DE LA RECHERCHE À L'INDUSTRIE

Instrumentation in Astrophysics

D. Baudin (Dédip)
S. Bounissou (DAp)
F. Ceraudo (DAp)
T. Guy (Larsim)

DDAYS IRFU **10 JUILLET 2018**

INTRODUCTION

- WHY DO WE NEED INSTRUMENTS IN SCIENCE ? (SOUNDS OBVIOUS NOW BUT « ONLY » 400 YEARS)

  - « EPISTEMIC ENHANCERS » (P. HUMPHREYS):

Extrapolation : extend human senses (e.g optical telescopes).
Augmentation : new modality of detection (e.g. Neutrino detetctors).

  - « PHENOMENOTECHNIC » (G. BACHELARD): THE PHENOMENA ARE NOT SIMPLY GIVEN BUT PRODUCED BY THE TECHNICAL INSTRUMENTS.

INTRODUCTION

- IN ASTRONOMY, LIGHT IS THE PRIMARY INFORMATION CARRIER + DIFFERENT INFORMATION CAN BE PROVIDED DEPENDING ON:
    - THE RANGE OF ENERGY (GAMMA, X, UV, IR …)

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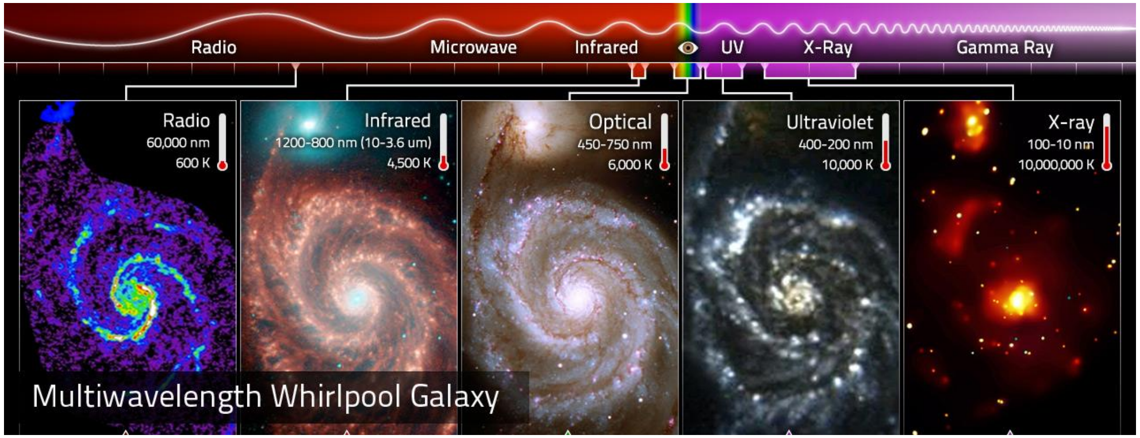

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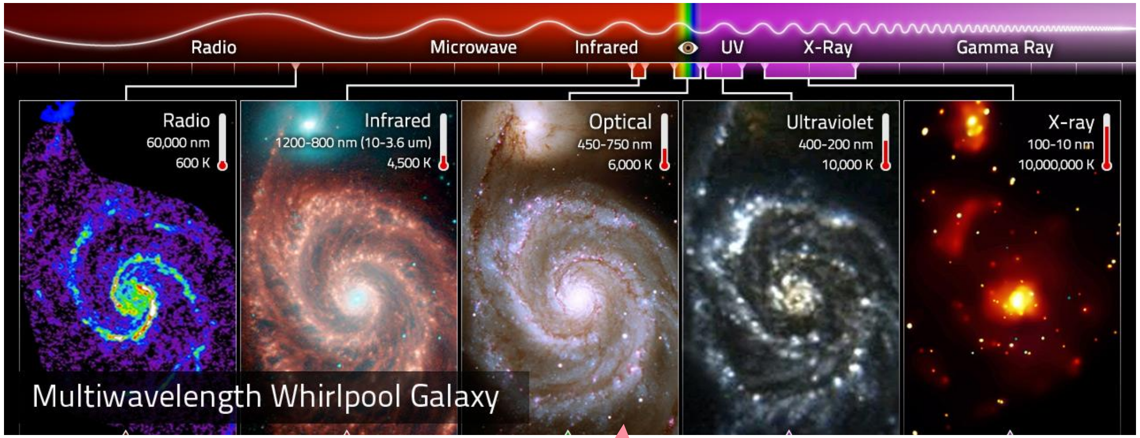

Multiwavelength Whirlpool Galaxy

  - The methods of investigation (photometry, spectroscopy, polarimetry …)

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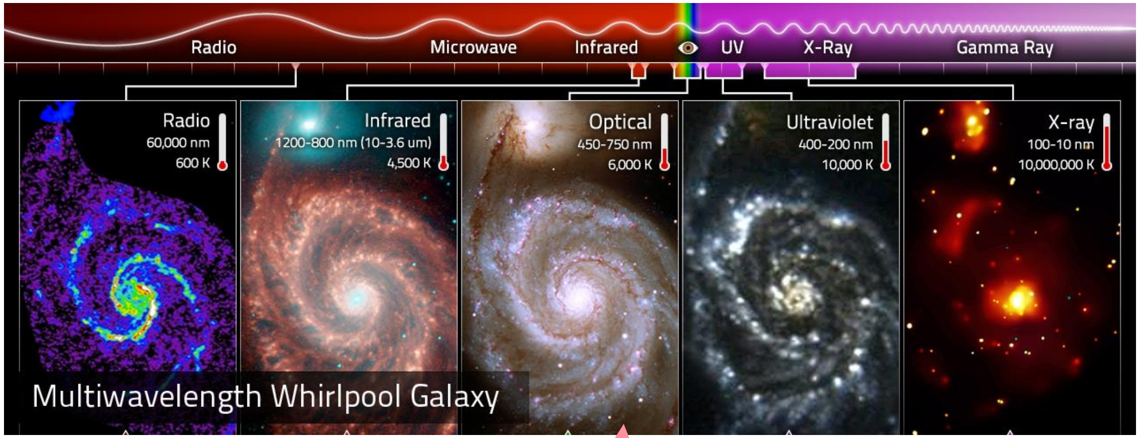

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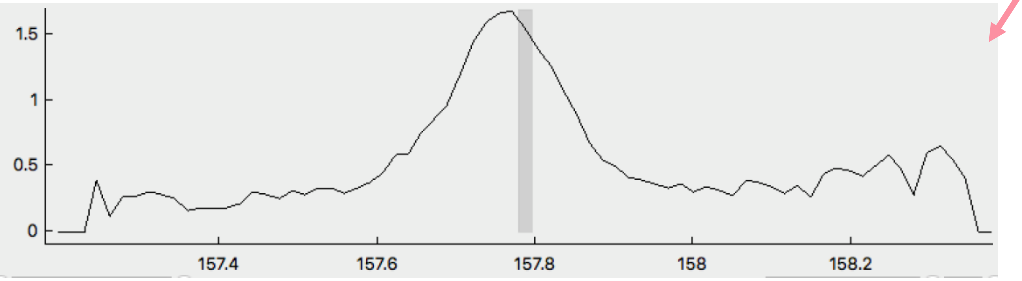

C+ line – SOFIA

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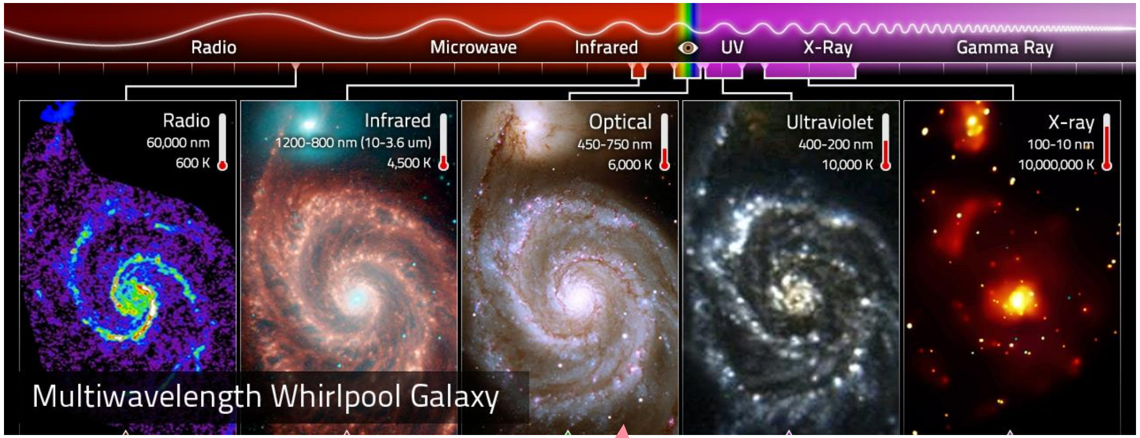

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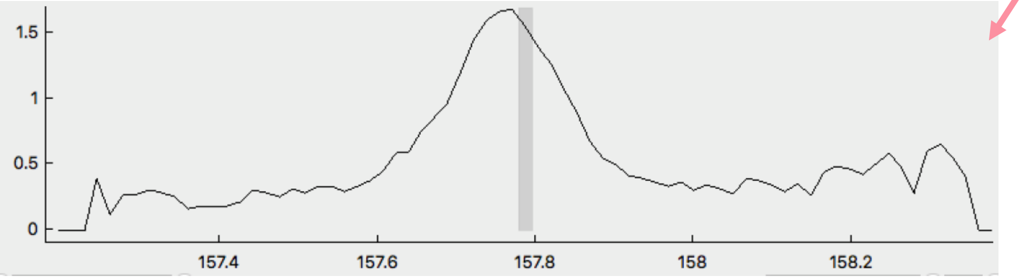

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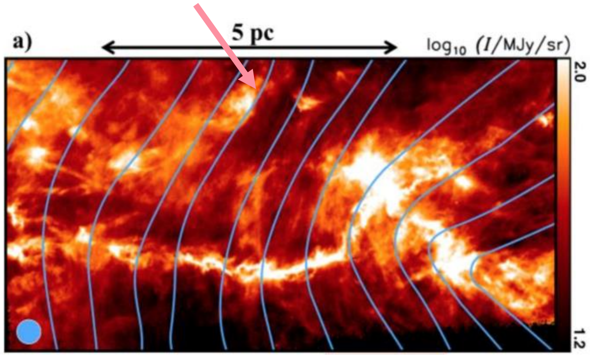
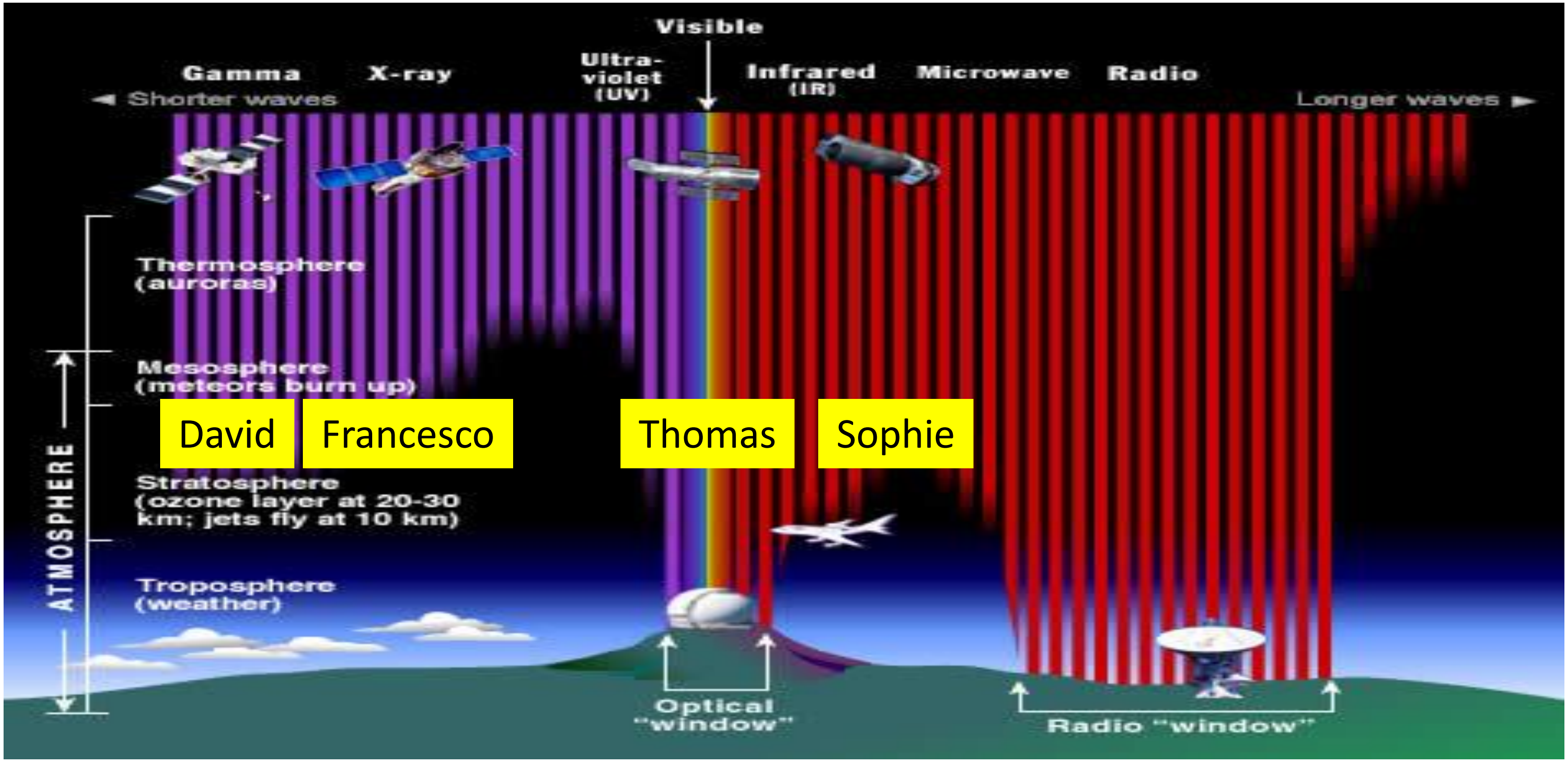


HERSCHEL + PLANCK

INTRODUCTION

TECHNICAL DEVICE -> ASSOCIATED ENVIRONMENT

- GEOGRAPHICAL
- TECHNICAL

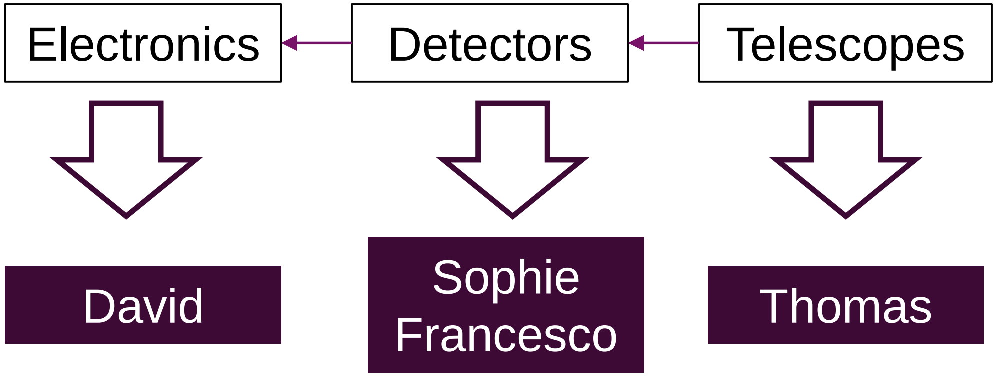


INTRODUCTION

Knowledge

Data

Information



Electronics ← Detectors ← Telescopes

David

Sophie
Francesco

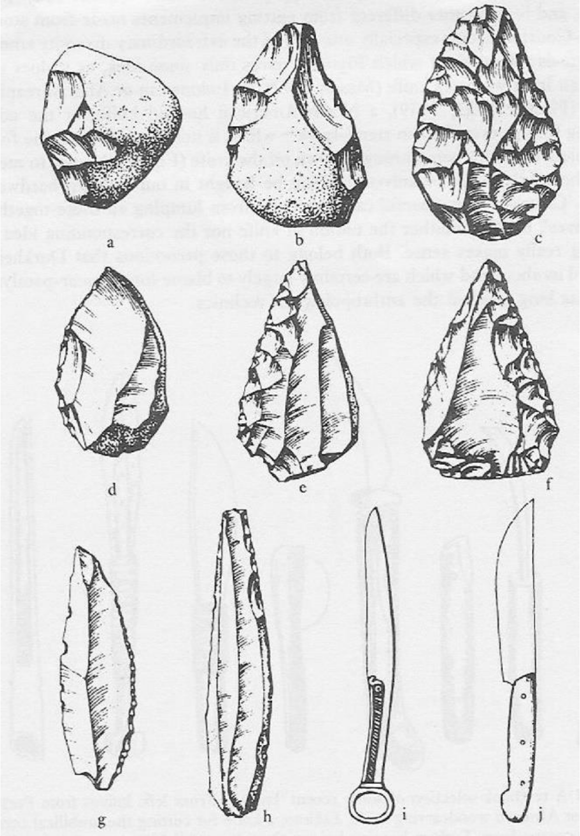
Thomas

DE LA RECHERCHE À L'INDUSTRIE

Genetic mechanology and innovations on large instruments

T. Guy (Larsim)

V. Bontems (Larsim)
V. Minier (DAp)



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How do we go from this:

Galileo's 1st refractor

and this:

Newton's 1st reflector

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How do we go from this:

Galileo's 1st refractor

and this:

Newton's 1st reflector

to this:

VLT

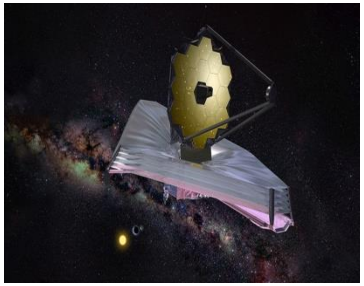
and this:

HST

but also this:

FAST

and - maybe one day - this:



JWST

OBJECTIVES

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Propose a new method and some new tools allowing to:

- Exhibit the operation(s) of technical object.
- Analyze the major technical developments.
- Understand design choices.

Case study: the telescope.

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This method should propose a new insight for current knowledge databases and explore theoretical hypothesis in the field of philosophy of technics.

