HERMES: a swarm of nano-satellites for high energy astrophysics and fundamental physics

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on behalf of the HERMES team

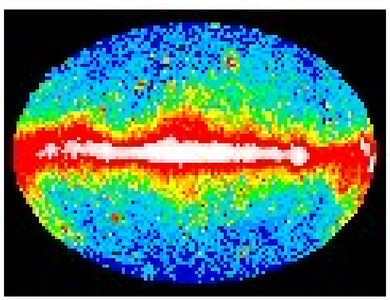
 

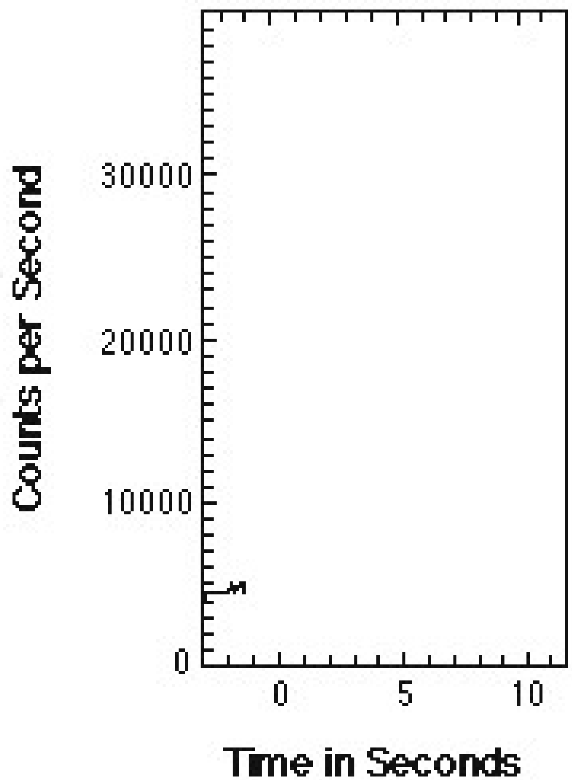
HERMES: High Energy Rapid Modular Experiment Scintillator

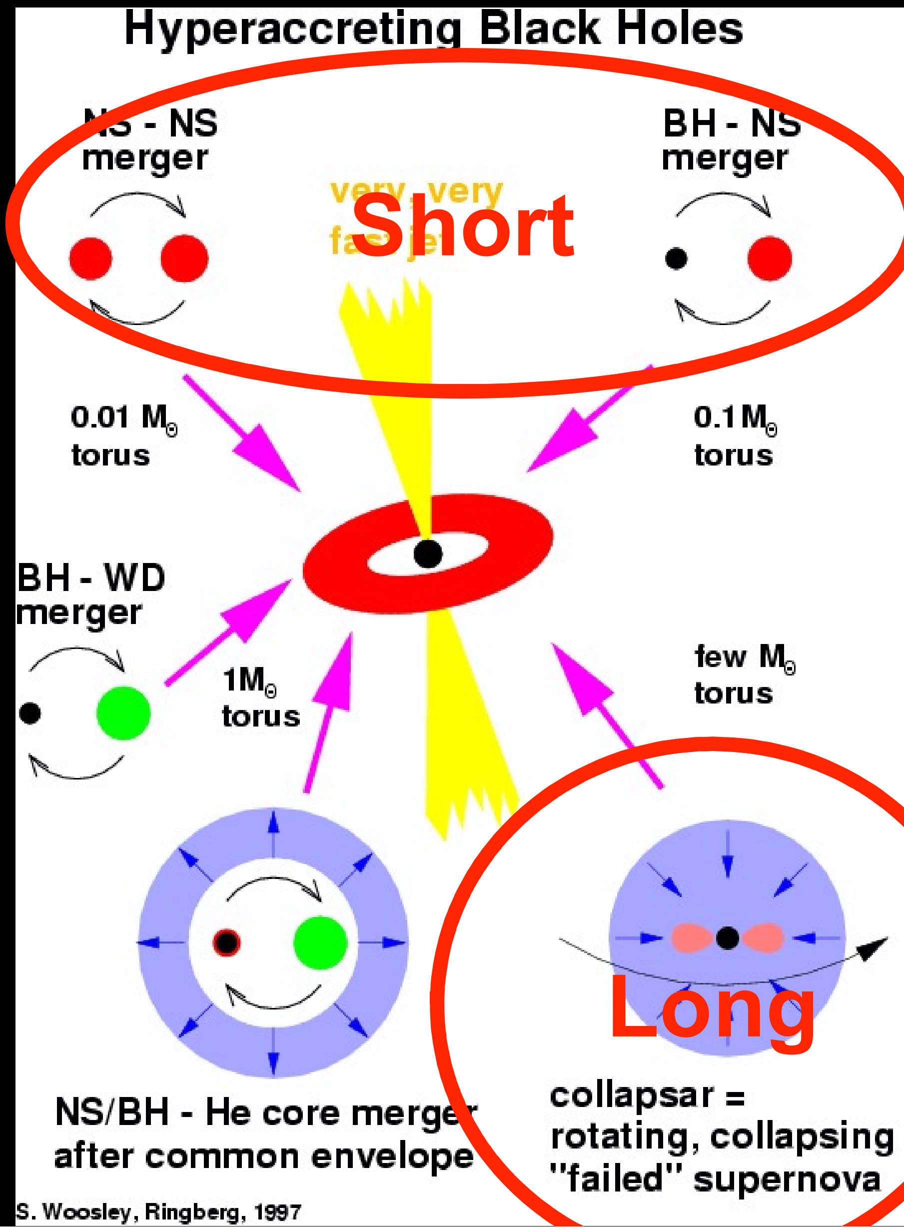
A constellation of cubesats for the localization of Gamma Ray Burst sources

GRBs in a nutshell

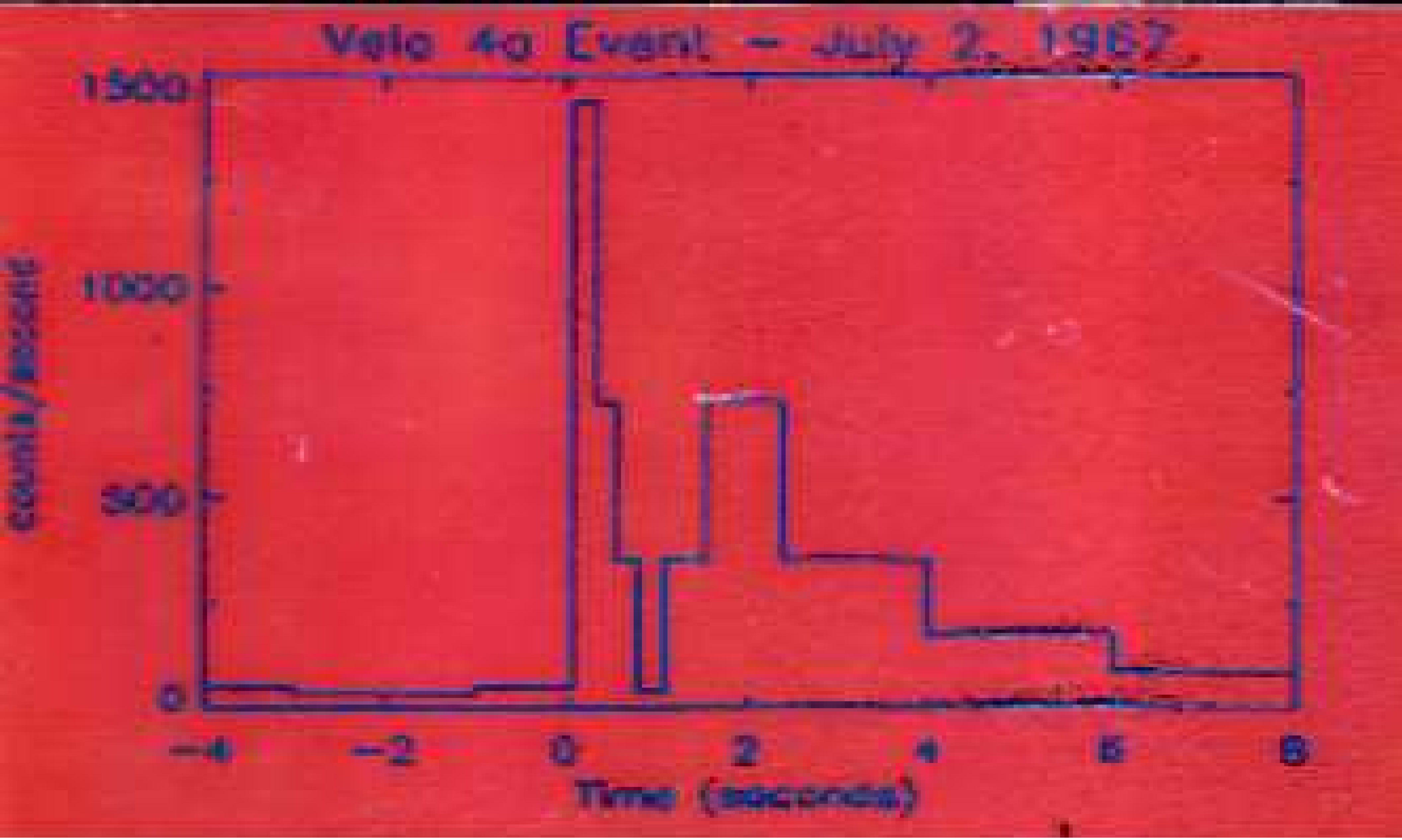
Sudden bursts of soft γ-rays up to 10^{-3} ergs/s/cm^2 (μW/m^2)





