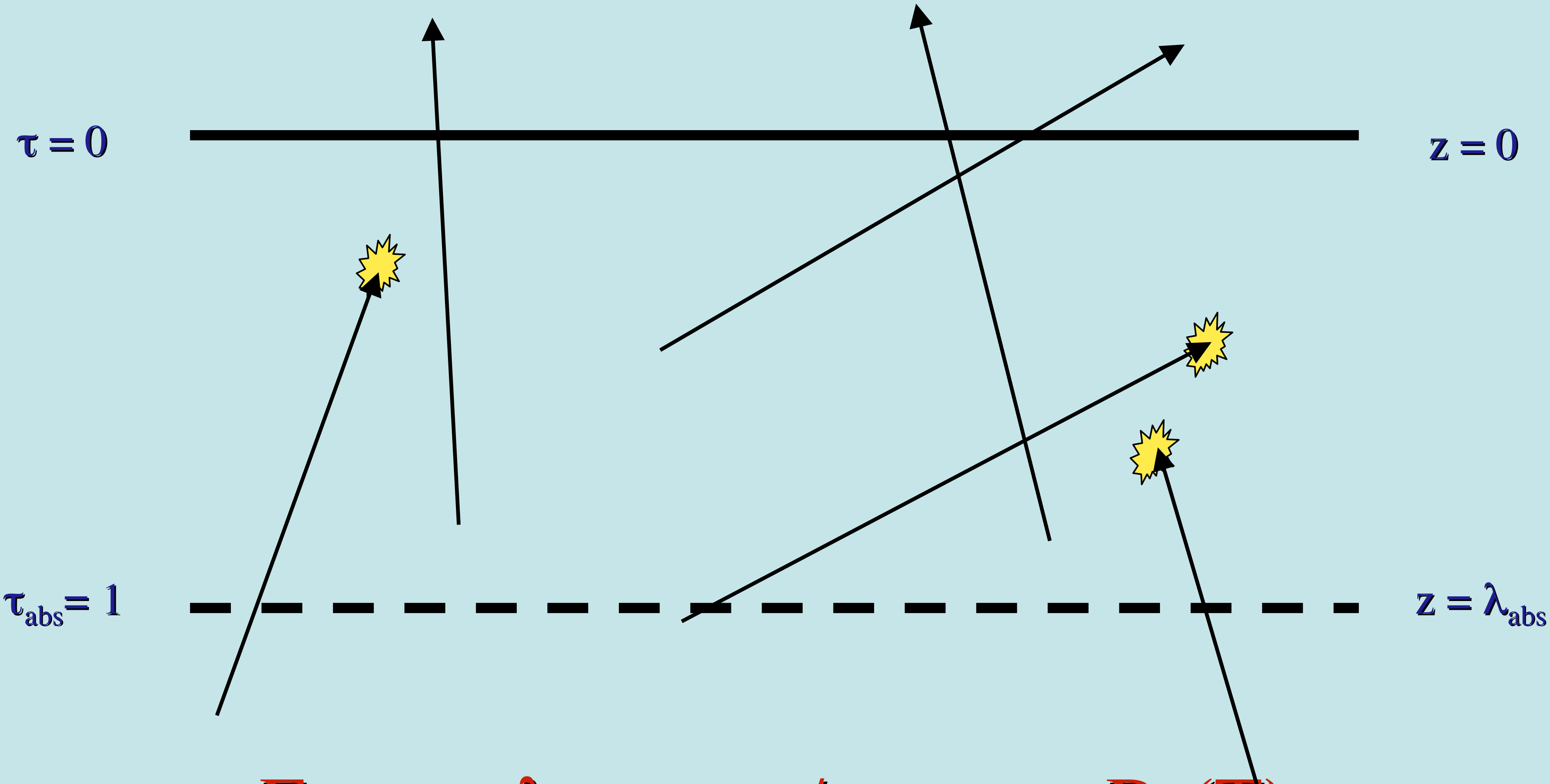
Spectral Formation



$$F_\nu = \eta_\nu \, \lambda_{abs} = \eta_\nu / \kappa_{abs} \, \rho = B_\nu(T)$$