Based on :

- Mechanology : « Study of the operating principles of technical devices and science of correlations and transformations of these principles ». (G. Simondon, 1950s)
- TRIZ: Theory of Inventive Problem Solving. (G. Altshuller, 1970s)
- MASK: Method of Analysing and Structuring Knowledge. (J.-L. Ermine, 1990s)

SOME CONCEPTS AND TOOLS

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- Technical class defined by its function.
  - eg: neutrino telescopes, muons telescopes…
- Technical family defined by its operating principles.
  - eg: light focusing instruments …
- Technical lineage defined by the intersection of the two.
  - eg: reflectors’ lineage, refractors’ lineage …

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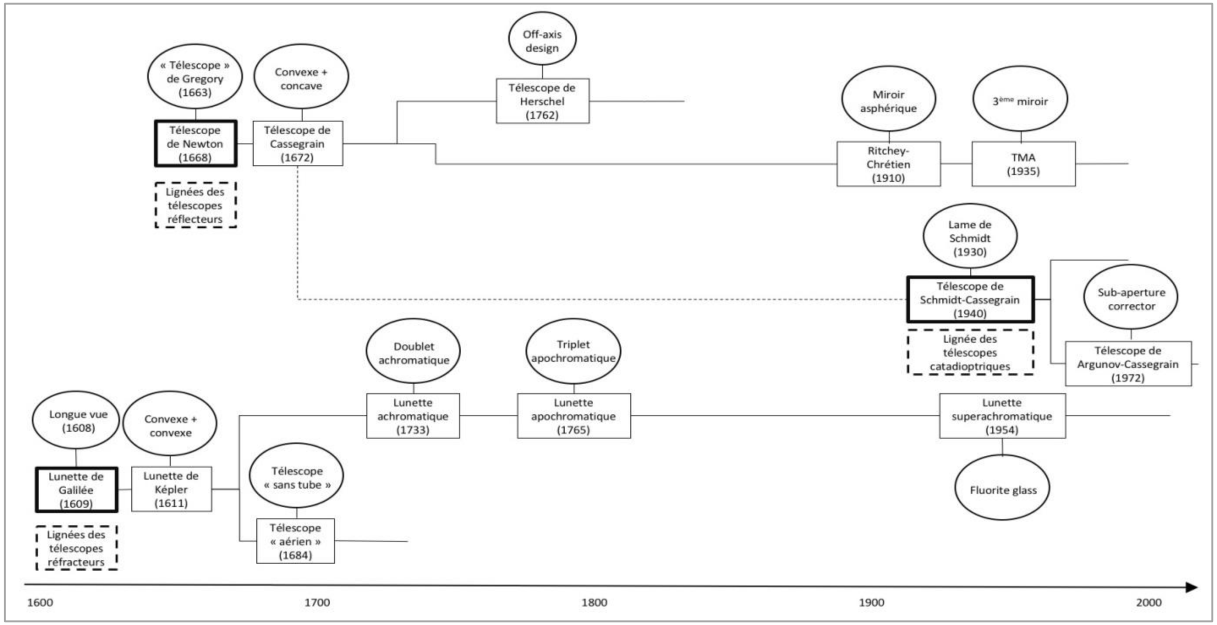

« Lineages diagram » of optical telescope

FIRST ANALYSES

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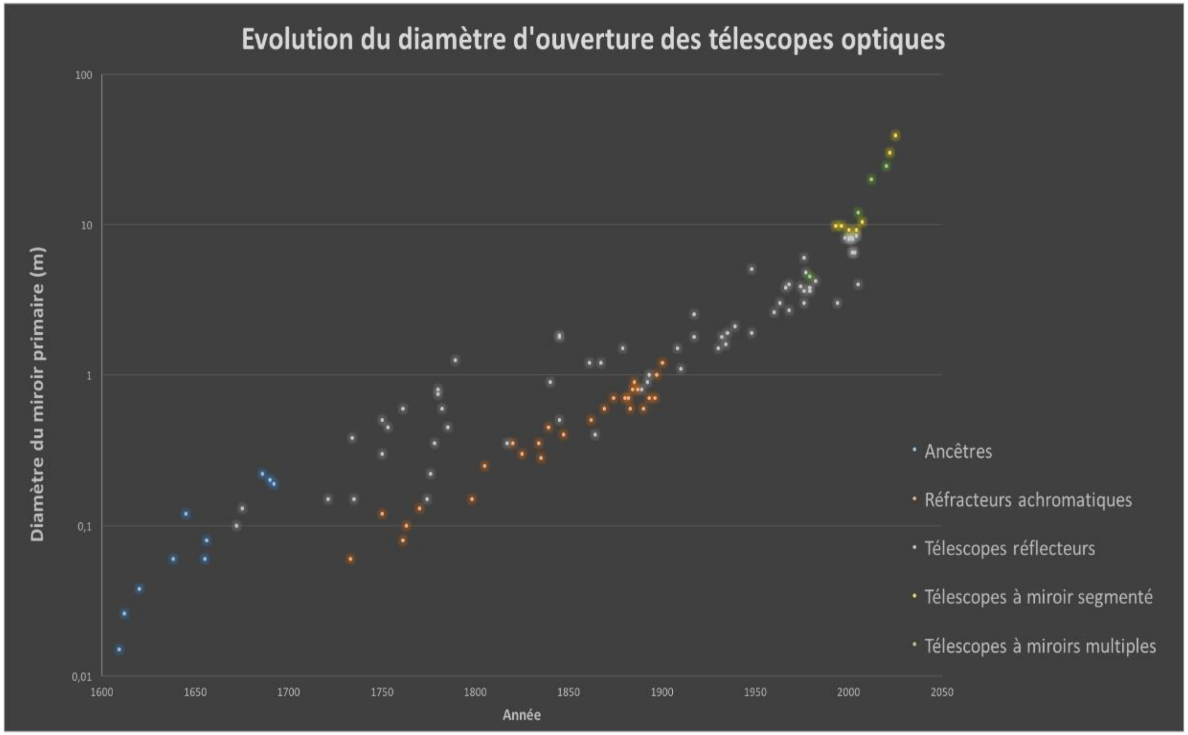
From quantitative analysis …



« The diameter of the primary doubles every 50 years »

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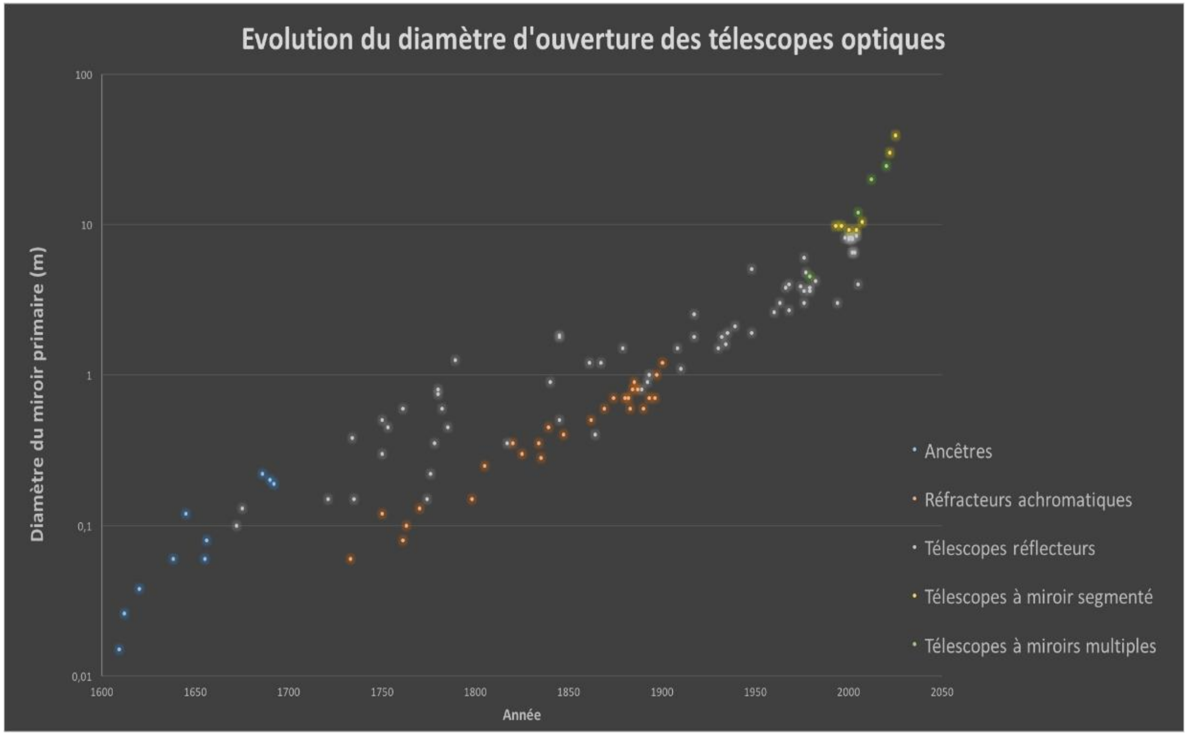

« The diameter of the primary doubles every 50 years »

…to qualitative analysis:

- Complexification: more sub-systems.
- Concretization: more synergies.
- Scale changing: going bigger or going micro.

PERSPECTIVES & CONCLUSION

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Continue the analyzes at:

- Other wavelengths
- Other scales

Focus the analysis on a particular telescope (Euclid)

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... and to anticipate the future ?

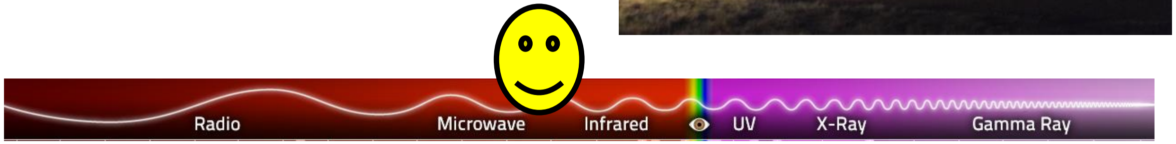
DE LA RECHERCHE À L'INDUSTRIE

Study of a compact submillimeter imaging spectrometer

Sophie Bounissou (DAp)

V. Revéret (DAp)
L. Rodriguez (DAp)

R&D project that may find an astrophysics application
(in a balloon-borne experiment)



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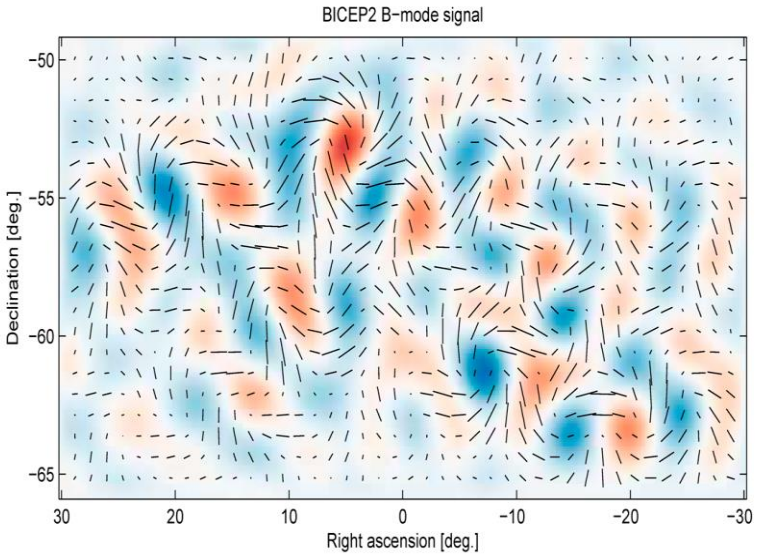
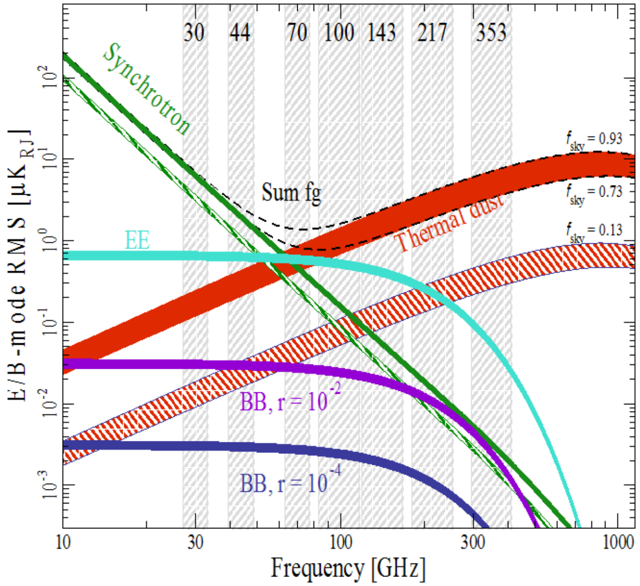
USING ALL THE INFORMATION THAT WE HAVE FROM LIGHT

OBSERVATIONS OF B-MODES → NEED TO MAP THE POLARIZATION OF CMB IN DIFFERENT SPECTRAL BANDS



« B Modes » of CMB at 150 GHz *detected (?)* by BICEP 2



COMBINE ALL THE LIGHT ANALYSIS FUNCTIONS INSIDE ONE SINGLE INSTRUMENT

Other applications (in astrophysics): InterStellar Medium

TOWARDS COMPACT INSTRUMENTS …

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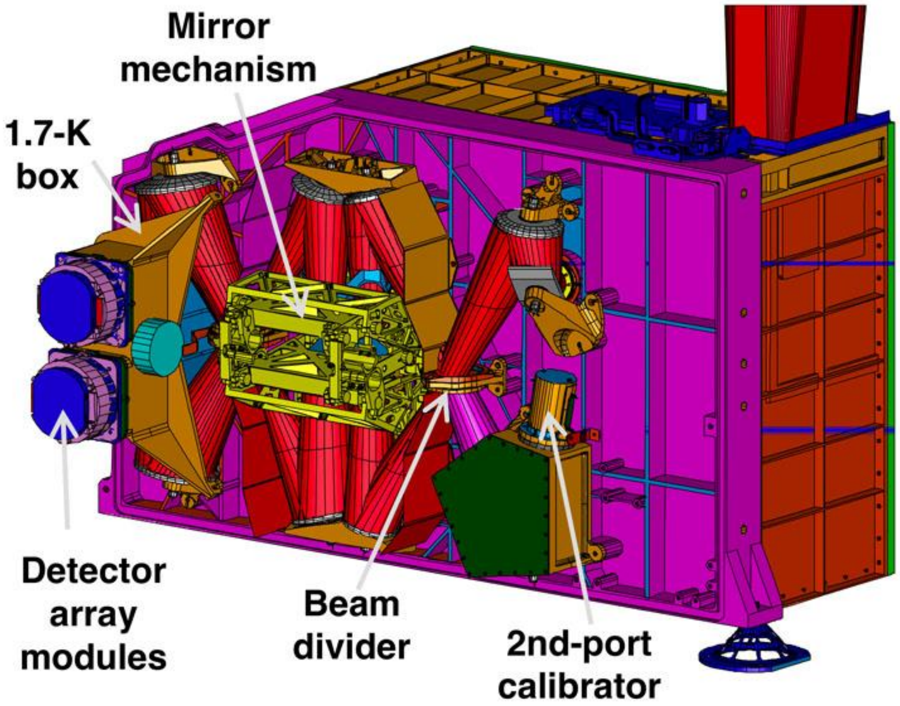
SPIRE FTS on HERSCHEL



TOWARDS COMPACT INSTRUMENTS …

BOLOMETER FOCAL PLANE

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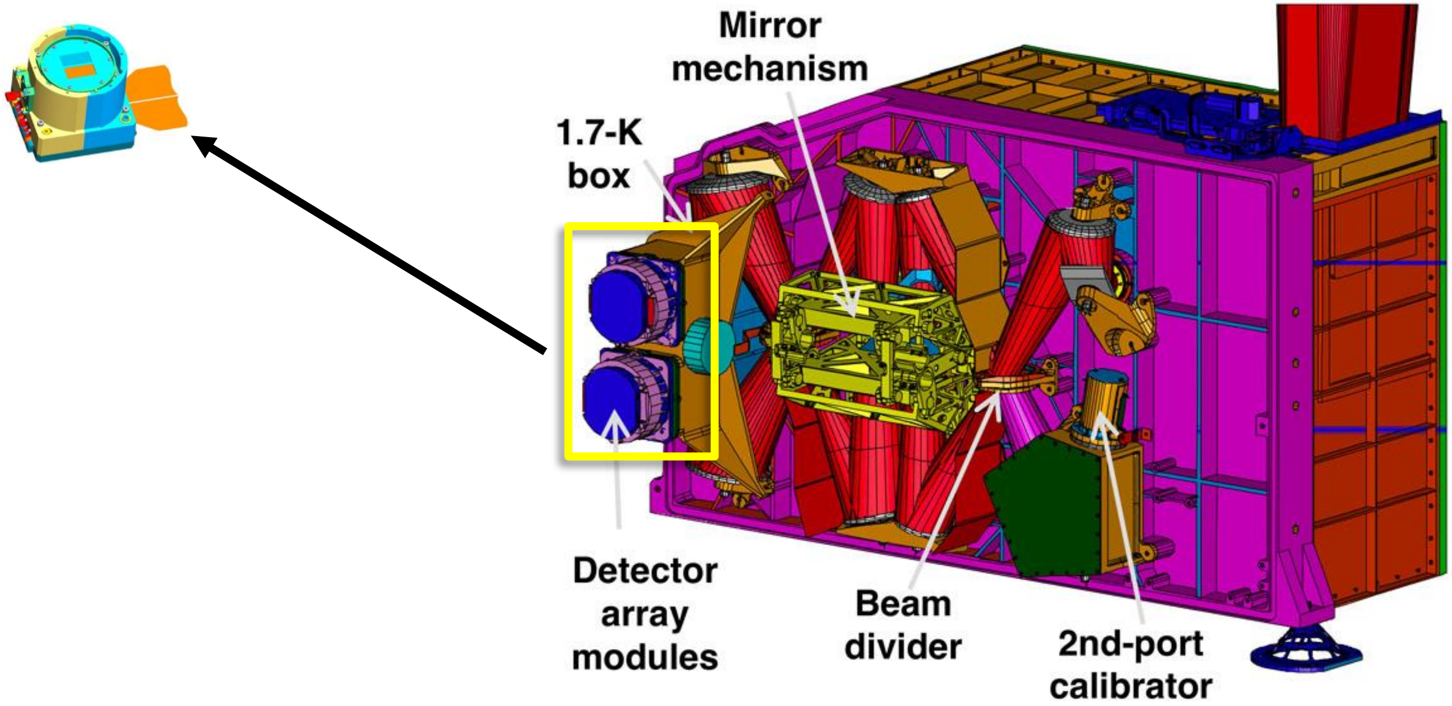

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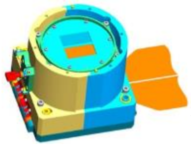

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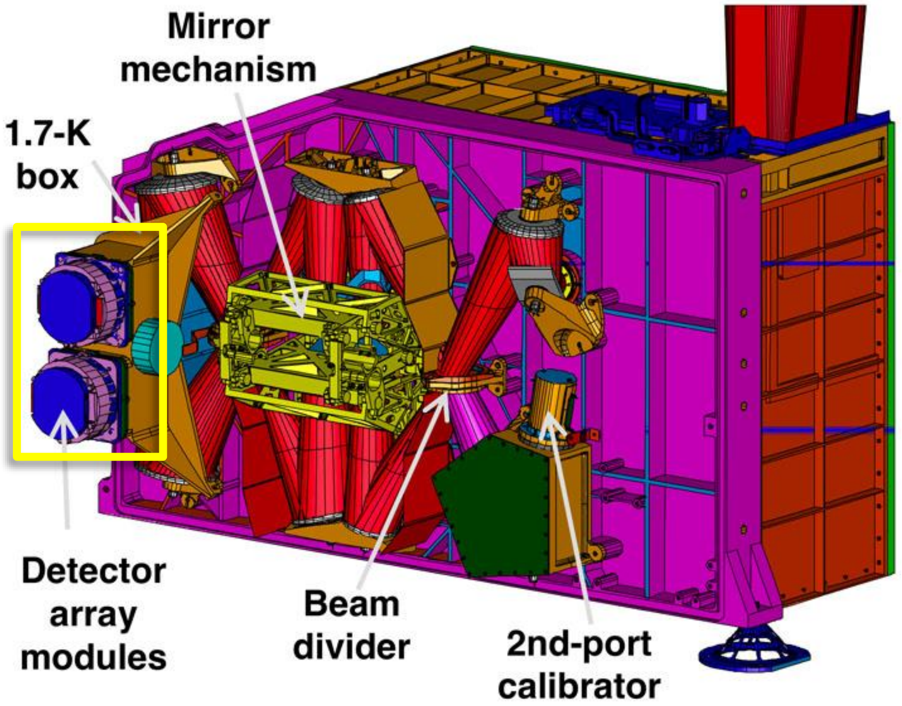


