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Millennium Essay

The Immutability of the Heavens[1]

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1. FROM AQUINAS TO HUBBLE

Thomas Aquinas (1225–1274) generally receives credit (or blame) for the 13th century synthesis of Aristotelian philosophy and church doctrine into a "unified theory" of the heavens that then dominated Western European thought for the next three centuries. Much of this synthesis will be familiar to you because introductory astronomy textbooks still often begin by telling us what the ancient Greeks thought about things, including the Ptolemaic or geocentric picture of the universe, the four terrestrial elements (earth, air, fire, and water) in contrast to the heavenly quintessence, the perfection and sphericity or circularity of celestial objects and orbits, the instantaneous propagation of light, and so forth.

The immutability of the heavens was an important aspect of this synthesis, with a distinction being drawn between Earthly ("secular") affairs, which could change any old way, and the affairs of the heavenly and angelic spheres, in which only cyclic changes occurred, like the seasons, phases of the Moon, and motions of the wandering planets. The connection between eclipses and phases of the Moon was well enough understood for them to fall within this allowed, sacred calendar.

Obviously, there were things in the sky that did change erratically, including lightning, meteors, aurorae, rainbows, and comets. These were all attributed to processes in the Earth's atmosphere (well, four out of five isn't bad). The Chinese, approaching the skies with a different set of preconceptions, used names for comets ("broom star") and novae or supernovae ("guest stars") suggesting a connection with their long-lived asterisms rather than with the Earth. They also recorded a good many more such apparitions. A few European records of the supernovae of 1006 and 1054 have turned up, but, if asked, the recorders would presumably have also associated these with "meteorology" (things happening in the air).

This bring us to Tycho Brahe (1546–1691), the most accurate of the pre-telescopic observers. He recorded stellar positions with unprecedented precision and set limits to the annual parallax of stars so small that he himself concluded that the Sun must go around the Earth (though carrying the other planets with it). He also destroyed forever the immutability of the heavens.

Supposedly there are 86 naked-eye comets per century and a naked-eye nova every decade or two. Nevertheless, it is hard not to feel that providence was at work in arranging for Tycho's nova stella (later recognized as a supernova, 1572) and the comet of 1577. Among other observations, he looked hard for geocentric parallaxes for both. That of the Moon was already known, and Tycho's upper limits put both the new star and the comet farther away, well out of the sphere of the Earth and into the heavens. His monumental books, presenting the observations and their implications, appeared in 1588 (for the comet) and 1602 (for the star).

Kepler's "new star" of 1604 lasted long enough and attracted enough attention for additional stargazers to confirm its translunar location. It too is now recognized as a supernova. Meanwhile, Fabricius had announced a 1596 nova in Cetus and Holwarda another in 1638. Both astronomers were Frisians (this was known at the time). Both "novae" were actually the same star, now called Mira Ceti (this was not known until Hevelius gathered all the observations together in 1662). Hevelius had too sparse a database to recognize Mira's periodicity amidst the erratic changes, so it was left for the Frenchman Ismael Boulliau to announce in 1667 that Mira was at maximum brightness. It therefore counts as the first periodic variable star.

Boulliau also proposed a mechanism for variability based on what he knew about the Sun—regular rotation plus irregular spots. This spotted star model gets laughs in books from the early 20th century, but we do, of course, now recognize spottedness as one of the many causes of stellar variability (though the record amplitude is only 0.6 mag, and that is for a T Tauri star).

Which and when was the first "real" nova reported? For some reason, I only thought of looking into this a few weeks ago. The answer is Anthelm's nova (no, I don't know anything else about him) in 1669. The star is now called CK Vul, and its extreme faintness now is an important piece of support for the "hibernating nova" scenario in which mass transfer onto a white dwarf from its companion declines substantially for some time after a major explosion. The

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second was WY Sge, seen in 1783 by D'Agelet and Hevelius. Remarkably, the next novae do not turn up until Nova Oph (V841 Oph) in 1848 and T Sco in 1860. One does not really deduce a nova drought in the 18th century, but only a small and otherwise occupied astronomical community.

At least a few members of that community were busy with other kinds of variable stars. Charles Goodricke and Edward Pigott followed Algol, recognizing its periodicity and proposing eclipses by a planetary companion as the cause in 1782. Eclipses then gradually became the preferred way of accounting for variable stars, including δ Cephei (whose variability was also a Goodricke discovery), until Harlow Shapley showed in 1914 that one star would have to be inside the other. Arthur Eddington is probably the best known of the contributors to the pulsation model for Cepheids, and by about 1920 he fully understood that it implied a more copious source of stellar energy than mere Kelvin-Helmholtz contraction.

What about immutability of the position of the fixed stars? Precession was known to Hipparchus in the second century B.C. and, correctly, attributed to a shift in the pole of the rotation of the heavens relative to the Earth. This somehow did not violate medieval sensibilities. But it was left for Edmond Halley to compare Ptolemaic stellar positions with later ones and conclude in 1718 that at least three of the brighter stars (and hence, he noted, probably the closest ones) had shifted relative to the others. Large compilations had, however, to wait for better understanding of atmospheric refraction and for James Bradley's 1729 measurement of aberration of starlight (also the death knell for instantaneous propagation of light) as well as Tobias Mayer's 1760 approach to deconvolving aberration and proper motion.

