An all-sky millimetre survey at subarcminute resolution

F.-Xavier Désert, *IPAG*

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mm Universe 2023

Abstract

There are several new projects to survey the sky with millimetre eyes, the biggest being Simons Observatory and CMB-S4, in the Southern Hemisphere. The NIKA2 collaboration has acquired a knowledge sufficient to build a large focal plane KID camera for a 15-m antenna. This would allow covering the whole Northern Hemisphere in a couple of years at subarcminute resolution and with milliJansky sensitivity. We describe the main scientific drivers for such a project: the SZ sky, the high-redshift millimetre Universe and the interstellar medium in our Galaxy and the nearby galaxies. Then we show the main difficulties (organisational, technical and financial).

HR15m is a mm telescope of 15 m diameter with a single photometric mapping instrument covering 1.2-3.3mm at 20-60 arcsec resolution. About 20,000 KIDs at 150 mK over a FOV diameter of 48 arcmin, covering the whole Northern Hemisphere in 5 years.

ACT atlas, Naess et al JCAP 2020, link

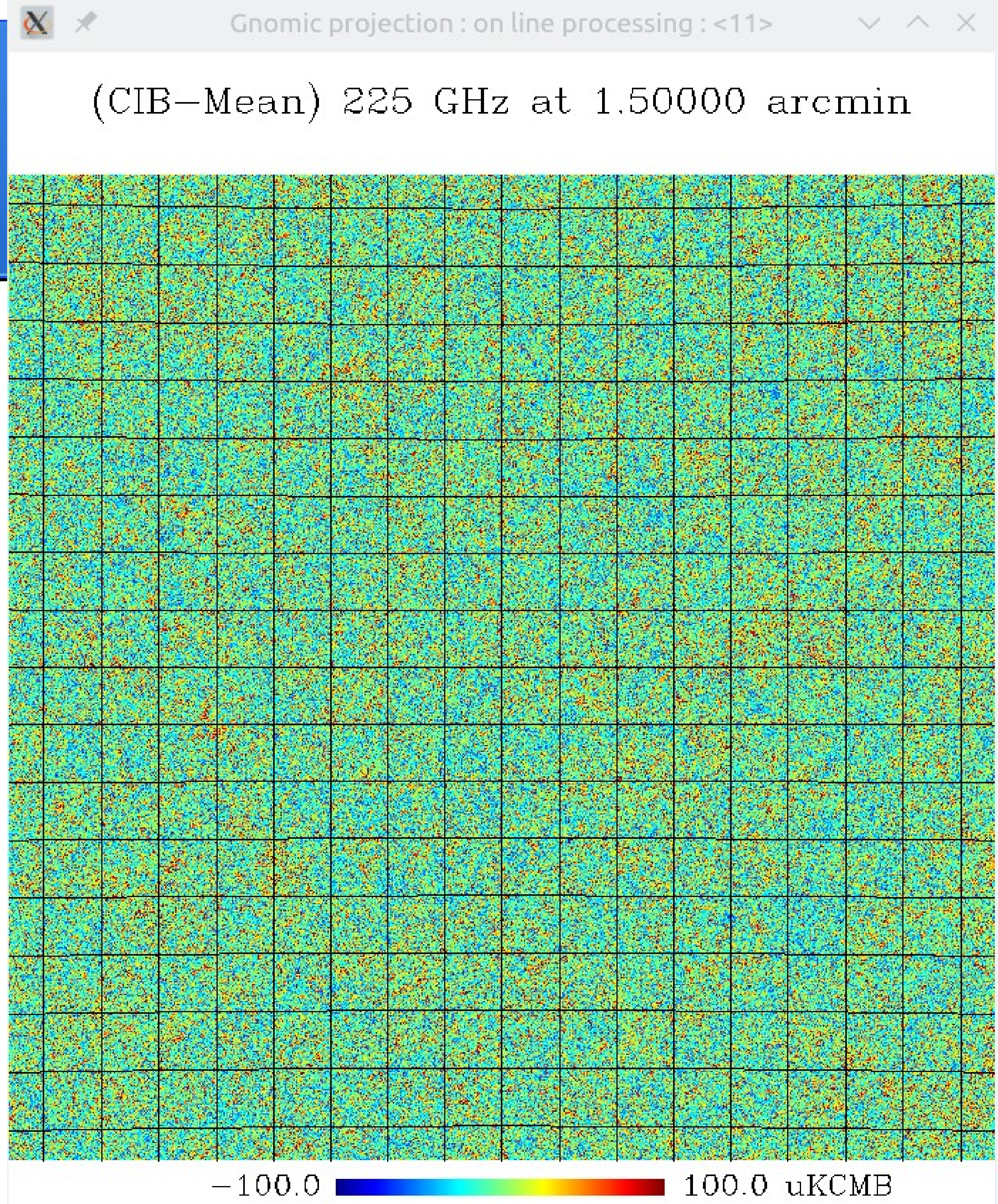
CIB

CIB 225 GHz

17 μK_{CMB}.arcmin

PS 1 σ at 1.4 mm:
0.23 mJy

Simulations from
WebSky
Stein *et al*
JCAP10(2020)012



Grid step = 1 deg

HR15m
Source detection rates

- Source counts of Bethermin+ 2017, Vieira+ 2013, Tucci+ 2012

  Wide survey, 6000 deg^2 , 1 year:

  * 7,700 sources at 5 σ (7.5 mJy) at 260 GHz,

  * Lensed above 10mJy at 220 GHz: 1300

  * 15,000 (150 GHz), 27,000 (90 GHz) Radio sources

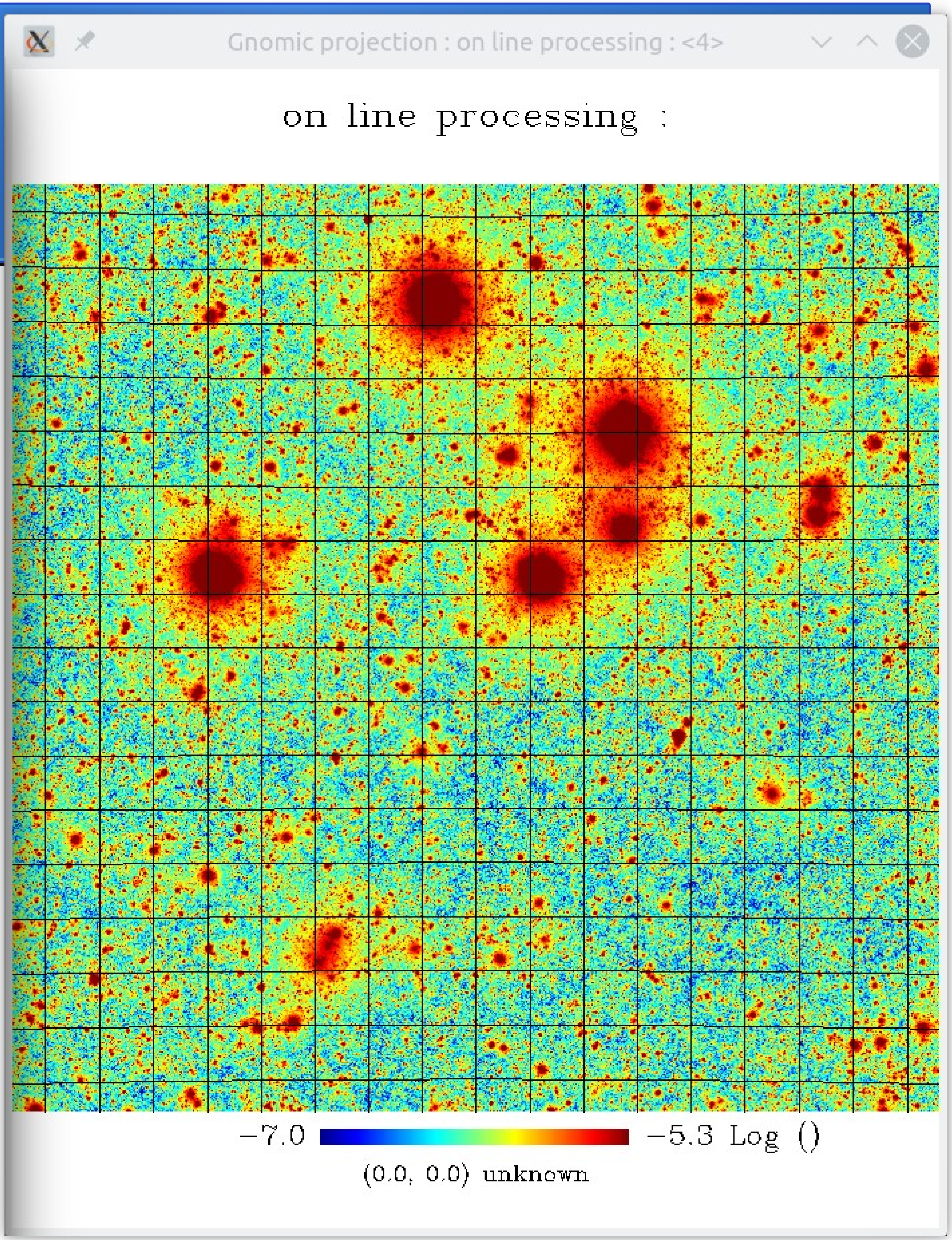
- ***Deep survey, 300 deg^2 , 1 year:***

  * 120,000 sources at 5 σ (1.8 mJy) at 260 GHz, confusion is at 320,000

  * 2,600 (150 GHz), 4,700 (90 GHz) Radio sources

The CIB mm mapper project. Implications for CMB delensing and CIB clustering to be investigated. Masking radio sources from CMB-SO/S4.

tSZ



300 deg2
tSZ *y*
1.5 arcmin pixel

1 arcmin, 1 σ :
2mm 2.5×10^{-6}
3mm 1.0×10^{-6}

HR15m, cluster counts

- From Planck source counts. Assume 2 arcmin diameter clusters

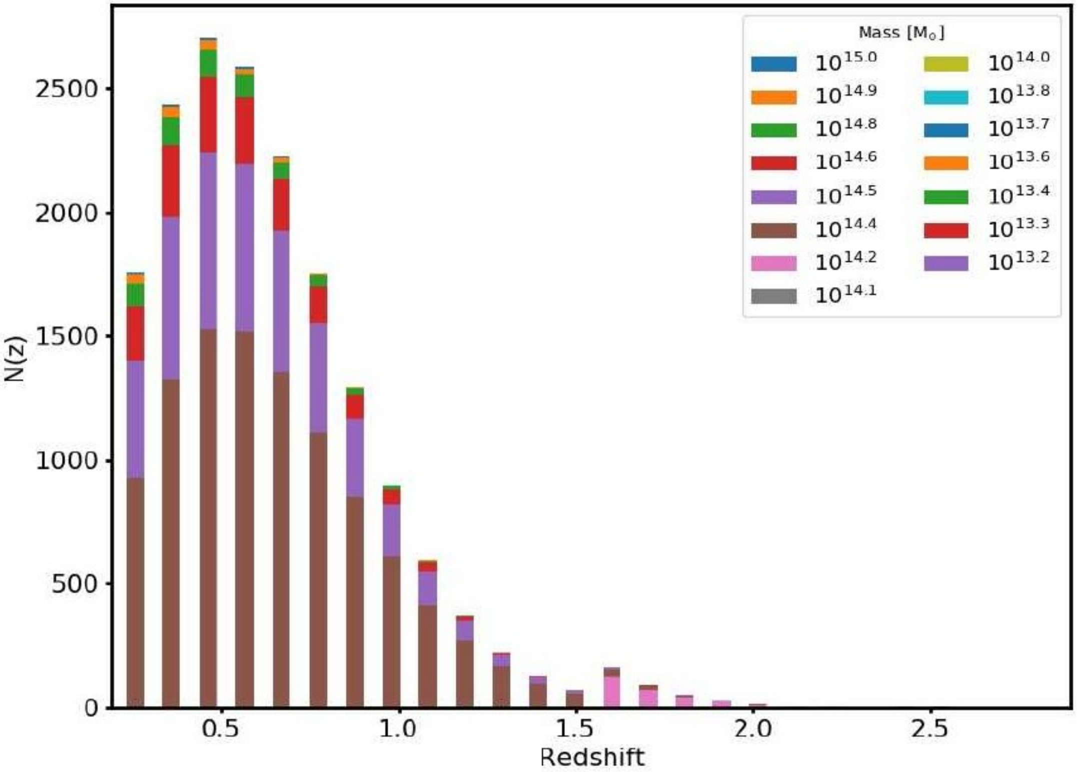
  - Wide survey:

  26,000 clusters at 5 σ (Y=8 10^{-5} $arcmin^2$) at 150 GHz

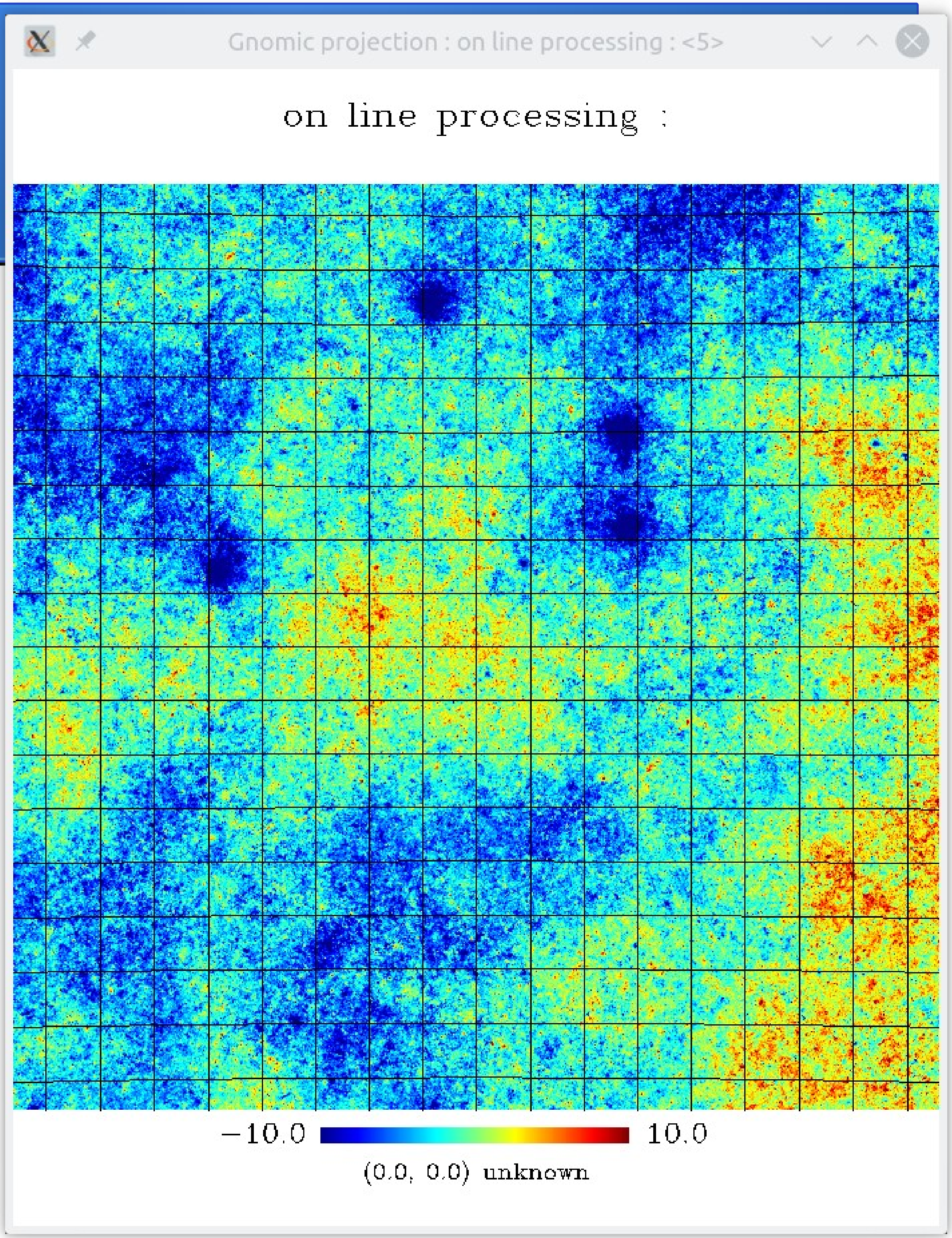
  - Deep survey:

