INAF
ISTITUTO NAZIONALE
DI ASTROFISICA
NATIONAL INSTITUTE
FOR ASTROPHYSICS

POLITECNICO
MILANO 1863

Agenzia Spaziale Italiana

HERMES

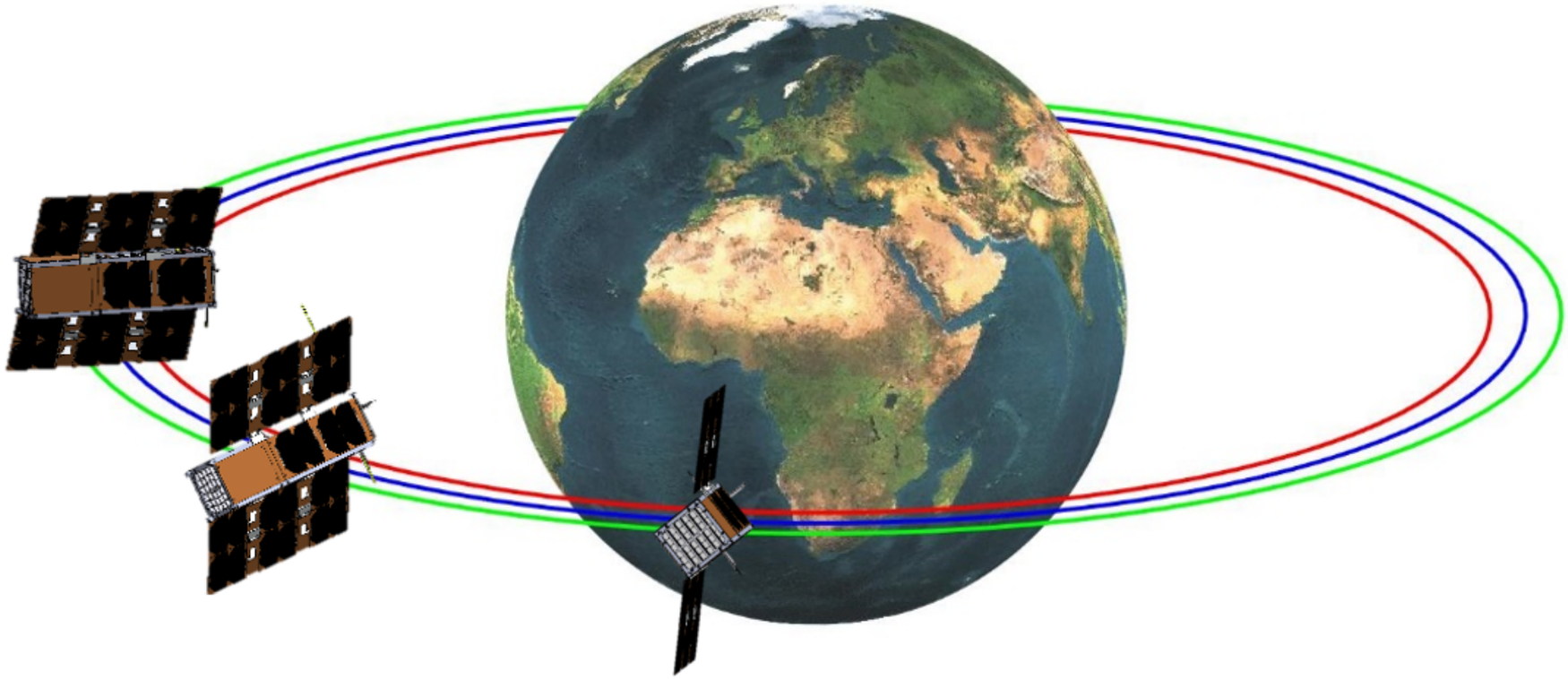
Theseus precursors:
HERMES-Technologic and Scientific Pathfinders

fabrizio.fiore@inaf.it

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the European Union's Horizon 2020 research and innovation programme under grant agreement No 821896

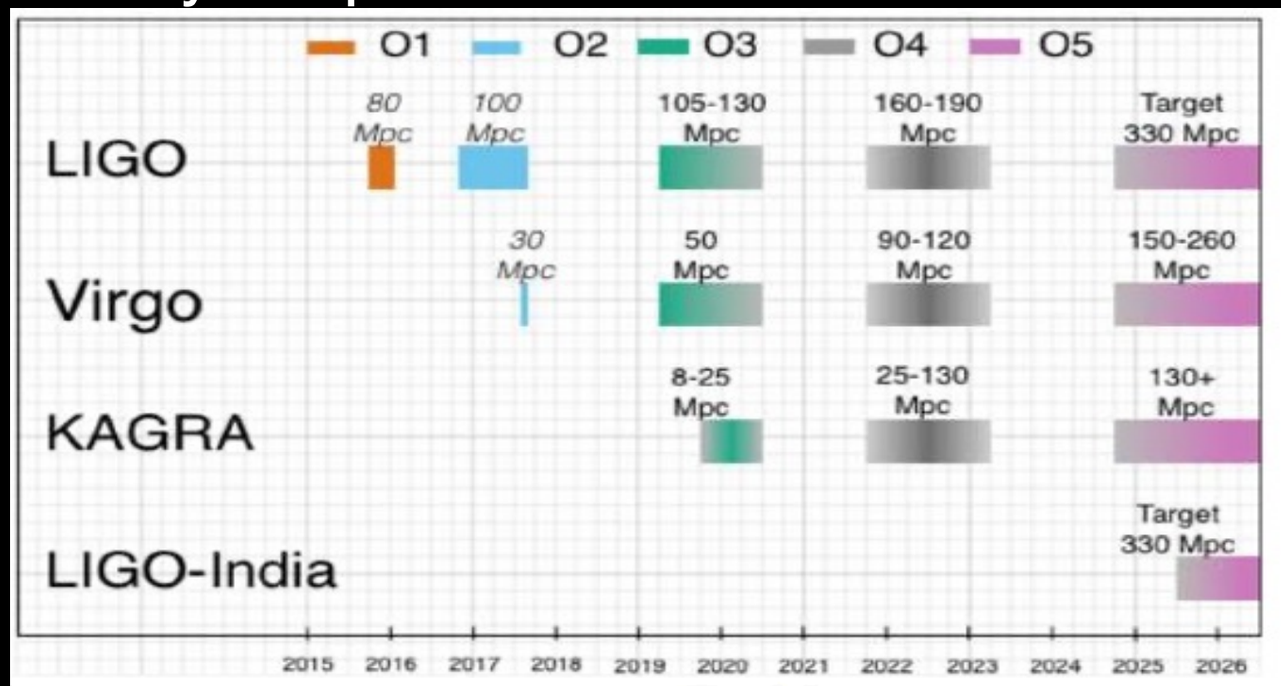
The project has received funding from the Accordo Attuativo ASI-INAF No 2018-10-H.1-2020

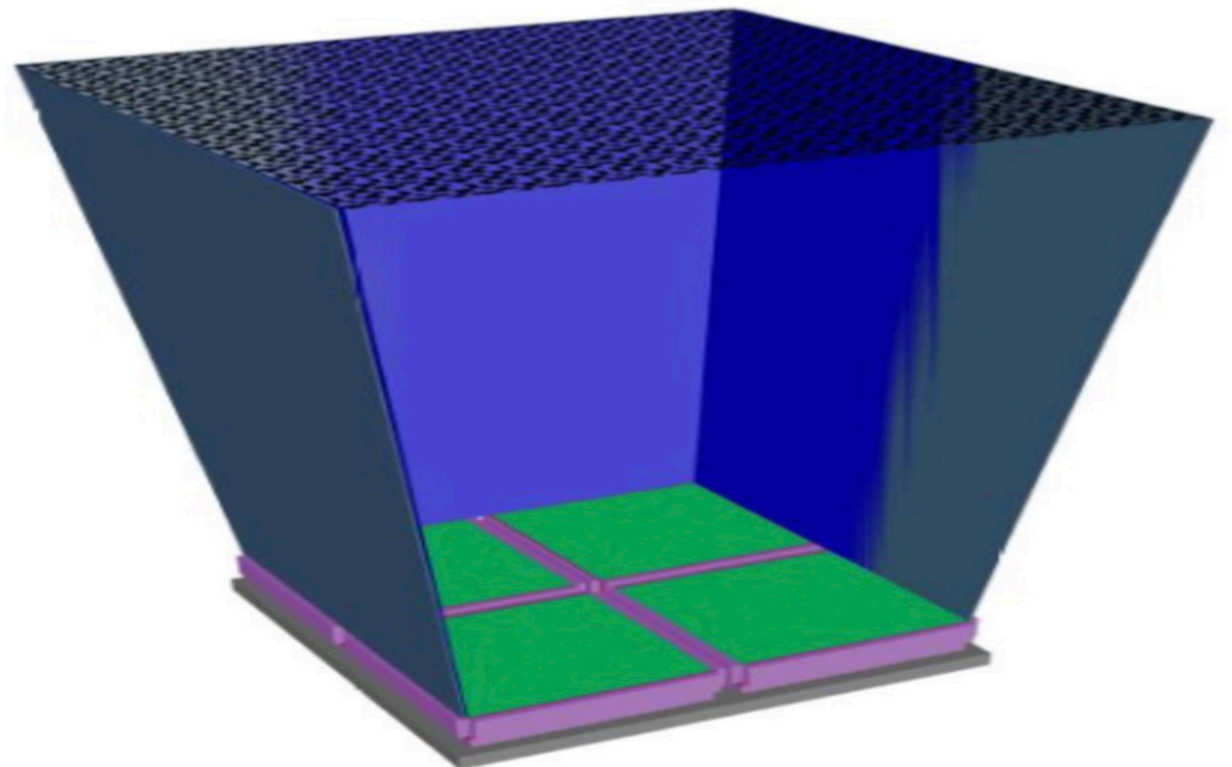
HERMES



HERMES as Theseus pathfinder

Planned observing runs prior to the O3 early suspension due to COVID-19

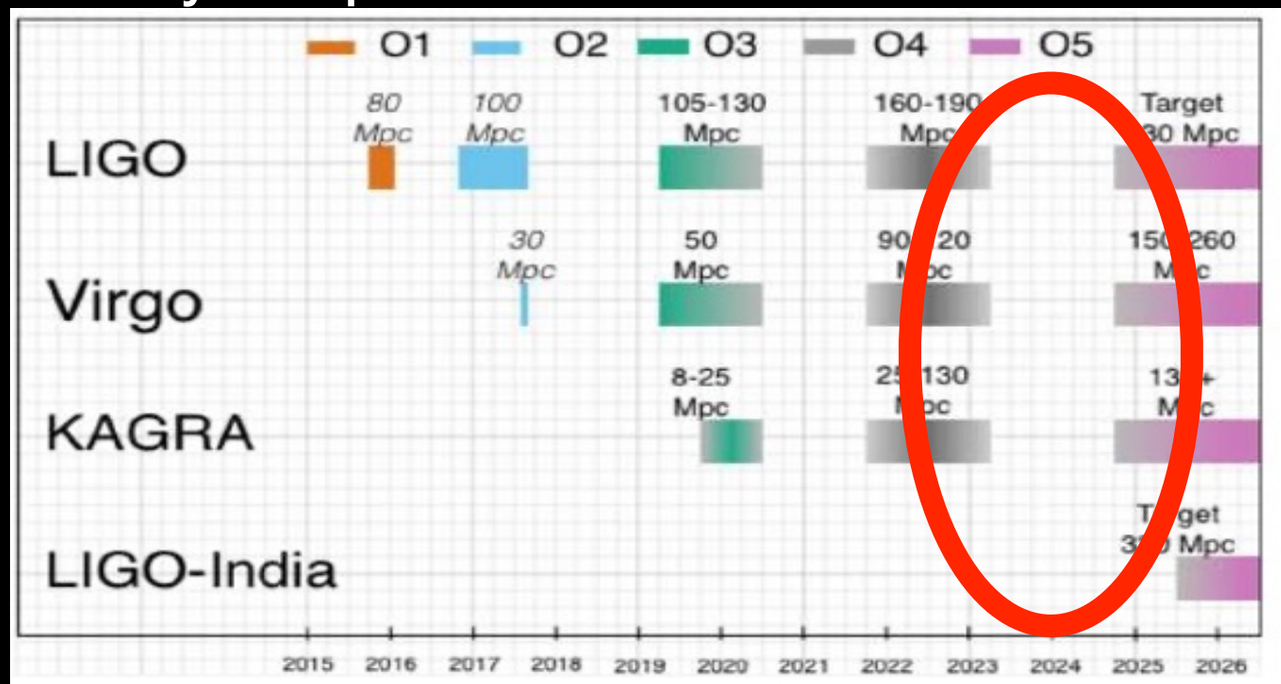


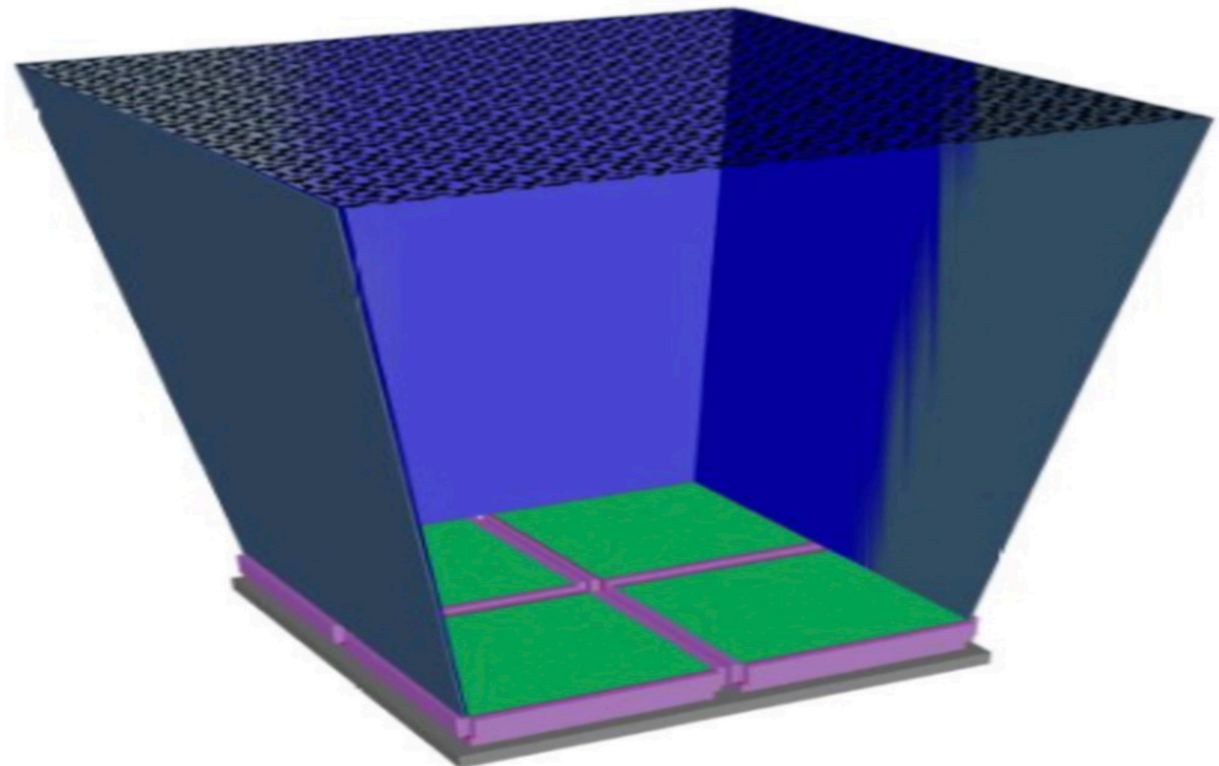


HERMES as Theseus pathfinder

- Science pathfinder: HERMES-TP/SP should overlap O4-O5

Planned observing runs prior to the O3 early suspension due to COVID-19

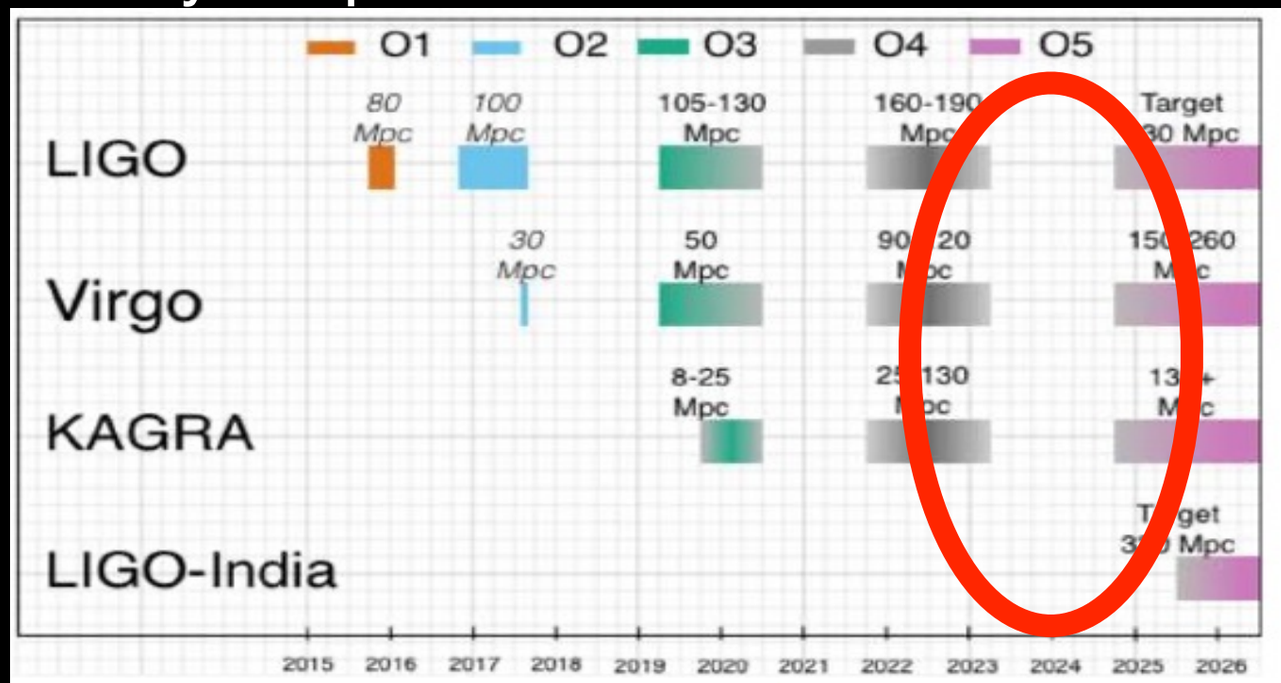


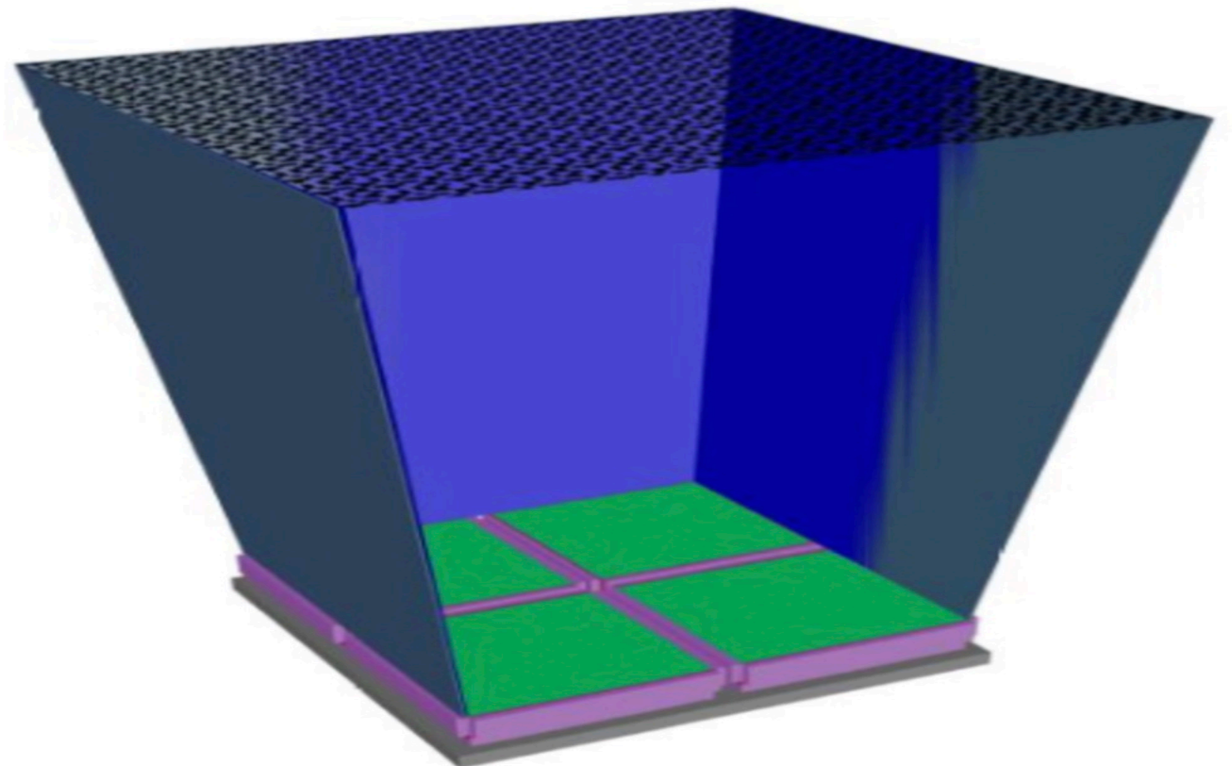


HERMES as Theseus pathfinder

- Science pathfinder: HERMES-TP/SP should overlap O4-O5
- XGIS Technology patfinder

Planned observing runs prior to the O3 early suspension due to COVID-19





Mission concept

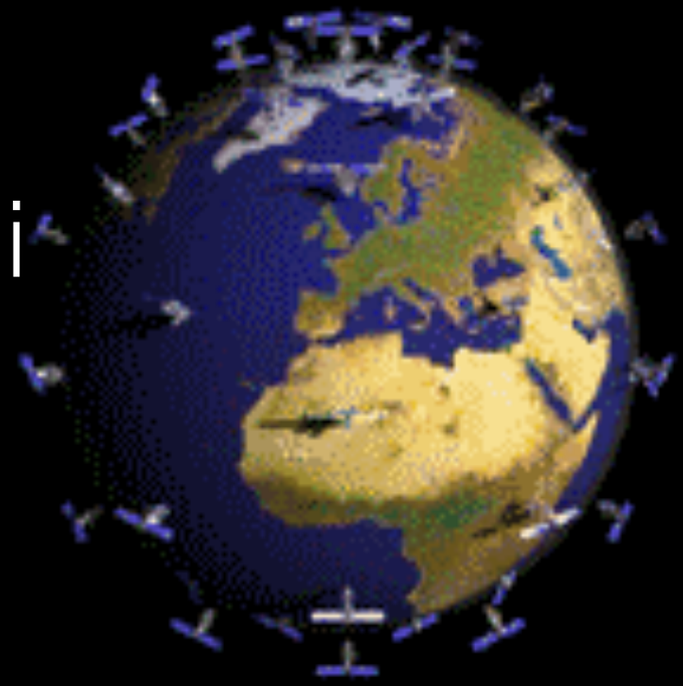
Disruptive technologies: cheap, underperforming, but producing high impact. Distributed instrument, tens/hundreds of simple units

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 (Progetti premiali 2015), managed by ASI
2018 H2020 Space-SCI-20 project
2019 ASI internal funds



Why HERMES now

Why HERMES now

Breakthrough scientific case:

- EM of GWE

Why HERMES now

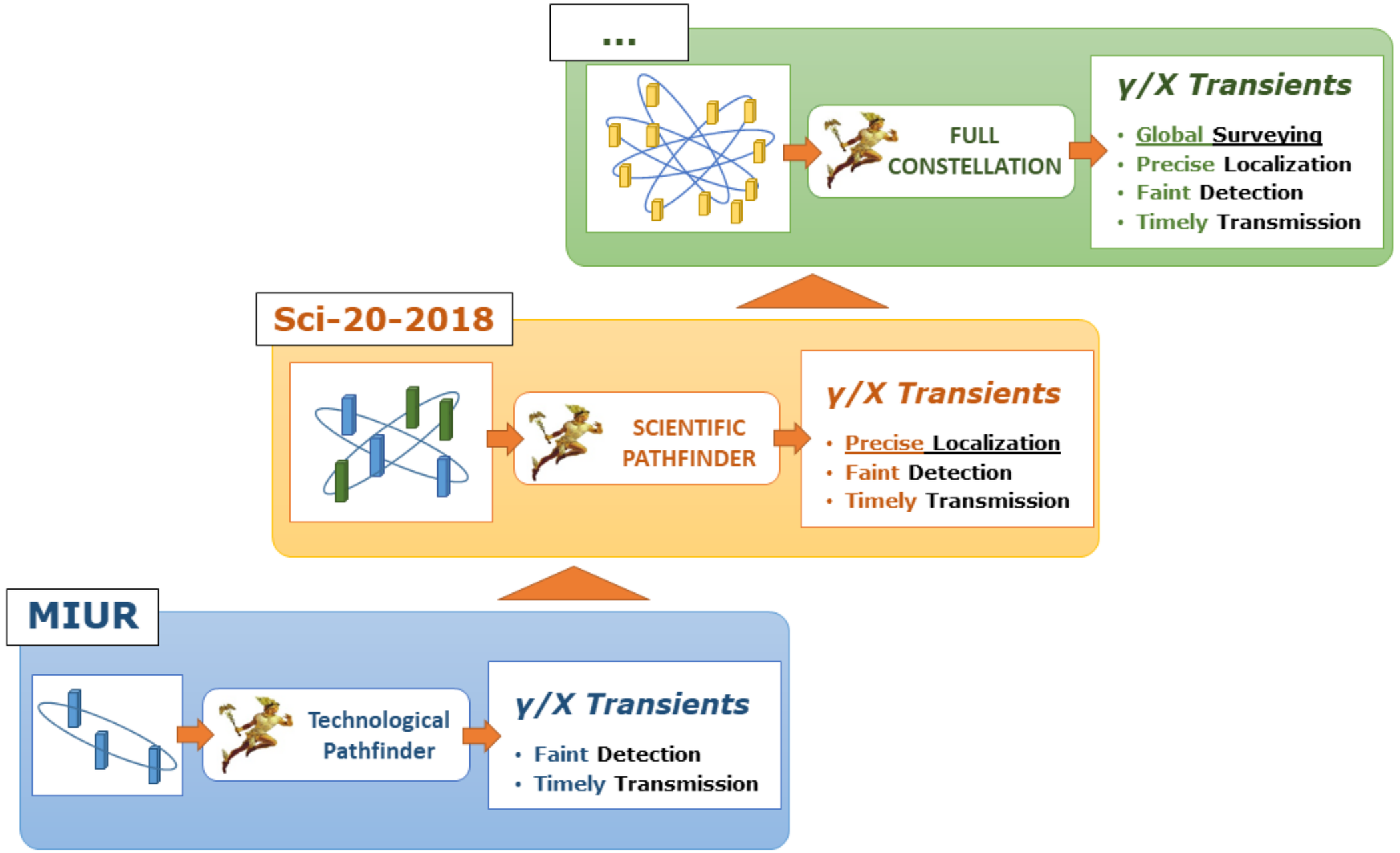
Breakthrough scientific case:

- 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

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

Why HERMES now

Breakthrough scientific case:

