Conseil Scientifique de l'IN2P3

The Simons Observatory

Josquin Errard (APC)
Thibaut Louis (IJClab)

Conseil Scientifique de l'IN2P3
Paris, July 3, 2023

IN2P3

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The Simons Observatory

The Simons Observatory

10 Countries
40+ Institutions
300+ Researchers

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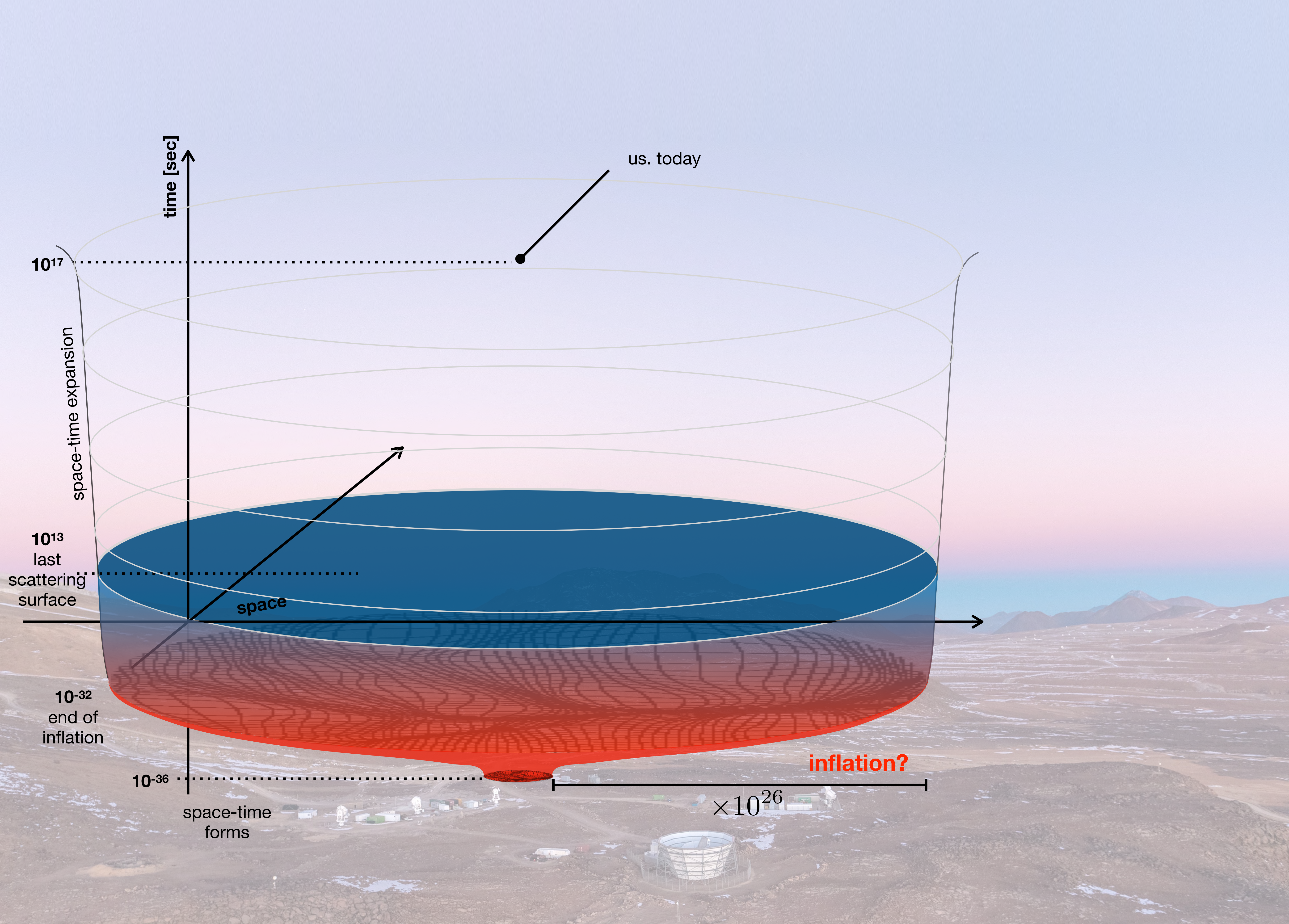
40+ Institutions
300+ Researchers

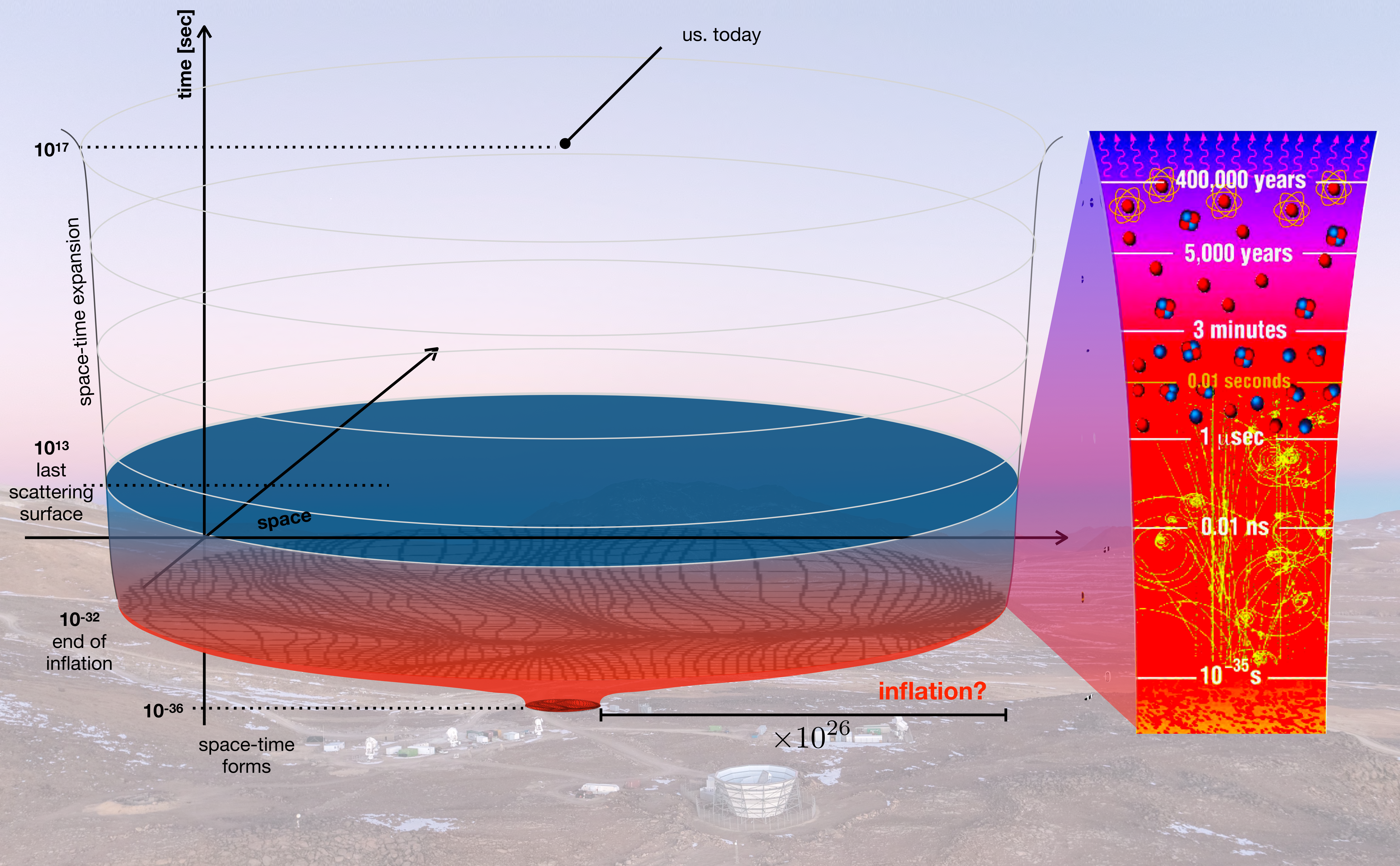
Thibaut Louis,[1,*] Josquin Errard,[2,†]
Ken Ganga,[2] James G. Bartlett,[2] Xavier Garrido,[1] Jean-Baptiste Melin,[3,2] and Radek Stompor[4,2]

External endorsers of the project: Juan Macias Perez (LPSC), Andrea Catalano (LPSC), Sophie Henrot-Versillé (IJClab), Laurence Perotto (LPSC), Matthieu Tristram (IJClab), Jacques Delabrouille (CPB), Manuel Gonzalez (APC).

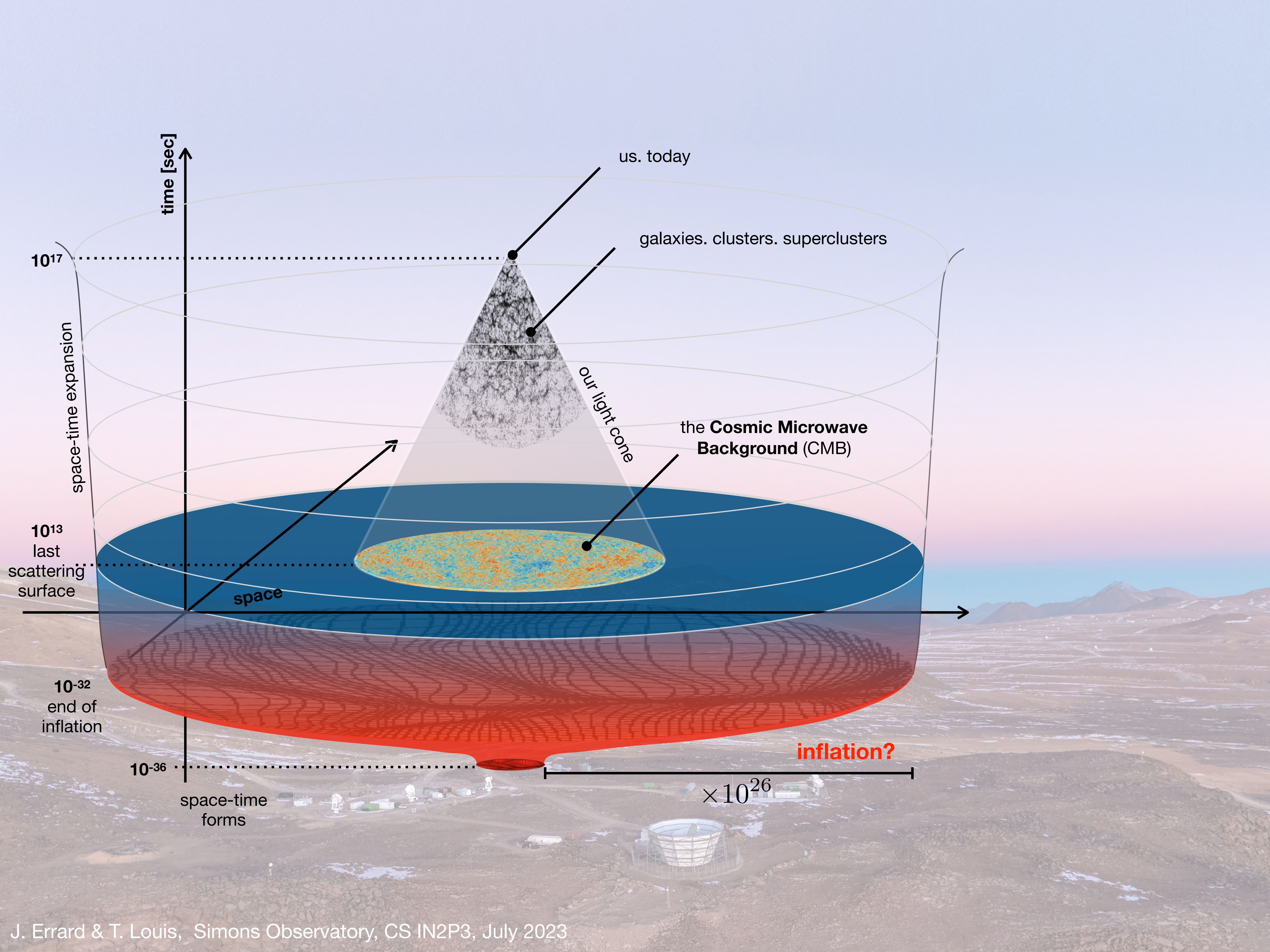

Chajnantor plateau
CCAT
ALMA
SIMONS OBSERVATORY
CLASS
POLARBEAR/Simons Array
Simons Observatory
ACT
17,000ft / 5,200m above see level



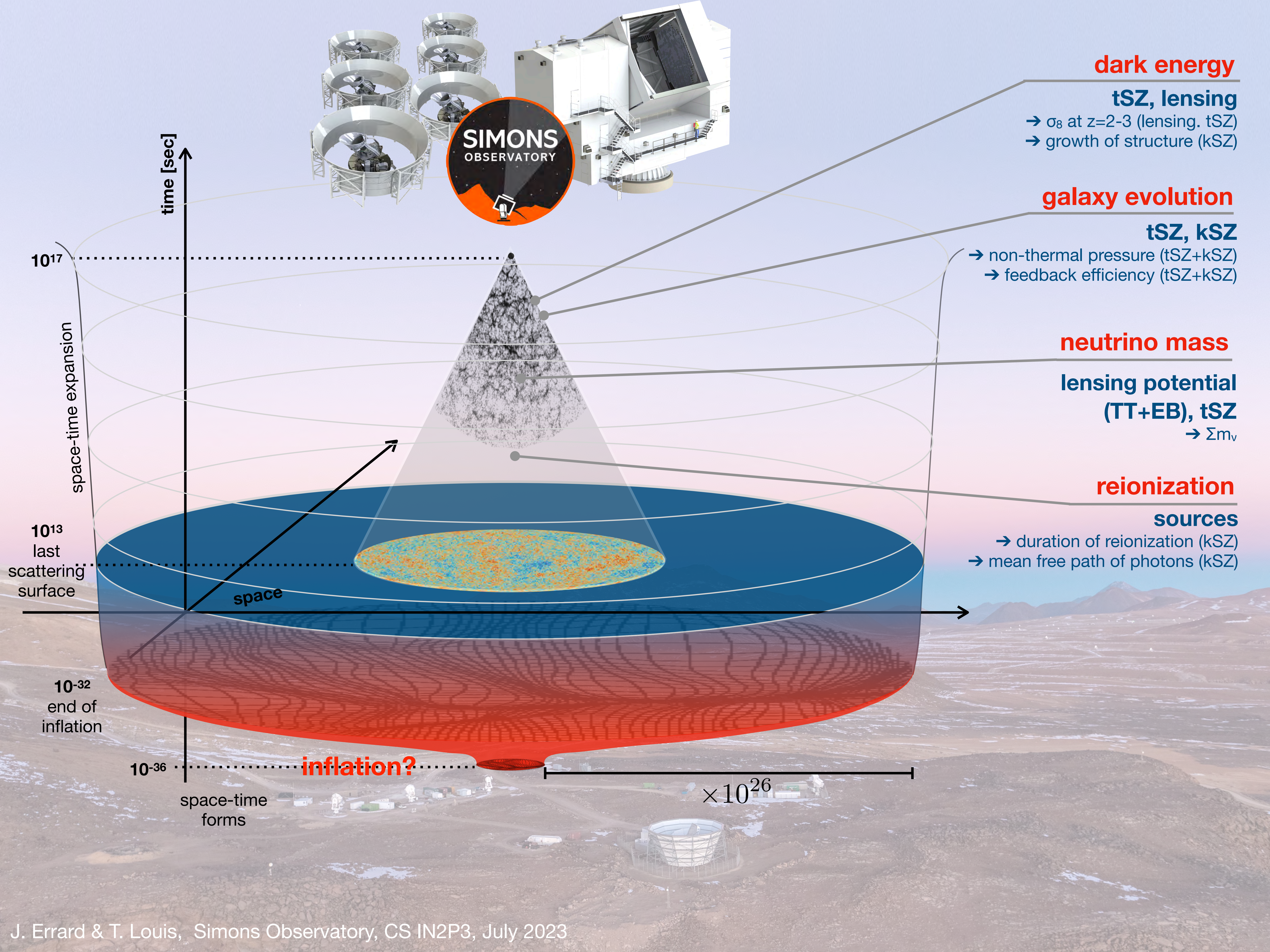
J. Errard & T. Louis, Simons Observatory, CS IN2P3, July 2023



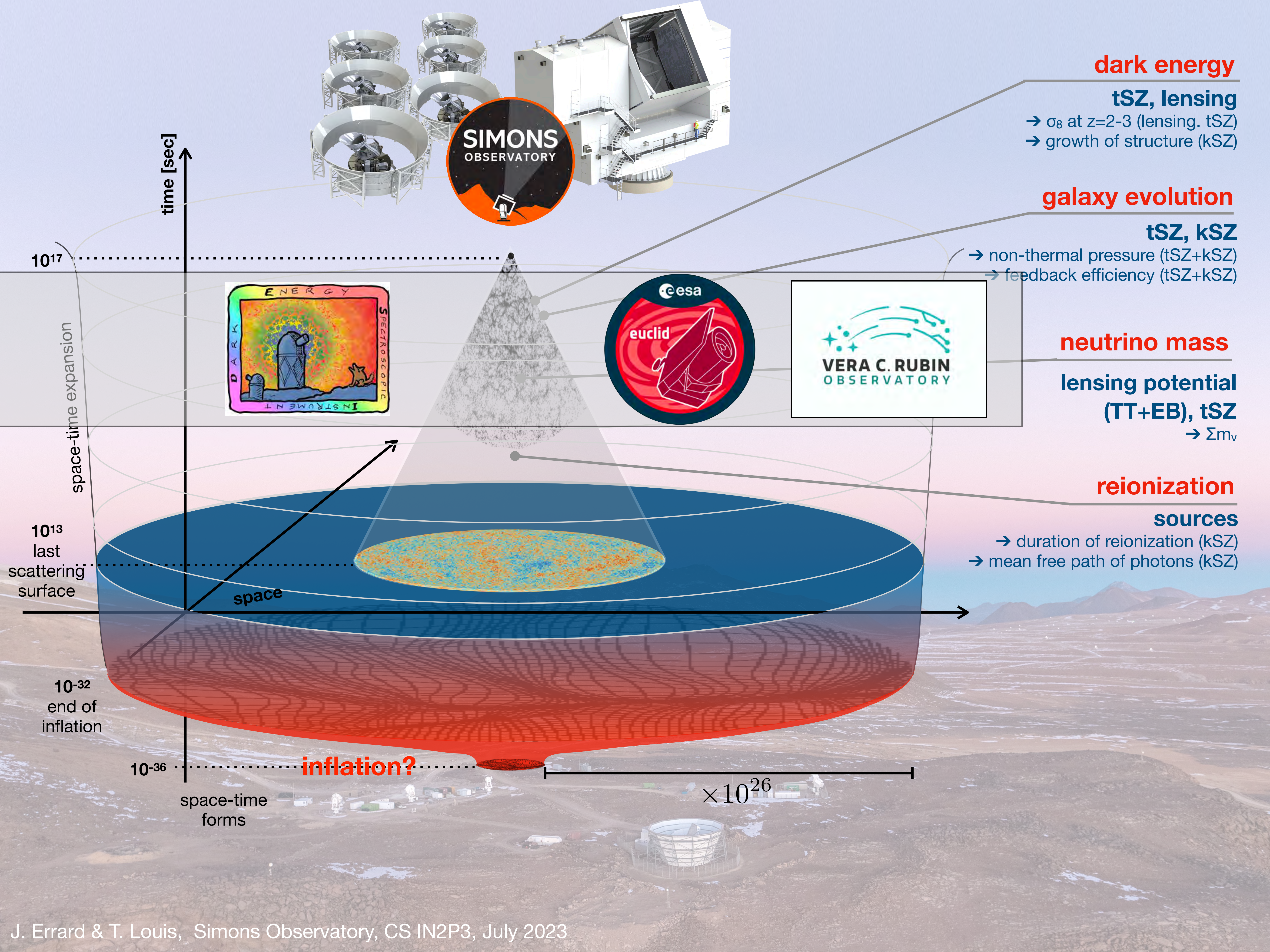
J. Errard & T. Louis, Simons Observatory, CS IN2P3, July 2023



time [sec]
us. today
galaxies. clusters. superclusters
10^{17}
space-time expansion
our light cone
the **Cosmic Microwave Background** (CMB)
10^{13}
last scattering surface
space
10^{-32}
end of inflation
inflation?
10^{-36}
$\times 10^{26}$
space-time forms
J. Errard & T. Louis, Simons Observatory, CS IN2P3, July 2023



SIMONS
OBSERVATORY
time [sec]
10^17
10^13
last
scattering
surface
10^-32
end of
inflation
10^-36
space-time expansion
space
inflation?
space-time
forms
×10^26
dark energy
tSZ, lensing
➔ σ8 at z=2-3 (lensing. tSZ)
➔ growth of structure (kSZ)
galaxy evolution
tSZ, kSZ
➔ non-thermal pressure (tSZ+kSZ)
➔ feedback efficiency (tSZ+kSZ)
neutrino mass
lensing potential
(TT+EB), tSZ
➔ Σmν
reionization
sources
➔ duration of reionization (kSZ)
➔ mean free path of photons (kSZ)
J. Errard & T. Louis, Simons Observatory, CS IN2P3, July 2023



dark energy
tSZ, lensing
➔ σ8 at z=2-3 (lensing. tSZ)
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reionization
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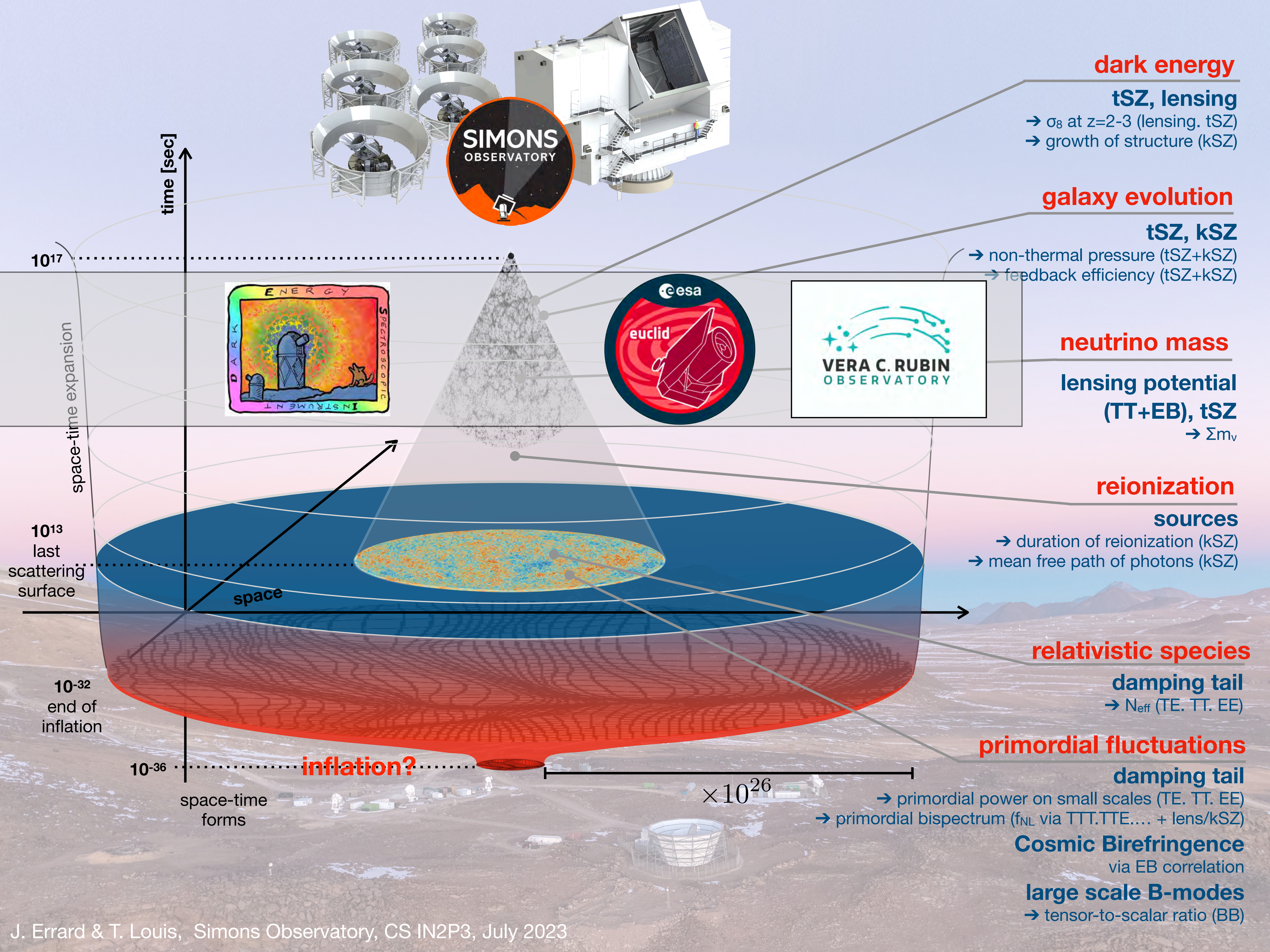
➔ duration of reionization (kSZ)
➔ mean free path of photons (kSZ)
SIMONS
OBSERVATORY
DARK ENERGY SPECTROSCOPIC INSTRUMENT
esa
euclid
VERA C. RUBIN
OBSERVATORY
time [sec]
space-time expansion
10^17
10^13
last
scattering
surface
space
10^-32
end of
inflation
10^-36
inflation?
space-time
forms
×10^26
J. Errard & T. Louis, Simons Observatory, CS IN2P3, July 2023



