The European Low Frequency Survey

observing the radio sky to understand the beginning of the Universe

A. Mennella for the ELFS collaboration

University of Milan, INFN

ELFS people

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Enrique Martinez Gonzalez
Patricio Vielva

Anthony Banday

Elena de la Hoz
Adrian Lee

Kam Arnold
Sean Casey

Darcy Barron

A bit of (also personal) history

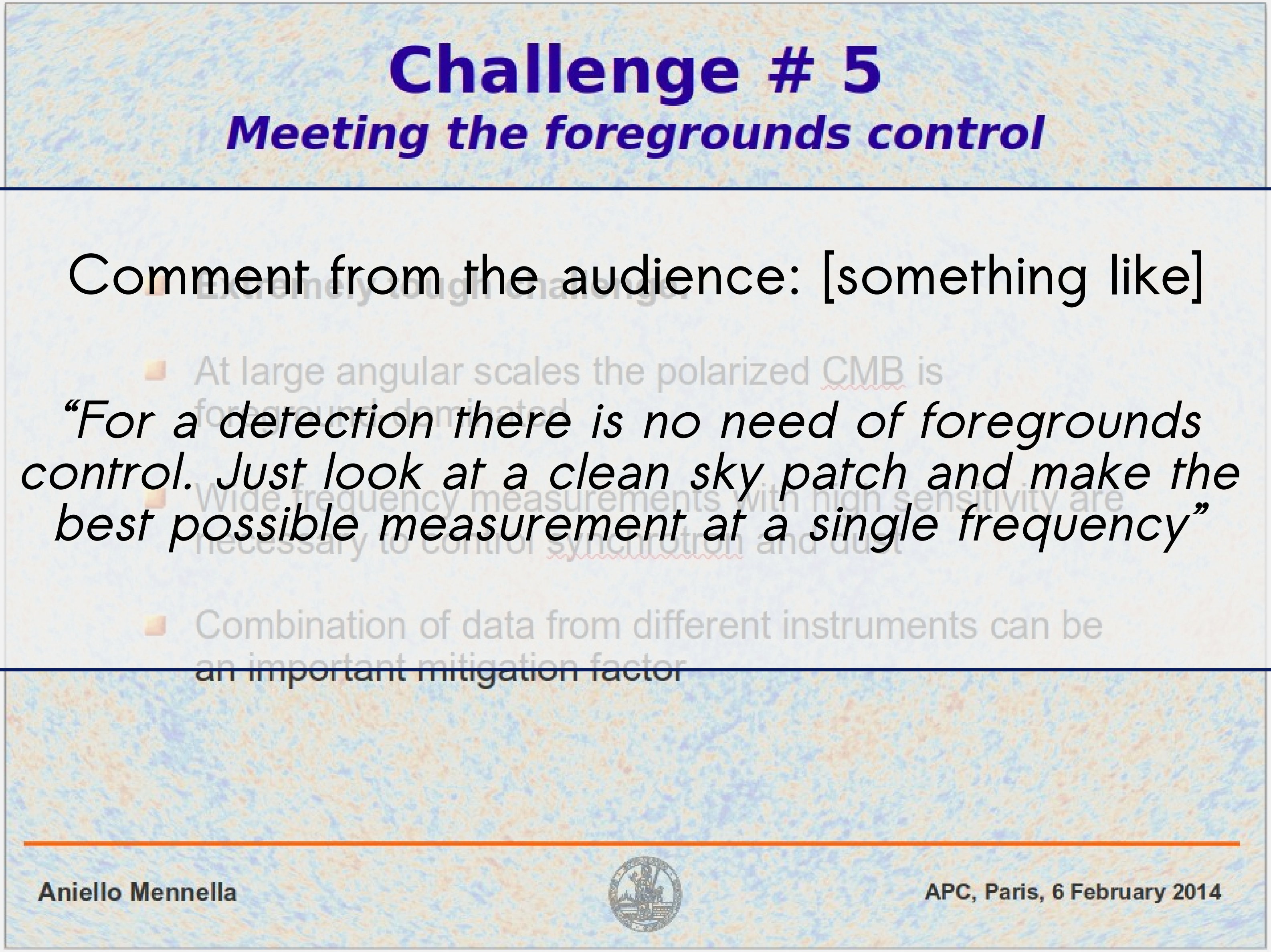
Feb 6th, 2014 – APC, Paris

Challenge # 5
Meeting the foregrounds control

- **Extremely tough challenge.**
- At large angular scales the polarized CMB is foreground-dominated
- Wide frequency measurements with high sensitivity are necessary to control synchrotron and dust
- Combination of data from different instruments can be an important mitigation factor

Aniello Mennella **APC, Paris, 6 February 2014**

Feb 6th, 2014 – APC, Paris



Comment from the audience: [something like]

"For a detection there is no need of foregrounds control. Just look at a clean sky patch and make the best possible measurement at a single frequency"

Mar 17th, 2014

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The Guardian

Primordial gravitational wave discovery heralds 'whole new era' in physics

Gravitational waves could help unite general relativity and quantum mechanics to reveal a 'theory of everything'

Scientists detected telltale signs of gravitational waves using the Bicep2 telescope (far left) at the south pole. Photograph: Keith Vanderlinde/NSF

Scientists have heralded a "whole new era" in physics with the detection of "primordial gravitational waves" - the first tremors of the big bang.

Mar 17th, 2014

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▲ Scientists detected telltale signs of gravitational waves using the Bicep2 telescope (far left) at the south pole. Photograph: Keith Vanderlinde/NSF

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Jan 30th, 2015

nature International weekly journal of science

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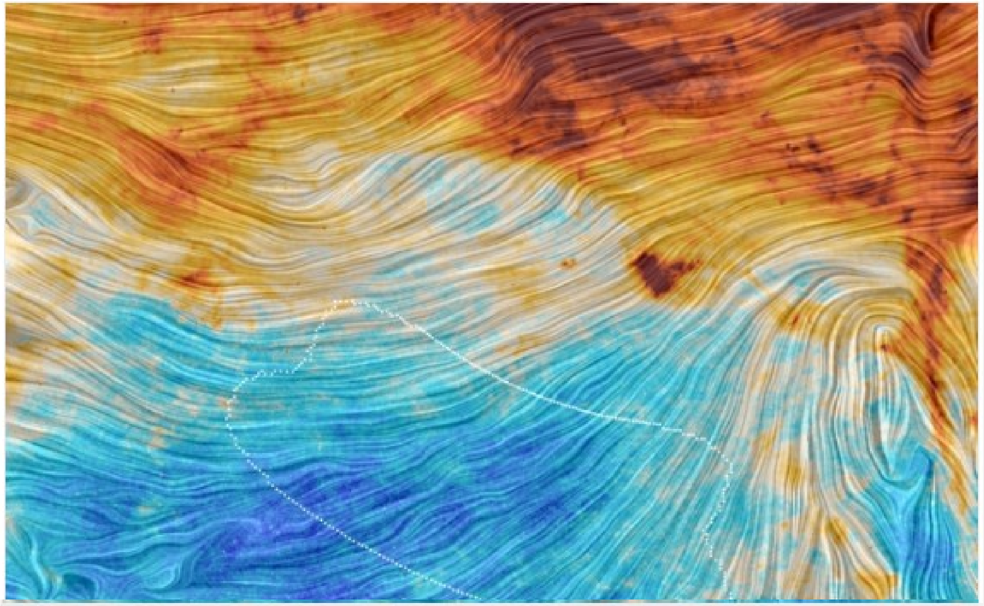
Gravitational waves discovery now officially dead

Combined data from South Pole experiment BICEP2 and Planck probe point to Galactic dust as confounding signal.

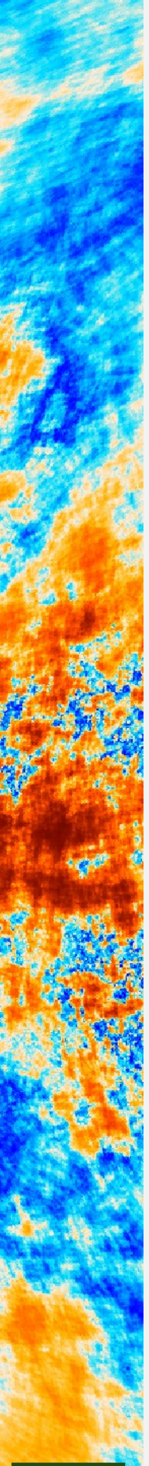
30 January 2015



ESA/Planck Collab. M.-A. Miville-Deschênes, CNRS, Univ. Paris-XI

The region of the southern sky where the BICEP2 telescope observed microwave polarization, shown as dotted lines over Planck data.

Mar 17th, 2014 | **Mar 26th, 2019** | Jan 30th, 2015



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Primordial gr... heralds 'whol...

Gravitational waves coul... quantum mechanics to re...

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Scientists have heralded a "whole new era" in physics with the detection of "primordial gravitational waves" - the first tremors of the big bang.

PHYSICS TODAY | Five years after BICEP2

Although competition still exists between various groups, the community seems to grasp—especially after the events five years ago—that no single experiment is going to provide smoking-gun evidence on its own. Says Kamionkowski: "We'll need measurements from multiple experiments to get a result that we really believe in our bones."

nature ... f science

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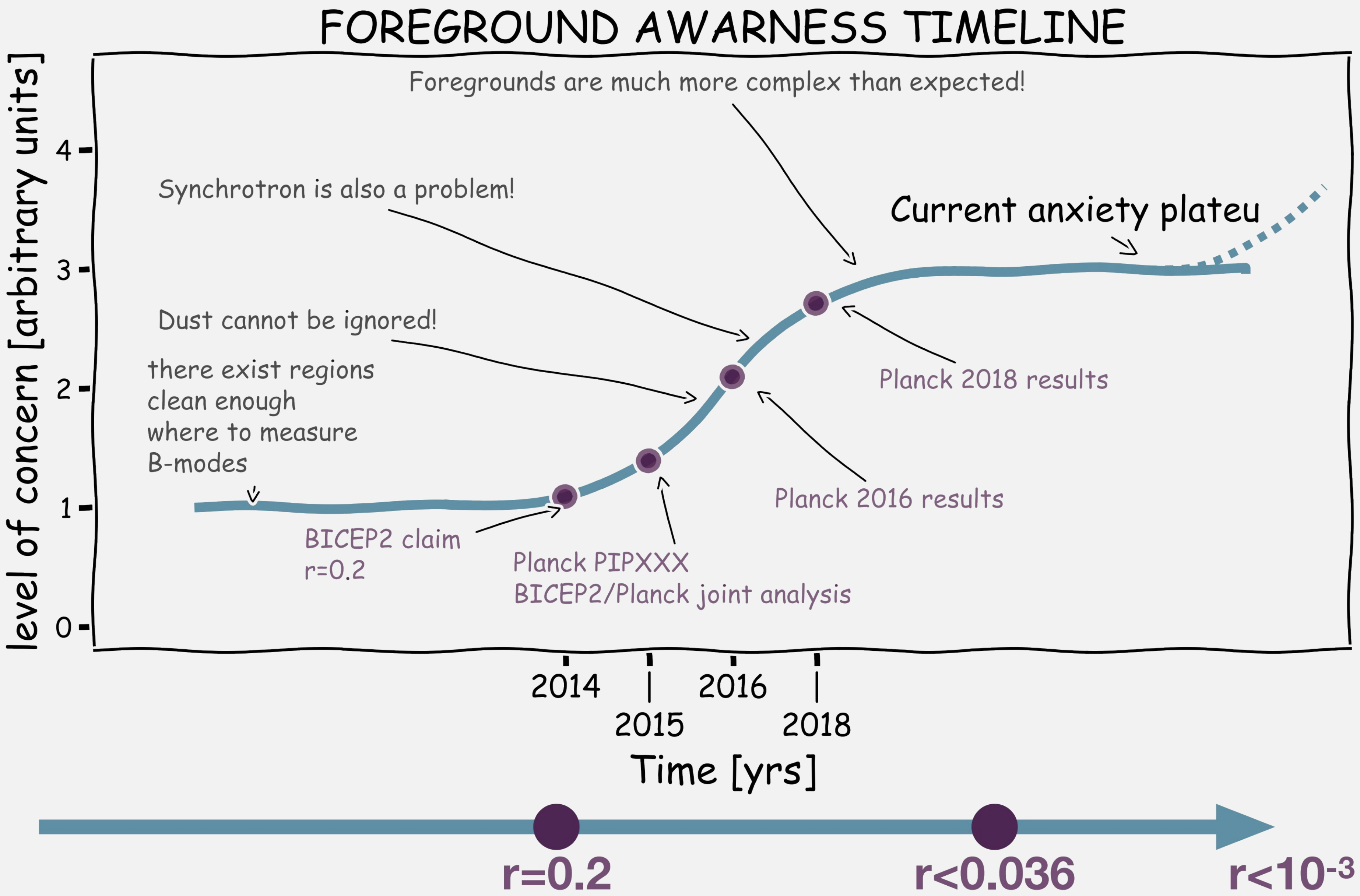
...w officially dead

...anck probe point to Galactic

ESA/Planck Collab. M.-A. Miville-Deschênes, CNRS, Univ. Paris-XI

The region of the southern sky where the BICEP2 telescope observed microwave polarization, shown as dotted lines over Planck data.

