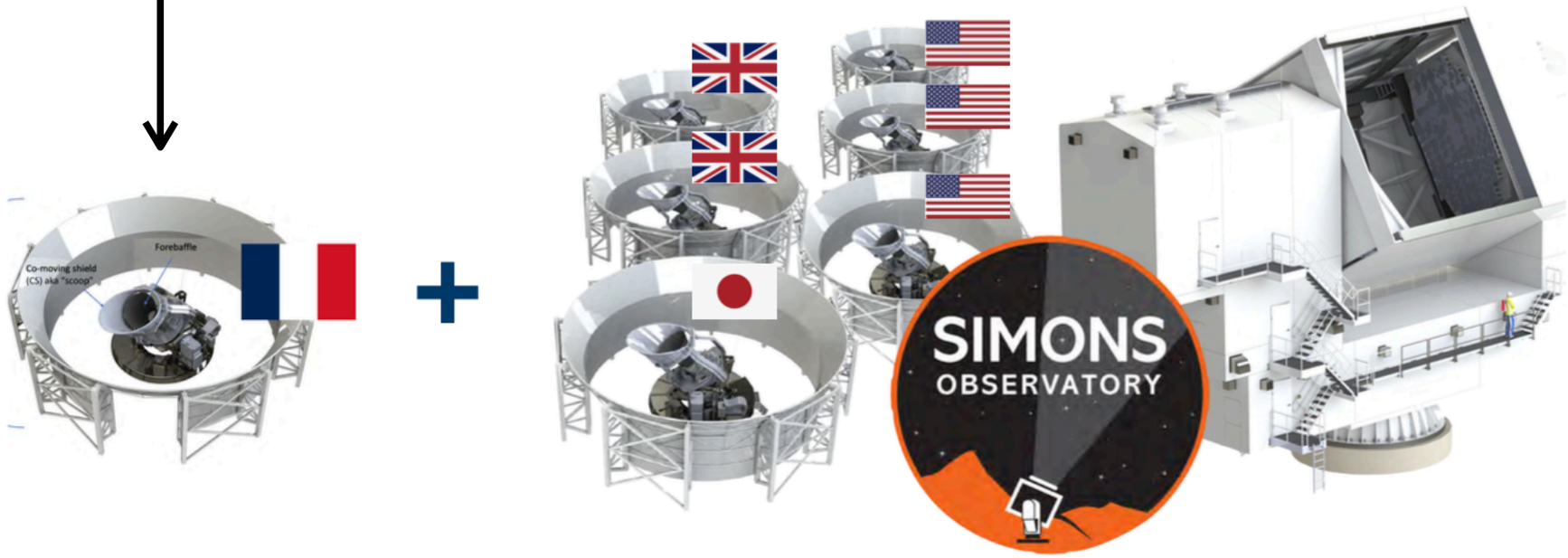
KAIROS

KID **A**rray **I**nstrument to **R**eveal the **O**rigin of **S**tructures



Josquin Errard (APC/CNRS), on behalf of the KAIROS collaboration

CMB-France # 7, IAP, Oct 14, 2025

KAIROS

KID **A**rray **I**nstrument to **R**eveal the **O**rigin of **S**tructures

➔ the Simons Observatory and its short term evolution

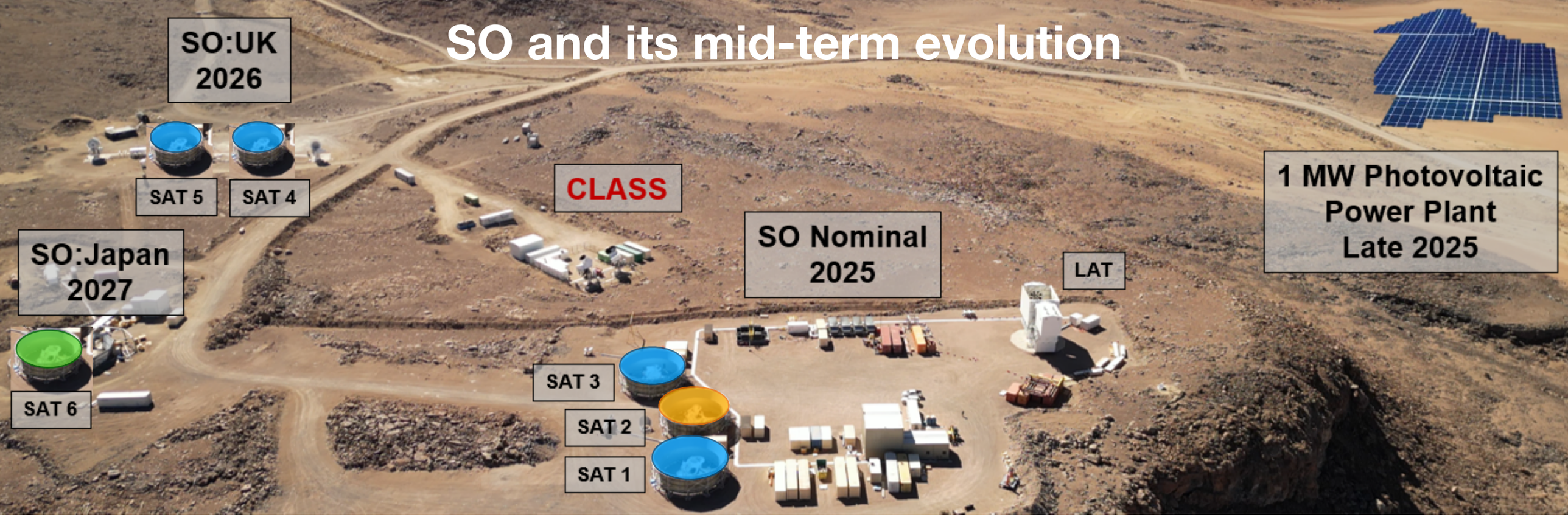
➔ the need for high frequencies: the component separation problem

➔ KAIROS concept

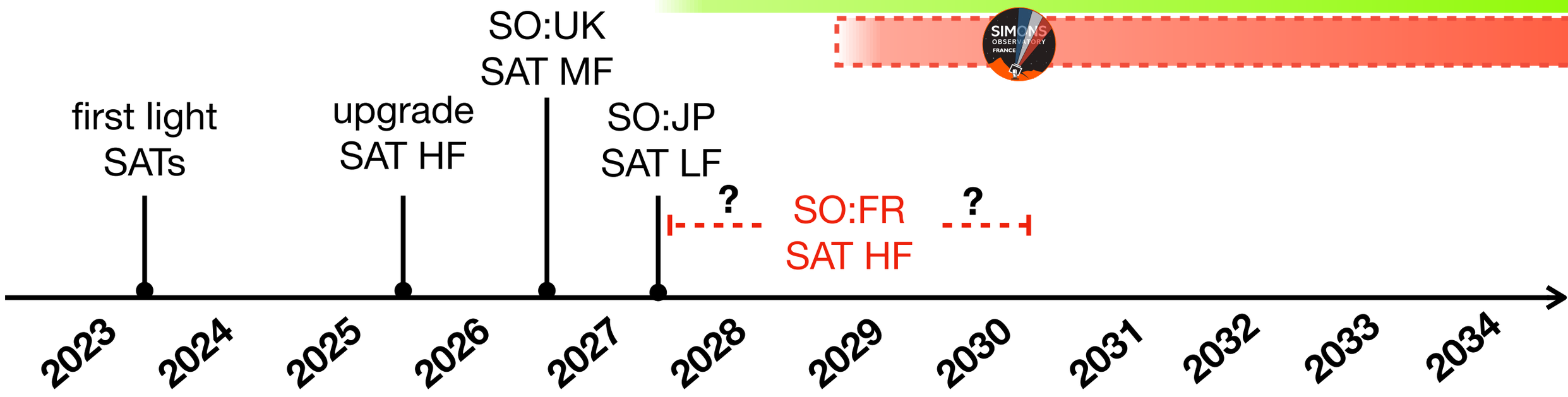
➔ technologies and know-how available in France

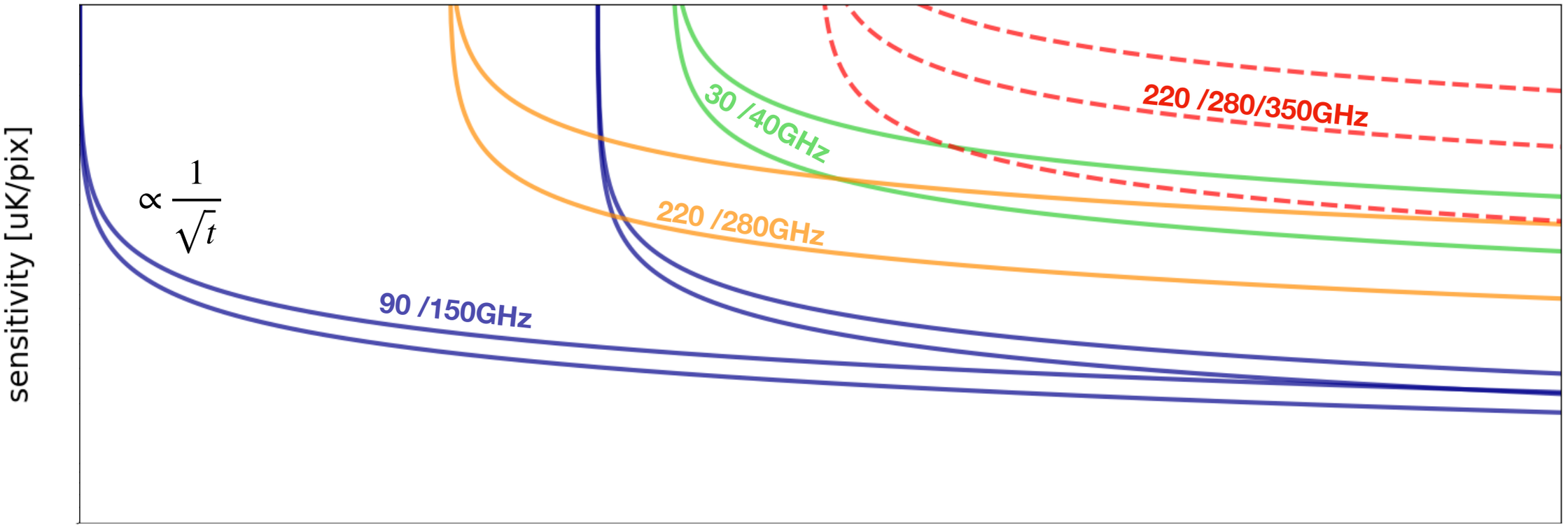
➔ preliminary forecasts

SO and its mid-term evolution



see talks by Thibaut Louis, Amalia Villarrubia Aguilar and Pierre Masson





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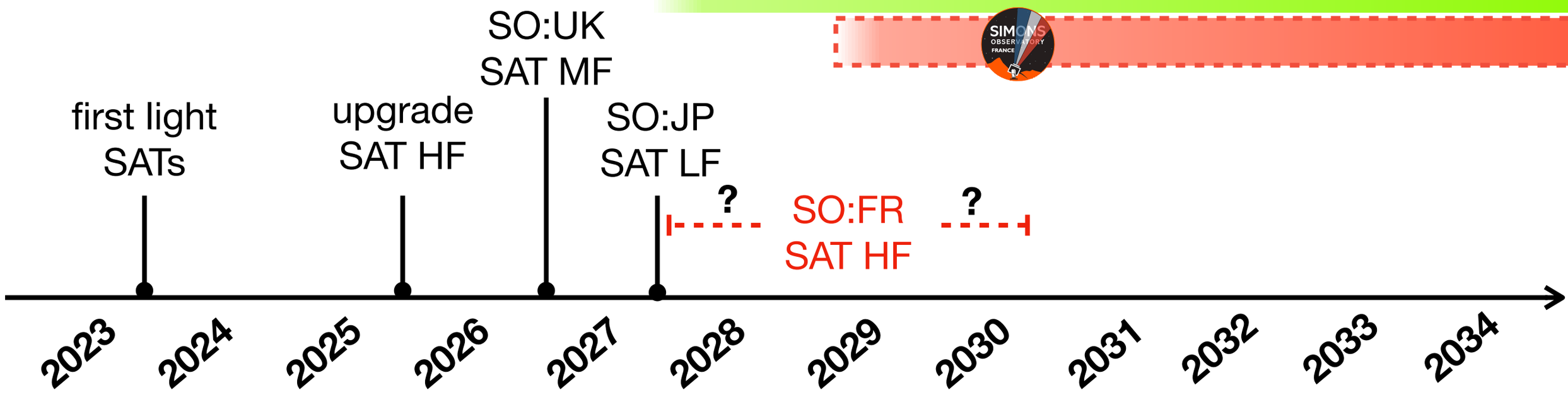

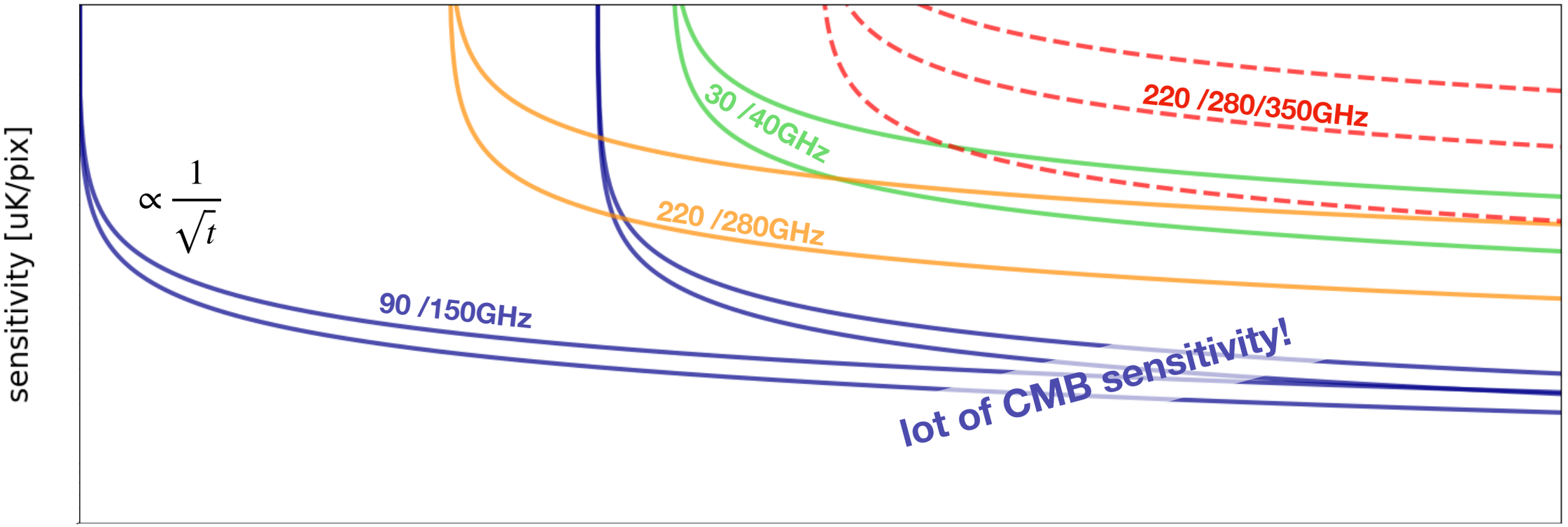

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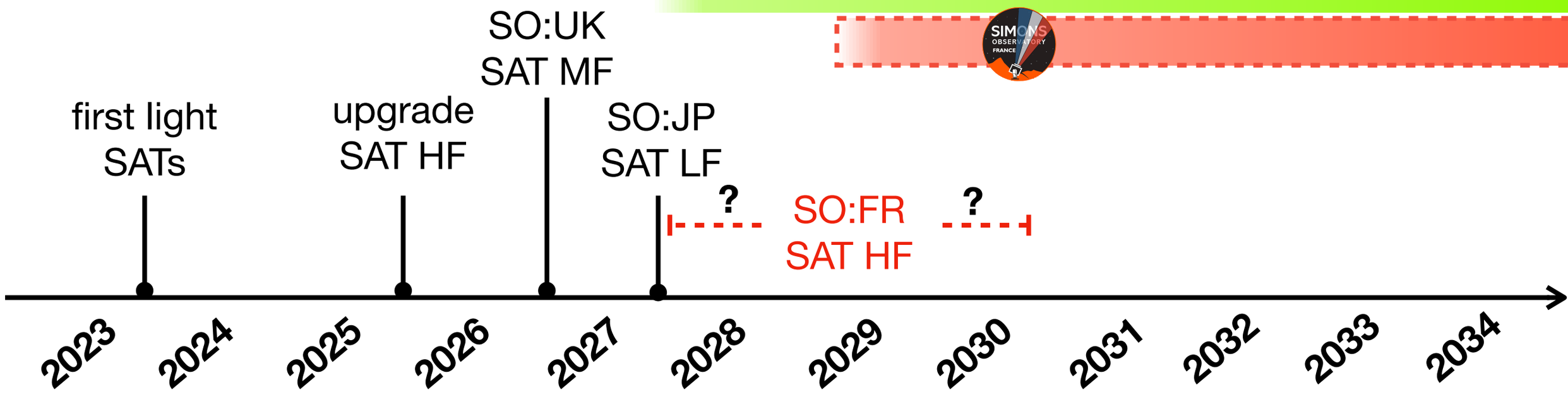

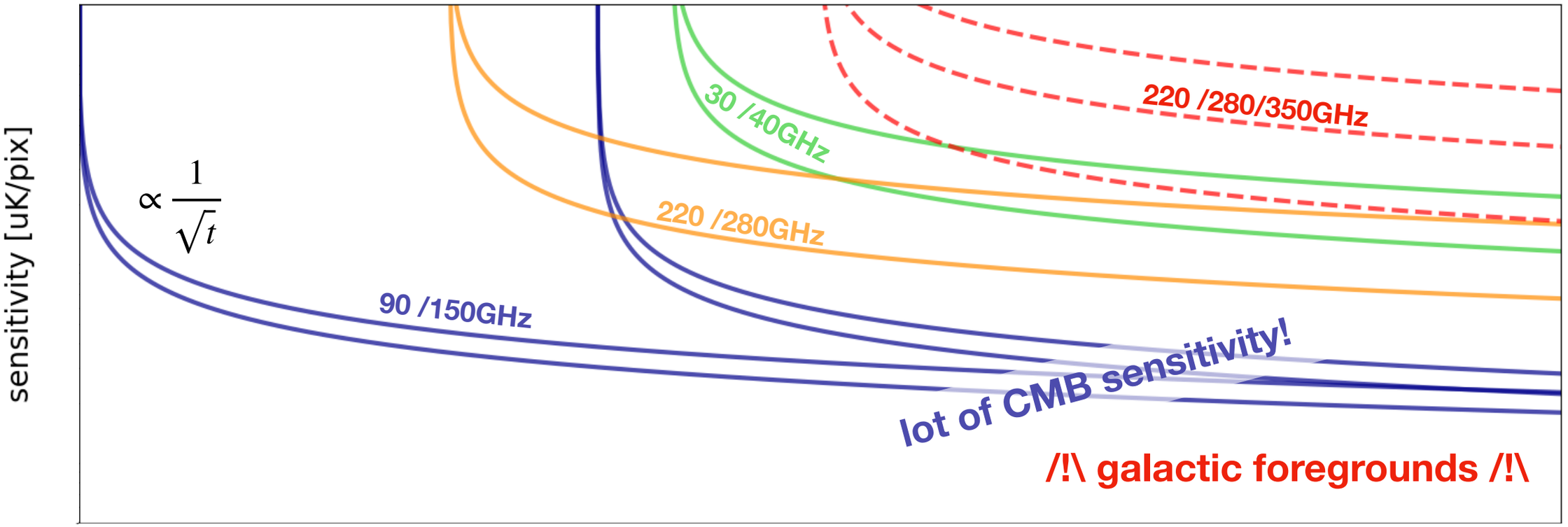

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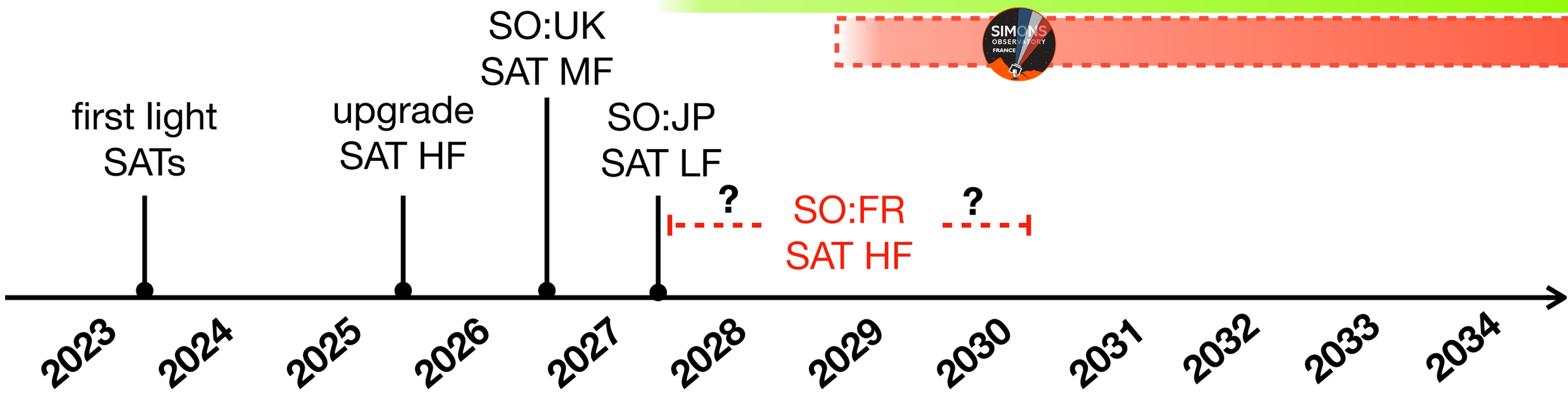
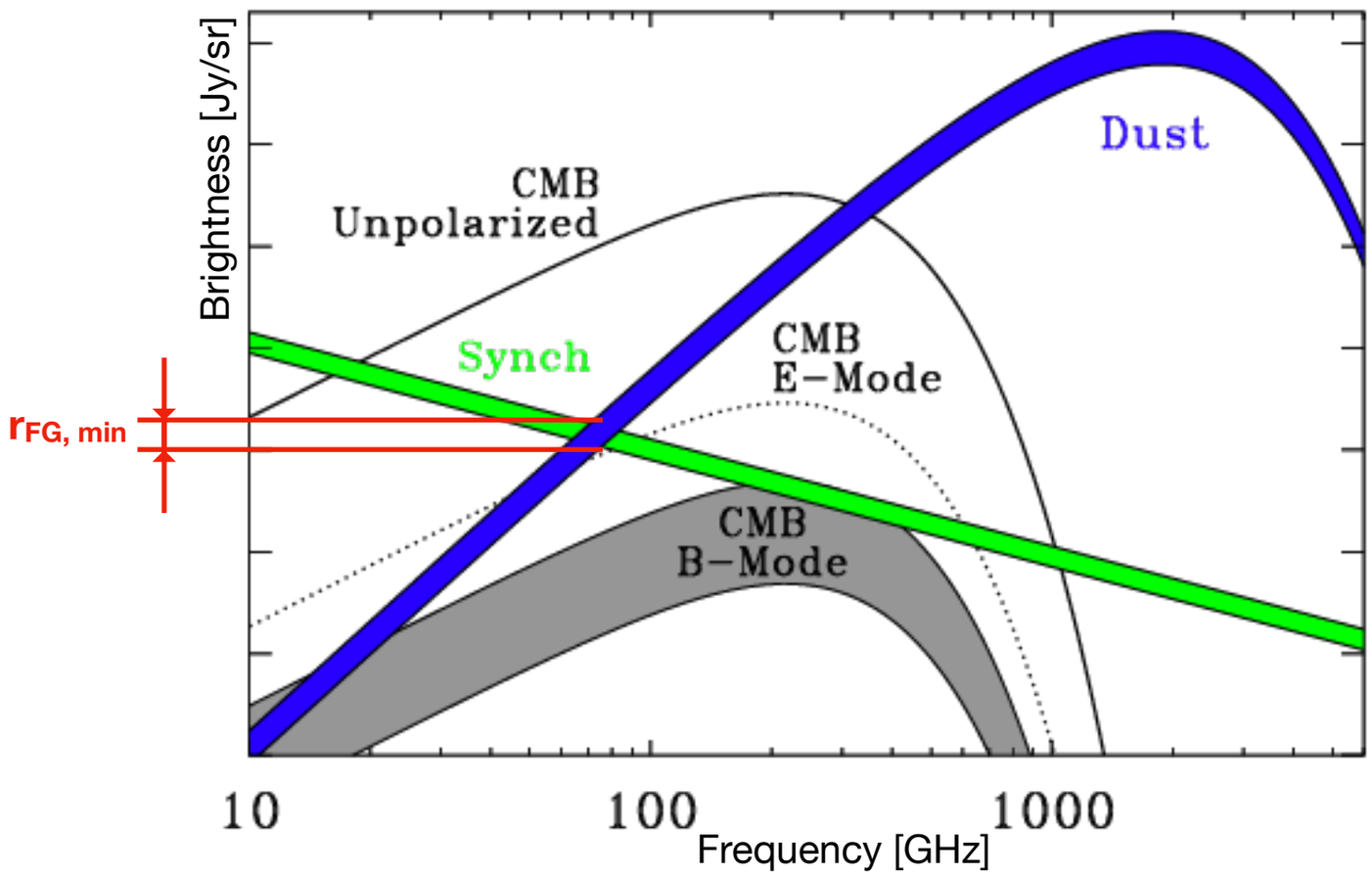