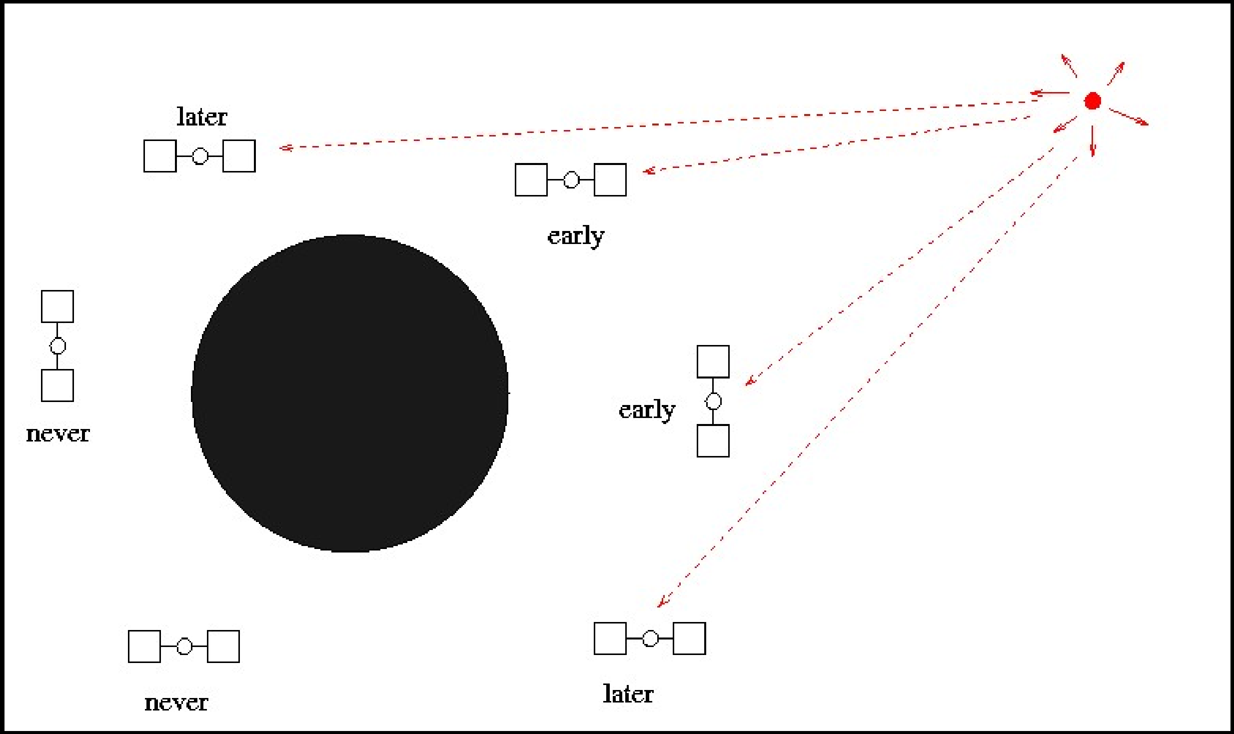


The discovery of GRBs by the Vela satellites



Vela satellites

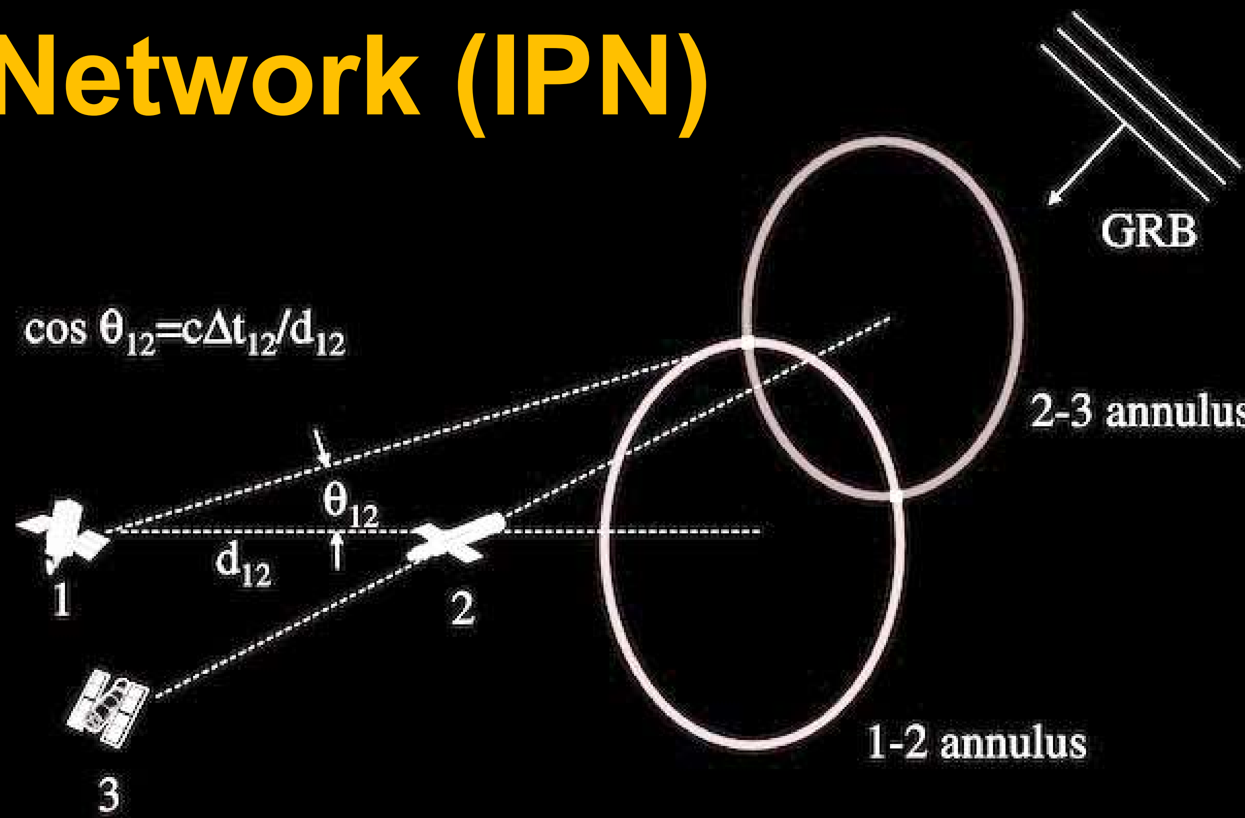
First 6 Vela equipped with X-ray and γ-ray detectors with limited timing capabilities: rough positions



Advanced Vela equipped with silicon photodiode sensors with millisec timing: ~10deg positions

Modularity —> improved performances

Interplanetary Network (IPN)

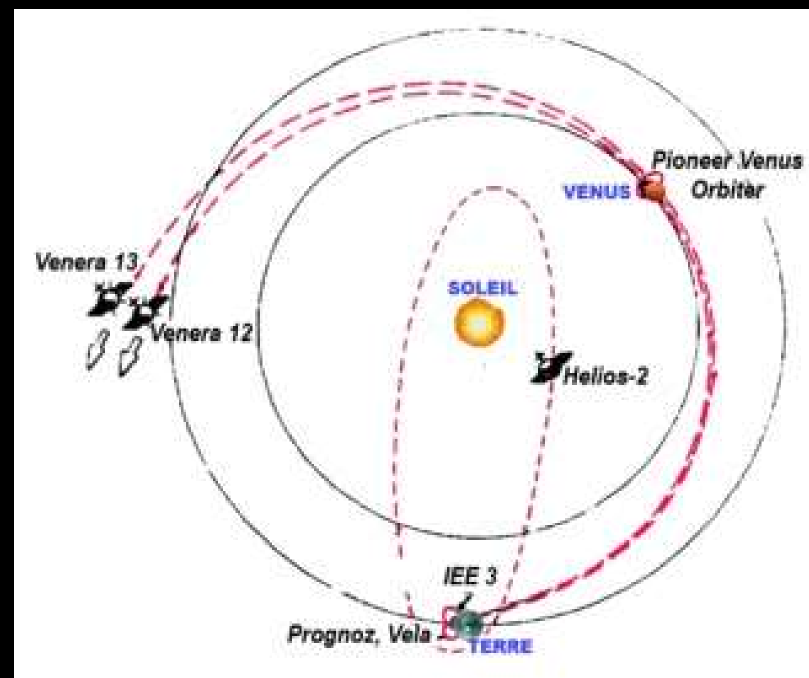


First IPN 1976
4-6 spacecrafts.
Baseline ~ 1 AU

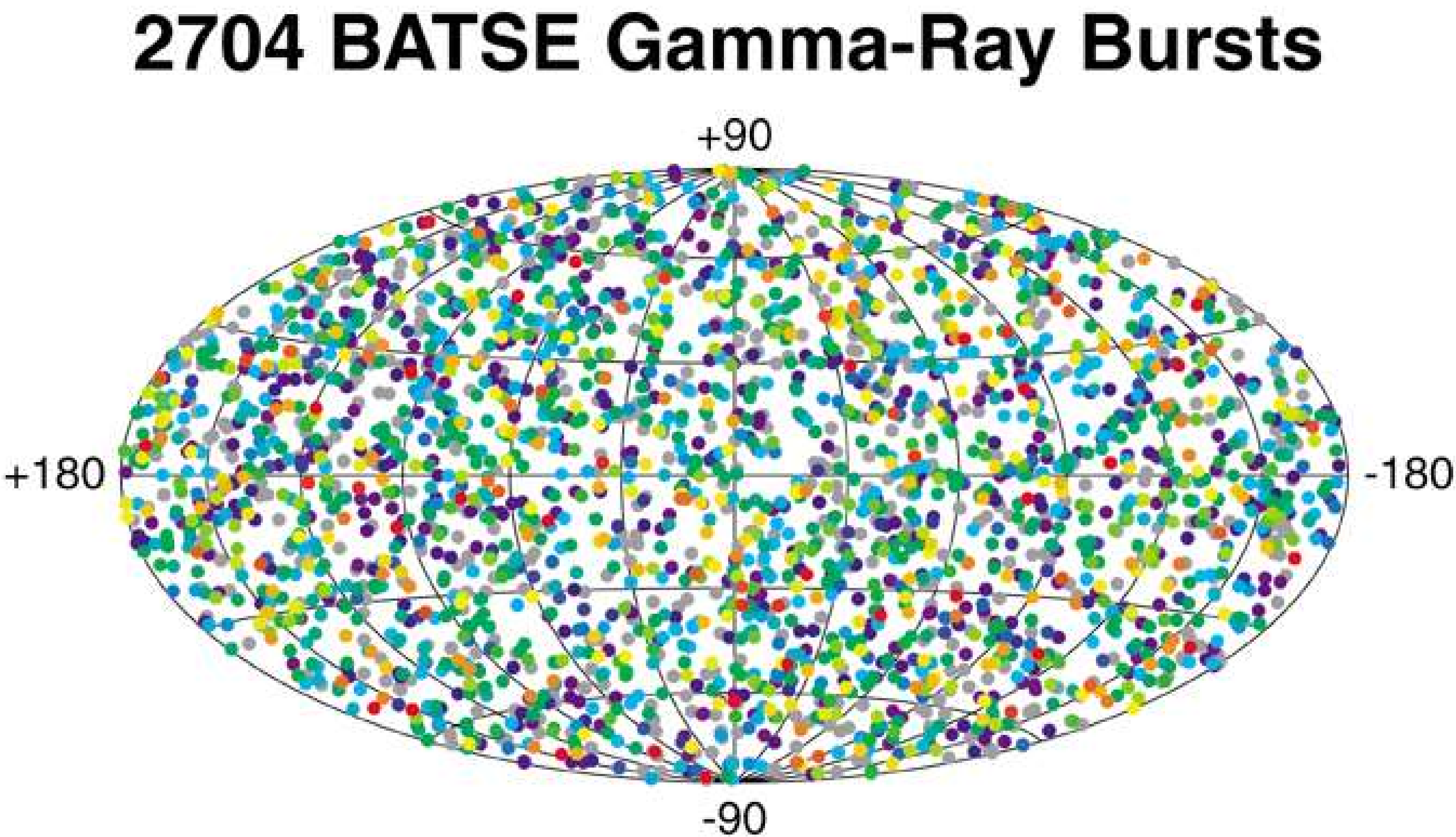
Second IPN 1990's
PVO, Ulysses, CGRO,
Wind, BeppoSAX

