Analyzing the CO(2-1) line of IRAS 13120-5453

We did some observations on the CO(2-1) emmision line of the ULIRG IRAS 13120-5453, these observations were taken at the APEX radio telescope in Chile. We calculated the luminosity of the galaxy to be $9.9 \pm 0.7 \times 10^9[\mathrm{Kpc}^2\mathrm{km/s}]$ *and further, assuming a COtoH*$_2$ *conversion factor* $\alpha_{\mathrm{CO}} = 1.7 \pm 0.4\mathrm{M}_{\odot}$*, found the mass of the interstellar dust to be* $4.0 \pm 0.4 \times 10^{10}\mathrm{M}_{\odot}$*.*

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1 Introduction

In this report we will analyze the CO(2-1) emission line of an ultra luminous infrared galaxy (ULIRG), IRAS 13120-5453. The observations were taken from the nFLASH230 receiver in the APEX telescope on Aug 20, 2013. The APEX telescope is a radio telescope which operates at millimeter(mm) and sub-mm wavelengths, and is located high on the Chajnantor plateau in Chile's Atacama region (APEX). The incoming signals are very weak at these frequencies to start off with, and after reaching our atmosphere, they are heavily absorbed by the vapor in our atmosphere. Therefore, this location is highly ideal for radio astronomy, being at an elevation of 5.1 km high and in one of the driest regions on Earth. The main dish of the APEX is 12 meters in diameter.

Figure 1: The APEX telscope. [4]

When looking for forming-galaxies, what we as astronomers want to find is H_2, Hydrogen in its molecular form, since this is what gives birth to stars. Unfortunately for us, H_2 is extremely difficult to detect, since its lowest energy transition (2-0) can only take place at around $150K$ and most of the gas is at $10 - 20K$, so we must look for elements or molecules that tend to also be present wherever H_2 is. As a side note, when we say (2-1) transition, what we mean is the molecule drops from its 2nd energy state to it's ground state, and this emits radiation which we are receiving, this is how we detect specific elements and molecules in Astronomy. Back to H_2 and it's elusivity, one of the molecules that tend to be present around H_2 is carbon monoxide (CO). We looked specifically at the (2-1) line since it is one of the lower energy levels and is easier to excite the particles, and therefore more common to find.

2 Method

When we first received the data, the signal to noise (S/N) was far too low (see figure data1), so we had to treat it, and we did so with GILDAS, a software created specifically for sub-mm astronomy. We threw away or "binned" some of the data until we deemed the S/N to be acceptable to work with, generally anything over 5 sigma is accepted in the astronomy community. We then exported our data, the data being Doppler velocities and the corresponding antennae temperature corrected for atmospheric losses T'_a. To explain the antenna temperature on a fundamental level is a tough task, but to simplify, it is radio astronomy's equivalent to optical astronomy's "observed intensity," or to simplify even more, it is the amount of light the telescope is actually receiving from the source of interest.

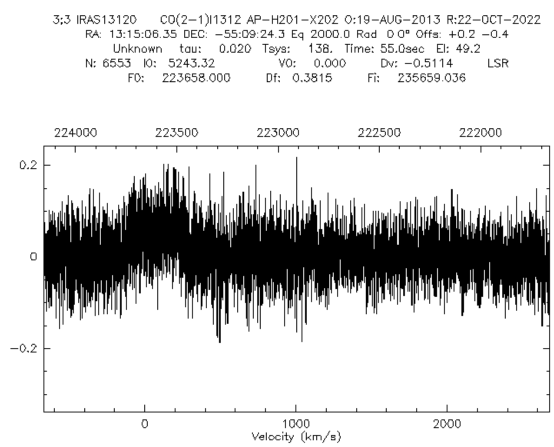

Figure 2: How our data looked in GILDAS before treatment.

Once we had our newly treated data, we converted our antenna temperature to flux density so that it would be easier to work with down the line. To convert the units from K to Jy we used the K/Jy calibration factor $\Gamma^{-}1 = 37.5 \pm 2.5[Jy/K]$ from 2019, and that was given in LN6. We then fit a Gaussian curve to our data in order to visualize the emission line better, which thankfully, wasn't hard at all thanks to GILDAS, which can spit out the parameters necessary for finding the Gaussian curve. We then took those parameters and the data, and fed them into a python script in order to get our curve.

