Molecular gas and and star formation in Hickson Compact Groups galaxies: Enhanced or deficient?

Ute Lisenfeld
Universidad de Granada

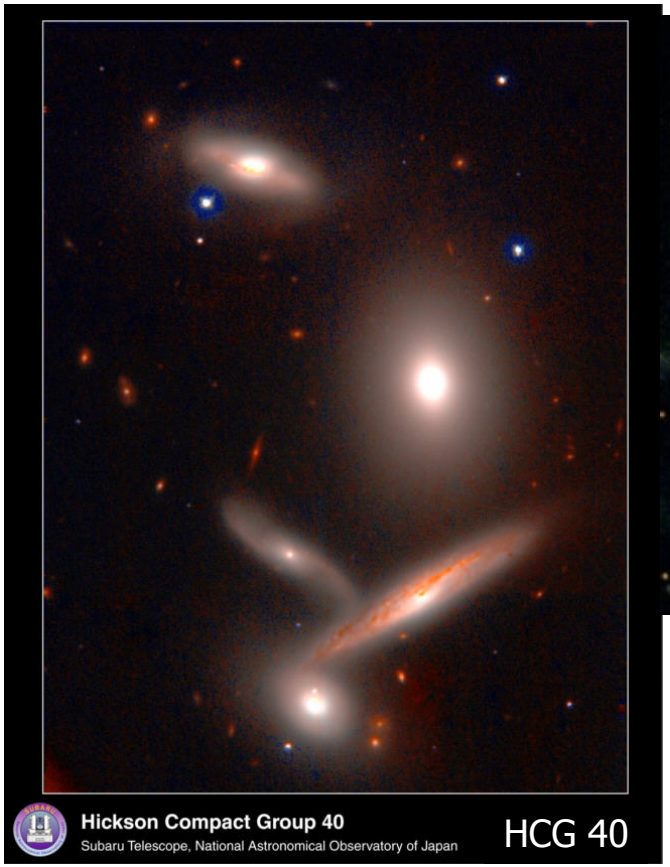
In collaboration with:

Vicent Martinez-Badenes (Instituto de Astrofísica de Andalucía, IAA),
Lourdes Verdes-Montenegro (IAA) & AMIGA team
Daniel Espada (National Astronomical Observatory of Japan)
Stephane Leon (Joint Alma Observatory/ESO, Chile)
Jack Sulentic (IAA)
Nario Kuno (Nobeyama Radio Observatory, Japan)
Min Yun (University of Massachusetts)
Santiago García-Burillo (OAN, Madrid)

See Martinez-Badenes, 2012, A&A, 540, 36

Hickson Compact Groups (HCG)

- Hickson Compact Groups are dense and relatively isolated groups of 4-8 galaxies, originally compiled by Hickon (1982)
- They have a particularly high galaxy density and a low systemic velocity dispersion



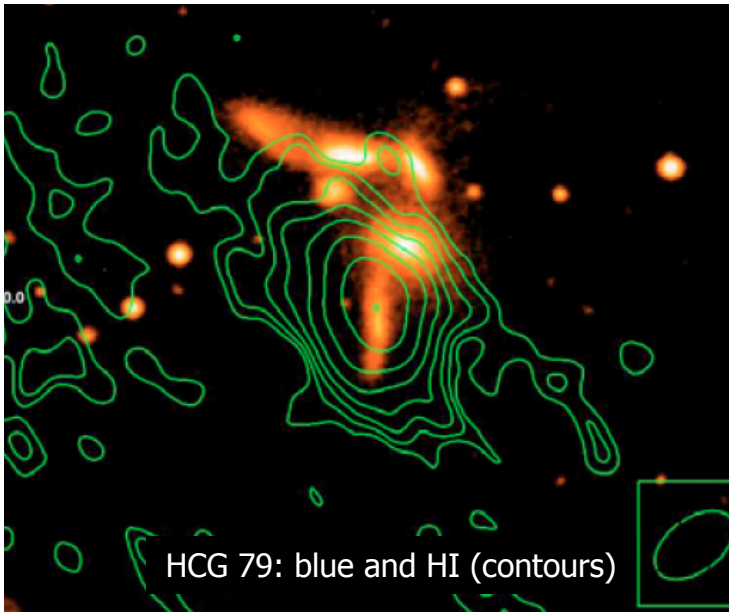
HCG 40

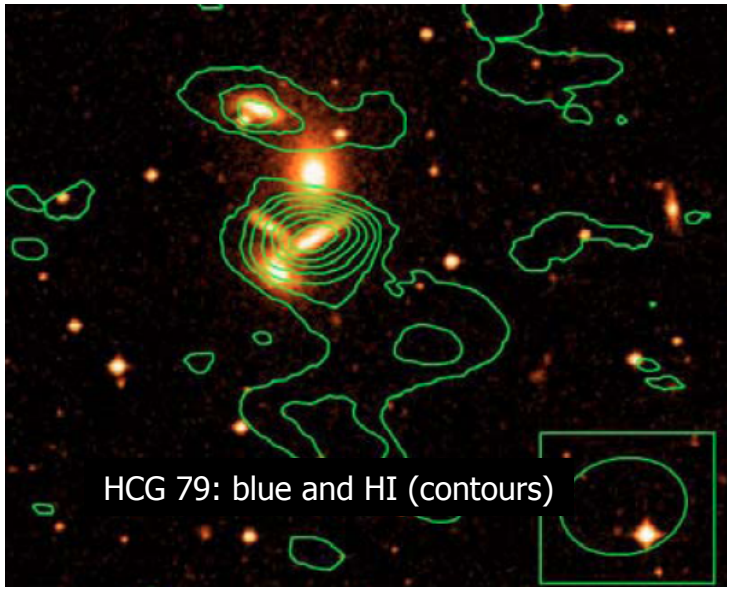
HCG 92

HCG 87

Deficient atomic gas in HCGs Hickson

- Groups and their galaxies are very HI deficient (only 40% of expected HI in groups, only 24% in individual galaxies, Verdes-Montenegro et al. 2001)
- It is unclear where missing gas is. Possibilities:
  - Low column density intergalactic HI: Borthakur et al. (2010) that on average 35% of total HI was in such a component with column densities down to 10^{19} cm^{-2}
  - Ionized intergalactic gas: Some associated x-ray emission is detected, but not in all of them (Ramussen et al. 2008).
  - Consumed by SF or in molecular gas?


