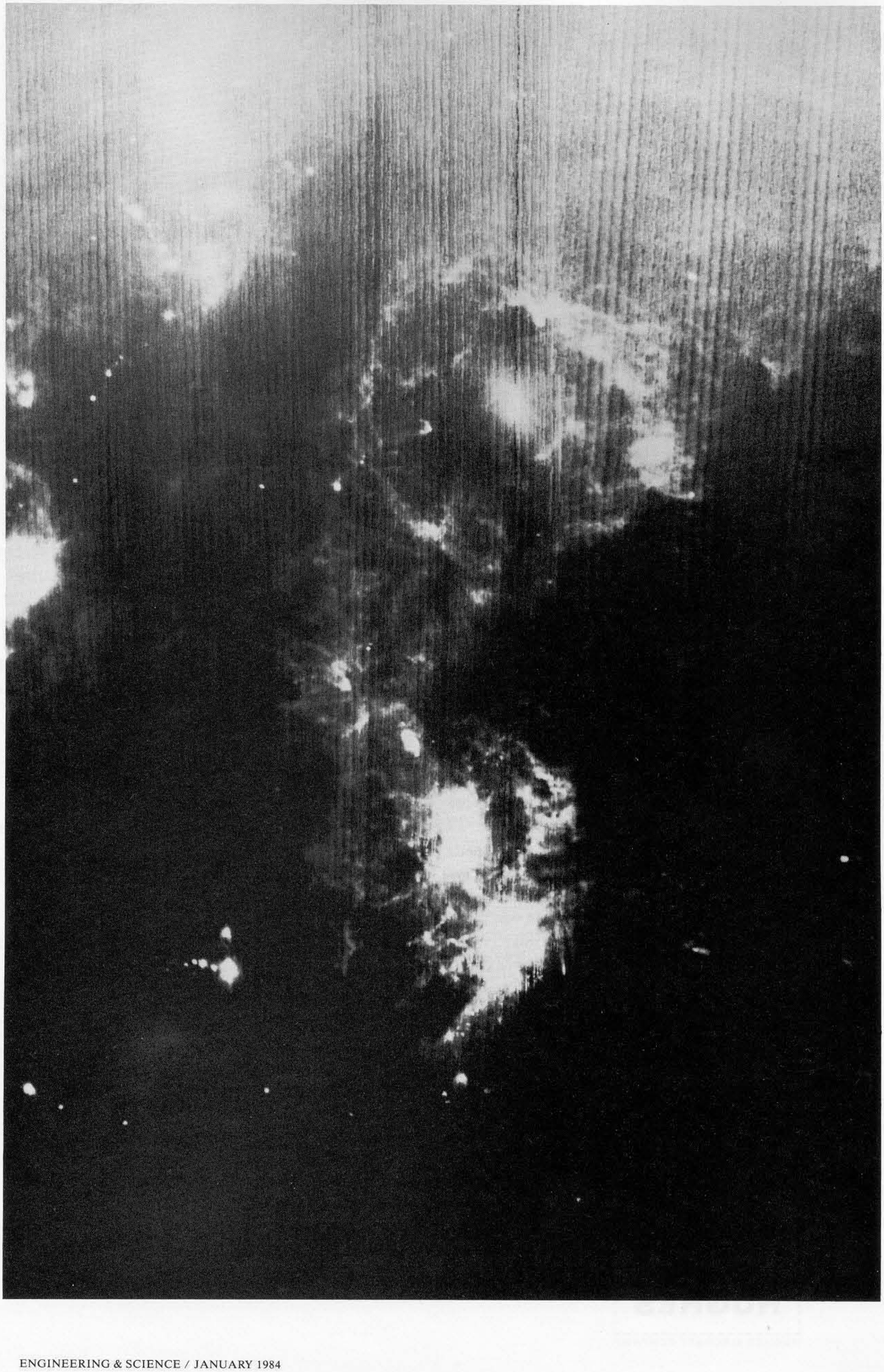


# Discoveries From IRAS

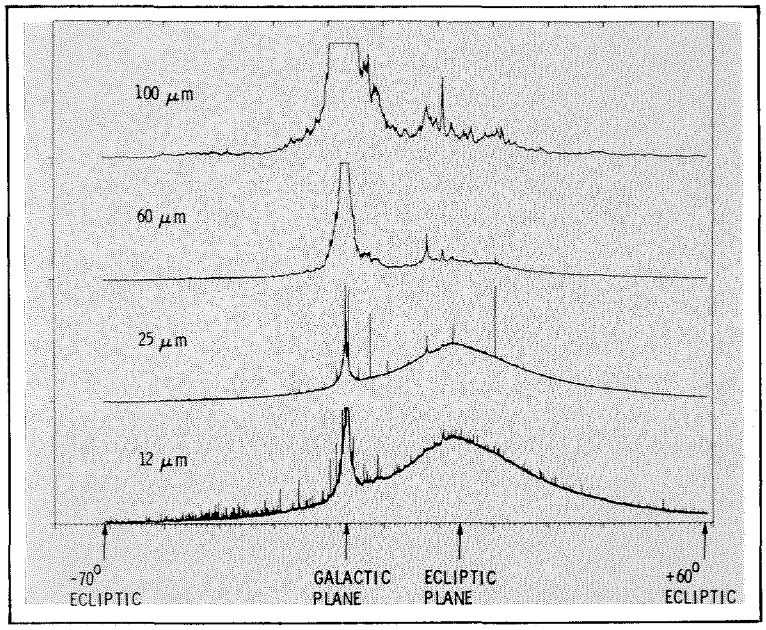
*This familiar region of the sky around the constellation Orion looks very different viewed by IRAS. In the lower half of the picture the gases of the Orion molecular cloud, a well-known region of star formation, obsure the stars of the hunter's sword and belt. The circular feature at top center corresponds to a region of ionized hydrogen gas and dust heated by the star Bellatrix. Part of the Milky Way can be seen at upper left, as well as infrared emission called "cirrus" from dust littering interstellar space within the galaxy.*

THE INFRARED ASTRONOMICAL SATELLITE (IRAS), a joint project of the United States, the Netherlands, and the United Kingdom, was launched a year ago. It finished its mission in November when its telescope's coolant was exhausted. During the time it flew, data from IRAS have led to discoveries of a variety of new phenomena in the universe, from unexplained celestial objects to rings of dust within the solar system. Other results include detection of unidentified cold astronomical objects; discovery of "infrared cirrus" clouds in interstellar space; infrared views of the Milky Way; and detection of large amounts of infrared radiation from visually inconspicuous galaxies. Papers on most of the findings summarized here will be published by the *Astrophysical Journal* in March.

IRAS was developed and operated by the Netherlands Agency for Aerospace Programs (NIVR), the U. S. National Aeronautics and Space Administration (NASA), and the United Kingdom's Science and Engineering Research Council (SERC). The Rutherford Appleton Laboratory operates the tracking station and preliminary science analysis center in England. Caltech's Jet Propulsion Laboratory (JPL) is the U. S. management center for the project.

