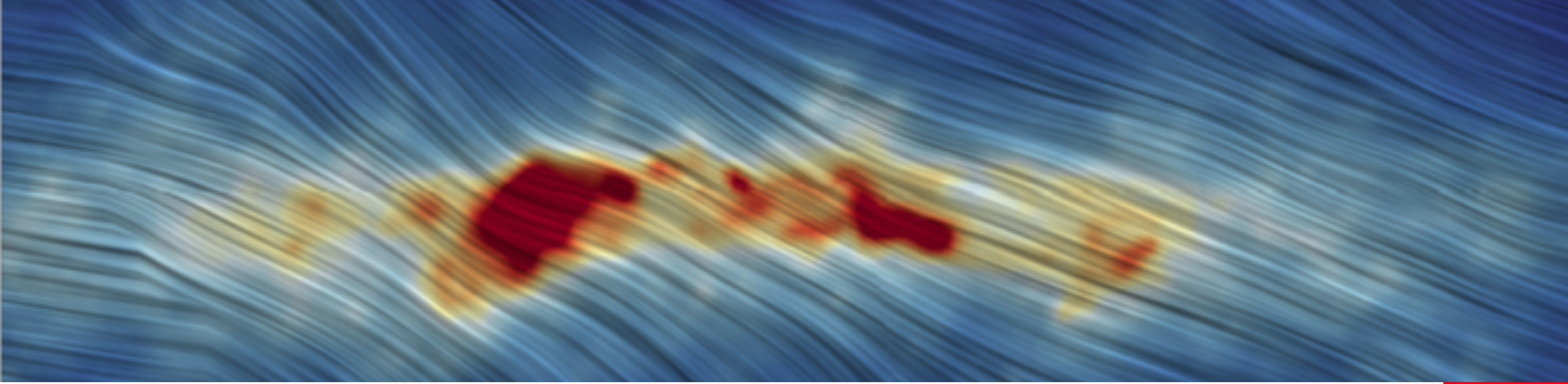
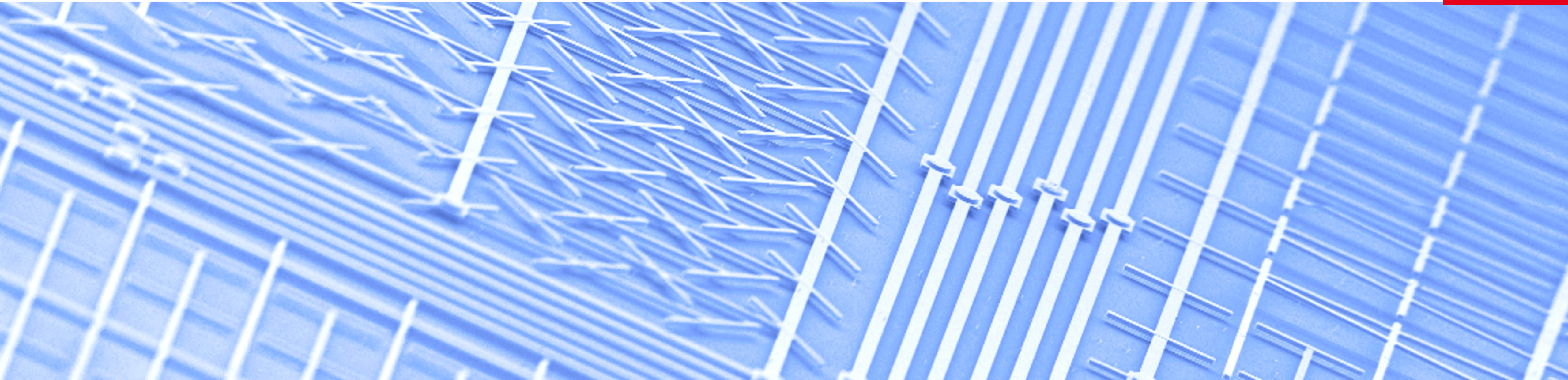
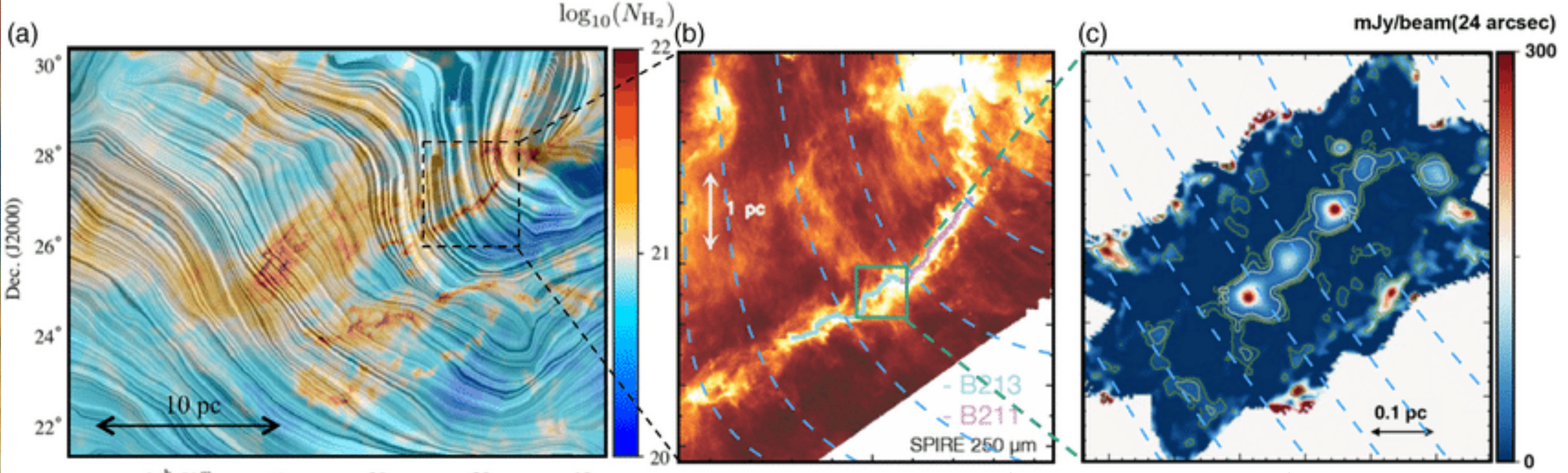


POLARYS a polarized bolometer camera

Vincent Revéret et al

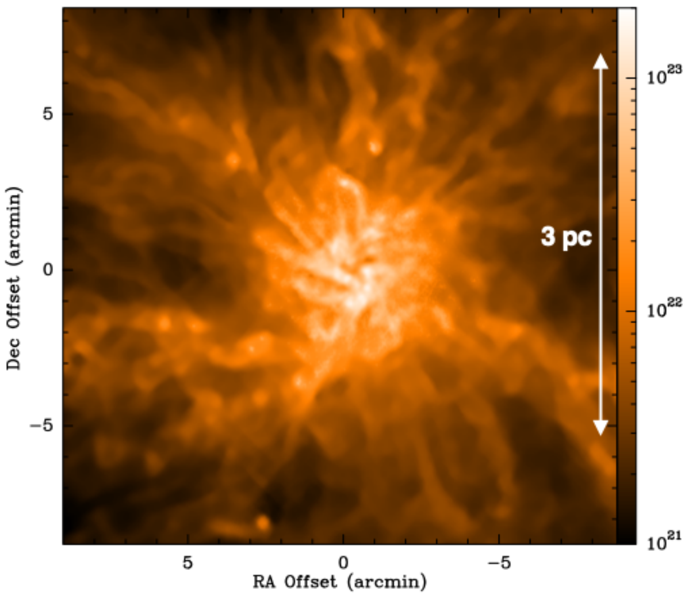


Unveiling the role of magnetic fields in filaments

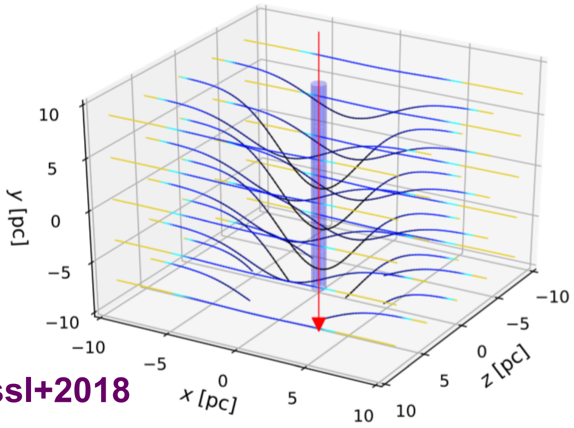


Taurus Molecular cloud (André et al PASP 2019)

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

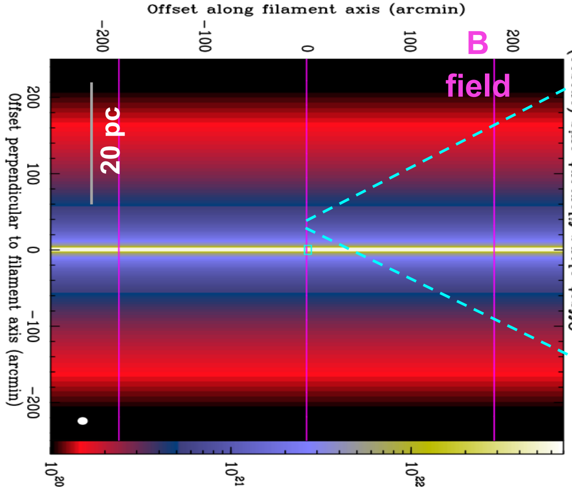


Plausible model of the B field in a SF filament

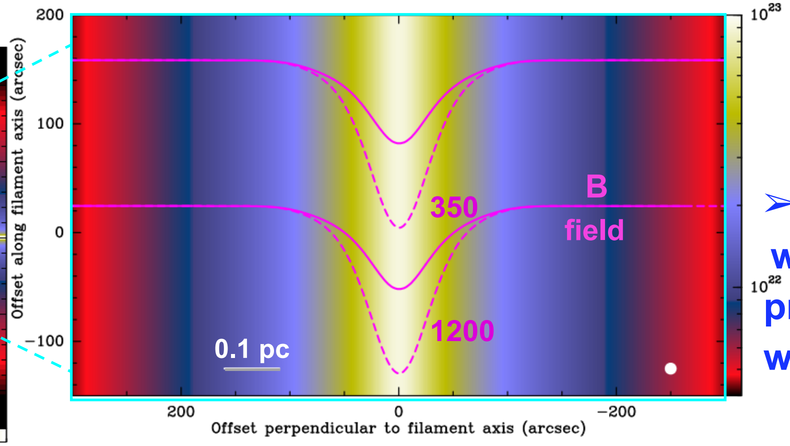


cf. Reissl+2018

Planck resolution



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



(for a model filament at d = 400 pc)

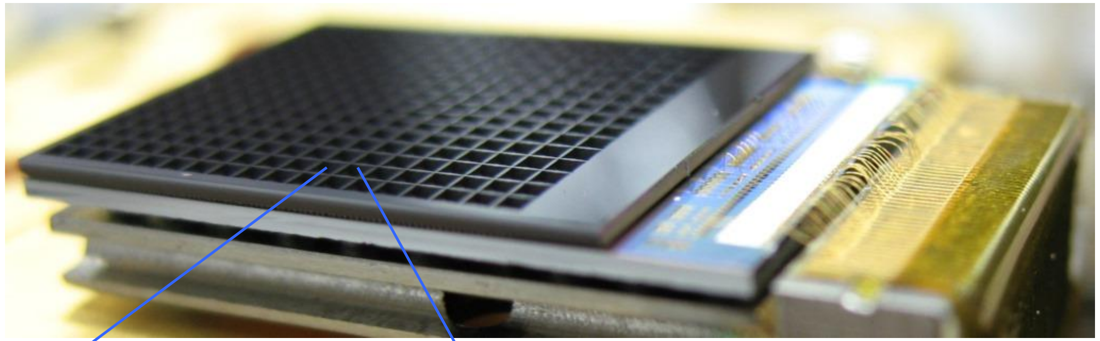
➢ Different wavelengths probe different depths within the filament