The component separation problem

Characterization of foreground emission at degree angular scale for CMB B-modes observations, Krachmalnicoff et al., arXiv:1511.00532,

$0.05 \leq r_{FG,\,min} \leq 1.5$



see also the recent *Cleaning Galactic foregrounds with spatially varying spectral dependence from CMB observations with fgbuster, Rizzieri et al.,* arXiv:2510.08534

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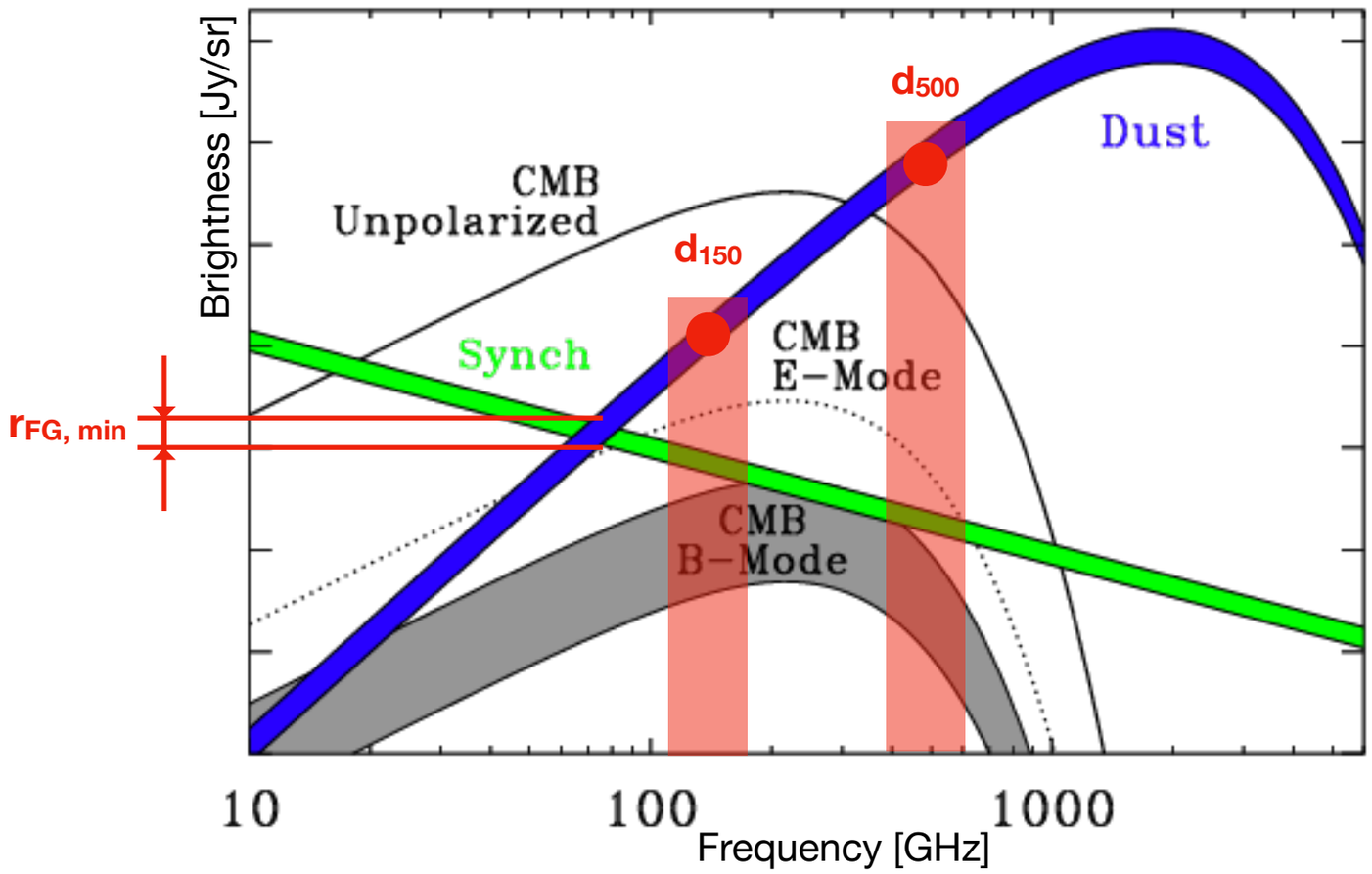

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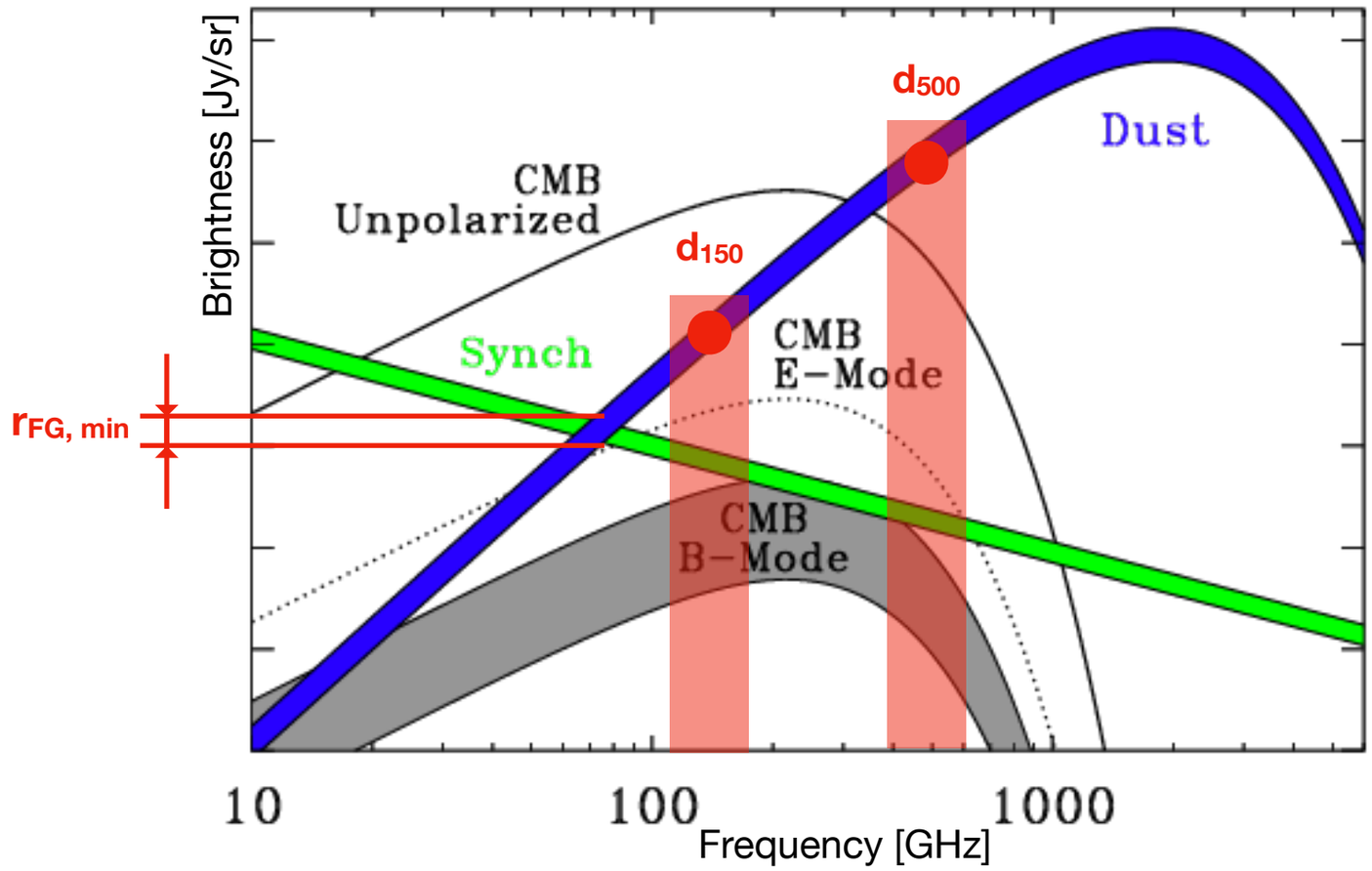
$$\begin{aligned} \delta s^{\mathrm{CMB}} &\equiv \bar{s}^{\mathrm{CMB}} - s^{\mathrm{CMB}} \\ &\equiv \delta s^{\mathrm{dust}} + \text{noise term} \end{aligned}$$

$$\text{noise term} = \frac{\bar{a}_{500} n_{150} - \bar{a}_{150} n_{500}}{\bar{a}_{500} - \bar{a}_{150}}$$



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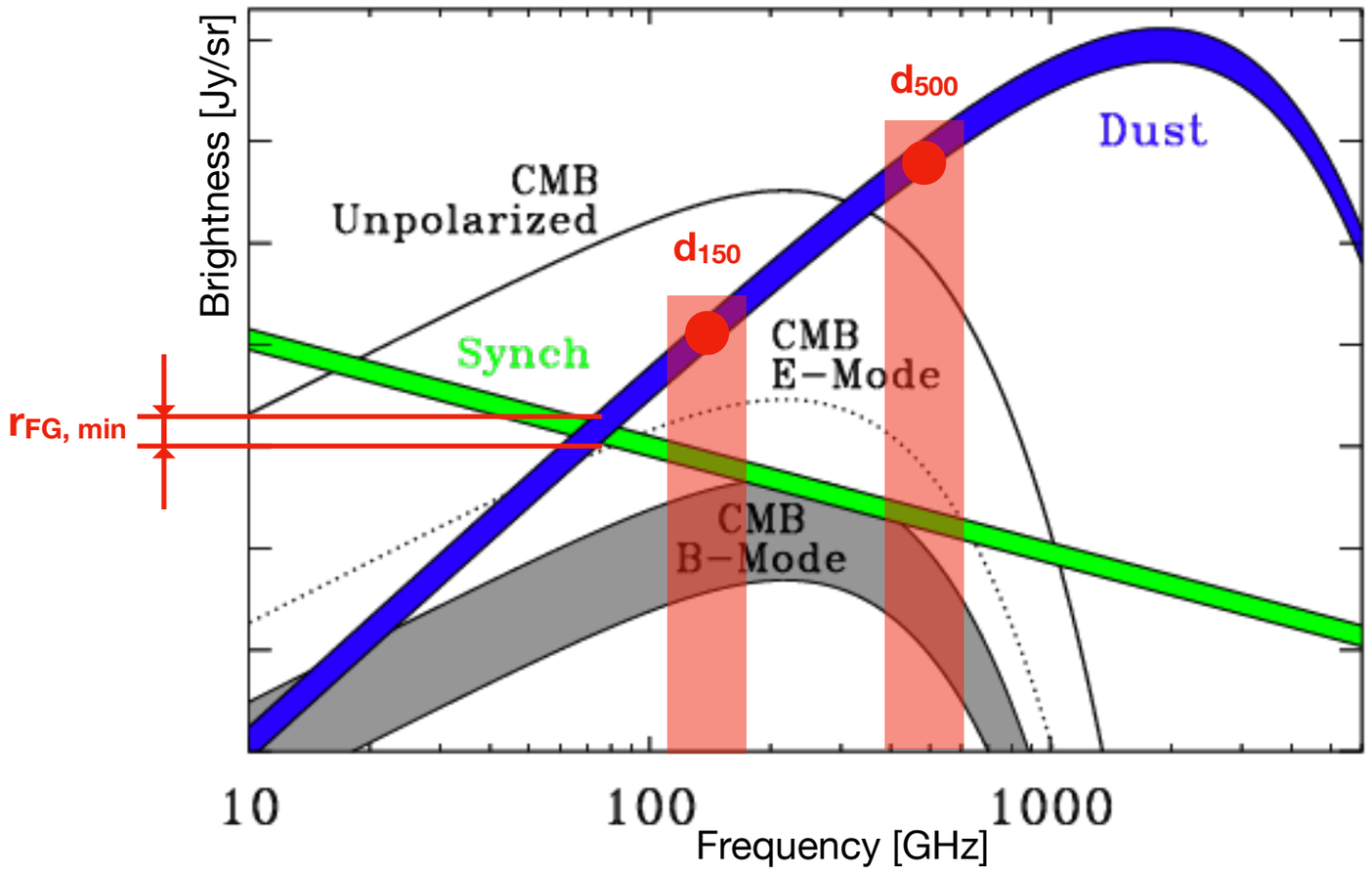

the variance of this post-component separation noise depends on the **frequency scaling law** (in particular the dust) and on **the noise levels** in each frequency bands

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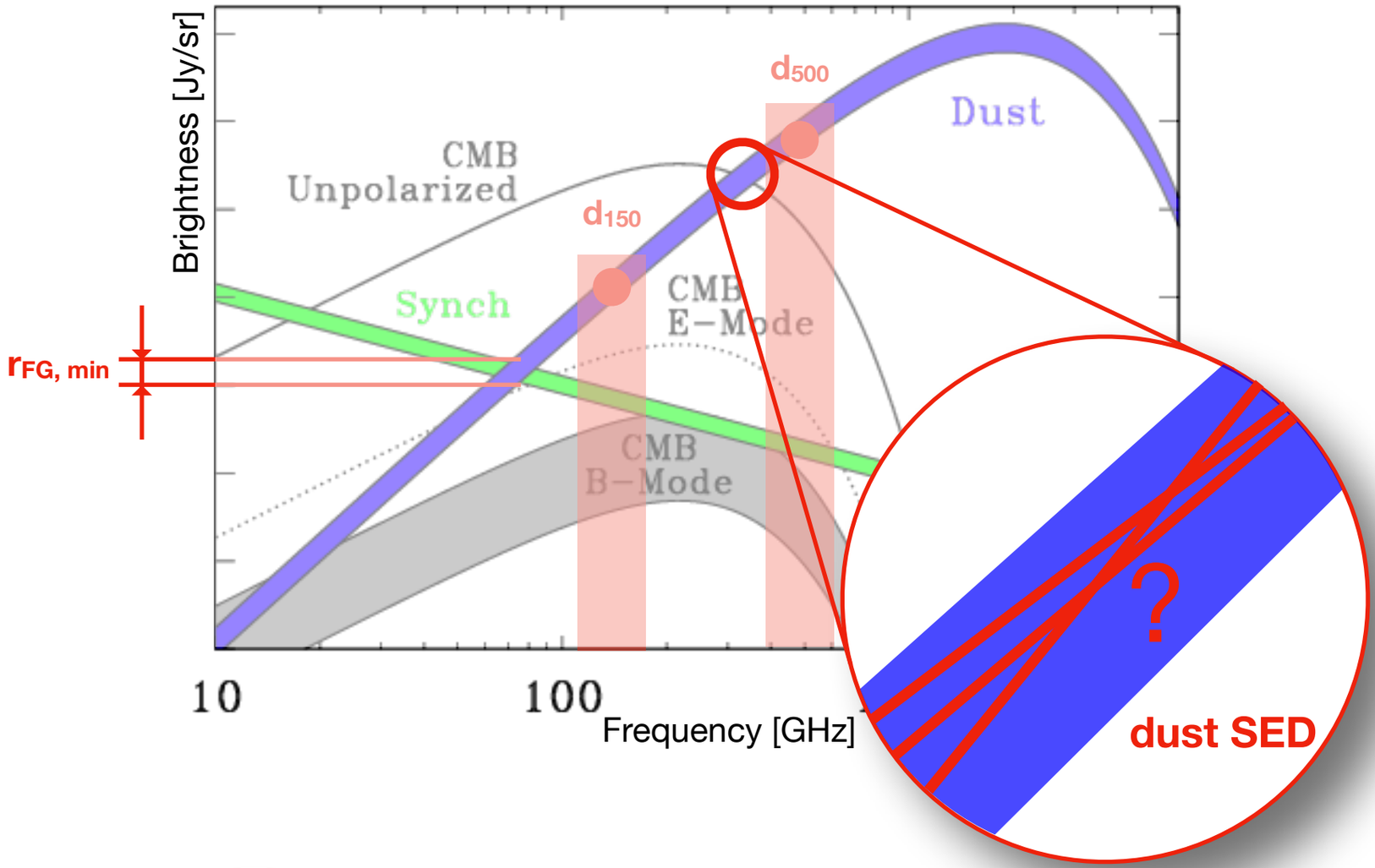

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The need for high frequencies

Robust forecasts on fundamental physics from the foreground-obscured, gravitationally-lensed CMB polarization, Errard, Feeney et al., 1509.06770

$$\Delta \equiv \left(\frac{\sigma_{\rm CMB}}{\sigma_{\rm quad}} \right)^2 \geq 1$$

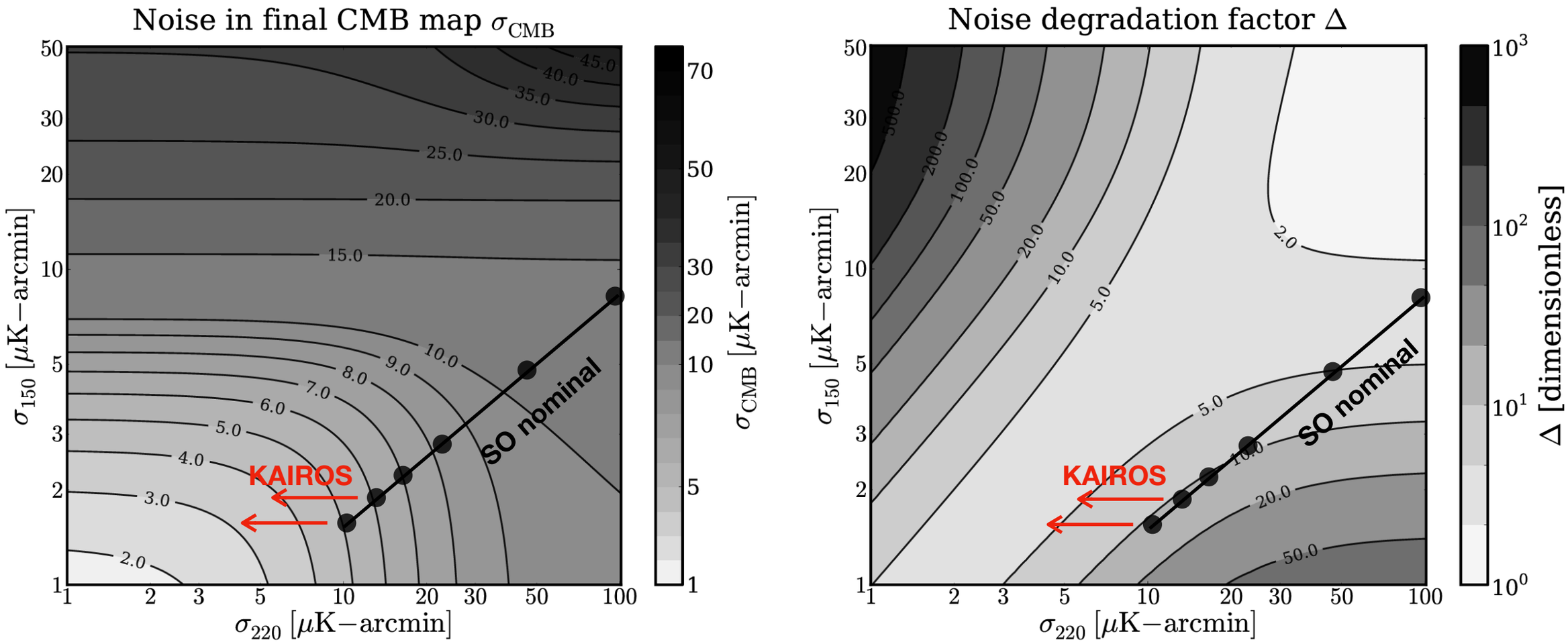
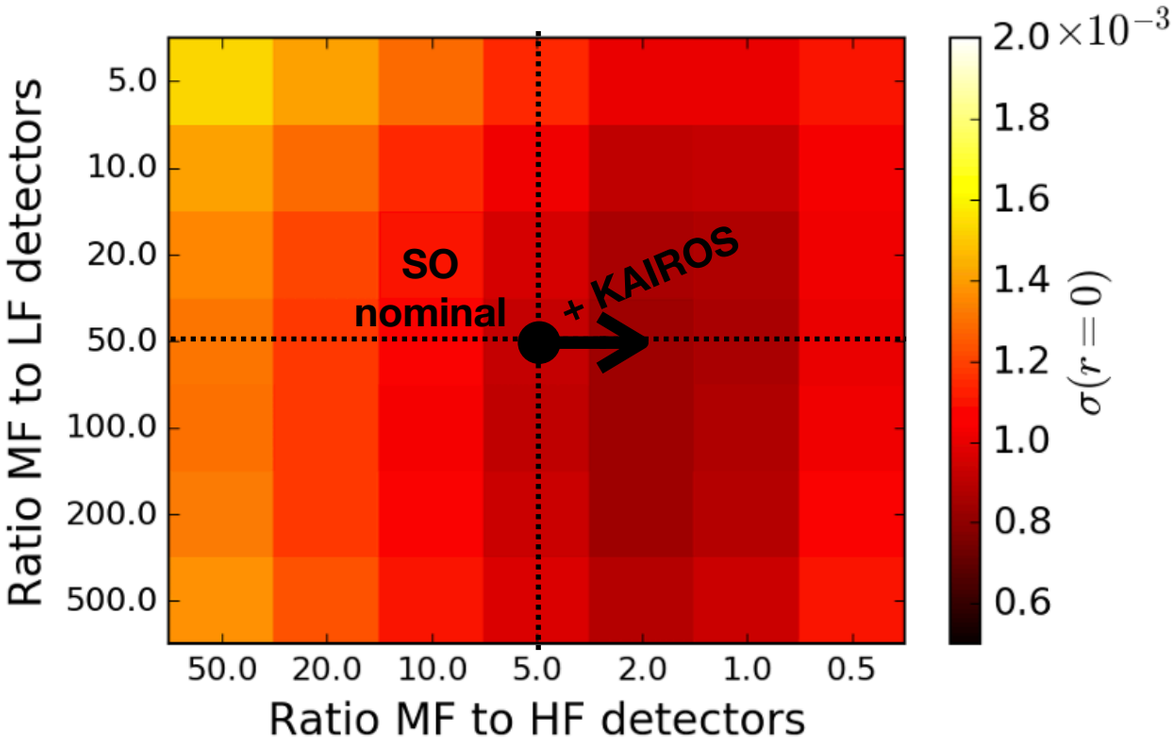
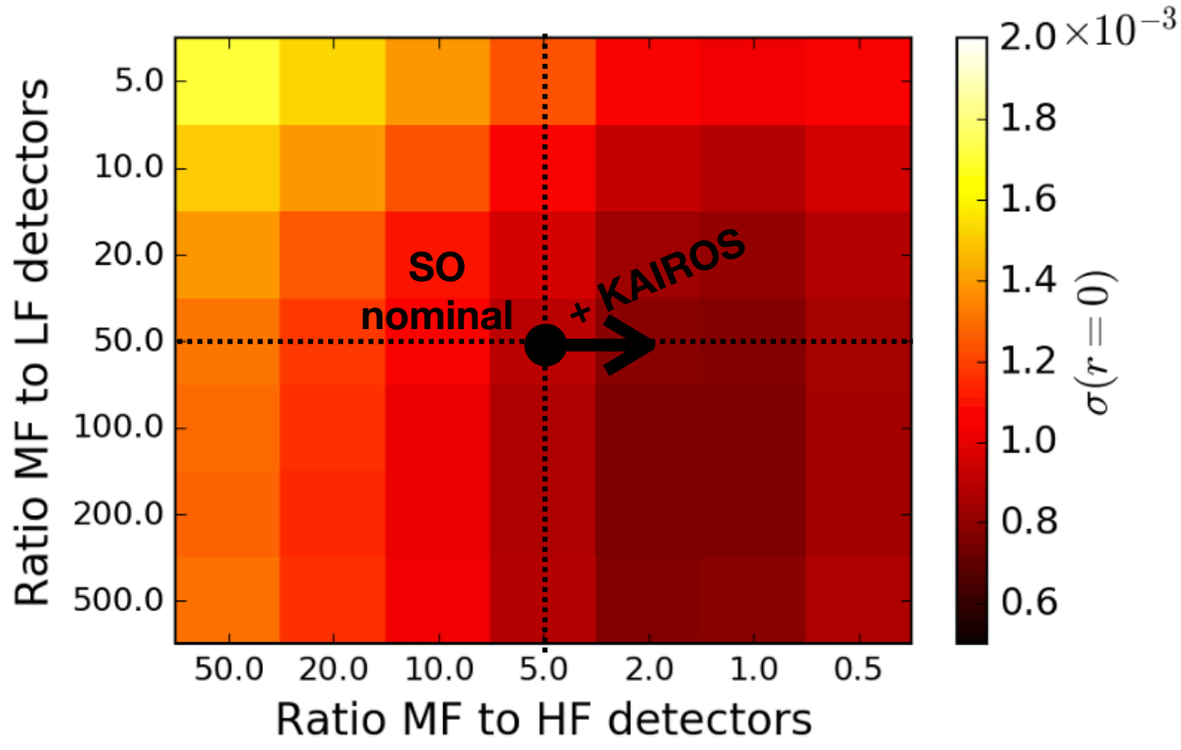


Figure 3. *Left panel:* the noise in the final CMB map for an experiment with two frequency channels of varying polarization sensitivity centered on 150 and 220 GHz, combined with *Planck*'s 353 GHz channel. The sole foreground contaminant is dust. *Right panel:* the noise degradation factor Δ between the final CMB map and the quadratic combination of all channels for the same experimental configuration.

