Astrophysics Faces the Millennium IV

Stellar, Stellar Bang Bang

by VIRGINIA TRIMBLE

What never? No, never! What never? Well, hardly ever.

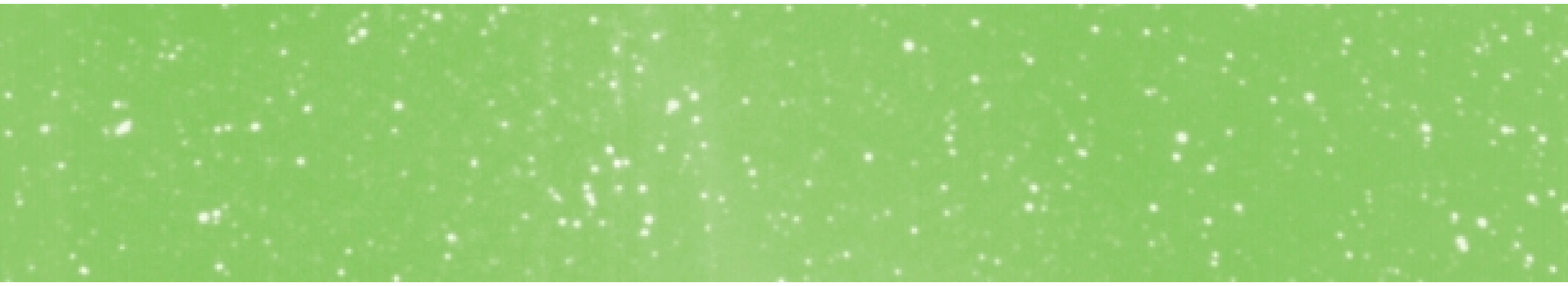
~~C~~aptain Corcoran and Chorus in HMS Pinafore, W. S. Gilbert

You would have to wait 2×10^{18} years for the sun to suffer even a glancing collision with another star in its present environment. Unfortunately, the total solar lifespan is only 10^{10} years, and even the environment is probably not good for much more than 10^{11} years. This is not a new discovery and has been remarked upon (typically with some sarcasm) over the past century, any time anybody has suggested stellar collisions as a mechanism for anything, whether planet formation, supernova explosions, or quasars.

Nevertheless, in recent years, stellar collisions and mergers have come to be taken seriously as part of the physics of the evolution of binary stars, clusters, and galactic nuclei. A modern estimate is that there is a collision every hour somewhere in the observable universe, though (as the resort T-shirts say) all we get may be some massive blue stragglers and a funny planetary nebula. Whether this is on the whole good or bad depends on your point of view, and both opinions go back at least two hundred years.

FEW OR MANY?

William Herschel, after resolving a good many nebulae into star clusters in the late eighteenth century, worried that "the shock of one star's falling upon another would lead to general destruction," but concluded that "the great Author has



amply provided for the preservation of the whole" and that "the destruction of now and then a star in some thousands of ages [is] perhaps the very means by which the whole is preserved and renewed."

Even earlier, at a time when comets, stars, and shooting stars were by no means so distinct as they now seem, G. L. Leclerc, Comte de Buffon (1707–1788) went on record with the idea that the planets might consist of material splashed out of the Sun by a comet impact. Just for the record, comets do actually hit the Sun, though the results, first spotted by the Solwind satellite in 1979 and soon after by the Solar Maximum Mission, are a good deal less dire (except for the comet) than Buffon envisaged. Laplace's 1796 "nebular hypothesis" for the origin of the planets was then more popular for a century or so, but the dawn of the twentieth century saw Thomas C. Chamberlin (also an active participant in the "age of the Earth" debate) and Forest Ray Moulton of the University of Chicago declaring that the nebular picture could not account for the fact that most of the angular momentum of the solar system resides in planetary orbits and only a few percent in the Sun. They advanced tidal encounters as an alternative.

