PLANTX

PLAnar NTd-Ge microcalorimeter array for hard X-rays

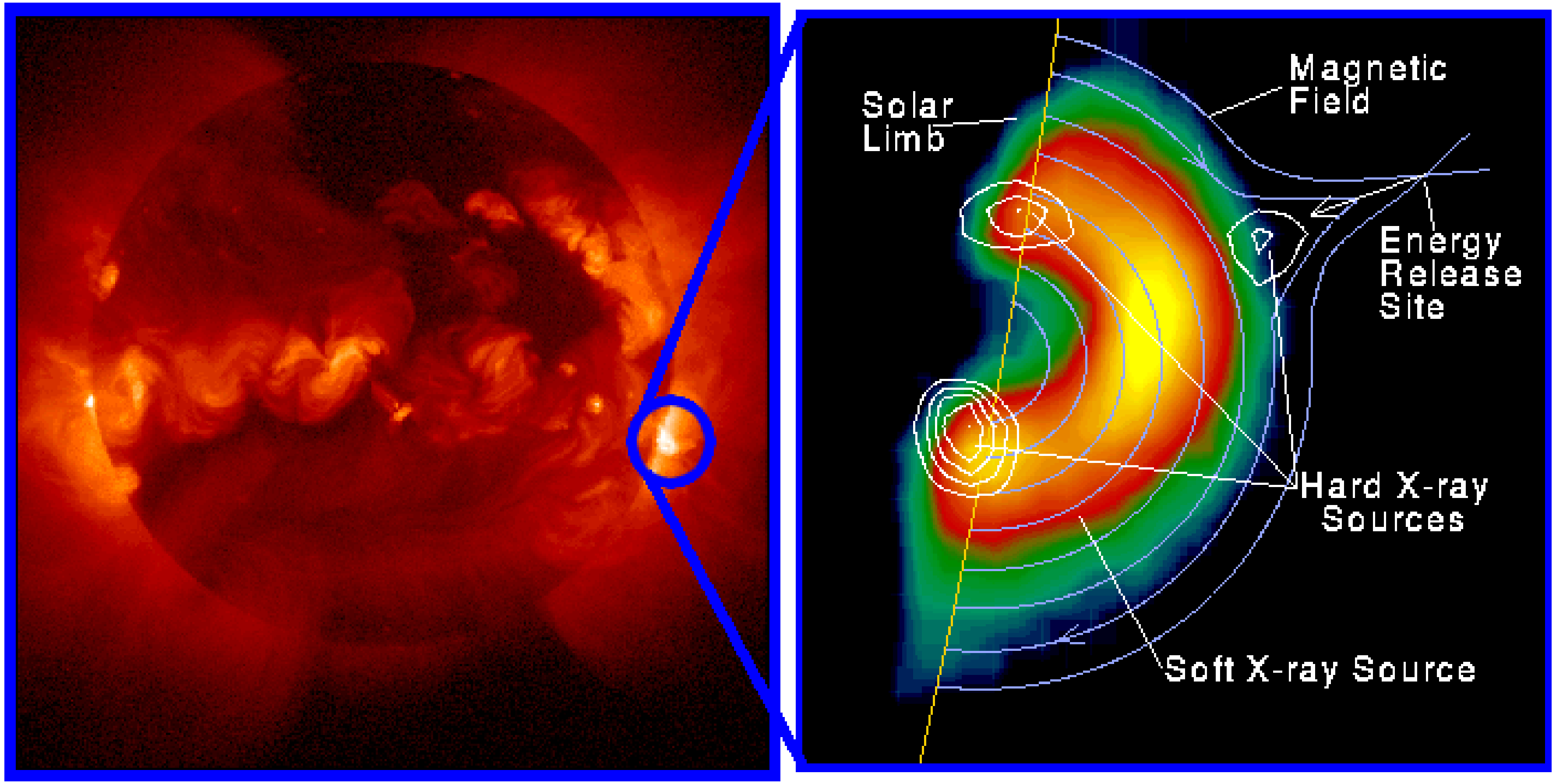
Ugo Lo Cicero
Osservatorio Astronomico di Palermo
locicero@astropa.inaf.it

Proposta MIS-19 in risposta al bando ASI-INAF "Attività di studio per la comunità scientifica di astrofisica delle alte energie e fisica astro-particellare"

Outline

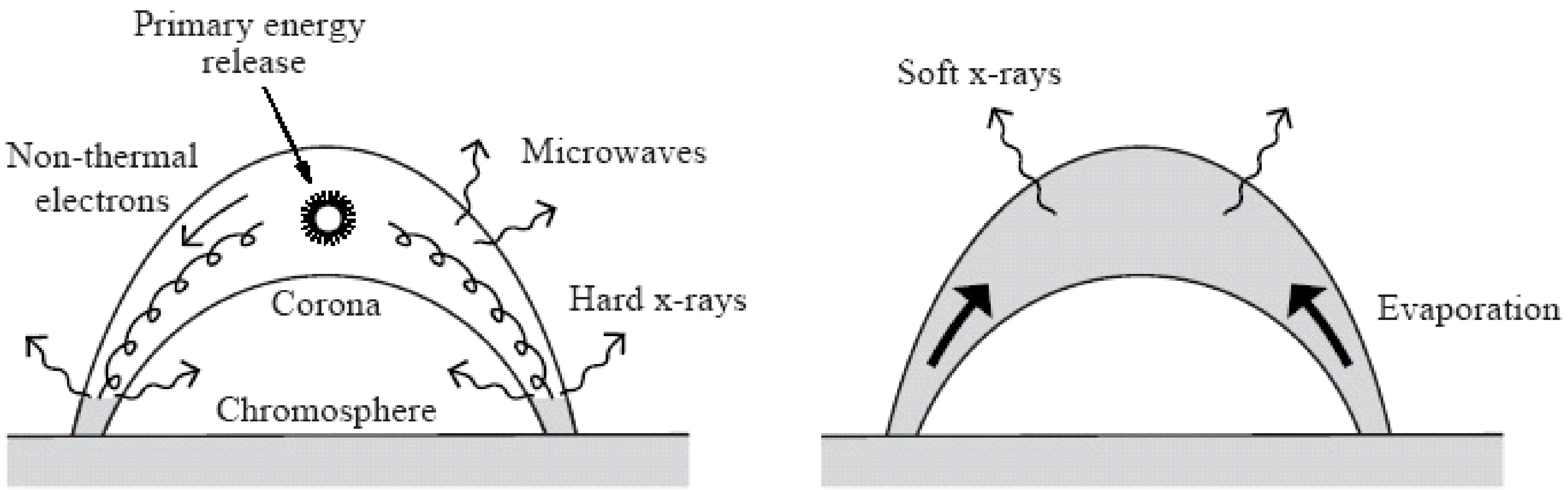
- Physics rationale
- NTD Ge microcalorimeters
- Planar technology – status
- Hard X-ray adaptations
- Low temperature testing
- Project timeline
- Project costs

Solar physics



Yohkoh X-ray Image of a Solar Flare, Combined Image in Soft X-rays (left) and Soft X-rays with Hard X-ray Contours (right). Jan 13, 1992.

