dwarfs). In the pulsar case, for which Joseph Taylor and Russell Hulse shared the 1993 Nobel Prize in physics, the physical processes include gravitational radiation and other strong-field effects, for which general relativity makes different predictions from those of other theories that would also fit the solar system, weak-field data.

Those pulsar orbits would be getting larger or smaller if the coupling constant, G, were changing with time. Non-zero dG/dt would also affect the lifetimes of stars (whose rate of energy generation scales like G^5), the range of masses possible for old white dwarfs (supported against gravity by degenerate electron pressure) and neutron stars (supported by degenerate neutron pressure), the dynamical evolution of clusters of stars, and distances within the solar system. Curiously, astronomical observations lead to just about the same limits on dG/dt from all of these systems: not more than about 10 percent either way in the 10–20 Gyr age of the universe. Such observations, as well as the Mercurian orbit advance, also tell us that the speed of gravitons is very close to the speed of photons in a vacuum. One always writes the equations with c, but one means c(gravity), not c(light).

OTHER HISTORICAL EXAMPLES AND FALSE ALARMS

Particle physics can perhaps be said to have begun with the discovery of entities beyond the n, p, and e found in ordinary atoms. The first were the positron, the mu ("Who ordered that?") meson, and the pi (Yukawa particle) meson. All first appeared as upper-atmosphere secondary cosmic rays (ones produced when primary cosmic ray protons hit atmospheric molecules—very hard). A convenient date to remember is 1937, when a shower of papers by people you have heard of in other contexts (Heitler, Oppenheimer, Serber, Homi Bhabha) clarified that these were indeed secondary products but also new particles with well-defined properties.

Astronomical considerations have also made occasional contributions to nuclear physics, most famously in 1953, when Fred Hoyle realized that the carbon-12 nucleus must have a particular excited state, or we would all be made out of pure hydrogen and helium, no further fusion being possible in stars. More recently, the need for lifetimes, energy levels, and cross sections of nuclides likely to form in exploding stars, but most unlikely in the lab, have driven both calculations and experiments.

Russell Hulse, co-discoverer of the binary pulsar 1913 + 16, whose behavior in the decades since has provided the most stringent available tests of general relativity. (It passed; Hulse won a Nobel Prize.) (Courtesy AIP Meggers Gallery of Nobel Laureates)

From time to time, astronomers have concluded that some set of observations simply could not be explained in terms of the (then) standard model of physics and have attempted to invent what they thought was needed. Like many other examples of hubris, this has typically been punished, exile from the community being the most frequent outcome. Some cases are relatively well known, like the Steady State universe, invented to allow stars and galaxies to be older than the apparent cosmic expansion time scale, but requiring the addition of a creation field to general relativity or other theories of gravity. The suggestion that atomic spectral lines can be redshifted by something that is not a Doppler effect, not the expansion of the universe, and not a strong gravitational field, at least when those lines come from quasars, is another well known example.

Less famous, perhaps, are James Jeans' proposal that spiral nebulae represent new matter pouring into the universe, "white hole" explanations of quasars, and the prestellar matter of Viktor Ambartsumian, who believed that clusters of new stars expand out of regions of very