  26,000 clusters at 5 σ (Y=2 10^{-5} $arcmin^2$) at 150 GHz

Formation and Evolution of clusters:
→ Access the high-redshift domain
Map the filaments between clusters: the food for cluster growth



kSZ



300 deg²
units μK$_{CMB}$
1σ in 1arcmin
1.2 mm: 26
1.4 mm: 17
2.0 mm: 12
3.3 mm: 5
All: 9

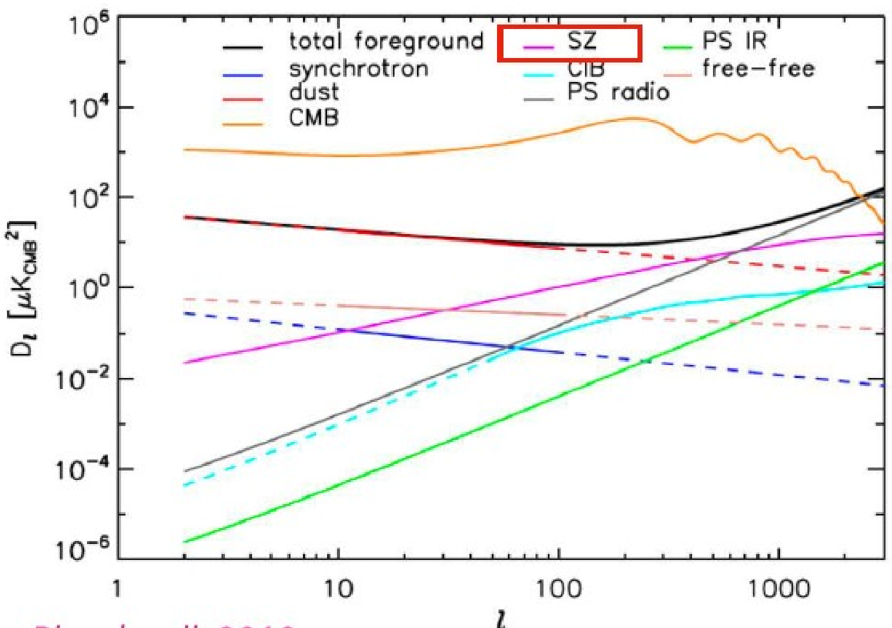
Stat. of cluster motion
Tail of CMB anisotropies
Reionization

tSZ in frequency maps (small scales)

- Primordial CMB becomes negligible
- tSZ is hidden among many other signals

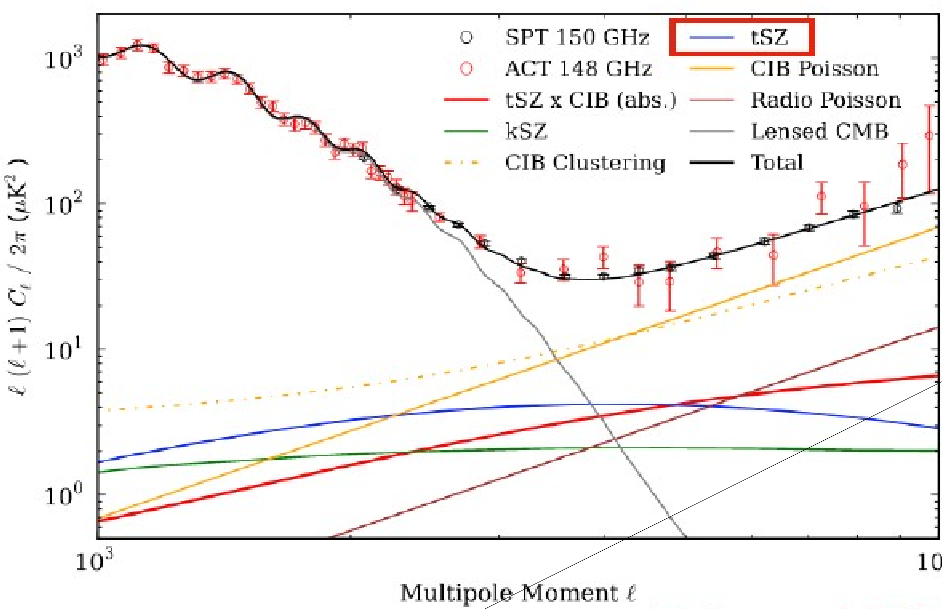
l_{max}=3 10^4

Planck/Large scales



Planck coll. 2013

SPT/small scales



Addison et al. 2012

HR15m 1 year Deep survey 1 σ for ΔEll=100

CMB Lensing

- Hu et al. 2007, Lewis&Challinor 2006
- Deep survey

  ΔT=13 μK.arcmin,

  20 arcsec, at 220 GHz
- Get a 10 σ effect

  using 1000 clusters.

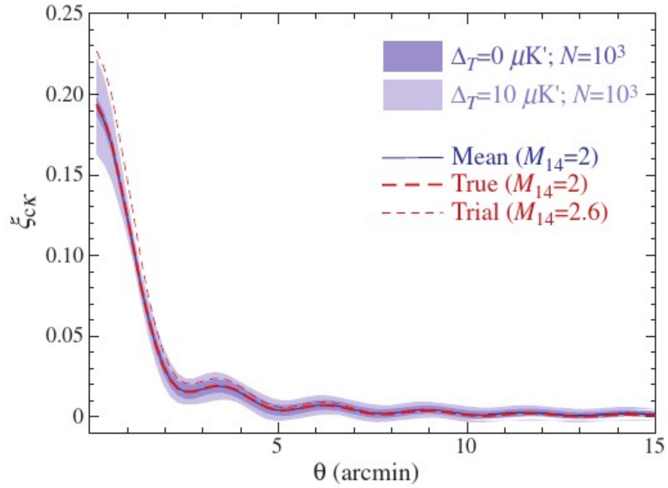
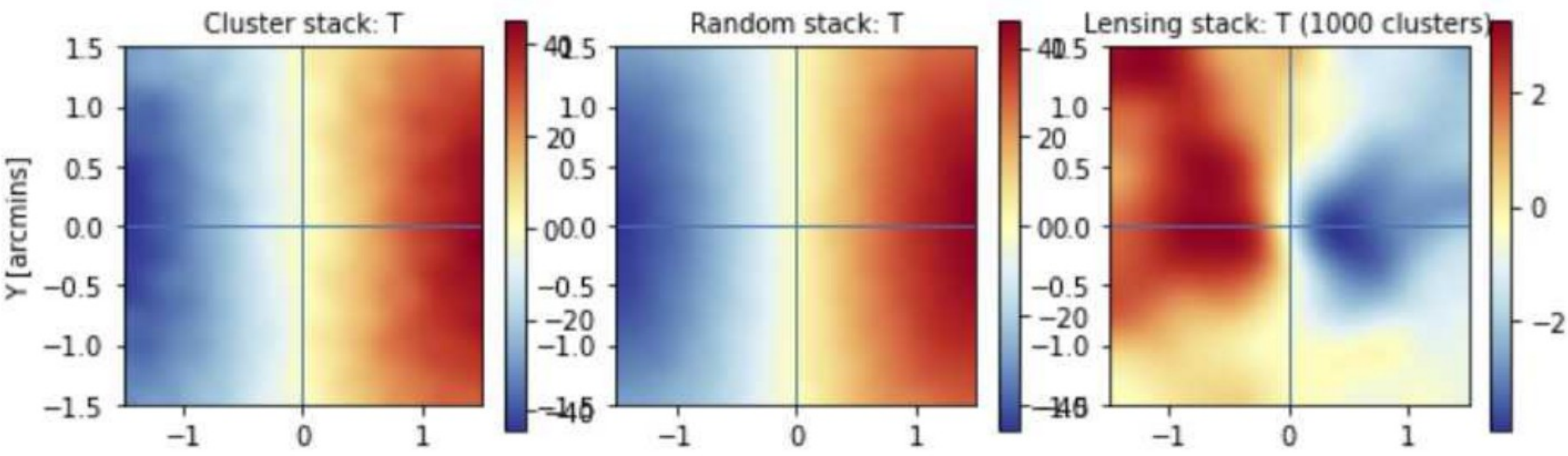


Figure 4. Beam filtered correlation function from 12 000 clusters. The reconstruction is low pass filtered at $l < l_{\rm beam} (= 8095)$ to remove contributions below the beam scale which introduces a well-defined ringing in the correlation function. Shown for comparison are the filtered input lens of $M_{14} = 2$ and a trial model of $M_{14} = 2.6$ for comparison. With a noise level of $<10\,\mu K'$ the two cases are clearly distinguished with 1000 clusters (bands).

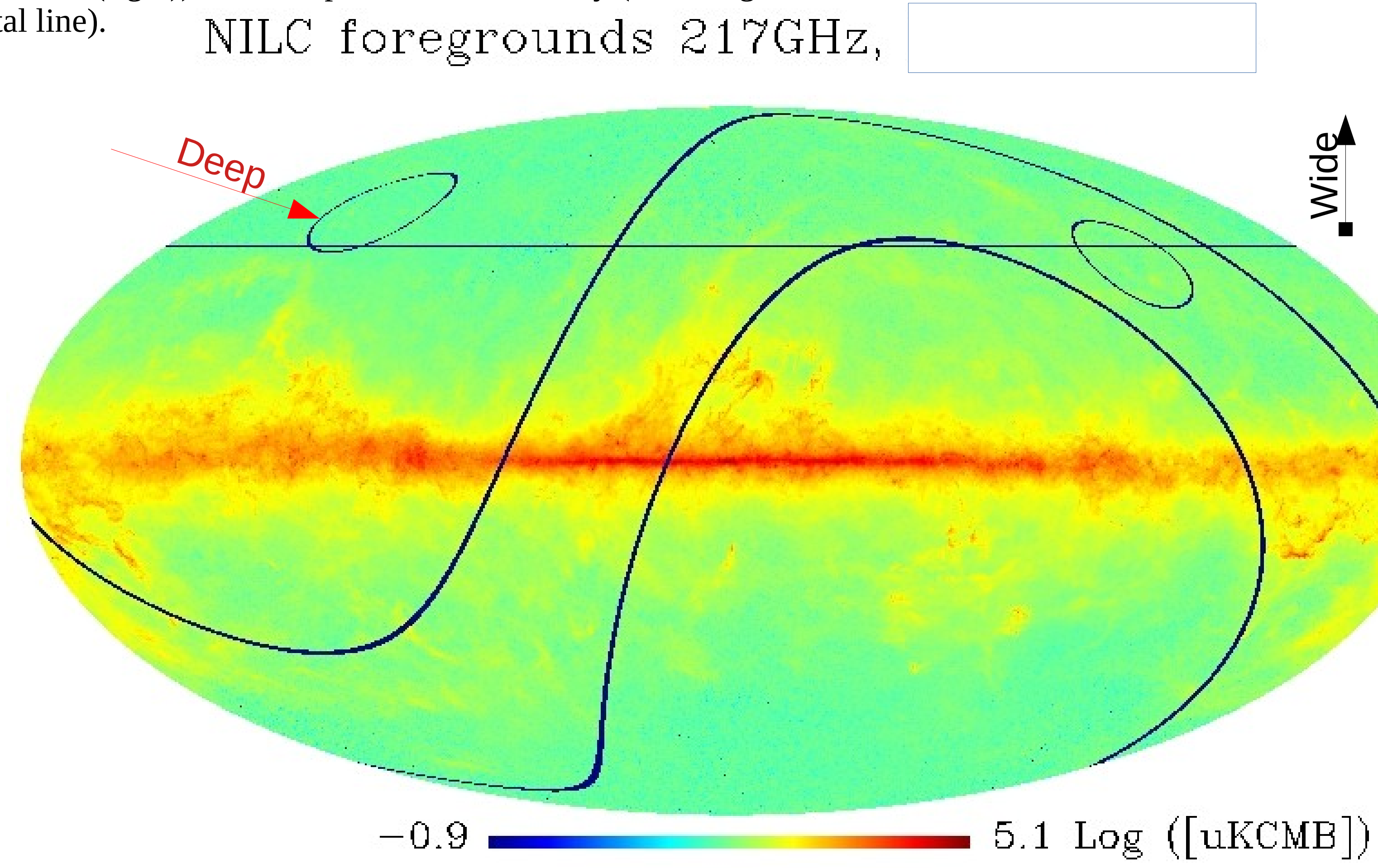
Table 1. Detection significance $\sqrt{\Delta\chi^2}$ or S/N for 10^3 clusters of $M_{14} = 2$, $z = 0.7$ and $\theta_{\rm FWHM} = 1'$.

Type	3 μK′	10 μK′	30 μK′
TT	22.9	11.5	6.1
ET	8.0	3.5	1.4
EB	8.6	2.4	0.6



Sky coverage

- Deep survey is 0.7% of sky and Wide survey is 15%
- f_{sky} ($|b| > 15$, $Dec > -15$) = 47% (20 000 deg^2); f_{sky} ($|b| > 30$, $Dec > -15$) = 33% (13 800 deg^2)
- $Dec = +22$ (ACT max), $Dec = -15$ (HR15m min): large overlap
- Here is an all-sky map showing 2 possible deep surveys (300 deg^2 each, the 2 circles centred on GOODS-North (left) and COSMOS (right)), and one possible wide survey (6000 deg^2 centred on the North Galactic Pole, constant galactic horizontal line).

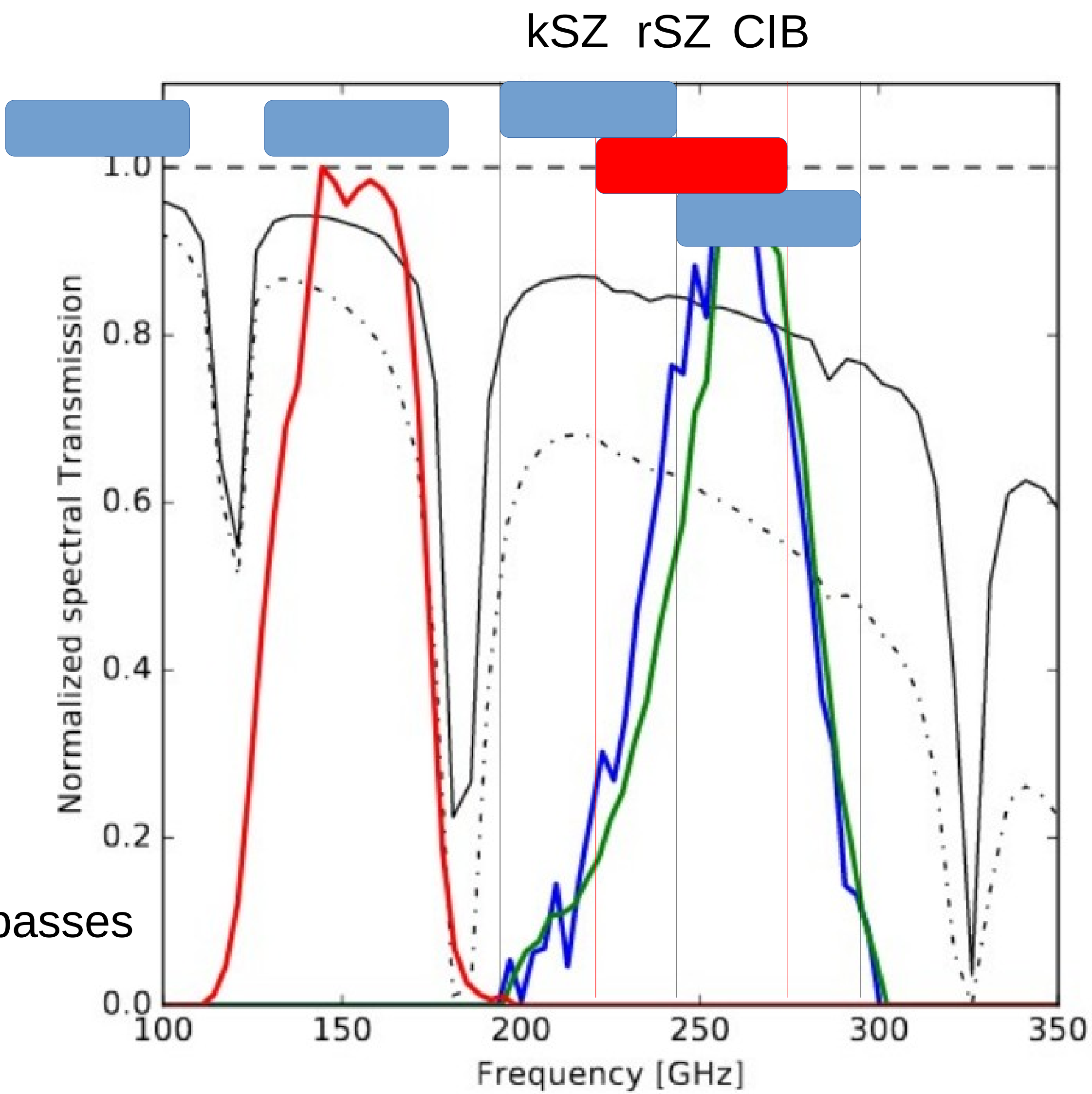


Bandpasses 1/2

- No need for polarizer grids, just a (warm) dichroic (1mm vs 2/3 mm)
- Strong case for a wide survey : cluster counts, CIB
- Strong case for a deep survey : cluster physics, kSZ, lensing + CIB
- Component separation is essential: 3 bands at 1 mm would be best, with 1 band at 2 mm and 1 band at 3 mm.

