Title: Is Cosmology in 300BC? The Search for Alternate Universes with Planck

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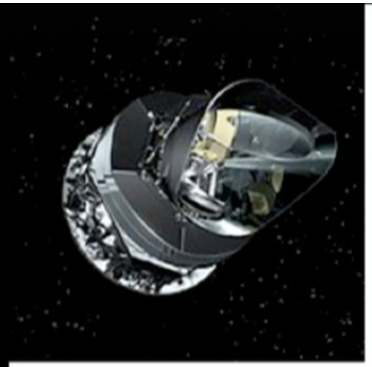
Abstract: In the last few years, we have made remarkable progress in understanding the properties of our observable Universe which appears to have evolved from a hot Big Bang 13.7 billion years ago. The fine-tuning of initial conditions required to reproduce our present day Universe suggests that our Universe may merely be a region within an eternally inflating super-region. Many other regions could exist beyond our observable Universe with each such region governed by a different set of physical parameters than the ones we have measured for our Universe. Collision between these regions, if they occur, should leave signatures of anisotropy in the cosmic microwave background. I will present our analysis of the Planck data which had led to the detection of spectral anisotropies at the location of some high-latitude cold spots associated with the CMB. I will argue that the excess emission may be due to enhanced Hydrogen Paschen-series emission from the epoch of recombination. The strength of the emission would favor a collision with an alternate Universe with a much higher baryon to photon ratio than our own and suggest an anthropic explanation for the value of the cosmological constant. Future, observational tests of this hypothesis will also be discussed.



Caltech

Is Cosmology in 300BC?

The Search for Alternate Universes

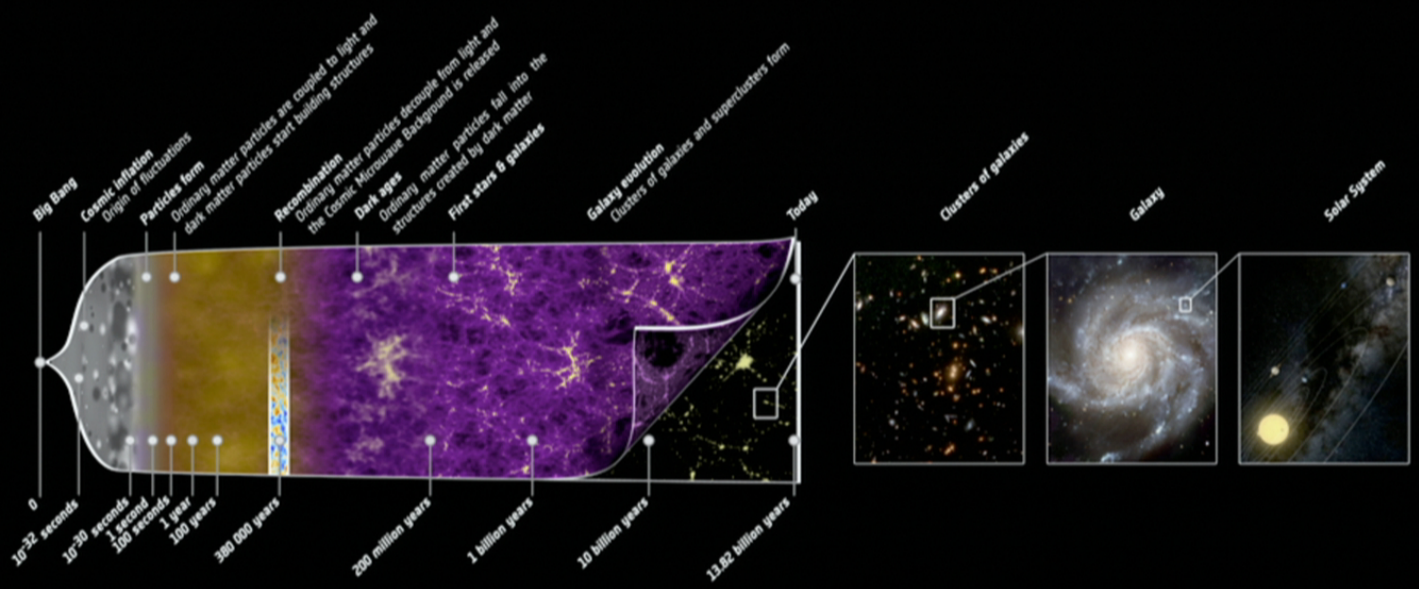
Ranga Ram Chary

U.S. Planck Data Center, IPAC/Caltech

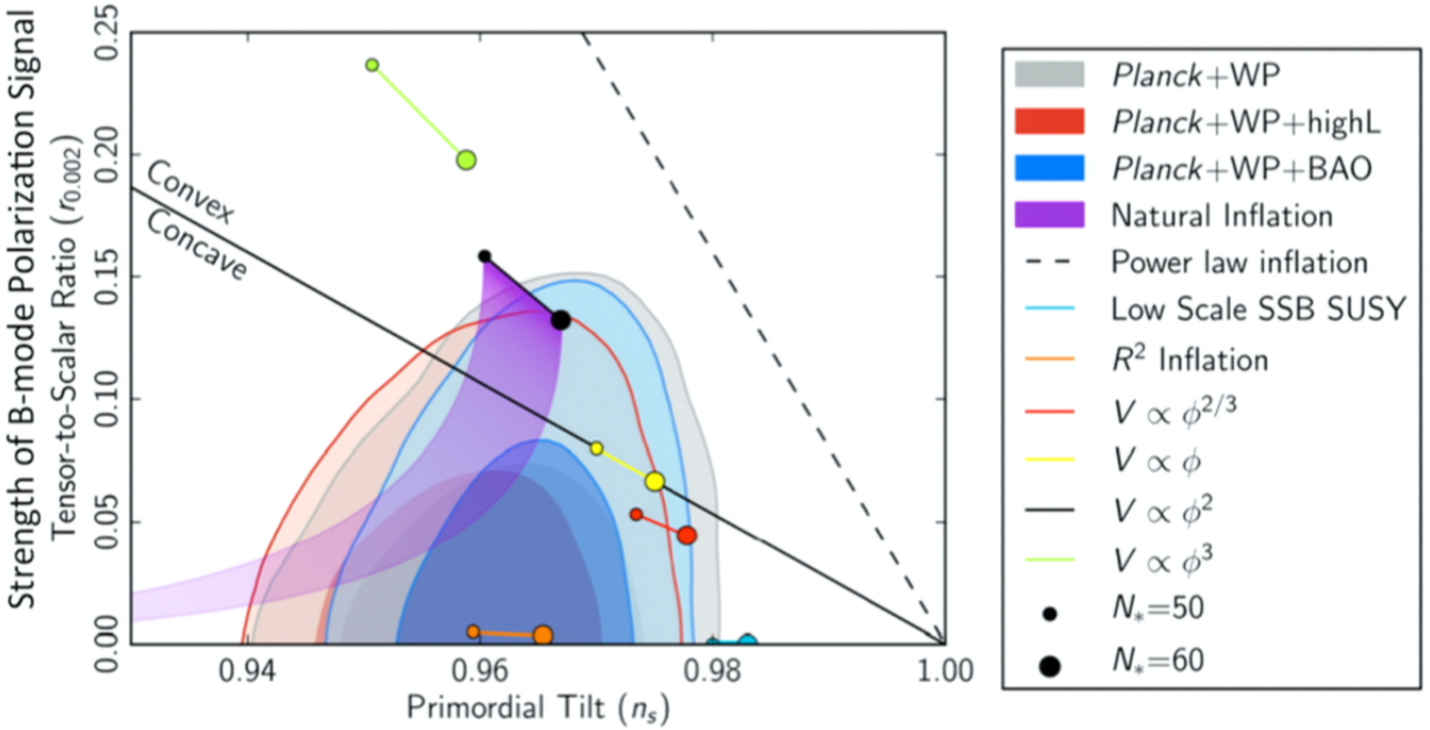
Planck Collaboration including RC et al. 2015
R. Chary 2016, ApJ, 817, 33
HFI PI is J-L Puget; Data manager is F. Bouchet

World view of 17th Century

Is our current picture of the Universe grossly incomplete?



