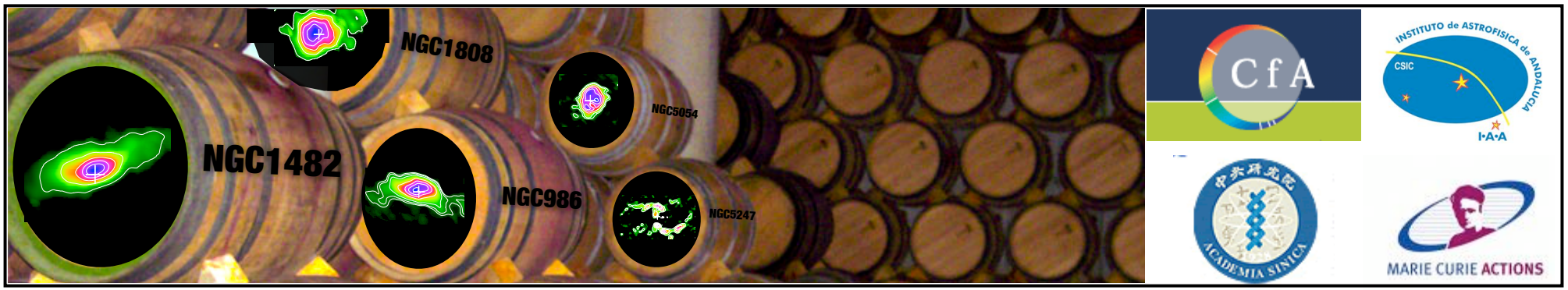
Molecular gas properties in spiral galaxies: The SMA CO(2-1) B0DEGA (Below 0 DEgree GAlaxies) legacy project

Daniel Espada

Marie Curie International Fellow
Instituto de Astrofisica de Andalucia-CSIC (Spain)
Harvard-Smithsonian Center for Astrophysics (USA)

S. Martin, P. Y. Hsieh, P. T. P. Ho, L. Verdes-Montenegro, S. Matsushita, J. Sabater, S. Verley, A. Lopez, B. Koribalski, M. Krips



Molecular gas properties

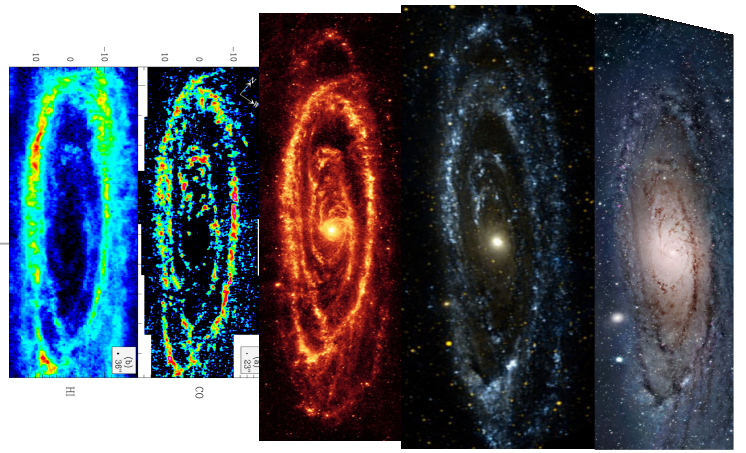
- Internal parameters (Nature, secular evolution): stellar morphology (intrinsic bar?), atomic gas content, star formation laws, AGN, etc.

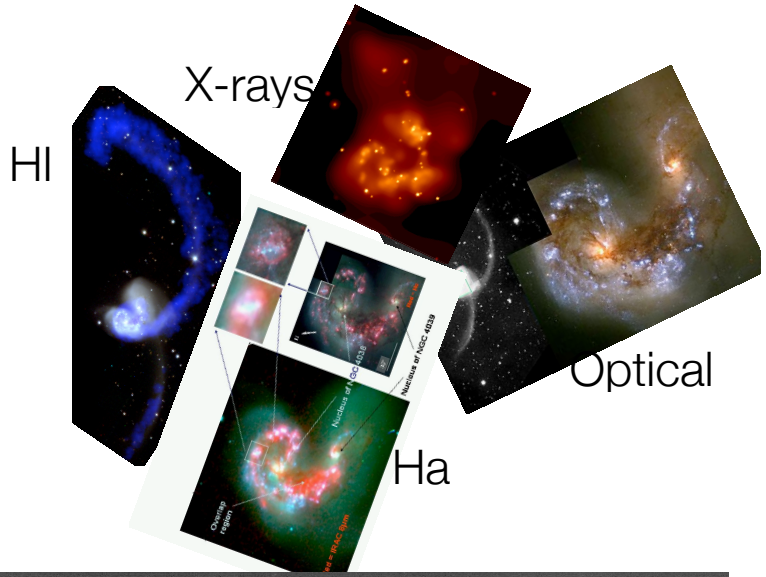
- External parameters (Nurture, environment):

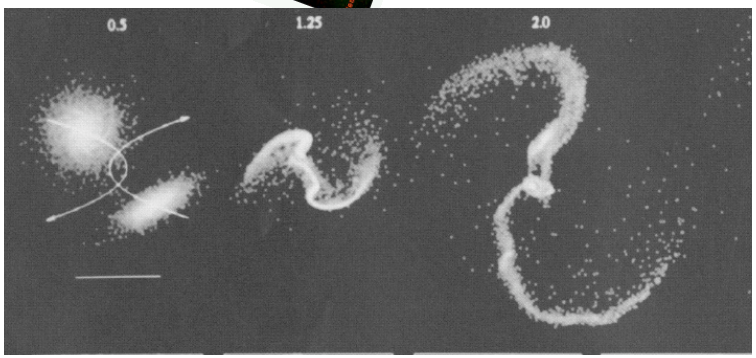
  - Minor and major interactions and mergers: properties of the tidal interaction such as mass ratio, strength impact parameters, etc.

  - Most luminous IR objects appear to be strong interaction / mergers of gas rich spirals (Sanders & Mirabel 1996), but not reciprocal, only ~15% (Bergvall et al. 2003).

  - Ram pressure, gas accretion in cosm. filaments...







Census high-resolution molecular gas surveys

Project	N	Line	Telescope	Aim
BIMA-SONG, Helfer et al. 2003. **THINGs**, Bigiel et al. 2008	44 18	CO(1-0), CO(2-1)	BIMA, IRAM30m	CO properties normal galaxies.
OVRO-NMA, Sakamoto et al. 1999	20	CO(1-0)	OVRO, NRT	Barred vs non-barred
NUGA, Garcia-Burillo, Combes et al.	25	CO(1-0), CO(2-1)	PdBI	Nuclear activity
Seyfert, Matsushita, Kohno et al.	~10	CO(1-0), CO(2-1),CO(3-2) , HCN, HCO+	NRT, SMA	Nuclear activity
LIRGs/ULIRGs, Wilson et al. 2008, Iono et al. 2009	11	CO(2-1), CO(3-2)	SMA	Physical properties gas in merger systems
Total	~200	...	...	...

Census high-resolution molecular gas surveys

Project	N	Line	Telescope	Aim
BIMA-SONG, Helfer et al. 2003. **THINGs**, Bigiel et al. 2008	44 18	CO(1-0), CO(2-1)	BIMA, IRAM30m	CO properties normal galaxies.
OVRO-NMA, Sakamoto et al. 1999	20	CO(1-0)	OVRO, NRT	Barred vs non-barred
NUGA, Garcia-Burillo, Combes et al.	25	CO(1-0), CO(2-1)	PdBI	Nuclear activity
Seyfert, Matsushita, Kohno et al.	~10	CO(1-0), CO(2-1),CO(3-2) , HCN, HCO+	NRT, SMA	Nuclear activity
LIRGs/ULIRGs, Wilson et al. 2008, Iono et al. 2009	11	CO(2-1), CO(3-2)	SMA	Physical properties gas in merger systems
Total	~200	...	...	...

