Title: The Planck Satellite

Date: Jun 05, 2008 11:15 AM

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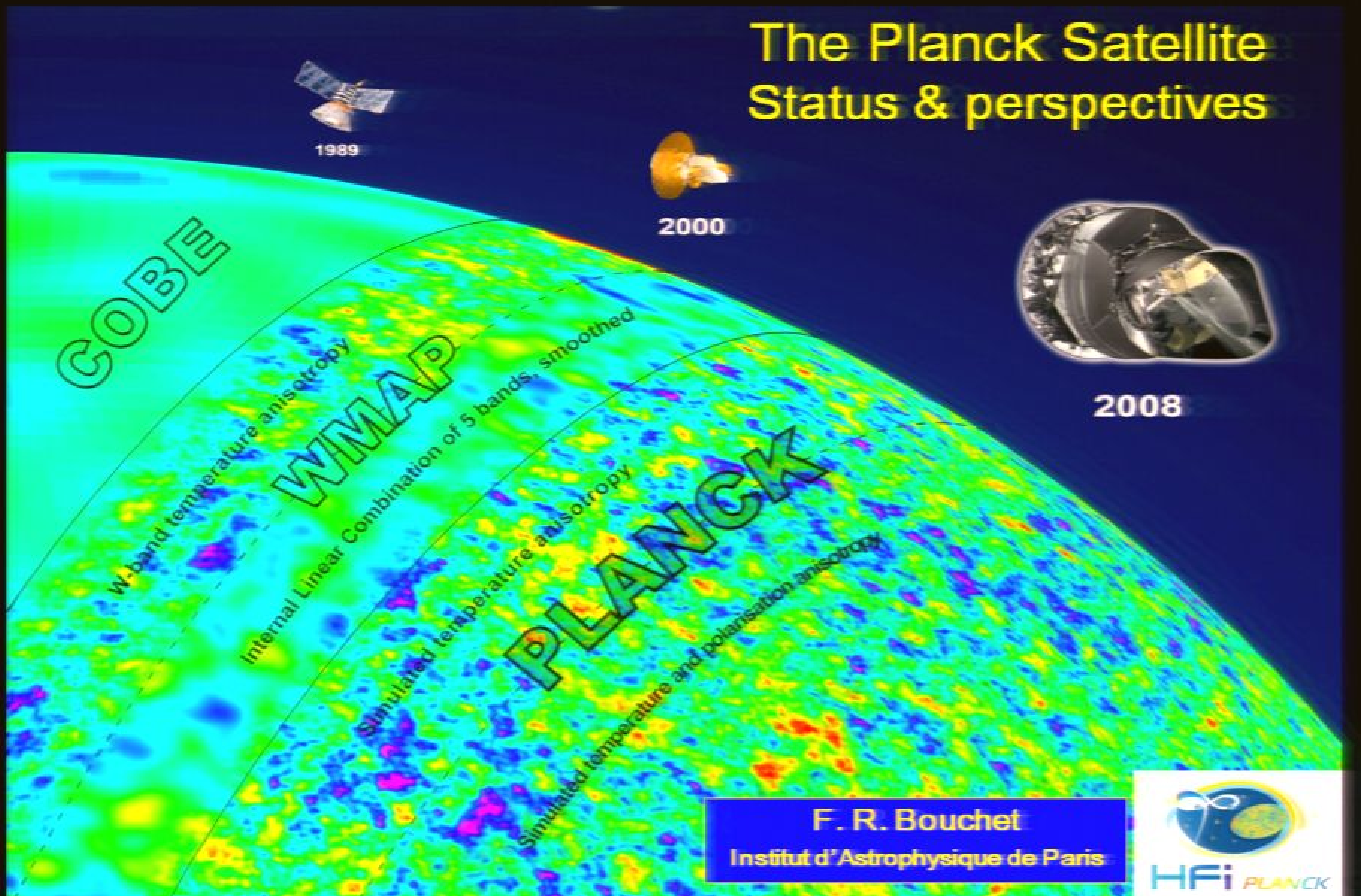
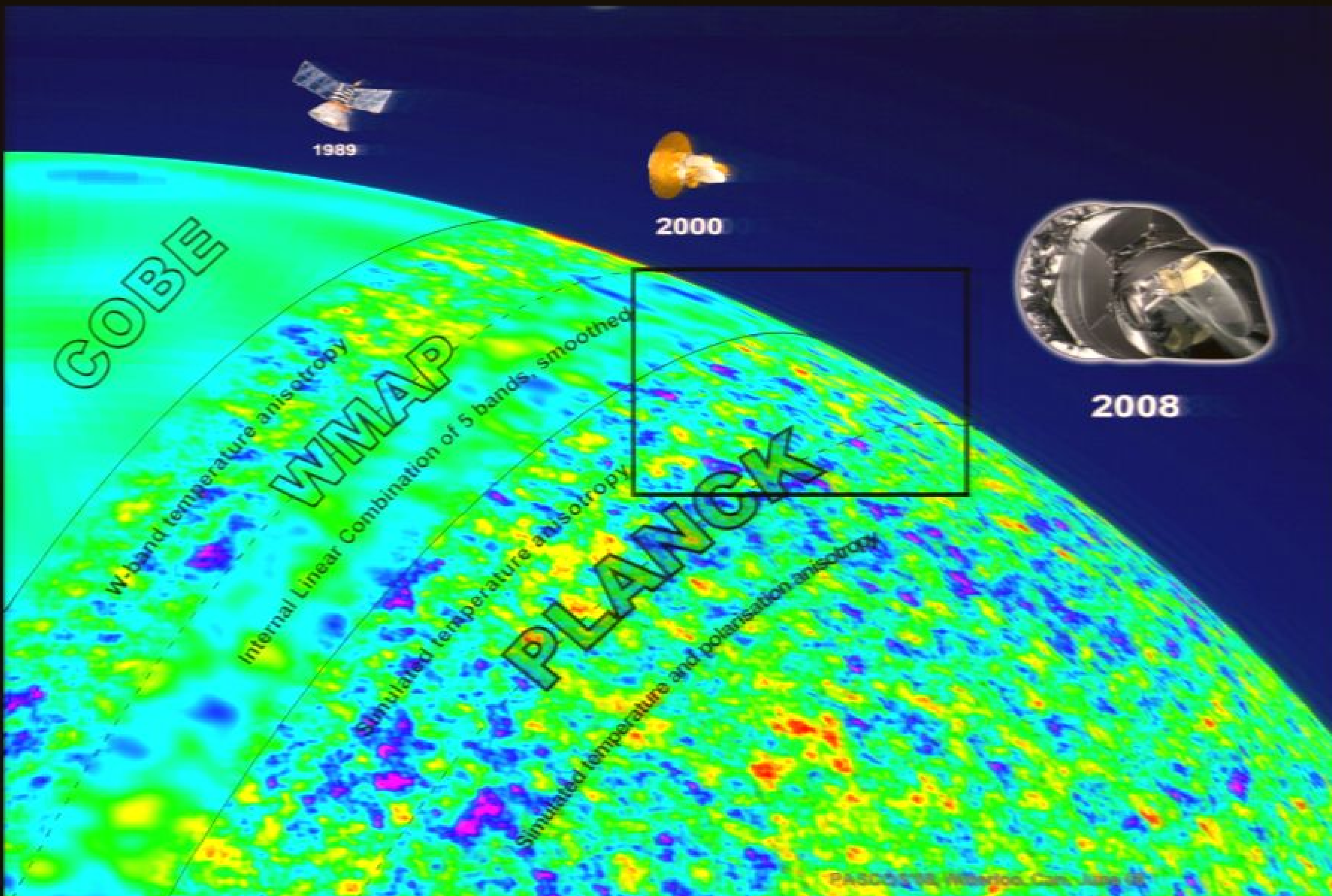
Abstract:


The Planck Satellite
Status & perspectives
1989
2000
2008
COBE
WMAP
PLANCK
W-band temperature anisotropy
Internal Linear Combination of 5 bands, smoothed
Simulated temperature anisotropy
Simulated temperature and polarisation anisotropy
F. R. Bouchet
Institut d'Astrophysique de Paris
HFI PLANCK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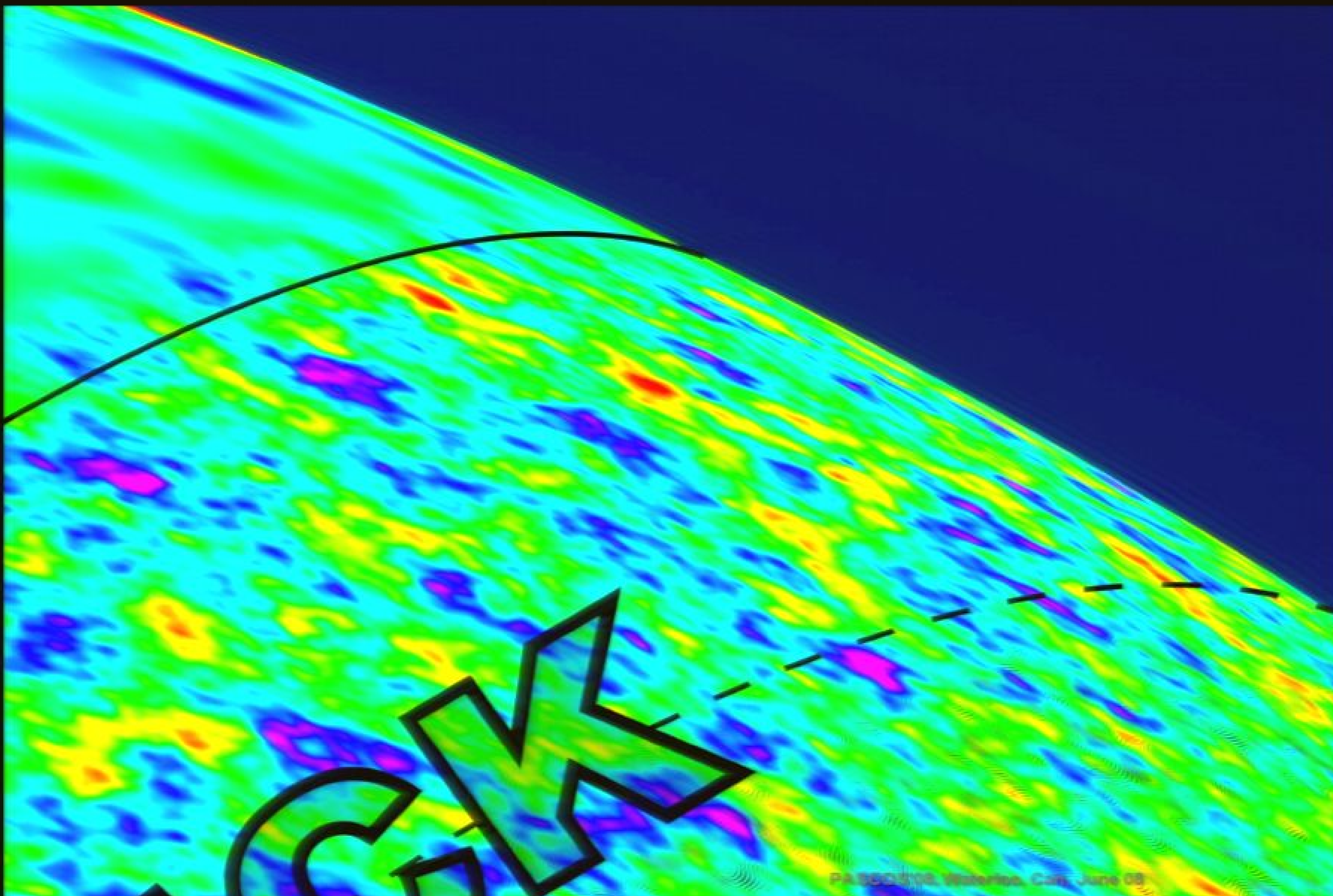

PASCOS'08, Waterloo, Can, June 08

The Planck concept

- to perform the "ultimate" measurement of the CMB temperature anisotropies:
  - *full sky coverage & angular resolution / to survey all scales at which the CMB primary anisotropies contain information (~5')*
  - *sensitivity / essentially limited by ability to remove the astrophysical foregrounds*

  ⇒ *enough sensitivity within large frequency range [30 GHz, 1 THz]*
- get the best performances possible on the polarization with the technology available

⇒ Selected by ESA in 1996 as 3rd Medium size mission-H2k

⇒ Goal can be achieved with a small number of detectors in each frequency band, limited by the photon noise of the background (for the CMB ones)

Sensitivity goals per channel

- Two instruments, covering a range of 30 in frequency
  - *LFI = Low Frequency instrument, using HEMTS*
  - *HFI = High Frequency instrument, using bolometers*

Instrument Characteristic	LFI			HFI					
Detector Technology	HEMT arrays			Bolometer arrays					
Center Frequency [GHz]	30	44	70	100	143	217	353	545	857
Bandwidth ($\Delta\nu/\nu$)	0.2	0.2	0.2	0.33	0.33	0.33	0.33	0.33	0.33
Angular Resolution (arcmin)	33	24	14	10	7.1	5.0	5.0	5.0	5.0
$\Delta T/T$ per pixel (Stokes I)[a]	2.0	2.7	4.7	2.5	2.2	4.8	14.7	147	6700
$\Delta T/T$ per pixel (Stokes Q & U)[a] ...	2.8	3.9	6.7	4.0	4.2	9.8	29.8	...	...

[a] Goal (μK/K, 1σ), 14 months integration, square pixels whose sides are given in the row "Angular Resolution".

- Robustness of design for T Component Separation

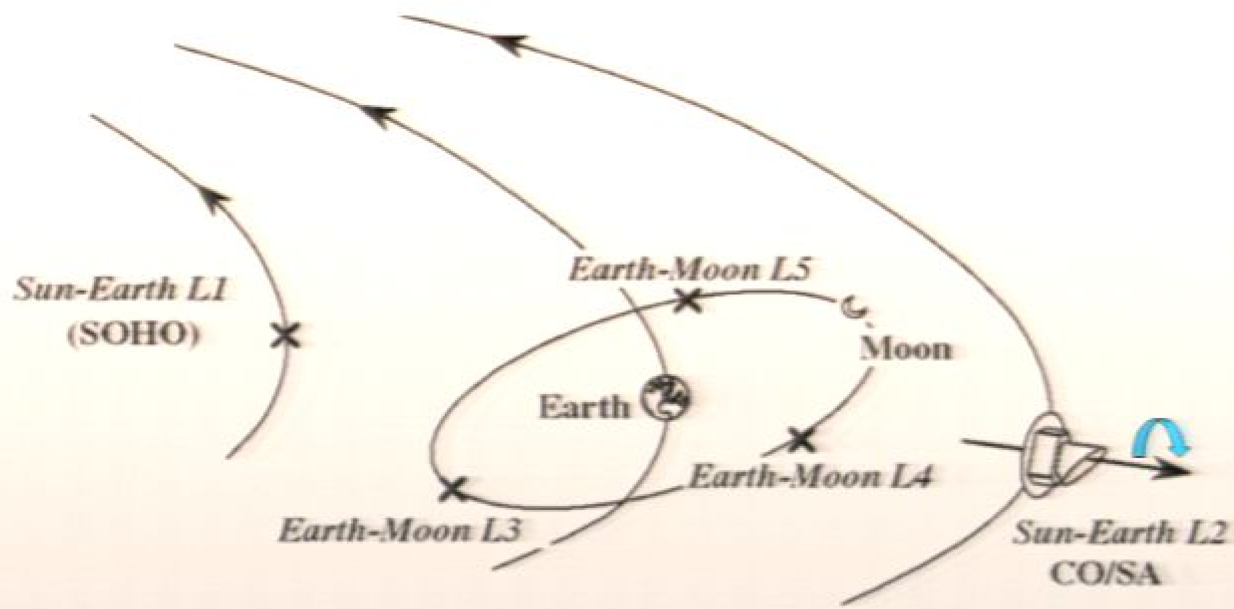
Goals in perspective

PLANCK	LFI			HFI					
Center Freq (GHz)	30	44	70	100	143	217	353	545	857
Angular resolution (FWHM arcmin)	33	24	14	10	7.1	5.0	5.0	5	5
Sensitivity in I [μK.deg] [$\sigma_{pix}\ \Omega_{pix}^{1/2}$]	2.7	2.6	2.6	1.0	0.6	1.0	2,9		
Sensitivity in Q or U [μK.deg] [$\sigma_{pix}\ \Omega_{pix}^{1/2}$]	4.5	4.6	4.6	1.8	1.4	2.4	7.3		

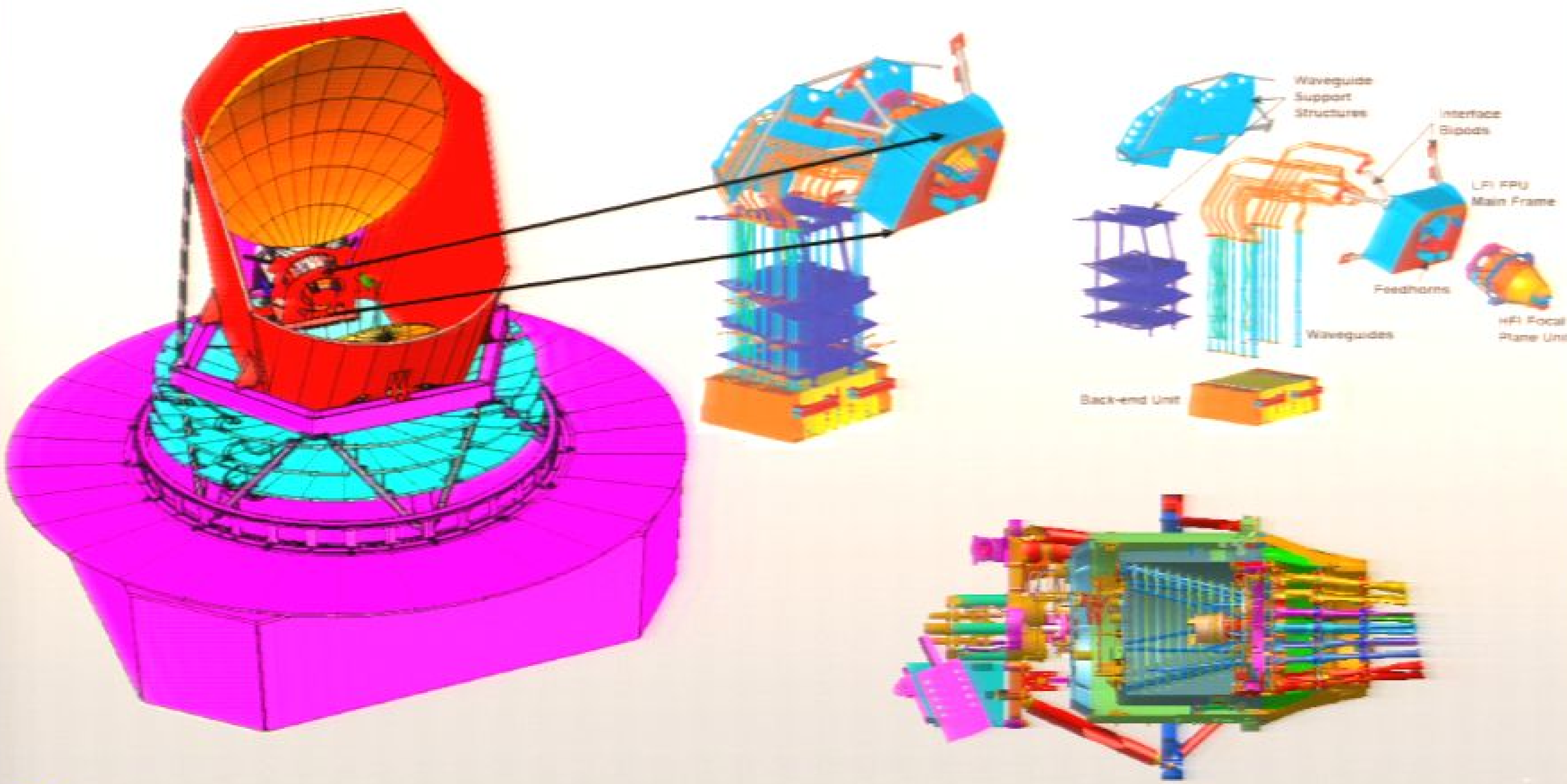
WMAP Center Freq.	23	33	41	61	94
Angular resolution (FWHM arcmin)	49	37	29	20	12,6
Sensitivity in I [μK.deg], 1 yr (8 yr)	12.6 (4.5)	12.9 (4.6)	13.3 (4.7)	15.6 (5.5)	15.0 (5.3)

The aggregated sensitivity of Planck core CMB channels is ~0.5μK.deg in T, 1 μK.deg QU

Observational site



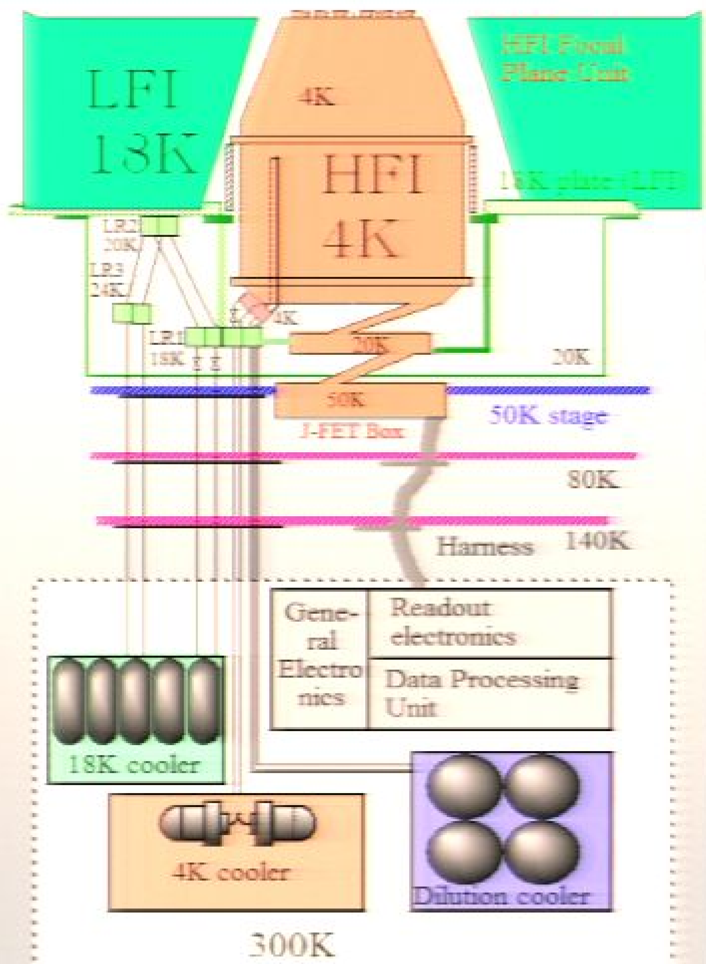
Tightly integrated design



Planck Cooling chain (1/4)

To Bring
- LFI HEMTS to 18K
- HFI Bolometers to 0.1K

40K: radiative cooling	≈2W
18K: H_2 J-T Sorption pumps (JPL, *USA*)	≈1W
4K: He J-T Mech. Pump (RAL, *UK*)	≈15mW
1.6K: J-T expansion	0.5mW
0.1K 3He/4He dilution (AL, CRTBT, IAS, *France*)	0.2μW



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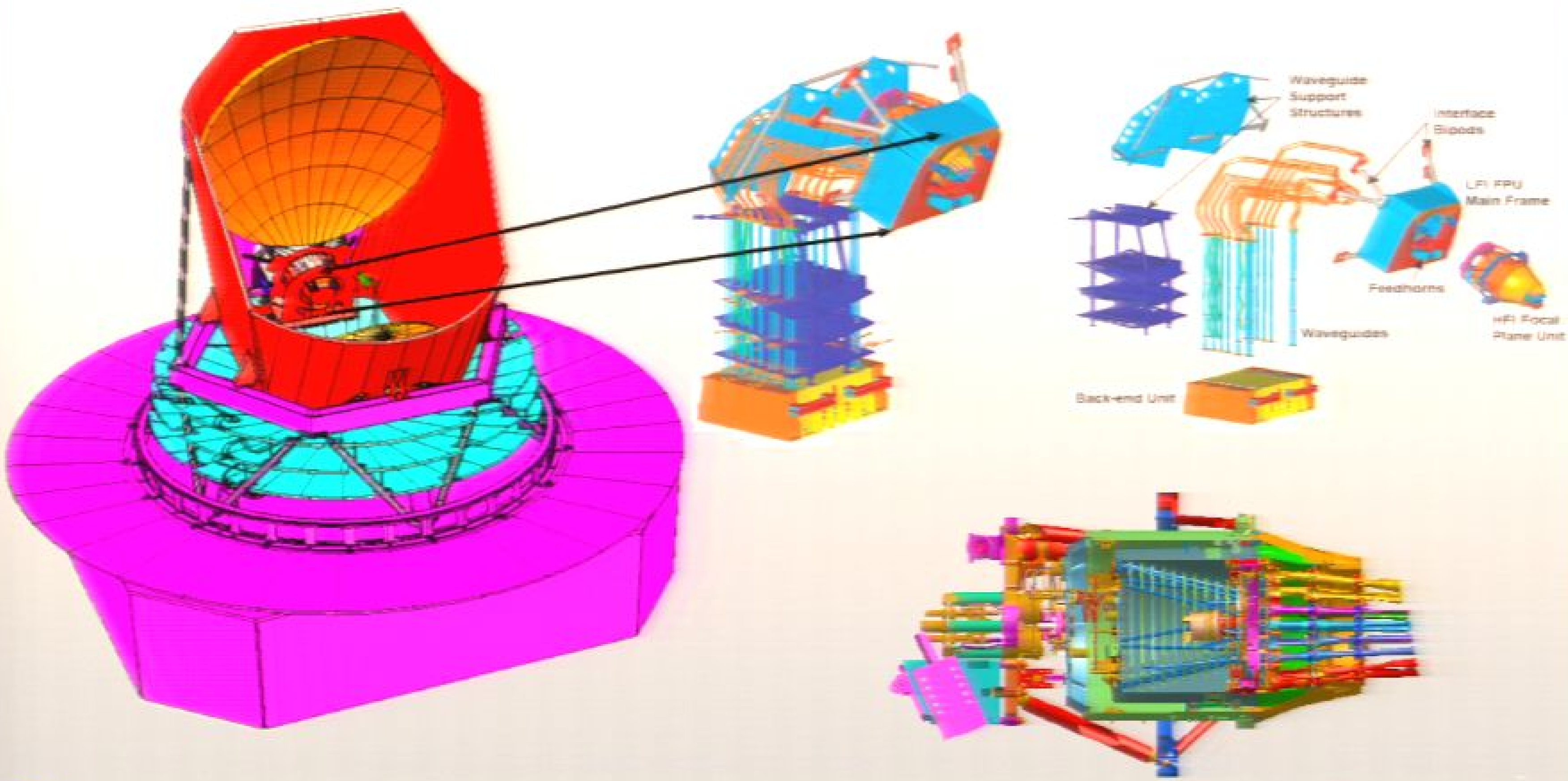

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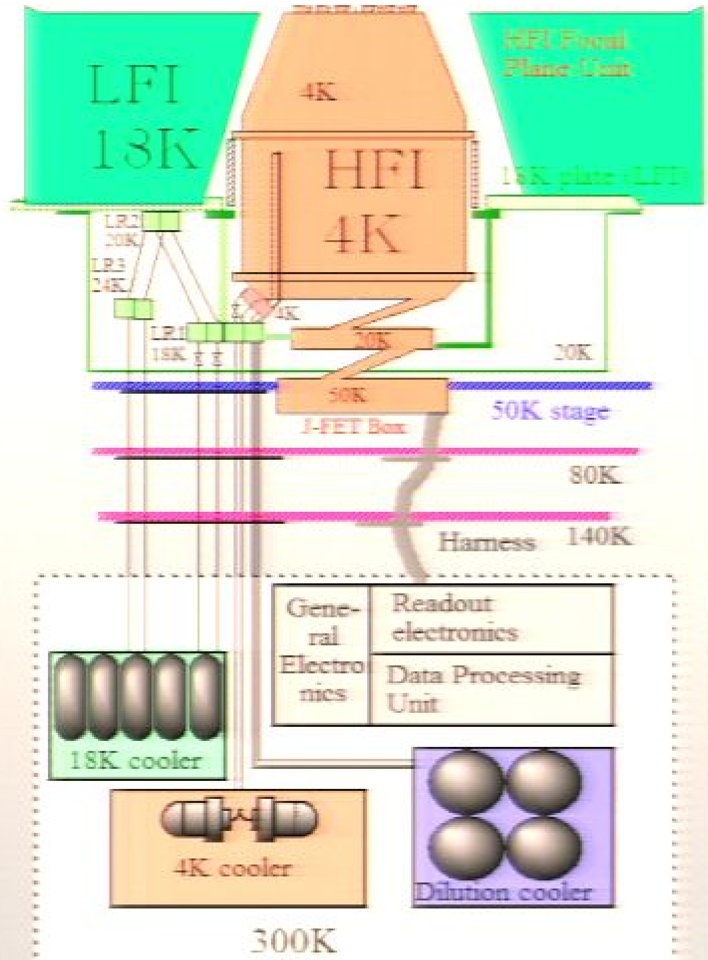

40K: radiative cooling	≈2W
18K: H_2 J-T Sorption pumps (JPL, *USA*)	≈1W
4K: He J-T Mech. Pump (RAL, *UK*)	≈15mW
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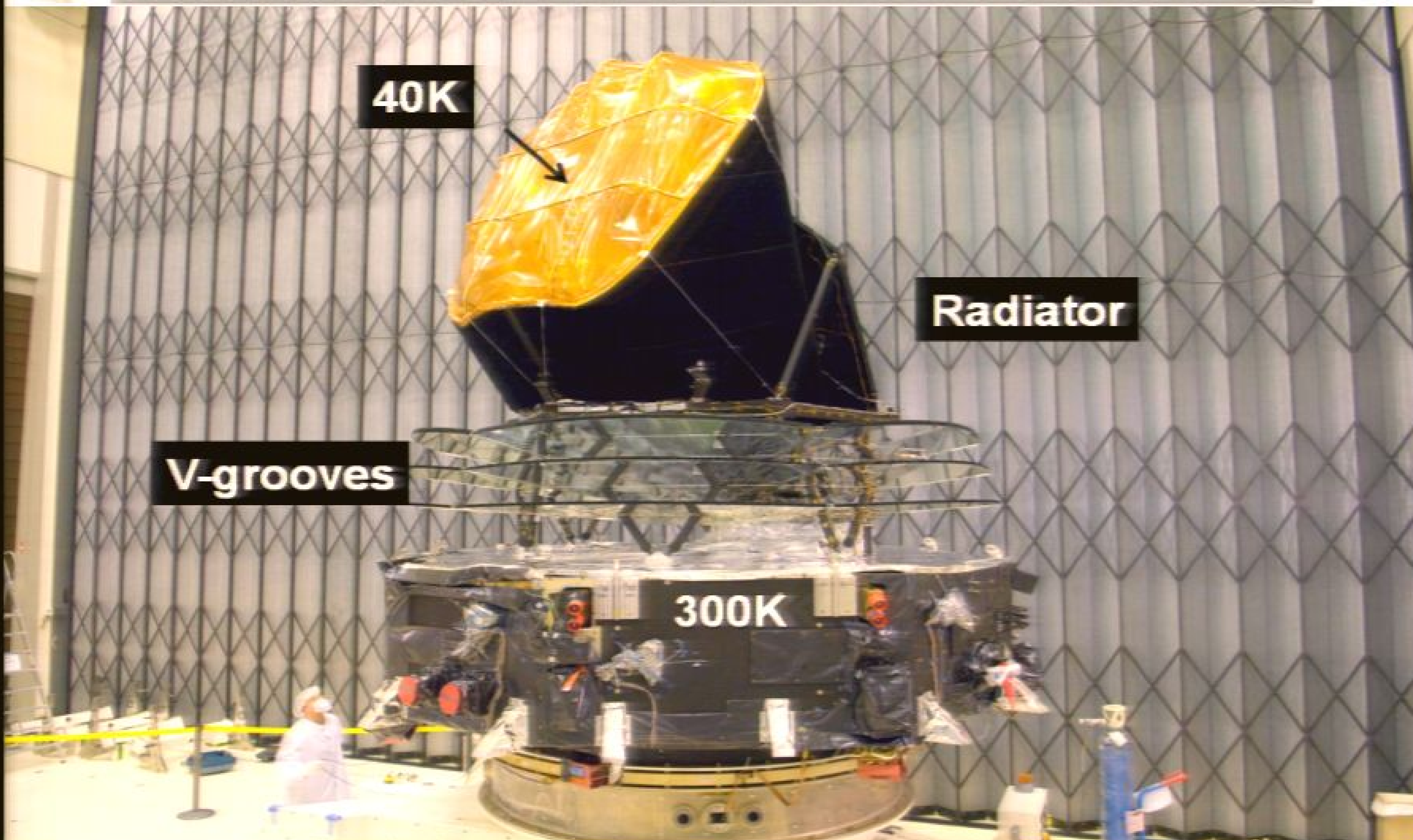
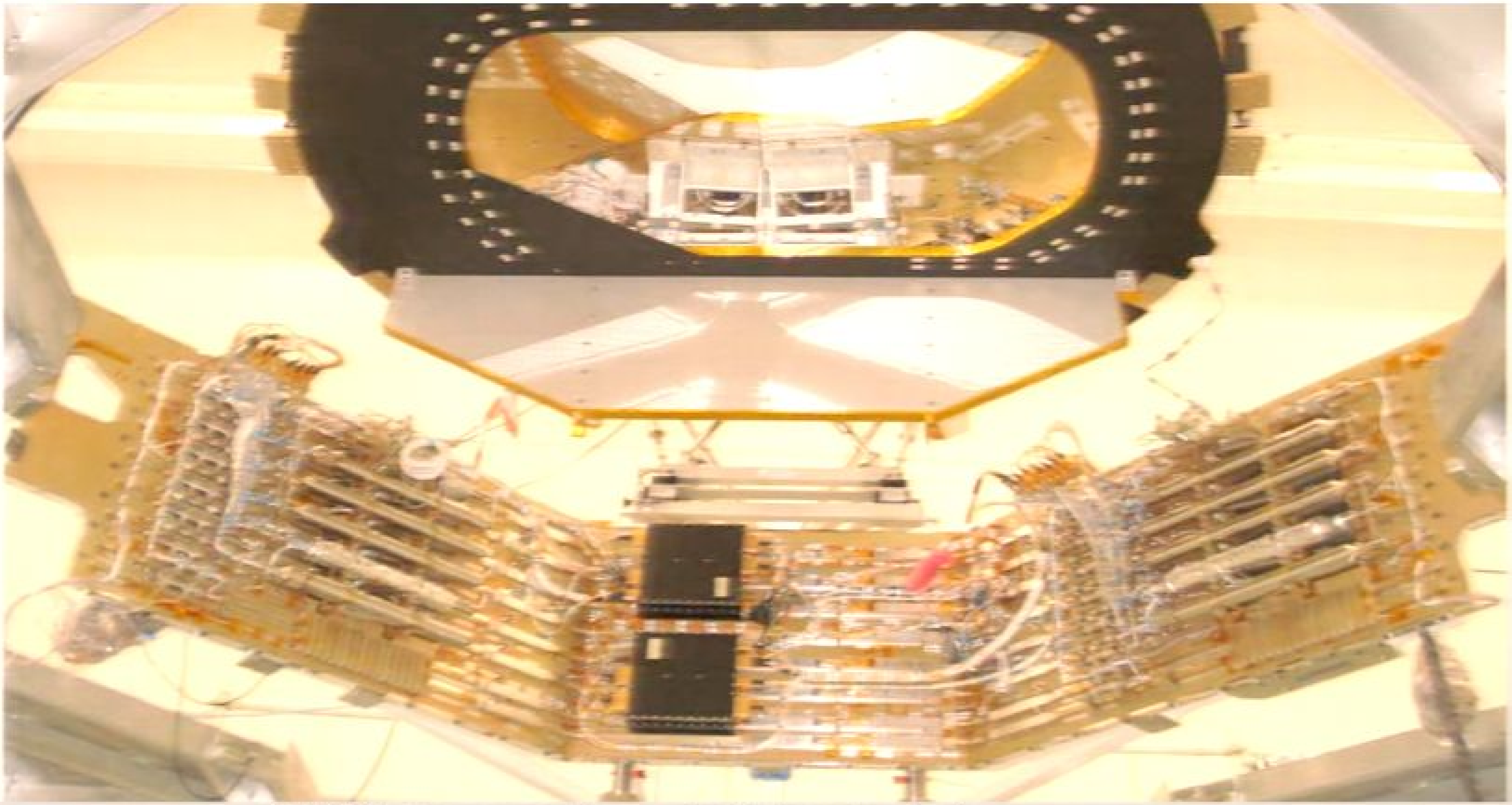
Cooling chain (2/4)



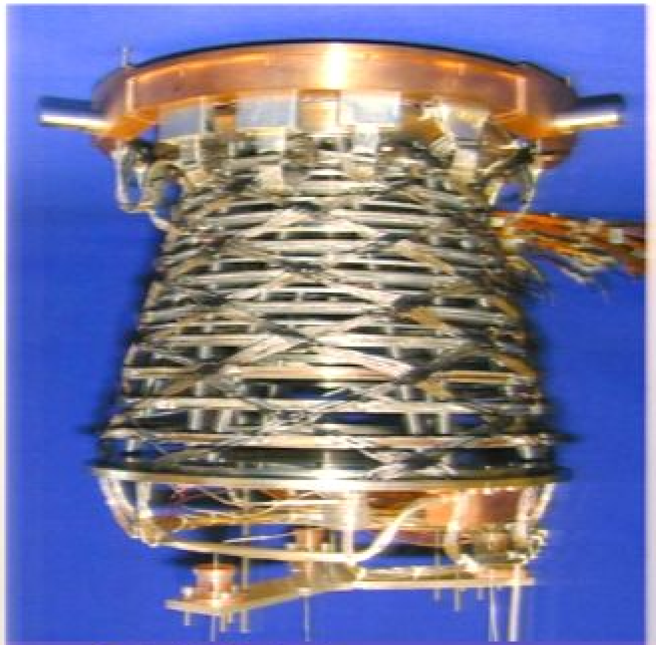
Cooling chain (3/4)



"20 K" Hydrogen sorption cooler (fully redundant)
- Cools LFI to < 20K
- Provides pre-cooling to HFI at ~ 18K

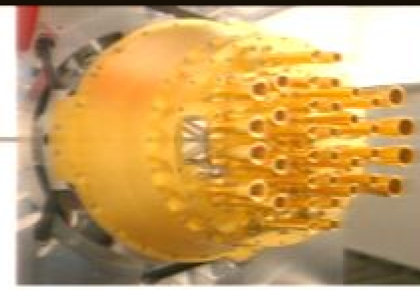
Cooling chain (4/4)

- "4K" ^4He JT cooler
  (w. Back to back compressors)
  - *Cools overall HFI structure to ~4K as well as LFI cold loads*
  - *Precools gas for dilution cooler*
- "0.1K" ^3He-^4He dilution cooler
  (using capillarity)
  - *JT expansion cools filter plate to 1.6K*
  - *Cools bolometers to 100mK*

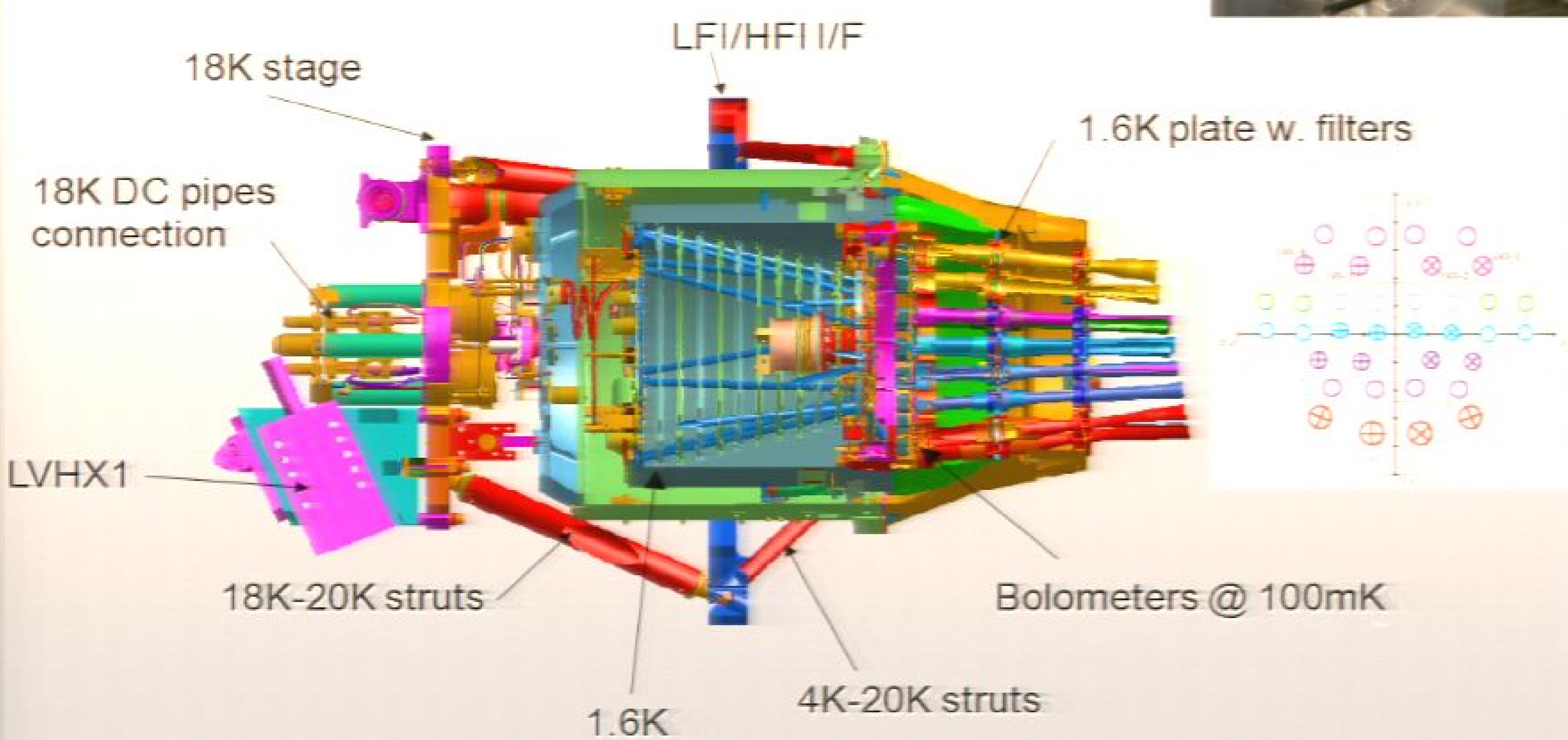


3He/4He Dilution system

HFI (Russian-doll) cut-away



THERMAL STABILITY ?



