Studying galaxy evolution in isolated galaxies with ALMA

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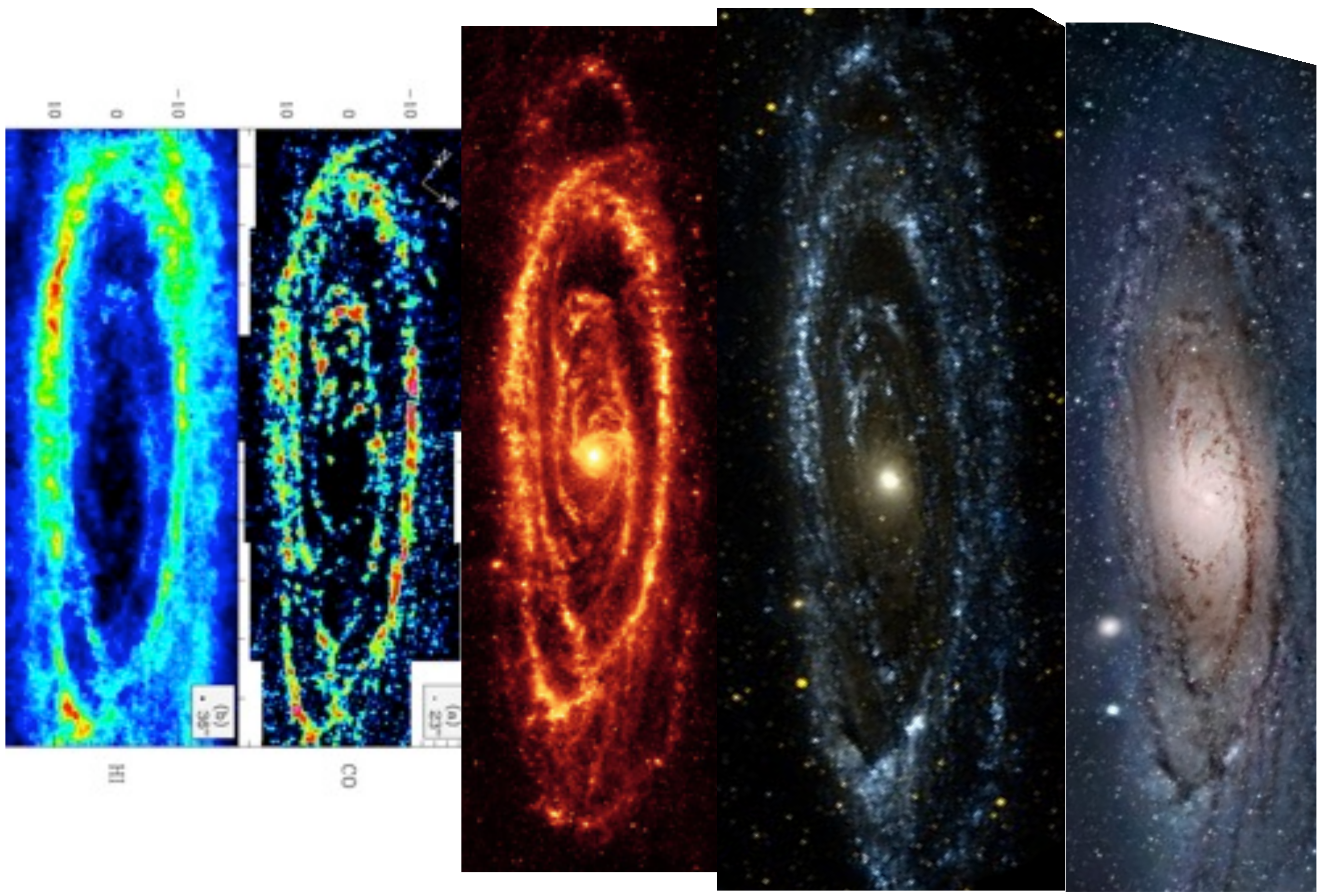
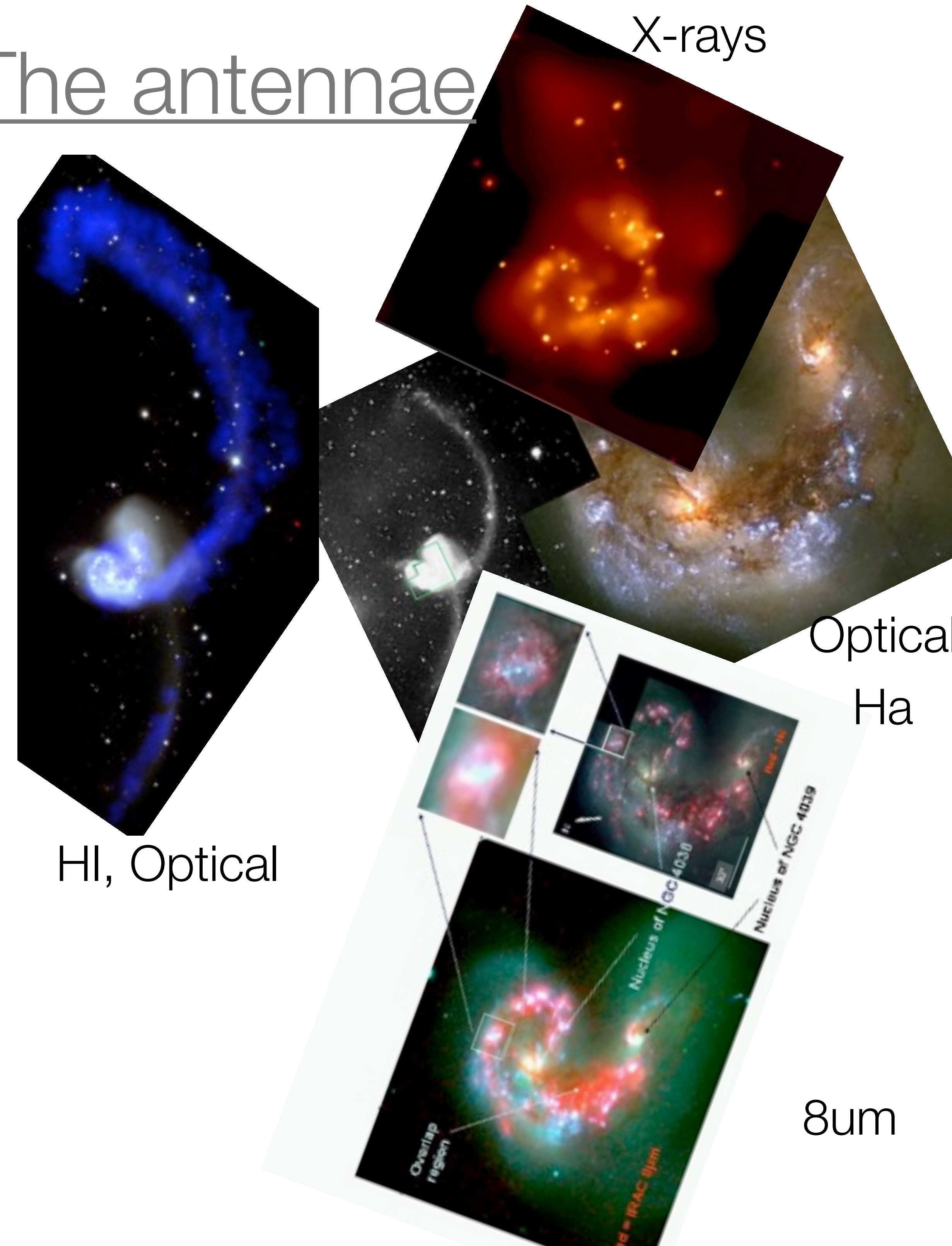
ISM, Star Formation and Environment