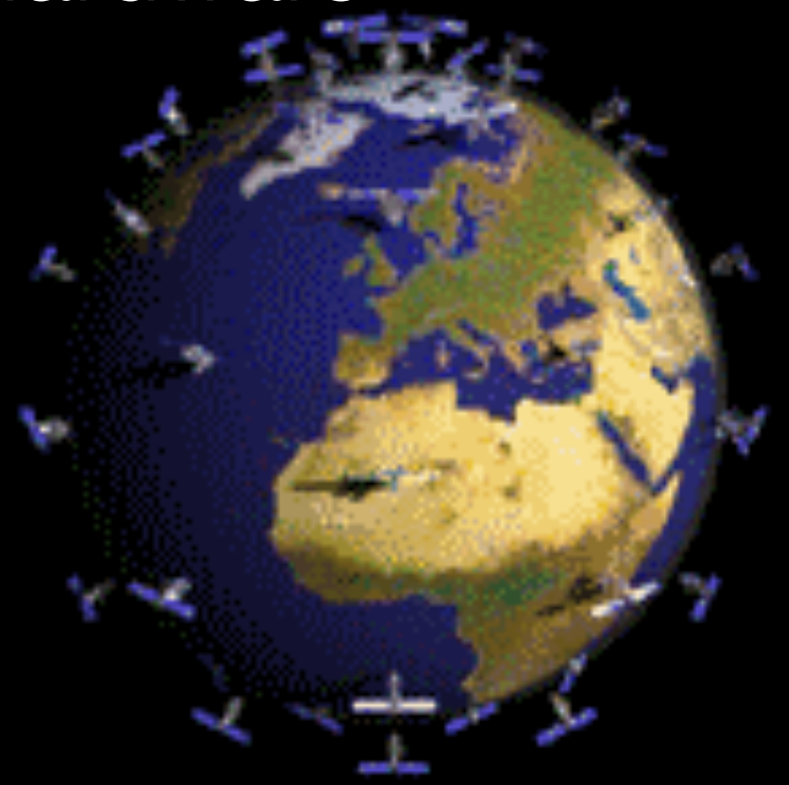
- EM of GWE

Modularity:

- Avoid single point failures, improve hardware
- Pathfinder

Open µsec - msec window:

- Accurate positions
- QG tests



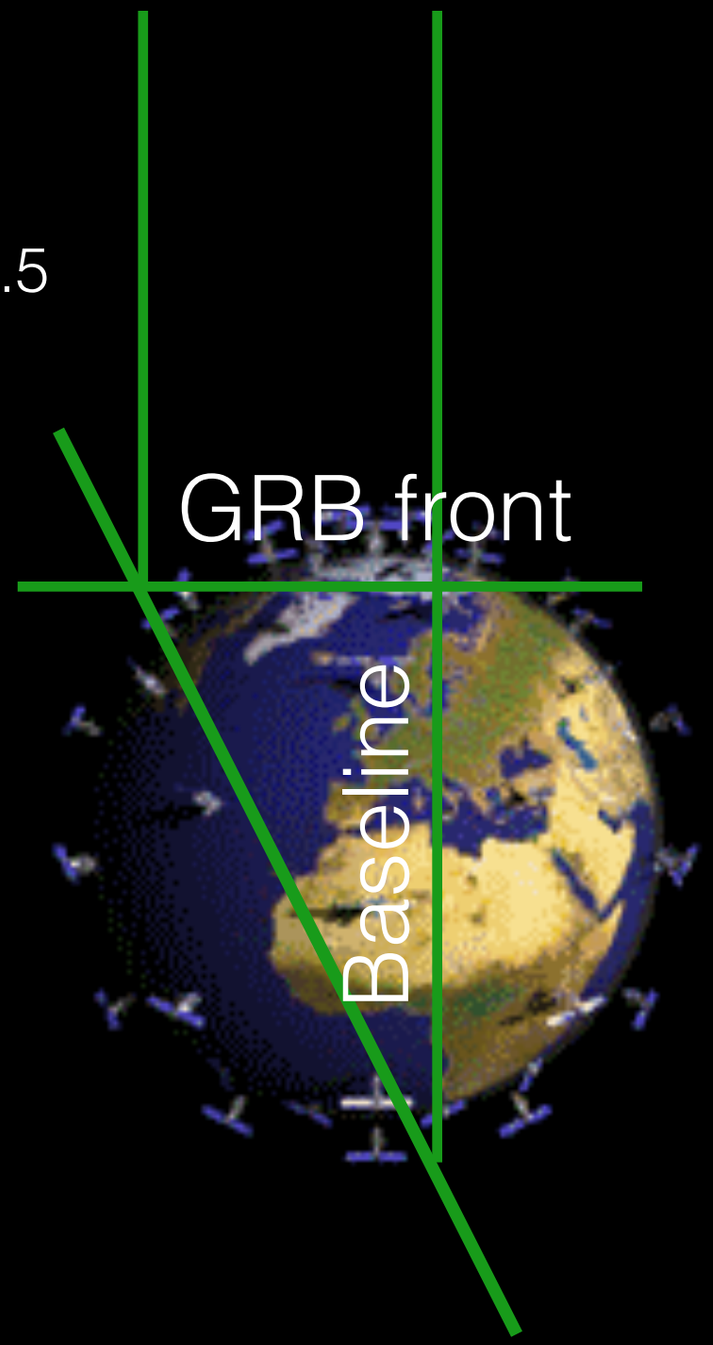
Limited cost and quick development

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

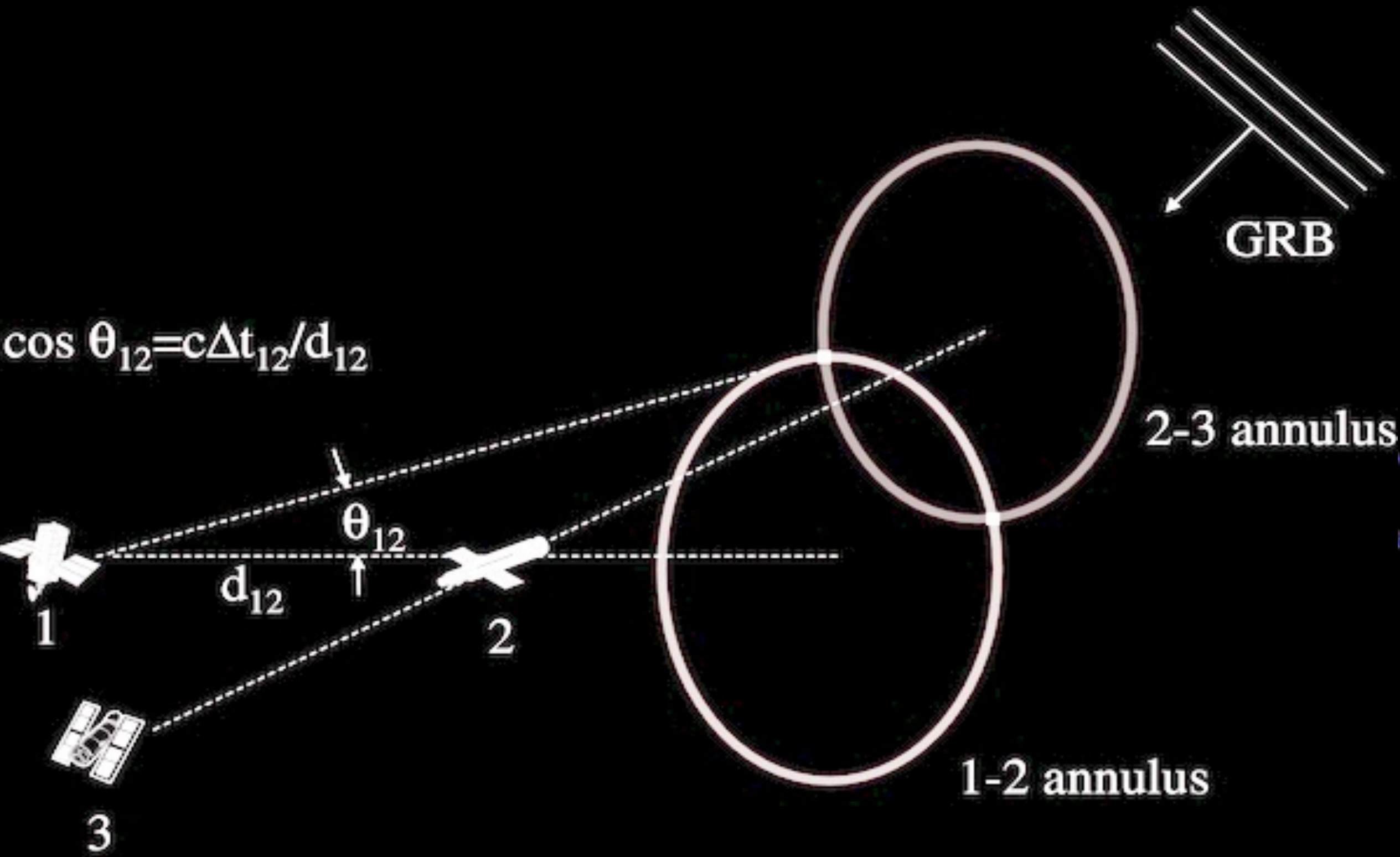
Experiment concept

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

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



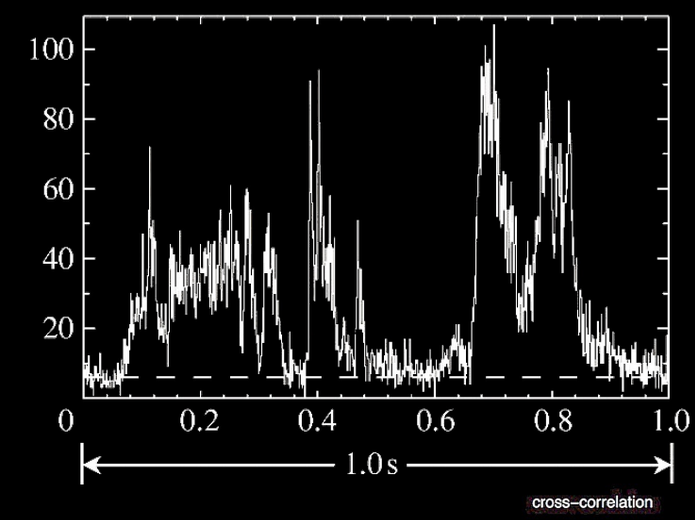
Experiment concept



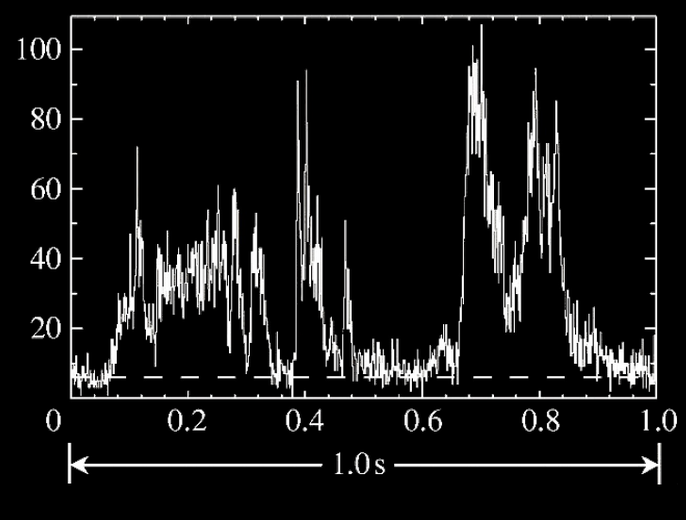
Experiment concept

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

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

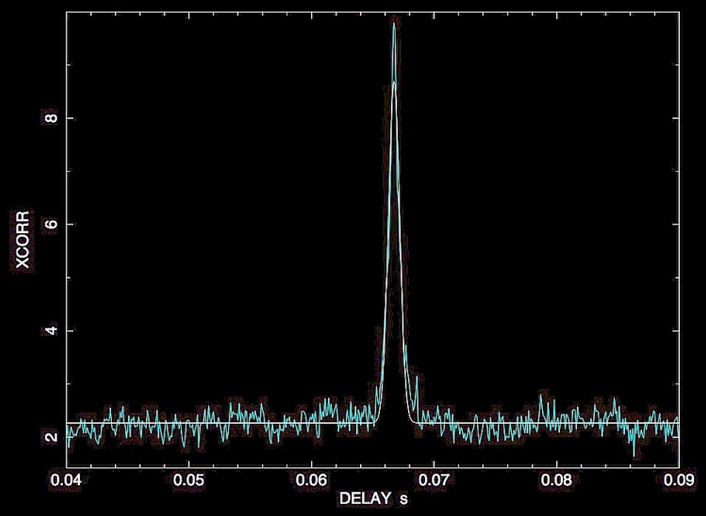


+



cross-correlation

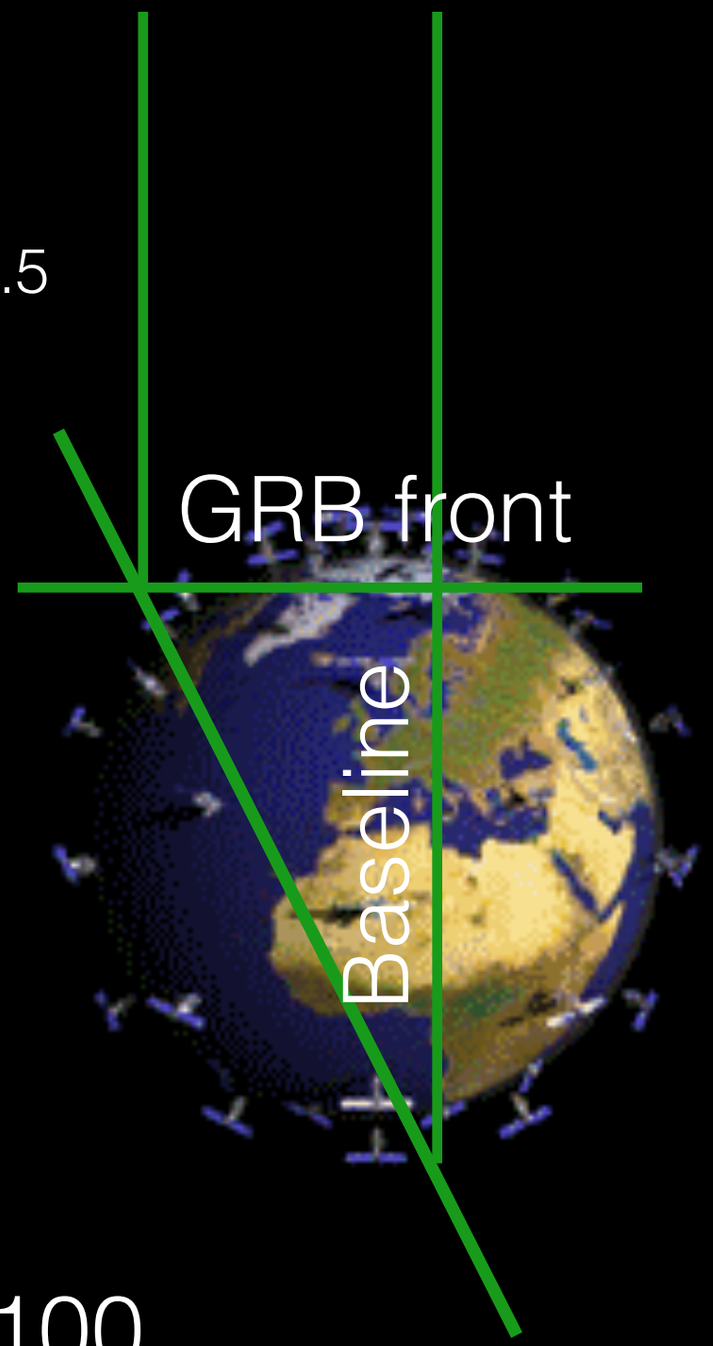
=



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

$\sigma_{Pos} \sim 10 arcsec$

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



Experiment concept

2. Add the signal from different units

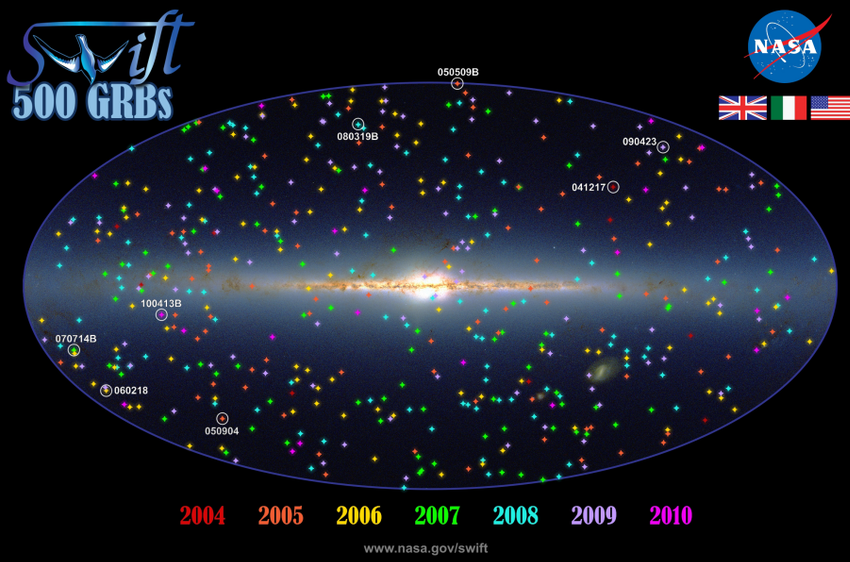
Total collecting area 50-100-cm^2 x 100-200 = 0.5-2 m^2

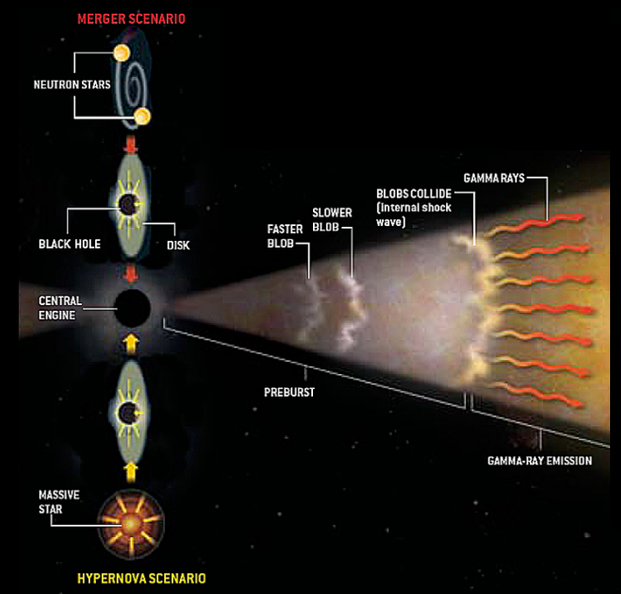
Experiment concept

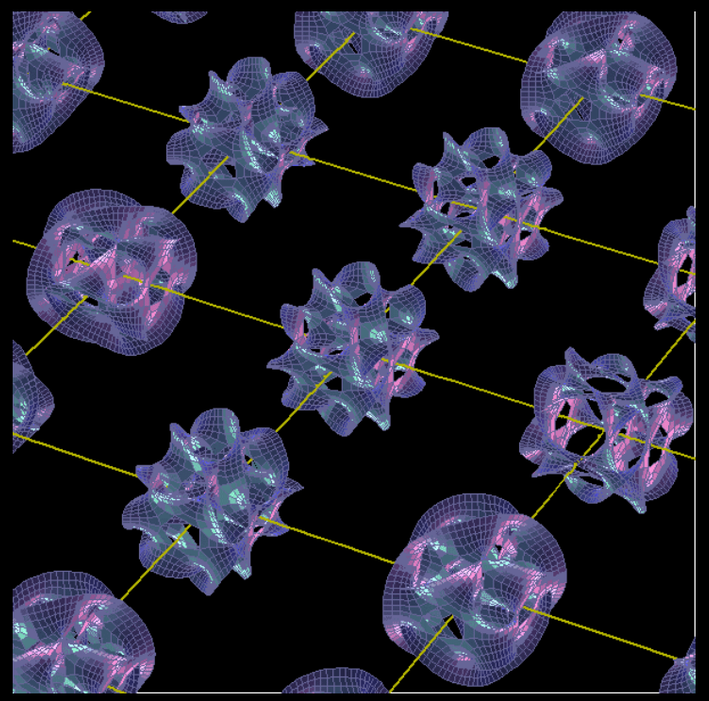
2. Add the signal from different units

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

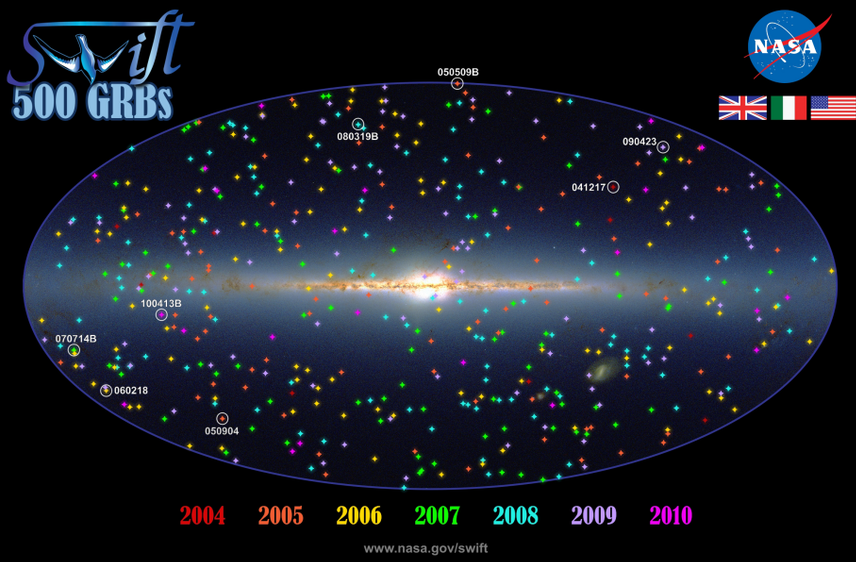
Transient fine (subμs-ms) temporal structure

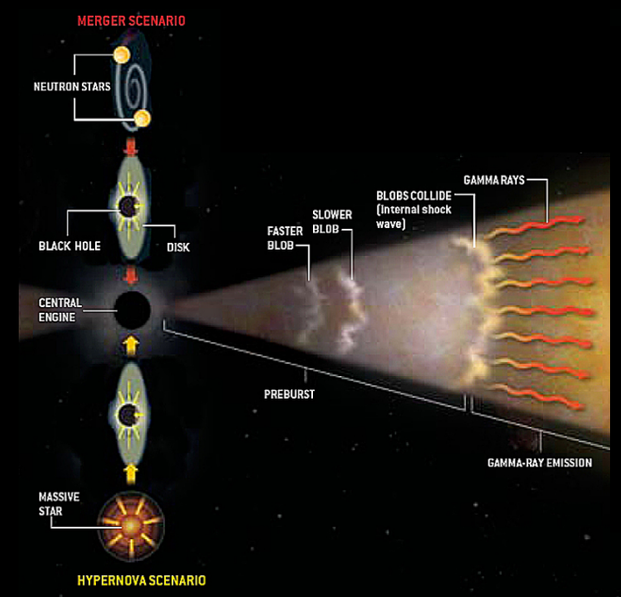

Swift
500 GRBs
050509B
080319B
090423
041217
100413B
070714B
060218
050904
2004
2005
2006
2007
2008
2009
2010
www.nasa.gov/swift

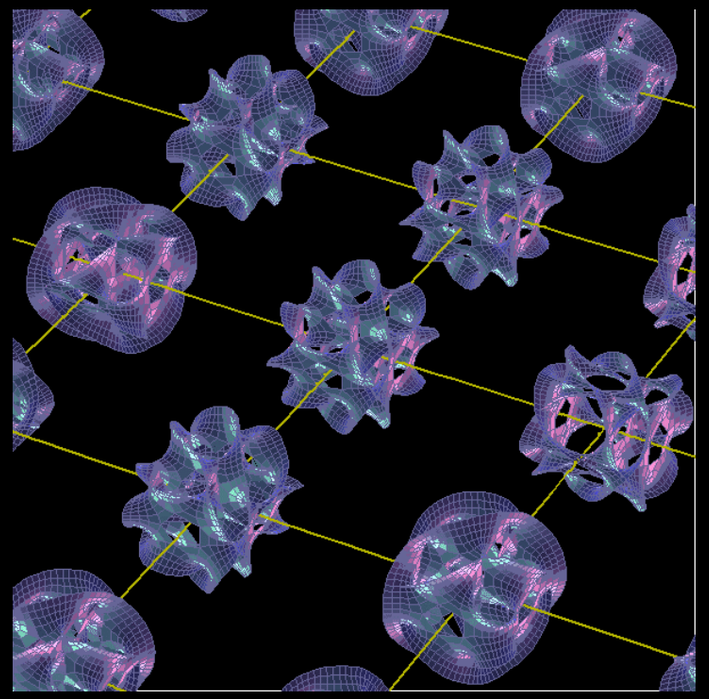

MERGER SCENARIO
NEUTRON STARS
BLACK HOLE
DISK
CENTRAL ENGINE
MASSIVE STAR
HYPERNOVA SCENARIO
FASTER BLOB
SLOWER BLOB
BLOBS COLLIDE (Internal shock wave)
GAMMA RAYS
PREBURST
GAMMA-RAY EMISSION



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

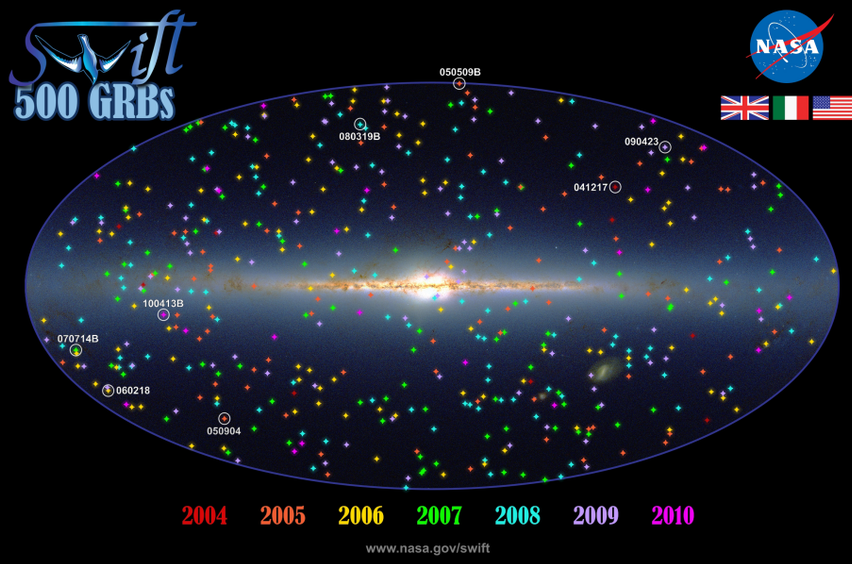


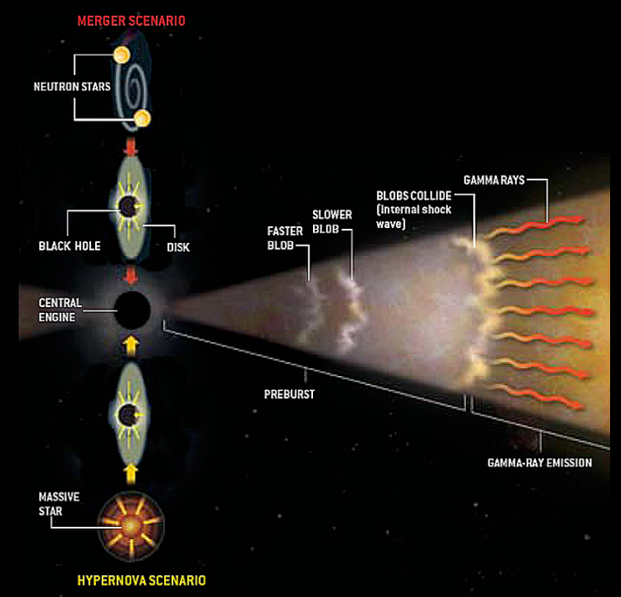


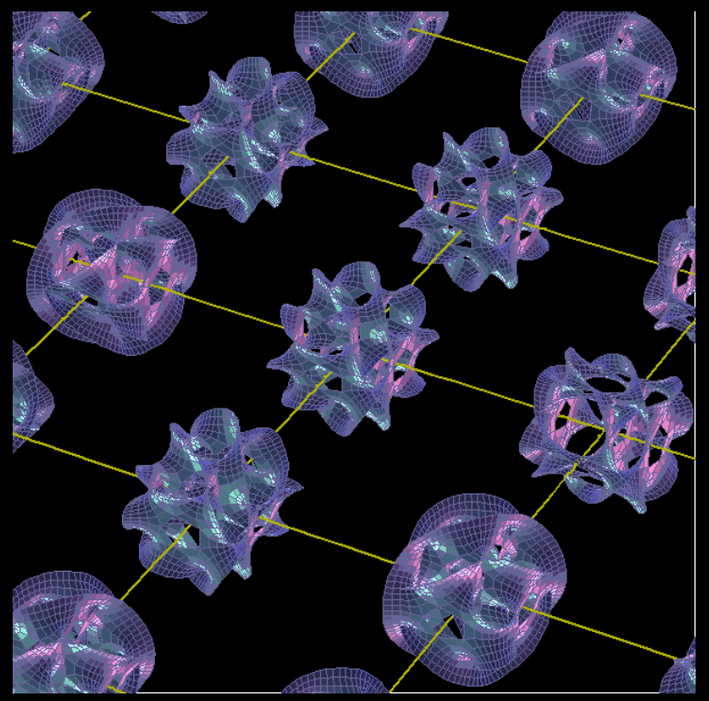


How to *promptly* localise a GRB *prompt* event?

