

AST 554 - Homework #3

Due – April 28, 2009

Question 1

A distant ($D = 110$ Mpc) ultraluminous infrared galaxy is observed to have a CO(1→0) line profile with a full width at half the maximum intensity (FWHM) velocity width of $\Delta v_{\text{FWHM}} = 300$ km s⁻¹ and a molecular gas extent (diameter) of $l_{\text{CO}} = 1$ kpc. The molecular gas mass is calculated to be $5 \times 10^9 M_{\odot}$. For the present problem, we will ignore cosmological effects.

(a)(4 points) Calculate the number density, ρ_{H_2} , of H₂ molecules in units of molecules per cm³. For simplicity, assume a spherical distribution of gas.

(b)(3 points) Calculate the column density ($\approx \rho_{\text{H}_2} l_{\text{CO}}/2$) of H₂ molecules towards the nucleus in units of cm⁻². How does it compare with $\sigma_T^{-1} = 1.5 \times 10^{24}$ cm⁻², i.e., the inverse of Thompson scattering cross section? In other words, is the column density towards the nucleus Compton thick?

(c)(2 points) The measured *IRAS* flux densities for the galaxy are 0.25, 1.42, 17.04 and 24.38 Jy at 12, 25, 60 and 100 μm , respectively. Calculate the infrared luminosity, $L_{\text{IR}}(8 - 1000\mu\text{m})$, of the galaxy in units of L_{\odot} .

(d)(2 points) High-resolution far-infrared observations of this galaxy are not available. However, both the available 10 μm and 1.5 GHz images show the galaxy to be round in projection, with a diameter of $l_{1.5\text{GHz}} = l_{10\mu\text{m}} = 1$ kpc. Using these measurements as a proxy for the extent of the far-infrared emission, calculate the infrared surface brightness of the galaxy in units of L_{\odot} kpc⁻². How does it compare with the infrared surface brightness of the Orion star-forming region ($\sim 2 \times 10^{12} L_{\odot}$ kpc⁻²)? I.e., based on this comparison, could the infrared emission be produced via dust heated by star formation alone?

(e)(4 points) Using equation for dust temperature

$$\left(\frac{T_{\text{dust}}}{\text{K}}\right) = - \left(\frac{82}{\ln(0.3f_{60\mu\text{m}}/f_{100\mu\text{m}})} - 0.5 \right),$$

where $f_{60\mu\text{m}}$ and $f_{100\mu\text{m}}$ are the 60 and 100 μm flux densities and T_{dust} is in units of Kelvin, calculate the thermal dust temperature of the galaxy. Treating the dust-emitting region as a perfect blackbody, calculate the size (in units of pc) of the dust-emitting region, and its corresponding infrared surface brightness (in units of L_{\odot} kpc⁻²: note that this sets an upper limit of what the infrared surface brightness can be). How does this size and the infrared surface brightness compare with l_{CO} and the infrared surface brightness calculated in 1(d) above? I.e., is the infrared surface brightness estimated in 1(d) physically plausible?

Question 2

In the April 9th, 2009 colloquium, Heckman gave a presentation on the evolution of AGN fueling and star formation in a large sample of galaxies observed with the Sloan Telescope. His talk was based to a large degree on Heckman et al. (2004, ApJ 613, 109).

(a)(2.5 points) How are the black hole mass, luminosity and accretion rate determined in Heckman et al. (2004)?

(b)(2.5 points) How is the mass of each galaxy and the star formation rate determined in Heckman et al. (2004)?