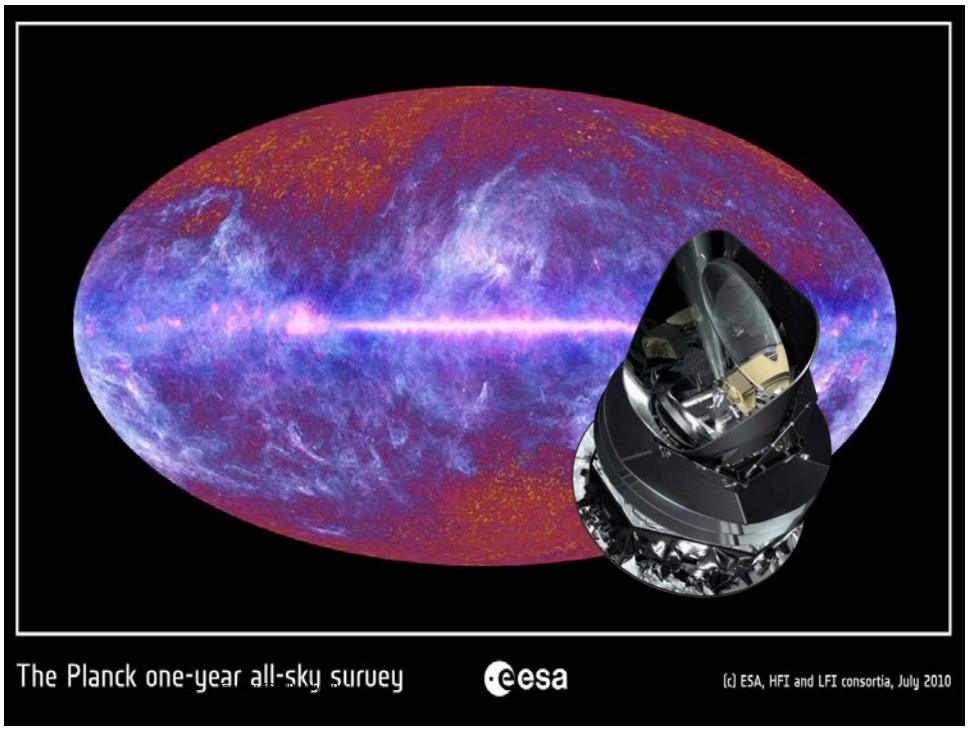
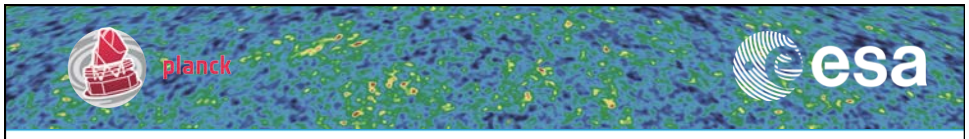
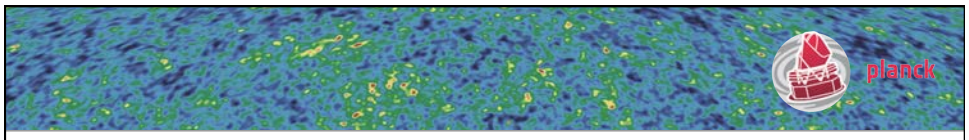




Latest results from Planck

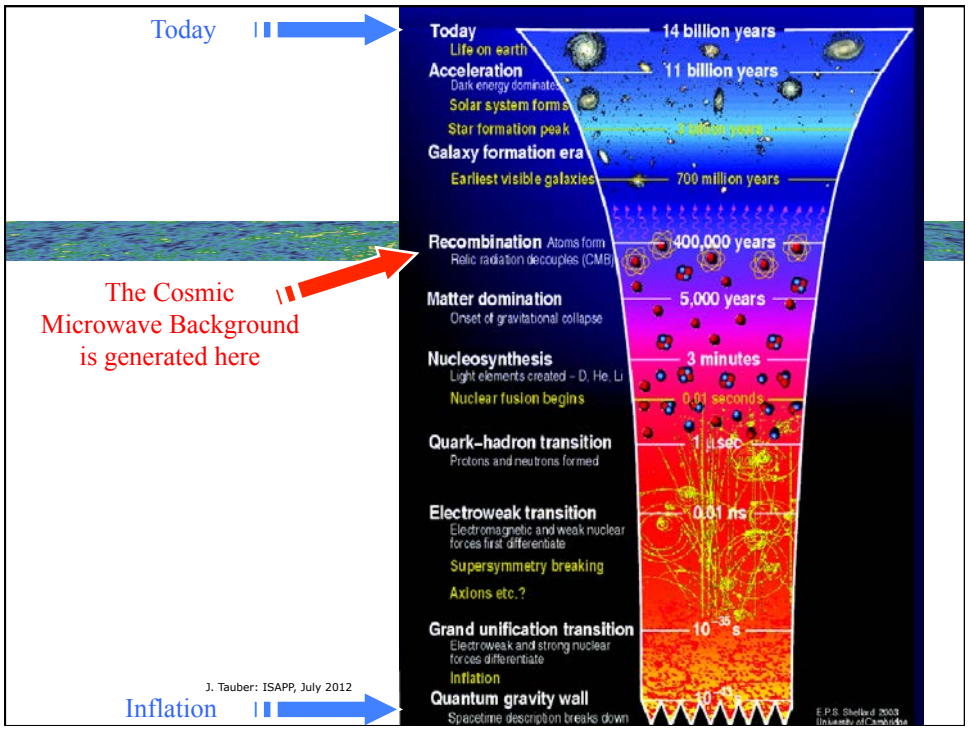
J. Tauber
Planck Project Scientist, ESA
on behalf of the Planck Collaboration

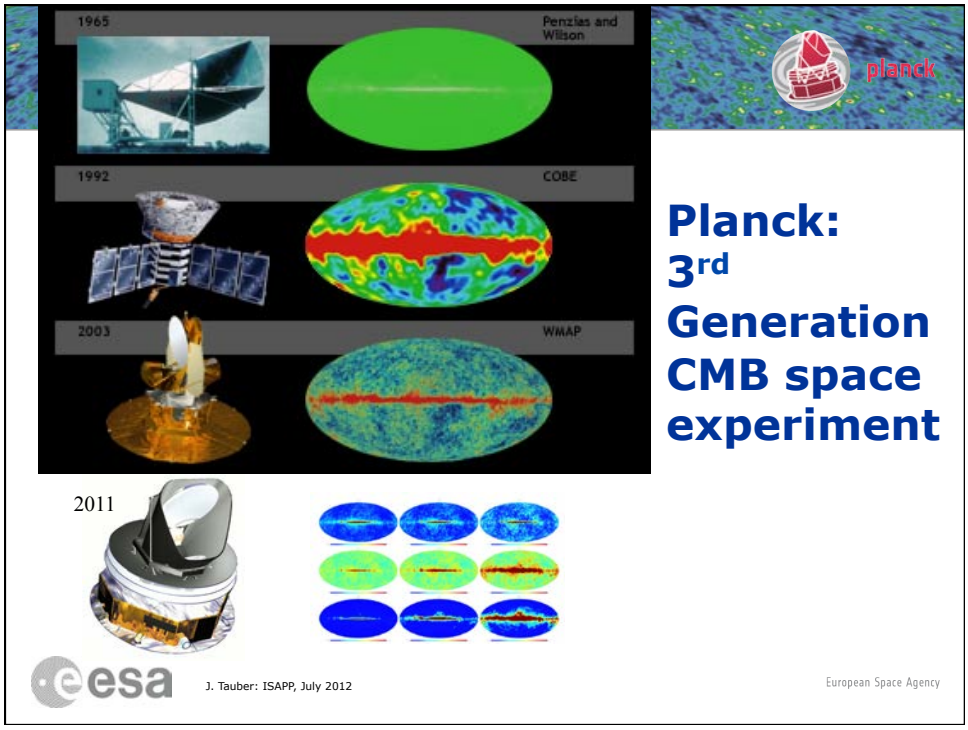


esa planck

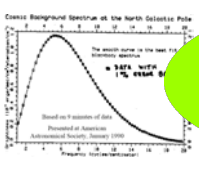
The European mission to map the Cosmic Microwave Background

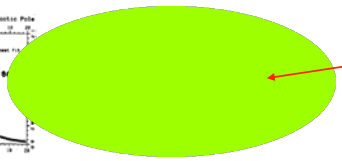
To image the temperature and polarisation anisotropies of the Cosmic Microwave Background (CMB), over the whole sky, with an uncertainty on the temperature limited by "natural causes" (foreground fluctuations, cosmic variance) rather than intrinsic or systematic detector noises, and an angular resolution ~5 arcminutes.


