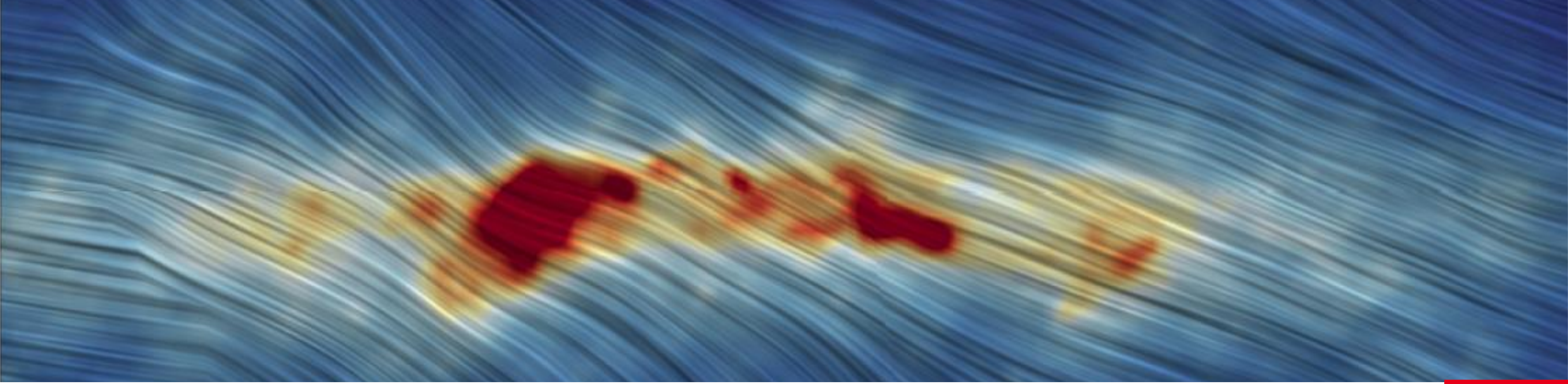
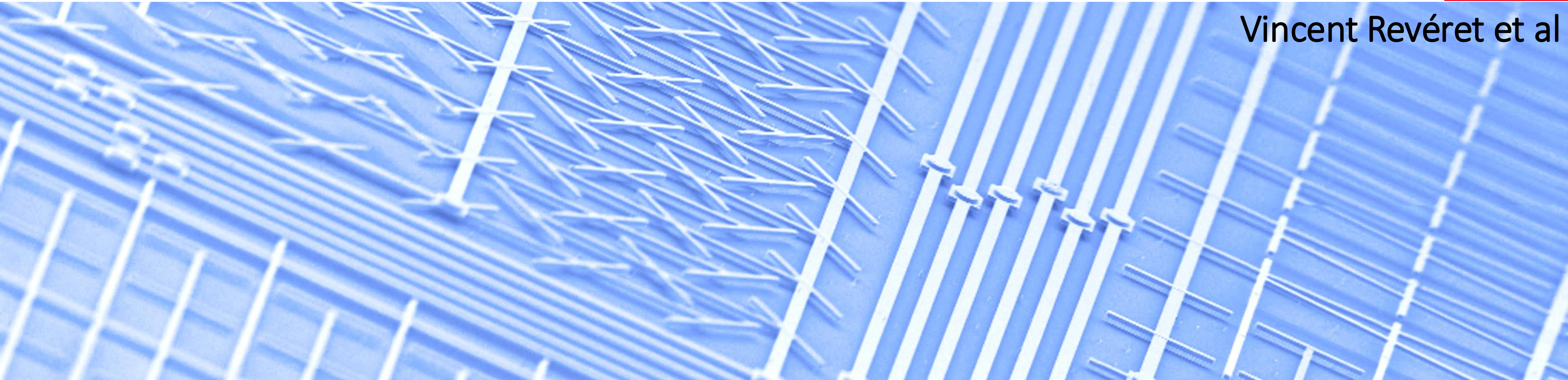
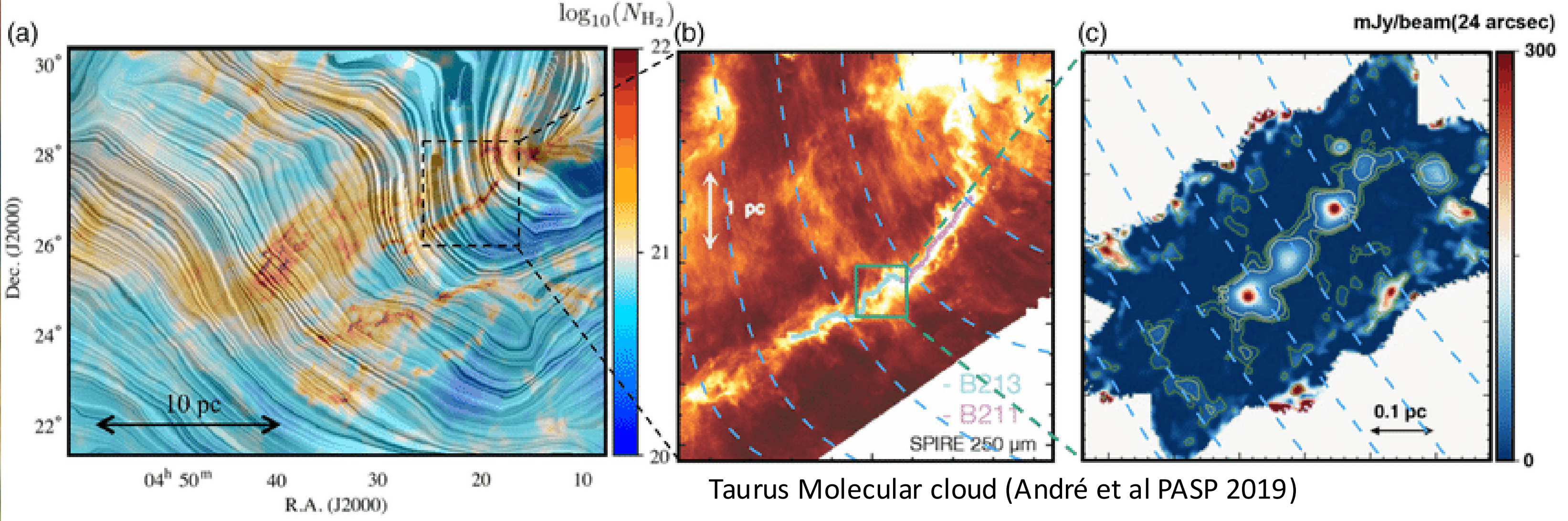


Capabilities for FIR/Submm observations with on-chip polarimeters – aka BBOP

Vincent Revéret et al

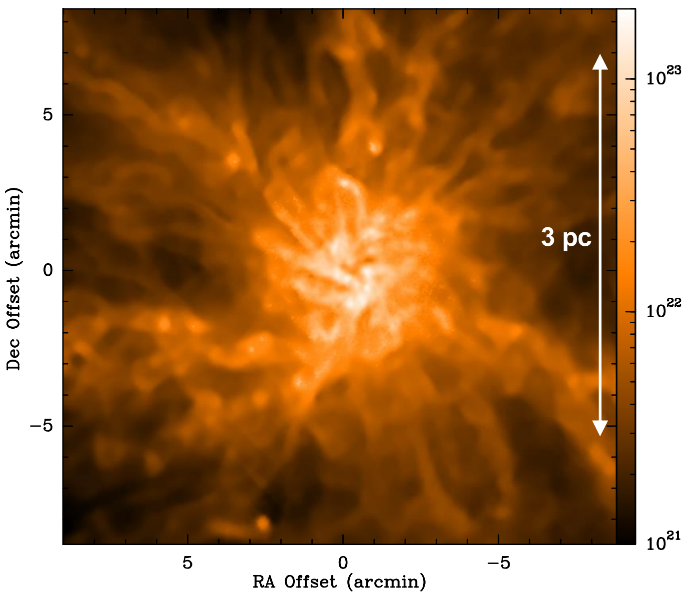


Unveiling the role of magnetic fields in filaments

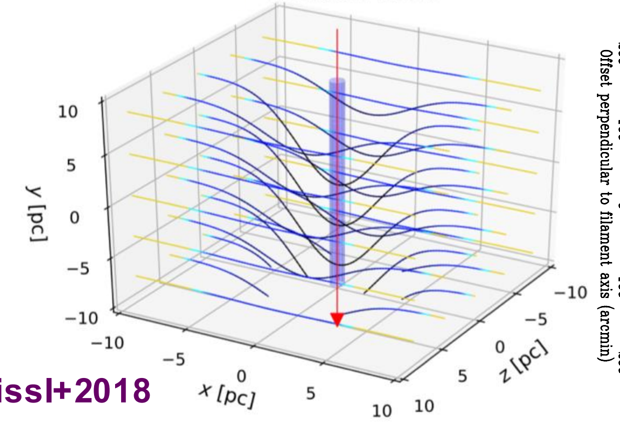


Taurus Molecular cloud (André et al PASP 2019)

MonR2: ArTéMiS + *Herschel* N_{H2} map (8" resolution)

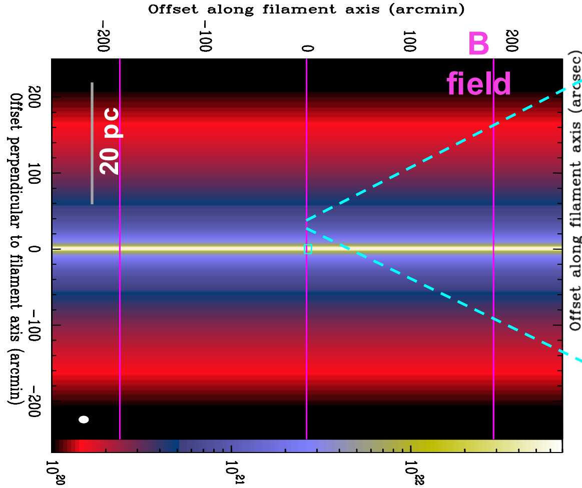


Plausible model of the B field in a SF filament

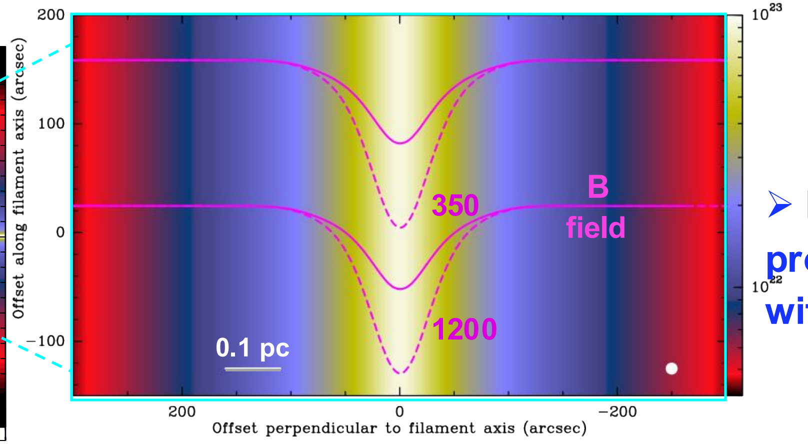


cf. Reissl+2018

Planck resolution



B-field lines inferred at 350 & 1200 µm at ArTéMiS/POLARYS resolution



(for a model filament at d = 400 pc)