Bandpasses 2/2

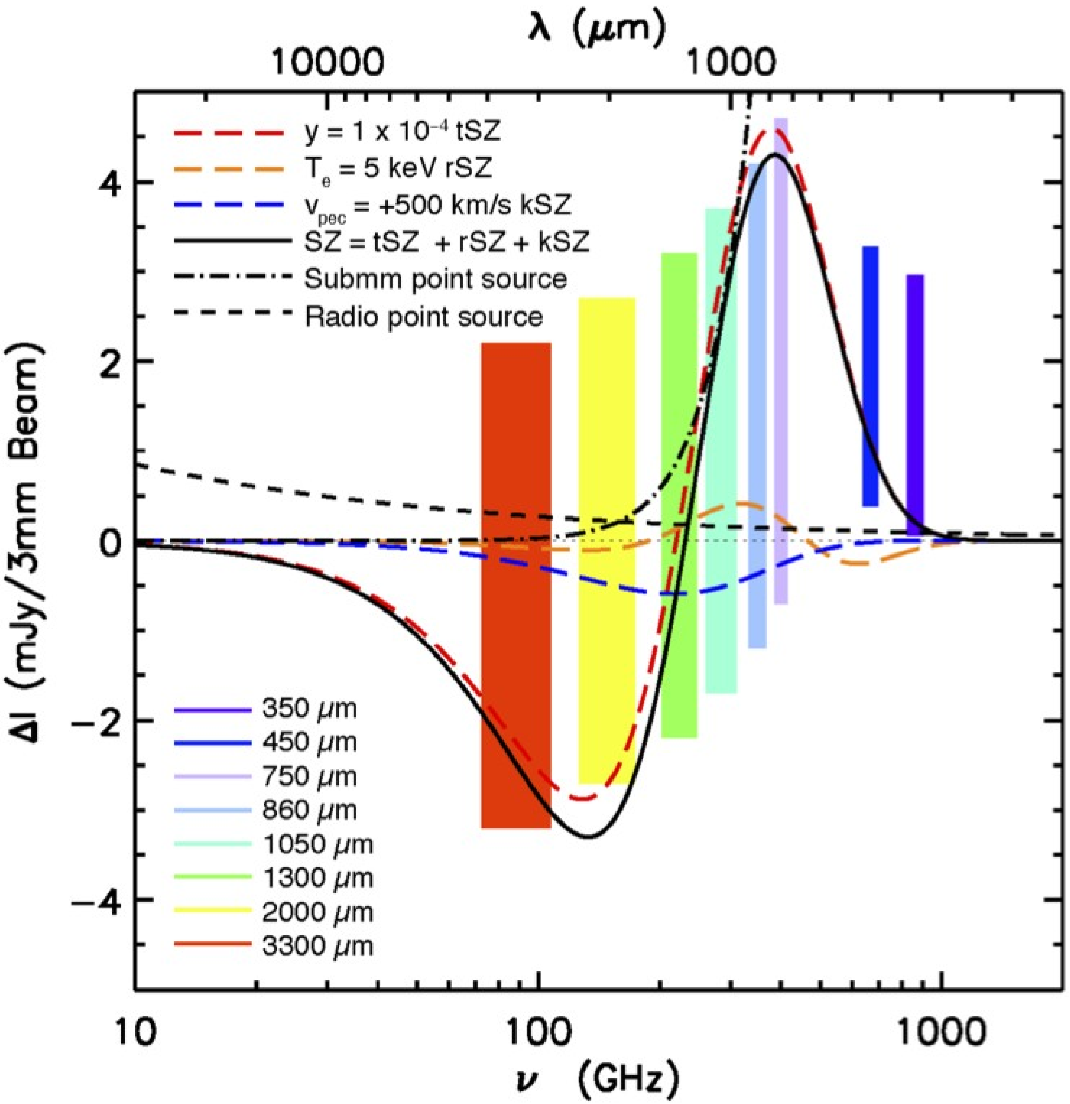
- 5 bands of 50 GHz width
- 90 GHz radio-sources tSZ
- 150 GHz tSZ
- 195-245, kSZ (zero of tSZ) and lensing
- 220-275, t+rSZ
- 245-295, CIB



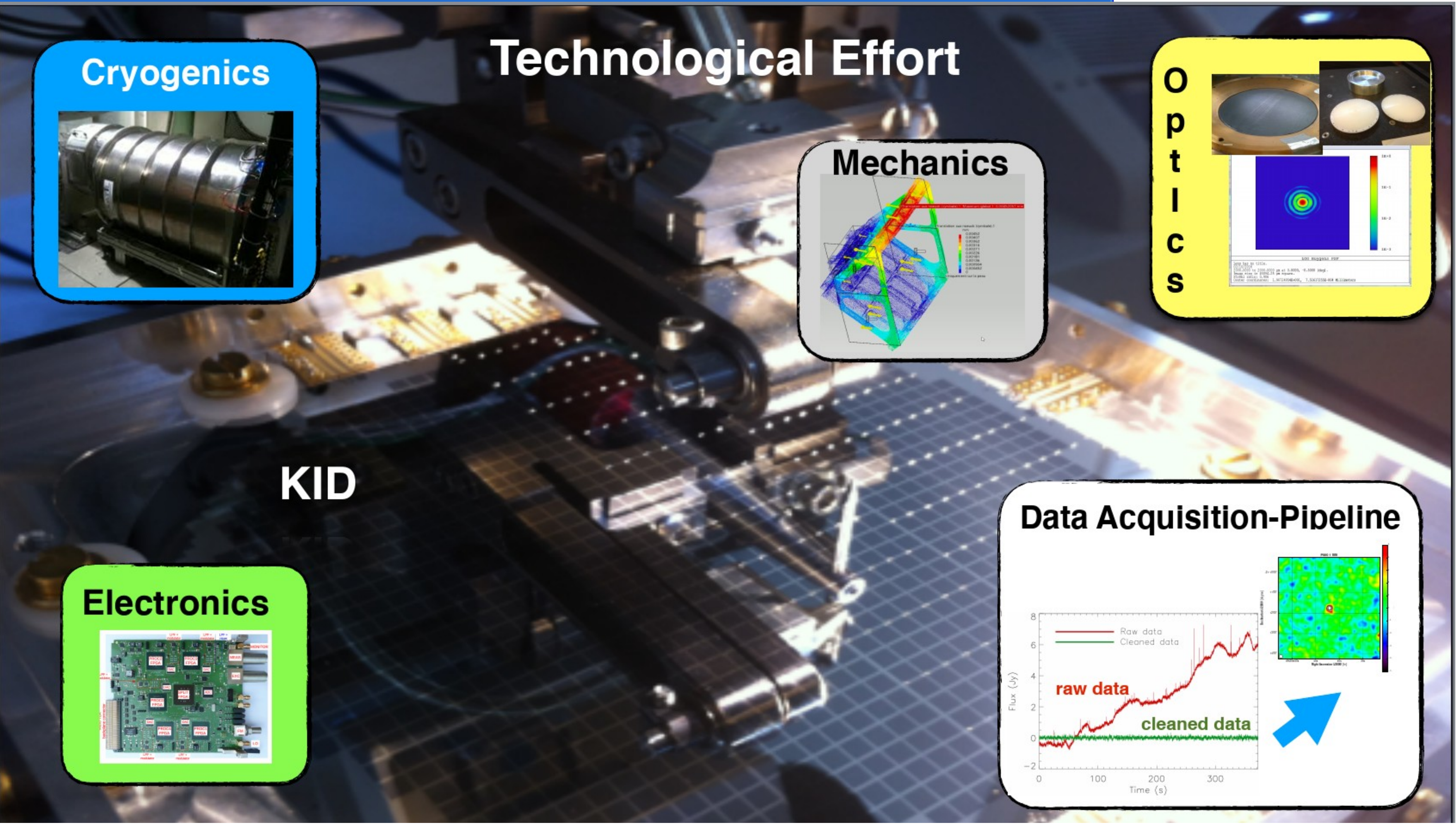
Nika2 bandpasses

CCat bands

Corresponds to the photo mode submm extension



NIKA2 legacy

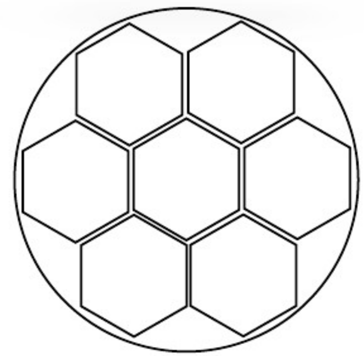


Detector Developments

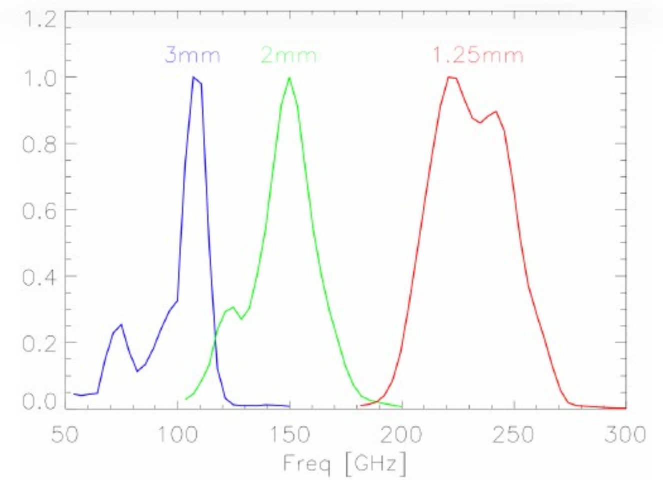
led to a GIS
LPSC I. Néel IPAG IRAM
nationally approved

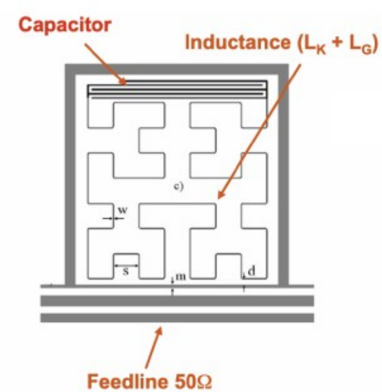
- Design Based on Al (already tested on sky) and TiAl (qualify in Lab.)
- Need to improve uniformity for 10kilo-pixel arrays.
- Plan A based on dual-pol pixels (R&D in ongoing on pol on-chip developments).
- Plan A based on mono-chromatic pixels (R&D in ongoing on pol on-chip developments).
- Plan A, Mosaic of few 4-inches wafer (need a new machine to fabricate an whole array on a single wafer).
- REU last Grenoble Version: 1GHz band-Multiplexing Factor = 500. Need to be improved.

FPUs can be arranged with several 4-inches LEKID arrays

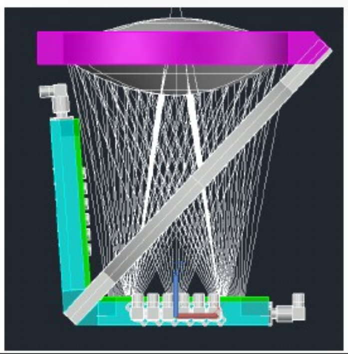


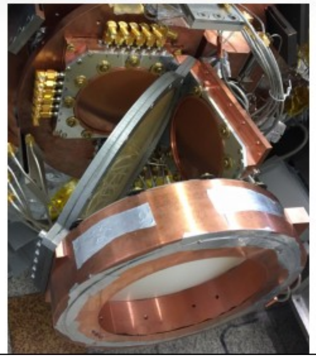
The three bands have been already tested





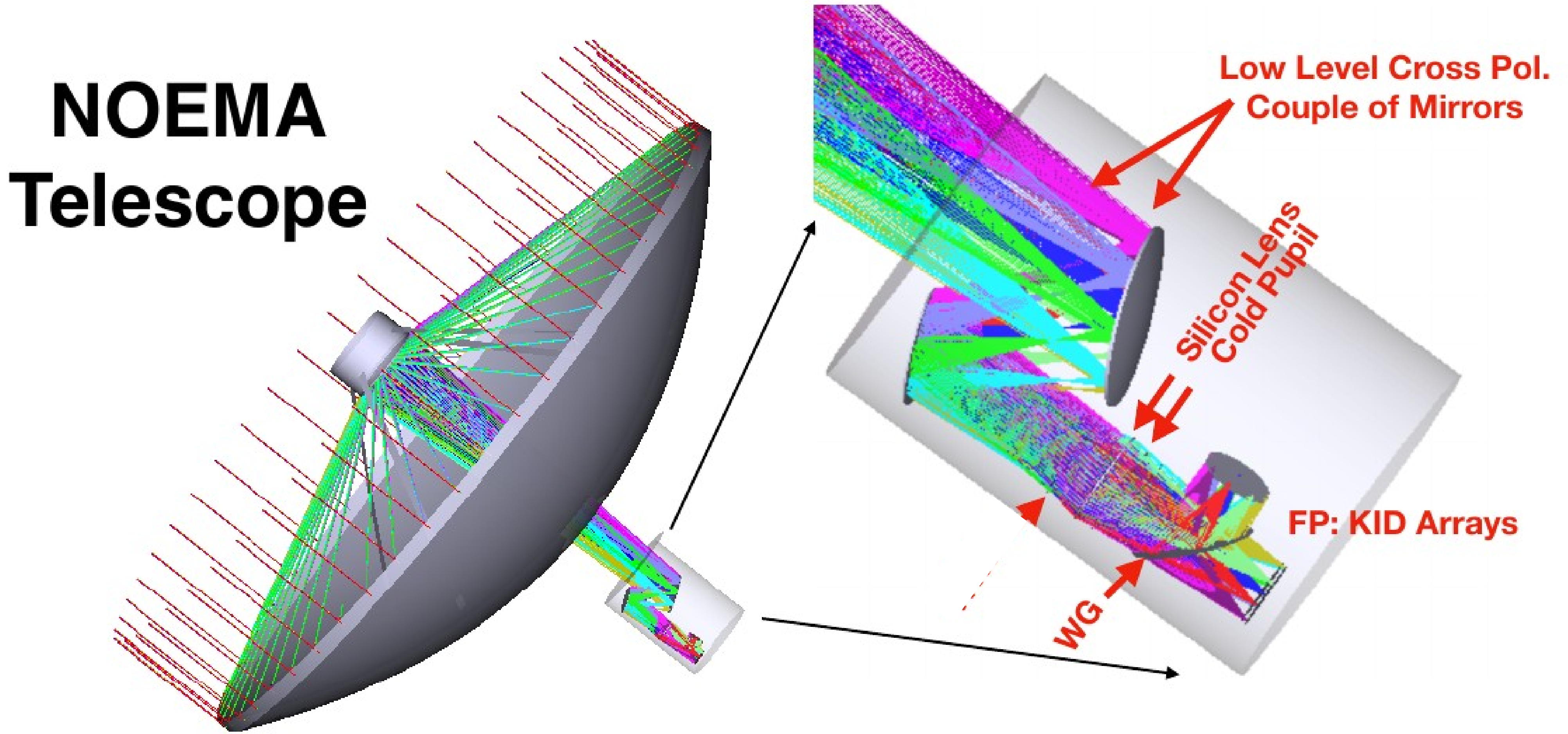
Dual Pol & Monochromatic is doable with a reasonable packaging (Ex. Concerto)





Qualified — In Progress — To be done

HR15m in a nutshell 1/2



FOV~1sq. degree., first draft for the cryostat to be redesigned with intensity only

Pointing Req. 10 arcmin/s (30 if possible), data sampling (72 Hz (240)), data rate about 1TB/day (eq. Concerto)

HR15m in a nutshell 2/2

- HR15m is a mm telescope of 15 m diameter with a single photometric mapping instrument covering 1.2-3.3mm at 20-60 arcsec resolution. About 20,000 KIDs at 150 mK over a FOV diameter of 48 arcmin, covering the whole Northern Hemisphere in 5 years.15m@ 1-2-3mm: beam 19-55 arcsec
- Intensity only with these assumptions: 0.8 fraction of good kids, pwv=4mm, elevation=45 deg. Weather efficiency=0.5, Calib overhead=0.67, means one hour of survey costs 3 hours of observations (CMB-HD assumes 20% efficiency, here we take 33%)
- Wide survey (1 year, 6000 sq. deg) 1.0-0.3 mJy 1 σ, 0.180-0.004 MJy/sr, beat cosmic variance, 14 μK_{CMB}.arcmin
- Deep survey (1 year 300 sq. deg) 0.4-0.1 mJy, 3 μK_{CMB}.arcmin, ell_{max}~30,000
- Project cost: 15-30 M€ = 5-10M€ (antenna) + 5-10M€ (instrument) + 1-2M€ annual running cost (x 5 years), Need for an observatory and community (Europe level) support
- Cosmological targets (SZ, lensing B-modes), Extragalactic targets (CIB, Galaxies), Galactic (complete mm census), Planet 9, The Transient Universe.
- Timing: 2024-2028 design-construction, then 2029 commissionning, 2030-2034 surveys
- A low cost, fast-track, all sky mm survey at high angular resolution: where ISM meets CMB! Find the needles in the haystack for follow-up by Noema/Alma/30m.

