Dust and Gas in NGC3627

Dust and Gas in NGC3627 Using Observations from SCUBA-2

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Abstract

Saw some dust and wanted to do something about it!

Ultra/Luminous infrared galaxies (U/LIRGs) are some of the most amazing systems in the local universe exhibiting extreme star formation triggered by mergers. Since molecular gas is the fuel for star formation, studying the warm, dense gas associated with star formation is important in understanding the processes and timescales controlling star formation in mergers. We have used high resolution (∼2.3") observations of the local LIRG Arp 299 (D= 44Mpc) to map out the physical properties of the molecular gas. The molecular lines ^{12}CO J=3-2, ^{12}CO J=2-1 and ^{13}CO J=2-1 were observed with the Submillimeter Array and the short spacings of the ^{12}CO J=3-2 and J=2-1 observations have been recovered using James Clerk Maxwell Telescope single dish observations. We use the radiative transfer code RADEX to measure the physical properties such as density and temperature of the different regions in this system. The RADEX solutions of the two galaxy nuclei, IC 694 and NGC 3690, show two gas components: a warm moderately dense gas with $T_{kin} \sim$ 30-500 K (up to 1000 K for NGC 3690) and $n(\mathrm{H_2}) \sim 0.3 - 3 \times 10^3$ cm^{-3} and a cold dense gas with $T_{kin} \sim$ 10-30 K and $n(\mathrm{H_2}) > 3 \times 10^3$ cm^{-3}. The overlap region is shown to have a well-constrained solution with $T_{kin} \sim$ 10-30 K and $n(\mathrm{H_2}) \sim 3\text{-}30 \times 10^3$ cm^{-3}. We estimate the gas masses and star formation rates of each region in order to derive molecular gas depletion times. The depletion time of each region is found to be about 2 orders of magnitude lower than that of normal spiral galaxies. This can be probably explained by a higher fraction of dense gas in Arp 299 than in normal disk galaxies.

To my family and Poly.

Acknowledgements

When life looks like easy street, there is danger at your door... -Robert Hunter

Thank Chris and group members of course. Don't forget Christian!

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Chapter 1

Hello

1.1 S'up

1.1.1 yo

Chapter 2

Observations and Data Preparation

2.1 SCUBA-2

The Submillimetre Common-User Bolometer Array 2 (SCUBA-2) was designed to decrease the observing time compared its predecessor SCUBA to allow for rapid data acquisition in the submillimetre regime of the electromagnetic spectrum, at the 450μm and 850μm bands. Prior to SCUBA-2, other bolometer camera's such as LABOCA, BOLOCAM and SHARC-II were limited to less than 100 pixels, while the new SCUBA-2 has been able to incorporate over 10,000 pixels in its design and effectively reduce observing time. Increasing the amount of pixels by a factor of 100 was possible by the advent of new technology such as high precision micromachining, superconducting transition edge sensors, and superconducting quantum interference device amplifiers Holland et al. (2013).

The observations of NGC3627 were taken from the Nearby Galaxies Legacy Survey's (NGLS) initial science images using SCUBA-2 from December 29, 2011 to January 21, 2012, and consist of 24 18'x18' scans taken in grade 3 weather or better ($0.08 < \tau < 0.12$). Out of the 24 scans, 16 were deemed useable. Whether or not an observation was deemed worthwhile was determined by factors such as the behavior of the image background and whether the image was flagged in observing to be unusable. An example of a good image background vs a poor image background can be seen in figure **??**. The observations of NGC3627 were taken using a daisy scanning pattern at 600“/second in order to reduce the white noise of the final data product.

2.2 Image Creation and Properties

For any imaging process to have been successful, the image needed to have limited white noise. White noise in the sense of our bolometer observations arose from thermal variations in the instrument and atmosphere during data acquisition. The random noise can be minimized through scanning methods and during image processing Chapin et al. (2013). To create the final SCUBA-2 data products we used the Submillimetre User Reduction Facility (SMURF) procedure MAKEMAP. This procedure reduced the noise of the observations while maintaining the source's emission by incorporating a combination of principal component analysis and a maximum likelihood analysis Chapin et al. (2013). Both of these methods have proven useful in reducing bolometer data on their own, but due to the size of raw SCUBA-2 data, specific aspects of each method would result in extreme run times or the process becoming resource intensive.

