ASTRONOMY

Dusty Roads of the Cosmos Lure New Explorers

TORONTO—Householders have an aversion to dust, and astronomers have never much liked it either. Says Asoka Mendis of the University of California, San Diego (UCSD): "For some reason, [astronomers have] neglected it" in favor of the universe's more glamorous denizens. "Maybe it's psychological—dust is a nuisance to normal people," he jokes. Yet, like the stuff that earthlings battle with feather dusters, cosmic dust is ubiquitous. It is left over from star birth, it blows from aging stars in sooty winds, and it is scattered by supernovas. And over the last few years, a growing band of researchers has started to find inspiration in the clouds of dust drifting between the stars. Their findings are gaining new respect for cosmic dust.

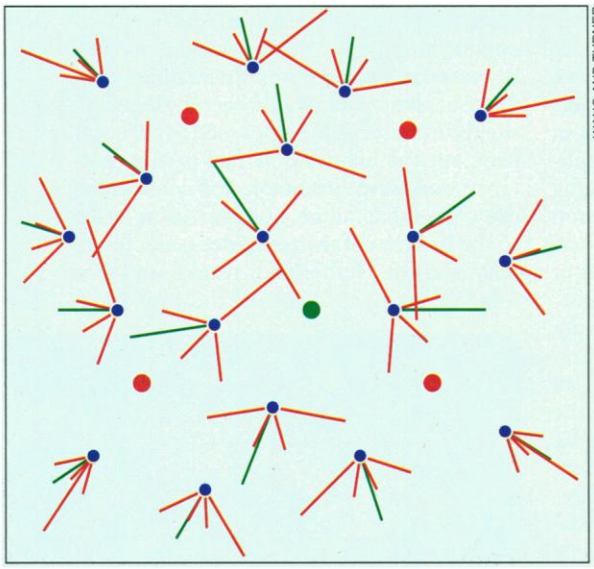
What captivates these researchers is the interplay of dust and starlight. At an American Astronomical Society (AAS) meeting here last month, that was the theme of presentations on topics ranging from how dust seems to line up with the weak magnetic field of the Milky Way, creating a giant polarizer for starlight, to the way gravitational "magnifying glasses" in clusters of stars could be burning away the clusters' dust. The new work shows, says Mendis with a touch of modesty bordering on defensiveness, that "in many places where interesting things are happening, you find dust."

Dusty Polaroids. For 50 years, says Bruce Draine of Princeton University, astronomers have known that they must be seeing starlight through a ubiquitous veil of dust, because the polarization of the light—the direction in which the electric field of its waves points—isn't random. Instead, it is oriented along the pervasive magnetic field that parallels the plane of our galaxy. Because the magnetic field alone can't polarize the light, astronomers believe that it does so with the help of interstellar dust.

Somehow, the dust "acts like a Polaroid filter," says Draine, snuffing out starlight polarizations that point across the galactic magnetic field. Because irregularly shaped dust grains, like tiny antennas, preferentially absorb light waves whose polarizations point in the longest dimensions of the grains, the dust itself must be oriented across the field lines. But that picture presents another puzzle: How could the weak galactic field align grains made of things like silicates, hydrocarbons, and ices, which make poor compass needles?

At the AAS meeting, Draine and his Princeton colleague Joseph Weingartner offered an answer. Astronomers already suspected that, to make an effective Polaroid filter, the dust would have to be spinning rapidly. Like a tiny gyroscope, each spinning grain would tend to maintain the same orientation, with its long dimension perpendicular to the spin axis. Spin could also produce electronic effects that might make the grains into better compass needles, more likely to align with the galactic field lines. But none of the mechanisms astronomers explored for spinning the grains—bombardment with gas atoms, for example, or the ejection of molecules from the dust's surface—seemed quite up to the job, says Draine. So he and Weingartner tried something else: a subtle torque generated by starlight.

If the grains were exactly spherical, or if starlight streamed with equal intensity in all directions, they realized, the grains would feel no torque. But space-dust grains are thought to be jagged and irregular, like their earthly counterparts, and the patchy distribution of stars on the sky ensures that there will always be asymmetries in the light that strikes them. The effect of starlight on the grains, says Draine, then becomes "like wind blowing on a pinwheel."



WANG AND TURNER

Hot lines. In a dense star cluster, stellar gravity focuses radiation from x-ray and ultraviolet sources (red and green), creating high-intensity beams that could destroy dust.