HCG 79: blue and HI (contours)


HCG 79: blue and HI (contours)

How is molecular gas and SF related to HI?

Previous works:

- Star formation normal in galaxies in HCGs, shown for different tracers:
  - FIR (Leon et al. 1998, Verdes-Montenegro et al. 1998)
  - MIR (Bitsakis et al. 2010)
  - Hα (Iglesias-Pármo & Vílchez 1999)
- Molecular gas content:
  - Normal (Verdes-Montenegro et al. 1998)
  - Higher (Leon et al. 1998)
  - Tentative correlation between def(H2) and def(HI) but low statistics (Verdes-Montenegro et al. 2001)

Question to be adressed in this work

- How is the SFR and molecular gas content of galaxies in HCGs compared to isolated galaxies?
- Is there a relation to the HI content or evolutionary phase?

The sample and CO data

- The sample consists of 20 HCG with different degrees in HI deficiency:
  - 4 groups with a normal HI content
  - 11 groups with 33-66% of expected value
  - 5 groups < 33% of expected value
- There are about the same number of galaxies in evolutionary phase 1, 2, 3, determined according to HI distribution (Verdes-Montenegro+2001)
- CO data for 86 galaxies from the literature (Leon et al. 1998, Verdes-Montenegro et al. 1998) and our own observations at the IRAM 30m telescope (47 galaxies). Only 2 galaxies in the groups were not observed.
- We use L_{FIR} from IRAS as a tracer for the SFR. We used the tool SCANPI to reprocess data and associate fluxes to individual galaxies.

Comparison sample: AMIGA isolated galaxies

- AMIGA (Analysis of the Interstellar Medium of Isolated GAlaxies) provides and analysises a multiwavelength data set for nearby isolated galaxies
- Basis for AMIGA project: Catalogue of Isolated Galaxies (CIG) (Karachensetva 1973)
- CIG consists of all galaxies from the Zwicky catalogue with:
  - mpg < 15.7mag, δ > -30
  - Galaxies were visually selected, without information about redshift. Criterion was: no similar sized galaxies (factor 4) within 40*R(companion) -> last interaction several Gyrs ago
- Total number of galaxies: 1050
- Advantages:
  - 80% complete down to m_{pg}= 15.0 mag
  - Large sample size, permits e.g. discrimination on basis of morphological type
  -Relatively nearby objects (up to 15 000 km/s, most closer) detectable at other wavelength, e.g. CO

Multiwavelength study so far: data from literature and own observations (available at http://amiga.iaa.es)

- Optical (B-mag) (Verdes-Montenegro et al. 2005)
- MIR and FIR (IRAS) emission (Lisenfeld et al. 2007)
- Radiocontinuum emission (Leon et al. 2008)
- AGN activity from IRAS colors and radiocontinuum (Sabater et al. 2008)
- Photometric analysis of Sb-Sc galaxies based on SLOAN i-band data (Durbala et al. 2008)
- Atomic gas (Espada, in preparation)
- Hα + NIR emission (work in progress)
- CO (Lisenfeld et al. 2011)

Conclusions so far:

- Galaxies have the lowest SF (from FIR and radio) and AGN activity in the local universe.
- Photometric profiles show pseudobulges indicating secular evoluion.

Molecular gas in isolated galaxies

- We observed a redshift limited sample (v = 1500 - 5000 km/s) with IRAM 30m and FCRAO (Lisenfeld et al. 2011)
  - FCRAO: Galaxies with d_{25}>100”
  - IRAM: Galaxies with $d_{25} \leq 100$”
  - Searched for galaxies in the literature.
  - Most galaxies were observed only at central position.
- We have:
  - CO data for 273 galaxies
  - 201 lie in velocity range 1500-5000 km/s,
  - 173 of these have no morphological indications for interaction → this sample is used for statistical analysis

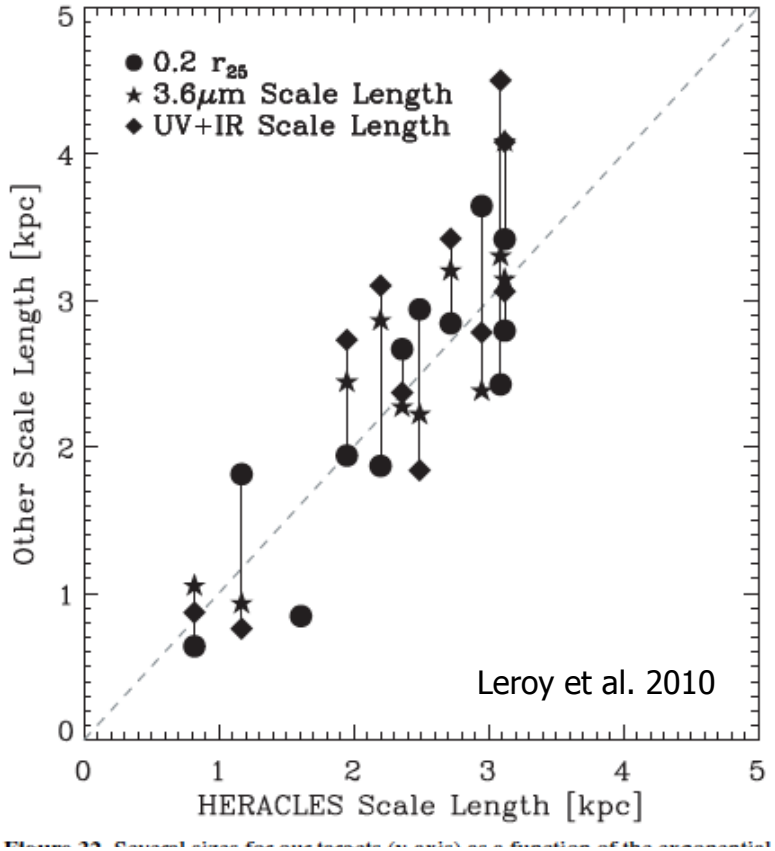
- Comment: We always use survival analysis (package ASURV) for the analysis in order to make use of upper limits.