η_ν : emissivity; λ_{abs} = mean free path to absorption

Spectral Formation

$\tau = 0$ — $z = 0$

$\tau_{es} = 1$ — $z = \lambda_{es}$

$\tau_{eff} = 1$ — $z = \lambda_{eff}$

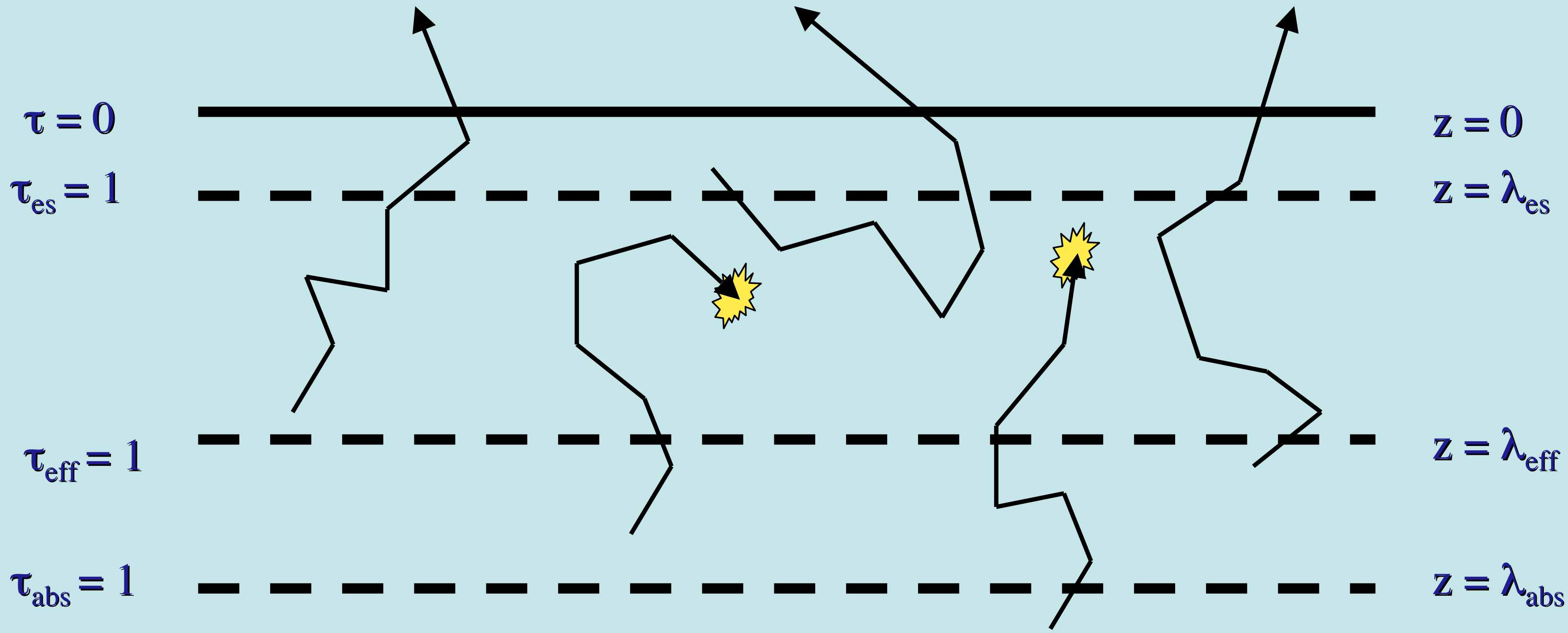
$\tau_{abs} = 1$ — $z = \lambda_{abs}$

$$\lambda_{abs} = 1 / \kappa_{abs}\,\rho; \;\; \lambda_{es} = 1 / \kappa_{es}\,\rho; \;\; \lambda_{abs} >> \lambda_{es}$$

