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AHEAD2020

Integrated Activities for the High Energy Astrophysics Domain

WP11.3
BGO detector for short GRBs

Small-Innovative sensors for GRB observation and Gamma-Ray Astronomy for balloon and small satellite experiments

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INAF/IAPS

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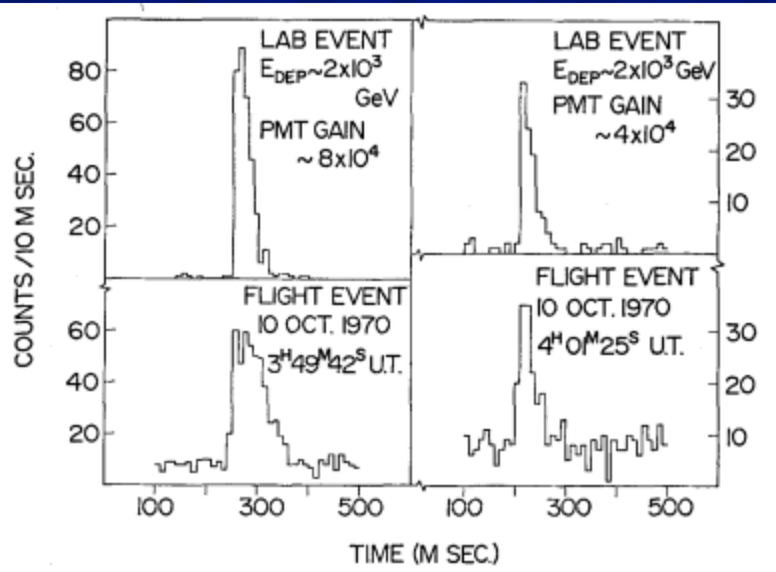
AHEAD 2020

Motivation

- γ-ray astronomy boasts decades of using balloon flights for experimental and observational purposes
- Since the ’70s, many teams worlwide have produced a wealth of measurements of cosmic sources, including gamma-ray bursts

NaI experiment,
15h flight from Palestine



Johnson, Kurfess & Bleach 1975

- These early flights have shed the first light on some important astronomical phenomena advanced our knowledge of the cosmic-ray, Solar and Earth albedo/athmospheric radiation

Main applications

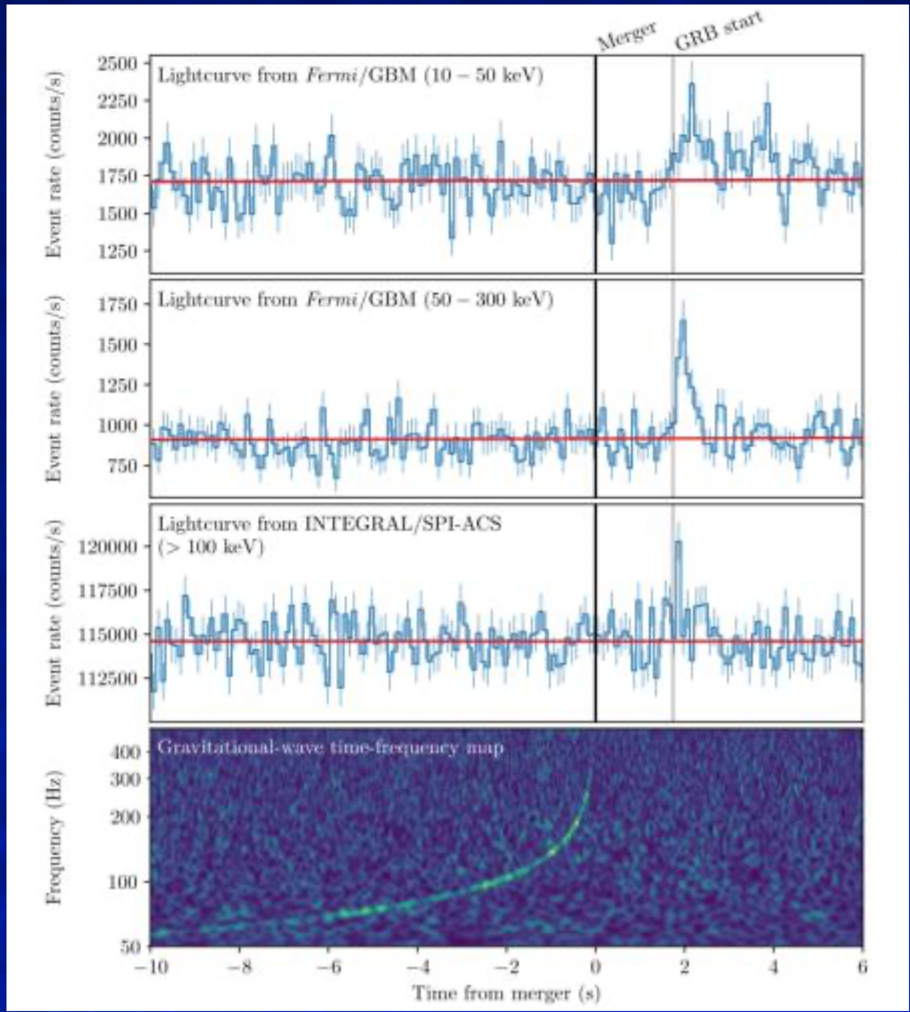
- Solar Physics and Athmospheric Physics
- Infrared and Microwave (CMB) measurements
- Gamma-ray astronomy