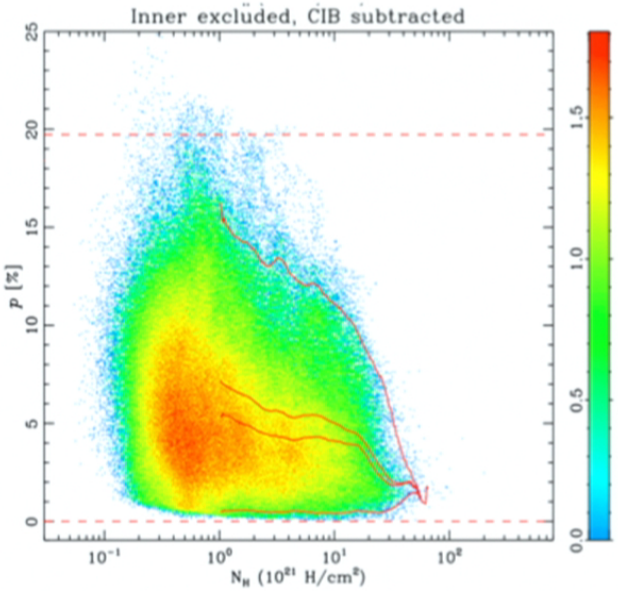
Parameters resulting from Higgs Inflation ($r\sim0.0033, n_s\sim0.97$)



Tilt in Temperature Power Spectrum

Courtesy of Bezrukov & Shaposhnikov 2008/2009, WMAP and Planck Collaborations 2015

Foregrounds (Dust+Synchrotron) make B-mode detection unlikely in the future



High dust polarized fractions in low dust intensity regions!

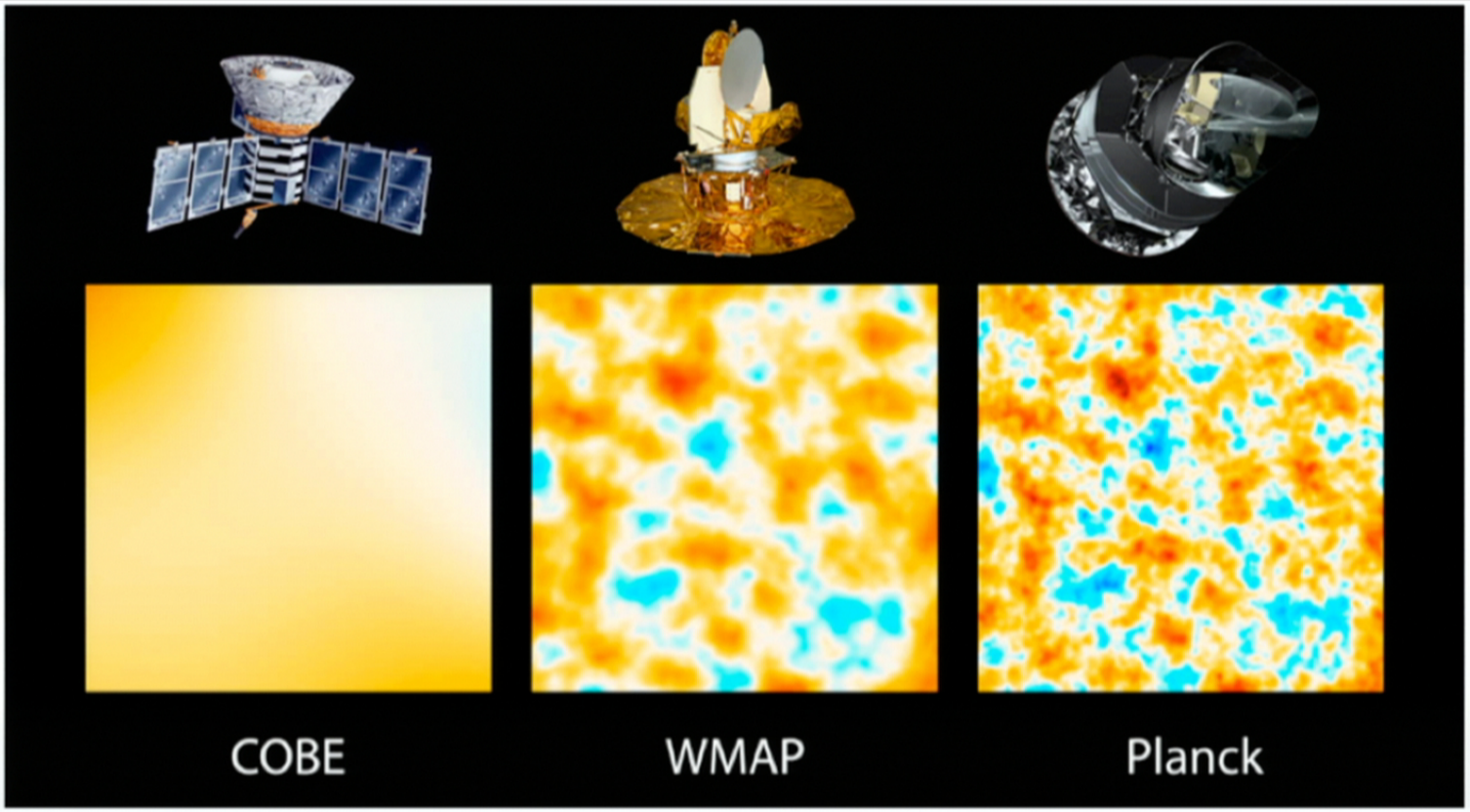
Planck Intermediate Results XIX (arXiv: 1405.0871) led by J-P Bernard;
See also PIP led by J. Aumont; including RC

Big Problems….

- Inflaton needs to be damped by an unknown mechanism at a very precise time (within a millionth billionth billionth of a second) all over the Universe's horizon

- Has no mechanism to explain the strength of the vacuum energy which is 10^{-120} times weaker than predicted.

- Planck probes unique observational phase space compared to WMAP by straddling wavelengths where Hydrogen recombination signals are present and by being a factor of ~40 sharper than COBE/FIRAS.



R. Hurt

- Planck improved over WMAP by a factor 3 in angular resolution and 25 in instantaneous map sensitivity with respect to WMAP.
- Control of foregrounds required 9 frequencies between 30 GHz and 1 THz.

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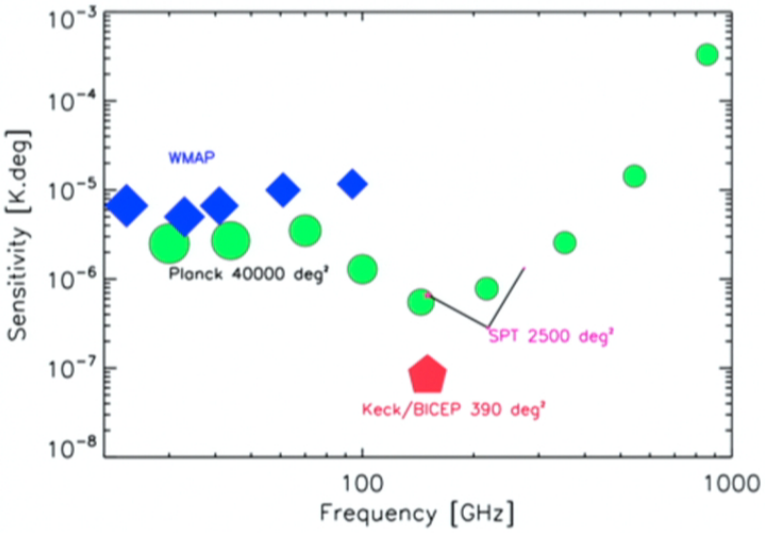
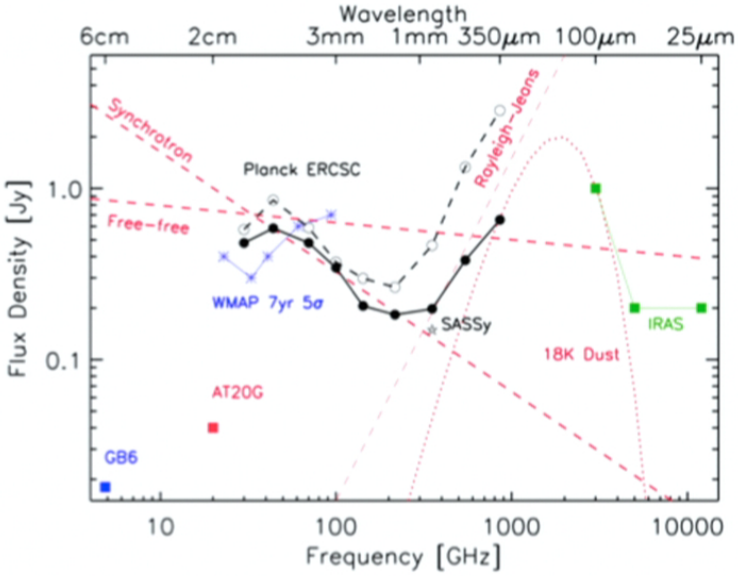
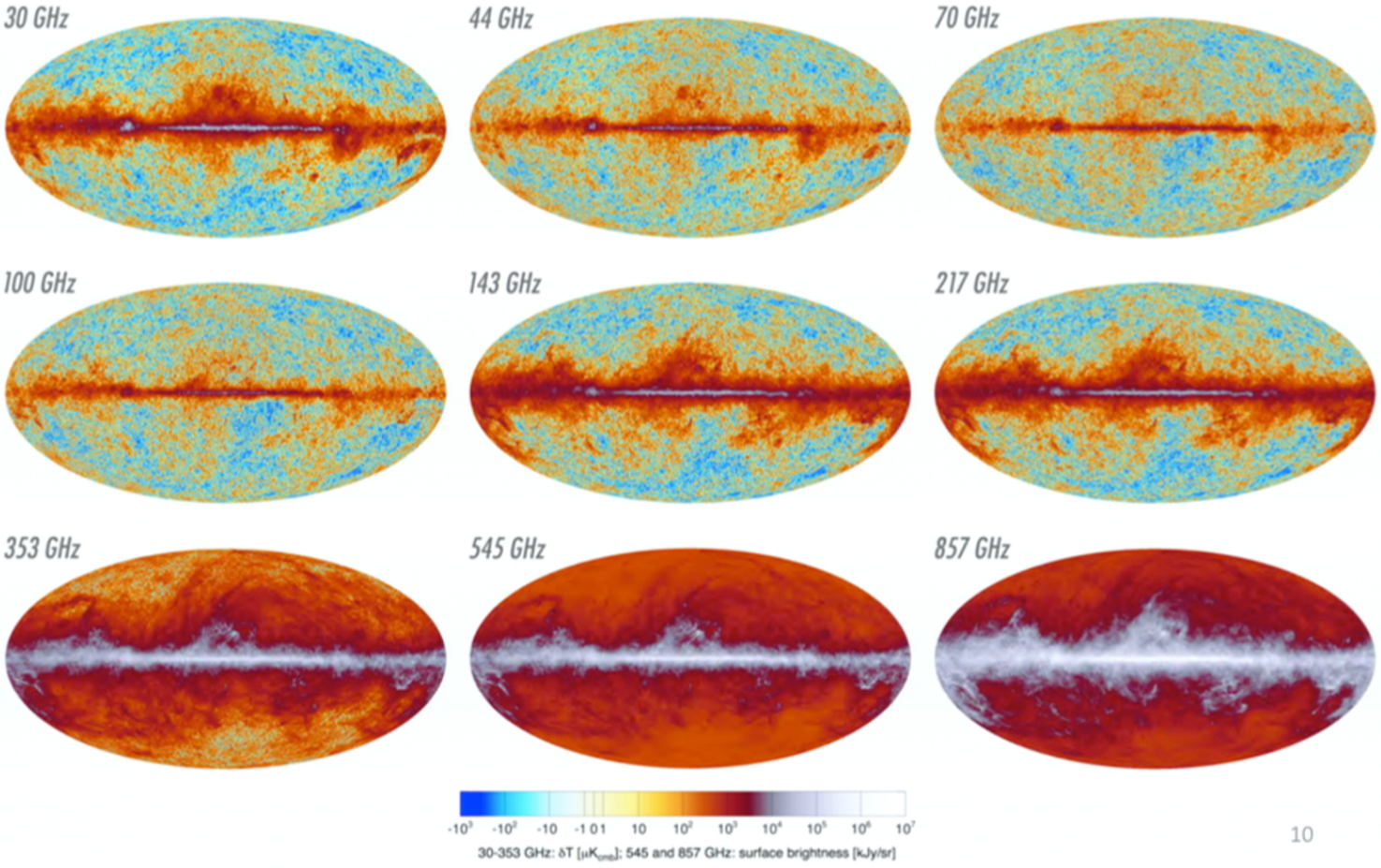
Comparison between CMB Experiments