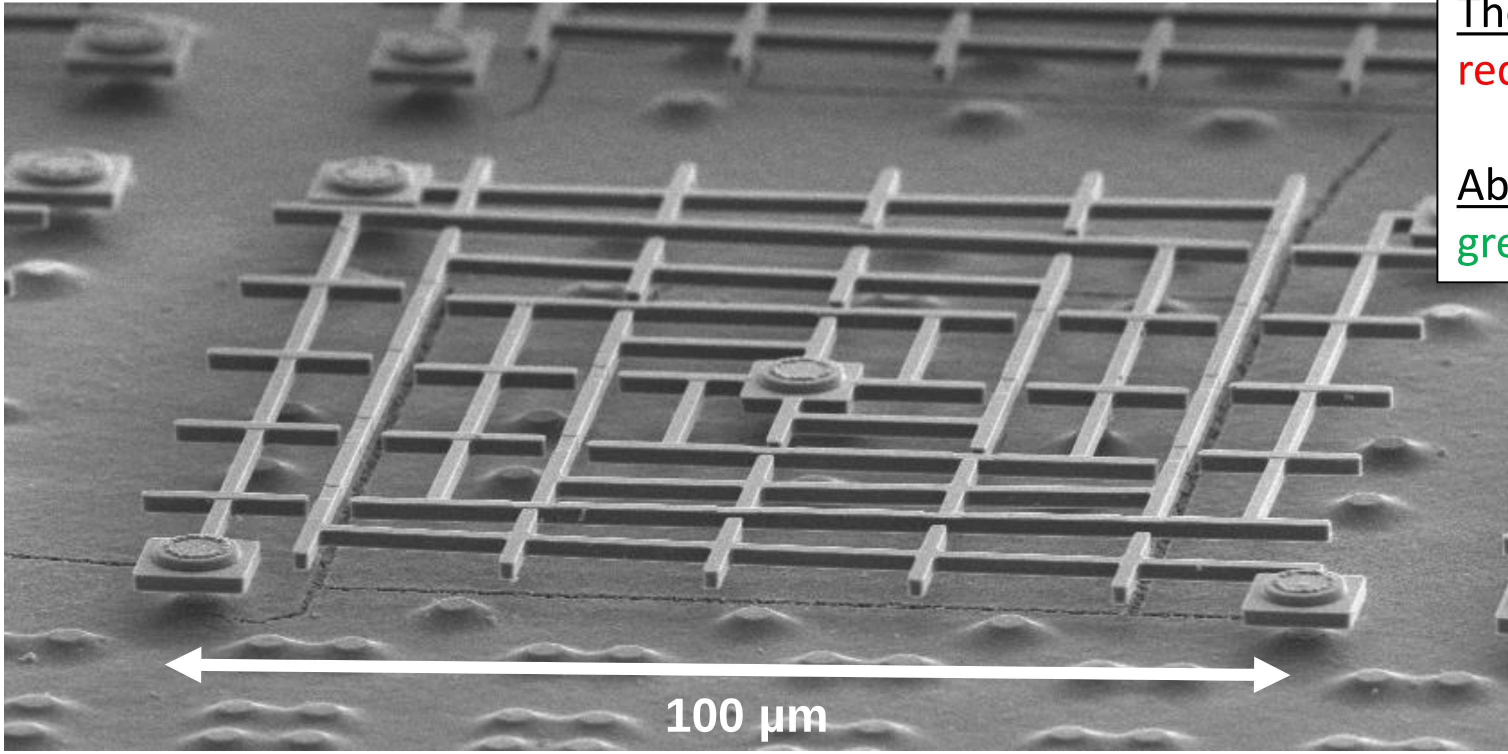
MY THESIS:

STUDY OF A COMPACT SUBMILLIMETER IMAGING SPECTROMETER FOR OBSERVATIONAL COSMOLOGY

WE ALREADY HAVE POLARIMETRY ON CHIP (SPICA/ POL INSTRUMENT)

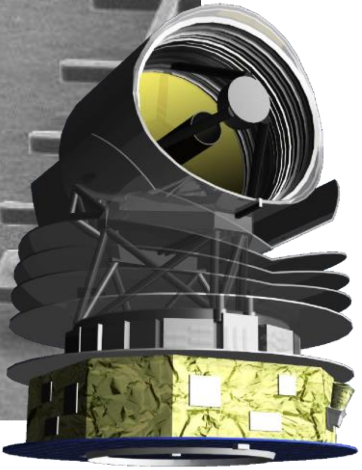
1^{rst} study: Optical optimization of the bolometers (sensitive to the polarization)

Bolometers: probe the incident EM wave by measuring temperature variations in the absorbers



Thermometers: red and blue

Absorbers: green and yellow



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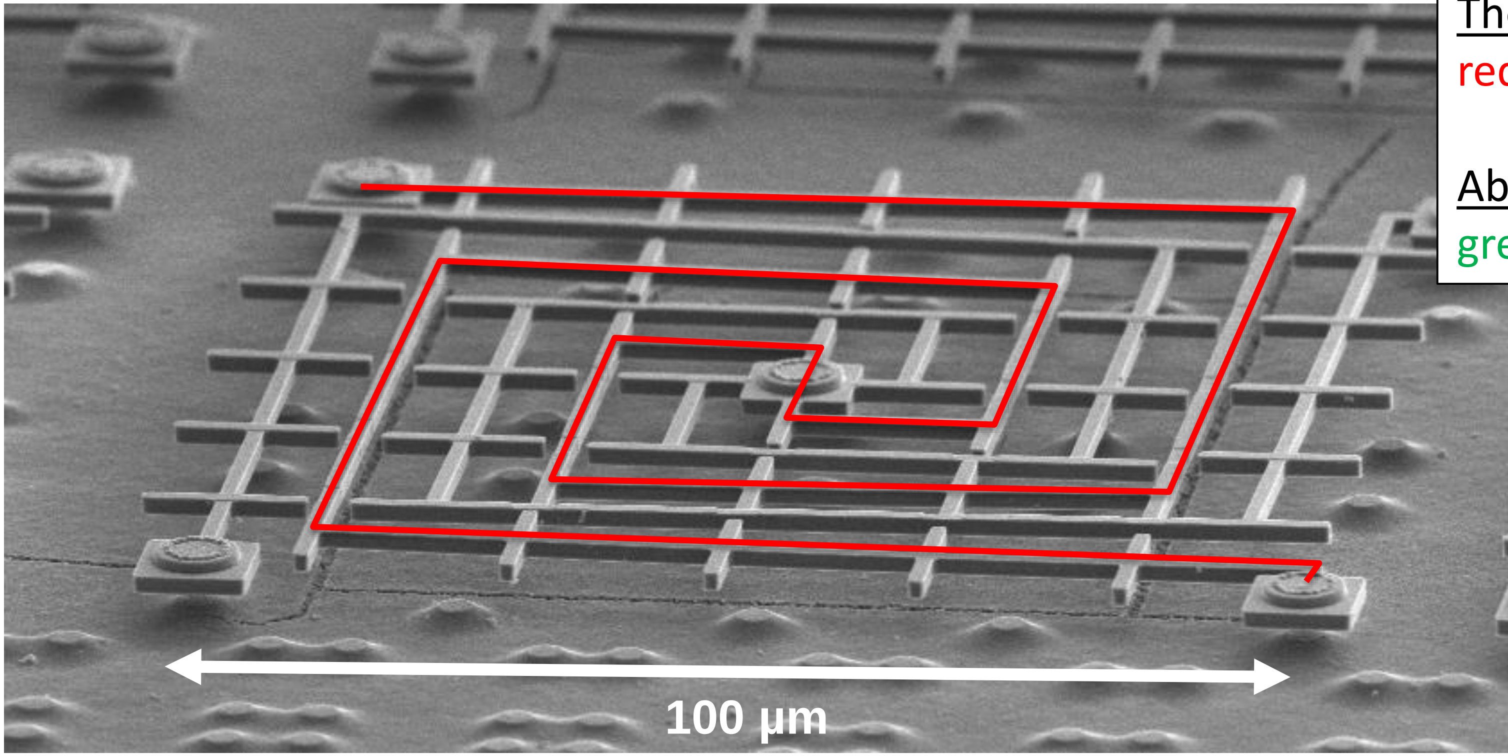

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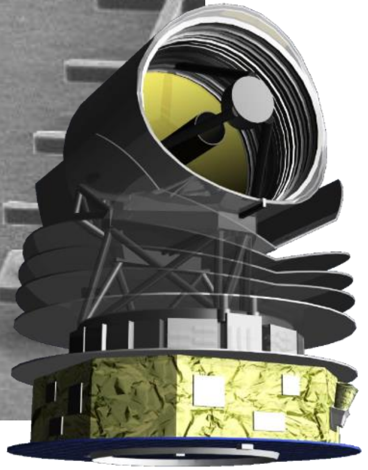

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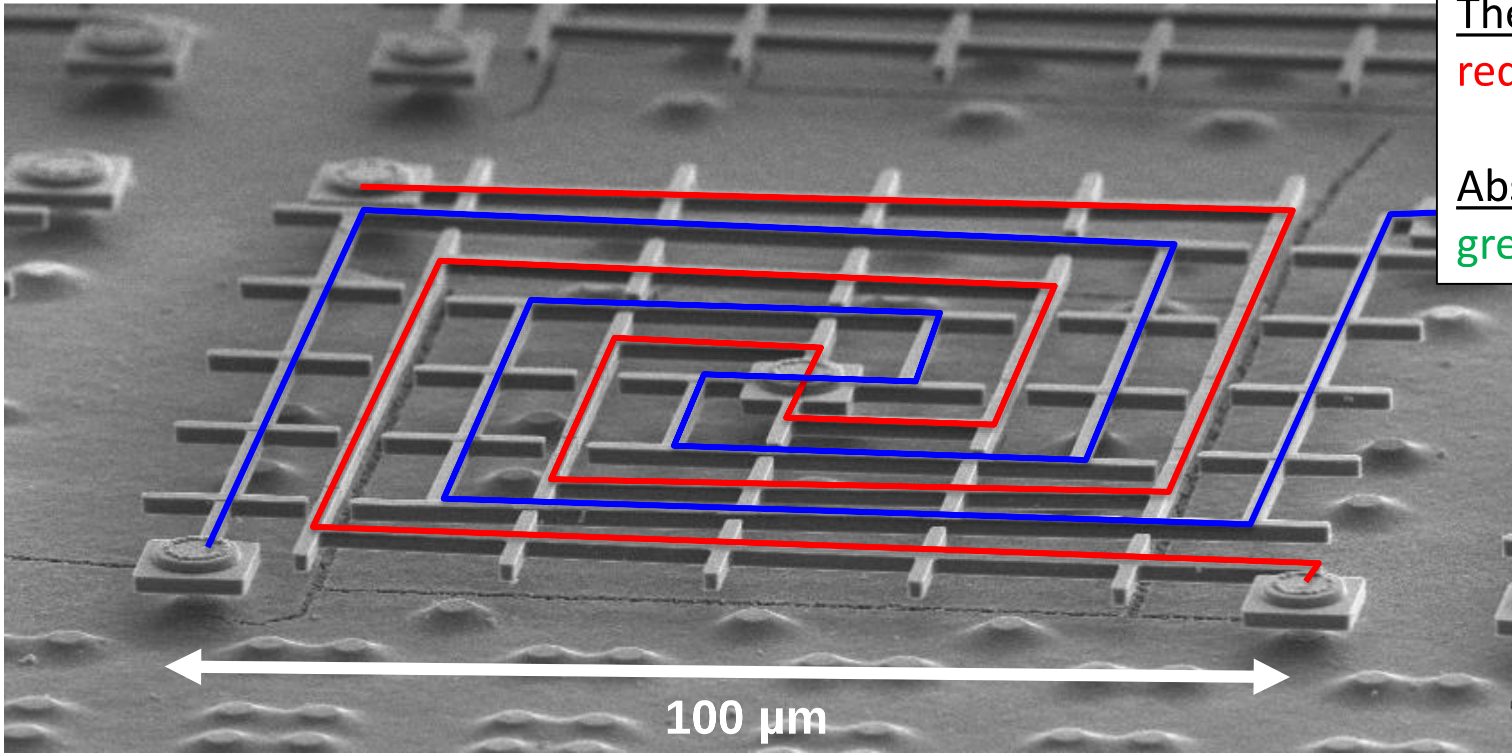

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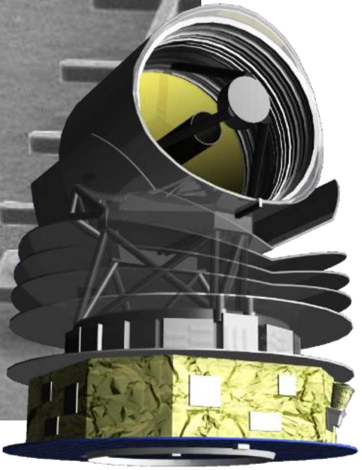

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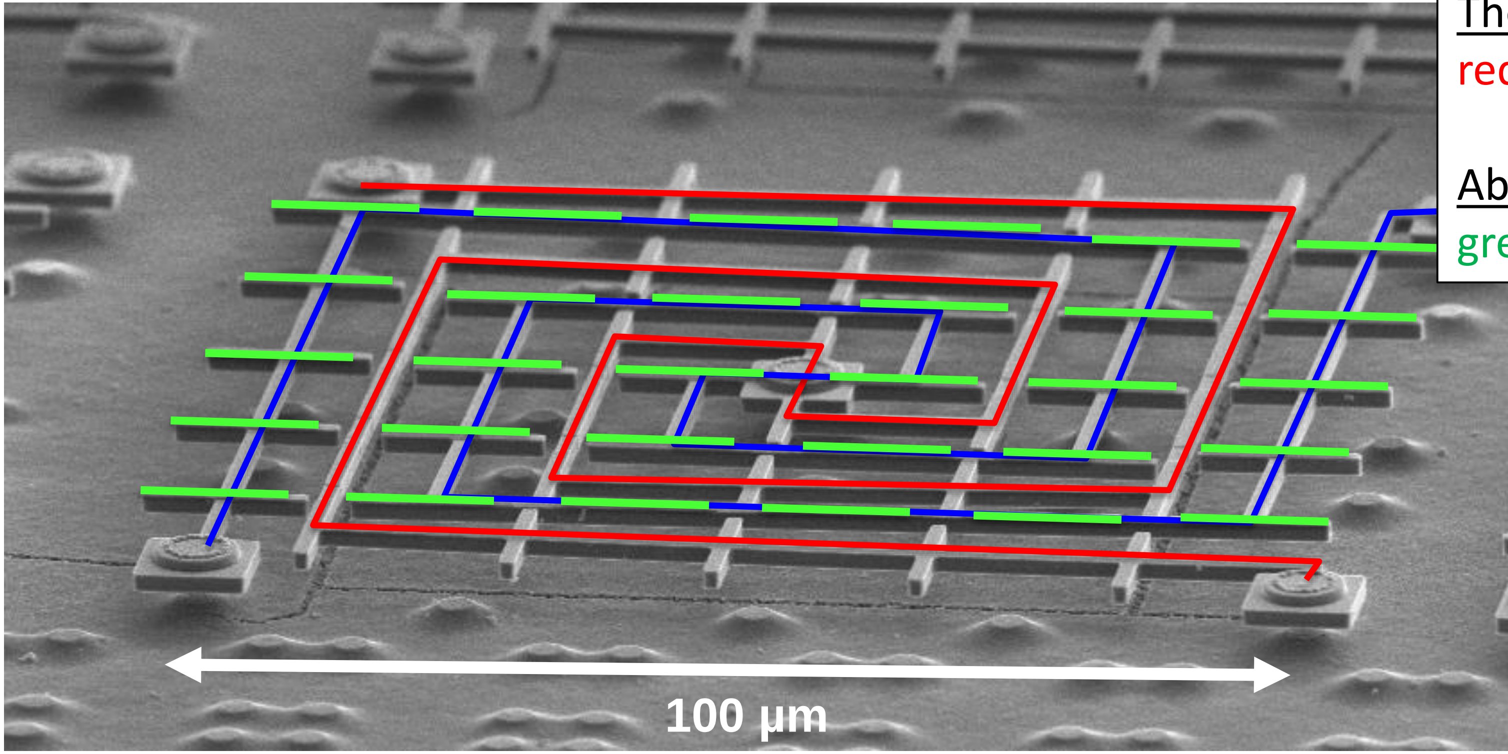

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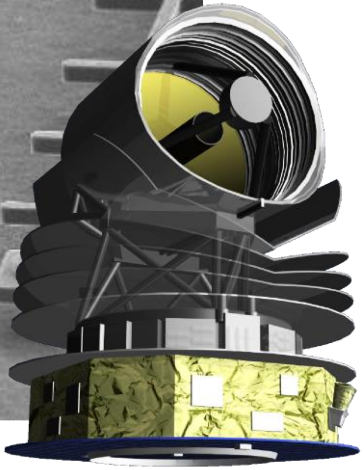

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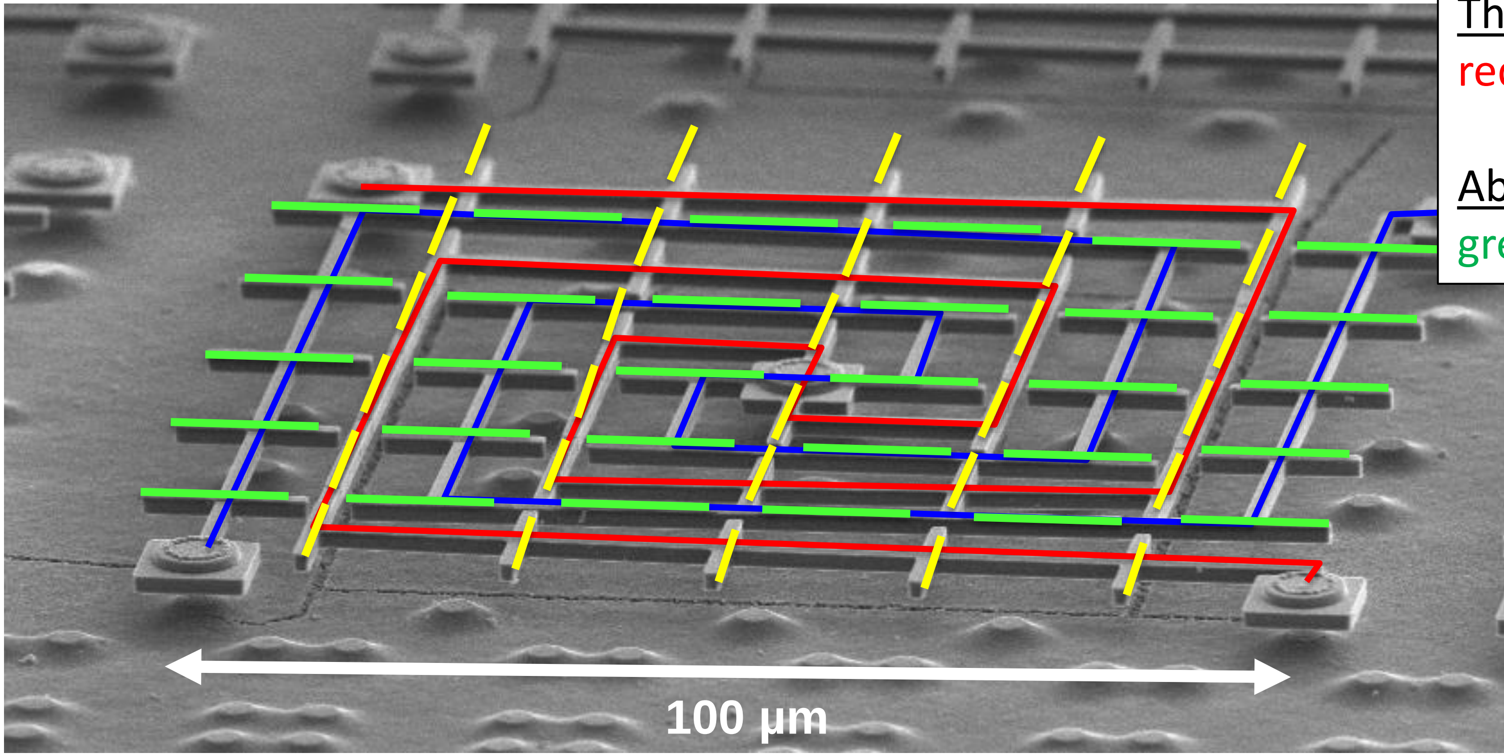

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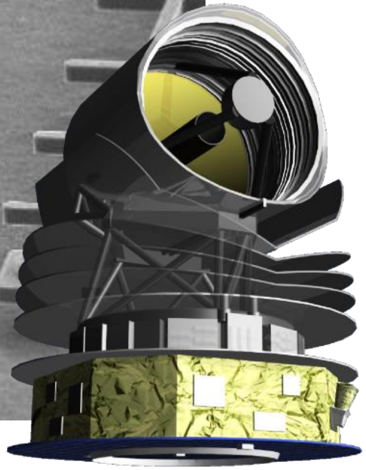

