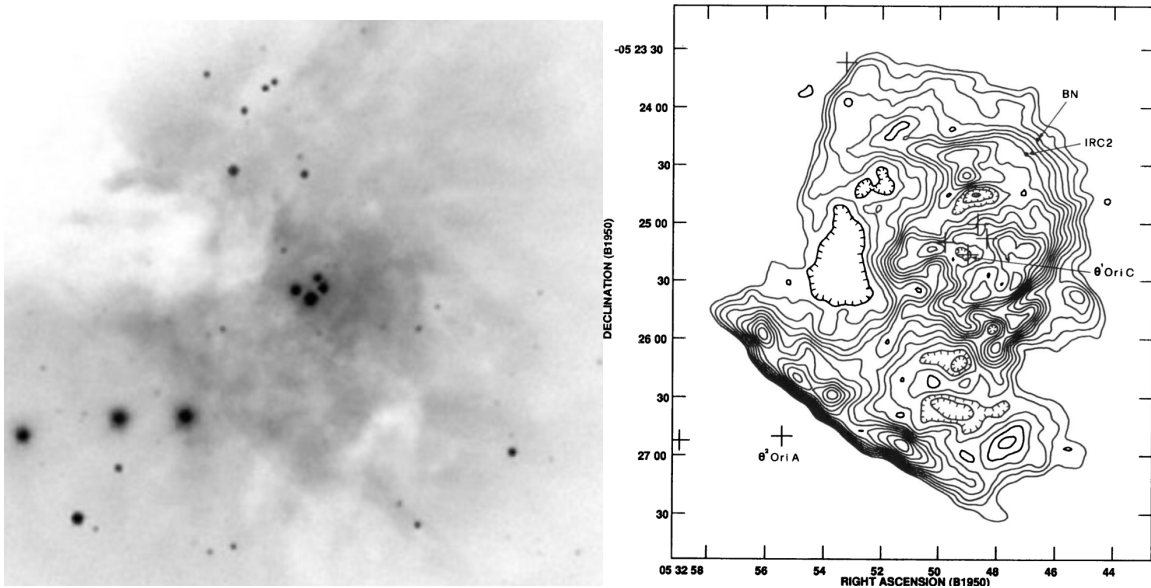


# DARA Unit 1

## Workshop 2

The figures below show an optical (left) and radio (right) image of the Orion nebula – our closest H II region at a distance of 475 pc.



1. The Strömgen radius,  $R_s$ , of an H II region with a constant electron density,  $n_e$ , is given by

$$N_{Ly} = \frac{4}{3} \pi \alpha_H n_e^2 R_s^3$$

where  $N_{Ly}$  is the number of ionizing photons emitted by the star per unit time,  $\alpha_H$  is the recombination coefficient for hydrogen ( $3 \times 10^{-19} \text{ m}^3 \text{ s}^{-1}$ ). The main ionizing star has a total luminosity of  $2 \times 10^5 L_\odot$  and an effective temperature of around 40 000 K. Assume that about a third of its luminosity is emitted shortward of 91.2 nm (i.e. energies higher than 13.6 eV) and estimate the ionizing photon flux by assuming all ionizing photons are at 91.2 nm. Then using the radio map above estimate the radius of the nebula and therefore estimate the average number density in the nebula. Note that the y axis is in degrees, arcminutes, arcseconds such that the tickmarks are separated by 30 arcseconds. Ignore the x axis.

