SUBMILLIMETER WAVE ASTRONOMY

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Scientific Overview

Astronomical observations at submillimeter wavelengths, between 40 μm and 1 mm, study astrophysical sources and problems which differ from and complement those accessible at other wavelengths. Although a few nonthermal sources are known, most of the radiation observed in this spectral band from astronomical sources outside of the solar system comes from extended clouds of gas and dust with temperatures in the range 10-500 K and densities between 10 and 10^6 atoms cm^{-3}. The submillimeter radiation consists of both continuous emission from the sub-micron sized dust particles, which make up ~ 1% of the total mass, and line emission from atomic and molecular species in the gas. The energy radiated at submillimeter wavelengths is generally supplied to such a cloud in the form of ultraviolet, optical, or near infrared radiation from stars or other luminous objects which is absorbed by the dust and goes into heating the dust and gas. Since only a small amount of dust is required to convert ultraviolet and optical radiation into submillimeter radiation, there are many astronomical sources from which most or all of the observed energy lies in this spectral region, although the objects which heat the dust and gas differ from one submillimeter source to another. Thus intense submillimeter radiation is seen from the center of our Galaxy [1] and from diffusely distributed matter within the galactic plane [2], where the heating is probably due to normal stars; from the nuclei of several other galaxies [3], where exotic heating sources may be important; and from shells of dust and gas which are expelled from and heated by evolving stars [4].

By far the most numerous, brightest, and best-studied submillimeter sources now known, however, are dense clouds of dust and gas within which stars appear to be forming in our Galaxy [5]. Most of the luminosity of the young and forming stars within such a region goes into heating the dust and is radiated away at submillimeter wavelengths, with a smooth, blackbody-like spectrum typically peaking between 50 μm and 200 μm. The gas in this type of region is studied by the microwave emission lines from numerous simple molecular species, including CO, HCN, H_2CO, etc. [6]. These observations supply information about the composition, density, temperature, and state of motion of the gas. The existence of this type of region has been known for less than a decade; however, observations of these regions have already provided a much clearer picture of the conditions under which stars form, and of the properties of newly formed stars, than was available previously. A conspicuous example of such a cloud is that associated with the well-known Orion Nebula [7]. This cloud is 10 light years in extent, contains 10^3 solar masses of gas and dust, and has a total submillimeter luminosity of 2 to 3 × 10^5 times the total luminosity of the sun. This cloud is heated from within by a cluster of stars which have recently formed within it and which are not yet visible at optical wavelengths.

Techniques and Instrumentation

Submillimeter astronomical observations are severely hampered and complicated by atmospheric water vapor. Wavelengths between 40 μm and 350 μm are inaccessible from any ground-based sites, and observations are carried out from airplane-, balloon-, and rocket-borne telescopes. The largest of these instruments have apertures ~ 1 m, so that the spatial resolution of the observations is no better than 15 to 20 arcseconds, which is much poorer than can be attained at shorter wavelengths on large ground-based telescopes. In the poor atmospheric windows around 350 μm, observations can be carried out on an irregular basis from a very few mountain top observatories which are at altitudes in excess of 10,000 ft. Finally, in the 1 mm region, the water vapor absorption is sufficiently low that many large optical telescopes can be used effectively.

Most of the observations to date have been carried out using broad band detectors, including bolometers and photoconductors, and a number of types of filters and spectrometers which define spectral bands having ($\nu/\Delta\nu$) between 1 and 100. These low resolution observations are mainly sensitive to the continuous emission from the dust in submillimeter sources and provide information about the luminosity of such regions and about the gross distribution of matter within them. The limiting fluxes which can be attained with existing telescopes and detectors are in the range 1 to 10 × 10^{-26} Watts m^{-2} Hz^{-1} throughout the submillimeter region.

Coherent detection techniques have not yet been used at wavelengths shortward of 1 mm, although several groups have reported observations of the CO $J = 2 \rightarrow J = 1$ rotational transition at 1.3 mm (260 GHz) using Schottky barrier [8] and InSb mixers [9], and plans are now under way to extend these observations to the $J = 3 \rightarrow J = 2$

line of CO at 390 GHz. Because of the large amount of information concerning the physical conditions and composition of a region which they provide, spectral line observations are essential to a detailed understanding of any astrophysical system. The submillimeter line observations will complement and extend the information already available from extensive spectral line observations at millimeter wavelengths.

Future Prospects and Requirements

In the next few years, several developments should give continued impetus to submillimeter astronomy. These include:

(A) Construction of major telescopes optimized for, and dedicated to, submillimeter observations, including the 10 m dishes being fabricated by R. B. Leighton at Caltech.

(B) Extension of coherent detection techniques into this spectral region.

(C) Development of more sensitive broad band detectors, including both photoconductors and bolometers.

(D) Performance of the first unbiased surveys of the sky in this spectral region, includint both balloon-borne investigations (P. L. Richards; F. J. Low) and that carried out from the joint American-Dutch-UK Infrared Astronomical Satellite. The submillimeter observations carried out to date have concentrated heavily on regions known from other observations to be of interest and are thus subject to a number of selection effects. The unbiased surveys will be crucial in establishing the true scope and promise of submillimeter astronomy.

Many of the parameters required for the interpretation of submillimeter observations, including, for example, the cross-sections for the excitation of molecular emission and the electromagnetic properties of likely interstellar grain materials, are at best only approximately known. Similarly, some of the observed properties of submillimeter sources, including, for example, the widths and profiles of the molecular emission lines, have not been interpreted satisfactorily. Thus the instrumental advances cited above will have to be accompanied by advances in theoretical and laboratory work if they are to be fully exploited.

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References

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