GRBs @ IASF-MI

Sandro Mereghetti
Presentation to the Visiting Committee
Jan 9, 2008
IASF-Mi contributions to the GRB field:

- INTEGRAL Burst Alert System (IBAS)
- X-ray afterglows – Dust halos
- Soft Gamma Ray Repeaters (Magnetars)
- FUTURE: An X-ray telescope for the SVOM Satellite

People:
- 1 Staff: S.Mereghetti
- 3 senior PostDoc: A. Tiengo, A. De Luca, A. Paizis
- 2 PhD Students: G. Vianello, P. Esposito

Results:
- GRBs: 27 refereed papers in last 5 years
- Magnetars: 22 refereed papers in last 3 years
CONCLUSIONS
CONCLUSIONS  1/4

We have led the proposal, development and implementation of the IBAS system:

- First to give GRB localizations at arcmin level in near real time

- important results on several interesting GRBs

- INTEGRAL extended until 2012
  is it useful to continue with IBAS in the ``Swift’’ era ?? → YES
Dust scattering rings discovered with XMM around GRBs can be used to:

- derive very accurate distances of galactic dust clouds
- infer the properties of GRB prompt emission in X-rays

We have developed a new method to analyze faint dust scattering halos around GRBs

Successfully applied also to Swift XRT data
CONCLUSIONS  3/4

Magnetars are isolated neutron star powered by magnetic energy \( B \sim 10^{14} - 10^{15} \) G

Only 13 known (4 Soft Gamma Repeaters + 9 Anomalous X-ray Pulsars) but very interesting for physics and astrophysics

Recent IASF-MI highlights on Magnetars
• 1\textsuperscript{st} gamma ray afterglow of a SGR giant flare (Dec 2004 event)
• Discovery of persistent hard X-rays from SGRs with INTEGRAL
• Correlations between bursting activities and X-ray emission properties

We will continue our long term monitoring of SGR 1806-20 with XMM-Newton, INTEGRAL, Suzaku

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SVOM is a French-Chinese mission satellite for GRB studies

To be launched in 2012-13

Two major improvements wrt. Swift

We plan to add a small focusing X-ray telescope on SVOM

We led a proposal submitted to the recent ASI Call for Missions of Opportunity
QUESTIONS

TIME

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SUMMARY

• **The IBAS system:**
  – important results on several interesting GRBs
  – First localizations at arcmin level in near real time
  – INTEGRAL extended until 2012: is it useful to continue with IBAS in the “Swift” era? YES

• **Dust scattering rings**
  – New analysis method with higher sensitivity
  – distances of dust and X-ray GRB prompt information

• **MAGNETARS highlights**
  – 1st gamma ray afterglow of a SGR giant flare (Dec 2004 event)
  – Discovery of persistent hard X-rays from SGR
  – Correlations between bursting activities and X-ray emission properties

• **The SVOM Satellite**
  – scientific requirements and expected performances
EXTRA SLIDES
• 1973: GRB discovery announced
• ~1992: BATSE results

Angular Distribution
Log N - Log S

“Great Debate”

• 1994/95: Selection of INTEGRAL instruments
  estimates of number of GRB in the INTEGRAL field of view

• 1997: BeppoSAX afterglows lead to optical/radio identifications

• 1997/98: Consolidation of IBAS concept on board

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IBAS = Integral Burst Alert System

- Arcmin localization for ~1 GRB/month

- It is part of the contribution given by IASF-Mi to the INTEGRAL Science Data Center
GRB LOCALIZATION PERFORMANCES - PreSwift Era!

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GRB 030227
The first INTEGRAL GRB with an XMM-Newton follow up

Evidence for
Mg, Si, Ar, Ca lines at z=1.4

Galactic $N_H = 2 \times 10^{21} \text{ cm}^{-2}$

Evidence for intrinsic absorption from EPIC spectrum

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GRB 031203 \( z=0.1 \)
Spectroscopic SN association
Apparent outlier of correlations
Dust scattering rings

- hard GRB spectrum (Sazonov et al 2004)
- \( E_{\text{iso}} \approx 6-14 \times 10^{49} \ \text{erg s}^{-1} \)

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GRB 041219

IR flash K~15.5


Thanks to the rapid IBAS localization (2.5 arcmin) robot telescopes could observe during the GRB emission.
Bursts from SGR 1806-20 seen with IBAS

DUST RINGS
For dust grains of radius \( a \):

\[
\text{SIZE OF HALO} \approx \frac{10 \text{ arcmin}}{E \text{ [keV]} \cdot a \text{ [0.1 \mu m]}}
\]

Halo profile is energy-dependent and is determined by:

- grain properties:
  - composition (e.g. silicates / carbonaceous)
  - size distribution

- dust distribution along line of sight
GRB 031203

58 ks observation starting at $t_o + 6$ hrs

Two dust layers at $D=880$ pc and $D=1390$ pc
\[ \text{TIME DELAY} = \frac{x}{1-x} \frac{D_s \theta^2}{2c} \]
How can we see much fainter halos than in GRB 031203?