SIMONS OBSERVATORY
time [sec]
10^17
10^13
last scattering surface
10^-32
end of inflation
10^-36
inflation?
space-time forms
space-time expansion
space
×10^26
ENERGY SPECTROSCOPIC INSTRUMENT
DARK
esa
euclid
VERA C. RUBIN OBSERVATORY
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sources
➔ duration of reionization (kSZ)
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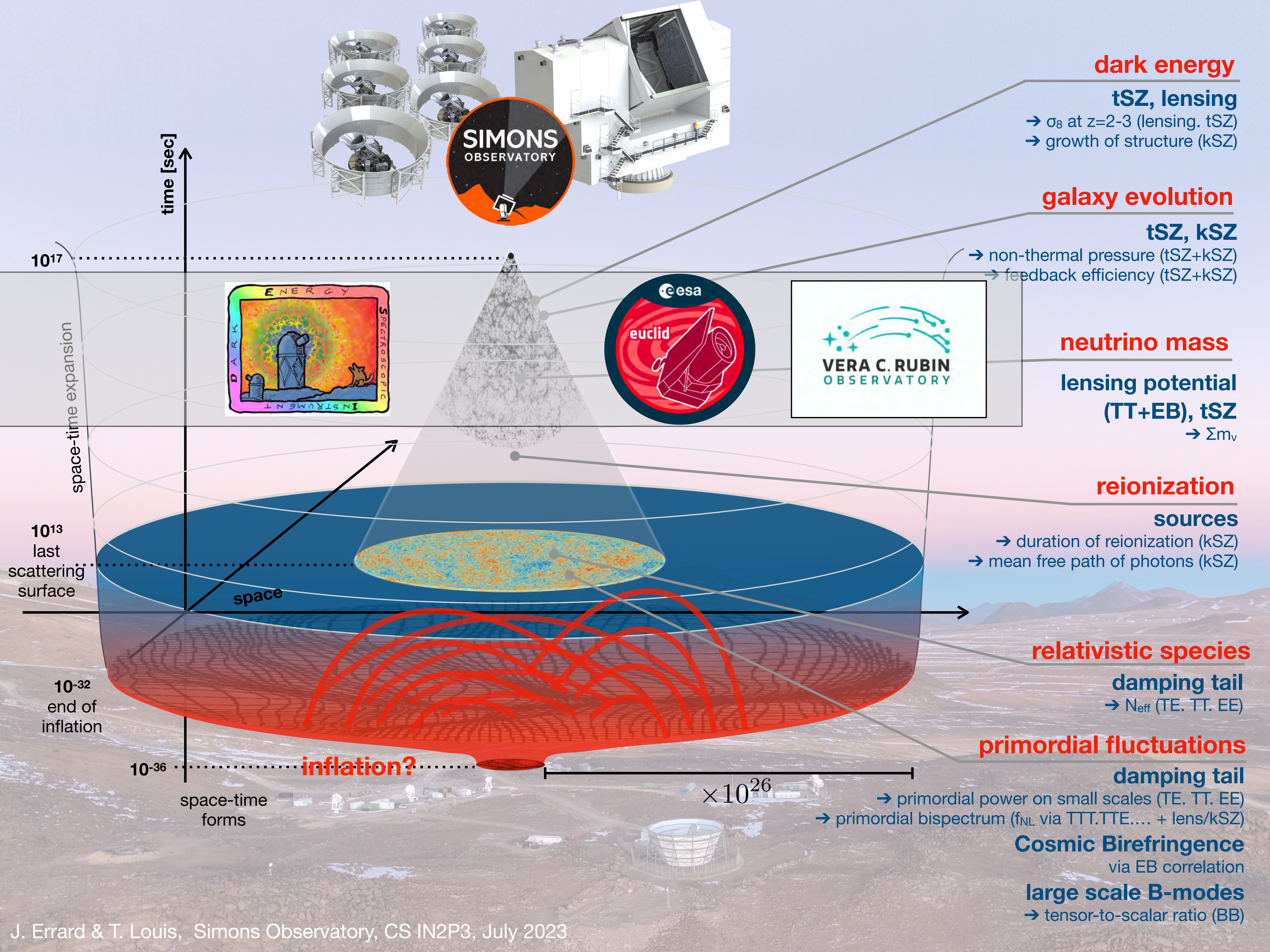
relativistic species
damping tail
➔ Neff (TE. TT. EE)
primordial fluctuations
damping tail
➔ primordial power on small scales (TE. TT. EE)
➔ primordial bispectrum (fNL via TTT.TTE.... + lens/kSZ)
Cosmic Birefringence
via EB correlation
large scale B-modes
➔ tensor-to-scalar ratio (BB)
J. Errard & T. Louis, Simons Observatory, CS IN2P3, July 2023



SIMONS
OBSERVATORY
time [sec]
10^{17}
space-time expansion
ENERGY
DARK
SPECTROSCOPIC
INSTRUMENT
euclid
esa
VERA C. RUBIN
OBSERVATORY
10^{13}
last
scattering
surface
space
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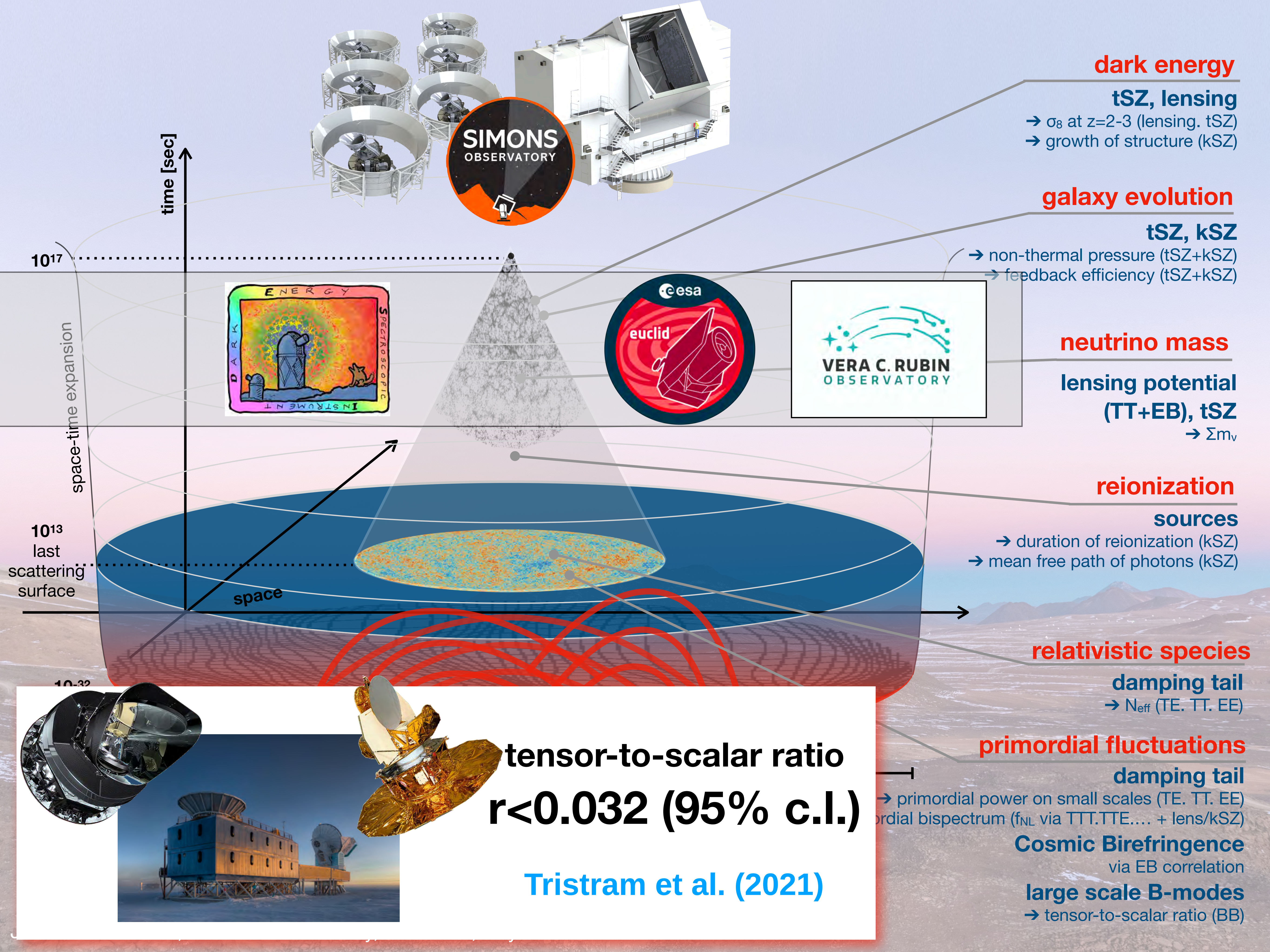
Cosmic Birefringence
via EB correlation
large scale B-modes
➔ tensor-to-scalar ratio (BB)
J. Errard & T. Louis, Simons Observatory, CS IN2P3, July 2023


dark energy
tSZ, lensing
➔ σ8 at z=2-3 (lensing. tSZ)
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galaxy evolution
tSZ, kSZ
➔ non-thermal pressure (tSZ+kSZ)
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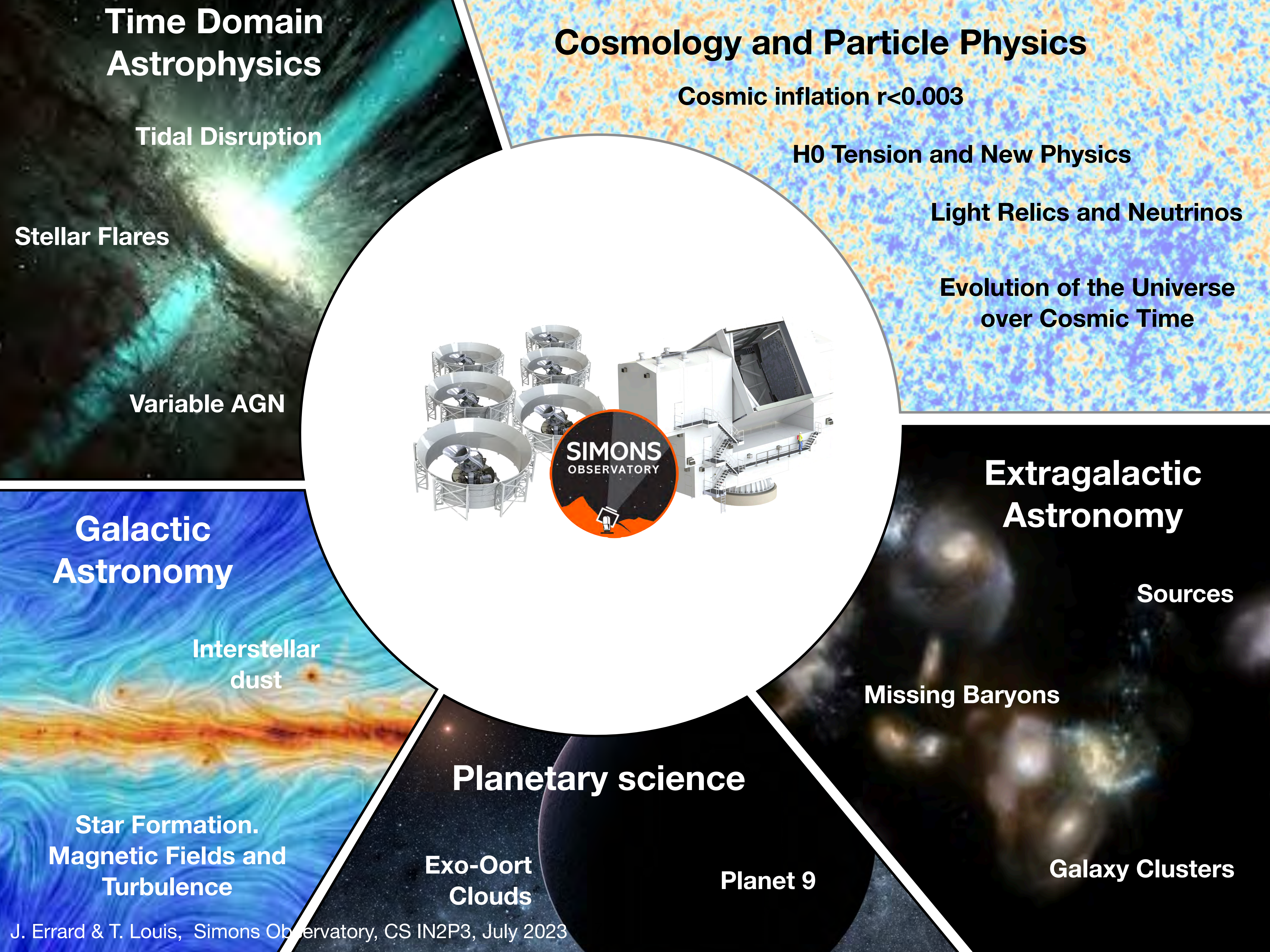
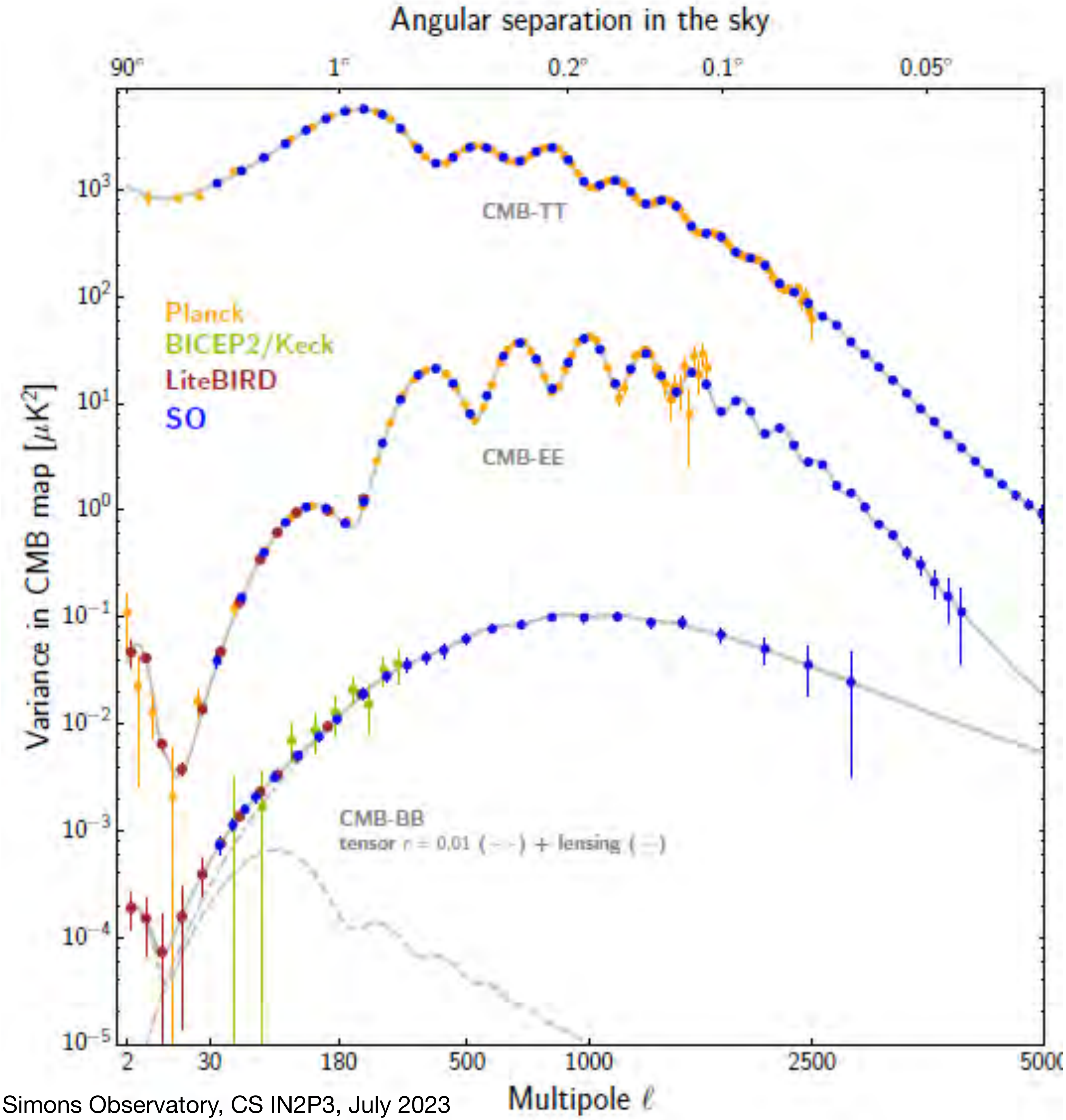
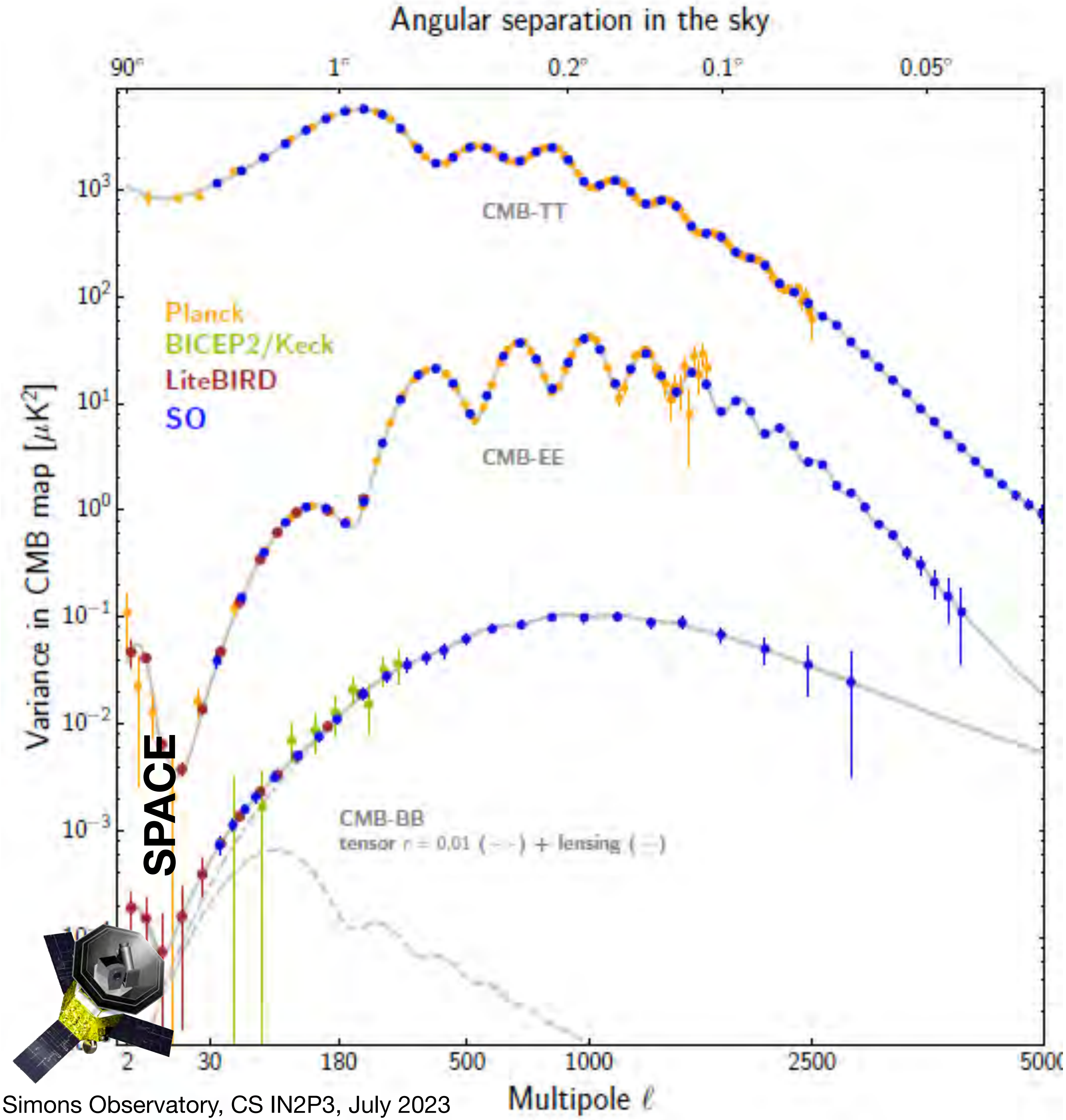
SIMONS OBSERVATORY
DARK ENERGY SPECTROSCOPIC INSTRUMENT
esa
euclid
VERA C. RUBIN OBSERVATORY
time [sec]
10^17
10^13
last scattering surface
space-time expansion
space
tensor-to-scalar ratio
r<0.032 (95% c.l.)
Tristram et al. (2021)