LET’S DO SPECTROSCOPY « ON CHIP »

2nd study: Simulations of a compact imaging spectrometer

With a **FABRY PEROT** above the bolometer array

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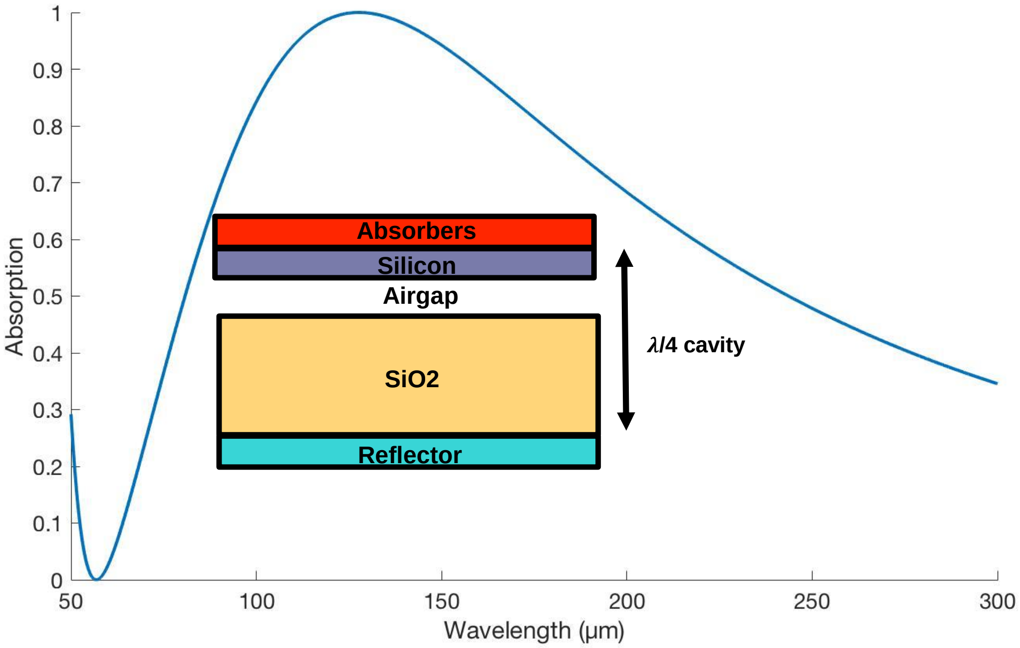
With a **FABRY PEROT** above the bolometer array

Assumptions for the simulations:

- Planar detector (made for λ~100 µm)

Detector array



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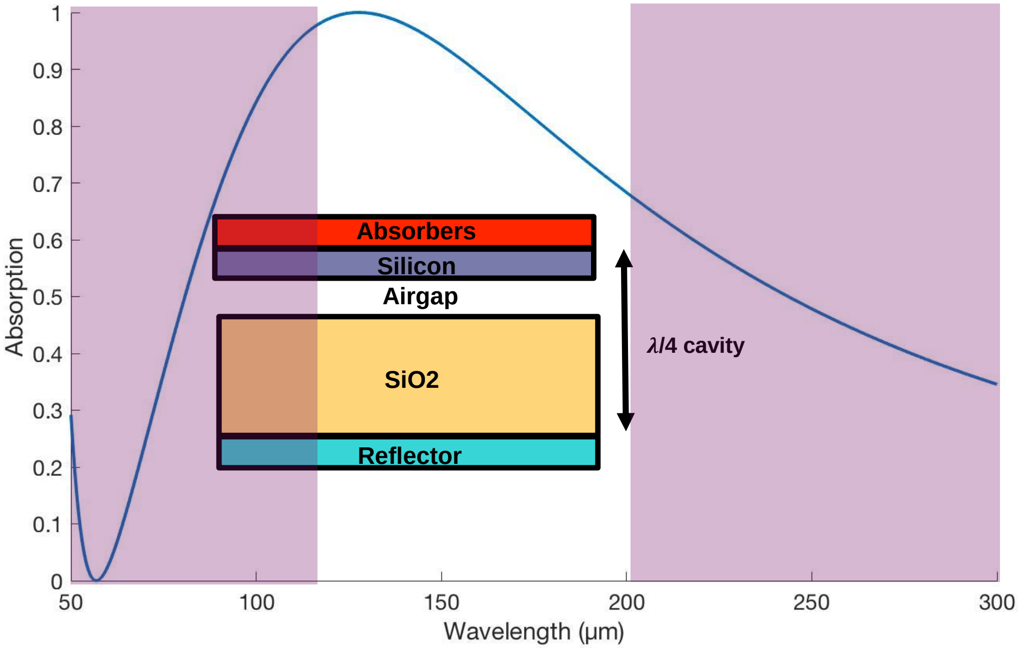

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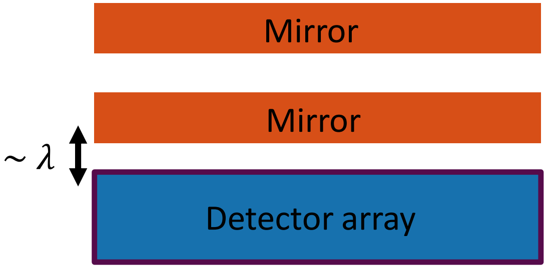

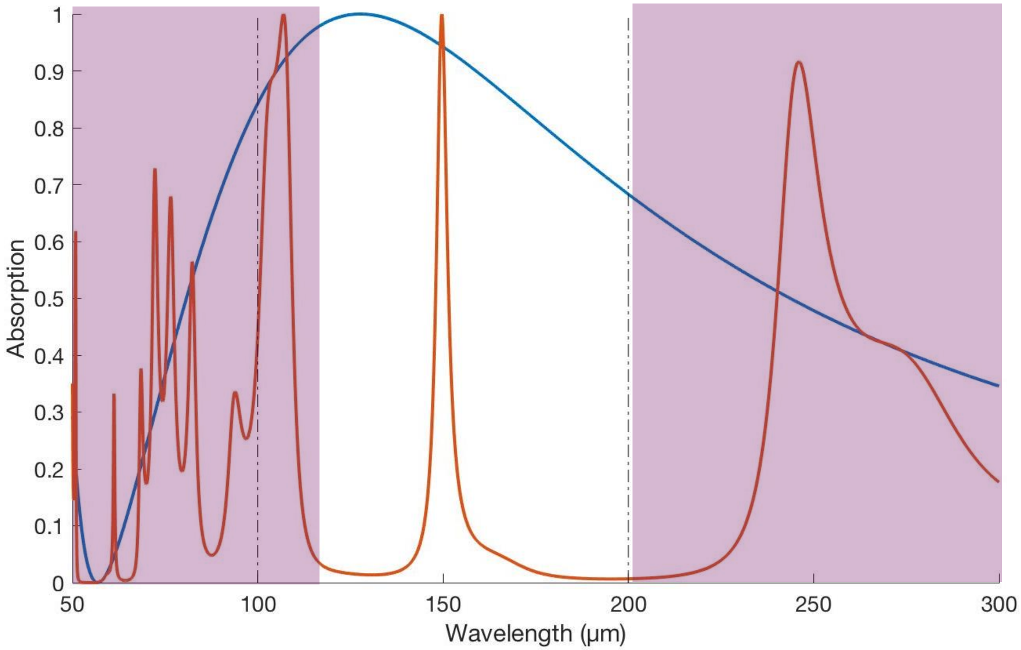

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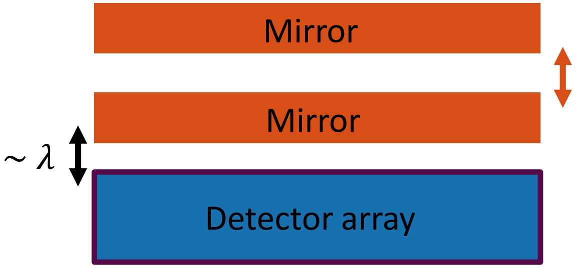

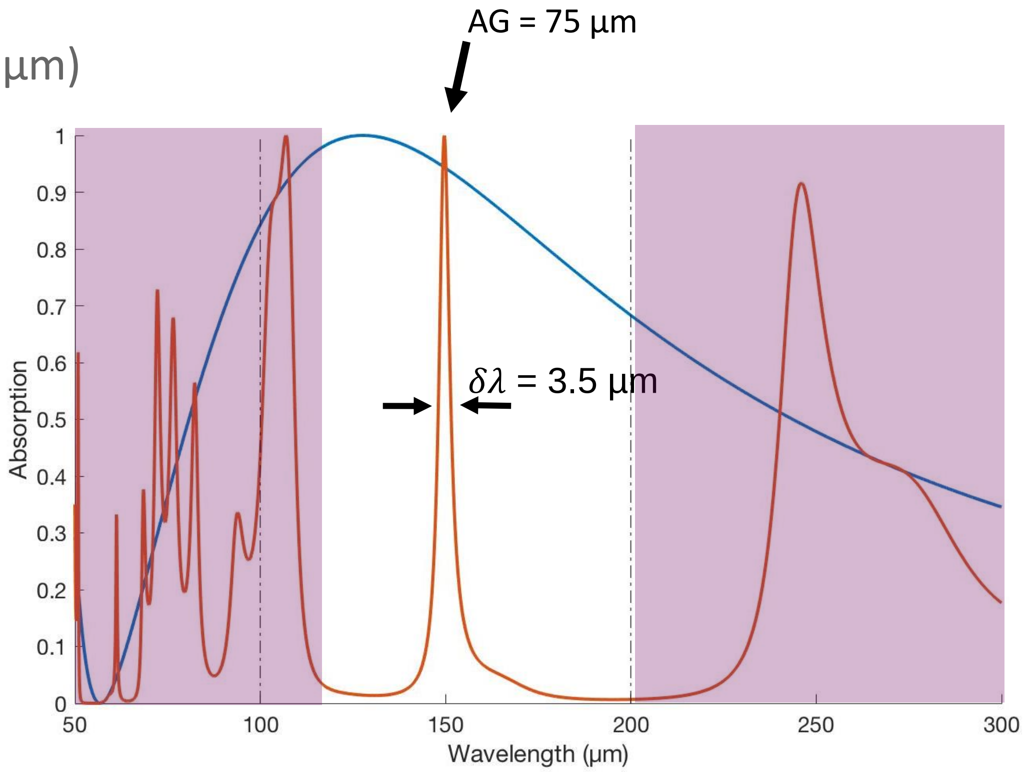

Expected spectral resolution :

$R = \lambda / \delta\lambda > 40$

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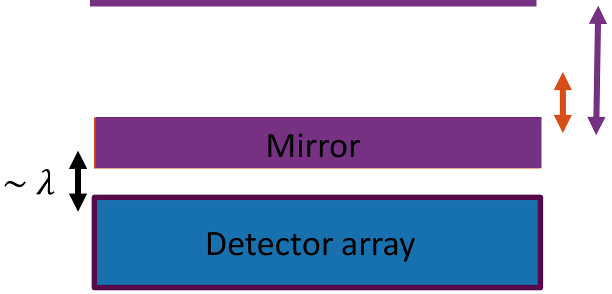
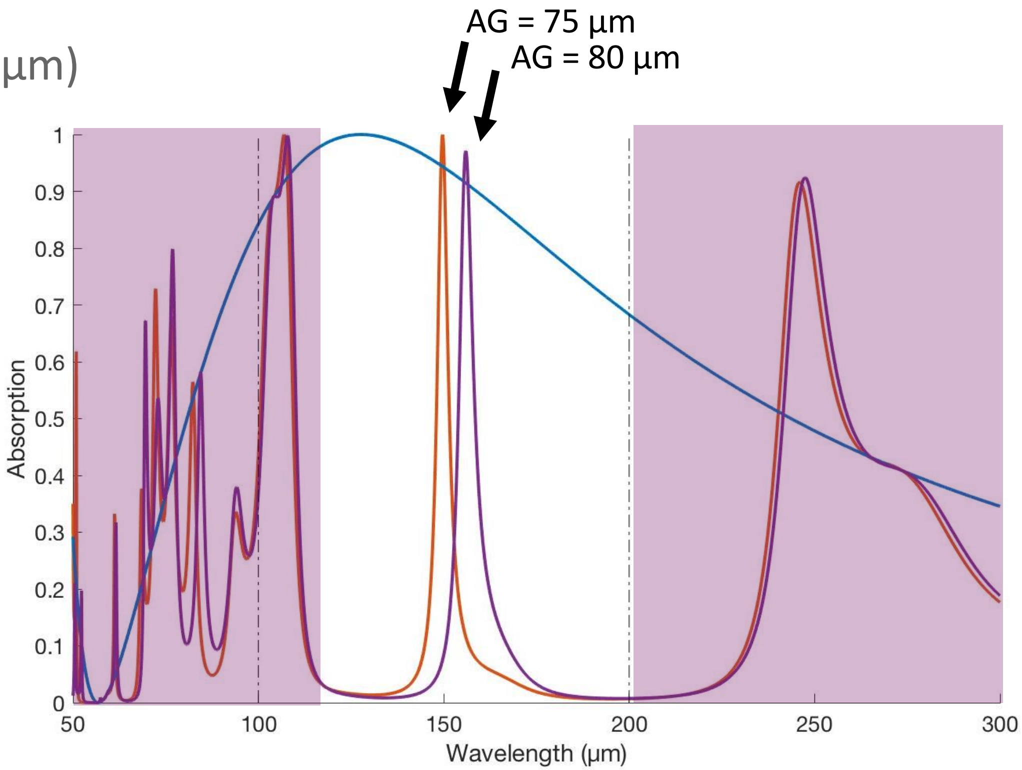


Mirror

Mirror

~ λ

Detector array



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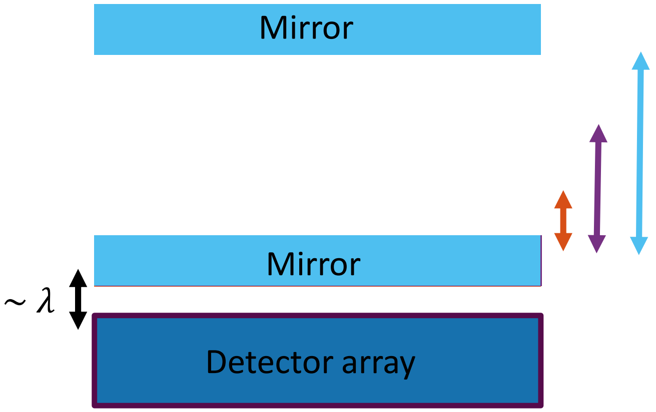

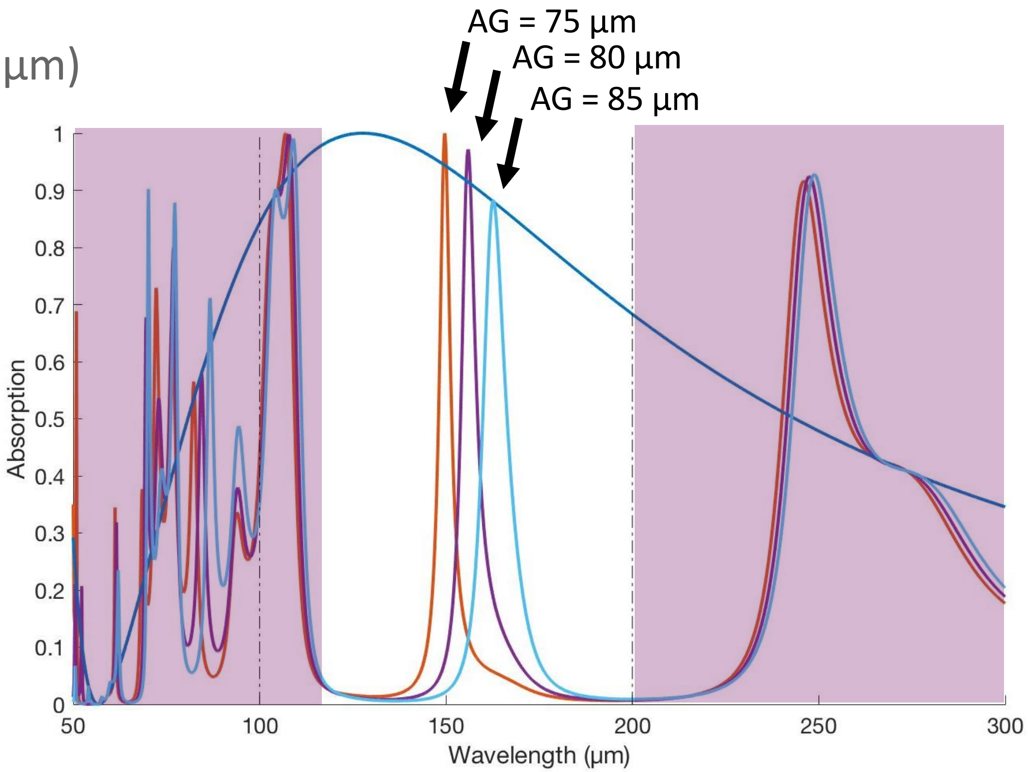

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LOW RESOLUTION SPECTROMETER

Coupling between detector and FP allows
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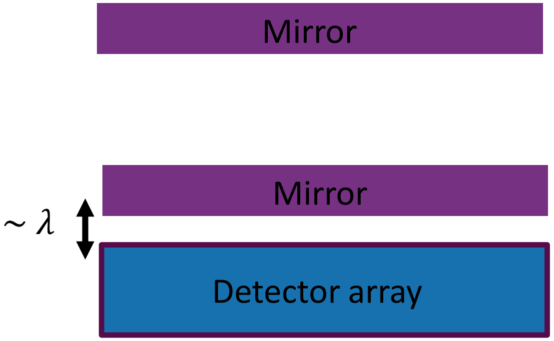
(over the whole bandwidth)



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$\sim \lambda$

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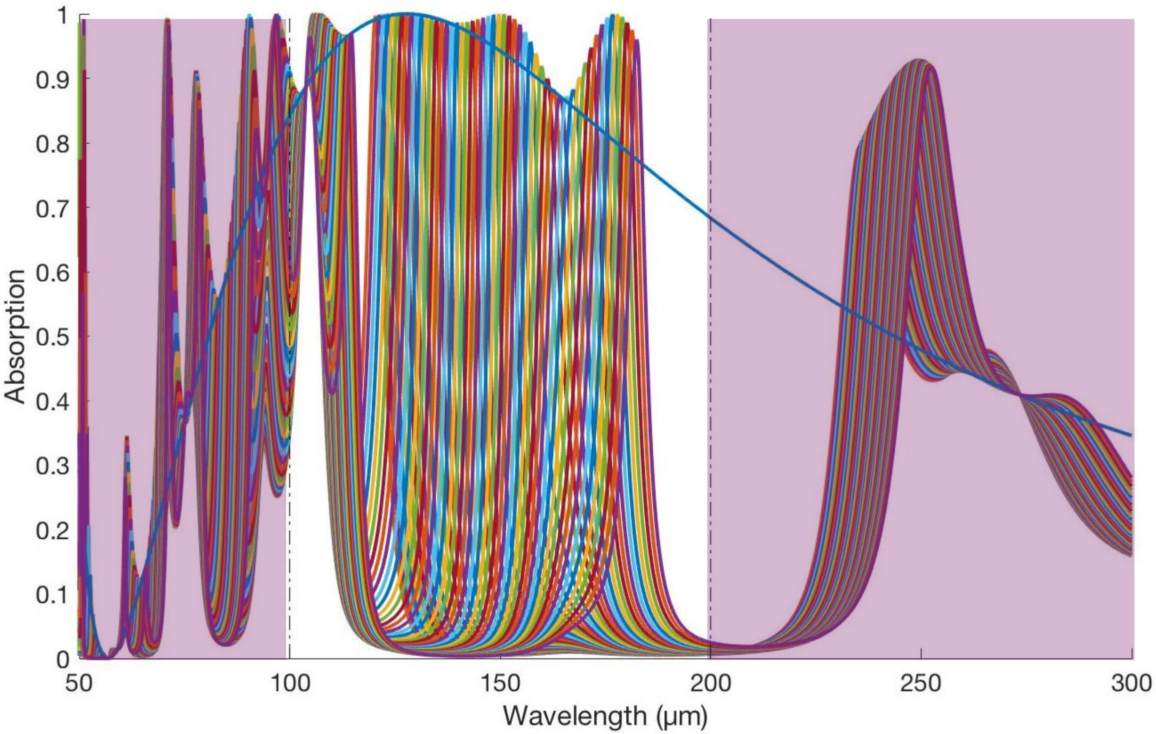