Planck needed breakthroughs

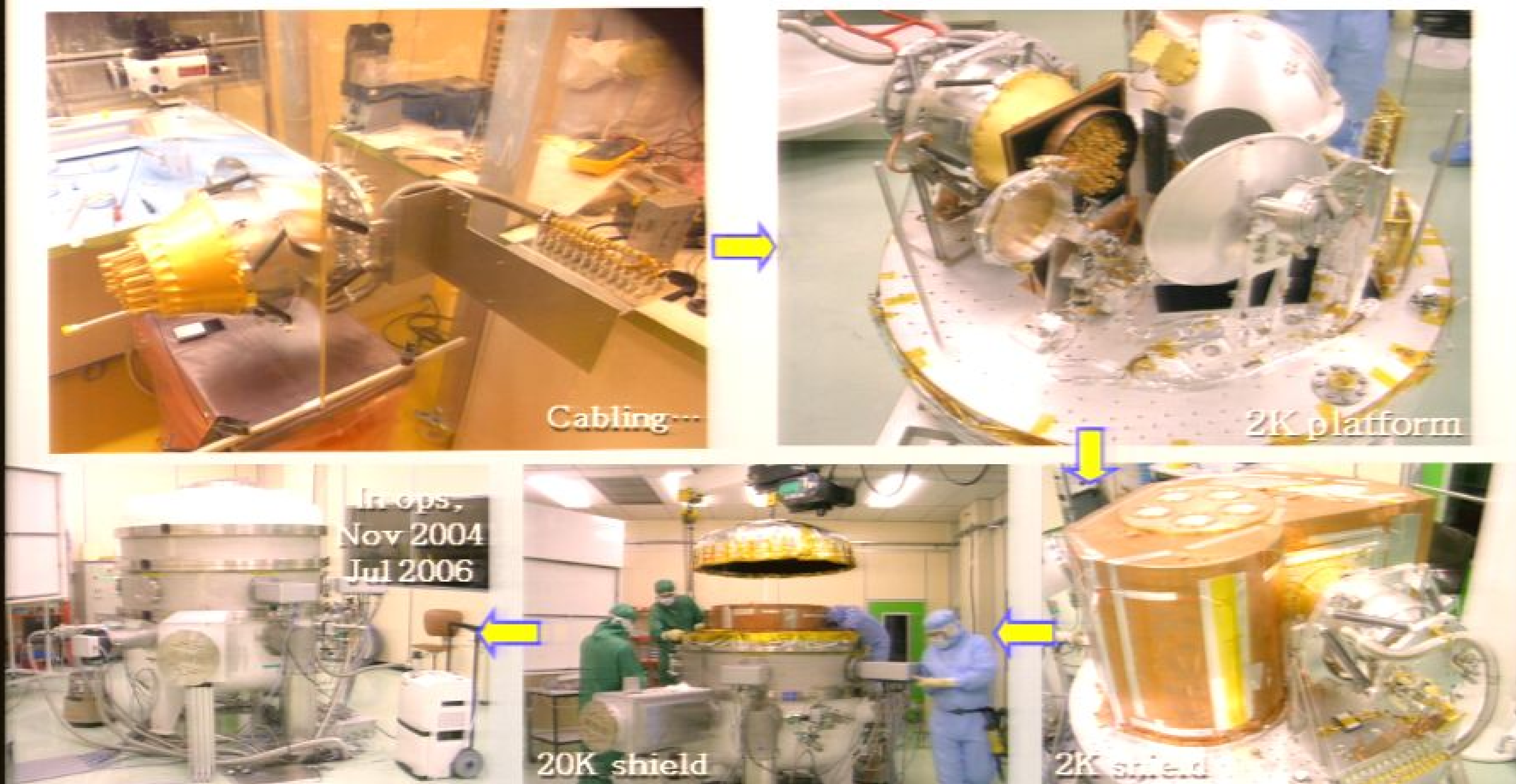
- The sensitivity goals of Planck requires several technological performance never achieved in space before
  - *Sensitive & fast bolometers with*
    - NEP< 2 10^{-17} W/$Hz^{1/2}$ & time constants typically < 5 msec

    (thus cooling them to 100 mK, very low heat capacity & charged particles sensitivity)
  - *total power read out electronics with very low noise*
    - < 6nV/$Hz^{1/2}$ from 10 mHz to 100 Hz
  - *Excellent temperature stability, from 10 mHz (1 rpm) to 100 Hz (cf. Lamarre et al. 04)*
    - < 10 μK/$Hz^{1/2}$ for 4K box (30% emissivity)
    - < 30 μK/$Hz^{1/2}$ on 1.6K filter plate (20% emissivity)
    - < 20 nK/$Hz^{1/2}$ for detector plate (~5000 damping factor needed)
  - *low noise HEMT amplifiers (⇒ cooled to 20K) & very stable cold reference loads (4K)*

- Additionally:
  - *low emissivity, very low side lobes, telescope (strongly under-illuminated)*
  - *no windows, minimum warm surfaces between detectors and telescope*
  - *Complex cryogenic cooling chain (50K passive+20K+4K+0.1K)*
    - 20K for LFI with large cooling power K (0.7W)
    - 4K, 1.6K and 100mK for HFI
    - Thermal architecture optimised to damp thermal fluctuations (active+passive)
  - *NB: 100mK cooling by dilution cooler does not tolerate micro-vibrations at sub-mg level or 7.10^{10} He atoms accumulated on dilution heat exchanger (typically He pressure 1.10^{-10} mb)*

HFI Integration & Calibration @ IAS

(reproduction of spatial and micro-wave environment)



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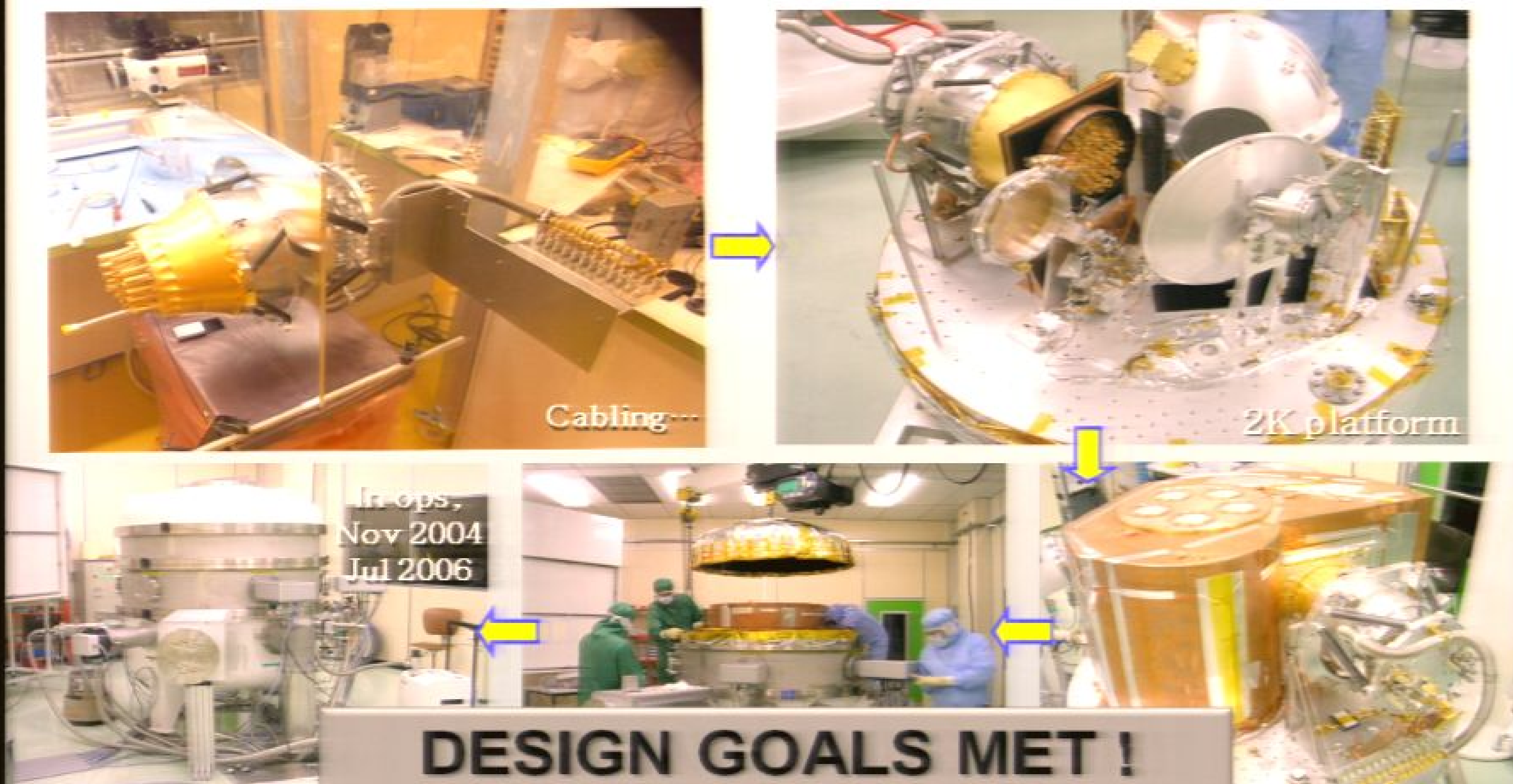

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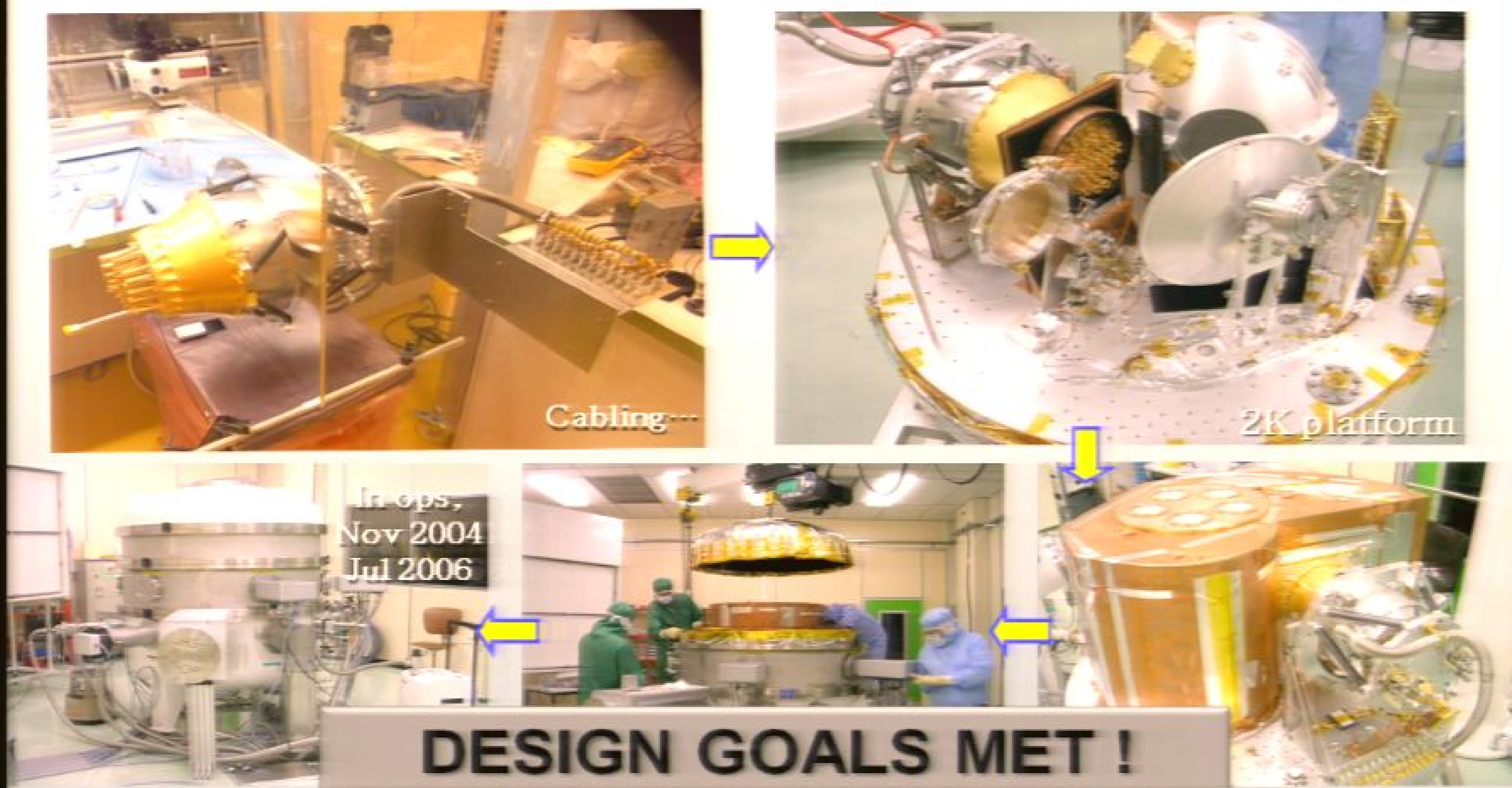
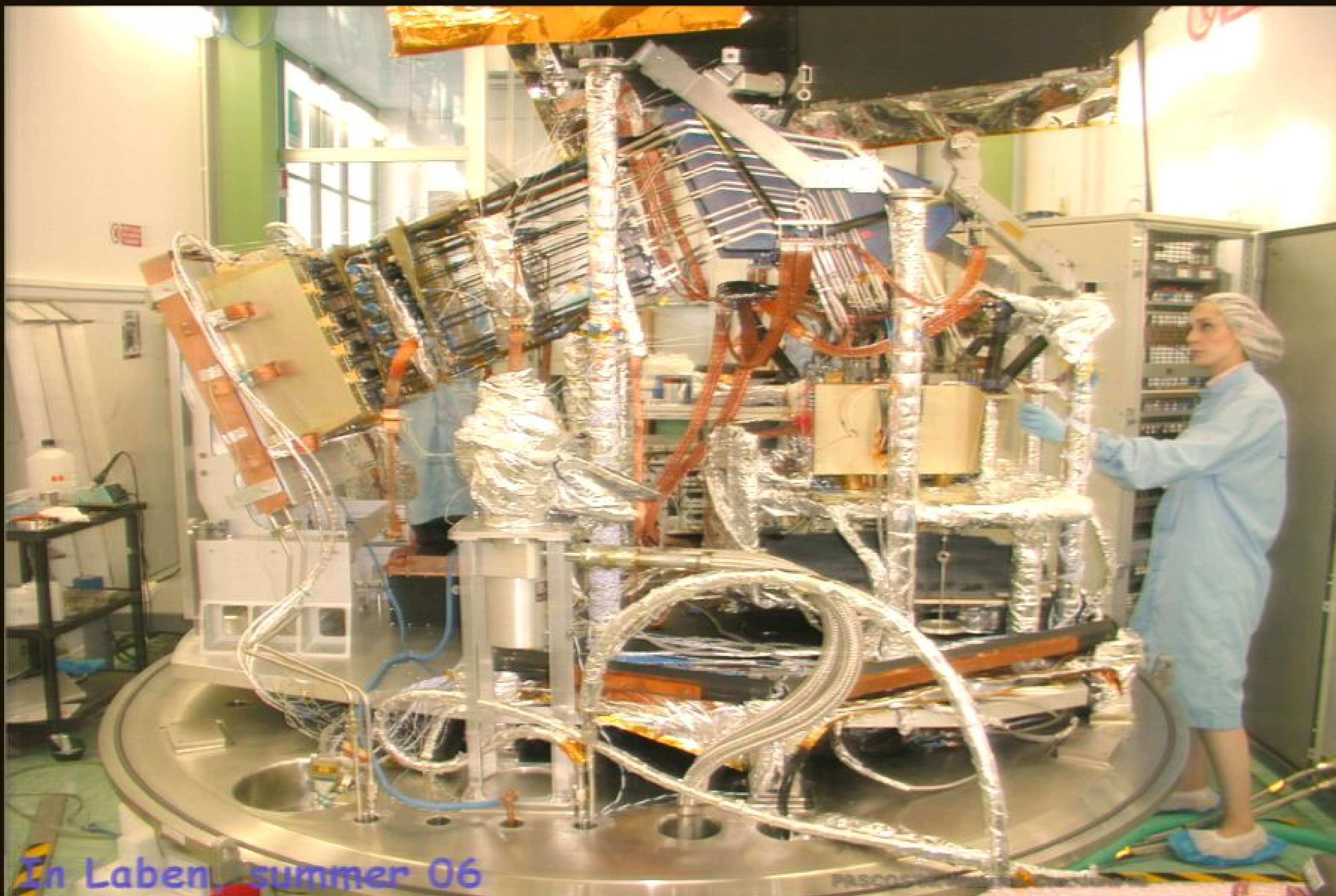
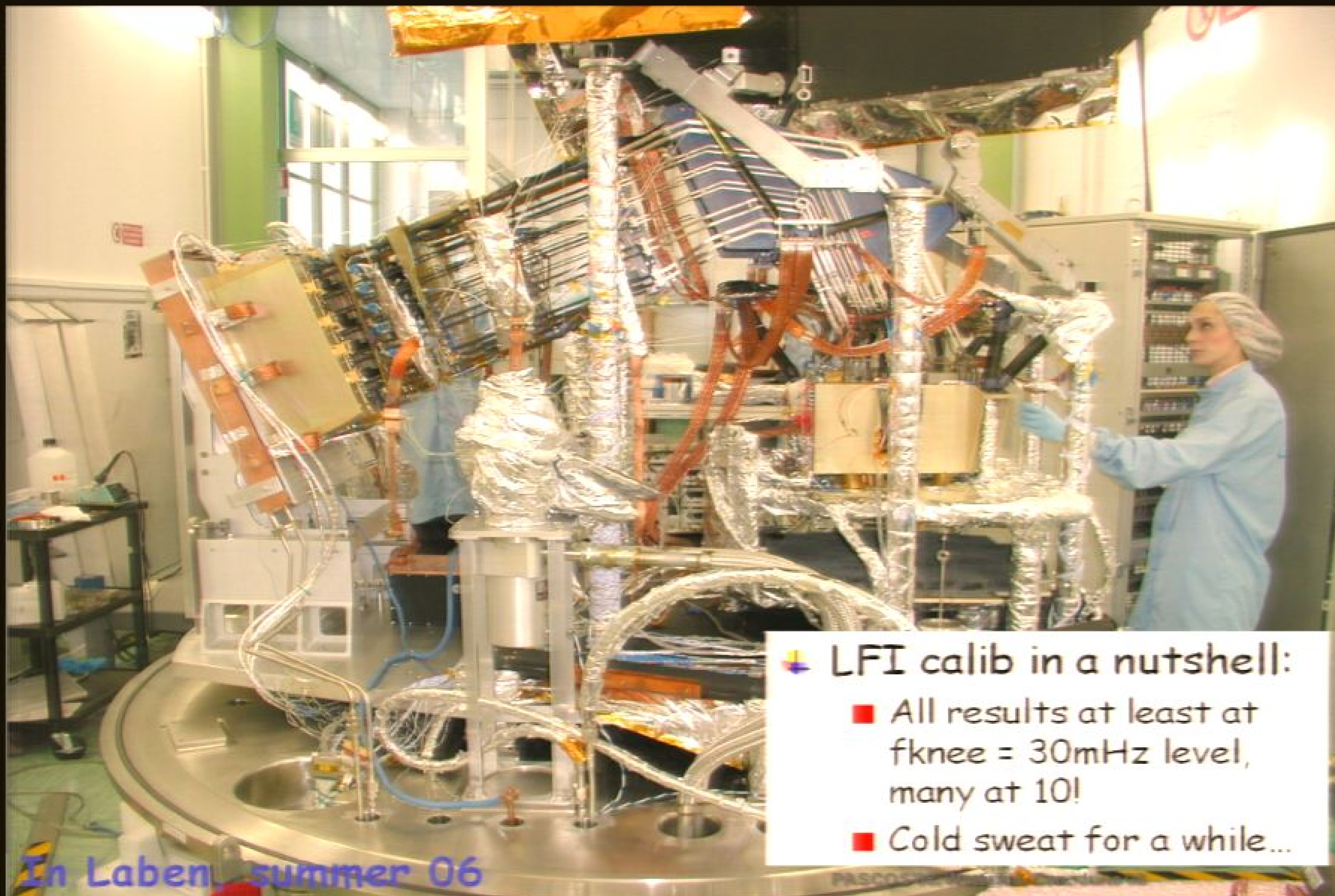


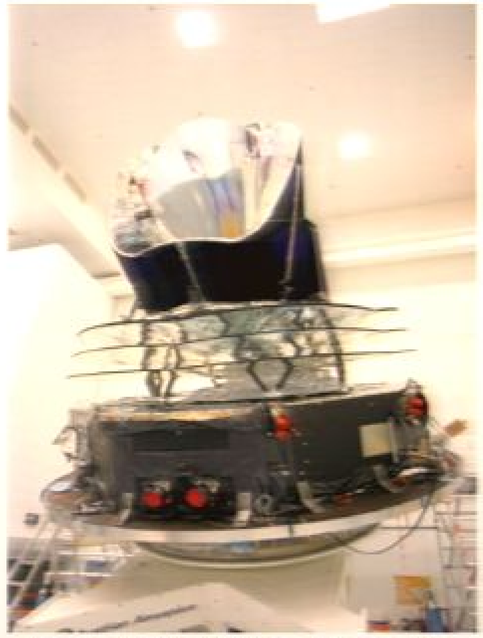
WMAP would need ~500 years of survey time to reach HFI 1yr sensitivity


In Laben, summer 06


LFI calib in a nutshell:
All results at least at fknee = 30mHz level, many at 10!
Cold sweat for a while...
In Laben, summer 06

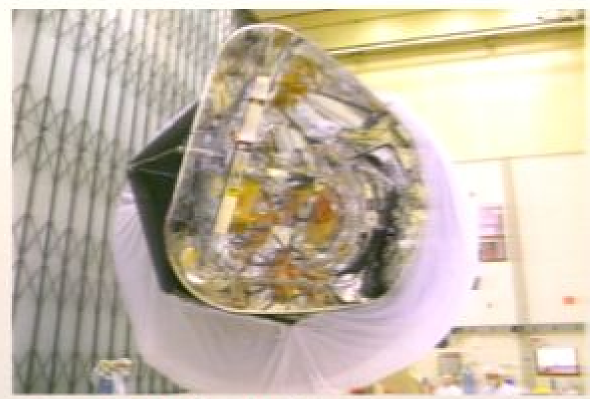
Integration is getting to an end

Nov 2006,
HFI + LFI
integration



Dec 9th 2007, Ready
for vibration testing

April 7th 08: load balancing



April 18th 2008: preparing
ESTEC → CSL

03/08: Antonov Nice → ESTEC

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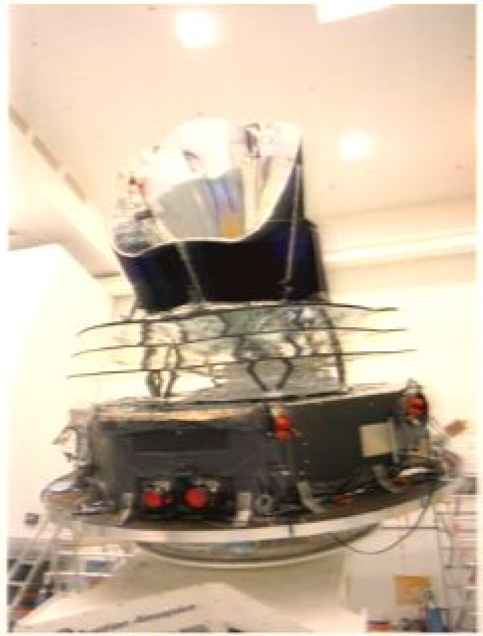

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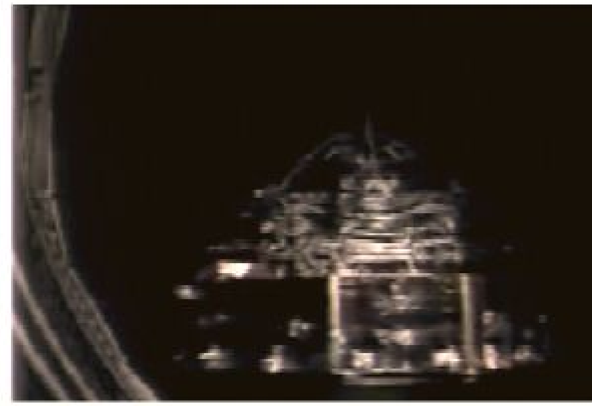

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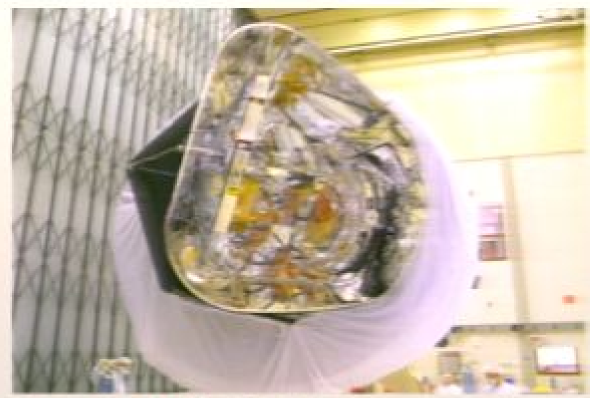

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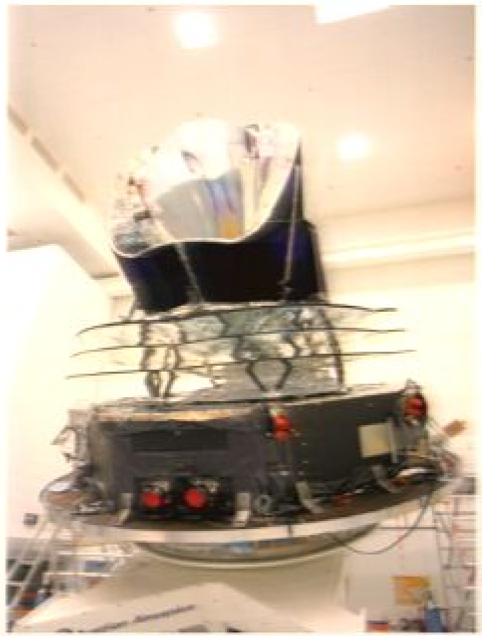

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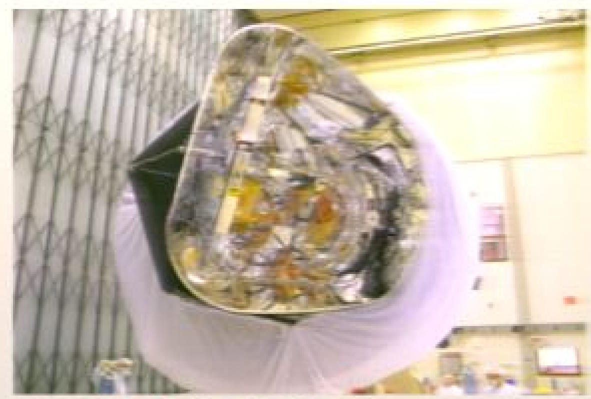

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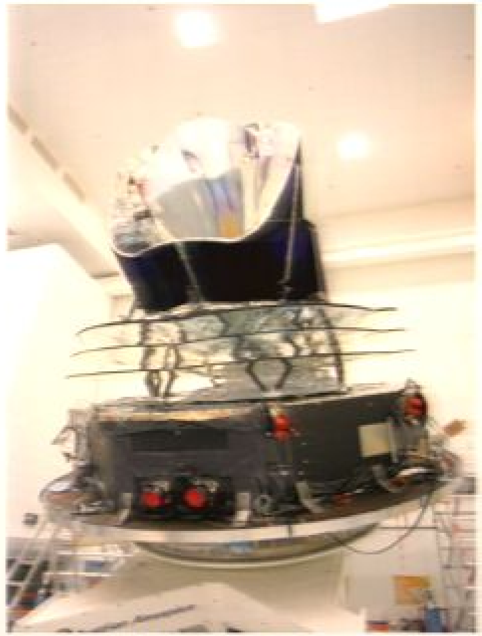

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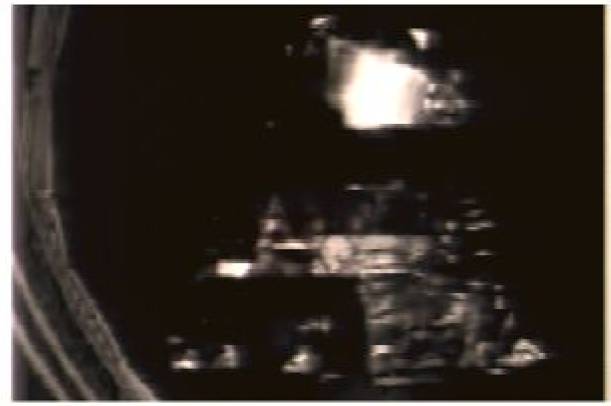

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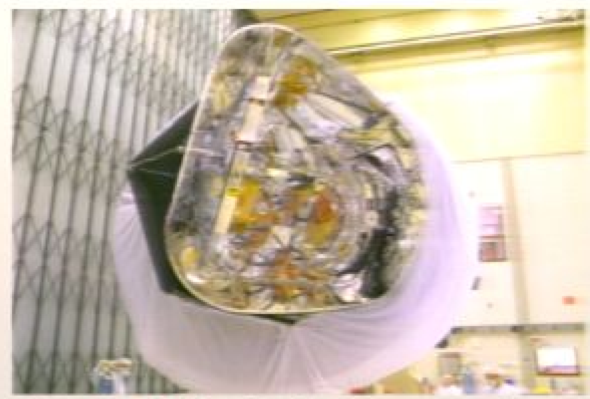

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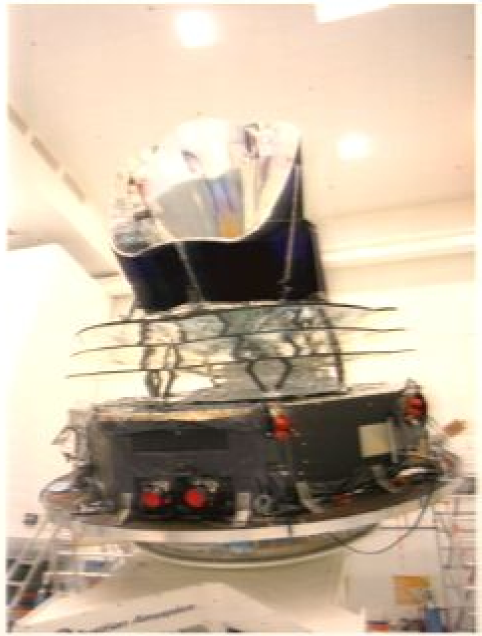

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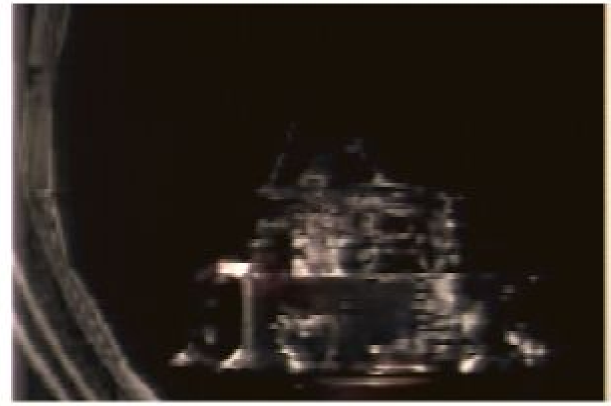

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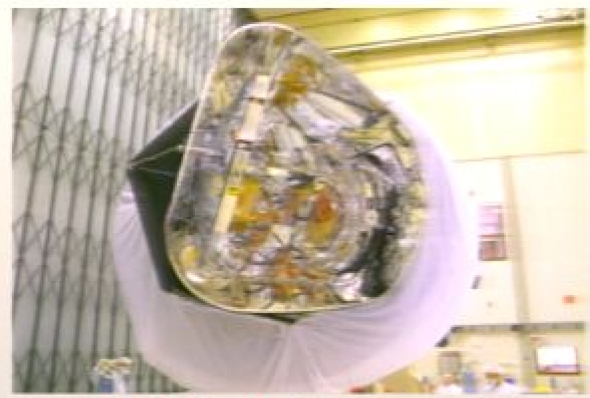

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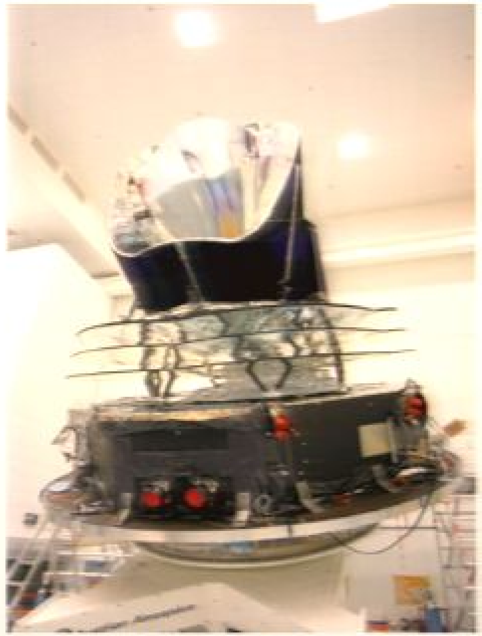