Aperture correction

- Most galaxies were observed only at central positon.
- Observations were done with different telescopes → different fraction of CO detected, depending on telescope beam and d_{25}
- Correct for this by extrapolating to the total molecular gas mass
- Assume an exponential distribution:

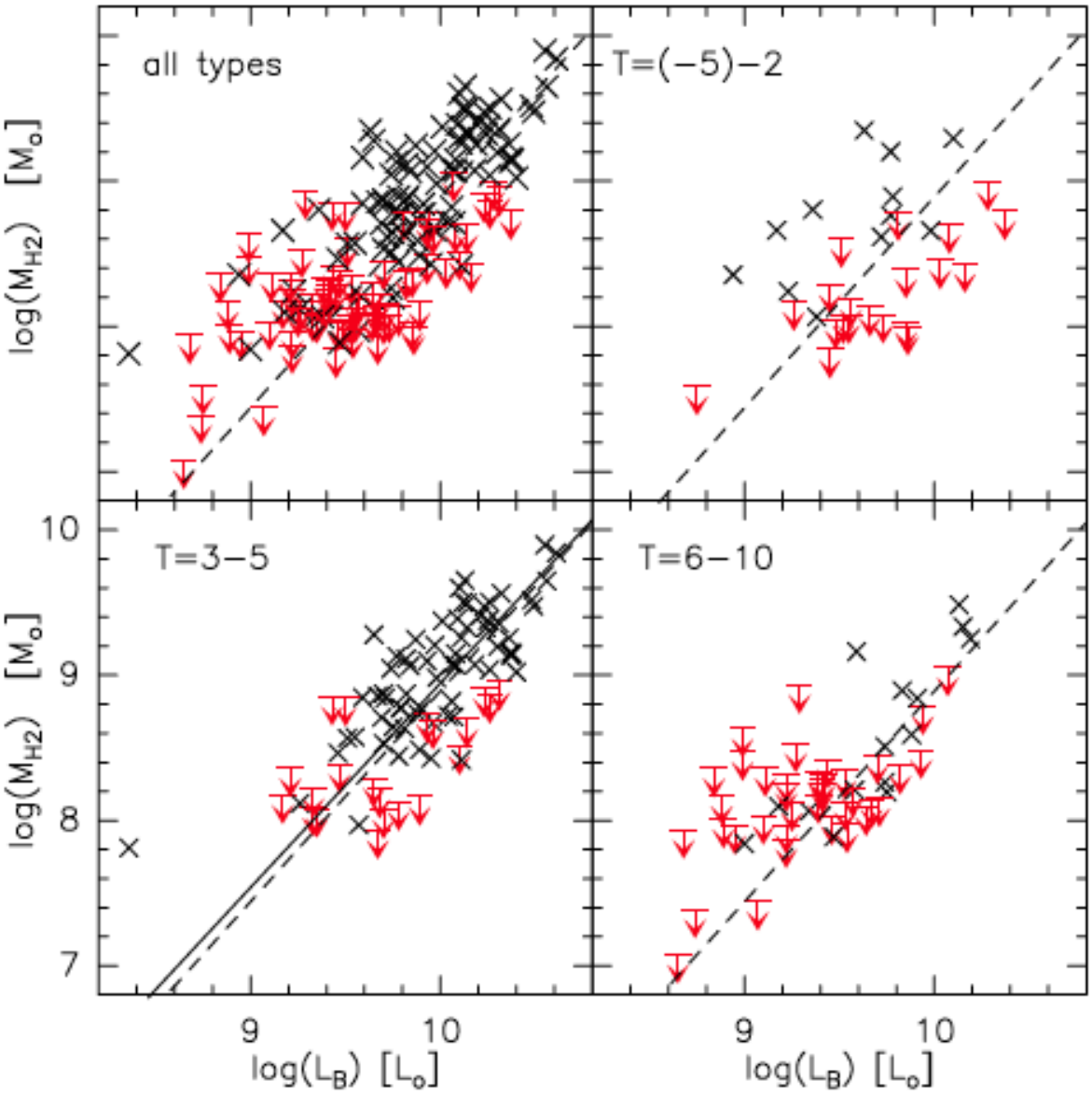
$$I(r) = Io \exp(-r/r_e) \text{ with } r_e = 0.2\ r_{25}$$

- This relation is in agreement with results from maps of nearby galaxies:
  - Herakles (Leroy et al. 2010)
  - BIMA-SONG (Regan et al. 2001)
  - Nobeyama Survey of Nearby Galaxies (Nishiyama & Nakai 2001)
  - FCRAO survey (Young et al. 1995)
- But: There is quite some scatter in this relation
- Most corrections are below a factor of 2.