Today
The Cosmic Microwave Background is generated here
Inflation
Today
Life on earth
Acceleration
Dark energy dominates
Solar system forms
Star formation peak
Galaxy formation era
Earliest visible galaxies
Recombination Atoms form
Relic radiation decouples (CMB)
Matter domination
Onset of gravitational collapse
Nucleosynthesis
Light elements created – D, He, Li
Nuclear fusion begins
Quark–hadron transition
Protons and neutrons formed
Electroweak transition
Electromagnetic and weak nuclear forces first differentiate
Supersymmetry breaking
Axions etc.?
Grand unification transition
Electroweak and strong nuclear forces differentiate
Inflation
Quantum gravity wall
Spacetime description breaks down
14 billion years
11 billion years
3 billion years
700 million years
400,000 years
5,000 years
3 minutes
0.01 seconds
1 μsec
0.01 ns
10^-35 s
10^-43 s
E.P.S. Shellard 2003
University of Cambridge
J. Tauber: ISAPP, July 2012

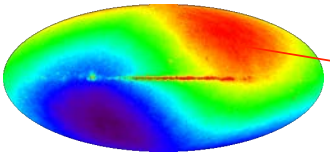

1965
Penzias and Wilson
1992
COBE
2003
WMAP
2011
planck
Planck:
3rd
Generation
CMB space
experiment
esa
J. Tauber: ISAPP, July 2012
European Space Agency

The sky as seen by a CMB experiment, e.g. Planck

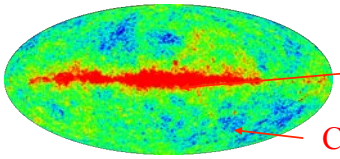




CMB, T ~ 2.7 K



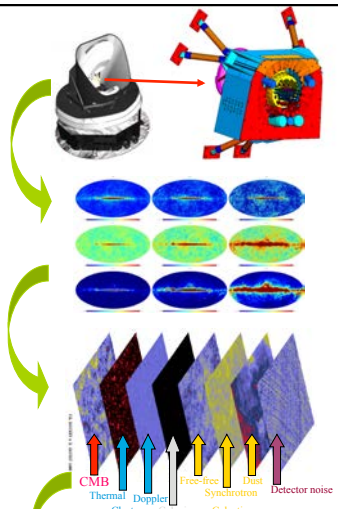
Dipole, ΔT ~3 mK

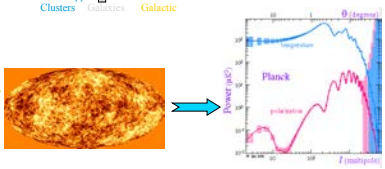


Milky Way, ΔT ~1 mK

CMB anisotropies, ΔT ~50 μK

esa



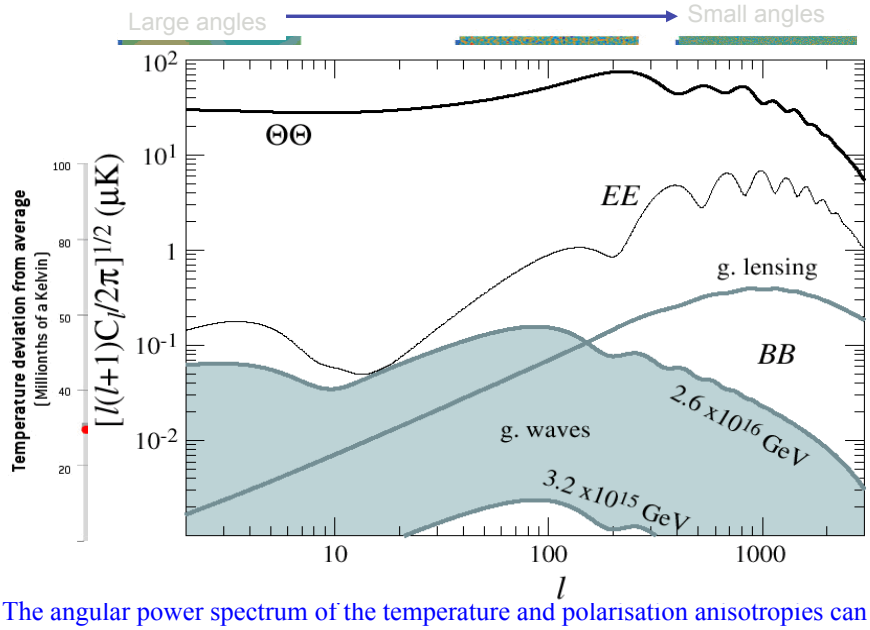


Acquiring and processing time-ordered information

Converting time-ordered data to maps of the sky emission at many frequencies

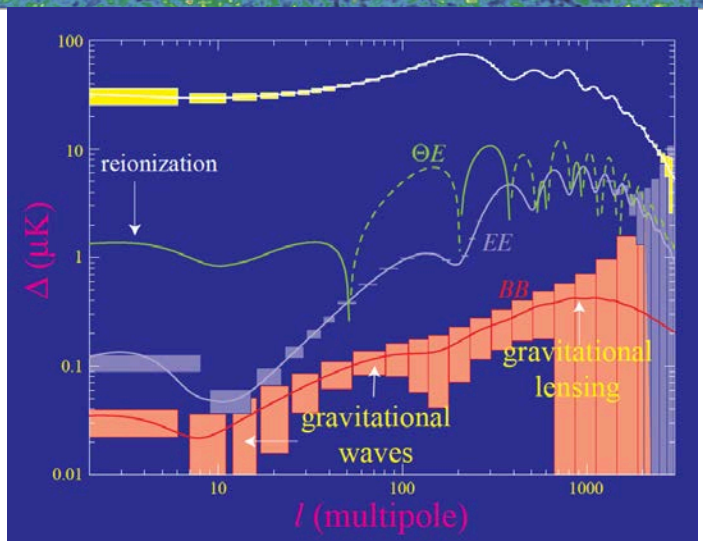
Converting frequency maps to component maps, e.g. the Cosmic Microwave Background

Estimating the CMB angular power spectrum and cosmological parameters



The angular power spectrum of the temperature and polarisation anisotropies can be used to extract the value of fundamental cosmological parameters

Planck expectations



Hu & Dodelson 2002

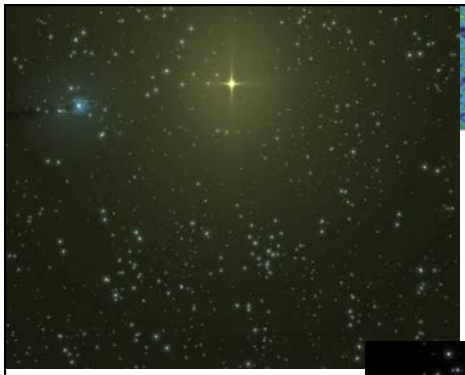
Scientific objectives

The unrivalled accuracy of Planck will allow us to:

- Pin down the basic characteristics of the Universe: age, contents, dynamics, geometry, …
- Examine the origins of the Universe and test inflation
- Probe physics at extremely high energies, e.g. superstrings, neutrinos
- Probe the birth of the first stars and galaxies

But also

- Understand the evolution of structures, galaxies and clusters of galaxies
- Observe our own Galaxy as never seen before…