The need for high frequencies

Optimization Study for the Experimental Configuration of CMB-S4, Barron et al., 1702.07467





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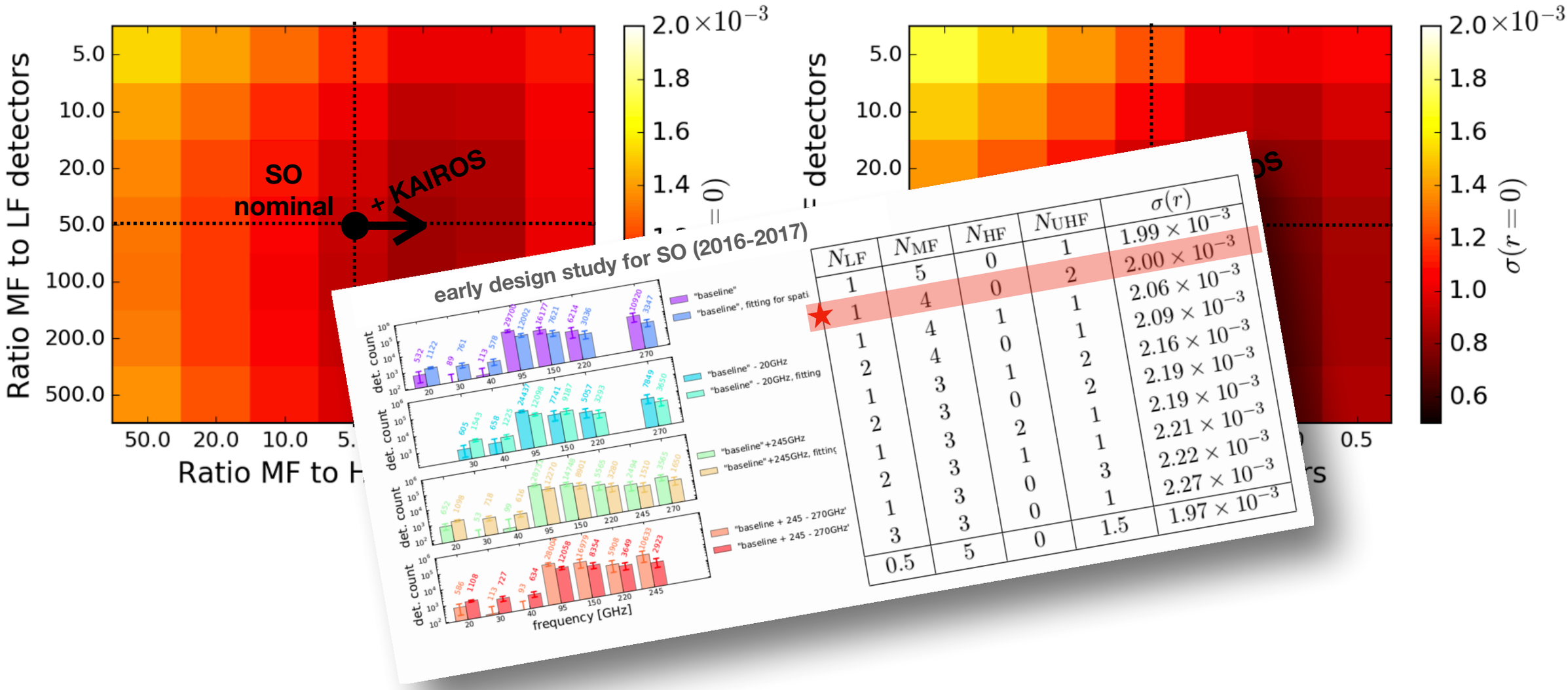

N_{LF}	N_{MF}	N_{HF}	N_{UHF}	$\sigma(r)$
1	5	0	1	1.99×10^{-3}
1	4	0	2	2.00×10^{-3}
1	4	1	1	2.06×10^{-3}
2	4	0	1	2.09×10^{-3}
1	3	1	2	2.16×10^{-3}
2	3	0	2	2.19×10^{-3}
1	3	2	1	2.19×10^{-3}
2	3	1	1	2.21×10^{-3}
1	3	0	3	2.22×10^{-3}
2	3	0	1	2.27×10^{-3}
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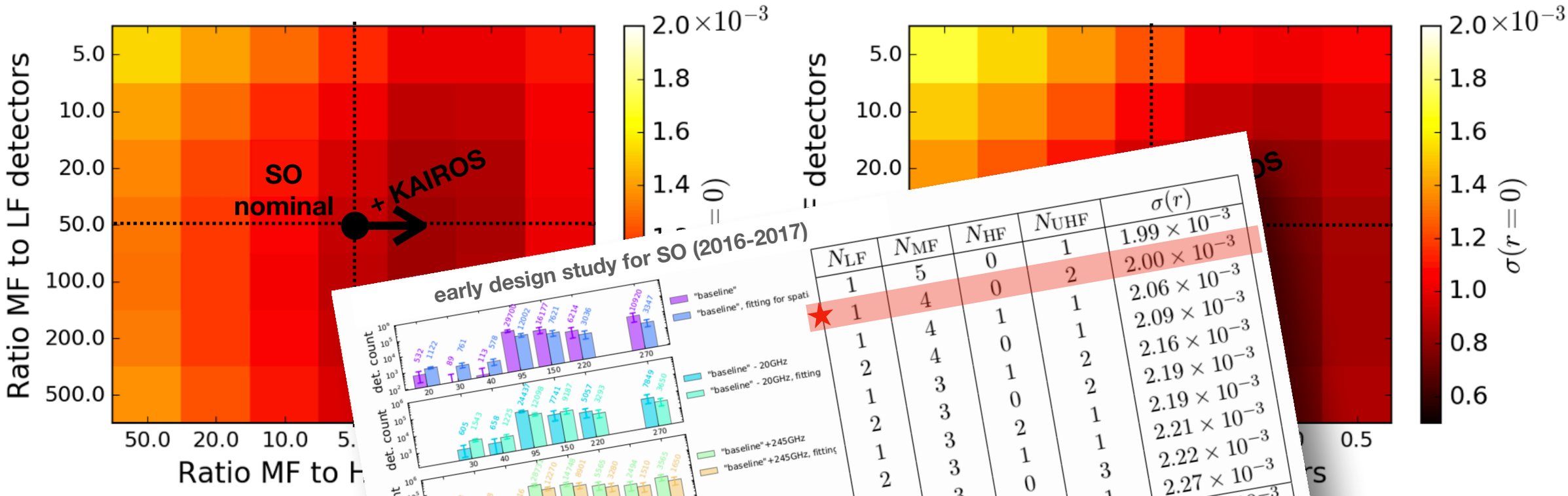

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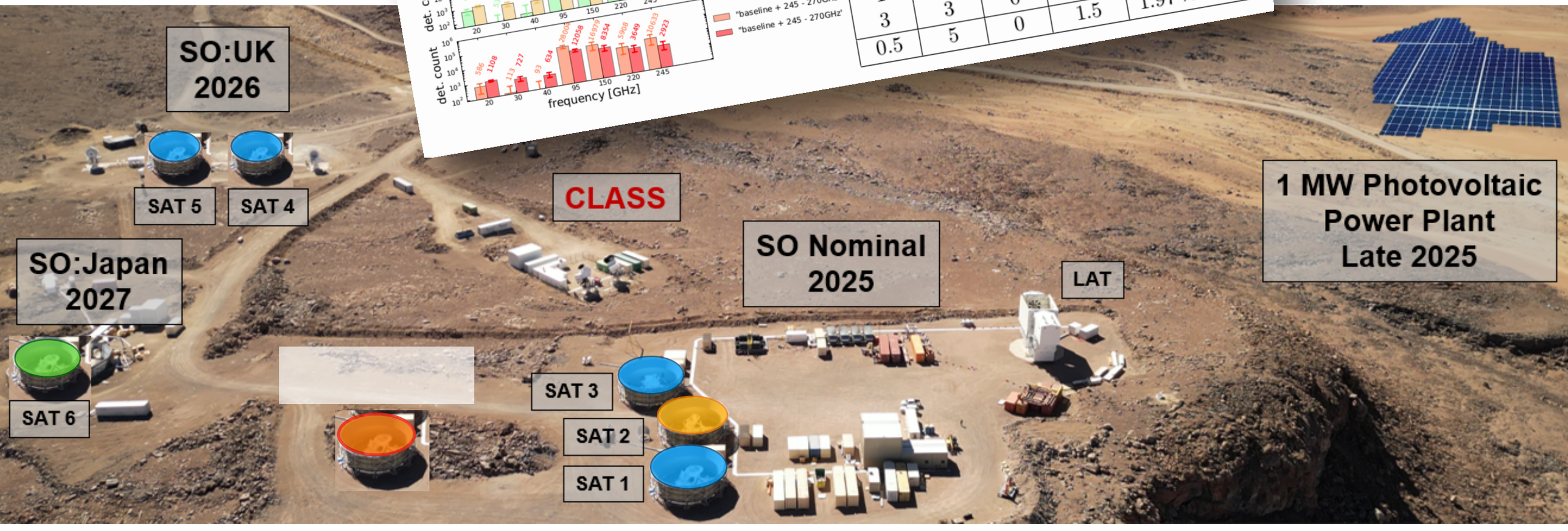

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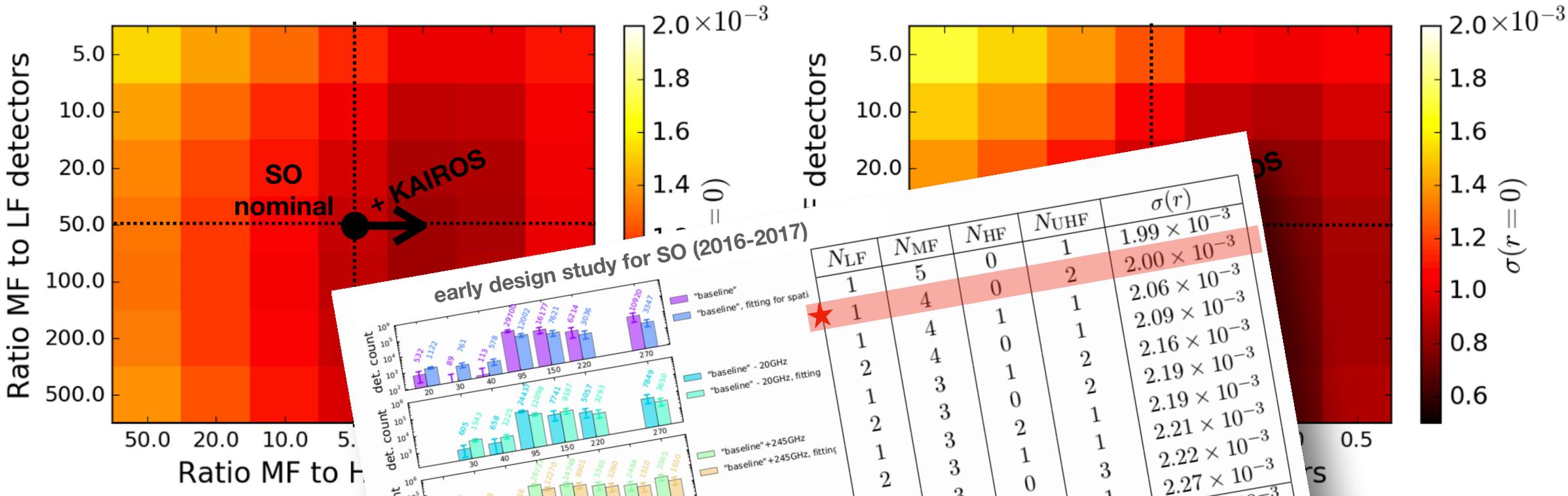

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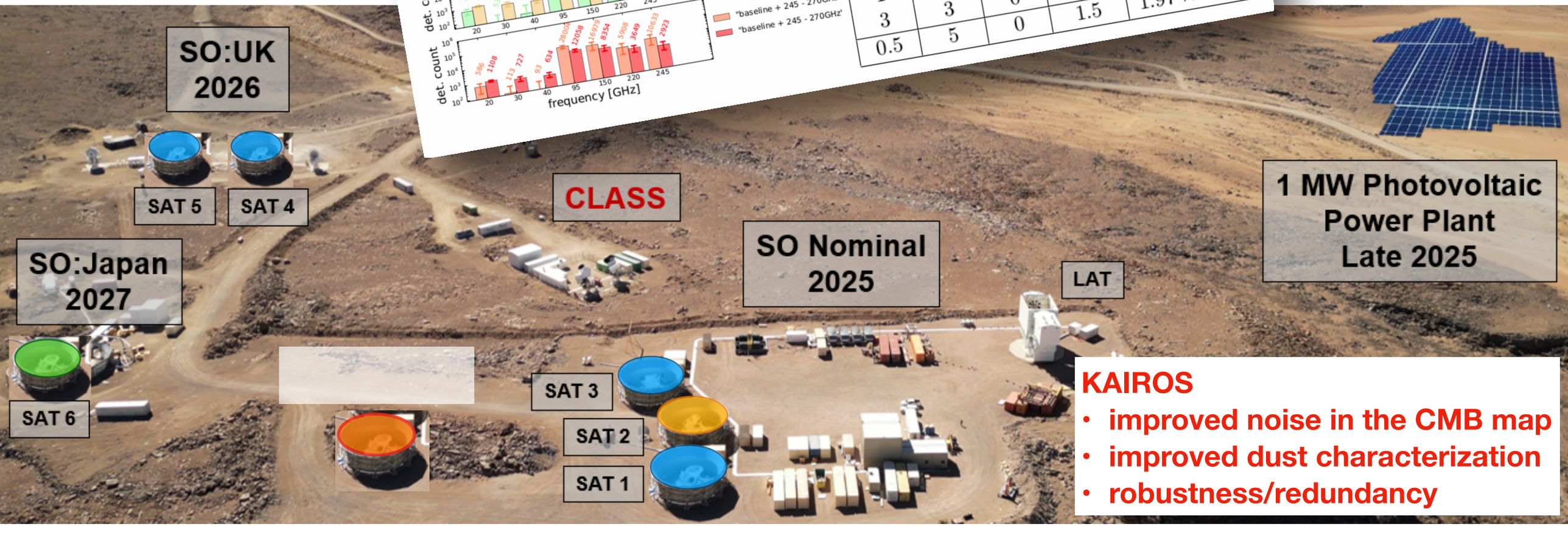
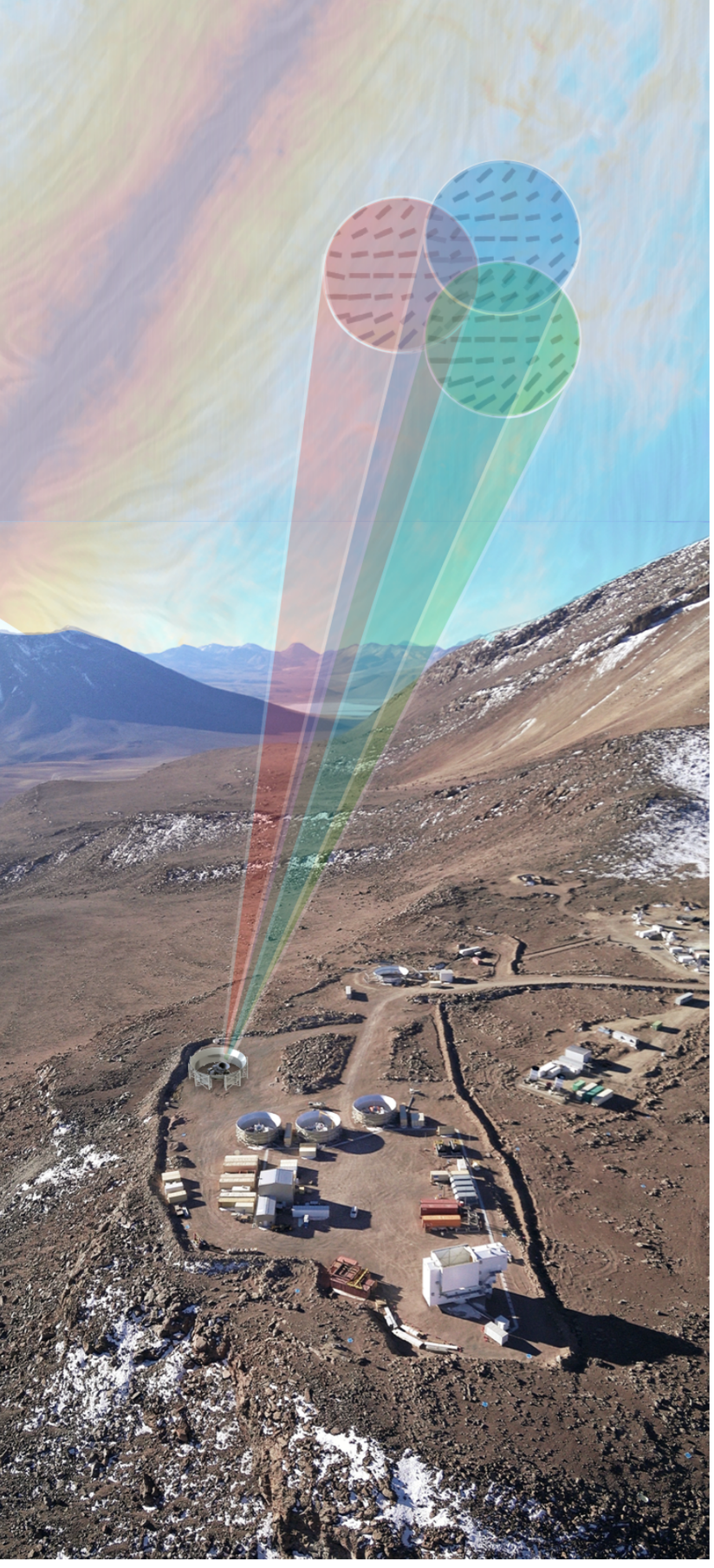


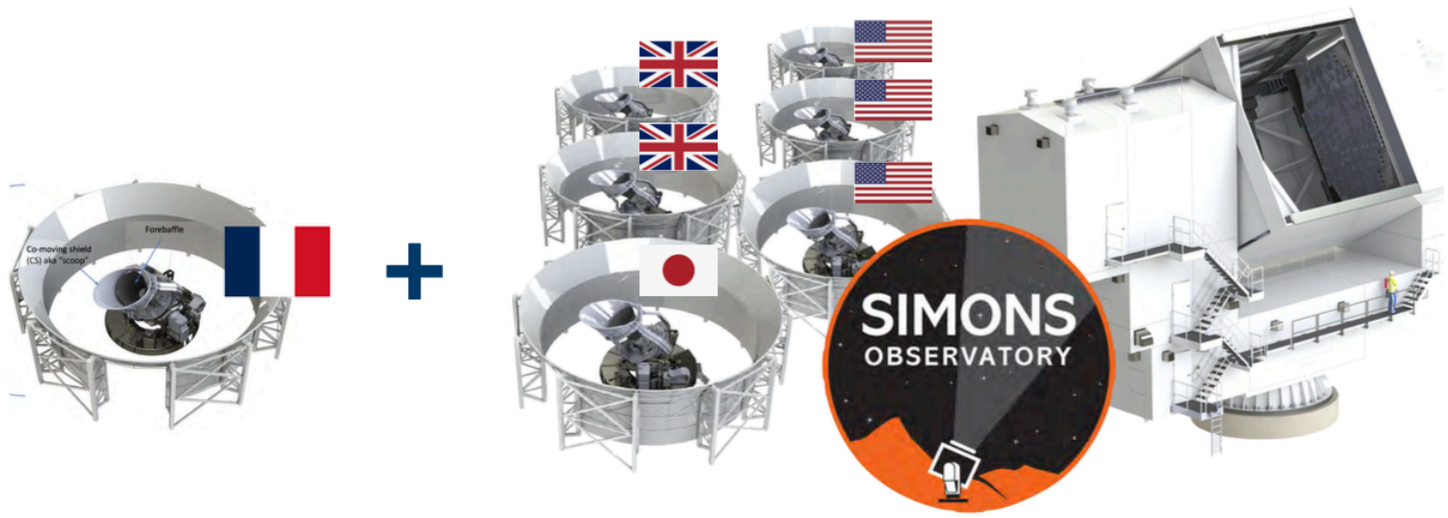
KAIROS

- **improved noise in the CMB map**
- **improved dust characterization**
- **robustness/redundancy**

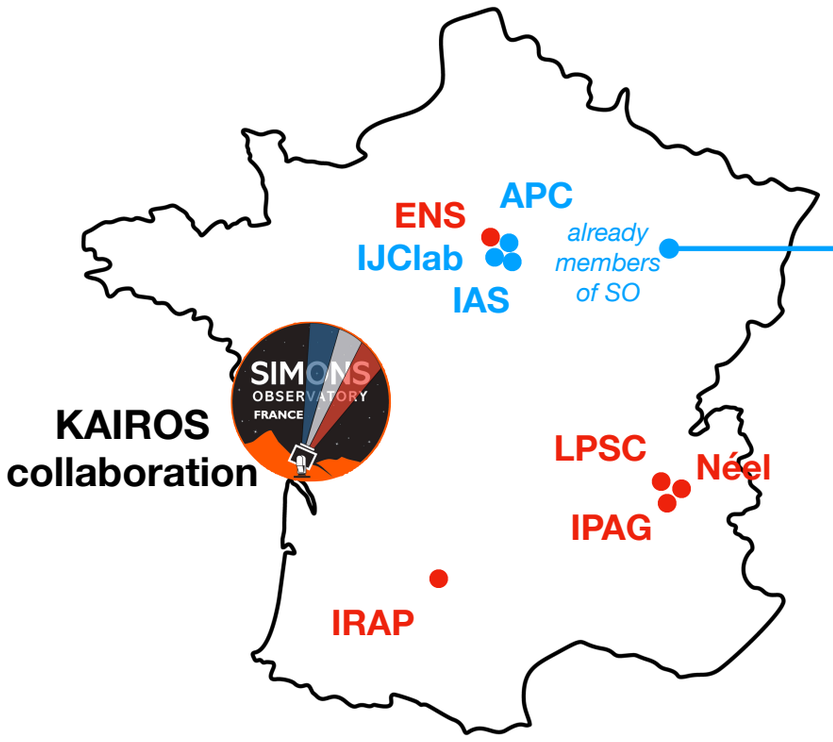


KAIROS concept

2-3 frequency bands above 200GHz



Our proposition is to **add a whole SAT infrastructure** to the existing ones (3 US + 2 UK + 1 Japan) putting **LEKID technology** on it. The platform pointing control and the 300K screen should remain the same wrt US/UK ones. Inside the cryostat we optimise things for KIDs.