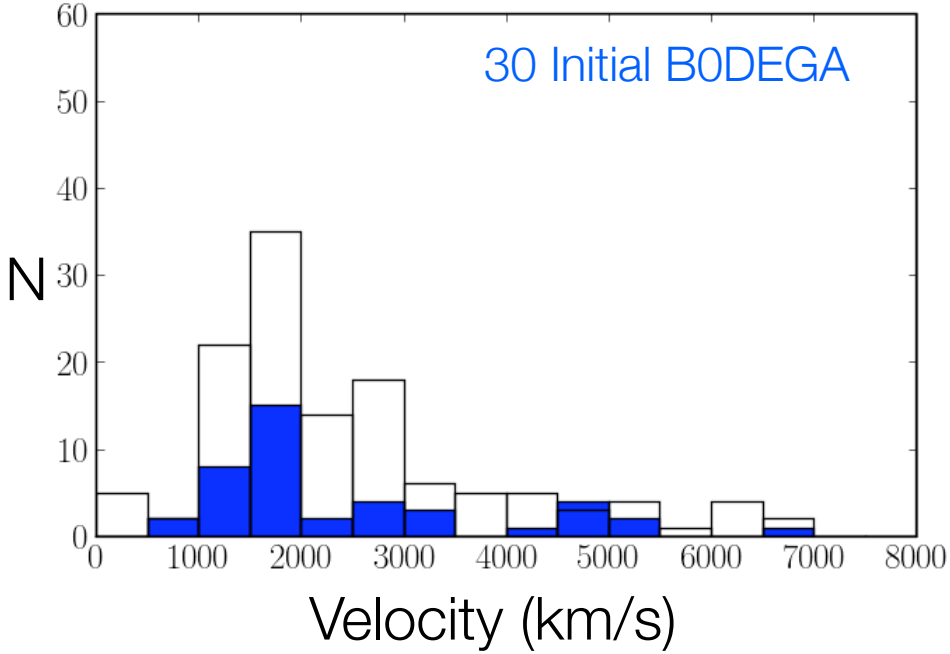
Census high-resolution molecular gas surveys

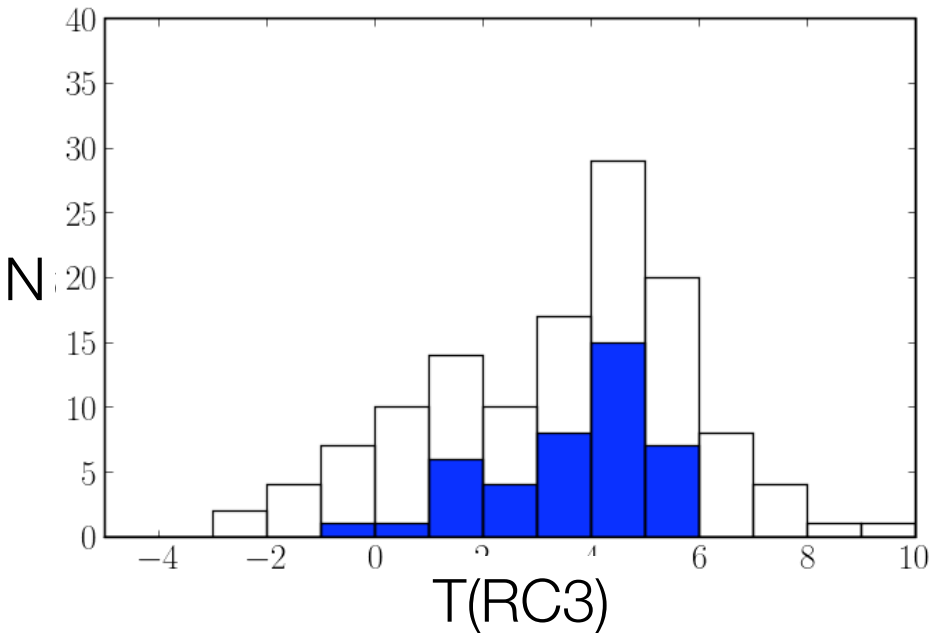
Project	N	Line	Telescope	Aim
BIMA-SONG, Helfer et al. 2003. **THINGs**, Bigiel et al. 2008	44 18	CO(1-0), CO(2-1)	BIMA, IRAM30m	CO properties normal galaxies.
OVRO-NMA, Sakamoto et al. 1999	20	CO(1-0)	OVRO, NRT	Barred vs non-barred
NUGA, Garcia-Burillo, Combes et al.	25	CO(1-0), CO(2-1)	PdBI	Nuclear activity
Seyfert, Matsushita, Kohno et al.	~10	CO(1-0), CO(2-1),CO(3-2) , HCN, HCO+	NRT, SMA	Nuclear activity
LIRGs/ULIRGs, Wilson et al. 2008, Iono et al. 2008	11	CO(2-1), CO(3-2)	SMA	Physical properties gas in merger systems
SMA B0DEGA, Espada et al.	70	CO(2-1)	SMA	CO properties IR-bright spiral galaxies

The SMA CO(2-1) B0DEGA legacy project

- CO(2-1) for N ~70 unexplored southern galaxies (-45º< dec. < 0º)
- IR-bright (2.58 S60um + S100um > 31.5 Jy)
- Spiral galaxies, mostly Sb - Sc (70%), usually members of pairs, triplets, groups
- Not mergers

- Other observations and archival data: HI (VLA, ATCA), mid-IR (Spitzer), Ha (1m-2m telescopes), UV (GALEX), dense gas HCO+, HCN (NRO, ATCA).

