The Infrared Astronomy Satellite (II)

IRAS is making the first all-sky survey in the infrared: the results, although slow in coming, should be dramatic

On 1 February 1983, one week after launch, the Infrared Astronomy Satellite (IRAS) ejected its telescope aperture cover, exposed its liquid helium-cooled detectors to the sky, and began taking data at the rate of 700 million bits per day. Of course, data are not quite the same as results; the science from IRAS is coming a little more slowly.

A joint endeavor of the United States, the Netherlands, and the United Kingdom, IRAS is making the first complete survey of the sky at infrared wavelengths between 8 and 120 micrometers. Despite horrendous problems in the development phase it is working perfectly in orbit, and the astronomers are ecstatic (*Science*, 24 June, p. 1365). As an infrared telescope it picks out the "cold," nonluminous matter of the universe, the stuff with temperatures between a few hundred degrees Kelvin and absolute zero. Included are asteroids, planets, protostars, interstellar molecules, and interstellar dust grains in this and other galaxies. This cold component of matter is probably at least as important in the universe as the luminous stars; indeed, during the last decade infrared astronomy has become one of the most active subdisciplines in the field. Unfortunately, infrared photons are strongly absorbed in the earth's atmosphere. Thus, IRAS.

IRAS is now about halfway through its estimated 340 day lifetime, the limits of which are set by the slow evaporation of its superfluid helium supply. The satellite telescope has already mapped more than half the sky; once it has finished, it will start a second, comparison scan to identify moving and/or variable objects. In addition, IRAS is spending about 40 percent of its time on more detailed observations of specific objects such as the Andromeda galaxy and the Orion nebula.

So far, however, despite the dramatic discovery of two new comets and a ring of dust around Andromeda, the scientific results from IRAS have been sparse. There is good reason. During the first three months of the mission, most of the IRAS data went straight into storage while the science team at the Jet Propulsion Laboratory (JPL) in Pasadena, California, struggled to certify the data processing software.

This phase of the mission had been allowed for in the prelaunch planning, of course—even in a ground-based observatory the instrument calibration and software certification can take a year or more—but in the case of IRAS the problem was exacerbated by an embarrassment of riches. The infrared sky is simply much more complicated than anyone anticipated.

"The detector array generates 100,000 detections per day," says JPL's John Duxbury, who coordinated the data processing effort. "And only 20 percent are real, stationary sources that you want to retain." A given blip in a given detector might result from a cosmic ray or a particle from the earth's radiation belts. It might be stray moonlight. It might be a satellite or an empty rocket casing in a higher orbit, or even a dust mote knocked from IRAS itself by a micrometeorite. Or it might be an asteroid: IRAS will see most of the 3000 asteroids known from the ground and an estimated 15,000 to 20,000 more besides.

"The amount of data coming in is nightmarish."

"There's a tremendous memory demand [on the computer system] as you winnow it down," says Duxbury. "Say you get a detection today. Then you ask, Did I see it yesterday? Six months ago? Has it moved? If so, where? You have to keep track of it *all*."

There is likewise a tremendous pressure to be accurate, he says. "We want positions accurate to 30 arc seconds and a reliability of 0.2 percent [only 2 false reports out of 1000]. But we also want to be 98 percent complete—we don't want to be so conservative we start throwing out real objects."

For "sky truth," the JPL team had IRAS survey one small patch of sky 6 times. Then they analyzed that data set repeatedly, refining their thresholds, acceptance windows, and match criteria until their software performance met specifications. "There are 500,000 lines of code in three different programming languages," says Duxbury. "We've put more than 100 man-years of development into the processing facility."

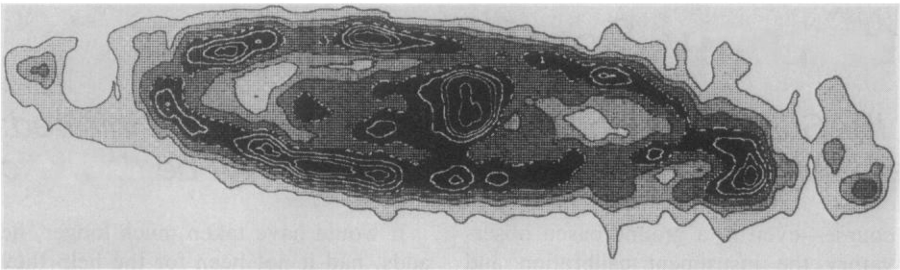
It would have taken much longer, he adds, had it not been for the help they received from the telescope engineers at the Ames Research Center in Mountain View, California, and the astronomers at the Goddard Space Flight Center in Greenbelt, Maryland—help given in a much more amicable spirit than the tension that prevailed between those centers during the development of the IRAS hardware (*Science*, 24 June, p. 1365).

The IRAS team completed certification of the data processing system in mid-May. That tool in hand, they have started digging into the backlog.

"To some extent," says Thomas Soifer of the California Institute of Technology, "we're finding what we expected to find. We're seeing lots of regions of star formation within our own galaxy, for example, including some new ones we only suspected before." [These regions, also known as molecular clouds, are dense masses of interstellar gas and dust that are essentially invisible against the blackness of space. But where they are being heated from within by newborn stars, they can be quite bright in the infrared (*Science*, 5 February 1982, p. 647).] One important example, says Soifer, is a cloud known as Barnard 5, where IRAS found what seems to be a newly-forming star of roughly one solar mass. Virtually all the previously known newborn stars have been further away than Barnard 5, or much, much larger than the sun.

