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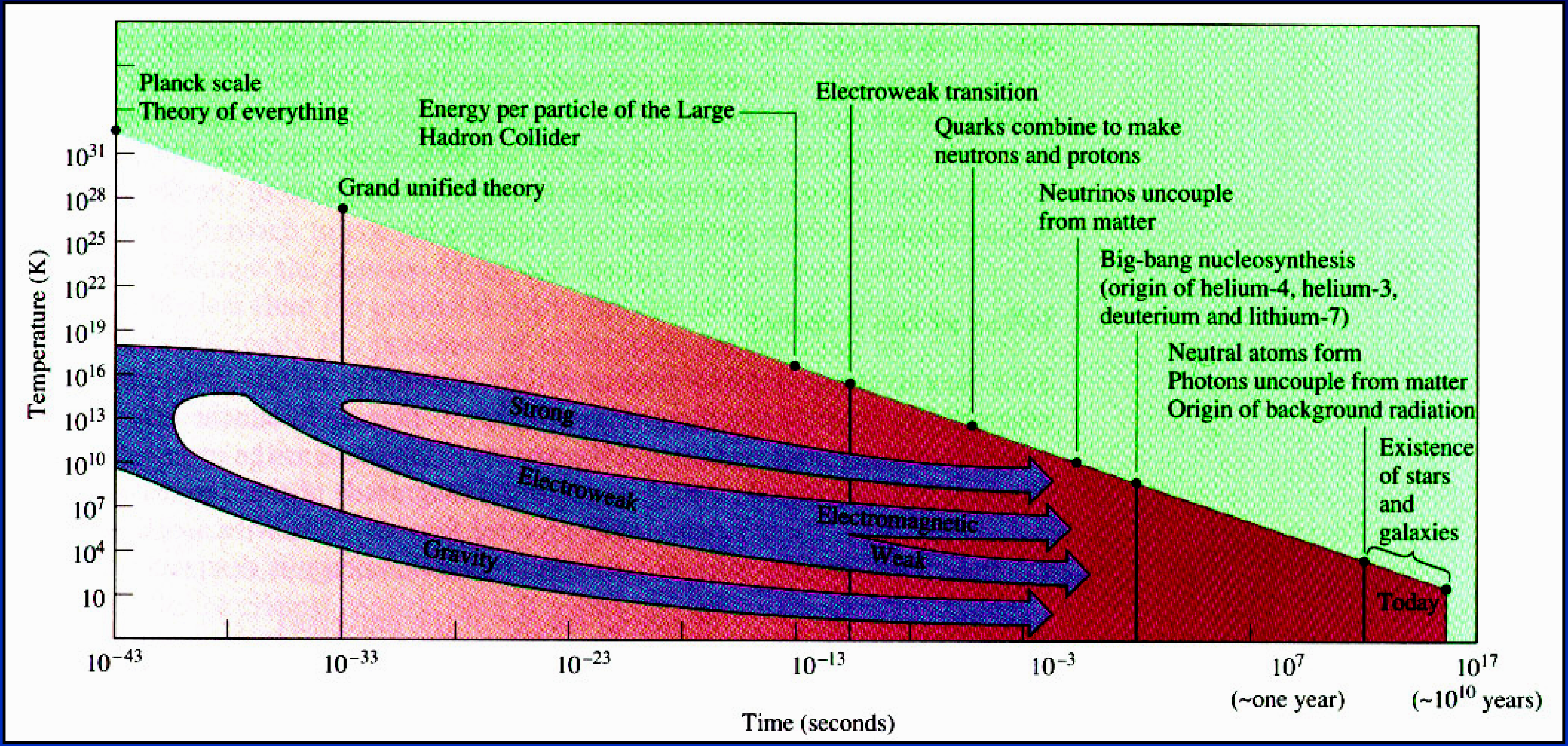
PARTICLE PHYSICS & COSMOLOGY