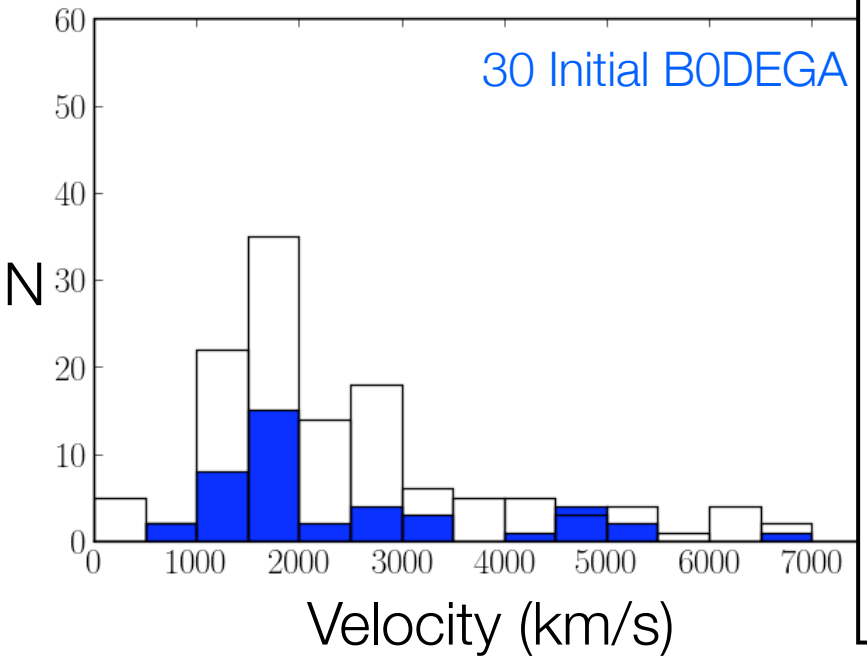


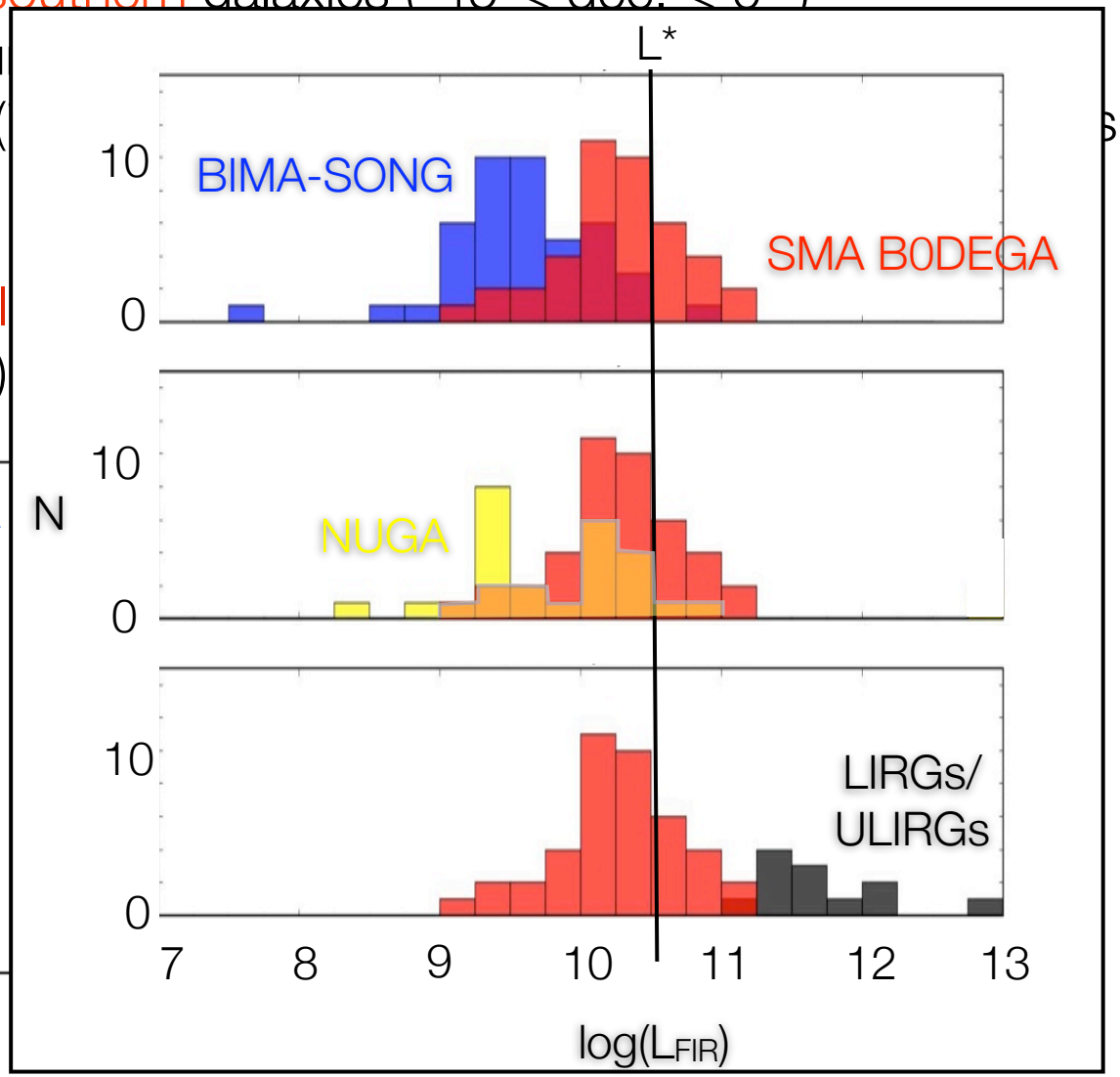


The SMA CO(2-1) B0DEGA legacy project

- CO(2-1) for N ~70 unexplored southern galaxies (-45º< dec. < 0º)
- IR-bright (2.58 S60um + S100u
- Spiral galaxies, mostly Sb - Sc (
- Not mergers

- Other observations and archival
(1m-2m telescopes), UV (GALEX)





Preliminary results

Preliminary results

I. CO(2-1) morphologies in inner few kpcs

Preliminary results

I. CO(2-1) morphologies in inner few kpcs

II. CO(2-1) concentration and environment

Preliminary results

I. CO(2-1) morphologies in inner few kpcs

II. CO(2-1) concentration and environment

III. Global SF law using CO(2-1) and SFE

Preliminary results

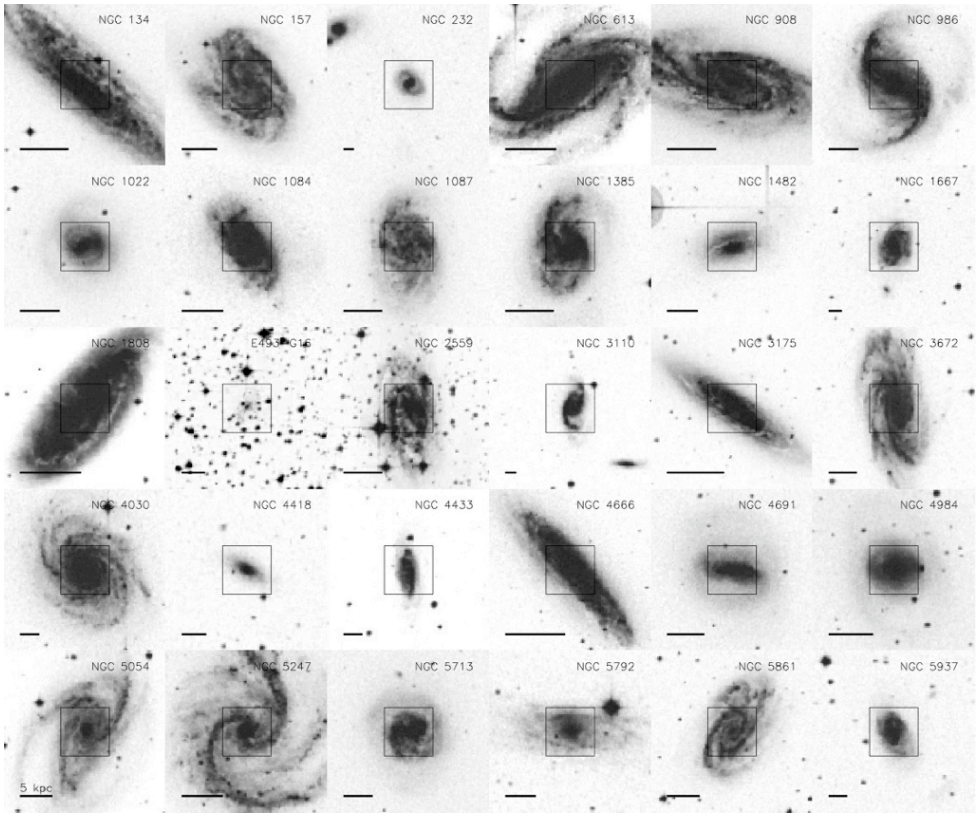
I. CO(2-1) morphologies in inner few kpcs