Scientific drivers for a high angular resolution mm observatory

The mass assembly and evolution in the Universe

- Secondary anisotropies
  - SZ cluster multiband census tSZ, stacking, lensing : Goal 1
  - SZ diffuse: cosmic web and kSZ, the missing baryons
  - Reionization: kSZ and intensity mapping

  Goal 2
- CIB and point-sources

  Goal 3
- Neargy galaxy mapping
- Planet 9
- Serendipity: finding transients
- Stacking and cross-correlating with other wavelengths
  - References for lensing: CMB-HD Sehgal et al. 2019, NGuyen et al, 2019, Phys.Rev.D

2030: Scientific and Political context

- eRosita, Euclid, Rubin-LSST, SKA, Athena, Litebird, Pixie, SphereX,
  all with big chunks of sky, all in the G€ land.
- SO being deployed in the 100M$, CMB-S4 2025-2035: 1-2G$ (600M$ + 32 annual ops.), .
- CCat-Prime 6m submm surveyor (started)
- ESO ATLAST 50m and Phase A Synergy ERC project 300 M€+
- Astrodecadal survey out, CMB-HD 2*30m= 1.5G$ was proposed (not approved), CMB-S4 is launched
- ESA Voyage 2050 out: an ESA mission, a microwave spectroscopy explorer, with plausible target launch date around 2040, with moderate resolution (R=300) for CMB and intensity mapping
- in France, strong community support, beyond Litebird, to get involved in ground-based CMB polarization experiments (INSU, IN2P3, INP)
- Local Grenoble context : Planck/Archeops, NIKA2, Concerto … (a kind of Moore's law), coordinated by GIS KIDs
- Key issue (completely open at this time): Telescope site and Observatory operations

Matrix for wide-field CMB experiments

Multiple choices for experiment diversity

- Intensity/Polarization
- Photometry/Spectroscopy,
- mm/submm and wavelength coverage,
- 10m+ or 6m,
- Ground-based/Space
- Sky coverage

Ground		> 10m		<10m
North	mm photom	This Project HR15m		AliCPT
	mm spectro			
	submm photom	Scuba2/JCMT		
South	mm photom	SPT, CMB-HD, Atlast		ACT, SO, CCATp, CMB-S4
	mm spectro	Concerto/Apex		CCATp
	submm	AtLast		CCATp

The niche for this project: the Northern Hemisphere, the high-angular resolution, the reasonable size of the project, the natural ground-based mm follow-up of Planck and Herschel, all-sky

Conclusions

- Deep survey: CIB, Cosmic web: the missing baryons and kSZ, reconstructing the gravitational potential observing reionization.
- Wide survey: go for counting clusters with SZ, find submm rare (lensed) sources and count radio sources.
- Map the northern sky (ISM and nearby galaxy studies)
- Remove the CIB and sources from S4 experiments. Help delensing CMB-B mode experiments.
- The telescope could be modified e.g. with more spectroscopic resolution in the future: line-intensity mapping or e.g. polarization capabilities
- Cross-correlation with other datasets will be critical

Backup slides

- 1306.2322: Ettori et al. advocate the use of Athena to observe the outskirts of clusters and the Cosmic Web. Athena will measure the dynamics of clusters (K line redshift), and the entropy profile will tell if AGN feedback is important over the graviational heating only

  → the main goal of Athena is the large-scale structure assembly in the Universe (groups and clusters)

- 1306.2324: Kaastra et al. The missing baryons.

  today's observations can only account for <60% of the baryons that our precision cosmology predicts in our local Universe, and that have been detected in the high-z linear Universe (e.g. Fukugita 2003; Shull et al. 2012)

  Cluster outskirts are a melting pot, where cosmic baryons convert their kinetic energy of the infall into the thermal energy of the hot gas.

Filaments between Clusters

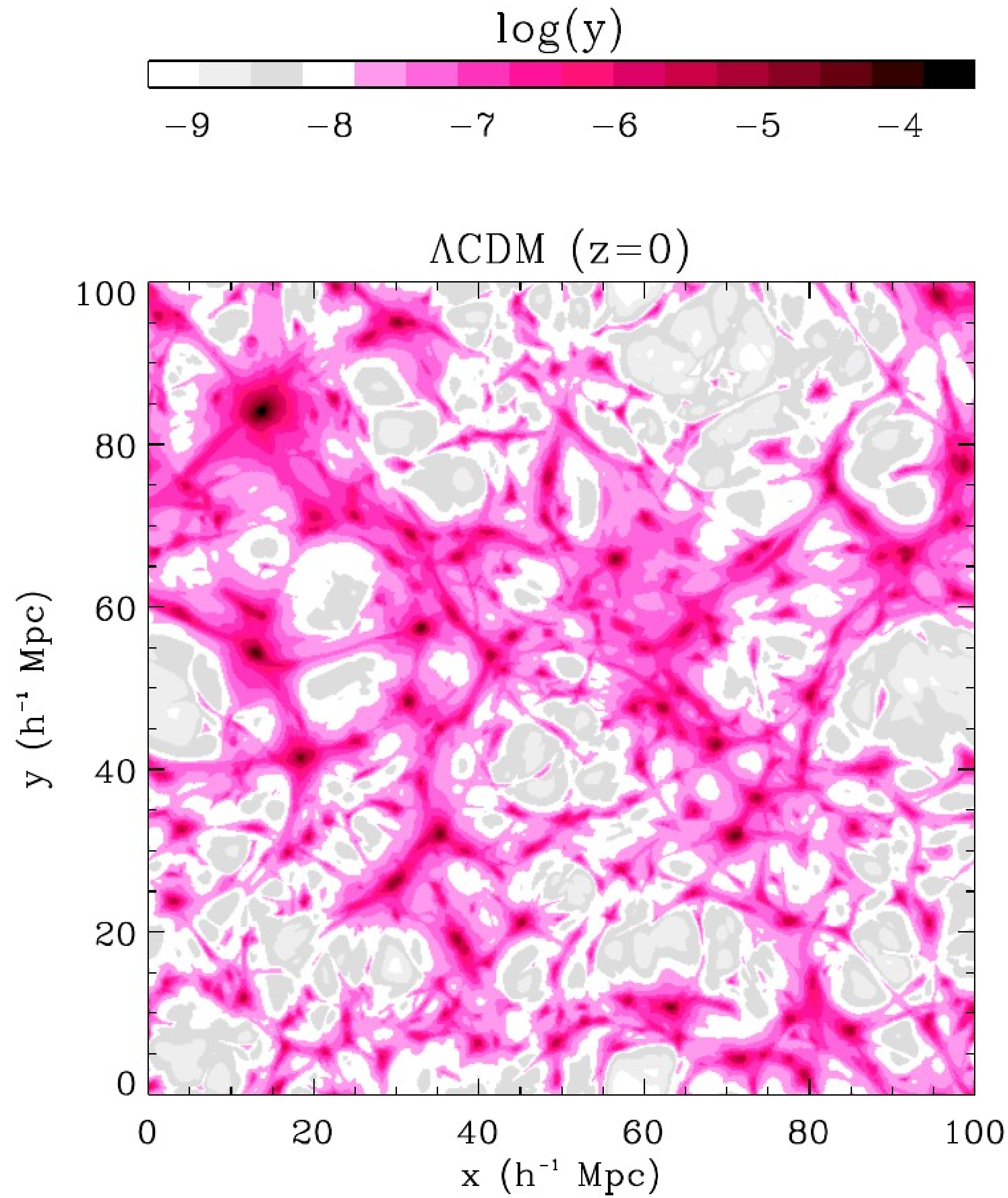
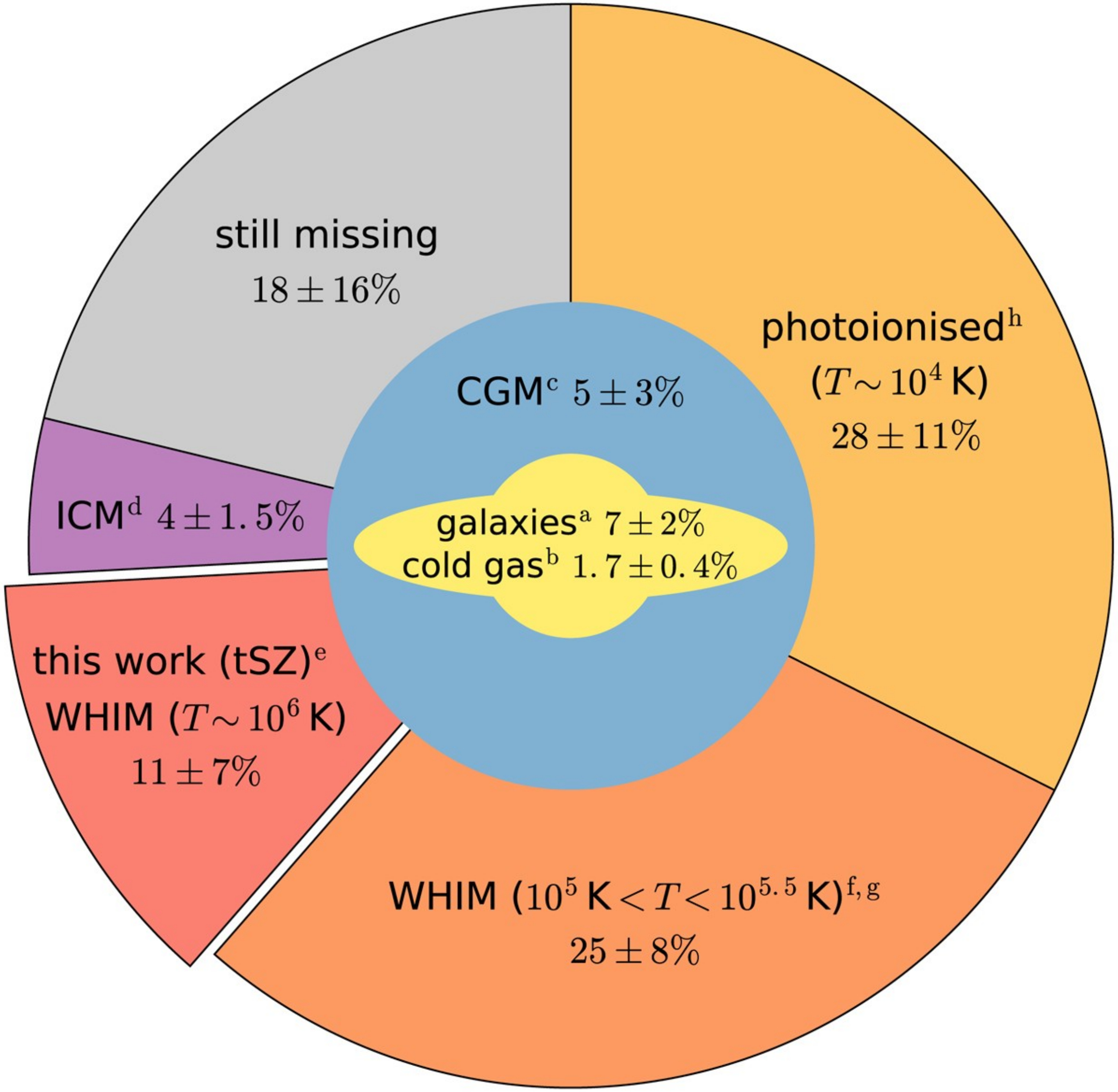


FIG. 2. Comptonization-parameter map for the ΛCDM simulation at $z = 0$.

Refregier et al 2000, 10.1103/PhysRevD.61.123001

Missing Baryons

de Graaf et al., 2019, AA, 624, A48
3σ detection of filaments between galaxies (SDSS), with Planck
See also Tanimura et al 2019, 2020



Atmosphere 1/2

- Raymond, et al. 2021 study VLBI sites for EHT

THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES, 253:5 (17pp), 2021 March — Raymond et al.

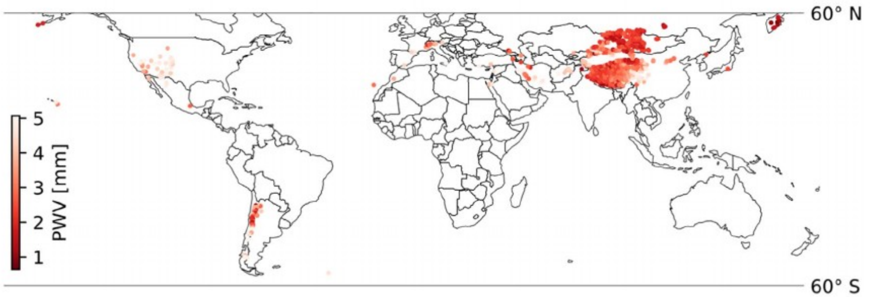


Figure 1. Worldwide March PWV for peaks above 2000 m in each 1° latitude/longitude square between 60° S and 60° N latitude. MERRA-2 data sets for years 2009 through 2012 were averaged. A cutoff of 5 mm is applied.

