Progetti futuri in astronomia dei raggi X duri e gamma molli

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Workshop ASI su “Scienze dell’Universo”
Roma, 26 marzo 2009
Organization of the presentation

- Italian tradition and heritage
- On going studies for future missions
- Conclusions
Italian tradition in hard X/gamma-ray astronomy

- Long tradition and heritage:
- Hard X-rays
  - Many balloon experiments (from 60’s to 90’s);
  - BeppoSAX (1996-2002);
  - INTEGRAL (2002-)
- Gamma-rays
  - COS-B (1975-1982);
  - AGILE (2007-);
  - GLAST (2008-);
BeppoSAX Heritage

- X-ray optics development with the Nickel electroforming replication technique.
- Development of a High performance hard X-ray detector (PDS);
- Industrial growth:
  - Medialario (X-ray optics)
  - Thales-Alenia Space, Italy (first space segment prime contractor experience)
  - Telespazio (first experience of ground segment prime contractor)
- Broad band NFI and wide field monitoring approach;
- Invaluable scientific results.
- Stimulation of the community to new proposals and ideas.
Hard X-/soft gamma-ray initiatives triggered by the past experience

- Hard X-ray optics development (E<60-80 keV)
- Laue lenses development (E>70-100 keV)
- New approaches to Gamma Ray Burst Monitors (broad band, low weight)
- Study of new missions:
  - HEXIT-SAT/SIMBOL-X (G.P.);
  - EXIST;
  - HAXTEL-P/GRI;
- Mission opportunities:
  - HXMT;
  - LOSTER-ISS;
  - etc
EXIST (Energetic X-ray Imaging Survey Telescope) study project
What is EXIST

- A medium class mission proposal for the most sensitive sky survey for
  - black holes on all mass scales in the hard X-ray energy range (5-600 keV) (candidate to be the NASA Black Hole Finder Probe mission);
  - GRB studies.

- Supported for one year by NASA for an Astrophysical Strategic Mission Concept program (*pre-phase A* study)

- It will participate to ASTRO 2010 *Astronomy and Astrophysics Decadal Survey* Study program (PI Josh Grindlay).
**EXIST payload**

- **HET**: coded mask 5-600 keV, 4.5 m² CZT detector, 0.6mm pixels, ~20" positional accuracy (INTEGRAL and Swift successor).
- **IRT**: 1.1m cooled optical/IR telescope (imaging and 0.3-2.3μm spectra)
- **SXI**: 3.5m focal length, 0.2-10 keV, 950cm² X-ray telescope (Wolter-I), images and spectra 0.2-10 keV

Satellite mass: ~6 tons
EXIST main scientific objectives

- **P1:** Measure the birth of stellar black holes from cosmic gamma-ray bursts to measure prompt redshifts, constrain GRB physics and enable GRBs as probes of cosmic structure and reionization at redshifts $z > 10$

- **P2:** Identify supermassive BHs in galaxies, whether obscured or dormant, to constrain SMBH properties, their role in galaxy evolution and the origin of the CXB, and accretion luminosity of the universe

- **P3:** Measure the stellar and intermediate mass BH populations in the Galaxy and Local Group by a generalized survey for Transients for which prompt IDs and X-ray/HX/IR spectra distinguish SNe, SGRs & Blazars and complement *Fermi, JWST, LSST, LISA* with prompt alerts for unique objects
EXIST sky survey coverage and sensitivity
(5σ survey threshold, 1 year of mission ops., full-sky; 15° orbit incl.)

EXIST-HET sky coverage over 1 orbit

5σ in 1 yr sky survey flux sens. over band ΔE=E, with image psf 2’ & pos. <20”

- 0.07mCrab = 7 x 10^{-13} cgs, (~5-10X below Swift/BAT) for HET (5-100 keV)
- ~0.5mCrab = 1 x 10^{-11} cgs (~20X below INTEGRAL/IBIS) for HET (100-600 keV)
- 300-700 GRBs/yr (~6X Swift/BAT rate) and ~30,000 AGN: IRT redshifts for most!
- unique ~15% duty cycle coverage on any source, ~90% full-sky every 3 hours!
The Italy contribution to EXIST

proposed by 3 INAF institutes
IASF-Roma, OA Brera, IASF-Milano

Submitted to ASI “New Missions and Mission Opportunities”, 3rd year
and now approved (PI, L. Natalucci)

HET/Veto design study
• Wolter I telescope: 26 Ni shells, 3.5m focal length, 60cm max. diam. shell
• 950 cm² at 2 keV & 120 cm² at 8 keV; 20’ FoV; ≤15” PSF (HEW, on axis)
• 4 x 4 cm² CCD (1K x 1K; 2.3” pixels); Sens.: $8 \times 10^{-15}$ erg/(cm² s) in 10 ks
• 40 kbs telemetry; 1msec temporal resol. (timing mode); -110C op. temp.
HAXTEL-P/GRI
Human resources

- **Main participants from:**
  - Dipartimento Fisica – Ferrara (PI, FF)
  - INAF/IASF- Roma (Co-PI – P. Ubertini)
  - INAF/IASF-Bologna
  - INAF/IASF-Milano
  - INAF- IASF- Palermo

- **Contributions (for scientific aspects) from:**
  - INAF-OA Bologna, Rome
  - SISSA-Trieste
  - Scuola Normale Superiore - Pisa
Why soft gamma-ray observations (>70/100 keV)

**Study of matter under extreme conditions:**
- Physics in the presence of super-strong magnetic fields (magnetars);
- Precise role of the Inverse Compton in cosmic sources (e.g., AGN, GC);
- Origin and distribution of high energy cut-offs in AGNs spectra;
- Origin of Cosmic X-ray diffuse background (CXB).
- Determination of the antimatter production processes and its origin from the detection of annihilation lines.

