Molecular gas and star formation in transitioning galaxies in Hickson Compact Groups

Ute Lisenfeld
Universidad de Granada

In collaboration with:

Katherine Alatalo

Catherine Zucker

Phil Appleton

Kelsey Johnson

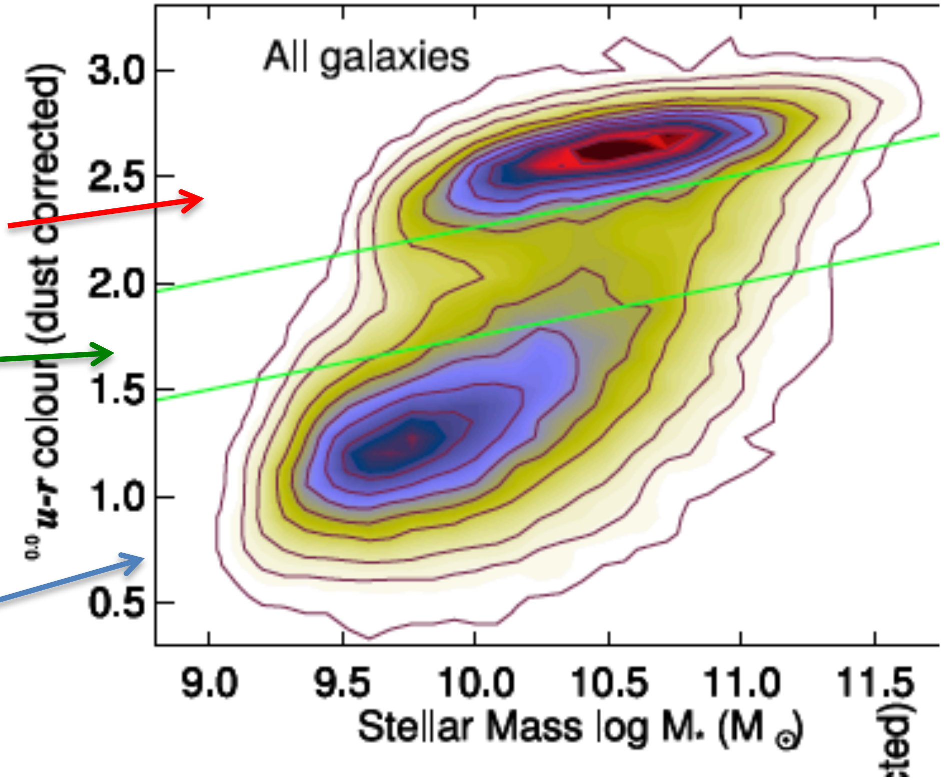
Sarah Gallagher

Lisa Walker

Optical colors of galaxies

- Galaxies can be classified according to their optical colors (e.g. Baldry et al. 2004):
  - Red sequence (quiescent, mostly early-types)
  - Green valley – transitioning population
  - Blue cloud (actively star forming, mostly late-types)

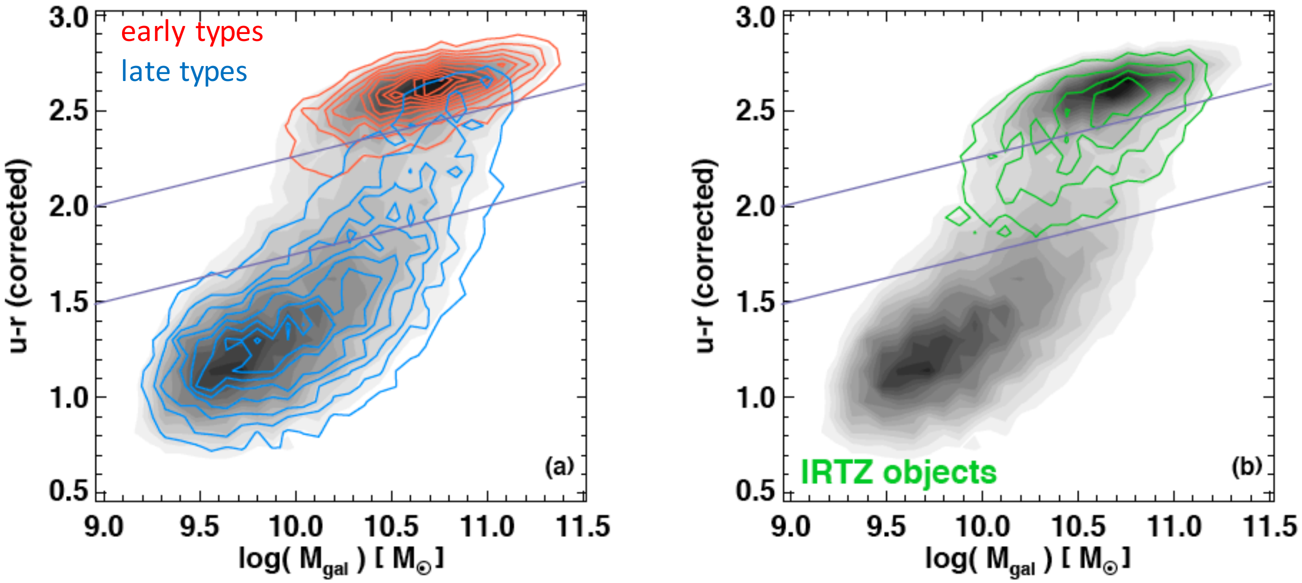
- What are the processes that cause the transition from blue to red?