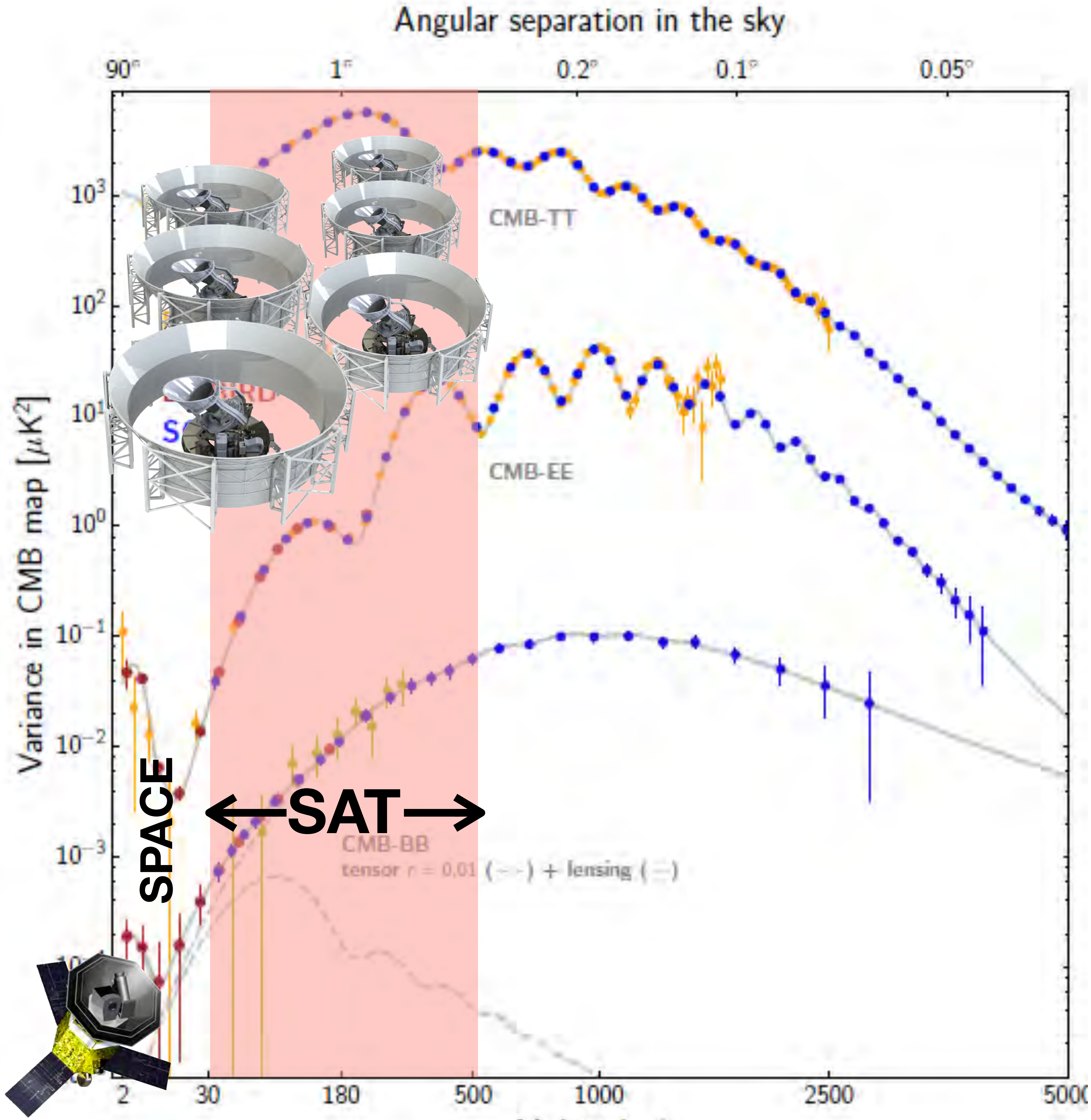

Time Domain Astrophysics
Tidal Disruption
Stellar Flares
Variable AGN
Cosmology and Particle Physics
Cosmic inflation r<0.003
H0 Tension and New Physics
Light Relics and Neutrinos
Evolution of the Universe over Cosmic Time
SIMONS OBSERVATORY
Extragalactic Astronomy
Sources
Missing Baryons
Galaxy Clusters
Galactic Astronomy
Interstellar dust
Star Formation. Magnetic Fields and Turbulence
Planetary science
Exo-Oort Clouds
Planet 9



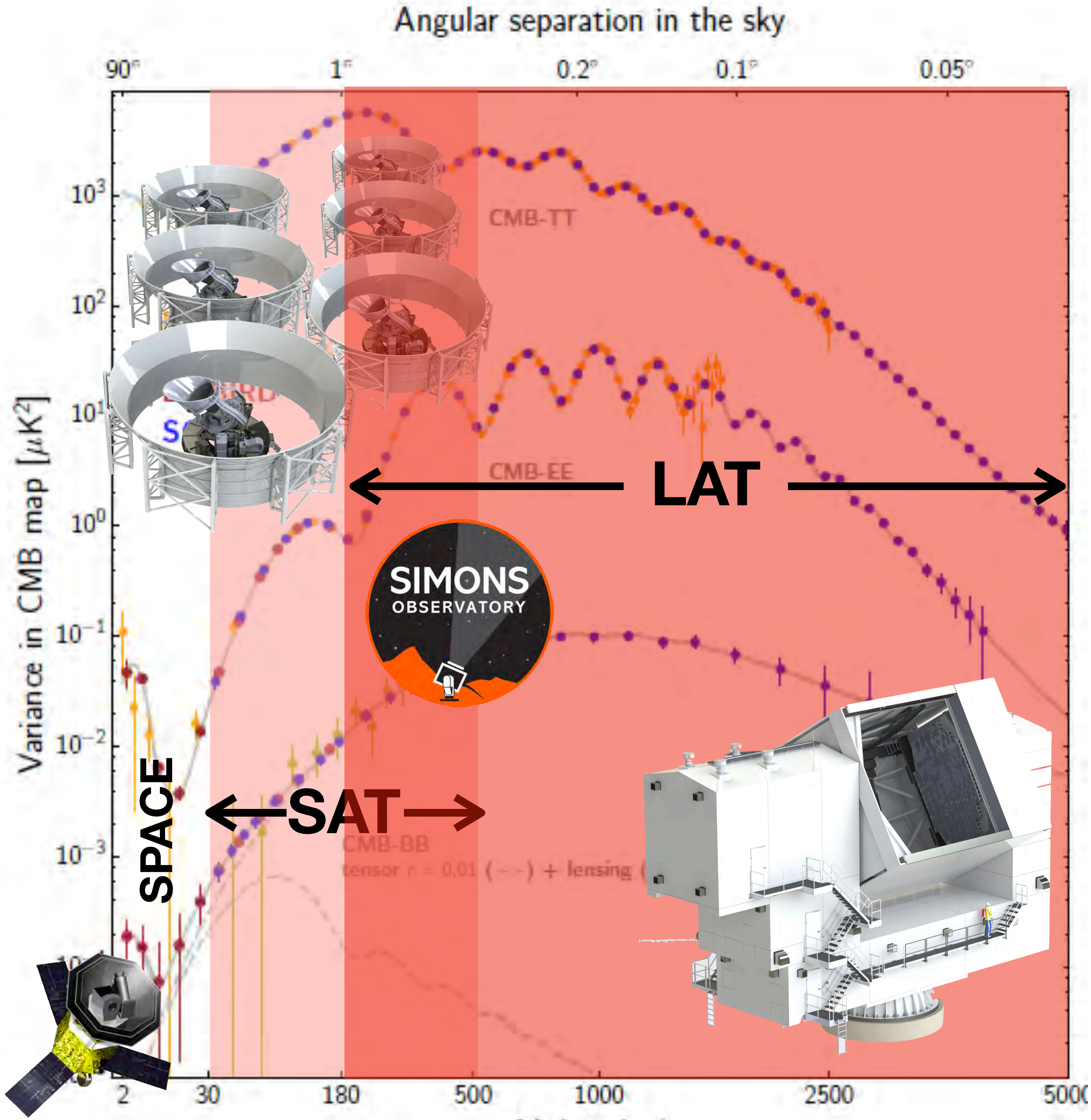
J. Errard & T. Louis, Simons Observatory, CS IN2P3, July 2023



Angular separation in the sky
90°
1°
0.2°
0.1°
0.05°
Variance in CMB map [μK²]
10³
10²
10¹
10⁰
10⁻¹
10⁻²
10⁻³
CMB-TT
Planck
BICEP2/Keck
LiteBIRD
SO
CMB-EE
CMB-BB
tensor r = 0.01 (---) + lensing (—)
SPACE
2
30
180
500
1000
2500
5000
Multipole ℓ

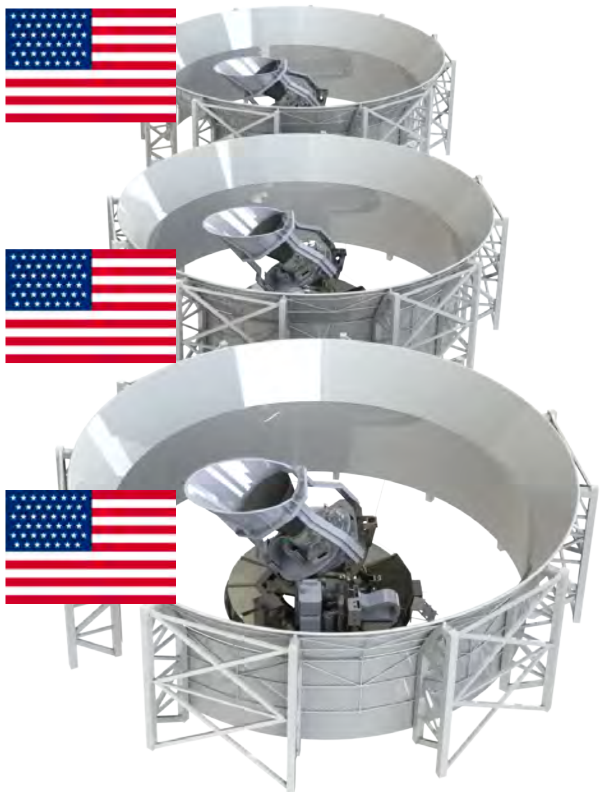


J. Errard & T. Louis, Simons Observatory, CS IN2P3, July 2023



J. Errard & T. Louis, Simons Observatory, CS IN2P3, July 2023

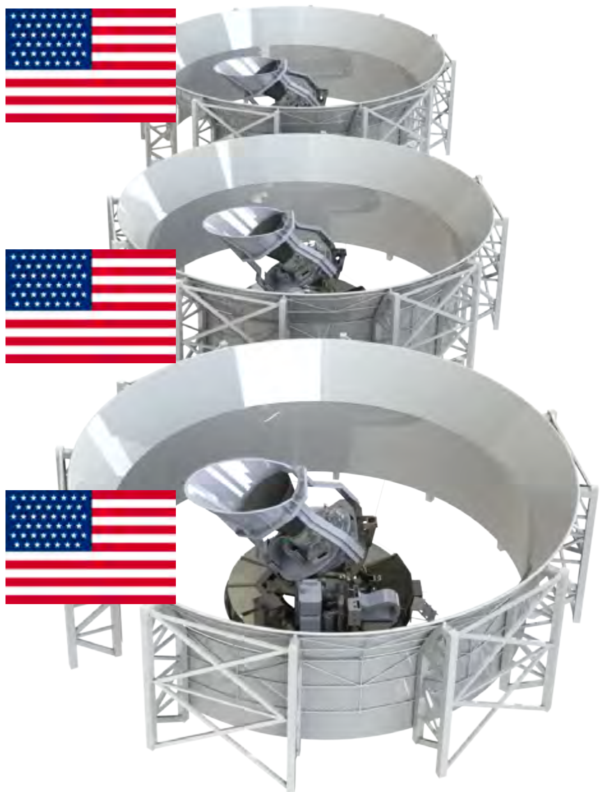
news #1 SO += SO:UK + SO:JP

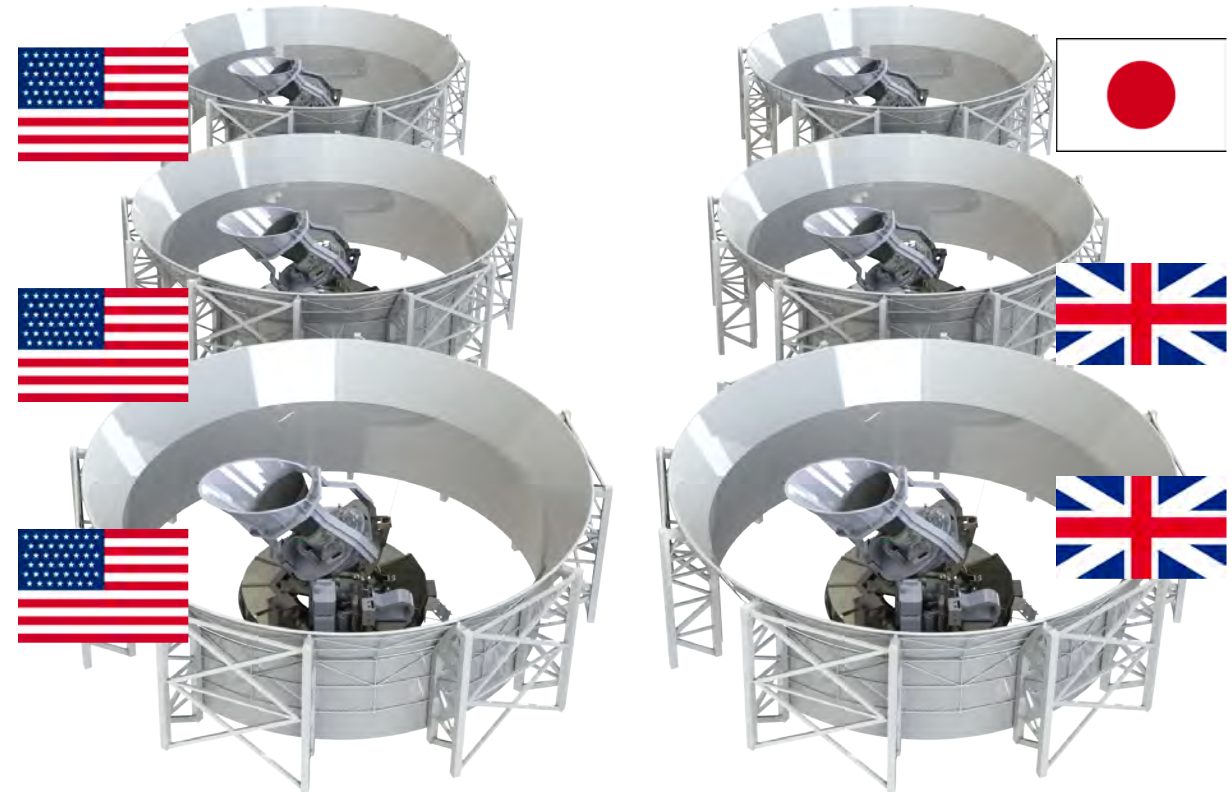


~ 2024

3 SATs
30,000 detectors in total
6 frequency bands

news #1 SO += SO:UK + SO:JP





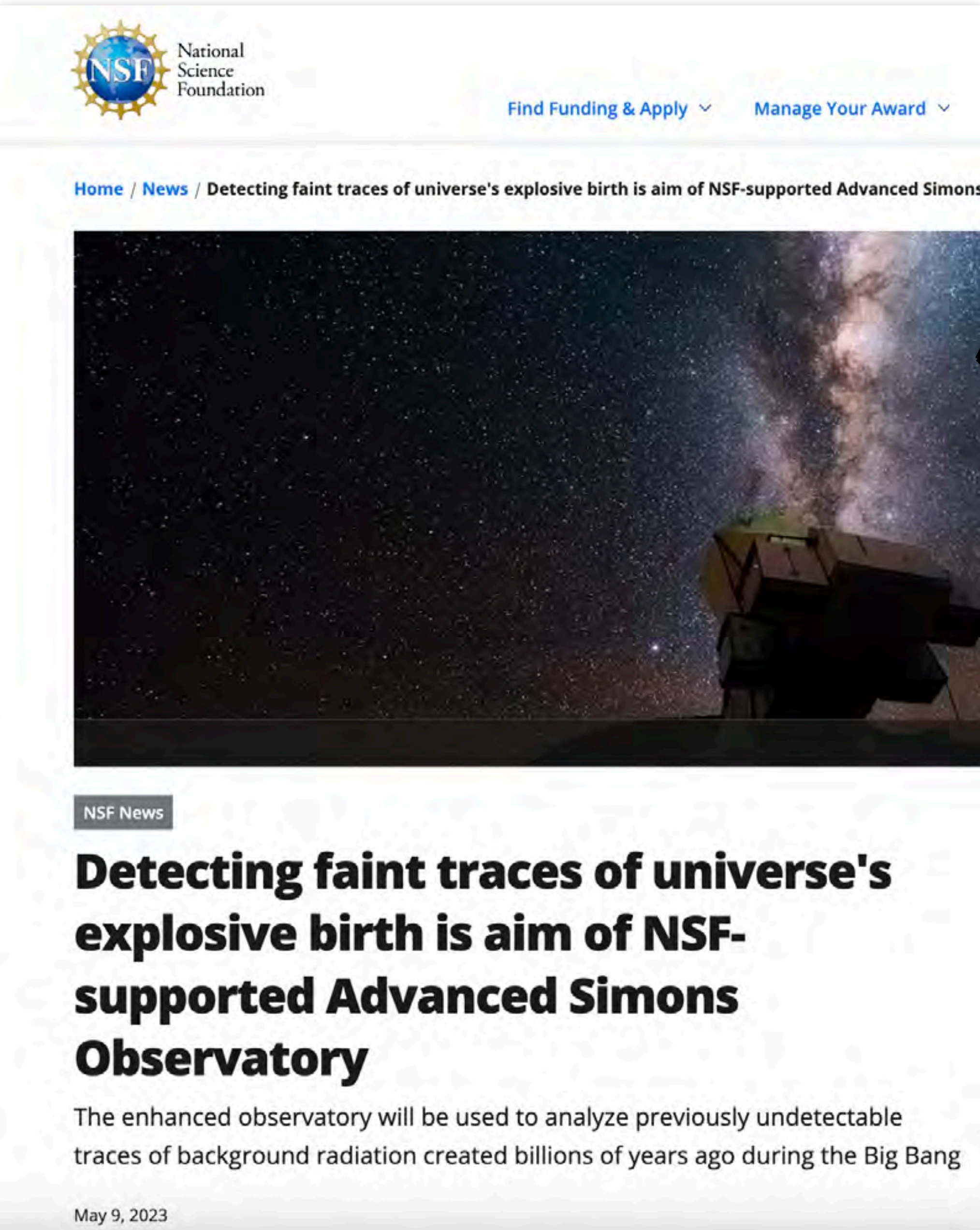
~ 2024

~ 2028

3 SATs
30,000 detectors in total
6 frequency bands

6 SATs
60,000 detectors in total
6 frequency bands

news #2
Advanced-SO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Home / News / Detecting faint traces of universe's explosive birth is aim of NSF-supported Advanced Simons

NSF News

Detecting faint traces of universe's explosive birth is aim of NSF-supported Advanced Simons Observatory

The enhanced observatory will be used to analyze previously undetectable traces of background radiation created billions of years ago during the Big Bang

May 9, 2023

LAT

- Six New Optics Tubes
- Double Mapping Speed for Delensing and other science
- Enable Transient Detection
- No Development Required

Data Management

- Full Maps Processed in 6 Months
- Daily Transient Alerts
- Verification and Systematics Mitigation
- Community Maps and Tools

Photovoltaic Array

- 9% increase in Observing Efficiency
- Reduced Carbon Footprint
- Reduced Maintenance Costs

	Parameter	SO-Baseline[a] (no syst)	**SO-Baseline[b]**	SO-Goal[c]	Current[d] (2018-19)	Method	Sec.	**Advanced-SO (2024-2032)**
Primordial	r	0.0024	**0.003**	0.002	0.03	BB + ext delens	3.4	**0.0012**
perturbations	$e^{-2\tau}\mathcal{P}(k=0.2/\mathrm{Mpc})$	0.4%	**0.5%**	0.4%	3%	$TT/TE/EE$	4.2	**0.4%**
	$f_{\mathrm{NL}}^{\mathrm{local}}$	1.8	**3**	1	5	$\kappa\kappa \times$ LSST-LSS + 3-pt	5.3	**1**
		1	**2**	1		kSZ + LSST-LSS	7.5	
Relativistic species	N_{eff}	0.055	**0.07**	0.05	0.2	$TT/TE/EE + \kappa\kappa$	4.1	**0.045**
Neutrino mass	Σm_ν	0.033	**0.04**	0.03	0.1	$\kappa\kappa$ + DESI-BAO	5.2	**0.03**
		0.035	**0.04**	0.03		tSZ-N $\times$ LSST-WL	7.1	
		0.036	**0.05**	0.04		tSZ-Y + DESI-BAO	7.2	
Deviations from Λ	$\sigma_8(z=1-2)$	1.2%	**2%**	1%	7%	$\kappa\kappa$ + LSST-LSS	5.3	**1%**
		1.2%	**2%**	1%		tSZ-N $\times$ LSST-WL	7.1	
	H_0 (ΛCDM)	0.3	**0.4**	0.3	0.5	$TT/TE/EE + \kappa\kappa$	4.3	**0.3 km/s/Mpc**
Galaxy evolution	η_{feedback}	2%	**3%**	2%	50-100%	kSZ + tSZ + DESI	7.3	**2%**
	p_{nt}	6%	**8%**	5%	50-100%	kSZ + tSZ + DESI	7.3	**4%**
Reionization	Δz	0.4	**0.6**	0.3	1.4	TT (kSZ)	7.6	**0.3%**

[a] This column reports forecasts from earlier sections (in some cases using 2 s.f.) and applies no additional systematic error.

[b] This is the nominal forecast, increases the column (a) uncertainties by 25% as a proxy for instrument systematics, and rounds up to 1 s.f.

[c] This is the goal forecast, has negligible additional systematic uncertainties, and rounds to 1 s.f.

[d] Primarily from [44] and [287].

[44] BICEP2 and Planck collaborations, Joint Analysis of BICEP2/Keck Array and Planck Data, Phys. Rev. Lett. 114 (2015) 101301
[287] Planck collaboration, Planck 2018 results. VI. Cosmological parameters

Table 9. Summary of SO key science goals. All of our SO forecasts assume that SO is combined with *Planck* data.

