X-ray Polarization: The Dawn of a New Age in Black Hole Astrophysics

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GEMS: Gravity and Extreme Magnetism SMEX

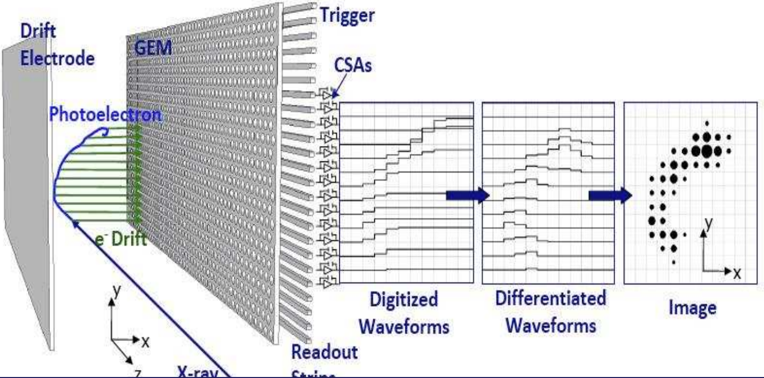
- Approved for "phase A" funding in recent round of SMEX proposals
- Sensitive down to $\lesssim 1\%$ at 1 milliCrab (10^6 s exposure)
- Energy bandwidth of 2-10 keV
- Energy resolution of 2 keV
- If approved, could launch in 2012

GEMS: Gravity and Extreme Magnetism SMEX

- Selected for full funding in recent round of SMEX proposals
- Sensitive down to $\lesssim 1\%$ at 1 milliCrab (10^6 s exposure)
- Energy bandwidth of 2-10 keV
- Energy resolution of ~ 2 keV
- ~~If~~ *Now* approved, ~~could~~ *will* launch in ~~2012~~ ~~2015~~ *2014*

GEMS: Gravity and Extreme Magnetism SMEX

- Image pixels are formed by readout strip pitch (y) and drift velocity/sampling rate (x)
- Quantum efficiency (depth) is perpendicular to readout (drift) direction

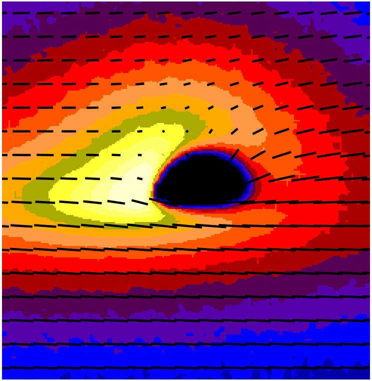


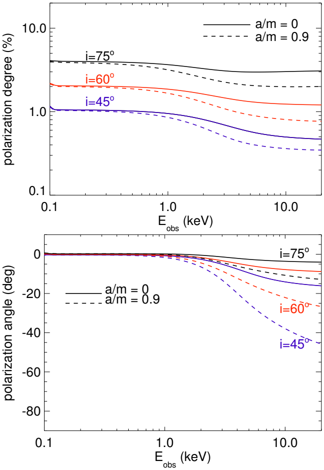
Description of model

- disk parameters:
    - BH mass M
    - BH spin a/M
    - accretion rate $\dot{M}/\dot{M}_{\rm Edd}$
    - emissivity profile
- corona parameters:
    - temperature, density profile $T_c(r)$, $\rho_c(r)$
    - coronal geometry (sandwich, clumpy, sphere, etc.)
    - optical depth to Compton scattering $\tau_{\rm es}$
- observer parameters:
    - inclination
    - distance to source