Third IPN 2000
~ 20 spacecrafts

Long baseline: arcmin positions
Main disadvantage: long data acquisition ~days



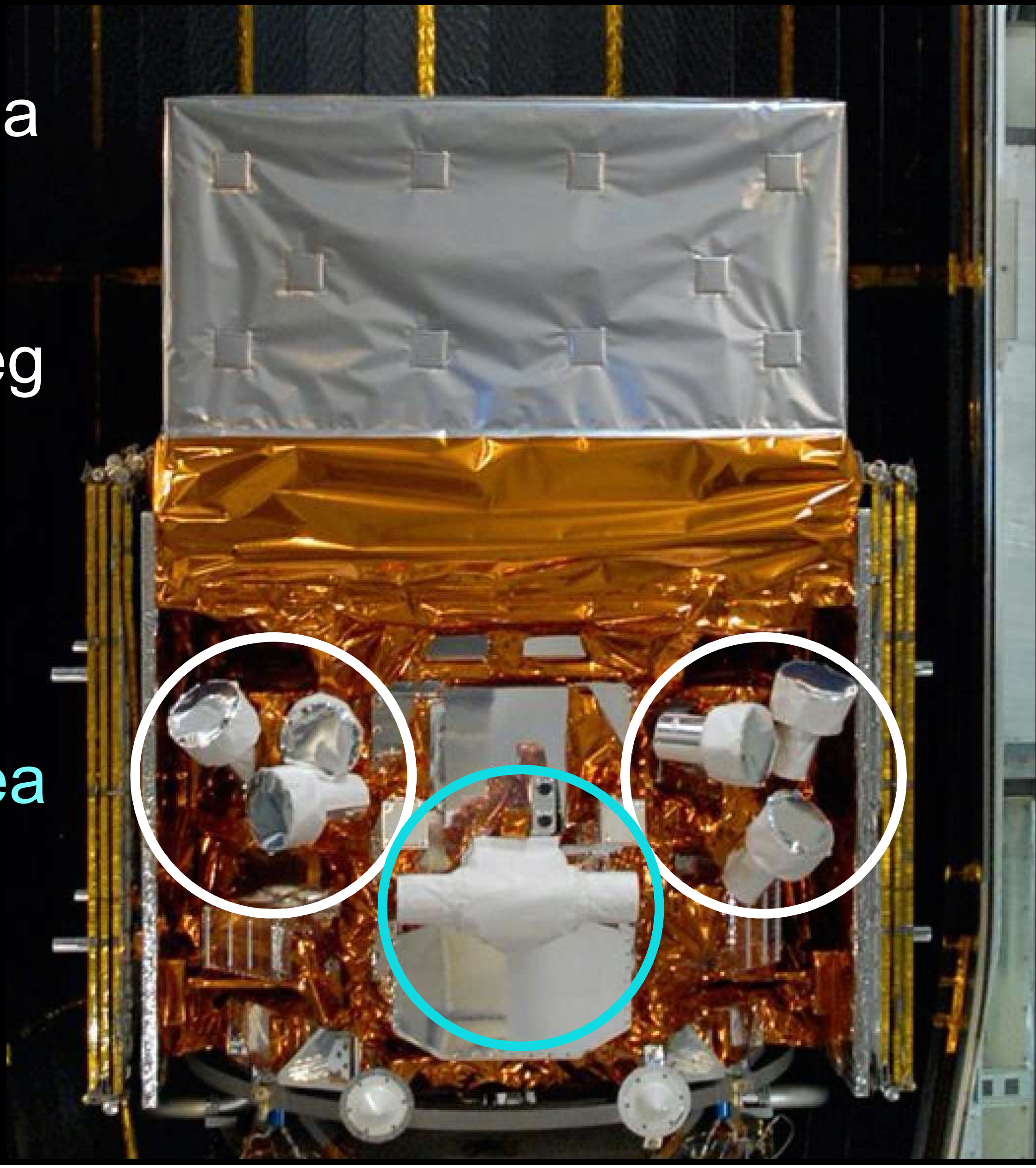
CGRO/BATSE



Fermi/GBM

12 NaI scintillators
each ~120cm^2 collecting area
Best temp. res. 2μs
8-1000 keV
Position accuracy ~10-20 deg

2 BGO scintillators
each ~ 120cm^2 collecting area
0.2-40 MeV



BeppoSAX

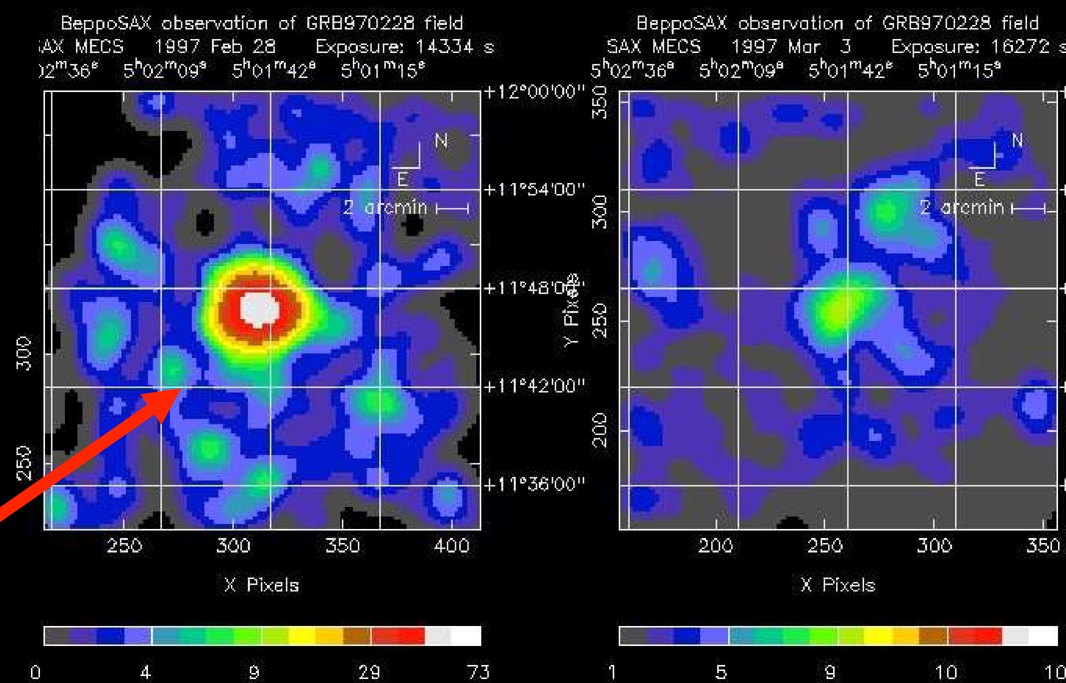
GRB 970228

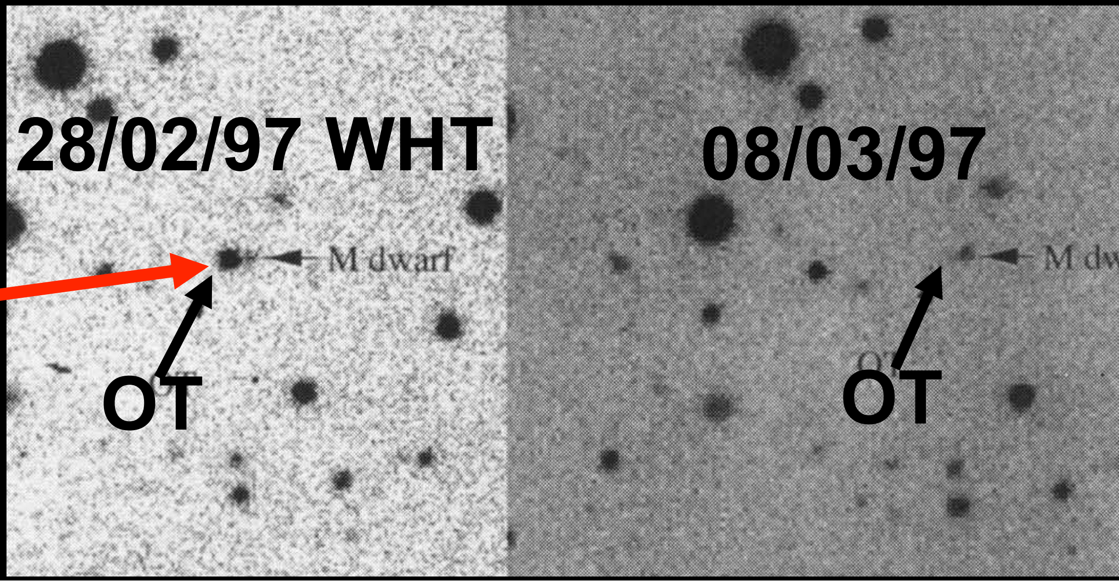
Detected and localised to a few arcmin by the BSAX/WFC

Satellite repointed and observed the field with X-ray telescopes 8hr after the event

Discovery of first X-ray afterglow. <1arcmin position disseminated

Discovery of first optical afterglow





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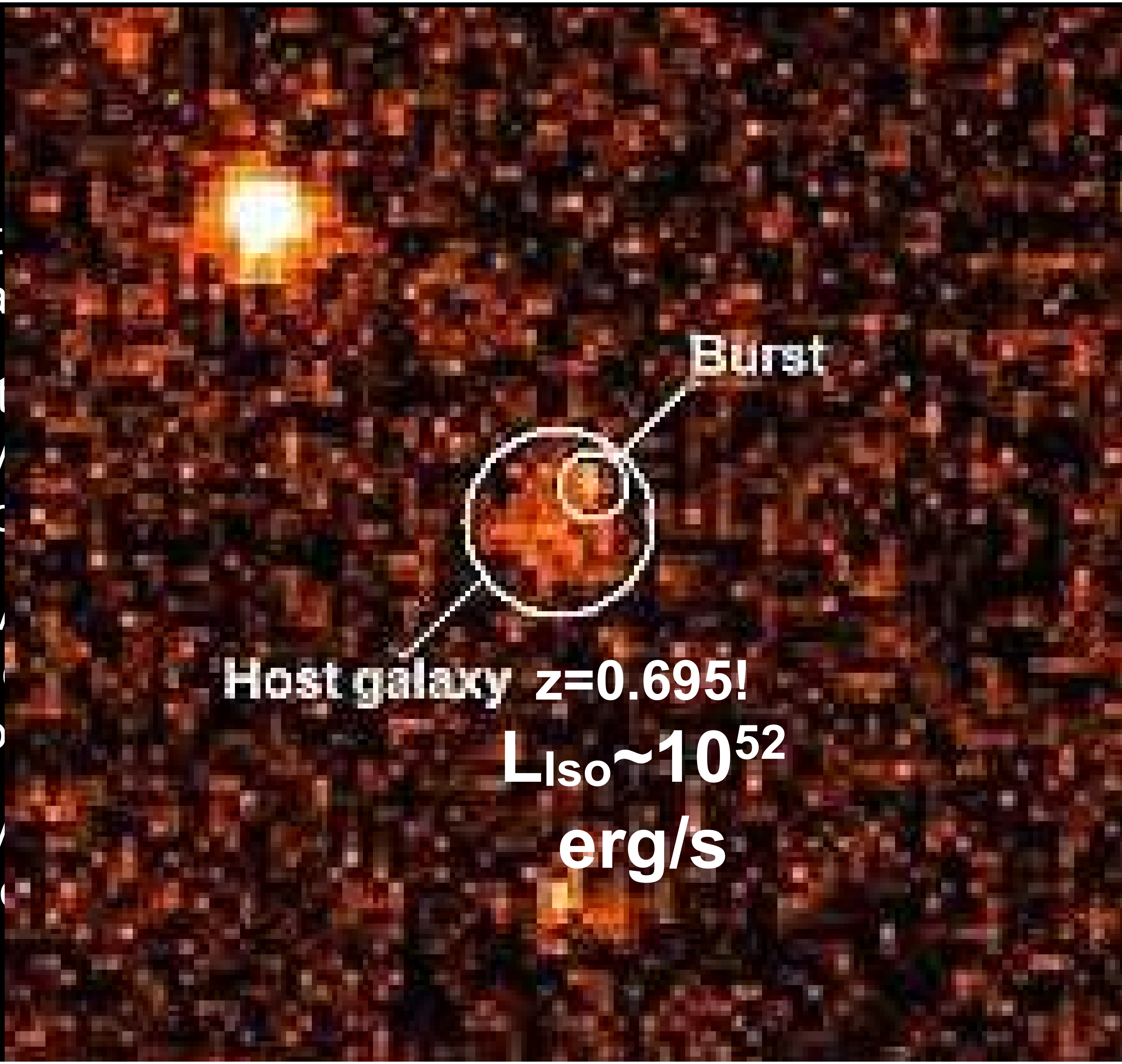
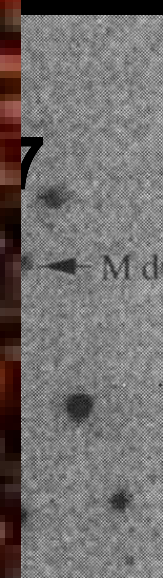


z=0.695!

L_{Iso}~10^{52} erg/s

7



Lessons learned

Distributed instrument —> arcmin-deg positions

Modularity —> improved performances

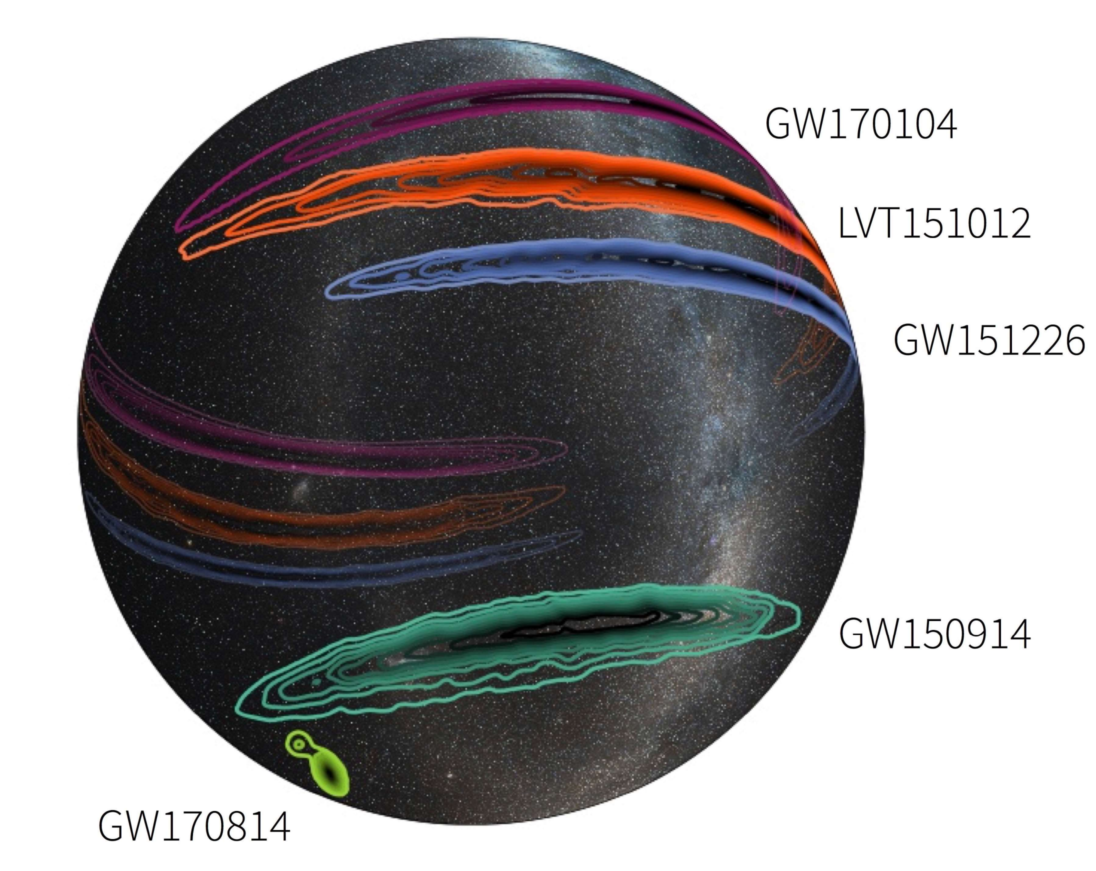
Prompt arcmin-arcsec positions —> game changer

The multi-messenger revolution

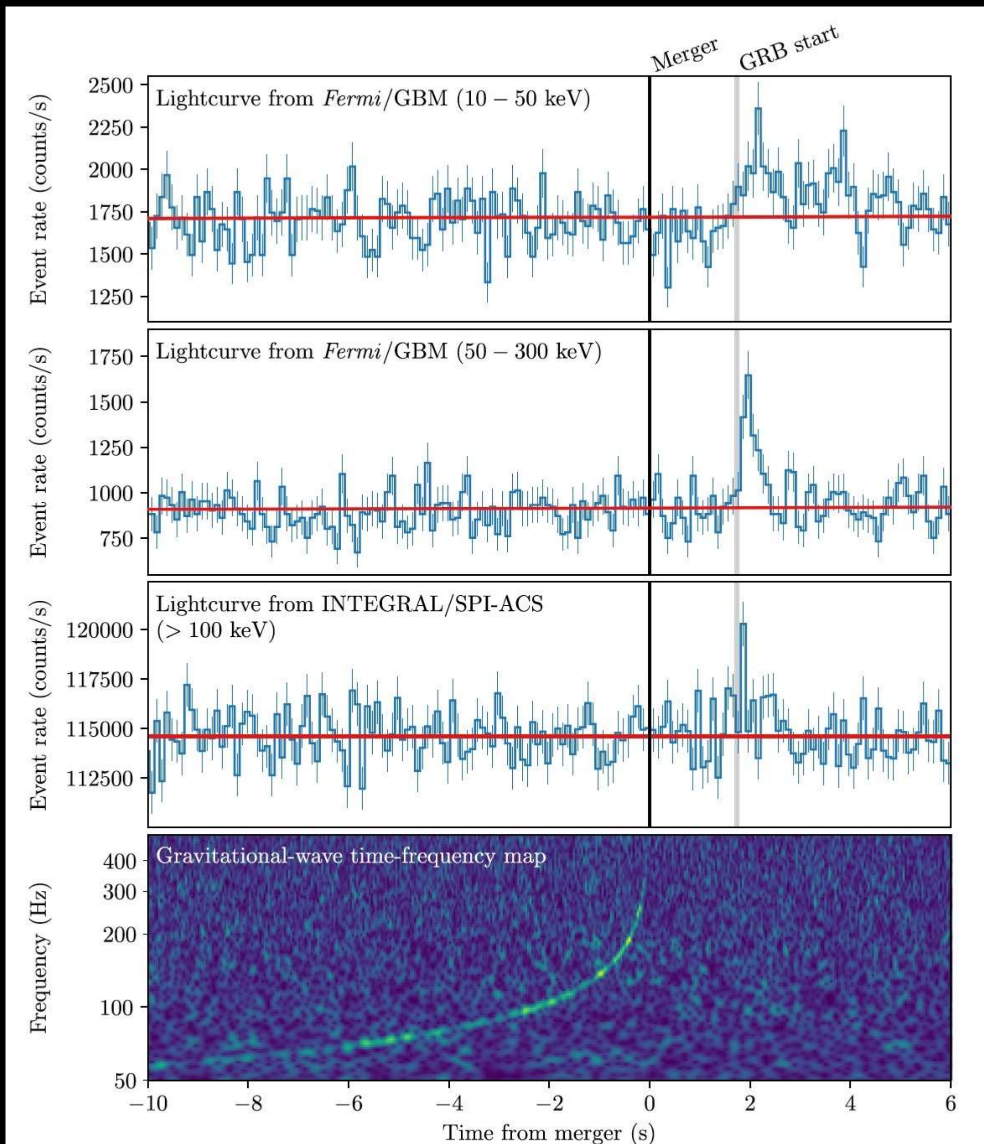
Large volumes difficult to survey at optical λ.