ASP/Yerkes Observatory

Sir James Jeans

Sir James Jeans and Sir Harold Jeffreys revisited the tidal idea in the interwar years, with Jeans, at least, explicitly acknowledging that planetary systems must, under this hypothesis, be very rare, accompanying at most one star in 10^5, even after the 10^{12} years that he claimed for the age of the galaxy and Universe.* Curiously, in a 1942 *Nature* paper not long before his

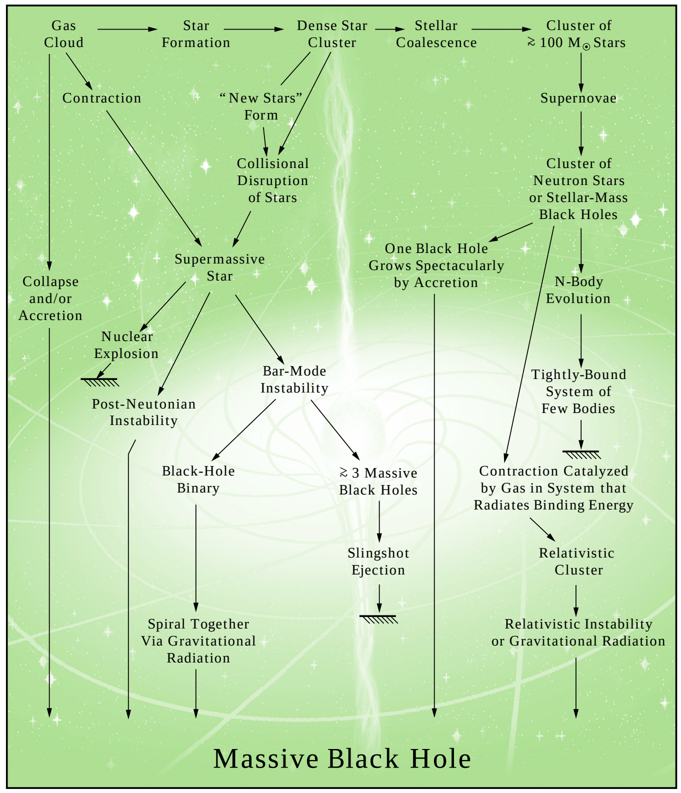
** How Jeans got 10^{12} years where we now find 10^{10} is a somewhat related story, too long to tell here, which involves tidal interactions of stars in clusters, galaxies, and binary systems.*

death, Jeans managed to bump his estimate up to one star in six, by allowing for interactions while the stars were forming and much more extended than our Sun is now.

The last gasp at a stellar encounter model for formation of the solar system came from Raymond Arthur Lyttleton in the early 1950s, even as fashion was swinging back to the nebular scenario. His version involved three stars, an initial close binary and an intruder, with the potential for star exchange as well as planetary extrusion. Perhaps not by chance, Jeffreys and Lyttleton appear also to have been the last practicing geophysicists to deny fimly the existence of mantle convection and plate tectonics in the earth.