M31



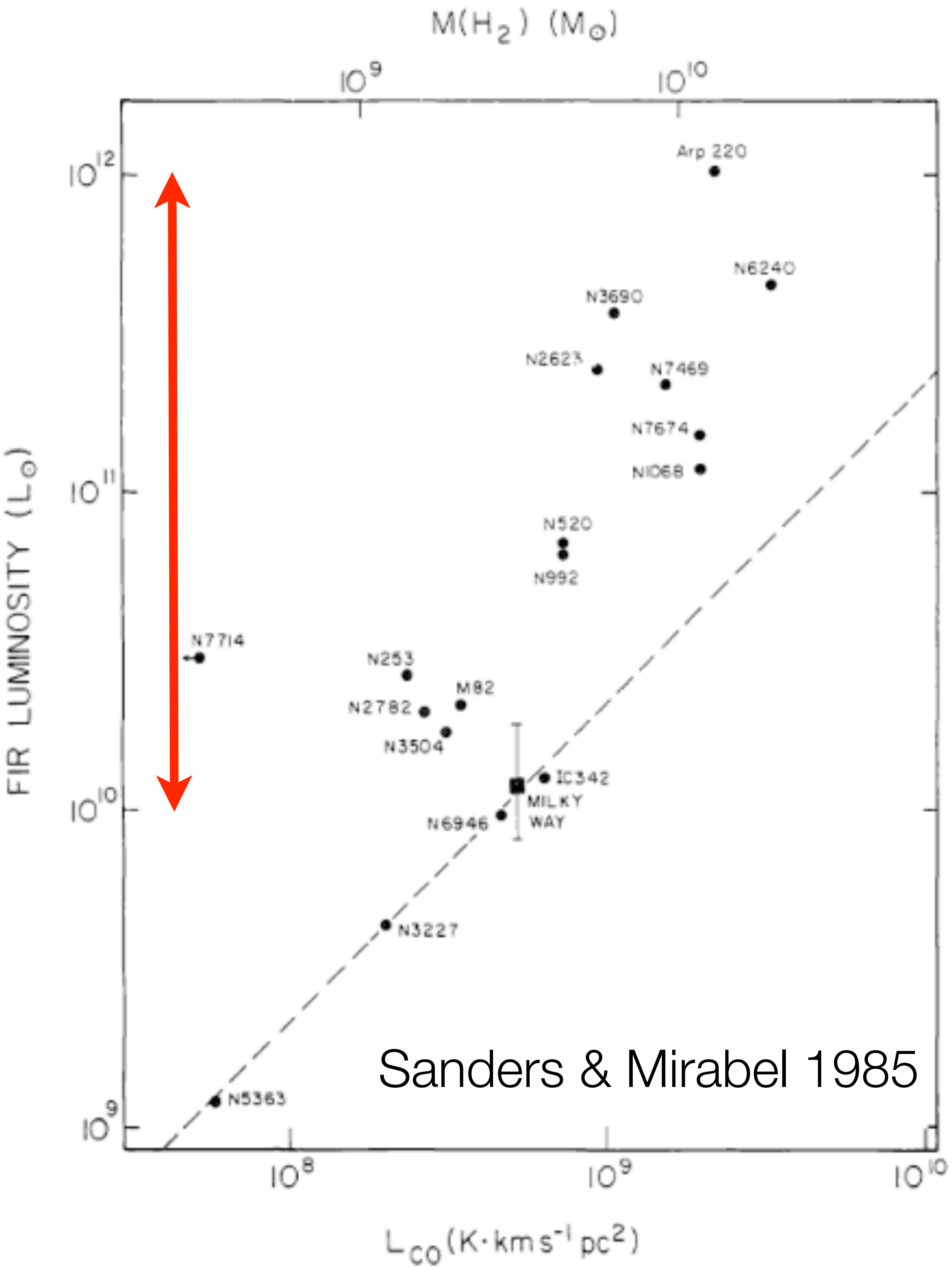
HI CO 24um UV Optical

The antennae



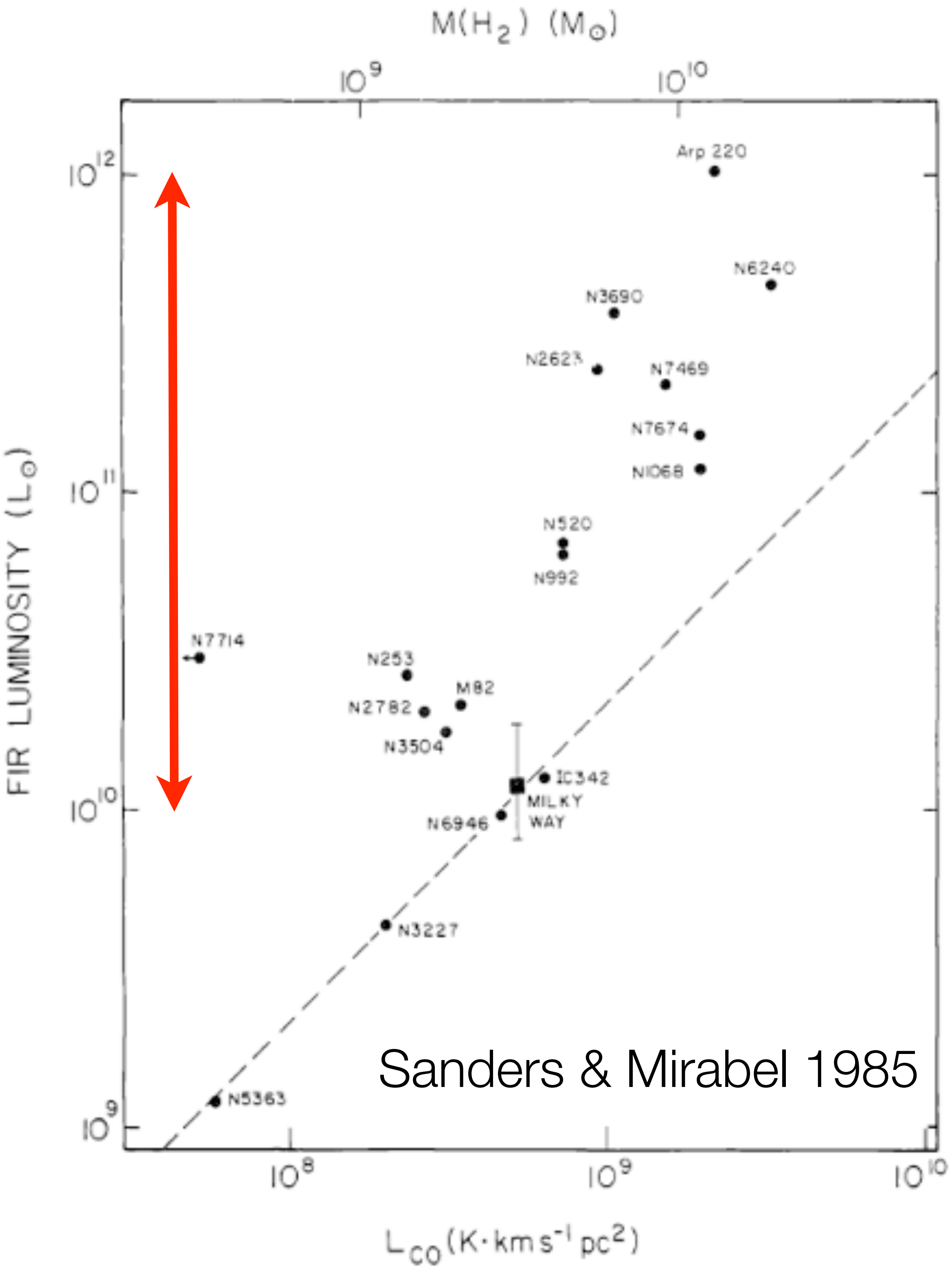
HI, Optical

ISM, Star Formation and Environment



- L_{FIR}/M_{H2} is a good estimate of star formation efficiency.
- In normal spiral galaxies SFE = 1 - 3, in starburst ~ 20 and ULIRGs is >100 Lsun/Msun.
- This is directly linked to the environment: SFE is higher in perturbed galaxies.

ISM, Star Formation and Environment



Sanders & Mirabel 1985

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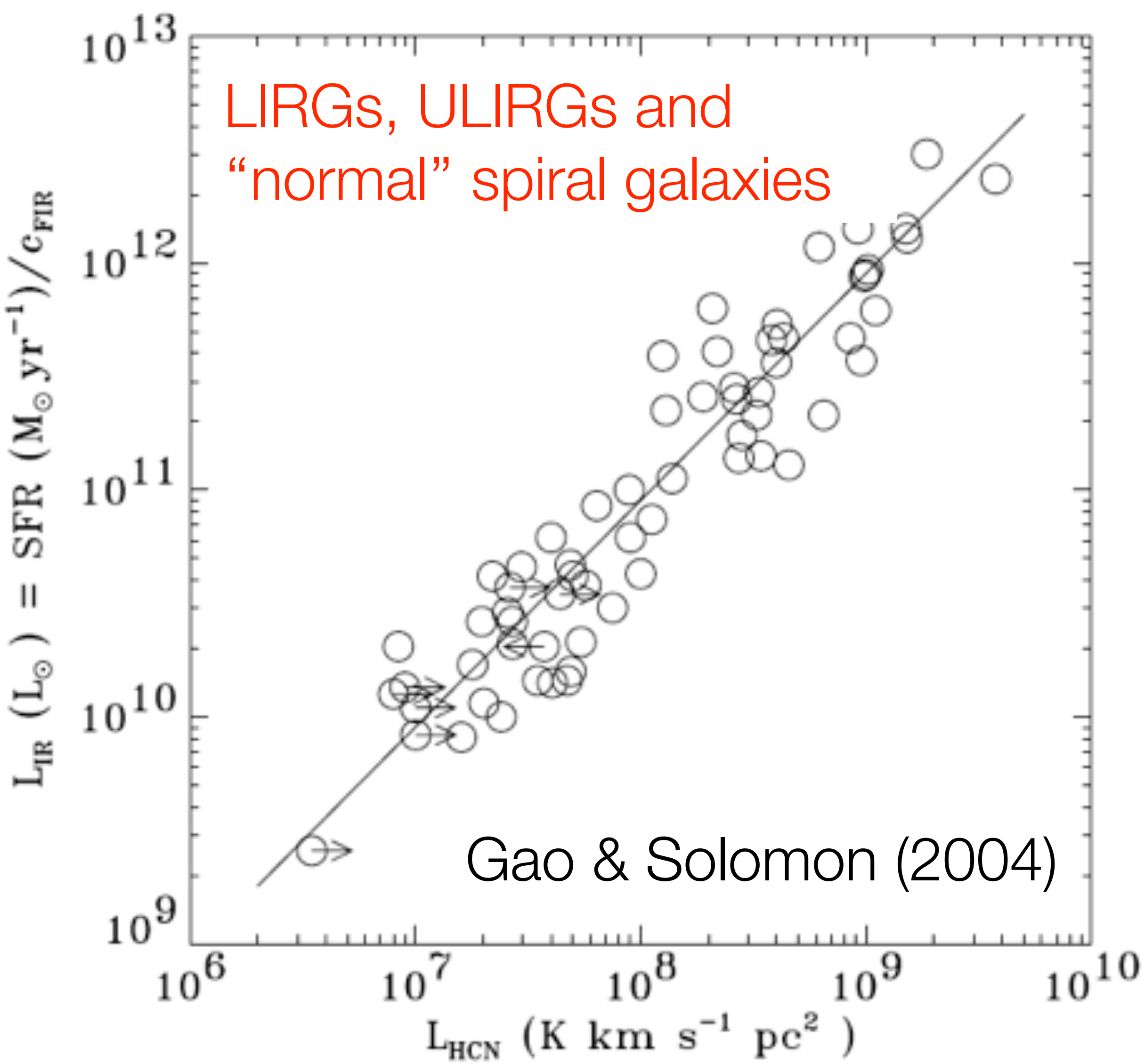
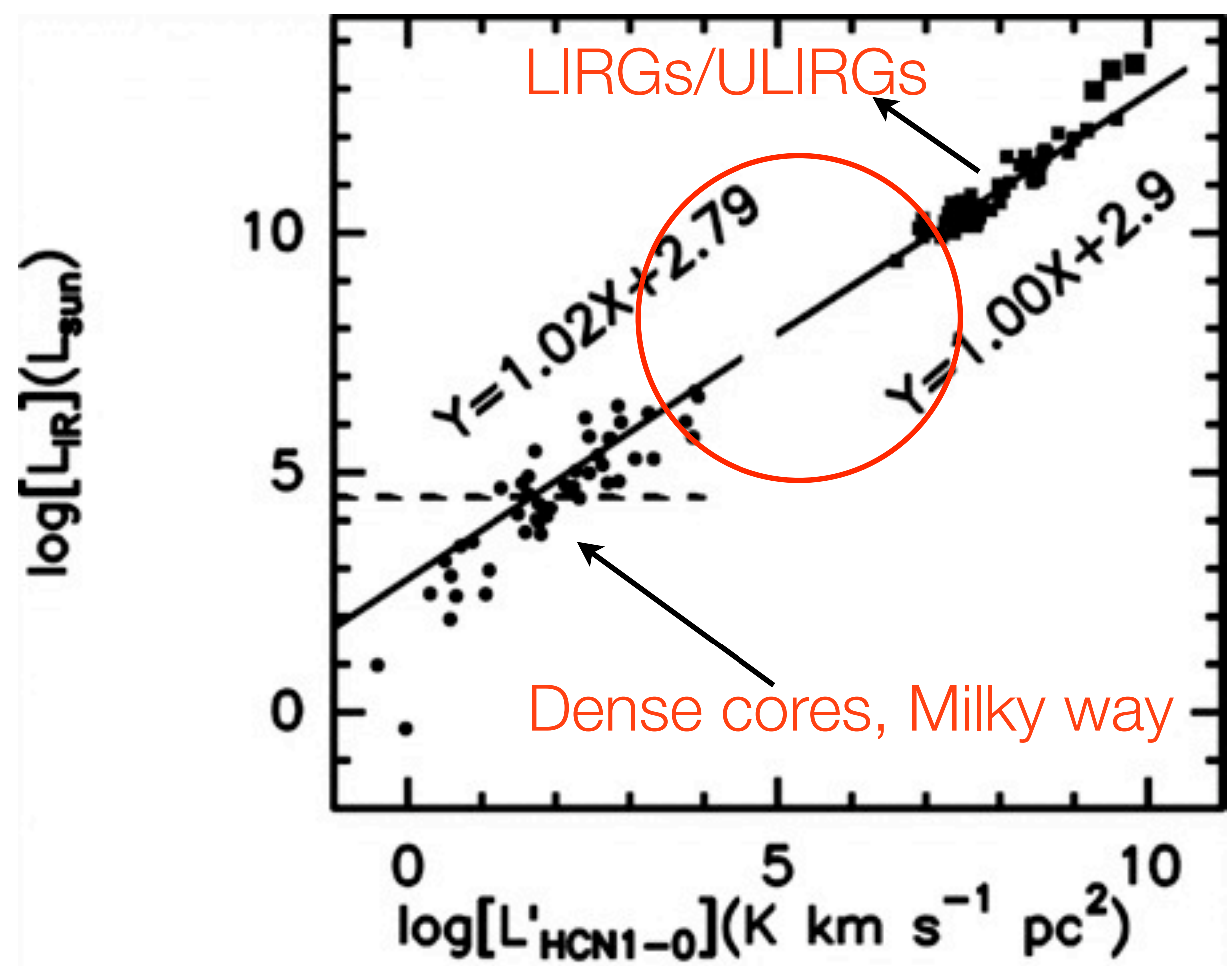
ISM, Star Formation and Environment