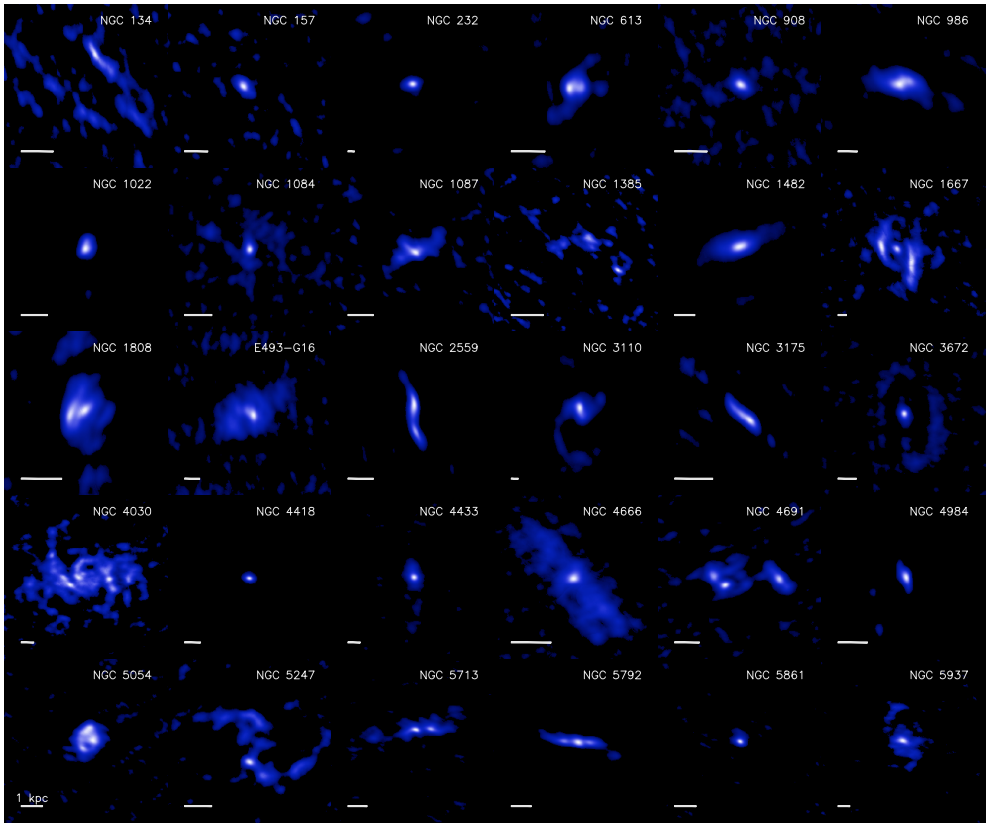
II. CO(2-1) concentration and environment

III. Global SF law using CO(2-1) and SFE

IV. $^{12}CO/^{13}CO$ radial distribution. Origin of the molecular gas?

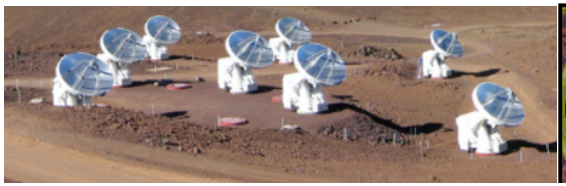
I. The B0DEGA SMA CO(2-1) Atlas

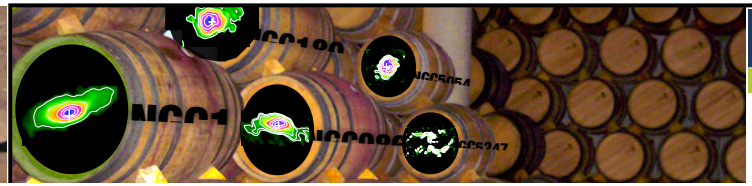




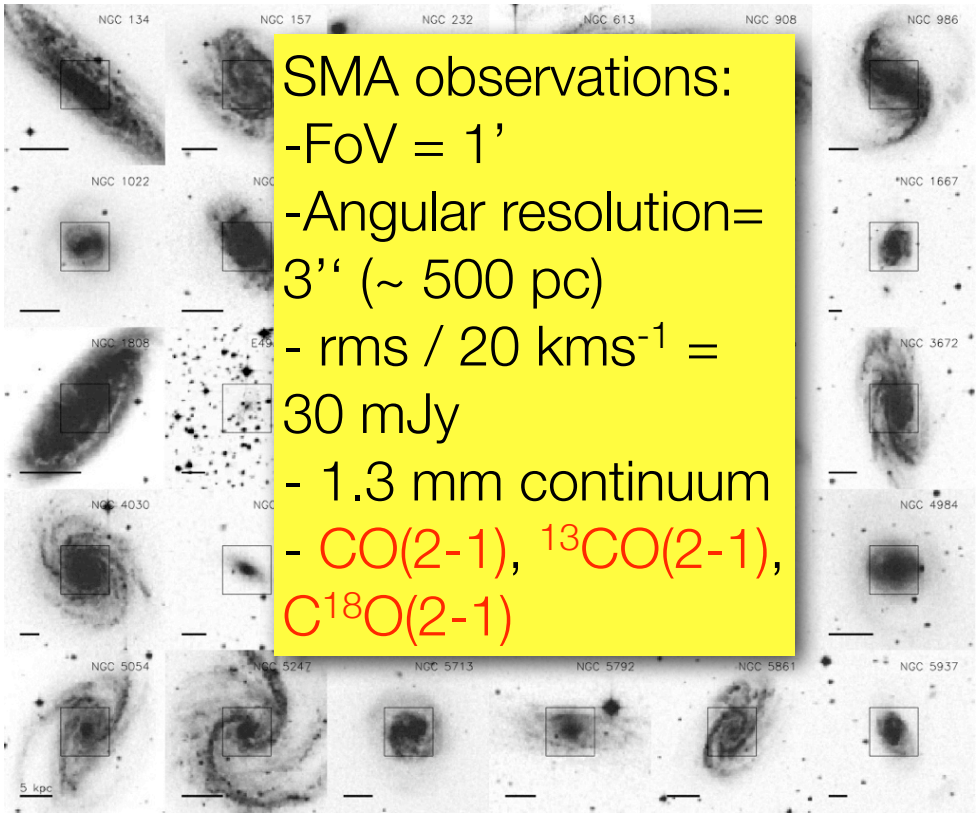
DSS Optical

SMA CO(2-1)