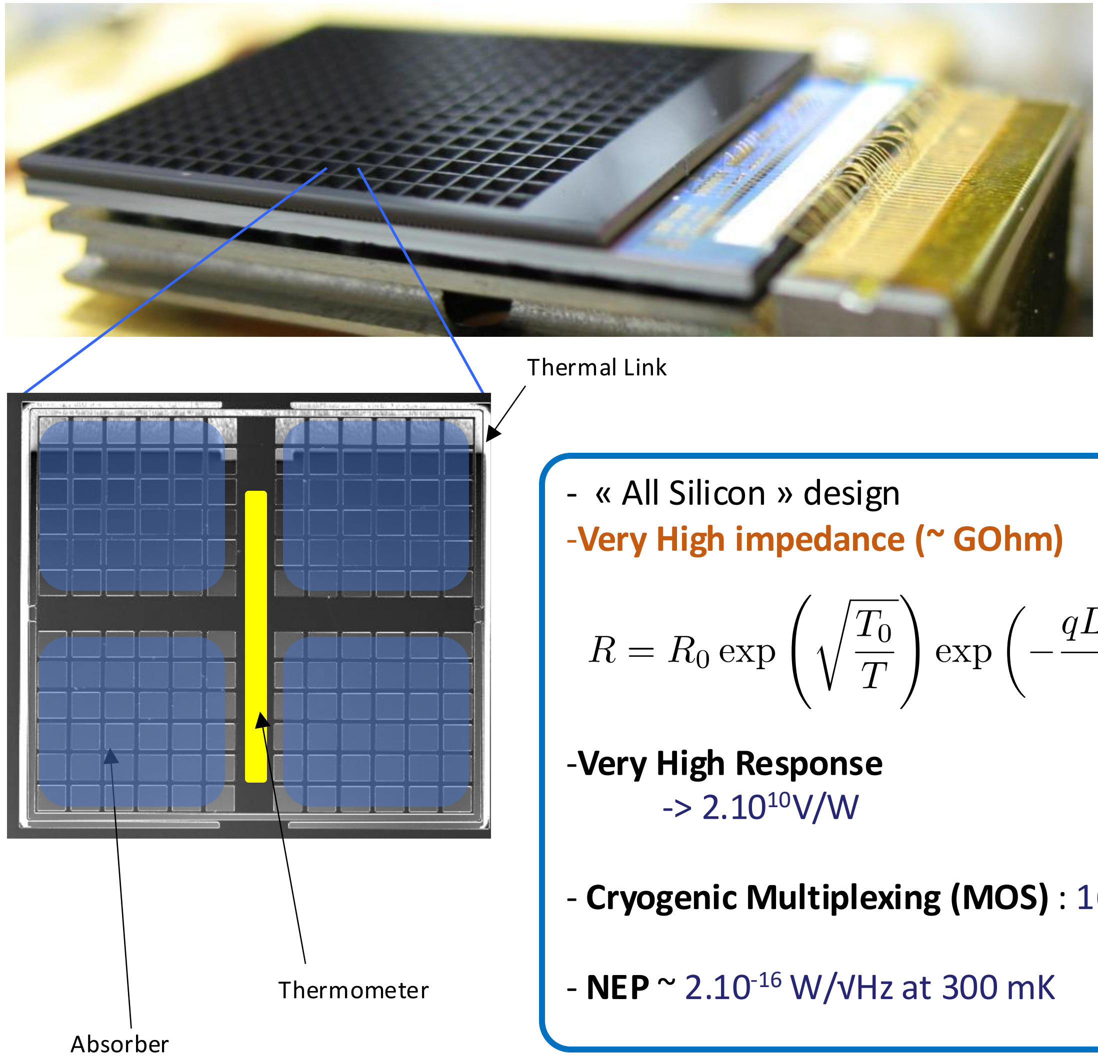
- **Different wavelengths probe different depths within the filament**

-> Needs for a high sensitivity polarimeter camera in the submm

Our starting point : Herschel / PACS Silicon Resistive Bolometers in the 2000's

The goal : large format high sensitivity detectors in the 50 – 200 µm range.

CEA's choice : 16x16 Silicon array of bolometers working at 300 mK



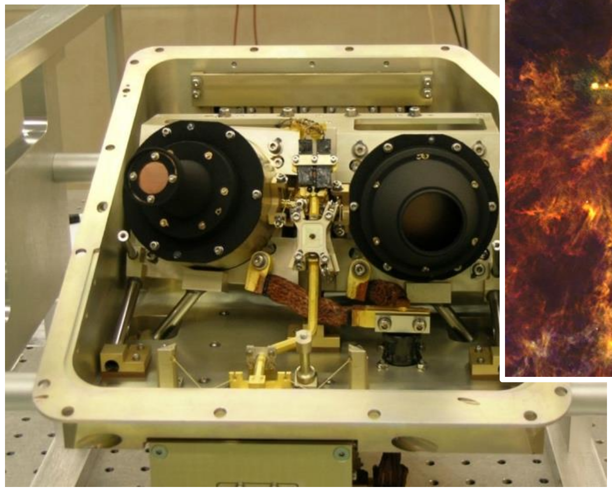
- « All Silicon » design
- **Very High impedance (~ GOhm)**

$$R = R_0 \exp\left(\sqrt{\frac{T_0}{T}}\right) \exp\left(-\frac{qL_{(T)}E}{kT}\right)$$

- **Very High Response**
  -> 2.10^{10} V/W
- **Cryogenic Multiplexing (MOS)** : 16 to 1
- **NEP** ~ 2.10^{-16} W/√Hz at 300 mK

PACS Photometer (2009 – 2012)

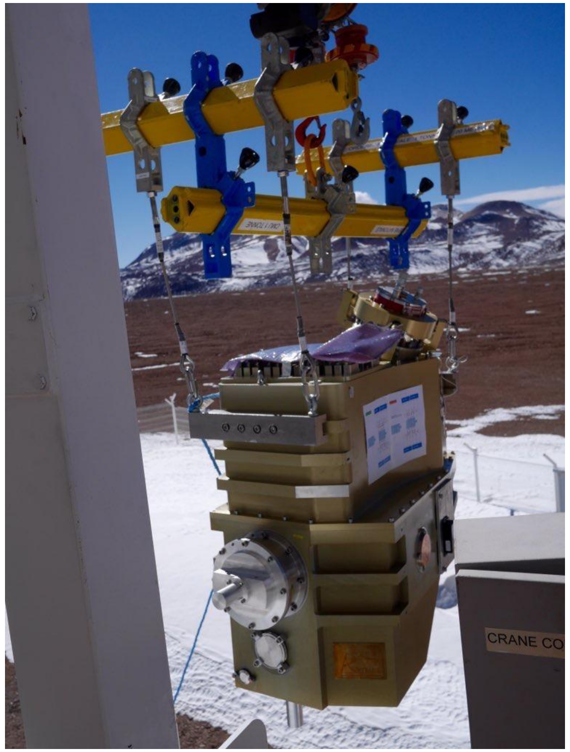
- 2560 pixels, 3 bands (70, 100, 160 µm)
- 30% of observing time, most used instrument
- (40 % if parallel mode included)

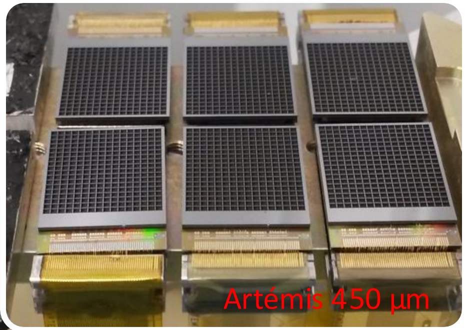


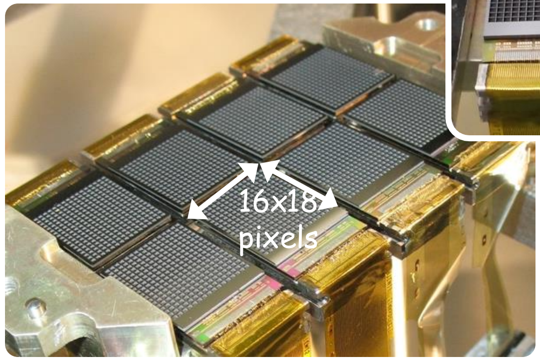
Horsehead Nebula (André et al)

Cygnus X
Herschel PACS & SPIRE
Credits: ESA/PACS/SPIRE/Martin Hennemann & Frédérique Motte

ArTéMiS on APEX : A Dual Band camera (**350 & 450 µm**) since 2013, still operating



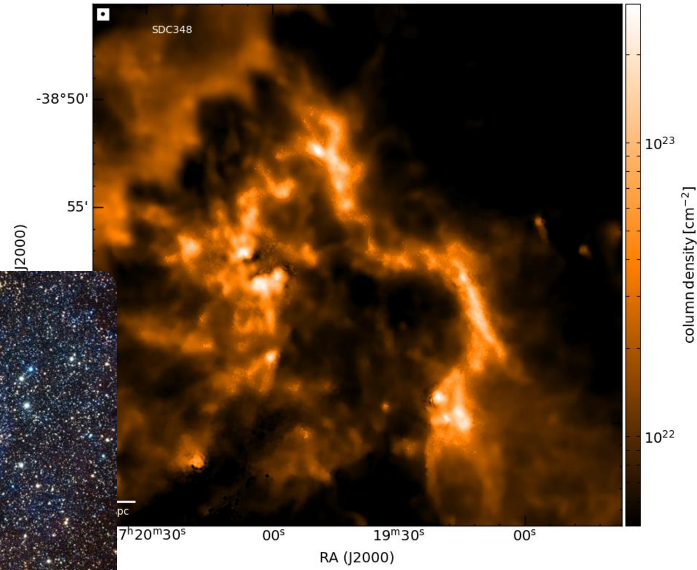


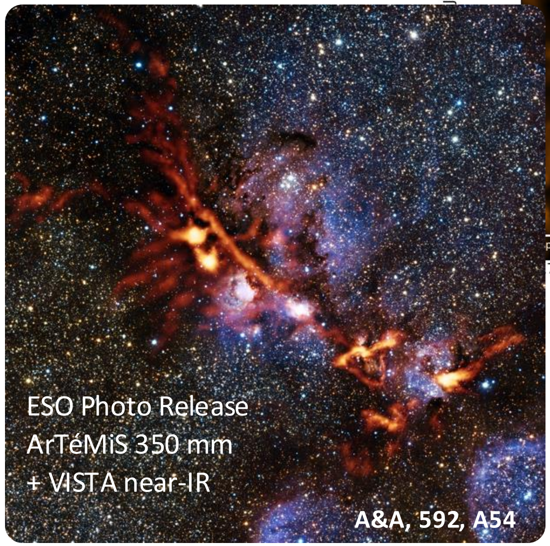


Artémis 350 µm focal plane

- Complementary to Herschel Data at 350 µm (extended emission + spatial resolution)
- **Observing Run in Sept. 2024**
- **Another Observation run in July/August this year**

Number of operational pixels	2400
Spatial Resolution **350 µm** **450 µm**	 8’’ 10.5’’
FOV (350µm)	4,7 x 2,3 arcmin^2



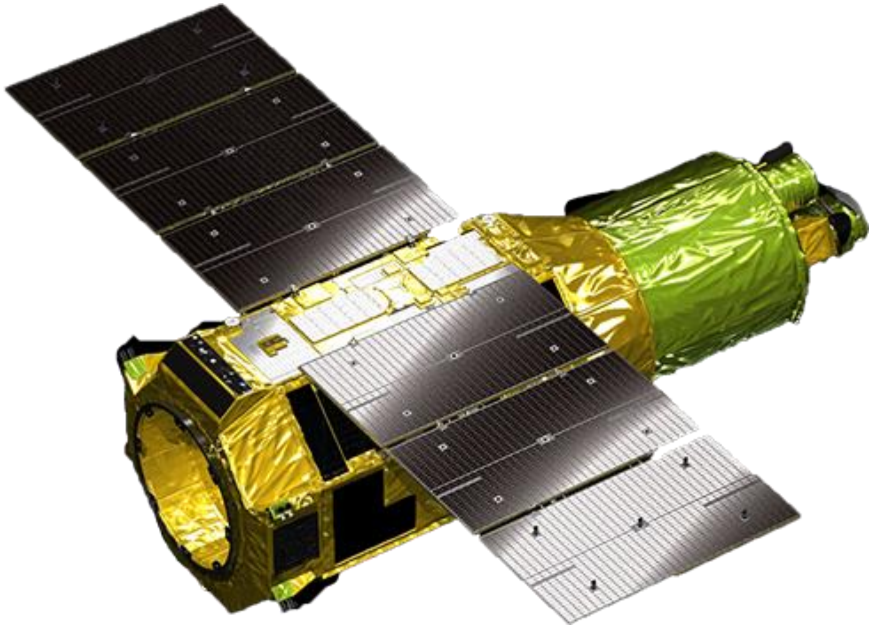


Column density map of the cloud SDC348
(M. Mattern, A&A 2024)

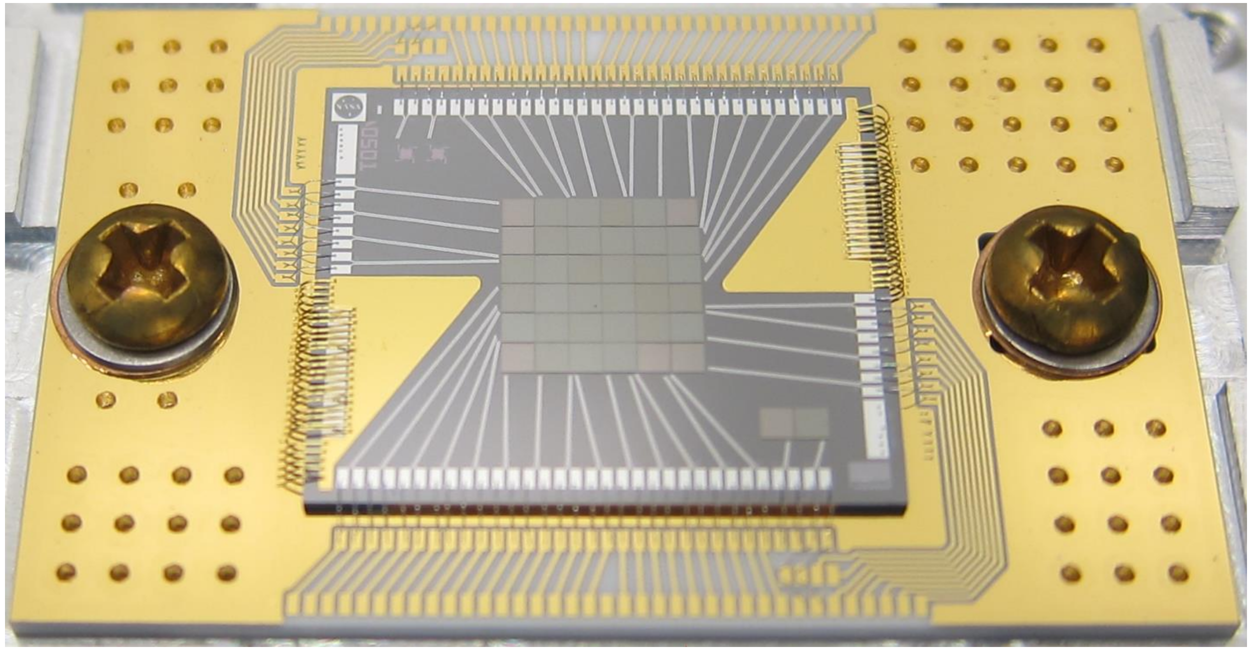
Why Silicon bolometers?