- Which molecular gas tracer is more adequate? CO, HCN, HCO+,..?
- L_{FIR} - L_{HCN} correlation holds well from dense cores with $L_{FIR} > 10^5$ L_{sun} to LIRGs/ULIRGs. In dense cores with $L_{FIR} < 10^5$ L_{sun} there is a deviation.
- Lack of resolution (and sensitivity) in studies with statistical significance.





Wu et al. (2004)

High-resolution molecular gas surveys

Project	N	Line	Telescope	Aim
BIMA-SONG, Helfer et al. 2003	44	CO(1-0)	BIMA	CO properties normal galaxies.
OVRO-NRT, Sakamoto et al. 1999	20	CO(1-0)	OVRO, NRT	Barred vs non-barred
SCONES, Petitpas et al. 2006	~10	CO(2-1), CO(3-2)	SMA	Warm gas in normal galaxies.
NUGA, Garcia-Burillo, Combes et al.	25	CO(1-0), CO(2-1)	PdBI	Gas and Nuclear activity
Seyfert, Matsushita, Kohno et al.	~10	CO(1-0), CO(2-1),CO(3-2), HCN, HCO+	NRT, SMA	Gas and Nuclear activity
LIRGs/ULIRGs, Wilson et al. 2008	11	CO(2-1), CO(3-2)	SMA	Physical properties (U)LIRGs

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No statistics ... and for other molecules, hopeless!
let’s wait for ALMA...

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SMA BODEGA, Espada et al.	>40 100	CO(2-1)	SMA	CO properties IR-bright spiral galaxies

High-resolution molecular gas surveys

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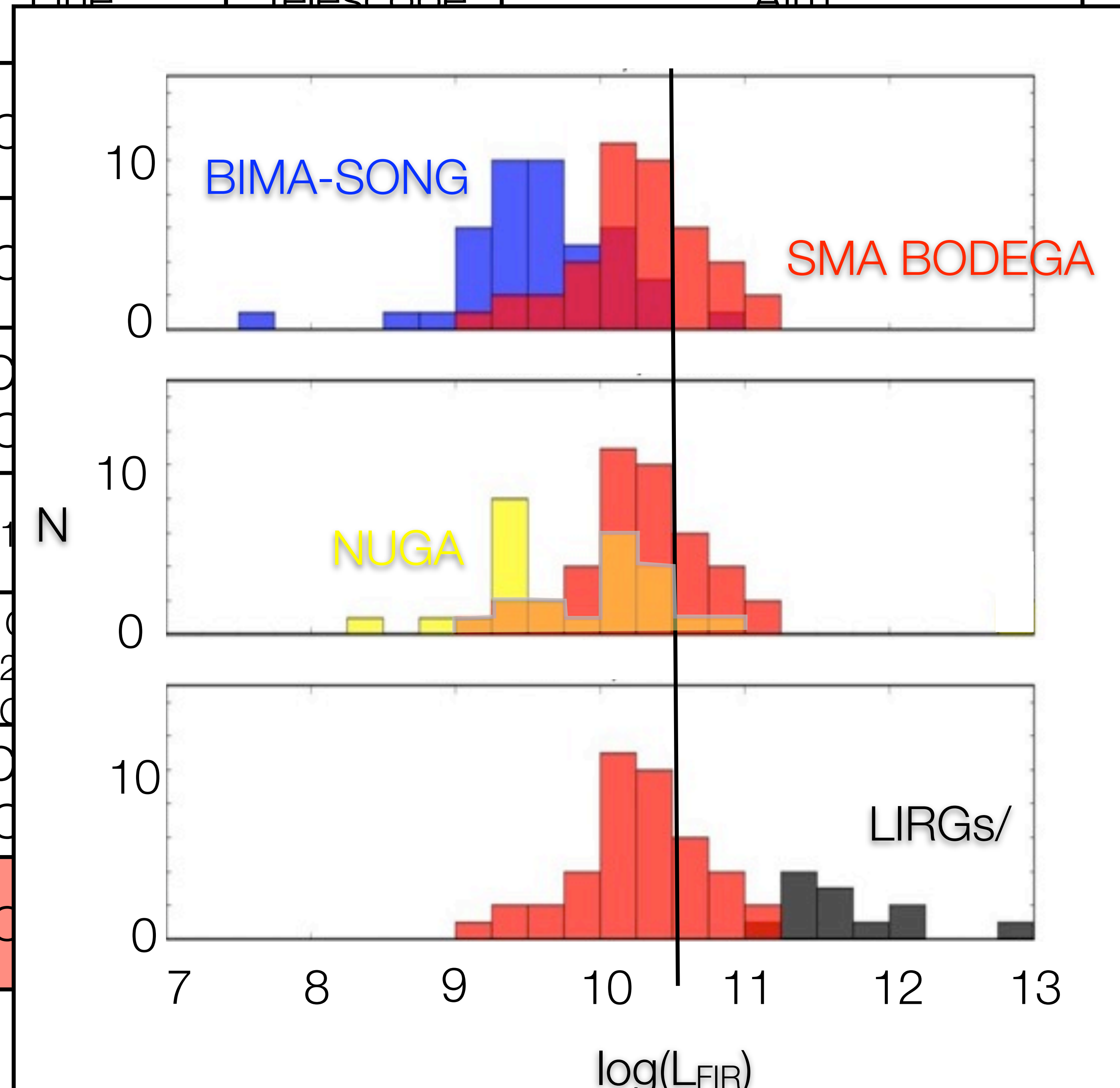
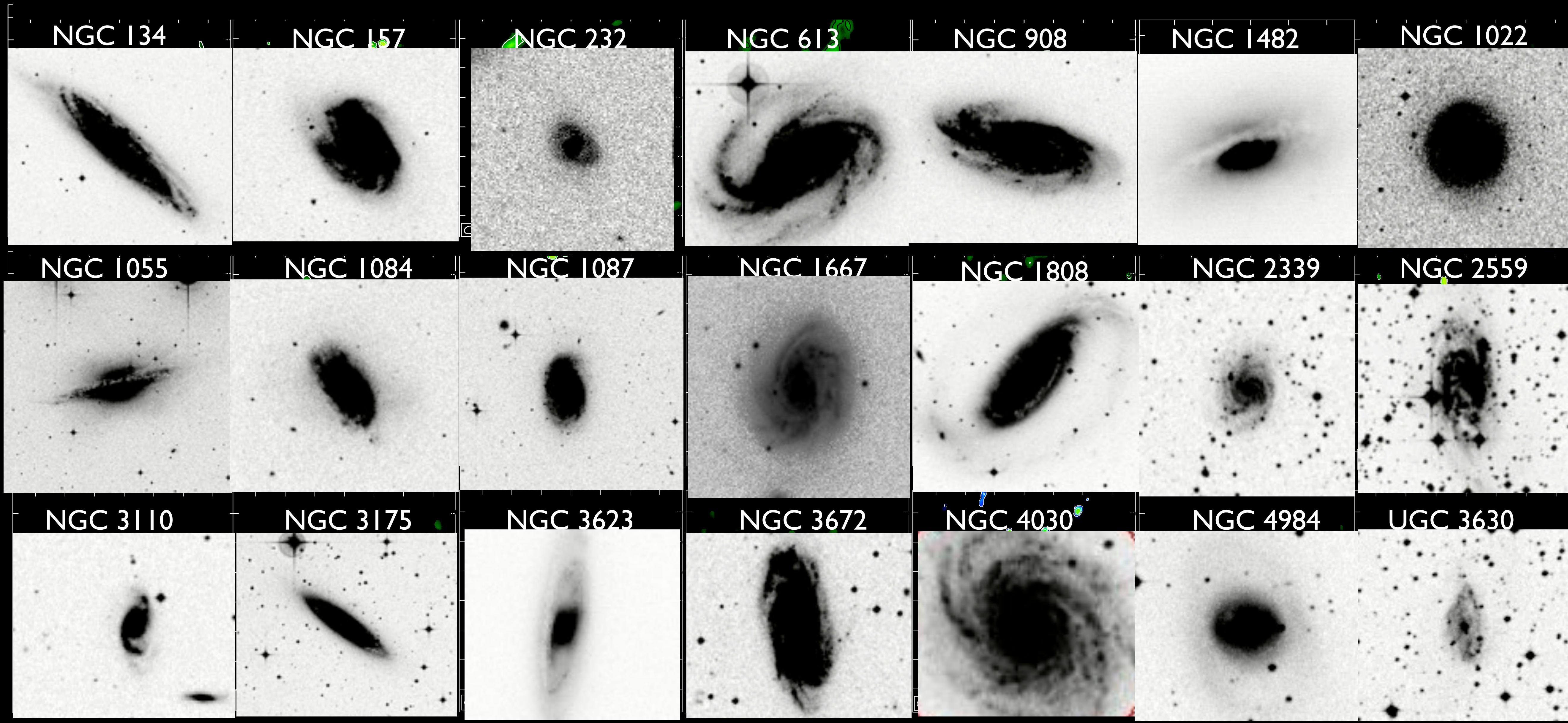


SMA CO(2-1) BODEGA (Below 0 DEgrees GAlaxies)

(D. Espada, S. Martin, P. Ho, P. Hsieh, L. Verdes-Montenegro, S. Matsushita, M. Krips)



- Unexplored Southern hemisphere galaxies, N = 40 (up to 100).
- IR-bright spiral galaxies, most of them with bar. Signs of perturbation.
- bulk of the galaxies V ~ 1500 km/s.