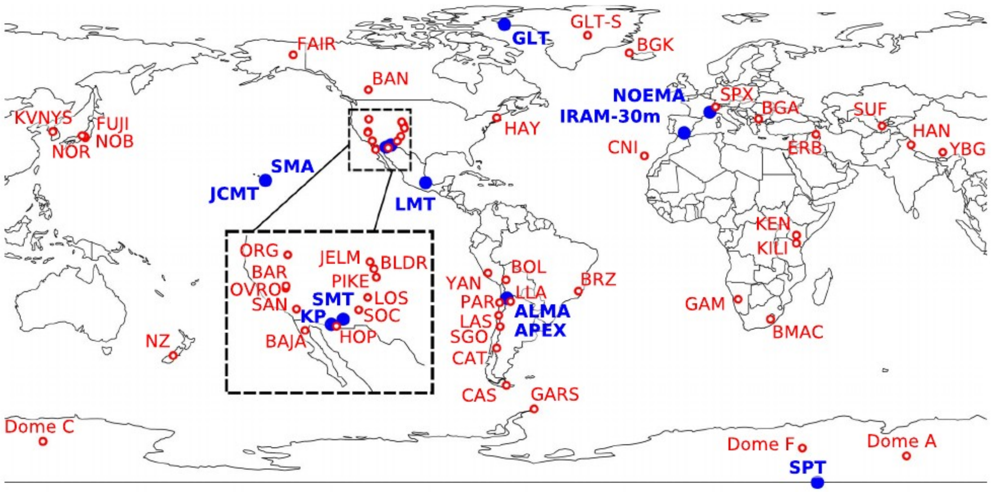
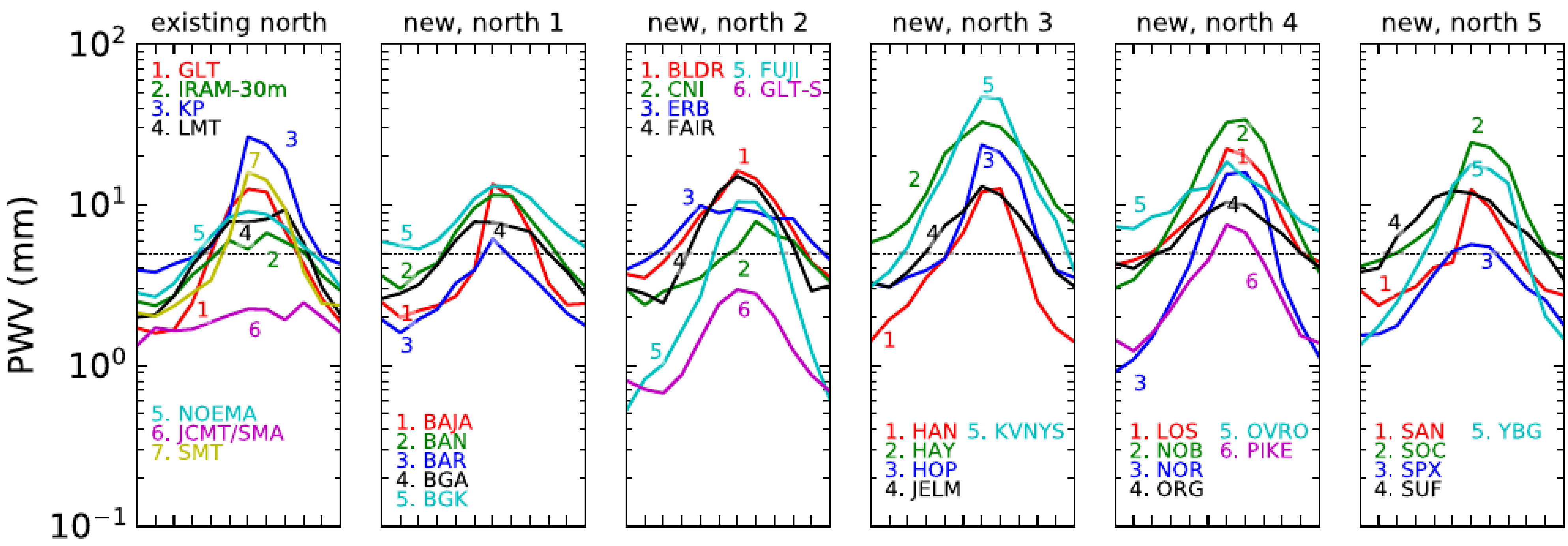


Figure 2. Map of planned 2021 EHT sites (blue, bold) listed in Table 1 and 45 potential new sites (red) for the ngEHT listed in Table 2. The map is centered on the 2021 EHT sites.

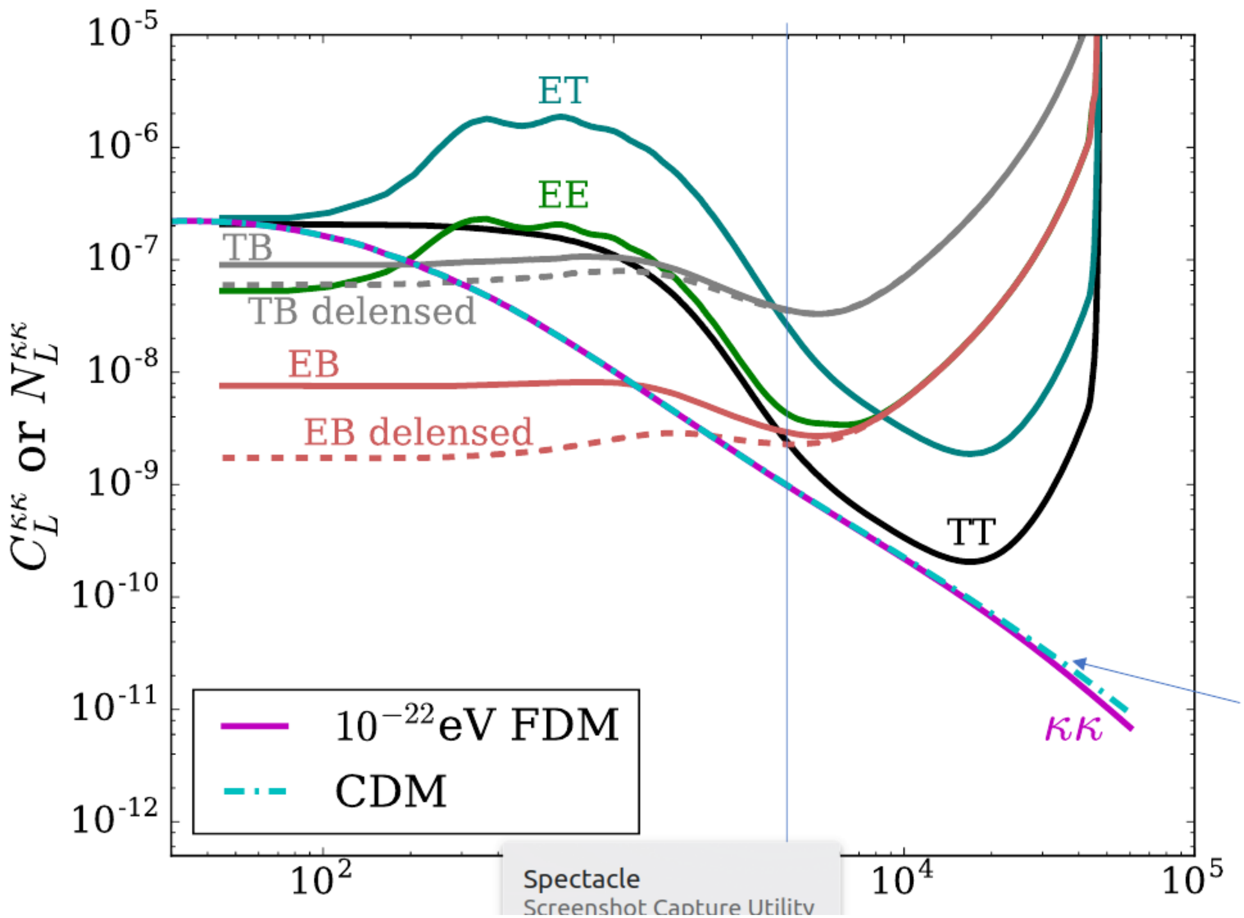
Atmosphere 2/2



For sensitivity calculations, we have adopted: pwv=4, elevation 45 deg.
and 0.5 weather efficiency and 0.67 efficiency (calibration/technical overheads)

Cosmology from large scale structure

HR CMB lensing in Nguyen+2017



Noises using various map combinations

- At ell>4000 (FWHM < 2.5′), lower noise from temperature only than from polar.
- lensing powspec measurement at scales non-accessible by SO or CMB-S4 (5000 < L < 20000)

Signal (matter power spectrum)

Cluster cosmology

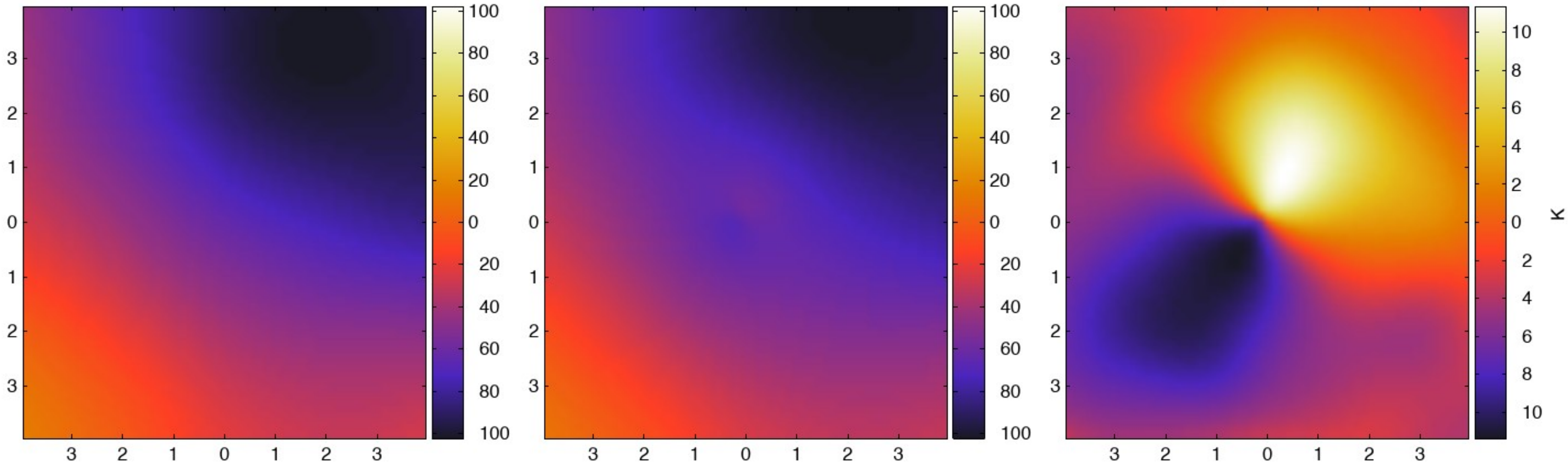


Fig. 19. Simulated effect of cluster lensing on the CMB temperature. Left: the unlensed CMB; middle: the lensed CMB; right: the difference due to the cluster lensing. The cluster is at redshift one, and has a spherically symmetric NFW profile with mass of $m_{200} = 10^{15} h^{-1} M_\odot$ and concentration parameter $c = 5$ (see Refs. (160; 162)). Distances are in arcminutes, and can be compared to the cluster virial radius of 3.3 arcmin. In the middle figure note the direction of the gradient inverts inside the ~ 1 arcmin Einstein radius where the lensing deflections cross the centre of the cluster. This is a rather clean realization, in general the dipole pattern can be weaker and/or more complicated.

Lewis, A., & Challinor, A. 2006, PhR, 429, 1

Sensitivity ½
Deep survey

19 … 23 …… 33 …..55 arcsec

SynKid 15m		Intensity					
		1.2mm	1.4mm	2mm	3.3mm		
	Central Frequency	260	220	150	90	GHz	
	DEEP SURVEY						
2920	Observing time on source (hr)					hr	
8760	Effective total observing time (hr)					hr	
365	id. (days)					days	
0.007	Sky fraction observed						
300	(sq. degree)					deg^2	
597	Number of FOV in survey	1,364	1,061	1,190	1,198		
	Time per field of view	2.14	2.75	2.45	2.44	hr	
	dTCMB rms per beam	83.5	35.5	11.2	4.8	uKCMB	
	Point source sensitivity (1sigma)	0.37	0.23	0.13	0.08	mJy	
	y sensitivity (1sigma) per beam	45.5	346.0	4.3	1.1	micro	
	1 sigma diffuse emission per beam	0.0381	0.0172	0.0045	0.0010	MJy/sr	
	1 sec, dTCMB per det	7,328	3,537	1,055	448	ukCMB.s1/2	
	1 sec, dTRJ per det	1,612	1,151	608	365	ukRJ.s1/2	
	mission noise in sqrt(Cl)	25	12	6	4	uKCMB.arcmin	
	aggregated			3.2		uKCMB.arcmin	For kSZ, nulling tSZ gives a sensitivty of 9 uK.arcmin
10000	ell_ref					No smoothing, per mode	
	ell(ell+1)DeltaCl/(2pi)	114.0	30.7	8.4	9.7	uKCMB^2	
	Density of sources at 5sigma	1.30E+06		28,143.0	51,203.8	sr-1	
	Number of sources at 5sigma	1.18E+05		2,572	4,679	Over the surveyed area	
	Lensed source above 10mJy		65			Over the surveyed area	
	Y(5 sigma) over cluster diam.			1.86E-05	7.90E-06	$arcmin^2$	
	Number of clusters at 5sigma			26,276	146,285	Over the surveyed area	

Sensitivity 2/2
Wide Survey

SynKid 15m		Intensity					
		1.2mm	1.4mm	2mm	3.3mm		
	Central Frequency	260	220	150	90	GHz	
	WIDE SURVEY						
2,920	Observing time on source (hr)					hr	
8,760	Effective total observing time (hr)					hr	
365	id. (days)					days	
0.143	Sky fraction observed						
6,000	(sq. degree)					deg²	
11,937	Number of FOV in survey	27,284	21,221	23,791	23,956		
	Time per field of view	0.11	0.14	0.12	0.12	hr	
	dTCMB rms per beam	373.3	158.9	50.2	21.4	uKCMB	
	Point source sensitivity (1sigma)	1.65	0.86	0.45	0.27	mJy	
	y sensitivity (1sigma) per beam	203.6	1547.2	19.3	4.9	micro	
	1 sigma diffuse emission per beam	0.1705	0.0769	0.0200	0.0043	MJy/sr	
	1 sec, dTCMB per det	7,328	3,537	1,055	448	ukCMB.s1/2	Clas
	1 sec, dTRJ per det	1,612	1,151	608	365	ukRJ.s1/2	
	1 sec, dTCMB array	78	39	18	13	ukCMB.s1/2	Clas
	mission noise in sqrt(Cl)	111	56	26	18	uKCMB.arcmin	Clno
	aggregated			14		uKCMB.arcmin	Plan
1000	ell_ref						ell(el
	ell(ell+1)DeltaCl/(2pi)	13.85	3.51	0.75	0.38	uKCMB^2	
	Density of sources at 5sigma	4.21E+03		8,033.1	14,666.3	sr-1	
	Number of sources at 5sigma	7.70E+03		14,682	26,806	Over the surveyed area	
	Lensed source above 10mJy		1,292			Over the surveyed area	
	Y(5 sigma) over cluster diam.			8.34E-05	3.53E-05	arcmin²	
	Number of clusters at 5sigma			26,276	146,285	Over the surveyed area	

An all-sky millimetre survey at subarcminute resolution

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mm Universe 2023

Hello I would like to present you with the Grenoble project that we have set up to make a millimeter survey of the whole sky that's below the arcminute resolution. This project is not yet funded. At this stage we are seeking a feedback from the community to see if there is a general interest. Clearly we come from the NIKA2 environment. We have learned many lessons from NIKA2 at the 30 meter both in terms of scientific outputs and in astronomical instrumentation and we can put this knowledge to good use for this new project

25=20min talk+5 min questions.