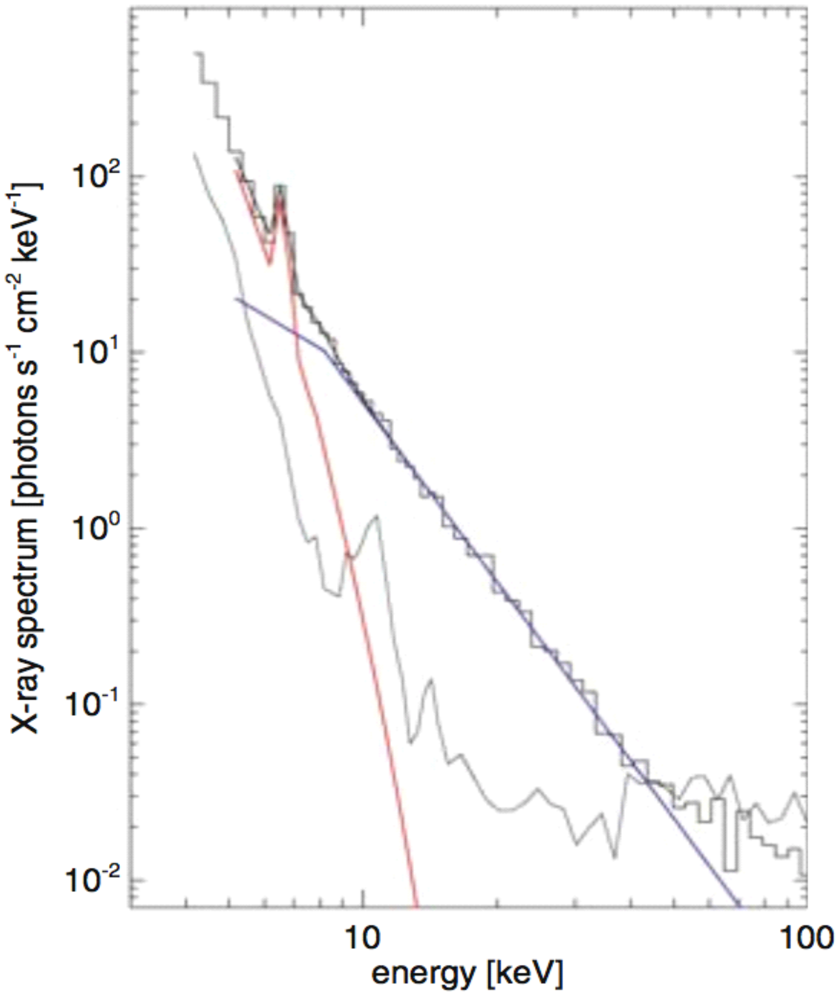
Solar physics



Schematic model of a solar flare [Priest & Forbes 2002]

Hot plasma fills closed magnetic channels (soft X-ray emission) then the plasma slowly cools down and drains to the surface; accelerated electrons hit dense solar surface (hard X-ray emission)

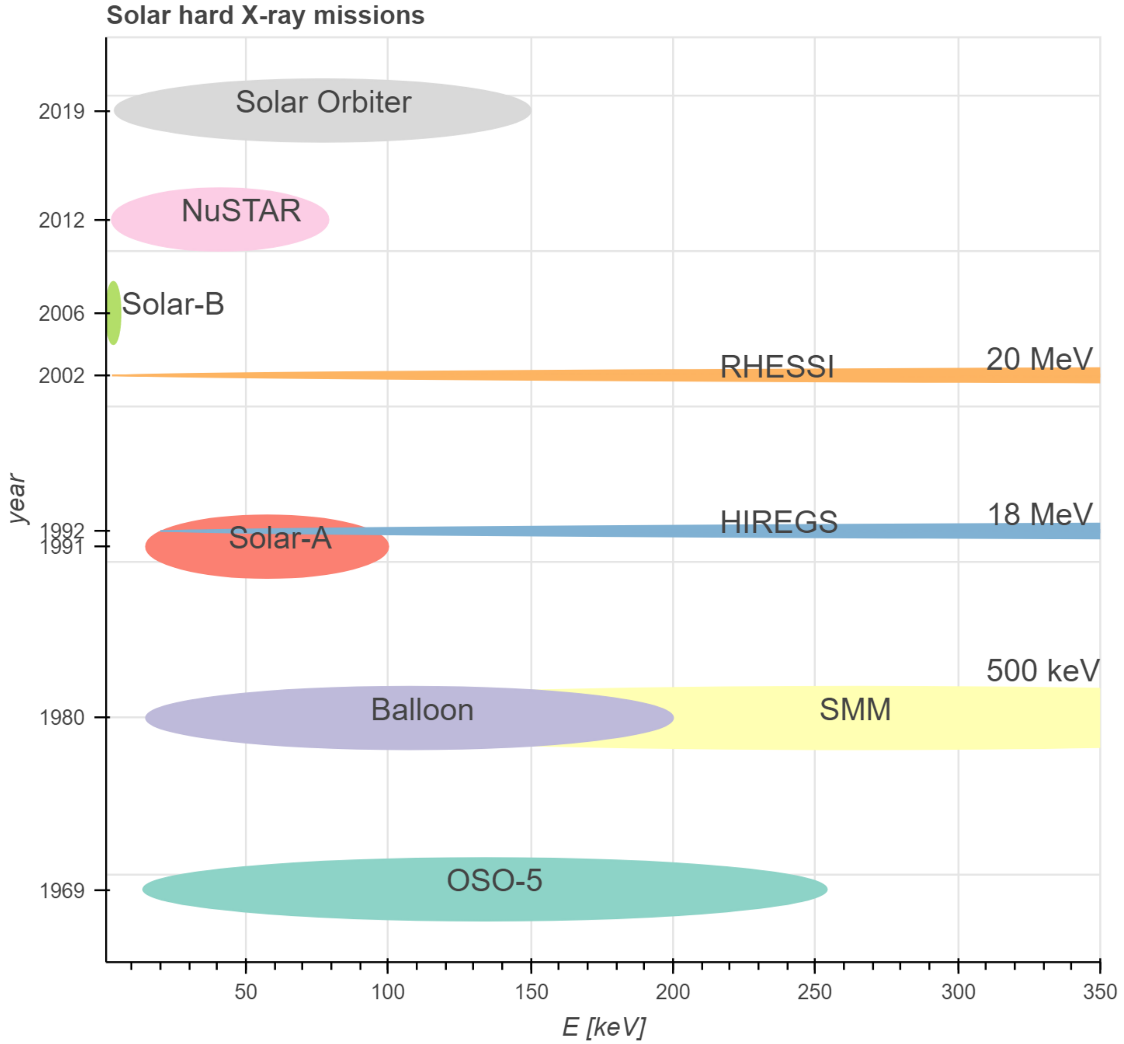
Solar physics



Typical flare spectra are fit by a thermal component at temperatures >10 MK and a non-thermal one.
The flare explosions accelerate electrons up to hundreds of MeV and ions up to tens of GeV.

Example of flare spectrum well-observed by RHESSI and related fitting with a thermal (red) and a non-thermal (blue) component. The low thin line is the background [Krucker+ 2007]

Solar physics – hard X-ray missions



1 keV FWHM resolution:

- appropriate to constrain the general features of the non-thermal component of the solar emission, e.g. the slope of the power law
- does not allow to distinguish any possible deviation from the envelope trend, nor to resolve any possible spectral line, which might come from highly ionized heavy elements.

Mission idea

Goals

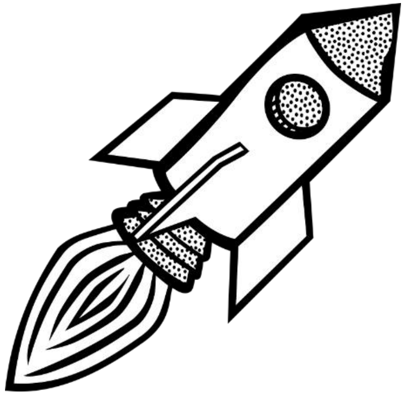
- High energy resolution hard X-rays investigation
- Study of impulsive magnetic reconnection and heating mechanisms
- Diagnostics of the thermal and non-thermal emission

Tools

- Small satellite
- Small array of NTD-Ge microcalorimeters
- Lightweight grazing-incidence plastic-based optics