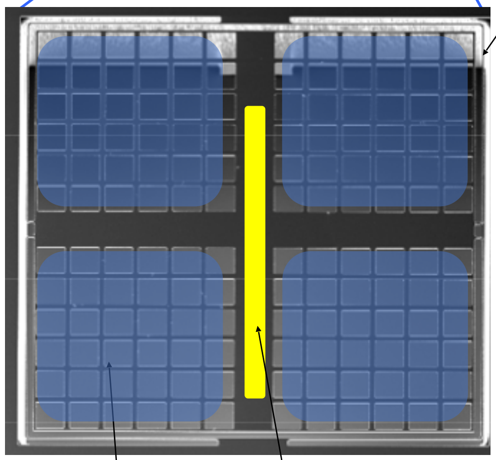
-> Needs for a high sensitivity polarimeter camera in the submm

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



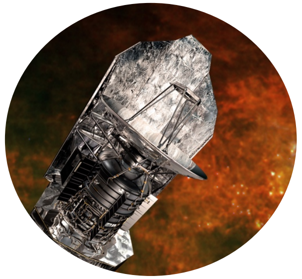


- « All Silicon » design
- **Very High impedance (~ GOhm)**

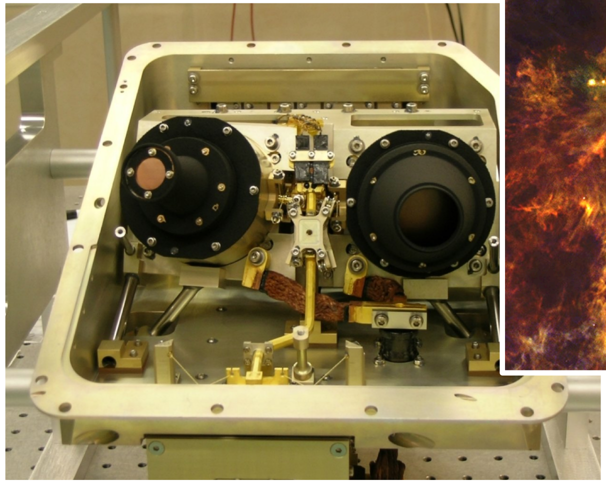
$$R = R_0 \exp\left(\sqrt{\frac{T_0}{T}}\right) \exp\left(-\frac{qL_{(T)}E}{kT}\right)$$

- **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)



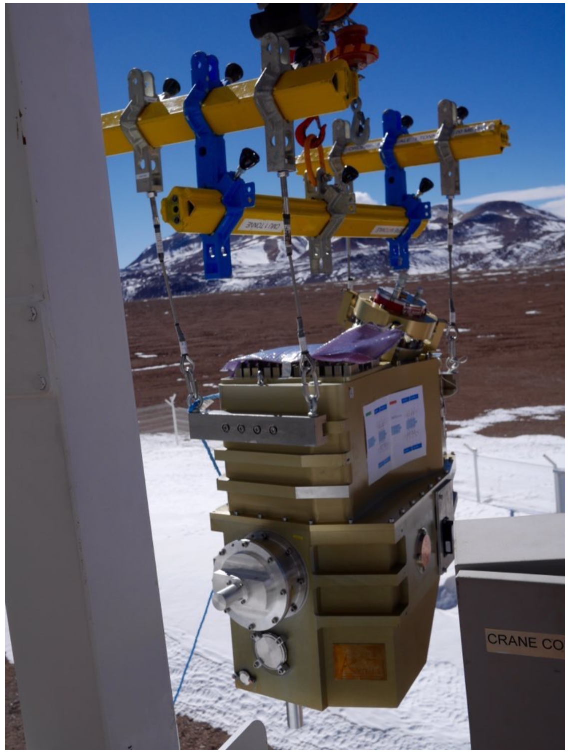
- 2560 pixels, 3 bands (70, 100, 160 µm)
- 30% of observing time, most used instrument
- (40 % if parallel mode included)

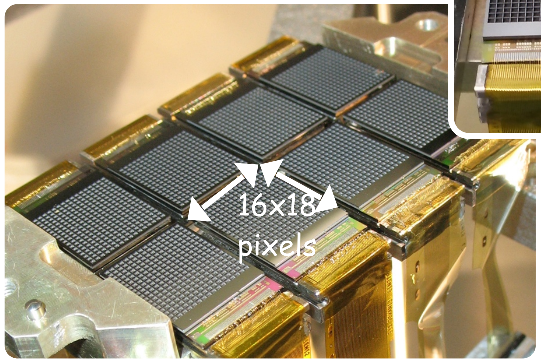


Horsehead Nebula (André et al)

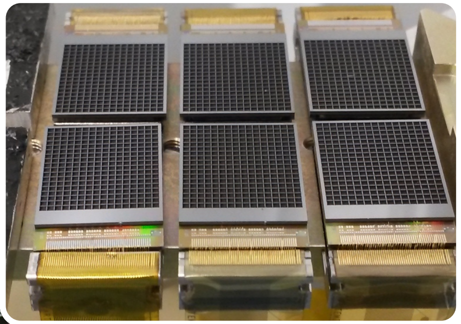
Cygnus X
Herschel PACS & SPIRE
Credits: ESA/PACS/SPIRE/Martin Hennemann & Frédérique Motte

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





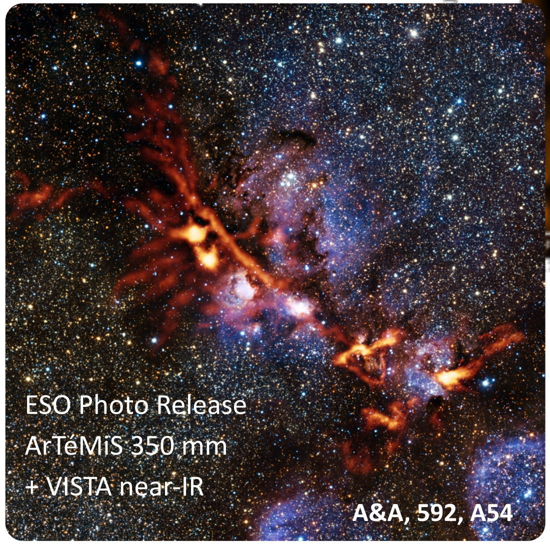
Artémis 350 µm focal plane

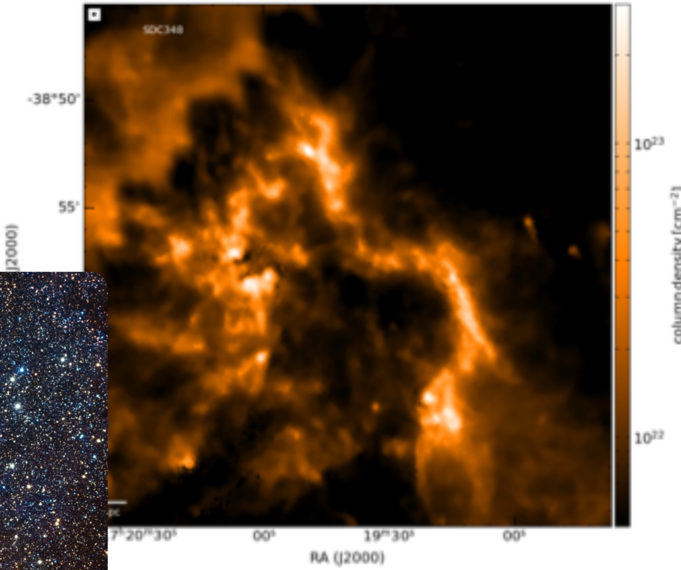


Artémis 450 µm

- 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

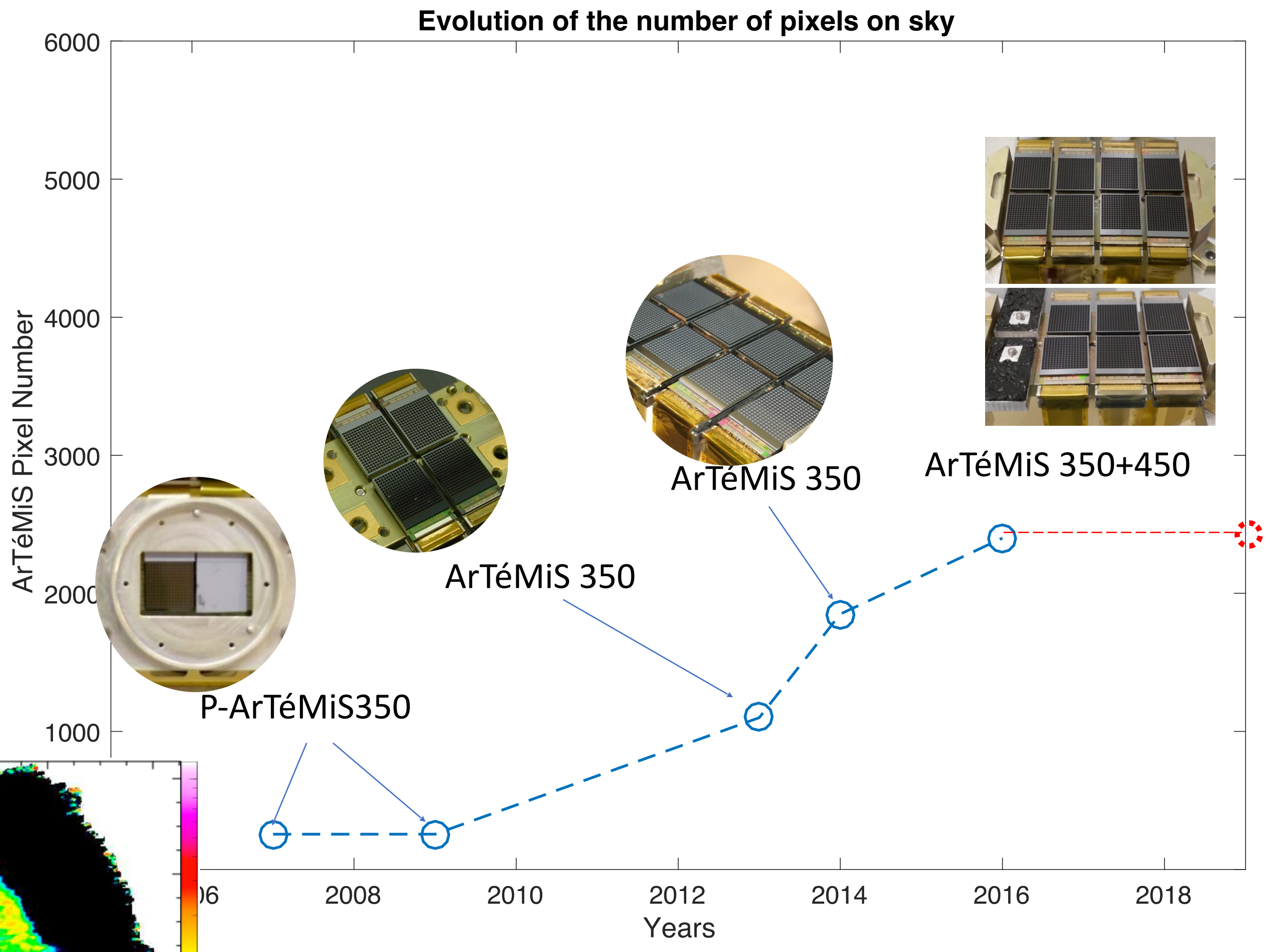


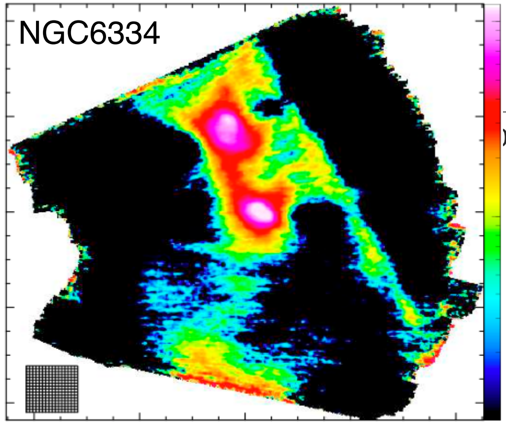


Column density map of the cloud SDC348

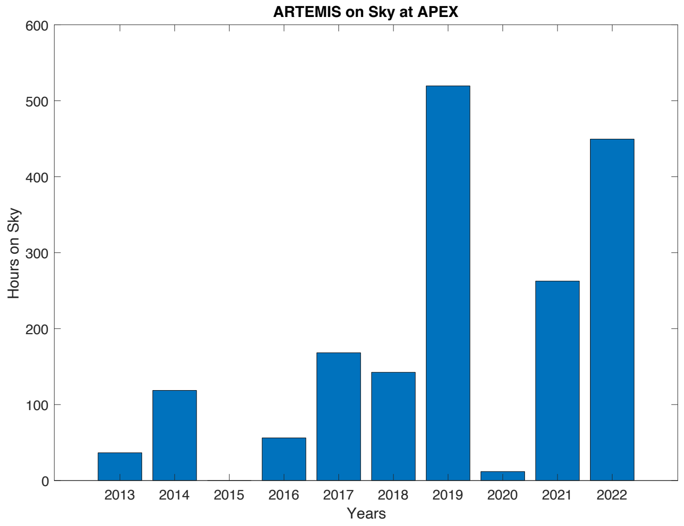
(M. Mattern, A&A 2024)