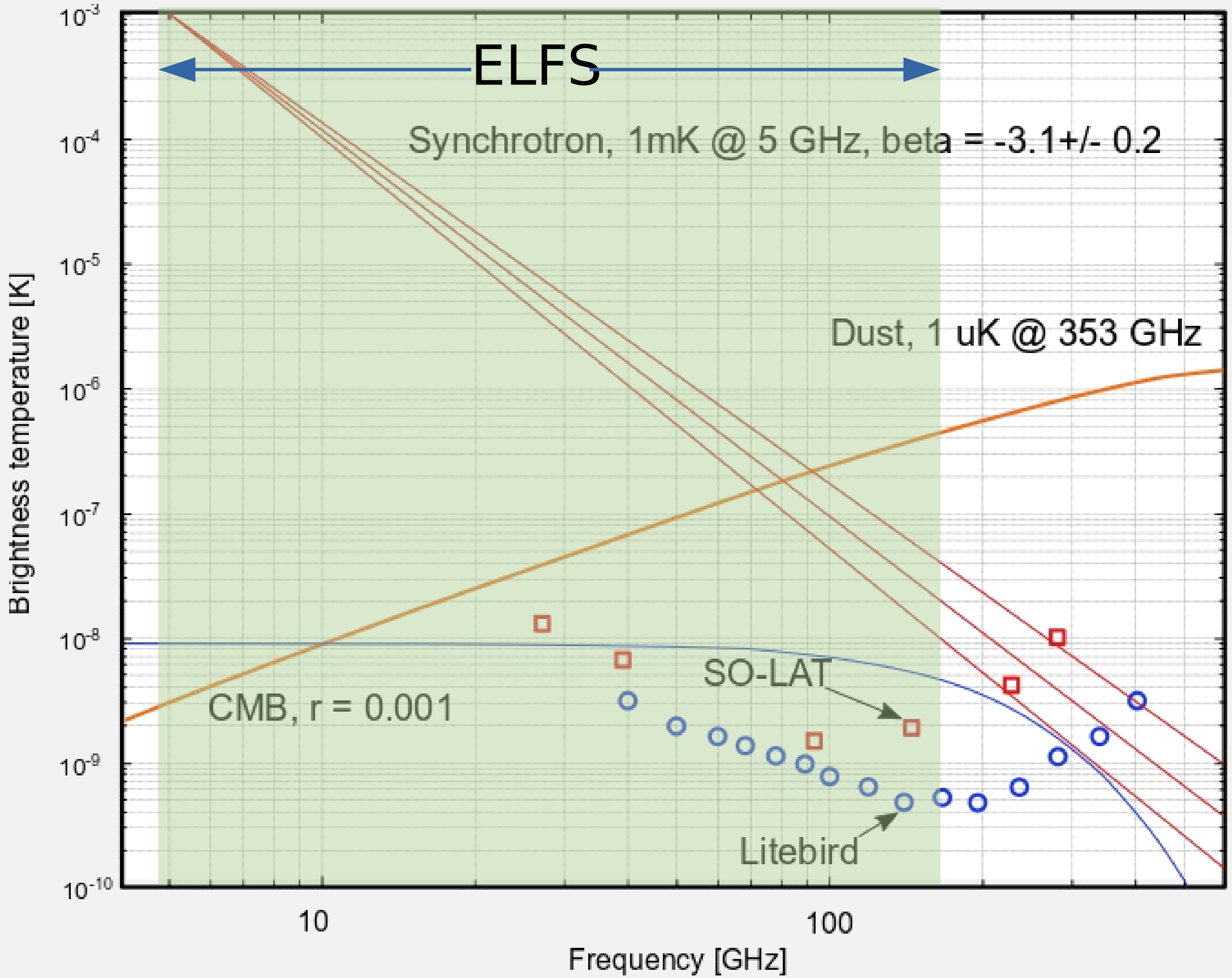
Ferrara, 2022 (presentation by N. Krachmalnicoff)



ELFS on SA

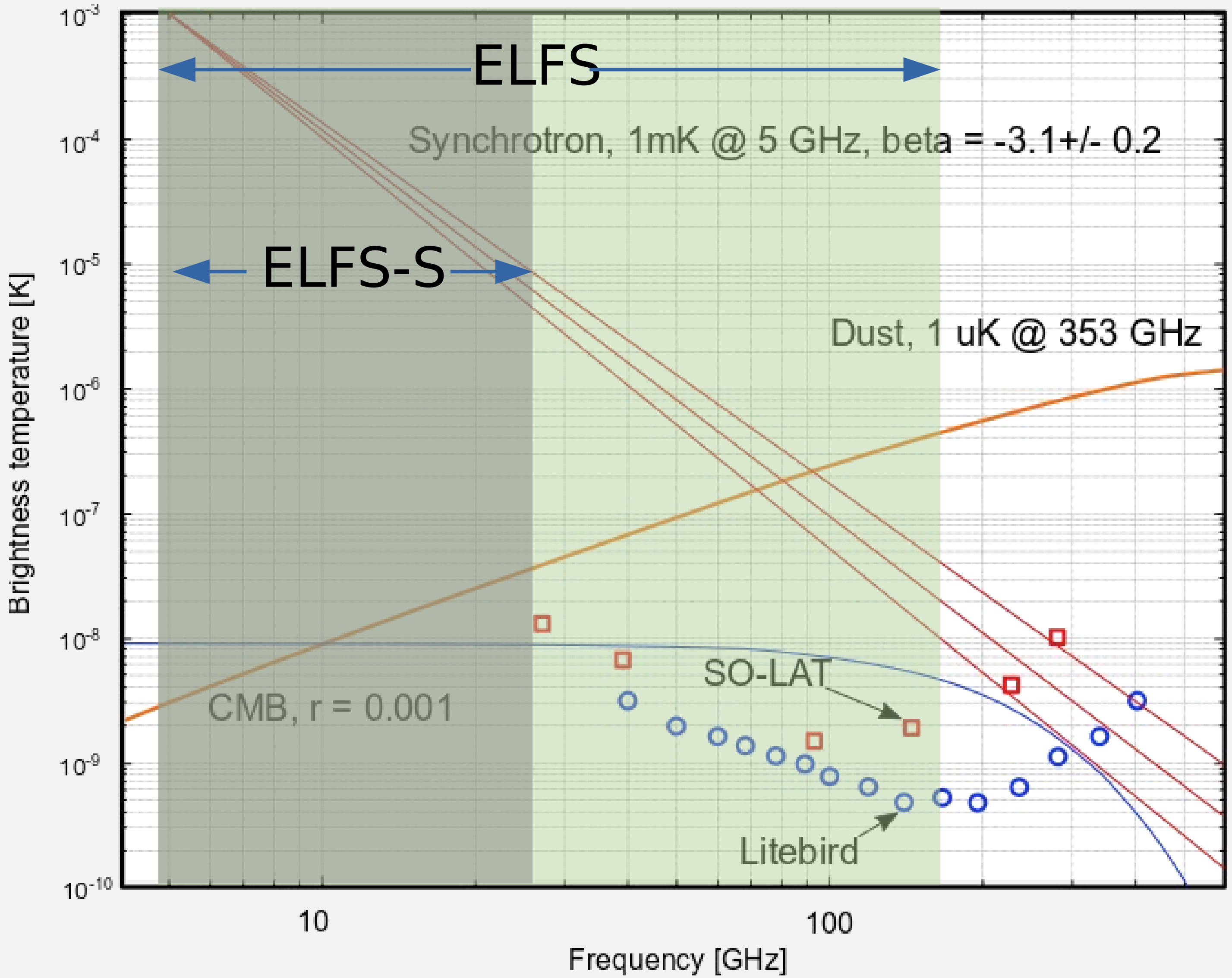
two receivers to observe the sky from Atacama between 5.5 and 20 GHz

ELFS from the vision to the first step



- ELFS: a full-sky low frequency survey ranging from 5–120 GHz

ELFS from the vision to the first step



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- ELFS-S: a low frequency survey from 5 to 30 GHz from the Southern hemisphere (ERC-Synergy 2020 proposal)

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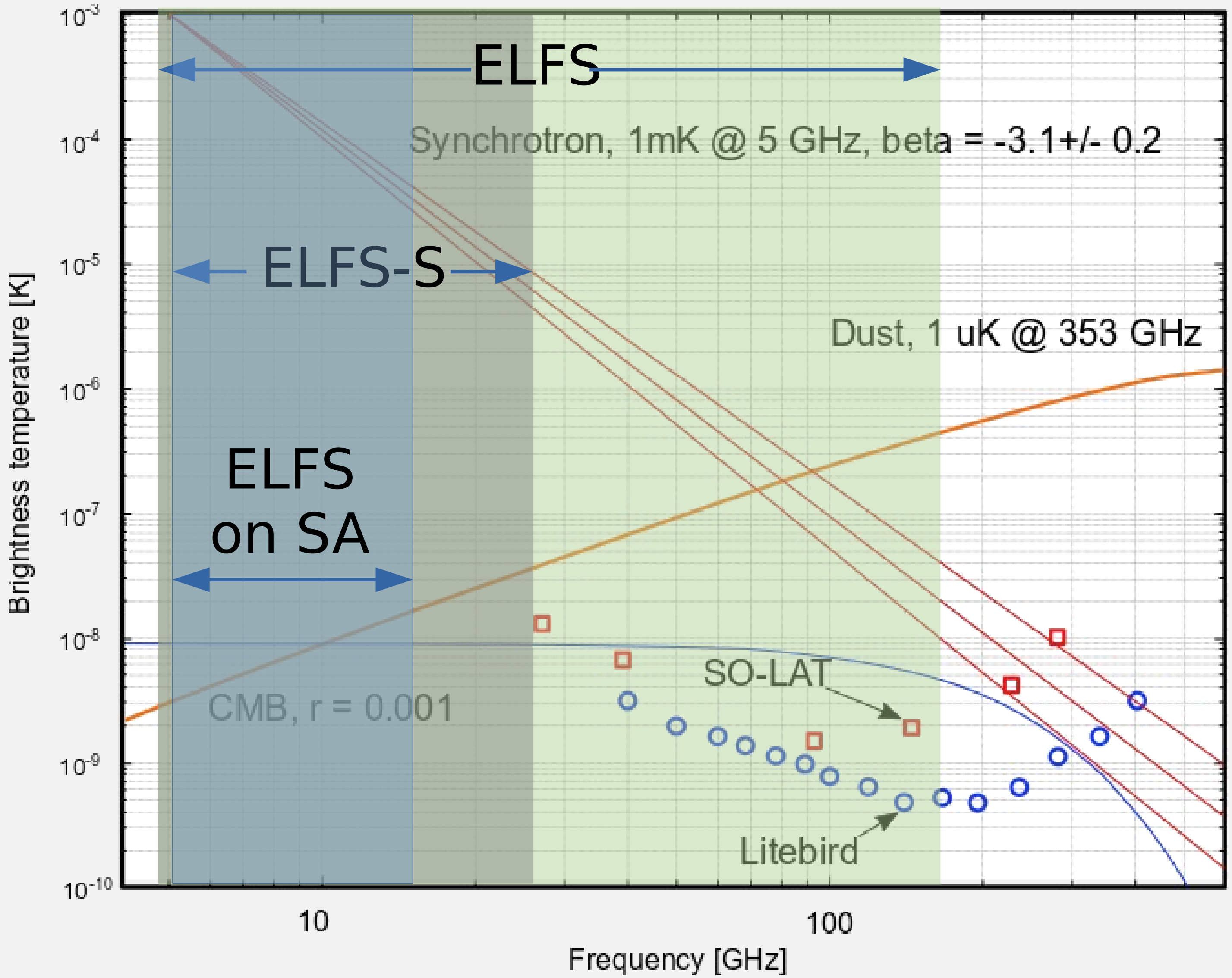
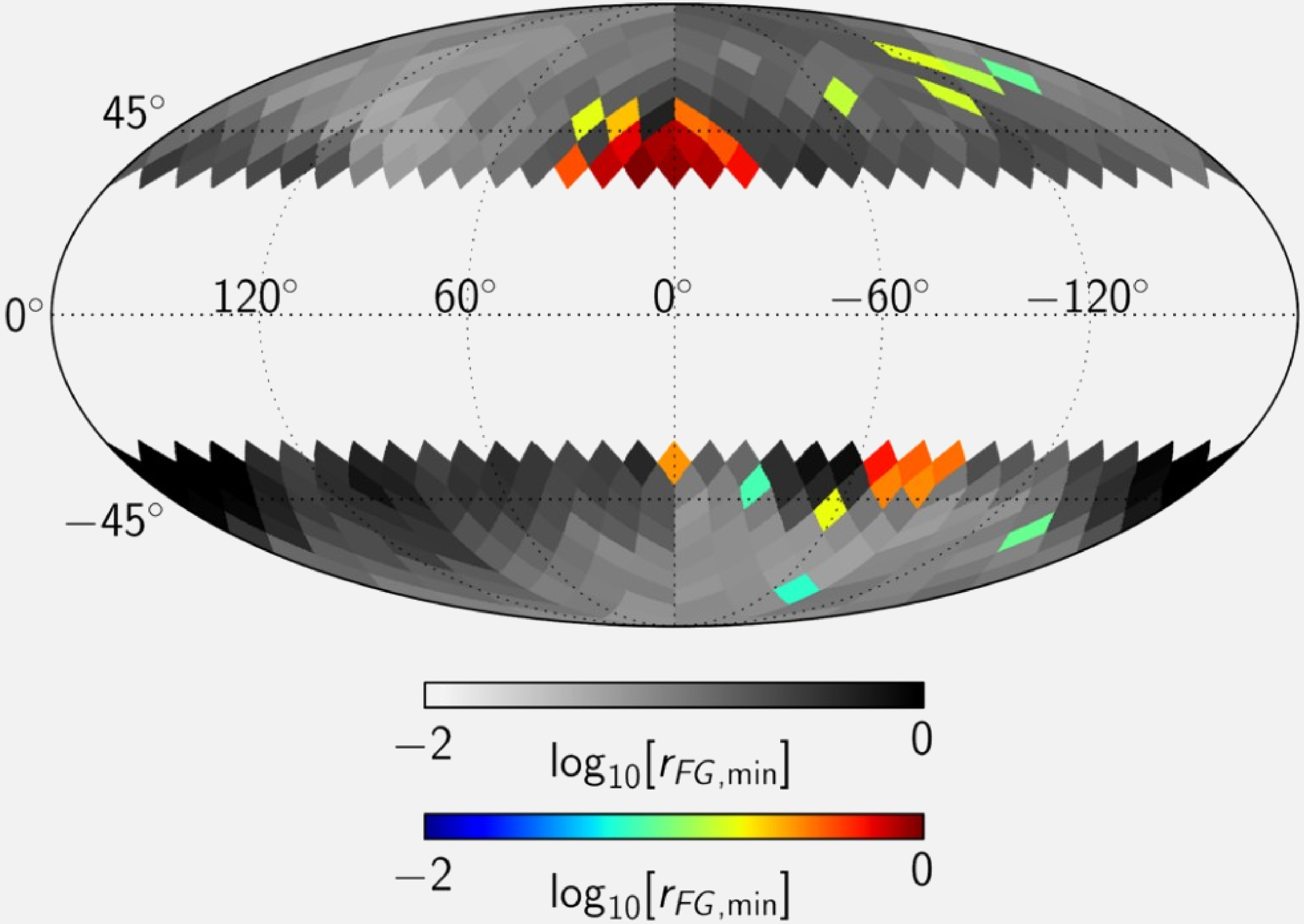