Nearly 500 scientists, engineers, and technicians from the three countries have been involved in the project. Gerry Neugebauer, Caltech professor of physics and director of Palomar Observatory, is U.S. co-chairman of the Joint IRAS Science Working Group. Also a member of the working group and head of the final data processing team is B. T. Soifer, senior research associate in physics. At JPL Gael Squibb is currently the IRAS project manager; Jerry Smith was project manager during much of the pre-launch fabrication and testing periods.

Launched into a 900-kilometer orbit in January 1983 from Vandenberg Air Force Base at Lompoc, California, IRAS carried a highly sensitive, cryogenically cooled, 57-centimeter, infrared astronomical telescope, which conducted an all-sky survey of objects in the universe that radiate infrared energy. Its detectors are cooled to about 2.5 degrees above absolute zero (2.5 kelvin, or −270 degrees Celsius, or −455 degrees Fahrenheit) by superfluid helium, making the instrument the coldest man-made object ever flown in Earth orbit.




*A scan across half the celestial sphere crossing both the galactic plane and the ecliptic plane of the solar system, produced these data from the four infrared telescope focal plane detectors, one for each of IRAS' wavelength bands. Cool dust from the galaxy produced peaks in the 60- and 100-micron regions (as well as some stars and hot dust in the 12- and 25-micron bands). Warm dust particles in the solar system radiate strongly at 12, 25, and 60 microns, but only weakly at 100 microns.*

The first stage of the IRAS all-sky survey was completed in August. A second look at the sky has been under way since then to achieve 99.8 percent reliability for objects observed by the telescope.