« Si Technology is not (completely) dead…! »

RESOLVE onboard the JAXA-NASA **XRISM Mission**



Launched in 2023



6x6 Silicon µ-Calorimeters from NASA Goddard working at ~50 mK

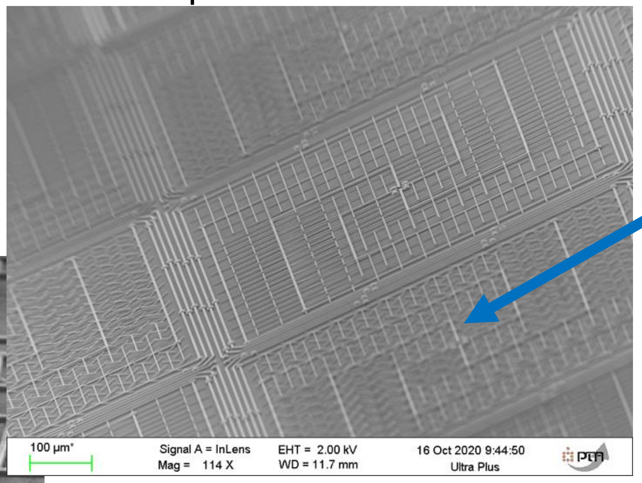
(with ESA participation)

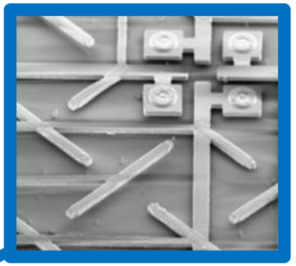
Why Silicon bolometers?

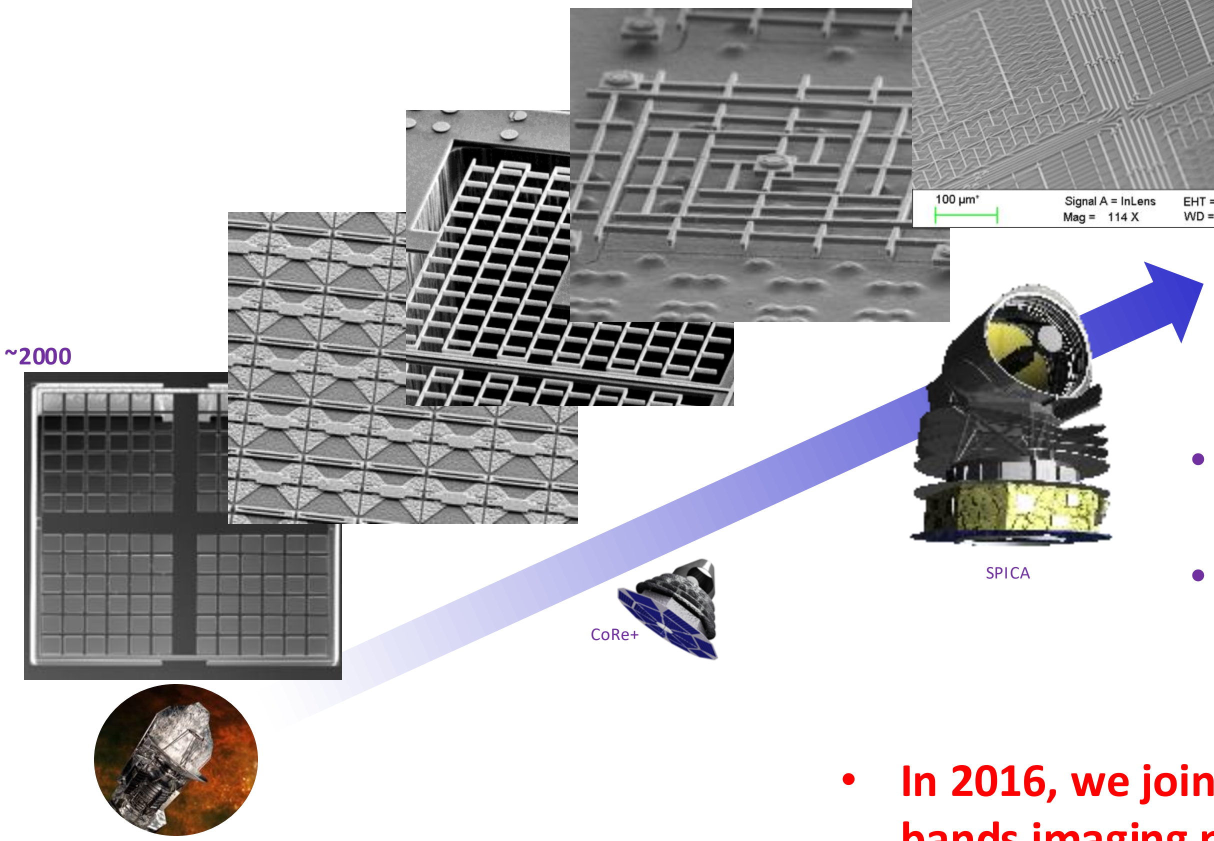
Pushing the limits of this technology

B-BOP's polarimetric bolometers

2021





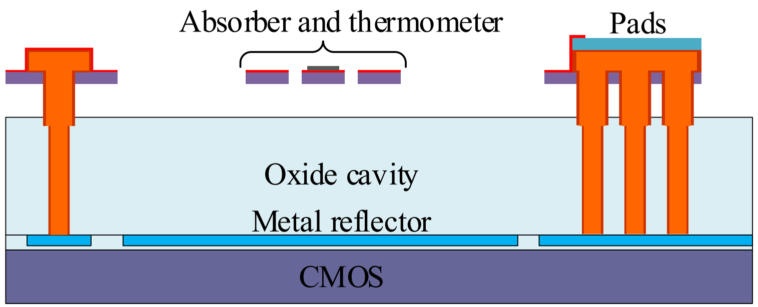


- Silicon is an amazing material : very high thermal resistance can be reached at low temperature => *high sensitivity*
- Si micro-machining enables to design *complex pixel structures to build compact space instruments*
- *No Need of Magn. shielding*

- **High Sensitivity Imaging-Polarimetry inside the pixel is a direct application of these possibilities**
- Also, « High impedance » is compatible with CMOS classical electronics that works at 50 mK (EU CESAR project).

- **In 2016, we joined the SPICA mission with the B-BOP Instrument : a 3 bands imaging polarimeter (70, 200 and 350 µm)**
- **Science Case : Magnetic Field in the ISM**

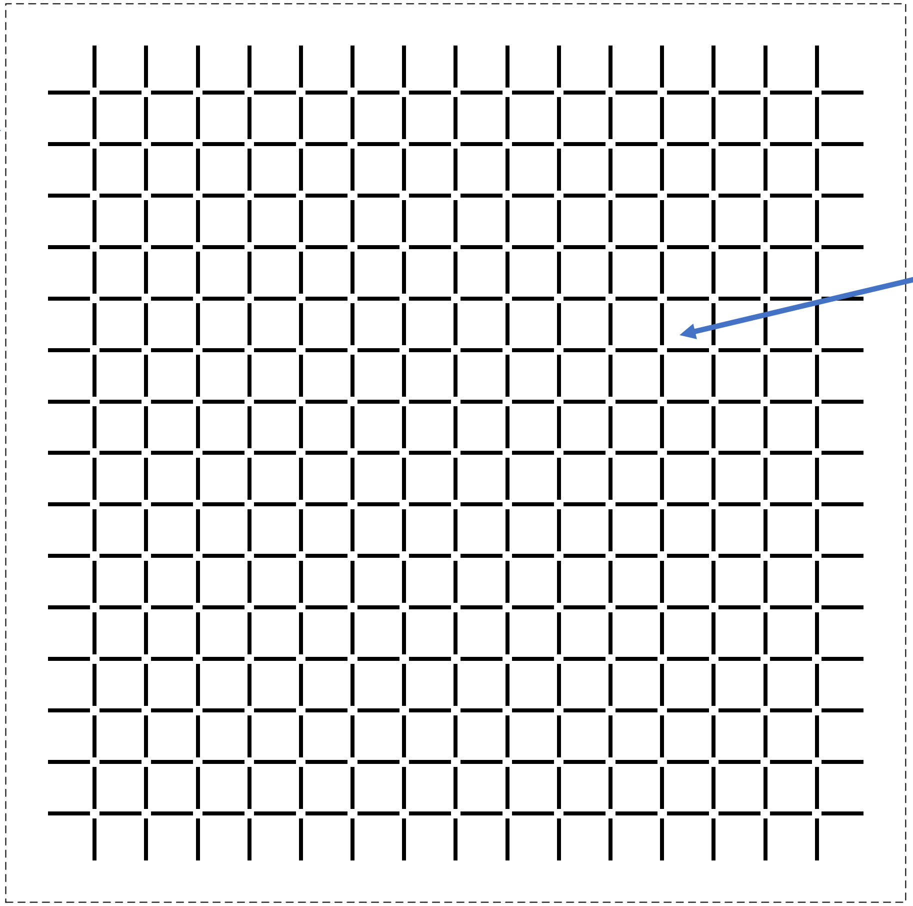
The B-BOP Detectors



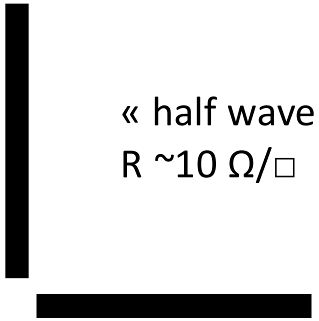
Each Pixel detects dual polarization. How ?

16x15 H dipoles
15x16 V dipoles

This is one Pixel
750x750 µm

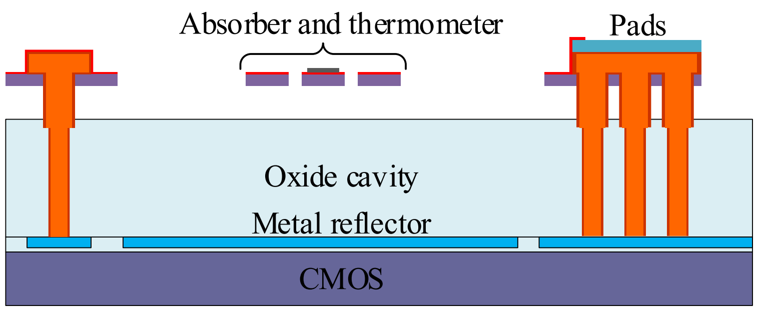


This is not a phased array antenna.

