Cosmology III : The Universe as a high energy physics laboratory

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August 7, 2014

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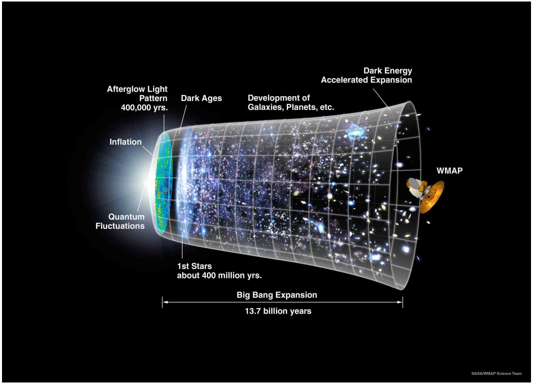

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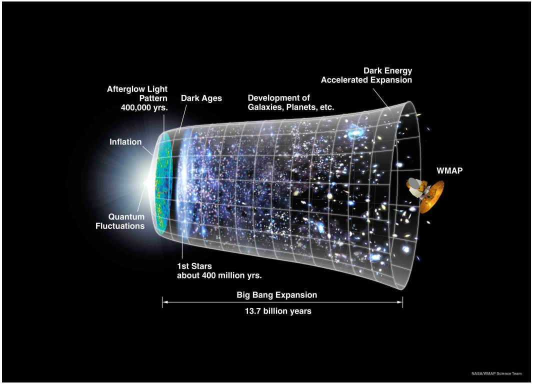

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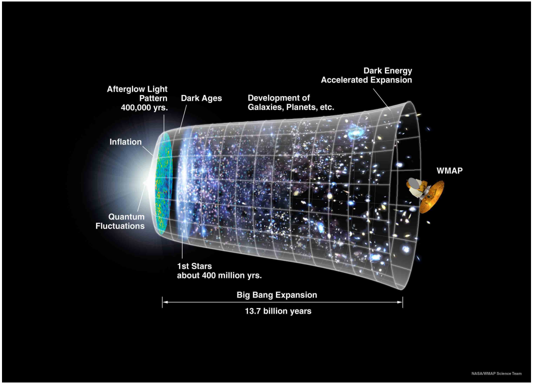

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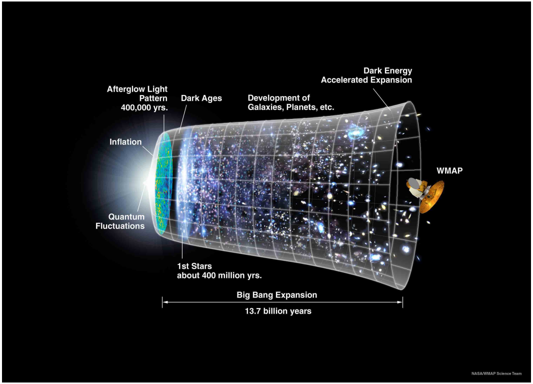

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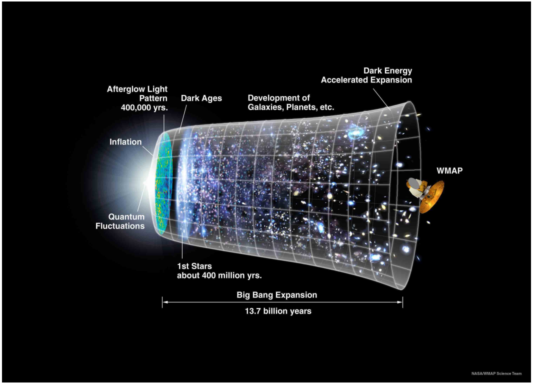

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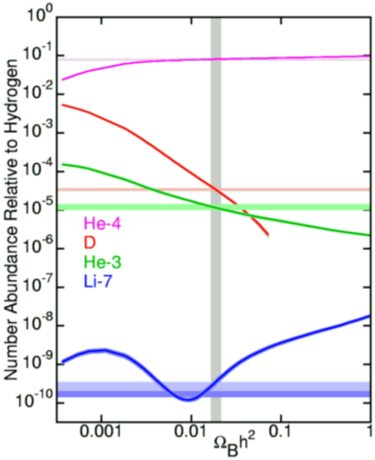
Nucleosynthesis

A $T_{\rm nuc} \simeq 0.08$MeV $\simeq 10^9$K Deuterium ($p + n$) becomes stable. At this moment virtually all the neutrons present in the Universe are 'burned' into He^4. Only traces of Deuterium, Helium^3 and Lithium^7 remain. Their abundance depends strongly on the baryon density.



