EXIST: Surveying the Obscured & Extreme Universe

Josh Grindlay (CfA/Harvard)
Lars Bildsten (ITP/UCSB)
Roger Blandford (Caltech)
Deepto Chakrabarty (MIT)
Andy Fabian (IOA, Cambridge, UK)
Fabrizio Fiore (Rome Obs./BeppoSAX, IT)
Jerry Fishman (MSFC)
Martin Elvis (CfA/SAO)
Neil Gehrels (GSFC; Study Scientist)
Chuck Hailey (Columbia Univ.)
Fiona Harrison (Caltech)
Dieter Hartmann (Clemson Univ.)
Chryssa Kouveliotou (MSFC)
Tom Prince (Caltech)
Brian Ramsey (MSFC)
Rick Rothschild (UCSD)
Gerry Skinner (CESR/Toulouse, FR)
Stan Woosley, (UC Santa Cruz)

Dieter H. Hartmann
Clemson University

Astronomy with Radioactivities
Seeon, Germany, May 30, 2003

10 - 600 keV
Energetic X-ray Imaging Survey Telescope

Beyond Einstein Roadmap:
“Observe BHs manipulate ST&matter”
Mission Goal: Black Hole Census

- BHs in Obscured AGN: accretion history
- BH in blazars and the diffuse IR background
- BH formation in GRBs out to z ~20-30

- Obscured supernovae
- Accreting pulsars
- Be/X-ray systems
- Magnetars
- **Novae** (M. Hernanz)

**Galactic rate uncertain**

$^7$Be (478 keV), 511 keV:
……….. All-sky monitors in the 20-600 keV range are required to discover novae.

Mission parameters:

- Sensitivity (~0.05mCrab) to >100 keV
- All-sky imaging every orbit
- 5’ resolution; ~5-50” position

http://EXIST.gsfc.nasa.gov
EXIST probes the obscured Universe
Science: Extragalactic

First all-sky (every orbit) imaging and variability hard x-ray survey

- Gamma-ray Bursts at the limit: Star Formation Rate to z~30(?!)
  - Highest spectral/temporal resolution images of GRBs (and SGRs)

- Survey Black Holes on All Mass Scales; Hard X-ray Background
  - Obscured AGN: Accretion History of the Universe
    - Spectra of Seyfert II’s and Type II QSOs: Contribution to HX Background

- Diffuse IR Background: Cosmic Star Formation History
  - HX spectra of Blazars simultaneous with AGILE/GLAST | VERITAS/MAGIC
Resolving the Multi-wavelength Background

Obscure AGNs
The accretion history of the Universe
Science: Galactic

• Accretion onto Black Holes
  - Spectra and variability (QPOs)
  - Survey for persistent HX sources in GMCs
  - Survey for transients: BH content of Galaxy; Local Group(!)

• Neutron Stars
  - Cyclotron lines in LMXBs and HMXBs: B-decay
  - Soft Gamma Ray Repeaters (SGRs): in Local Group (!)

• Galactic Supernova and Nova Rate
  - Map of entire Galaxy in 68, 78 keV lines of $^{44}$Ti: hidden SNR
    * SN 1987A: $F \sim 4 \times 10^{-6} \gamma \text{ cm}^{-2} \text{ s}^{-1}$ (Yuko Motizuki)
  - All sky monitoring/imaging of 478, 511 keV fast (~8h) line transients: nova rate
EXIST Mission Concept

Free-Flyer (500 km, i ~ 20°):

• Zenith pointing (Survey mode)

• 3-axis pointing (Observatory and survey)

• 3 coded aperture telescopes (60° x 75° each)

  → 180° x 75° fan-beam: all sky per orbit

Mission Parameters:

• CZT tiled arrays: 8m² total area

• Passive and active shielding

• Mass, power, telemetry: 8500kg, 1200W, 1.2mbs (X-band)

• Delta-IV launch
Timelines

Gamma Ray
- BATSE
- Beppo-SAX
- HETE-II
- Swift
- GLAST
- EXIST

X-ray
- ROSAT, ASCA, RXTE
- Chandra, XMM, ASTRO-E2
- Con-X

Optical/IR
- HST
- Ground-based (Keck, etc.)
- NGST
- SNAP

Rapid Optical
- LOTIS, ROTSE
- LOTIS-II, ROTSE-II
- REACT

Radio
- VLA
- VLA upgrade
- ALMA

Grav. Waves
- LIGO-1
- LIGO-2
- LISA
## EXIST Overview

<table>
<thead>
<tr>
<th>Mission Parameters</th>
<th>low -- high energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy range (resolution):</td>
<td>10-100 (1) keV; 100 - 600 (3) keV</td>
</tr>
<tr>
<td>FOV &amp; angular resolution:</td>
<td>180° x 75°; 5'</td>
</tr>
<tr>
<td>central-field for pointing:</td>
<td>5° x 5°; 50° x 40°</td>
</tr>
<tr>
<td>Sensitivity (5σ):</td>
<td>2mCrab --&gt; 20mCrab/orbit</td>
</tr>
<tr>
<td>(0.05mCrab=5x10^{-13} cgs)</td>
<td>0.05mCrab --&gt; 0.5mCrab/year</td>
</tr>
<tr>
<td>Temporal resolution:</td>
<td>1µsec --&gt; ~30min; 95min --&gt;1 year</td>
</tr>
<tr>
<td>Telescopes/detectors:</td>
<td>coded aperture/8m² CZT (1.2mm pix)</td>
</tr>
</tbody>
</table>
Survey Exposure & Sensitivities

Exposure uniformity (galactic coords.) each day (increased exp. at orbital poles)

Continuum and line sensitivities (3σ)
(≈6-12mo. Survey; dep. on orb. lat.)