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

- $M = 10 M_\odot$
- N-T emission
- $L = 0.1 L_{\rm Edd}$

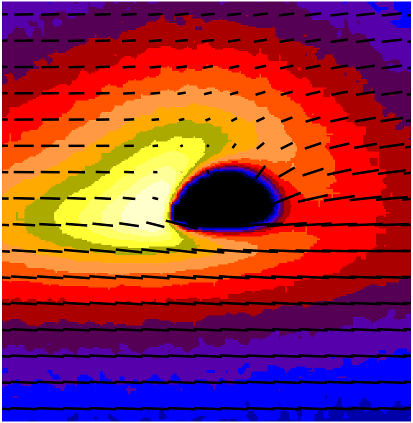




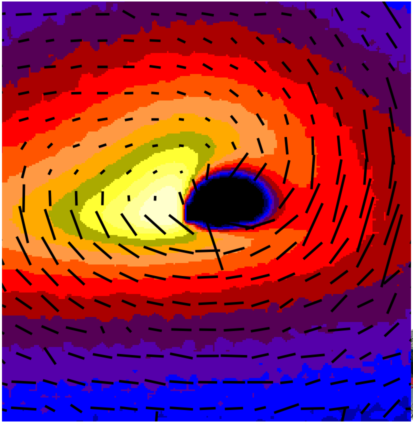
(cf. Connors et al. 1980)

Return radiation near the BH changes the polarization signature significantly

direct only

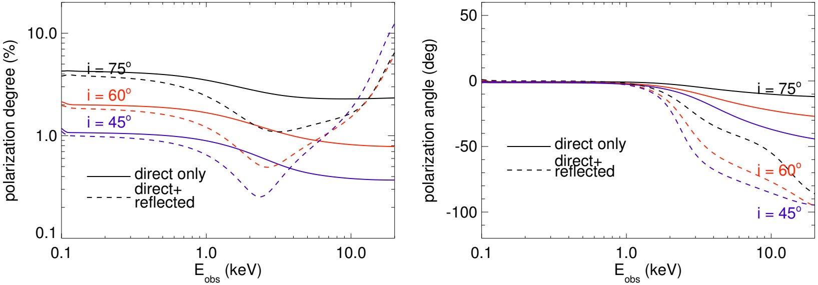


direct+return



Return radiation near the BH changes the polarization signature significantly

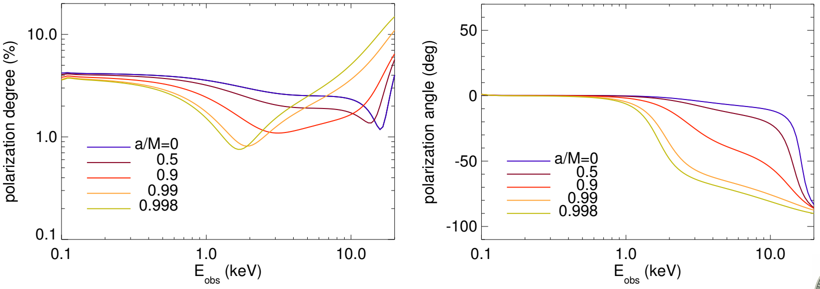
$M = 10M_{\odot}$ $a/M = 0.9$ $L = 0.1L_{\rm Edd}$



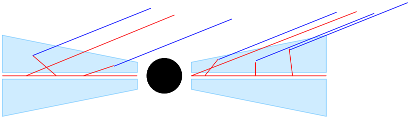
JS & Krolik (2009a)

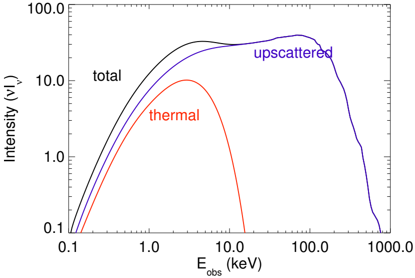
Polarization in thermal state can be used to measure BH spin