- ELFS: a full-sky low frequency survey ranging from 5–120 GHz
- ELFS-S: a low frequency survey from 5 to 30 GHz from the Southern hemisphere (ERC-Synergy 2020 proposal)
- ELFS on SA: a 5.5–11 GHz survey from Atacama, in collaboration with the Simons Array, future deployment of QUIJOTE MFI2 (10-20 GHz)

The (low frequency) foregrounds challenge

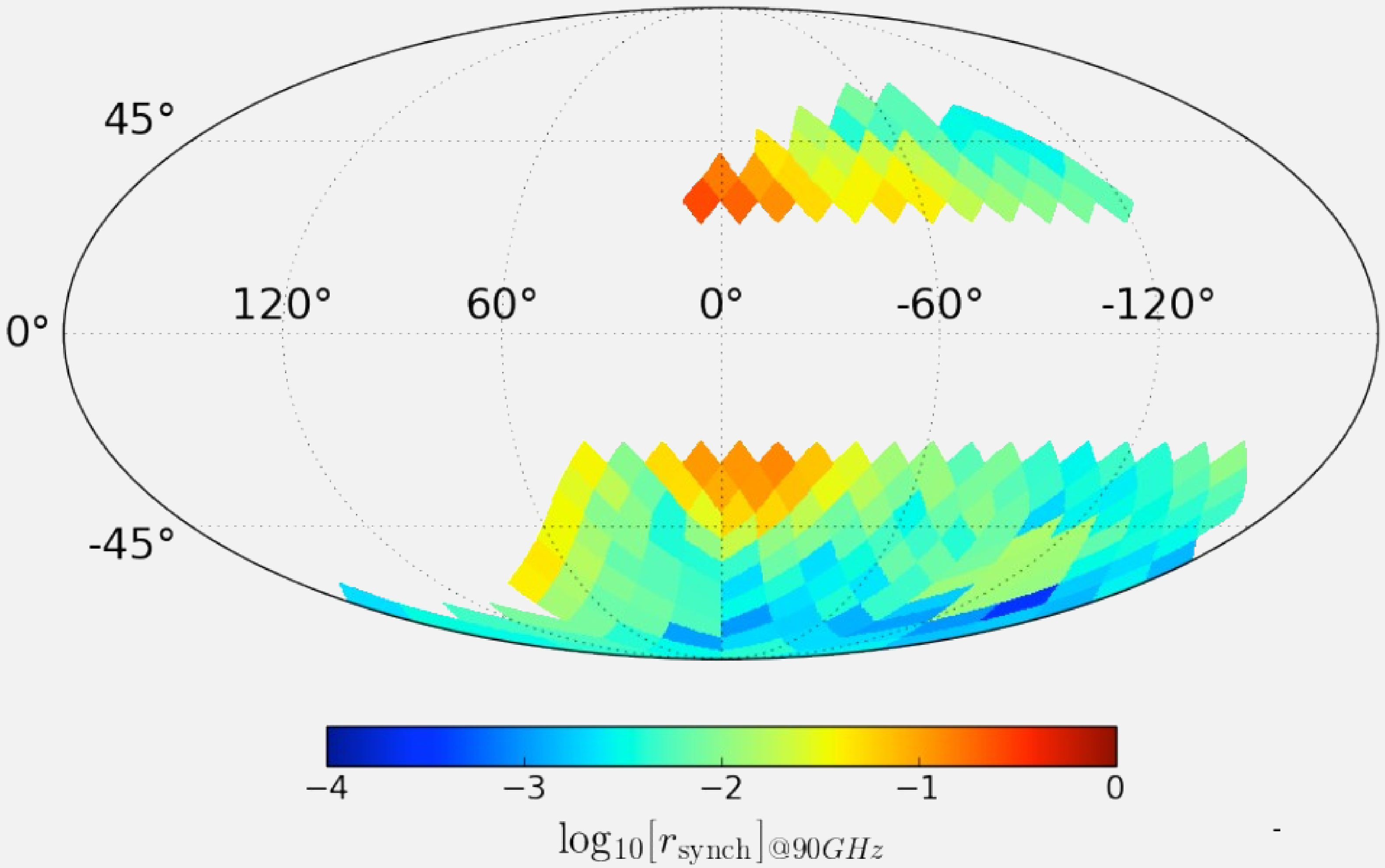
Krachmalnicoff et al, 2016 – Planck + WMAP data (synchrotron + dust)



- "Fake" tensor-to-scalar ratio, r_{FG}, due to foregrounds (dust + synchrotron).
- Foregrounds outshine CMB B-modes, for $r < 10^{-2}$

The (low frequency) foregrounds challenge

Krachmalnicoff et al, 2018 – Planck + WMAP + S-PASS data (synchrotron only)



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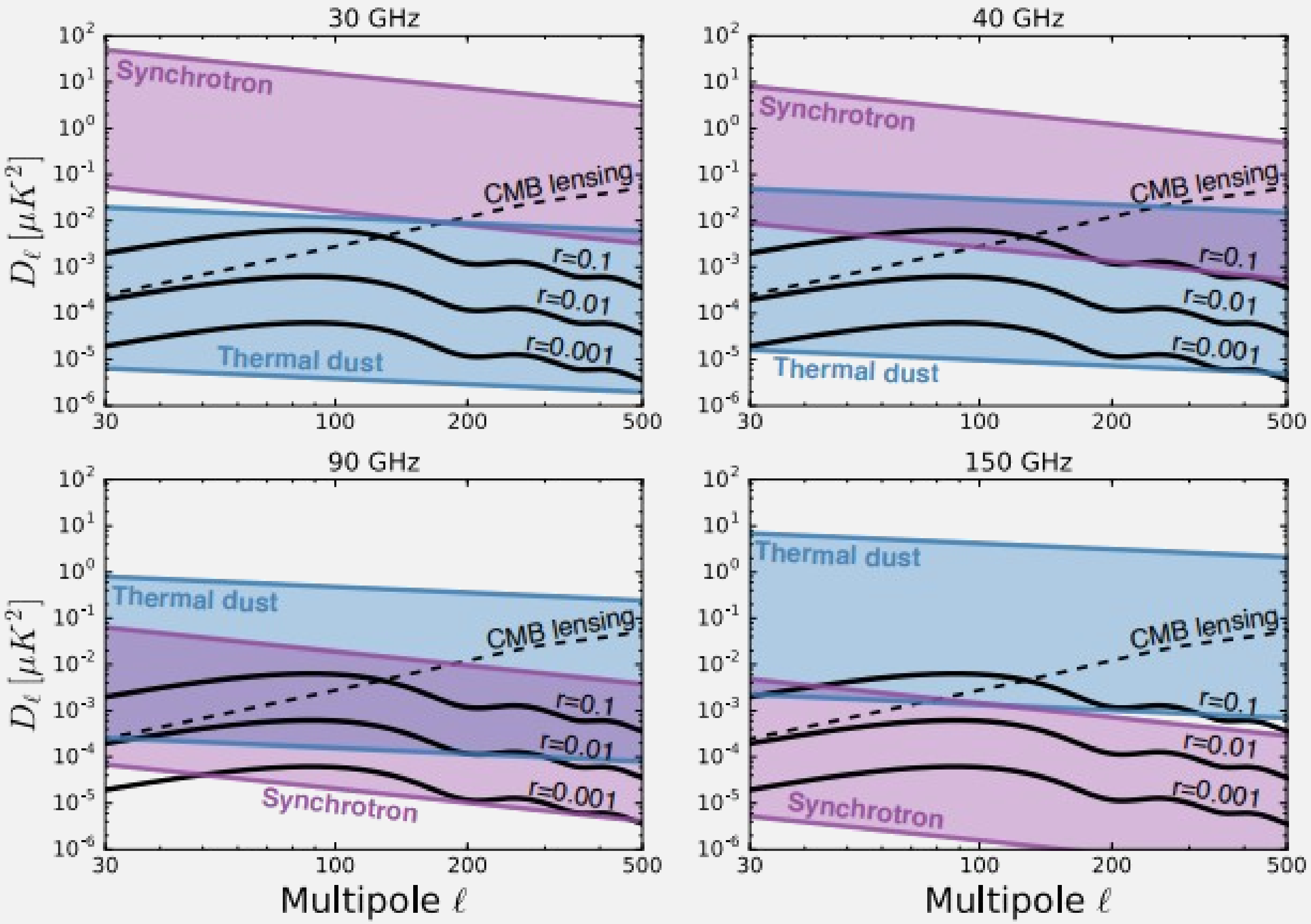