Comment: We use the same correction for HCG galaxies

Relation between M_{H2} and L_B

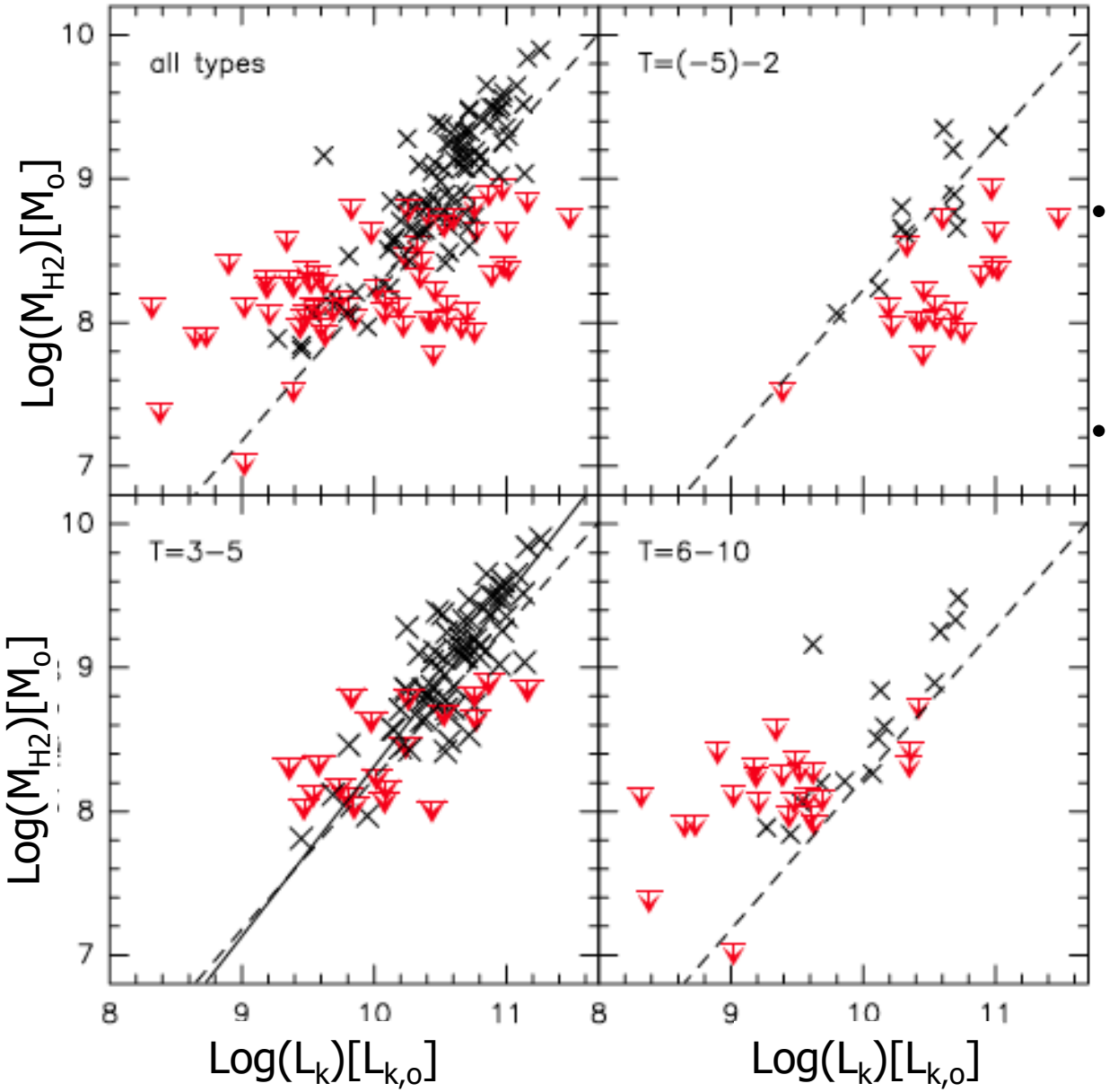


Good correlation for spiral galaxies, especially T = 3-5

$M(H_2) \propto L_B^{1.4}$

Relation is nonlinear → caution with M_{H2}/L_B: it changes with L_B

Relation between M_{H2} and L_k



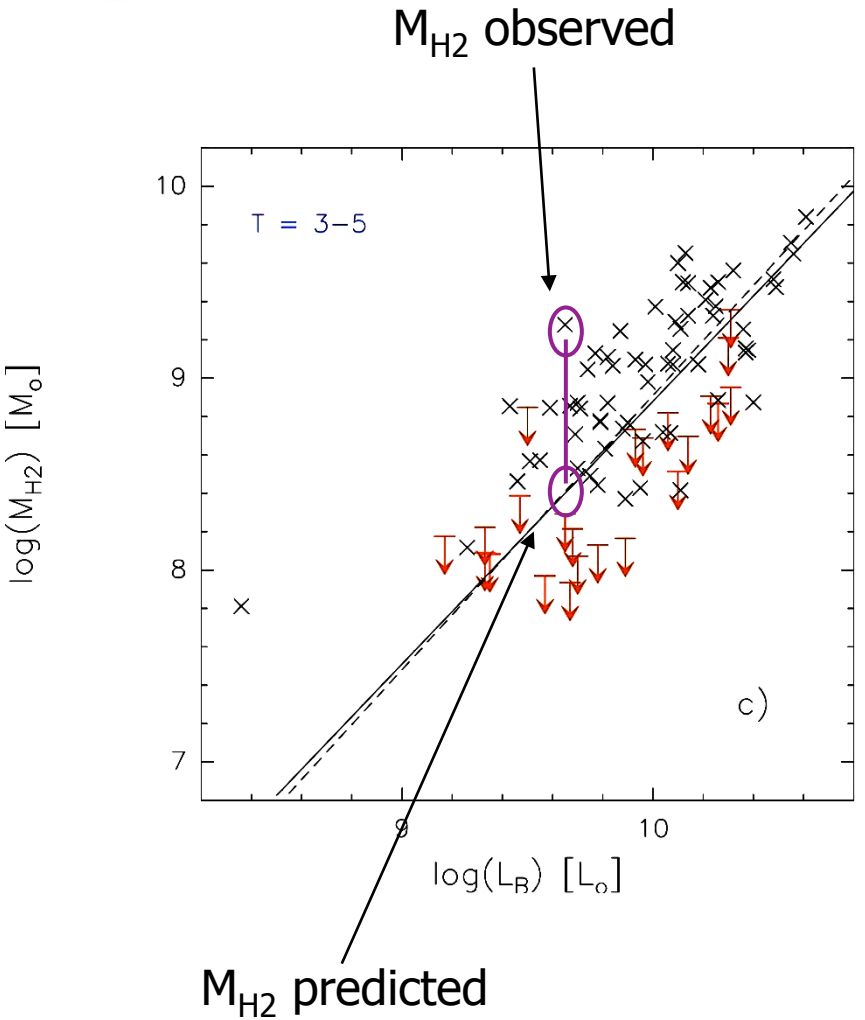
- Good correlation for spiral galaxies, especially T = 3-5
- $M(H_2) \propto L_k^{1.18}$

Search for deviations in the molecular gas content of HCG galaxies

- We use the correlations with L_B and L_k to search for deviations in the molecular gas HCG galaxies.
- We use the ratios M_{H2}/L_B (with caution to compare the same luminosity range) and M_{H2}/L_k
- We define a deficiency parameter (in analogy to parameter used for HI) a:s