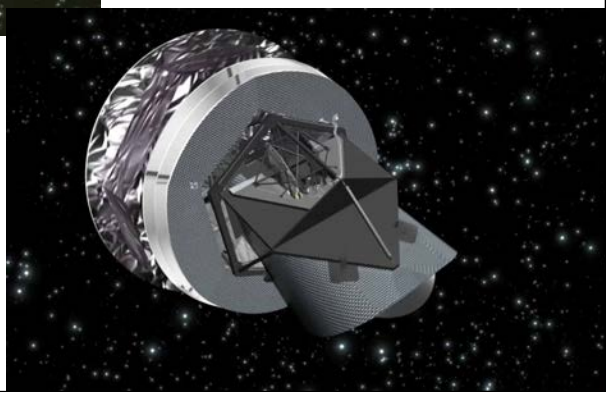


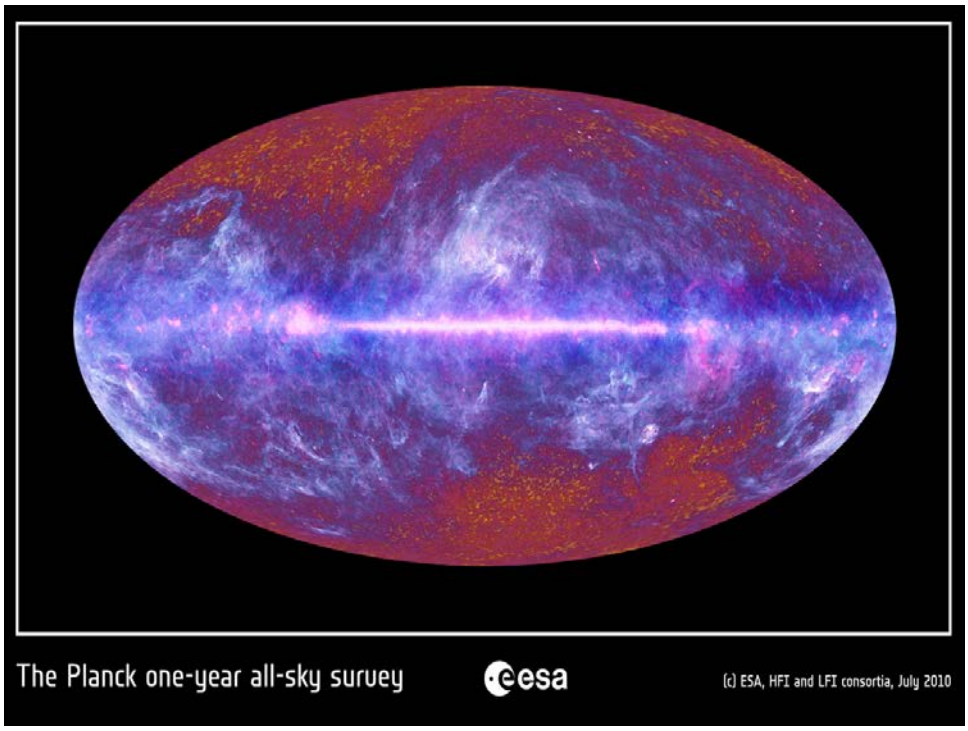
Launch = 14 May 2009

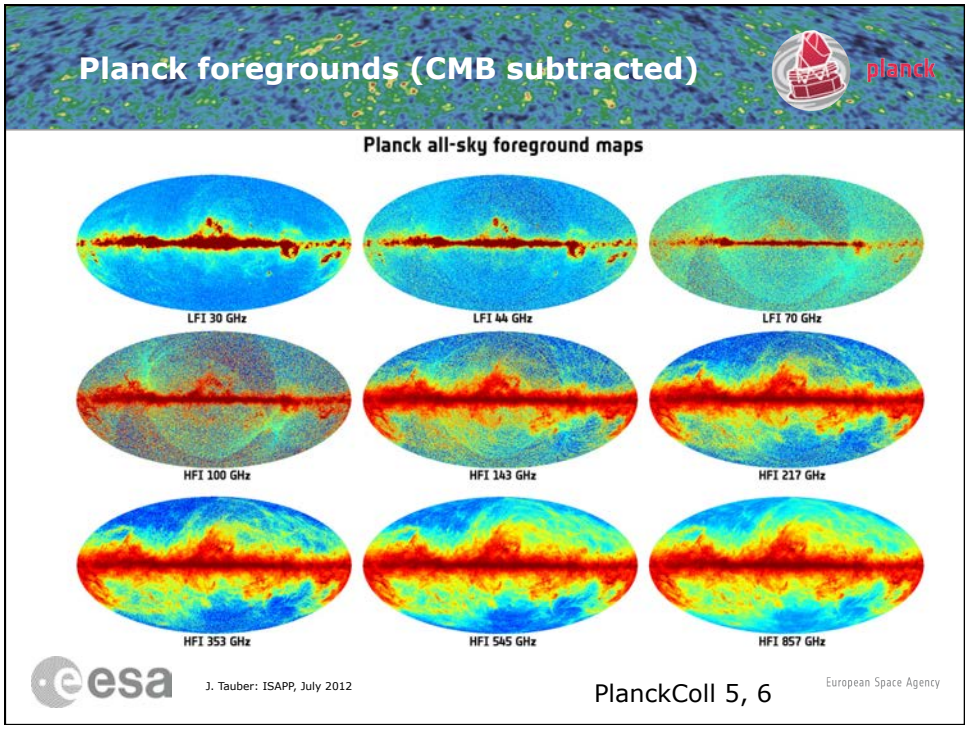
Nominal mission
= 15 months
= 2 full sky surveys
HAS BEEN COMPLETED in NOV 2010 !

Extended cryogenic mission
= 15 + 12 months
= >4 full sky surveys
HAS BEEN COMPLETED IN JAN 2012 !

First LFI-only Extension:
> Dec 2012




The Planck one-year all-sky survey
esa
(c) ESA, HFI and LFI consortia, July 2010


Planck foregrounds (CMB subtracted)
planck
Planck all-sky foreground maps
LFI 30 GHz
LFI 44 GHz
LFI 70 GHz
HFI 100 GHz
HFI 143 GHz
HFI 217 GHz
HFI 353 GHz
HFI 545 GHz
HFI 857 GHz
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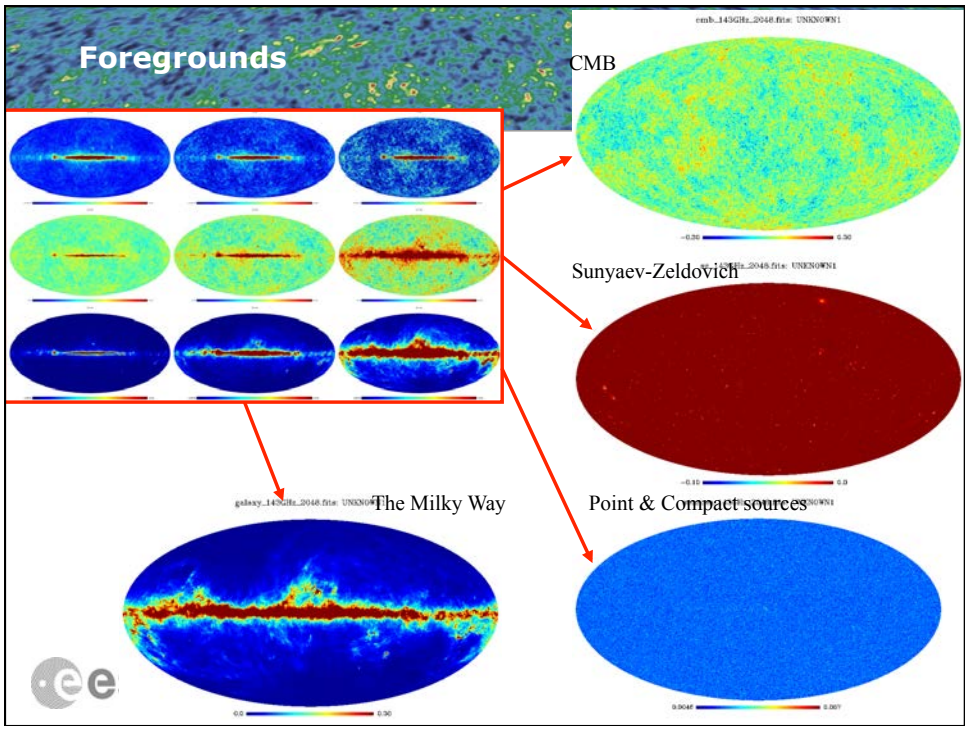
J. Tauber: ISAPP, July 2012
PlanckColl 5, 6
European Space Agency



Key non-CMB science with Planck

Sunyaev-Zeldovich-selected sources

- Measurement of y in ~ 10^3 galaxy clusters
- Cosmological evolution of clusters to z ~ 1
- Gas properties (w/ X-ray, IR measurements)
- Bulk velocities on scales > 300 Mpc

Extragalactic sources and backgrounds

- SEDs of IR and radio galaxies
- SEDs of AGN's, QSO's, blazars
- Evolution of galaxy counts to z > 1
- Far-IR background fluctuations

Maps of Milky Way at frequencies 30-1000 GHz

- Dust properties, Cloud and cirrus morphology
- Star forming regions, Cold molecular clouds
- Galaxy-scale distribution of gas and dust
- Polarisation-based science, e.g. Galactic magnetic field

Recent releases

1. The **Early Release Compact Source Catalogue** was released to the public on 11 January 2011
   a. A catalogue of compact sources extracted from the first all-sky survey with high reliability (>90%) - designed for follow-up. Available through
      http://www.rssd.esa.int/Planck
   a. It contains
      - ~15000 individual sources with detectable fluxes in individual Planck channels (range 30-857 GHz)
        - Sources in the Milky Way
        - Near and distant galaxies
      - A catalogue of cold cores, selected by their temperature
      - A catalogue of galaxy clusters selected via the Sunyaev-Zeldovich effect

Access from http://www.sciops.esa.int/index.php?project=planck&page=Planck_Legacy_Archive

2. Together with the catalogue, **25 scientific papers** were submitted to Astronomy & Astrophysics, covering
   a. The performance of Planck and its payload in the first year of operations, and the initial data processing steps
   b. The production of the ERCSC and the characteristics of the main source populations that it contains, including validation of the catalogues by correlation with other catalogues and follow-up
   c. Selected astrophysical topics related to diffuse emission
   d. They are accessible through the same site above or at astro-ph

Planck Early Results (Jan 2011)

1. Planck early results 01: The Planck mission
2. Planck early results 02: The thermal performance of Planck
3. Planck early results 03: First assessment of the Low Frequency Instrument in-flight performance
4. Planck early results 04: First assessment of the High Frequency Instrument in-flight performance
5. Planck early results 05: The Low Frequency Instrument data processing
6. Planck early results 06: The High Frequency Instrument data processing
7. Planck early results 07: The Early Release Compact Source Catalogue
8. Planck early results 08: The all-sky early Sunyaev-Zeldovich cluster sample
9. Planck early results 09: XMM-Newton follow-up for validation of Planck cluster candidates
10. Planck early results 10: Statistical analysis of Sunyaev-Zeldovich scaling relations for X-ray galaxy clusters
11. Planck early results 11: Calibration of the local galaxy cluster Sunyaev-Zeldovich scaling relations
12. Planck early results 12: Cluster Sunyaev-Zeldovich optical scaling relations
13. Planck early results 13: Statistical properties of extragalactic radio sources in the Planck Early Release Compact Source Catalogue
14. Planck early results 14: Early Release Compact Source Catalogue validation and extreme radio sources
15. Planck early results 15: Spectral energy distributions and radio continuum spectra of northern extragalactic radio sources
16. Planck early results 16: The Planck view of nearby galaxies
17. Planck early results 17: Origin of the submillimetre excess dust emission in the Magellanic Clouds
18. Planck early results 18: The power spectrum of cosmic infrared background anisotropies
19. Planck early results 19: All-sky temperature and dust optical depth from Planck and IRAS – constraints on the "dark gas" in our Galaxy
20. Planck early results 20: New light on anomalous microwave emission from spinning dust grains
21. Planck early results 21: Properties of the interstellar medium in the Galactic plane
22. Planck early results 22: The submillimetre properties of a sample of Galactic cold clumps
23. Planck early results 23: The Galactic cold core population revealed by the first all-sky survey
24. Planck early results 24: Dust in the diffuse interstellar medium and the Galactic halo
25. Planck early results 25: Thermal dust in nearby molecular clouds