From: The Simons Observatory: science goals and forecasts
Peter Ade et al., JCAP02 (2019) 056
https://ui.adsabs.harvard.edu/abs/2019JCAP...02..056A/abstract

	Parameter	SO-Baseline[a] (no syst)	**SO-Baseline[b]**	SO-Goal[c]	Current[d] (2018-19)	Method	Sec.	**Advanced-SO (2024-2032)**
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	$f_{\mathrm{NL}}^{\mathrm{local}}$	1.8	**3**	1	5	$\kappa\kappa \times$ LSST-LSS + 3-pt	5.3	**1**
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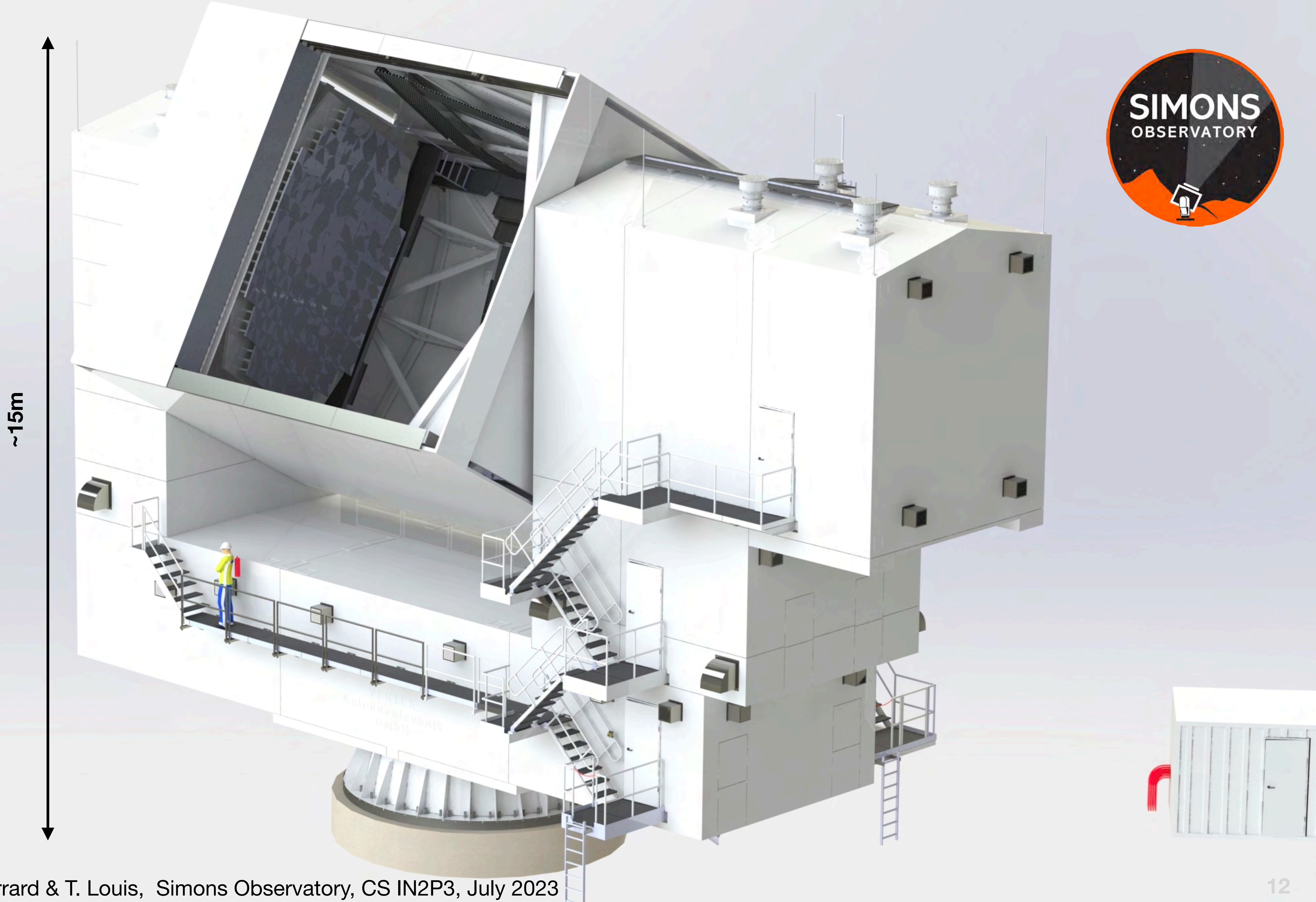
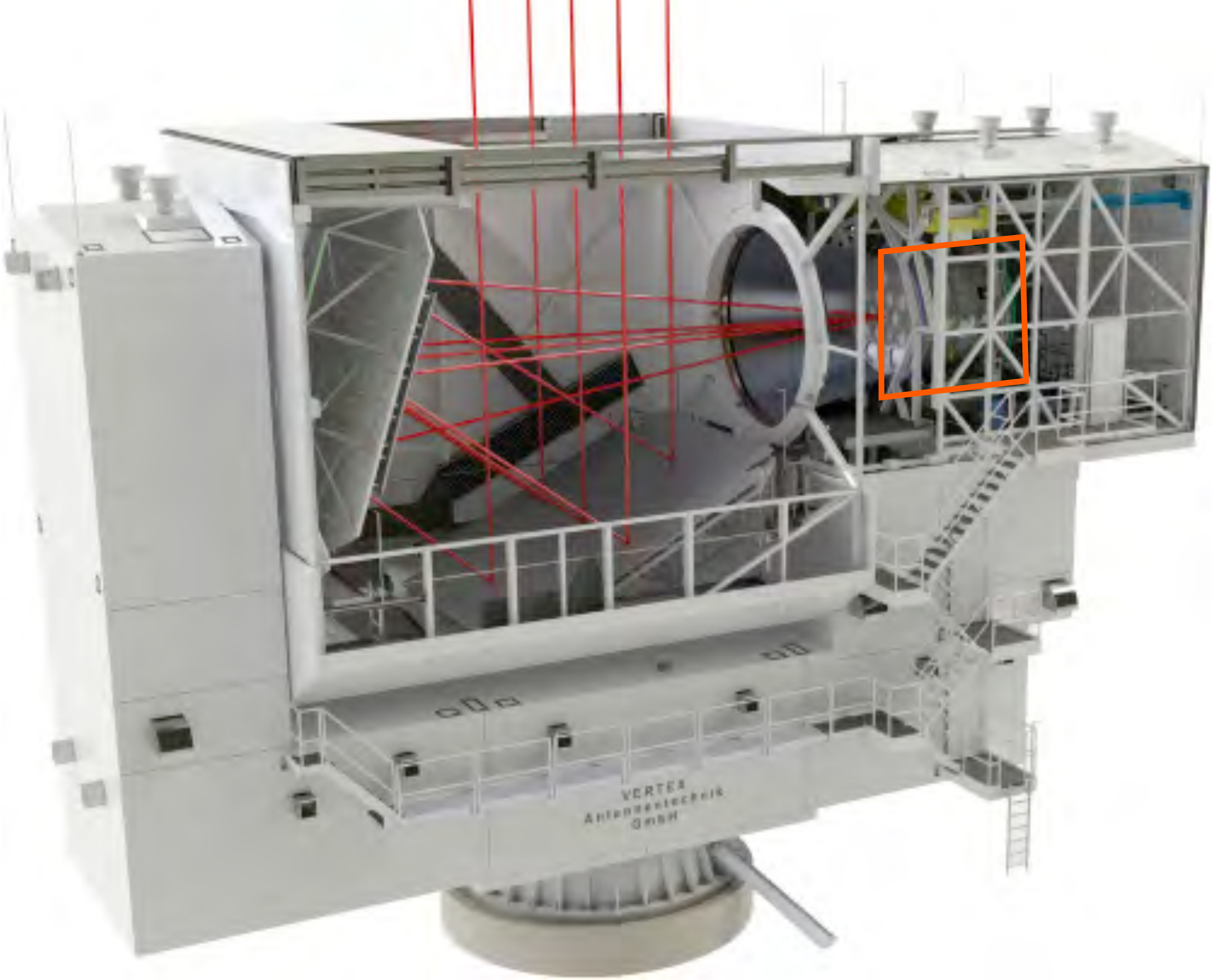
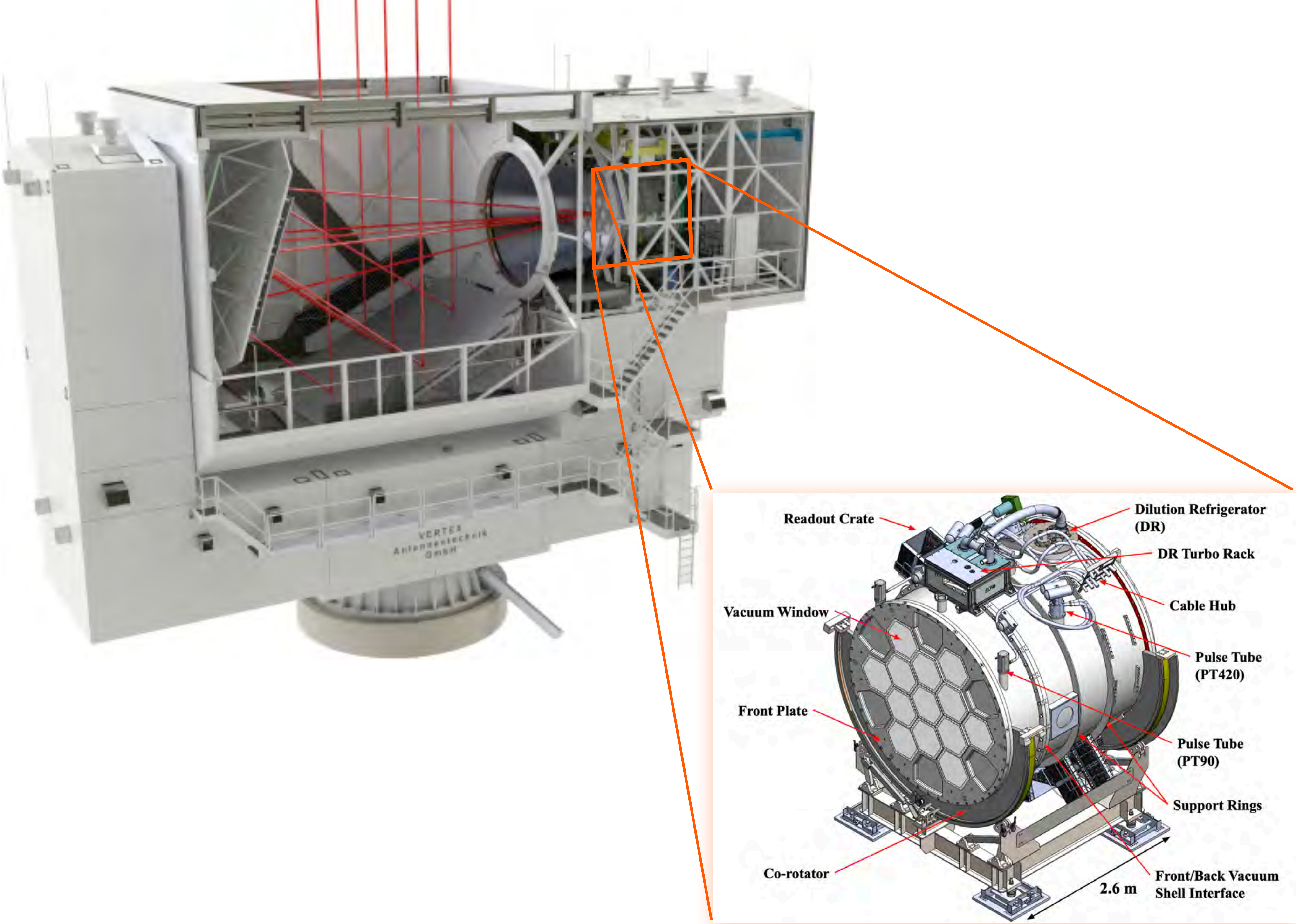
Reionization	Δz	0.4	**0.6**	0.3	1.4	TT (kSZ)	7.6	**0.3%**

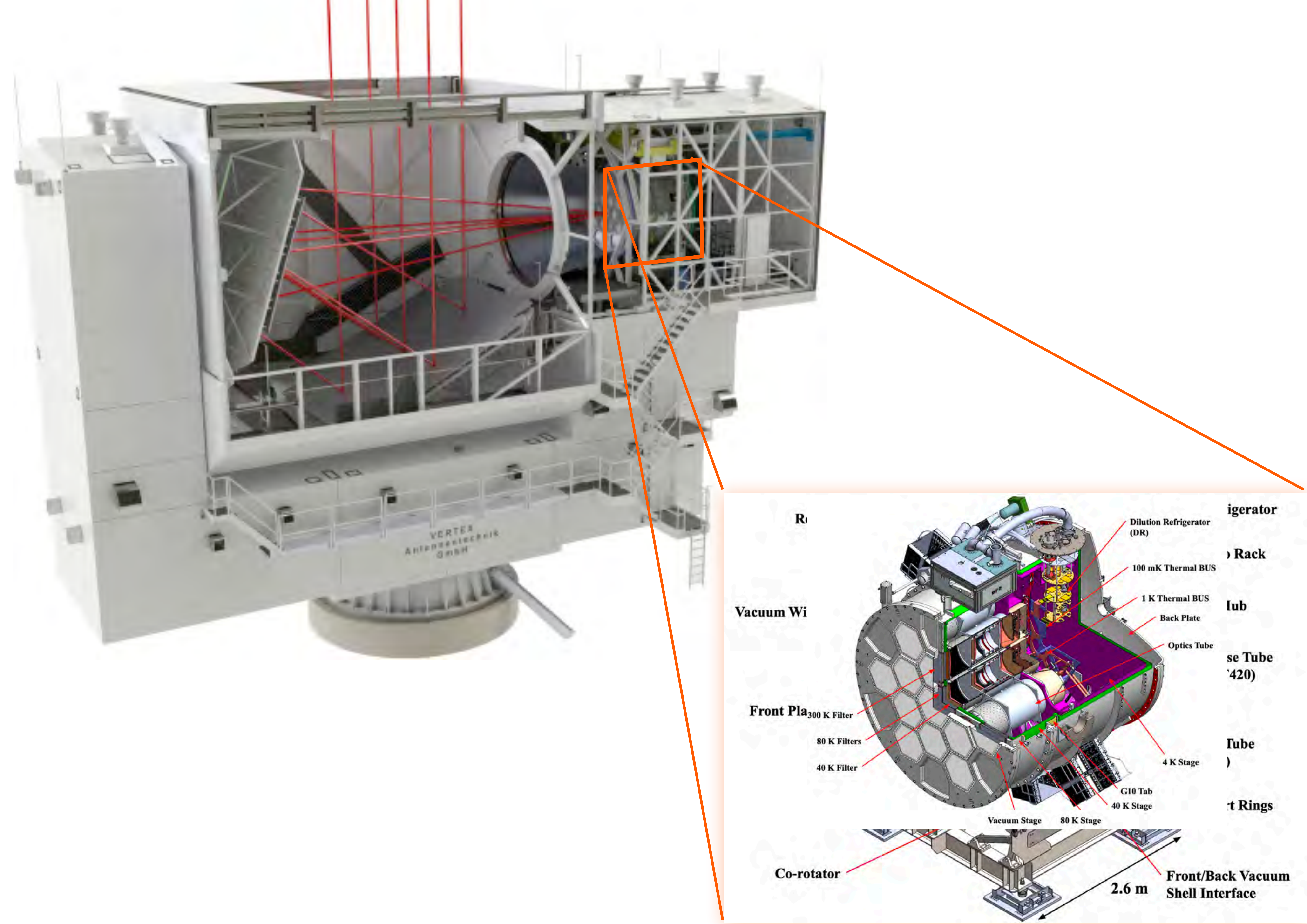
- broad coverage of angular resolutions
- high sensitivity
- exquisite control of astrophysical and instrumental systematic effects

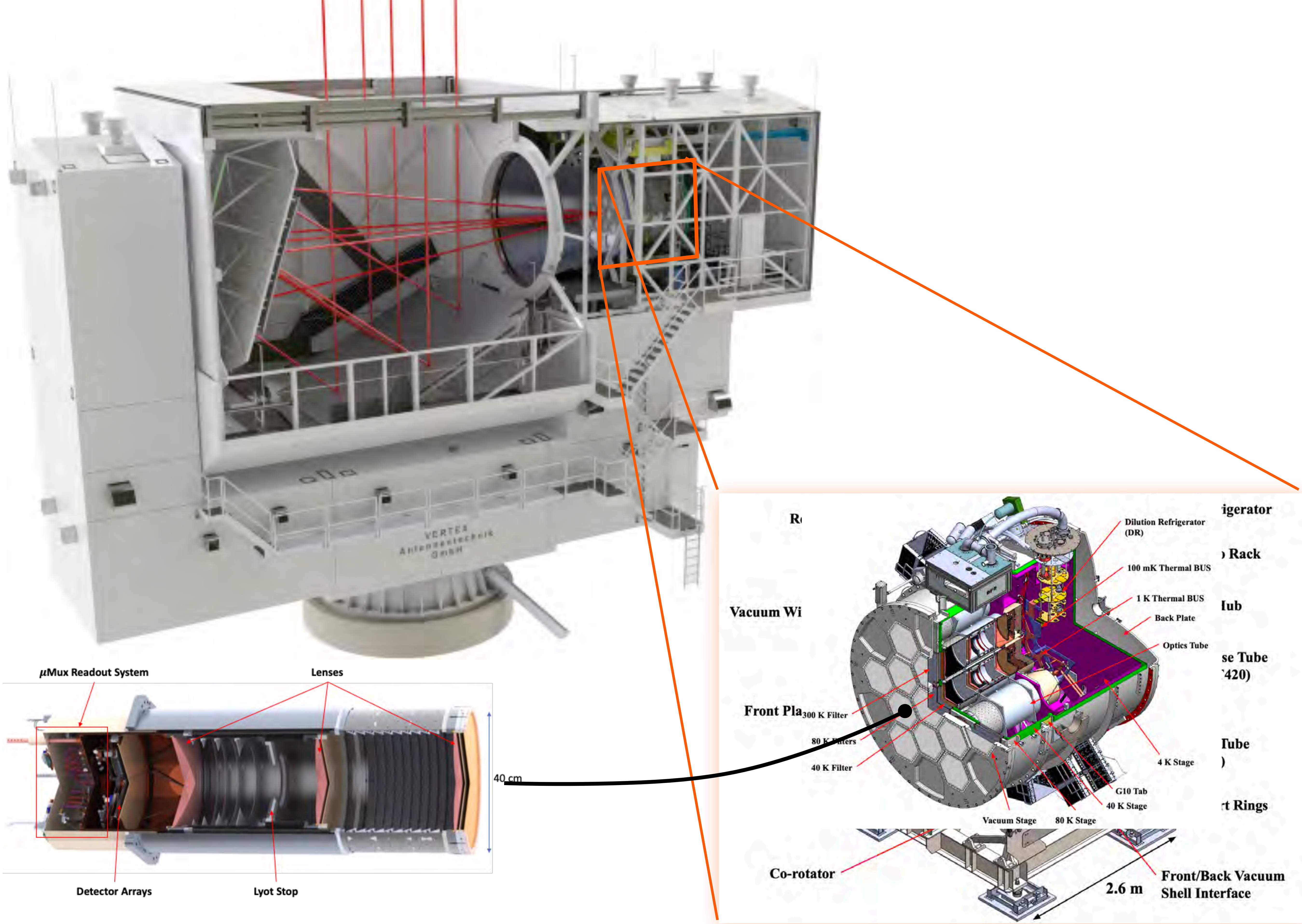
From
Peter Ade et al., JCAP02 (2019) 056
https://ui.adsabs.harvard.edu/abs/2019JCAP...02..056A/abstract


~15m
SIMONS
OBSERVATORY




Readout Crate
Dilution Refrigerator (DR)
DR Turbo Rack
Cable Hub
Vacuum Window
Pulse Tube (PT420)
Front Plate
Pulse Tube (PT90)
Support Rings
Co-rotator
Front/Back Vacuum Shell Interface
2.6 m


VERTEX
Antennentechnik
GmbH
Dilution Refrigerator
(DR)
100 mK Thermal BUS
1 K Thermal BUS
Back Plate
Optics Tube
300 K Filter
80 K Filters
40 K Filter
4 K Stage
G10 Tab
40 K Stage
Vacuum Stage
80 K Stage
Co-rotator
2.6 m
Front/Back Vacuum
Shell Interface


VERTEX
Antennentechnik
GmbH
μMux Readout System
Lenses
40 cm
Detector Arrays
Lyot Stop
Dilution Refrigerator
(DR)
100 mK Thermal BUS
1 K Thermal BUS
Back Plate
Optics Tube
300 K Filter
40 K Filter
4 K Stage
G10 Tab
40 K Stage
Vacuum Stage
80 K Stage
Vacuum Wi
Front Pla
igerator
Rack
se Tube
420)
Tube
t Rings
Co-rotator
2.6 m
Front/Back Vacuum
Shell Interface

LATR

Chile,
January
2023

LATR

Chile,
January
2023

LATR

Chile,
February
2023

LATR

Chile,
February
2023

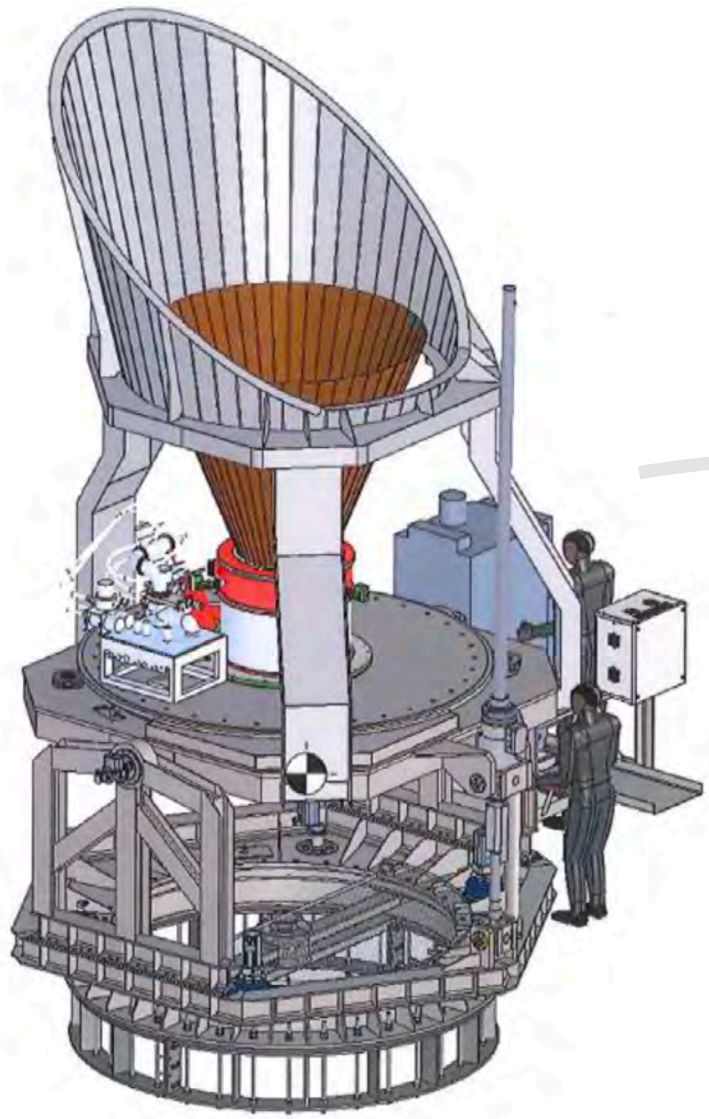
LAT in April 2023 (Chile)

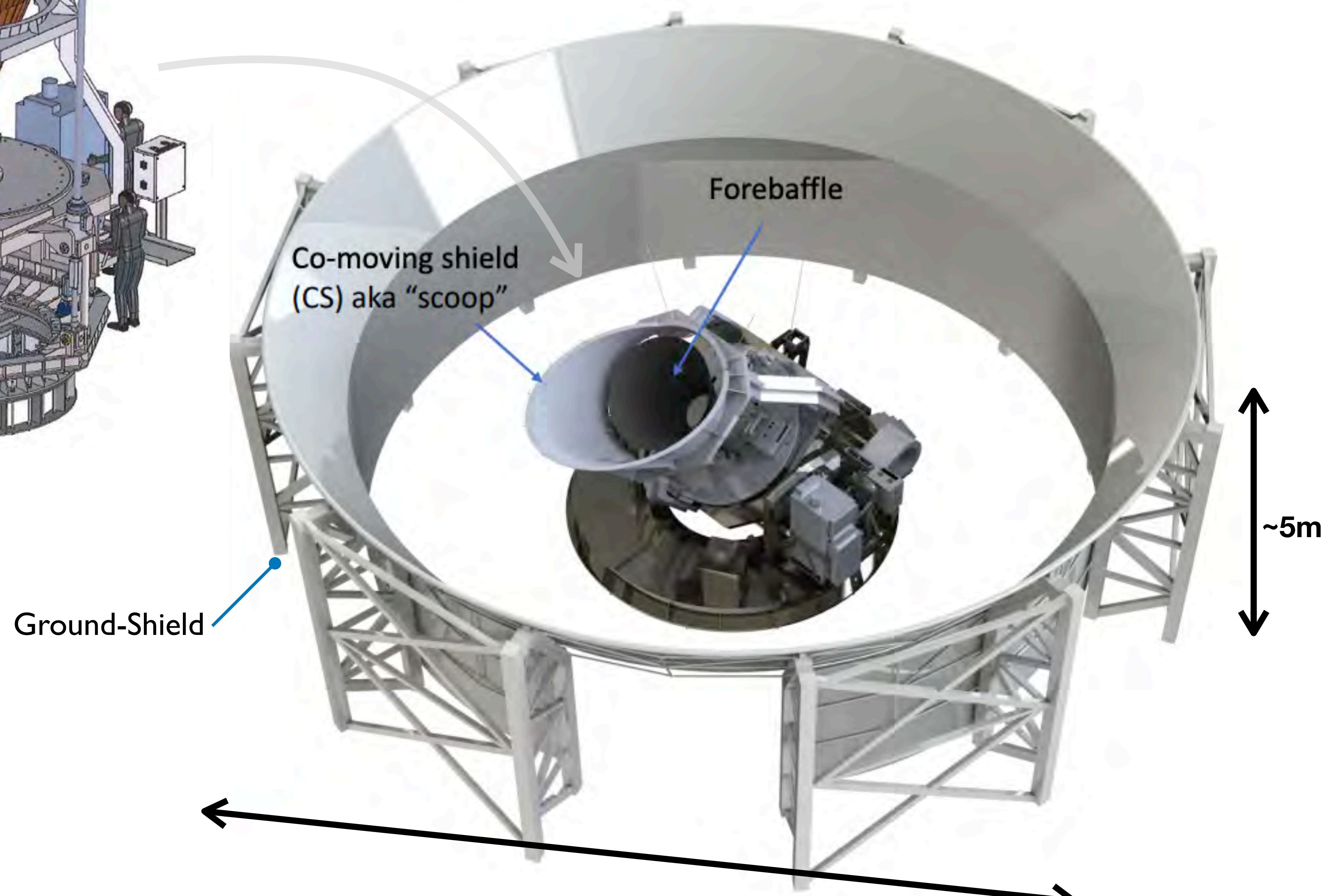
LAT in April 2023 (Chile)

