

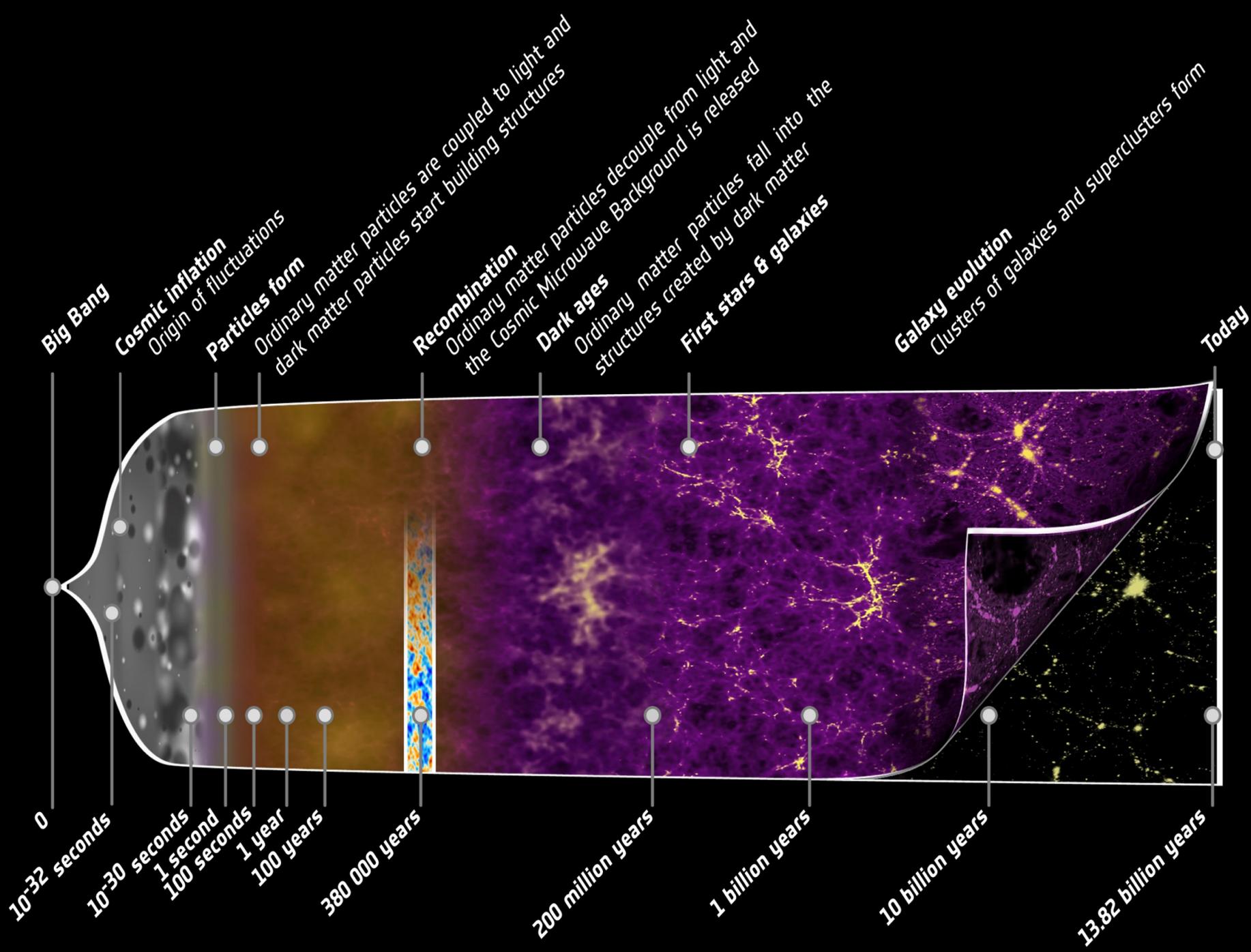


planck



Cosmology with Planck
Nazzeno Mandolesi
ASI, INAF, Università di Ferrara
Santander, 24 June 2013

Planck unveils the Cosmic Microwave Background



Planck History in Brief

- **First conceived in 1992, proposed to ESA in 1993**
- **Payload approved in 1996**
- **Launched in May 2009, started to survey the sky in August of the same year**
- **Nominal mission completed at the end of 2010**
 - **but continued to gather data with the full payload until January 2012**
 - **... and it continues to gather data with LFI only until the fall (August end of 8 full sky survey)**
- **Planck is an ESA mission: ESA, European industries, and the international technological and scientific community have contributed to its realisation and success**
- **The Planck payload has been founded by the European members state Space Agencies and by NASA: ASI and CNES are the leading Agencies.**
 - **Thousands of engineers and scientists were involved from ~100 scientific institutes in Europe, the USA, and Canada**
 - **Two scientific Consorzia (LFI led by N. Mandolesi and HFI by Jean Loup Puget) were responsible for the delivery of the Instruments to ESA, the mission data analysis and the delivery of the data and results to the open scientific community**

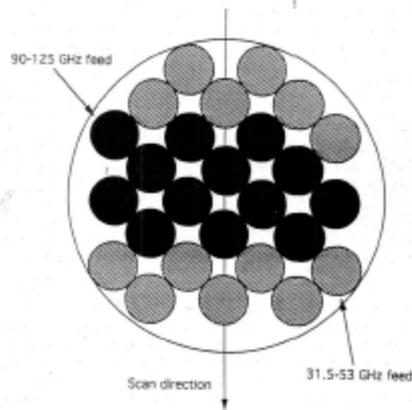
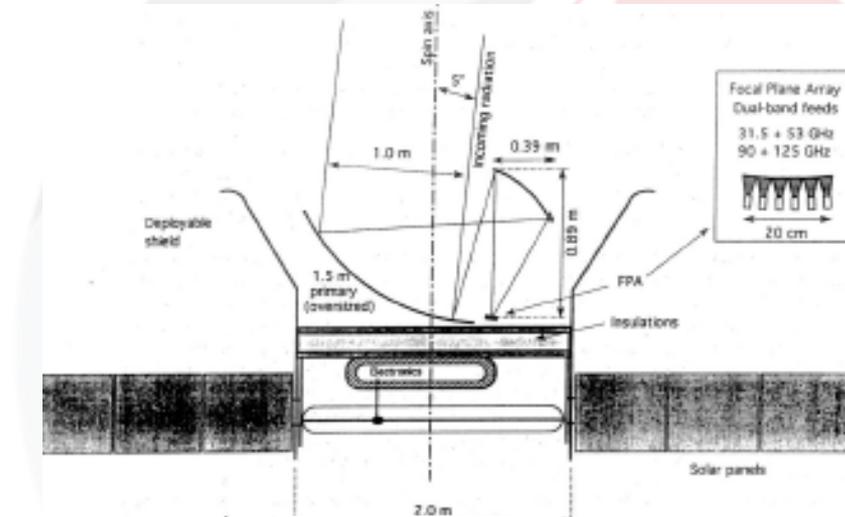
1993

COBRAS

COsmic Background Radiation Anisotropy Satellite

SAMBA

Satellite for Measurements of Background Anisotropies



ian optical system assumed in our let from the spin axis (here assumed the details of the scan strategy. The lobe pickup and cooling efficiency. feeds. Placing their apertures on a

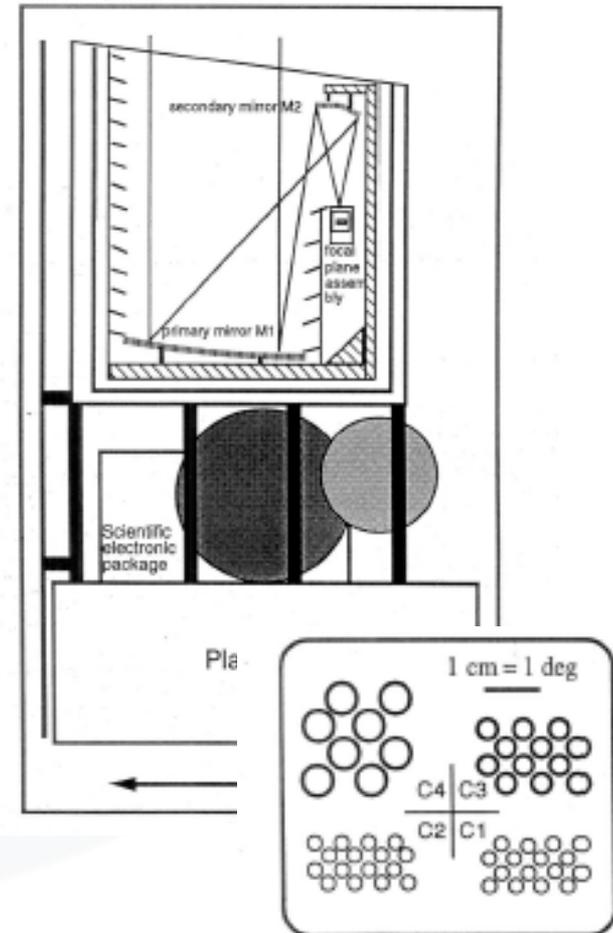
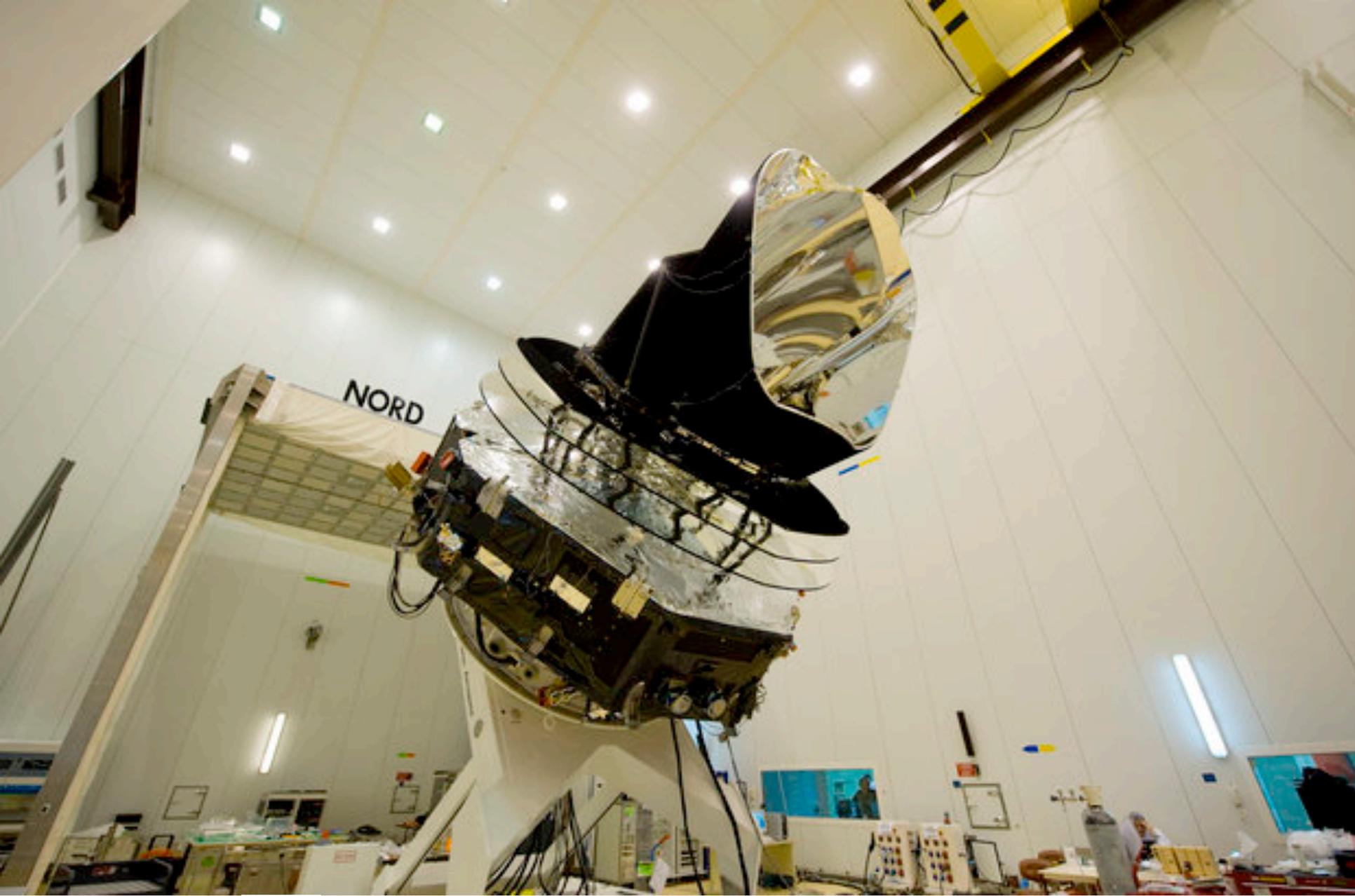
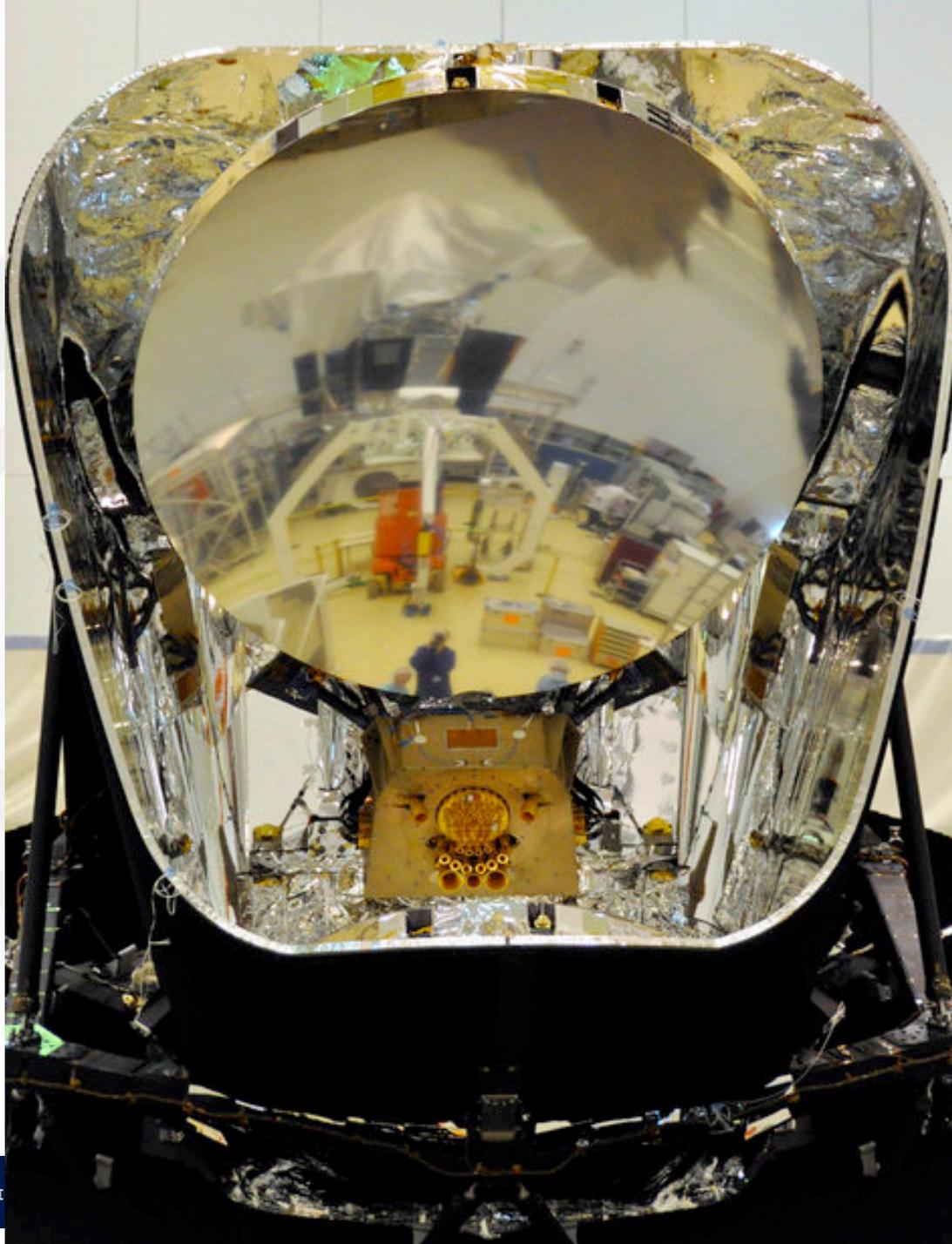
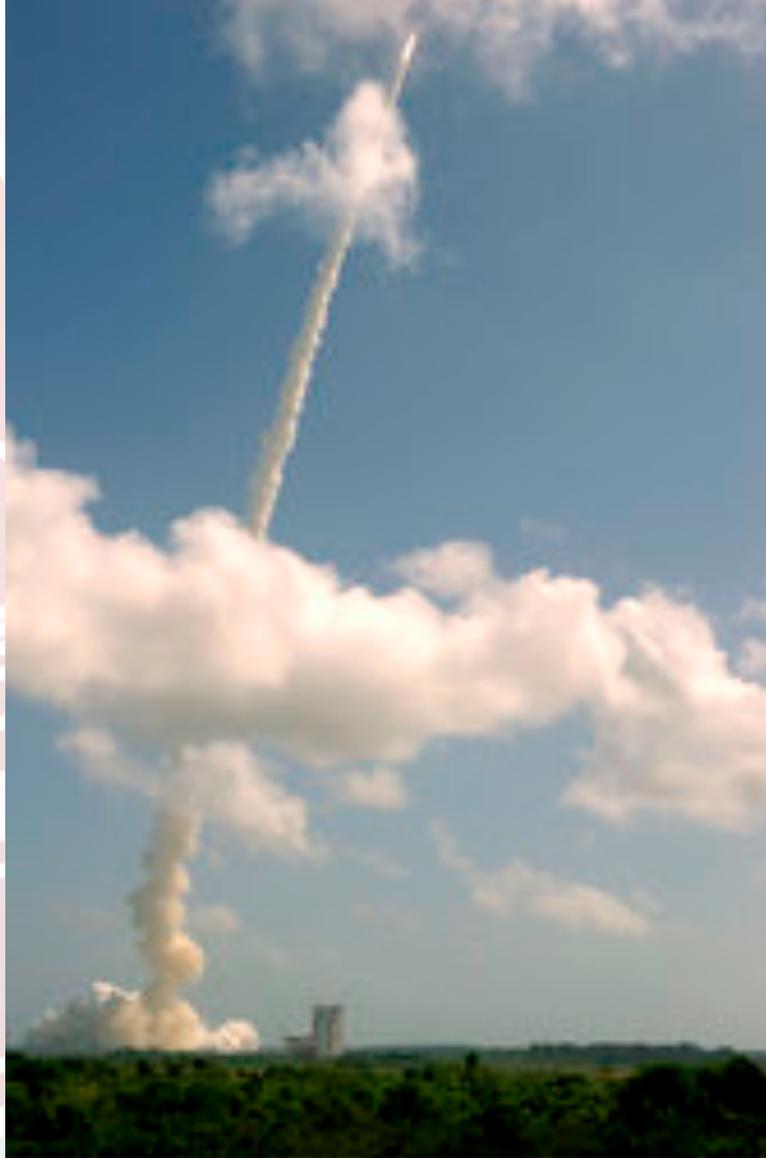


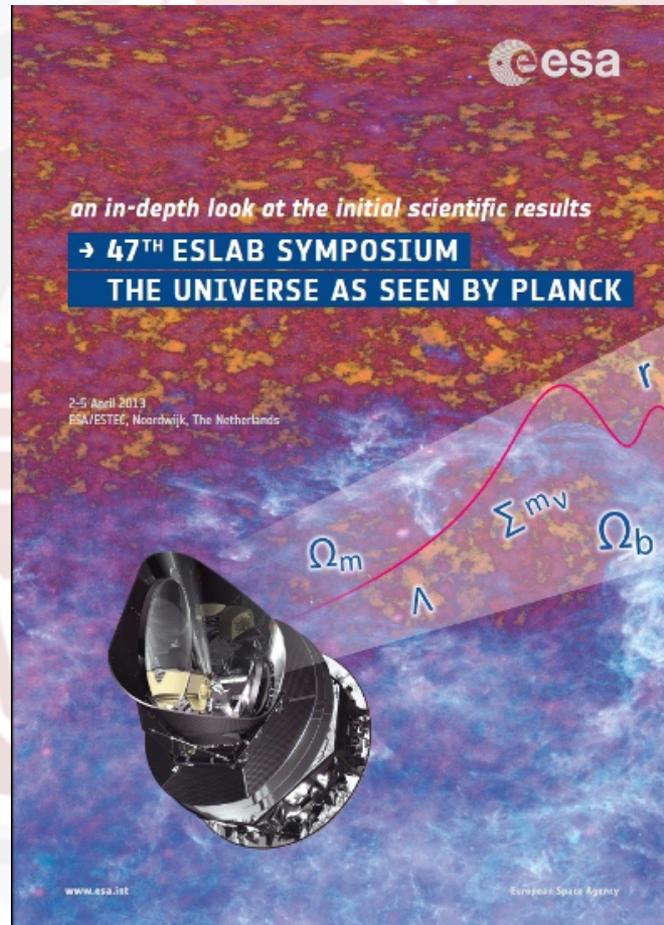
Figure 7 - The proposed geometrical disposition of the feed elements in the focal plane array is shown. The higher frequency elements (90-125 GHz) are more sensitive to beam distortion effects and have been clustered near the center of the array. Our preliminary study shows that coma lobes of the most decentered elements are expected to be below -40 dB (10^{-4}) at 125 GHz and below -55 dB (10^{-5}) at 30 GHz.





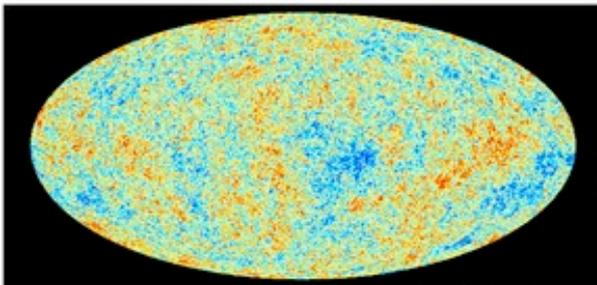


21 March 2013: 29 papers delivered About 1000 pages all together





Late Edition
Buyer's Guide and other special
highlights. Sample, partly cloudy,
mostly clear, low 50. Tomorrow, sun-
ny to partly cloudy, a chilly wind,
high 60. Weather map, Page A2.



The Cosmos, Back in the Day
An image from NASA is called by a European Space Agency satellite shows a heat map of the universe as it appeared 370,000 years after the Big Bang. Page A10.

Bronx Inspector, Secretly Taped, Suggests Race Is a Factor in Stops

By ROBERT D'AVINO
For years, the debate over the stops practiced in the South Bronx, a violent neighborhood that records the highest number of police stops in the Bronx in 2010, has centered on whether officers are guilty of racial profiling. Now a recording suggests that, at least on some occasions, a person's skin color can be a deciding factor in who is stopped.
The recording, placed on Thursday in Federal District Court in Manhattan, was a conversation between a pair of officers and his commanding officer in the Bronx.
The stop, practiced in the South Bronx, a violent neighborhood that records the highest number of police stops in the Bronx in 2010, has centered on whether officers are guilty of racial profiling. Now a recording suggests that, at least on some occasions, a person's skin color can be a deciding factor in who is stopped.
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Officer Pedro Rivera.

Fast-Growing Brokerage Firm Often Tangles With Regulators

By NATHANIEL POPPER
The first month after an upset March 15 election, the investment house that brought Wall Street to Main Street.
The company, L.P. Financial, has 12,000 brokers, 1,000 offices, 1.5 million customers, and a growing list of problems with regulators.
At a time when many big brokerage firms are being bought or sold, L.P. Financial is a company that has been a particular target of regulators. Federal and state regulators have been critical of the company's practices, and the firm has been fined several times for selling complex investments to unsophisticated investors. For regulatory trouble in particular.
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Once Few, Women Hold More Power in Senate

By HENNER STEINBERGER
Ms. America's reduction that Democrats did in 2010 into the most powerful body of the nation's political system — female senators — has begun.
"The thing that I think you should think about," Ms. America said, "there will just aren't that many of us."
In the 80 years since Barbara Fister at Chicago, Seattle the first woman in the United States Senate — voters in a state in 1911 — women senators are gradually in the upper chamber, but with 18 female senators now in office, an all-time high, women have reached from the country they were for much of the 20th century into an important new force on key committees and legislation.
A record nine women now lead committees, including some of the most powerful ones. For the first time there is a woman — Senator Barbara A. Mikulski, a Maryland Democrat — in charge of the Senate Appropriations Committee, which determines where the government and has long been particularly dominated by men. Senator Patty Murray, a Washington Democrat, is the first woman to be in charge of the Senate's strategy in the Senate.
The Senate's strategy in the Senate.



Mood Darkens in Cyprus Ahead of Bailout Deadline
As protests grew in Cyprus, the nation's Parliament put off a vote on a bailout plan. Page B1.