We wished to calculate the mass of the H2+He gas in IRAS 13120-5453 (in solar masses), which we could do with this formula:

$$M_{\mathrm{H_2+He}}\,[\mathrm{M_\odot}] = \alpha_{\mathrm{CO}} L'_{\mathrm{CO}}$$

In order to use this formula we needed the luminosity of the CO(2-1) line, L'_{CO}. The other factor is α_{CO}, which is the conversion factor from CO to $\mathrm{H_2}$ (which also takes into account Helium and other heavy elements), hence why we solved for $\mathrm{H_2}$ + He. We used $\alpha_{\mathrm{CO}} = 1.7 \pm 0.4\mathrm{M_\odot}(\mathrm{Kpc^2 km/s})^{-1}$ which is a typical conversion rate for ULIRGs, as stated in LN6. Back to the luminosity, in order to find this we needed to use this formula:

$$L'_{CO}\,\left[\mathrm{Kpc^2 km/s}\right] = \left(3.25 \times 10^7\right) \frac{D_L^2}{\nu_{\mathrm{obs}^2}(1+z)^3} \int_{\Delta v} S_\nu dv$$

which takes the the cosmological redshift of the galaxy Z (not having anything to do with Doppler redshift, but instead the expansion of the universe), the luminosity distance D_L(the distance at which the object has a specific luminosity), and the observed frequency of the CO line ν_{obs} (we received the first two from LN6, and the last from GILDAS). Finally we needed the total flux within the CO line (the integral in the formula), which we also received from GILDAS. We needed only to use the K-to-Jy conversion factor again to get the correct units. We then had everything we needed to calculate the mass of the interstellar medium.

3 Results

When we first received our data, it looked like this the picture on the left of Figure 3.

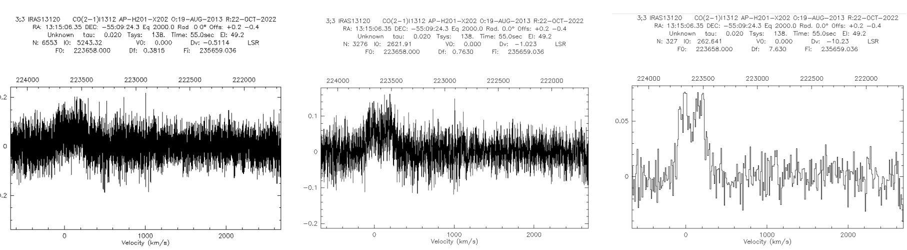

Figure 3: Our data in several steps of treatment.

As one can see in Figure 3, we binned the data several times until we deemed the line to be sufficiently visible and at the same time not so treated as to where we start to lose critical information. We stopped binning the data at

$S/N = 6.27\sigma$. Which means that our source is resolved. After treating the data, we exported that to a Python script where we plotted the Gaussian curve over the data (See Figure 4).

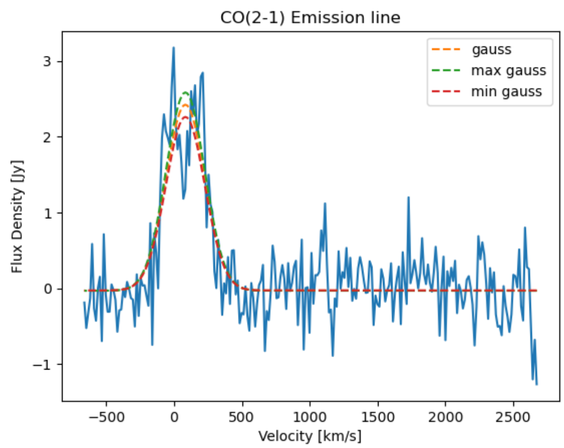

Figure 4: The data and the Gaussian curve with error taken into account, visualized using Python.

