Examining the Interstellar Medium For The First Stages of Stellar Formation

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The Interstellar Medium

The space between the stars is not empty: it is filled with an interstellar medium (ISM) of gas and dust. The ISM can be imagined as a galactic ecosystem in which stars live and die, only to provide the material for new stars to be born. Star formation requires interstellar clouds that are cold and dense enough for self-gravity to overcome internal pressure from gas thermal motions and other factors, thus leading to cloud contraction and eventual collapse to stellar densities. These cold and dense conditions are not present in all clouds in the ISM, but they can be identified using observations of neutral atomic hydrogen gas (HI).

Analyzing HI Regions

Mapping the properties of HI clouds involves finding the optimal combination of parameters for each part of the cloud. For emission regions, the parameters fitted are: temperature (Ts), optical depth (tau0), line width (FWHM), and average velocity (v0). Absorption has all of these parameters plus one more describing the fraction of the emission (p) that is behind the absorbing cloud. To find an optimal combination of parameter values, we used the Fitter-Mead ‘amoeba’ method to explore a chi squared space. The ‘amoeba’ travels through the chi squared space until it finds a minimum that satisfies the given requirements. Equations (1) and (2) are used for both emission and absorption fitting routines, with (3a) for emission and (3b) for absorption. The amoeba method was successful in finding emission features, but not absorption, which appears not to have an adequately constrained solution in the scenario we have considered.

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\sigma_{\text{line}} = \frac{FWHM}{\sqrt{8 \ln 2}} \]

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\tau_0 = \frac{1}{\sqrt{2 \ln 2}} \frac{(p \cdot \text{FWHM})^2}{v_0^2} \]

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T_{\text{on-off}} = T_b (1 - e^{-\tau}) + T_{bg} e^{-\tau} \]

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T_{\text{on-off}} = (T_b - T_s - \text{FWHM}) (1 - e^{-\tau}) \]

Stage I

Stage II

Stage III

Regions in the ISM can either emit or absorb radiation. In an emission region, the object is brighter than the background in maps of the sky (top left), and the spectrum shows a peak at the cloud velocity (bottom left). An absorption feature occurs when the background brightness is greater than the object being observed (top right). The corresponding spectrum has a decrease in brightness at the cloud velocity, resulting in a trough (valley feature) (bottom right).

Quality of the Analysis

A combination of 1250 emission spectra was tested 1000 times in order to determine the effectiveness of the amoeba fitting routine. The simulation was tested over varying line widths, temperatures, and optical depths. We added different levels of noise to each emission spectrum, ranging from 0.02 - 20 K. Our simulation builds on previous work by Rohlfs et al. (1972). Their results determined that the tests are very susceptible to noise, and only very high-quality data can be properly analyzed. Our simulation shows that at noise levels of more than a few percent of signal, the emission fitting routine will give an incorrect answer, including a systematic underestimate of the real temperature value.

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E_r = \frac{X_{\text{model}} - X_{\text{actual}}}{X_{\text{actual}}} \]

References


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