

Editorial

## Galaxies: An International Multidisciplinary Open Access Journal

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Received: 23 October 2012 / Accepted: 1 November 2012 / Published: 8 November 2012

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The knowledge of the universe as a whole, its origin, size and shape, its evolution and future, has always intrigued the human mind. Galileo wrote: “*Nature’s great book is written in mathematical language.*” This new journal will be devoted to both aspects of knowledge: the direct investigation of our universe and its deeper understanding, from fundamental laws of nature which are translated into mathematical equations, as Galileo and Newton—to name just two representatives of a plethora of past and present researchers—already showed us how to do. Those physical laws, when brought to their most extreme consequences—to their limits in their respective domains of applicability—are even able to give us a plausible idea of how the origin of our universe came about and also of how we can expect its future to evolve and, eventually, how its end will take place. These laws also condense the important interplay between mathematics and physics as just one first example of the interdisciplinarity that will be promoted in the *Galaxies* Journal.

Although already predicted by the great philosopher Immanuel Kant and others before him, galaxies and the existence of an “Island Universe” were only discovered a mere century ago, a fact too often forgotten nowadays when we deal with multiverses and the like. By summarizing some of the developments of this last magic century, my aim is to provide an excuse, a motivation, and even a scheme for the role of the new journal *Galaxies*, and especially its intrinsic interdisciplinary nature. By recalling the important discoveries of Slipher, Leavitt, Hubble and others on the size and nature of the observable universe and, on the mathematical side, the construction of solutions to Einstein’s field equations by Schwarzschild, de Sitter and Friedmann, and their interpretation, in the scope of a complete theory developed by Lemaître, we are led to the crucial instant when Einstein abandoned his cosmological constant. The extraordinary discovery by Penzias and Wilson, that a Big Bang once took

place, an actual origin of the universe, put an end to the steady state theory. The modification of the Big Bang model by the addition of an inflationary phase, the very recent discovery of the acceleration of its expansion and, before that, the cosmological constant issue, as viewed through the eyes of quantum physics, by Pauli, Zel'dovich and others, led to the 'old' problem of the cosmological constant—as termed by Weinberg—and now leads us to the 'new' problem: to explain the universe acceleration (since numbers do not match at all). Even when dealing with whether to keep Einstein's equations untouched as *the* universal description of gravity at all scales, or to modify them, as reasonable quantum corrections (Starobinsky and others) seem to suggest—scalar-tensor gravities, f(R) theories and the like—*Galaxies* should remain understandable to a very wide readership.

After this short overview, let us further concentrate on *Galaxies* and the large scale structure of the universe: in particular, on the laws of physics which allow us to describe and try to understand the present universe behavior as a whole and as a global structure made of myriads of smaller substructures. The vision we have now of the so-called global or large-scale universe (which astrophysicists term the extragalactic universe) began to take shape during the second and third decades of the past century. We should start by recalling that, at that time, everybody thought that the universe was reduced to just our own galaxy, the Milky Way. It is indeed true that a very large number of nebulae had been observed by then, but there was no clear proof that these objects were not within the domains of our own galaxy. Actually, the first nebulae had already been identified many centuries ago by Ptolemy who, in his celebrated work *Almagest* [1], reported five of them in AD 150. Later, Persian, Arabic and Chinese astronomers, among others, discovered some more nebulae, over several centuries in the history of mankind. Concerning scientific publications, Edmond Halley [2] was the first to report six nebulae in the year 1715, Charles Messier [3] catalogued 103 of them in 1781 (now called Messier objects), while confessing his interest was “*detecting comets, and nebulae could just be mistaken for them, thus wasting time.*” William Herschel and his sister Caroline published three full catalogues of nebulae [4], between 1786 and 1802, where a total of 2,510 were identified. However, in all these cases the dominant belief was that these objects were merely unresolved clusters of stars, in need of more powerful telescopes. On 26 April 1920, in the Baird auditorium of the Smithsonian Museum of Natural History, a debate took place (now called by astronomers, in retrospective, *the Great Debate*), on the basis of two works by Harlow Shapley and Heber Curtis, later published in the *Bulletin of the National Research Council*. During the morning, the two scientists presented independent technical results on “*The Scale of the Universe*” and then took part in a joint discussion. Shapley defended the Milky Way to be the entirety of the universe and believed that objects such as Andromeda and the Spiral Nebulae were just part of it. Curtis, in contrast, affirmed that Andromeda and other nebulae were separate galaxies, or “*island universes*” (a term coined by the philosopher Immanuel Kant, who believed that the spiral nebulae were extragalactic). Curtis showed that there were more novae in Andromeda than in the Milky Way and argued that it would be very unlikely within the same galaxy to have so many more novae in one small section of the galaxy than in the other sections. This led him to support Andromeda as being a separate galaxy with its own signature age and rate of novae occurrences. He also mentioned Doppler redshifts found in many nebulae. Following this debate, by 1922 it had become clear that many nebulae were most probably other galaxies, far away from our own. Yet it was Edwin Hubble [5] who, between 1922 and 1924, presented clear proof that one of this nebulae, Andromeda, was far beyond the limits of our own

