HERMES

A constellation of nano-satellites for high energy astrophysics and fundamental physics research

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on behalf of the HERMES-TP and HERMES-SP collabotations

HORIZON 2020

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

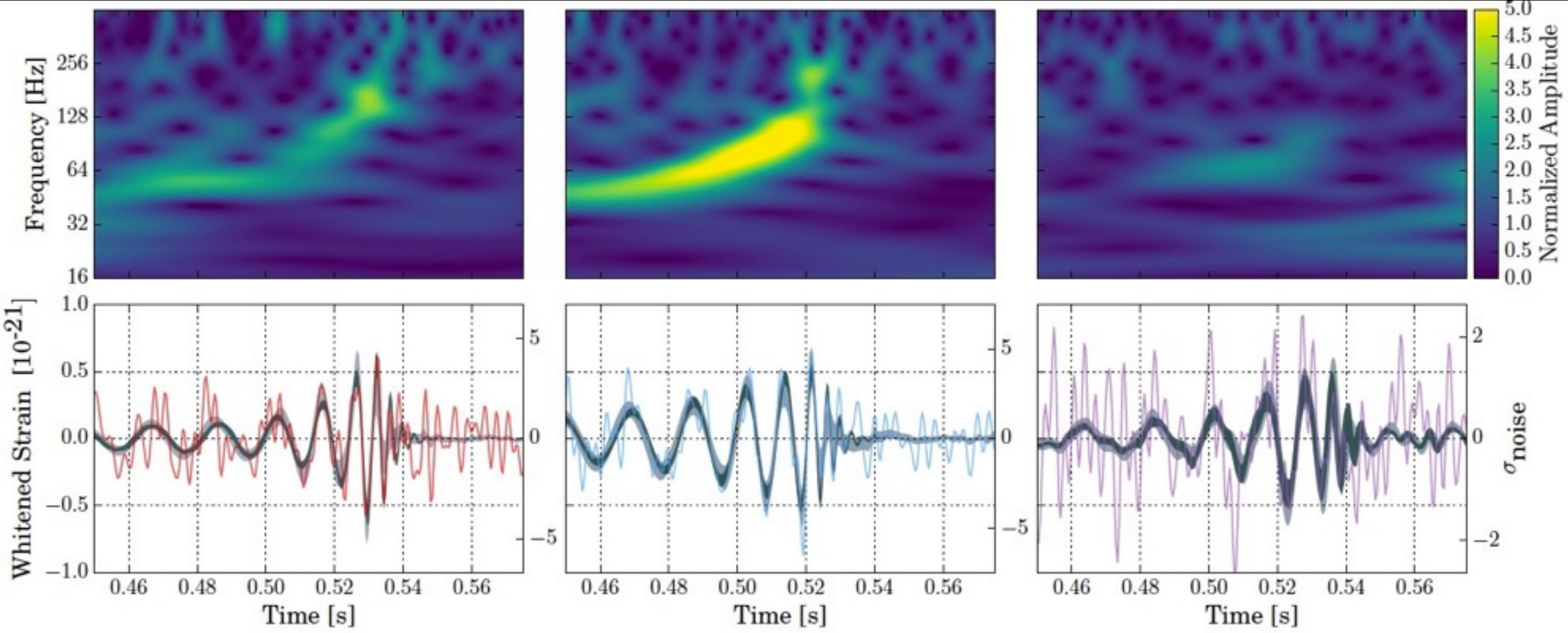
POLITECNICO MILANO 1863

ASI
Agenzia Spaziale Italiana

Two revolutions

Multimessenger astrophysics

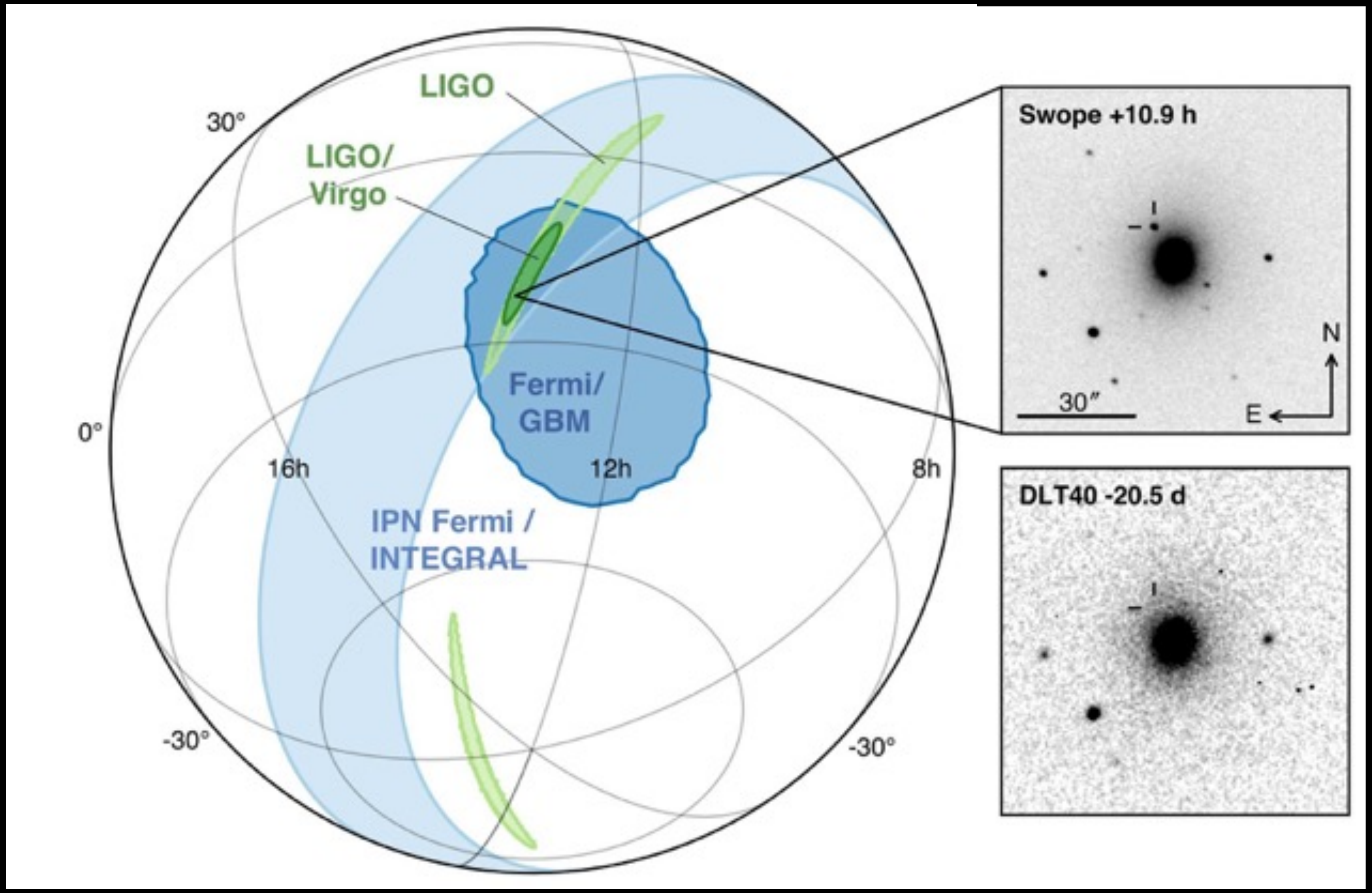
GW170814



Two revolutions

Multimessenger astrophysics

GW170817

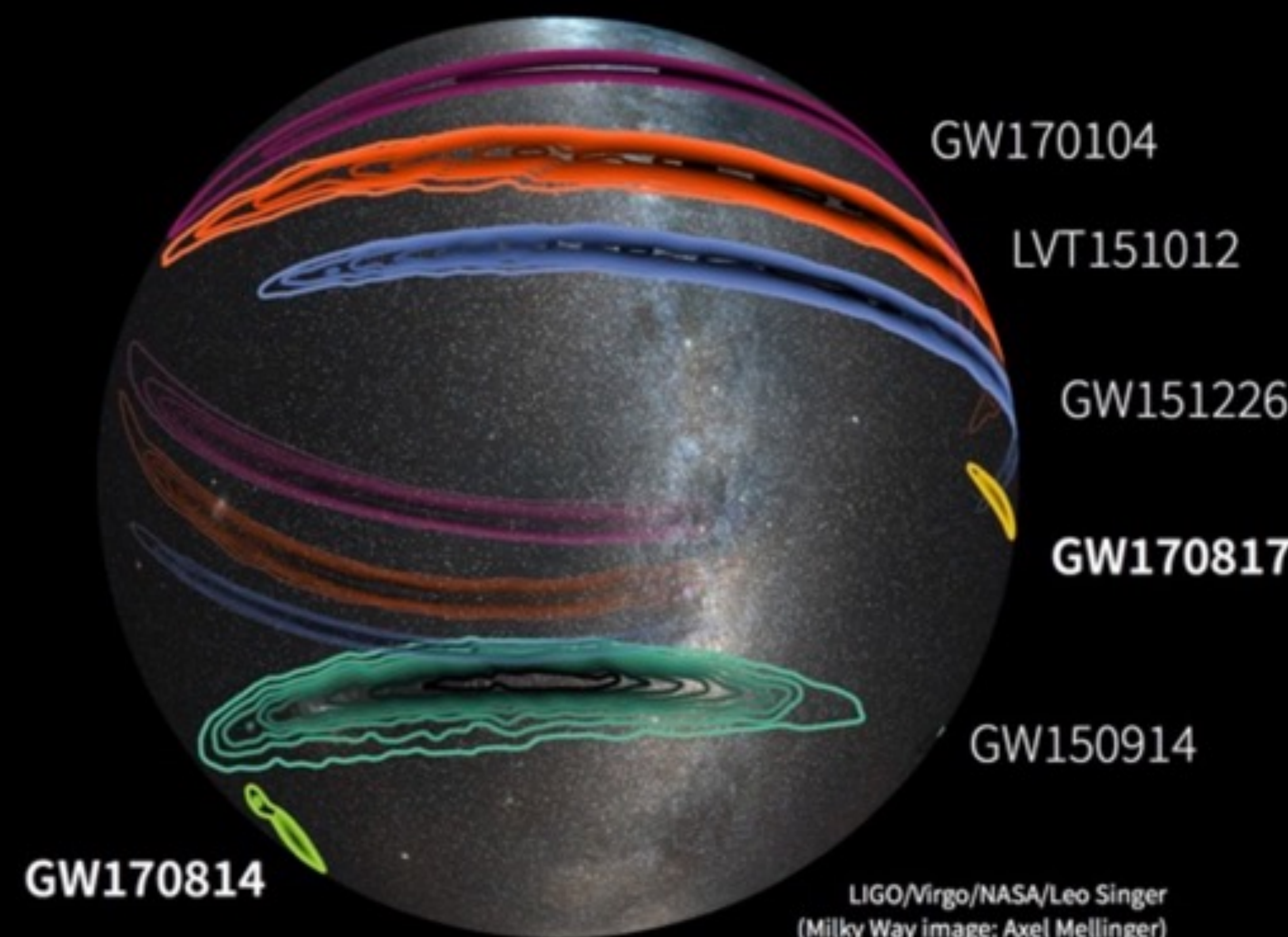


The multimessenger revolution

Advanced Ligo/Virgo provide position with accuracy ~ tens deg

NS-NS and BH-NS coalescence:
100-200 Mpc horizon
GRB, cocoon, kilonova..

BH-BH coalescence:
>Gpc horizon
no expected EM counterpart (even more exciting if one is found…)