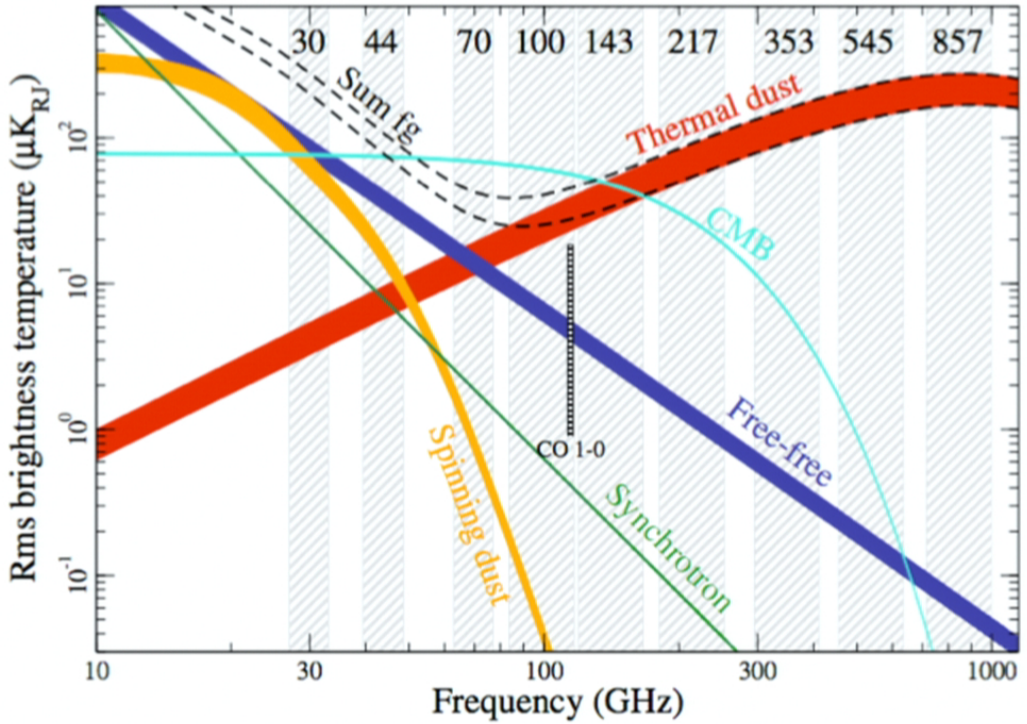


Planck Collaboration 2011, led by RC

Planck Data: All-Sky Temperature Maps

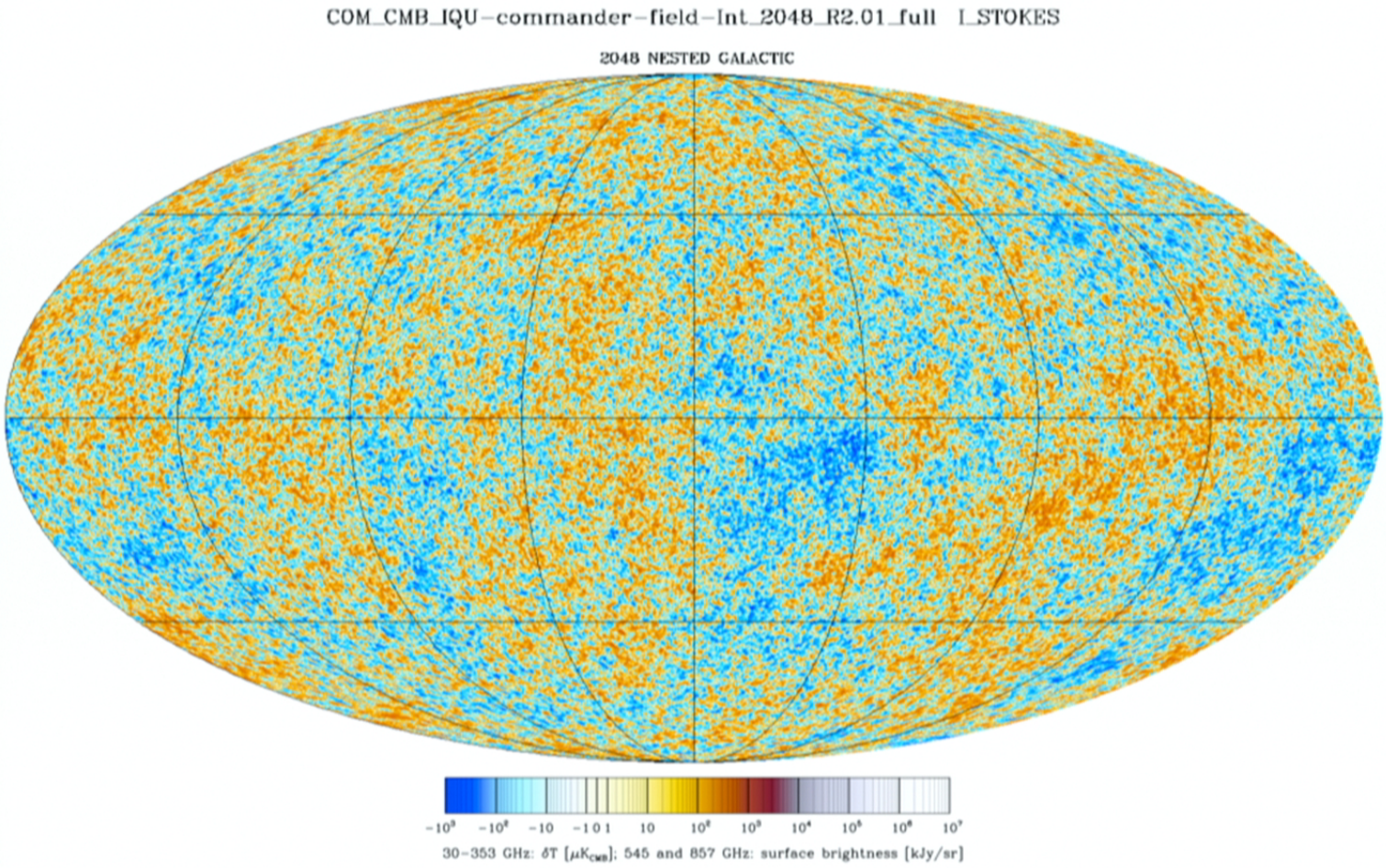


One persons signal is another persons noise



Planck Collaboration 2015; Overview paper
Relative intensities of high latitude foregrounds

This is the CMB map resulting from a multi-frequency fit to foregrounds



But what about the frequency dependence of the CMB?