Specifications

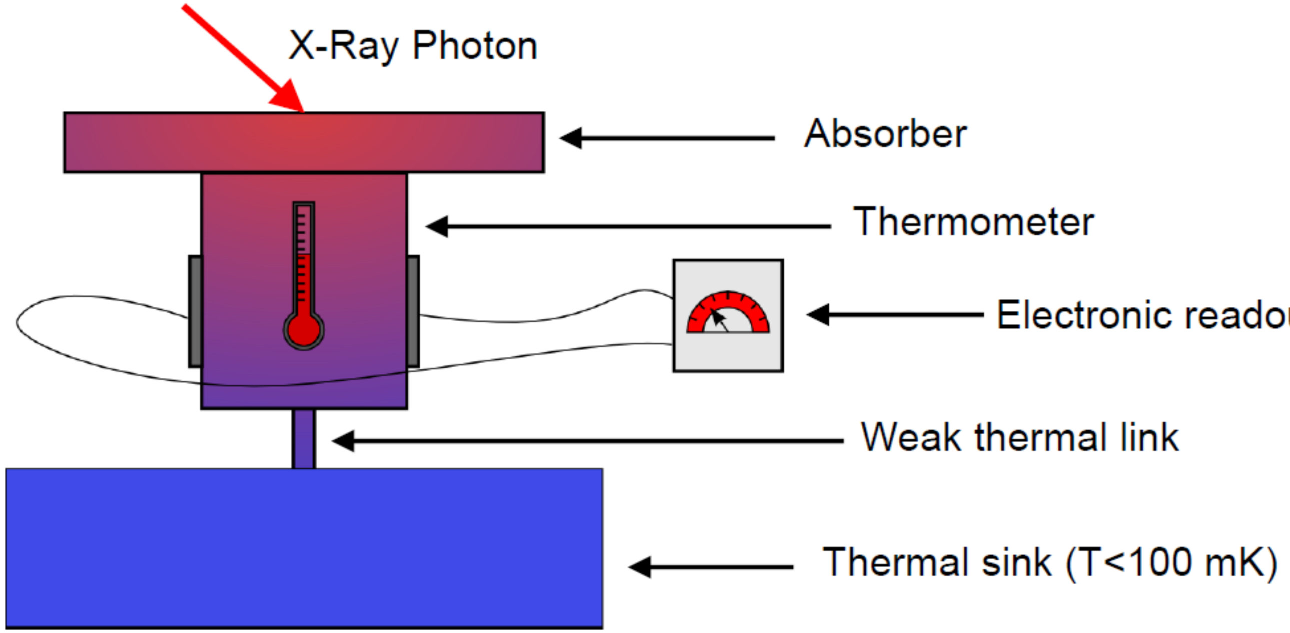
- Energy range 20 keV – 100 keV
- Energy resolution better than 100 eV FWHM in the whole range



Cooling needed:
a commercial ADR, not optimized for flight, weights about 90 kg.

A balloon borne experiment could validate the technology while also providing scientific data.

Microcalorimeters for X-ray detection



$$\Delta T = \frac{E_{ph}}{C}$$

ΔT: temperature increment
Eph: photon energy
C: heat capacity

NTD-Ge microcalorimeters

3.1 eV FWHM @ 6 keV
- (Silver 2005)

50 eV FWHM @ 60 keV
- (Silver 2000)

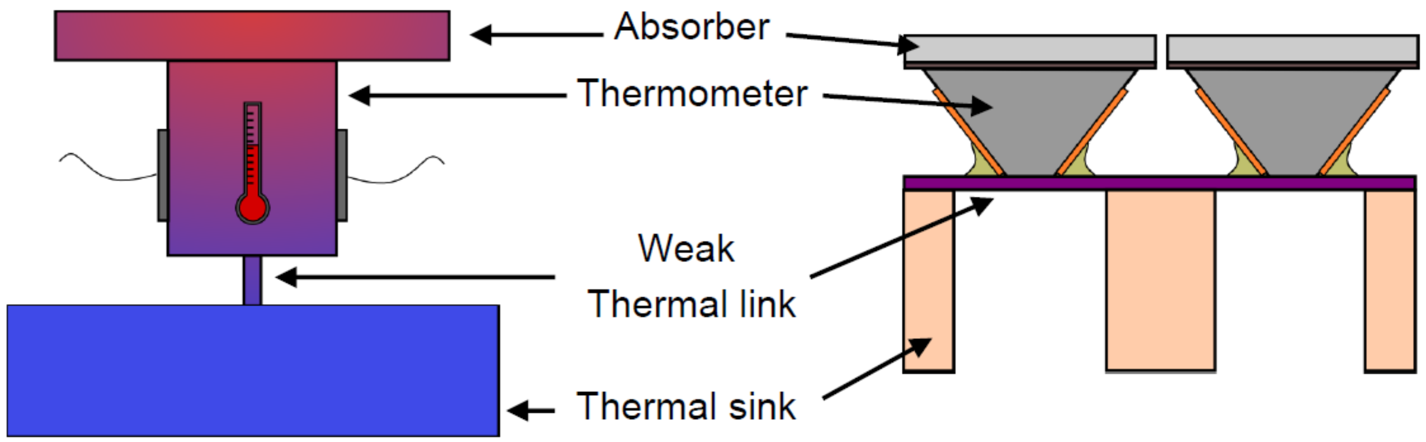
Planar technology develop.
- (Lo Cicero 2009 – 2017)

Technology advantages:

- Robust & reliable
- Low sensitivity to static magnetic fields
- Easily usable in a wide temperature range
- Wide dynamic energy range
- Simple electronics

Project aim: increment NTD-Ge array TRL from 3 to 4

Fabrication process for soft X-rays



Collaborations:

- Dep. Of Physics and Chemistry, UNIPA
- Harvard-Smithsonian Center for Astrophysics (USA)
- CEA (France)
- Centre de Nanosciences et de Nanotechnologies (France)

U. Lo Cicero, et al., 17th Int. Workshop on Low Temp. Detectors - LTD17, Kurume, JP, 17-21 July (2017)
U. Lo Cicero, et al., J. of low temperature physics 167, 3-4, 535-540 (2012)
U. Lo Cicero, et al., J. of Low Temperature Physics, 167, 3-4, 541-546 (2012)
U. Lo Cicero, et al., AIP Conf. Proc., 13th Int. Workshop on Low Temp. Detectors - LTD13, 1185, 112–114 (2009)
U. Lo Cicero, et al., IEEE NSS Conference Record, pp. 1789–1792 (2008)

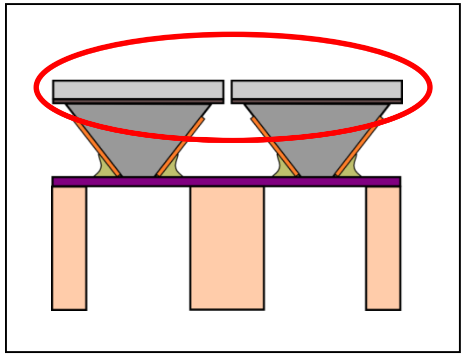
Absorbers

Insulating layer (150 nm)

Doped Germanium

Cr-Cu metallization (100 nm)

Electroplated tin (8-10 μm)