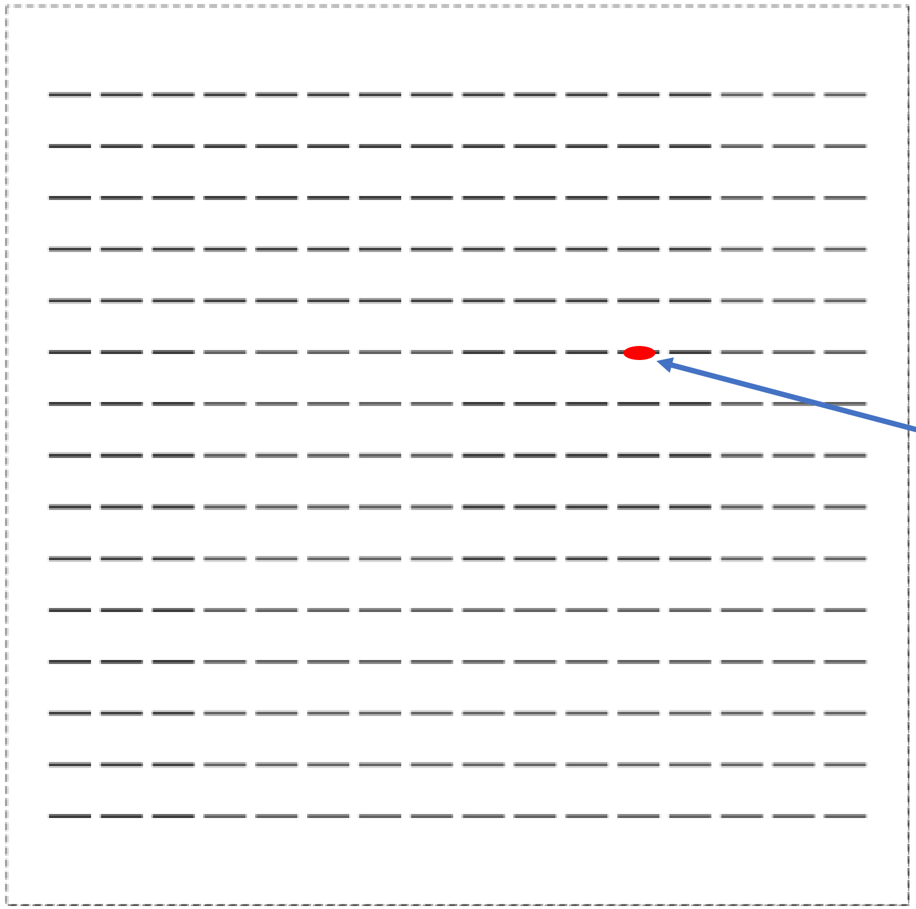


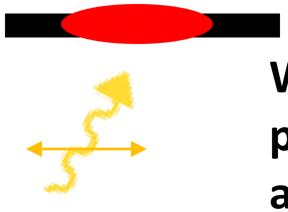
« half wave » dipoles (1.6 x 34.6 µm)
R ~10 Ω/□

Electro-thermal scheme of the pixel



H Dipoles

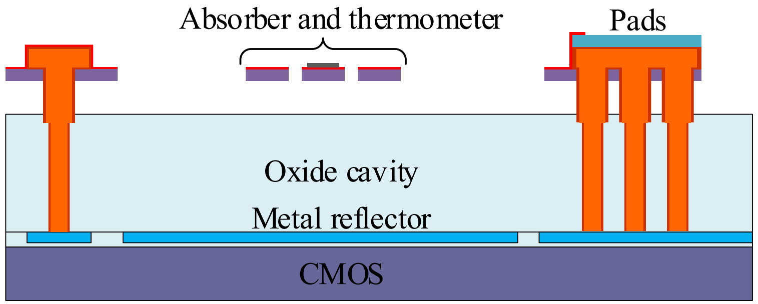


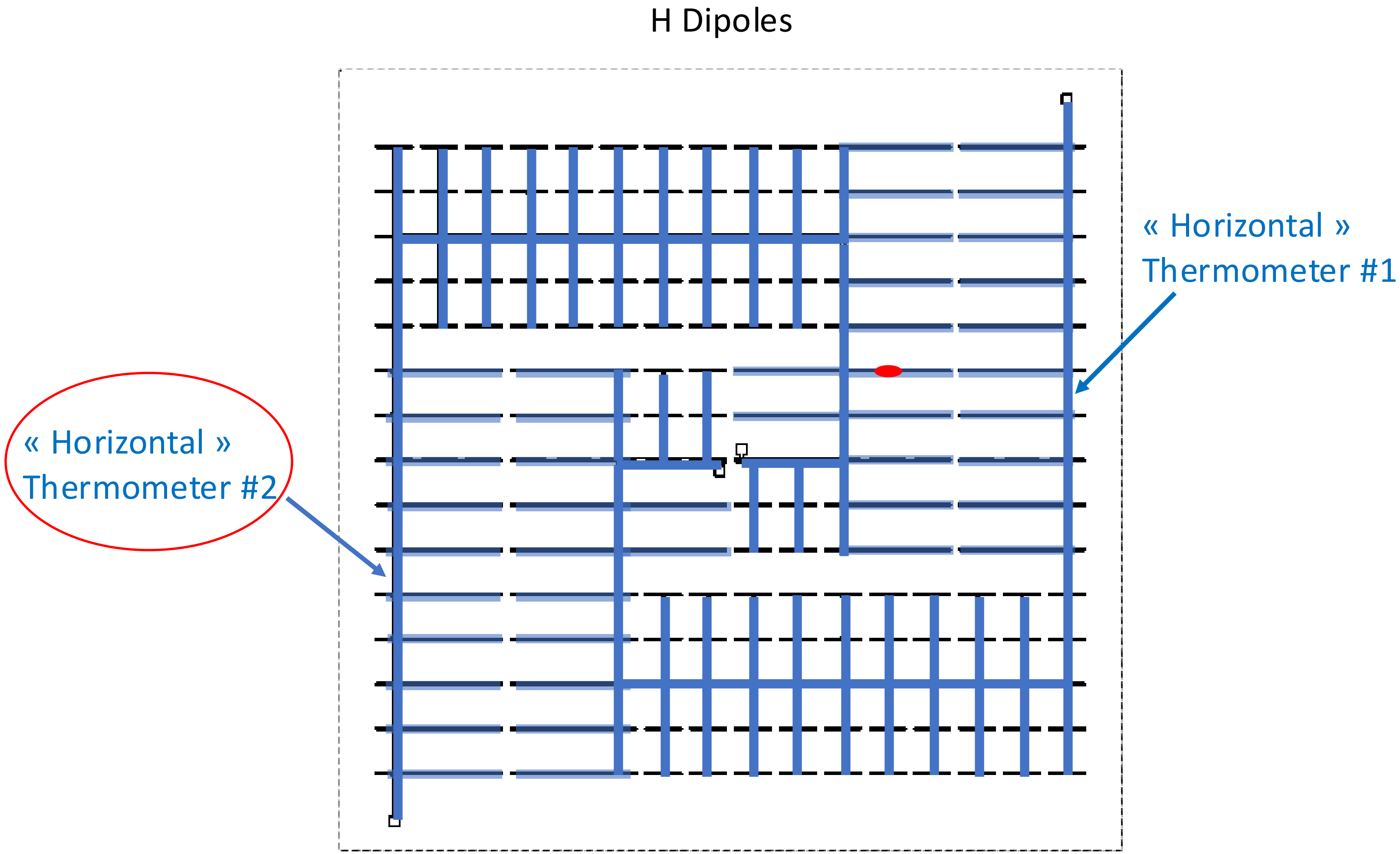


When a linearly polarized photon couples to the resistive antenna, its temperature rises.

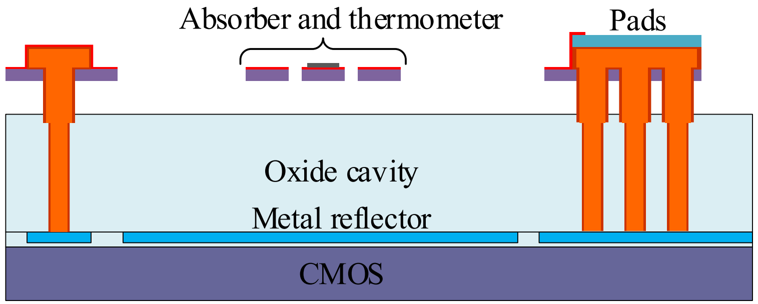
A (sensitive) thermometer measures this rise.