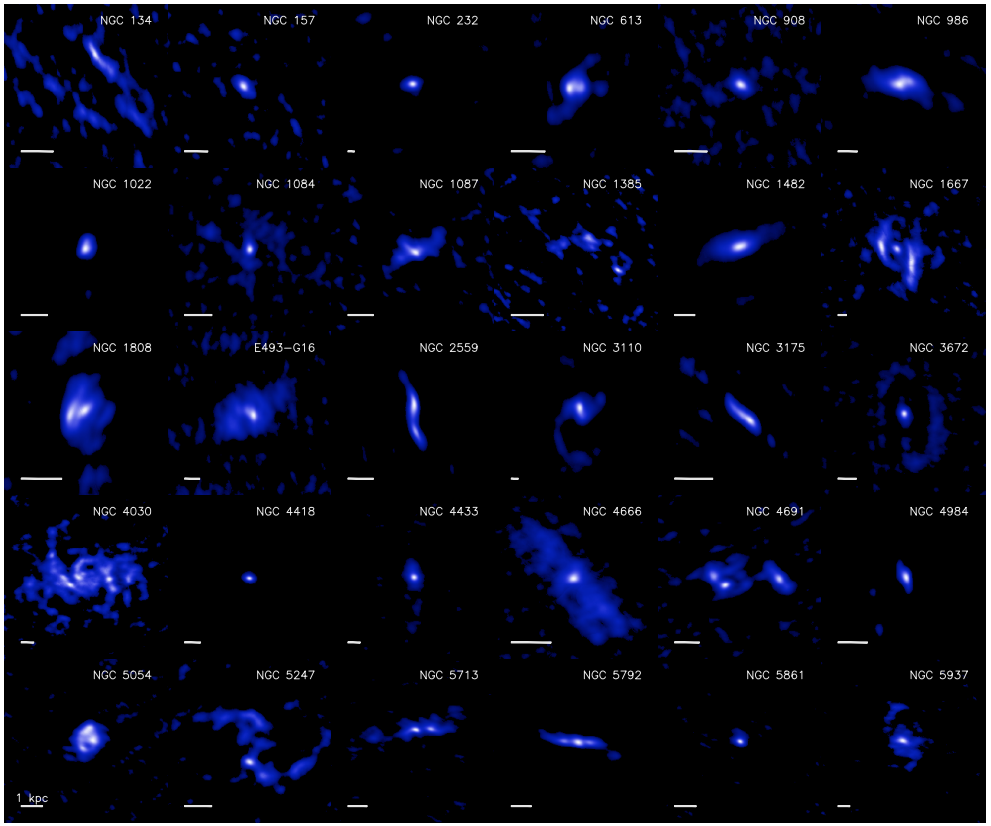




I. The B0DEGA SMA CO(2-1) Atlas

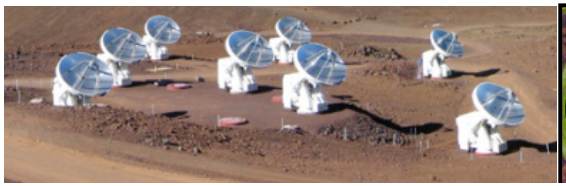


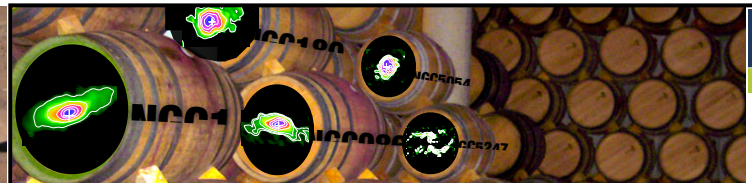
SMA observations:
-FoV = 1'
-Angular resolution= 3'' (~ 500 pc)
- rms / 20 kms^{-1} = 30 mJy
- 1.3 mm continuum
- CO(2-1), ^{13}CO(2-1), C^{18}O(2-1)

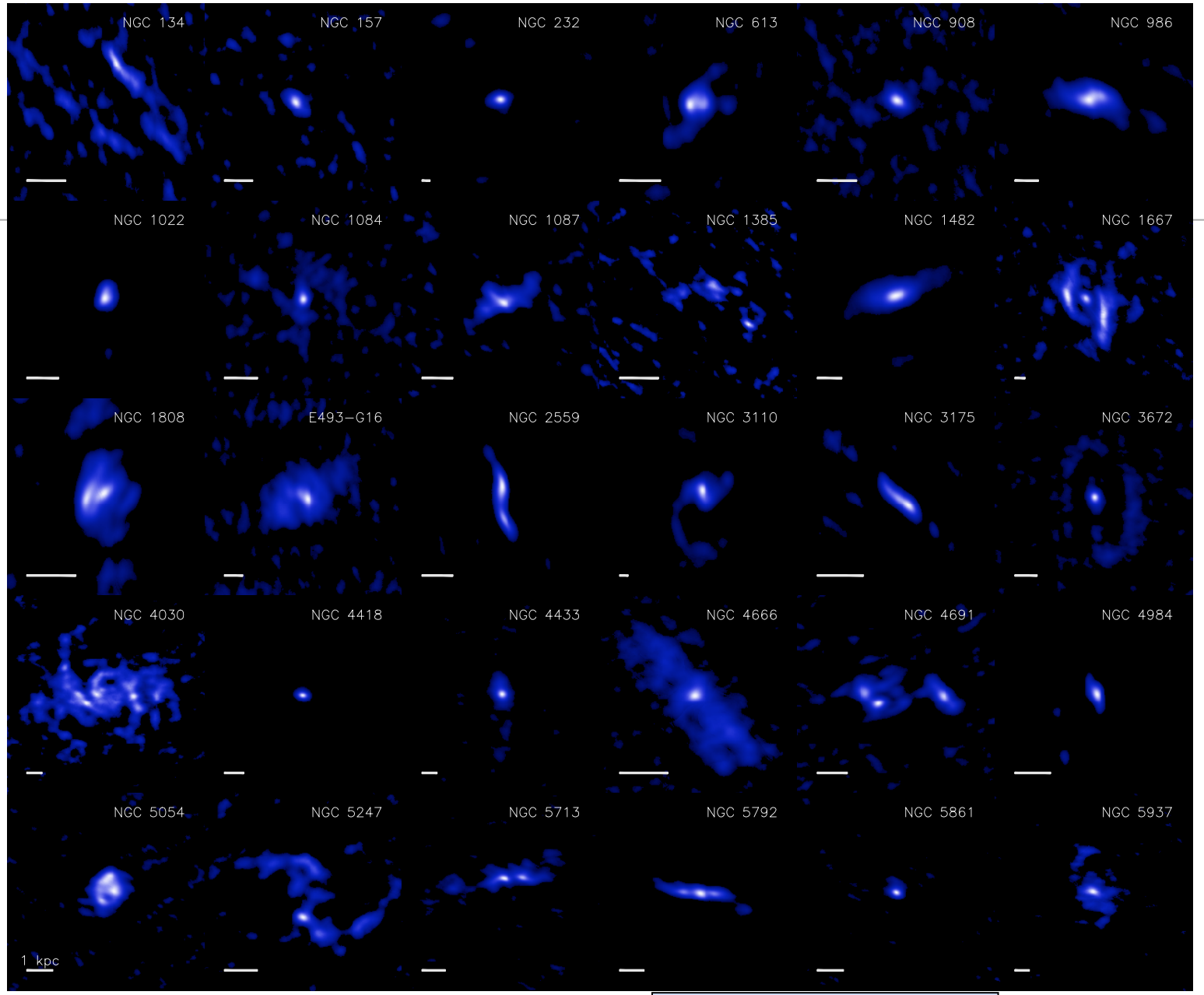


DSS Optical

SMA CO(2-1)