ArTéMiS - évolution





RCW106 CAFFEINE N_{H2} map overlaid on VLTST optical image (2024)

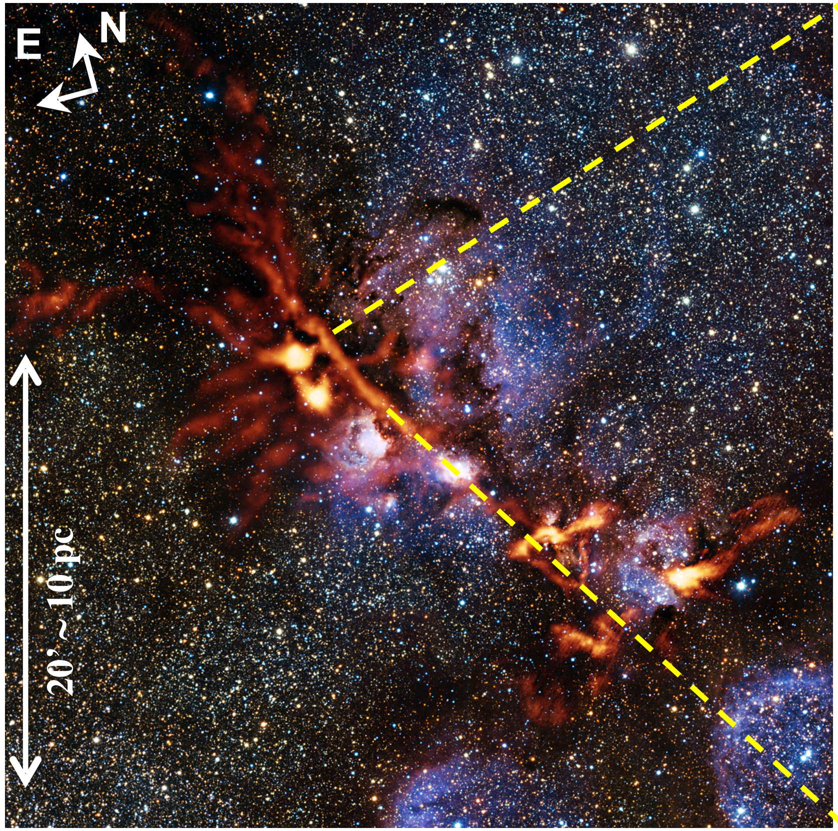


- 1765 hrs observed between 2013 and 2022,
- 56 projects → 5 Chile, 25 ESO, 26 OSO
- 2019 to 2022 → 1250h,
- 29 publications since 2008 and 19 since 2013

APEX/ArTéMiS as a « pathfinder » for higher-resolution studies of cloud/ filament structure with ALMA and JWST

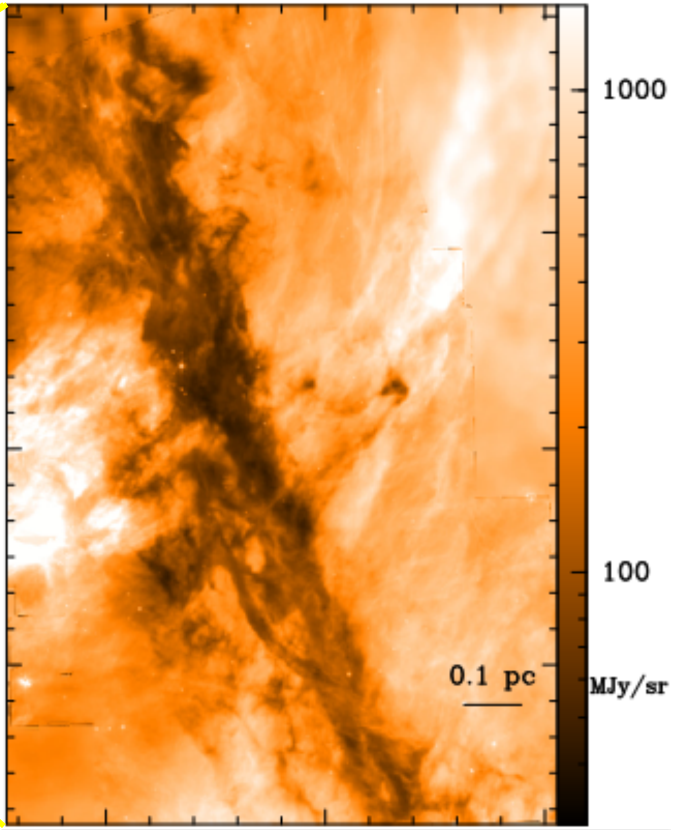
➢ **ArTéMiS bridges the gap in resolution between *Herschel* and ALMA + JWST**

ArTéMiS 350 μm image of NGC 6334 (d ~ 1.5 kpc)

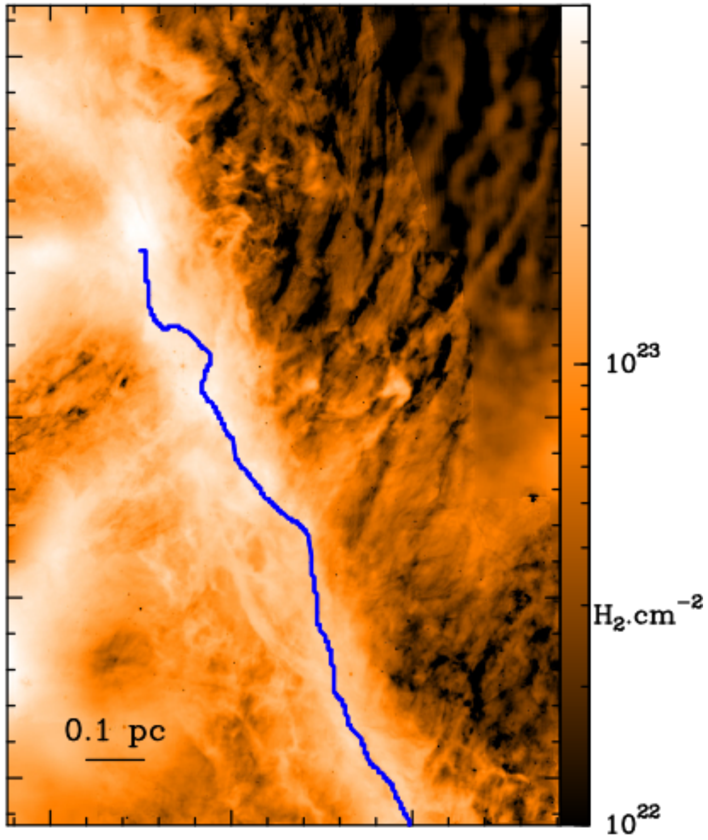


ArTéMiS « first-light » paper
A&A, 592, A54 (2016)

JWST/MIRI 7.7 μm image
→ mid-IR-dark filament



Column density image derived from JWST absorption

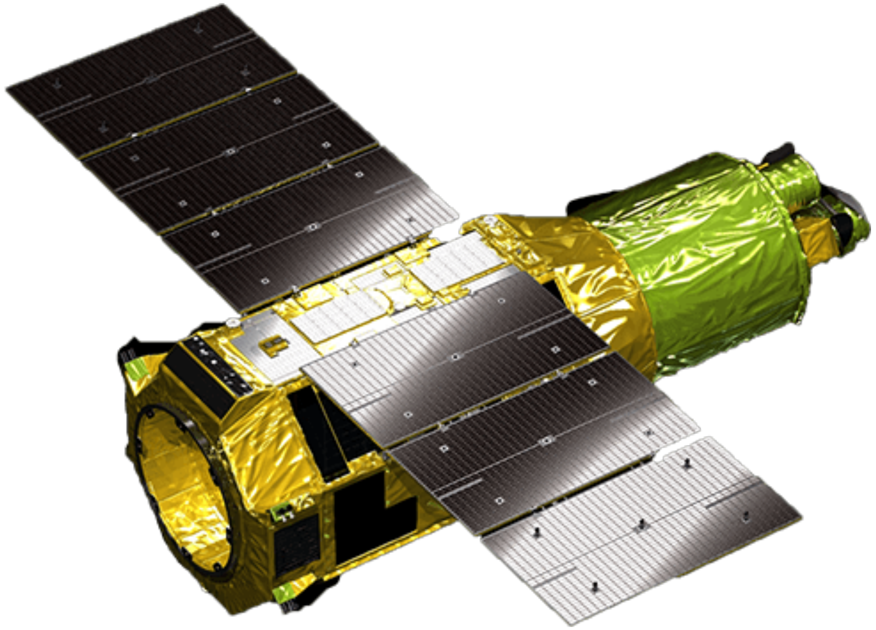


André et al, APJ Let. 2025

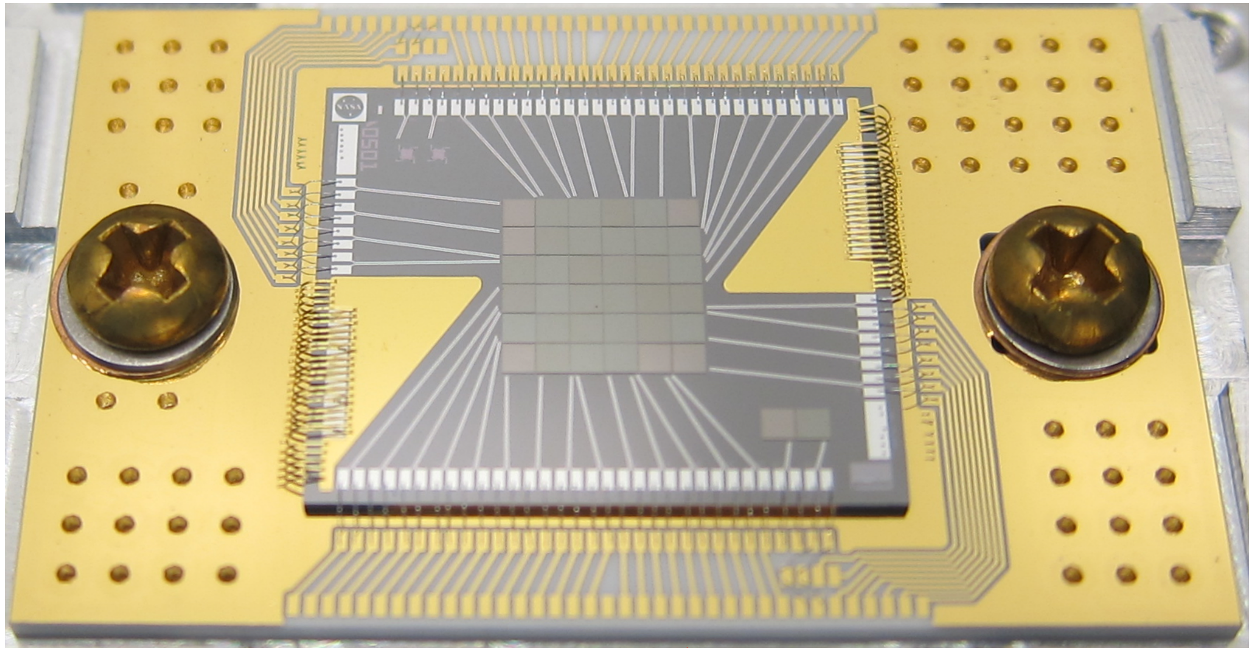
Why Silicon bolometers?

