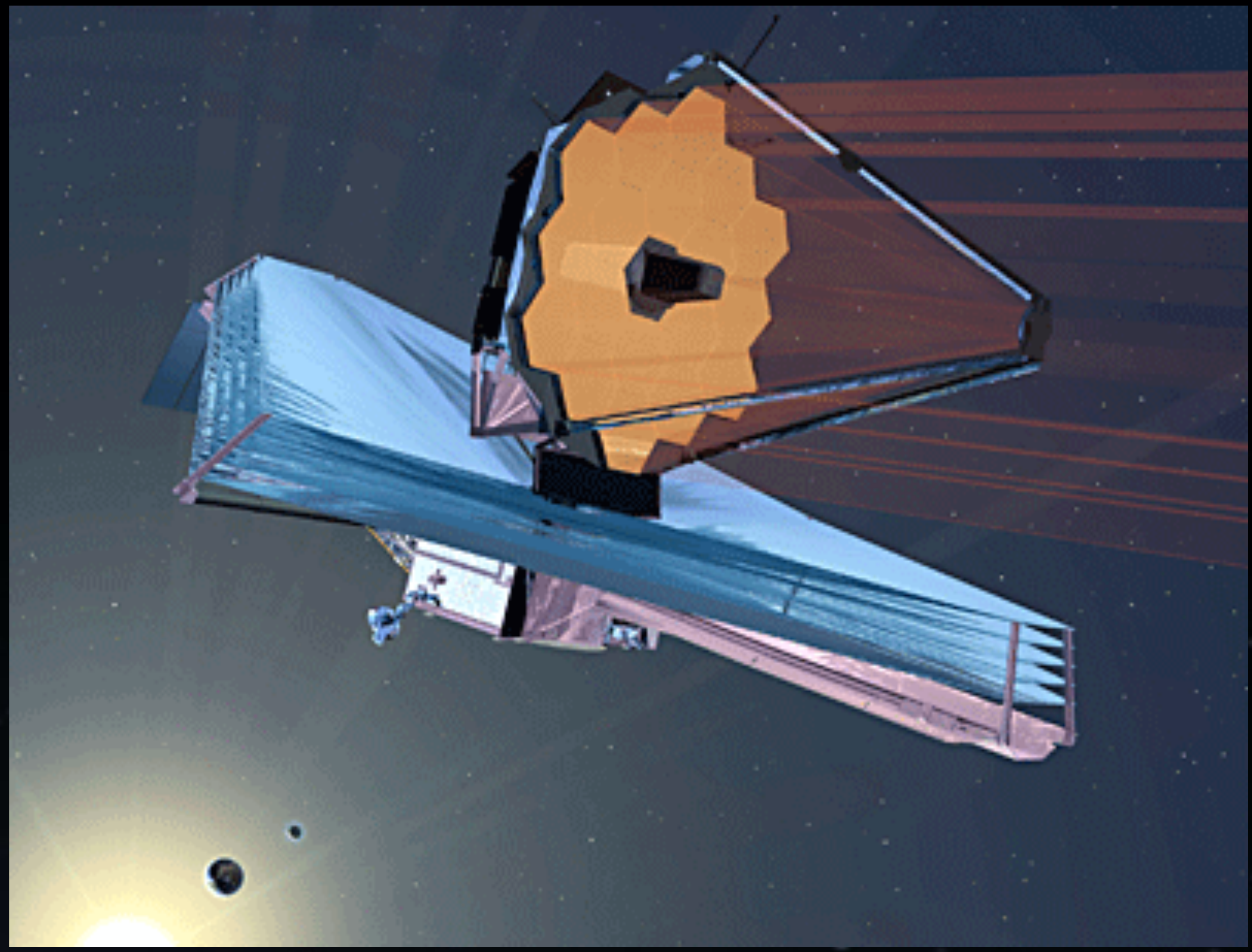
HERMES



From Nano to Giga

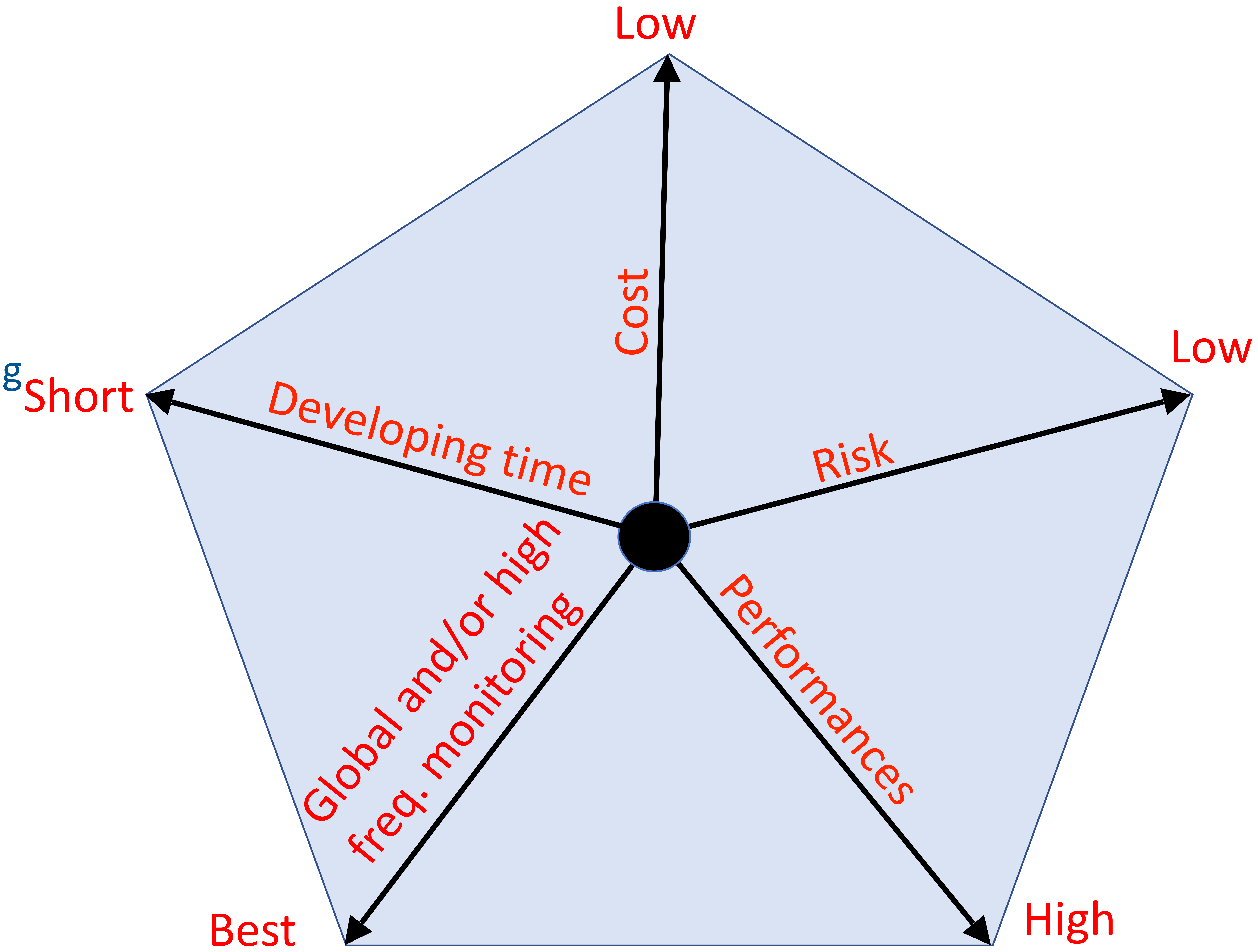
fabrizio.fiore@inaf.it

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

The project has received funding from the Accordo Attuativi ASI-INAF and ASI-POLIMI

Trade-offs

- Development time
- Cost
- Risk
- Performances
- Global and/or high frequency monitoring



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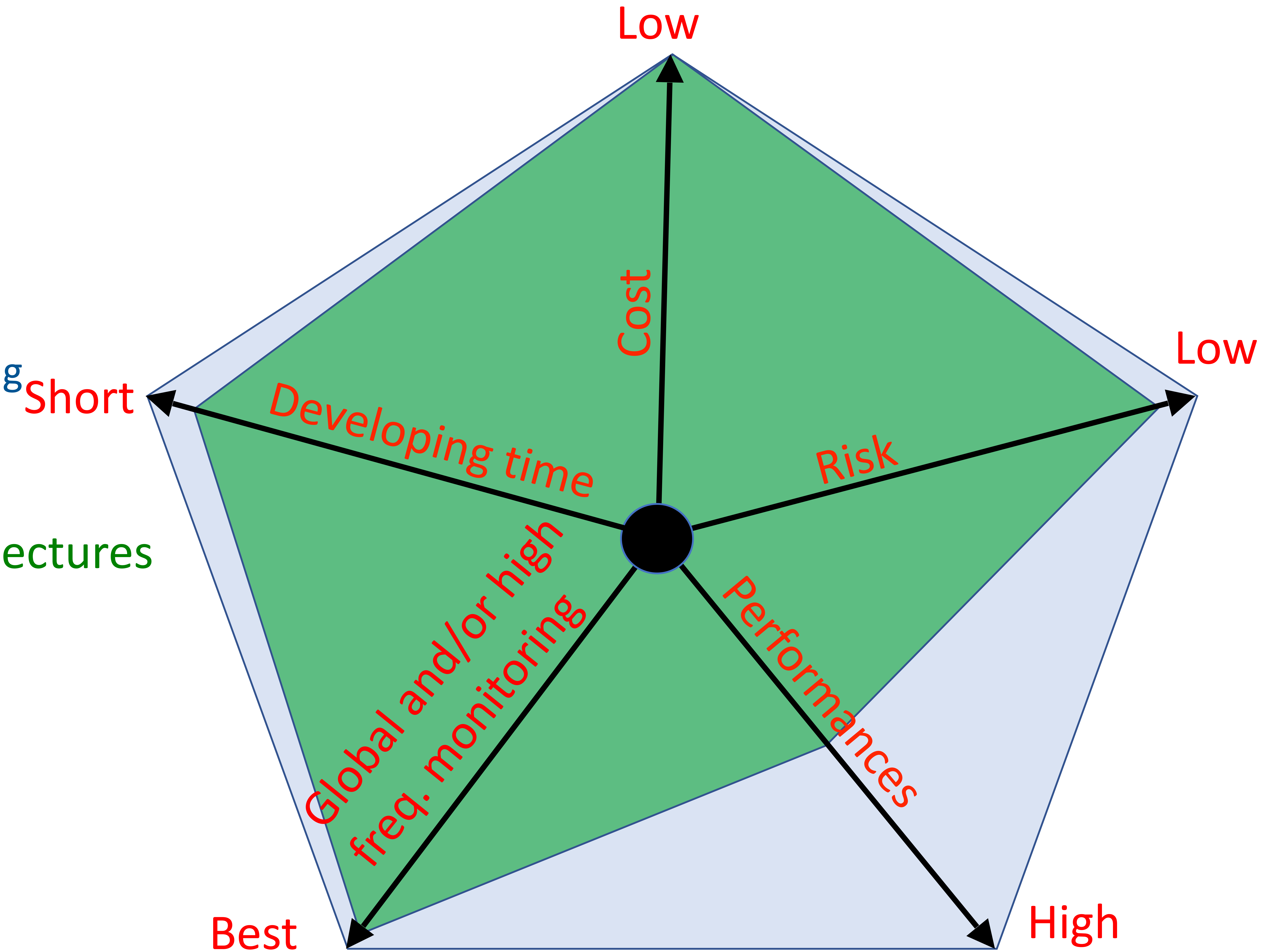
Distributed architectures of nanosatellites



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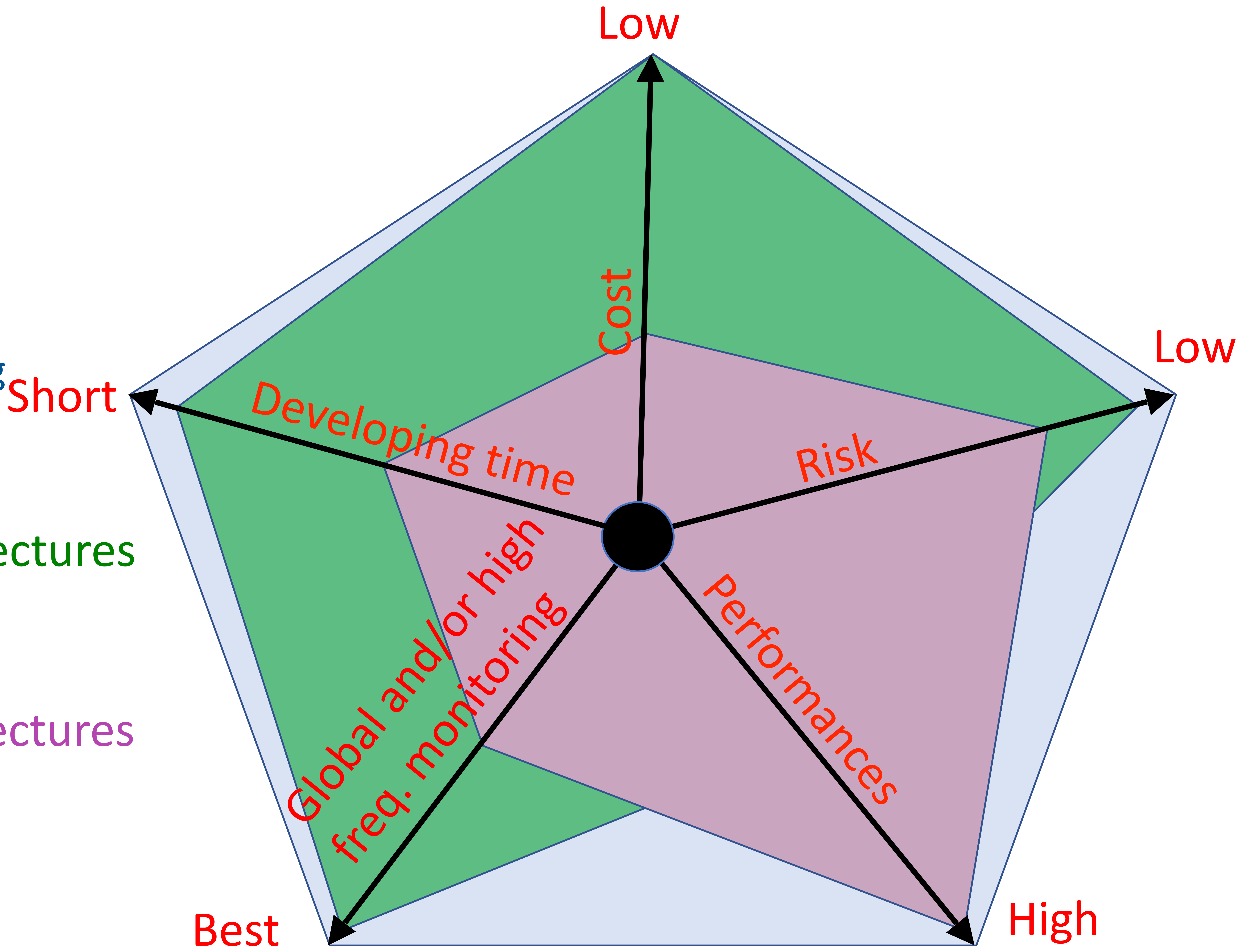


Distributed architectures of nanosatellites

Monolithic architectures

Motivation

- Prove that ***breakthrough science*** can be done with nano-sats, not only with large, complex, expensive missions. ***"Smaller"*** enables the"***faster, better, cheaper***"[1] mantra, but also ***expand usership,*** increasing competition ***and*** collaborations

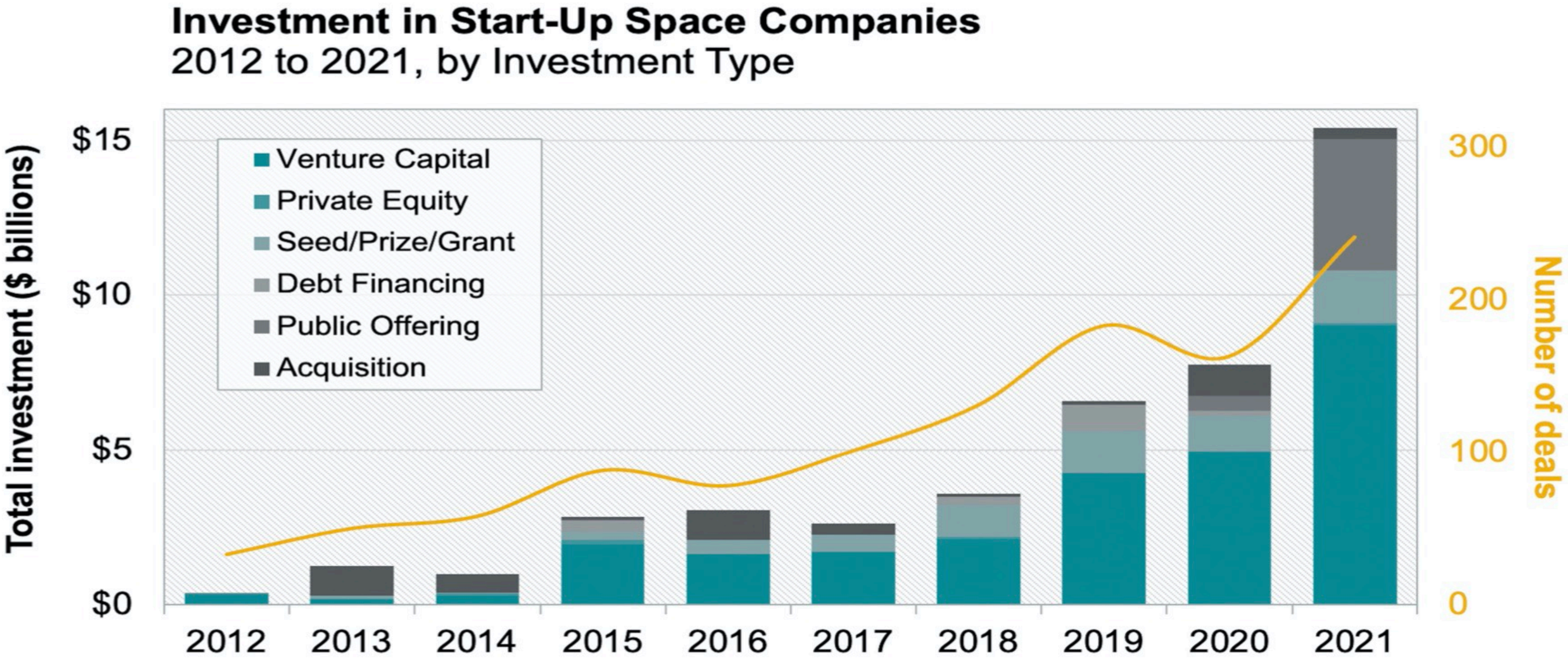
- ***Join the multimessenger revolution*** by providing a first mini-constellation for GRB localizations

- Develop miniaturized payload technology for breakthrough science and demonstrate COTS applicability to challenging missions, contribute to Space 4.0 goals

- Push and prepare for a high reliability, large constellation

1 Dan Goldin 1992

Two revolutions: Space 4.0



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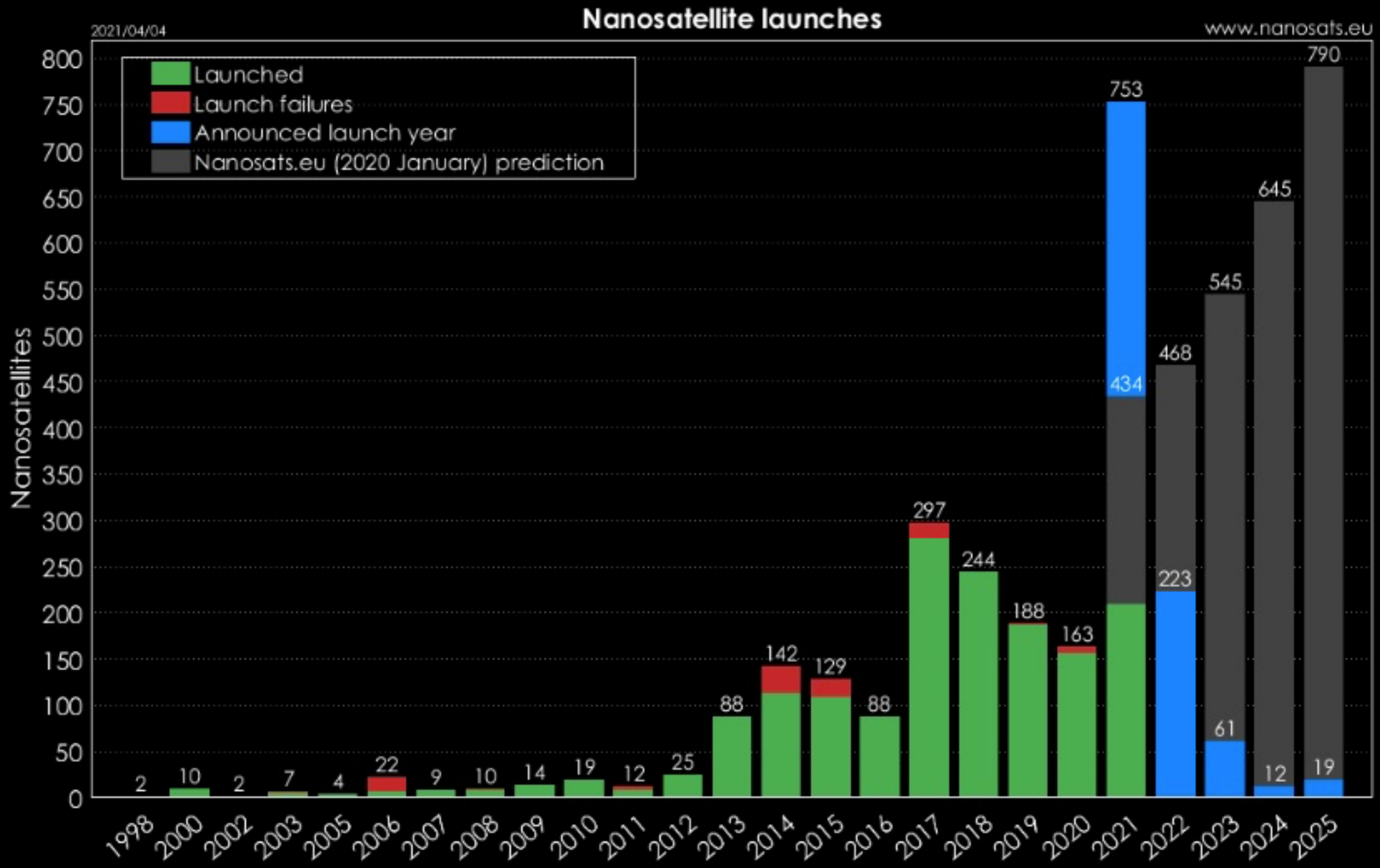
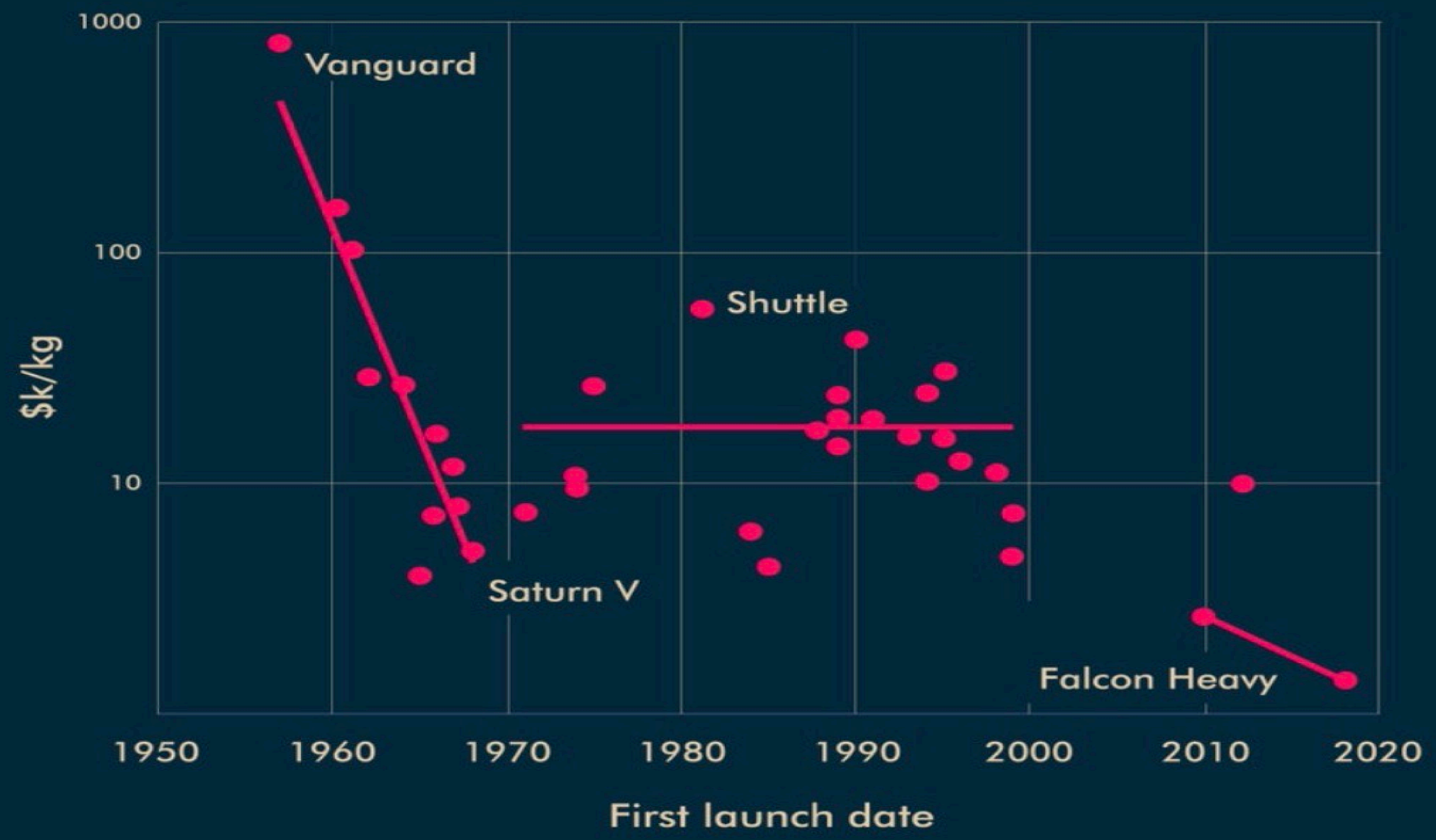


Hedonova

Launch cost per kilogram to low earth orbit vs first launch date



$ per kg (log scale)
$51,200
$25,600
$12,800
$6,400
$3,200
$1,600
$800
$400
$200
$100
1960
1970
1980
1990
2000
2010
2020
2030
1 Soyuz
2 Saturn V
3 Space Shuttle
4 Long March 3b
5 Delta Heavy
6 Angara
7 Falcon 1
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10 Starship (estimate)
SpaceX
Today, launching a spacecraft is 10x cheaper than it was a decade ago.

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SpaceX
1ton=200k$ 10ton=2M$!!!!!

An intriguing perspective

- Present:

  Reduction of launch cost + Miniaturization + COTS components + ride-share launches:
  —> CubeSat proliferation, few kg payloads, M$, few years dev.

- Future

  Further reduction of launch cost + COTS components
  —> large missions, hundred kg/tons payloads as “ride-share” missions, at the cost of ground based experiments (tens/hundreds M$ vs. 1-10B$, few year dev. vs. few decades): from Theseus to Te Deus!

