A setup for soft proton irradiation of X-ray detectors and mirror shells
Overview of the talk

- Soft (E < 1 MeV) proton effects on X-ray detectors
- Reflection of soft protons on X-ray mirrors
- Experimental setup at the accelerator facility
- Examples of measurements performed
- Sudden CTI increase of front-illuminated CCDs of the *Chandra ACIS* instrument (e.g. Lo et al., 2003)
- Background studies with *EPIC* pn-CCDs of *XMM-Newton* (Kendziorra et al., 2000)

*Proton Spectrum measured in orbit with a low gain mode of the pn-camera of XMM-Newton*
Electron scattering $\Rightarrow$ ionization (TID)
Nuclear scattering $\Rightarrow$ lattice defects and vacancies (NIEL)
Degradation of the photon detection performance (sensitive volume, energy resolution, spatial resolution)

- Charge trapped in insulator $\Rightarrow$ increased voltage for full depletion
- Creation of intermediate levels $\Rightarrow$ increased leakage current
- Creation of charge traps $\Rightarrow$ decreased charge collection efficiency

Observational background

- Energy deposition via direct interaction in the detector
- Induction of fluorescent line emission in the vicinity of the detector
Firsov Scattering

- Protons interact with electron plasma above mirror surface
- Efficient at low incident angles
- Very small energy loss
- Boost to forward angles

(Fioretti, 2011)
Aschenbach Description

- Describing protons by means of de Broglie wave formalism
- Reflection occurs analog to X-ray photons ("Proton Telescope")
- Critical incident angle is energy dependent
- Zero energy loss
- Angular distribution peaks at \( \Theta_{\text{scatter}} = 2 \cdot \Theta_{\text{inc}} \)

(Asschenbach, 2007)
- 3 MV Van de Graaff accelerator
- Current terminal voltage range: 0.7 – 2.0 MV
- Beam current: 10 nA – 10 µA continuous current
- Ion types: $p, H_2^+, d, D_2^+, ^4He^+, ^{12}C^+, ^{13}C^+, ^{16}O^+$
- 6 beam lines
Detector Irradiation

Soft Proton Irradiation Setup (1)

beam
beamstop vacuum shutter
slit
pinhole aperture
different energy degrader foils
shutter

~ 2.4m

scaler/ADC
detector under irradiation
monitor detectors

ψ ~ 11cm
Originally designed for LOFT detector irradiation

- Allows homogeneous distribution over large detectors (11 cm diameter)
- Fluences of 0.5x, 1x, 5x and 10x mission lifetime were applied at different energies
- Leakage current was measured at different temperatures and annealing was monitored in the following months

![LOFT Detector Prototype](image)

**Input Spectrum Measured at the Detector Location**

<table>
<thead>
<tr>
<th>energy (keV)</th>
<th>cts/ch</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>0</td>
</tr>
<tr>
<td>400</td>
<td>0</td>
</tr>
<tr>
<td>600</td>
<td>0</td>
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<tr>
<td>800</td>
<td>5000</td>
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<tr>
<td>1000</td>
<td>0</td>
</tr>
<tr>
<td>1200</td>
<td>0</td>
</tr>
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</table>

**Homogeneity of the Irradiation**

<table>
<thead>
<tr>
<th>horizontal position (cm)</th>
<th>vertical position (cm)</th>
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</thead>
<tbody>
<tr>
<td>-4</td>
<td>0.975</td>
</tr>
<tr>
<td>-2</td>
<td>0.976</td>
</tr>
<tr>
<td>0</td>
<td>0.979</td>
</tr>
<tr>
<td>2</td>
<td>0.98</td>
</tr>
<tr>
<td>4</td>
<td>0.982</td>
</tr>
</tbody>
</table>

**Input Spectrum Measured at the Detector Location**

![Input Spectrum Measured at the Detector Location](image)

**Homogeneity of the Irradiation**

![Homogeneity of the Irradiation](image)
LOFT (Large Observatory for X-ray Timing) currently in the ESA M4 selection process.
Mirror Scattering

13/34 | Soft Proton Scattering on X-Ray Mirror Shells

HEA Group Seminar, 6 Feb. 2015

Chris Tenzer - IAAT, University of Tübingen, Germany - Soft Proton Irradiation of X-ray Detectors and Mirror Shells
Mirror Scattering

Experimental Setup

Implementation at the Accelerator Facility
Mirror Scattering

Incident Flux Determination via Monitor Detectors

Experimental Setup

Wahrscheinlichkeitsverteilung vor Korrektur

Dr. Chris Tenzer - IAAT, University of Tübingen, Germany - Soft Proton Irradiation of X-ray Detectors and Mirror Shells
- scan the target area with a movable SSB detector
- record the scattering efficiency for different incidence angles and energies
- accumulate spectra and determine the average energy loss
we are currently updating the setup to improve on the resolution of the energy measurement and the angular distribution
we are preparing measurements with multi-layer coated mirrors and are open for other interested groups to test their mirrors (or detectors)
the results obtained so far for eROSITA are published and will now be compared with recent Geant4 simulations and a raytracing code developed in a collaboration with INAF Palermo
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Thank you!