pattern in the atmosphere might appear whether the disturbance was somewhere in the tropics or the mid-latitudes.

The pattern and position of the Pacific–North American connection may be unchanging, but whether it is strong, weak, or shows up at all has been far less predictable—the winter of 1976–1977 (accompanied by a moderate El Niño) was brutally cold in the East, that of 1982–83 (a record-breaking El Niño) was mild. Geisler and Blackmon found that the difference may lie in part in the position along the equator of the unusually warm water. When they moved it eastward from the 1976–1977 date line location, the strength and reliability of the mid-latitude response decreased at each of two more eastward positions. Timothy Palmer of the British Meteorological Office has also found a particular sensitivity in the GCM to surface warming in the western Pacific, where the already warm water gives a boost to the resulting atmospheric disturbance. The tropical far-western Pacific, he notes, was 1°C warmer than normal in 1976–1977.

Another highlight at Liège was the oceanic equivalent of the atmospheric GCM's presented by George Philander of GFDL. Like its atmospheric counterpart, this model contains mathematical descriptions of how fluids flow, but the fluids are the tropical waters of the ocean. Instead of the ocean temperature determining atmospheric circulation, it is the surface winds that are specified and that drive ocean currents. And once again the model's circulation, that of the ocean, is determined by its boundary conditions. "We can reproduce all oceanic features quite accurately," says Philander. The simulated and observed oceans "are remarkably similar."

Thus, meteorologists and oceanographers possess complex, reliable models of their respective parts of Earth. Modelers are focusing on the tropics because both air and water in that zone are so responsive to each other and the behavior of both components is uncomplicated by the small, variable eddies typical of mid-latitudes. The next step essential to understanding and predicting that behavior, including ENSO episodes, is to eliminate the predetermined, unresponsive boundary conditions of each model and form a single ocean-atmosphere GCM. In contrast to their uncoupled versions, coupled tropical models will be unstable, but it is the resulting variability, the ENSO episodes, that must be understood. Researchers believe that in the tropics they have the best chance to do so.—**RICHARD A. KERR**

Interferometry in Space

At the American Astronomical Society's meeting in Baltimore last month,* the emphasis was on astronomy in space. Not only was the meeting itself cohosted by the Space Telescope Science Institute of Johns Hopkins University but there were sessions on the instruments of the Space Telescope, on mechanisms for allocating observing time on Space Telescope, and on the National Aeronautics and Space Administration's plans for future astronomical missions beyond Space Telescope.

However, in many ways the most intriguing session was a 1-day workshop on optical interferometry in space. Interferometry is a way of combining the signals from several telescopes so as to produce images as fine-grained as those from a single giant telescope. It has been a staple of radio astronomy for years, of course, but at centimeter wavelengths it is relatively easy: the receivers only have to maintain their positions to within a fraction of a centimeter. At optical wavelengths, however, interferometry is an extraordinary challenge: tolerances are on the order of Ångstroms.

Recently, however, given the availability of extremely accurate laser ranging devices and the rapid advances in active optics (*Science*, 16 April 1982, p. 280), people have begun to take the idea quite seriously. Several optical interferometers are already operating on the ground, and just within the last year or so there has been a spontaneous groundswell of interest in interferometry in space. A day-long workshop at the Baltimore meeting featured more than half a dozen conceptual designs from as many independent groups. In fact, the workshop was organized by Irwin I. Shapiro, director of the Harvard-Smithsonian Center for Astrophysics (CFA), as a first step in pulling these ideas into a coherent program of interferometer missions for the 1990's.

There is no doubt about the scientific value of such missions. A space-based imaging interferometer could achieve spatial resolutions at the milli–arc second level, one or two orders of magnitude better than those of space telescope. That would be sufficient to resolve the details of surface activity on some of the nearby stars, and perhaps even to examine the central regions of quasars. Astrometric interferometers, either based on the shuttle or free-flying, could measure stellar positions to within a few *micro*–arc seconds. Among other things, such a system could easily detect the perturbations in a star's motion due to Jupiter-sized planets. Not only would it allow for the detection of other solar systems, in fact, but it would allow for a comprehensive statistical survey of solar systems in the neighborhood of the sun.

*164th Meeting of the American Astronomical Society, 10 to 13 June 1984, Baltimore, Maryland.

IRAS

Launched in 1983, the Infrared Astronomy Satellite, IRAS, performed the first all-sky survey at infrared wavelengths—specifically, at 12, 25, 60, and 100 micrometers (*Science*, 1 July 1983, p. 43). In the 7 months since the completion of the mission, the IRAS scientists have continued to refine their data and their understanding. Several sessions in Baltimore were given over to the results.

Infrared Bright Galaxies: In most galaxies, including our own, the infrared and visible luminosities are roughly the same. However, IRAS discovered a new class of galaxies, comprising about 5 percent of all galaxies, that are a bit like a hot frying pan: dim in the visible and bright in the infrared, by a factor of 50 to 100. In fact, their total luminosity puts them in the quasar class. The most dramatic example, Arp 220, has power output equivalent to 2 trillion suns.

It is hard to say what these things are, exactly. Many are very distant and unresolved objects. On the other hand, many of those that *are* close enough to show structure often seem abnormal and disturbed. In fact about 30 percent of the infrared bright objects appear to be pairs of galaxies in the process of collision or merger. So one reasonable model is that shock waves produced in the collision are triggering bursts of star formation; certainly it is true that star formation produces lots of infrared emission in normal galaxies. Unfortunately, certain other spectral features are not consistent with normal star formation, so the picture is still muddy.