$$M = 10M_\odot \qquad i = 75^\circ \qquad L = 0.1L_{\rm Edd}$$

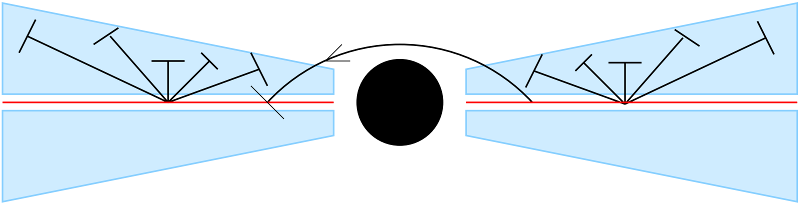


Hard X-rays come from inverse-Compton scattering in a hot corona





Scattering through optically thin corona rotates net polarization angle

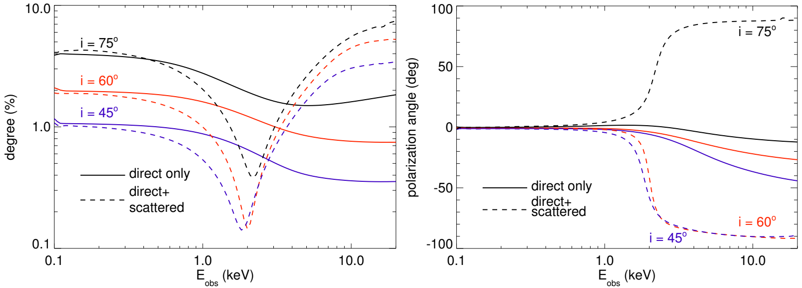


e.g. Sunyaev & Titarchuk (1985)

Haardt & Matt (1993)

Corona scattering preferentially changes polarization angle of high-energy photons

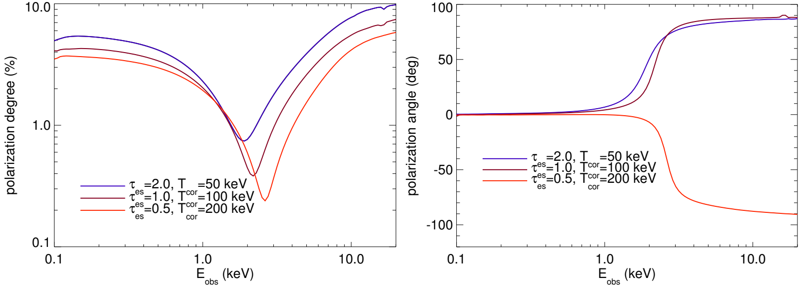
$$M = 10M_{\odot} \qquad a/M = 0.9 \qquad L_{\rm seed} = 0.1 L_{\rm Edd}$$



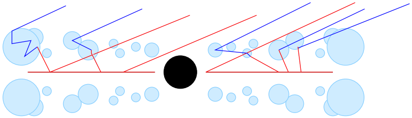
JS & Krolik (2009b)

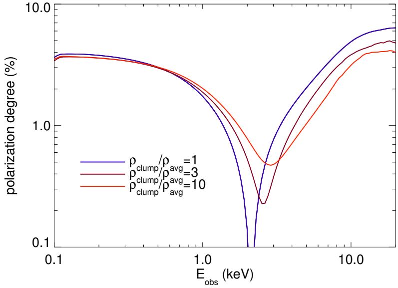
Polarization as probe of coronal properties

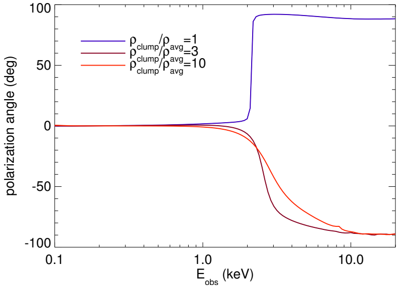
$$M = 10M_\odot \qquad i = 75^\circ \qquad L_{\rm seed} = 0.1L_{\rm Edd}$$