The molecular clouds are studied from the ground by means of line emissions from interstellar molecules, especially that of carbon monoxide at 2.6 millimeters wavelength. These studies can produce a great deal of information about velocities, temperatures, and pressures within the clouds. "But you *can't* do an all-sky survey that way because it takes an enormous amount of time," says Soifer. The radio telescopes have very small fields of view and, because of the infrared absorption bands of water vapor in the atmosphere, "the signal-to-noise kills you."

IRAS, he says, is complementary. It does not look at individual molecular lines, so it misses out on velocity information. But it has a wide field of view. It does not have to contend with water vapor. And most important, because it does not have to exist in a warm, moist



IRAS looks at Andromeda

In the infrared our nearest large neighbor looks decidedly different from its portrait in visible light (left). Prominent is a ring of warm dust about 30,000 light years out from the center. Presumably it marks a region of active star formation.

atmosphere, IRAS can have its whole telescope cooled with liquid helium. (On the ground, only detectors are cooled.) Eliminating the thermal emission from the telescope structure thus makes for an enormous gain in sensitivity. In a single scan, says Soifer, IRAS detects sources that could barely be seen after hours of exposure on the ground.

Looking beyond the Milky Way, IRAS sees lots of galaxies that are bright in the infrared. The standard interpretation—which needs to be checked, warns Soifer—is that the infrared emissions correspond to vigorous star formation. That is, IRAS is seeing interstellar dust warmed up by newborn stars.

"One thing confirming our earlier prejudices is that we are seeing the kind of galaxies we expect," he says. "We see the spirals, which have lots of dust and young stars, but not the ellipticals, which have almost none."

But there is a mystery here, he points out. (Actually, it predates IRAS.) "*If* you take the simple view that the IR luminosity measures the star formation rate," he says, "why do apparently similar galaxies have very different rates?"

A good example is our nearest large neighbor, the Andromeda galaxy. It is a spiral, much like the Milky Way. IRAS has even found a ring of infrared emission about 30,000 light years out from the core, presumably analogous to a ring of gas and dust in a similar position in our own galaxy. (Why rings? Nobody knows, says Soifer.) And yet, Andromeda is one of the more placid spirals, with a much lower rate of star formation than the Milky Way. Why?

Looking still further from home, IRAS has also been studying the active galaxies—Seyferts, BL Lacertae objects, and the like—and the quasars. "More and more in the last few years, there has been a unification," says George Miley. "There seems to be a continuum, from the quasars to the active galaxies to the normal galaxies like our own."

The most popular theory, he explains, is that a quasar is a more-or-less normal galaxy that happens to have a supermassive black hole at the core. Calculations indicate that gas spiraling into a sufficiently large hole—millions or billions of solar masses—would be compressed and heated enough to radiate much of its mass as energy, thus explaining the quasar's fabulous luminosity. A somewhat smaller black hole would produce a Seyfert galaxy (a normal-looking spiral with an abnormally energetic core). Indeed, many astronomers suspect that virtually every galaxy harbors a core black hole of some kind. [There is intriguing evidence for just such an object at the center of our own galaxy (*Science*, 21 May 1982, p. 838).]

It is important for IRAS to study these objects, says Miley, because the infrared is the only way of studying dust in these active galaxies. Not only would the observation of dust in quasars be strong support for the black-hole-in-a-galaxy model, "but maybe it would let us say something about the food that feeds the monster in the middle."

When IRAS has observed enough quasars, he adds (or more accurately, when the data is reduced for the hundreds it has already looked at), the statistics may help resolve another question. There are two types of quasars: the radio quiet, which are essentially invisible at radio wavelengths; and the radio loud, which have big lobes of radio emission on either side. In the black hole model, says Miley, these lobes are presumably energized by high-velocity jets of material emerging from the vortex in the middle. The question is then why some quasars have the jets and some do not.

A clue comes from looking at the nearby active galaxies. Jets and radio lobes do show up in active ellipticals, such as M87 in the Virgo Cluster, but not in the Seyferts, which are spirals. "Perhaps the dust in the spirals stops the jets," says Miley (ellipticals are essentially dust-free), "or perhaps the jets wobble for some reason and the lobes just wash out." Be that as it may, that same correlation could be extended to the quasars if IRAS consistently sees dust in the radio-quiet specimens and none in the radio-loud.

Finally, IRAS has a heavy schedule of observations much closer to home, in the solar system. For example, because it detects things by warmth instead of reflected light, it will compile a catalog of some 15,000 asteroids. IRAS will see the darker asteroids more easily, in fact, since they absorb and reradiate more of the sun's heat. Their infrared emissions also happen to be a particularly good indication of their composition. The darkest ones are thought to be laced with a tarry, carbonaceous gunk left over from the condensing solar nebula; statistics on their number, size, and distribution could thus be helpful in understanding how the solar system formed.

IRAS will likewise be looking at other carriers of primitive material, the comets. One of the satellite's first discoveries, in fact, was a small comet that now bears the names of its codiscoverers: Comet IRAS-Araki-Alcock. Comet Halley, although still faint and distant, will also be a prime target.

But perhaps the most exciting single thing about IRAS' solar system work is the possibility of seeing new planets beyond Pluto. A giant, gaseous planet such as Jupiter would be very hard to see by reflected light at that distance. But it would be anomalously warm—like Jupiter, it would still be cooling off from its formation, 4.6 billion years ago—and IRAS could see it in its long wavelength channels. It would then identify the source as a planet during its second scan later this year, when the source would show up in a slightly different position.

Almost unanimously, the IRAS scientists talk about years and years of work ahead. As George Miley says, "The amount of data coming in is nightmarish." Many of the best results may not appear for six months or more. The final catalog of sources will not appear until the latter half of 1984. But from all accounts, the floodgates are beginning to open.—**M. Mitchell Waldrop**