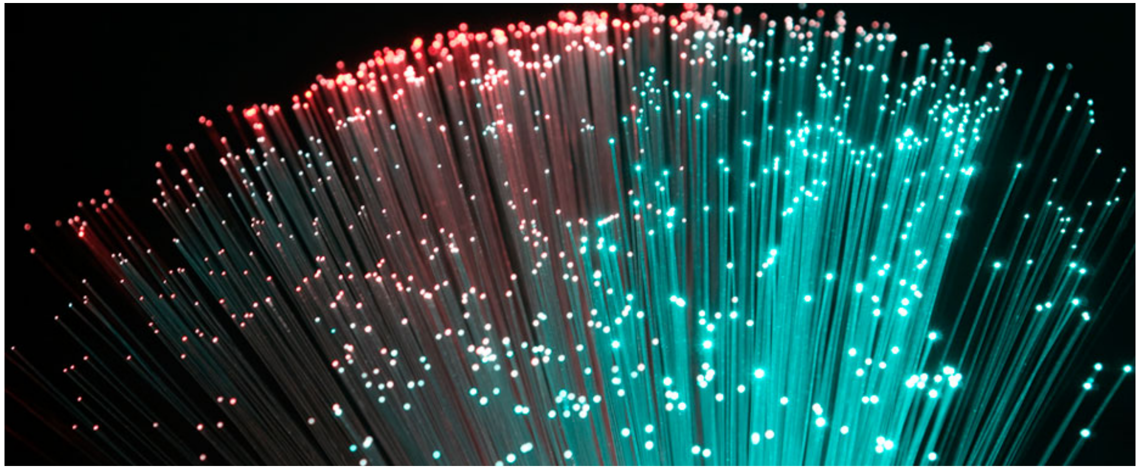
Light in life and science



Georg Wolschin

TR 33 The Dark Universe
Bonn München Heidelberg

Light fascinates people…

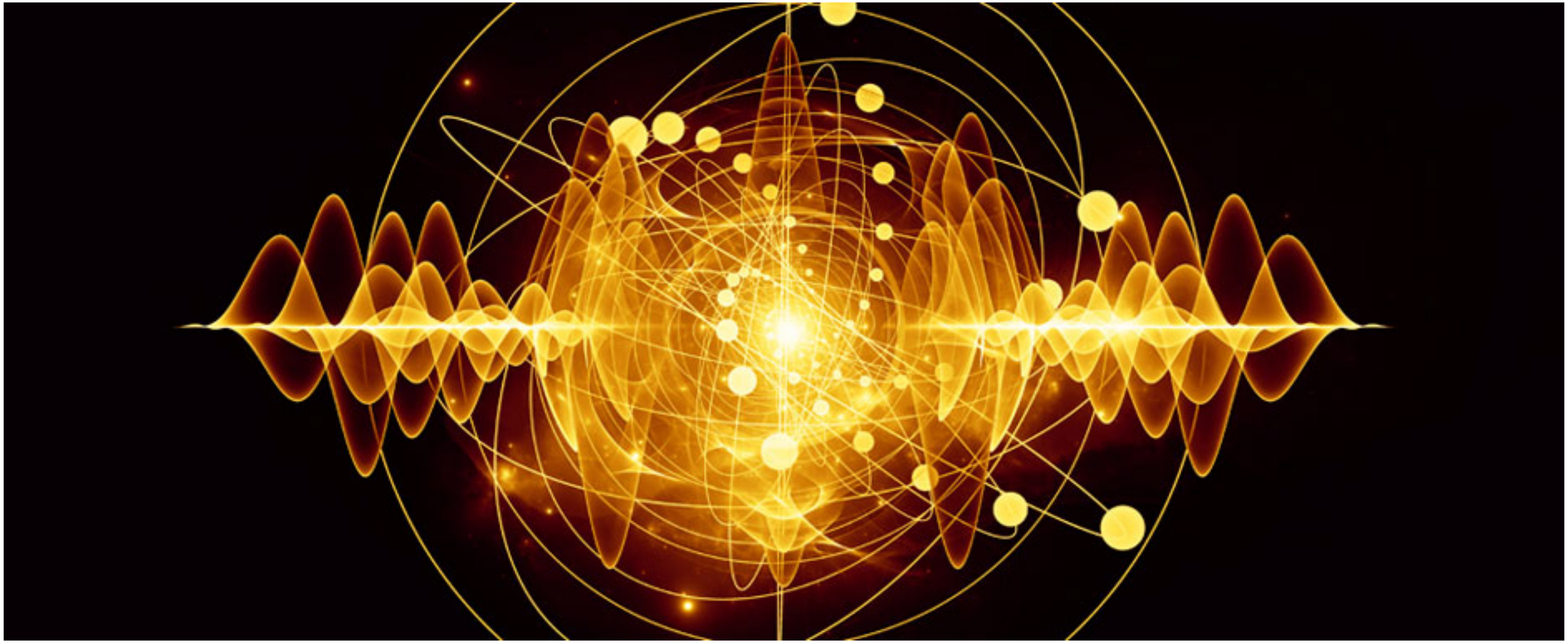
© Måns Zelmerlöw, Eurovision song contest 2015

and beautifies nature

Polar light, © International year of light 2015

It has a cultural dimension…

and it has influenced all areas of science and technology



See this example in biology…

Female glowworms and fireflies attract males with their light

(efficiency ≈ 95 %)

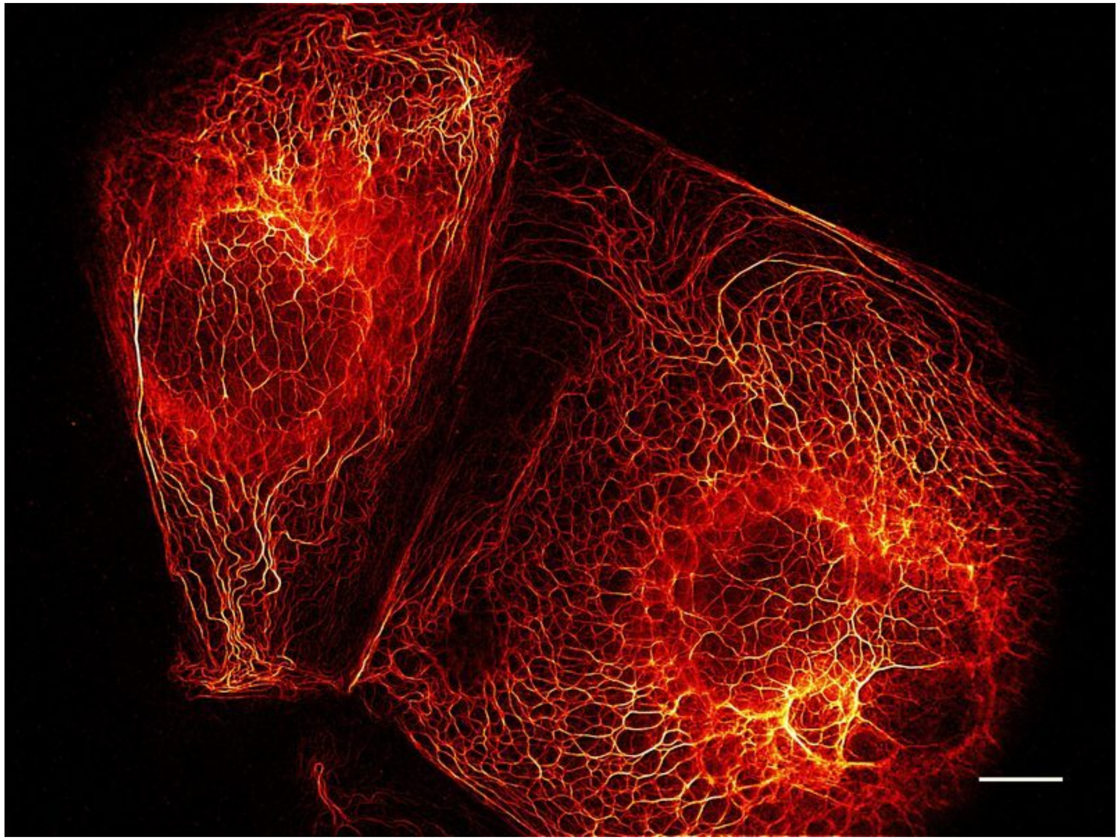
…optical microscopy below the Abbe limit[1]…

Optical microscopy provides images of protein structures (here: Keratin) in living cells[2]

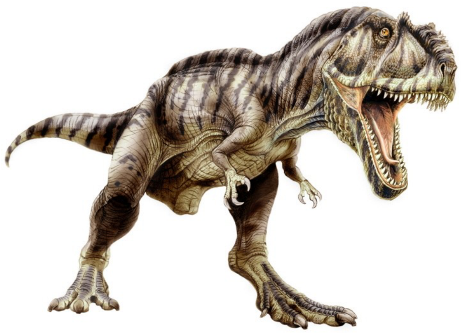
[1] **$d = \lambda / (n \cdot \sin\alpha)$**