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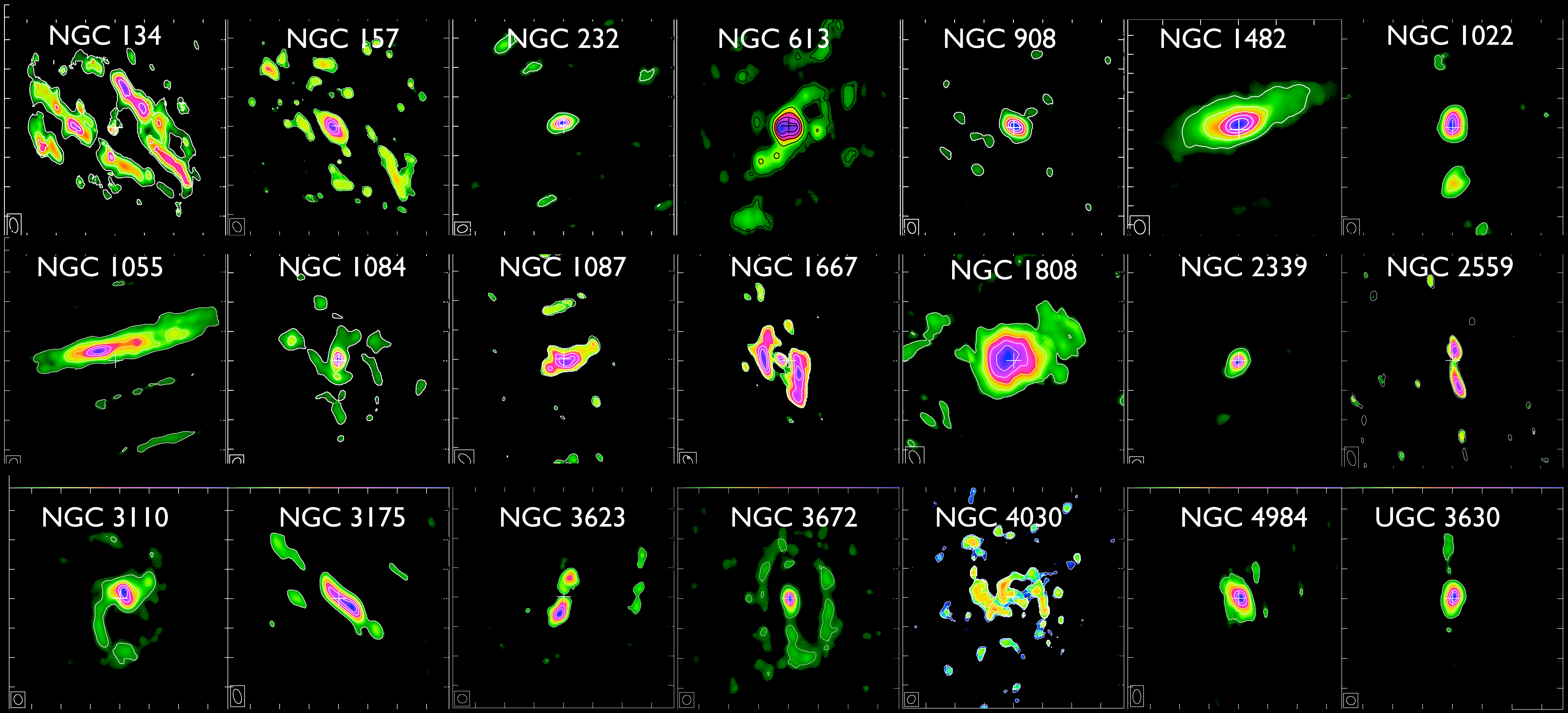


- FOV = 1’, resolution = 2”.
- CO(2-1), 13CO(2-1) and C18O(2-1).
- Different morphologies: circumnuclear disks, spiral arms, rings.
- Archival data: HI, Ha, MIR.

AMIGA: Characterization of isolated galaxies

- AMIGA project: Analysis of the interstellar Medium of Isolated GAlaxies
  (PI: L. Verdes-Montenegro) http:/amiga.iaa.csic.es
  -2003: Project started @ IAA
  -2006: Coordinated project between IAA-group + IRAM-30m @ Granada

- + International collaboration: Obs. Marseille, Obs. Paris, CfA, ASIAA-Taiwan, MPIfA (Bonn), Univ. Alabama, UMass-Amherst, Mc Donald Observatory, Arcetri, UNAM, IAC, Kapteyn Institute.

- Need for a large (N ~ 1000 galaxies) reference sample of isolated galaxies to quantify properties of galaxies in denser environments.

- Build & analyze a multi-wavelength catalog including information for ISM – SF – Nuclear activity

AMIGA
Analysis of the Interstellar Medium of Isolated GAlaxies

AMIGA: Characterization of isolated galaxies

-AMIGA: refinement of CIG (Catalogue of Isolated Galaxies) (Karachensetva 1973), selected from CGCG (Zwicky), $m < 15.7$ and $\delta > -3$.

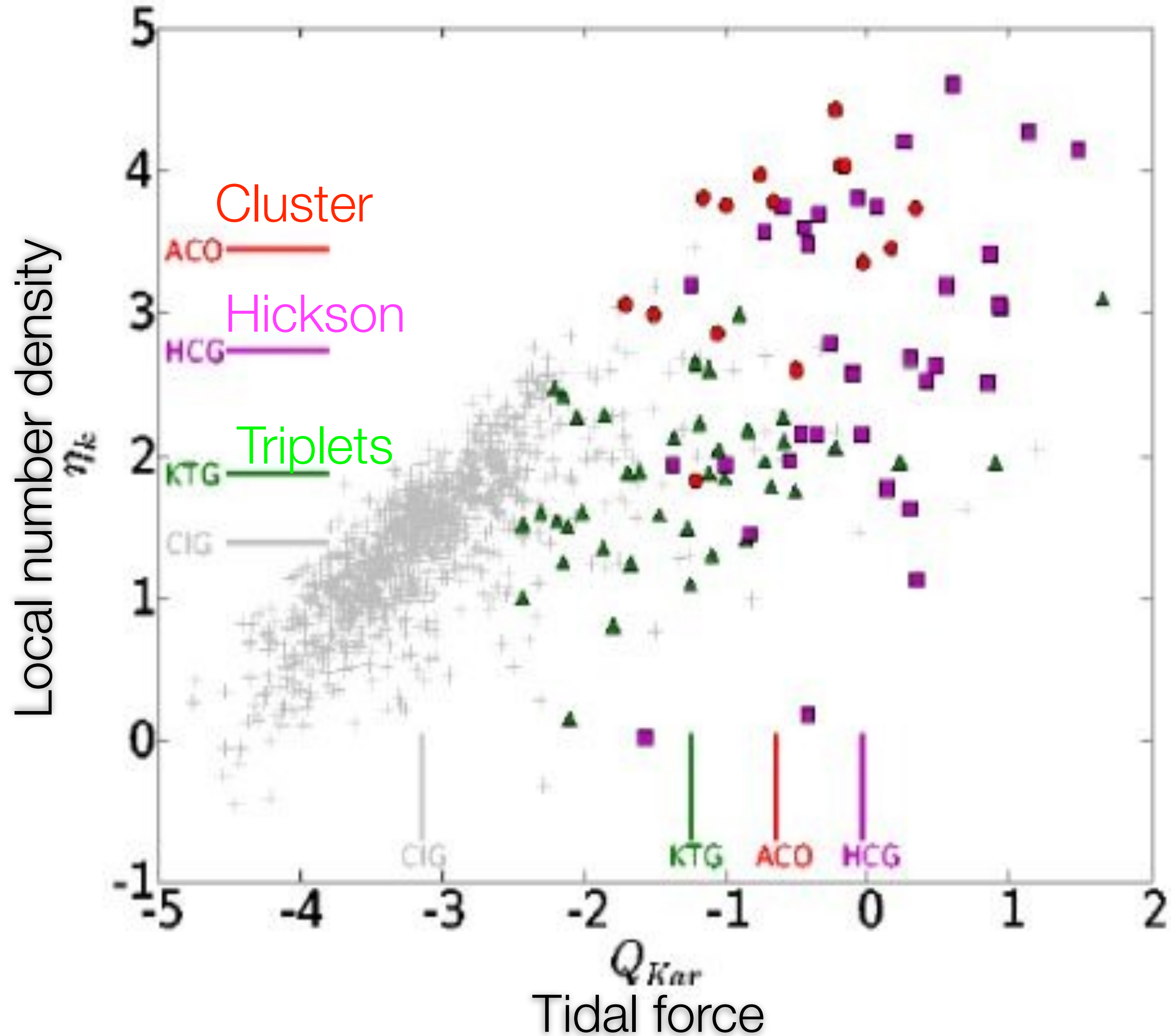
-Karachentseva's criteria: No close and similarly sized companions.

