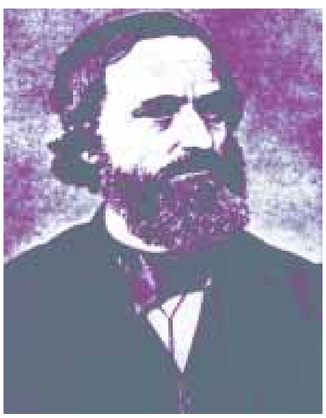
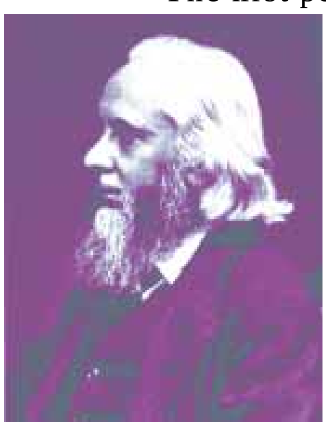
Part II
Can't You Keep Einstein's Equations Out of My Observatory?

by VIRGINIA TRIMBLE

Part I of Virginia Trimble's two-part article was published in the Spring 1998 issue of Beam Line, *Vol. 28, No. 2. It can be accessed from our Web site at* http://www.slac.stanford.edu/pubs/beamline.





Gustav Kirchhoff, above, and Sir William Huggins, right. (Courtesy Yerkes Observatory and Lick Observatory, respectively)

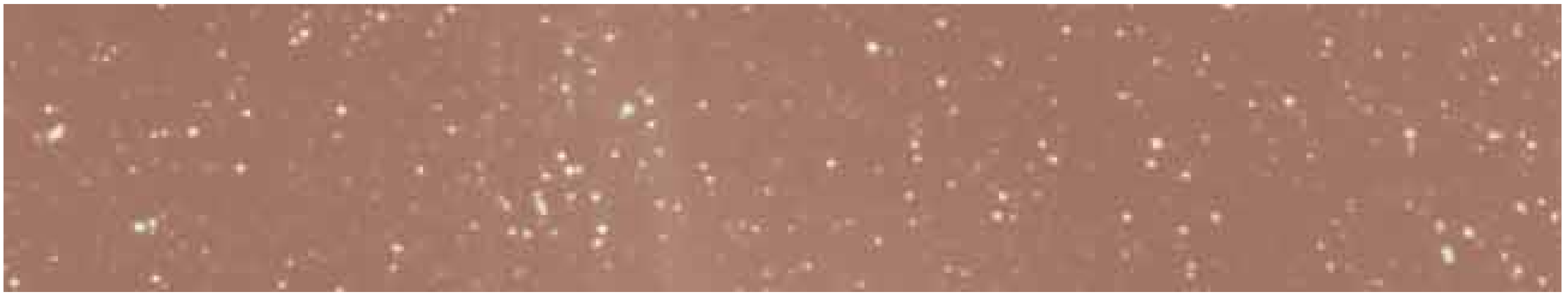
SPECTROSCOPY AND THE RISE OF ASTROPHYSICS

Our ability to recognize the chemical elements from their patterns of emission or absorption lines dates from 1859, when chemist Robert W. Bunsen (who had a burner) and physicist Gustav R. Kirchhoff (who had an assortment of laws) joined forces in Heidelberg to show that sodium in the laboratory mimicked a pair of yellow lines in the spectrum of the sun (called "D" by Fraunhofer and also by modern astronomers).

The first people to aim their spectroscopes at the sun, stars, and nebulae were richly rewarded when (as described by Sir William Huggins) "nearly every new observation revealed a new fact, and almost every night's work was red-lettered by some discovery." (Huggins' own discoveries included the gaseous nature of many nebulae that had formerly been regarded as dense crowds of stars.) This was very different from the astrometry, celestial mechanics, and practical astronomy that generations of classical astronomers had labored over their equations and transit circles to accomplish. And it was correspondingly unwelcome among much of the existing community. Two reactions, one from each side of the Atlantic:

The Victorian astronomer royal, Sir George Biddle, declared that

> what astronomy is expected to accomplish is evidently at all times the same . . . rules by which the movements of the celestial bodies, as they appear to us upon the earth, can be computed. . . . All else which we may learn respecting these bodies . . . possesses no proper astronomical interest.