Another possibility, given the extraordinary luminosities involved, is that these galaxies are quasars or Seyfert galaxies that are shrouded in dust, so that most of their prodigious energy comes out as heat rather than light. Once again, however, the other spectral features are not quite consistent. An even more exotic suggestion is that the infrared bright sources are protogalaxies, just undergoing their first wave of star formation.

Protoplanetary Systems: The ring of grit and dust discovered last year around the star Vega, or Alpha Lyrae, now seems to be a widespread phenomenon (*Science*, 26 August 1983, p. 845). A similar ring has been verified around Fomalhaut (Alpha Pisces Austrini), and a systematic search has turned up highly suggestive evidence, in the form of enhanced infrared emissions, in more than 40 other nearby stars. The presumption is that these rings will eventually condense into solar systems like our own; if so, that makes the Vega phenomenon the first semidirect evidence that planets are indeed common in the universe.

The ongoing studies of the Vega phenomenon were reported at Baltimore by Hartmut H. Aumann of NASA's Jet Propulsion Laboratory, codiscoverer of the Vega ring. He emphasizes that IRAS has not discovered planets—even a Jupiter-sized object would be invisible at interstellar distances—and he is careful to point out the uncertainties. In particular, a given infrared excess might not be due to a ring, but rather to mass loss from the star, or to a cool, dim stellar companion.

Nonetheless, says Aumann, the evidence is intriguing. An infrared excess appears in roughly 10 percent of the bright dwarf stars lying within 75 light years of the sun—"dwarf" in this case meaning a normal, stable, "main sequence" star in its youth or middle age. Most of them turn out to be relatively cool, long-lived, F- and G-type stars in the same general class as the sun, which is a G2 star having an estimated lifetime of 10 billion years. However, no excesses appear among the nearby giant stars, which are evolving away from the main sequence into the swollen, bloated state typical of stellar old age. Thus, the infrared excess is consistent with being a phenomenon of solar type stars in their youth, which is what one would expect from protoplanetary systems.

Taking the data at face value, says Aumann, it is tempting to speculate that 10 percent of the nearby stars show excesses because each of them spends the first 10 percent of its lifetime with a protoplanetary ring. In the case of the F and G stars, that would fix the lifetime of the rings at roughly 500 million years—which happens to be just about the time people estimate for the condensation of giant planets like Jupiter and Saturn.

Vega and Fomalhaut are exceptions to the rule, says Aumann, in that both are bright, massive A-type stars, with an estimated lifetime of less than 1 billion years. On the other hand, it is interesting that the temperature of the Vega cloud is 80 K, roughly what the sun would produce in a cloud at the distance of Jupiter. (The cloud is about 80 astronomical units from Vega itself, 16 times further away than Jupiter is from the sun and twice as far as Pluto—but then Vega is also 80 times more luminous than the sun.)

In any case, there are still a host of questions about the phenomenon, says Aumann. Do the infrared emissions correlate with the ages of the stars, for example, and in particular do they correlate with the young stars? Do the emissions occur in multiple star systems? (Roughly half of the nearby stars are multiples.) Assuming that the emissions really do come from protoplanetary clouds, is there anything there besides dust? (A preplanetary nebula would presumably contain water ice and a great deal of hydrogen gas, but such things are invisible to IRAS.) Will it be possible to image the clouds with the techniques of speckle interferometry, and if so, will the size measurements be consistent with the IRAS temperature measurements? Are the clouds in the form of flat disks, as predicted by most theories of the solar system's origin? And finally, do the clouds really have anything to do with solar systems?

The Canterbury Swarm

In the early morning of 25 June 1178, something hit the moon. "[The] upper horn of the moon seemed to split in two and flame shot from it," wrote Gervase of Canterbury, who had seen it while out walking with several of his fellow monks. Today there is a very young impact crater, Giordano Bruno, in exactly that place; Gervase may have witnessed its creation.

In the early morning of 30 June 1908, something exploded 8 kilometers over the Tunguska region of Siberia. The devastation was extensive, although there was no crater and little meteoritic debris. The object may well have been an icy fragment of a comet.

Between 22 and 26 June 1975, the network of seismometers left on the moon by the Apollo astronauts recorded a storm of meteorite impacts—10 to 15 per day, as opposed to a more typical rate of one per day. It was the largest such storm detected in a decade of operation.

According to Kenneth Brecher of Boston University and NASA's Goddard Space Flight Center, these isolated events are the result of a previously unknown cluster of meteoroids and asteroids whose orbit is intersected by the earth every year in late June. In honor of Gervase, he calls it the "Canterbury Swarm."

The objects in the swarm probably range from chunks of about a kilogram, to kilometer-sized objects weighing a billion tons, Brecher told the Baltimore meeting. They appear to be the remains of a fragment of Comet Encke; according to his calculations, both the shape of the two orbits and the orbital periods—3.3 years—are almost identical, albeit the paths do not exactly overlap. Other likely fragments of Encke are already known: the Taurid meteor stream that comes in November; the "Beta Taurid" stream that arrives during the daylight hours of, interestingly enough, late June; and the two asteroids 2212 Hephestos and 1982 TA. His own best guess, said Brecher, is that the fragmentation event occurred about 1500 years ago.

Perhaps fortunately for us, the Canterbury Swarm is usually somewhere else when the earth crosses its orbit. The last time the earth-moon system actually passed through the swarm was 1975. The next time will be June 2042. However, the swarm should pass about 30 million kilometers from the earth next year, in June 1985. If it is really there, said Brecher, astronomers may be able to detect it then.

—M. Mitchell Waldrop