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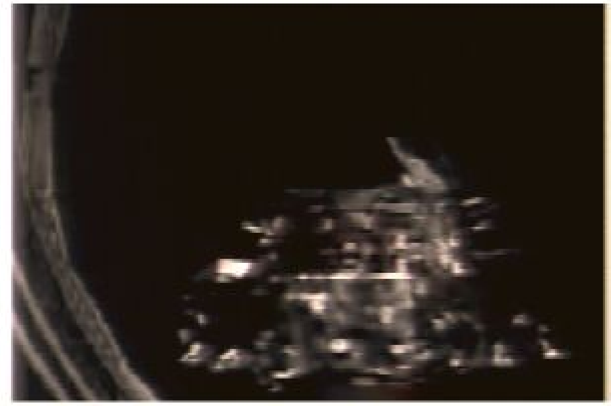

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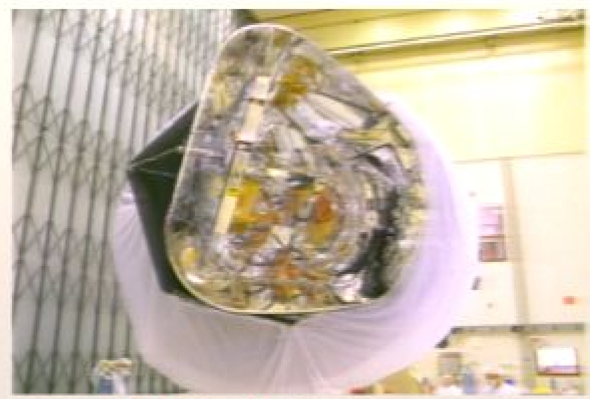

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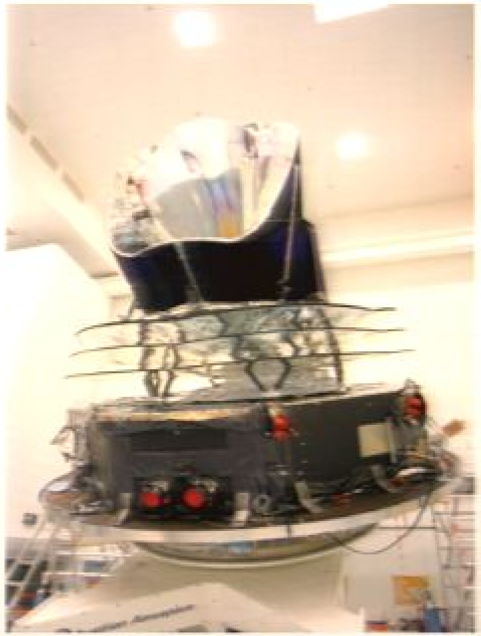

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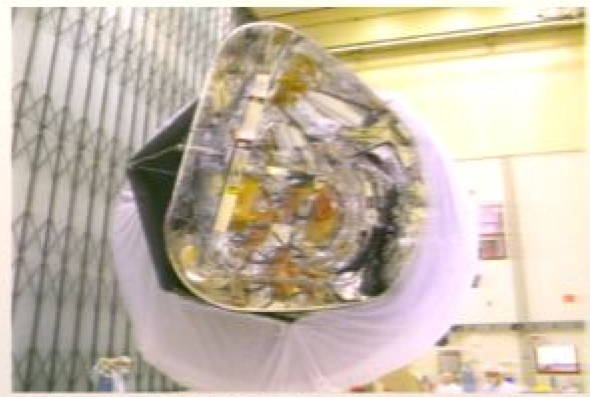

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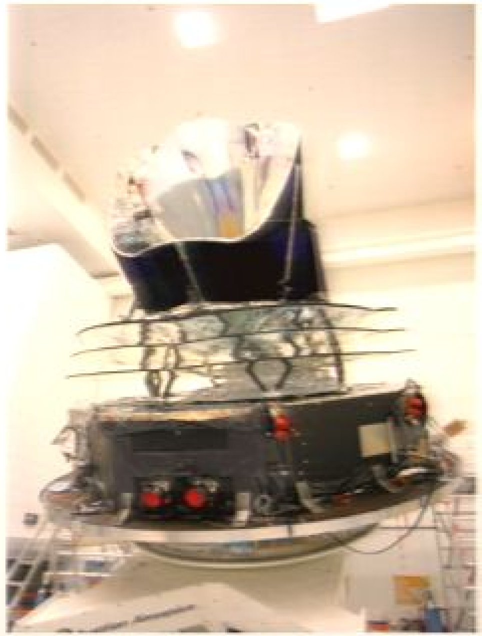

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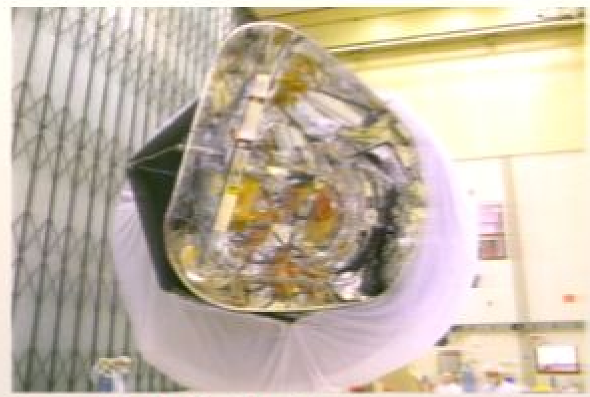

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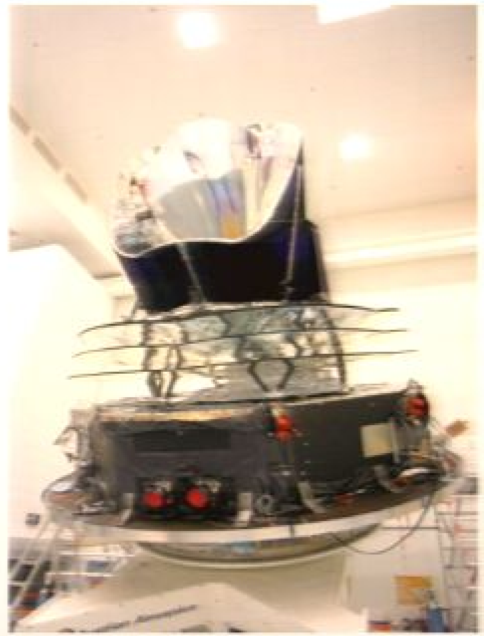

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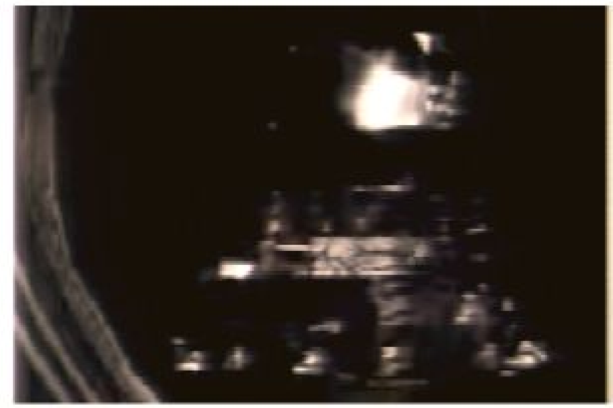

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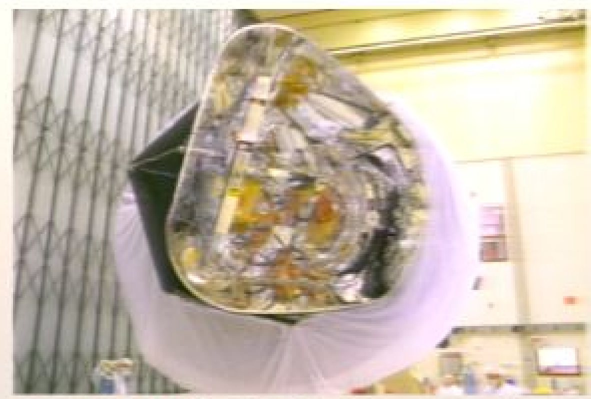

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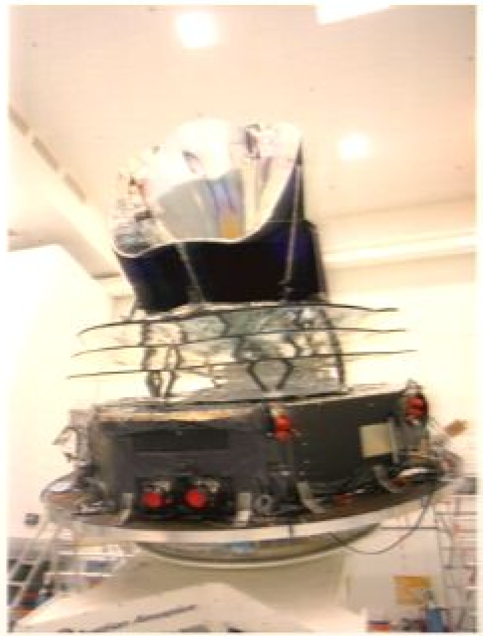

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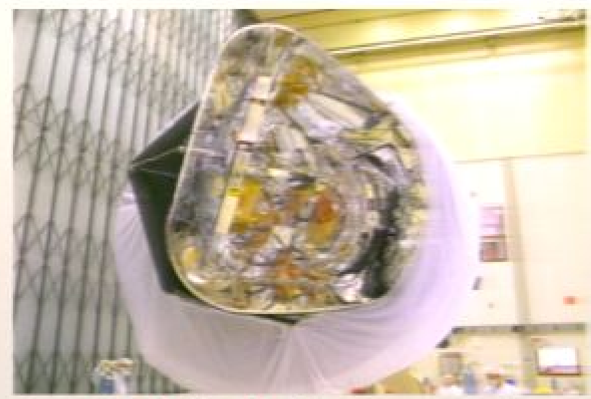

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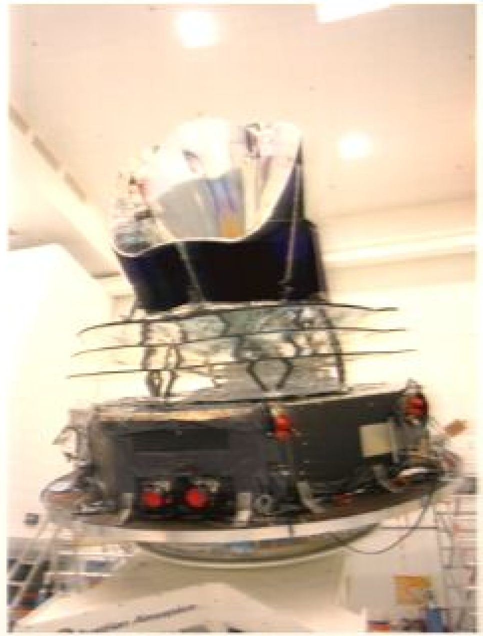

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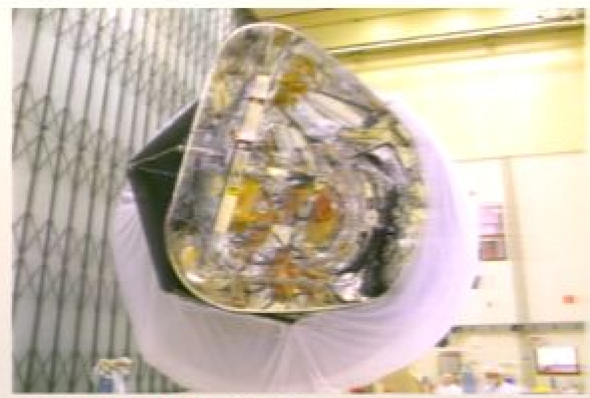

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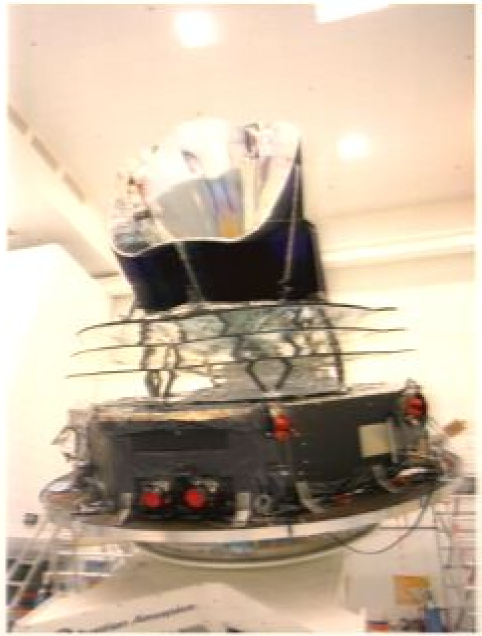

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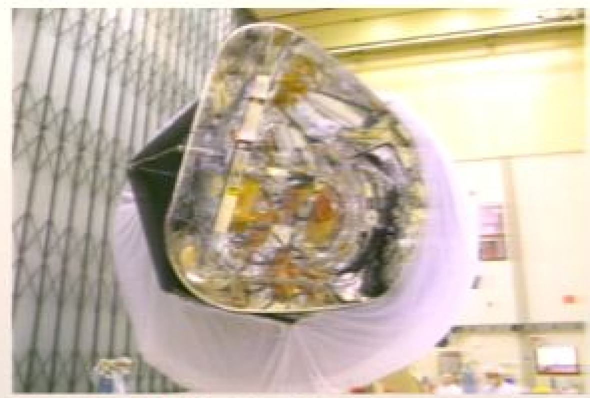

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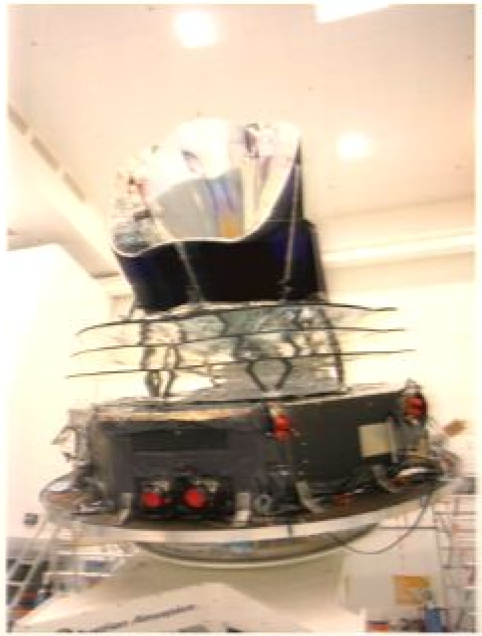

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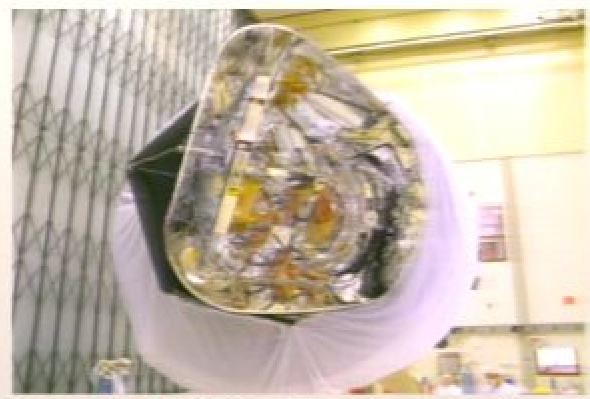

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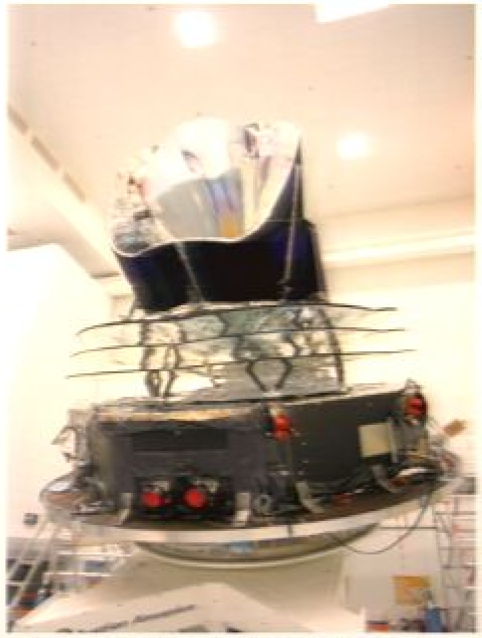
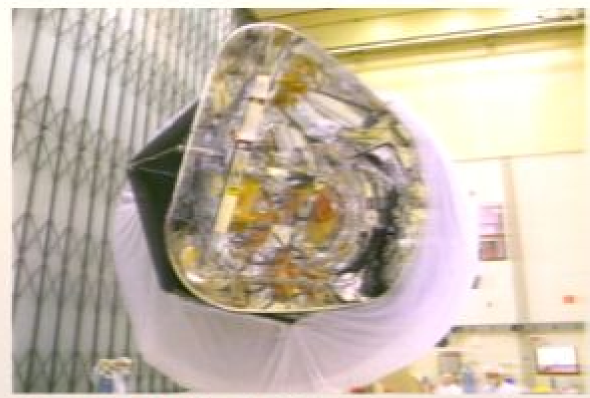


Dec 9th 2007, Ready for vibration testing

03/08: Antonov Nice → ESTEC

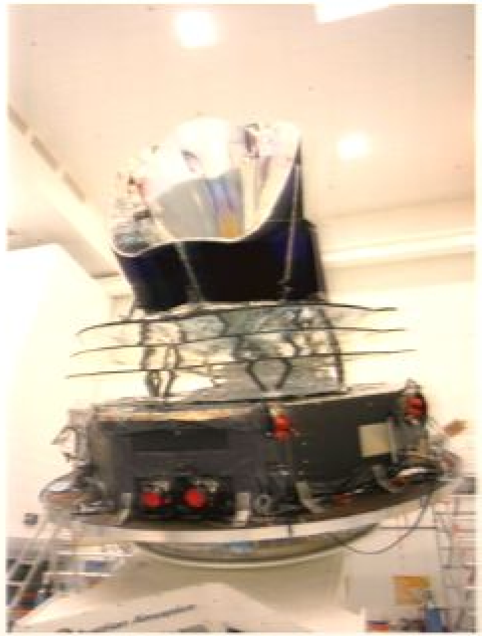
April 7th 08: load balancing



April 18th 2008: preparing
ESTEC → CSL

Integration is getting to an end

Nov 2006, HFI + LFI integration



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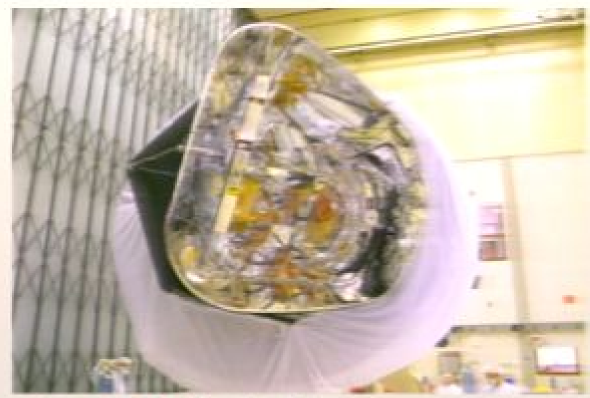

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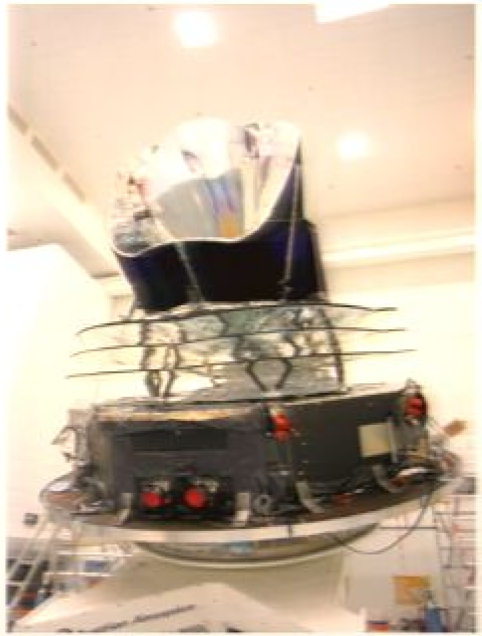

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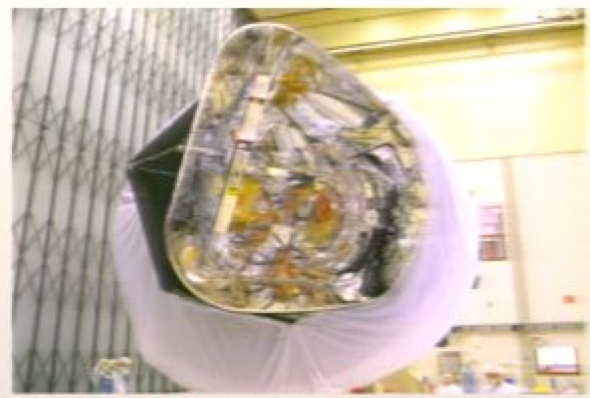

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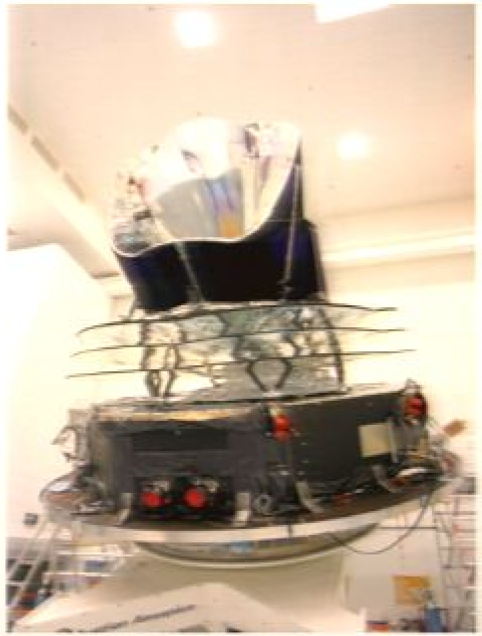

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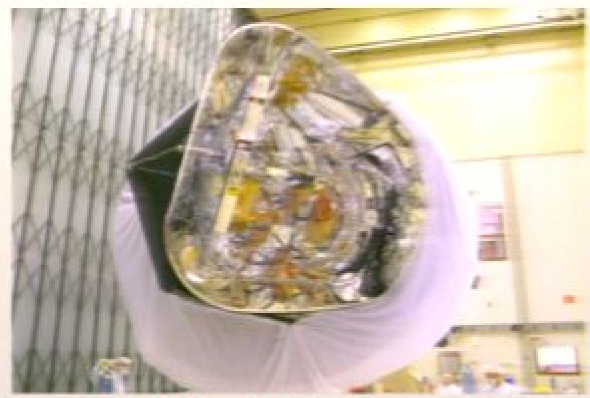
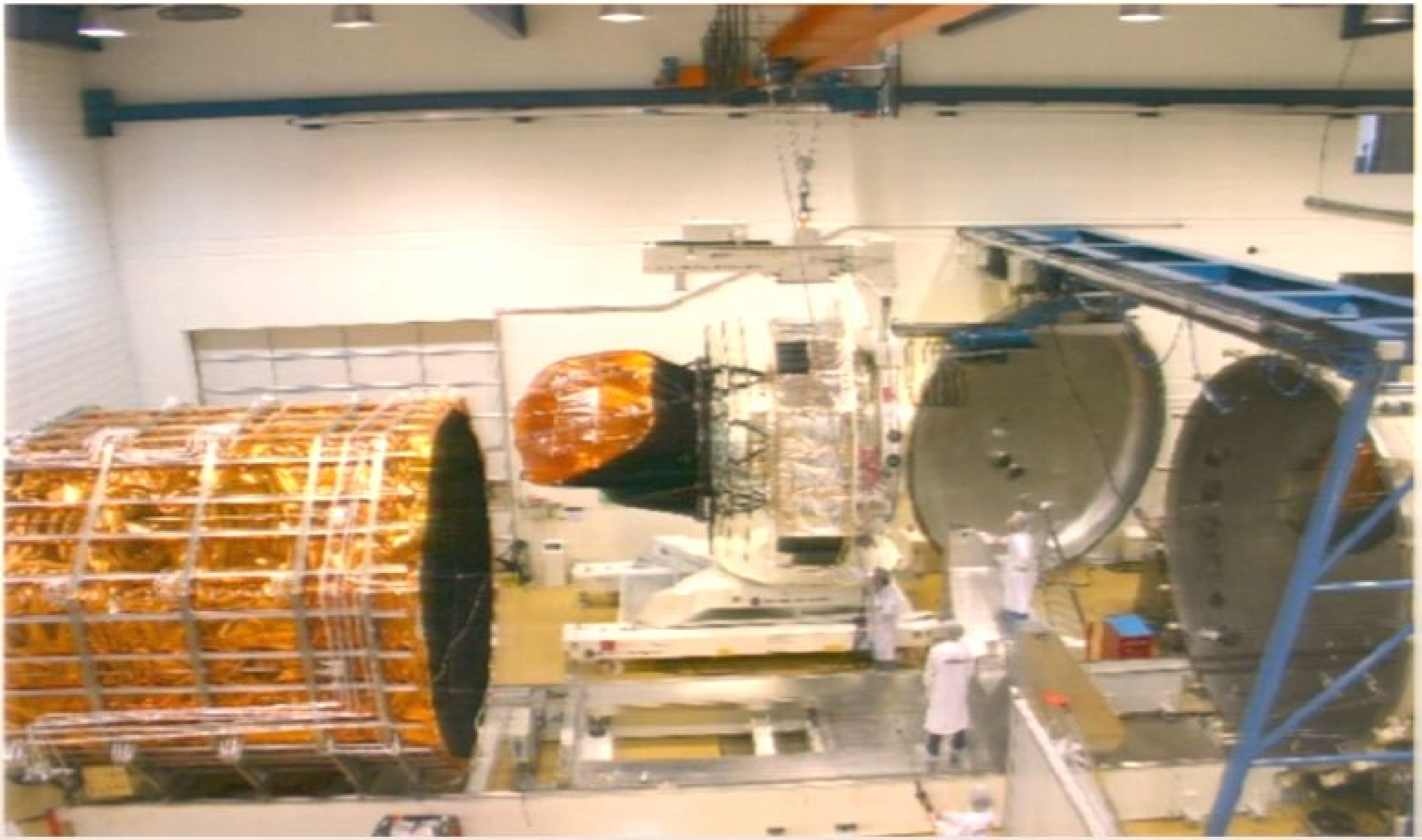


April 18th 2008: preparing ESTEC → CSL

1st & last full thermal vacuum test



19 May 2008: fitting test @ CSL **(SOVT was last week)**

WHAT WHEN

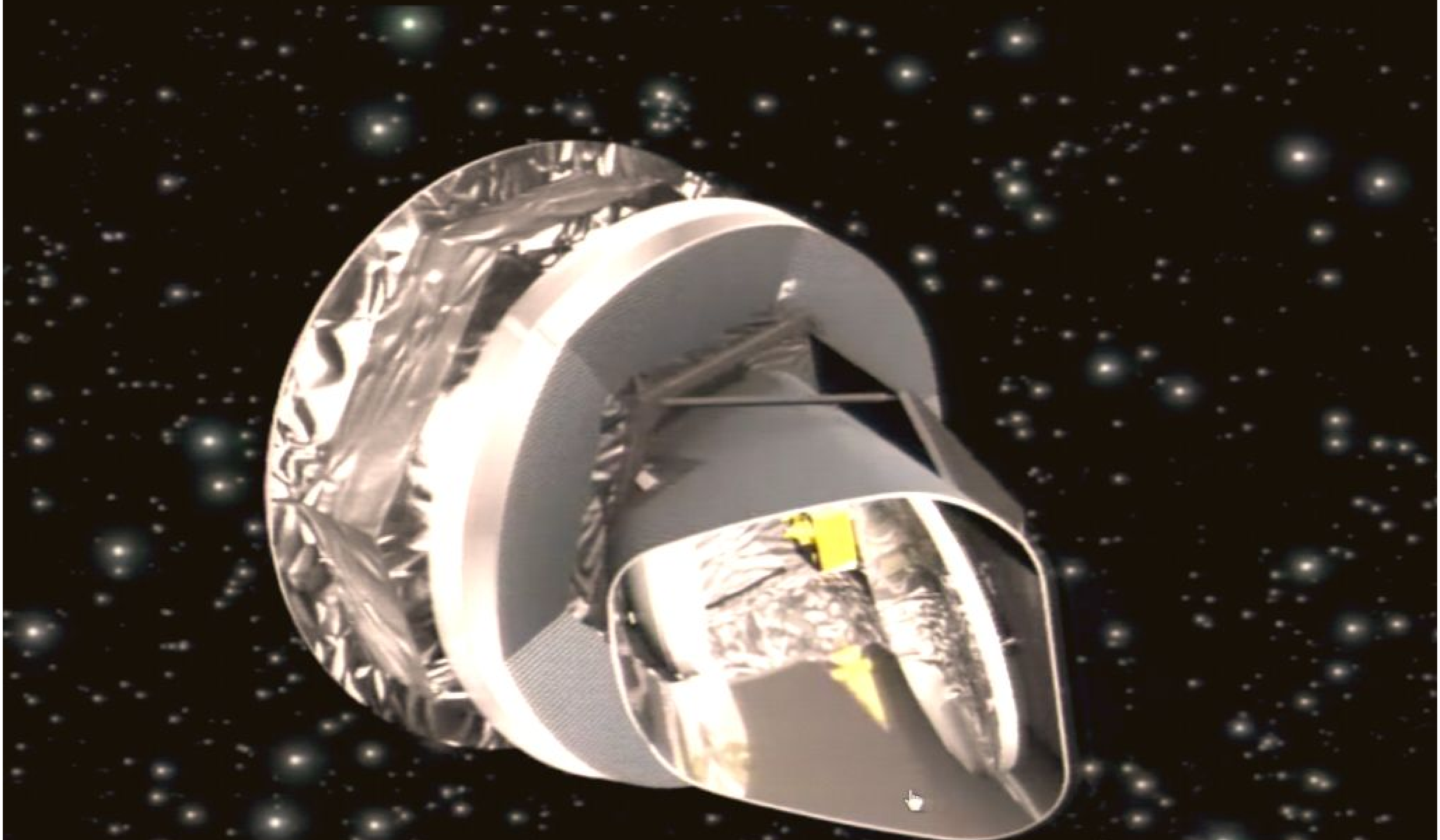
- Launch from Kourou planned for December 2008
- Travel for 2 months to L2 (100mK after 50d), Calibration & Performance Verification (< 2months), 14+? months of operations to complete > 2 surveys

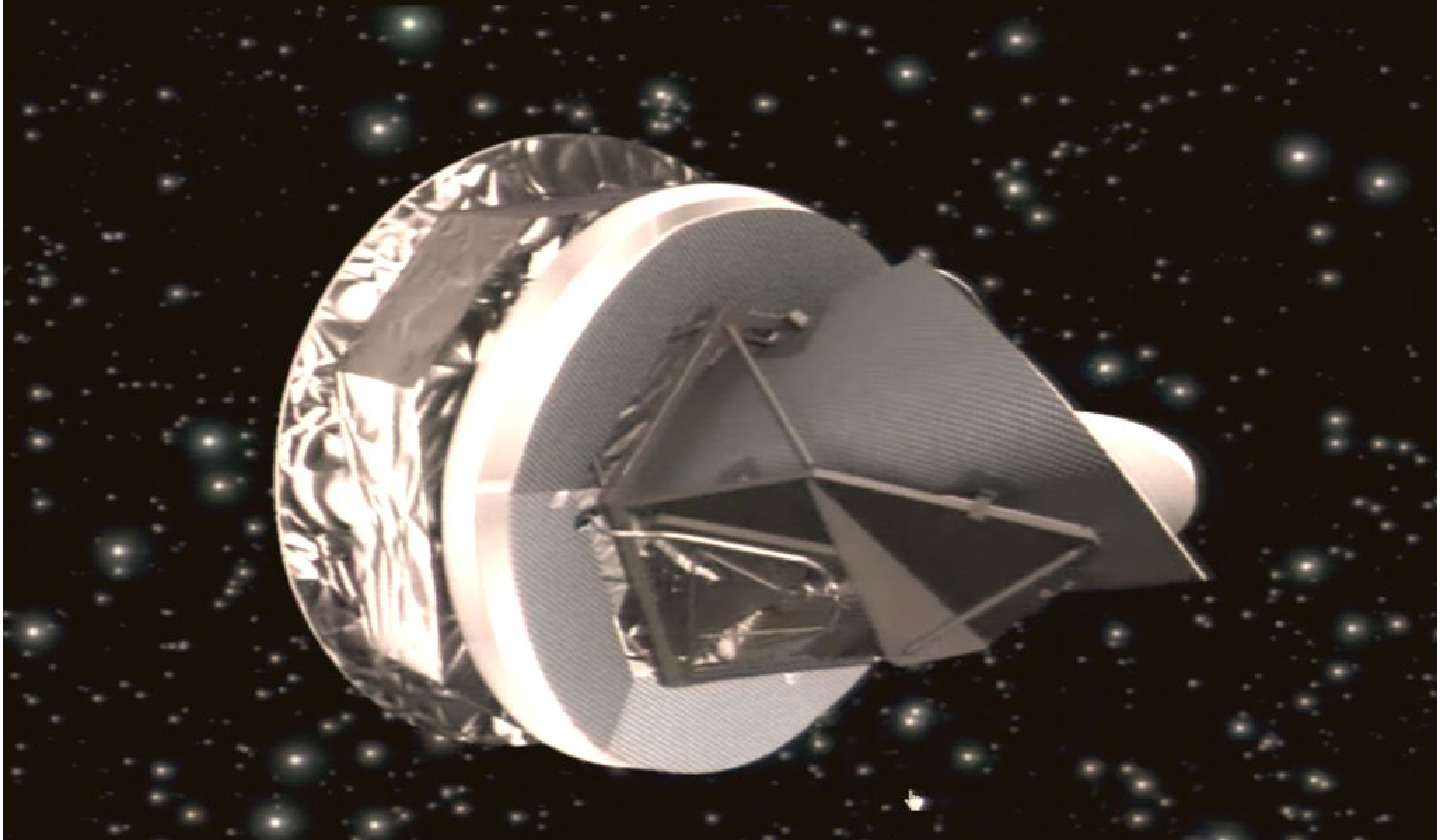
- Early 2010 : "Early Release Point Source Catalogue" (Herschel followup)
- Early 2012 : First public data release by ESA of 14 month of data + ~50 papers
  - *Clean calibrated time-ordered data*
  - *Full sky maps in (HFI 6+ LFI 3) frequencies*
  - *Maps of identified astrophysical components (1st Generation)*
    - CMB
    - Galactic Emissions (sync. Free-free, dust)
    - Extragalactic sources catalogue
  - *CMB characterisation (C(l), likelihood...)*

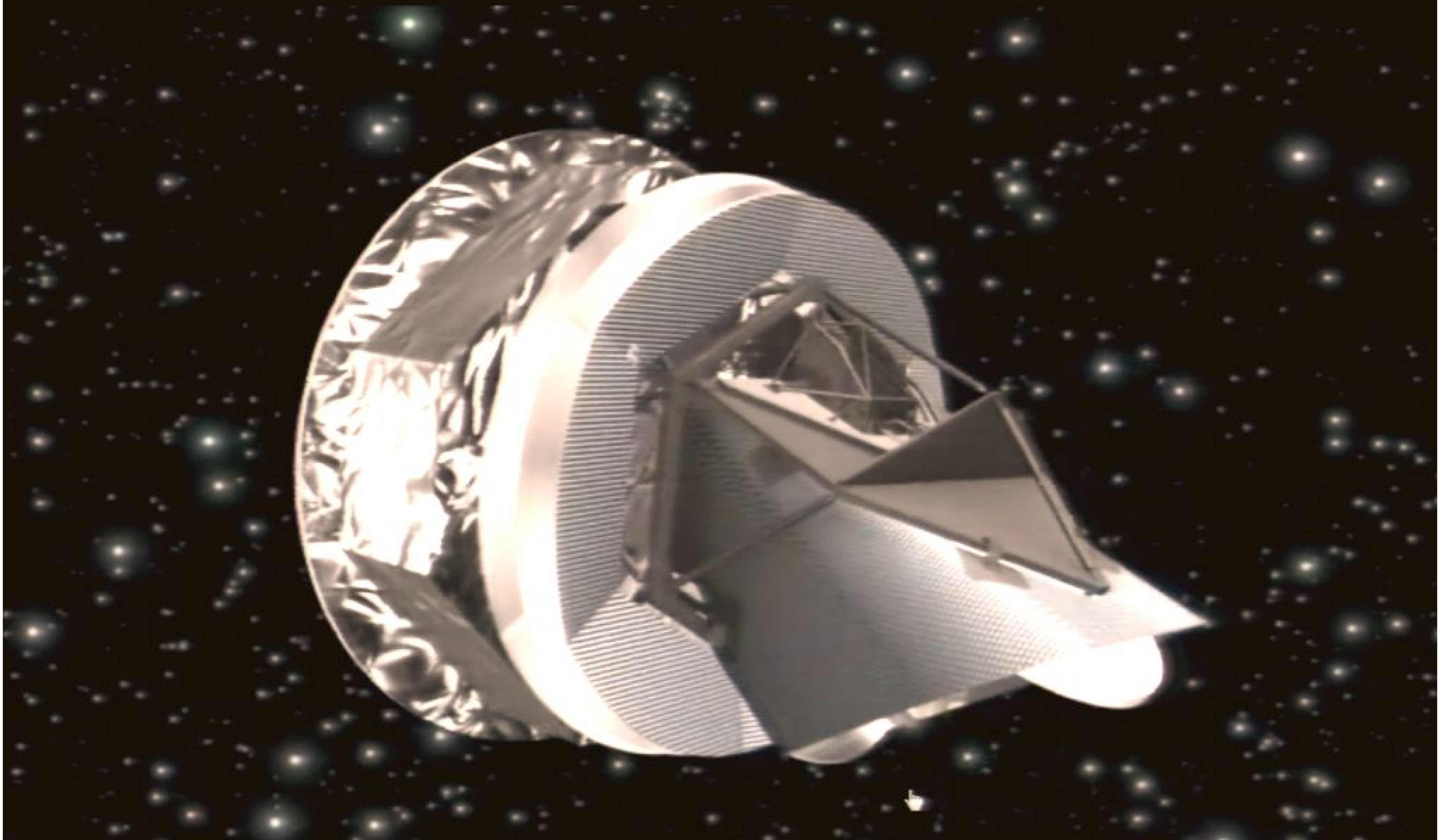
- ≥ 2013 : Potential second data release (helium permitting)

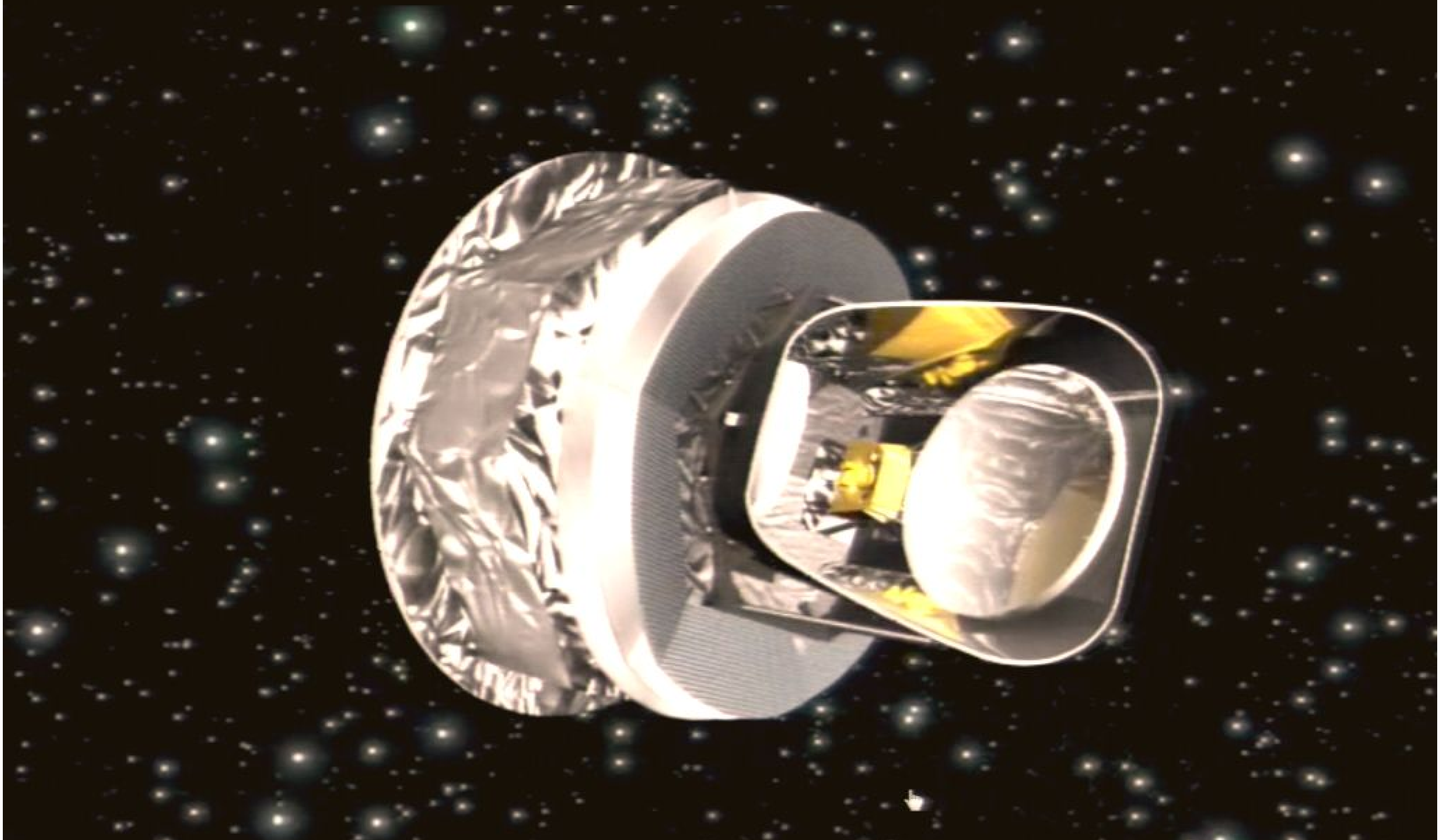
- Intermediate products, ~ every 6 months, for scientific exploitation/preparation by the Planck collaboration during the operations (1.2 yr) and the analysis (1yr) and proprietary time (1 year),.