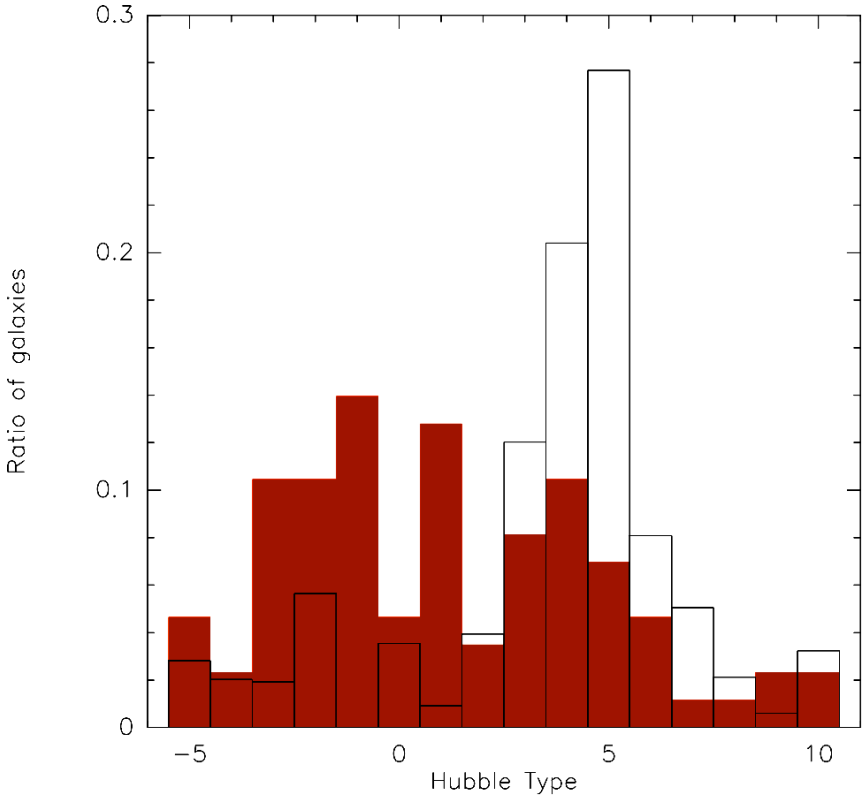
  $Def(M_{H2}) = \log(M_{H2}\text{-predicted}) - \log(M_{H2}\text{-observed})$

- Where $\log(M_{H2\text{-predicted}})$ is the predicted value from a correlation with L_B, or L_K
- Def > 0 → deficiency
- Def < 0 → enhancement



Comparison of HCG and AMIGA galaxies

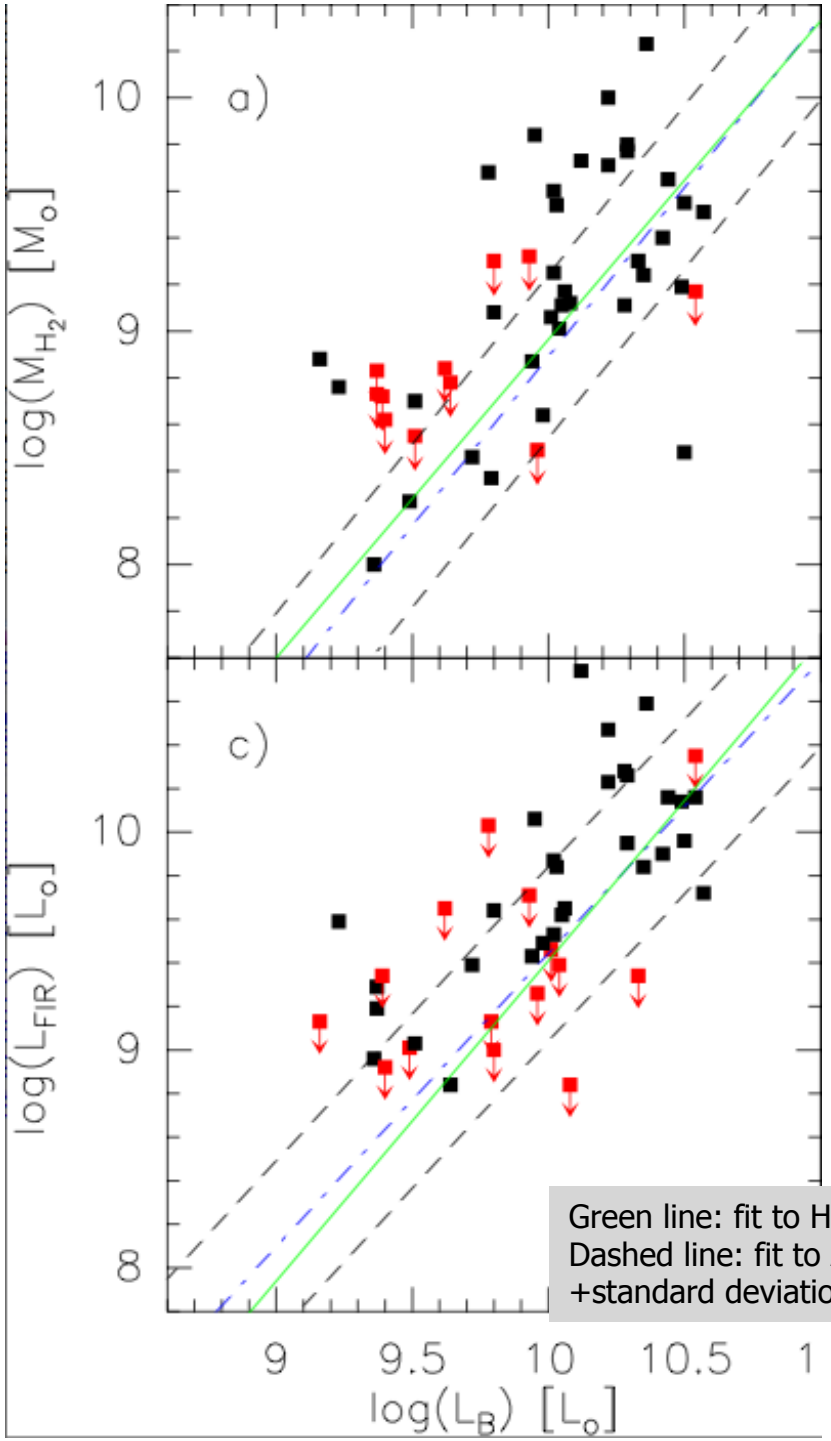
- Take into account the different morphological type distributions: There are more ellipticals and S0s in HCG
- We make the comparison separate for early (E+S0) and late types (Sa and later)
- Further reason for distinction: In early-types relation between L_{FIR} and SFR might be different (dust heated by older stellar population)