O Revelations! Letters, Once Banned, Flesh Out Wilka Cather

By HENNER STEINBERGER
The first time she was a woman writer often seen as a model for the 1920s and 1930s. Her letters, once banned, now flesh out her story.
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INTERNATIONAL
Struggle Over Drone Program
The Obama administration is struggling to keep promises to bring more transparency and accountability to the drone program and its controversial — program of using these strikes for targeted killings. PAGE 10

Kards Soak Truce With Turkey
In part of a new bid to end a three-decade-old conflict with Turkey, the latest Turkish ruler leader Abdullah Gul ordered all his fighters off Turkish soil. PAGE 10

NO PROGRESS ON BORDER DATA
The years after selling Congress they would produce border statistics to officials across the board they had not completed the new measures. PAGE 17

54 Chicago Schools Closing
Chicago officials in private schools, about 1 percent of the district. The city said that the closures would save \$200 million over 10 years. PAGE 18

WITNESS BUT HELP
Phoner Inquiry in Europe
Regulators are examining the contracts Apple makes with telephone carriers that will be offered to possible wireless providers after several carriers said the deal had competition. PAGE 10

Computers at a New Level
Lawmakers in preparing for a real-world test of a computer based on quantum technology, using for much higher computing speeds. PAGE 10

SPKTOPFORDS
New Legal Tactics for Bonds
Major League Baseball plans to use several legal tactics to sue the National Football League, which is linked to pay bonuses and signing drugs. PAGE 10

HISTORICAL
Paul Krugman PAGE 10

PRESIDENT URGES ISRAELIS TO PUSH EFFORT FOR PEACE

APPEAL AIMED AT YOUNG
In Jerusalem, He Expects Stance on Settlements
Eli Bekeem Talks

By NARA LINDNER
JERUSALEM — President Obama, appearing to defy the odds, is appealing to young Israelis to push for peace.
Addressing an audience of more than 1,000, Mr. Obama offered a message, comparing Israel to the young people of the world. He said that the Israeli government's position on negotiating a peace treaty with the Palestinians, even as he personally expressed sympathy for the Palestinians, was not the best way to get ahead of their own leaders in the push for peace.
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Obama urged the Palestinians to return to the negotiating table even if Israel did not meet their conditions of having construction of Jewish settlements in Palestine suspended — a demand he has made at the start of his first term but which had only a temporary impact.
"It was a striking sign of big-stage negotiation and leadership," Obama said, praising the Palestinian president, Mahmoud Abbas, and Prime Minister Benjamin Netanyahu. Mr. Obama was also praising the Israeli government for its willingness to engage in dialogue with a younger generation of Israeli leaders who had been seen as more open to peace.
"It is also striking in the intangible nature of Middle East peacekeeping over the past decade. It is not surprising that Obama has not been able to get a more rapid pace of talks started. Mr. Obama was, in effect, reminding that years of careful study about how to manage the peace process forward had failed to produce tangible results.
"Speaking as a politician, I can promise you that political deals are not made unless the people do not demand that they do," Mr. Obama said, in his characteristic style of his own political style.

Outriggering Waitlines
President Obama captured the hearts of many Israelis this week, but a speech on Thursday that targeted them, too. PAGE 12

Outriggering Waitlines
President Obama captured the hearts of many Israelis this week, but a speech on Thursday that targeted them, too. PAGE 12

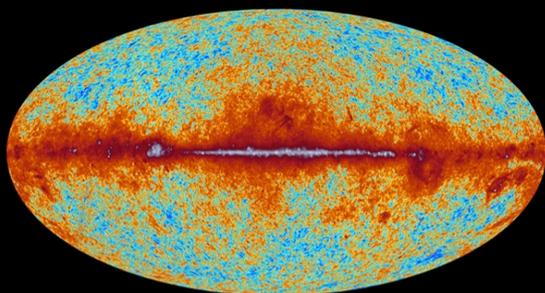
The visible night sky



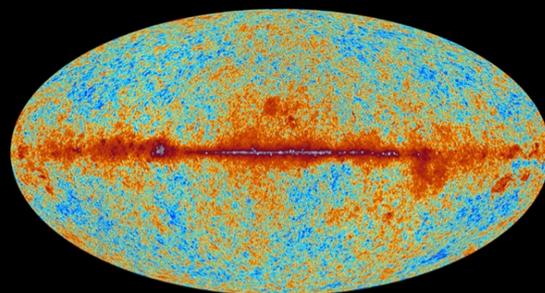


planck

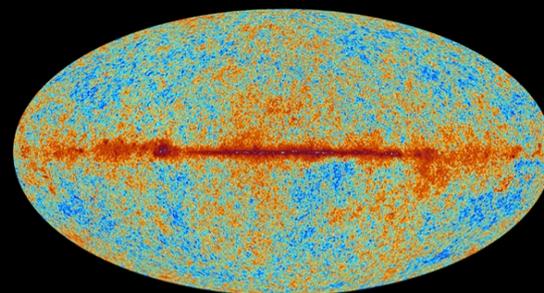
The sky as seen by Planck



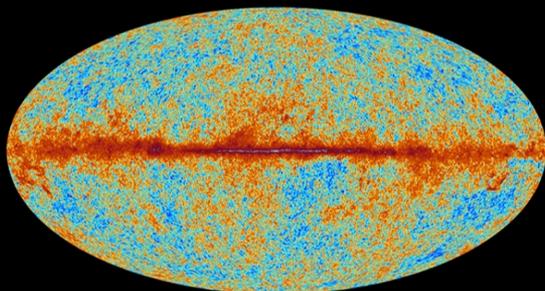
30 GHz



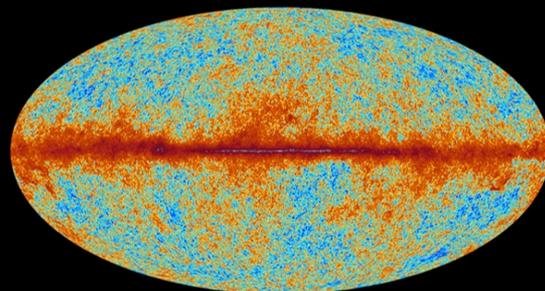
44 GHz



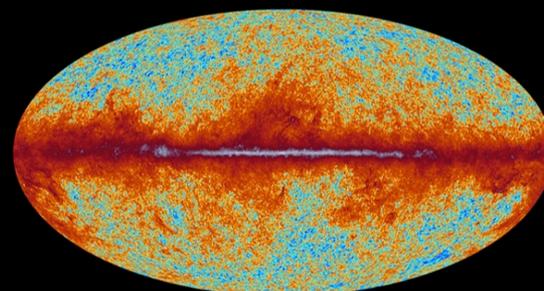
70 GHz



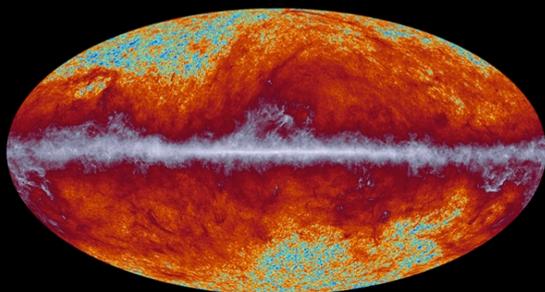
100 GHz



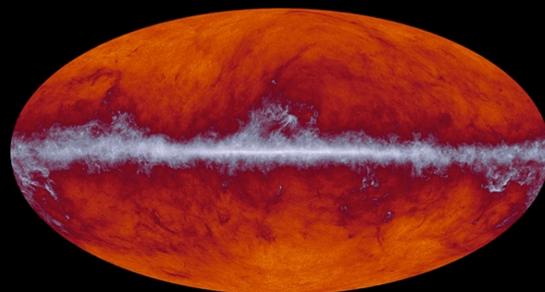
143 GHz



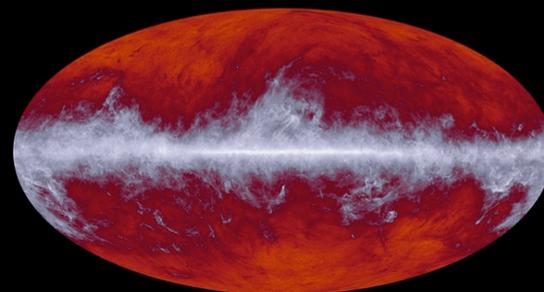
217 GHz



353 GHz



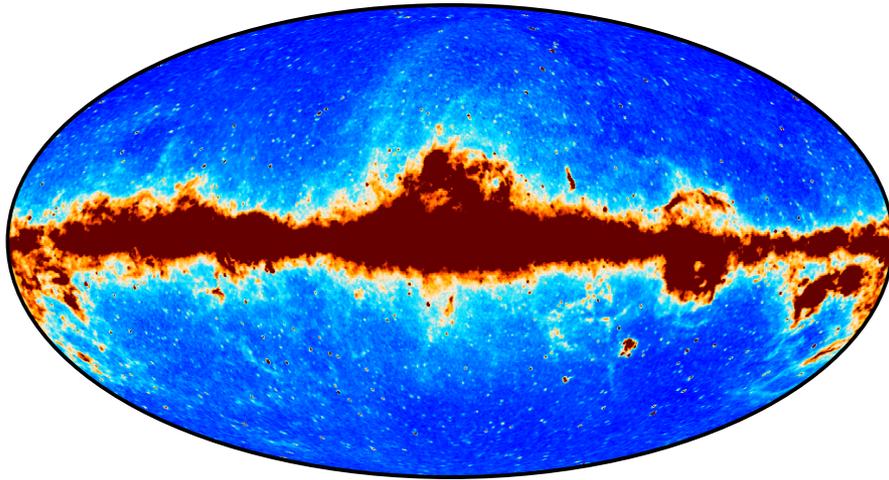
545 GHz



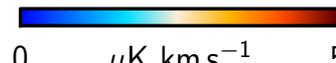
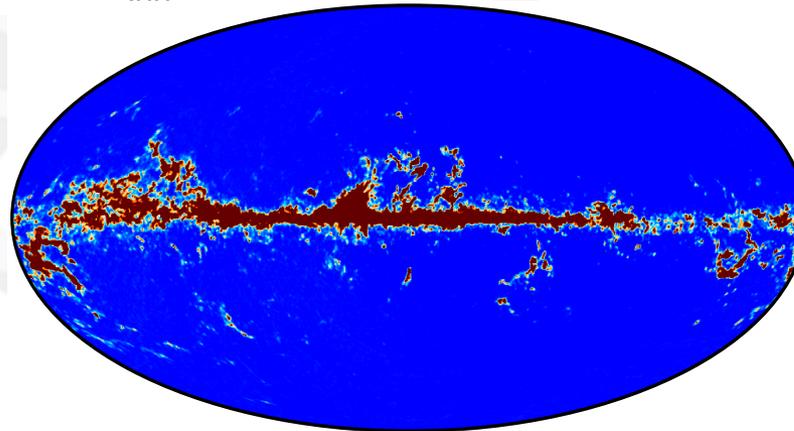
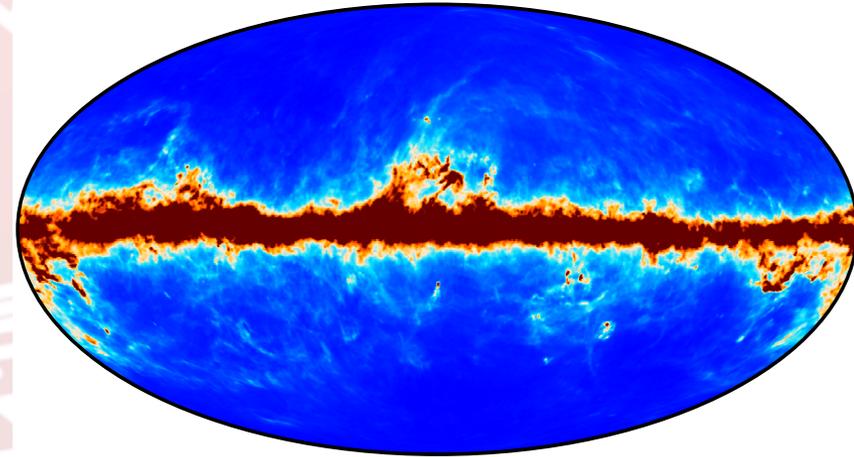
857 GHz

Emission from the Milky Way

Non-thermal radio emission

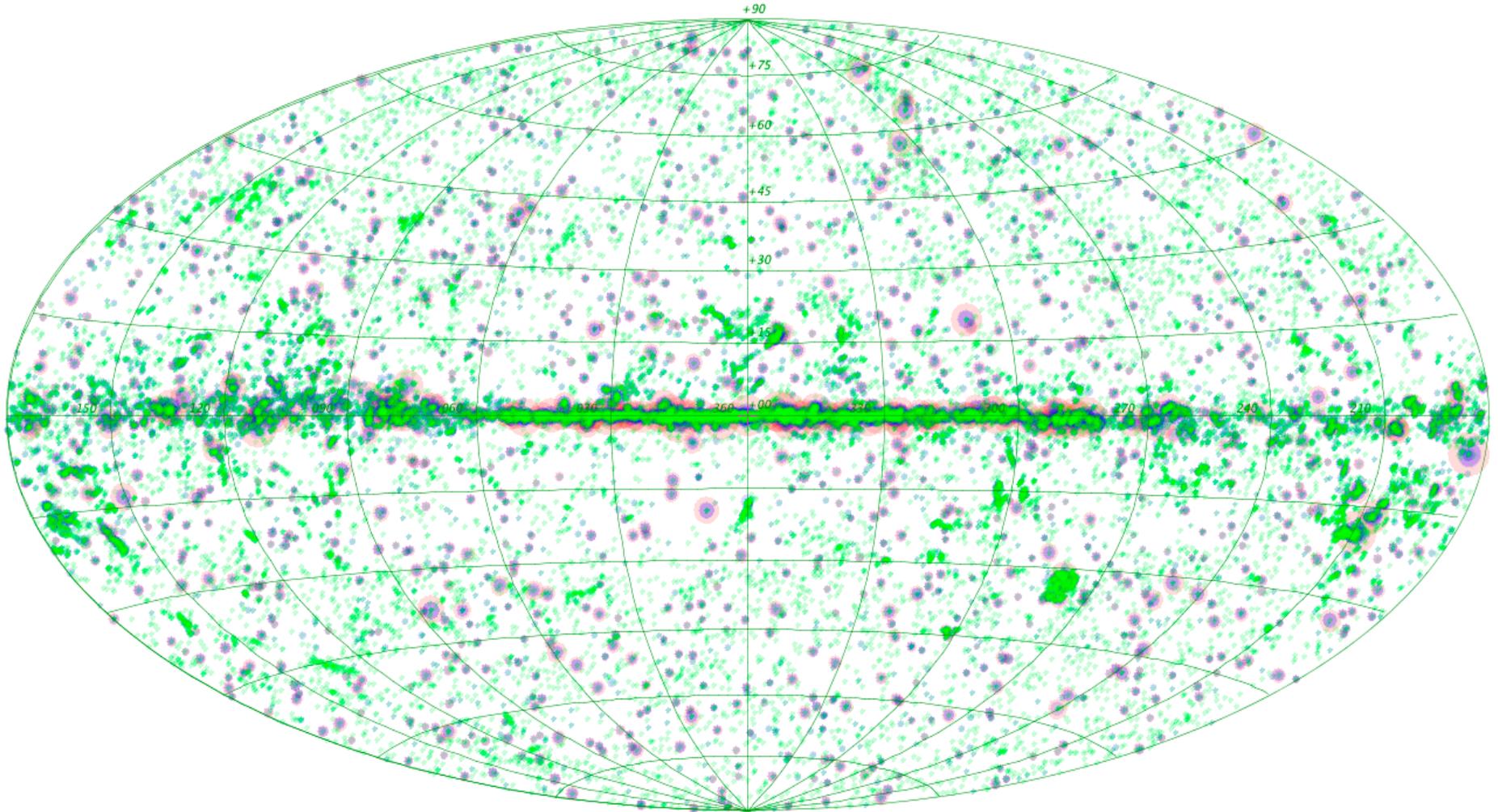


Thermal dust emission



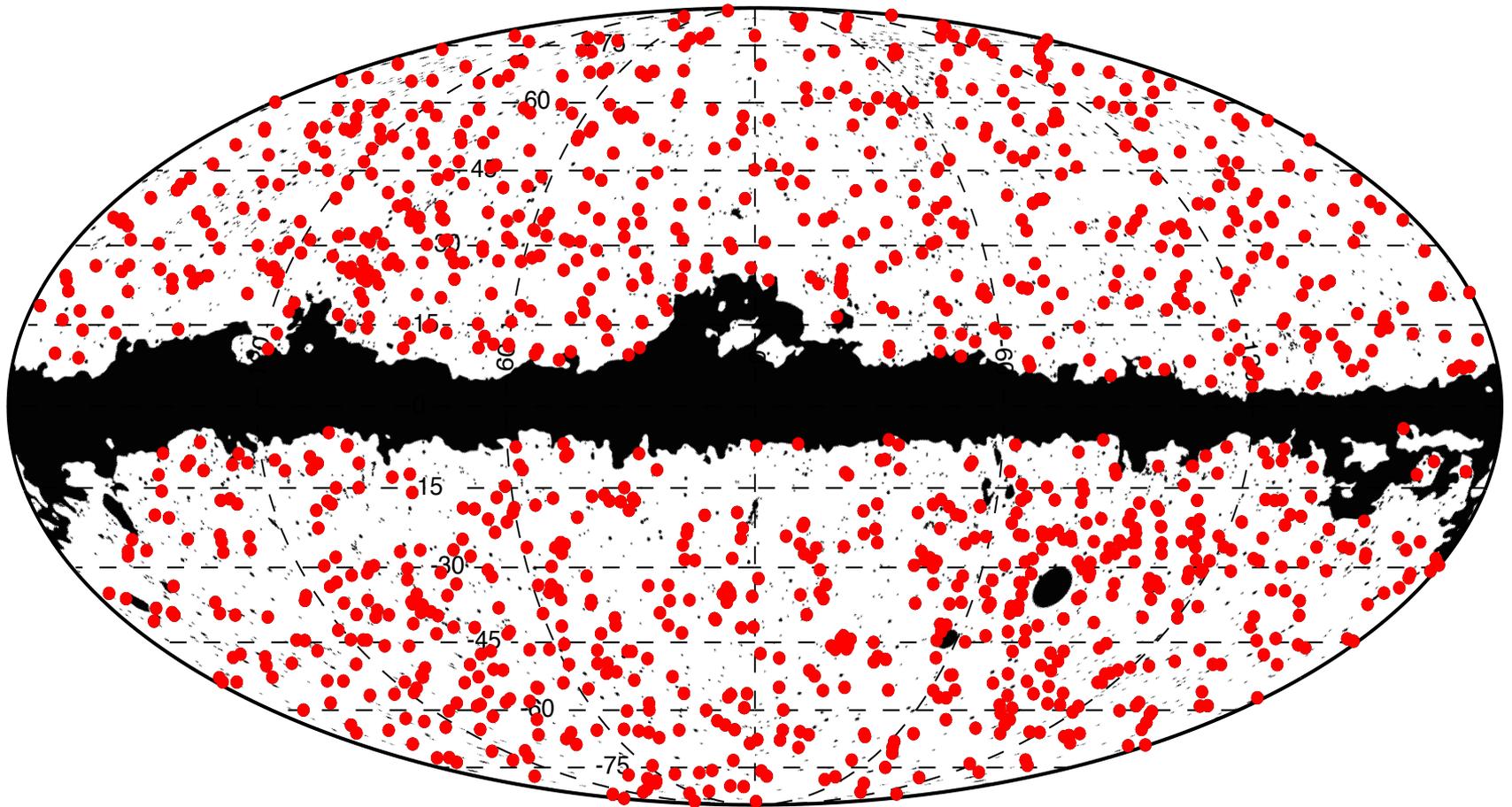
Carbon monoxide

Compact galactic and extragalactic sources

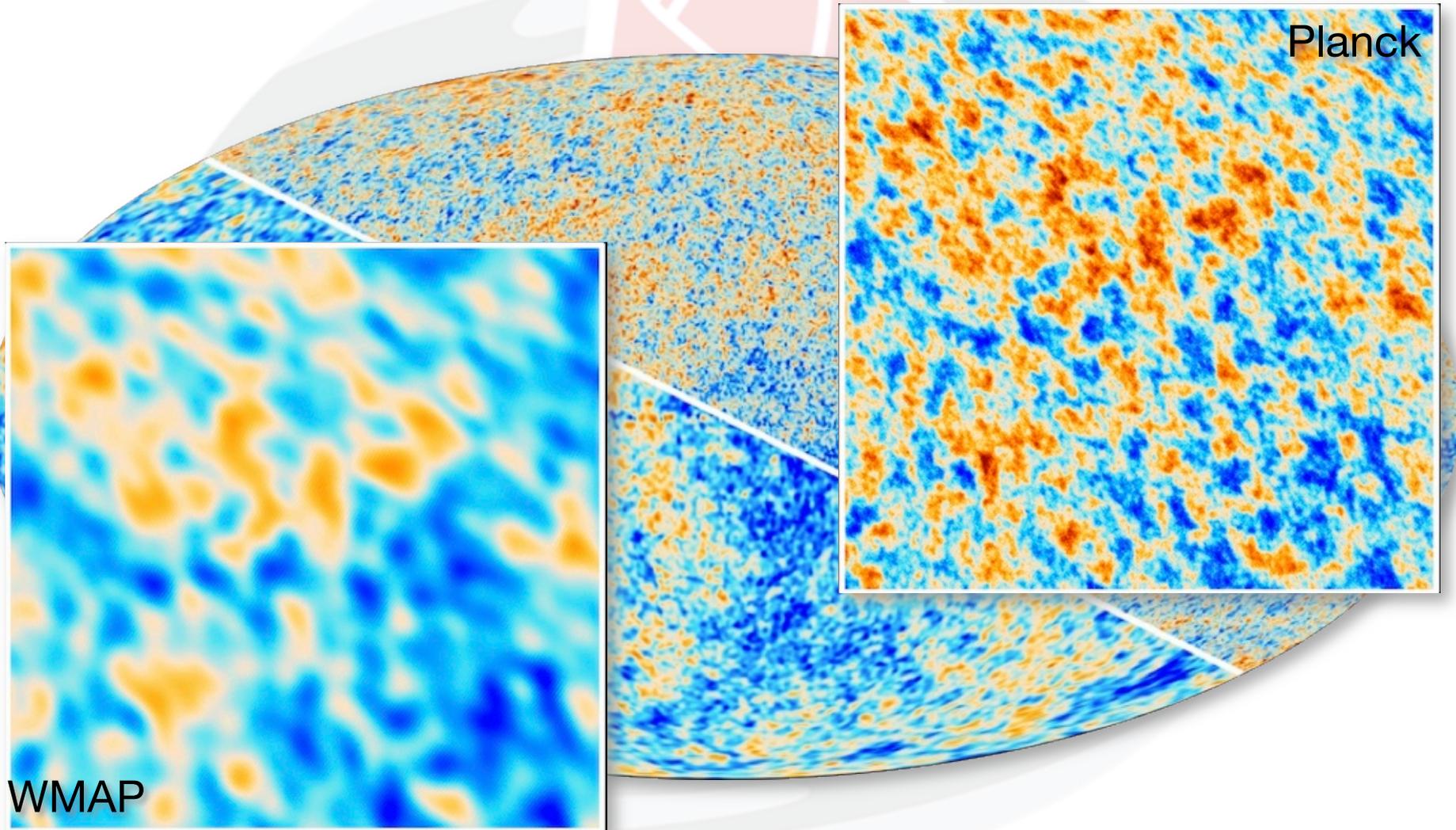


Clusters of galaxies

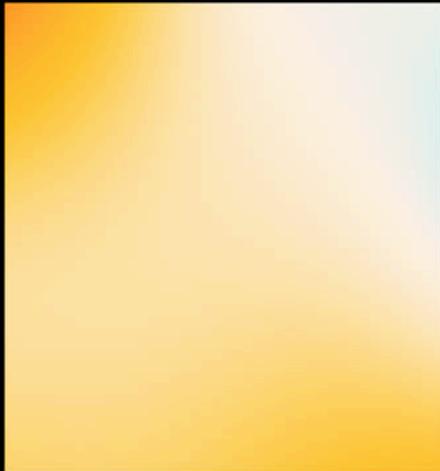
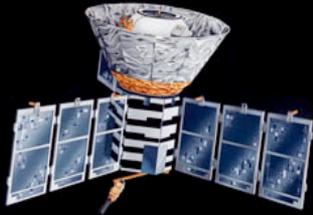
Planck SZ catalog



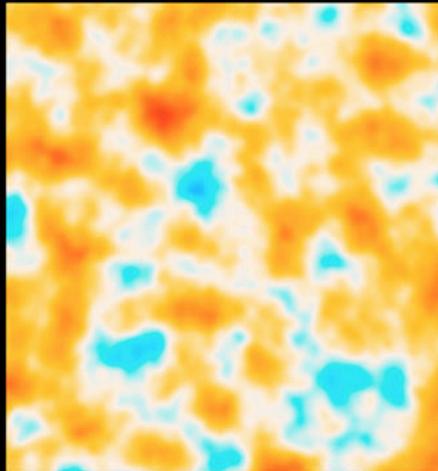
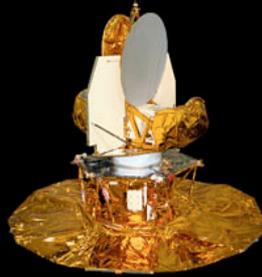
Planck versus WMAP



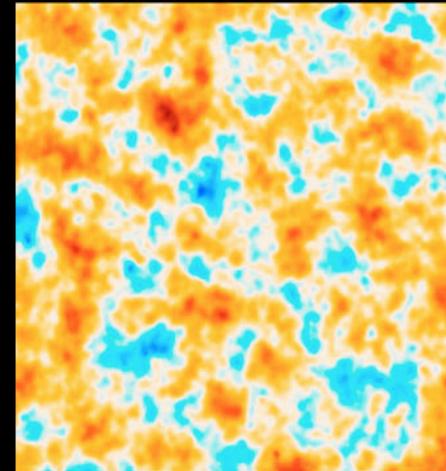
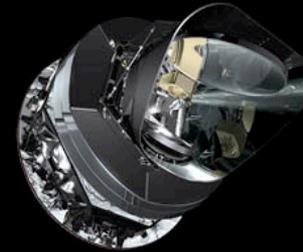
Comparison w/ forerunners