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

RESOLVE onboard the JAXA-NASA XRISM Mission



Launched in 2023

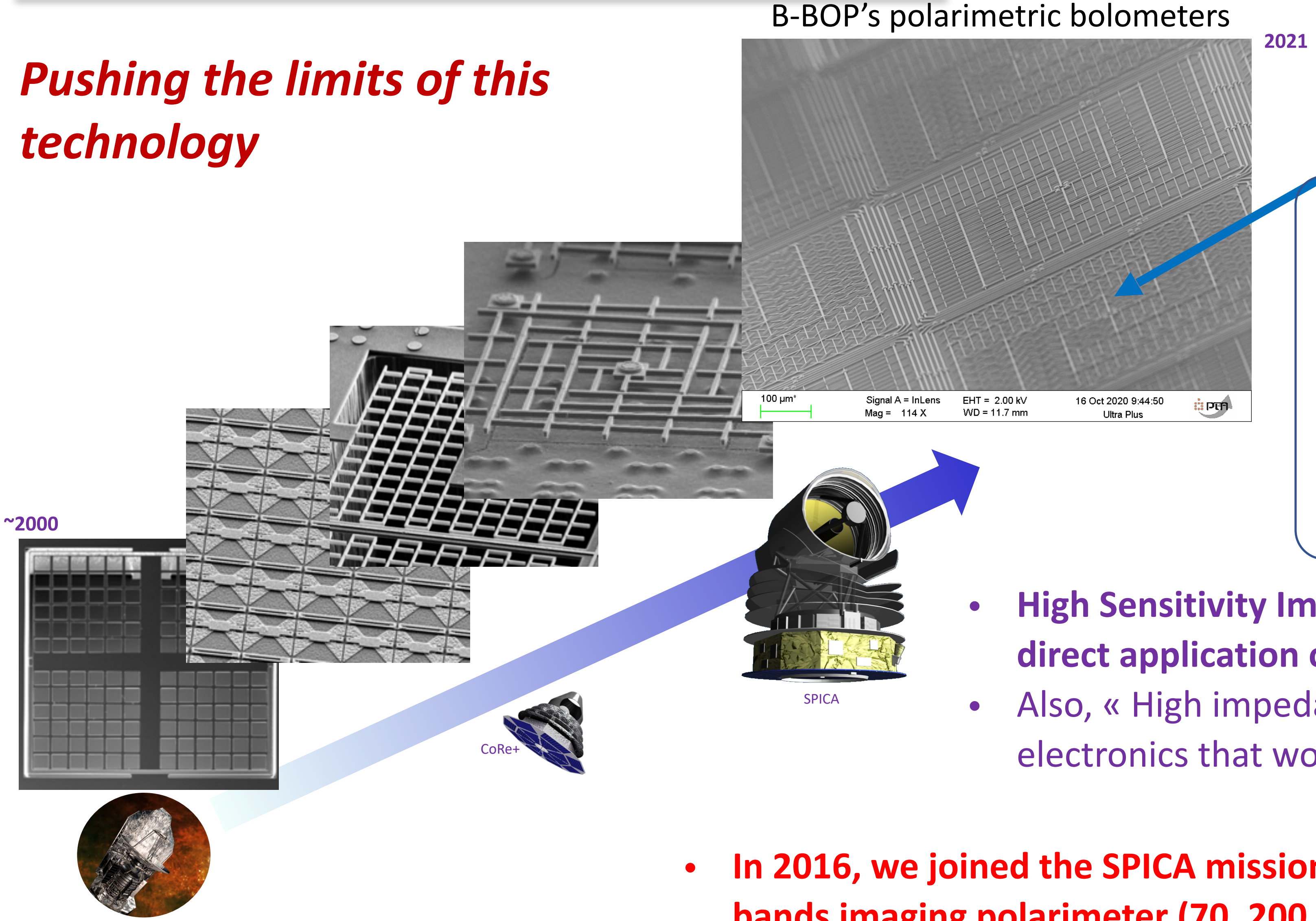


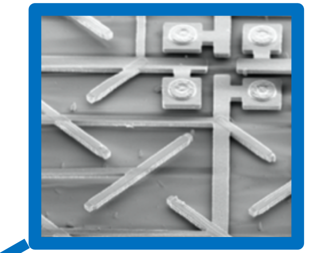
6x6 Silicon µ-Calorimeters from NASA Goddard working at ~50 mK

(with ESA participation)

Why Silicon bolometers?

Pushing the limits of this technology



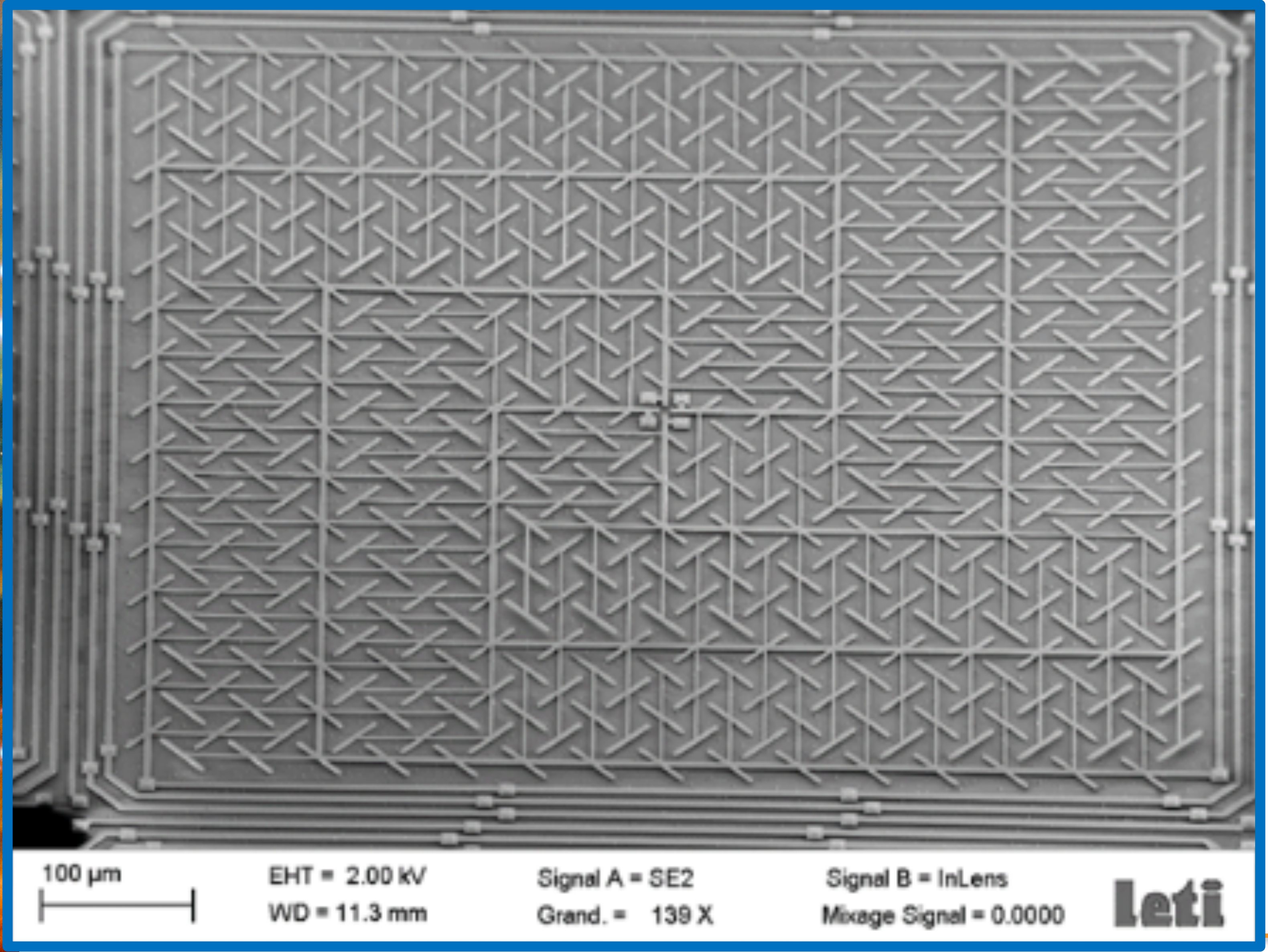


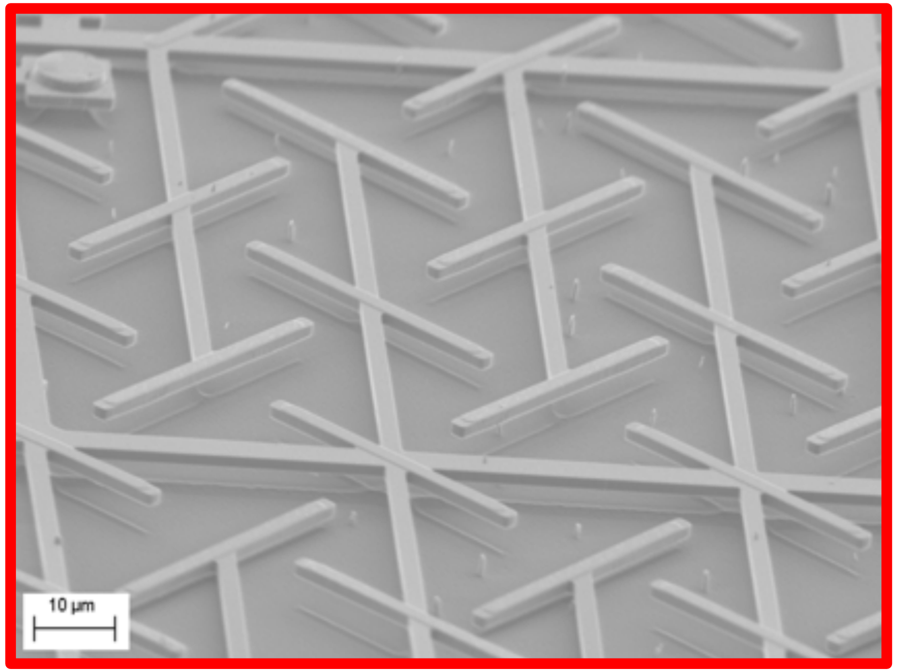
- Silicon is an amazing material : very high thermal resistance can be reached at low temperature => *high sensitivity*
- Si micro-machining enables to design *complex pixel structures to build compact space instruments*
- *No Need of Magn. shielding*

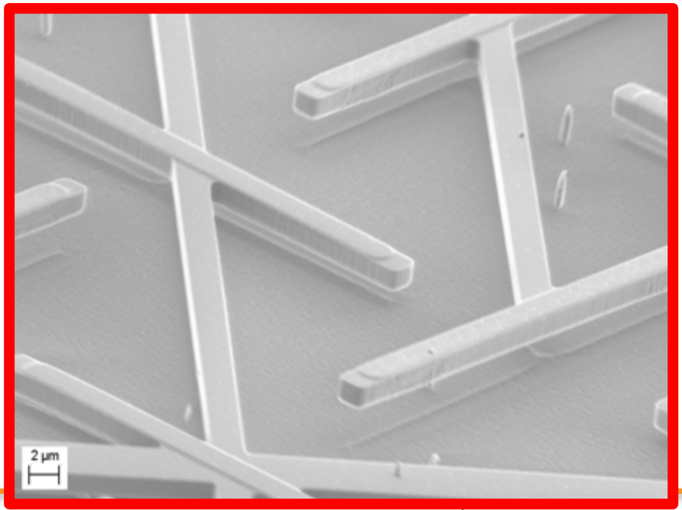
- **High Sensitivity Imaging-Polarimetry inside the pixel is a direct application of these possibilities**
- Also, « High impedance » is compatible with CMOS classical electronics that works at 50 mK (EU CESAR project).