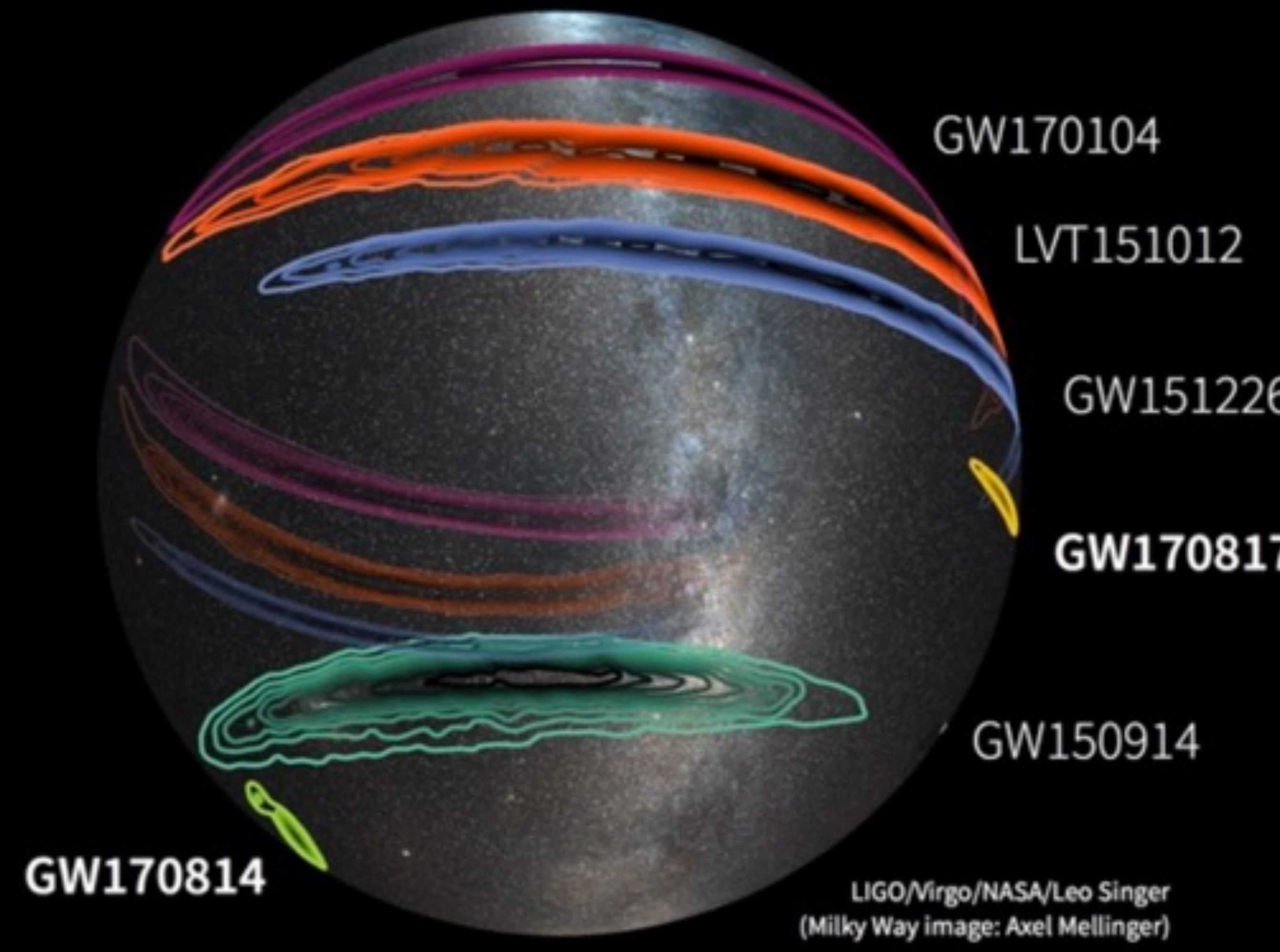


The multimessenger revolution

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

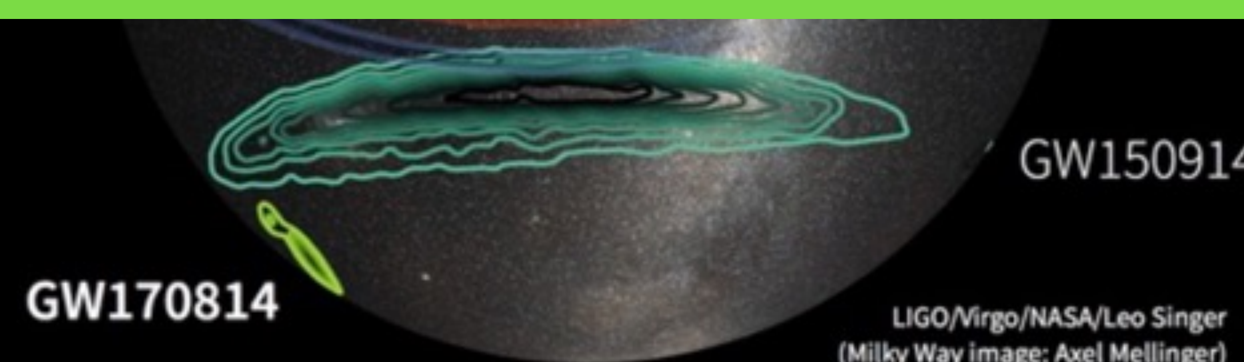


The multimessenger revolution

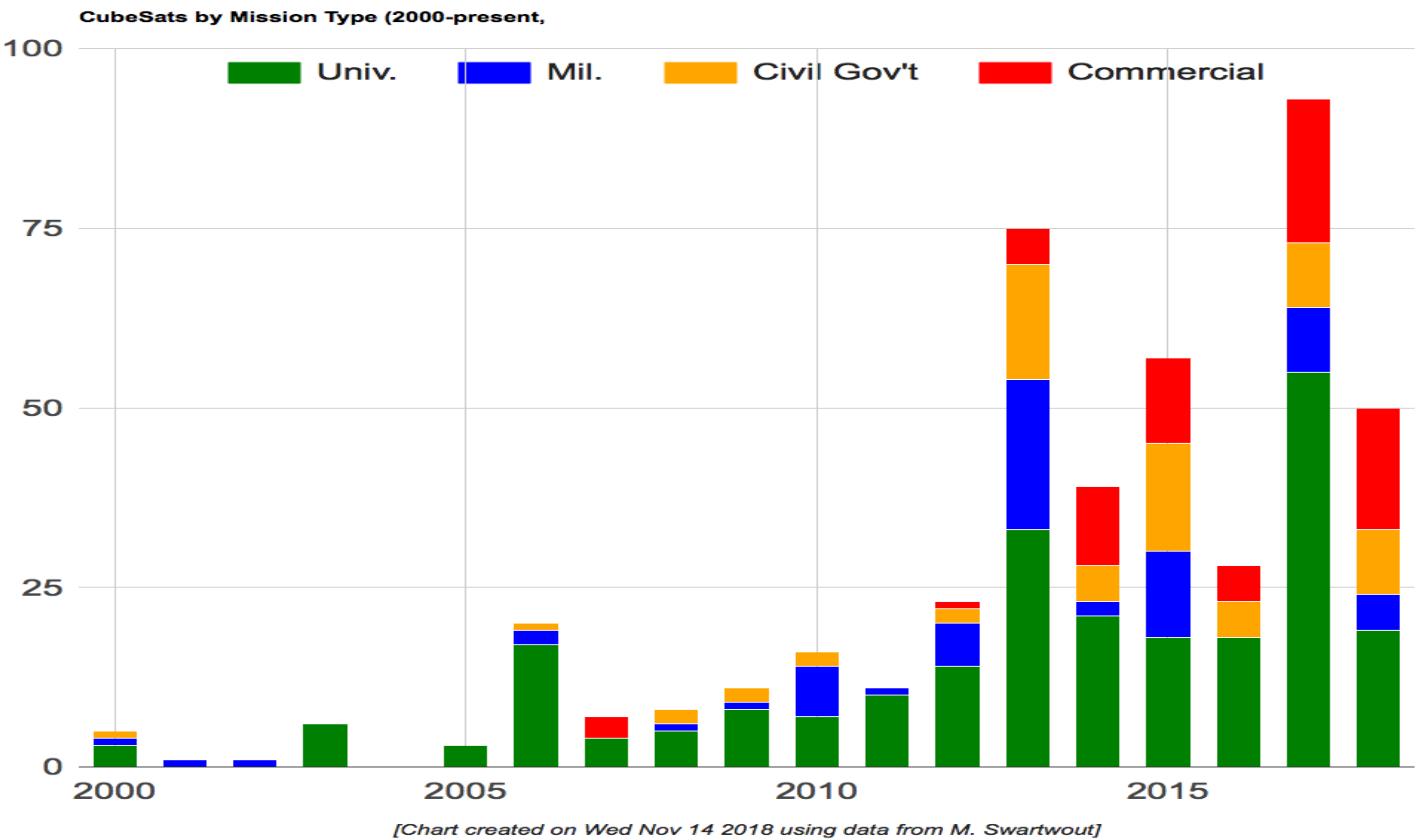
Current facilities, Swift, INTEGRAL, FERMI, AGILE, are aging:

A sensitive X-ray all sky monitor during the 20’

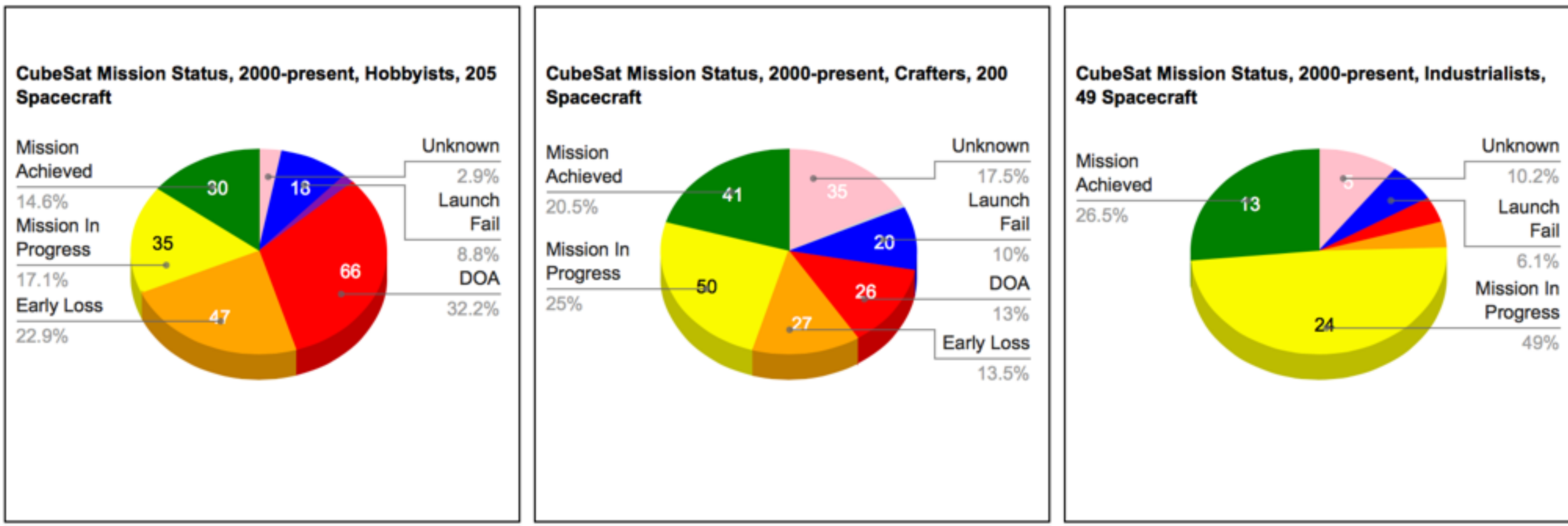
~ all sky prompt search for transients at high energies. Negligible probability to find an uncorrelated HEA transient at the time of GWE



Space 4.0

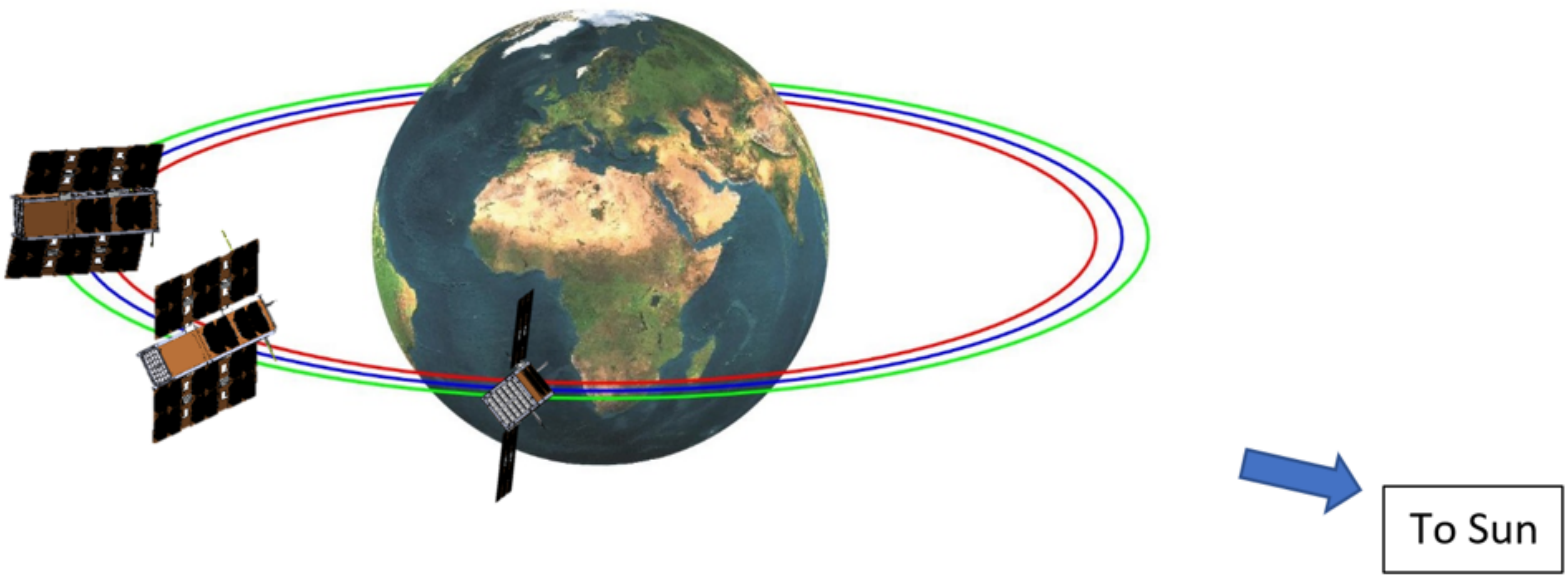

CubeSats by Mission Type (2000-present,
100
75
50
25
0
Univ.
Mil.
Civil Gov't
Commercial
2000
2005
2010
2015
[Chart created on Wed Nov 14 2018 using data from M. Swartwout]

Space 4.0



[Chart created on Wed Nov 14 2018 using data from M. Swartwout]

HERMES



Mission concept

Disruptive technologies: cheap, underperforming, but producing high impact. Distributed instrument, tens/hundreds of simple units

HERMES constellation of cubesat

2016: ASI funds for detector R&D
2018: MIUR funds for pathfinder (Progetti premiali 2015)
2018 H2020 Space-SCI-20 project
2019 ASI internal funds

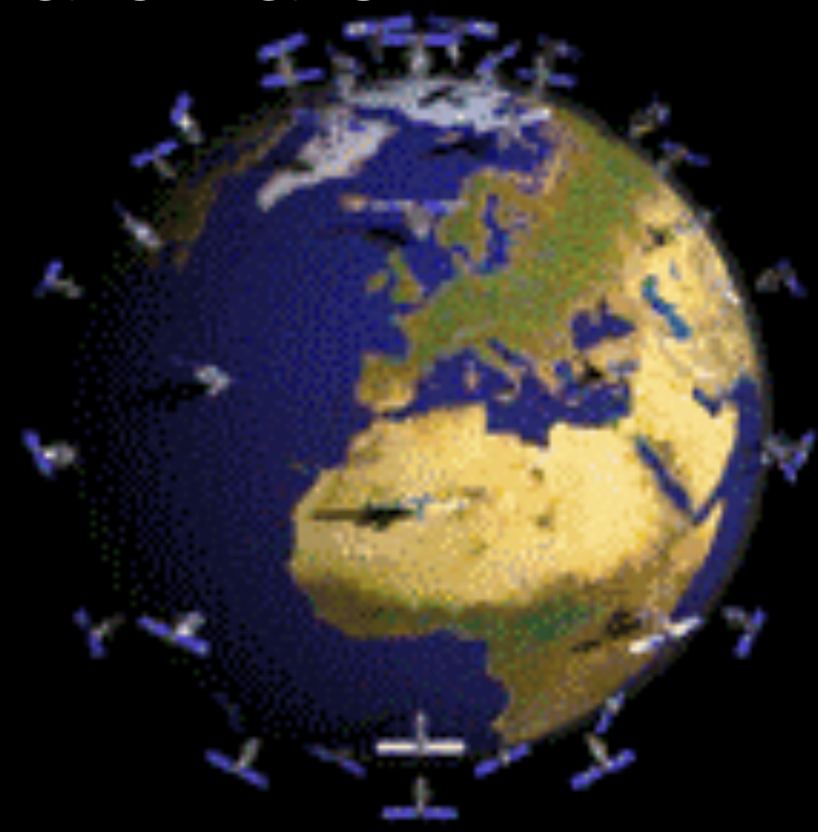
Why HERMES now

Breakthrough scientific case:

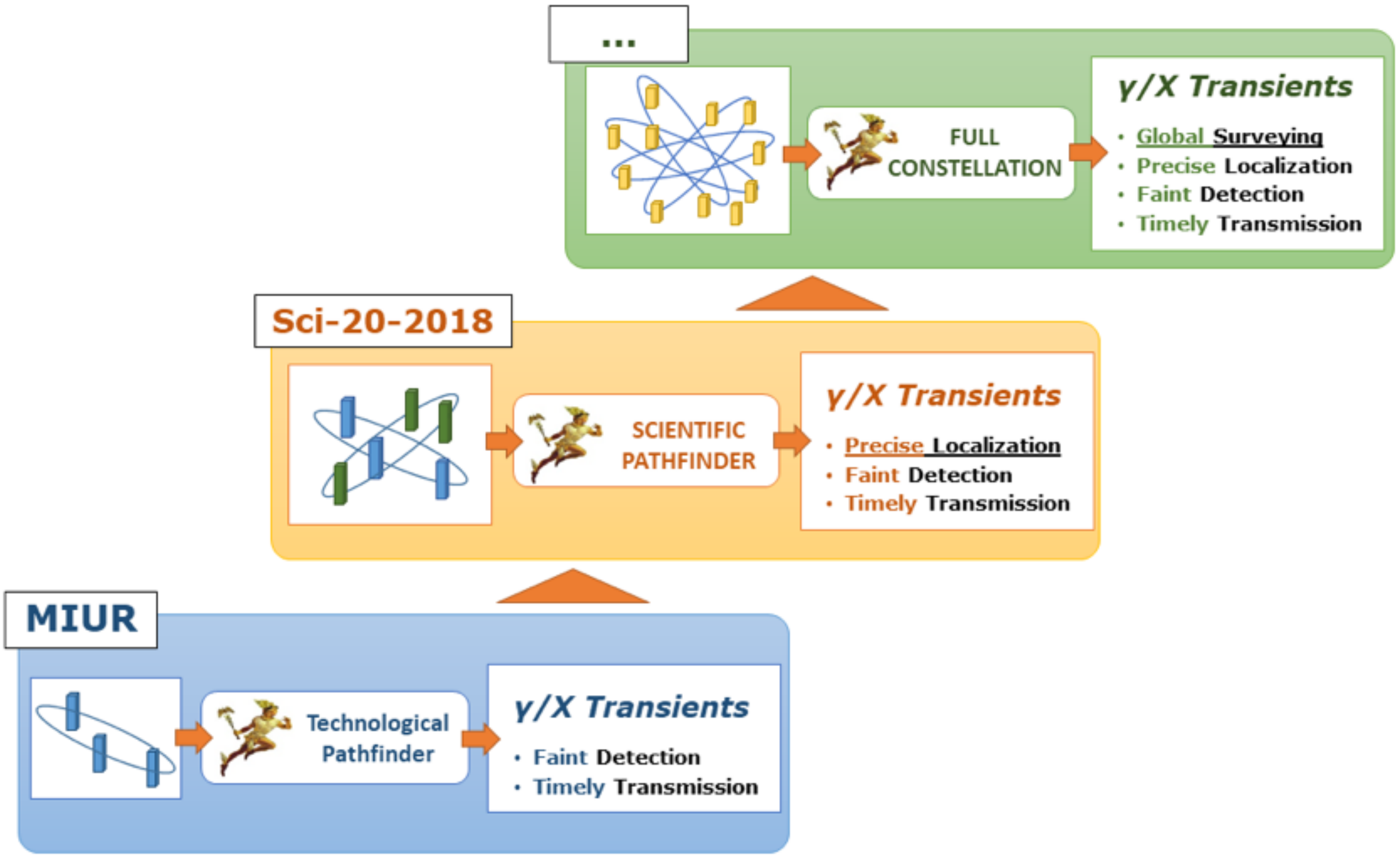
- EM of GWE

Modularity:

- Avoid single point failures, improve hardware
- Pathfinder



Why HERMES now



Why HERMES now

Breakthrough scientific case:
- EM of GWE

Modularity:
- Avoid single point failures, improve hardware
- Pathfinder

Open μsec - msec window:
- Accurate positions
- QG tests

Limited cost and quick development
- COTS + in-house components
- Trend in cost reduction of manufacturing and launching QS

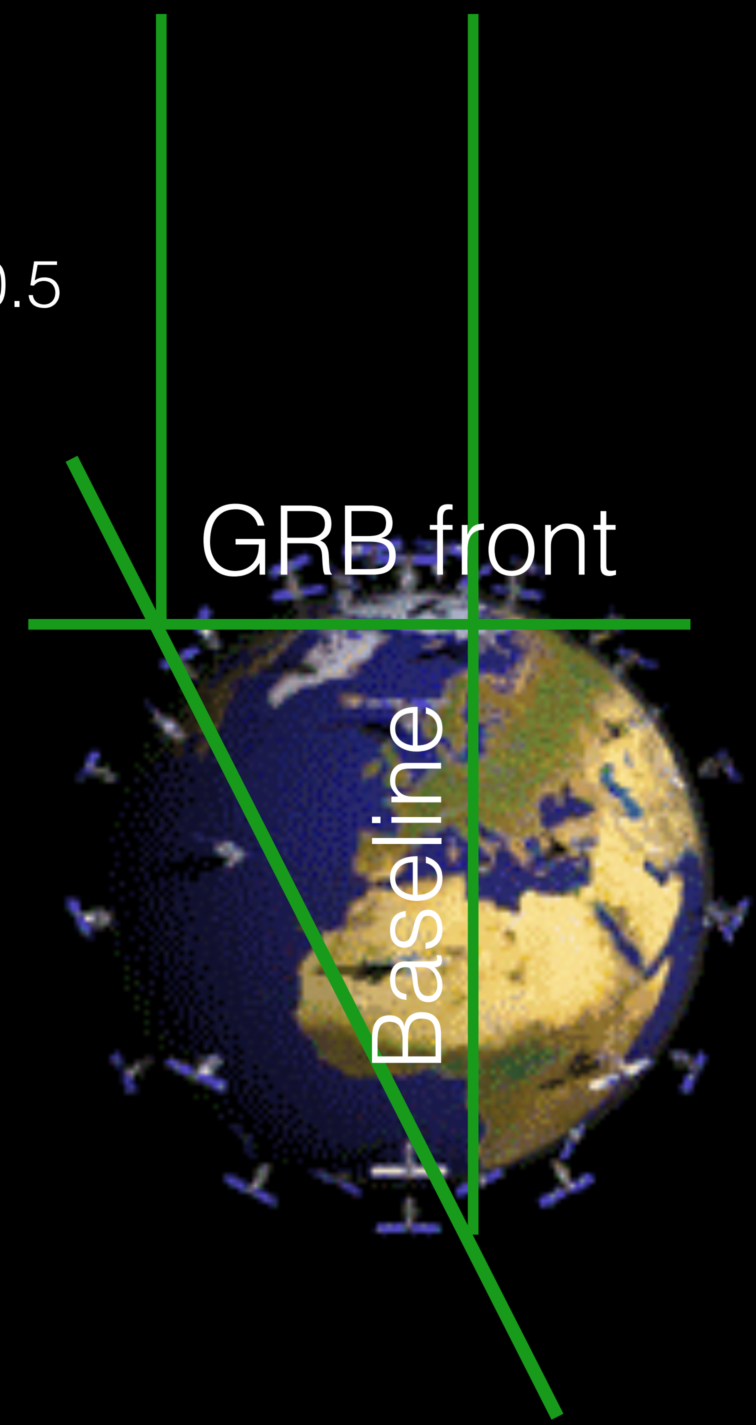
HERMES-SP goals

1. ***join the multimessenger revolution*** by providing a first mini-constellation for GRB localizations
2. develop ***miniaturized payload technology*** for breakthrough science
3. demonstrate COTS applicability to challenging missions, ***contribute to Space 4.0 goals***
4. push and prepare for a high reliability, large constellations

