A (Broad-band) Soft X-ray Polarimeter

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A Science Goal: Neutron Star Atmospheres

- Isolated neutron stars are often soft, emit below 1 keV
- Atmospheres show features now found in spectra of isolated N-stars
- Features will be polarized more than continuum
- Atmosphere models are used to determine $R^2$, $g$ to give $M, R \rightarrow$ Nuclear Equation of State

\[ H_{\text{E}} \text{ (erg cm}^{-2}\text{ s}^{-1}\text{ keV}^{-1}) \]

\[ T_{\text{eff}} = 1.2 \times 10^6 \text{ K} \]
\[ B = 4 \times 10^{13} \text{ G} \]
\[ \Sigma = 10 \text{ g cm}^{-2} \]

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Suleimanov+ 2011
Broad-band Soft X-ray Polarimetry

• Start with general use broad-band focusing mirror
• Use gratings to disperse X-rays: Critical Angle Transmission (CAT) gratings
• Add Bragg reflector: multilayer coated, flat mirror
  • Period is laterally graded (LGML) along mirror to match dispersion
  • Set at 45±5° angle for >90% modulation of linearly polarized X-rays
• Useful bandpass: 0.15-0.7 keV
• Components verified at MIT Polarimetry Beamline or ALS (Berkeley)
• Designed a sounding rocket instrument
  • Rocket Experiment Demonstration of a Soft X-ray Polarimeter (REDSoX Polarimeter)
  • Received funding for raytracing and mechanical engineering
  • Submitting to NASA for launch in 2022, concurrent with IXPE
Multilayer Polarimeter
Schematic Layout

0th Order

Polarizing ML mirror

CCD
Current Reflectivities of LGMLs

LGMLs – Measured Reflectance at 45 degrees incidence

 Reflectance, R

Wavelength, λ [Å]

La/B,C (RXO #A14080)
C/Co$_{75}$Cr$_{25}$N$_2$ (RXO #A13164)
Cr/Sc (CXRO #CX170419A1)

H. L. Marshall — REDSoX Polarimeter

Alsatian Polarimetry 2017
CAT Gratings

- MIT/SNL CAT gratings are now available
- Gratings etched from Si wafers
- 5 gratings are in lab, others tested at MSFC
- Efficiencies are as expected, up to 25%
- See papers by Heilmann et al.
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Sounding Rocket Experiment (Proposed)

- Wolter-I optics (MSFC, ML)
  - 9 shells, 640 cm$^2$
  - 15-25” HPD
  - $F = 2.5$ m, 44 cm diam.
- CAT gratings (MIT)
- 4 CCDs (XCAM)
- 3 LGMLs (RXO)
- Launches in 2022
- Achieve $MDP = 11\%$ for Mk 421 in 300 s exposure
Suborbital Mission:
Entrance Aperture & Focal Plane
Sounding Rocket Predictions

- 300 s exposure (h > 110 km)
- Achieved ML reflectivities
- Measured CAT grating efficiencies
- Simulated Mk 421 observation:
  - easily detect 20% polarization
  - MDP is 11%
- MDP for Isolated NSs: 59-75%
- Her X-1: MDP = 20%

Simulation of Mk 421, 20% polarized perp. to CCD 1
The X-ray Polarimetry Probe

- 0.15-0.7 keV: like REDSoX
- 2-8 keV: like IXPE
- 3-50 keV: like X-Calibur
Prediction for a Probe

• Same focal plane
• Added improved LGML
• Added mirror shells
• 200 ks exposure on 3C 273

• MDP = 2% in 10Å bands
  (30-70 Å, 0.18 to 0.4)
• Total rate: 2.3 cps
Summary

- Soft X-ray (0.15 - 0.7 keV) polarimetry is feasible
  - Suborbital flight proposal: REDSoX Polarimeter (1st launch: 2022)
  - Preliminary design validates approach & achievable tolerances
  - Targets include blazar jets and isolated neutron stars
- For a Polarimetry Probe: add an instrument of the REDSoX design
  - Praxys detector for 2-8 keV band, Excalibur detector for 10-50 keV
  - REDSoX Polarimeter adds 0.15-0.7 band, common optics
  - Add GPD for X-ray imaging
- Improved X-ray polarimetry science in an X-ray Polarimetry Probe
  - Blazar jets, quasar cores: polarization over x50 in E
  - Nstars below 1 keV: QED (RX J0720-31)
  - Pulsars (Her X-1, PSR 0656+14)
  - AGN disk orientation & GR effects
  - XRB jets from low N_H BH transients (XTE J1118+480)
Polarimetry Raytrace

- Software components from MARXS in python
- Can compute effective area & modulation factor, verify design
- Examine tolerances for mirror HPD, aspect jitter, misalignments