Einstein Probe

----- exploring the dynamic x-ray universe

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On behalf of
the EP consortium

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Scientific drivers for future X-ray all-sky monitors

- The Universe is rich in high-energy transients and variables

- New transients continue to be discovered, and need observational characterisation in large samples

- Exciting examples:
  - Tidal disruption events
  - Supernova shock breakouts
  - High-z GRBs
  - EM sources of gravitational wave events

- Expected/unexpected new types!

Really need next generation of ASM
Lobster-eye Micro-Pore Optics (MPO): enabling true focusing imaging for wide-field X-ray instruments

- Wide FoV: > $10^3$ sq.deg
- Moderate angular resolution: arc-minutes
- Moderate sensitivity: < ~ 1mCrab @1 ksec

significant improvement upon current instruments (non-focusing)

see P. O'Brien's talk

Measured X-ray image of point source @NAOC/CAS

PSF ~ 4.5' (fwhm)
Einstein Probe (EP) : main science goals

- Carry out systematic survey of soft X-ray transients and variability of X-ray sources at an unprecedented combination of high sensitivity and cadence.
- Discover otherwise quiescent Black holes at almost all astrophysical mass scales and other compact objects by capturing their transient flares.
- Detect and localize the electromagnetic-wave sources of gravitational-wave events by synergy with gravitational-wave detectors.
EP payloads and features

**WXT (12 modules)**
Wide-field X-ray Telescope
- FoV: 3600 sq deg (1.1 sr)
- Band: 0.5 – 4 keV
- Resolution: ~5’ (FWHM)
- Sensitivity: 10s better than ASM now

**FXT (2 modules)**
Follow-up X-ray Telescope
- FoV: ~1 deg
- Band: 0.3-10keV
- Eff. area: 300cm² @1keV (1 unit)
- Resolution: 30” (HPD)

**spacecraft**
- On-board data processing
- Quick slew & autonomous follow-up
- Fast alert data downlink and uplink (ToO)

**lobster-eye MPO**
- FoV: 3600 sq deg (1.1 sr)
- Band: 0.5 – 4 keV
- Resolution: ~5’ (FWHM)
- Sensitivity: 10s better than ASM now

**Wolter-1 telescope**
- FoV: ~1 deg
- Band: 0.3-10keV
- Eff. area: 300cm² @1keV (1 unit)
- Resolution: 30” (HPD)
EP consortium

- Chinese Academy of Sciences (CAS)
  - Managed by CAS’s National Space Science Centre (NSSC)
  - Institutes: NAOC, IHEP, SITP, MicroSAT, NSSC

- European Space Agency (Mission of Opportunity)
  - Hardware contribution (mainly FXT)
  - Ground station support
  - Science management support

- Max-Planck-Inst. for extraterrestrial Physics
  - Hardware contribution (FXT)

- CNES/CEA (collaboration in discussion)
  - VHF network & support/tools (contribution to EP Science Centre)
Project timeline

Phase A
- selected
- launched Dec. 2022
- joined by ESA and MPE

Phase B
- proposal

Phase C
- now

Phase D
- operations (nominal 3 years)
- +2 years (goal)
- launch Dec. 2022

Year

2013
2017
2022
2026
2028

Project phase
Wide-field X-ray Telescope (WXT)

One of 12 WXT modules

Focal length: 375mm
eff. area: ~3 cm$^2$ @1keV (PSF centre)

The largest-format detector for focusing X-ray telescopes ever (total 1728 cm$^2$)

Development
- CAS (SITP+NAOC)
- MPO: NNVT
- CMOS

Testing/calibration
- CAS (NAOC+IHEP)
- ESA (+ MPE)
WXT FoV and Grasp

WXT FoV (1.1sr)

Compared with typical GW source locus

Zhao D. et al. 2017
Simulated WXT sensitivity (goal)

5-sigma c.l. power-law $\Gamma = 2$

$N_H = 3.20 \text{cm}^{-2}$

for central spot of PSF

tens times better than current X-ray ASM (e.g. MAXI, Swift)
Follow-up X-ray Telescope (FXT)