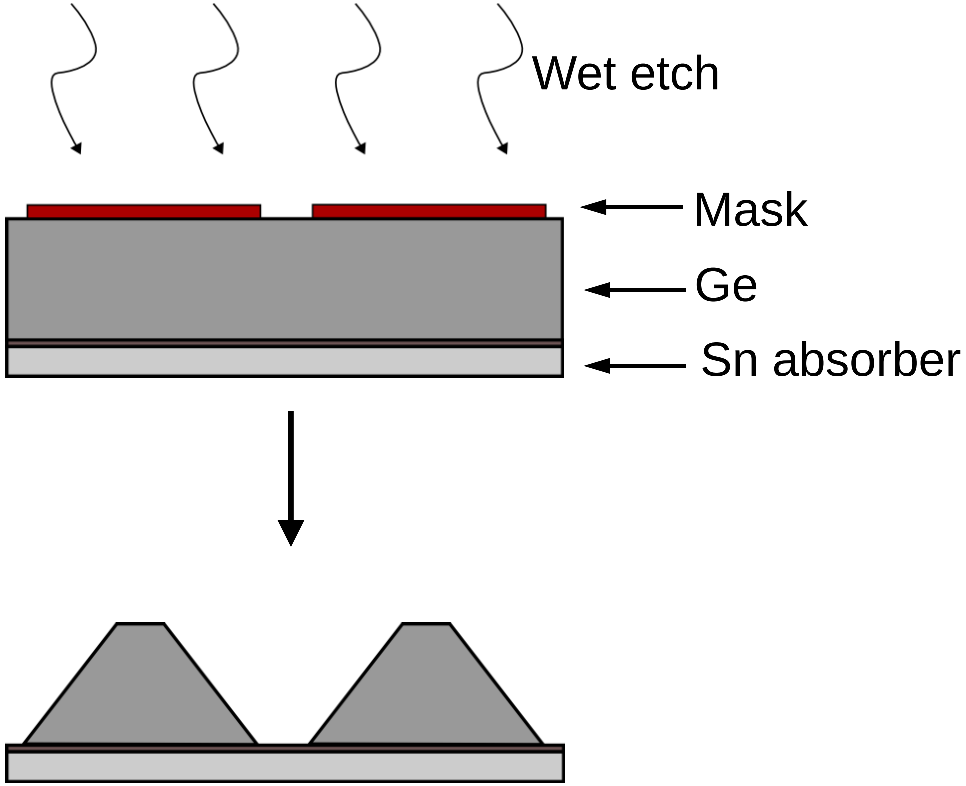


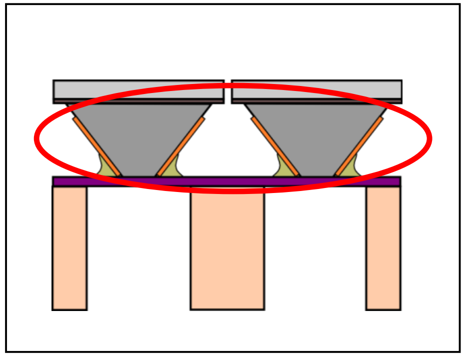
Electroplating:

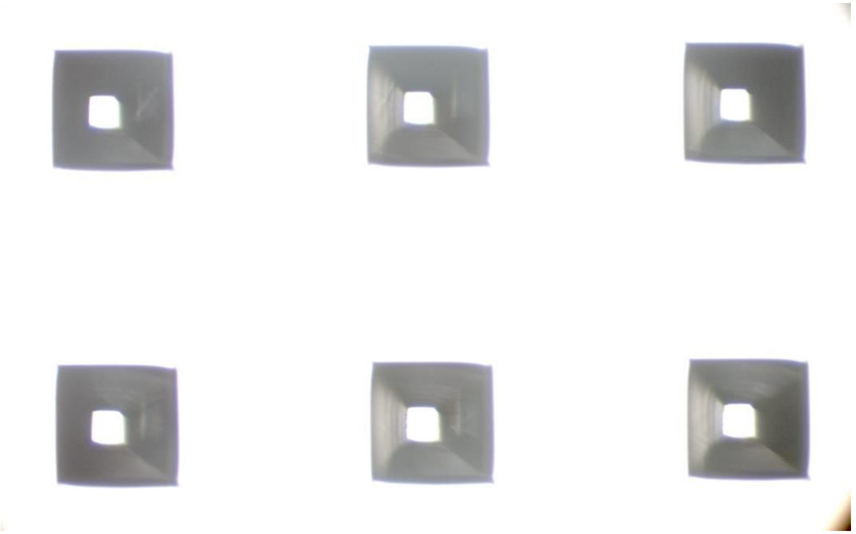
- Thick
- Uniform
- Uniform thermal contact