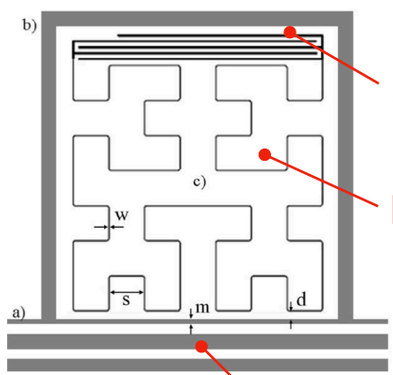
~20 French researchers already members of the SO collaboration
(8 permanent, 12 non-permanent)

KAIROS concept

Our approach on KID development for Polarimeters

Lumped Element KID

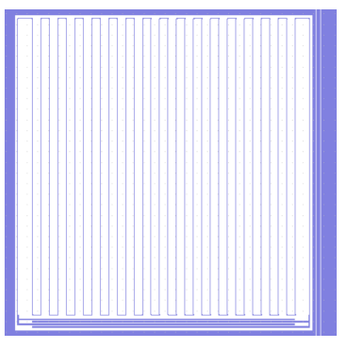
Dual Polarisation
(3rd-order Hilbert pattern)



Capacitor

Inductance

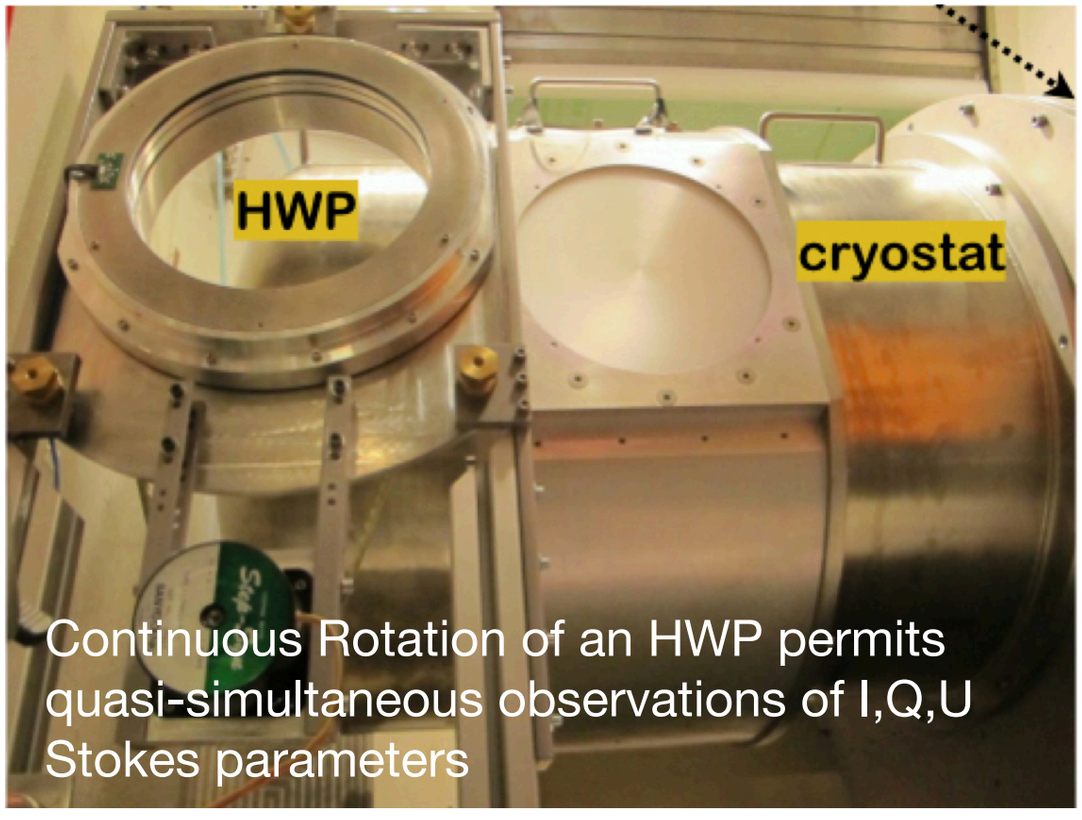
Single Polarisation

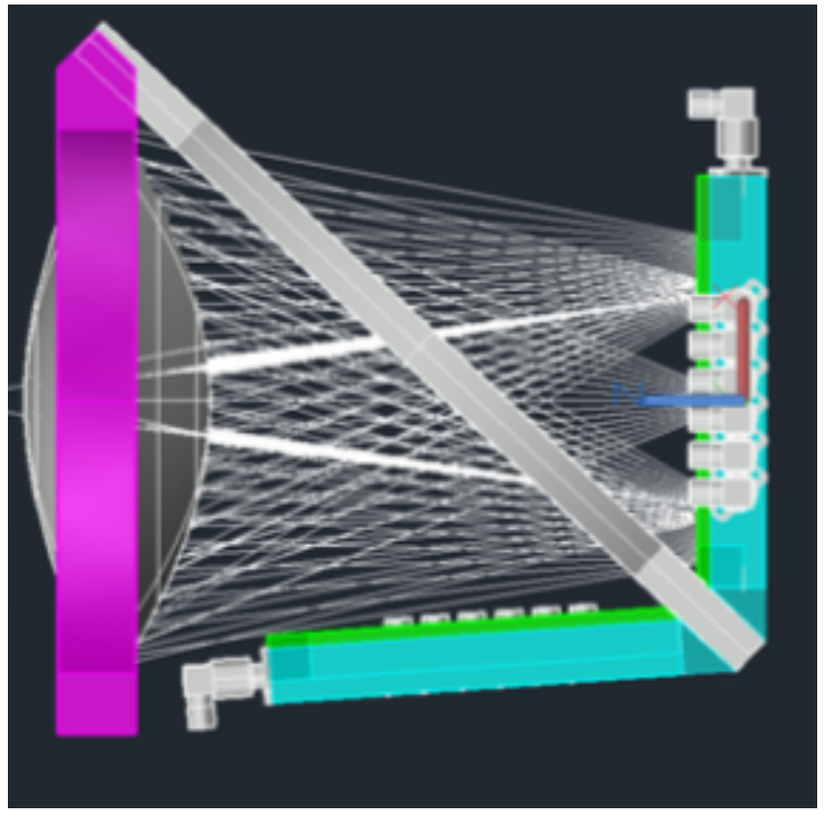


Feedline 50Ω

Filled arrays LEKID:

- **Large filling factor**
- **Very high quantum efficiency in a 30% mm-band**
- **Easy to fabricate**

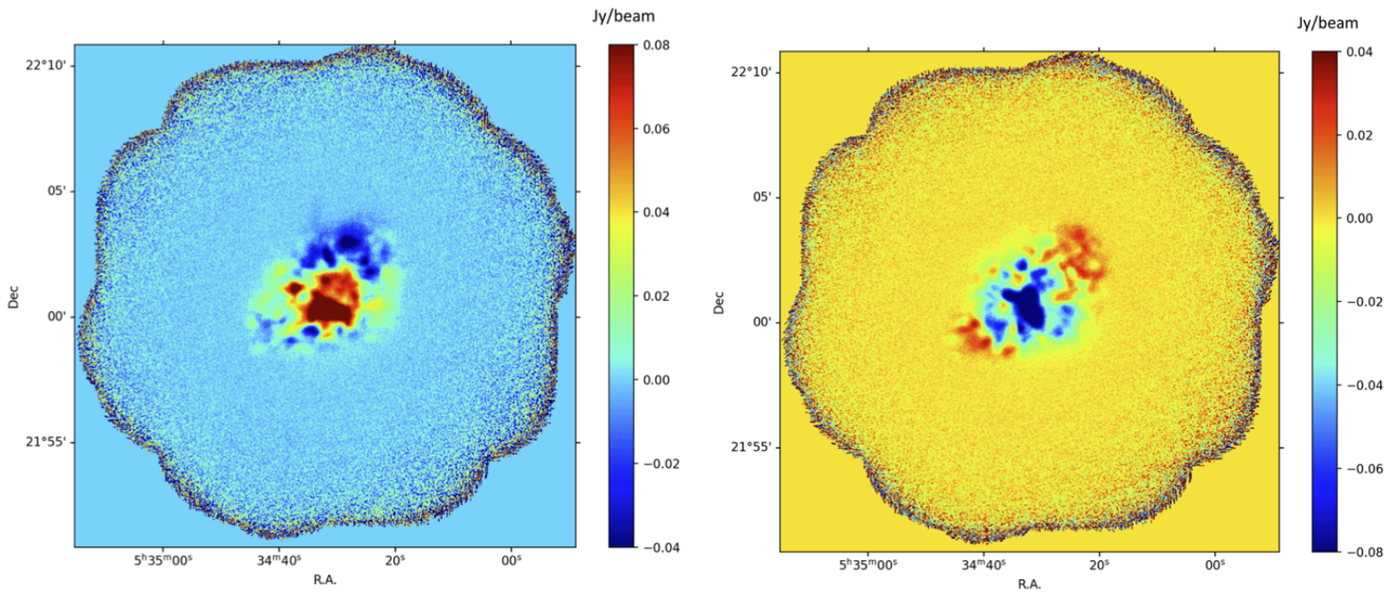




from Andrea Catalano (LPSC)

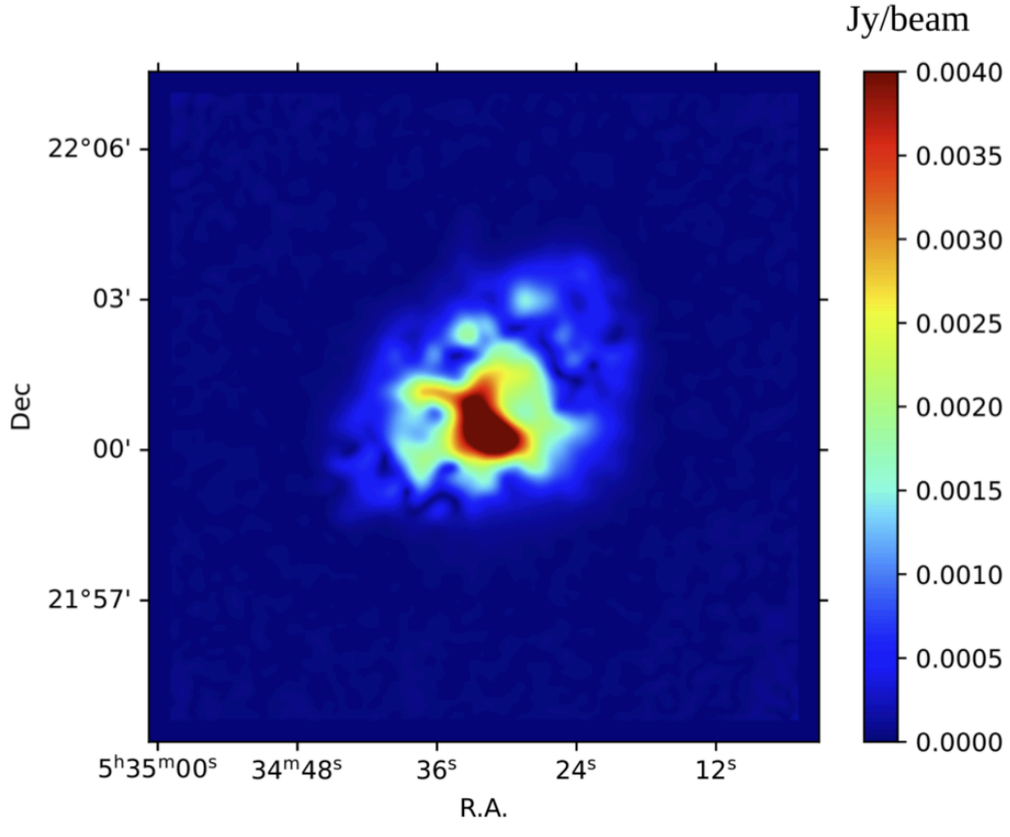
Observations with NIKA2

Stokes Q and U maps of the **Crab nebula** observed at 260 GHz

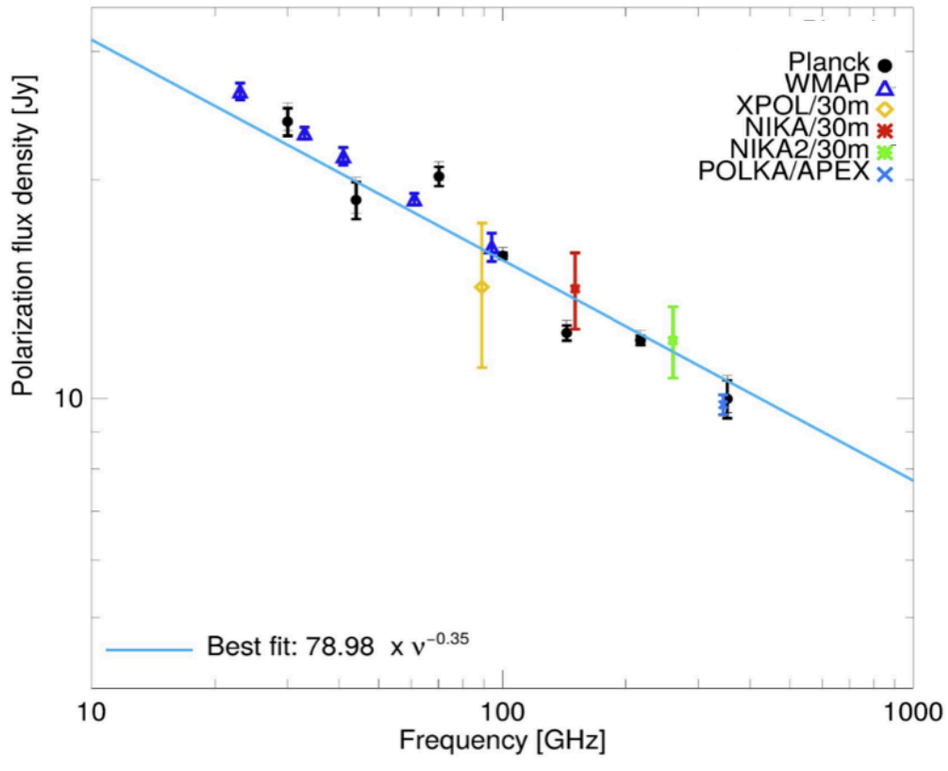


Ritacco et al. (2021) - arXiv:2111.02143

NIKA2 polarized intensity map



Spectral energy distribution obtained by previous measurements accounting for the new value obtained from NIKA2 (green).



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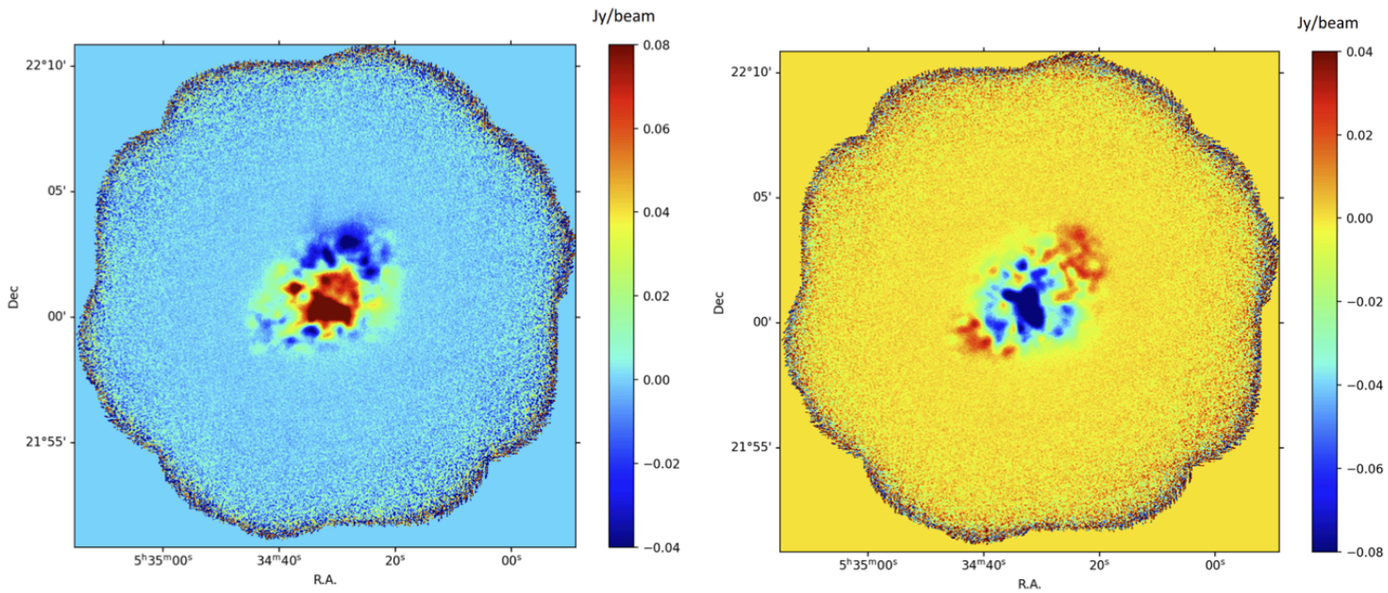

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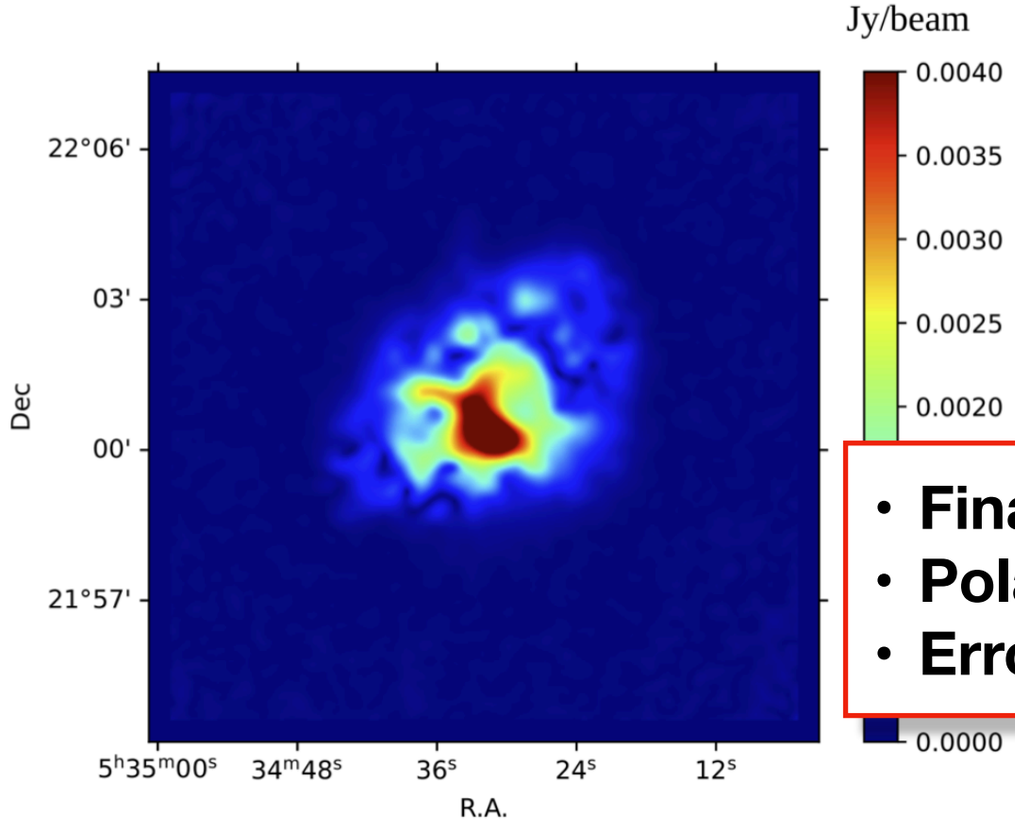

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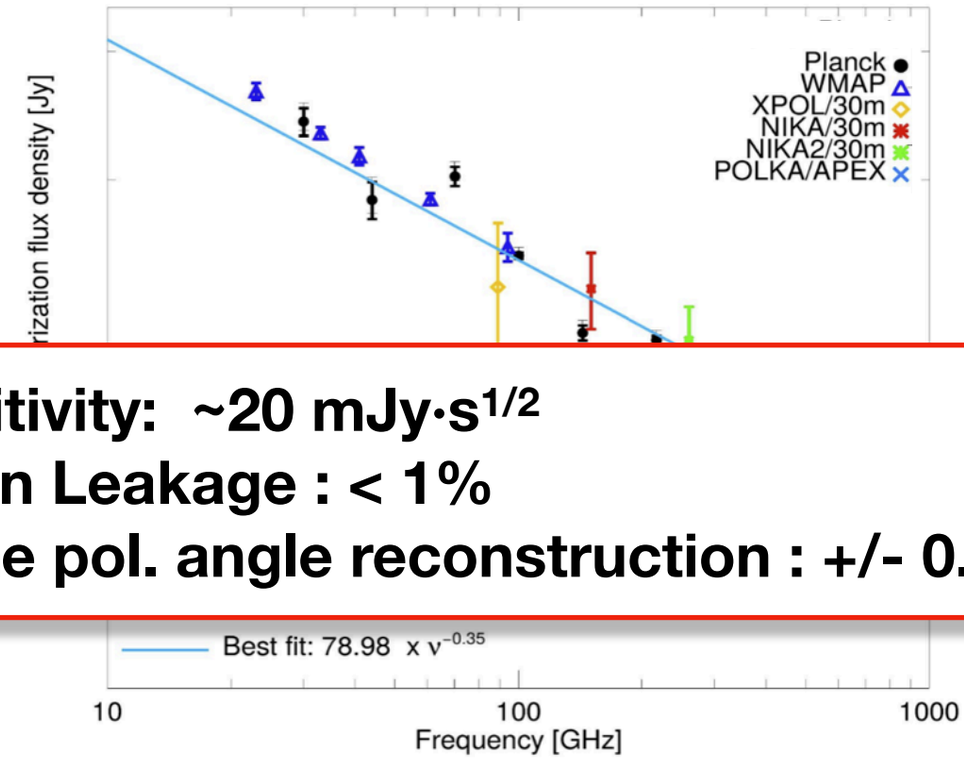
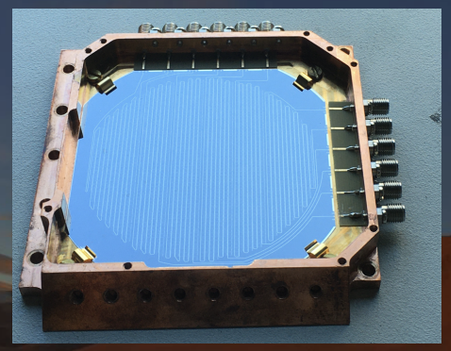


from Andrea Catalano (LPSC)