- **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**

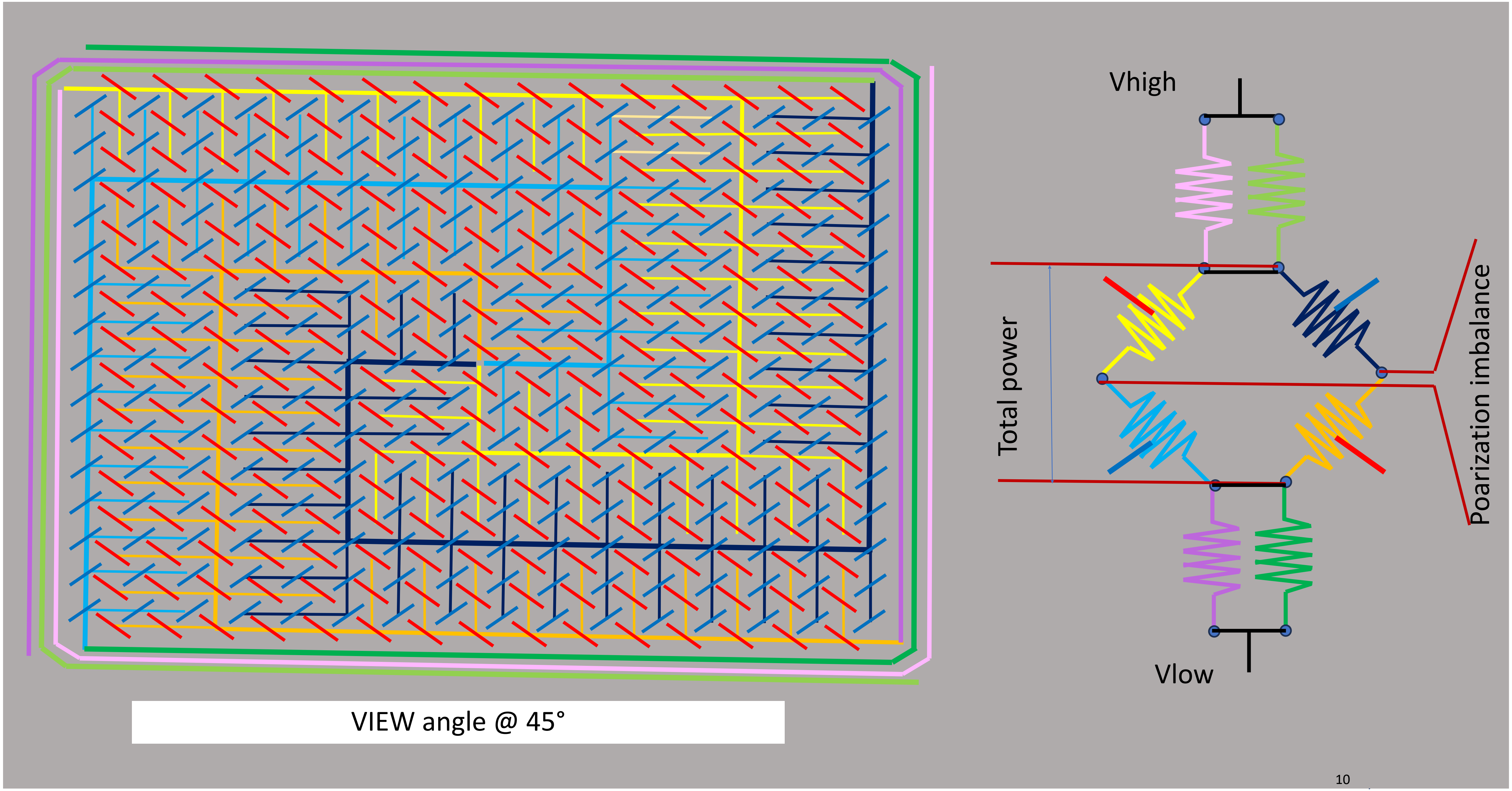
The BBOP detectors

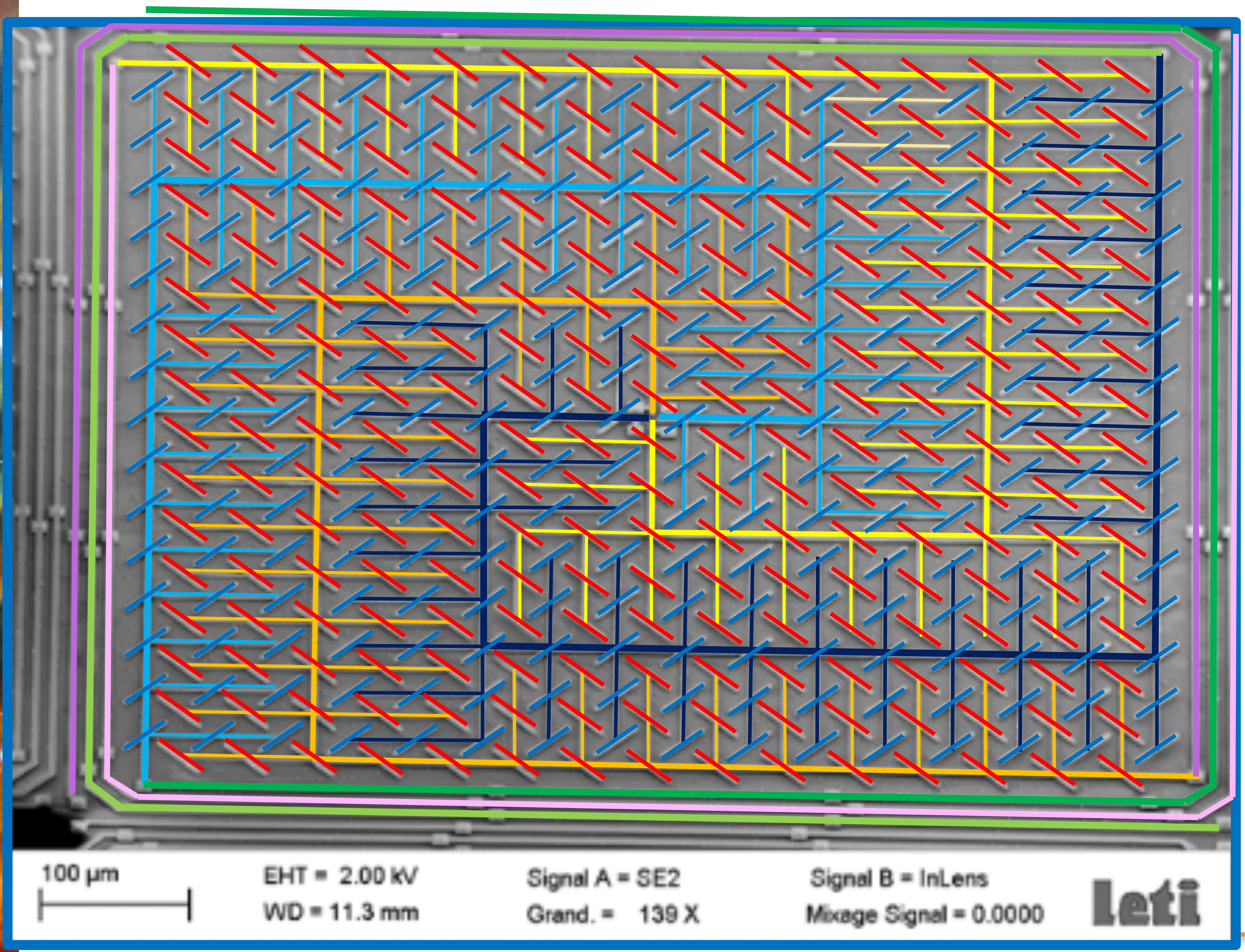






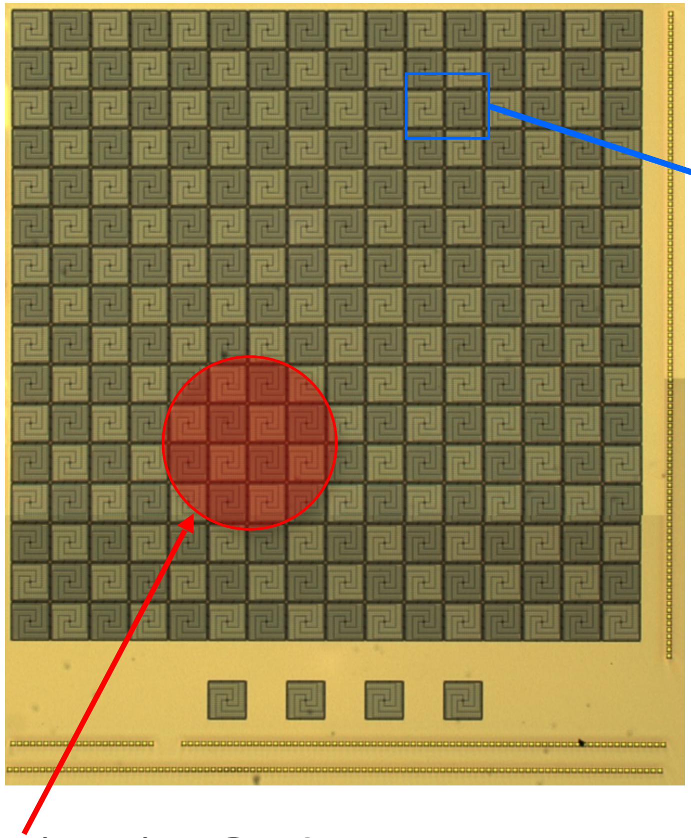
The BBOP detectors

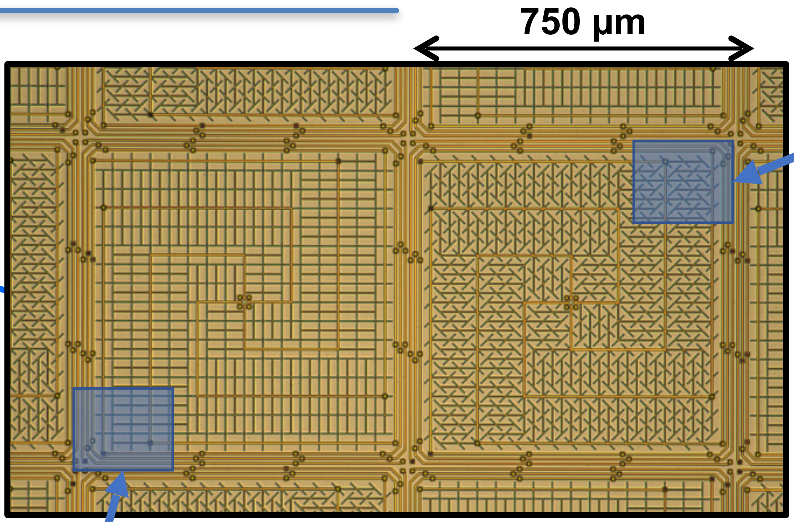


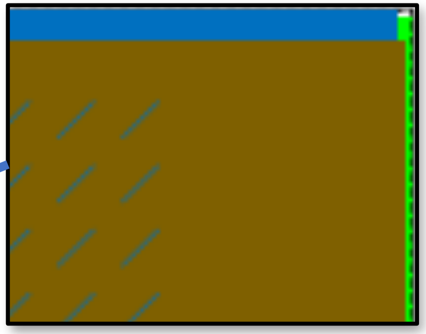

100 µm
EHT = 2.00 kV
WD = 11.3 mm
Signal A = SE2
Grand. = 139 X
Signal B = InLens
Mixage Signal = 0.0000
leti