SORA (ASI) launch from Longyearbyen, Svalbard, 2009

COSI experiment on NASA super-pressure balloon, New Zealand, 2017

Targets for gamma-ray astronomy measurements. Among other topics:

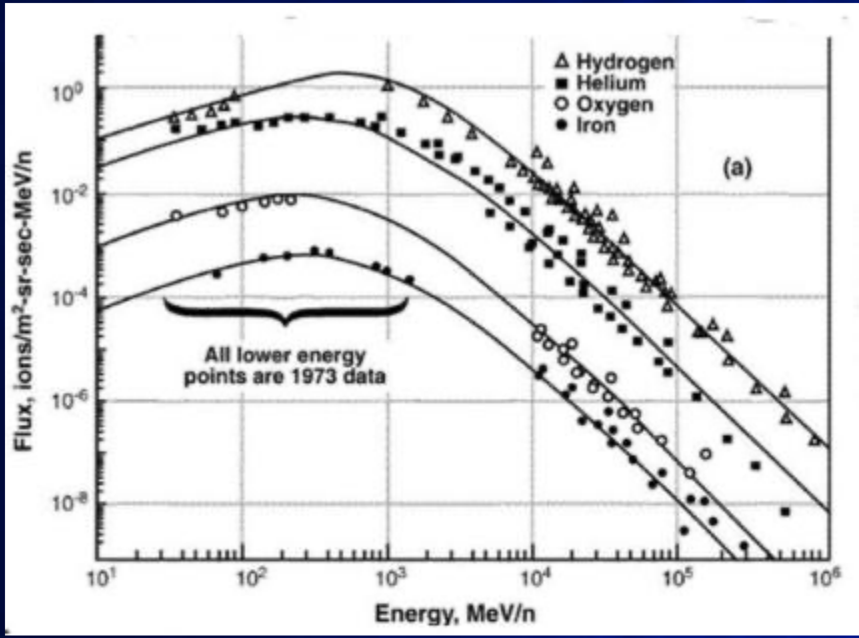
- Typically bright sources (Supernova Remnants or luminous accreting BHs, X-ray binaries)
- Gamma-ray bursts & connection to multi-messenger astronomy
- Gamma-ray polarisation
- Cosmic and atmospheric background
- …more



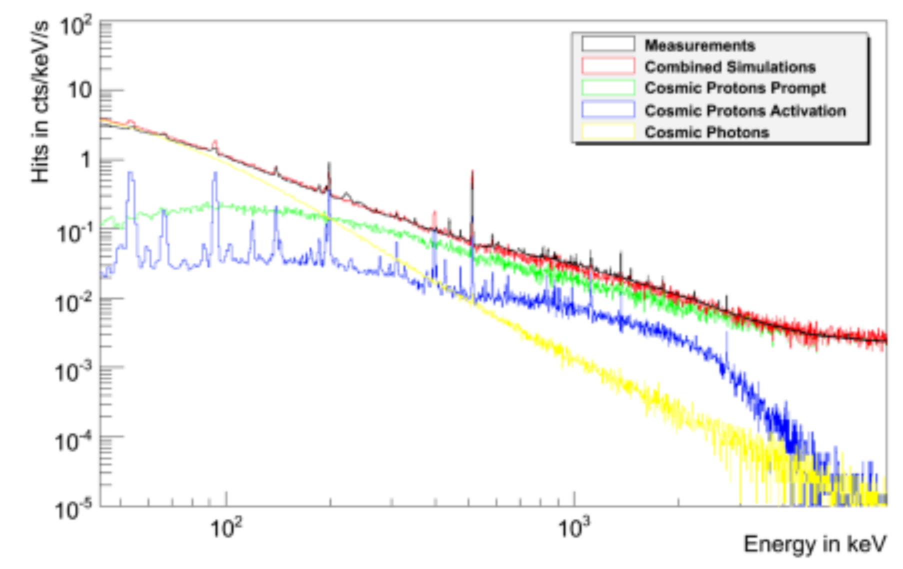
Sources of background

Gamma-ray detectors on board balloon or spacecraft are exposed to sources of background generated in space or in the atmosphere

- Photon induced (cosmic-diffuse, locally produced)
- Hadrons: CR and solar radiation: protons, ions, neutrons, eavy nuclei etc