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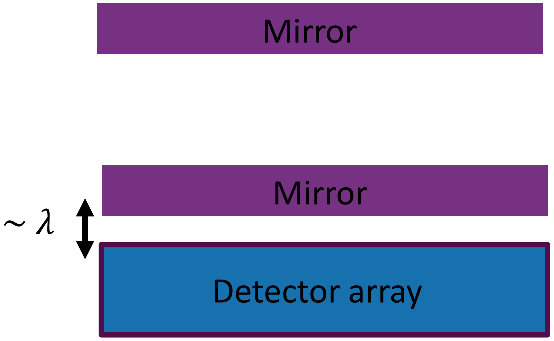

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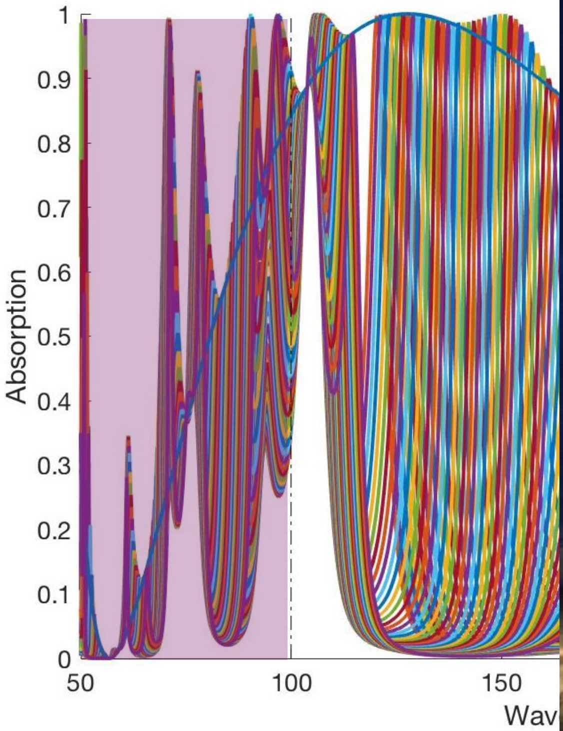

Mapping the C+ line at 158 µm with the CoPILOT balloon

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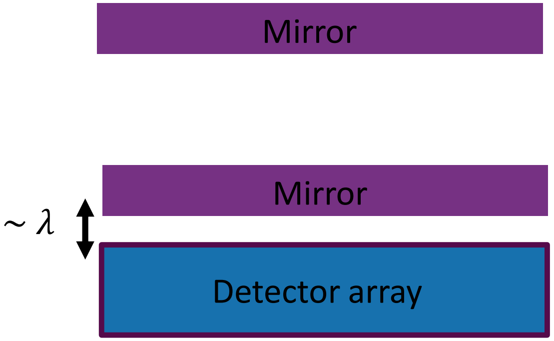
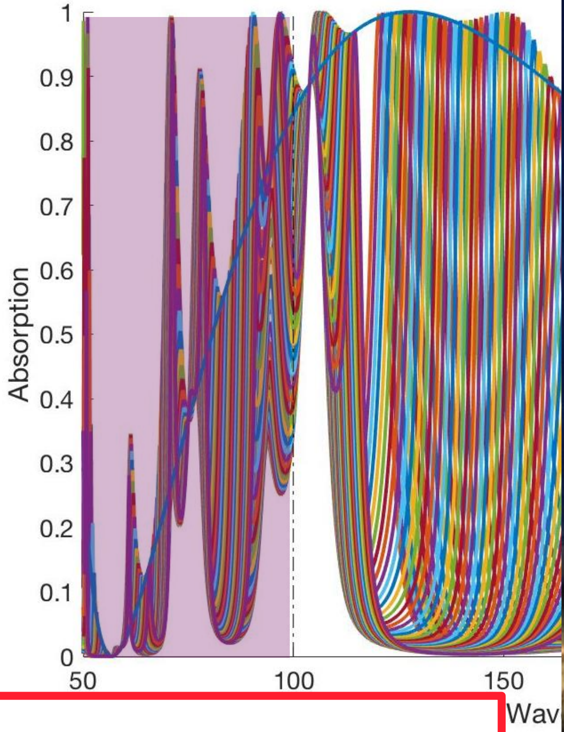
LOW RESOLUTION SPECTROMETER

Coupling between detector and FP allows ~ 100% absorption (over the whole bandwidth)





Mapping the C+ line at 158 µm with the CoPILOT balloon

Perspectives:

- Build the spectrometer
- Measurements at cryogenic temperatures

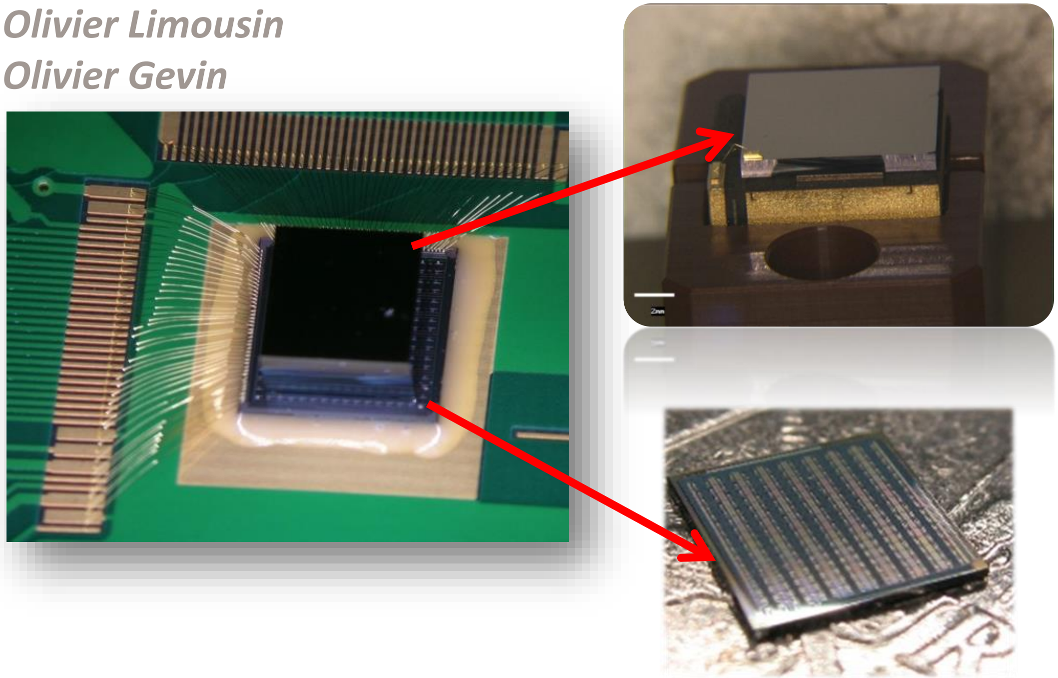
DE LA RECHERCHE À L'INDUSTRIE

Development of a Digital CdTe Spectro-imaging system for spatial application

David Baudin (Dédip)

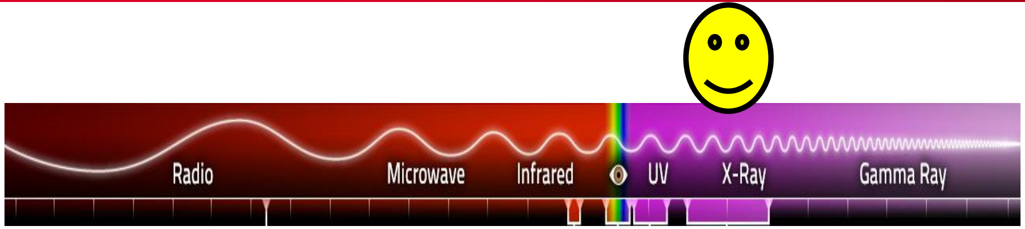
Olivier Limousin
Olivier Gevin

SemiConductor Detector



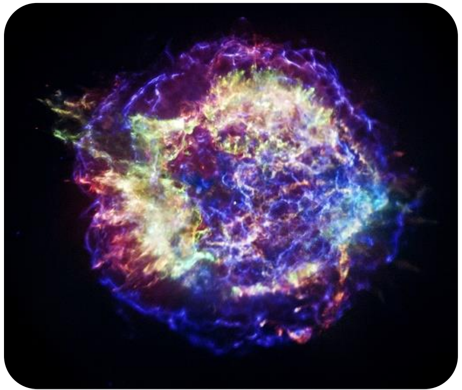
ASIC

SWITCHING ON THE OTHER PART OF THE SPECTRA
THE HARD X-RAY

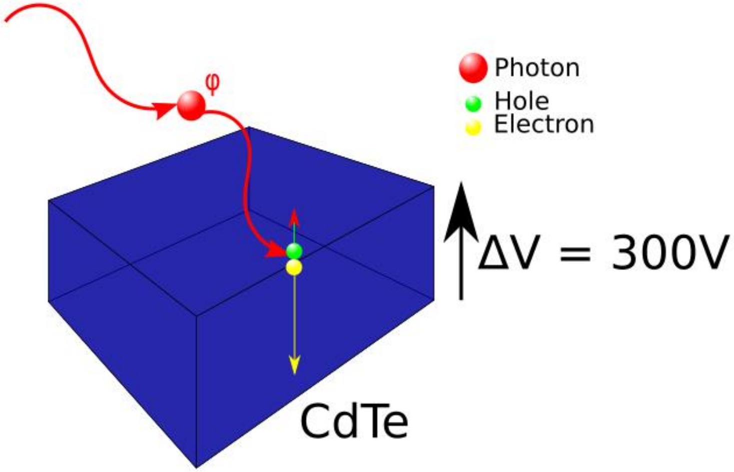


Our interaction:

Photoelectric effect



Cas A supernova remnant
NASA/CXC/SAO

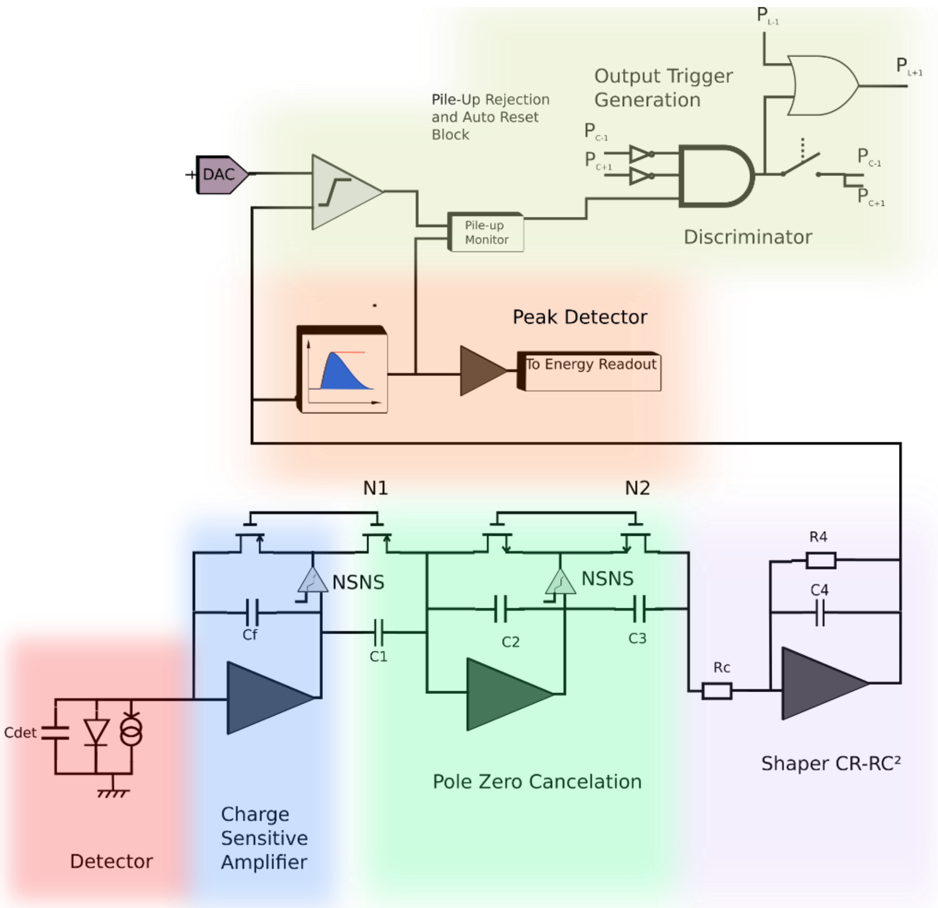


Objectives :

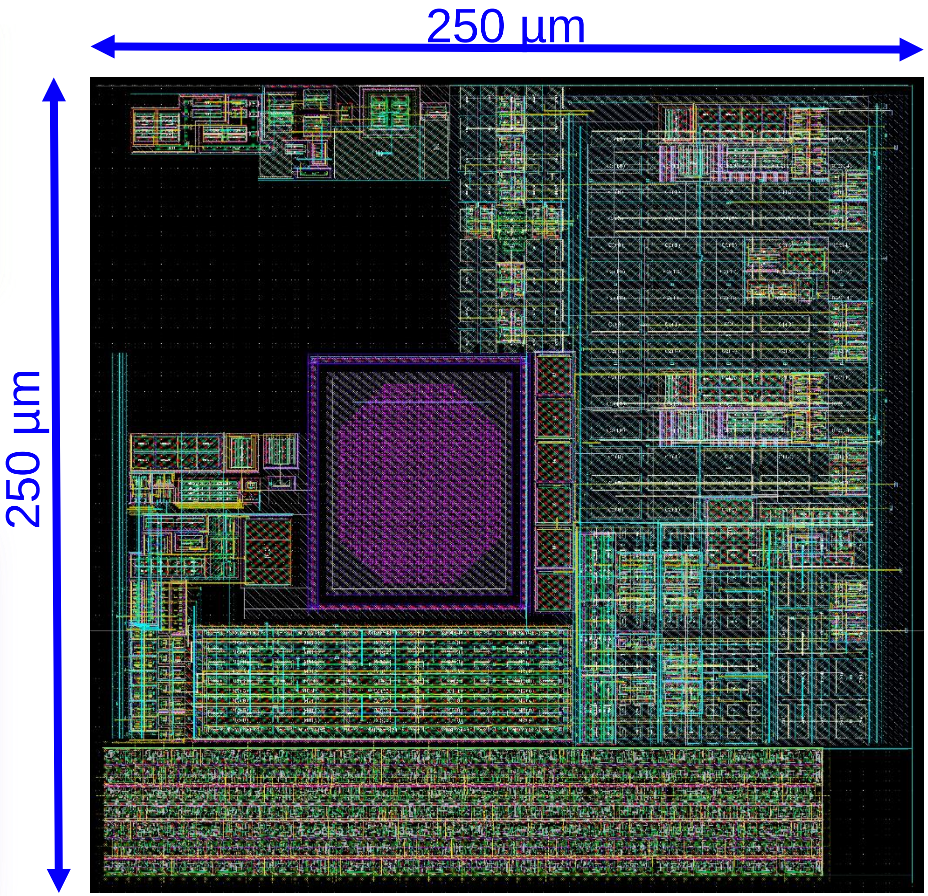
- R&D to improve Detector Quality :
  - Spectroscopy : **Noise < 580eV @ 60keV**
  - Imaging : **Pixel ≤ 250 µm x 250 µm**