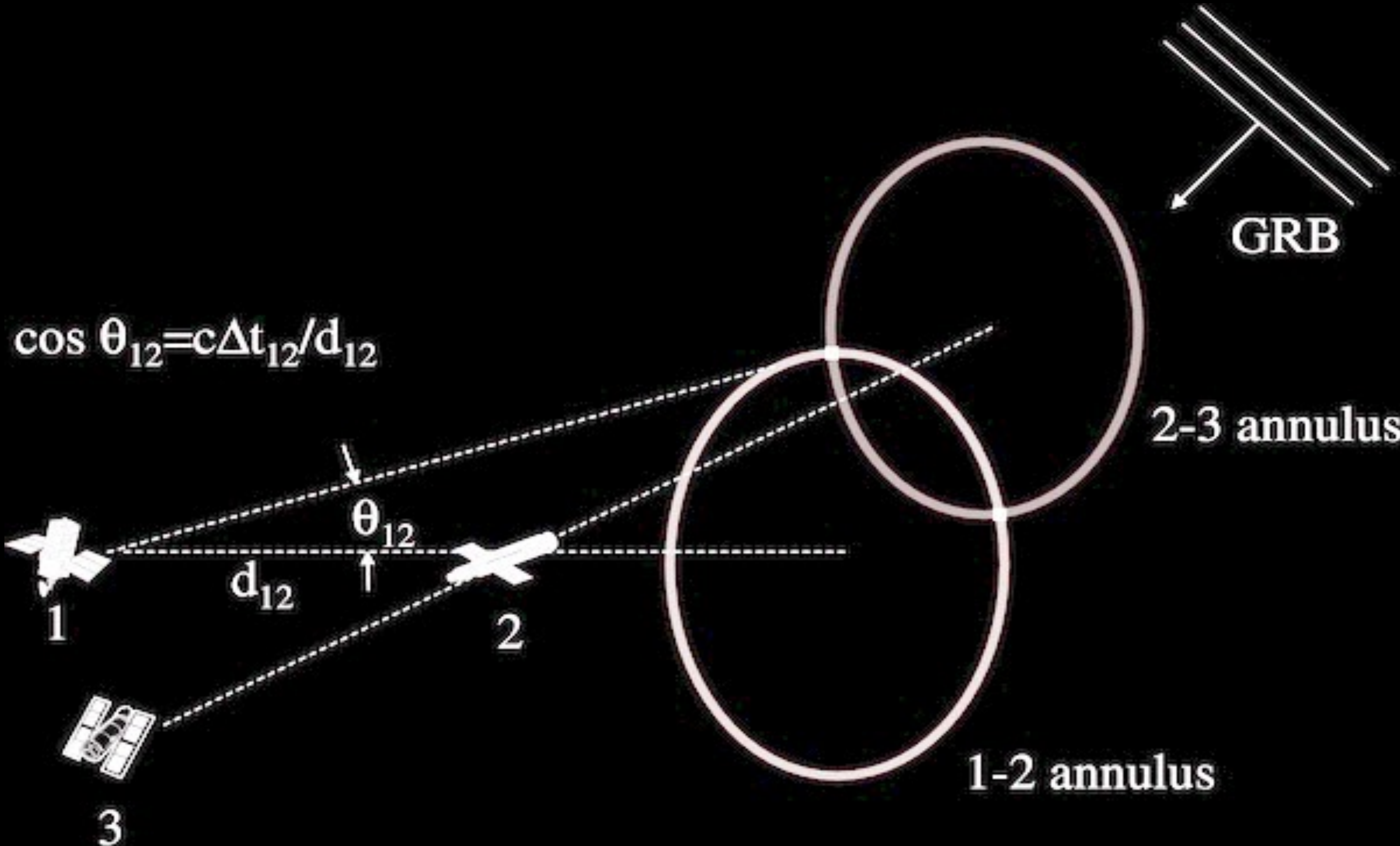
Experiment concept

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

$$\sigma_{Pos} = (\sigma^2_{CCF+}\sigma_{sys}^2)^{0.5} \times c / <B> / (N - 1 - 2)^{0.5}$$



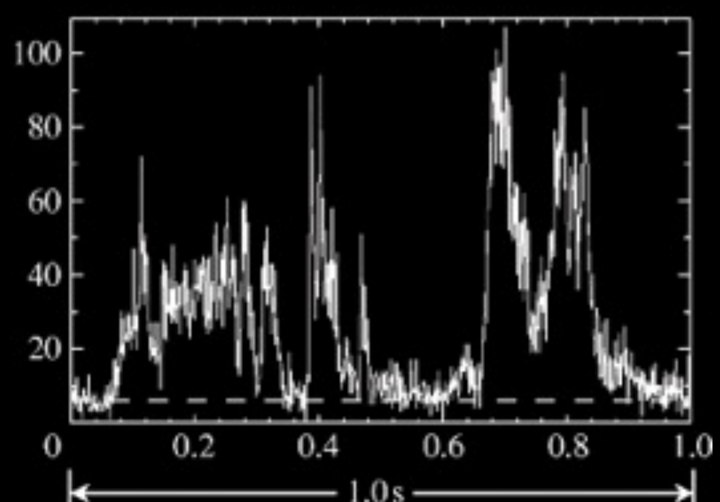
Experiment concept



Experiment concept

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

$\sigma_{Pos} = (\sigma^2_{CCF} + \sigma_{sys}^2)^{0.5} \times c \,/\, \langle B \rangle \,/\, (N - 1 - 2)^{0.5}$



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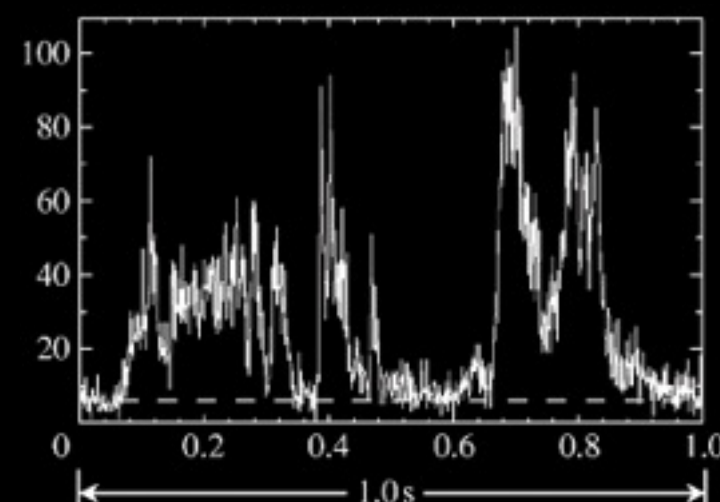

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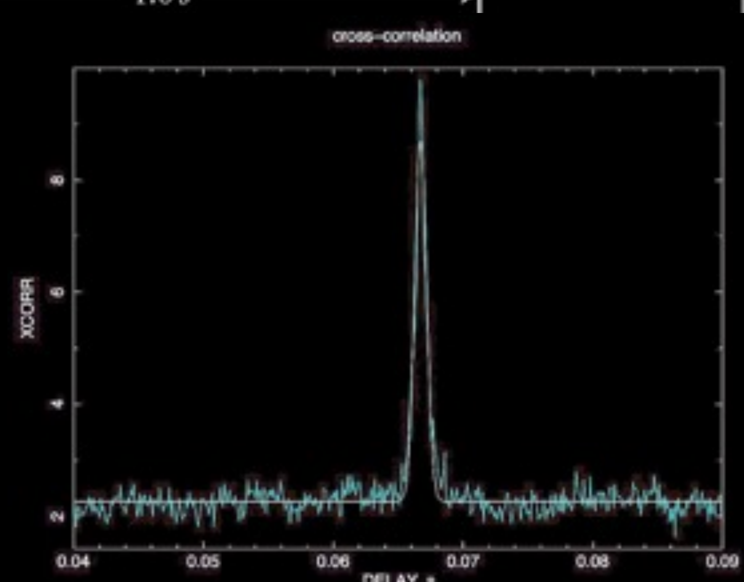
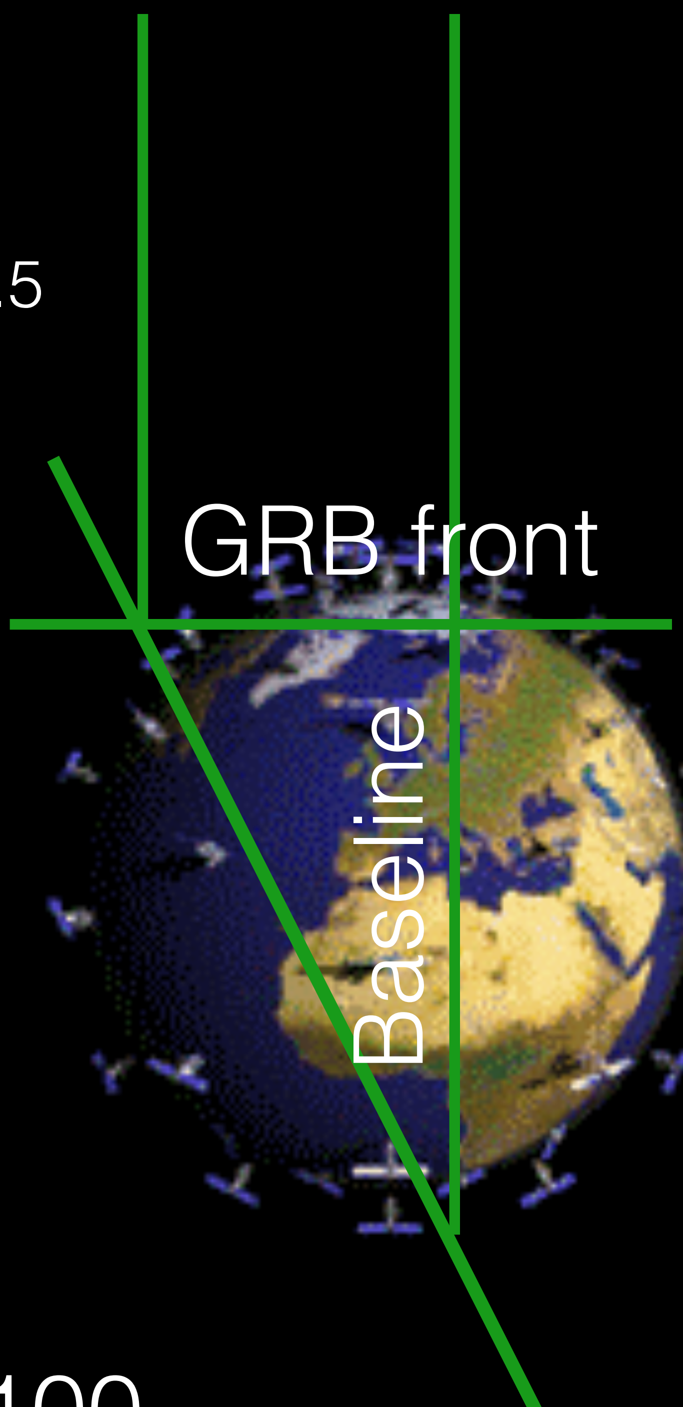


$\sigma_{CCF} \sim 10\mu s$

$\sigma_{Pos} \sim 10$ arcsec

if $\langle B \rangle \sim 7000$ km, $N \sim 100$

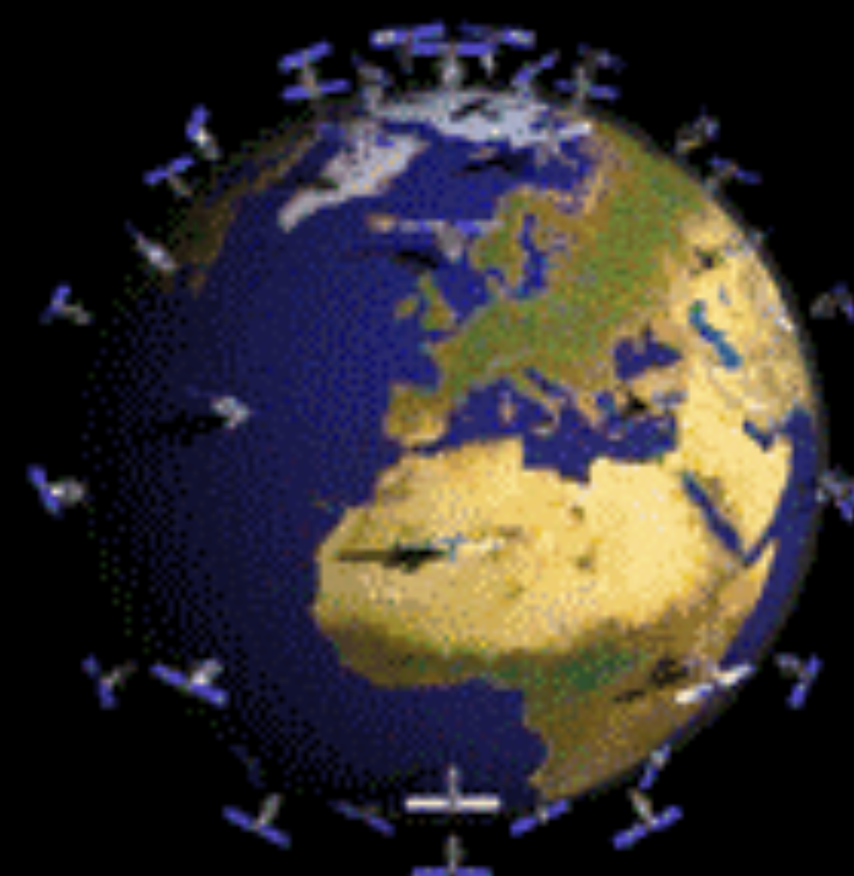


Experiment concept

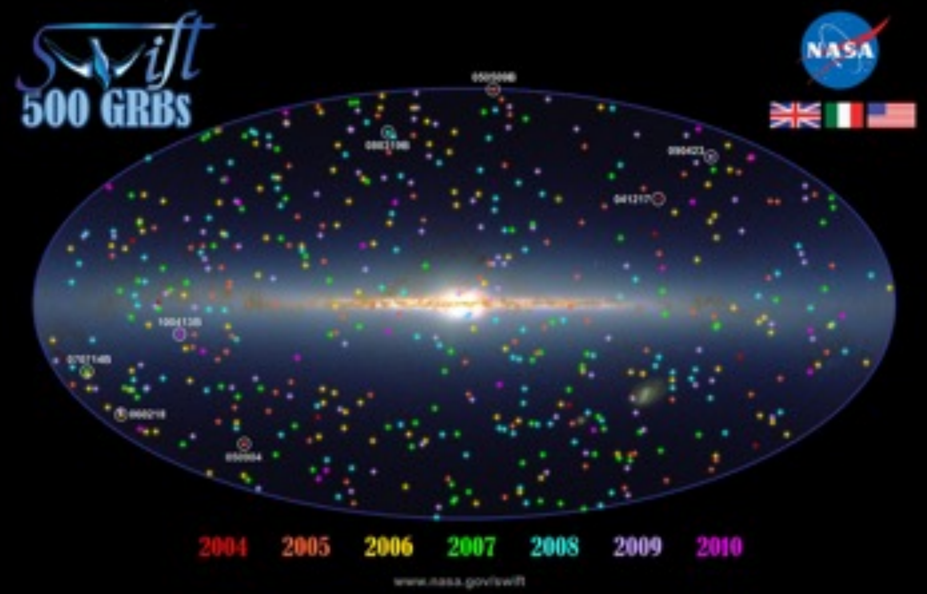
2. Add the signal from different units

Total collecting area 50-100-cm^2 x 100-200 = 0.5-2 m^2

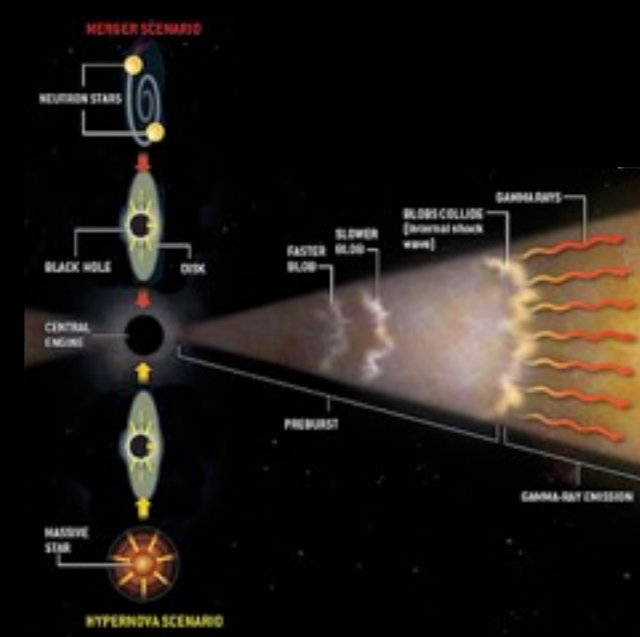
Transient fine (subμs-ms) temporal structure