DONE

Sensors

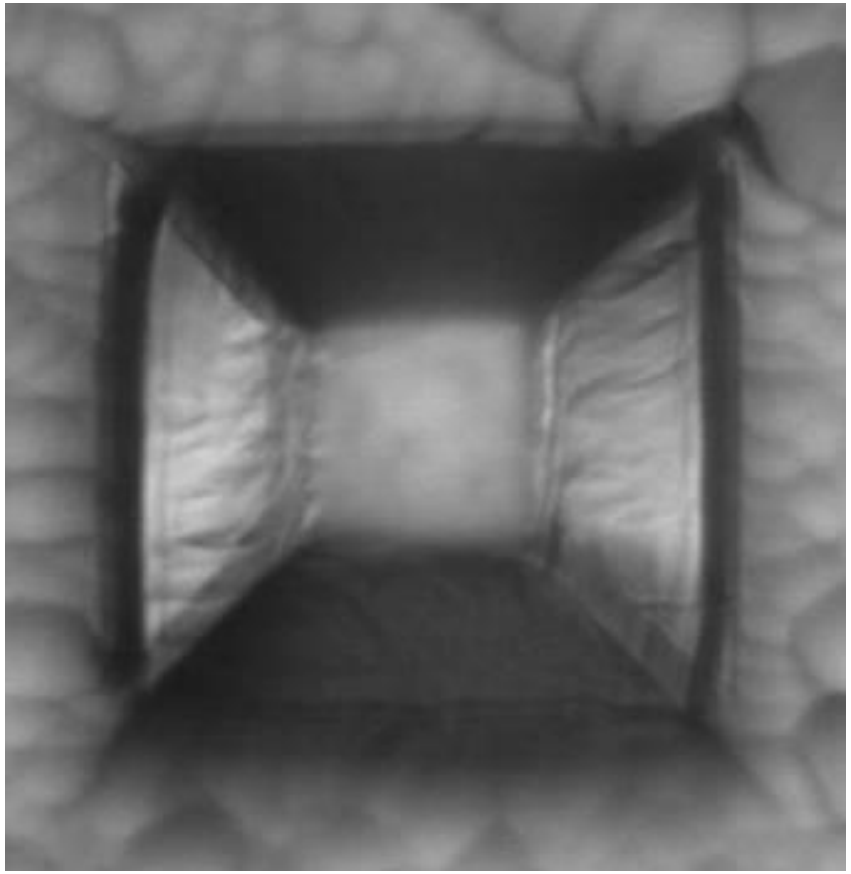






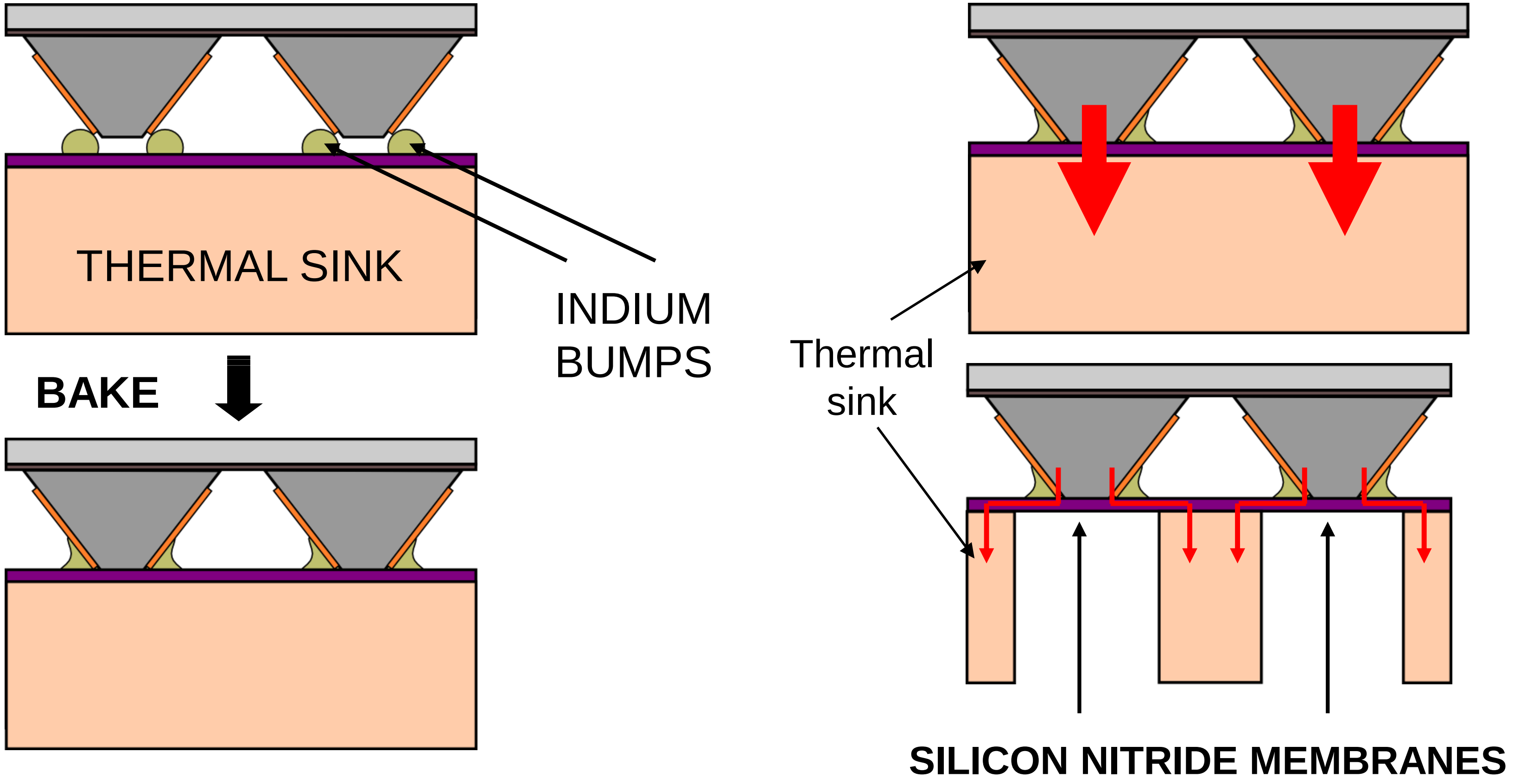
DONE

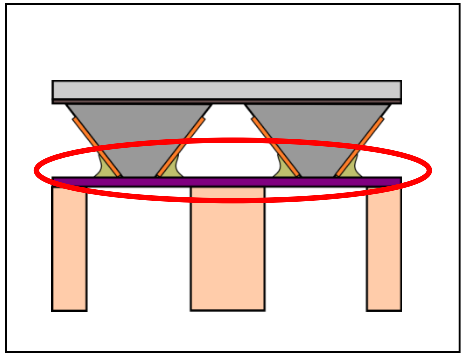
Sensor contacts



DONE

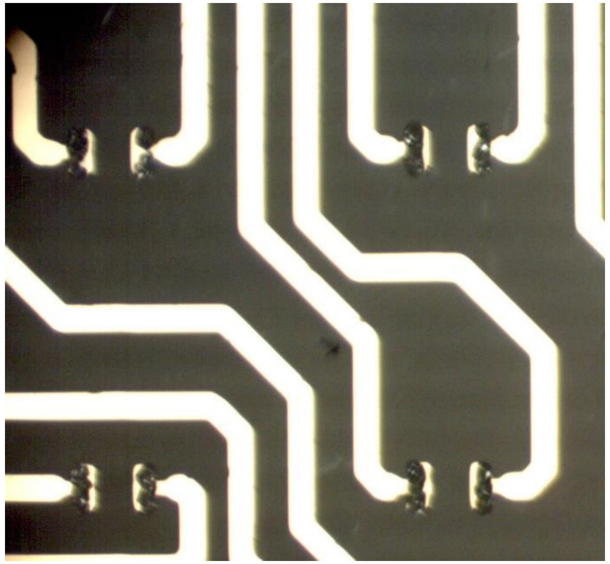
Bonding with substrate

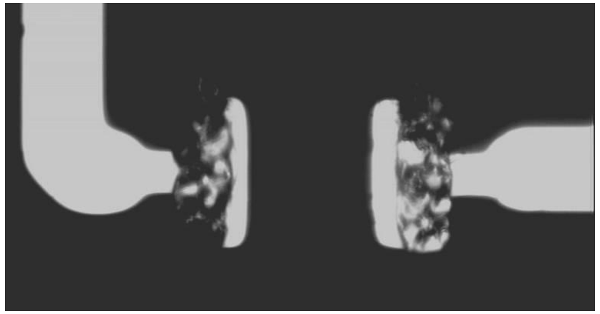


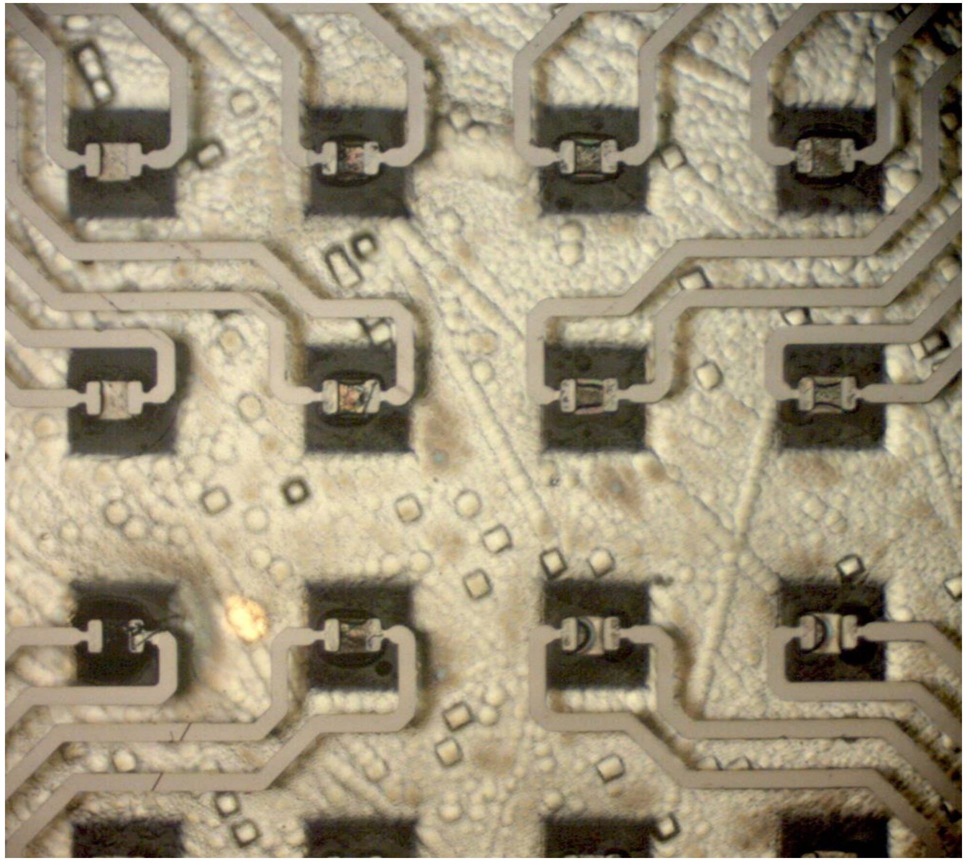


EXISTS

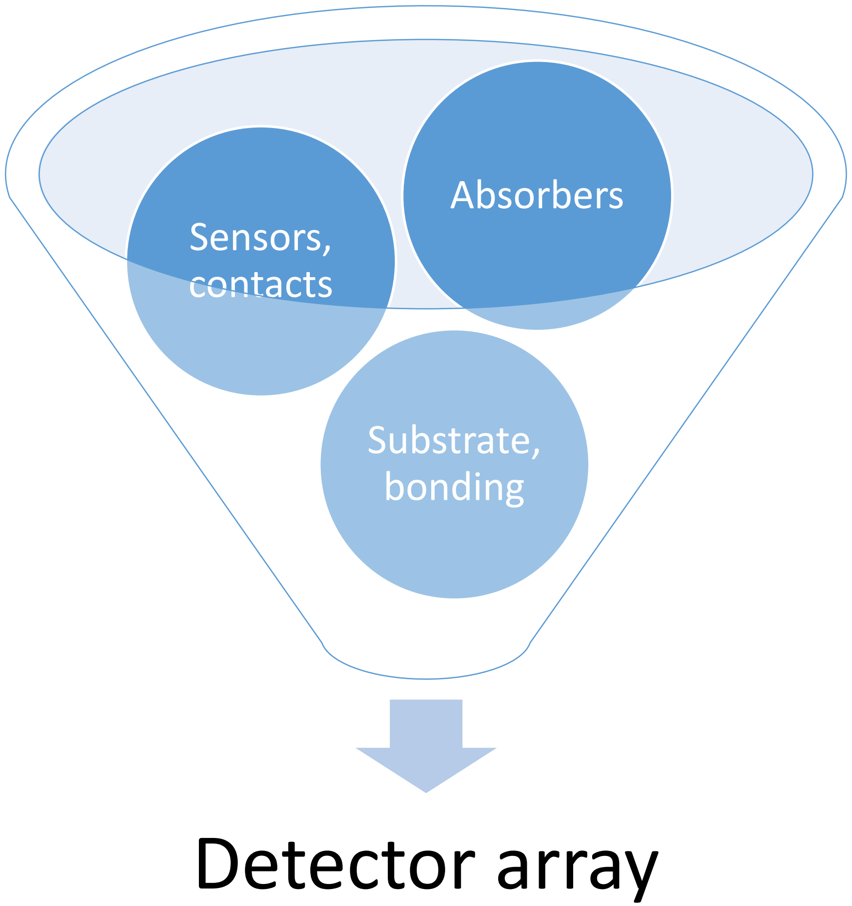
Bonding with substrate







Integration



- All the technological steps have been specifically developed or they are commonly employed in other fields.
- They all have to be integrated to fabricate a laboratory prototype.
- Adaptations needed for the integration are planned, but still to be implemented and tested.

