Multi-line CO imaging of two ULIRGs

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Introduction

- ULIRGs are Ultraluminous Infrared Galaxies. These are galaxies that are anywhere from 100 to 1000 times brighter in the infrared wavelength than any other typical galaxy.
- ULIRGs are the most luminous galaxies in the universe, radiating at least 90% of their light in the infrared wavelength.
- The majority of these galaxies are found in merging and interacting galaxy systems, which leads many to believe that their brightness is produced by galactic collisions.
- Other sources of such bright infrared light are interstellar gas, dust, and stars.

Introduction (continued)

- The observations of ULIRGs are used to estimate the total mass of a galaxy's molecular cloud, as well as its total gravitational mass (dynamical mass).
- The data and observations we analyzed for this project were obtained from the IRAM Plateau de Bure Interferometer (PdBI), which is a facility in the French Alps.
- This facility is now part of the Northern Extended Millimeter Array (NOEMA).
- We were provided with 4 sets of ULIRG observations of 2 ultraluminous infrared galaxies. 2 sets for CO($1 \rightarrow 0$) lines and 2 sets for CO($2 \rightarrow 1$) lines.
- IRAS 15250co10, IRAS 15250co21, IRAS 17208co10, & IRAS 17208co21.

Purpose

To Determine:

1. Key properties of the spectral axis of each dataset provided.
2. Range of velocities relative to systemic redshift over which each galaxy shows CO emission.
3. Whether each dataset shows evidence of continuum emission, and if so how to correct the estimates of spectral line flux due to the contribution of such emission.
4. The total molecular gas mass of each galaxy.
5. Estimate the flux ratio of the $CO(2 \rightarrow 1)$ and $CO(1 \rightarrow 0)$.
6. The total dynamical mass of each galaxy.
7. The total molecular gas mass fraction for each of our targets.

Tools Used For Analysis:

- Astrolab Servers
- Difmap Software
- Jupyter Notebooks (Python)

Procedure

1. Determine the Key properties of the spectral axis of each dataset provided:
    - How many frequency channels does the spectral axis have?
    - What is the central frequency ←→ redshift of the dataset?
    - How wide is each channel in frequency ←→ velocity?

- Through the use of Difmap, we loaded in a particular data set (observation) and created a pseudo-continuum data set of frequency channels to observe. We would look for when an indication of a peak initially became apparent, as well as when it would blend away and no longer be seen. (More detail on next slide)...

Difmap Procedure

#initial setup to properly view data set (observation)
>difmap
>observe iras15250co10.uvf #This initial setup was run on all four provided data sets.
>mapunit arcsec
>mapsize 256,0.125
>uvweigth 0,-2

#selection of specific frequency channels to observe
>select RR,1,10 #selected frequency channels 1 to 10.
>mapplot #this plotted the above selection

- The above selection command was repeated until we found a span of channels which we felt were appropriate in showcasing a clear indication of a peak in emission. So select RR,XXX,XXX was repeated with different frequency channel numbers indicated by the XXX,XXX which we had a range to work with from 1 to 112 to work with.

Equations Used:

(1) $$z = \frac{\nu_0}{\nu} - 1$$

(2) $$\Delta v_0 = \frac{\Delta \nu}{\nu} \times c$$

(3) $$\frac{M_{H_2}}{M_\odot} = 1.180 \times 10^4 (\frac{D}{Mpc})^2 (\frac{X}{3 \times 10^{20}}) (\frac{F_C O(1-0)}{Jykms^{-1}})$$

(4) $$X \equiv N_{H_2}/I_{CO(1-0)} = 3 \times 10^{20} cm^{-2} (Kkms^{-1})^{-1}$$

(5) $$D \approx cz/H_0 \quad H_0 \approx 70kms^{-1}Mpc^{-1}$$

(6) $$\frac{M_{dyn}(< R)}{M_\odot} = k \times (\frac{R}{kpc})(\frac{v}{kms^{-1}})^2$$

Difmap Findings For Each Dataset

	IRAS15250co10	IRAS15250co21	IRAS17208co10	IRAS17208co21
Channel Width	41 Channels (40 - 80)	46 Channels (30 - 75)	56 Channels (30 - 85)	110 Channels (3-112)
$f \longleftrightarrow z$	0.0554	0.0552	0.0428	0.0427
$f \longleftrightarrow v$	13.721km/s	6.862km/s	13.558km/s	6.779km/s

Procedure

2. Determine the range of velocities relative to the systemic redshift over which each galaxy shows CO emission.

   - This was determined by initially finding the v width:

$$\Delta v_0 = \frac{\Delta \nu}{\nu} \times c$$

   - This v width value was then multiplied by the number of channels within the range of emission: Δv_0*(#'s of channel in range).
   - This highlighted value gave us the channel width in terms of velocity.
   - Dividing this value by 2 gives us the range of velocities relative to the systemic redshift over which each galaxy shows CO emission.