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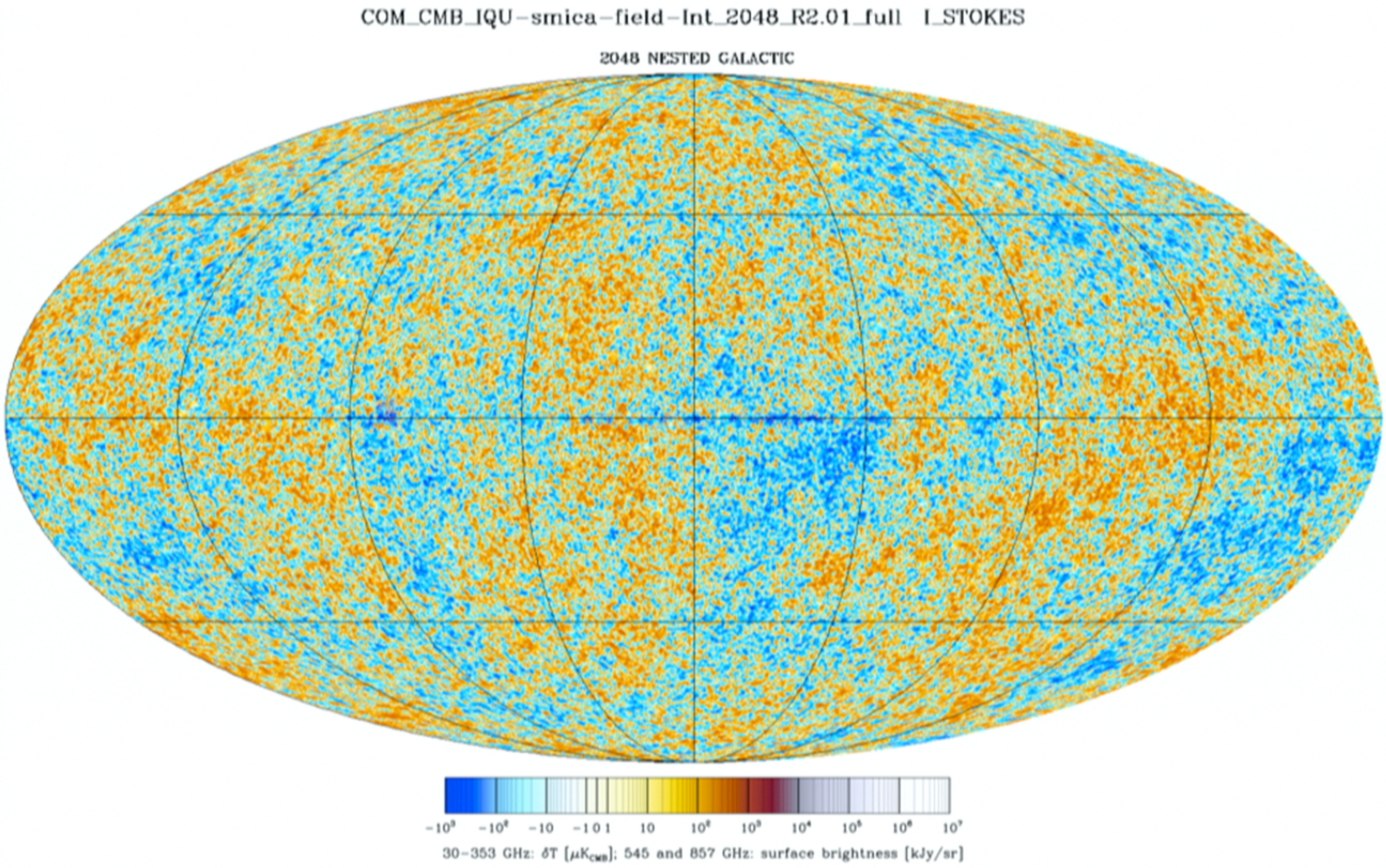

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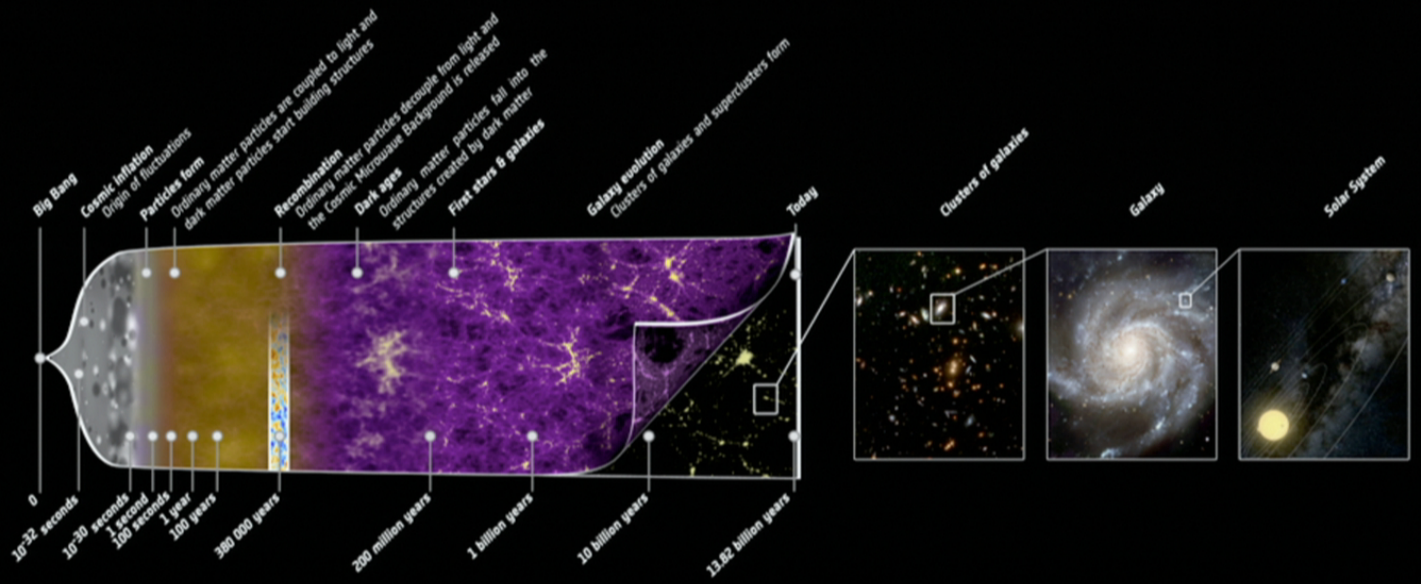
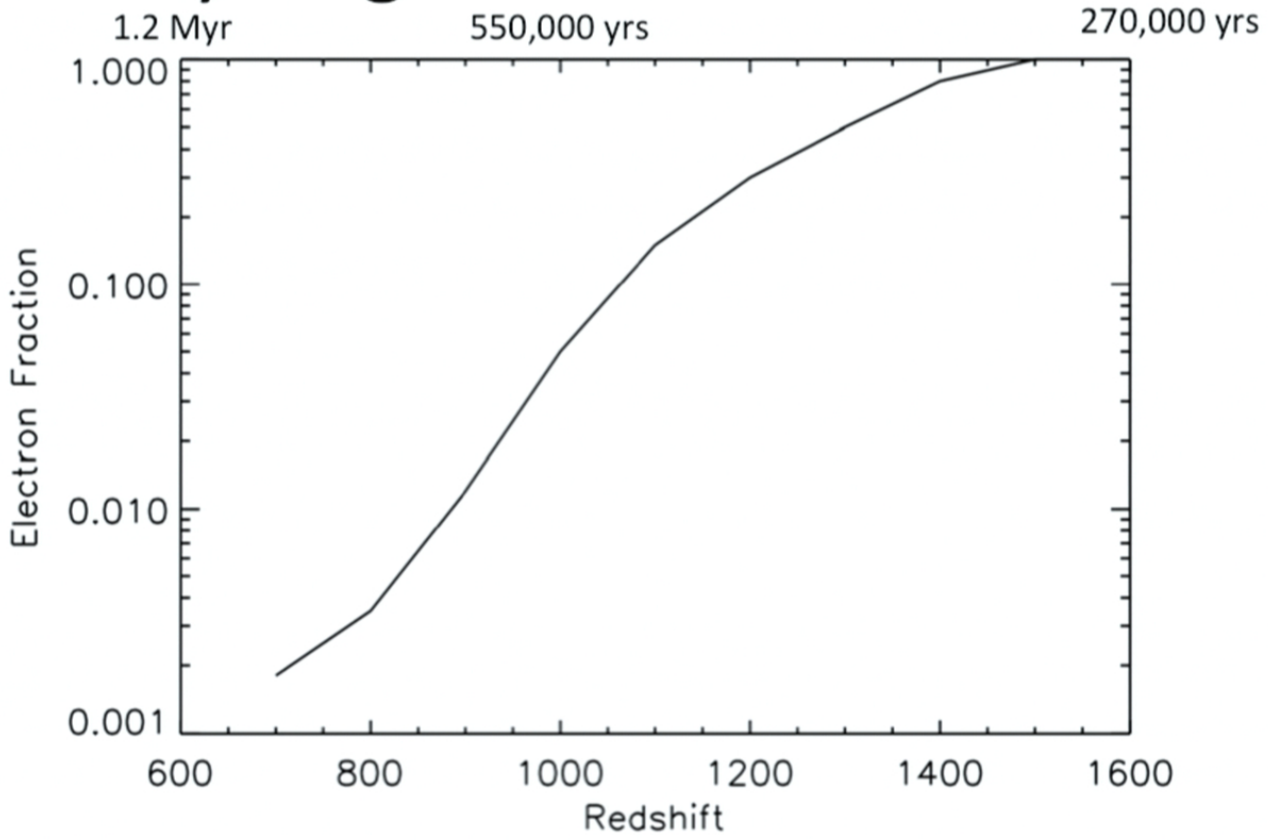
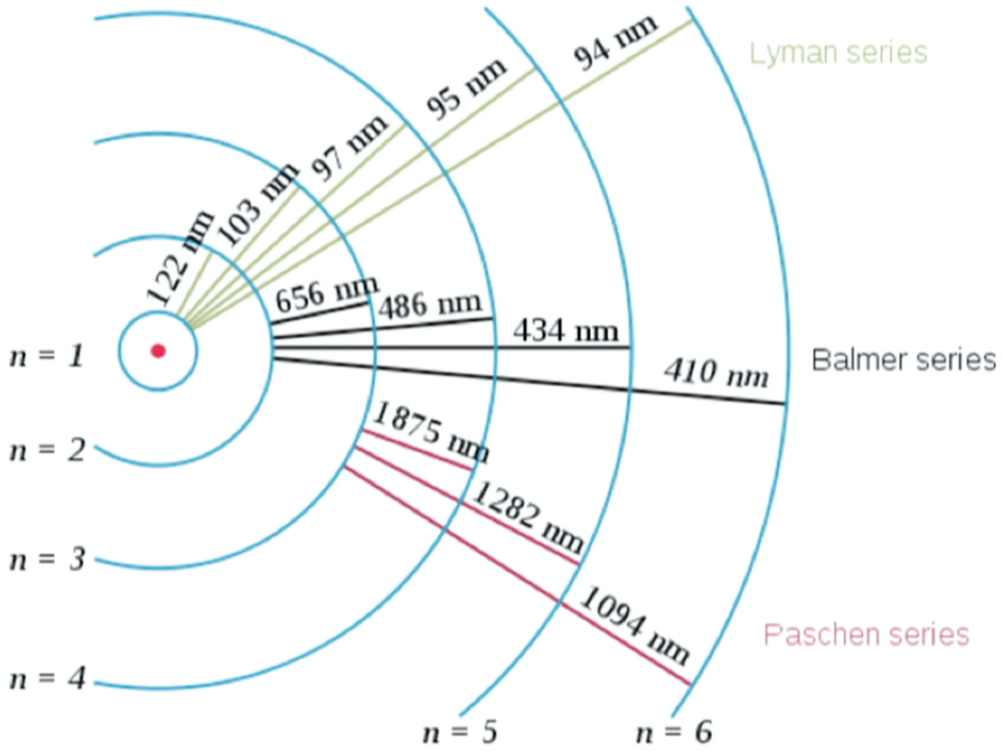