galaxy. Hubble had arrived at Mount Wilson, California, in 1919 and, using the new Hooker telescope there, soon identified Cepheid variable stars in several spiral nebulae, including Andromeda and the Triangulum. His observations, made from 1922–1923, proved conclusively that these nebulae were much too distant to be part of the Milky Way and should be considered as separate galaxies. This was the first clear evidence of the “island universe” theory. In this way, he definitely changed the until then predominant vision of our universe, and opened to human knowledge the much more complex extragalactic cosmos [6], whose study is the main goal of this new Journal. Hubble, who was by then 35, found opposition to his results in the astronomy establishment and had his finding first published in the *New York Times*, on November 23, 1924, before being formally presented in the 1925 meeting of the American Astronomical Society. Crucial to this discovery was the identification of the Cepheid variable stars in those nebulae, which brings us to Henrietta S. Leavitt, who, in 1912, discovered the very important period-luminosity relation: a straight line connecting the luminosity and the logarithm of the period of variability of these brilliant stars. Hubble publicly recognized the importance of Leavitt’s discovery for his work (saying that she deserved the Nobel Prize). Later, in 1929, Hubble derived his famous law: velocity–distance relationship for nebulae using, as he later wrote to Vesto Slipher: “*your velocities and my distances.*” He acknowledged Slipher’s seminal contribution to his own work by declaring that “*the first steps in a new field are the most difficult and the most significant. Once the barrier is forced, further development is relatively simple.*”

Another very important fact to recall, this one from a theoretical perspective, is that when Albert Einstein constructed—in 1915, starting from very basic physical postulates such as the principles of covariance and equivalence of the laws of physics—his theory of General Relativity (GR), scientists (himself included) were firmly convinced that our universe was stationary. *Static*, is a more appropriate terminology, albeit rather counterintuitive, since this does not mean that celestial bodies do not move, but that stars and their clusters, in their wandering and distribution, would always have remained from the utmost far past, and would continue to do so into the utmost far future, as we see them at present, with no essential changes. No beginning or end of the universe was foreseeable, nor needed or called for. However, to his extreme disappointment, Einstein realized that a universe of this sort was not compatible with his equations, that is, the static universe is *not* a solution of Einstein’s field equations for GR [7]. The reason (not difficult to grasp) is that a universe of this kind cannot be stable: it will ultimately collapse with time owing to the attraction of the gravity force. This led Einstein astray, until he came up with a solution: while keeping all physical principles that led him to construct his equations, there was still the remaining freedom to introduce an extra term, a constant (with either sign) multiplied by the metric tensor. This is the now very famous *cosmological constant*, but the problem was that it had no physical interpretation, of any sort. However, endowed with the right sign, it did produce a repulsive pressure to precisely counter the gravitational attraction and keep the universe solution static. Einstein was happy with this arrangement for quite a long time.