λ = wavelength of light

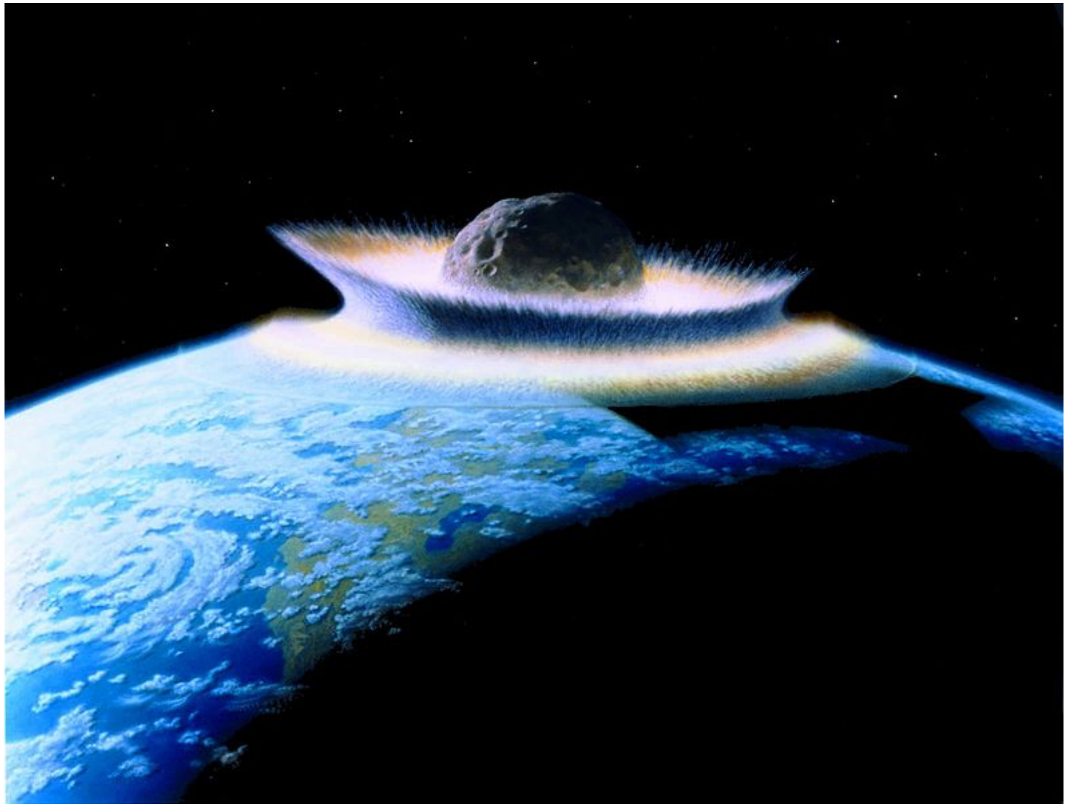
[2] **RESOLFT-microscopy (*reversible saturable optical fluorescence transitions*); Scale = 10 μm**



…or in geology/ astrophysics



Giganotosaurus.(Foto: Forschungsinstitut/ Naturmuseum Senckenberg)

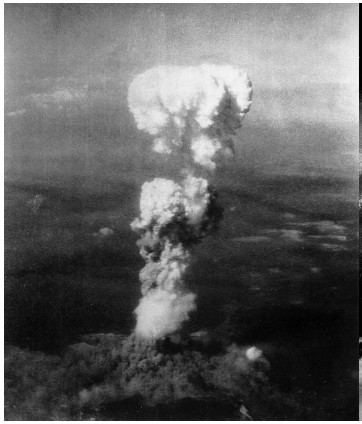


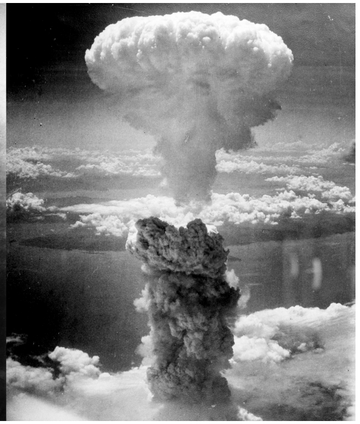
Asteroid hits the earth, with spectacular optical emissions (artist's view, © Don Davis)

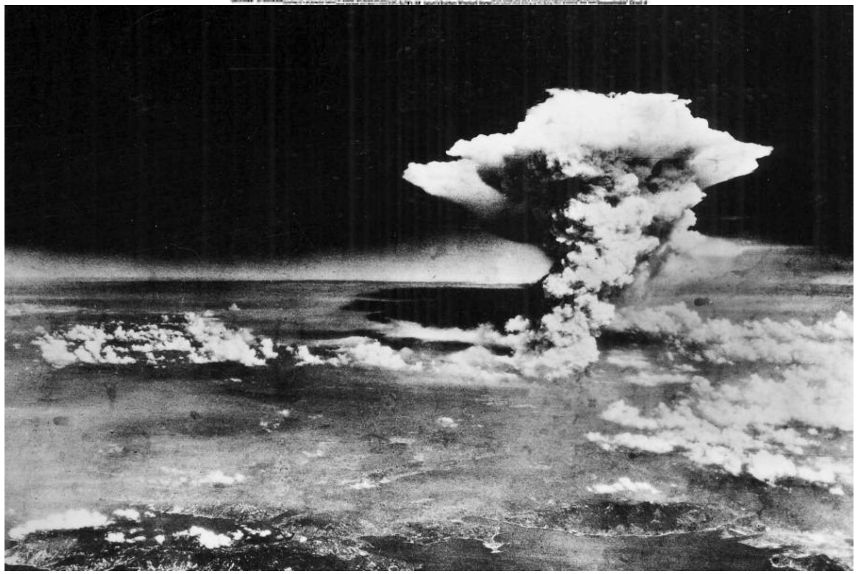
August 6/9, 2015 is the 70th anniversary of the 1945 Hiroshima/ Nagasaki bombs


The New York Times.

FIRST ATOMIC BOMB DROPPED ON JAPAN; MISSILE IS EQUAL TO 20,000 TONS OF TNT; TRUMAN WARNS FOE OF A 'RAIN OF RUIN'

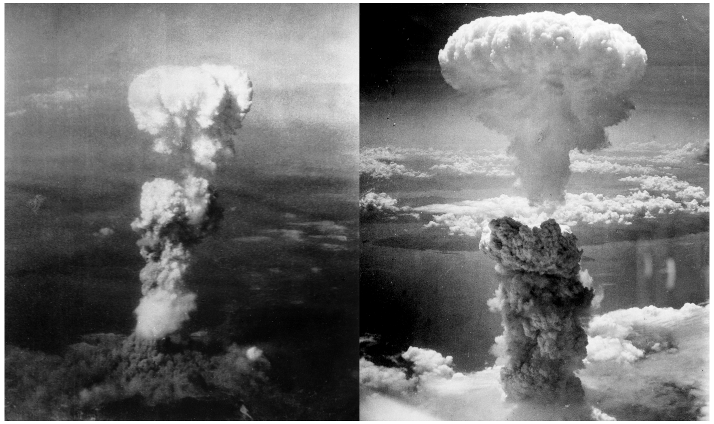


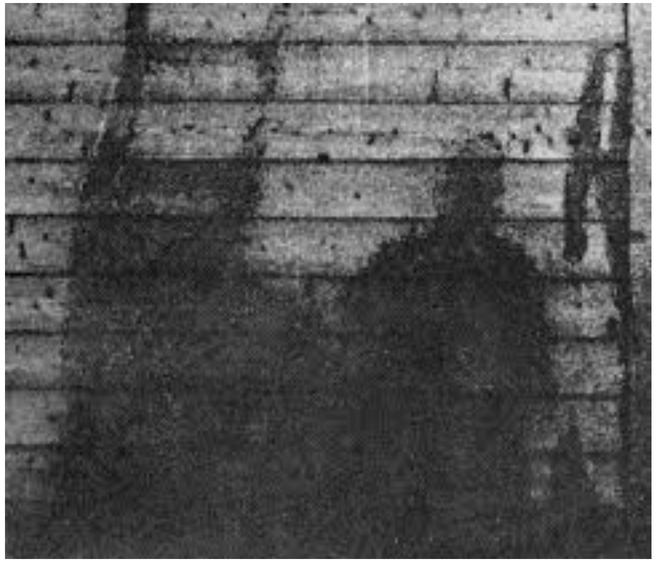




Fission bomb mushroom clouds above Hiroshima (uranium) and Nagasaki (plutonium). The two bombings, which killed at least 129,000 people, remain the only use of nuclear weapons for warfare in history.

August 6/9, 2015 is the 70th anniversary of the 1945 Hiroshima/ Nagasaki bombs

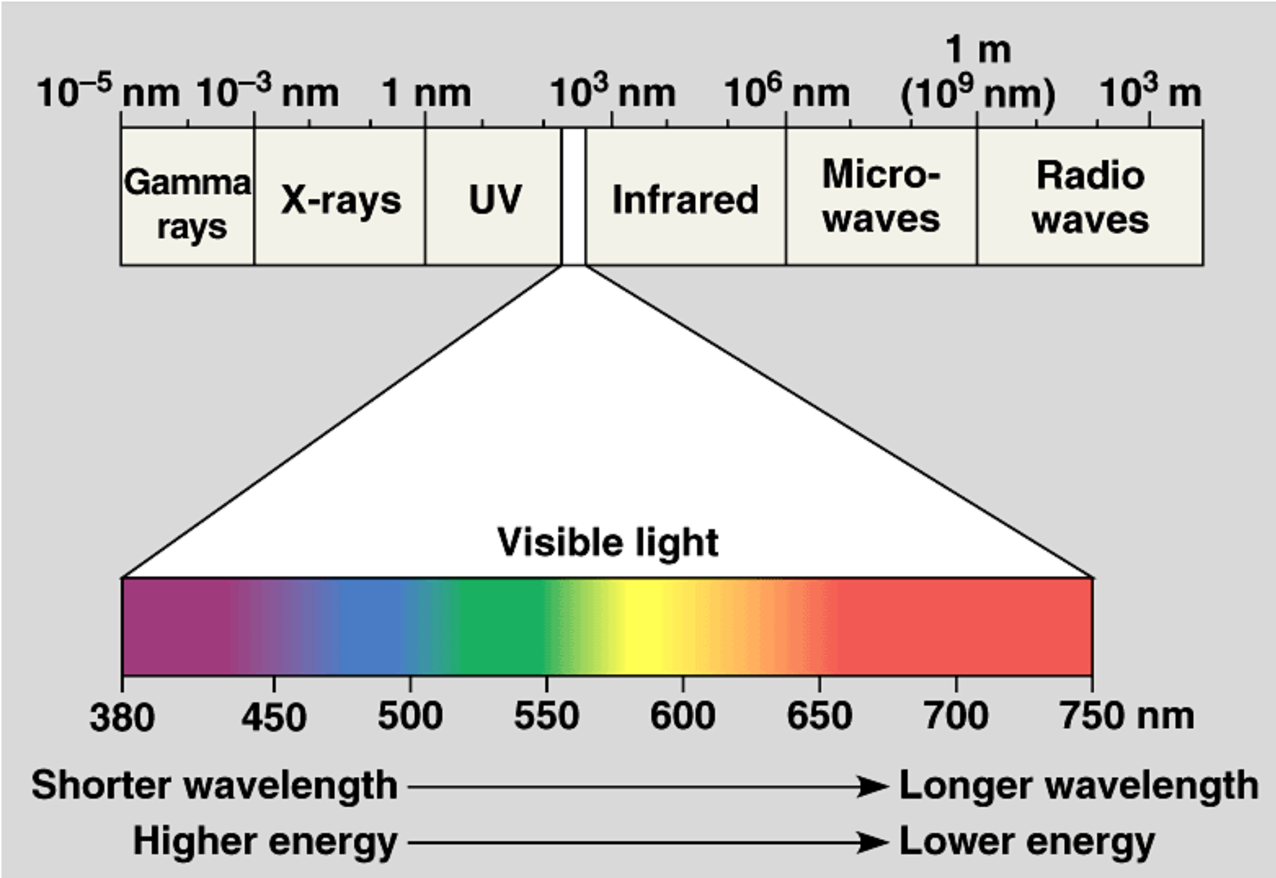




Fission bomb mushroom clouds above Hiroshima (uranium)
and Nagasaki (plutonium). The two bombings, which killed at least 129,000 people, remain the only use of nuclear weapons for warfare in history.

