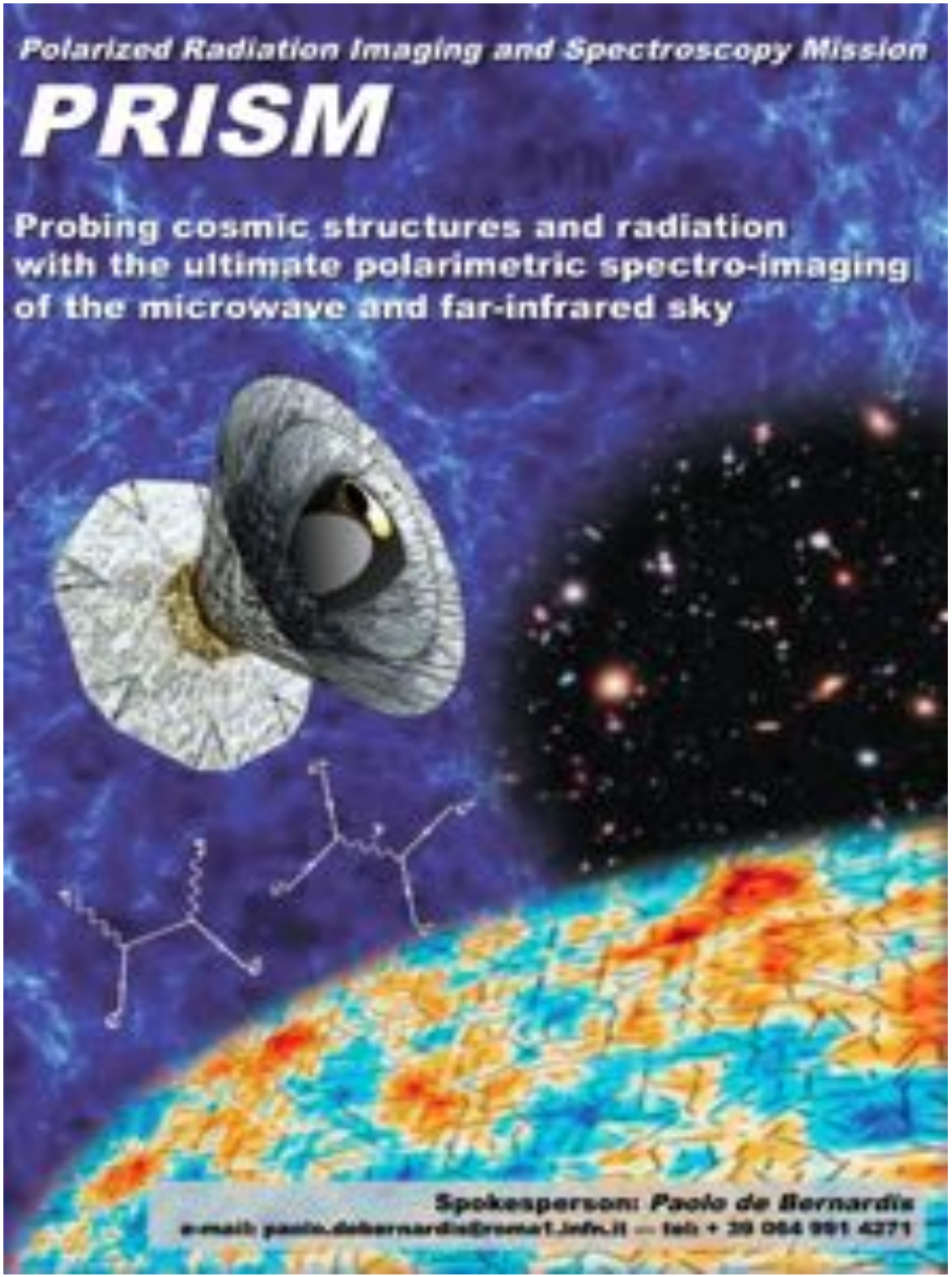
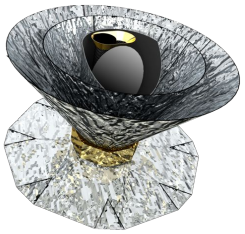


PRISM

Science case and mission concept

Jacques DELABROUILLE

for the PRISM team



Context and calendar

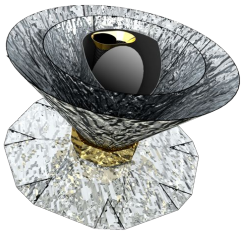
ESA call for proposed ***science areas*** for the next two L-class missions, L2 (≈2028) and L3 (≈2034).

Came as a surprise:

- Call issued early March,
- White paper due May 24th
- Open workshop September 3rd - 4th in Paris
- Selection of two science areas for L-class missions in October
- *Before* the call for the next M-class mission (2014, for a launch ≈ 2027)!

Budget (rather ambitious):

- 900 million euro (ESA cost)
- Instruments from national space agencies
- Up to 20% foreign (non-European) participation



A proposed L-class ESA mission

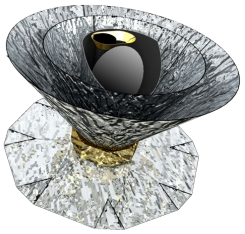
IDEA: survey the complete sky in total intensity and polarisation from 30 GHz to 6 THz with two instruments jointly operated:

- A polarimetric imager with a 3.5 m mirror actively cooled to 4 K
  - 32 large frequency channels with $\Delta\nu/\nu \approx 0.25$
  - ≈300 narrow bands with $\Delta\nu/\nu \approx 0.025$

- An absolute spectro-photometer with a 50 cm mirror, and two operation modes ($\Delta\nu$=0.5 GHz and $\Delta\nu$=15 GHz), for two compromises between spectral resolution and sensitivity.
  - Measure the zero-level of maps at all frequencies
  - Absolute calibration of the polarimetric imager on sky data

---

IDEA: a few well-identified areas for science breakthrough + a legacy survey useful for many scientific applications, with a very large discovery potential.



Science case: why PRISM ?

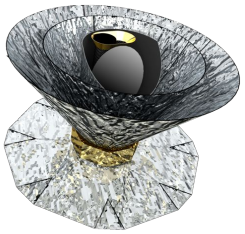
- Primordial CMB B-modes, high precision CMB T (absolute!) and E

- CMB spectral distortions
  - thermal history, energy exchanges between CMB and matter
  - reionisation, decaying dark-matter particles, small scale primordial P(k)

- 3D structures:
  - A complete census of galaxy clusters (hot baryons and mass up to z>3)
  - CMB lensing (projected mass)
  - The CIB and dusty galaxies (up to z>6) – dust, AGNs and interplay, P(k) in shells

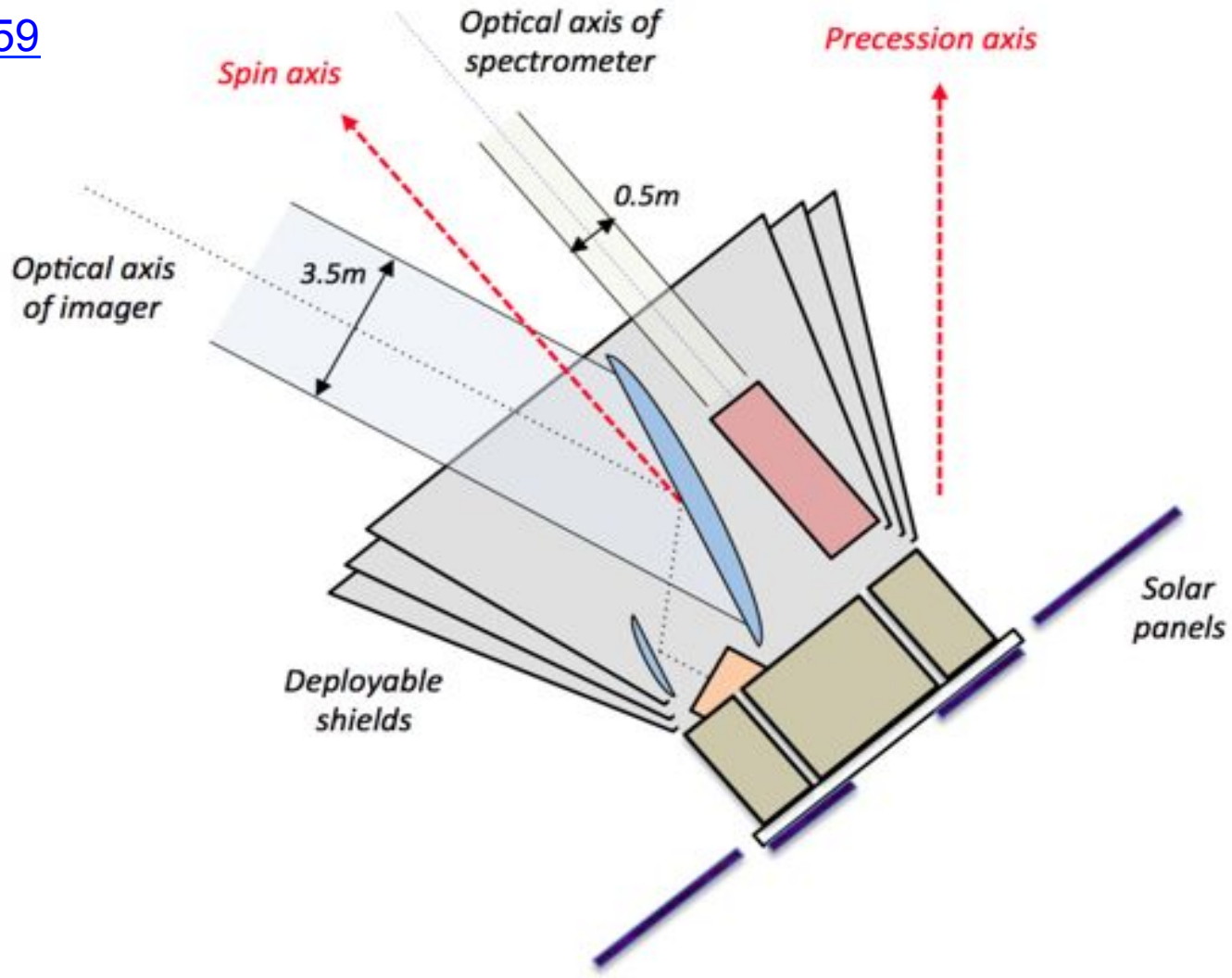
- 3D cosmic velocity flows

- All phases of the galactic interstellar medium:
  - Dust (thermal, spinning, size and chemical composition)
  - Cosmic rays (synchrotron components)
  - Gas (neutral and ionised), free-free, atoms and molecules, molecular clouds,
  - Magnetic field via polarisation of dust (and synchrotron)