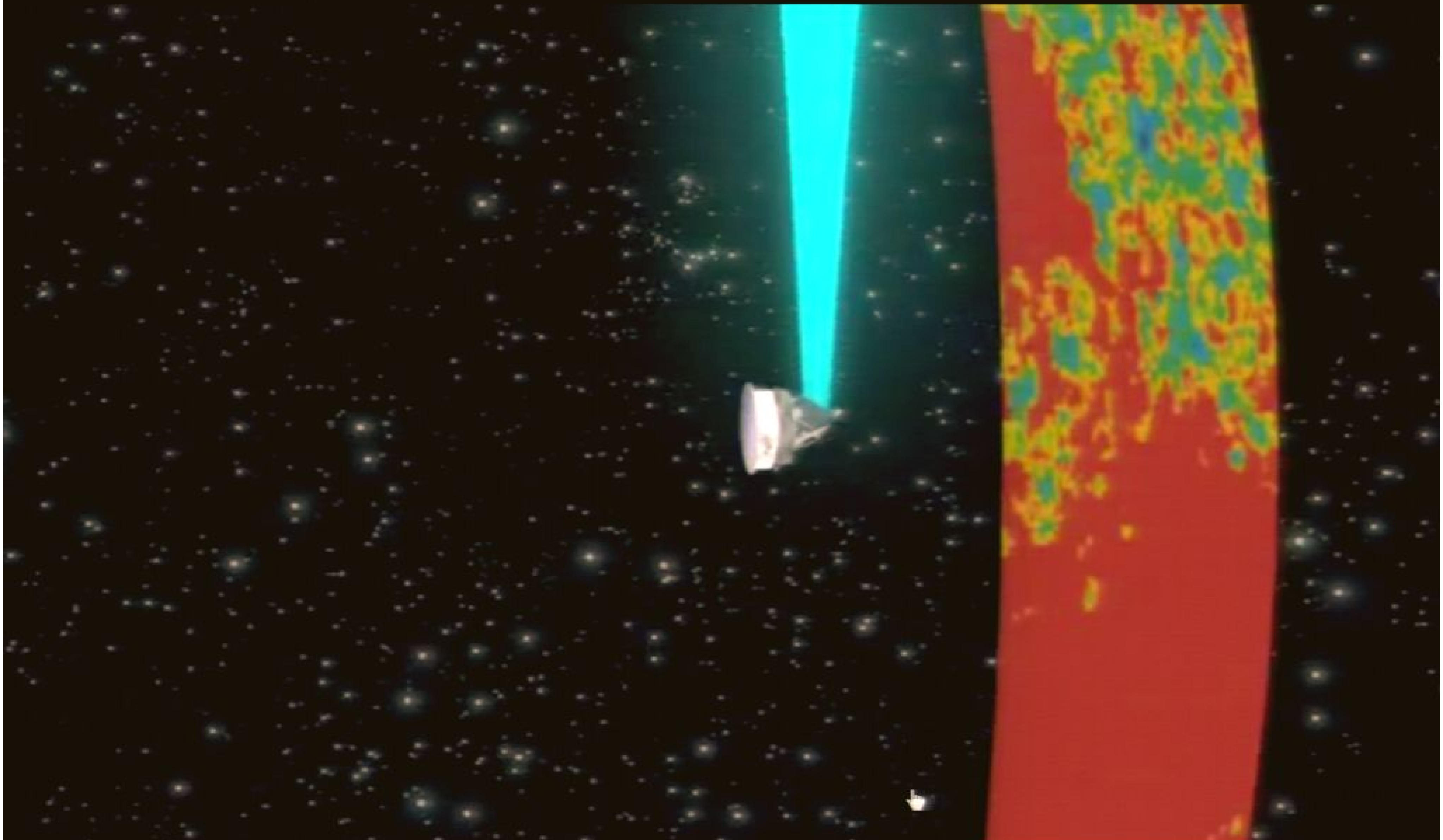
Observational site: L2 halo orbit

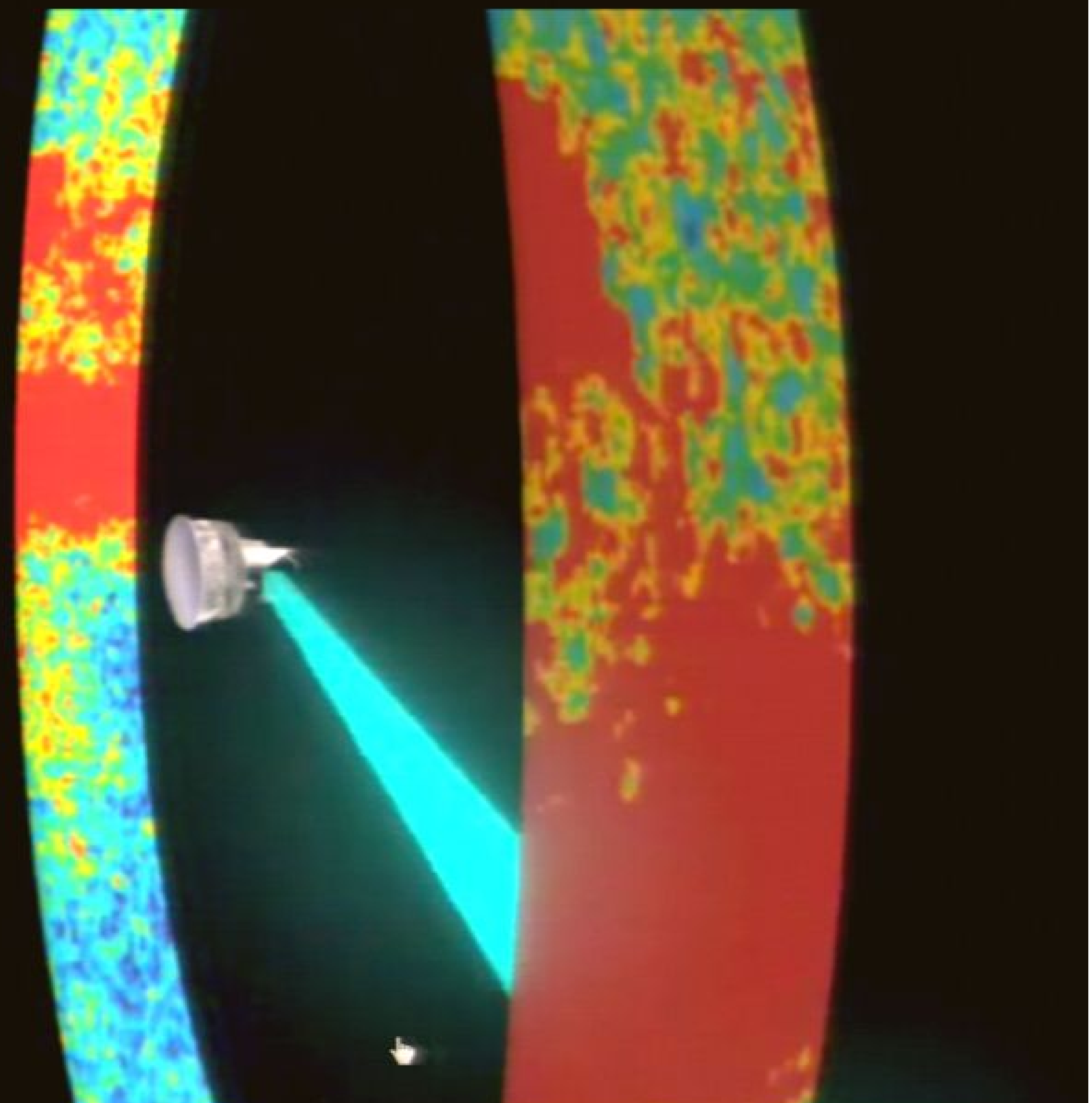


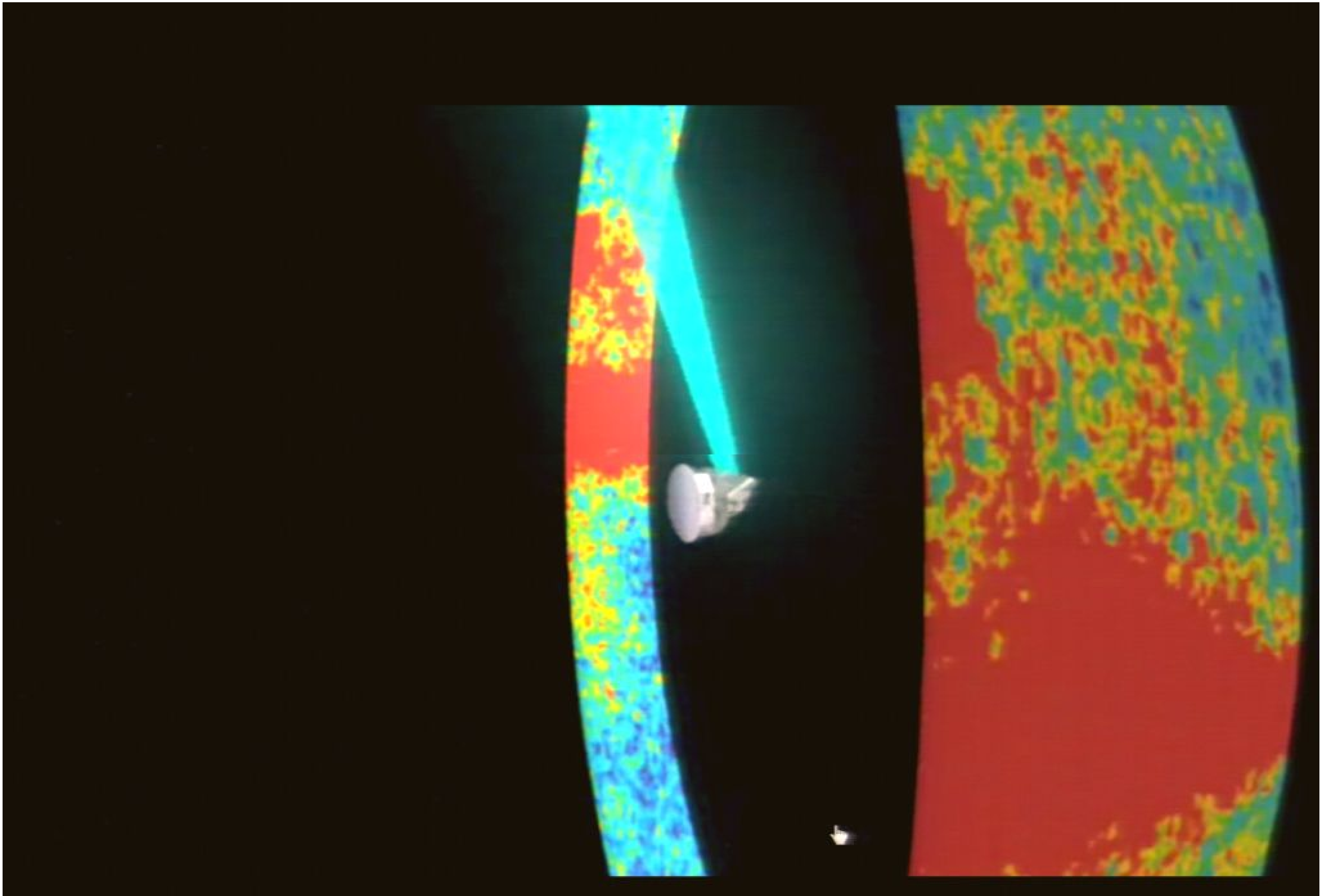


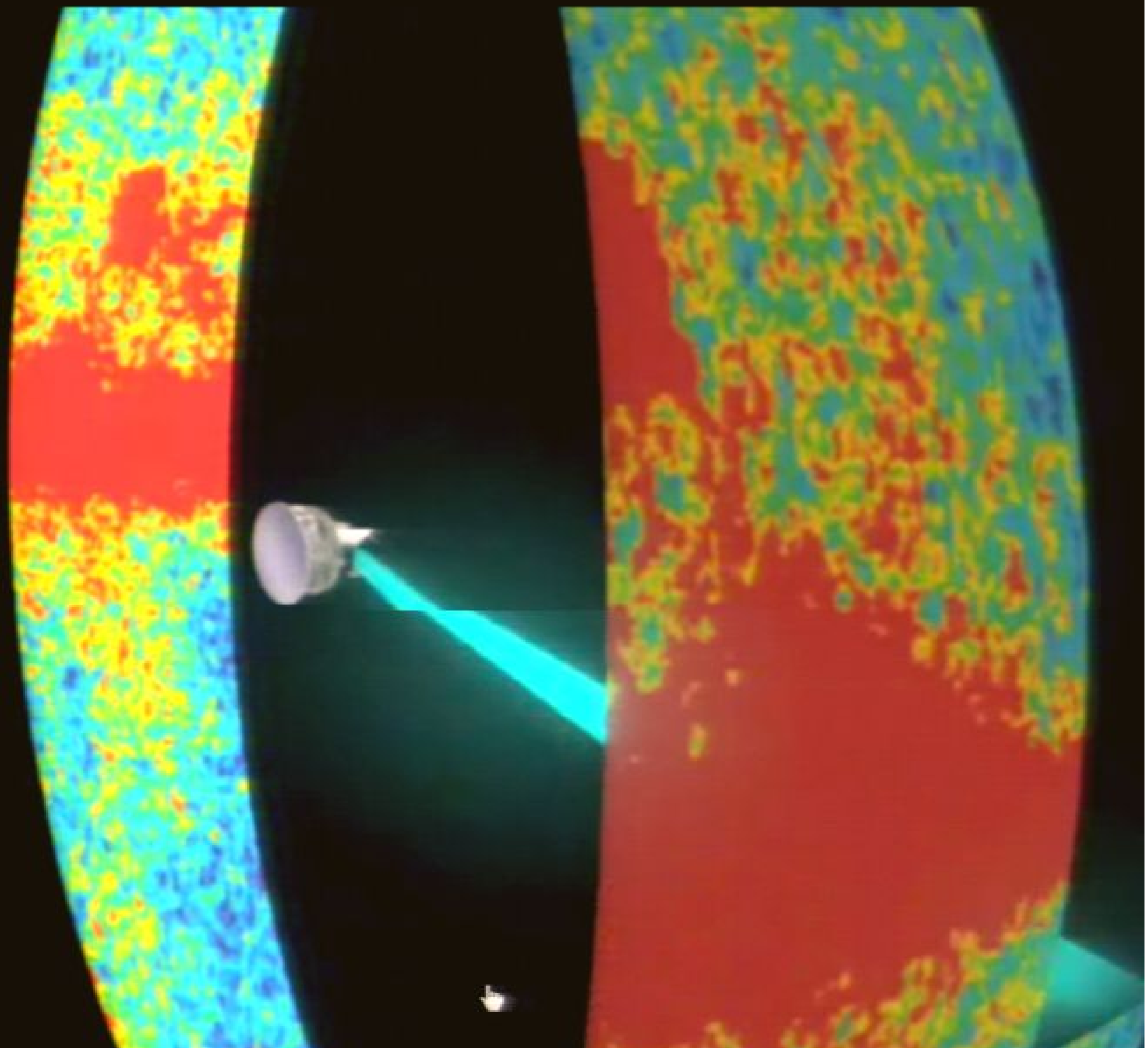


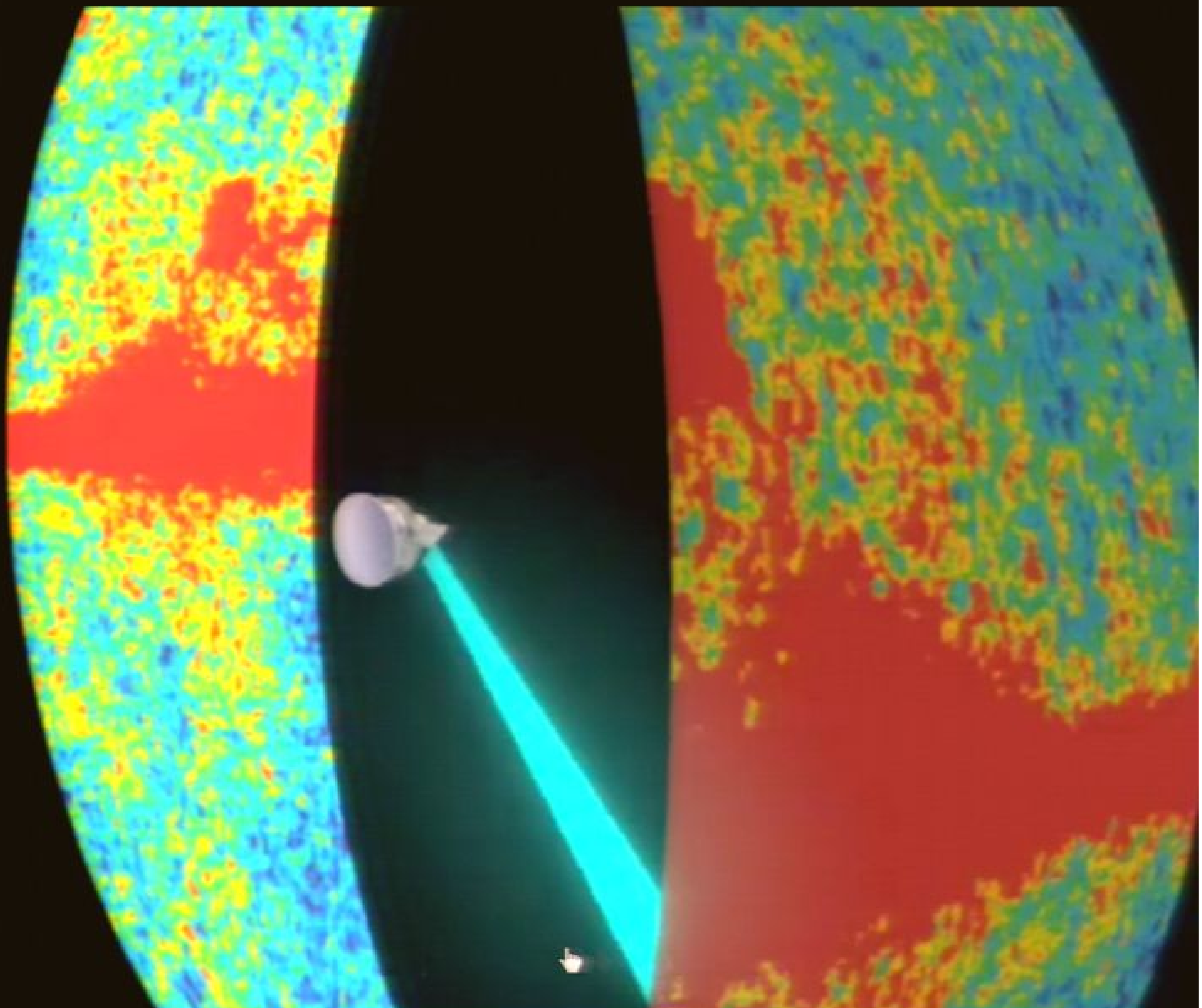


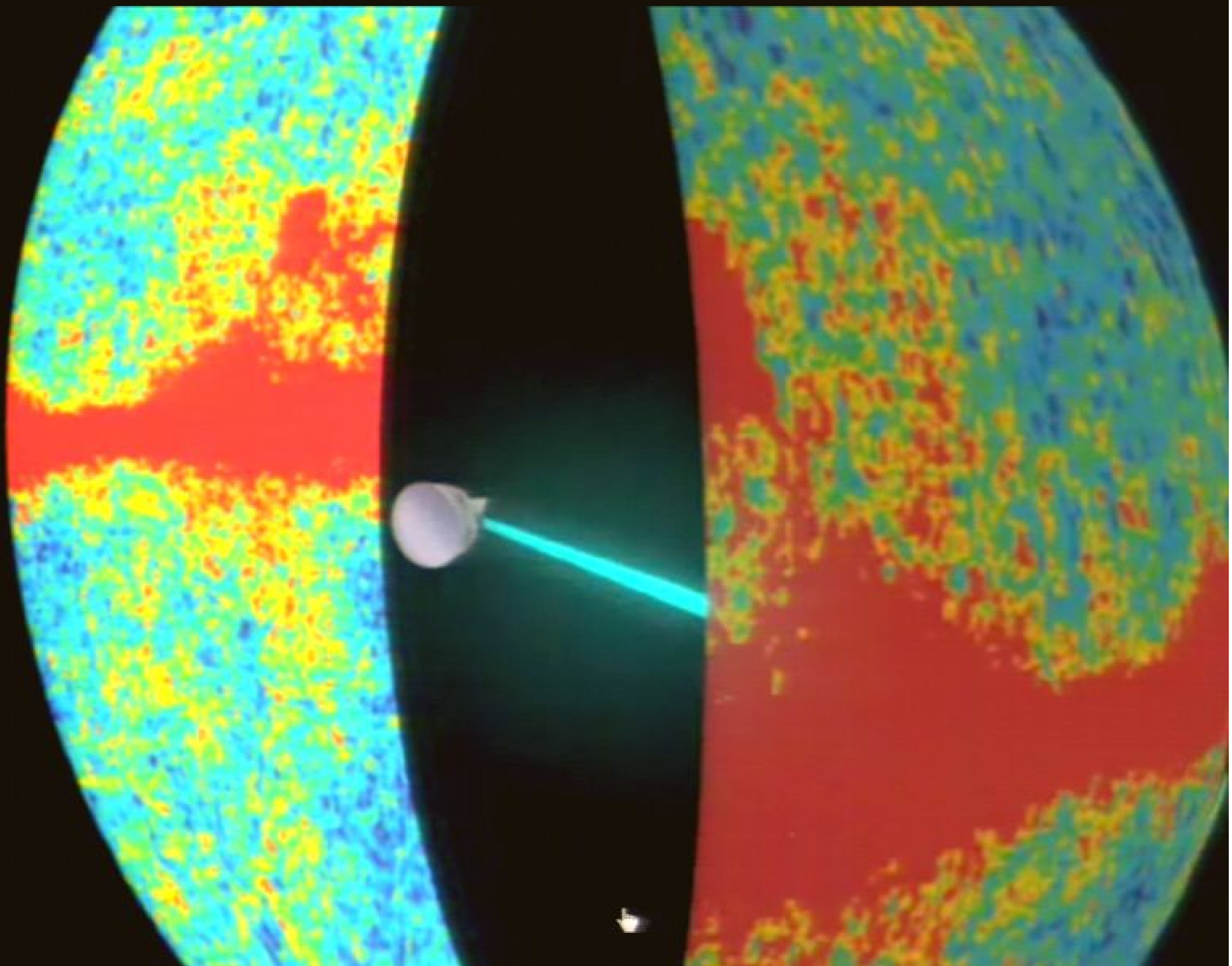


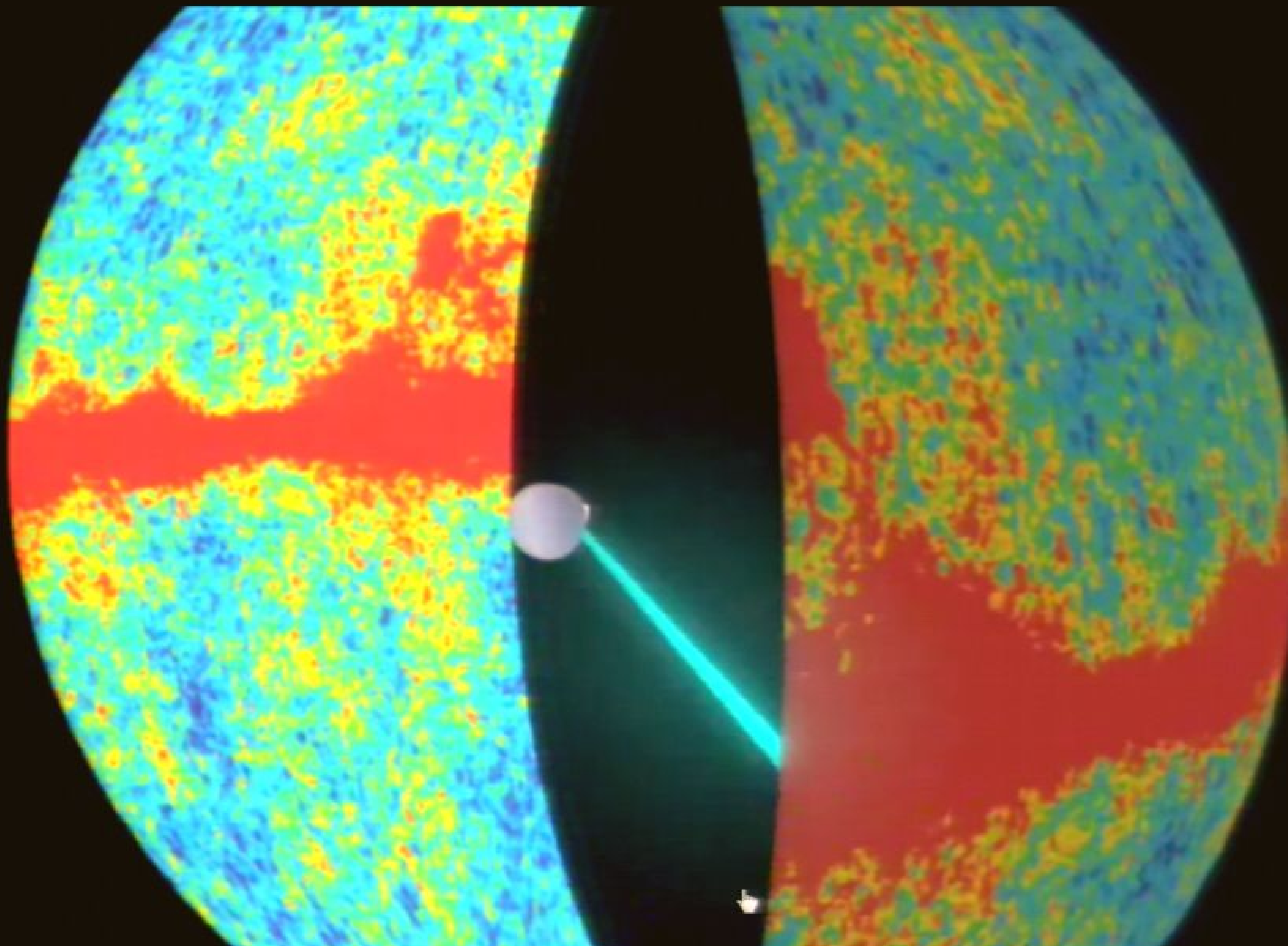


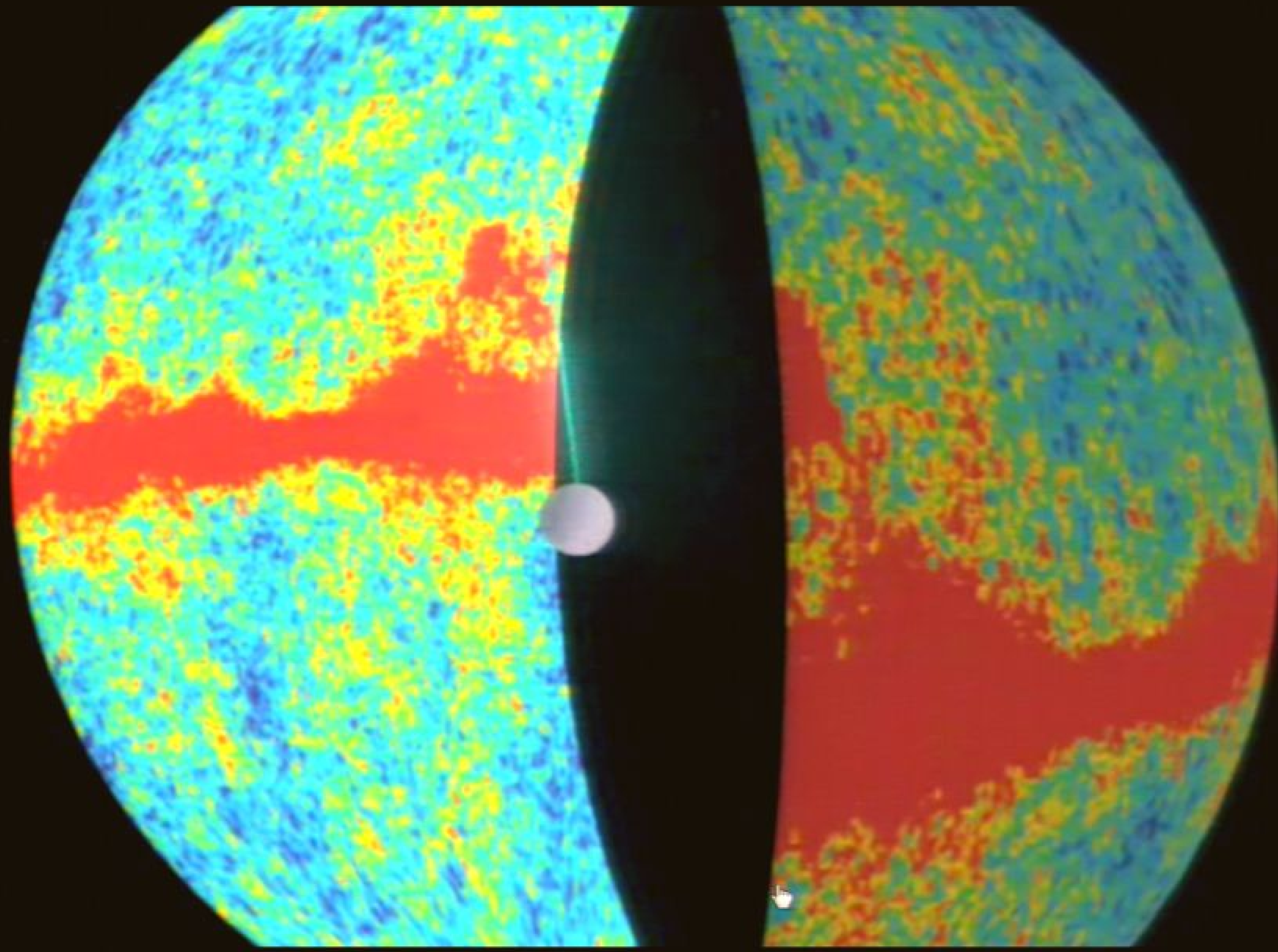


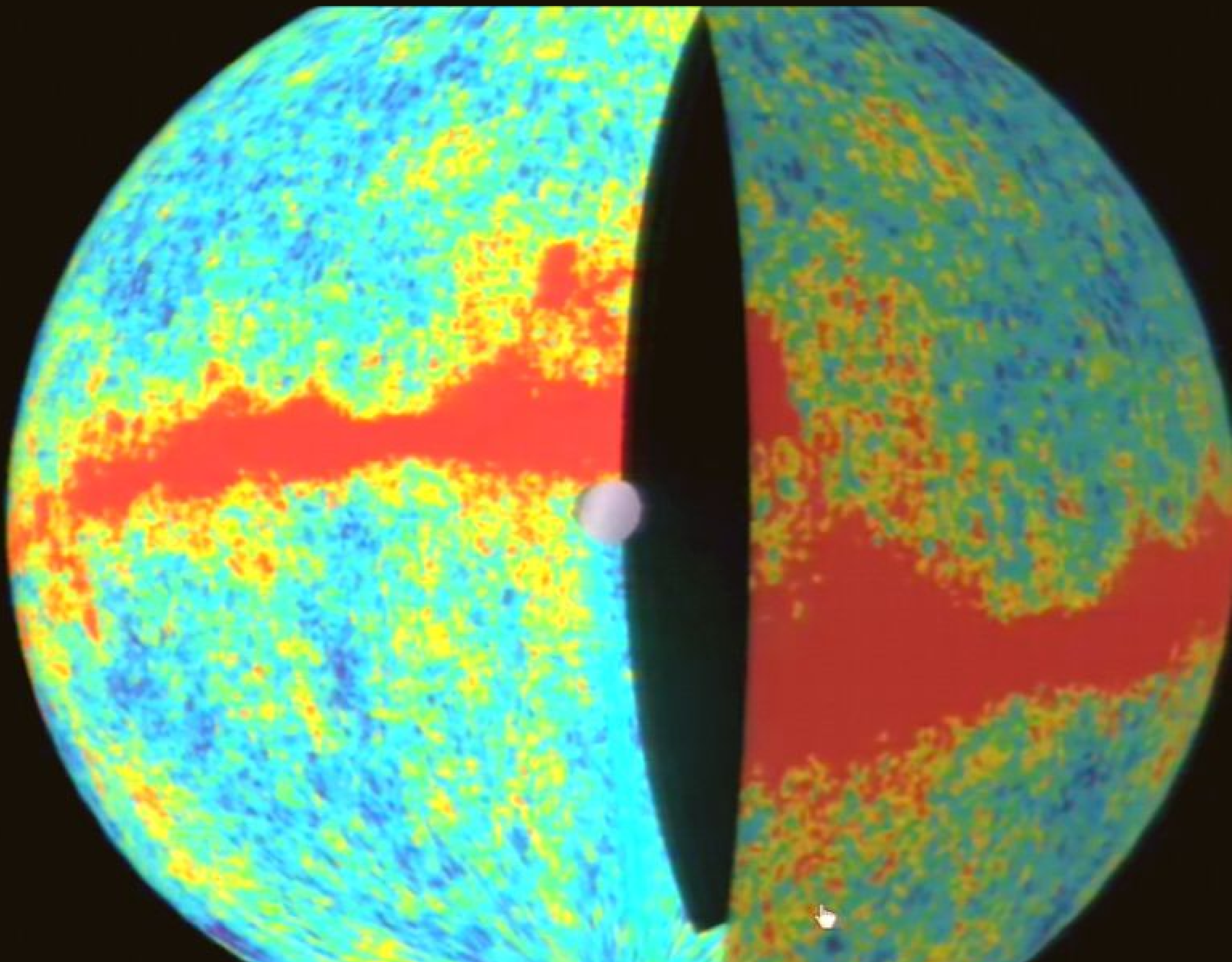


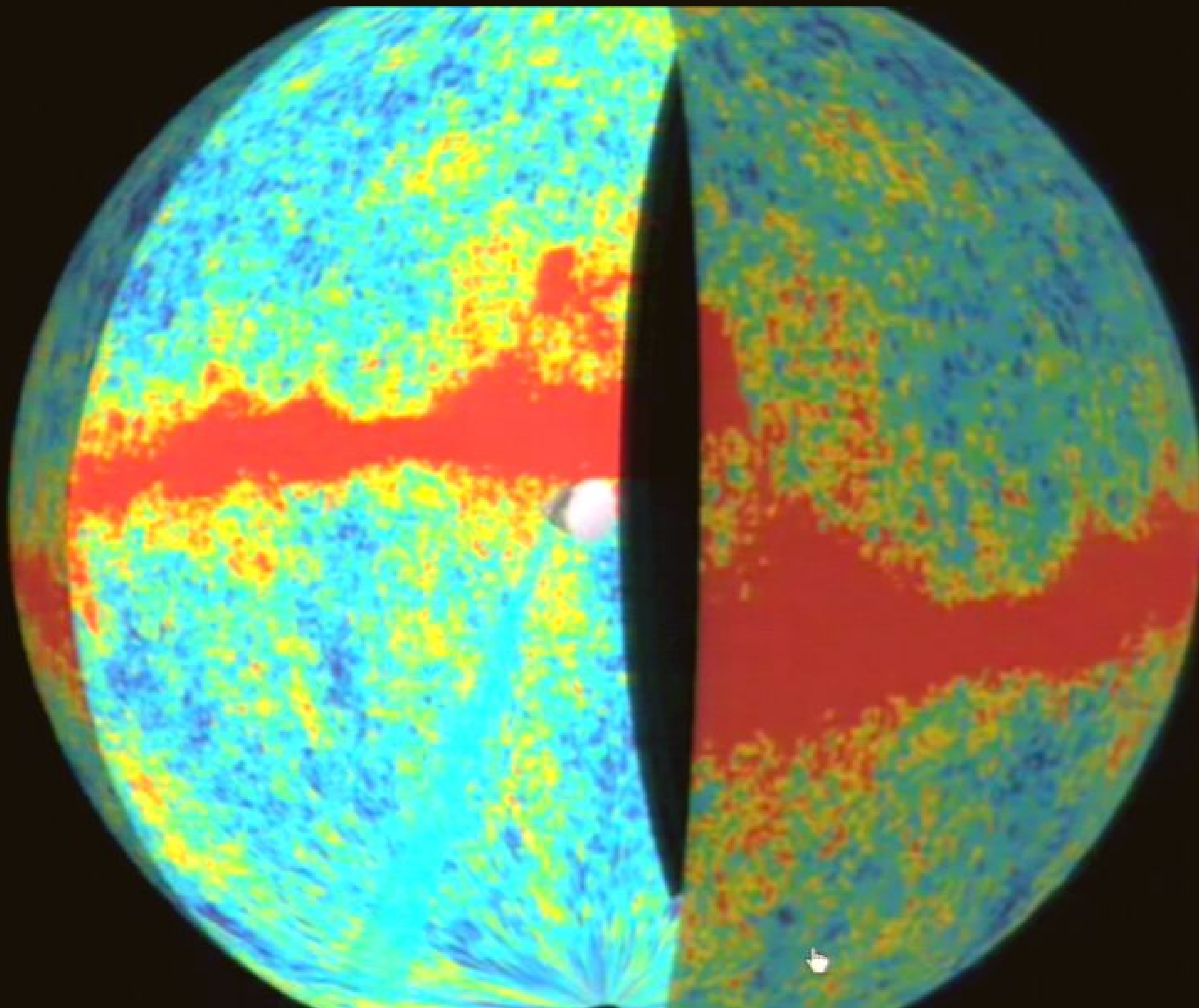


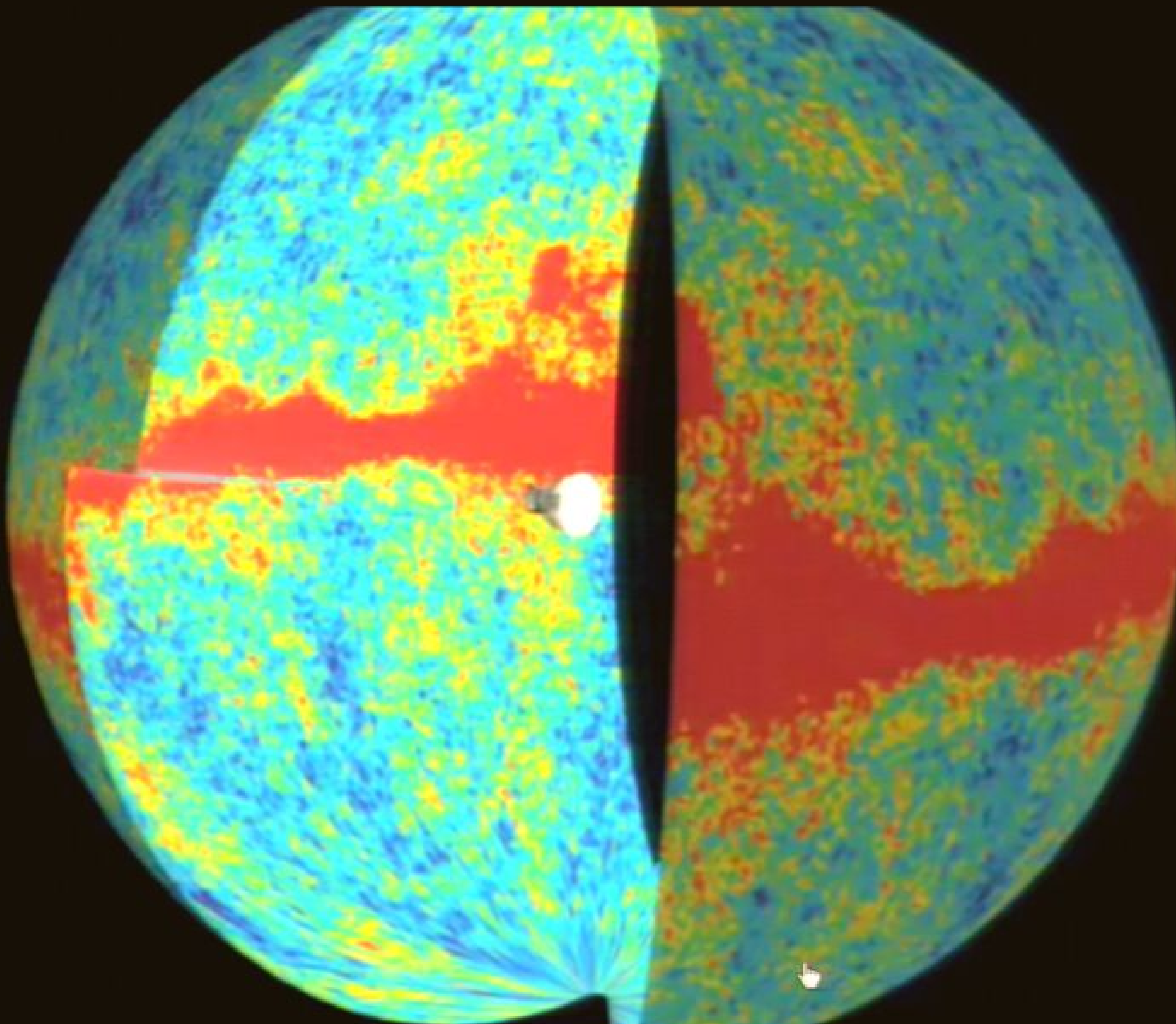


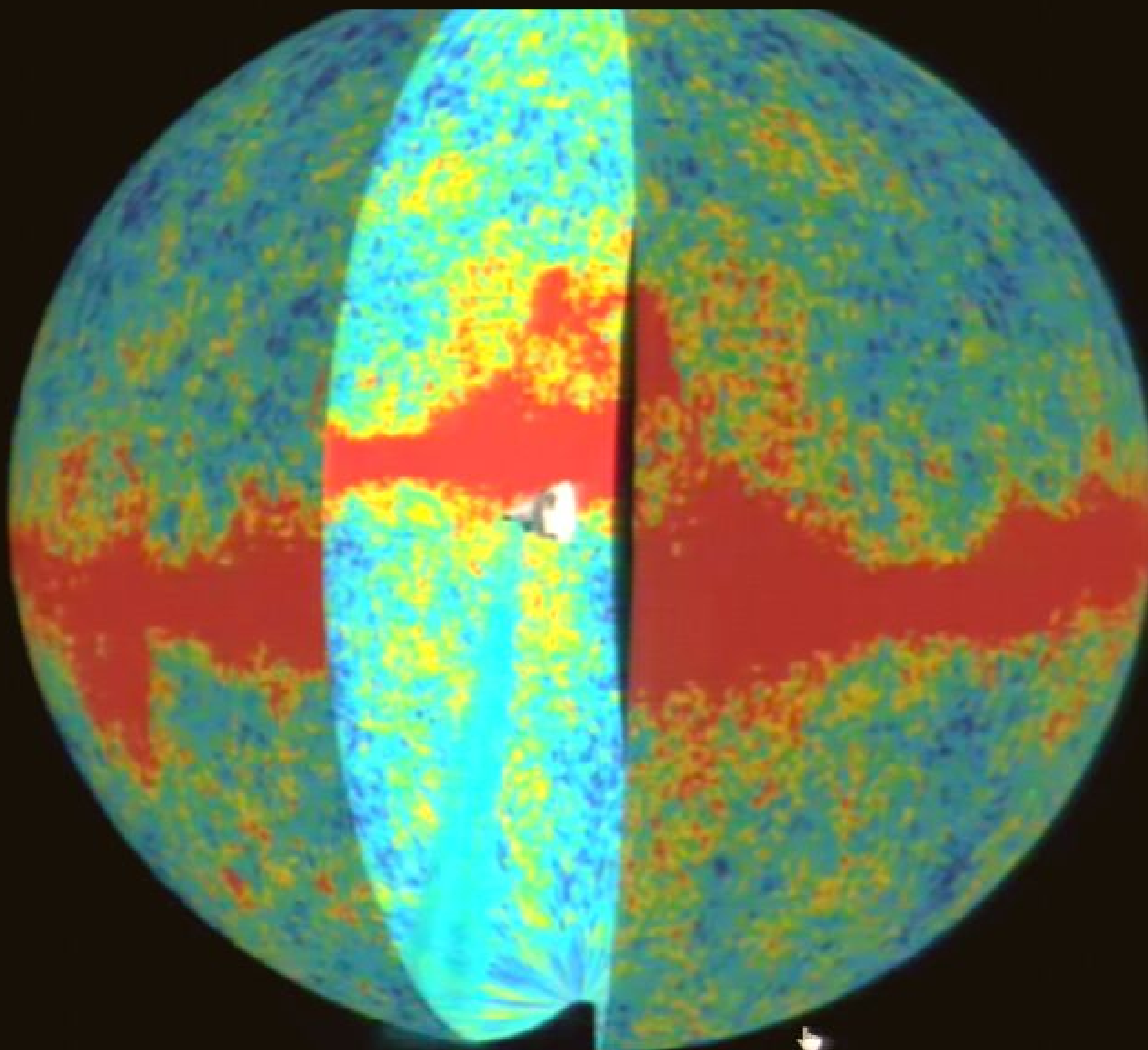


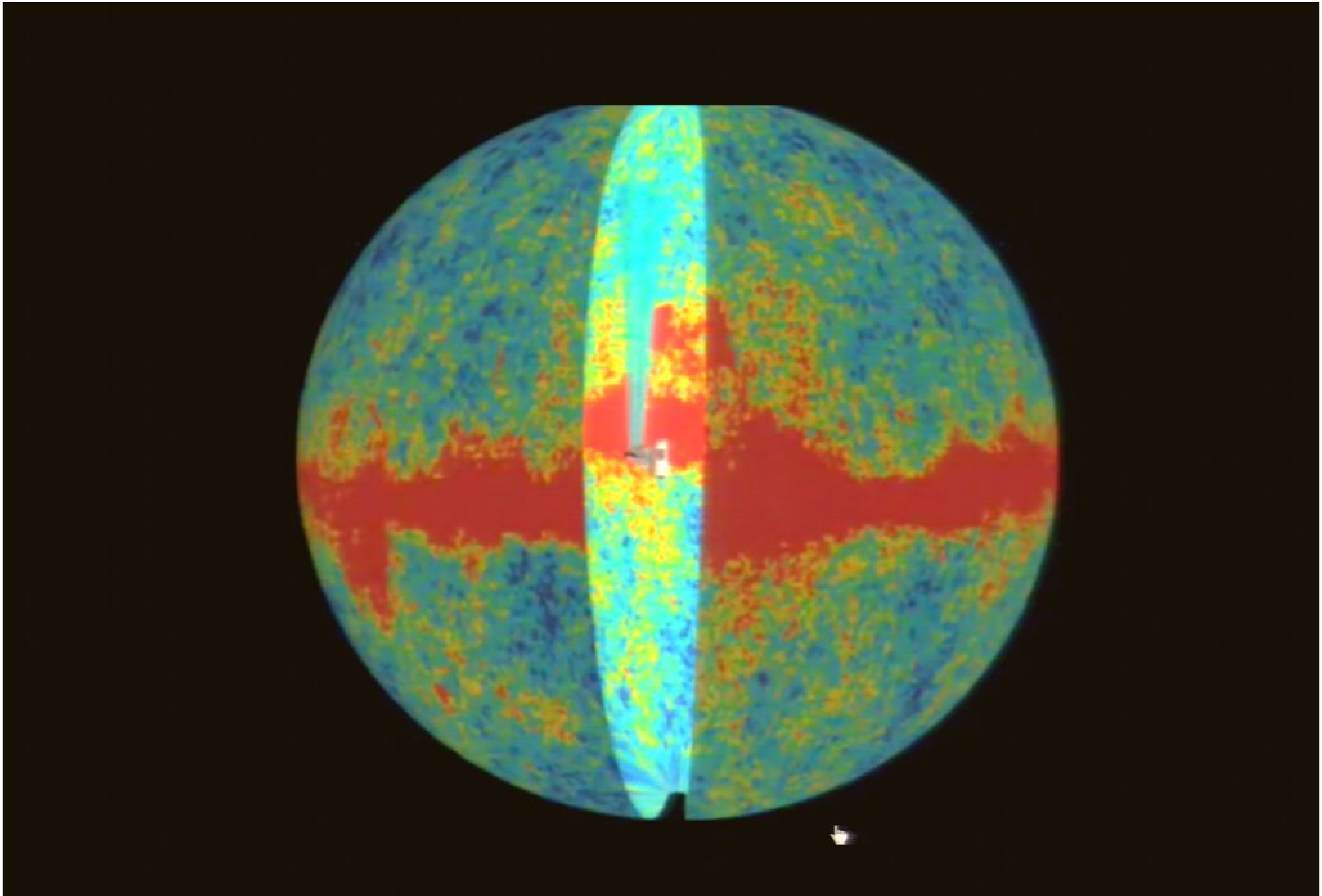


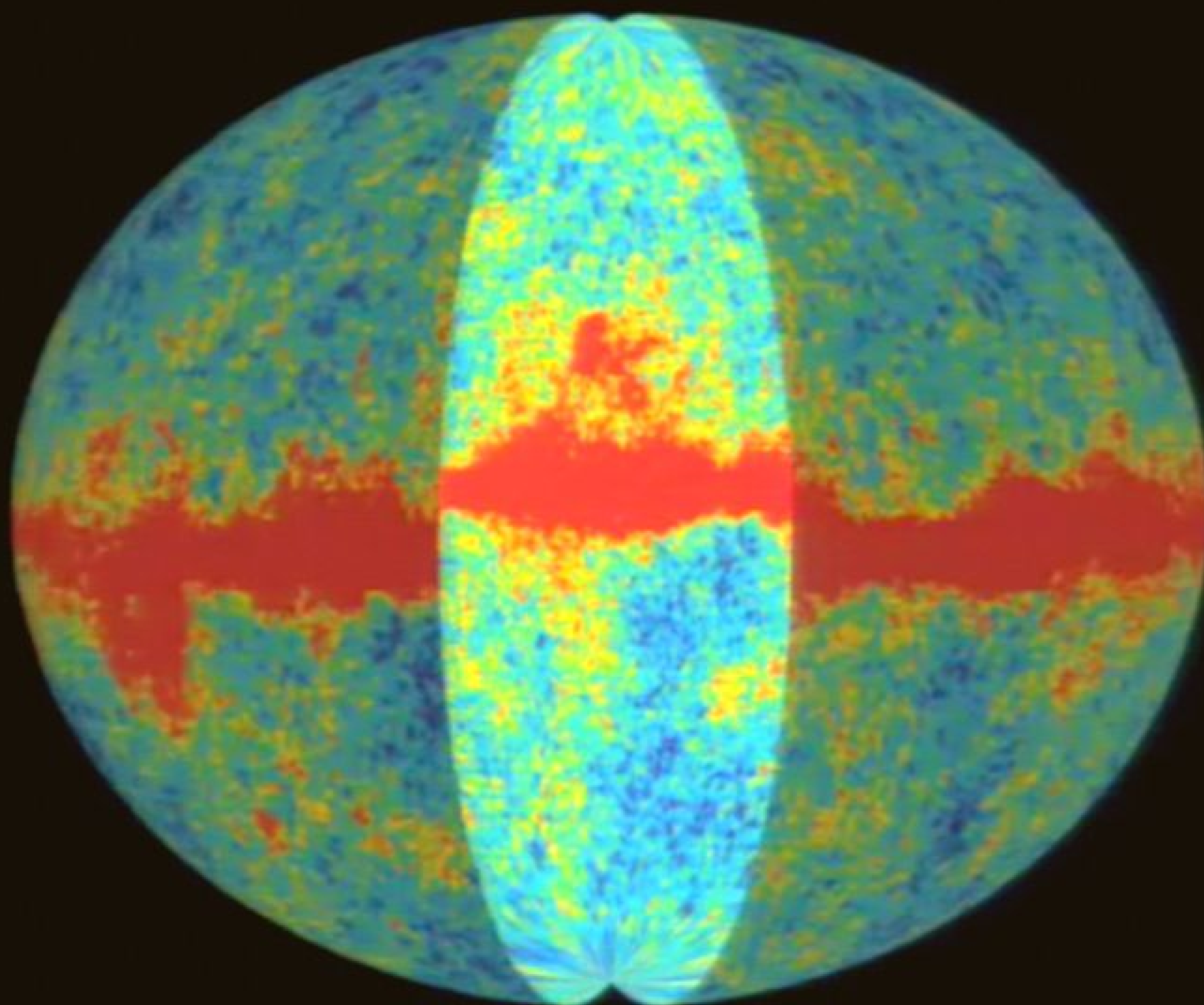


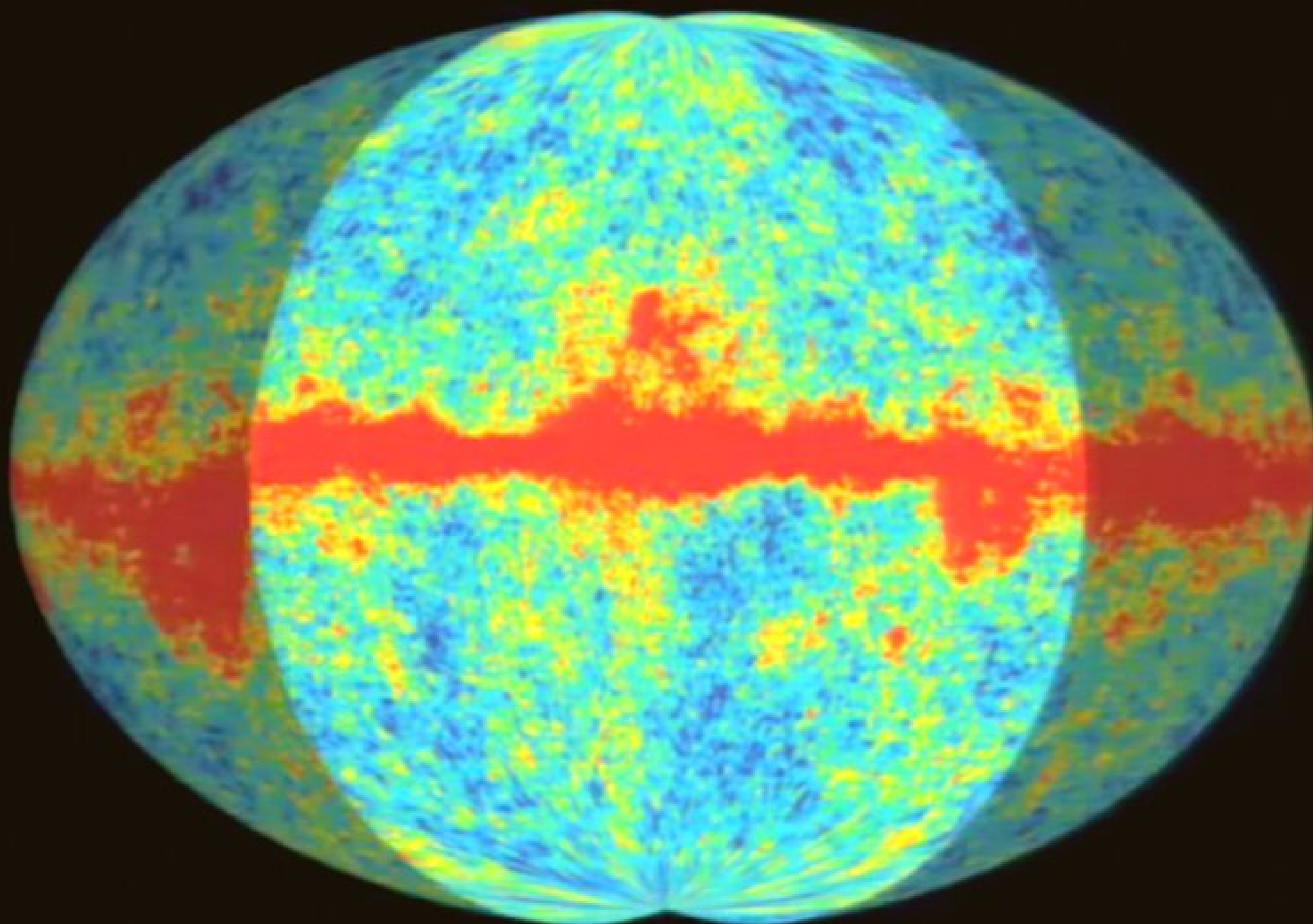


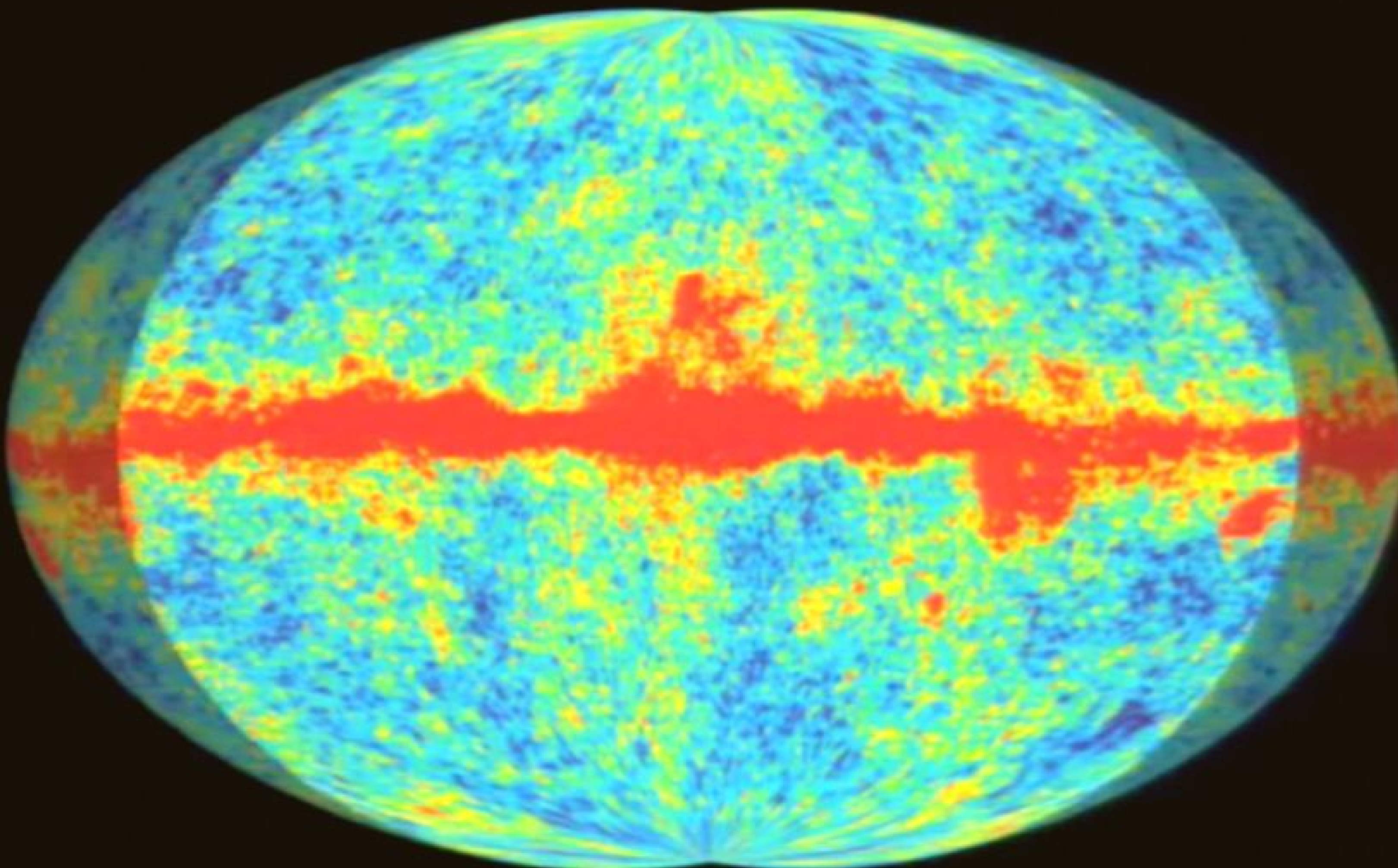


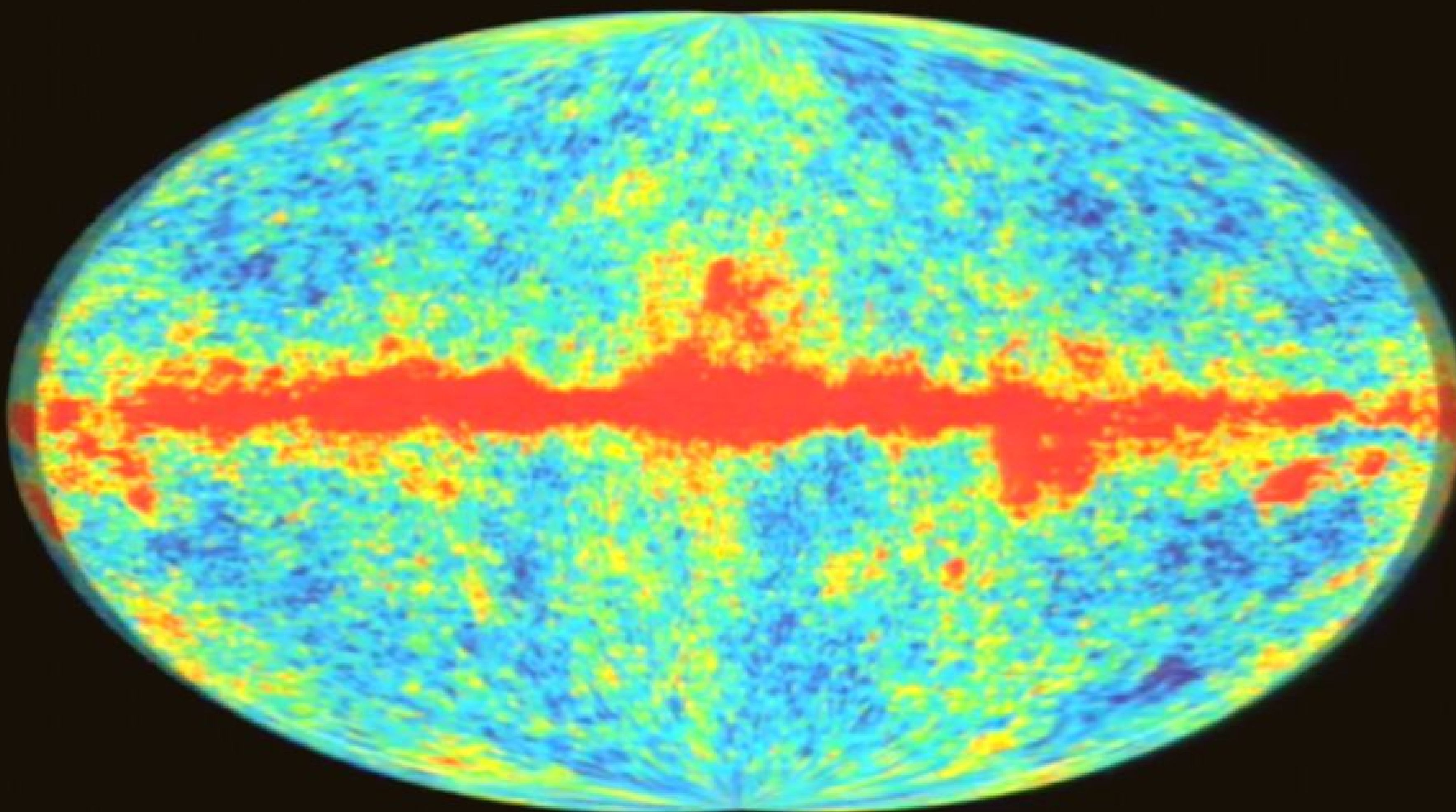


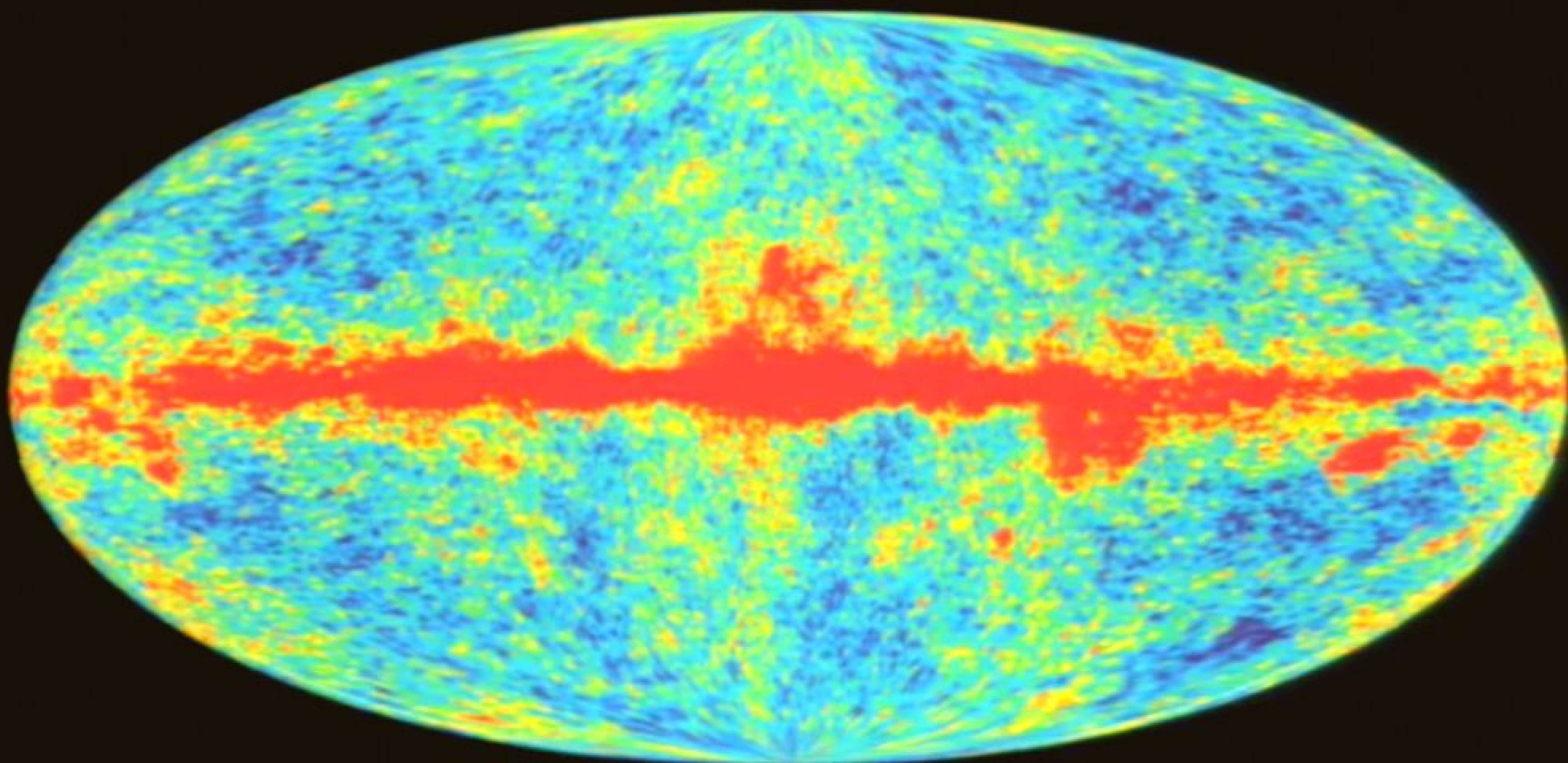


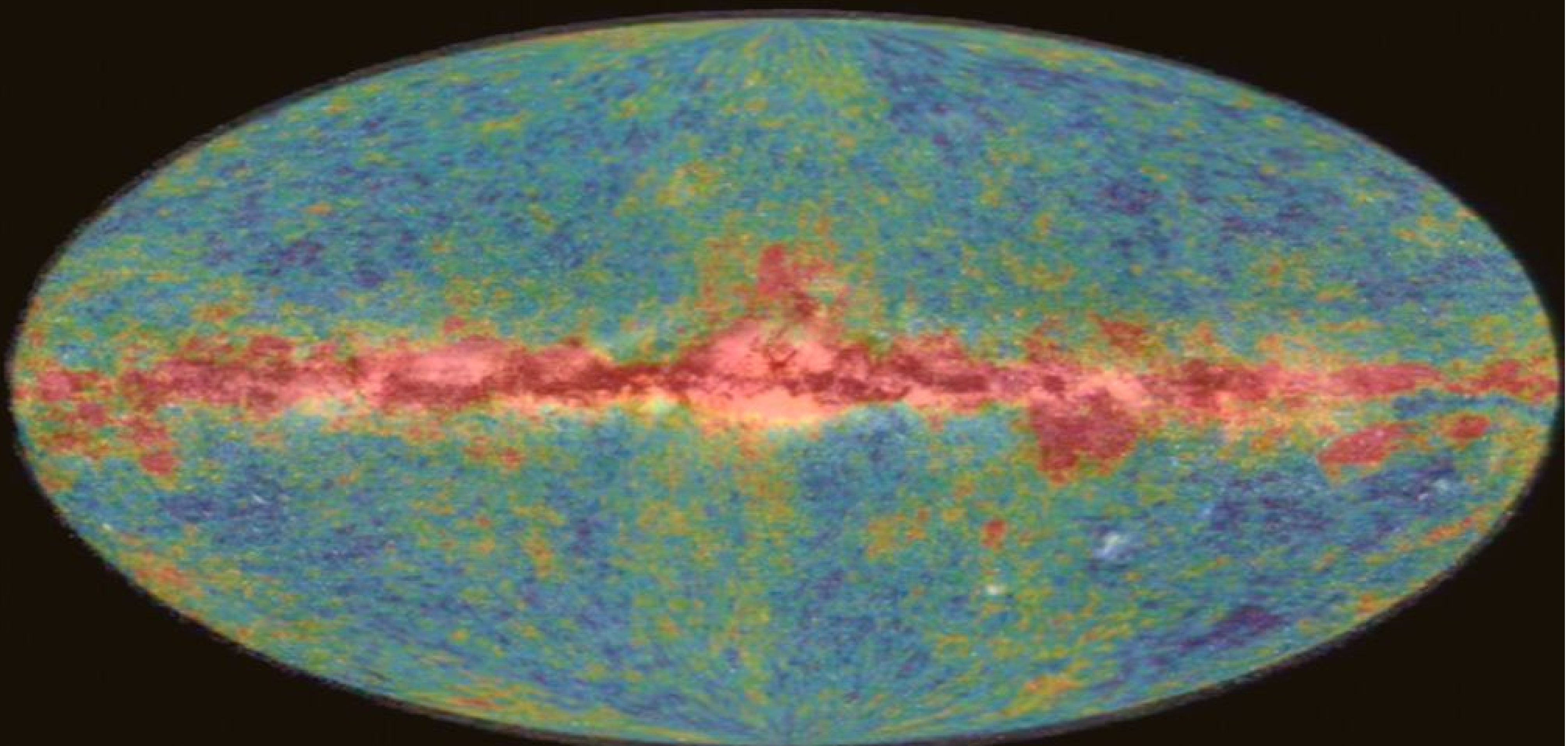


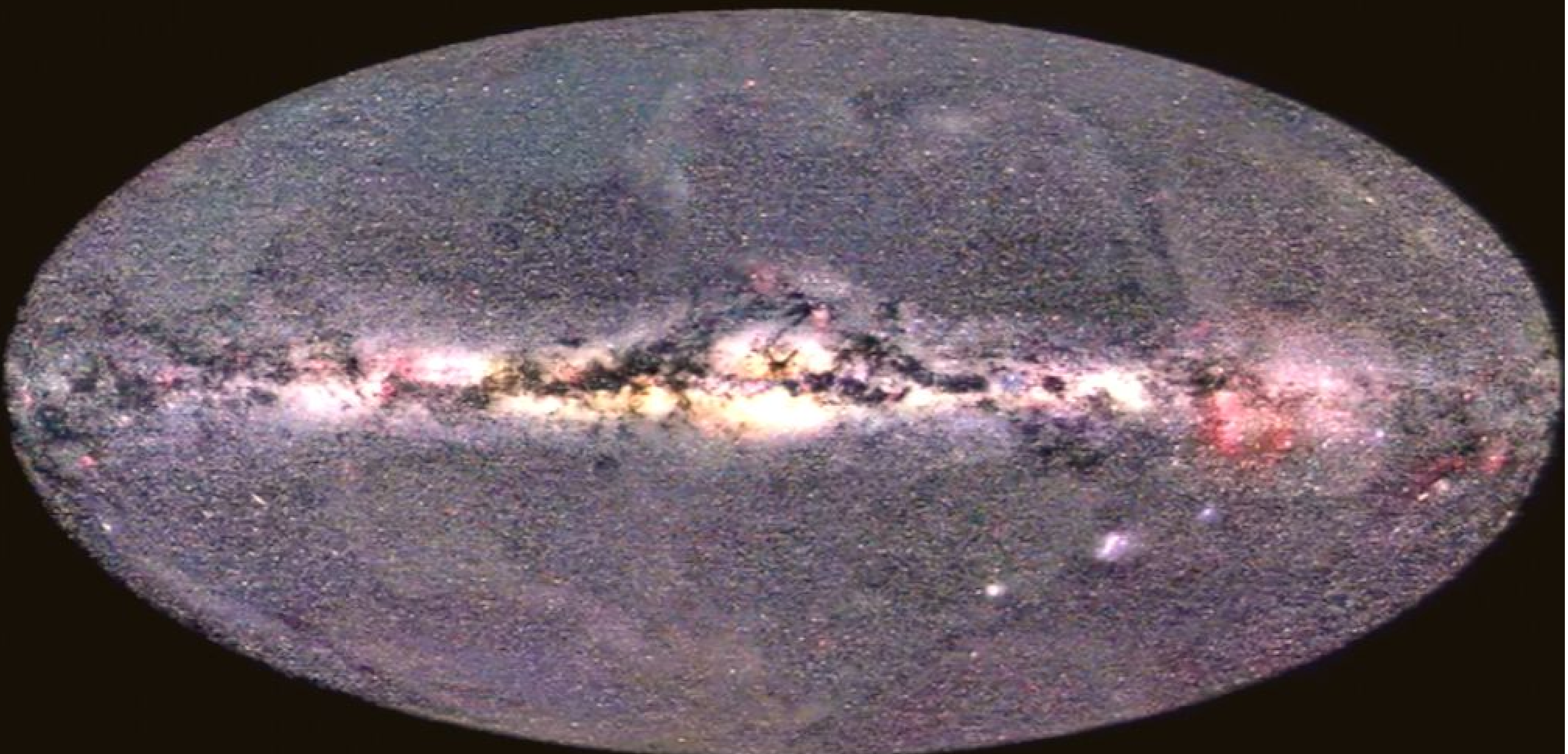


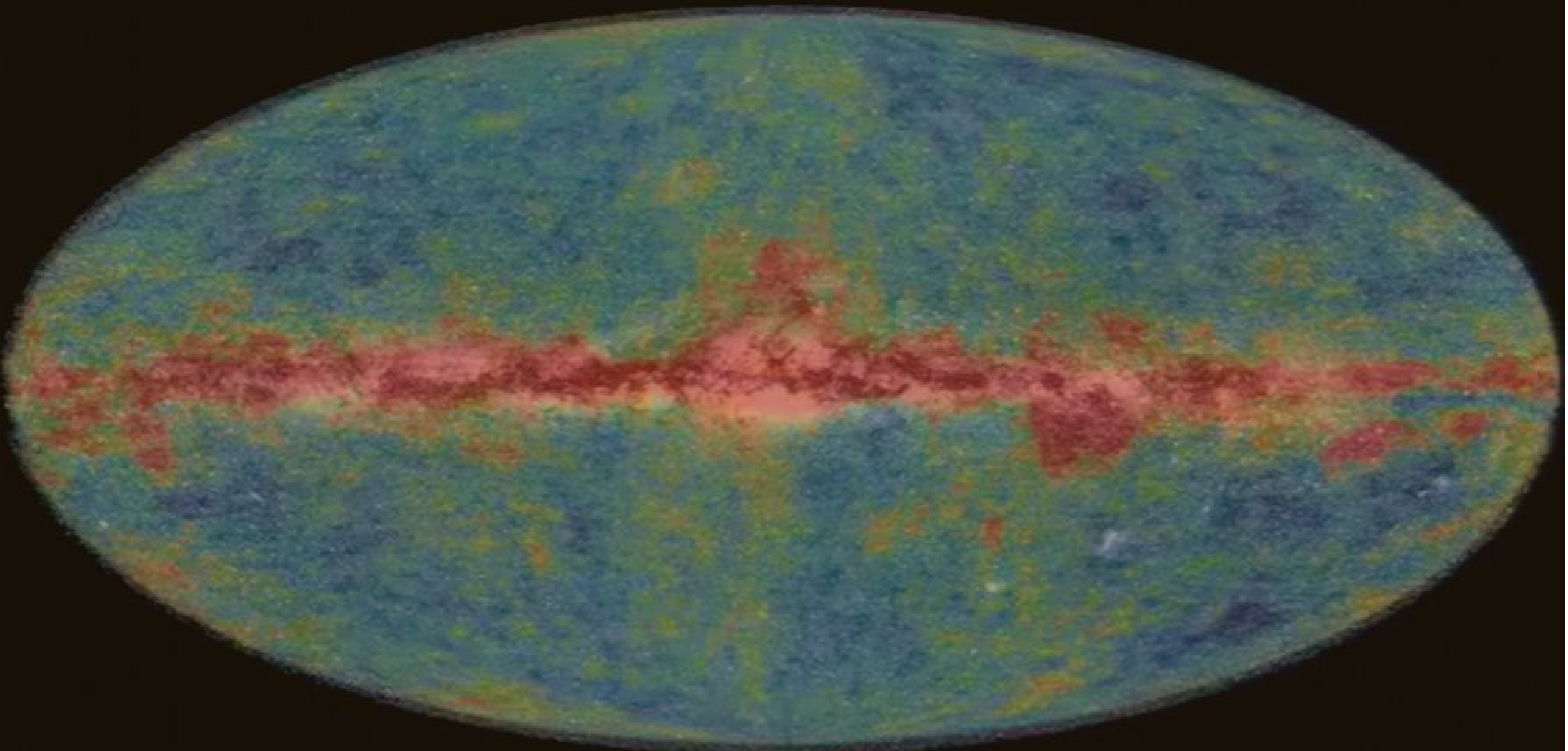


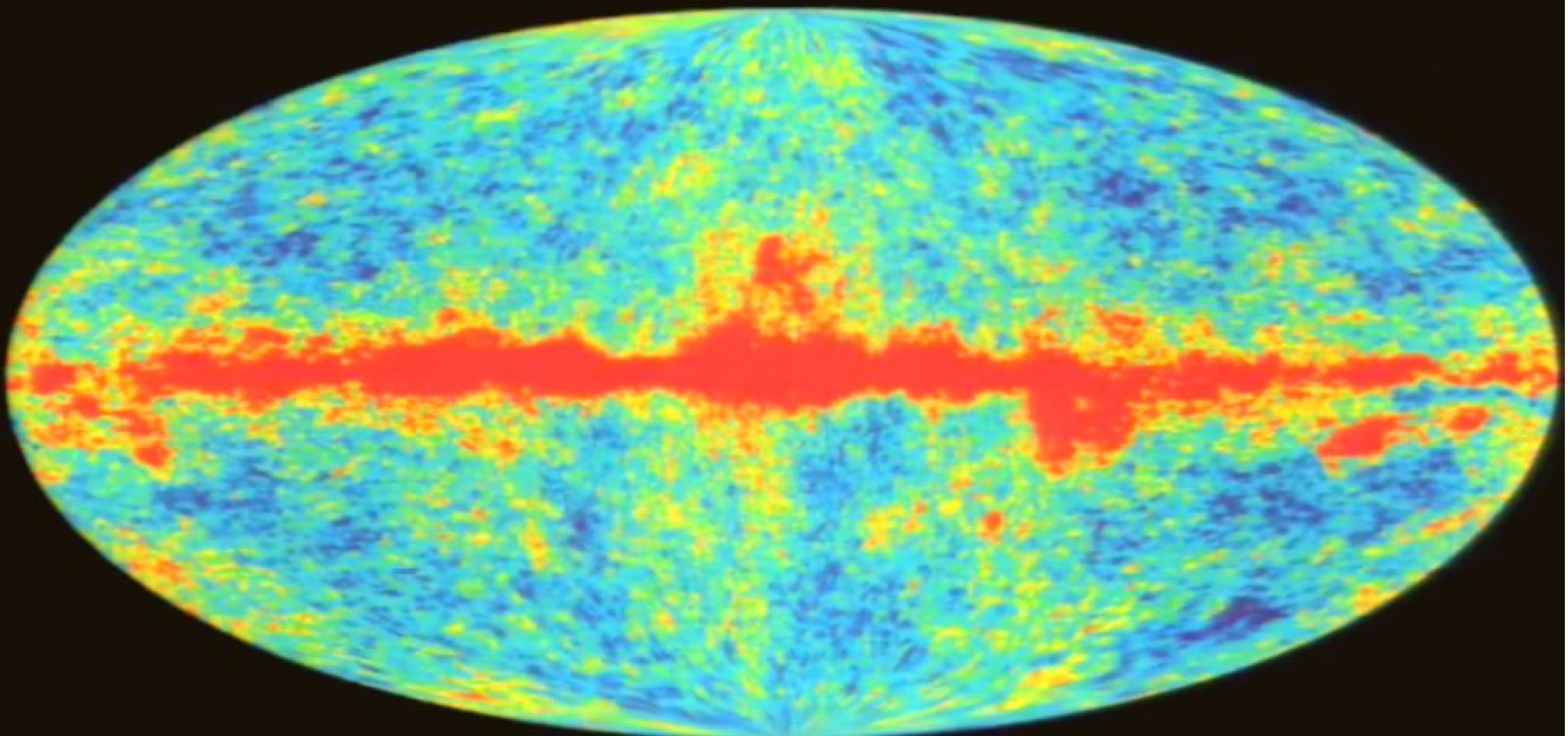


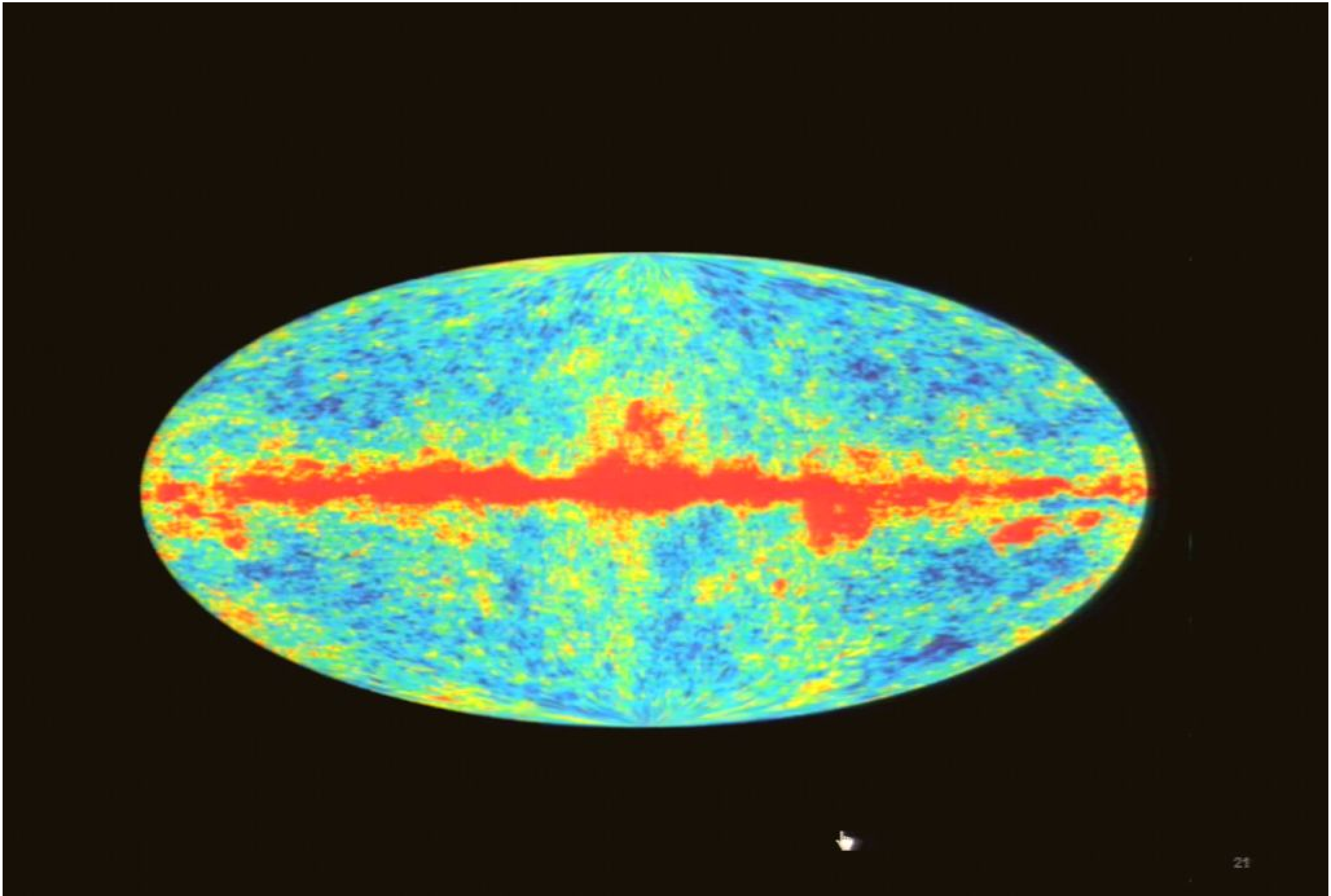











21

Data Processing

- Physics → CMB sky → Frequency sky → TOI
- TOI → frequency maps → CMB map → Physics

- One needs to write and verify a model of TOI = f(Physics) and to invert it and to assess errors.
  - *The frequency response is measured on the ground.*
  - *The optical response is measured on the ground, modelled, and partially verified on planets, Crab, etc.*
  - *The detector chain response is measured on ground*