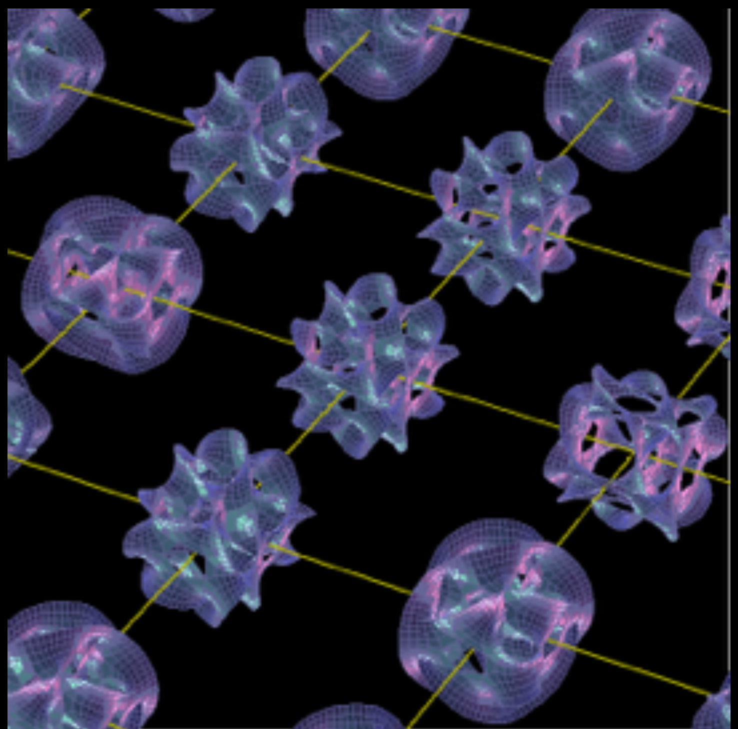
How to *promptly* localise a GRB *prompt* event?



How to construct a GRB engine?

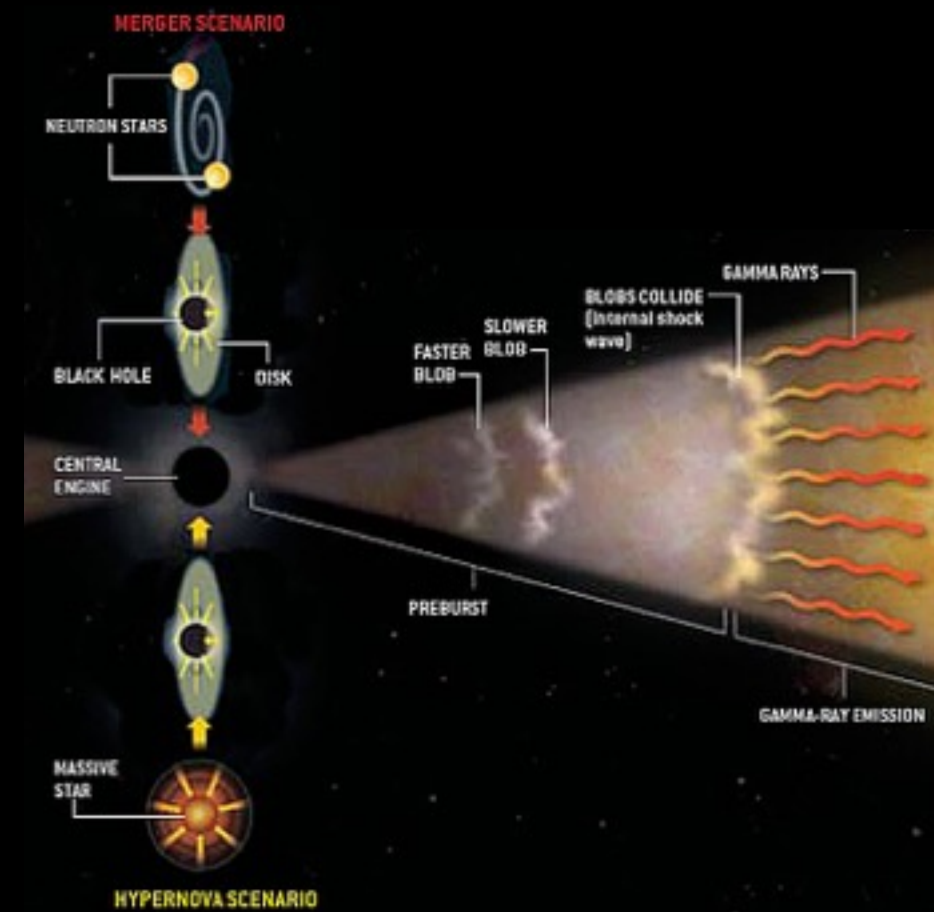


Which is the ultimate granular structure of space-time?

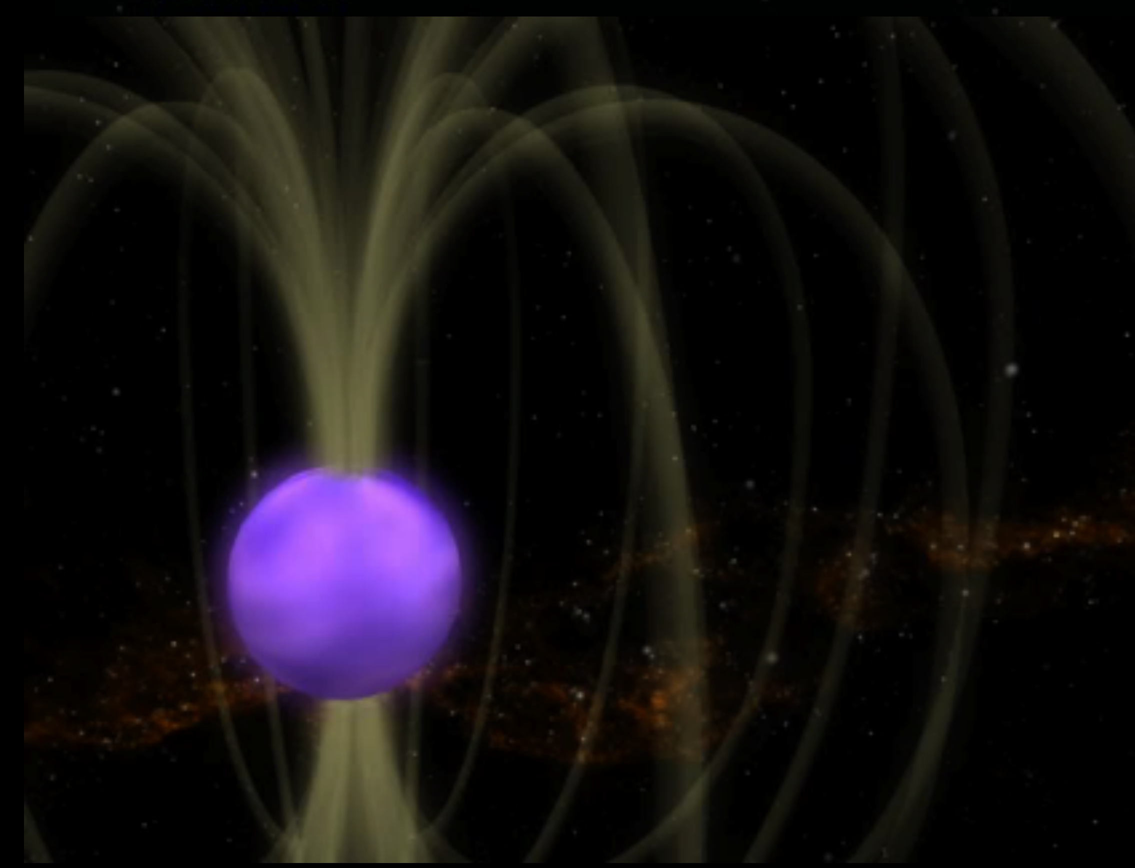


GRB
inner engine

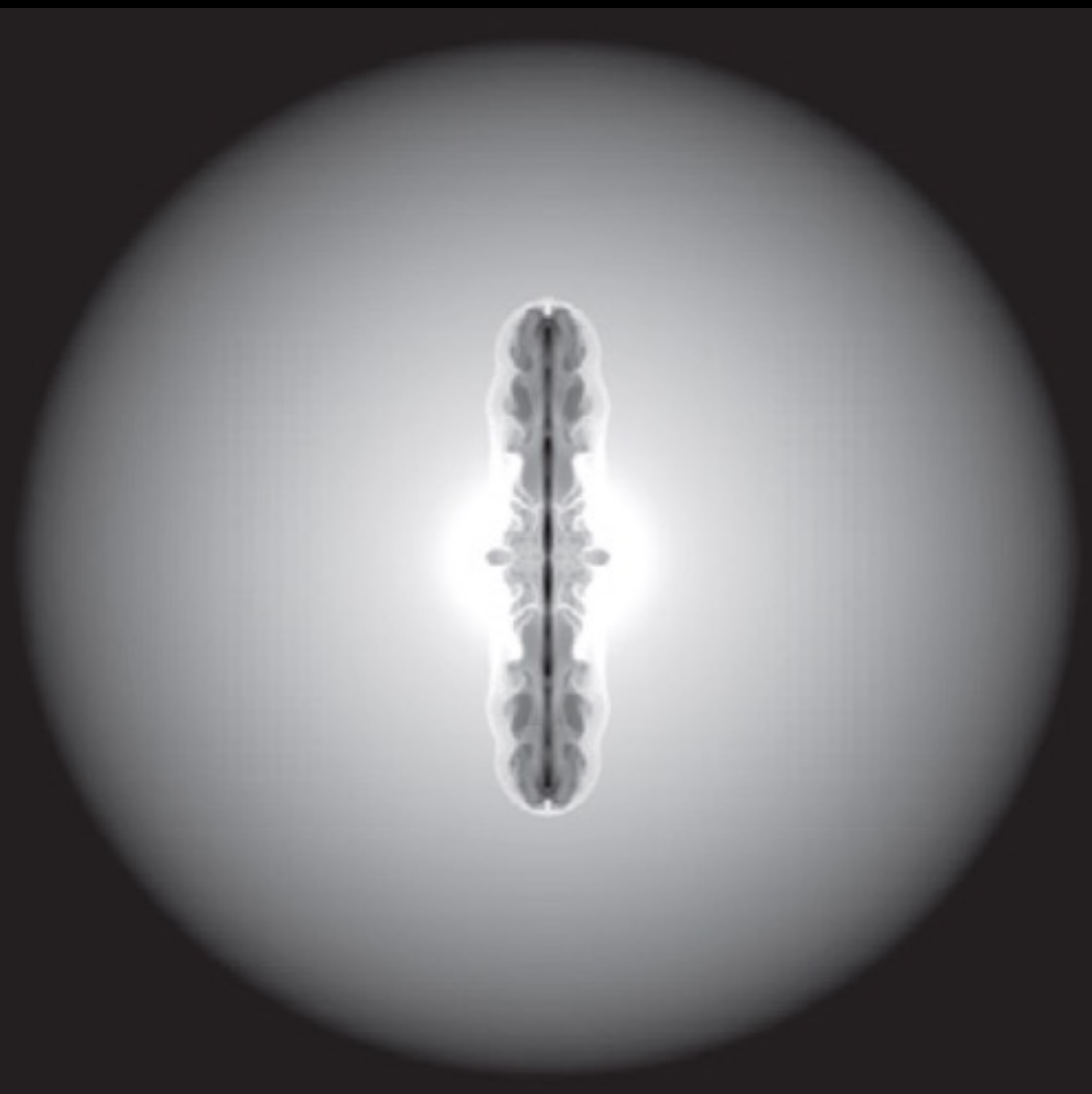
BH accretion,
internal shocks

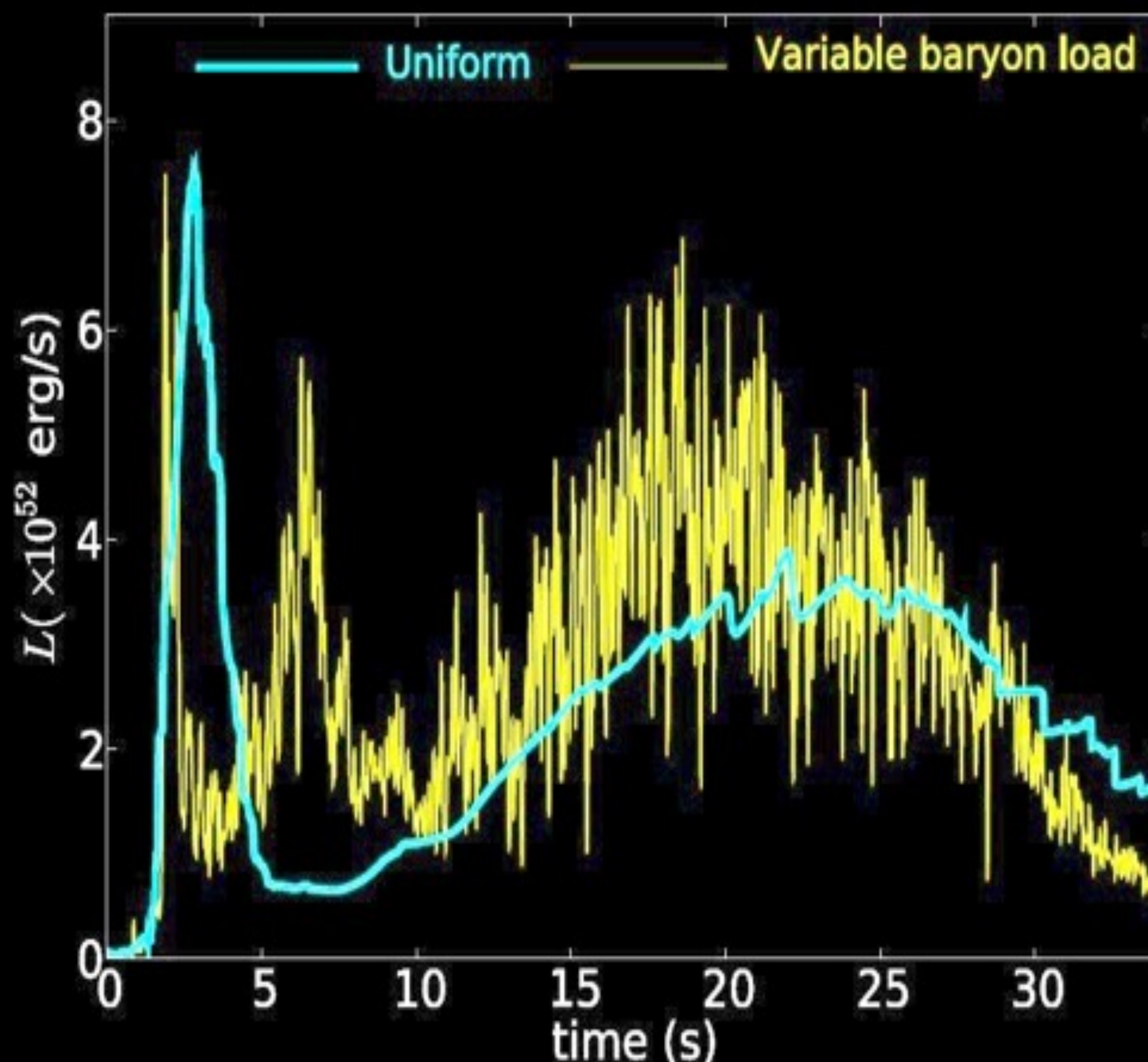


Magnetars



GRB inner engine





Morsony, Lazzati, Begelman 2010

Observed light curves reproduce activity of inner engine

Requirements

Scientific:

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

Prompt(minute) localisation

sub-μs timing

$\Delta t/\Delta E$~3μs/100keV 30μs/1MeV—> M_{QG}~M_{Planck}

Requirements

System:

≈from a few to hundreds detectors

single collecting area ≥50cm^2

total collecting area ≥1m^2

Energy range 3-10 — 300-1000 keV

Temporal resolution a few hundred ns

Position reconstruction of each satellite < 300m

Absolute time reconstruction <100 ns

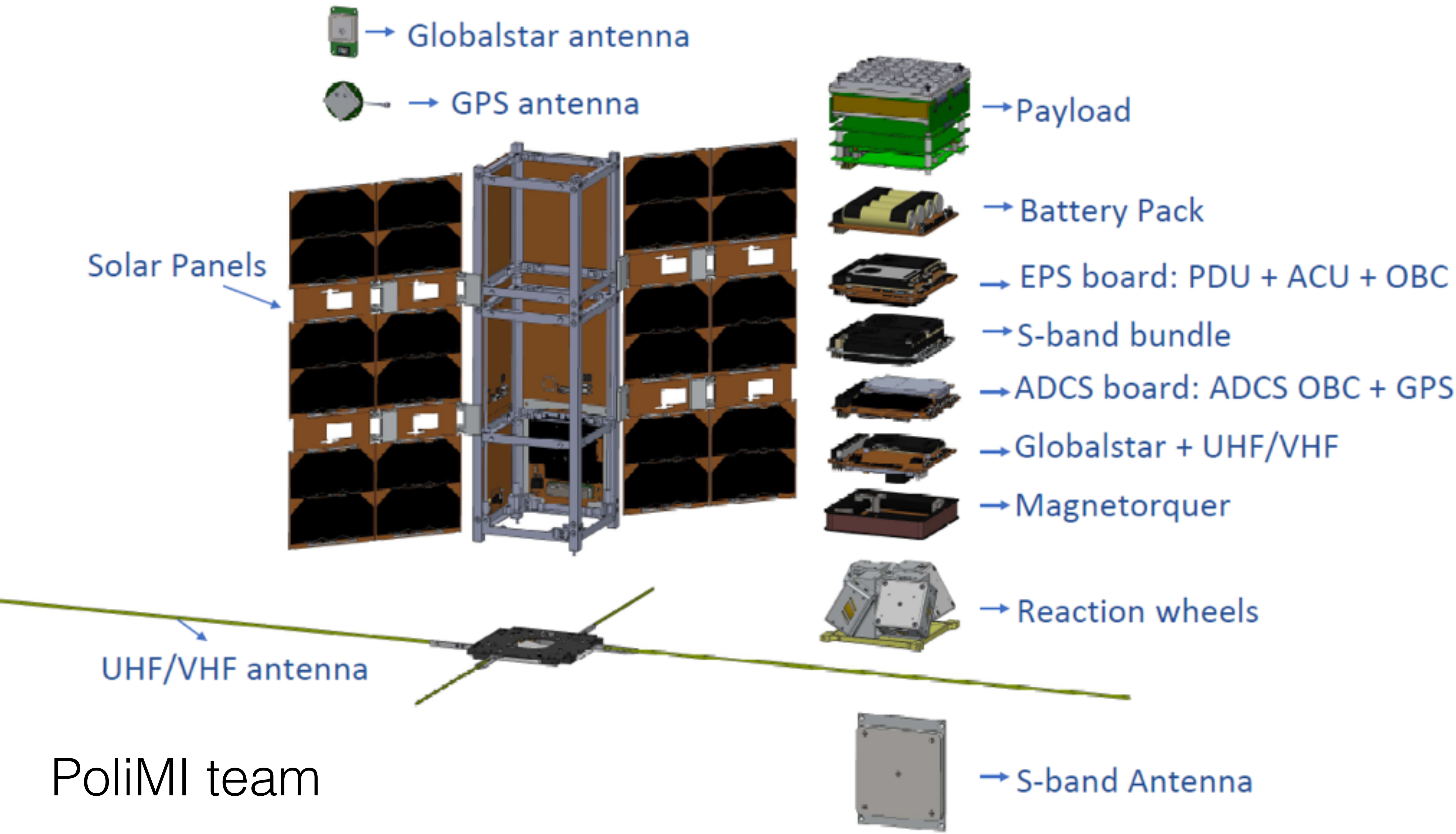
Download full burst info in minutes

Spacecraft

3U minimum, simplest basic configuration
$\leq 100 cm^2$ detector

6U more performing configuration
$\leq 200 cm^2$ detector, more accurate GPS, more accurate AOCS

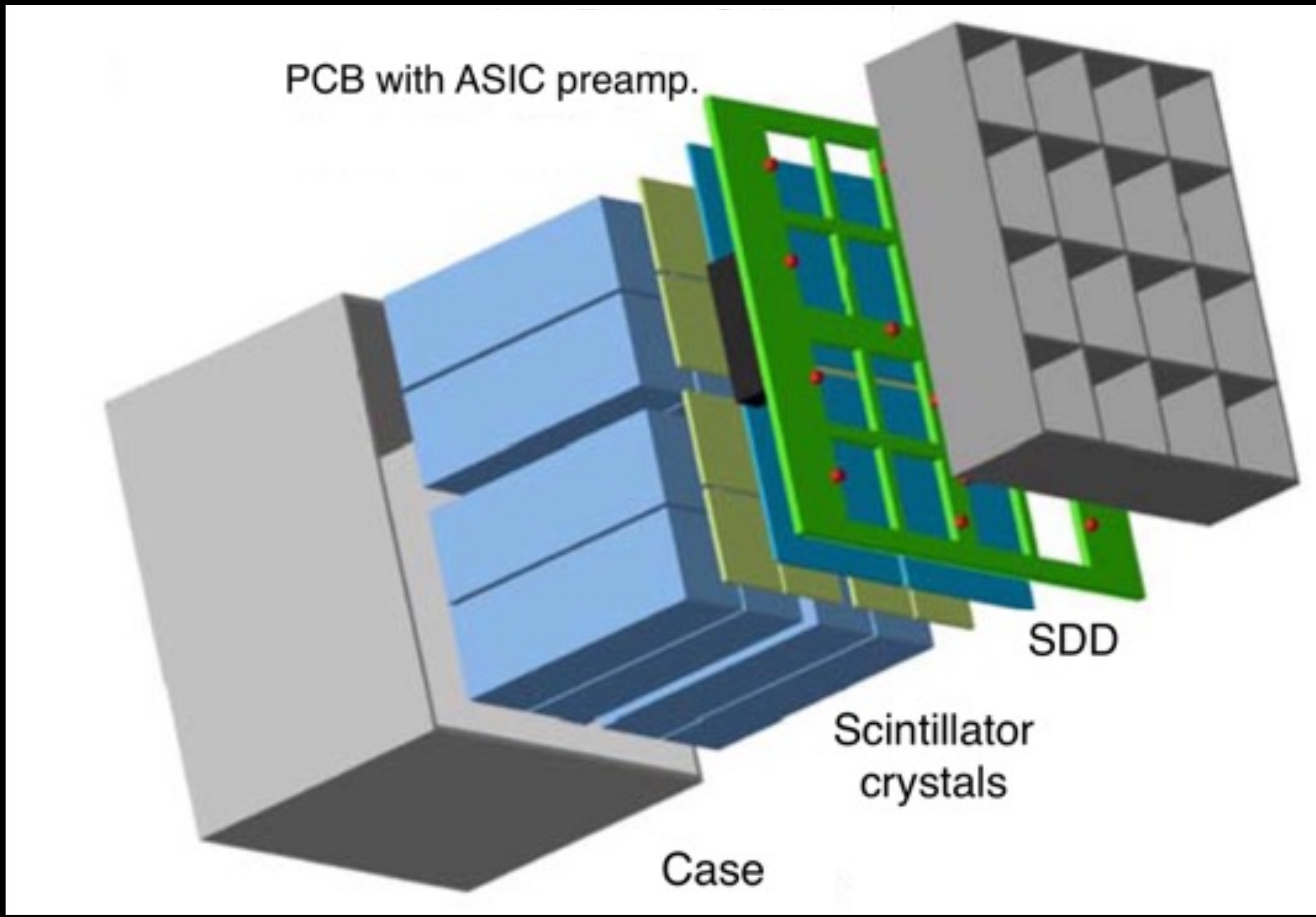
Spacecraft



PoliMI team

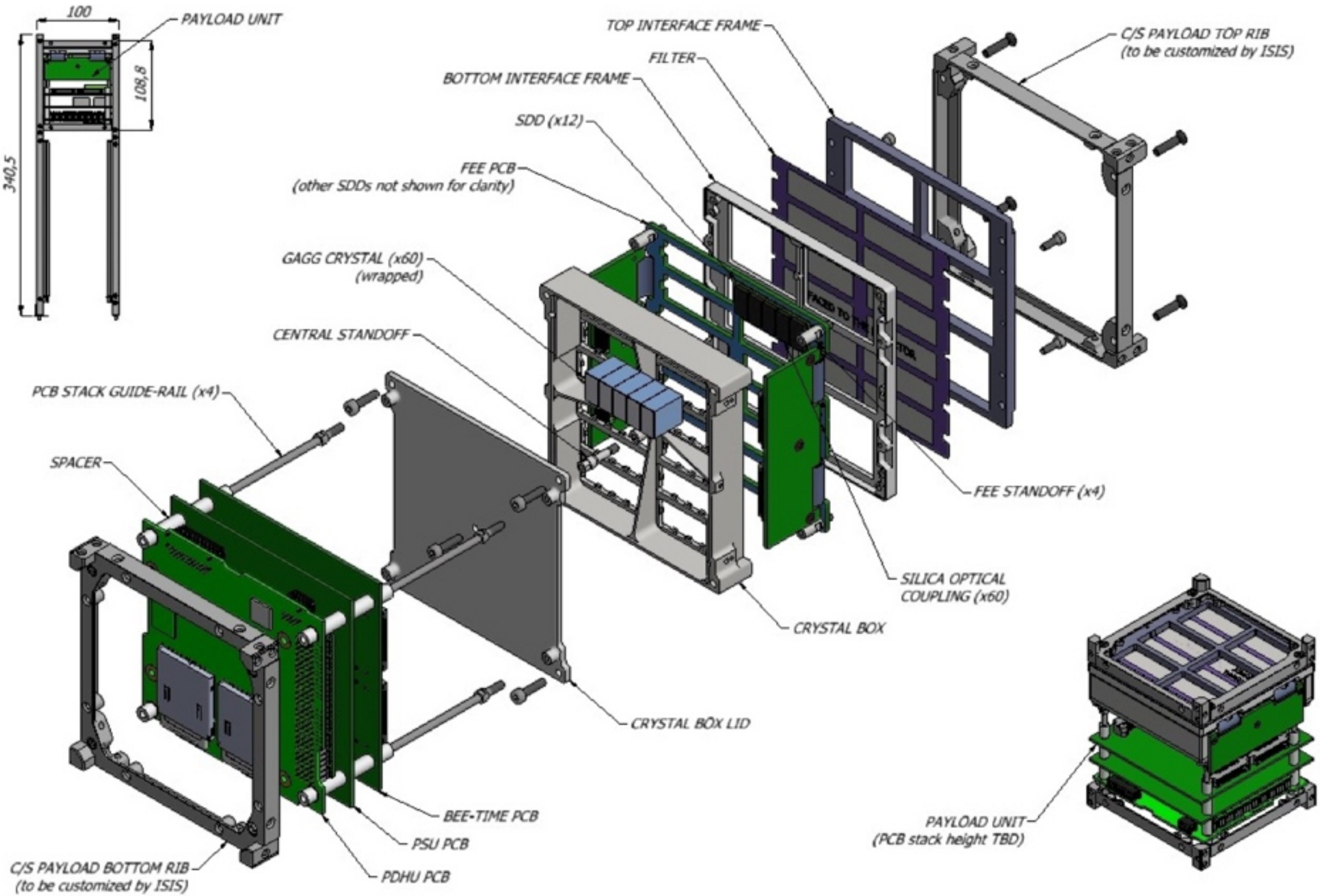
Payload concept

- Scintillator crystal GAGG
  Photo detector, SDD
- 5-300 keV (3-1000 keV)
- ≥50 cm^2 coll. area
- a few st FOV
- Temporal res. ≤300 nsec
- ~1.6kg

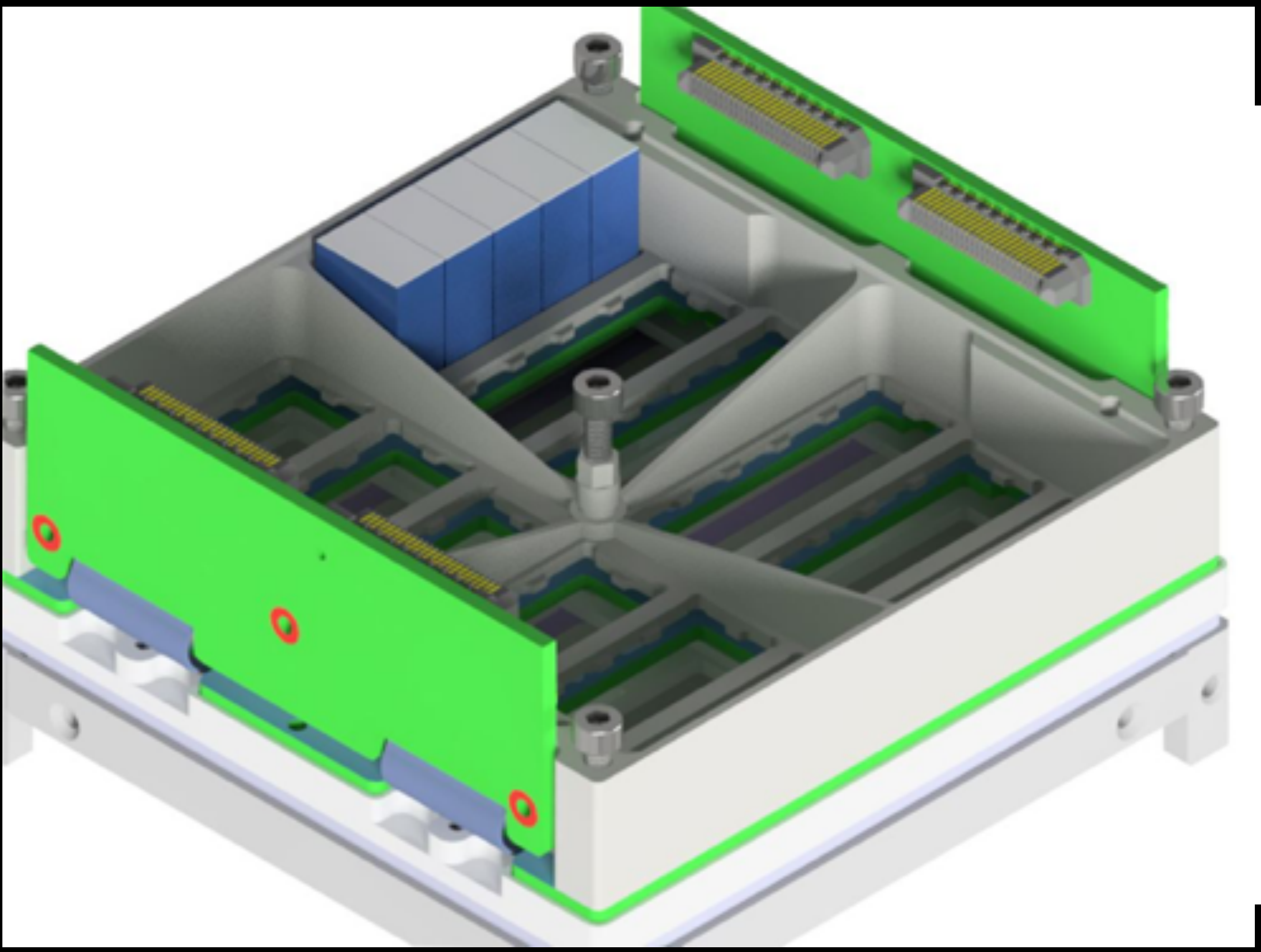


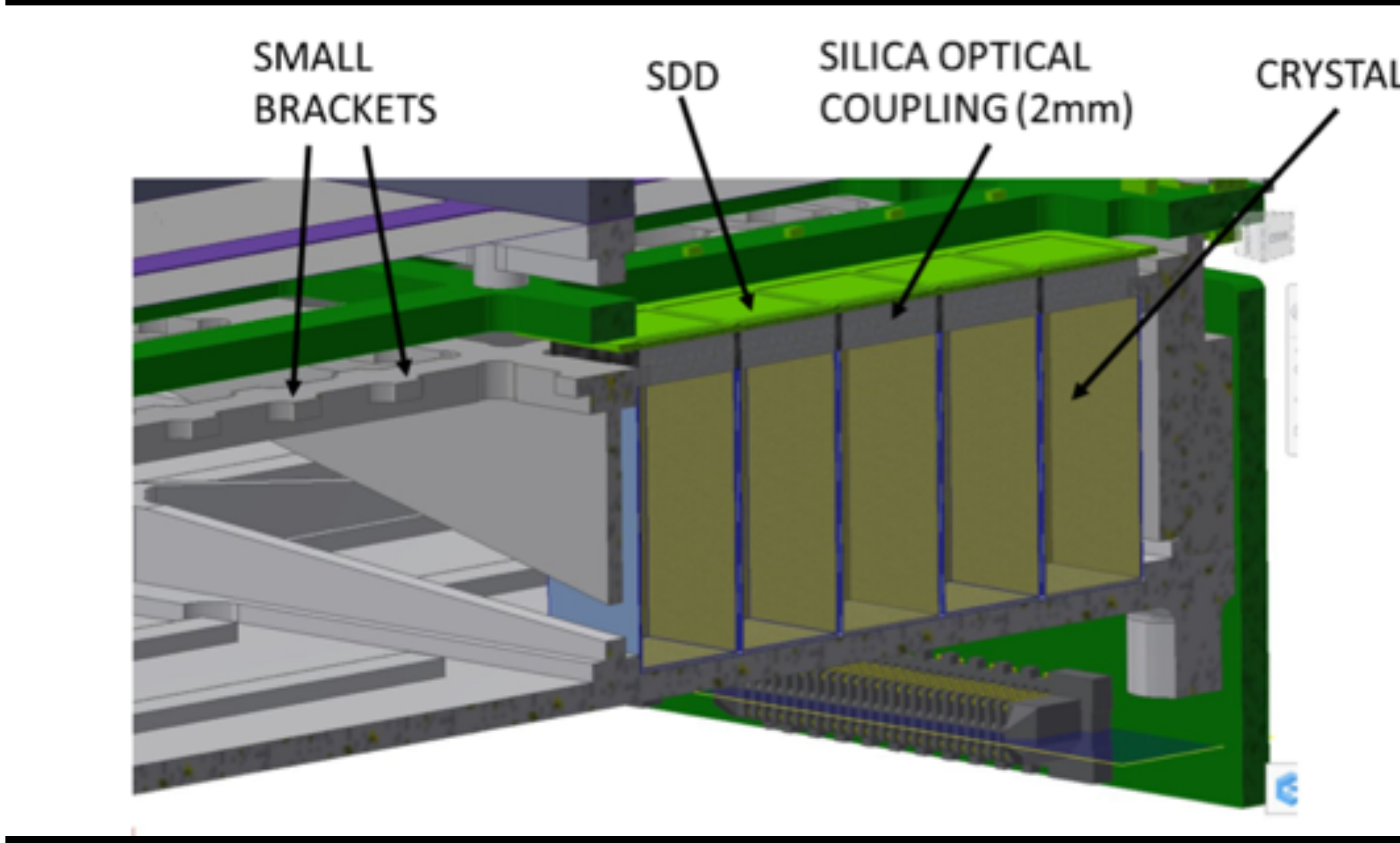
Fuschino+2018, 2020
Evangelista+2020
Campana+2020