Download from http://www.rssd.esa.int

Planck Intermediate Results (>Jan 2011)

1. Planck intermediate results 01: Further validation of new Planck clusters with XMM-Newton
2. Planck intermediate results 02: Comparison of Sunyaev-Zeldovich measurement from Planck and from the Arcminute Microkelvin Imager for 11 galaxy clusters
3. Planck intermediate results 03: The relation between galaxy cluster mass and Sunyaev-Zeldovich signal
4. Planck intermediate results 04: The XMM-Newton validation programme for new Planck clusters

+ ~20 additional intermediate results papers expected to be submitted in the coming 6 months

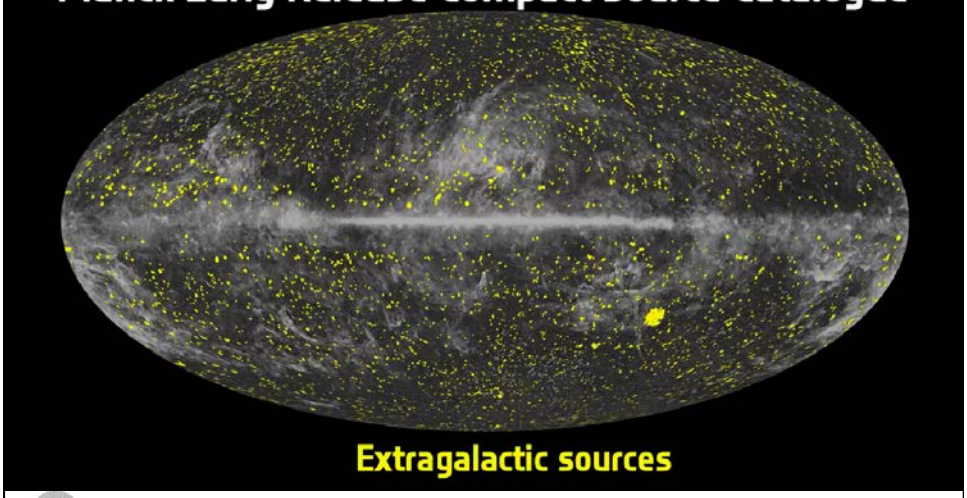
Highlights of early results

a. Study of massive and distant clusters of galaxies via the Sunyaev-Zeldovich effect, and the relationship of the SZ flux with X-ray and optical properties
b. Study of the Spectral Energy Distributions of radio sources, including data not only from Planck but other ground- and space-based observatories
c. Study of dust emission in nearby infrared galaxies, based on the Planck and IRAS data
d. Measurement of the angular power spectrum of the Cosmic Infrared Background
e. Study of the radial distribution of molecular, neutral and ionised gas in the Milky Way
f. Study of the physical properties of dust in both molecular clouds and the diffuse interstellar medium
g. Study of the distribution and properties of the coldest clumps in the Milky Way, and in-depth studies of some specific objects
1. Study of components of the interstellar medium whose properties the Planck data allows to pin down better: spinning grains, CO-less gas

Early Release Compact Source Catalogue

planck

Planck Early Release Compact Source Catalogue



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J. Tauber: ISAPP, July 2012

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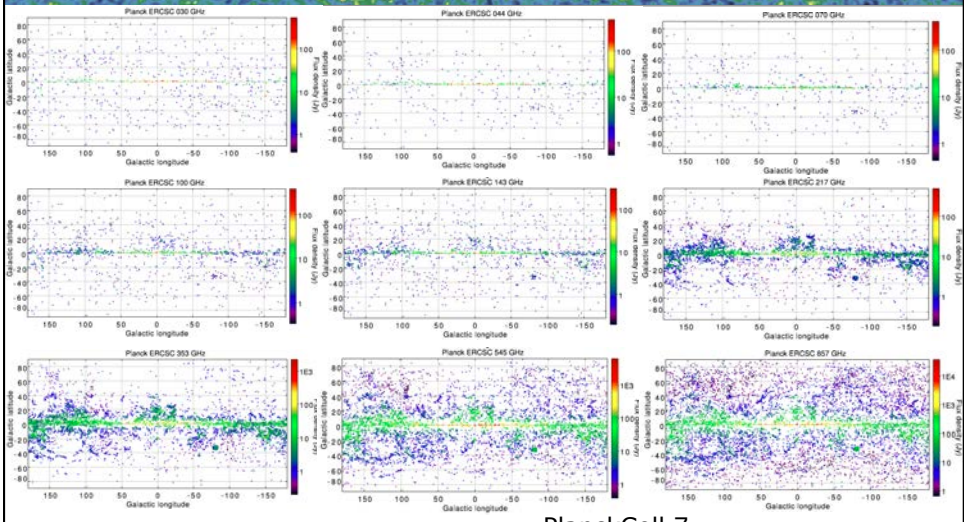
European Space Agency

Early Release Compact Source Catalogue

planck



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J. Tauber: ISAPP, July 2012

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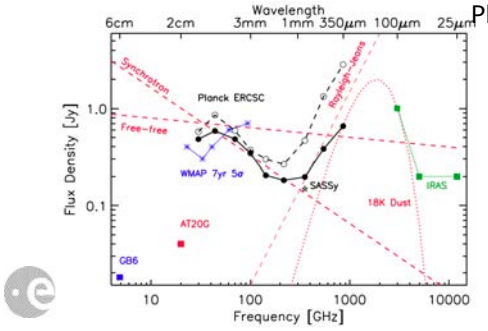
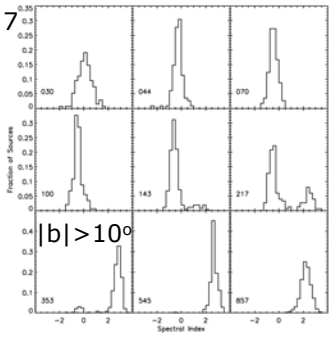
European Space Agency

Early Release Compact Source Catalogue

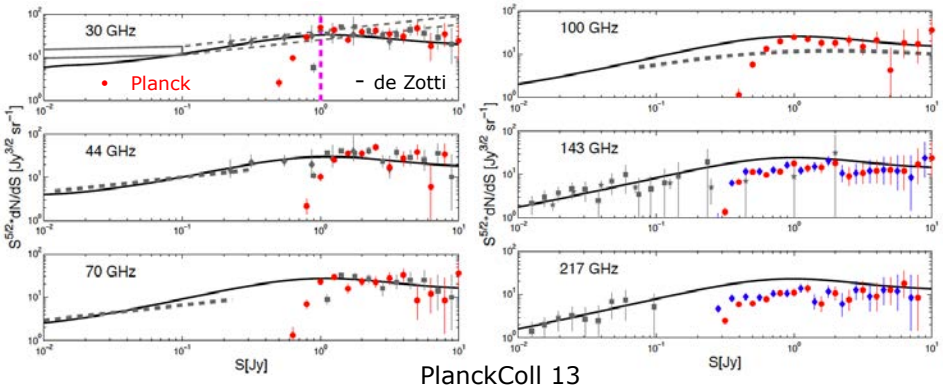
Freq [GHz]	30	44	70	100	143	217	353	545	857
λ [μm]	10000	6818	4286	3000	2098	1382	850	550	350
Sky Coverage in %	99.96	99.98	99.99	99.97	99.82	99.88	99.88	99.80	99.79
Beam FWHM [arcmin][a]	32.65	27.00	13.01	9.94	7.04	4.66	4.41	4.47	4.23
# of Sources	705	452	599	1381	1764	5470	6984	7223	8988
# of $\|b\| > 30°$ Sources	307	143	157	332	420	691	1123	2535	4513
$10\sigma^b$ [mJy]	1173	2286	2250	1061	750	807	1613	2074	2961
$10\sigma^c$ [mJy]	487	1023	673	500	328	280	249	471	813
Flux Density Limit[d] [mJy]	480	585	481	344	206	183	198	381	655



PlanckColl 7



A complete radio source sample

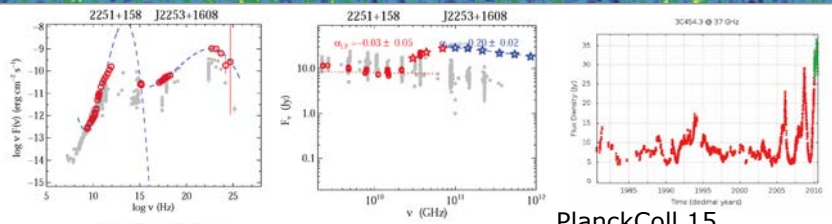


PlanckColl 13

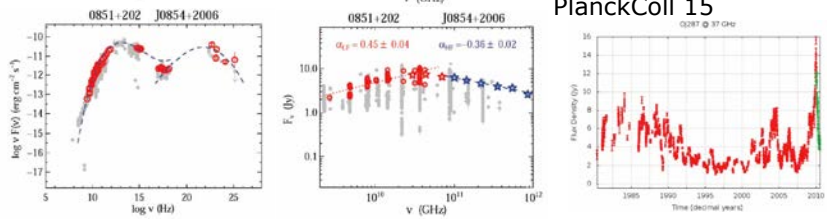
- A complete extragalactic radio sample can be defined by known sources at 30 GHz
- Cosmological evolution models (e.g. de Zotti 2005) overpredict counts at 143 and 217 GHz by a factor of 2 and 2.6 (resp)