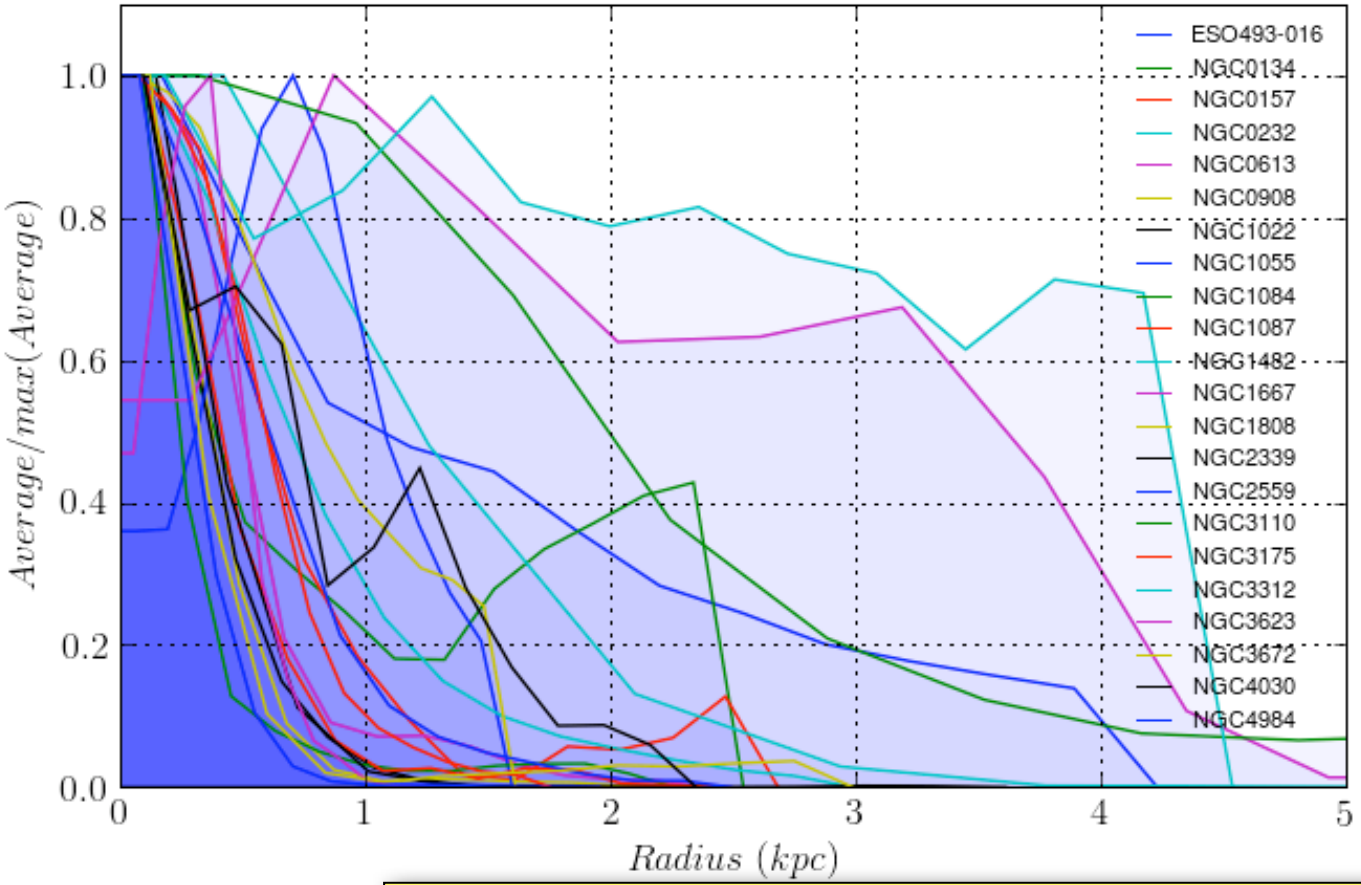
Circumnuclear disk: 85%
(e.g. NGC4984)

Extended disk: 33%
(e.g. NGC1482)

Ring structure: 15%
(e.g. NGC 134)

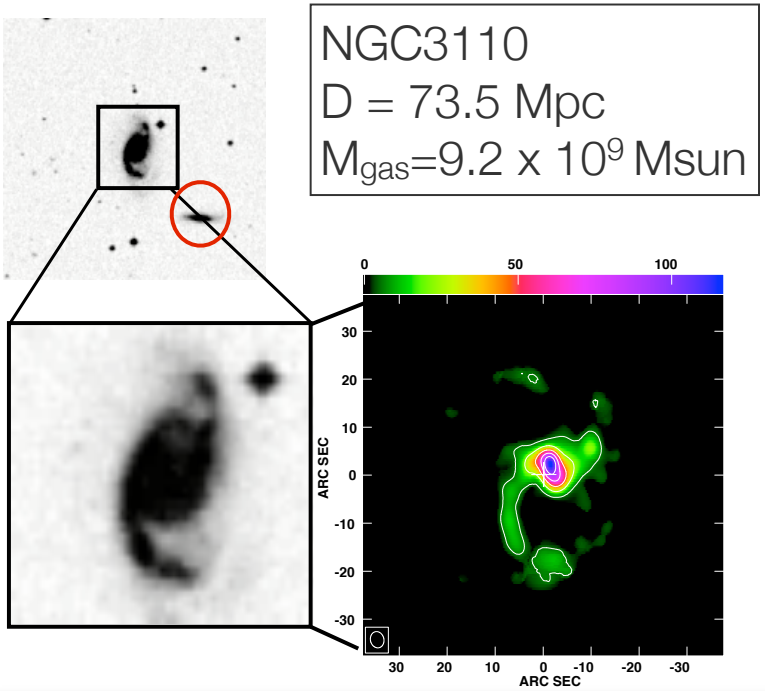
Nuclear bar/arms: 20%
(e.g. NGC 5247)

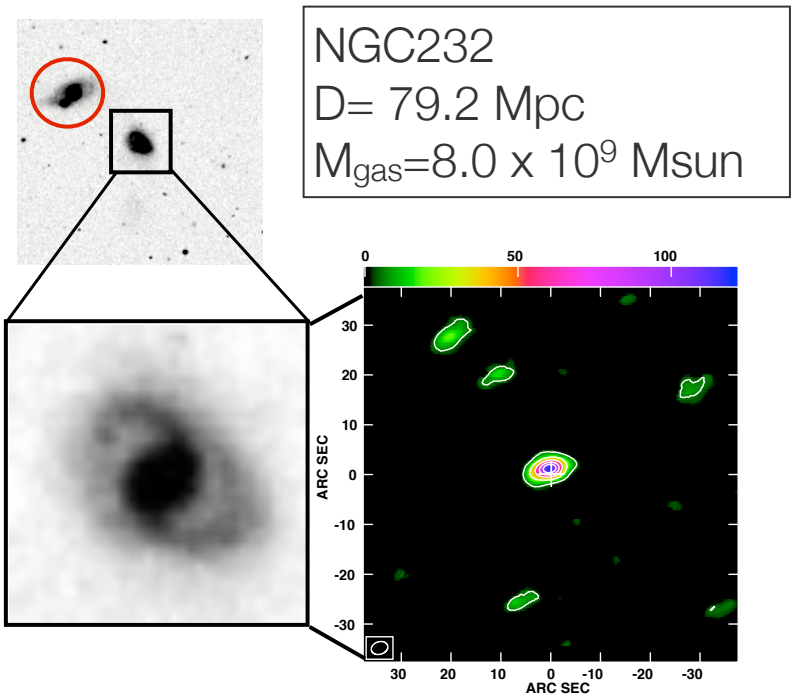
II. CO(2-1) concentration and environment



- 87% of the galaxies peak in the center
- Size scale is ~ 0.5 - 1 kpc, circumnuclear disks
- Larger concentration rate than in normal galaxies (BIMA-SONG), although similar bar rate.