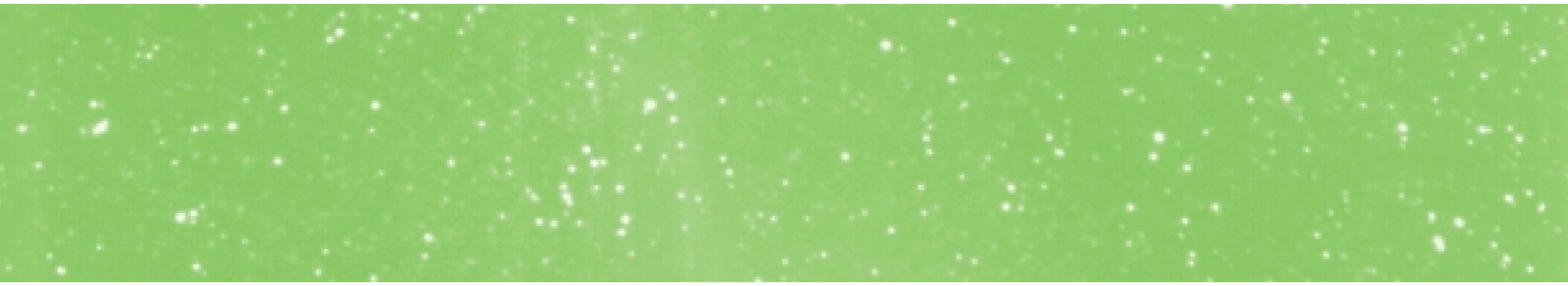
SUPERNOVAE AND QUASARS

In 1933–1934, Walter Baade and Fritz Zwicky drew the first clean cut between common novae and super-novae (though the word, also with hyphen, appears in a 1932 paper by Knut Lundmark). They also suggested a correct energy source, collapse of a normal star to a neutron star. The idea has a precursor in the 1931 suggestion by E. A Milne that novae might represent the collapse of ordinary stars to white dwarfs. The stellar collision model for supernovae came from Fred Whipple in 1939 (yes, the same Whipple you associate with the dirty iceberg model of comets, on which he is still working). This mechanism also had a precursor, in the form of novae as stars being hit by planets or asteroids, put forward by William S. Pickering, H. von Seeliger, and others in the 1920s. Pickering, at least, had in mind that the intruder would penetrate deeply enough to release a burst of what was then called subatomic energy. This is actually more or less how modern novae work, though the intrusion is by diffuse gas accreted over the whole star surface not by a compact object (and the star has to be a white dwarf). Whipple made use only of the kinetic energy of the collision of fast moving galaxies in galactic nuclei. Thus his suggestion is at most a very distant prequel of our current understanding of another sort of supernova (called Type Ia), which may arise when two white dwarfs spiral together, collide, and release oodles of “subatomic energy,” completely disrupting the star(s) involved.



Possible evolutionary paths for a large gas cloud at the center of a galaxy. A number of intermediate processes involve stellar collisions and mergers, but the end product is nearly always a massive black hole, and this is currently regarded as the most likely central engine for quasars and other galaxies with active nuclei. The scheme is that of Martin Rees (in his 1978 Halley lecture); the drawing is in the hand of Roger Griffi, then one of the editors of Observatory *magazine and is reproduced with their permission.*

Quasars and other active galactic nuclei are even more vigorous blow-offs than supernovae. The 1954 identification of the radio source Cygnus A with what, at fist sight, appeared to be two galaxies in collision, inspired, if not quite a thousand theoretical flowers to bloom,



at least a few dozen, many of them (including stellar collisions, but also multiple supernovae and infall of gas into a galactic nucleus) in the garden tended by Iosef S. Shklovsky. The weeding-out process was far from complete in 1963, when the discovery of the first two quasi-stellar radio sources (QSRSs, later quasars) added considerable fertilizer to the problem.

The first to say "stellar collisions" in this context were Thomas Gold, Ian Axford, and E. C. Roy in the *Proceedings* of the December 1963 meeting that we now think of as the First Texas Symposium, and Lodewijk Woltjer in *Nature*. Perhaps the most prescient aspect of the Woltjer paper is that it is followed on the same page by a comment from Fred Hoyle, pointing out that the requisite crowded system of stars will inevitably evolve to some sort of supermassive object via a succession of stellar collisions and mergers. Hoyle and William Fowler had thought of such an object as an engine for radio galaxies just before quasars were added to the mix.

The required succession of collisions and mergers can be a remarkably complicated one (see figure on the opposite page), but no matter which path you follow, eventually you end up with, or in, a black hole. Martin Rees, who sketched the original figure, said that, if you were going to end up with a black hole anyhow, you might as well start your model with one, and indeed quasars (etc.) powered by a succession of supernovae (perhaps collisionally triggered) or other sums of many little things have gradually gone out of fashion, strongly aided by observations of luminosity fluctuations containing more energy than a stellar rest mass, jets that preserve directionality for a million years or more, and so forth.