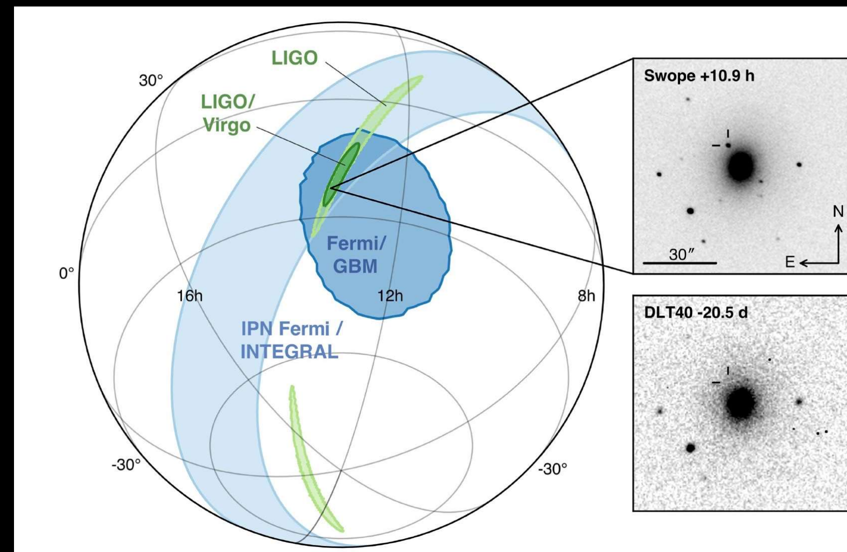
Tens/hundreds/thousands optical transients.

Best strategy:
~ all sky prompt search for transients at high energies.
Negligible probability to find an uncorrelated HEA transient at the time of GWE



The multi-messenger revolution is already here! GW 170817





$M_1 = 1.36\text{-}2.26\ M_{Sun}$

$M_2 = 0.86\text{-}1.36\ M_{Sun}$

$M_{chirp} = 1.188$

$D_L = 40^{+8}_{-14}$ Mpc

$E_{rad} = 0.025\ M_{Sun}\ c^2$

Error box ~ 30deg^2

Mission concept

Disruptive technologies: fast, cheap, underperforming, but producing high impact.

Distributed instrument, tens/hundreds of simple units.

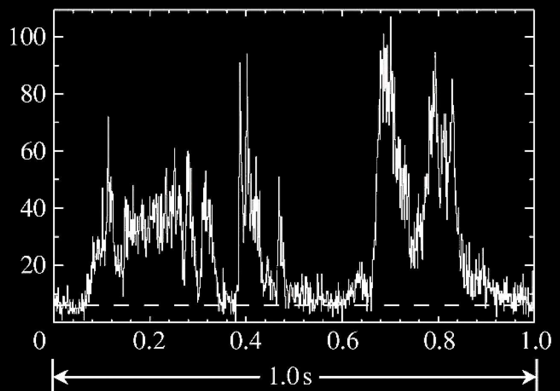
High redundancy.

HERMES constellation of cubesats

Experiment concept

1. Measure GRB positions through delays between photons arrival times:

$$\sigma_{Pos} = \sigma_{CCF} \times c \, / <B> / \, (N \times (N - 1 - 2))^{1/2}$$



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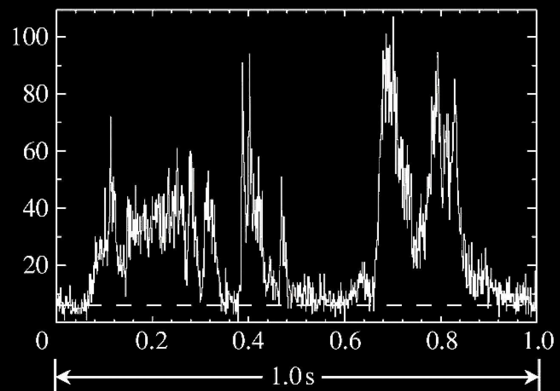

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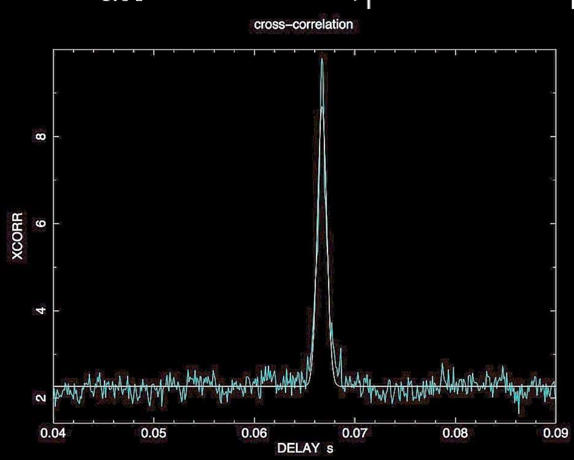
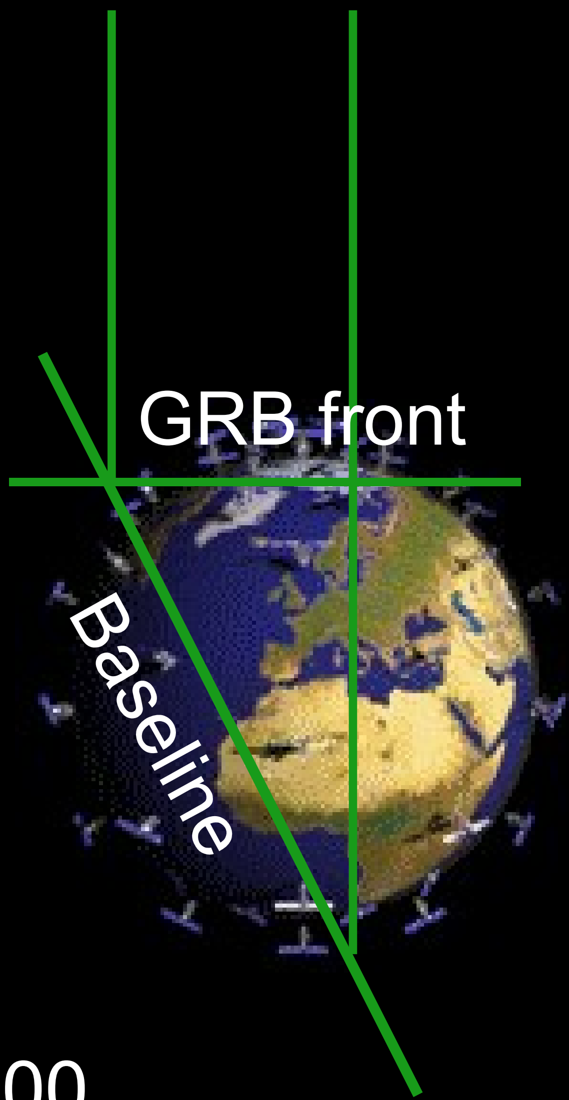


σ_{CCF}~10μs

σ_{Pos}~10arcsec

if <B>~7000km, N~100



Experiment concept

2. Add the signal from different units

Total collecting area 100-200cm^2 x 100 = 1-2 m^2

Transient fine (μs-ms) temporal structure of GRBs

Requirements

Scientific:

Arcmin-arcsec positions of ~a few dozens GRB/yr

Prompt(minute) localisation

μs timing

Requirements

System:

