Soft X-ray X-ray Polarimetry

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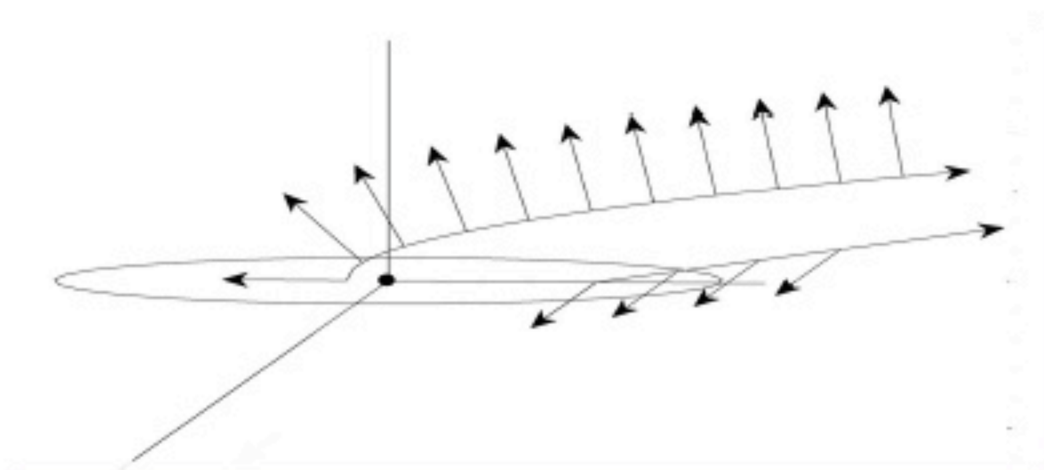
and the help of others: Steve Kissel, Bev Ferguson...

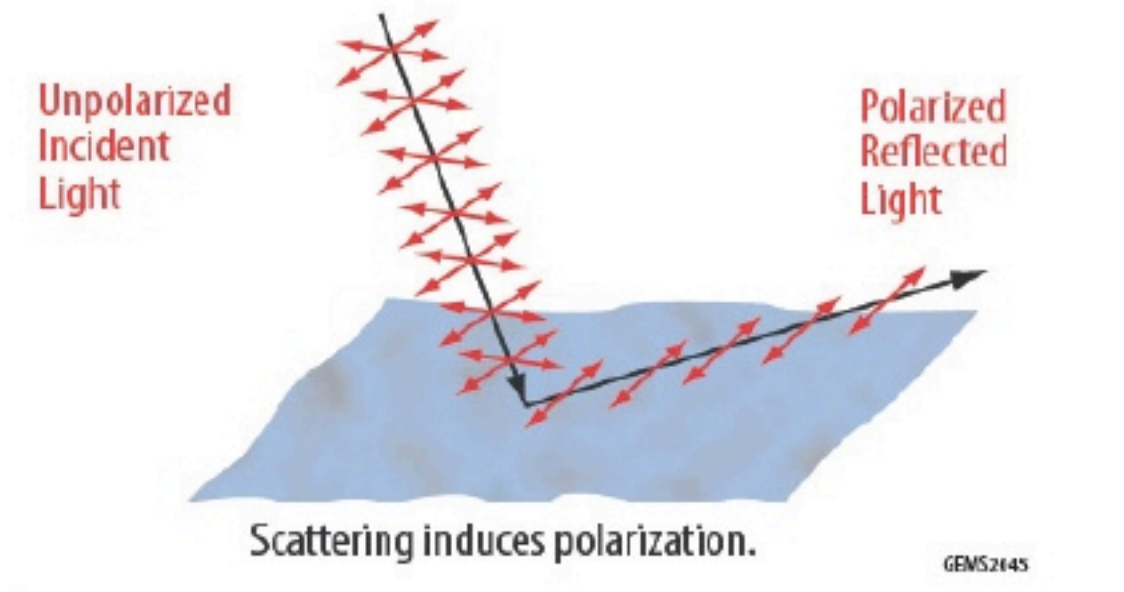
Context & Overview

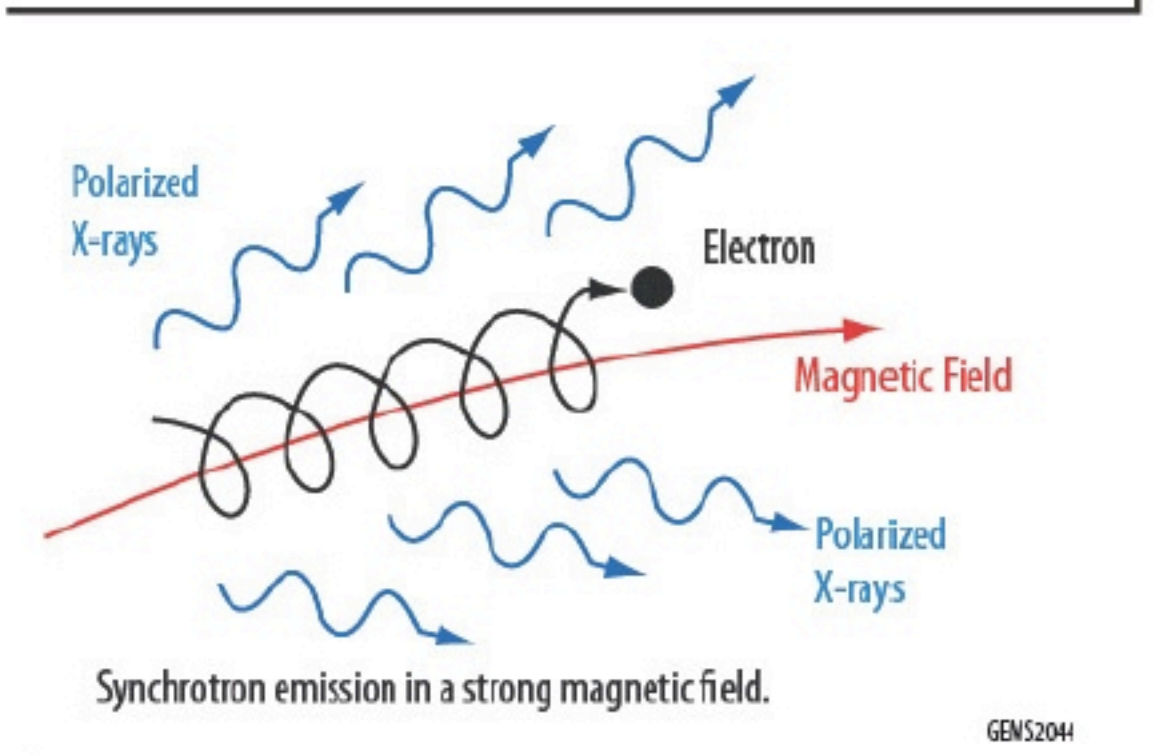
- Polarimetry provides a new view
  - Current predictions suggest application to IXO goals
  - GEMS may verify predictions, cause adjustments
  - Predictions expand as data prospects improve
  - Opens “discovery space”
- Likely Applications
  - Isolated neutron stars — NS equation of state
  - Blazars — measurements of outflows from BHs
  - AGN — accretion disk physics and BH spin and mass
  - Other science — X-ray binary pulsars, XRB jets, CVs, XRB accretion....

Polarimetry Probes of Physics

- Polarization measurements allow us to study:
  - ✓ Scattering
  - ✓ Magnetic fields
  - ✓ Strong gravity







Propagation near BH

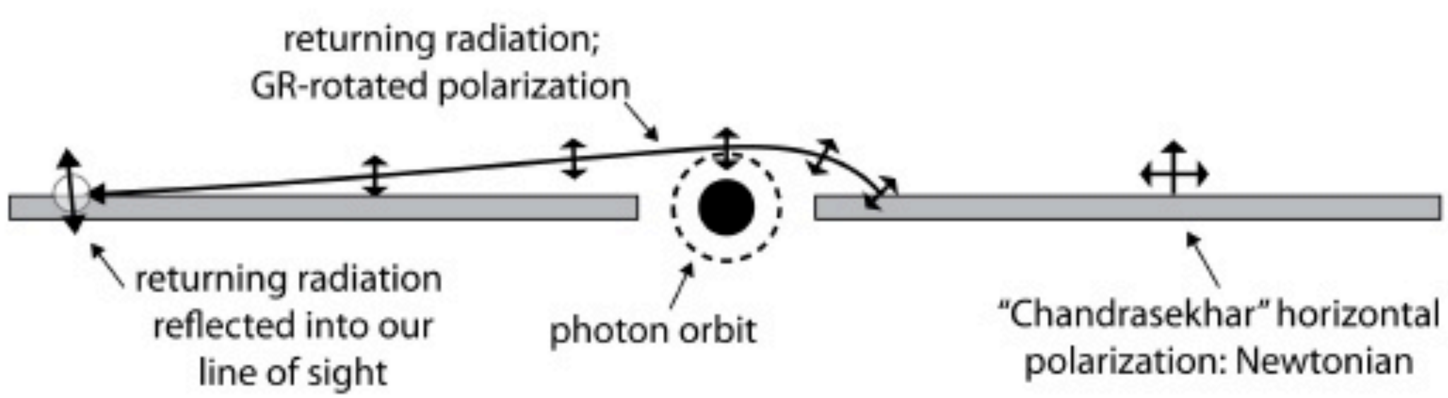
Propagation to the observer is affected by:

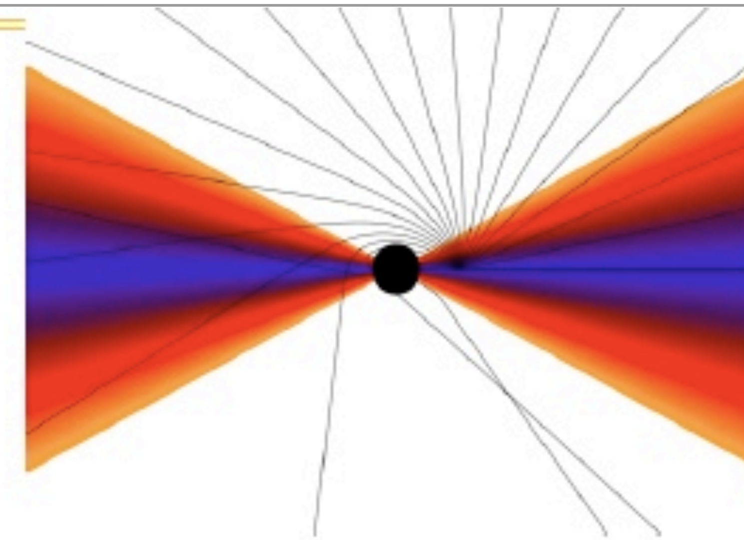
•Special relativistic effects: Doppler shift, aberration, beaming

•General relativistic effects: gravitational redshift, light-bending

Plus, the disk illuminates itself via gravitational effects

This returning radiation, which scatters 90° into our line of sight, has a significant effect on polarization





(Schnittman)

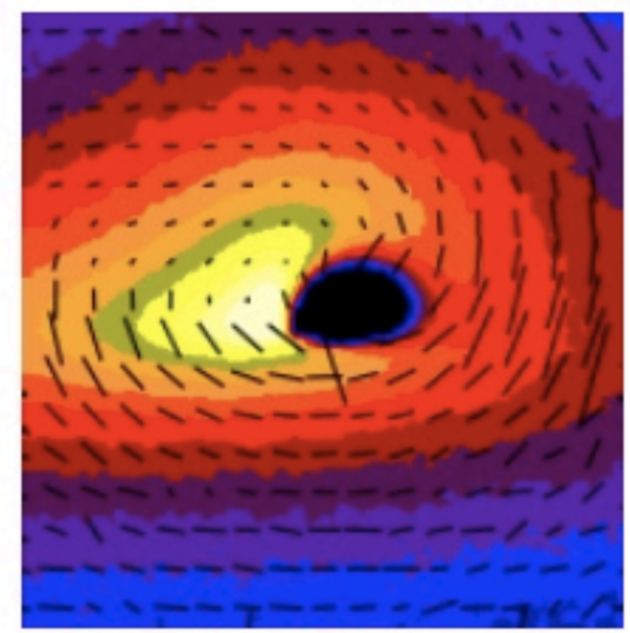
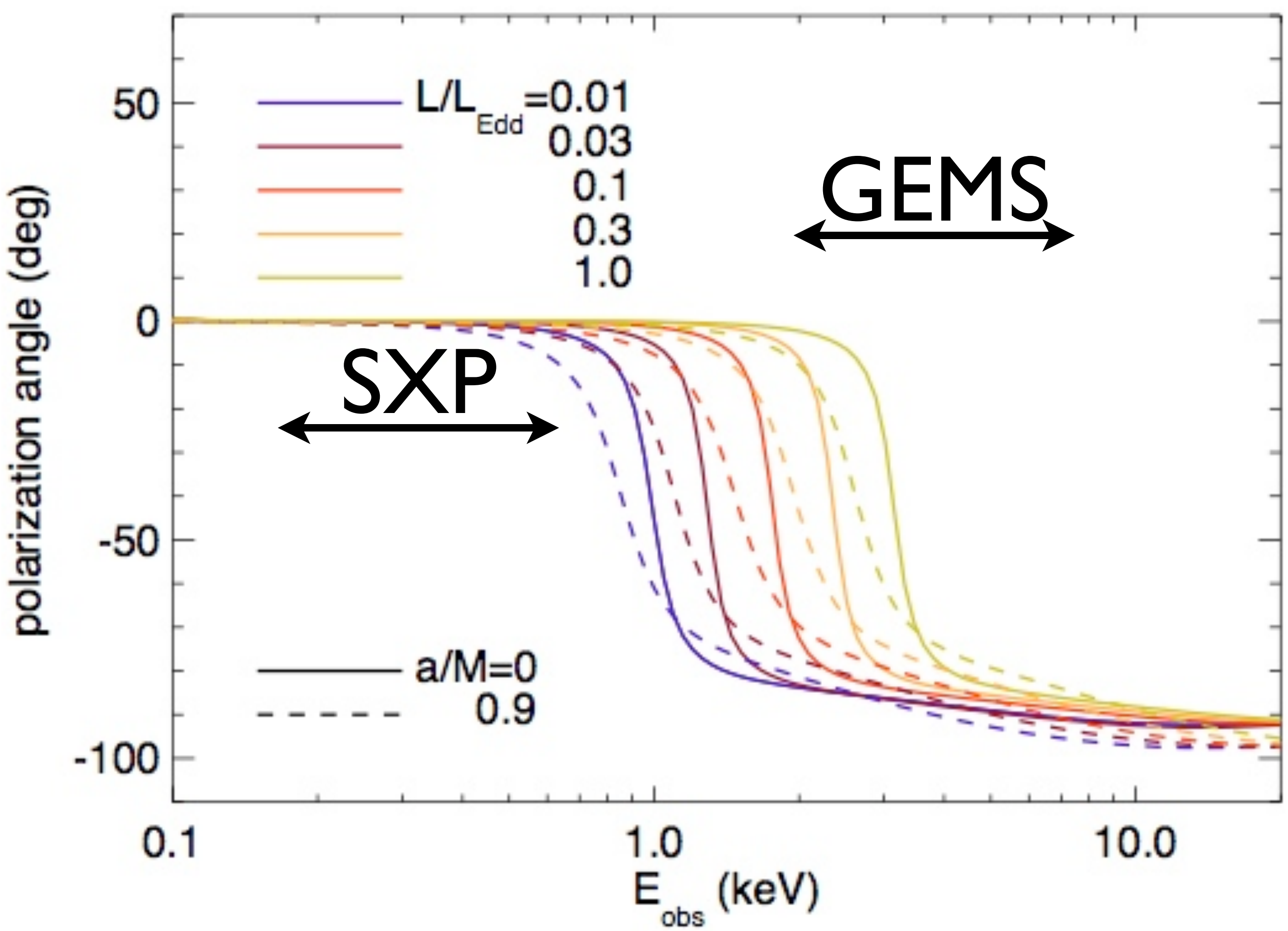


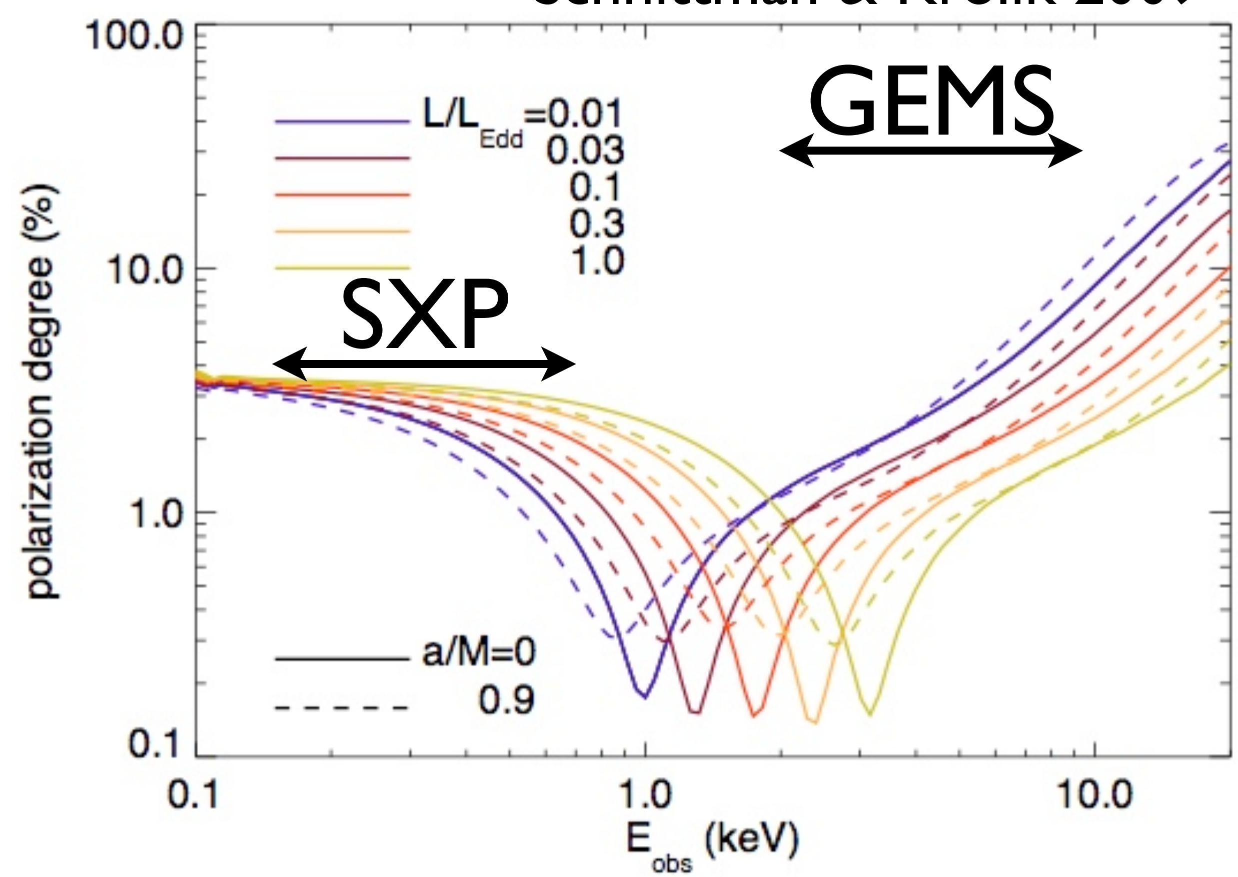
Image of disk showing intensity as color, polarization vectors
a/m=0.998 i=70°