LAT on 26 of June 2023 (Chile)

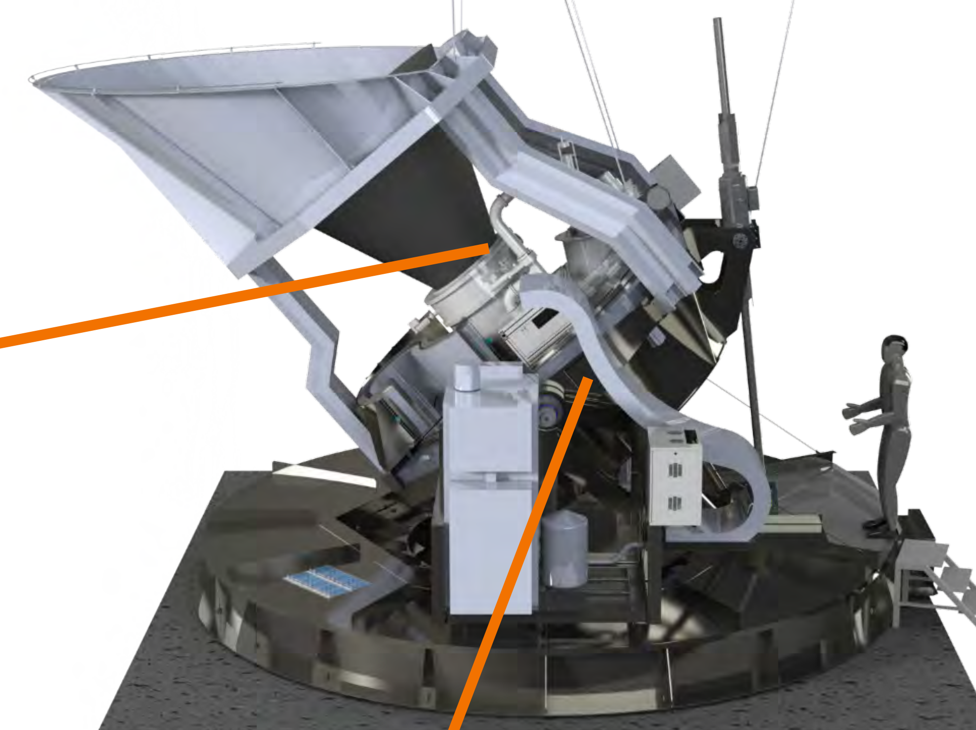
site Feb 2023 (Chile)

SO SAT

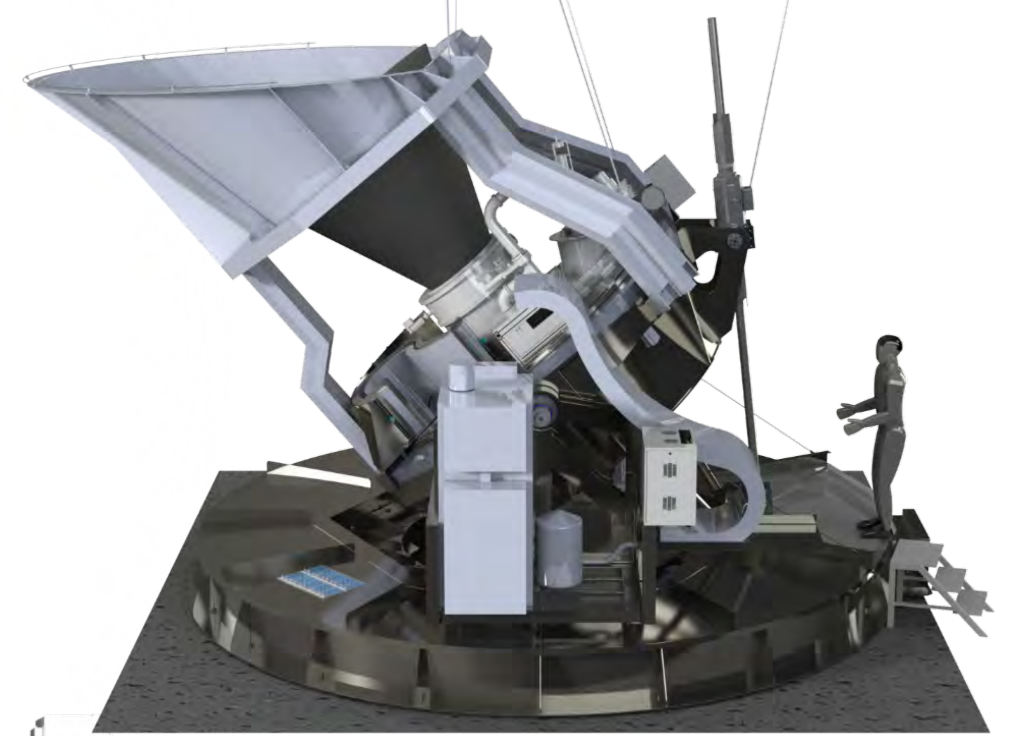


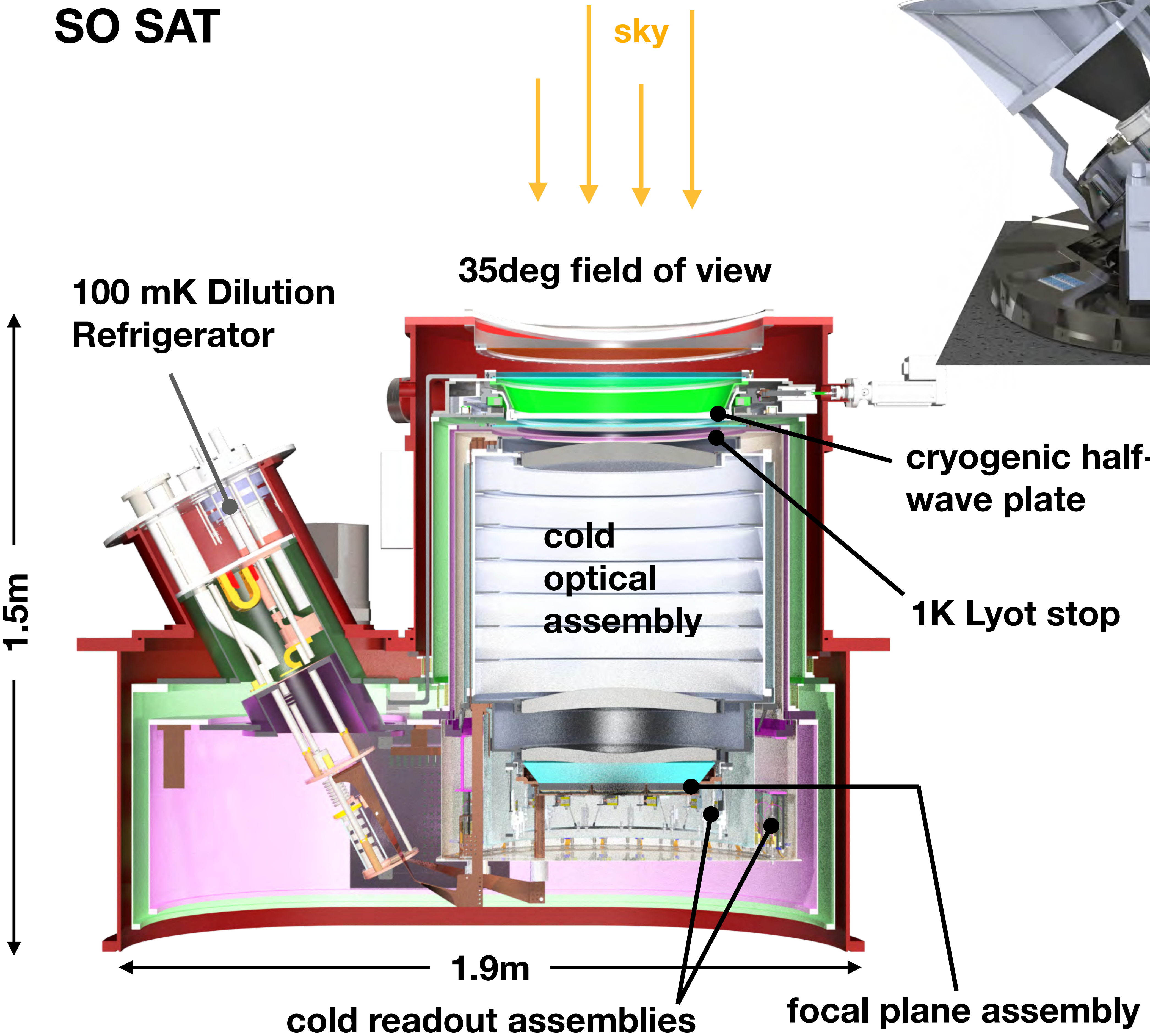

Forebaffle
Co-moving shield
(CS) aka "scoop"
Ground-Shield
~5m
~16m

SO SAT



SO SAT




sky
35deg field of view
100 mK Dilution Refrigerator
cryogenic half-wave plate
1K Lyot stop
cold optical assembly
1.5m
1.9m
cold readout assemblies
focal plane assembly
~ 10.000 bolometers

credits: Simons Observatory
April 2023

credits: Simons Observatory
April 2023

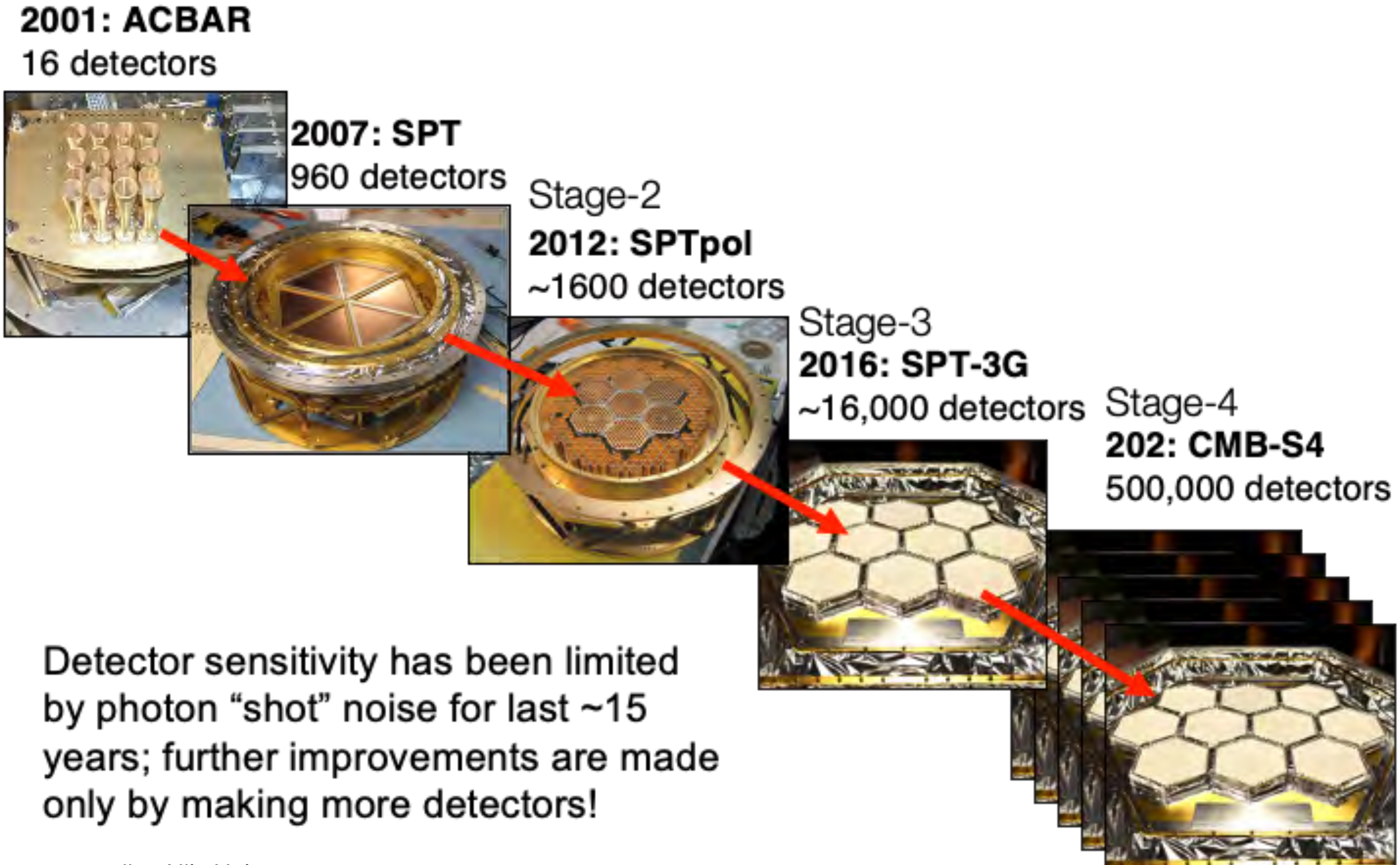
SO SAT

April 2023
Credit: Dave Boettger

SO SAT

credits: Simons Observatory
June 2023

SO sensitivity

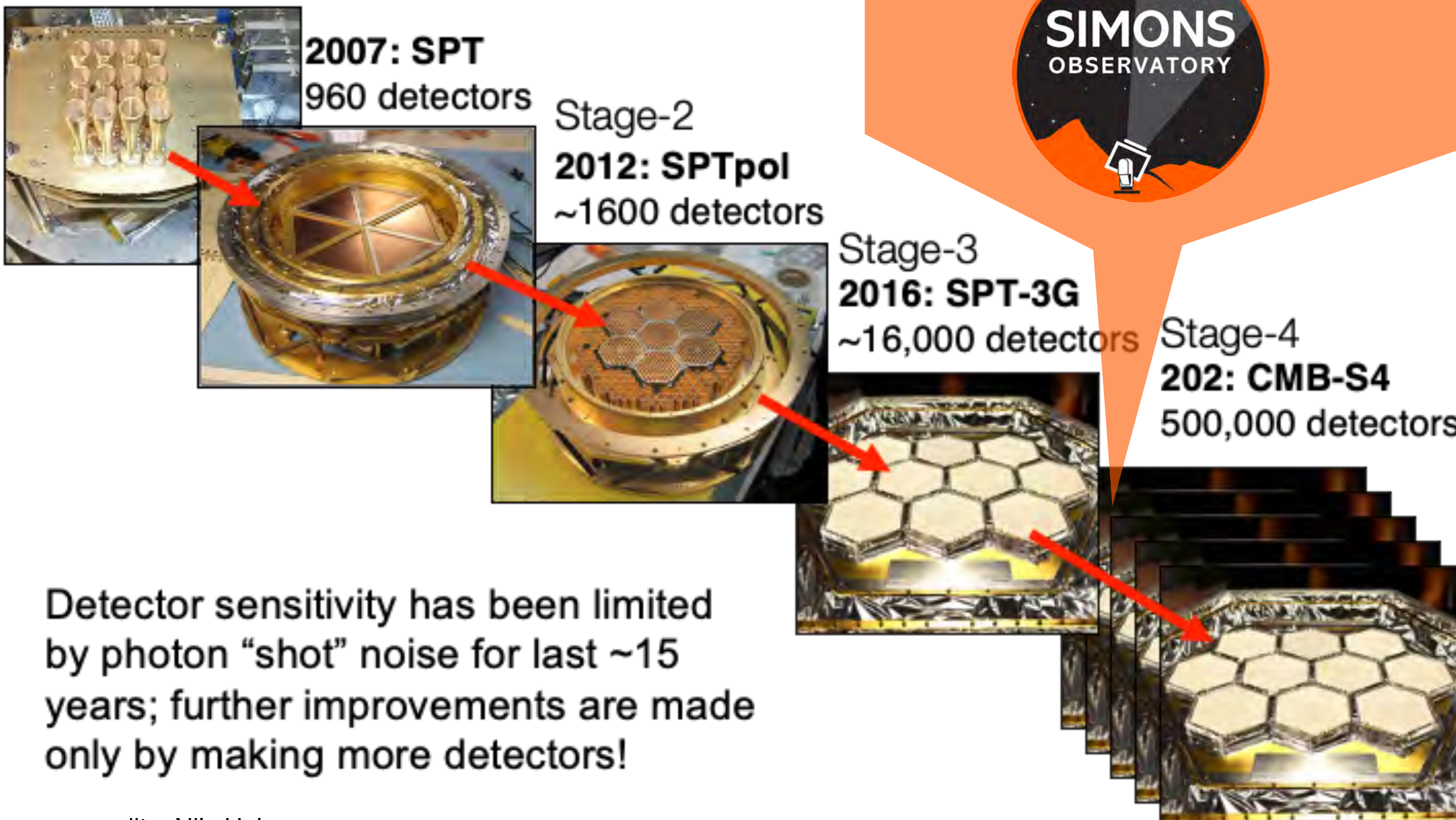


Detector sensitivity has been limited by photon “shot” noise for last ~15 years; further improvements are made only by making more detectors!

credits: Nils Halverson

SO sensitivity

- 2024: 60,000 detectors
- 2028: 120,000 detectors



Detector sensitivity has been limited by photon "shot" noise for last ~15 years; further improvements are made only by making more detectors!

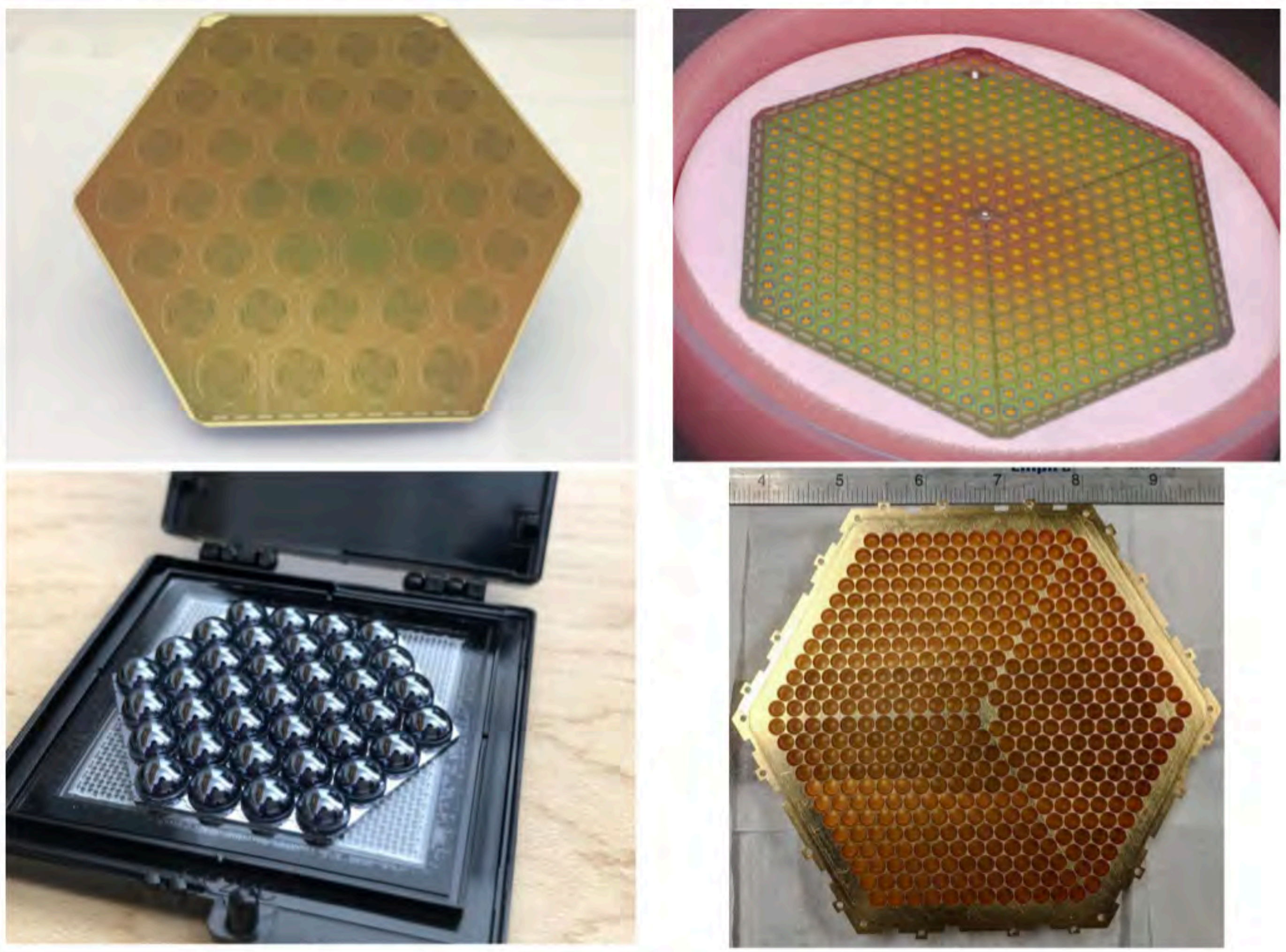
credits: Nils Halverson

SO sensitivity

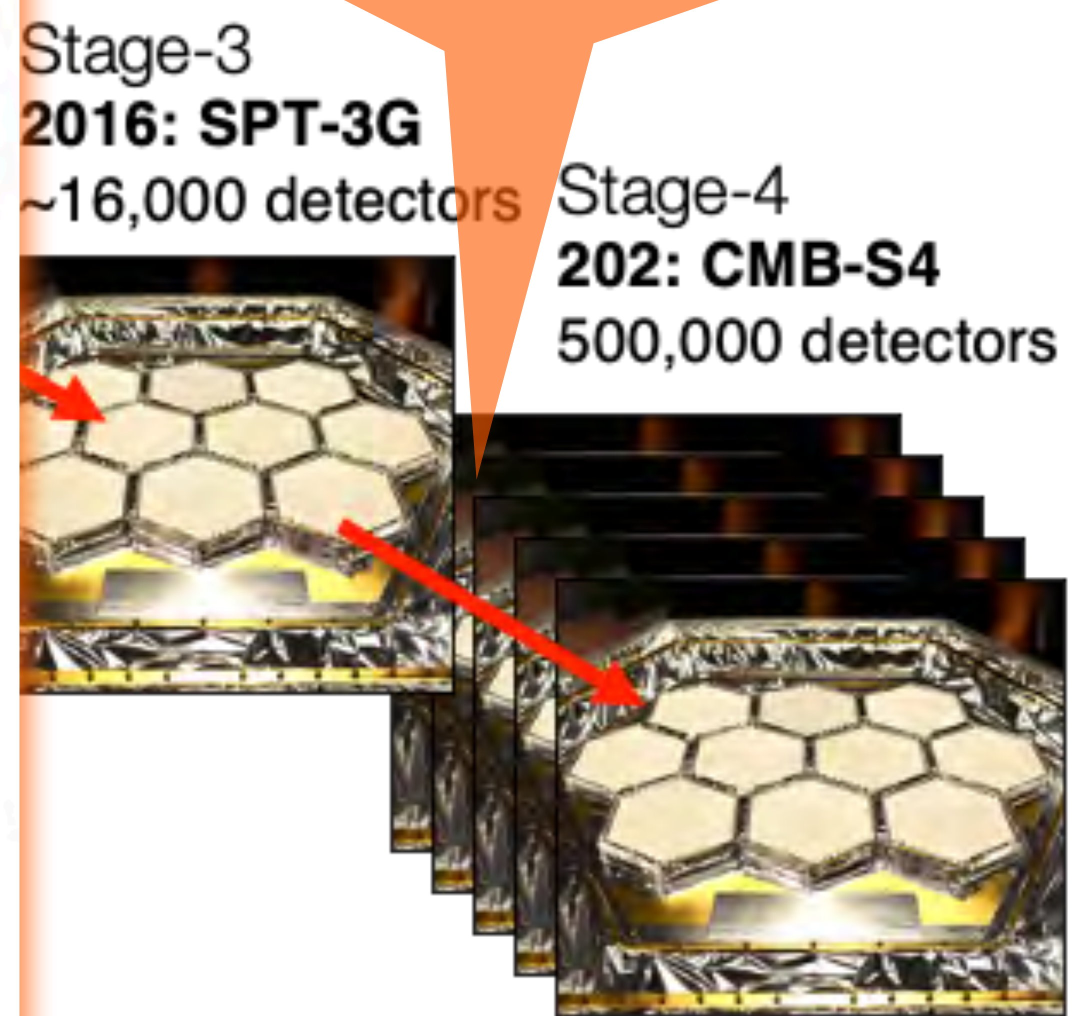
- **2024: 60,000 detectors**
- **2028: 120,000 detectors**

