Quantifying the Relationship between Dense Gas and Star Formation in Nearby Galaxies

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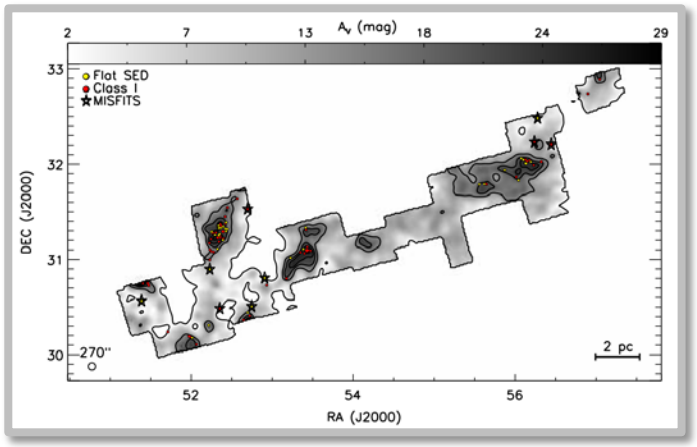
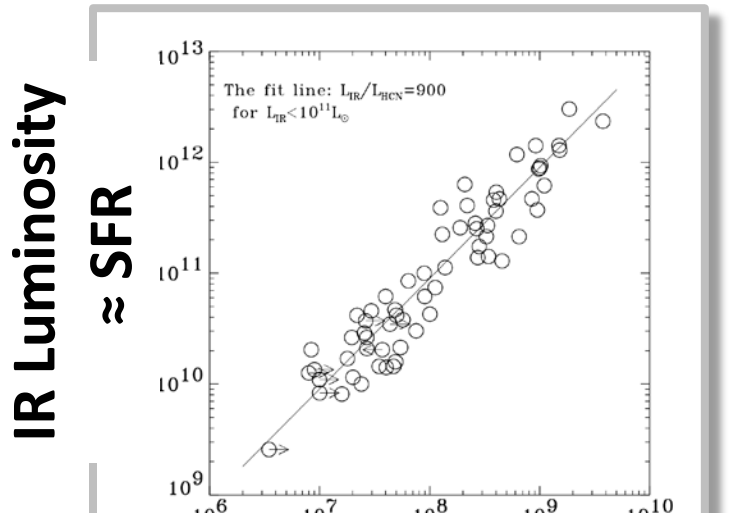
Star formation correlates most strongly with dense molecular gas.

Resolved measurements in the Milky Way



Heiderman+ 2010

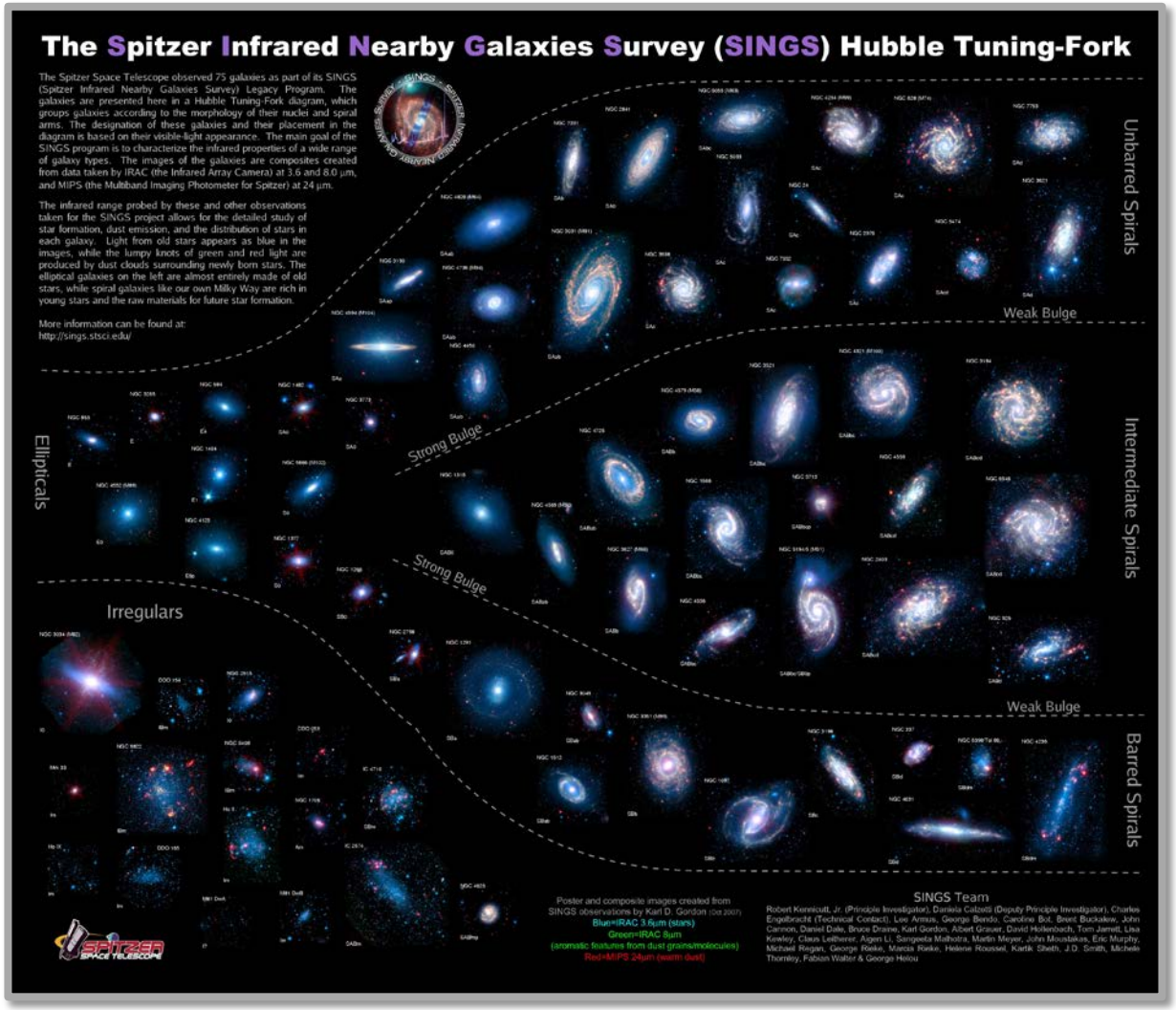
Integrated measurements in nearby galaxies