- Revision of CIG:
  - Positions
  - Optical characterization
  - Morphological revision + OLF/types
  - Degree of isolation

- Multi-wavelength study:
  - FIR properties, IRAS data, N=1000
  - Radio-continuum emission, NVSS FIRST
  - Radio-FIR for radio-AGNs selection
  - SDSS spectra for optical AGNs selection
  - Atomic gas: content and profiles ~ 1000 galaxies
  - CO(1-0) (N = 200)
  - Hα + R (N = 200): study of bars ~ 50 galaxies

AMIGA: Isolation revision

- Quantification of the isolation:
  - Q_{Kar}: Tidal force.
  - η_K : Local number density to the k-th companion.



(Verley PhD; Verley et al 2007, A&A 470, 505; Verley et al 2007 A&A 472, 121)

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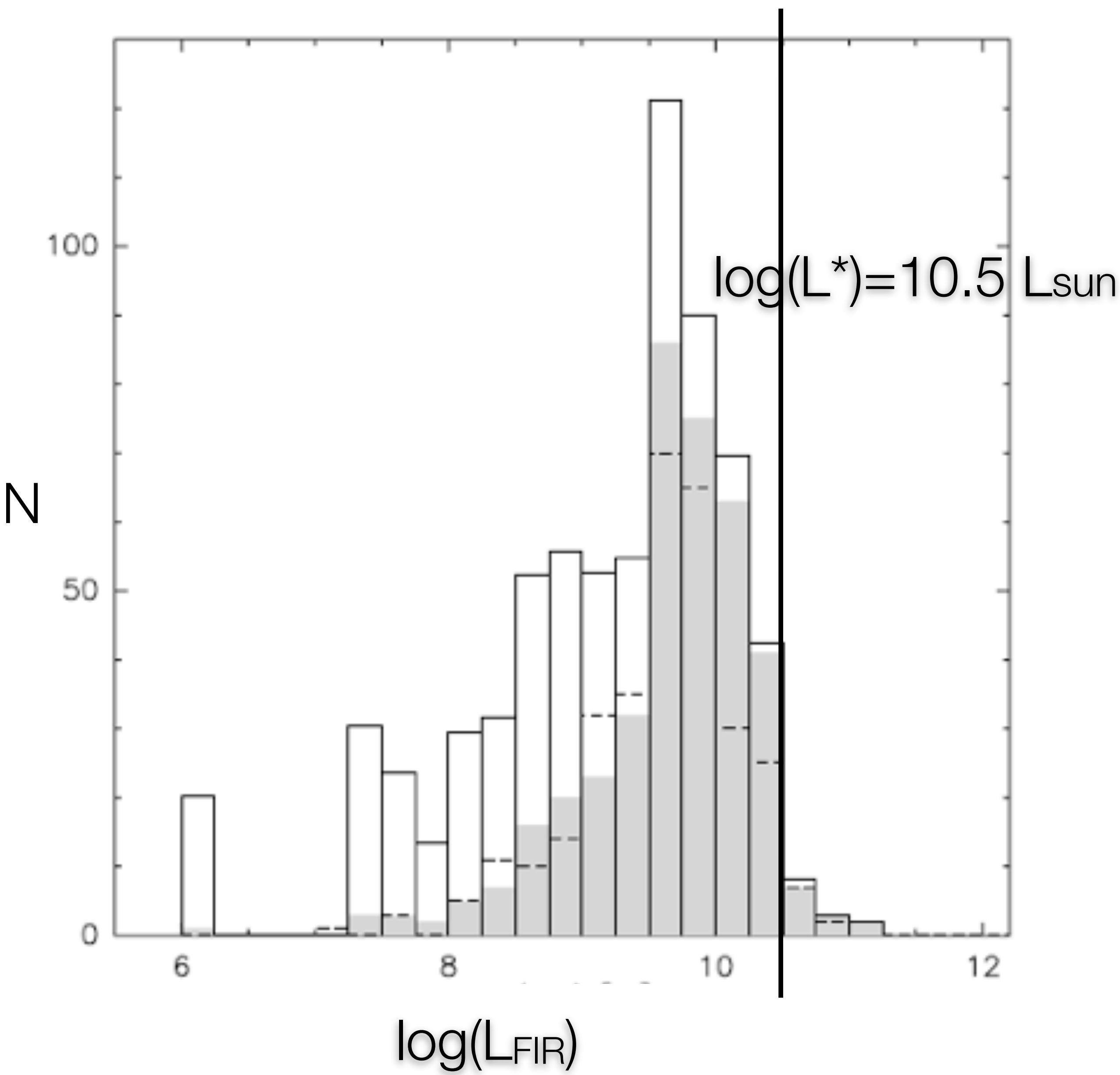
AMIGA: FIR characterization

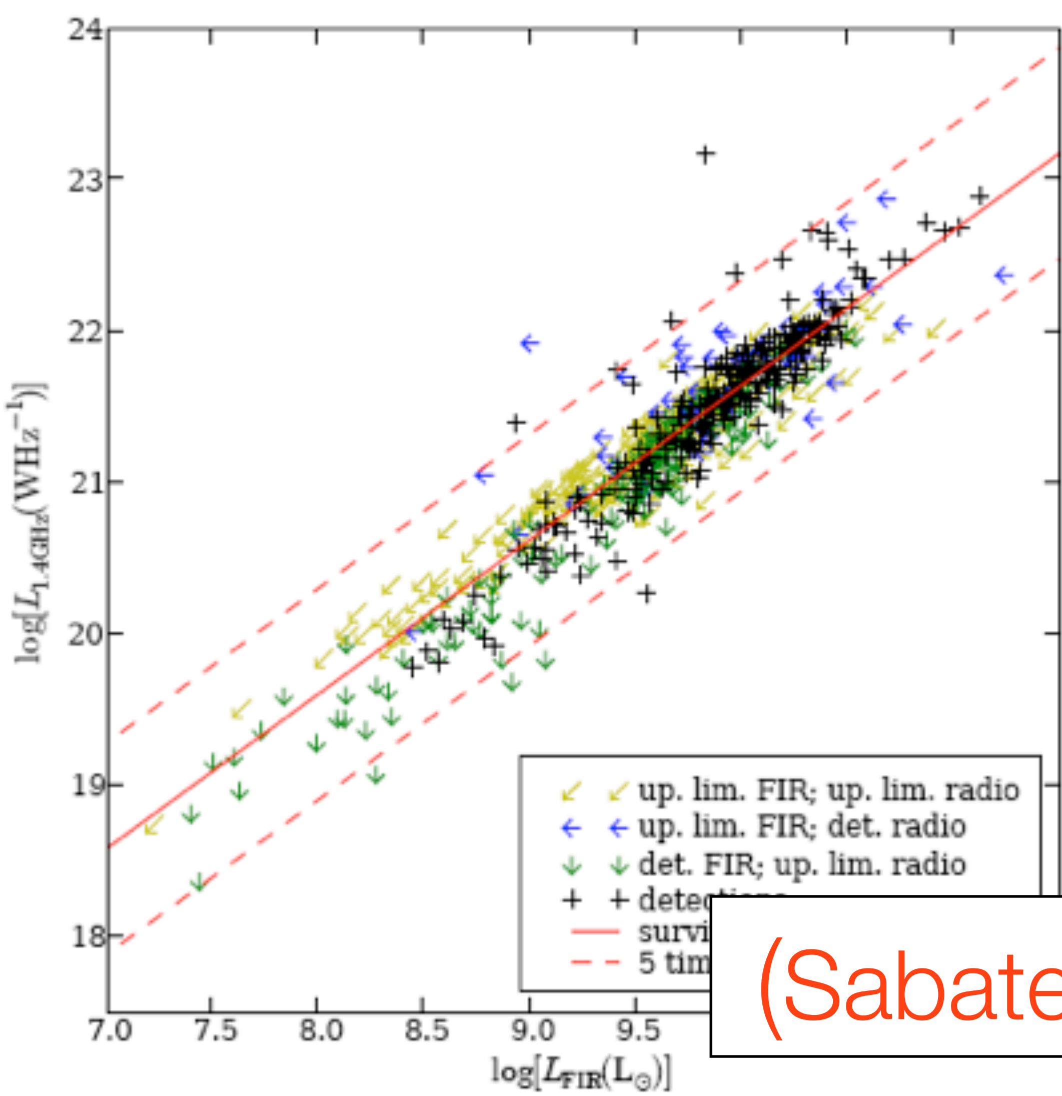


- Only 2% with $\log(L_{FIR}) > \log(L^*)$.
- F_{60}/F_{100} lower than for interacting galaxies: lower dust temperature.
- L_{FIR} AMIGA < L_{FIR} CfA sample (Huchra et al. 1983, not selected with respect to environment)

(Lisenfeld et al. 2007, A&A 462 507)

AMIGA: Nuclear activity

- Radio emission dominated by SF in the disk rather than AGN. (Leon et al 2008, A&A 485)
- Radio-FIR correlation to select radio-excess galaxies: 0.8% of radio-excess galaxies excess factor 5 (Sabater et al 2008, A&A 486, 73)
- Optical classification using SDSS spectra: 60% are HII dominated, 18% TO.



(Sabater PhD)