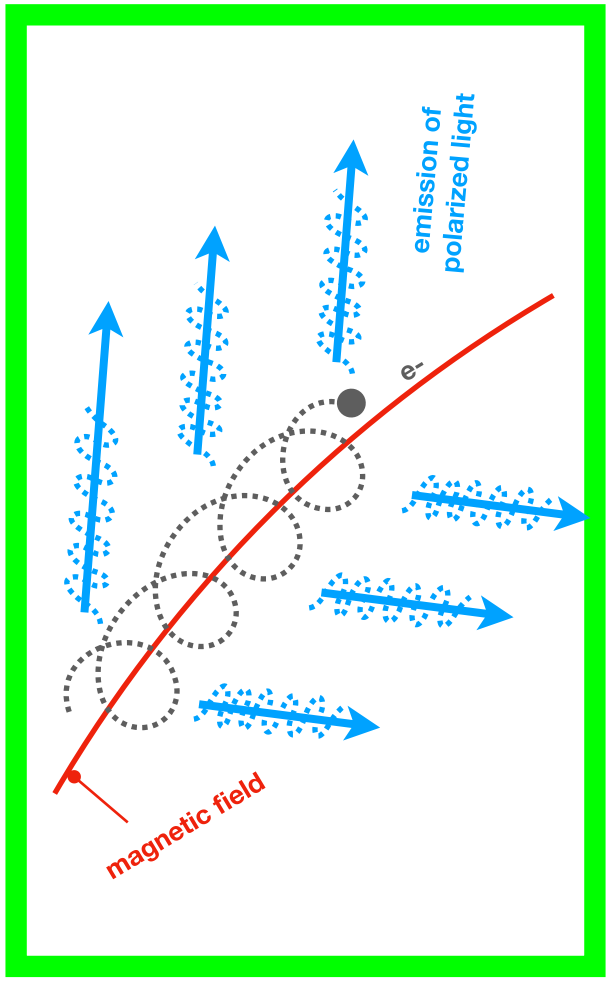
Low frequency (LF) detector arrays & lenslets

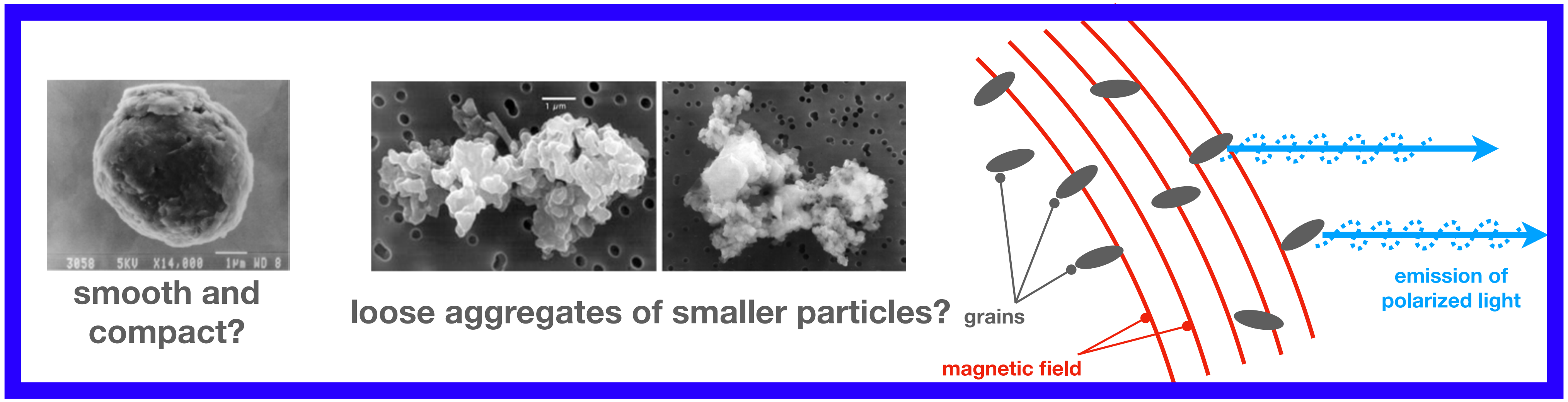
Mid frequency (MF) and ultra-high frequency (UHF) detector & horn arrays



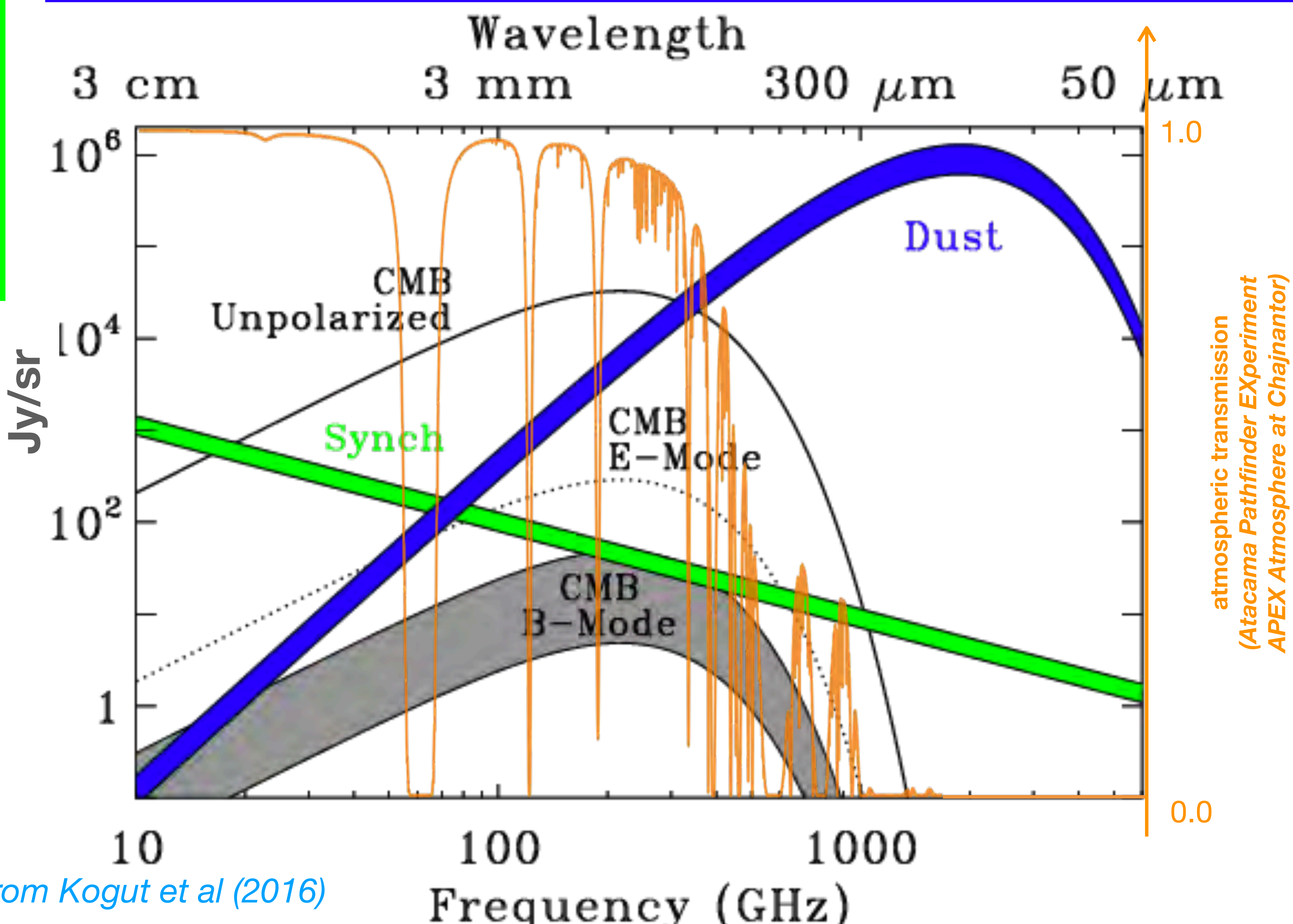
SO will use dual-polarization. dichroic TES bolometer detectors. cooled to 100 mK. The LF detector arrays build on the proven performance of POLARBEAR and the MF and UHF on ACT.



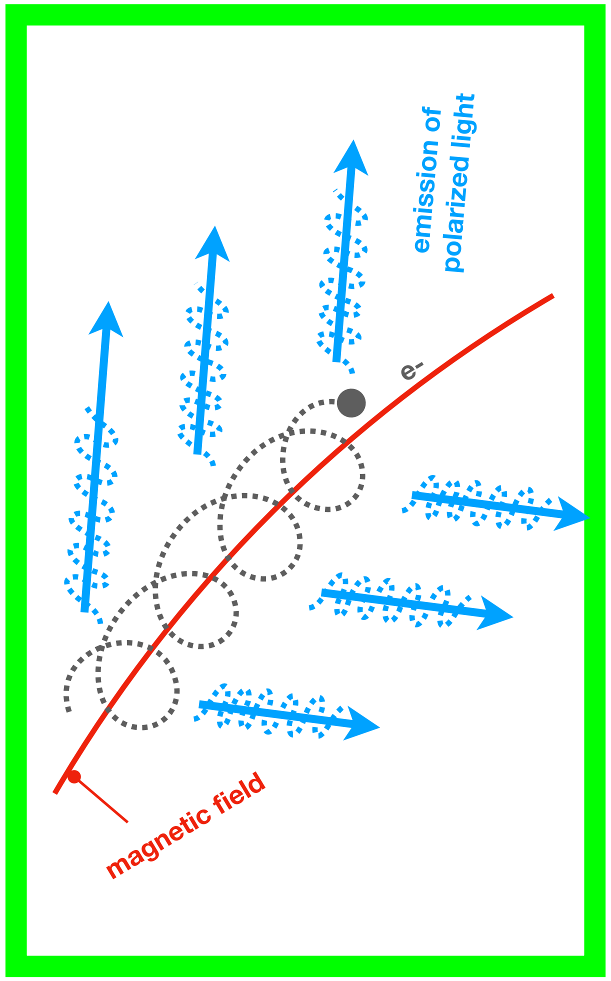


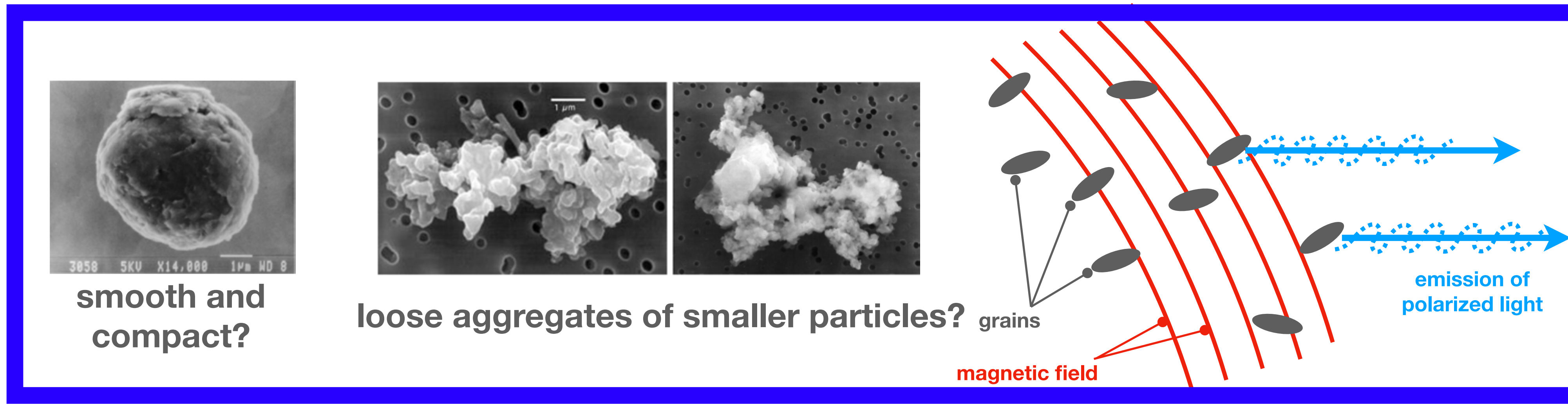


SO observed frequencies



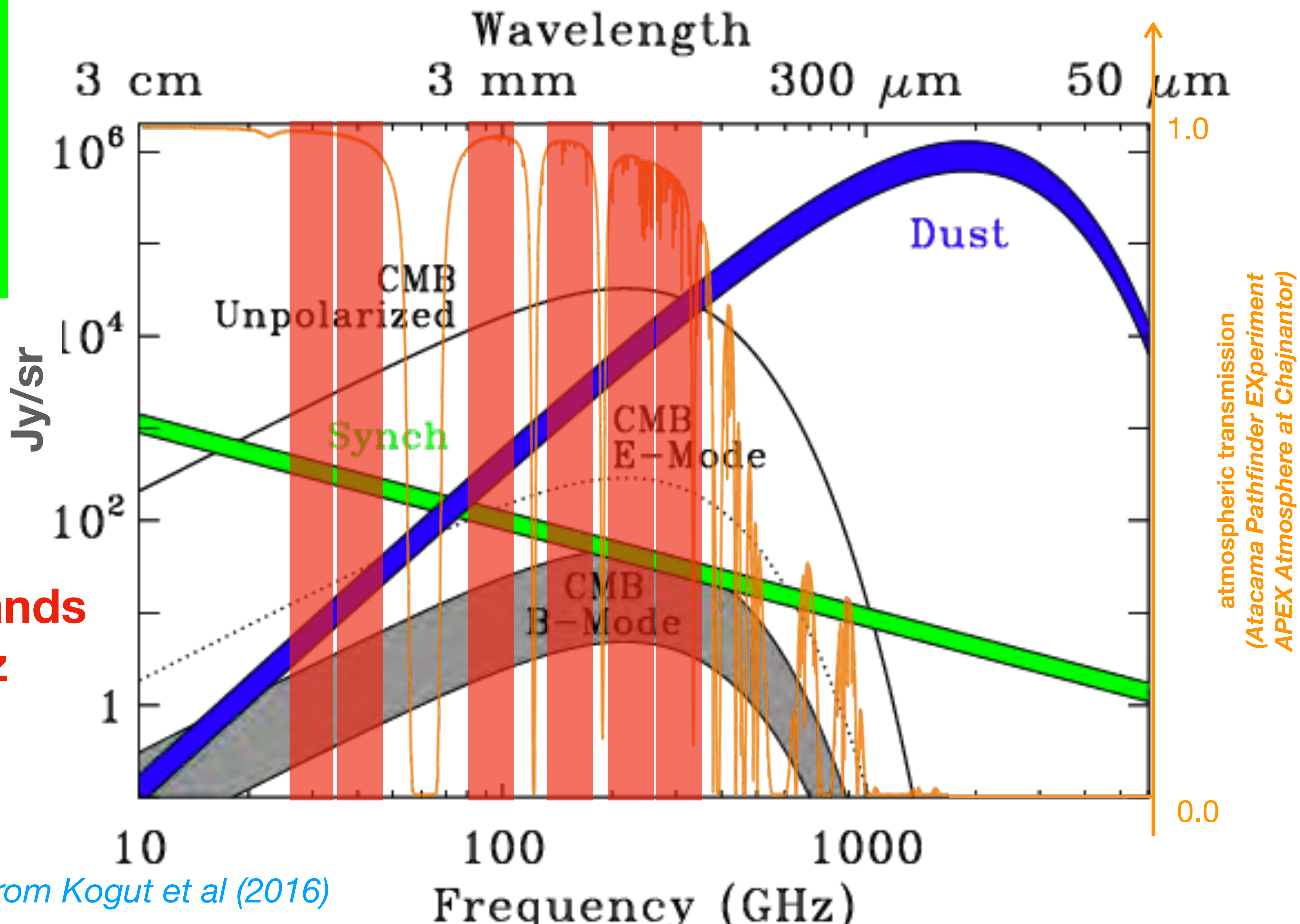
adapted from Kogut et al (2016)





SO observed frequencies

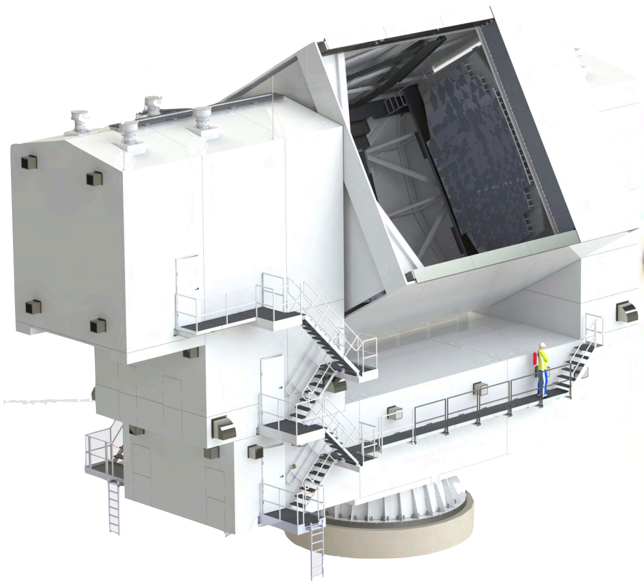
6 frequency bands 27-270 GHz

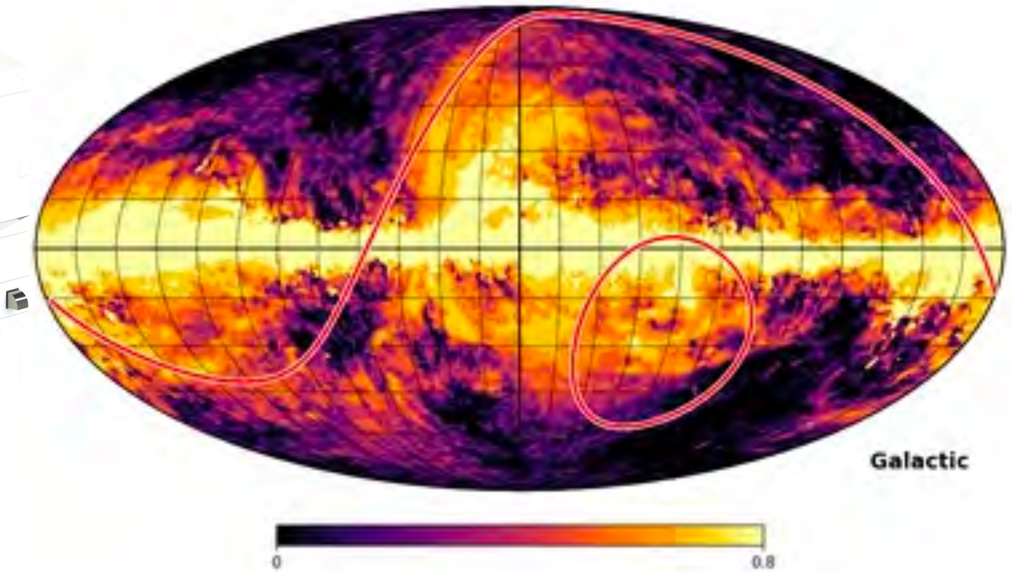


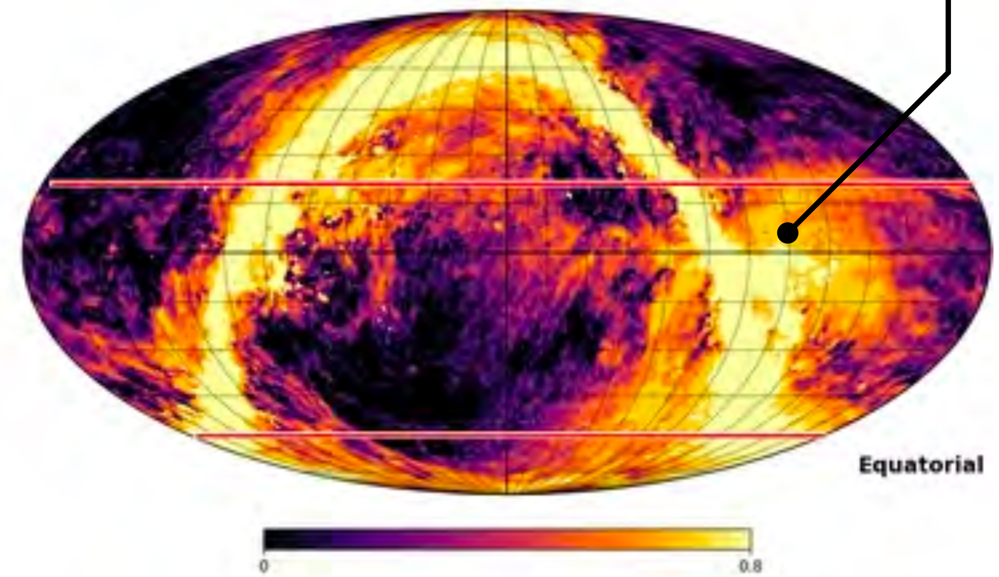
adapted from Kogut et al (2016)