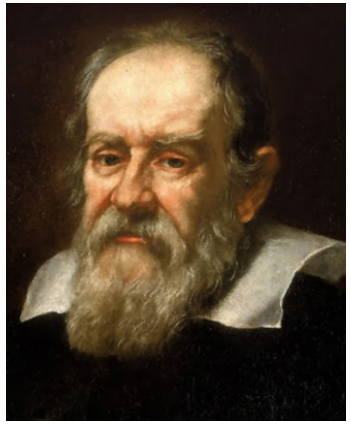
Visible light

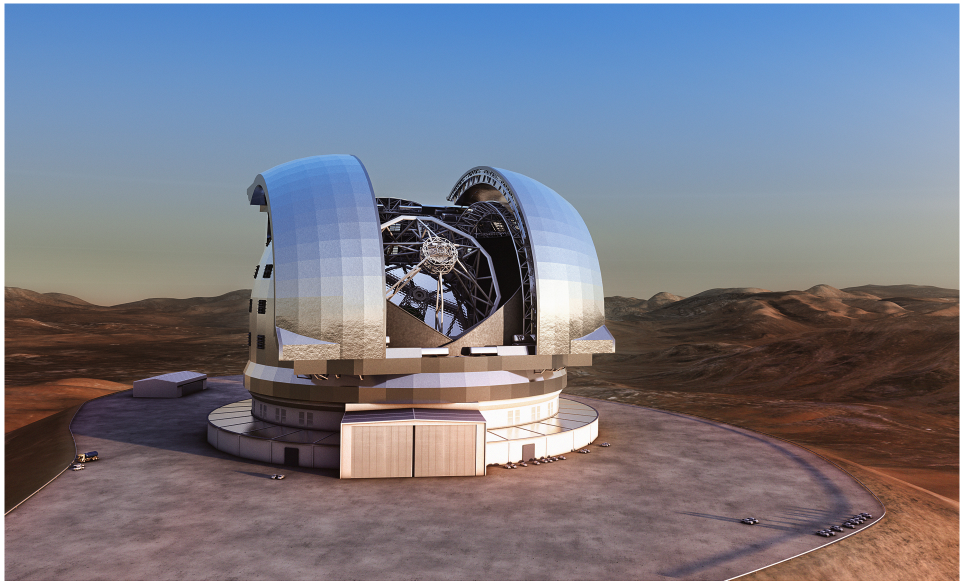
spans only a small fraction of the electromagnetic spectrum; the rest is quite significant and we shall consider some of it today:



Astronomy with telescopes usually relies on visible light –

as Galileo Galilei did when he discovered Jupiter's moons with a small telescope

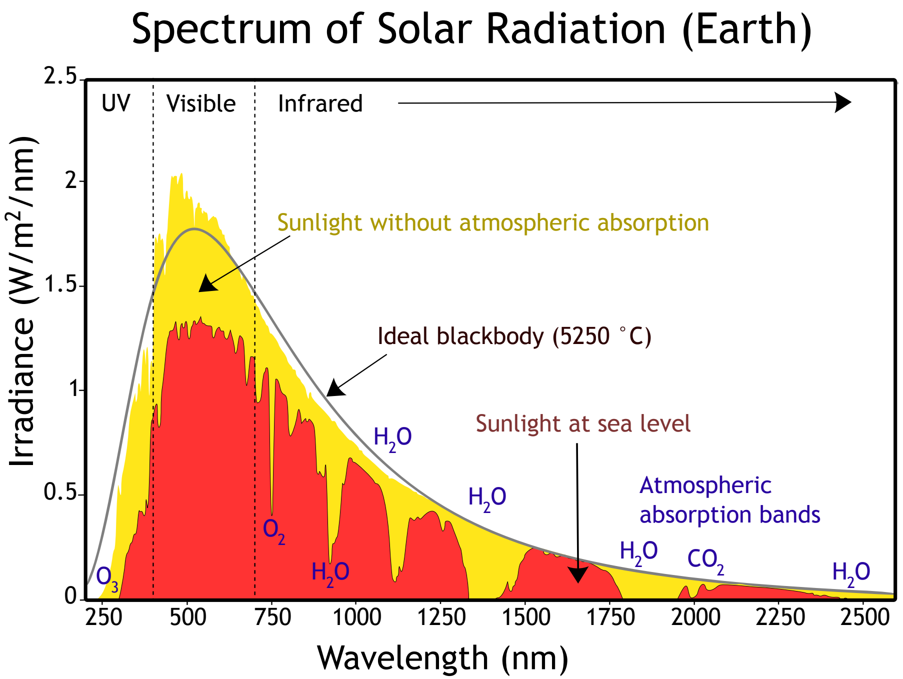




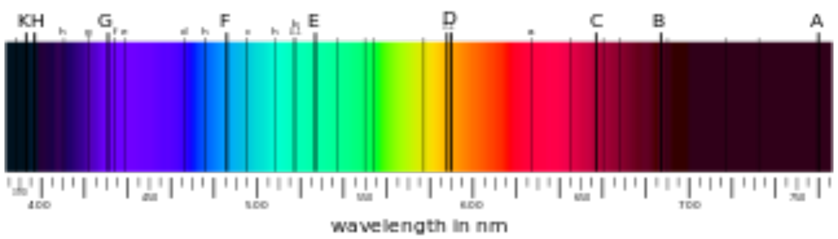
and as today's telecopes do when investigating distant stars and galaxies

E-ELT: optical and infrared wavelengths. © ESO

The sun and stars emit UV, visible and IR light



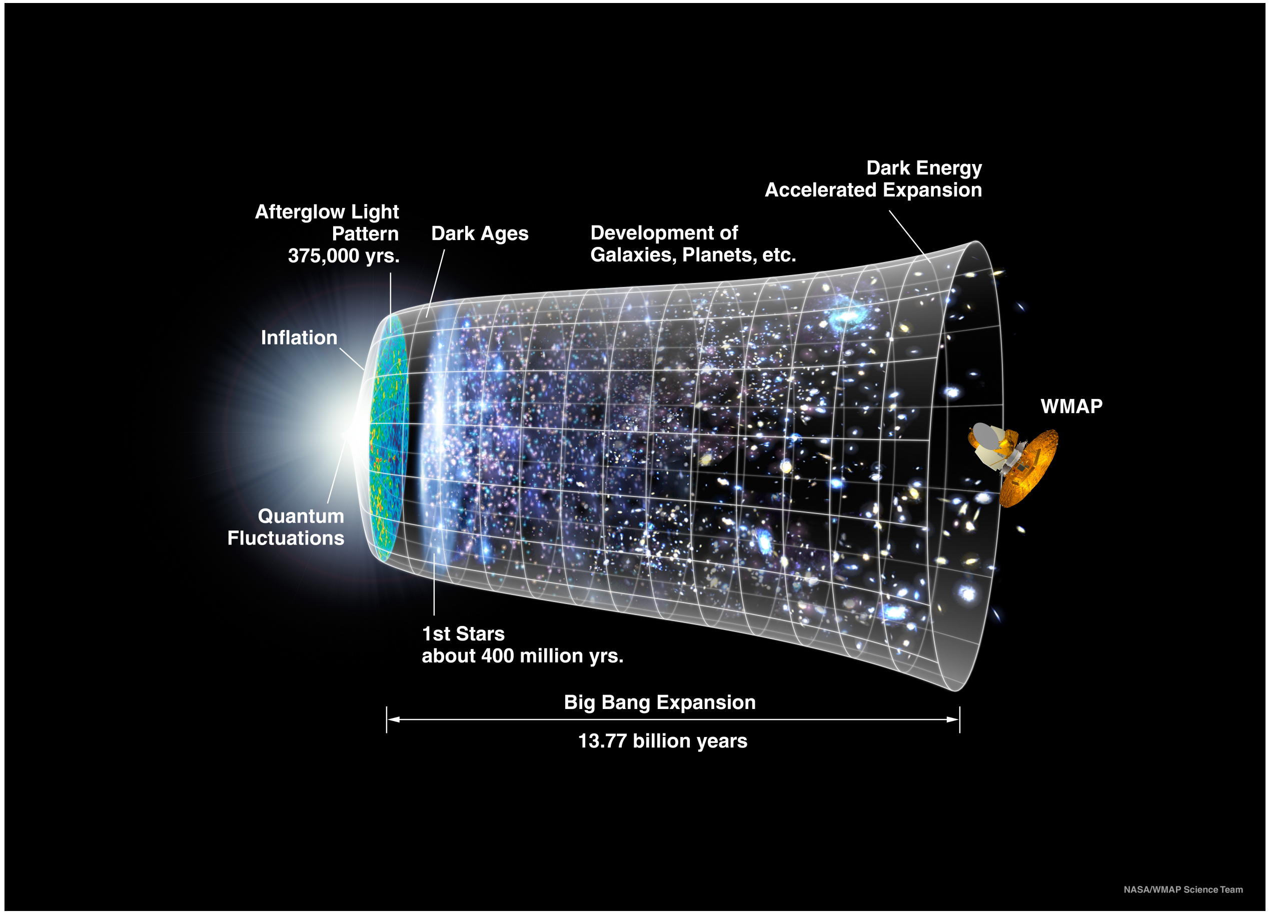
Fraunhofer absorption lines



Source: Wikipedia

The spectrum is close to a blackbody spectrum, it is in thermal equilibrium.
Note however, that many astrophysical processes are not -