INTEGRAL/SPI

44Ti(SN1987A)

Yuko Motizuki
Comparison with other Surveys

EXIST will extend the ROSAT (soft x-ray) all sky imaging survey. 
EXIST will complement GLAST (γ-ray) all sky imaging survey.

(~12 month)
Cyg X-1

Galactic Center

M, L, Q

Log Mass

primordial

Named by J. A. Wheeler (1967)

NGC 6240

Hubble Optical

Chandra X-ray
Two states of Cyg X-1

Probing the accretion rate... in binaries and BH/MC systems

GRO J0422+32
GRO J1655-40

.........less than 20 candidates........

~1,000 in MW,
...LMC, SMC,
........ M31

---
Black Holes and Galaxy Evolution

Does every galaxy harbor a central black hole?

How do galactic BHs grow and radiate in time (z) ?

Watching the central “monster” digest

Chaotic loss cone accretion \((10^{-3} \text{ yr}^{-1})\)

X-ray flares from the Galactic center:
Chandra: Baganoff et al. 2001, Nature 413, 45

SMBHs in optically non-active galaxies:
Chandra & XMM: e.g., Komossa, astro-ph/0209007
Blazars and Cosmic Diffuse IR

EXIST provides monitoring of all AGN classes, including Blazars.

Hard x-ray (synchrotron) spectral breaks (~10-200 keV) allow γ-ray (~10 GeV - 10 TeV) spectral breaks measured by GLAST/VERITAS...... constrain evolution of the diffuse IR background.

SSC model for Mkn 501 (Coppi & Aharonian 99)
The evolving MGRF

→ optical depth at $E \sim \text{TeV}$

Testing strong field GR with BH Accretion in GRB central engines and galactic SMBHs:

Efficiency: $6\%-42\% \ M_D c^2 + 29\% \ f(J/M^2) \ M_{BH} c^2$

via: Shape of fluorescent Fe lines

- requires monitoring the continuum

AGN QPOs! (>hrs): Lense-Thirring precession
Gamma Ray Bursts

$\delta \Omega \ll 4\pi$

$R_{\gamma\text{rb}} \sim 1\% R(\text{SN})$

GRB - SN connection

Cosmic SFR

GRB/SN diversity

e.g. hard X-ray flashes (Heise et al.)
Star formation in early universe favors massive stars.

Redshift records:

- QSOs: \( z \sim 5 \)
- Galaxies: \( z \sim 6 \sim z_{\text{reionization}} \)
- GRBs: \( z \sim 4.5 \)
- Pop III stars: \( z \sim 10-20 \) - predicted

GRB rate vs SFR: EXIST will trace changes with metallicity.
GRBs as Probe of Pop III and SFR at z >> 1

EXIST could detect bright GRBs to z~50 and BATSE-threshold GRBs to z~5.

Response to E>100keV needed even for z~10!

2-3 GRBs/day; 5-50" positions
Next Generation GRB Observatory
## Comparison of EXIST vs. Swift

<table>
<thead>
<tr>
<th>Parameter</th>
<th>EXIST</th>
<th>Swift/BAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy range</td>
<td>10-600 keV</td>
<td>15-150 keV</td>
</tr>
<tr>
<td>FOV (instantaneous)</td>
<td>5 sr (180° x 75°)</td>
<td>2 sr</td>
</tr>
<tr>
<td>CZT area (thickness)</td>
<td>8 m² (10 mm)</td>
<td>0.5 m² (2 mm)</td>
</tr>
<tr>
<td>GRB sensitivity</td>
<td>~20X BATSE</td>
<td>~5X BATSE</td>
</tr>
<tr>
<td>Full sky imaging</td>
<td>each orbit (95 min)</td>
<td>~1 month(?)</td>
</tr>
<tr>
<td>Angular res./loc.</td>
<td>5’/&lt;10-50”</td>
<td>22’/&lt;4’</td>
</tr>
</tbody>
</table>
EXIST Technology

Imaging and detector technology development

• Coded aperture hard x-ray imaging
  – Developed on SR&T/balloon payloads
  – Demonstrated in space on SIGMA/GRANAT

• Cd-Zn-Te (CZT) detectors
  – Backgrounds measured & CZT imagers for balloons
  – Large-area (0.5m²) CZT array to be flown on Swift (2003)
  – Medical x-ray imaging lowering CZT imager costs

• CZT imagers for 10-600 keV: 64cm² module, partial image & Ba-133 spectra
  (lines at 276, 302, 356, 383keV)
EXIST Heritage and Support

• Mission concept heritage
  – Selected as New Mission Concept (1994)
  – GRAPWG Priority mission (1999)
  – Formed Science Working Group (EXSWG) (1999)
  – Identified Project Scientist & Project Formulation Manager (1999)
  – Recommended in NRC Decadal Survey as Medium Mission (2000)
  – GSFC/IMDC study for Free Flyer (2001)

• Current support for EXIST
  – Partial CZT development support (~$300K) under balloon-program SR&T grants
  – Limited funding ($70K) for initial GSFC/ISAL studies (2000, 2001)

• Support needed for technology development/mission formulation
  – CZT - ASIC design optimization (for depth-sense sparse readout): ~$1.5M
  – Development of low-cost, high yield CZT-ASIC contacts: ~$1M
  – Development of shield design & detector-shield packaging: ~$1M

• Estimated cost for EXIST mission (Free-Flyer) development & Ops
  – Total mission and ops (incl. GO prog.) cost ~$350M (FY02$)