POLARYS: An imaging polarimeter for the APEX submillimeter telescope

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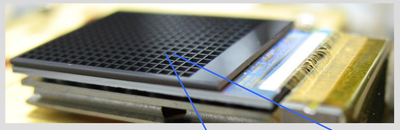
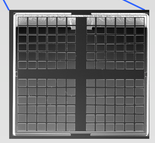
Introduction

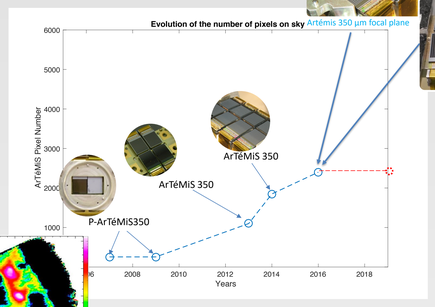
Recent progress in imaging magnetic fields within the interstellar medium (ISM) has been achieved by instruments such as PILOT, NIKA2, and HAWC+, through the detection of polarized light. These instruments, working in the submillimeter and millimeter wavelengths, have demonstrated that magnetic fields are usually perpendicular to the filamentary structures found in star-forming regions of the ISM. Nevertheless, extensive surveys of star forming regions across the galaxy as well as observations at higher spatial resolution are needed to better understand the physical mechanisms at play in these regions and disentangle between different theoretical models.
Our group has started the development of a new ground-based imaging-polarimeter called **POLARYS** that will be installed on the APEX submillimeter telescope, located at an altitude of 5100m in the Atacama desert. POLARYS, **operating at a wavelength of 350 µm**, will be a major upgrade of the **ArTéMiS** submillimeter camera which is in operation at APEX since 2014. The major innovation is that the detectors are directly sensitive to the polarization of the light, eliminating the need for a device that modulates the incident radiation, such as a rotating polarizer. These detector arrays are made of semiconducting bolometers, that have been initially developed in the framework of the SPICA/BBOP space mission. The arrays, building upon the legacies of Herschel/PACS, ArTéMiS, and PILOT, mark a considerable improvement in sensitivity, achieving a pixel Noise Equivalent Power close to 10E-18 W/sqrt(Hz) at 50 mK, as well as enhanced polarimetric capabilities. The bolometer arrays utilize a differential read-out mechanism, enabling them to simultaneously measure both the total intensity and polarization level of light for each pixel.

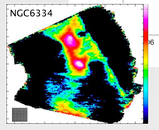
The ArTéMiS Camera

ArTeMiS detectors consist in Si:P:B bolometers arranged in 16 x 18 sub- arrays operating at 300 mK. These detectors are similar to the ones developed for the **Herschel PACS photometer** but they are of course adapted to longer wavelength and to the high optical load encountered at APEX site. ArTeMiS contains 8 sub-arrays at 350 µm (7 are functionnal) and 3 operating sub-arrays at 450 µm.



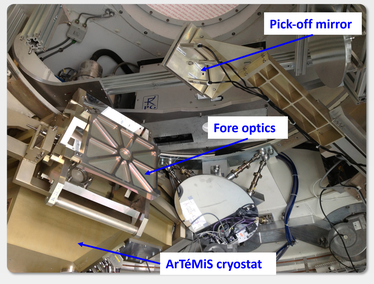


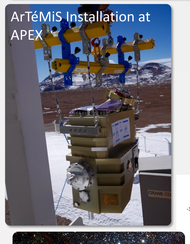


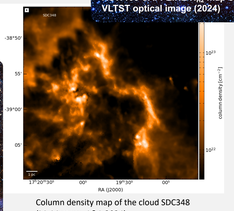


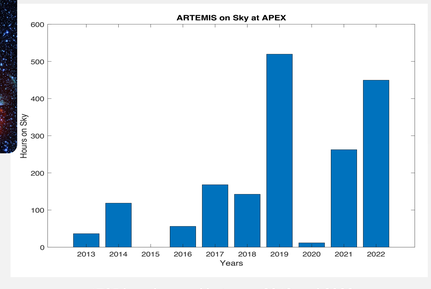
Number of operational pixels	2400
Spatial Resolution 350 µm 450 µm	8'' 10.5''
FOV (350µm)	4,7 x 2,3 arcmin²
Median NEFD	580 mJy.s$^{1/2}$
Best NEFD	~ 300 mJy.s$^{1/2}$
Mapping speed @ 350 µm (relatively to Saboca)	~ x 5