- **Final Sensitivity: ~20 mJy·s$^{1/2}$**
- **Polarization Leakage : < 1%**
- **Error on the pol. angle reconstruction : +/- 0.5 Deg.**

Observations with Concerto

2 KID Arrays (4304 pixels)

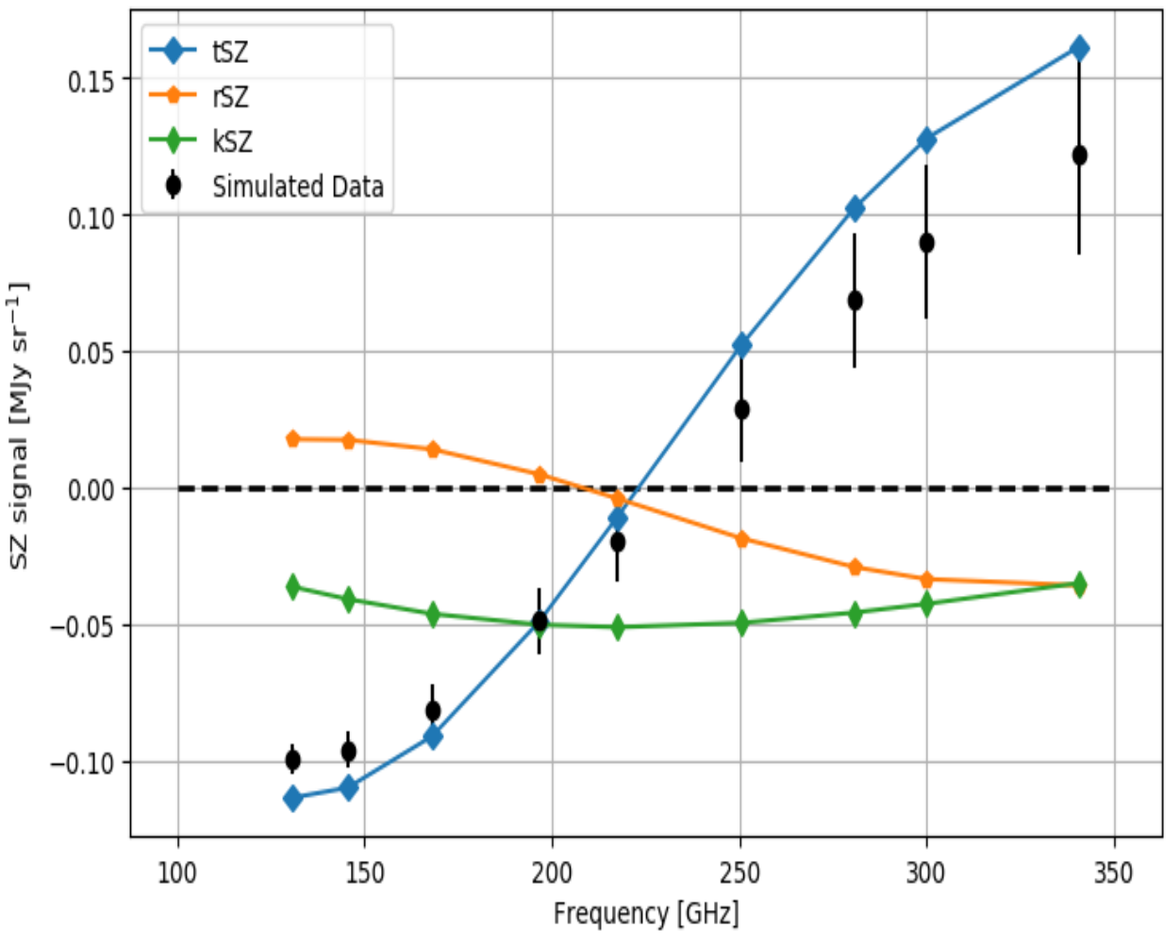


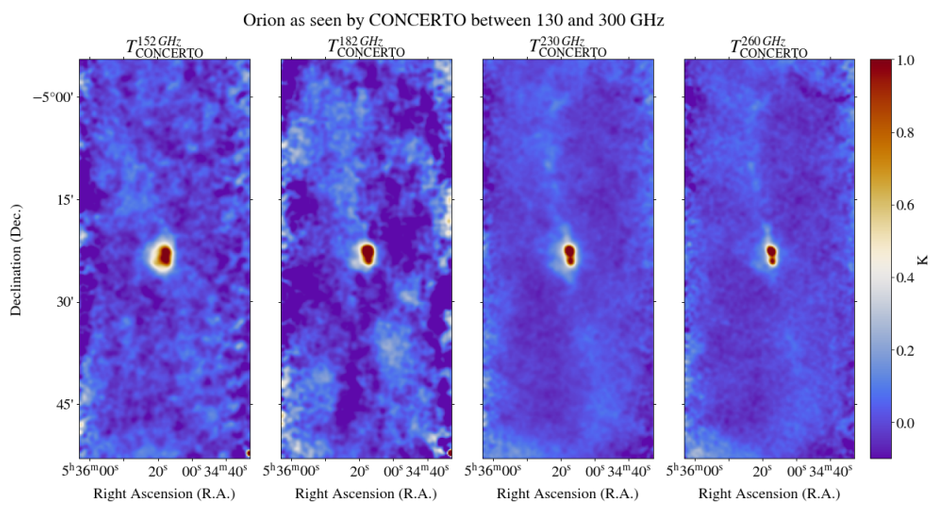
12 readout boards NIKEL

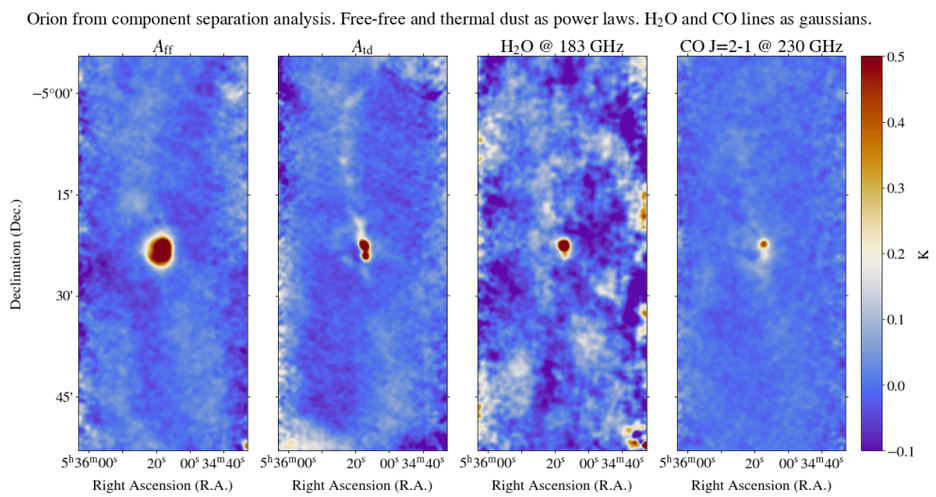
- Spectro-Interferometer (spectral resolution R > 100)
- Observing from 120 GHz to 350 GHz at 12 m APEX Tel.
- Large Field of View (20 arcmin)
- LEKID Technology
- Collaboration LAM - Inst. Néel - LPSC - IPAG

Scientific case:

- Observations of [C II] line emission at z > 5
- Sunyaev–Zel'dovich effect in galaxy clusters
- Galactic emission, others







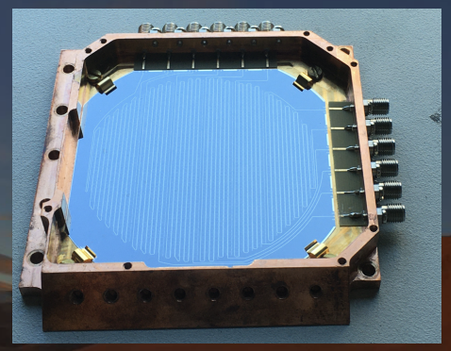
Preliminary results
Mateo Fernandez Torreiro et al., (in prep)

+ see Désert et al. 2504.20487

from Andrea Catalano (LPSC)

Observations with Concerto

2 KID Arrays (4304 pixels)

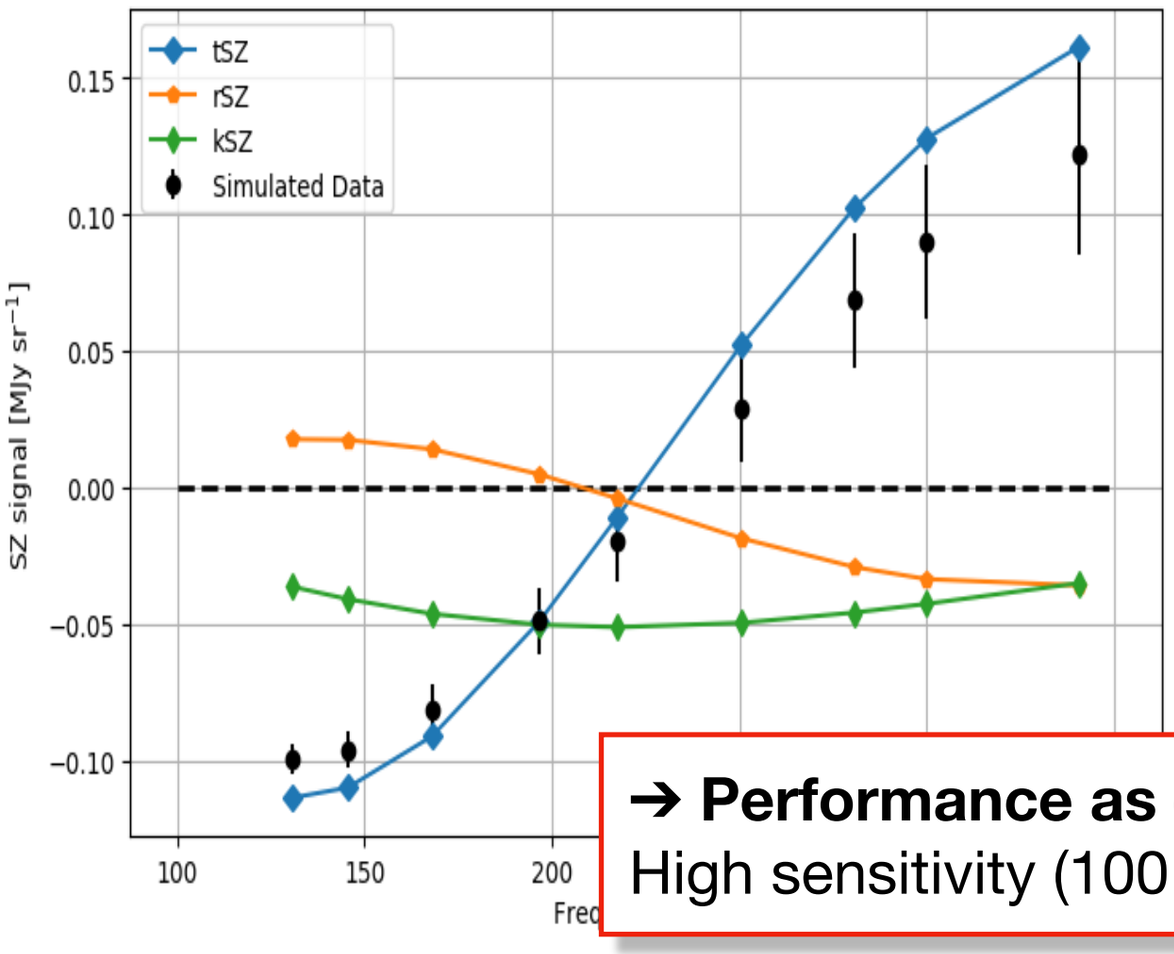


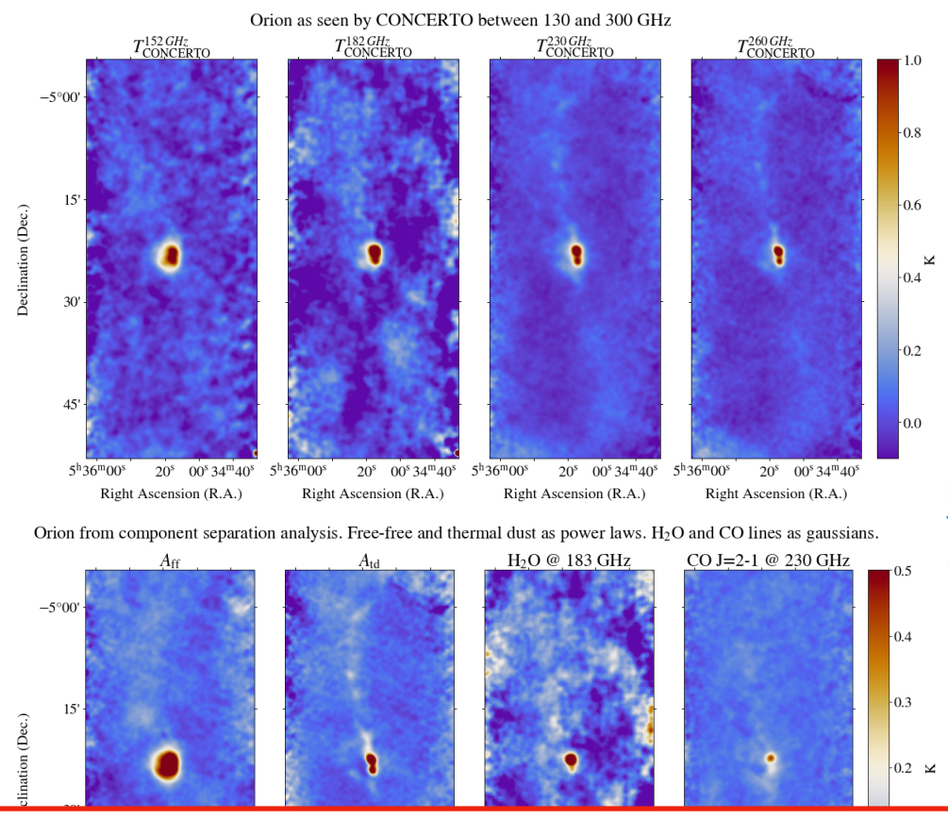
12 readout boards NIKEL

- Spectro-Interferometer (spectral resolution R > 100)
- Observing from 120 GHz to 350 GHz at 12 m APEX Tel.
- Large Field of View (20 arcmin)
- LEKID Technology
- Collaboration LAM - Inst. Néel - LPSC - IPAG

Scientific case:

- Observations of [C II] line emission at z > 5
- Sunyaev–Zel'dovich effect in galaxy clusters
- Galactic emission, others





Preliminary results
Mateo Fernandez Torreiro et al., (in prep)

+ see Désert et al. 2504.20487

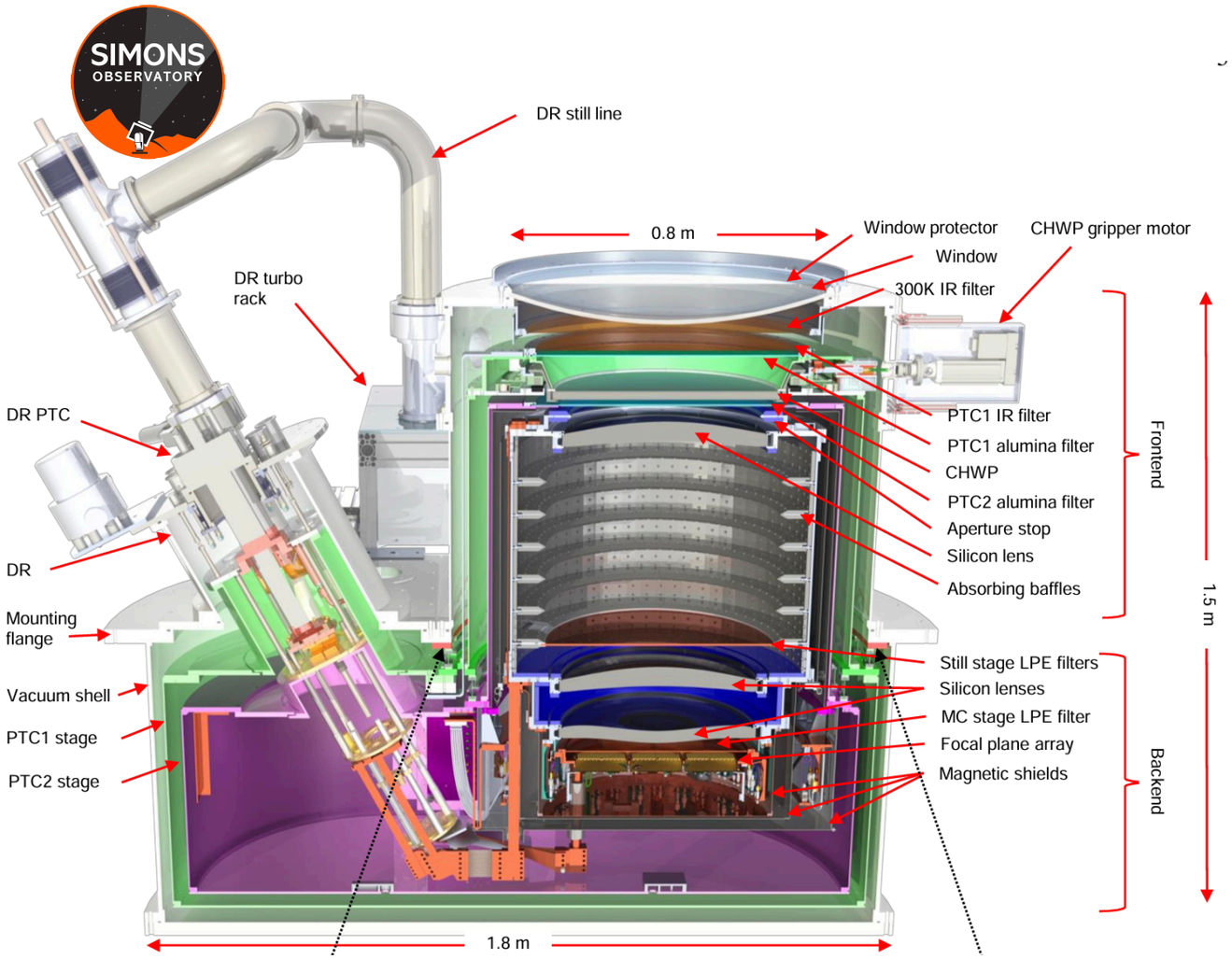
➔ Performance as expected

High sensitivity (100 mJy·s$^{1/2}$), 80% valid KIDs, 3% calibration error

from Alfredo Catalano (LPSC)

KAIROS concept

Starting from the constraints imposed by SO, we propose to adapt the French SAT to host a **30k-KID** focal plane with adapted optics



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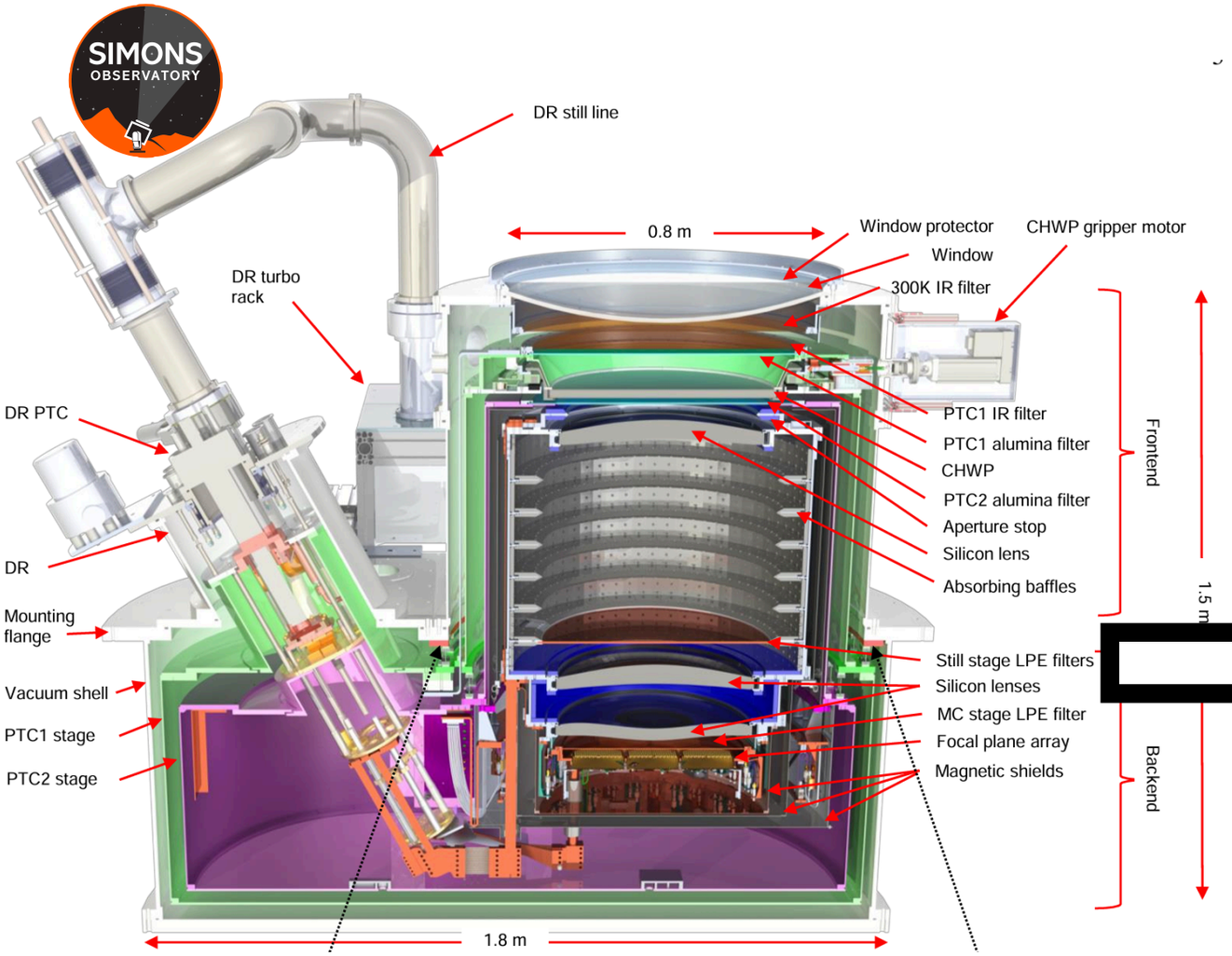