  - ...
- One uses templates (Thermometers, Foreground tracers) and redundancy

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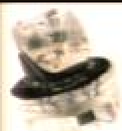
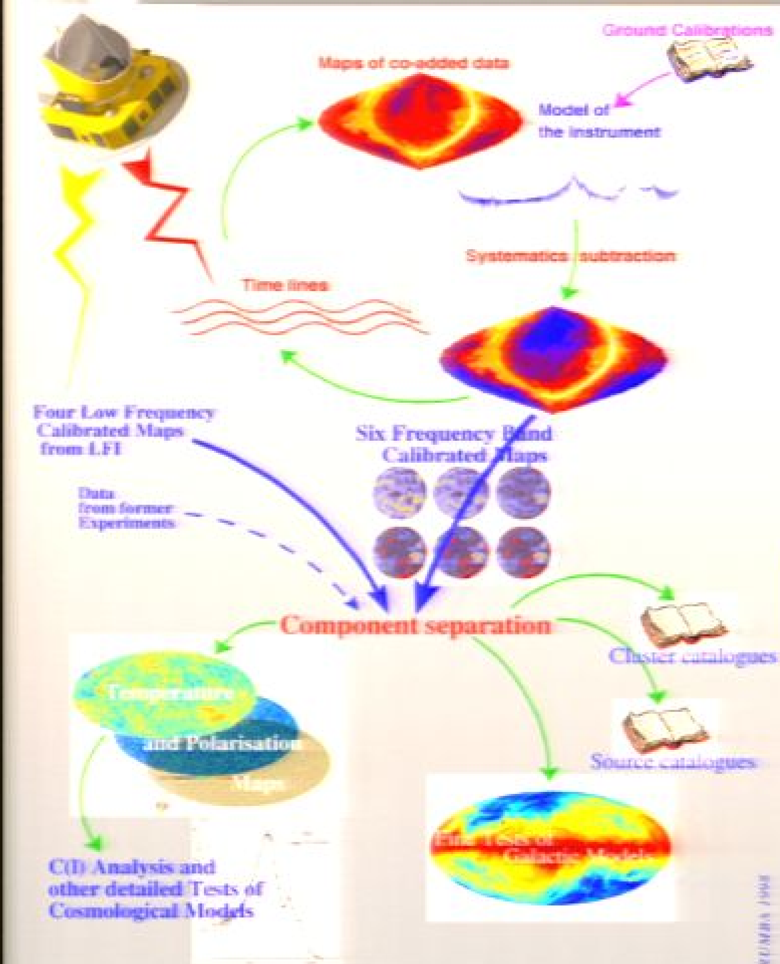
Data reduction





Measurements (HFI)
~10 000 /s ~3 x 10^{11}/an (~2 TB/an w. aux)

Measurement Model including systematics

ERCSC

57 Clean calibrated TOIs (57 x 30GB)
14 maps (~ 14 x 50 x 10^6 pixels) &
Statistical characterization

3 x 3 maps from LFI (lower res.)

> 10^4 sources

6 x 3 component maps
(CMB+SZ+CIRB+Sync+Free+Dust)

4 angular power spectra (~4x200) + Cov.Matrices

~ 20 cosmological parameters ?

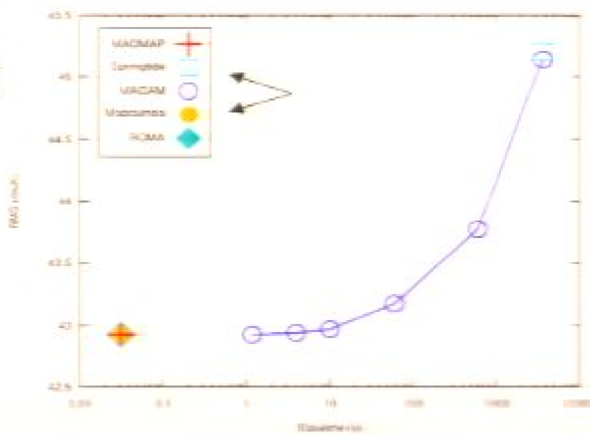
Data Processing Center preparation

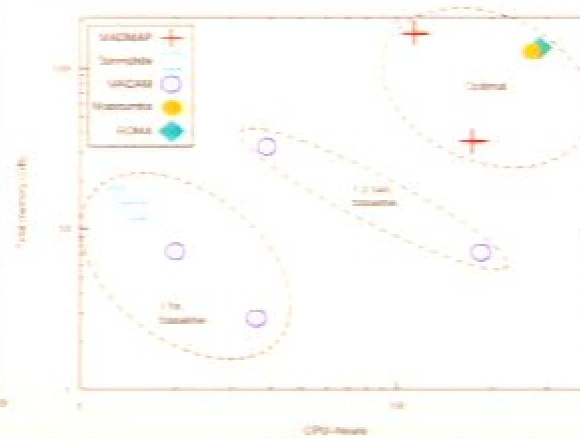
- One for each instrument,
  - *with exchange at the level of clean calibrated timelines for cross-checks& validation*
- Developed an ad-hoc **information management infrastructure**
  - *with requirement of traceability and efficiency*
- Developed a **simulation pipeline to** produce a realistic rendering of data
  - *plausible sky + known instrumental non-idealities*
- Establishing a pre-flight **minimal processing pipeline;**
  - *will undoubtly need be upgraded, but only where/when necessary.*
- Very active (mostly) internal **R&D** continues to improve
  - *processing steps (methods/codes challenges on speed, accuracy, robustness on benchmark data, including blind tests)*