Polarimetry of AGN

- Scattered return radiation will be polarized
- Polarization fraction and angle depend on a/M, L/L_{Edd}
- Soft and Hard X-ray measurements are needed

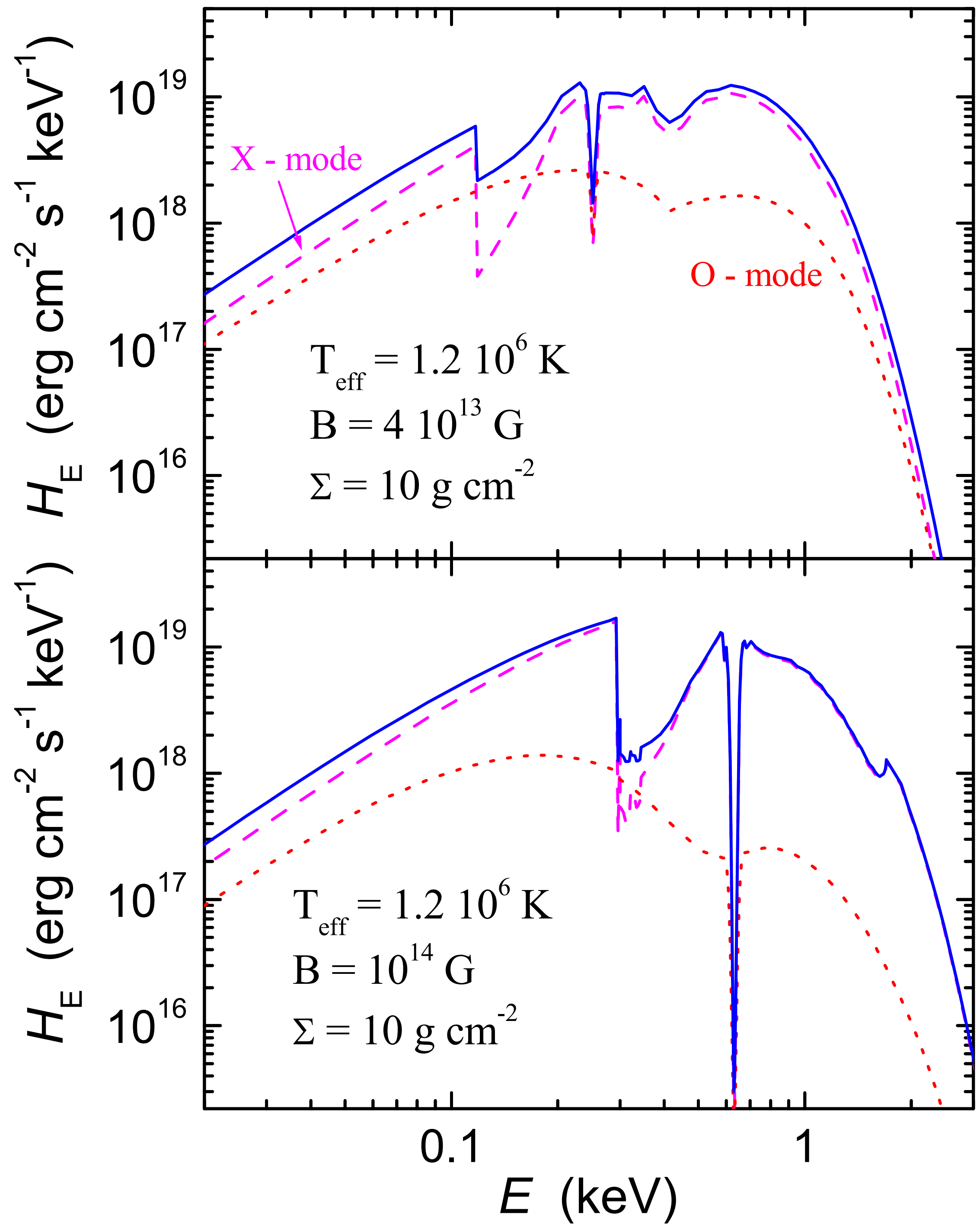
Schnittman & Krolik 2009





Neutron Star Atmospheres

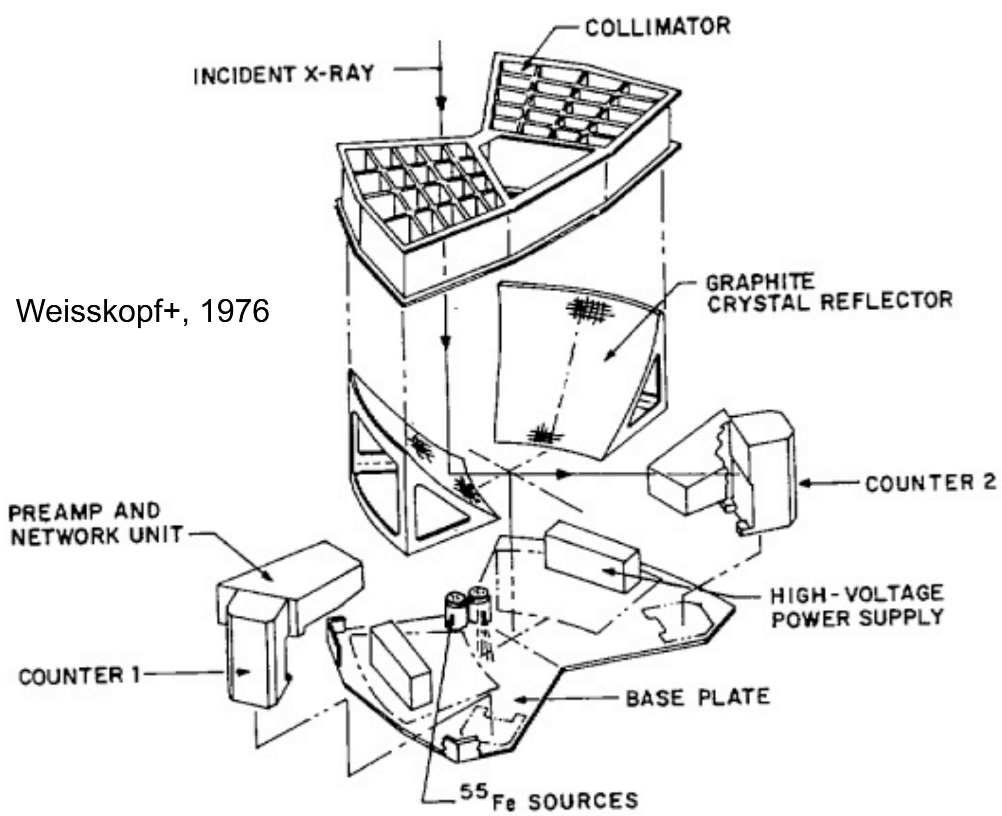
- Isolated neutron stars are often soft, emit below 1 keV
- Polarization amplitude and angle v. rotation phase depends on B-field direction and NS orientation
- Atmospheres show features now found in INS spectra
- Polarization data would distinguish features in spectra
- Atmosphere models are used to determine R^2, g to give M,R