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

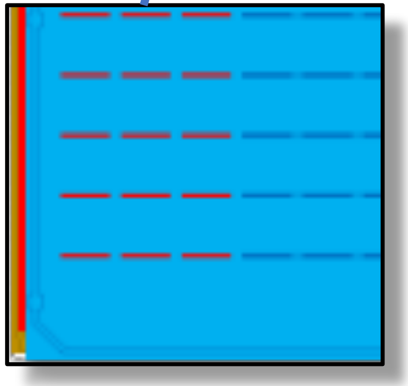
16x16 Bolometer Array







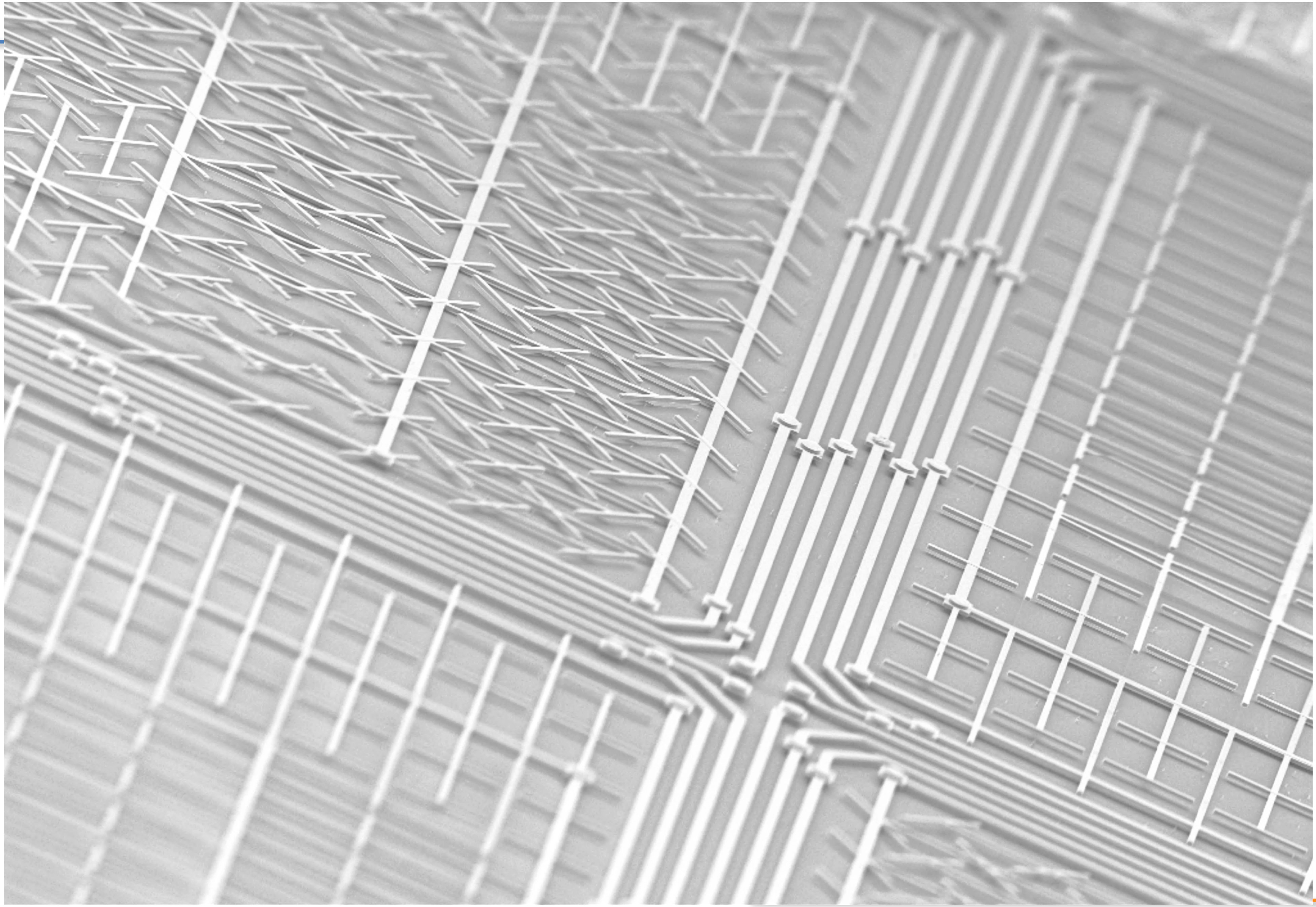
Orthogonal dipoles network



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

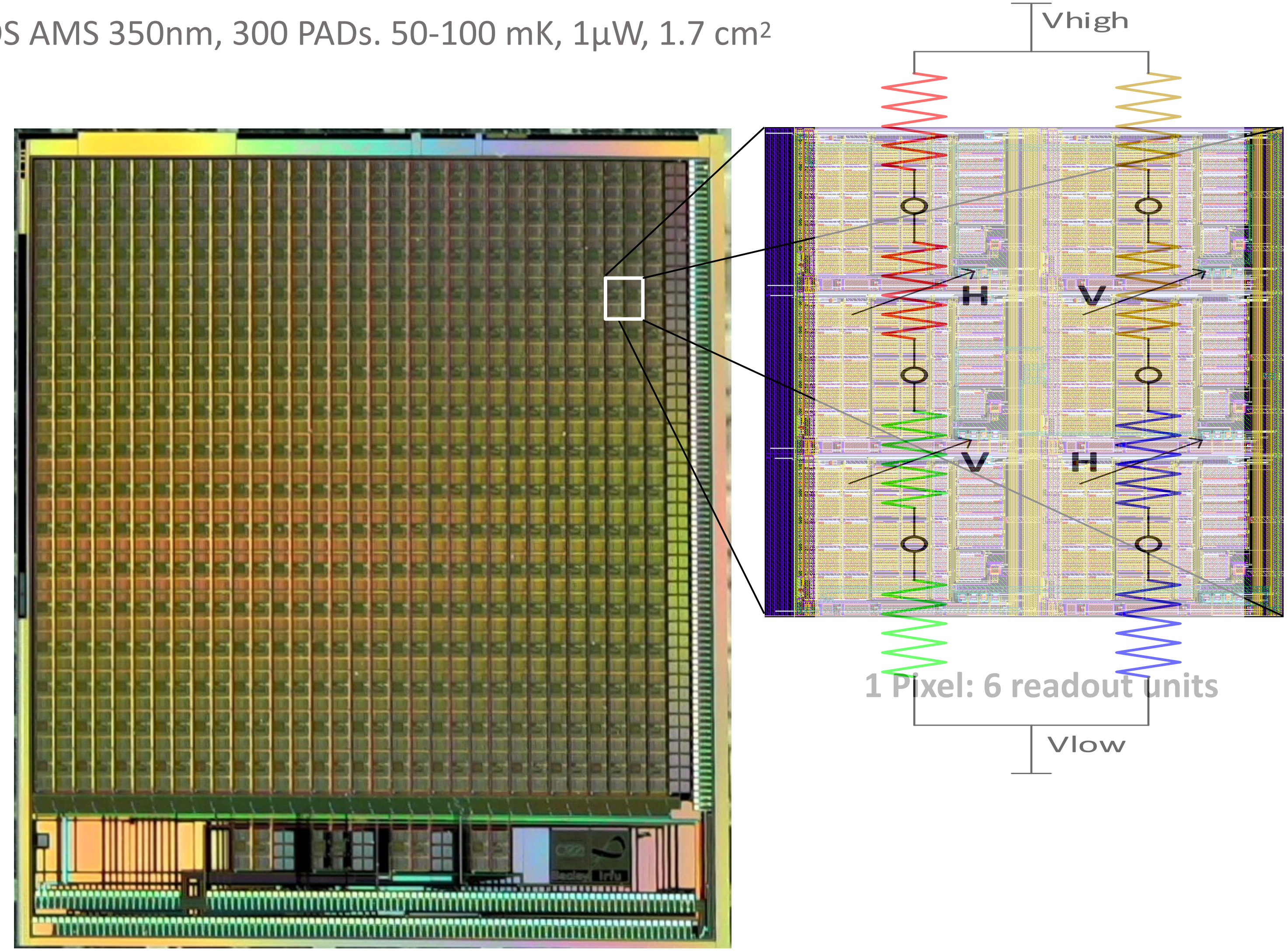
FOCUS Focal Plane Array for Universe Sensing



« 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



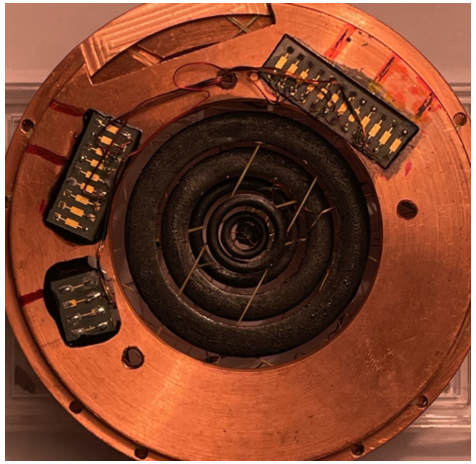
With this Wheatstone bridge circuit, for each pixel we get :

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

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

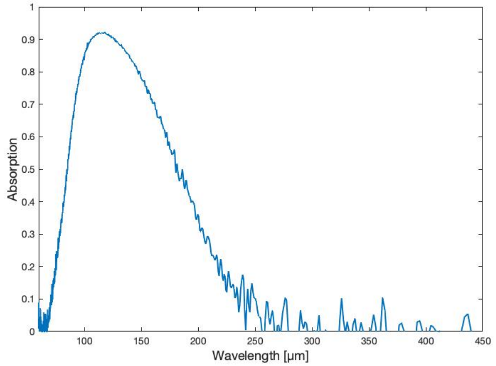
Testing the Arrays

Extreme challenge : the optical background is ~ fW/pixel



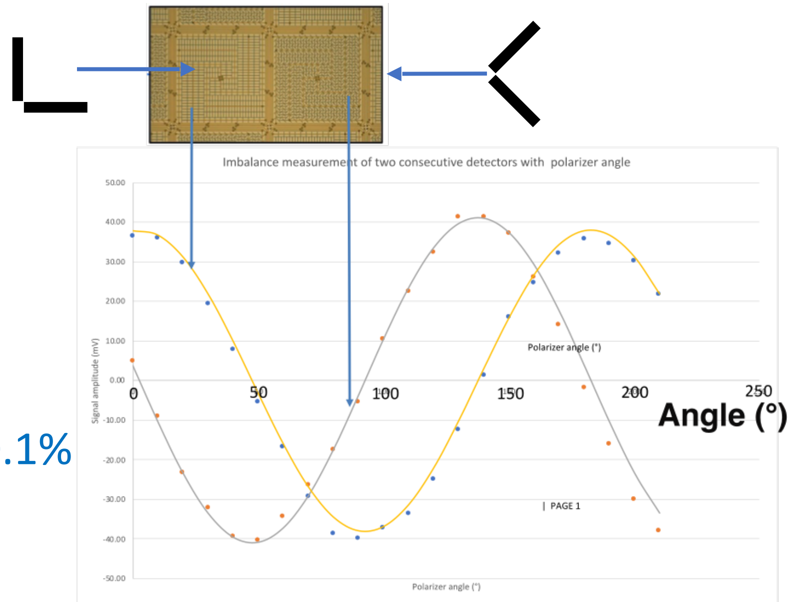
30K Optical source, using concentric emitting rings

Pixel Absorption
> 90% at 100 µm

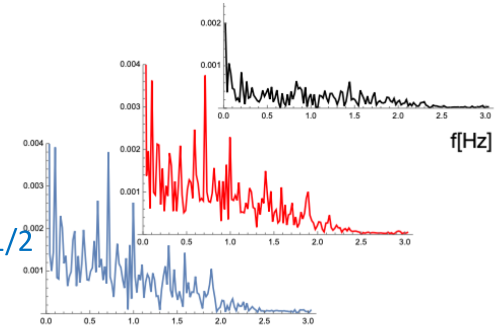


(Cryogenic FTS)

Polarimetry
Cross pol ~ 0.1%



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



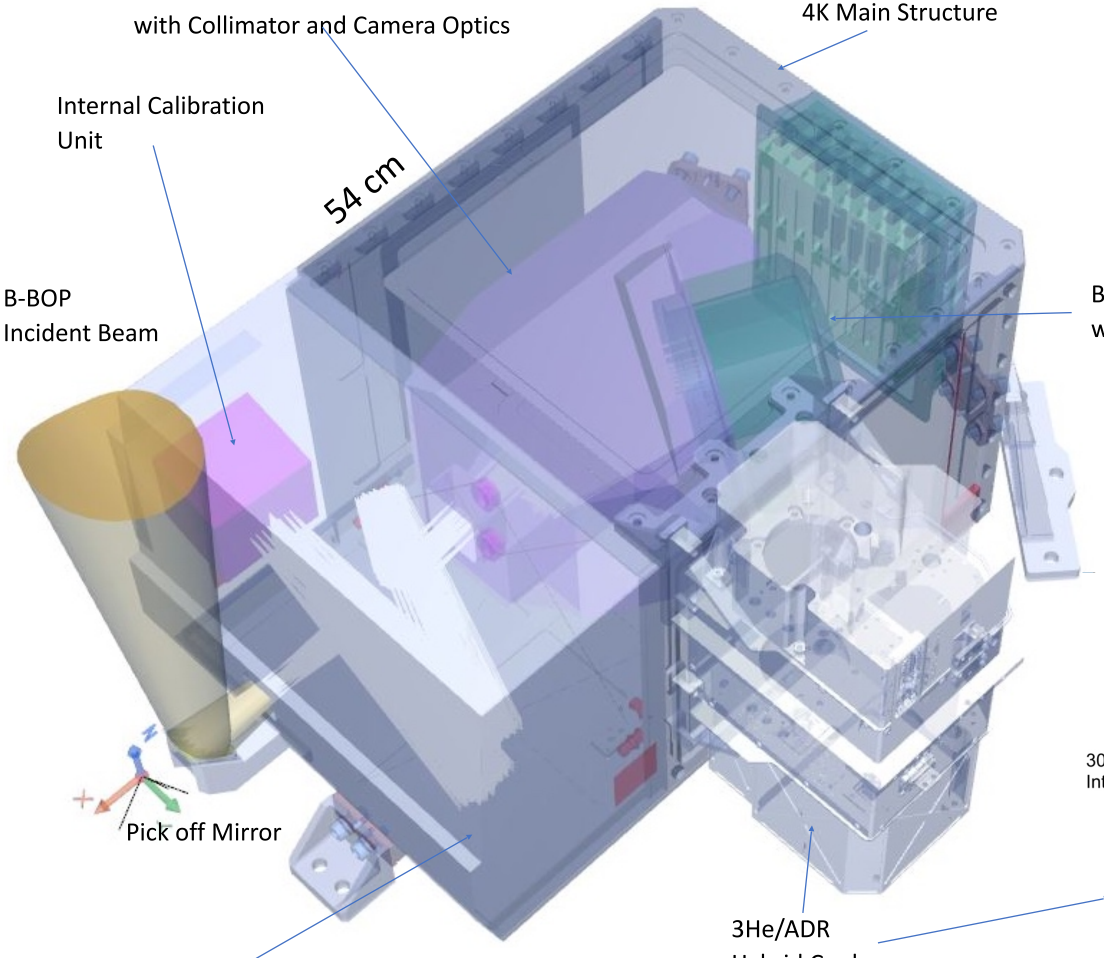
- Main parameters have been measured at cold temperature
- Very good results (***NEP Goal for SPICA/BBOP reached***)
- Challenges : thermal issues (readout currents), full MUX demonstration