Payload design



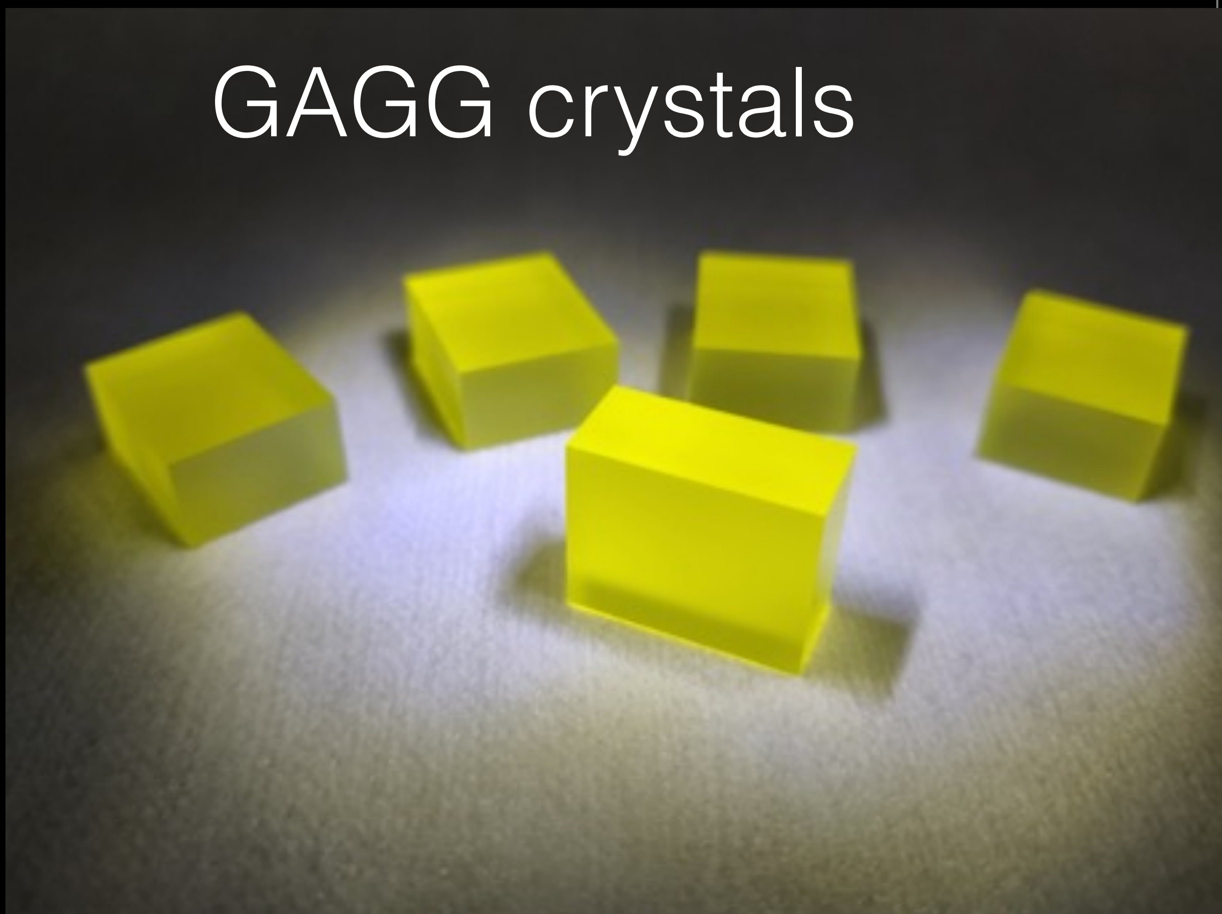
Detector design

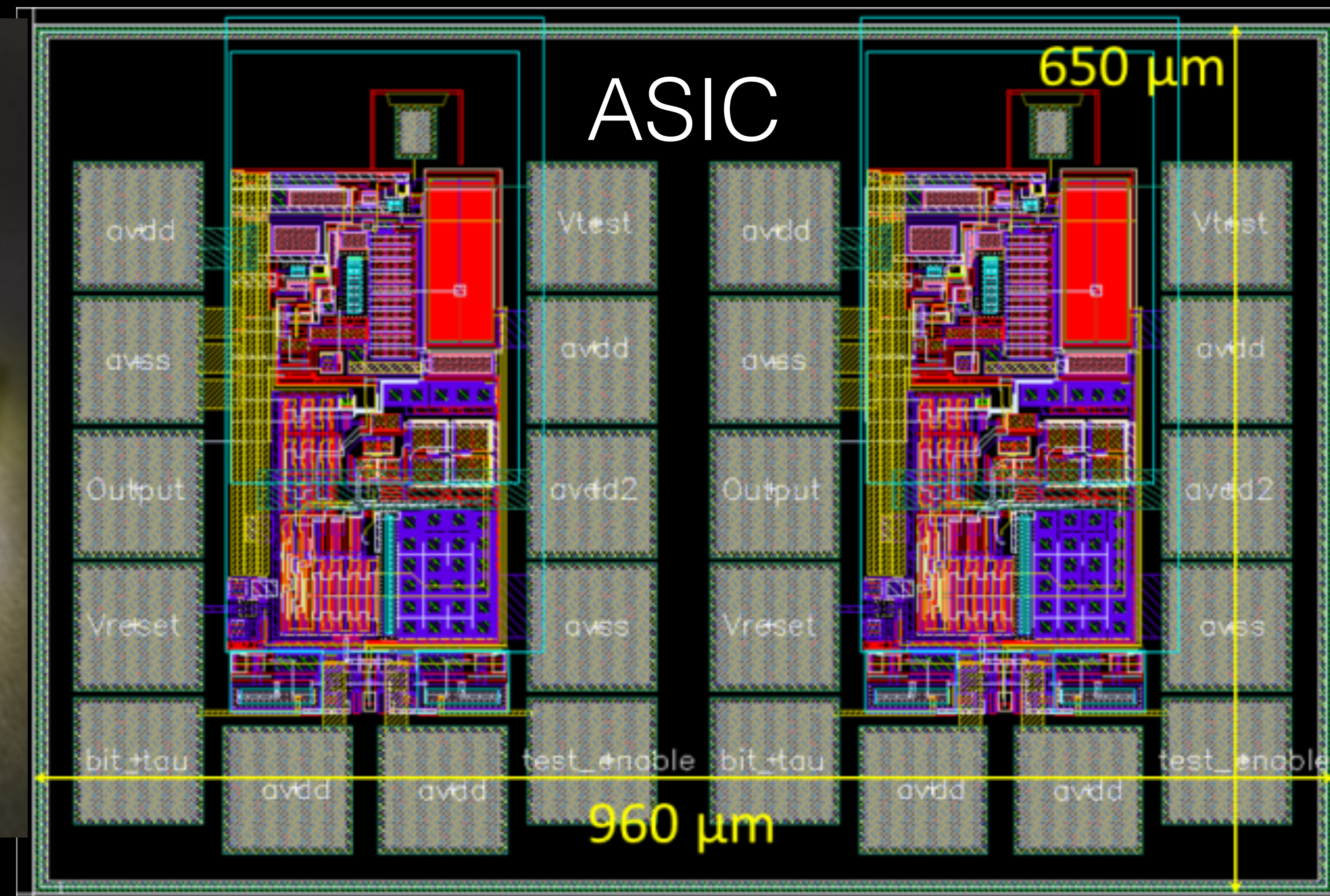




Stainless stell crystal box + tungsten layers on bottom and sides to reduce X-ray background