SCAM RISES AGAIN

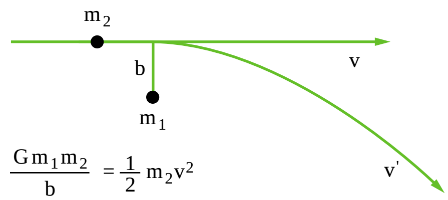
Stellar Collisions And Mergers leads to a perhaps unfortunate acronym for a process you are expected to take seriously, but into every life a little RAIN (Random And Inconvenient Noise) must fall. You can estimate the rate of occurrence of collisions and mergers in any context that interests you by remembering that

$$1/t = n\,\sigma\,v,$$

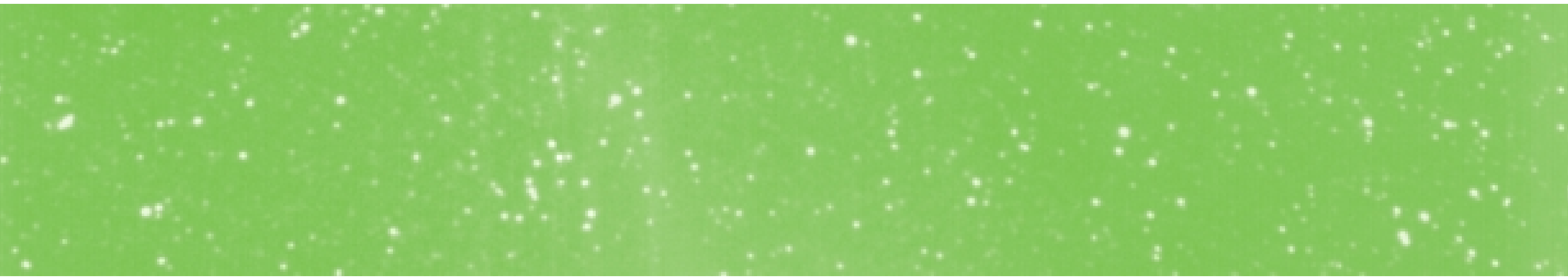
where t is the average waiting time for one particle to experience an encounter; n is the number density of particles; σ is the cross-sectional area of a typical particle; and v is the average relative velocity. While $1/t$ is always small for any one star (except in binary systems), the aggregate for a star system can be many collisions over its lifetime.

Obviously collisions become more likely if n is large (crowded conditions). This favors the centers of the dense star clusters found in galactic halos (called globular clusters) and centers of galaxies, where n can exceed our local value (0.1 stars per cubic parsec) by factors of a million and more. Large σ (big particles) should also enhance the rate. But there is a catch. Stars are large as they are forming and again late in their lives when they become red giants or supergiants. Neither phase, however, lasts very long, so that the total number of collisions is not much larger than for normal, solar-sized stars. Close encounters in crowded environments may, however, lead to red giants stripping each others' extended envelopes or to protostars capturing each other into bound orbits or merging when they are young.

Finally, you might reasonably conclude that large velocities are a good thing, as is indeed the case if you are talking about nuclear reaction rates. But in the stellar case, the effective size of a star is often not its geometrical radius but a sort of impact parameter at which



The effective cross section for stellar interactions is often that defined by an impact parameter, b, *such that the kinetic energy of the passing particle is equal to its gravitational potential relative to the other particle and its path is significantly perturbed. This can be much larger than the geometric cross section. Since* b *scales as* $1/v^2$*, the collision rate ends up with* v^3 *in the denominator.*



gravitational potential and kinetic energies are equal. This leads to a collision rate (l/t) with v^3 in the denominator, so that slow and steady wins the race. Two isolated stars with zero initial velocity must eventually fall together, even if they start out very far apart. This was the point that worried Herschel.

