Dense Molecular Gas in Star-Forming Regions –
The Importance of Submillimeter Observations

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Abstract: An account of the prospects for astronomy in the submillimeter range is given, emphasizing spectral line measurements.

1 Introduction

The submillimeter band remains one of the last portions of the electromagnetic spectrum that have yet to be systematically explored by astronomers. Between wavelengths of 300 \(\mu m\) and 1 mm (1 THz > \(\nu\) > 300 GHz) there exist several broad “windows” in which astronomical observations from the ground are possible from favourable sites such as high mountain tops or Antarctica under good weather conditions (Fig. 1). At far-infrared wavelengths, i.e. between 300 \(\mu m\) and 30 \(\mu m\), comparable windows do not exist and ground-based observations are essentially impossible.

While submillimeter observations of spectral lines and dust continuum emission are providing significant contributions to many areas of astronomy from planetary science to cosmology (see Phillips & Keene 1992 for a recent review), we shall in the following mostly discuss molecular line observations of the warm (\(T \gtrsim 100\) K), compact (\(r \lesssim 0.05\) pc), and dense (\(n \gtrsim 10^6\) cm\(^{-3}\)) core regions of giant molecular clouds. These regions are of great astronomical interest since they are giving birth to massive stars. Furthermore, the high molecular column densities and excitation temperatures in these cores make them important laboratories for studying interstellar chemistry; indeed, many molecules, although also present in colder, lower density gas, are only observable toward dense cores. Most high-mass star-forming regions are at distances greater than 1 kpc, and the emitting regions have angular extents smaller than \(\approx 10''\). Therefore, systematic studies in the submillimeter range had to await large ground-based telescopes with high precision surfaces, namely the 10.4 m telescope of the Caltech Submillimeter Observatory (CSO) and the 15 m James Clerk Maxwell Telescope (JCMT). These telescopes have angular resolutions of order 10'' at their highest operating frequency, which is at the atmospheric cutoff near 1 THz. Both the CSO and the JCMT started operating in the late 1980’s on the top of Mauna Kea, Hawaii. Before then, several of the most
prominent spectral lines had been detected with the 0.9 m telescope aboard the Kuiper Airborne Observatory (KAO) and optical telescopes on Mauna Kea. A third large dish that will operate throughout the submillimeter range, the 10 m Heinrich Hertz Telescope, is currently nearing completion on Mt. Graham in Arizona. Even higher spatial resolutions will be obtained with the Submillimeter Array (SMA) currently under construction by the Smithsonian Institution (Moran 1994). Apart from the large telescopes now available, molecular line astronomy at submillimeter wavelengths is greatly benefitting from breathtaking new developments in heterodyne receiver technology (see Blundell & Tong 1992 for a recent review).

Fig. 1. Atmospheric transmission on Mauna Kea for 1 mm of precipitable water.

In section 2 of this article, we give examples for the unique information that submillimeter observations of molecular lines are providing on the physics and chemistry of dense molecular cores. We summarize some recent results and point out a number of open questions that will be addressed by future observations. In the third section we describe recent submillimeter observations of the particularly important water molecule.

2 Submillimeter Observations of Hot, Dense Cloud Cores

2.1 Hot Cores

It is clear from the association of hot, dense molecular cloud cores with ultracompact H II regions and luminous infrared sources that these regions are the sites of recent or on-going high-mass star formation (see, e.g., Wilson & Walmsley 1989). Because of its proximity, $D = 460$ pc, the dense molecular