Extreme radio sources

3C454.3



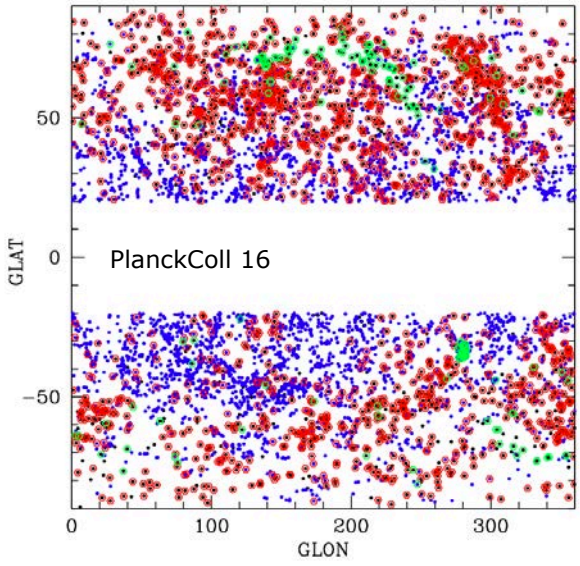
OJ287



- Planck allows to build complete samples of all classes of radio sources
- Scanning strategy permits simultaneous observations
- Organised campaign following ~100 sources from ground and space (Fermi)

Dusty galaxies in the ERCSC

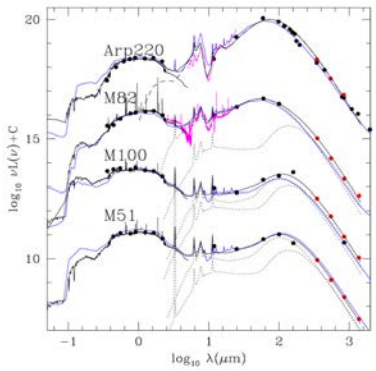
- The ERCSC contains thousands of dusty galaxies
- Confusion with cirrus complicates analysis



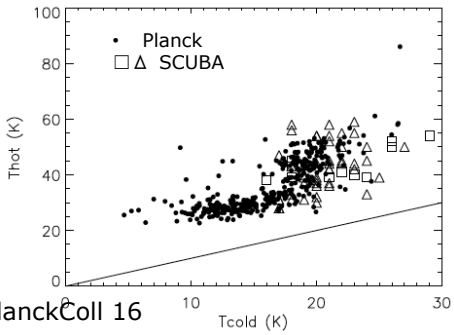
- objects matching IRAS/FSC
- extended objects
- NED objects

IR galaxies

- Planck



2-temperature fit



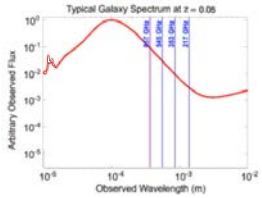
PlanckColl 16

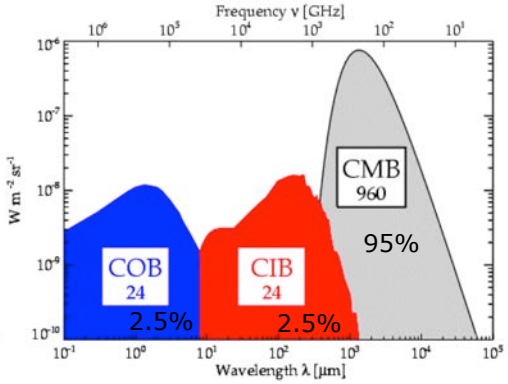
- SED of archetypal galaxies fit well the Planck observations
- Nearby galaxies detected by Planck appear to have colder dust than previously found – hints for a new population

esa J. Tauber: ISAPP, July 2012 European Space Agency

The Cosmic Infrared Background

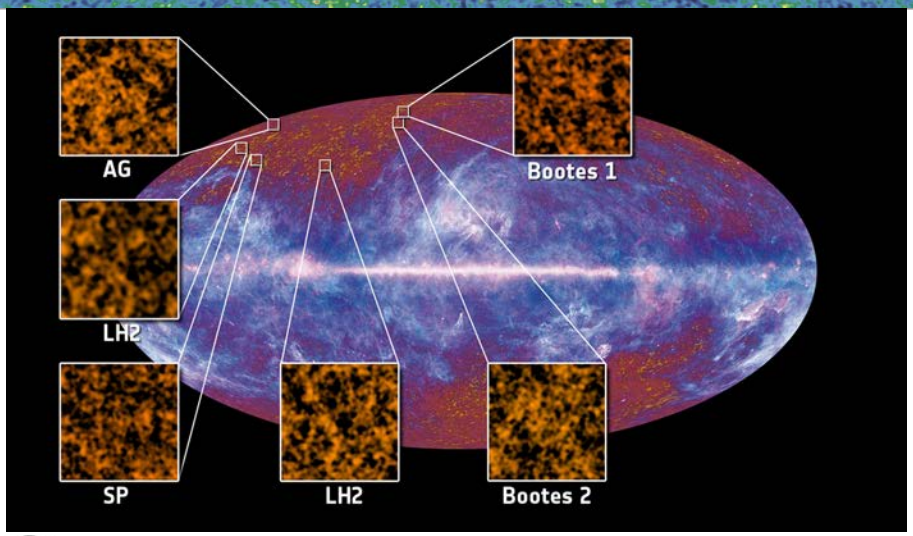
1. The Cosmic Infrared Background is the integrated light from unresolved distant galaxies
2. It traces large scale structure to high redshift
3. It is "contaminated" by the Cosmic Microwave Background and Galactic dust





PlanckColl 18

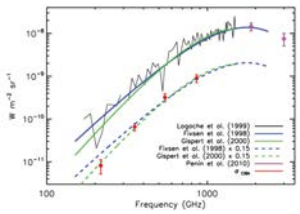
Planck CIB fields



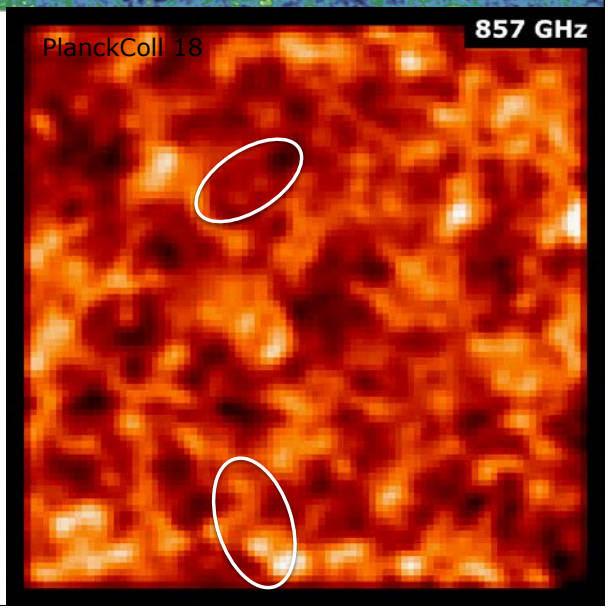
PlanckColl 18

Planck images the earliest structures

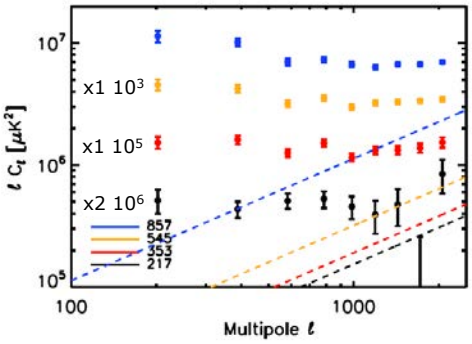
- the growth of structure is visible at different frequencies (2/3 power from z>3.5 at 217 GHz)
- These ultraluminous structures are forming stars at very high rates
- the CIB intensity is only about 1% of the CMB at the lowest frequencies
- The spectrum of the mean has the same shape as the anisotropies

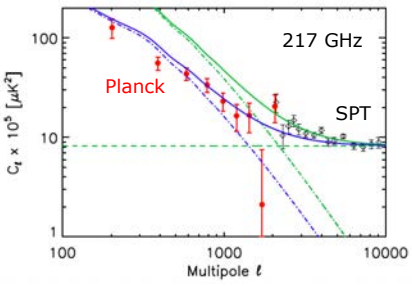


2012



CIB angular power spectrum

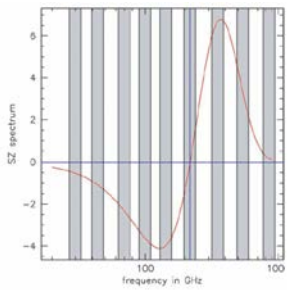




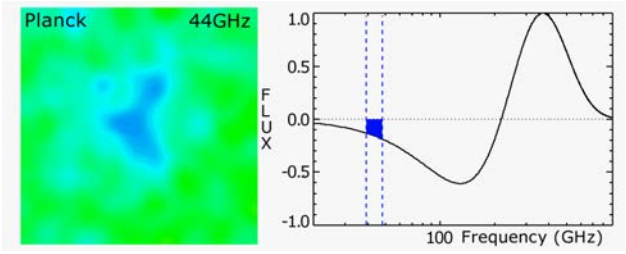
PlanckColl 18

- The anisotropies of the CIB are clearly detected over a large range of angles (10′ to 2 degrees) at 4 frequencies
- The sensitivity is enough to constrain structure formation model parameters

