4. Infrared Space Astronomy

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I. INTRODUCTION

The period from 1984 through 1987 saw no new infrared space missions. Investigations, however, continued with airborne, balloon, and rocket activities, and follow-up analysis of data from the Infrared Astronomical Satellite (IRAS). Two major ephemeral events occurred during this time, the Comet Halley apparition and SN 1987a, the supernova in the Large Magellanic Cloud. With improved analysis on the database and follow-up observations new results have been forthcoming from IRAS. This work may help astronomers understand everything from the origin and evolution of quasars to the composition of material in cometary nuclei.

No short review can do justice to all the remarkable science that has resulted from the efforts of the many investigators involved in near space and space missions. As such only a few highlights can be given below.

II. NEAR SPACE ACTIVITIES

The year 1986 marked the return of Halley's Comet. The Kuiper Airborne Observatory (KAO), a modified Lockheed C-141 cargo transport airplane operated by NASA-Ames which carries a 91-cm telescope to altitudes above 12.8 km, was deployed from Moffett Airfield in Mountain View, California, and from Christchurch, New Zealand, to provide 2-200μm observations of the comet. The result was the first detection of water in a comet (Mumma et al. 1986, Weaver et al. 1986). Water is expected to be the primary volatile constituent in cometary nuclei. Previous evidence, however, had been circumstantial based on abundances and velocities of H, O and OH seen in the coma and taken to result from photodissociation of H_2O that sublimed from the nucleus. The deduced abundance of water indicates its primary role. Observations of the dust continuum emission were made from 5 through 160μm (Campins et al. 1986b, Herter et al. 1986, Glaccum et al. 1986, Campins et al. 1986a). This is the first such comprehensive coverage. The data fit a greybody emissivity for wavelengths greater than 15μm indicating the existence of large grains. These measurements provide an excellent comparison for the Halley fly-by missions which make in situ measurements of the dust.

In light of the success of the Comet Halley mission, a Southern Hemisphere expedition to observe the recently discovered Comet Wilson was undertaken in April 1987. Comet Wilson had the virtue of being a nonperiodic comet that was detected well in advance of perihelion and as such represented an excellent candidate to perform a comparative study to Comet Halley. Again water was detected in Comet Wilson (Mumma, 1987). Whereas the water and dust production rates for Comet Halley were very variable (sometimes on the timescale of hours) Comet Wilson displayed no such variability.

During the planning stages of the comet mission another spectacular event occurred, SN 1987a, the Supernovae in the Large Magellanic Cloud. As a result observations of SN 1987a were made during the Comet Wilson expedition. A spectrum of the SN from 5.3 to 12.5μm at a resolving power of about 100 was obtained by Rank et al. (1987). They find strong evidence for an infrared excess (over photospheric emission alone) possibly indicating an early infrared echo. Hydrogen recombination lines are also seen as well as a broad feature at 5.3μm which may be due to a blend of iron lines. Larson et al. (1987) measured the 1.5-3.0μm spectrum of SN 1987a using a Michelson interferometer at a resolution of 2000 (subsequently degraded to a resolution of 300). They see Pα and several Brackett recombination lines. Pα shows an asymmetric double peaked structure separated by approximately 4000 km/sec. At 2.7 to 3μm a broad absorption feature, believed to be due to dust, is also seen. Over the next few years further Southern Hemisphere missions to observe the SN with the KAO are planned.

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The KAO has been used to obtain solar limb intensity profiles at 30, 50, 100, and 200μm with arc second resolution during a solar occultation (Lindsey et al. 1986). The brightness of the limb agrees roughly with plane-parallel model predictions at all wavelengths. However, at 100 and 200μm the limbs are extended significantly beyond that expected from models. This is taken to be strong evidence for large departures from gravitational-hydrostatic equilibrium almost immediately above the chromospheric temperature minimum.

Jaffe et al. (1986) recently report the detection of the $^3P_2$-$^3P_1$ [CI] fine structure line at 370μm in the Orion molecular cloud. This line complements a longer wavelength line at 609μm due to the $^3P_1$-$^3P_0$ transition observed previously (Phillips et al. 1980). Although at present the emission region cannot be uniquely identified, the observations are consistent with the observed lines emanating from the warm optically thin interface between the Orion HII region and the molecular cloud which lies behind it. Earlier results with the 609μm line alone have indicated that the C I abundance is substantial in many clouds and possibly could be comparable to the CO abundance (Phillips et al. 1980, Phillips and Huggins 1981). If these early results were proved valid, the implication is that a large neutral carbon abundance exists throughout the clouds, requiring a revision of current interstellar carbon chemistry models and/or of the usual accepted lifetimes of molecular clouds ($\gg 10^6$ years). With the new 370μm observations this now does not appear to be required.