  - no longer sensible to minimize risks by multiplying costs
  - mass production

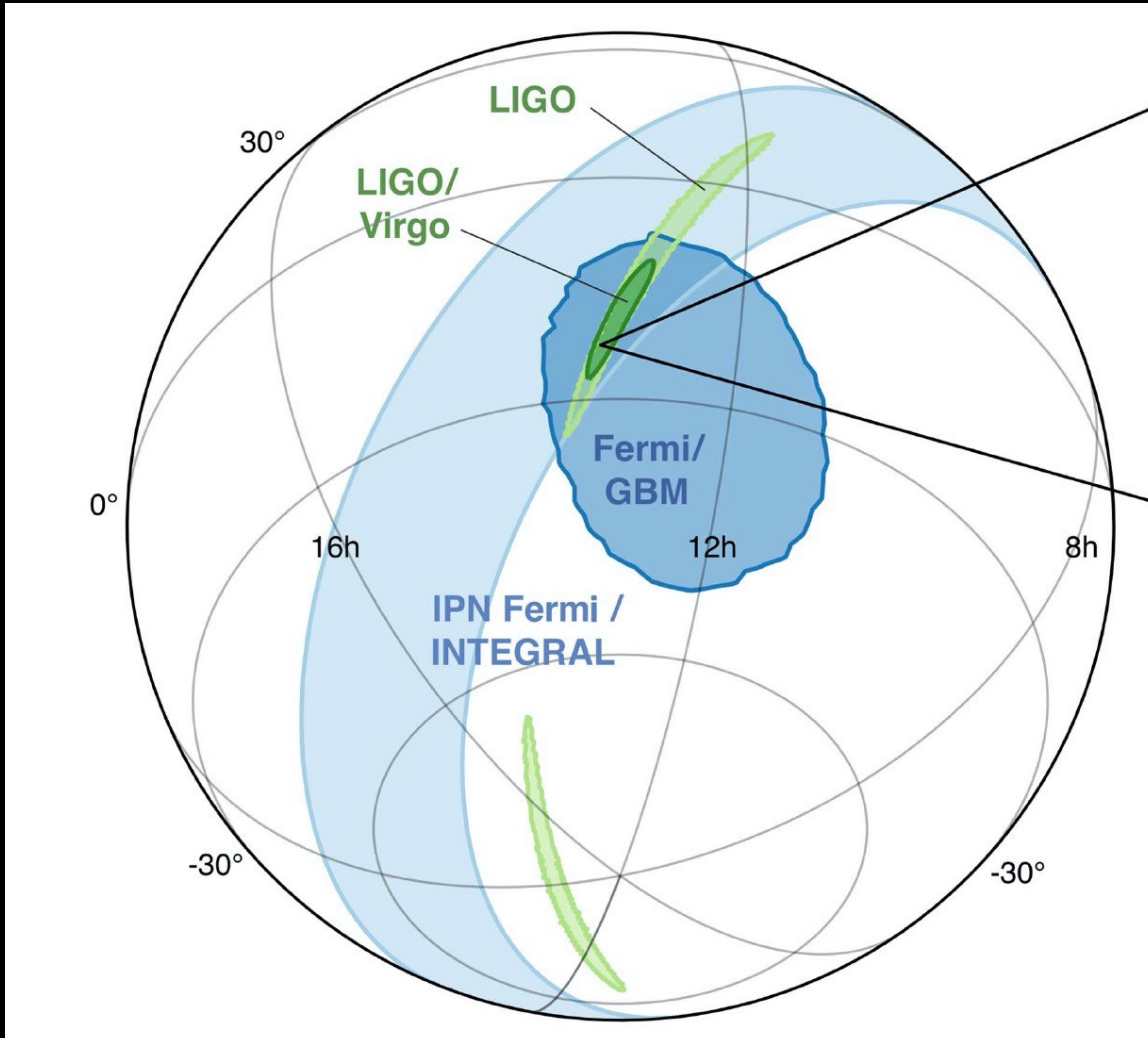
Two revolutions: multimessenger revolution

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…)

GW170817



Two revolutions: 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

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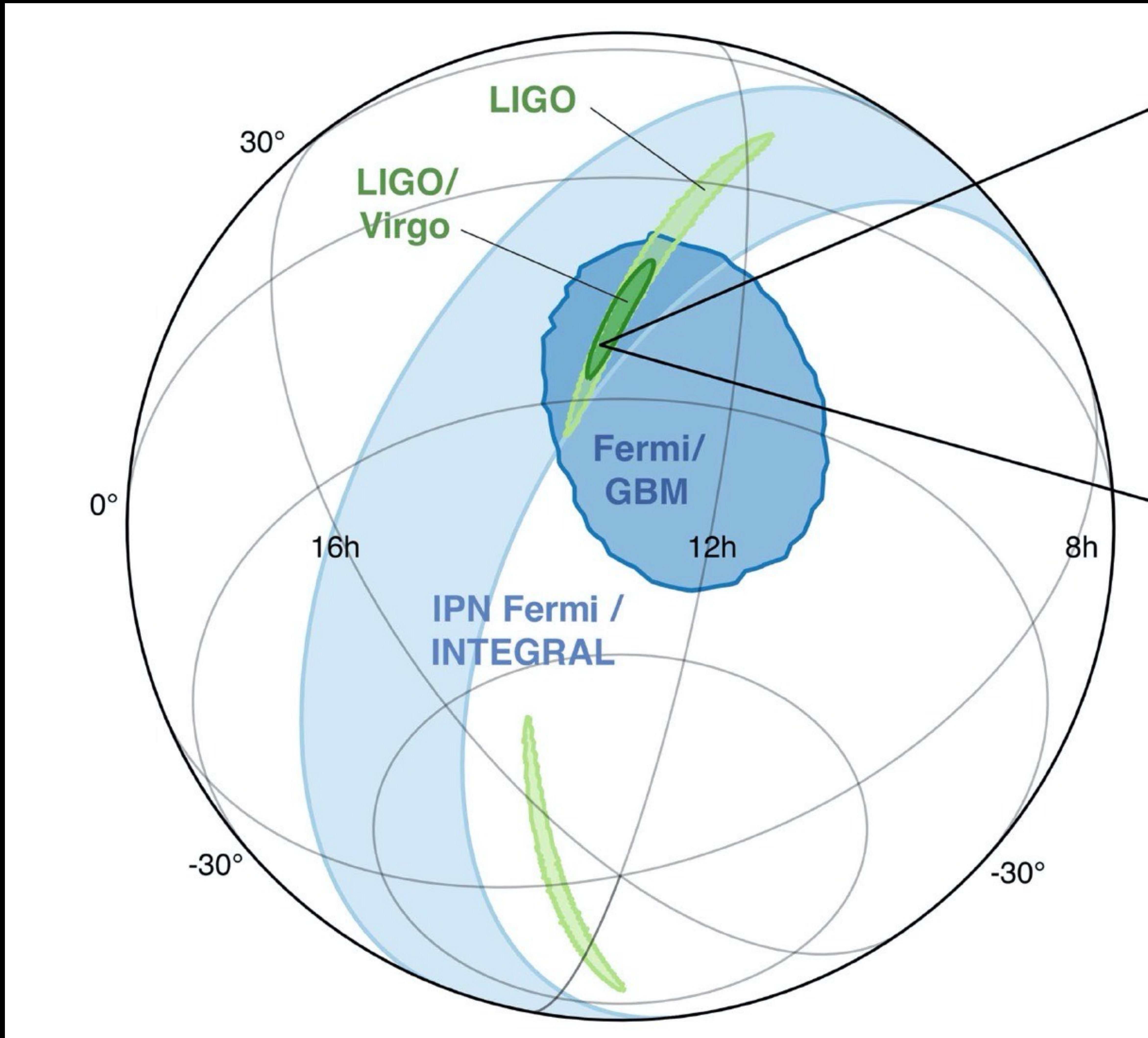

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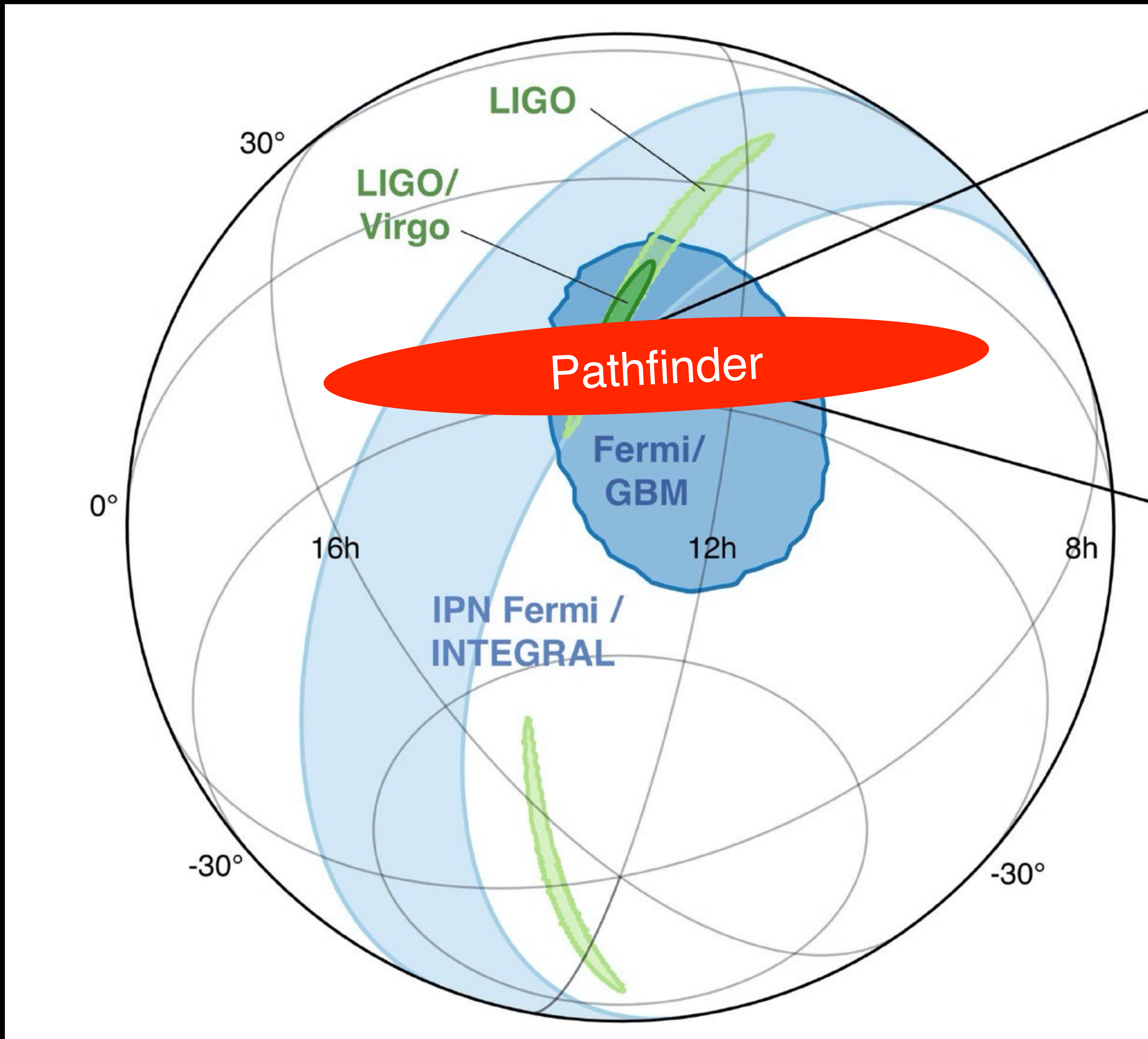

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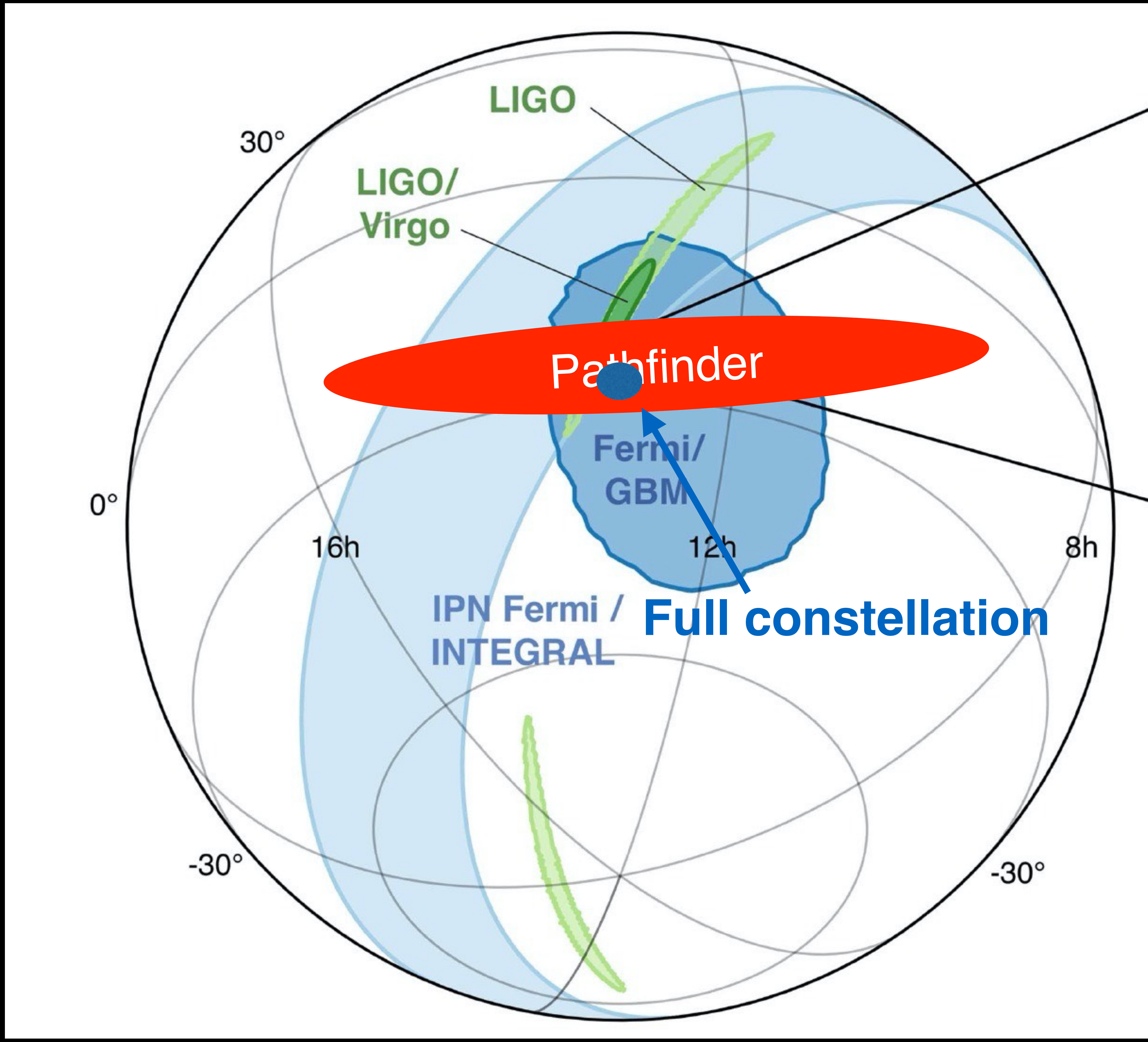
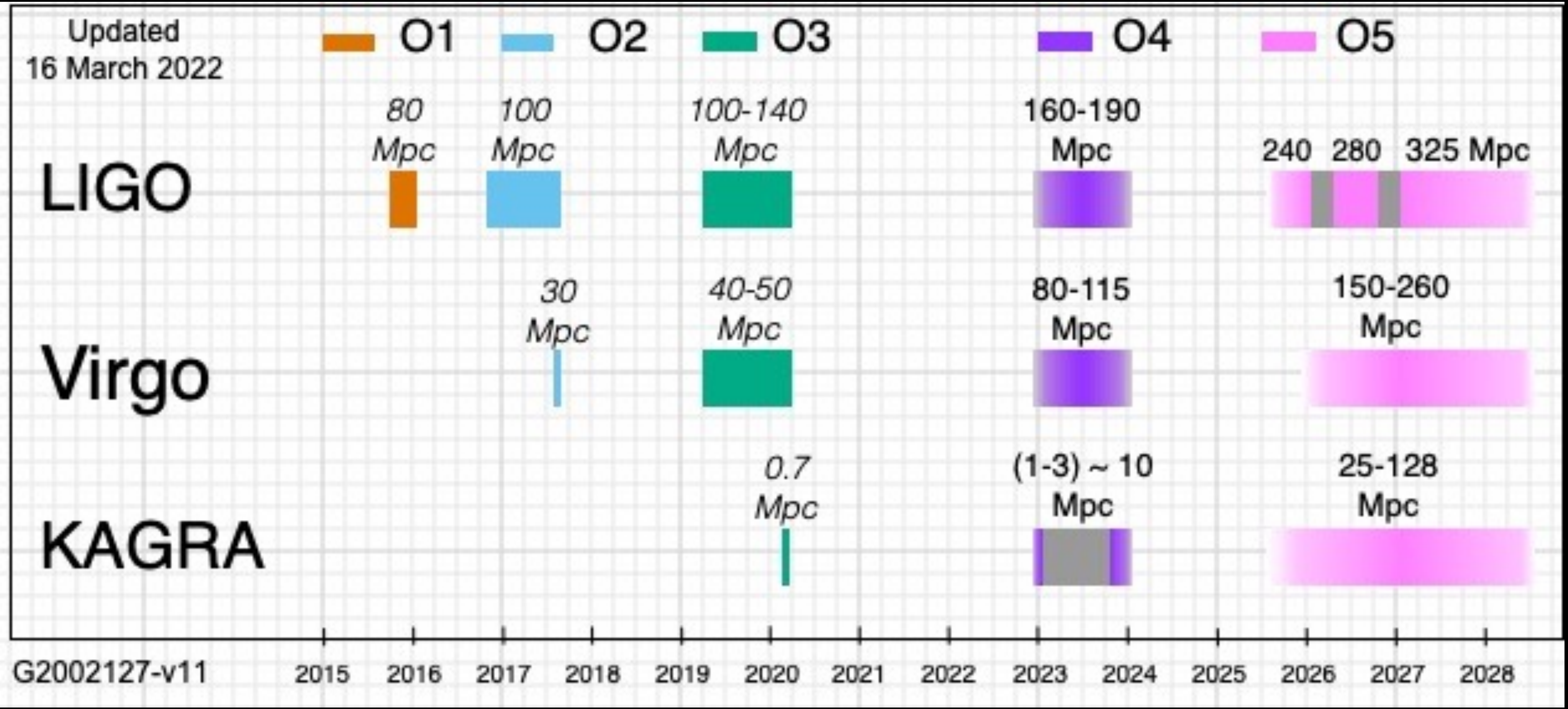


Why: GRBs and Compact binary coalescence



HERMES PF DAMA

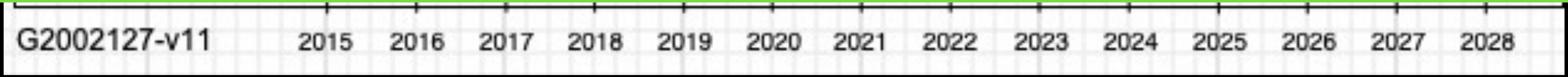
Why: GRBs and Compact binary coalescence

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

Loosing one event is a big science loss

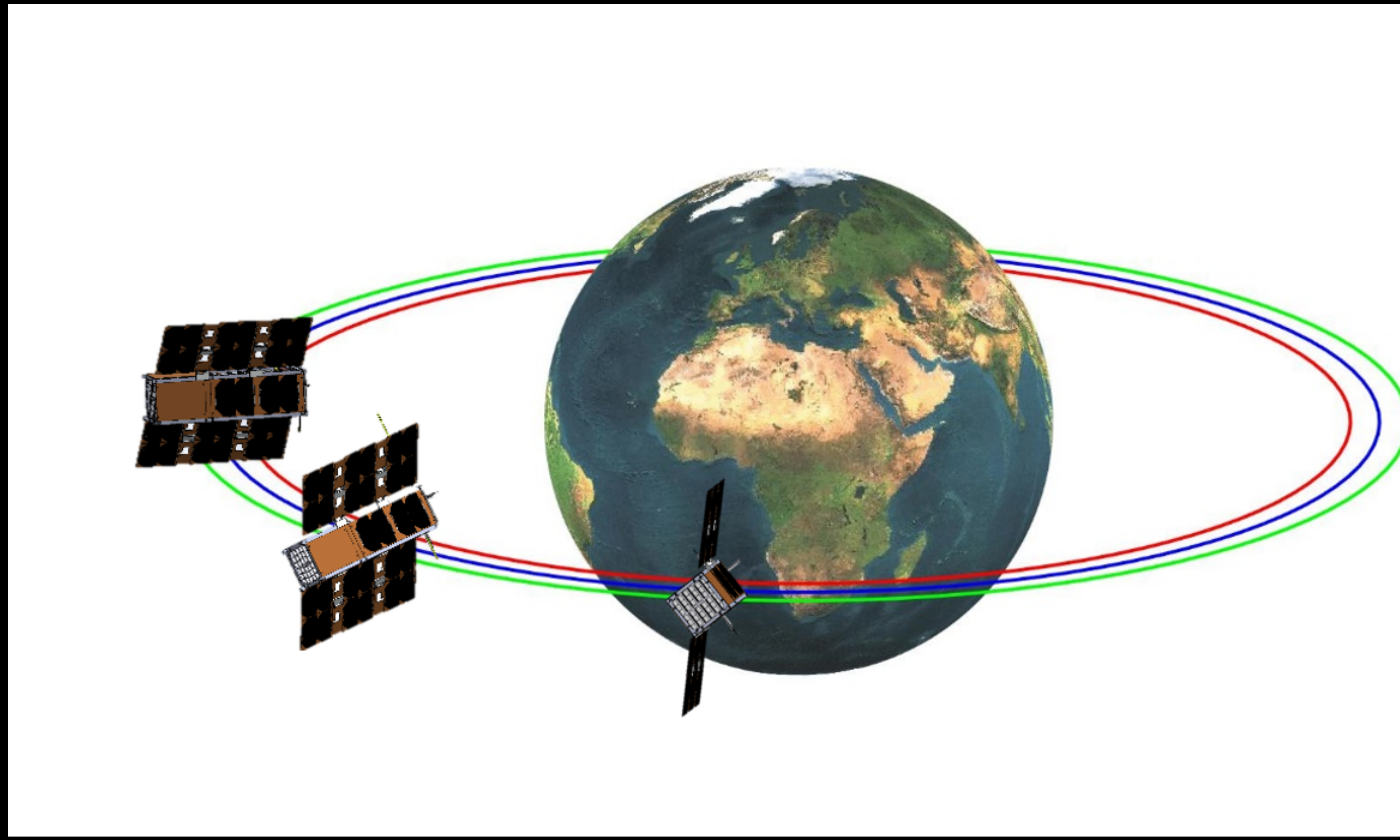
A sensitive X-ray all sky monitor during the 20’:

DAMA: Distributed Architectures for Multimessenger Astrophysics



HERMES-PF & SpIRIT in a nutshel

- In orbit demonstrations:
  - HERMES Pathfinder: six 3U cubesat equipped with advanced X-ray/gamma/ray wide field detector. Nearly equatorial LEO.
  - SpIRIT: 6U cubesat managed by University of Melbourne and funded by ASA. Host 1 HERMES-PF X-ray/gamma-ray payload + S-band system. SSO.



Mission concept

Disruptive technologies: cheap, underperforming, but producing high impact.
Distributed instrument: tens/hundreds of simple units to form a sensitive ***all sky monitor***

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

2019-2022 ASI internal funds

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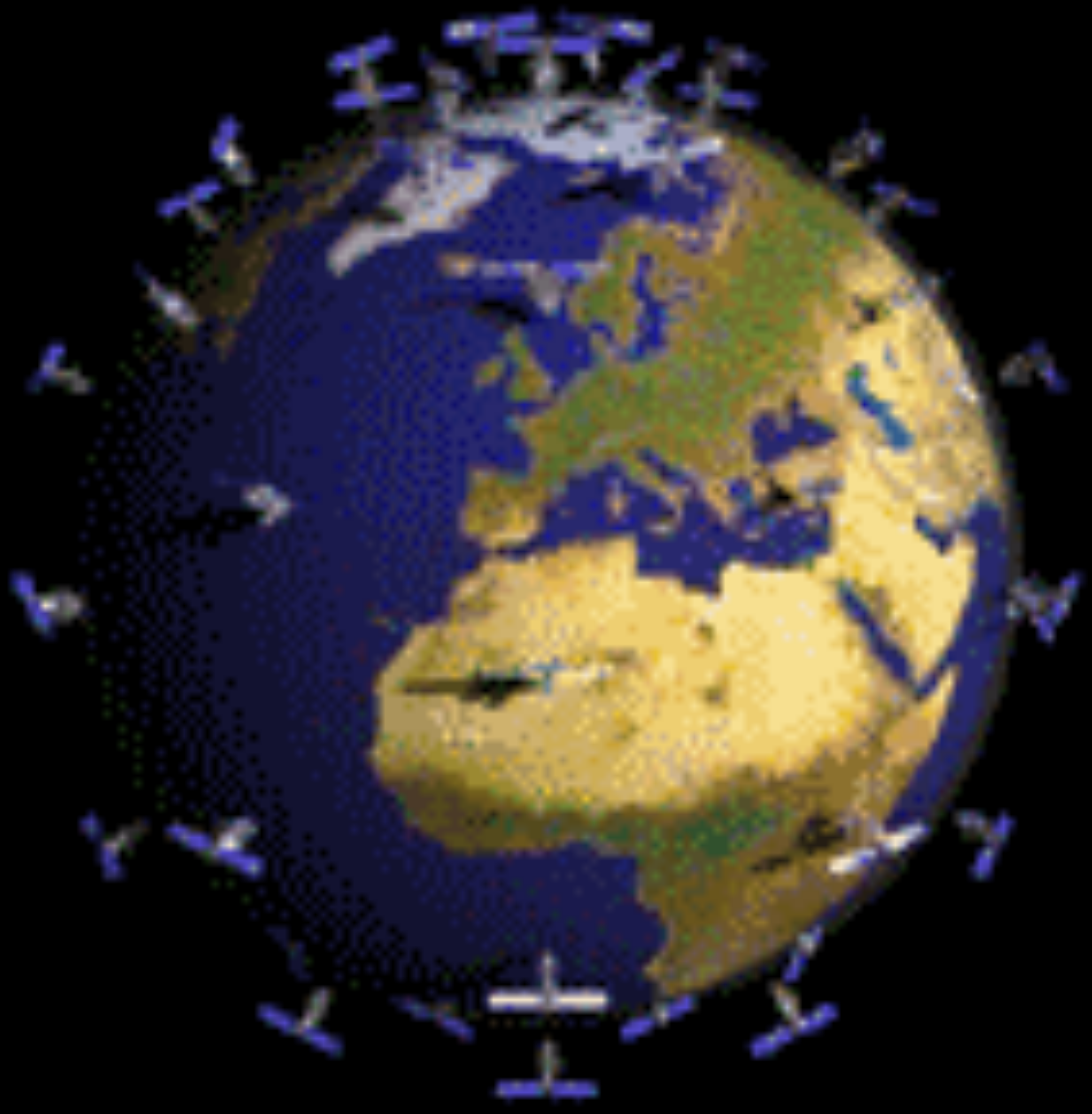

Why HERMES now

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Breakthrough scientific case: EM counterparts of GW events