η_ν : emissivity; λ_{abs}, λ_{es} = mean free path to absorption/scattering

$\tau_{eff} = (\tau_{es}\,\tau_{abs})^{1/2}$; $\lambda_{eff} = (\lambda_{abs}\,\lambda_{es})^{1/2}$

Spectral Formation



$$\lambda_{abs} = 1 / \kappa_{abs}\,\rho; \;\; \lambda_{es} = 1 / \kappa_{es}\,\rho; \;\; \lambda_{abs} >> \lambda_{es}$$

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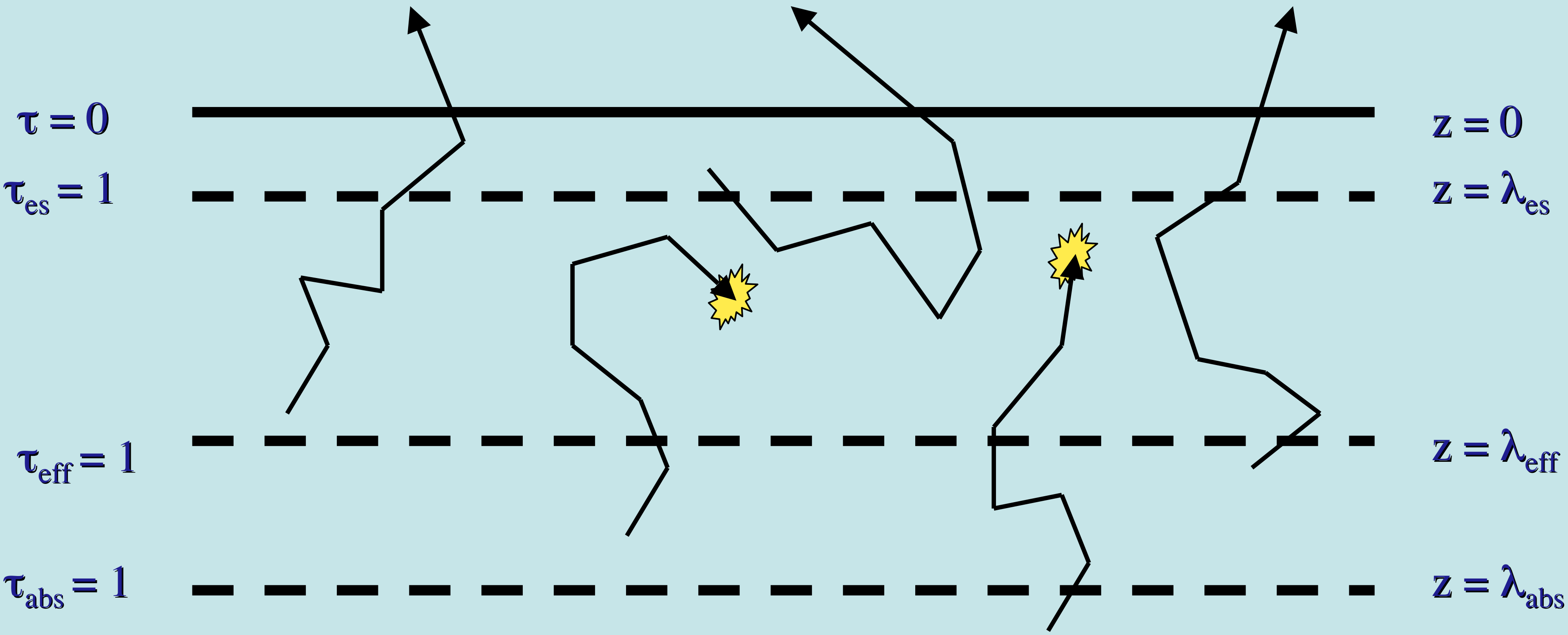
Spectral Formation



$$F_\nu = \eta_\nu \, \lambda_{eff} = \eta_\nu \, \lambda_{abs} \, (\lambda_{es} / \lambda_{abs})^{1/2} = B_\nu \, (T)(\kappa_{abs} / \kappa_{es})^{1/2}$$