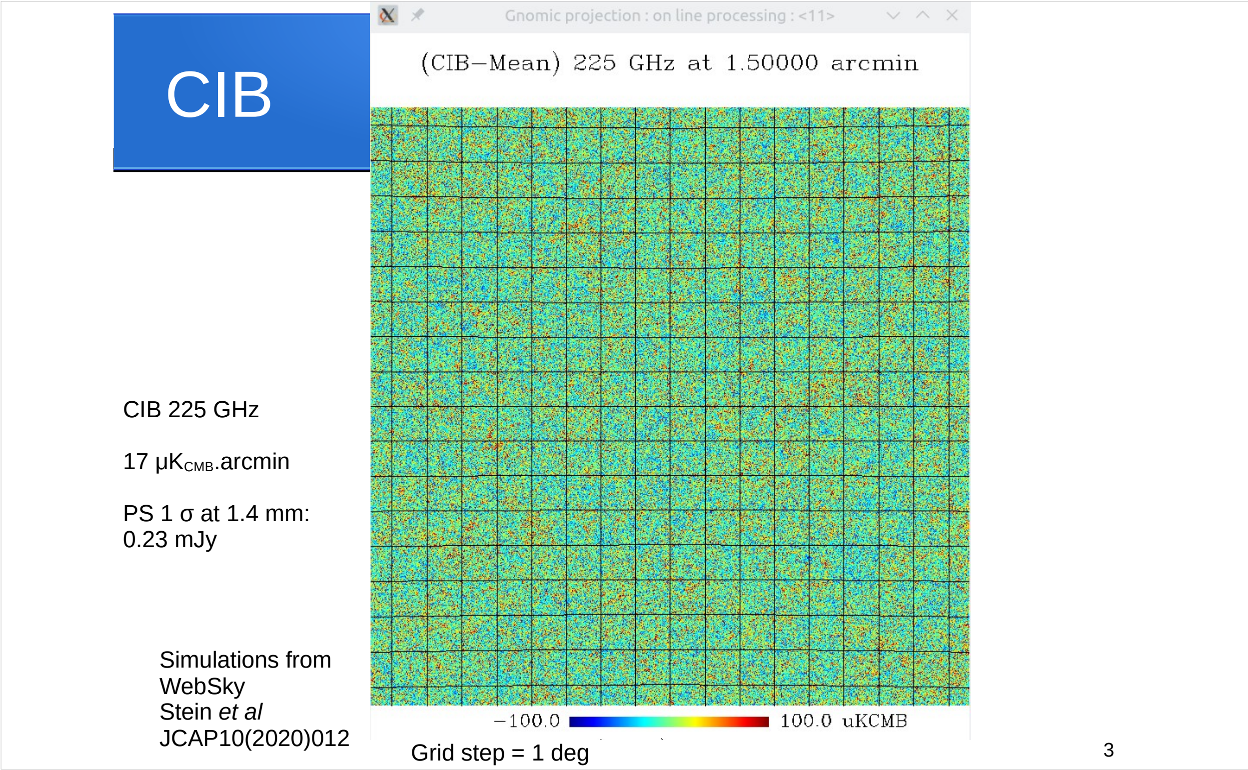
Abstract

There are several new projects to survey the sky with millimetre eyes, the biggest being Simons Observatory and CMB-S4, in the Southern Hemisphere. The NIKA2 collaboration has acquired a knowledge sufficient to build a large focal plane KID camera for a 15-m antenna. This would allow covering the whole Northern Hemisphere in a couple of years at subarcminute resolution and with milliJansky sensitivity. We describe the main scientific drivers for such a project: the SZ sky, the high-redshift millimetre Universe and the interstellar medium in our Galaxy and the nearby galaxies. Then we show the main difficulties (organisational, technical and financial).

HR15m is a mm telescope of 15 m diameter with a single photometric mapping instrument covering 1.2-3.3mm at 20-60 arcsec resolution. About 20,000 KIDs at 150 mK over a FOV diameter of 48 arcmin, covering the whole Northern Hemisphere in 5 years.

ACT atlas, Naess et al JCAP 2020, link

Mapping speeds at least 10 times above NIKA2.



What would we do with such a telescope. Clearly a deep survey is needed. We show here a simulation of the portion of a sky which would be a typical deep survey 300 square degrees with this instrument and it's using websky simulations at one millimeter wavelength and we are dominated by the CIB. So we would get a survey of that zone at the 1 milliJy level, five sigma level.

17 degrees wide.

HR15m
Source detection rates

- Source counts of Bethermin+ 2017, Vieira+ 2013, Tucci+ 2012

  Wide survey, 6000 deg^2 , 1 year:

  * 7,700 sources at 5 σ (7.5 mJy) at 260 GHz,

  * Lensed above 10mJy at 220 GHz: 1300

  * 15,000 (150 GHz), 27,000 (90 GHz) Radio sources

- ***Deep survey, 300 deg^2 , 1 year:***

  * 120,000 sources at 5 σ (1.8 mJy) at 260 GHz, confusion is at 320,000

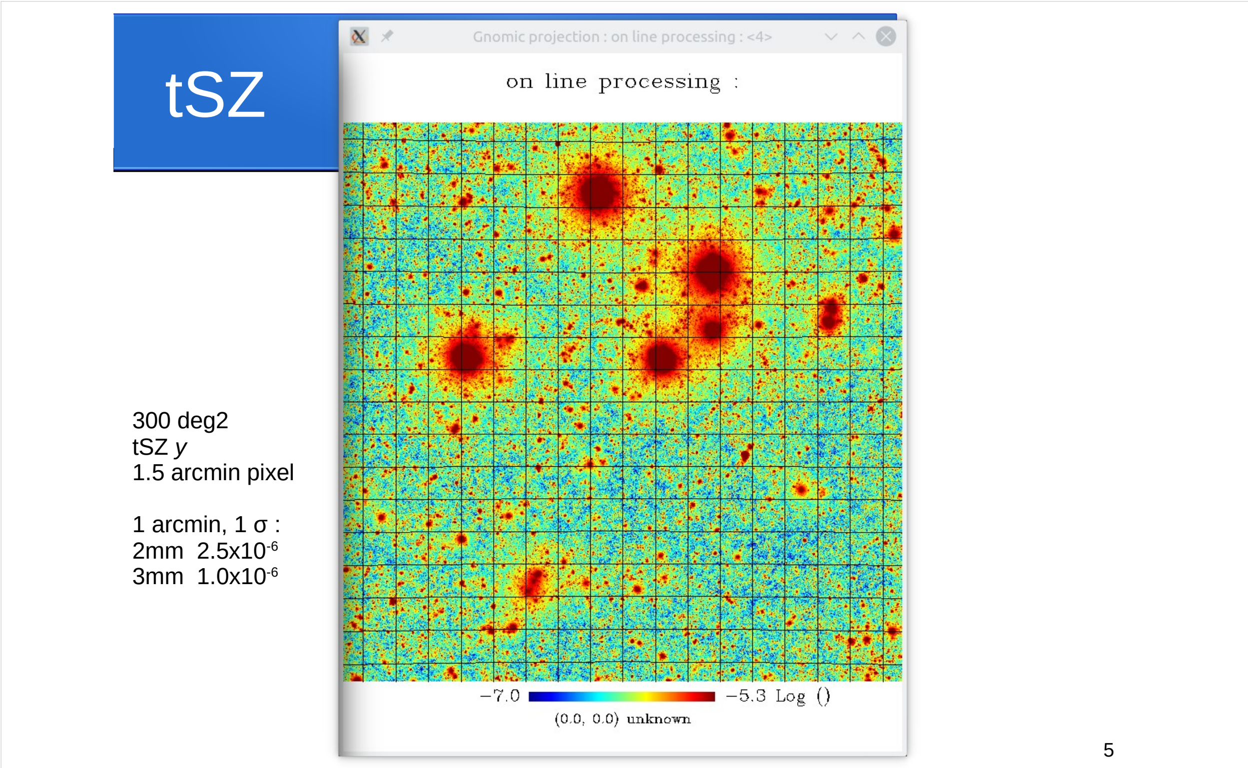
  * 2,600 (150 GHz), 4,700 (90 GHz) Radio sources

The CIB mm mapper project. Implications for CMB delensing and CIB clustering to be investigated. Masking radio sources from CMB-SO/S4.

So using the number counts which are matching the different current observations, we can evaluate the number of sources that could be detected in such a deep survey and this is equivalent to 200,000 sources which has to be compared with the few 1000 sources that we get with NIKA2.

So we are near the confusion limit of a 15 metre telescope and we can also do wide surveys say six thousand Square degrees and in that case we are aiming at finding rare objects which are probably lensed images of very distant galaxies.

This can be compared with Herschel successful surveys of ten to hundred lensed objects



Now we have the same survey but using mostly the two millimeter channel. We can recover that SZ effect with high precision, typically at 2millimeter we will cover 2.5 ten to minus 6 in the y parameter at 1.5 arcminute scale and here this is a typical SZ map that we would get in the Deep Field (I have selected a patch with prominent local clusters).

HR15m, cluster counts

- From Planck source counts. Assume 2 arcmin diameter clusters

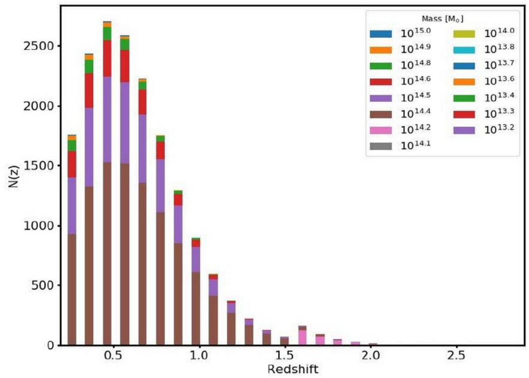
  - Wide survey:

  26,000 clusters at 5 σ (Y=8 10^{-5} arcmin^2) at 150 GHz

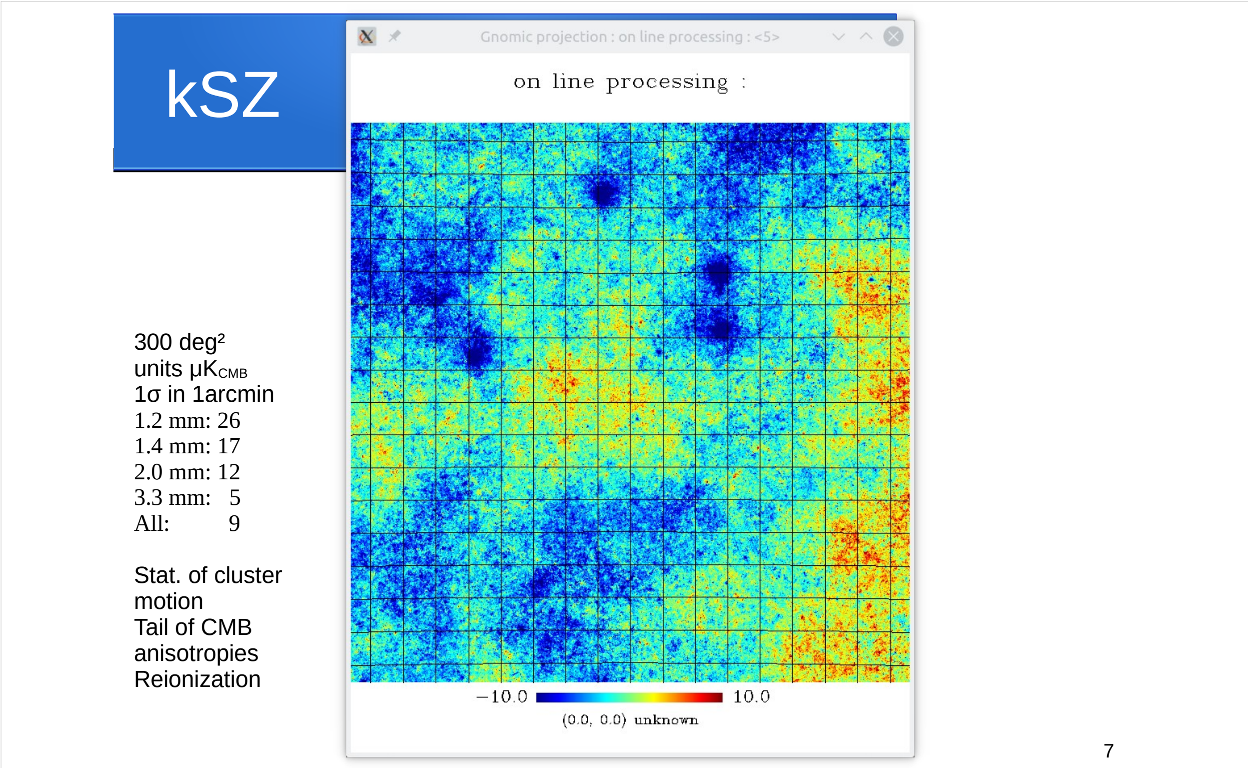
  - Deep survey:

  26,000 clusters at 5 σ (Y=2 10^{-5} arcmin^2) at 150 GHz

Formation and Evolution of clusters:
→ Access the high-redshift domain
Map the filaments between clusters: the food for cluster growth

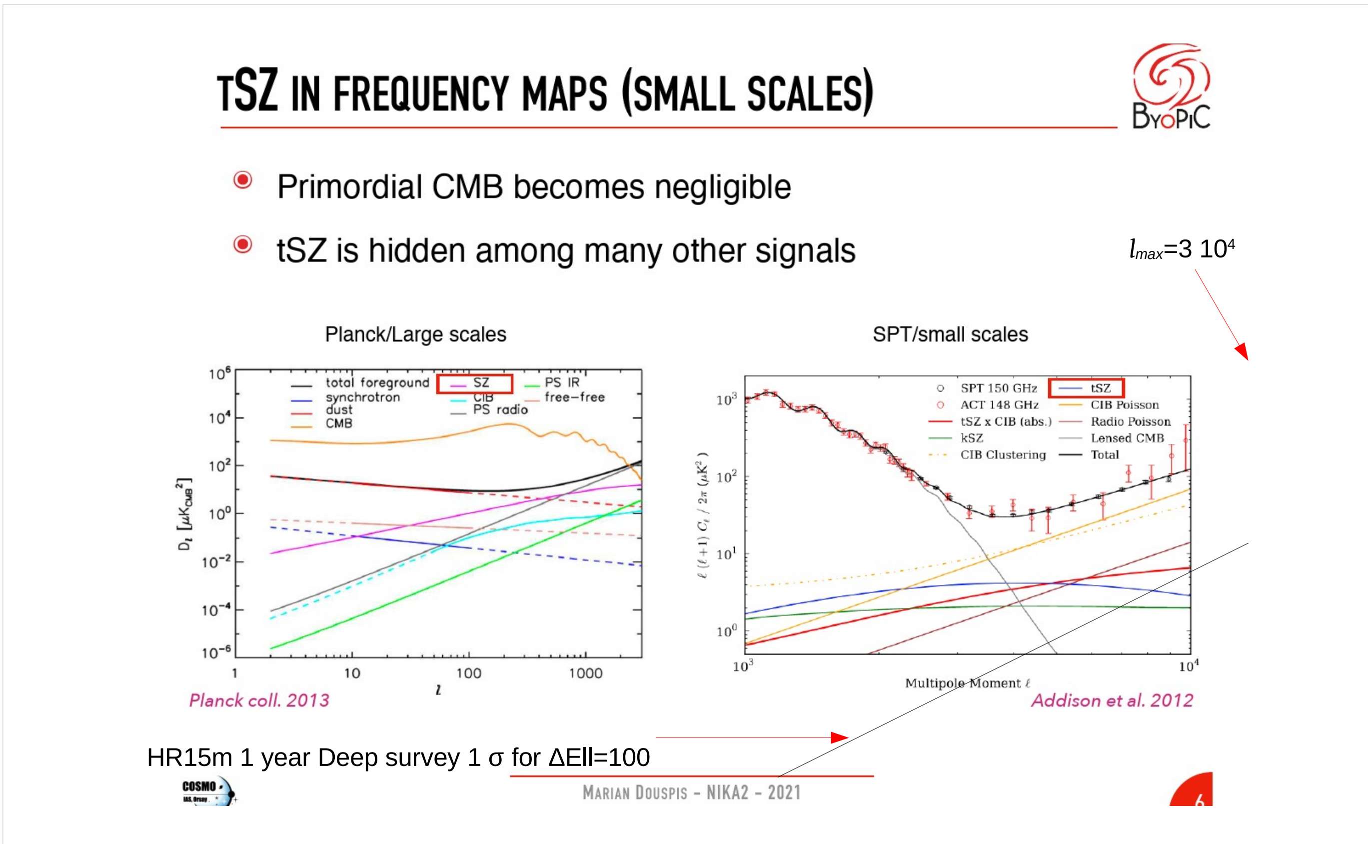


So we did a typical cluster number count deduction from the cluster surveys that exist and it is amazing that we expect as many clusters in the deep survey as in the white survey and we get something like 30,000 clusters, for each survey, at five Sigma.
And the histogram of redshifts reveals that we can have access to clusters at high redshift so these are clusters being formed and we could measure the relative contribution from the SZ and infrared sources in these clusters.