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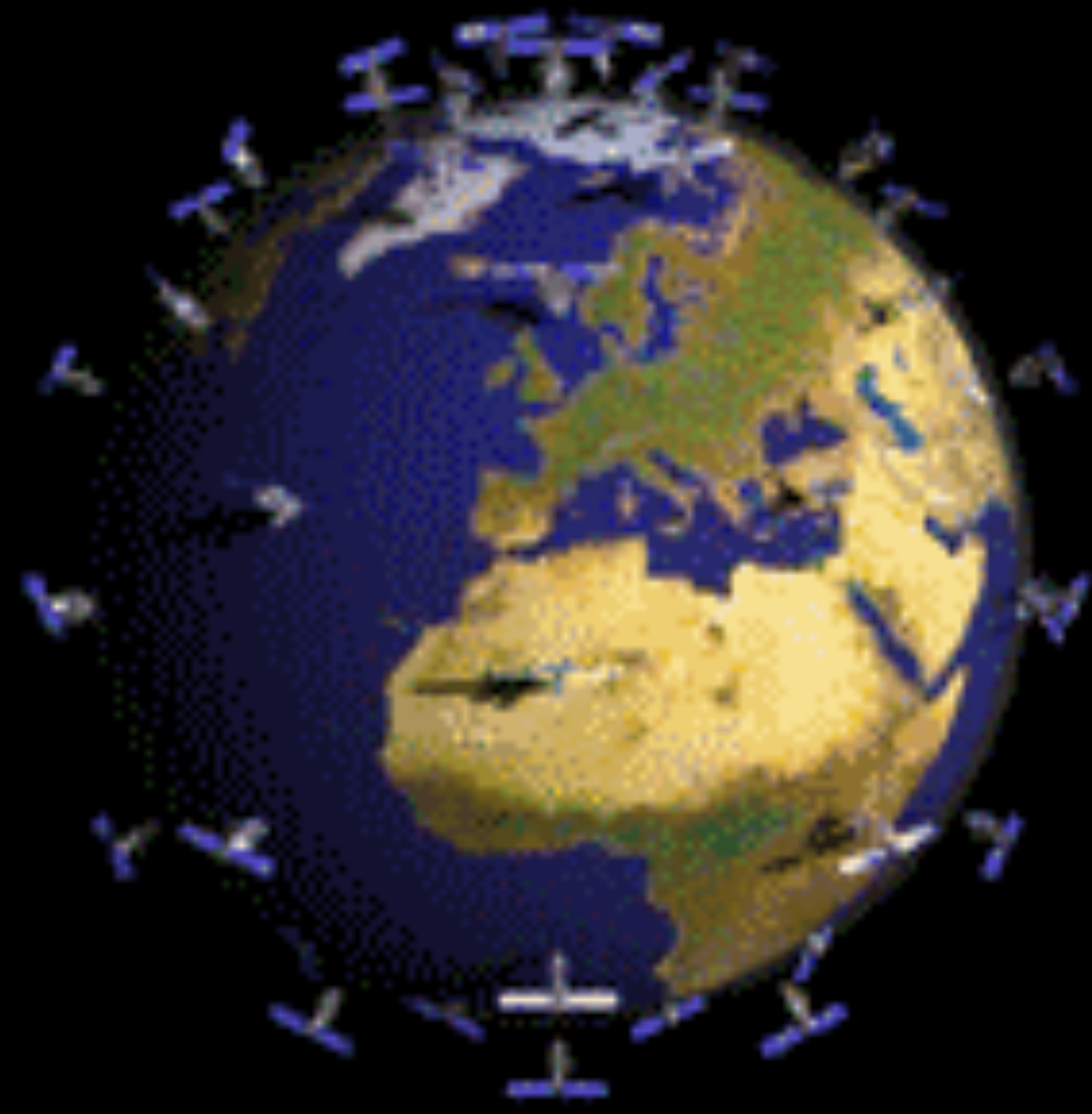
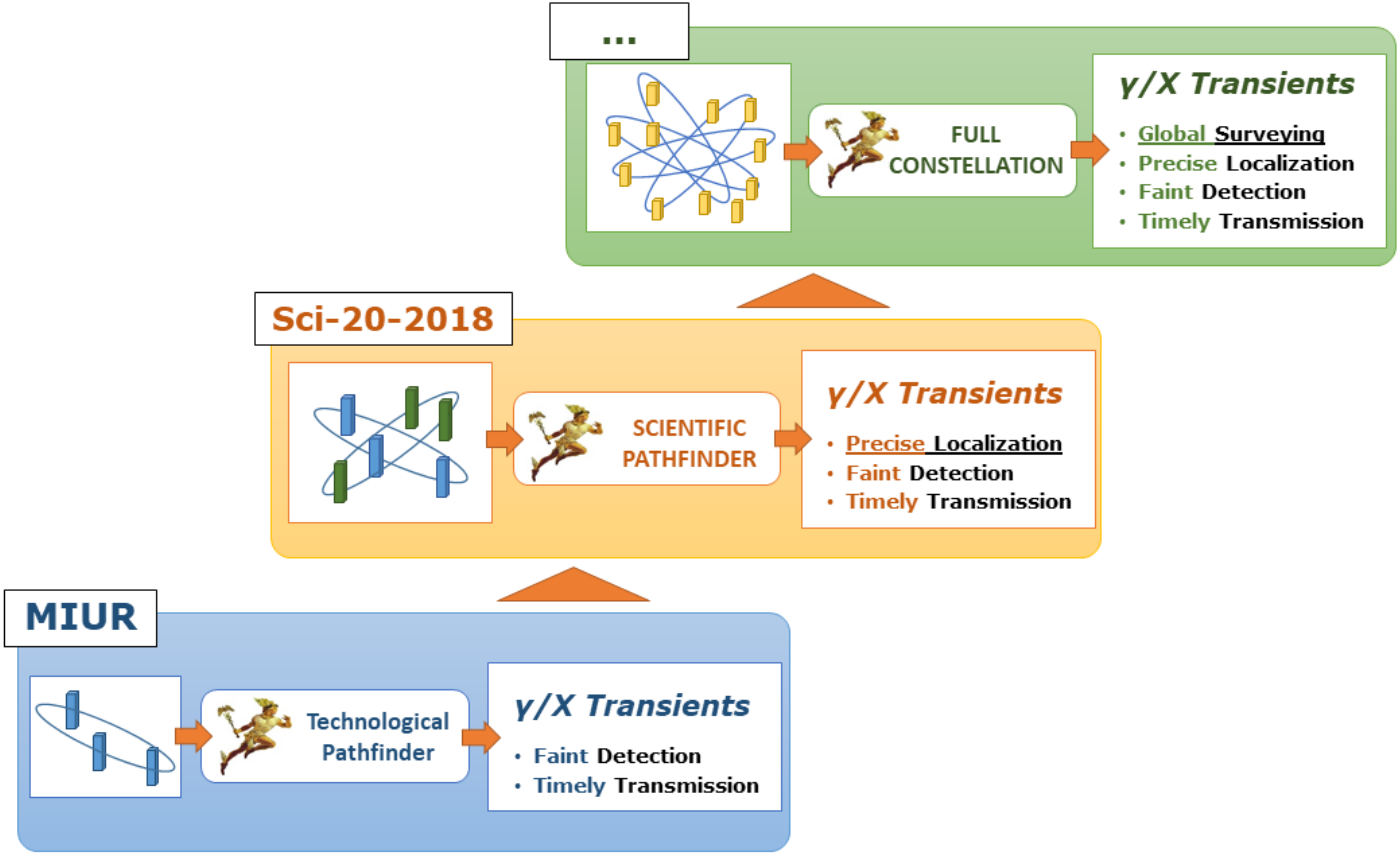
Breakthrough scientific case: EM counterparts of GW events

Modularity:

- Avoid single point failures, improve hardware
- Pathfinder




...
γ/X Transients
• Global Surveying
• Precise Localization
• Faint Detection
• Timely Transmission
FULL
CONSTELLATION
Sci-20-2018
SCIENTIFIC
PATHFINDER
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Open μsec - msec window:
- Accurate positions
- QG tests

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Breakthrough scientific case: EM counterparts of GW events

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Open μsec - msec window:
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Limited cost and quick development
- COTS + in-house components
- Trend in cost reduction of manufacturing and launching QS

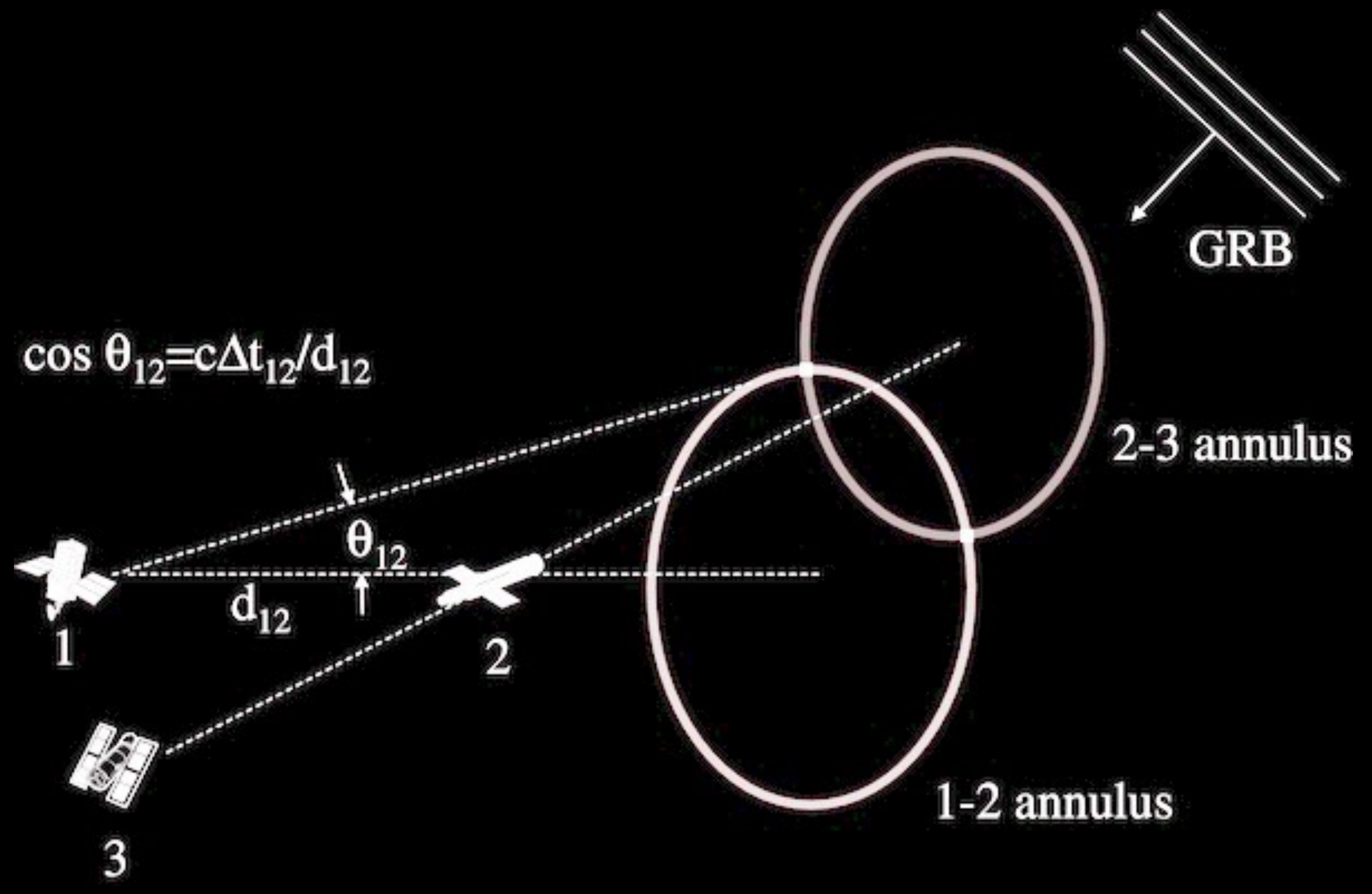
IPN legacy

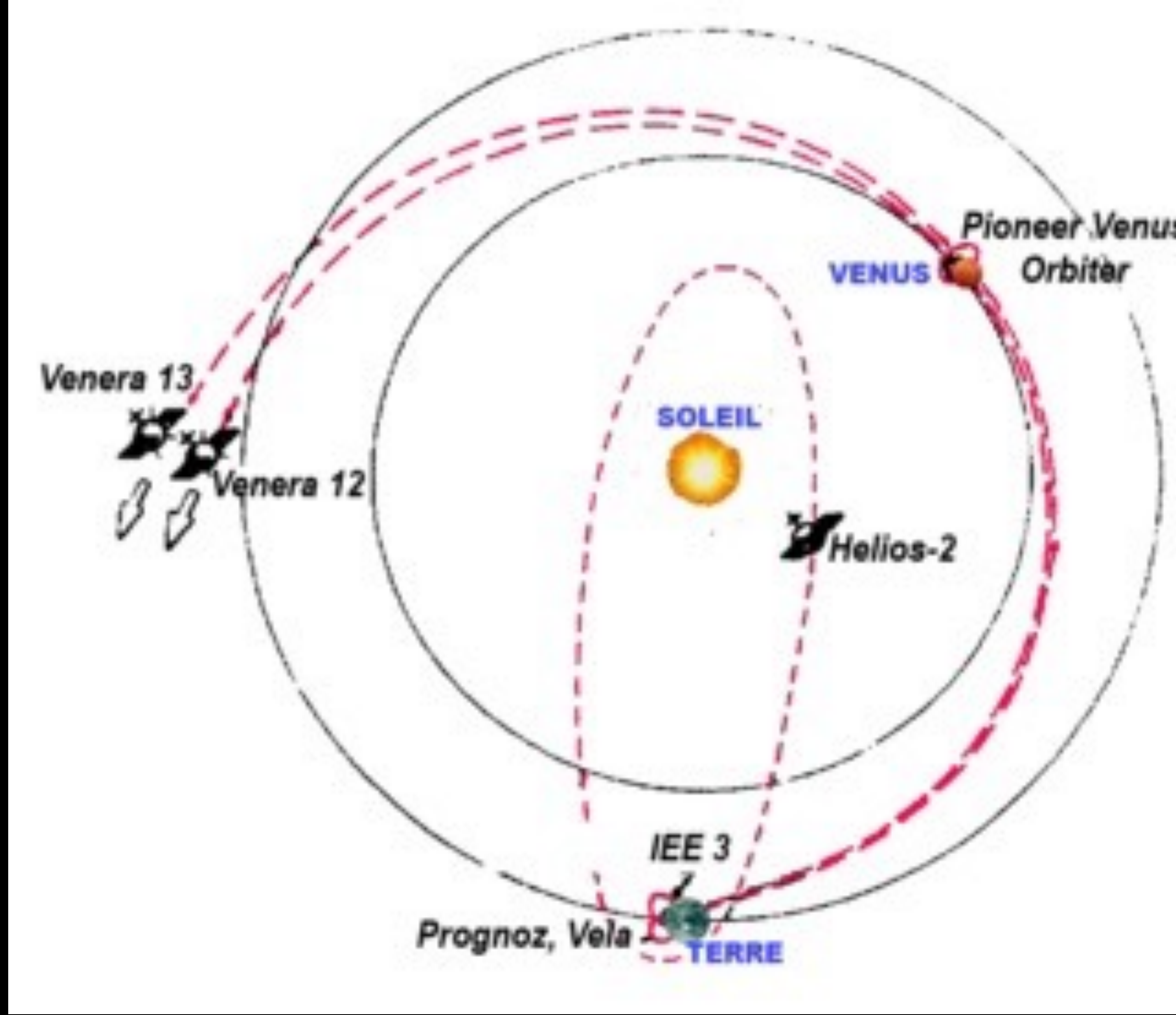
First IPN 1976
4-6 spacecrafts.
Baseline ~ 1 AU

Second IPN ~1990
PVO, Ulysses, CGRO, Wind

Third IPN 2000
~ 20 spacecrafts

Localisations: arcmin-deg
Main disadvantages: long data acquisition ~days, large systematic errors





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All sky monitor during the 2020’

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- sub-deg localization capability

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- prompt(minute) localisation
- sub-μs timing

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in orbit demonstrator: HERMES Pathfinder

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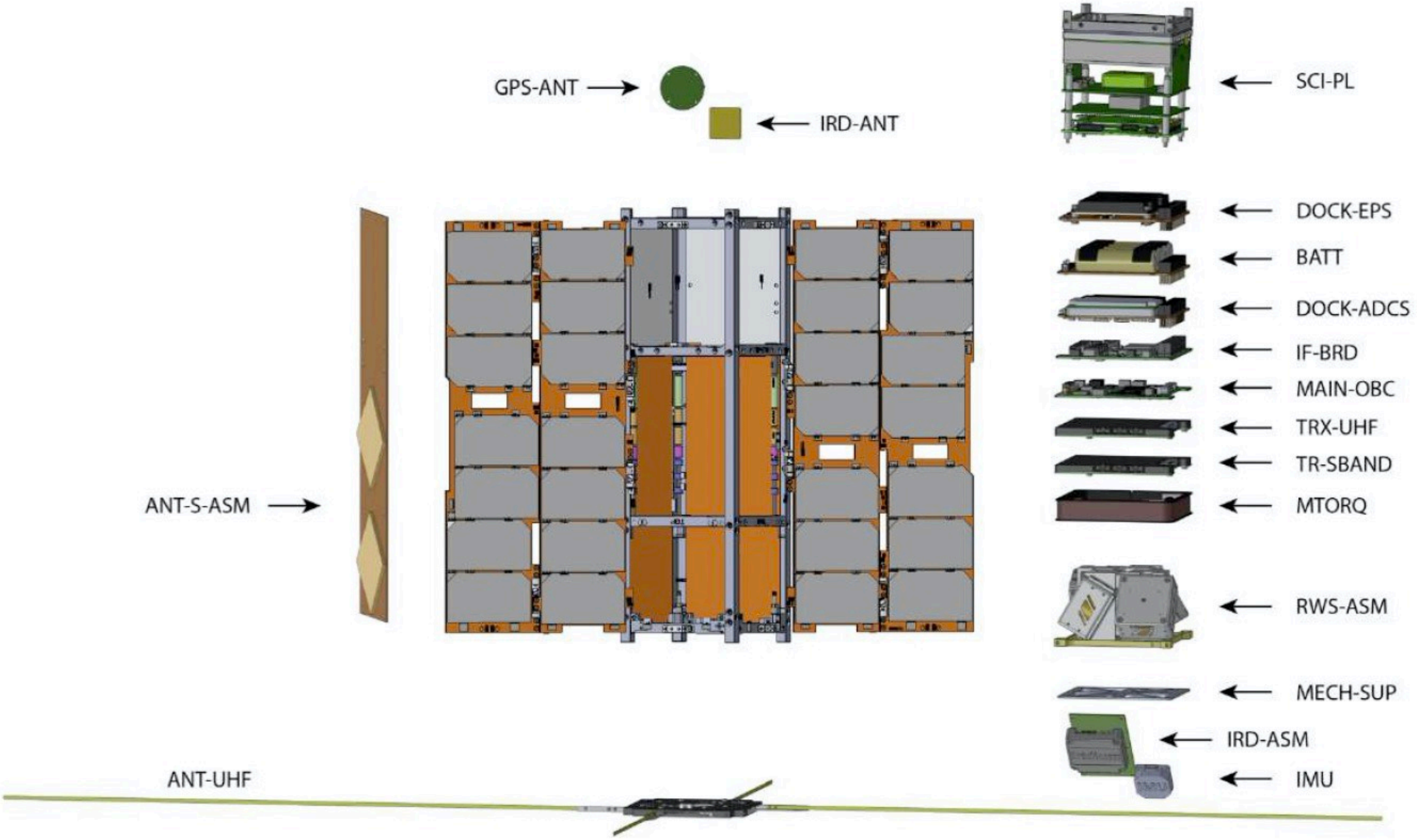
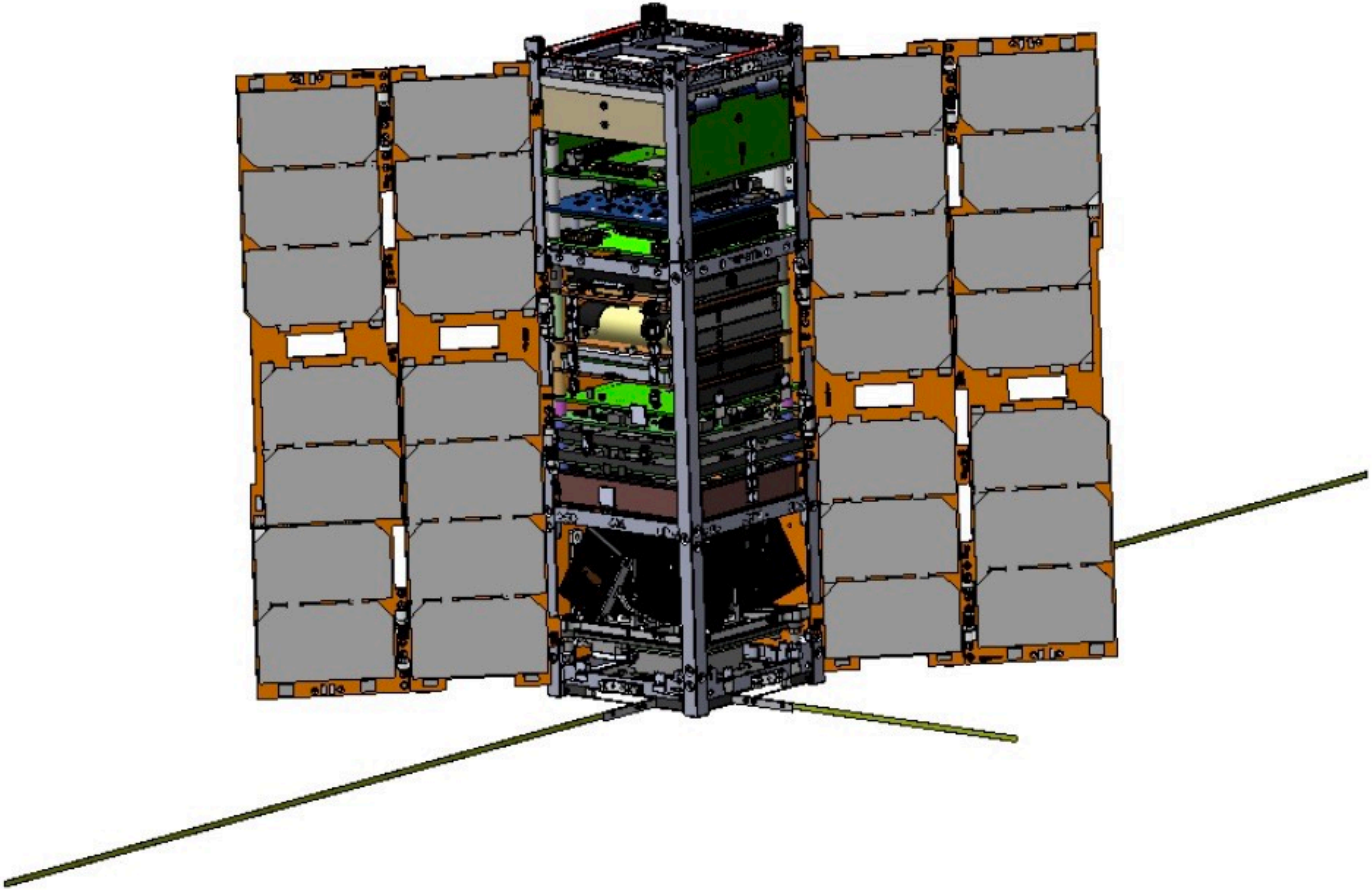
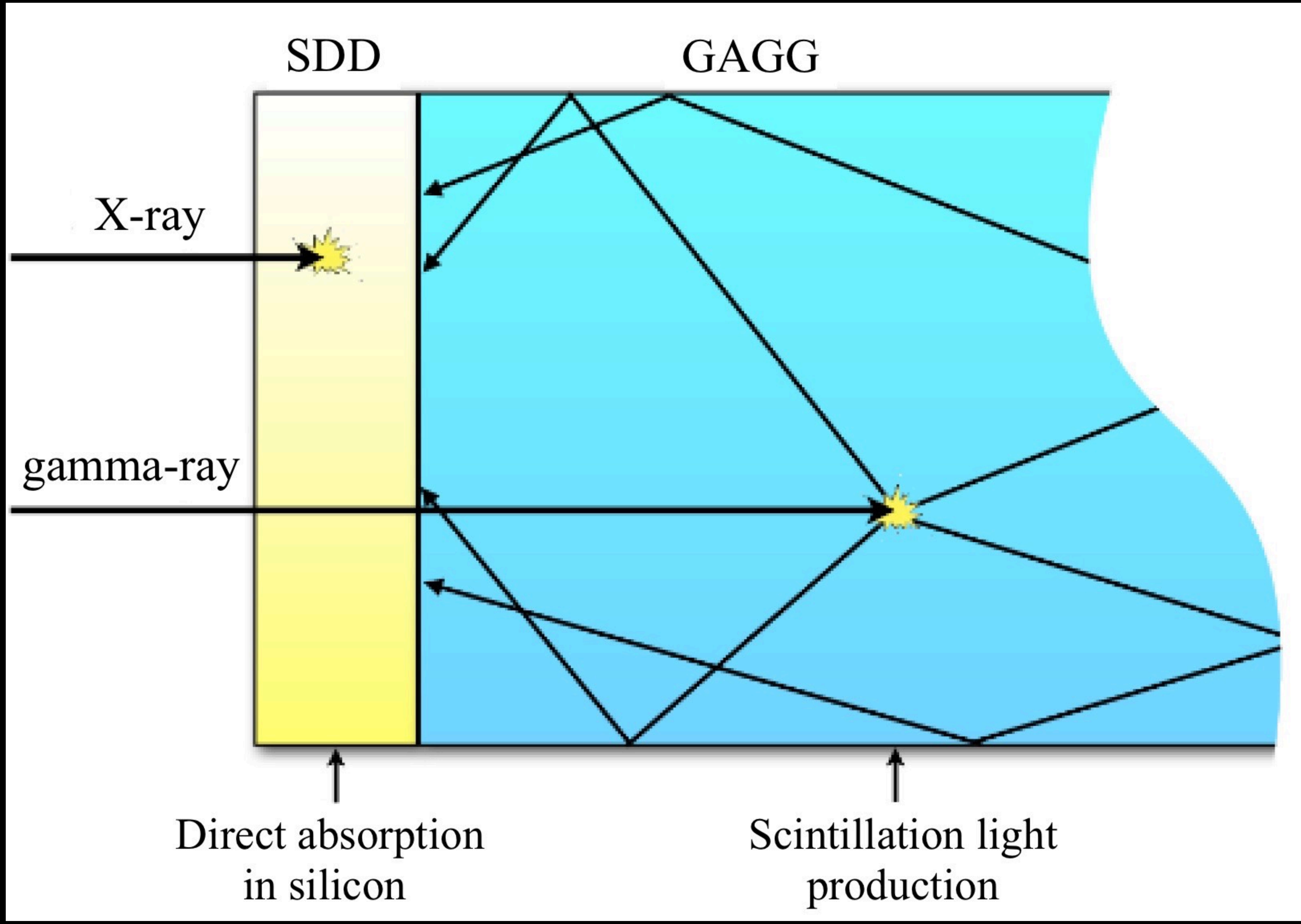
- Download full burst info in minutes


GPS-ANT
IRD-ANT
SCI-PL
DOCK-EPS
BATT
DOCK-ADCS
IF-BRD
MAIN-OBC
TRX-UHF
TR-SBAND
MTORQ
ANT-S-ASM
RWS-ASM
MECH-SUP
IRD-ASM
IMU
ANT-UHF



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+2020,2022, Campana+2020,2022

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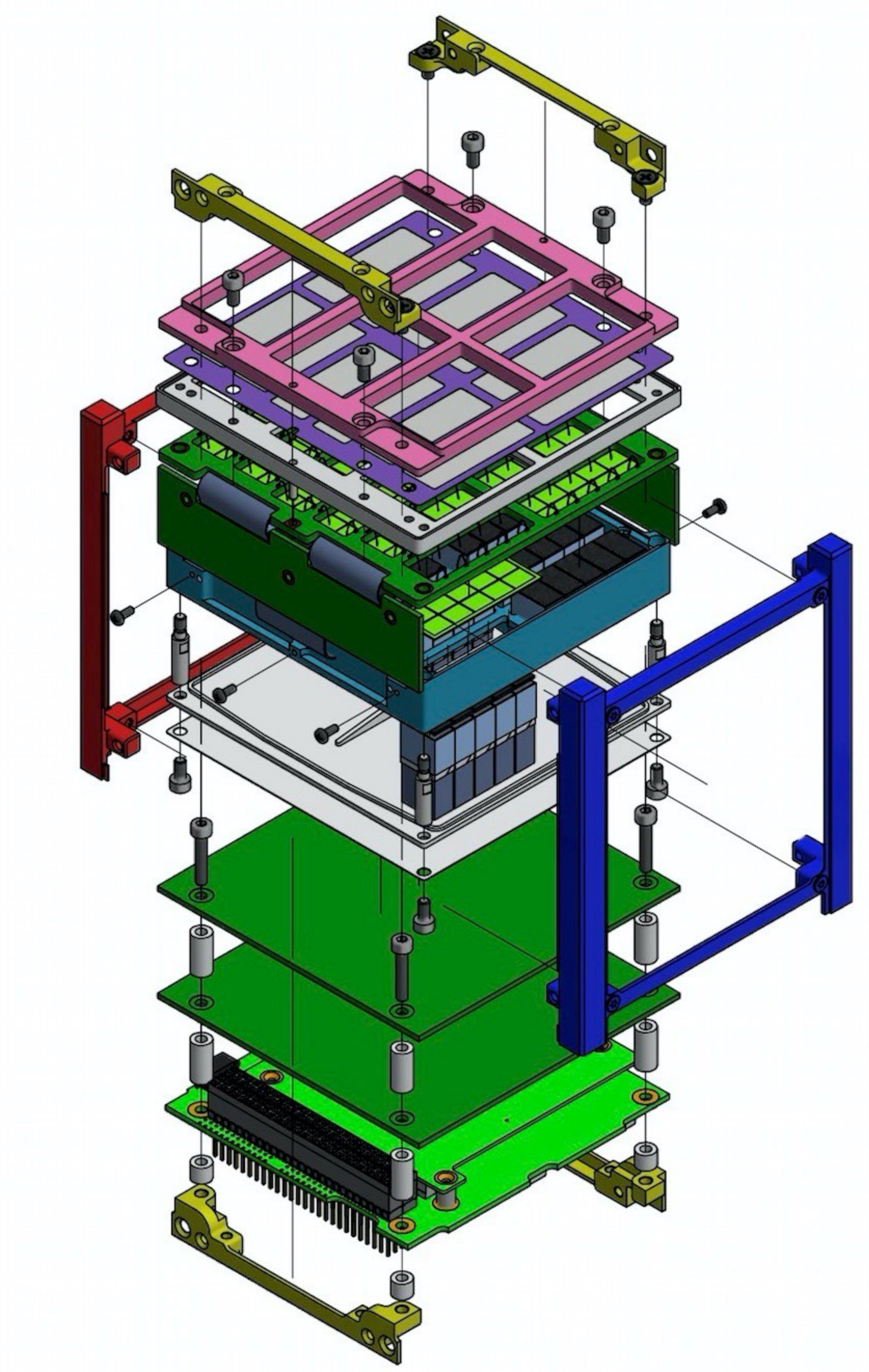

