observer assume that the internal processes of the wiffle ball are random? No, what we have is a deterministic problem with an infinite number of initial conditions. The behavior is describable only statistically, but is not due to random processes. Statistical behavior at any level is not proof of randomness in the physical world.

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Wilczek replies: Each correspondent has a valid point. I enthusiastically agree with Marcia Bjørnerud: The nonuniversal problems that arise in describing our specific place in the world are not only valid but often fascinating and important. I was building toward this major point in the entire series, and it was emphasized explicitly in the final sentence: "Such necessary concessions to reality compromise the formal purity of the ideal of understanding the world by analysis and synthesis, but in compensation, they allow its spirit much wider scope."

I also agree with Joe Lacetera, though more reservedly. The idea that the statistical aspect of quantum theory might reflect our incomplete comprehension of an underlying deterministic theory has had some extremely eminent champions, from Albert Einstein at the beginning to Gerardus 't Hooft today. It is a difficult program, however, since the success of quantum theory is broad and deep, especially in the atomic and subatomic realms. I'd be more optimistic about finding surprises in the recent, promising, but relatively poorly tested application of quantum theory to cosmology, as I mentioned in the column: "We can test the hypothesized quantum origin of primordial fluctuations by checking whether those fluctuations satisfy statistical criteria for true randomness."

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Shapley and Hubble: Different Views Brought Galaxies Into Focus

The existence of galaxies beyond the outer limits of our Milky Way system has only become a certainty within the last century. Much of the credit for that discovery goes to Edwin Hubble and Harlow Shapley, who were, in many respects, the two outstanding early 20th-century US astronomers most devoted to the study of external galaxies. Both were born in rural Missouri; Shapley in November 1885 and Hubble in November 1889. As soon as they had obtained their doctorates, both were hired by George Ellery Hale to work at Mount Wilson Observatory in California.

Both men entered astronomy almost by chance. Hubble started out by training as a lawyer. Perhaps his legal training contributed to the clear and convincing way in which he presented scientific arguments. Shapley began his career as a journalist; that training made many of his articles and books a joy to read.

In 1918, Shapley used observations of the distribution of globular clusters to establish that the center of our galaxy was located in the constellation Sagittarius.[1] We now know that his estimated distance of 17–25 kiloparsecs to the galactic center was larger than the actual distance of 8 kpc. Shapley was unaware of the existence of interstellar dust, which makes clusters appear dimmer, and hence more distant, than they really are. His discovery that the Sun is located far from the center of our galaxy had an impact on human thought similar to the paradigm shift caused by Copernicus's change from a geocentric to a heliocentric model for the universe. Jan Oort in the Netherlands and Bertil Lindblad in Sweden were subsequently able to show that the Milky Way system is in differential rotation around the galactic center in Sagittarius; they thus supported Shapley's discovery.

With Adelaide Ames, Shapley discovered and studied large-scale structure in the universe;[2] that work turned out to have a profound influence on modern theories of the universe's early evolution. Surprisingly, large-scale structure never appears to have attracted Hubble's interest. In his monumental study of the distribution of galaxies, Hubble concluded that, after correction for the effects of dimming by dust in the galactic foreground, the distribution of galaxies is essentially uniform on large scales. Furthermore, he found that counts of the surface distribution of galaxies were essentially Gaussian in log N, where N is the number of galaxies per square degree in the sky. Perhaps Hubble obtained the result he wanted (and so

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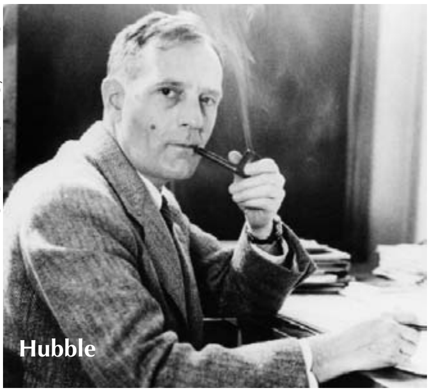
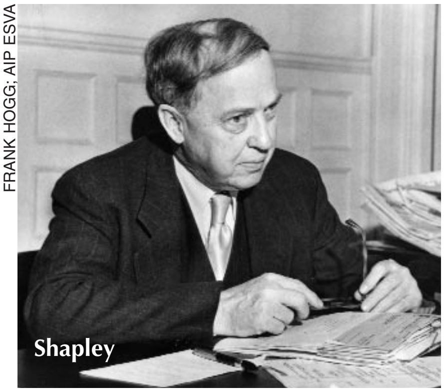