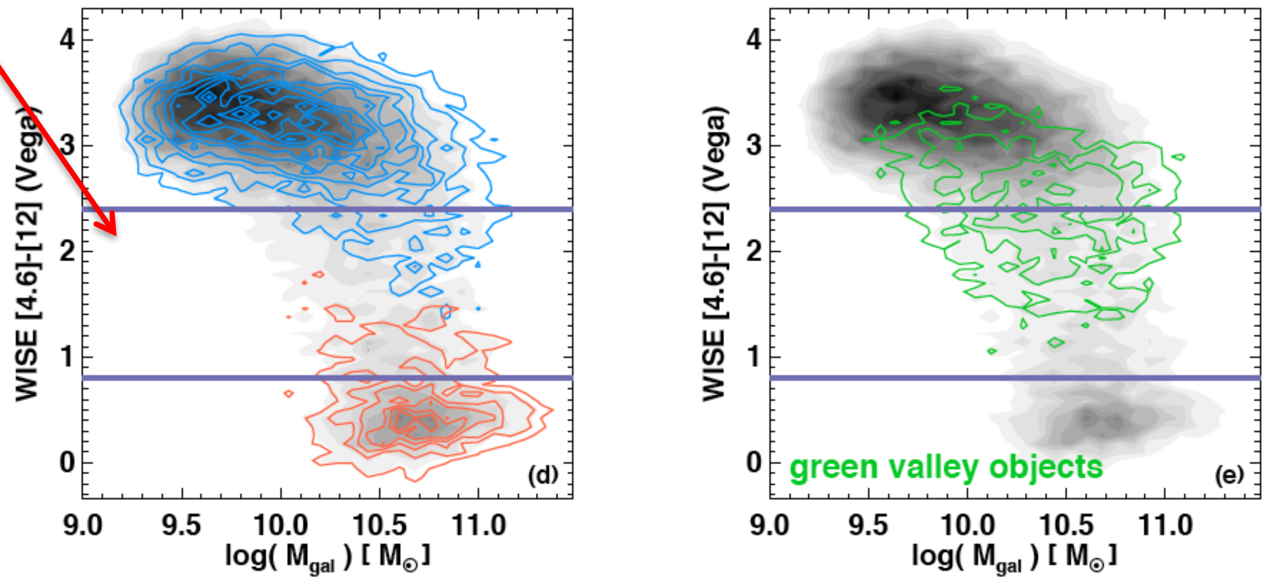
From Schawinsky et al. (2014)

Infrared colors of galaxies

- **Infrared emission is from** different components of galaxies: dust and old stars.
- Infrared colors from WISE show a pronounced **bimodal structure** with an Infrared Transition zone (IRTZ).
- The IRTZ is **not the same** as optical green valley:
  - Galaxies in IRTZ are mostly in the optical red sequence.
  - Galaxies seem to pass first the optical green valley and later IRTZ.



From Alatalo et al. (2015), sample WISE detected Galaxy-Zoo galaxies.