### Unidentified Objects

The orbiting telescope has detected more than 200,000 infrared sources, a fraction of which have not yet been correlated with previously known objects. Early in the mission, a small region of the sky was scanned repeatedly to provide the IRAS scientists with a basis for understanding the subsequent data. In this so-called "minisurvey," 8,709 sources were detected and confirmed, of which 133 cold, pointlike sources were selected for further study. Most of these could either be correlated with already known objects or otherwise identified. It has not been possible to reach definite conclusions for some of the objects that are located in crowded regions of the sky. Nine objects remained in uncrowded regions of the sky, however, that could not be correlated with known sources, nor could evidence be found that they had been previously detected in any other sky survey.

The nine objects, which are quite cold (less than about −220 degrees C, −364 degrees F), do not cluster either around the planes of the Milky Way or the solar system. Since the initial analysis of the unidentified objects in the minisurvey, dozens more have been found in the main survey. The nature of the objects cannot be determined without more information about their distances; additional IRAS and other observations are required to allow approximate distances to be derived. Half the objects have been re-observed six months after they were initially discovered, and are at a distance of more than 6,000 astronomical units (one AU is 93 million miles, the distance from the Earth to the Sun). The distances of the other objects have yet to be determined.

If the objects are within the Milky Way, IRAS scientists speculate that some that appear near clusters of sources or in regions of star formation may be protostars (newly formed stars). Others that appear more isolated may be old stars obscured from view by thick shells of circumstellar material. In either case, they would be unusual in that they are colder than most objects of either type.

An intriguing possibility is that these objects are galaxies detectable only at infrared wavelengths and exist far beyond the Milky Way. Their very low temperatures are similar to the temperatures determined for distant spiral galaxies. No spiral galaxies have been detected in visible light at the locations of the nine objects. Therefore, if they are galaxies, they have unusually large ratios of infrared-to-optical emission — about 100-to-1 or more.

### Zodiacal Dust Bands

IRAS has also discovered three narrow, continuous rings of dust within the solar system. These new features of the solar system may be the result of countless asteroid collisions in the main belt between Mars and Jupiter at a distance from 2.3 to 3.3 astronomical units from the Sun. It is also possible that a single, catastrophic collision between two solar system objects, such as between an asteroid and a comet or between two asteroids, produced the two outer bands of material.

IRAS mapped infrared emission from this interplanetary dust at wavelengths from 12 to 100 microns. The dust is also known as the zodiacal dust since it lies mainly in the zodiacal or ecliptic plane in which the planets travel. The temperature of the dust is −123 to −73 degrees C (−189 to −99 degrees F). This characteristic, in addition to the symmetry and position of the bands with respect to the ecliptic plane, associate them in space with the main-belt asteroids, according to IRAS scientists. The central band may be a permanent feature of the solar system, since it would be constantly replenished by dust from asteroid collisions.

Rather special conditions are required to form the two outer bands that are seen about nine degrees above and below the broad central band. According to the comet-asteroid collision scenario, a comet approaching the Sun at about a nine-degree angle smashed into one of thousands of asteroids in the main belt. After many orbits around the Sun, the remaining dust would spread evenly around the asteroid belt along part of a spherical surface extending nine degrees on both sides of the ecliptic. Each particle would orbit in a plane, tipped with respect to the ecliptic, that includes the Sun. The resultant distribution of dust appears as two parallel bands, since each orbiting particle spends more time at its most distant point from the ecliptic rather than closer to the plane. The estimated amount of material in the bands corresponds to the mass of an asteroid one kilometer in diameter.

### Infrared Cirrus and Background Infrared Emission

IRAS has found that much of interstellar space is littered with wispy clouds of dust, which the science team termed "infrared cirrus," and which are believed attributable to dust particles found in interstellar space within our Milky Way galaxy. Viewed in the 100-micron wavelength region of the spectrum by IRAS, the sky appears largely highlighted by these cloudy features. Because of its temperature, IRAS scientists believe the cirrus consists mainly of graphite (carbon) particles formed in the outer atmosphere of stars and heated by starlight.