η_ν : emissivity; λ_{abs}, λ_{es} = mean free path to absorption/scattering

$\tau_{eff} = (\tau_{es} \, \tau_{abs})^{1/2}$; $\lambda_{eff} = (\lambda_{abs} \, \lambda_{es})^{1/2}$

Spectral Formation

- **Depth of formation τ_*: optical depth where $(\tau_{es}\,\tau_{abs})^{1/2} \sim 1$**

  $\tau > \tau_*$: absorbed

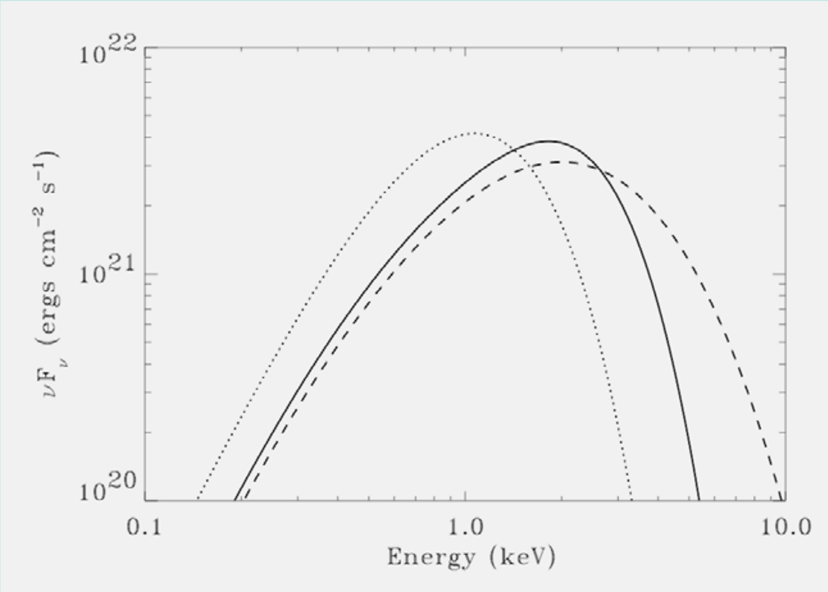
  $\tau < \tau_*$: escape
- **Thomson scattering produces modified blackbody:**

$$I_\nu \approx B_\nu \sqrt{\frac{\kappa_{\rm abs}}{\kappa_{es}}}$$

- **Due to temperature gradients Compton scattering gives a softer Wien spectrum**
- **Very approximately:**