How to construct a GRB engine?



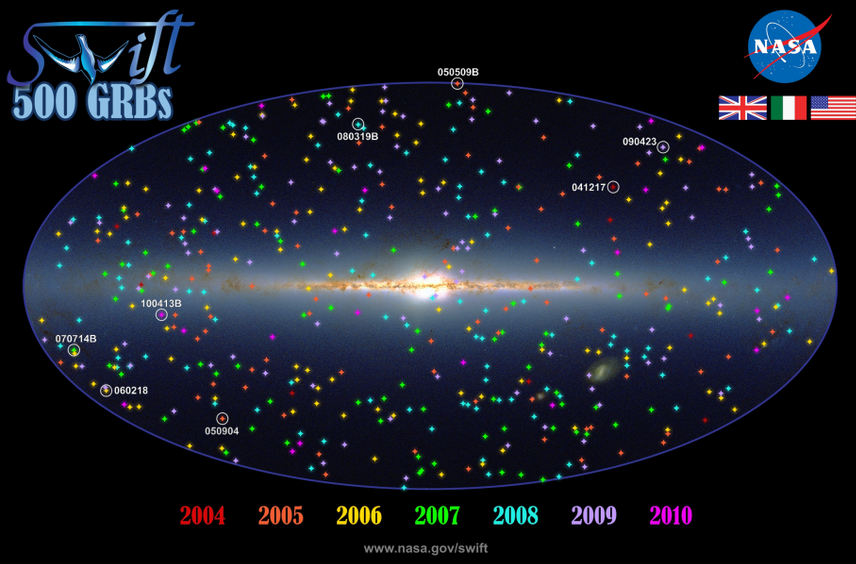


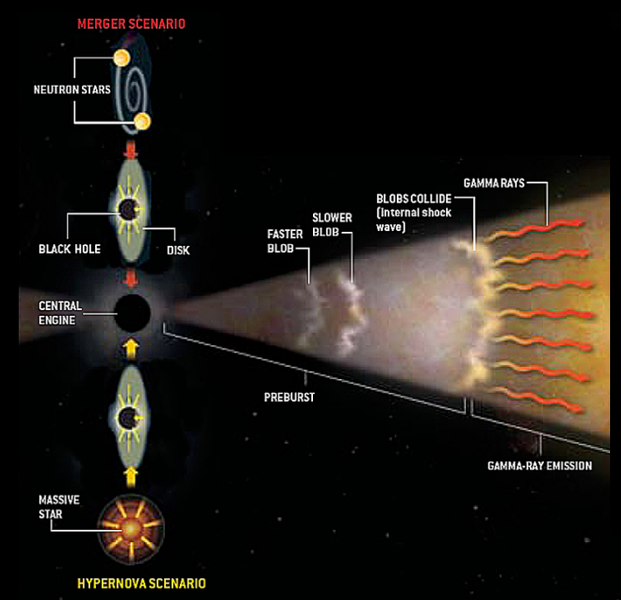


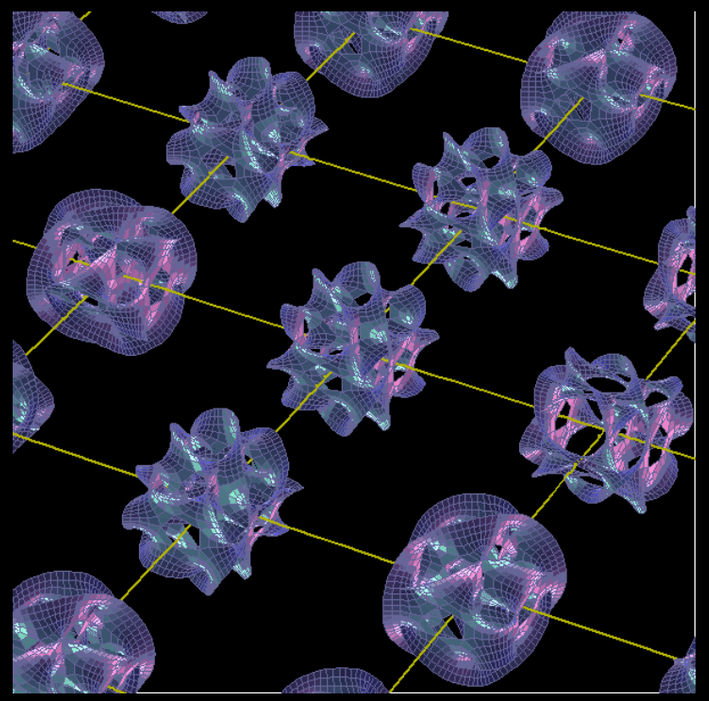
How to *promptly* localise a GRB *prompt* event?

How to construct a GRB engine?

Which is the ultimate granular structure of space-time?







Requirements

Scientific:

Requirements

Scientific:

Arcmin positions of ~a few dozen GRB/yr

Requirements

Scientific:

Arcmin positions of ~a few dozen GRB/yr

Prompt(minute) localisation

Requirements

Scientific:

Arcmin positions of ~a few dozen GRB/yr

Prompt(minute) localisation

sub-μs timing

Requirements

System:

Requirements

System:

≈from a few to hundreds detectors

Requirements

System:

≈from a few to hundreds detectors

single collecting area ≥50cm^2

Requirements

System:

≈from a few to hundreds detectors

single collecting area ≥50cm^2

total collecting area ≥1m^2

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

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

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 < 30m

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 < 30m

Absolute time reconstruction <100 ns

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 < 30m

Absolute time reconstruction <100 ns

Download full burst info in minutes

Spacecraft

Spacecraft

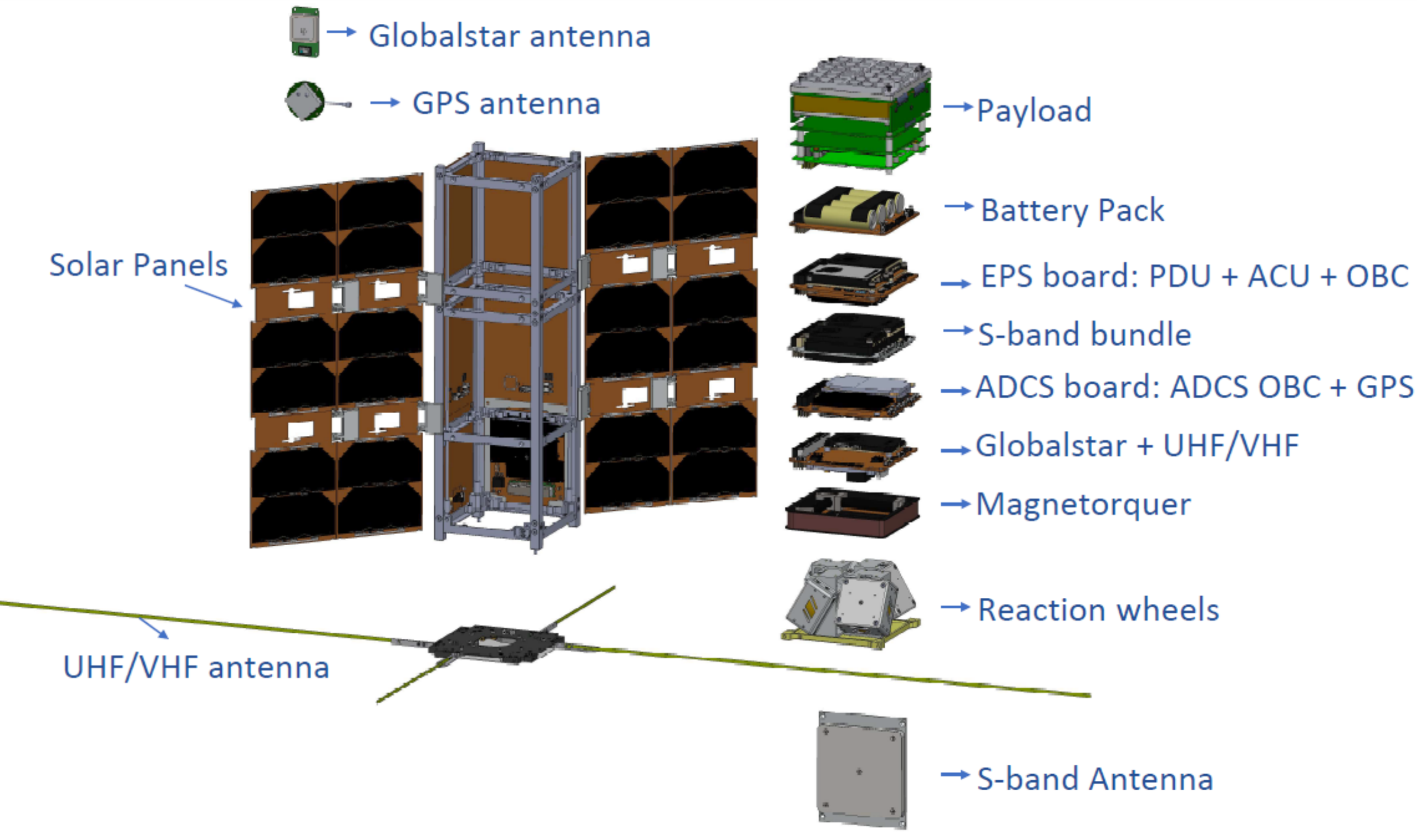
3U minimum, simplest basic configuration
50 cm^2 detector: Pathfinder

Spacecraft

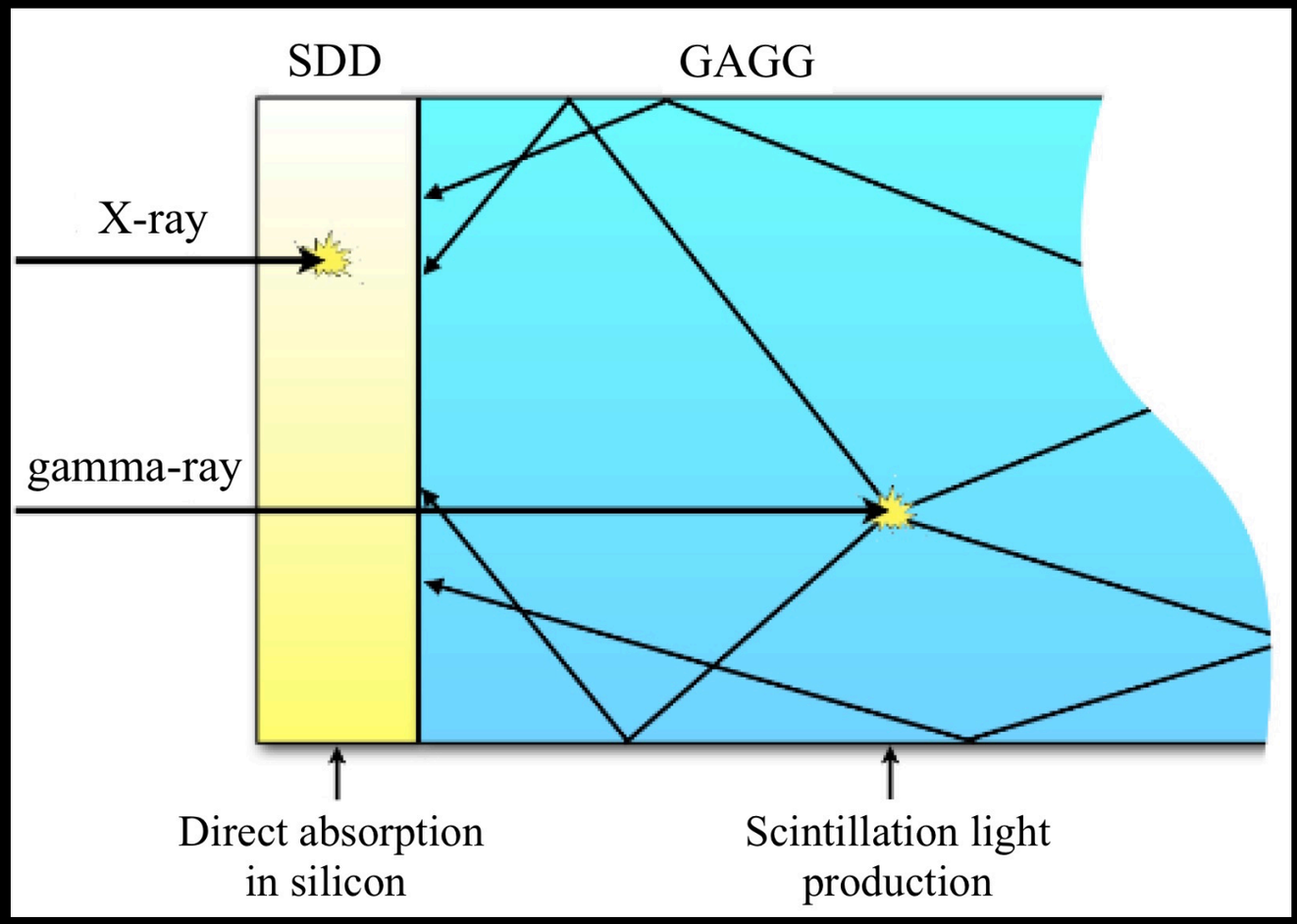
3U minimum, simplest basic configuration
50 cm^2 detector: Pathfinder

6U more performing configuration
~200cm^2 detector, more accurate GPS, more accurate AOCS: Full Constellation

Spacecraft


Globalstar antenna
GPS antenna
Solar Panels
Payload
Battery Pack
EPS board: PDU + ACU + OBC
S-band bundle
ADCS board: ADCS OBC + GPS
Globalstar + UHF/VHF
Magnetorquer
Reaction wheels
UHF/VHF antenna
S-band Antenna

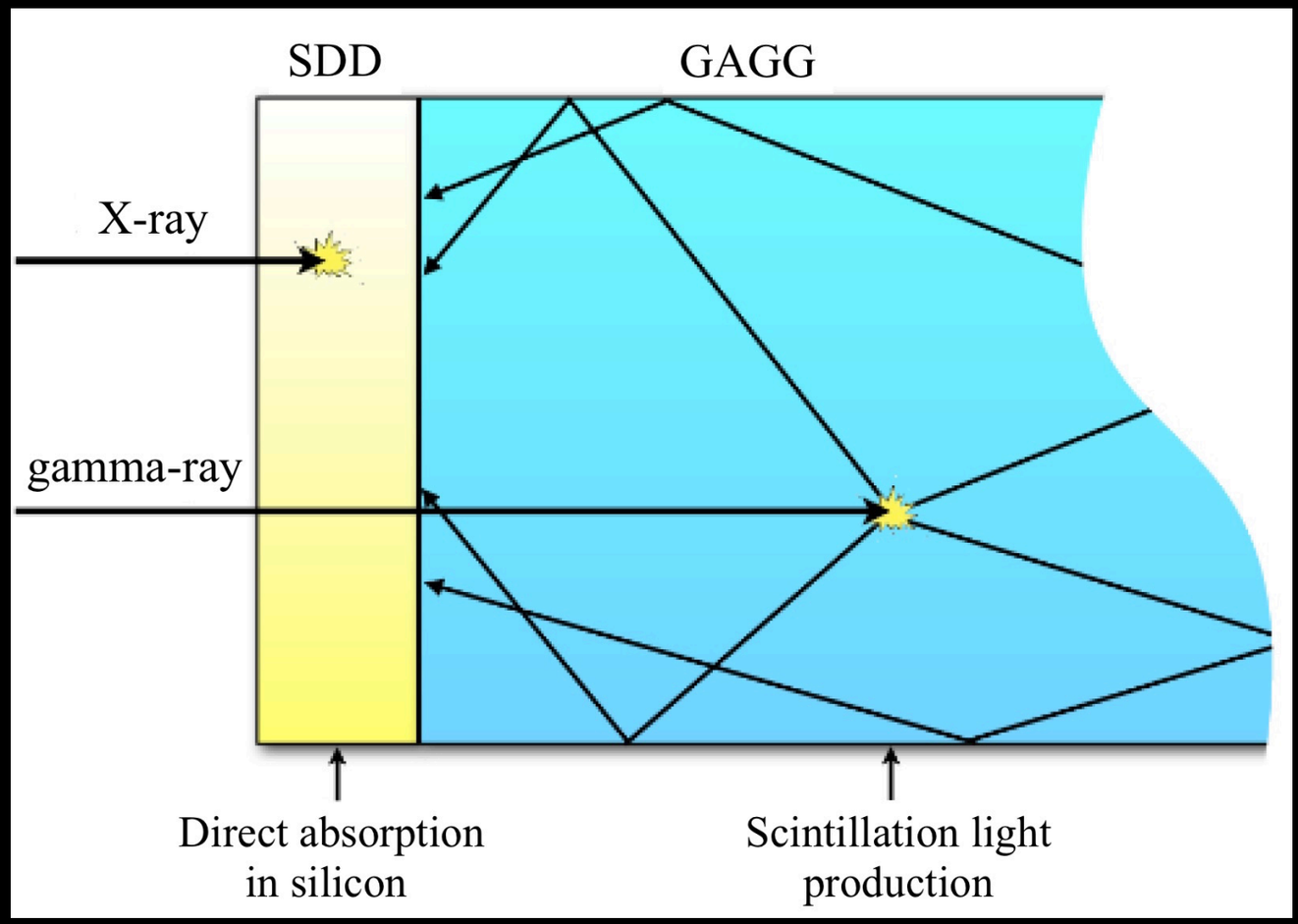
Payload concept



Fuschino+2018, 2020
Evangelista+2020
Campana+2020

Payload concept

- Photo detector, SDD
  Scintillator crystal GAGG

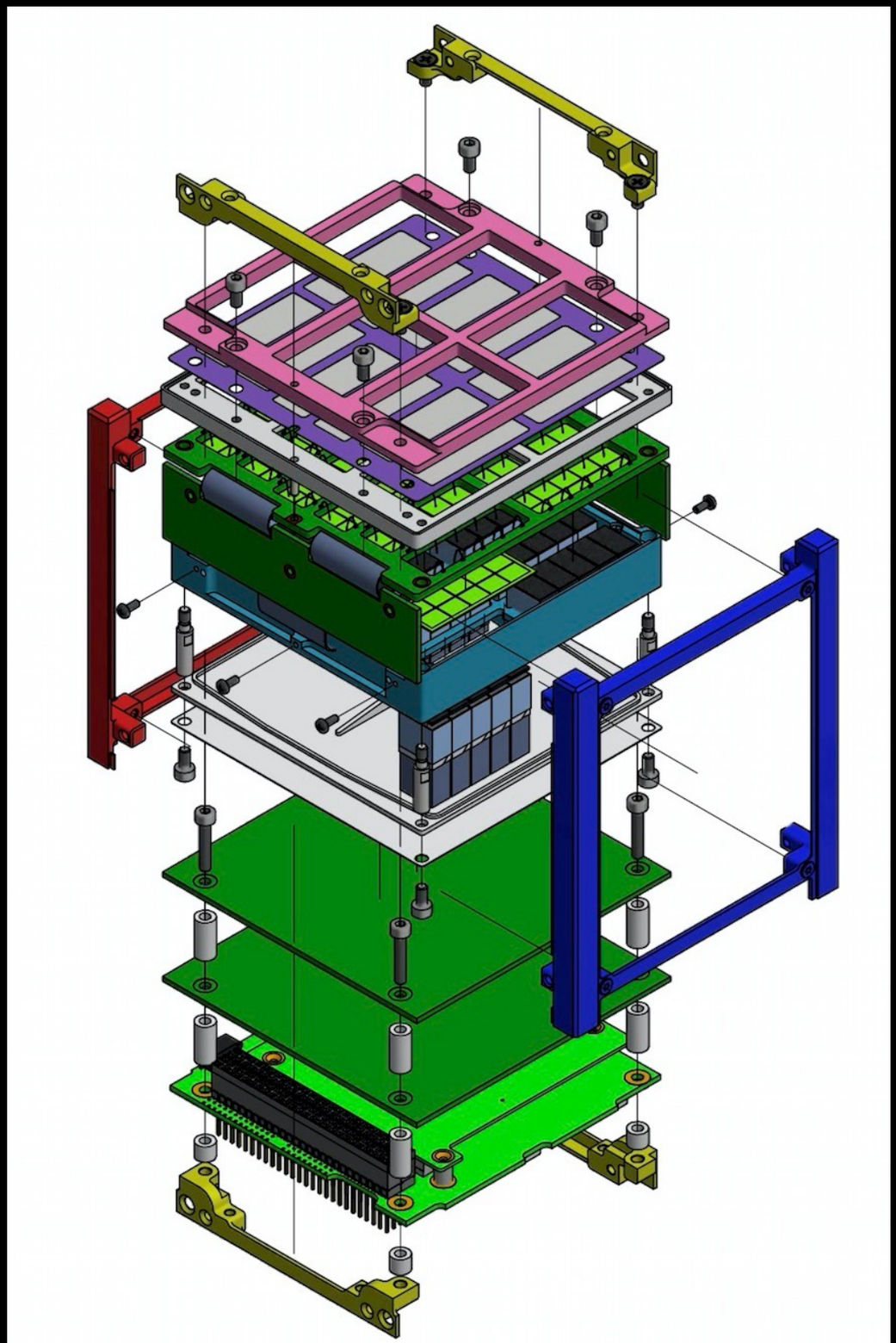


Fuschino+2018, 2020
Evangelista+2020
Campana+2020

Payload concept

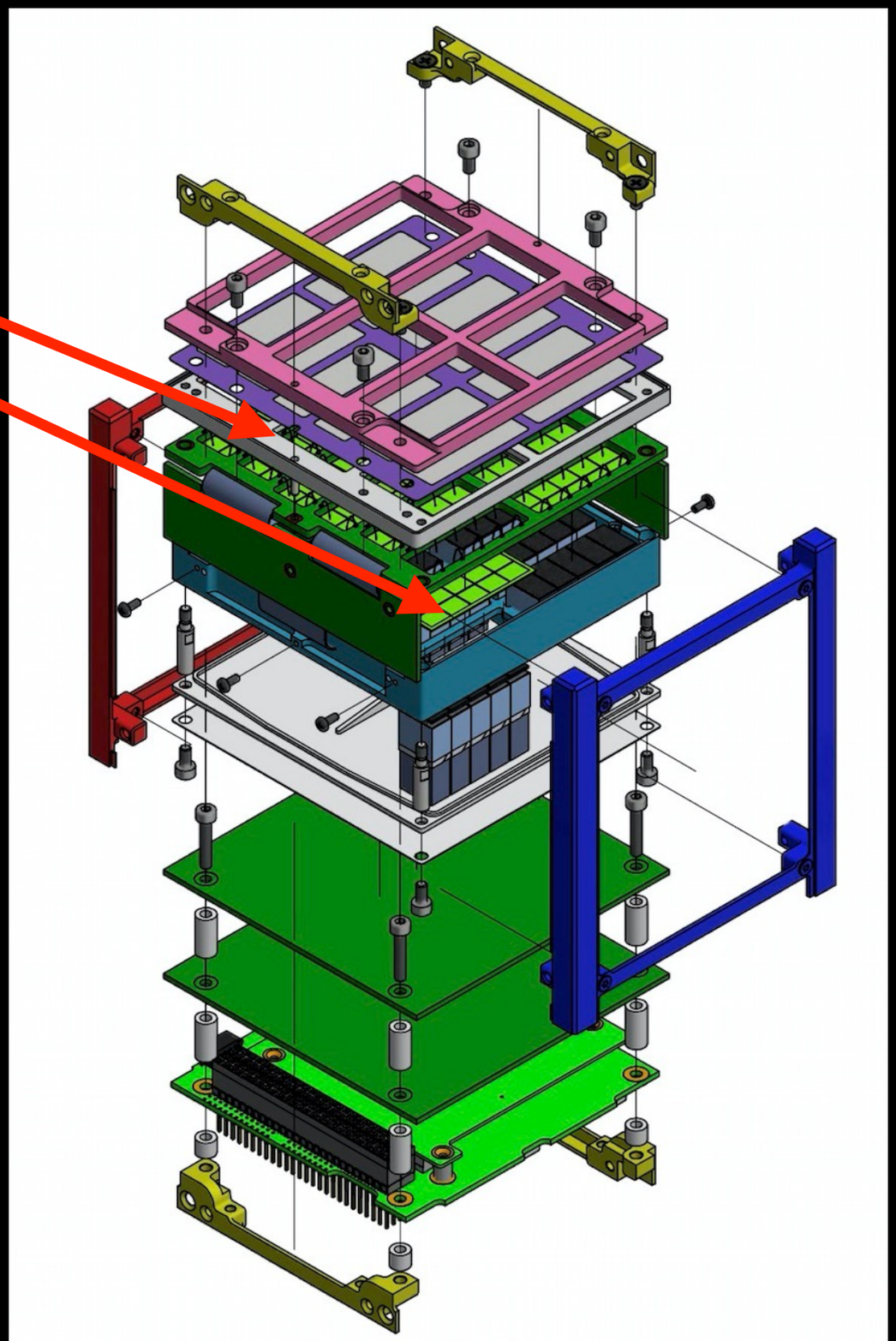
- Photo detector, SDD
  Scintillator crystal GAGG