MAKEMAP broke down the image creation into several steps performed in iteration in order to successfully reduce any background noise Chapin et al.

(2013). The steps used in MAKEMAP were: COM and GAI which remove any common noise features detected by the superconducting quantum interface devices (SQUIDs), EXT to apply extinction corrections, FLT applied a high- and low-pass filters to remove any noise features not removed in the COM and GAI filtering, AST which regrids the data and detects sources to be removed from reduction, the final step is NOI which determines the noise in the gridded map after each step has been performed. A convergence check is then issued and if the check failed the COM, GAI, EXT, and FLT values are inverted and the process is repeated.

In our production of maps, we altered the AST and FLT sections of the image creation by introducing a mask made from Herschel's 250μm map shown if figure **??**. The purpose of the map was to exclude the target from interfering with the noise minimization as well as prohibit any emission from the galaxy to be significantly altered during image production. The filter size of the high-pass filter was also modified and an appropriate value was determined to be 175Hz. The maps were returned from MAKEMAP in units of pW with a pixel size of 2 square arc seconds for both the 450μm and 850μm.

The finalized 450μm image was then re-gridded down to a 4“ by 4“ pixel grid, and a flux calibration value of 491000 and 4710 were applied to convert from pW to mJy/beam and mJy/sq arc second respectively. The 850μm maps were re-gridded to an 8“ by 8“ pixel size and used flux calibration values of 537000 and 2340 for mJy/beam and mJy/sq. arc second. For ease of analysis the images were also converted to Jy/pixel by multiplying the mJy/sq arc seond by 0.001/pixel area. The calibration values were determined from observations of Uranus. The overall noise in the finalized image scan be seen in table ??.

2.2.1 Beam Shape of the 450μm and 850μm

The Uranus calibration images were also used in determining the shape of the beam for the 450μm and 850μm observations. The beam shape of both the 450μ and 850μm deviate from a single gaussian due to the second maximum of the airy diffraction pattern in the response function of the telescope. This abnormality was best represented by a sum of two gaussians whose amplitude totals to unity Dempsey et al. (2013). The average beam resolution for the 450μm and 850μm are reported in table ?? and match the values within error found in Dempsey et al. (2013). The contribution of the error beam in the 850μm emission was negligible and allowed for the beam to be approximated by a single gaussian however the contribution of the error beam in the 450μm images was large enough to require special treatment.

In order to accommodate the 450μm's error component, we used a method employed by another SCUBA-2 survey team, the Gould-Belt Survey team. This method utilized the distributive nature of the Fourier transform to create similar error components in the beam resolutions we were convolving to and from. This relationship is shown in equation 2.1 where X_{desire} is the beam width of the resolution we are convolving to, α is the amplitude of the main beam of the 450μm emission, β is the amplitude of the 450μm error beam, X_α and X_β are the main and error beam of the 450μm observations, and $X_{450\mu m}$ is the composition of X_α and X_β beams.

$$(X_{desire} * X_{\alpha}) * \alpha + (X_{desire} * X_{\beta}) * \beta = X_{450\mu m} * X_{desire} \tag{2.1}$$

2.3 Ancillary Data

The science goals of this thesis required data outside the capabilities of SCUBA-2. Determining the dust mass needed the spectral energy distribution (SED) for NGC3627 to be accurately fit. To successfully fit an SED, we needed shorter wavelength data to fully probe the cold component of this galaxy. We used data ranging from 100μm to 500μ from the KINGFISH survey Kennicutt et al. (2011) to fulfill this need. Secondly, the bandpass of the 850μm emisison contains the $CO_{j=3-2}$ transmission line. In order to get a valid approximation on the dust mass, this contribution had to be removed. We used emmisison data from the NGLS using HARP instrumentation on the JCMT Wilson et al. (2012). When a dust mass was obtained, we used $CO_{j=1-0}$ from the Nobeyama 45-m telescope (Kuno et al. (2007)), $CO_{j=2-1}$ from HERACLES (Leroy et al. (2009)), and HI observations from THINGS (Walter et al. (2008)).

