Cosmology in the first half of the 20th century

Hermann Bondi, Cambridge, UK

In various fields of science an essential early step consists of abandoning a long held assumption that was considered 'obvious', any alternative being viewed as inconceivable and indeed absurd. This happened in celestial dynamics when the notion that the Earth was at rest and was the centre of the solar system had to be given up before a sensible description of its functioning could be formulated. (Interestingly, this development was due to intellectual dissatisfaction with previous attempts at a description of the motion of the planets rather than to a crucial experiment or observation. This only came in 1728 with James Bradley's discovery of the aberration of star light and his explanation of this phenomenon as due to the changes in the velocity of the Earth in its annual orbit)

It happened in atomic physics when the absurd notion of universal determinacy had to be (most reluctantly) abandoned. It was not appreciated that in a fully deterministic Universe experimentation becomes meaningless, since the outcome is the result not of any recent set-up, but of endless chains of causal links starting in the most remote past.

In cosmology the essential step was the abandonment of the 'obvious' assumption that the Universe had to be static, i.e. without any large systematic motions. Even as radical a thinker as Einstein thought that the only way to apply his new General Relativity to the cosmos was to add a 'cosmological' term to his equations so as to balance gravitational attraction. This step indeed made it possible for him to admit as a solution a static uniformly matter-filled model Universe. He expressed the hope that this might in fact be the only solution of his equations with the cosmological term. This hope was soon dashed by de Sitter. He showed, as a mathematical counter example, that another solution was an empty model Universe in an exponential state of expansion. Thus this model of 'motion without matter' was contrasted with Einstein's 'matter without motion'.

In the early 1920's a Russian meteorologist, Friedmann, showed that there existed a range of intermediate solutions. Curiously, though his work was published in widely read journals, it was ignored. Independently of his work and of each other, H.P. Robertson and A.G.Walker found the complete set of solutions of Einstein's equations for a uniform matter-filled Universe in the 1930's, making models with motion familiar to theoreticians. The assumption of uniformity implied that the relative velocity of any two co-moving bodies was along the line joining them and was proportional to their separation.

At the beginning of the 20th century it was still debated among observers whether the 'nebulosities' in the sky were in the main diffuse matter within our galaxy or 'external galaxies' much like our own at very great distances. The second option gradually gained adherents. In 1915 Slipher noted that in the spectra of these external galaxies red shifts were much more common than blue shifts. But it was Hubble's and Humason's remarkable efforts on the then new 100" telescope to define a distance scale for these distant galaxies and measure their red shifts that established beyond reasonable doubt (i) that most of the nebulosities were external galaxies, (ii) that they were reasonably uniformly distributed and (iii) that their red shifts, interpreted as velocities of recession, were proportional to their distance. Though a number of astronomers, including Hubble himself, at first thought that the red shifts should not necessarily be regarded as due to velocities, this alternative interpretation soon lost its popularity.

In the velocity-distance relation, the ratio of velocity to distance is called the Hubble constant and is broadly the same for all galaxies. Its inverse is a time that Hubble evaluated as 1.8 billion (10^9) years. There is of course a corresponding distance, the same number of light years. Accordingly the Universe has a scale.

This is a most important point that is often not sufficiently stressed. In a scale-free cosmos we could never know whether our observations revealed anything about the Universe or only about our local, perhaps unrepresentative, neighbourhood. In a Universe with a scale it is plain whether our observations extend over a significant portion of the whole or not. If the largest red shifts observed were, say, 0.01, we could not infer much about the system as a whole. As red shifts of the order of 5 have been measured, we survey a very significant part of the whole system. Hubble's estimate was in fact difficult to accept as it was hard to reconcile it with the figures then current for the age of rocks, of the Earth, of the Sun. Moreover, it meant that the other galaxies were much smaller than ours. "If they were islands in space, our galaxy was a continent". The upward revision of Hubble's time by Baade and Minkowski in 1952 was therefore greeted with great relief.

The first half of the twentieth century established cosmology as a science in its own right. The universality of the red shift, the large-scale uniformity of the system, the applicability of the geometries of Friedmann, Robertson and Walker were substantial legacies to leave for subsequent researchers. The initial singularity of many of the solutions was first spotted by George Lemaître (followed by George Gamow) as a possible oven for making all the elements from aboriginal hydrogen. Though the output was later seen to be confined to the lightest isotopes, the high temperature and density of the initial 'Big Bang' makes a happy playing field for high-energy particle physicists.

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