Fuschino+2018, 2020
Evangelista+2020
Campana+2020



Payload concept

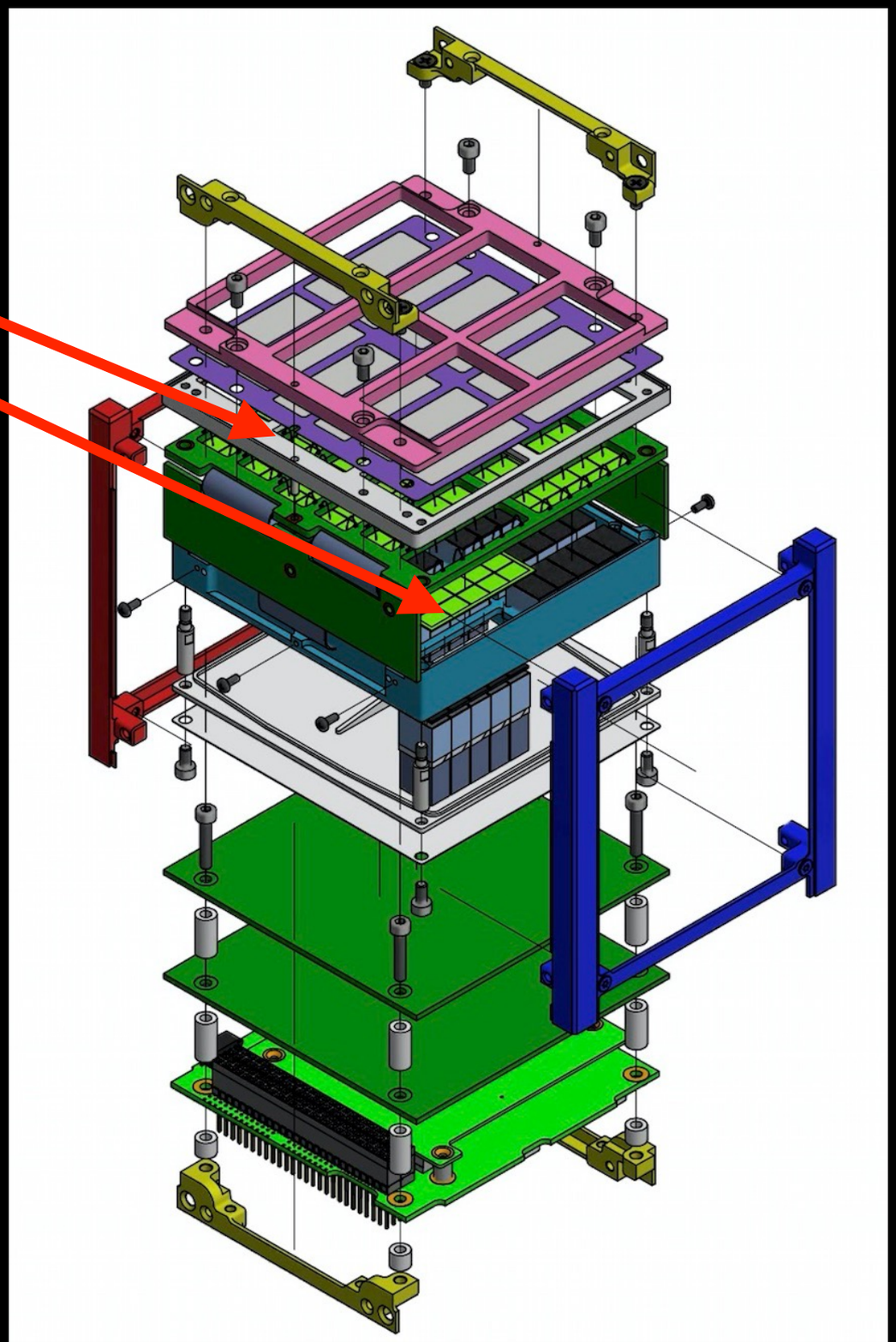
- Photo detector, SDD
  Scintillator crystal GAGG



Fuschino+2018, 2020
Evangelista+2020
Campana+2020

Payload concept

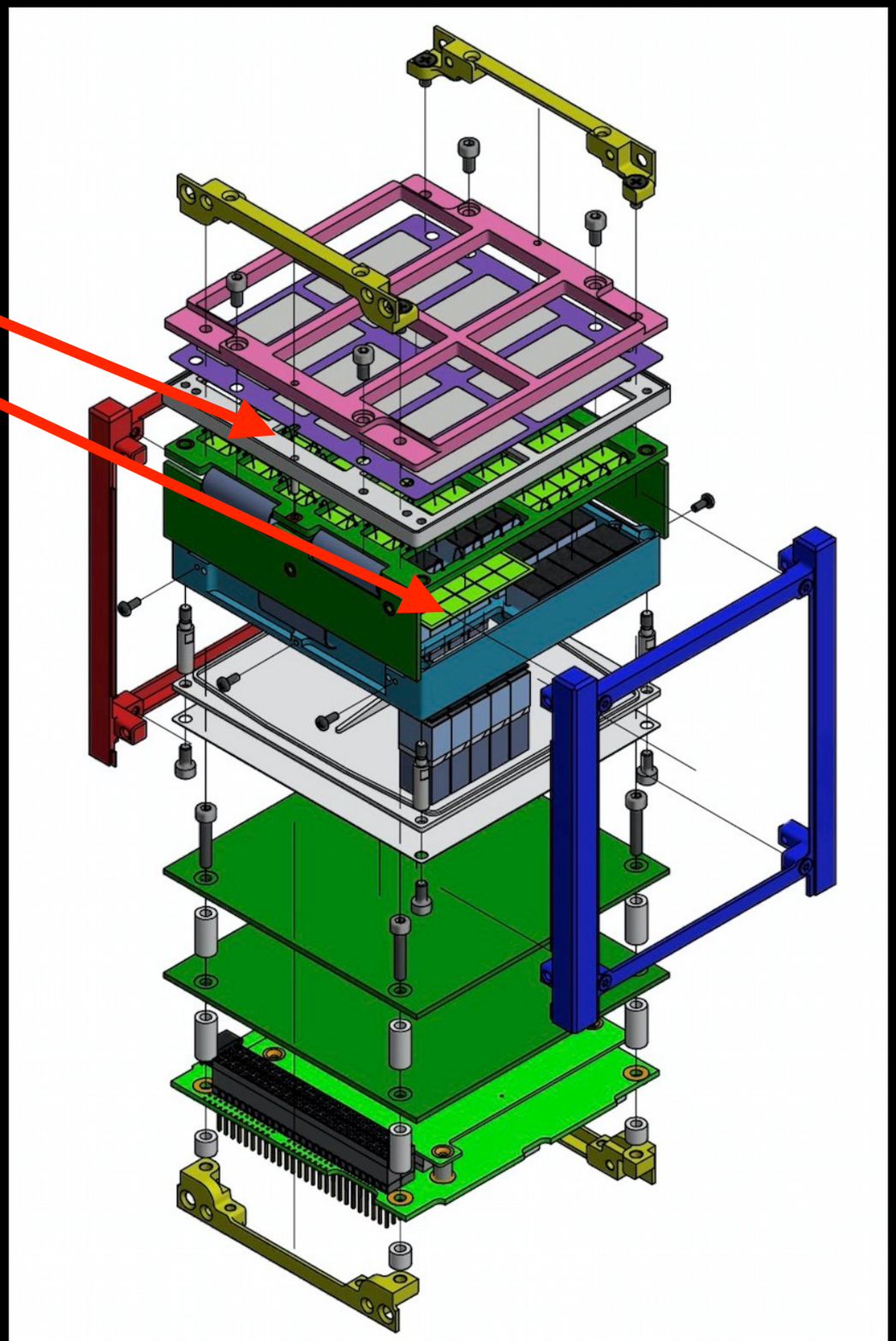
- Photo detector, SDD
  Scintillator crystal GAGG
- 5-300 keV (3-1000 keV)



Fuschino+2018, 2020
Evangelista+2020
Campana+2020

Payload concept

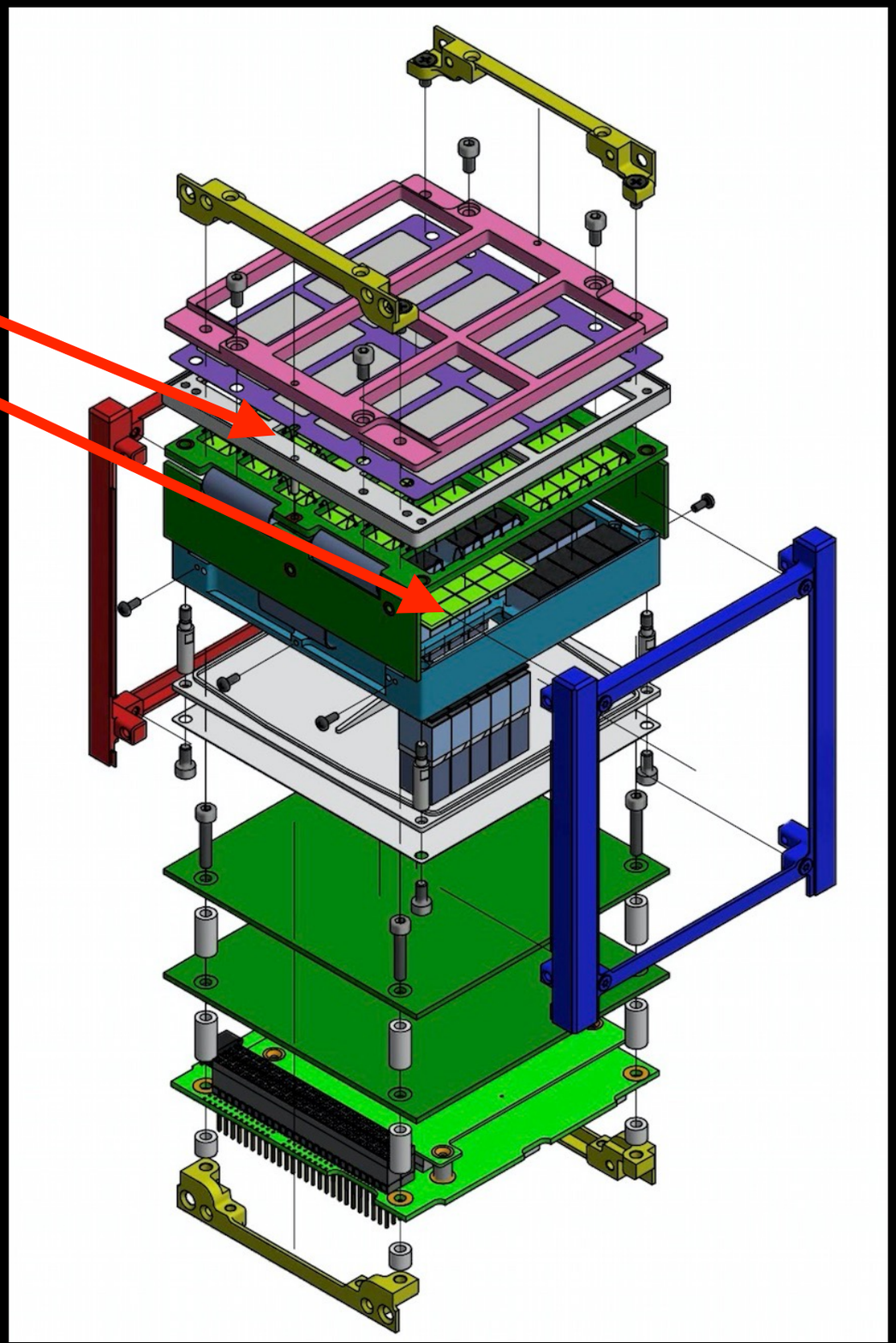
- Photo detector, SDD
  Scintillator crystal GAGG
- 5-300 keV (3-1000 keV)
- ≥50 cm^2 coll. area



Fuschino+2018, 2020
Evangelista+2020
Campana+2020

Payload concept

- Photo detector, SDD
  Scintillator crystal GAGG
- 5-300 keV (3-1000 keV)
- ≥50 cm^2 coll. area
- a few st FOV

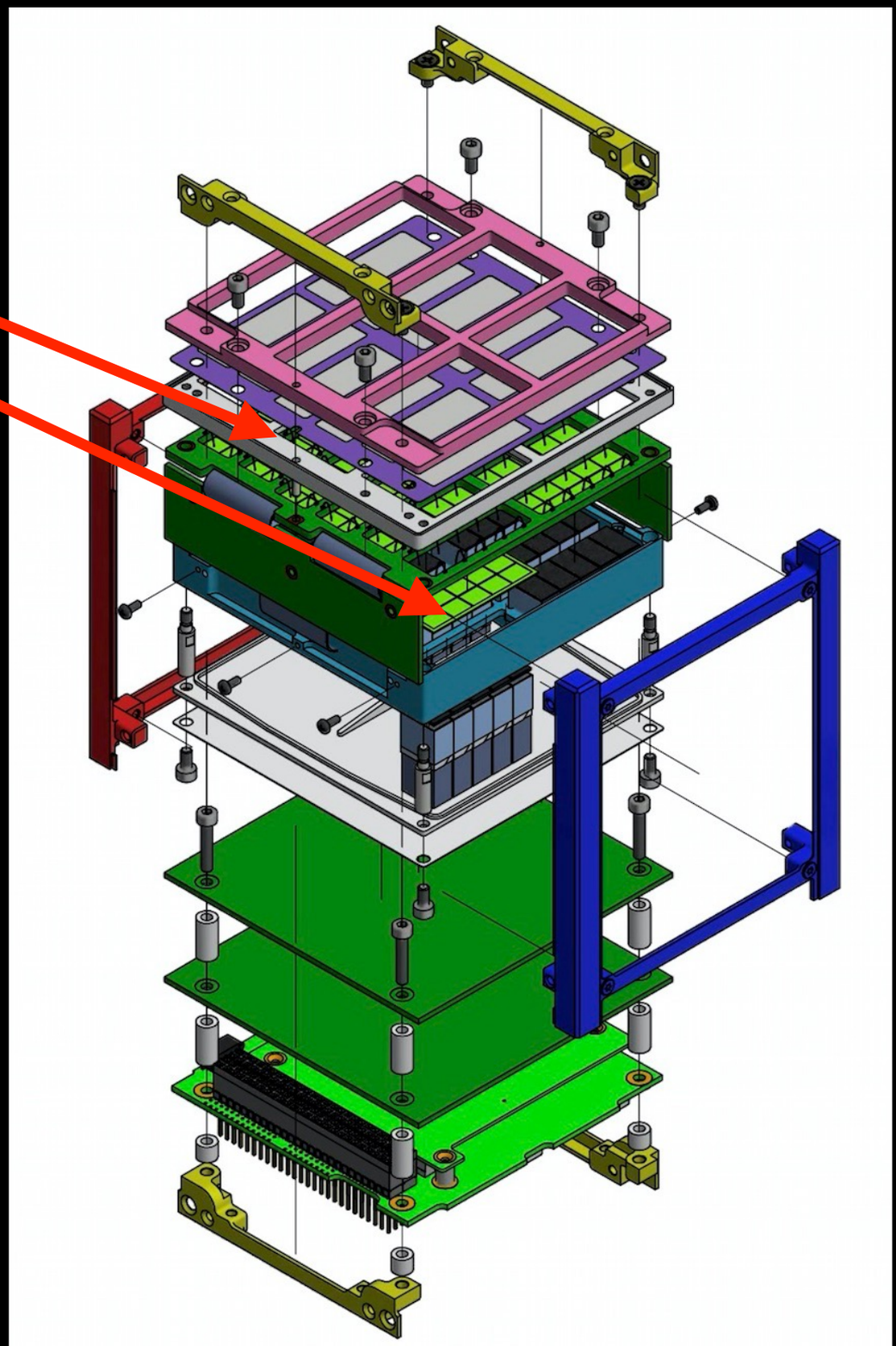


Fuschino+2018, 2020
Evangelista+2020
Campana+2020

Payload concept

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

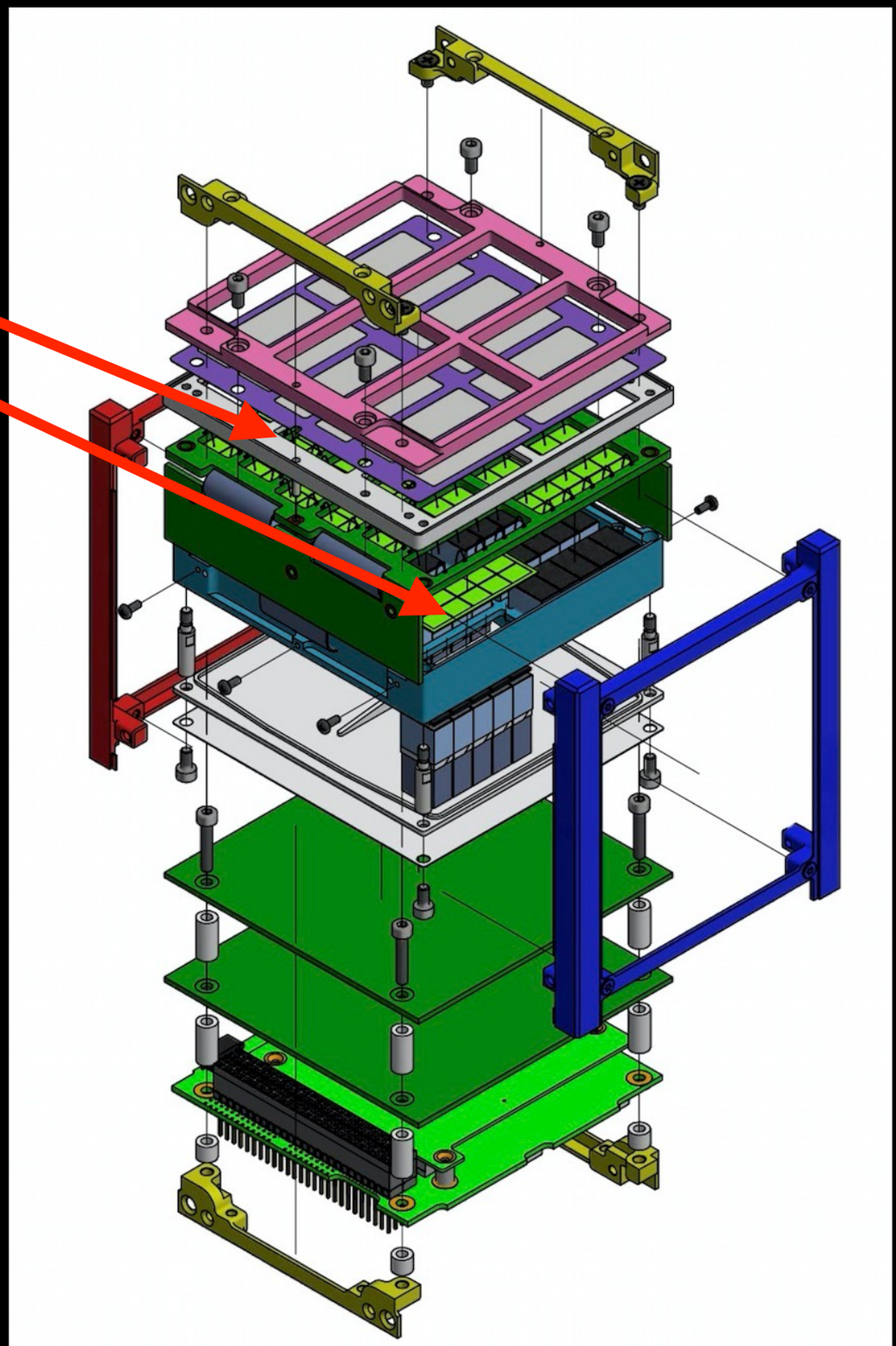
Fuschino+2018, 2020
Evangelista+2020
Campana+2020



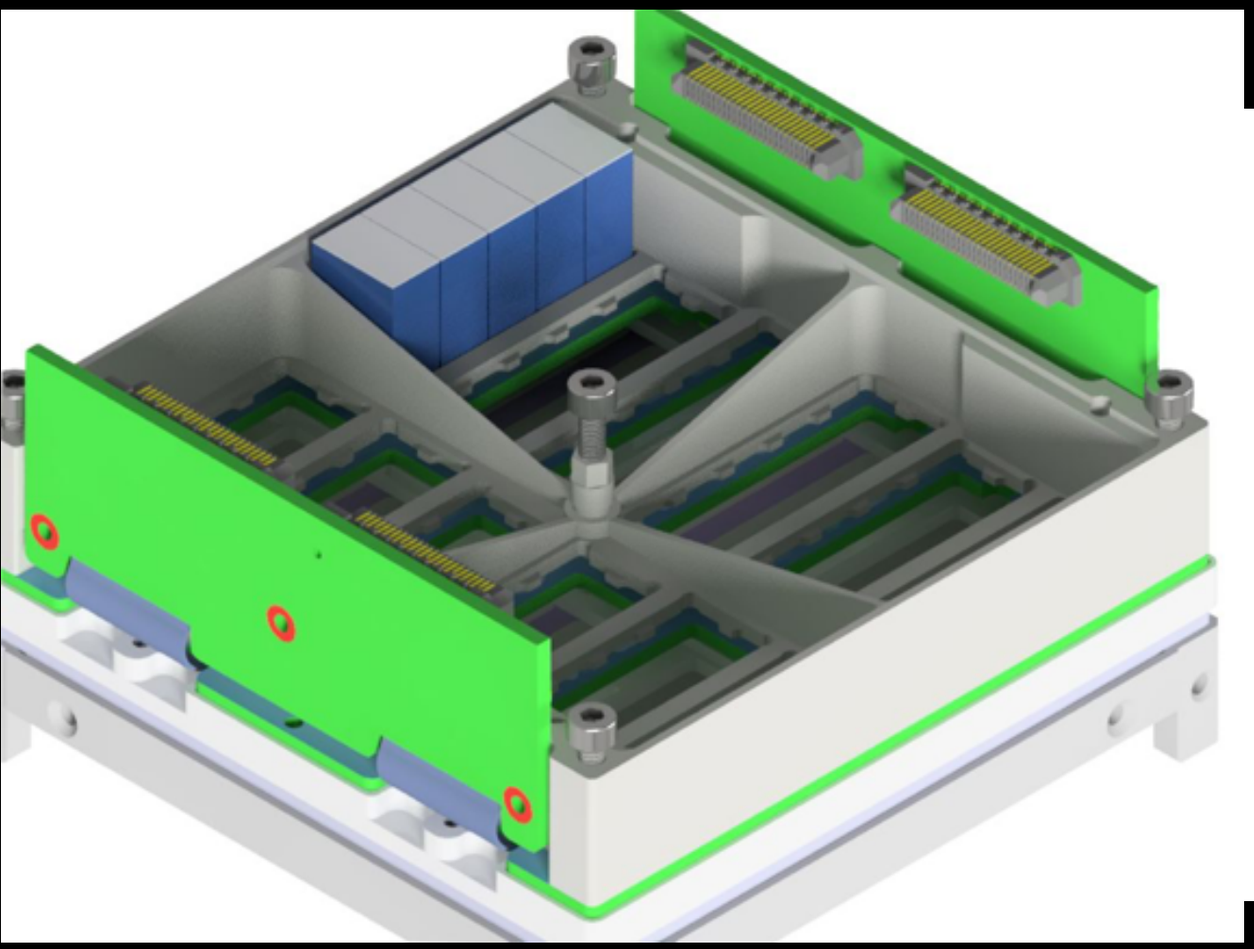
Payload concept

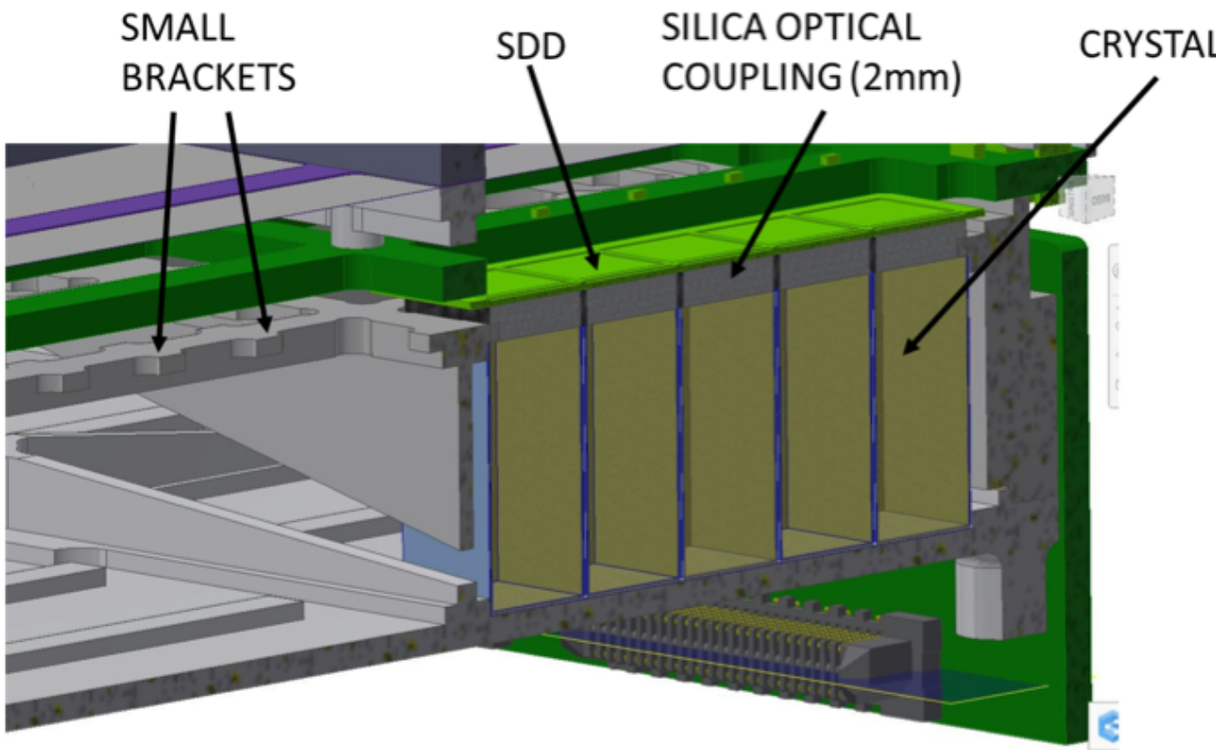
- Photo detector, SDD
  Scintillator crystal GAGG
- 5-300 keV (3-1000 keV)
- ≥50 cm^2 coll. area
- a few st FOV
- Temporal res. ≤300 nsec
- ~1.6kg