Thus a twenty-first century astronomer in search either of observations that might be explained by SCAMs or of likely scenarios to calculate and predict something from will head for (a) galactic nuclei, (b) star clusters (either dense old ones, or less dense ones where star formation is still in progress), or (c) gravitationally bound pairs of stars (binaries), whose effective stellar density can be as large as 10^{10} stars per cubic parsec, and which will inevitably collide or merge if angular momentum is removed by magnetic stellar winds or gravitational radiation. Typical velocity dispersions are a few to a few tens of km/sec in the clusters and hundreds to thousands of km/sec in galactic nuclei.

Incidentally, the Universe as a whole is a totally useless site. Early on, when it was dense, there were no stars. In the distant future, if the Universe should recollapse (unlikely), rising radiation temperature will evaporate the stars long before they hit each other. Galaxies do collide, merge, and cannibalize each other—the Milky Way is currently nibbling on a small snack called the dwarf spheroidal in Sagittarius. But even when one galaxy smacks another face on, very few stars hit others. The process does, however, make a real mess of the gas in the galaxies, and we see the effects.

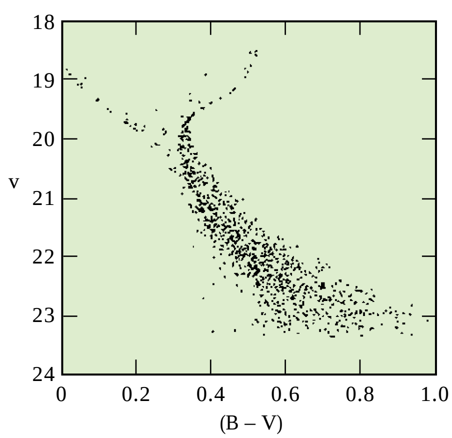
WHAT ARE THEY GOOD FOR?

It is possible, at least for a rambler like the present author, to ramble on for pages about specific collision/merger sites and processes and the astronomical phenomena that probably result. (See the concluding paper in the conference proceedings advertised under "Further Reading.") But, instead, here is a list of astronomical questions and problems to which some sort of SCAM may well be the answer. All are topics of current investigation, meaning that some astronomer earns his precarious living by writing papers and giving seminar talks about them:

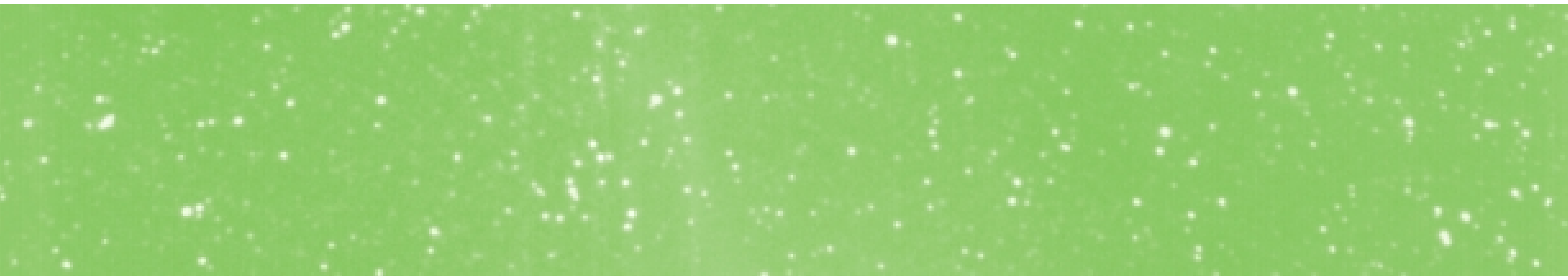
1. How does Nature assemble stars exceeding 10 times the mass of the Sun, when continued accretion onto a core of 10 $M_\odot$ would release so much radiation that the gas gets blown back out?

2. What are the origins of very rapidly rotating giants (called FK Comae stars) if angular momentum is conserved as the stars expand from the main sequence?