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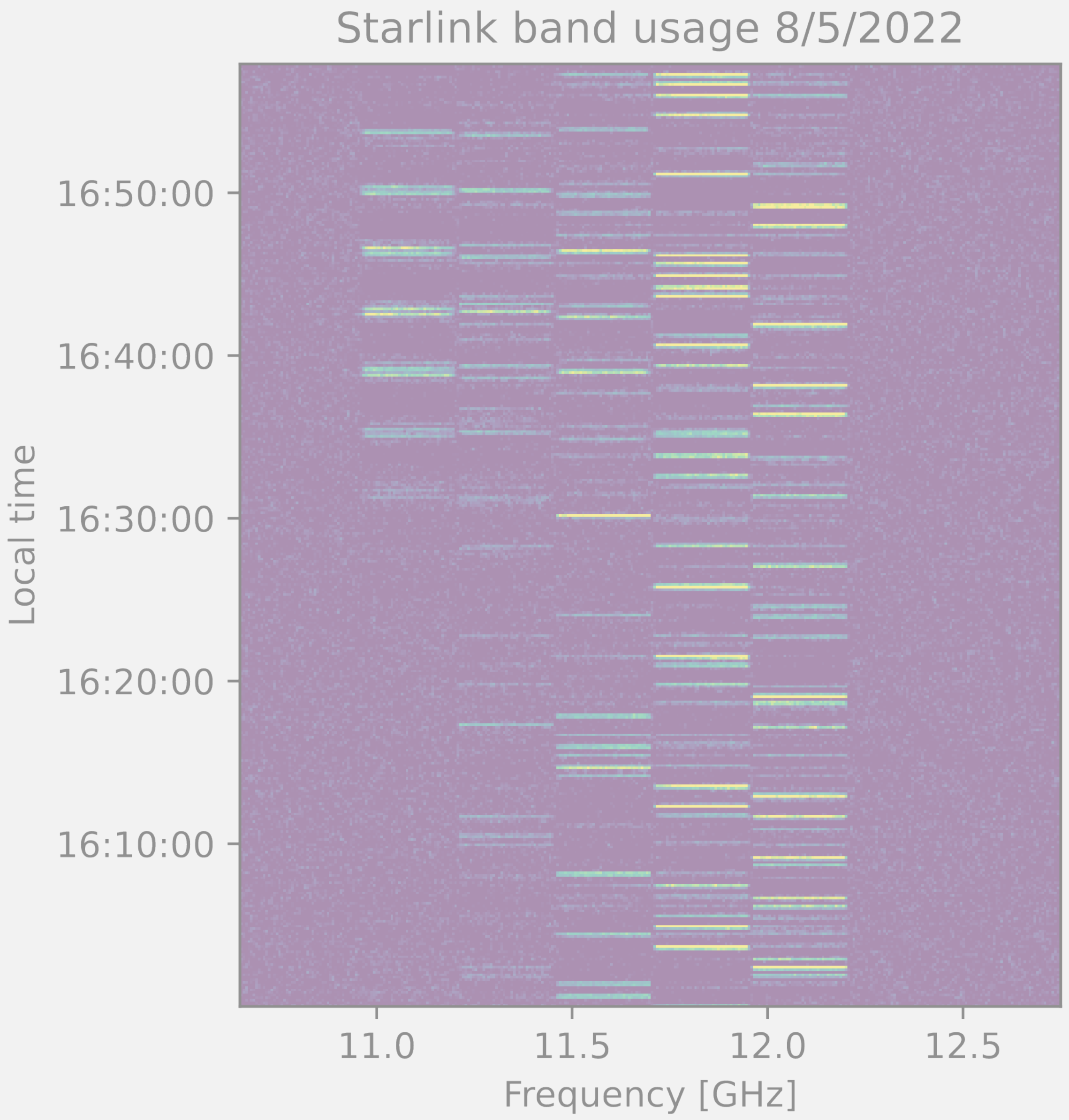
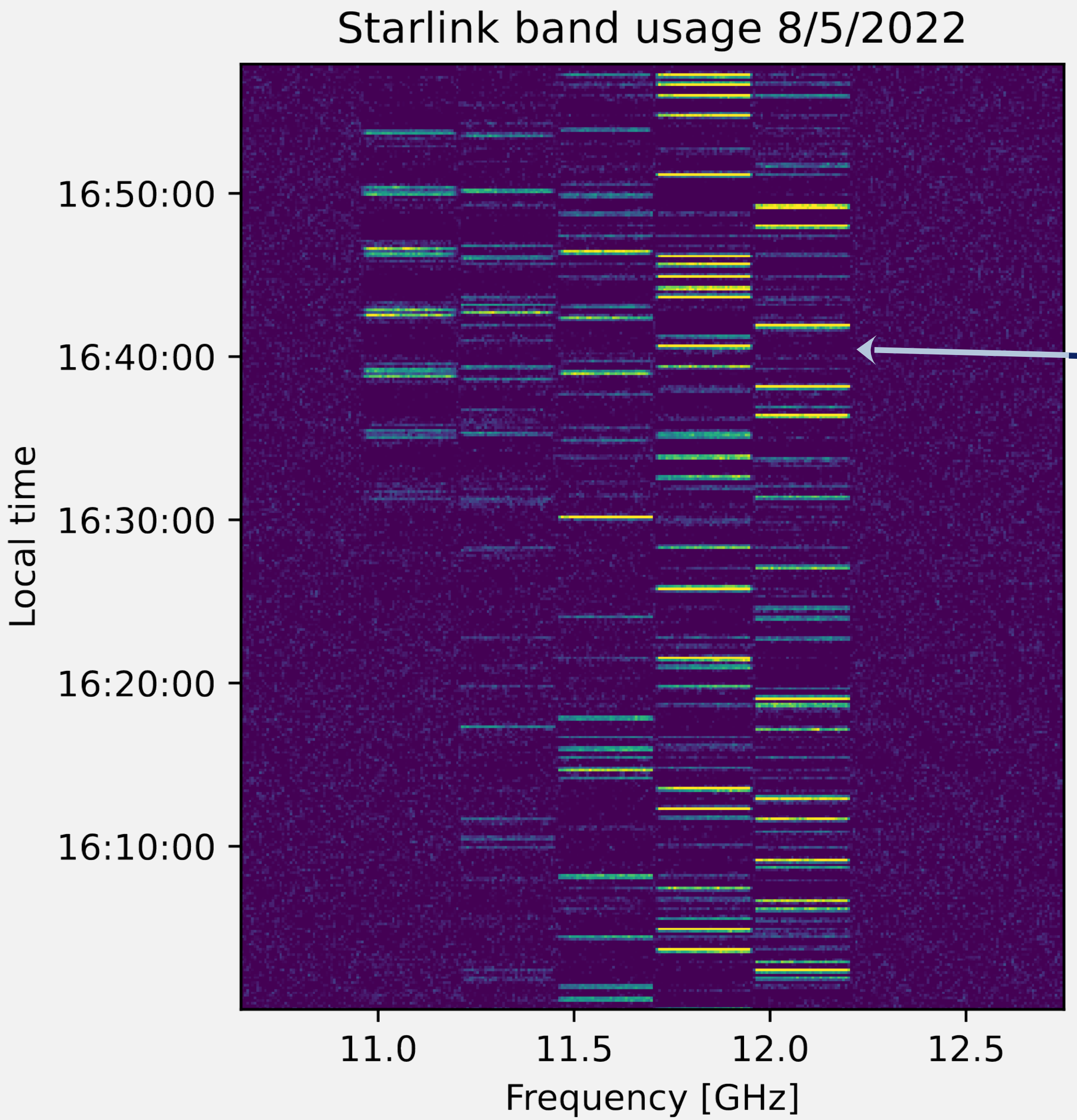
- Same result when considering power spectra inferred from S-PASS data ($\beta = -3.2$)

The radio frequency interference (RFI) challenge



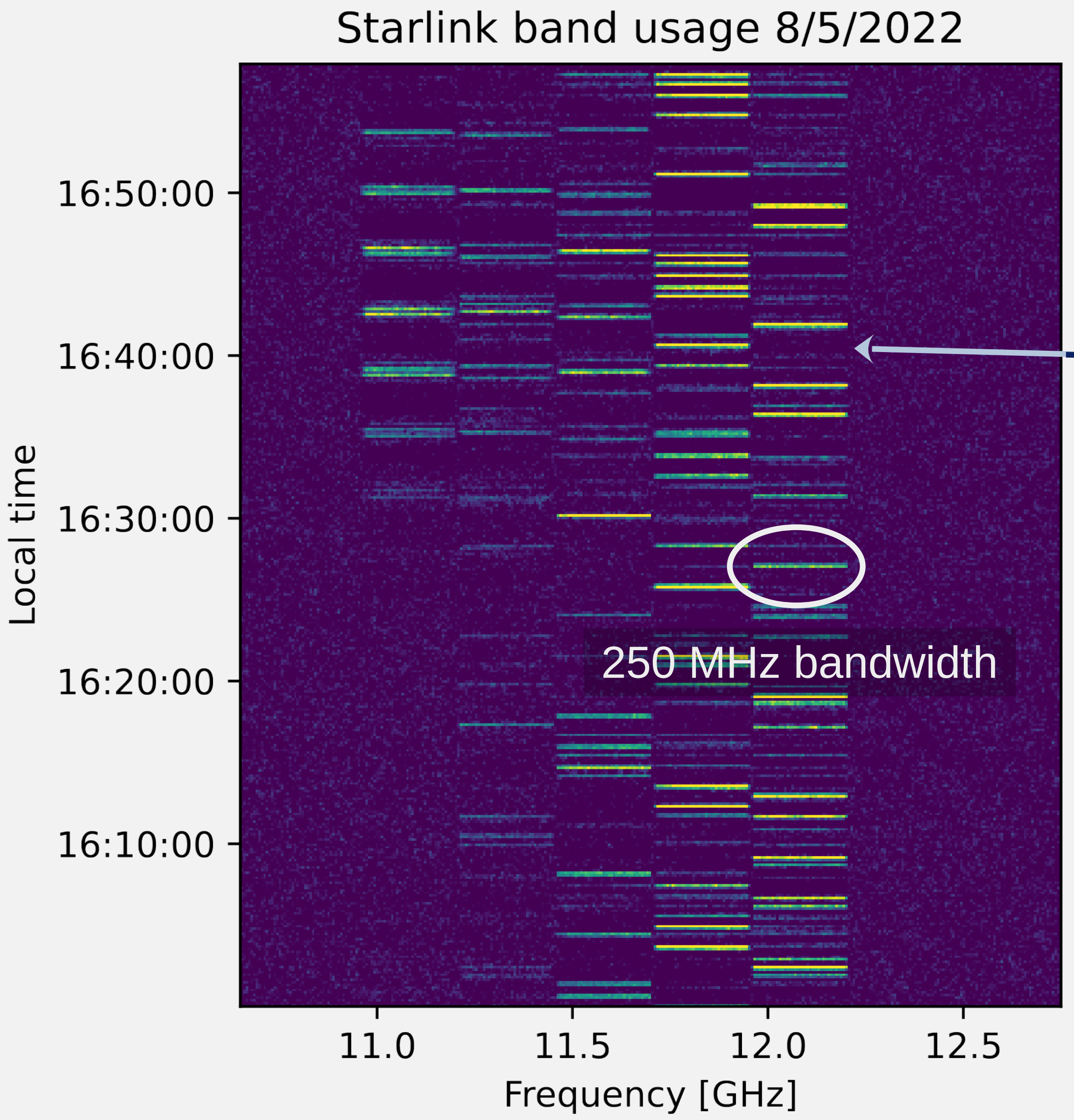
- Strong, narrow-band signals from communication satellites, an increasing concern

The radio frequency interference (RFI) challenge



- Strong, narrow-band signals from communication satellites, an increasing concern
- Starlink data example from Teide observatory (Tenerife)

The radio frequency interference (RFI) challenge



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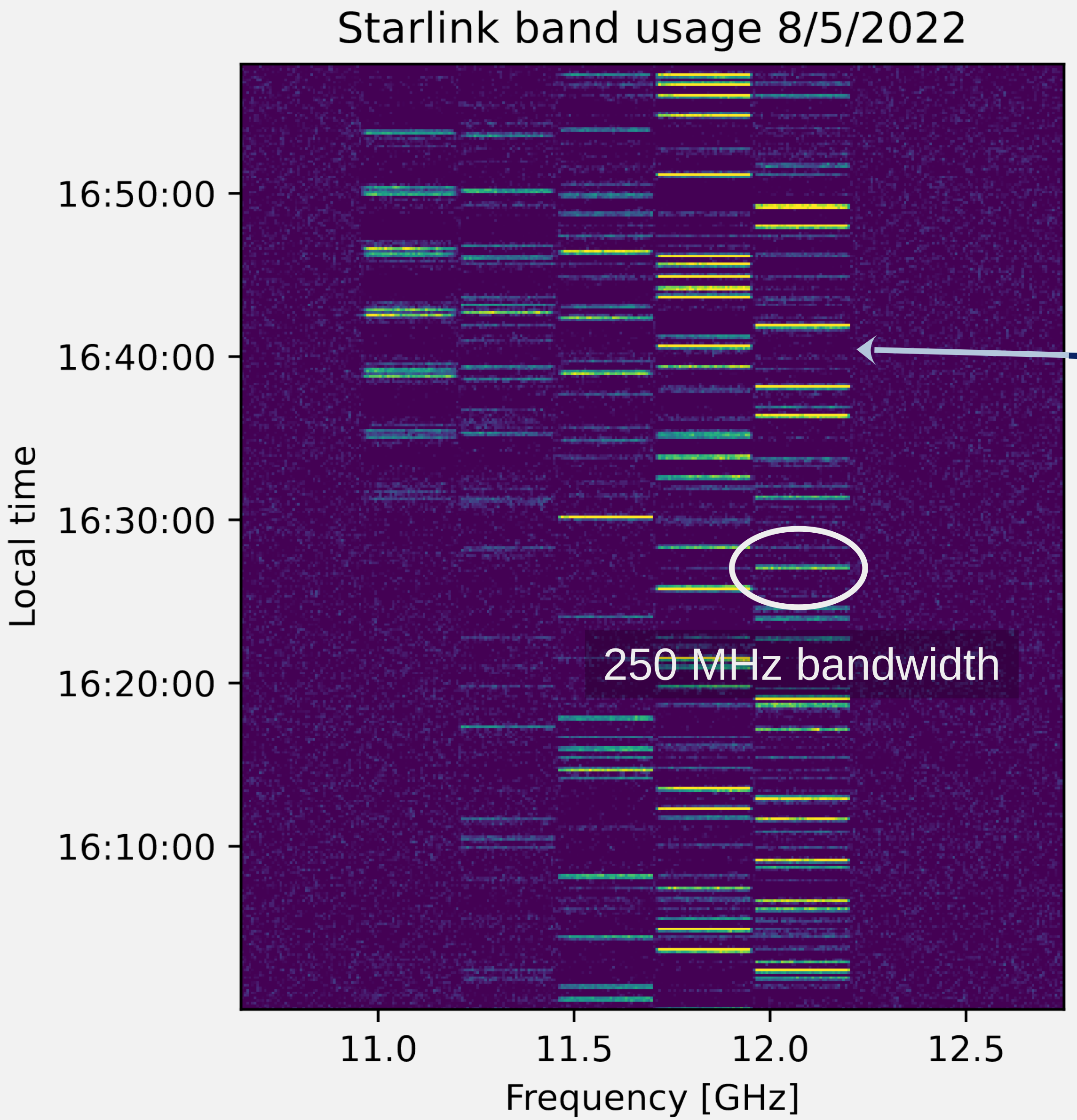
The radio frequency interference (RFI) challenge



- Strong, narrow-band signals from communication satellites, an increasing concern
- Starlink data example from Teide observatory (Tenerife)
- Frequency of comunication satellites will increase in the future.
- Broadband receivers cannot mitigate these problems.