There was light in the beginning of the universe -

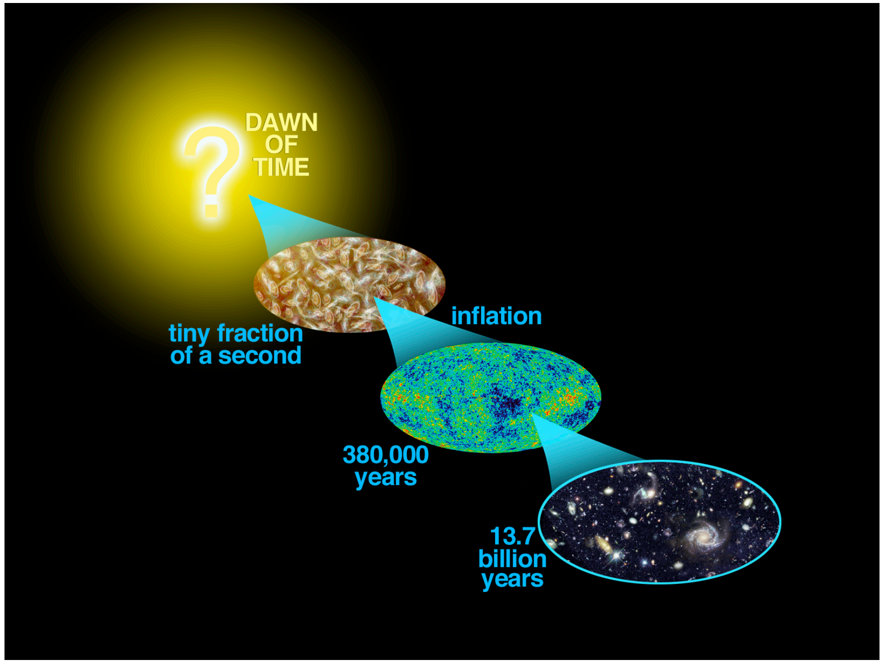


Matter and antimatter was then created from energy,
$E = \sqrt{(p^2 + m^2)}$, and the universe became opaque, it expanded and cooled..

Source: WMAP-Collaboration

Vesto Slipher
(discovered the red shift)

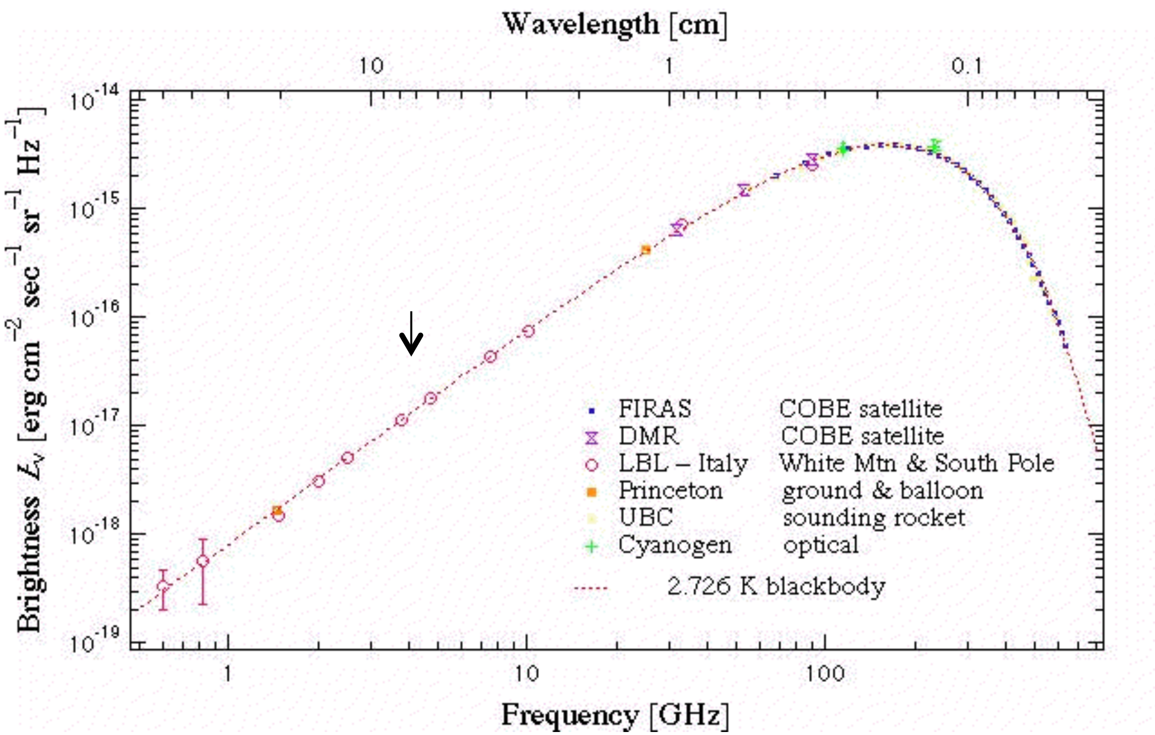
Edwin Hubble



source: WMAP collaboration

...until 380 000 years after the big bang electrons and protons formed hydrogen atoms, and the universe became transparent: we can now look back to this dawn of time

…and measure the spectrum of the cosmic microwave background radiation



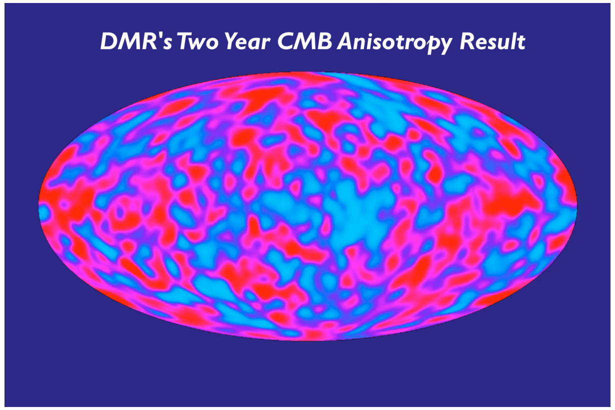
- Discovered by Arno Penzias und Robert Wilson 1964/5 at 4.1 GHz. Physics Nobel Prize 1978
- Due to expansion, the temperature has dropped to 2,73 Kelvin today
- It is a **Planck-spectrum**

The most precise blackbody spectrum realized in nature

$$U_\nu^o(\nu,T)\,\mathrm{d}\nu = \frac{8\pi h\nu^3}{c^3}\frac{1}{e^{\left(\frac{h\nu}{kT}\right)}-1}\,\mathrm{d}\nu$$

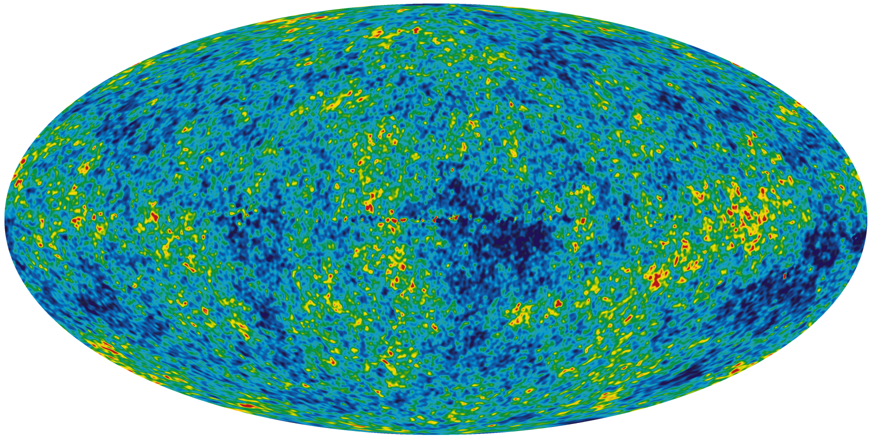
Source: COBE-Collaboration, 1992

and also the temperature fluctuations in the microwave sky which give us information about the seeds of structure formation, the matter/energy content etc.

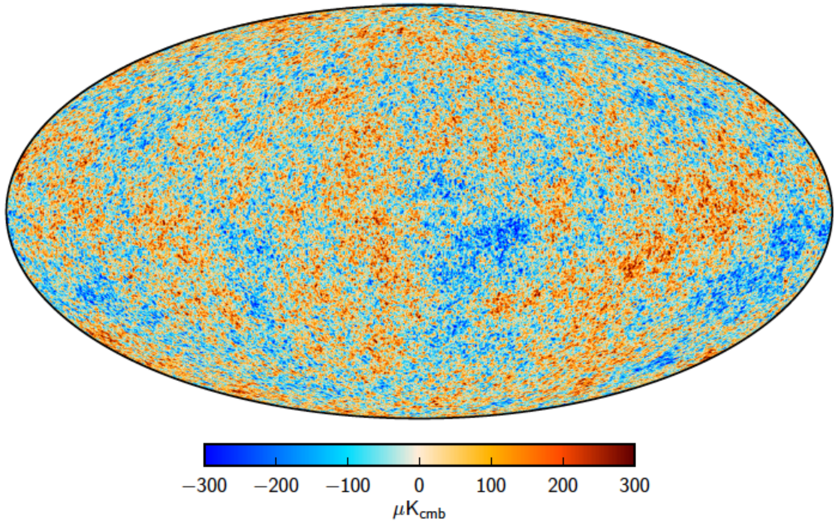


COBE, 1992

- Formation of the first stars: ≈ 400 million years after the big bang
- Accelerated expansion below $z \approx 1$ in the late universe

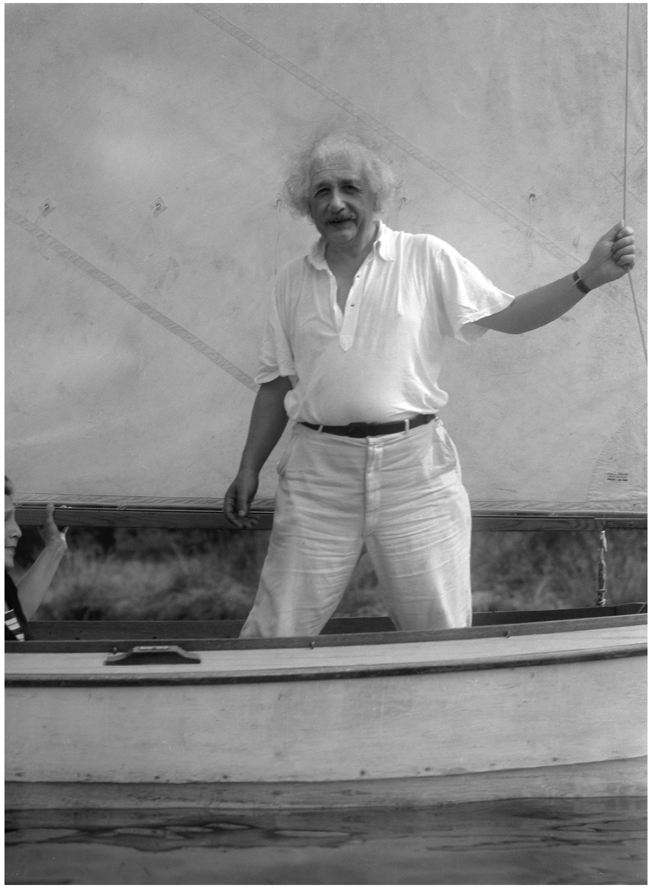


WMAP-Collaboration, 2008



Planck-Kollaboration, 2013

Most interpretations are based on the general relativity theory (GRT)



A. Einstein

- 1915/16 Albert Einstein formulated the field equations of general relativity. Friedman's solutions of these equations describe the expanding universe

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

G the gravitational constant, *c* the velocity of light, $R_{\mu\nu}$ the Ricci-Tensor, *R* the curvature scalar, $g_{\mu\nu}$ the metric tensor, $T_{\mu\nu}$ the energy-momentum tensor and **Λ the cosmological constant** (corresponding to a constant density of dark energy).