Mutability among the nebulae was a later and fuzzier discovery, marred by a good many false alarms. In the prephotographic era, successive drawings of a given nebula, even by the same observer, often seemed to display major changes (though transmutation of the pineapple to the crab claw for NGC 1952 was surely a misidentification of one of Lord Rosse's mid-19th century drawings). Among the pioneer photographers, Carl O. Lampland at Lowell stands out for having recognized around 1920 the expansion of the Crab Nebula, a sort of lengthening of part of the Veil Nebula in Cygnus (NGC 6992), and very complex week-to-week changes in the cometary nebula NGC 2261, associated with R Mon. Hubble's variable nebula (NGC 6729) is the same sort of beast, with perceptible changes even day to day, which we now attribute more to variable illumination than to motions in the gas and dust clouds.

Even earlier, G. W. Ritchey, of Yerkes Observatory, had measured the expansion of the nebular remnant of Nova Persei 1901, and, soon after, Adriaan van Maanen reported an average expansion velocity of $0\farcs022\ \mathrm{yr}^{-1}$ for nine planetary nebulae. The number is in the right ballpark (corresponding to 100 km s^{-1} at 1 kpc), but I am not sure that the detailed measurements were ever confirmed. Modern work on proper motions in planetaries began with William Liller much later.

Mention of van Maanen naturally brings us to a "boner of the century," connected with apparent motions in spiral nebulae. Notoriously, he thought he had measured proper motions resembling rotation in the plane of the sky for several spirals before 1920. Shapley, among others, relied on the result, when (in the 1920 Curtis-Shapley debate) he came out strongly against the existence of external galaxies on the grounds that the rotation speeds would be implausible large unless the nebulae were quite close and inside the Milky Way. Later measurements by Knut Lundmark, using both van Maanen's plates and his measuring engine, did not confirm the rotations, but it has never been clear what the latter did wrong. Van Maanen's spirals had leading arms, and the direction of rotation was, even then, contradicted by radial velocity gradients reported by Wolf, Slipher, and Pease, though Heber D. Curtis seems to have been one of very few to appreciate the contradiction.

Hubble turns up at the end of this section both for showing that external galaxies do exist and for plotting the first redshift-distance relations in 1929.

2. THE REST OF THE 20TH CENTURY

The current situation is easily described: everything in the universe, including the universe itself, changes on every timescale permitted by special relativity and some that, at first blush, are not. There is space to remind you of only a few examples.

The Sun is a variable star, with a whole spectrum of nonradial pulsations, whose study (helioseismology) has helped to pin down the radial distributions of helium, rotation, temperature, and density, thereby, indirectly contributing to our understanding of stellar nuclear reactions and neutrino production. The 11 (or 22) year solar activity cycle serves as a prototype for similar cycles in other cool stars, which is not to say we understand it. Actually, numerous theorists understand it; they just understand different things. Other longer solar cycles, including the one incorporating the Maunder minimum, are also in need of further work. Stellar analogs should start turning up in only a century or two. And, of course, the Sun is getting brighter over billions of years. This must have made it difficult for the Earth to maintain habitable conditions, but somehow it managed.

New classes of pulsational variables continue to wink into existence every year or two including, recently, pulsating subdwarf OB stars and the γ Doradus variables. Secular changes have also proliferated. A striking case is FG Sge, which started tramping across the H-R diagram

near the turn of the century and now seems to be settling into a new lifestyle as an R Coronae Borealis variable. At least two other stars are doing the same thing, with at least Sakurai's object also developing R CrB–ish traits. Three progenitors in a century for a class with only about 40 members seems a bit much, but we must leave something for the theorists to worry about. The phenomena are best explained (well, I guess only explained) by a last flash of the helium-burning shell in a star that thought it was already a post–asymptotic giant en route to becoming a planetary nebula.

Of all the 20th century proper motions, my favorite is the change in core-jet structure of radio-bright galaxies and quasi-stellar objects, revealed with very long baseline interferometry beginning in the early 1970s. Like van Maanen's spiral rotations, these seemed to imply motions at more than the speed of light. Indeed, the Pasadena Star-News reported a California contribution under the headline "Einstein is dead" (which had actually happened some time before). Also, as in the spiral case, some astronomers concluded that the radio sources were quite close to us. And, again, this was the wrong answer. The observations were fine this time, but it was essential to allow for special relativity, rather than to try to disprove it. Simplifying not quite beyond recognition, if something is headed almost straight at you very fast and emitting photons as it goes, the ones emitted later won't have so far to travel and so will arrive not long after the ones emitted earlier. The moving jets and associated variable brightnesses of these objects require relativity parameters of 2–10 and angles relative to the line of sight of a few to a few tens of degrees.

Finally, the universe as a whole changes with time. It was, as you know, hotter in the past (which is sort of like luminosity changes) and denser (a sort of proper motion analog). We see the evidence lying about in the form of the cosmic microwave background radiation and a uniform minimum helium content, as well as in monotonic changes in the average numbers, size, shapes, and brightnesses of galaxies and radio sources.

3. FOR FURTHER READING

The 1999 publication of Michael Hoskin's *The Cambridge Concise History of Astronomy* has made it enormously easier for us all to pontificate with some authority on events before our own Ph.D. theses marked the beginning of "modern astronomy." Edward Harrison's *Darkness at Night* (Cambridge: Harvard Univ. Press, 1987) is pearl beyond price. Old textbooks are a nice way to verify what people really thought at various times. My favorite is H. N. Russell, R. S. Dugan, and J. Q. Stewart's *Astronomy* (Boston: Ginn & Co., 1926). Most of the recent events mentioned here have been highlighted previously in the *PASP* in the sequence of review articles "Astrophysics in 199x," starting in volume 104.

Note added in proof.—Dom Pere Anthelme was a Carthusian monk of Dijon, France. He first saw the nova on 1670 June 20. Hevelius recorded it a month later. See M. M. Shara, A. F. J. Moffat, & R. F. Webbink (1985, ApJ, 294, 271) for details.