Using all of these factors: the galaxy's cosmological redshift $z = 0.0308$, which corresponds to $D_L = 139.4[Mpc]$, and the observed frequency which we found to be $223.6[GHz]$, we calculated the luminosity to be $9.88 \times 10^9[\text{Kpc}^2\text{km/s}]$. Finally, using α_{CO} and the calculated luminosity, we then found the mass of the interstellar gas to be $1.68 \times 10^10\text{M}_\odot$.

4 Discussion

In our calculations we have 2 variables with a room for error, the α_{CO} and $\int_{\Delta v} S_\nu dv$, so in order to calculate our margin of error we used the general formula for error propagation.

$$\Delta f\left(x_1, x_2, \ldots\right) = \sqrt{\left(\frac{\partial f}{\partial x_1}\Delta x_1\right)^2 + \left(\frac{\partial f}{\partial x_2}\Delta x_2\right)^2 + \cdots}$$

In our case, where we are setting $x = \int_{\Delta v} S_\nu dv$ for simplicity's sake:

$$M_{\text{H}_2+\text{He}}(\alpha_{\text{CO}}, x) = \alpha_{\text{CO}}(3.25 \times 10^7)\frac{D_L^2}{\nu_{\text{obs}^2}(1+z)^3}x$$

$\frac{\partial M}{\partial \alpha_{\text{CO}}} = (3.25 \times 10^7)\frac{D_L^2}{\nu_{\text{obs}^2}(1+z)^3}x$, $\frac{\partial M}{\partial x} = \alpha_{\text{CO}}(3.25 \times 10^7)\frac{D_L^2}{\nu_{\text{obs}^2}(1+z)^3}$

And with those:

$$\Delta M_{\mathrm{H_2+He}}(\alpha_{\mathrm{CO}},x)=\sqrt{\left((3.25\times10^7)\frac{D_L^2}{\nu_{\mathrm{obs}^2}(1+z)^3}x\Delta\alpha_{\mathrm{CO}}\right)^2+\left(\alpha_{\mathrm{CO}}(3.25\times10^7)\frac{D_L^2}{\nu_{\mathrm{obs}^2}(1+z)^3}\Delta x\right)^2}$$

From that formula we calculated an error of $\pm 4.11\times10^9 \mathrm{M}_\odot$, which corresponds to a 0.245% room for error.

We noticed very quickly the double peak in our data and thought that quite strange, but after further research, we found that it is quite normal for spinning galaxies due to something called the "rotating disk distribution." This can be explained by the fact that one half is moving away from us and the other is moving towards us, and therefor one side is blue-shifted and the other red-shifted.

When it came to our luminosity and mass results, we looked towards other sources to compare and see if these sounded correct. From [3] we saw that the number we got for our luminosity, being 10^{10}[Kpc^{2}km/s] is quite run-of-the-mill for ULIRGS. From source [2] we see that its most common for galaxies to have $M > 10^9[\mathrm{M}_\odot]$. We are aware that these observations do not prove our calculations to be 100% correct but rather say that we are in the right ballpark.

5 Conclusion

In this report we have received data from an observation of the CO(2-1) line of the ULIRG IRAS 13120-5453 that was taken at the APEX telescope. We then treated this data until we had a acceptable S/N ratio. We calculated the luminosity of the line, which we found to be $9.9 \pm 0.7 \times 10^9$[Kpc^{2}km/s], and further, using $\alpha_{\mathrm{CO}} = 1.7 \pm 0.4 \mathrm{M}_\odot$, found the mass of the interstellar dust to be $4.0 \pm 0.4 \times 10^{10} \mathrm{M}_\odot$.

References

[1] AST2210 Assignment 2 - Analysis of APEX CO(2-1) emission line observation of a nearby galaxy. 21 Oct. 2022.

[2] Lagos, Claudia del P. "Molecular Hydrogen Abundances of Galaxies in the EAGLE Simulations Claudia Del P. Lagos." Academic.oup.com, 6 Aug. 2015, https://academic.oup.com/mnras/article/452/4/3815/1056641.

[3] Lonsdale, Carol J. "3. THE PHYSICS OF LOCAL ULIRGs." Ultraluminous Infrared Galaxies - C.J. Lonsdale Et Al.., https://ned.ipac.caltech.edu/level5/Sept06/Lonsdale/Lonsdale3.html.

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