  - *Assessment of magnitude of residual systematic effects and various ways to minimize them*
    - (e.g. asymmetric beams, cross-polar leakage, finite knowledge of polariser angles, limited accuracy of calibration sources, etc)

WG2, WG3 & DPC Codes

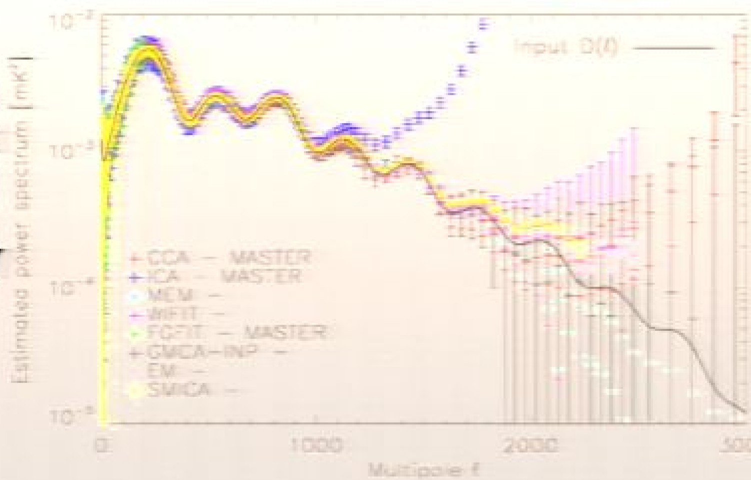
CTP (WG3): map-making codes comparison,

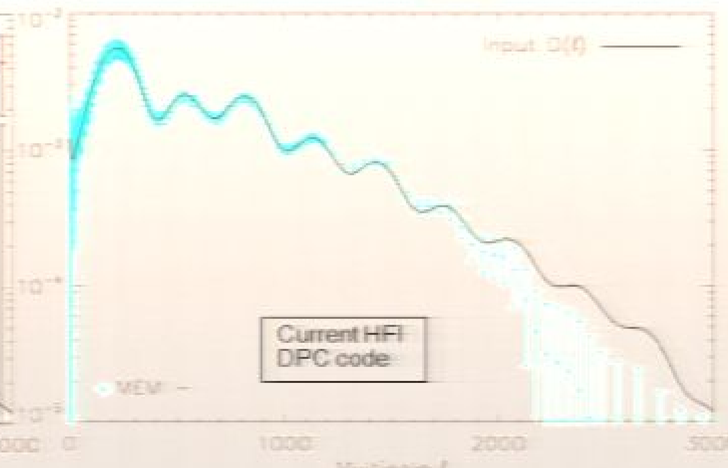
power spectra & L codes (ongoing) comparison





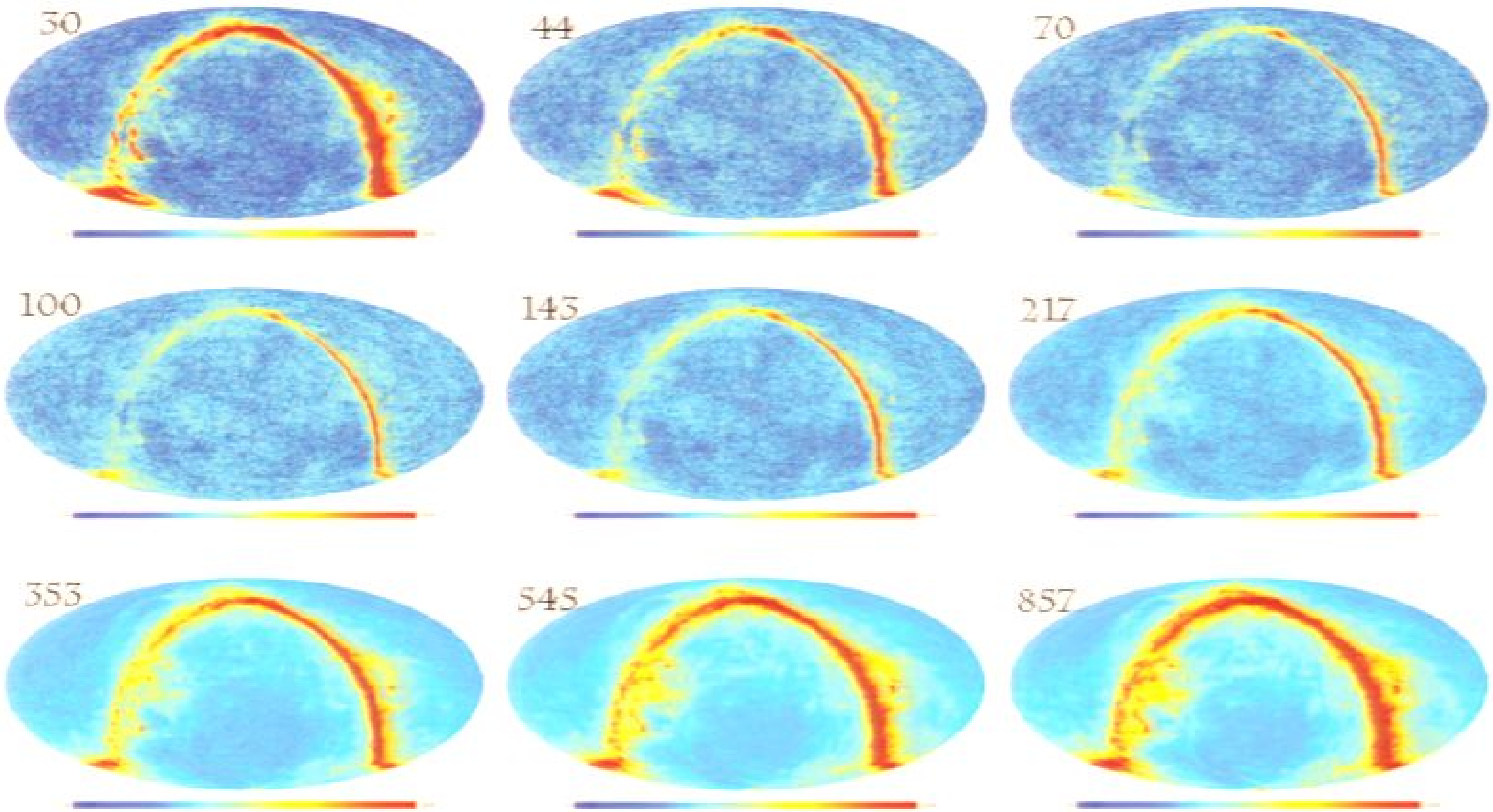
WG2: Blind Component Separation Challenge, as of Jan 07





WG2&3 thus provides useful guidance / performance verification to HFI DPC

(simulated) Planck Intensity maps



+ 14 Q & U maps

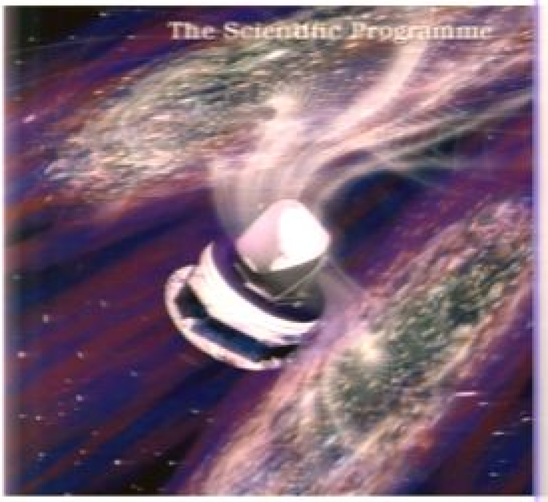
Broad science

- Primary anisotropies
  - *Cosmological parameters, fundamental physics probes, non-Gaussianity*
- Secondary anisotropies
  - *ISW, Gravitational lensing, reionisation, galaxy clusters*
- Extragalactic sources
  - *Radio-sources, dusty galaxies and their background*
- Galactic & solar system

esa

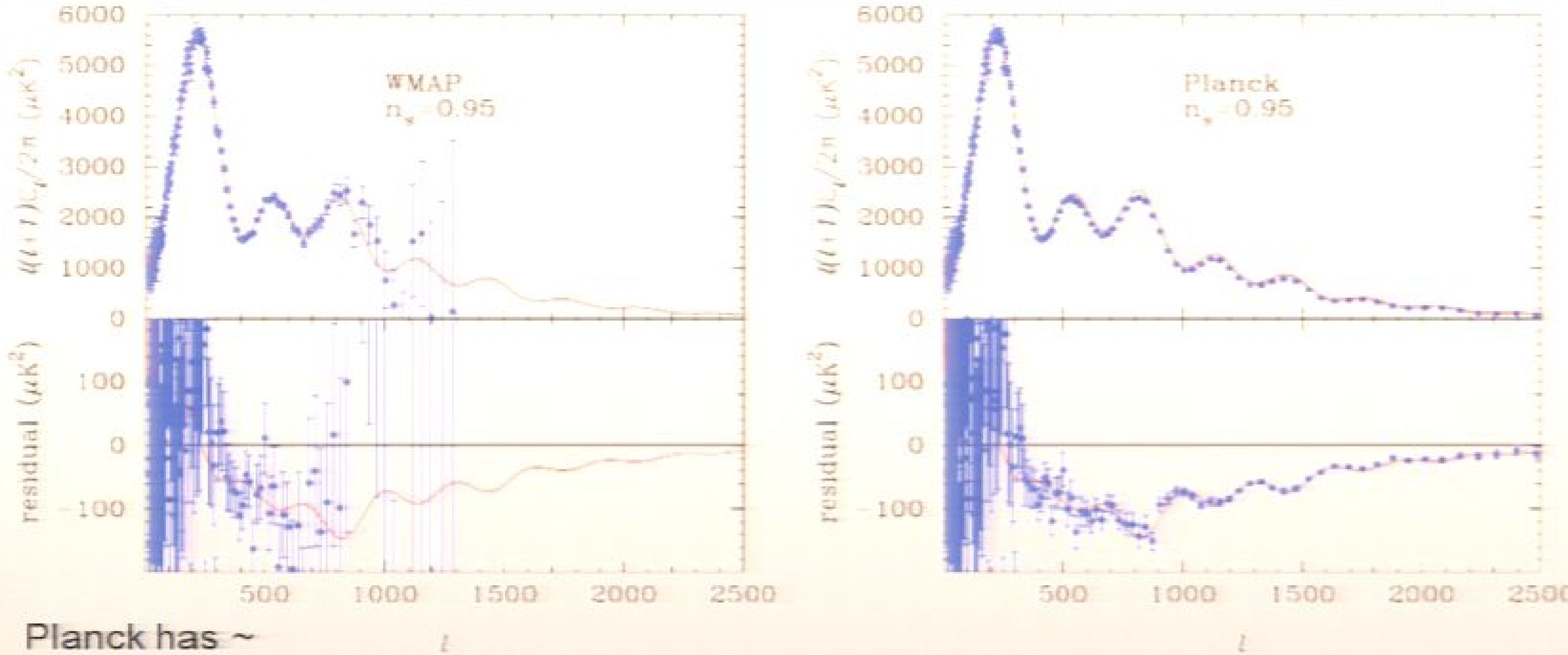
ESA-SCI(2005)1

PLANCK



"Blue book" (2005)
www.rssd.esa.int/Planck

TT Forecast



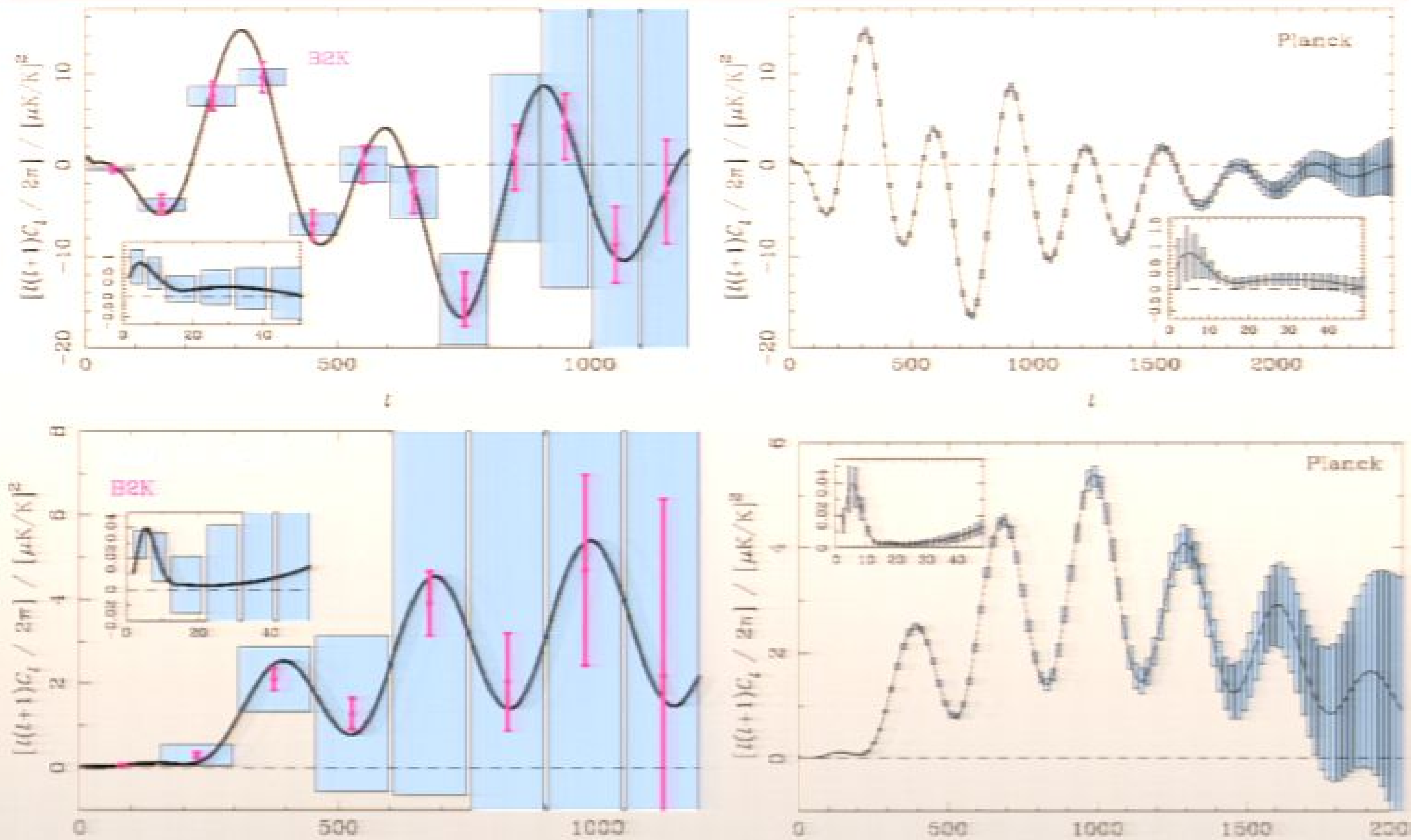
Planck has ~
- *25 × the sensitivity of WMAP*
- *3 × the angular resolution*

→ Planck limited by cosmic variance only well into the damping tail.

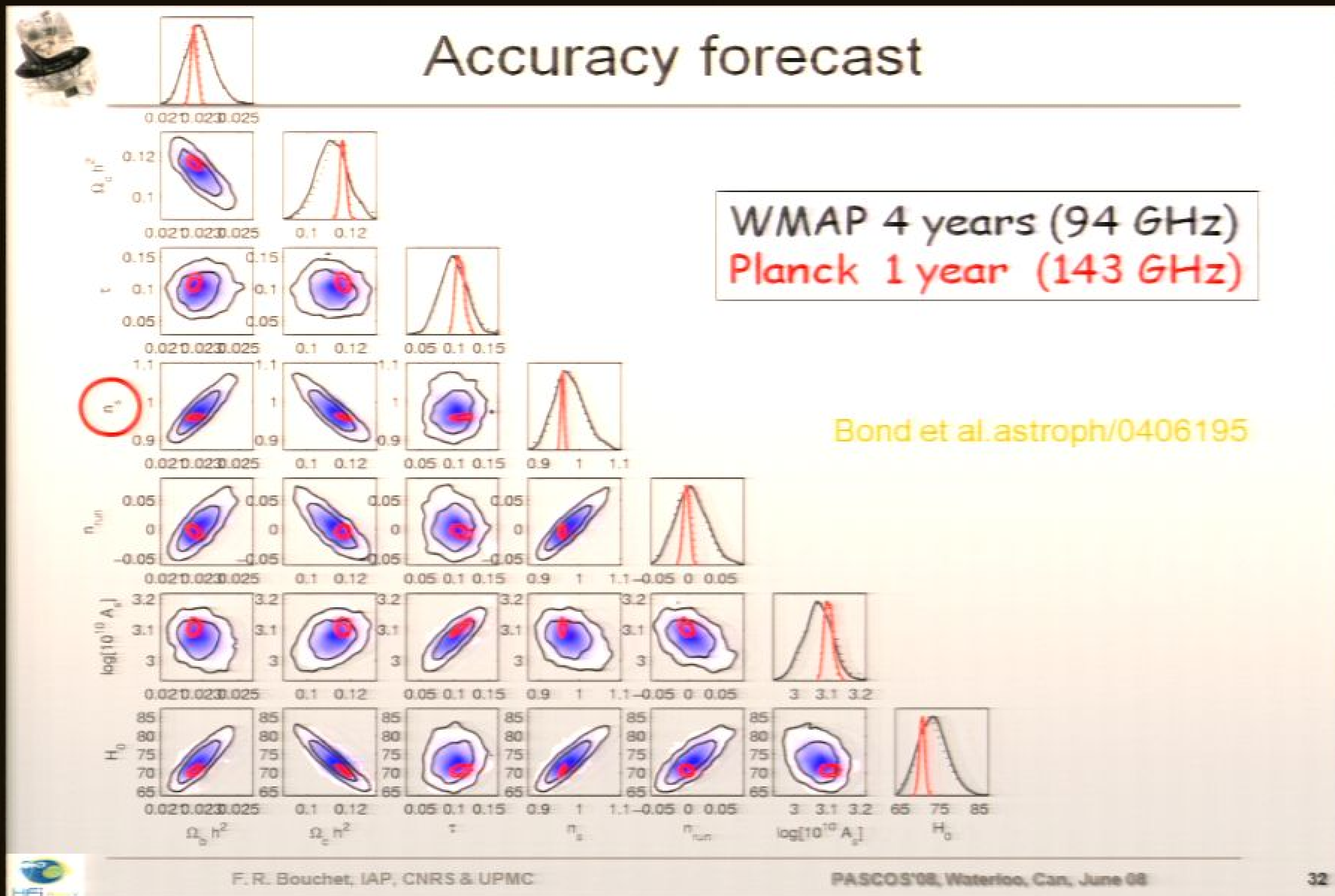
WMAP measures ~10% of the modes with SNR ≥ 1. Planck will get them all.

