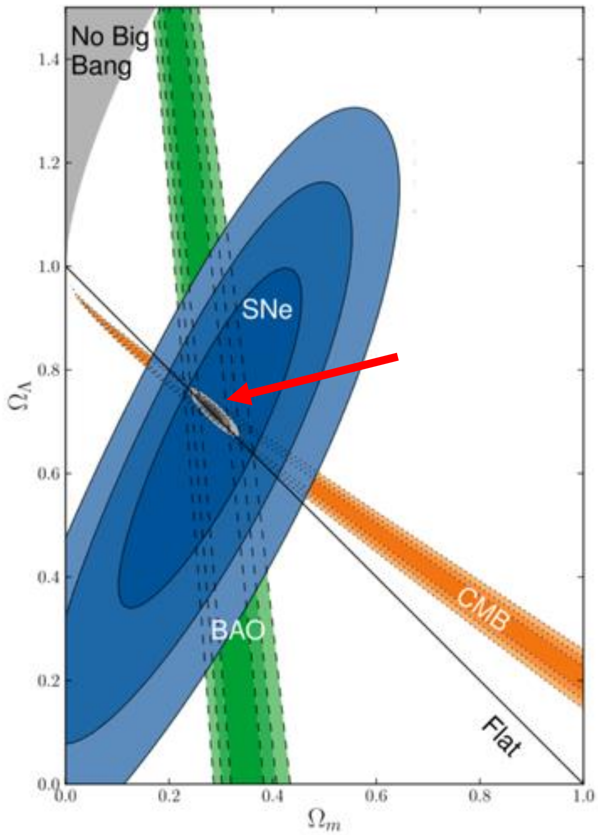
Dark Energy

The entity now accounting for more than two-thirds of the Universe in terms of energy density is believed to be an enigmatic form of black energy of which we know nothing other than it is accelerating the Universe's expansion.

This surprising finding is based on the observation of very distant thermonuclear supernovae. Resulting from the nuclear conflagration of white dwarfs of the same masses (1.4 $M_{\odot}$), thermonuclear supernovae are all known to release comparable fluxes of light. Since the amount of light received from a star is inversely proportional to the square of its distance, measuring the intensity of the light flux emitted by a thermonuclear supernova provides a good estimate of its distance. Furthermore, by studying the redshift of this same radiation, we can estimate how much the Universe has expanded since the supernova appeared. The observation of a large number of thermonuclear supernovae, located at various distances, thus produces a useful set of data to determine whether the expansion of the Universe is slowing down or accelerating.

Under careful scrutiny, the most distant thermonuclear supernovae have turned out be less luminous and therefore further away than expected, indicating an acceleration of the Universe's expansion. In addition, many astronomical observations imply that the Universe contains large amounts of dark matter, which can only slow down the expansion. The acceleration thus indicates the existence of a great amount of dark energy. These conclusions are supported by studies on fluctuations in the intensity of the cosmic microwave background radiation and on galaxy clusters. The findings of this research lead to new relations between the density of matter and the density of dark matter, which independently intersect with that produced by thermonuclear supernovae.



Credit: Suzuki et al., The Astrophysical Journal, 2011
(The Supernova Cosmology Project)

Physicists are very much puzzled by this dark energy, of which nothing in physics suggested the existence. It is also intriguing that its density is currently of the same order of magnitude as that of dark matter, while these two quantities may well be evolving very rapidly and independently from each other. Would thermonuclear supernovae be more diverse than expected? Would the most distant ones, the oldest, be intrinsically less luminous? Would the part of the Universe we are exploring be a little less dense than average and therefore expanding faster? If this dark energy does exist, an alternative remains: either it is constant in time and space, and its observed value is sheer coincidence; or it varies in space and especially in time, and ingenious mechanisms have to be devised to solve an irritating problem of numerical coincidences. But this requires introducing new particles, new forces or new space-time dimensions. Dark energy would then be the mere tip of the iceberg formed by a new physics yet to discovered.

Dark energy in the Universe

This graph displays the most likely values of dark energy density (Ω_Λ) and ordinary and dark matter density (Ω_M) in the Universe. The small grey-shaded elliptical area (red arrow) synthesises the constraints brought about by observations of thermonuclear supernovae (blue, SNe-labelled area), by studies of the cosmic microwave background radiation (orange, CMB-labelled area), and by studies of galaxy clusters (green, BAO-labelled area). The most likely values of the two quantities are $\Omega_\Lambda = 0.7$ and $\Omega_M = 0.3$, meaning that more than two-thirds of the energy content of the Universe is in the form of dark energy, the rest being matter (dark matter and ordinary matter).

Translated from 'L'énergie noire',* Passeport pour les deux infinis*, IN2P3/Dunod, https://pass2i.ijclab.in2p3.fr/ (French); updated with ICHEP2024 conference (https://ichep2024.org) for IPPOG