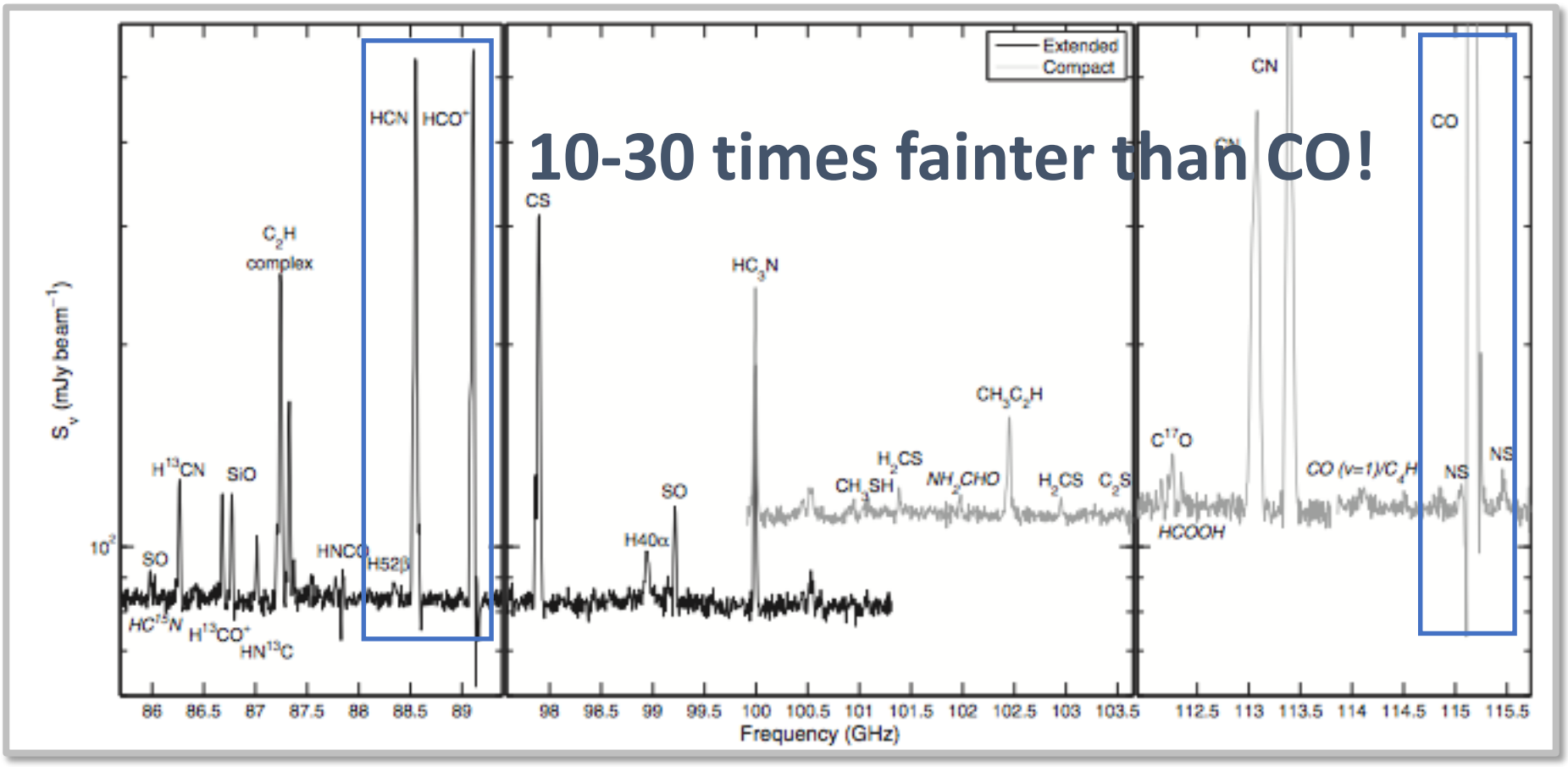
Dense Gas (as traced by HCN)

Gao & Solomon (2004)

Mapping dense gas in nearby galaxies probes a wider range of physical conditions.



Mapping dense gas tracers in nearby galaxies is difficult because these lines are faint.



Meier+ 2015

Sensitivity of latest generation of telescopes is opening up new frontiers in dense gas studies.

EMIR Multi-line Probe of the ISM Regulating Galaxy Evolution (EMPIRE)