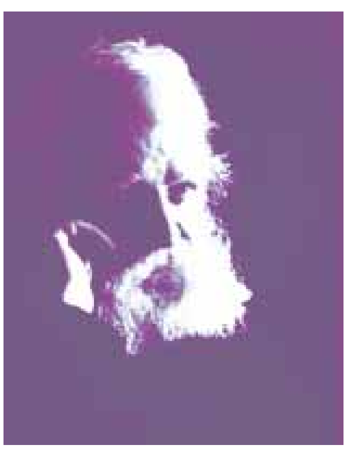
Seth Chandler, a member of the National Academy of Sciences and calculator of comet orbits and Earth's polar motion, opined that the work of astrophysicists "will disappear like smoke in the air" and its "authors will lie in forgotten graves." Both were pontificating in the 1890s, and the bitter feelings between practitioners of traditional astronomy and of the new astrophysics nearly fractured the community and darkened efforts to form a single professional society (eventually the American Astronomical Society, but only after several iterations on names).

It was a rather motley crew of people with backgrounds in medicine, brewing, chemistry, physics, the silk trade, and occasionally even traditional astronomy who came rather quickly to constitute the community of solar physicists (by about 1870) and astrophysicists (by about 1890, with the *Astrophysical Journal* founded in 1899). Among the items they offered back were the discovery of the first element in a new column of the periodic table (helium; Jules Janssen at the eclipse of 1868), the demonstration of the existence of metastable atomic levels with exceedingly long radiative lifetimes ("nebulium" explained by Ira Bowen in 1927), and, down to the present time, accurate wavelengths and energy

Left, Cecilia Payne Gaposchkin. The second edition of Cecilia Payne Gaposchkin *(ed. K. Haramundanis, Cambridge University Press, 1996) contains roughly equal numbers of her own words and those of friends and family. Right, Henry Norris Russell, who was, of course, the R of the HR diagram as well as the originator of the (very transient) giant and dwarf theory of stellar evolution. Judging from a 1939 conference photo, the two were exactly the same height. (Courtesy Yerkes Observatory)*

levels for molecules difficult or impossible to study in the laboratory. HCO^+ (initially X-ogen) and HC_9N are among those first seen in interstellar gas.

Quantitative spectroscopy was built upon two equations, named for Ludwig Boltzmann and M. N. Saha. These describe the fraction of atoms that ought to be in various states of excitation and ionization as a function of kinetic temperature (yes, I also offer egg-sucking lessons for grandmothers). The astronomical hero* here is Cecilia Payne (later Payne Gaposchkin), who, in her 1925 Harvard PhD dissertation applied the equations to the line spectra of stars of various colors (temperatures) and concluded, first, that nearly all stars have



Left, Jules Jansson (1824–1907) depended on temporary scientific jobs and stipends for his living until 1865, when his contributions to spectroscopy were recognized with an appointment to the chair of physics at the Ecole Speciale d'Architecture in Paris. He reached the eclipse of 1870 after escaping by balloon from beseiged Paris, only to be clouded out in Oran, North Africa. (Courtesy Yerkes Observatory) Right, Ira S. Bowen about 1968. For many years he was director of the Hale (Palomar and Mt. Wilson) observatories. (Courtesy Hale Observatories)

**Personal taste still inclines very strongly to "heroine," for I can remember when the girl cast as Louise in* Carousel *accidentally said to the barker, "I want to be an actor," and it got a giant laugh. But modern usage seems to have abandoned the feminine forms for authors, actors, poets, and so forth—so, I suppose, also for heroes.*

much the same chemical composition, and, second, that this is heavily dominated by hydrogen and helium, at least in the surface layers. So improbable did this dominance seem (remember Eddington) that the sun was allowed to have as much as 7 percent hydrogen only in 1929 when Henry Norris Russell applied the same equations and 75 percent (by mass) only in the late 1940s. Until then, the official excuse for the strong hydrogen lines was "anomalous excitation conditions," that is, a flat refusal to believe Boltzmann and Saha.