Due to the combination of methods used in MAKEMAP, small scale/extended structure is removed from the final SCUBA-2 images. However, in all of our ancillary data the small scale emission was present in the initial maps. The removal of the extended features from our support data was carried out by converting the images from their native units into pW using the 850μm flux calibration factor. The images were overlaid on the original scans as a fakesource and passed through the reduction process. The original scan was then subtracted from the scan with the fakesource present and the residual of the process was the ancillary data with its extended structure removed.

2.3.1 Key Insights on Nearby Galaxies: a Far-Infrared Survey with Herschel (KINGFISH)

The Key Insights on Nearby Galaxies: a Far-Infrared Survey with Herschel (KINGSFISH) was designed to be a follow up to the Spitzer Infrared Nearby Galaxies Survey (SINGS) with observations of the warm and cold component of dust emission using the increased resolution from Herschel Kennicutt et al. (2011). The main science goals of the KINGFISH survey were to better understand the processes of star formation that were shielded by dust, resolved studies of heating and cooling of the interstellar medium (ISM), and to build an inventory of how cold dust emission relates to other dust components in the ISM Kennicutt et al. (2011). The survey consisted of studying 61 nearby galaxies (d<30Mpc) that cover a range of environments each observed at 70μm, 100μ, 160μm, 250μm, 350μm, and 500μm.

We were interested in fitting the cold component of NGC3627's SED, hence we omitted the 70μm emission, and used the 100μm, 160μm, 250μm, 350μm and 500μm. Since the Kingfish data was acquired by a space-based telescope, a significant amount of small scale emission was recovered due to the lack of interference from the atmosphere. The small scale emission was removed by treating the KINGFISH data as a fakesource in the image reduction process. The first step to successfully incorporating the data as a fakesource was to convert the 250μm, 350μm, and 500μm from MJy/sr to mJy/sq. arc second, and similarly the 100μm and 160μm from Jy/pixel to mJy/sq. arc second. After the unit conversion, the 850μm flux calibration factor was applied in reverse, and the new image was then scaled down to better mimic the 850μm emission. After these steps the image was passed into MAKEMAP and treated as an 850μm image. The final data output were gridded to 8" x 8" pixels and can be seen in figures **??** to **??**. The beam size and rms for each image after it has been passed through make map can be seen in table **??**.

2.3.2 Nearby Galaxy Legacy Survey (NGLS)

The Nearby Galaxy Legacy Survey is an HI-selected set of 155 galaxies contained in the annulus of $2Mpc \leq r \leq 25Mpc$ using the instrumentation aboard the JCMT Wilson et al. (2012). The NGLS contains data observed in several wavelengths that include the 450μm and 850μm data used for this thesis. As mentioned previously, the bandpass for SCUBA-2's 850μm emission contains the $CO_{j=3-2}$ line which is contained in the NGLS data set. We used the zeroth moment $CO_{j=3-2}$ maps from the NGLS to determine the percentage of $CO_{j=3-2}$ emission present in the 850μ band as well as removing it for an accurate SED analysis.

Removing the molecular gas contamination from the 850μm images required passing the data through MAKEMAP in a similar manner as the KINGFISH data. The only significant difference was converting the $CO_{j=3-2}$ data from $K*km/s$ to pW. The change of units was done using conversion factor of 0.51 $[K*km/s][mJy/beam]^{-1}$ found by Drabek et al. (2012). The final image product can be seen in figure **??**. We found the average ratio of $CO_{j=3-2}$ to be around 25% in most of the galaxy while rising as high as 50% in the nucleus indicative of AGN activity.

2.3.3 Nobeyama 45-m $CO_{j=1-0}$

2.3.4 HERA CO-Line Extragalactic Survey (HERACLES) $CO_{j=2-1}$

test

2.3.5 The HI Nearby Galaxy Survey (THINGS)

Chapter 3

Results

3.1 Will they ever get here?

Chapter 4

Discussion

4.1 Talk to the hand

Chapter 5

Conclusions

Sandstrom et al. (2013)

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