ISM COURSE (2020)
ASSIGNMENT 3
Deadline for submission: 11 May 2020

1. Free-Free emission from the HII region: Radio continuum emission from a HII region at a distance 5.7 kpc from us is given in the table below. Observed size (diameter) of this HII region is 0.6” and radio recombination lines suggest a gas kinetic temperature of 7000 K. Find the emission measure and electron density of this HII region. If the star is a typical O star what can you say about the measured size.

Table 9. Flux densities of G28.20-0.04 N

ν (GHz)	Instr.	Synth. Beam ($'' \times ''$)	S_ν (mJy)	Ref.
5.0	VLA	2.0×1.6	150±15	1
6.7	ATCA	∼1.9	326[a]	2
8.3	VLA	0.9×0.8	297±45	3
8.3	VLA	4.9×2.7	300±30	4
14.7	VLA	1.5×1.4	494±50	9
14.7	VLA	0.6×0.5	543±81	3
22.4	VLA	0.3×0.2	980[a,b]	5
22.4	VLA	0.1×0.1	630±63	9
43.0	VLA	1.9×1.4	710±70	9
43.0	VLA	0.17×0.13	645±65	6
231.9	SMA	1	720[a,c]	7
231.9	SMA	0.6×0.2	890±30[c]	8

[a]Uncertainties are not provided in the referenced papers.

[b]The 1.3 cm flux density given by Sollins et al. (2005) seems to be anomously high relative to other measurements (see Fig. 12).

[c]Both 231.9 GHz flux densities are from the same SMA observations. Any difference in flux density represents a difference in the data reduction.

References. — (1) Purcell et al. 2008; (2) Walsh et al. 1998 ; (3) Kurtz et al. 1994; (4) Sewiło et al. 2004a; (5) Sollins et al. 2005; (6) Sewiło et al. 2008; (7) Keto et al. 2008; (8) Qin et al. 2008; (9) this paper

2. N(HI) and metallicity estimate: In the assignment 1, you have measured the column densities of different ions from our ISM towards the blazer 1553+113. The file "LAB_1ES1553+113_21cm.txt" in the assignment page has the 21-cm spectrum measured close to this line of sight. The columns are velocity with respect to our rest frame and brightness temperature (K). Estimate the HI column density from this spectrum. Compare this to the N(HI) you have obtained towards the quasar by fitting the Damped Lyman-α systems. Using the column density of HI obtained using the Voigt profile and column densities of Si II, SII, Fe II and Ni II (you got with single component curve of growth) obtain the metallicity of Si,S, Fe and Ni assuming that the singly ionised state is the dominant ionisation state of these species. What do you say about the relative abundance of these elements?

3. Ionization and fine-structure excitation of C : The column densities (in log units, cgs) of C I, C II and CII* measured towards the star HD 185418 are 15.60, 17.80 and 14.90 respective. Using the column densities of CI and CII estimate the electron density-temperature constraints assuming ionisation equilibrium. Use the ionisation and recombination rates given in my lecture slide (page 32 of ISM_diffusegas.pdf). Independent temperature density constraints can be obtained using CII and C II* column densities (assuming collision by electron and UV pumping and spontaneous emission). For this you take the required information from page 36 of ISM_diffusegas.pdf. Do you have a consistent n_e and T where you can have solution for ionisation and fine-structure excitation of Carbon atoms along this sightline.

4. Simple estimates using H_2 column densities: Column density of H_2 in different rotational levels (J=0,…5) are [in log units] given below. The log N(HI) = 21.11. Estimate (i) H_2 molecular fraction in this cloud, (ii) temperature of the gas using T_{01}, (iii) Plot the excitation diagram and see wether the rotational levels are consistent with single excitation temperature and (iv) estimate $\beta(0)$ using the discussions in page 27 of the lecture side (or Jura 1975, ApJ, 197, 581)

$H_2(J = 0)$	20.30 ± 0.10
$H_2(J = 1)$	20.50 ± 0.10
$H_2(J = 2)$	18.34 ± 0.10
$H_2(J = 3)$	16.20 ± 0.15
$H_2(J = 4)$	15.00 ± 0.20
$H_2(J = 5)$	14.30 ± 0.80

5. Isothermal shock: A strong shock moves with velocity 100 km s^{-1} into atomic hydrogen of density 10^2 cm^{-3} and temperature 10^2 K. The shocked gas cools at a rate 10^{-32} n^2 erg s^{-1} cm^{-3}, where n is the density of the post-shock gas. Estimate the time for the shocked gas to cool to the pre-shock gas temperature and the distance the gas has travelled relative to the shock in doing so. Will you consider this case as an isothermal shock?

6. Influence of the stellar wind: A star emits a stellar wind with a mass outflow rate of 10^{-6} $M_{\odot}$ yr^{-1} at 2000 km s^{-1} into interstellar gas of density 100 cm^{-3} and temperature 10^4 K. Assuming that the outer shock is isothermal estimate the density, velocity and mass of the swept-up interstellar gas after 10^4 yrs.

7. Supernova ejection: Consider a supernova explosion of energy 10^{51} ergs in the interstellar medium of density 10 cm^{-3}. Estimate the time (t_0) and radius (R_0) when the remnant dynamics will transition from energy driven to the momentum driven phase. What is the amount of interstellar matter swept up at this time. As we discussed in the class you can take a typical velocity at the transition point to be 250 km s^{-1}. How long the snowplough phase will continue if the sound speed of the external medium is 10 km s^{-1}. What will be the size of the SNe remnant at that time?

8. Dust optical depth: Let us consider a uniform interstellar medium having dust density 1 cm^{-3}. Let us also assume the dust particles to be spheres of radius 10^{-5} cm and have Q_{ext} = 0.3 at the wavelength of 5500Å. Find the extinction in magnitudes at the same wavelength for a star at a distance 1 kpc from the earth.