SO observed sky areas

VERA C. RUBIN
OBSERVATORY

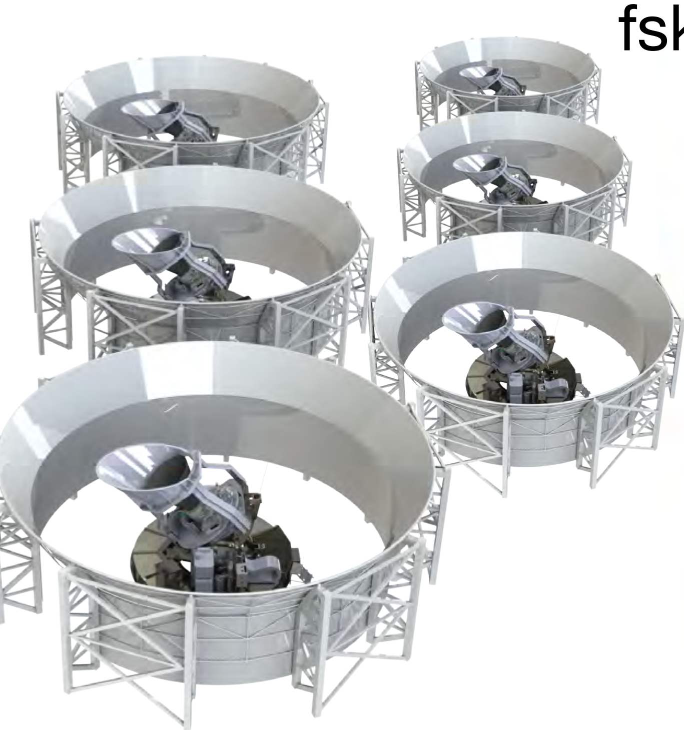


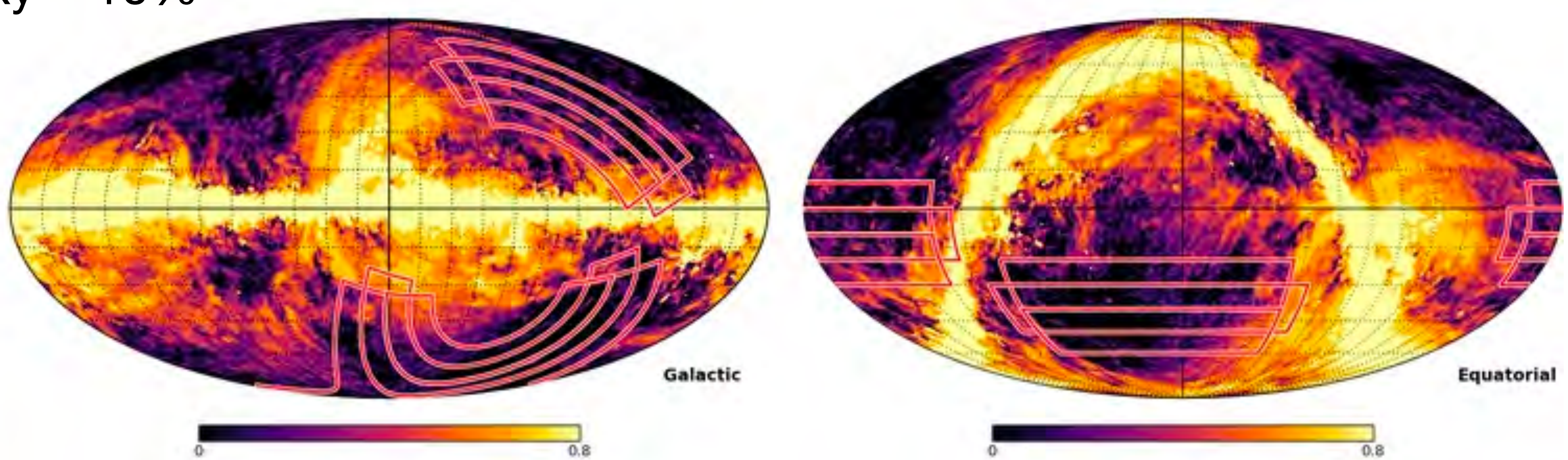




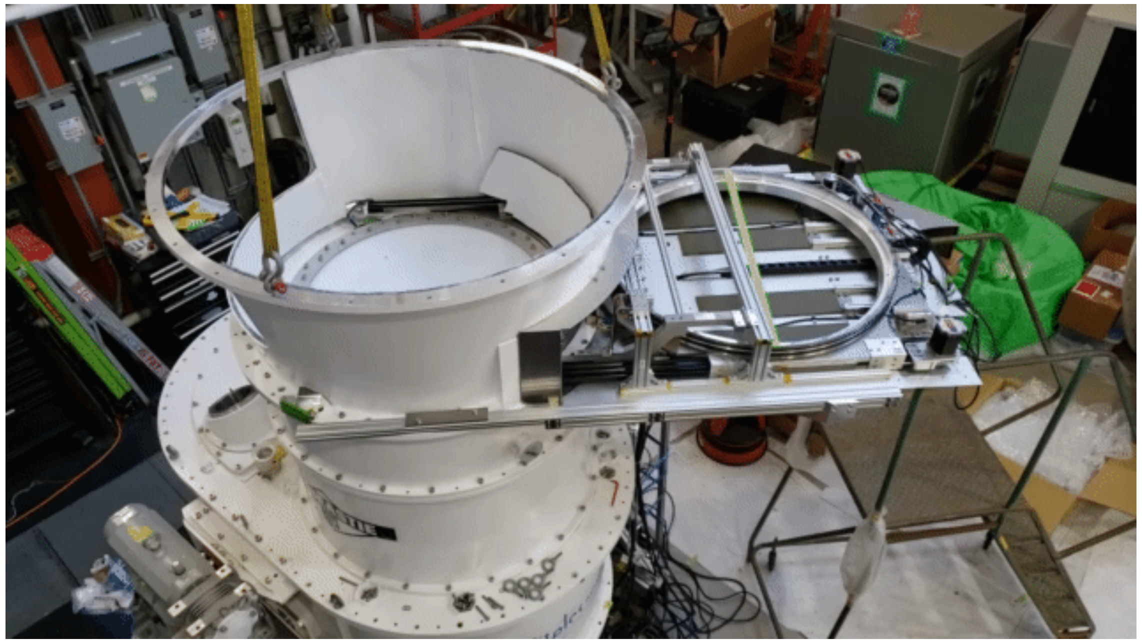
fsky ~ 40%

fsky ~ 10%



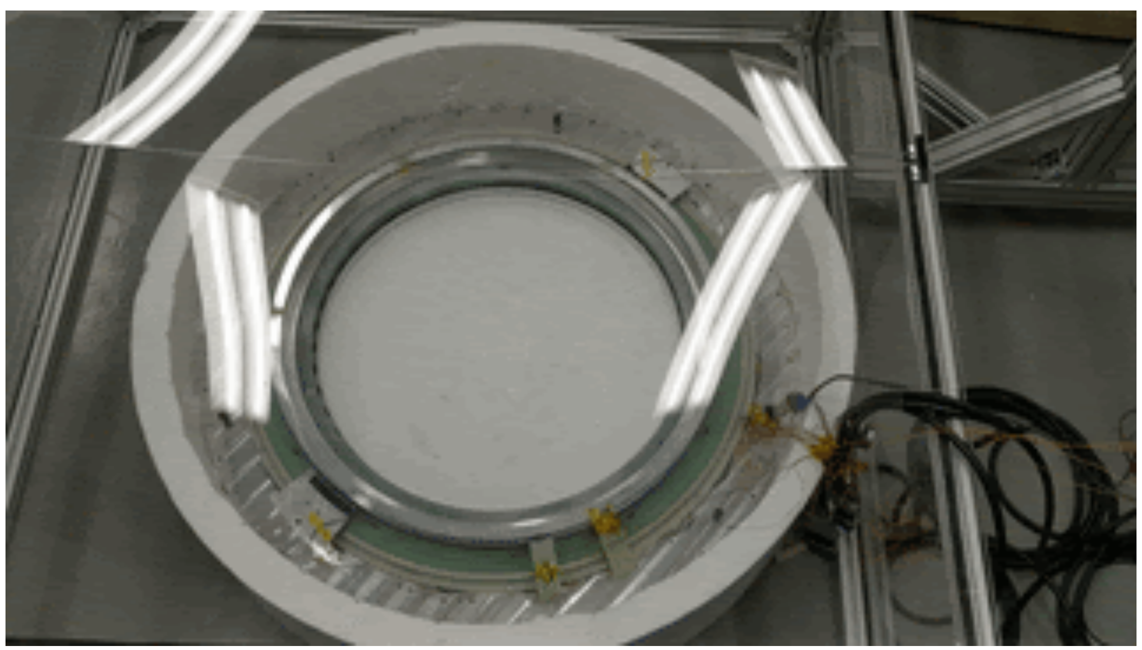


control of instrumental systematics effects: examples



credits: H. Nakata

Polarization grid for relative and absolute polarization angle calibration



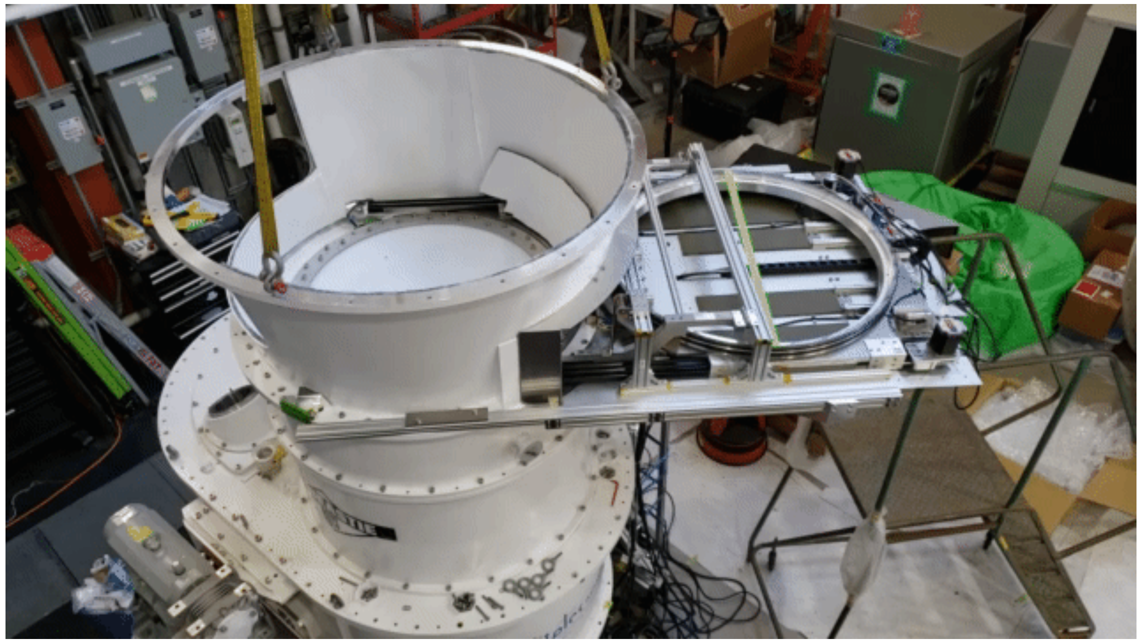
credits: J. Sugiyama

Cryogenic Rotative Half Wave Plate

credits: T. Matsumura

Assembly of Baffles

control of instrumental systematics effects: examples



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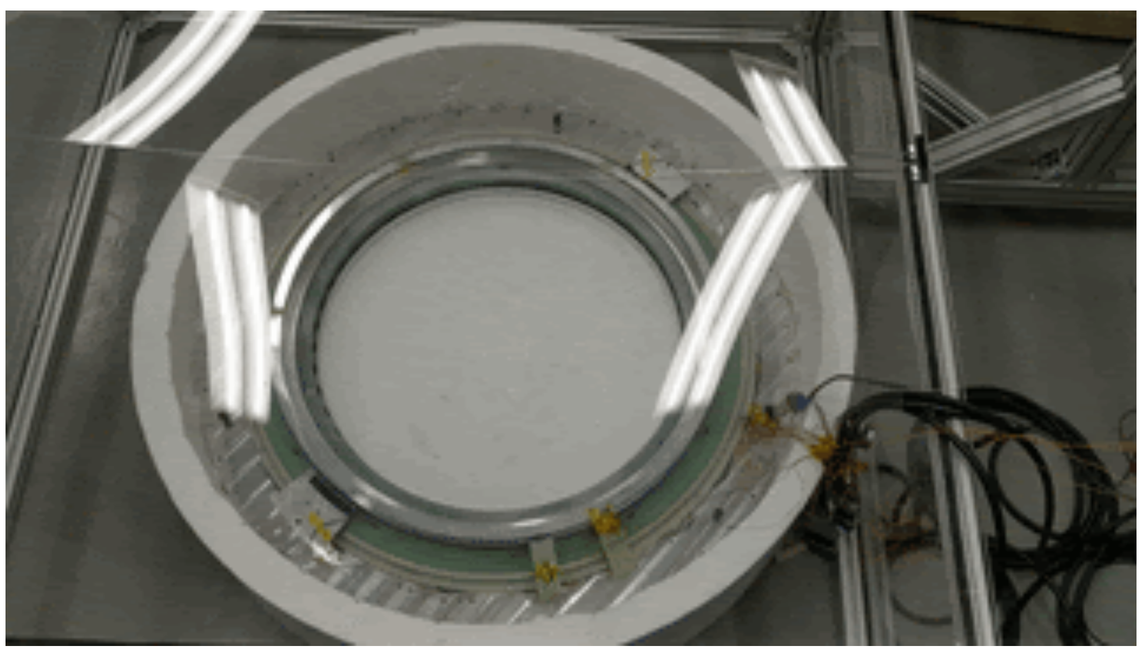
Polarization grid for relative and absolute polarization angle calibration



credits: J. Sugiyama

Cryogenic Rotative Half Wave Plate

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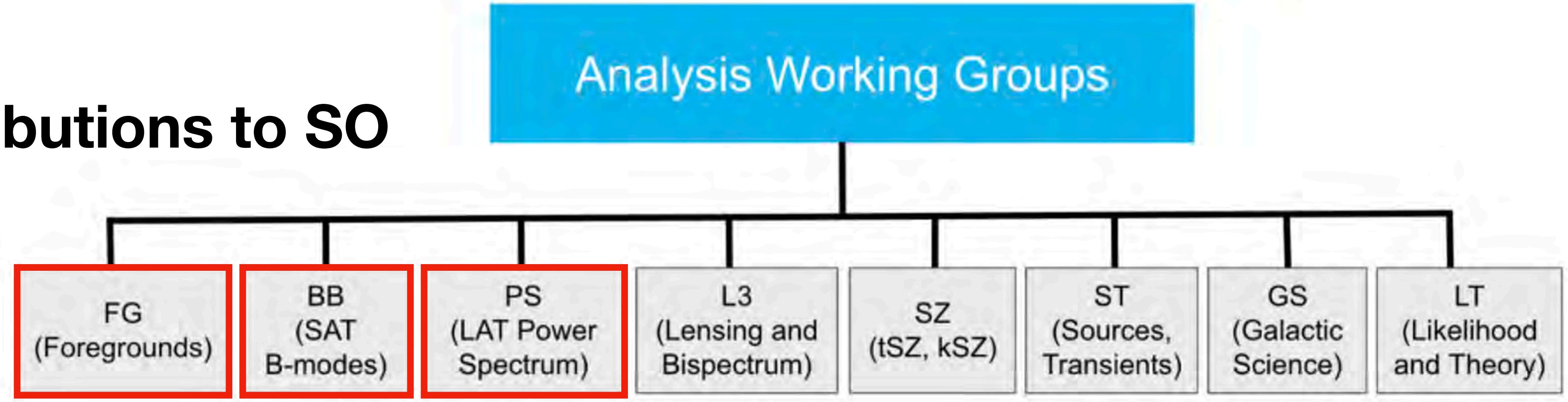
Assembly of Baffles

control of instrumental systematics effects: examples

Current IN2P3 contributions to SO

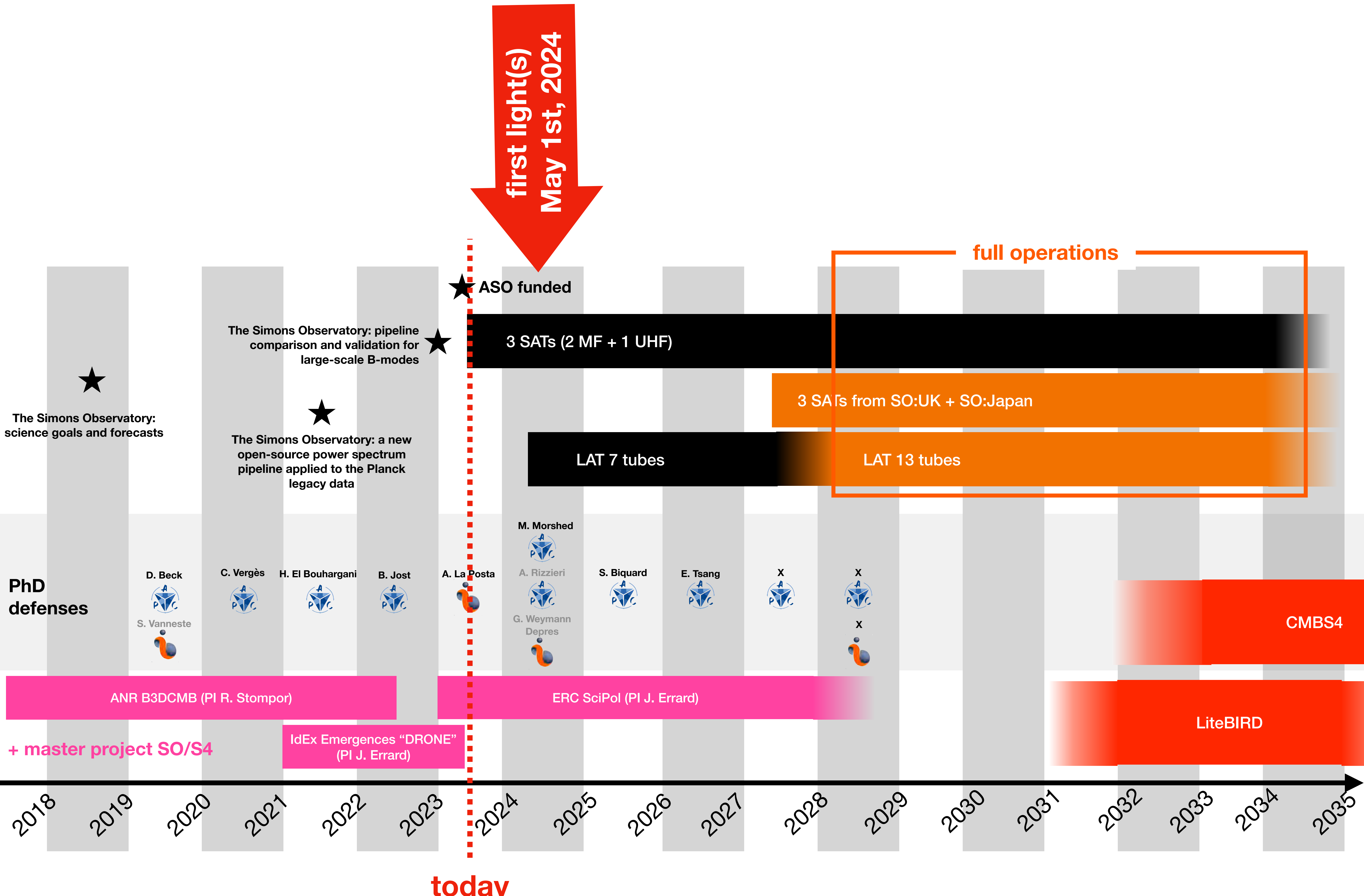


- co-leading the **PS Analysis Working Group** (Thibaut Louis)
- co-leading the **BB Analysis Working Group** (Josquin Errard)
- co-leading the **FG Analysis Working Group** (Benjamin Beringue, joining on Nov 1st)
- member of the Talk Panel (Ken Ganga)
- also members of the Calibration&Systematics group, TOD2MAP, FirstLightAnalysis, SZ, Galactic Science, etc.
- participation to the calibration campaigns and data analysis with the drone (APC supplied the high frequency source)

F2F, hackathons, exchanges with the US, Japan and Chile, weekly telecons, pipeline development (github.com/simonsobs), etc.

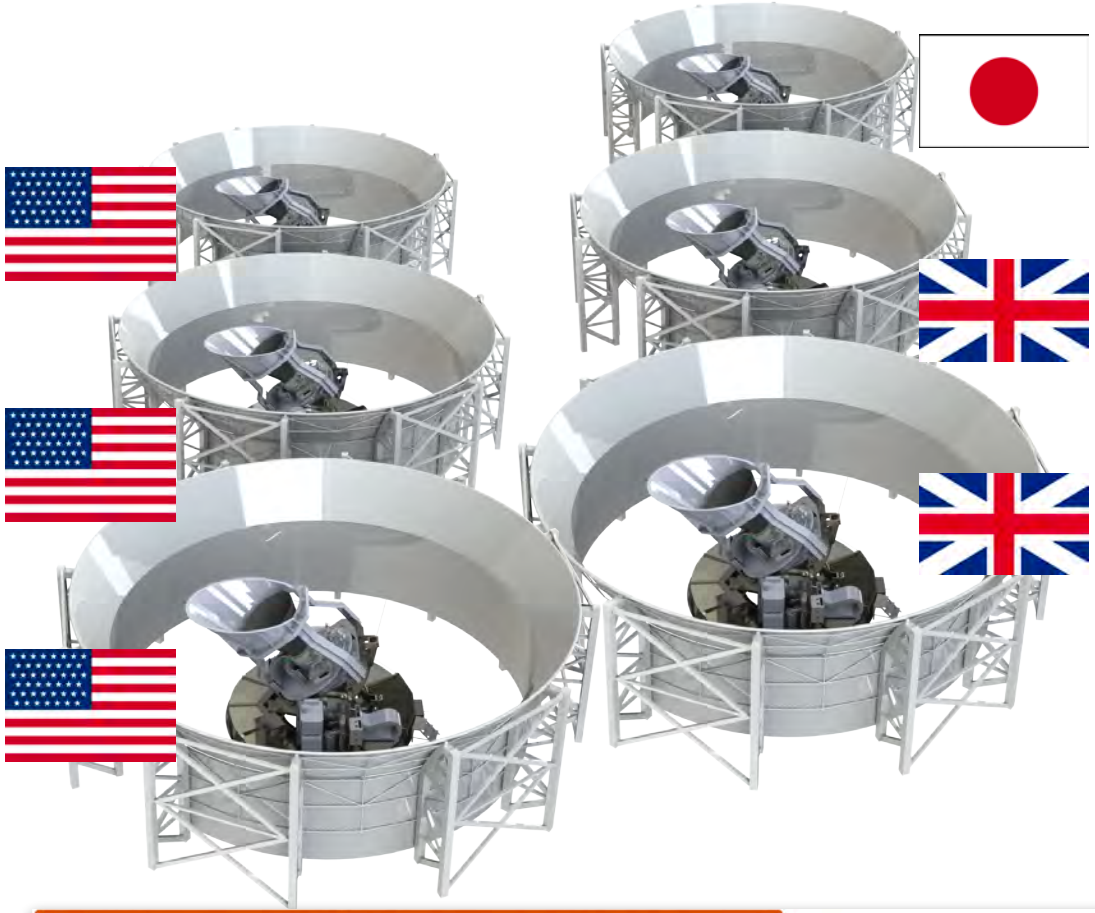
[1] P. Ade et al., The Simons Observatory Collaboration, The Simons Observatory: science goals and forecasts, 2019, 056 (2019), arXiv:1808.07445 [astro-ph.CO].
[2] C. Vergès, J. Errard, and R. Stompor, Framework for analysis of next generation, polarized CMB data sets in the presence of Galactic foregrounds and systematic effects, Phys. Rev. D 103, 063507 (2021), arXiv:2009.07814
[3] M. H. Abitbol, et al., Simons Observatory: gain, bandpass and polarization-angle calibration requirements for B-mode searches, 2021, 032 (2021), arXiv:2011.02449.
[4] T. Louis et al., Fast computation of angular power spectra and covariances of high-resolution cosmic microwave background maps using the Toeplitz approximation, Phys. Rev. D 102, 123538 (2020), arXiv:2010.14344.
[5] Z. Li, T. Louis et al., The Simons Observatory: a new open-source power spectrum pipeline applied to the Planck legacy data, arXiv e-prints , arXiv:2112.13839 (2021),
[6] A. La Posta et al., Assessing the consistency between CMB temperature and polarization measurements with application to Planck, ACT, and SPT data, Phys. Rev. D 107, 023510 (2023), arXiv:2204.01885.
[7] J. T. Ward et al., The Effects of Bandpass Variations on Foreground Removal Forecasts for Future CMB Experiments, Astrophys. J. 861, 82 (2018), arXiv:1803.07630
[8] D. Beck, J. Errard, and R. Stompor, Impact of polarized galactic foreground emission on CMB lensing reconstruction and delensing of B-modes, 2020, 030 (2020), arXiv:2001.02641.
[9] H. El Bouhargani et al., MAPPRAISER: A massively parallel map-making framework for multi-kilo pixel CMB experiments, Astronomy and Computing 39, 100576 (2022), arXiv:2112.03370.
[10] B. Jost, J. Errard and R. Stompor, Characterising cosmic birefringence in the presence of galactic foregrounds and instrumental systematic effects, arXiv:2212.08007 (2022).
[11] K. Wolz et al.: The Simons Observatory: pipeline comparison and validation for large-scale B-modes, arXiv:2302.04276 (2023).
[12] S. Azzoni et al., A hybrid map-C_ℓ component separation method for primordial CMB B-mode searches, 2023, 035 (2023), arXiv:2210.14838.
[13] B. S. Hensley et al., The Simons Observatory: Galactic Science Goals and Forecasts, Astrophys. J. 929, 166 (2022), arXiv:2111.02425.

