Next Generation X-ray Telescope: Science and Possible Instrumentation with Grazing Incidence Photon-Counting Imager

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and
The NGXT sub-WG
Grazing Incidence Imager

- Much of the sub-WG discussion on GI have concentrated on photon-counting-type imager.
  - NI discussion made by Shimojo-san.
  - No advantage present for photon-counting NI imager because of poor energy resolution of Si detectors for EUV wavelengths.
  - Spectroscopic investigation of hot plasmas can only be performed by GI.
  - Photon-integration-type GI (direct extension of Yohkoh/SXT and Hinode/XRT) yet to be investigated in great detail.
Loops become differentiated at low temperatures

- Loop evolution in XRT is not well reproduced. Can’t even find the loop!

(H. Warren)
X-ray Spectra from the Sun
(Model Output with CHIANTI V5)
X-ray Spectra from the Sun
(Model Output with CHIANTI V5)

Imaging Observation in SXRs
(No photon-counting capability)

Flare (M2)

Active Region

Coronal Hole

Quiet Sun

Photon Counting in HXRs
(Insufficient image quality)

EUV Spectroscopic Obs.
X-ray Spectra from the Sun
(Model Output with CHIANTI V5)

- Emission Lines
  - Thermal Bremsstrahlung
  - Non-Thermal Bremsstrahlung
- Continuum
  - Independent T info. from lines
  - Particle acceleration

Imaging Observation in SXRs
(No photon-counting capability)

Flare (M2)

Coronal Hole

Quiet Sun

EUV Spectroscopic Obs.

flare_ext
active_region
quiet_sun_brooks
coronal-hole

energy [keV]

photons [cm^2 sr^-1 s^-1 keV^-1]
GI Telescope: Science Targets

• Soft X-ray corona in <1 – 10 keV
  ... Discovery space with imaging spectroscopy

• Imaging spectroscopy of hot (>5 MK) plasmas in active regions
  – Can never be investigated with EUV spectroscopy
  – What is the highest temperature in ARs?
    → Heating and thermal energy transport
Active Regions and Quiet Sun

- DEM determination

(Brosius et al. 1996)

* DEM above 5 MK not known.
High-Temperature Components across Active Regions and Quiet Sun

Hot plasmas with temperature 5–32 MK (most likely >10 MK) present not only in Active (X-ray bright) Regions but also in the Quiet Sun and near the poles, even during solar minimum.

→ How are they heated?
→ How are they maintained?
→ What DEM?

(Ishibashi 2008)
GI Telescope: Science Targets

- **Flares**
  - Spectral features in the global magnetic structure associated with reconnection
    → Investigation of shock
  - Spatial distribution and temporal evolution of non-thermal X-rays in the early phase of flares.
  - Fe line mapping for 20-30 MK plasmas
- **Accelerated particles:** Manifest themselves as NT deviation from ambient thermal plasmas
  → Thermal + Non-thermal emission
  → <1 – 10 keV energy range essential
Shock Acceleration of Electrons in Cosmic Plasmas

(Koyama et al. 1995)
Possibilities: Particle Acceleration Site

Non-Thermal Imaging

Larger image dynamic range with focusing optics as compared to Fourier synthesis type imagery.

→ Suited for observing NT X-rays in the corona
They analyzed the B6 flares observed by the RHESSI and found that the non-thermal spectrum (power-law) continue to around 6 keV.
Asai et al. (in press): 2002-July-23 X4.8 flare

- The non-thermal signal from the pre-flare stage of the X4.8 flare.
- The source is in corona.
- The loop top source is non-thermal based on the HXR and Radio Observations.
Re-analysis (2002-July-23 X4.8 / preflare)

AR count spectrum
Extrapolation of non-thermal compo.
Table 5.3-1: Draft scientific specification needed for the photon-counting telescope.