$\Lambda = 0$ results already in Friedman's solutions for an expanding space; for $\Lambda > 0$ the expansion is accelerated.

(calculating Λ from the vacuum energy gives, however, a wrong order of magnitude)

$$\rho_{(\mathrm{vac})} := \frac{\Lambda c^2}{8\pi G}$$

Friedman's equations

- For a spatially homogeneous und isotropic universe the »metric« (squared distance between two space-time points) can be written as

$$ds^2 = a(t)ds_3^2 - dt^2$$

- The time evolution of the »scale factor« a(t) is determined from the field equations through the energy-momentum tensor. Alexander Friedman has subsequently 1922 derived the equations

$$H^2 = \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho - \frac{kc^2}{a^2} + \frac{\Lambda c^2}{3}$$

$$\dot{H} + H^2 = \frac{\ddot{a}}{a} = -\frac{4\pi G}{3}\left(\rho + \frac{3p}{c^2}\right) + \frac{\Lambda c^2}{3}$$

The Hubble parameter H (t) at the present time determines the expansion rate in Hubble's law, d = H·v .

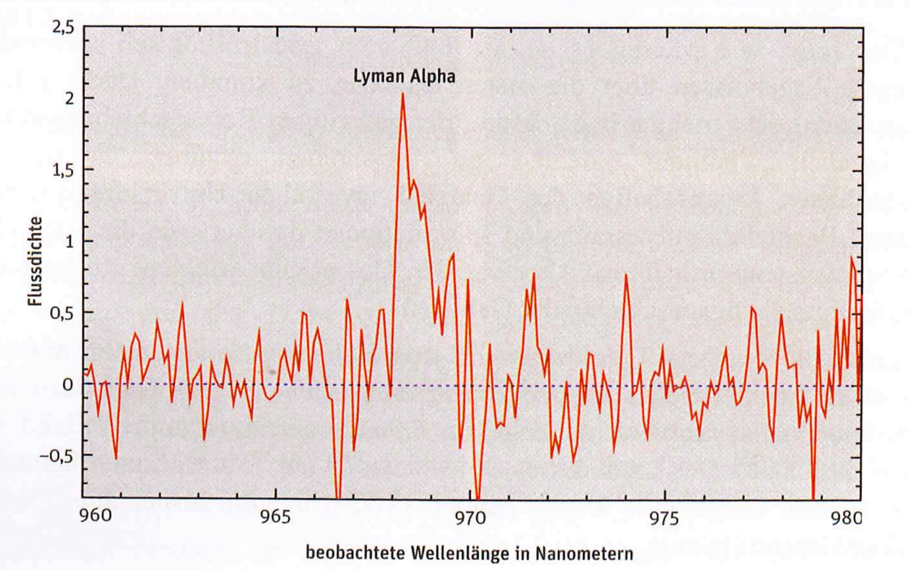
Accelerating expansion as inferred from supernovae Ia

SN 1994 D in NGC 4526

Distance of the galaxy
55 Mio lightyears

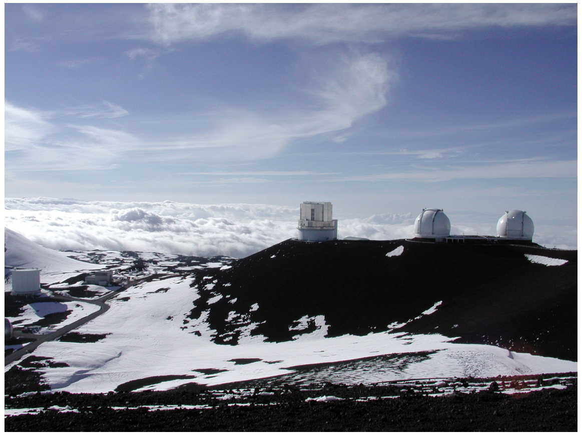
Redshift $z = 2.01 \cdot 10^{-6}$

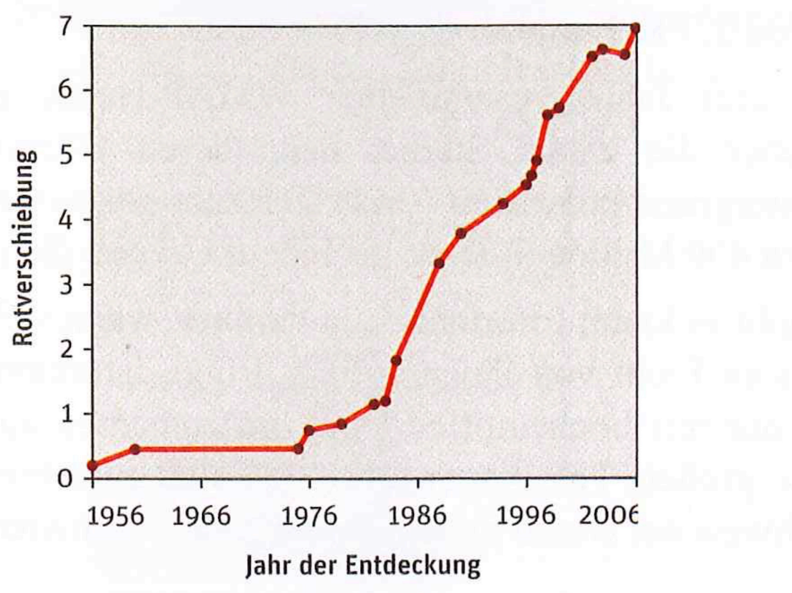
Redshift of distant galaxies



In the spectrum of the galaxy IOK-1 with a redshift of $z = 6.96$ (measured with the Subaru-teleskope, Hawaii) The Lyman-alpha emission line is visible at **λ = 968.2 Nanometer**. This spectroscopic result is based on eleven exposures of ½ hours each. The laboratory wave length is **λ_0 = 121.6 Nanometer**:

$\lambda = (1 + z)\,\lambda_0$



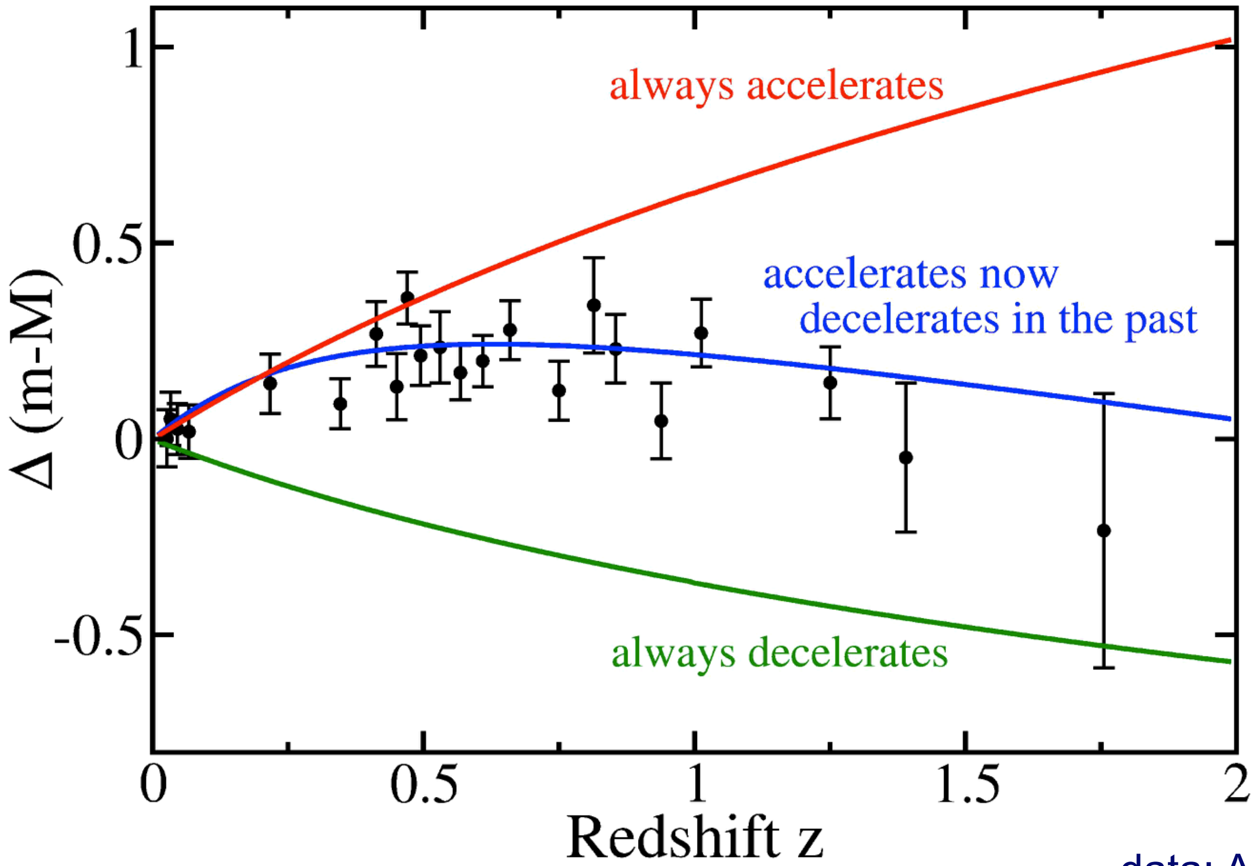


In the past decades galaxies with ever increasing redshift were discovered.