Top: samples drawn from a LCDM model w. n_s=0.95 versus an n_s=1 (red line) one.
Bottom: residuals (red is now expectation)

TE & EE forecasts



Planck will measure polarisation about as well as WMAP measure temperature


Accuracy forecast
WMAP 4 years (94 GHz)
Planck 1 year (143 GHz)
Bond et al.astroph/0406195
F. R. Bouchet, IAP, CNRS & UPMC
PASCOS'08, Waterloo, Can, June 08
32

ISOCURVATURE MODES

	MAP T adia only	MAP TP adia only	MAP T all modes	MAP TP all modes	PLANCK T adia only	PLANCK TP adia only	PLANCK T all modes	PLANCK T−P all modes	PLANCK TP all modes
$\delta h/h$	12.37	7.42	175.84	20.40	9.93	3.69	40.13	7.31	4.36
$\delta\Omega_b/\Omega_b$	27.76	13.34	325.38	28.57	19.37	7.26	68.85	14.42	8.61
$\delta\Omega_k$	9.79	2.72	75.32	4.55	4.92	1.83	20.56	3.59	2.18
$\delta\Omega_\Lambda/\Omega_\Lambda$	12.92	5.02	123.63	18.53	2.74	1.21	5.93	2.45	1.49
$\delta n_s/n_s$	7.02	1.62	89.89	6.53	0.73	0.37	3.92	0.90	0.70
τ_{reion}	37.39	1.81	104.81	2.23	8.25	0.41	35.35	0.74	0.56
$\langle NIV, NIV \rangle$	...	...	114.34	11.47	...	...	43.45	1.36	1.14
$\langle BI, BI \rangle$	...	...	573.46	29.71	...	...	53.29	6.16	4.23
$\langle NID, NID \rangle$	...	...	351.79	29.87	...	...	19.18	4.77	2.37
$\langle NIV, AD \rangle$	...	...	434.70	44.06	...	...	121.59	8.21	4.69
$\langle BI, AD \rangle$	...	...	1035.02	59.25	...	...	58.75	15.03	8.97
$\langle NID, AD \rangle$	...	...	1287.60	67.49	...	...	114.39	13.87	5.77
$\langle NIV, BI \rangle$	...	...	601.70	32.29	...	...	46.91	7.72	3.67
$\langle NIV, NID \rangle$	...	...	744.00	46.46	...	...	80.01	7.55	2.97
$\langle BI, NID \rangle$	...	...	534.32	39.11	...	...	100.97	7.56	4.60

TABLE I. This table indicates the one sigma percentage errors on cosmological parameters and isocurvature mode amplitudes anticipated for the MAP and PLANCK satellite experiments. In the column headers, T denotes constraints inferred from temperature measurements alone, TP those from the complete temperature and polarisation measurements, and T−P those inferred if temperature and polarisation information is used separately without including the cross-correlation.

Bucher, Moodley, Turok, astroph/0012141

NB: Still assuming simple scale-invariant (initial) P(k)...

(Can add LSS, or HST+SN1A to improve Ω_k, cf. Dunkley et al. astroph/0507473, but reliance on external data)

ISOCURVATURE MODES

$\Pi = 8.10^{-11}$ $\Pi = 7.10^{-24}$

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τ_{reion}	37.39	1.81	104.81	2.23	8.25	0.41	35.35	0.74	0.56
$\langle NIV, NIV\rangle$	...	...	114.34	11.47	...	...	43.45	1.36	1.14
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$\langle NIV, NID\rangle$	...	...	744.00	46.46	...	...	80.01	7.55	2.97
$\langle BI, NID\rangle$	...	...	534.32	39.11	...	...	100.97	7.56	4.60

TABLE I. This table indicates the one sigma percentage errors on cosmological parameters and isocurvature mode amplitudes anticipated for the MAP and PLANCK satellite experiments. In the column headers, T denotes constraints inferred from temperature measurements alone, TP those from the complete temperature and polarisation measurements, and T−P those inferred if temperature and polarisation information is used separately without including the cross-correlation.

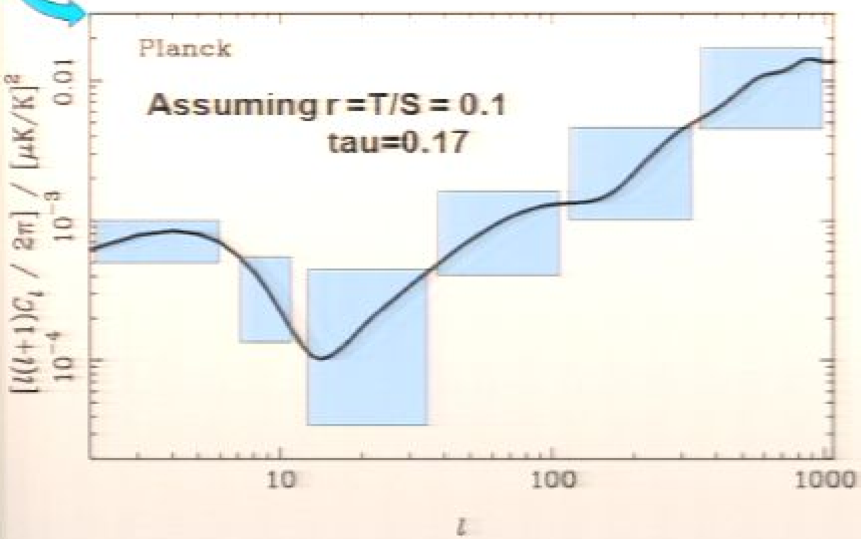
NB: Still assuming simple scale-invariant (initial) P(k)...

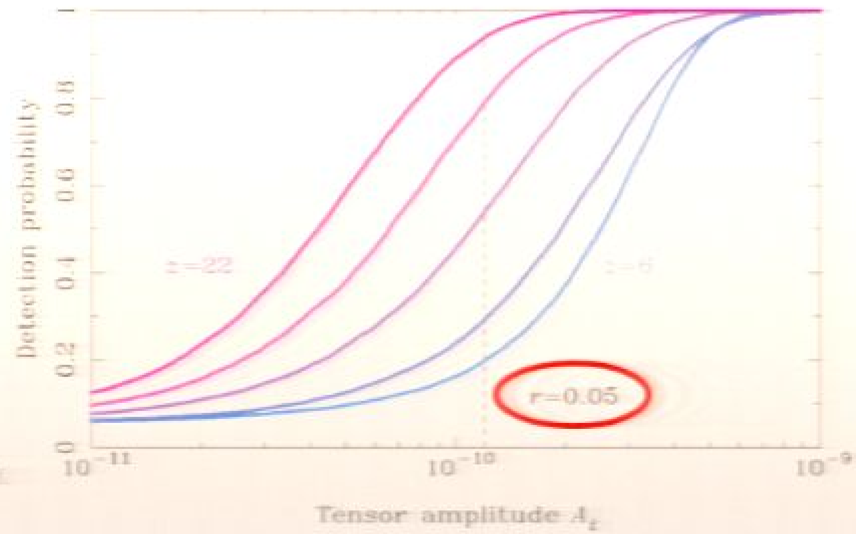
(Can add LSS, or HST+SN1A to improve Ω_k, cf. Dunkley et al. astroph/0507473, but reliance on external data)

B polarisation forecasts

(Assuming no unforgiving foregrounds ☹)

0.01 μK² !





WMAP5 → $\tau \sim 0.17/2$, $z_{inst}=11\pm1.4$

Planck will be limited by its (polarisation) sensitivity (~60 μK.arcmin at best)

Indeed, it was conceived to be limited by unpolarised foregrounds confusion

Science with Planck

- Of course Planck will improve on standard constraints... when the data is at hand!
  - r
  - Σm_ν
  - N_{eff}
  - $w1, w2...$

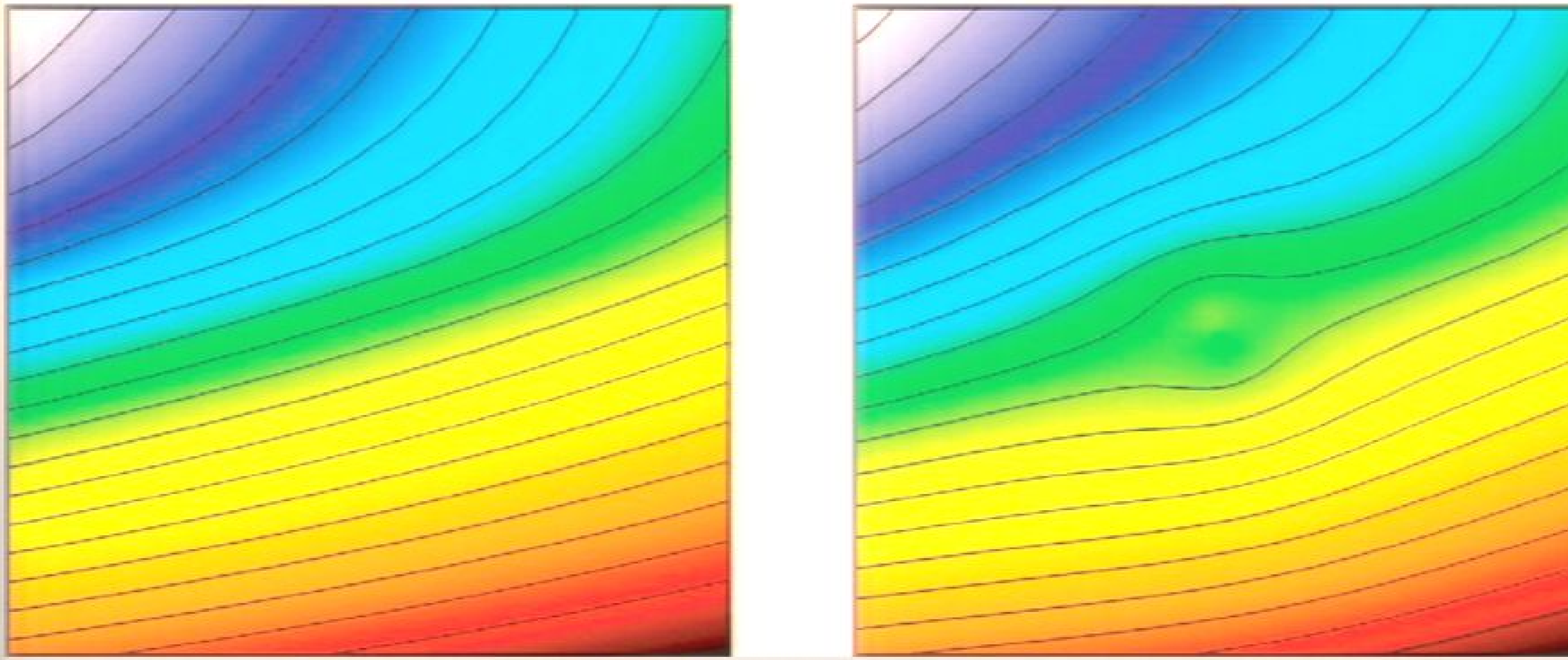
- Planck lesser reliance on external dataset (often with complicated astrophysical processing) will allowing cross-checks of parameters and assumptions and provide a foundation for future dedicated project (e.g. on w)

Departures from Isotropic Gaussian...

- A broad topics...
- Will undoubtly be found owing to processing weaknesses, since the observed sky is NG
  - *Well known astrophysical sources (point sources, Galaxy)*
  - *Secondary effect (kinetic effect, Lensing)*
  - *Inhomogeneous/correlated noise, systematics...*
- We will search for the signature of
  - *non-trivial topologies*
  - *primordial magnetic field*
  - f_{NL} *(see below)*
  - *topological defects, eg cosmic strings*
  - *New physics*

Secondary anisotropies - Lensing

10'x 10' T field lensed by a 10^{15} $M_{\odot}$ at z=.4



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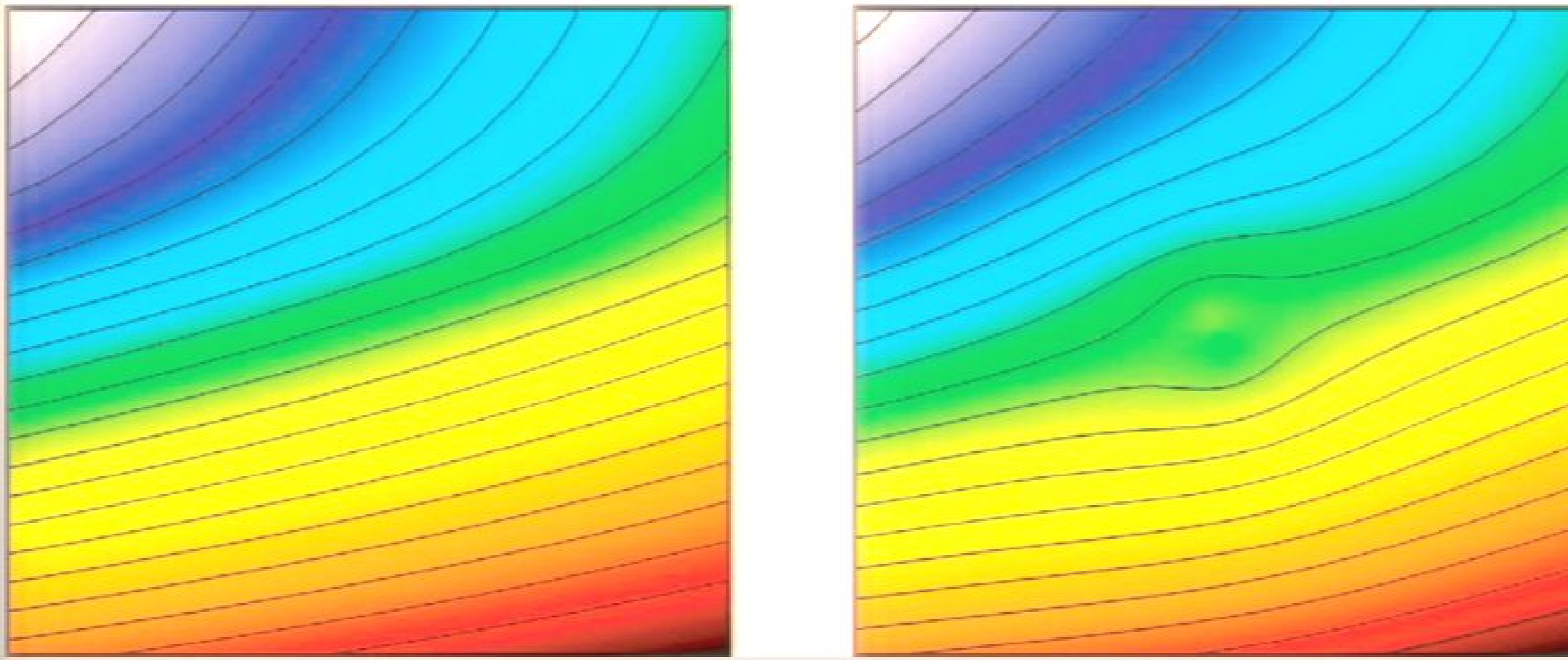

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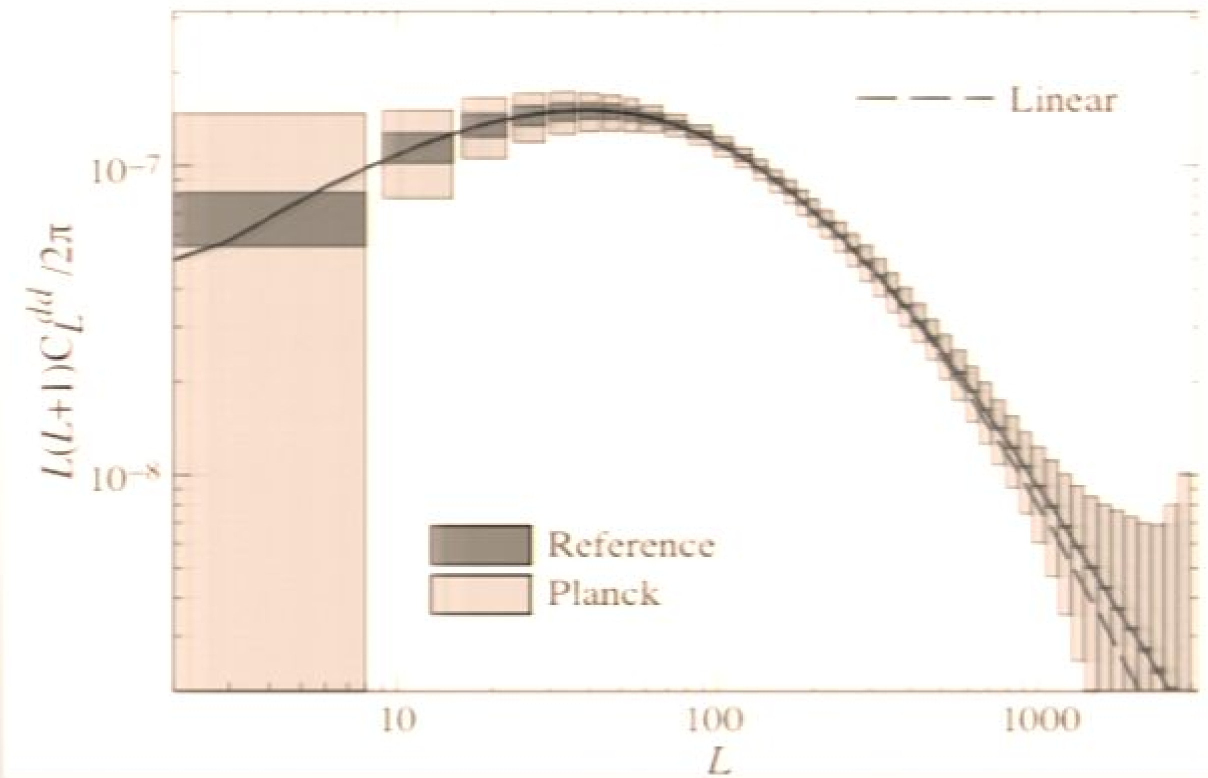
Quadratic Reconstruction



→ Low z constraints on curvature, m_ν, dark energy…

f_{NL}

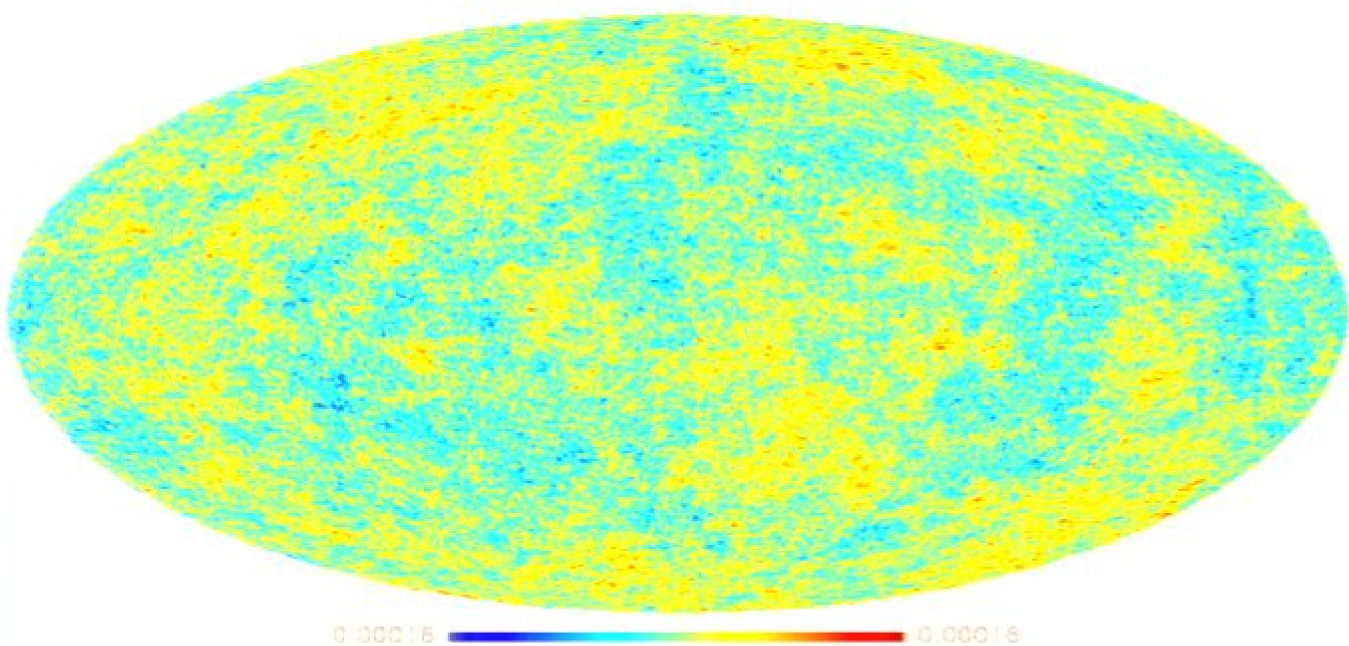
- Parameterize non-Gaussianity as $\Phi=\Phi_L+\mathbf{f_{NL}\Phi_L^2}$ as in (*Salopek & Bond 1990)*
  - *Φ_L~10^{-5} is a Gaussian, linear curvature perturbation in the matter era*
  - *Therefore, f_{NL}<100 means that the distribution of Φ is consistent with a Gaussian distribution to ~$100\times(10^{-5})^2/(10^{-5})$=**0.1% accuracy** at 95% CL.*

- Non-Gaussianity from Inflation
  - *f_{NL}~ 0.05 canonical inflation (single field, couple of derivatives) (Maldacena 2003, Acquaviva etal 2003)*
  - *f_{NL}~ 0.1--100 → higher order derivatives*
    - ~100: DBI inflation (Alishahiha, Silverstein and Tong 2004)
    - ~0.1 : UV cutoff (Creminelli and Cosmol, 2003)
  - *f_{NL} >10 curvaton models (Lyth, Ungarelli and Wands, 2003)*
  - *f_{NL} ~100 ghost inflation (Arkani-Hamed et al., Cosmol, 2004)*
  - ... *Your name here*

- Of course, oversimplified, propagation corrections...

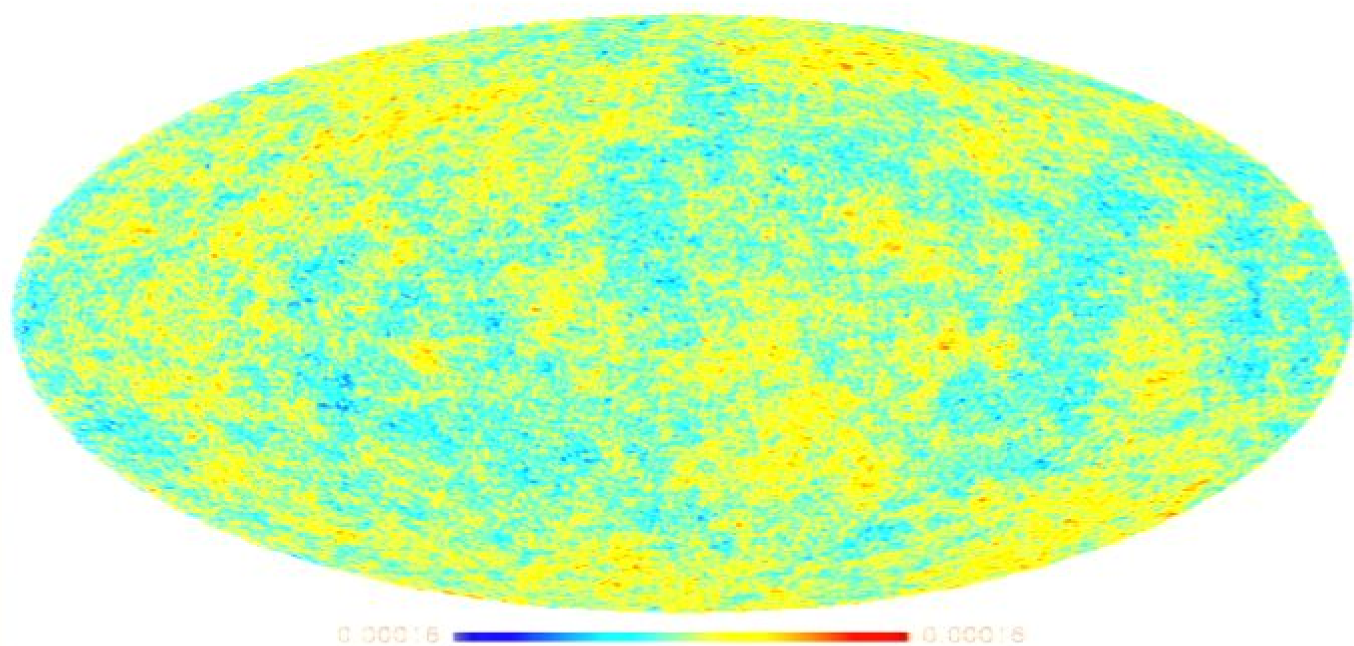
$f_{NL} = 100$

Positive f_{NL} = More Cold Spots



Liguori, Yadav, Hansen, Komatsu, Matarrese, Wandelt 2007

$f_{NL} = 0$



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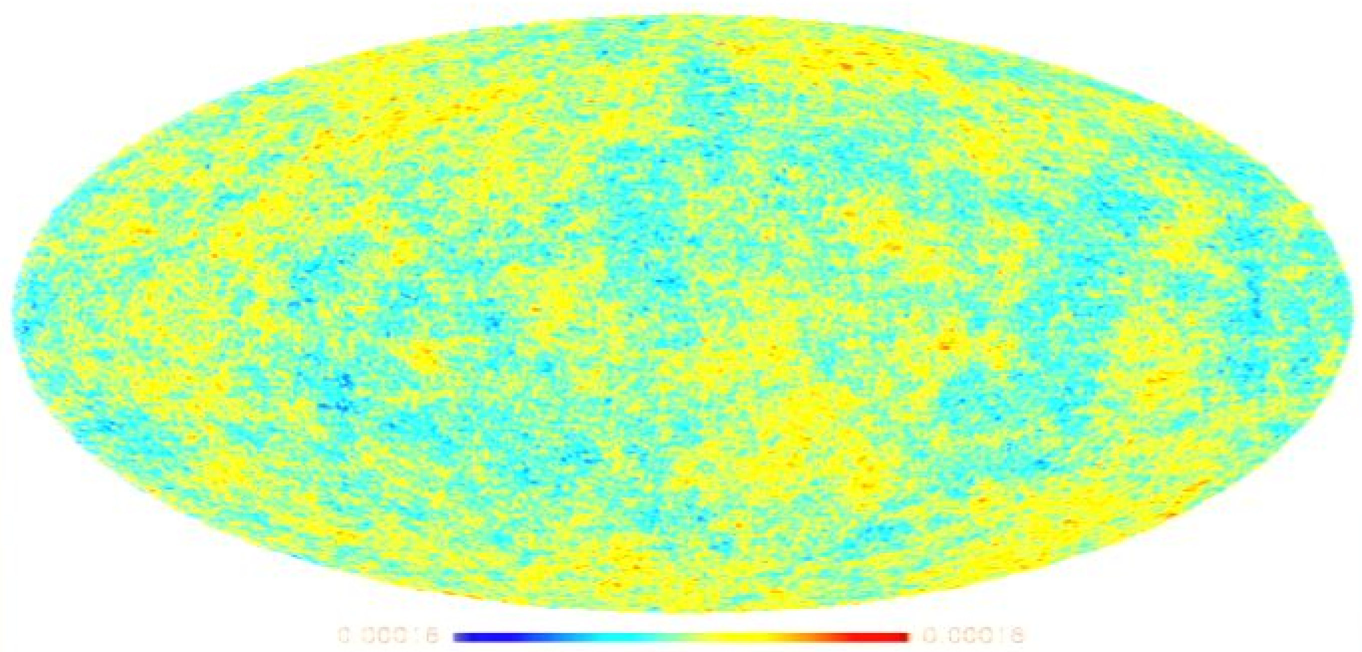

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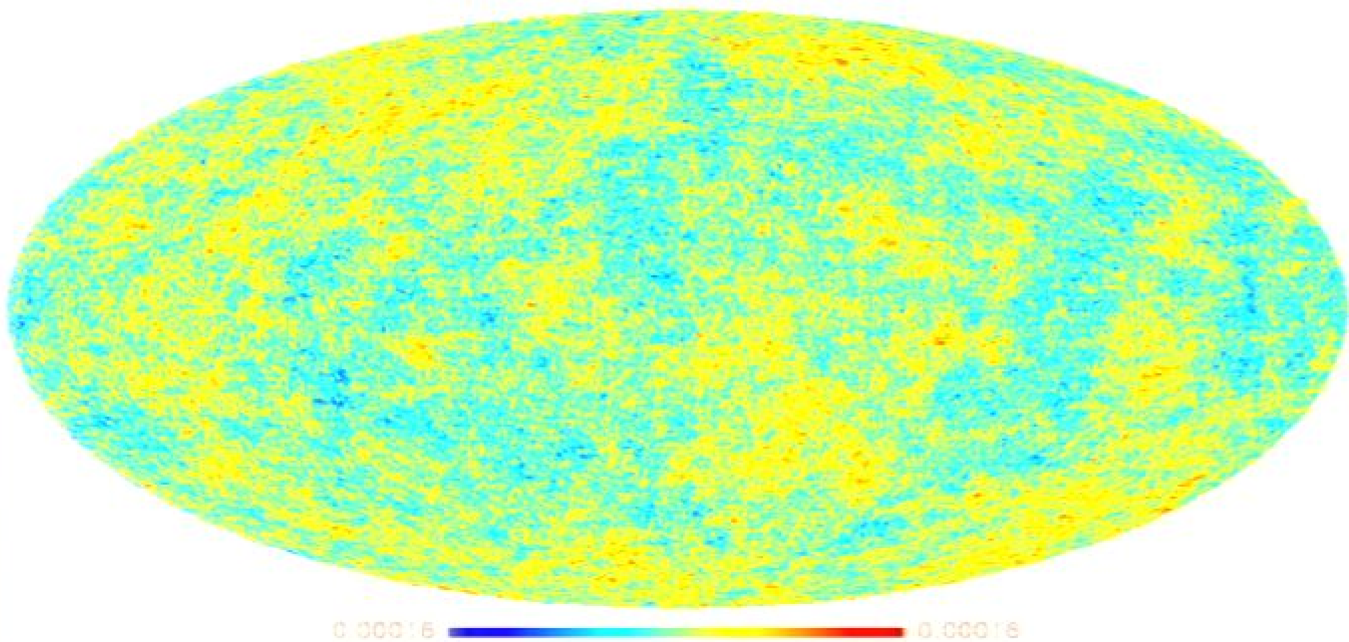

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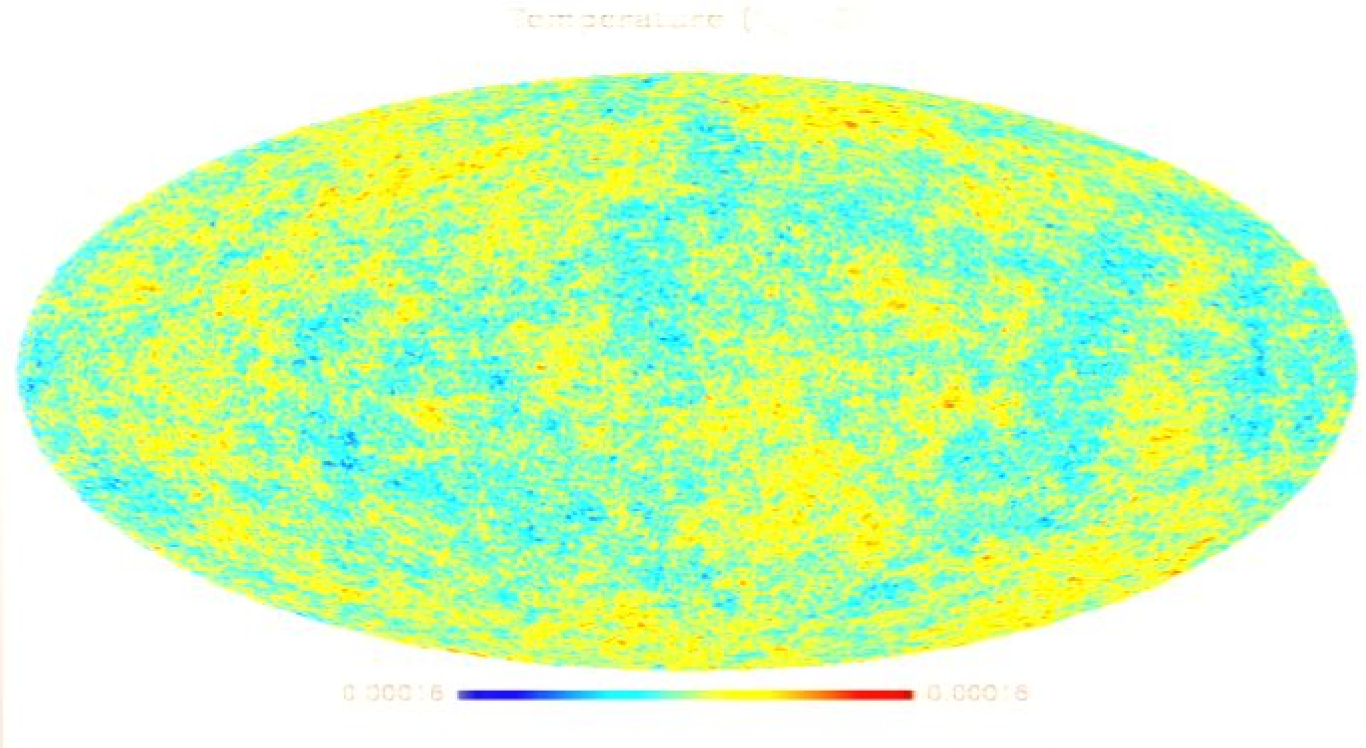

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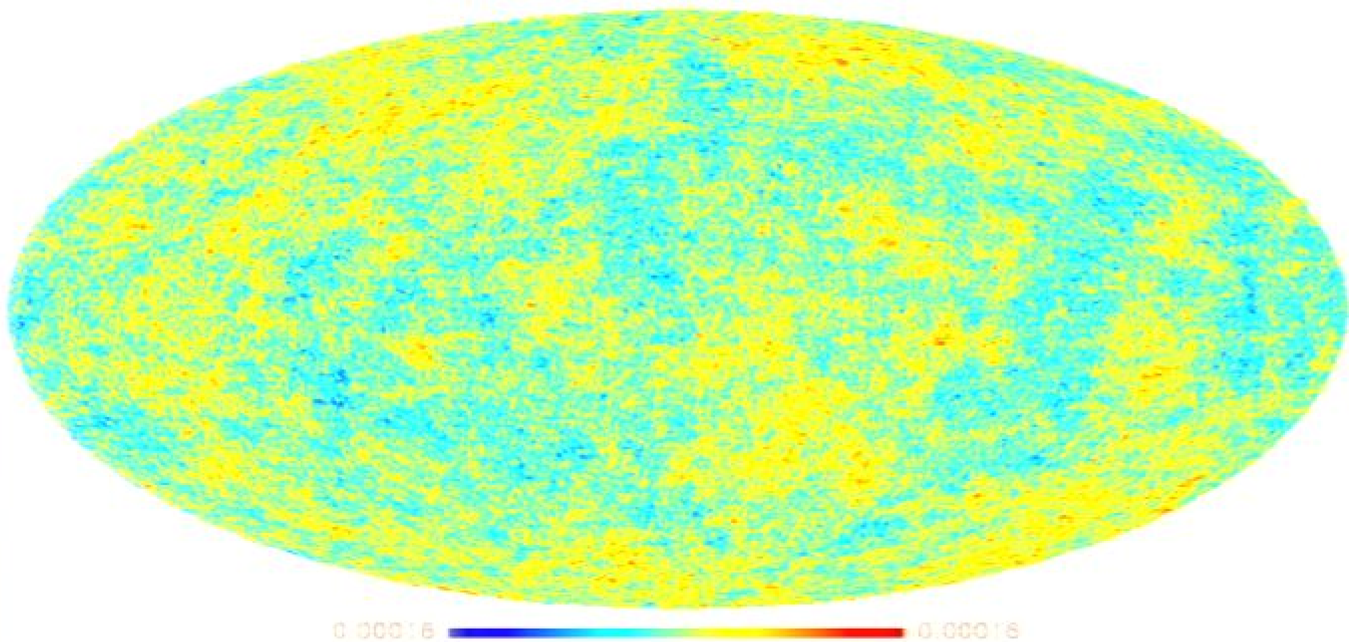
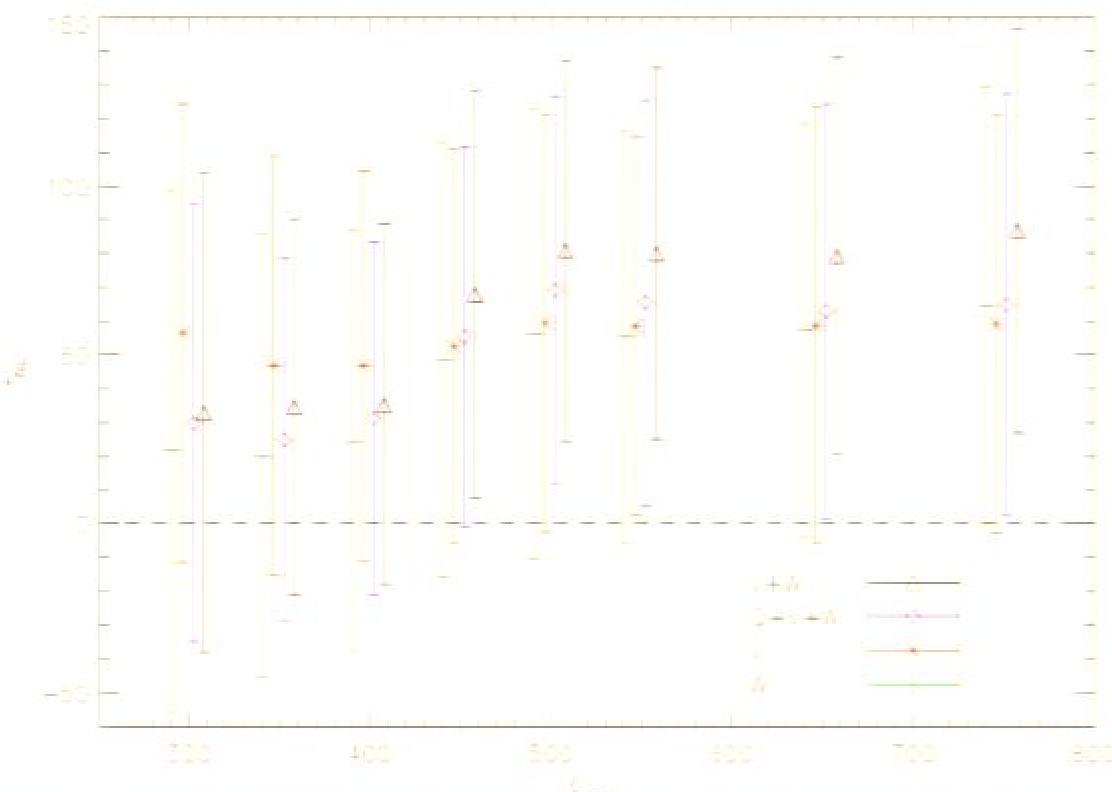


Liguori, Yadav, Hansen, Komatsu, Matarrese, Wandelt 2007

f_{NL} Bi-spectrum

- Natural probe
  - $<T^3> \propto 0+f_{NL}\Phi_L^3$, $<T^4> \propto <T^2>^2 + f_{NL}\Phi_L^4$ +HOT
  - *Nearly all the f_{nl} information (Babich 2005)*
- Polishing (& using) the estimator
  - *Komatsu & Spergel 2001 – CMB bispectrum from fNL*
  - *Komatsu, Wandelt, Spergel, Banday, Gorski 2001 – fNL from COBE*
  - *Komatsu Spergel & Wandelt 2003 – fast fNL estimator*
  - *Komatsu et al (WMAP team) 2003 – WMAP1 analysis using KSW*
  - *Babich and Zaldarriaga 2004 – temperature + polarization*
  - *Creminelli, Nicolis, Senatore, Tegmark, Zaldarriaga 2006 – introduce linear term to improve KSW estimator*
  - *Spergel et al (WMAP team) 2006 – WMAP3 analysis using KSW*
  - *Creminelli, Senatore, Tegmark, Zaldarriaga 2006 – apply cubic + linear term to WMAP3 data*
  - *Yadav Komatsu & Wandelt 2007 – KSW generalized to T+P*
  - *Liguori, Yadav, Hansen, Komatsu, Matarrese, Wandelt 2007 – calibrate YKW estimator against non-Gaussian simulations*
  - *Yadav, Komatsu, Wandelt, Liguori, Hansen, Matarrese 2007 – Creminelli et al. corrected and generalized to T+P*
- Till recently only upper limits
  - $-58 < f_{NL} < 137$ *(95%) WMAP 1 yr*
  - $-54 < f_{NL} < 114$ *(95%) WMAP 3 yr refined to* $-36 < f_{NL} < 100$ *(95%) by Creminelli etal 06*
  - *NB: this is for the local form (ekpyrotic, curvaton), weaker constraints exist for equilateral configuration (Ghost condensation, DBI, low speed of sound models)*

Tantalising evidence ?