Left unexplained at present is another component of background infrared radiation spread more broadly across the sky as a whole. Its intensity and temperature will be determined when all the IRAS results have been processed and analyzed.

### Milky Way

The Sun is located in the outer part of the Milky Way disk, about 30,000 light-years from the center. The space between the stars in the disk contains clouds of gas and dust that block our view in visible light. Infrared light, however, because of its much longer wavelength, moves through this dust with very little attenuation, allowing a view of distant regions within the galactic plane.

Images assembled from IRAS observations near the nucleus of the galaxy show, in addition to the nucleus, molecular clouds such as Sagittarius B2, seen for the first time at 12 and 25 microns. In addition, the images at 60 and 100 microns show the infrared cirrus described above as wisps of material all along the plane and extending into much of the sky.

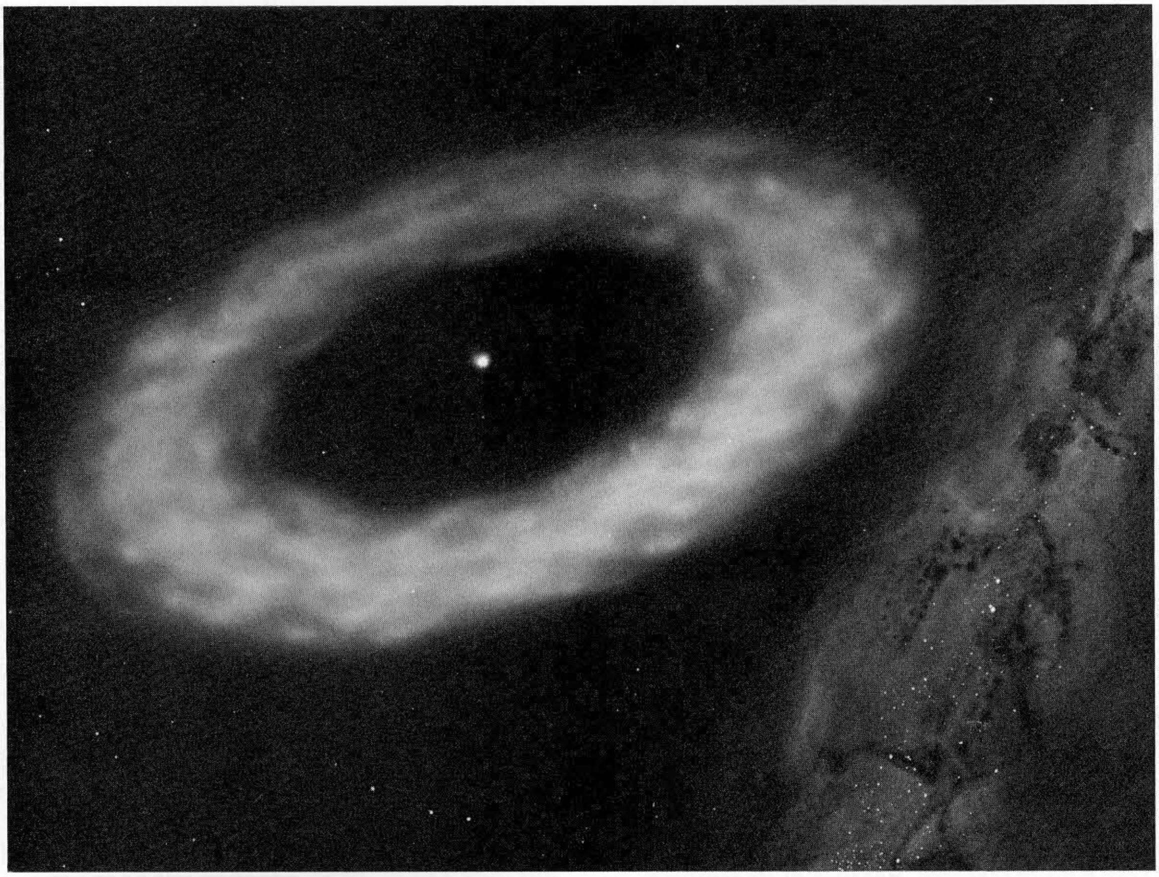
### Galaxies

IRAS observations have revealed many infrared-emitting galaxies previously seen only as inconspicuous smudges in the most sensitive photographic atlases. In the minisurvey, which sampled only one percent of the sky, more than 80 galaxies were found that are faint optically but very bright in infrared light; some emit 50 times as much energy in the infrared as in the visible. For comparison, the infrared luminosity of the Milky Way is roughly equal to its visible luminosity. To achieve a better understanding of the energy sources and physical conditions within these galaxies will require further studies with other telescopes.