Expansion of space and SN Ia data

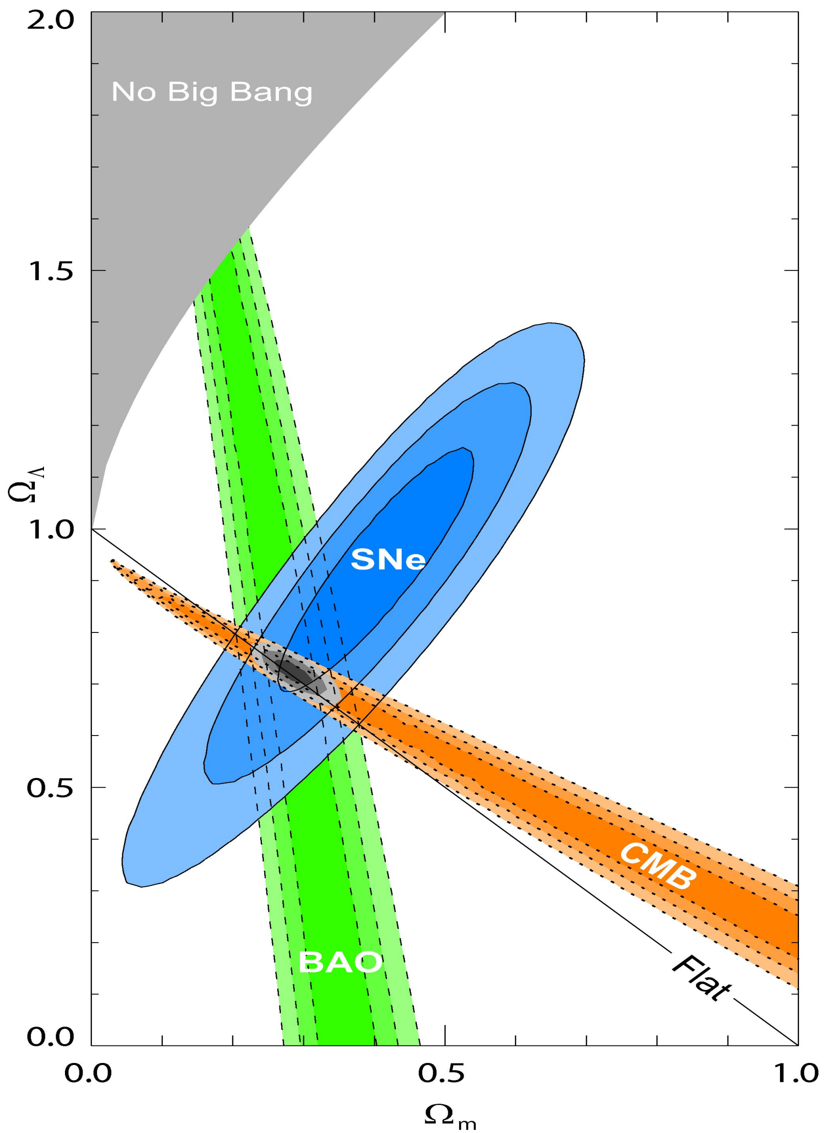
Effect of a cosmological constant $\Lambda > 0$ in GRT / time-dependent »dark energy«:
Acceleration at small redshifts $z < 1$

A deceleration at $z > 1$ (corresponding to $t > 5.9$ billion years)
tends to be confirmed by data from the Hubble space telescope.



data: A. Riess et al.;
plot: M. Turner, D. Huterer

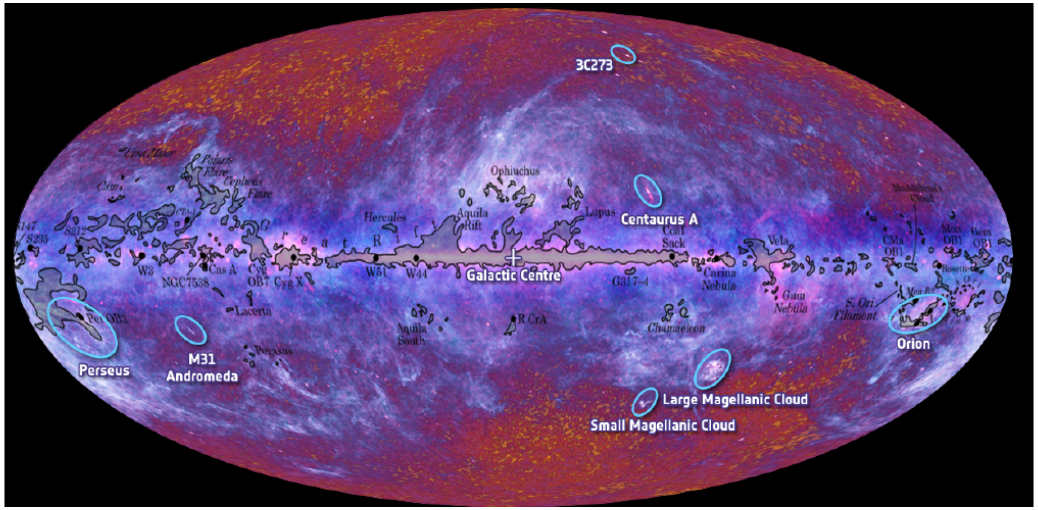
Indicators for the accelerated expansion of the universe



Evidence for accelerated expansion from

- **Supernovae** Ia
- temperature fluctuations of the **cosmic microwave radiation**
- »**baryonic acoustic oscillations**« in the large-scale galaxy distribution (generated by the interplay of gravitational attraction and gas pressure in the primordial plasma).

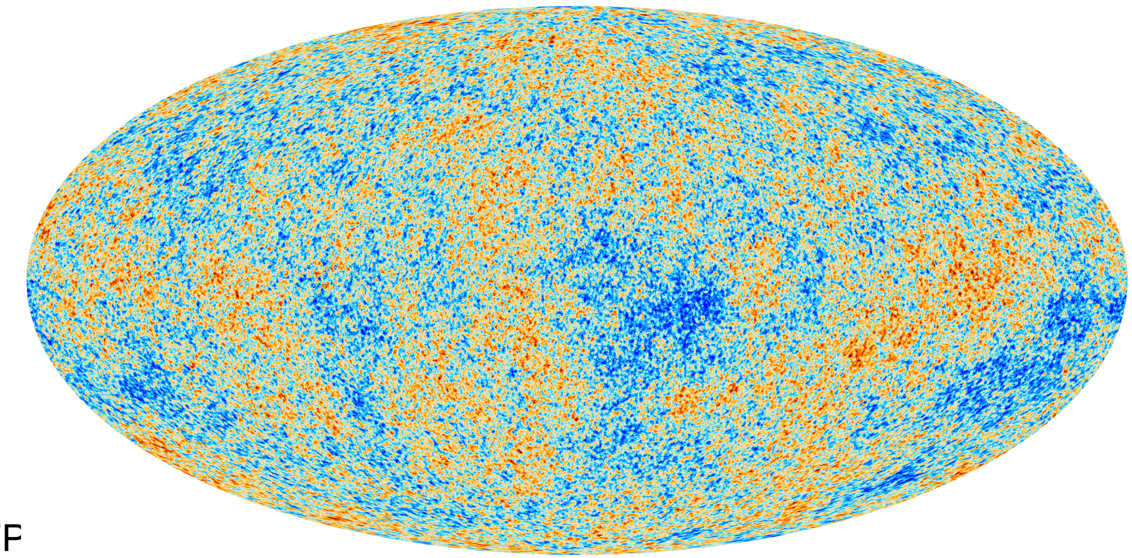
Temperature fluctuations in the CMB: Planck results



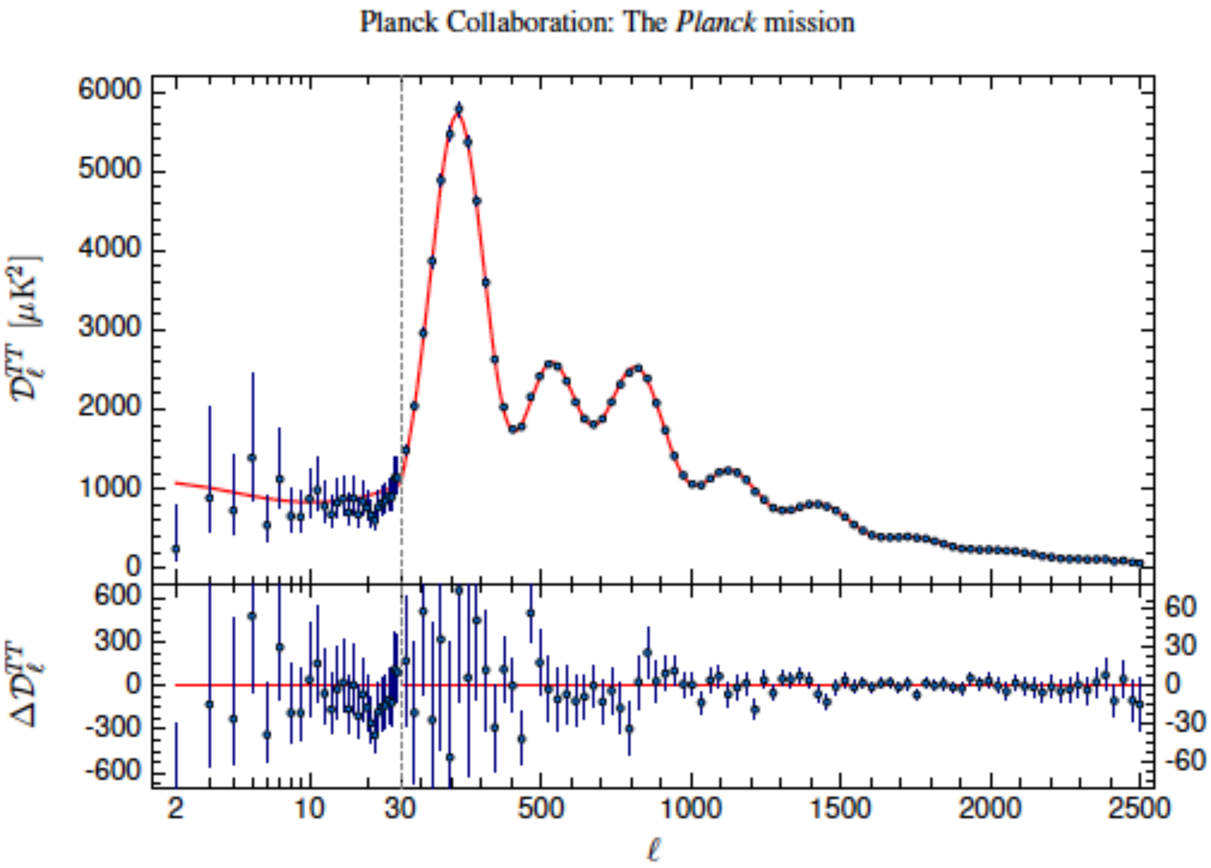
Raw data with foreground emissions
from dust that absorbs optical starlight
ond re-emits it in the microwave part
of the spectrum
(1 yr full sky all frequencies)

