Probing the Accretion Geometry of Black Holes with X-ray Polarization

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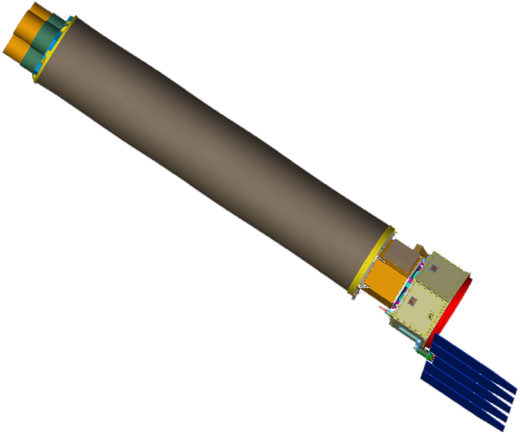
(past) Future Work

- Integrated model will be useful to
  - probe plunging region
  - estimate coronal properties
  - **predict polarization signatures**
  - compute line emissivity scaling functions
- 3-D numerical MHD simulations
  - develop realistic heating, cooling functions
  - measure effects of corona/jet structure
  - study plunging region
  - calculate time-dependent spectra

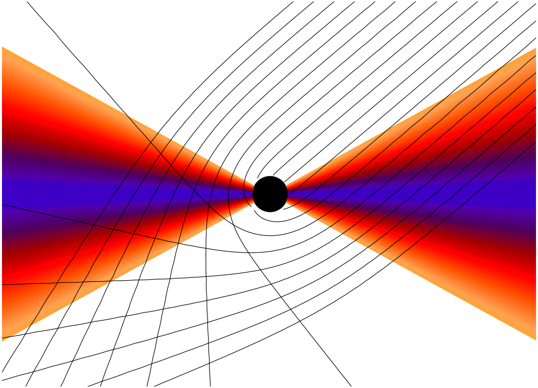
GEMS: Gravity and Extreme Magnetism SMEX



- Approved for “phase A” funding in recent round of SMEX proposals, to launch in 2012
- Sensitive down to $\lesssim$ 1% at 1 milliCrab (10^6 s exposure)
- Energy bandwidth of 2-10 keV

Observer-to-Emitter

The "traditional" paradigm traces photons along geodesic paths from a distant observer to the disk

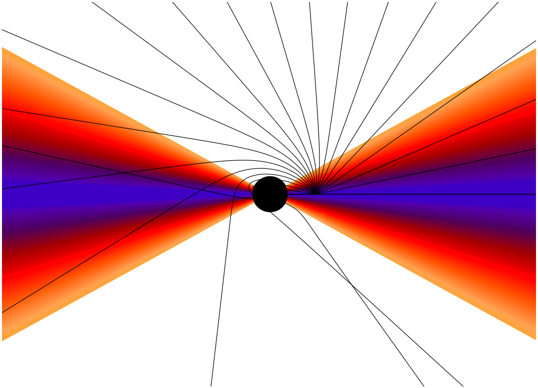


cf. Schnittman, Krolik, & Hawley (2006)

Noble et al. (2007)

Emitter-to-Observer

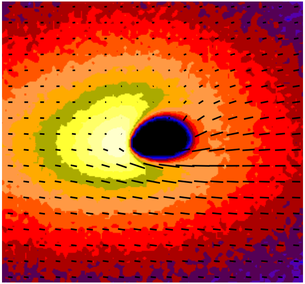
To include scattering effects and return radiation, we trace the photon paths from the emission region to the observer



cf. Schnittman (2005; 2008)

Transport of polarization vectors

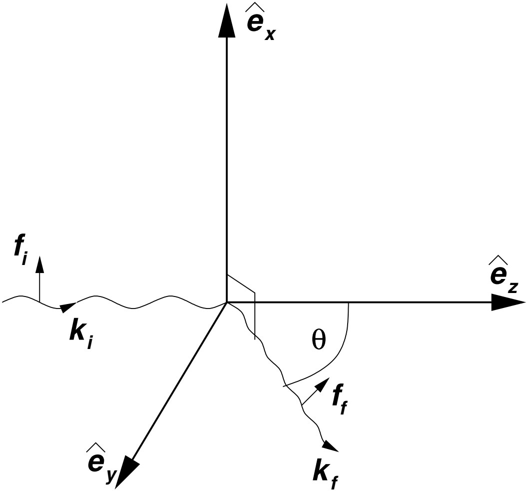
- Polarization vector is space-like and normal to wave vector: $\mathbf{f} \cdot \mathbf{k} = 0$ and $\mathbf{f} \cdot \mathbf{f} = 1$.
- Walker-Penrose constant of motion $\kappa_{\rm PW}$, conserved along null geodesics, gives remaining components of $\mathbf{f}$. (Connors et al. 1980)
- Emission from scattering-dominated atmosphere is polarized parallel to disk surface. (Chandrasekhar 1960)



The thermal seed photons come from a relativistic thin disk

- disk parameters:
  - BH mass M
  - BH spin a/M
  - accretion rate $\dot{M}/\dot{M}_{\rm Edd}$
  - emissivity (Novikov-Thorne vs. power-law to horizon)
- corona parameters:
  - temperature, density profile $T_c(r)$, $\rho_c(r)$
  - optical depth to Compton scattering $\tau_{\rm es}$