Big Bang
Cosmic inflation
Origin of fluctuations
Particles form
Ordinary matter particles are coupled to light and dark matter particles start building structures
Recombination
Ordinary matter particles decouple from light and the Cosmic Microwave Background is released
Dark ages
Ordinary matter particles fall into the structures created by dark matter
First stars & galaxies
Galaxy evolution
Clusters of galaxies and superclusters form
Today
0
10-32 seconds
10-30 seconds
1 second
100 seconds
1 year
100 years
380 000 years
200 million years
1 billion years
10 billion years
13.82 billion years
Clusters of galaxies
Galaxy
Solar System

Hydrogen Recombination

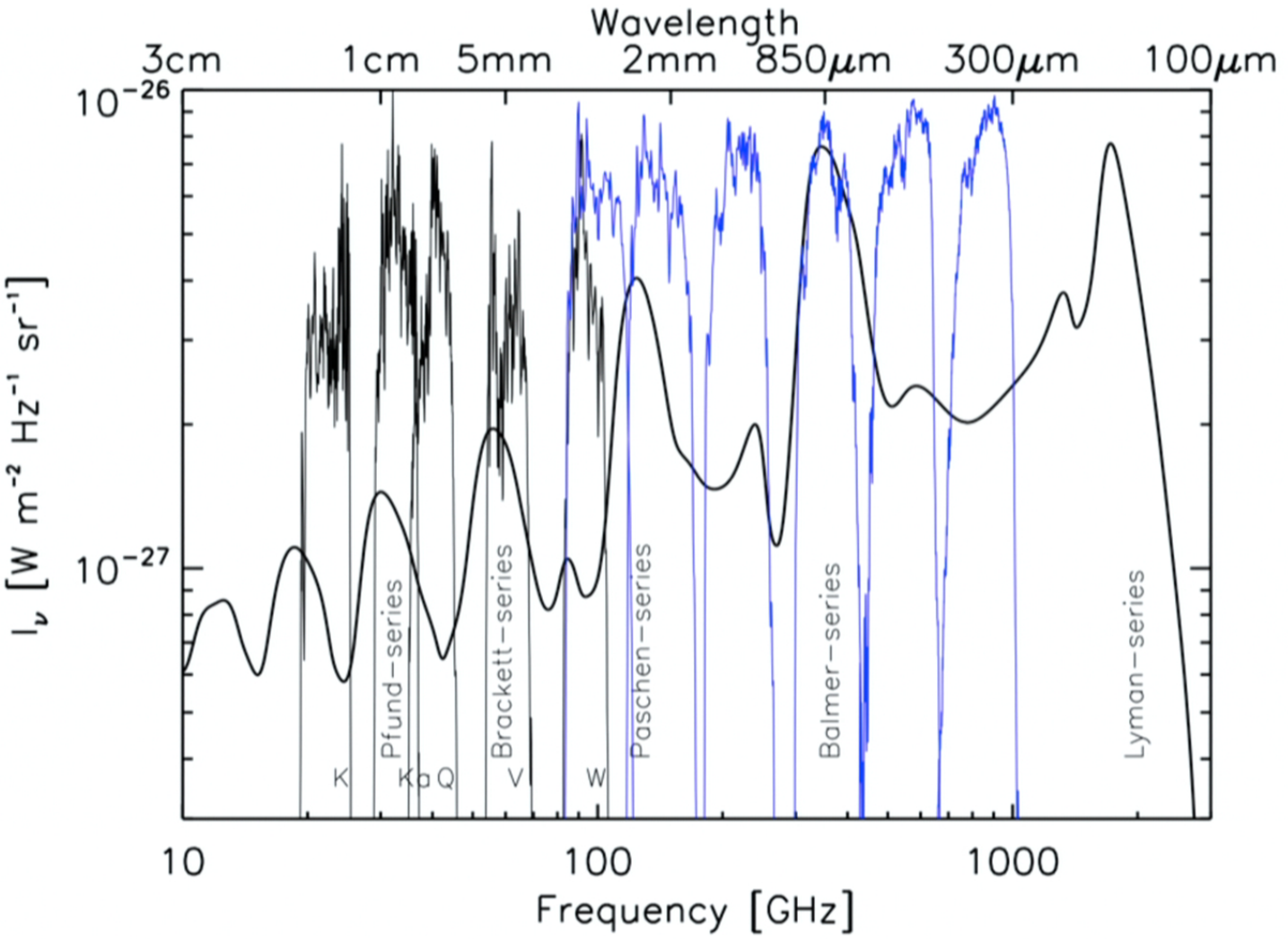


Initial work by Seager et al. 1999, 2000
Built upon by Chluba & Sunyaev, Rubino-Martin et al., Ali-Haimoud&Hirata, Lewis et al.