Measurements at 9 frequencies (30-857 GHz)

Cosmological signal after
data reduction
(the dust signal depends
on frequency)



Planck 2015: Spectrum of CMB fluctuations



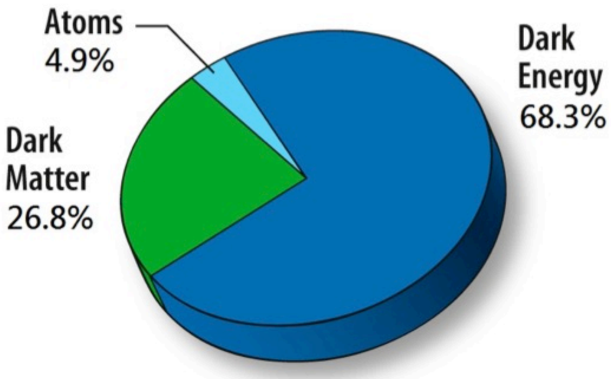
Source: Planck-Collaboration, 2015

- Angular distances $\theta=180^0/\ell$
- Multipole moments ℓ
- Resolution 5 arcmin

Conclusions Planck 2015:

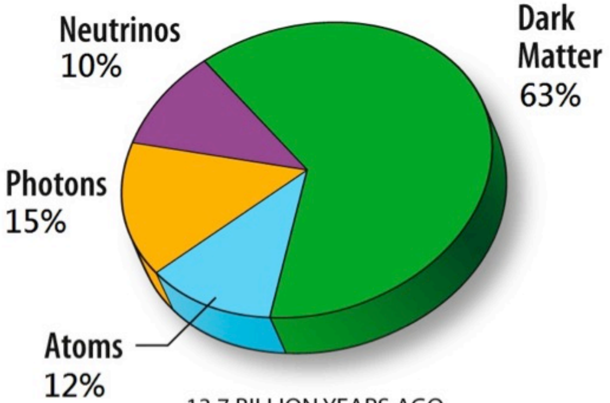
- Flat geometry of space
- Age of the universe 13.799 billion years, H_0 = (67.8±0.038) Gyr
- Today's percentage of dark matter: 26.2 % of the energy density, dark energy 69.2 %, atoms (baryonic matter) 4.6 %
- Polarisation data

Dark matter and dark energy



TODAY

heute

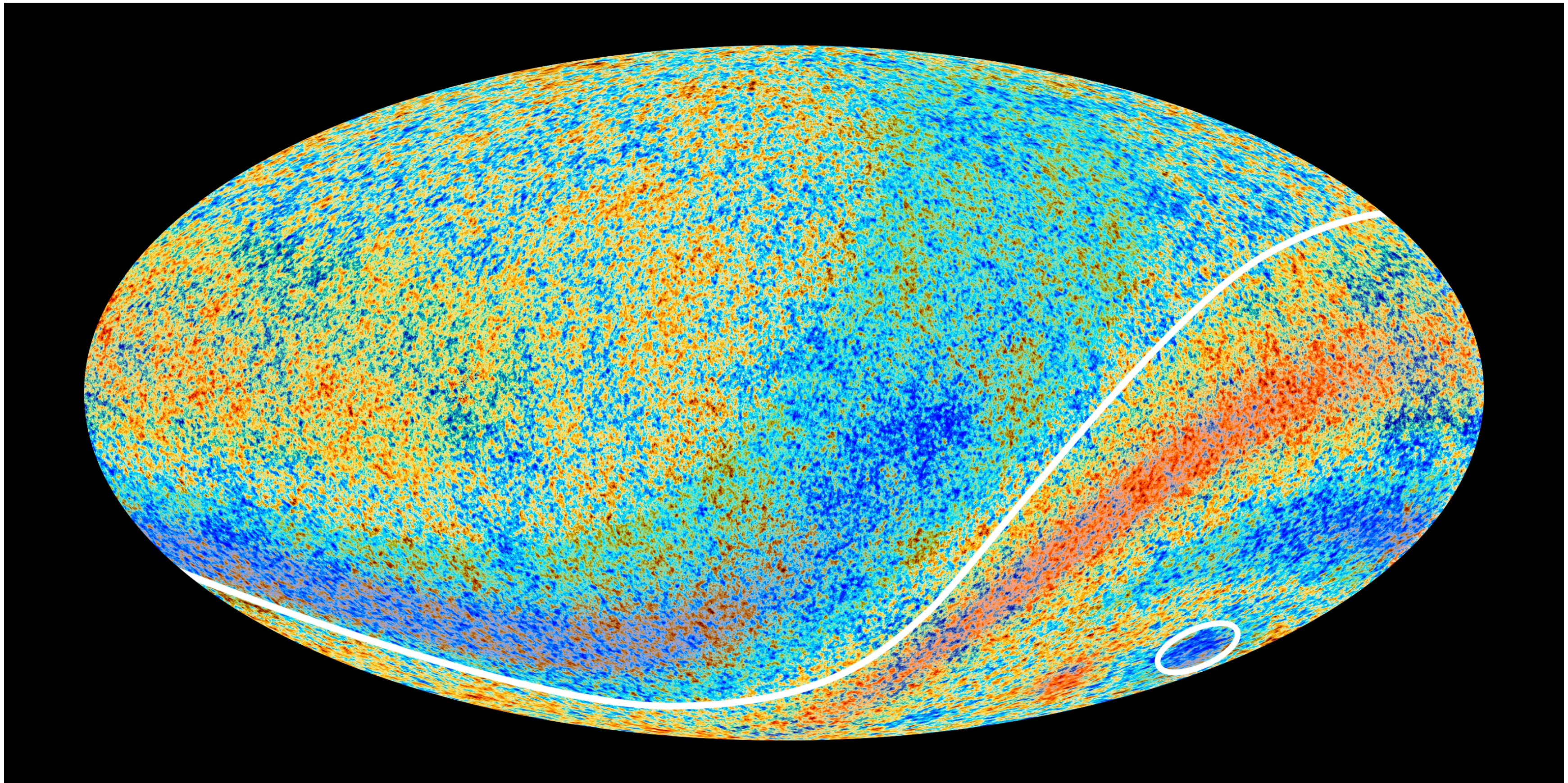


13.7 BILLION YEARS AGO
(Universe 380,000 years old)

380 000 Jahre nach dem Urknall

- Today the fraction of dark and baryonic matter has decreased, the fraction of dark energy has increased
- Neutrinos and photons represent today a tiny fraction of the energy density; at decoupling of radiation and energy, they built up 25 %.

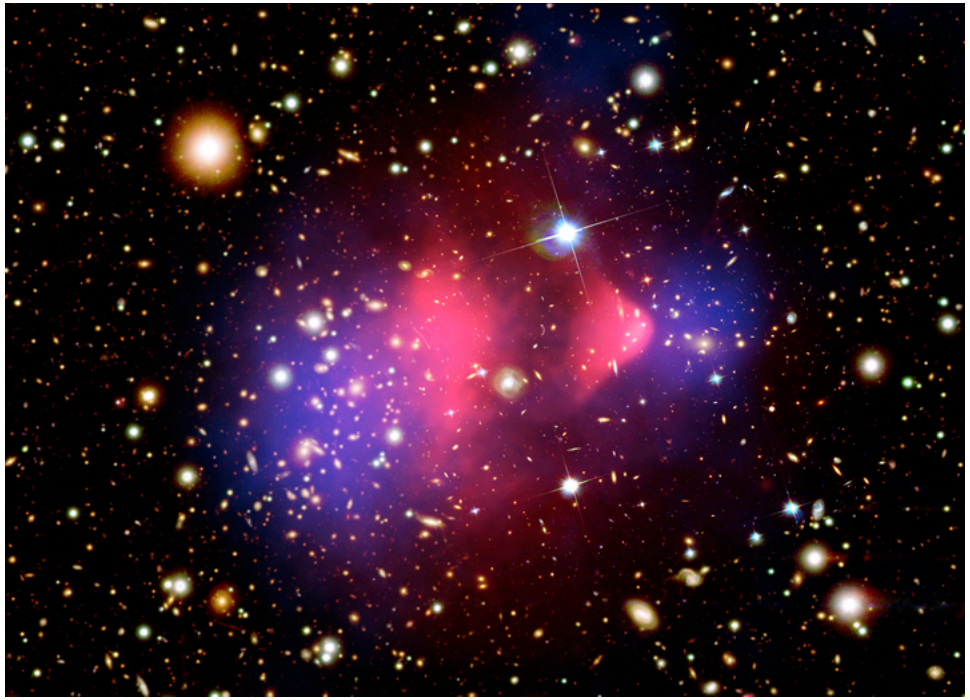
Anisotropies of the CMB fluctuations



These anisotropies must be traced back to the inflationary phase, which apparently was not isotropic

»Cold spot«

Dark matter: Galaxy cluster collision ('bullet cluster')