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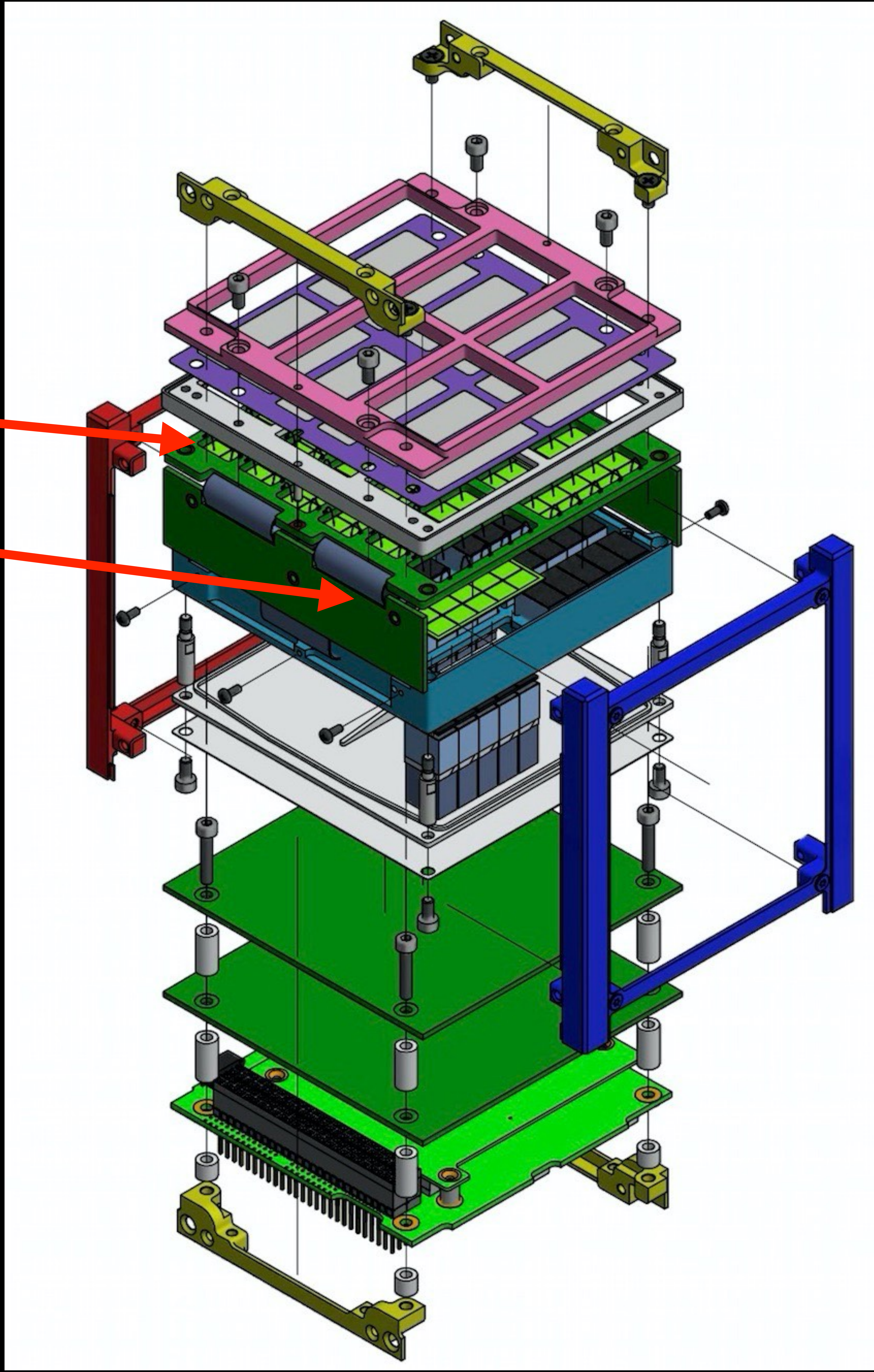

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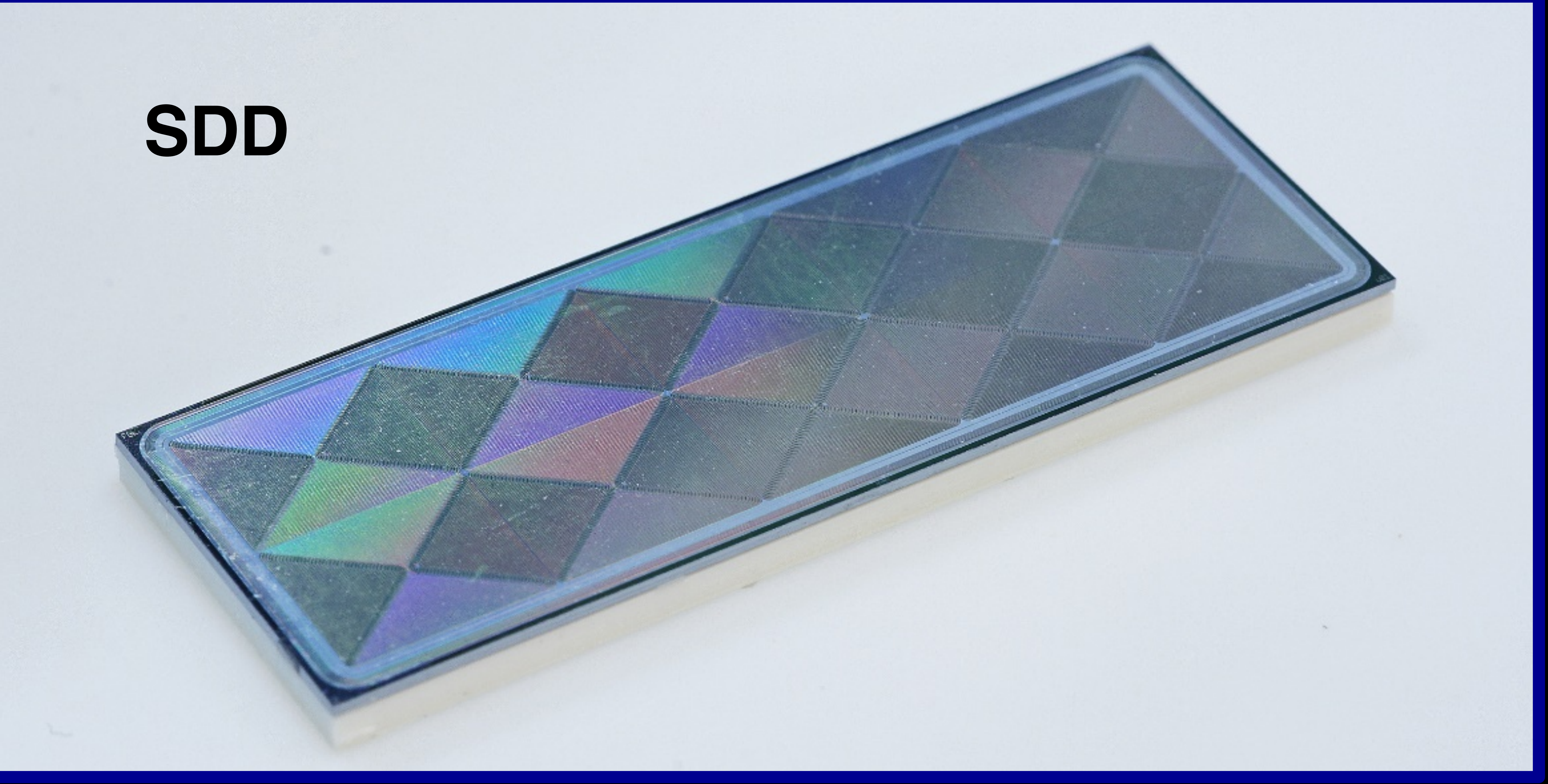
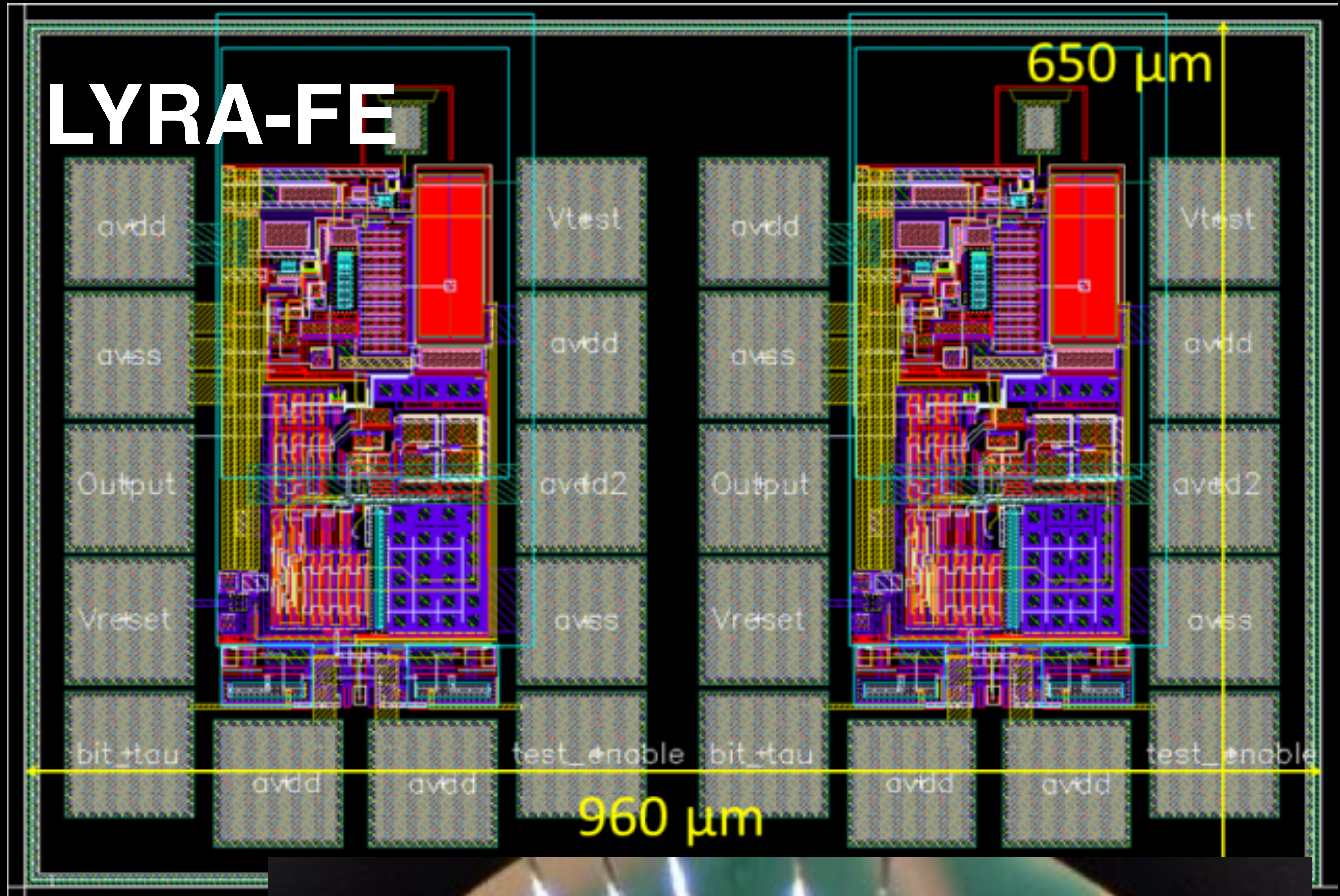
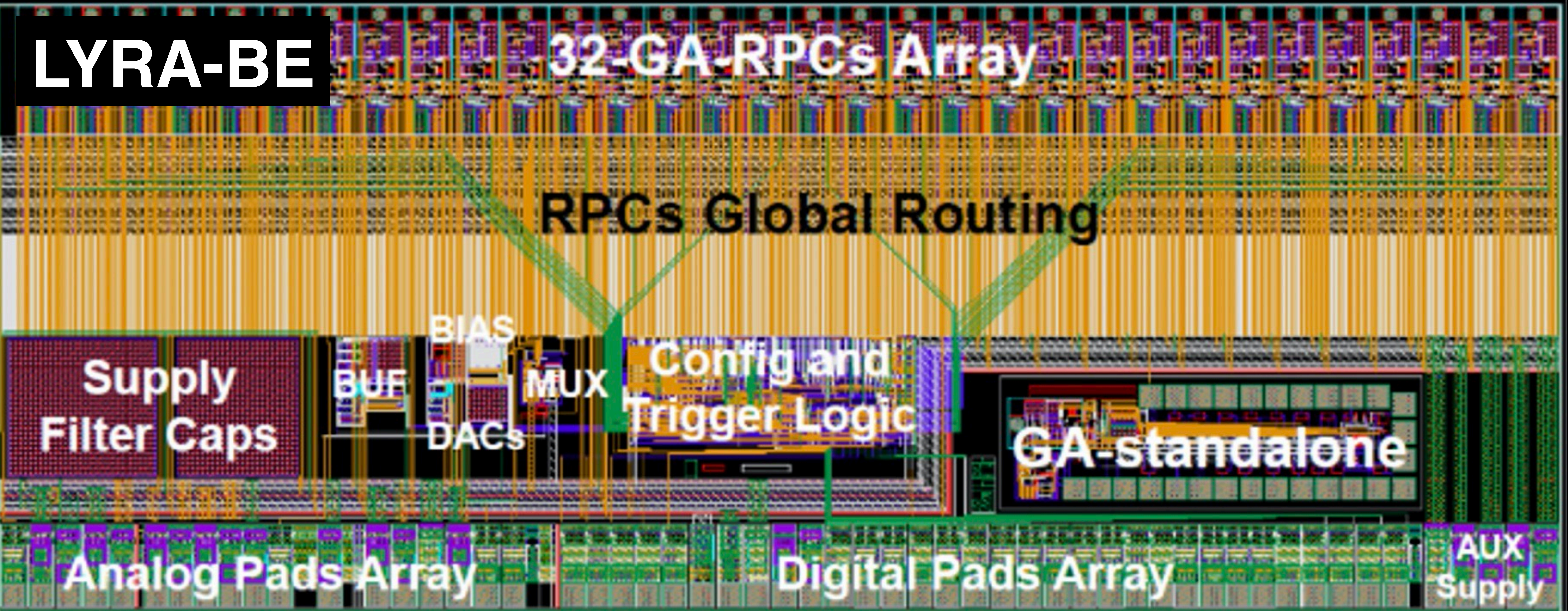
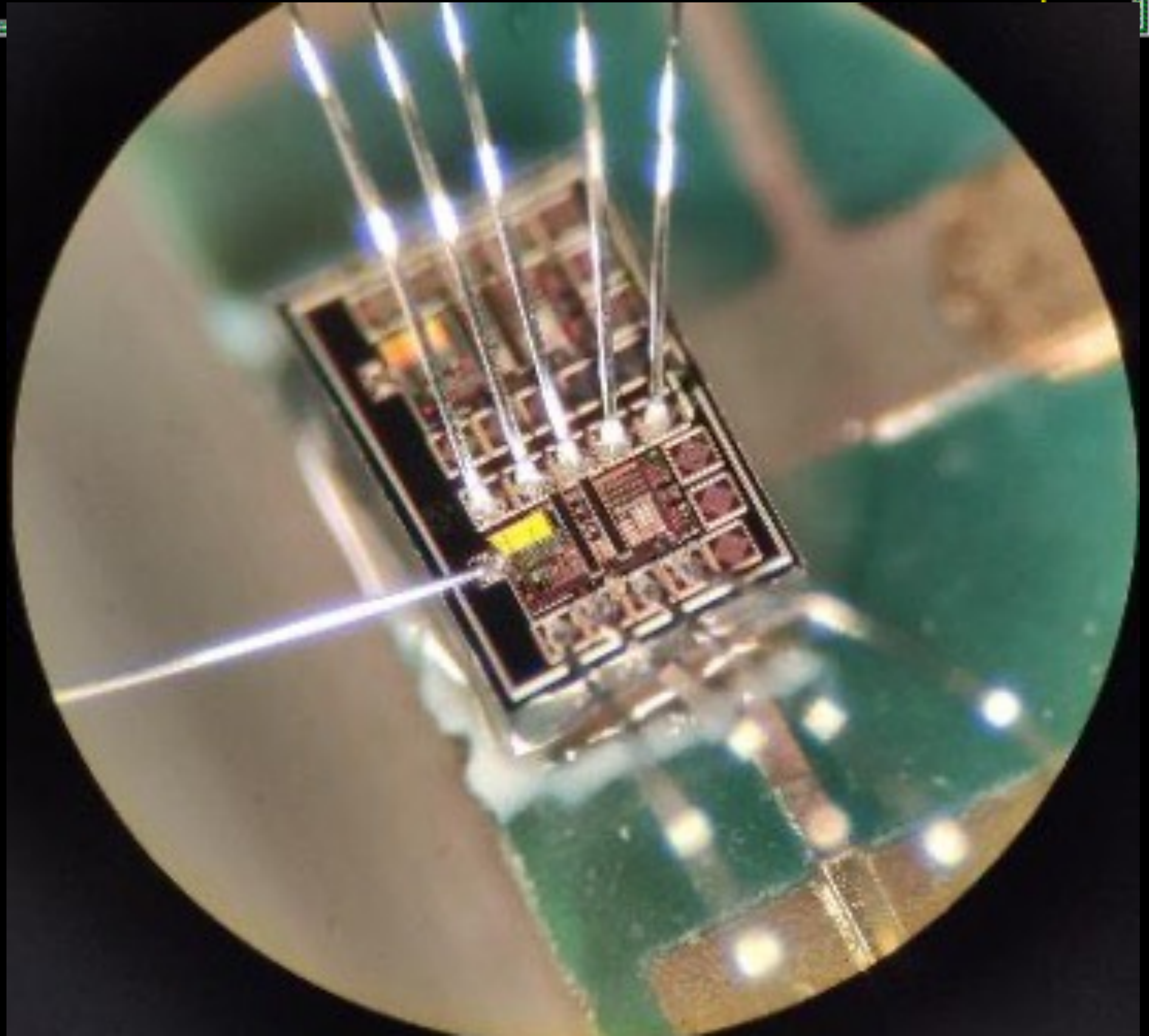
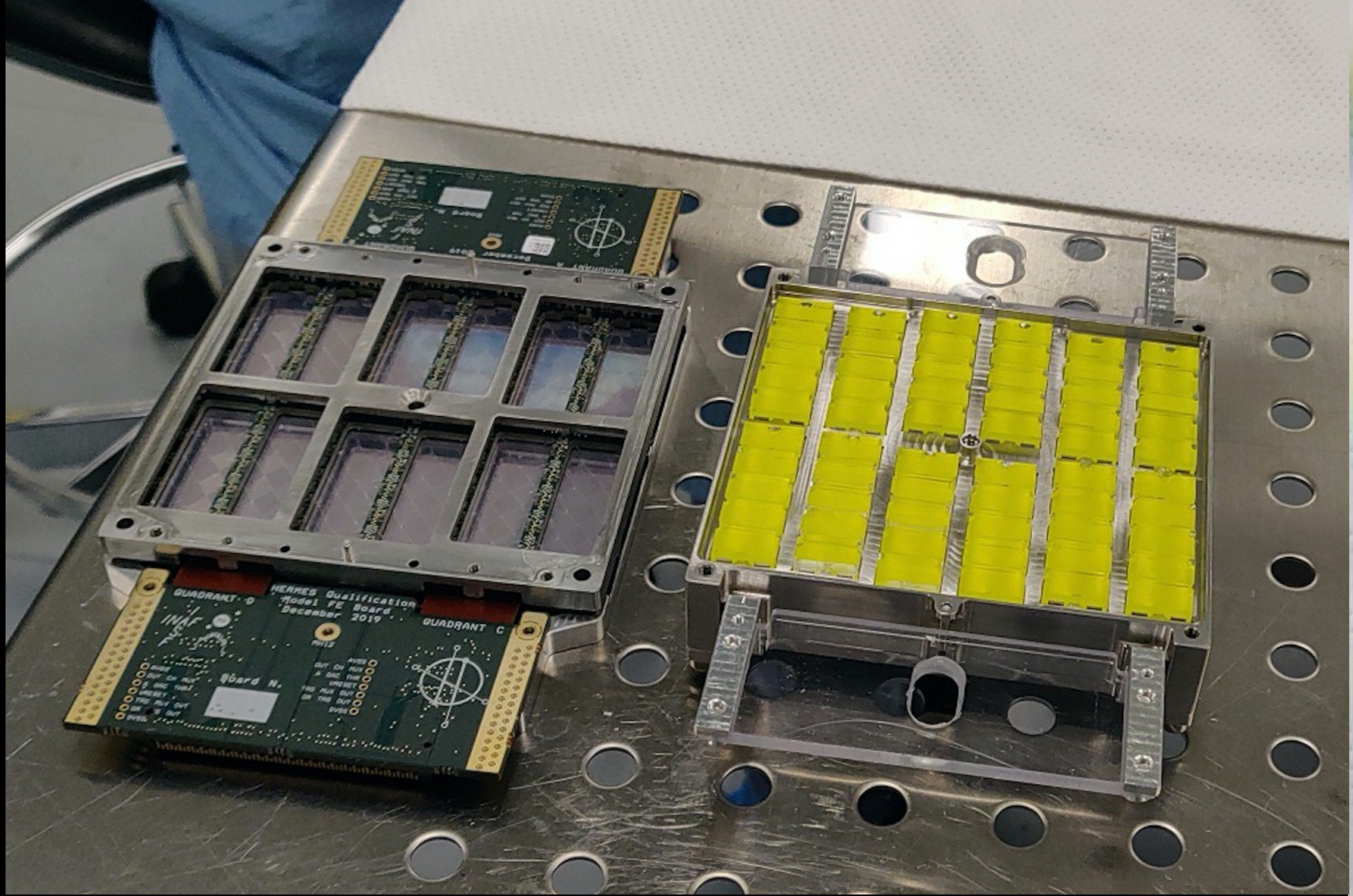
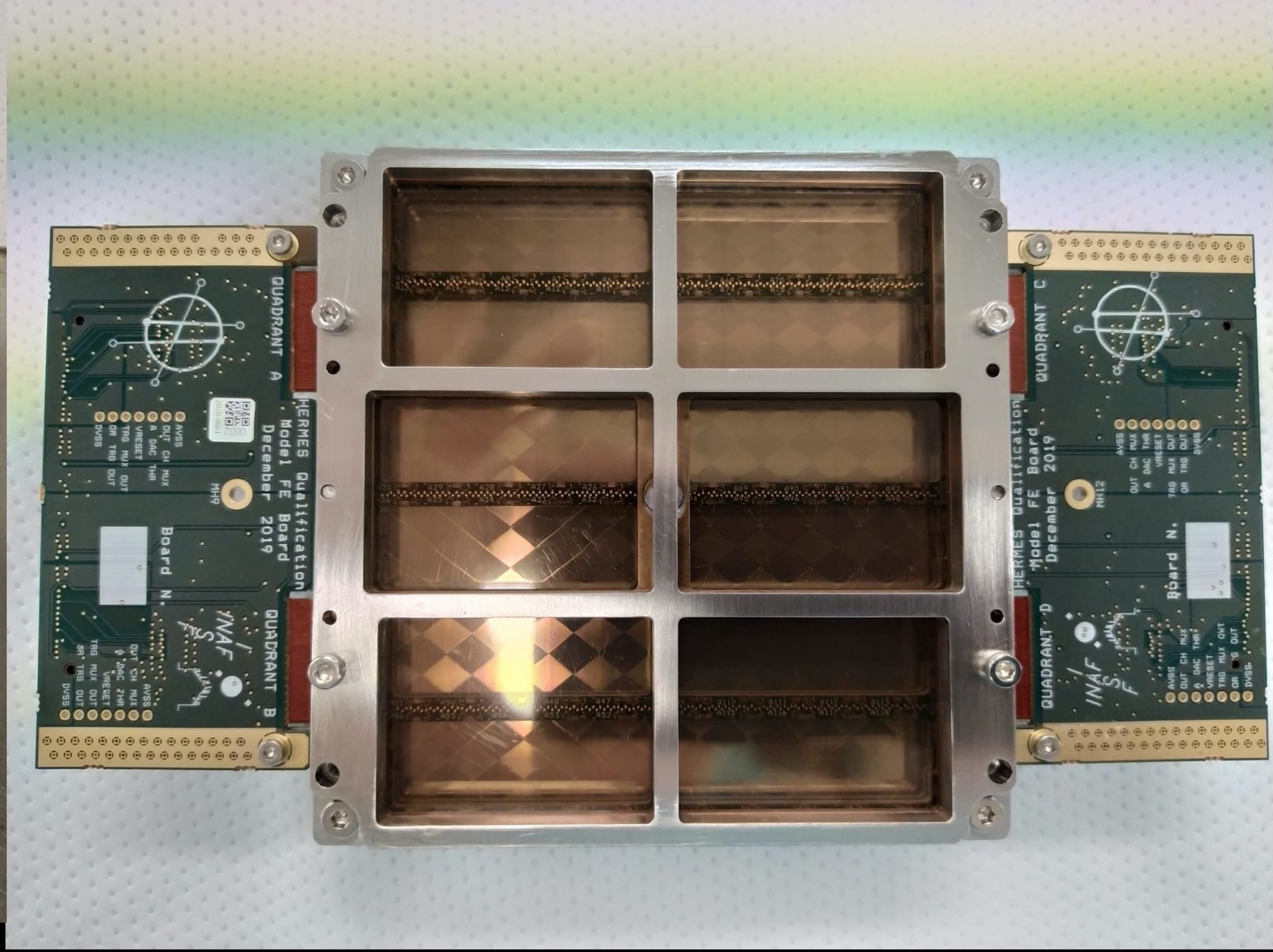

SDD

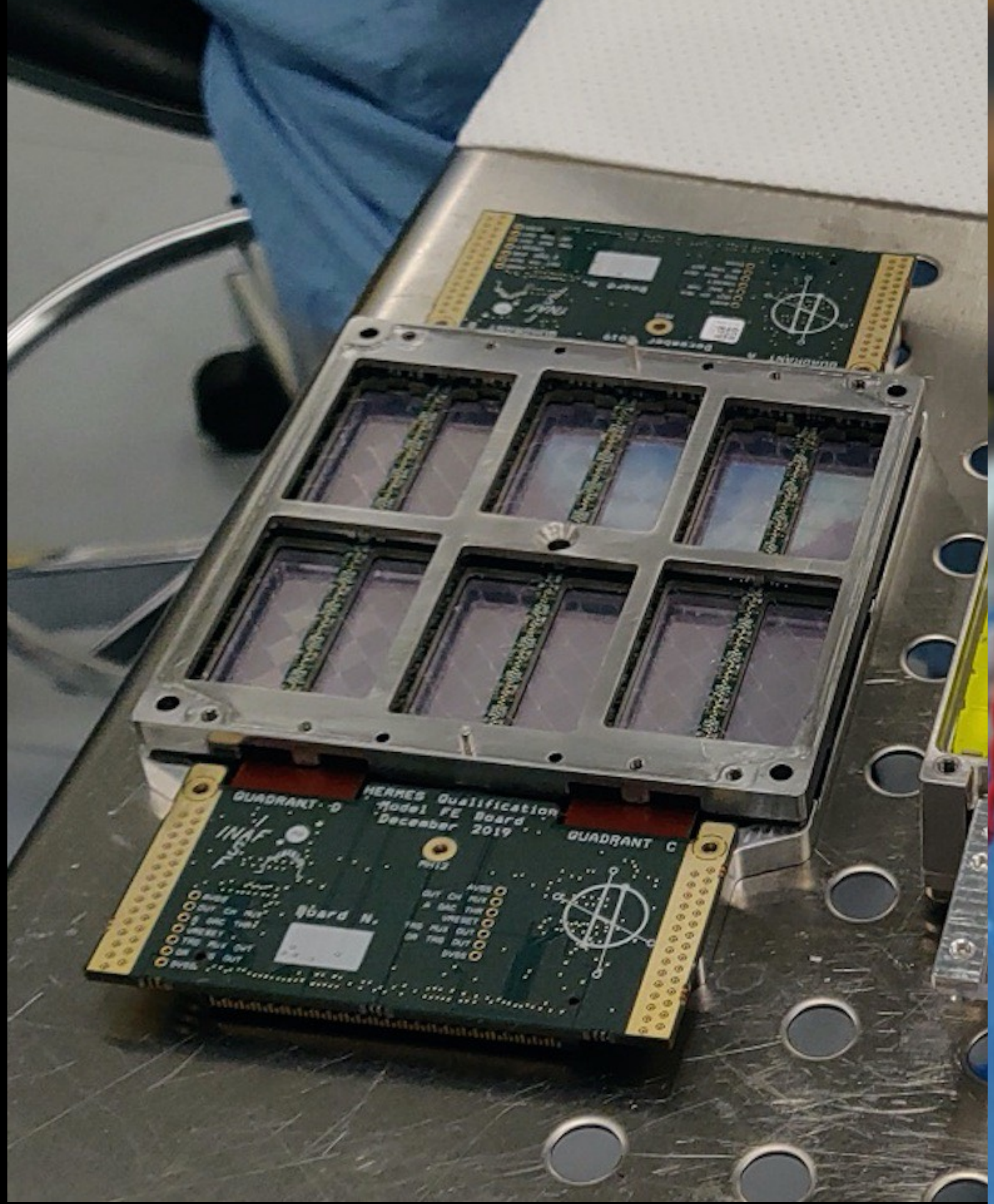

LYRA-FE
650 µm
avdd
avss
Output
Vreset
bit_tau
Vtest
avdd
avdd2
avss
test_enable
avdd
avdd
960 µm