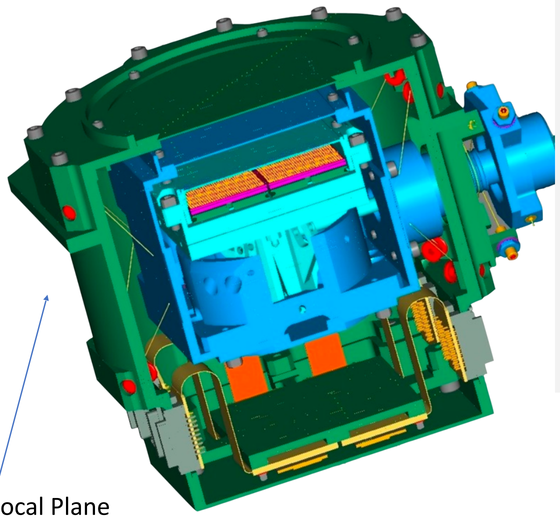
L. Rodriguez, SPIE 2024

B-BOP, the instrument on SPICA

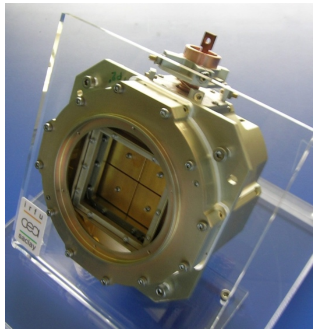
« **Simple & Compact Design** » : No moving part, no rotating plate (except for calibrator unit), no **Magn. Shield.**

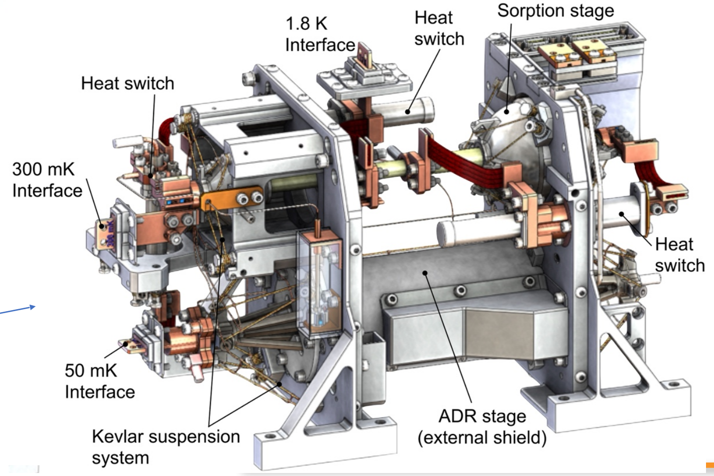
Big Advantage on the System Point of View





- 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)



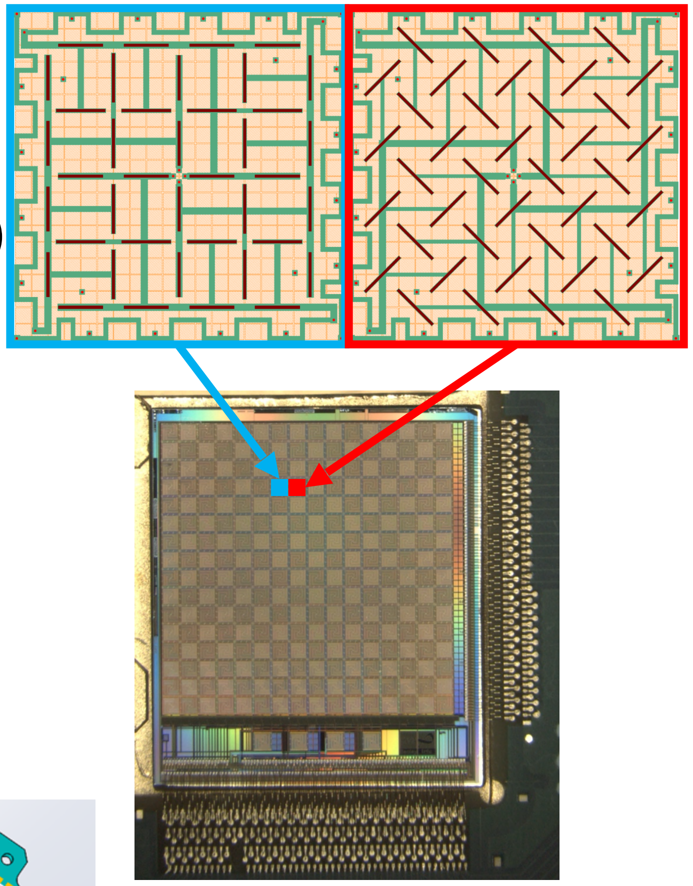


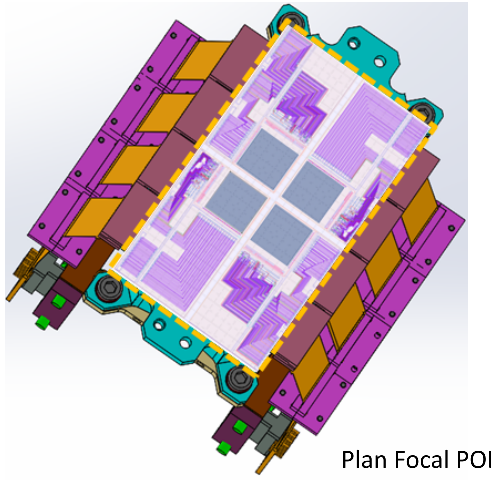
- Mass ~ 25 kg (63 kg including warm electronics)
- Power : 86 W (warm electronics)
- Power dissipation @ 50 mK ~1 µW

POLARYS in a nutshell

- **Adding Polarimetry to ArTeMiS, at 350 µm**
- 350 µm arrays are being built at CEA-LETI (**funded** by labex FOCUS + internal CEA funds)
- **Re-use the ArTeMiS mechanical structure at maximum**
- Optical study to characterise the instrumental polarization
- Optimizing the cryogenic system (working < 300 mK)
- Readout Electronics to be tested
- **Funding applications in progress (ANR, DIM Origines,…)**
- **On sky at APEX in …? 2028/2029?**

BBOP 350





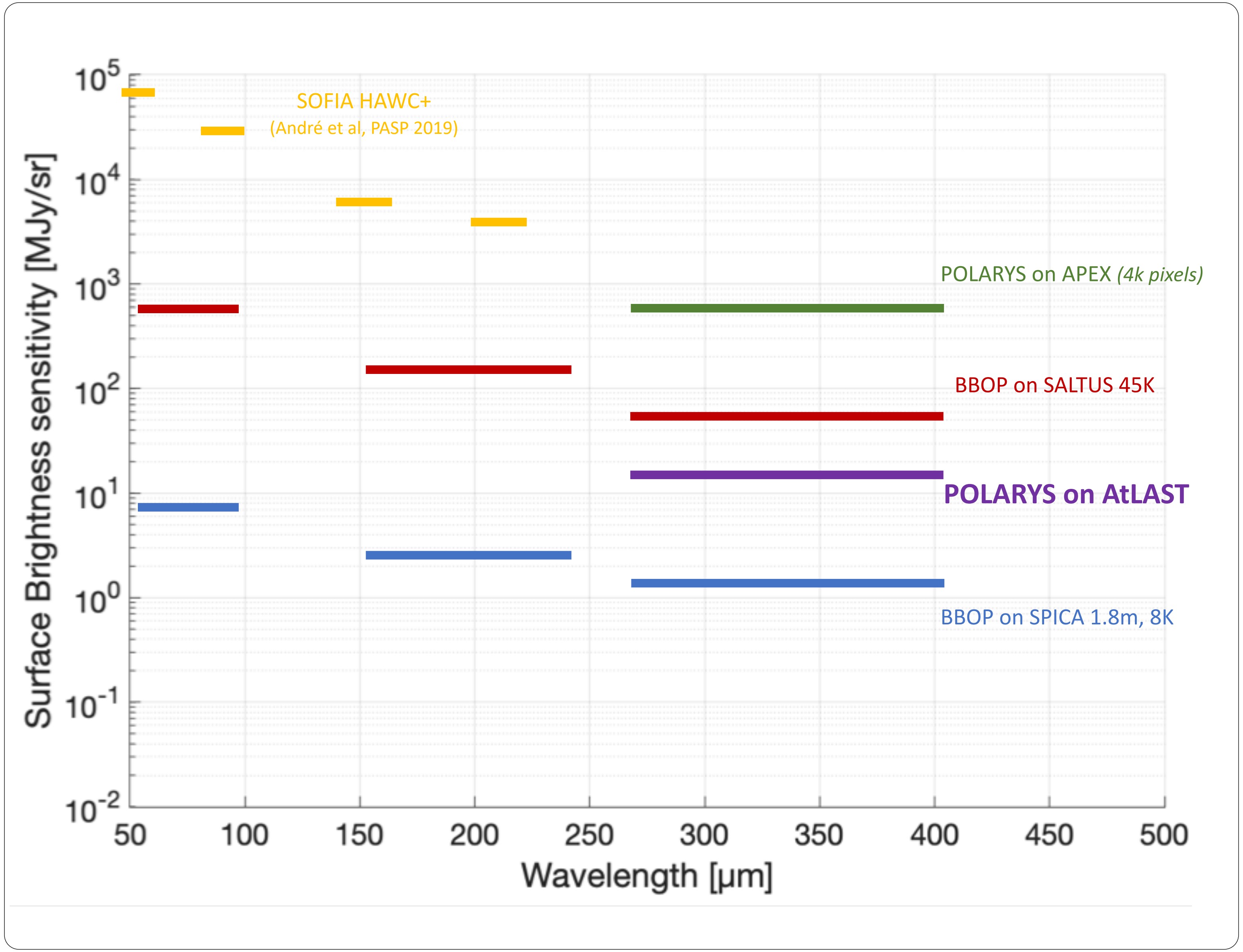
Plan Focal POLARYS

POLARYS (& BBOP) Polarization Sensitivity

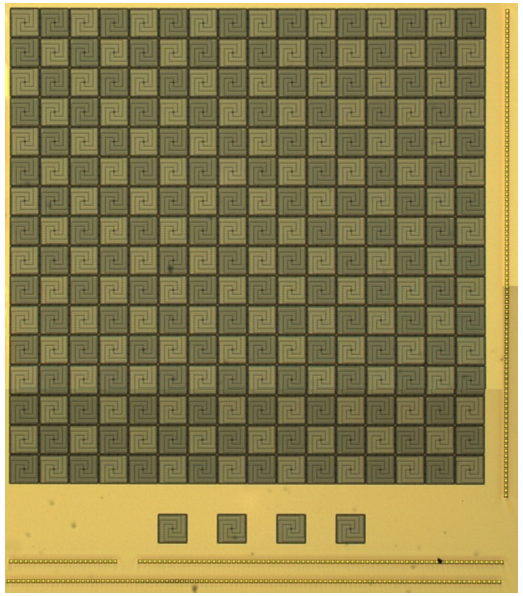
Surface Brightness Sensitivity [$MJy.sr^{-1}$] of BBOP for polarimetric imaging.