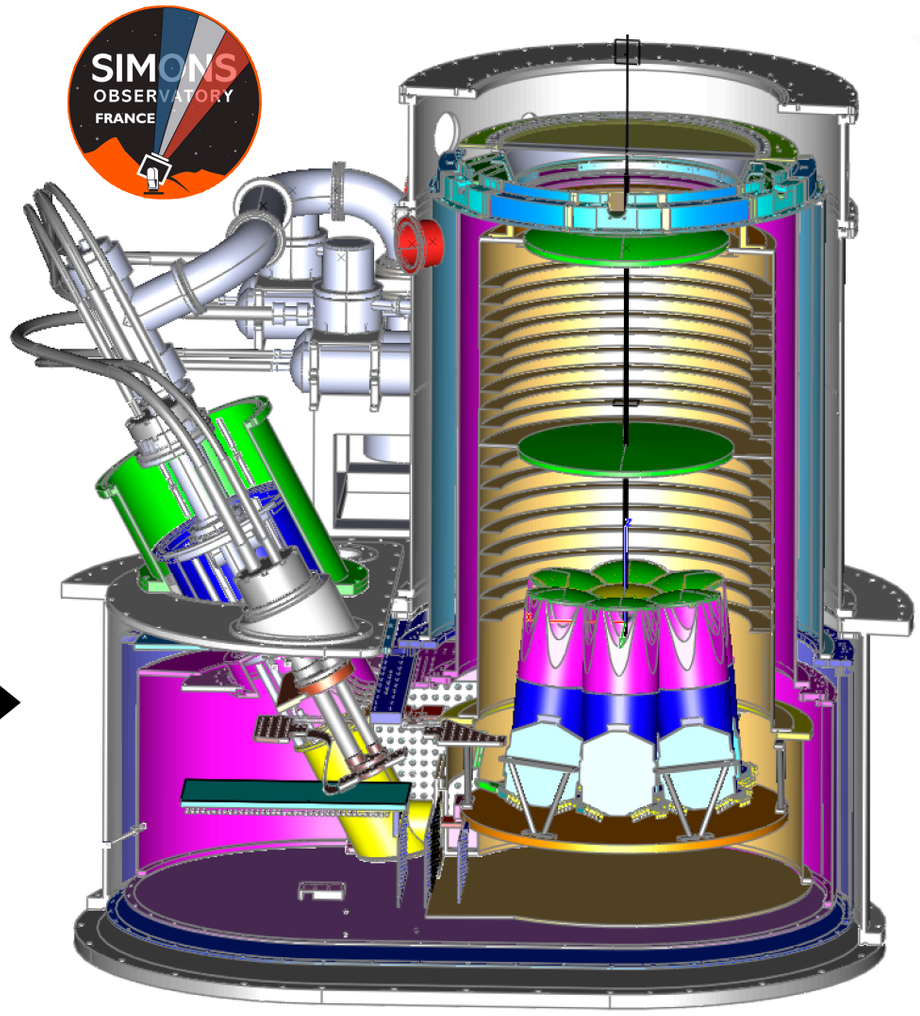

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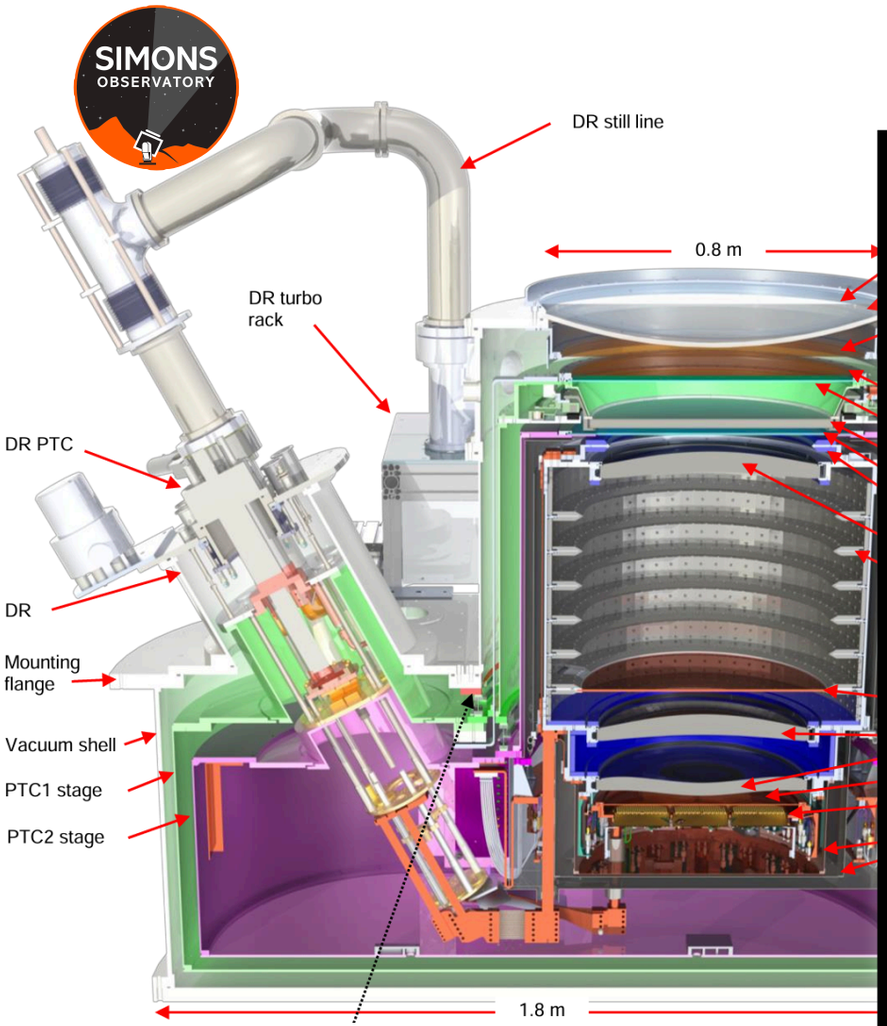
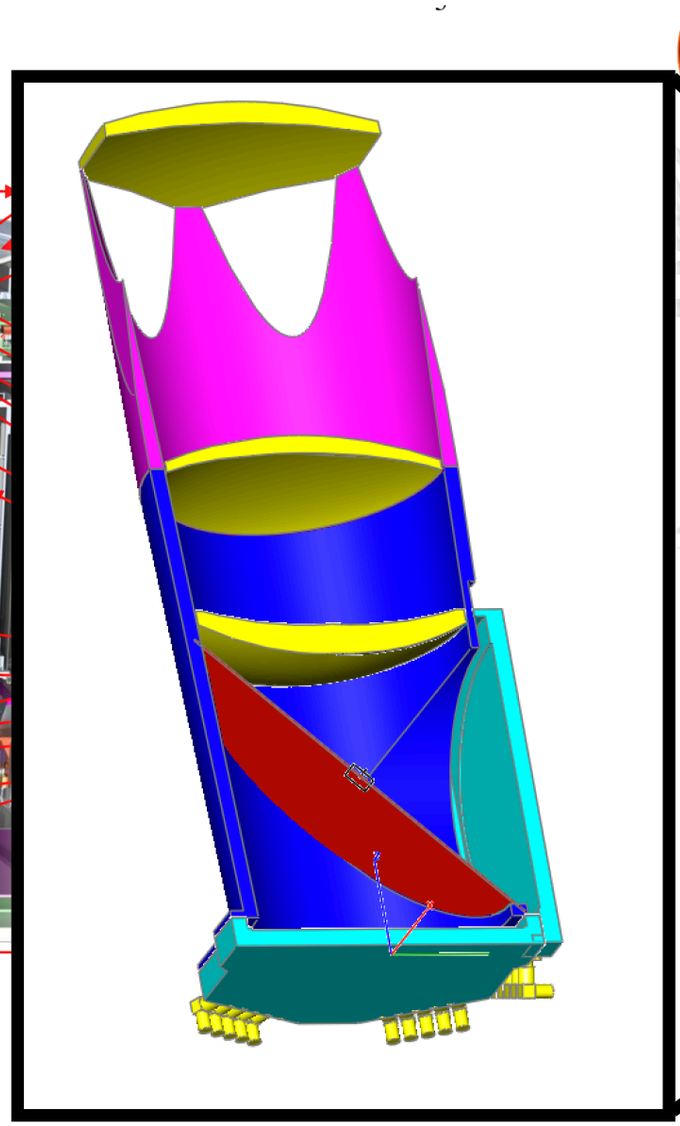
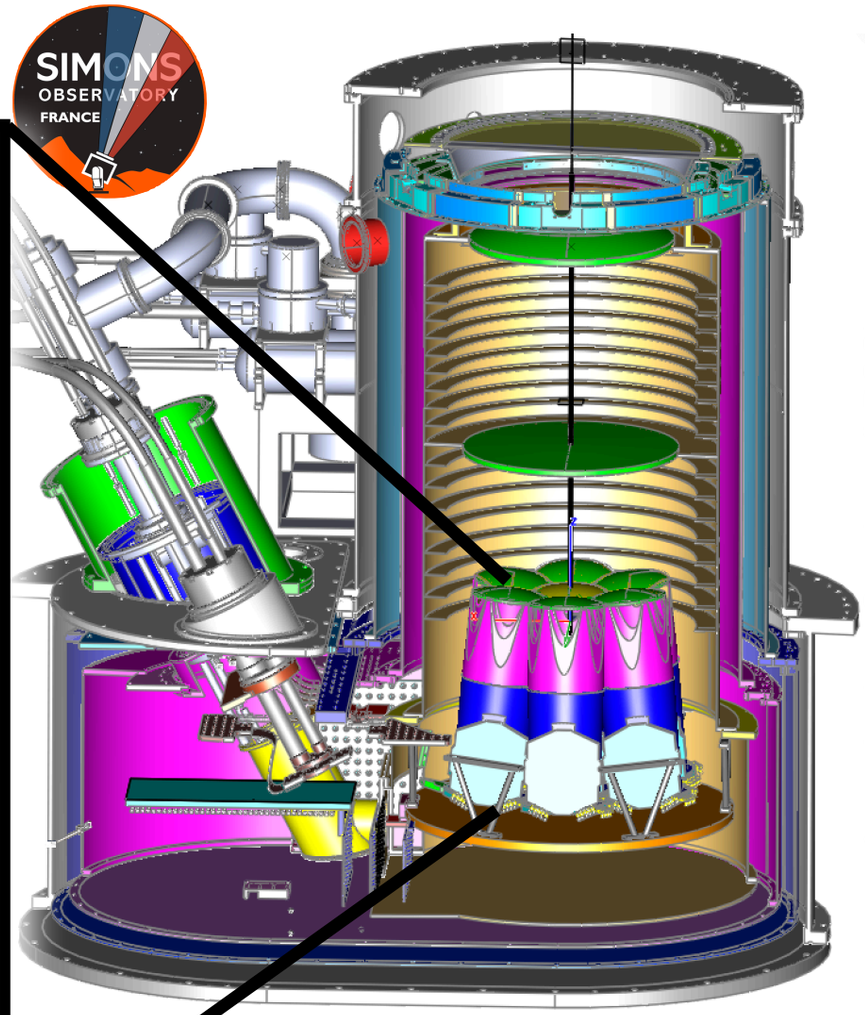




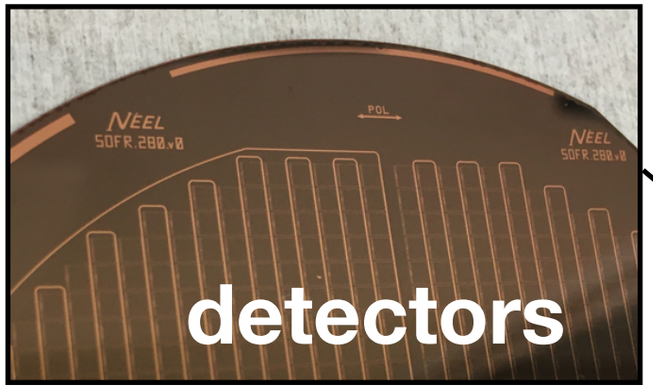


from Andrea Catalano (LPSC)

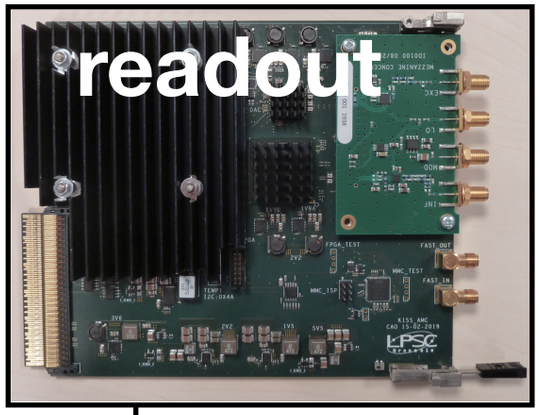
Entrance Pupil = 420 mm
Total F.o.V. = 35 Deg.
# of channels = 2
BandPass = 200-400 GHz
# of Optical Tubes = 7
F.o.V per Tube = 6 Deg
Total # of Si lenses per Tube = 5
Total # of Det. ~ 30k
# of LEKID array = 36 (4-inches wafer)
# of Readout Boards = 50-70
(multiplex. Factor~ 600-800)
Total Data Rate ~ 100 MBytes/s

KAIROS concept

Not Critical
Challenging
Critical

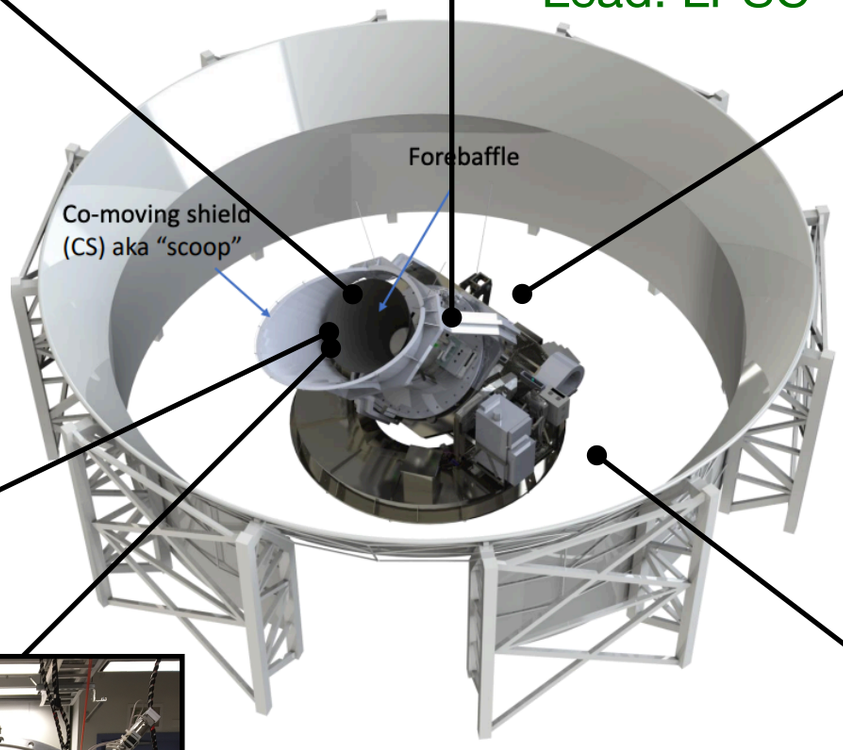


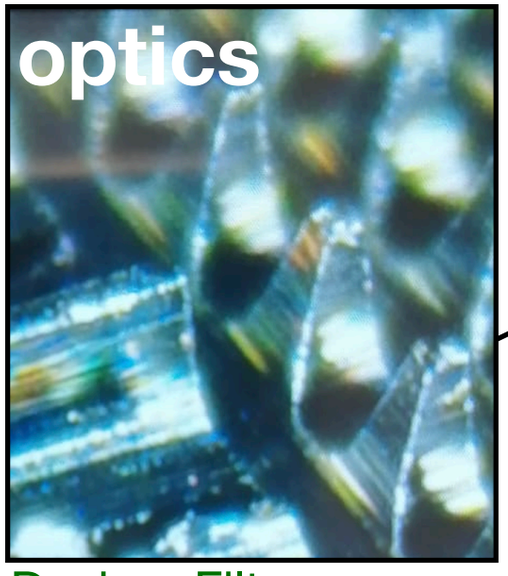
30k-pixel in 38 k-pixel arrays
Lead: Néel



About 70 Boards
(Concerto Version)
Lead: LPSC

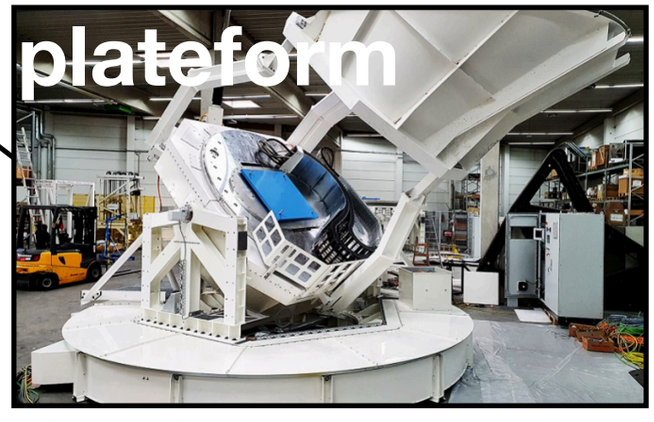
Modified US Cryostat
adapted for filled
arrays LEKID optics.
Lead: Néel





Design, Filters,
Polarizers … but
critical point Si
Lenses with AR.
Lead: LPSC

Sapphire HWP
+ Rotation system by
magnetic levitation
Lead: IJCLab (with GIS)



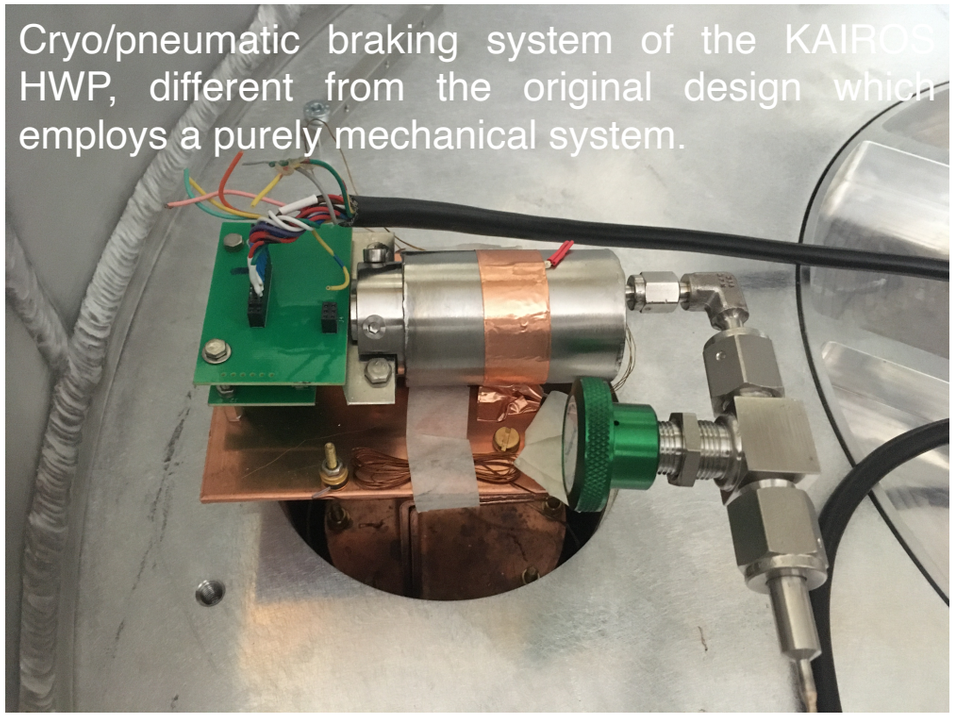
Same Platform and ground
shield -- Fabricated in
Germany (Vertex). Lead: APC

KAIROS concept

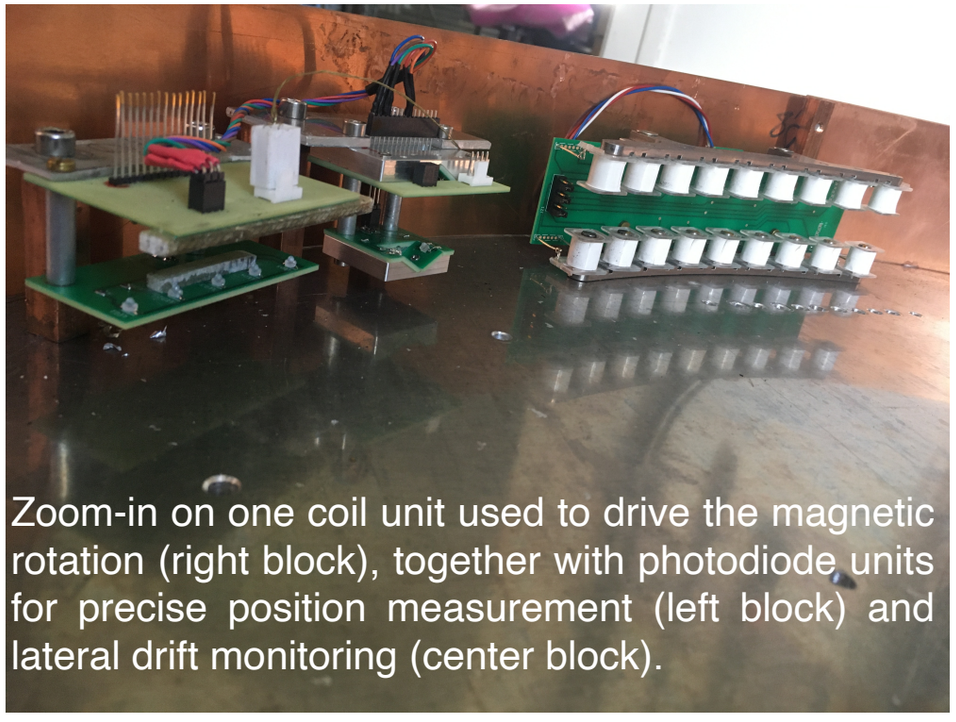
On-going fabrication of a test cryostat

Complete system with an aluminum disk (to replace the Sapphire HWP) set in rotation (it works both at room temperature and at cryogenic temperature) by a magnetic field generated by multiple coil units.

➔ benefiting from the high speed KIDS, we are thinking of making the HWP spin 2-3x faster than nominal ones, potentially reducing the atmospheric contamination (higher at high frequencies)



Cryo/pneumatic braking system of the KAIROS HWP, different from the original design which employs a purely mechanical system.



Zoom-in on one coil unit used to drive the magnetic rotation (right block), together with photodiode units for precise position measurement (left block) and lateral drift monitoring (center block).