He and Weingartner found that after 100,000 years or so—a tick of the clock in galactic terms—the starlight could spin the grains up to millions of rotations a second. That's fast enough for substantial numbers of electrons in the grains to siphon off some of this kinetic energy and align their "magnetic moments," turning each grain into a weak bar magnet. By calculating how the tugs of the starlight and the magnetic field would combine—an effort that took "several [computer workstations] running flat-out for months," says Draine—they found that the grains' spin axes end up either parallel or antiparallel to the field, on average, with their long axes whirling across the field lines.

"We think we have found a mechanism that is potent enough" to create a polarization filter for starlight, says Draine. Wayne Roberge of Rensselaer Polytechnic Institute in Troy, New York, agrees. He points out that because very small grains would feel less torque in this picture, they shouldn't align as easily, so the shorter wavelengths most affected by these grains should be less polarized—and that's just what is observed. Roberge thinks that other alignment mechanisms, such as the breezes of background gas in some parts of the galaxy, could also be acting on the dust. Still, he says, "it's a plausible solution to a problem that's been around for half a century."

Clean clusters. That scenario has dust leaving its mark on starlight. But in the dense knots of old stars in our galaxy known as globular clusters, starlight may have the upper hand, Princeton astronomers Yun Wang and Edwin Turner propose. Astronomers have long wondered why globular clusters are nearly dust-free, as the spectra of their starlight imply, in spite of the thousands of stars there that should be churning out dust. It's like finding a coal town where the inhabitants wear spotless white shirts. In search of an answer, Wang and Turner turned to the destructive effects of radiation pumped out by the cluster's brightest members.

A typical globular cluster, Wang explained during her presentation here, has five to 10 especially powerful sources of x-rays or ultraviolet light, each powered by matter streaming into a superdense neutron star or perhaps a black hole. On their own, the sources would have little effect on the dust. But Wang noted that, according to Einstein's theory of general relativity, the gravity of each of the million-odd ordinary stars in the cluster should bend the rays of strong radiation streaming in their direction. The result is a million huge magnifying glasses. "If I'm sitting behind [one such] lens," says Wang, "then the flux I get can be a million times larger than if there were no gravitational lensing."

The very gradual bending of the light by a star's gravity leads to a long, slender focus rather than a pointlike one. Because the stars in globular clusters are packed so densely, these hot, narrow beams of radiation, each a few light-years long and 40 or 50 kilometers across, form a close-stitched network extending throughout the cluster. The network "zaps the dust" as it flows through, says Wang, breaking it down and vaporizing it fast enough to eliminate most of it. "If there was dust there, it would probably be destroyed," says Turner. "The concept is interesting," says A. G. W. Cameron of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts, although he says that details of how radiation heats and destroys the dust still need to be pinned down.

Rosy lenses? Dust may also be affecting our view of the distant universe, well beyond our galaxy, as Turner, Sangeeta Malhotra of Caltech, and James Rhoads of Kitt Peak National Observatory suggested in a separate presentation. On its way to Earth, light from quasars—brilliant, galaxylike objects at the far edge of the universe—sometimes passes through vast lenses created by the gravity of entire galaxies along the line of sight. The multiple quasar images that result are often surprisingly red, Turner and his colleagues found. They suggest that dust in the lensing galaxies is responsible, reddening the light just as dust in the atmosphere tints sunsets on Earth.

If they are right, then the redness of the quasar spectra could serve as a probe of distant dust, which seems to be far more abundant in the lensing galaxies than in nearby massive galaxies. That might imply more frequent galaxy collisions in the past, which would keep the large lensing galaxies well stocked with dust. What's more, Turner and colleagues reason that if dust reddens some of the images, it may completely block others. That effect would hamper efforts to use the frequency of optical lenses to gauge how the "shape" of space has changed over time because of changes in the universe's expansion rate—a technique akin to estimating the size of a flock of birds at night by how often one of them is silhouetted against the moon. (Lensed radio sources would not suffer from this limitation, because they are unaffected by dust.)

So far, says Masataka Fukugita of Kyoto University in Japan, the evidence that dust is altering our view of the quasar images is "quite suggestive" but not yet convincing, as it's hard to be sure what the quasars behind the lenses really look like. Settling the question could require some detailed sleuthing. But the devotees of dust are likely to welcome the task, says UCSD's Mendis: "What is a nuisance to some people is a wonderful area of study for others."