The PRISM mission concept

http://arxiv.org/abs/1306.2259



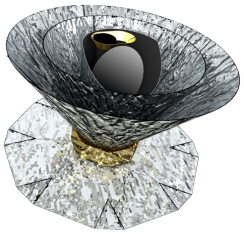
Polarised

Radiation

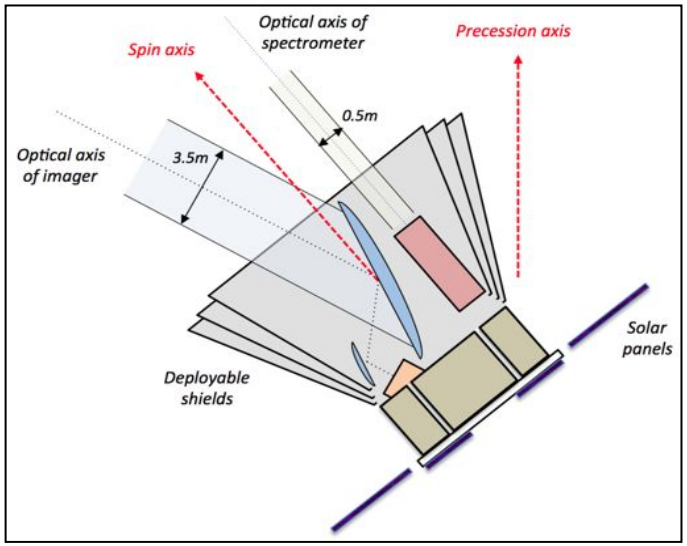
Imaging and

Spectroscopy

Mission

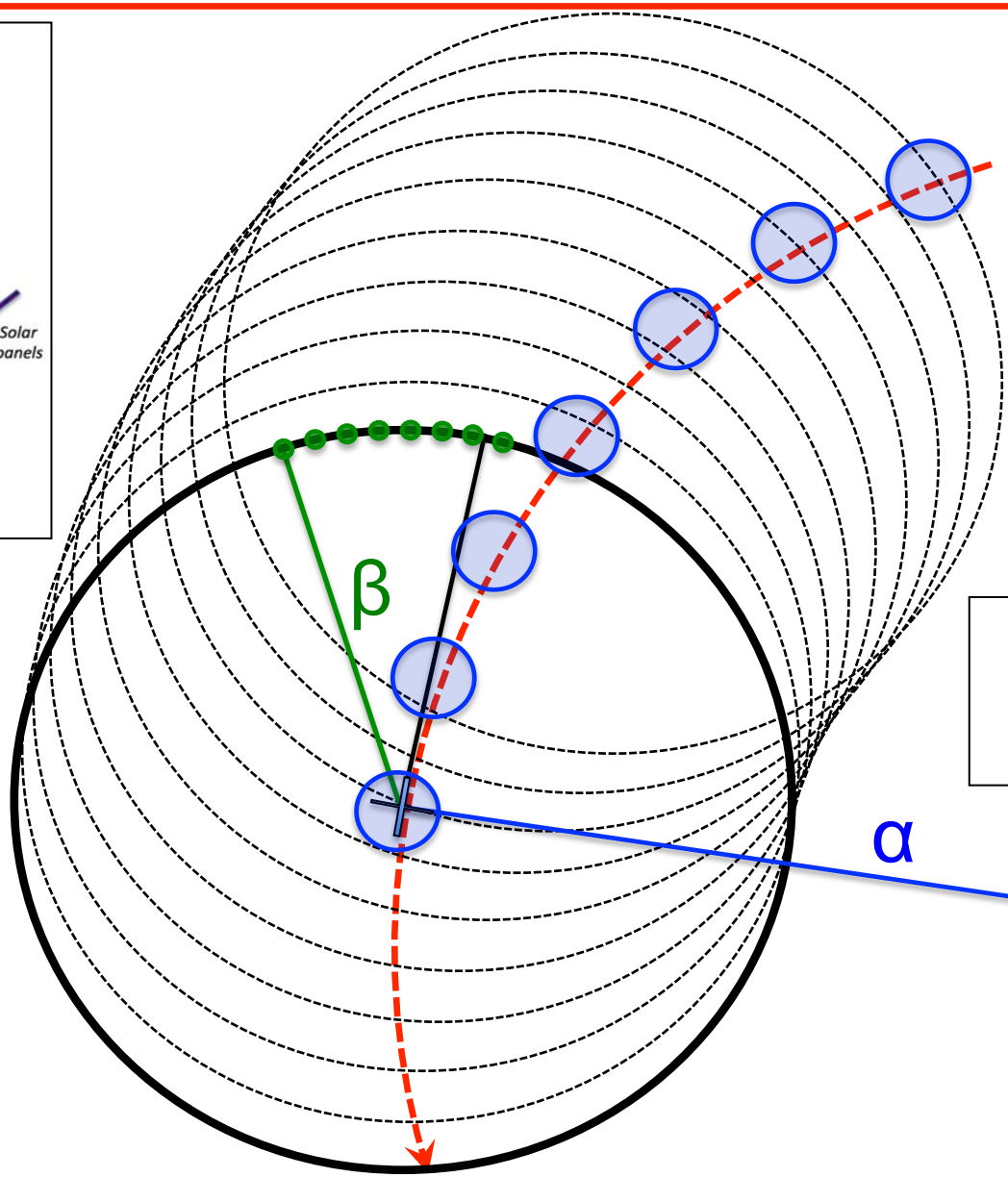


Scanning strategy

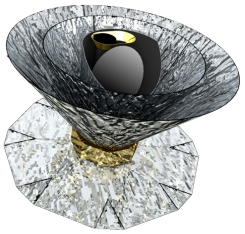


Imager
≈ 1' beam

Spectrometer
≈ 1.4° beam



To be optimised:
α ≈ 45°
β ≈ 30°

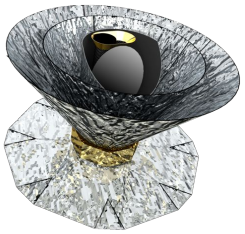


The polarimetric imager

- The polarimetric imager (PIM) is designed to map the full sky brightness fluctuations in intensity and polarisation
  - in as many bands as possible between 30 GHz and 6 THz
  - with the best possible angular resolution and sensitivity

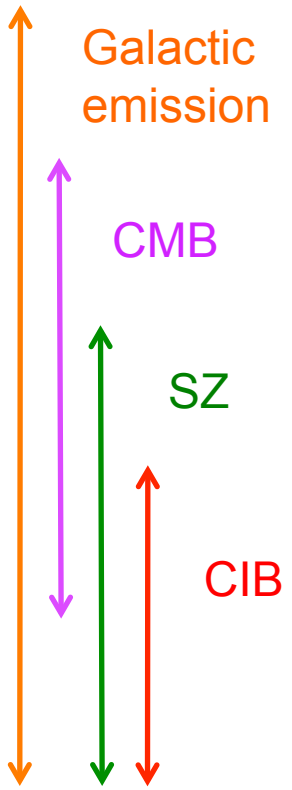
- Compromise between sensitivity and spectral resolution
  - 50% of detectors in 32 broad-band channels with $\Delta\nu/\nu \approx 0.25$
  - 50% of the detectors in 300 narrow-band channels with $\Delta\nu/\nu \approx 0.025$

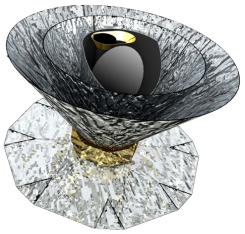
- Compromise between sensitivity and angular resolution
  - For the moment, angular resolution is preferred (single mode detectors at the diffraction limit).
  - Can be reconsidered for the narrow-band detectors (to map faint spectral lines at high frequency)



The polarimetric imager

ν_0 GHz	range GHz	$\Delta\nu/\nu$	n_{det}	θ_{fwhm}	σ_I per det 1 arcmin μK_{RJ}	σ_I per det 1 arcmin μK_{CMB}	$\sigma_{(Q,U)}$ per det 1 arcmin μK_{RJ}	$\sigma_{(Q,U)}$ per det 1 arcmin μK_{CMB}	main molec. & atomic lines
30	26-34	.25	50	17'	61.9	63.4	87.6	89.7	
36	31-41	.25	100	14'	57.8	59.7	81.7	84.5	
43	38-48	.25	100	12'	53.9	56.5	76.2	79.9	
51	45-59	.25	150	10'	50.2	53.7	71.0	75.9	
62	54-70	.25	150	8.2'	46.1	50.8	65.2	71.9	
75	65-85	.25	150	6.8'	42.0	48.5	59.4	68.6	
90	78-100	.25	200	5.7'	38.0	46.7	53.8	66.0	HCN & HCO^+ at 89 GHz
105	95-120	.25	250	4.8'	34.5	45.6	48.8	64.4	CO at 110-115 GHz
135	120-150	.25	300	3.8'	28.6	44.9	40.4	63.4	
160	135-175	.25	350	3.2'	24.4	45.5	34.5	64.3	
185	165-210	.25	350	2.8'	20.8	47.1	29.4	66.6	HCN & HCO^+ at 177 GHz
200	180-220	.20	350	2.5'	18.9	48.5	26.7	68.6	
220	195-250	.25	350	2.3'	16.5	50.9	23.4	71.9	CO at 220-230 GHz
265	235-300	.25	350	1.9'	12.2	58.5	17.3	82.8	HCN & HCO^+ at 266 GHz
300	270-330	.20	350	1.7'	9.6	67.1	13.6	94.9	
320	280-360	.25	350	1.6'	8.4	73.2	11.8	103	CO, HCN & HCO^+
395	360-435	.20	350	1.3'	4.9	107	7.0	151	
460	405-520	.25	350	1.1'	3.1	156	4.4	221	CO, HCN & HCO^+
555	485-625	.25	300	55"	1.6	297	2.3	420	C-I, HCN, HCO^+, H_2O, CO
660	580-750	.25	300	46"	0.85	700	1.2	990	CO, HCN & HCO^+