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Remarks</th>
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<tbody>
<tr>
<td>Optics</td>
<td>Grazing incidence</td>
<td></td>
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GI Telescope

- Employ CMOS imager sensor as the focal-plane array
  - Sarnoff CMOS sensor consired to be the baseline device.
- Use of “segment mirror”
Instrument Features (Preliminary)

- **Focal Length & Plate Scale:** \( \sim 4 \text{ m and } \sim 0.4''/8\mu\text{m pixel, respectively} \)
- **X-ray Mirror:**
  - Walter-I like GI segment mirror (1/8 segment of a cylinder)
  - Coating with Ir mandatory to increase high-energy response
- **Grazing angle:** 0.9 deg. (TBD; investigation ongoing between 0.45° and 1.8°)
- **Exposures:**
  - Either Photon Counting mode or Photon Integration mode
  - P-C to be performed with ROI size of \( \sim 256 \times 256 \) pixels
- **Focal Plane Filters:**
  - Attenuation for photon counting exposures
  - Analysis filters for photon integration exposures
- **Detector:**
  - Sarnoff CMOS image sensor (front illuminated) considered as the baseline
  - \( 2k \times 2k \) (TBD) 8 \( \mu \text{m} \) pixel size
- **Frame Readout Rate:**
  - 1000 fps for photon counting mode
  - \( \geq 10\)-bits A/D conversion
- **Data Output Rate:**
  - 110 Mbps for 512x512 ROI
  - 6.9 Mbps for 128x128 ROI
  (Preliminary; no attempt in reduction)
Assumed FI/BI QE Profiles

Red: FI CMOS (15 μm Si + 4.2 μm SiO₂ + 0.2 μm Si₃N₄)
Black/Dashed: BI CMOS (5 μm Si + 100 A SiO₂)
Black/Dotted: XRT (BI) [for reference purpose only]

(N.B. Deep edge at ~< 2 keV for BI CMOS is due to small (5 μm) Si thickness.)
Sample Active Region
(NOAA AR 10978 on 10 Dec. 2007)

XRT Med-Be 16.0s; 16:35:47 UT

Expected full-Sun image with
FI CMOS (ignoring FOV size...)

GOES 11 X-Rays:

- B3.4
- A5.8
Presence of Partial-Opening in Each Pixel

AR with Partial Opening (0.9deg): Black=0%, Red=1%, Green=5%
Exploring Active Regions with NGXT: Science Cases

Presence or absence of higher-temperature plasmas (>~5 MK) in ARs not known until now.

Active Region energetics:
- How is thermal energy distributed in ARs?
- What is the maximum temperature that a non-flaring AR can attain?

Cannot be investigated with EUV line spectroscopy.

Even better low-T diagnostics expected with BI or front-thinned FI detector.

High-T lines to be clearly imaged for the first time with NGXT.

Sample pixel binning for NGXT imaging spectroscopy.

Simulated AR spectrum with baseline NGXT

\( T_{\text{NET}} = 3000 \text{ s} \)

Photon Integration
Exploring Flares with NGXT: Science Cases

NGXT acts as both thermal and non-thermal imager.

Where are the reconnection/shock signatures in the global magnetic field configuration?

Flare dynamics:
- Investigation on energy release, particle acceleration, and shock formation.
- Creation of super-hot plasmas and their spatial relationship with N-T sources.

- How are non-thermal electrons spatially distributed, and in what spectra, during the triggering phase of a flare?
- Down to what energy is flare N-T emission present?

Simulated FL spectrum with baseline NGXT

\[ T_{Net} = 300 \text{ s} \]

Emission lines provide high-T thermal information while the continuum provides both non-thermal and thermal information.

Rich non-thermal emission should be imaged in the NGXT energy range.
Improvement in detector sensitivity

Limit from charge spreading and event detection method
Photon Counting GI X-ray Telescope:

- **Photon-counting Mode:**
  - Moderate angular resolution but should be able to provide new information on:
    - Physics of flares
    - Thermal distribution across ARs
    - Spectroscopic imaging observations of the hot corona in soft X-rays

- **Photon-Integration Mode:**
  - Imaging of the hot (>~1 MK) plasma with the highest angular resolution (0.5") as GI
  - Temperature diagnostic with filter-ratio
  - Context information for photon-counting data