≈ hundreds detectors

single collecting area ≥50cm^2

total collecting area ≥1m^2

Energy range: few keV to ~1 MeV

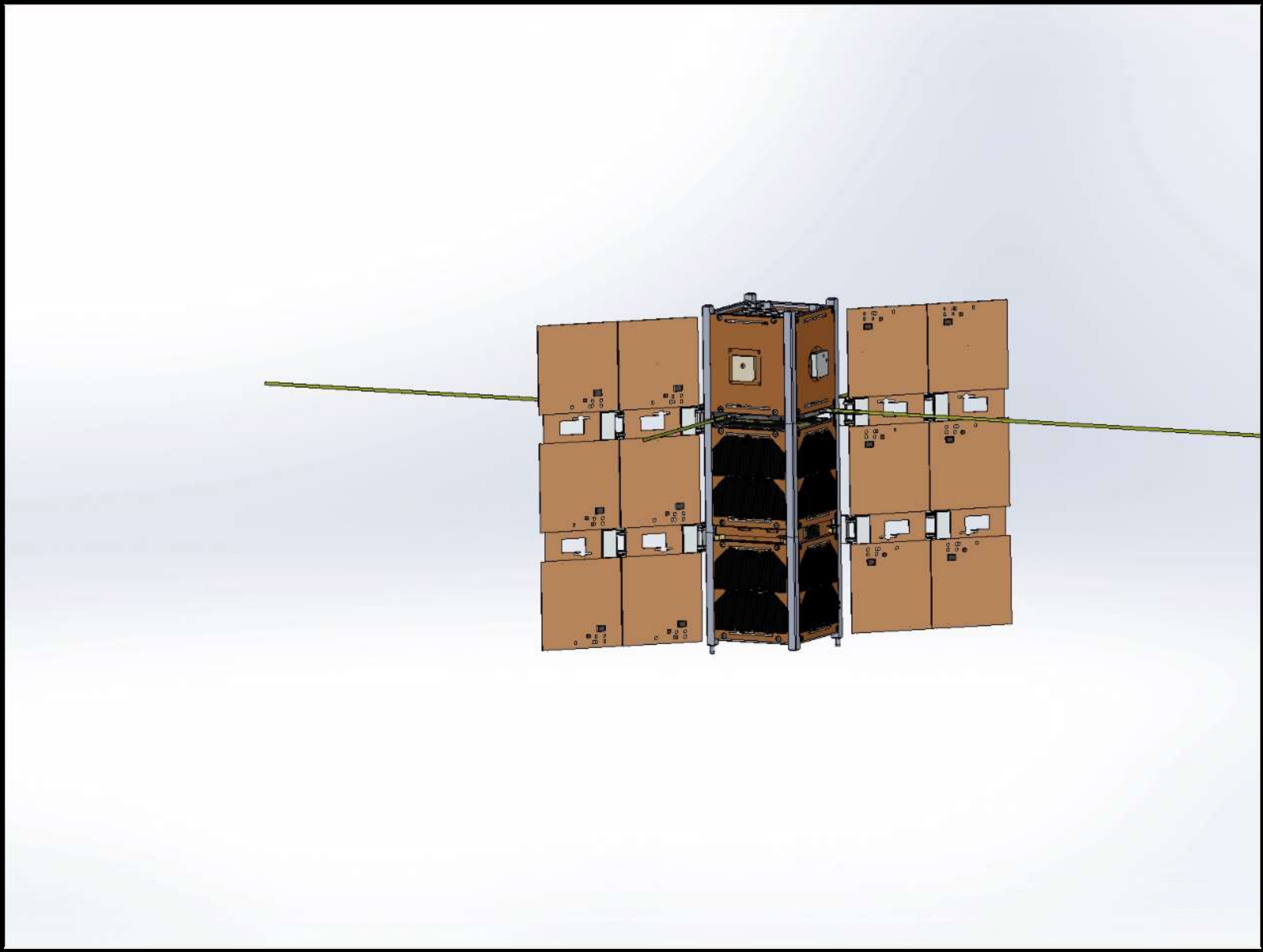
Temporal resolution ~100ns

Position reconstruction of each satellite < a few m

Absolute time reconstruction <100 ns

Download full burst info in minutes

Implementation: HERMES cubesat



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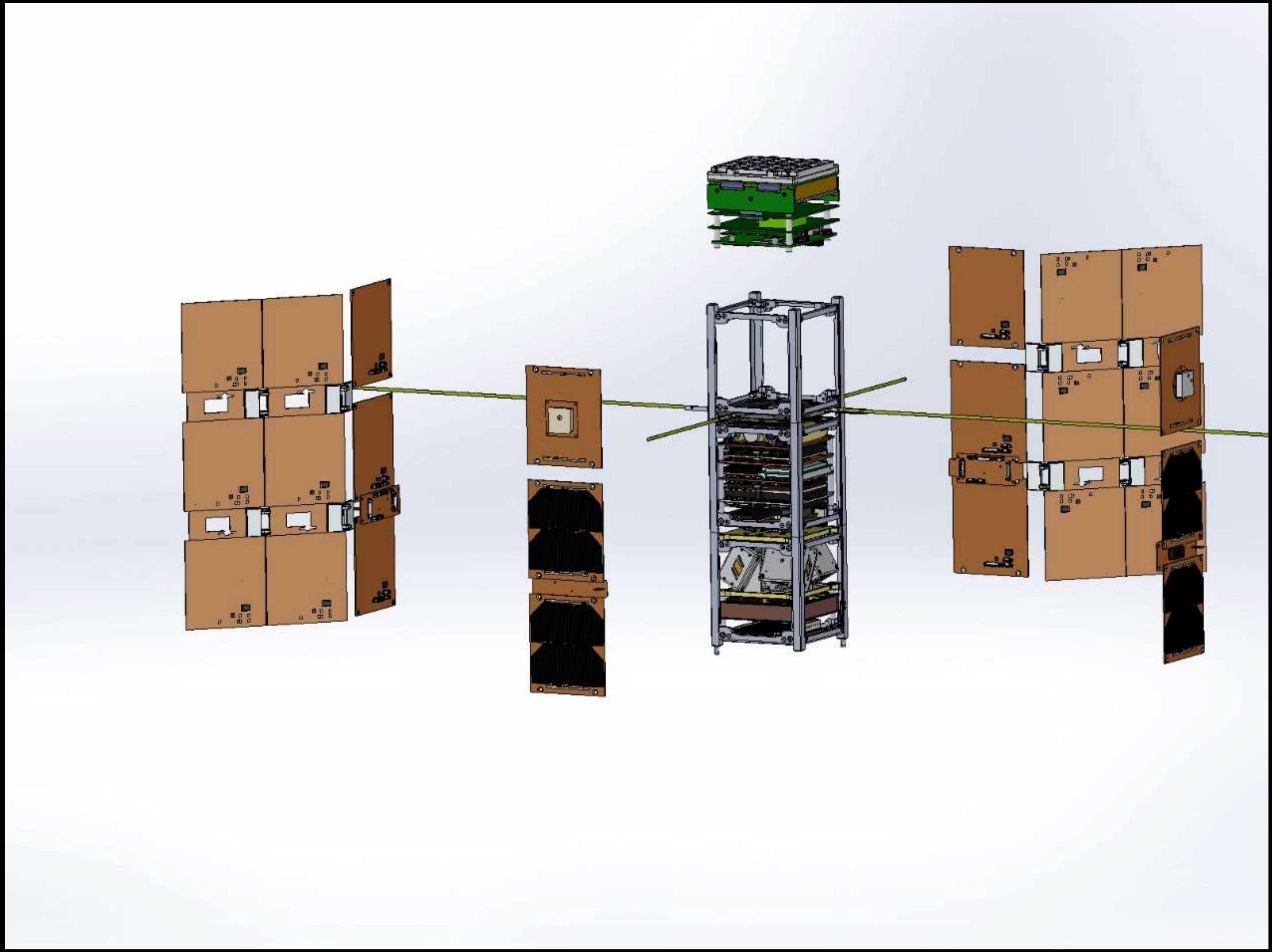
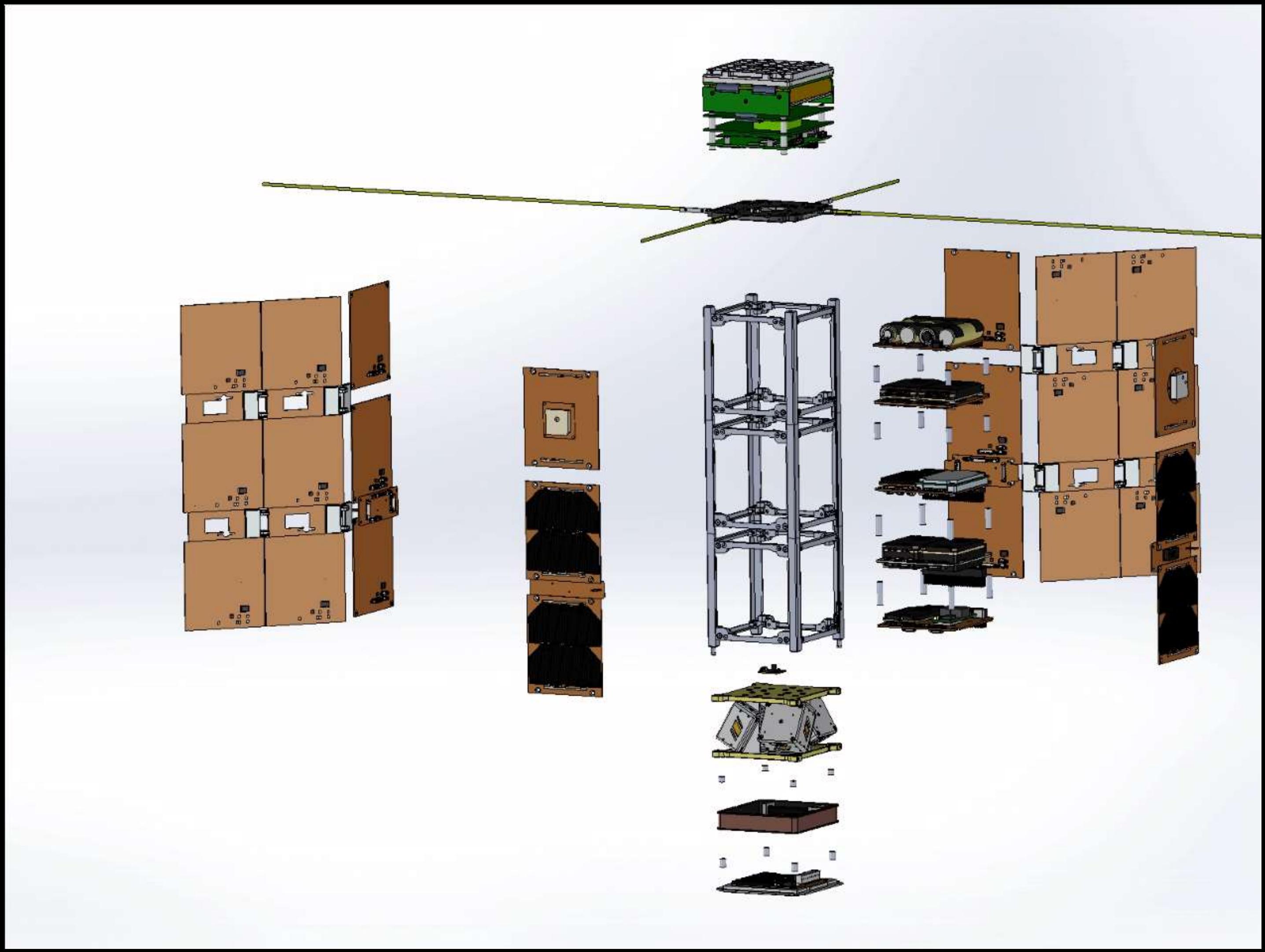
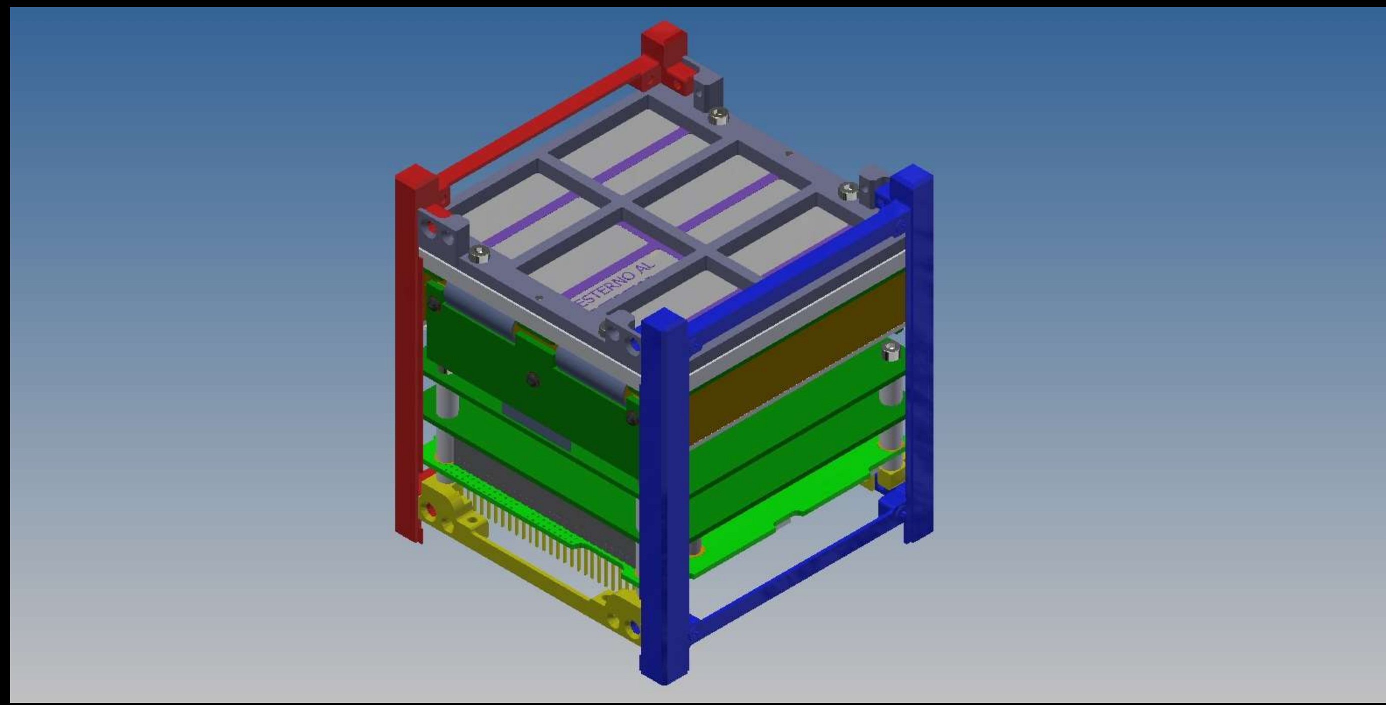


Implementation: HERMES cubesat



Payload

- Scintillator cristal (GAGG) + Photo detector (SDD)
- 3-1000 keV
- ~50 cm^2 coll. area
- Several sr FOV
- Time res. <1 us
- Power < 4W
- ~1.8kg



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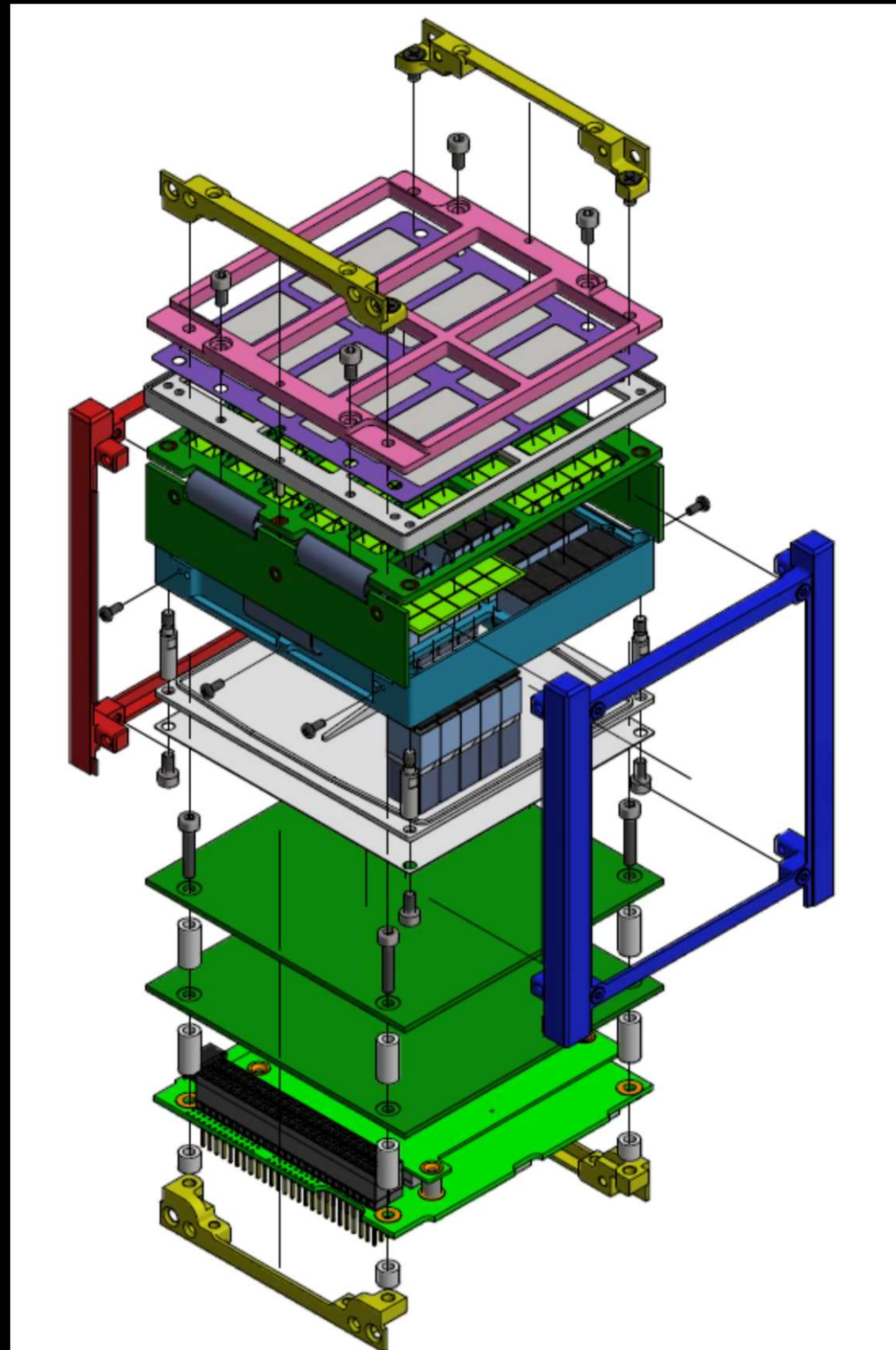
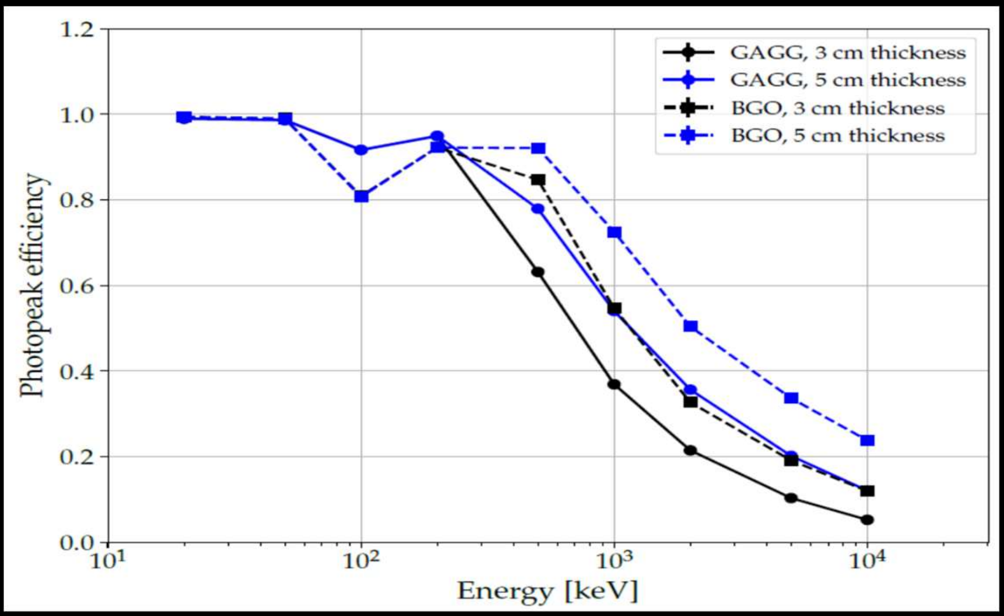
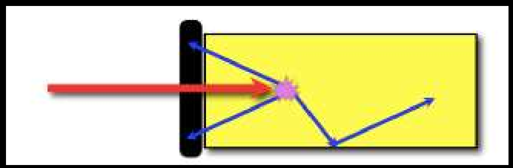