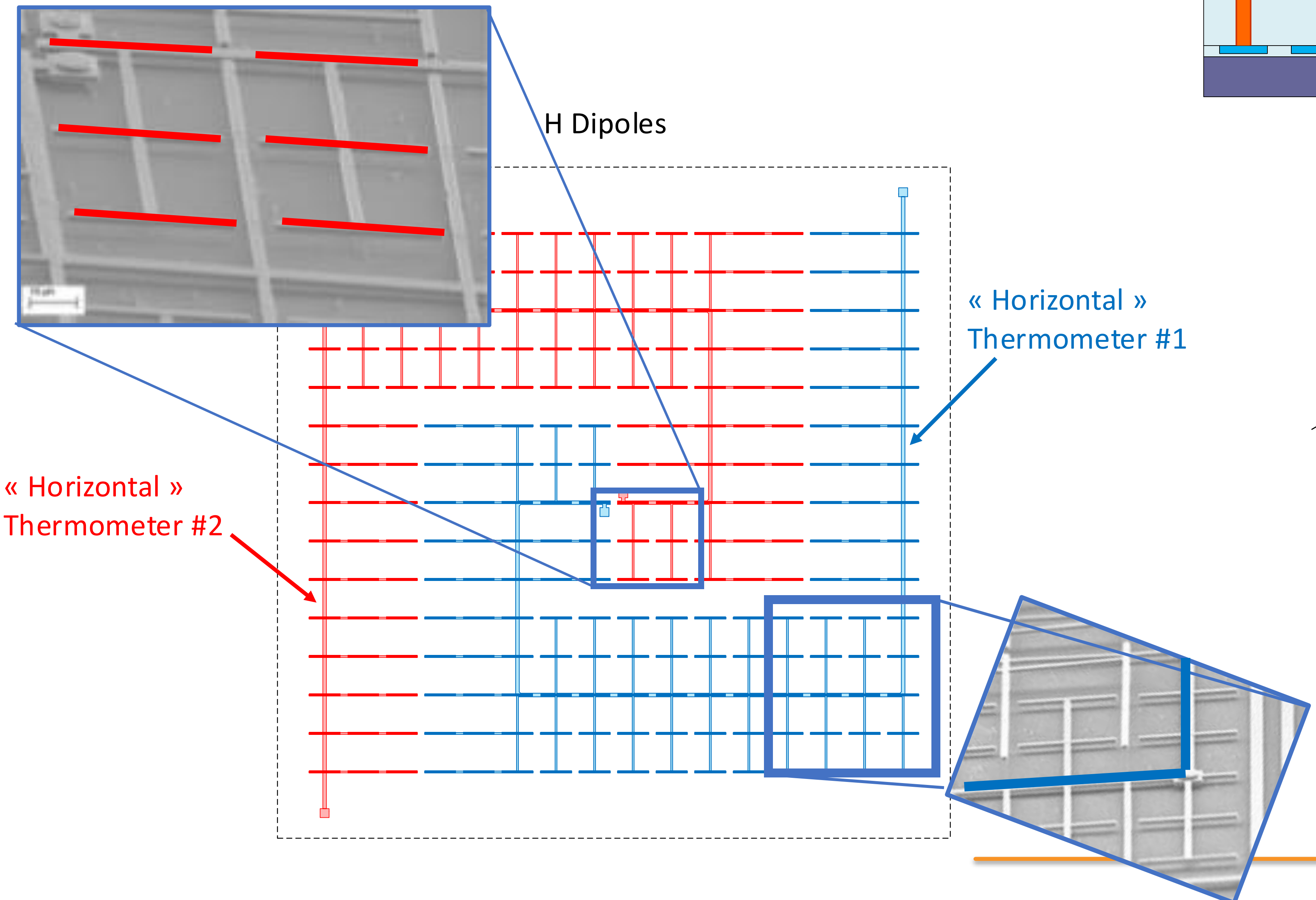
Electro-thermal scheme of the pixel

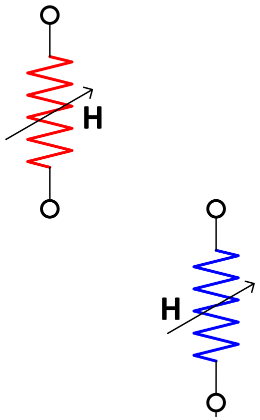




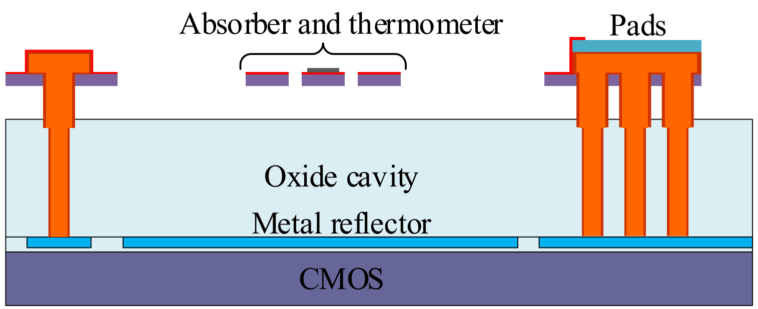
Electro-thermal scheme of the pixel





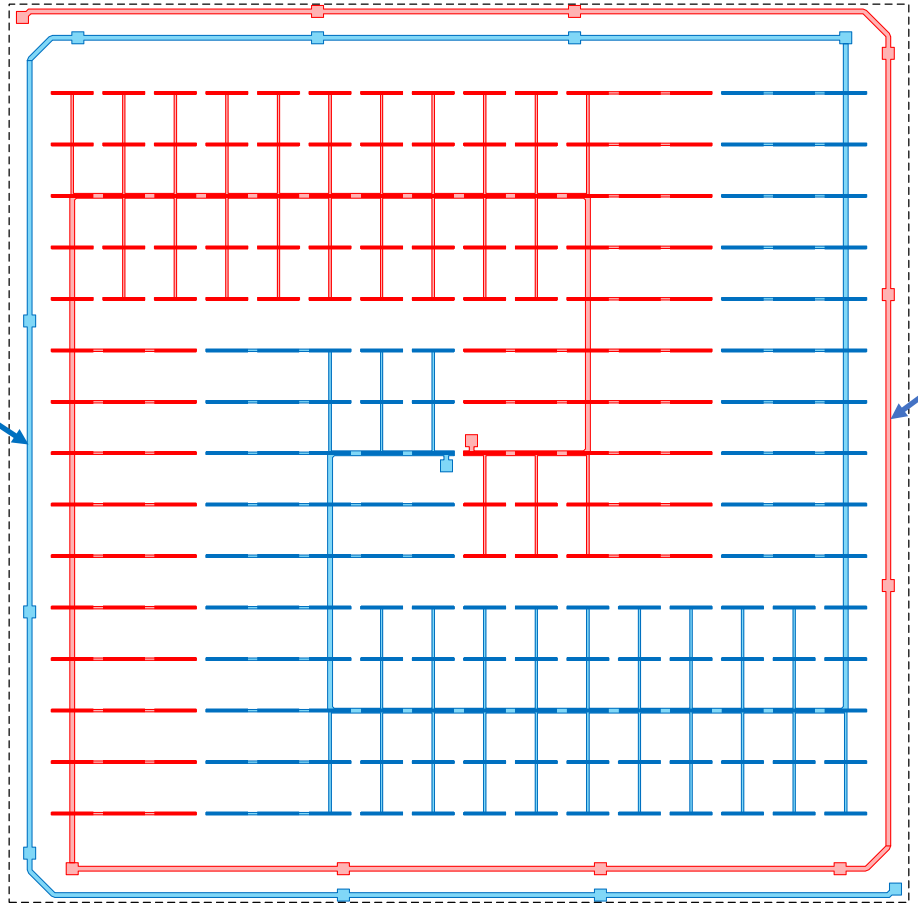


Electro-thermal scheme of the pixel

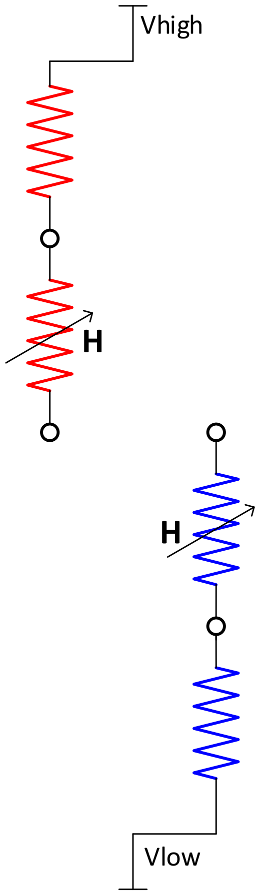


H Dipoles

Reference Resistor

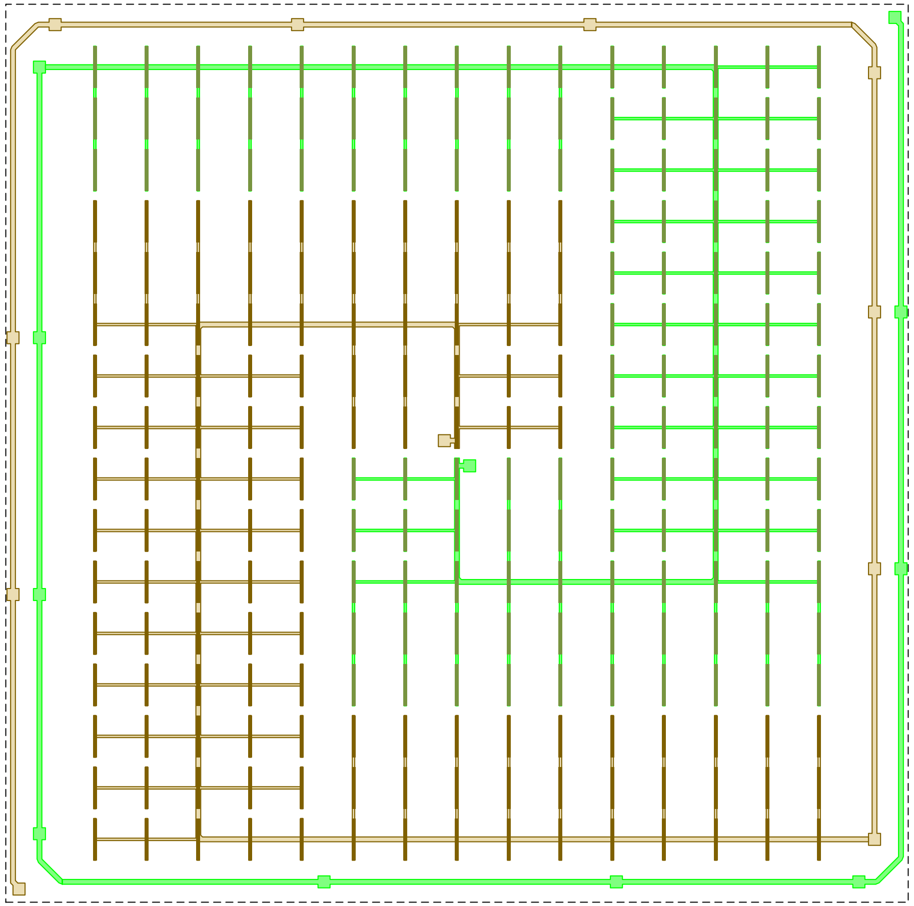


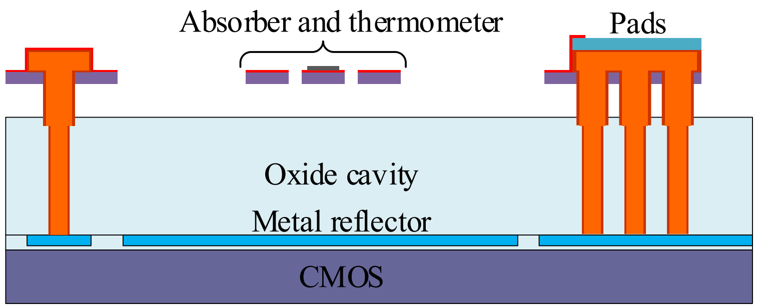
Reference Resistor

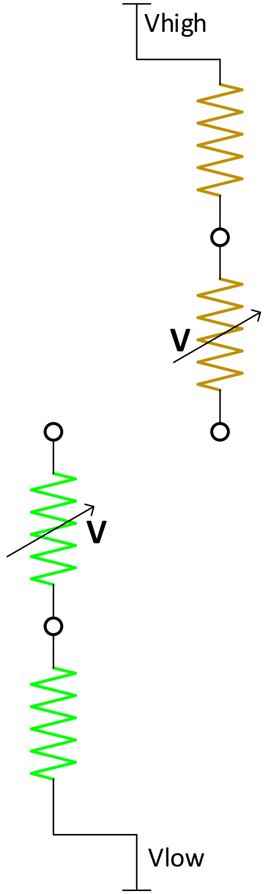


Electro-thermal scheme of the pixel

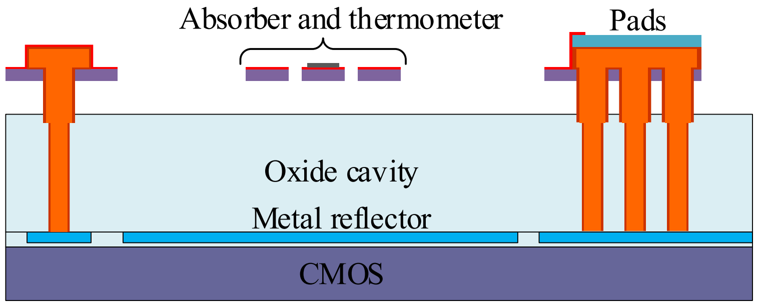
V Dipoles