Hydrogen transitions



Redshift them from z~1000 to Planck bandpasses



Recombination model of Chluba & Sunyaev 2006, 2007; Rubino-Martin et al. 2008

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Are Cold Spots Regions of Higher Recombination Rate?

$$\frac{\Delta T}{T} = -\frac{\Delta \phi}{c^2}$$

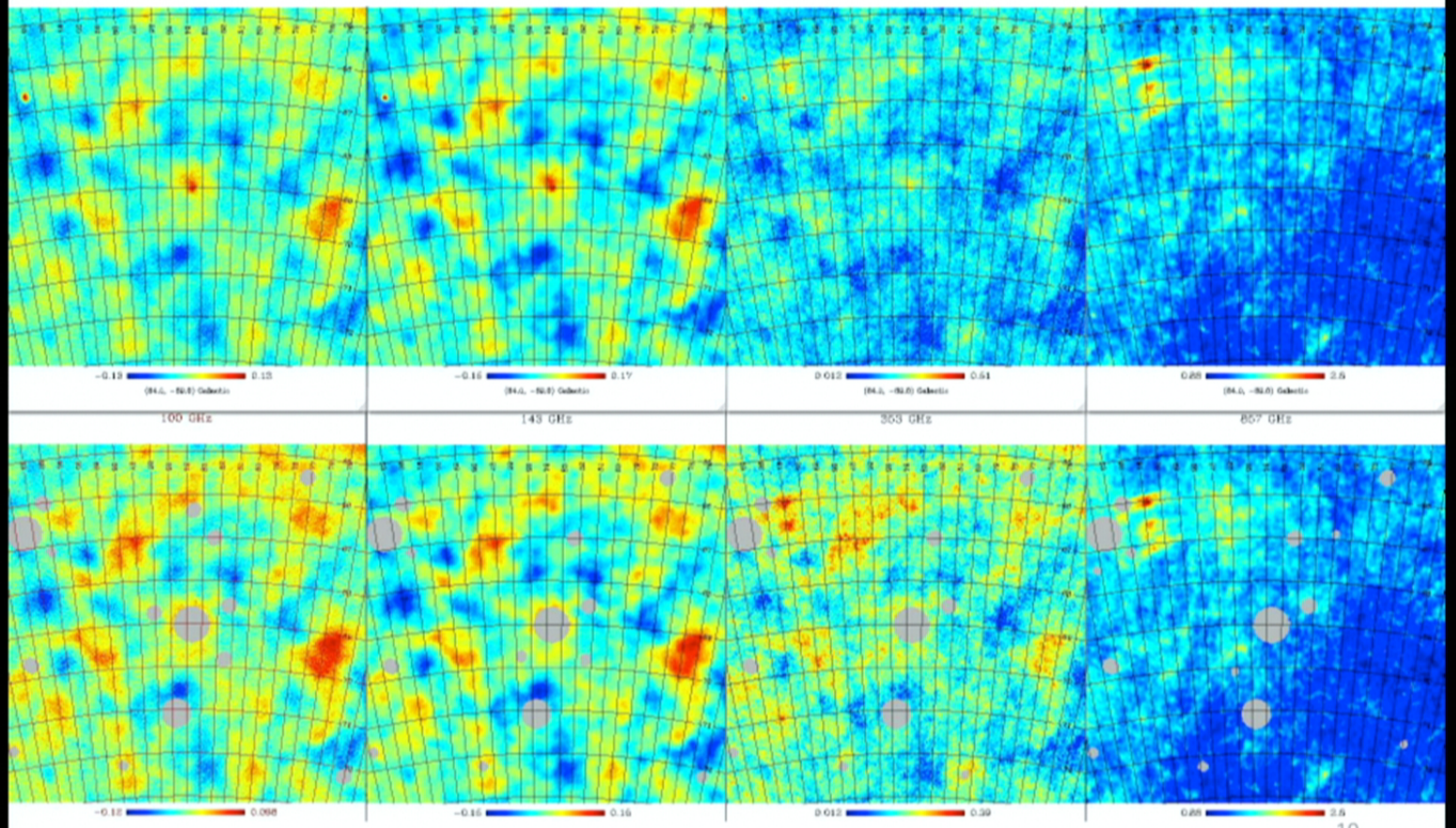
$$R = n_e n_{\mathrm{H\,II}} \alpha_{\mathrm{B}} C \ \mathrm{s}^{-1}\ \mathrm{Mpc},^{-3}$$

Sachs & Wolfe 1965; RC 2008

The Data Processing Pipeline

- Mask out individual sources and SZ clusters
- Mask out Galactic Plane |b|<20 deg.
- Subtract off joint-fit CMB from all frequencies
  - Use two best-estimate fits for the CMB (Commander & SMICA)
- Subtract off ISM foregrounds at all frequencies
  - Use 857 GHz as template for ISM
  - Use location of hot spots to estimate foregrounds at cold spots with search radii of 0.5 and 1.5 deg
- Fit for residual emission
  - Some synchrotron and free-free is present
- Search for excess at all frequencies in low ISM regions

Data processing (8° images)



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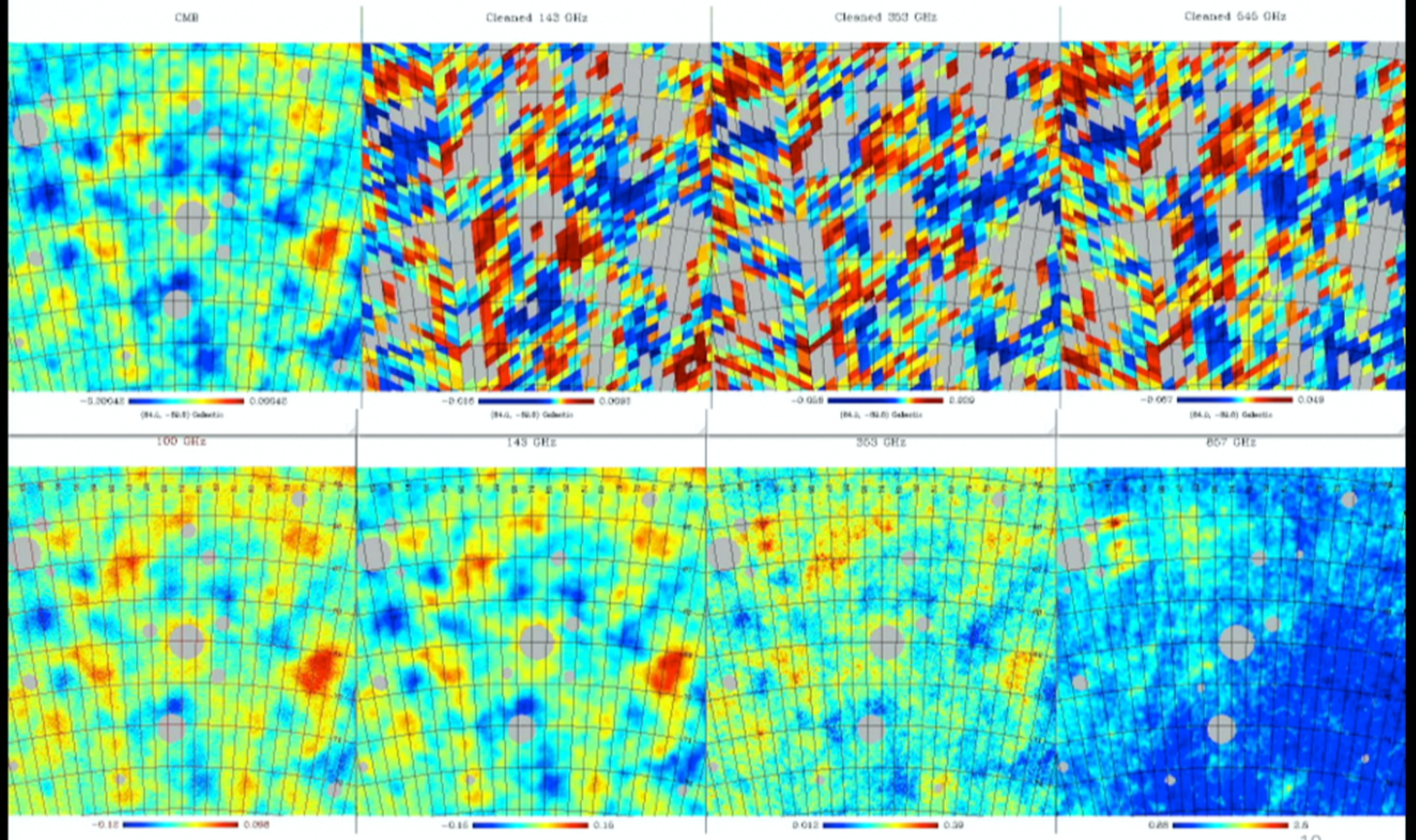