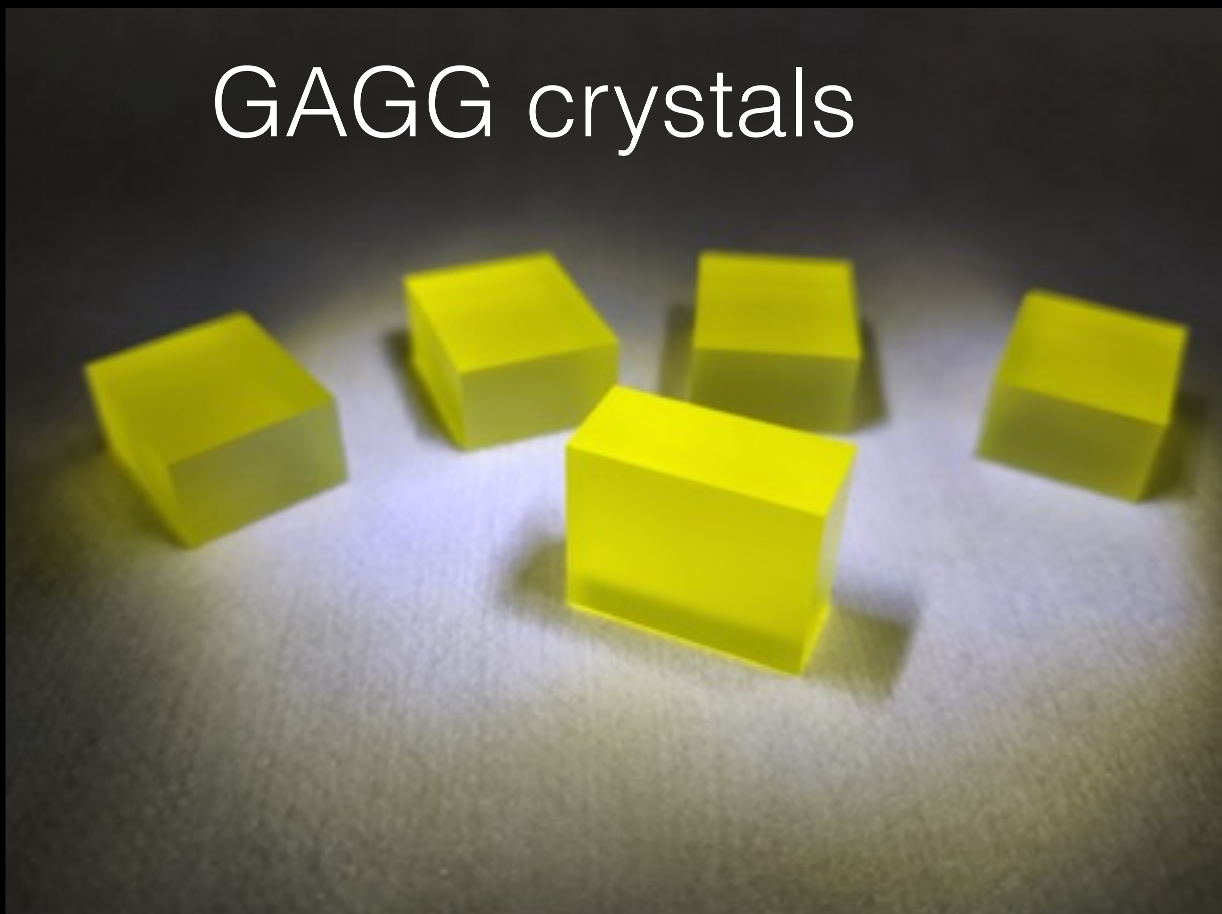
Hardware

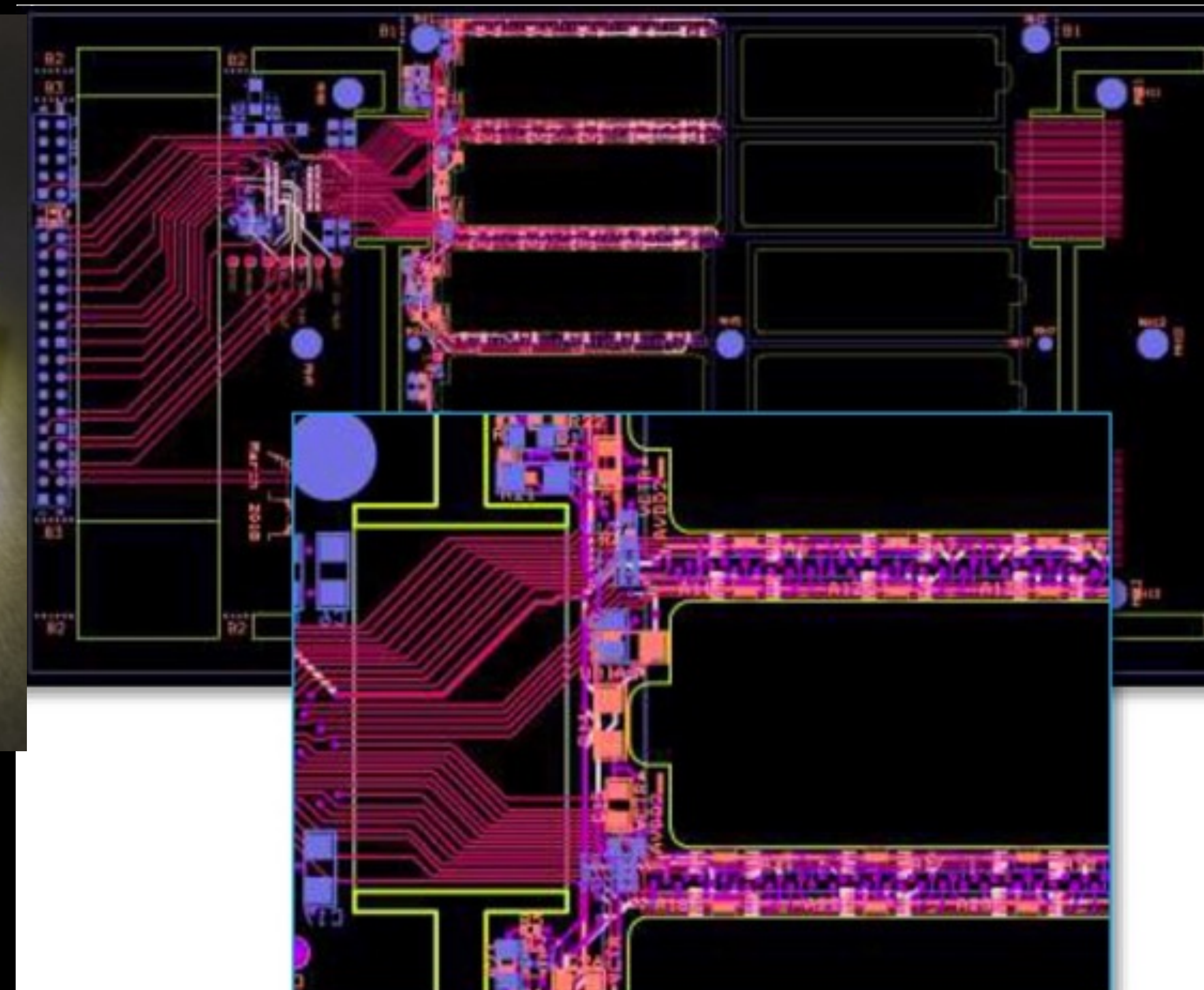

GAGG crystals


ASIC
650 µm
960 µm
avdd
avss
Output
Vreset
bit_tau
Vtest
avdd2
test_enable


SDDs

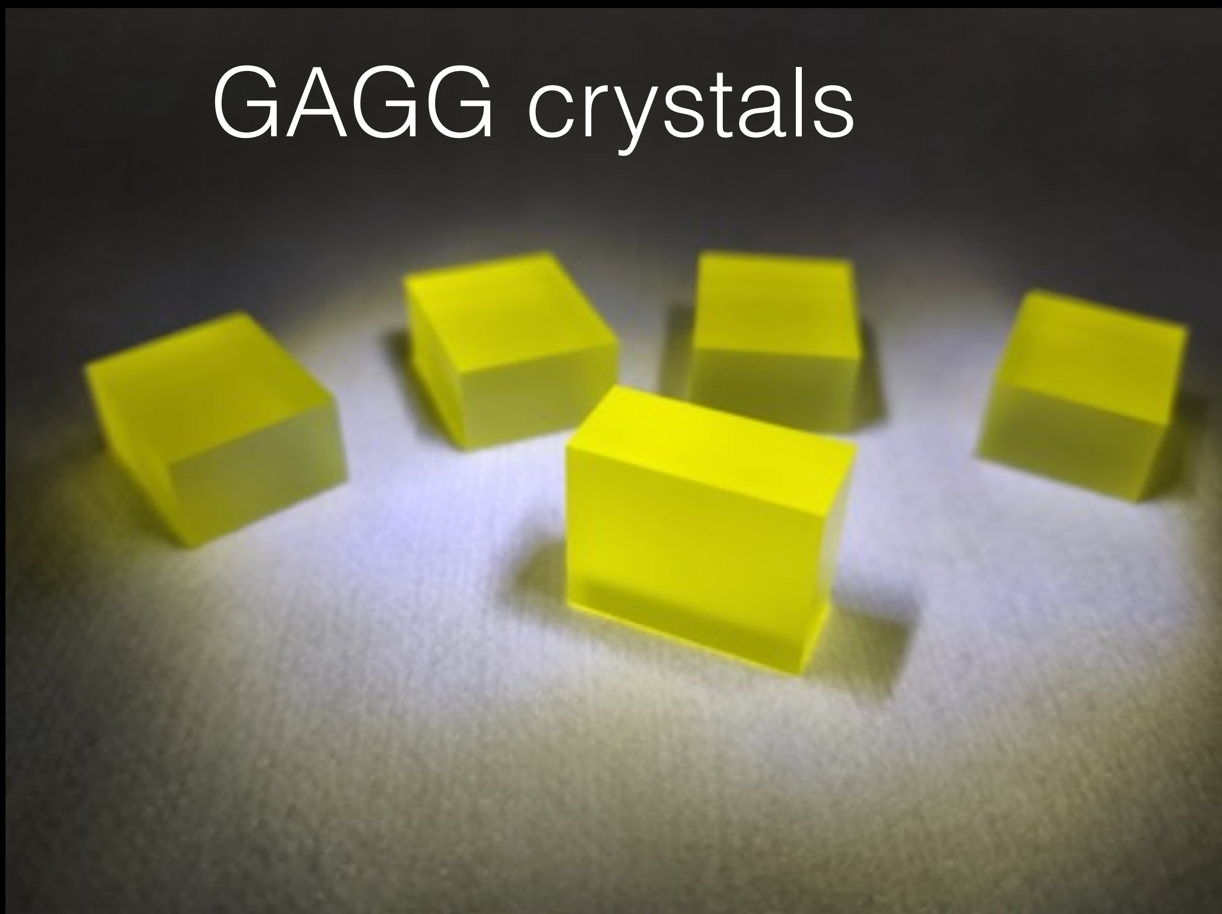
Hardware

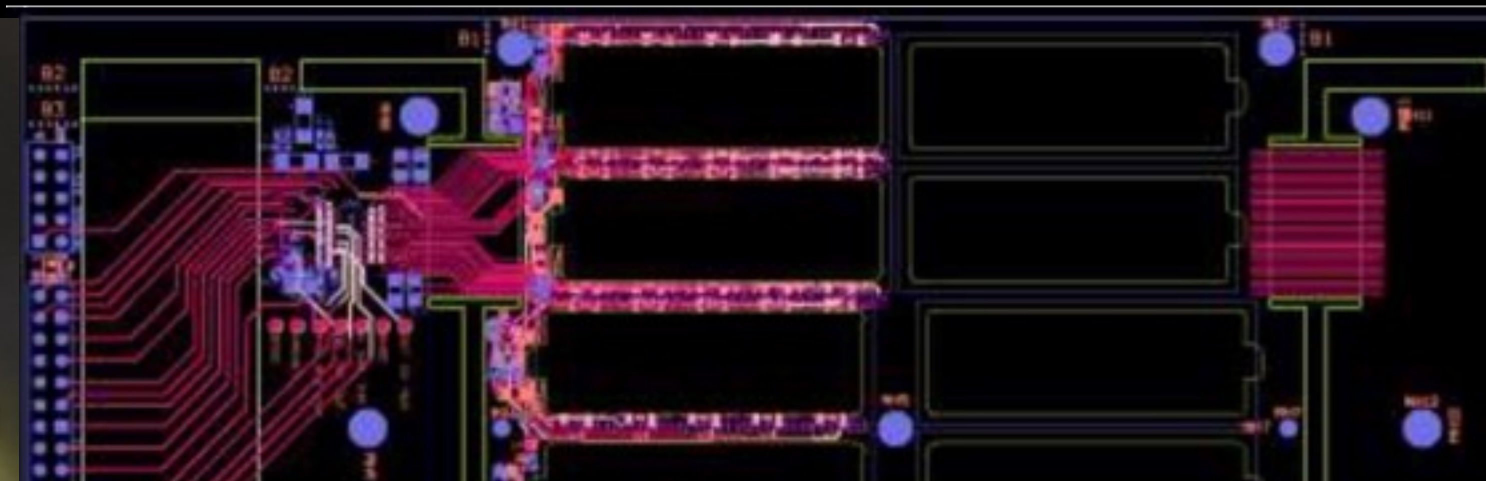


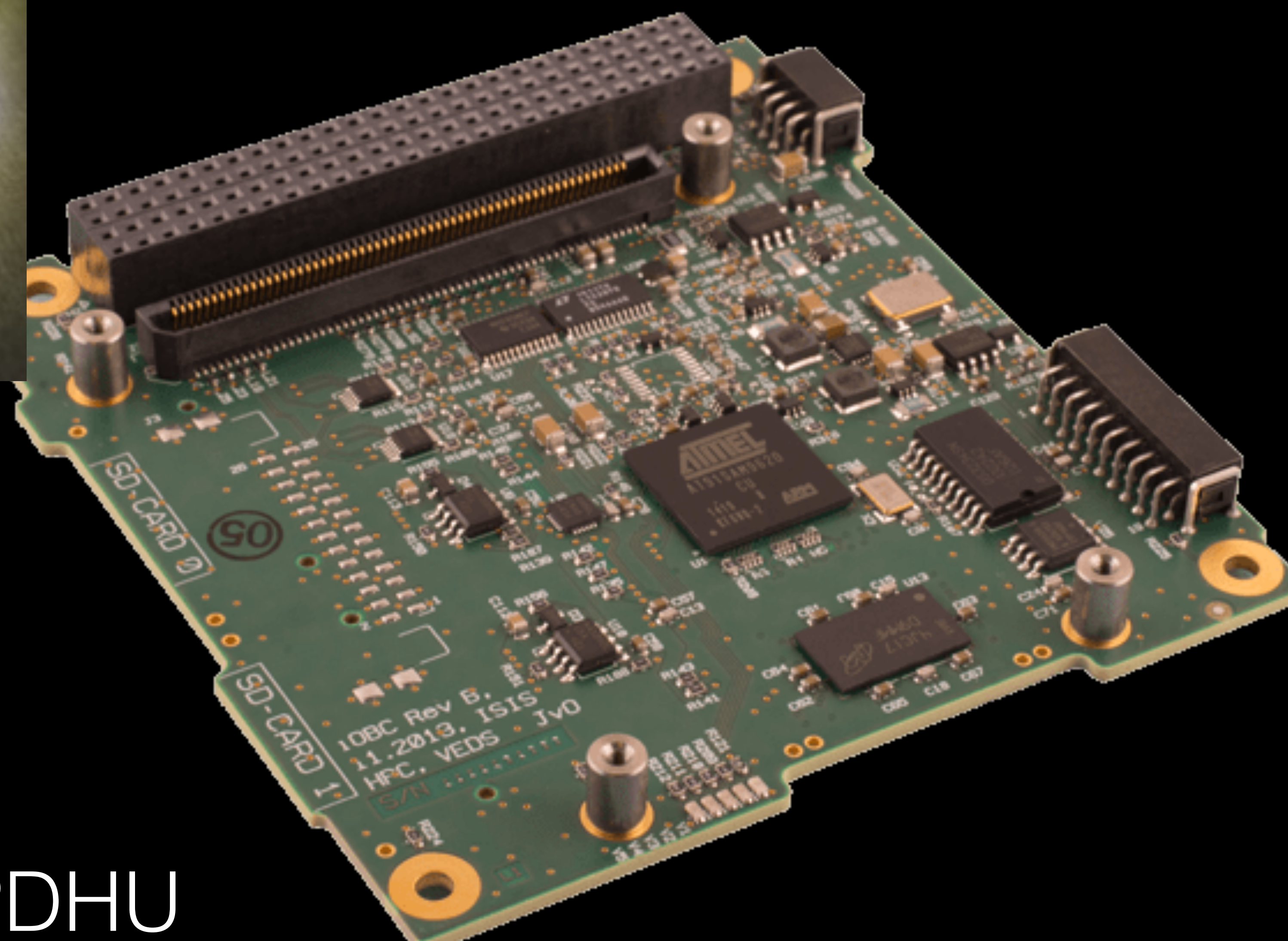


PCB supporting SDD & ASICs

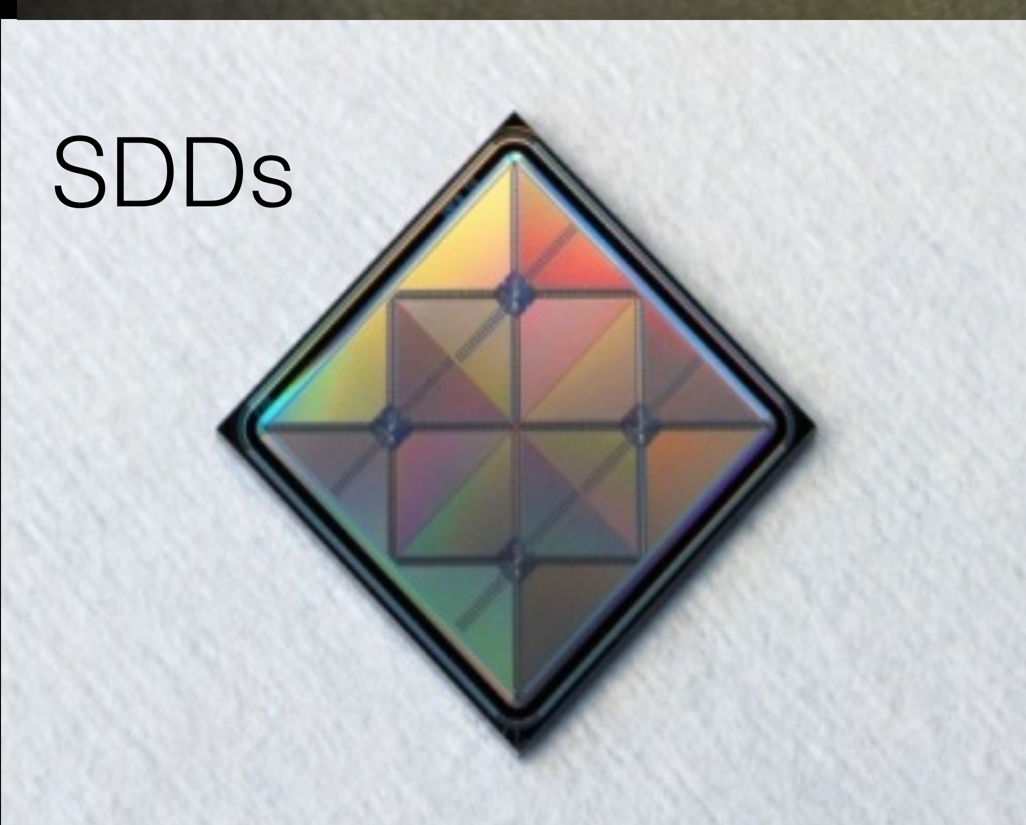
Hardware







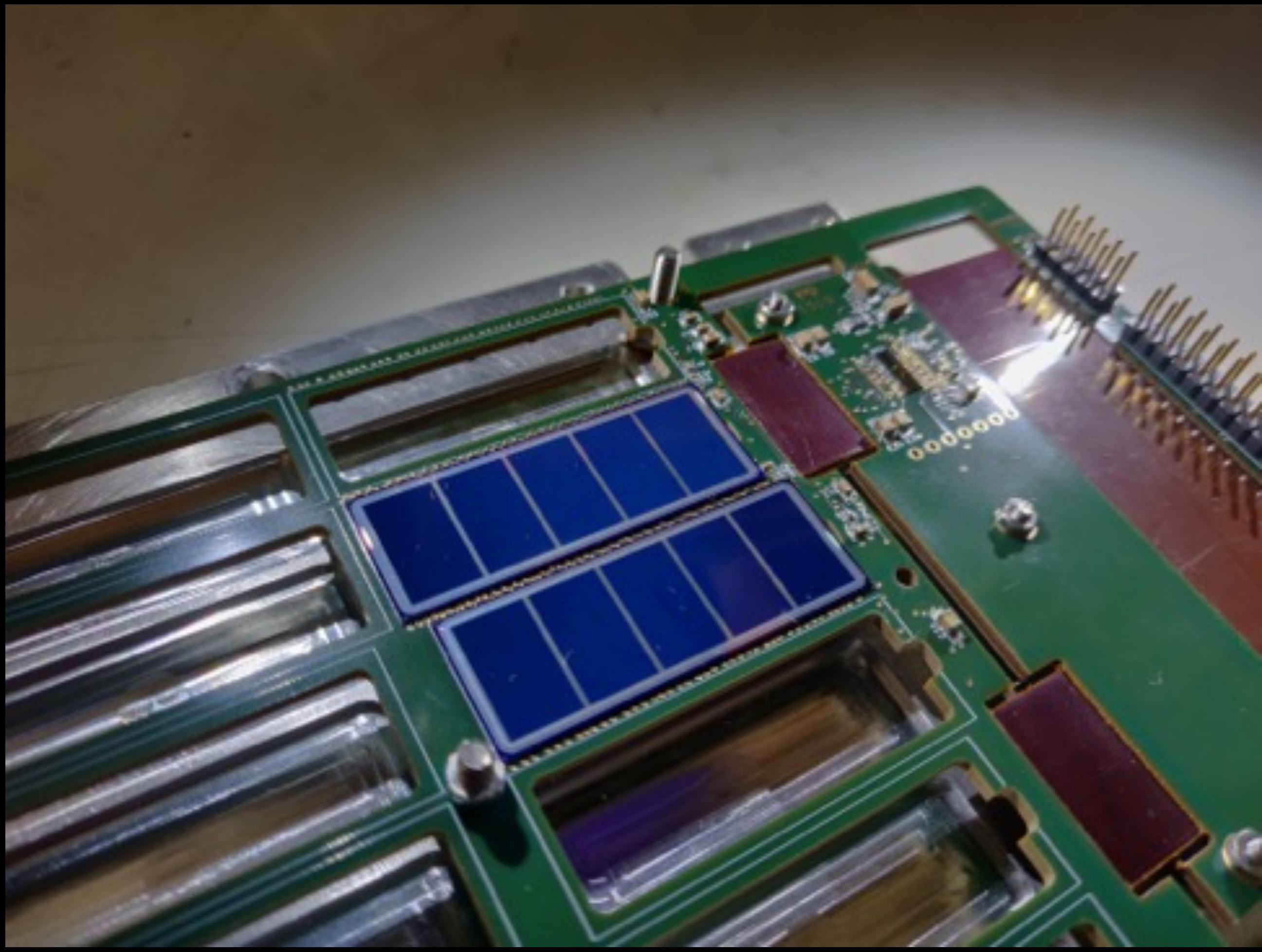
PDHU



Breadboards

http://www.hermes-sp.eu/?p=4070

- Assembly, Integration procedure and test plan consolidation
- FEE PCB functional tests
- FEE PCB (preliminary) performances verification
- SDD + ASICs power consumption verification
- Absence of channel-to-channel electrical cross-talk
- Room-temperature performance as expected. Spectroscopic characterisation with ^{241}Am



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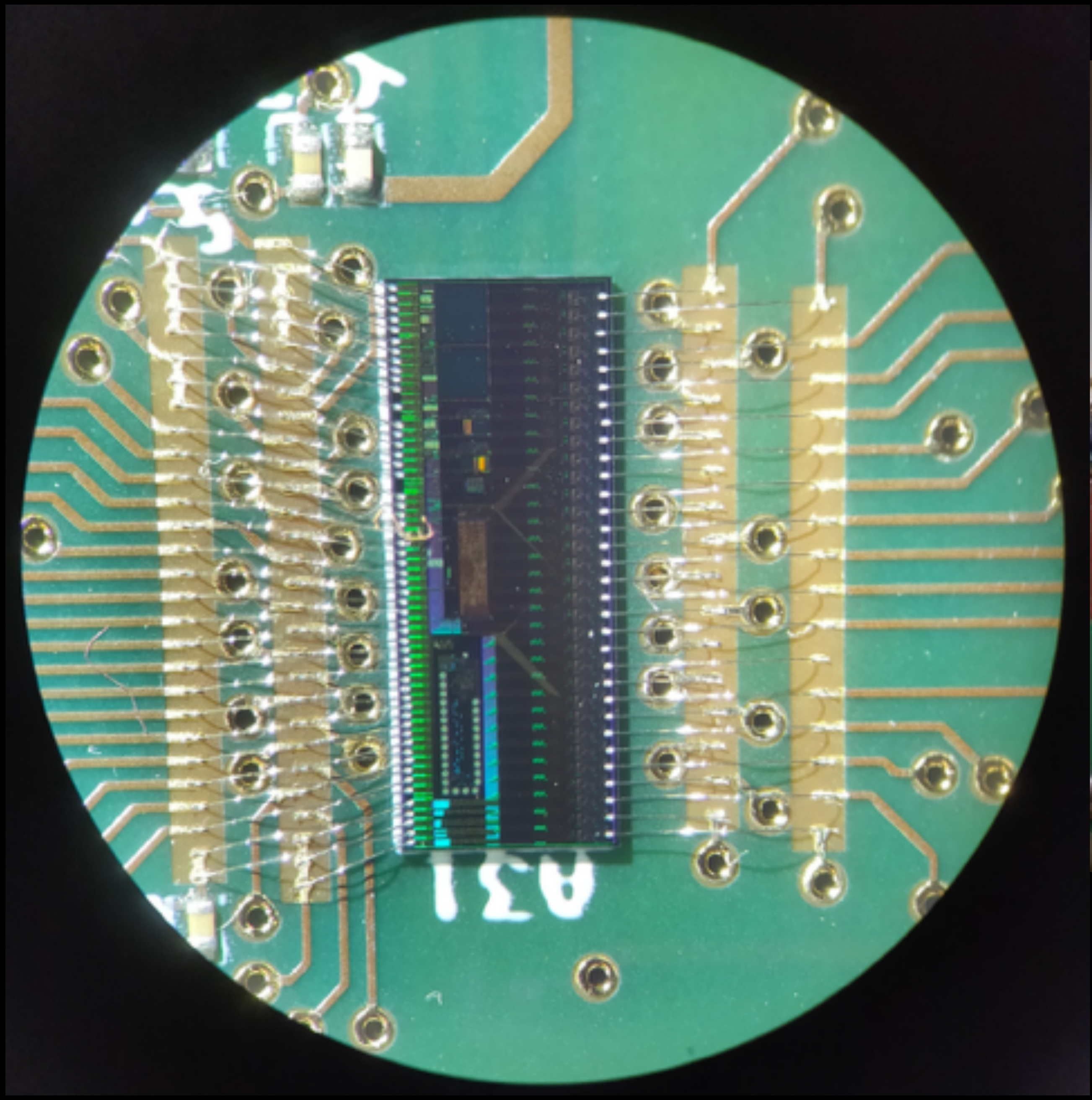