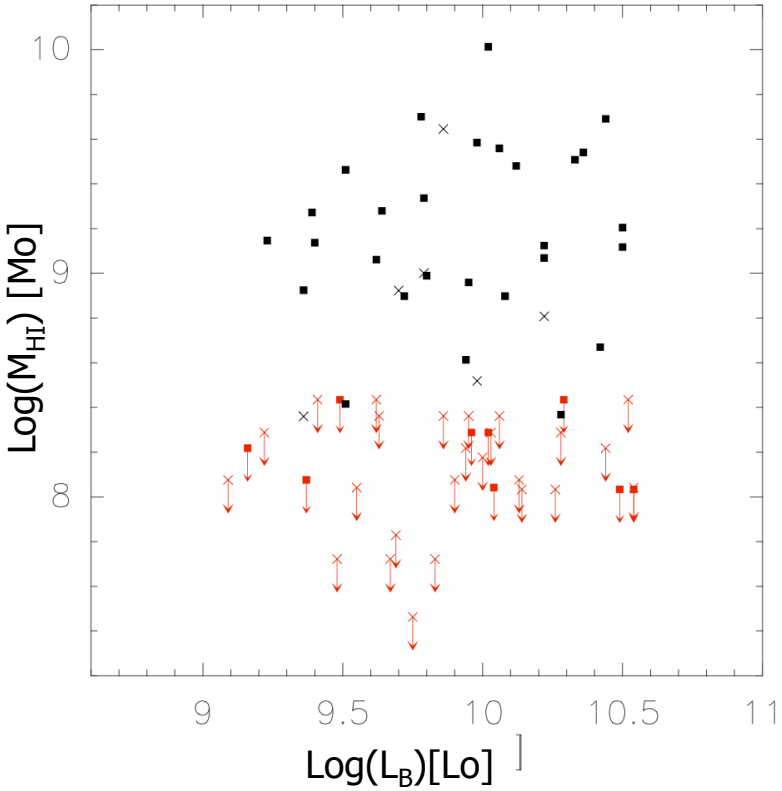
Red: galaxies in HCGs
Black line: AMIGA galaxies

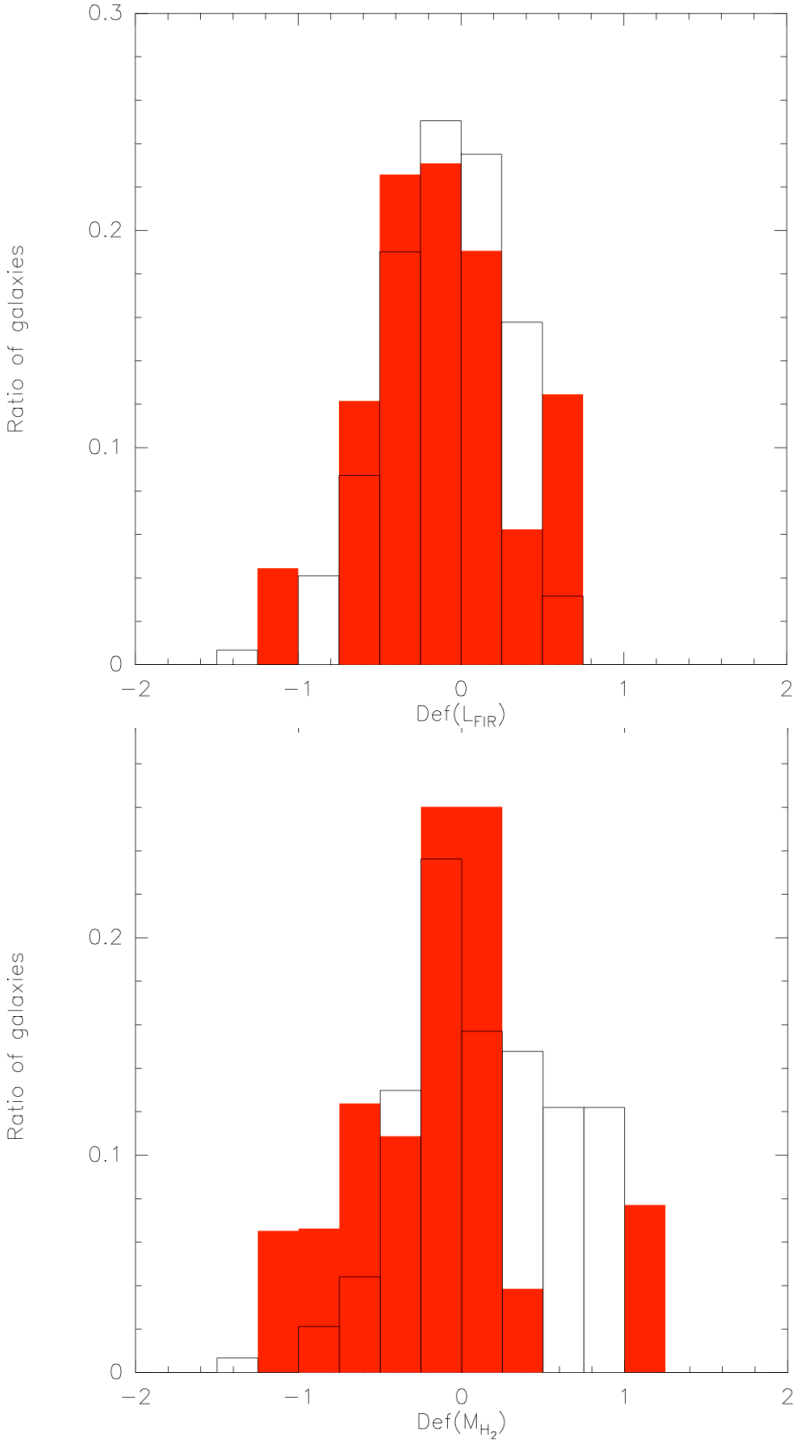
Relation to L_B

- Correlation of L_{FIR} and M_{H2} with L_B is very similar to that of AMIGA.
- A similar result holds for relation with L_k
- No correlation of M_{HI} with L_B. For most galaxies deficiency of $M_{HI\ is}$ very large compared to "normal" galaxies.