Measure : electron movement
=> Very fast current

HOW TO READ THIS VERY FAST CURRENT

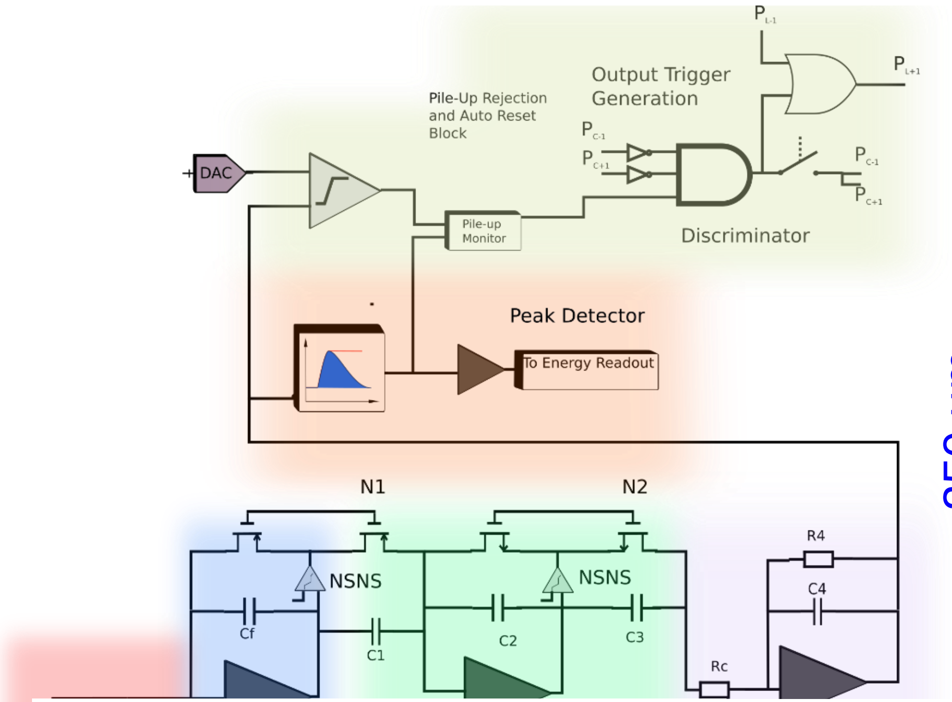


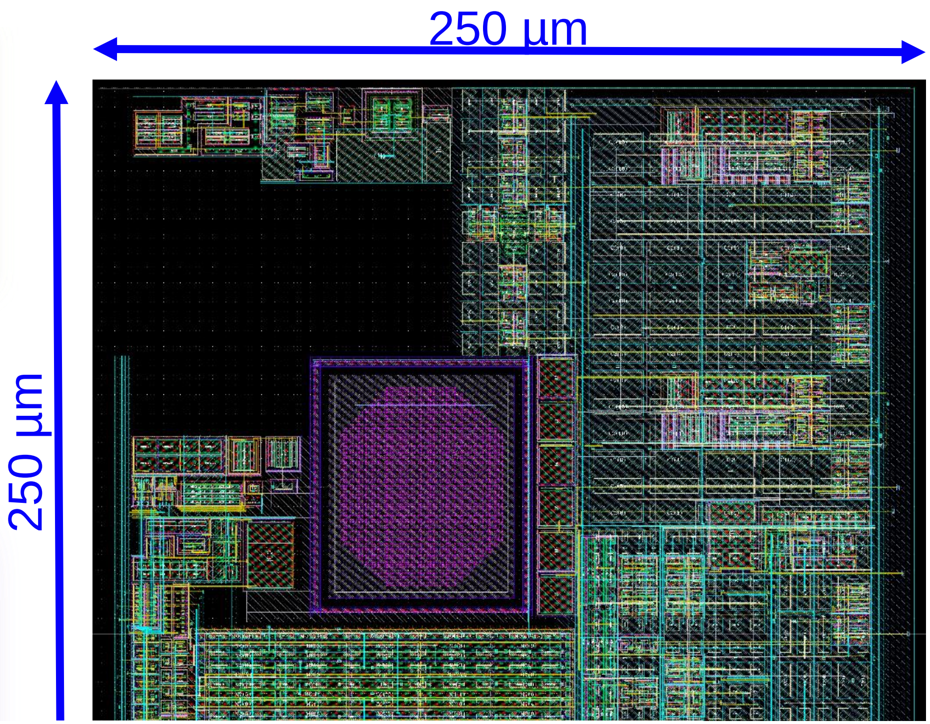
Global Pixel Schematic

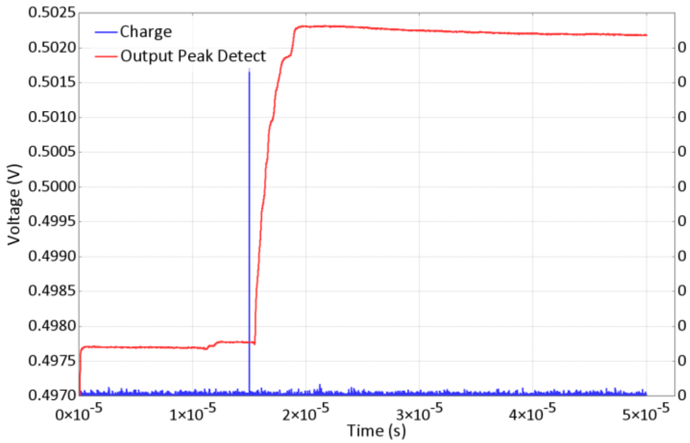


Layout Pixel 22/06/2018

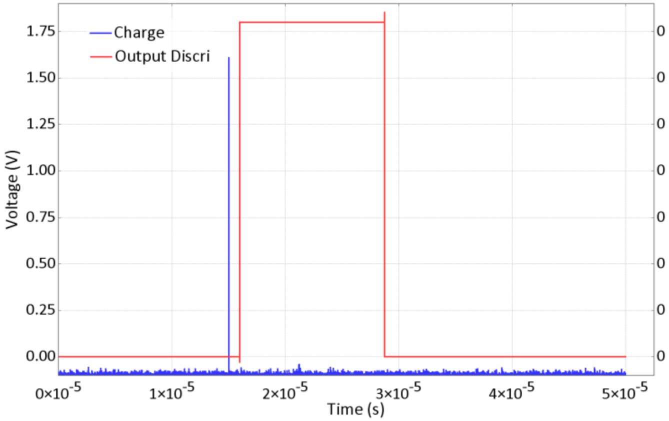
HOW TO READ THIS VERY FAST CURRENT





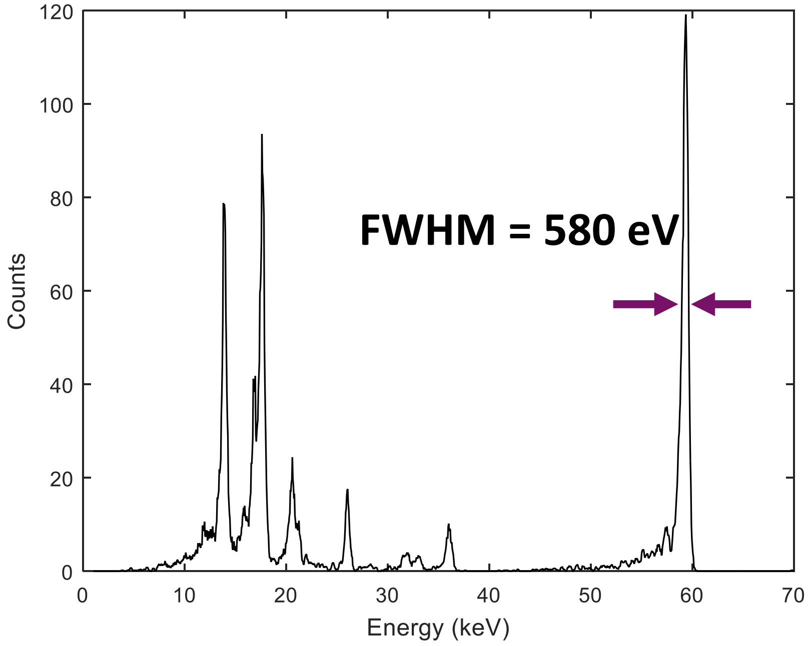


Analog output
$(V \propto Q)$



Digital output

PERFORMANCES OF A GOOD CHARGE READOUT



D^2R_1 ^{241}Am Best Pixel Spectrum at -6°C with HV = 300 V
And detector thickness : 750 µm

The « good » spectra:
To be able to have the sharpest rays

FWHM = 580 eV at 59,5 keV (0,1% / 103)

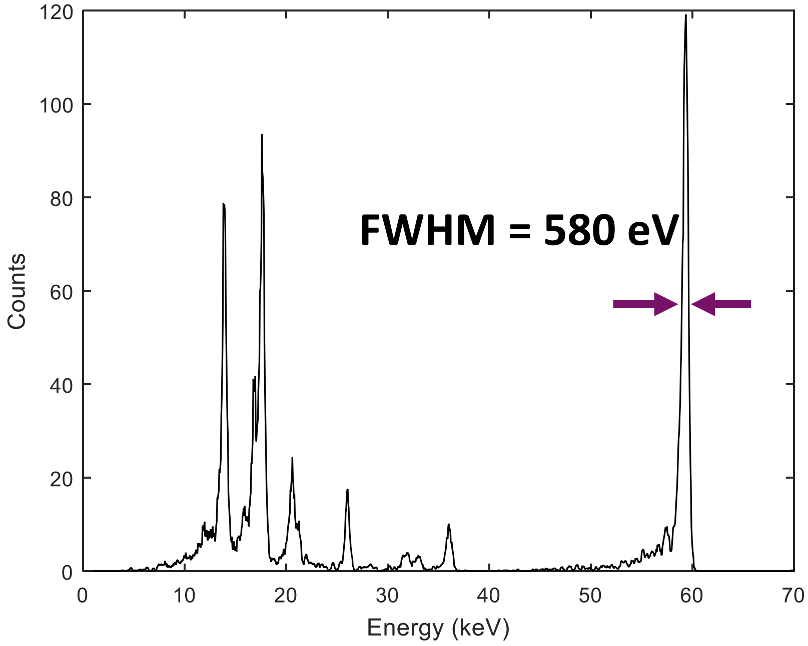
That is to say :

The smallest electronic noise
Expressed in Equivalent Noise Charge (ENC)

Noise causes:

$$\begin{aligned} ENC^2 = {} & A_{||} * \boldsymbol{T_{peak}} * i_{leak}^2 \\ & + A_f * C_{det}^2 * v_f^2 \\ & + A_s * C_{det}^2 * \frac{v_{th}^2}{\boldsymbol{T_{peak}}} \end{aligned}$$

PERFORMANCES OF A GOOD CHARGE READOUT



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Leakage Current

$$ENC^2 = A_{||} * \boldsymbol{T_{peak}} * i_{leak}^2 \\ + A_f * C_{det}^2 * v_f^2 \\ + A_s * C_{det}^2 * \frac{v_{th}^2}{\boldsymbol{T_{peak}}}$$

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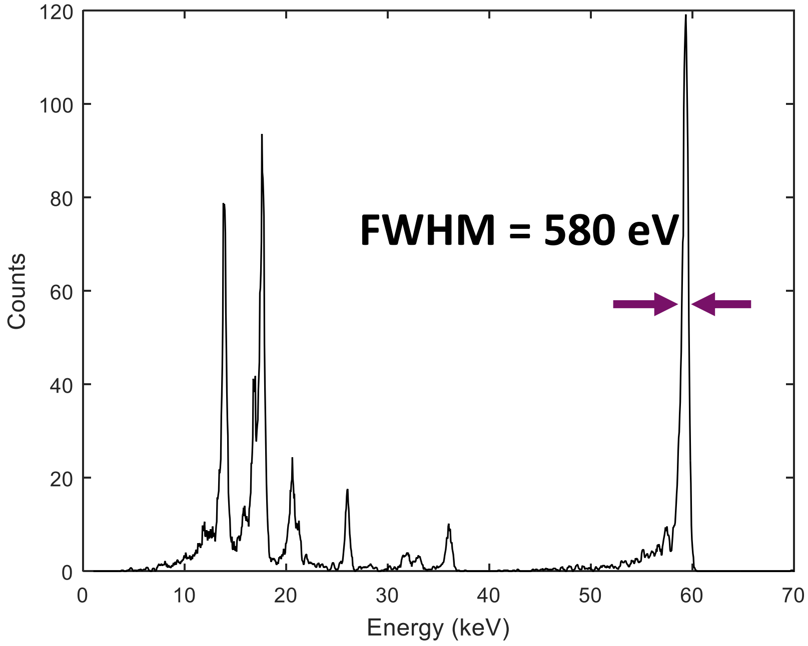

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Input capacitance

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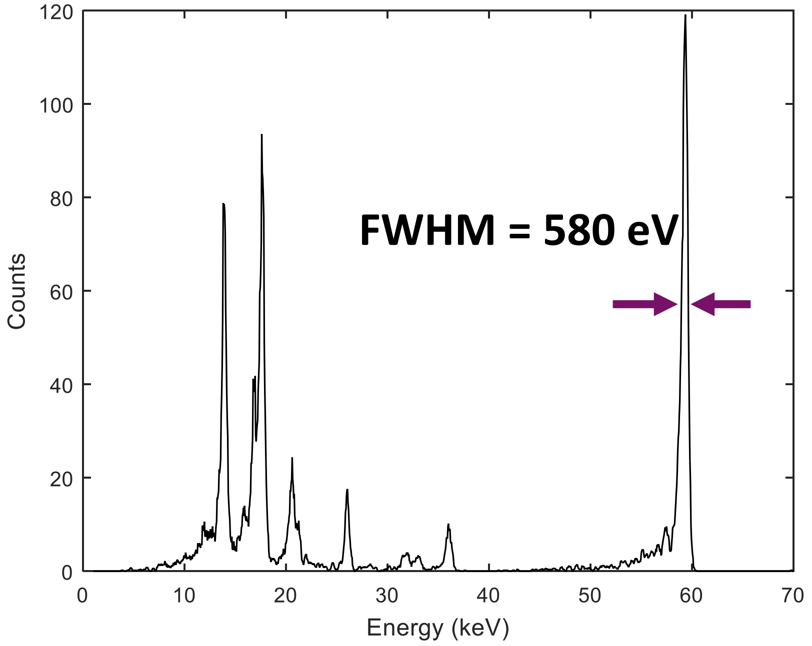
PERFORMANCES OF A GOOD CHARGE READOUT



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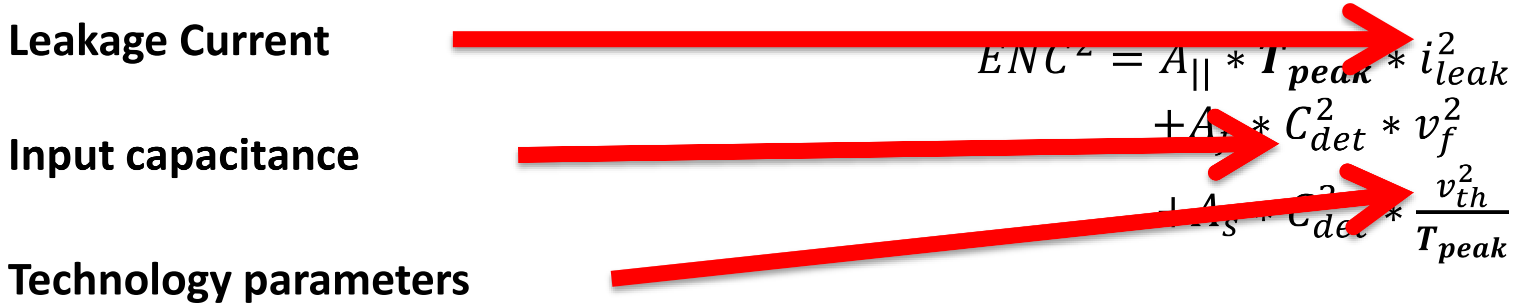


Leakage Current

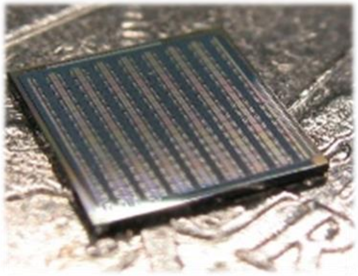
Input capacitance

Technology parameters

$$ENC^2 = A_{||} * \boldsymbol{T_{peak}} * i_{leak}^2 + A_f * C_{det}^2 * v_f^2 + A_s * C_{det}^2 * \frac{v_{th}^2}{\boldsymbol{T_{peak}}}$$

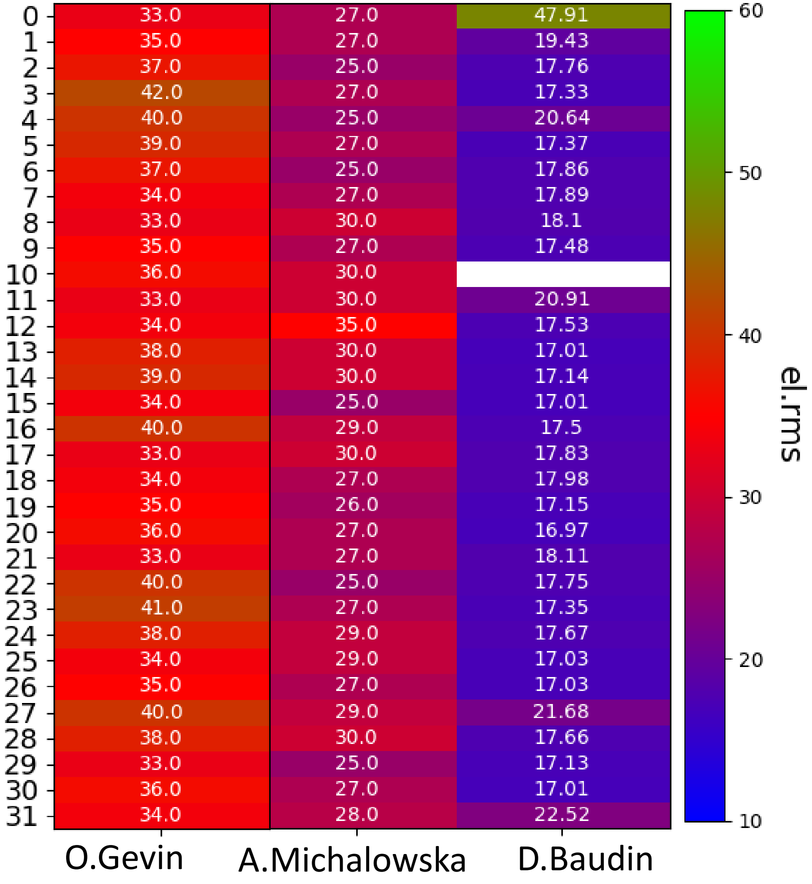
SOME RESULTS

IDeF-X HDBD



D^2R_1

Pixel Size :



	500 µm* 500 µm **IDeF-X HD**	300 µm 300 µm **D^2R_1**	500 µm* 500 µm **IDeF-X HDBD**
0	33.0	27.0	47.91
1	35.0	27.0	19.43
2	37.0	25.0	17.76
3	42.0	27.0	17.33
4	40.0	25.0	20.64
5	39.0	27.0	17.37
6	37.0	25.0	17.86
7	34.0	27.0	17.89
8	33.0	30.0	18.1
9	35.0	27.0	17.48
10	36.0	30.0	
11	33.0	30.0	20.91
12	34.0	35.0	17.53
13	38.0	30.0	17.01
14	39.0	30.0	17.14
15	34.0	25.0	17.01
16	40.0	29.0	17.5
17	33.0	30.0	17.83
18	34.0	27.0	17.98
19	35.0	26.0	17.15
20	36.0	27.0	16.97
21	33.0	27.0	18.11
22	40.0	25.0	17.75
23	41.0	27.0	17.35
24	38.0	29.0	17.67
25	34.0	29.0	17.03
26	35.0	27.0	17.03
27	40.0	29.0	21.68
28	38.0	30.0	17.66
29	33.0	25.0	17.13
30	36.0	27.0	17.01
31	34.0	28.0	22.52
	O.Gevin	A.Michalowska	D.Baudin

** : For Caliste configuration*

Thesis Development

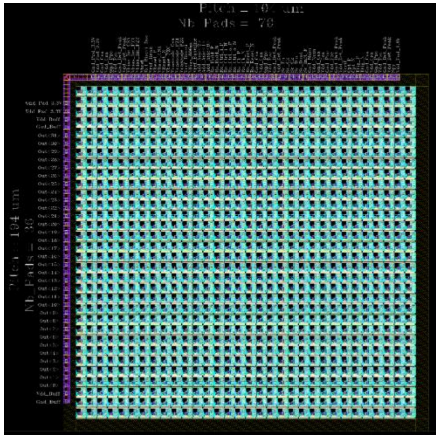
D^2R_2

Pixel Size :

250 µm x 250 µm

ENC : ~15 el.rms

eq FWHM = 510 eV @ 60keV



D^2R_2 Layout

DE LA RECHERCHE À L'INDUSTRIE

Effects of space radiation on detectors: the case of SVOM/MXT

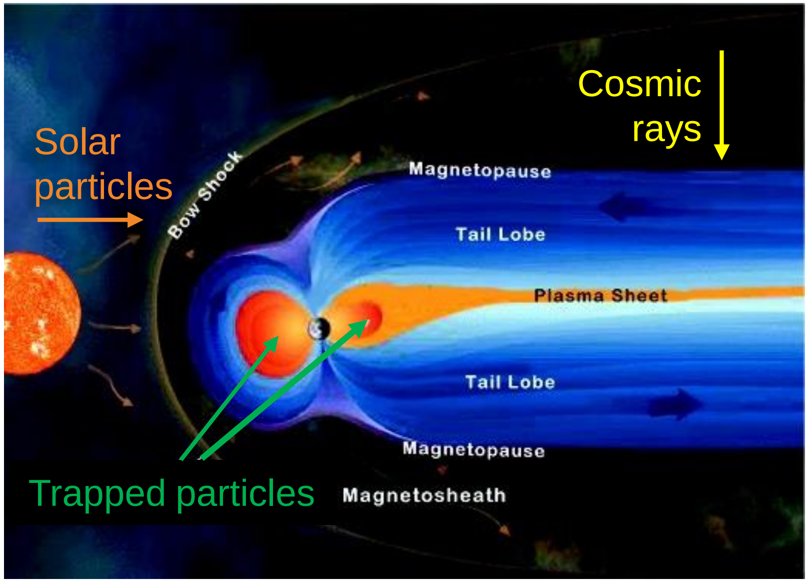
F. Ceraudo (DAp)

Bertrand Cordier (DAp)
Aline Meuris (Dap)

DDAYS IRFU 2018

RADIATION EFFECTS

Space radiation

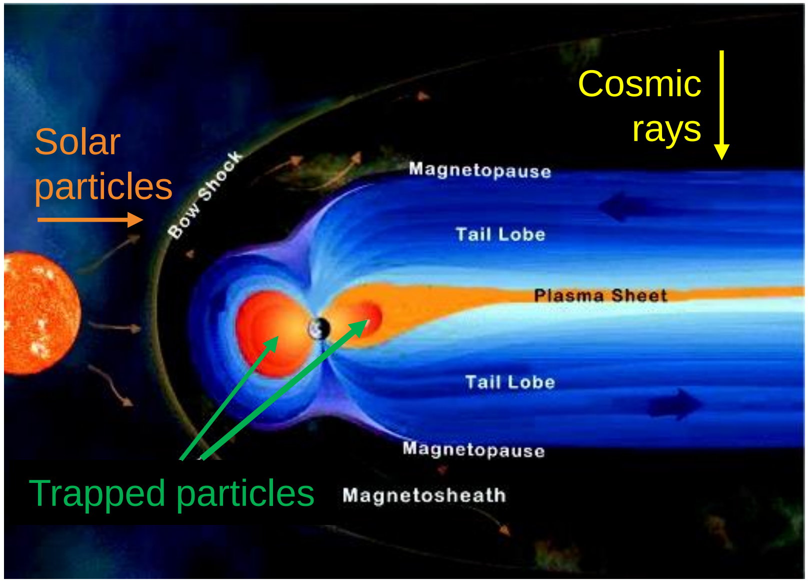


- Environment alters detector performances.