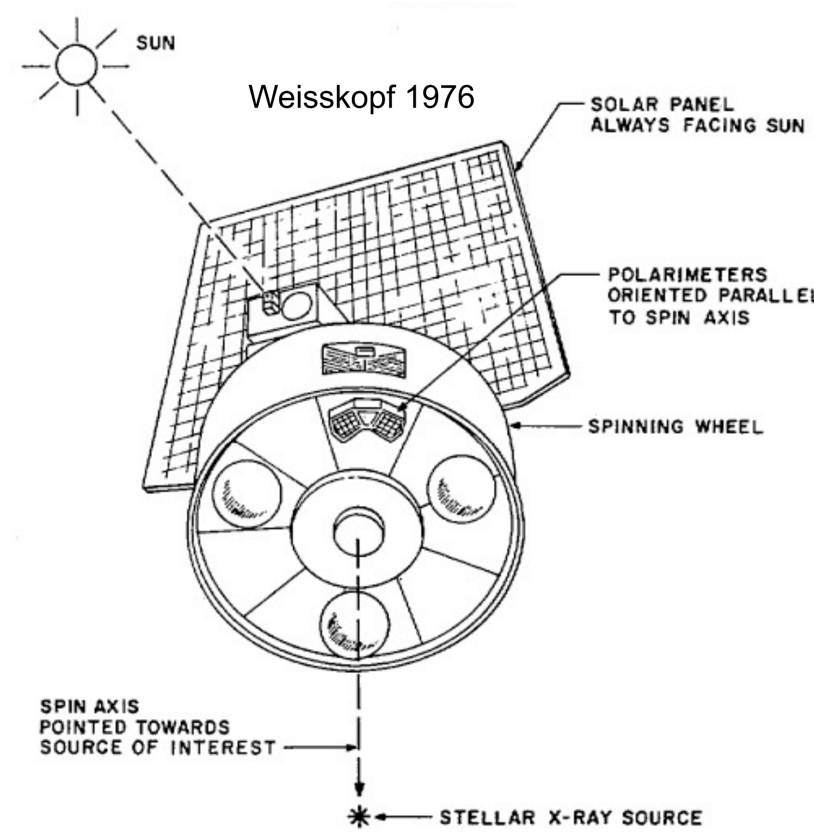
Polarimetry — History

- Only one good case, using OSO-8
    - Crab Nebula, 19±1% (Weisskopf+ 78)
    - 2 energies via Bragg reflection off Graphite crystals at Brewster angle
- Later, XRBs showed < 5% polarization or weak (OSO-8; Long+, Silver+)

Weisskopf+, 1976



Weisskopf 1976

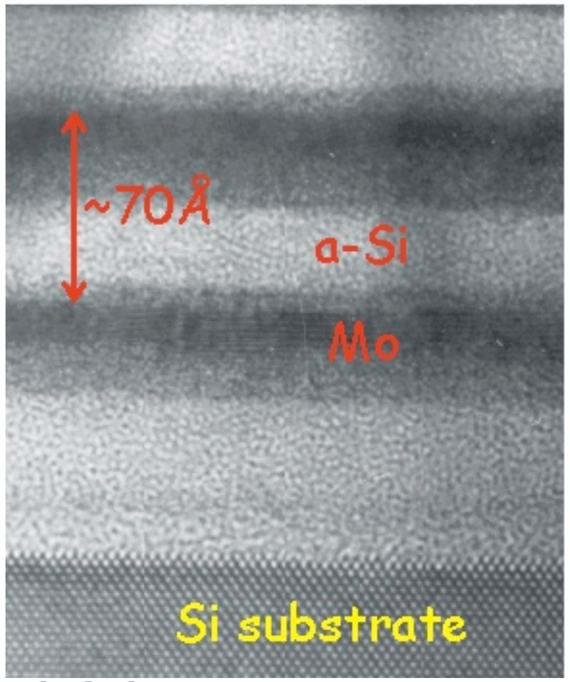


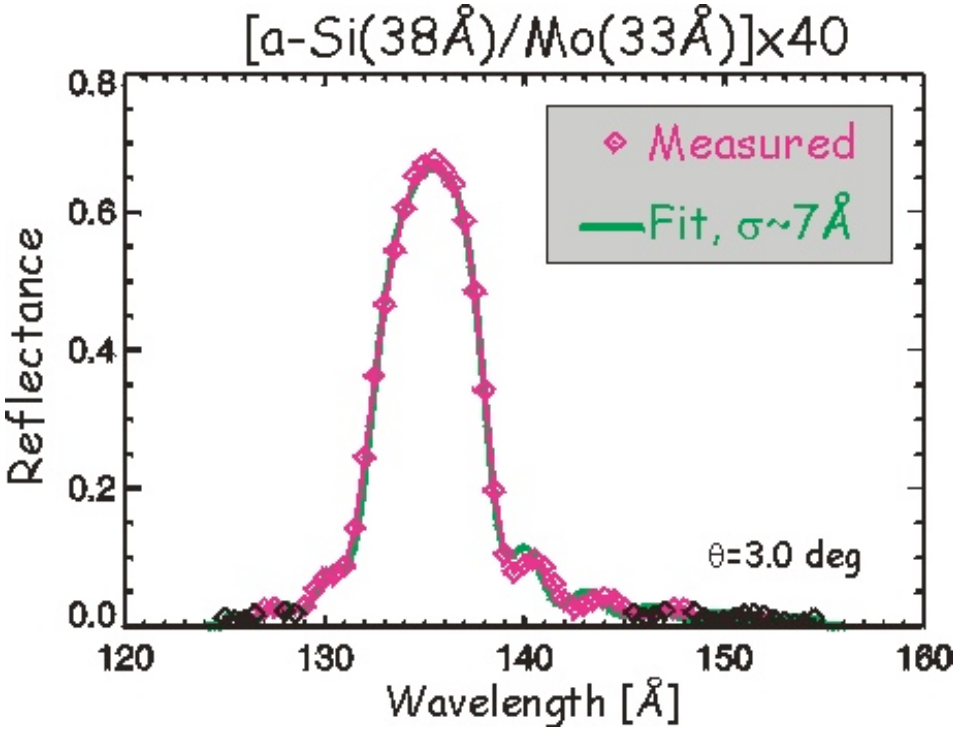
Polarimetry with Multilayer Coatings

- Multilayer coatings: crude crystals
- Peak reflectivity at E given by Bragg condition:

$$E = hc/\lambda, \lambda = 2D \sin\theta_g$$

- Reflectivity increases with number of layers
- At t=45° (Brewster angle), p-polarization nulls