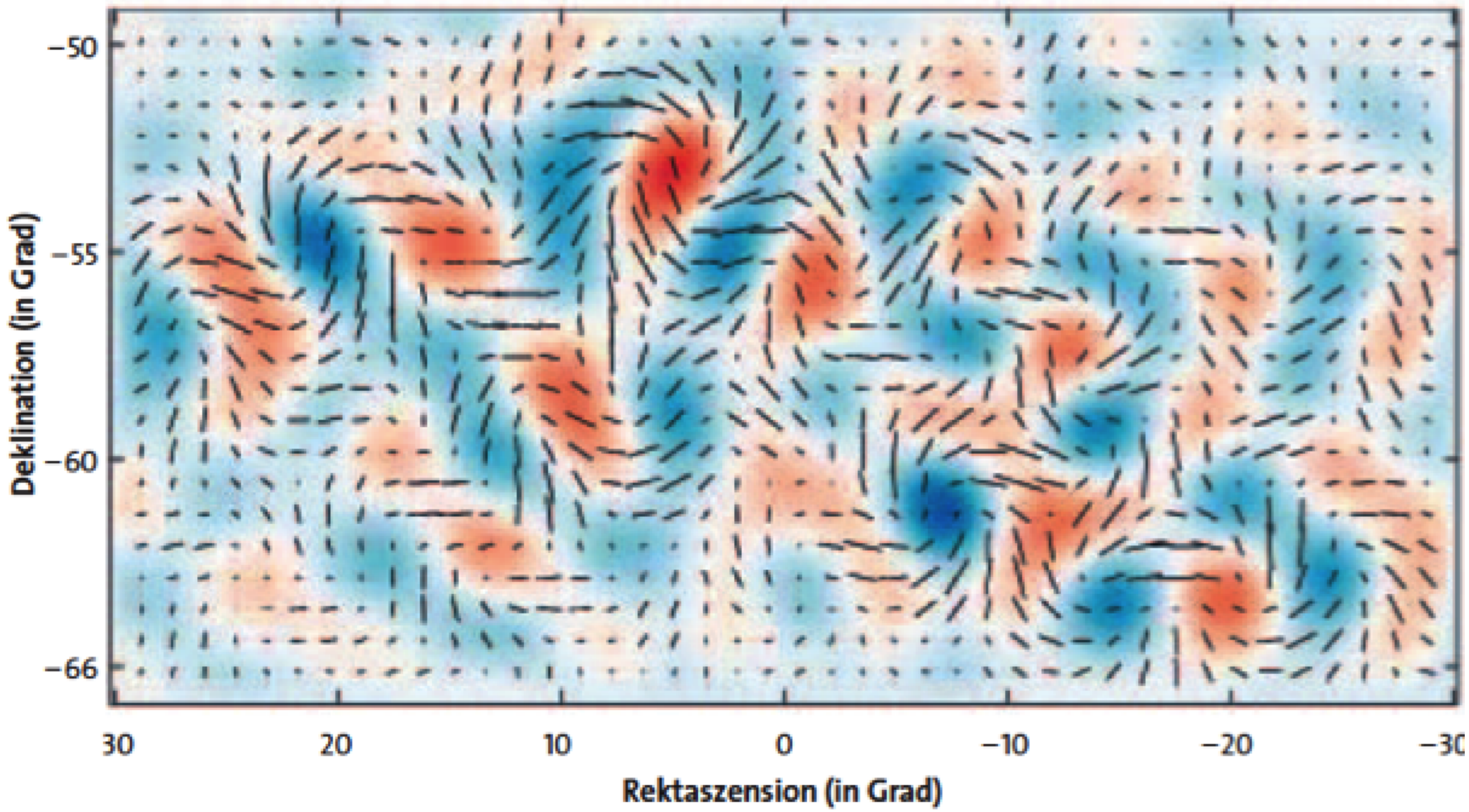


This composit from optical and X-ray photographs shows the »Bullet Cluster«. Red: hot gas (Chandra/X-rays), yellow/white: galaxies (Magellan, HST), blue: Simulation of dark matter through the gravitational lens effect.

Polarisation: Primordial gravity waves leaving their imprint on the CMB?

South Pole Teleskope (SPT, left) und BICEP2 instrument (right)

B-mode polarisation pattern



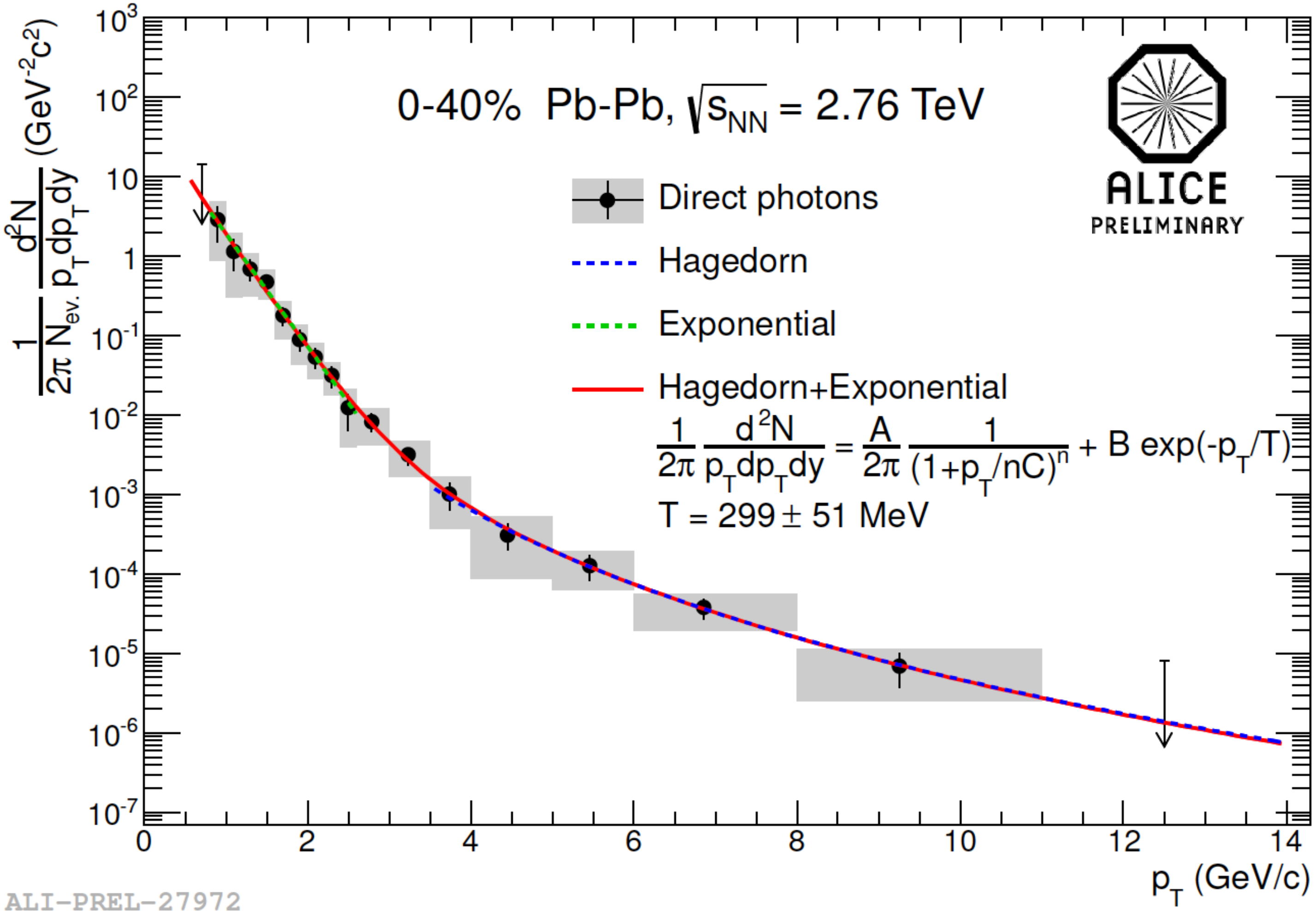
BUT: Result of the combined Planck/BICEP2-analysis in Phys. Rev. Lett. 114,101301 (2015):

»...We find strong evidence for dust and no statistically significant evidence for tensor modes.«

Role of light/photons at the Large Hadron Collider

Direct photons from Pb+Pb collisions at the LHC...

..determine the mean temperature in the fireball as T ≈ (299 ± 51) MeV



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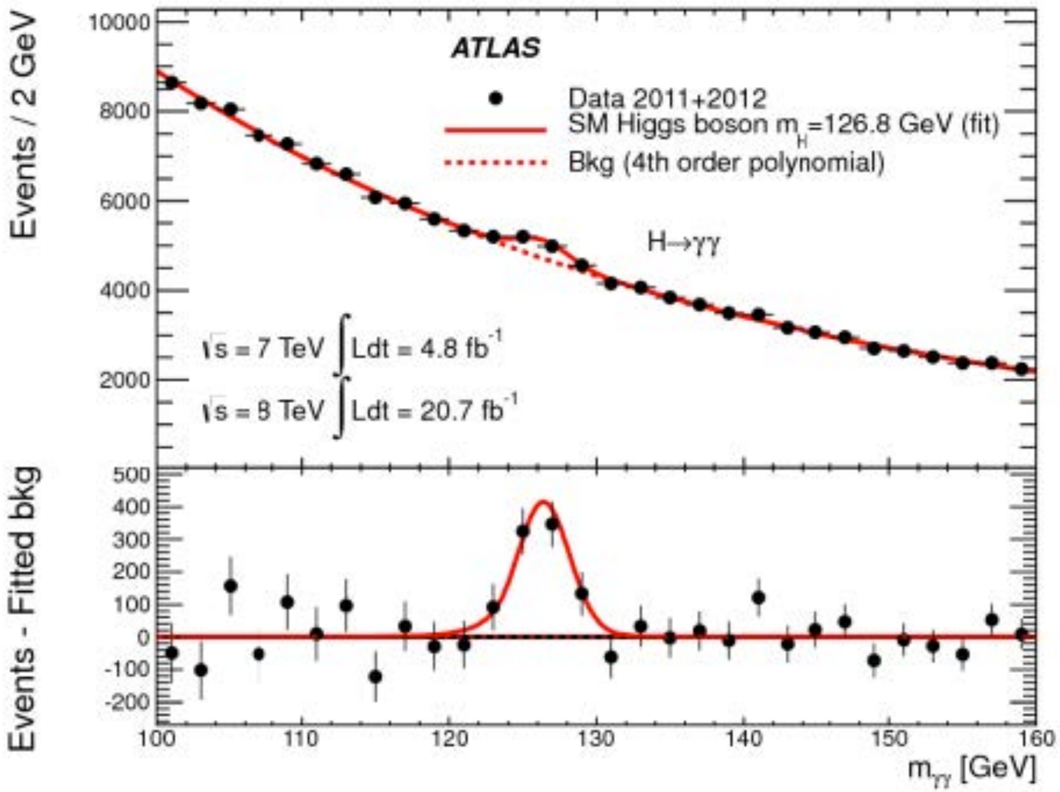
Mar 2015
preliminary

H ->γγ channel: decisive in the Higgs boson discovery



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(CMS: 4-lepton-channel)

Castle illumination: Mostly visible light

Thank you for your patience.