Is it:

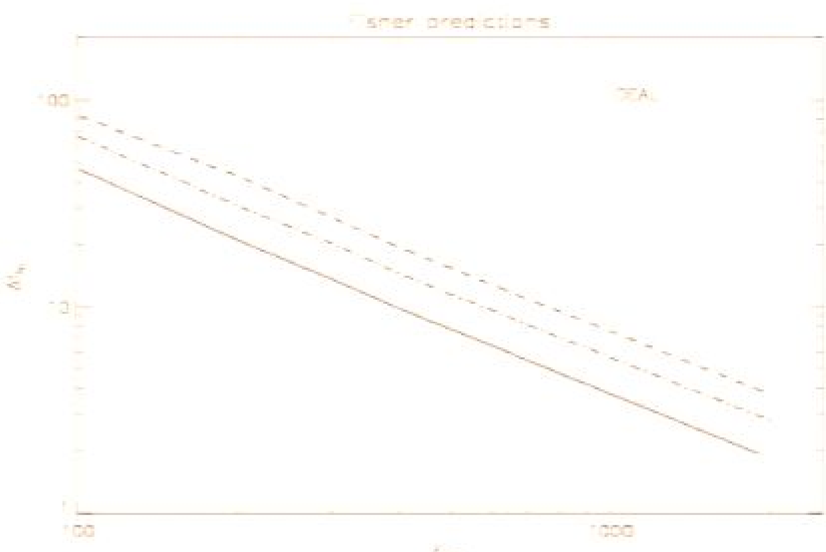
- Instrument systematics?
- Foregrounds?
- Secondary anisotropies?
- Rediscovery of other non Gaussian signals?
- Noise fluctuation?
- Primordial?

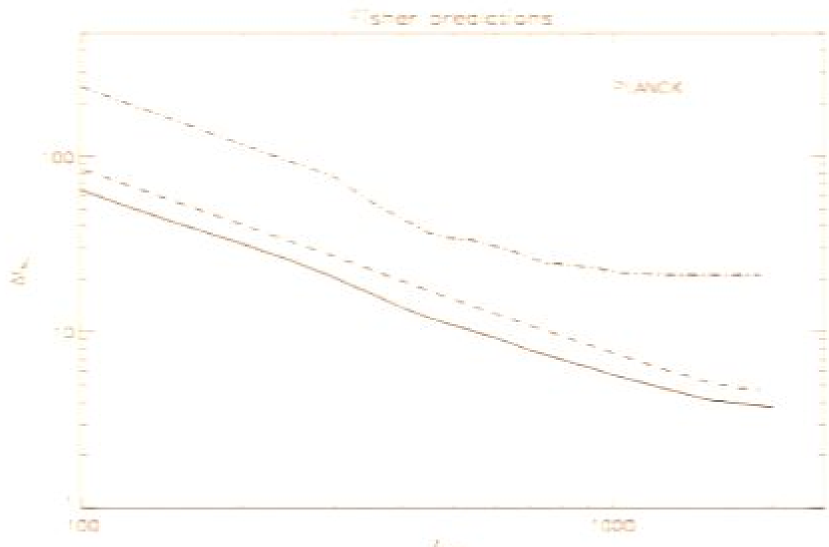
$27 < f_{NL}^{(local)} < 147$ (95%CL, a 2.5σ result)

Yadav & Wandelt Phys. Rev. Lett. 100, 181301 (2008)

Komatsu et al. have more generous error bars...

f_{NL} quest





- Ideal CMB experiment, using temperature & polarization could reach $\Delta f_{NL} \sim 1$
- For Planck, the Cramer Rao limit is $\Delta f_{NL} \sim 3$.

Yadav, Komatsu and Wandelt, astro-ph/0701921

NB: WMAP-8yr could reach ~21 (/30 w. 3yr data)

WMAP-5 summary

TABLE 2
SUMMARY OF THE 95% CONFIDENCE LIMITS ON DEVIATIONS FROM THE SIMPLE (FLAT, GAUSSIAN, ADIABATIC, POWER-LAW) ΛCDM MODEL

Section	Name	Type	*WMAP* 5-year	*WMAP*+BAO+SN
§ 3.2	Gravitational Wave[a]	No Running Ind.	$r < 0.43^b$	$r < 0.20$
§ 3.1.3	Running Index	No Grav. Wave	$-0.090 < dn_s/d\ln k < 0.019^c$	$-0.0728 < dn_s/d\ln k < 0.0087$
§ 3.4	Curvature[d]		$-0.063 < \Omega_k < 0.017^e$	$-0.0175 < \Omega_k < 0.0085^f$
	Curvature Radius[g]	Positive Curv.	$R_{curv} > 12\ h^{-1}$Gpc	$R_{curv} > 23\ h^{-1}$Gpc
		Negative Curv.	$R_{curv} > 23\ h^{-1}$Gpc	$R_{curv} > 33\ h^{-1}$Gpc
§ 3.5	Gaussianity	Local	$-9 < f_{NL}^{local} < 111^h$	N/A
		Equilateral	$-151 < f_{NL}^{equil} < 253^i$	N/A
§ 3.6	Adiabaticity	Axion	$\alpha_0 < 0.16^j$	$\alpha_0 < 0.067^k$
		Curvaton	$\alpha_{-1} < 0.011^l$	$\alpha_{-1} < 0.0037^m$
§ 4	Parity Violation	Chern-Simons[n]	$-5.9° < \Delta\alpha < 2.4°$	N/A
§ 5	Dark Energy	Constant w[o]	$-1.37 < 1 + w < 0.32^p$	$-0.11 < 1 + w < 0.14$
		Evolving $w(z)$[q]	N/A	$-0.38 < 1 + w_0 < 0.14^r$
§ 6.1	Neutrino Mass[s]		$\sum m_\nu < 1.3$ eV[t]	$\sum m_\nu < 0.61$ eV[u]
§ 6.2	Neutrino Species		$N_{eff} > 2.3^v$	$N_{eff} = 4.4 \pm 1.5^w$ (68%)

Komatsu et al 0803.0547

Planck starts from there...

Conclusions

- CMB unique in tightening together so many fundamental elements (Fundamental laws, census, i.e. cosmography and cosmogony)
  - *Mining polarisation will surely be challenging, but in proportion to the potential pay-offs*
- First survey data in less than a year! + 3 intensive years of data massaging.
  - *Theorists hurry if you prefer pre-dictions to post-dictions*
- Planck is in line with design goals
  - *but nothing like the real sky...*
- Cosmological science: moving from confirming broad expectations (flat, Gaussian, adiabatic, power-law, scale-invariant) to actually detecting highly revealing deviations.

  Possibilities include Ω_k, f_{NL} (Gμ...), α_{ISO}, n_s-1, n_{run}, r, Σm_ν, Neff-3.04, 1+w_0, w_1...
  - *NB: Cosmology has a record of surprises, not least DM&DE, in which CMB played prominent role*
- Of course other cosmological probes will remain needed
  - *To confirm paradigm by cross-checks (not many now)*
  - *Break remaining degeneracies, in particular low-z possible variations of w*

  "Planck prior" is assumed by future projects (eg JDEM concepts, Cosmic Inflation Probe, CMBPol)
- Planck legacy will also be a unique set of maps of the microwave polarized sky, with all induced spin-offs "à la IRAS"

Small Scale Anisotropies from Strings

A. Fraisse, C. Ringevald, D. Spergel
& F. R. Bouchet, arXiv:0708.1162

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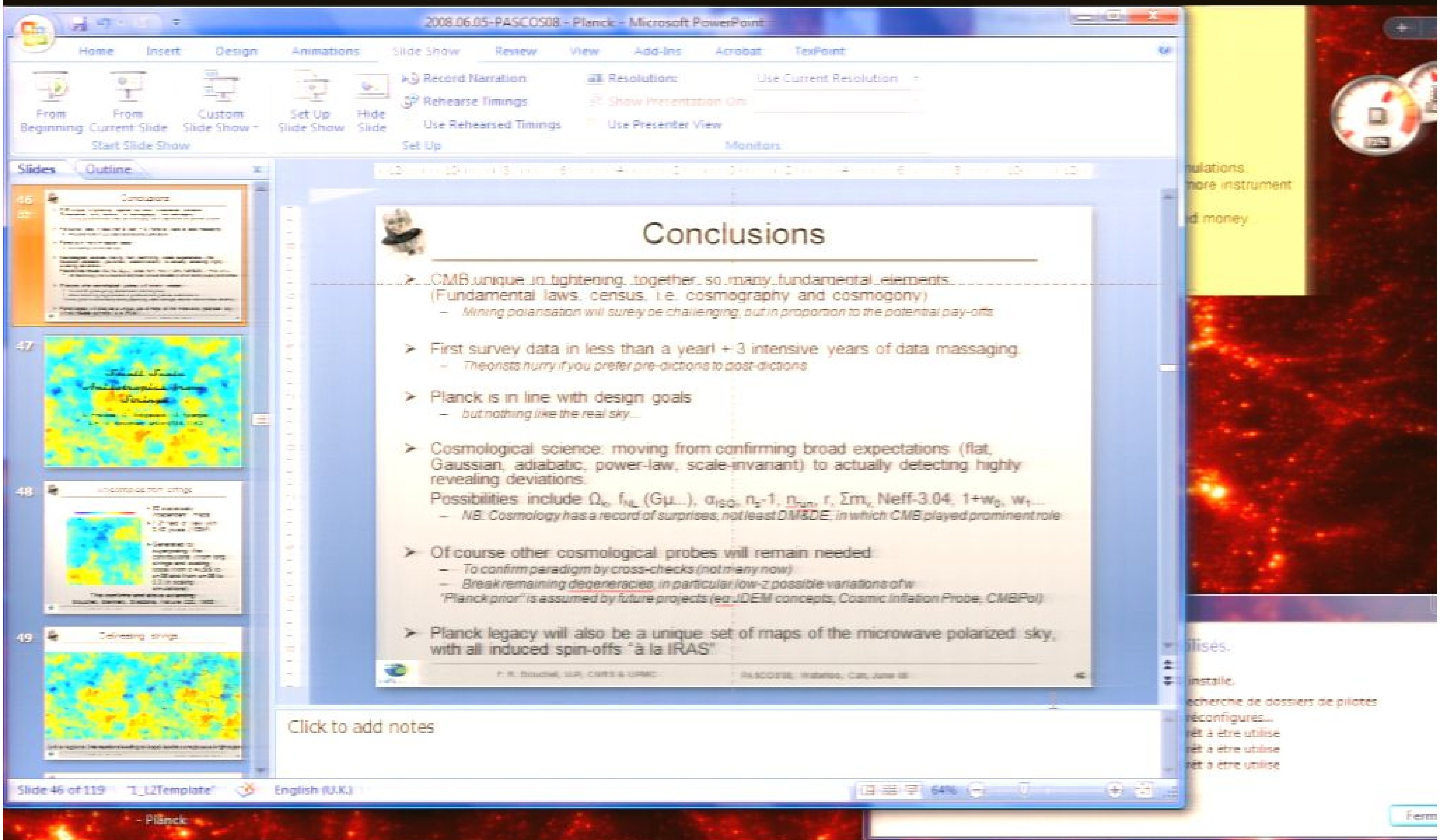
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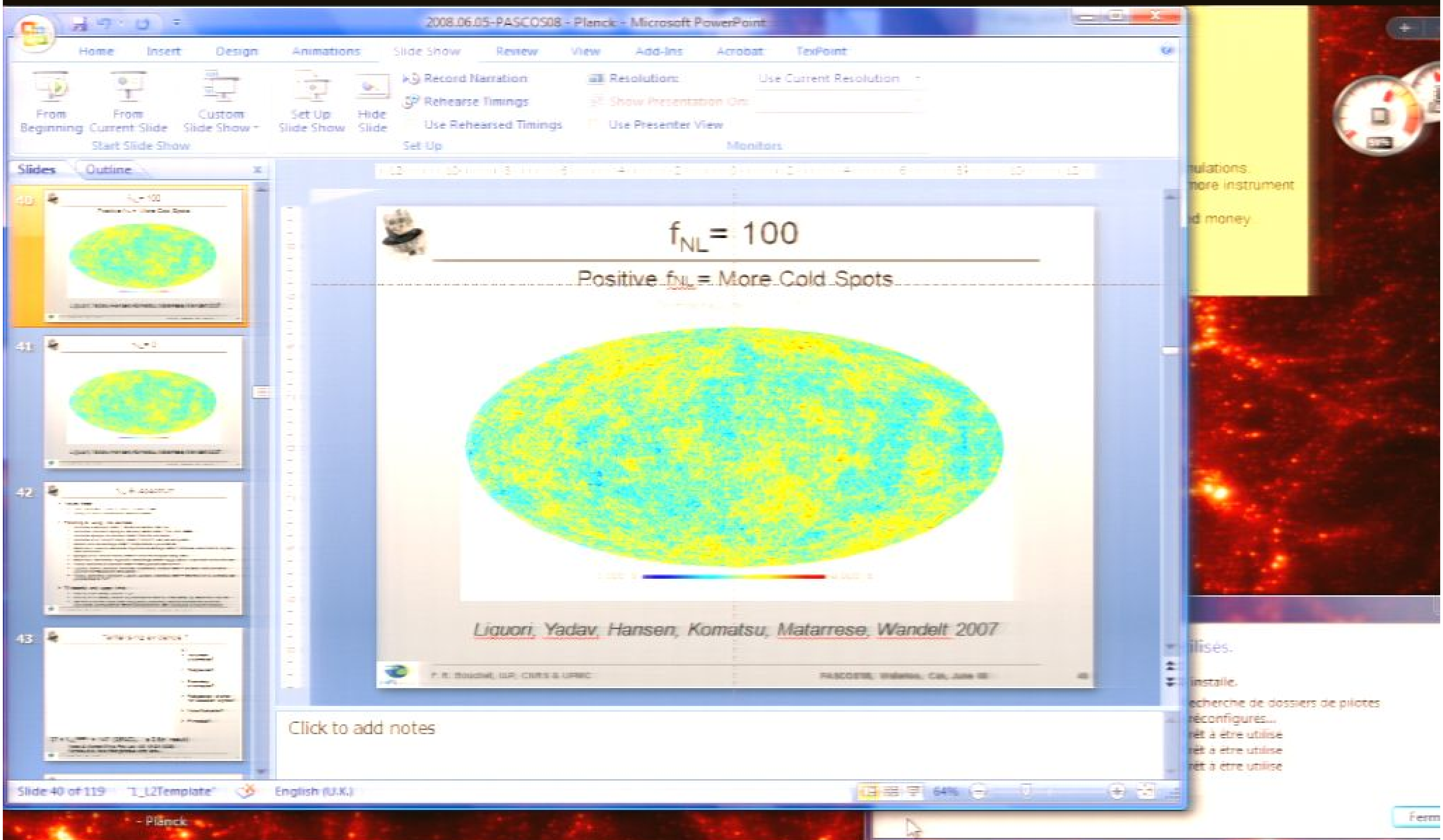
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fNL = 100
Positive fNL = More Cold Spots
Liguori, Yadav, Hansen, Komatsu, Matarrese, Wandelt 2007
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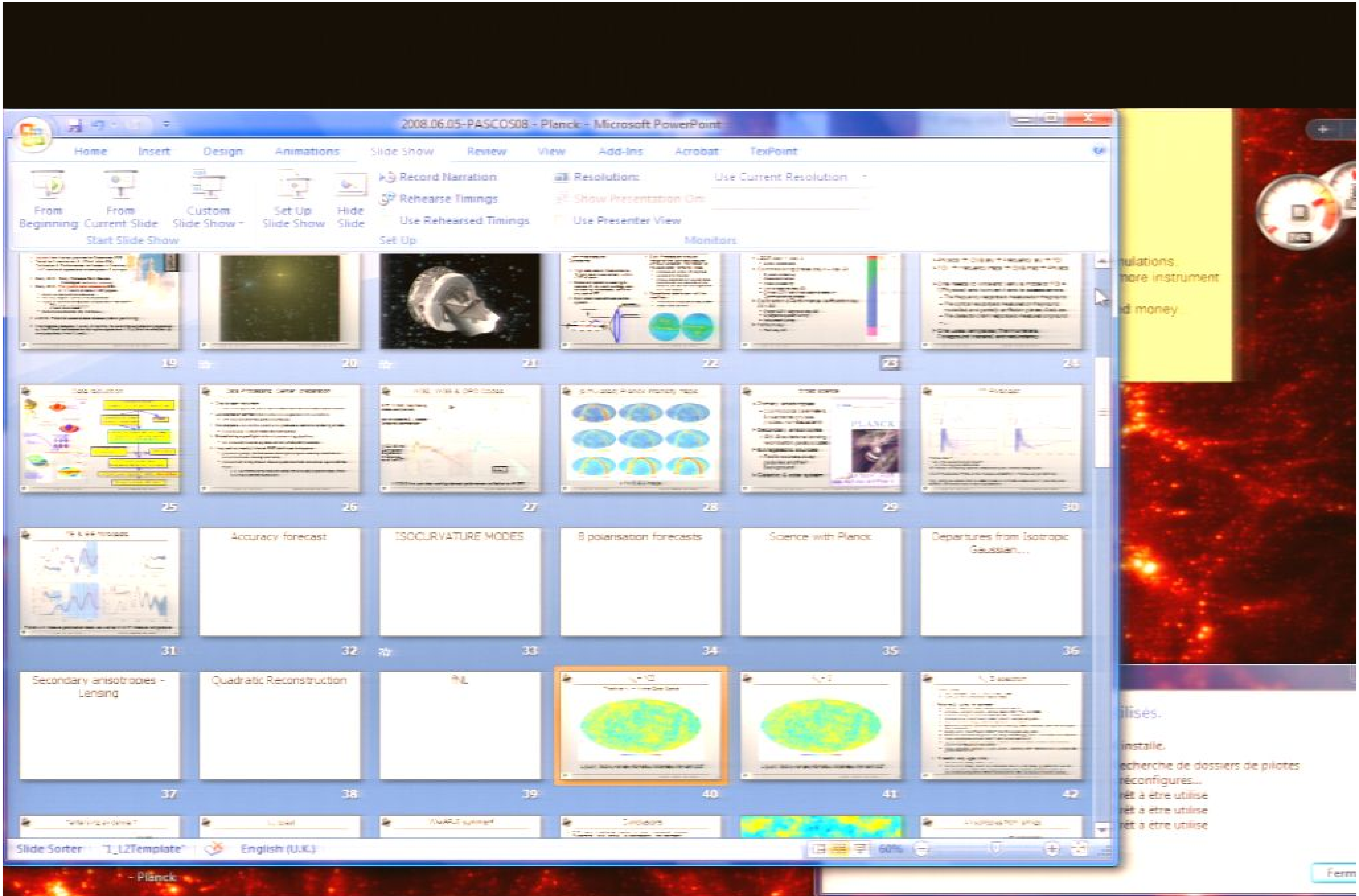
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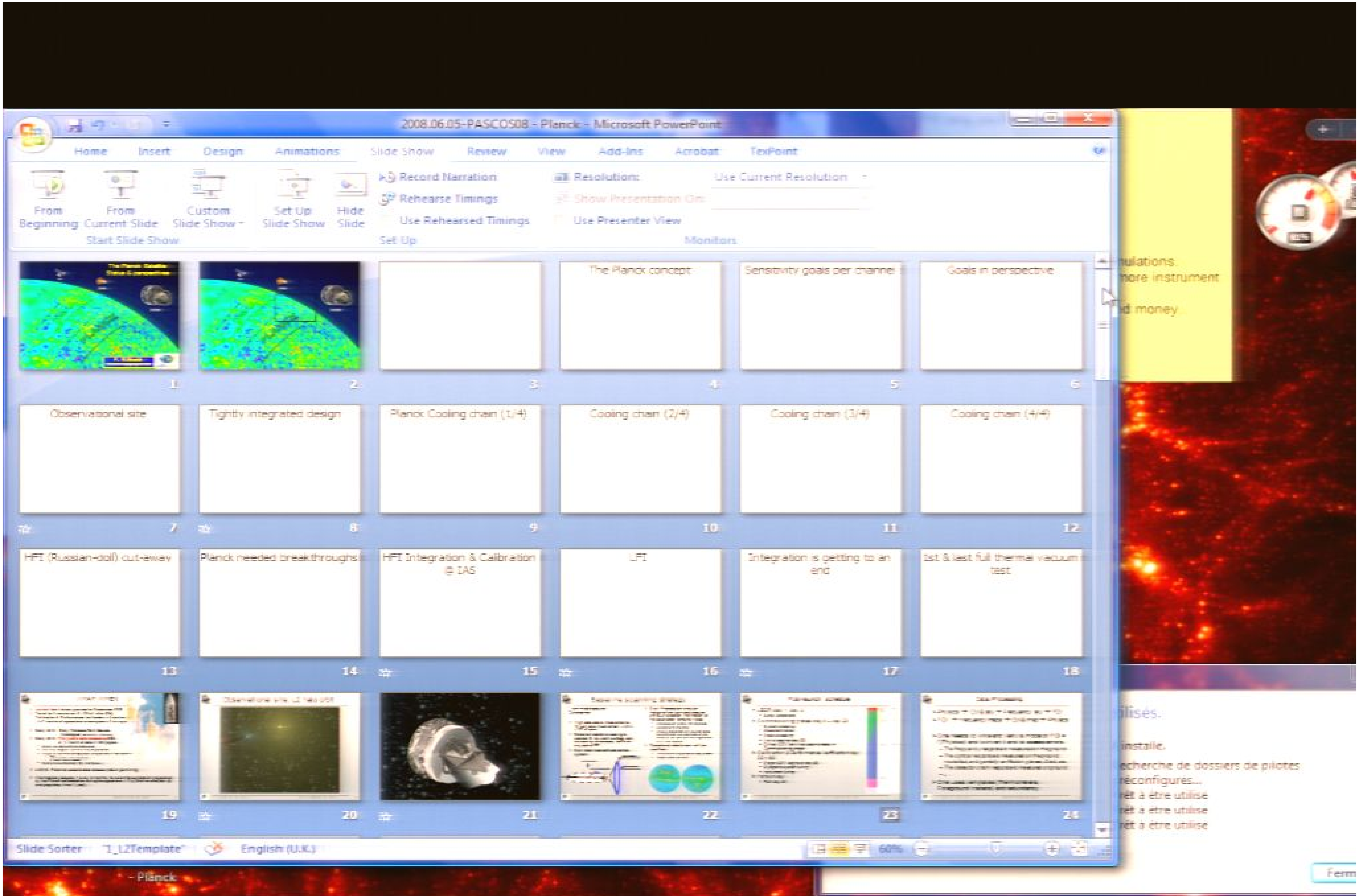
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Sensitivity goals per channel
Goals in perspective
Observational site
Tightly integrated design
Planck Cooling chain (1/4)
Cooling chain (2/4)
Cooling chain (3/4)
Cooling chain (4/4)
HFI (Russian-doll) cut-away
Planck needed breakthroughs
HFI Integration & Calibration @ IAS
LFI
Integration is getting to an end
1st & last full thermal vacuum test
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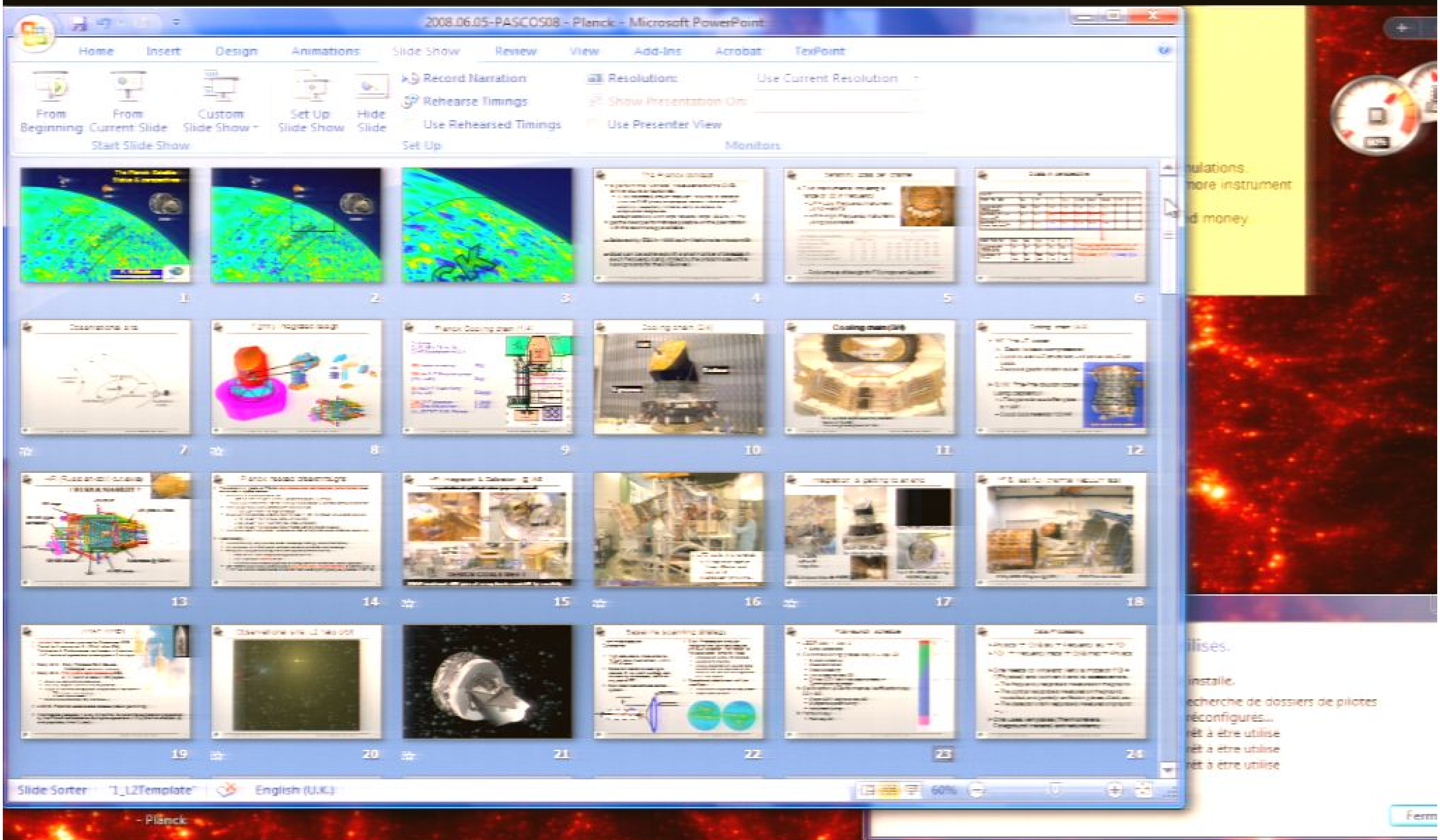
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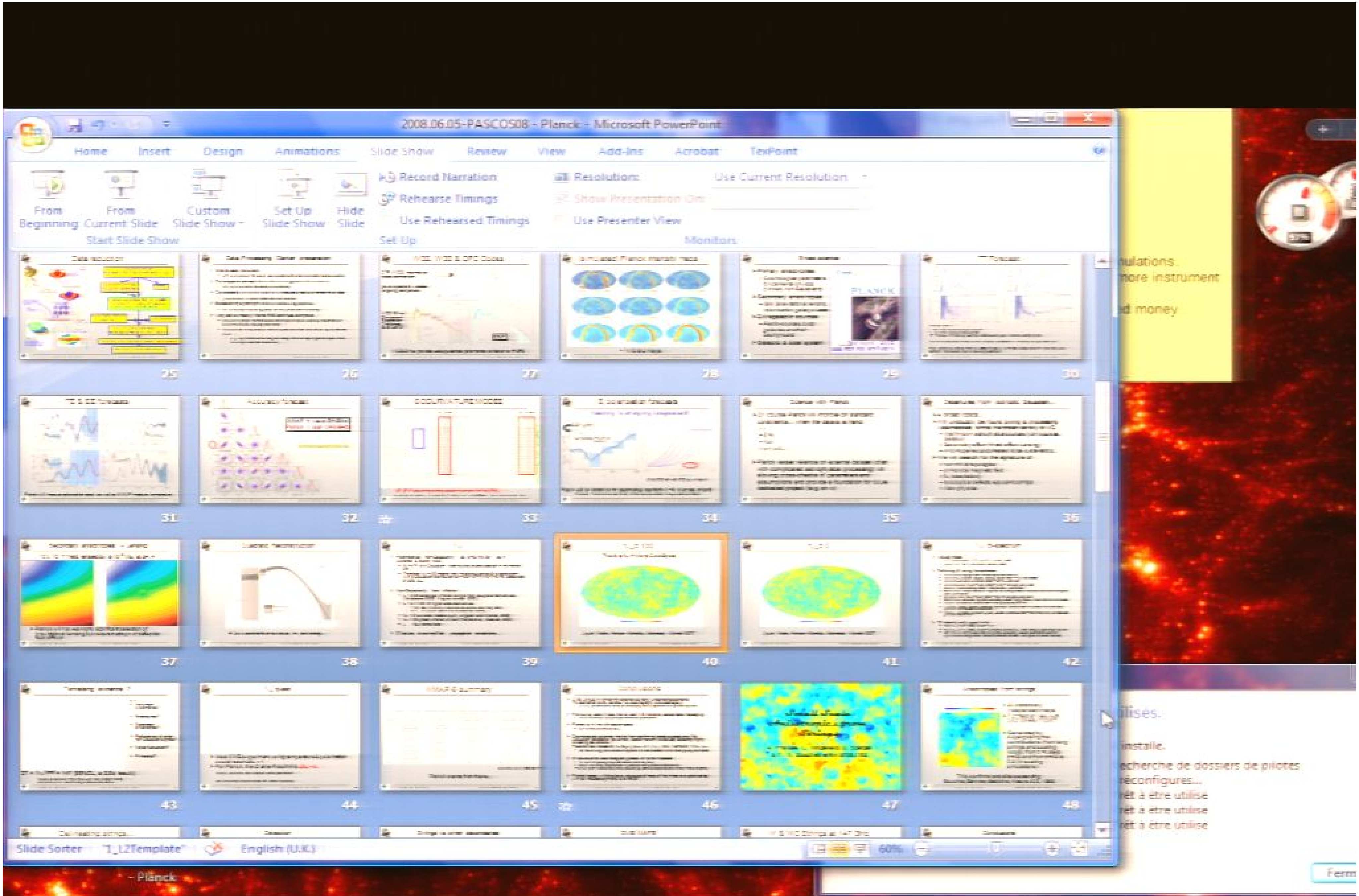
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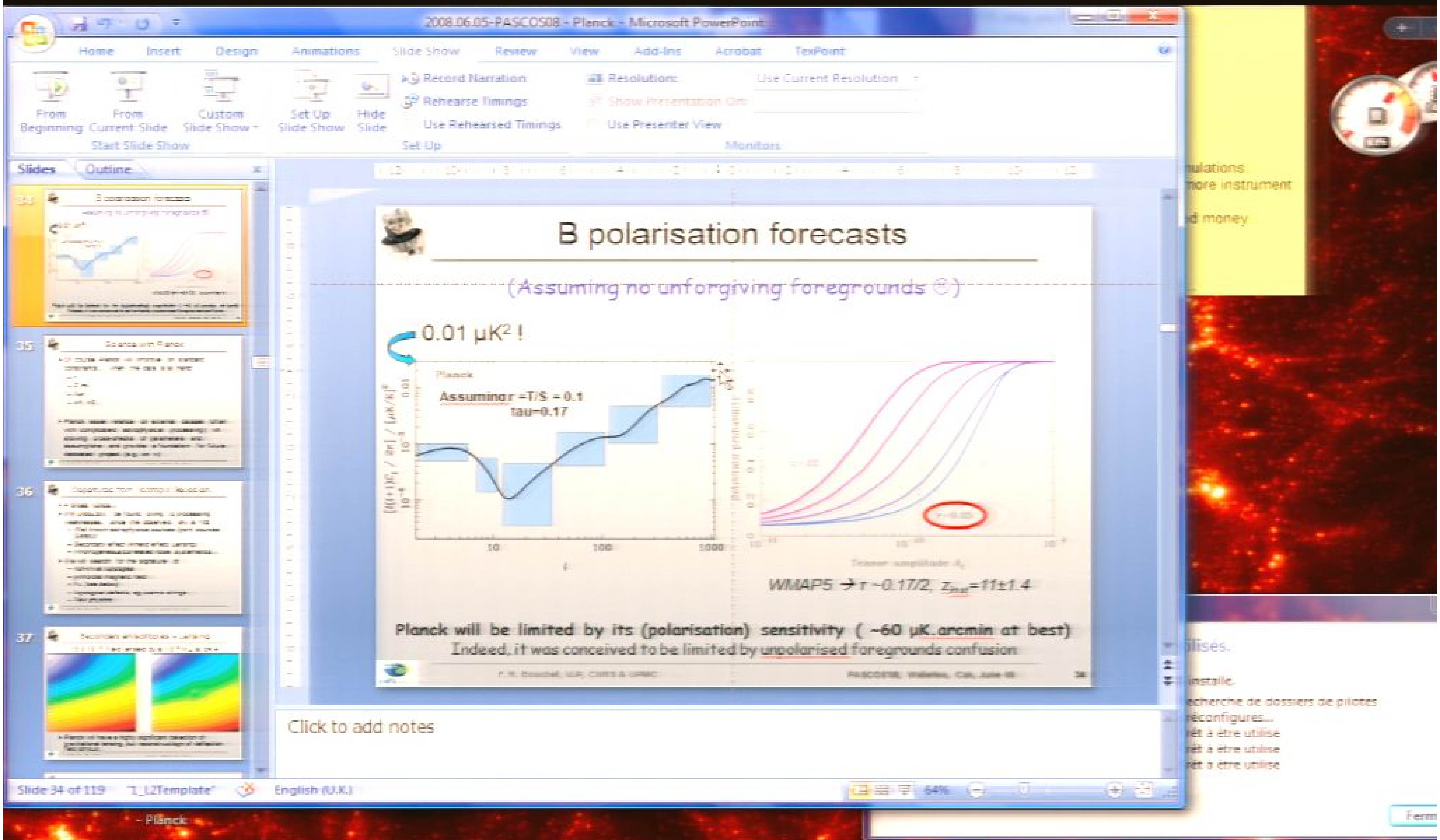
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B polarisation forecasts
(Assuming no unforgiving foregrounds ☹)
0.01 μK² !
Assuming r =T/S = 0.1
tau=0.17
WMAP5 → τ ~0.17/2, z_reion=11±1.4
Planck will be limited by its (polarisation) sensitivity (~60 μK.arcmin at best)
Indeed, it was conceived to be limited by unpolarised foregrounds confusion
Click to add notes
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