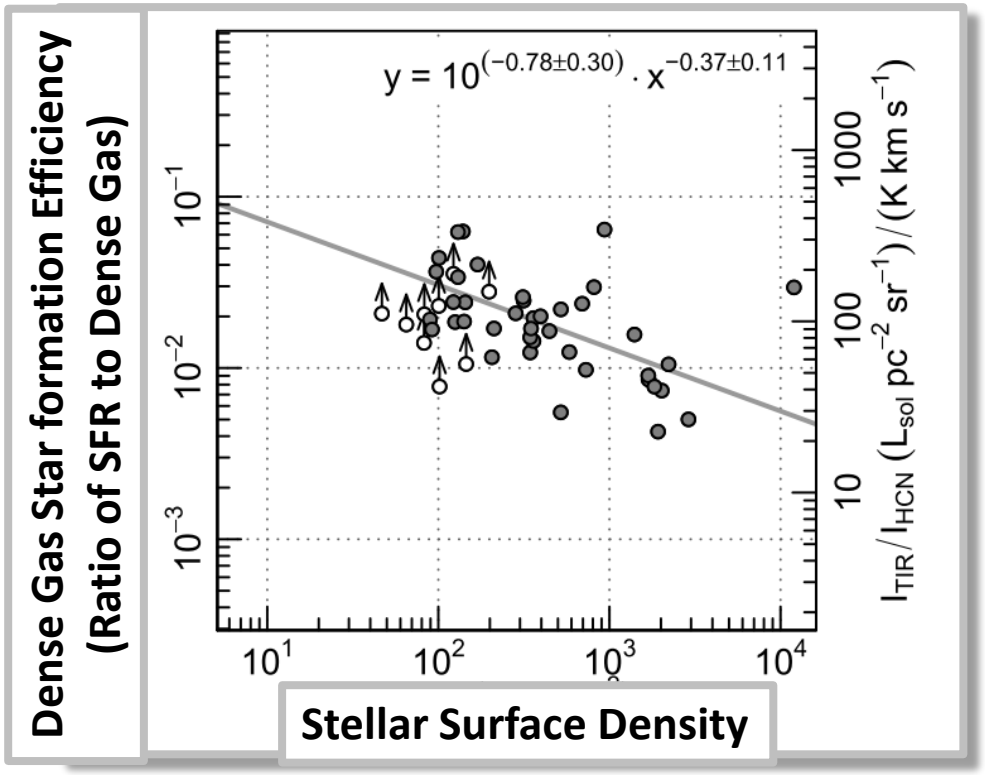
- PI: Frank Bigiel
- Co-Is include A. Kepley
- IRAM Large Program ~2015-2017, ~440 hr
- Disks of nine galaxies mapped in HCN, HCO+, CS, ^{13}CO, $C^{18}O$
- Spatial resolution ~1.5kpc (at 10Mpc)
- Observations are complete. Papers are coming out.

ALMA Dense Gas Observations of Galaxies

- PI: Adam Leroy
- Co-Is include A. Kepley
- All data taken
- Inner 3 kpc of 4 nearby galaxies with a range of SFE and nuclear starburst behavior
- Resolution ~ 200pc
- Paper submitted (Gallagher+). See A. Bolatto's talk.

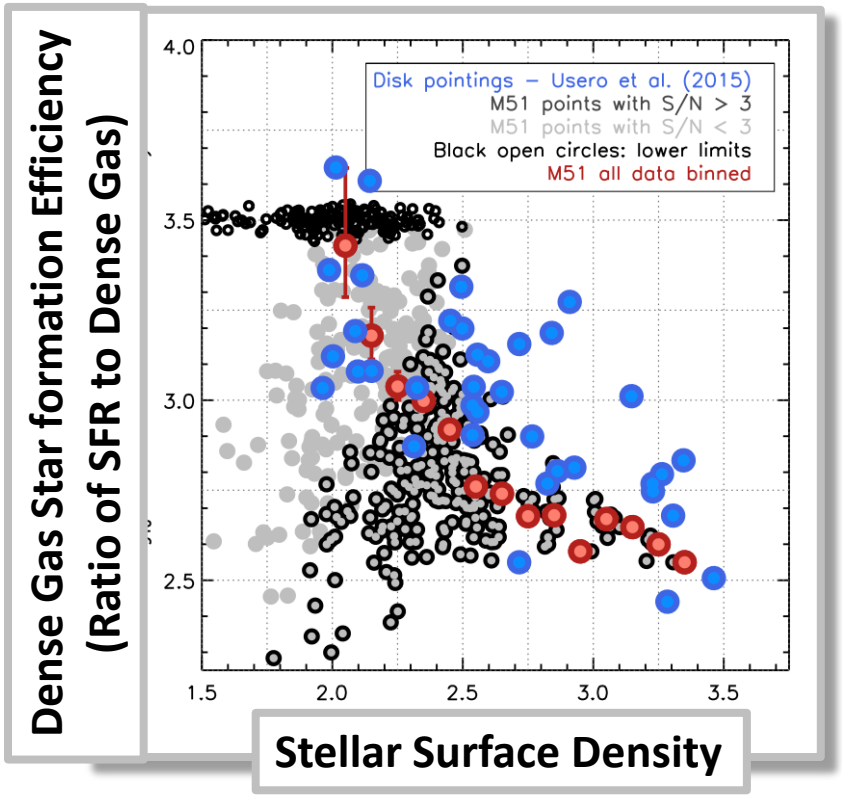
These types of studies are already starting to see trends with physical conditions within galaxies.