Hard X-rays detection

Optimization for hard X-rays detection:

- ❑ Absorber
- ❑ Sensor parameters (geometry, doping)
- ❑ Thermal link

ABSORBERS

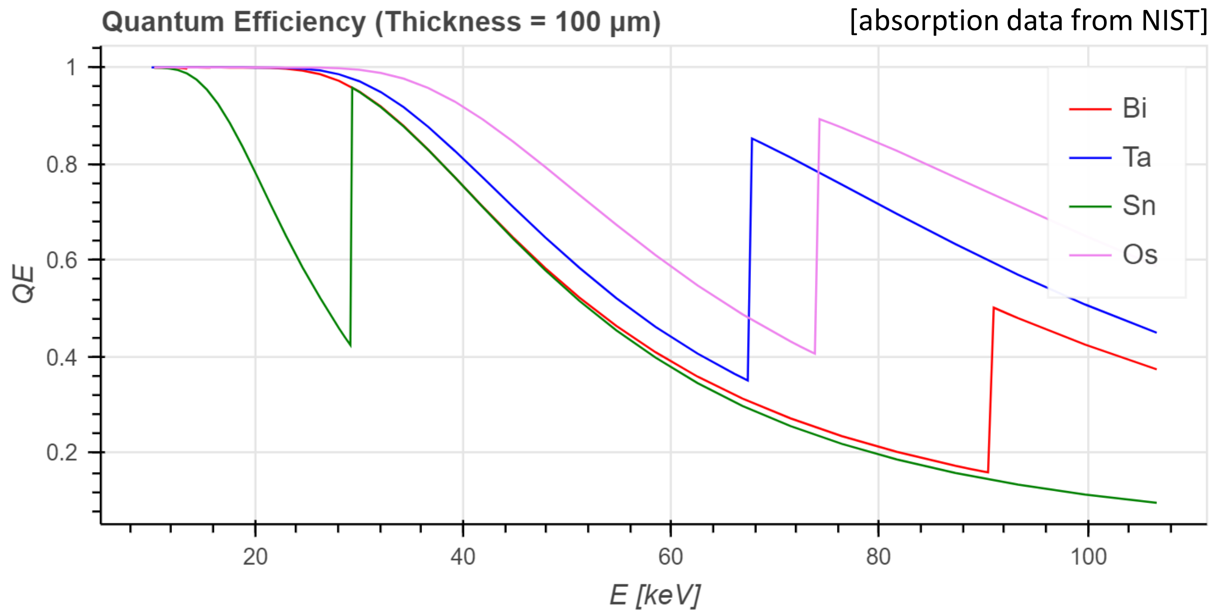
Tin

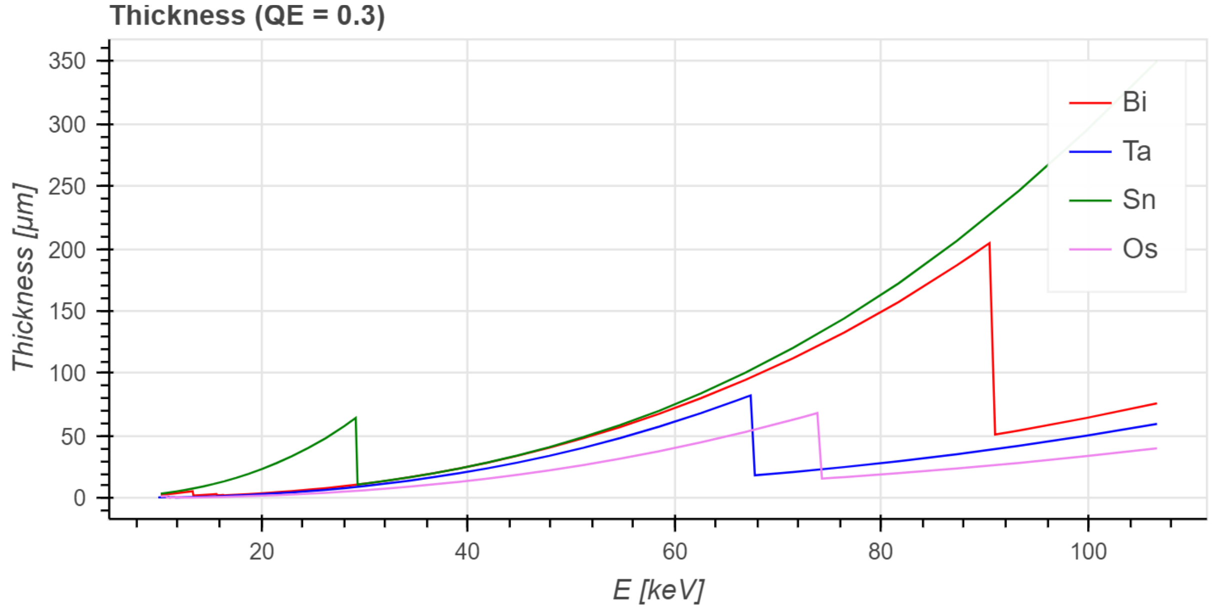
- Might be an option in range 30 keV – 90 keV
- Superconductor: very low heat capacity
- Thermalization issues to be weighted

Bismuth

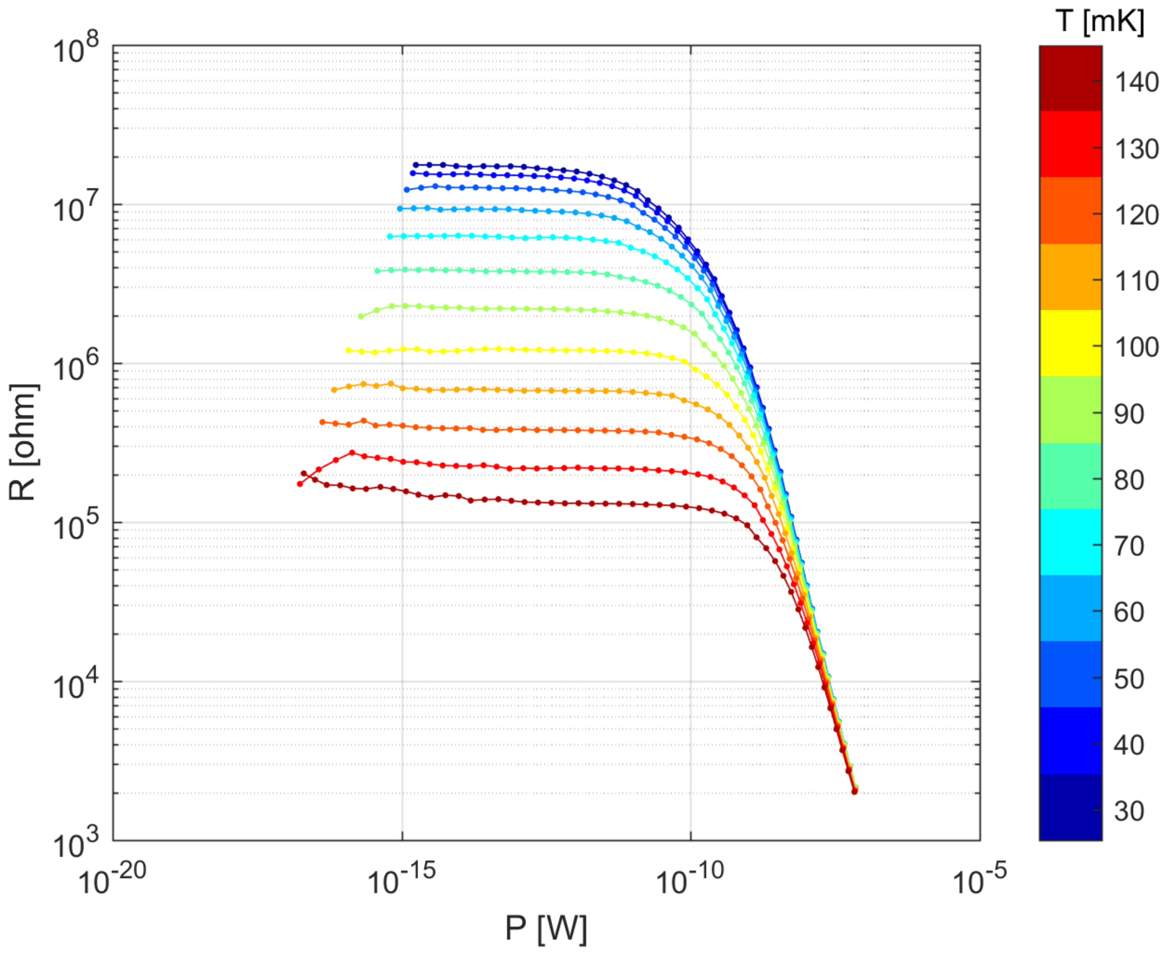
- Can be deposited by electroplating
- Presents a quite low heat capacity
- Not a superconductor: better thermalization