RELATIVELY SPEAKING

Each year, the annual meeting of the American Association for the Advancement of Sciences brings forth a coven of audience members who do not believe in special relativity. None, as far as I know, is currently employed as an astronomer, though one or two were in the past. Nor do I know exactly what they mean, because each year one of them starts the question period by saying that there are alternative explanations of the Michelson-Morley experiment, and I, or whoever is at bat at the time, start by answering that our confidence in special relativity does not today rest primarily on experiments from the nineteenth century. They then say that there are other explanations for everything else as well. And the chairman then says that further discussion will have to be deferred until after the session is over. Anyhow, all recent considerations of acceleration of particles to high energy, whether in the lab or in cosmic sources, of radio emission from jets moving at close to the speed of light, and all the rest have special relativity built in. It is even done correctly much of the time.

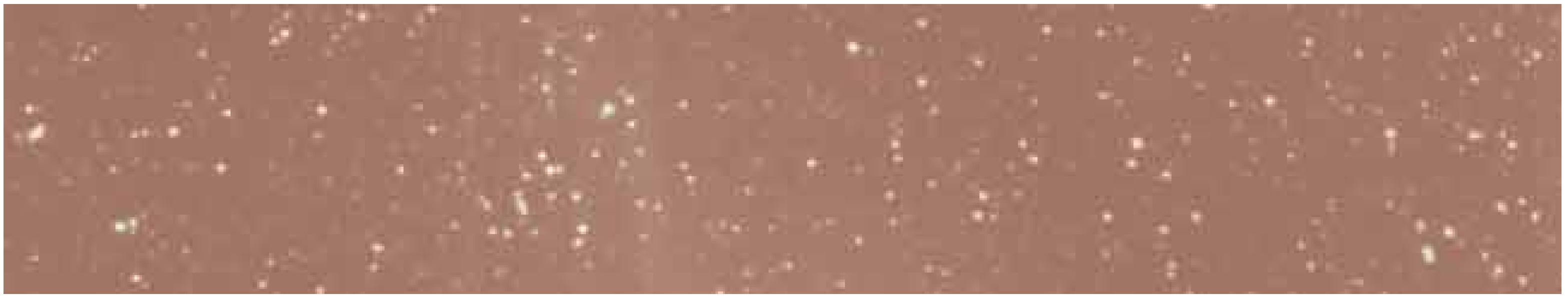
Karl, the elder Schwarzschild, published fundamental work on the analysis of stellar atmospheres, stellar kinematics, comet tails, and many other subjects as well as deriving the solution to the Einstein equations that bear his name. He also inspired H. Rosenberg (1910 Astron. Nach. 186, 71) to draw the very first example of what we now call a Hertzsprung-Russell diagram. (Courtesy Yerkes Observatory)

General relativity has a more checkered history. There was initial enthusiasm from at least parts of the astronomical community. Karl Schwarzschild devised the solution of the Einstein equations that still bears his name to describe the space-time around a spherical or point mass. Eddington undertook to make sure there were astronomers at the right places in 1919 to look for the deflection of light during a solar eclipse. There were and they did. The precise quality of the data has been debated on and off ever since; but it doesn't matter. The observation has been repeated and improved many times, especially at radio wavelengths, where you don't have to wait for an eclipse.

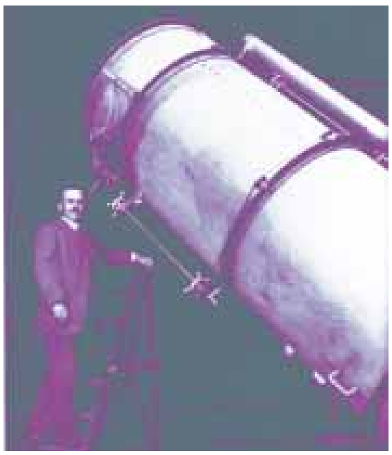
Thus, at the founding of the International Astronomical Union in 1919, one of the Commissions was devoted to General Relativity. Its founding president was Levi-Civita (who had a tensor). But, a couple of General Assemblies later, the Commission was disbanded for lack of need and interest, and GR did not come back to the IAU until 1970, with the establishment of Commissions on Cosmology and High Energy Astrophysics (meaning quasars, pulsars, and such).