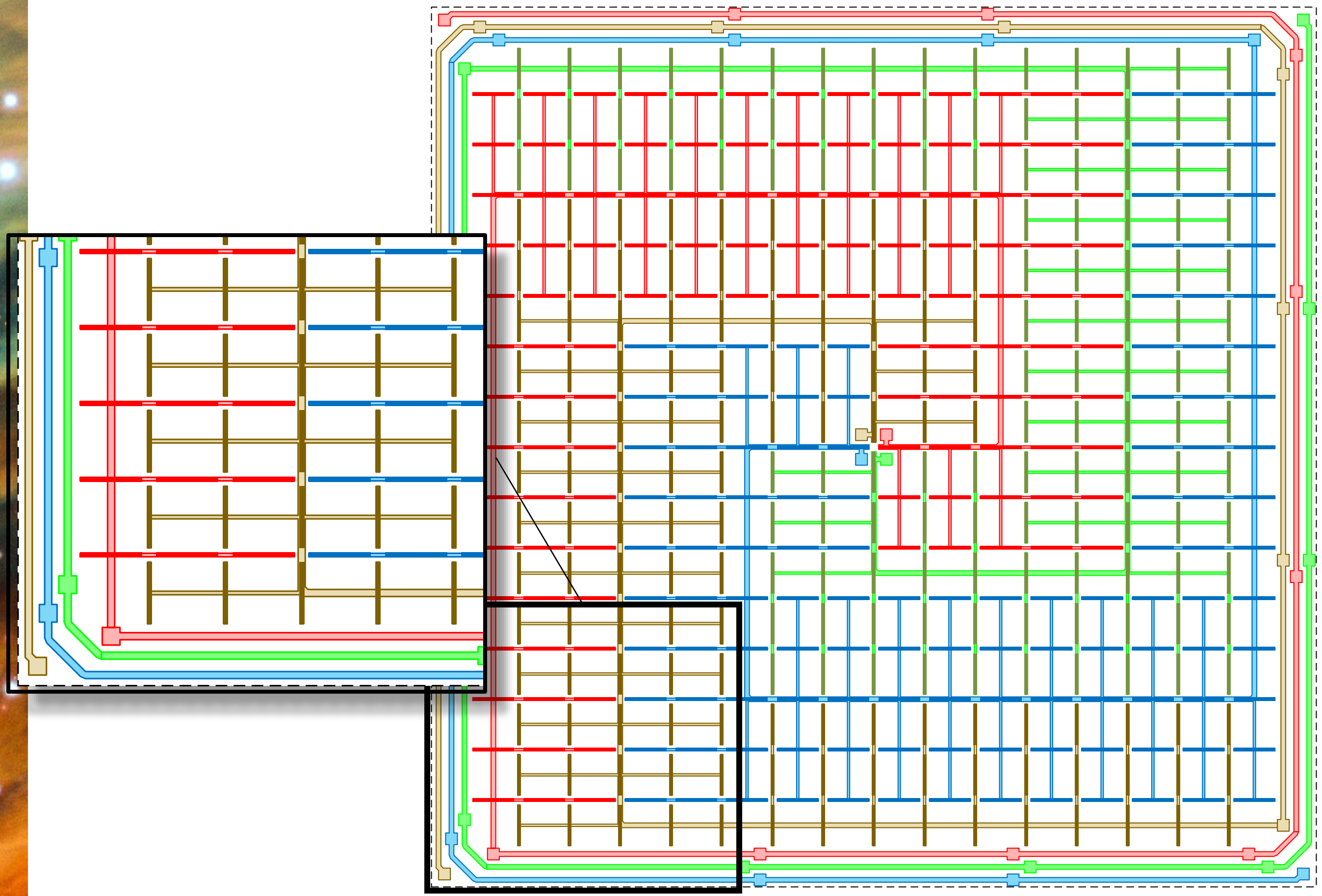


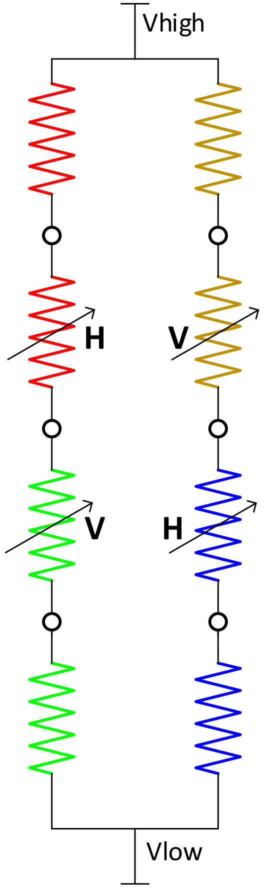


Electro-thermal scheme of the pixel

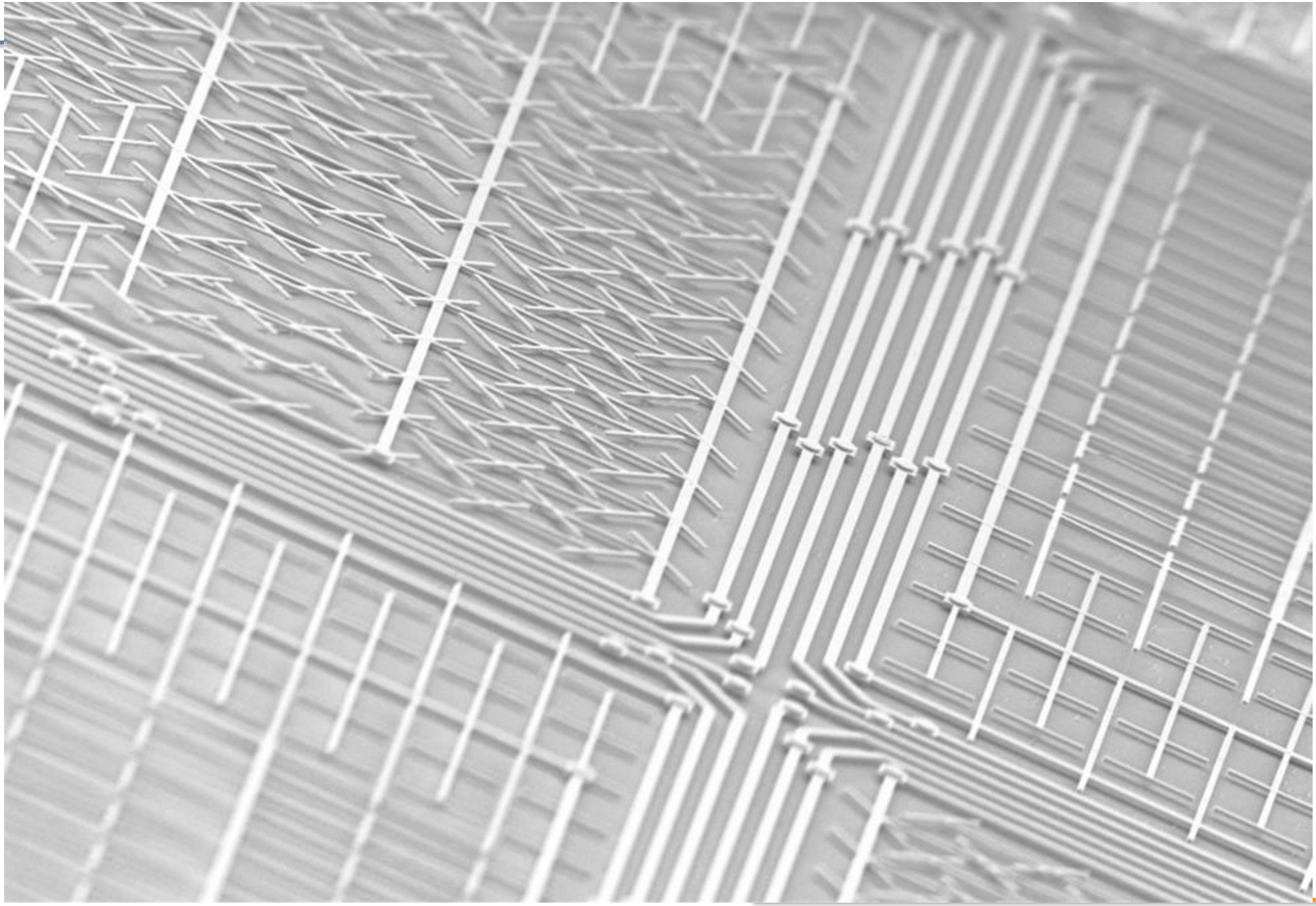


H+V Dipoles

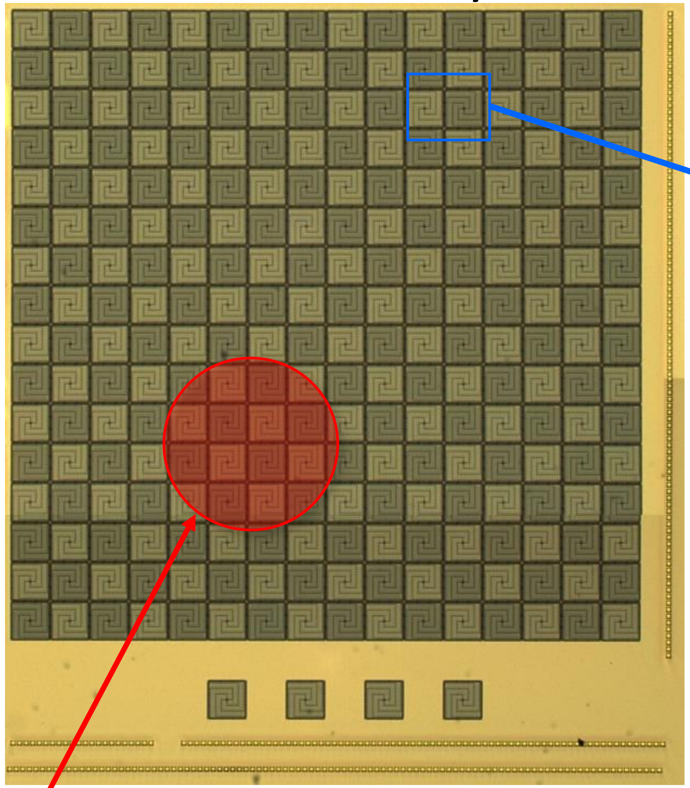


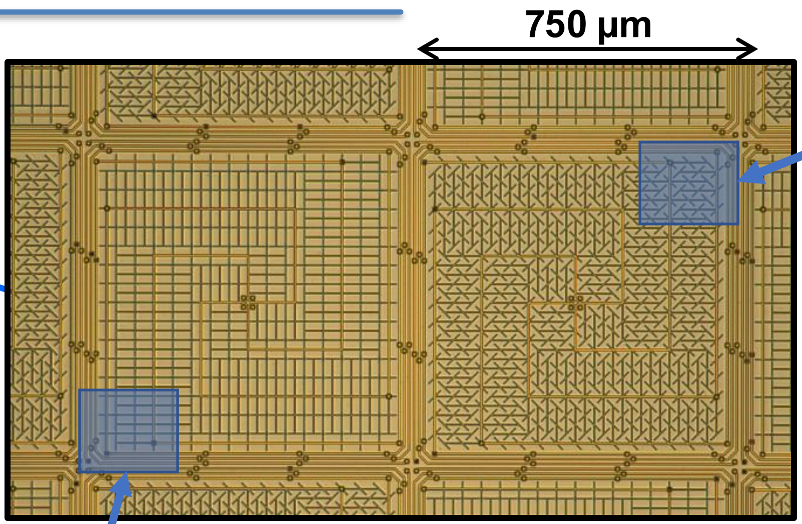


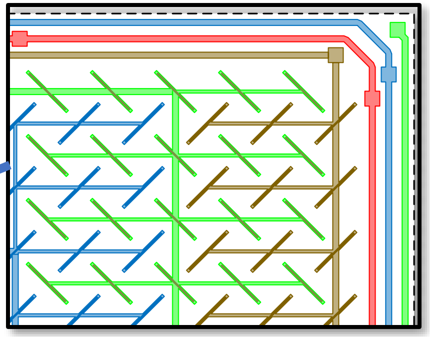
- Classical Wheatstone Bridge
- 6 points of measurement for the prototypes (will be optimized in future versions)

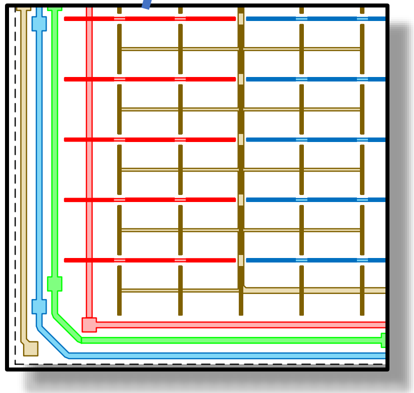


The SPICA BBOP test arrays (for the 100 µm band)









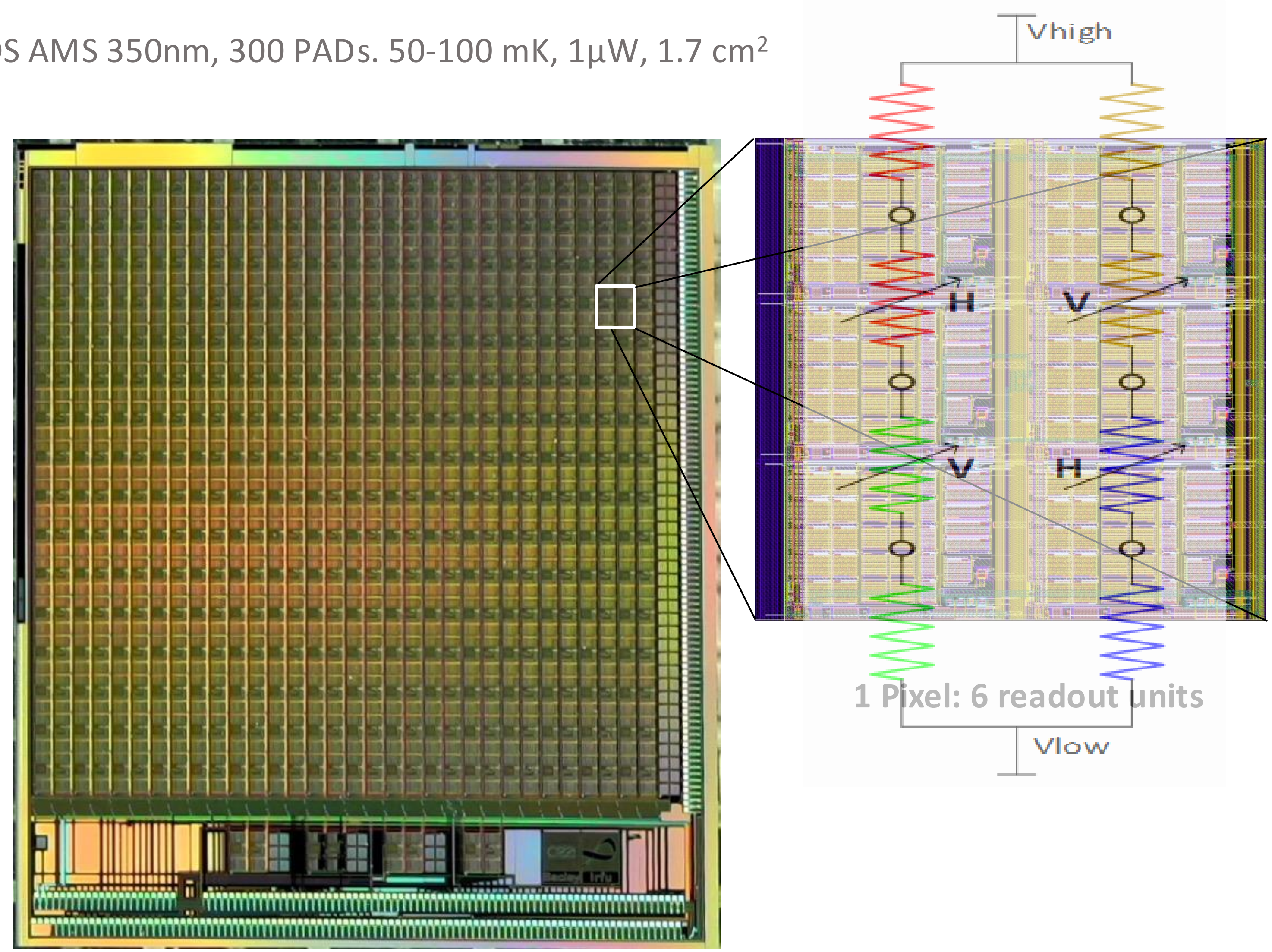
Airy Disc @ 70 µm
Nyquist sampling –> we get Stokes parameters

