### Updates from the Dense Extragalactic GBT+ARGUS Survey (DEGAS)

### A Direct, Quantitative Test of the Role of Gas Density in Star Formation

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# The GBT has the potential to make major contributions to the study of molecular gas in nearby galaxies.



- GBT has a collecting area 20% larger than ALMA and 4x that of the next largest single dish (LMT).
- ~10arcsec beam means you can distinguish 30 Doradus sized regions at the distance of M82.



Deep, moderately high resolution maps of nearby galaxies

# The GBT has demonstrated that it can do deep observations of dense molecular gas tracers in nearby galaxies.



Kepley, Bittle, et al 2018

Kepley + 2014

# Argus significantly increases the mapping speed of the GBT at 4mm.



- Major limitation of previous, effectively single pixel receiver was its slow mapping speed.
- Argus is 16 pixel focal plane array built by Stanford (PI Sarah Church), Caltech, JPL, U. Maryland, U. Miami, and NRAO.
- 16 pixels means that you can map galaxies in the order of 5-10 hours instead of >50 hours.

### IC 342 100micron





### IC 342 100micron





IC 342 GBT+Argus

12CO(1-0) 10 hours total (including overhead)!









## The mapping speed of GBT and Argus opens up the possibility of mapping dense gas in a wide variety of nearby galaxies.



### The goal of DEGAS is to quantify the relationship between dense gas and star formation in a large sample of nearby galaxies.



### DEGAS = Dense Extragalactic GBT+Argus Survey

- ~500hr GBT large project
- 2' by 2' maps of 4 dense molecular gas tracers in 36 nearby galaxies with ~750pc resolution.
- Supported by multiple NSF grants
  - AST1615277, 1616088, 1615647, 1
    615109, and 161682 (DEGAS)
  - ATI 0905855, 1207825 (Argus)
- Started 17A and goes through 20A.
- First full observing season complete and DR1 in progress.

DEGAS will complement work being done by the IRAM 30m and ALMA with a large sample size at moderate resolution.



- 9 galaxy disks
- HCN(1-0), HCO+ (1-0), HNC(1-0), <sup>13</sup>CO(1-0), C<sup>18</sup>O(1-0), <sup>12</sup>CO(1-0)
- Resolution ~1.5kpc
- Bigiel+16
- Jimenez-Donaire+17a,b,
  +18 in prep
- Cormier+ 18

ALMA PI: Adam Leroy

- Inner 3 kpc of 4 nearby galaxies
- HCN(1-0), HCO+(1-0), CS(2-1), <sup>13</sup>CO(1-0), C<sup>18</sup>O(1-0)
- Resolution ~ 200pc
- Gallagher+ 2018



- Central 2' by 2' of 36 galaxies
- HCN(1-0), HCO+(1-0), <sup>13</sup>CO(1-0), C<sup>18</sup>O (1-0)
- Resolution ~750pc
- DR1 paper: Kepley+ 2019 in prep

Plus surveys of higher J transitions like MALATANG (Tan+ 2018)

cf. Molly Gallagher's talk

# Initial DEGAS data quality is excellent and we are working towards DR1.

- Preliminary internal reduction shows that the data is in good shape (see next slide for known issues)
- Beta pipeline: https://github.com/GBTSpectroscopy/degas
  - For more details, see Erik Rosolowsky's talk
- We are currently working on DR1.
  - https://github.com/GBTSpectroscopy/degas/pr ojects/3
  - Within this effort, also embarking on an effort to measure the main beam efficiency at different frequencies
- DR1 paper will likely be published in an AAS journal
  - Aiming for submission date first half of 2019
  - Page charges will be covered by associated NSF grant.
  - Might be more difficult for groups without grants to publish.



# Round up of current DEGAS data issues.

- Can't use a simple end of row OFF position (some pixels are over the galaxy at the end of the row).
- Need to tune flagging and masking parameters
- Beam labeling issue easy to deal with once found
- Some observations were taken during high winds (~10m/s) so we need to correct for the feed arm motion using the quadrant detector.
  - But possibly larger scheduling issue.
- All solvable issues!









#### All plots courtesy Jialu Li

## High frequency observing needs to be scheduled dynamically, but this can be personally difficult.

- We have a recruited a large pool of remote qualified observers so that we can spread the load among more people.
  - I can't pay people, but I do offer them co-authorship on papers.
  - Trained via GBT remote observing workshops
- We have moved to an on-call rotation so that people can better schedule around any potential observing.
- I coordinate and plan the observations for each observing session.
- I have put together a detailed observing guide specifying exactly how we want the observations to be performed for DEGAS.
- Scripts are organized and labeled, so that the observer has to modify as little as possible and can just execute the scripts in order.
- David Frayer provides support as needed during observing.
  - Large load on David to support so many projects.
- Simplifications to observing have led to higher observing efficiency (e.g., recent improvements to astrid for calculating pointing corrections).
  - Worth spending time making this observing as smooth as possible.



#### We have modified our usage of the DSS to support an on-call rotation.

- On-call slots are Monday at noon to next Monday at 11:59 a.m.
- Primary and secondary for each slot
  - Avoids overload in good weather and provides backup in case of scheduling issues
- Qualified remote observers are asked to fill a number of slots.
- People select what slots they want in a google spreadsheet
- I send out reminder emails in advance.
- Observers are responsible for keeping their black out dates up to date.
- I manually switch out observers in the DSS on Saturday afternoon.
- I'm always selected as an observer so that I get all notifications, but black out everything except my on-call rotations.
- If moving to more surveys, would be nice to have the DSS deal with on-call rotations more gracefully.
  - It's not as simple as just setting blackout dates. Black out dates are per person and people can be observers for multiple projects.