clumpy coronas





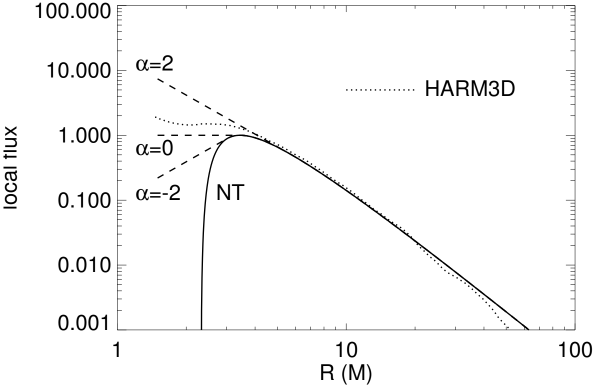


Applications/Future Work

- New polarization measurements will allow us to
  - probe plunging region
  - estimate coronal properties
  - infer emissivity profiles (Fe Kα lines)
  - measure BH spin
  - measure geometry of accretion flow in NS's
- 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
- Fitting observations
  - Green's function-type transfer
  - orthogonal basis of fitting functions to minimize parameter degeneracy
  - fold through *GEMS* response function, develop `XSPEC` packages for data analysis

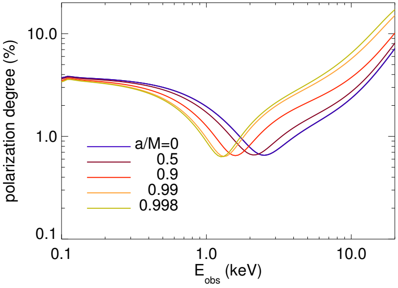
Emissivity in the plunging region

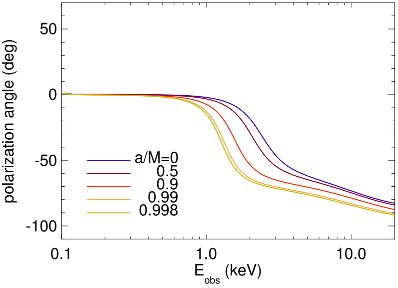
Inside the ISCO, the gas follows geodesic trajectories determined by E and ℓ at the ISCO, yet with (possibly) non-zero emissivity.



Emission inside ISCO reduces sensitivity on spin

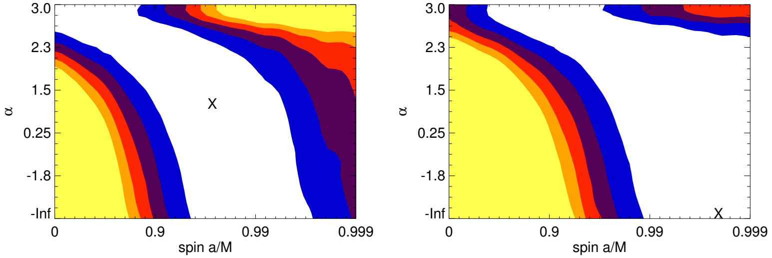
"quasi-Newtonian" emissivity ($I \sim r^{-3}$ inside ISCO)





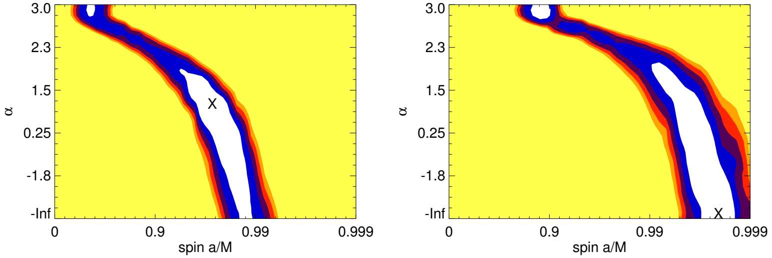
Degeneracy between spin and emission profile

"first-generation" polarimeter: $\delta \sim 1\%$, $\Delta E/E \sim 1$
(contours are 1σ confidence intervals)



Spectropolarimeter on *IXO* could greatly improve spin measurements

"next-generation" polarimeter: $\delta \sim 0.3\%$, $\Delta E/E \sim 0.1$



spherical coronas