  $f_{col} \sim T_*/T_{eff} \sim 1.5\text{-}1.8$

  for BHBs



Overall Vertical Structure of Disk with $P_{rad} \sim P_{gas}$

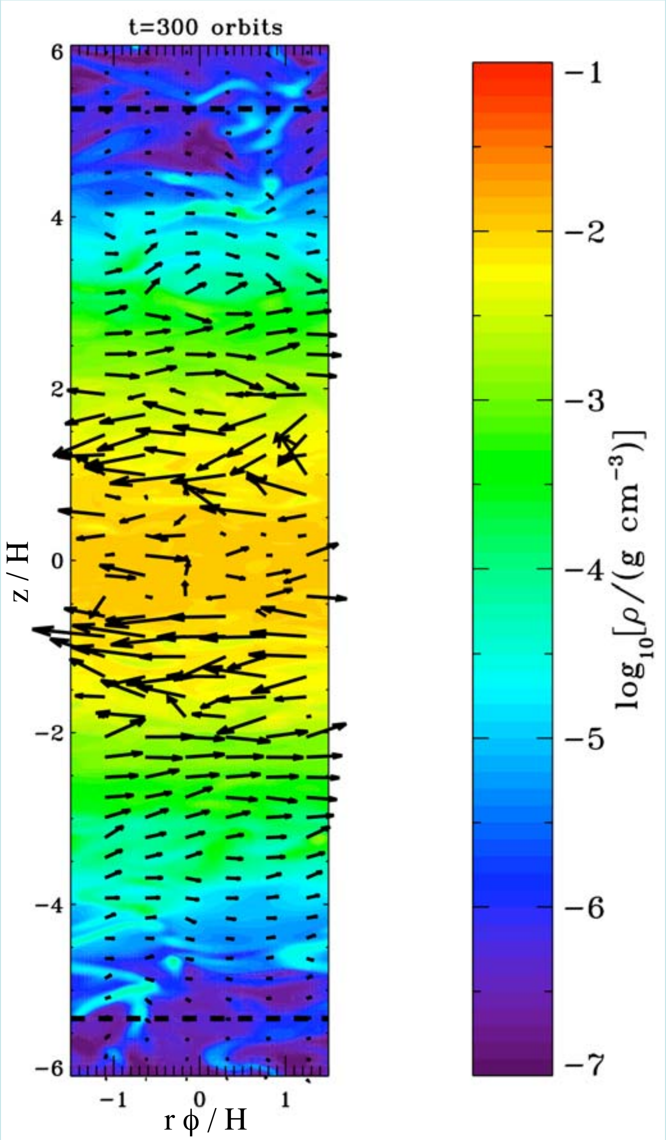
Photosphere

$P_{mag} > P_{rad} \sim P_{gas}$ — Parker Unstable Regions

$P_{rad} \sim P_{gas} > P_{mag}$ — MRI - the source of accretion power

$P_{mag} > P_{rad} \sim P_{gas}$ — Parker Unstable Regions

Photosphere



Hirose et al.

Magnetic Pressure: Vertical Structure

- $P_{mag} = B^2/8\pi$ **taken from simulations**
- **Extra magnetic pressure support increases scale height:**

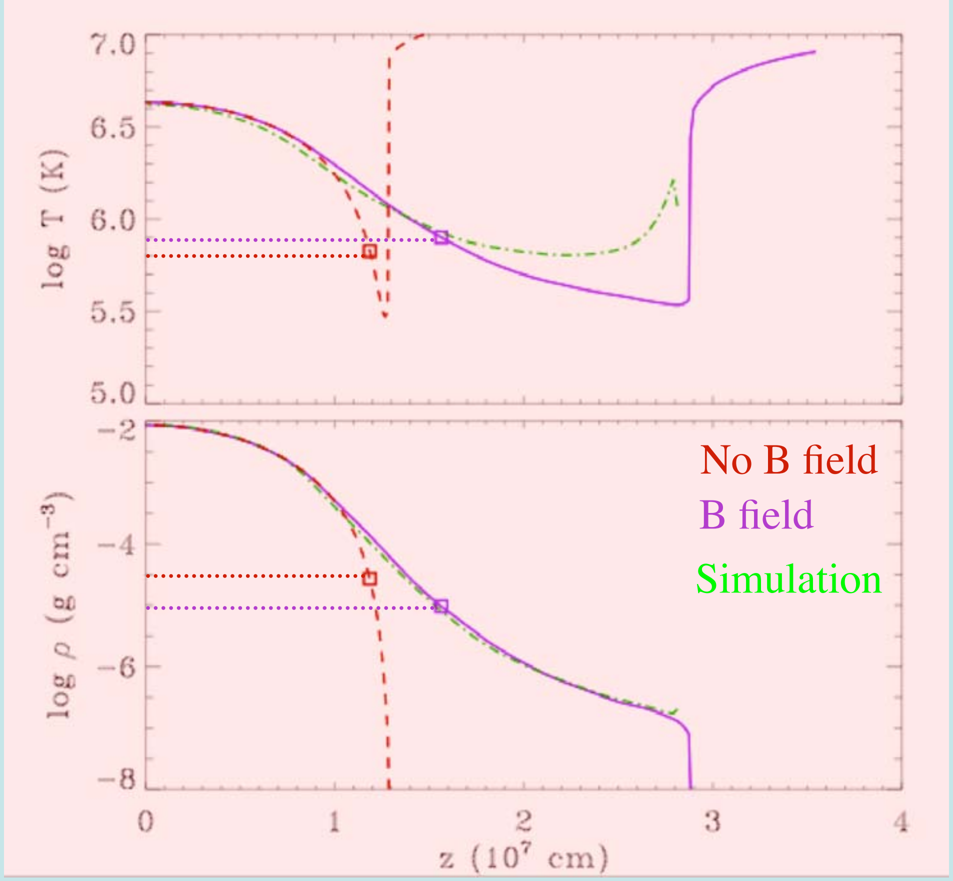
  $h_{mag} = P_{mag}/(d\, P_{mag}/dz) > h_{gas}$
- **This leads to density *reduction* at** τ_***:**