- This design enables
  - Very good optical coupling without horns or Si lenses
  - Full knowledge of Stokes parameters inside the Airy disk, without polar. modulation

« ECLIPSE » : the 50 mK readout electronics

256 pixels with 6 readout units in each pixel=>1536 readout units

CMOS AMS 350nm, 300 PADs. 50-100 mK, 1µW, 1.7 cm^2



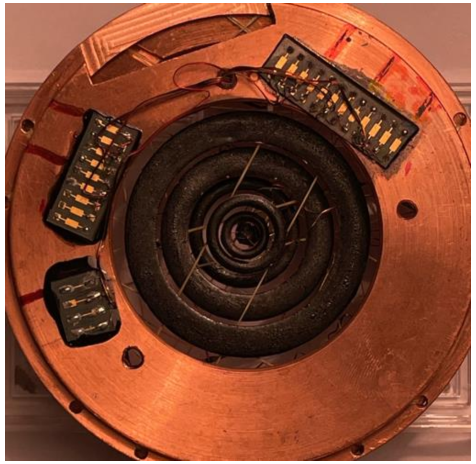
With this Wheatstone bridge circuit, for each pixel we get :

- **Differential polarization unbalance between H and V signals**
- **Differential amplitude signal**

The ADC's are optimized to adapt to the **very different dynamic ranges.**

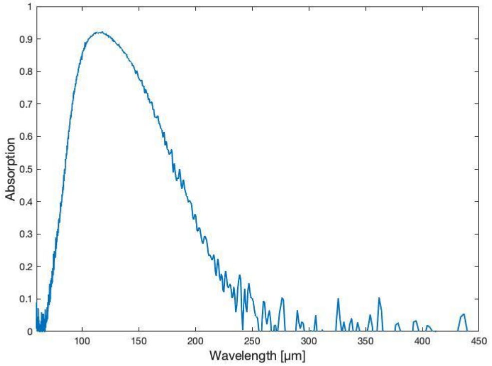
Testing the Arrays

Extreme challenge : the optical background is ~ fW/pixel



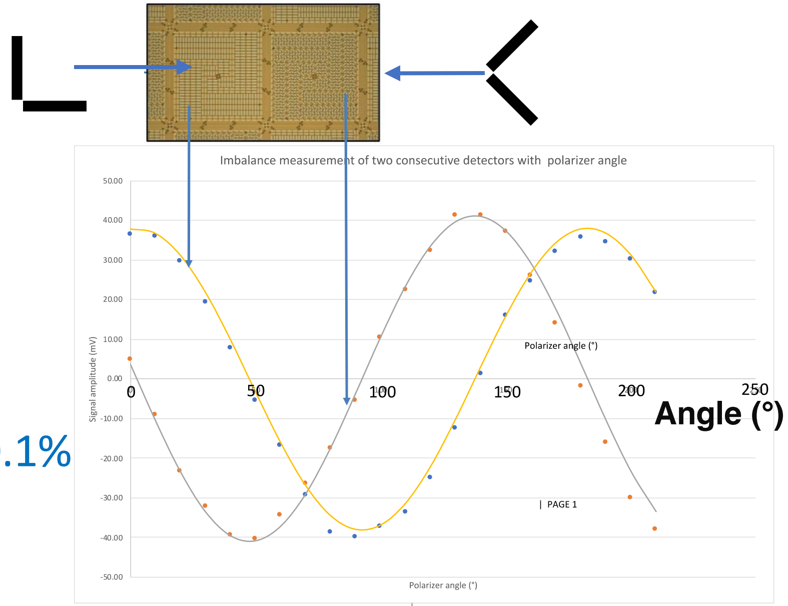
30K Optical source, using concentric emitting rings

Pixel Absorption
> 90% at 100 µm

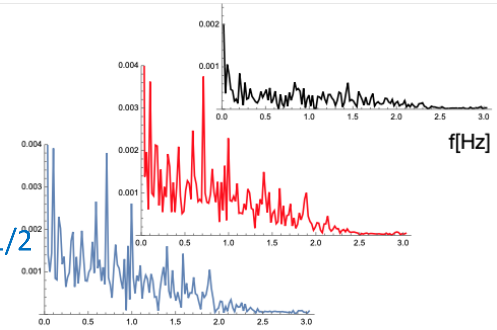


(Cryogenic FTS)

Polarimetry
Cross pol ~ 0.1%



Noise / Sensitivity
NEP = 1.4 10^{-18} W/$Hz^{1/2}$

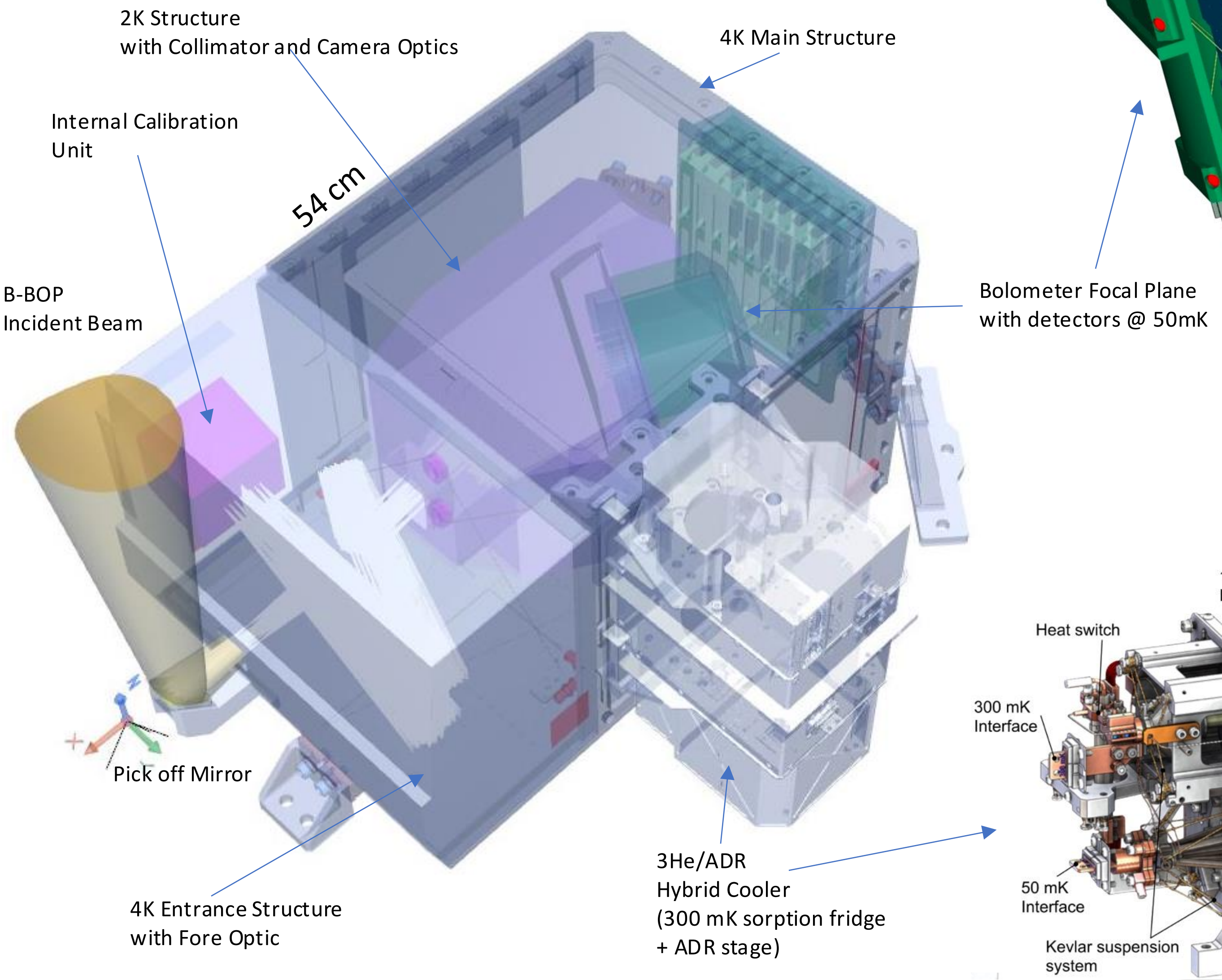


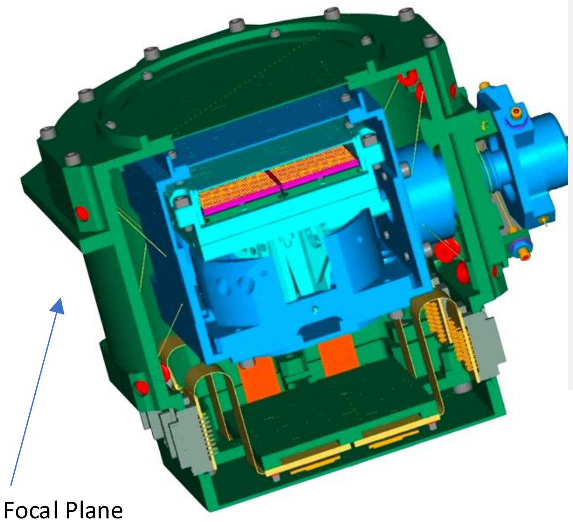
- Main parameters have been measured at cold temperature
- Very good results (***NEP Goal for SPICA/BBOP reached***)
- Challenges : thermal issues (readout currents), full MUX demonstration

L. Rodriguez, SPIE 2024

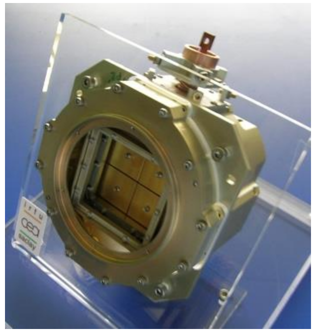
B-BOP, the instrument on SPICA

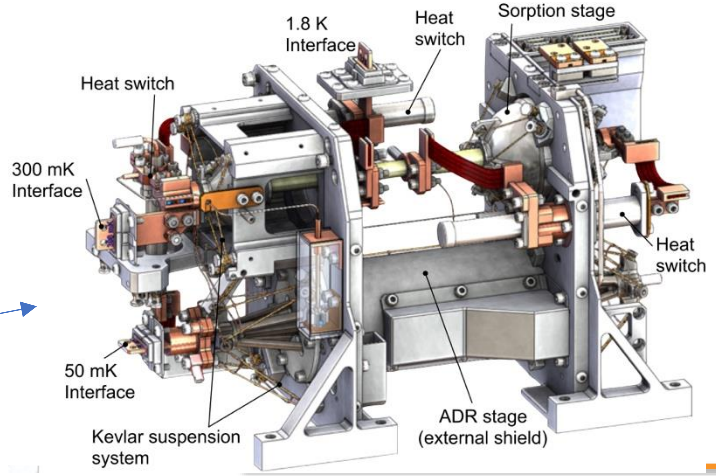
« Simple & Compact Design » : No moving part, no rotating plate (except for calibrator unit), no **Magn. Shield.**
Big Advantage on the System Point of View





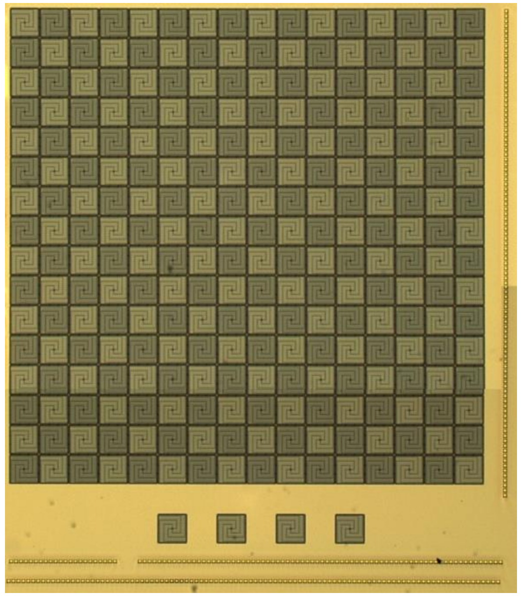
- The Focal Plane Assembly contains 6 bolometer modules (1344 bolometers in total).
- It is a « 3 levels » system : 2K housing, 300mK and 50mK stage (structures suspended by Kevlar wires)



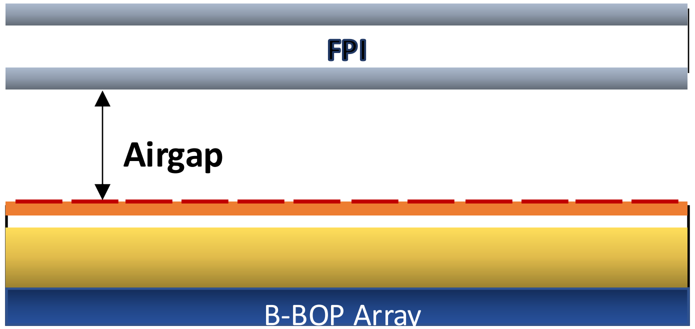


- Mass ~ 25 kg (63 kg including warm electronics)
- Power : 86 W (warm electronics)
- Power dissipation @ 50 mK ~1 µW

