(Astro)Physics 343 – Spring 2010

Lab # 5: Measuring the Molecular Gas Mass and Dynamical Mass of a ULIRG

"Observations": week of 5 April 2010

Reports due: 19 April 2010

Purpose: For a galaxy outside the Milky Way, we can use observations of the relatively rare CO molecule (typically 10^{-4} times as abundant as H_2) to estimate not only the total mass of the galaxy's molecular clouds, but also the total *gravitational* (a.k.a. "dynamical") mass that includes gas, stars, and dark matter. To achieve the latter goal, it is necessary to obtain a spatially resolved rotation curve $v(R)$, where "spatially resolved" means that one has information on the gas motions in at least two independent pixels. For galaxies that are relatively compact, a spatially resolved rotation curve can only be obtained by mapping with an interferometer. Hence, for this lab, you will be measuring the molecular gas and dynamical masses of a galaxy outside the way using pre–calibrated data from the IRAM Plateau de Bure Interferometer (PdBI) in the French Alps. The particular target of these observations is an ultraluminous infrared galaxy (ULIRG), whose substantial dust luminosity ($> 10^{12}\,L_\odot$, i.e., over 100 times that of the Milky Way) is due to the burst of star formation triggered by the merger of two gas–rich progenitor galaxies.

Before the lab period: Carefully read through these instructions and §1–7 (excluding §4.2) of the "Difmap cookbook," which will be a reference for the software package you will be using to produce maps from the calibrated uv (i.e., Fourier plane) data.

Procedure:

During your lab period, you and your teammates should familiarize yourself with the properties of your dataset and at least begin the process of generating the figures that you will include in your lab writeup. Further use of Difmap can proceed during the "on call" office hours next week, or via remote login to the computers of the Department of Physics & Astronomy. Each team can use a shared set of figures, but writeup of the text must be done independently.

Analysis (Part I):

Using the raw `CODATA.UVF` file you will find in your team's account, go through the following series of steps:

1. Load in the data file with the `observe` command, and create a pseudo–continuum dataset that includes the first ten frequency channels with the command `select RR,1,10`.

2. Using natural weighting (`uvweight 0,-2`), create a map that has 256×256 pixels, each of size $0.25'' \times 0.25''$ (note that Difmap by default will only show the inner quarter of this map). Make a note of (a) the estimated beam size, (b) the noise in the map (for which you will need to use the command `print rms(map)`, rather than the "estimated noise"), and (c) the location and flux density of the map peak (for which you can use the commands `print peak(x)`, `print peak(y)`, and `print peak(flux,max)`).

3. Repeat the above exercise for a pseudo–continuum dataset that covers the *last* ten frequency channels, and for a pseudo–continuum dataset that covers the *middle* ten frequency channels. How do the three beams compare to each other, and how would you account for any differences? How do the three map peaks compare to each other, and how would you account for any differences?

4. For the pseudo–continuum dataset near the center of the observed band, use the `clean` command to deconvolve the dirty map. When you have cleaned deeply enough (you may need to use more than one clean box, defined interactively using the left mouse button after invoking the `mapplot` command), the source should have effectively disappeared from the residual map, and the positive and negative peaks in the residual map should be roughly comparable. Is the rms in the residual map what you would expect given the rms levels you measured at the frequency extremes? What is the total cleaned flux density that Difmap reports (in units of Jy), and what does this actually correspond to in flux units of $\mathrm{Jy\,km\,s^{-1}}$? (Hint: recall how you integrated brightness temperature in K to line intensity in $\mathrm{K\,km\,s^{-1}}$ in Lab # 3.)

5. Produce and include with your lab writeup plots that show (a) the dirty beam, and (b) the clean map. Has the source emission in these channels been spatially resolved?

6. Produce a plot of the *uv* sampling of the dataset. From looking at the central gap in the *uv* plane, what limits can you set on the diameter of the antennas in the PdBI? What can you say about the array's maximum projected baseline?

Analysis (Part II):

Devise strategies for using Difmap to measure two masses for your target galaxy:

1. The total molecular gas mass, for which you can use the "standard" formula

$$\frac{M_{\mathrm{H_2}}}{M_\odot} = 1.180 \times 10^4 \left(\frac{D}{\mathrm{Mpc}}\right)^2 \left(\frac{X}{3\times10^{20}}\right) \left(\frac{F_{\mathrm{CO}}}{\mathrm{Jy\,km\,s^{-1}}}\right) \tag{1}$$

   that assumes a conversion factor

$$X \equiv N_{\mathrm{H_2}}/I_{\mathrm{CO}} = 3\times10^{20}\,\mathrm{cm^{-2}}\,(\mathrm{K\,km\,s^{-1}})^{-1} \tag{2}$$

   like that measured in the Milky Way. For reference, the redshift of your target galaxy is $z = 0.09724$.

2. The total dynamical mass, for which you can use the formula for $M(< R)$ stated in lecture. For this and the molecular gas mass, you should explain your method, execute it, and include any salient plots in your writeup of it.

3. In some ULIRGs, we find that $M_{\mathrm{H_2}} > M_{\mathrm{dyn}}$ using these two approaches. Is this a problem? If so, can you think of any ways to explain the apparent paradox?