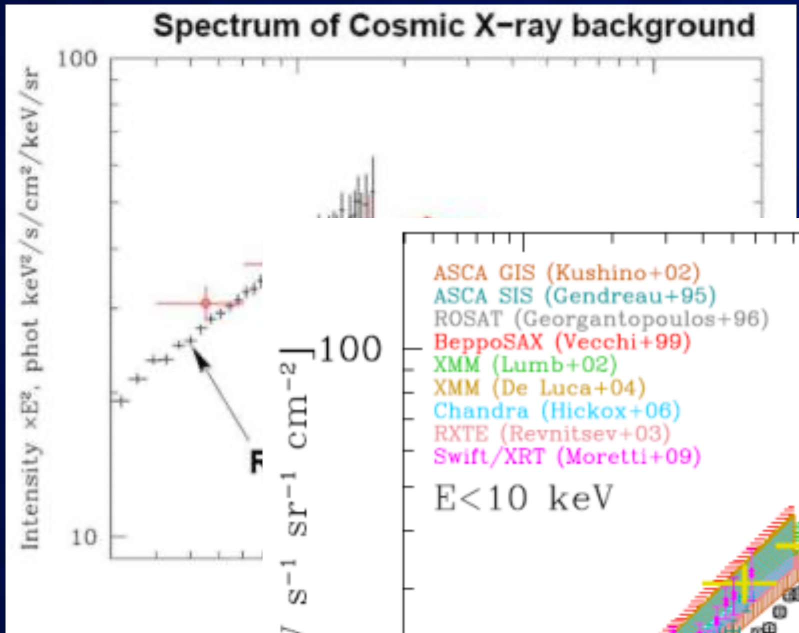


Parnell+98

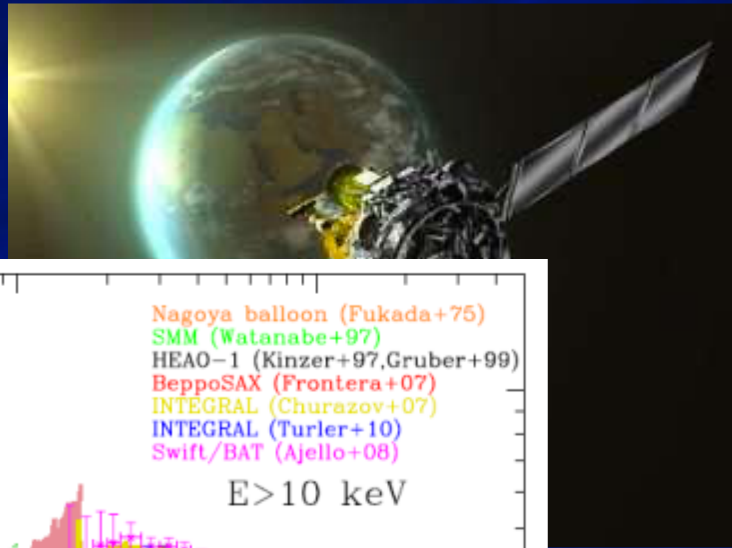


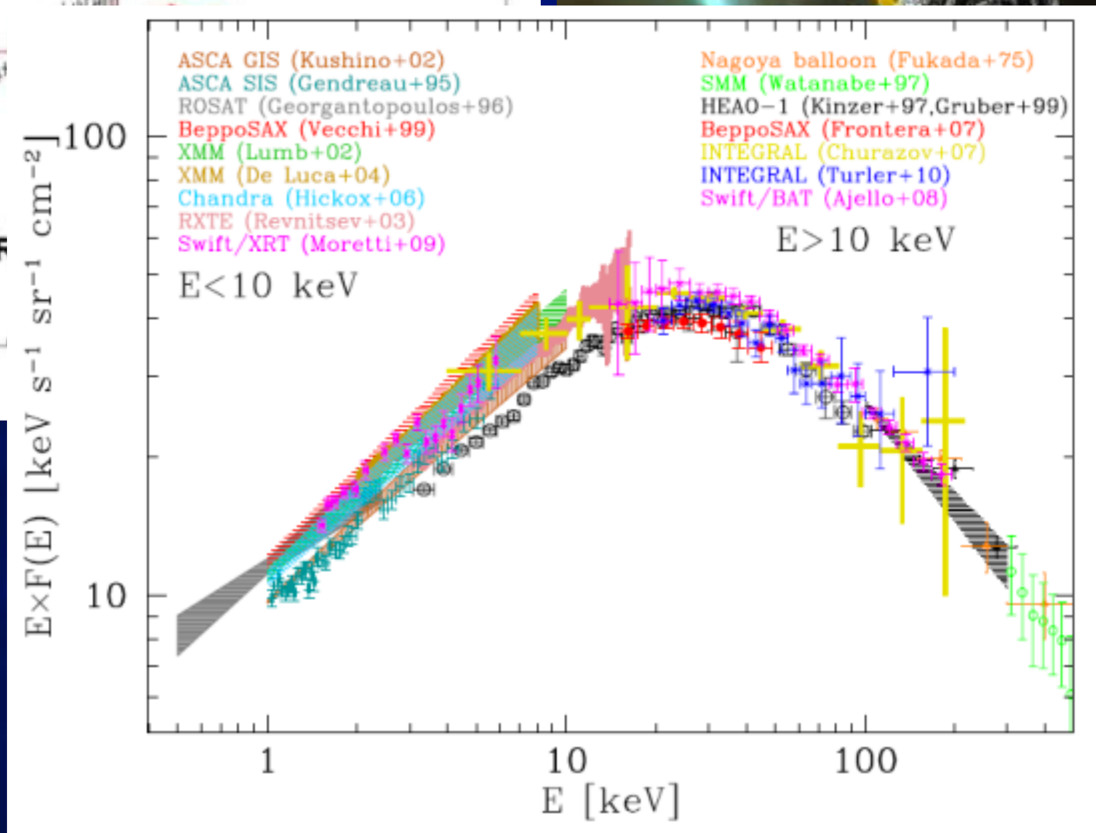
Credit: A. Zoglauer

Cosmic Diffuse X-/gamma-ray background



Churazov, E.