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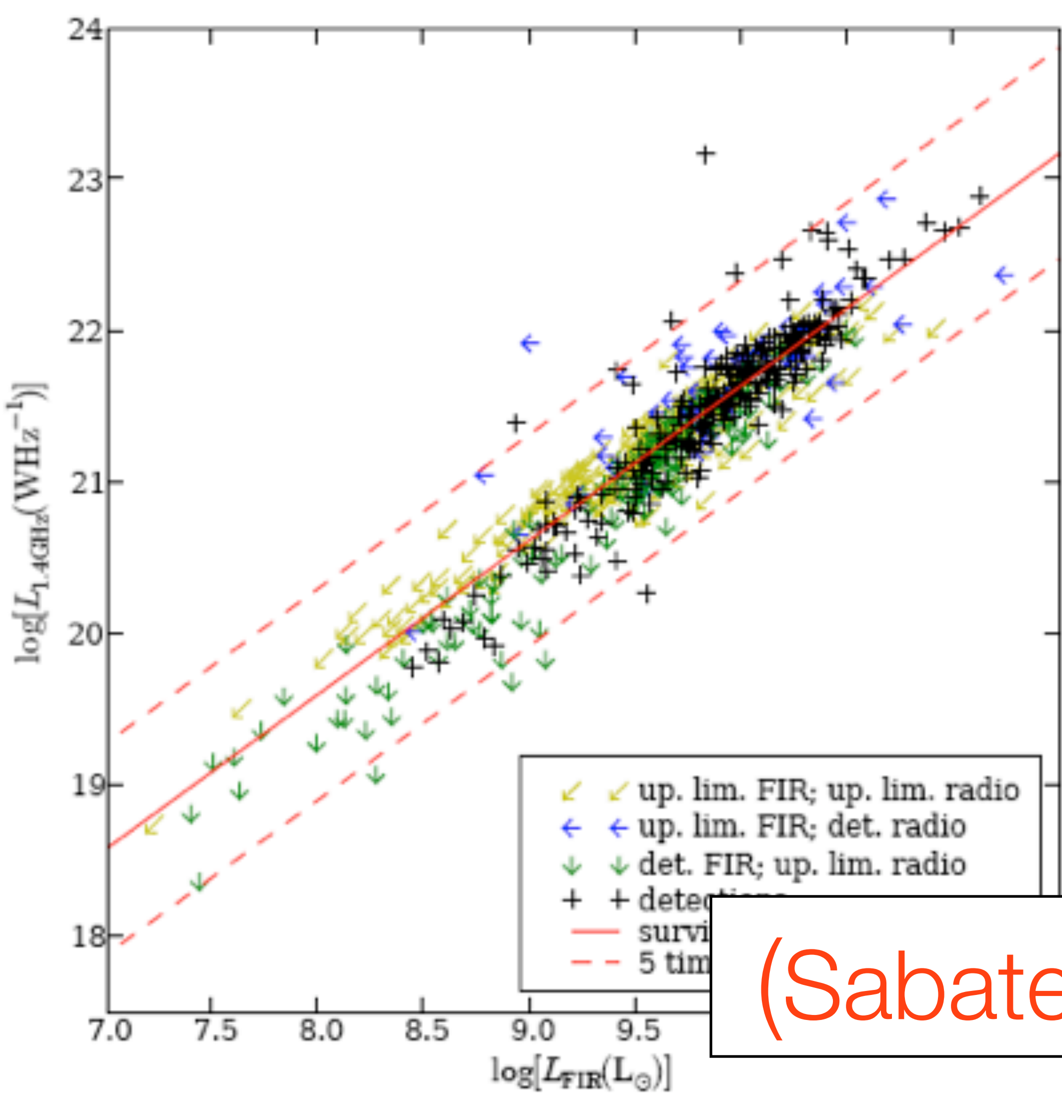
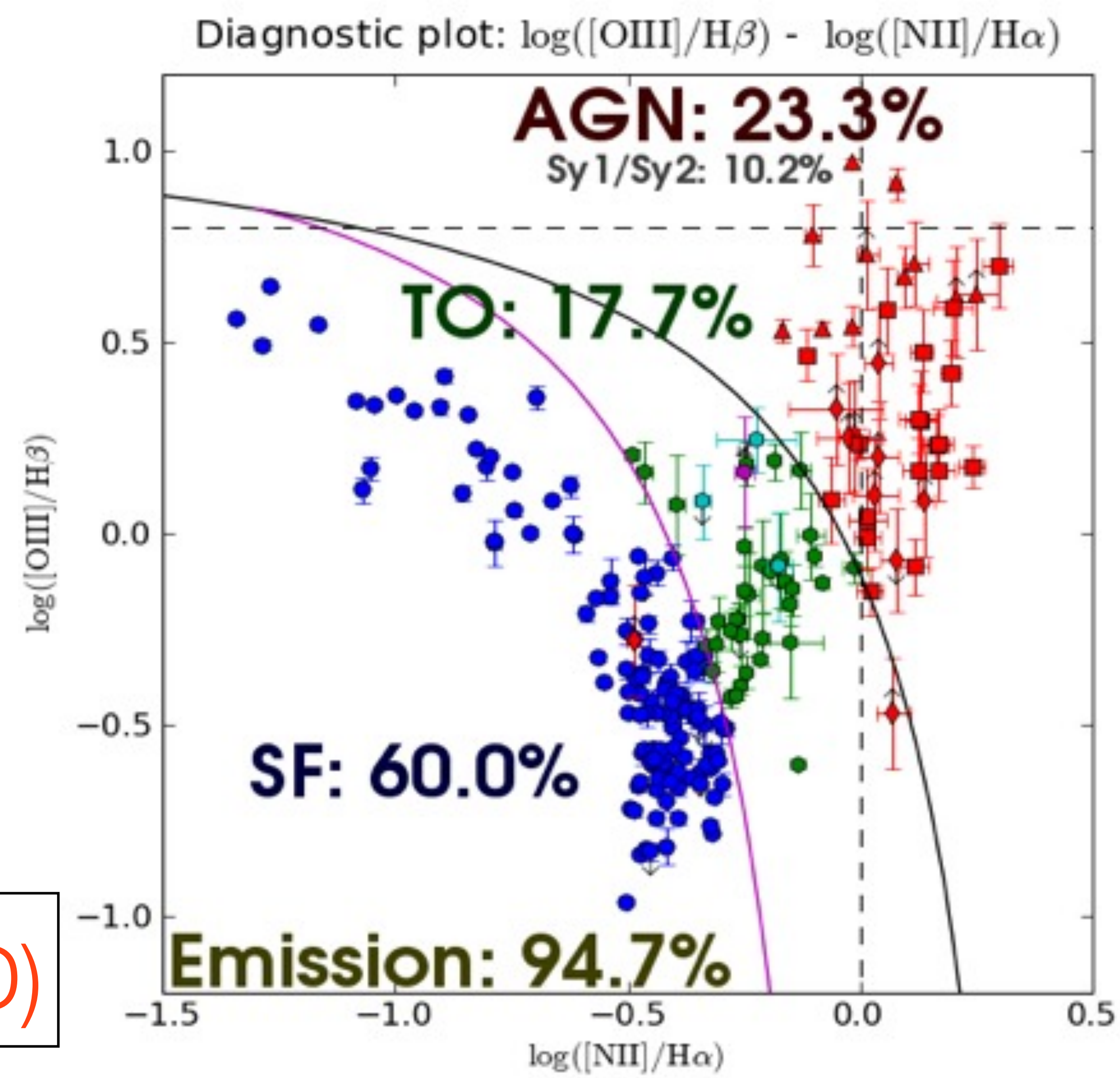
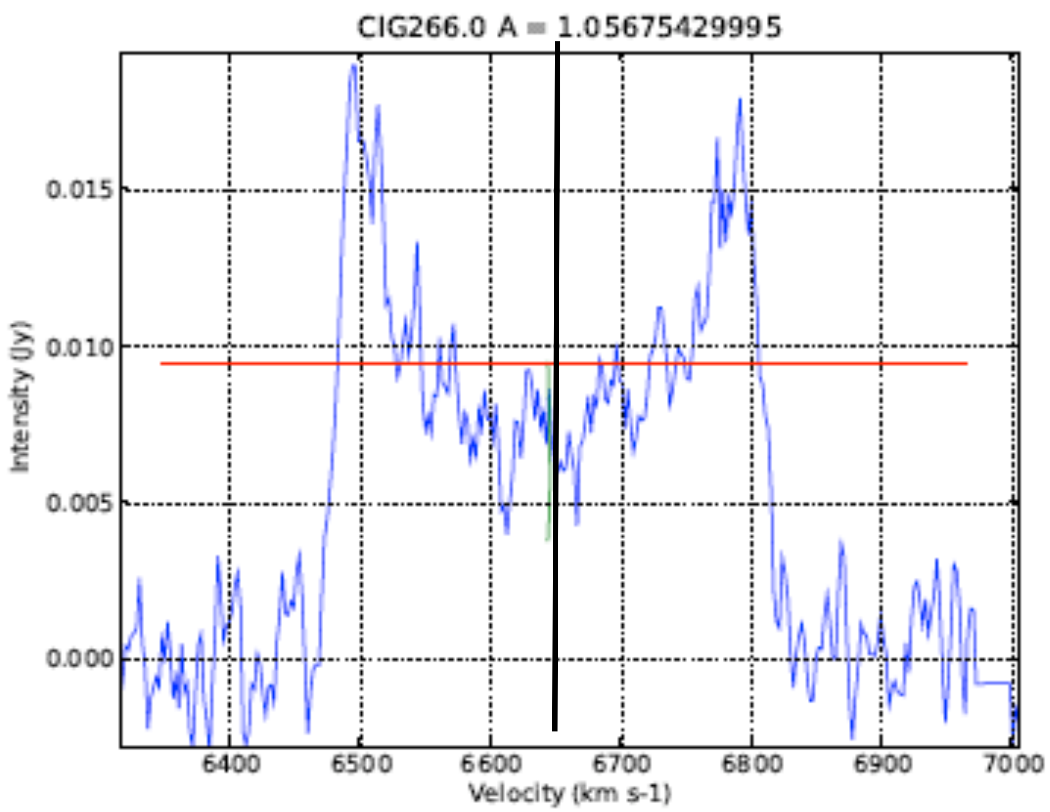


(Sabater PhD)