Neutrino decoupling

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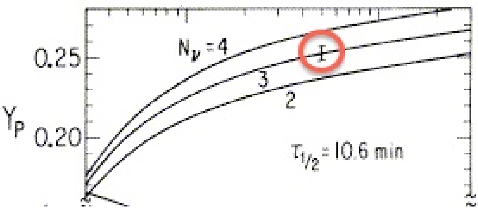
- A neutrino background at a 'temperature' $T_\nu = 1.9\text{K}$ should exist in the Universe.
- But even if these neutrini have a density of about 300 particles per cm^3 they have not been detected directly so far due to their extremely weak interaction.

Neutrini are however 'observed' indirectly by their gravitational effects:

- They contribute to the expansion of the Universe (Friedmann eqn) which is relevant for the abundance of Helium-4. $\Rightarrow$ N_ν (number of relativistic neutrino species at $T \simeq 0.1$MeV).



(Sarkar et al. '06)

Abundance of relativistic particles

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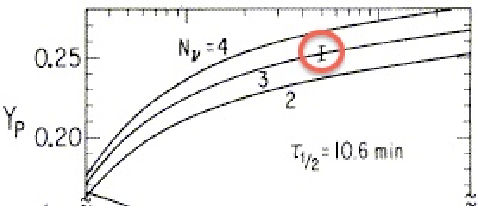

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$$\Rightarrow \quad \boxed{N_\nu \simeq 3 \pm 1}$$

- This limit applies to any species of relativistic particles with thermal abundance at $T \simeq 0.1$MeV.

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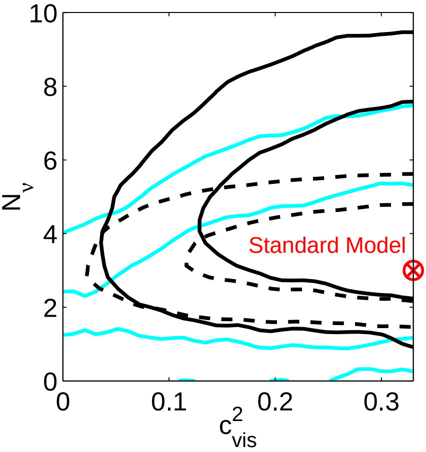
They contribute to the anisotropies of the CMB where one can even mesure the consequence of the fact that neutrini are not a perfect fluid but collisionless particles.
($c_{vis} = 0$ perfect fluid, $c_{vis}^2 = 1/3$, relativistic, collisionless particless.)



(Melchiorri & Trotta, 2004)

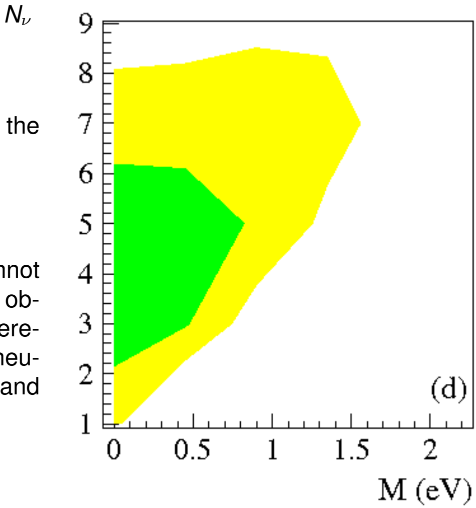
Neutrino mass

Massive neutrini contribute to the dark matter density,

$$\Omega_{m\nu} h^2 = \frac{m_\nu}{94\mathrm{eV.}}$$

As they are very light, the cannot form small scale structure. The observed small scale structure therefore limit the contribution of neutrini to the dark matter density and hence their mass.