Between 1916 and 1929, solutions of the Einstein equations to describe the Universe as a whole came from several people. Willem de Sitter (whose universe was expanding but empty) had previously worried about how to extract numbers for the mass of Mercury, the dipole moment of the earth, and similar Newtonian quantities from astronomical objects. Alexander Friedman(n) (whose universes contained ordinary matter and still expanded) was a man of many parts, mostly meteorological, and all sadly short-lived. Georges Lemaitre independently found one of the expanding models and also wrote down (as part of his PhD dissertation) what we now call the Tolman-Oppenheimer-Volkoff relativistic equation of state, useful for neutron star models.

After the 1929 announcement of the redshift-distance relation (Hubble's law or "the expansion of the Universe") other physicists and mathematicians, including



R. C. Tolman and H. P. Robertson, took up examination of the cosmological solutions and their implications. But their work was not somehow perceived as being part of mainstream astronomy. Even some of the people whom you might have expected to display great enthusiasm were doubtful. Hubble himself never took a strong stand in favor of cosmic expansion over tired light (proposed by Fritz Zwicky in 1929). Heber Doust Curtis, defender of the existence of external galaxies in the Curtis-Shapley debate of 1920, "never had much use for that fellow Einstein," according to Ralph Baldwin, one of his later students. And not all the early conversions were permanent. Sir William H. McCrea, who was writing about relativistic cosmology and Newtonian analogs as early as 1931, has recently expressed doubts about the correctness of the whole picture of a relativistically expanding universe.



Heber D. Curtis at the Crossley telescope, some time before 1921, when he left Lick Observatory to take up the directorship at Allegheny. Time has shown that Shapley and Curtis were right about roughly equal numbers of issues in their 1920 debate. Doust rhymes with "soused," according to Ralph Baldwin. (Courtesy Lick Observatory)

But an astronomer cannot evade GR forever. The first revival came with the discovery of quasars, leading to the invention of a subdiscipline called "gravitational collapse and other topics in relativistic astrophysics." Then came pulsars and X-ray emitting neutron stars. These forced us to think about how matter should behave in deep gravitational potential wells and how the radiation would come out. Today there are binary pulsars whose orbit evolution is precisely described by Einsteinian relativity and by no other combination of physics. And, as our telescopes have seen to larger and larger redshifts (5.64 is the record this afternoon), converting the fluxes and colors you see to energies and time scales is so model dependent that you have to assume some particular version of an expanding universe to make any sense at all of your data.

At the moment, the largest number of people earning their precarious livings by checking each others' relativistic calculations are probably the students and postdocs attempting to predict the gravitational radiation signal that should be seen by LIGO and its European cousins (a) when they are built and (b) when neutron stars collide. Most of these people do not think of themselves as astronomers, or even astrophysicists. Rather, they are part of the subset of members of the American Physical Society who recently formed a Topical Group on Gravitation, apparently because the larger Division of Astrophysics did not feel like home.

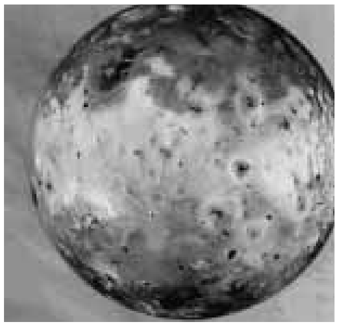
POSTMODERN PHYSICS

Like most things, interaction between astronomy and particle physics started just a little earlier than most of us noticed.* The year 1965 saw not only the discovery of the cosmic microwave background (by radio engineers!) but also the first calculation of a limit on neutrino rest masses from cosmological considerations and an explication of the conditions needed if we are to have more baryons than anti-baryons in the Universe, with credit to Zeldovich and Sakharov respectively.