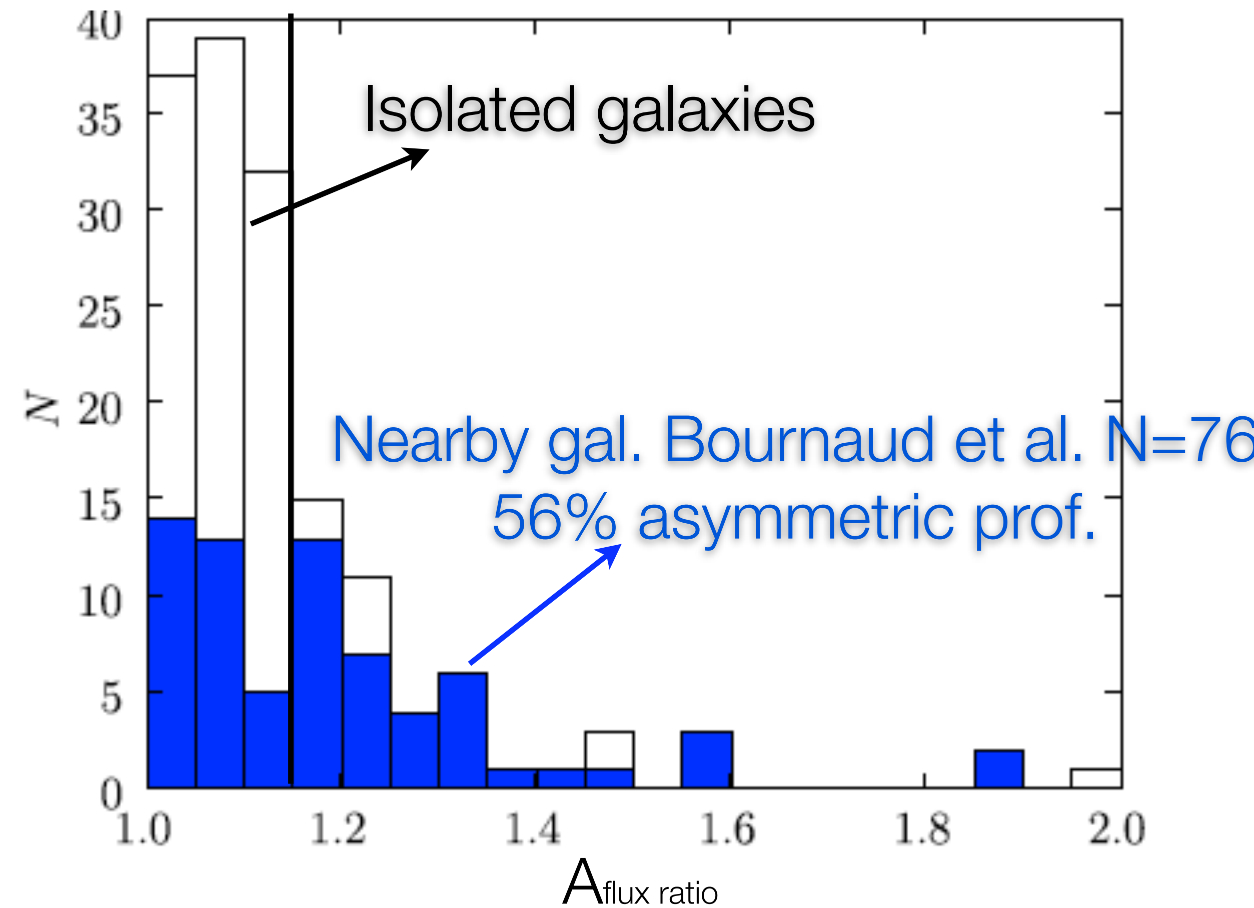


AMIGA: Atomic Gas

- Reference for M(HI) = f(LB, Ø, T) (N=910 galaxies)
- What is the rate in isolated gaseous disks?
- 28% profiles with relevant asymmetry parameter (N=150).
- What is the origin of asymmetries? VLA observations.

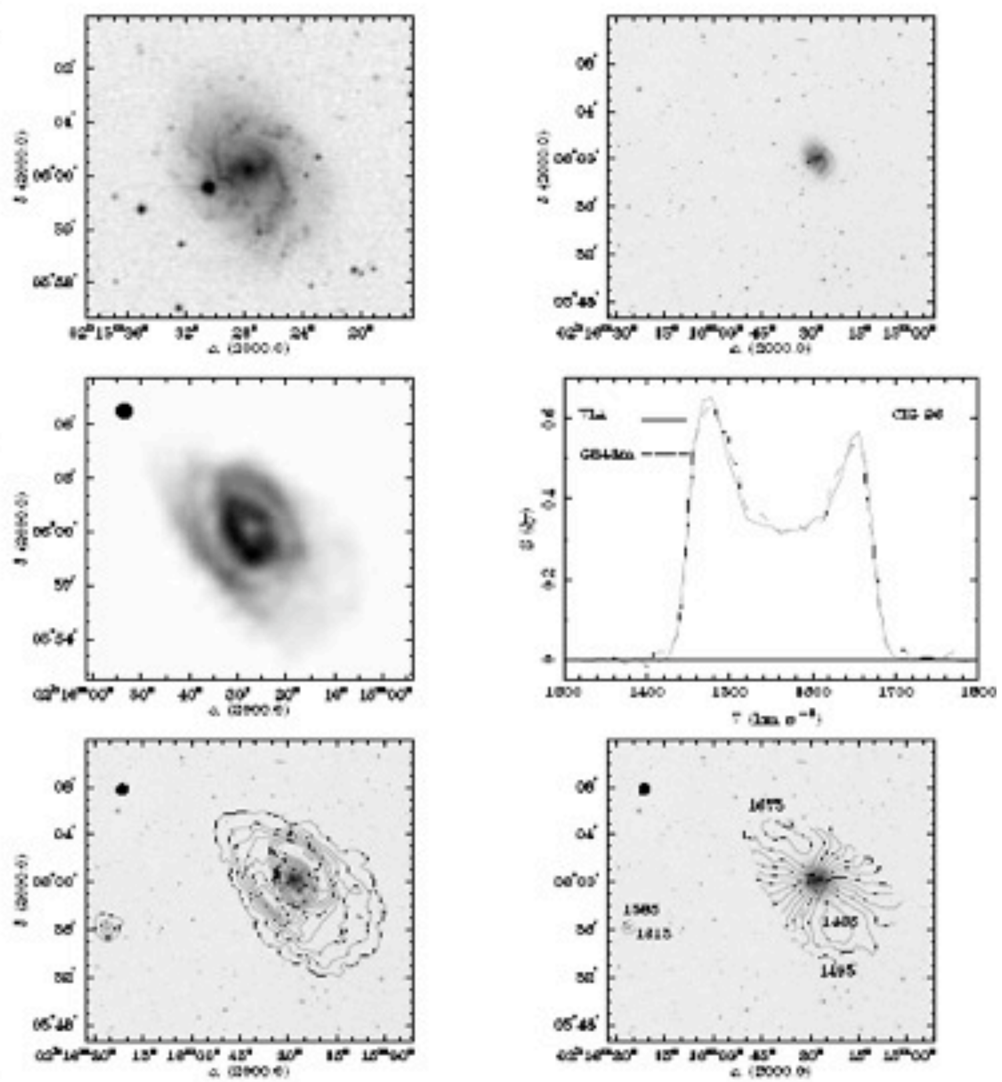


(Espada PhD)



HI ATLAS VLA subsample (N = 12): most asymmetric + control sample

Source: CIG 96		
Morphology		SBc
$\alpha(2000)$	(hh:mm:ss)	02:15:27.6
$\delta(2000)$	(dd:mm:ss)	06:00:09.0
Optical field sizes	($' \times '$)	5.6×5.6, 25.4×25.4
Observing time	(hours)	4
Central velocity	(km s^{-1})	1572
Spatial resolution	($''$)	15
Number of channels		64
Velocity resolution	(km s^{-1})	10.4
Beam size	($\alpha \times \delta$, $'' \times ''$)	49.8×46.0
Conv. beam size	($\alpha \times \delta$, $''$)	70.4×65.3
PA (N to E)	($^\circ$)	-6
HI data parameters		
Channel maps		
Field size, channels	($'$)	17.0×17.0, 22 - 46
Velocities	(km s^{-1})	1436.7 - 1686.6
rms noise channel	(mJy/beam)	0.66
Contours	(mJy/beam)	3, 10, 21, 42, 56, 70, 84, 98, 112
Global HI profile		
		VLA — GB43m (HG98)
HI flux	(Jy km s^{-1})	103 — 102.8
Heliocentric velocity	(km s^{-1})	1557 — 1562
HI profile width 20%	(km s^{-1})	238 — 239
M_{HI}	(10^9 $M_\odot$)	7.24 — 7.53
HI maps		
Field size	($' \times '$)	5.6×5.6
HI map contours	(mJy/beam km s^{-1})	1, 100, 250, 750, 1000, 1250, 1500, 1750, 2000, 2250, 2500
	(10^{20} cm^{-2})	0.1, 6, 15, 45, 60, 75, 90, 105, 120, 135, 150
Velocity contours	(v_{max} - v_{min}, δv) (km s^{-1})	1465 - 1675, 15
Comments		
Companion α=02:16:26.90,	δ=05:56:24.0, v=1605	(1572-1655), $M_{HI} \simeq 10^8$ $M_\odot$

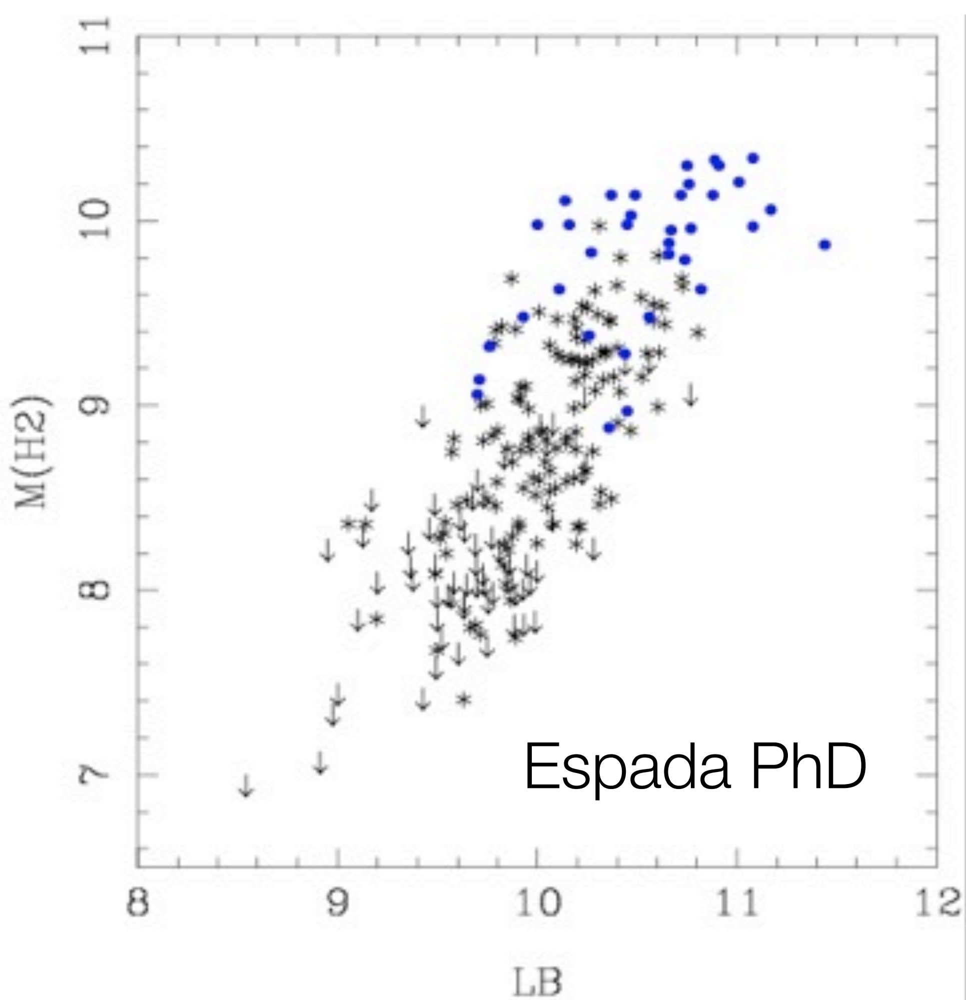


- No HI-rich companions
- No tidal tails
- Upper limit to cloud accretion of 5 x 10^6Msun.
- Asymmetry mostly in velocity field.