Fuschino+2018, 2020
Evangelista+2020
Campana+2020

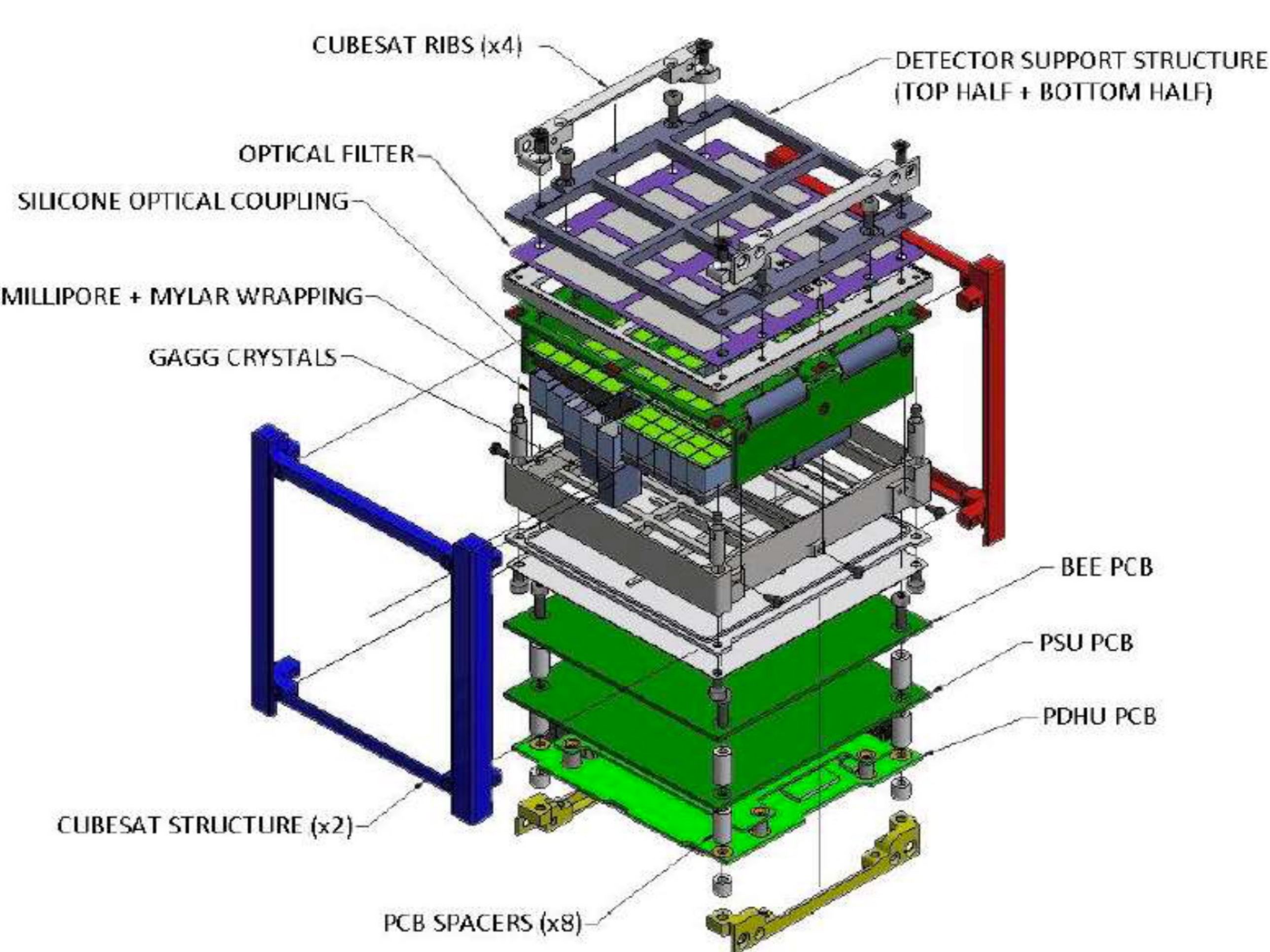


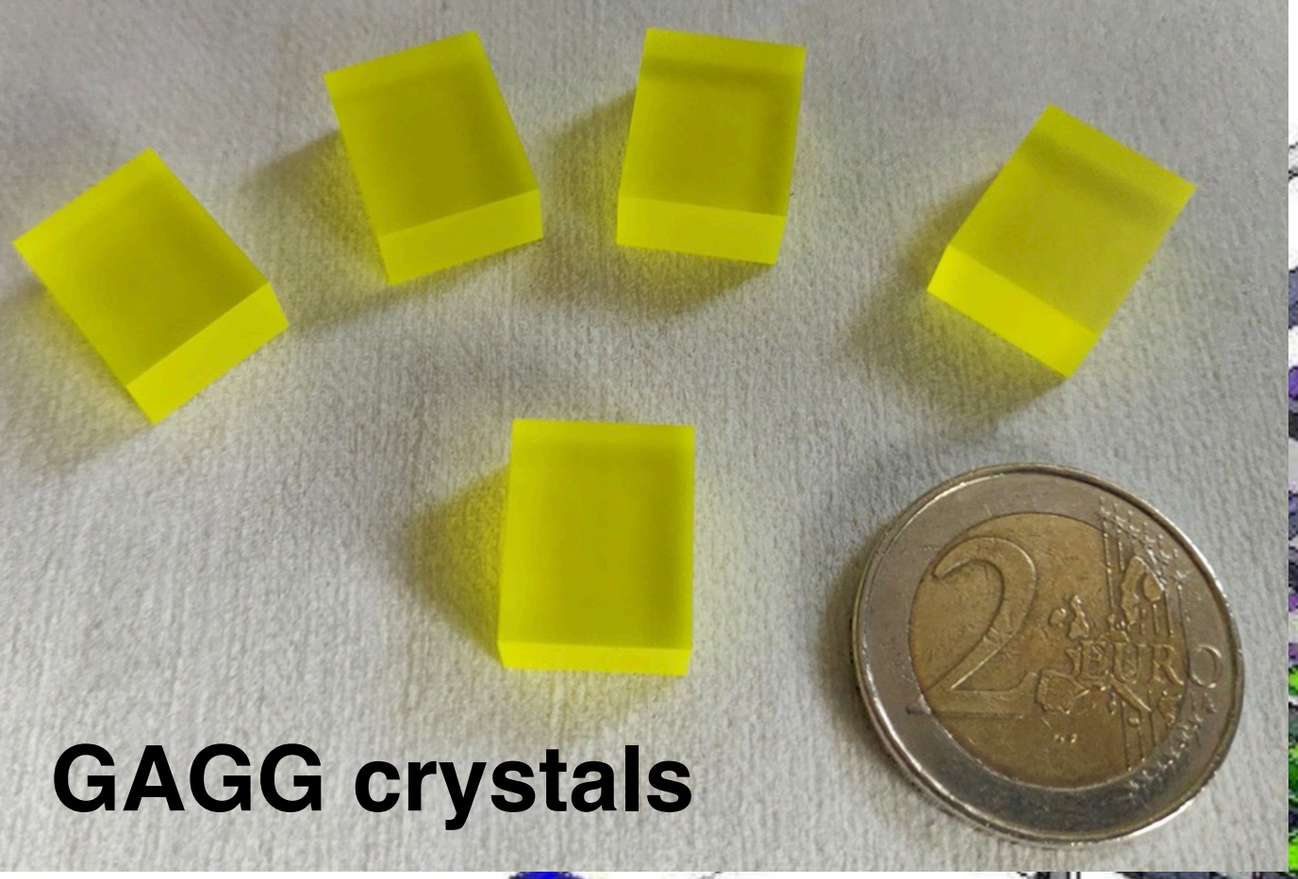
Detector design

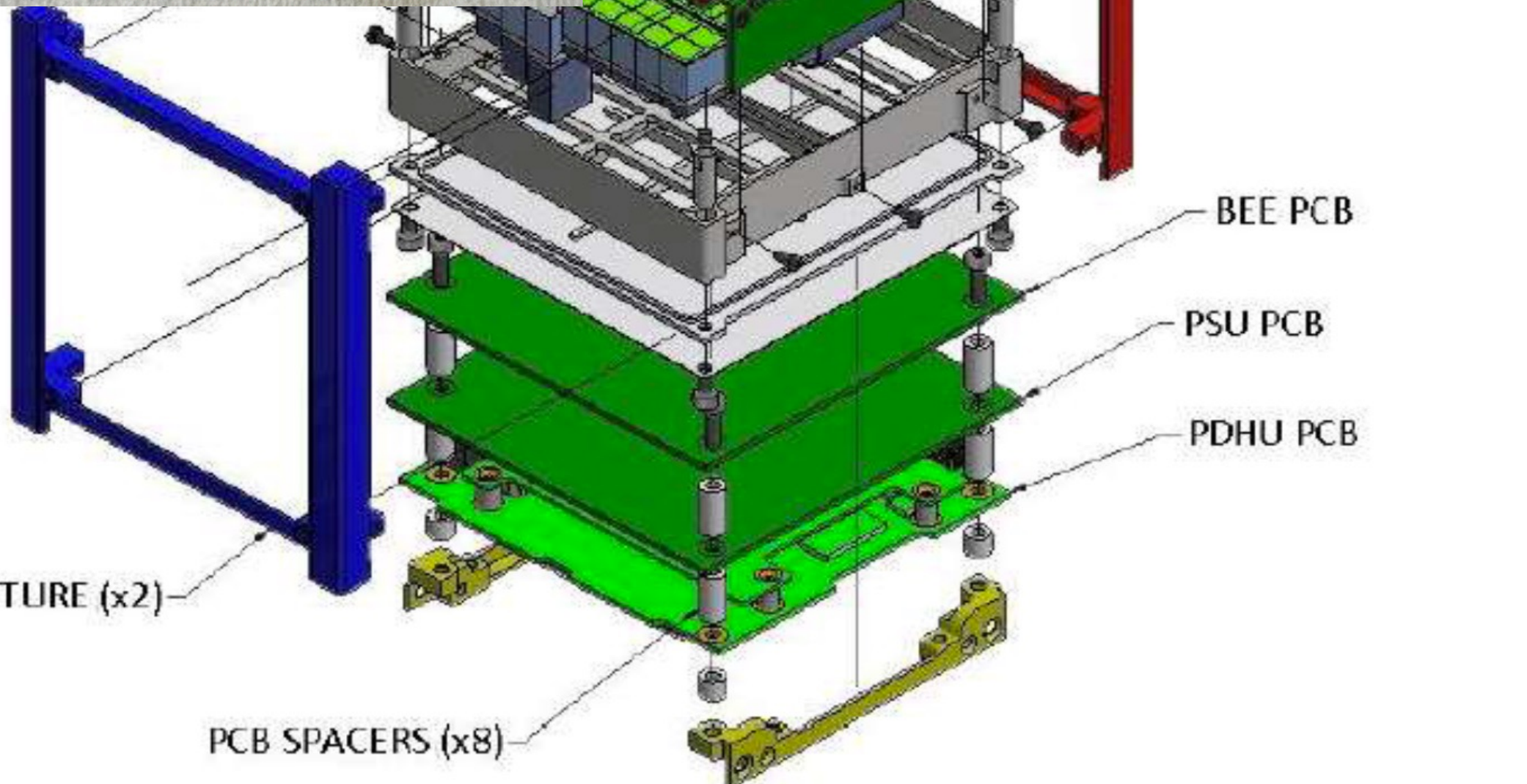


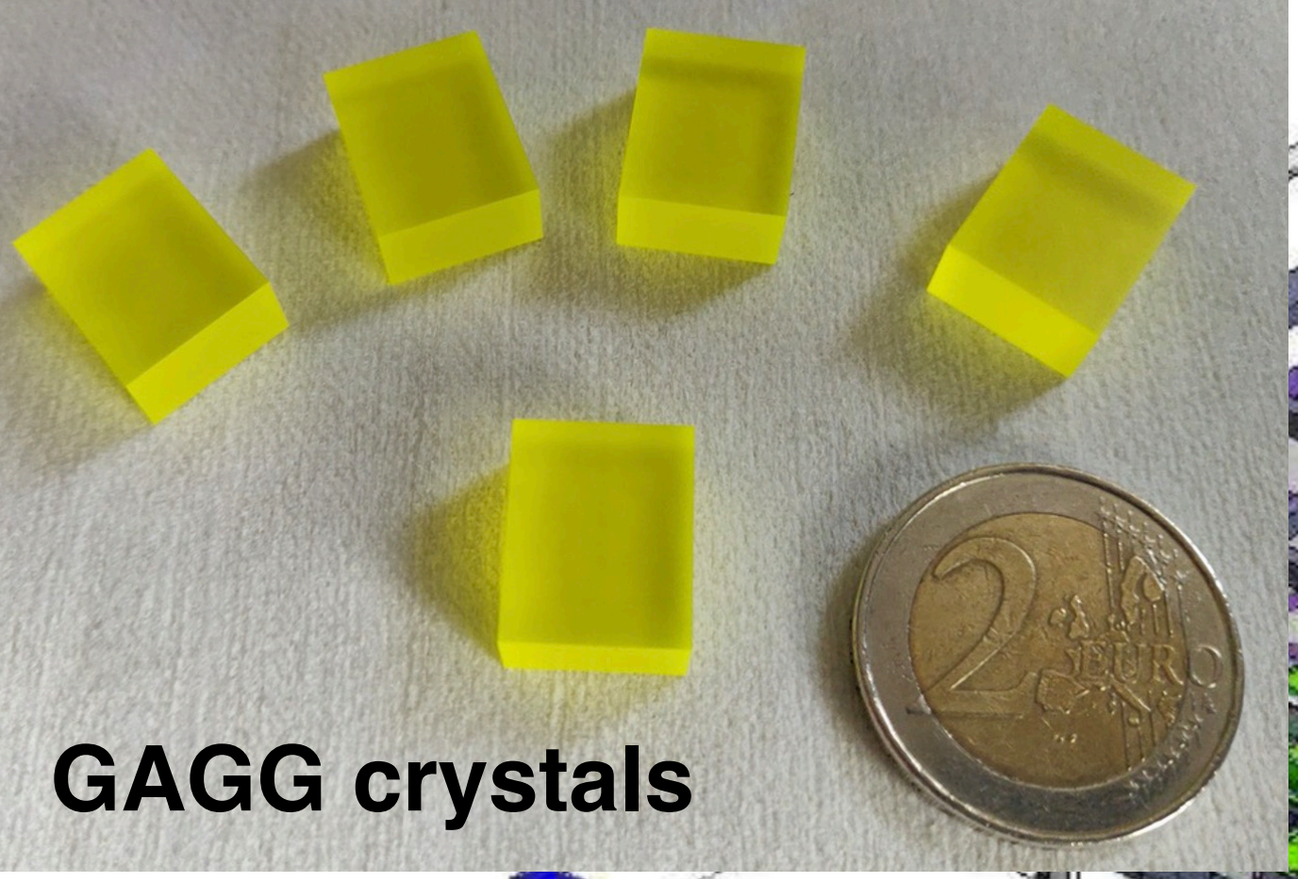


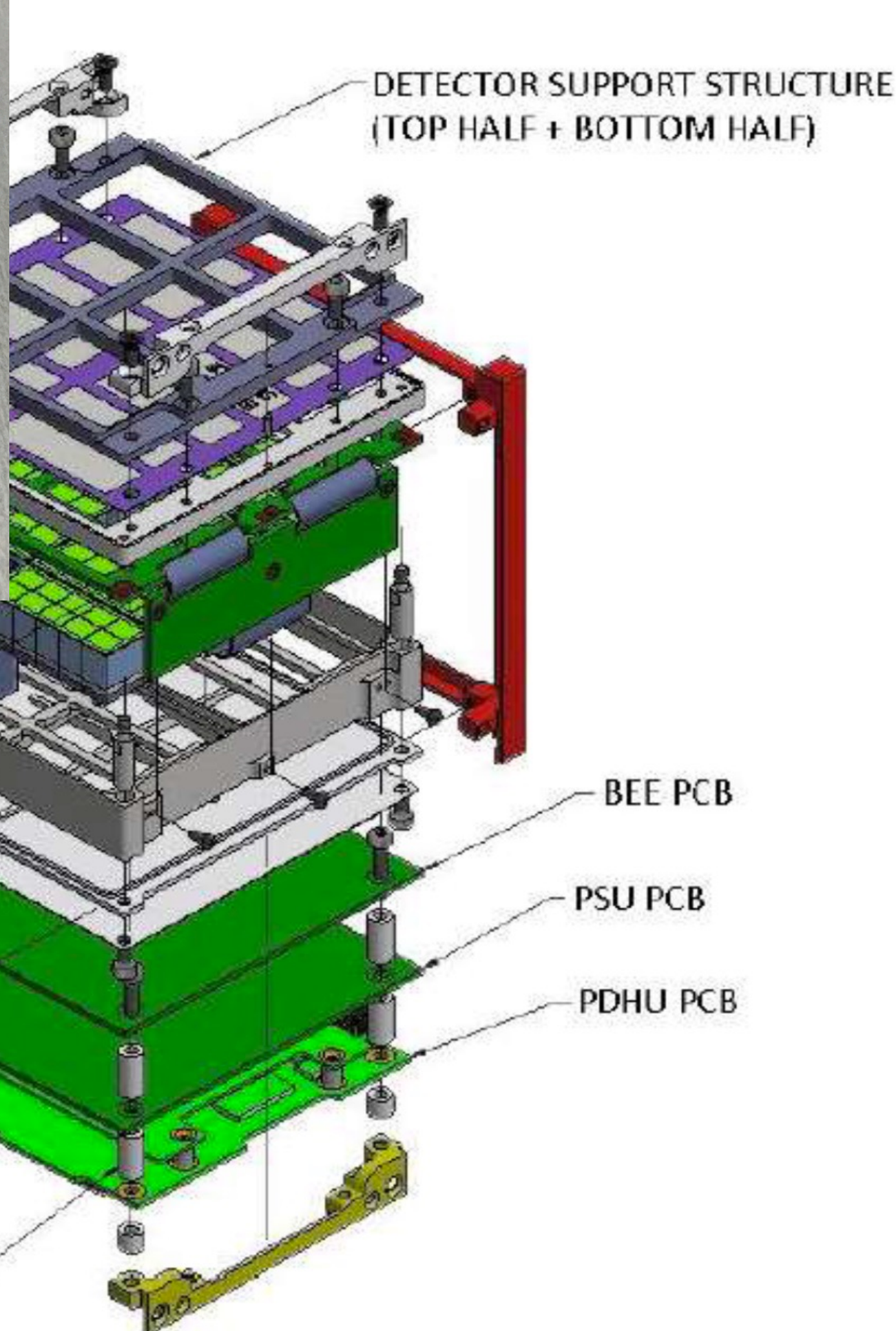
Stainless stell crystal box + tungsten layers on bottom and sides to reduce X-ray background

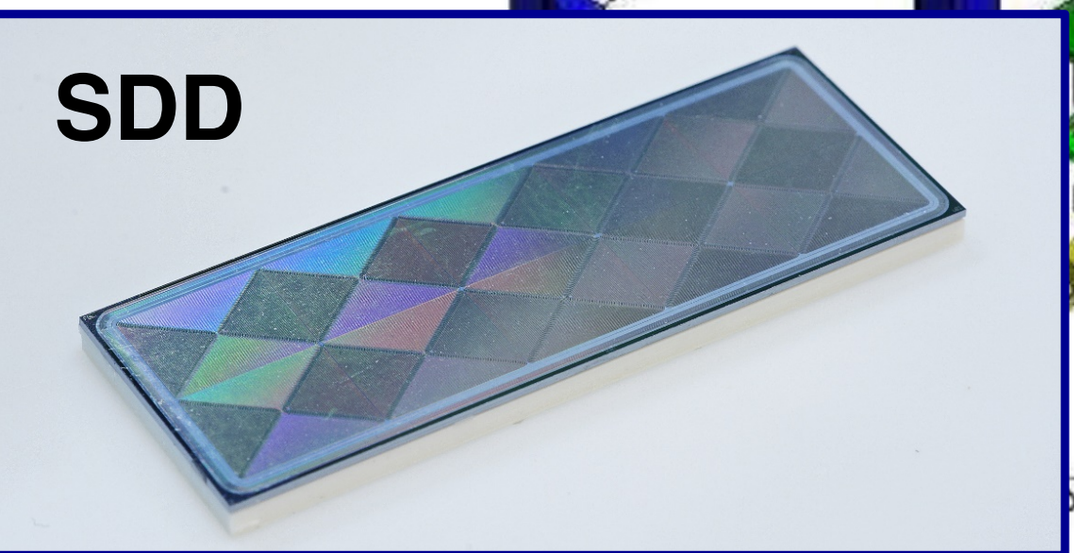

CUBESAT RIBS (x4)
DETECTOR SUPPORT STRUCTURE
(TOP HALF + BOTTOM HALF)
OPTICAL FILTER
SILICONE OPTICAL COUPLING
MILLIPORE + MYLAR WRAPPING
GAGG CRYSTALS
BEE PCB
PSU PCB
PDHU PCB
CUBESAT STRUCTURE (x2)
PCB SPACERS (x8)

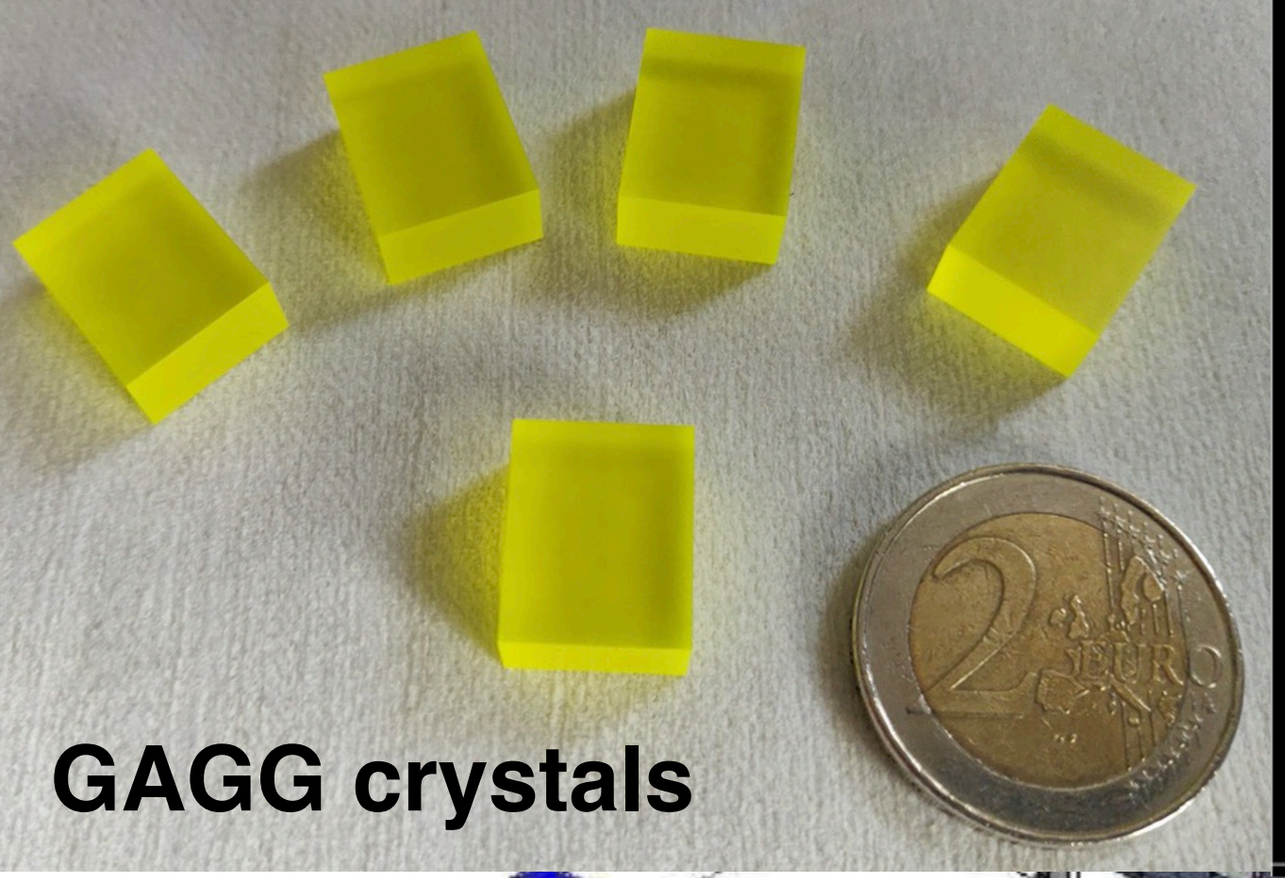

GAGG crystals

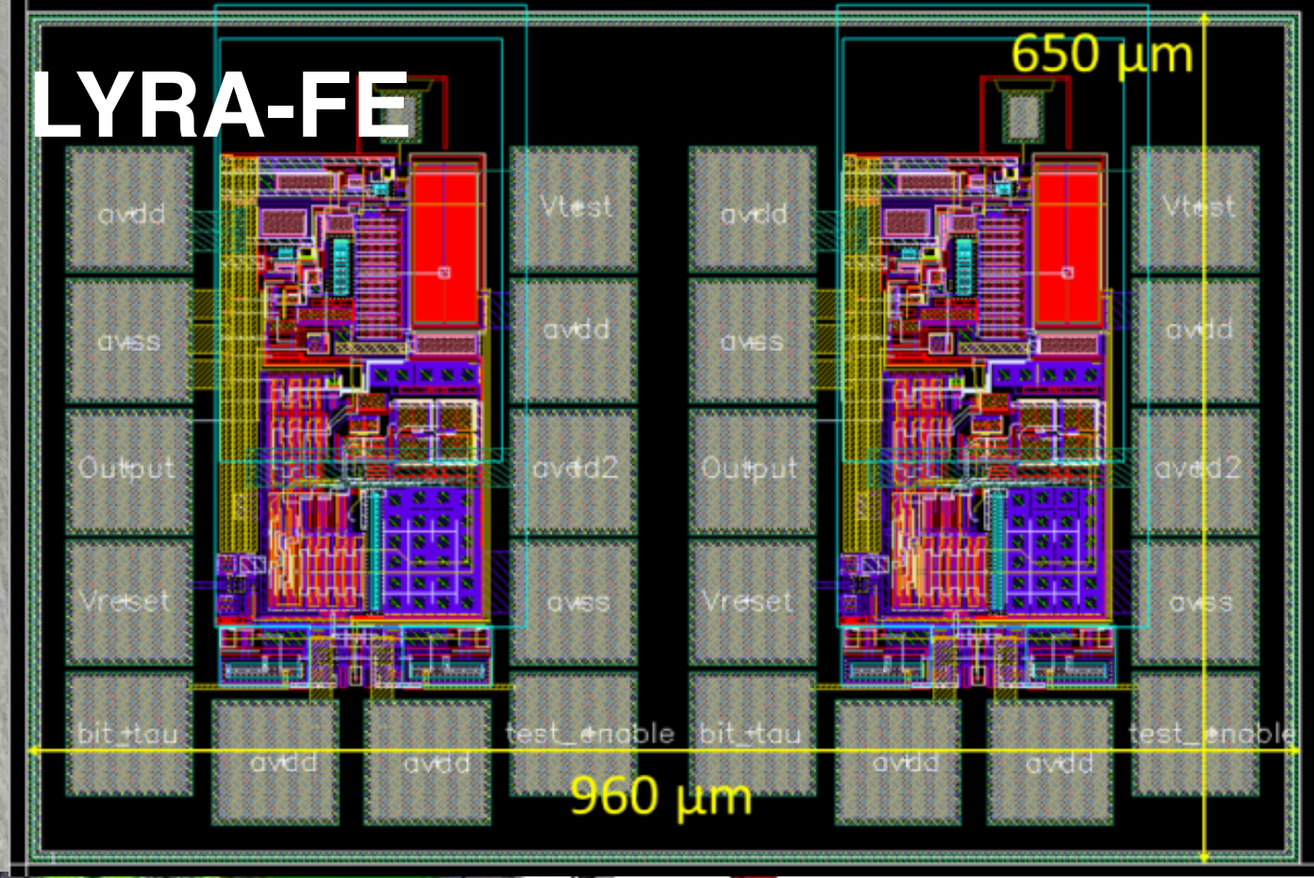

DETECTOR SUPPORT STRUCTURE
(TOP HALF + BOTTOM HALF)
BEE PCB
PSU PCB
PDHU PCB
CUBESAT STRUCTURE (x2)
PCB SPACERS (x8)