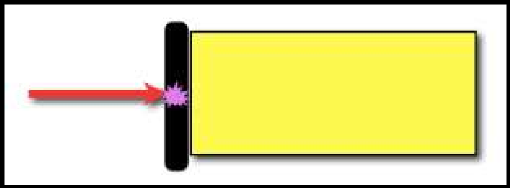
HERMES wide-band sensitivity



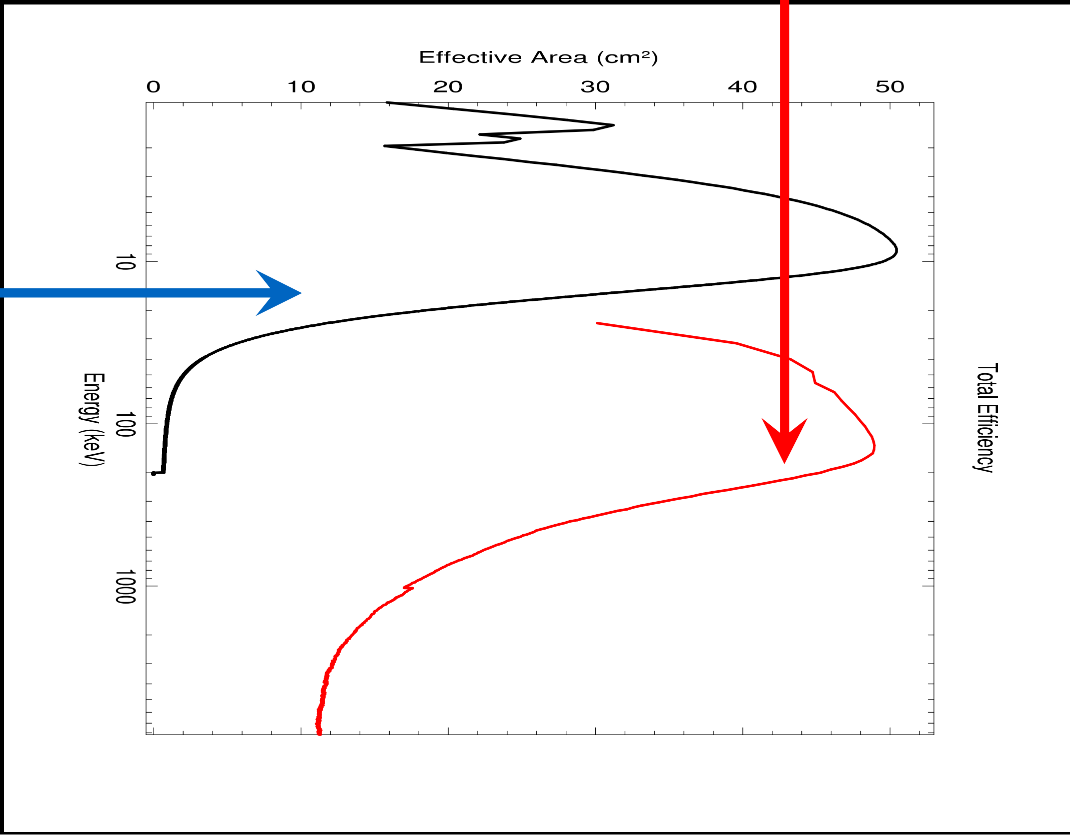
Dual Simultaneous Functionality for SDDs:



Scintillator readout system for Higher Energy X/γ-rays

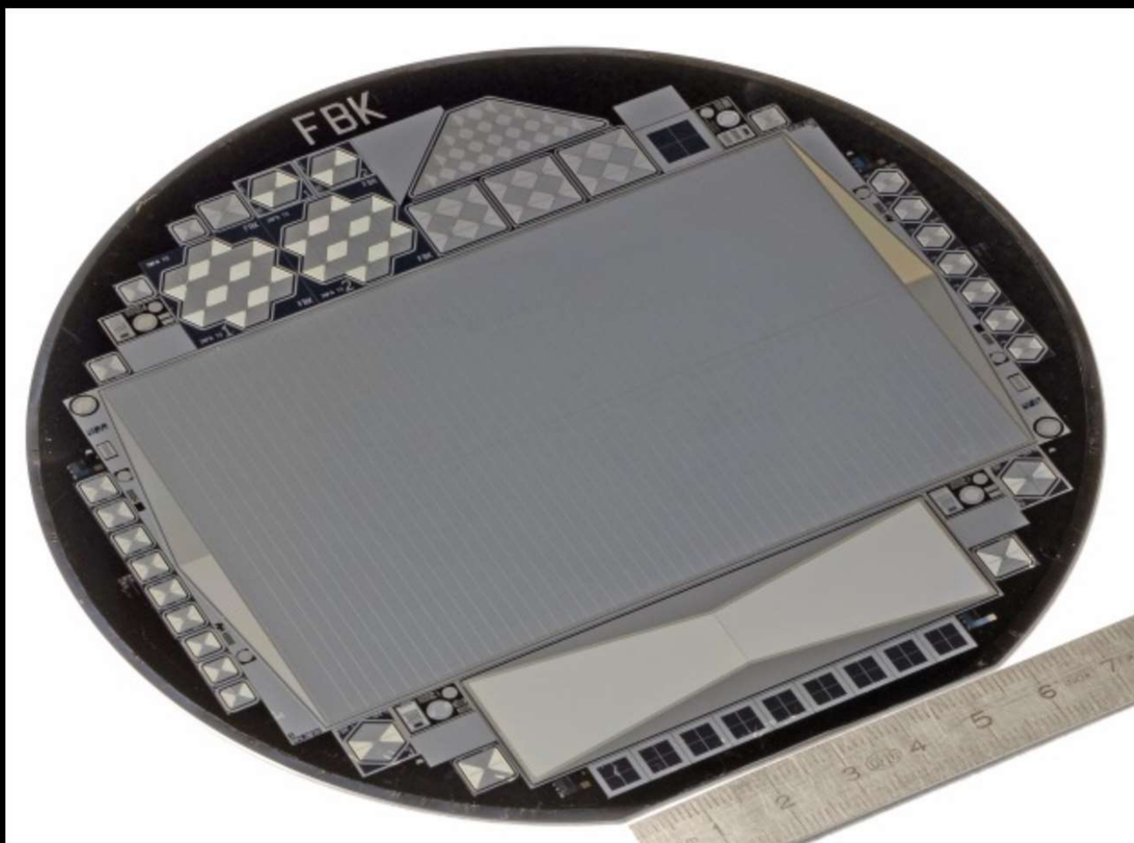


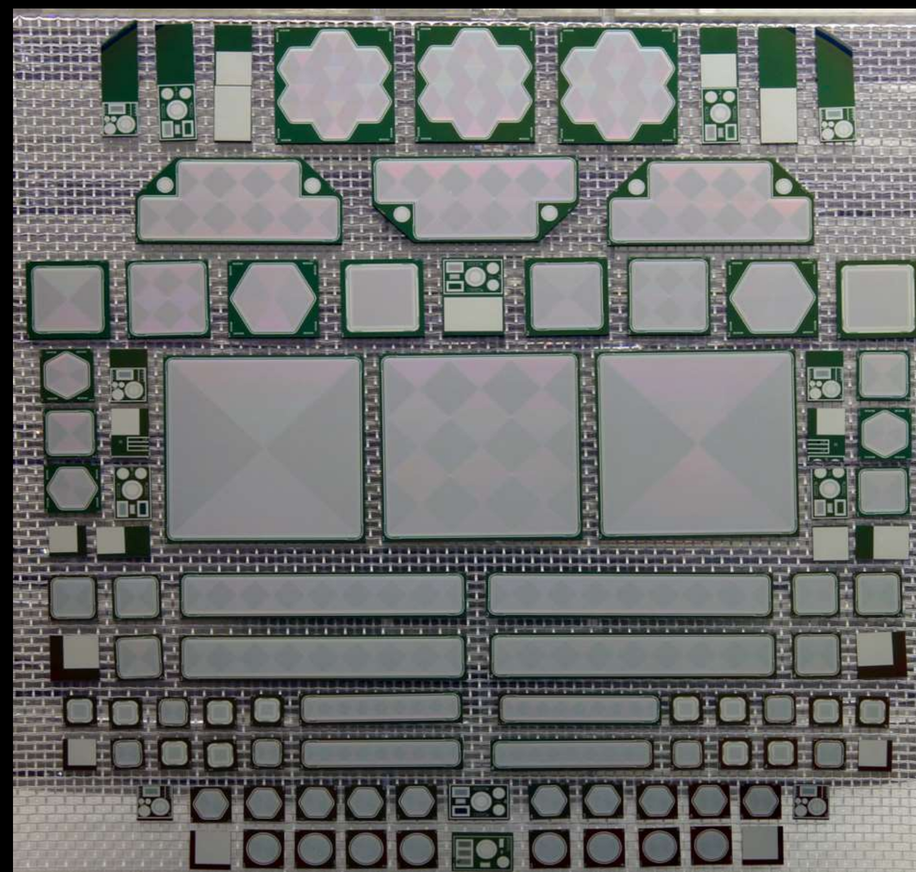
Solid State Detector for Low Energy X-rays



Feasible only with SDDs & Low Noise FEE

SDD within redSOX Collaboration





Low anode capacitance (few tens of fF)
Low leakage current (tens of pA/cm^2)

SDD Quantum Efficiency (QE) > 80%

Ce:GAGG

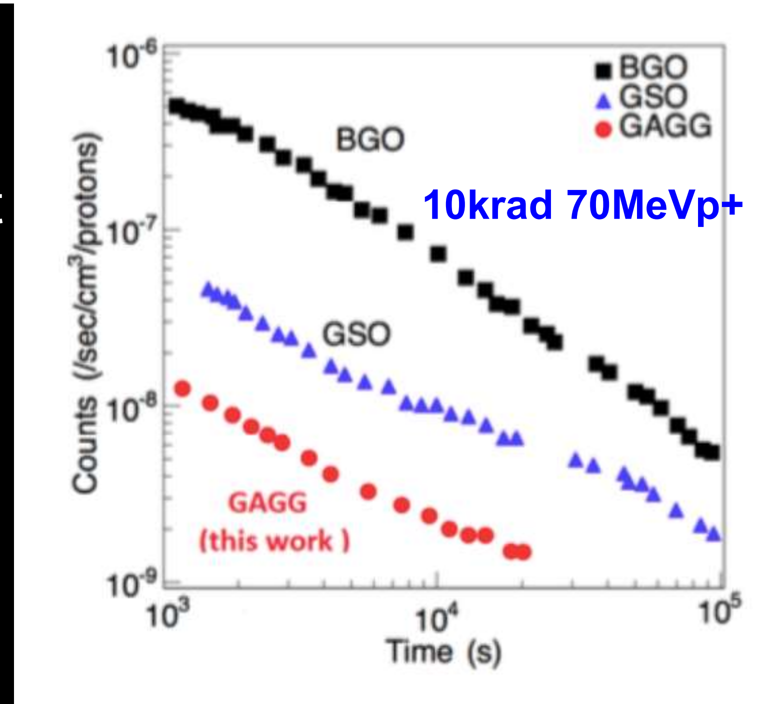
Cerium-doped Gadolinium-Aluminum-Gallium Garnet

$Ce:Gd_3(Ga_xAl_{1-x})_5O_{12}$ (x=1-5, typ.=3)