- total surface-brightness level required to detect polarization at 7σ ($p/\sigma=7$)
- 5% fraction polarization
- NEP = 3.10^{-18} $WHz^{-1/2}$
- Background includes:
  - Zodiacal light, ISM, CIB, CMB at location typical of **low-emission Galactic** regions
  - Telescope
  - Instrument optics (transmission 50%)
  - Atmosphere
- For space : 70 µm Band : 1024 pixels, 200 µm Band:

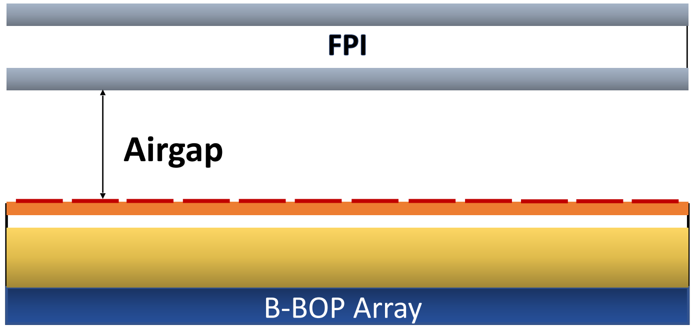
Instrument	Diameter [m]	Telescope Temperature [K]
SPICA	1.8	8
Millimetron	10	45
SALTUS	14	45 & 30
APEX (4096 pixels)	12	270
AtLAST	50	270



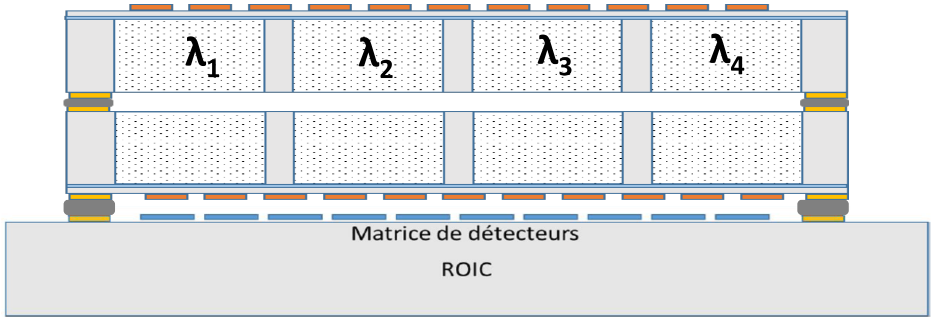
Adding (mid-R) Spectroscopy to the Array



(1) A Compact Scanning Fabry-Perot

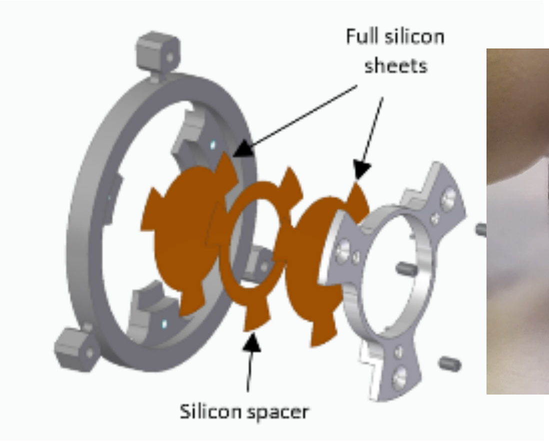


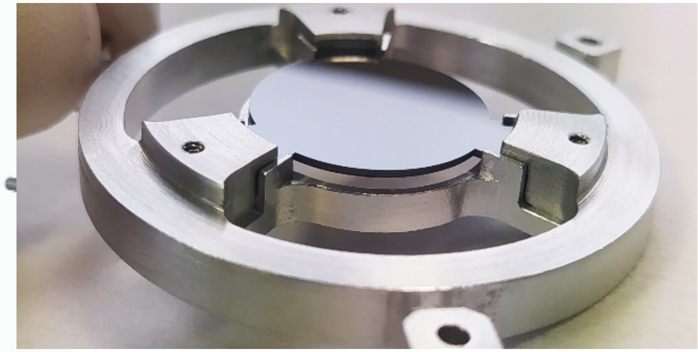
(2) A Bayer Filter Array

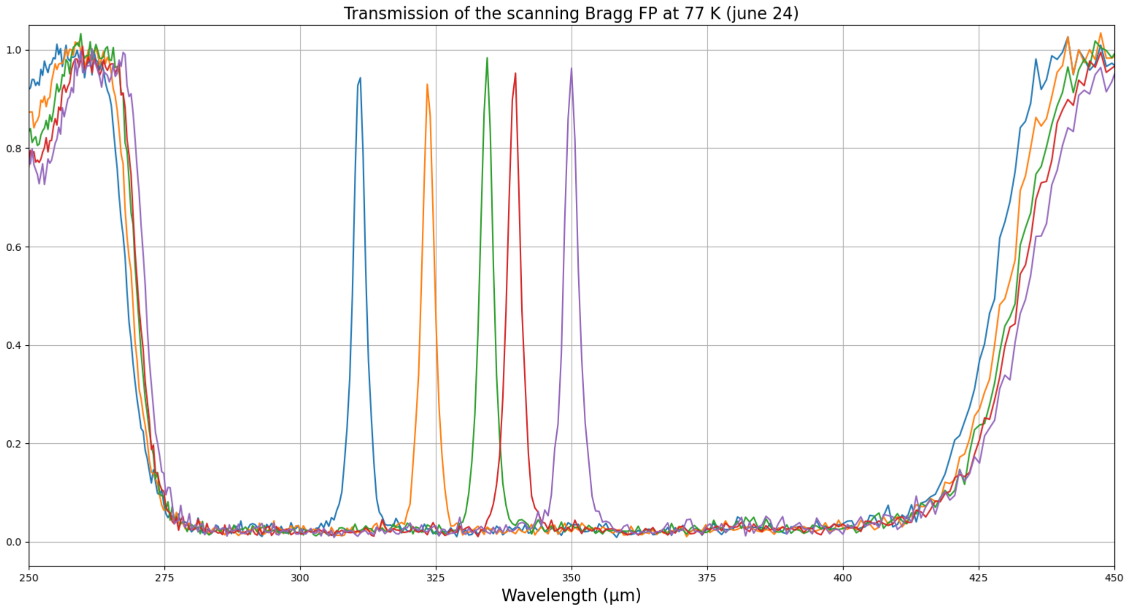


Spectroscopy – Preliminary results (R ~ 200 / 300)

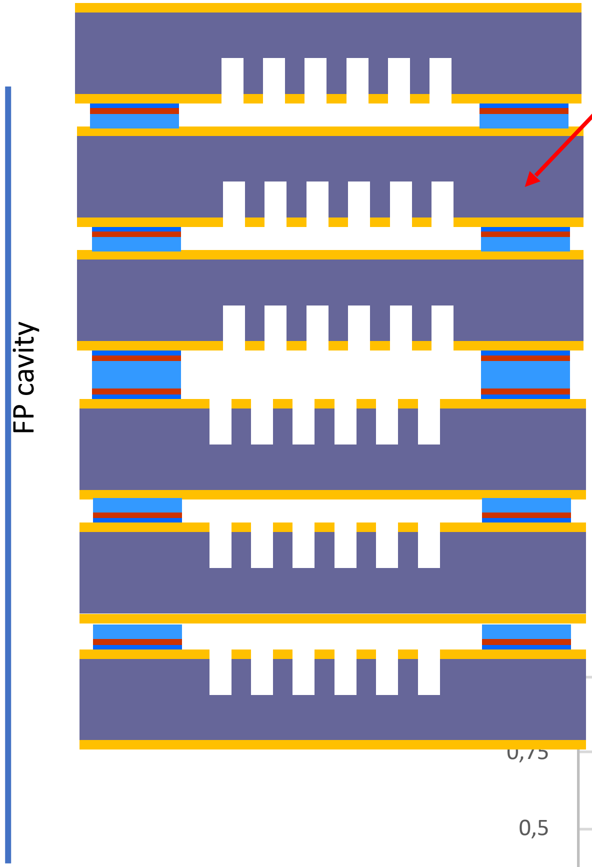
Adjustable cryogenic Fabry-Perot made of Si Bragg mirrors

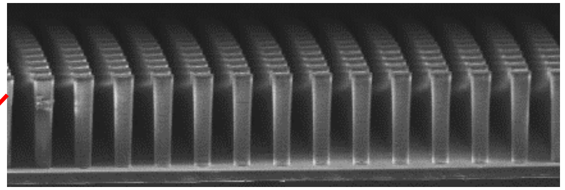


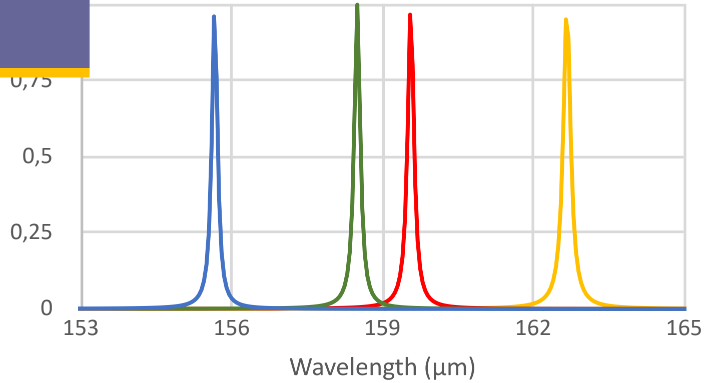




Stationary array of Fabry-Perot made of microstructures Si.

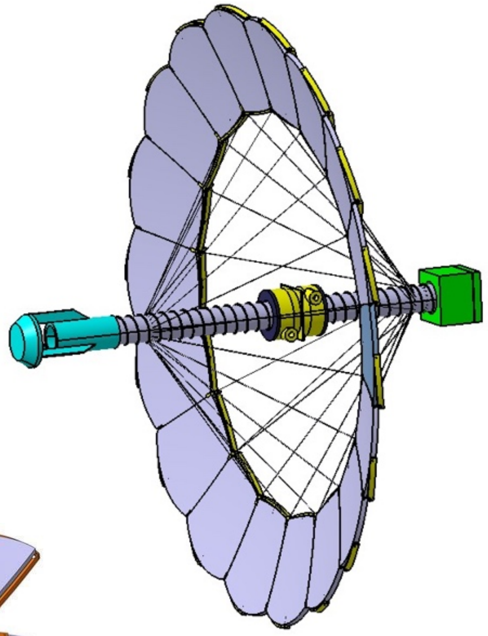




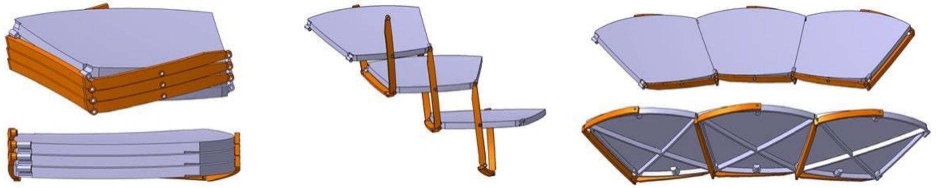


Other opportunities

- CO-PILOT
  - *Detection of C+ @ 158 µm*
  - *CNES balloon*
  - *CEA bolometers, SRON Fabry Perot, PI : IRAP*

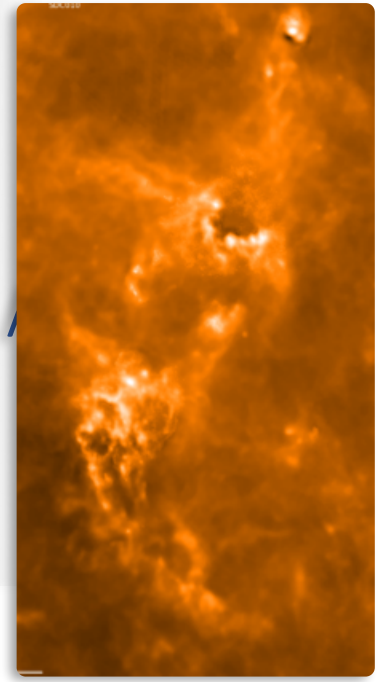


- The TALC Deployable Space Telescope
  - 20 m diameter annular telescope



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 POLARYS, TALC (?), Co-PILOT(?)



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Fundings

Spectroscopy with metamaterials / High Impedance Surfaces

Project HIS350 : Proof of concept

- Very good absorption (room and cold temp.)
- Absorption independant of the dipole angle

Idea = Modulation of the spectral response using an external magnetic field and / or « varactors ».

Motif élémentaire:

- ***période 37.5 µm***
- ***gap 4.6 µm***
- ***via ∅ 3 µm***