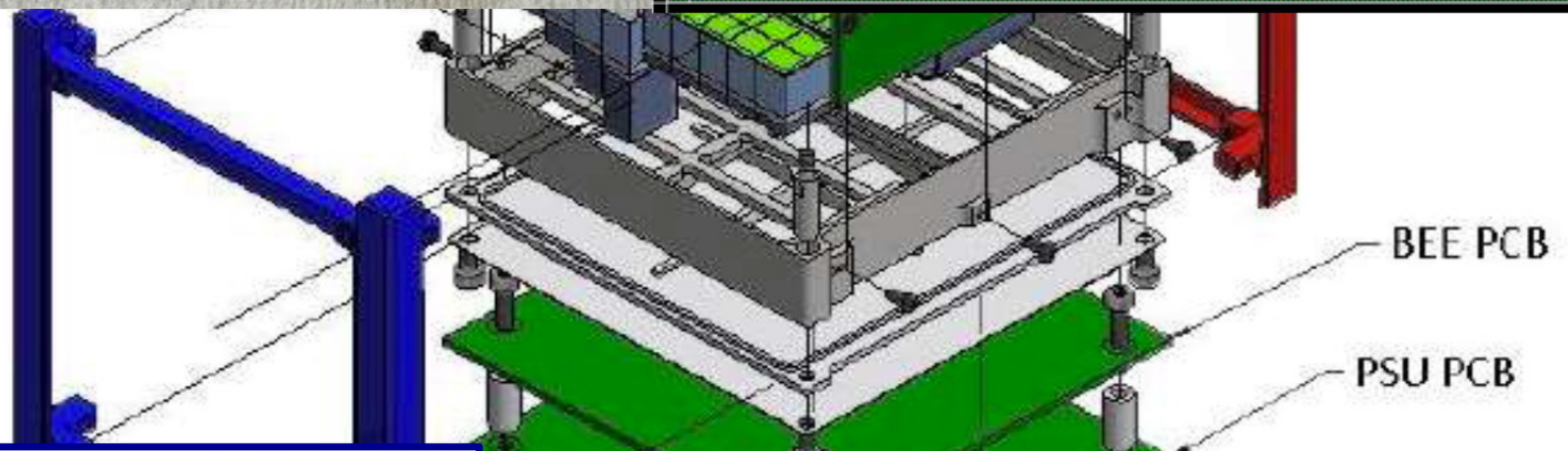

GAGG crystals

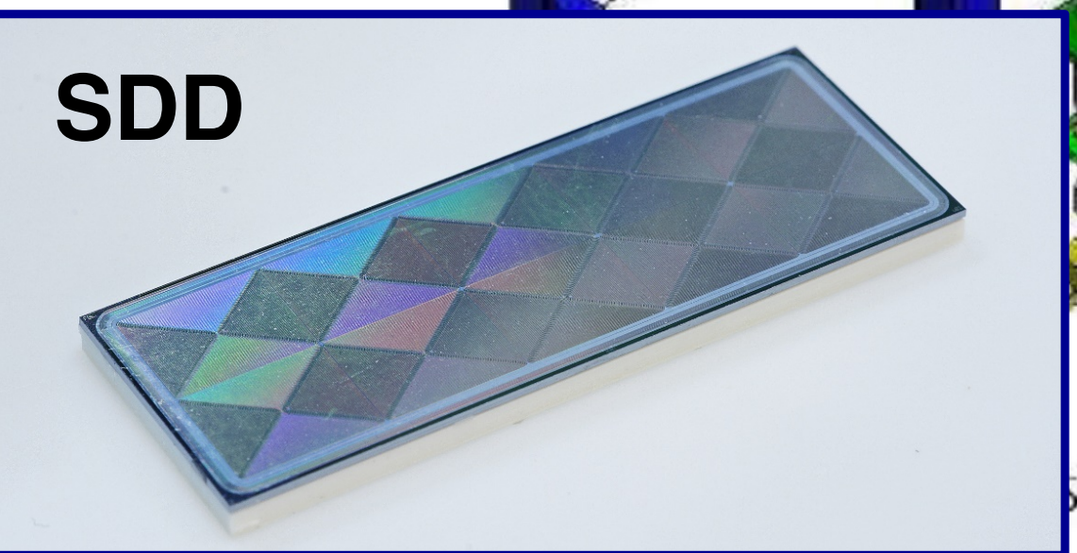

DETECTOR SUPPORT STRUCTURE
(TOP HALF + BOTTOM HALF)
BEE PCB
PSU PCB
PDHU PCB
(x8)

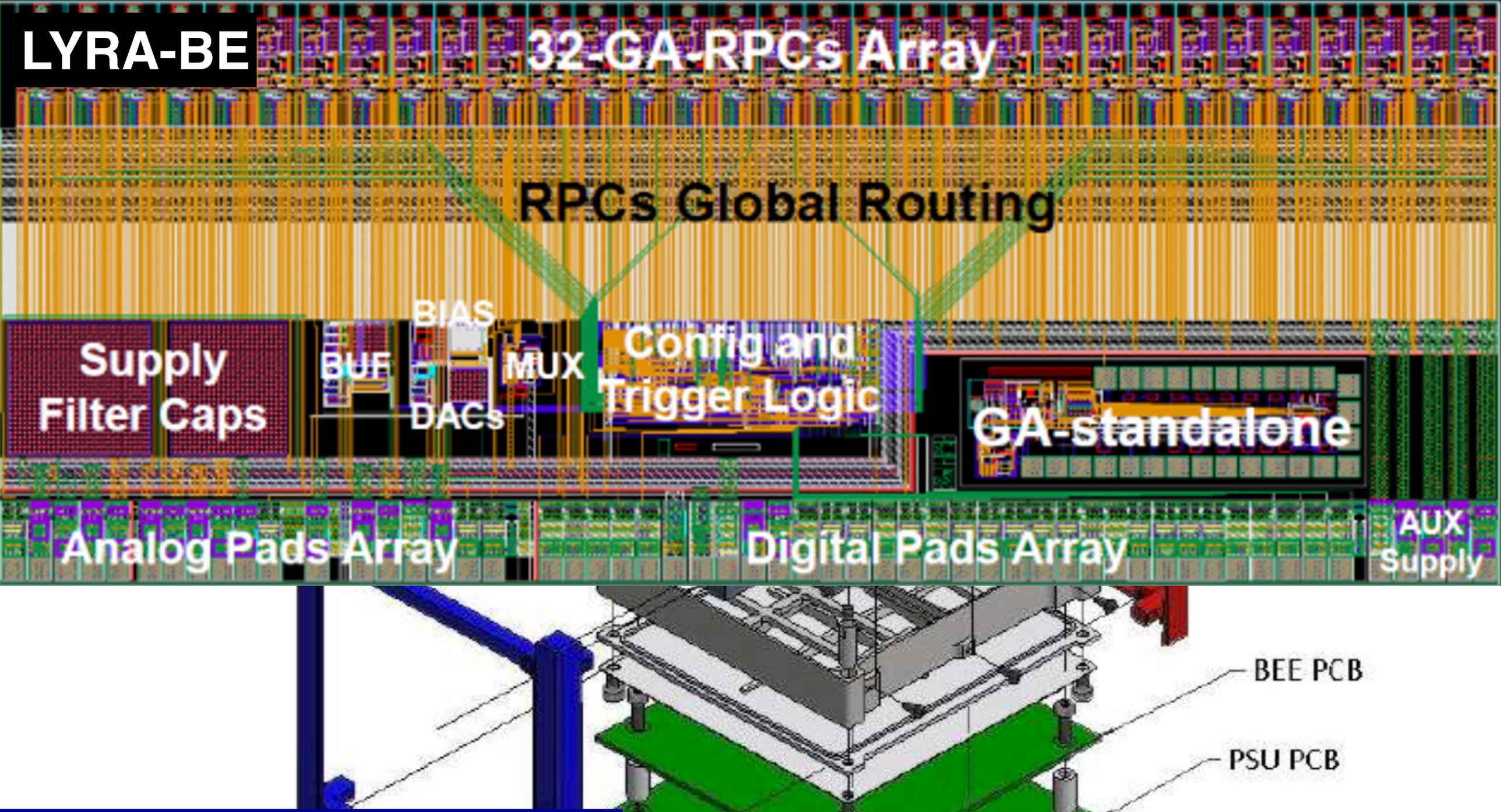

SDD

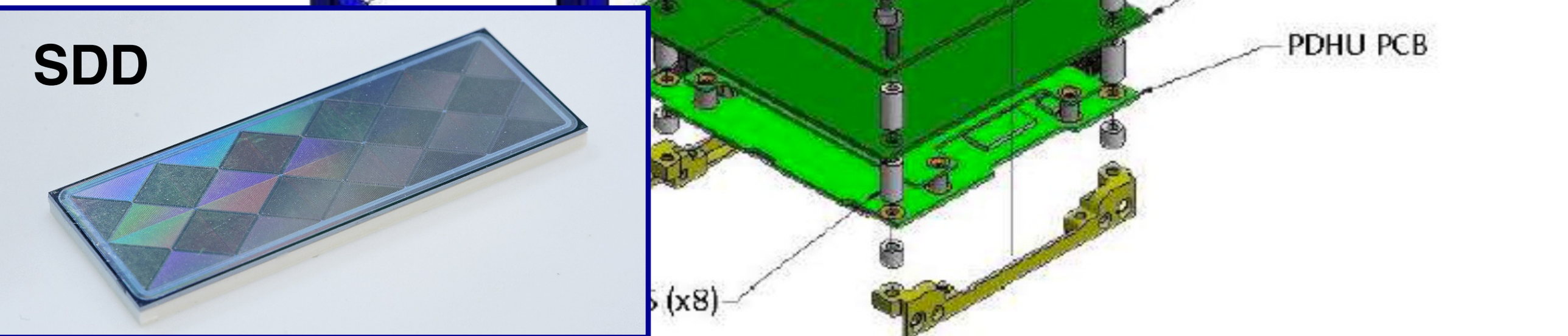

GAGG crystals


LYRA-FE
650 µm
960 µm
avdd
Vtest
avss
avdd2
Output
Vreset
bit_tau
test_enable

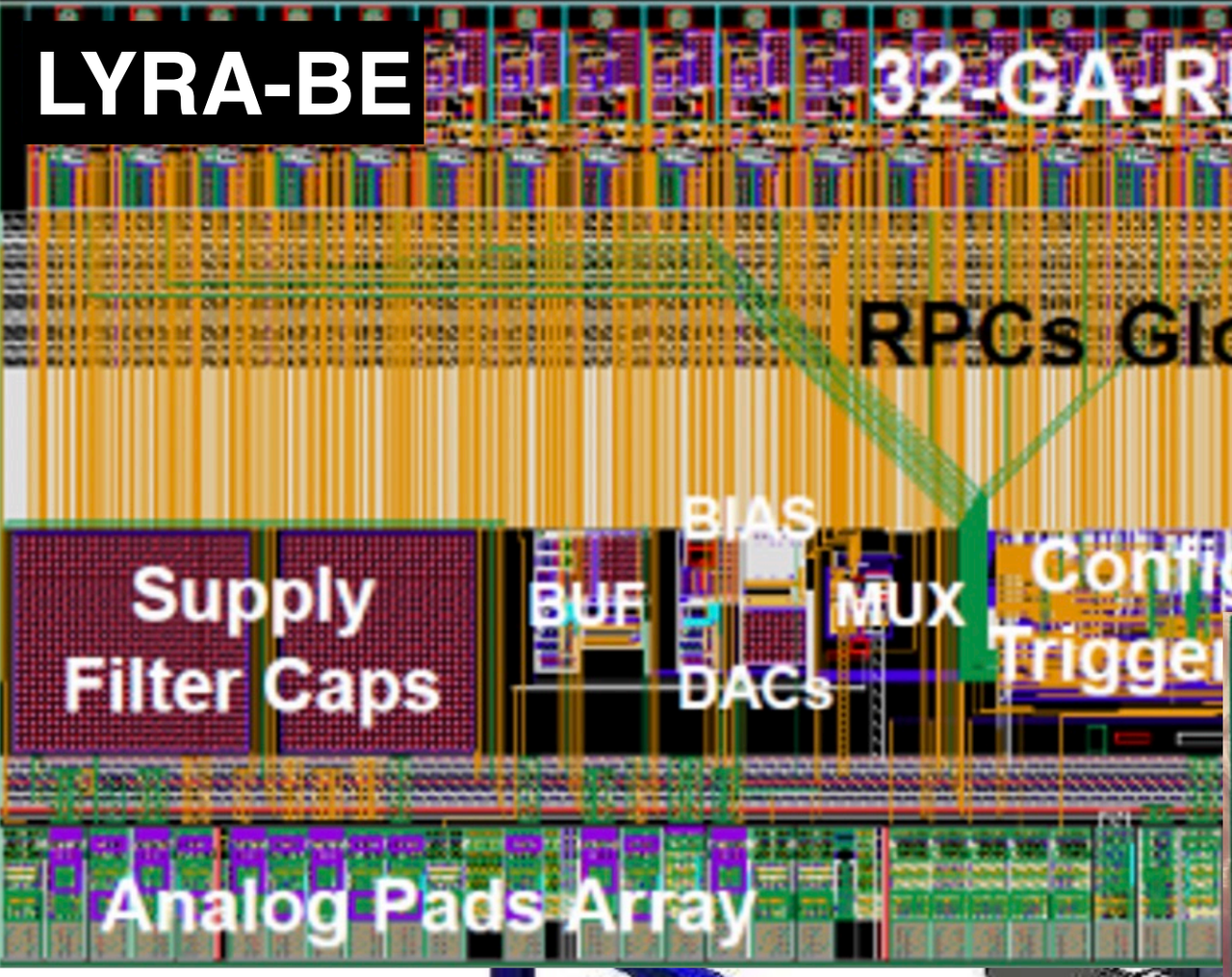

BEE PCB
PSU PCB
PDHU PCB
(x8)

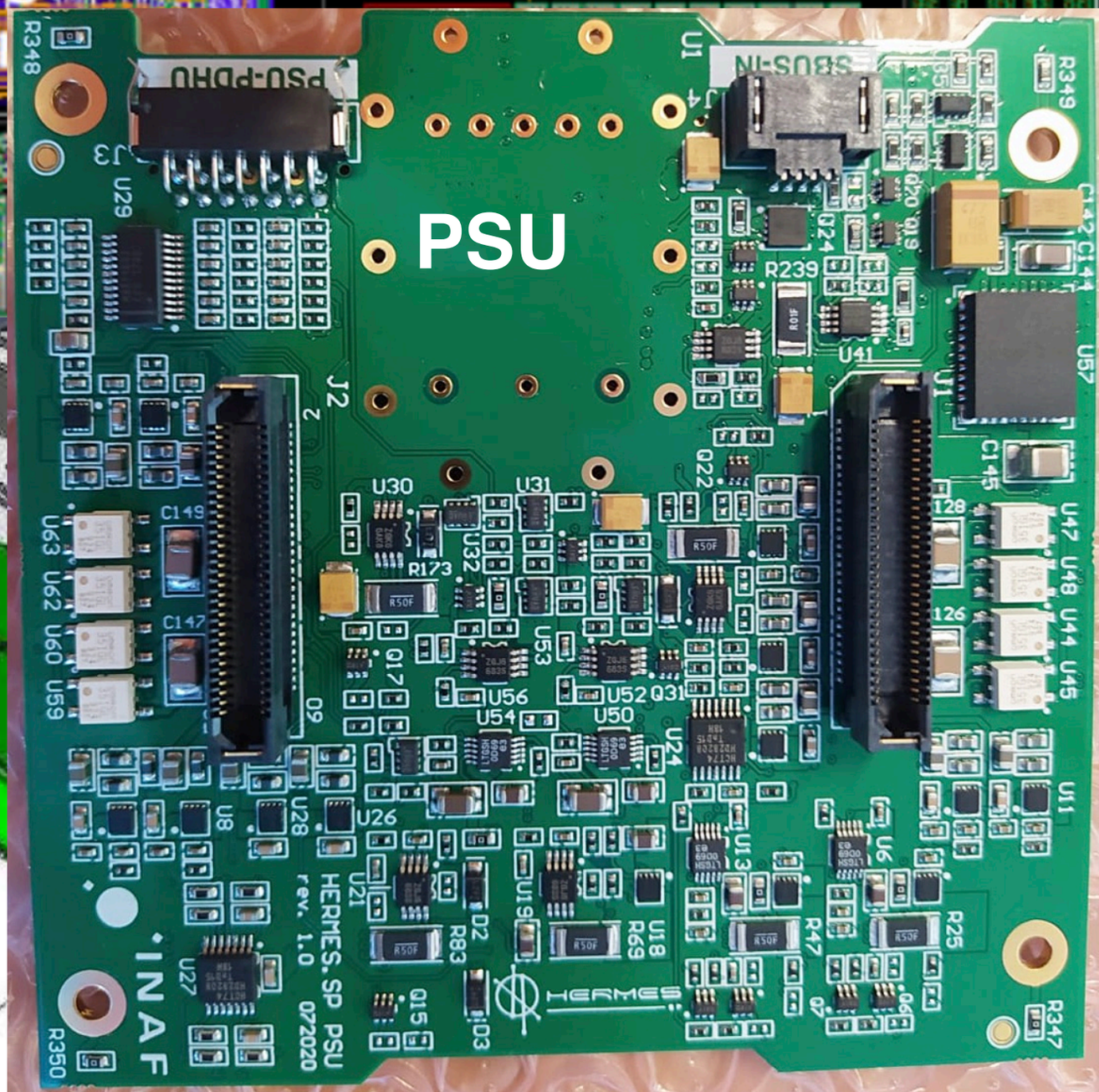

SDD

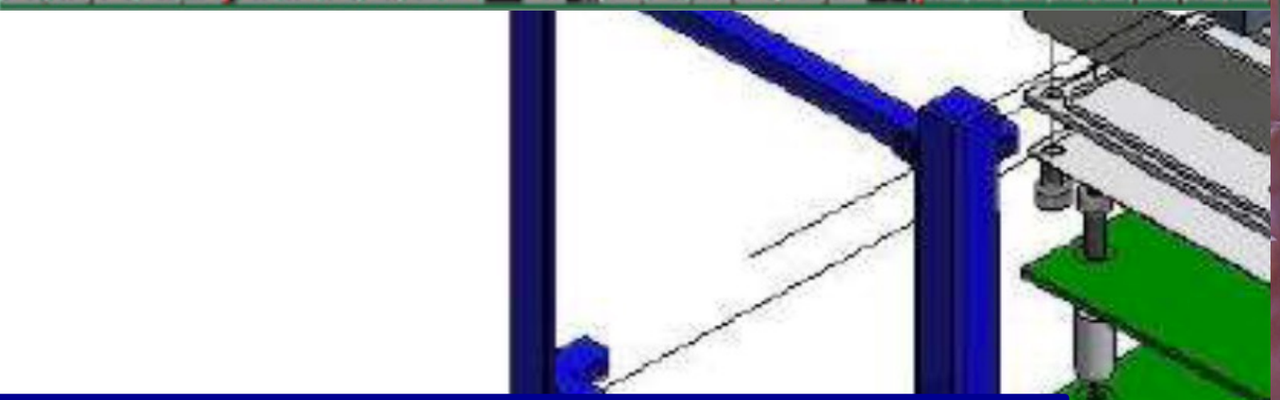

LYRA-BE
32-GA-RPCs Array
RPCs Global Routing
Supply
Filter Caps
BUF
BIAS
DACs
MUX
Config and
Trigger Logic
GA-standalone
Analog Pads Array
Digital Pads Array
AUX
supply

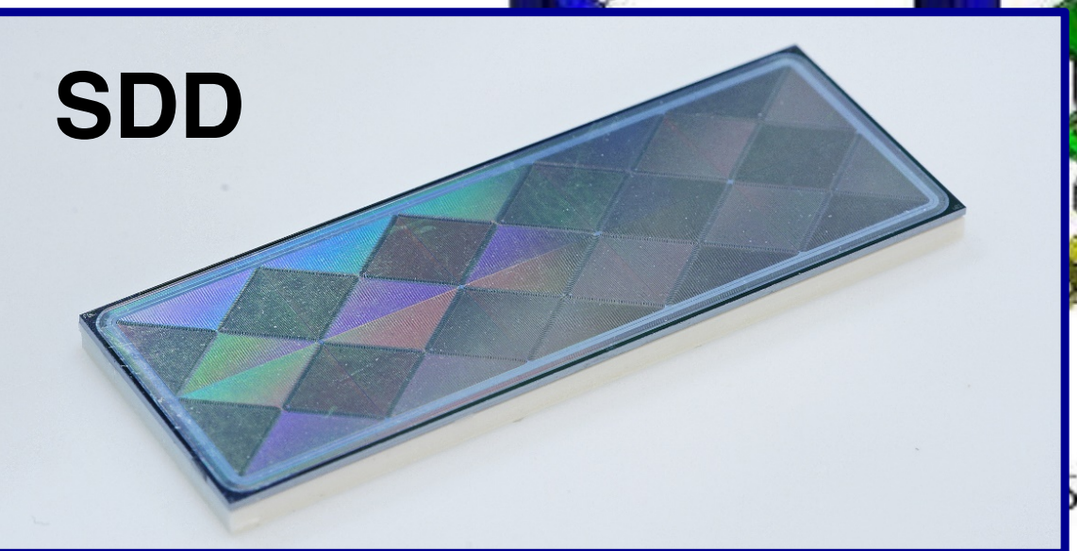

SDD
BEE PCB
PSU PCB
PDHU PCB
(x8)

LYRA-BE

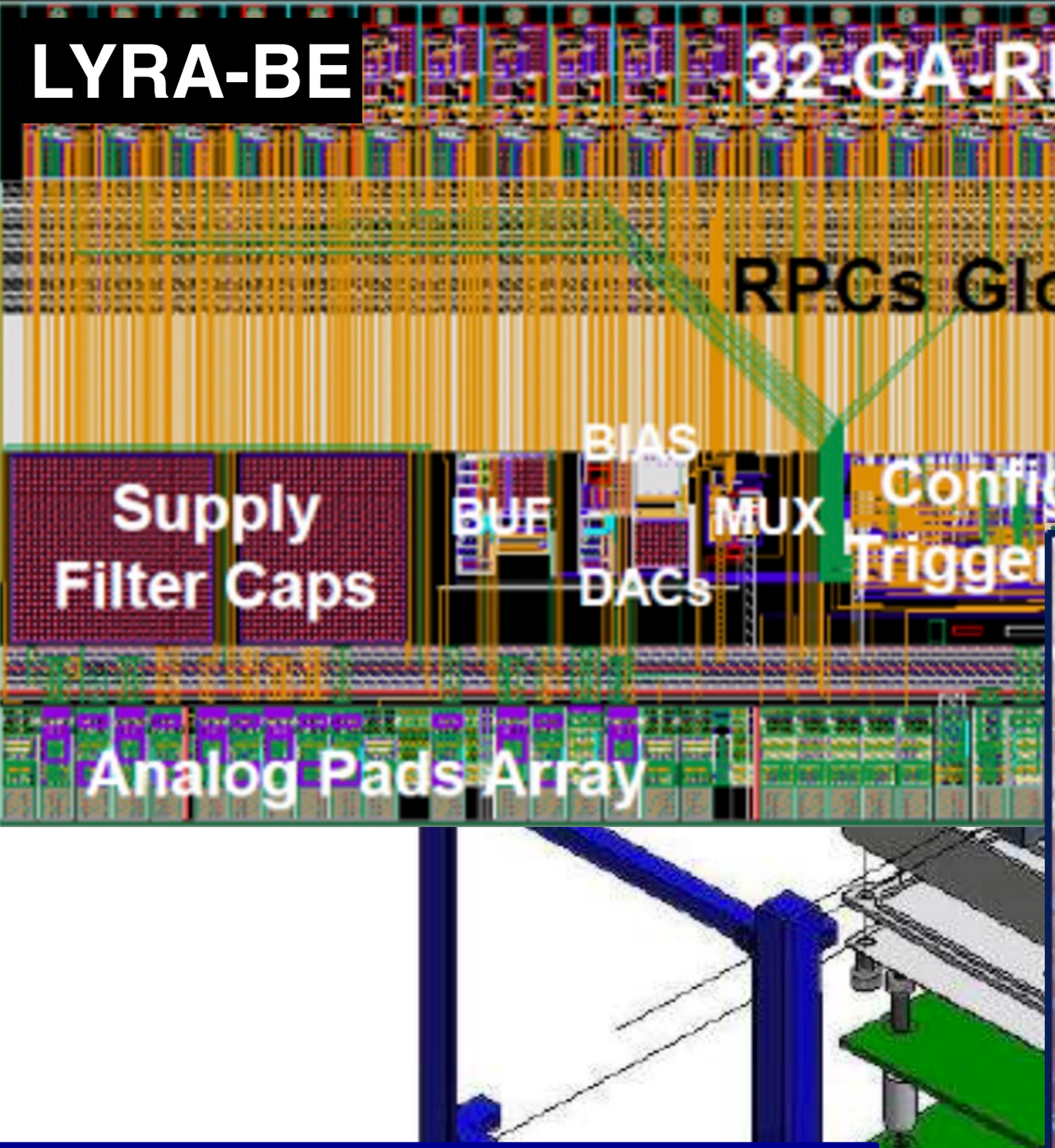

32-GA-RPCs Array
RPCs Global Routing
Supply
Filter Caps
BIAS
BUF
DACs
MUX
Config and
Trigge
Analog Pads Array