Breadboards

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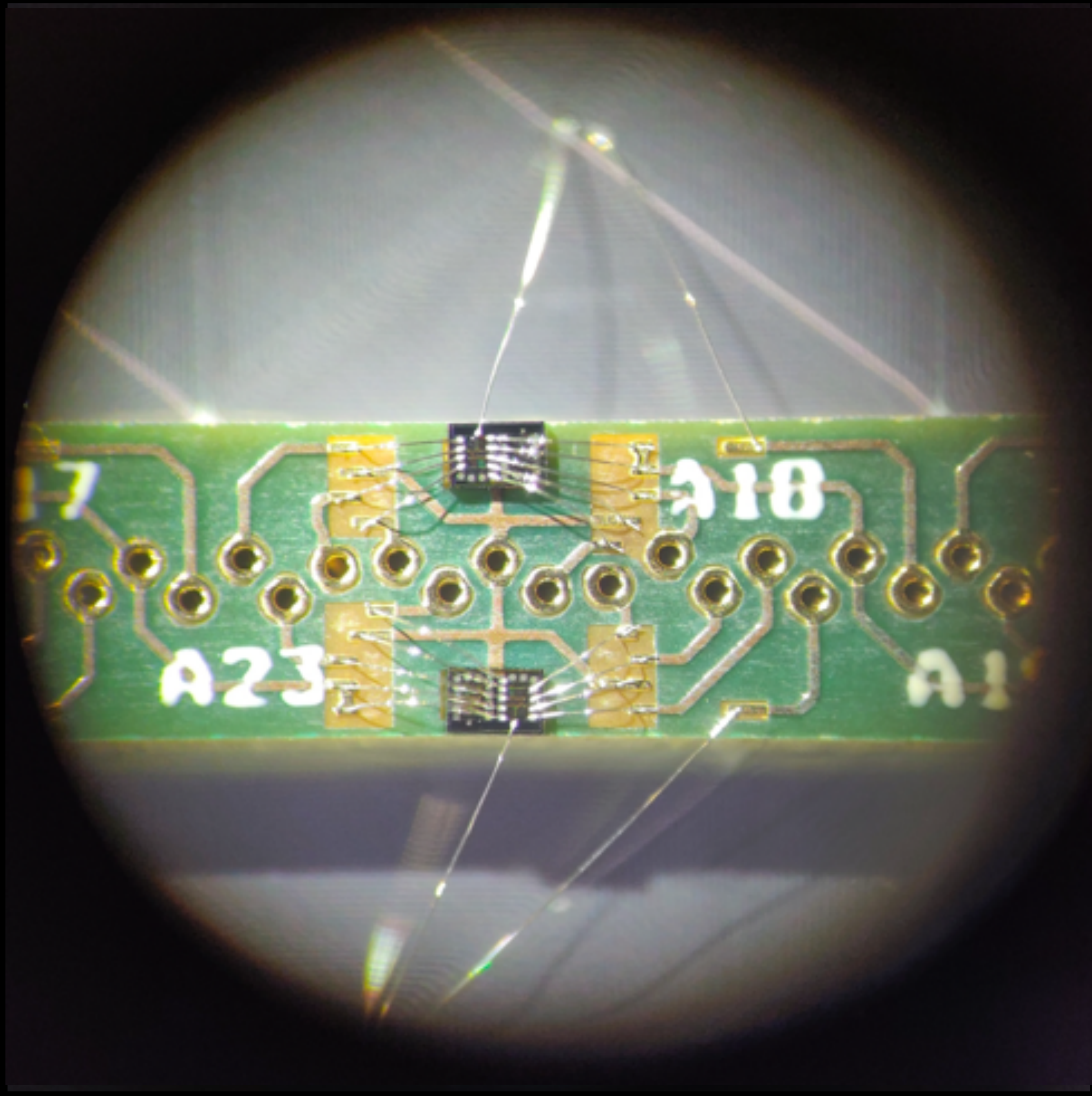
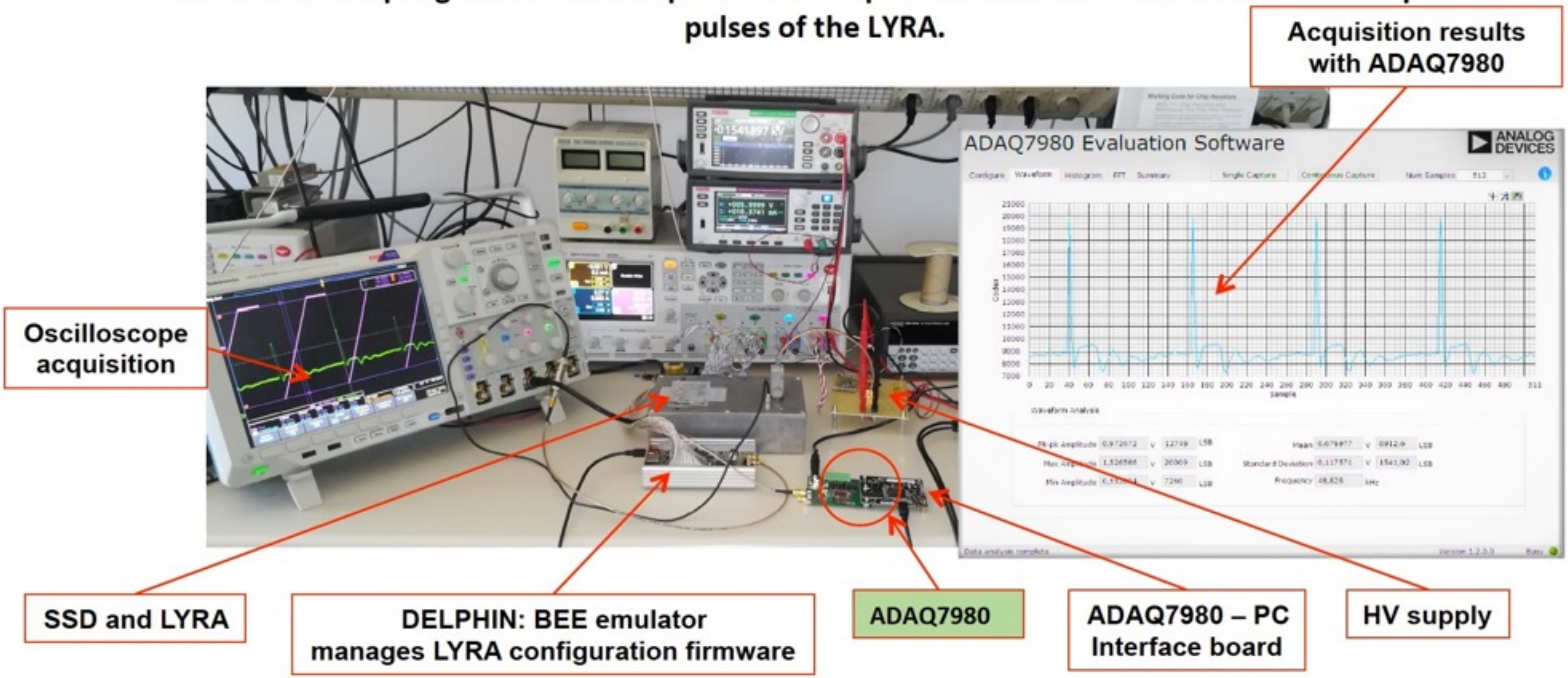
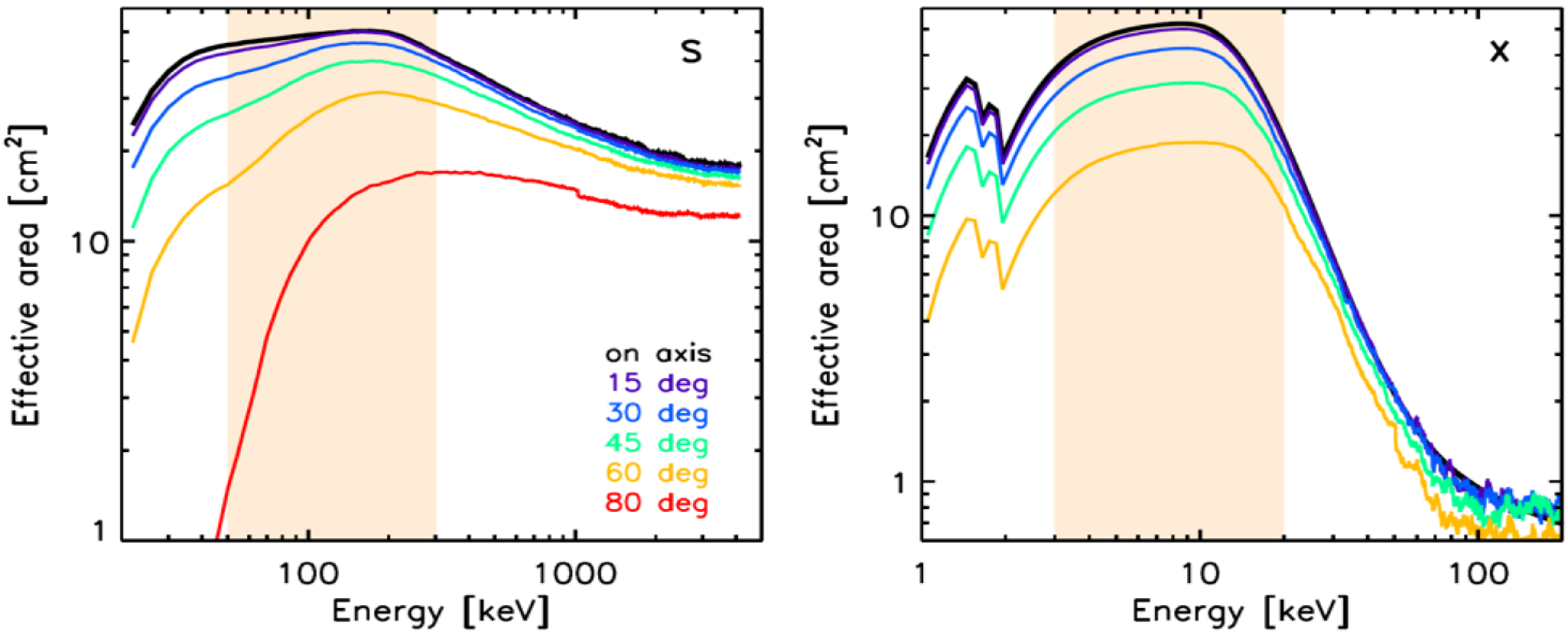


Breadboards

SETUP to test LYRA - ADC interfacing. The ADAQ7980 given positive results working at the its maximum sampling rate. Oscilloscope and ADC captured the same measurements on output pulses of the LYRA.



HERMES performances

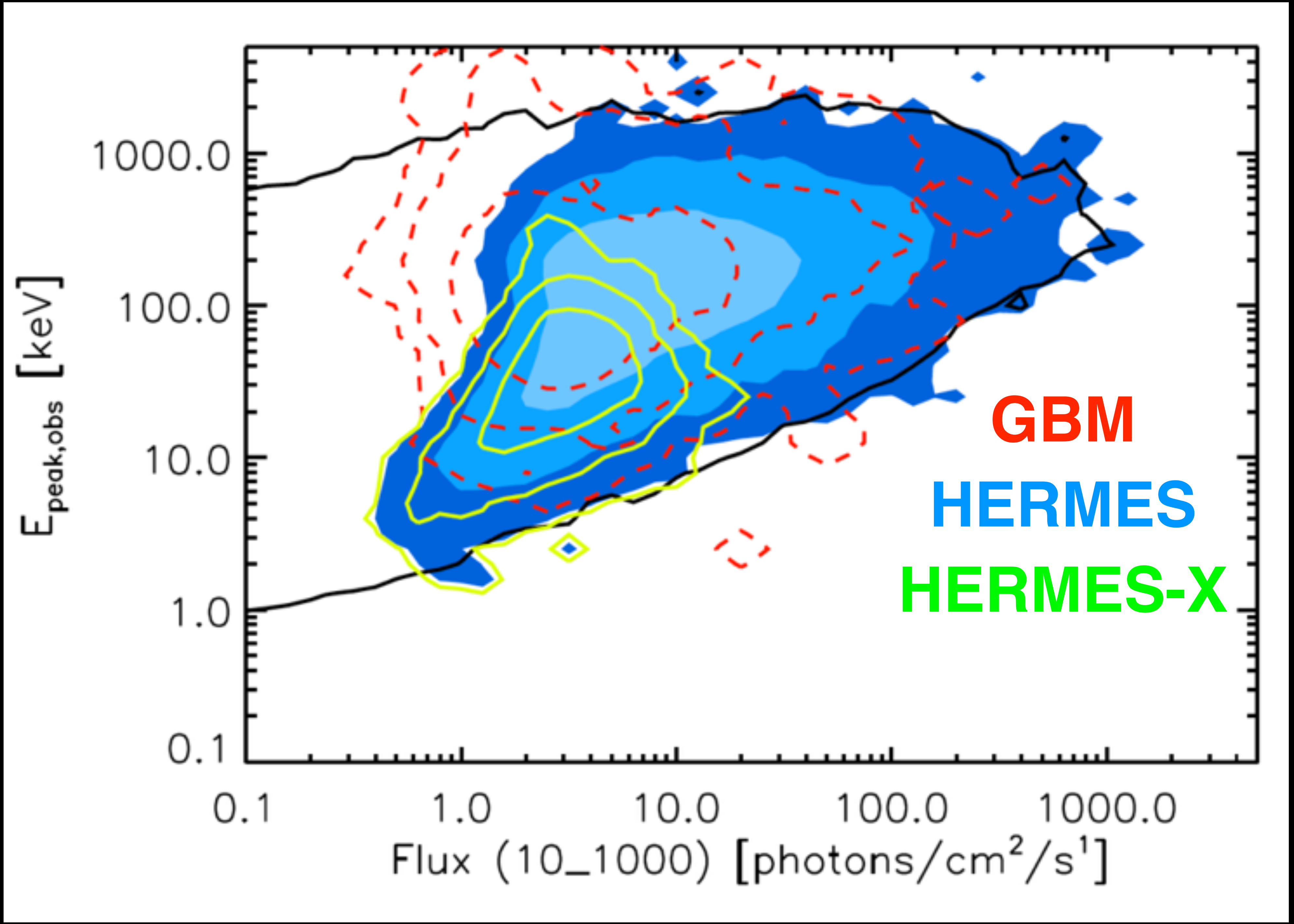


Background: 50-300 keV =75counts/s; 3-20 keV 390counts/s

HERMES vs. GBM: half collecting area but ~1/3 lower background and soft energy band

HERMES performances

Using Ghirlanda/Nava Mock GRB catalog



HERMES performances

$$\sigma_{Pos} = 2.4°[(\sigma_{CCF}^2 + \sigma_{sys}^2)/(N-3)]^{0.5}$$

<B>~7000km

N(pathfinder)~6-8, active simultaneously 4-6

N(final constellation) ~100, active 50

$\sigma_{Pos(pathfinder)}$ ~ 2.4 deg if $\sigma_{CCF}, \sigma_{sys}$~1ms

$\sigma_{Pos(FC)}$ ~ 3 arcmin if $\sigma_{CCF}, \sigma_{sys}$~1ms

HERMES Institutes

- INAF, ASI, PoliMi, UniCagliari, UniPalermo, UniUdine, UniTrieste, UniPavia, UniFedericoII, UniFerrara, FBK, FPM
- University of Tubingen (Germany)
- University of Eotvos Budapest, C3S (Hungary)
- University of Nova Gorica, Skylabs, AALTA (Slovenia)
- Deimos (Spain)

Programmatics

Progetto Premiale 2015: **HERMES-Techonogic Pathfinder**

H2020 SPACE-SCI-20: **HERMES-Scientific Pathfinder**

Main objectives:

1. Detect GRBs with simple payload hosted by a 3U CubeSat
2. Study statistical and systematic errors in the CCF determination
3. **First GRB localization experiment with ≥3 CubeSat**

- KO May 2018, Nov. 2018
- PDR February-March 2019, DeltaPDR November 2019
- CDR+QR Q2 2020 QM—> PFM1
- AR Q4 2021 —> FM2+FM3+FM4+FM5+FM6
- Launch 2022, ASI provided

Near Future

- Increase the number of units/orbits through:
  - additional programs in Italy/EU
  - synergies with SkyHopper
  - Interest in Israel, Switzerland, USA, Cina…
- First global all sky monitor by mid ‘20

Thanks!