Individual pointings in many galaxies



Usero+ 2015

Deep observations of M51



Bigiel+ 2016

Radius

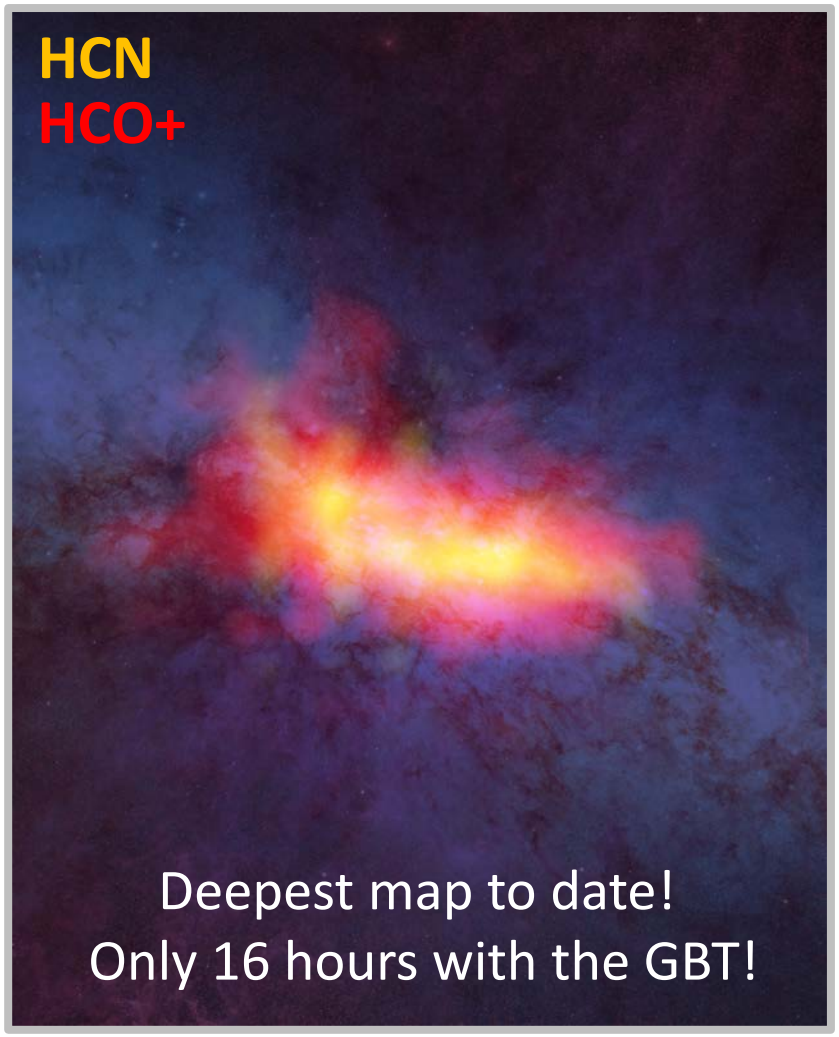
Radius

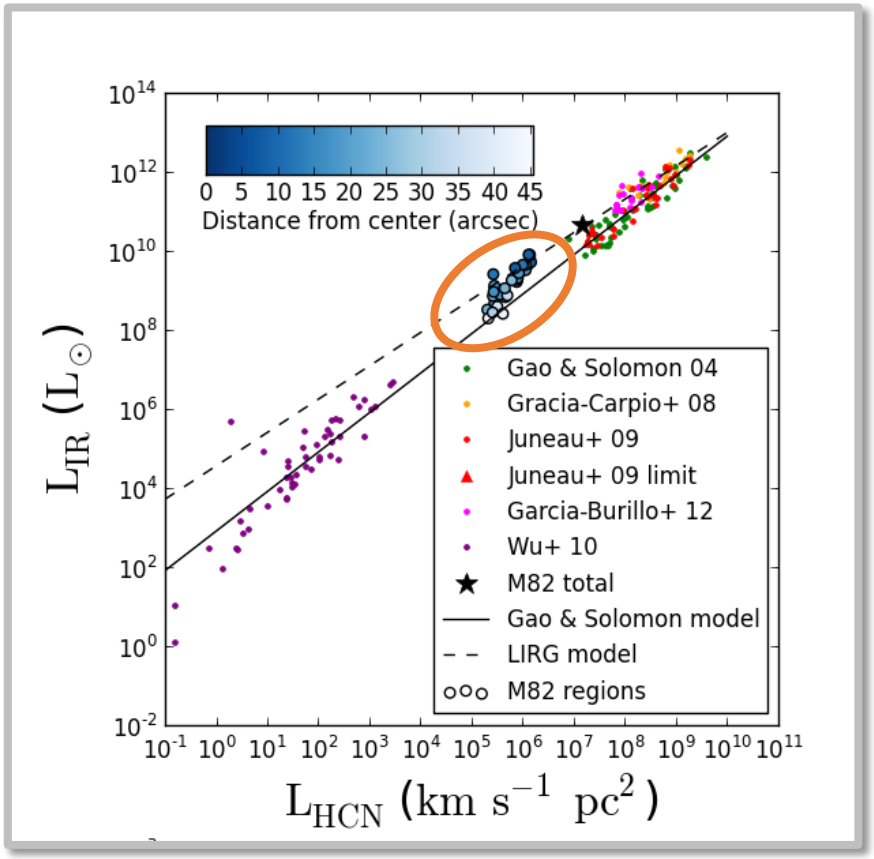
The GBT has the potential to make major contributions to this field.

- 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

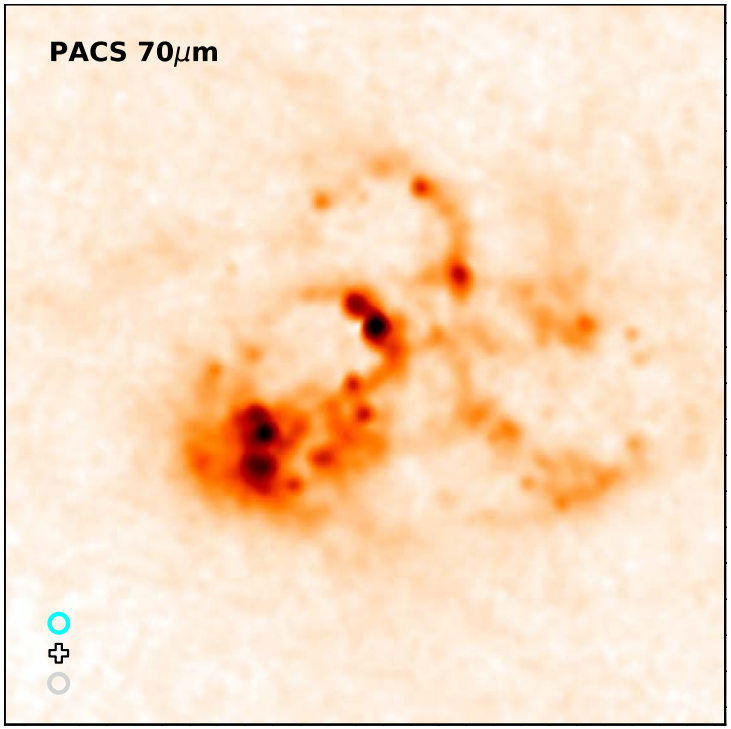
The GBT has demonstrated that it can do deep observations of dense molecular gas tracers.