**Study of the violent Universe:**
- Origin and emission mechanisms in cosmic explosions (e.g. SNIa) from the detection and study of nuclear lines
High-energy spectra of magnetars

XMM and INTEGRAL spectra of magnetars: different behaviour of SGRs and AXPs. A better sensitivity at E>100 keV is required to fix the origin of the high energy component.
AGNs – open questions

- Relative numbers of
  - Unabsorbed ($\log_{10}N_H < 21.5$)
  - Compton-thin ($21.5 < \log_{10}N_H < 24.5$)
  - Compton-thick ($\log_{10}N_H > 25$) RQ populations;
  - Blazars (RL)

- Distribution of power-law indices of each population;
- Distribution of high energy cut-offs of each radio quiet population;
- Luminosity function of each population with energy.

Gilli et al. 2007
RQ-AGN cutoff energies

Perola et al. 2002

Sample of 8 BeppoSAX Seyfert 1

Risaliti 2002

Sample of 20 BeppoSAX Seyfert 2

Cut-off energies fix the energy of the accelerated electrons that Comptonize the low energy seed photons. A much better sensitivity is needed to measure them for a larger sample of AGN population.
Cosmic X-ray background and AGN synthesis models

Currently, in synthesis models of CXB (Gilli et al. 2007) up to 100 keV, a combination of unobscured, Compton thin and Compton thick RQ-AGN populations with different scatter in the photon index distribution and fixed $E_F$ are assumed. Is it right to assume a fixed $E_F$? Which is the real contribution to CXB from RL-AGNs? Measurements beyond 100 keV of a large sample of AGNs of different populations are crucial.
Annihilation lines

- Claim for an annihilation line from a compact source (Nova Muscae) reported and never confirmed;
- Diffuse annihilation line emission found with INTEGRAL, whose origin is still unknown;
- Search of 511 keV lines in compact sources require much more sensitivity.
A new-generation gamma-ray telescope is strongly requested

- Requirements:
  - Continuum sensitivity two-three orders of magnitude better than INTEGRAL at the same energies (design goal: a few \(10^{-8}\) ph/(cm\(^2\) s keV) in 10\(^6\) s, \(\Delta E=0.5 E\)).
  - much better (\(\leq\) arcmin) imaging capability
Laue lens development status

• Ongoing developments
  – at CESR Institute, Toulouse;
  – at Physics Dept, University of Ferrara
  – Dublin University.

• Main open issues:
  – Assembling many thousands crystals in a reasonable time and with the due accuracy;
  – Positioning accuracy: increases with the focal lens \( e \) with the crystal mosaic spread (<10” for 100 m FL, corresponding to sub-\( \mu \)m accuracies).
  – Thermal stability within ±1 deg;
  – Lens folding in the launch phase and their unfolding in flight;
  – Metrology issues.
First lens prototype

Developed at the University of Ferrara

- Mosaic crystals of Cu[111]
- Tile size: 15x15x2 mm³
- Mosaic spread: 3/4 arcmin
- Lens support: carbon fiber
A new lens prototype is under development.

A industrial involvement is of key importance.
Crystal development status

- Mosaic crystals made of Cu are currently produced by ILL, Grenoble;
- Mosaic crystals of Ge can be supplied by IKZ, who is developing Ge$_x$Si$_{1-x}$ crystals with variable d spacing.
- Mosaic crystals of GaAs are being developed by CNR, IMEM, Parma, Italy;
- Commercially available crystals (Mateck) are being tested.
- Bent crystals are being developed by LSS, University of Ferrara;
- Main open issues:
  - quality control;
  - mass production.
Preliminary results: Ag

Sample Ag #2
E = 403 keV

111 reflection

200 reflection

Crystals are raw (no surface treatment, which create the red traces).
This sample is slightly distorted but very low mosaicity:

FWHM = 6 pixels
⇒ mosaicity 53 ± 10 arcsec
Bending by anistropy-induced effects in silicon

- A primary external deformation results in a secondary anisotropy-driven deformation and in turn in broadening of the rocking curve.
Detector development for Laue lenses

High efficiency- low background 3D detectors

- Development of a new type CZT detector prototype suitable for building high efficiency 3D focal plane operating in both modes
  - Compton;
  - Photoelectric.