Clusters – Sunyaev-Zeldovich



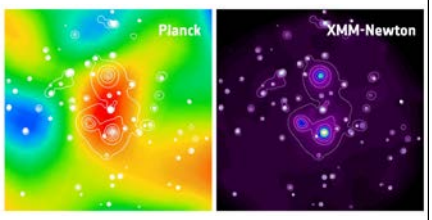
Abell2319



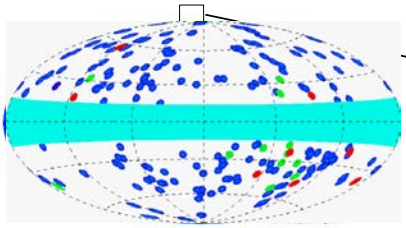
- Unique capability of detecting the *rarest and most massive* clusters

→ **To trace largest structure, to reveal the cosmic seeds, to probe cosmological models**

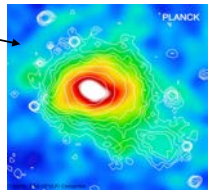
PlanckColl 9



Clusters – the ESZ

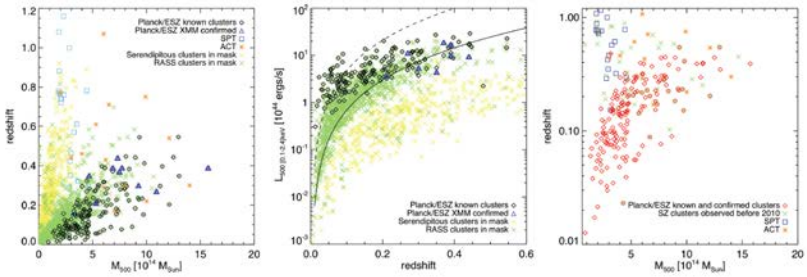


➢ **Coma cluster seen by Planck**



The ESZ clusters tend to be the most massive and X-ray luminous

> The 189 Planck/ESZ clusters distributed over the whole sky

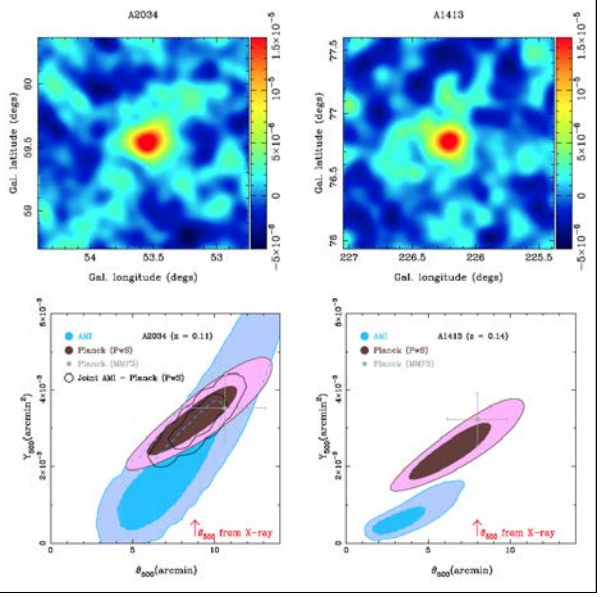


Flux-size degeneracy

Low-resolution experiments such as Planck suffer from Flux-size degeneracy.

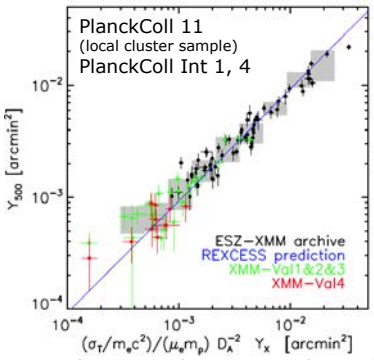
High- and low-resolution imaging can be combined to obtain a more complete picture of total SZ flux and source size

Planck Coll Int 2

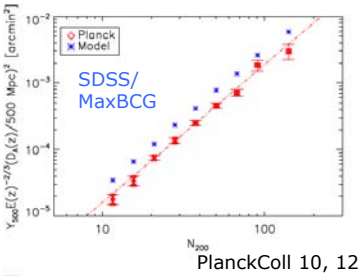


Clusters - physics

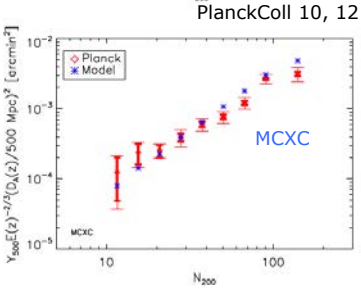
$SZ \sim n_e T$; $X_{ray} \sim n_e^2 T^{1/2}$



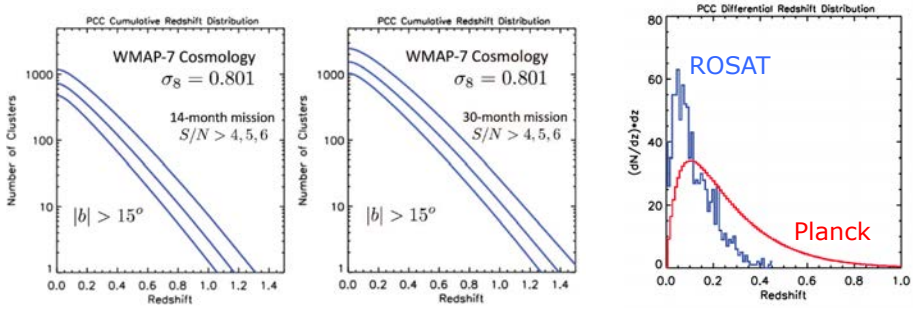
- Good agreement between SZ and X-ray derived quantities
  - Validation of cluster detection via XMM
- SZ signal detected down to very-low-mass systems



PlanckColl 10, 12



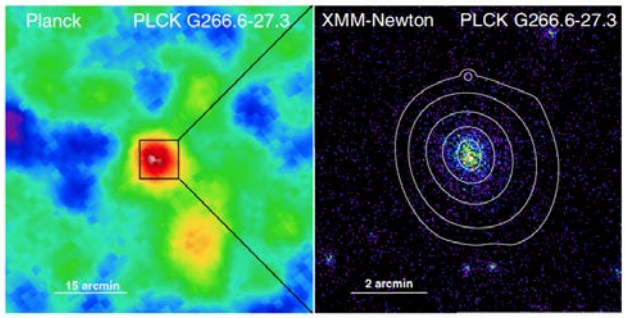
Clusters - future

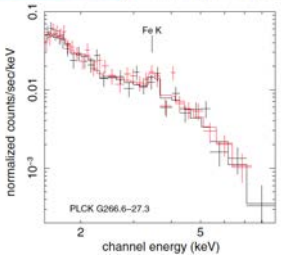


A deeper Planck SZ catalogue will be published in Jan 2013

A high-redshift cluster detected by Planck

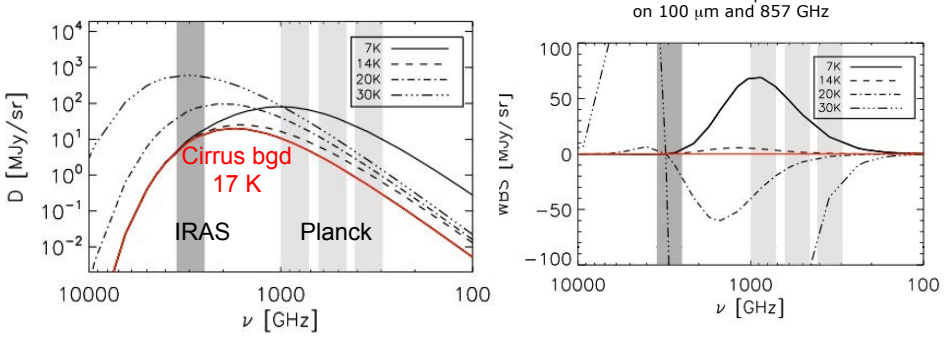
PLCK G266.6-27.3 is the first blindly discovered Planck cluster of galaxies at z~1





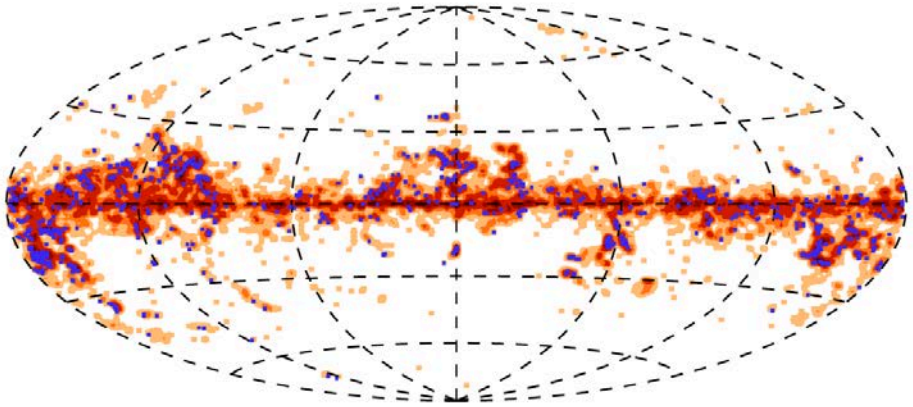
PlanckColl 26

Measuring dust temperature



- The combination of IRAS and Planck allows to measure accurately the temperature of the coldest dust (if we know the dust physical properties)