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




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


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


HERMES Qualification
Model FE Board
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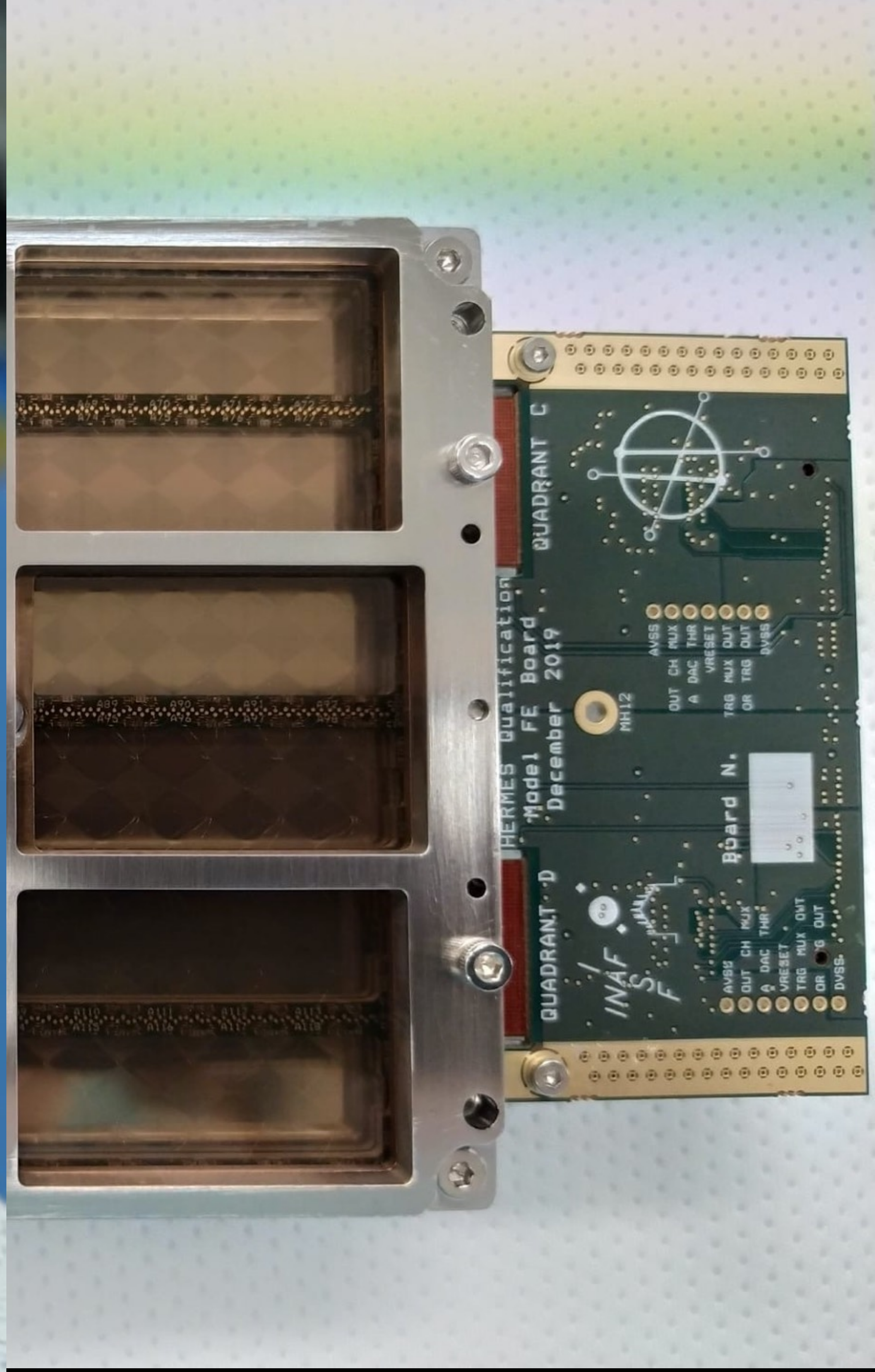
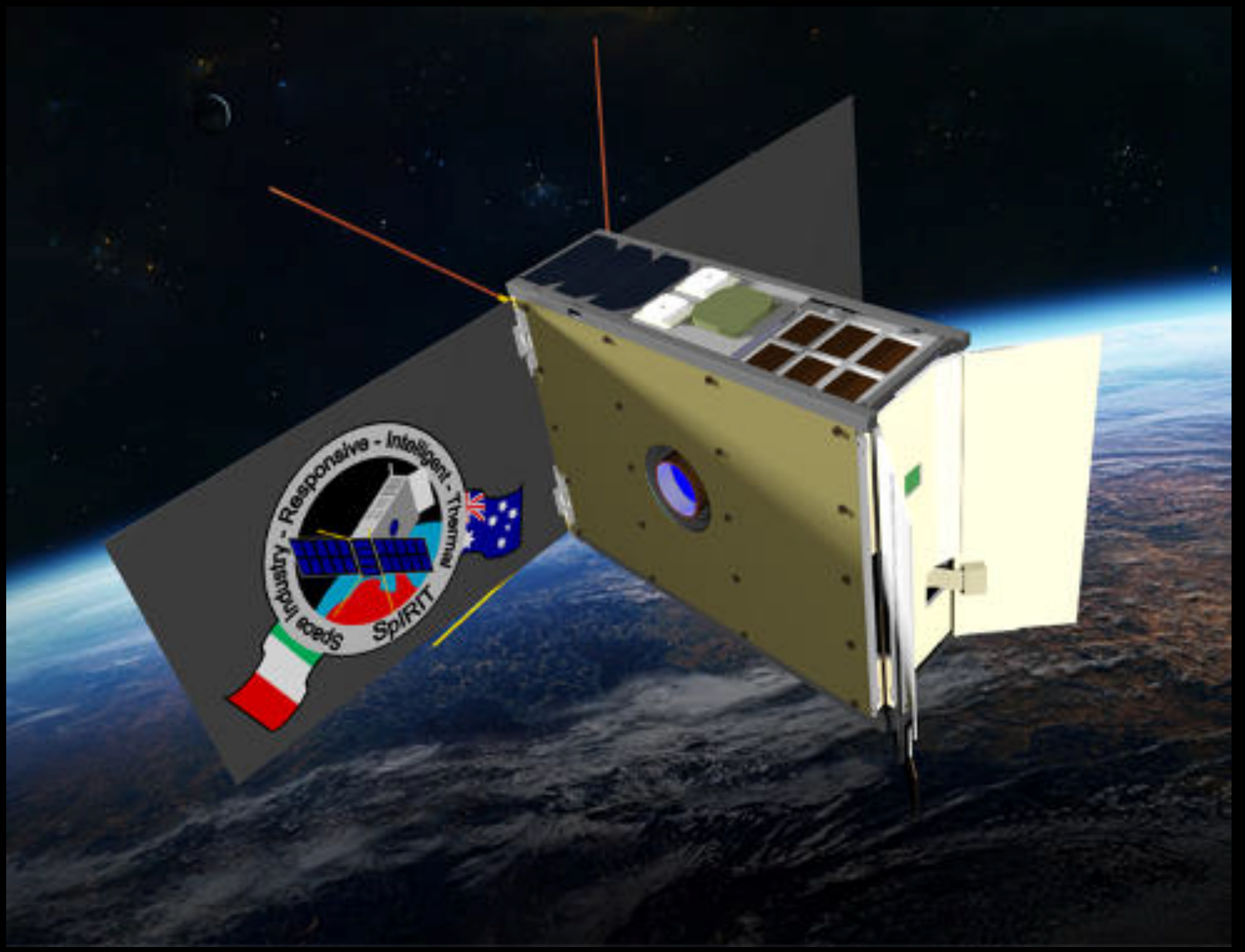
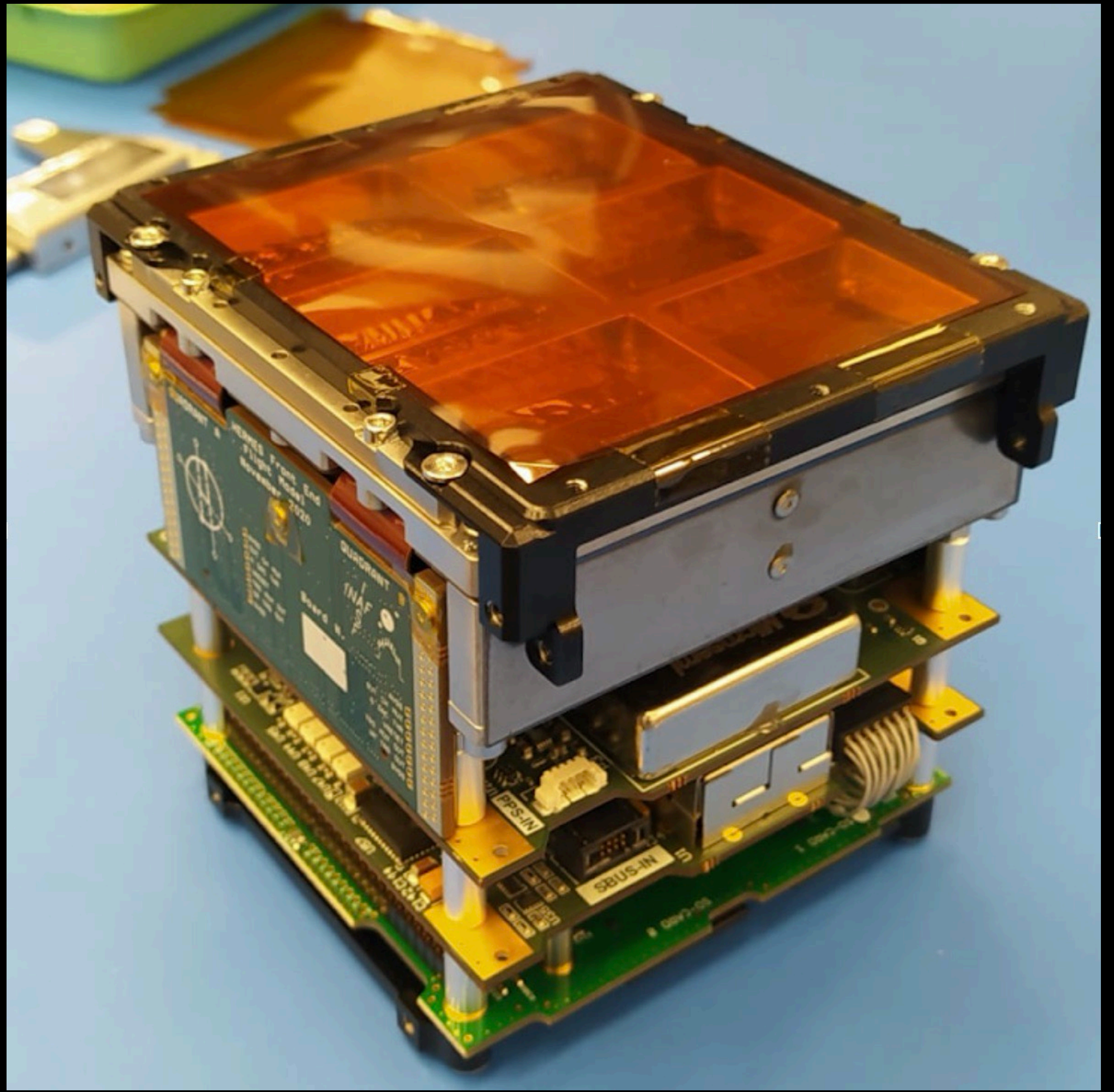
QUADRANT C
INAF
Board N.

QUADRANT C
Board N.
HERMES
SP

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

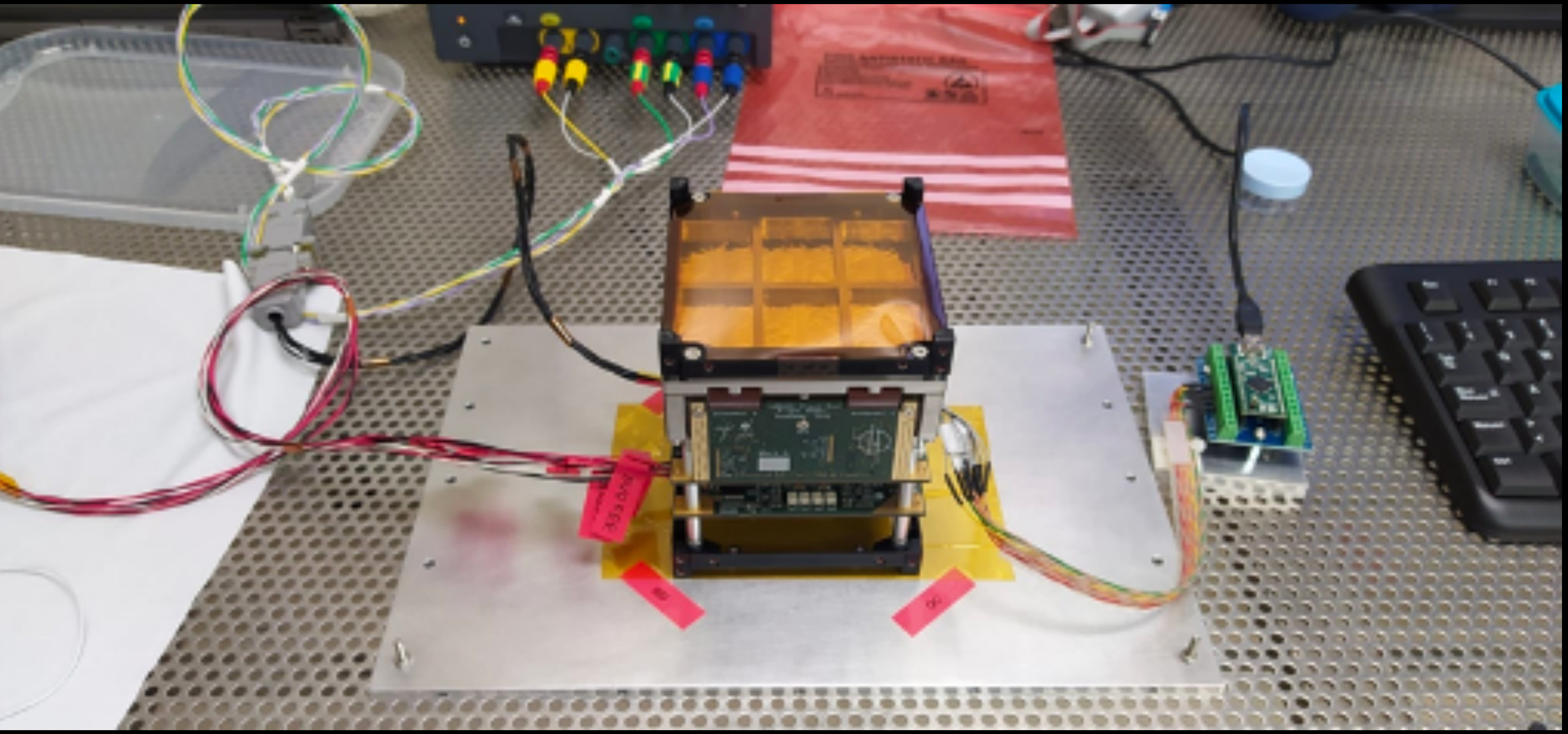
Where we are: SpIRIT

- SpIRIT paylod FM delivered to UoM on July 2022 after calibration and qualification (evironmental tests @ SERMS on June 2022).
- SpIRIT S-band system delivered to UoM Q2 2022
- Integration tests (mechanical, electrical, electronic) performed in July 2022



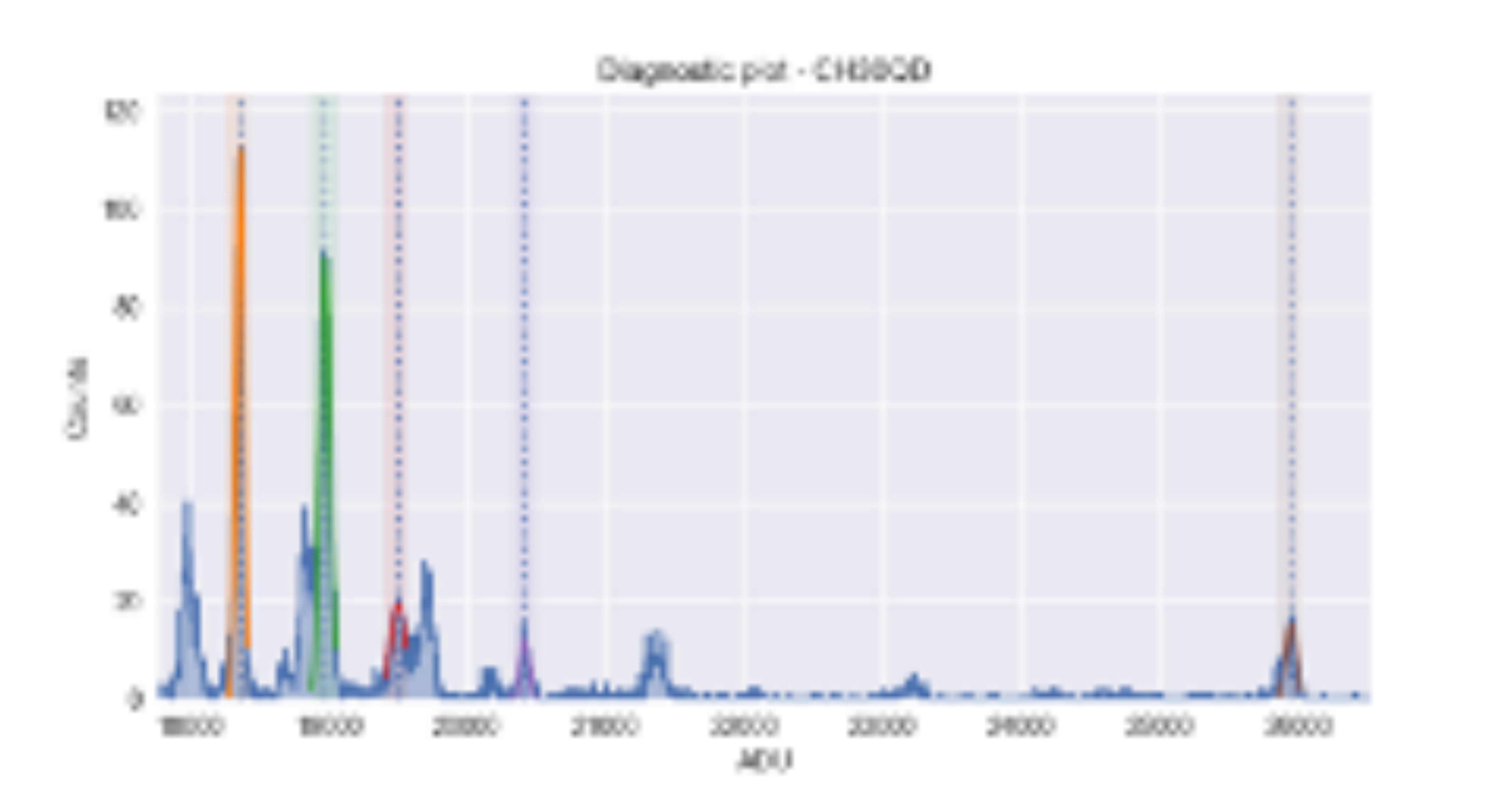


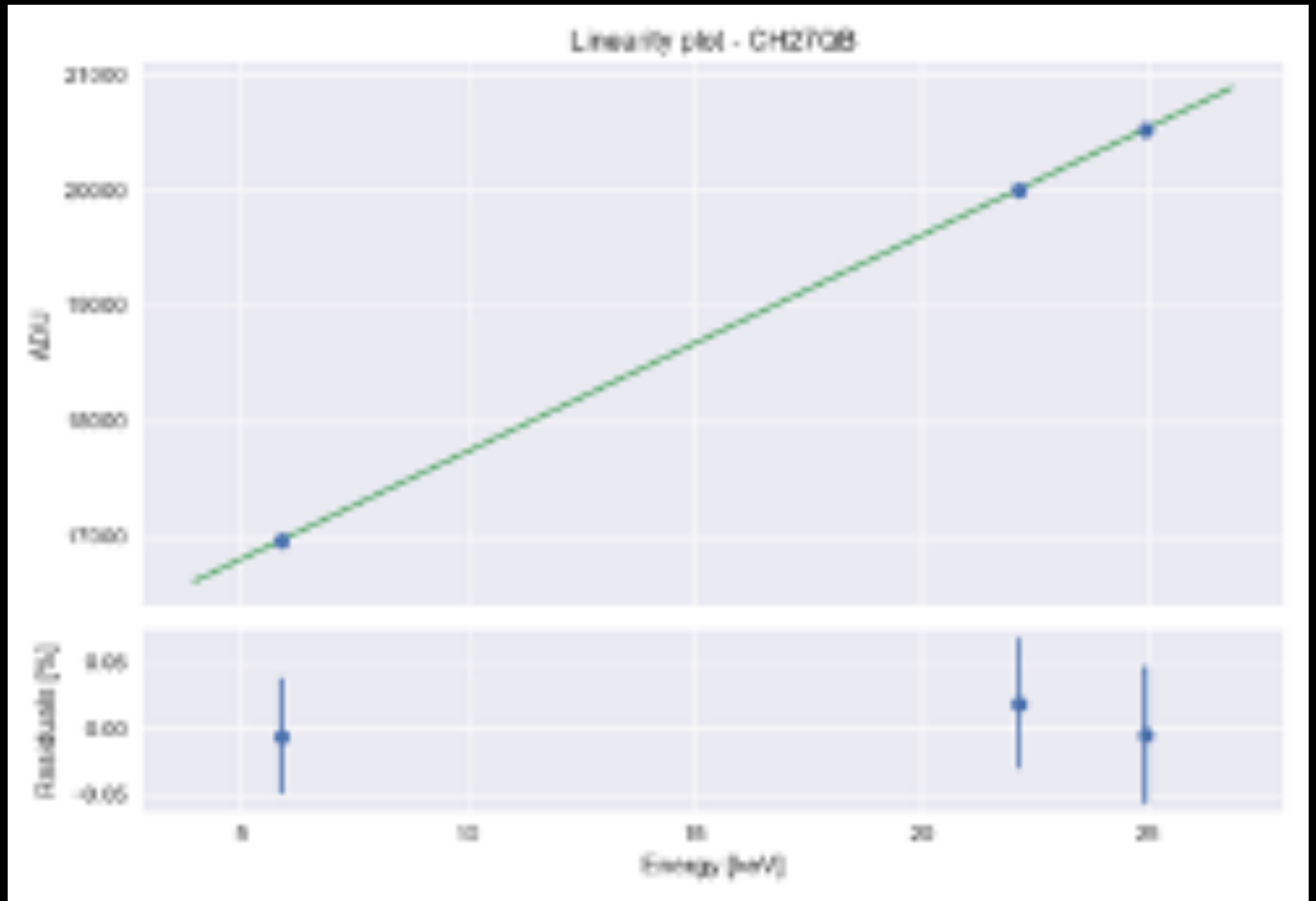
SpIRIT payload FM

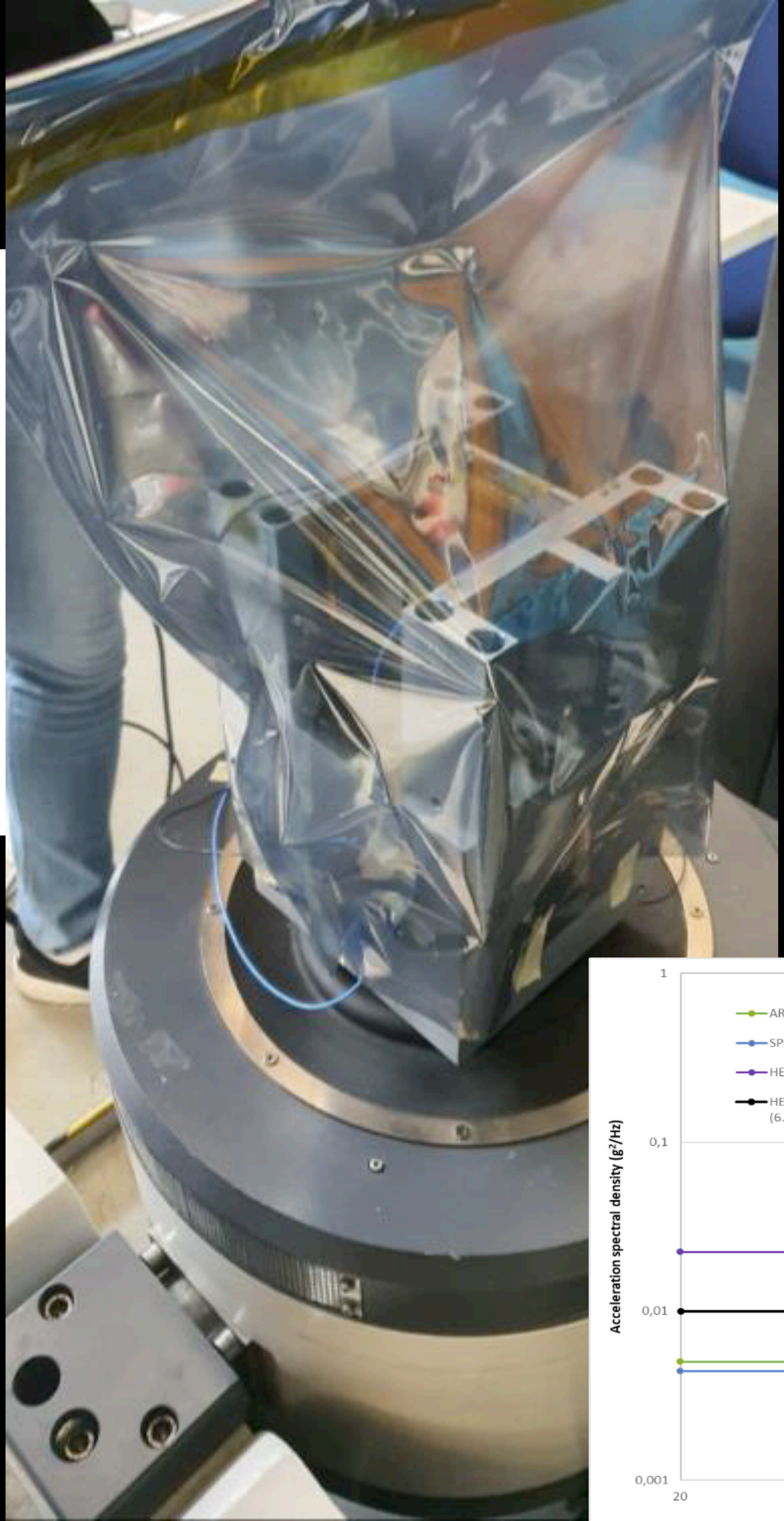


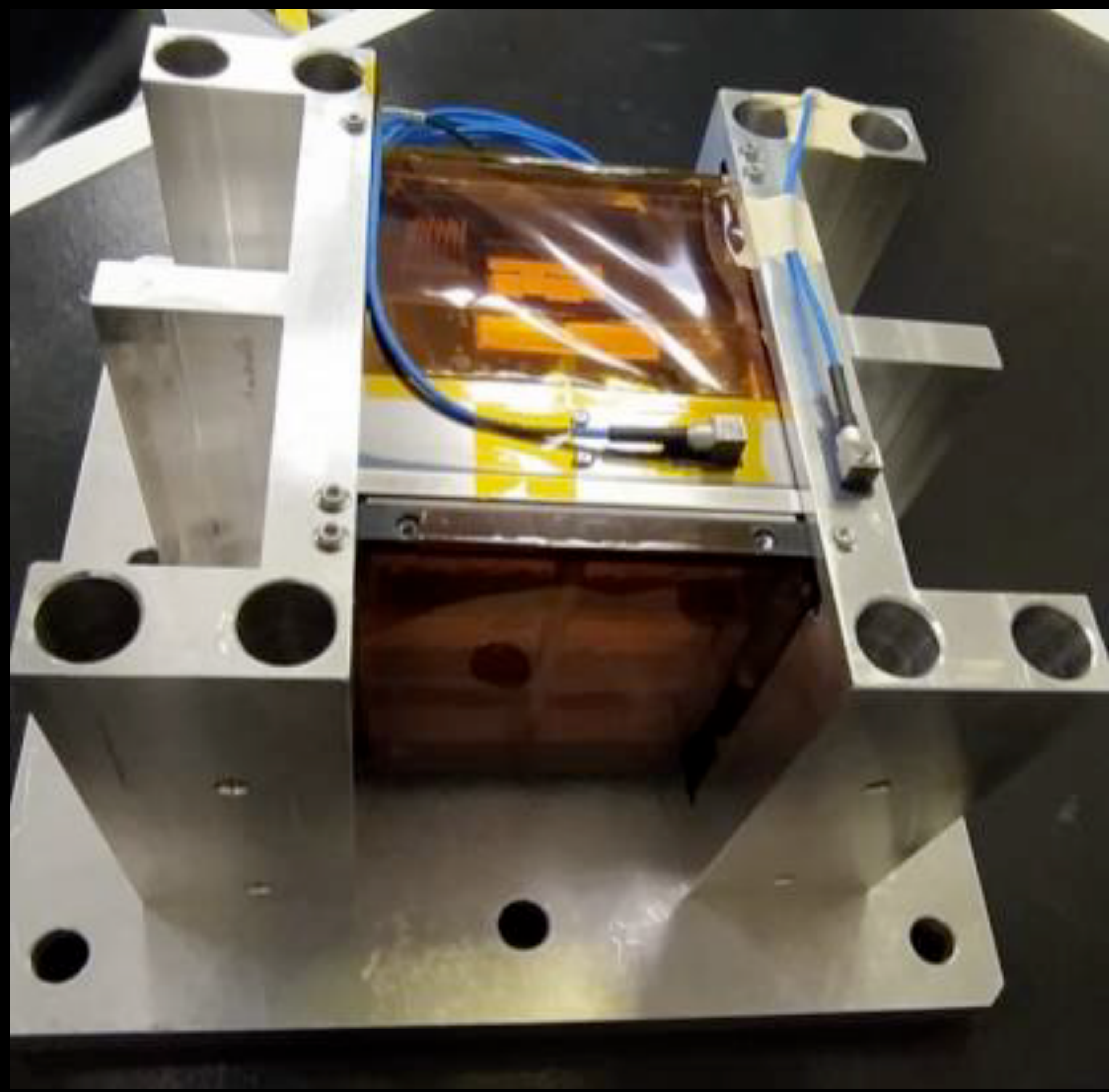
Step	Mode	Measurement	Temperature	Notes	Integration time [s]
1	X	$^{109}Cd + ^{55}Fe$	20 °C	≥ 10 kcts/channel	900 s
2	X	$^{109}Cd + ^{55}Fe$	0 °C	≥ 10 kcts/channel	900 s
3	X	$^{109}Cd + ^{55}Fe$	–10 °C	≥ 10 kcts/channel	900 s
4	X	$^{109}Cd + ^{55}Fe$	–20 °C	≥ 10 kcts/channel	900 s

