Exercises VIII
Dense clouds, star formation & extragalactic ISM

ISM course 2009
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Dense clouds and star forming regions

1. Cold molecular clouds commonly exhibit absorption features in the infrared arising from ices. Measurements of a number of these features are summarized in the table below for the star forming region NGC 7538 IRS 9.

Species	λ (μm)	τ	$\Delta\nu$ (cm^{-1})
H_2O	3.0	3.1	440
CO	4.67	2.6	4.8
CO_2	15.2	0.8	21
CH_3OH	3.54	0.07	29
CH_4	7.6	0.09	11
NH	9.0	0.2	68

   (a) Determine the column densities of ice components observed towards NGC 7538 IRS 9.

   (b) The observed 10 μm silicate optical depth is τ=2.2. Typical interstellar silicate properties can be found in section 5.5.1 in the book. Use this to translate the column densities into abundances for the ices.

   (c) The column density of *gas phase* CO towards this source is 1.4×10^{19} cm^{-2}. What is the depletion factor of CO in this case?

2. (a) Explain why a dense molecular cloud cannot form stars of $\sim$1 $M_\odot$ unless heavy elements are present.

   (b) What are the differences in physical conditions between a quiescent molecular cloud and a star forming region?

   (c) Why do star forming regions contain more complex molecular species than quiescent molecular clouds?

Extragalactic ISM

3. Figure 1 shows the spectral energy distributions of Messier 31 (the Andromeda galaxy) and Messier 82.

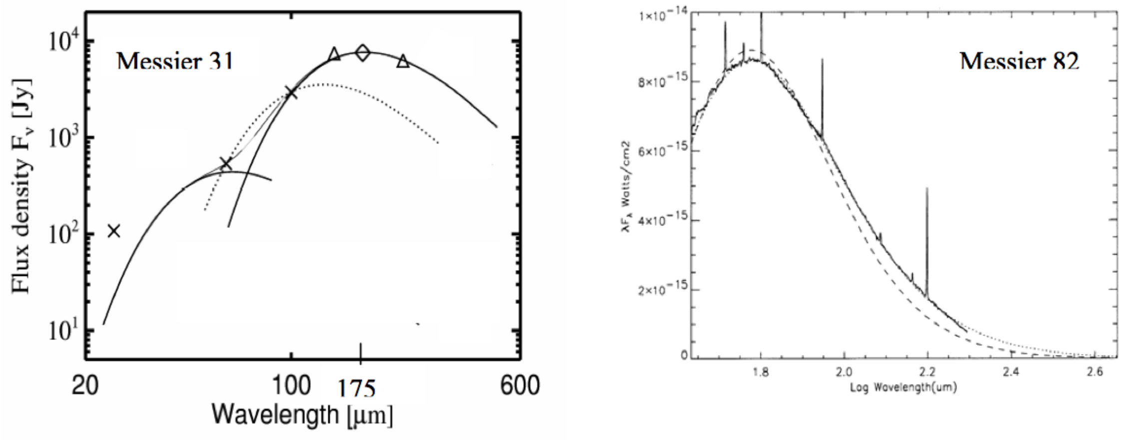

Figure 1: Spectral energy distributions of two galaxies: M31 and M82.

(a) Use the infrared spectra from figure 1 to determine the dust temperature in both galaxies.

(b) What can be the reason that the dust temperature in M82 is different from that in M31?

(c) Assuming that the absorption and emission efficiencies are 100% and 0.1% respectively, calculate the integrated mean intensity of the radiation field.

(d) Assuming that the mean wavelength of the radiation field is 10 nm, what is the UV flux (in photons s^{-1} cm^{-2})?

4. The spectra in figures 2 and 3 provide information about the gas content of M31 and M82, respectively.

(a) From the figures on the next page, determine the integrated line strengths of CO (1–0), CO (2–1) and CO (3–2). (If you cannot fit a Gaussian by eye, approximate the integrated line strength by multiplying the amplitude by the line width at the base.)

(b) In what respect are the lines of M82 different from those of M31?

(c) Calculate the line ratios: CO (2–1)/(1–0), CO (3–2)/(2–1) and CO (3–2)/(1–0). Use these ratios and the information in the table below to calculate an average gas temperature in both galaxies.

