Centennial Highlights in Astronomy

Owen Gingerich
Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138; ginger@cfa.harvard.edu

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For many years Harlow Shapley, director of the Harvard College Observatory, eminent observer of variable stars, and patron of the AAVSO, delivered an annual after-dinner talk at the AAVSO meetings where he summarized the highlights in astronomy in the past year. In 1961, at the AAVSO's 50th anniversary, he expanded his talk, giving nineteen highlights from the previous half century, beginning with the founding of the AAVSO itself.

In following in Dr. Shapley's footsteps (and "Doctor Shapley" was how we always referred to him), I decided to divide the century into its ten decades and to select a single highlight from each ten-year interval. Please note that in many cases the highlight is an important theme for the decade, even though the actual initial discovery may have been made earlier; this is particularly true for the discovery of dark matter, placed in the 1980s decade. In the event, choosing a single highlight proved in many cases rather more difficult than it might appear at first glance. Let me demonstrate with the problems of choosing a single highlight from the years 1911 to 1920.

The teens were the decade of Einstein's general relativity and the critical eclipse test of 1919, but also Shapley's own pioneering work on the structure of the Milky Way and the sun's place within our galaxy. Curiously, Shapley didn't mention his own Milky Way work in his 1961 list, nor did he mention Hubble's work on galaxy distances in the next decade. But, anonymously, he cited the pulsation theory of variable stars in connection with Henrietta Leavitt's period-luminosity relation. Now, around this time, in 1959 or '60, he showed me the preliminary list of selections he was proposing for his *Source Book in Astronomy, 1900–1950*. I noticed that he included his 1914 paper on δ Cephei, where he showed that if this famous variable star were an eclipsing binary star, as many astronomers thought at the time, then the secondary star had to revolve inside the primary! In other words, δ Cephei had instead to be an intrinsic variable, probably explained by physical pulsations. Nevertheless, I thought it was a little idiosyncratic to choose this paper for inclusion, and I told him so.

Recently I stumbled on his letter in reply. "Young man, you weren't there in 1915!" is essentially what he said. In effect, his paper provided the credentials for Henrietta Leavitt's period-luminosity relation to be used as a distance indicator, for if Cepheids were simply eclipsing binaries, Miss Leavitt's relation was simply accidental.

That's the first half of this story. The second half is that Shapley's English contemporary Arthur S. Eddington also made a list of highlights, but much earlier, in 1920 for the centennial of the Royal Astronomical Society. The only highlight he included from the 1911–1920 decade was the measurement of the diameter of Betelgeuse, made by Michelson and Pease with an interferometer attached to the Mt. Wilson 100-inch Hooker reflector. Why was this so significant? Because it credentialed the implications of the to-become-famous diagram drawn by Henry Norris Russell and independently by Einar Hertzsprung.

In fact, the sorting of stars made possible by the H-R diagram held the key for using highly luminous stars, such as supergiants and Cepheids, as distance indicators. The understanding it provided concerning the diverse luminosities of stars laid the foundation for Shapley's work on the structure of our galaxy, and for Hubble's work in the following decade on the distances of galaxies. Ultimately the diagram would enable astronomers to get a grip on the life history of stars themselves, and the clusters in which they live.

Therefore, my choice for **highlight number one, for the 1911–1920 decade, is establishing the H-R diagram**.

As the decade waned, in April of 1920, there was a famous debate between Harlow Shapley, then from Mt. Wilson Observatory, and Heber D. Curtis, from Lick Observatory, on the scale of the universe. Everyone knows what Shapley got wrong. At the time he didn't believe that the spirals were extragalactic nebulae. But few people realize what Curtis got wrong. He apparently didn't believe in the period-luminosity relation of the Cepheids, nor appreciate the significance of dwarf and giant stars!

For 1921–1930: In 1921, by finding Cepheid variables in the Andromeda nebula, Edwin Hubble demonstrated its great distance and opened up the universe of galaxies. Before the decade was out Georges Lemaître found the distance-red shift correlation, later established more firmly by Hubble. **Highlight number two is Hubble's opening the realm of the galaxies and the explosive flight as the universe expands.**

For 1931–1940: Although Cecilia Payne got some hint of the high hydrogen abundance in her 1925 thesis, her method was novel, unsubstantiated, and in any event it referred only to the atmospheres of the stars. Additional evidence marshaled by Russell helped credential the early hint, and in the next decade stellar interior calculations by Bengt Strömgren and Eddington showed that stars could be primarily hydrogen all the way through. Before the decade was out, C. F. Von Weizsäcker and Hans Bethe showed that a nuclear carbon cycle could power stars. **The hydrogen composition of the stars and the nuclear fusion that powers them is highlight number three.**

For 1941–1950: Taking advantage of the dark skies provided by the wartime blackout of Los Angeles, Walter Baade probed the starry composition of the Andromeda galaxy and developed his idea of **stellar populations**. Not until the following decade did he identify the populations with the ages of stars, nor did he yet use the concept to double the accepted age of the universe.

For 1951–1960: The flowering of radio astronomy, and the discovery of the 21-cm line of hydrogen, led to the **delineation of the spiral structure of the Milky Way.**

For 1961–1970: New windows on the universe, epitomized by the discovery of quasars, pulsars, and X-ray sources, but above all for purposes of cosmology and the origin of the universe, the **discovery of the 3º background radiation.**

For 1971–1980: Recognition that our universe has an evolving history, brought about by studies of nucleosynthesis and by the cosmological distances of quasars.

For 1981–1990: The widespread appreciation that rather than hydrogen, mysterious **"dark matter" provided the overwhelming mass in the universe.** This had been suggested much earlier by Fritz Zwicky and in the 1970s advocated by Jan Oort, by Jerry Ostriker, James Peebles, and Amos Yahil, and observationally established by Vera Rubin and Kent Ford.

For 1991–2000: The Hubble Space Telescope decade, settling the much-debated age of the universe, but also **the discovery of the accelerating universe or dark energy.** A runner-up: the COBE mission and the Big Bang anisotropy, the "seeds" of galaxies.

And finally, for 2001–2011: The discovery of large numbers of exoplanets, and recognition of the long-term migration of planets. Another runner-up: WMAP, whose accurate measurements of the cosmic microwave background fluctuations not only demonstrated the cosmological flatness of our universe, but also showed within a few percent that non-baryonic "dark matter" is five times more abundant than the baryonic matter that makes up you, me, and the visible universe.

And now, through the looking glass: **A few predictions for 2012–2061!**

First, I predict the success of attempts to detect the gravitational waves, the ripples in space propagated from appropriate massive movements of material in the universe (sought by LIGO, the Laser Interferometer Gravitational-Wave Observatory and its successors). Second, the detection of non-equilibrium chemistry in the atmospheres of selected exoplanets (and I predict that the interpretation of the existence of life on distant planets will be highly controversial). I would also look forward to the clarification of two of the deepest mysteries now facing astrophysicists: the so-called dark energy and dark matter.

From the vantage point of 2011, with the world economy in confusion, it is difficult to predict the future of the giant James Webb space telescope. Let us hope it will be successfully launched, and that it will reap surprising, unpredicted new phenomena. Dare one predict unpredicted phenomena will be found? Such I predict! And I predict that the AAVSO, venerable by 2061, will still be collecting data, but in new and more efficient ways.