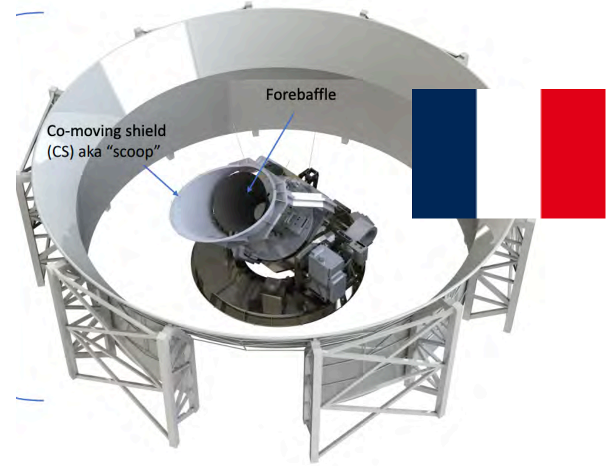
Global timescale for the Simons Observatory



SO funding

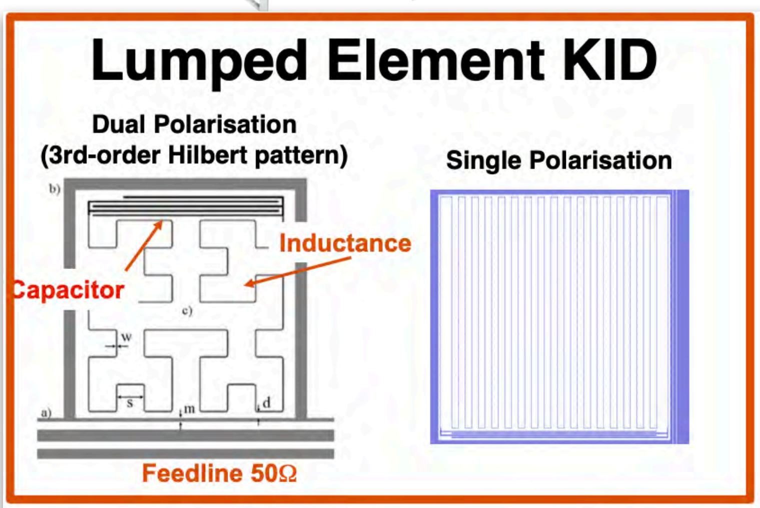
	SIMONS FOUNDATION, HEISING-SIMONS FOUNDATION	**~$70M**
	the **founding universities** (University of Pennsylvania, Princeton University, UC San Diego, UC Berkeley, the LBNL)	**~$70M**
NSF	➔ advanced SO (30,000 extra detectors, solar panels. etc.)	**$52.7M**
	SO:UK from the UK Research and Innovation Infrastructure Funds ➔ 2 extra SATs	**$20M**
	SO:JP ➔ 1 extra SAT	**$3.5M**
cnrs	master project IN2P3 SO/S4 researcher salaries (FTE x 120k€/year)	**20k€/year** **720k€/year (7.2M€/10 years)**
erc European Research Council Established by the European Commission	ERC SciPol (PI J.Errard). 2M€. 2023-2028	**2M€ (2023-2028)**
cnrs	➔ 1 extra SAT ?	ARR ~ O(5M€)?





we are preparing a document for the upcoming ARR call

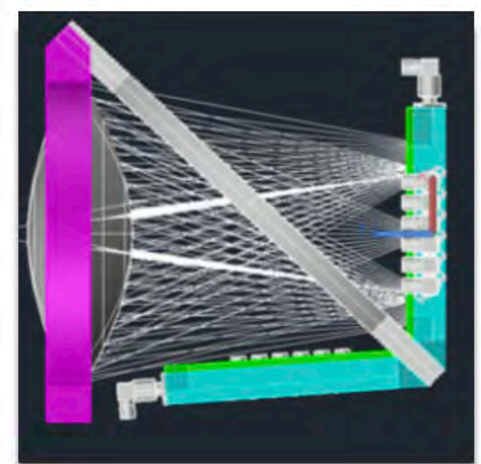
Our proposition is to **add a whole SAT infrastructure** to the existing ones (3 US + 2 UK + 1 Japan) putting **LEKID technology** on it. The platform pointing control and the 300K screen should remain the same wrt US/UK ones. Inside the cryostat we are going to optimise things for KIDs.

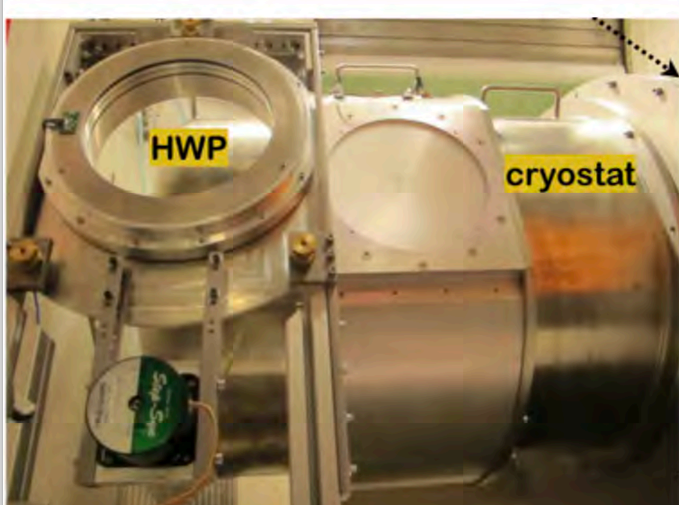


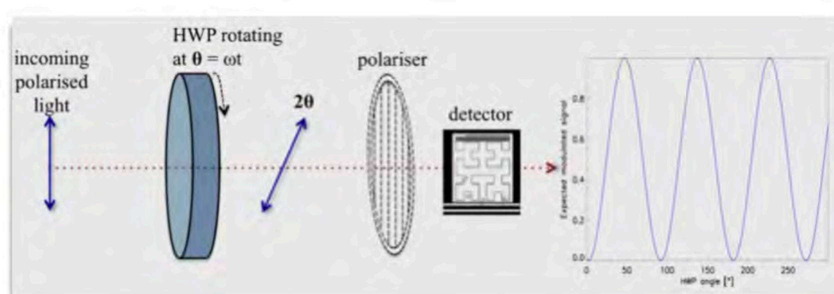
from Andrea Catalano

Filled arrays LEKID:

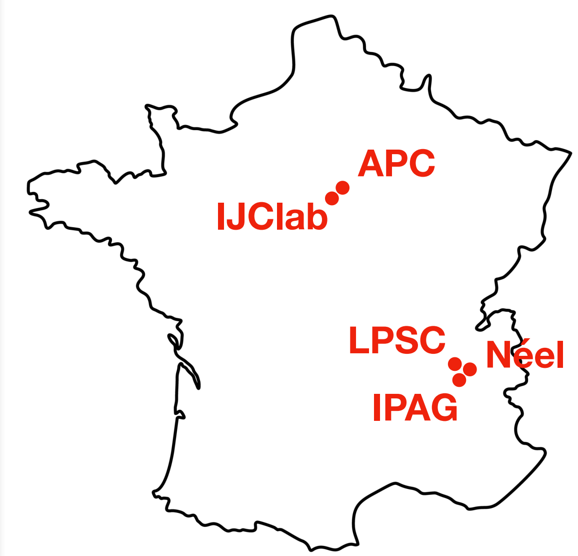
- **Large filling factor**
- **Very high quantum efficiency in a 30% mm-band**
- **Easy to fabricate**







Continuous Rotation of an HWP permits quasi-simultaneous Observations of I,Q,U Stokes parameters



preliminary discussions with O(15) researchers

SO France: human ressources

		2022	2023	2024	2025
Jim Bartlett	Prof. U Paris	0.15	0.15	0.15	0.15
Benjamin Beringue	postdoc (Nov 1. 2023)		0.10	0.70	0.70
Simon Biquard	PhD 2	0.50	0.50	0.40	0.40
Pierre Chanial	IR CDD		0.60	0.60	0.60
Josquin Errard	CR	0.50	0.60	0.60	0.60
Ken Ganga	DR	0.50	0.50	0.50	0.50
Xavier Garrido	MdC U. Paris Saclay	0.30	0.30	0.30	0.30
Baptiste Jost	PhD	0.45			
Adrien La Posta	PhD 3	0.75	0.75		
Thibaut Louis	CR	0.70	0.70	0.70	0.70
Magdy Morshed	PhD 3	0.60	0.60	0.60	
Jean-Baptiste Melin	CEA. associé APC	0.10	0.10	0.15	0.15
Radek Stompor	DR. associé APC	0.20	0.20	0.20	0.20
Ema Tsang	PhD 1		0.75	0.75	0.75
ERC SciPol	postdoc (Fall 2024)			0.35	0.70
ERC SciPol	PhD (Fall 2024)			0.35	0.70
ERC SciPol	postdoc (Fall 2025)				0.35
Doctorant IJClab	PhD				0.75
permanents		**7**	**7**	**7**	**7**
non-permanents		**4**	**6**	**7**	**8**
FTE		**4.75**	**5.85**	**6.35**	**7.55**
FTE Permanents		**2.45**	**2.55**	**2.60**	**2.60**
FTE Non-permanents		**2.30**	**3.30**	**3.75**	**4.95**

SO France

Successful impact through the international funding of Centre Pierre Binétruy (UC Berkeley) PhD students such as Baptiste Jost, Magdy Morshed.

We started a discussion among the SO:France team members in order to improve the visibility and promotion of the SO project in front of IN2P3, with the possibility of creating a new, dedicated master project.
As a short term development, we would like to propose the **renaming of the current CMB-S4 master project** for something like CMB-SO>S4, in order to avoid confusions between the master project and its dependencies (SO and CMB-S4 projects).

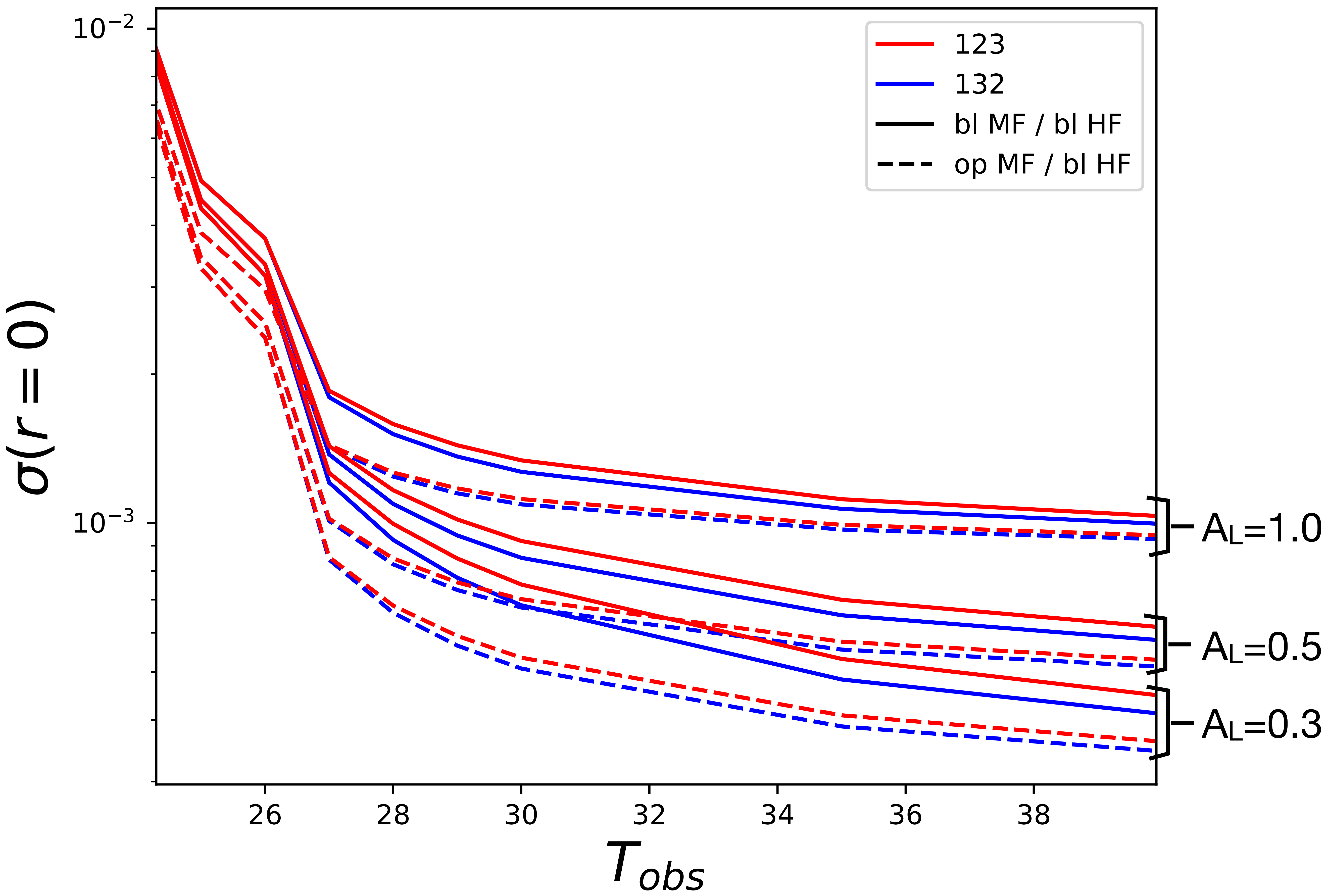
Creation of **engineer and research positions** would be crucial to keep the expertise and motivation of the students who have joined the project

Continuous support from the institute to make **computation solutions** (CCIN2P3, e.g. IDRIS/Jean Zay) durable would be important.

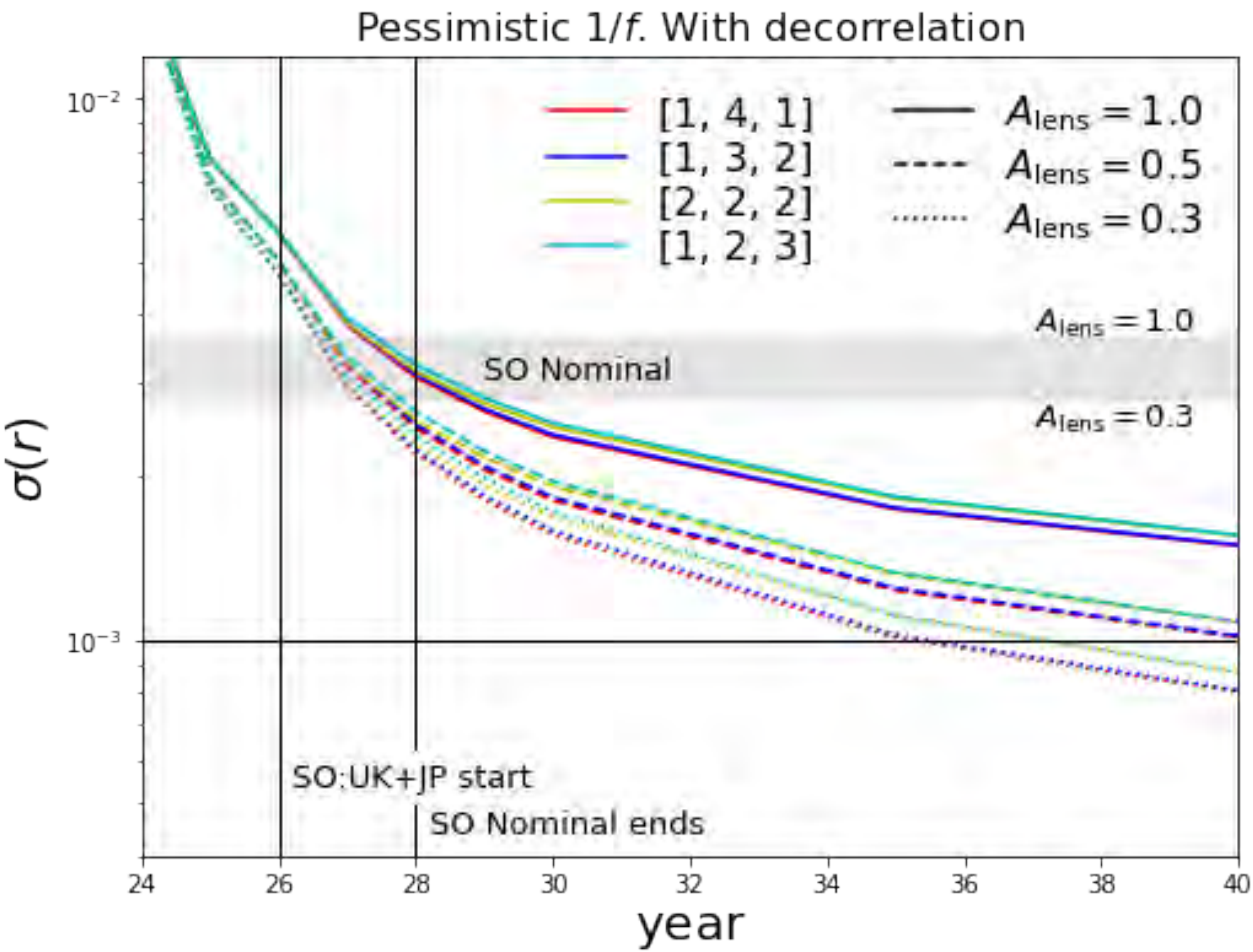
Support of the SO:France's SAT project for our upcoming application to the ARR call

BACKUP

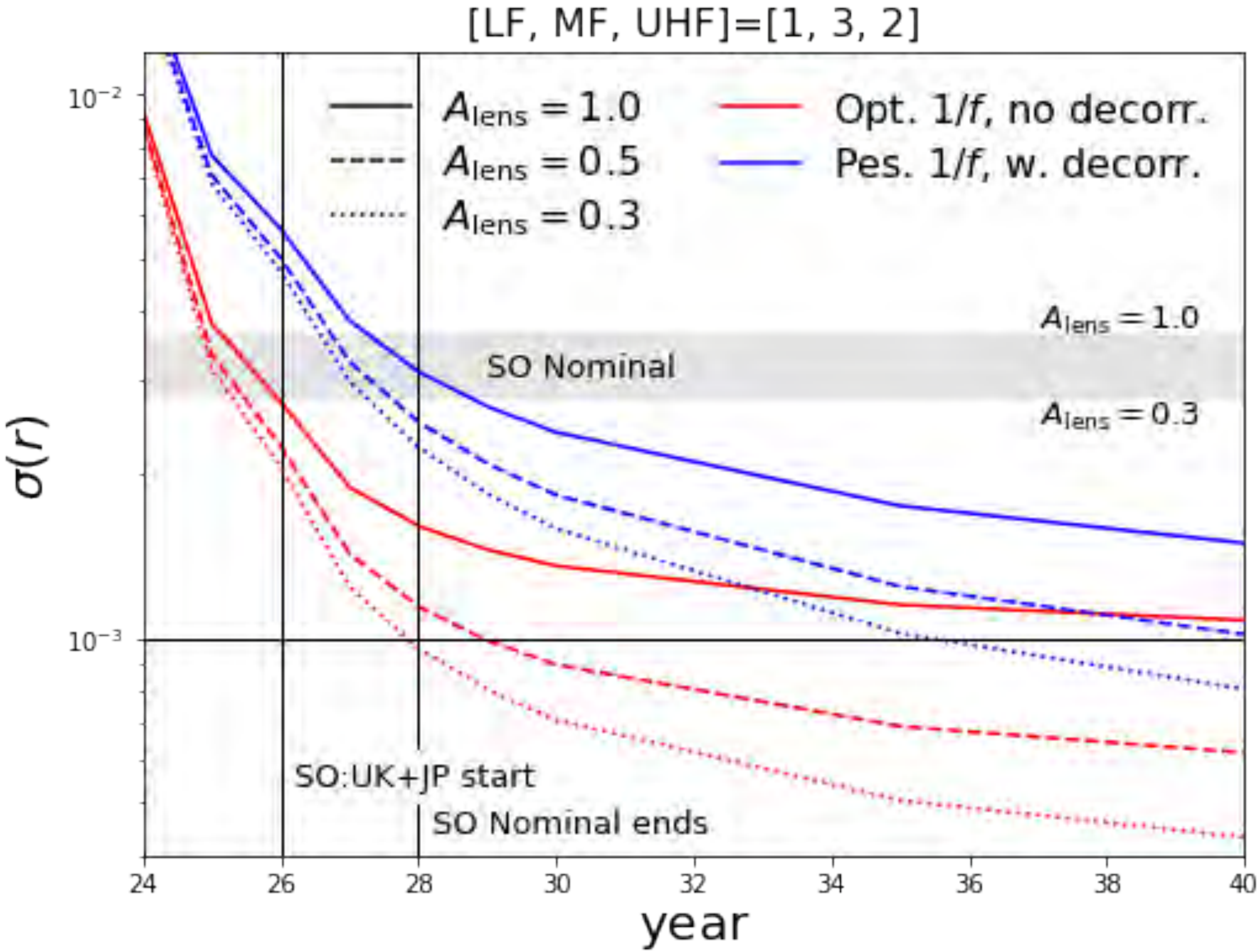
table of sigma(r) (biases on r are, in all cases, << sigma)	**2027**			**2032**		
	AL = 0.25	**AL = 0.5**	**AL = 1.0**	**AL = 0.25**	**AL = 0.5**	**AL = 1.0**
SO baseline	0.00187	0.00227	0.00307	0.0012	0.00163	0.00239
SO baseline + SO:UK MF only	0.00123	0.00163	0.00245	0.000893	0.0013	0.00208
SO baseline with LF_years = 5/10 + SO:UK MF only	-	0.00161	0.0023952	-	0.00127	0.0021
SO baseline + SO:UK one additional tube in all frequency bands	-	0.00172	0.00257	-	0.00136	0.00216
decadal *baseline* = uK-arcmin of the SO baseline / sqrt(3)	-	-	-	0.0010	0.00143	0.00225
decadal *goal* = uK-arcmin of the SO goal / sqrt(3)	-	-	-	0.000795	0.00119	0.00199



10^{-2}
10^{-3}
$\sigma(r = 0)$
26
28
30
32
34
36
38
T_{obs}
123
132
bl MF / bl HF
op MF / bl HF
A_L=1.0
A_L=0.5
A_L=0.3



Pessimistic 1/f. With decorrelation
[1, 4, 1]
[1, 3, 2]
[2, 2, 2]
[1, 2, 3]
$A_{lens} = 1.0$
$A_{lens} = 0.5$
$A_{lens} = 0.3$
$A_{lens} = 1.0$
SO Nominal
$A_{lens} = 0.3$
SO:UK+JP start
SO Nominal ends
10^{-2}
10^{-3}
$\sigma(r)$
24
26
28
30
32
34
36
38
40
year


[LF, MF, UHF]=[1, 3, 2]
$A_{lens} = 1.0$
$A_{lens} = 0.5$
$A_{lens} = 0.3$
Opt. 1/f, no decorr.
Pes. 1/f, w. decorr.
$A_{lens} = 1.0$
SO Nominal
$A_{lens} = 0.3$
SO:UK+JP start
SO Nominal ends
$\sigma(r)$
10^{-2}
10^{-3}
24
26
28
30
32
34
36
38
40
year