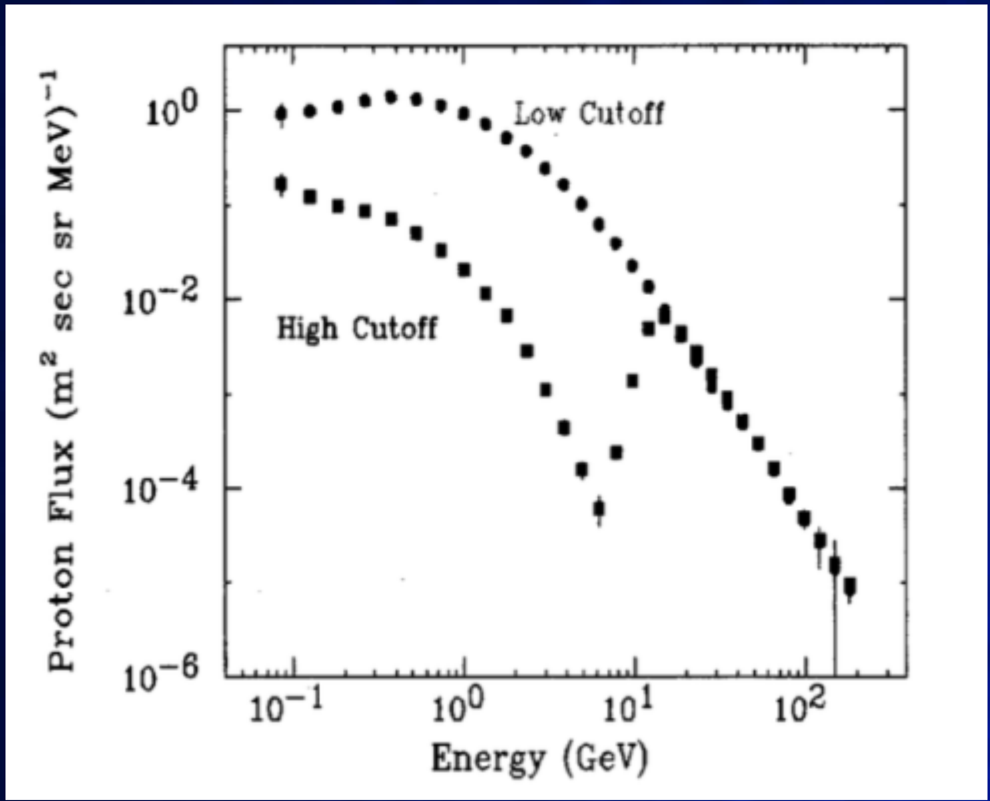




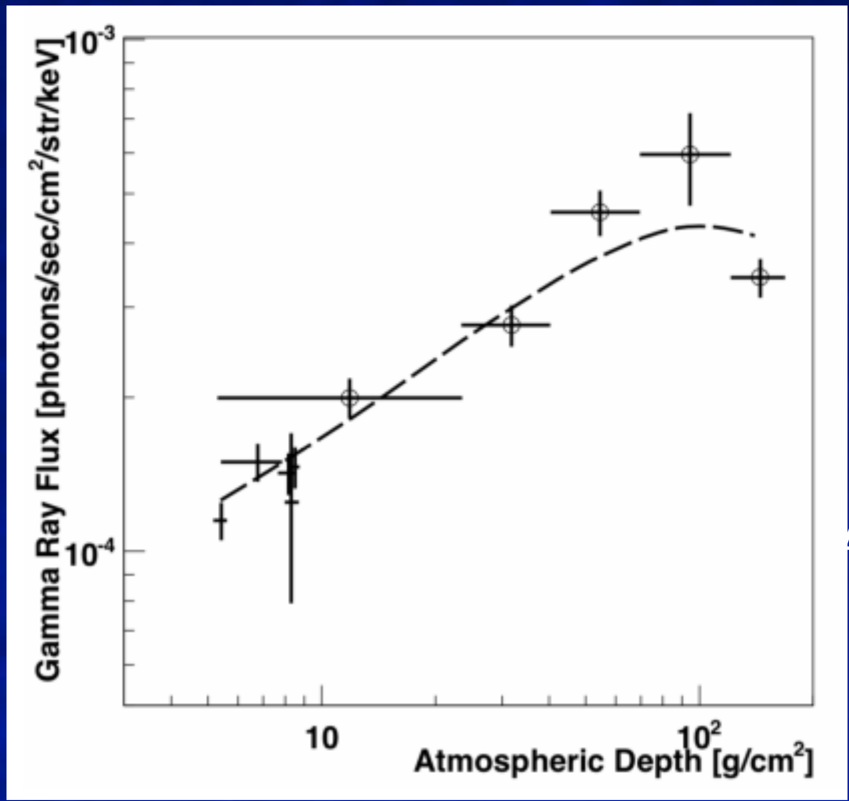
was pointed
o measure the
ctrum

Revnitsev 2014

Varying background components



Clem et al. 2011



Takada et al.2011

- The CXB, athmospheric and internal detector background components vary with atmospheric depth and cutoff rigidity

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The IAPS light-small-innovative detectors program

HEMERA

- Started a few years ago (Lorenzo Natalucci Lead)
- This program has two fold approach:

1. **New detector for short GRB detection with sub-ms resolution targeted to GW counterpart prompt emission and MM-A science**
2. **Small-light innovative detectors within the HEMERA EU program**

https://www.hemera-h2020.eu

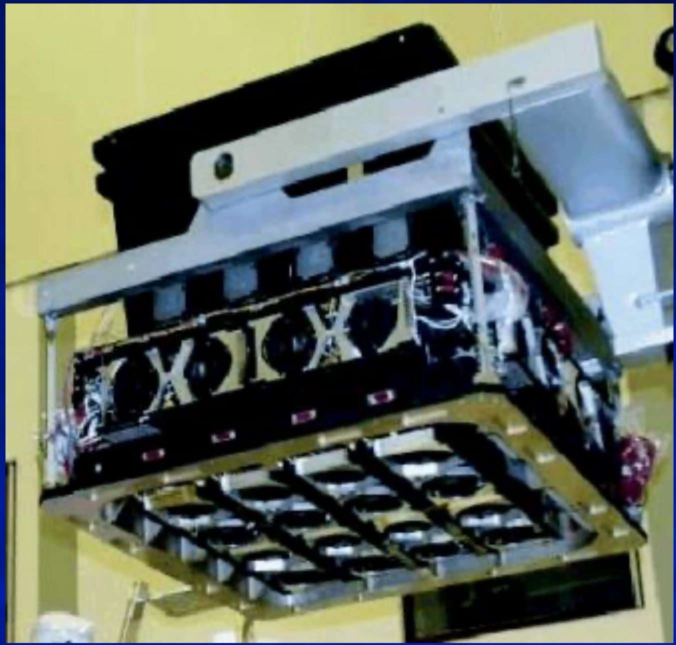
AHEAD2020 is funding manpower and hardware procurement

HEMERA is funding flight campaign, ASI is supporting H/W related to the flight

Two flights are planned aboard stratospheric balloons for 2021 (from Kiruna, Sweden) and 2022 (from Timmins, Canada), PI Lorenzo Natalucci

Concept for GRASS