COBE

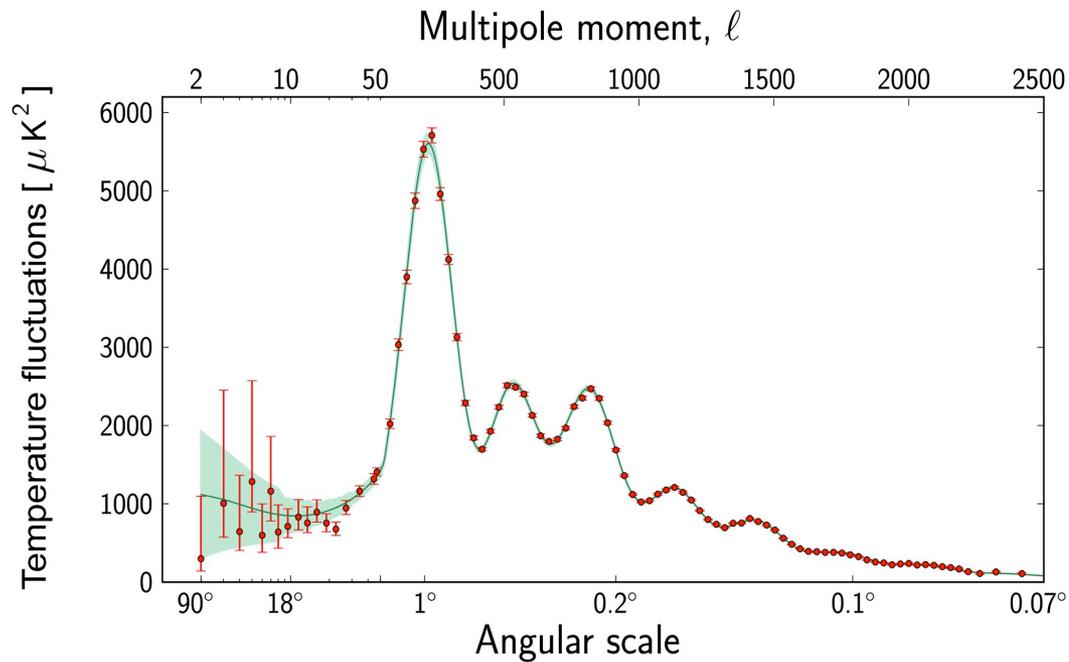


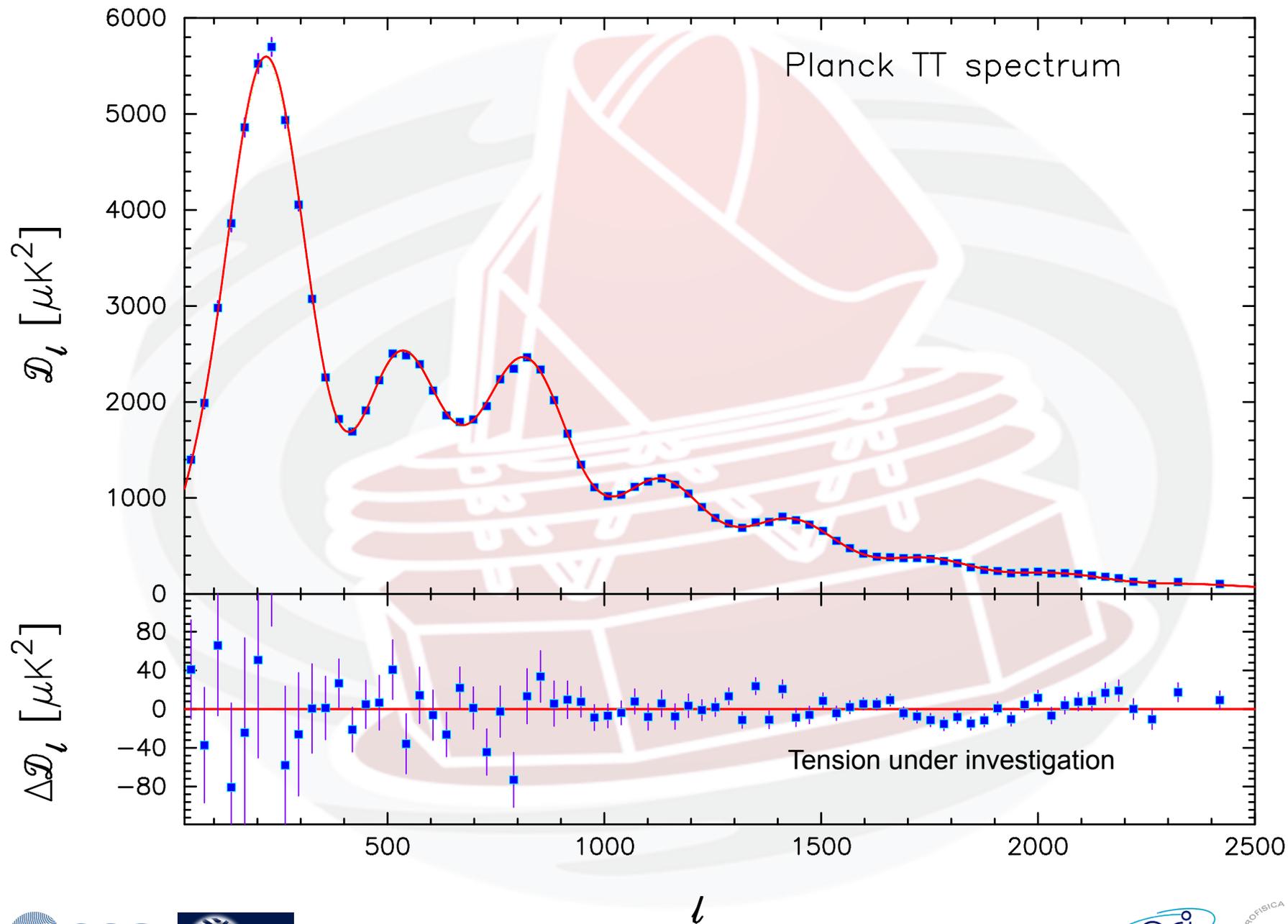
WMAP

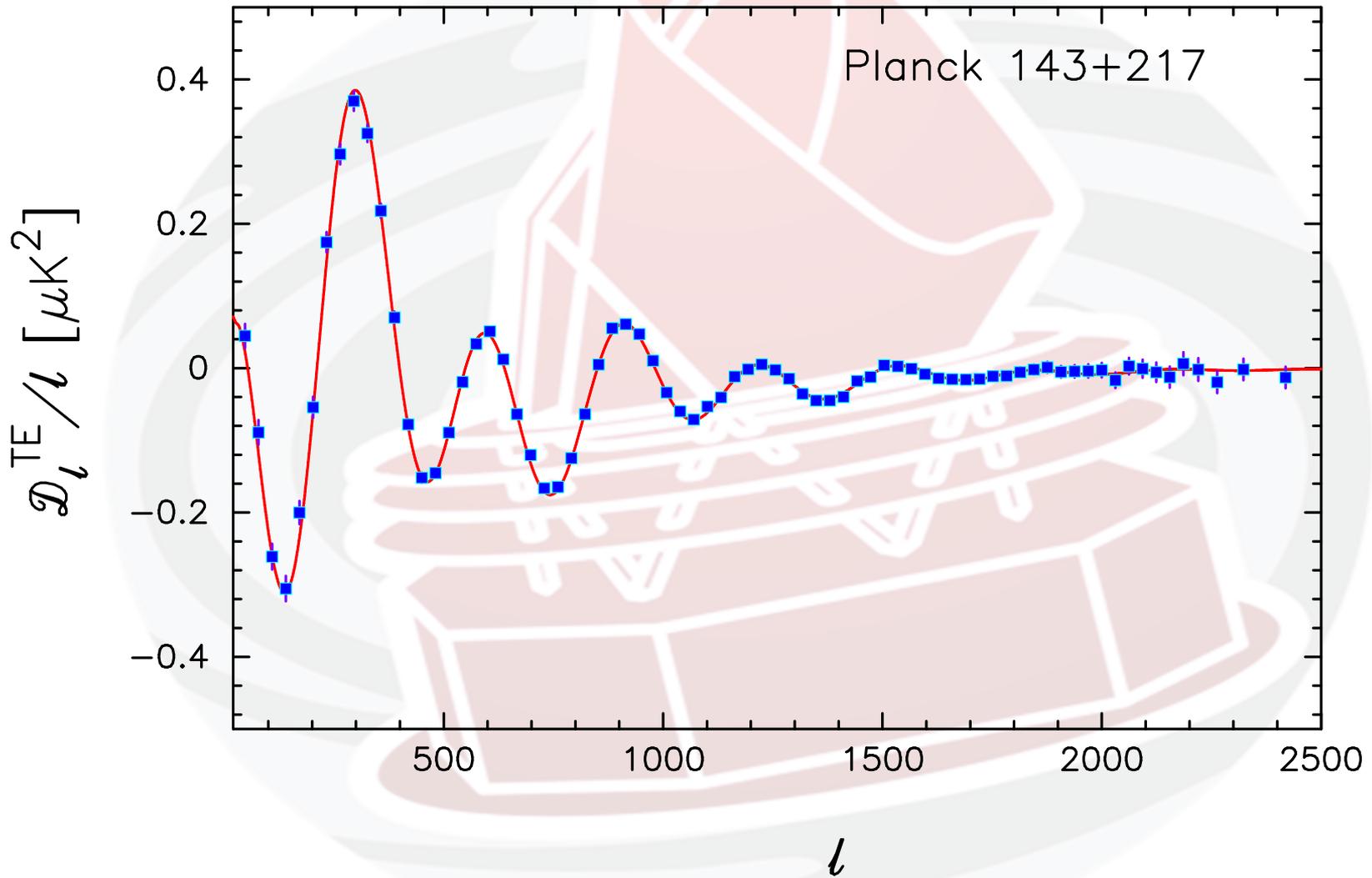


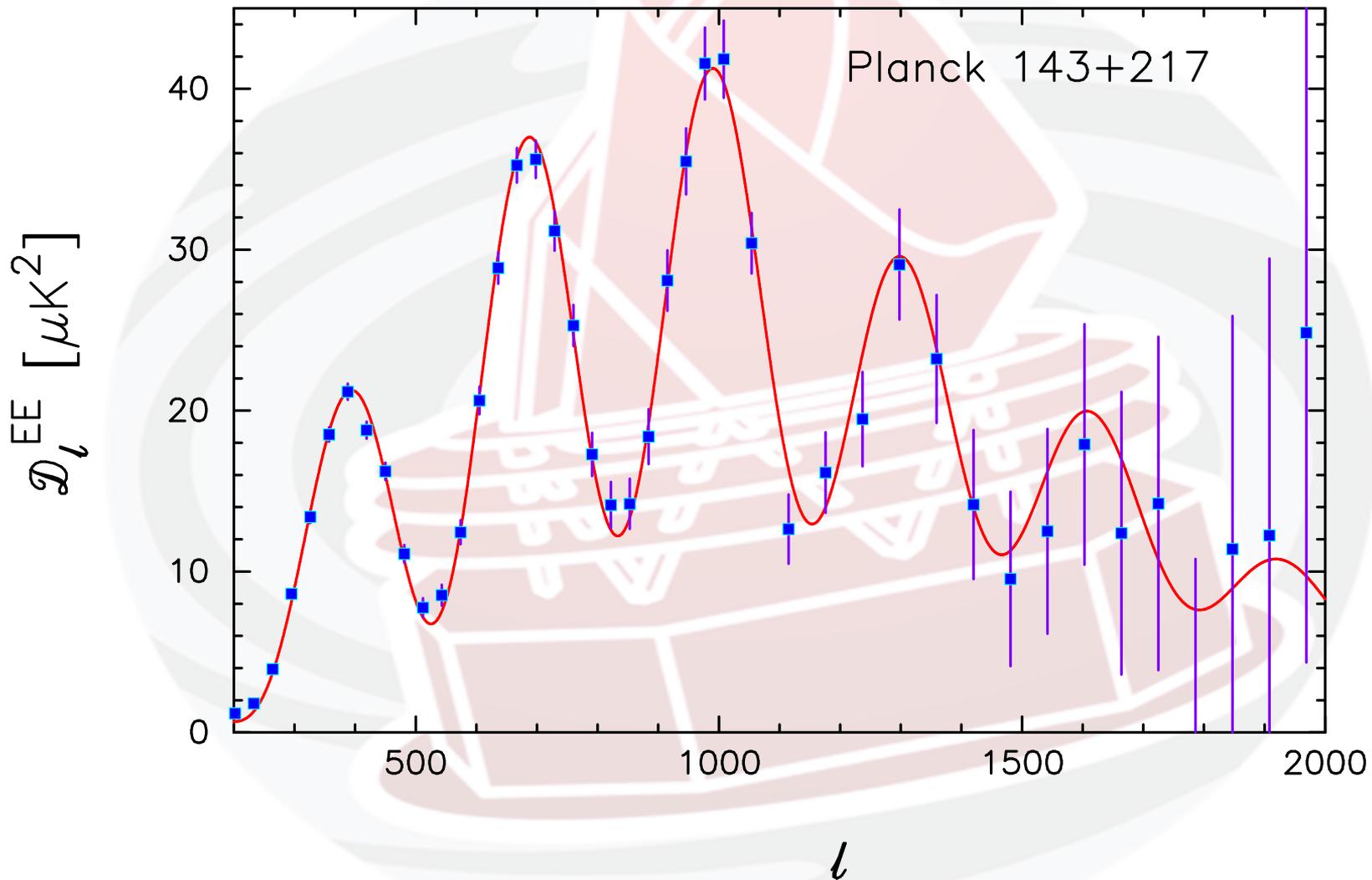
Planck

The anisotropies of the CMB





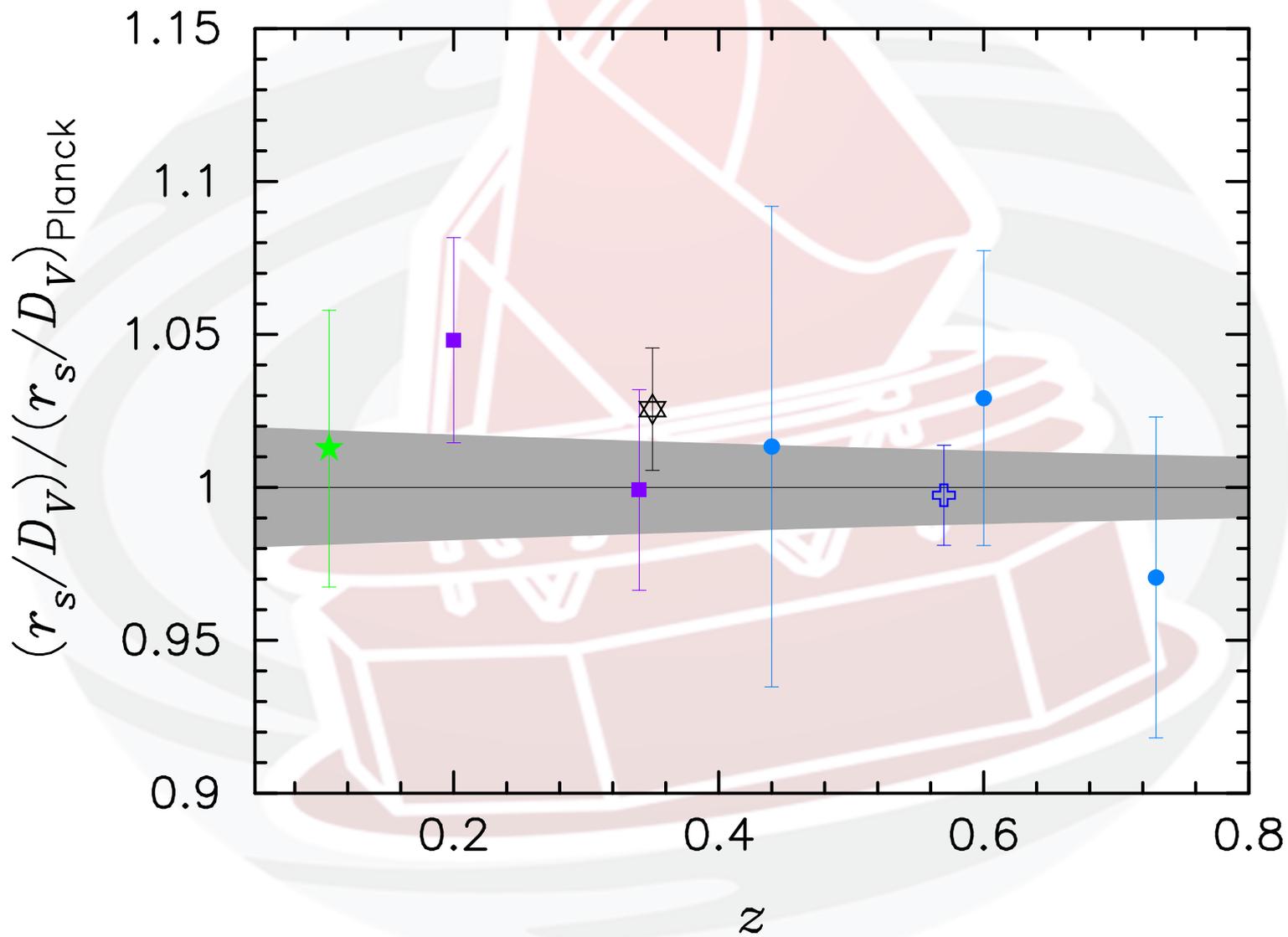




6 parameters of Λ CDM

- Baryon density
- Peak scale
- Cold dark matter density
- Primordial spectral index
- Reionisation optical depth
- Primordial amplitude

Parameter	<i>Planck</i> (CMB+lensing)		<i>Planck</i> +WP+highL+BAO	
	Best fit	68 % limits	Best fit	68 % limits
$\Omega_b h^2$	0.022242	0.02217 ± 0.00033	0.022161	0.02214 ± 0.00024
$\Omega_c h^2$	0.11805	0.1186 ± 0.0031	0.11889	0.1187 ± 0.0017
$100\theta_{MC}$	1.04150	1.04141 ± 0.00067	1.04148	1.04147 ± 0.00056
τ	0.0949	0.089 ± 0.032	0.0952	0.092 ± 0.013
n_s	0.9675	0.9635 ± 0.0094	0.9611	0.9608 ± 0.0054
$\ln(10^{10} A_s)$	3.098	3.085 ± 0.057	3.0973	3.091 ± 0.025
Ω_Λ	0.6964	0.693 ± 0.019	0.6914	0.692 ± 0.010
σ_8	0.8285	0.823 ± 0.018	0.8288	0.826 ± 0.012
z_{re}	11.45	$10.8^{+3.1}_{-2.5}$	11.52	11.3 ± 1.1
H_0	68.14	67.9 ± 1.5	67.77	67.80 ± 0.77
Age/Gyr	13.784	13.796 ± 0.058	13.7965	13.798 ± 0.037
$100\theta_*$	1.04164	1.04156 ± 0.00066	1.04163	1.04162 ± 0.00056
r_{drag}	147.74	147.70 ± 0.63	147.611	147.68 ± 0.45
$r_{drag}/D_V(0.57)$	0.07207	0.0719 ± 0.0011		

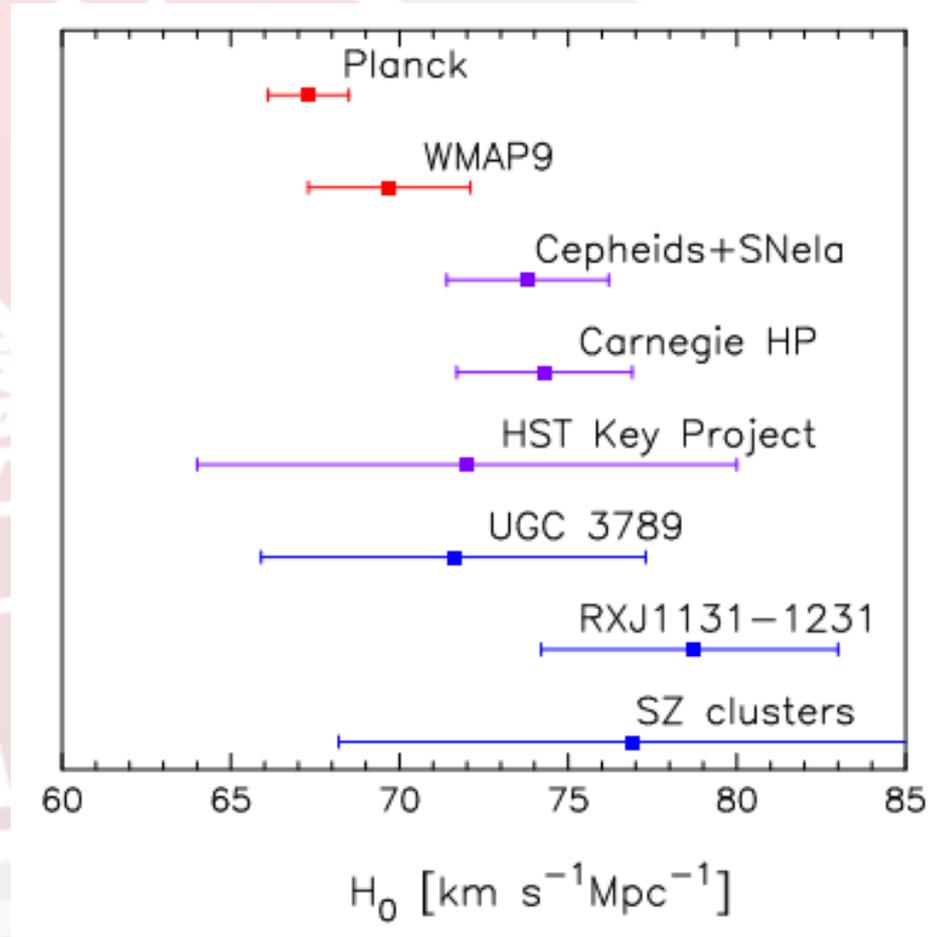


Tension with Hubble Constant astrophysical measurements

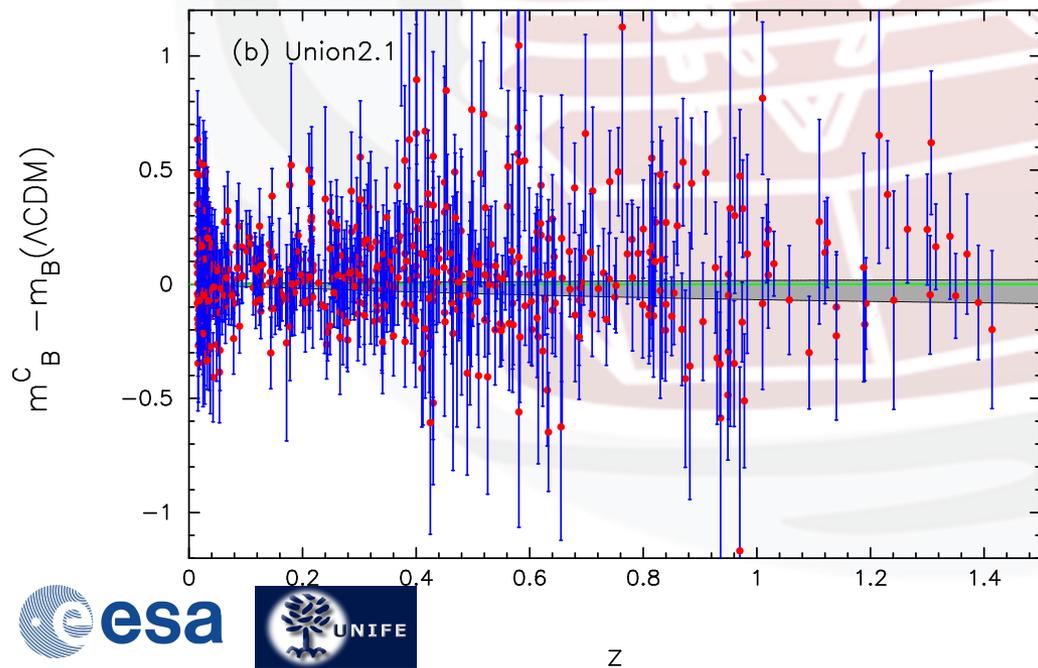
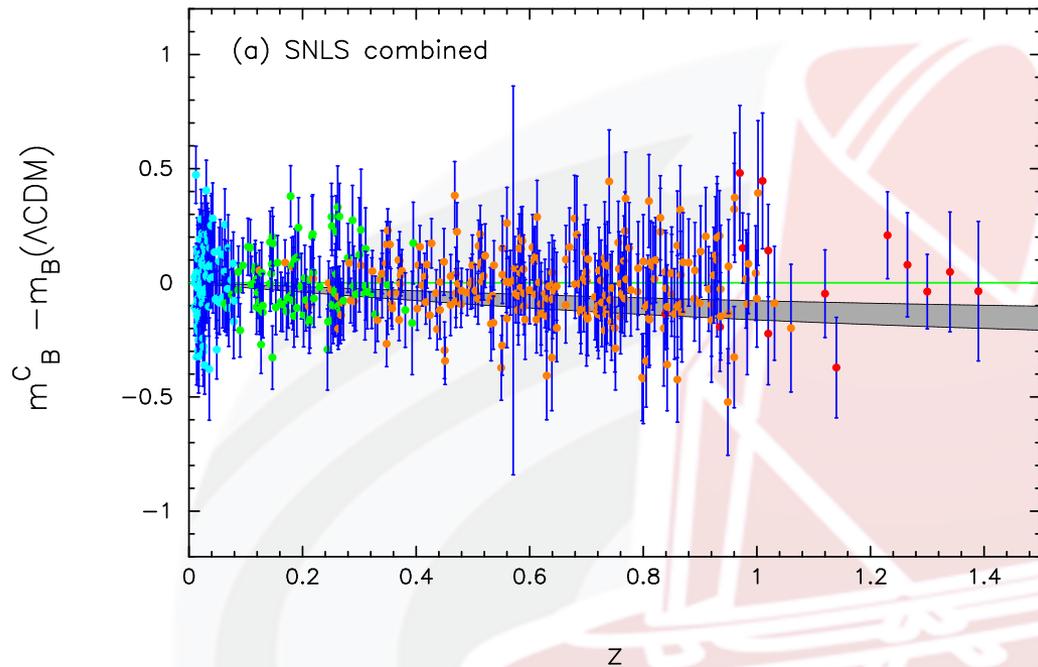
Planck value for the Hubble constant is in a tension with several other measurements (most notably the HST determination).

Systematics in luminosity distance measurements can be clearly there, however this tension could be also hinting towards new physics.

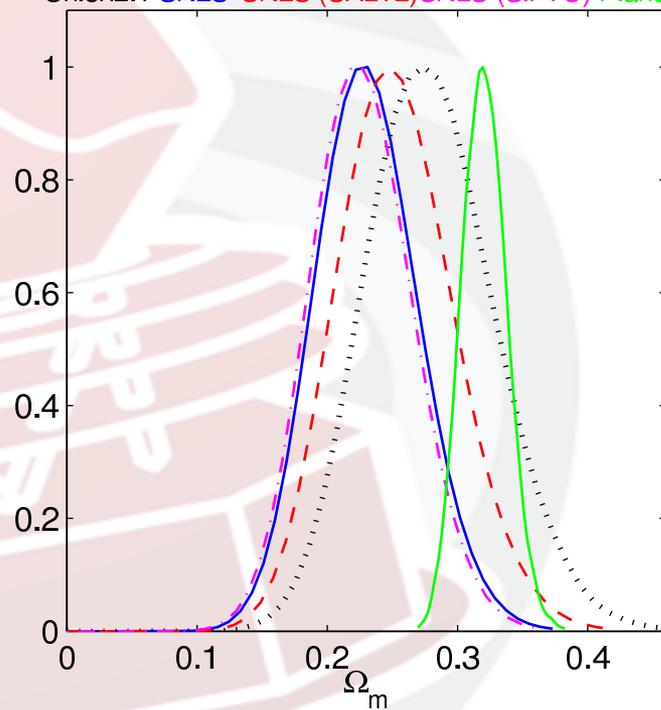
The determination of H_0 from Planck is indeed **model dependent**.