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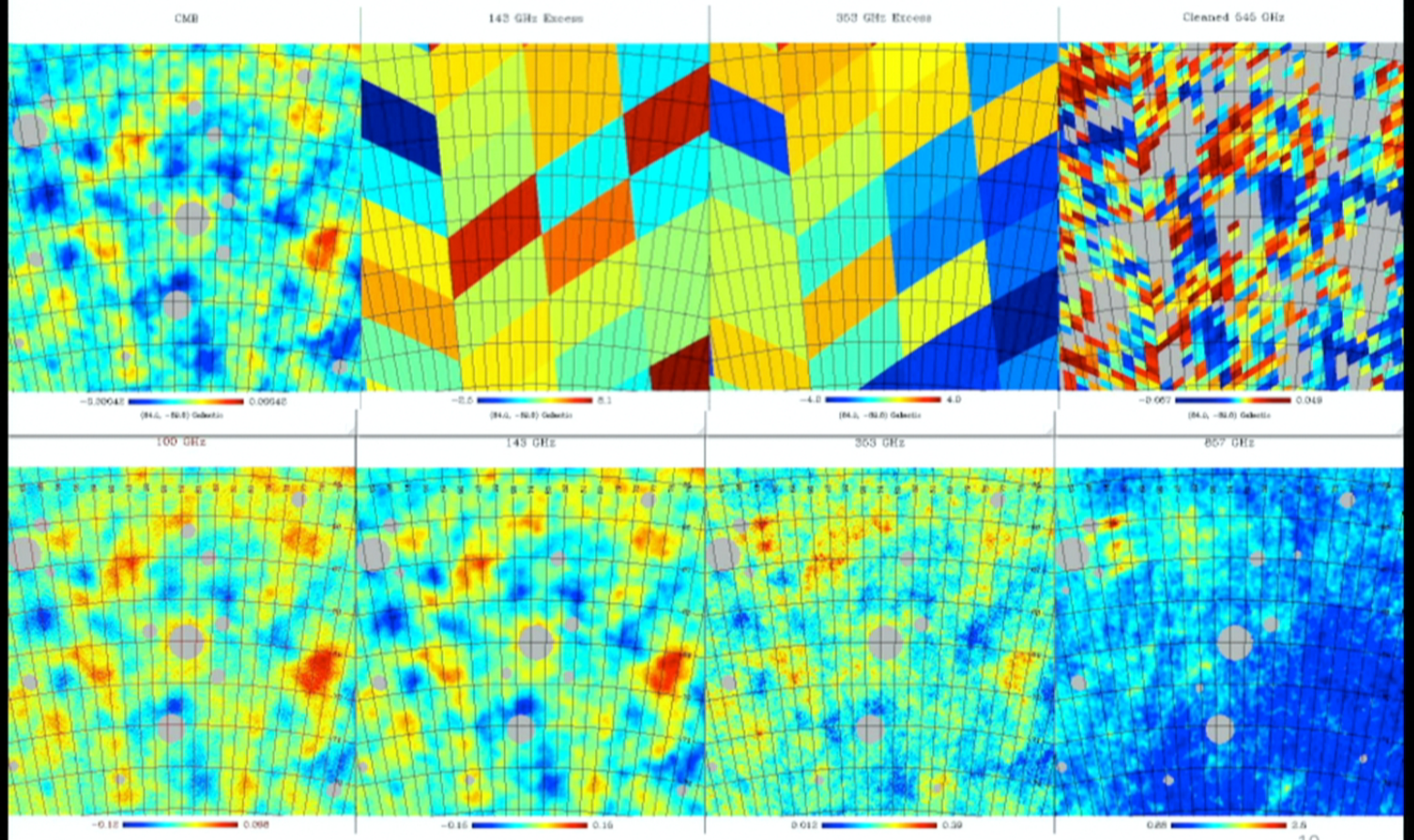
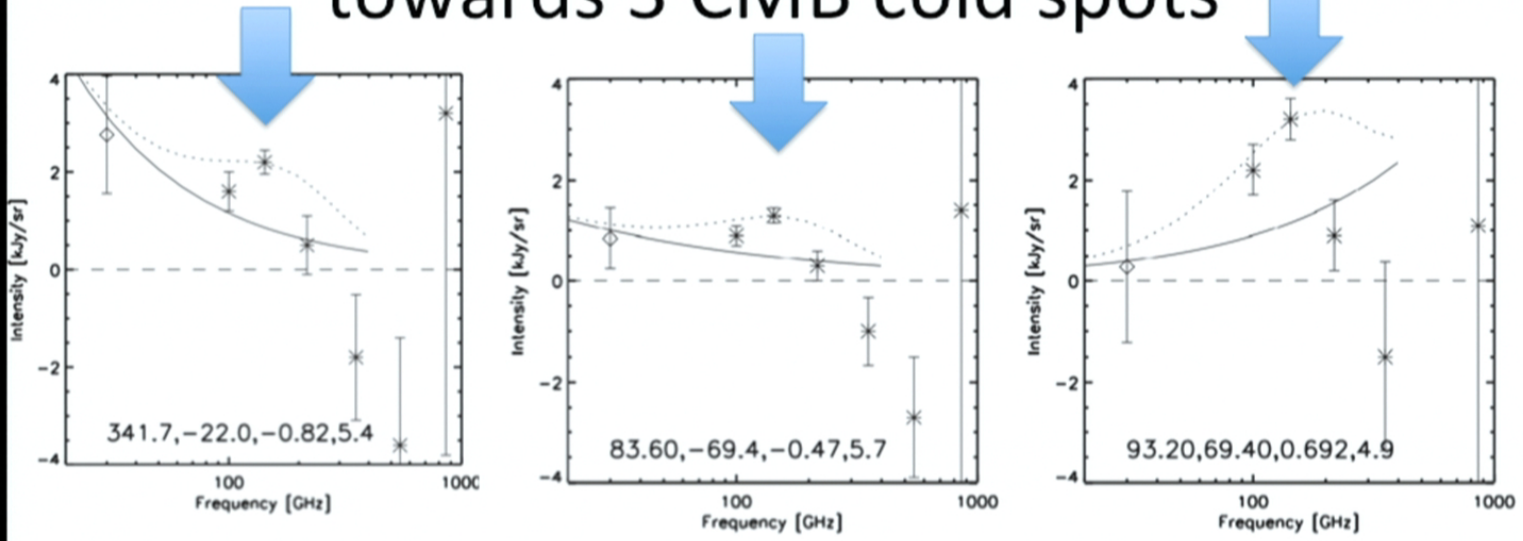


>5σ Excess 143 GHz Emission towards 3 CMB cold spots



5sigma should occur only 1 in 70 maps

5.7sigma has a 1 in 70000 maps

Solid line is best fit residual foregrounds
Dotted line is adding a 3K continuum which violates 100 & 217 GHz
μ~3-9E-6, x30-100 below FIRAS constraints

Spectral Anisotropies in CMB Cold Spots

1.8 deg Pixels with SNR>5 Excess at 143 GHz and low ISM emission

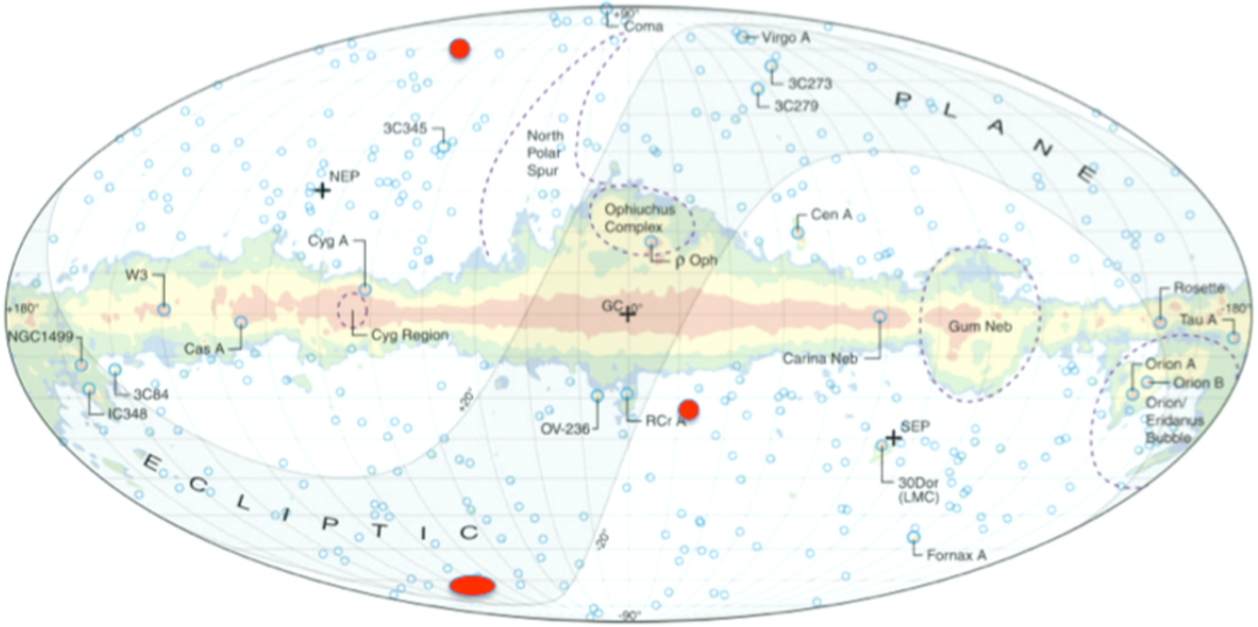


Figure 12. Microwave emission near the Galactic plane is traced by a *K*-band minus *W*-band difference map, which eliminates CMB anisotropy. A log scale is used for the color region and blue circles represent the positions of the brightest point sources, as seen by *WMAP*.