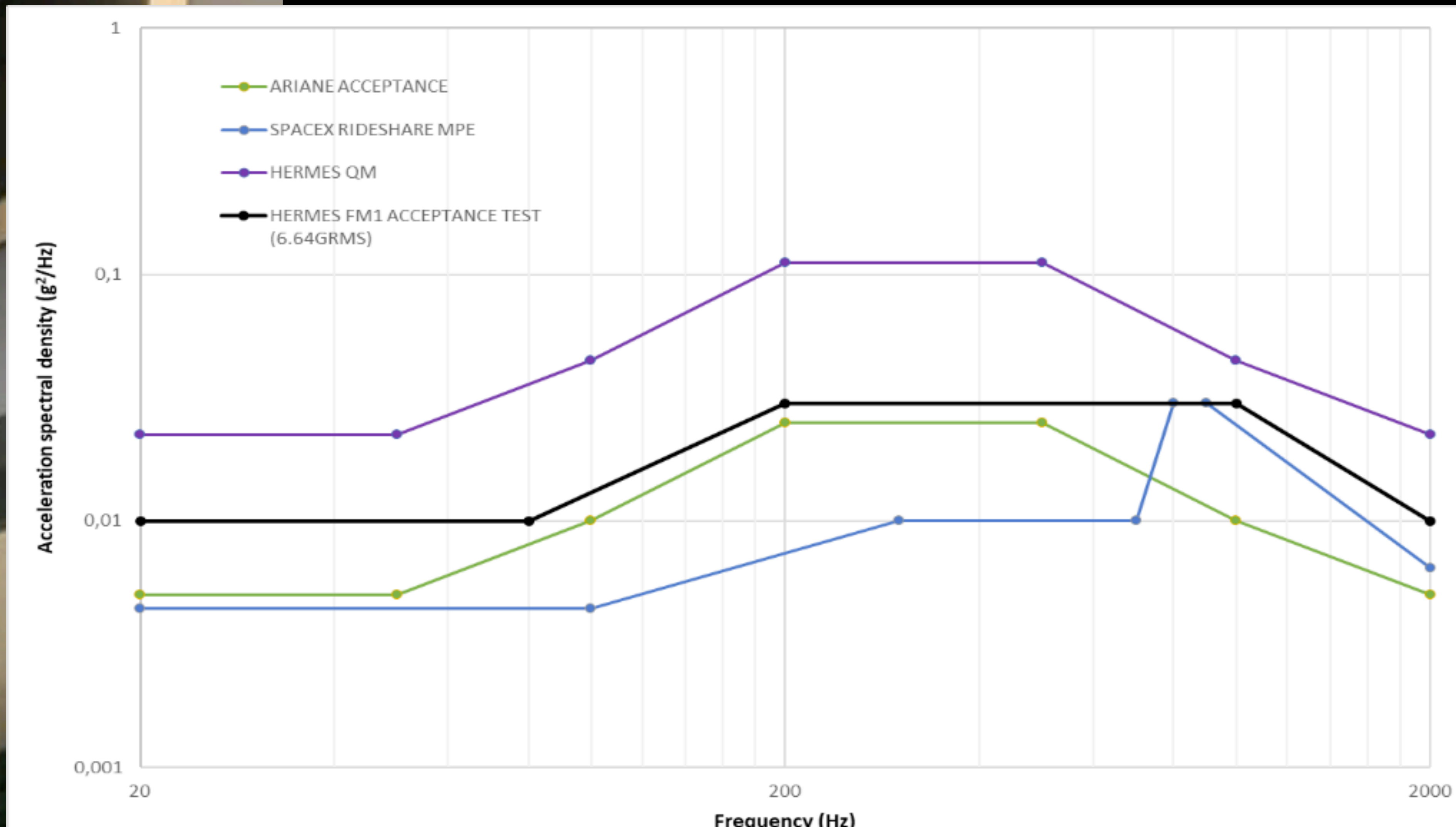
SpIRIT payload FM





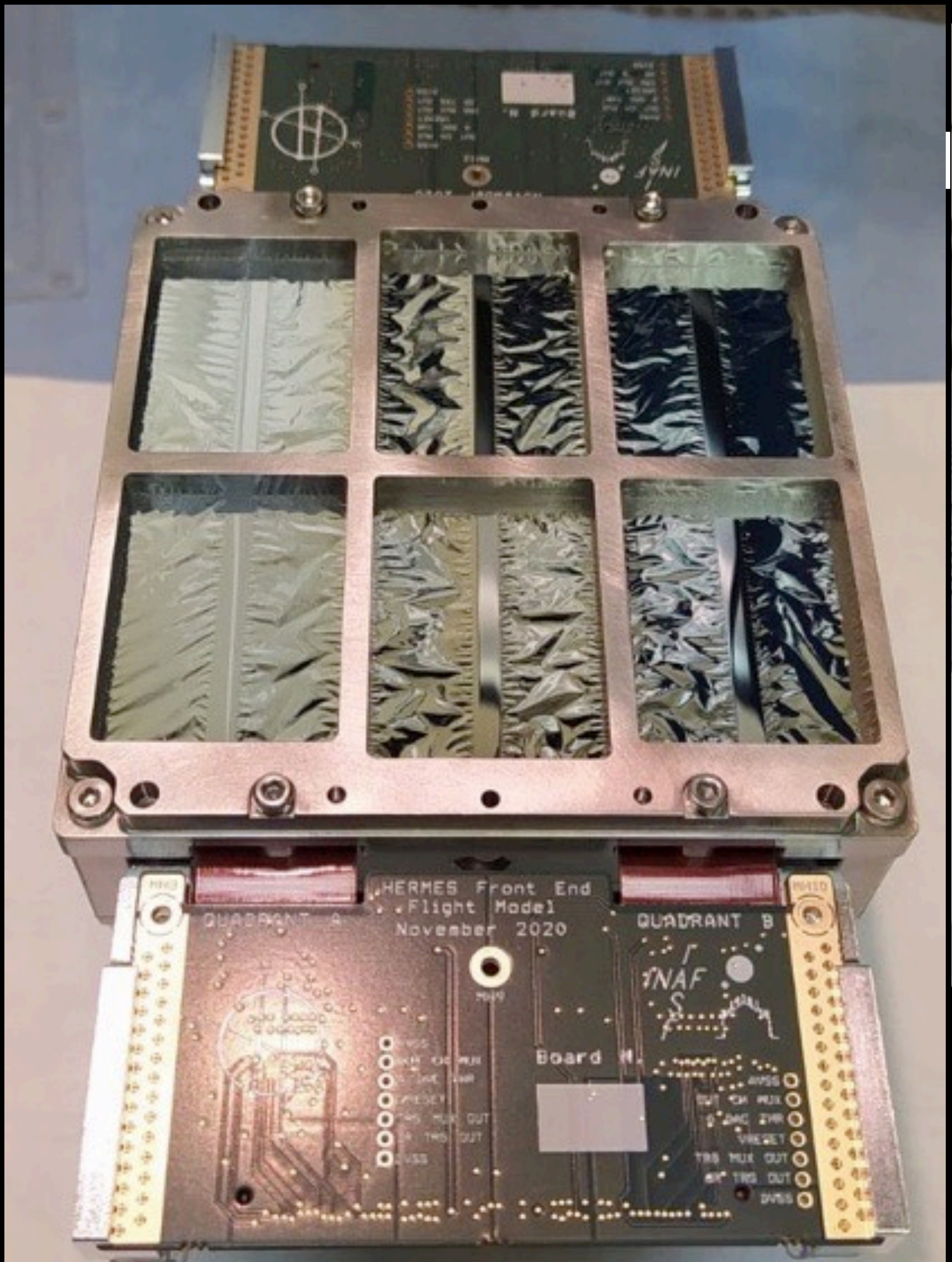




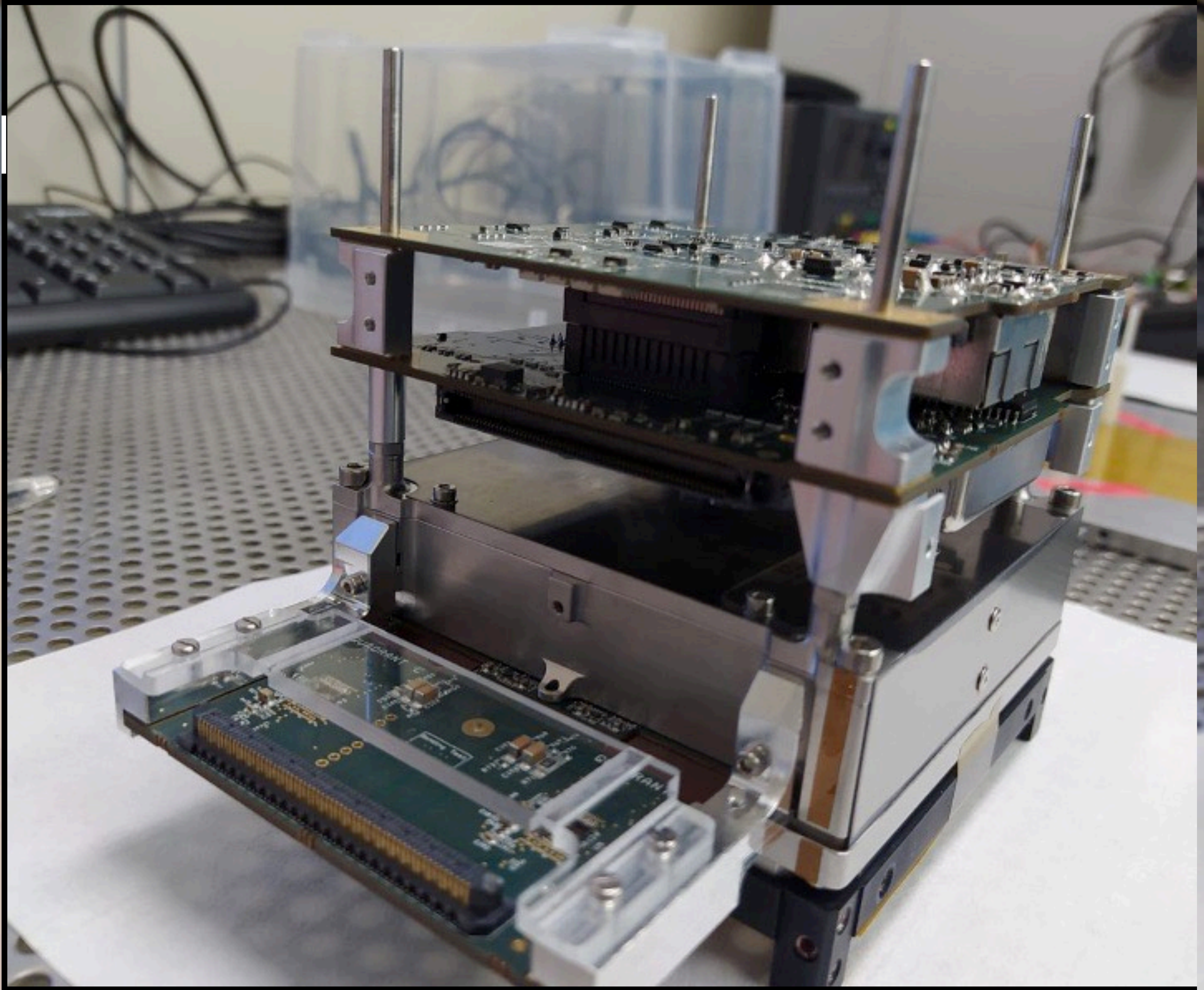


HERMES payload PFM

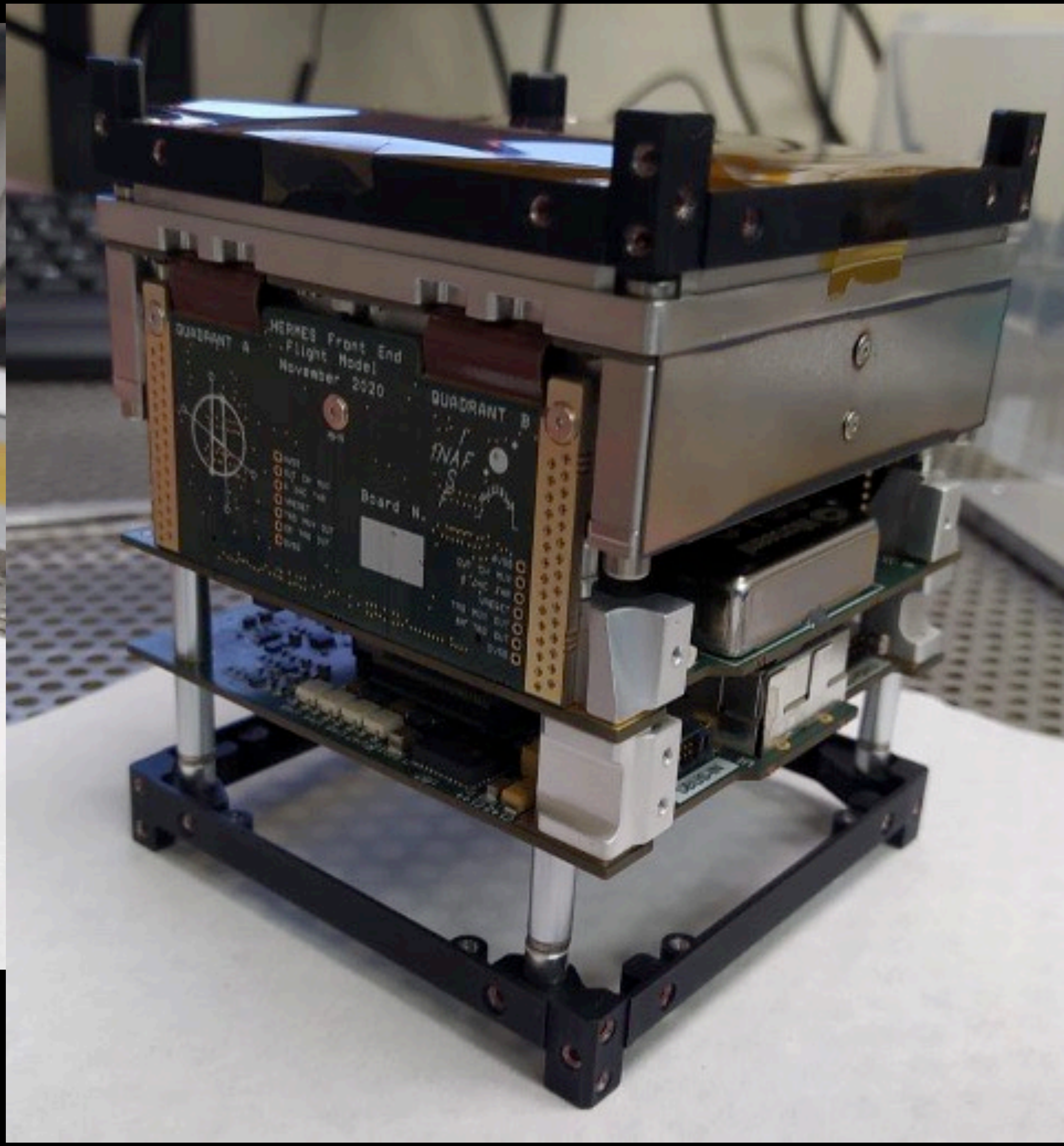
Detector system



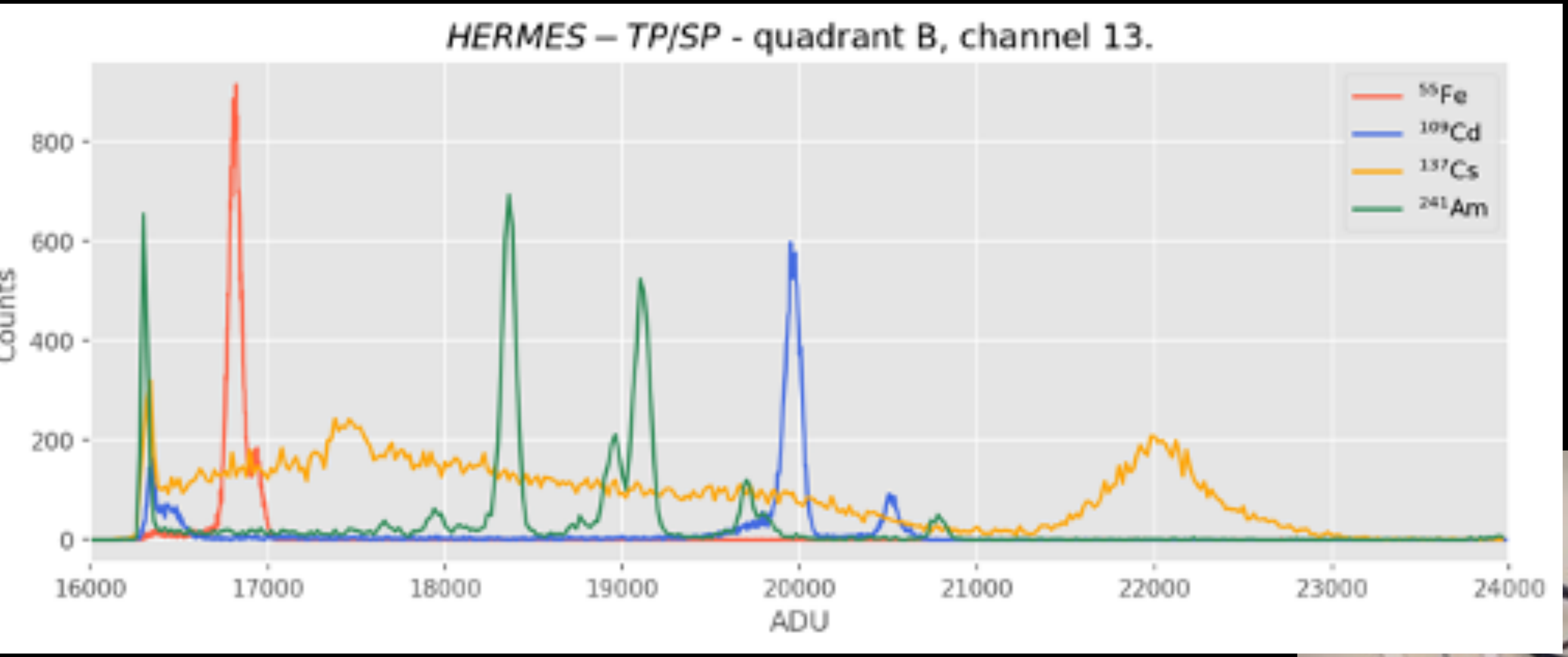
+BEE+PSU



Side wings connected



HSP payload PFM



Example acquisition of four radioactive sources, showing different X and gamma-ray photon lines acquired with one representative channel.

Where we are: HERMES pathfinder payload

- PFM ready for integration in the S/M after calibration. Integration planned for Q1 2022, qualification test planned for Q1 2023
- FM2, FM3 detector system integrated and tested @FBK labs in Trento. Full payload integrated and tested at @INAF-IAPS Q4 2022
- FM4, FM5 and FM6 integration and test planned for Q1 2023

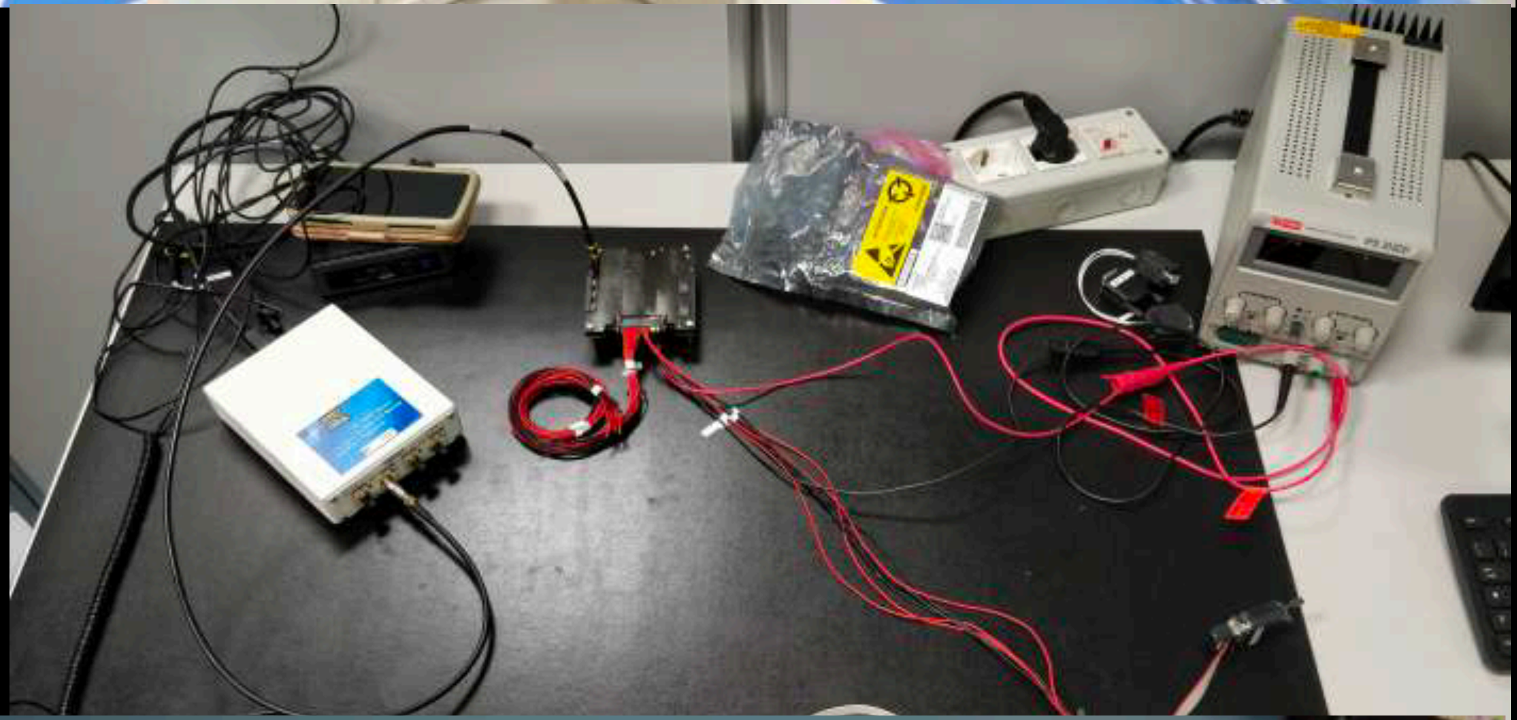
Where we are: HERMES pathfinder payload

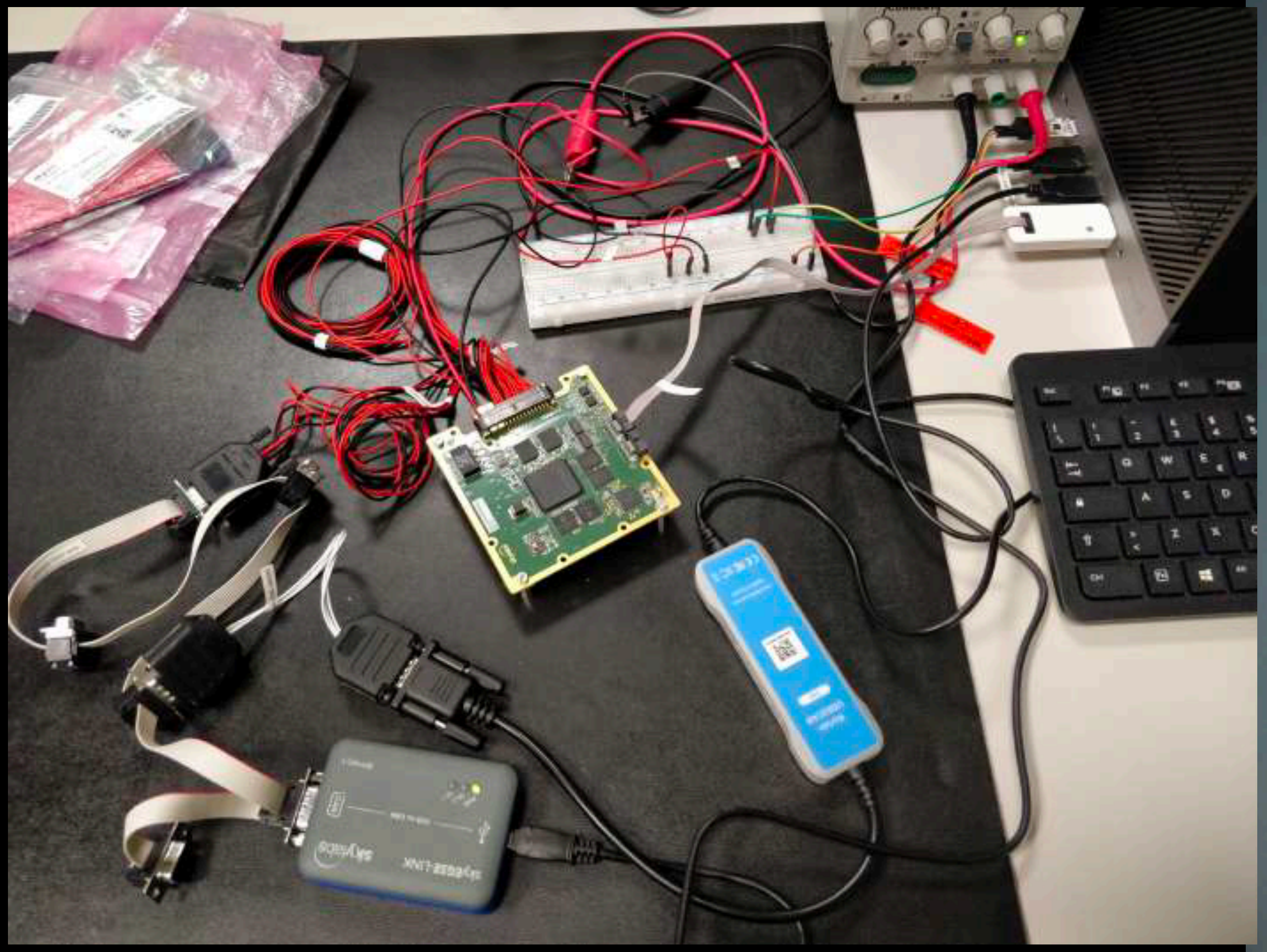
Where we are: HERMES pathfinder S/M

- PFM integration planned @POLIMI in Q1 2023, qualification test planned for Q1 2023