Tension under investigation



Union2.1 SNLS (SALT2) SNLS (SiFTO) Planck

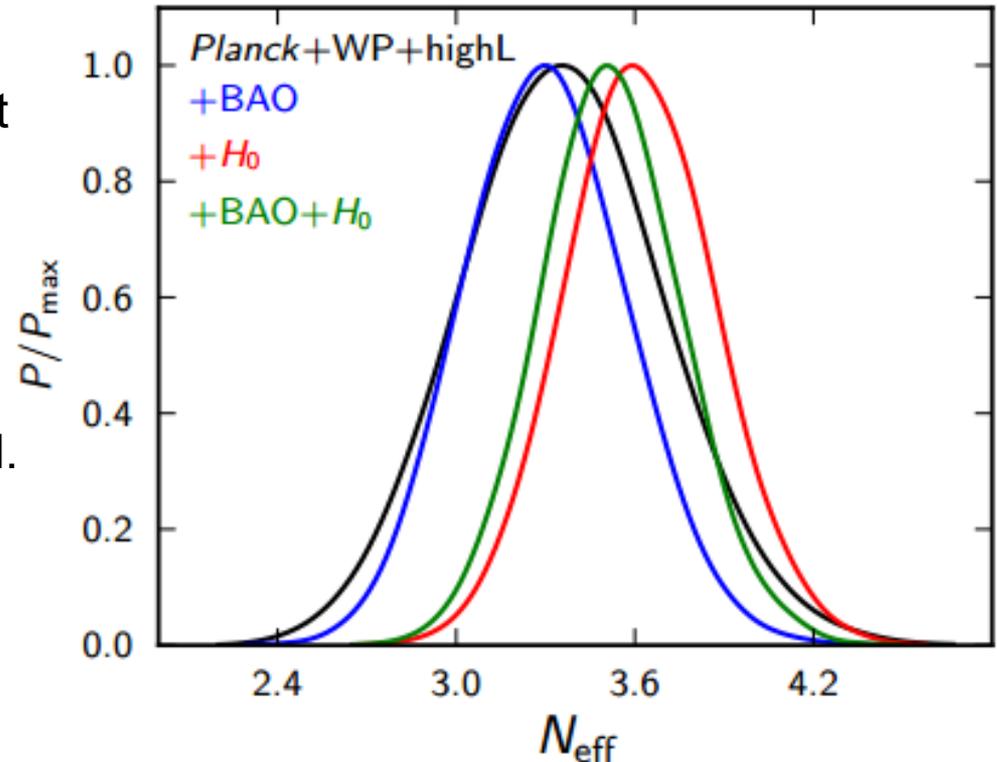


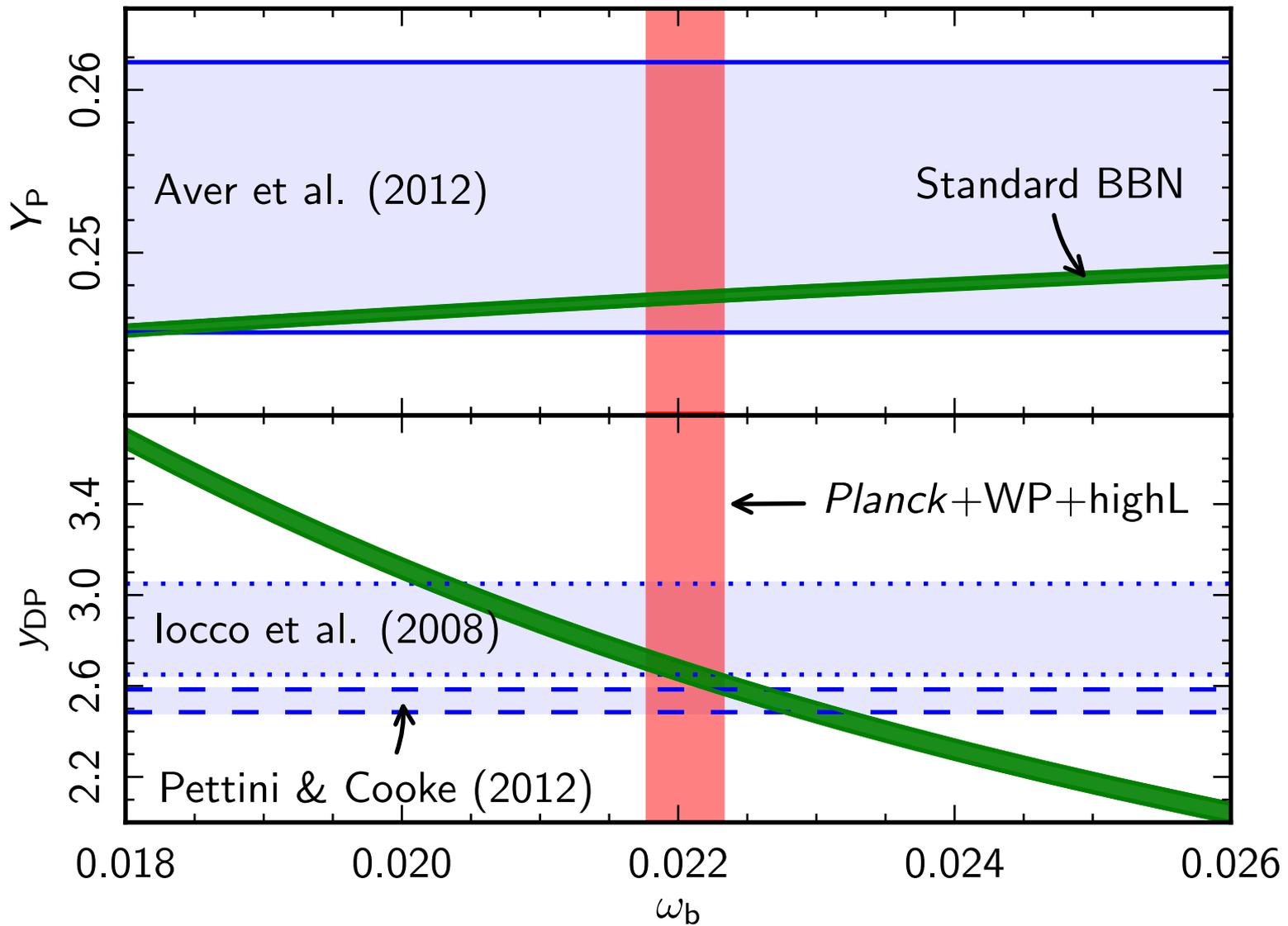
Example: extra degrees of freedom from Planck+HST ?

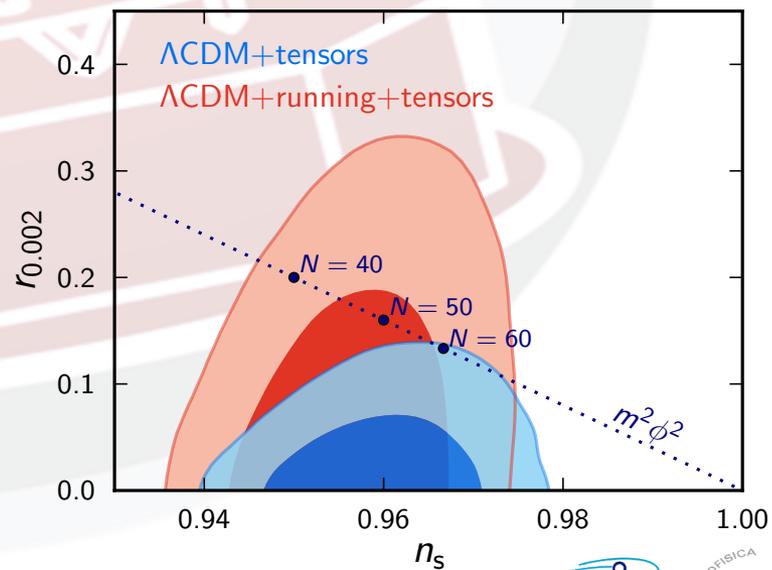
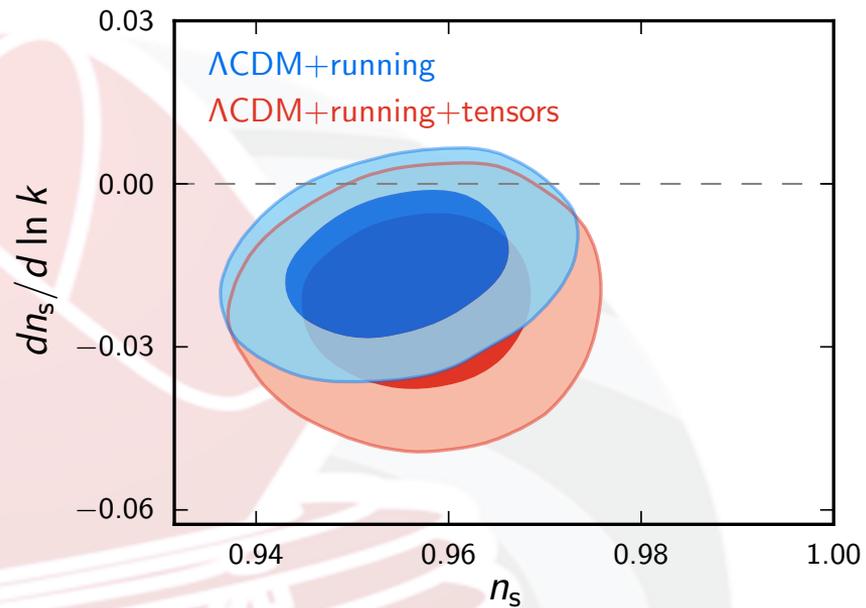
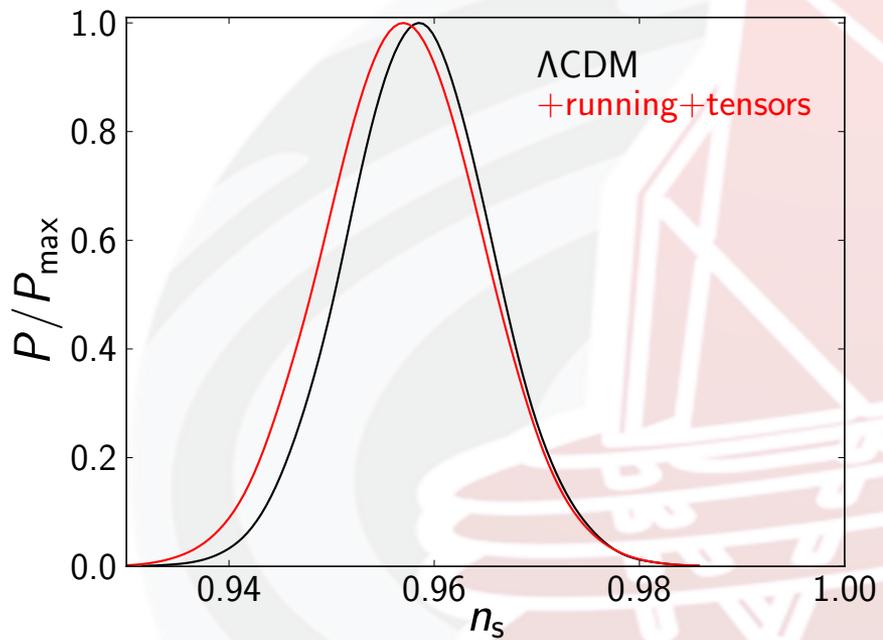
While the Planck+WP+highL dataset is consistent with the standard 3 neutrino families framework, when we include the HST value for the Hubble constant we see a preference for extra degrees of freedom at about 95% c.l. with $N_{\text{eff}}=3.6$.

A sterile neutrino with non standard decoupling could explain this effect.

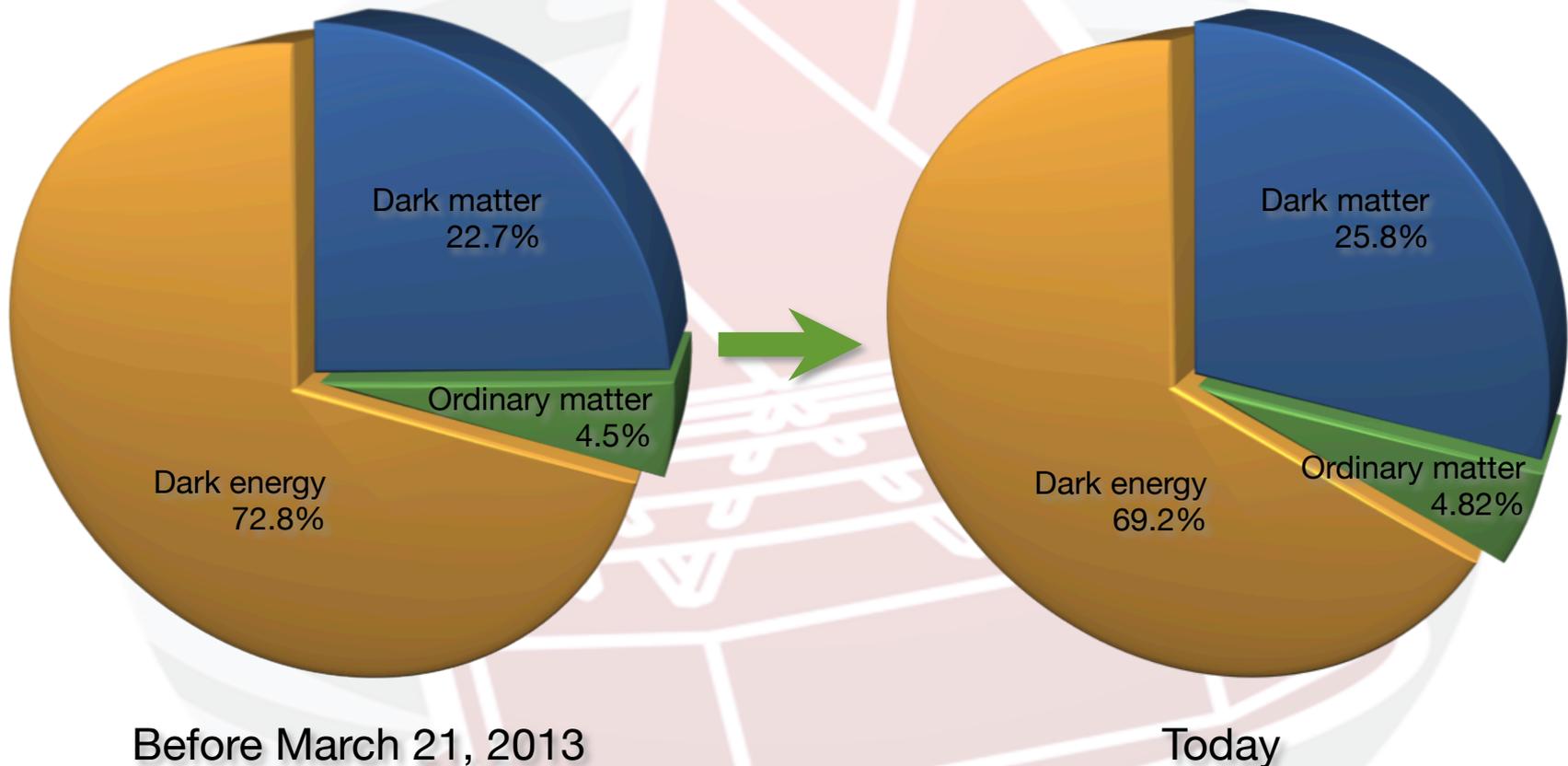
Other new physics mechanisms could explain this tension.







A new cosmic recipe



Age of the Universe : 13.798 ± 0.037 Gyr

Hubble constant : 67.80 ± 0.77 km s⁻¹ Mpc⁻¹

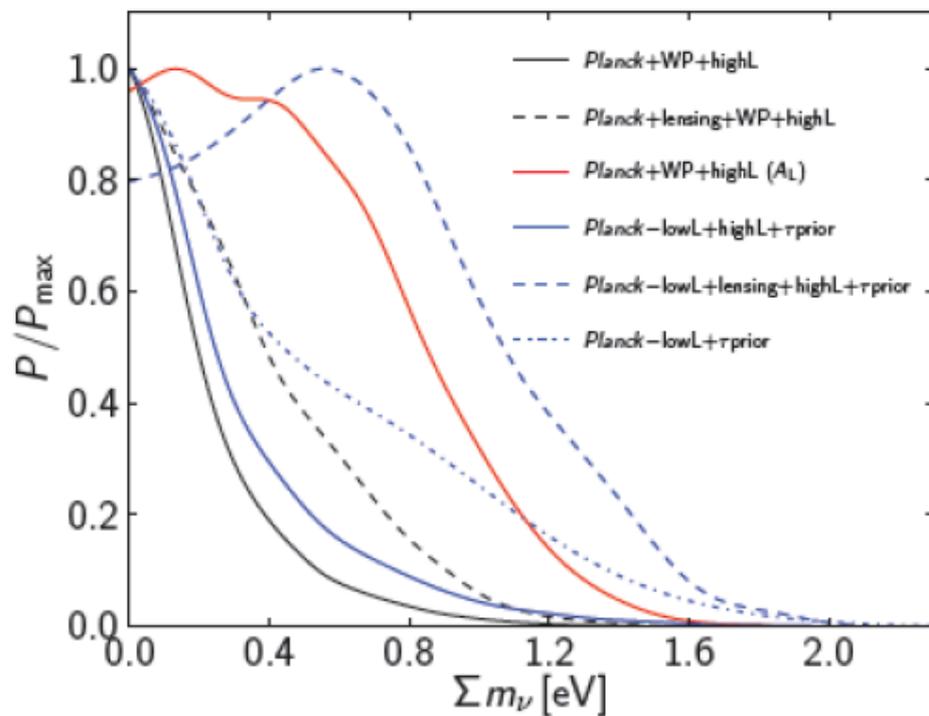
Parameters based on Planck + WMAP polarisation + highL + BAO

Baryonic matter : $\pm 0.05\%$

Dark matter : $\pm 0.4\%$

Dark energy : $\pm 1.0\%$

Constraints on Neutrino Mass (standard 3 neutrino framework)



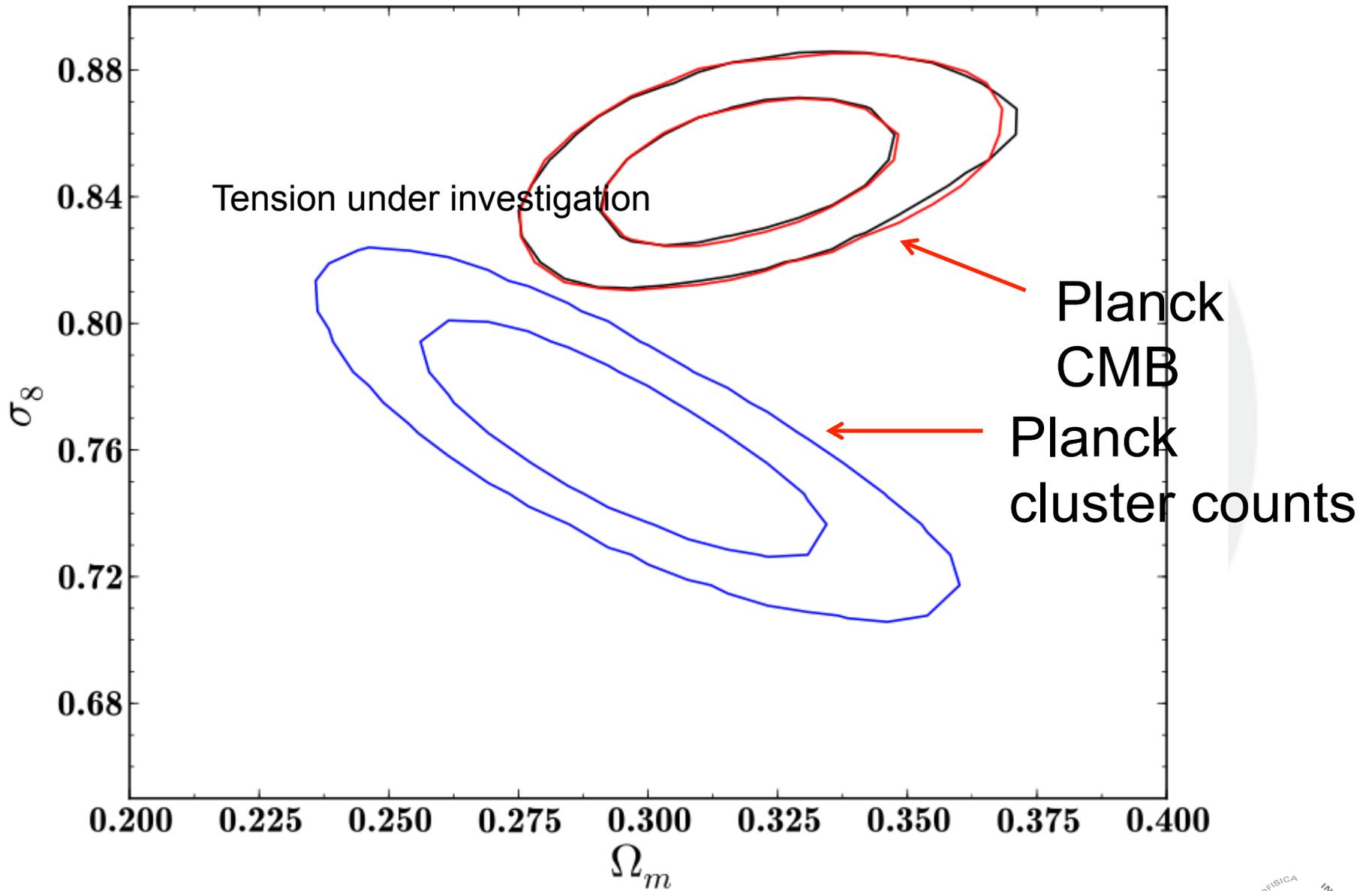
$$\sum m_\nu < 0.66 \text{ eV} \quad (95\%; \textit{Planck+WP+highL}).$$

$$\sum m_\nu < 1.08 \text{ eV} \quad [95\%; \textit{Planck+WP+highL (A}_L\text{)}],$$

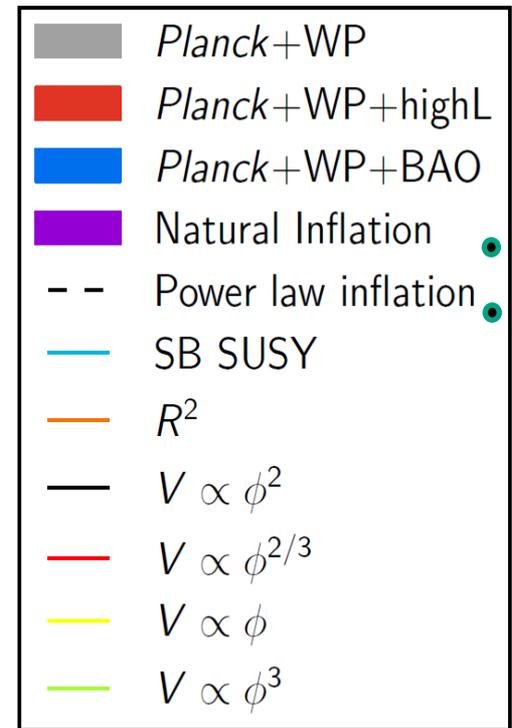
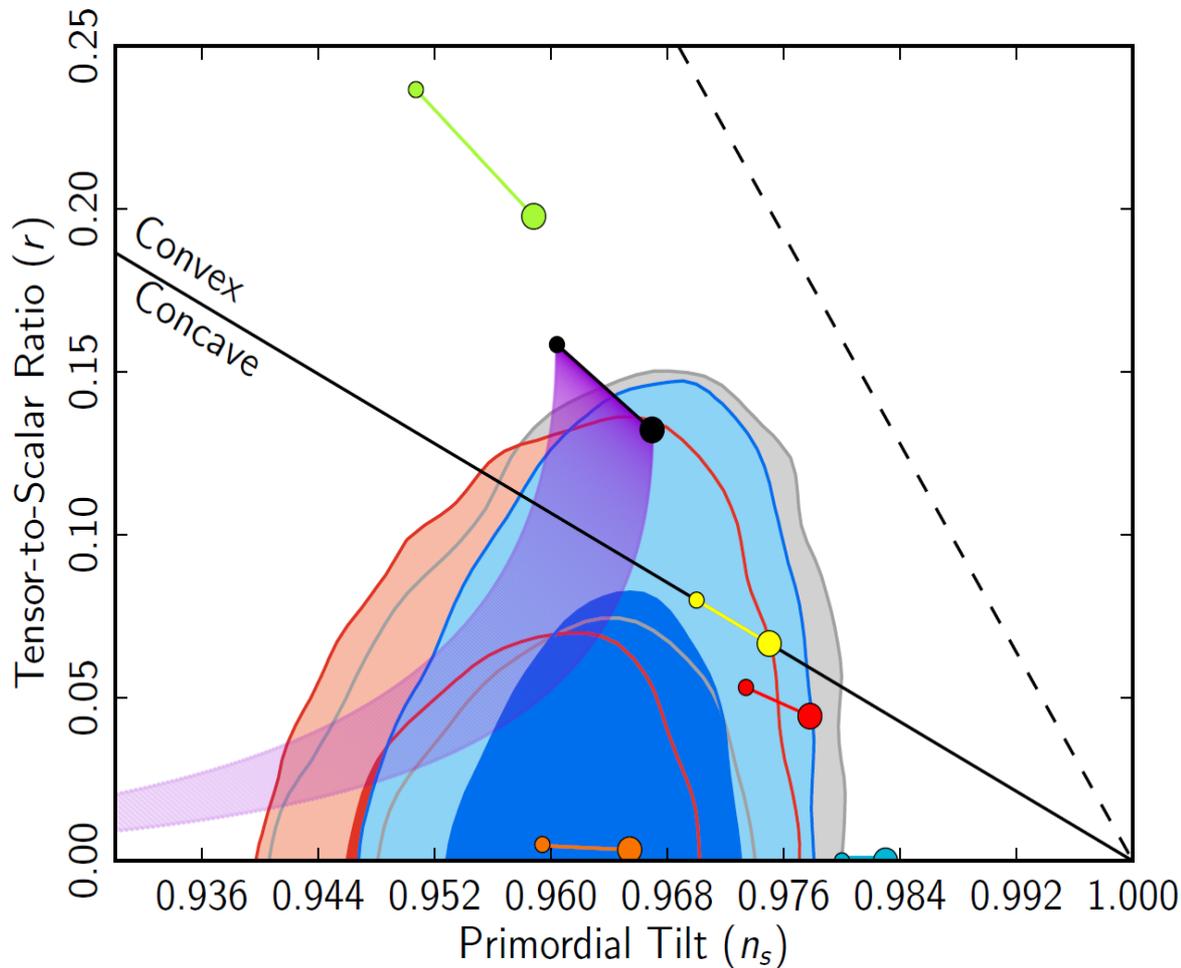
$$\sum m_\nu < 0.85 \text{ eV} \quad (95\%; \textit{Planck+lensing+WP+highL}),$$

$$\sum m_\nu < 0.23 \text{ eV} \quad (95\%; \textit{Planck+WP+highL+BAO}).$$

- Planck strongly improves previous constraints on neutrino masses.
- Planck TT spectrum prefers a lensing amplitude higher than expected ($A_{\text{LENS}}=1.2$).
- Inclusion of lensing from TTTT weakens the Planck constraint by 20%
- Including BAO results in the best current constraint on neutrino masses of 0.23 eV