- Millimiter spatial resolution with drift electrodes: 3D reconstruction of the photon interaction position based on signal shape analysis

Polarimetry

- MC simulations to exploit the polarimetric capabilities of CZT pixel detector

- Experiment at ESRF in March 2008 with a CZT pixel detector and a mosaic Cu crystal used as Laue element.
The GRI mission proposal 1/2

- Proposed by a Large International Collaboration to the 1\textsuperscript{st} ESA call within the “Cosmic Vision 2015-2025” plan in June 2007.
- Based on the use of single reflection multilayer mirrors (10-300 keV) and 2 Laue lenses (200 - 600, 800 - 1000 keV)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Requirement</th>
<th>Goal</th>
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<tbody>
<tr>
<td>Energy coverage (keV)</td>
<td>20 - 900</td>
<td>10 - 1300</td>
</tr>
<tr>
<td>Continuum sensitivity (ΔE/E=1/2, 3σ, 100 ks)</td>
<td>$10^{-7}$ ph cm$^{-2}$ s$^{-1}$ keV$^{-1}$</td>
<td>$3 \times 10^{-8}$ ph cm$^{-2}$ s$^{-1}$ keV$^{-1}$</td>
</tr>
<tr>
<td>Line sensitivity (ΔE/E=3%, 3σ, 100 ks)</td>
<td>$3 \times 10^{-6}$ ph cm$^{-2}$ s$^{-1}$</td>
<td>$10^{-6}$ ph cm$^{-2}$ s$^{-1}$</td>
</tr>
<tr>
<td>Energy resolution (FWHM)</td>
<td>3%</td>
<td>0.5%</td>
</tr>
<tr>
<td>FoV (arcmin)</td>
<td>5 diameter</td>
<td>10 diameter</td>
</tr>
<tr>
<td>Angular resolution (arcsec)</td>
<td>60</td>
<td>30</td>
</tr>
<tr>
<td>Timing</td>
<td>100 µs</td>
<td>100 µs</td>
</tr>
<tr>
<td>Polarimetry (MDP, 3σ)</td>
<td>5% for 10 mCrab</td>
<td>1% for 10 mCrab</td>
</tr>
<tr>
<td>Observing constraints</td>
<td>ToO response &lt; 1 day 50% sky coverage</td>
<td>ToO response &lt; few hours; all-sky coverage</td>
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The GRI mission proposal 2/2

- The GRI proposal unsuccessful mainly for readiness problems: “In summary, it was felt that the scientific and technical concept of GRI is currently not yet ripe for making this a good candidate for a launch in 2017”.

- Resubmission of the proposal in the next ESA call (2010?). But:

- In the meantime initiatives for other missions with Laue lenses have been taken.
Studies for gamma-ray missions with Laue lenses

- Study for a possible addition of a second satellite hosting Laue lenses in flight formation with a Japanese satellite (PI: T. Takahashi) with a Compton telescope aboard (DUAL mission).
  - Preliminary meeting held in Marseille (July 2008).
  - Kick-off meeting on 9-10 March 2009 in Japan.

- Test of a 70-300 keV Laue lens aboard a balloon
The double requirement - large-scale exposure and very deep pointed observations - is naturally addressed by the DUAL mission concept, which employs a wide-FoV Compton telescope (CAST) performing all-sky surveys in combination with a Laue-lens (LLT) that enables simultaneous very deep observations of selected narrow-field targets, utilizing the CAST Compton camera as its focal plane.
Laue lens configuration

**Assumptions**
- Focal length: 6m
- Spiral configuration of crystals
- Nominal energy band: 70-300 keV
- Inner radius: 12 cm
- Outer radius: 50 cm
- Crystal material: Cu (111)
- Mosaic spread: 3 arcmin
- Crystal ingot: from ILL
- Crystal size: 15x15x2-3 mm³
- Filling factor: ~0.8
- No. crystals: ~2000

Total Lens weight: 12/25 kg
Focal Plane detector

- **Performance**
  - Energy band: 50-300 keV
  - Energy resolution: 5% @ 100 keV
  - Total Efficiency: > 50% up to 300 keV
  - Sensitive area: 10x10 cm²

- **Main characteristics**
  - Spatial resolution: 2x2 mm (1/10 PSF)
  - Thickness: 5-10 mm
  - Number of channels/pixels: 2500
  - FE Electronics dynamics: 10-500 keV
  - Material: CZT (baseline)/LaBr₃ (option)

- **Active Shield and baffle**
  - Active shield: 20 mm thick CsI/PD. Lateral sides 100 mm above the Focal plane
  - Baffle: 2 mm thick Pb up to ~400 cm above the Focal plane for a FOV (FWZR) of ~ 10°.

**TOTAL FP Weight:** 25 kg
Expected sensitivity

$T_{\text{obs}} = 10^4 \text{ s}$

$\Delta E = E/2$

$\eta_D \approx 1$
Expected on-axis source image
Conclusions

• It is crucial to continue:
  – The development activity
  – The scientific return studies;
  – The mission studies.

• A proposal to ASI on Laue lenses (PI, DTM) as a response to “Bando tecnologico” has been submitted, but no outcome thus far.

• A new contract for the prosecution of the AAE studies should be approved.