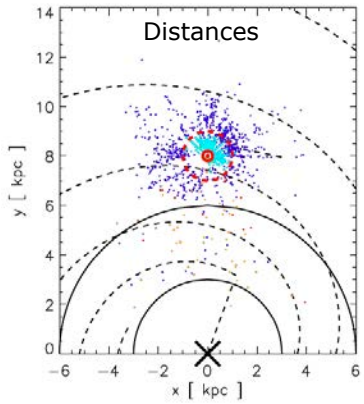
Cold Clumps in the ERCSC

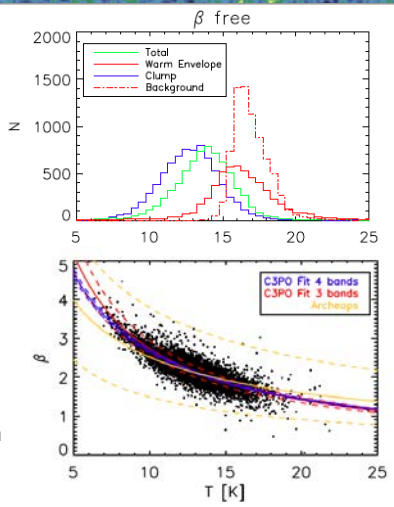


All-sky map of the number of C3PO objects per square degree
(10783)

■ ECC Selection
(915)

Cold clump properties

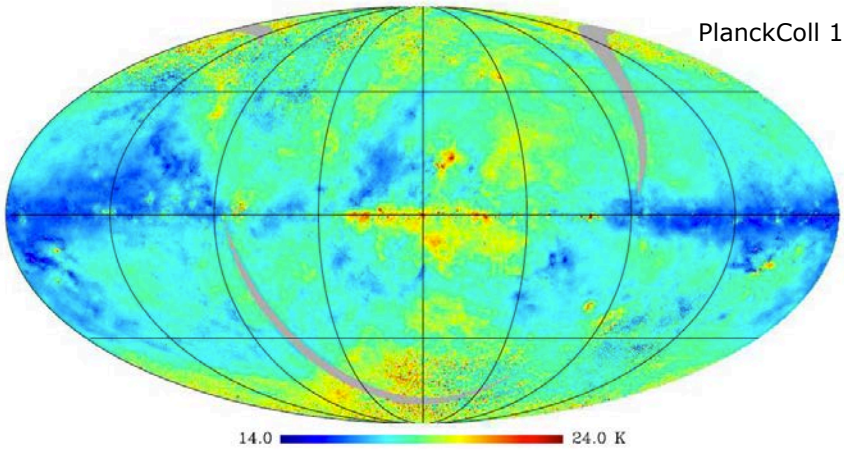




- Distances can be obtained from extinction or association
- Many of the clumps approach the lower temperature limits for the ISM !

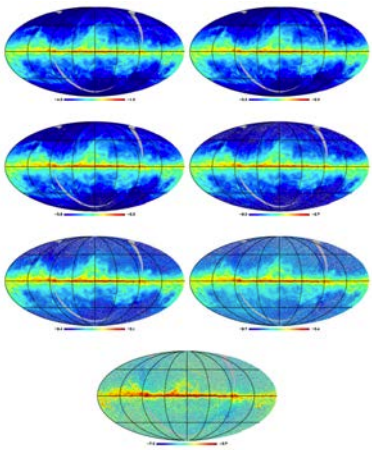
The temperature of dust

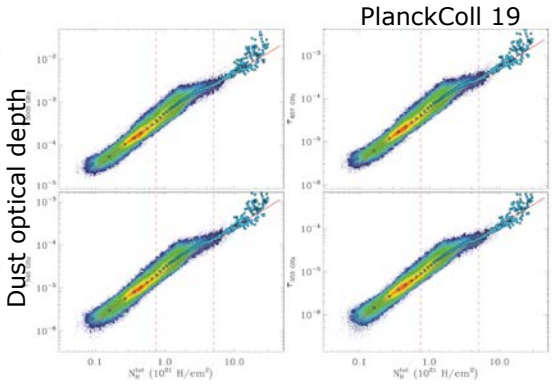
PlanckColl 19



- As expected, there is a temperature gradient in the galactic plane

Dust optical depth

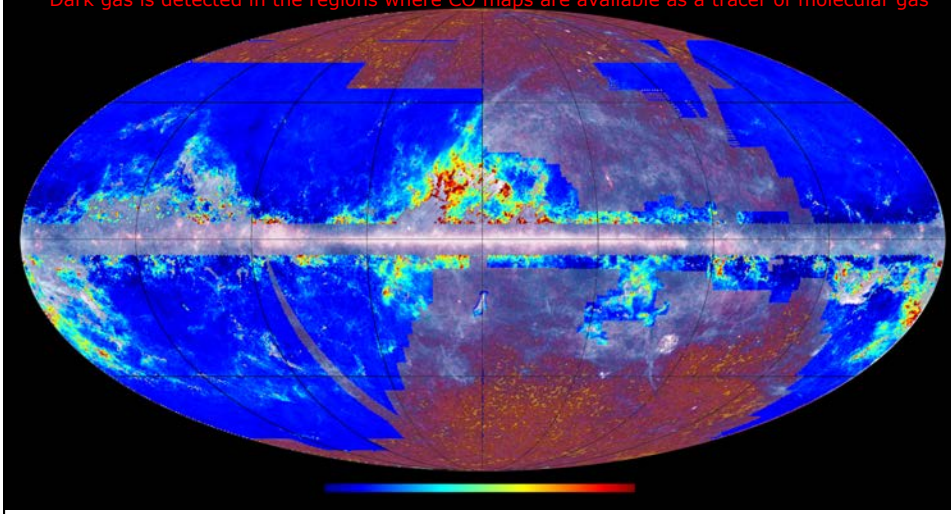




Correlation of dust optical depth to the total gas column density (HI+H2) shows the presence of a molecular gas component which does not contain CO: "dark gas"

Dark gas

Dark gas is detected in the regions where CO maps are available as a tracer of molecular gas

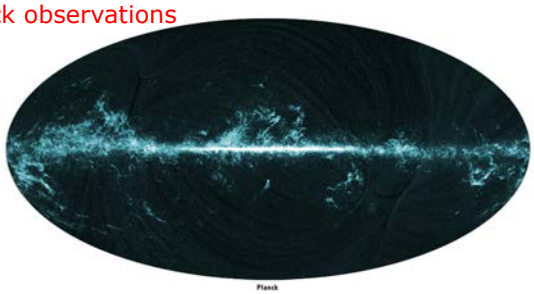


Planck maps molecular emission lines !

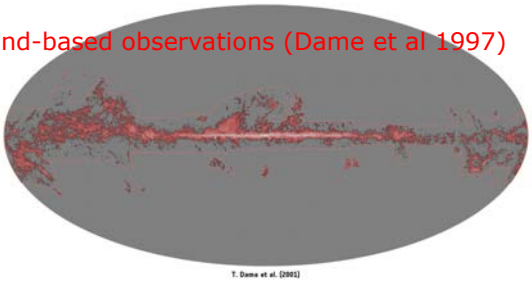
planck

- CO emission dominates the total galactic flux in some of Planck's bands
- Maps can be derived of some strong lines over the whole sky

Planck observations



Ground-based observations (Dame et al 1997)



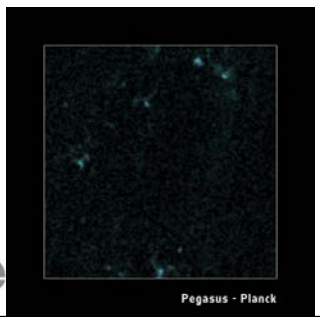
esa

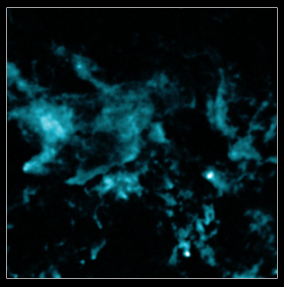
J. Tauber: ISAPP, July 2012

Planck-measured CO

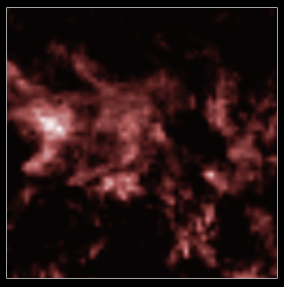
Detailed comparison of small regions reveals no specific bias

Planck's all-sky maps reveal faint CO in unexplored regions



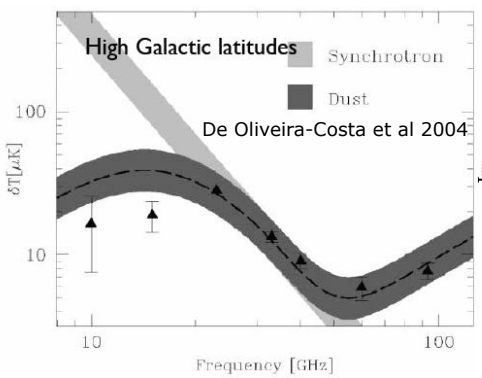


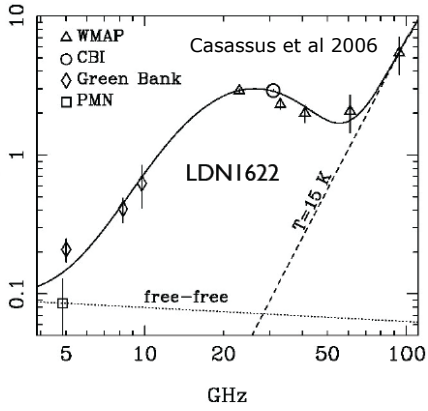
Cepheus - Planck



Cepheus - T. Dame et al. (2001)

