# Dust and Gas in NGC3627

# Dust and Gas in NGC3627 Using Observations from SCUBA-2

By

Jonathan H. Newton, B.A.

A Thesis

Submitted to the School of Graduate Studies

in Partial Fulfilment of the Requirements

for the Degree

Master of Science

McMaster University

Master of Science (2014) McMaster University

(Physics and Astronomy) Hamilton, Ontario

TITLE: Dust and Gas in NGC3627 Using Observations from SCUBA-2

AUTHOR: Jonathan Newton, B.A. (Western Kentucky University)

SUPERVISOR: Christine D. Wilson

NUMBER OF PAGES: ix, 10

# 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 $n(\mathrm{H}_2) \sim$ 3-30 $\times$ $10^3$ 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!

# Table of Contents

# List of Figures

# List of Tables

# 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 450$\mu$m and 850$\mu$m 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

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 arised 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 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 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 250$\mu$m 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 450$\mu$m and 850$\mu$m.

The finalized 450$\mu$m image was then regridded 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 arcsecond respectively. The 850$\mu$m maps were regridded to an 8" by 8" pixed and used flux calibration values of 537000 and 2340 for mJy/beam and mJy/sq. arcsecond. For ease of analysis the images were also converted to Jy/pixel by multiplying the mJy/sq arcseond 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 450$\mu$m and 850$\mu$m

The Uranus calibration images were also used in determining the beam shape of the 450$\mu$m and 850$\mu$m observations. The beam shape of both the 450$\mu$ and 850$\mu$m deviate from a single gaussian due to the second maximum of the airy diffraction pattern in the response function of the telescope, and is best represented by a sum of two gaussians whose amplitude totals to unity Dempsey et al. (2013). The average beam resolution for the 450$\mu$m and 850$\mu$m are reported in table **??** and match the values found in Dempsey et al. (2013). The contribution of the error beam in the 850$\mu$m emission was negligible and allowed for the beam to be approximated by a single gaussian.

In order to accomodate the 450$\mu$m's error compenent, we used a method employed by another survey team using SCUBA-2, the Gould-Belt Survey team. This method utilized the distributive nature of the Fourier transform to create similiar error components in the beam resolutions we are 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, $\alpha$ is the amplitude of the main beam of the 450$\mu$m emission, $\beta$ is the amplitude of the 450$\mu$m error beam, $X_\alpha$ and $X_\beta$ are the main and error beam of the 450$\mu$m observations, and $X_\alpha$ are is the 450$\mu$m beam.

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

## 2.3 Supporting Images / ancillary data

- Discuss what you need other images for. Herschel for SED fits. THINGS, KUNO, and Heracles for dust-to-gas ratio.
- Images needed to be run through makemap as a fake source in order to remove any small scale structure from original images. I should have several figures showing the amount of flux removed from each of the images.
- Reference the Kingfish Survey, Kuno et al., Heracles survey and THINGS survey for their sources. ¡–Leave this as a paragraph on it's own or introduce smaller subsections?

# 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)

# Bibliography

Chapin, E. L., Berry, D. S., Gibb, A. G., Jenness, T., Scott, D., Tilanus, R. P. J., Economou, F., & Holland, W. S. 2013, MNRAS, 430, 2545

Dempsey, J. T., Friberg, P., Jenness, T., Tilanus, R. P. J., Thomas, H. S., Holland, W. S., Bintley, D., Berry, D. S., Chapin, E. L., Chrysostomou, A., Davis, G. R., Gibb, A. G., Parsons, H., & Robson, E. I. 2013, MNRAS, 430, 2534

Holland, W. S., Bintley, D., Chapin, E. L., Chrysostomou, A., Davis, G. R., Dempsey, J. T., Duncan, W. D., Fich, M., Friberg, P., Halpern, M., Irwin, K. D., Jenness, T., Kelly, B. D., MacIntosh, M. J., Robson, E. I., Scott, D., Ade, P. A. R., Atad-Ettedgui, E., Berry, D. S., Craig, S. C., Gao, X., Gibb, A. G., Hilton, G. C., Hollister, M. I., Kycia, J. B., Lunney, D. W., McGregor, H., Montgomery, D., Parkes, W., Tilanus, R. P. J., Ullom, J. N., Walther, C. A., Walton, A. J., Woodcraft, A. L., Amiri, M., Atkinson, D., Burger, B., Chuter, T., Coulson, I. M., Doriese, W. B., Dunare, C., Economou, F., Niemack, M. D., Parsons, H. A. L., Reintsema, C. D., Sibthorpe, B., Smail, I., Sudiwala, R., & Thomas, H. S. 2013, MNRAS, 430, 2513

Sandstrom, K. M., Leroy, A. K., Walter, F., Bolatto, A. D., Croxall, K. V., Draine, B. T., Wilson, C. D., Wolfire, M., Calzetti, D., Kennicutt, R. C., Aniano, G., Donovan Meyer, J., Usero, A., Bigiel, F., Brinks, E., de Blok, W. J. G., Crocker, A., Dale, D., Engelbracht, C. W., Galametz, M., Groves, B., Hunt, L. K., Koda, J., Kreckel, K., Linz, H., Meidt, S., Pellegrini, E., Rix, H.-W., Roussel, H., Schinnerer, E., Schruba, A., Schuster, K.-F., Skibba, R., van der Laan, T., Appleton, P., Armus, L., Brandl, B., Gordon, K., Hinz, J., Krause, O., Montiel, E., Sauvage, M., Schmiedeke, A., Smith, J. D. T., & Vigroux, L. 2013, ApJ, 777, 5