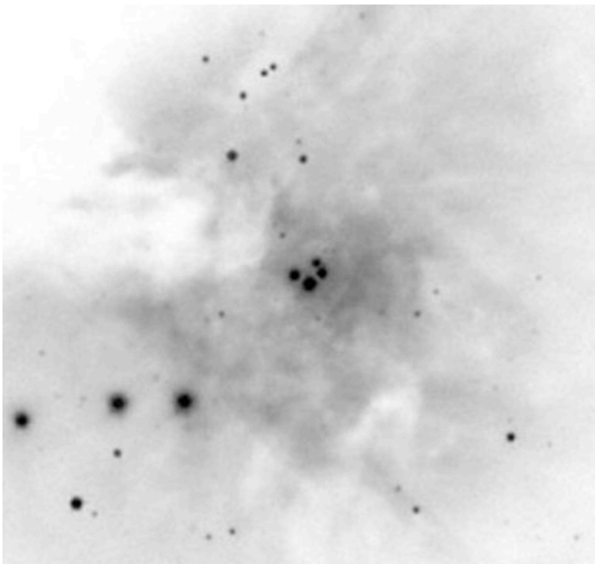
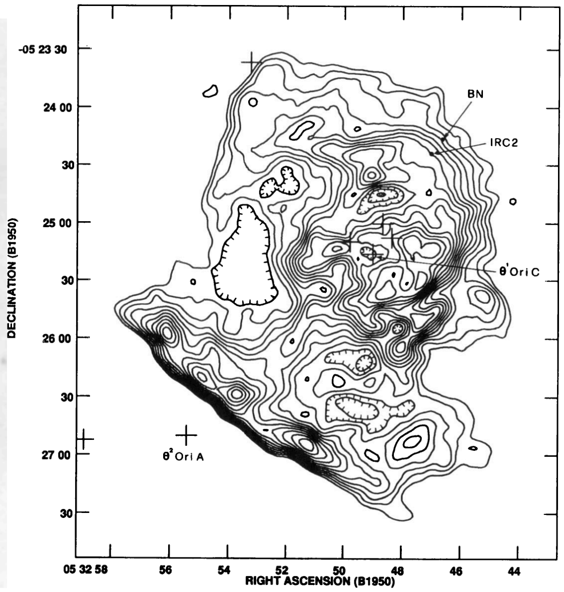
# Workshop 6

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.






In equilibrium the number of photo-ionizations by Lyman continuum photons is balanced by recombinations between protons and free electrons. This can be written as:

$$N_{Ly} = \int \alpha_H n_p n_e dV$$

where $N_{Ly}$ is the number of ionizing photons emitted by the star per unit time, $\alpha_H$ is the recombination coefficient for hydrogen ($3\text{x}10^{-19}$ $m^3s^{-1}$) and $n$ is the number density (particles per unit volume). If we assume a constant density, fully ionized ($n_p$=$n_e$), spherical nebula then this becomes

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

The main ionizing star has a total luminosity of 2 x $10^5$ $L_\odot$ 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 (the y axis is in degrees, arcminutes, arcseconds) estimate the radius of the nebula and therefore estimate the average number density in the nebula.

The optical depth for free-free radiation is given by

$$\tau_\nu(ff) = 8.3\times10^{-2} T^{-1.35} \nu^{-2.1} \int n_e^2 ds$$

where $T$ is the temperature of the gas in K, $\nu$ is in GHz, $n_e$ is in 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. Radio astronomers use the unit of flux density of the Jansky or Jy, which is $10^{-26}$ Wm$^{-2}$Hz$^{-1}$. Compare your estimate with the radio spectrum of the Orion nebula in the notes.

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.