## Observing completion is good, but having more available high frequency time would be excellent.



- On-call rotation means that we are not missing observing opportunities.
- Time lost in 18A was largely from amplifier failure in March 2018 (lost about a month's worth of time).
- 18A summer didn't have much good high frequency weather.
- More high frequency time available from laser scanning project will be welcome
  - Not clear what impact testing will have on current projects.

#### **DEGAS will compensate for lost time by reducing our sample.**

| Name    | Semester | HCN/HCO+ 17A |                       | 13CO/C18O |                       |
|---------|----------|--------------|-----------------------|-----------|-----------------------|
|         |          | Session      | Has Target # of Maps? | Session   | Has Target # of Maps? |
| IC0342  | 17B      | 1            | yes                   | 37        | yes                   |
| NGC0337 | 18B      | 2            | started               | 38        | yes                   |
| NGC1068 | 19B      | 3            | no                    | 39        | no                    |
| NGC2146 | 18A      | 4            | yes                   | 40        | yes                   |
| NGC2903 | 17B      | 5            | yes                   | 41        | yes                   |
| NGC3147 | 18B      | 6            | started               | 42        | yes                   |
| NGC3198 | 19A      | 7            | no                    | 43        | no                    |
| NGC3521 | 18A      | 8            | started               | 44        | no                    |
| NGC3627 | 19B      | 9            | no                    | 45        | no                    |
| NGC3631 | 20A      | 10           | no                    | 46        | no                    |
| NGC3690 | 19A      | 11           | no                    | 47        | no                    |
| NGC4030 | 18A      | 12           | no                    | 48        | no                    |
| NGC4038 | 17B      | 13           | yes                   | 49        | yes                   |
| NGC4051 | 18B      | 14           | no                    | 50        | no                    |
| NGC4254 | 19B      | 15           | no                    | 51        | no                    |
| NGC4258 | 20A      | 16           | no                    | 52        | no                    |
| NGC4303 | 19A      | 17           | no                    | 53        | no                    |
| NGC4321 | 20A      | 18           | yes                   | 54        | started               |
| NGC4414 | 18A      | 19           | started               | 55        | no                    |
| NGC4501 | 17B      | 20           | yes                   | 56        | yes                   |
| NGC4535 | 19A      | 21           | no                    | 57        | no                    |
| NGC4536 | 18B      | 22           | no                    | 58        | no                    |
| NGC4568 | 19B      | 23           | no                    | 59        | no                    |
| NGC4569 | 17B      | 24           | started               | 60        | started               |
| NGC4654 | 20A      | 25           | no                    | 61        | no                    |
| NGC4666 | 18B      | 26           | no                    | 62        | no                    |
| NGC4736 | 18A      | 27           | no                    | 63        | no                    |
| NGC4826 | 19B      | 28           | no                    | 64        | no                    |
| NGC5005 | 19A      | 29           | no                    | 65        | no                    |
| NGC5033 | 20A      | 30           | no                    | 66        | no                    |
| NGC5055 | 17B      | 31           | no                    | 67        | no                    |
| NGC5247 | 18B      | 32           | no                    | 68        | no                    |
| NGC5248 | 18A      | 33           | no                    | 69        | no                    |
| NGC5457 | 19A      | 34           | no                    | 70        | no                    |
| NGC5713 | 19B      | 35           | no                    | 71        | no                    |
| NGC7331 | 20A      | 36           | started               | 72        | no                    |



We will also re-propose for dropped sources after 2020A

## Effectively managing a distributed team is key for the success of DEGAS.

- We use commercial tools to communicate
  - multiple email lists through Google groups
  - zoom for telecons
  - google drive (sheets, docs, etc) for project documentation
  - github for software version control as well as issue reporting system
  - overleaf for writing papers and proposals
  - trello for issue tracking for specific data sets
- Most tools have a free version, but not all.
  - Provide small grants to collaborations to pay for communication tools?
- Communication is key for the success of distributed teams
  - Include specific prompts in the Large Program call to get people thinking early about how to communicate information within the survey [E.g., JCMT template?]
  - Regular check-ins with the observatory (every 6months) to make sure things are on track and/or help remove roadblocks that may exist.
- Having David Frayer actively involved in the project on both the support and science side has been crucial.
  - He provides our link to what's happening at the observatory.

#### **Summary**

- GBT+ARGUS is an excellent combination for mapping nearby galaxies.
- DEGAS data quality is excellent.
- We are working toward a data release 1 (DR1) for its first full observing season.
- Lessons learned from DEGAS can be used to improve future surveys.



#### **Recommendations**

- Modify the DSS to deal more straightforwardly with on-call rotations to make it easier to manage observing for large teams.
- Take a closer look at DSS weather predictions (in particular wind speed predictions) to determine whether they need to be tuned further for work at >100GHz.
- Schedule an "official" backup project that can take over observing in okay weather if the predicted weather conditions do not match the forecast.
- Continue to improve 4mm observing procedures (e.g., improved pointing correction calculations) to make observing more efficient.
- Involve GBO staff in survey projects on both the science and support side to improve communication between the observatory and the projects, but make sure to manage their workloads to avoid overcommitting.
- Increase the amount of 4mm observing time available via the laser scanning project to improve our observing completion statistics.
- Provide some level of GBO page charge support for groups without grants.
- Good communication is essential for the success of distributed teams [c.f., Harriet Parsons' talk]
  - Provide small grants to collaborations to pay for communication tools (e.g., zoom, google drive, dropbox, github, trello, etc).
  - Include specific prompts in the Large Program call for proposals to get people thinking early about how to communicate information within the survey
  - Perform regular check-ins with the observatory (every 6months) to make sure things are on track and/or help remove roadblocks that may exist
- Facilitating communication between surveys (e.g., this workshop) to allow groups to leverage each others experience rather than re-invent the wheel.