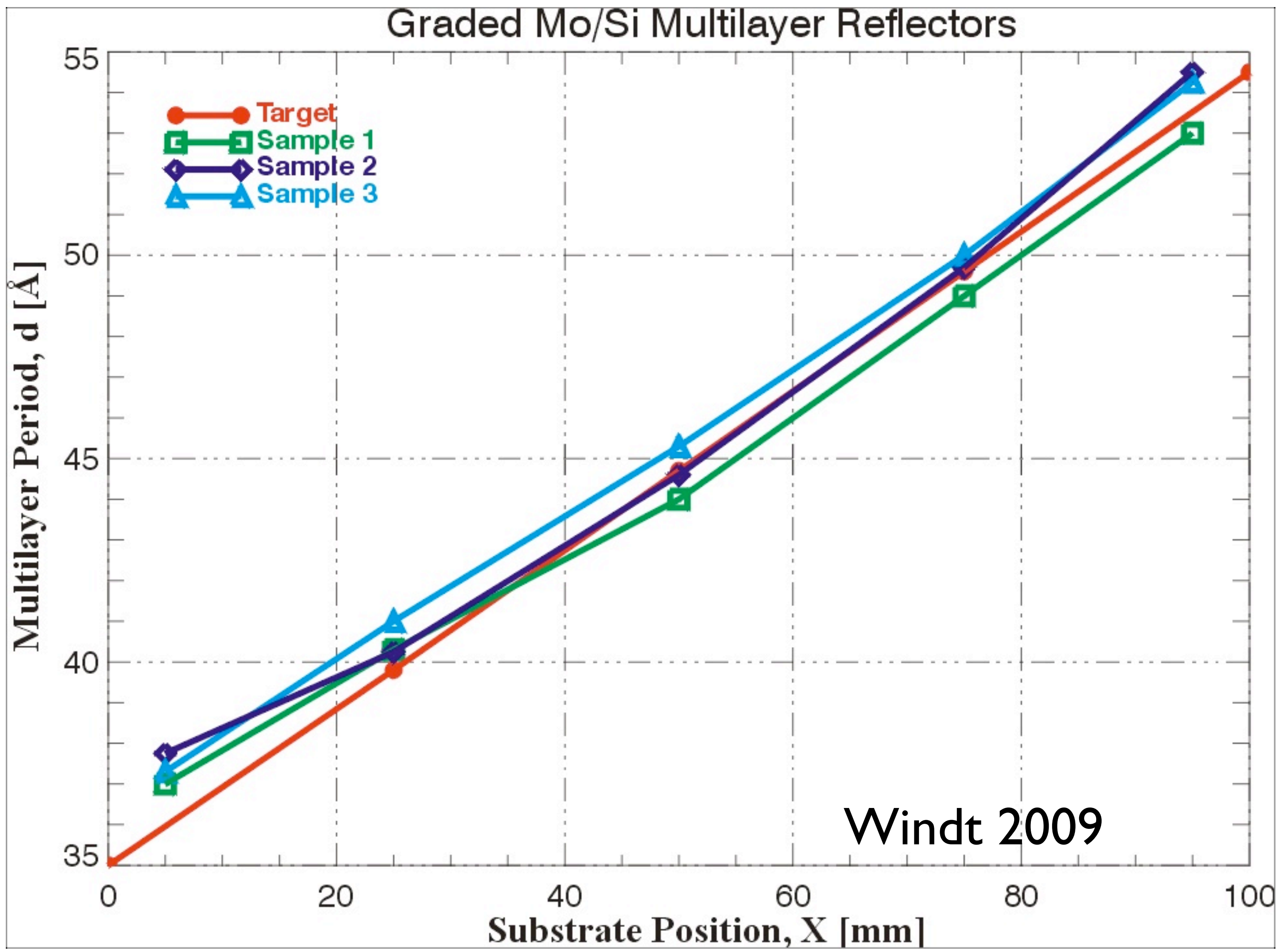




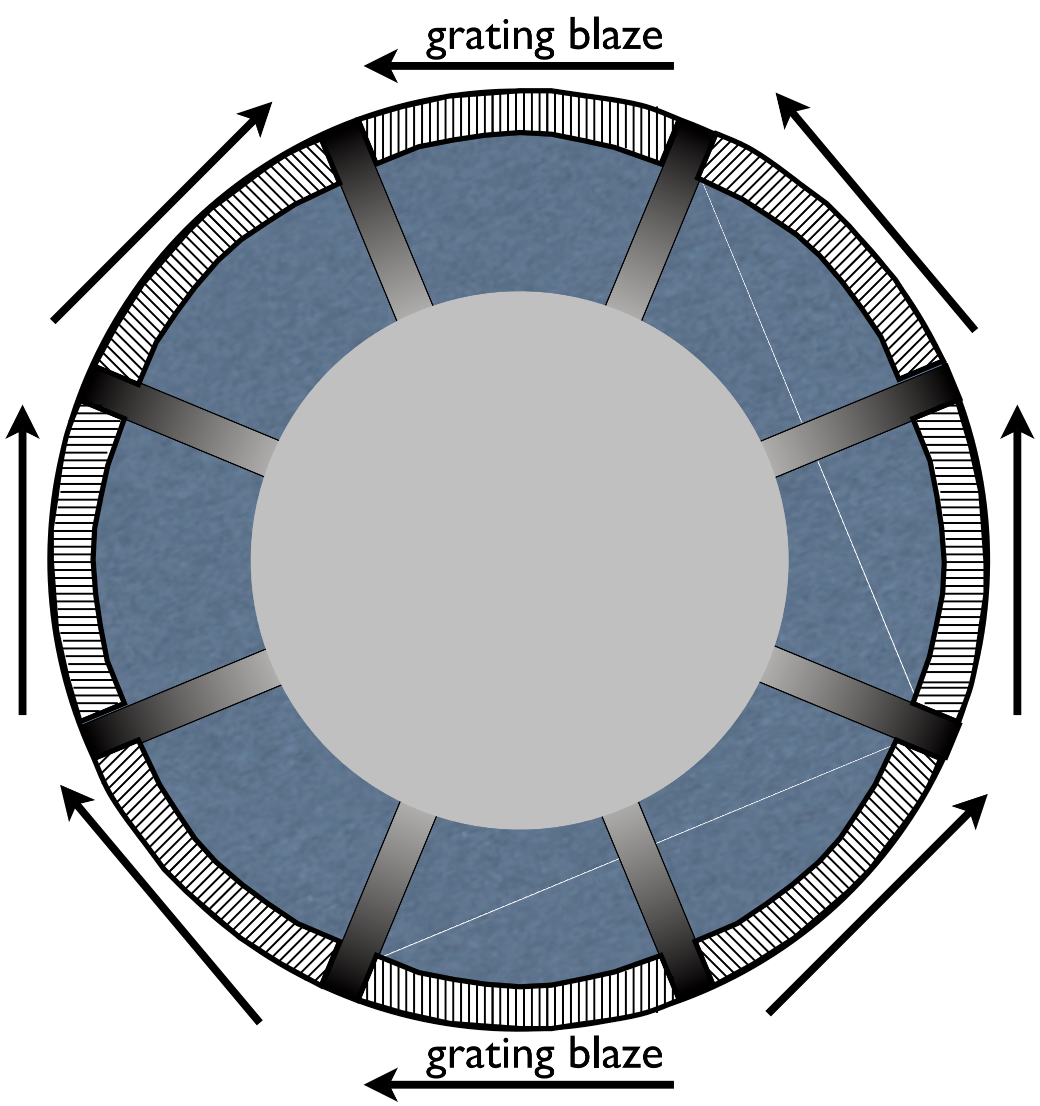
Soft X-ray Polarimetry

- Start with general use broad-band mirror
- Add gratings to disperse X-rays
  - Blazed gratings — high efficiency to one side
  - Resolution: E/dE ~ 100, can be > 1000
- Multilayer coated, flat polarizer
  - Use lateral grading to pick out proper wavelength
  - Reflect at 35-45° angle for high modulation
  - Many layers in ML mirror brings reflectivity to 10-20%
- Total bandpass: 0.2-0.7 keV
- Currently testing concept at MIT lab