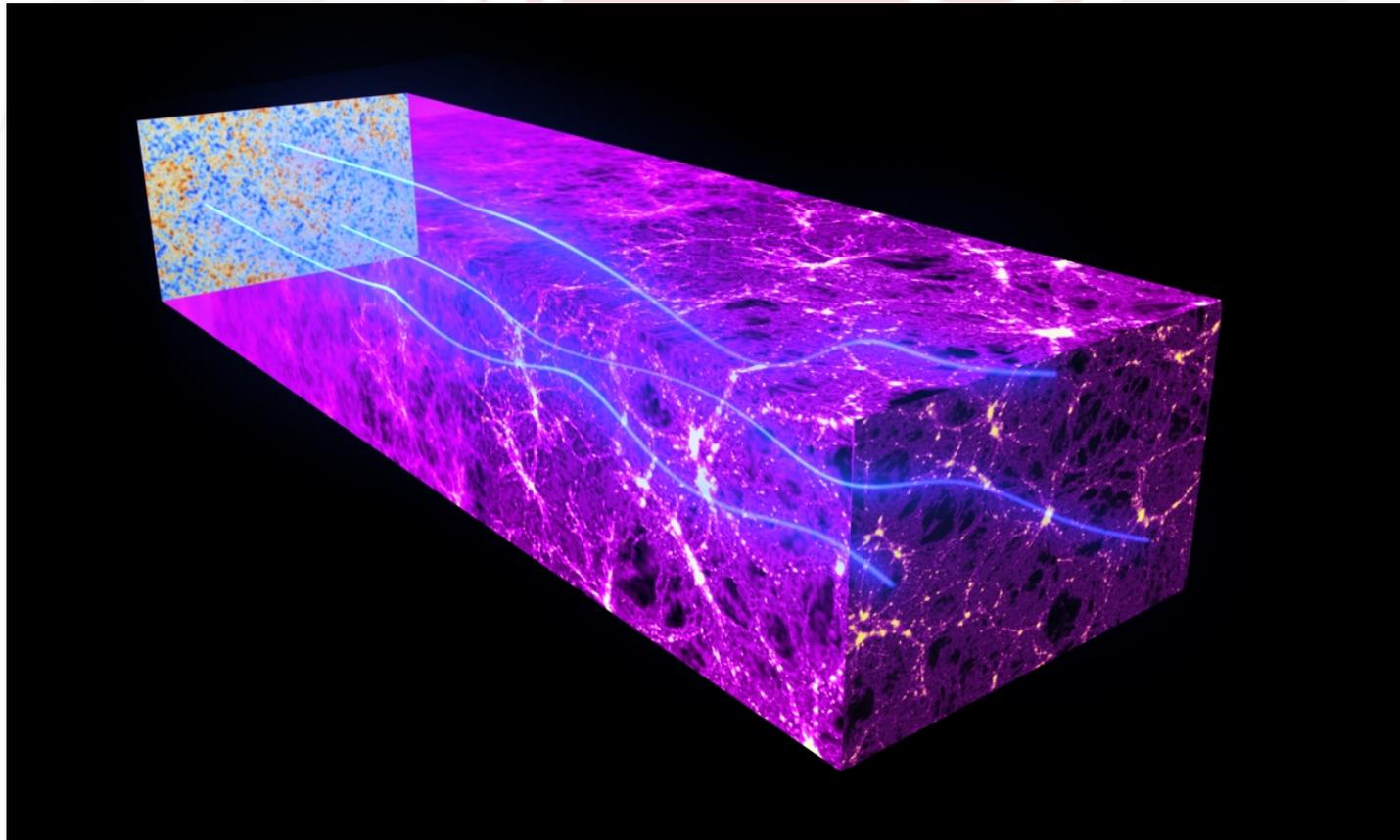
Main constraint on Inflation physics



→ Consistent with single field slow roll, standard kinetic term & vacuum (with f_{NL} upper limits).

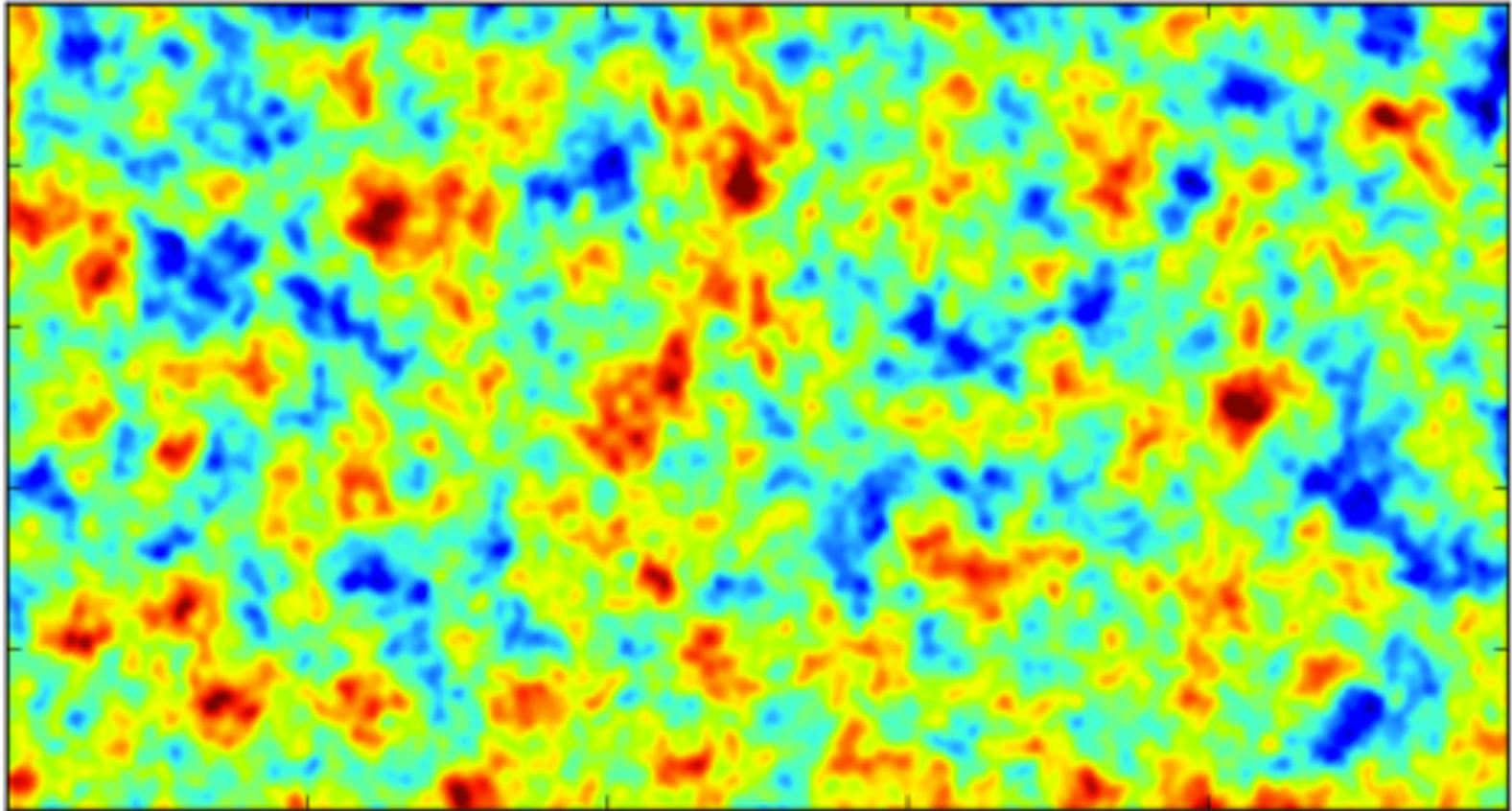
GRAVITATIONAL LENSING DISTORTS IMAGES

The gravitational effects of intervening matter bend the path of CMB light on its way from the early universe to the Planck telescope. This “gravitational lensing” distorts our image of the CMB



GRAVITATIONAL LENSING OF THE CMB

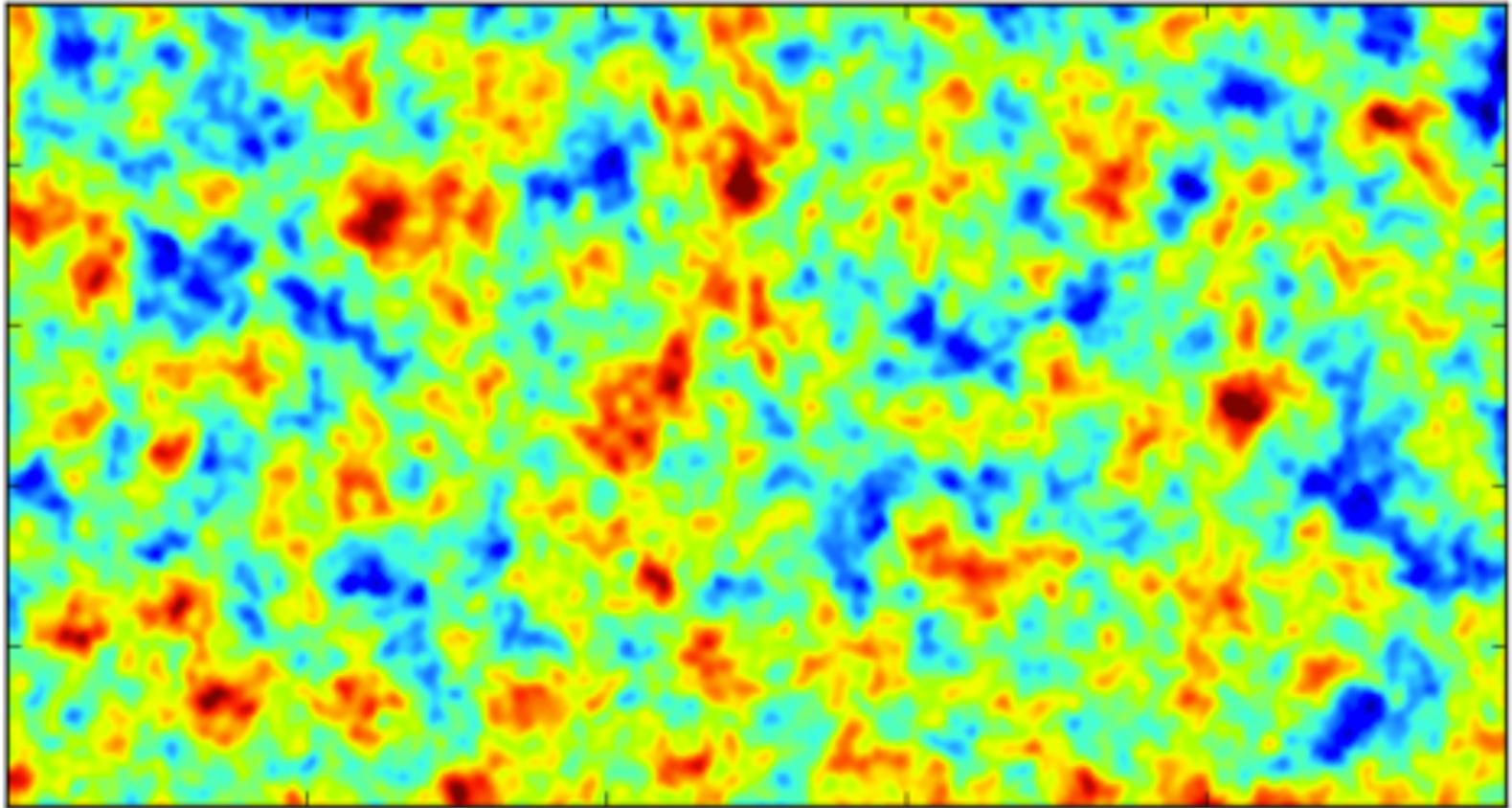
A simulated patch of CMB sky – **before lensing**



← 10° →

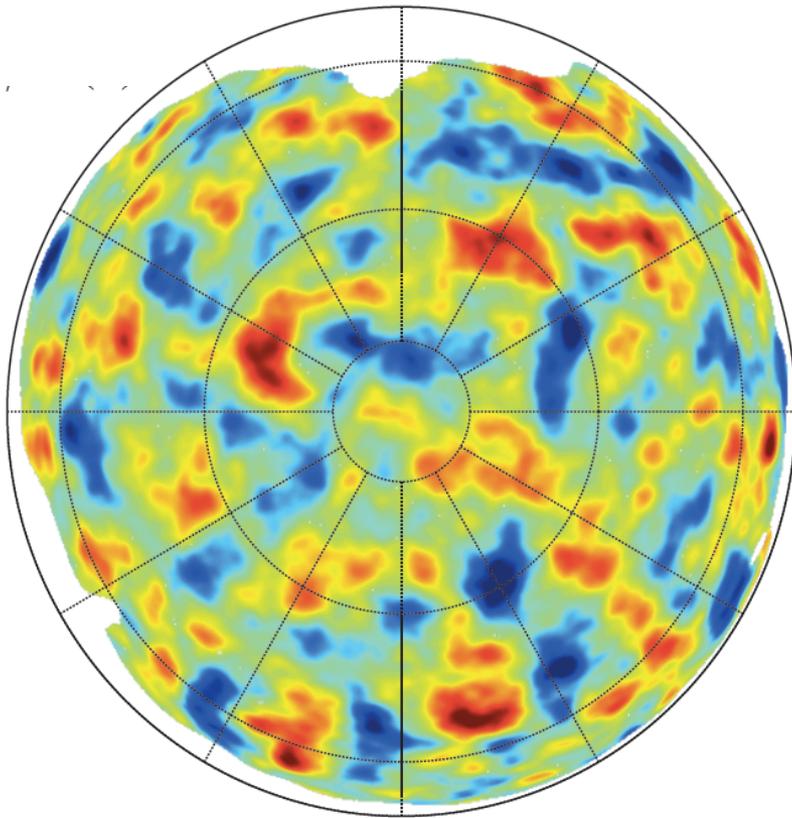
GRAVITATIONAL LENSING OF THE CMB

A simulated patch of CMB sky – **after lensing**

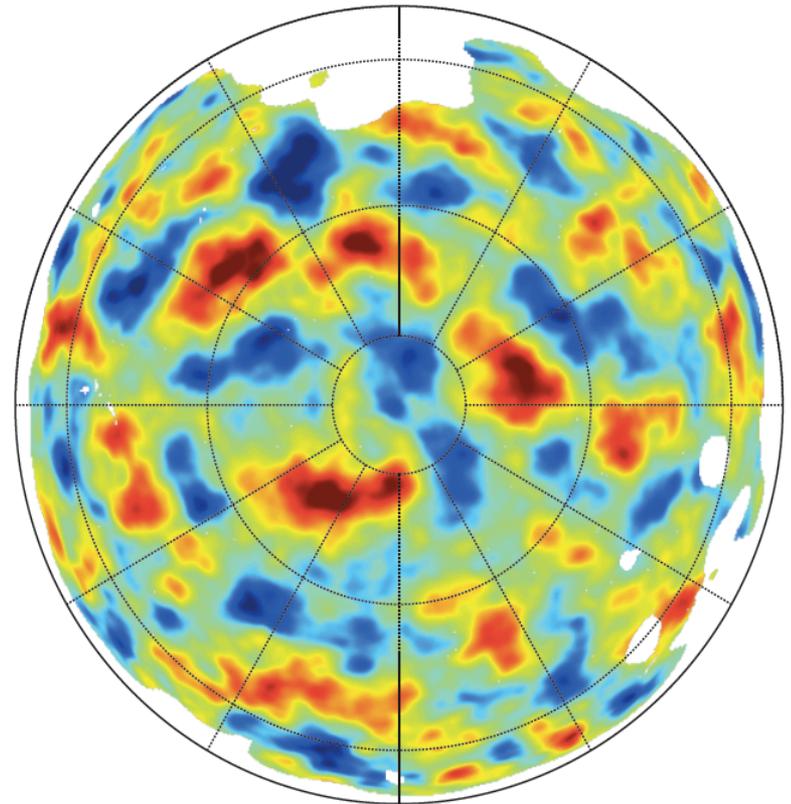


Planck dark matter distribution

Planck images of the mass distribution throughout (almost) the entire visible Universe. This is 85% Dark Matter, 15% ordinary matter....

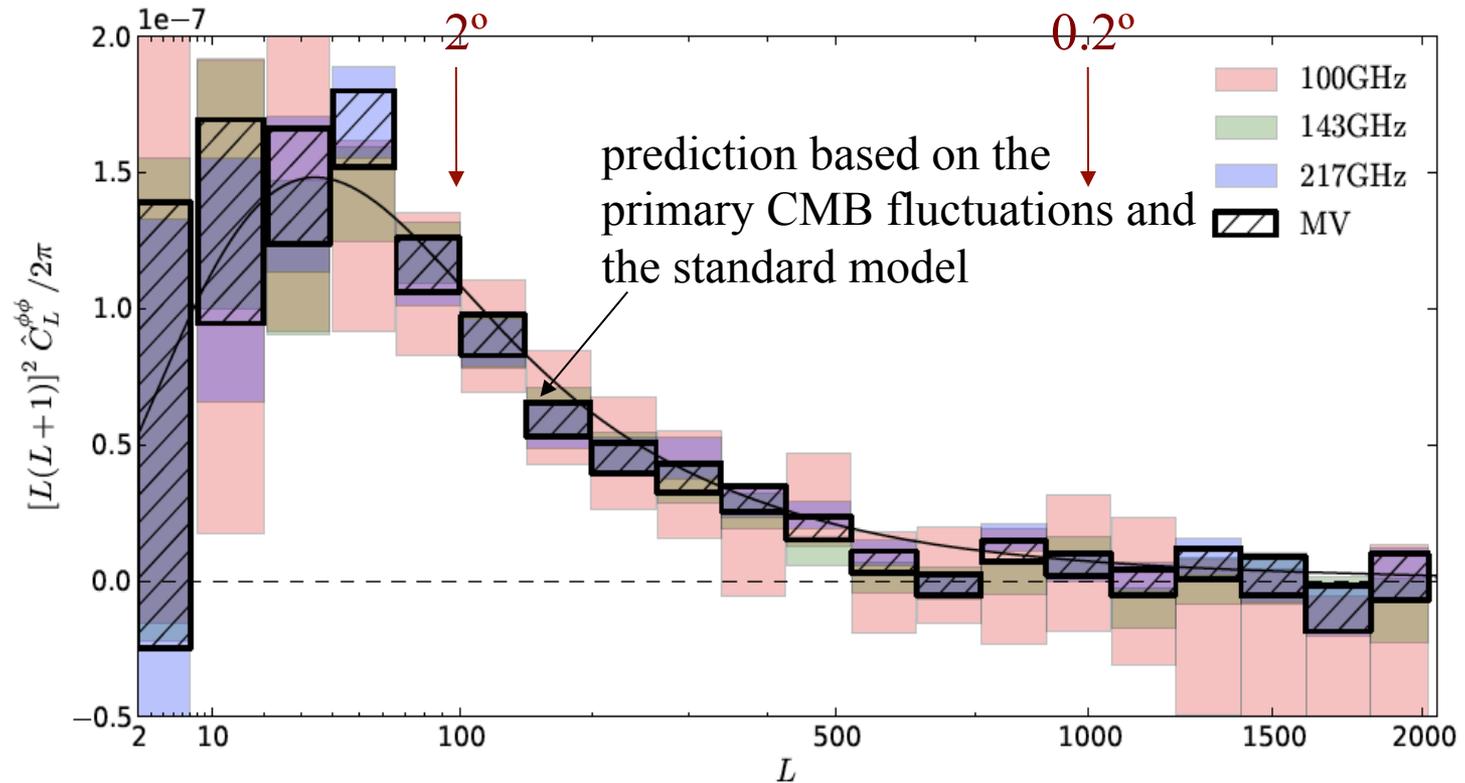


Galactic North



Galactic South

PLANCK LENSING POTENTIAL POWER SPECTRUM



It is a 25 sigma effect!!

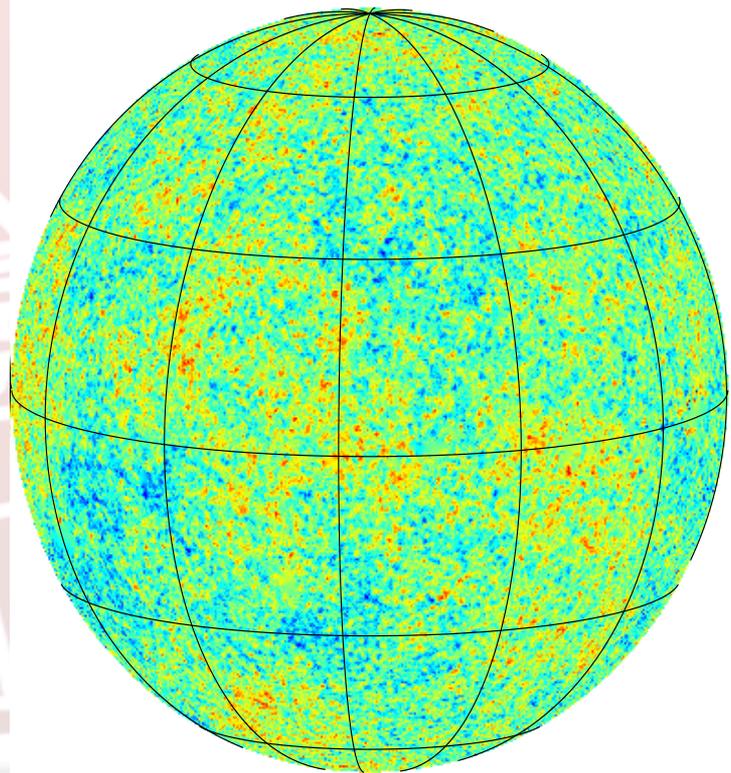
Non Gaussianity in the CMB

Nearly perfectly Gaussian fluctuations are a prediction of the inflation.