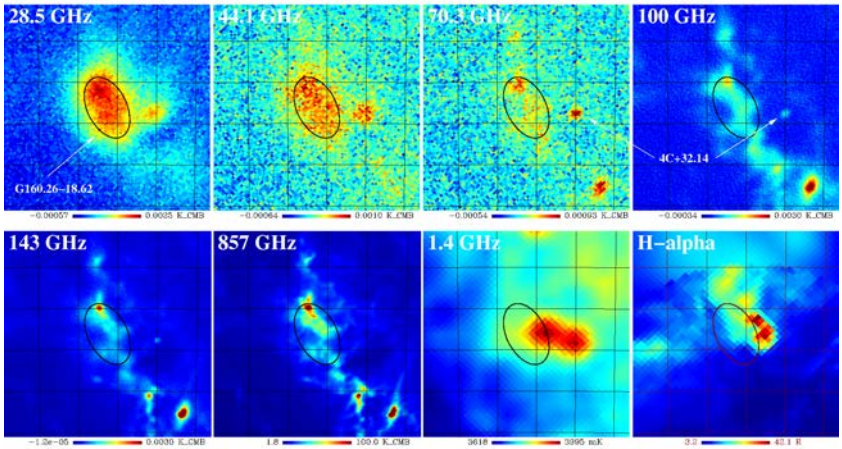
Anomalous emission





- Anomalous emission has been observed for about a decade
- The favoured explanation is emission due to small rapidly spinning dust grains

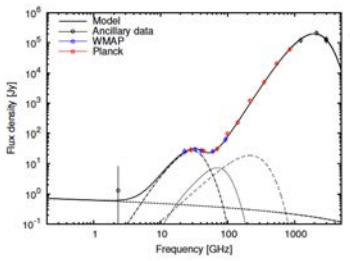
AME in Perseus

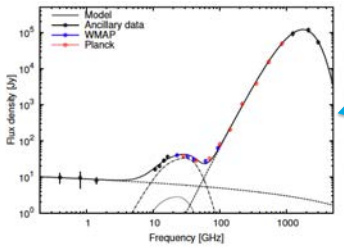


PlanckColl 20

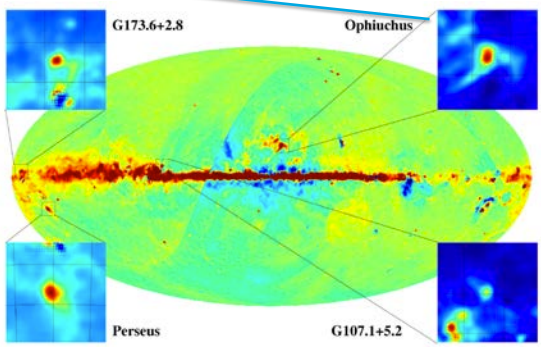
- Planck detections are very robust: in some regions, the AME can be isolated by eye !

Anomalous emission seen by Planck





PlanckColl 20

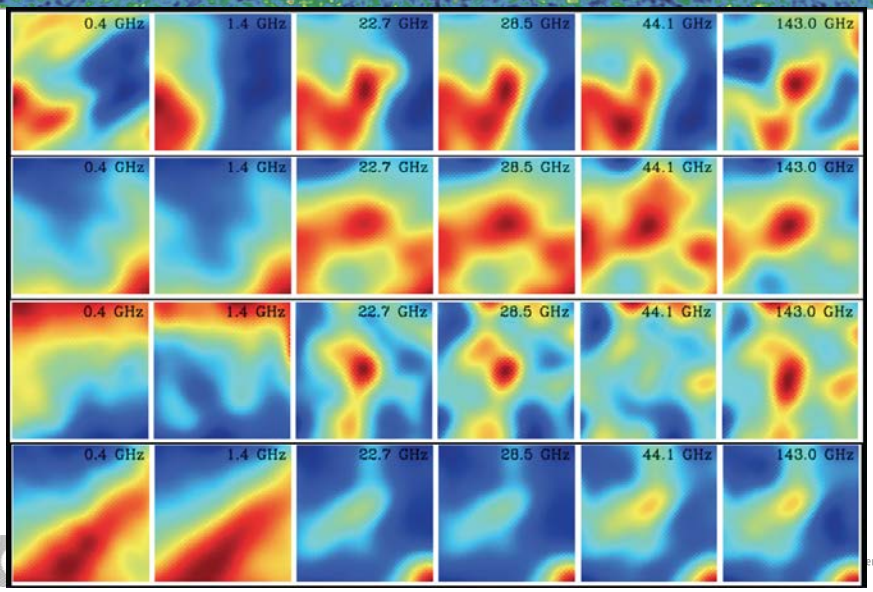


- Simple removal of synchrotron, free-free, and dust emission reveal anomalous mission permeating the galactic plane

J. Tauber: ISAPP, July 2012

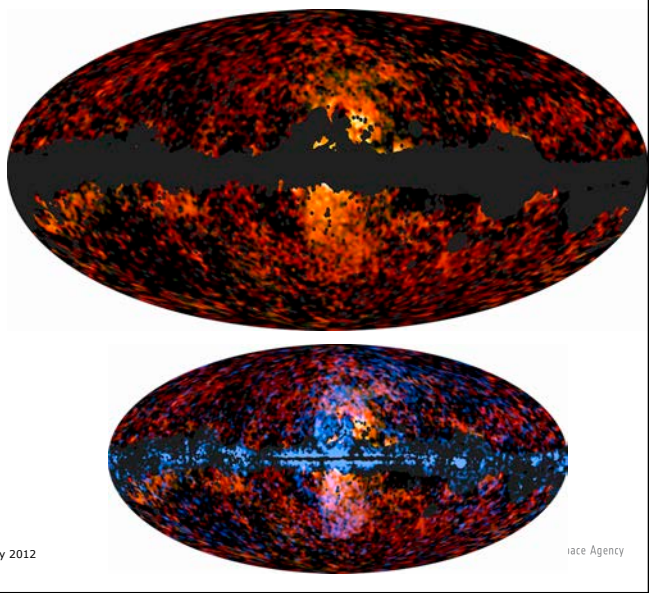
European Space Agency

Many new AME regions are being identified



The Galactic Haze

- component separation reveals the presence of residuals which correspond to "non-standard" foregrounds.
- One of these is the "Galactic Haze", an emission concentrated near the GC, with a hard-synchrotron-like spectrum, whose origin is poorly understood

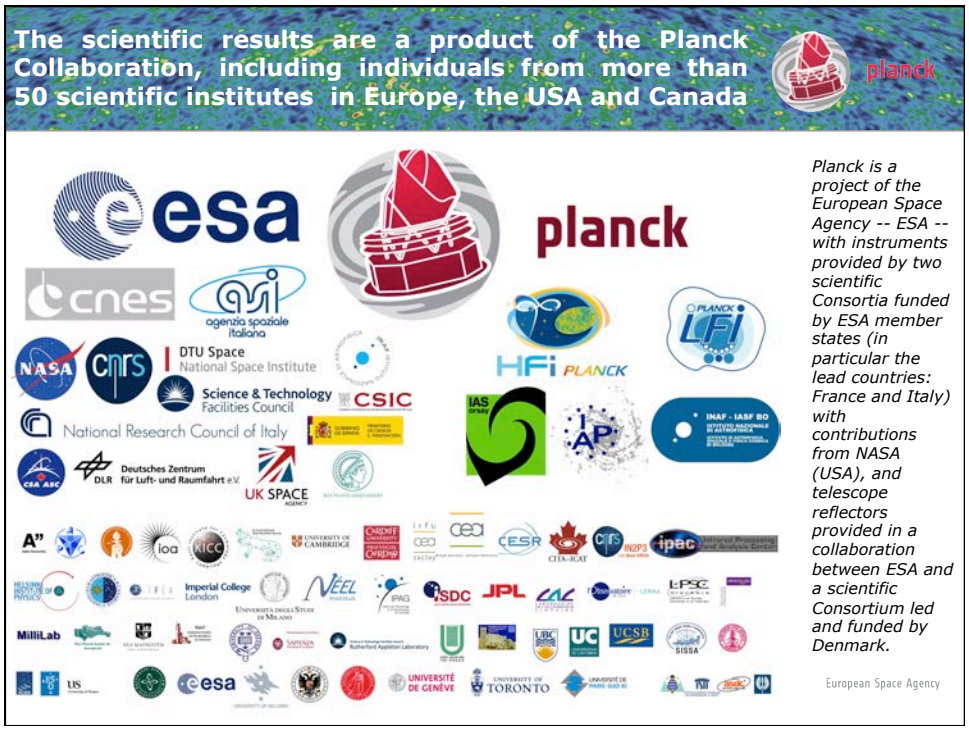


Summary & outlook

1. Planck has been working flawlessly and without interruption since it started surveying the sky in mid-August 2009
2. It has completed its cryogenic mission (5 surveys), and continues to acquire data with one instrument
3. It will continue to operate until at least the end of this year, and probably longer
4. Although designed for cosmology, Planck also provides a wide range of astrophysics
5. The data and early scientific results already released emphasize the high quality of the data that is being produced, and provide a foretaste of the far better results which are yet to come
6. In early 2013, Planck will release its first map data and the first cosmological results

WATCH THIS SPACE !

The scientific results are a product of the Planck Collaboration, including individuals from more than 50 scientific institutes in Europe, the USA and Canada



Planck is a project of the European Space Agency -- ESA -- with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.

European Space Agency