GRB 031203

GRB 050713A

EPIC pn
0.5-2 keV
A new method for detection of faint expanding rings → “dynamical images”
For each count detected in the X-ray image compute the quantity:

\[
\frac{2ct_i}{\theta_i^2} \equiv D_i
\]

\(t_i\) = time from the GRB

\(\theta_i\) = angular distance from GRB position

and plot the distribution of the \(D_i\) values
By fitting the peaks with Lorentzians one gets number of counts in the rings and distance of the dust layer

Can be done in different energy bins to extract halo spectrum

\[ D_1 = 870 \pm 5 \text{ pc} \]
\[ N_1 = 840^{+210}_{-180} \text{ counts} \]
\[ \text{FWHM}_1 = 82^{+17}_{-14} \text{ pc} \]

\[ D_2 = 1389 \pm 5 \text{ pc} \]
\[ N_2 = 1740^{+270}_{-240} \text{ counts} \]
\[ \text{FWHM}_2 = 240 \pm 30 \text{ pc} \]
GRB 050713A

D = $364^{+6}_{-7}$ pc

$N = 185^{+120}_{-90}$ counts

$\text{FWHM} = 33^{+18}_{-12}$ pc
D = 148^{+4}_{-6} \text{ pc}
N \sim 130 \text{ counts}
\text{FWHM} = 24^{+19}_{-13} \text{ pc}
5 GRBs with expanding dust rings

Vianello, Tiengo & Mereghetti, 2007, A&A

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Information on the prompt emission

Uncertainties on:
- measure of halo intensity $I_{HALO}$
- knowledge of $\tau = \sigma_{\text{scat}} n D$

\[ I_{HALO} = I_{GRB} \left(1 - e^{-\tau}\right) \cong I_{GRB} \tau \]

$\tau$ can be estimated from optical absorption:

Draine & Bond 2004 $\Rightarrow \tau \approx 0.15 A_V E_{keV}^{-1.8}$

Predehl & Schmitt 1995 $\Rightarrow \tau \approx 0.056 A_V E_{keV}^{-2}$
X-ray prompt estimated from dust halo

Ghisellini, Ghirlanda, Mereghetti et al. 2007, MNRAS
MAGNETARS
What is a Magnetar?

Isolated neutron star powered by magnetic energy \( B \approx 10^{14}-10^{15} \) Gauss

How do we observe magnetars?

1) “Persistent” X-ray emission
   \( L_x \approx 10^{35} \) erg/s
   \( P \approx 5-12 \) s
   \( \text{spin-down} \ 10^{-11} - 10^{-13} \) s/s
   \( \frac{dE_{\text{ROT}}}{dt} \ll L_x \)

2) Short (<1 s), super-Eddington bursts
   \( kT \approx 30 \) keV

3) Giant Flares - rare events!
   \( L \approx 10^{44} - 10^{46} \) ergs

How many are known?

9 AXPs + 4 SGRs in our Galaxy and in Magell. Clouds

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Importance of Magnetars

- **Physics:**
  unique laboratories to study processes in high magnetic fields

- **Astrophysics:**
  a different perspective on neutron stars and massive stars evolutionary end points

we are biased by 40 yrs of radio pulsars observations
A variety of initial conditions

- Magnetars
- "normal" radio pulsars
- Central Compact Objects
- CCO in RCW 103?

Initial spin period $P_0$ (msec)
IASF-Milano contribution to magnetar studies


• In the last 3 years:
  – 12 refereed papers as first authors
  – 11 refereed papers as co-authors
AXP 1E 1048.1-5937


- First clear flux variability in AXP
- Anticorrelation between flux and pulsed fraction
SGR 1806-20

- Long term monitoring with XMM-Newton, INTEGRAL, Suzaku

- Flux (and burst rate) increase in hard and soft X-rays before the Giant Flare
- From XMM data: pulsed fraction reduction and spectral softening in first observation after the Giant Flare
SGR 1806-20

- Discovered in 1979 (Laros et al. 1986) and very active since then

- $P = 7.5\,\text{s}$  \( P\dot = 8 \times 10^{-11}\,\text{s/s} \rightarrow B = 8 \times 10^{14}\,\text{G} \)
  (Kouveliotou et al. 1998)

- High absorption: $N_H \sim 6 \times 10^{22}\,\text{cm}^{-2}$  \( A_v \sim 30 \)