Hubble

FRANK HOGG; AIP ESVA



Shapley

missed a great discovery) by adopting what he called “the general principle of omitting the great isolated clusters in discussing the general distribution of the background on which they are spotted.”[3]

In his magnum opus, *The Inner Metagalaxy*, Shapley summarizes the work on the large-scale structure of the nearby universe that he and his associates at the Harvard College Observatory had carried out over the preceding quarter century.[4] That work revealed stunningly large variations in galaxy density. For example, the Shapley–Ames survey of galaxies brighter than the 13th magnitude showed that the number of galaxies in the Galactic Northern Hemisphere is twice as large as that in the Southern Hemisphere.[2] Furthermore, the Shapley–Ames mapping of the sky showed that the clumping of galaxies occurs on scales much larger than the approximately 1-milliparsec size of typical clusters. The first truly three-dimensional large-scale survey of the universe was made by Valérie de Lapparent and colleagues,[5] who published radial velocities and positions for a large sample of galaxies that are brighter than magnitude 15.5. Their observations revealed for the first time that the spatial distribution of galaxies exhibits a rich texture of filaments and bubbles. Perhaps the most stunning example of the large-scale inhomogeneity of the distribution of galaxies in nearby regions of the universe is provided by the so-called Shapley Concentration, an enormous supercluster of half a dozen massive galaxy clusters.

Astronomers now generally believe that the cosmic structure revealed by the large-scale distribution of galaxies resulted from the gravitational amplification of primordial density fluctuations, which were subsequently modified by other physical processes such as gas dynamics, radiative cooling, and photoionization. It is thought that such processes contributed to the striking dependence of the morphology of individual galaxies on the density of their environment.

In summary, Hubble mainly studied galaxies and the distance scale in the universe. His work was complemented by Shapley’s, which mostly concentrated on the clumpiness of galaxy distribution in space. We now know that the study of both individual galaxies and the inhomogeneity of their distribution provide vital clues about the evolution of the universe.

References

1. H. Shapley, *Astrophys. J.* **48**, 154 (1918).
2. H. Shapley, A. Ames, *Harv. Ann.* **88**(2), (1932).
3. E. Hubble, *Astrophys. J.* **79**, 27 (1934).
4. H. Shapley, *The Inner Metagalaxy*, Yale U. Press, New Haven, CT (1957).
5. V. de Lapparent, M. J. Geller, J. P. Huchra, *Astrophys. J. Lett.* **302**, 1 (1986).

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More on Numerical Lattice QCD

The article by Carleton DeTar and Steven Gottlieb (PHYSICS TODAY, February 2004, page 45) misleads readers from outside lattice field theory (LFT) about its past, present, and future. At best, the article may present a consensus in the collaboration, known as MILC, of which the authors are a part.

In their historical overview, the authors miss too many of the field’s truly remarkable achievements. The renormalization group, a conceptual organizing principle of all field theories, was first concretely formulated in LFT. A non-gauge result relevant to particle physics was that the Higgs mass must be less than 700 GeV. Duality and the role monopoles play in it also originated in LFT, and so did confinement and finite-temperature deconfinement. The first decade of LFT has been extremely productive and has had a long-lasting impact on theoretical particle physics and field theory. One could call this period the bosonic era of LFT, and it is an illustrious one.

The inclusion of fermions, a much needed step beyond the bosonic era, has preoccupied a large fraction of the community. Fermions had a conceptual defect in their original formulation by Kenneth Wilson 30 years ago. Only quite recently has that problem been finally solved. The solution constituted important theoretical progress, validating continuum ideas in a fully nonperturbative setting and restoring precise chiral symmetry.

A significant physical step was the formulation of the valence approximation and the discovery of its surprising numerical agreement with experiment. Technically, a most important development was the discovery of an algorithm that could take us beyond the valence approximation to truly ab initio numerical quantum chromodynamics (QCD). Neither of