(d) Do the same as in (a) and (c) for the ^{13}CO lines of M82. Also determine the ^{12}CO/^{13}CO line ratios. What do the results for ^{13}CO tell you about the CO emission?

data for ^{12}CO			data for ^{13}CO		
stat. weights	transition	frequency	stat. weights	transition	frequency
$g_1 =$ 3	1–0	115 GHz	$g_1 =$ 3	1–0	110 GHz
$g_2 =$ 5	2–1	230 GHz	$g_2 =$ 5	2–1	220 GHz
$g_3 =$ 7	3–2	345 GHz	$g_3 =$ 7	3–2	330 GHz

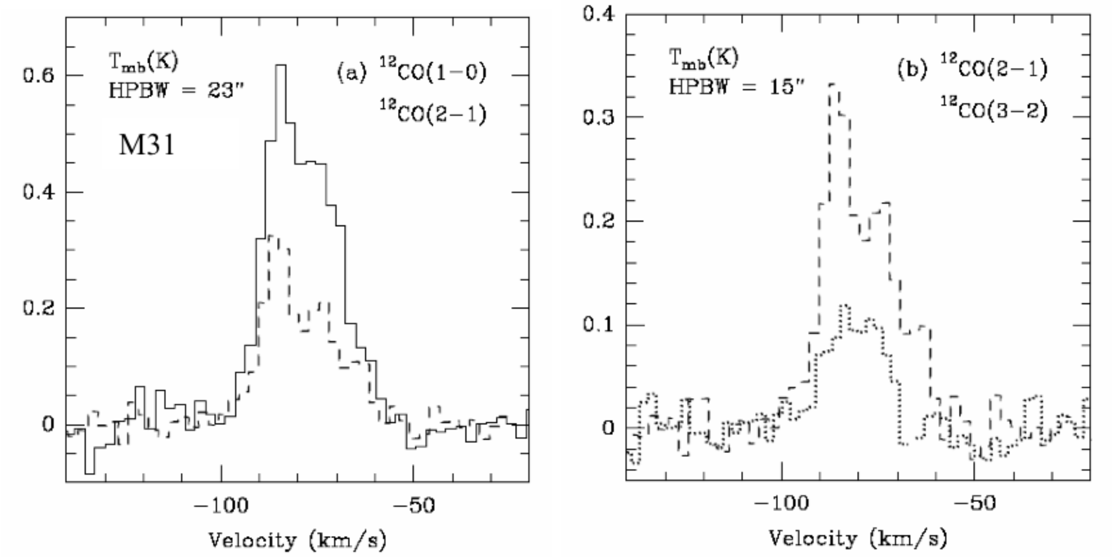

Figure 2: CO emission lines in M31.

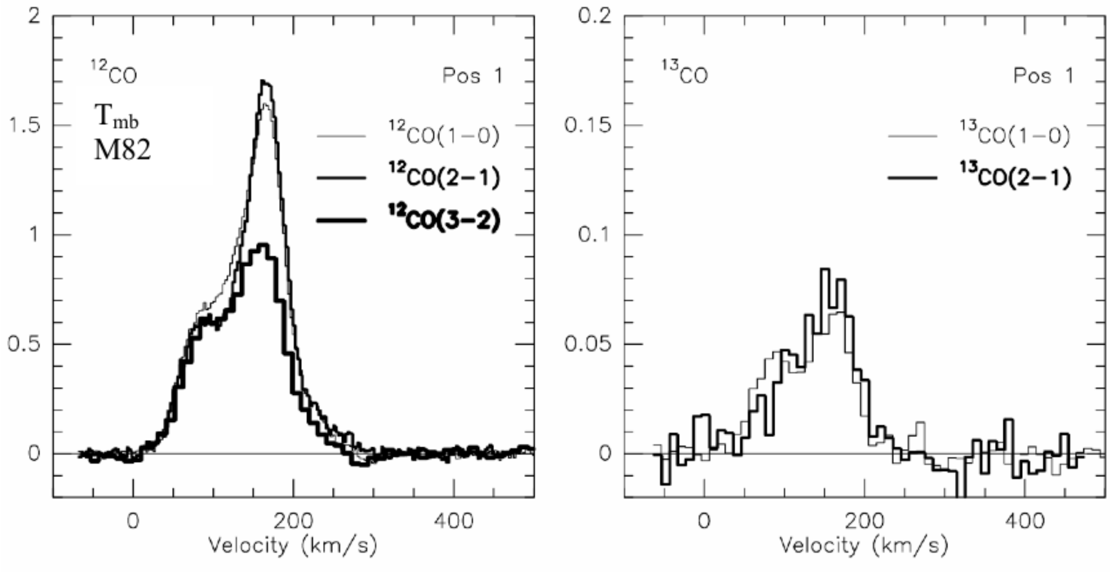

Figure 3: CO emission lines in M82.