3. What is responsible for the small set of stars that look younger than their host clusters or galaxies when there is no gas around to support ongoing star formation? They are called blue stragglers, SX Phe stars, and worse things, and are to be found in nearly all compact, old star clusters and in some less compact ones, in dwarf galaxies, and in the halo of the Milky Way. The stars call attention to themselves by being bluer and brighter than the vast majority of unevolved (single) stars that belong there.



A plot of brightness vs. color (surface temperature) for the stars of the globular cluster NGC 5053. This almost looks like real data, but it is in fact a simulation that begins with a certain fraction of the cluster stars in binary systems and lets both single and binary stars evolve for about 14 billion years. The stars are then subjected to typical amounts of observing error. The blue stragglers, produced by mass transfer and mergers in close binaries, are the ones with B-V less than 0.35 and v between 18.5 and 20.0, meaning that they are both too blue and too bright for single stars on the main sequence (the broad diagonal swath of stars upwards from lower right). Courtesy of the calculators, P. J. E. Leonard and G. G. Fahlman, Astrophysical Journal *102, 996 (1992).*



4. Who ordered that? Meaning not Rabi's muon but single, stray, odd stars, each of which is loved (and owned, at least as much as you can own a cat) by some practicing astronomer. They have names like V652 Her, WN8 stars, and the planetary nebula in M15 and are too massive for their surroundings.

5. Where do r-process isotopes (the ones made by rapid capture of neutrons onto seeds of iron-group elements) come from? In this case, at least one of the stars had better be a neutron star.

6. Given that Type Ia supernovae exist and are important (they're the ones used for cosmologicai distance measurements that suggest an accelerating universe), why haven't we found many promising progenitors?

7. Do we have a complete inventory of the things that can happen around massive black holes in quasars (etc.) to feed gulps of gas to the monster and cause flaring?

8. What makes gamma-ray bursters, now that we know they are things of $10^{52\pm1}$ ergs in distant galaxies not piddling surface explosions in our own? Just at the moment, the best-buy scenario has two answers: The collapse of a single, very massive star to a rapidly rotating black hole makes the events with long-lived X-ray, optical, and radio afterglows; and mergers of close neutron star pairs make those without such tails.

9. Even if Herschel was wrong to worry about stars all eventually being destroyed by collisions, what would an environment denser than ours do to (a) the stability of planetary orbits, and (b) the continued existence of a cloud of future comets (outside the orbit of Neptune) that can be perturbed down into the central solar system by passing stars? People who actually work on stellar dynamics don't take this one very seriously, but, in a brief "it's summer vacation" discussion. Gregory Benford and I concurred that the answer was a series of "good, bad, good, bad," in the following sense. Stars very far apart, as in our neighborhood, trigger only rare episodes of cometary impacts. A bit closer together and you get hit too often to recover in between. Still closer, the pre-comet (Oort) cloud is destroyed early and life evolves in peace (perhaps too much peace, with no recycling of ecological niches?). Still closer and the planets themselves go truly wandering. Fold in the need for heavy elements to make terrestrial planets, and you can end up with a galaxy that is a patchwork of good and bad places to live!

The Earth seems to be one of the better ones and, in case I haven't mentioned it lately, the hard work and broad-mindedness of the editors of *Beam Line* is one of the many things that make it so.

SUGGESTIONS FOR FURTHER READING

I have found a brand new historical volume to crib from! It is *The Book of the Cosmos: Imagining the Universe from Heraclitus to Hawking*, by Dennis R. Danielson of the University of British Columbia (Perseus Publishing, 2000). The contents include extracts from the writings of nearly 100 philosophers, scientists, poets, and popularizers from something BC to roughly now, plus introductions, bridges, and explanations from the author.

The proceedings of a May 2000 conference called "Stellar Collisions and Mergers" should appear sometime in 2001 in the Conference Series of the Astronomical Society of the Pacific, edited by Michael M. Shara.