A break-through in the Cosmic Perspective:
Relating the beginning to the end of the Universe!

The recent work of two physicists, Prof. Thanu Padmanabhan at IUCAA, Pune and Dr. Hamsa Padmanabhan at ETH, Zurich, beautifully connects up and answers two fundamental questions about the cosmos, and embeds the solution into a comprehensive, elegant and novel perspective for Cosmology.

There are two tantalising mysteries about our universe - thought to be unconnected with each other - which have intrigued cosmologists for decades. The first one is about the existence of something called 'dark energy' which is speeding up the expansion of the Universe at present. Current observations strongly suggest that the nature of dark energy can be explained by invoking a term in Einstein's equations of gravity, called the Cosmological Constant. But, for this idea to work, the cosmological constant should have a very specific - and enormously tiny - value. Explaining this tiny but non-zero number is considered to be ***the*** greatest challenge faced by Theoretical Physics today.

Observations also reveal that all cosmic structures, like stars, galaxies etc. originated from very tiny fluctuations created during the earliest stages in the formation of the Universe. An equally fascinating mystery in Cosmology is to understand how these tiny fluctuations were created, and explain their magnitude. In standard cosmology, these two mysteries are considered unrelated, one dealing with the earliest phase of the universe and the other with a very late phase, separated in cosmic time by about 14 billion years!

Padmanabhans, in their forthcoming paper to be published in Physics Letters B, argue that the very existence, as well as the tiny numerical value of the cosmological constant can be understood as a direct consequence of the information content of cosmic space and time. As a bonus, their analysis also leads to the correct value for the size of the small fluctuations in the early universe, which acted as the seeds for the cosmic structures like galaxies. Both these numbers are obtained from a description of the universe in which 'cosmogenesis' - the creation of the universe - takes place nearly 14 billion years ago, from a primordial phase described by quantum gravity, to the classical phase described by Einstein's equations.

The new ingredient brought in by the authors is the concept of cosmic information, called as CosmIn. In Einstein's theory, gravity controls the amount of information accessible to any particular observer. This is why, for example, you cannot obtain information from the inside of a black hole, if you are at a safe distance away from it. Padmanabhans show that the maximum amount of cosmic information, accessible to an observer in our Universe, will be finite, only if the universe undergoes an accelerated phase of expansion at late times, exactly as we observe.

What is more, the concept of cosmic information is robust enough to connect up the phantom world of quantum gravity - in which the notions of space and time dissolve - with the standard classical phase described by Einstein's equations. Using results repeatedly suggested by several models of quantum gravity, they argue that the total information transferred from the quantum gravitational phase to the classical phase must be equal to a simple number: $\mathbf{4\pi}$, which is just the area of a sphere of unit radius! This allows them to relate the numerical value of the cosmological constant - dubbed as the greatest unsolved problem in theoretical physics - to the scale at which the universe made a transition from the quantum gravitational phase to the classical phase.

This scale, in turn, can be related to the second enigmatic feature of our universe: the magnitude of the tiny quantum fluctuations in the early universe. It is these fluctuations which grew to form the largest objects in the universe like galaxies, clusters of galaxies, etc. today through a process known as gravitational instability. The magnitude of the initial fluctuation is very well determined by observations, but is again a puzzle from the theoretical point of view. The popular way of obtaining this quantity is from the so-called inflationary models of the universe. But inflationary models come in all shapes and sizes and can be designed to produce any value whatsoever for this amplitude. Because of this reason, Thanu and Hamsa Padmanabhan do ***not*** postulate an inflationary phase in their description of the universe. Instead, they succeed in showing that the fluctuations can be generated directly from the quantum gravitational phase itself. Such ideas have been explored originally by E.R. Harrison in 1970 and, later on, by several other authors. In this description, one can relate the size of the fluctuations to the energy scale at which the universe makes a transition from a primordial, quantum gravitational phase to the standard cosmological evolution without any Big Bang.

So, you can relate two key numbers - the numerical value of the cosmological constant and the size of the primordial fluctuations - to a single parameter in the theory related to the energy scale at which the classical universe came into being. Lo and behold, one obtains the correct observed value for both these quantities for a suitable value of this single parameter! As Thanu Padmanabhan says, "This is extremely non-trivial. In conventional cosmology, nobody had ever thought of linking the numerical value of the cosmological constant to the size of the initial fluctuations. And nobody knows how to get either of these two numbers from first principles; we can get both of them in terms of the scale at which the classical universe came into being."

The framework is extremely simple and elegant because it is described by a single parameter - unlike standard inflationary models that contain scores of possibilities, thereby lacking any predictive power. In fact, the work by Hamsa and Thanu Padmanabhan does ***not*** use any untested physics either in the form of an inflationary phase - which they do not require - or for explaining the late time acceleration. The ***only*** postulate they make is that the information content of the universe should be equal to $\mathbf{4\pi}$, the area of a unit sphere. From this minimal investment in assumptions, they are able to reap huge dividends.

The approach also draws upon an obvious - but not sufficiently emphasized - feature of our Universe, which is highlighted in another related paper of the Padmanabhans, to be published in a special issue of International Journal of Modern Physics D. Because light takes a finite amount of time to travel from a distant source to us, we can see our past. When we look at a galaxy 1 billion light years away, we are actually seeing it, as it was, 1 billion years earlier. The observations of the cosmic microwave background take us back to a time when the universe was just 380,000 years old, compared to its current age of nearly 14 billion years. Extrapolating this idea, it is clear that you can, in principle, see the universe at its birth, if only you could receive signals from a sufficiently far away region. In other words, what happened before the - so called - Big Bang is completely spelt out and imprinted in the sky!

Padmanabhans explain their model of cosmogenesis by the following analogy: “Think of a large chunk of ice which contains a point source of heat inside it. The heat source melts the ice around it, creating a region of water, which in turn expands, reaching local thermodynamic equilibrium. The water molecules in the liquid phase have a higher level of symmetry (viz. the rotational invariance) compared to the solid ice lattice surrounding the water. At large scales, close to the boundary of the phases, the molecules have not yet reached equilibrium, since the chunk of ice is being heated up from the inside. Incredibly enough, this is similar to how our universe behaves. The region with water is analogous to the observed universe (described by Einstein's theory) and it is surrounded by a pre-geometric phase (analogous to ice) which is described by - as yet unknown - laws of quantum gravity. The Big Bang is replaced by a transition from one phase to another at the boundary.” The concepts in this paper link this picture both to the information content of the universe, and to the present day expansion, thereby obtaining a holistic description of cosmology.

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