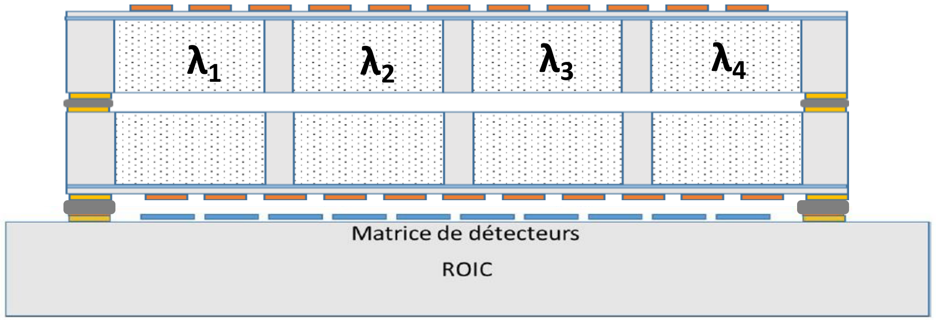
Adding (mid-R) Spectroscopy to the Array



(1) A Compact Scanning Fabry-Perot

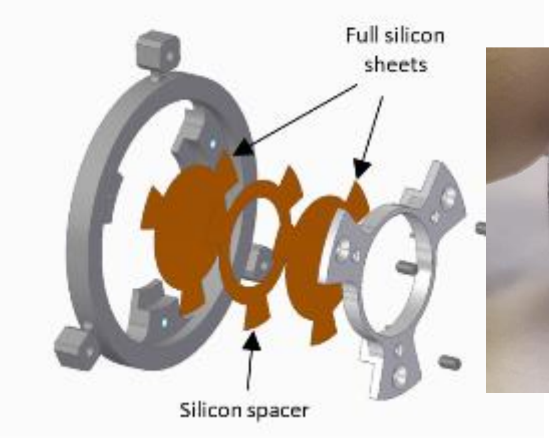


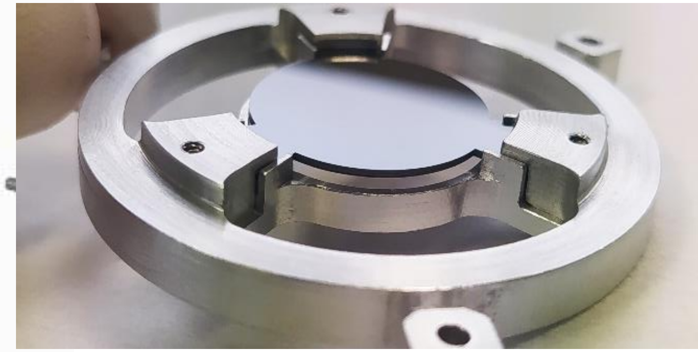
(2) A Bayer Filter Array

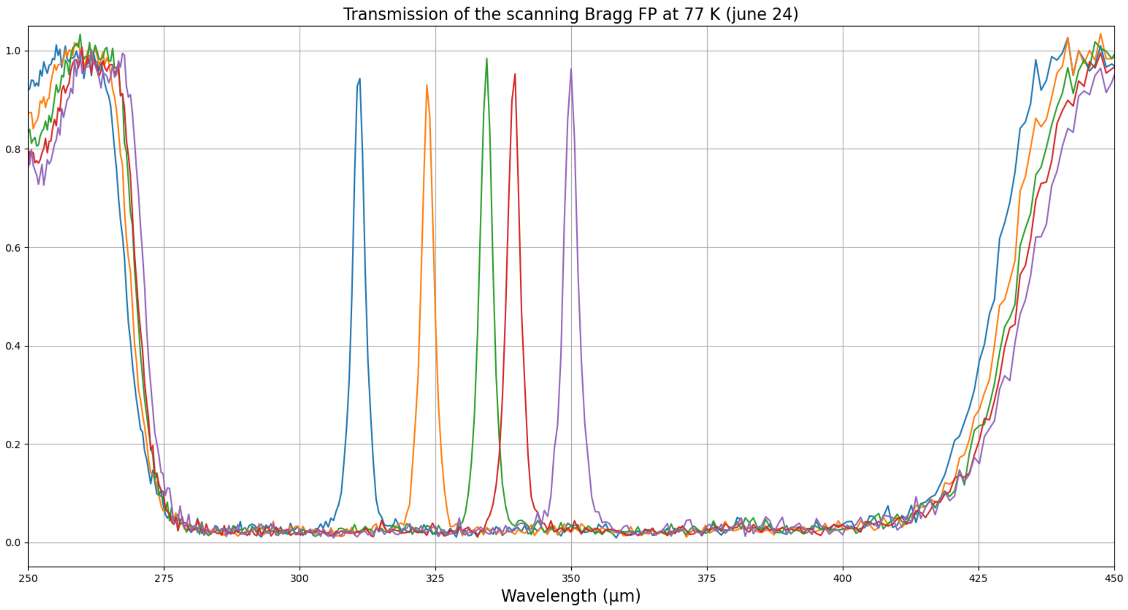


Spectroscopy – Preliminary results (R ~ 200 / 300)

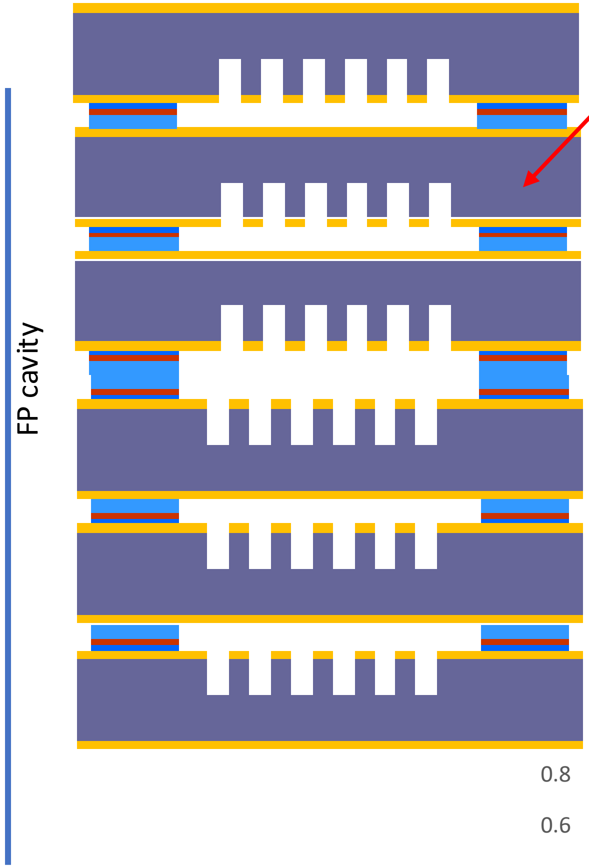
Adjustable cryogenic Fabry-Perot made of Si Bragg mirrors

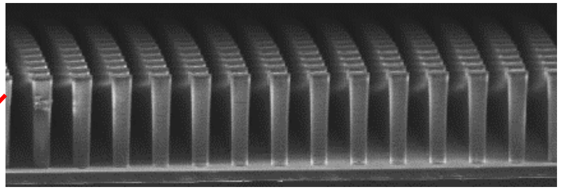


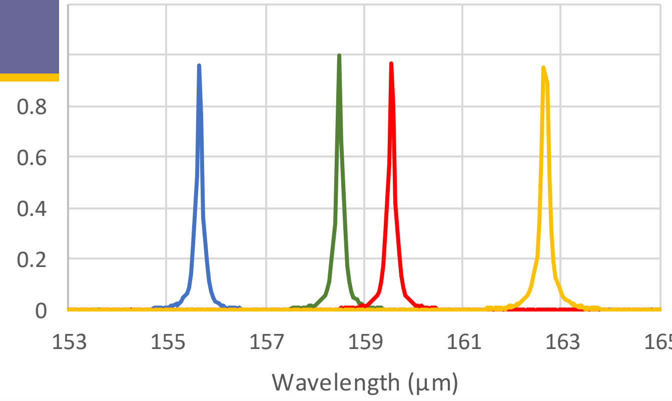




Stationary array of Fabry-Perot made of microstructures Si.







What's Next?

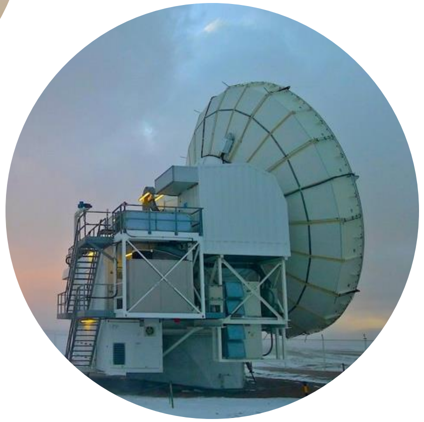
- CO-PILOT (?)

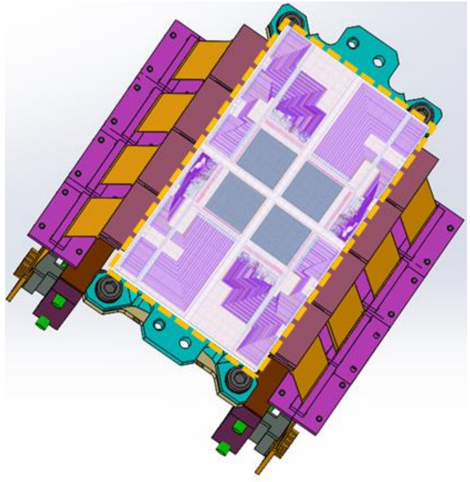
(C+ @ 158 µm)

- POLARYS – Future Large ground-based telescopes

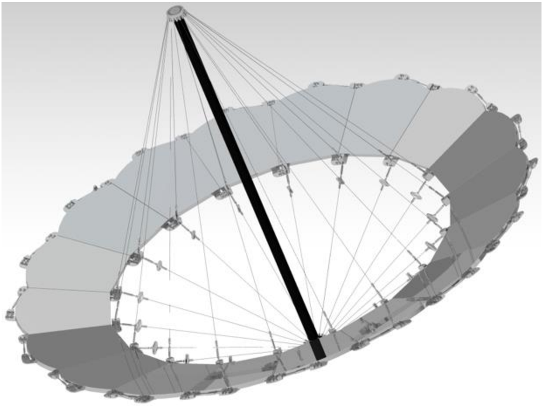
(atmospheric bands at 350 / 450 µm)

POLARYS



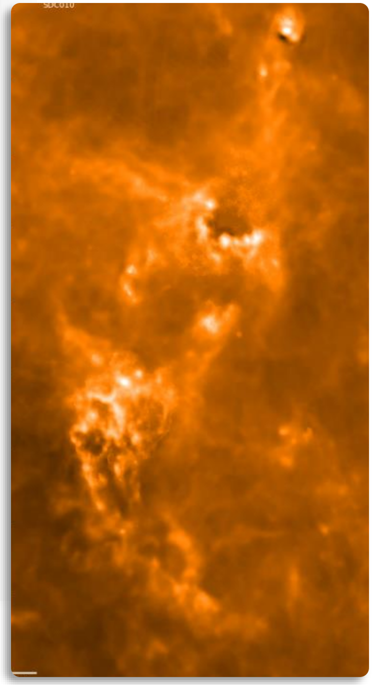


- The TALC Deployable Space Telescope



Summary

- We push Silicon technology to its limits : high sensitivity & in-pixel functions
- The in-pixel polarimetry enables **very compact and simple instrument** (no moving part) – **Optimization of the system**
- Robust & High TRL : Herschel heritage, PhaseA study for SPICA
- Challenges on RO electronics / Detection layer on thermal aspects / MUX
- Opportunities toward Artemis2, TALC (?)



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Potential development for a future far-IR space mission

- A multi-band polarimetric camera « à-la BBOP », i.e. with photon noise performance and polarimetric capabilities **inside the pixels**

  - Several bands possible between 50 µm and 500 µm. Bands at λ>500µm are possible (our technology has been demonstrated up to the mm), but that requires more R&D for pixel design.

  - Multiplexed 32x32 arrays should be possible to build (that was the plan for BBOP), and can be abutted on 3 sides to build large focal planes.

  - For a SPICA like telescope, at 70 µm (BBOP Band 1), a FOV of 7.5’x3.7’ could be reached with a focal plane made with 4 x 2 arrays.