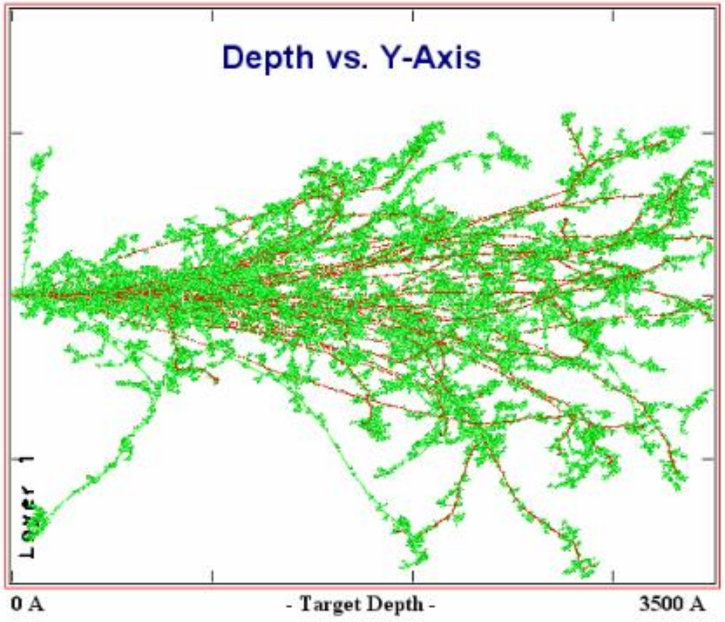
- Assess end-of-life performances and compliance with scientific requirements.

RADIATION EFFECTS

Space radiation



Displacement damage



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RADIATION EFFECTS

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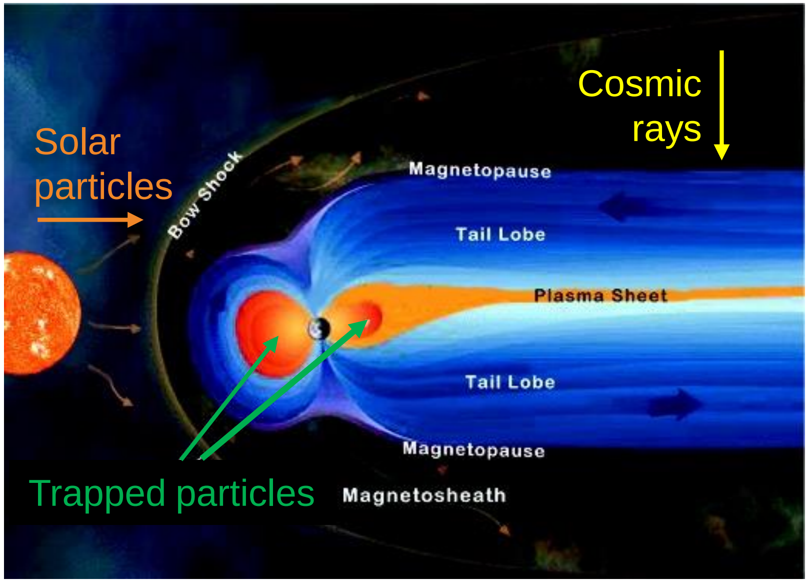

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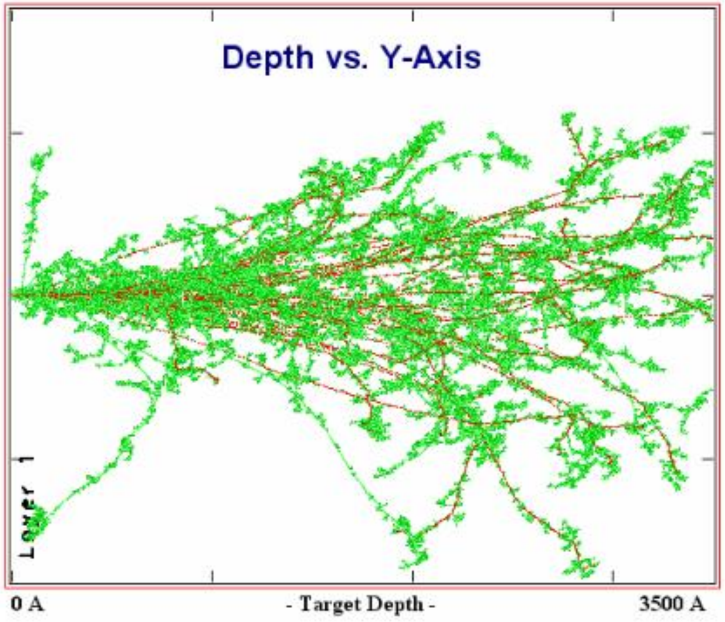
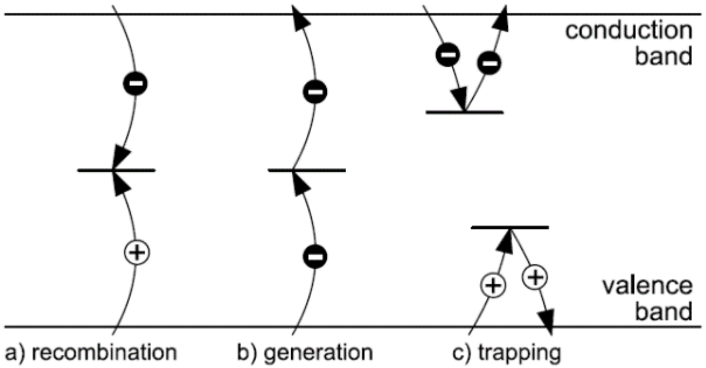
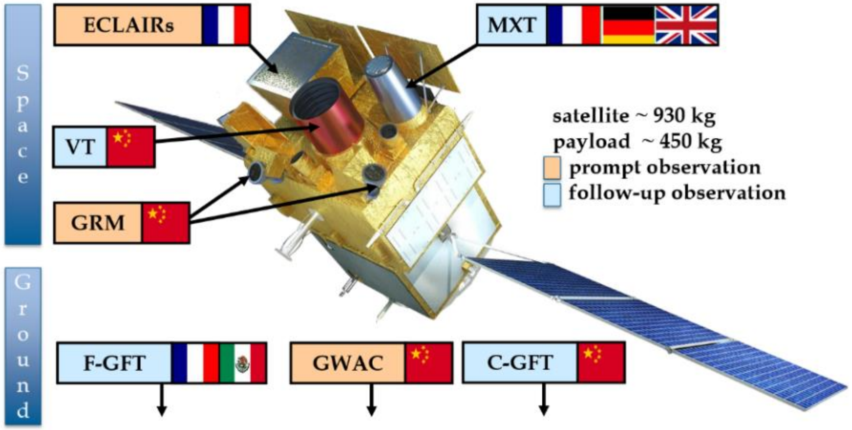




MISSION OVERVIEW

- Space-based multi-band astronomical Variable Object Monitor
- Science: GRBs, AGNs, transients…
- Launch in 2021, LEO (625 km altitude, 30 deg inclination)



MISSION OVERVIEW

- Space-based multi-band astronomical Variable Object Monitor
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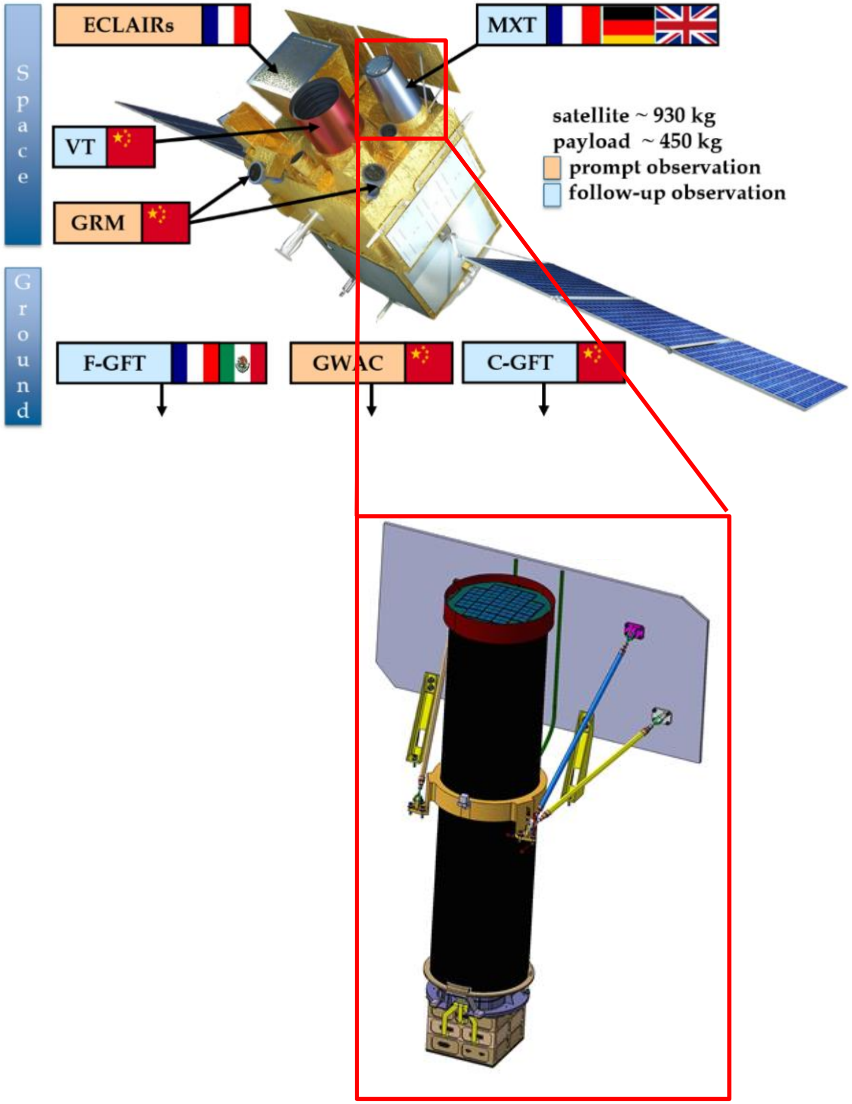
- Launch in 2021, LEO (625 km altitude, 30 deg inclination)
- Micro-channel X-ray Telescope



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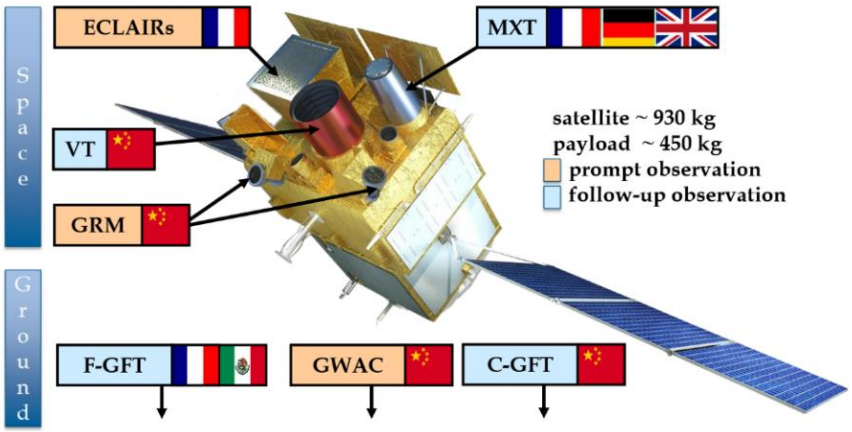

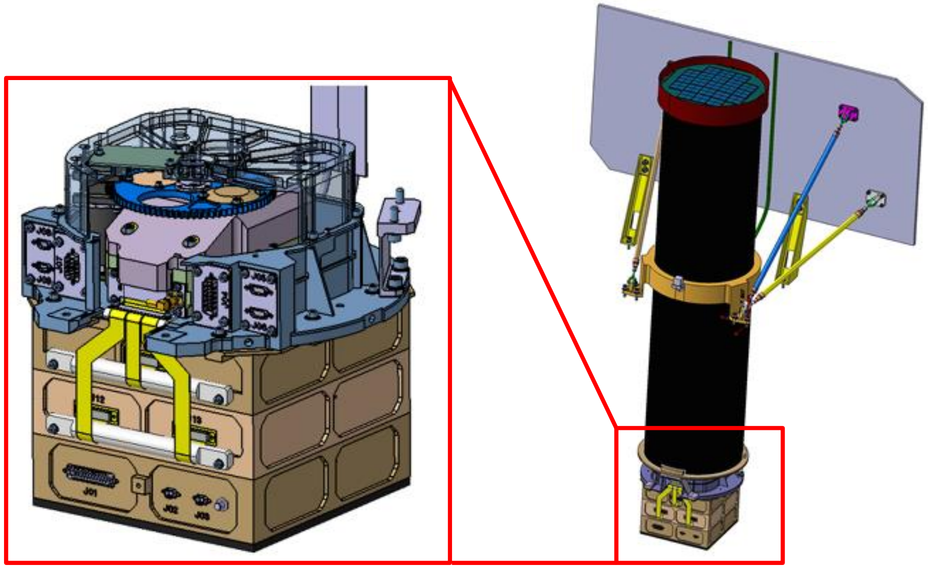

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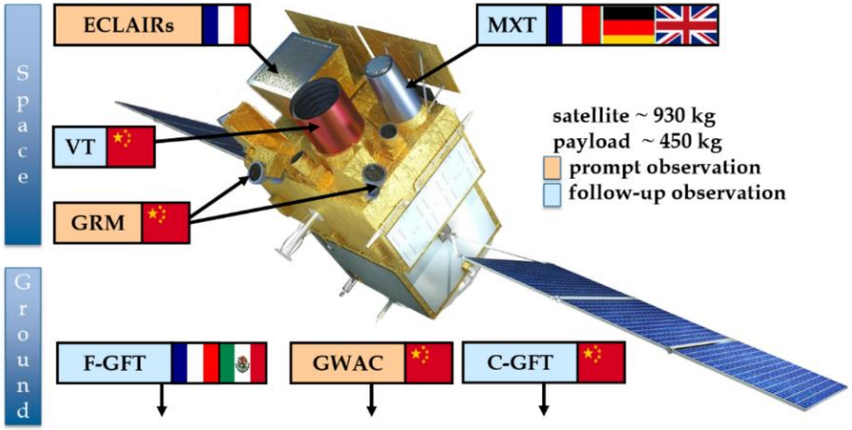
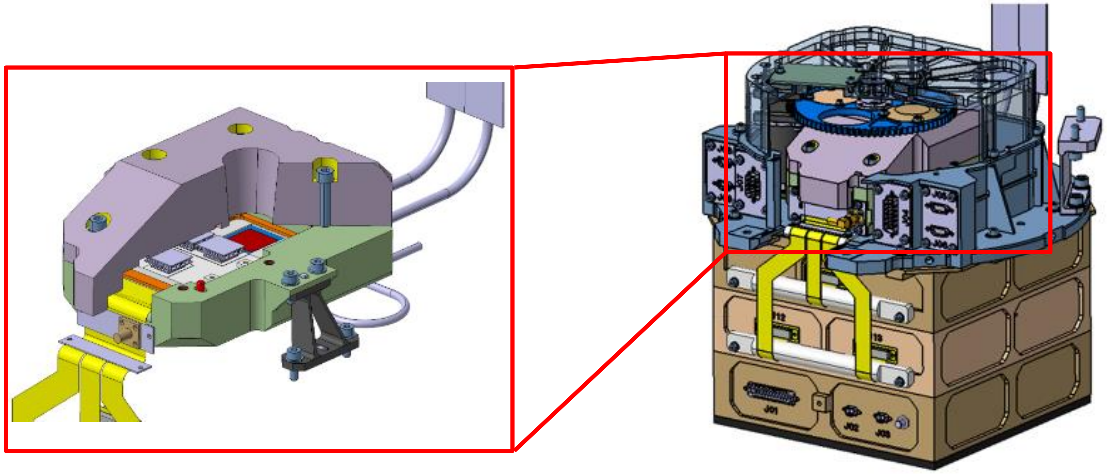
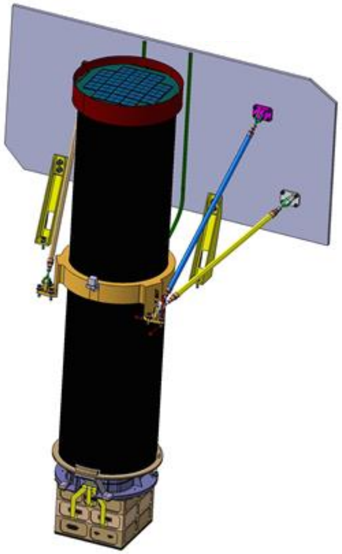
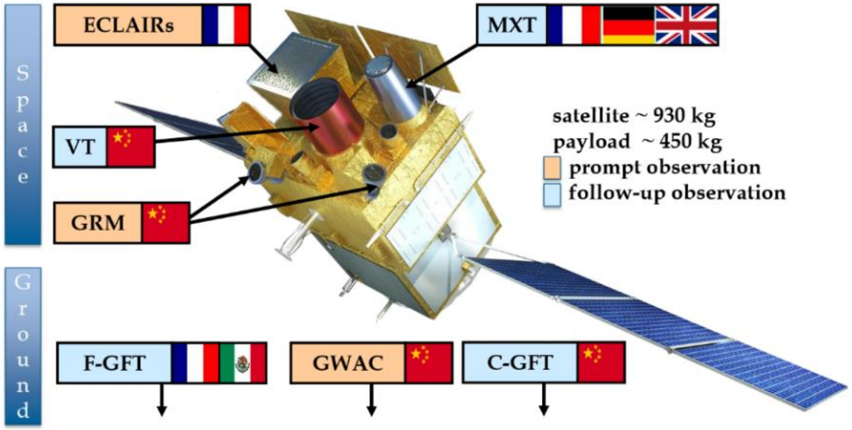




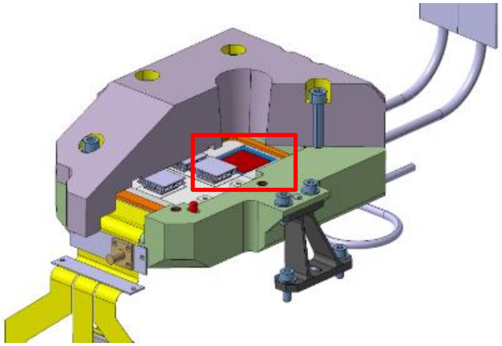


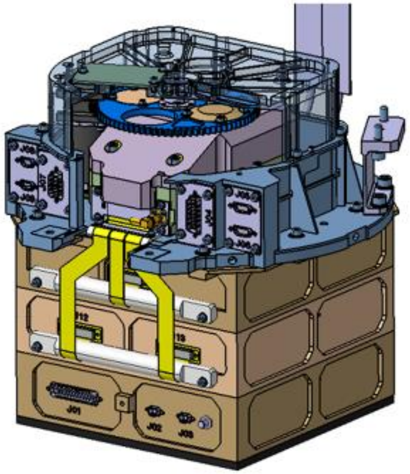
MISSION OVERVIEW

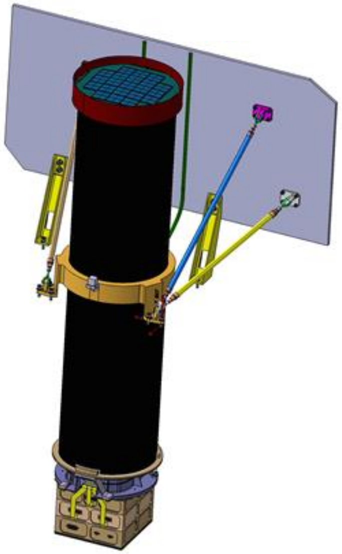
- Space-based multi-band astronomical Variable Object Monitor
- Science: GRBs, AGNs, transients…
- Launch in 2021, LEO (625 km altitude, 30 deg inclination)
- Micro-channel X-ray Telescope
- First time pnCCd in LEO at $T = -65^{\circ}C$



satellite ~ 930 kg
payload ~ 450 kg
🟧 prompt observation
🟦 follow-up observation

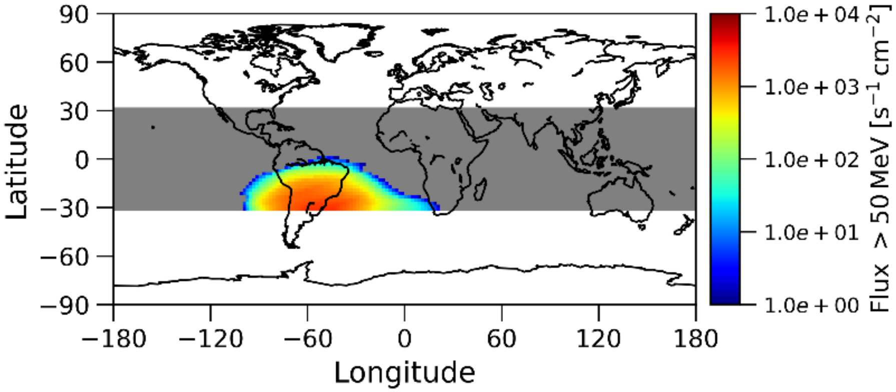






IN-ORBIT SCENARIO

- Orbit and environment parameters to model radiation exposure (particle flux on the spacecraft).