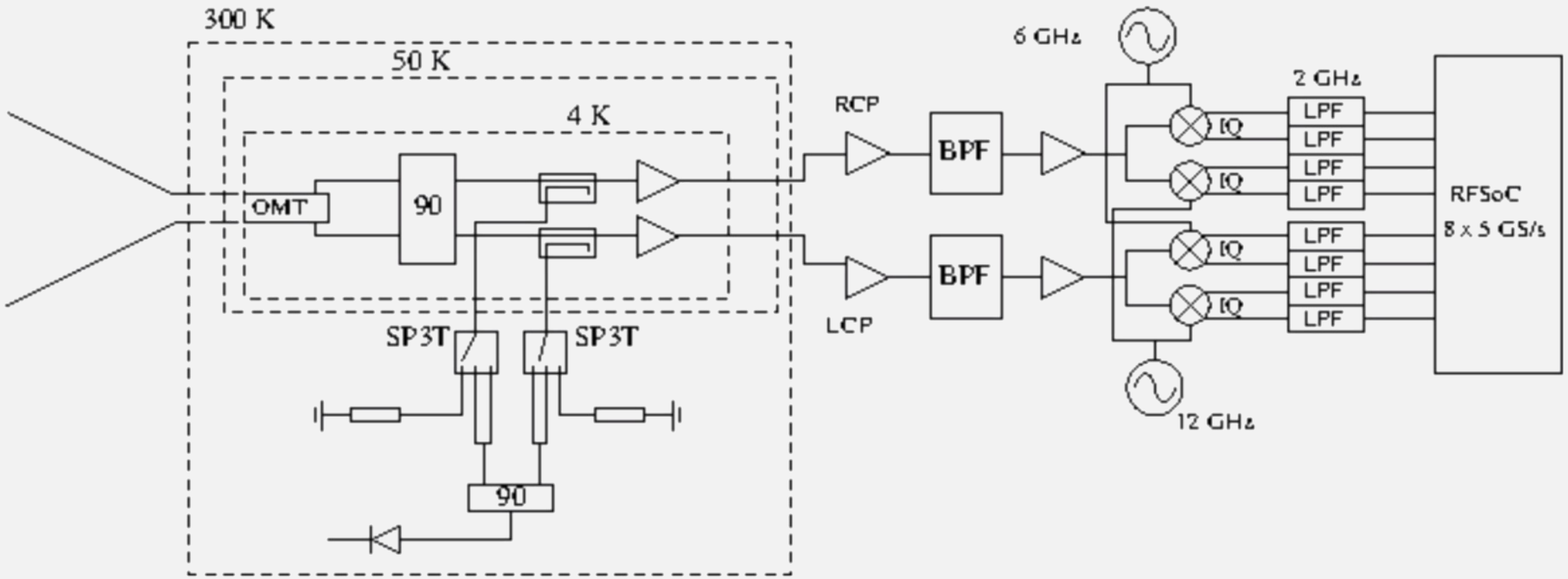
ELFS-SA opportunity

- Increased awareness of synchrotron contamination in the next generation of CMB polarization experiments.
- Simons Array and ELFS teamed to evaluate the possibility to deploy a low frequency receivers in one of the three POLARBEAR telescopes in Atacama
- Brand-new 5.5 – 11 GHz receiver with back-end digital electronics for improved spectral resolution and RFI rejection
- Future deployment of QUIJOTE MFI2 to cover the 10–20 GHz band

Instrument: frequency bands and sensitivities

ν [GHz]	FWHM [arc min]	N_b^P [μK-arcmin]	N_g^P [μK-arcmin]	ℓ_{knee}	α_{knee}
6.3	46.6	539	539	15	-2.4
7	42.2	512	512	15	-2.4
7.7	38.1	487	487	15	-2.4
8.6	34.4	465	465	15	-2.4
9.5	31.1	443	443	15	-2.4
10.5	28.1	423	423	15	-2.4

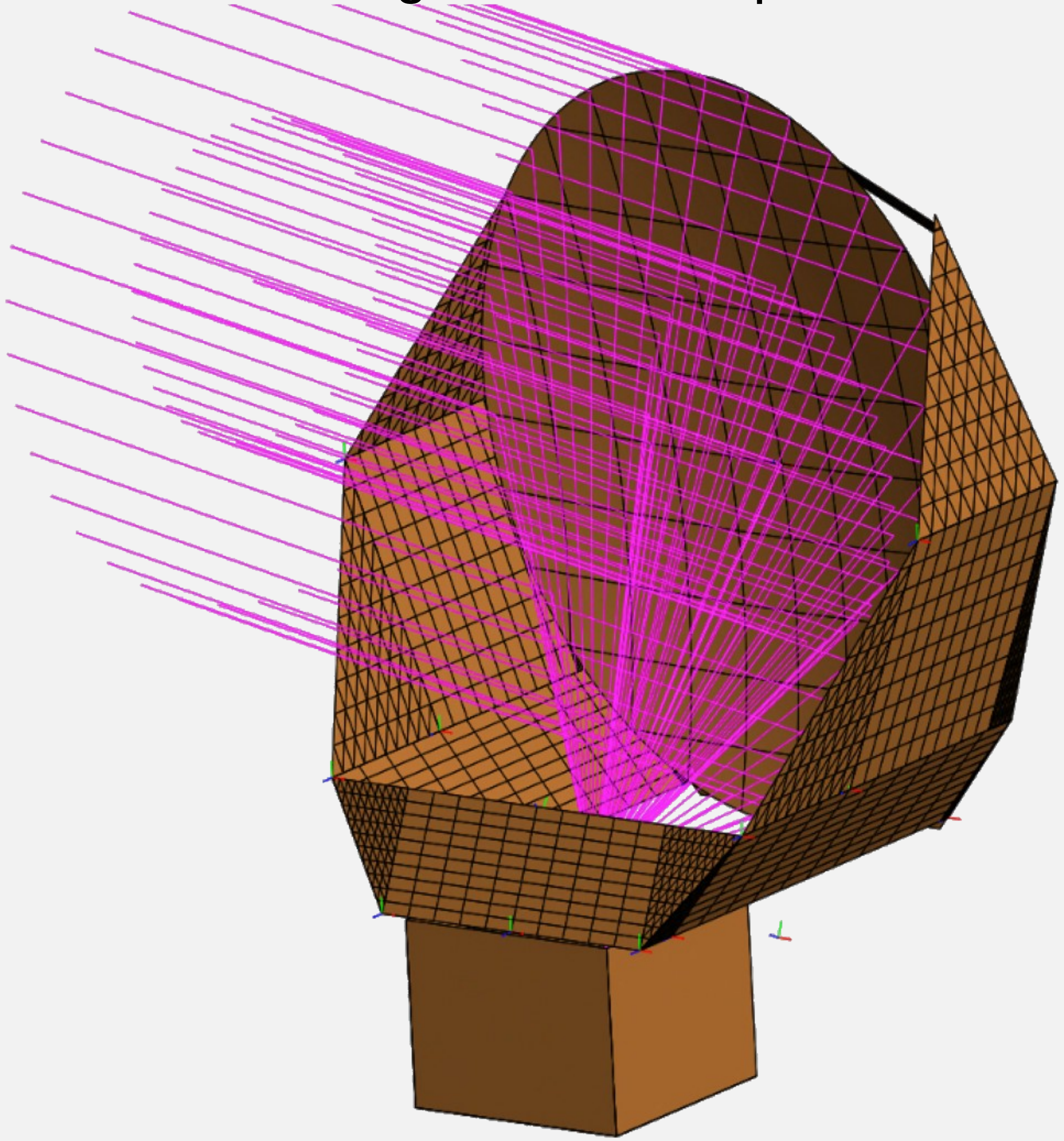
Instrument: receiver schematics



- Switched noise source allows injection of Q or U calibration signal. RF signals down-converted to base-band (0–2 GHz) for digitization
- RF system-on-chip digitizes and processes signals - forms I, Q, U, V from RCP, LCP in narrow frequency channels
- Exact frequency range TBD - avoid very bright RFI bands, complement CBASS (4.5–5.5 GHz) and MFI2 (10–20 GHz) bands

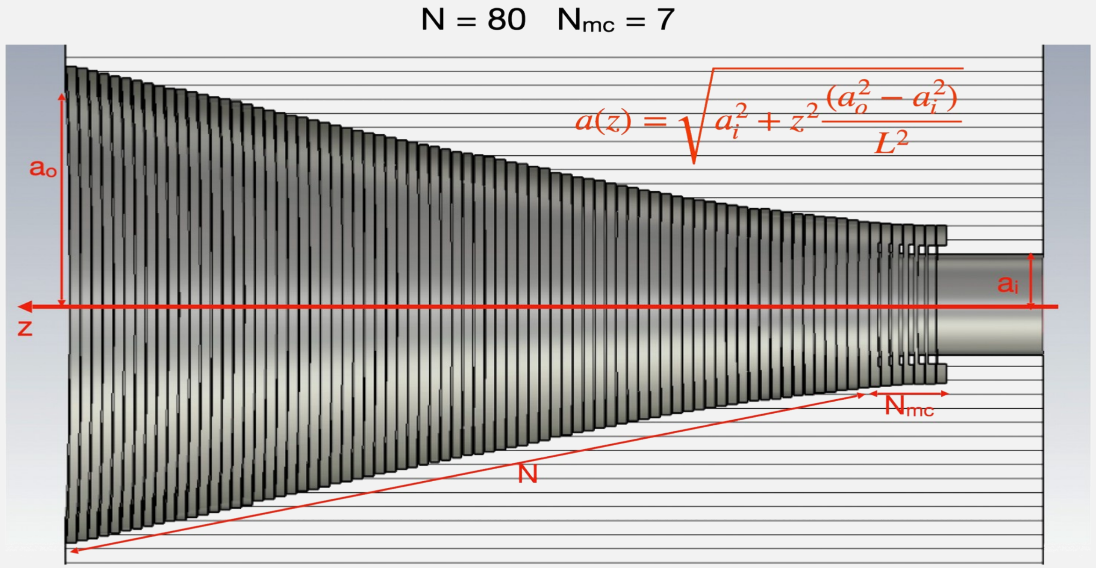
Instrument: optics (telescope)

Off-axis Gregorian telescope



- Edge taper = −20 dB
- Taper angle = 24.5 deg
- Main reflector = 4.24 m
- Subreflector = 1.42 m

Instrument: optics (feedhorn)



Hyperbolic profile,

ring-loaded mode converter

ao = 92.85 mm

ai = 21.69 mm

L = 403.38 mm

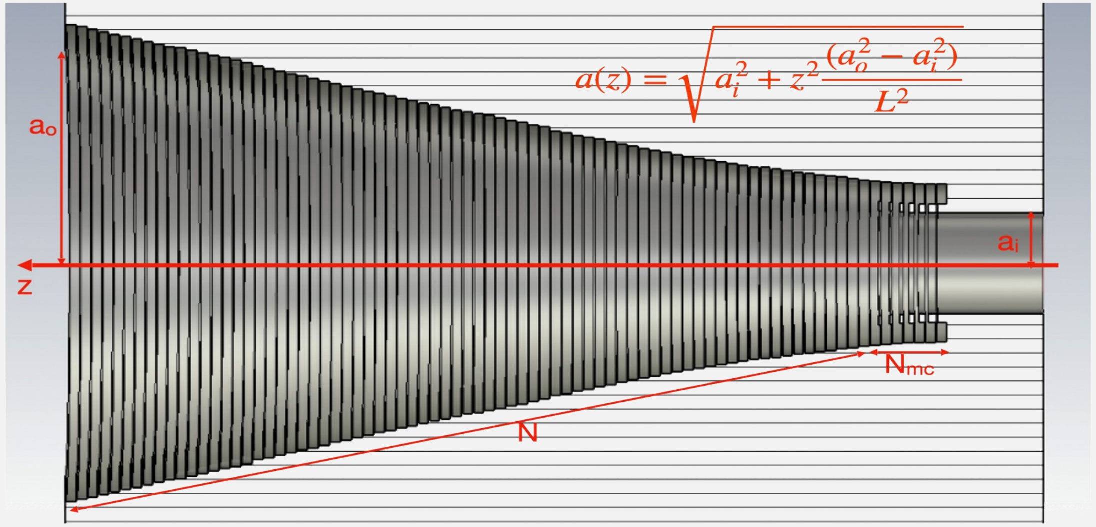
Central frequency = 8.25 GHz

Frequency band 5.5 - 11 GHz

F. Montonati
C. Franceschet

Instrument: optics (feedhorn)

N = 80 N_{mc} = 7



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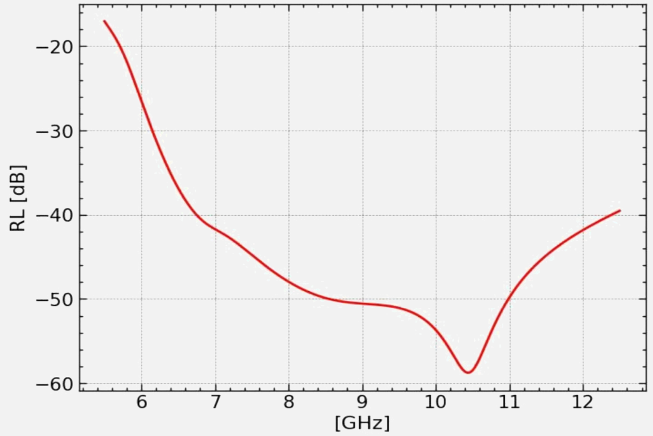
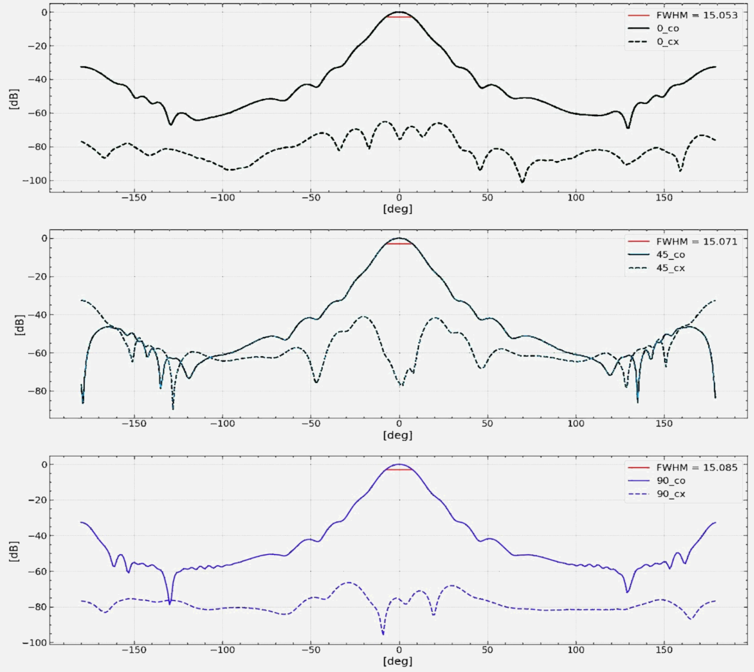