  $\tau_* \sim \kappa_{es}\, \rho_*\, h$ **so**

  $\rho_* \sim \tau_* / (\kappa_{es}\, h)$
- **Lower** ρ_* **means lower ratio of absorption to scattering:**

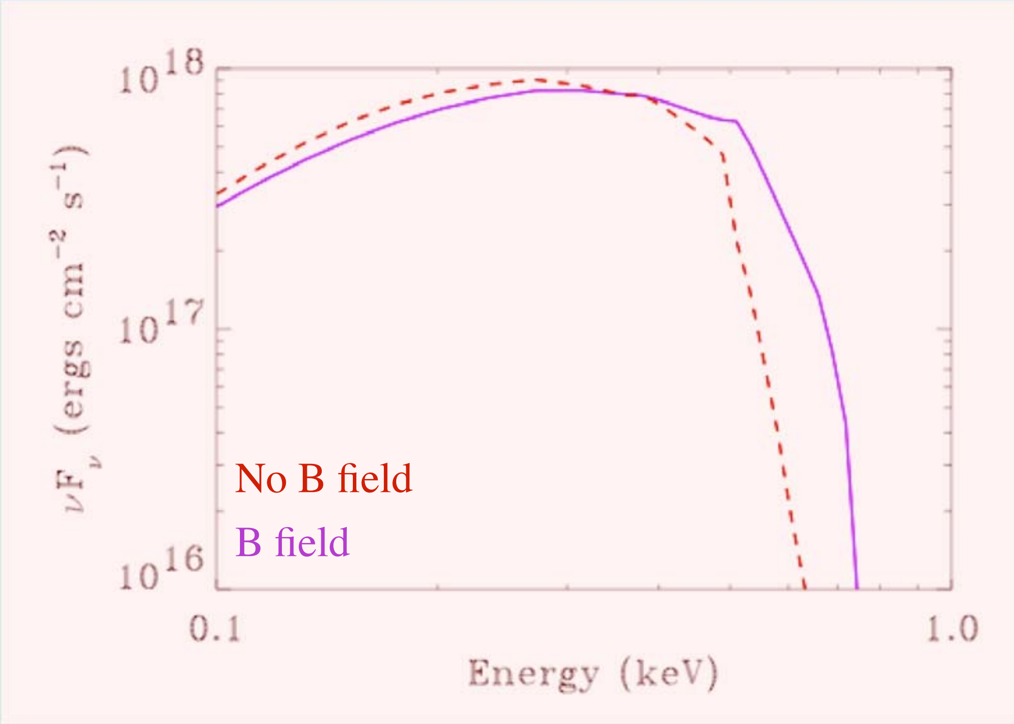
  $\kappa_{abs}/\, \kappa_{es}\ \alpha\ \rho_*$