- GRASS: Gamma-Ray Astronomical Small Sensor
- Experimental Light Innovative Instrument for HEMERA: γ-ray and high precision measurements relevant for astronomy
- Based on High-TRL, consolidated technology (space qualified, rad-hard devices)
- Technology heritage by application to the INTEGRAL mission (BGO scintillation detectors for VETO subsystem)
- planned initially for Hemera flights in 2020, 2021: Aire-sur-L'Adour, Kiruna -> Covid delayed 1y



INTEGRAL/IBIS detector with BGO VETO system

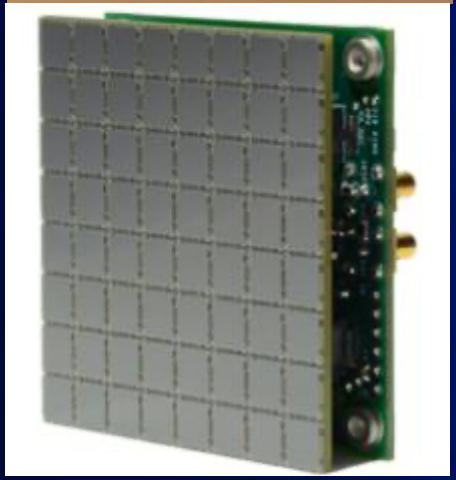
VETO module EM

Motivation for a small sensor flight on HEMERA: an H2020 program

- Background subtraction is essential for correct data exploitation
- On balloon flights, typical integration times do no allow a detailed modelling of instrument response to background conditions
- Acquisition of data as a function of altitude, cutoff rigidity and other parameters are a useful tool for background modelling
- Monitoring of background noise rate in several energy bands from ~10 keV to 1 MeV
- Plan to fly a « standard » small detector on any HEMERA payload.

