LECX: a nanosat experiment to detect cosmic explosions in X rays

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Cubesat: 10cm x 10cm x 10cm, 1.3 kg

California Polytechnic State University – Cal Poly
MIRAX: Monitor e Imageador de Raios X

- First Brazilian-led astronomical satellite project
- High-energy astrophysics **observational window** for the Brazilian community
- International collaboration ⇒ **expertise in high-energy astrophysics and space astronomy**
- Project **under revision** due to new directives in the Brazilian Space Program (AEB, INPE, DCTA)
At INPE/CRN/UFSM/ITA there are several initiatives to develop cubesat missions: nanosat-BR, SPORT (6U), ITASAT (6U), CONASAT

People working on cubesat subsystem developments, especially on OBDH and ground systems

Brazilian Space Agency has the SERPENS program and is interested in having a cadency of launches
Opportunity: put a few of MIRAX’s CZT detectors in space in a nanosat platform

- Test the detectors in space
- Measure the hard X-ray/soft gamma-ray diffuse radiation in orbit
- Map the South-Atlantic Magnetic Anomaly (SAA) at specific orbits

protoMIRAX CdZnTe (CZT) detectors: 10 x 10 x 2 mm
Energy Resolution @ 60 keV: 6.6 keV with intrinsic width of 4.8 keV (8%).
What if we could do astrophysics with this?

**LECX:** detect and locate bright cosmic explosions

“Localizador de Explosões Cósmicas de raios X”
• Would it be possible to build a **nano-MIRAX** in a cubesat?
• Is it possible to **detect** and give a **rough location** of a bright cosmic event/explosion?
• And what if it is **simultaneous** with a **GW event** detected by LIGO/VIRGO?

Well, maybe…
protoMIRAX: a pathfinder for MIRAX


- Test several MIRAX subsystems in a near-space environment
- Develop CdZnTe detector technology and data acquisition systems
- Test X-ray imaging system and a new attitude control system
- Produce images and spectra of Crab and CG regions
- Measure atmospheric hard X-ray radiation at Brazilian SAA region
Detectors: 

Detectors need to be adjacent to one another to improve angular location of detected events.

Detectors are surrounded underneath and on the sides by a passive shielding of Pb-Sn-Cu (1.0 - 1.7 - 0.3 mm) - an open box - to provide a graded shield. 
mass: 160 g  
dimensions: 50mm x 30mm x 20 mm (height)
Detector electronics

Every hit produces a signal (a charge cloud) that is analyzed and stored

BIAS: -200 V
R = 150 MΩ bias resistor
C = 0.150 nF coupling capacitor
LNA: 60-70 dB
ADC: Wilkinson type
• 256 energy channels (8 bits)
• Converts pulse height in time and then measures it

conversion electronics: CPDL and microcontrollers
multiplexing electronics (MUX):
• processes signals from CE at 1 Hz,
• identifies the detector hit,
• attaches time tag from GPS for each event (5 μs),
• sends datasets to OBDH
Simulations using GEANT4: LECX mass model
Dimensions: 50mm x 30mm x 20mm
Mass: 160 g
Mission baseline parameters

Data creation rate: **630 bits/sec**

Onboard storage: **4 Mbits** (science data)

Telemetry: **6 kbits/sec** (LEO 10 min passages)

Total mass: < **2kg (?)**

Power consumption: ≤ **6 W**

(very preliminary)
Background count rate in LECX is approximately $3.5 \text{ counts cm}^{-2} \text{s}^{-1}$ (10 – 200 keV)
Sensitivity: 

$$F_{\text{min}} = \frac{2N_\sigma}{\epsilon(E)} \sqrt{\frac{B(E)}{A_{\text{det}} T \Delta E}} \text{ photons cm}^{-2} \text{ s}^{-1} \text{ keV}^{-1}.$$
Detection of GRBs

For a typical GRB: flux at Earth is \( F = A E^{-\alpha} \)
Flux in photons cm\(^{-2}\) s\(^{-1}\) keV\(^{-1}\)

\[
A \approx 200 \\
\alpha \approx 1.7
\]
(Fishman&Meegan ARAA, 1995)

In 1 sec, **242 counts** on LECX from 10 to 200 keV
Short GRBs are electromagnetic counterparts of neutron star-neutron star coalescence Gravitational Wave events

- ~22 counts bkg
- ~242 counts GRB
How many GRBs can we detect?