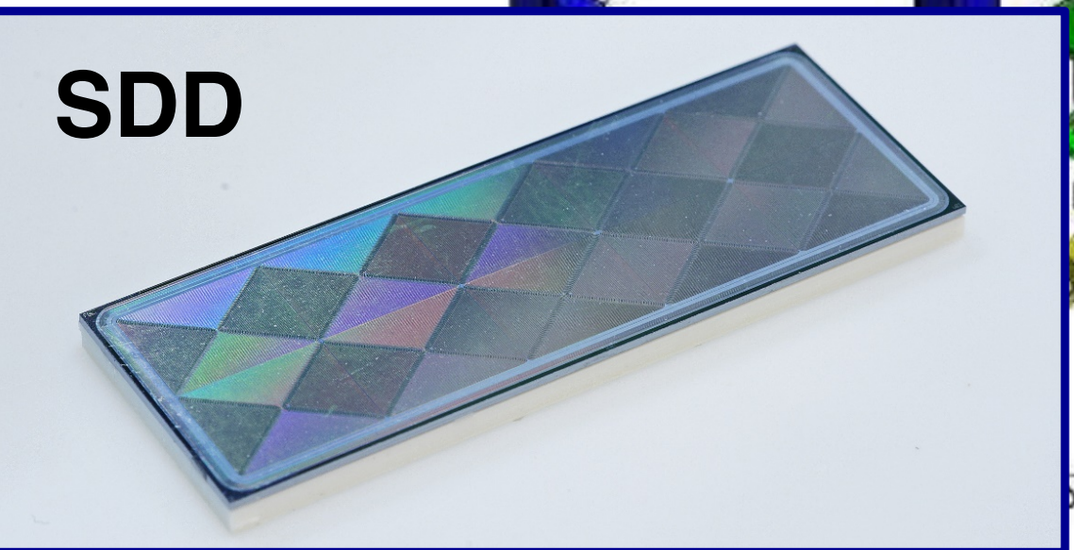

PSU
HERMES.SP PSU
rev. 1.0
072020
INAF



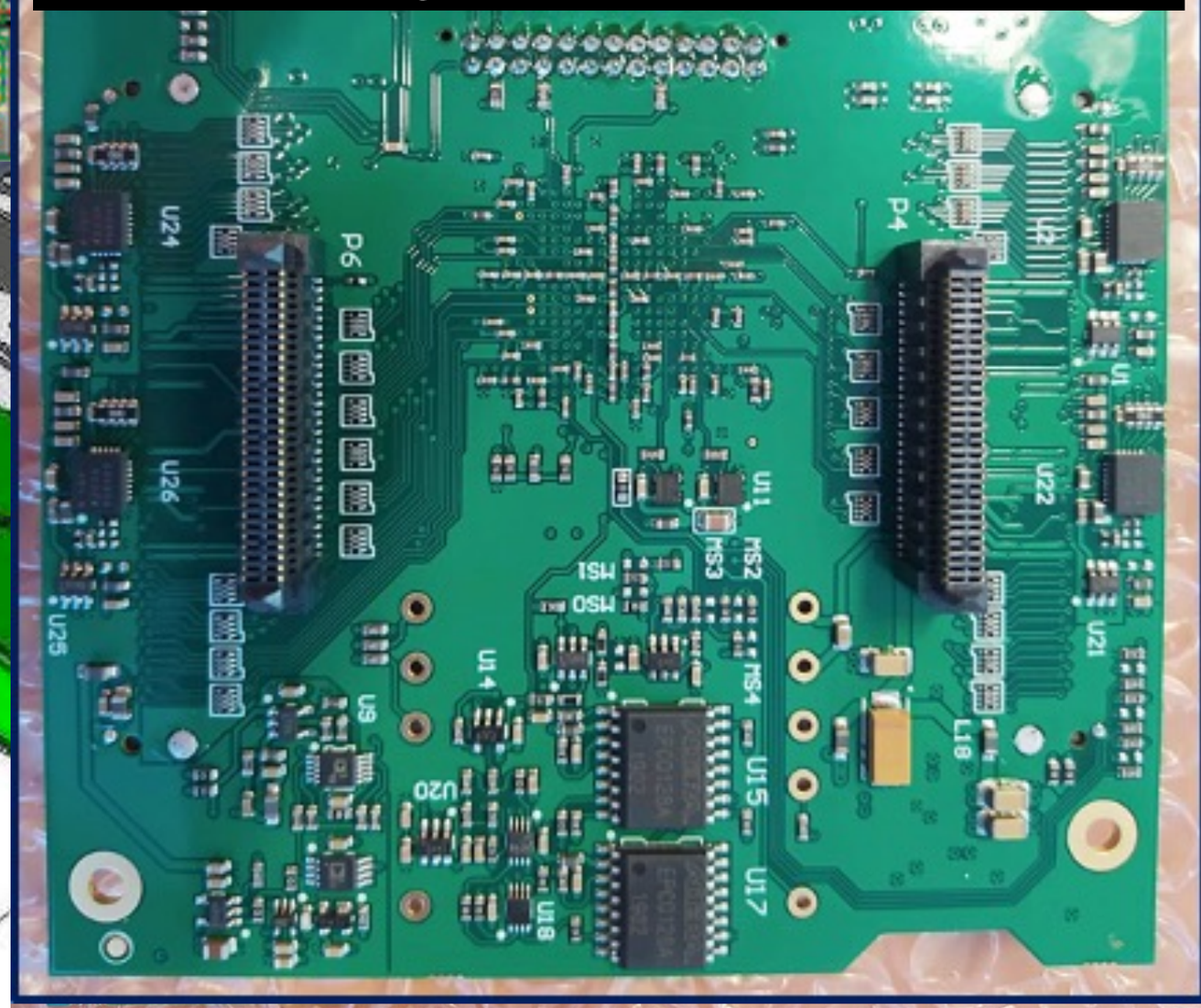

SDD

LYRA-BE

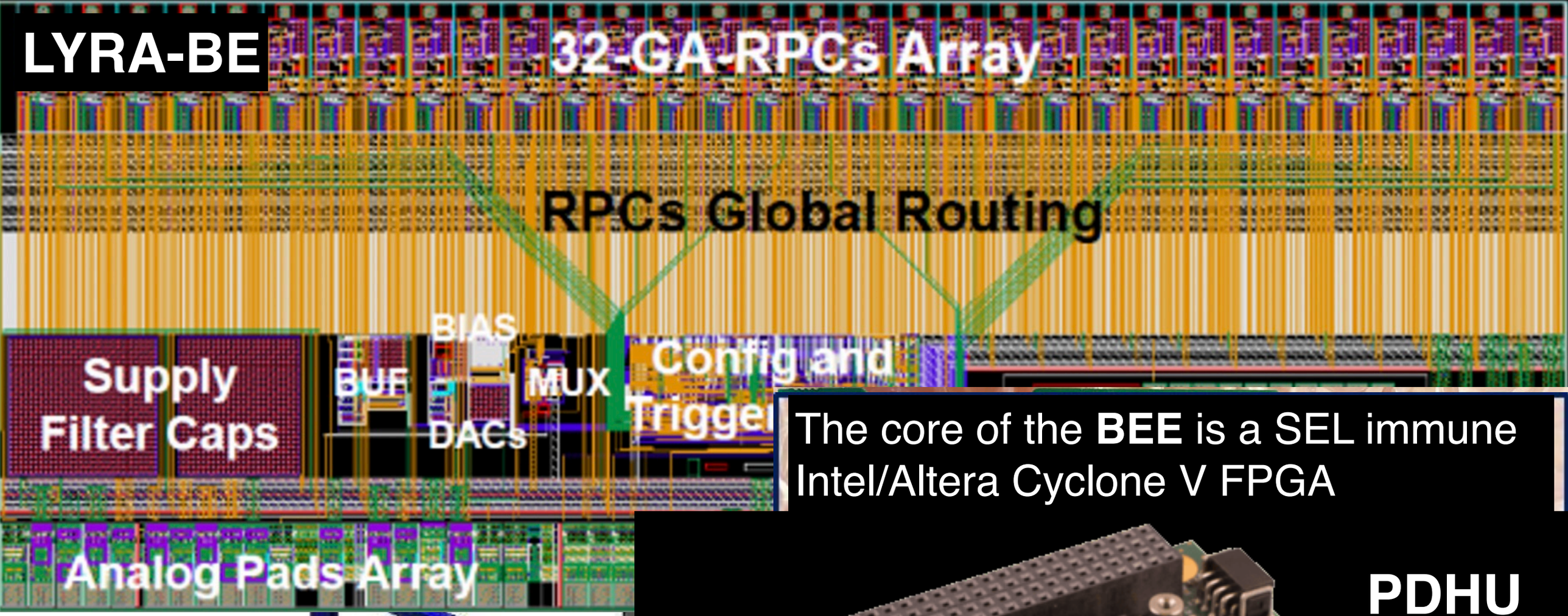




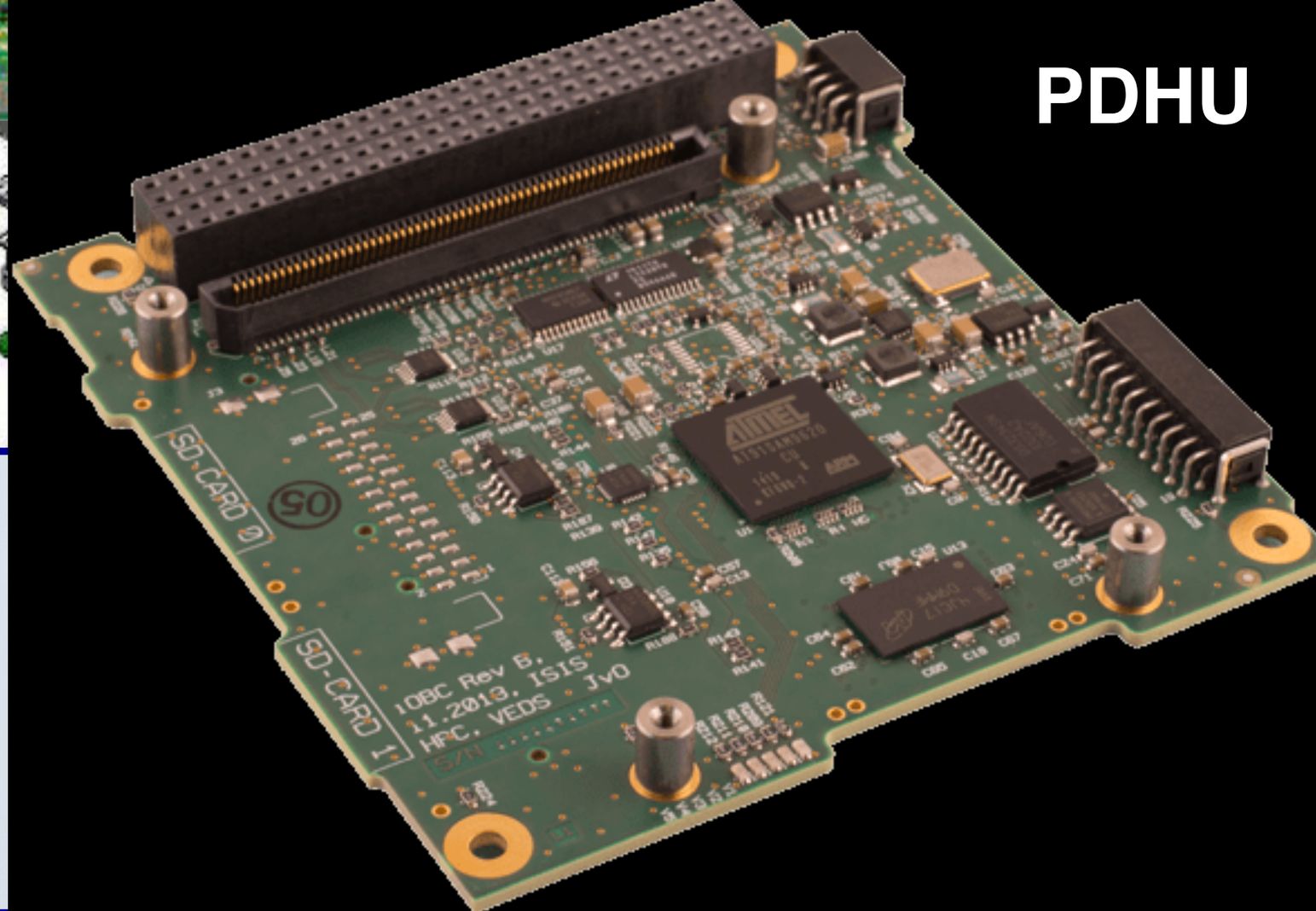
The core of the **BEE** is a SEL immune Intel/Altera Cyclone V FPGA



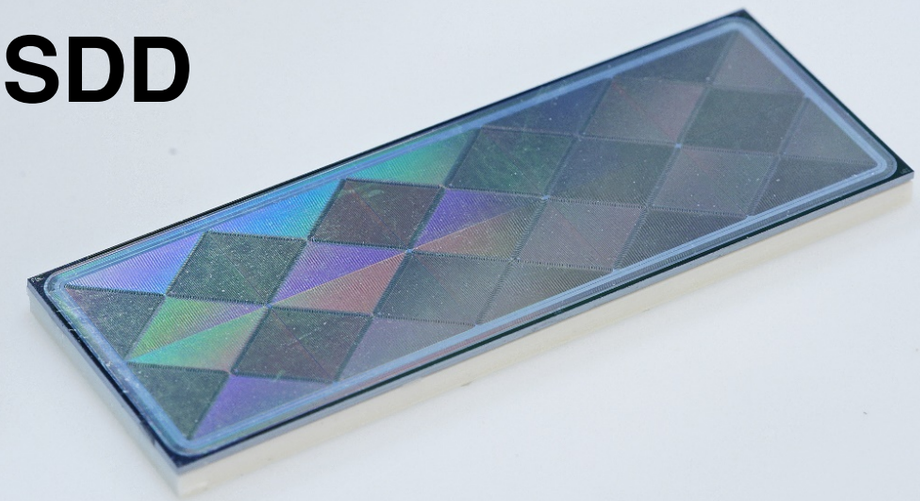
LYRA-BE



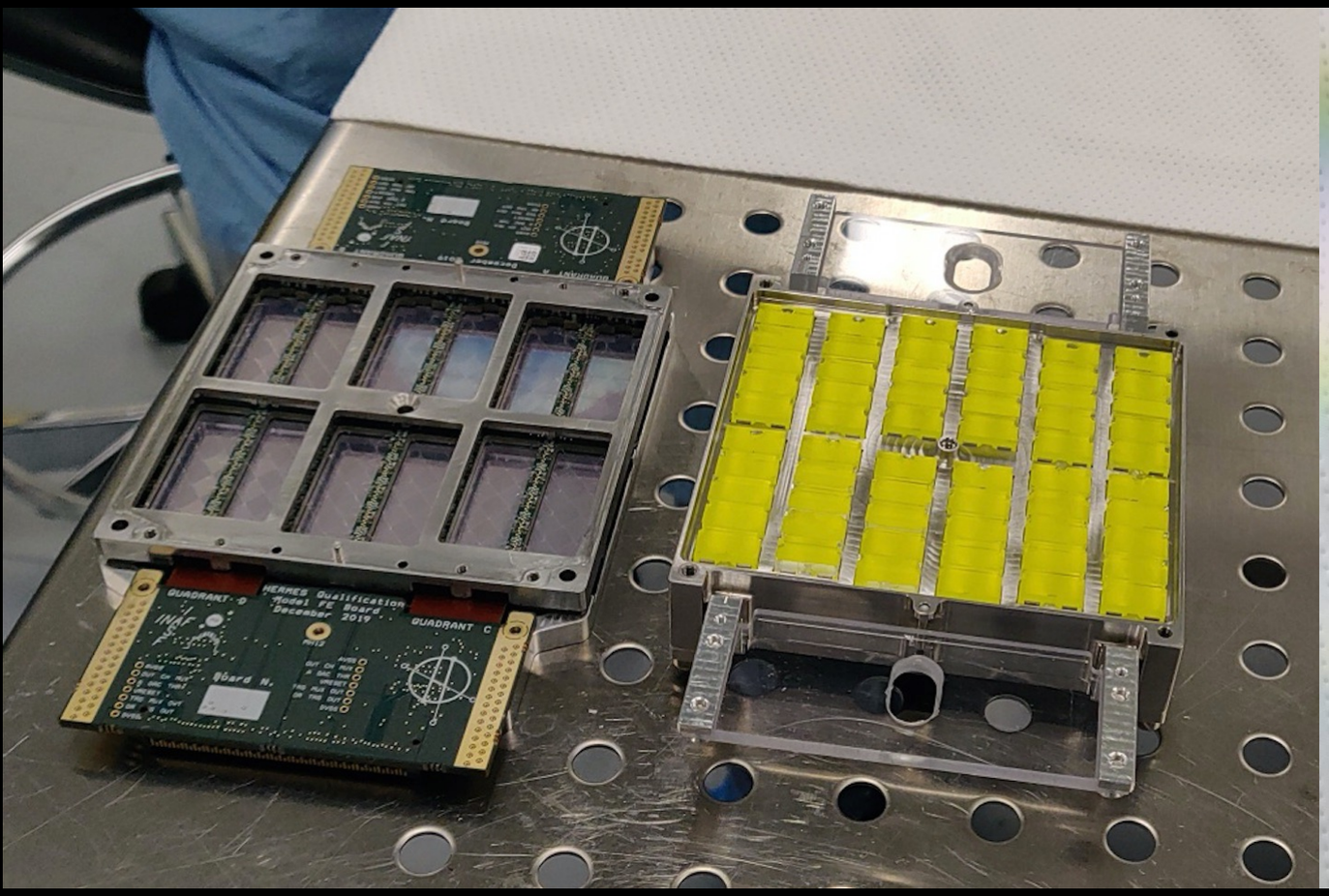
The core of the **BEE** is a SEL immune Intel/Altera Cyclone V FPGA

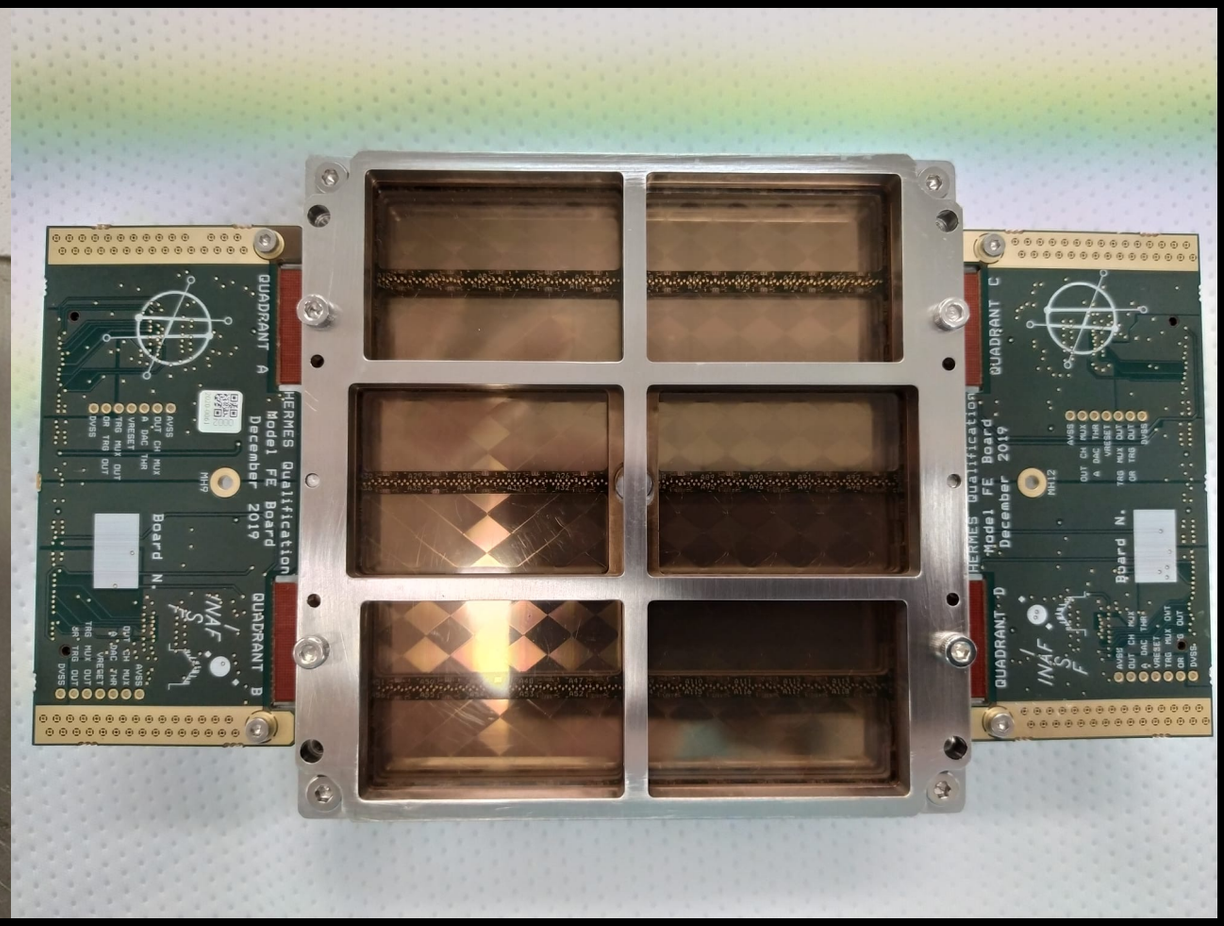


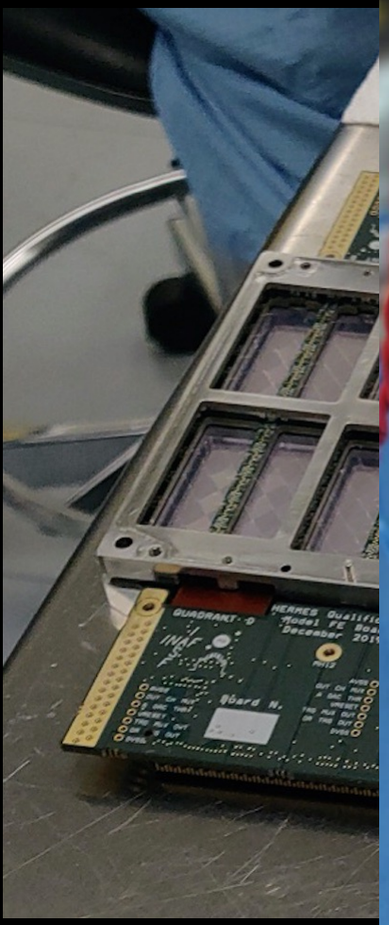
SDD



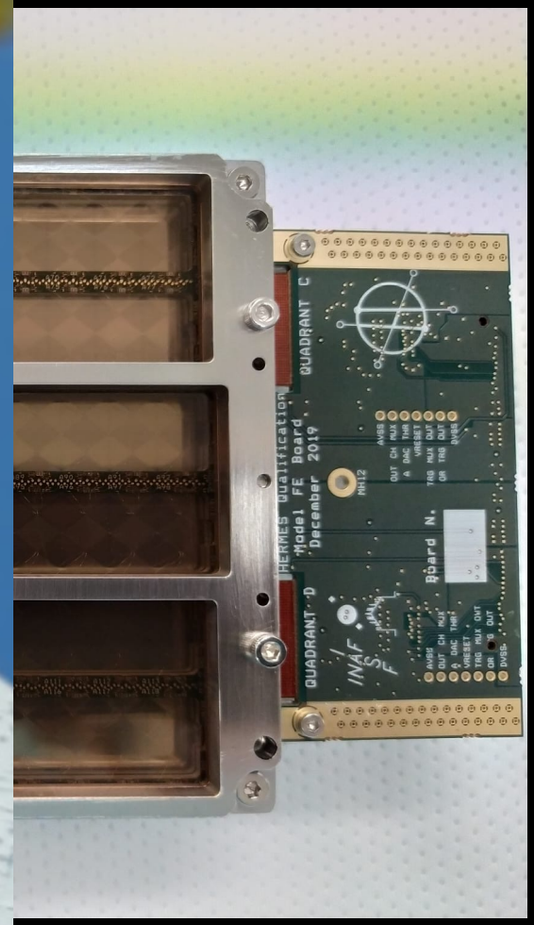
Hardware


HERMES Qualification
Model FE Board
December 2019
QUADRANT D
QUADRANT C
Board N.


QUADRANT A
QUADRANT B
QUADRANT C
QUADRANT D
HERMES Qualification
Model FE Board
December 2019
Board N.


QUADRANT D
INAF

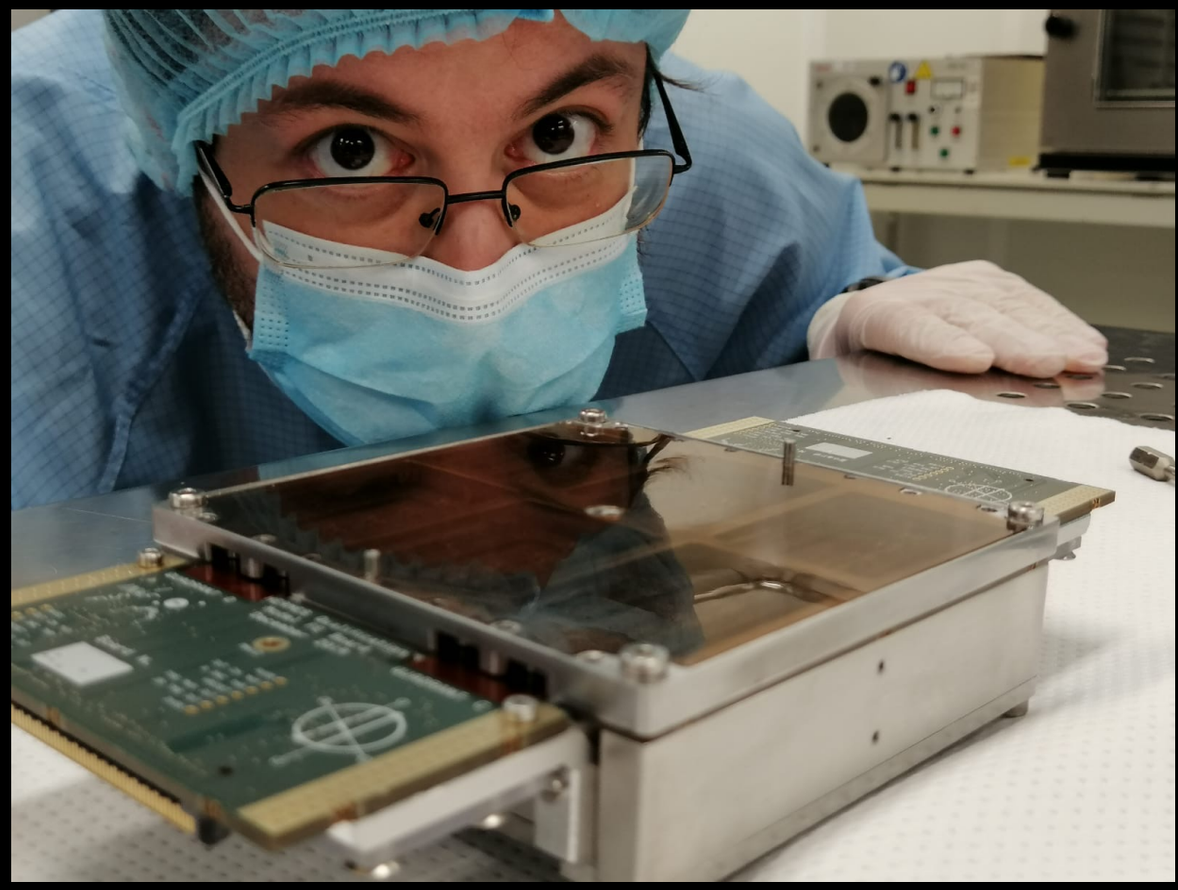

QUADRANT C
INAF
HERMES
SP


QUADRANT C
INAF

Payload DM

http://www.hermes-sp.eu/?p=5010

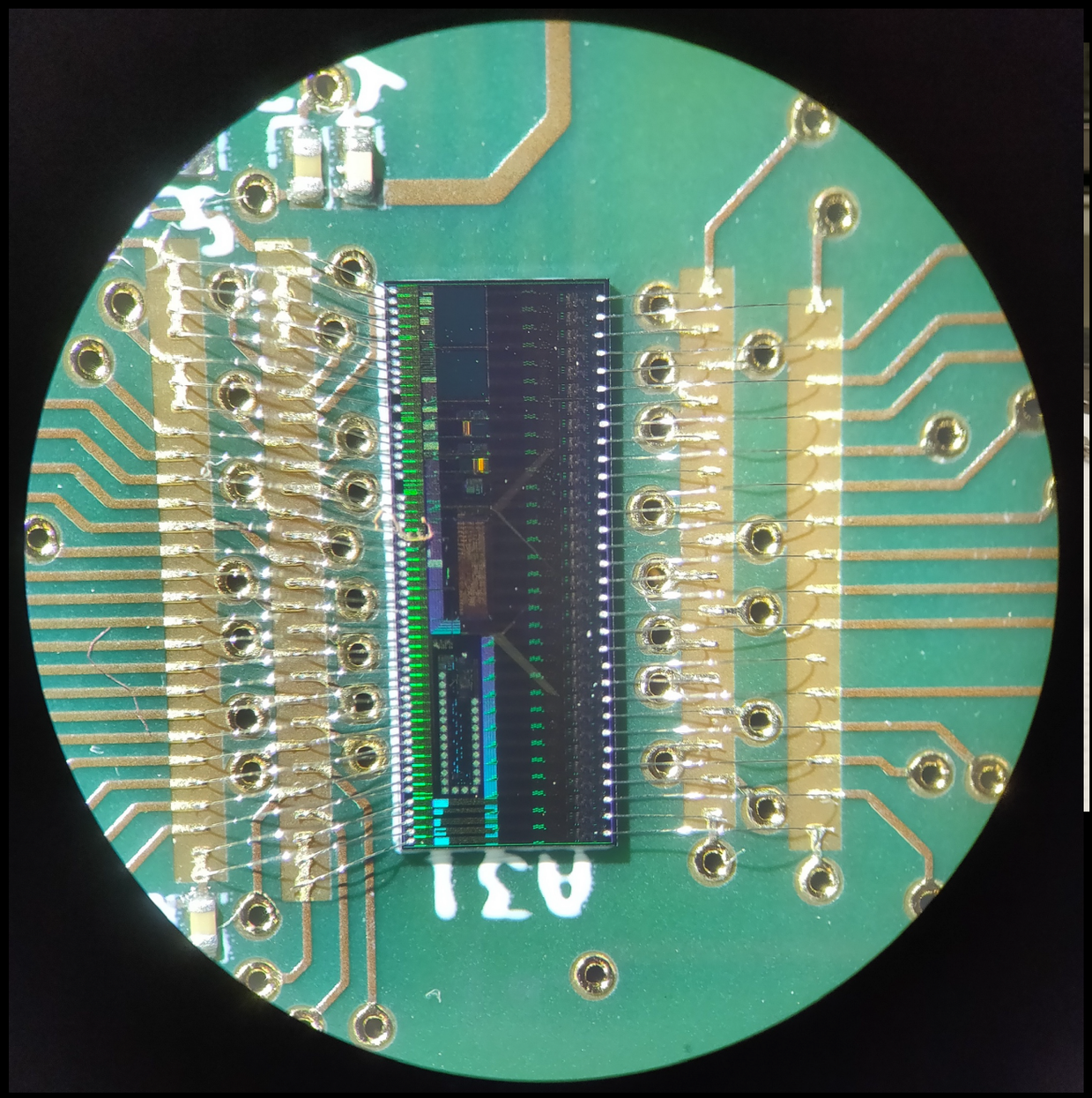
- Assembly, Integration procedure and test plan consolidation
- FEE PCB functional tests
- FEE PCB (preliminary) performances verification
- SDD + ASICs power consumption verification
- Absence of channel-to-channel electrical cross-talk
- Room-temperature performance as expected. Spectroscopic characterisation with ^{137}CS