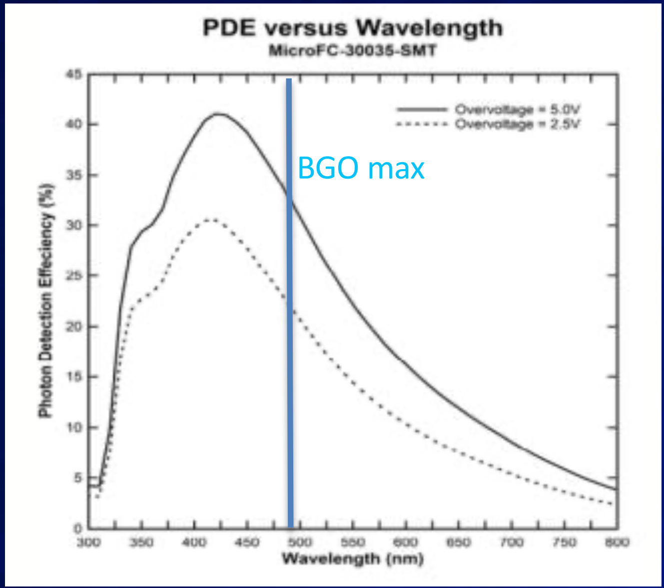
Instrument design

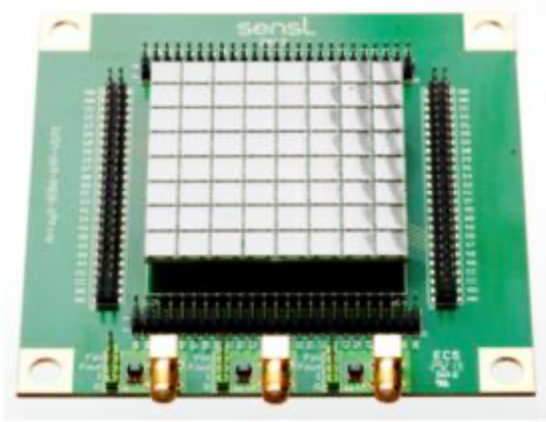
- Design based on square BGO scintillator coupled to a single, large sensitive area SiPM array readout
- Compact, light configuration optimised for background measurements



Energy range	**0.1-10 MeV**
Field of View	**4 PI**
Energy resolution	**~20% @100 keV**
Timing resolution	**100µs**
Detection area, thickness	**~50 cm^2, 1cm**
Readout	**SiPM 8x8 array, sensitive area 30cm^2**
Weight	**3kg**
Power	**10 W**

