NOBEL SYMPOSIA

Report from the lecture presented by Martin Rees

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Our picture of the universe with galaxies spread through expanding space is fairly recent. In the early days of Einstein, the notion of a universe beyond our galaxy was not known. This led him to introduce a new term in his field equations, the cosmological constant Λ, leading to a repelling force to account for the possibility of a static universe in spite of the attractive nature of gravity. This modification has proven to be very useful to explain the current acceleration of the universe, as suggested by most, if not all cosmological probes. Among these are the observations of the anisotropies in the Cosmic Microwave Background (CMB), exhibiting a first peak in their power spectrum at about 1 degree, corresponding to the region in causal contact at the epoch of radiation decoupling from matter a few hundred thousand years after the Big Bang. The density contrast at that time was very small. The temperature fluctuations in the surface of last scattering differing in various parts in the sky by only one part in hundred thousand. Through the effect of gravity the density contrast grew rapidly to produce the first structures, stars and galaxies, about 100 million years after the Big Bang. The onset of nuclear fusion in stars at $z\sim20$ also marks the end of the "dark age" and the beginning of the history of the universe which is more complicated to model, as it involves non-linear perturbations.

However, the appearance of galaxies, often including supermassive black holes in their nuclei, allows us to model the universe, as these are tracers of the large scale structure. Besides central black holes, galaxies are powered by stars with lifetimes ranging from only millions of years for the heaviest stars to several trillion years for the lightest ones. Once the nuclear fuel runs out, a star may contract so much (into a neutron star or a black hole) that more gravitational energy is released than ever emerged from nuclear reactions. The observational evidence for black holes is today very compelling. X-ray telescopes are used to probe the domains around black holes in galactic nuclei through the 6.4 KeV Fe-line, which exhibits about 50% broadening due to Doppler shift in the rapidly spinning matter in the accretion region. In the future, dramatic collisions of supermassive black holes may be studied with space missions like LISA, sensitive to the generated gravitational waves from such sources.

Yet, we still lack detailed knowledge about most of the energy density of the universe. All “visible” (baryonic) matter in stars, gas and dust can only account for about 5 % of the total budget. About one fourth of the universe is in “Dark Matter”, possibly made up of yet undetected heavy elementary particles, and about 70% in “Dark Energy”. The best candidate for Dark Energy is Einstein’s Λ, although dynamical alternatives have been suggested. If the Dark Energy is indeed constant, the universe will expand for ever. The table below shows how the universe will turn into an ever darker and colder place.

Question section

Q: Why is Dark Matter lumpy and Dark Energy not?

A: Unlike Dark Matter, which is essentially pressureless, Dark Energy has high negative pressure and is thus not sensitive to local density. The simplest DE candidate, Einstein’s Λ, is (by definition) *constant* in space and time and thus does not clump. Observationally, the possible clumping of DE is limited by the measurements of CMB anisotropies.

Q: Could DM or DE be detected directly?

A: DM, if consisting of heavy (elementary) particles, is being searched for in “direct detection experiments” deep underground. The recoil of a nucleus in the detector could be signature of the scattering off a heavy neutral particle. DM particles could also be detected “indirectly” through their annihilation products: gamma-rays, anti-particles or neutrinos. However, there seems not to be any means of detecting DE other than by astronomical observations.