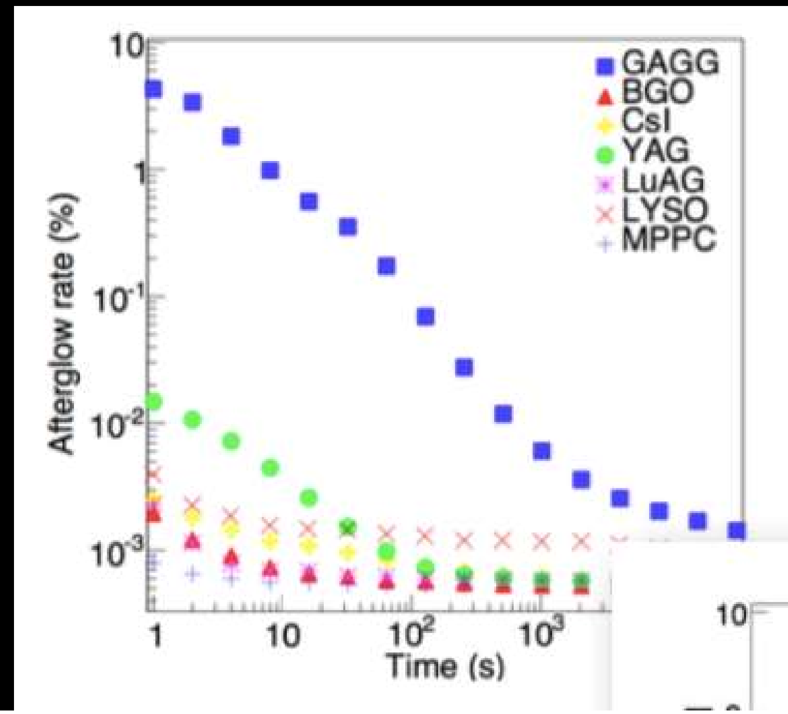
Available from industry since ~2014

- Light output: 40 – 60 ph/keV
- No intrinsic background
- Not hygroscopic
- Decay time ~90 ns
- High density (6.63 g/cm3)
- Peak emission at 520 nm
- Hardness: 8 Mohs scale
- Energy resolution ~ 5% @ 662 keV

Very promising literature radiation tests.
Additional tests performed to better understand afterglow effects.



Yoneyama+2018



HERMES performance

$$\sigma_{Pos} = 2.4°[(\sigma_{CCF}^2 + \sigma_{sys}^2)/(NxN\text{-}2\text{-}1)]^{0.5}$$

<B>~7000km

N(pathfinder)~6, active simultaneously 4

N(final constellation) ~100, active 50

Bright GRBs with msec structure:

$\sigma_{Pos(pathfinder)}$ ~ 1 arcmin if σ_{CCF}, σ_{sys}~10usec

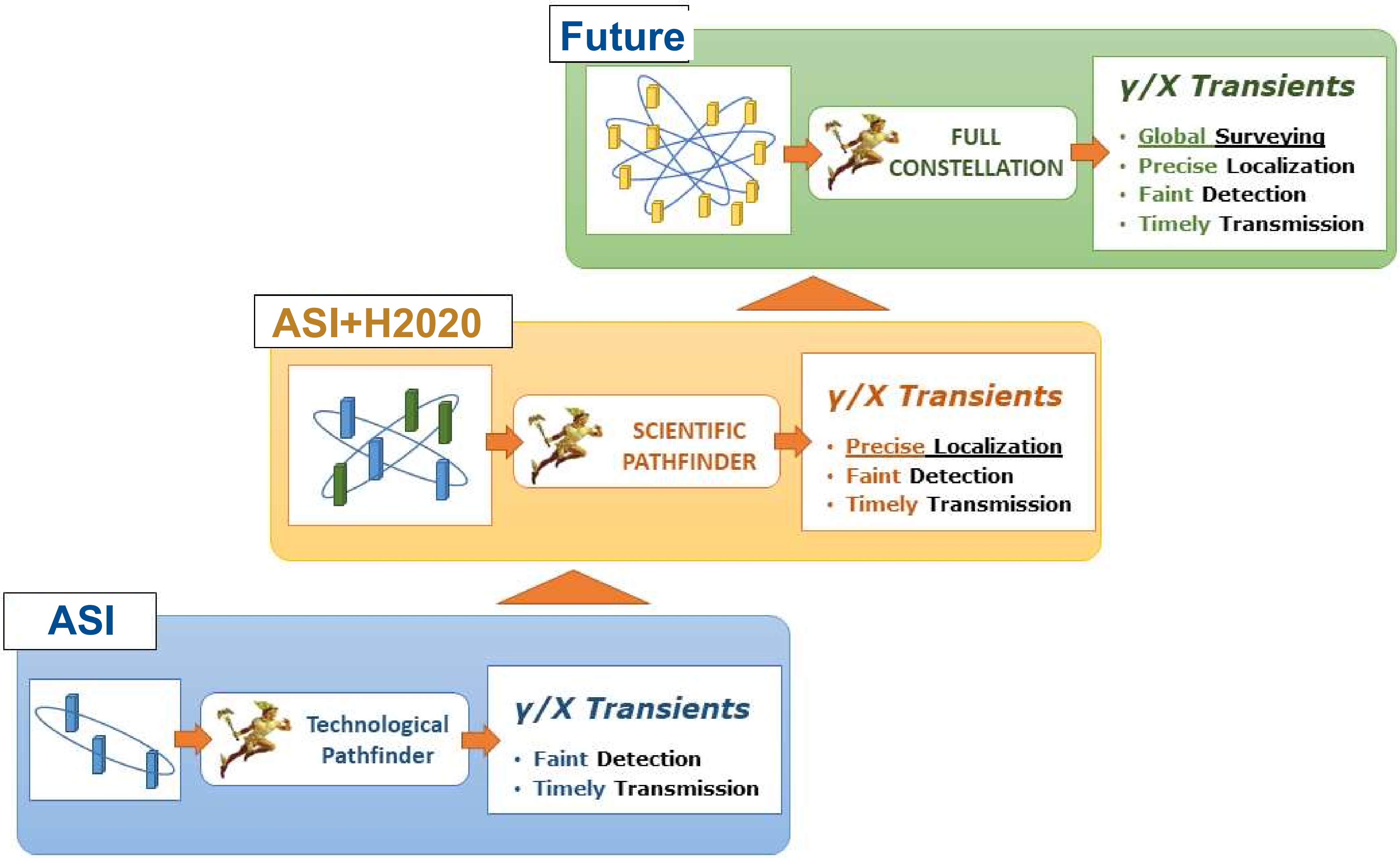
$\sigma_{Pos(FC)}$ <1arcsec if σ_{CCF}, σ_{sys}~10usec

Short GRBs without substructure, risetime fraction of second.

$\sigma_{Pos(pathfinder)}$ ~ 2.4 deg if σ_{CCF},σ_{sys}~0.001s

$\sigma_{Pos(FC)}$ ~ 3 arcmin if σ_{CCF},σ_{sys}~0.001s

HERMES



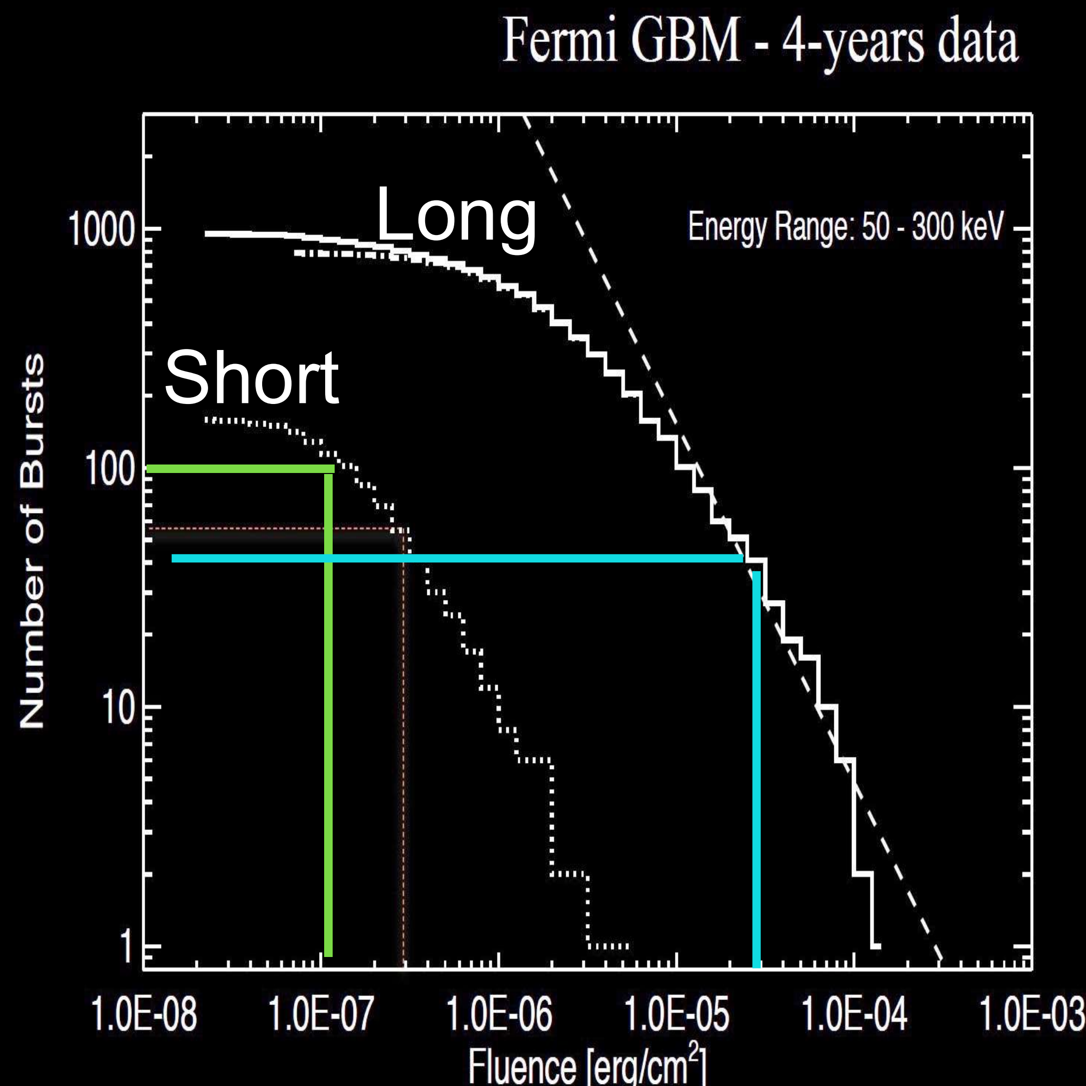
Future
γ/X Transients
FULL CONSTELLATION
Global Surveying
Precise Localization
Faint Detection
Timely Transmission
ASI+H2020
SCIENTIFIC PATHFINDER
γ/X Transients
Precise Localization
Faint Detection
Timely Transmission
ASI
Technological Pathfinder
γ/X Transients
Faint Detection
Timely Transmission

[redacted]

Performance: How many GRBs?

- **Long**: $Fl \geq 10^{-5}$ erg/cm^2
  ≥ 8 ph/s/cm^2
  40/yr

- **Short**: $Fl \geq 10^{-7}$ erg/cm^2
  ≥ 1-2 ph/s/cm^2
  100/yr



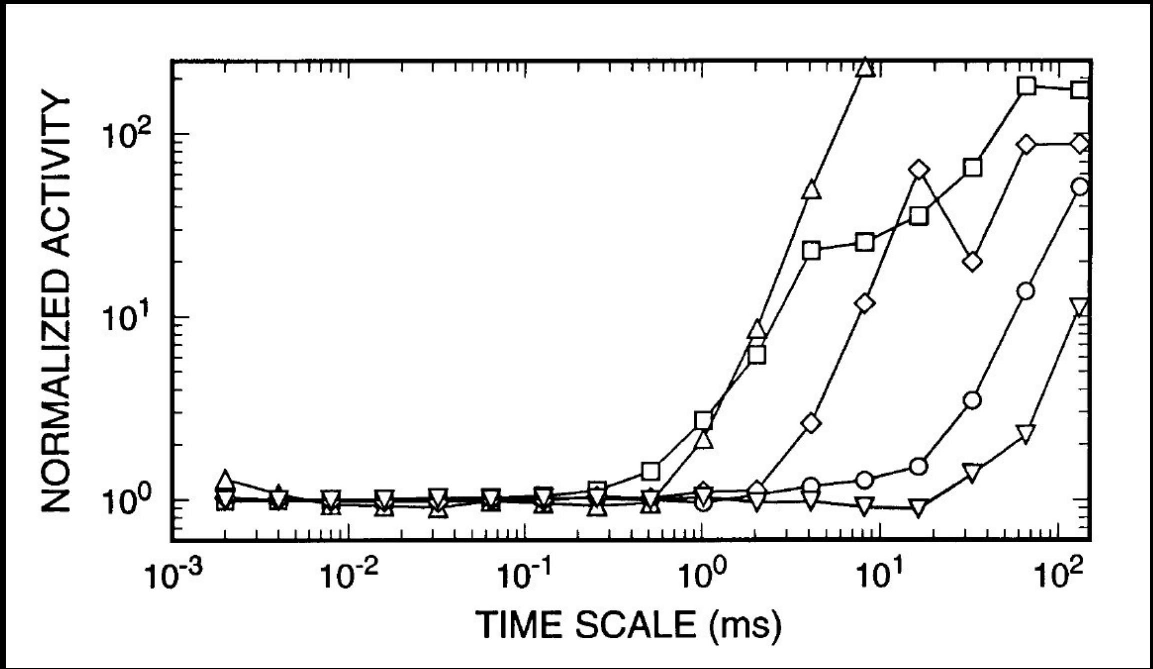
GRB fast variability

Walker+2000

20 strong BATSE GRB TTE, 2us resolution

msec variability in 30-40 % cases

sub msec variability in a few cases



HERMES people

Burderi, Fiore, Negri, Pirrotta, Puccetti, Carpentiero, Lavagna, Lunghi, Labanti, Fuschino, Campana, Feroci, Vacchi, Evangelista, Del Monte, Di Cosimo, Malcovati, Fiorini, Bertuccio, Ahangarianabhari, Santangelo, Tenzer, Amelino-Camelia, Riggio, Sanna, Di Salvo, Iaria, Celletti, Di Salvo, Nava, Bongiorno, Piranomonte, Antonelli, Papitto, Della Valle, Capozziello, De Laurentis, Pucacco, Costa, Amati, Frontera, Rosati, Baldazzi, Zampa, Rachevski, Scarano, Gambino, Calderini, Ubertini, Natalucci, Pacciani, Rapisarda, Rubini, Di Salvo, Zaccheo, Perelli, Gronchi, Arzano, D'amico, Palmisano, Ghirlanda, Ghisellini, D'Avanzo ….