II. CO(2-1) concentration and environment

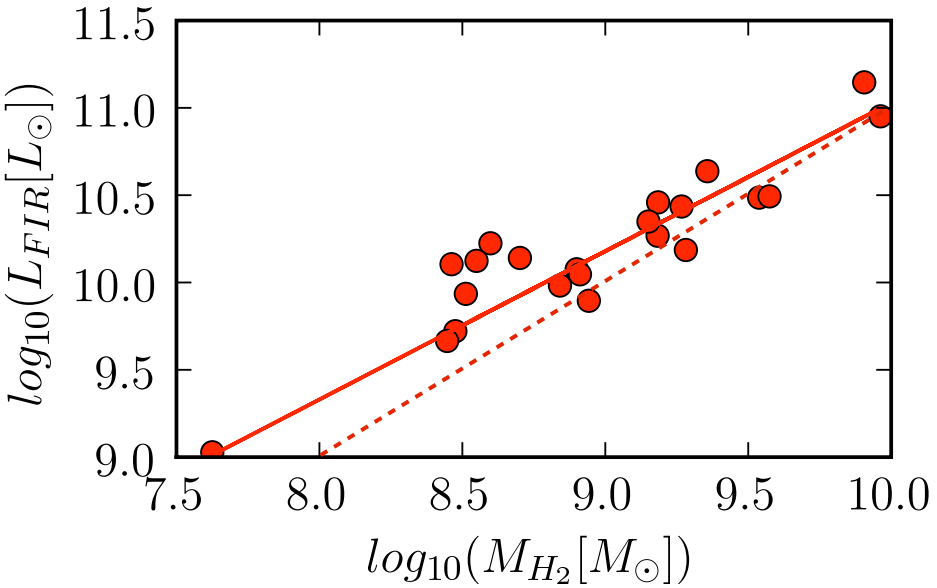


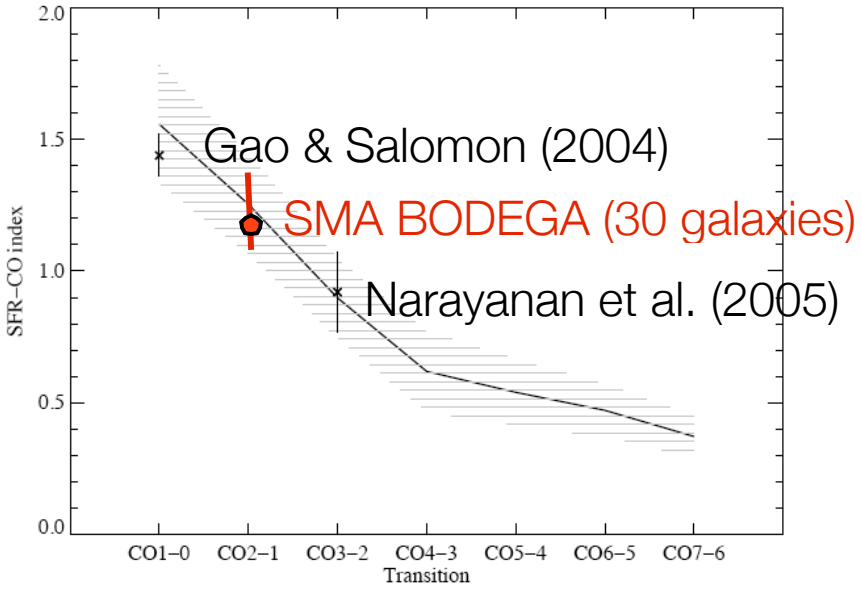


-Fly-by interactions (companion at 2 arcmin ~ 40 kpc, Delta V ~ 200 km/s) is an efficient mechanism to fuel gas to the central regions.

-Formation of spiral arms (shocks) and bar (central component) as a result of the interaction, as in numerical simulations.

III. Global SF laws CO(2-1) and SFE





-SFR - CO(2-1) slope = 1.15 - 1.21 (p=0.91)

-Agrees with predicted SFR-CO(2-1) index from simulations (Narayanan et al., 2007)

-SFE: 8 - 43 Lo/Mo, between normal spiral galaxies and ULIRGs

IV. $^{12}CO/^{13}CO$ radial distribution

-$R_{12/13}$ ~10 in actively star forming disk galaxies (Sage & Isbell 1991, Sakamoto et al. 2005)

-ULIRGs and high-z $R_{12/13} > 20$ (Aalto et al. 1991, Casoli et al. 1992, Henkel & Mauersberger 1993, Henkel et al. 2010)

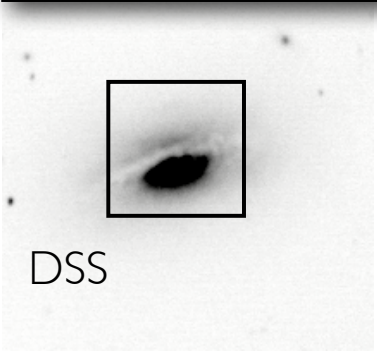
- $$R_{12/13} = \frac{(1 - e^{-\tau_{12}})}{(1 - e^{-\tau_{13}})} \frac{\left[J\left(T_{\mathrm{ex},12}\right) - J(T_{\mathrm{CMB}})\right]}{\left[J\left(T_{\mathrm{ex},13}\right) - J(T_{\mathrm{CMB}})\right]} \frac{f_{b,12}}{f_{b,13}},$$

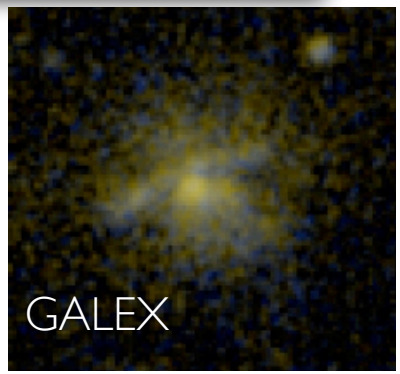
-Less processed gas: 12C/13C abundance ratio is considered to be a diagnostic of “primary” vs. “secondary” nuclear processing (e.g., Wilson & Rood 1994, Henkel et al. 1991)

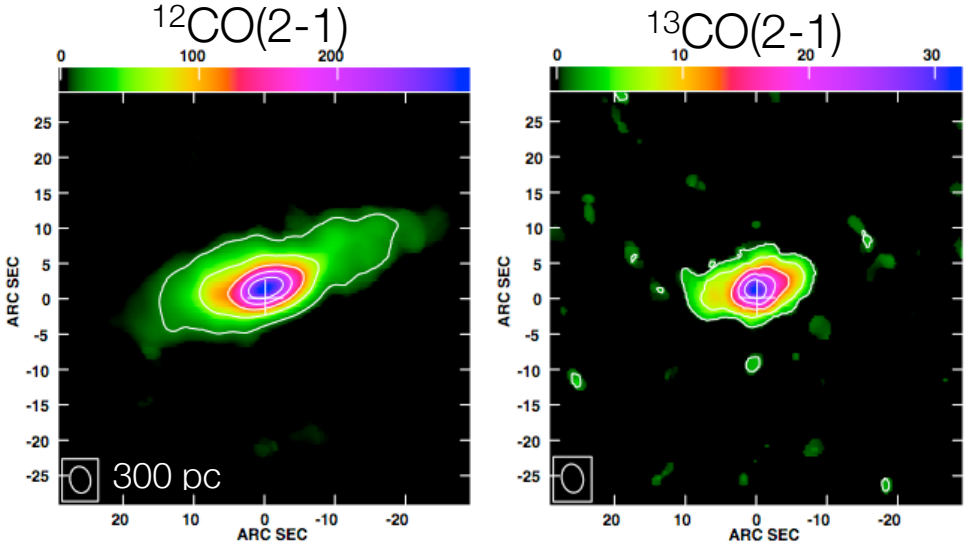
IV. $^{12}CO/^{13}CO$ radial distribution

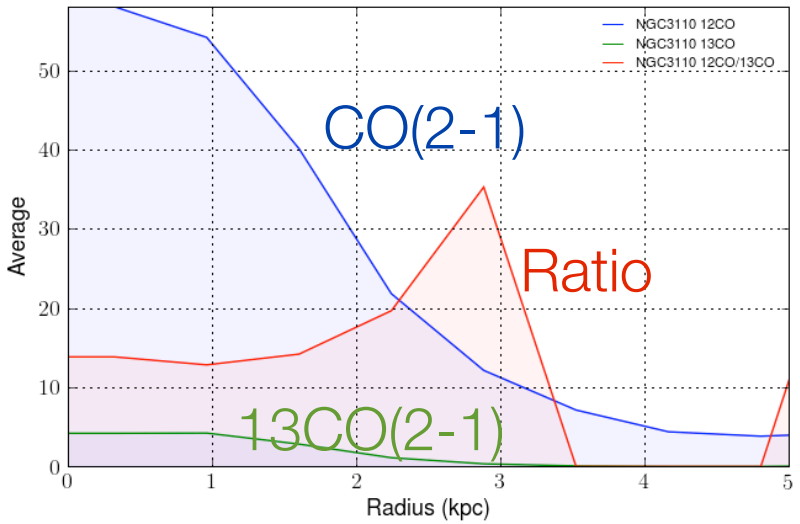
IV. $^{12}CO/^{13}CO$ radial distribution