Others: deposition issues





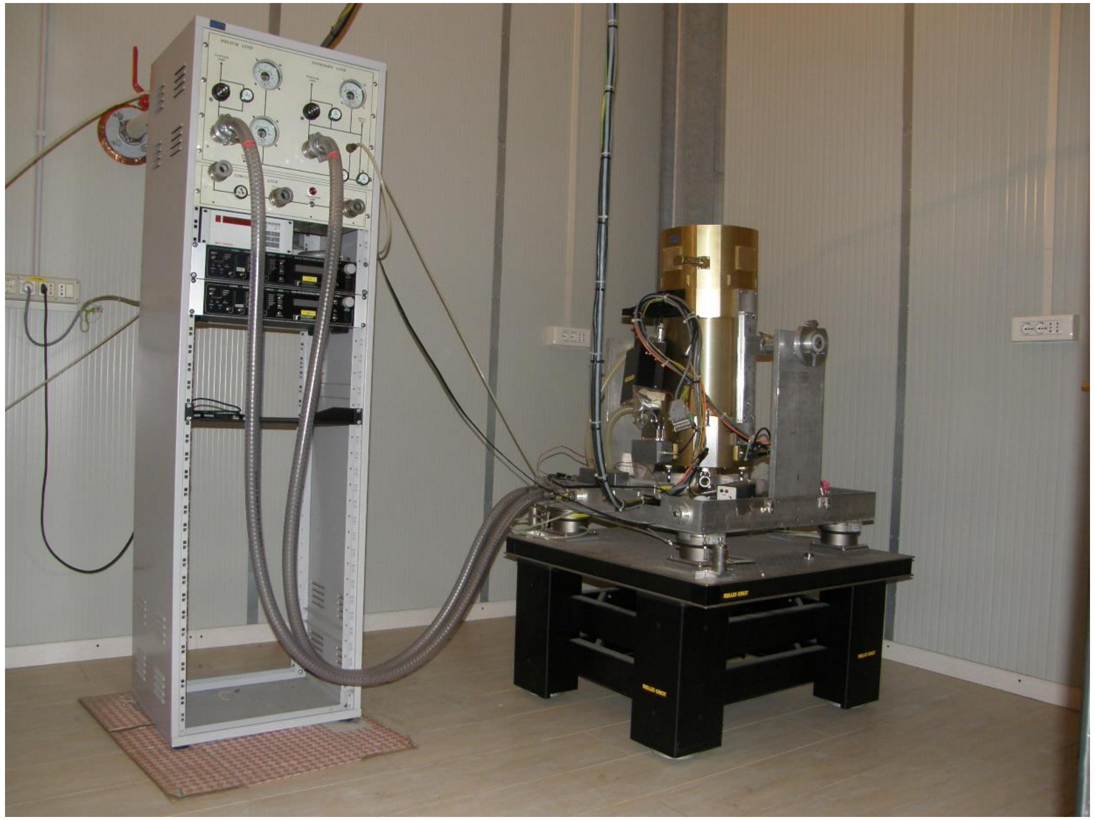
Low temperature testing



Testing at low temperature is needed to develop and characterize the detector parts and the detector assembly.

Cryogenic electrical measurements performed at CEA, Paris, on a NTD-Ge sample (2016)

Low temperature testing



Liquid based ADR at OAPA

With liquid based ADR:

- impossibility to rearrange the experiment during the same cryogenic session
- low cooling power and reduced wiring
- very complex logistic to organize each session
- very high cost for each session
- strong logistic problems to organize more sessions in a row

→ Liquid-free cryostat is mandatory to allow for further development

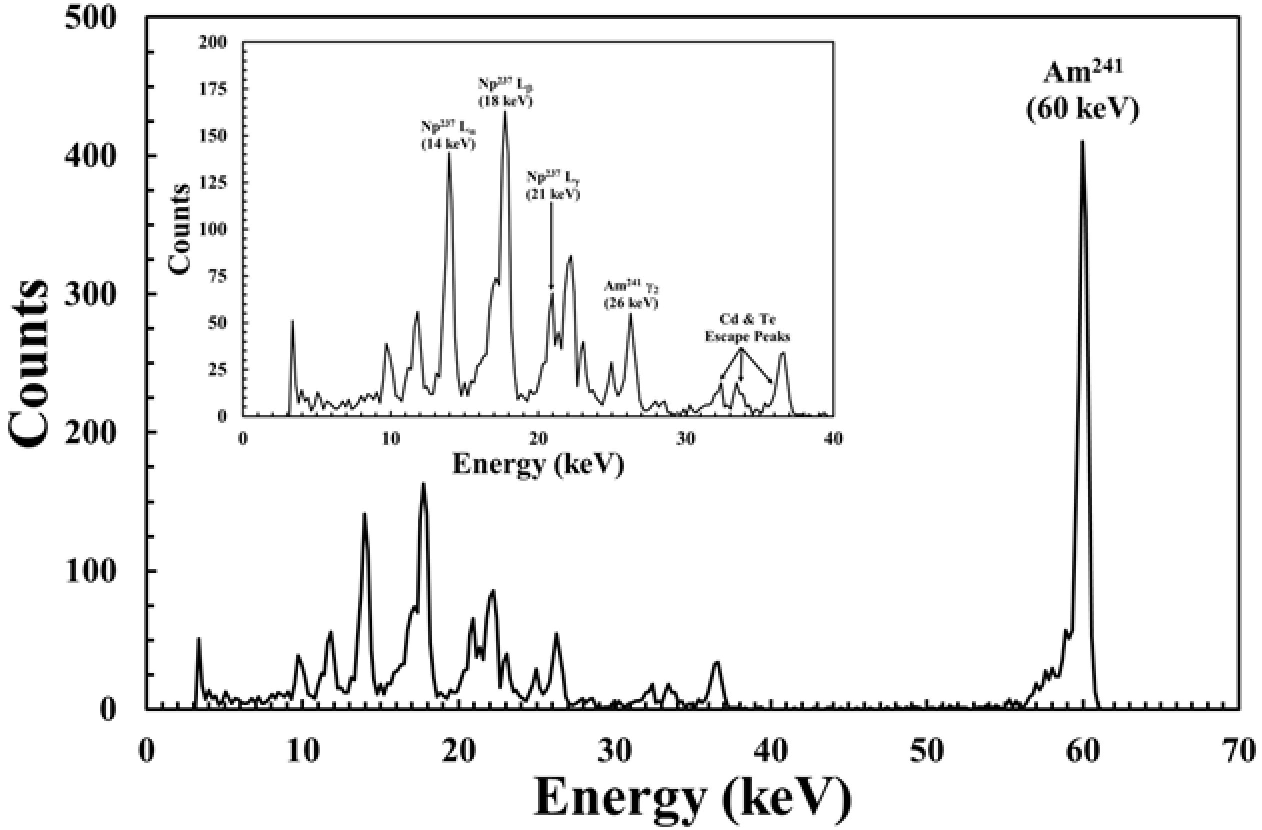
With liquid-free ADR:

- cooling during the night
- several sessions per week feasible
- two sessions per week per two years repay the cost

Hard X-ray / gamma-ray sources

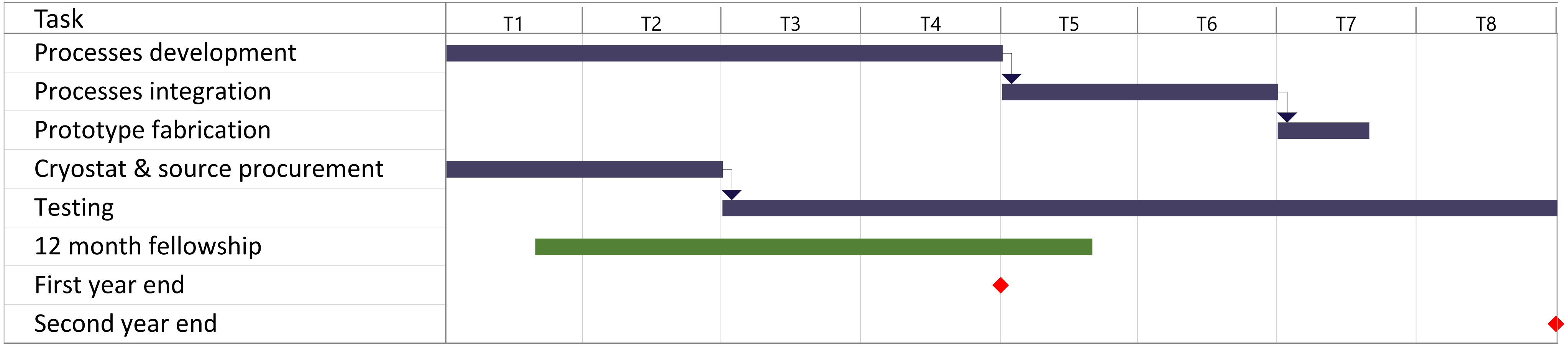
241-Americium, HL 432.2 y
90-Strontium, HL 28.8 y
137-Caesium, HL 30.2 y
60-Cobalt, HL 5.3 y
192-Iridium, 73.8 d

241-Am source
[education.scichem.com]



241-Am gamma-ray spectrum measured with a CdTe detector
[DrMattV at English Wikipedia]

Project timeline



Deliverables after one year:
Reports on technological processes developed to build an integrated hard X-ray detector array.

Deliverables at the conclusion of the project:
Reports on integration process, prototype array description and testing results.
Flyer for outreach.

Project costs

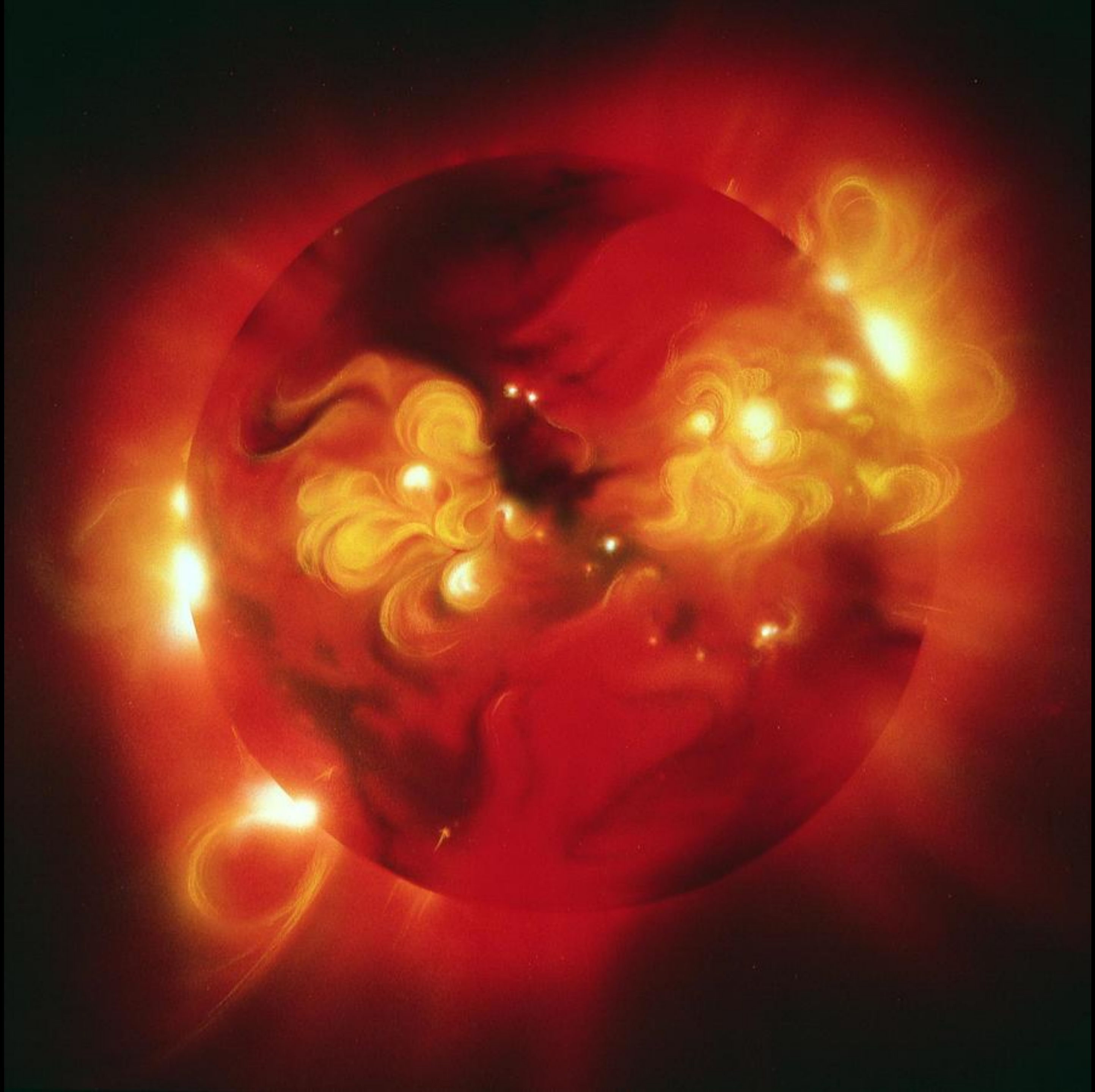
Personnel	12 month fellowship	24000 €
Equipments	Liquid free cryostat, X-ray source	285000 €
Consumables	NTD Ge, micro-photolitography consumables, electroplating solutions and electrodes, chemicals and glassware, SiN on Si, evaporation crucible liners and targets	15000 €
Travels	4x2 Italy, 4x2 Europe	13784 €
Other	Metrology (SEM, optical 3D micro-profilometry, material analysis), services (germanium doping, flip-chip bonding, SiN/Si patterning and etching, wire bonding)	20000 €
TOTAL		357784 €

People – research unit

Name	Institute	Position
Ugo Lo Cicero	INAF – Osservatorio astronomico di Palermo	Technologist
Alfonso Collura	INAF – Osservatorio astronomico di Palermo	Astronomer researcher
Marco Barbera	UNIPA, INAF – Osservatorio astronomico di Palermo associate	Associate professor
Domenico Spoto	ASI, INAF – Osservatorio astronomico di Palermo associate	Senior technologist

Expertise and equipment available at OAPA XACT (X-ray Astronomy Calibration and Testing) facility enable project development.

- Micro-technologies
- Cryogenics
- X-ray instruments for astrophysics
- Vacuum technologies



Artwork Of The Solar Corona Based On X-ray Imagery is a photograph by Detlev Van Ravenswaay [fineartamerica]