An obituary of David Schramm mentioned that there had been a time when he was just about the only astronomer in the world interested in neutral currents and the correct form of the weak interaction (because of their role in driving supernova explosions). Still earlier in the 1970s, however, came the realization that model stars would evolve to match a particular observed class of hydrogen-poor red giants only if we included what was then called "the universal Fermi interaction." The idea came from Bohdan Paczyński, then in Warsaw, but I co-authored one of the relevant 1973 papers, so the "we" for once does not mean Queen Victoria.

More recently, non-baryonic dark matter, GUTS, axions, WIMPs, inflation, supersymmetry, and so forth have glutted the literature to the point where your desire to

**Would you believe that the first telecast from the Metropolitan Opera was March 10, 1940?! No, I wasn't there; but I did see the first, 1951, televised* Amahl.



You might think that Io has very little to do with our topic. It is, however, the only body known to be more volcanically active than Earth and so must be useful at the interface between astronomy and geophysics, not otherwise mentioned here.
(Courtesy NASA)

read about it all again is surely even less than my desire to write about it (but see the Spring 1997 issue of *Beam Line*, Vol. 27, No. 1 if appetite should revive). And, naturally, mainstream astronomy has welcomed the collaboration with the same enthusiasm it extended to spectroscopy, relativity, and all the rest. For instance, a generally outstanding 1991 encyclopedia of astronomy mentions both dark matter and Io. But Io gets four pages, and dark matter only one.

The following paragraphs could have been written by many of the people who are primarily interested in Io, stars, and other traditional subjects (but I think you will be surprised at who actually wrote them).

> We understand the concern of cosmologists that unbridled speculation should not take over the field, that it is better to persist with the standard model, warts and all, than for opinions to become splintered, with the decline of professional standards which would then almost inevitably ensue.
>
> Our response to this point of view, with which we have some sympathy, is that undesirable fragmentation has been permitted already, through the invasion of cosmology by Particle physicists. If the invasion had the precision and the certainty of earlier invasions of astrophysics by atomic theory and nuclear physics, the consequences would obviously be positive. However, one can have reservations about the advantages of becoming caught up in speculations from a different field, especially when those speculations are announced with an air of authority that will probably turn out to have been taken too seriously.

Notice that the earlier inputs, rejected by our astronomical ancestors, have been accepted. Only the most recent is being resisted. But the real startler is that these lines come from the pens or word processors of Sir Fred Hoyle, Geoffrey R. Burbidge, and Jayant Narlikar, who have championed other ideas from outside the mainstream, particularly steady state cosmology and non-cosmological redshifts.

L'ENVOI

What should one make of these curious histories? Perhaps we have merely uncovered another of those "irregular verbs," of the form, "I evaluate new ideas carefully. You are a bit of a stick-in-the-mud. He is slightly to the right of Genghis Khan." Or perhaps the last word belongs to Darius Milhaud, who is supposed to have said (concerning music, of course) that the advance guard of today is the rear guard of tomorrow.

SOURCES & SINKS

THE FACTALS in the preceding pages and Part I came from many sources, most lost in the mists of time, but the victims of the most extensive plagiarism are the following:

Henry Norris Russell, Raymond Smith Dugan, and John Quincy Stewart, *Astronomy* (in two volumes) 1926, Ginn. & Co. Boston. This was the standard astronomical textbook for about twenty years.

George Ogden Abell, *Astronomy* (4th edition) 1982, Saunders College Publishing, a second-generation textbook.

Edward Harrison, *Darkness at Night*, 1987, Harvard University Press. Deals mostly with Olbers' Paradox.

Stephen P. Maran (Ed.) *The Astronomy and Astrophysics Encyclopedia*, 1991, Van Nostrand.

John Lankford, *American Astronomy*, 1997, Harvard University Press. Mostly about people.

Karl Hufbauer, *Exploring the Sun*, 1991, Johns Hopkins Press. Recounts the development of solar physics from Galileo to the present time.

More on the difficulties astronomers and astrophysicists had in getting together in the 1890s to found a society will appear in the centenary volume of the American Astronomical Society edited by David DeVorkin and scheduled for 1999 publication.

The quote from Hoyle, Burbidge, and Narlikar appears in *Monthly Notices of the Royal Astronomical Society* 286, 173 (1997).