  which means larger T_*/T_{eff} **and larger** f_{col}



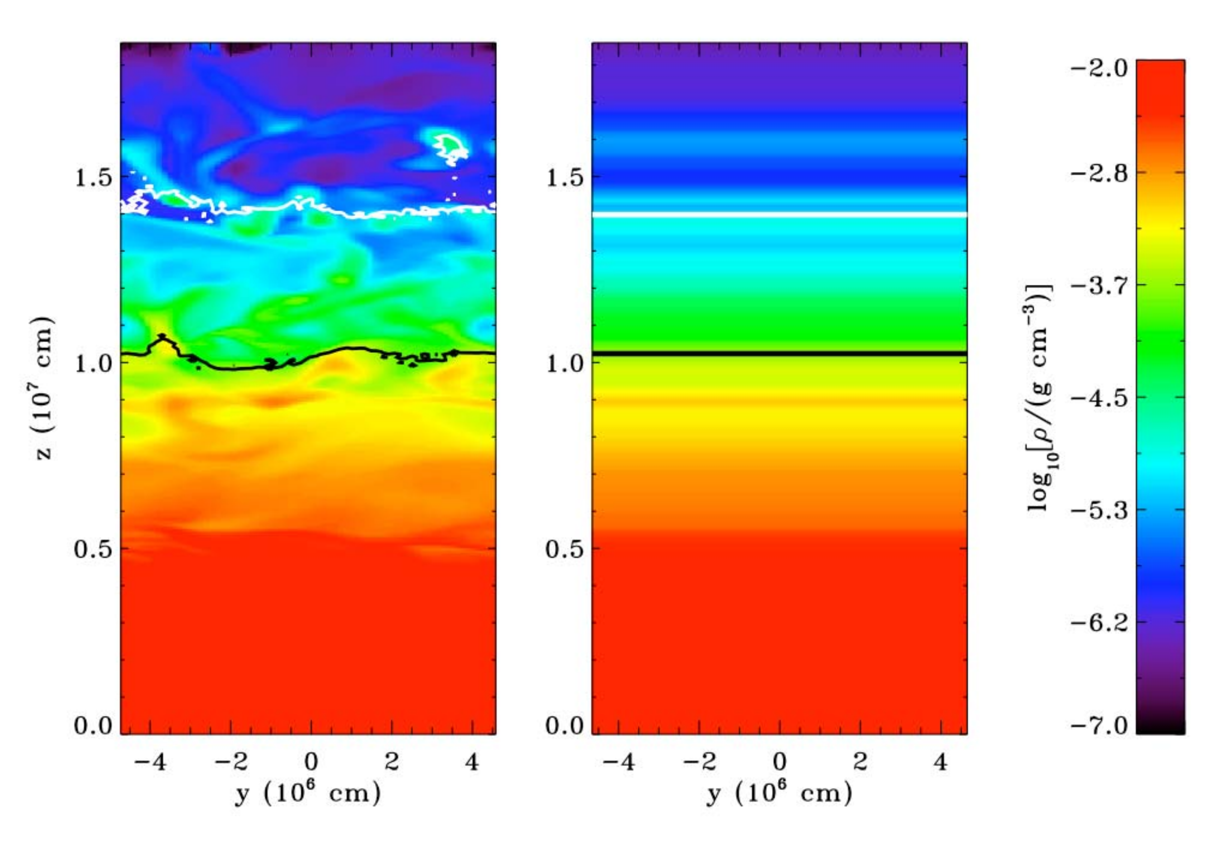
Magnetic Pressure: Spectrum

- **Lower ρ_* and higher T_* combine to give a harder spectrum**
- **In this case lower ρ_* alters statistical equilibrium -- lower recombination rate relative to photoionization rate yield higher ionization and weaker edges**
- **Overall effect is an *enhancement* of f_{col} by ~10-15%**