The camera is fully operational at **APEX** since 2016 and has been used by ESO, OSO and Chilean communities.



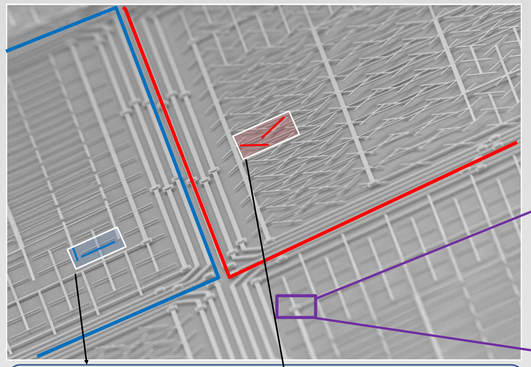


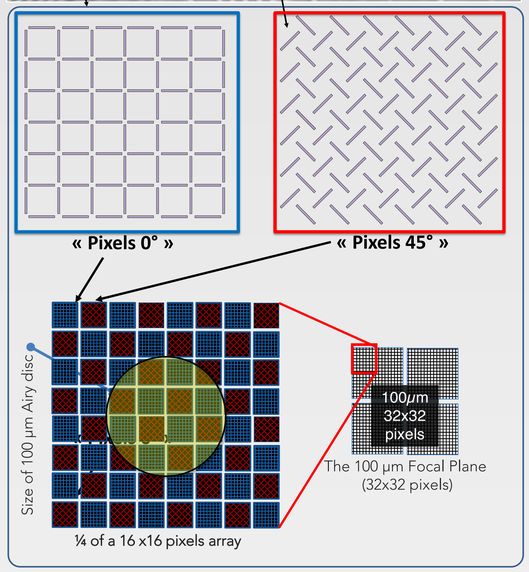




- 1765 hrs observed between 2013 and 2022,
- 56 projects → 5 Chile, 25 ESO, 26 OSO
- 2019 to 2022 → 1250h,
- 29 publications since 2008 and 19 since 2013

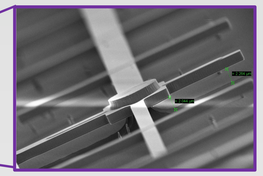
Adding Polarimetry to ArTéMiS : toward POLARYS





Zooming into a 100 µm array (SEM image)

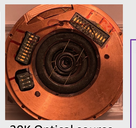
Inside each bolometric pixel, 2 networks of orthogonal **dipole antennas** (illustrated inside the small white rectangles) absorb 2 polarization components of the incoming wave. They transmit the absorbed heat to the supporting legs that are 4 independant **resistive thermal sensors (Si:P:B).**



Details of a copper nail acting as a 50 mK heat sink, a mechanical support and an electrical link to the RO circuit.

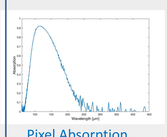
« Stokes array » : the pixel arrangement consists in periodically rotated (45°) networks of dipoles. I, Q, U parameters can be obtained without any modulation of a HWP.