Results

	IRAS15250co10	IRAS15250co21	IRAS17208co10	IRAS17208co21
v-width	13.721 km/s	6.862 km/s	13.558 km/s	6.779 km/s
Channel Width	41 Channels = 745.69 km/s	46 Channels = 315.652 km/s	56 Channels = 759.248 km/s	110 Channels = 745.69 km/s
Range of Velocities	+/-372.845 km/s	+/-157.826 km/s	+/-379.624 km/s	+372.845 km/s -379.624 km/s

Procedure

3. Determine whether each dataset shows evidence of continuum emission, and if so how to correct the estimates of spectral line flux due to the contribution of such emission.

    - This requires the use of difmap. Here, with a data set being observed, and the range of your frequency channels selected as a pseudo-continuum data set...
    - Example...
        - Take IRAS17208co10.uvf for example:
            a. 0>select RR,1,30,85,112
            b. *Selecting the peak on the map*, *x* to exit
            c. 0>clean 50
        - This returns the continuum flux density in difmap.
            a. 0>select RR,30,85
            b. *Selecting the peak on the map*, *x* to exit
            c. 0>clean 50
        - This returns the spectral line flux in difmap.

Results and Correction

- Knowing both the Continuum flux density and spectral line flux from all data sets...

	IRAS15250co10	IRAS15250co21	IRAS17208co10	IRAS17208co21
Continuum Flux Density	0.00311 Jy	0.0225 Jy	0.0120296 Jy	0.0904736 Jy
Spectral Line Flux Density	0.0148 Jy	0.0738 Jy	0.0987376 Jy	0.422559 Jy

- So essentially, we use clean to get the spectral line flux density and continuum flux density. With these values we then calculate continuum line flux and the spectral line flux based on our velocity width which we have shown in previous slides. From there we subtract out the continuum flux from the spectral line flux, correcting the estimate of spectral line flux due to the contribution of such emission.

Calculation and Correction

	IRAS15250co10	IRAS15250co21	IRAS17208co10	IRAS17208co21
Continuum Flux Density	0.00311 Jy	0.0225 Jy	0.0120296 Jy	0.0904736 Jy
Spectral Line Flux Density	0.0148 Jy	0.0738 Jy	0.0987376 Jy	0.422559 Jy
Continuum Flux Present	1.75 Jy km/s	7.11 Jy km/s	9.133 Jy km/s	67.465 Jy km/s
Spectral Line Flux (Uncorrected)	8.31 Jy km/s	23.31 Jy km/s	74.966 Jy km/s	315.098 Jy km/s
Spectral Line Flux (Corrected)	6.56 Jy km/s	16.2 Jy km/s	65.833 Jy km/s	247.642 Jy km/s

So with the contribution of continuum emission, the corrected estimates of the spectral line flux is a result of: Spectral Line Flux (Uncorrected) - Continuum Flux Present.

Calculating the total molecular gas mass

4. Determine the total molecular gas mass of each galaxy.

$$\frac{M_{H_2}}{M_\odot} = 1.180 \times 10^4 (\frac{D}{Mpc})^2 (\frac{X}{3 \times 10^{20}})(\frac{F_CO(1-0)}{Jykms^{-1}})$$

IRAS15250co10: $\frac{M_{H_2}}{M_\odot} = (1.180*10^4) * (237.26)^2 * (6.56)$

$\frac{M_{H_2}}{M_\odot} = 4.36*10^9\ cm^{-2}\ (k\ ks^{-1})^{-1}$

IRAS17208co10: $\frac{M_{H_2}}{M_\odot} = (1.180*10^4) * (183.30)^2 * (65.67)$

$\frac{M_{H_2}}{M_\odot} = 2.60*10^{10}\ cm^{-2}\ (k\ ks^{-1})^{-1}$

5. Estimate the flux ratio of the $CO(J = 2 \rightarrow 1)$ and $CO(J = 1 \rightarrow 0)$ lines.

For this we took the flux ratio of the $CO(J = 2 \rightarrow 1)$ and $CO(J = 1 \rightarrow 0)$ lines of all the channels and compared it to the middle channel. Including a wider set of channel data includes all higher and lower frequency (more red/blueshifted) emissions. The results seem to be the averages tend toward a value for the flux ratios within the same galaxy that are smaller than those determined from only emissions collected from center channels alone. Since flux ratio is a scalar quantity, it makes sense than the highest and lowest frequency emissions are of similar magnitude due to conservation of energy. We can also observe that the flux ratios across the two galaxies are remarkably similar (approx. $\sim 92\%$). This could indicate that *the flux ratio galaxy is dependant primarily on galaxy classification (elliptical, spiral, etc..), rather than other factors.