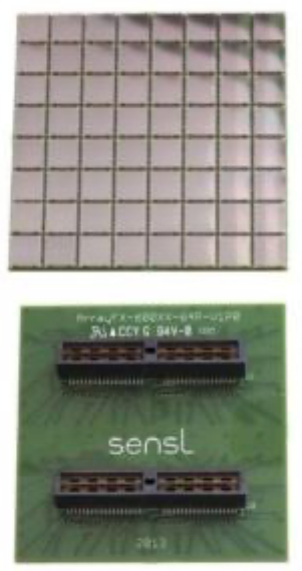
SiPM array technology



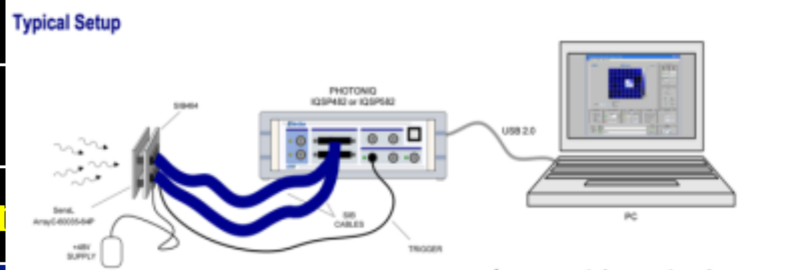


8x8 array of 6mm pixels,
Board size: 57.4x57.4 mm^2

On Semiconductor
C-series array



Gain	~2.3-3x10^6
Dark count	
Capacitance	
Temperature coefficien	



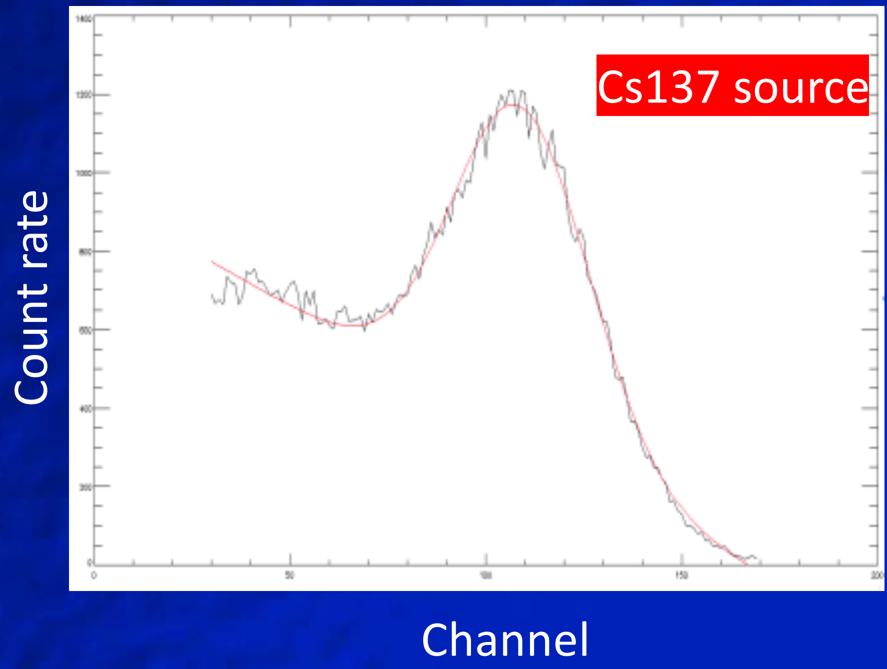
SIB464 Sensor I/F Board (Vertilon)

Pre Covid-19 laboratory activities

- Two available BGO laboratory samples from small (~few cm^2) to larger size (~250 cm^2) are under study using PMT readout
- Preliminary characterisation of crystal light collection efficiency and spectral resolution
- Procurement of flight BGO crystal, readout electronics and customized test devices is ongoing

This was the plan and status in 2019

BGO with PMT readout

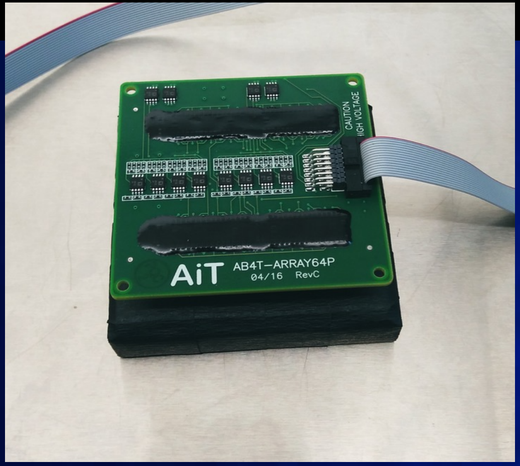


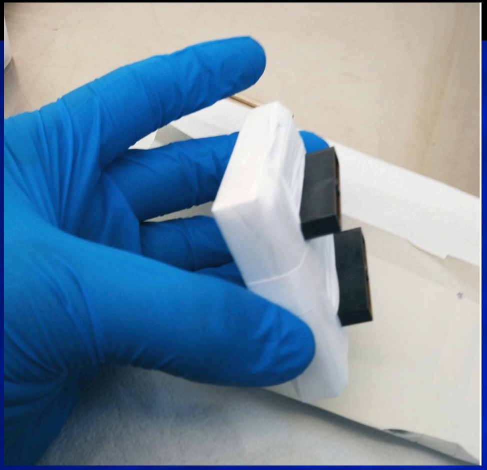
The 2020 Covid-19 emergency

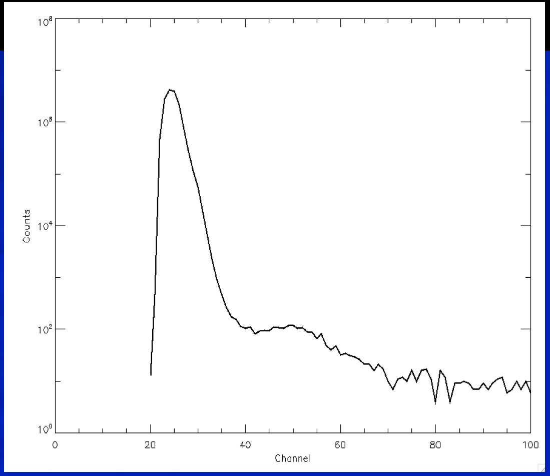
- At the beginning of March 2020 the lock-down Italian law prevented any laboratory activity, planned in view of the scheduled HEMERA flight for summer 2020 from Kirune.
- As a consequence was prohibited to access the Laboratory and to progress with the new detector test.
- The IAPS engineers continued the activity moving to their own house the instrumentation, allowing to perform months later the first IAPS laboratory tests was soon as was possible to re-start the activity (last month)
- We had the chance to join together only one day and tried to perform the first light of the new detector: the BGO Crystal (50x50x10 mm^3 crystal) coupled with an array of 8x8 Sipm and front end electronics read-out, operated at ambient temperature.
- A ^{137}Cs source available at the time was used to have a first indication of the detector array operational capability