Espada et al. 2005 A&A 442 455

AMIGA: Molecular gas

- CO single-dish data for N = 205, 1500 < V < 5000 km/s.
- $M(H_2)$ = f(LB, Ø, t) Is H_2 increased in interactions? Contradictory results. (Braine & Combes 1993, Perea et al 1997, Verdes-Montenegro et al 1998, Leon et al 1998)
- $M(H_2)/M(HI)$: Relative content increases in galaxies in denser env.



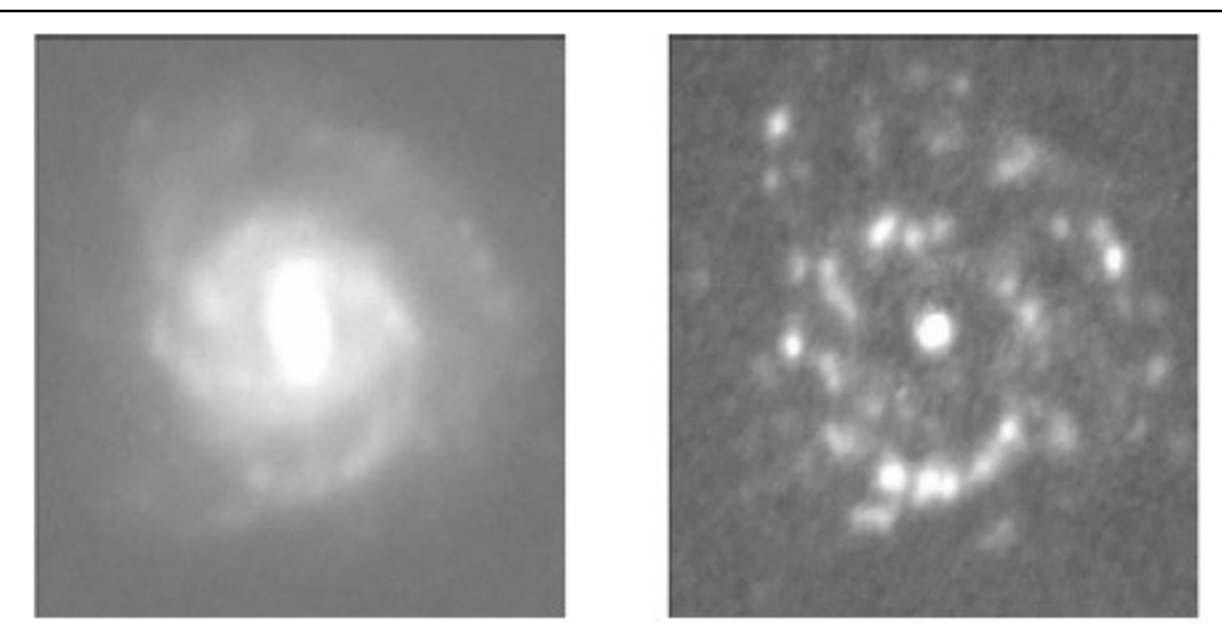
- HCN-FIR (dense gas vs FIR) correlation holds in isolated galaxies? IRAM 30m observations of AMIGA subsample.

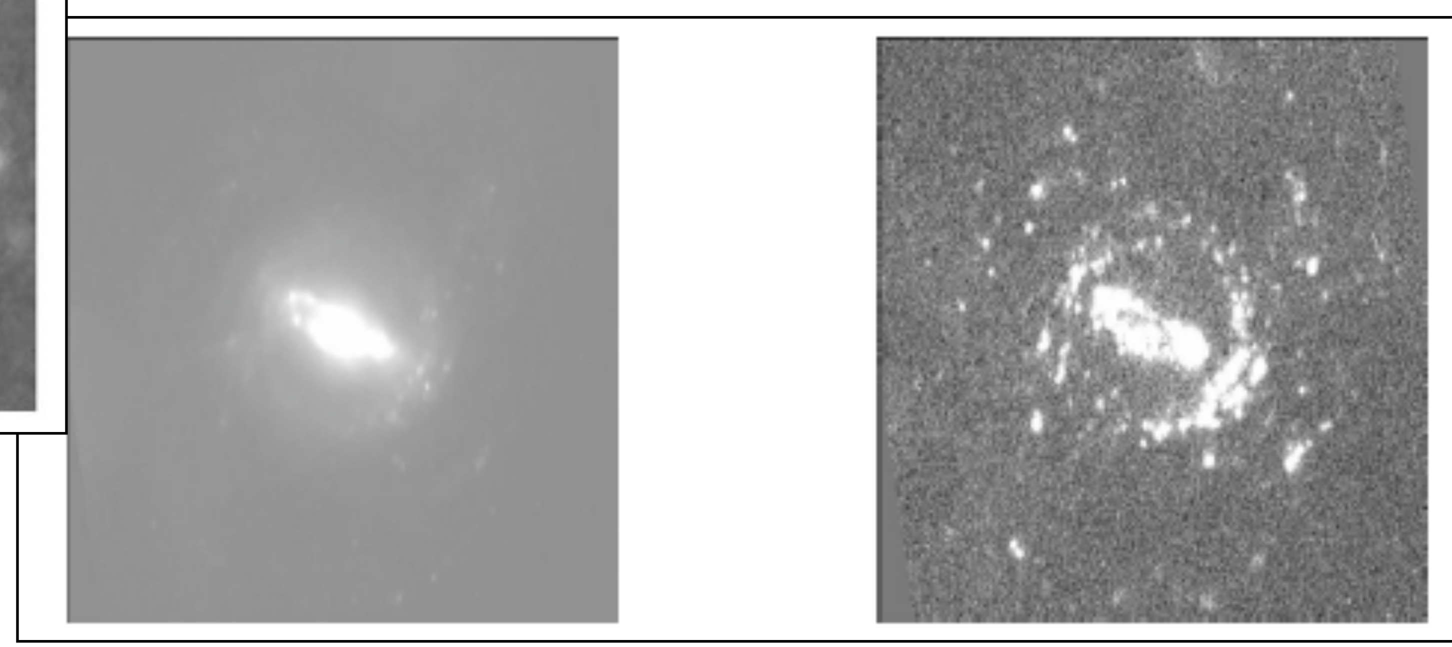
B. Ocaña PhD thesis

AMIGA Analysis of the Interstellar Medium of Isolated GAlaxies

AMIGA: Ionized gas (Hα)

- Hα+R images for 205 galaxies 1500 < V < 5000 km/s.
- Frequency and origin of bars: 45 largest and low *i* galaxies: 42% strong central peaks, 18% in the bar, 20% smoother morphology, no central emission. Interpreted as secular evolution.
- Mapping the molecular gas in individual galaxies to test .





(Verley et al 2007, A&A 474, 43)

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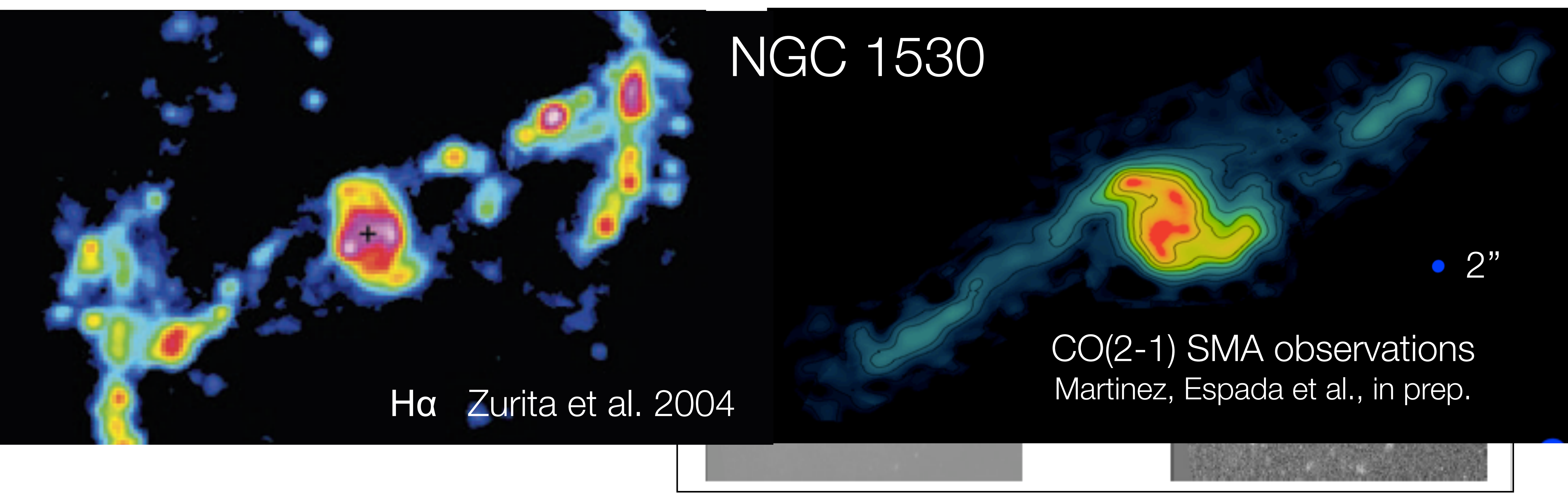

(Verley et al 2007, A&A 474, 43)

Perspectives for ALMA

- AMIGA: The most quiescent sample in the nearby Universe,
  -unique for ALMA to quantify the role of the environment on secular evolution.

N = 100 galaxies within 1500 - 5000 km/s , 2’ mosaic, CO(2-1) resolution < 1” (160pc a 2500 km/s) and enough S/N will be possible in 200 hours, one order of magnitude less than current instrumentation. + More lines in one shot!

- SMA BODEGA: IR-bright (likely) interacting spiral galaxies
  -CO-bright, could be part of the early science of ALMA.
  -even dense gas tracers to see the SF laws transition from normal galaxies to ULIRGs.

A long-standing question in galaxy evolution involves the role of nature vs nurture on the observed properties of galaxies. Interactions among galaxies can increase their molecular gas content and trigger the star formation. However, most of the studies are biased towards the most IR luminous galaxies, which in general are strongly interacting galaxies. Only a few studies about the molecular