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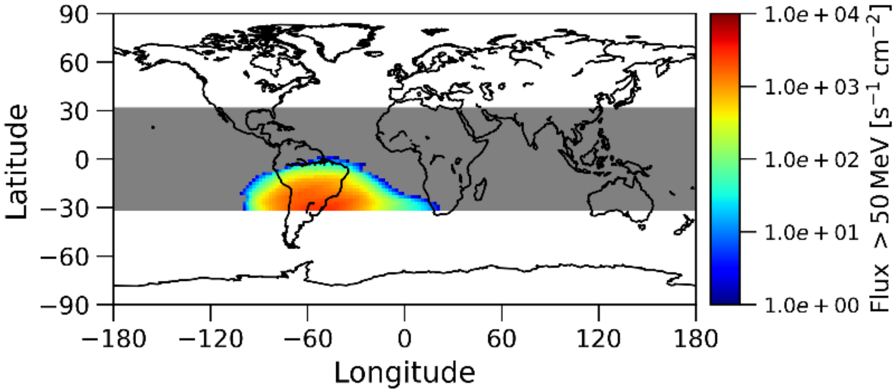
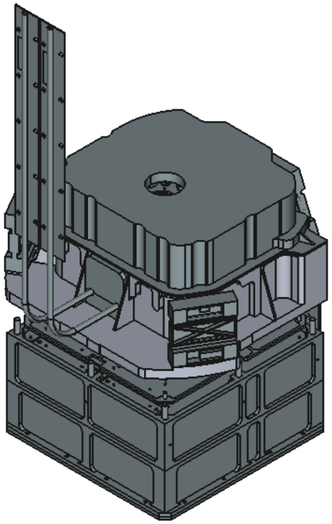


- Propagate the particle flux on the detector (Geant4).



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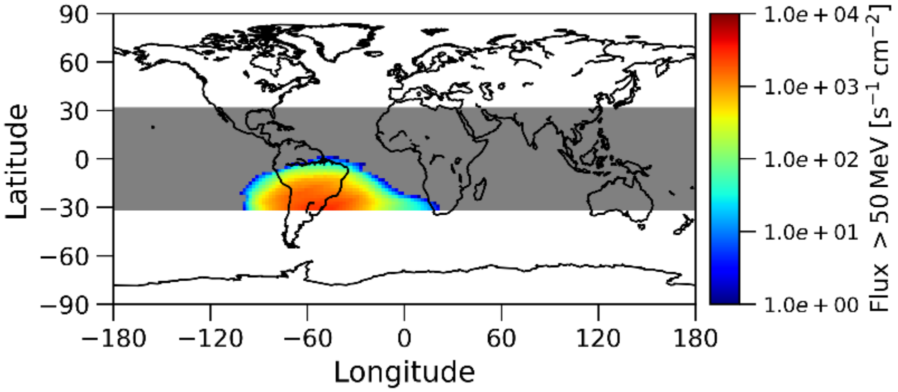

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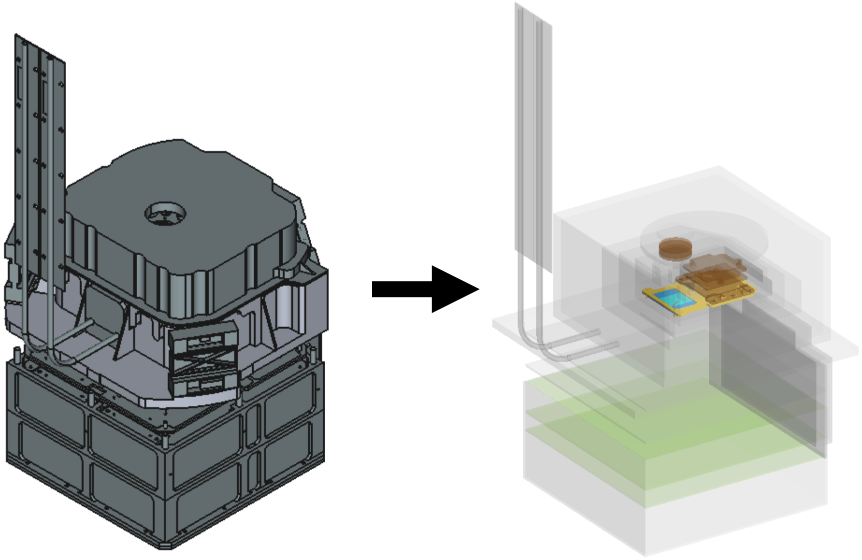

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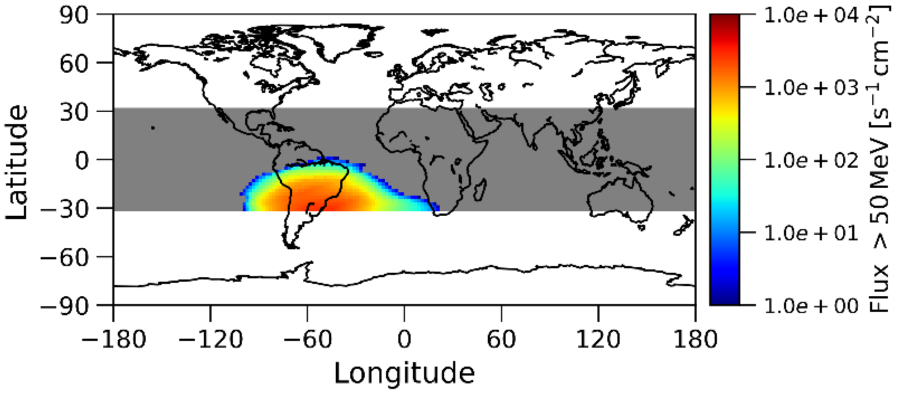

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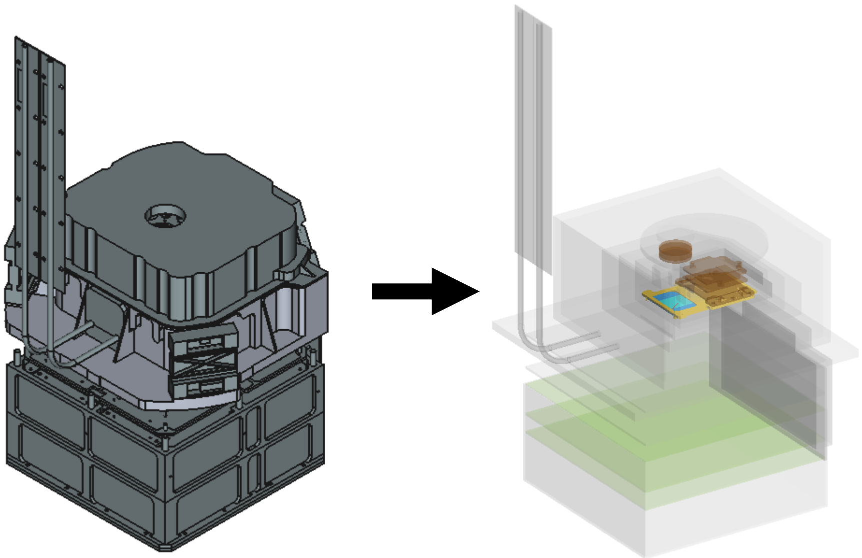
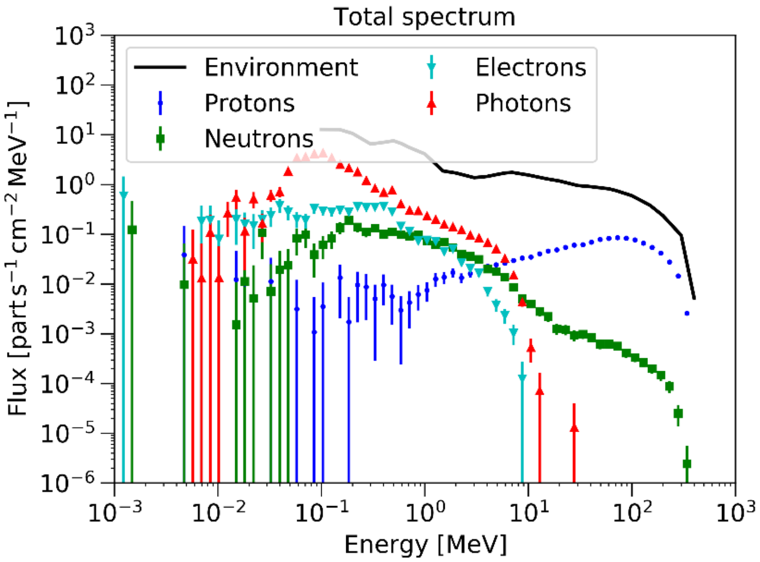
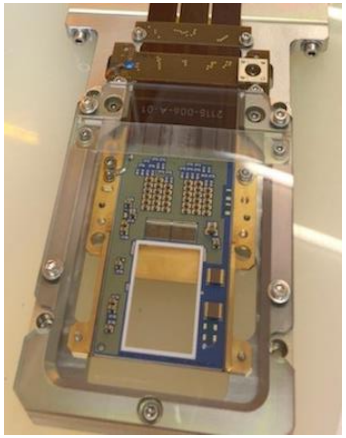


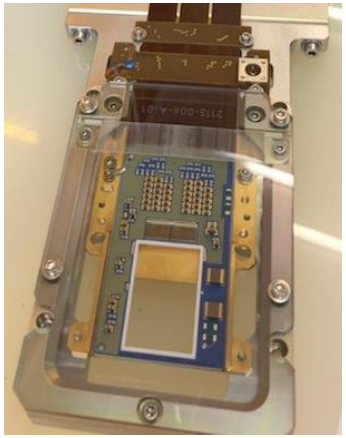


ON-GROUND TESTS



- Full characterization of the detector:
    - Spectroscopy
    - Noise level
    - Charge Transfer Efficiency
    - Quantum efficiency
    - …

ON-GROUND TESTS



- Full characterization of the detector:
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  - Charge Transfer Efficiency
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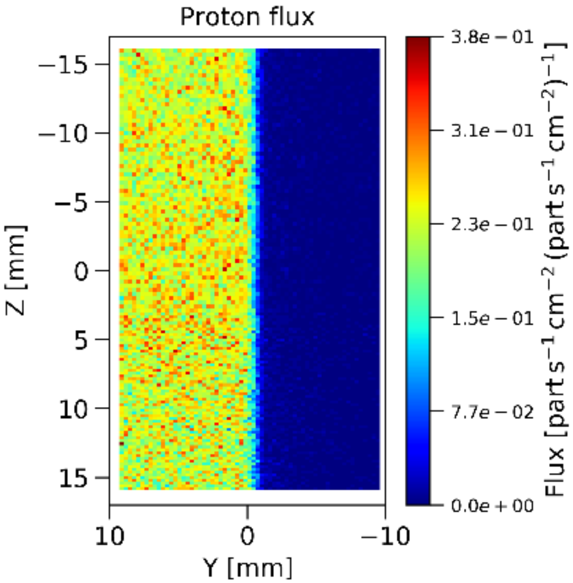
  - ...

- Recreate the space environment with particle beams.



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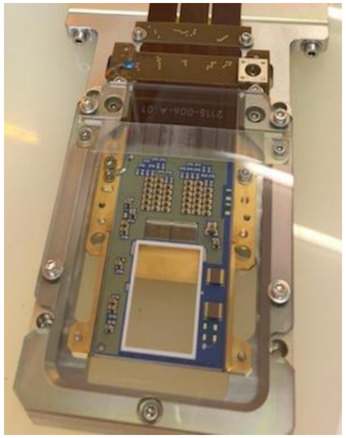
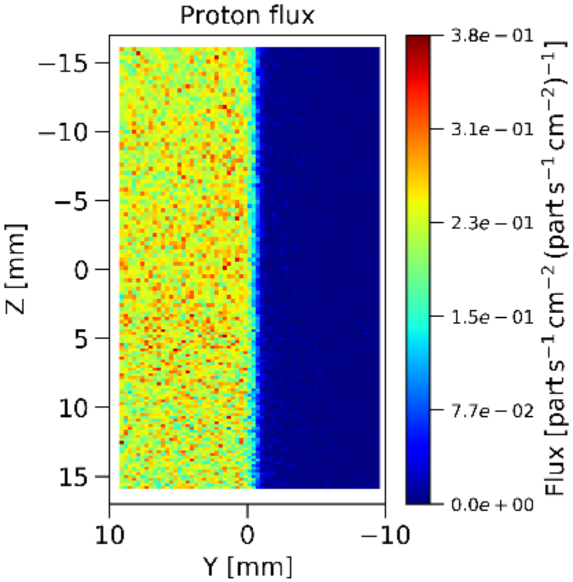


- Full characterization of the detector:
  - Spectroscopy
  - Noise level
  - Charge Transfer Efficiency
  - Quantum efficiency
  - ...

- Recreate the space environment with particle beams.
- Extensive characterization after irradiation.



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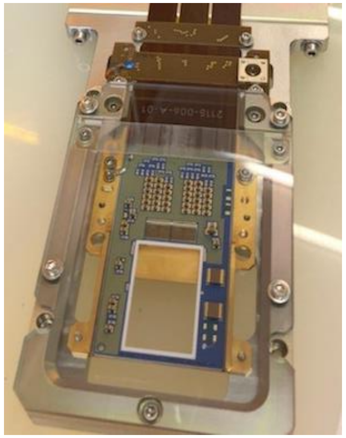

- Full characterization of the detector:
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  - Noise level
  - Charge Transfer Efficiency
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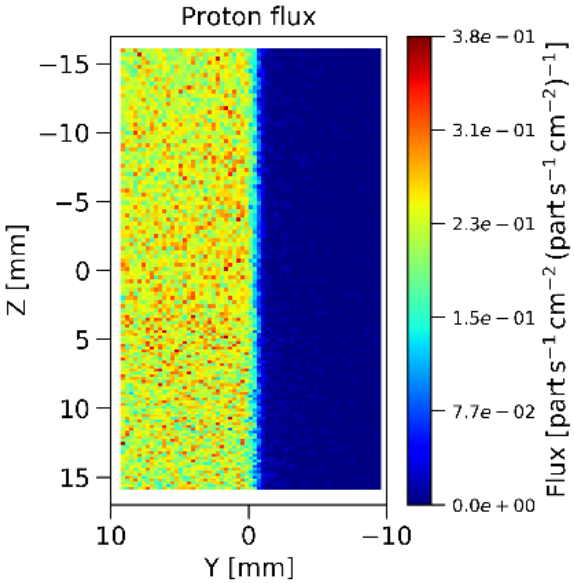
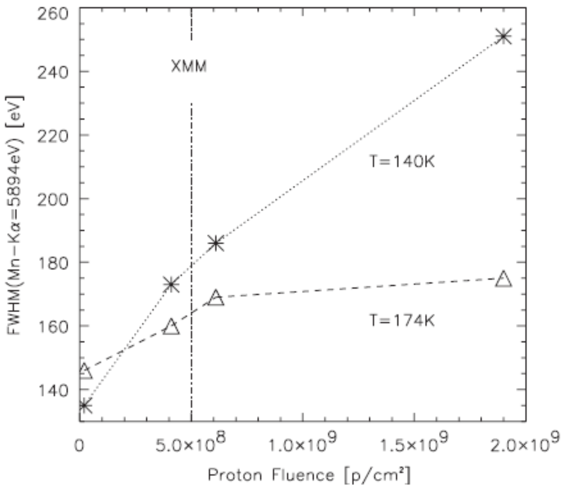
  - ...

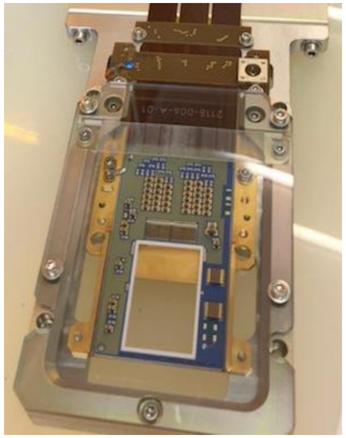


- Recreate the space environment with particle beams.
- Extensive characterization after irradiation.

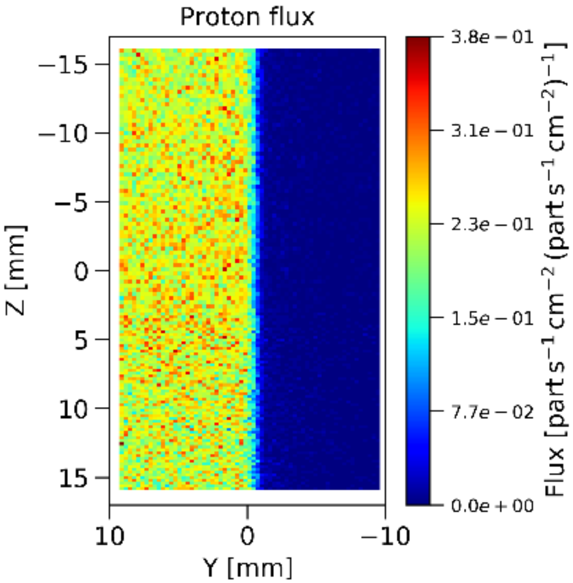


- Performance – irradiation relation

ON-GROUND TESTS



- Full characterization of the detector:
  - Spectroscopy
  - Noise level
  - Charge Transfer Efficiency
  - Quantum efficiency
  - ...



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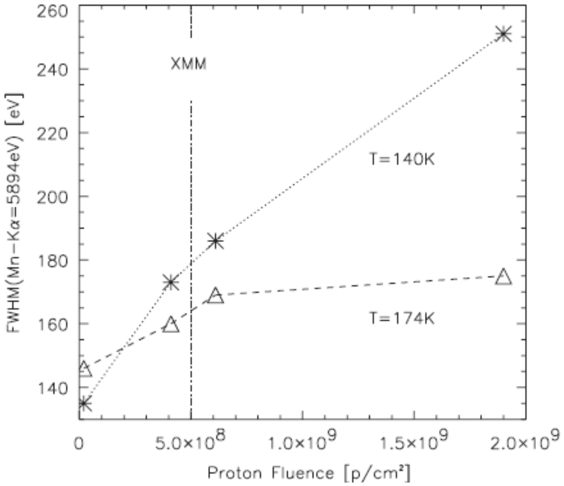

- Performance – irradiation relation
- Investigations to recover performance loss (e.g. annealing)
- Feedback on the mission work plan

SUMMARY

- COMBINE ALL THE INFORMATION CARRIERS OF LIGHT INSIDE ONE DEVICE
- BUILD COMPACT INSTRUMENTS
- MAINTAIN PERFORMANCES
- TAKE INTO ACCOUNT SPACE ENVIRONMENT