$$\frac{\Delta T}{T} \approx 10^{-5}$$

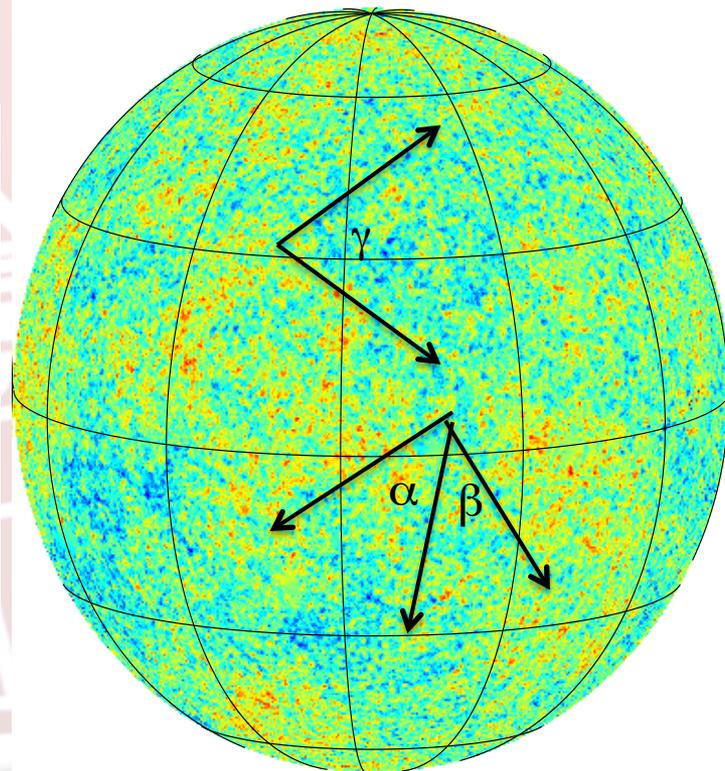
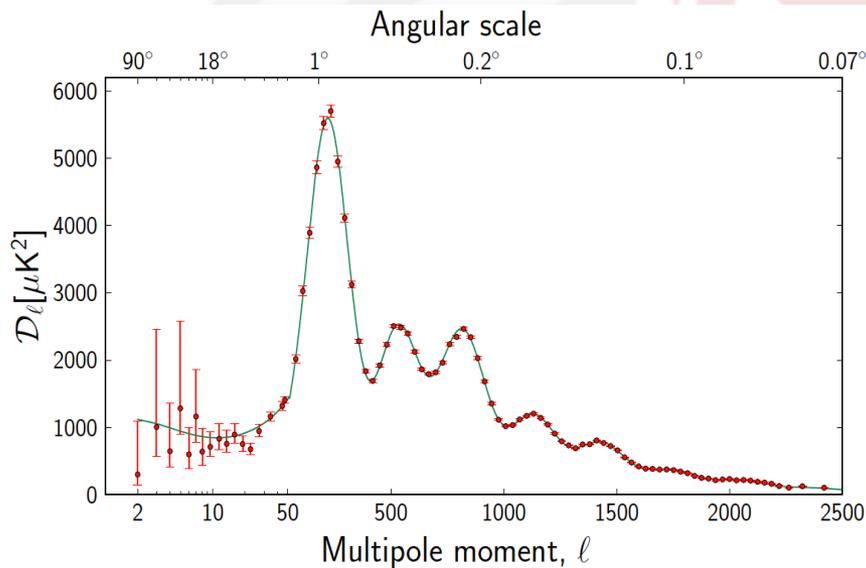
$$\frac{\Delta T}{T} + f_{NL} \left(\frac{\Delta T}{T} \right)^2$$

$$\left(\frac{\Delta T}{T} \right)^2 \approx 10^{-10}$$

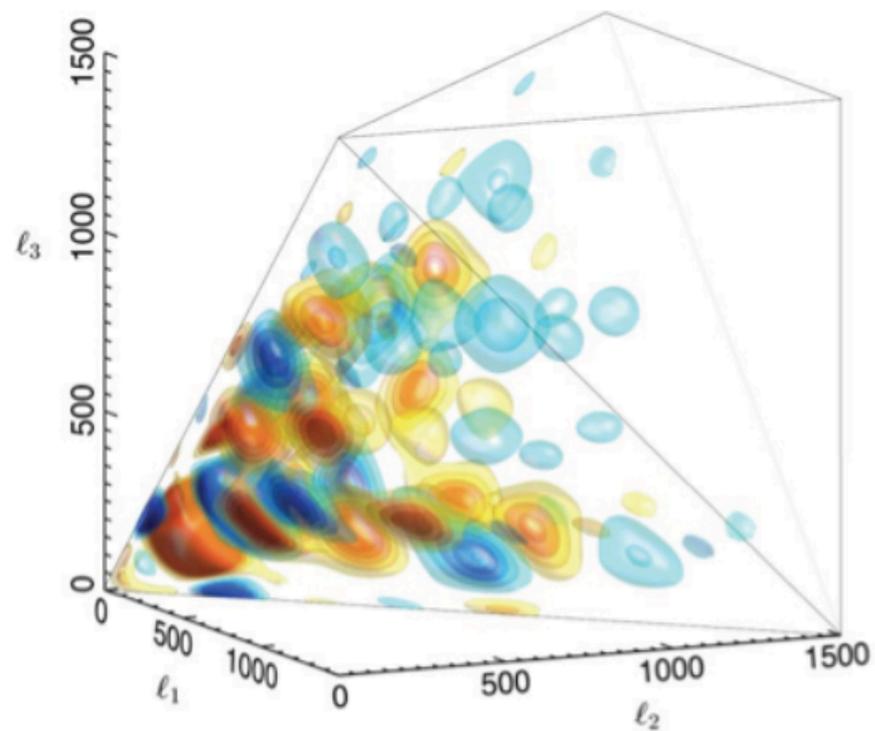
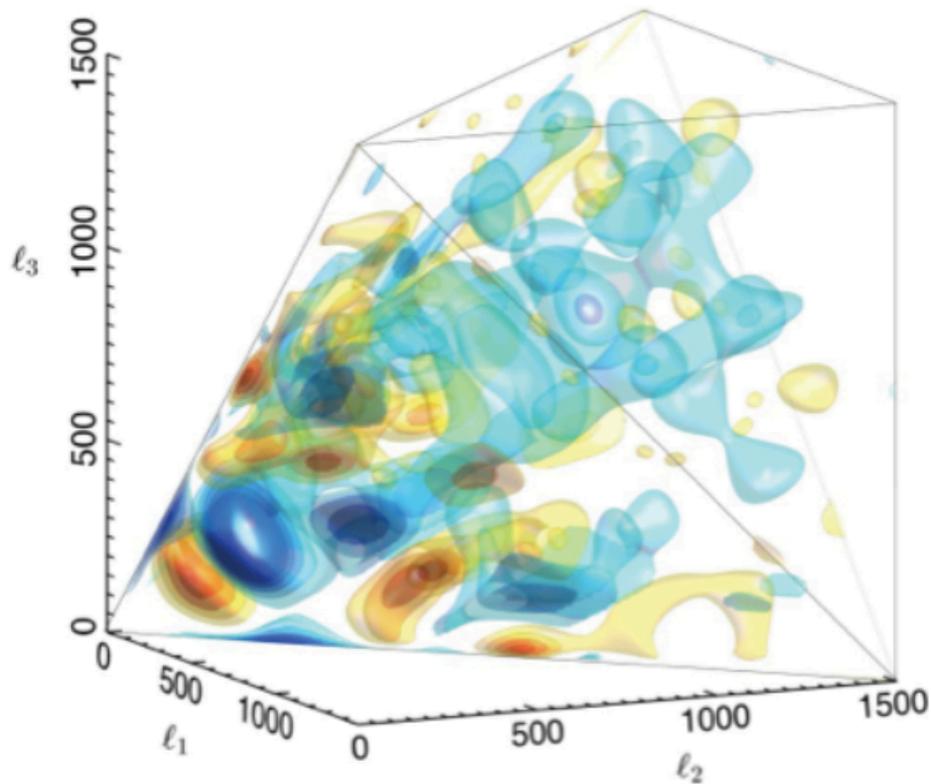


How test for Gaussianity? And how?

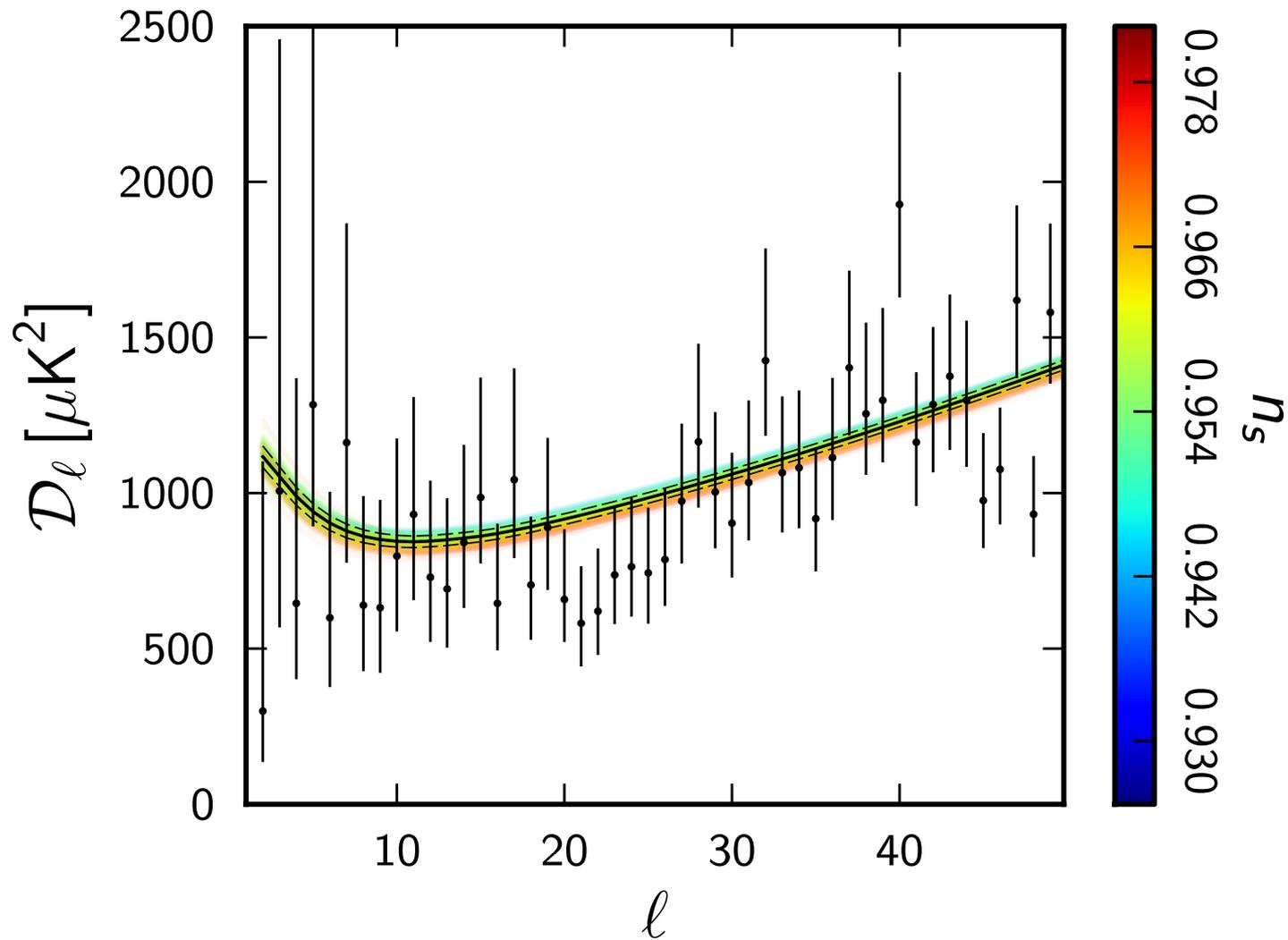
The power spectrum compares two points separated by one angle:



To check for non Gaussianity you can compare three points at two angles: the “power” bispectrum.



Phase Wavenumber	$\phi = 0$ $f_{NL} \pm \Delta f_{NL} (\sigma)$	$\phi = \pi/4$ $f_{NL} \pm \Delta f_{NL} (\sigma)$	$\phi = \pi/2$ $f_{NL} \pm \Delta f_{NL} (\sigma)$	$\phi = 3\pi/4$ $f_{NL} \pm \Delta f_{NL} (\sigma)$
$k_c = 0.01000$	$-110 \pm 159 (-0.7)$	$-98 \pm 167 (-0.6)$	$-17 \pm 147 (-0.1)$	$56 \pm 142 (0.4)$
$k_c = 0.01125$	$434 \pm 170 (2.6)$	$363 \pm 185 (2.0)$	$57 \pm 183 (0.3)$	$-262 \pm 168 (-1.6)$
$k_c = 0.01250$	$-70 \pm 158 (-0.4)$	$130 \pm 166 (0.8)$	$261 \pm 167 (1.6)$	$233 \pm 159 (1.5)$
$k_c = 0.01375$	$35 \pm 162 (0.2)$	$291 \pm 145 (2.0)$	$345 \pm 147 (2.3)$	$235 \pm 162 (1.5)$
$k_c = 0.01500$	$-313 \pm 144 (-2.2)$	$-270 \pm 137 (-2.0)$	$-95 \pm 145 (-0.7)$	$179 \pm 154 (1.2)$
$k_c = 0.01625$	$81 \pm 126 (0.6)$	$177 \pm 141 (1.2)$	$165 \pm 144 (1.1)$	$51 \pm 129 (0.4)$
$k_c = 0.01750$	$-335 \pm 137 (-2.4)$	$-104 \pm 128 (-0.8)$	$181 \pm 117 (1.5)$	$366 \pm 126 (2.9)$
$k_c = 0.01875$	$-348 \pm 118 (-3.0)$	$-323 \pm 120 (-2.7)$	$-126 \pm 119 (-1.1)$	$137 \pm 117 (1.2)$
$k_c = 0.02000$	$-155 \pm 110 (-1.4)$	$-298 \pm 119 (-2.5)$	$-241 \pm 113 (-2.1)$	$-44 \pm 105 (-0.4)$
$k_c = 0.02125$	$-43 \pm 96 (-0.4)$	$-186 \pm 107 (-1.7)$	$-229 \pm 115 (-2.0)$	$-125 \pm 104 (-1.2)$
$k_c = 0.02250$	$22 \pm 95 (0.2)$	$-115 \pm 92 (-1.2)$	$-194 \pm 105 (-1.8)$	$-148 \pm 107 (-1.4)$
$k_c = 0.02375$	$70 \pm 100 (0.7)$	$-56 \pm 94 (-0.6)$	$-159 \pm 93 (-1.7)$	$-164 \pm 101 (-1.6)$
$k_c = 0.02500$	$106 \pm 93 (1.1)$	$6 \pm 97 (0.1)$	$-103 \pm 98 (-1.1)$	$-153 \pm 94 (-1.6)$

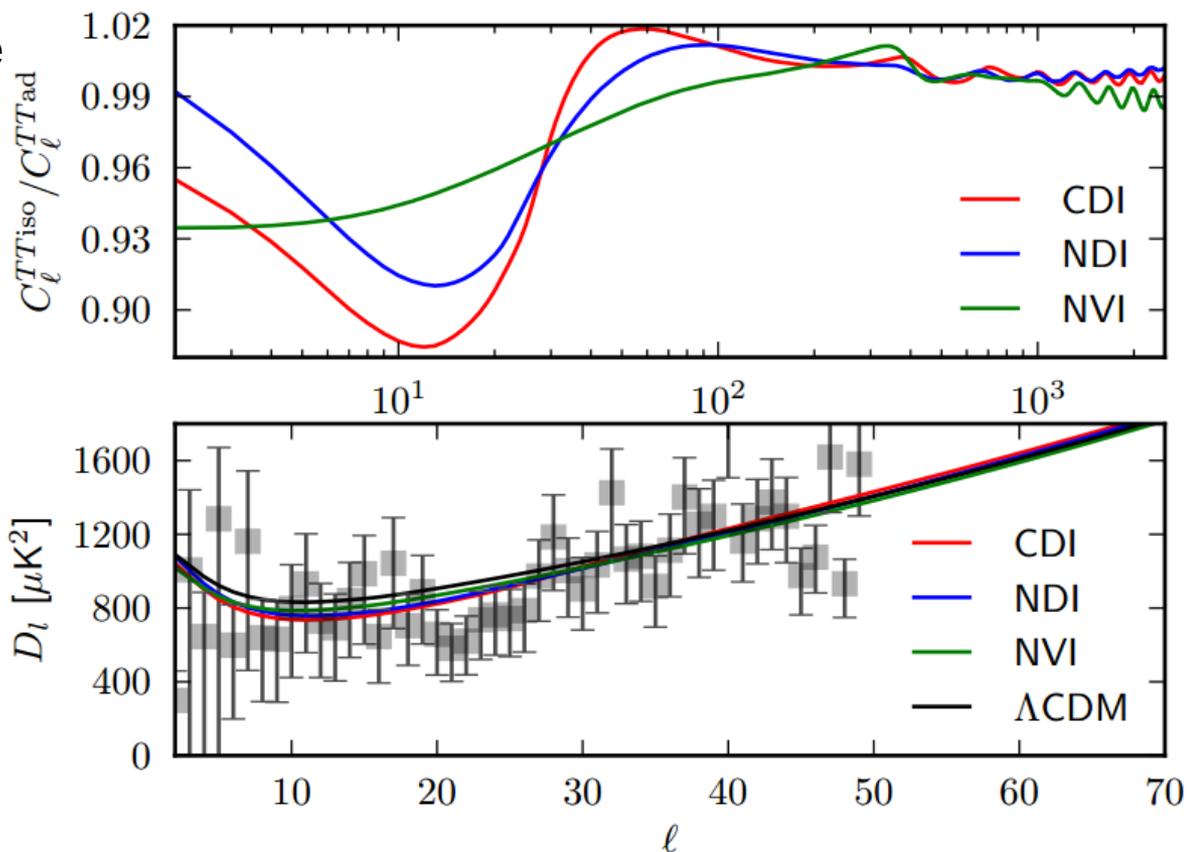


Isocurvature modes ?

A mixed adiabatic-isocurvature model can provide a better fit to the low- l region.

In the Figure we see 3 models:

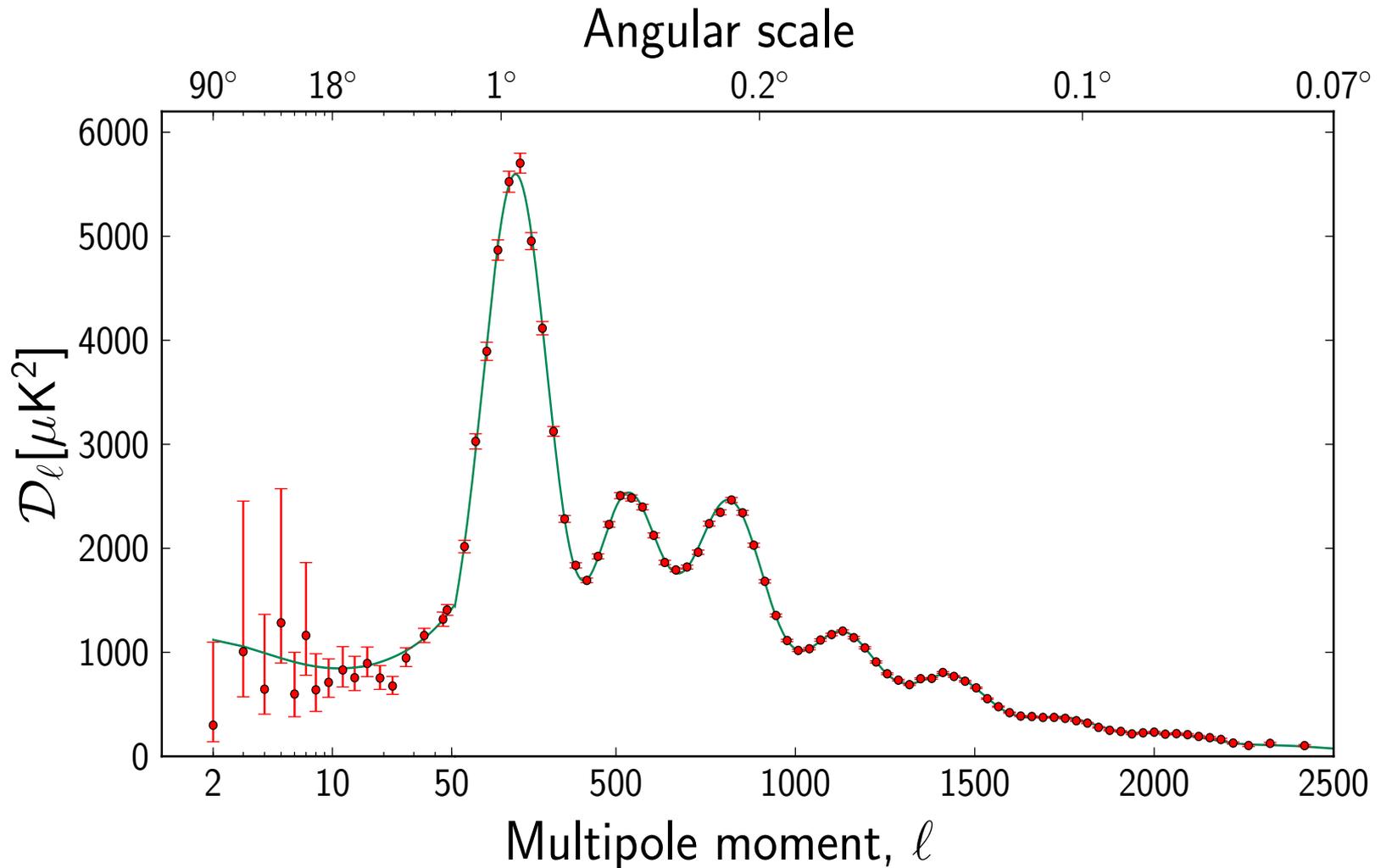
CDI: Cold Dark Matter Density Isocurvature Mode
NDI: Neutrino Density Isocurvature Mode
NVI: Neutrino Velocity Isocurvature Mode



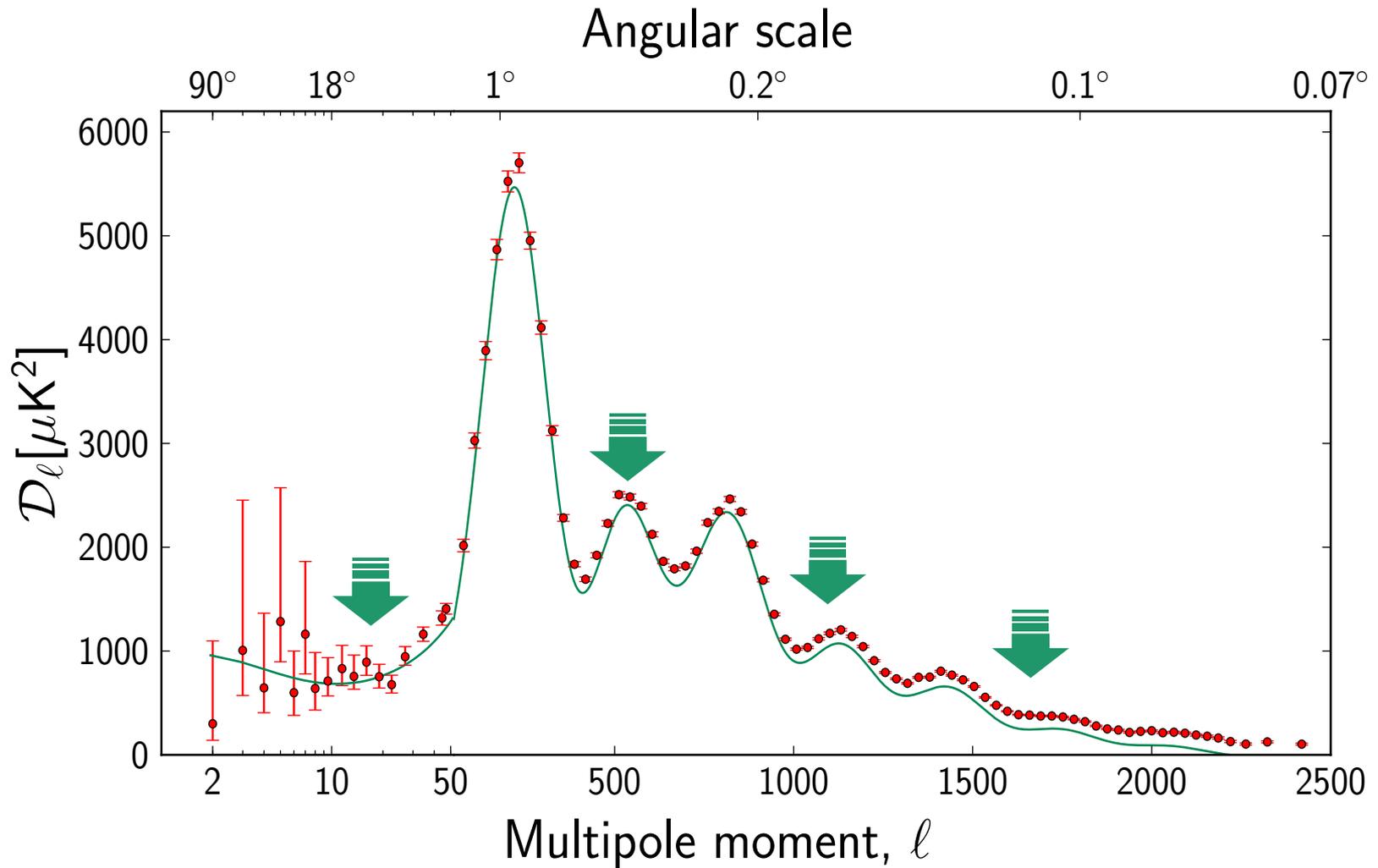
The isocurvature mode is favoured at the level of 2 sigmas.
This kind of model is compatible with multi-field inflation.

But as we can see from the data, isocurvature modes are not enough to compensate the low- l signal!