NGC 1482 T=S0 pec V=1916



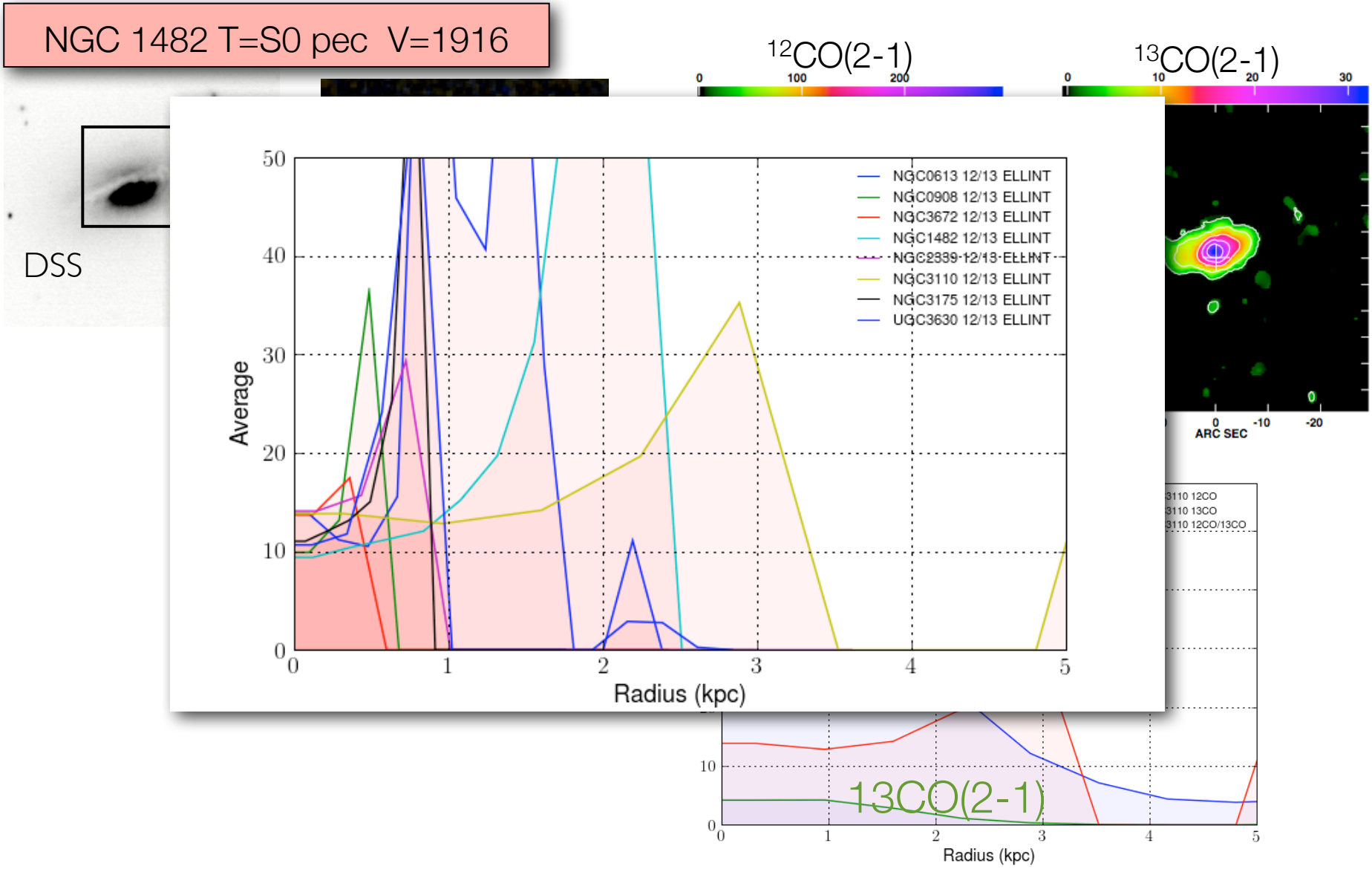






IV. $^{12}CO/^{13}CO$ radial distribution

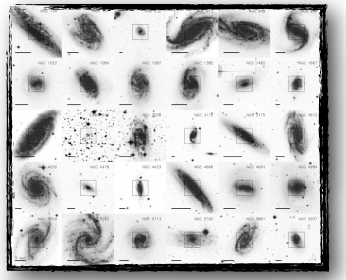
NGC 1482 T=S0 pec V=1916



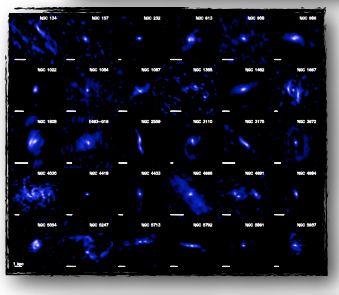
Prospects 2010-2011

- Study environment of B0DEGA galaxies, as well as observing and compiling HI data as a good tracer of interactions.
- Study of dense gas: HCO+(1-0), HCN(1-0).
- Radial point to point SF laws (Spitzer midIR, GALEX UV, Ha).
- AGN census via homogeneous optical spectroscopy.
- Compile CO interferometric data for other galaxies from the literature for statistical analysis of: concentration, asymmetries.
- Prepare for ALMA Early Science.

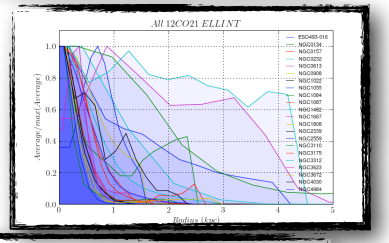
Summary



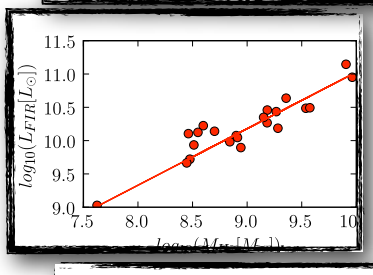
- B0DEGA galaxies: - Nearby IR-bright
  - Interacting (barred) spirals, but not mergers
  - Starburst
  - Southern sky



- Wide variety of molecular gas morphologies: cnds (85%), rings (15%), nuclear arms (20%) and extended structures (33%)

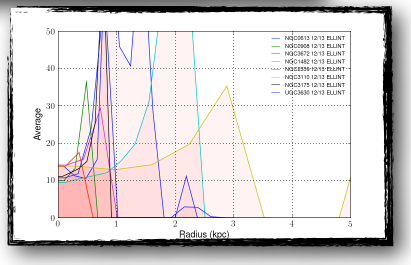


- 87% galaxies with central peak, unlike normal galaxies (45 %)
  - Gas concentrated 0.5 - 1 kiloparsec
  - Fly-by interactions as an efficient mechanism for gas inflow



- SFR-CO(2-1) law: N = 1.2, in agreement with simulations.

-SFE between normal galaxies and mergers.



- $^{12}CO/^{13}CO$ ratio varies with radius from 10 - 50.

-External origin of the gas?