- FM2, FM3 integration and test planned for Q1-Q2 2023

- FM4, FM5 and FM6 integration and test planned for Q2-Q3 2023

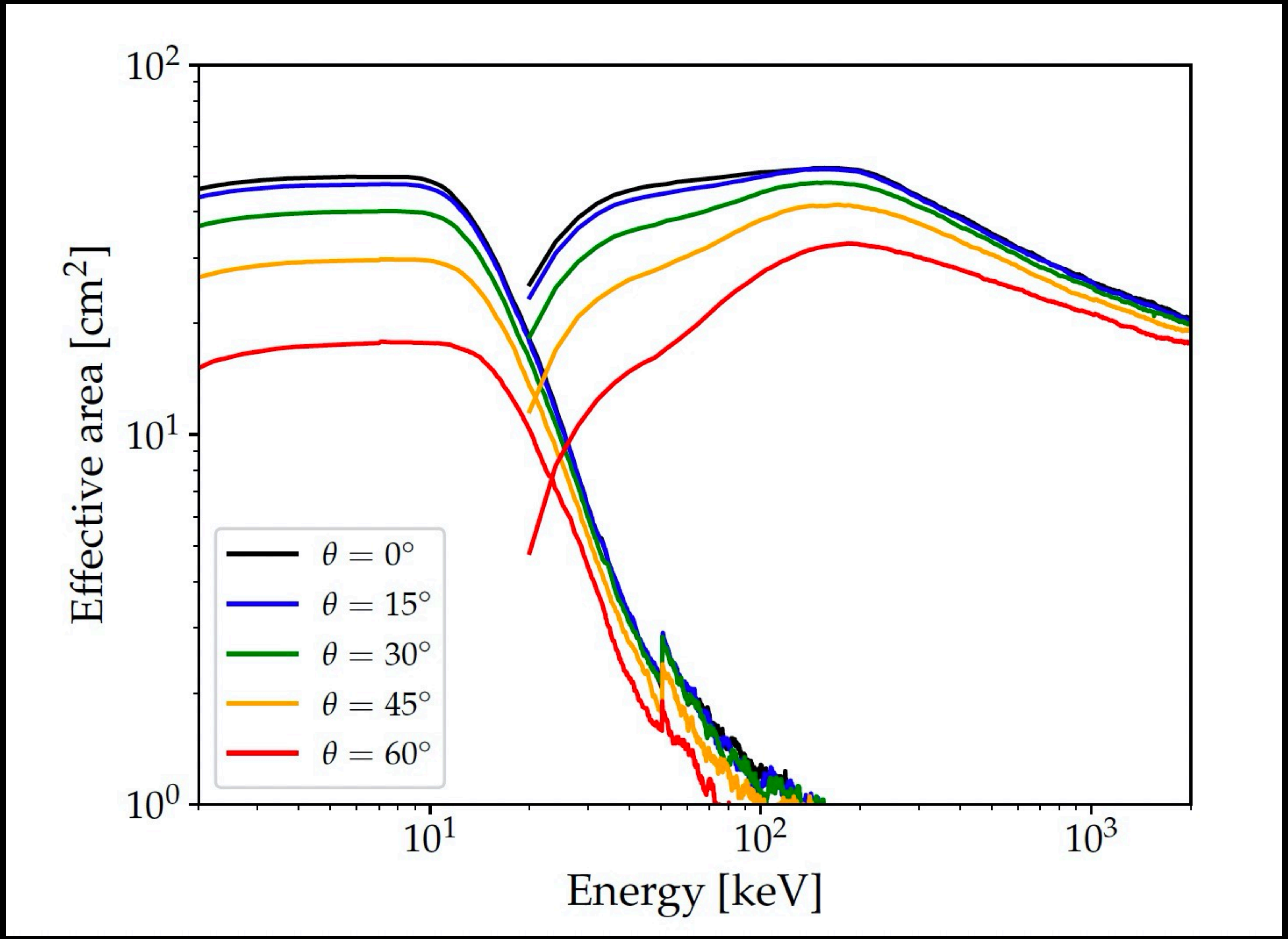


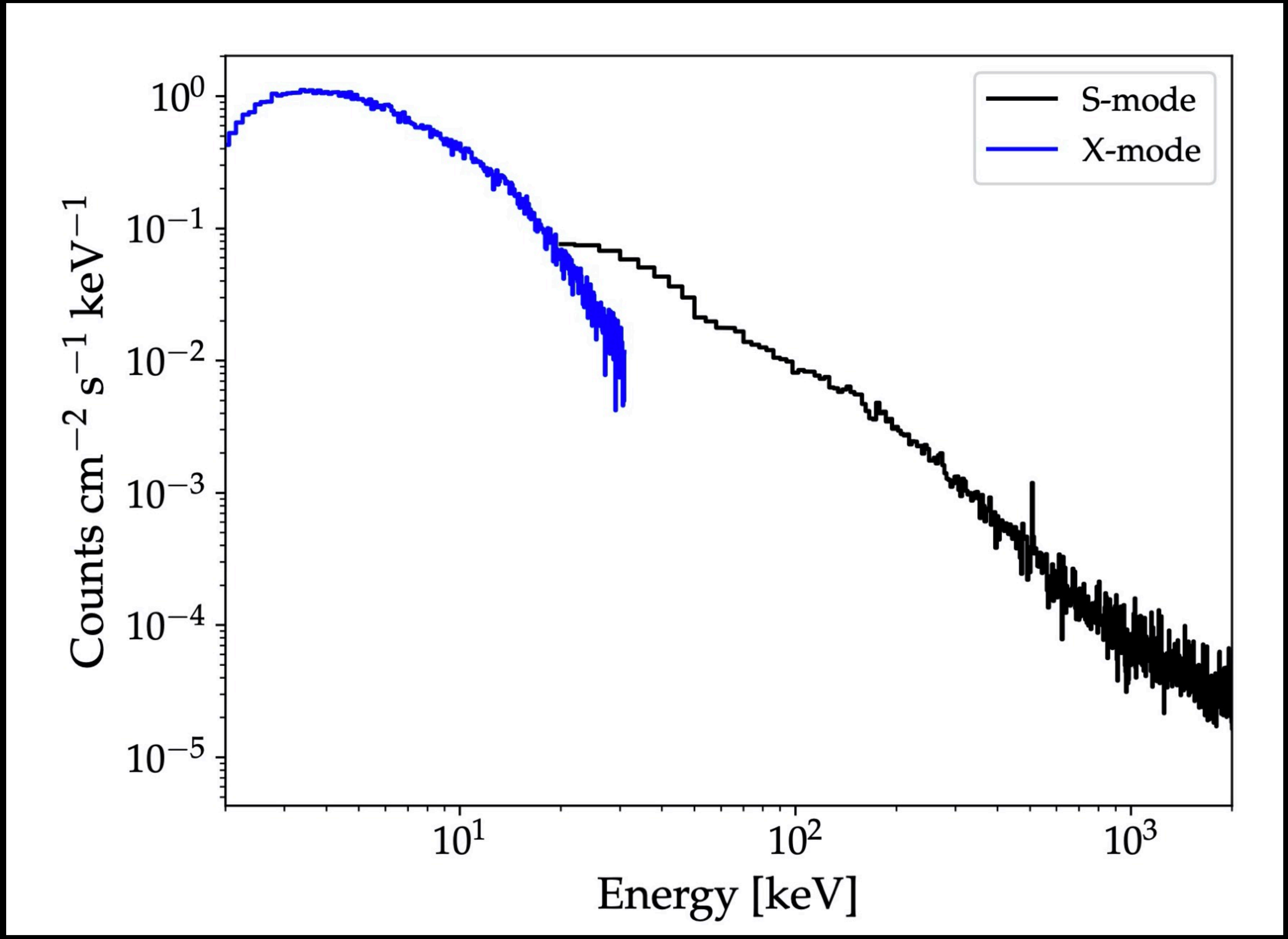


Where we are: HERMES Pathfinder program

- Launch contract negotiation on going, Contract signature Q42022. Launcher: Virgin Orbit, lauch date June 2024
- MOC deployment contract under negotiation. Three industrial operators are partecipating to the bid. Contract signature predicted by the end of the year 2022. A contract for operations will be issued to the same industrial operator.
- Ground Station implementations: two identical dedicated GS, one in Malindi managed by ASI, one in Katherine (NT, AU), managed by a consortium led by INAF and including Masaryk University, University of Tasmania, University of Melbourne and partly funded by AHEAD2020.

HERMES PF expected performances



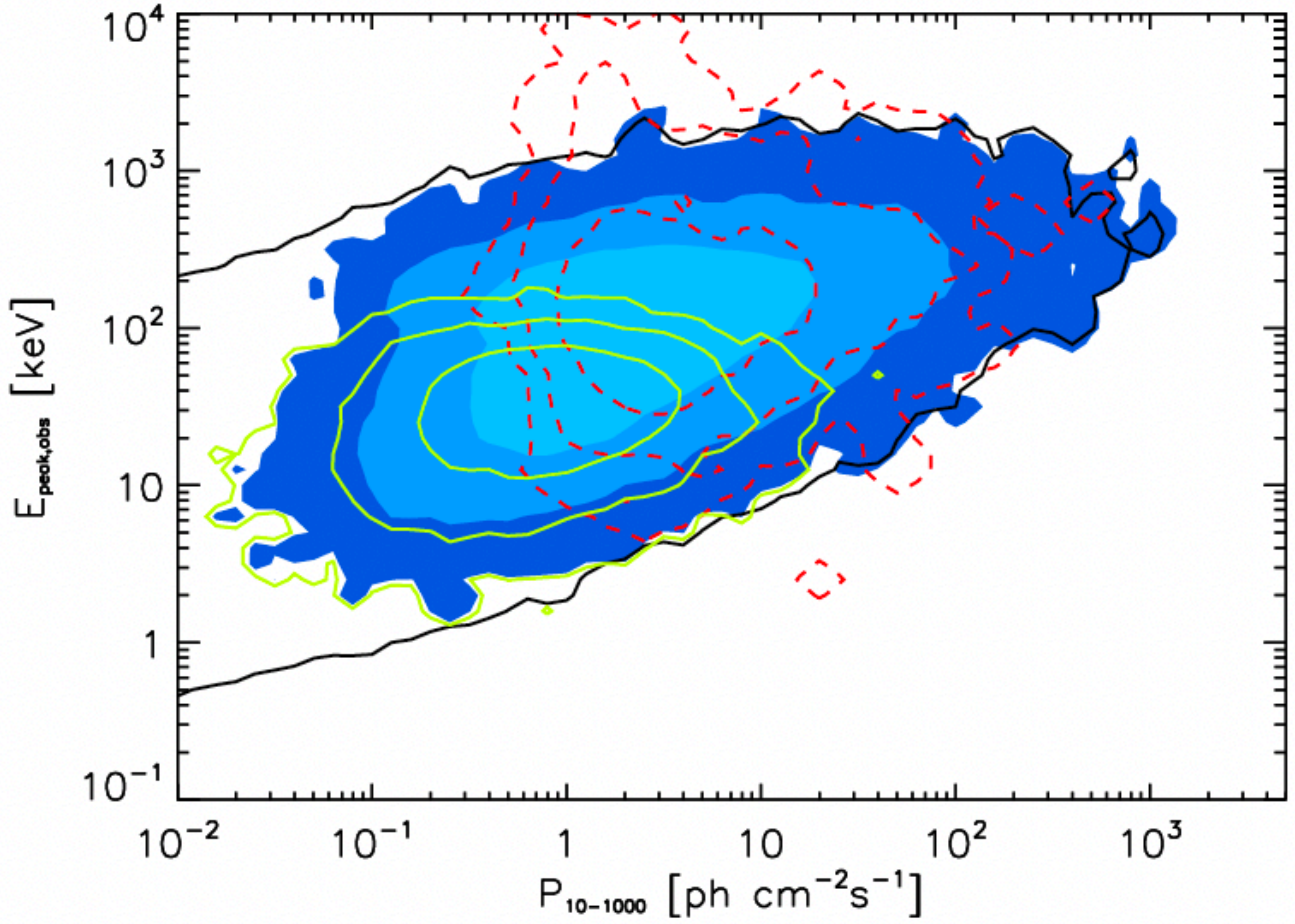


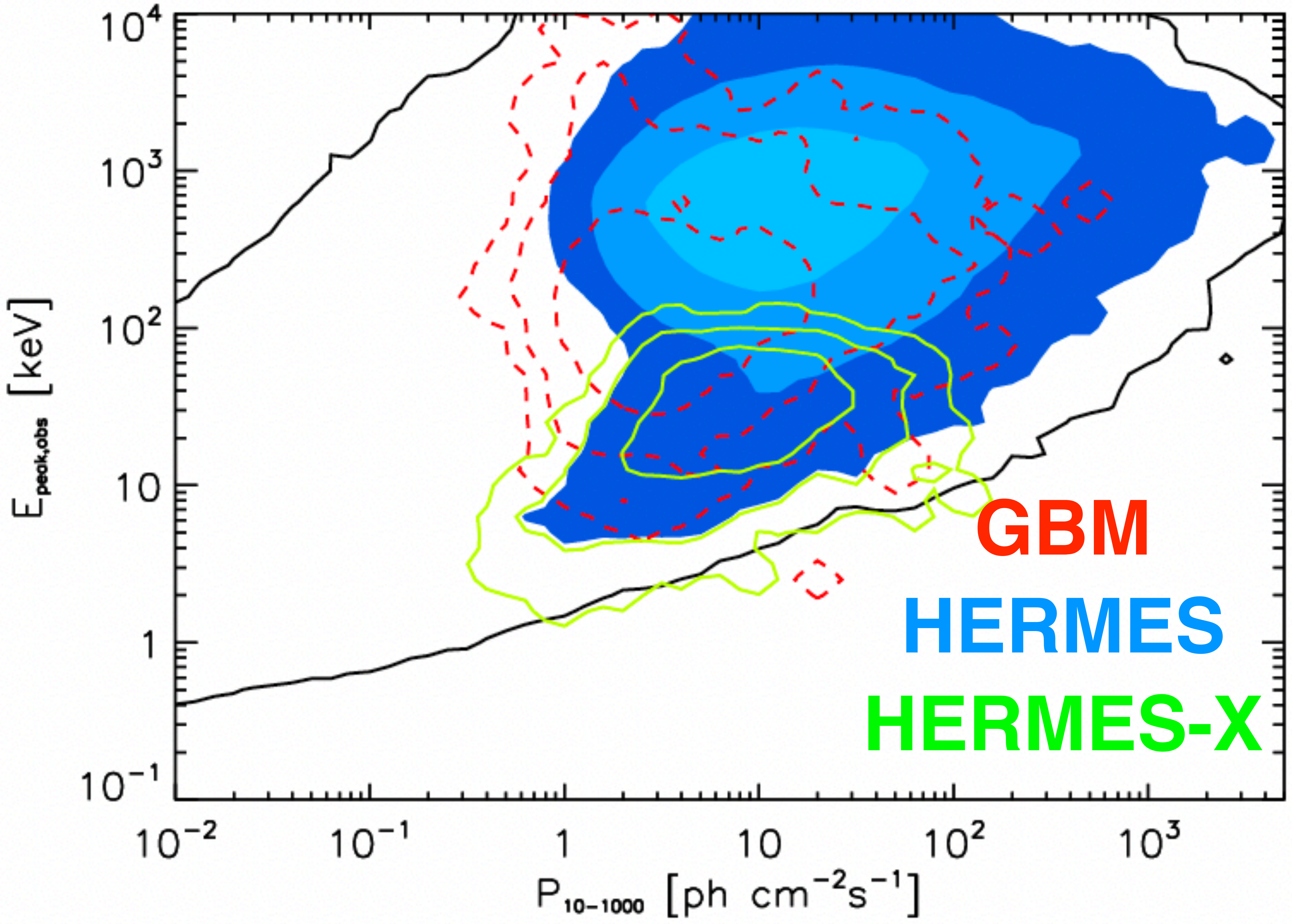
Background: 50-300 keV ~75cts/s; 100-500 keV~35cts/s; 3-20 keV 390counts/s

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

Campana et al. 2020

Performances



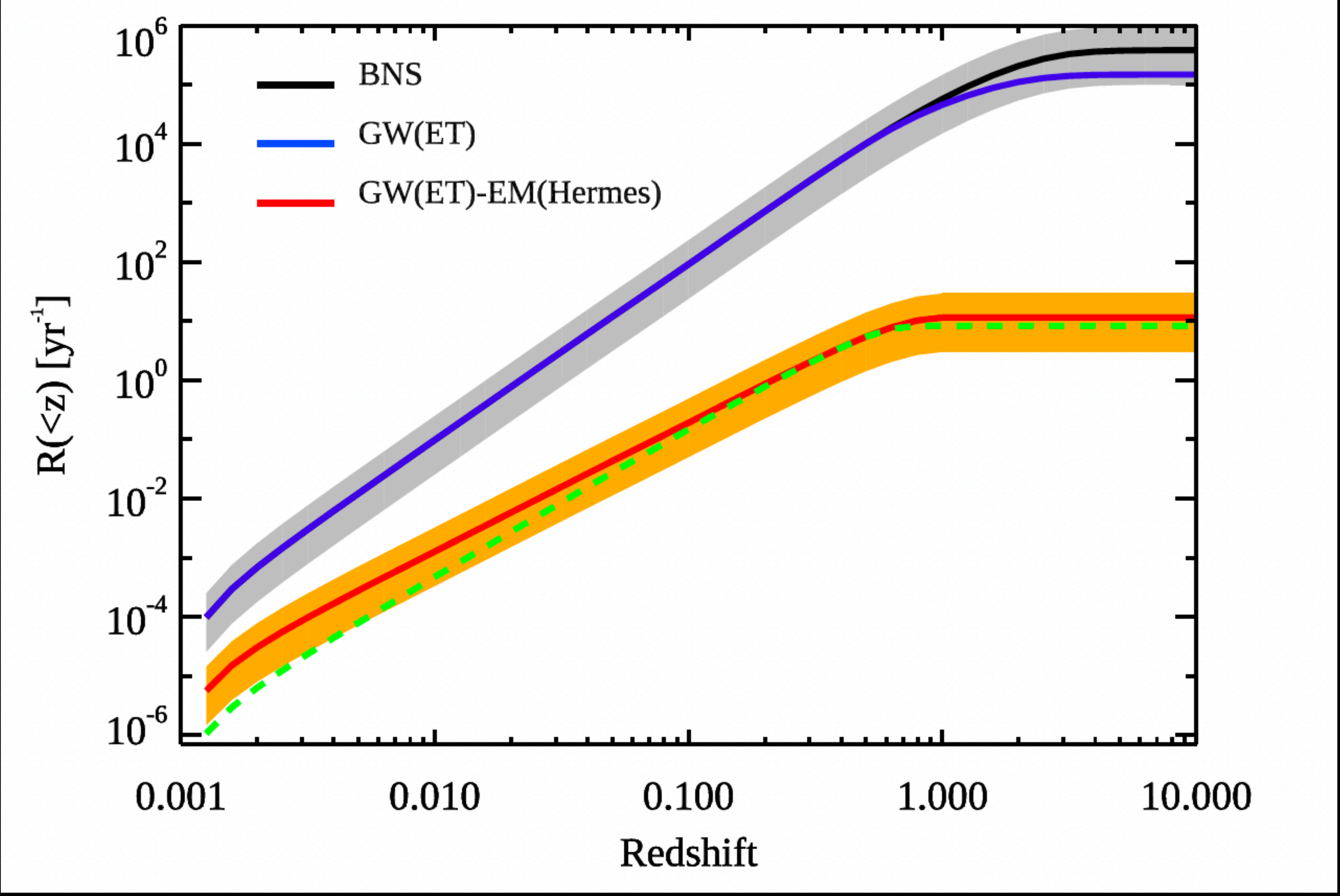


Long

Short

Ghirlanda & Nava

Binary Neutron Stars



Ghirlanda & Nava

Localization performances

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

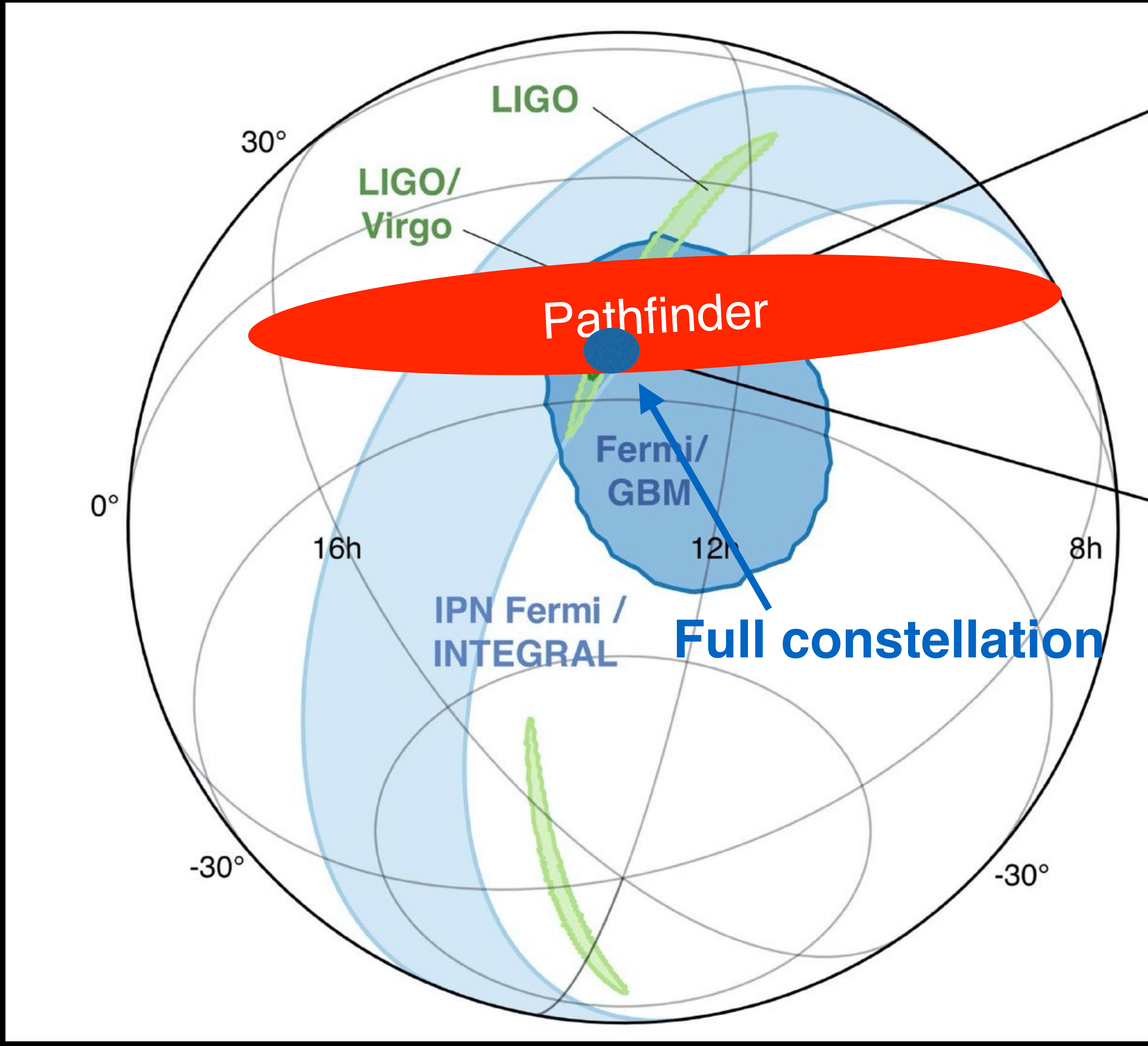
<B>~7000km

N(pathfinder)~6-8, active simultaneously 3-4

σ_{Pos}~ 2.4 deg if **σ_{CCF},σ_{sys}~1ms**

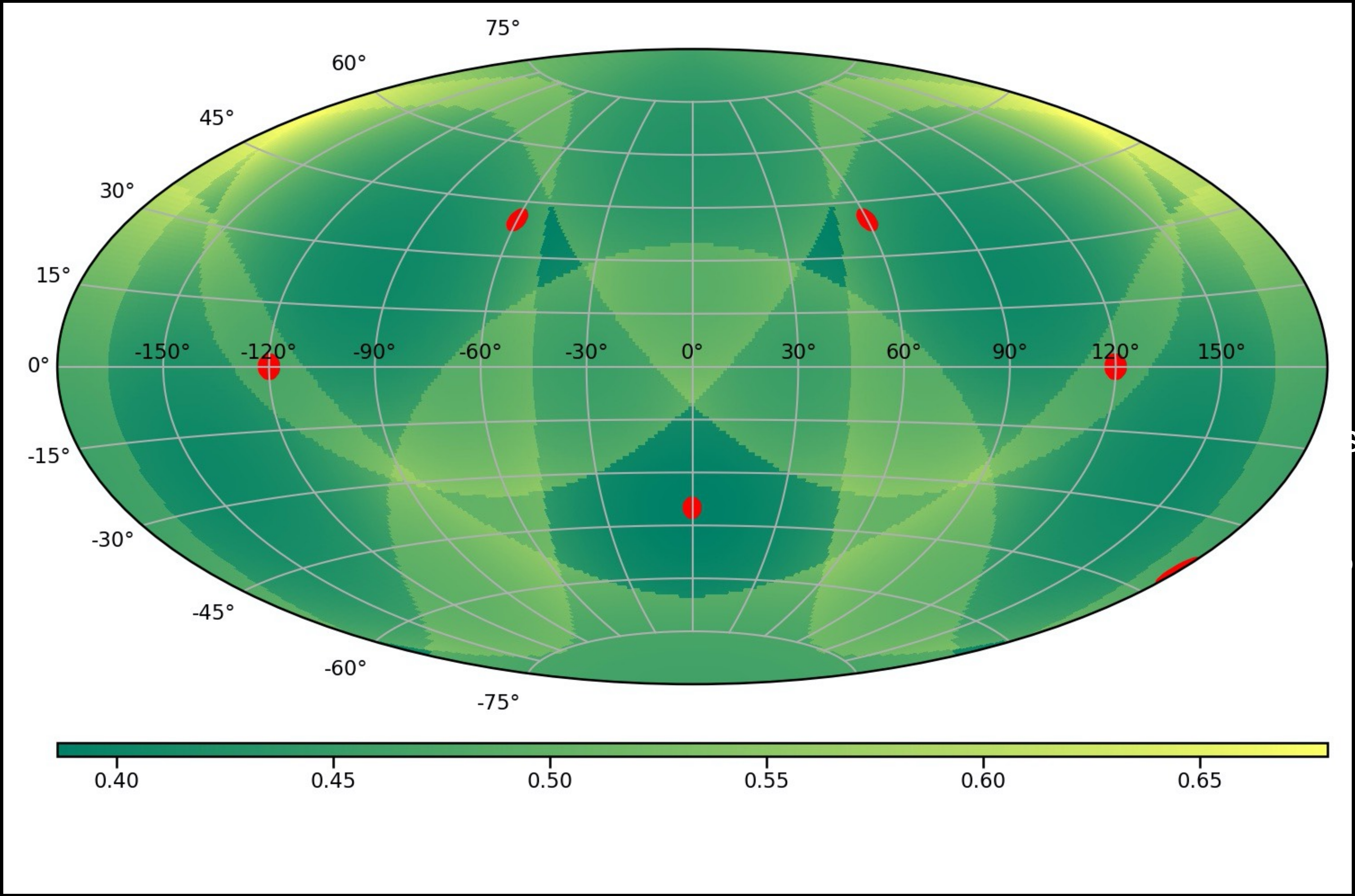
Goal for a real observatory (more units, longer baseline)