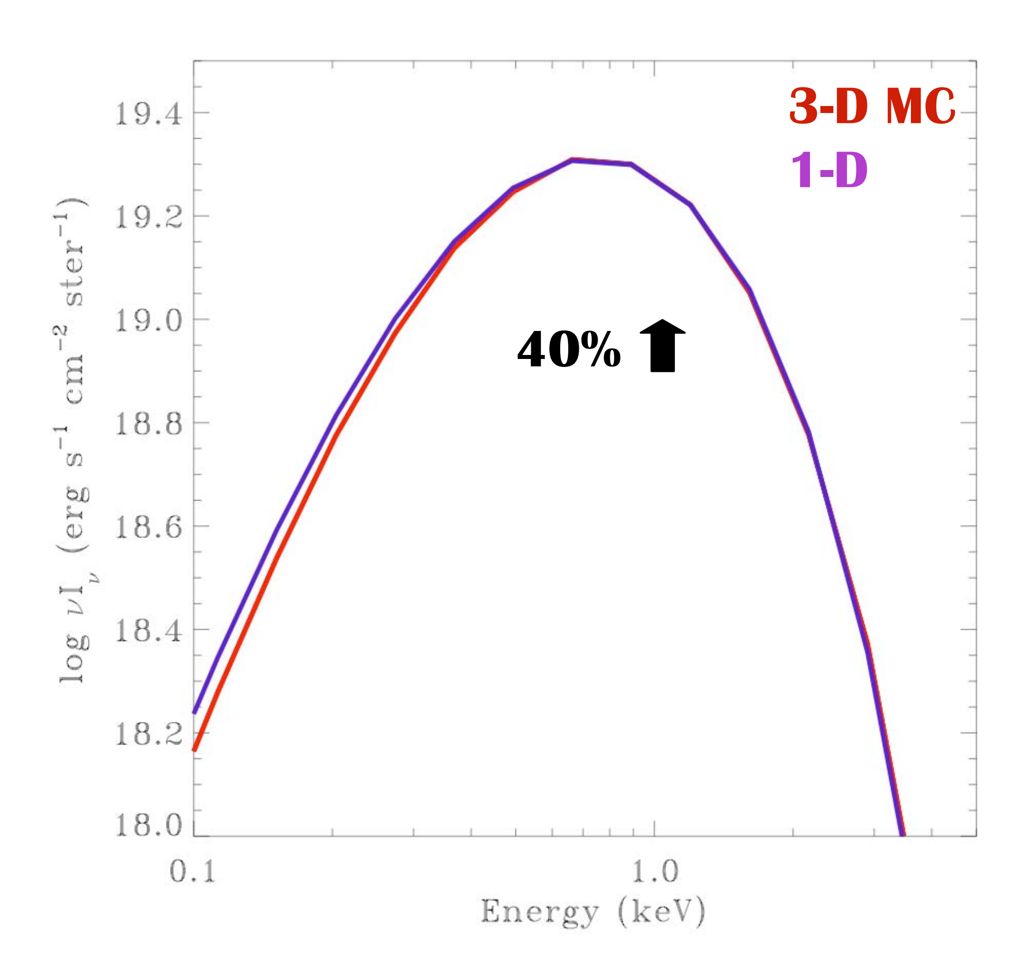
Inhomogeneities: Vertical Structure

- **Compare 3D with 1D average: ρ dependence is important:**
  $\eta_\nu \propto \rho^2$; $\lambda_{abs} \propto \rho^{-2}$
  $\lambda_{es} \propto \rho^{-1}$
- **Non-linear dependence of η_ν on ρ leads to enhanced emission**
- **Due to weaker dependence on ρ, photons escape predominantly through low ρ regions**



Inhomogeneities: Monte Carlo Spectra

- **Spectral shape is approximately unchanged, but flux is enhanced by ~40%**
- **Increased efficiency allows lower T_* to produce equivalent flux**
- **Would lead to *reduction* of f_{col} by ~15-20%**



Conclusions

- **Magnetic pressure support acts to make disk spectra harder -- larger** f_{col}
- **Density inhomogeneities will tend to make disk spectra softer -- smaller** f_{col}
- **These uncertainties should be accounted for in black hole spin estimates -- approximately 20% uncertainty for a/M ~ 0.8 if** f_{col} **is off by ~15%**