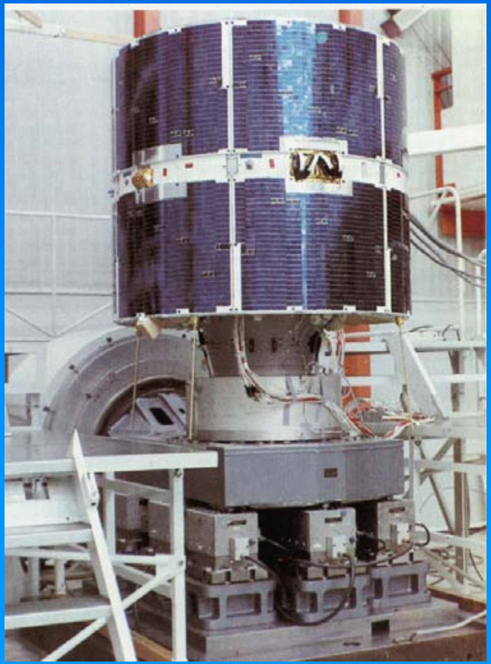
The energies needed to probe the unification of the forces are beyond our reach- at 10^{16} times higher than at CERN! They only ever existed once- right after the big bang. The physics at such energy scales (energy here in temperature units, with 1 eV ~ 11,600 K) is shown along with the time when the universe was at this temperature. Note the unification of Strong & Electroweak forces at 10^{28} K, & the unification of weak & EM to make electroweak at 10^{16} K (the CERN LHC works at this energy). We believe gravity unifies Somehow with the others at ~ 10^{33} K. In the very early universe can we probe this physics

Seeing to the Edge of the Universe

The 2 main tools giving us our understanding of the early universe are (i) powerful earth-based radio telescopes, and (ii) optical telescopes, principally the Hubble Space Telescope (HST). Although the HST mirror is only 2.5 m in diameter, there is no atmospheric interference, and it can take week-long exposures. Radio telescope arrays connect dishes far apart, giving v high resolution. Orbiting telescopes are also designed to see in the IR, UV, X-rays, and Gamma rays (none of which penetrate the atmosphere).

The HST (above) & its launch (below right)

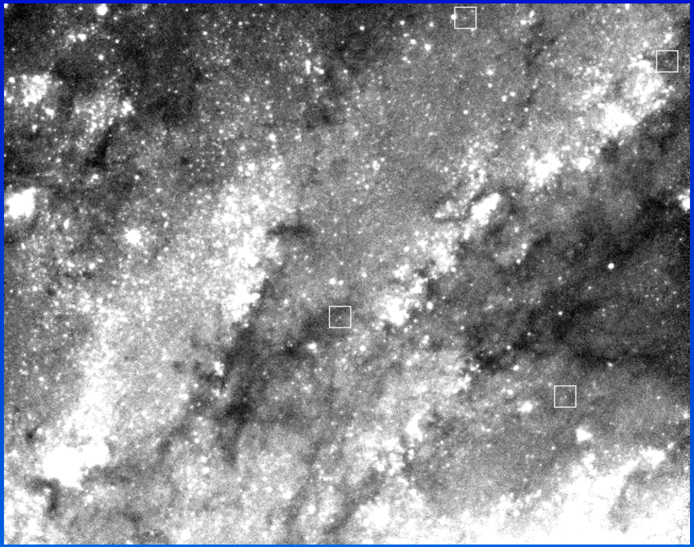
The VLA (Very Large Array), a set of 26 dishes, each of 25 m, which can be moved along rails stretching 15 miles from the centre



