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Editorial

The accelerating universe: evidence and theories

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Abstract We give a short overview of the accelerating Universe paradigm and a brief description of articles in this special collection.

The present era is one where there are two Standard Model paradigms. One is the Standard Model of cosmology, in which the universe is composed of 4.9 % ordinary baryonic matter, 26.8 % dark matter and 68.3 % dark energy. The second is that of elementary particle physics, which is based on a spontaneously broken as well as confining gauge theories of the electro-weak and strong interactions, which contains quarks, leptons, gluons, the $W-$ and $Z-$ bosons, the photon and the Higgs particles. The latter does not have dark matter candidates that are required by the former and is therefore incomplete and requires extensions thereof. This is the setting in which the present collection of intriguing articles has been put together. The thrust of our collection is indeed the most recently discovered feature of the properties of the Universe and is therefore entitled 'The Accelerating Universe—Evidence and Theories'. The evidence for the discovery of the accelerating Universe by Saul Perlmutter, Adam Riess and Brian P. Schmidt led to the award of the 2011 Nobel Prize with one half going to Perlmutter and the other half to Riess and Schmidt.

We begin with a little history to motivate this collection. The existence of dark matter was surmised by Fritz Zwicky who on the basis of the observations of X-rays from galactic clusters speculated that the must be a non-luminous mass to gravitationally bind the hot electrons to the clusters [1]. The existence of dark matter was put on a firmer footing with the measurement of the rotation curves of galaxies by Vera Rubin and her colleagues [2]. Dark matter at the cosmological scales is believed to account for the observed anisotropies of the cosmic microwave background (CMB) [3] and formation of large scale structure in the universe. The history of the idea of the cosmological constant or dark energy (as it is presently called) has however been checkered.

Albert Einstein introduced the cosmological constant in 1917 [4] with the aim of obtaining a static universe solution in general relativity. After Alexander Friedman's [5] (1922) and Georges Lemaître [6] (1927) found the expanding universe solution from the field equations of general relativity, and Edwin Hubble's discovery of a correlation between the redshift and distance of the Cepheid variables [7] (1929), Einstein in 1931 [8] retracted the cosmological constant as being no longer necessary, for a historical discussion, see e.g. [9].

In Einstein's original proposal, where a constant of nature was introduced to balance the gravitational of the matter density in the Universe ($G\rho = \Lambda$), is what in modern usage would be described as 'unnatural', whereby a cancellation between quantities emerging from two different sectors is invoked to explain observations. The cosmological constant being a problem of naturalness where a cancellation of 'large' particle physics parameters, to explain a many order of magnitude smaller cosmological density was highlighted by Yakov Zel'dovich [10].

The connection of the cosmological constant to the zero point energy of the vacuum in quantum field theory was first made by Wolfgang Pauli in the 1920's. Pauli observed that if the zero-point energy of electromagnetic fields were to contribute to the cosmological constant, the curvature radius of the universe "...could not even reach to the Moon" as described in ref. [9]. Paul Dirac explained 'spontaneous emission' or the transition between stationary atomic states as being caused by zero-point fluctuations of the vacuum in 1927 [11]. The physical effect of vacuum fluctuations were tested precisely in the 1947 experiment of Willis Lamb and Robert Retherford where they measured the split between the $^2S_{1/2}$ and $^2P_{1/2}$ levels of Hydrogen atoms (the 'Lamb shift') and explained it as being due to the zero-point energy [12]. In the following year Hendrik Casimir and Dirk Polder observed the first and macroscopic manifestation of vacuum energy in which they measured the force of attraction between parallel conducting plates (the 'Casimir effect') [13].

In 1989, Steven Weinberg [14] wrote an influential review where he listed particle physics models, and their implication for the zero-point energy and the cosmologi-

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cal constant. In supersymmetric models, the zero-point energy of the fermionic fields exactly cancels the corresponding contributions of the bosonic fields and if supersymmetry were to be an exact symmetry there would be no cosmological constant from zero-point energies. However, supersymmetry if present, must be a broken symmetry, as in the real world no fermion has an identical mass bosonic partner. Supersymmetry breaking would then give rise to a large cosmological constant, which is of course not observed. When supersymmetry is promoted to a local symmetry then the corresponding Supergravity Theory does provide in the so-called 'no scale SUGRA models' a mechanism for breaking supersymmetry without generating a tree-level cosmological constant. These no-scale SUGRA models also arise in some string theory compactifications. (These aspects are discussed at length in two of the articles in this collection.)

The discovery of the accelerating universe by Perlmutter et al. [15], Riess et al [16] and Schmidt et al [17] from the luminosity redshift plots of Type-Ia supernova which are regarded as standard candles as they arise from the collapse of white dwarfs with mass close to the Chandrashekhar limit of $1.44M_\odot$. The discovery of the accelerating universe came as a surprise to particle physicists who had hitherto been busy in trying to explain a zero cosmological constant and who now faced the task of explaining the observed cosmological value of $\rho = 3.02174\times10^{-47}\mathrm{Gev}^4 \simeq M_P^2 H_0^2$ from microphysics.