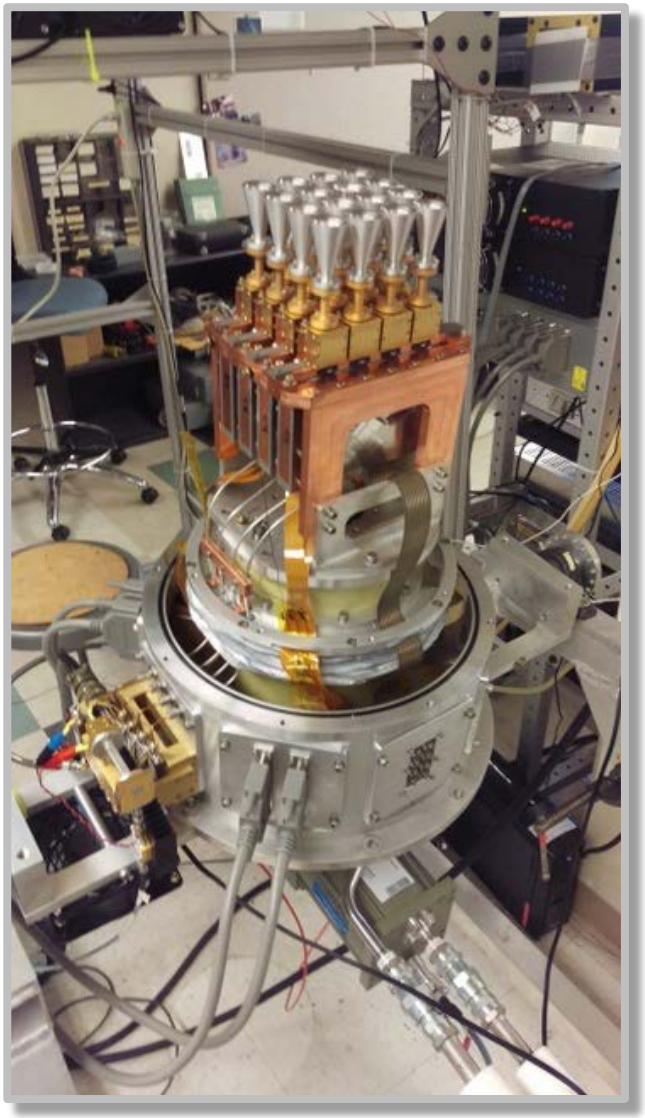
Kepley + 2014

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



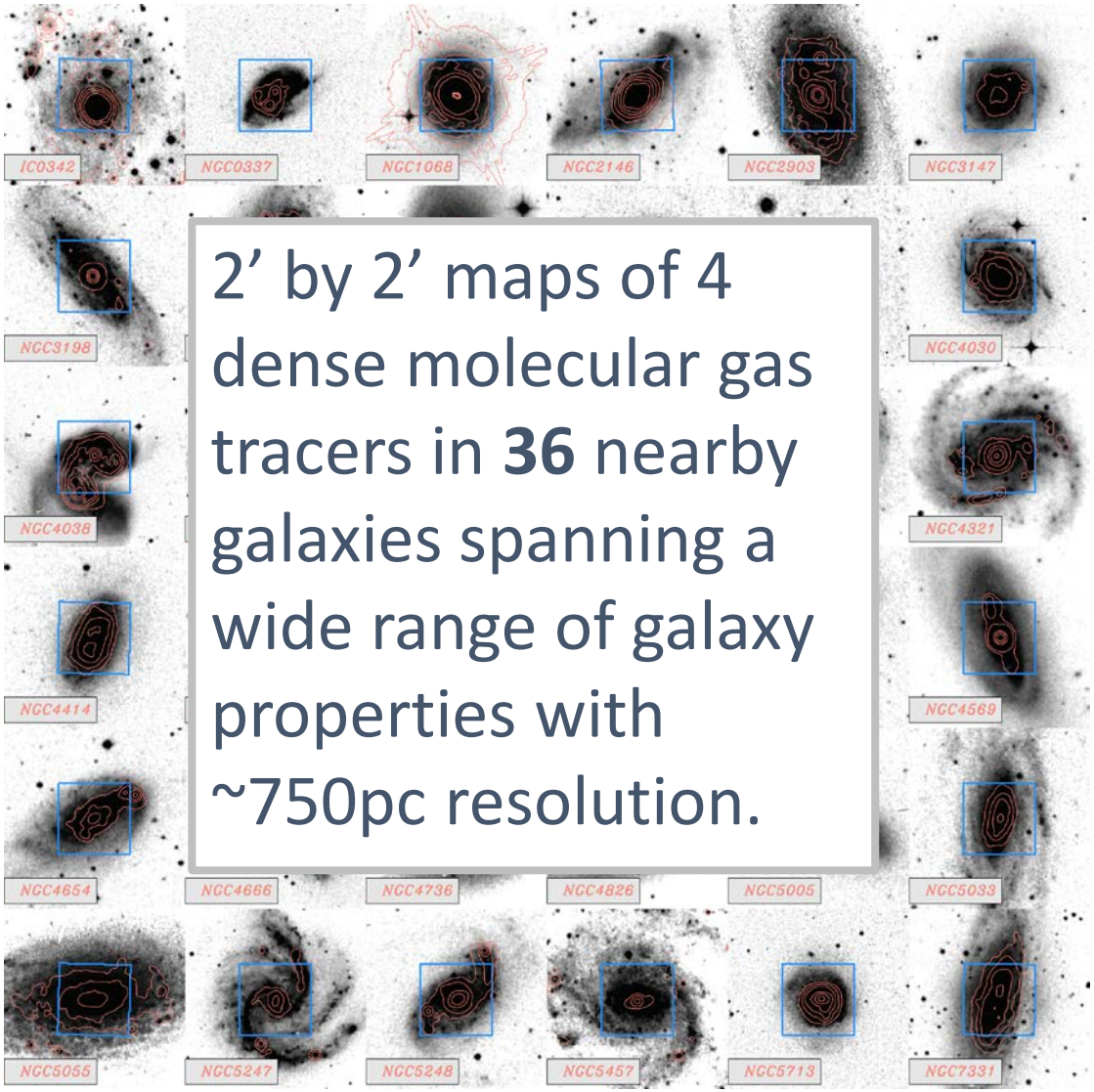
Kepley et al, in prep (to be submitted by 10/31)

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.