• ~ 1 GRB/day in the universe are detectable (are pointed toward us)

• LECX covers ~4.7% of the sky at any given time

→ 0.047 GRBs/day → 1 GRB every 21 days

~ 1 cosmic explosion / month
What about determining the position in the sky?
protoMIRAX:
MURA 13x13 repeated 4 times
(minus 1 row and 1 column)

coded mask imaging
(Braga 1990)

blue: <0; green: >0; red: >3; white: >8 (std.dev.)
Is it possible to build a coded mask for LECX? **YES!**

The shielding box has dimensions $50 \times 30 \times 20$ mm.

LECX **field-of-view** is $26.5^o \times 14.0^o$ (total sensitivity), $51.3^o \times 36.9^o$ (FWHM).
SIMULATIONS with IDL: FIXED DETECTOR COUNT, NO BACKGROUND

Calculate x and y offsets of mask element on detector plane for each (z, A) pair

Z = 14°; A = 90°

detector map 3 x 2

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Z = 0°; A = any

detector map 3 x 2

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Algorithm:
- Input $z$ and $A$
- Calculate $x$ and $y$ offsets
- Calculate detector counts
- Correlate
- Find peak of correlation map
- Average row and column for $x$ and $y$ position
- Transform back to $z$ and $A$

Reconstructed zenith angle = 7.00000 degrees
Reconstructed azimuth angle = 130.000 degrees
Monte Carlo simulations: random counts, Poisson statistics. (IDL randomn function with POISSON property)
Use estimated count rates for bkg and GRB.

Ex.: $Z = 7^\circ$ ; $A = 130^\circ$

![LECX DETECTOR MAP](image)

100 identical simulations

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Mean Value</th>
<th>Error</th>
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<tbody>
<tr>
<td>$z$</td>
<td>$6.88494 \pm 3.48894$</td>
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<tr>
<td>$A$</td>
<td>$133.671 \pm 38.5855$</td>
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<tr>
<td>SNR</td>
<td>$10.43 \pm 2.79$</td>
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IDL>

For an event 100 times brighter:

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Mean Value</th>
<th>Error</th>
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</thead>
<tbody>
<tr>
<td>$z$</td>
<td>$6.59424 \pm 0.461526$</td>
<td></td>
</tr>
<tr>
<td>$A$</td>
<td>$126.731 \pm 5.70864$</td>
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</tr>
<tr>
<td>SNR</td>
<td>$59.1 \pm 3.56$</td>
<td></td>
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\begin{align*}
Z &= 14^\circ \quad A = 90^\circ \\
\text{detector map} \quad 3 \times 2 \\
&\quad 4087 \quad 4149 \\
&\quad 11 \quad 4091 \\
&\quad 4034 \quad 3985 \\
\text{mean } z &= 13.4467 \pm 0.299 \\
\text{mean } A &= 90.4295 \pm 2.51454 \\
\text{mean SNR} &= 62.1946 \pm 2.3957 \\
\text{Expected signal-to-noise} &= 56.8
\end{align*}
Conclusions:

- LECX could be an interesting rapid-development and low-cost Brazilian X-ray astronomy experiment in a cubesat (nanosat) platform.
- LECX could in principle detect and localize bright cosmic explosions in hard X rays at a rate of ~1/month with an accuracy of a few degrees.
- LECX (with a lot of luck) could find electromagnetic counterparts to GW compact-object merger events.
- A constellation of LECXs could greatly enhance the likelihood of finding and localizing Cosmic Explosions.
- Currently, we have a FAPESP grant to develop a 1U or 2U satellite and launch it (CRON company and INPE).