$$m_\nu \leq 1\text{eV}$$



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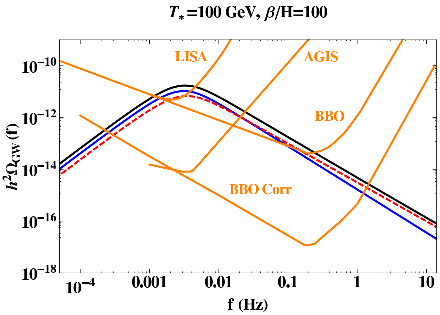
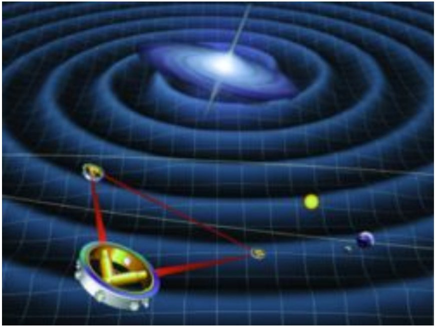
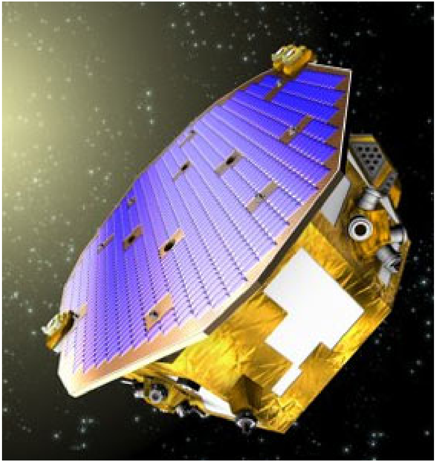


(Caprini, Durrer & Servant, 2009)

The satellite eLISA



The eLISA satellite projet (artist's impression). Launch >2018.



The LISA pathfinder satellite (the real thing). Scheduled for launch in 2015.

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With small variations of the standard model particle physics can obtain a 1st order electroweak phase transition which would lead to out of equilibrium processes and allow the generation of a baryon asymmetry.

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But an inflationary phase has also other consequences...

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Fluctuations from inflation in the CMB

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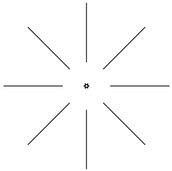
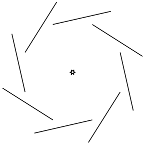
Like scalar fluctuations, gravitational waves generate anisotropies in the CMB. In addition, they generate a slight polarisation of the CMB photons.

Density perturbations (scalars) generate only one type of polarisation (E) while gravitational waves (tensor perturbations) generate also a second type (B).



pure E-polarisation (scalars and grav. waves)



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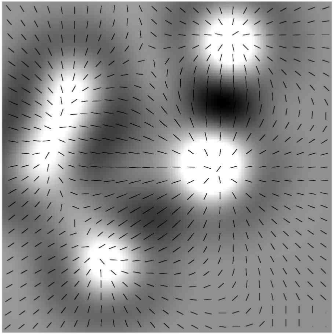

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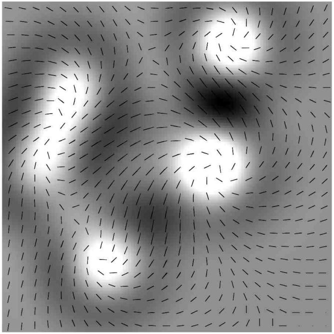
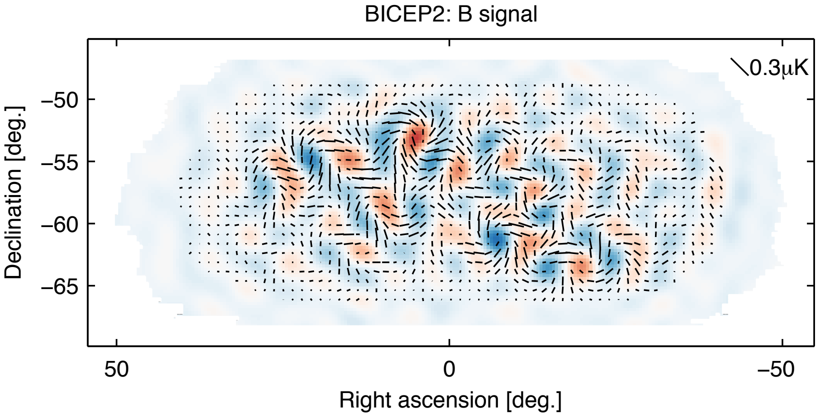
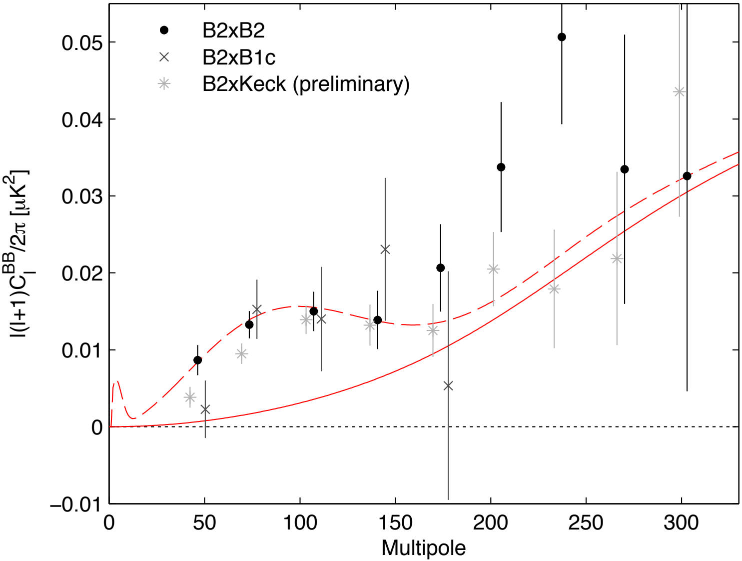