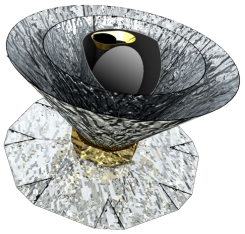


The polarimetric imager

					nK_{RJ}	kJy/sr	nK_{RJ}	kJy/sr	
800	700-900	.25	200	38"	483	9.5	683	13.4	
960	840-1080	.25	200	32"	390	11.0	552	15.6	
1150	1000-1300	.25	200	27"	361	14.6	510	20.7	
1380	1200-1550	.25	200	22"	331	19.4	468	27.4	N-II at 1461 GHz
1660	1470-1860	.25	200	18"	290	24.5	410	34.7	
1990	1740-2240	.25	200	15"	241	29.3	341	41.5	C-II at 1900 GHz
2400	2100-2700	.25	200	13"	188	33.3	266	47.1	N-II at 2460 GHz
2850	2500-3200	.25	200	11"	146	36.4	206	51.4	
3450	3000-3900	.25	200	8.8"	113	41.4	160	58.5	O-III at 3393 GHz
4100	3600-4600	.25	200	7.4"	98	50.8	139	71.8	
5000	4350-5550	.25	200	6.1"	91	70.1	129	99.1	O-I at 4765 GHz
6000	5200-6800	.25	200	5.1"	87	96.7	124	136	O-III at 5786 GHz

Galactic emission

CIB & dusty galaxies

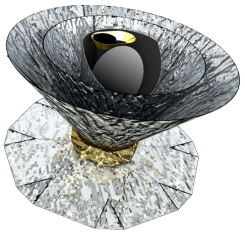


The spectrophotometer

- The absolute spectrophotometer (ASP) is designed both to
  - measure the absolute sky emission between 30 GHz and 6 THz
  - serve as an absolute on-sky calibrator for the PIM

- Main idea: complementarity
  - The spectrophotometer measures the l=0 mode
  - Both the ASP and the PIM measure modes from l=1 to l≈100 (Intensity)
  - The PIM measures modes up to l≈6000 or more in Intensity and Polar

- Compromise between sensitivity and spectral resolution
  - Two operating modes: high resolution for matching band with PIM (by coadding ASP high-res channels) and for spectral line survey, low resolution for sensitivity to CMB.



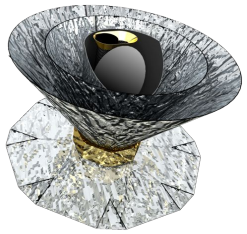
The spectrophotometer

band (GHz)	resolution (GHz)	$A\Omega$ ($cm^2 sr$)	background (pW)	NEPν ($W/m^2/sr/Hz \times \sqrt{s}$)	global 4-yr mission sensitivity ($W/m^2/sr/Hz$)
30-6000	15	1	150	1.8×10^{-22}	1.8×10^{-26}
30-500	15	1	97	7.0×10^{-23}	7.2×10^{-27}
500 - 6000	15	1	70	1.7×10^{-22}	1.7×10^{-26}
30-180	15	1	42	3.5×10^{-23}	3.6×10^{-27}
180-600	15	1	57	6.3×10^{-23}	6.5×10^{-27}
600-3000	15	1	20	7.4×10^{-23}	7.6×10^{-27}
3000-6000	15	1	28	1.6×10^{-22}	1.6×10^{-26}

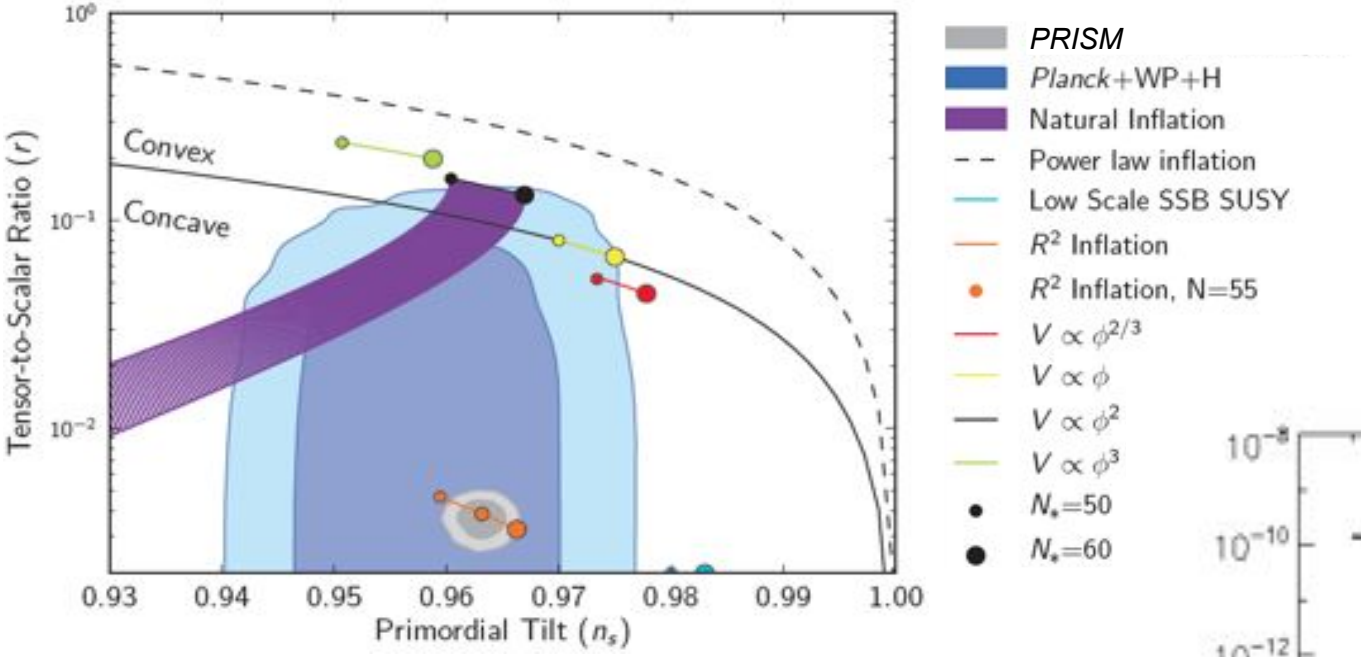
Martin-Puplett FTS

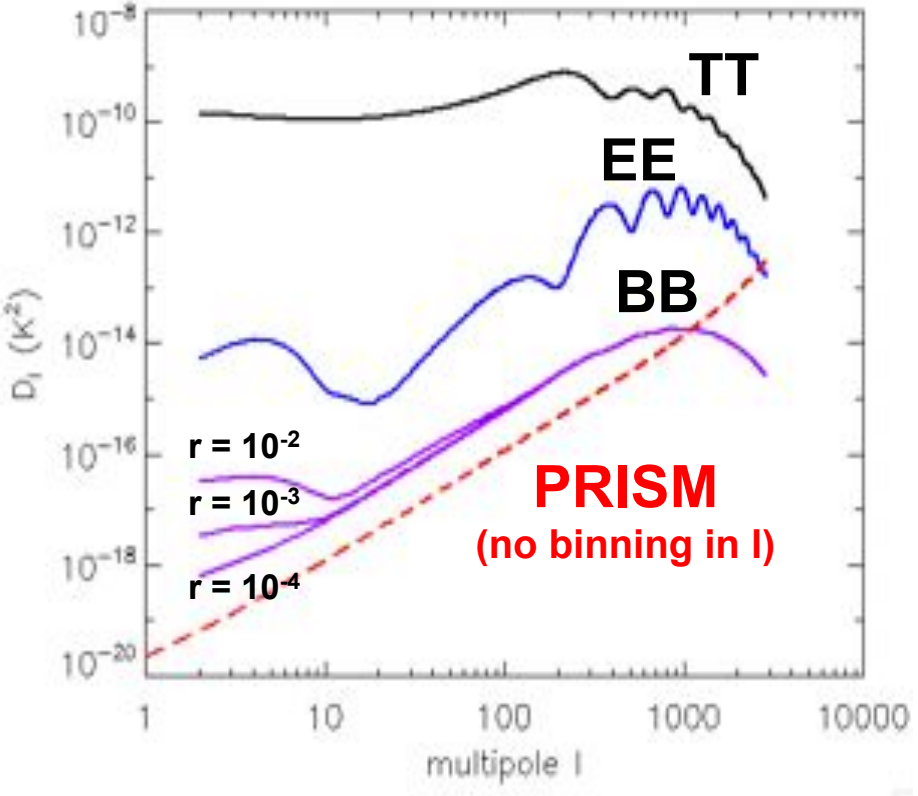
Three possible configurations, best option TBD:

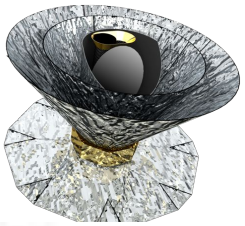
- Full band at both outputs
- Half the band at each output
- Half the band at each output + dichroic to split the band on two detectors