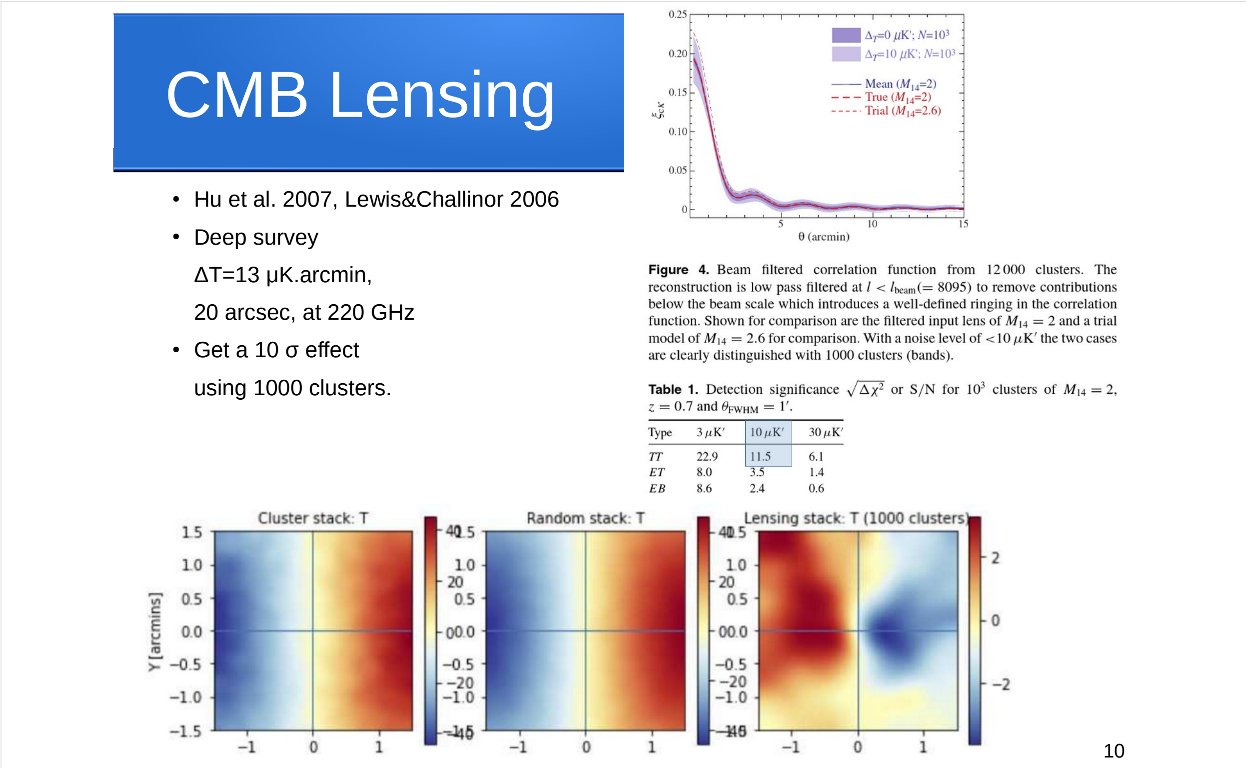


We can even go after the kinetic SZ effect which has the same color as CMB anisotropies. So we can combine the different photometric bands to get the kinetic SZ sensitivity by nulling the main thermal effect.

We get a sensitivity of nine microKelvin in one arc minute pixel. This sensitivity is limited for individual clusters but statistics of clusters will be the name of the game to detect large-scale motions.



Of course the situation is a bit more complex and we have to take into account all the components and in particular the CIB so if we remove sufficiently well the sources we can see that the CIB component and the kSZ components are at similar levels in terms of C sub ell so we have a leverage on reionization at high ell modes and in particular by compounding with SKA.

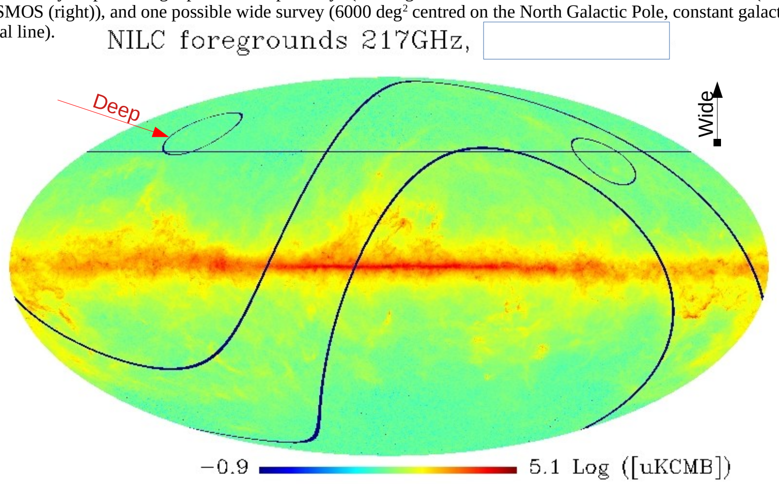


CMB lensing could be detected using this experiment if many clusters are stacked along the gradient of the CMB. The gravitational effect of clusters is to invert locally the gradient and by differentiating the left map one can obtain the right map which shows a typical dipole signal. It should prove an interesting statistical measure of the lensing by clusters on the CMB.

Here the cluster mass convergence cross-correlation function is shown as a function of angular distance. Different masses of clusters can be distinguished at the 13% level.

Sky coverage

- Deep survey is 0.7% of sky and Wide survey is 15%
- f_{sky} ($|b| > 15$, $Dec > -15$) = 47% (20 000 deg^2); f_{sky} ($|b| > 30$, $Dec > -15$) = 33% (13 800 deg^2)
- $Dec = +22$ (ACT max), $Dec = -15$ (HR15m min): large overlap
- Here is an all-sky map showing 2 possible deep surveys (300 deg^2 each, the 2 circles centred on GOODS-North (left) and COSMOS (right)), and one possible wide survey (6000 deg^2 centred on the North Galactic Pole, constant galactic horizontal line).



So why is the Northern Hemisphere important to survey? First because it is a complement to Chile wide surveys . In order to show that I have shown the 1mm Planck sky galactic coordinates. The high declination line is the ACT boundary. The low declination is the Northern sky boundary. And you can see a big overlap in the galactic regions and in extragalactic regions.
Second reason is that there are so many surveys in the North.
So typically the wide survey would cover 15% of the sky in one year covering something like 6,000 square degrees at the North Galactic pole, whereas the Deep surveys could be concentrated on goods North and cosmos Fields which are covered at many wavelengths. If we are even more ambitious we can imagine to cover the whole northern Sky in five years at subarcminute resolution

Bandpasses 1/2

- No need for polarizer grids, just a (warm) dichroic (1mm vs 2/3 mm)
- Strong case for a wide survey : cluster counts, CIB
- Strong case for a deep survey : cluster physics, kSZ, lensing + CIB
- Component separation is essential: 3 bands at 1 mm would be best, with 1 band at 2 mm and 1 band at 3 mm.

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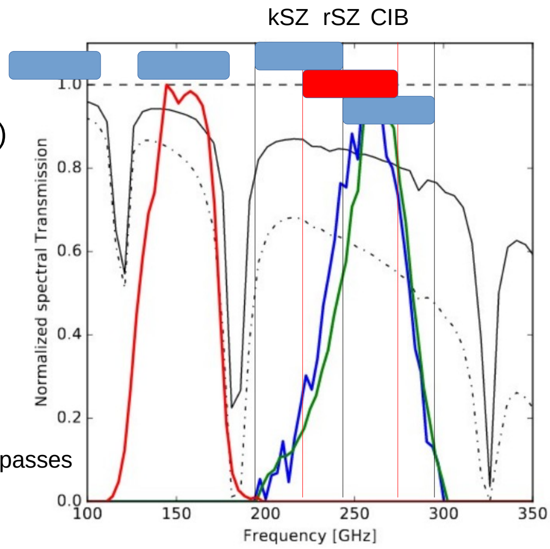
Now I enter into more technical discussions and one of them is about the band passes and the choice of photometric bands so I think the 1mmr band is dedicated to the CIB and dusty point sources but also the kSZ case is strong so we need to split the one millimeter band into several bands. the three millimeter channel is very useful for radio sources. The 2mm is thermal SZ sweet spot.

Bandpasses 2/2

- 5 bands of 50 GHz width
- 90 GHz radio-sources tSZ
- 150 GHz tSZ
- 195-245, kSZ (zero of tSZ) and lensing
- 220-275, t+rSZ
- 245-295, CIB

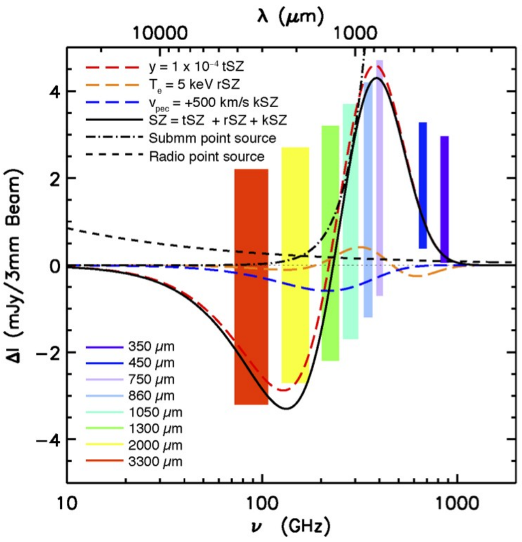


Nika2 bandpasses

Here is a possiblity of frequency distribution.

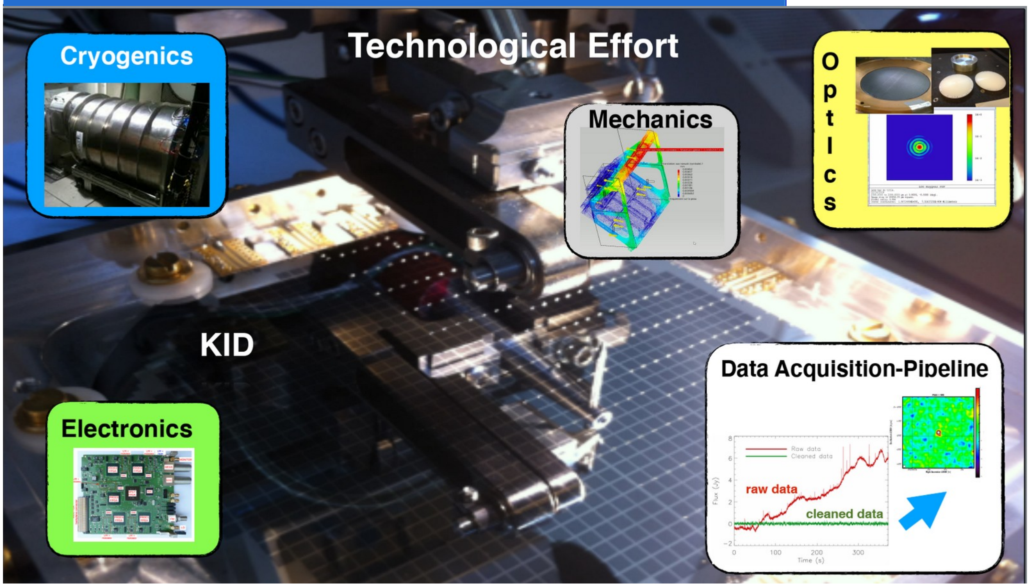
CCat bands

Corresponds to the photo mode submm extension



which is similar to the CCAT approach

NIKA2 legacy



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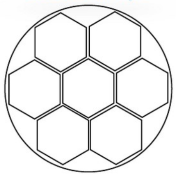
The NIKA2 legacy is there with cryogenics know-how, optics, mechanics, electronics and data acquisition. This has been followed by Kiss and Concerto instruments.

Detector Developments

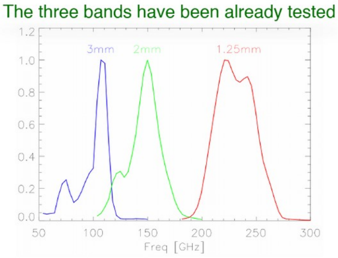
led to a GIS
LPSC I. Néel IPAG IRAM
nationally approved

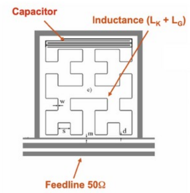
- 🟢 Design Based on Al (already tested on sky) and TiAl (qualify in Lab.)
- 🟡 Need to improve uniformity for 10kilo-pixel arrays.
- 🟢 Plan A based on dual-pol pixels (R&D in ongoing on pol on-chip developments).
- 🟢 Plan A based on mono-chromatic pixels (R&D in ongoing on pol on-chip developments).
- 🔴 Plan A, Mosaic of few 4-inches wafer (need a new machine to fabricate an whole array on a single wafer).
- 🔴 REU last Grenoble Version: 1GHz band-Multiplexing Factor = 500. Need to be improved.

FPUs can be arranged with several 4-inches LEKID arrays

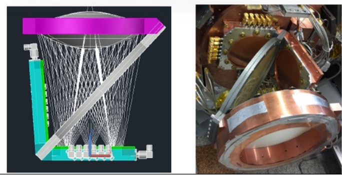


The three bands have been already tested





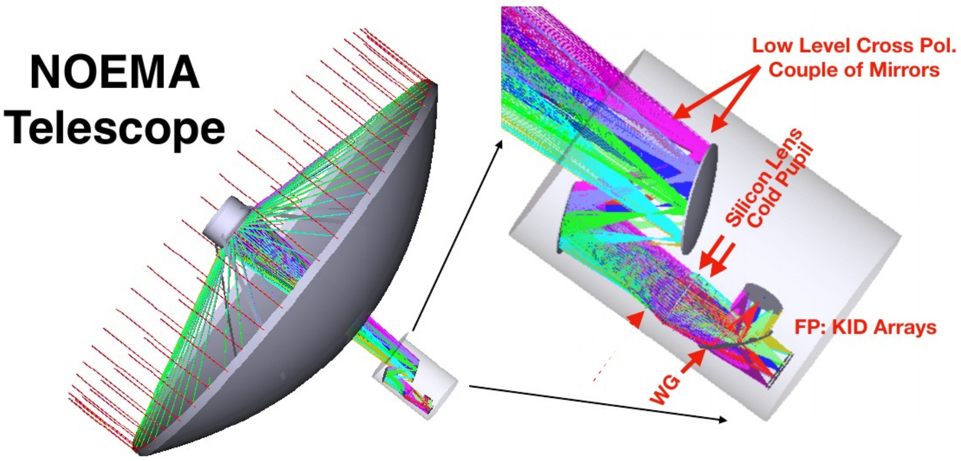
Dual Pol & Monochromatic is doable with a reasonable packaging (Ex. Concerto)



🟢 Qualified 🟡 In Progress 🔴 To be done

The major hurdle here is the scaling of the number of KIDs by a factor of 10.
We have a group of Grenoble laboratories that has a long history of taking innovative detectors to the telescopes.

HR15m in a nutshell 1/2



FOV~1sq. degree., first draft for the cryostat to be redesigned with intensity only

Pointing Req. 10 arcmin/s (30 if possible), data sampling (72 Hz (240)), data rate about 1TB/day (eq. Concerto) 17

So here is the possible implementation of a 15 Meter Telescope of NOEMA type and you can see the cryostat at the Cassegrain focus here in this implementation we considered polarization option. the Optics would be a bit simpler without polarization directly and we can accommodate a diameter for the field of view of typically 50 arcminutes so the system would split the different wavelengths with dirchroic and polarizing grids.

This design is very preliminary but it shows that it is basically feasible to cover a large field of view in a 15-meter telescope.

One of the constraints that we have identified comes from the Pointing requirements to beat the sky noise. We need to be able to scan the sky as fast as possible and because the kids have negligible time constant we can try to scan the sky typically at 10 arcminutes per second which is one field of view every four seconds and the data rate wouldn't be a major problem because it's typically the same as in Concerto instrument

HR15m in a nutshell 2/2

- HR15m is a mm telescope of 15 m diameter with a single photometric mapping instrument covering 1.2-3.3mm at 20-60 arcsec resolution. About 20,000 KIDs at 150 mK over a FOV diameter of 48 arcmin, covering the whole Northern Hemisphere in 5 years.15m@ 1-2-3mm: beam 19-55 arcsec
- Intensity only with these assumptions: 0.8 fraction of good kids, pwv=4mm, elevation=45 deg. Weather efficiency=0.5, Calib overhead=0.67, means one hour of survey costs 3 hours of observations (CMB-HD assumes 20% efficiency, here we take 33%)
- Wide survey (1 year, 6000 sq. deg) 1.0-0.3 mJy 1 σ, 0.180-0.004 MJy/sr, beat cosmic variance, 14 μK_{CMB}.arcmin
- Deep survey (1 year 300 sq. deg) 0.4-0.1 mJy, 3 μK_{CMB}.arcmin, ell_{max}~30,000
- Project cost: 15-30 M€ = 5-10M€ (antenna) + 5-10M€ (instrument) + 1-2M€ annual running cost (x 5 years), Need for an observatory and community (Europe level) support
- Cosmological targets (SZ, lensing B-modes), Extragalactic targets (CIB, Galaxies), Galactic (complete mm census), Planet 9, The Transient Universe.
- Timing: 2024-2028 design-construction, then 2029 commissionning, 2030-2034 surveys
- A low cost, fast-track, all sky mm survey at high angular resolution: where ISM meets CMB! Find the needles in the haystack for follow-up by Noema/Alma/30m.