Soon Karl Schwarzschild (in a letter to Einstein from December 1915) found a solution to Einstein’s equations, which corresponds to what is now known as a black hole. Einstein was very surprised to see such a beautiful solution and there is now evidence that he himself had been working hard to find such a solution but had failed, probably because he was looking for a more general solution. Schwarzschild’s insight was namely to look for the simplest one, with spherical symmetry. Alexander Friedmann, in 1922, obtained another, which was derived by solving the (now named)

Friedmann equations and is even more interesting for cosmology than Schwarzschild's solution, because it corresponds to *the whole universe*. Friedmann's early death prevented him from realizing that, indeed, his solution would describe an expanding universe. This honor was reserved for Georges Lemaître who rediscovered essentially the same solution while he was working at the Massachusetts Institute of Technology on his second Ph.D. thesis, which he submitted in 1925. Around the same time, Willem de Sitter had also been working on a universe solution (now called the de Sitter space), which is the maximally symmetric vacuum solution of Einstein's field equations with a positive (therefore repulsive) cosmological constant  $\Lambda$ , which corresponds to positive vacuum energy density and negative pressure. This was a very simple solution of Einstein's equations that undoubtedly corresponded to an expanding universe. In fact, in 1917 De Sitter had theorized, for the first time, that the universe might be expanding. The big problem was that it only could describe a universe devoid of matter, just a vacuum, and this seemed to be at that time not very useful or physically meaningful. Nowadays, however, this solution has gained extreme prominence as an asymptotic case to describe with good approximation the most probable final stages of the evolution of our universe (if it continues to expand indefinitely) and also its initial stages, namely the inflationary epoch: the fact that the de Sitter expansion is exactly exponential is very helpful in the construction of inflationary models.

Jumping now to present developments, special emphasis deserves the observational revolution that we have witnessed during the last couple of decades in the areas of Astronomy and Cosmology. Our understanding of the universe has been revolutionized by observations of the cosmic microwave background (with COBE, several balloons, and very specially the Wilkinson Microwave Anisotropy Probe, WMAP), the large-scale structure of the universe (the Two-degree-Field, Galaxy Redshift, and Sloan Digital Sky Surveys), and distant supernovae (the Supernovae Projects and other). The use of a variety of instruments of ever increasing precision (on top of the already mentioned, the Hubble Space Telescope, VLT, *etc.*) and the creation of worldwide collaborative consortia (SSDSII, Euclid, and many other), have opened exciting new prospects for the forthcoming adventure of understanding our Universe. The PLANCK satellite collaboration will publish the first cosmological results by early 2013. A number of ground-based experiments measuring polarization of the CMB (as ACTpol, SPTpol, Polarbear, BICEP, BLISS, *etc.*) will soon report results, as also the next-generation galaxy surveys (BOSS, DES, HSC, HETDEX, *etc.*). These new data will allow us to address deep questions, as, e.g., on the nature of dark energy and dark matter, on what did power the Big Bang, on the reality and specific properties of inflation, and on when and how did the first stars and galaxies actually form.

May this brief memory of old and recent important developments serve as a motivation for further research, not only on the subjects explicitly discussed before, or at the historical level, but on the very fine details of the observations, data issues, and deep theoretical analyses. As Editor-in-Chief, I hope that *Galaxies* will stimulate the rapid dissemination of information from scientists from around the world on topics and developments in all these fields, which are further specified on the *flyer*. The journal will offer a base for scientists to expose scientific evidence, theories and reasonable speculation, where permitted, which will help to better understand the universe we live in. I do expect that *Galaxies* will become a serious journal for interdisciplinary research on the cosmos and that, in order to achieve this goal, all members of the editorial and production offices will work hard to provide the best service possible. We depend on you, our potential authors, to submit high-quality,

original articles that can attract attention, as well as detailed technical developments and comprehensive review articles which are also useful and in demand by our multidisciplinary scientific community.

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