Laterally Graded Multilayer Coatings

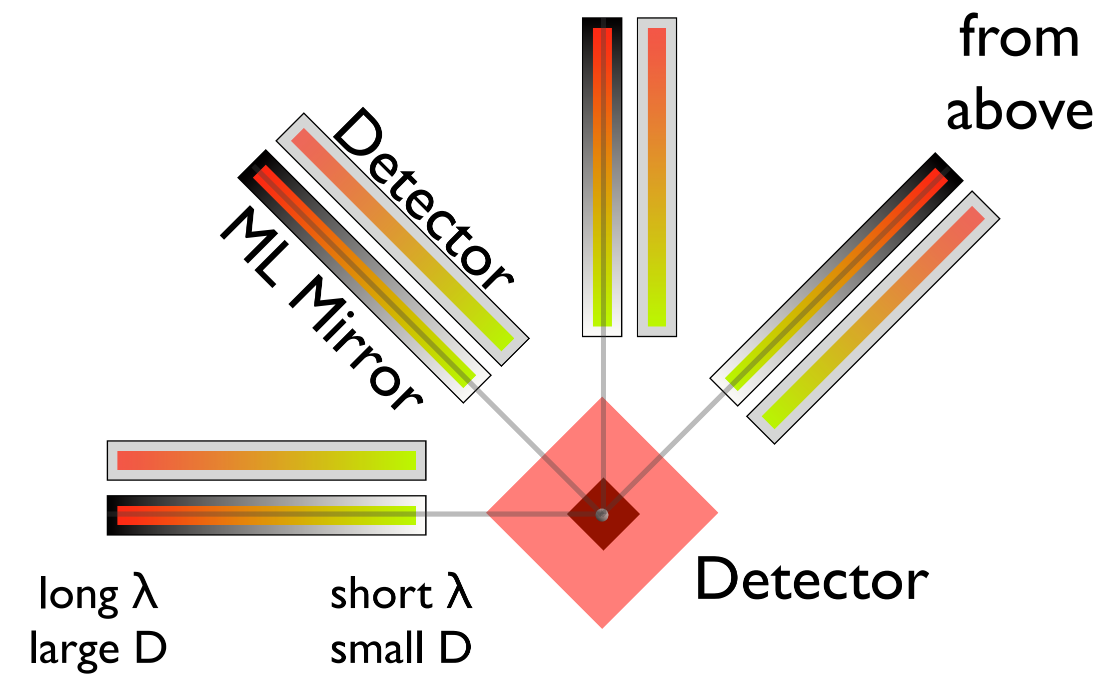


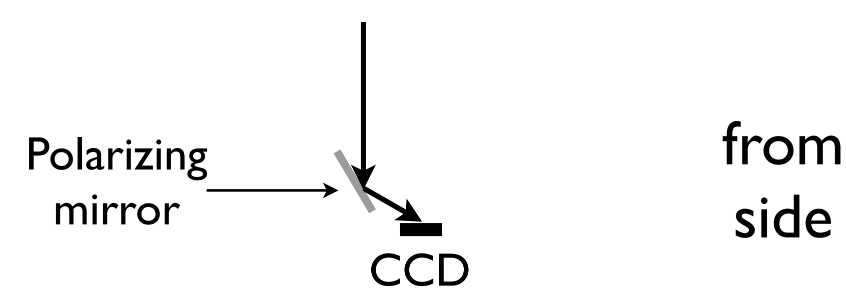
A Soft X-ray Spectropolarimeter

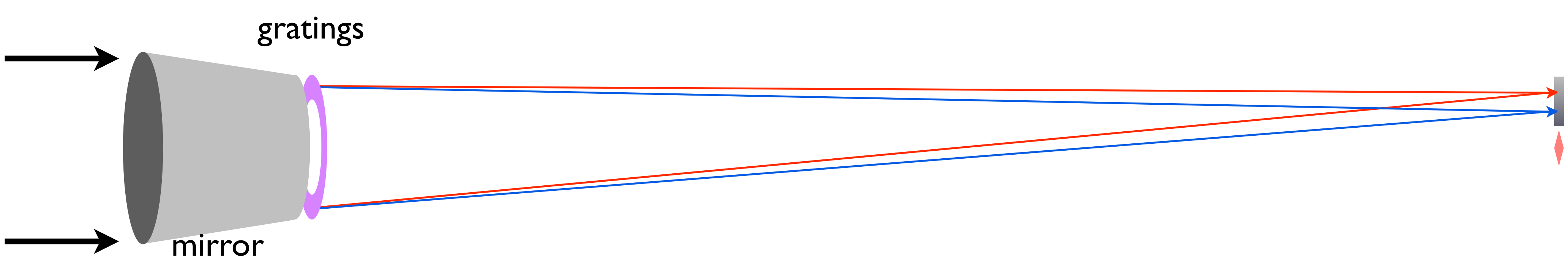


View of front aperture

View of focal plane

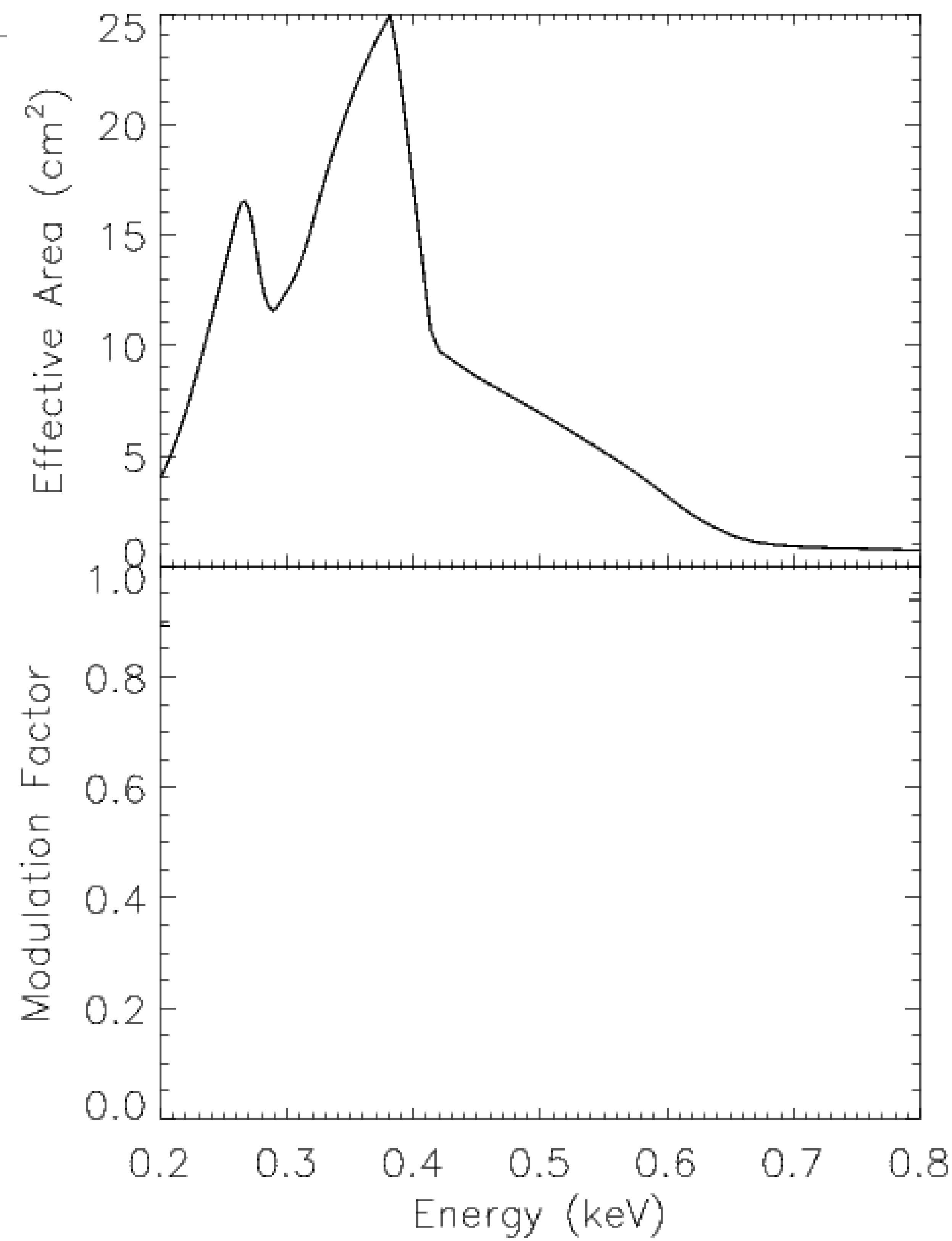




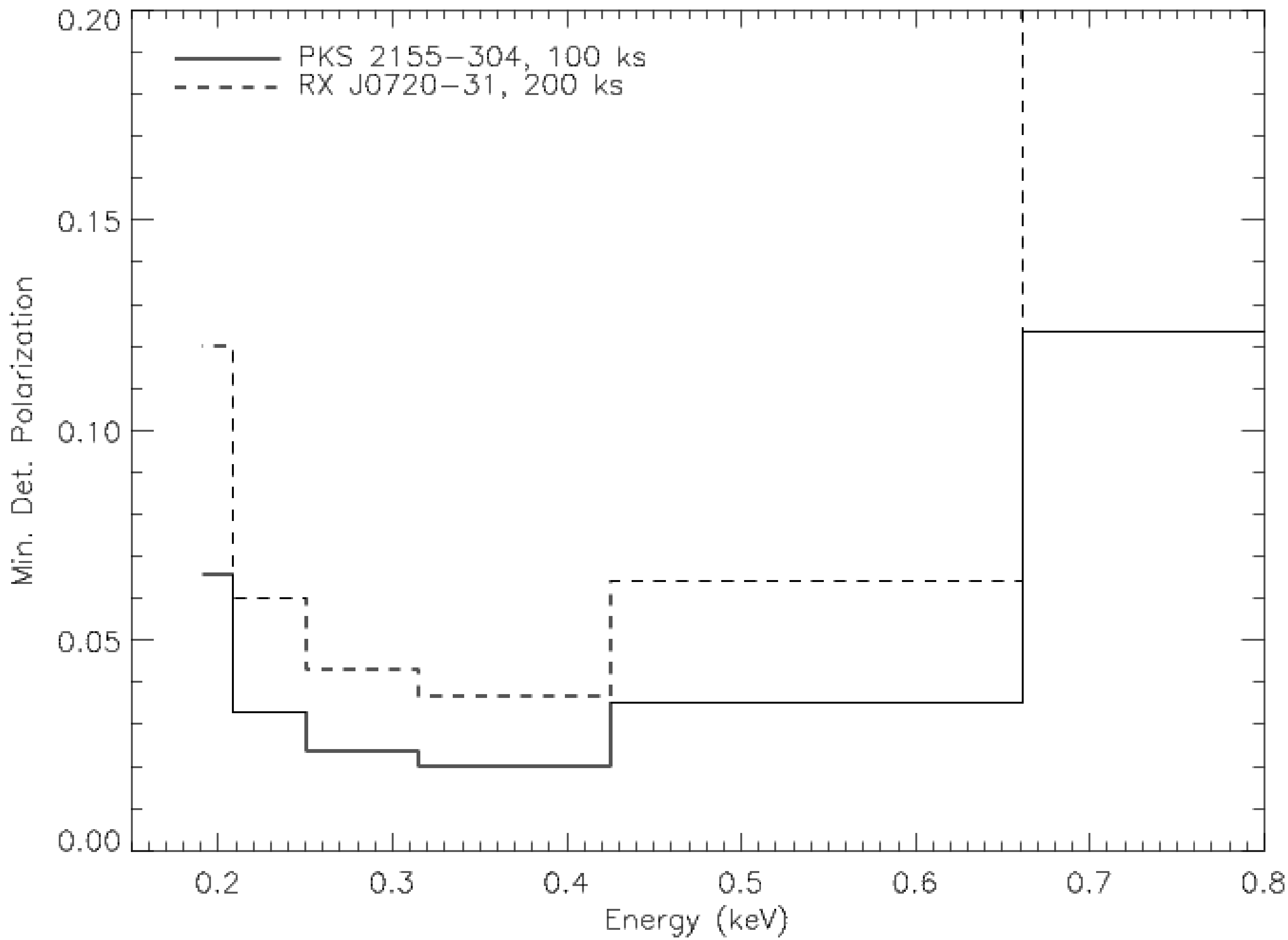


Strawman System Throughput

- Telescope 30 cm diam.
- CCD detectors
- Realistic ML reflectivities
- Sample observation of PKS 2155
  - 100 ks exposure
  - detect <5% polarization
  - 4 bands from 0.2 to 0.65 keV
- Sample 200 ks on RX J0720-31
  - detect <10% polarization
  - in same 4 bands