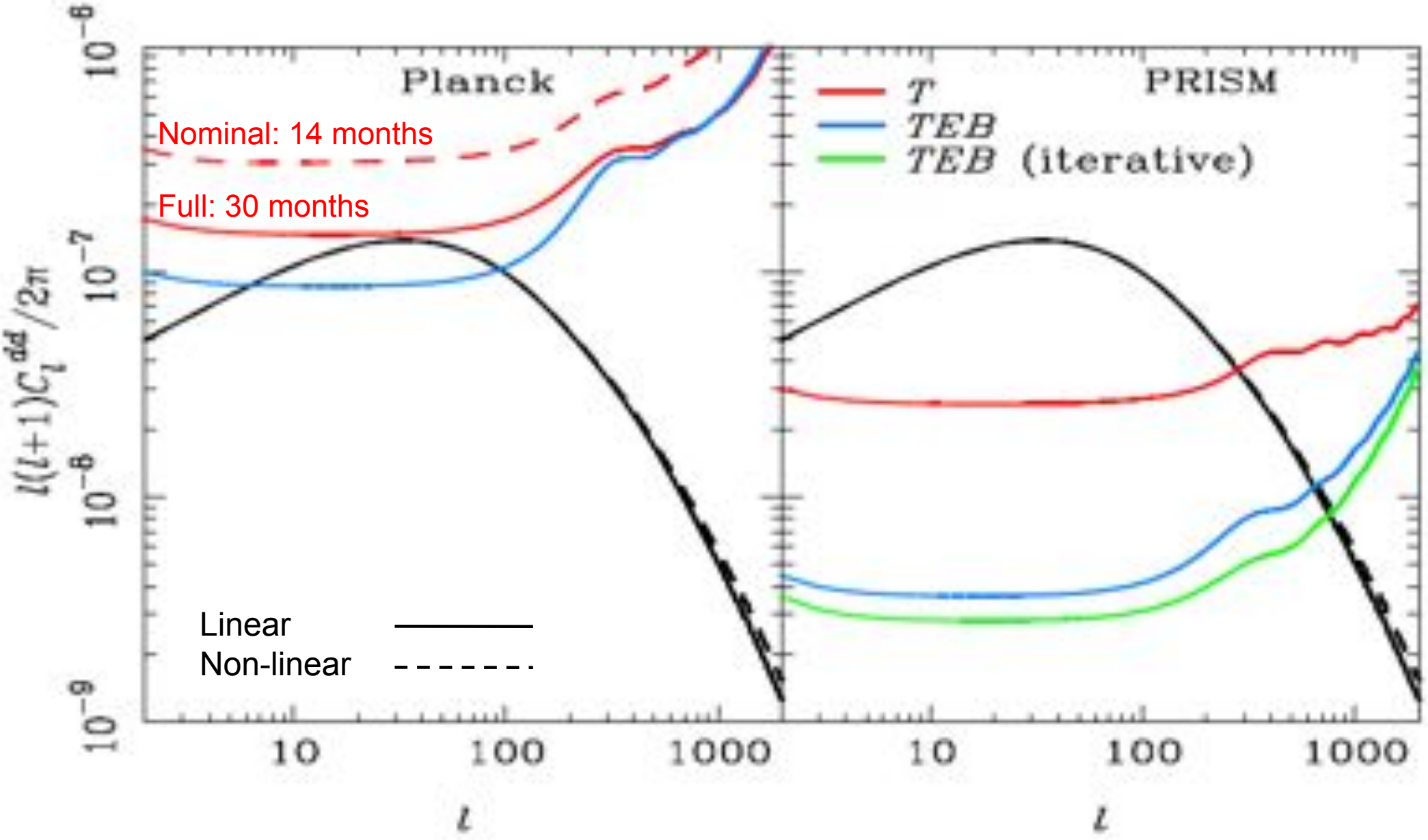
CMB B-modes

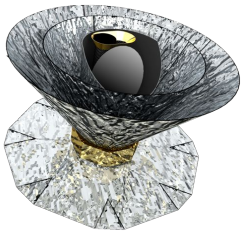

Tensor-to-Scalar Ratio (r)
Primordial Tilt (n_s)
Convex
Concave
PRISM
Planck+WP+H
Natural Inflation
Power law inflation
Low Scale SSB SUSY
R^2 Inflation
R^2 Inflation, N=55
$V \propto \phi^{2/3}$
$V \propto \phi$
$V \propto \phi^2$
$V \propto \phi^3$
N_*=50
N_*=60


TT
EE
BB
r = 10-2
r = 10-3
r = 10-4
PRISM
(no binning in l)
D_l (K^2)
multipole l

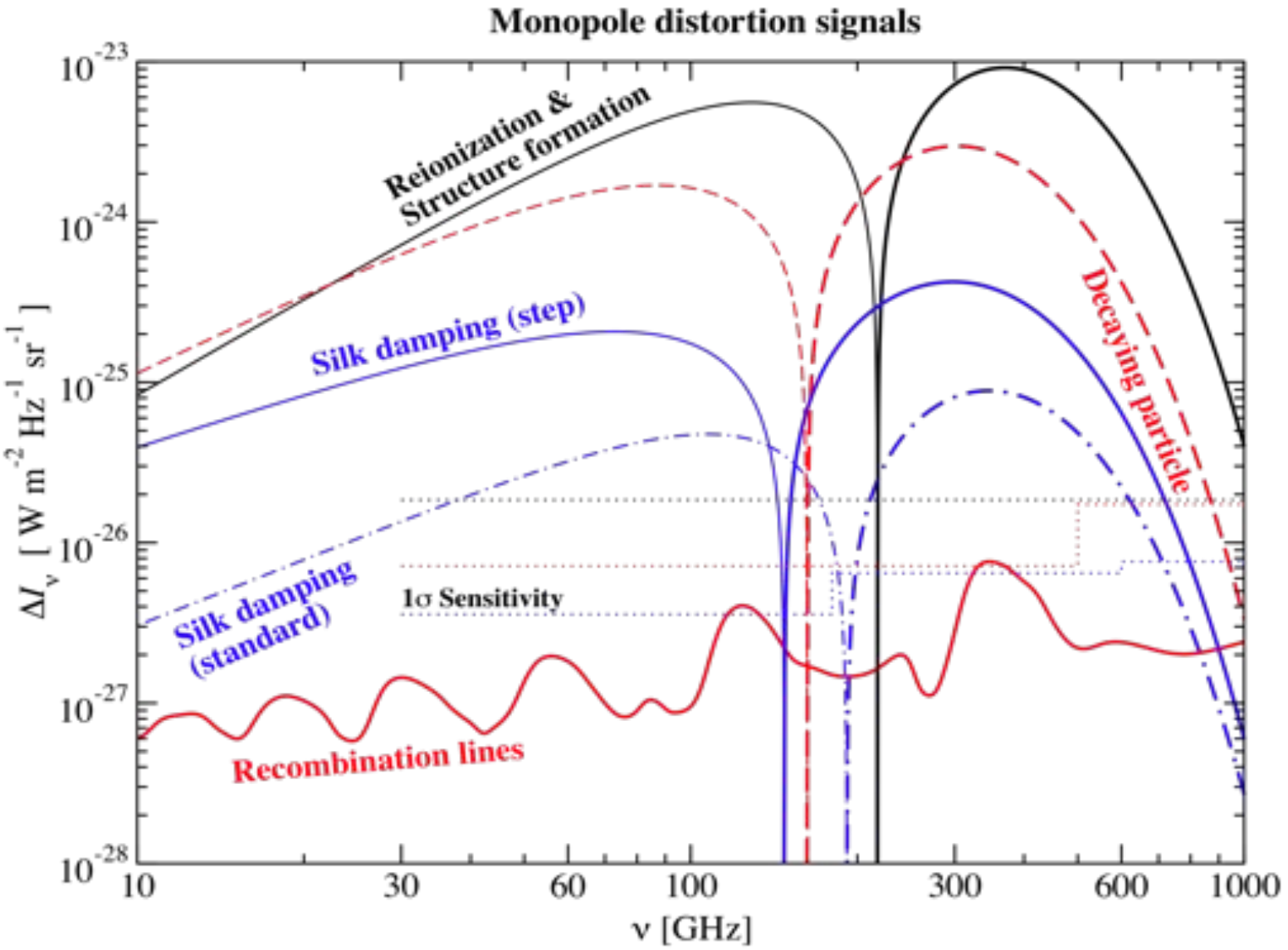


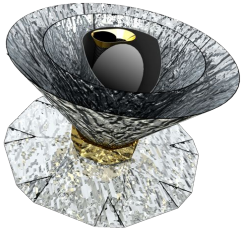
CMB lensing


Planck
PRISM
Nominal: 14 months
Full: 30 months
T
TEB
TEB (iterative)
Linear
Non-linear
$l(l+1)C_l^{dd}/2\pi$
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10
100
1000
l