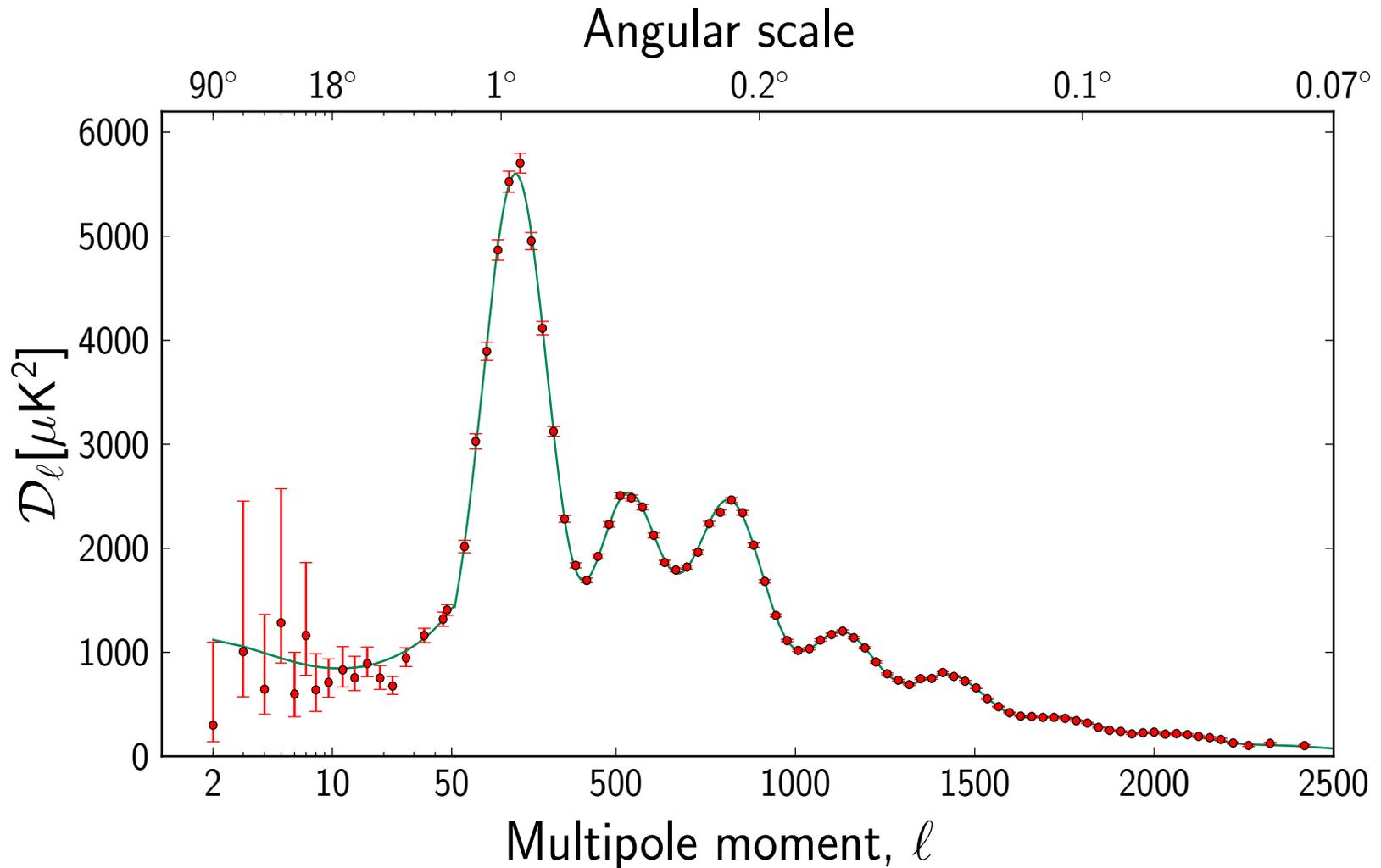
The low- l anomaly



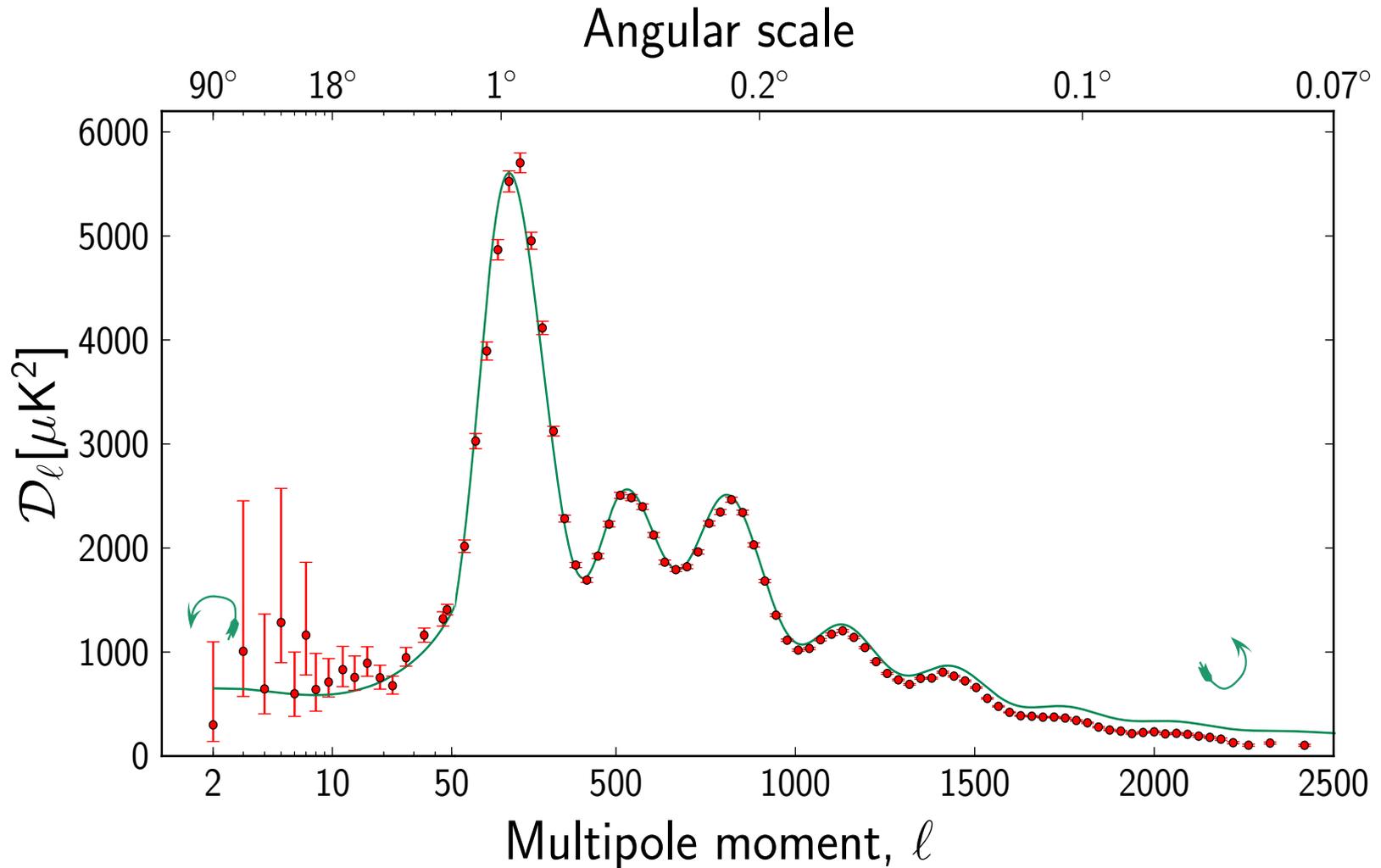
The low- l anomaly



The low- l anomaly



The low- l anomaly

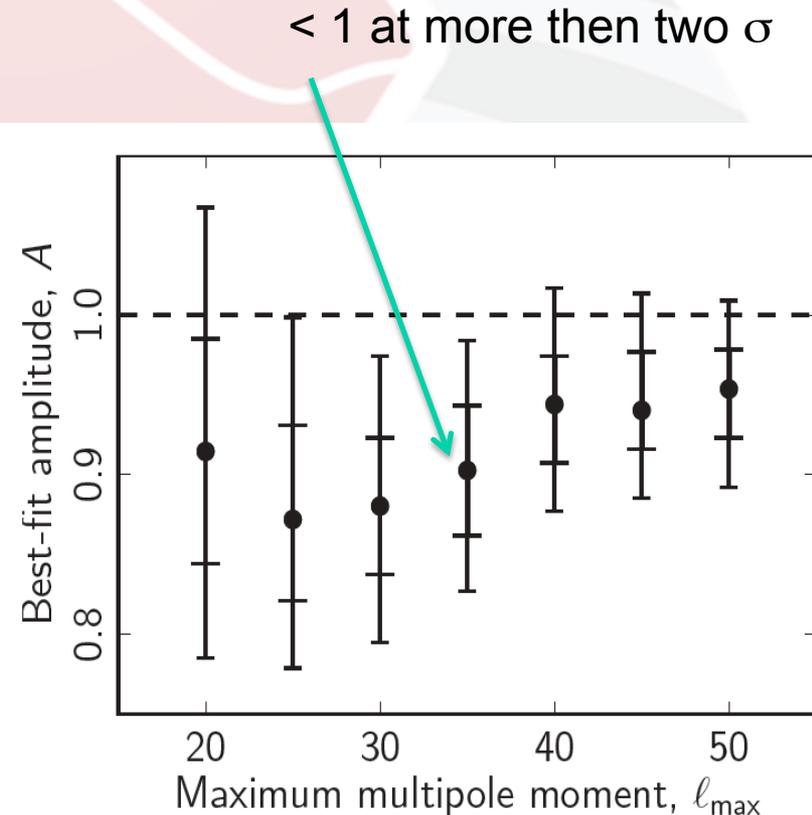


A simple amplitude test

- Rescale the power spectrum in amplitude:

$$C_l(A) = A C_l^{\Lambda\text{CDM}}$$

- Find the best-fit A as a function of maximum multipole l .
- There is a 99% “anomaly” for $l_{\text{max}}=30$.
- The anomaly fades away at higher multipoles \rightarrow where theory and data agree remarkably well.



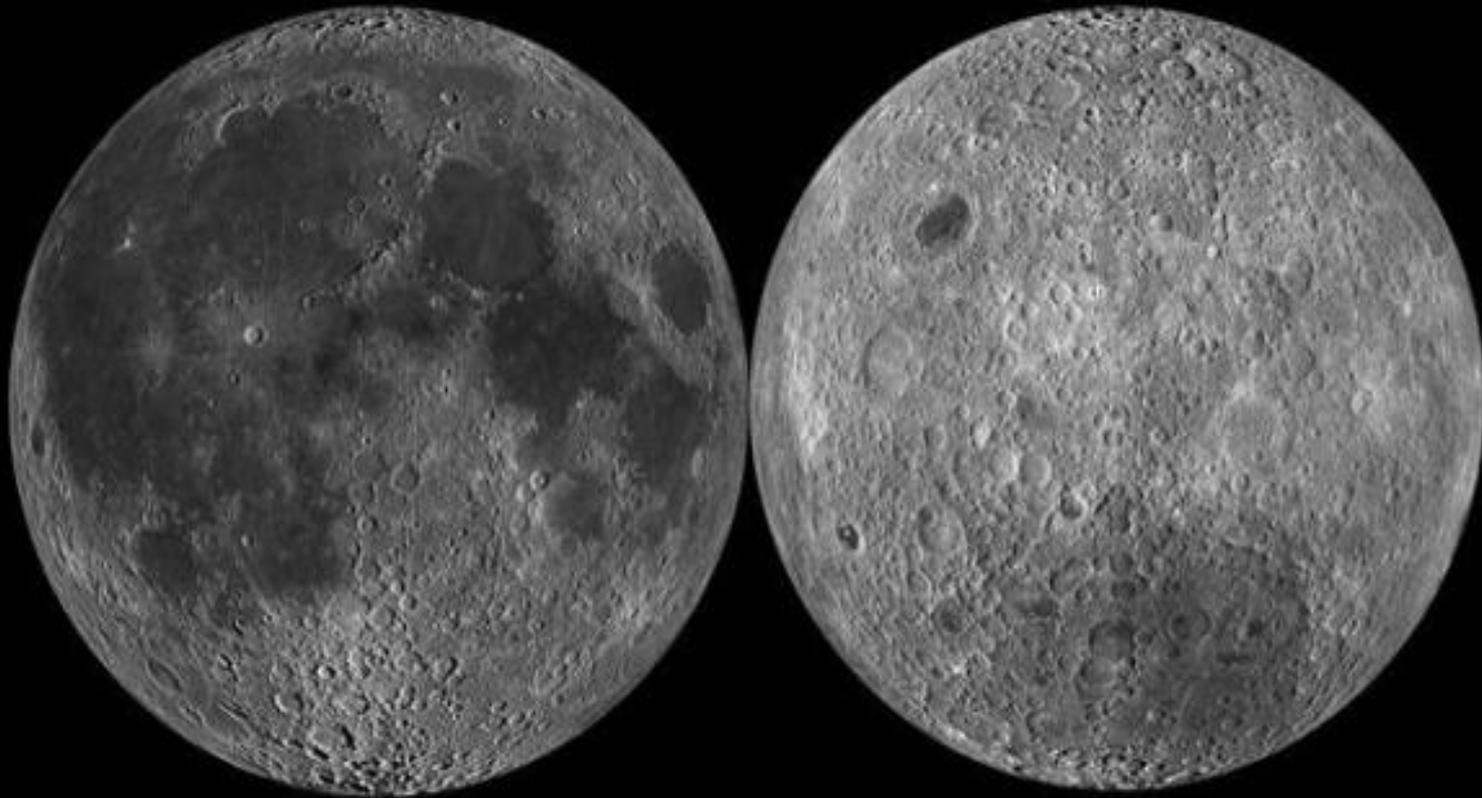
The low- l anomaly

- Theory (the Λ CDM model) fits the Planck data remarkably well at small and intermediate angular scale
- Planck shows that, at very large scales, the fit is not good \rightarrow there is an “anomaly”?
- This may suggest that the standard accepted model is incomplete.

A known celestial source

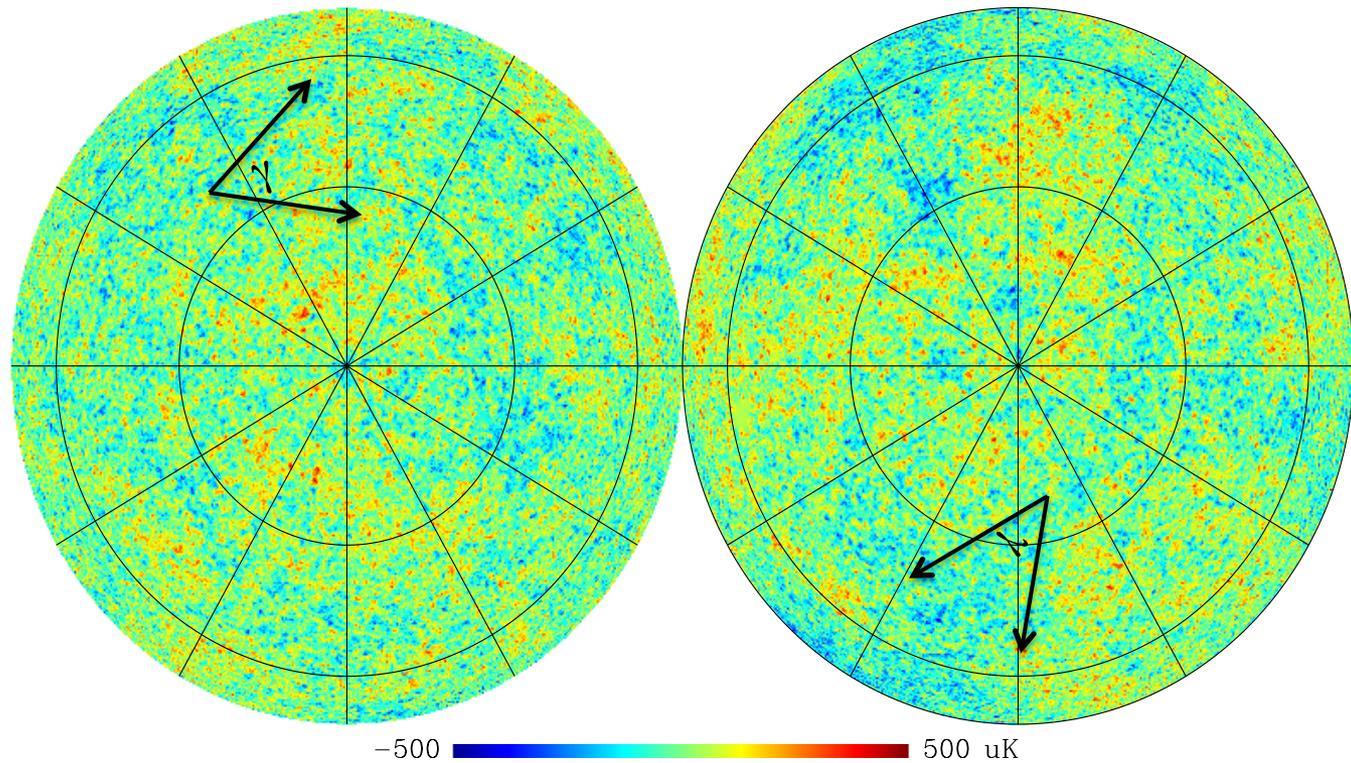


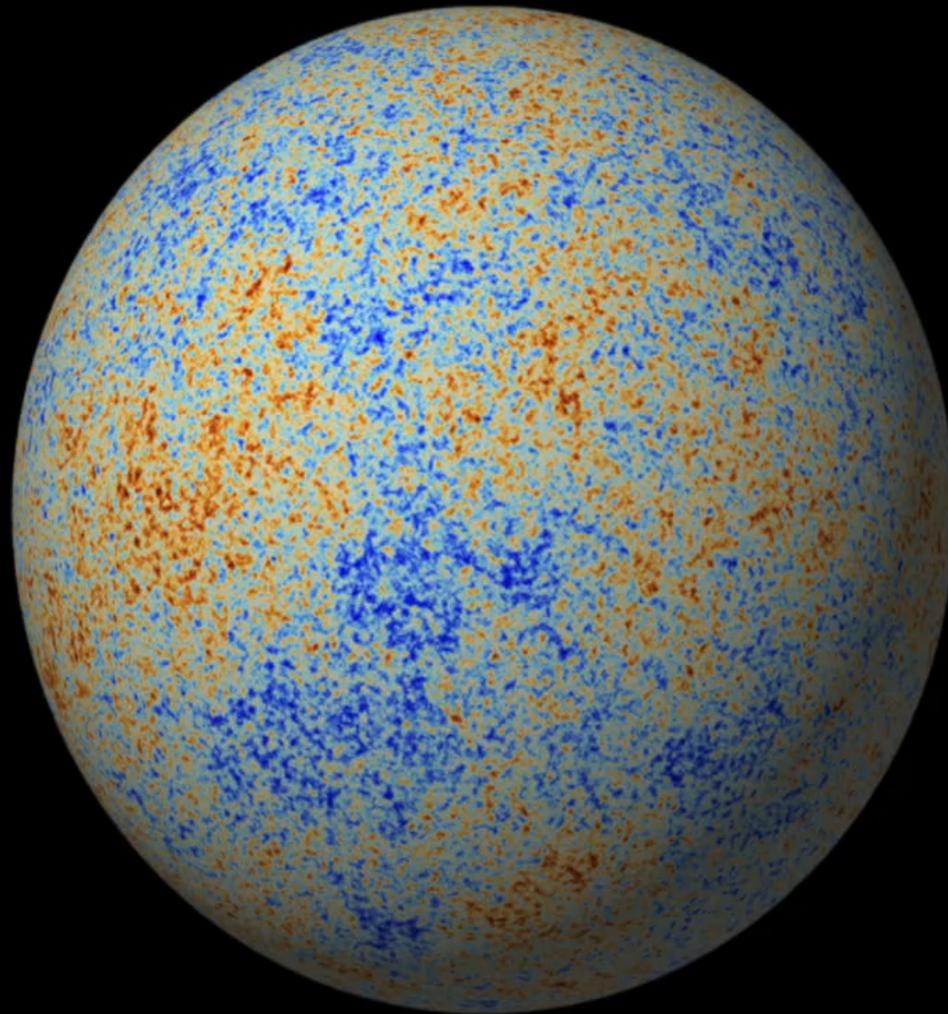
Does the other side of the Moon look alike?



Is the Universe statistically isotropic?

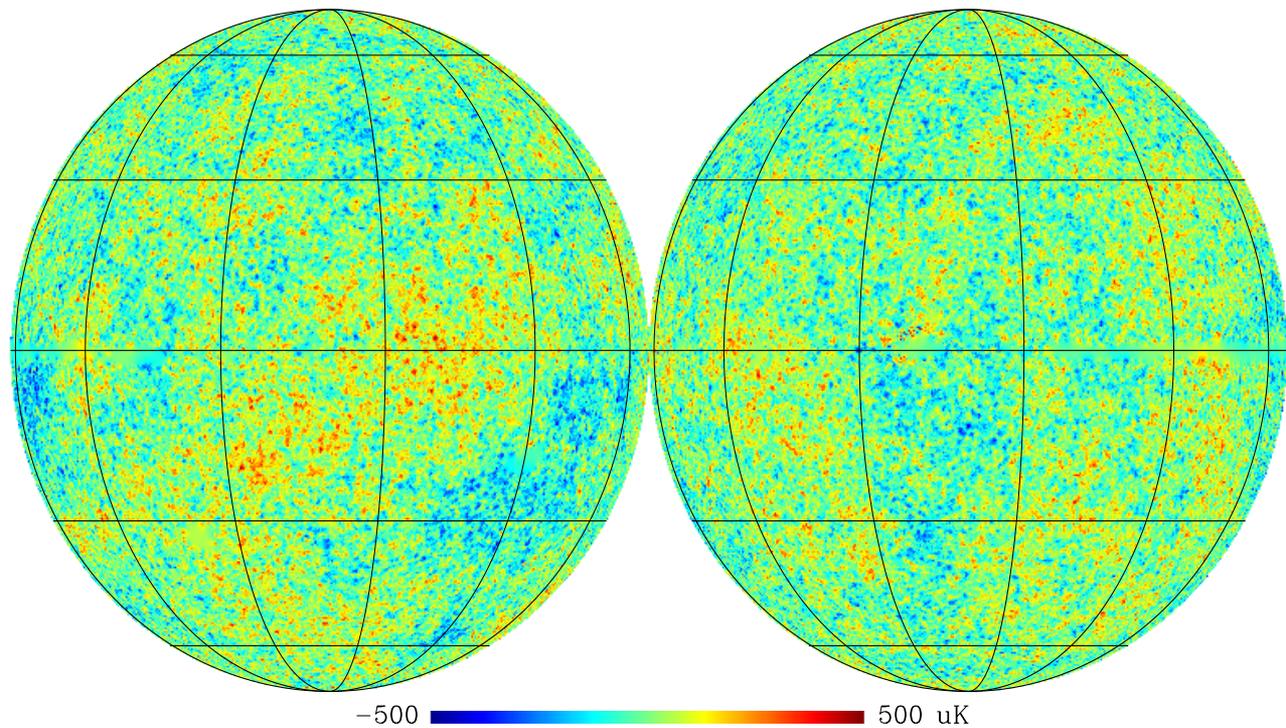
Isotropy is a fundamental assumption of the LCDM model
It must be tested.



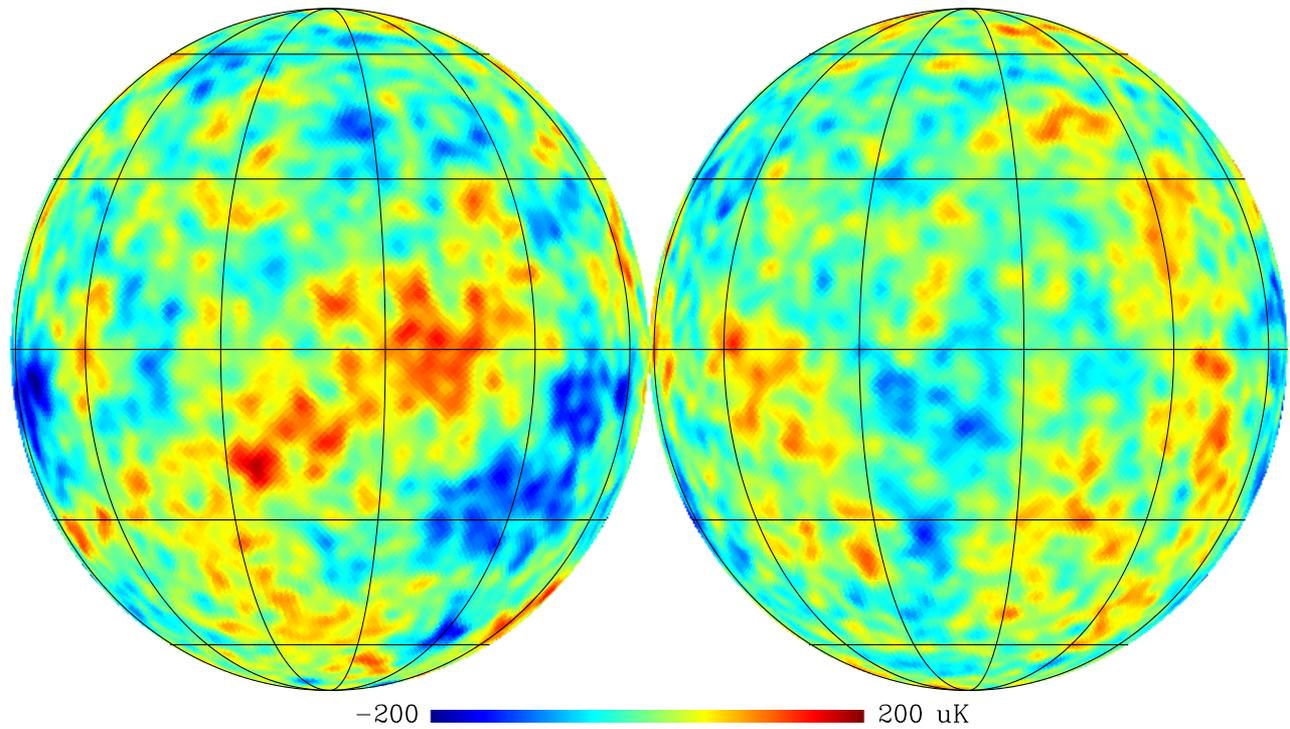


Is the Universe isotropic?

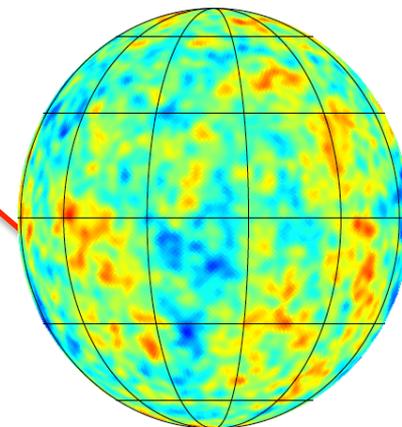
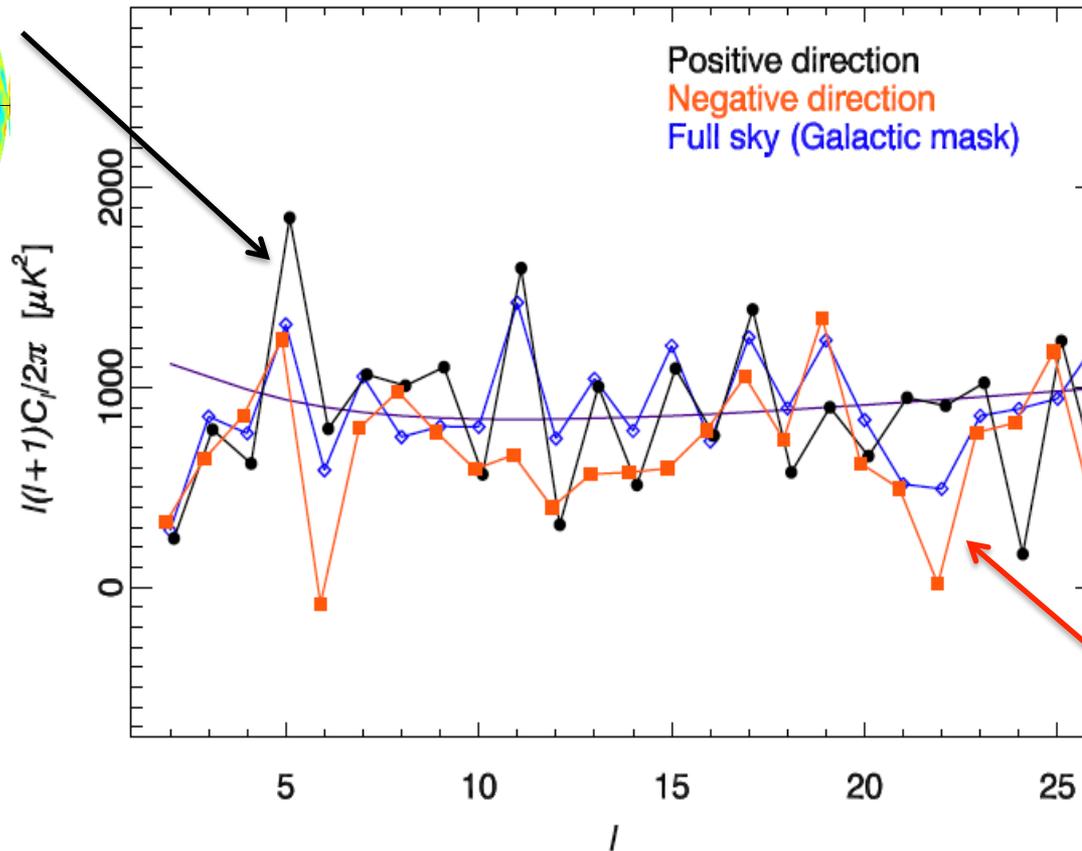
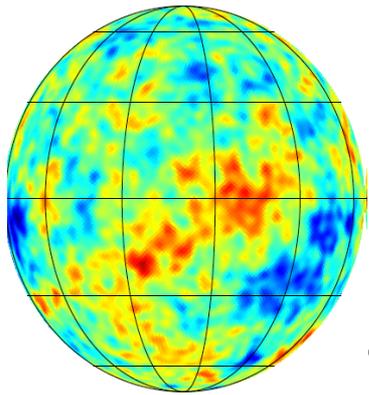
Two sides of the same (celestial) sphere



Take the high resolution stuff out



Are the two hemispheres compatible?