Green line: fit to HCGs
Dashed line: fit to AMIGA
+standard deviation



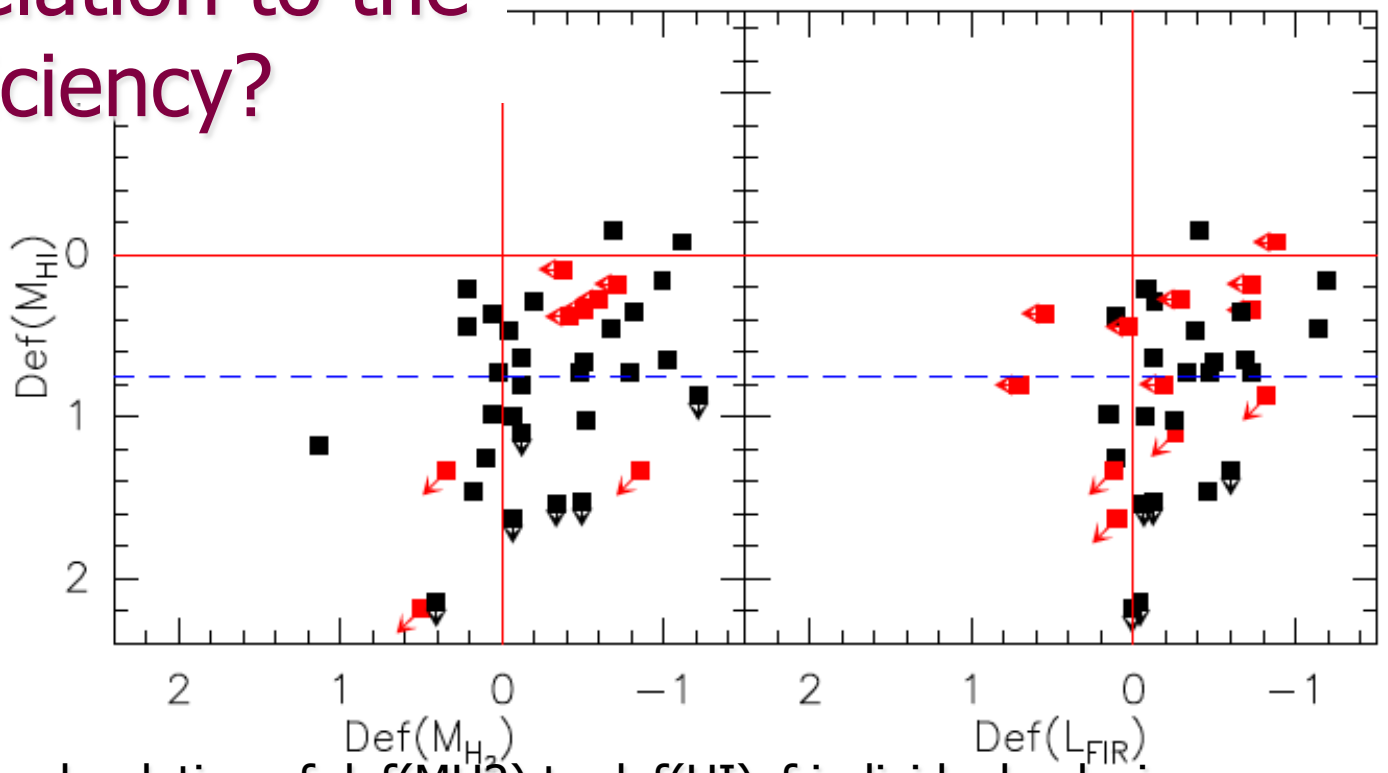


Deficiencies of M_{H2} and L_{fir}

- Def(LFIR)
  - Only spirals:-0.11±0.08
- Def(MH2)
  - Only spirals:-0.22±0.09 (slight excess) (corresponds to about 50% more M_{H2} than isolated galaxies)
  - This slight excess seems to be statistically signifcant, but could be to an overestimate of MH2 in extrapolation if molecular gas is more concentrated than in isolated spirals

Black: AMIGA
Red: HCG

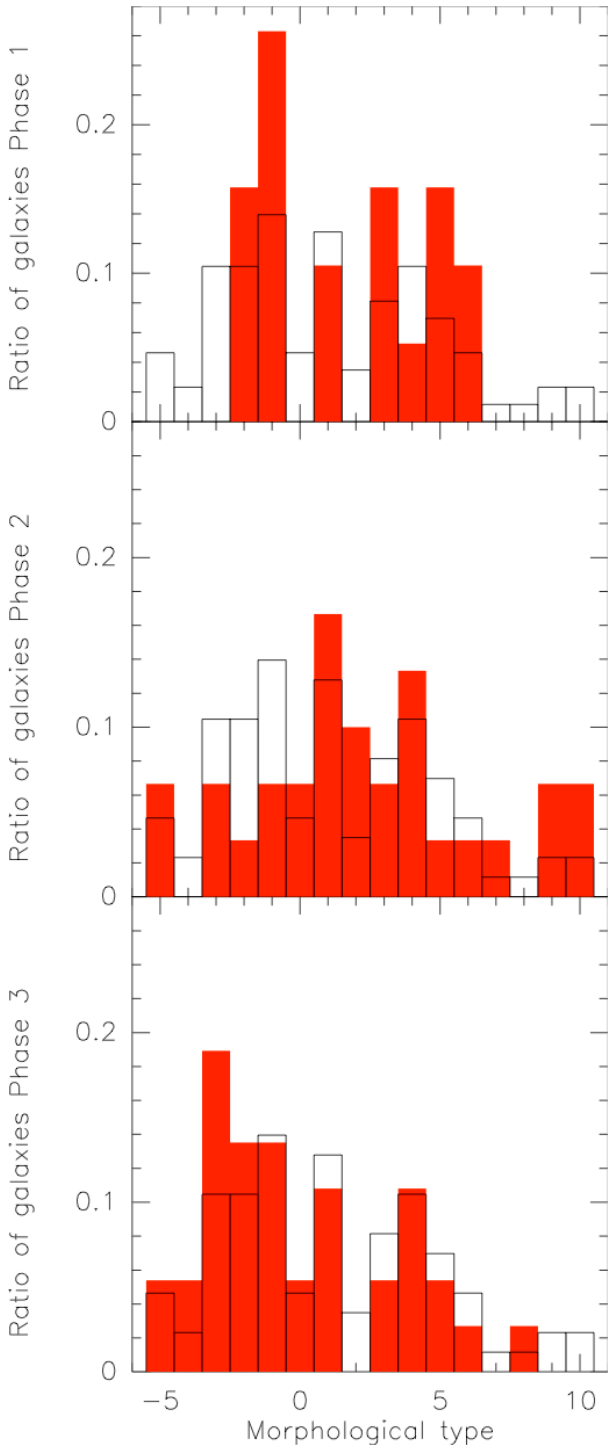
Is there a relation to the HI deficiency?



- There is only a weak relation of def(MH2) to def(HI)of individual galaxies.
  - Spirals with def(M_{HI})<0.75: def(M_{H2})=-0.34±0.10
  - Spirals with def(M_{HI})>0.75: def(M_{H2})=-0.07±0.16

But most noticeable: There are very HI deficient galaxies with normal H_2 and Lfir content!