A joint effort between the Japanese and the United States using sounding rockets has resulted in the measurement of the infrared background from 100μm to 1mm (Matsumoto et al. 1987). This resulted in the first detection of the deep minimum expected in this spectral region due to the falling off of the 2.7K cosmic microwave background (CMB) with increasing frequency and a subsequent rise in emission due to interstellar dust emission. Unlike IRAS these measurements are not influenced by interplanetary dust emission because of the elongation angle difference for the two sets of observations, 180 deg. for the rocket measurements versus 90 deg. for IRAS. An excess of an order of magnitude is seen in the 2.7K CMB emission over that expected from the Wien falloff of the Planck function. This excess appears to be a real effect and is explicable in terms of several different cosmological scenarios; distortion of the CMB due to Compton scattering at $z > 8$ from a hot ionized nonrelativistic gas; excess radiation due to dust (created and) heated by population III stars at $z \sim 15$-20; or enhancement of emission through the decay of exotic particles (Hayakawa et al. 1987).

The excess in the CMB discussed above should not be confused with the earlier reported excess near the peak of the 2.7K radiation by Woody and Richards (1981). Subsequent balloon work remeasuring the spectrum near the peak shows that these deviations are not present (Peterson, Richards, and Timusk 1985).

III. The Infrared Astronomical Satellite (IRAS):

IRAS was a cryogenically cooled 57-cm telescope conceived as a joint venture between the United States, the Netherlands and the United Kingdom. It was launched in early 1983 and performed a sensitive survey of the sky at 12, 25, 60 and 100μm until its cryogen was depleted some ten months later. The spectacular success of IRAS and its results revolutionized many aspects of our views of the universe. Among many other discoveries the accomplishments of IRAS include our first view of the stellar distribution of the Milky Way; the discovery of excess emission due to dust around stars such as a Lyra; the discovery of highly luminous, infrared active galaxies; and the discovery of galactic infrared cirrus emission. Many of the initial results and discoveries are contained in the March 1984 issue of The Astrophysical Journal (Letters), Vol. 278. The science resulting from this short duration mission did not stop, however, after these initial discoveries. Through a vigorous data archival program and the application of new data-processing techniques, IRAS continues to generate new surprises.

New data products which promise to enhance the IRAS database further include the Faint Source Survey (FSS) and Super Sky Flux Plates (SSFP). The FSS will co-add approximately three-fourths of the sky, focussing on filtering the data to enhance point and slightly extended sources. This should result in a survey approximately three times deeper than the original point source catalog and the addition of about 250,000 new sources. Image format plates and a catalog of observations will be available. The SSFP will provide higher (1 arc minute) spatial resolution and improved calibration plates. Destriping and removal of the zodiacal emission are also being performed on the SSFP.

Much of the IRAS "follow-up" work is summarized in three international conferences. The first, entitled "Light on Dark Matter," was held on 1985 June 10-14 in Noordwijk, The Netherlands (Israel, 1986). This was followed by "Star Formation in Galaxies" on 1986 June 16-19 in Pasadena, California, (Lonsdale Persson 1987) and "Comets to Cosmology" on 1987 July 6-10 at Queen Mary College, London. Two review papers summarize the IRAS view of the extragalactic sky (Soifer, Houck and Neugebauer 1987), and of the galaxy and the solar system (Beichman, 1987). It is not possible to cite the wealth of scientific results emanating from IRAS and only a few selected examples are given below. The reader is directed to the above references for a more complete and in-depth summary of IRAS-related work.

IRAS has resulted in the discovery of a new class of extragalactic sources -- ultraluminous infrared galaxies (Sanders et al. 1988). At the very highest luminosities, infrared loud galaxies dominate and an abundance of advanced merger systems is evident. In addition these galaxies show evidence for both star formation and nonthermal power sources and may represent the initial dust-enshrouded stages of quasars. As dust from the merger is shed, the active galactic nuclei (AGN) visually dominate the decaying starburst. The discovery of these objects gives astrophysicists new clues to understanding quasars and the AGN phenomena.

Jura et al. (1987) and Tytler (1987) have examined the infrared emission from Shapley-Ames elliptical galaxies using the IRAS database. More than half of the bright "normal" ellipticals emit detectable 100μm emission due to cool dust and therefore contain a significant amount of interstellar gas, often 10^7 or 10^8 $M_\odot$. The origin and evolution of this interstellar matter is not fully understood. Certainly interstellar matter is expected from stellar mass loss. In fact, estimates of the amount of ejected material should greatly exceed that observed if the galaxies have existed for a Hubble time. This situation is not relieved by outflows since interstellar material does not appear to be flowing out of these galaxies as winds. Sinks of material include the possibility that the gas lost resides in a very hot extended halo or goes into the formation of new low-mass stars.