LEFT: The Cos-B satellite under construction. It carries a gamma-ray telescope

Cosmic Distance Scales

NGC 4603, @ 108 million lt. yrs

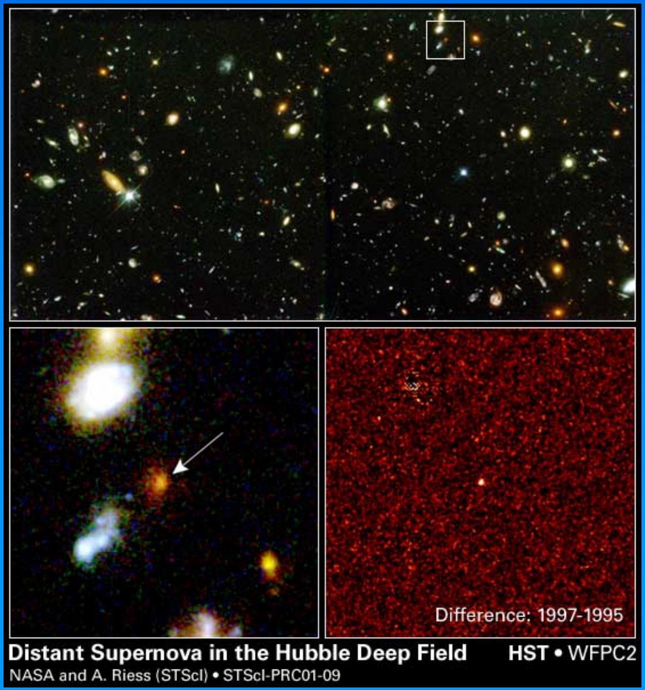


ABOVE: Close-up of NGC 4603- some Cepheids are identified in boxes

Measuring large distances is complex. Cepheids play a crucial role- these giant pulsating stars have pulsation time simply related to their luminosity. They can be seen out to ~ 10^8 light yrs with modern telescopes- we know their real luminosity because some Cepheids are near enough to have their distances measured in other ways (parallax, etc).

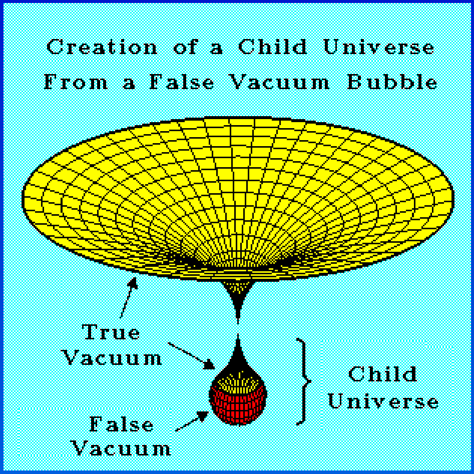
At much greater distances one relies on supernovae, whose luminosity is known fairly accurately from their spectra. These are so bright they can be seen as far as the farthest galaxies.

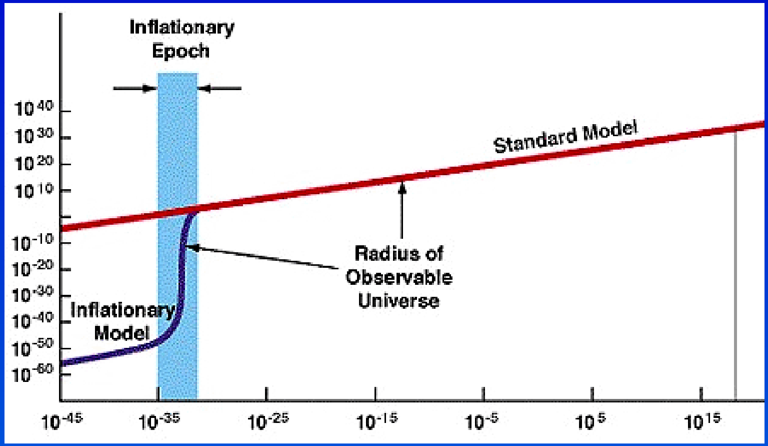
From all this work we find that the radius of the visible universe is ~ 14 billion (1.4 x 10^{10}) light years, & the age of the universe is ~ 1.4 x 10^{10} yrs



LEFT: Supernova in HST deep field- note difference between 1996-7.