DEGAS* will quantify the relationship between dense gas and star formation in a large sample.



2’ by 2’ maps of 4 dense molecular gas tracers in **36** nearby galaxies spanning a wide range of galaxy properties with ~750pc resolution.

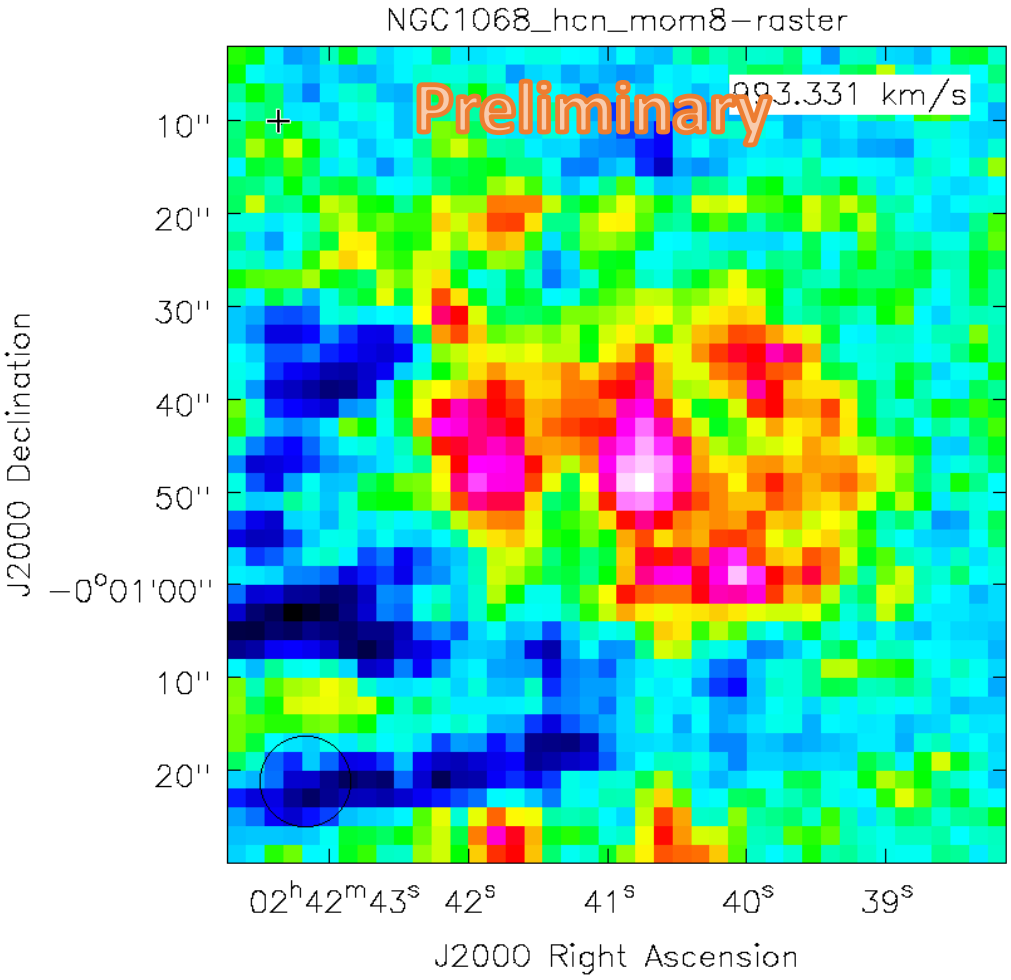
FULL PROPOSAL ACCEPTED!
~500HR OVER 3 YEARS (GULP)

A. Kepley (PI)
A. Leroy
S. Church
K. Cleary
D. Frayer
E. Rosolowsky
A. Harris
A. Bolatto
F. Bigiel
M. Gallagher
J. Gunderson
A. Hughes
M. J. Jimenez
S. Kessler
C. Lee
J. Li
J. Meyer
K. Sandstrom
A. Schruba
M. Sieth
E. Schinnener
A. Usero

Supported by NSF AST Grant to co-Is.

*** Dense Extragalactic GBT+Argus Survey**

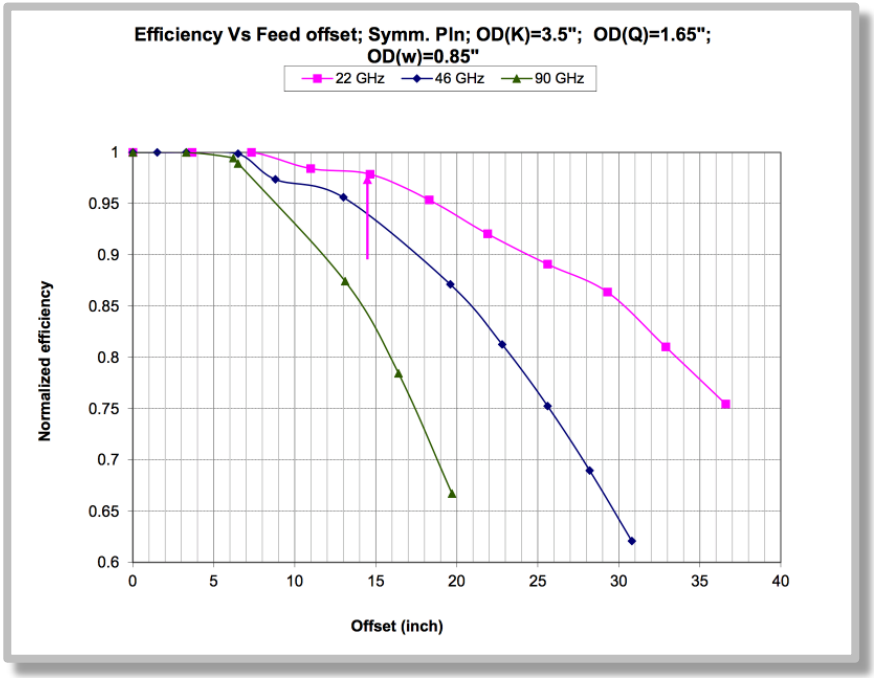
Observations started Spring 2017 and will go through 2020.