IRAS 16293-2422 is an extremely cold source in the Rho Ophiuchi molecular cloud which follow-up observations reveal is associated with a high-velocity molecular flow (Walker et al. 1986). Line asymmetries associated with this source appear best explained by the presence of in-falling material in the inner regions of the cloud. The observed luminosity, density structure and velocity profiles agree well with predictions of collapsing protostar models for low-mass stars. This indicates that IRAS 16293-2422 may represent the first discovery of a true protostar, a young stellar object in the process of acquiring mass through accretion of an in-falling envelope.

Initial examination of the zodiacal emission demonstrated the presence of a band structure shown to be associated with material produced by multiple collisions between certain families of main belt asteroids (Low et al. 1984). The zodiacal dust bands are now thought to have substructure (a breaking up into finer bands) which is interpreted as preliminary evidence for a recent collision between two asteroids (Sykes 1987). In addition, recent work has found comet trails that appear as large trails of infrared radiation due to large dust particles which remain in orbit for long periods of time (Sykes 1986; Sykes, Hunten and

Low 1986). These trails extend over 2 AU in some cases. The largest particles thus far seen are those associated with Temple-2. Particle sizes of at least 1 cm (on the basis of dynamical arguments) must be present. Although this source of particles cannot replenish the zodiacal dust, it does represent the refractory component of the nucleus, independent of the gas and ice components of the comet, and provides information on the nature of the dark material. Albedos of these particles are on the order of a few percent, providing additional confirmation of the (necessary) low albedo of cometary nuclei.

IV. FUTURE MISSIONS

The wealth of information gained from suborbital programs and the revolution in infrared astronomy brought about by IRAS clearly demonstrates the necessity of extending existing capabilities. Some of the major missions being carried forward now or planned for the future are discussed below.

A. The Infrared Space Observatory (ISO):

ISO is an astronomical satellite containing a cryogenically cooled 60-cm telescope with four focal plane instruments to be used for imaging, photometric, spectroscopic and polarimetric observations at wavelengths from 3 to 200μm. The observatory, which is an approved and funded project of the European Space Agency (ESA), will be launched around 1993 and operate for 18 months. The instruments are being built by an international consortia of scientific institutes.

B. The Stratospheric Observatory for Infrared Astronomy (SOFIA):

SOFIA is a proposed 3-meter class telescope in a Boeing 747 airplane, anticipated as a joint development by NASA and the West German Science Ministry (BMFT). The concept is an extension of the KAO which operates a 91- cm telescope in a Lockheed C-141 jet transport. Focal plane instruments providing imaging, photometry, and spectroscopic capability over the range from 0.3μm to 1.5mm will be provided mainly by the investigators. A program of roughly 120 flights/year is planned and with an anticipated operational lifetime of 20 years SOFIA will complement future astronomical space missions.

C. The Cosmic Background Explorer (COBE):

COBE is a mission to make measurements of the spectrum and large-scale anisotropy of the cosmic microwave background (CMB) and to search for a diffuse cosmic infrared emission. This satellite is being developed by the National Aeronautics and Space Administration (NASA). It utilizes three instruments: a Far Infrared Absolute Spectrophotometer to measure the CMB spectrum from 100μm to 1 cm; Diffuse Microwave Radiometers to search for anisotropies in the CMB at frequencies of 31, 93 and 90 GHz on scales of seven degrees and larger; and a Diffuse Infrared Background experiment to search for a diffuse cosmic infrared background from 1 to 300μm. COBE was originally designed for launch by the Space Shuttle, but it is now being modified for a Delta launch in early 1989.

D. Next Generation Hubble Space Telescope (HST) Instruments:

As part of an approved program of ongoing maintenance and refurbishment for HST, a second generation of focal plane instruments is being developed. Included in these instruments will be an infrared imager/spectrograph operating from roughly 0.8 to 2.5μm. Selected in a competitive review with instruments at other wavelength ranges, two near-infrared instruments designs are being studied by groups headed by Rodger Thompson of the University of Arizona and by Don Hall of the University of Hawaii. Present planning is to have one of these instruments ready for installation into the HST during the second planned maintenance mission six years after launch.

E. The Space Infrared Telescope Facility (SIRTF):

SIRTF is envisioned to be a long-lived, meter-class cryogenically cooled space observatory for infrared astronomy. The goal of SIRTF is to achieve the highest sensitivities, limited only by the faint infrared background of the earth's (space) environment. The focal plane instruments consist of cameras, photometers and spectrographs covering the range from 2.5 to 200μm, and a 700μm photometer. Being developed by NASA, SIRTF is expected to be launched in the mid-1990s and have a lifetime of greater than ten years through cryogen refills.

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