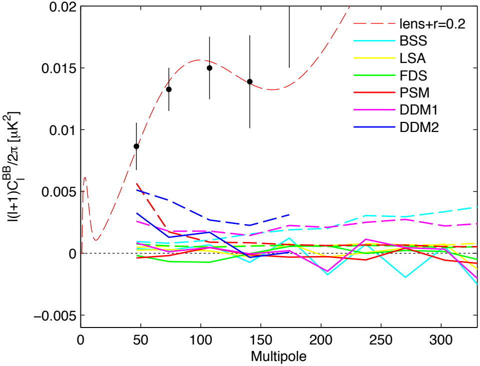
The discovery of B-polarisation is considered the 'holy grail' of inflation. It determines the energy scale of inflation.

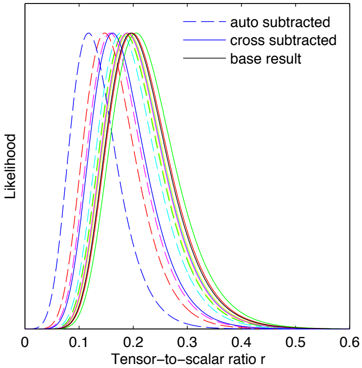


Single frequency at 150GHz, $15^o \times 100^o$ patch, beam size $\sim 0.5^o$
$\Rightarrow \quad (\ell_{\rm min} \sim 20, \ell_{\rm max} \sim 350)$.

The BICEP 2 experiment

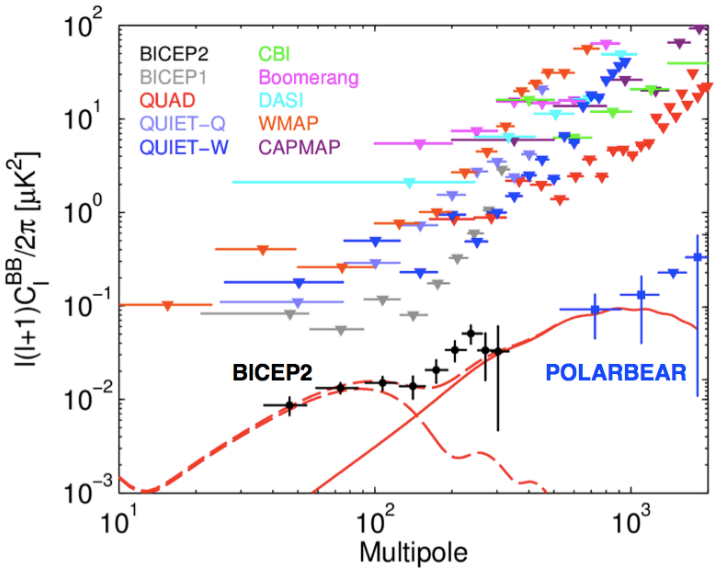






The value of the tensor to scalar ratio $r = A_T/A_S$ when using different models for foreground subtraction.

The BICEP 2 Comparison with previous experiments



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- Hopefully the Planck polarisation results due to come out this fall will clarify the issue...

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Cosmology seems to be one of the most promising directions to give us access to the physics at very high energies, $E \gg 10\text{TeV}$.