Payload DM

http://www.hermes-sp.eu/?p=5010

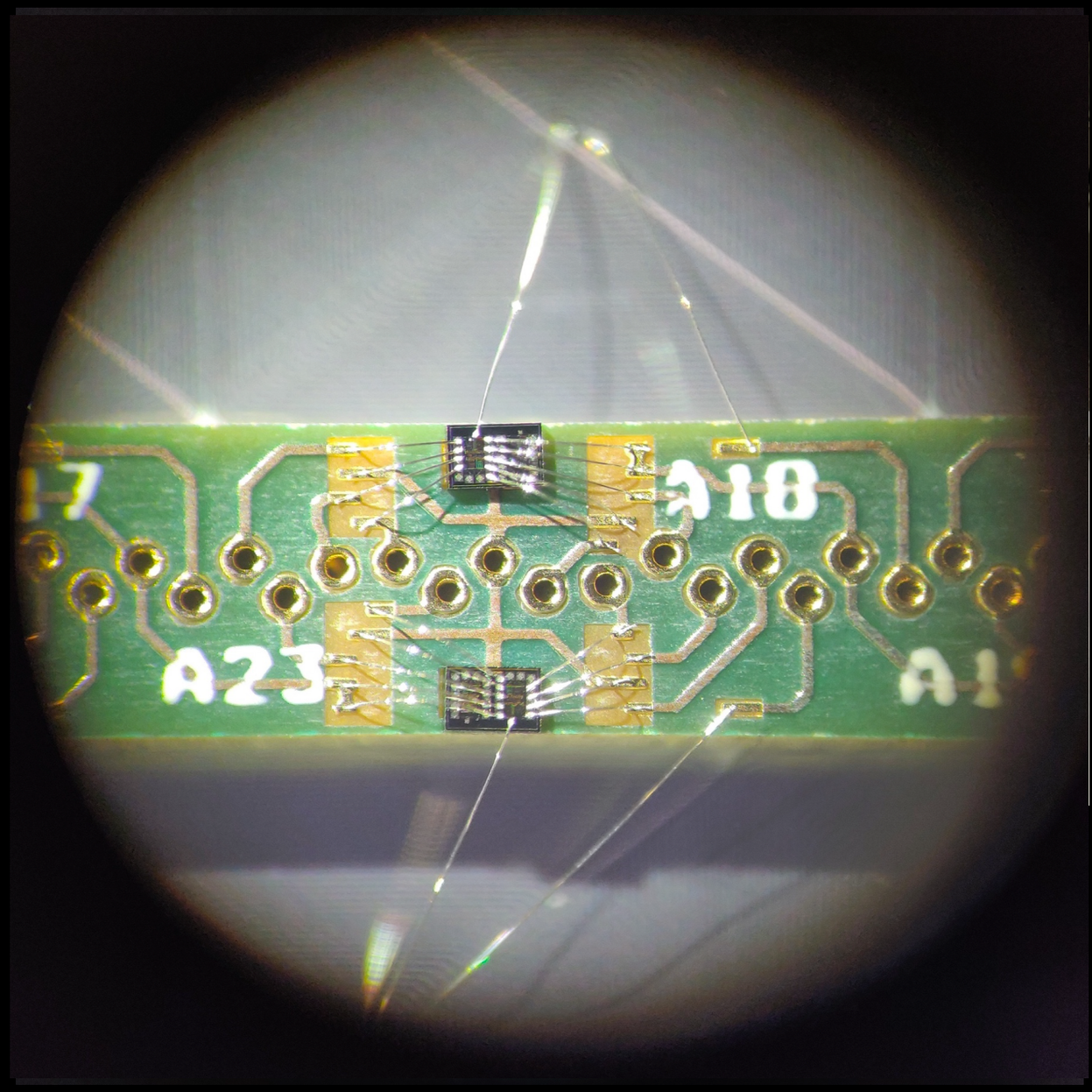
- Assembly, Integration procedure and test plan consolidation
- FEE PCB functional tests
- FEE PCB (preliminary) performances verification
- SDD + ASICs power consumption verification
- Absence of channel-to-channel electrical cross-talk
- Room-temperature performance as expected. Spectroscopic characterisation with ^{137}CS



Payload DM

http://www.hermes-sp.eu/?p=5010

- 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 ^{137}CS

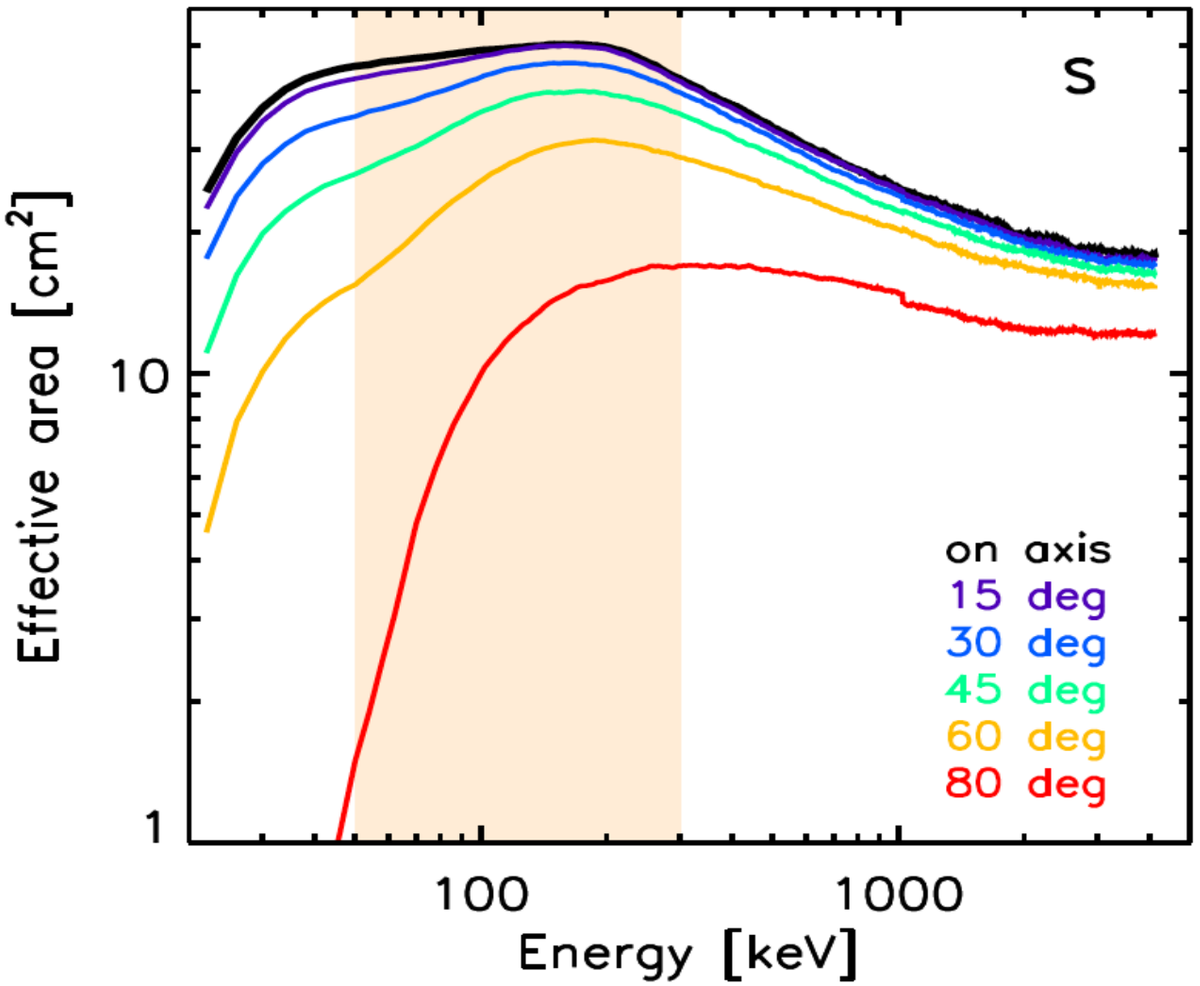


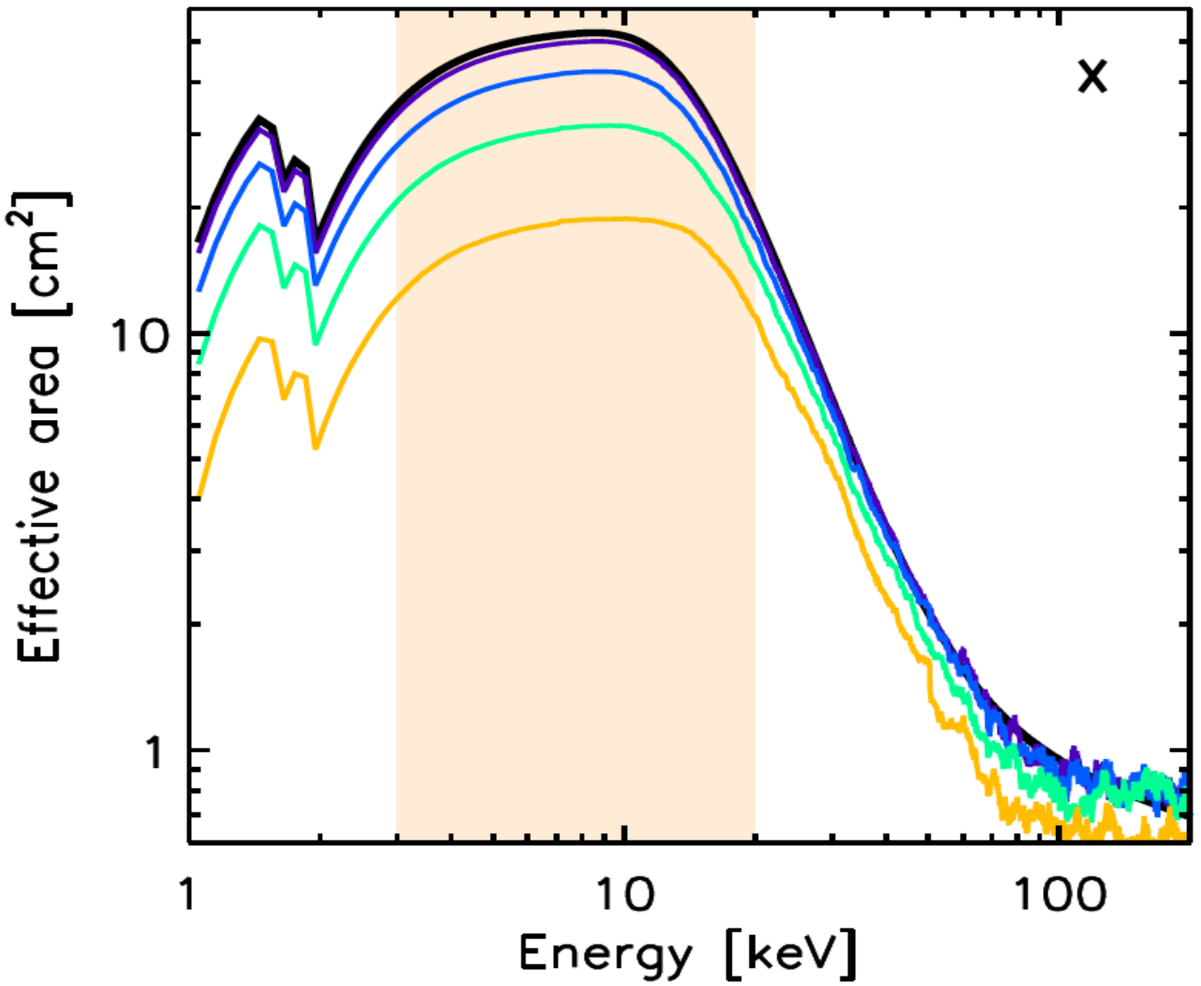
Payload

http:

- 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 ^{137}CS

HERMES performances



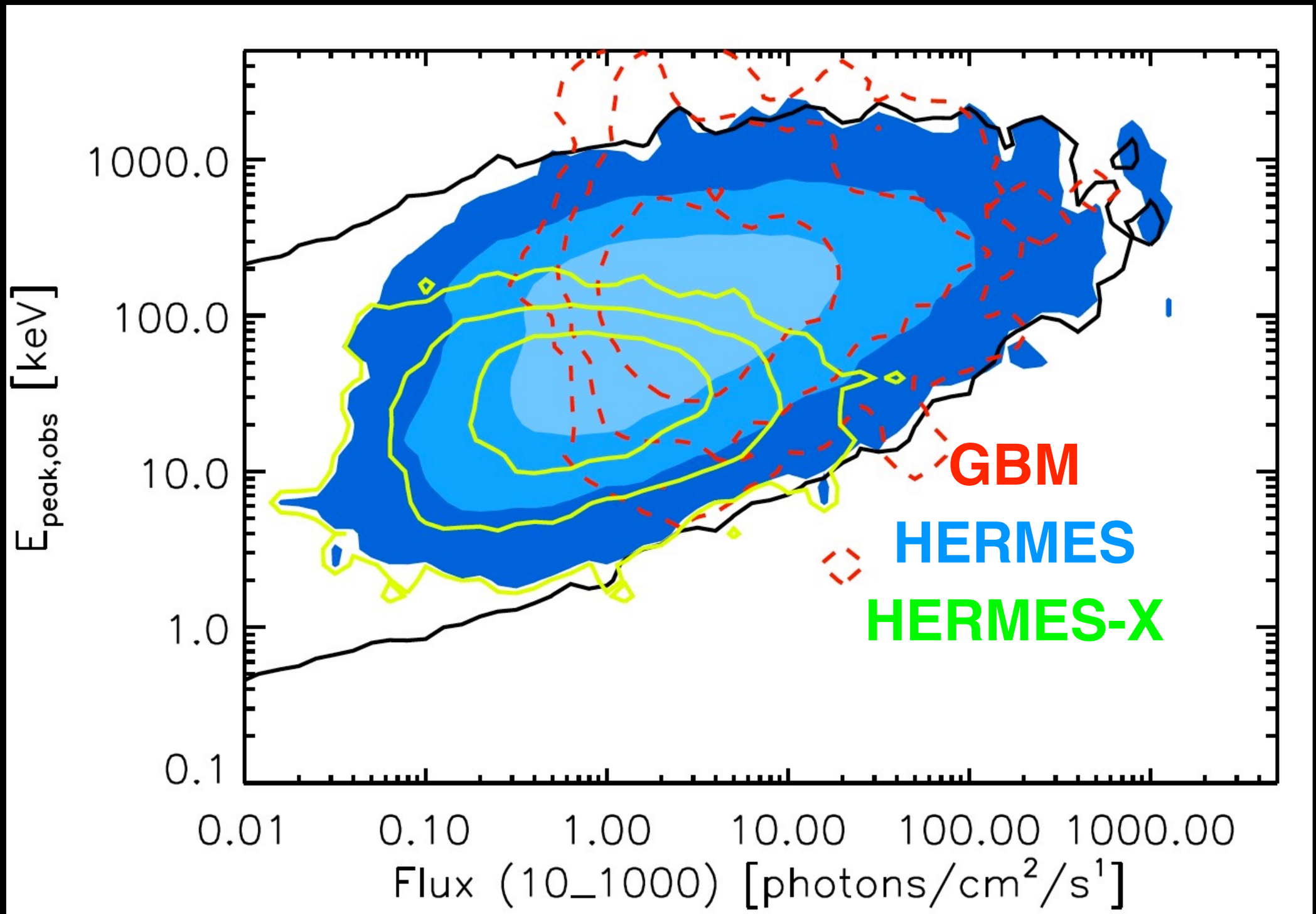


Background: 50-300 keV =75counts/s; 3-20 keV 390counts/s

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

HERMES performances

Ghirlanda & Nava



HERMES performances

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

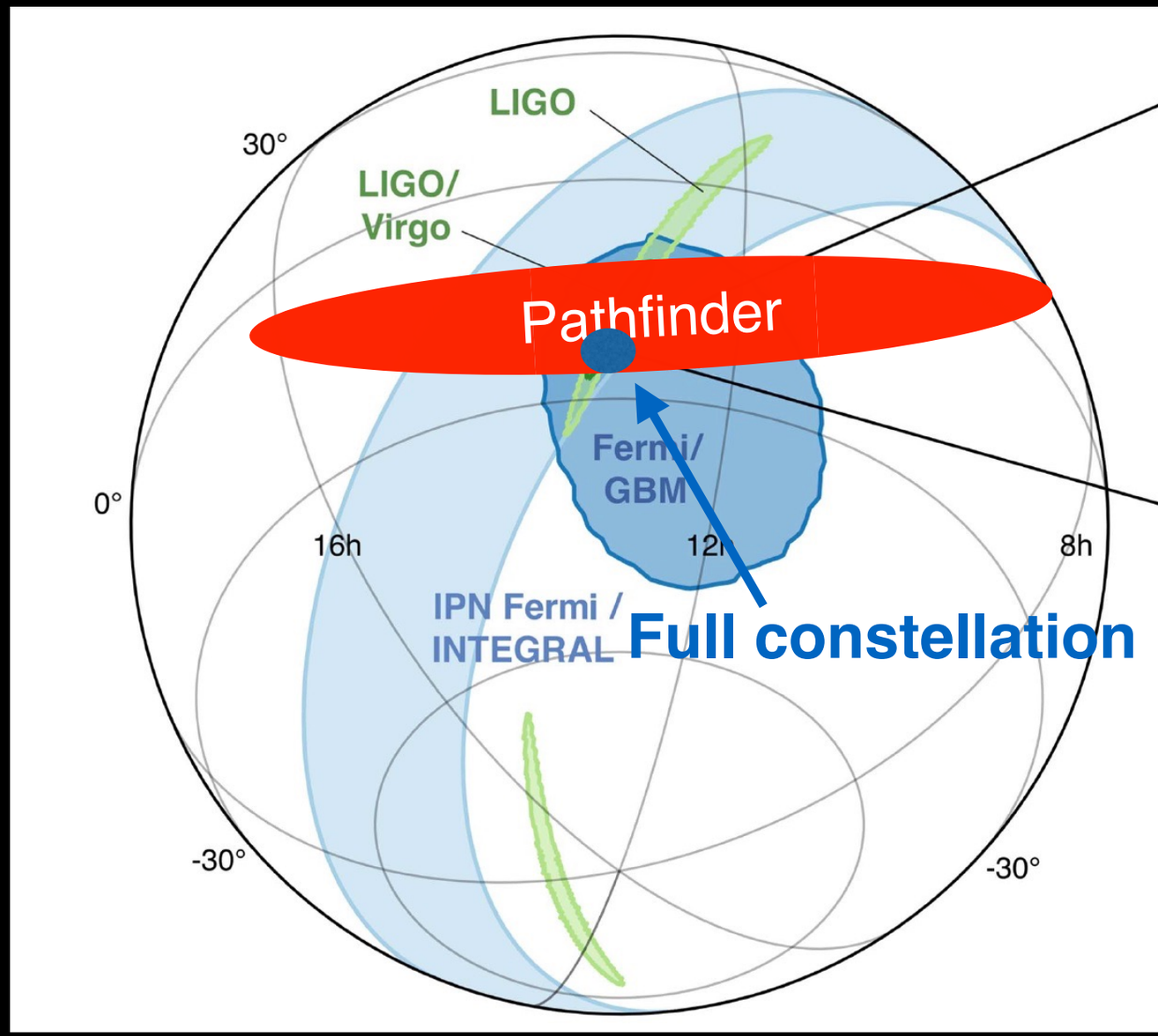
<B>~7000km

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

σ_{Pos}~ 2.4 deg if $\sigma_{CCF,}\sigma_{sys}$~1ms

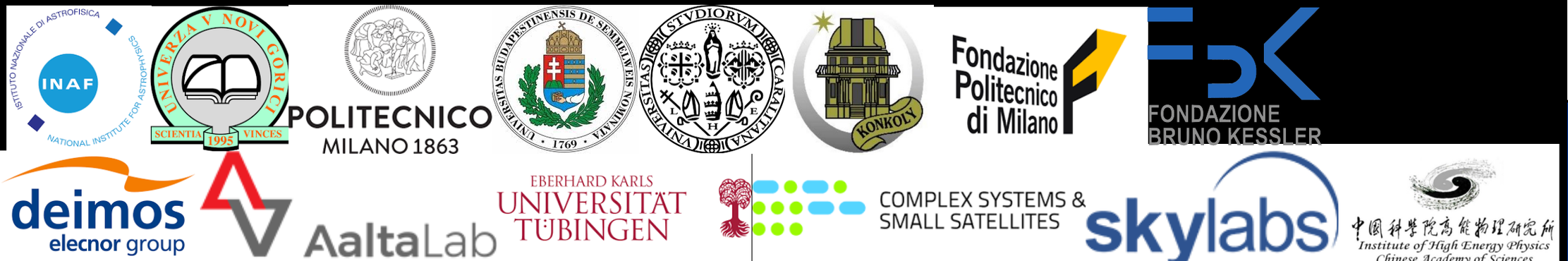
N(Full constellation) ~100, active 50

$\sigma_{Pos(FC)}$ ~ 15 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)
- Institute of High Energy Physics, Chinese Academy of Science



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

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

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

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 Q3 2020

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 Q3 2020
- QR Q3 2021—> PFM1

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 Q3 2020
- QR Q3 2021—> PFM1
- AR Q2 2022 —> FM2+FM3+FM4+FM5+FM6

Programmatics

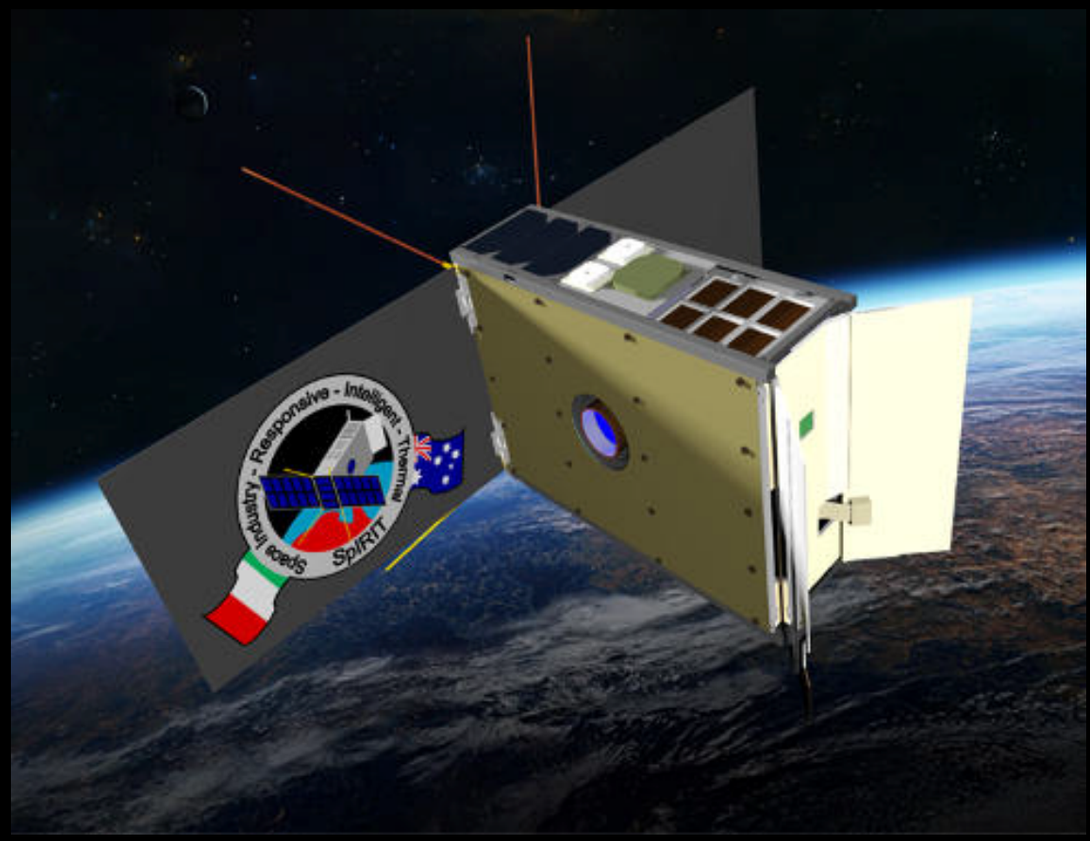
- Progetto Premiale 2015: **HERMES-Techonogic Pathfinder**
- H2020 SPACE-SCI-20: **HERMES-Scientific Pathfinder**
- Main objectives:

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 Q3 2020
- QR Q3 2021—> PFM1
- AR Q2 2022 —> FM2+FM3+FM4+FM5+FM6
- Launch 2022, ASI provided

Next Step

- ✦ Addition of a seventh unit: SpIRIT!
  - Australian Space Agency, University of Melbourne
  - 6U hosting 1 HERMES payload
  - Launch: Q3 2022
  - SSO



Thanks!