- Giant Flare on 2004 December 27

- Variable NIR counterpart $K \sim 19-20$
  (Israel et al. 2004, 2005; Kosugi et al. 2005)

- Distance is debated: $>6\,\text{kpc}$;  $8-15\,\text{kpc}$ ??
  (Cameron et al. 2005, McClure-Griffiths & Gaensler 2005,)
  we assume $15\,\text{kpc}$ (Corbel & Eikenberry 2004)

- Persistent 20-150 keV emission discovered with INTEGRAL
  (Mereghetti et al. 2005b, Molkov et al. 2005)
Hard X-rays

Soft X-rays

Near Infra Red

SGR 1806-20

Dec. 2004 Giant Flare

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- Spectrometer SPI
- Imager IBIS
- Giant Flare
Anti Coincidence Shield (ACS)
(512 kg, 91 BGO blocks)

The ACS is also used as an omni-directional GRB detector (E > 80 keV)

Provides:
• 50 ms light curve
• No direction information
• No energy information
SPIACS lightcurve around 2004/12/27 21:30:25.823 UTC

Figure and data were public after 10 minutes on http://ibas.iasf-milano.inaf.it/!!
SGR 1806-20 - INTEGRAL – Dec. 27, 2004 Giant Flare

E > 80 keV

7.5 s period "signature" of SGR 1806-20


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SPIACS lightcurve around 2004/12/27 21:30:25.823 UTC

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- Peak affected by instrument saturation
- Initial giant pulse backscattered by the Moon
- 2.8 light seconds

SGR 1806-20
Giant Flare
2004 Dec 2004
3 Giant Flares from SGRs

1979 March 5 - SGR 0626-66
Initial spike: $1.6 \times 10^{44} \text{ erg}$  Pulsating tail: $4 \times 10^{44} \text{ erg}$

1998 August 27 - SGR 1900+14
Initial spike: $> 7 \times 10^{43} \text{ erg}$  Pulsating tail: $5 \times 10^{43} \text{ erg}$

2004 December 27 – SGR 1806-20
Initial spike: $4 \times 10^{46} \text{ erg}$  Pulsating tail: $10^{44} \text{ erg}$


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ACS
Sensitive to charged particles and photons

PSAC
Sensitive mostly to charged particles

The bump after the GF is the only one without a correlated peak in the PSAC
Hard X-ray emission lasting ~1 hr after GF

- E > 80 keV - No spectral information
- No pulsations
- Power law time decay $F(t) \sim t^{-0.85}$
- Same counts fluence as in pulsating tail
  $(3 \times 10^{-4} \text{ ergs cm}^{-2} \text{ assuming } kT \sim 30 \text{ keV})$
- *Apparently* seen only by INTEGRAL

The first hard X-ray afterglow seen in a SGR?

Mildly relativistic asymmetric outflow expanding in the ISM

Flux evolution of radio nebula after the Giant Flare

\[ v/c \sim 0.5 \text{ -- } 0.8 \]

Gaensler et al. 2005
Taylor et al. 2005
Gelfand et al. 2005
Granot et al. 2006
Salmonson et al. 2006
G3/G2 ratio $\Rightarrow$ Hard power law spectrum: $\Gamma \sim 1.6$
Summary

Long lasting hard X-ray / soft gamma-ray emission discovered by INTEGRAL has recently been confirmed by two other satellites.

Evidence for hard spectrum - photon index ~ 1.7

If it is indeed an afterglow emission due to relativistic outflow could help in breaking degeneracy of models for the expanding radio nebula.
SGR 1806-20

Dec. 2004 Giant Flare

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8 XMM-Newton observations of SGR 1806-20

Folded light curves at P=7.5 s

27 Dec 2004 Giant Flare

See also Woods et al. 2006

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SVOM scientific requirements

1) Obtain the redshift for the majority of the detected bursts

→ Provide quickly accurate GRB positions
→ Optimize pointing strategy for ground telescopes
→ Optimize detection of high redshift GRBs (trigger logic, soft E range)

Swift detected a larger number of high redshift GRBs than previous missions

But $z$ is known for only $<30\%$ of Swift GRBs!!
SVOM  scientific  requirements

1)  Obtain the redshift for the majority of the detected bursts

→ Provide quickly accurate GRB positions
→ Optimize pointing strategy for ground telescopes

(cfr.: redshift is known for only <30% of Swift GRBs !!)

2)  Derive the  GRB spectral parameters,  E peak

→ Broad energy range
→ high energy spectrometer

(cfr: $E_{\text{peak}}$ is measured only for ~15% of Swift GRBs )
Energy

$E_{\text{peak}}$ is fundamental quantity in all empirical correlations to use GRBs as “standard candles”
GRB with 15-150 keV fluence $10^6$ erg cm$^2$ and $E_p=300$ keV.