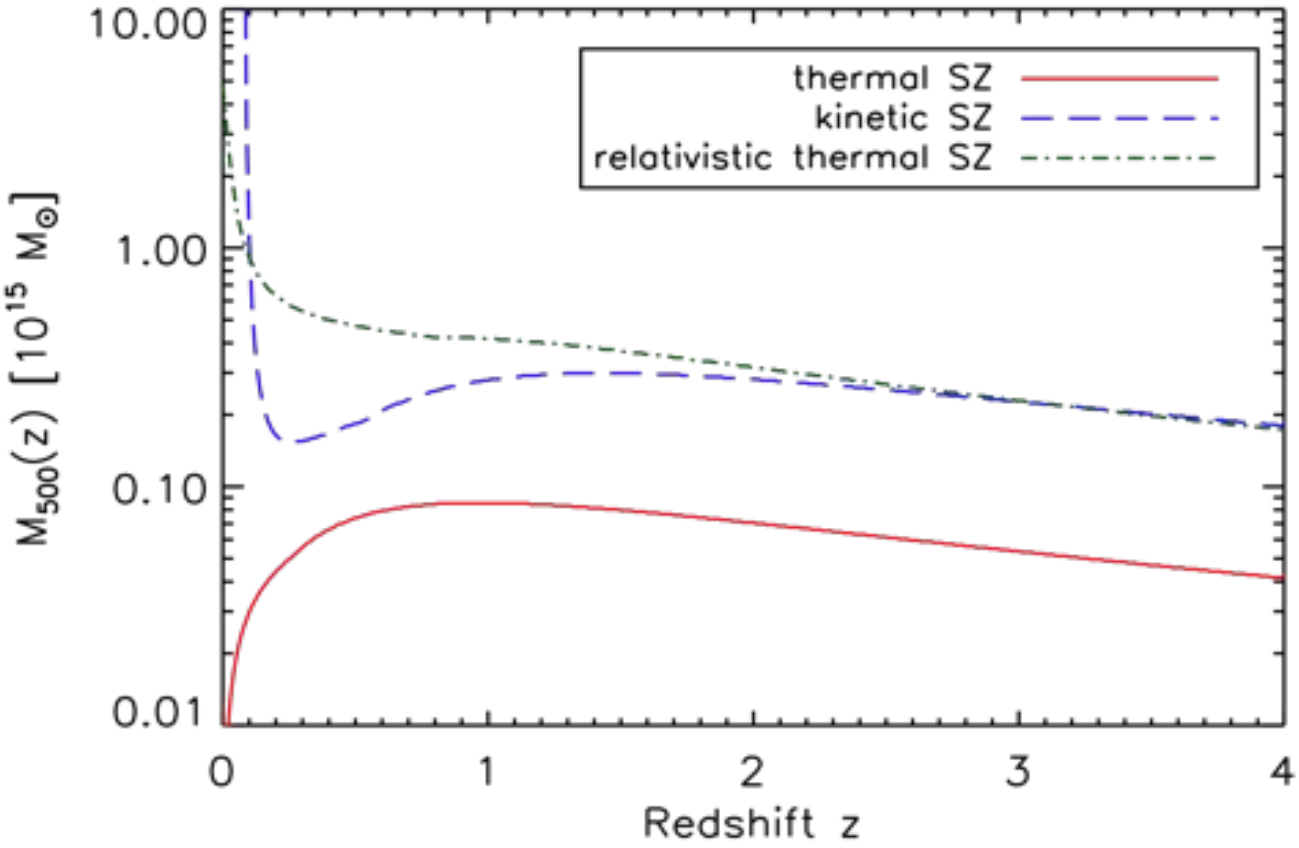


CMB spectral distortions





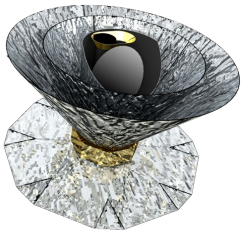
The ultimate SZ survey



5σ detections

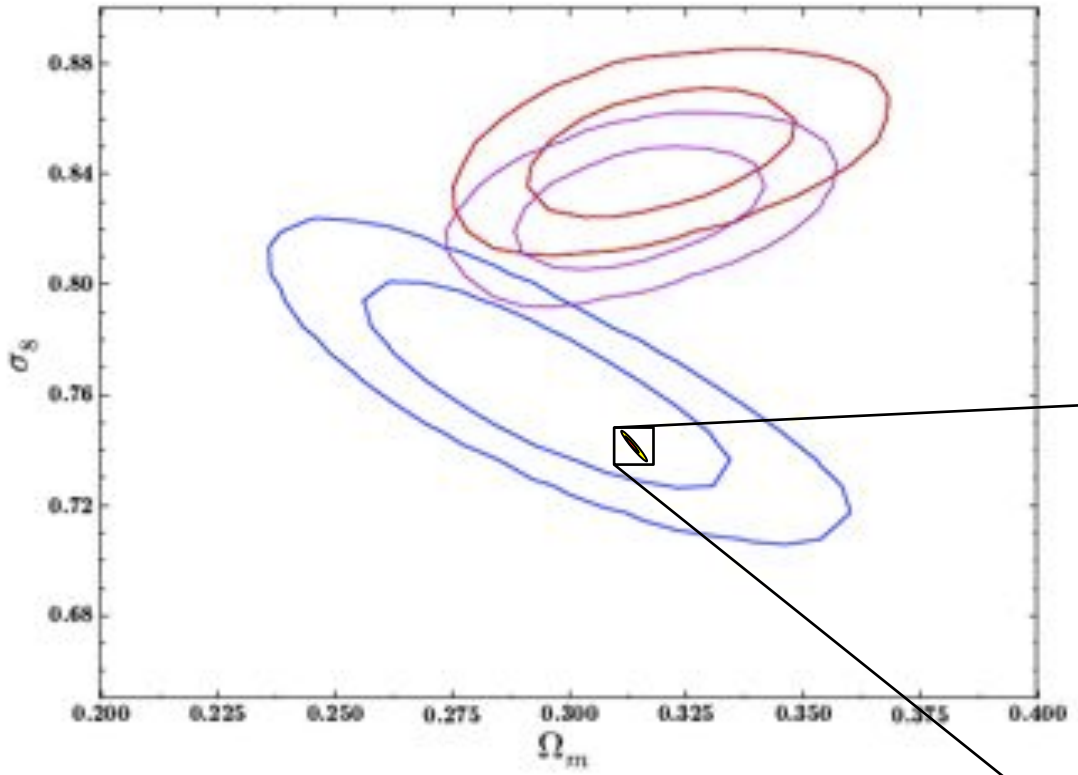
$M_{500} = 4\times10^{-13}M_{\odot}$ at z=4

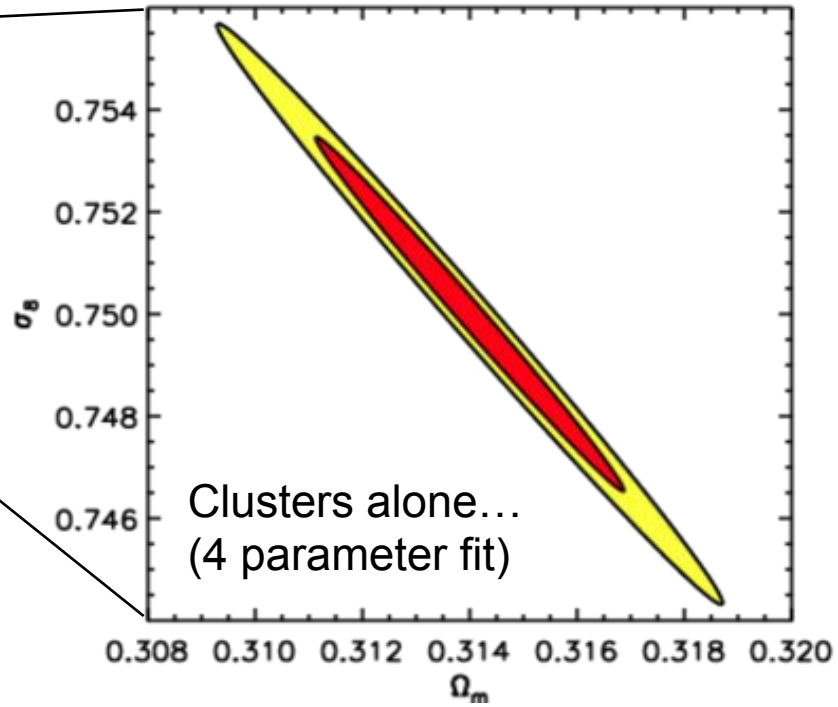
TOTAL clusters detected: ≈ 10^6
TOTAL peculiar velocities: ≈ a few 10^5
TOTAL relativistic SZ: ≈ a few 10^4



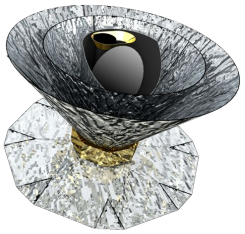
Cosmology with SZ clusters

Planck CMB + Σm_ν=0 eV
Planck CMB + Σm_ν=0.06 eV
Planck cluster counts





WARNING: illustrative only.
Our understanding of cluster physics will have to be improved to get there!