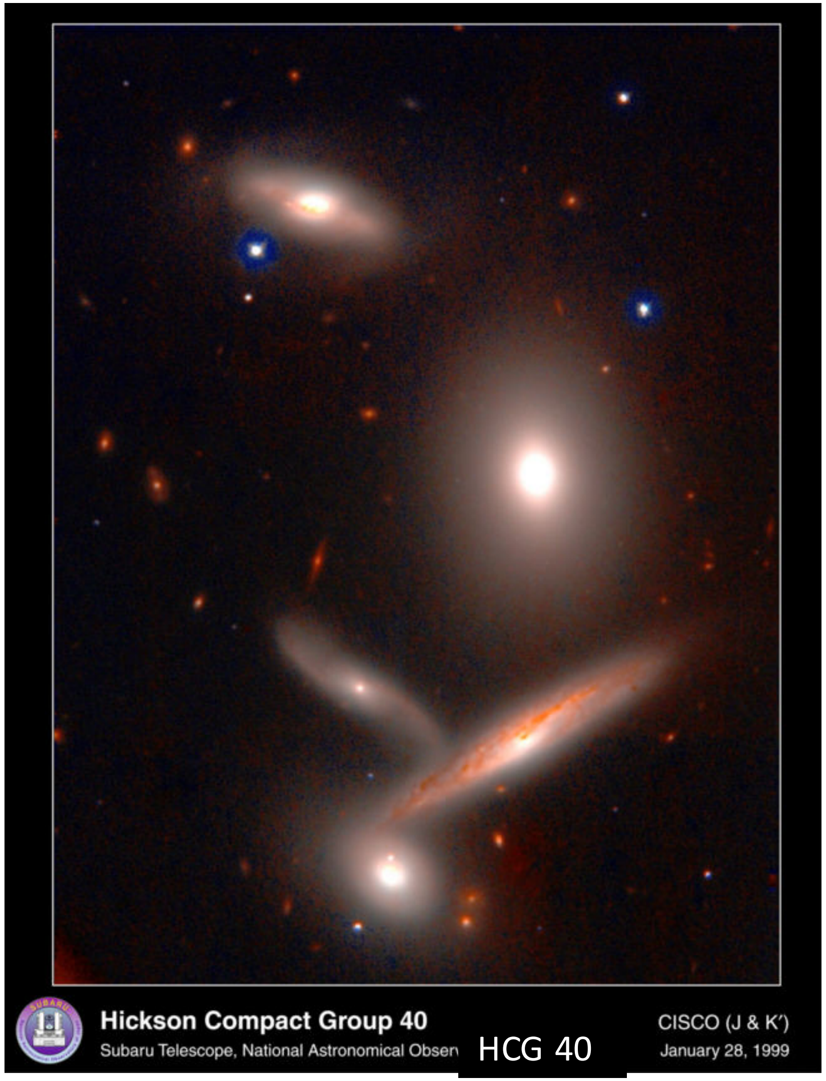


Hickson Compact Groups (HCG)

- Hickson Compact Groups are dense and relatively isolated groups of 4-8 galaxies, originally compiled by Hickon (1982)
- They have high galaxy densities and low velocity dispersion -> interactions are important
  - Between galaxies
  - Between galaxies and inter-group medium
- Effects are evident:
  - Morphological changes take place, fraction of S0s is very high.
  - Large amount of HI in the IGM.
  - Many show a deficiency of atomic gas.

➔ Ideal objects to study galaxy transformation and which processes play a role in it

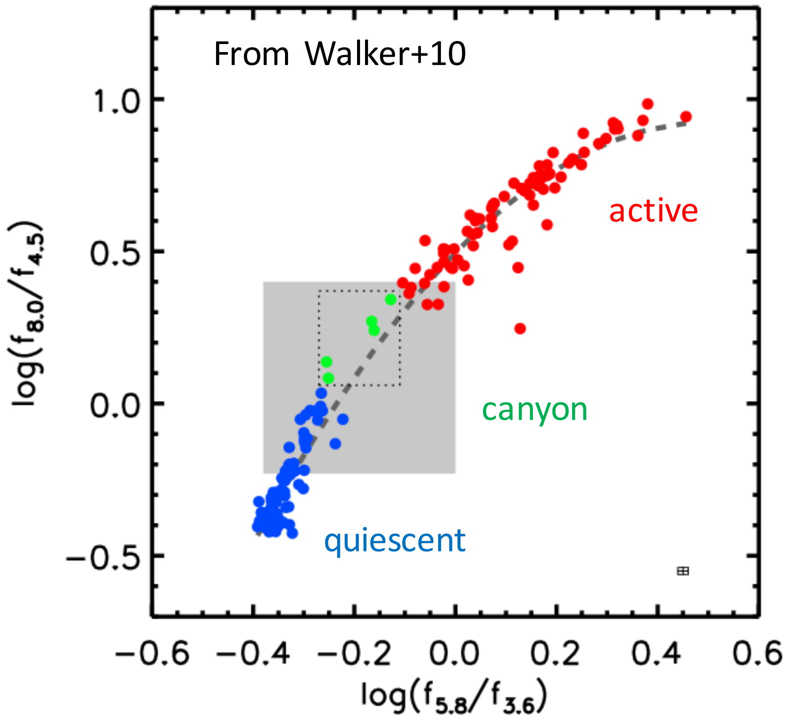
➔ Similar to what happened in the early universe