Joint developed by IHEP/CAS, ESA and MPE

- X-ray optic systems
  - ESA + MPE
  - eROSITA design
- X-ray cameras
  - PN-CCD module (MPE)
Mission profile

- **Orbit:** ~ 600 km (96min), \( i = 29 \) deg

- **Observation modes**
  - **Survey:** 3 snapshots per orbit in night-sky, each ~ 1 ksec
  - **Autonomous X-ray follow-up**
    - spacecraft slew-time 3 - 5 min
  - **ToO**

- **Alert data rapid downlink**
  - Beidou system (China)
  - VHF (CNES)
  - Alert information will be publicly released quickly

- **ToO command uplink**
  - Normal (S-band): < 1 day
  - Time critical (Beidou): < 10 min

- **Mission Centre**
  - NSSC/CAS (host)
  - ESA (GS telemetry support)

- **Science Centre**
  - NAOC+IHEP (CAS)
In 3 orbits (~ 5hr) WXT covers most of the night sky (can be disrupted)
Cover the whole sky in half year
Good synergy with other M-W & M-M facilities (LSST/SKA/Swift/SVOM/LIGO/...)
**WXT status**

- 3 qualification models (QM) of mirror modules built and being tested
  - QM3 to be tested at Panter next week
- 2 qualification models of complete WXT modules built, and tests and calibration being/to be carried out

- **WXT QM**
  - In thermal test @SITP/CAS

- **fwhm ~ 5 arcmin**

- **mirror module QM @NAOC/CAS**
FXT Status

- Structural-thermal model (STM) of mirror module (provided by ESA/MediaLario) has been tested at Panter and is being tested at CAS/IHEP
- An X-ray camera QM built at CAS/IHEP using detector module provided by MPE
Satellite status

- Satellite STM built and tested by MicroSat/CAS in 2019
- QM to be built by June 2021, afterwards Phase-D
# Estimated detection rates for some transients

<table>
<thead>
<tr>
<th>Type of transients</th>
<th>detections per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal disruption event (TDE)</td>
<td>tens - 100</td>
</tr>
<tr>
<td>TDE with jet</td>
<td>10 (?)</td>
</tr>
<tr>
<td>Supernova shock breakout</td>
<td>10 (?)</td>
</tr>
<tr>
<td>Long GRB</td>
<td>~ 80</td>
</tr>
<tr>
<td>High-z GRB (z &gt; 6)</td>
<td>several</td>
</tr>
<tr>
<td>Short GRB</td>
<td>~ 10</td>
</tr>
<tr>
<td>Low-luminosity GRB</td>
<td>~ 10</td>
</tr>
<tr>
<td>Magnetar</td>
<td>a few</td>
</tr>
<tr>
<td>Stellar flares</td>
<td>several $10^3$</td>
</tr>
<tr>
<td>AGN monitored daily/weekly</td>
<td>tens/hundreds</td>
</tr>
</tbody>
</table>

*Challenging to identify!*
Example: simulated detection of a nearby TDE

\[ M_{\text{BH}} \sim 10^4 \, M_{\text{Sun}} \quad \text{IMBH} \]

\[ L_{0.5-4\,\text{keV}} = 4.3 \times 10^{41} \, \text{ergs}^{-1} \]

\[ f_{0.5-4\,\text{keV}} = 7 \times 10^{-12} \, \text{ergs}^{-1} \text{cm}^{-2} \]
Summary

- The future of monitoring the transient X-ray sky is promising enabled by Lobster-eye MPO technology
- EP will be a powerful mission in this field in the years to come
- Synergy with other M-W & M-M facilities offers great science opportunities
- Follow-up by ground-based telescopes are needed
- EP will be a good pathfinder for THESEUS, esp. in soft X-ray MPO technology and science
Thank colleagues and friends in European community for long-standing support and interest in EP!
Good luck for Theseus!

http://ep.nao.cas.cn