Cosmology with SZ clusters

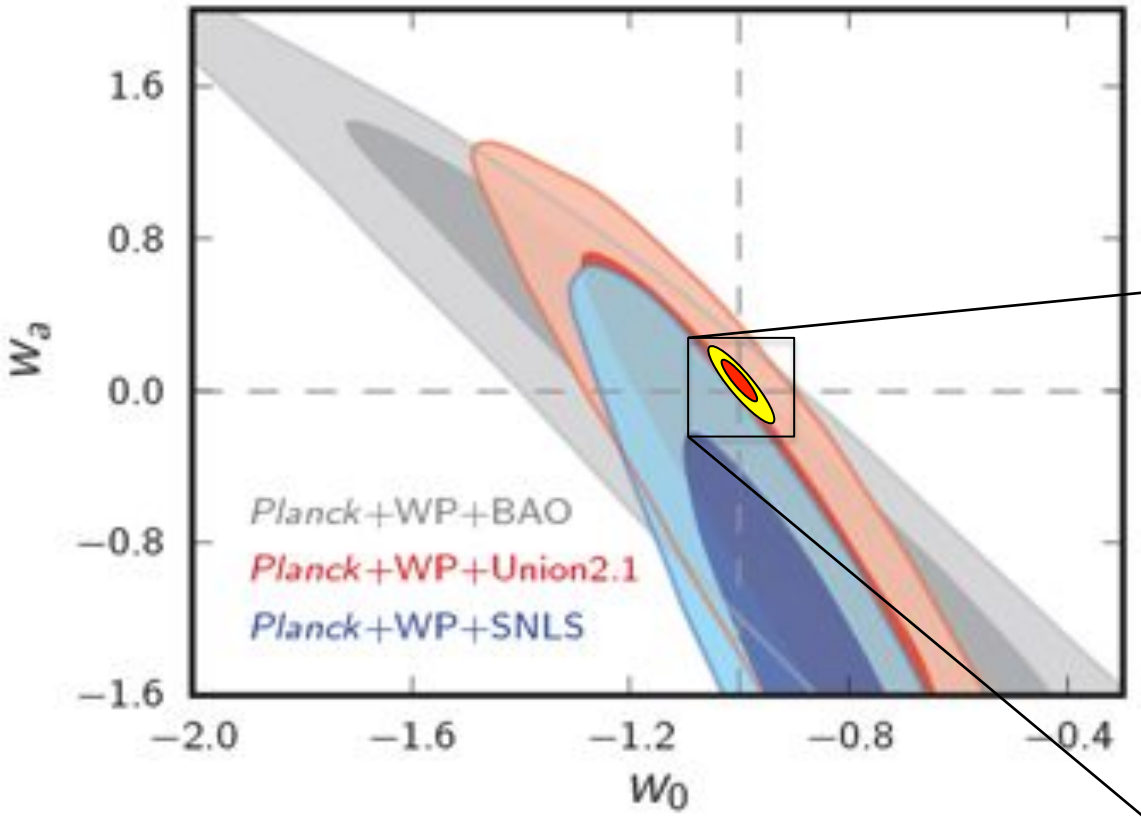
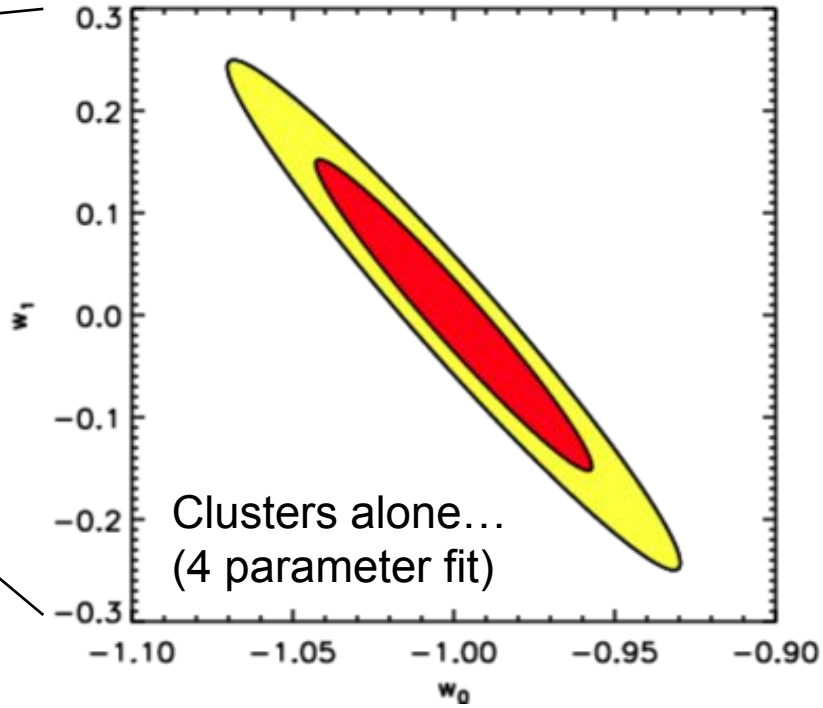
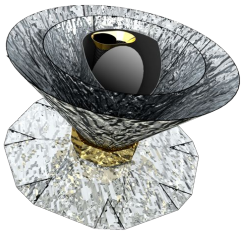


Fig. 36. 2D marginalized posterior distributions for w_0 and w_a, for the data combinations *Planck*+WP+BAO (grey), *Planck*+WP+Union2.1 (red) and *Planck*+WP+SNLS (blue). The contours are 68% and 95%, and dashed grey lines show the cosmological constant solution.

WP: WMAP Polarization
Union2.1: Supernovae
SNLS: Supernovae (different sample)

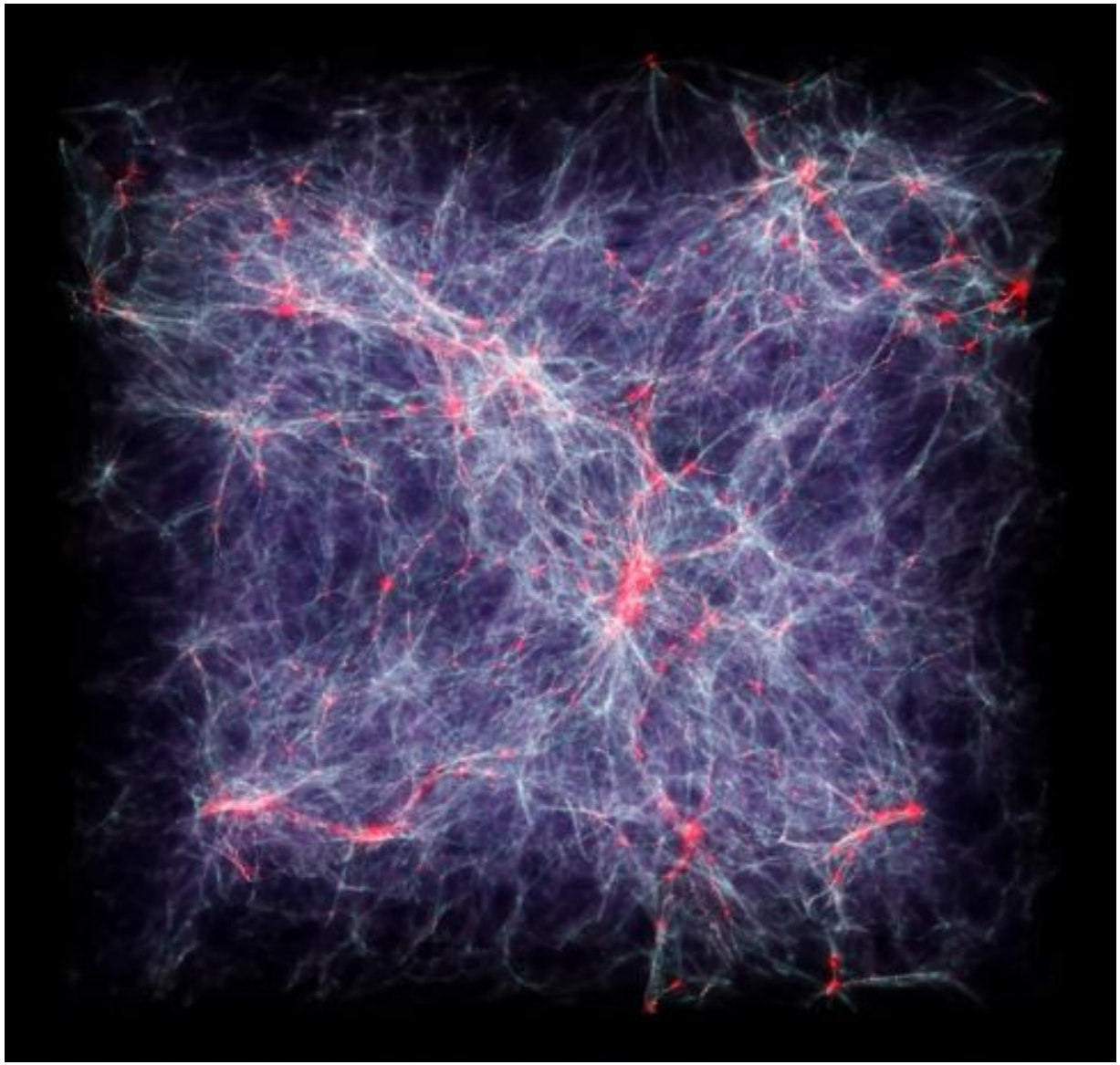


WARNING: illustrative only!



Detecting the cosmic web?

25 h^{-1} Mpc
Planck ΛCDM

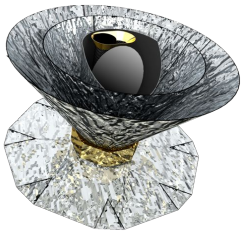


Simulation: Courtesy A. Borde and N. Palanque-Delabrouille

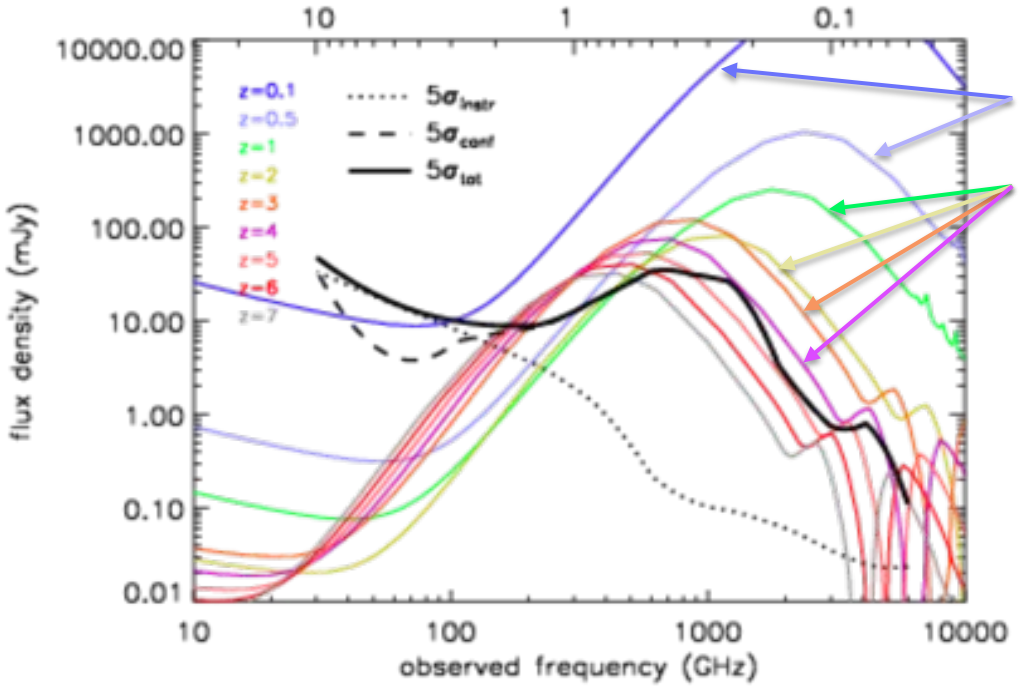
In filaments:
$T \approx 10^5$-10^7 K
$\rho_{gas} \approx 5$-$200 \times \bar{\rho}_{gas}$