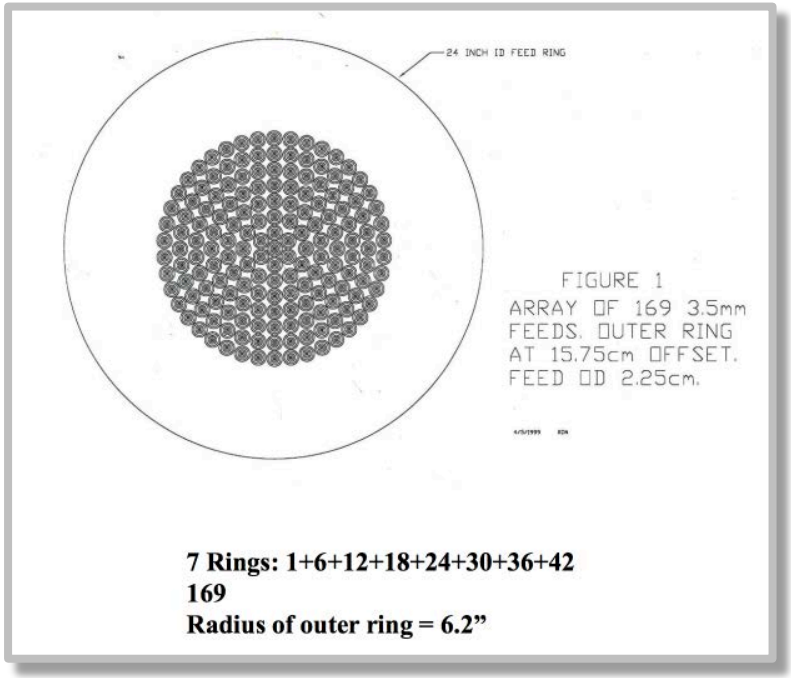


- Data during 17A season limited by poor weather.
- On sky for 9.25h tonight and 8h tomorrow!
- Preliminary results will be shown in GBT special session at the AAS on January 11 at 10:00 a.m.

A. Kepley

The focal plane of the GBT can accommodate even larger arrays.





Freq (GHz)	Pixels	Footprint	HPBW	Worst Coma	Diameter	
22	91	15.8'	34″	-20 dB	~36 in.	13x
46	500	18.1'	16″	-15 dB	~40 in.	500x
90	800	12.0'	8.3″	-15 dB	~30 in.	50x

GBT memos 198 & 199 (Norrod and Srikanth) and 295 (Lockman). See also talk by S. Church.

Large arrays would enable mapping of entire disks of large samples of nearby galaxies.