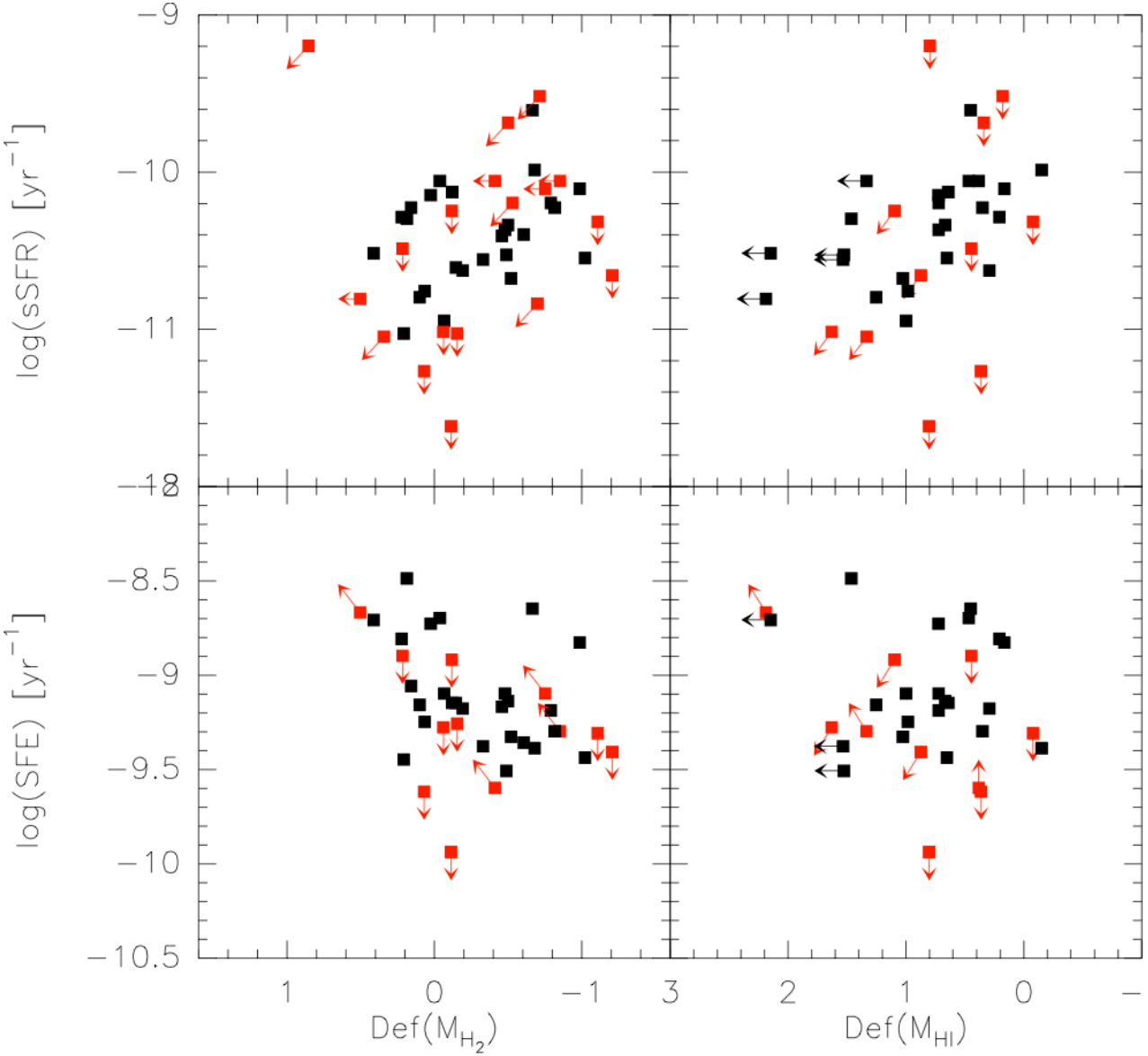
- No trend with def(Lfir)
- No relation to HI deficieny of groups.



Is there a trend with the evolutionary phase?

- There is a trend of morphological type with phase:
  - Phase 1: more sprial galaxies
  - Phase 3: More S0 and E
- Only a weak trend with def(MH2):
  - Phase 1: def(M_{H2}) = -0.35±0.14
  - Phase 2: : def(M_{H2}) = -0.16±0.13
  - Phase 3: : def(M_{H2}) = -0.04±0.09
- Enhancement in early phase. Very tentative interpretation: Increased molecular gas formation from HI in early phase due to tidal interactions, followed by HI stripping and decrease of H2 due to lack of replenishment
- No trend of def(Lfir) with evolutionary phase

Deficiency in MH2, SFE and sSFR



- No trend of SFE with neither def(MH2) nor def(MHI)
- Trend of sSFR with both def(MH2) and def(MHI)

	log(sSFR)(yr^{-1})	
	Mean	n_{UL}/n
Def(M_{HI}) <0.75	-10.31±0.10	(5/19)
Def(M_{HI}) >0.75	-10.85±0.13	(6/16)
Def(M_{H_2}) < -0.25	-10.33±0.07	(6/22)
Def(M_{H_2}) > -0.25	-10.81±0.12	(8/22)
	log(SFE)(yr^{-1})	
	Mean	n_{UL}/n
Def(M_{HI}) <0.75	-9.08±0.07	(5/19)
Def(M_{HI}) >0.75	-9.16±0.12	(6/16)
Def(M_{H_2}) < -0.25	-9.05±0.07	(6/22)
Def(M_{H_2}) > -0.25	-9.04±0.13	(8/22)

Summary

- Main result: Galaxies in HCGs have a very normal molecular gas content and SFR (normal for their L_B and L_K) in spite of their sometimes very high HI deficiency.
- No strong deficiency neither in M_{H2} nor in SFR in galaxies in HCGs compared to AMIGA galaxies.
- The star formation efficiency is very similar to isolated galaxies.
- There is a weak excess (about 50%) in MH2 which could be either more molecular gas or a more centrally concentrated molecular gas distribution.
- No strong of M_{H2} or L_{fir} trend with the HI deficieny.
- There is a weak trend of def(M_{H2}) with the evolutionary phase (enhancement in early phases and decreasing later).
- SFE is independent on def(M_{H2}) and def(M_{HI}) and similar to isolated galaxies.
- There is a trend of sSFR with def(M_{H2}) and def(M_{HI}) (lower for higher deficiency.