For cosmologists the addition of a cosmological constant to the energy density budget was had an immediate application, in that the age of the universe which from the measurement of Hubble expansion rate turned out to be $8-10$ Gyrs which was embarrassingly lower than the inferred age of some globular clusters, with the inclusion of the cosmological constant the age of the universe from the Hubble expansion rate was a reassuringly large 13.8 Gyrs consistent with all observations.

The inclusion of the cosmological constant was also consistent while fitting the Cosmic Microwave Background (CMB) anisotropy and structure formation theory with observations. There is however a problem of naturalness in cosmology: why is the cosmological constant which does not dilute unlike matter and radiation during the expansion of the universe have similar density as dark matter and baryonic matter in the present epoch. To solve this 'why now' problem the concept of a negative pressure 'dark energy' fluid which could have evolved during the early history of the universe has replaced the 'cosmological constant' in the lexicon of physics and astronomy [18].

A point of view in a different direction is that the acceleration we measure is not due to fundamental negative pressure fluid but due to our peculiar motion in an in-homogenous patch of the universe [19]. This is supported by increasing evidence of an dipole axis in the CMB, quasars and supernovae luminosity [20, 21].

To explain the accelerated universe as vast array of theoretical ideas (zero-point energy and renormalisation, dark energy scalar field, supersymmetry breaking in supergravity, quantum gravity , string relics and cosmological anisotropy) have been brought forth. With the present state of observations there are favourites (depending on who one asks) but there is no clear winner . It will be no exaggeration to state therefore that further refined measurements of the acceleration of the universe from diverse observations will open up a new paradigm in fundamental physics and cosmology.

In this collection we have curated an eclectic collection of 7 articles which list the observational evidence of an isotropic accelerating universe and also survey diverse theoretical ideas about the nature vacuum energy.

Mazumdar et al. [22] present the canonical picture of the evidence for dark energy from type 1a supernovae, CMB, galaxy surveys, observations of the Sunyaev-Zeldovich effect from clusters, and lensing by clusters. They also point out that not all is well with the standard ΛCDM (cosmological constant and cold-dark matter) model of cosmology and discuss the discrepancy in the values of H_0 and σ_8 between CMB and large scale structures observations in the ΛCDM model and discuss if varying dark energy models are able to resolve these tensions between different observations.

Mohayee et al. [23] present the experimental evidence which challenges the notion that the universe at the scales we have probed is homogenous and isotropic. They point out that the distribution of quasars shows a dipole distribution contrary to expectations from the standard cosmological model. They also show that the Hubble expansion rate deduced from supernova data also shows a dipolar distribution which is aligned with the dipole distribution of quasars. All this supports the idea that the acceleration is due to our local motion in an in-homogenous universe rather than due to a cosmological dark energy fluid.

Mavromatos and Peracaula [24] espouse the idea that the fields from the gravity multiplet of string theory, namely the graviton, the dilaton and the axion can explain the acceleration both during the epoch of inflation and in the present epoch. In this Running Vacuum Model they explain all epochs of cosmological evolution from relics of string theory. Inflation can arise from the gravitational chiral anomaly term of axions due to chiral gravitational waves in the background. The same axions can acquire a mass due to instanton effects and act as dark matter in the late universe. And in the present epoch the axions can behave as running vacuum energy which is distinct from the cosmological constant.

Dutta and Maharana [25] give a survey of dark energy models from which arise in different string compactification and supergravity models. They discuss how in the orbifold compactification of Type II strings the field theory that emerges is the 'no-scale supergravity' where the Kahler structure of the bosonic fields ensures that we may have supersymmetry breaking at TeV energies while still having zero cosmological constant. They also discuss scenarios where the cosmological constant can be uplifted to give a de-Sitter space in the present epoch. The give a comprehensive list of models which arise from string theories which can generate the observed dark energy.

Capozzielllo and Lambiase [26] discuss the extended gravity models which can phenomenologically act as dark energy fluid. The two theories they discuss in detail are the generalised curvature $f(R)$ theories and the generalised torsion $f(T)$ theories to account for the cosmological acceleration in the present epoch of the universe.

Venkatramani and Newell [27] discuss the dark matter part of the dark sector. They argue that the symmetry considerations rather than energy minimisation accounts for the distribution of matter in the galaxy. They show that this 'pattern dark matter" can explain the observed rotation curves of both elliptic and bar type galaxies.

Pomeau [28] discusses an interesting scenario where he considers the screening introduced when massive fermions are scattered by a gravity field. It produces an effect whereby Newton's constant has a value that is modified at large distances. Thus, in this scenario, there is no requirement of a dark matter candidate, nor does it require a modification of Newtonian dynamics, unlike, e.g., the popular MOND scenarios. An intriguing possibility indeed.

We thank all the authors who have contributed to this issue for their time and effort. And finally we hope that the reader perusing the articles this volume may find some of the ideas are stimulating enough to provide new directions for their own investigations.

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