Spectral studies with Swift/BAT (and INTEGRAL) suffer from the limited energy range and poor sensitivity at high $E$.

Addition of a high $E$ detector (e.g. Scintillator) is required to measure spectral curvature.
**VT**
Visual Telescope
45 cm aperture
400-900 nm

**GRM**
Gamma Ray burst Monitor
50 keV-5 MeV
$2\pi$ sr FoV
2 Phoswich detectors

**XIAO**
X-ray Imager
for Afterglows
Observations
0.3-2 keV
FoV 23’x23’

**CXG**
Camera X Gamma
4 – 300 keV
2 sr FoV
Coded mask + CdTe array

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The center of the ECLAIRs field of view will be well above the horizon of large ground based telescopes all located at tropical latitudes.
Grazing incidence X-ray mirror
Wolter I design
~100 cm² @ 1.5 keV

Focal length ~ 1 m

Small CCD camera
Radiator
Summary of XIAO performances

- Energy range: 0.3-2 keV
- Field of view: 23 x 23 arcmin²
- Ang. Resolution: 30 arcsec HEW
- Effective area: ~80 cm² @ 1.5 keV
- Localiz. Accuracy: ~10 arcsec for ~5σ source; < 5 arcsec for >10σ source
- Sensitivity (5σ): ~10 mCrab in 10 s; 5-10 µCrab in 10 ks
- Throughput: 1 mCrab = 0.4 ct/s for $N_H=3\times10^{21}$; = 1 ct/s for $N_H=3\times10^{20}$
- Energy resolution: ~150 eV FWHM @ 1.5 keV
- Time resolution: ~10 ms in standard mode; ~0.1 ms in timing mode
XIAO

X-ray Imager for Afterglows Observations

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PRELIMINARY OPTICS DESIGN

H = 30 cm  \( \varnothing = 14 - 22 \) cm Au coating  \( \text{Ang. Resol } 30'' \) HEW

11 shells  0.3 mm thickness  \(~5\) kg (mirrors only)

Focal length  100 cm
XIAO expected count rates
(0.2- 5 keV)

• 1 mCrab ($\sim 2 \times 10^{-11}$ erg/cm$^2$/s 2-10 keV)

$N_H = 0$ \quad \rightarrow \quad \sim 4 \text{ ct/s}$

$N_H = 3 \times 10^{20} \text{ cm}^{-2}$ \quad \rightarrow \quad \sim 1 \text{ ct/s}$

$N_H = 3 \times 10^{21} \text{ cm}^{-2}$ \quad \rightarrow \quad \sim 0.4 \text{ ct/s}$
XIAO source location accuracy

90% error radius vs. number of counts

90% error radius = 5.38759 \times n^{-0.5}

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Example of NON-GRB Science: 1 - Blazars

Simultaneous X-ray and optical observations to understand origin of second peak in spectral energy distribution

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Example of NON-GRB Science: 2 - Active stellar coronae

Flares are the most spectacular manifestation of stellar magnetic activity.

Simultaneous multi-\(\lambda\) observations of flares crucial to test flare models – very relevant to understand coronal heating mechanisms.

Very few simultaneous data secured so far because of logistic/observational difficulties (only \(\approx 3\) cases so far!!)

SVOM multi-\(\lambda\) capabilities will allow simultaneous optical-X-ray observations of flares for different classes of active stars.

Proxima Centauri

Guedel et al. 2002

LP 412-31

Stelzer et al. 2006

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Example of NON-GRB Science: 3 - Cataclysmic Variables

Dwarf Novae show recurrent (from weeks to months), large outbursts

MWL simultaneous observations, unveiling time behaviors in different ranges (including QPOs), crucial to test “disk instability” model for outbursts.

So far only fragmented (nearly) simultaneous data available due to difficulties in scheduling

175 dwarf Novae known at $|b| > 30^\circ$

SS Cyg: X-rays delayed wrt. Optical; Soft/Hard X-ray anticorrelation

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• **Italian participation to SVOM / Eclairs**
  Study performed with support from ASI/INAF contract *Astrofisica delle Alte Energie* (WP opportunità di missioni)

• **XIAO proposal consortium**
  **INAF:**
  - IASF Milano
  - Osservatorio Astronomico Brera
  - IASF Bologna
  - Osservatorio Astronomico Roma

  **Industries:**
  - Thales Alenia Space Italia (ex Laben)
  - Media Lario
  - BCV Progetti

• **Participation of other INAF structures is welcome**

• **Other contributions to SVOM:**
  - ASI ground station at Malindi (X- and S- band antennas)
  - ASI Science Data Center
  - Involvement in Dedicated Ground Based Telescopes