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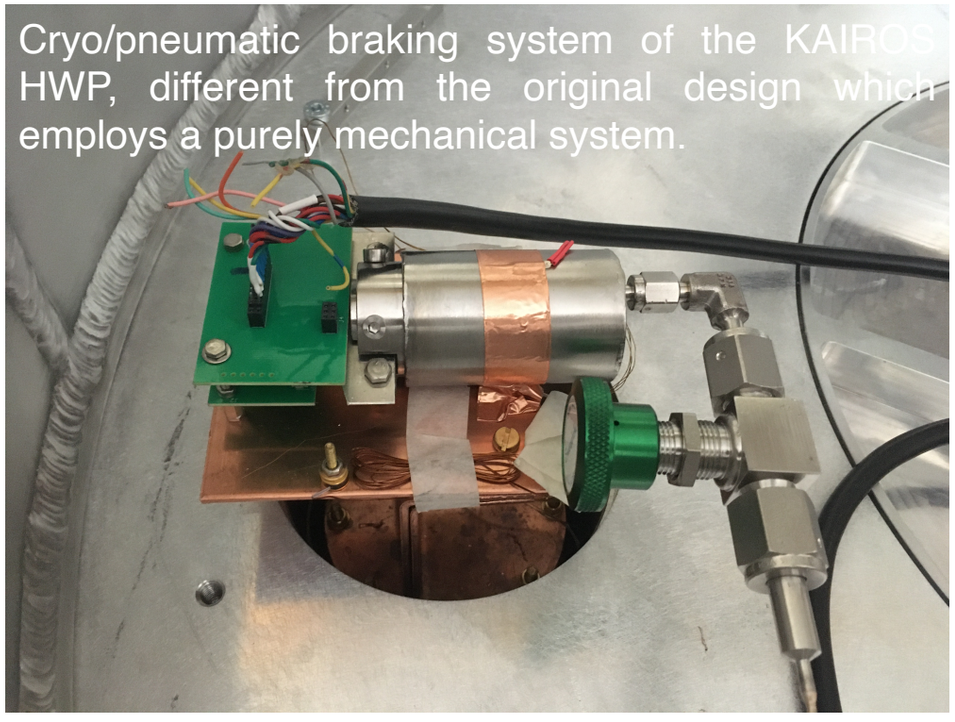

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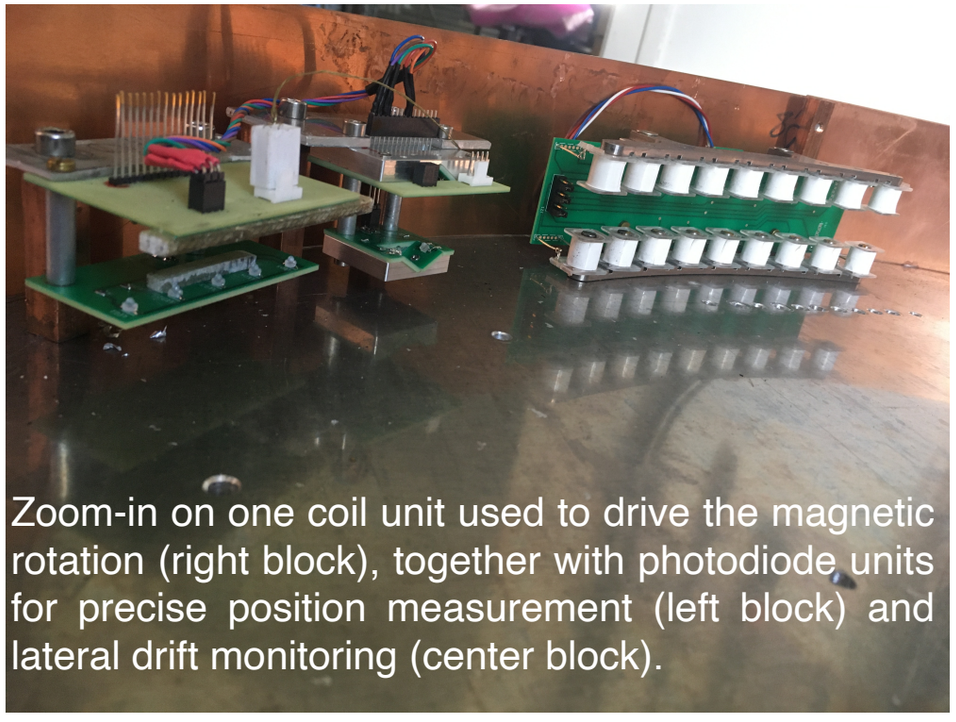

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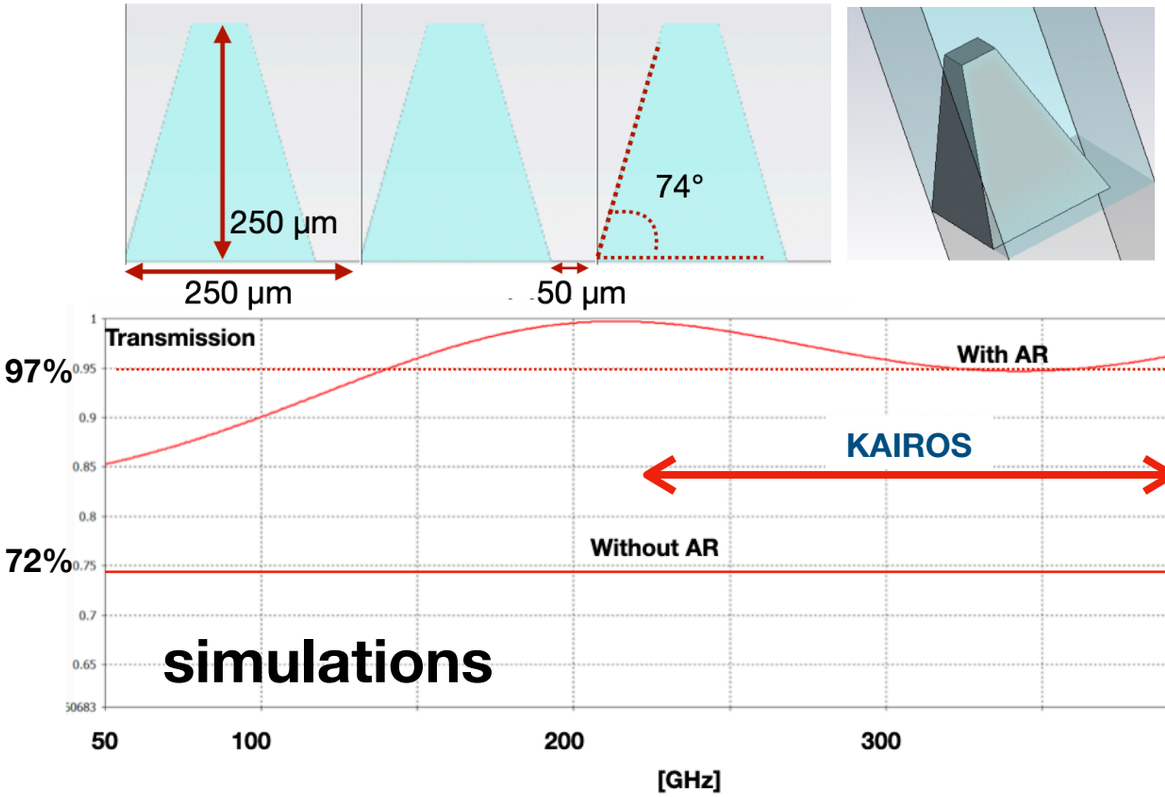
KAIROS concept

lenses ➔ up to now we have used for mm-wave instruments plastic lenses (HDPE or Polypropylene). Skills at LPSC

Anti-Reflection coating needed!



Bigger FoV

↓

Bigger Lenses

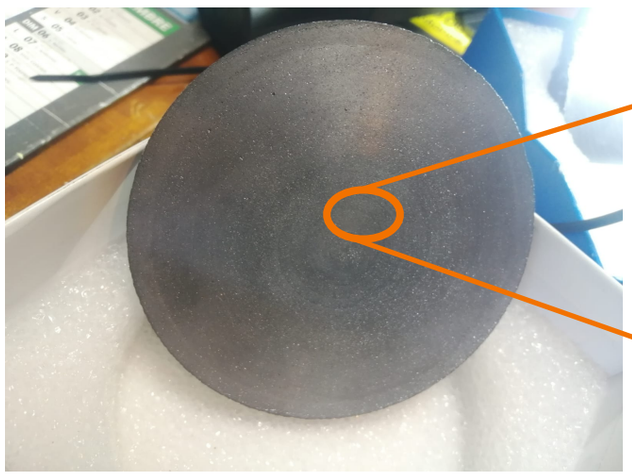
↓

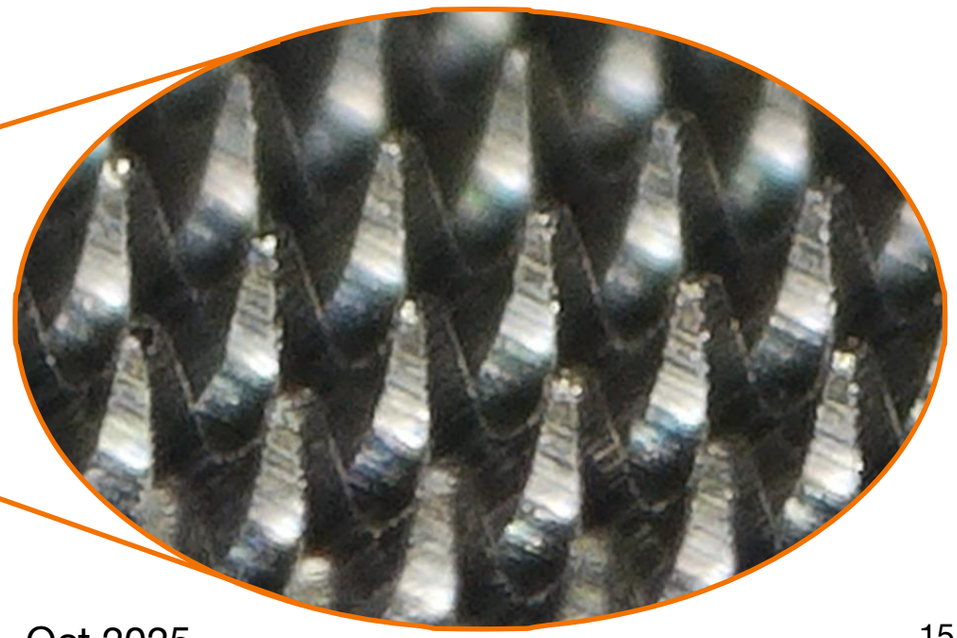
Thicker Lenses

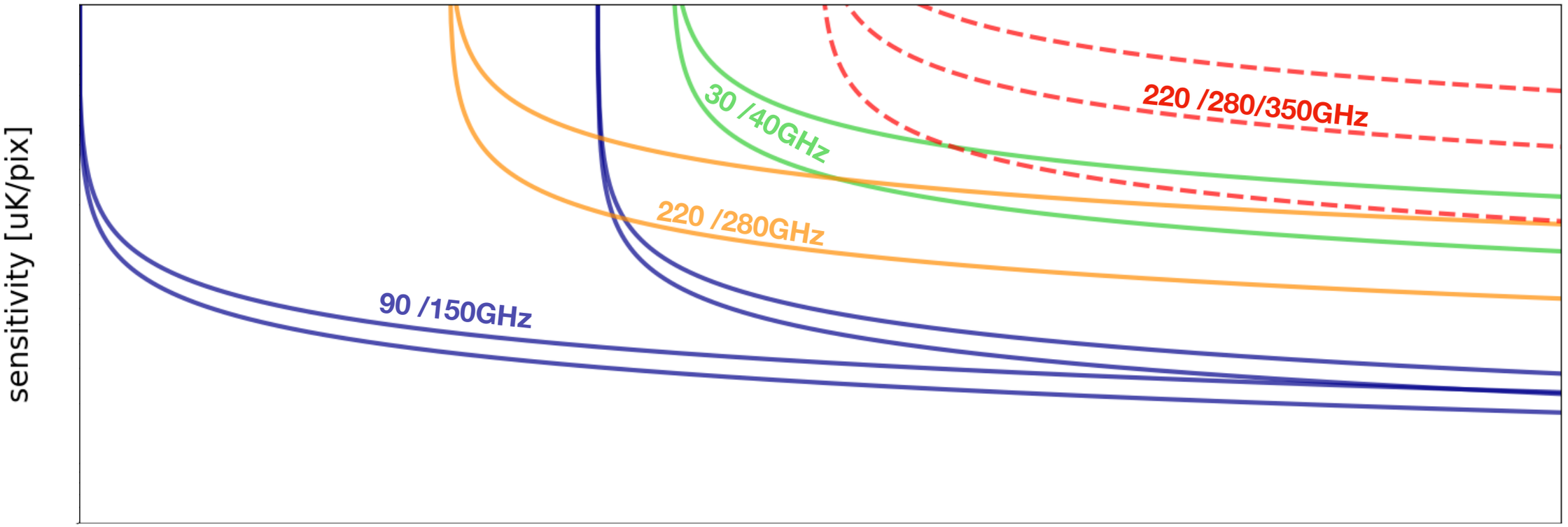
Plastic — low refr. index, higher absorption 👎

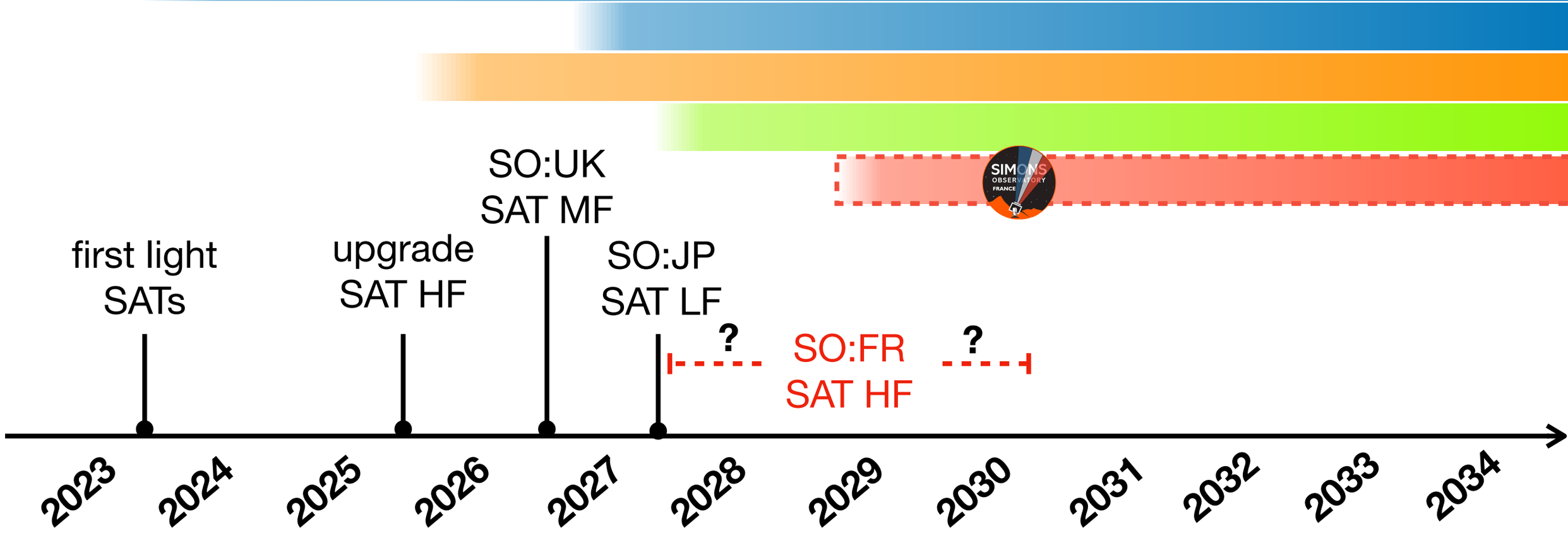
Silicon — high refr. index, lower absorption 👍

Prototype fabricated in October 2024






sensitivity [uK/pix]
90 /150GHz
220 /280GHz
30 /40GHz
220 /280/350GHz


SO:UK
SAT MF
first light
SATs
upgrade
SAT HF
SO:JP
SAT LF
?
SO:FR
SAT HF
?
2023
2024
2025
2026
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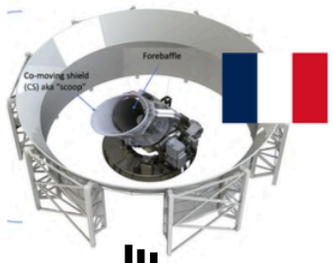
2031
2032
2033
2034

KAIROS: science case

30k detectors
220-280-350GHz



+

longer term

Galactic science

- is there one or two dust populations?
- map of Bd ➔ impact on our understanding of dust life cycle
- what is the amplitude and properties of the EB correlation for the interstellar dust ➔ potentially a huge impact for the cosmic birefringence

Impact on component separation and inflation

- improved quality and robustness of component separation ➔ better CMB map depth and stronger control of biases/systematics
- better and more robust constraints on inflation

Reionization

in its extended version, KAIROS would have potentially a unique access to low ell through

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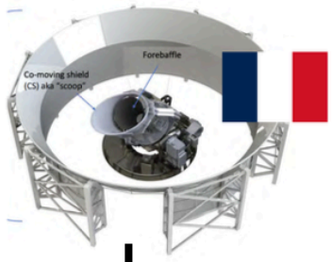
KAIROS: science case

30k detectors
220-280-350GHz



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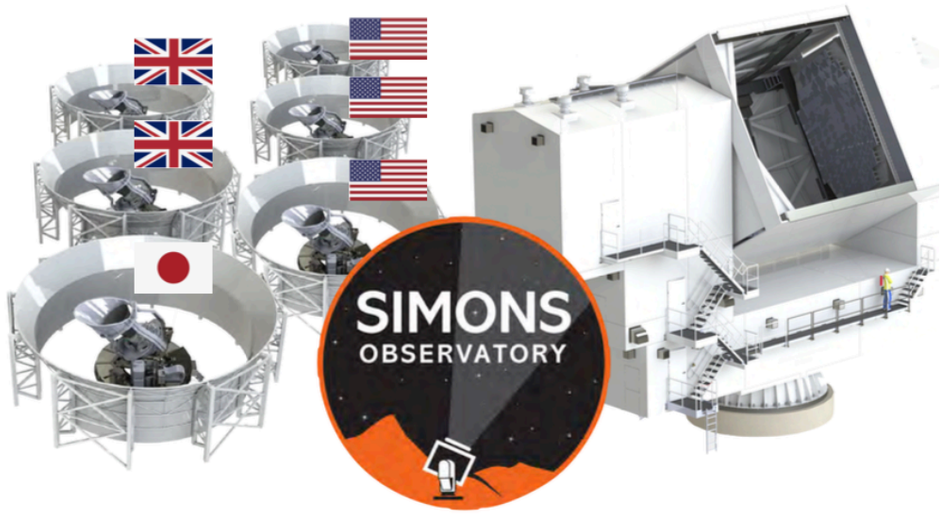

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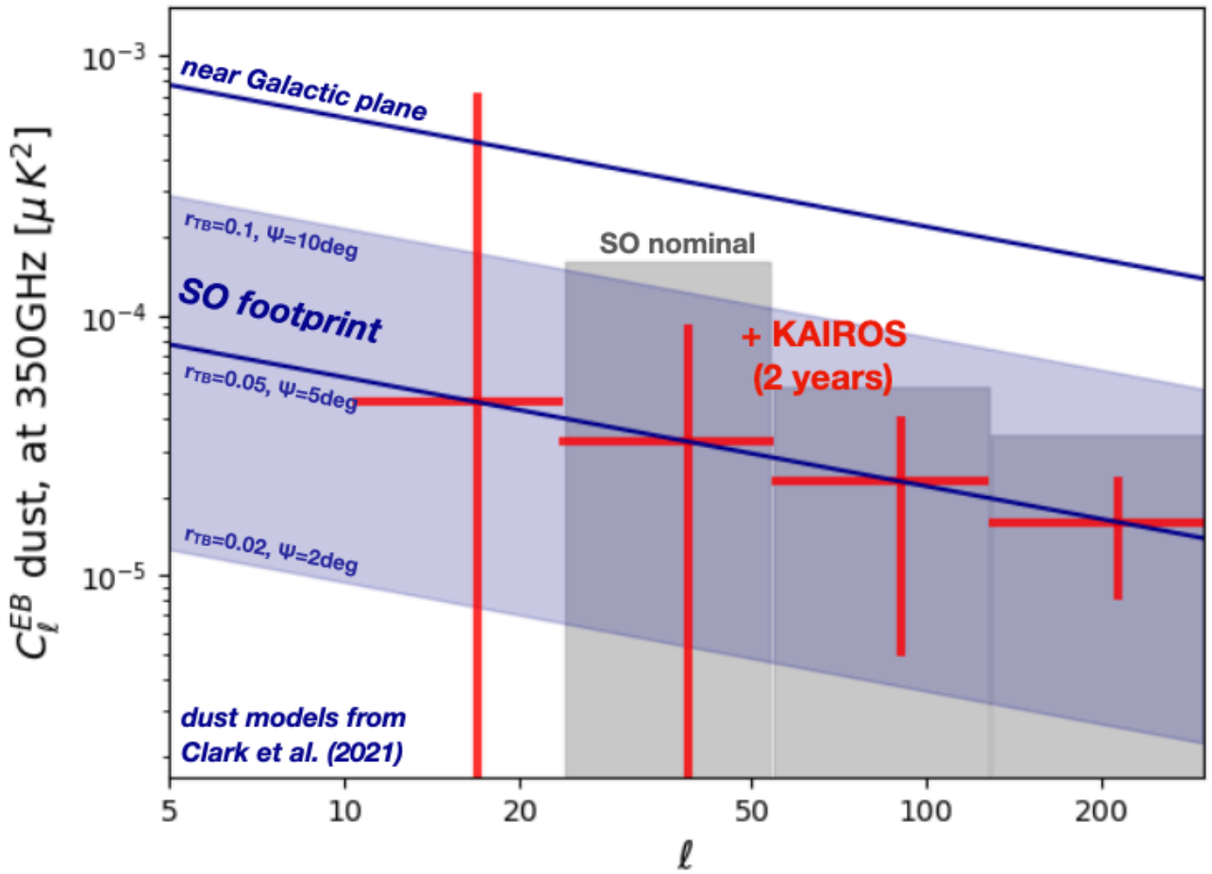
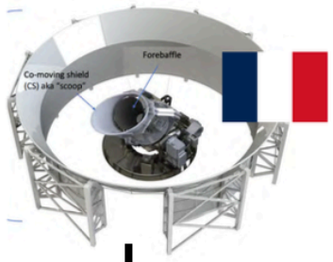


KAIROS: science case

30k detectors
220-280-350GHz



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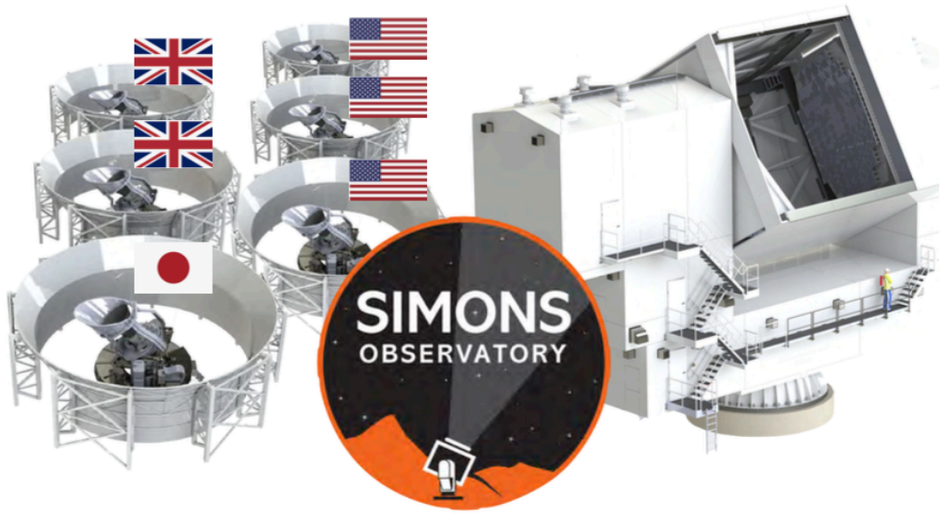

