Infall in Collapsing Protostars

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1. Introduction

High spectral resolution observations of dense cores in lines of NH_3 have provided no clear evidence for infall, even when the cores possess embedded low mass protostars or young stellar objects (Menten et al., 1984; Menten and Walmsley, 1985; Myers and Benson, 1983). Infall is expected to continue until protostellar winds begin to affect the dynamics of the cores.

Menten et al. (1984) suggested that the freeze-out of molecules containing heavy elements on to dust grains in the higher density infalling gas prevents these high velocity regions from contributing broad wings to the NH_3 line profiles.

Though NH_3 gas phase abundances decline as freeze-out continues, the abundances of some other species, e.g. CH (Hartquist and Williams, 1989), actually increase, at least initially. Thus, CH lines may show broad wings, while NH_3 profiles remain narrow. Comparisons of such line profiles would give information about freeze-out rates, and the dynamics, and age of the collapse.

We have calculated the abundances of molecular species in a collapsing core, in which freeze-out of molecules on to dust and gas-phase chemistry are both occurring. We determine the velocity distribution of parcels of gas within the core and determine the line profiles of a variety of observable species.

2. The Model

Calculations are performed for a spherical core of 1 $M_\odot$ with initial number density $n = n(H) + 2n(H_2) = 2.8 \times 10^3$ cm^{-3} and temperature 10 K. A

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modified free-fall collapse to a truncated singular isothermal sphere occurs, giving a density profile of r^{-2} and an outer radius of 1.58×10^{17} cm, and a number density, n, at the boundary of 1.86×10^4 cm^{-3}.

Immediately following the establishment of the singular isothermal configuration, the self-similar collapse begins, with a collapse expansion wave (CEW) propagating outwardly in a self-similar fashion (Shu, 1977). Inside the CEW, matter approaches free-fall with density $\alpha\ r^{-\frac{3}{2}}$, and infall speed $\alpha\ r^{-\frac{1}{2}}$.

During the collapse we follow the time-dependent chemistry of 85 species involving H, He, C, N, O, S, Na, and electrons, linked in 1147 chemical reactions in a closed network. Photoprocesses stimulated by the cosmic ray induced radiation field (Prasad and Tarafdar, 1983) are included. Freeze-out rates adopted include an allowance for grain charge (Umebayashi and Nakano, 1989). We also consider the possibility of enhanced freeze-out due to the presence of many small grains (Duley and Williams, 1984).

3. Results

Nine calculations were performed for depletion rates which are D = 1,2, and 3 times the canonical rate, and for three values of the collapse age, t_c : 4×10^{12} s, 6×10^{12} s, and 8×10^{12} s. The chemical results show clearly that while NH_3 declines in abundance as radius decreases, other species show significant enhancements as the inflow progresses. The ten most abundant species showing significant enhancements as the collapse proceeds are OH, OCN, CH, HCO^+, HCO, SO, N_2H^+, HNO, H_2S, and SH. These species may be expected to show broad profiles.

For most parameter combinations, the calculated NH_3 line profiles are narrow, confirming the suggestion of Menten et al. (1984). Profiles of other species depend sensitively on the parameters D and t_c. Detailed observations of these lines towards a few of the nearest globules should provide direct evidence for the infall of protostellar envelopes, and will allow an understanding of the dynamics of protostellar collapse.

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