More work needed…

$T \approx 10^4$ K  $T \approx 10^7$ K



High redshift dusty galaxies

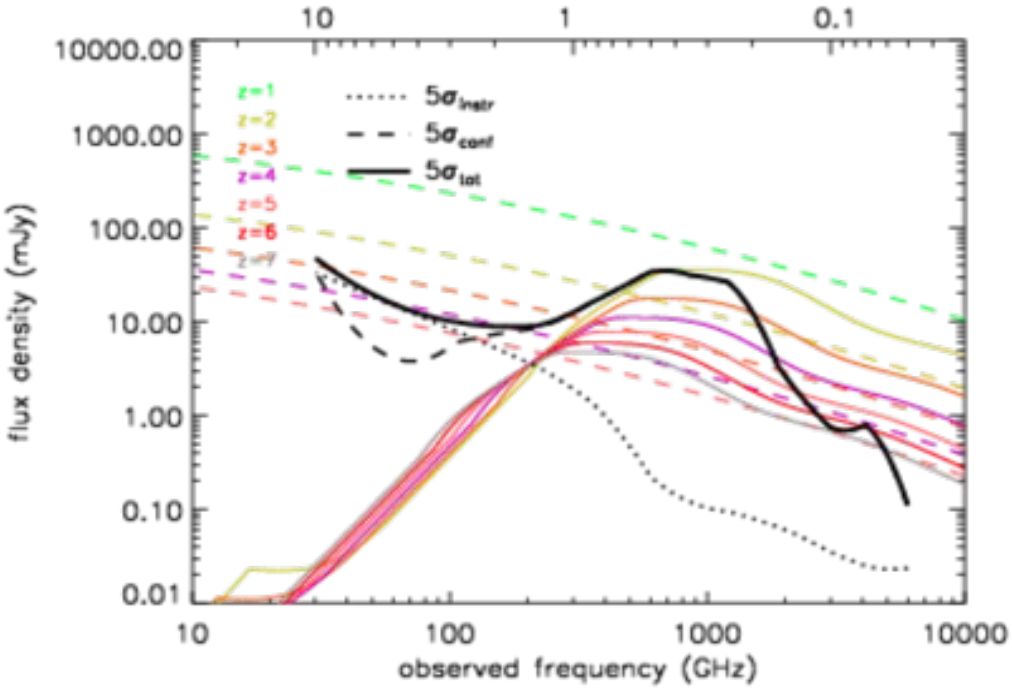


Dusty galaxies at z = 0.1–7 :

ARP 220 scaled to $L_{IR} = 10^{12} L_{\odot}$

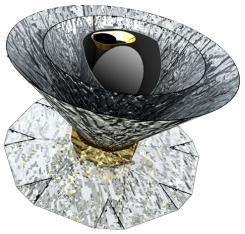
SMM J2135-0102 (z ≈ 2.3)
scaled to $L_{IR} = 1\text{-}3 \times 10^{13} L_{\odot}$

- Typical $L_{IR} = 10^{13} L_{\odot}$ type 2 QSO
- 3C 273 blazar



Detect thousands of strong lenses (case for full sky)

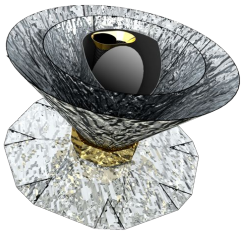
Use the many frequency bands
- to separate dust from CIB (cover all peaks)
- to identify the nature of the sources
- to measure the total bolometric luminosities
- to measure photometric redshifts
- to bin the CIB emission in redshift shells



Correlations

- Between CIB maps across frequencies: separate CIB in redshift shells, push down the confusion limit
- CIB (in redshift shells) – lensing: growth of structures
- Clusters (in z-Y bins) – lensing: Y-M relations for clusters
- Clusters – sources (by types): halo population (by type)
- SZ map (after masking clusters) – CIB (by shells): sources in cosmic web, hot gas in galaxy haloes
- ~~CMB – tracers of mass: ISW~~

All of this requires statistics: *case for a full sky survey*.



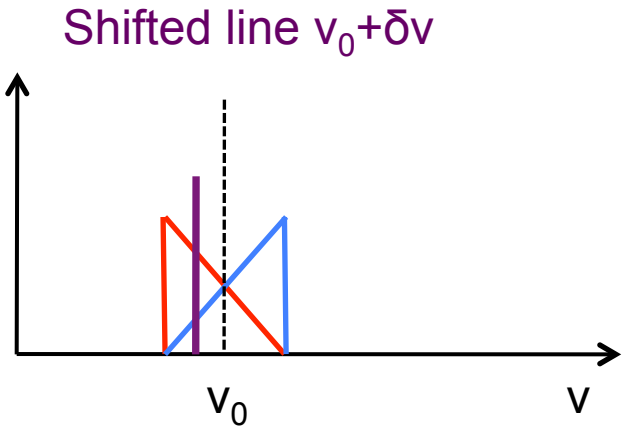
The Galactic ISM

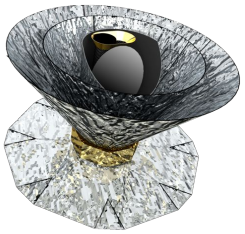
- A global view of the ISM – various components

- Dust polarisation: map the galactic magnetic field (5-10 arcsec resolution)
  - Investigate its role in star formation
  - Interplay between turbulence, gravity, and galactic magnetic field

- Nature of dust
  - Sizes and emissivity of grains
  - alignment mechanisms
  - composition (graphite / silicates)

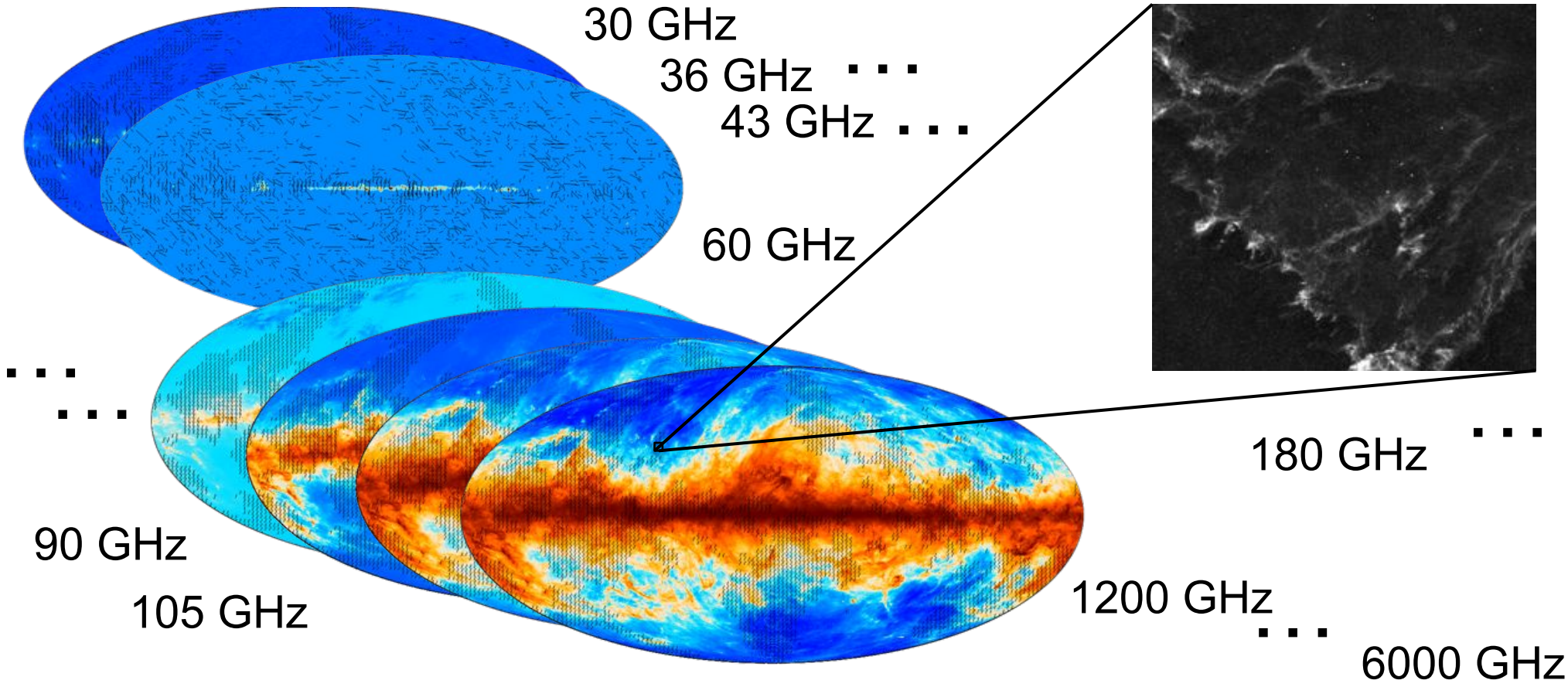
- Physical and chemical processes
  - Spectral lines trace matter in various phases
  - Line ratio constrains density and temperature
  - Velocities ? (TBC)

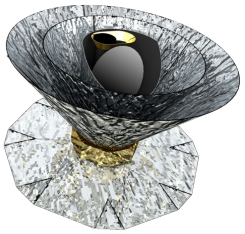




The PRISM Legacy

PRISM will provide ***hundreds of intensity and polarization maps***, assembling a legacy archive useful for almost all branches of astronomy for decades to come. Combining low resolution spectrometer data and high resolution full-sky polarized maps, PRISM will deliver a full spectro-polarimetric survey of the complete sky from 50 μm to 1 cm.