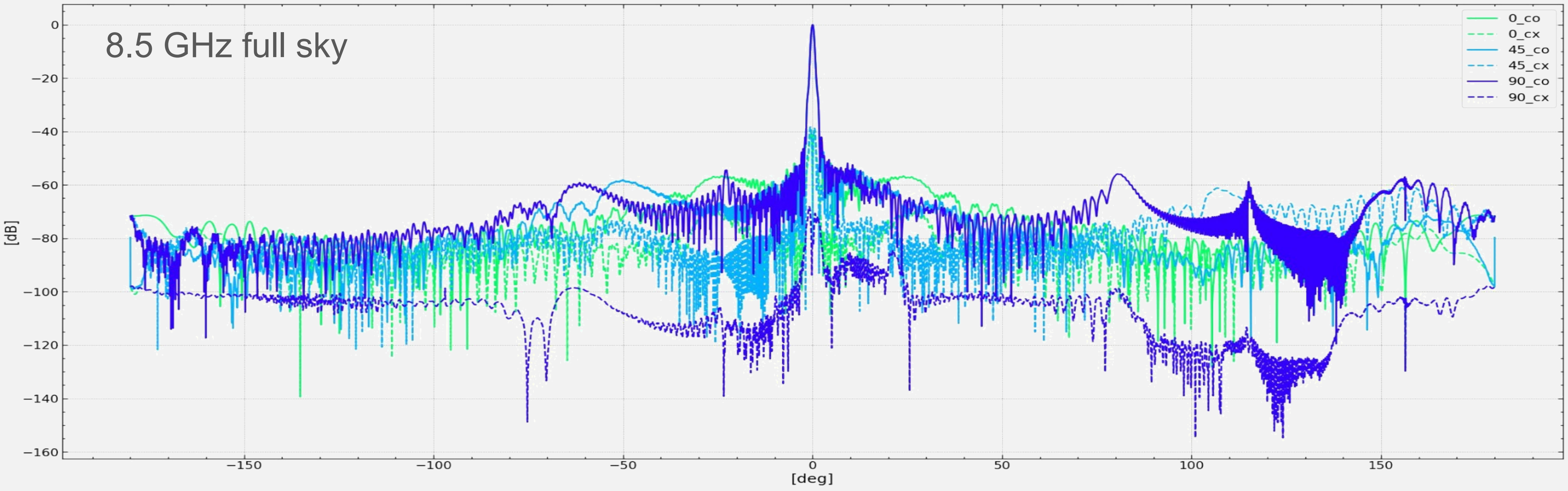
- Return loss < - 40 dB in the range 7-12 GHz

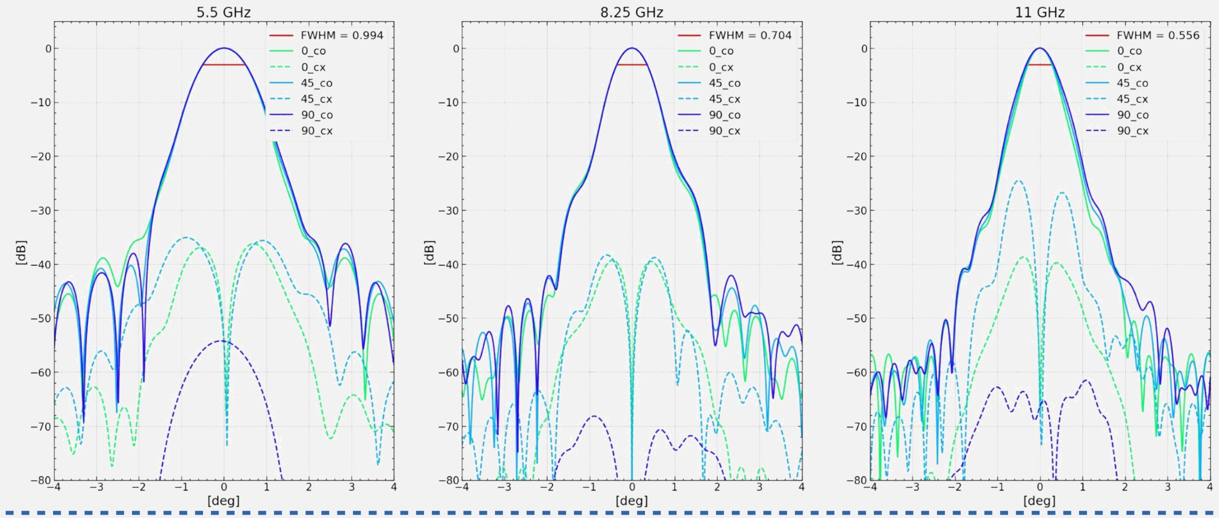


- Central frequency: 8.25 GHz
- Bandwidth: 5.5 GHz
- FWHM ~ 15°
- Cross-pol < - 40 dB

F. Montonati
C. Franceschet

Instrument: optics (beam simulations)





F. Montonati
C. Franceschet

Receiver modifications

M. Jones
A. Taylor

Receiver modifications

Remove old horn

Add new feedhorn

M. Jones
A. Taylor

Receiver modifications

Remove old horn

Extend cryostat top section

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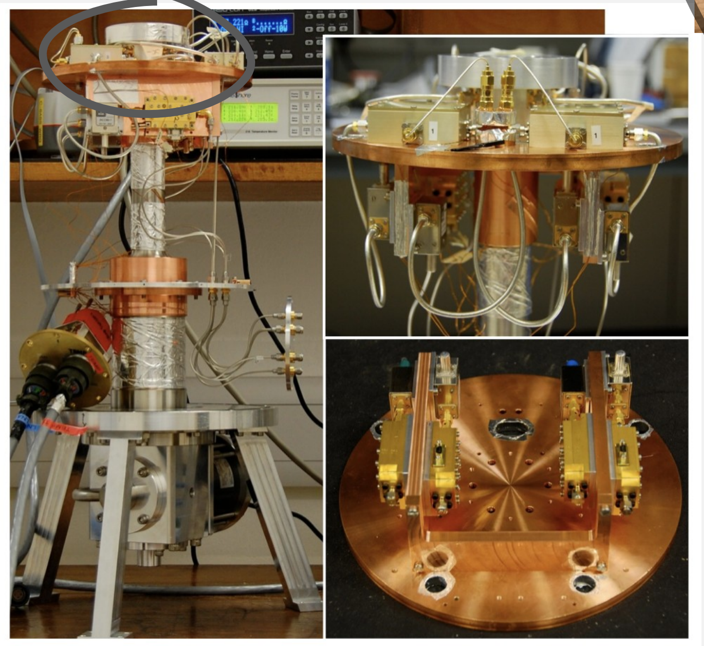
Replace CBASS OMT with broadband (SKA) design

M. Jones
A. Taylor



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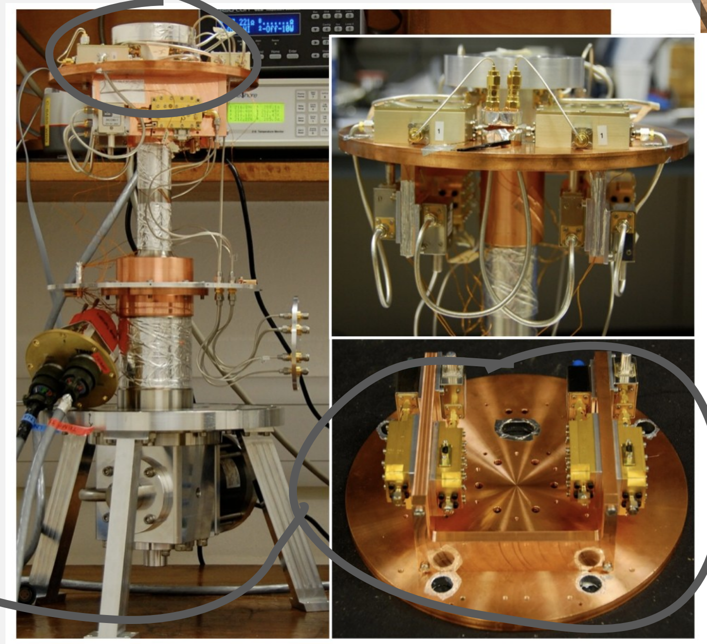


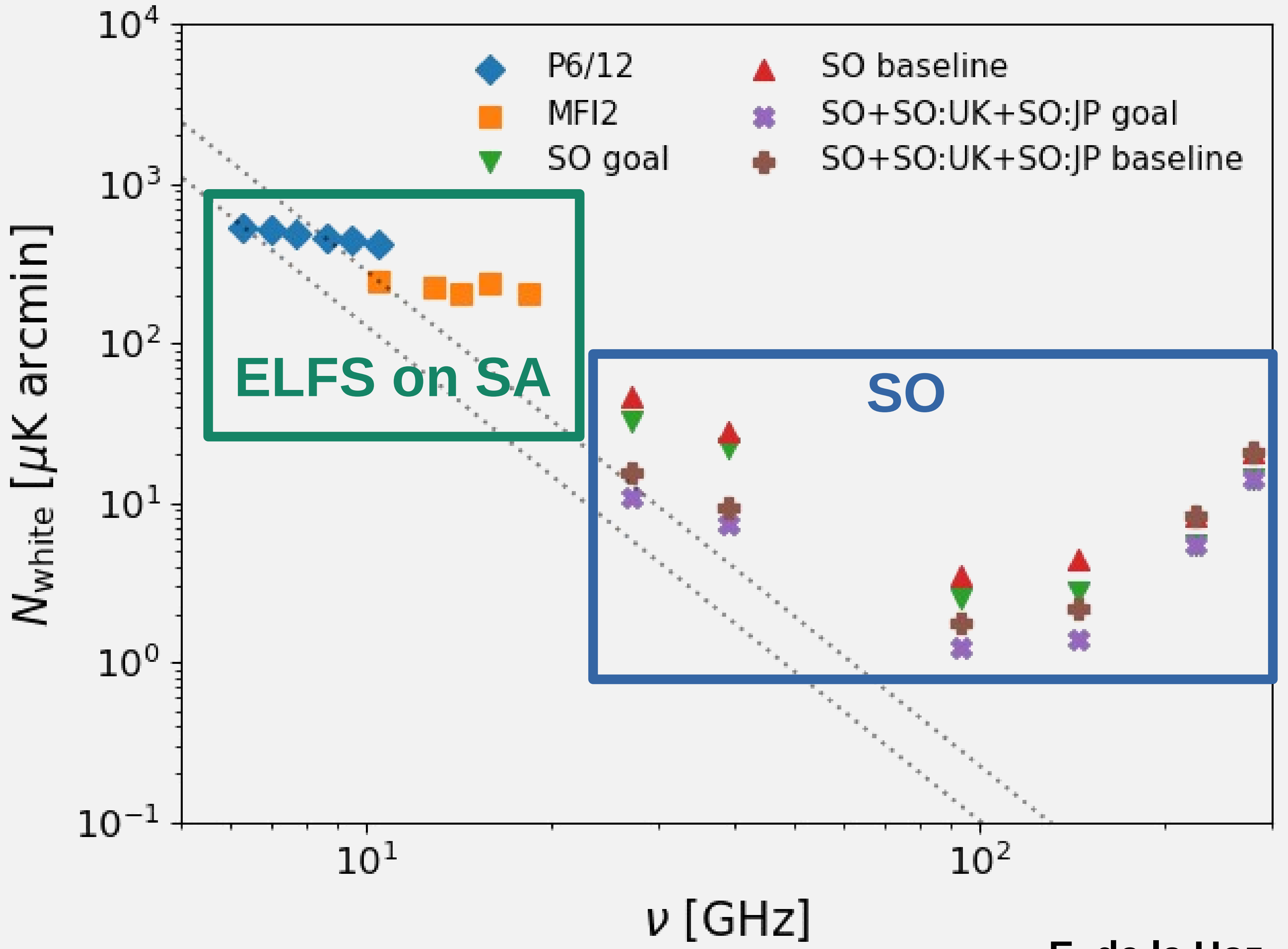
Replace 4-8 GHz LNAs with 4-16 GHz

Expected impact on science

- Evaluated impact of ELFS on SA on foregrounds parameters and tensor-to-scalar ratio, r
- Considered Simons Observatory as baseline case study (experiment in the nearest future)
- Can extend to future experiments like CMB-S4 and LITEBird
- **Spoiler:** the inclusion of low frequency channels significantly improves the estimate of the foreground parameters

Expected impact on science

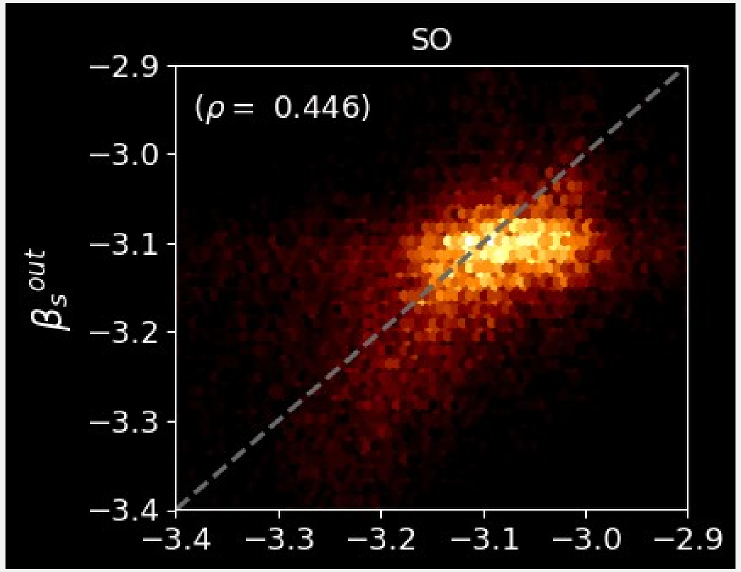
- SO with various configurations
- ELFS 5.5–11 GHz (6 years, 25% duty cycle)
- ELFS-MFI2 (5 years, 25% duty cycle)
- 10% sky fraction