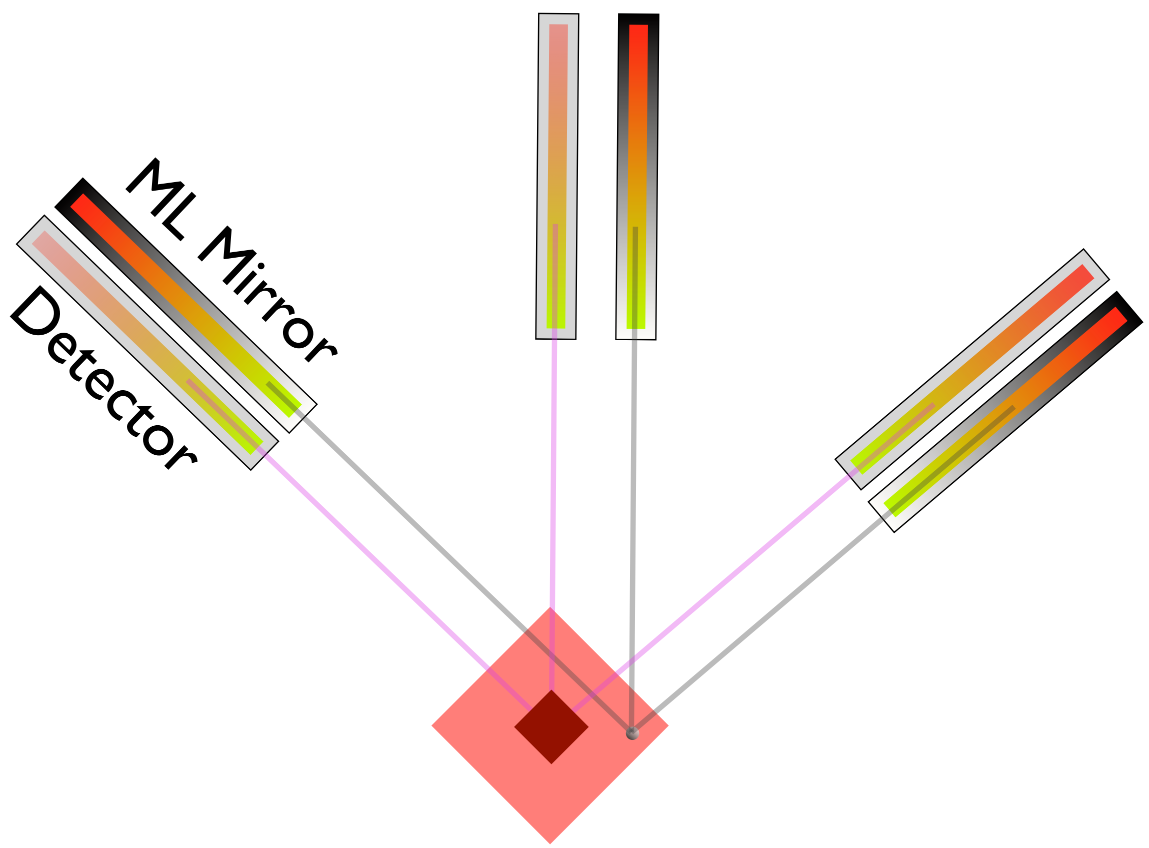


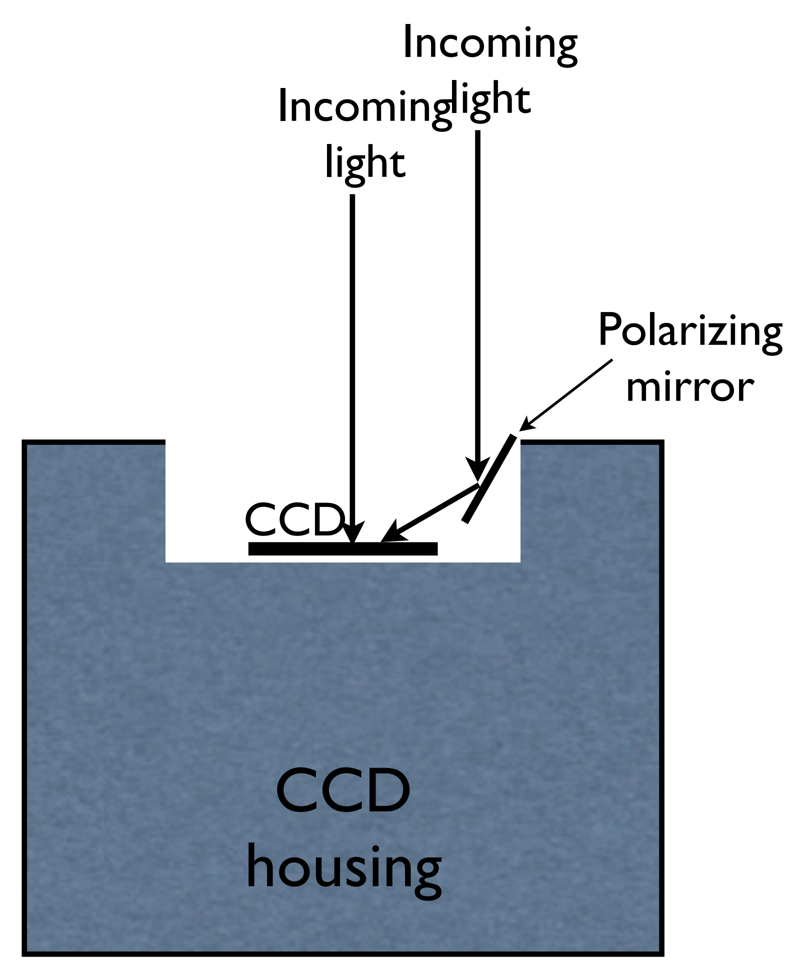
Small Mission Capability



A Design for a Large X-ray Telescope

- Start with a Grating Spectrometer
- Require >2 readouts
- Add ML coated mirrors
- Offset point