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This would require two telescopes I can discuss that during the questions here I'm talking mostly about a Northern Hemisphere 15 meter survey telescope. That survey would require an observatory fully funded so that's why we have updated for project costs which is realistic and we cannot invent such a facility and would have to be implemented in existing facility so principally I'm talking about the IRAM facilities in France or Spain or Spanish activity in Tenerife or in Greenland but it would require infrastructure.

Scientific drivers for a high angular resolution mm observatory

The mass assembly and evolution in the Universe

- Secondary anisotropies
  - SZ cluster multiband census tSZ, stacking, lensing : Goal 1
  - SZ diffuse: cosmic web and kSZ, the missing baryons
  - Reionization: kSZ and intensity mapping

  } Goal 2
- CIB and point-sources — Goal 3
- Neargy galaxy mapping
- Planet 9
- Serendipity: finding transients
- Stacking and cross-correlating with other wavelengths
  - References for lensing: CMB-HD Sehgal et al. 2019, NGuyen et al, 2019, Phys.Rev.D

We have centered the project on 3 equal goals. Of course, many other scientific topics would benefit from such a project.

2030: Scientific and Political context

- eRosita, Euclid, Rubin-LSST, SKA, Athena, Litebird, Pixie, SphereX, all with big chunks of sky, all in the G€ land.
- SO being deployed in the 100M$, CMB-S4 2025-2035: 1-2G$ (600M$ + 32 annual ops.), .
- CCat-Prime 6m submm surveyor (started)
- ESO ATLAST 50m and Phase A Synergy ERC project 300 M€+
- Astrodecadal survey out, CMB-HD 2*30m= 1.5G$ was proposed (not approved), CMB-S4 is launched
- ESA Voyage 2050 out: an ESA mission, a microwave spectroscopy explorer, with plausible target launch date around 2040, with moderate resolution (R=300) for CMB and intensity mapping
- in France, strong community support, beyond Litebird, to get involved in ground-based CMB polarization experiments (INSU, IN2P3, INP)
- Local Grenoble context : Planck/Archeops, NIKA2, Concerto … (a kind of Moore’s law), coordinated by GIS KIDs
- Key issue (completely open at this time): Telescope site and Observatory operations

Matrix for wide-field CMB experiments

Multiple choices for experiment diversity

- Intensity/Polarization
- Photometry/Spectroscopy,
- mm/submm and wavelength coverage,
- 10m+ or 6m,
- Ground-based/Space
- Sky coverage

Ground		> 10m	<10m
North	mm photom	This Project HR15m	AliCPT
	mm spectro		
	submm photom	Scuba2/JCMT	
South	mm photom	SPT, CMB-HD, Atlast	ACT, SO, CCATp, CMB-S4
	mm spectro	Concerto/Apex	CCATp
	submm	AtLast	CCATp

The niche for this project: the Northern Hemisphere, the high-angular resolution, the reasonable size of the project, the natural ground-based mm follow-up of Planck and Herschel, all-sky

Conclusions

- Deep survey: CIB, Cosmic web: the missing baryons and kSZ, reconstructing the gravitational potential observing reionization.
- Wide survey: go for counting clusters with SZ, find submm rare (lensed) sources and count radio sources.
- Map the northern sky (ISM and nearby galaxy studies)
- Remove the CIB and sources from S4 experiments. Help delensing CMB-B mode experiments.
- The telescope could be modified e.g. with more spectroscopic resolution in the future: line-intensity mapping or e.g. polarization capabilities
- Cross-correlation with other datasets will be critical

Backup slides

- 1306.2322: Ettori et al. advocate the use of Athena to observe the outskirts of clusters and the Cosmic Web. Athena will measure the dynamics of clusters (K line redshift), and the entropy profile will tell if AGN feedback is important over the graviational heating only

  → the main goal of Athena is the large-scale structure assembly in the Universe (groups and clusters)

- 1306.2324: Kaastra et al. The missing baryons.

  today's observations can only account for <60% of the baryons that our precision cosmology predicts in our local Universe, and that have been detected in the high-z linear Universe (e.g. Fukugita 2003; Shull et al. 2012)

  Cluster outskirts are a melting pot, where cosmic baryons convert their kinetic energy of the infall into the thermal energy of the hot gas.

Filaments between Clusters

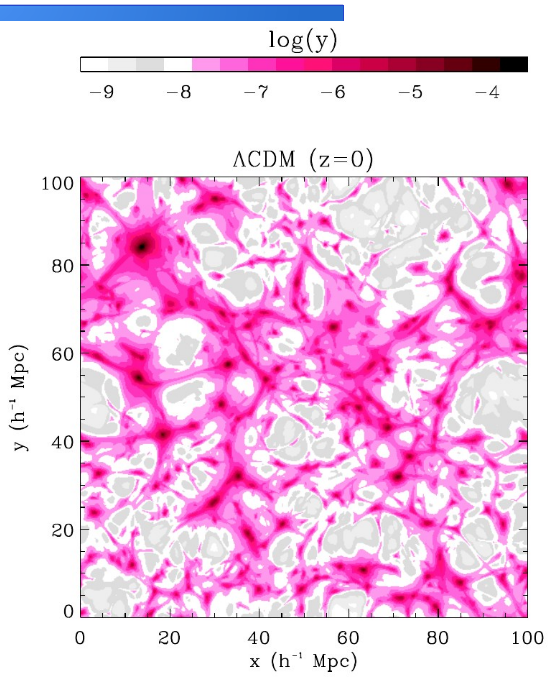
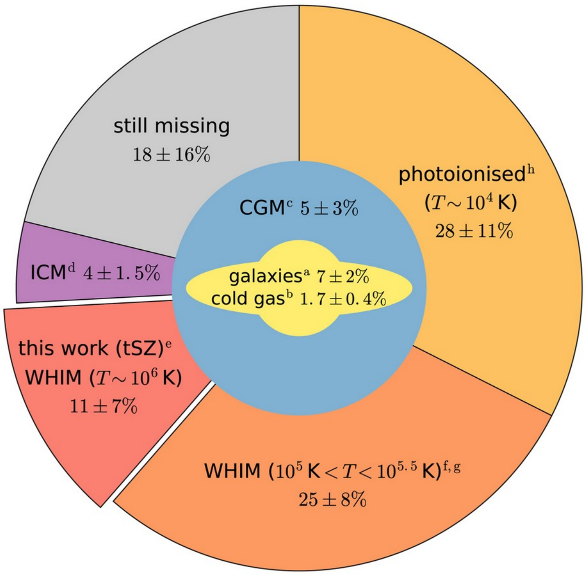


FIG. 2. Comptonization-parameter map for the ΛCDM simulation at $z = 0$.

Refregier et al 2000, 10.1103/PhysRevD.61.123001

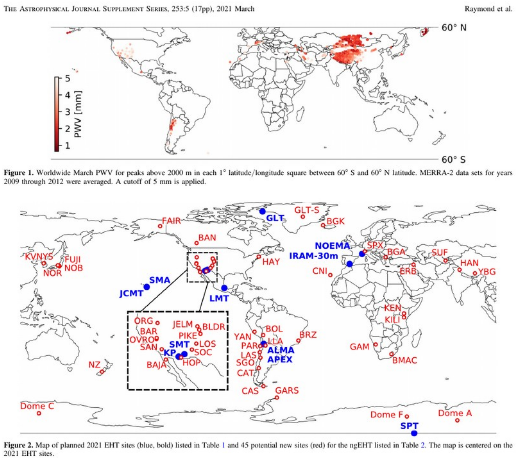
Missing Baryons



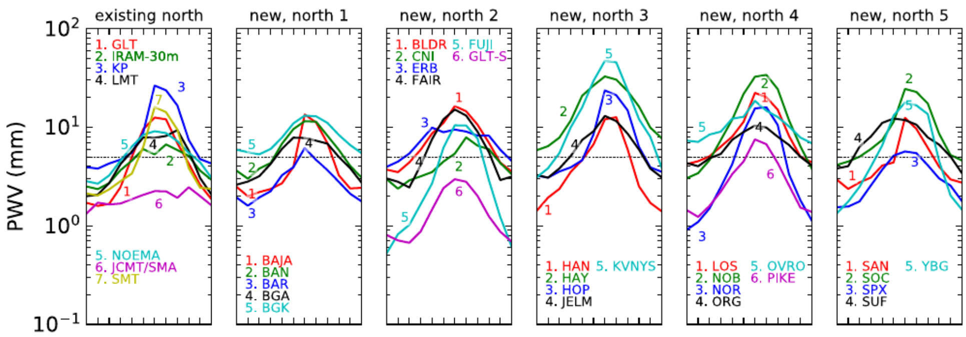
de Graaf et al., 2019, AA, 624, A48
3σ detection of filaments between galaxies (SDSS), with Planck
See also Tanimura et al 2019, 2020

Atmosphere 1/2

- Raymond, et al. 2021 study VLBI sites for EHT



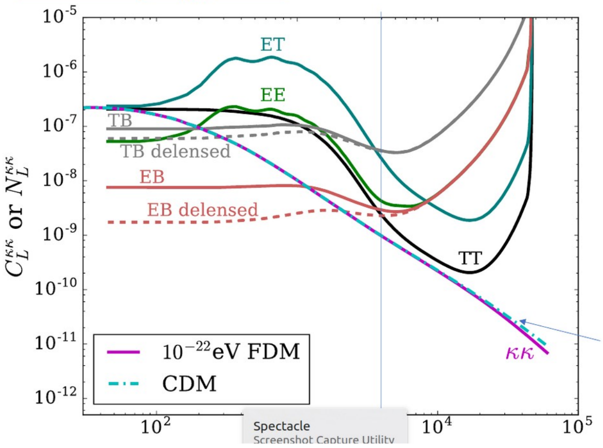
Atmosphere 2/2



For sensitivity calculations, we have adopted: pwv=4, elevation 45 deg.
and 0.5 weather efficiency and 0.67 efficiency (calibration/technical overheads)

Cosmology from large scale structure

HR CMB lensing in Nguyen+2017



Noises using various map combinations

- At ell>4000 (FWHM < 2.5′), lower noise from temperature only than from polar.
- lensing powspec measurement at scales non-accessible by SO or CMB-S4 (5000 < L < 20000)

Signal (matter power spectrum)

Cluster cosmology

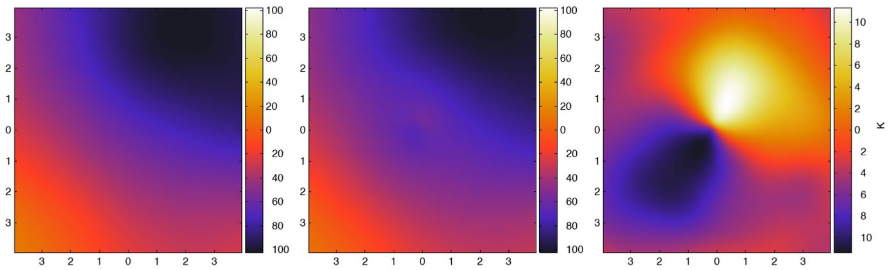


Fig. 19. Simulated effect of cluster lensing on the CMB temperature. Left: the unlensed CMB; middle: the lensed CMB; right: the difference due to the cluster lensing. The cluster is at redshift one, and has a spherically symmetric NFW profile with mass of $m_{200} = 10^{15} h^{-1} M_{\odot}$ and concentration parameter $c = 5$ (see Refs. (160; 162)). Distances are in arcminutes, and can be compared to the cluster virial radius of 3.3 arcmin. In the middle figure note the direction of the gradient inverts inside the ~ 1 arcmin Einstein radius where the lensing deflections cross the centre of the cluster. This is a rather clean realization, in general the dipole pattern can be weaker and/or more complicated.

Lewis, A., & Challinor, A. 2006, PhR, 429, 1

Sensitivity ½
Deep survey

19 … 23 …… 33 …..55 arcsec

SynKid 15m		Intensity					
		1.2mm	1.4mm	2mm	3.3mm		
	Central Frequency	260	220	150	90	GHz	
	DEEP SURVEY						
2920	Observing time on source (hr)					hr	
8760	Effective total observing time (hr)					hr	
365	id. (days)					days	
0.007	Sky fraction observed						
300	(sq. degree)					deg²	
597	Number of FOV in survey	1,364	1,061	1,190	1,198		
	Time per field of view	2.14	2.75	2.45	2.44	hr	
	dTCMB rms per beam	83.5	35.5	11.2	4.8	uKCMB	
	Point source sensitivity (1sigma)	0.37	0.23	0.13	0.08	mJy	
	y sensitivity (1sigma) per beam	45.5	346.0	4.3	1.1	micro	
	1 sigma diffuse emission per beam	0.0381	0.0172	0.0045	0.0010	MJy/sr	
	1 sec, dTCMB per det	7,328	3,537	1,055	448	ukCMB.s1/2	
	1 sec, dTRJ per det	1,612	1,151	608	365	ukRJ.s1/2	
	mission noise in sqrt(Cl)	25	12	6	4	uKCMB.arcmin	
	aggregated			3.2		uKCMB.arcmin	For kSZ, nulling tSZ gives a sensitivty of 9 uK.arcmin
10000	ell_ref					No smoothing, per mode	
	ell(ell+1)DeltaCl/(2pi)	114.0	30.7	8.4	9.7	uKCMB^2	
	Density of sources at 5sigma	1.30E+06		28,143.0	51,203.8	sr-1	
	Number of sources at 5sigma	1.18E+05		2,572	4,679	Over the surveyed area	
	Lensed source above 10mJy		65			Over the surveyed area	
	Y(5 sigma) over cluster diam.			1.86E-05	7.90E-06	arcmin²	
	Number of clusters at 5sigma			26,276	146,285	Over the surveyed area	

Sensitivity 2/2
Wide Survey

SynKid 15m		Intensity					
		1.2mm	1.4mm	2mm	3.3mm		
	Central Frequency	260	220	150	90	GHz	
	WIDE SURVEY						
2,920	Observing time on source (hr)					hr	
8,760	Effective total observing time (hr)					hr	
365	id. (days)					days	
0.143	Sky fraction observed						
6,000	(sq. degree)					deg²	
11,937	Number of FOV in survey	27,284	21,221	23,791	23,956		
	Time per field of view	0.11	0.14	0.12	0.12	hr	
	dTCMB rms per beam	373.3	158.9	50.2	21.4	uKCMB	
	Point source sensitivity (1sigma)	1.65	0.86	0.45	0.27	mJy	
	y sensitivity (1sigma) per beam	203.6	1547.2	19.3	4.9	micro	
	1 sigma diffuse emission per beam	0.1705	0.0769	0.0200	0.0043	MJy/sr	
	1 sec, dTCMB per det	7,328	3,537	1,055	448	ukCMB.s1/2	Clas
	1 sec, dTRJ per det	1,612	1,151	608	365	ukRJ.s1/2	
	1 sec, dTCMB array	78	39	18	13	ukCMB.s1/2	Clas
	mission noise in sqrt(Cl)	111	56	26	18	uKCMB.arcmin	Clno
	aggregated			14		uKCMB.arcmin	Plan
1000	ell_ref						ell(el
	ell(ell+1)DeltaCl/(2pi)	13.85	3.51	0.75	0.38	uKCMB^2	
	Density of sources at 5sigma	4.21E+03		8,033.1	14,666.3	sr-1	
	Number of sources at 5sigma	7.70E+03		14,682	26,806	Over the surveyed area	
	Lensed source above 10mJy		1,292			Over the surveyed area	
	Y(5 sigma) over cluster diam.			8.34E-05	3.53E-05	arcmin²	
	Number of clusters at 5sigma			26,276	146,285	Over the surveyed area	