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# Infrared spectroscopic diagnostics for initial mass function

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**Abstract.** The diagnostic values of various atomic / nebular infrared spectral lines of relatively abundant elements (in different ionization states) in Galactic star forming regions, have been studied quantitatively. The code CLOUDY (Ferland 1996) has been used to model spherically symmetric interstellar clouds with embedded ZAMS stars / young star clusters. In particular, the question of deciphering the upper mass limit of initial mass function has been addressed, in the light of the capabilities of the two spectrometers onboard Infrared Space Observatory (ISO-SWS covering 2.5 – 45 μm; & ISO-LWS covering 45 – 200 μm).

## 1. Introduction

The sensitivity of the emerging infrared spectra (continuum & lines) from a spherically symmetric gas and dust cloud (as shown in fig. 1) with an embedded ZAMS star or young star clusters, to the input stellar spectral shape (for a fixed total luminosity), has been studied

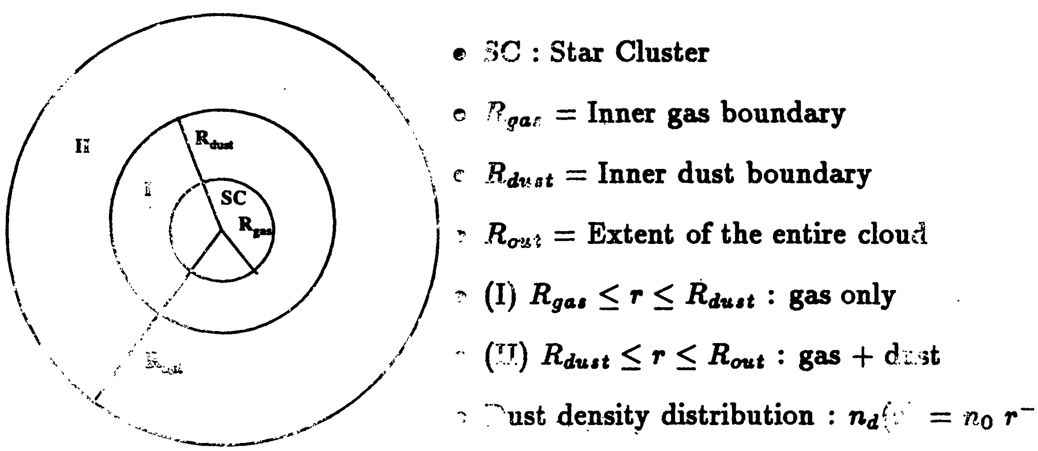


Figure 1. Schematic diagram of the spherically symmetric cloud

in detail, using the code CLOUDY, developed by G. Ferland (1996). Three different spectral shapes corresponding to ZAMS O4, O7 and B0.5 type stars, have been considered. The above study has been extended to (i) different cloud masses; and (ii) radial density distributions (n(r) ~ $r^0$, $r^{-1}$ & $r^{-2}$). We have explored models having masses ranging from 2.5 $M_\odot$ to 6.5 × $10^3$ $M_\odot$ and radial dust optical depth at 100 μm having values as 0.0067, 0.02, 0.06. The diagnostic values of individual lines (27 in all; from C, N, O, Ne, Mg, Si, S & Ar), in various ionization stages have been quantified in term of their absolute and relative strengths as well as reliable detectability above the continuum as determined from the ISO-SWS and ISO-LWS instrument details. The continuum mainly originates from the dust component.

The spectral lines useful in distinguishing the exciting stellar spectra have been highlighted.

## 2. Detailed radiation transfer through gas

The code CLOUDY considers the physical processes like photo-ionization, collisional excitation, recombination, deexcitation, grain heating-cooling, grain photo-ionization, gas-dust coupling etc. in full detail. Since CLOUDY predicts the unreddened luminosities of the emitted lines, we have incorporated the effect of dust reddening. The entire cloud is considered to be consisting of two spherical shells, the inner one made of gas alone and the outer one with gas and dust. The boundary between the two shells is determined by the grain sublimation point i.e., for the given radiation field, the point up to which the dust grains can exist. CLOUDY is run twice, the first time (RUN1) for the inner pure gas shell with the central energy source assumed to be a black body of given temperature and total luminosity. The continuum, emerging from RUN1 is used as input to the second run (RUN2) for the outer shell. The emerging line spectrum from RUN1 is transported to an outside observer, through the second (outer) shell by considering the extinction due to the entire dust column present there. For every spectral line considered, its emissivities from individual radial zones of RUN2 are also transported through the corresponding relevant dust column densities within the outer (second) shell. The line luminosity contributions from RUN1 and RUN2 are finally added to predict the total observable luminosity.

In the models explored, the relative abundance of different elements, has been assumed to be the same as that in the solar neighbourhood. The dust is composed of Silicate and Graphite and we have assumed the gas to dust ratio by mass to be 100 : 1. Other parameters, which remain unaltered for all the models include, total luminosity of the star cluster = 1.29 × $10^6$ $L_\odot$, $R_{gas}$ = 1.05 × $10^{14}$ cm, $R_{out}$ = 6.17 × $10^{18}$ cm, $R_{dust}$ = 7.1 × $10^{15}$ cm (determined by the sublimation temperature of dust).

The instrumental resolutions have been adopted to be similar to those of the instruments like the LWS and the SWS onboard the ISO satellite and a spectral line is considered to be detectable if the power from line photons is at least 10% of the same from the neighbouring continuum in a single resolution element (Swinyard et al., 1996, Valentijn et al., 1996).