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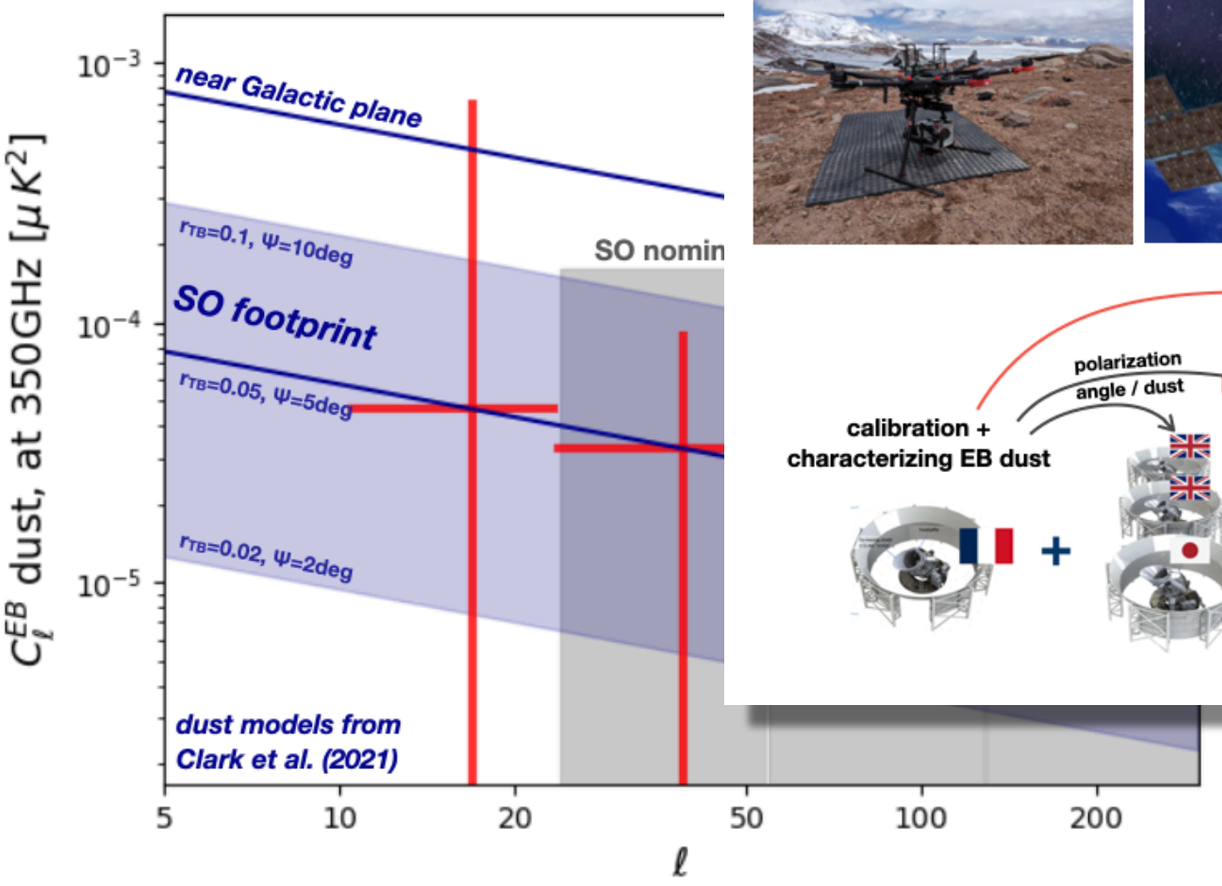
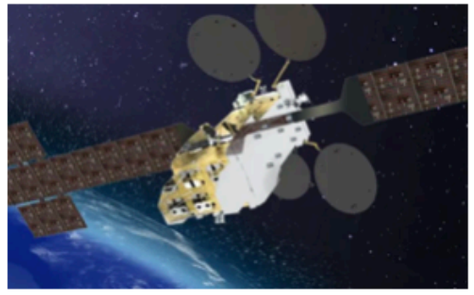
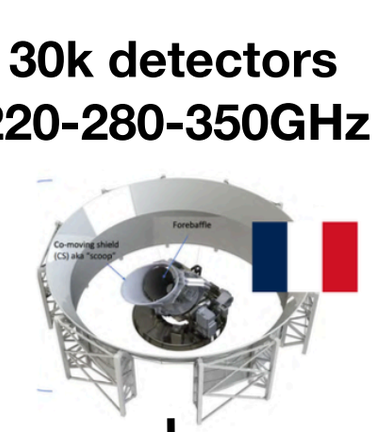


KAIROS in collaboration with the
SO **drone** / **CosmoCal** / wiregrid projects



KAIROS: science case

30k detectors
220-280-350GHz



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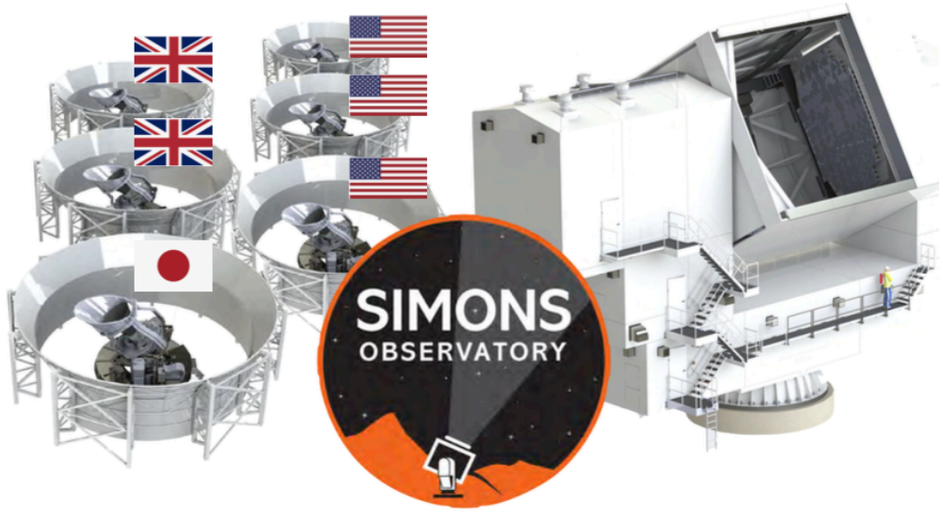

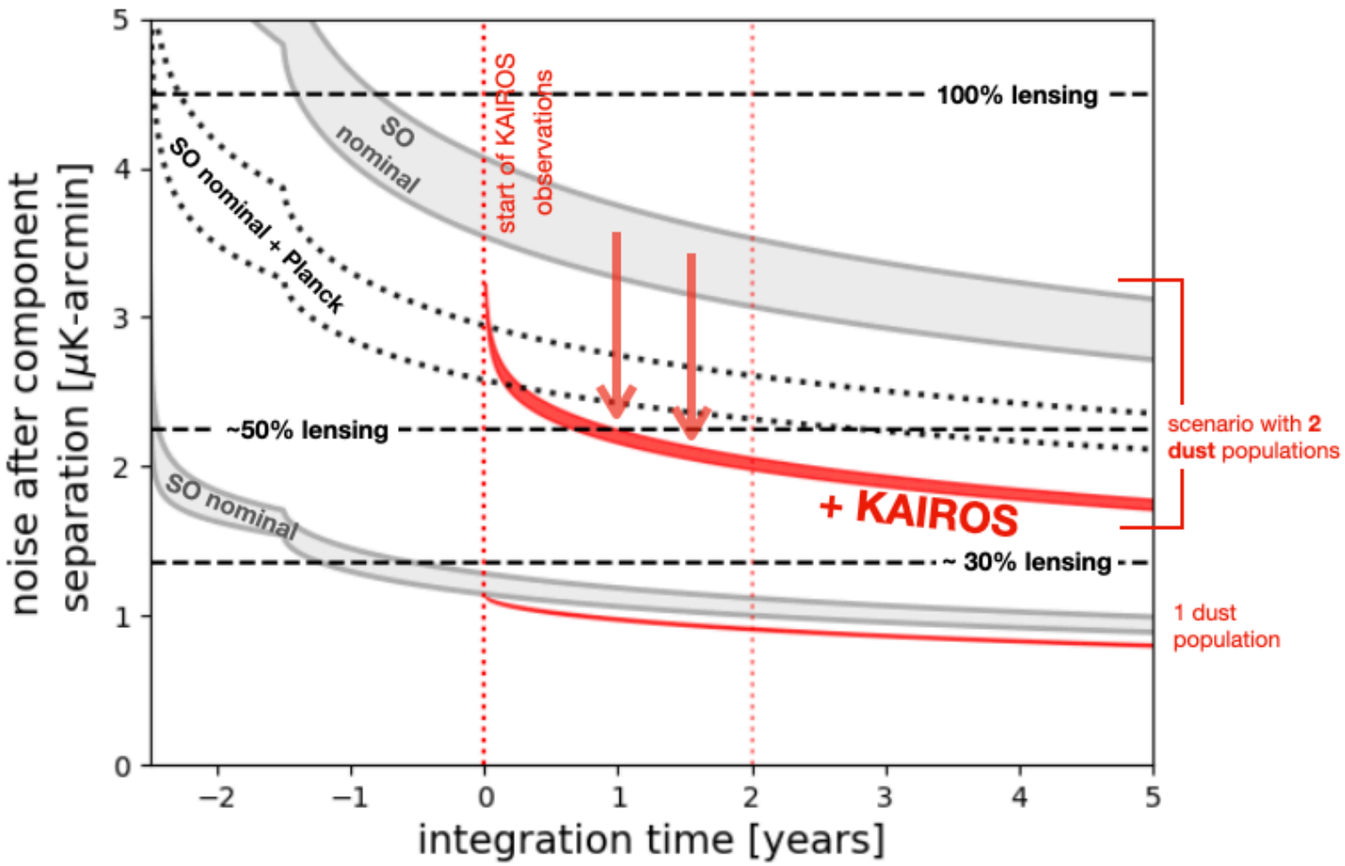

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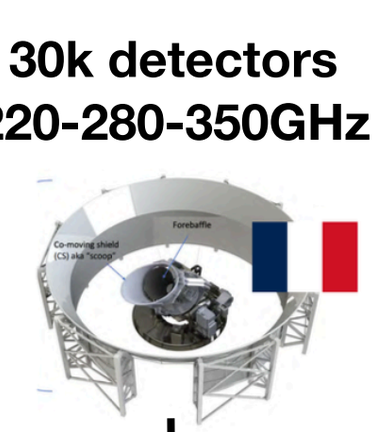
KAIROS: science case

30k detectors
220-280-350GHz



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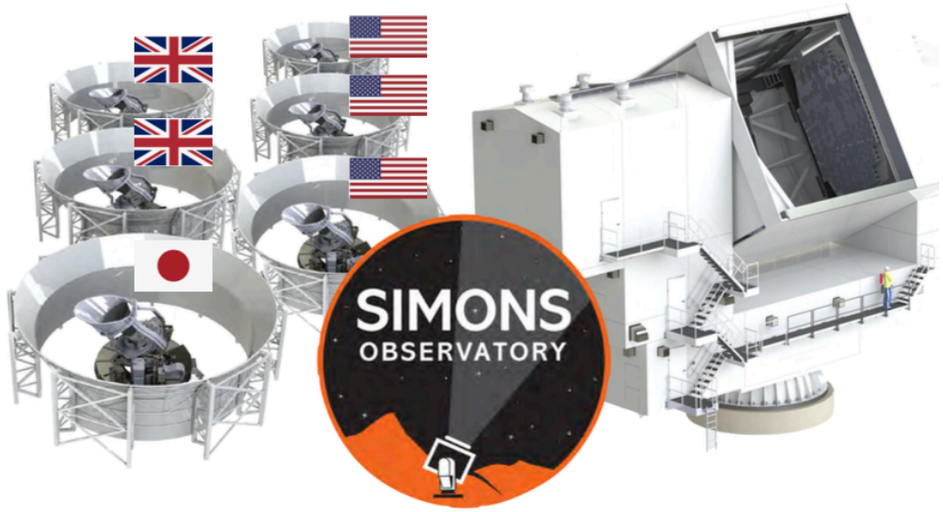

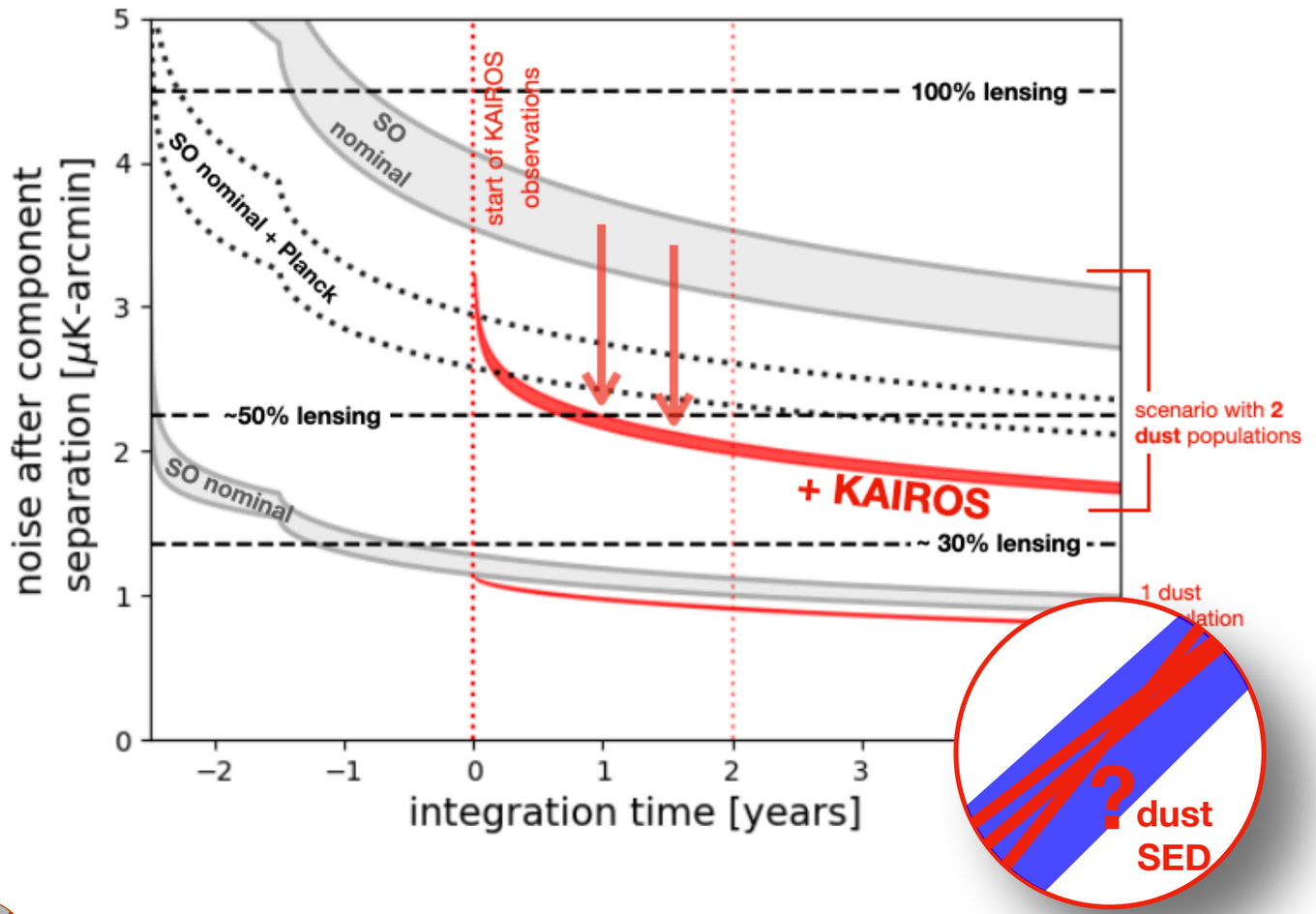

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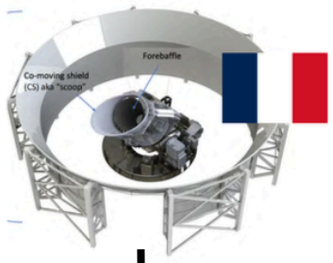
220-280-350GHz



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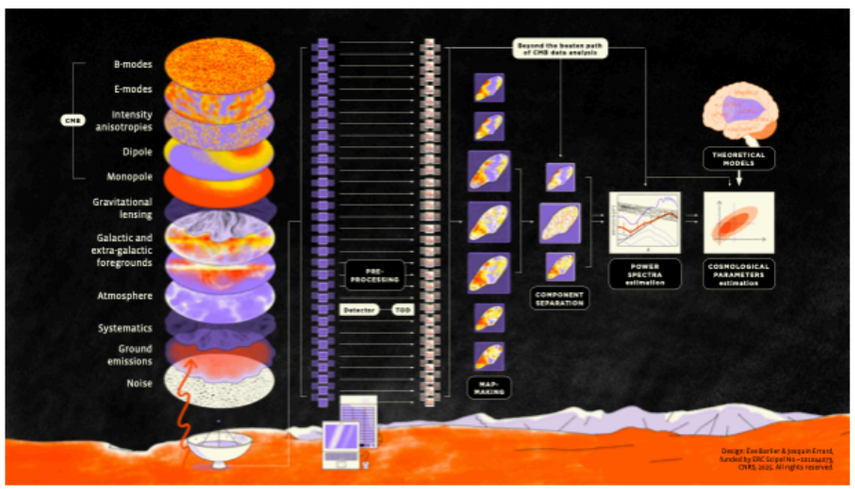
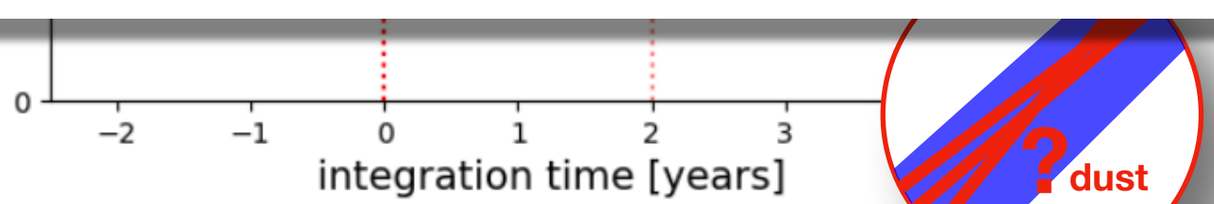
KAIROS in collaboration with the ERC SciPol project



FURAX

see talks by Ema Tsang King Sang, Wuhyun Sohn, Artem Basyrov, Amalia Villarrubia Aguilar and Pierre Masson, Pierre Chanial, Simon Biquard

➔ optical systematics treatment, ground-signal treatment, atmospheric treatment, etc.



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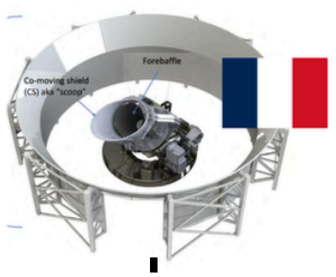
30k detectors
220-280-350GHz



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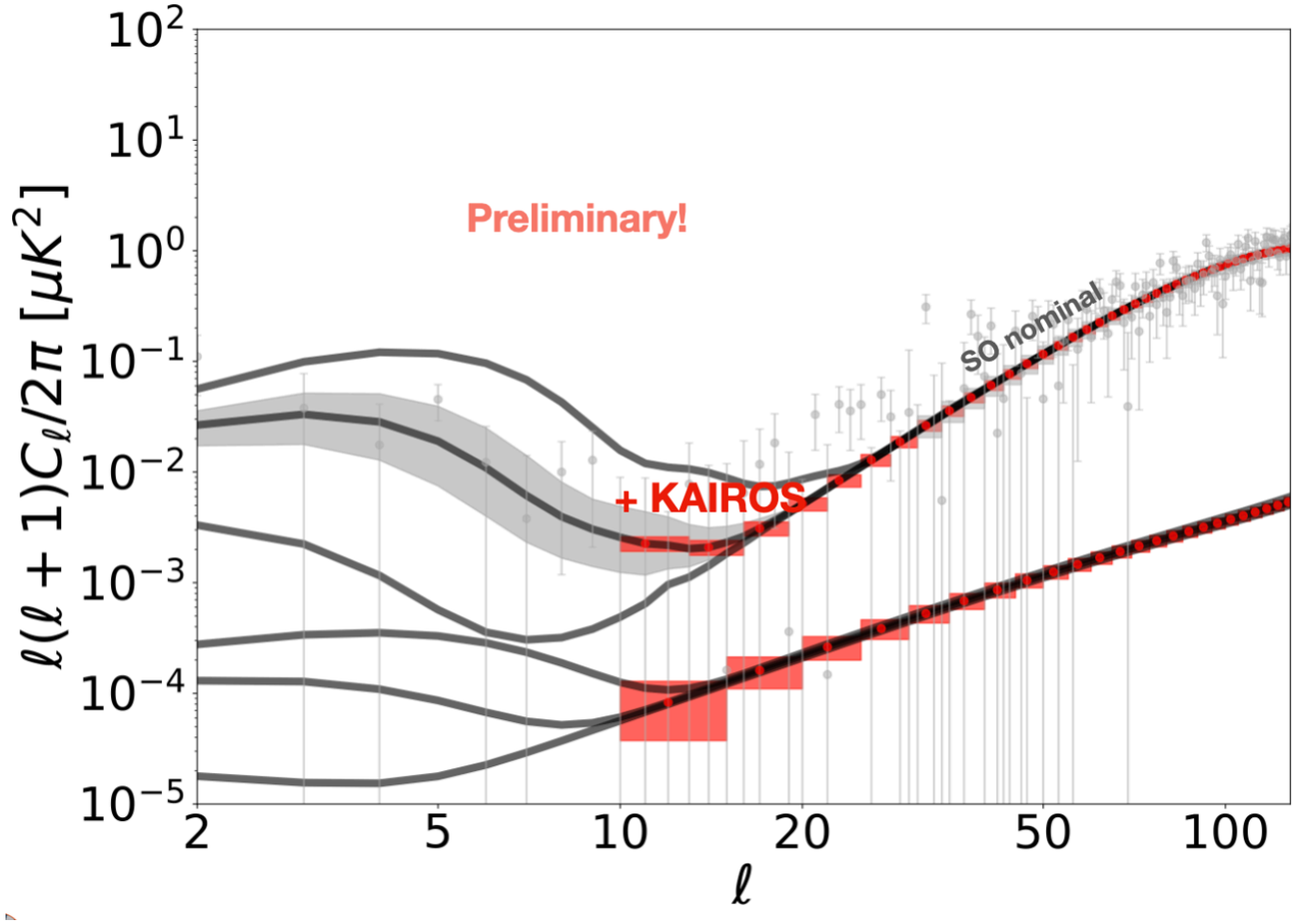
longer term



Reionization

in its extended version, KAIROS would have potentially a unique access to low ell through

- improved calibration and treatment of environmental systematic effects (atmosphere)
- optimized scanning strategy for large sky area

KAIROS: Funding and next steps

- **Potential Funding**
  - Participation to the CNRS *(RI2)* program to design, install and commissioning the KID French SAT. Support of the three CNRS institutes (IN2P3,INSU and INP).
  - ERC Synergy in preparation (4 PIs: Catalano, Ponthieu, Calvo, Ganga)
  - Started discussions with DOE / LBNL / UCB
- **Interface with the SO Observatory Execution Office.**
  Close contact with S. Staggs, M. Devlin and A. Lee. Preparation of a first Collaboration agreement between OEO and Kairos Consortium. Once funded, the OEO will discuss directly with CNRS institutions.
- **Planning is very hard to keep,** KAIROS should start now!
- Eventually, France and Europe could have a CMB platform in Chile
  ➔ strategic investment for future instrumental steps, tests (e.g. LiteBIRD)?

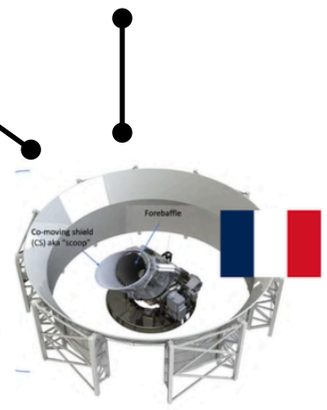
technology is ready, the scientific need is identified

participation/possible access to SO

strategic investment for future CMB observations

strong synergies with on-going French efforts (ERC SciPol, Cosmolidar, CosmoCal, etc.)

good training for the next generation



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