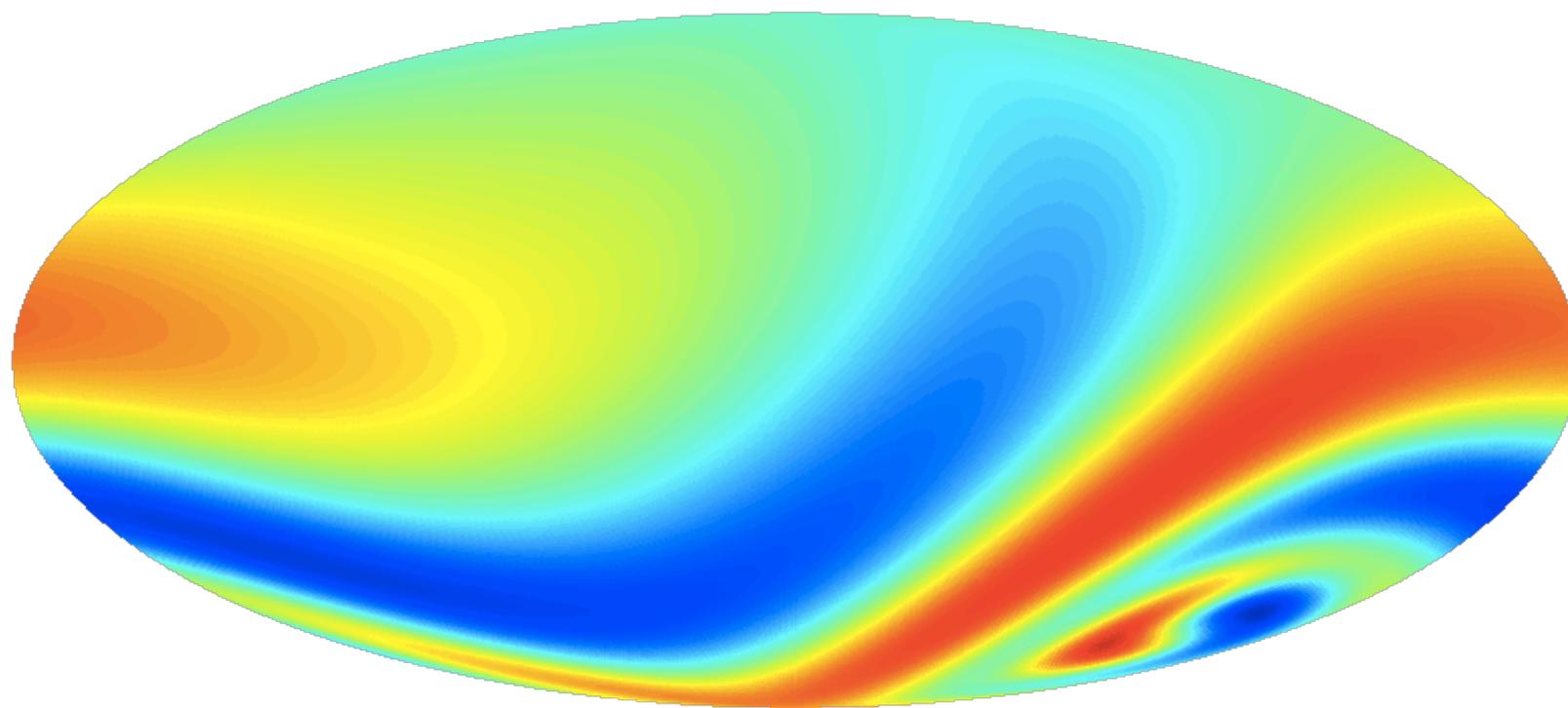


So, what are we seeing?

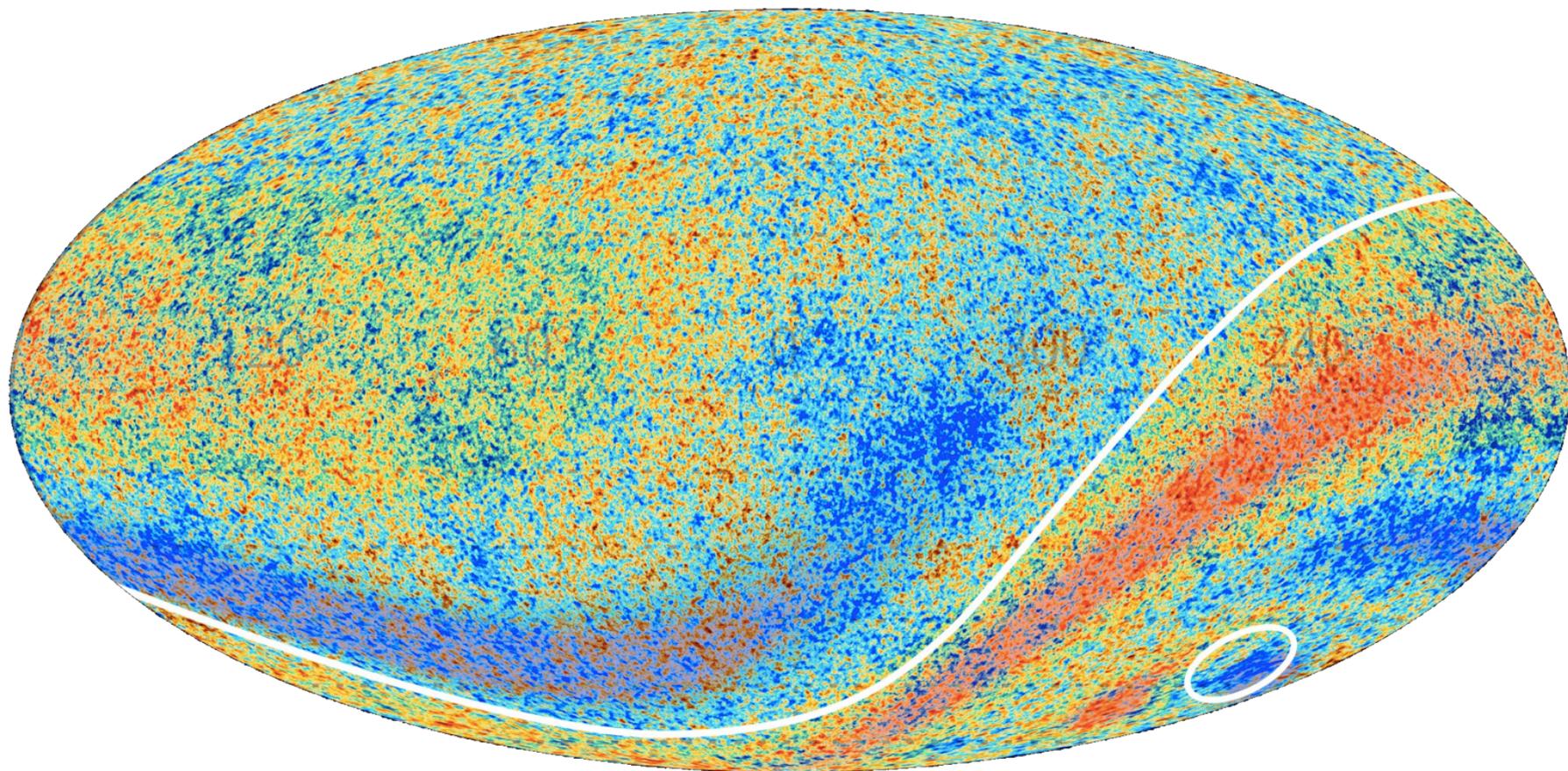


- Are these anomalies a manifestation of some yet unknown physics? Perhaps. Are there interpretations?
 - Phenomenological, e.g. dipole modulation. Is the dipole influencing the higher multipoles for some reason?
 - Physical, e.g. Bianchi models (cosmologies of a non isotropic universe, Bianchi VII looks appealing.)
- But no really convincing explanation exists yet.
- The large scale modes in the CMB are very primordial. They can be traced back directly to the inflation. If there is really physics behind the anomalies, rest assured it is exiting.
- How do we move further?
- New theories → new models to test
- Better observations by Planck → polarization

Bianchi model VII



Does Mr Bianchi get along with Mr Planck?



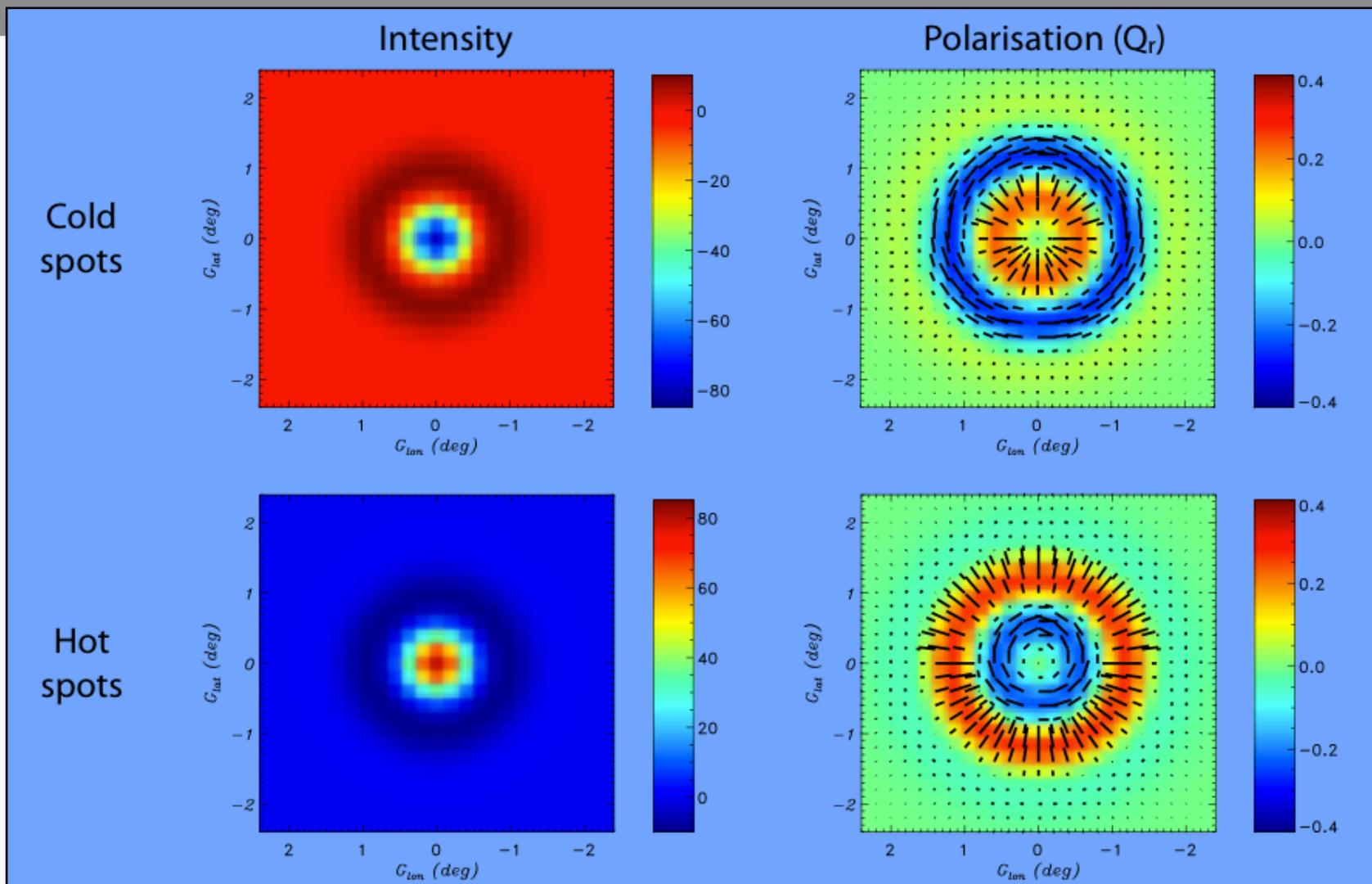
Large scale isotropy is challenged by Planck data.



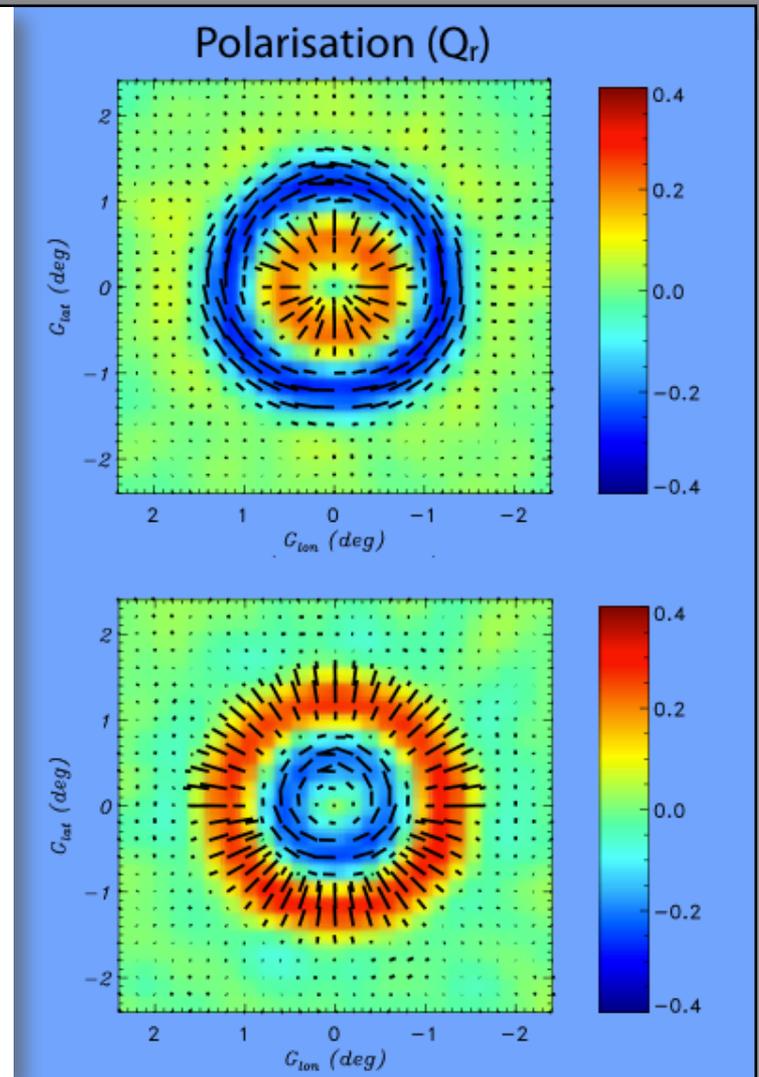
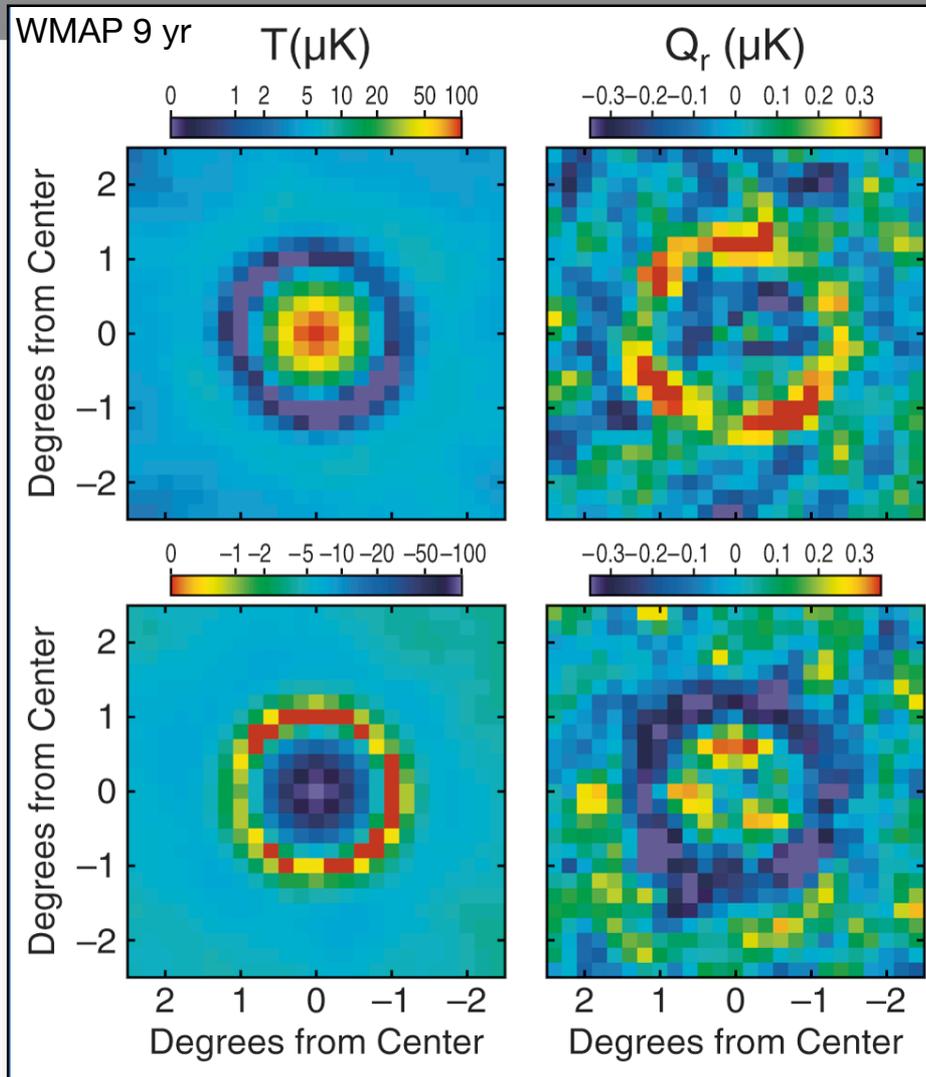
Several effects at 99% statistical significance or more:

- Λ CDM in tension with large scale anisotropy
- Hemispherical asymmetry in power spectrum
- And there are other, possibly related anomalies. Read Planck Collaboration XIII today.
 - Multipole alignment
 - A very "cold" spot
 - Phase correlations
 - Even-odd parity power asymmetry
 - And others further.
- Thanks to Planck, we are certain that they are genuine features of the CMB.
- Are they related? Is there a fundamental reason?

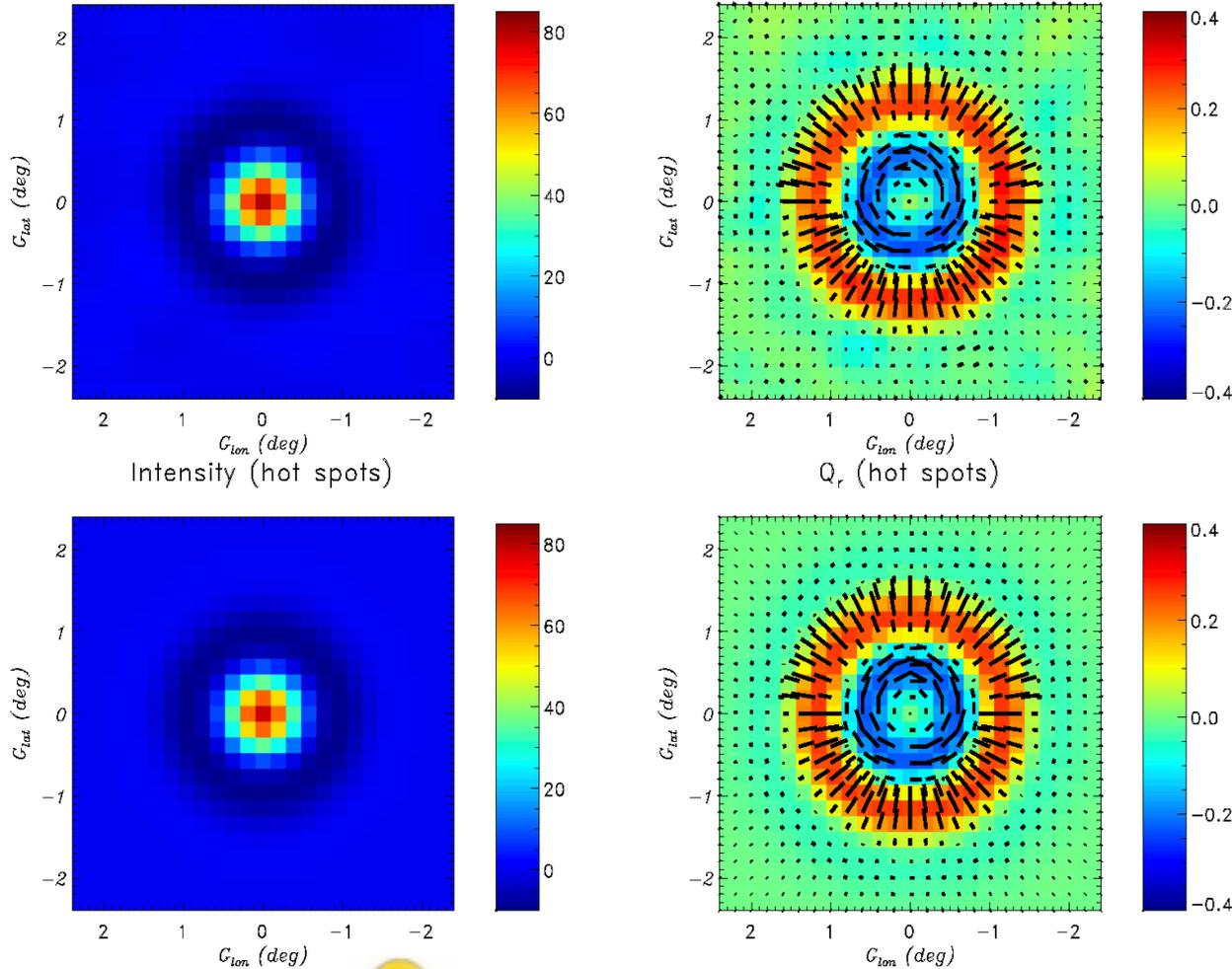
Testing polarisation via stacking



Testing polarisation via stacking



Polarisation around hot spots



Data (top) versus expectation (bottom)

→ Planck “sees” precisely the dynamics of fluctuations, at ~380 000 years



- 6-parameter “vanilla” Λ CDM model fits data very well
 - No need for additional physics
- Estimated parameters are different from previous best results
 - More matter, less dark energy
 - Hubble constant smaller than commonly-held
 - Curvature very tightly constrained
- No evidence for >3 types of neutrinos
- No evidence for non-gaussianity
- New constraints on inflationary models
 - Single field slow-roll inflation is preferred (n_s clearly just less than 1)
- Confirmation of WMAP anomalies
 - Deficit of power at large angular scales
- High significance of CMB lensing and CMB-CIB cross-correlation

The future for Planck



- Planck has already been a huge success
 - Has worked near-flawlessly since launch and well beyond baseline
 - Has met all performance requirements
 - With March 2013 release, has met most of its science goals already
- But Planck is not done: much more to come, including polarisation

- August 2013:
 - End of second LFI-only extension (total 8 sky surveys)
- October 2013:
 - Decommissioning / injection into “museum orbit”
- February 2014:
 - Delivery of full cryo- and first LFI-only extension data to ESA; release March 2014
- August 2014:
 - Delivery of new generation of products, including second LFI-only extension data to ESA; release September 2014

Conclusions

- The 2013 Planck T map anisotropy leaves behind it a legacy which will stay for many years (...before next Planck release) and will not be replaced easily.
- Excellent agreement between the Planck temperature spectrum at high l and the predictions of the Λ CDM model.
- But...anomalies are also seen and will be investigated

Next release

- **2014**: Twice as much data (LFI is still in operation and in August 2013 it will reach 8 sky observed surveys)
- Expected results:
 - By measuring polarisation B modes Planck may detect primordial gravitational waves
 - From B modes we can measure the energy scale of inflation and constrain the nature of the "inflaton"
 - Next release will be the input to understand if the "deviations" are fundamental and if we need a "new physics"

Cosmological parameters

6-parameters model

Parameter		2013 uncertainty (Planck+WP)	Expected 2014 (Planck T+P)
Baryon density today	$\Omega_b h^2$	0.00028	0.00013
Cold dark matter density today	$\Omega_c h^2$	0.0027	0.0010
Thomson scattering optical depth	τ	0.013	0.0042
Hubble constant [km/s/Mpc]	H_0	1.2	0.53
Scalar spectrum power-law index	n_s	0.007	0.0031

Constraints on other parameters

Parameter		2013 uncertainty (Planck+WP)	Expected 2014 (Planck T+P)
Effective number of neutrino species	N_{eff}	0.42	0.18
Fraction of baryonic mass in helium	Y_p	0.035	0.010
Dark energy equation of state	w	0.32	0.20
Varying fine-structure constant	α/α_0	0.0043	0.0018

→ Expected reduction in error bars by factors of 2 or more

The scientific results that we present today are a product of the Planck Collaboration, including individuals from more than 100 scientific institutes in Europe, the USA and Canada



Planck is a project of the European Space Agency, 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.

A. Zacchei
"Frequency maps"