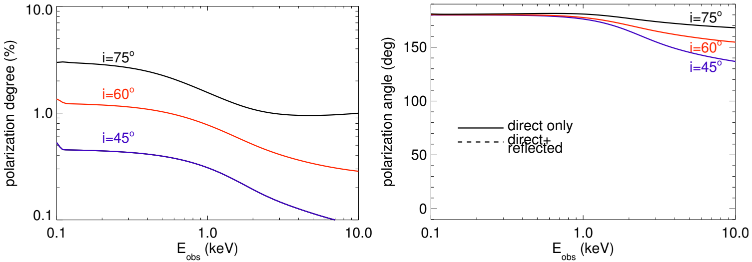
Thompson scattering of polarized photons



- $\mathbf{f}_i \cdot \mathbf{k}_i = 0$
- $\mathbf{f}_f \cdot \mathbf{k}_f = 0$
- $(\mathbf{f}_i \times \mathbf{k}_f) \cdot \mathbf{f}_f = 0$
- $\delta = (X^2 + Y^2)^{1/2}$
- $\psi = \frac{1}{2} \tan^{-1}(Y/X)$

Plane polarization from a thermal disk is rotated by relativisitc beaming and lensing

$a/M = 0.9$, $R_{\rm in} = R_{\rm ISCO}$, N-T emission, $L = 0.1 L_{\rm Edd}$

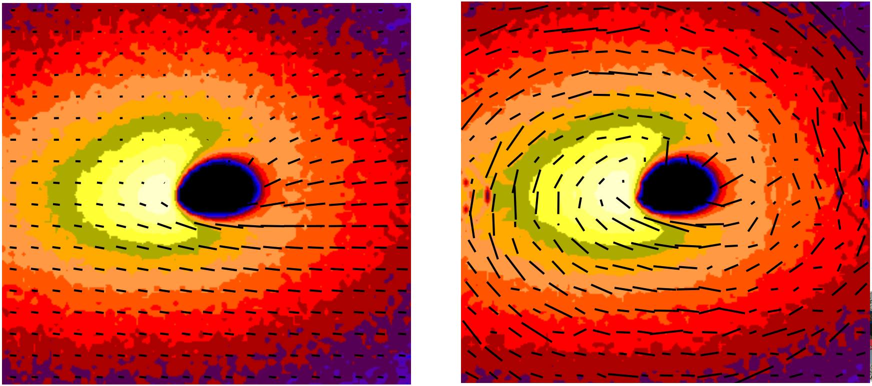


(cf. Connors, Stark, & Piran 1980)

Return radiation near the BH changes the polarization signature significantly

direct only

direct+return



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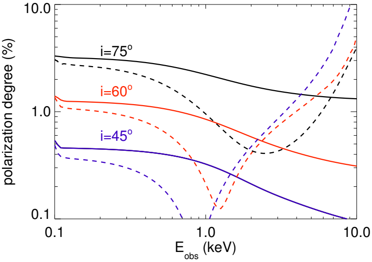
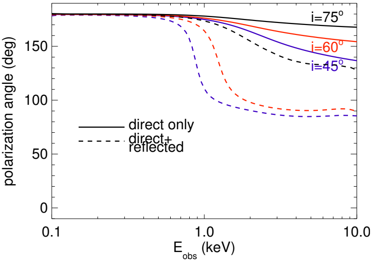
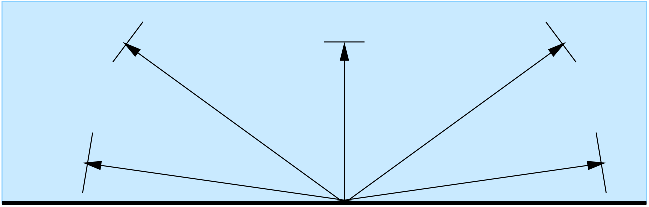
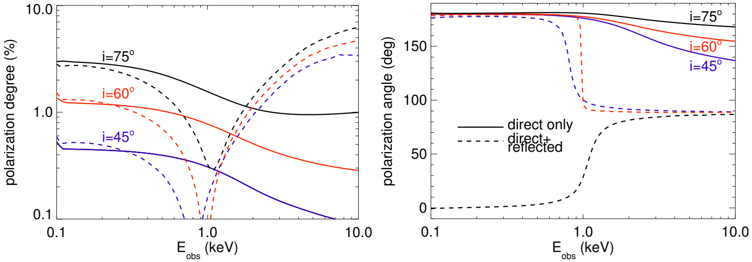




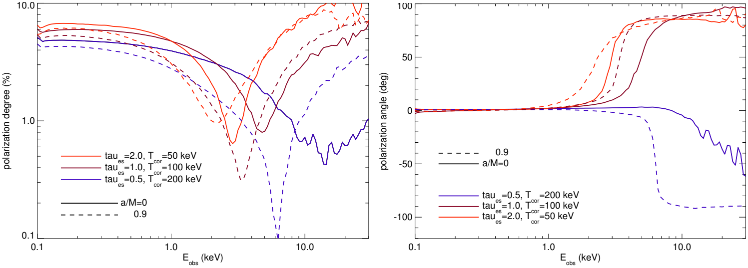
Scattering through optically thin corona rotates net polarization angle



Corona scattering preferentially changes polarization angle of high-energy photons



Polarization as probe of coronal properties



Applications/Future Work

- New polarization measurements will allow us to
  - probe plunging region
  - estimate coronal properties
  - infer emissivity profiles
  - measure BH spin
- Fitting observations
  - Green's function-type transfer
  - fold through *GEMS* response function
- 3-D numerical MHD simulations (Noble, Krolik, & Hawley 2008)
  - develop realistic heating, cooling functions
  - define electron temperature everywhere
  - self-consistently calculate inverse-Compton spectrum and polarization