HERMES is open to ideas and collaboration

Want to be involved? Send an e-mail

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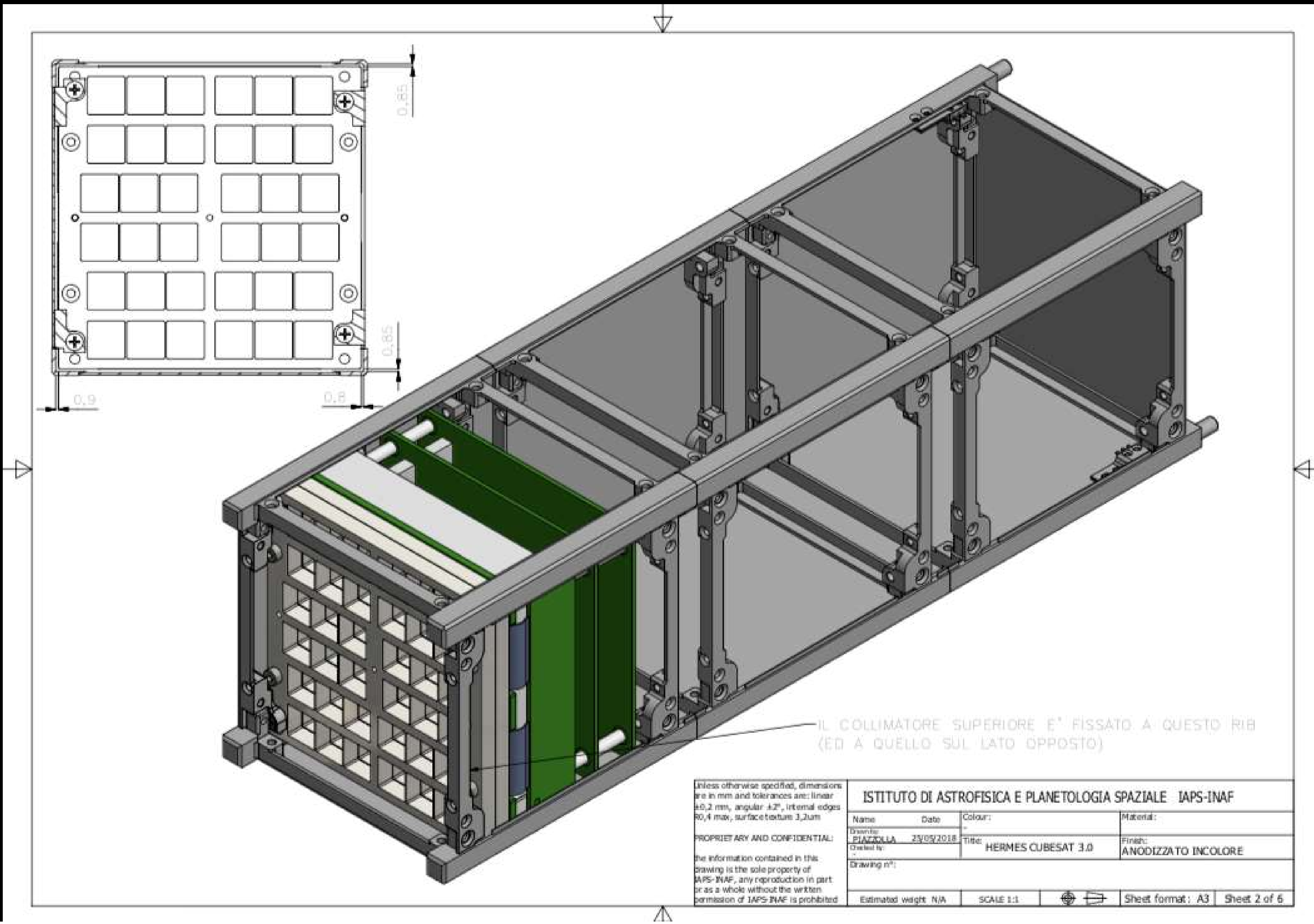
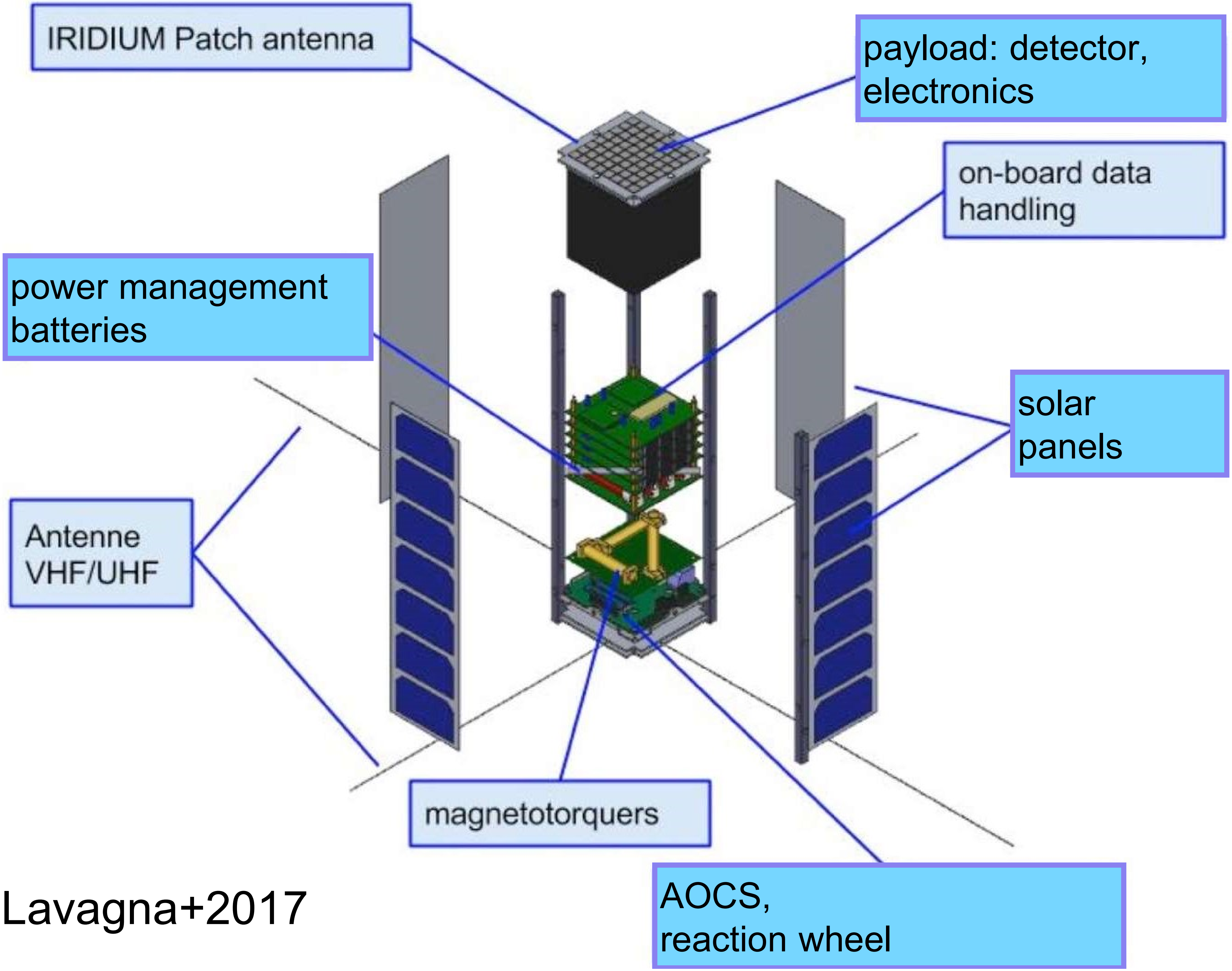
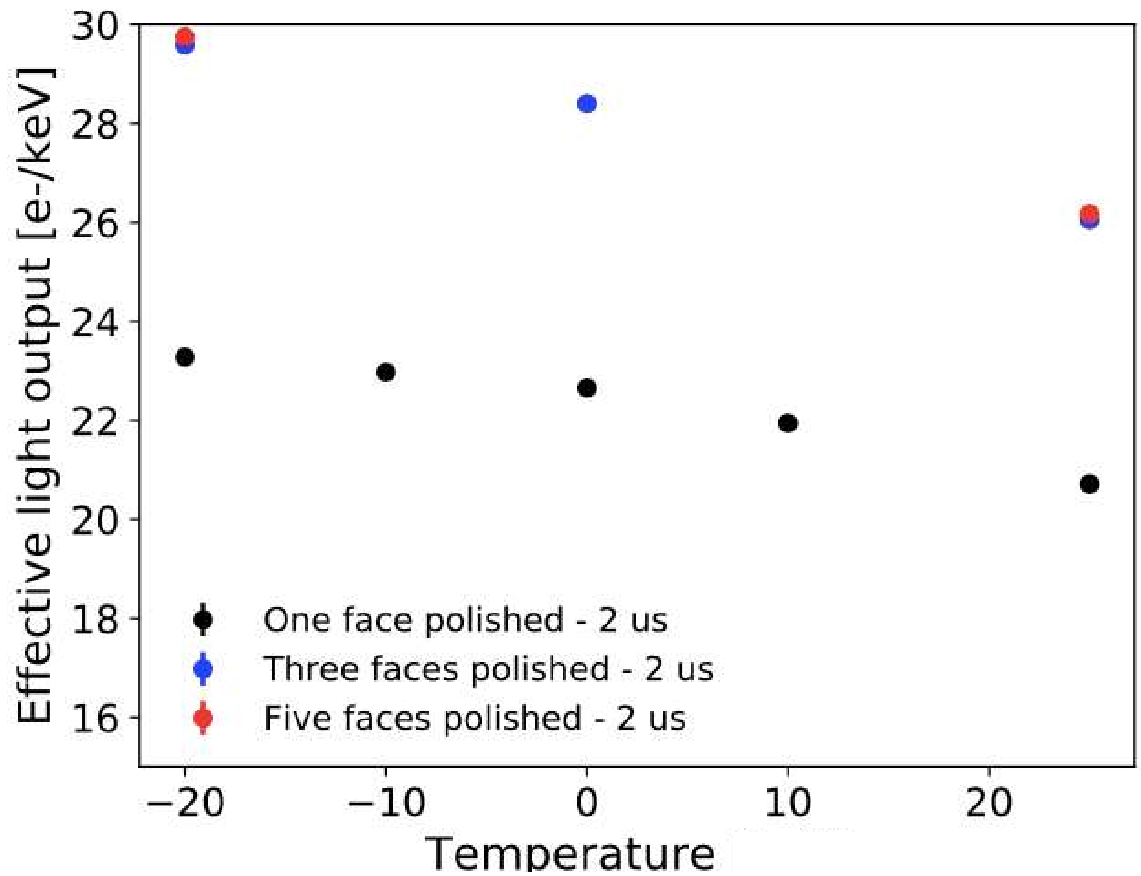
P/L Unit: overall assembly





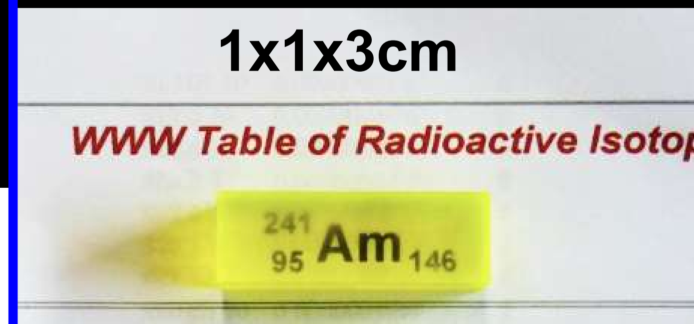
Lavagna+2017

Characterization with PIN diode



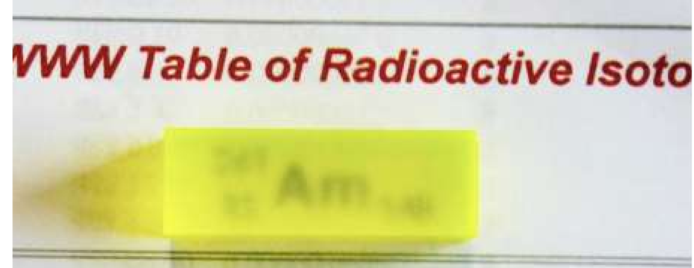
Small residual gain by polishing the two remaining faces

1x1x3cm



Measured @ Bo-Lab ~30 e-/keV

1x1x3cm



Measured @ Bo-Lab ~23 e-/keV