Spiral galaxies were found to exhibit a wide range of ratios between their visible and infrared luminosities. The infrared emission in normal galaxies is thought to be a measure of the rate at which new stars are forming, so the wide range in infrared-to-visible luminosity ratios is believed to reflect a similar range in the fraction of a galaxy's mass being formed into stars.

A detailed study of the Andromeda galaxy, our nearest neighbor giant spiral, has shown that much less star formation is occurring there than in most spiral galaxies and far less than in our own galaxy. IRAS observations have pinpointed the locations of current star formation processes in Andromeda as occurring predominantly in the outer dust lanes at roughly 30,000 light-years from the center. The luminos-

*The Andromeda nebula, our nearest neighbor spiral galaxy, is observed here with the 48-inch Schmidt telescope at Palomar Observatory (bottom) and by IRAS at a wavelength of 60 microns. The dark ring in the IRAS image indicates the location of current star formation processes. IRAS scientists believe that the dark nucleus does not represent an area of star formation but rather thermal emission from dust mixed in with the stars.*



*This artist's conception illustrates the ring of material that IRAS discovered around the star Vega. IRAS scientists think that the ring probably consists of dust and small meteor-like objects that may be accreting into larger particles. This might represent an early stage of planet formation.*

ity of these regions represents only four percent of the total energy emitted by this galaxy.

### Star Formation

IRAS has found numerous small clouds of molecular gas and dust that are sites of formation for stars like our Sun within 650 light-years of Earth. In the last decade, studies with Earth-based telescopes have shown that giant stars, 10 times more massive and a thousand times more luminous than the Sun, are forming within large clouds of gas and dust. But before IRAS, little could be learned about the formation of smaller stars — those like the Sun — because of their faintness.

IRAS has peered into these clouds and observed globules consisting of a few hundred solar masses of molecular hydrogen gas that could collapse under their own weight to spawn stars of about the same size as the Sun. The IRAS all-sky survey has found that many nearby dark clouds harbor newly formed stars in a stage of evolution much like that of the Sun when it formed 4.6 billion years ago. The visible light from a newly formed star is hidden from view by the material left over from its formation. The curtain of obscuring dust is, however, heated by absorbed starlight much warmer than most matter in interstellar space. It is this heat from the hidden star that IRAS is able to detect.

One object that is probably much like our early Sun has been found within a dark molecular hydrogen cloud called Barnard 5. The object, one of four detected within the cloud by IRAS, is radiating at about 10 times the rate of the present-day Sun, at a temperature between −243 to +227 degrees C (−405 to +440 degrees F). It appears to agree with theories of stellar formation, which suggest that a star like the Sun goes through an extremely luminous phase in its first 100,000 years of existence.

Two other objects within the cloud appear to be slightly more mature young stars separated from the molecular cloud itself but still hidden by the warm dust (about −70 degrees C or −100 degrees F). The fourth object within Barnard 5 is more enigmatic. It may be no more than a clump of material at the edge of the cloud, or it may be a very cold, dense part of the cloud (about −250 degrees C, −418 degrees F), starting its collapse into another star. More sensitive observations with greater spatial resolution are planned to understand this object.

In another cloud, called Chamaeleon I, 70 sources were detected. Of these, 17 resemble objects in Barnard 5 — either stars deeply embedded within the cloud or stars clear of the cloud but still dust-enshrouded. Twenty-five objects were shown to be cool clumps of material, some perhaps about to collapse into stars. The rest were either normal stars unrelated to the cloud or were impossible to identify because of confusion with emission from other sources.