RC 2016, ApJ, 817, 33

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Features of this emission

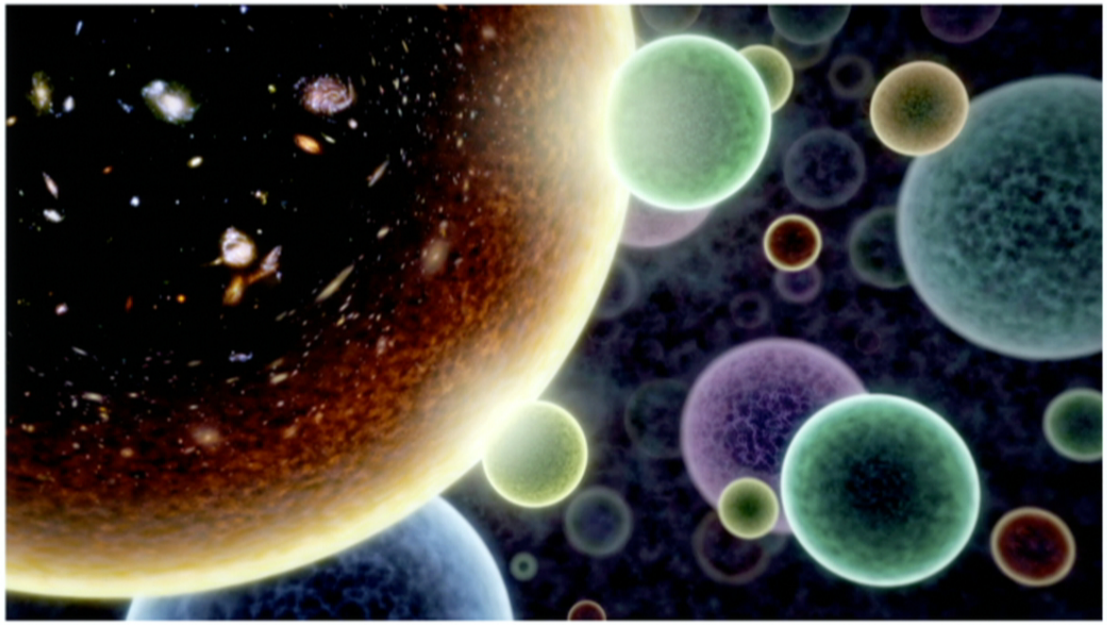
- So far, only at 143 GHz (2mm)
  - 353 GHz residuals contaminated by variation in foreground ISM colors [work in progress]
- Outside Galactic Plane in regions of low-ISM emission
- Strong at location of CMB cold spots
- Spanning 2-4 deg across

Some astrophysical implications?

- Residual thermal dust (ISM):
  - Needs to be unphysically cold ~3K and violates 217 GHz limits.
- Residual CMB:
  - Violates limits at 217 GHz
- Gigahertz peaked radio sources:
  - Appears to be x5 below what the intensity measured
- [CII] from z>10:
  - x100 lower than measured
- Unusual CS3->2?:
  - Plausible but its not a strong line and these are regions of low ISM.
- Carbon Monoxide:
  - Need unphysical velocities for the gas for 115 GHz line to enter 143 GHz bandpass. CO2->1 at z~0.7 structure would be too large spatially.

All are disfavored!

Enhanced Hydrogen Paschen-series lines from recombination?



- Stronger recombination signal in the direction of certain cold spots (~2-4 deg)?
- Requires a higher baryon density in those regions; enclosed mass is ~1E13 Msun
- The three regions would have 3000-10000 times more baryons than our Universe
- Would have to be from collisions with our bubble

RC, 2016, ApJ

Summary

- We are finding spectral anomalies (μ~3-9×10^{-6}) in the direction of CMB cold spots at 143 GHz with Planck i.e. *excess emission*.
- At the >5sigma level after removal of all foregrounds. Anomalies subtend 2-4 degrees, larger than Hubble horizon at z~1000.
- Due to Hydrogen Paschen-series redshifted from epoch of recombination at z>1000?
- Requires x4500 enhanced baryon density, which cannot be in our Universe and must be an alternate bubble.
  - Baryons from an alternate Universe falling into the fluctuations of ours?
- Need confirmation through spectral-mapping and detection of alternate Hydrogen transitions.
  - Proposed for GBT observations
  - COMap(PI: Cleary) could detect redshift Pfund-series at 30 GHz
- If true would favor eternal inflation models, with our Universe being a chance fluctuation among ~10^{1000} and a way to test string theory.

Important to keep an open mind about the Multiverse

- Martin Rees: I am sufficiently confident about the multiverse to bet my dog's life on it
- Andrei Linde: I am confident enough about the multiverse to bet my own life.
- S. Weinberg: I have just enough confidence about the multiverse to bet the lives of both Andrei Linde and Martin Rees's dog.
- Needs very very good data from independent observations. We currently have >5sigma anomalies at one frequency (143 GHz) from one mission (Planck).

R. Chary, 2016, ApJ, 817, 33

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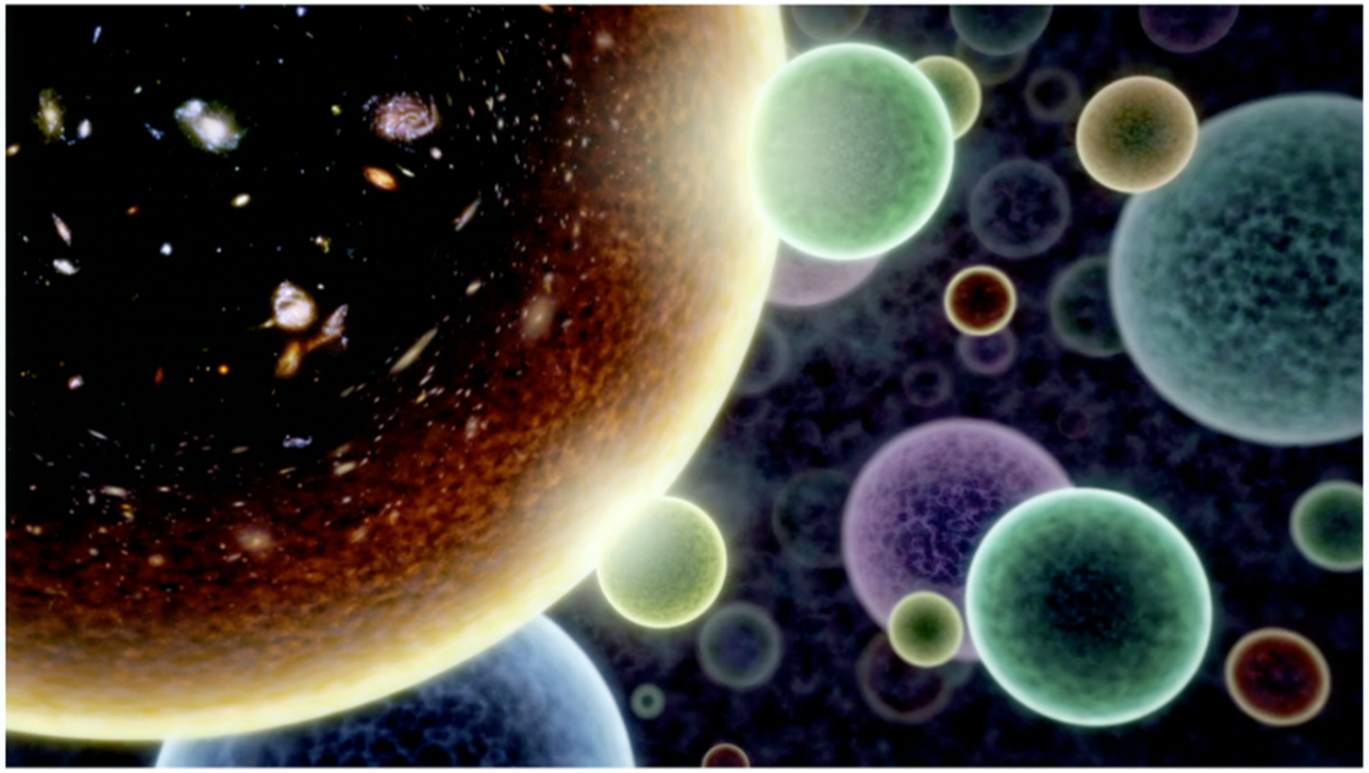

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