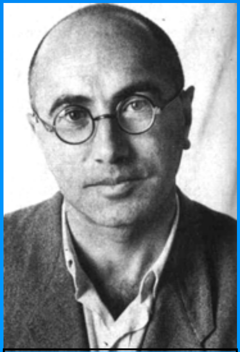
Theories of the Early Universe





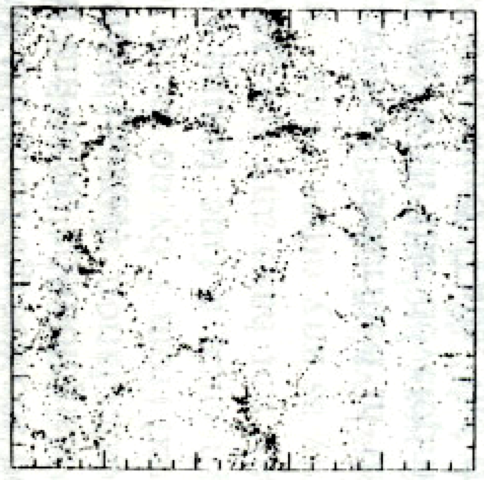
Theories of the early universe try to combine ideas about string and/or particle physics with gravity theory. This is hard without a proper quantum theory of gravity. There are very strong theoretical reasons for a modified Big Bang which begins with the quantum tunneling of all of spacetime from a 'false vacuum' state into the present universe (in a way reminiscent of the nucleation of a new phase) followed by a period of extremely fast expansion, or 'inflation' (above), and finally a long period of Hubble expansion, which still goes on.

At present the best way of testing these ideas is to look in great detail at the distribution of the microwave radiation in the sky – this is a relic from the time when radiation decoupled from matter shortly after the Big Bang. This idea goes back to work in the 1960's from the extraordinary Russian theorist Ya B Zeldovich, one of the founders of modern relativistic astrophysics.

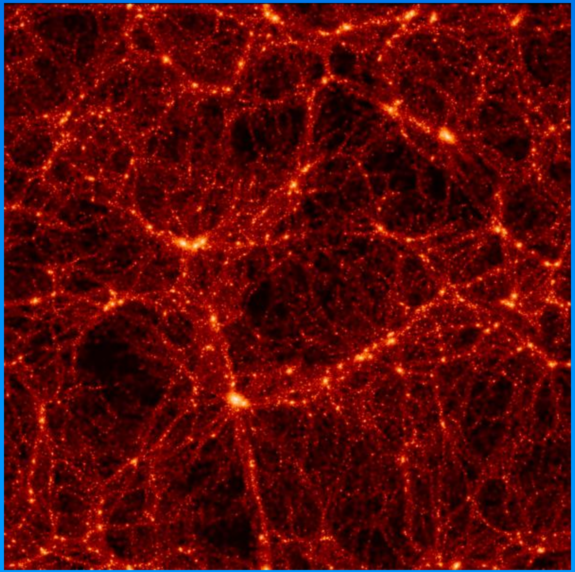


YB Zeldovich (1914-1984)

However there is a twist. In recent yrs it has been found that most of the universe is in the form of *DARK MATTER*, the nature of which is a complete mystery. The gravity from this changes the way in which the early universe evolved.