E. de la Hoz

Synchrotron reconstruction

- Synchrotron model **s5** (power law with constraints given by S-PASS)
- SO with various configurations
- Improvement in foregrounds reconstruction with low frequency channels is apparent



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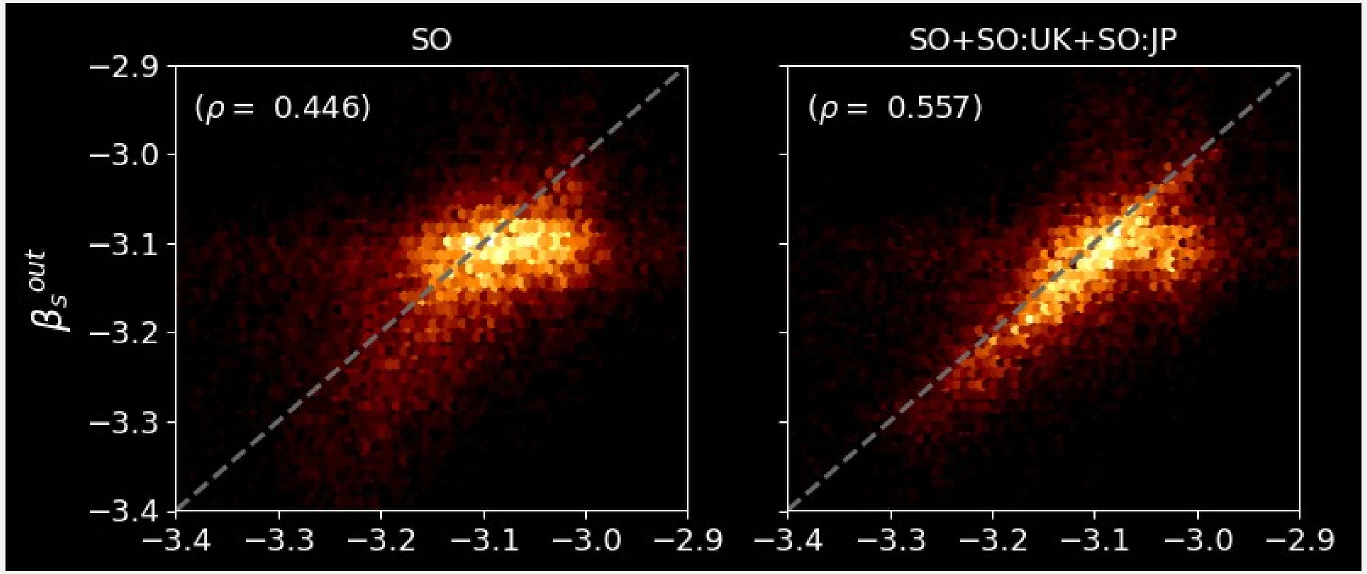

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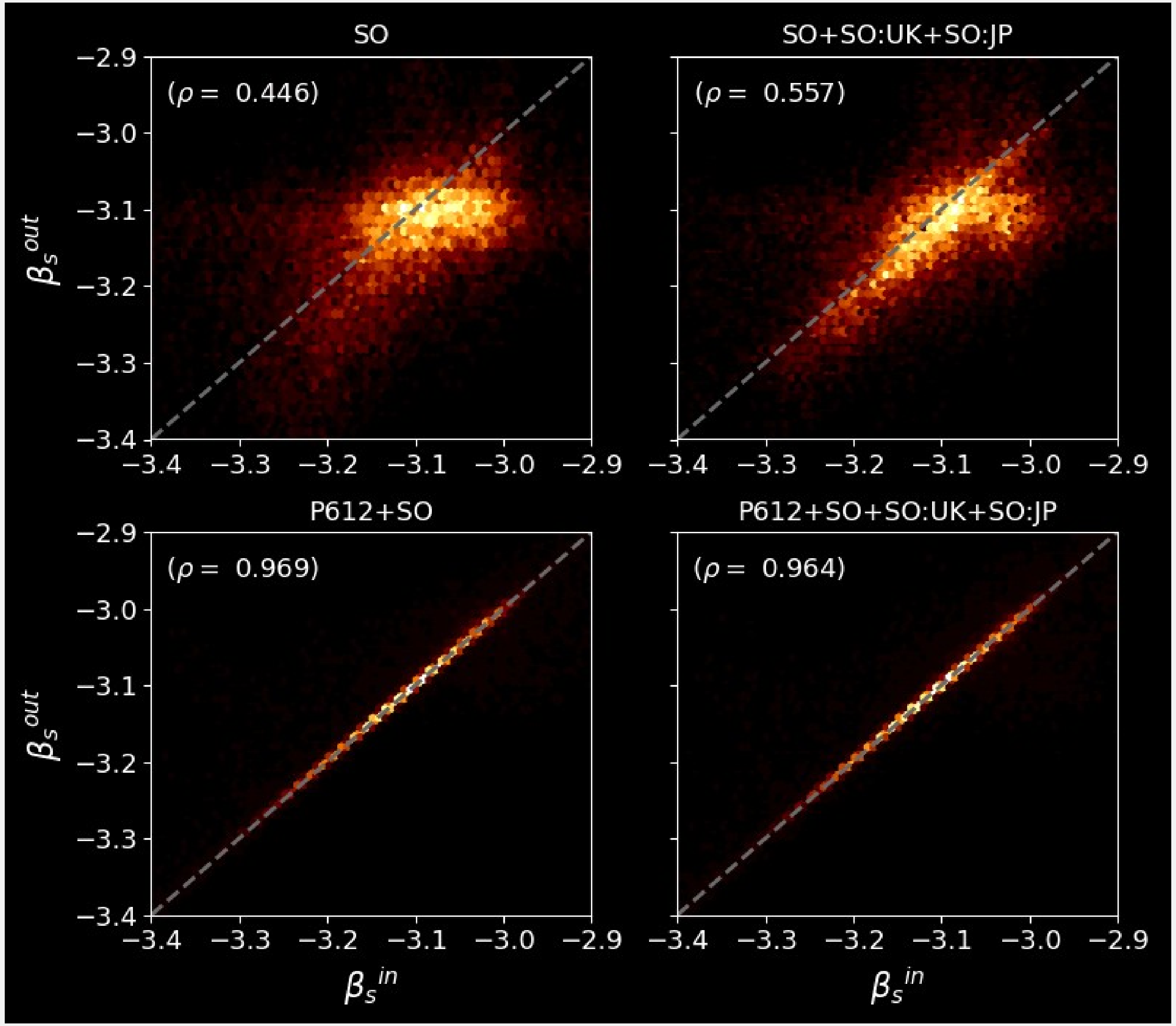
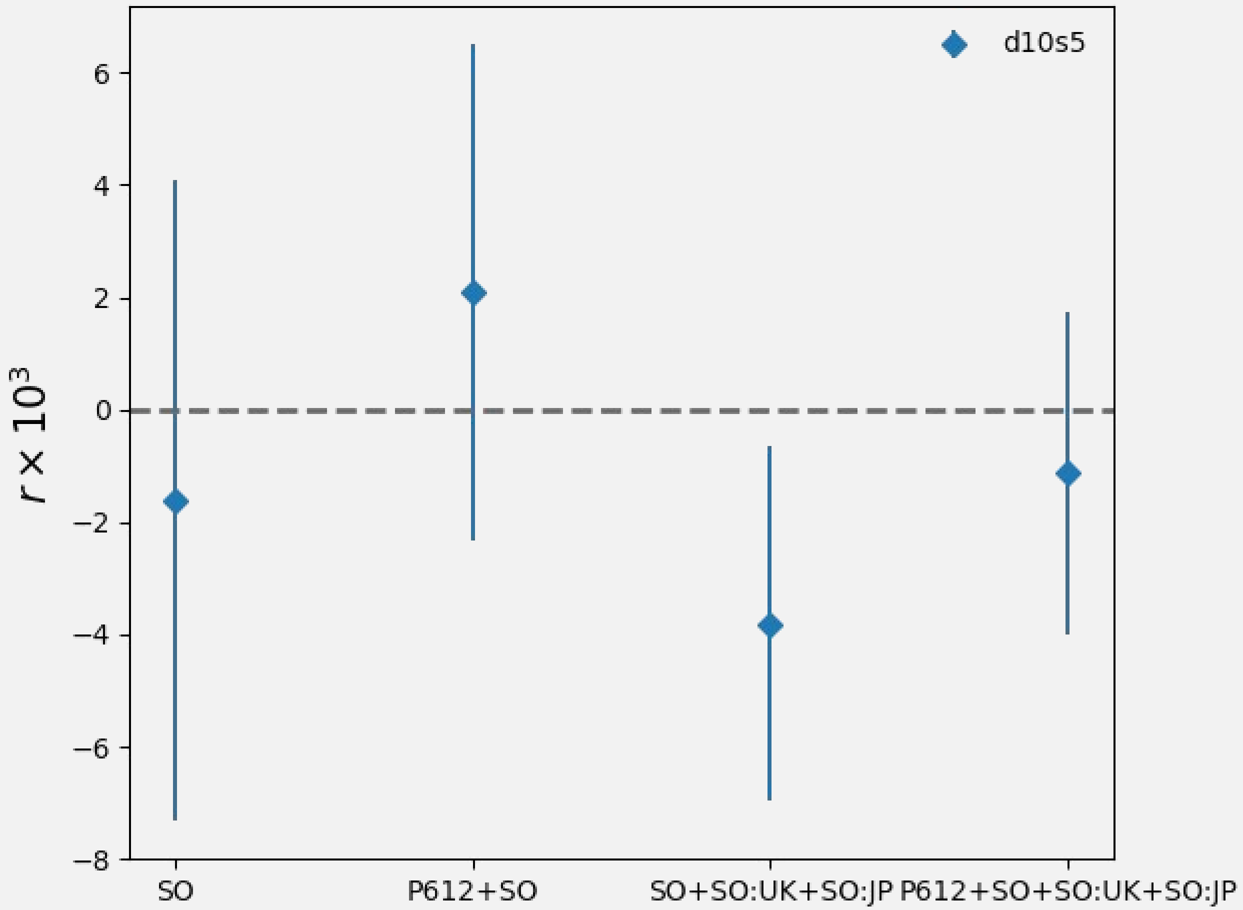
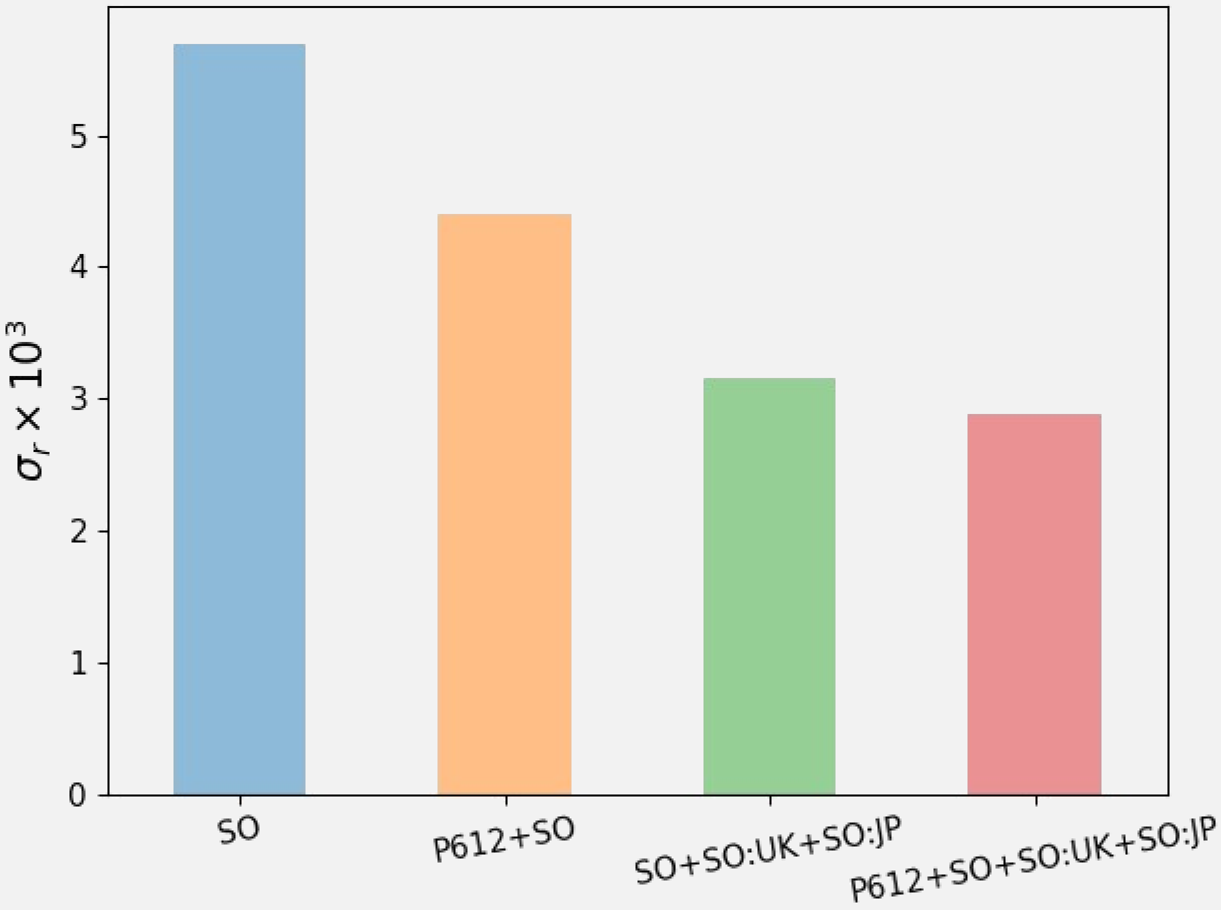