$\sigma_{Pos(FC)}$ ~ 15 arcmin **if σ_{CCF},σ_{sys}~1ms**



Next steps

- Toward a sensitive all sky monitor during the 20’:
- First phase: **crash program to deploy in LEO 6-8 units (6-12U) in three years** to provide a first all-sky monitor for Ligo/Virgo O5 events
- Second phase: deploy additional 6-10 units (6-12U) after ~2 years to boost monitoring and localization capabilities during Ligo/Virgo O5 - O6… ET!
- Third phase: deploy a few units in HEO or Moon orbits to boost localization capabilities


75°
60°
45°
30°
15°
0°
-15°
-30°
-45°
-60°
-75°
-150°
-120°
-90°
-60°
-30°
0°
30°
60°
90°
120°
150°
0.40
0.45
0.50
0.55
0.60
0.65

st

on

Next steps

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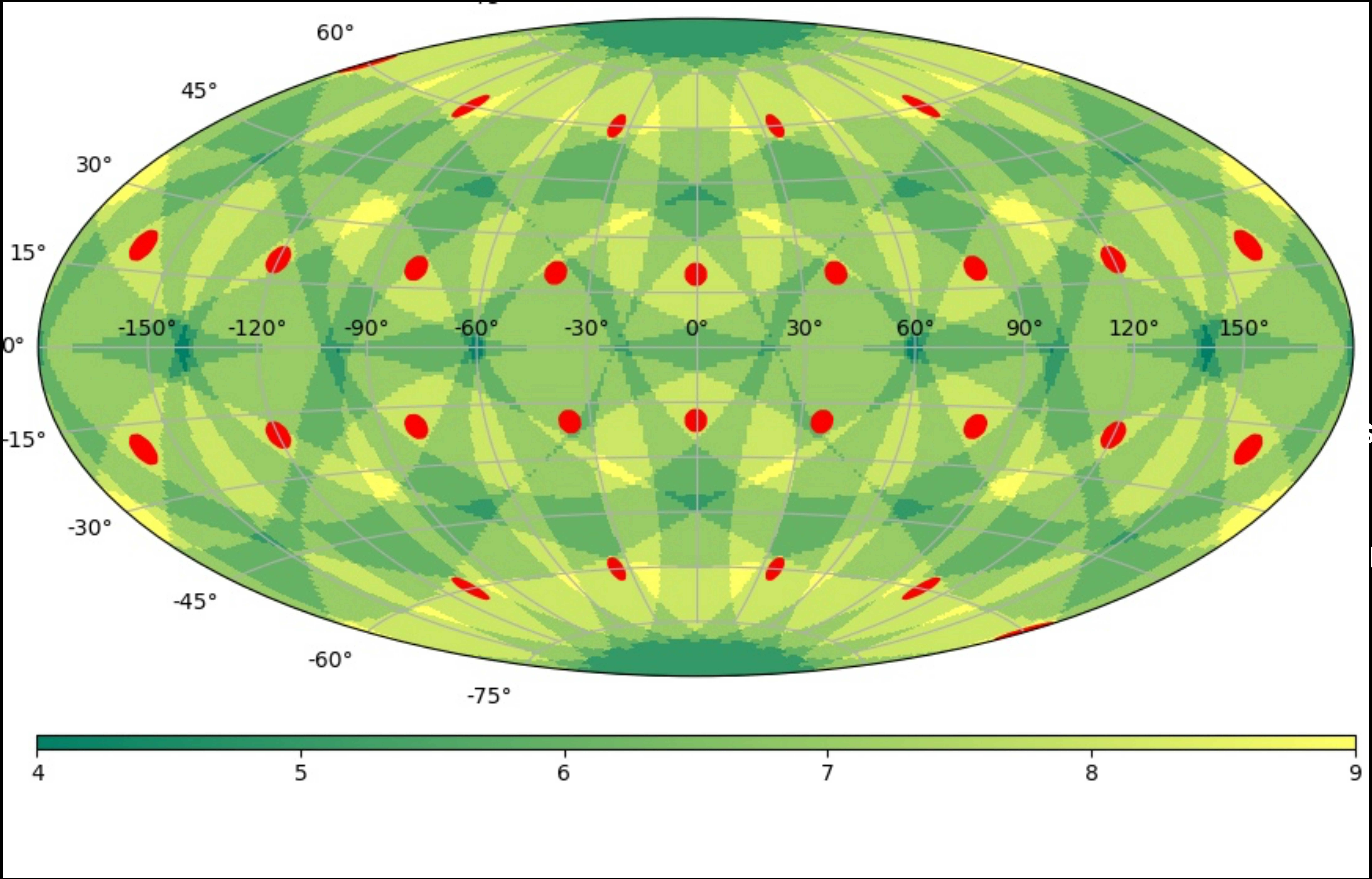
60°
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-15°
-30°
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-60°
-75°
-150°
-120°
-90°
-60°
-30°
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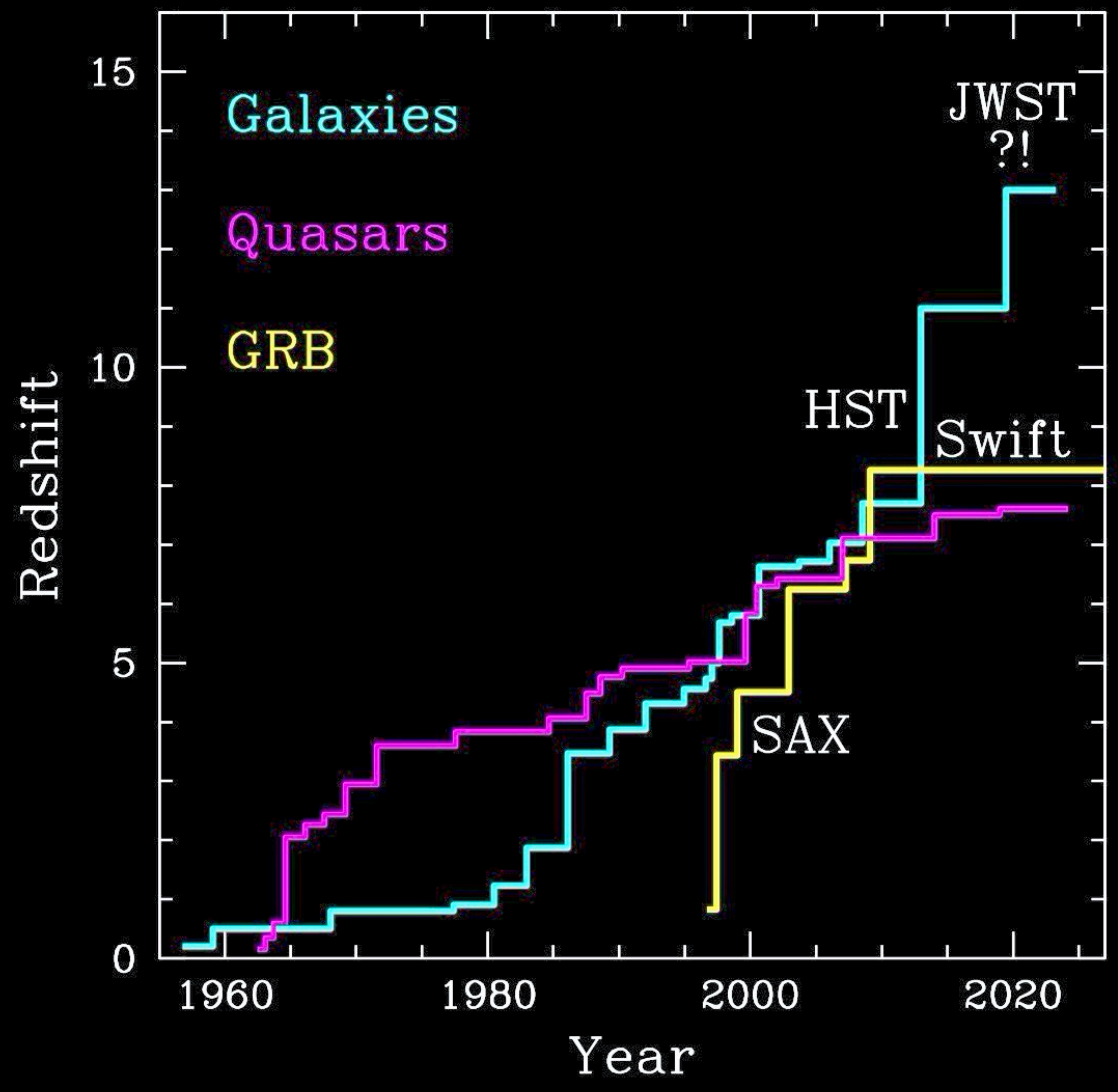
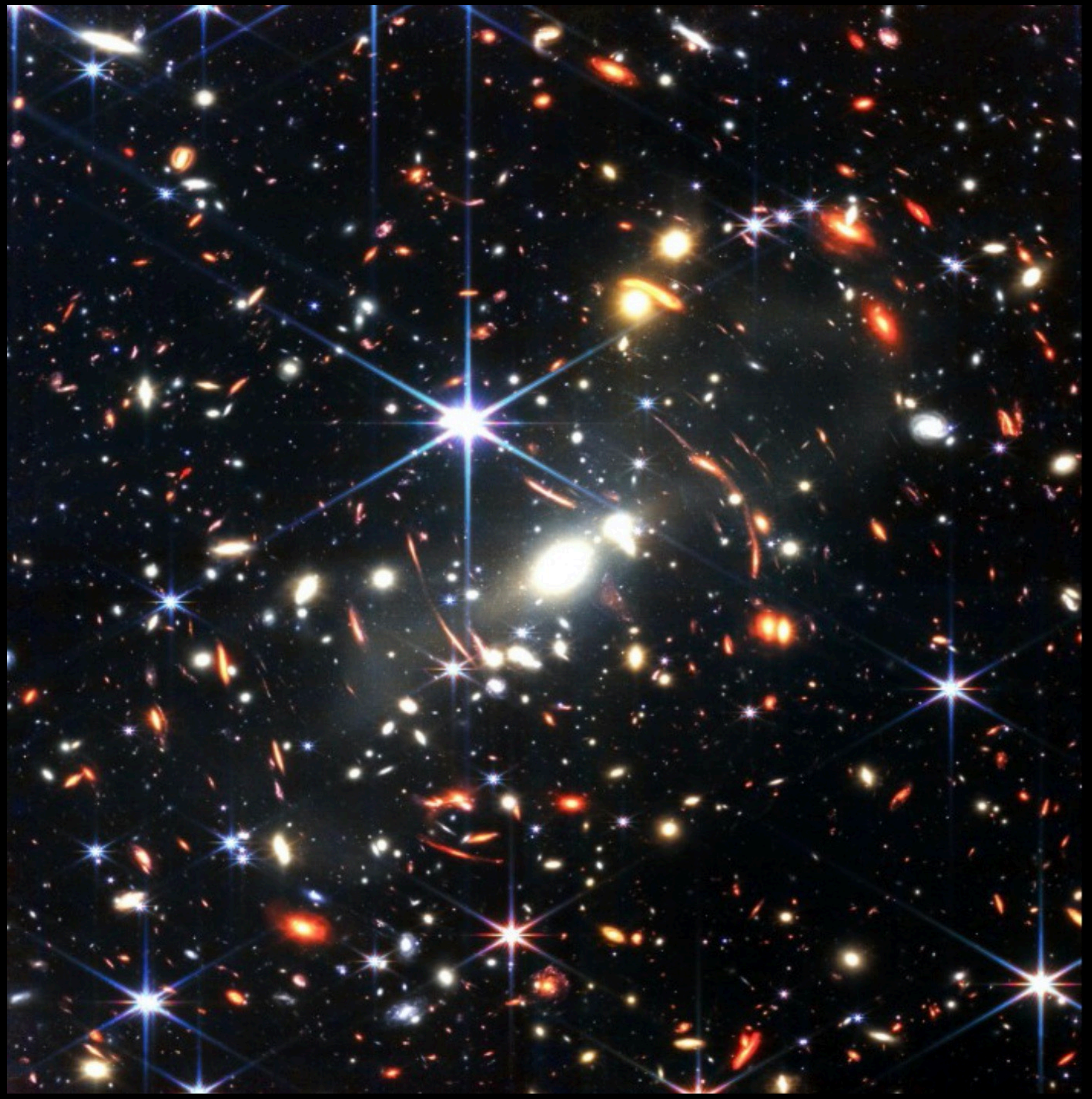
HERMES PF Institutes

- INAF, ASI, PoliMi, UniCagliari, UniPalermo, UniUdine, INFN, UniTrieste, UniPavia, UniFedericoII, UniFerrara, FBK, FPM
- University of Tubingen (Germany)
- University of Eotvos Budapest, C3S (Hungary), MUNI (CZ)
- University of Nova Gorica, Skylabs, AALTA (Slovenia)
- Deimos (Spain)
- Institute of High Energy Physics, Chinese Academy of Science

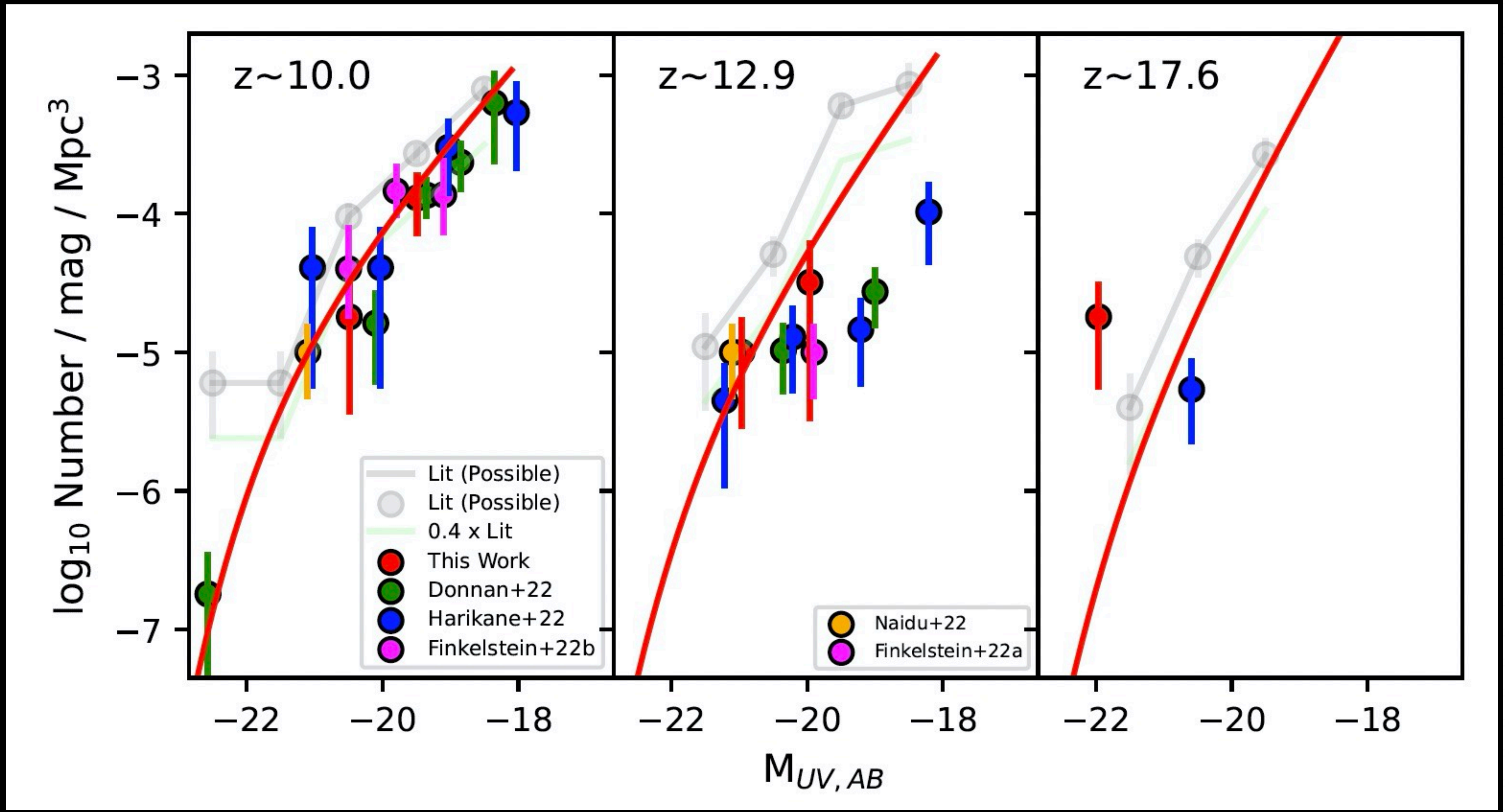
A flash in the dark: GRB and high-z galaxies

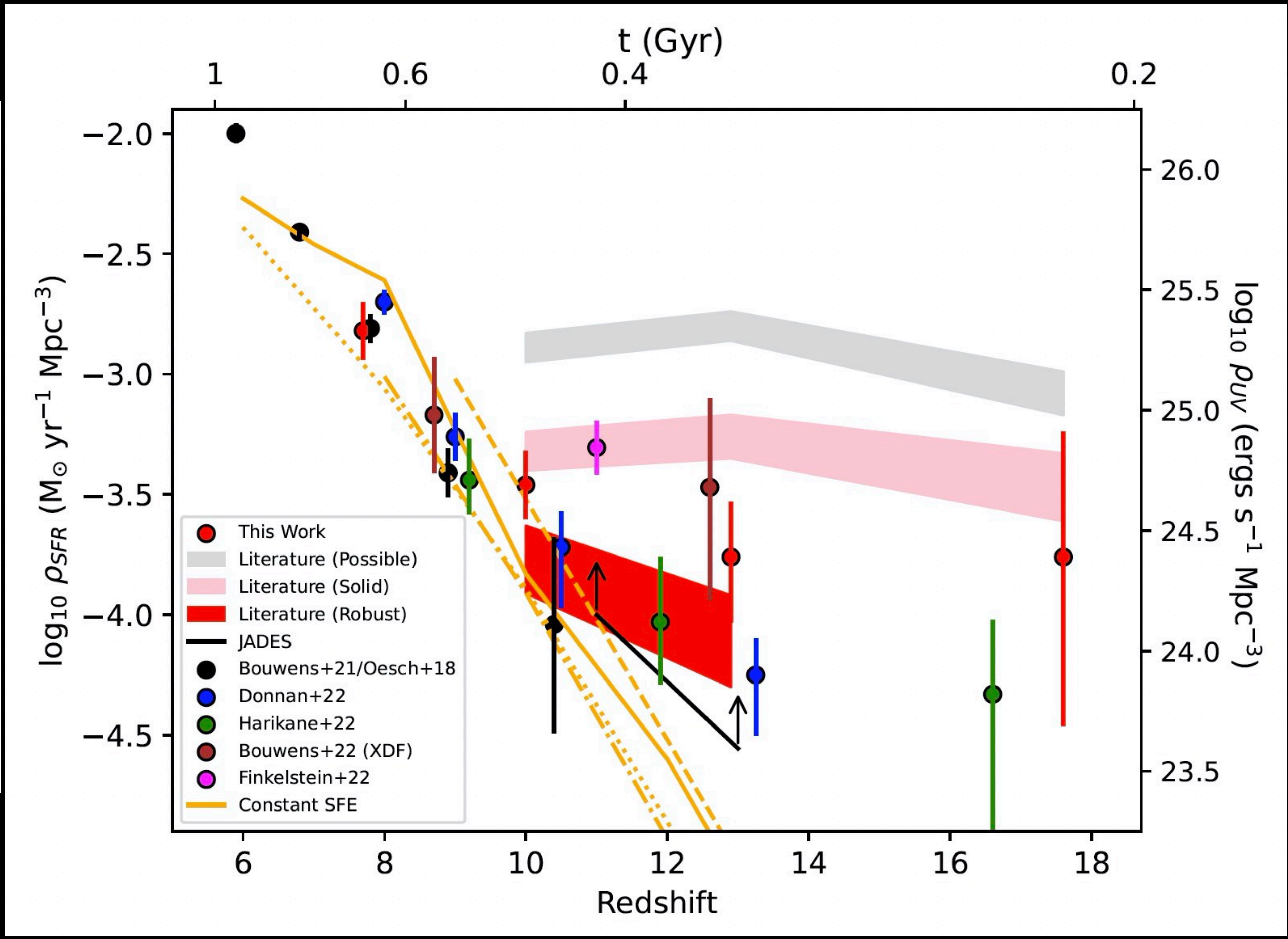
cosmic blasts spotting distant galaxies





JWST luminosity functions and SFRd evolution

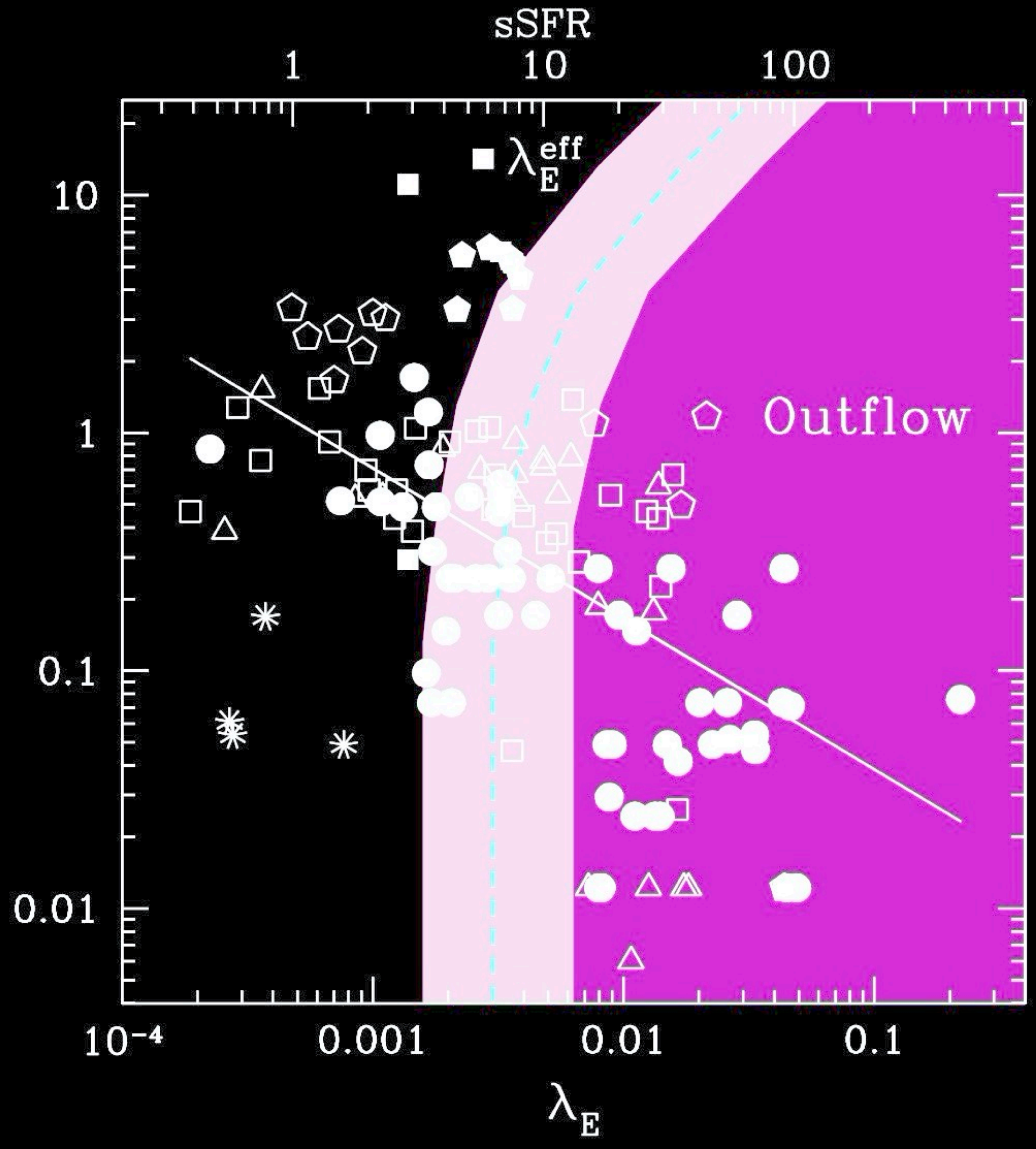


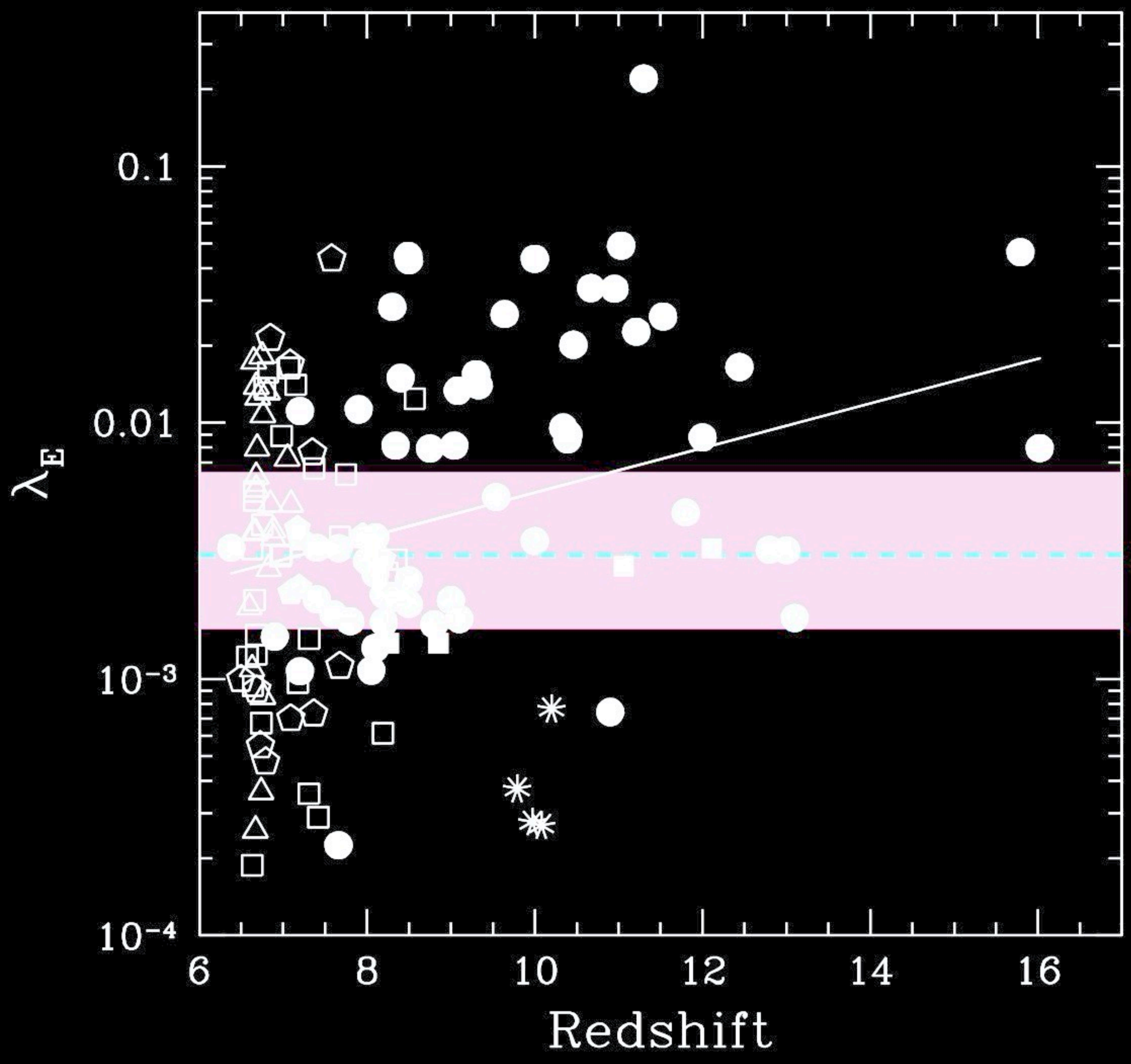


Bouwens+2022

Dusty winds clears up JWST galaxies

Fiore+2022





Dusty winds clears up JWST galaxies

Fiore+2022