### Vega

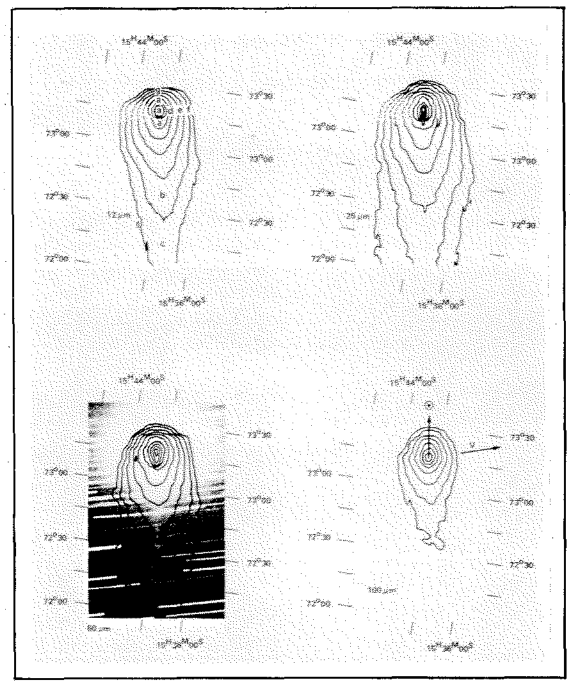
In studying observations of the bright star Vega, which was being used as a standard source to calibrate the telescope, IRAS scientists discovered evidence of a system of solid material orbiting the star. The telescope detected infrared emissions from large solid particles that are gravitationally bound to the star. The particles have probably grown from material left over after Vega's formation and may resemble meteoroids, zodiacal dust, and other solid material found in our solar system.

The discovery provides the first opportunity outside the solar system for scientists to study directly the phenomena that lead to formation of planetary systems around stars. Vega may represent a relatively early stage of planetary formation, where the material is accreting into larger particles, or it may have evolved along a path very different from that followed by the solar system.

Since the discovery, IRAS astronomers have searched for other stars that might also possess orbiting material. The search is complicated by several factors. Excess infrared radiation from a star does not in itself mean that the star possesses orbiting material, according to IRAS astronomers. Other types of processes are known to produce excess infrared emission. Conversely, a planetary system around a star may not produce a significant infrared excess. Our solar system, for example, would be difficult to detect by its infrared excess because most of the material is bound up in planets, which, because of their small surface areas relative to their volumes, radiate much less infrared than material like dust and small grains. In addition, there are only a few stars as bright or as well studied as Vega; thus an unusual infrared excess that might identify a star as a good candidate for possessing a planetary-like system would not be obvious around most other stars. To date, this search has turned up a number of interesting candidates but no other confirmed Vega-like system.

### Comets

IRAS has discovered five new comets, detected extensive envelopes of dust around comets not previously known to be dusty, and observed a long, thin, invisible trail of cometary debris from the well-known comet Tempel 2.



*Maps of the infrared emission at the four IRAS wavelengths of comet IRAS-Araki-Alcock show the comet's extensive invisible dust trail. The 60-micron map at lower left is superimposed on a photograph of the comet. Emission at 12 microns is shown at upper left with the 25- and 100-micron maps following clockwise. The flux at each contour (from outside inward) is twice as bright as the preceding one.*

It has also discovered a new object, designated 1983 TB, which appears to be the parent body for the Geminid stream of meteors, which is seen in December. If this is true (and current observations should make this clear), then 1983 TB may be the sixth comet discovered by IRAS. Most of the major meteor streams have been associated with parent comets; for example, the Orionid shower on October 21 is thought to be produced by debris in the orbit of Halley's Comet. Before the discovery of 1983 TB, no comet had been found to account for the Geminid shower.

The rapid detection of comets by IRAS is performed with the aid of computer programs developed jointly by the IRAS project at the Rutherford Appleton Laboratory and Leicester University. The great success of IRAS in detecting comets, beginning with IRAS-Araki-Alcock, is due to its extreme sensitivity and to the infrared emission from small, sun-warmed dust particles in the coma and tail. Detection of comets as faint as 17th visual magnitude (which would require a visual telescope of 20-inch diameter or larger for detection) is providing data to revise our present estimates of the total population of small comets.

Based on findings to date, IRAS scientists believe additional new information about the universe will certainly be revealed as the processing and analysis of IRAS data continue over the next several years. □