E. de la Hoz

Tensor-to-scalar ratio

- Tensor-to-scalar ratio recovered by fitting synchrotron with same input model (**d10s5**)

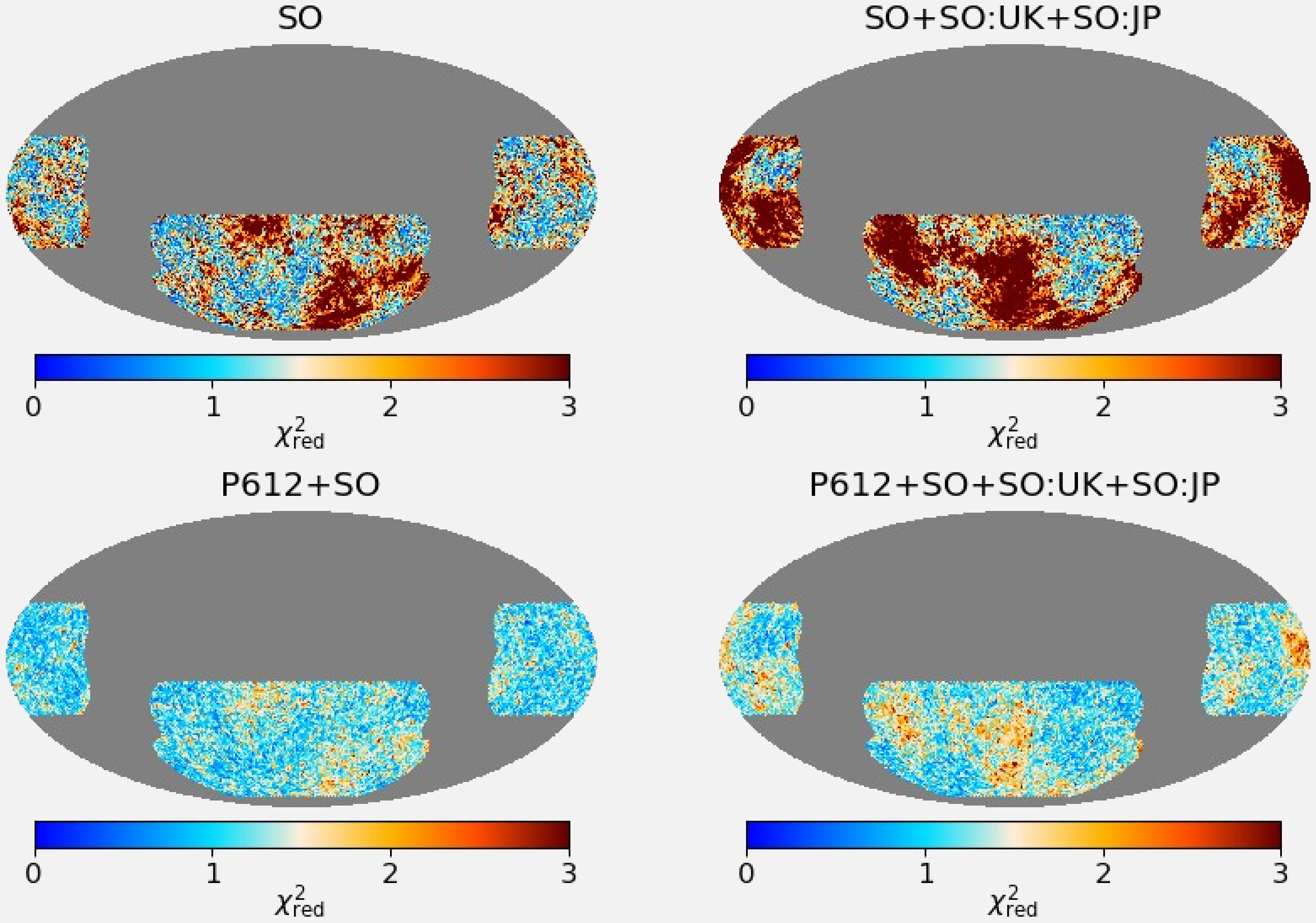




E. de la Hoz

Fitting synchrotron with correct model

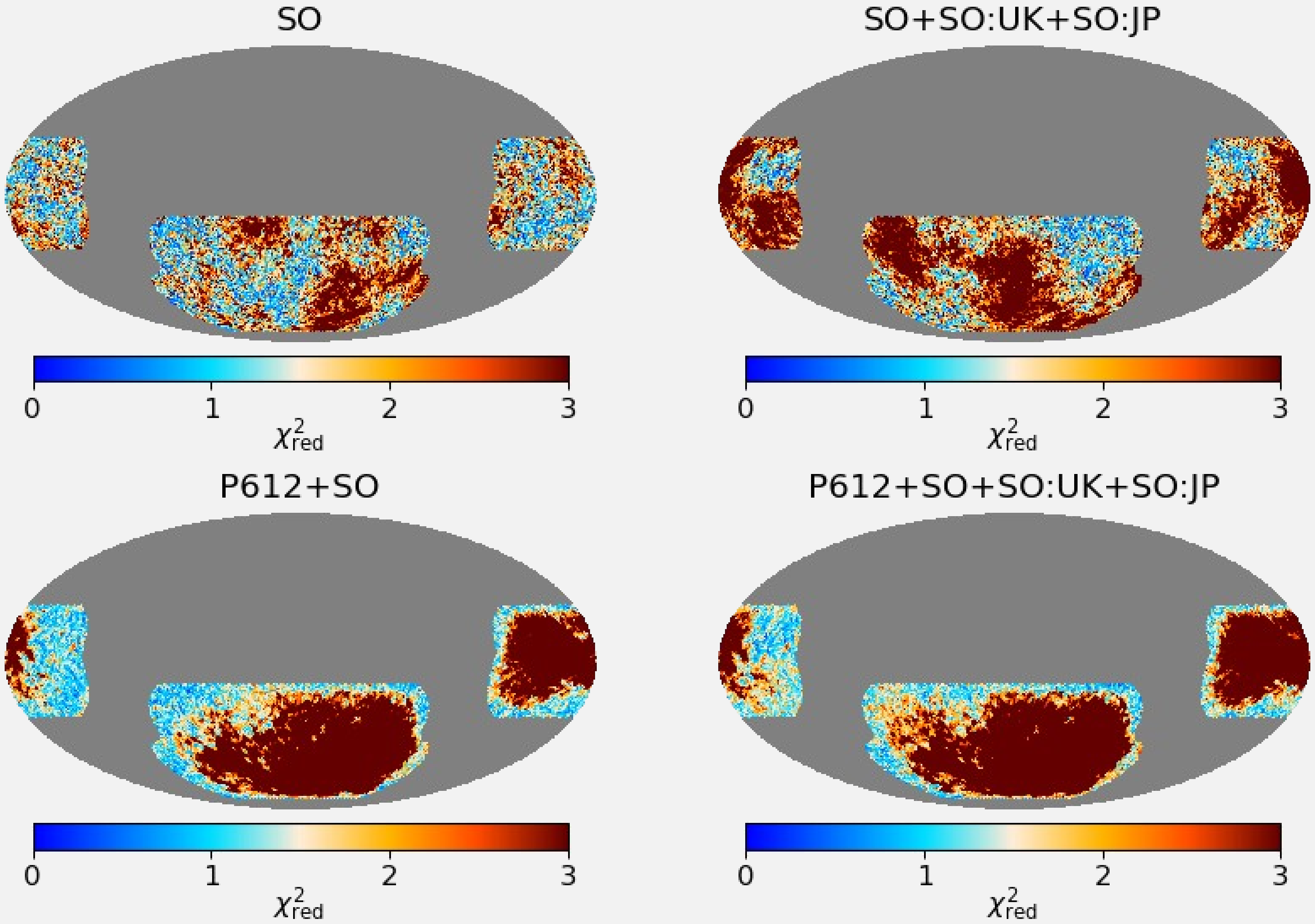
- Input and fitting model are the same (**d10s5**)
- Including low frequencies improves the fitting (reduced χ^2 becomes smaller)



E. de la Hoz

Fitting synchrotron with wrong model

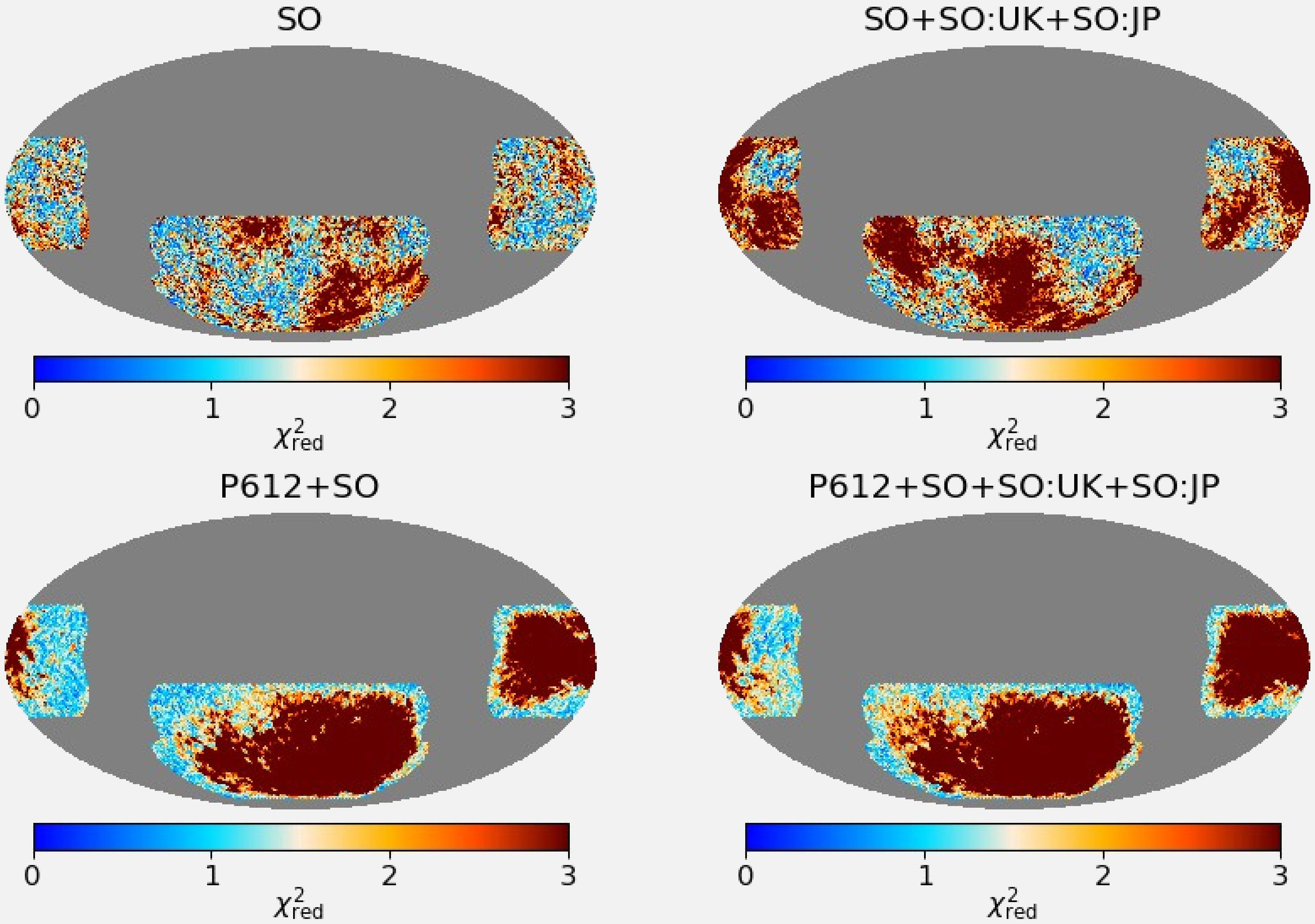
- Input and fitting model are different (input: **d10sC**, with curvature consistent with S-PASS; fitting: **d10s5**, without curvature)



E. de la Hoz

Fitting synchrotron with wrong model

- Input and fitting model are different (input: **d10sC**, with curvature consistent with S-PASS; fitting: **d10s5**, without curvature)
- Without low frequencies the χ^2 is essentially the same, $\Rightarrow$ SO would not understand that it is fitting with a wrong model.
- With low frequencies the χ^2 gets worse, raising an alarm bell on the assumed input sky



E. de la Hoz

Conclusions

- The measurement of the CMB polarization B-mode cannot be approached with a one-man-band strategy
- Sensitivity is key but foregrounds and instrumental systematic effects are the main limiting factors
- Synchrotron contamination cannot be ignored, cannot rely only on high frequencies
- Spectral resolution is also key
- ELFS aims at tackling the low-frequency foregrounds in a comprehensive and aggressive way – will complement data from future surveys like Litebird and S4
- ELFS on SA will be deployed approx. 2^{nd} half of 2024. First step in a broader vision, aiming at a full-sky survey with unprecedented combination of sensitivity, frequency coverage and spectral resolution