2. The optical depth for free-free radiation is given by

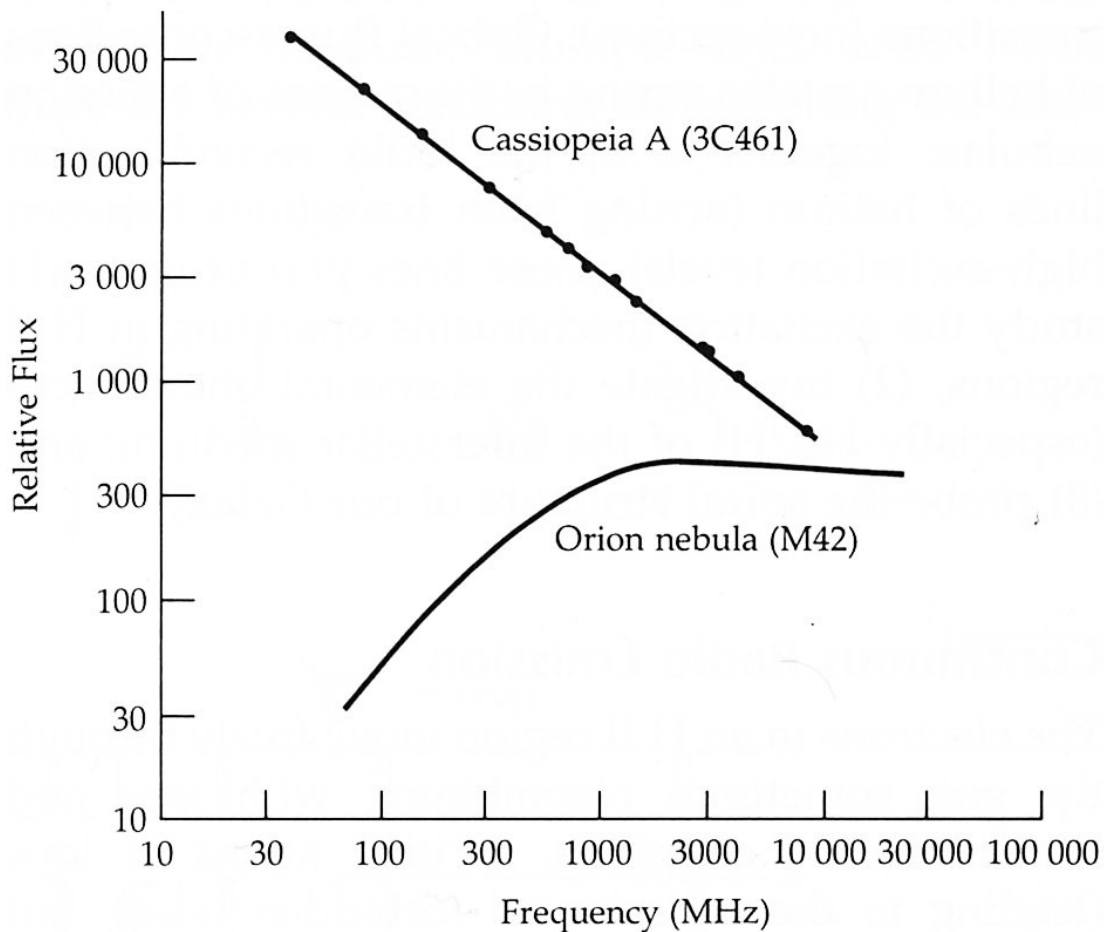
$$\tau_\nu(ff) = 8.3 \times 10^{-2} T^{-1.35} \nu^{-2.1} \int n_e^2 ds$$

where  $T$  is the temperature of the gas in K,  $\nu$  is in GHz,  $n_e$  is in  $\text{cm}^{-3}$ , and  $s$  is in pc.

Assuming a gas temperature of  $10^4$  K and a uniform number density, estimate the radio flux density of the nebula at 10 GHz. The flux density is related to the intensity in this case by

$$f_\nu = I_\nu \Omega$$

where  $\Omega = A/d^2$  is the solid angle subtended by the source with area  $A$  on the sky. Radio astronomers use the unit of flux density of the Jansky or Jy, which is  $10^{-26} \text{ Wm}^{-2}\text{Hz}^{-1}$ . Compare your estimate with the radio spectrum of the Orion nebula below where the y axis is in Jy.



3. The peak flux density measured at 330 MHz with a Gaussian beam of full-width-half-maximum (FWHM)  $\theta_B=70$  arcseconds is 3.3 Jy. Given that the solid angle of a Gaussian beam is

$$\Omega_B = \frac{\pi}{4 \ln 2} \theta_B^2$$

estimate the temperature of the gas in the nebula.