Innovative small sensors for astronomy

- Experimental Light Innovative Instrument for γ-ray and high precision measurements relevant for astronomy based on High-TRL, consolidated technology
- SiPM technology coupled to BGO crystals (first flight) and possibly GAGG (second flight): basic design for HEMERA flights is small, compact scintillator, volume ~50 cm^3.
- Testing activity exploited in-house due to Covid-19. Coordination with other HEMERA teams is in place.
- **A second test-day was permitted on Sept 22 →**



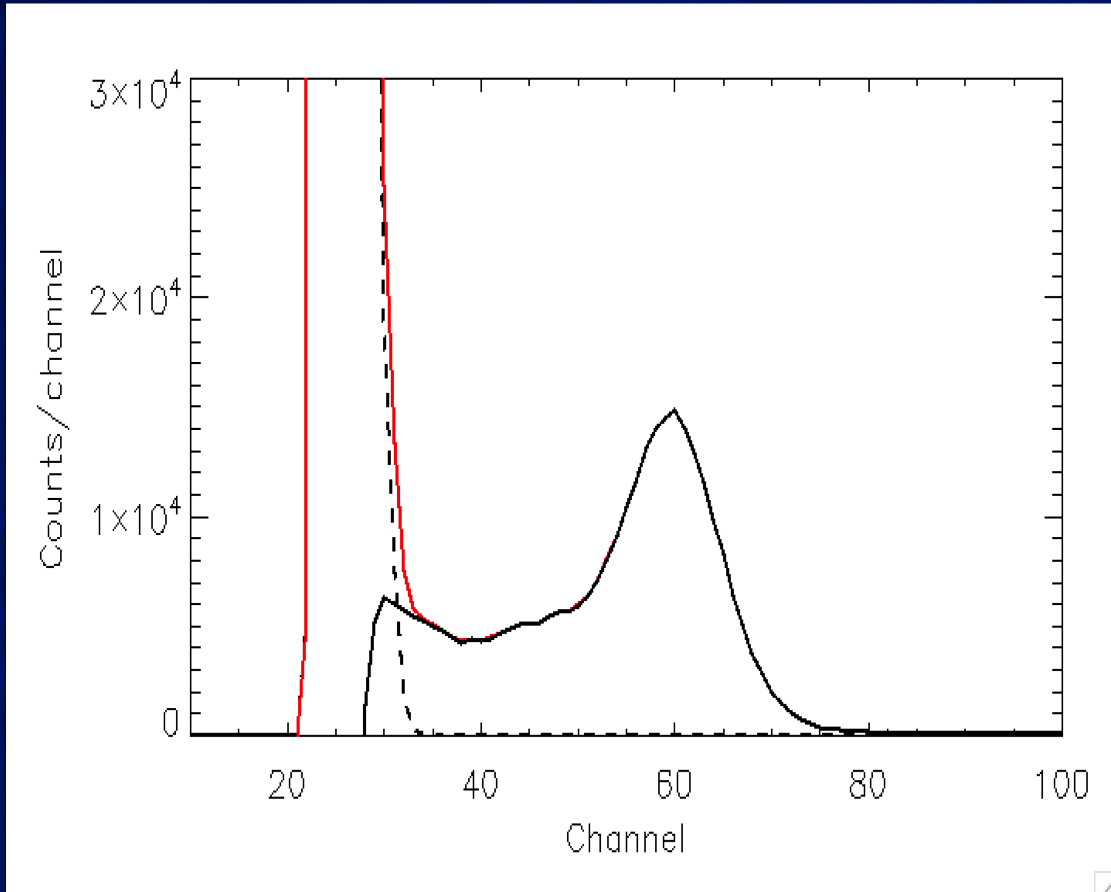




BGO integrated with SiPM readout during tests at IAPS

First lighgt with Co 57 source

First light with Cs137 calibration source



Black=Background subtracted spectrum (normalised by ratio of livetime)

$\Delta E/E$ ~18% FWHM

Testing facility TVLAB

- Testing activity are carried out essentially in-house. Coordination with other HEMERA teams is in place (discussed in Paris, January this year)
- Our facility TVLAB features a volume of 1600 litres and a limit vacuum of 10^{-7} mbar (the primary vacuum is 10^{-2} mbar). The temperature range control is between -70 and+100^{O}C.
- Automated or manually handed cycles
- Data recording and monitoring capabilities (National Instruments cRIO9074 plus nominal and redundant workstations)

Left, *Center*: The TVlab thermal vacuum chamber. *Right*: The MEX clean room at INAF/IAPS.

Conclusions

- GRASS is the Light Innovative Instrument for gamma-ray and high precision measurements relevant for astronomy
- Based on High-TRL, consolidated technology (space qualified, rad-hard devices)
- Technology Heritage by application to the INTEGRAL mission
- To do:

    H/W procurement

    Readout electronics full development

    Instrument assembly and functional tests

    Thermal vacuum tests (TVLAB)

    Full characterization and instrument calibration

    Delivery for flight from Kiruna in 2021 and Timmins 2022

We feel the first part of the AHEAD program very successful, also in view of the Covid-19 emergency restrictions.

No delay of the planned activity is foreseen at this stage.

Thanks for your attention!