Testing the Arrays (at 100 µm)

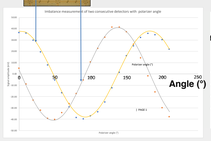


30K Optical source, using concentric emitting rings

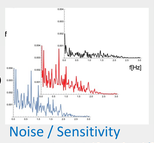
- Main parameters have been measured at cold temperature
- Very good results (***NEP Goal for SPICA/BBOP reached***)
- Challenges : thermal issues (readout currents), full MUX demonstration



Pixel Absorption
> 90% at 100 µm

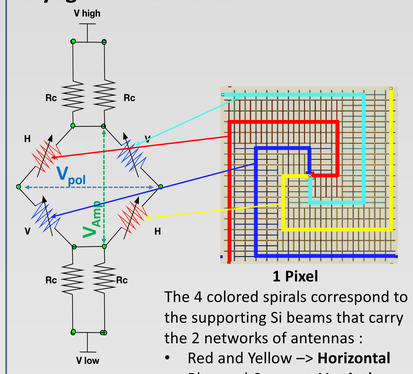


Polarimetry (Cross pol ~ 0.1%)



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

Cryogenic Readout Electronics

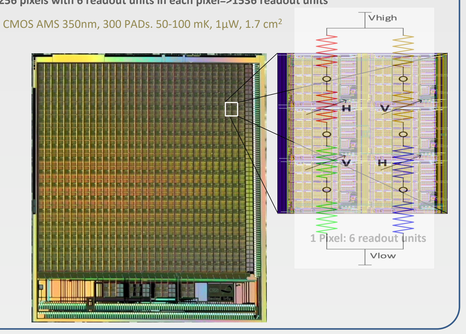


The 4 colored spirals correspond to the supporting Si beams that carry the 2 networks of antennas :
- Red and Yellow –> **Horizontal**
- Blue and Cyan –> **Vertical**

The Pixel Electrical Readout is a Wheatstone Bridge.
- V$_{pol}$ gives the differential polarization unbalance between the 2 orthogonal dipoles
- V$_{amp}$ is the differential amplitude signal

→ V$_{pol}$ and V$_{amp}$ have very different dynamic ranges, ADC are adapted to the expected levels.

« 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 cm²

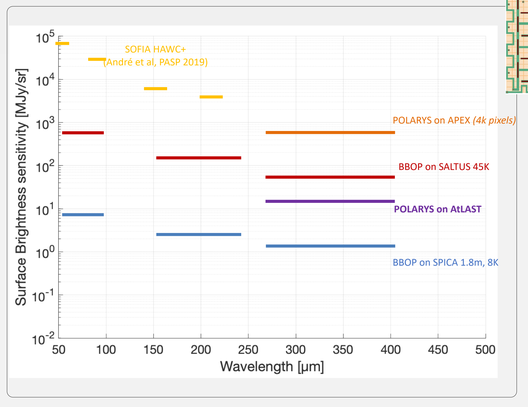


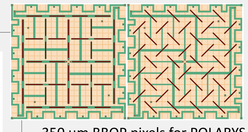
POLARYS Sensitivity

Surface Brightness Sensitivity [MJy.sr^{-1}] of BBOP detectors for polarimetric imaging on different telescopes.

- total surface-brightness level required to detect polarization at 7σ (p/σ=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: 256 pixels, 350 µm Band : 64 pixels

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





350 µm BBOP pixels for POLARYS

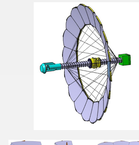
350 µm POLARYS Focal Plane

Conclusion / Perspectives

CEA's silicon bolometers have benefited from many years of development work on the Herschel and ArTéMiS projects. We have recently pushed back the limits of this technology: thanks to the extraordinary physical properties of silicon, we have demonstrated very high sensitivities for BBOP-type detectors. Silicon also enables us to design pixels with polarimetric capabilities.
Polarimetry within the pixel makes it possible to build very compact and simple instruments, with no moving parts. The POLARYS camera will be installed at APEX over the next few years, and we are looking at other possibilities, such as the TALC space project, the COPILOT stratospheric balloon or the AtLAST ground-based telescope.

COPILOT Balloon

AtLAST 50m concept



TALC 20m annular telescope

POLARYS