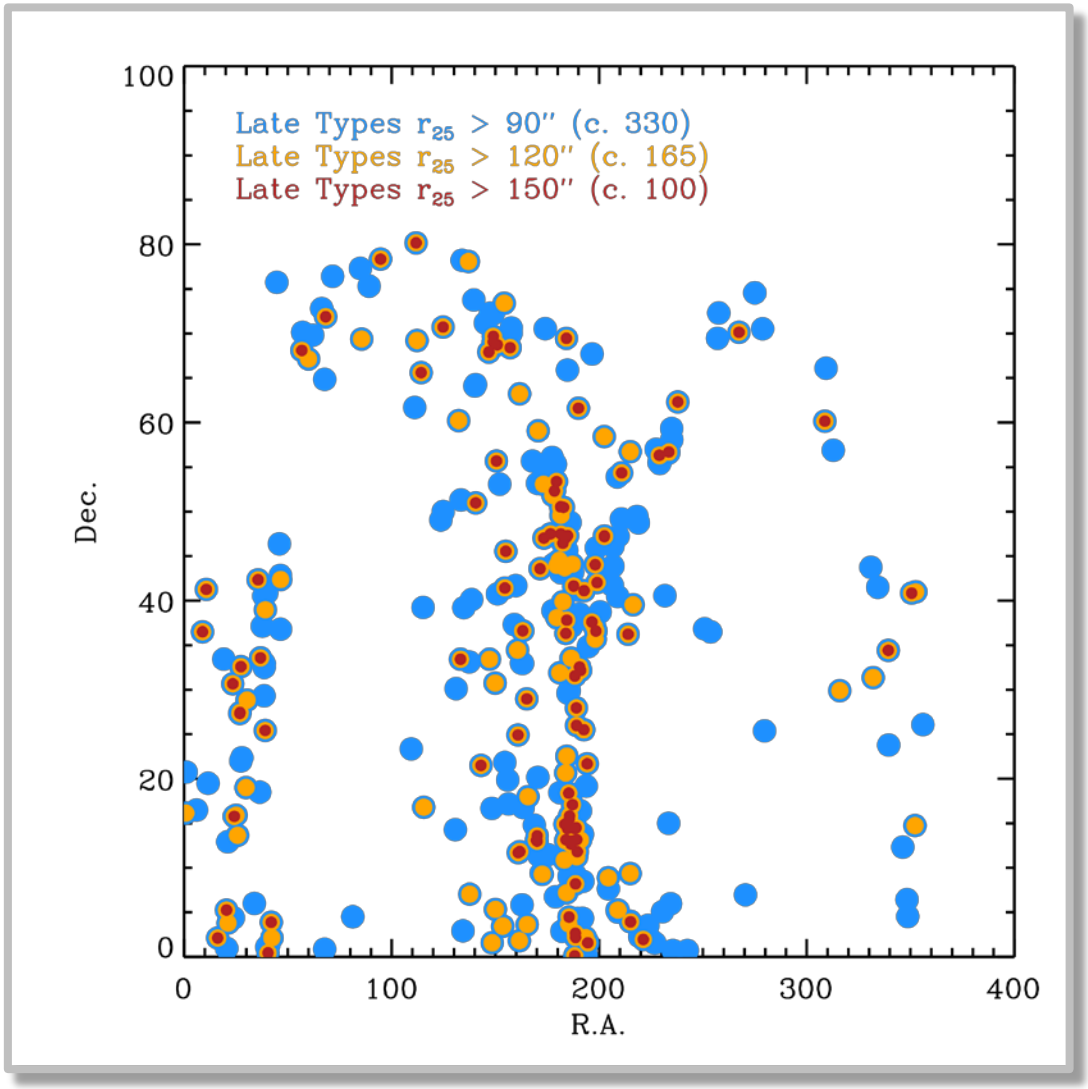


Figure courtesy Adam Leroy

Sensitivities would need to be on the order of ~0.1 mK per 25km/s.

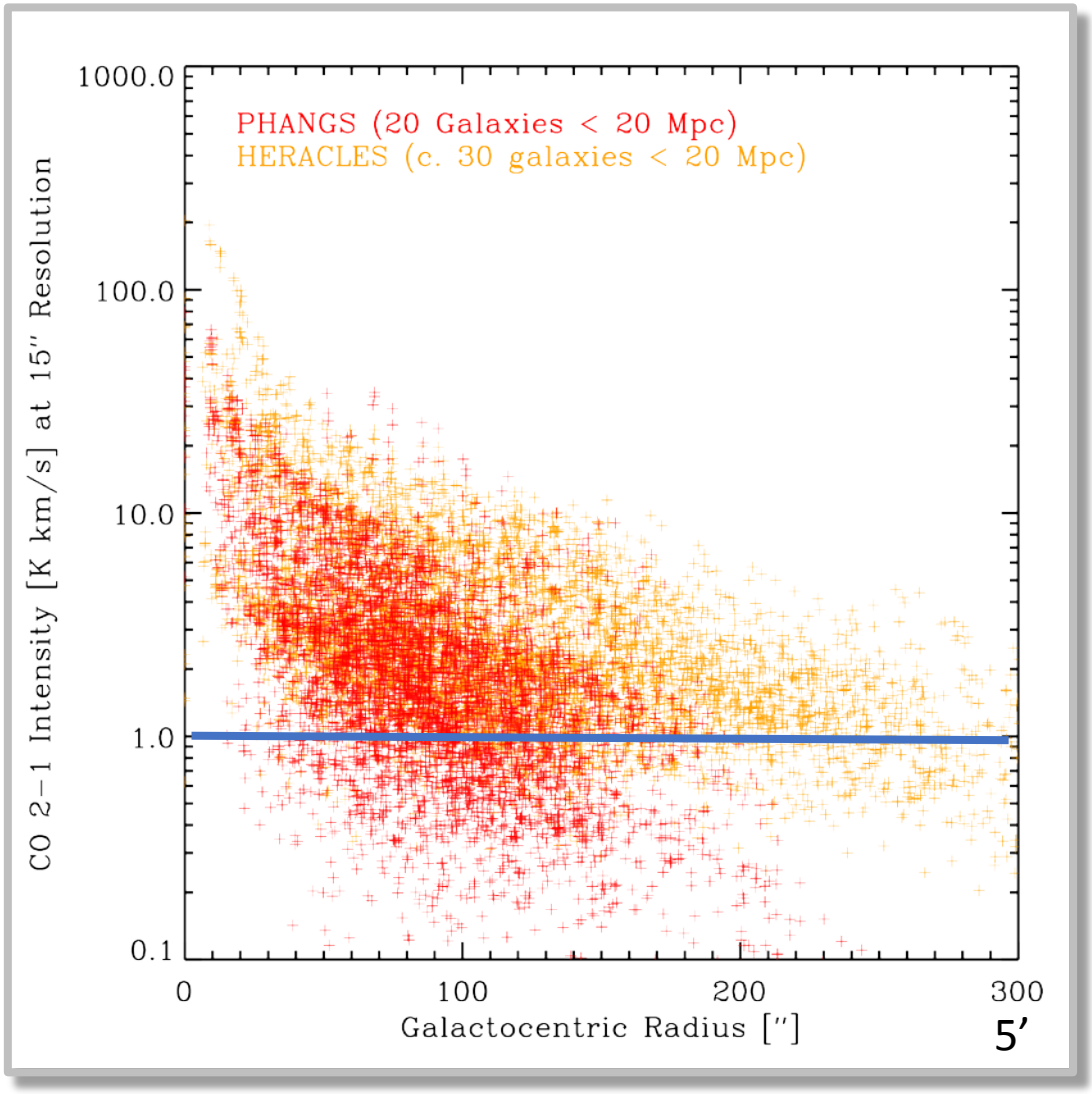


Figure courtesy Adam Leroy

- Line widths ~25km/s
- HCN/CO ratio ~0.01 (disk) to 0.1 (center)
- 0.1 mK to 1mK per 25km/s
- Stacking could enable deeper detections.

Re-cap

- Quantifying the relationship between dense gas and star formation under a wide range of physical conditions is a key step towards understanding star formation.
- Mapping dense gas in nearby galaxies allows us to probe a wide range of physical conditions with good spatial resolution.
- The GBT has the sensitivity and resolution at 4mm to be extremely competitive with other instruments operating at this frequency.
- Multi-pixel receivers like Argus significantly increase the mapping speed of the GBT.
- DEGAS will use the combination of GBT+Argus to do the largest resolved survey of dense gas in nearby galaxies to date.
- Even larger 4mm arrays are possible enabling us to map dense gas across the entire disks of ~100 of nearby galaxies.