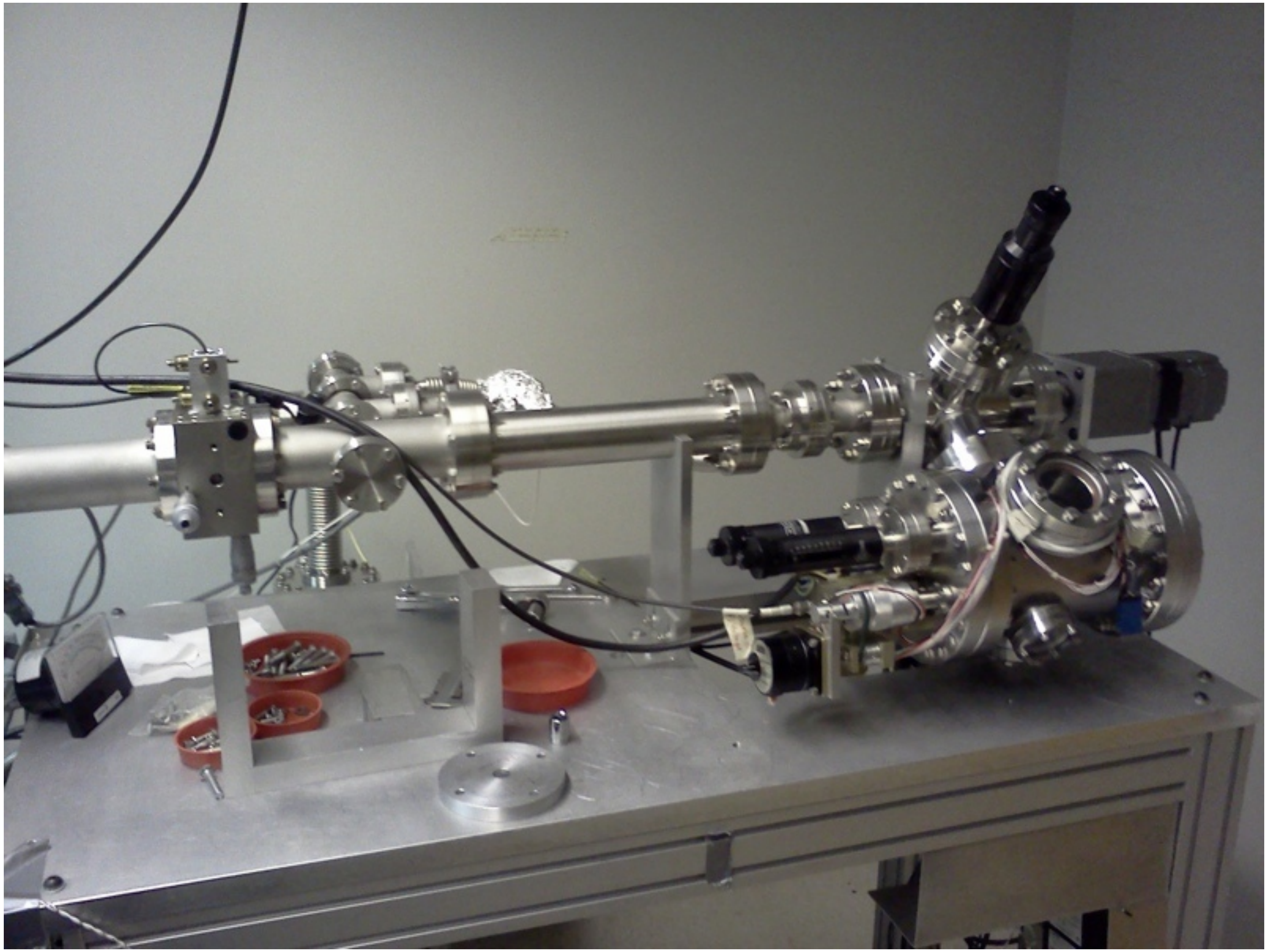




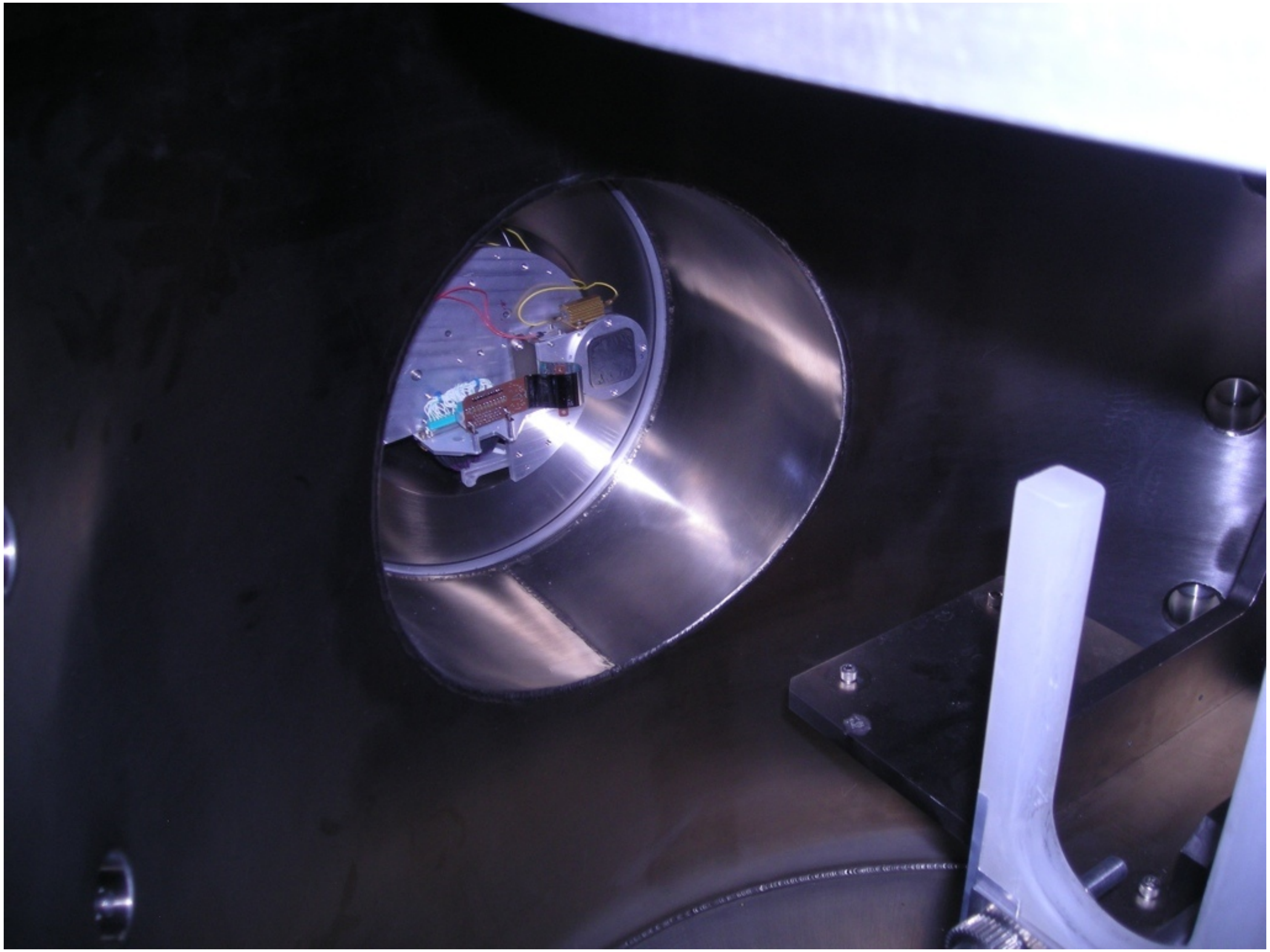
ML Polarimetry Testing Laboratory

- Goal: prove components for a flight instrument
- Method: adapt existing lab equipment at MIT
  - Polarize X-rays from existing source
  - Use existing spare Chandra HETG gratings and mounts
  - Add ML coated mirrors (need at least 2)
  - Using spare CCD detector
  - Reconfigure as needed
- Progress: Ready for end-to-end test at one energy (O-K line at .525 keV)
  - Polarizing source alignment nearly done, testing with CCD detector
  - Detector reconfiguration is next

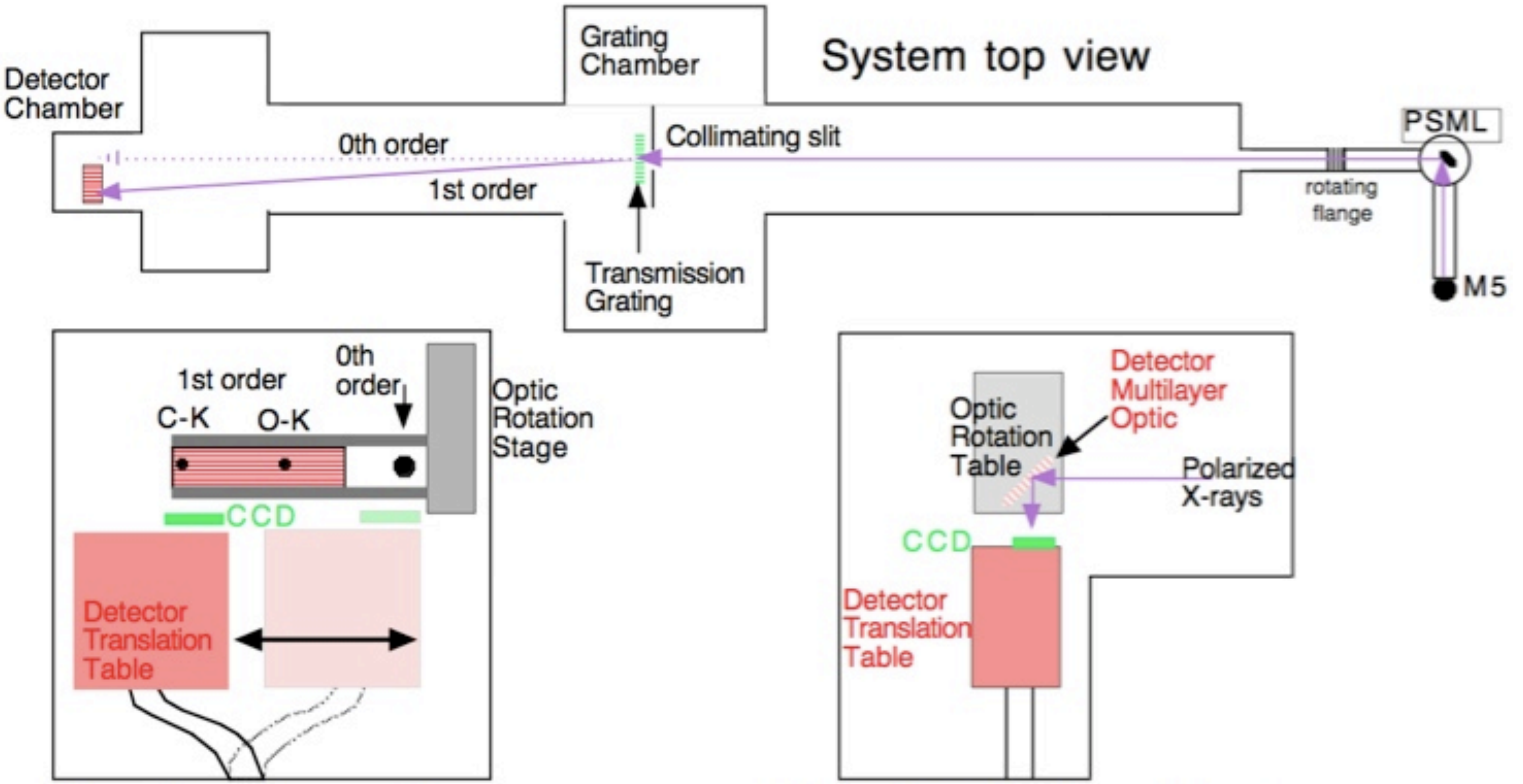
Polarimetry Lab Source



Polarimetry Lab CCD Detector



System Design



View from beam pipe

Detector chamber side view

Summary

- Prospective observations should break new ground
  - Can address IXO science (BH spin, NS EOS)
  - New discovery space
- Soft X-ray (.2-.8 keV) polarimetry is feasible
  - Simple lab demonstration is imminent
  - Flight proposals are likely within 3 yr
  - Can be adapted for use in a large facility
- Technology development need
  - About $500K for 2 yr to verify laterally graded ML coating
  - Opportunities to propose a small mission
  - Inclusion in studies of large missions with grating spectrometers