IRAS15250

$16.2/6.56 = 2.47$

$0.0905422/0.0212115 = 4.27$

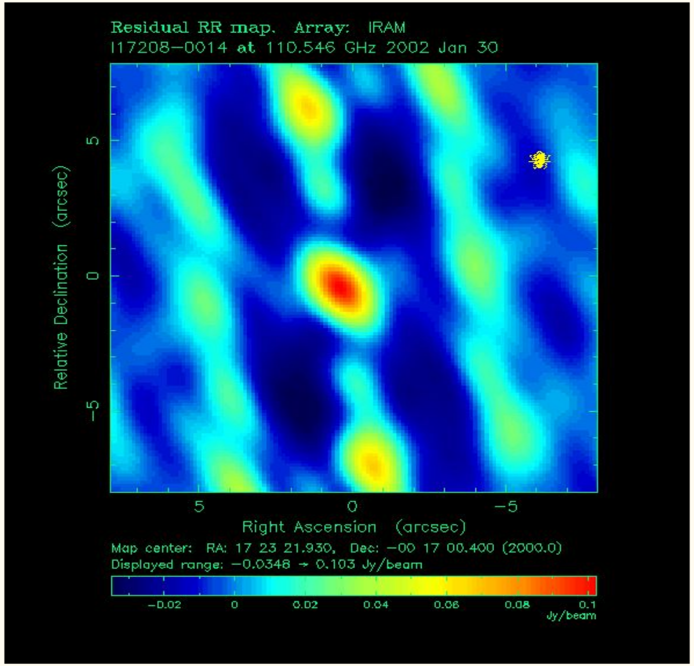
IRAS17208

$247.642/65.67 = 3.77$

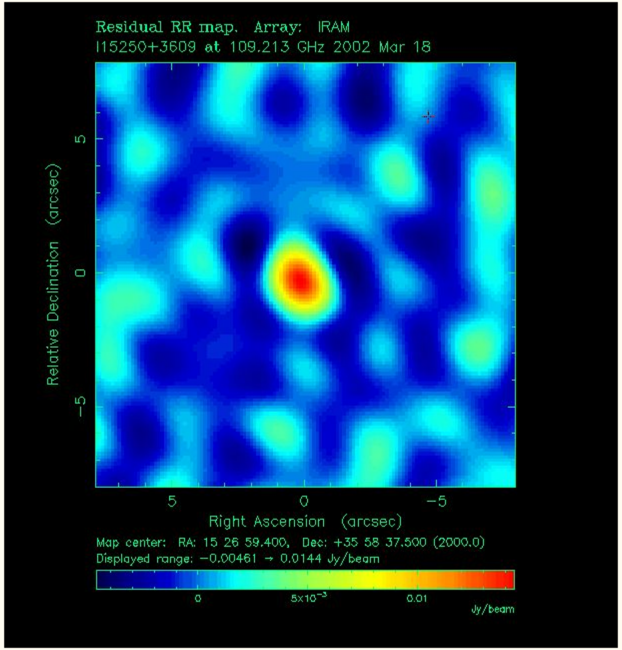
$0.69997/0.150048 = 4.66$

*Not enough data available about patterns to develop explanations.

Total Dynamic Mass



IRAS17208(1→0) 0.56 arcsec



IRAS15250(1→0) 0.18 arcsec

$$\frac{M_{dyn}(< R)}{M_\odot} = k \times (\frac{R}{kpc})(\frac{v}{kms^{-1}})^2$$

IRAS17208

k=232798.173

R=0.5 * ΔR=0.249kpc

v=0.5 * Δv=378.84km/s

Dynamic Mass= 8.32×10^9 solar masses

IRAS15250

k=232798.173

R=0.5 * ΔR=0.259kpc

v=0.5 * Δv=274.46km/s

Dynamic Mass= 4.54×10^9 solar masses

Mass Fractions

$$f_{gas} \equiv M_{H_2}/M_{dyn}$$

IRAS17208	IRAS15250
f=3.125	f=0.96035

Thank You!