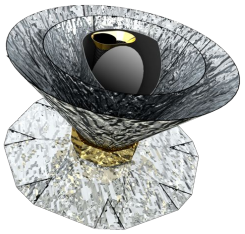
Synergies

- Cross-correlations / complementarity with other *surveys*
  - Euclid (population of cluster haloes, lenses of high-z FIR galaxies)
  - SKA (complementarity in frequency, reionisation, radio sources, neutral hydrogen - redshifts of objects)
  - eROSITA (common clusters at z<1, X-ray stacking at z>1)
  - LSST

- Follow-up with and large ground-based facilities *pointed observations*
  - Cluster substructures at high resolution from the ground
  - ALMA: complementarity in scales, follow-up spectra
  - CCAT: cluster velocities and substructures, temperatures (pointed + survey)
  - Validation of separation of CIB in redshift shells on patches at high resolution

- Follow-up with other space missions
  - X-rays (e.g. Athena or US equivalent)
  - SZ effect (e.g. Millimetron)
  - Galactic and extragalactic infrared targets (future FIR interferometer)

- PRISM: a very complete survey by itself, + an enhancer/improver of other instruments



Is it *feasible* ?

- ✓ Full design still TBD/TBC, but nothing very complicated – no deployable telescope, no formation flight, no futuristic designs, no moving parts.

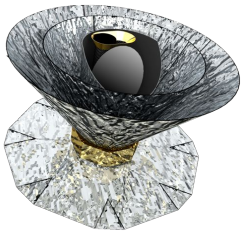
- ✓ Detectors
  - Technologies exist at TRL = 5+
  - Arrays of thousands of TES detectors, antenna coupling, channellizers
  - Build on Planck and Herschel experience + ground-based & balloon-borne exp.

- ✓ Cold telescope
  - Developed for SPICA for flight in early 20s, detailed cooling chain still TBD

- ✓ Scan strategy
  - Similar to WMAP, EPIC, SAMPAN designs

- ✓ Simple deployable screens + one solid inner shield – TBD

- ✓ Small ancillary spacecraft (optional, TBC)
  - Data transmission 40+ Mbit/s (e.g. Gaia, phased array)
  - In flight calibration

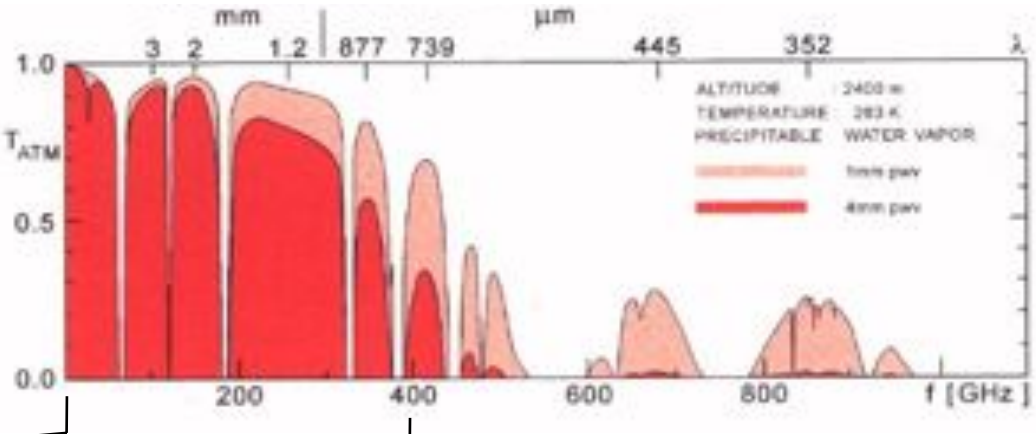


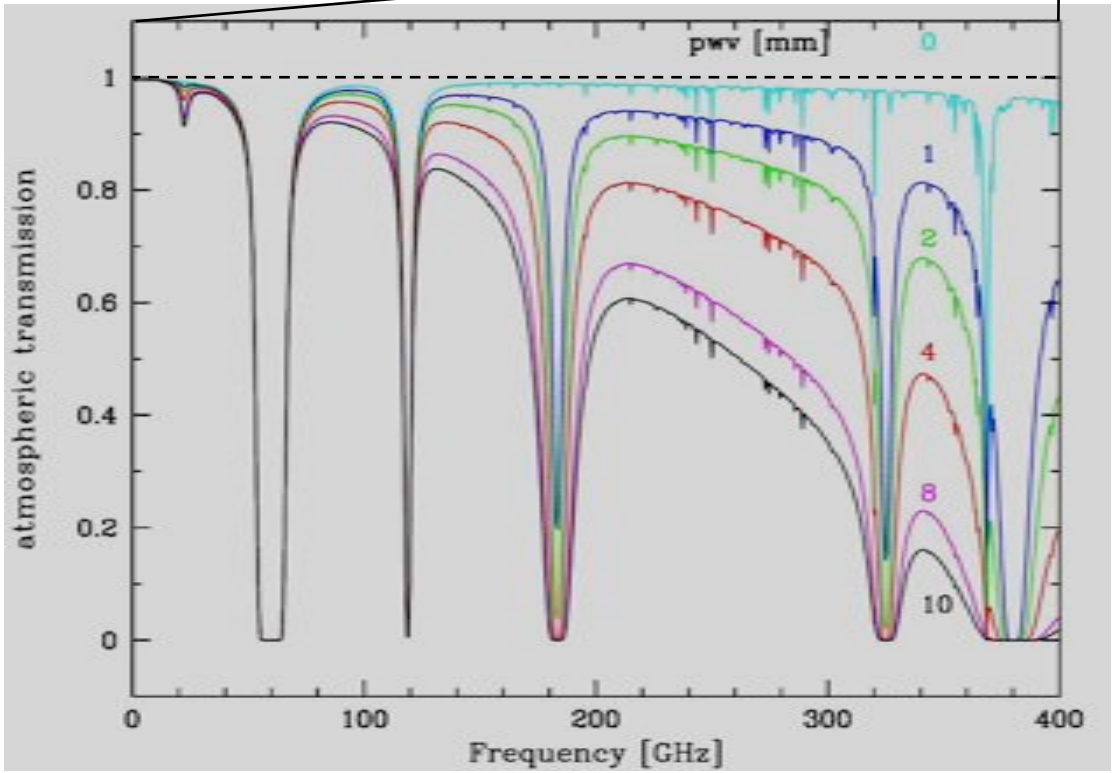
Why a space mission?

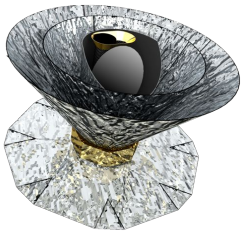
Atmospheric transmission and emission

Systematics

Complete survey





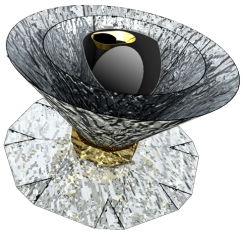


Impact of the PRISM proposal

- In a way, the PRISM white paper is the showcase of our science (CMB – cosmology – FIR)
  - measure the extent of the community and the interest these scientific objectives generate (supporters of the proposal)
  - measure the scientific value of the topics we advertise (through the review process)

- If selected, this science case proposal will
  - Stimulate the need for appropriate technological developments
  - Stimulate the need for pathfinder observations
  - Stimulate theoretical developments to consolidate and extend the science case
  - Encourage students to work in this field (with clear perspectives ahead)

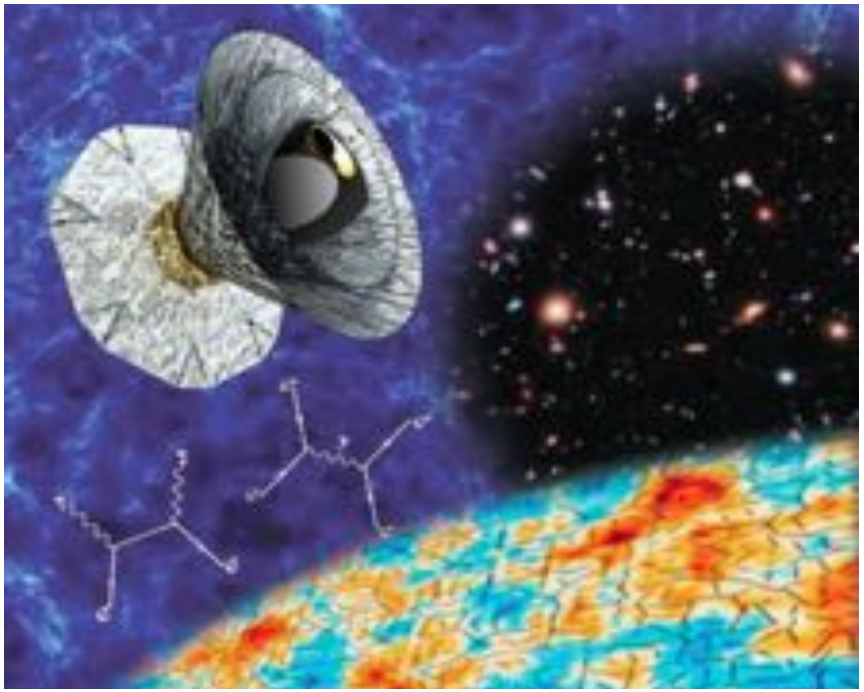
- It is a great opportunity for the CMB, for cosmology, and for FIR observations.



We need your support !

If you have not done so yet, please support this science case by signing in on the website

http://www.prism-mission.org



If you'd like to be involved in the next steps, let us know!
Questions? ideas? suggestions? Let us know!