## 3. Results

Lines with best diagnostic values and satisfying the detectability criteria are presented here. An example of the diagnostic value of these lines is shown in Fig. 2.

$$X \equiv log_{10}\,(L_{line}/L_{continuum});\ Y \equiv log_{10}\,(L_{line});\ \Delta Y \equiv Y(O4) - Y(O7) \text{ or } \Delta Y = Y(O7) - Y(B0.5)$$

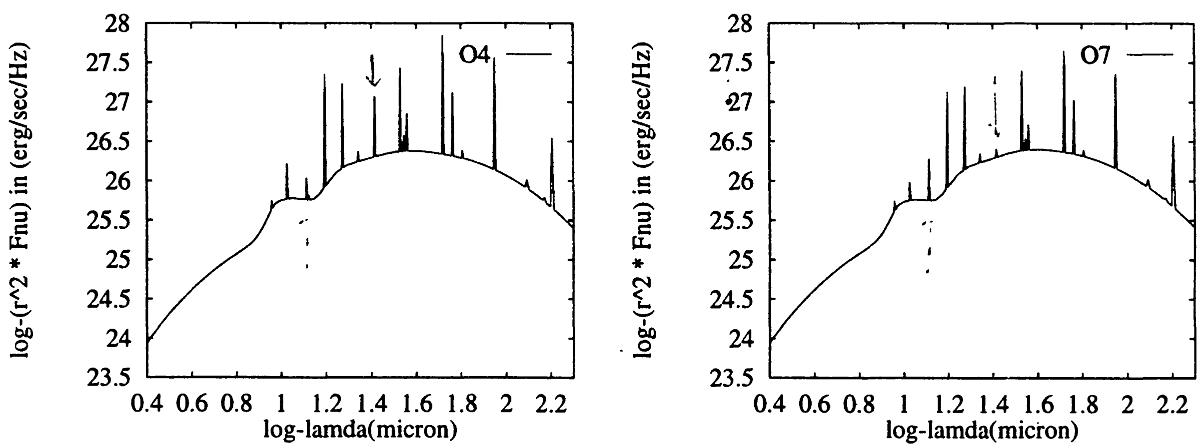


**Figure 2.** Emission (continuum & lines) from model clouds, having $\tau_{100\mu m} = 0.0067$, uniform density distribution and upper cutoff of the IMF at O4 and O7 like stars. The lines at 12.8 μm and 25.9 μm, as marked on the figures are found to be the most sensitive and hence happen to be diagnostically useful.

**Table 1.** Comparison of line emissions for O4 & O7 type exciting spectra (Best diagnostics).

| Dust dist. | Lines (μm) | $\tau_{100\mu m} = 0.0067$ | | | $\tau_{100\mu m} = 0.02$ | | | $\tau_{100\mu m} = 0.06$ | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $X_{O4}$ | $X_{O7}$ | ΔY | $X_{O4}$ | $X_{O7}$ | ΔY | $X_{O4}$ | $X_{O7}$ | ΔY |
| $r^0$ | 12.8 NeII | −0.05 | 0.37 | −0.41 | −0.54 | −0.13 | −0.40 | | | |
| | 25.9 OIV | 0.68 | −0.63 | 1.31 | 0.55 | −0.71 | 1.26 | | | |
| | 36.0 NeIII | | | | | | | −0.21 | −0.44 | 0.20 |
| | 145.6 OI | | | | | | | −0.78 | −0.75 | −0.12 |
| $r^{-1}$ | 51.8 OIII | | | | −0.50 | −0.76 | 0.16 | | | |
| | 88.4 OIII | 0.37 | −0.03 | 0.39 | | | | | | |
| $r^{-2}$ | 51.8 OIII | 0.19 | −0.07 | 0.26 | | | | | | |

**Table 2.** Comparison of line emissions for O7 and B0.5 type exciting spectra (Best Diagnostics).

| Dust dist. | Lines (μm) | $\tau_{100\mu m} = 0.0067$ | | | $\tau_{100\mu m} = 0.02$ | | | $\tau_{100\mu m} = 0.06$ | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $X_{O7}$ | $X_{B0.5}$ | $\Delta Y$ | $X_{O7}$ | $X_{B0.5}$ | $\Delta Y$ | $X_{O7}$ | $X_{B0.5}$ | $\Delta Y$ |
| $r^0$ | 12.8 NeII | 0.37 | 0.73 | −0.28 | −0.13 | −0.30 | −0.40 | −0.75 | −0.24 | −0.51 |
| | 15.6NeIII | 1.20 | 0.00 | 1.27 | 0.92 | −0.16 | 1.10 | 0.52 | −0.45 | 0.95 |
| | 121.8 NI | −0.64 | −0.41 | −0.27 | | | | | | |
| $r^{-1}$ | 12.8 NeII | −0.84 | −0.31 | −0.54 | | | | | | |
| | 15.6 NeIII | 0.62 | −0.13 | 0.73 | 0.12 | −0.38 | 0.51 | −0.30 | −0.85 | 0.57 |
| | 88.4 OIII | −0.03 | −0.96 | 0.92 | | | | −0.34 | −0.61 | 0.28 |
| $r^{-2}$ | 12.8 NeII | −0.63 | 0.14 | −0.78 | | | | | | |
| | 145.6 OI | −0.80 | −0.59 | −0.21 | | | | | | |

## References


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