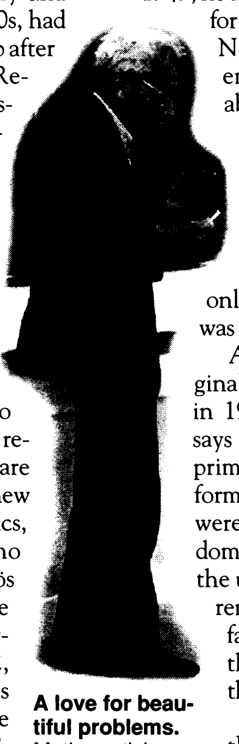
–James Glanz

MATHEMATICS

Homage to an Itinerant Master

SAN DIEGO—The mathematics community paid tribute here last month to one of its legendary figures. Unique in the world of modern mathematics, Paul Erdös, who died on 20 September at the age of 83, is considered the most prolific mathematician ever. Yet, Erdös, who was born in Hungary and came to the United States in the 1930s, had no permanent home and no formal job after 1954. Ronald Graham of AT&T Research, the moderator of the special session in Erdös's honor at the joint meetings here of the American Mathematical Society and the Mathematical Association of America, described his working style as "one lifelong, continuous lecture tour. He traveled from one mathematical center to another, passing along news, squeezing out all the mathematical juice he could, and moving on."

Along the way, Erdös found time to author or co-author more than 1400 research papers. His willingness to share credit led to the development of a new concept in the sociology of mathematics, the "Erdös number." A person who wrote an article with Erdös had Erdös number 1, one who wrote an article with someone who had written an article with Erdös had Erdös number 2, and so on. So numerous were Erdös's collaborators that the list includes more than 4500 people with Erdös number 2, and it is hard to find a mathematician with an Erdös number greater than 3 or 4—unless that mathematician has written no joint papers of any kind. (This unfortunate group has an Erdös number of infinity.)



GEORGE CSICSERY

A love for beautiful problems. Mathematician Paul Erdös.

The speakers at the Erdös session represented the broad spectrum of fields he worked in: number theory, set theory, combinatorics, graph theory, and geometry, among others. In number theory, he was fascinated by the large-scale properties of the number system. In 1949, he and Atle Selberg of the Institute for Advanced Study in Princeton, New Jersey, published an "elementary" proof that the probability that a randomly selected large number is prime is roughly equal to 1 divided by the natural logarithm of the number. Until then, mathematicians doubted that an elementary proof, one involving only the arithmetic of the integers, was possible.

Another characteristic and original theorem of Erdös's, published in 1940 with the late Mark Kac, says that a graph of the number of prime factors of very large numbers forms a bell curve, as if the numbers were choosing their factors at random. "God may not play dice with the universe," Erdös is said to have remarked, alluding to Einstein's famous quotation, "but something strange is going on with the prime numbers."

All six speakers described the love of specific problems that drove this work. "He succumbed to the seduction of every beautiful problem he encountered," said Joel Spencer of the Courant Institute at New York University. Instead of building sweeping theories, Erdös's gift was to pose problems that pointed the way to productive new areas of research. His result on the number of factors of large numbers, for example, launched the field of probabilistic number theory.

Carl Pomerance of the University of Georgia delighted the audience with the story of how an irresistible problem led to his first meeting with Erdös. In 1974, when the great baseball player Hank Aaron broke Babe Ruth's career home-run record, Pomerance noticed that the prime factors of both 714 (the number of home runs Ruth hit) and 715 (Aaron's new record) added to 29. Pomerance wrote a short note for the *Journal of Recreational Mathematics* about what he called "Ruth-Aaron numbers," pairs of consecutive numbers whose prime factors have the same sum. He speculated that such pairs become less and less frequent as their size increases. He added, "I had no idea how to prove such a result."

But within a week after his paper appeared, the young assistant professor received a phone call from the master. Erdös said he would show Pomerance how to prove his conjecture—provided that Pomerance invited him to Georgia. The meeting resulted in a joint paper—the first of over 40 papers Pomerance and Erdös would write together.

Years later, Pomerance said, the University of Georgia awarded honorary degrees to both Erdös and Aaron. He asked both recipients to autograph a baseball for him. "And thus," Pomerance concluded, "Henry Aaron also has Erdös number 1."

–Dana Mackenzie

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