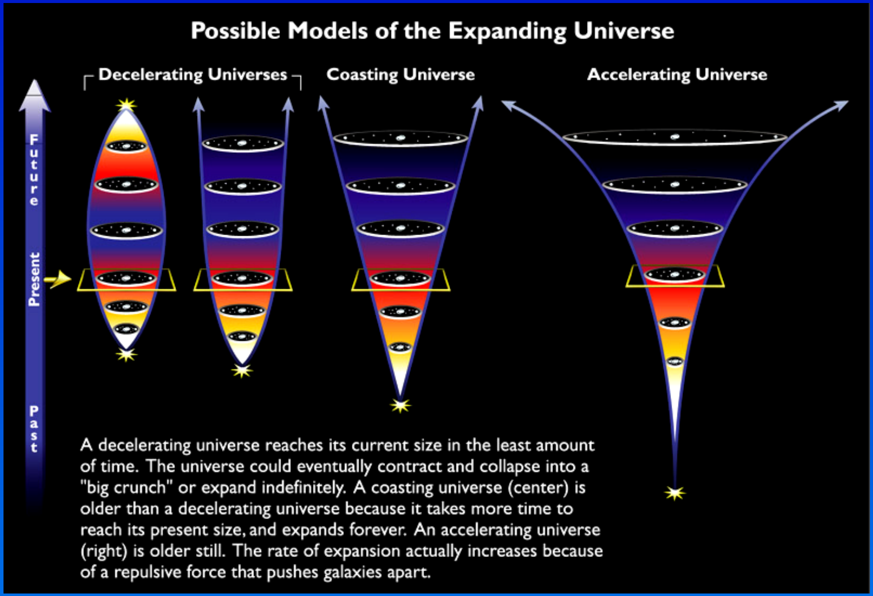


Predictions of mass distribution from Zeldovich theory



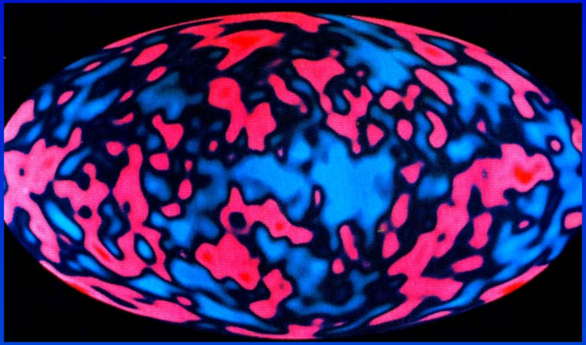
Simulations of mass distribution in early universe, including dark matter

Early Moments of the Universe


Possible Models of the Expanding Universe

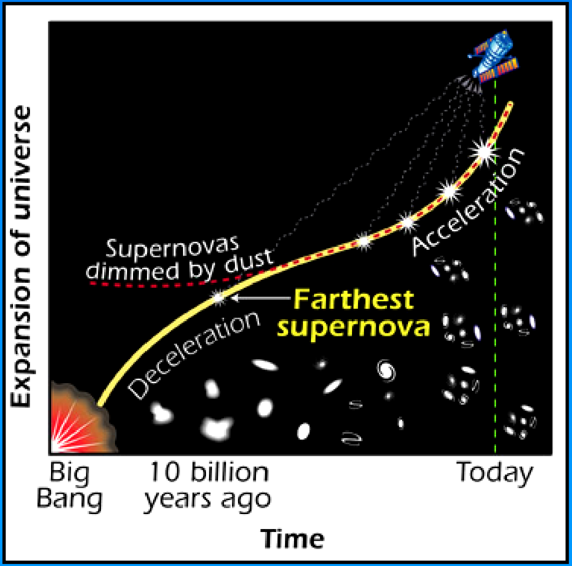
A decelerating universe reaches its current size in the least amount of time. The universe could eventually contract and collapse into a "big crunch" or expand indefinitely. A coasting universe (center) is older than a decelerating universe because it takes more time to reach its present size, and expands forever. An accelerating universe (right) is older still. The rate of expansion actually increases because of a repulsive force that pushes galaxies apart.

LEFT: a variety of Universes
RIGHT: COBE map anisotropic μwave background



There is now good evidence that the early universe indeed went through a period of very rapid expansion (inflation), followed by a slower uniform expansion- according to recent evidence now slowly accelerating.

This comes from measurements of tiny fluctuations in intensity of the microwave background, left over from the big bang. These fluctuations later self-gravitated into galaxies. The inflation scenario explains the small size of these fluctuations (a fraction **~ 10^{-5}** of the total μwave background).



Other pieces of the puzzle come from the distribution of galaxies in the early universe, inferred by deep space photographs of galaxies and supernovae

FAR LEFT: Use of supernovae to follow expansion of universe
NEAR LEFT: new galaxies in HST deep field photo