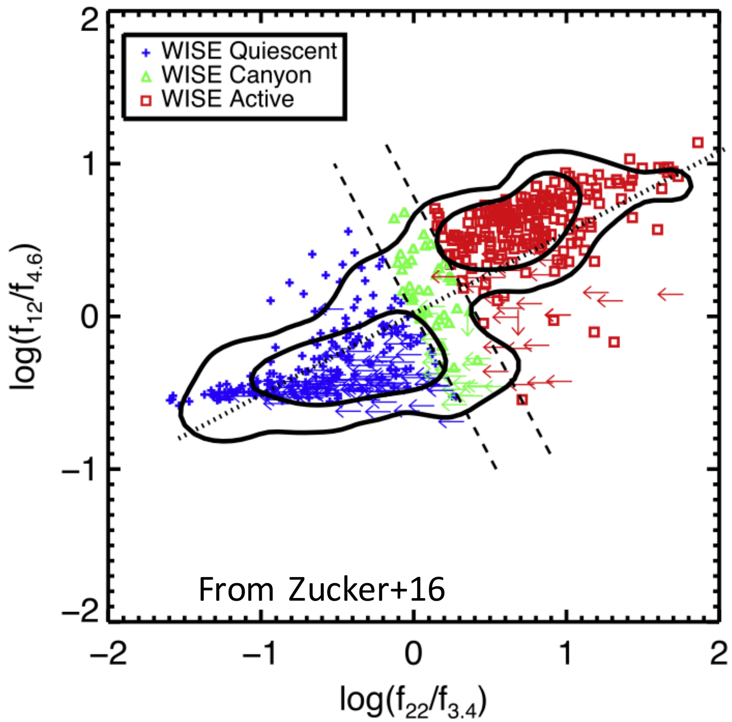


HCG 40

Infrared colors of HCG galaxies

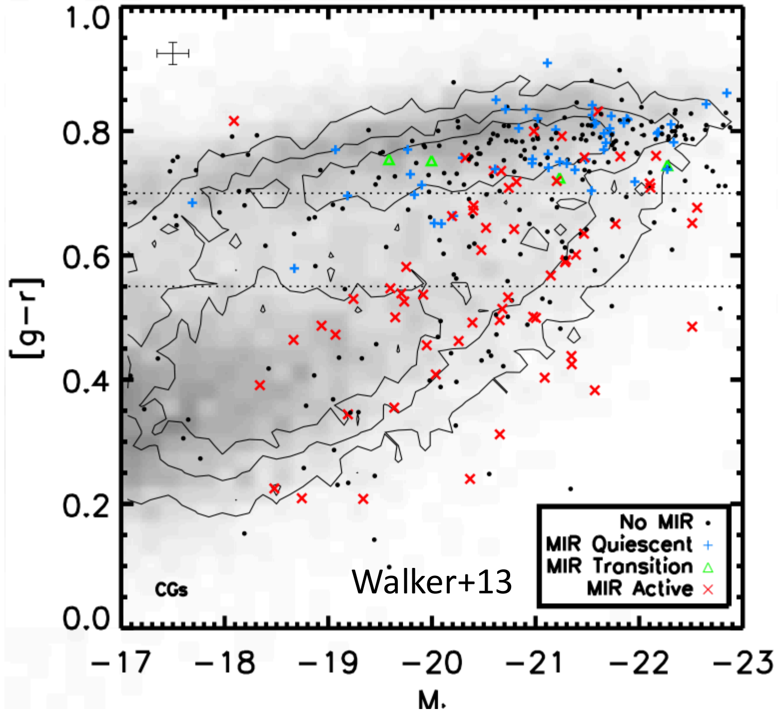
- A **gap/canyon** was found in Spitzer colors (Johnson et al. 2007, Walker et al. 2010, 2012) and sSFR (Tsanavaris et al. 2010) between **active** and **quiescent** galaxies with a low density of galaxies.
- The low density is indicative of a **fast transition** between active and quiescent
- A similar canyon can be defined with WISE colors for a larger sample (Zucker+16).

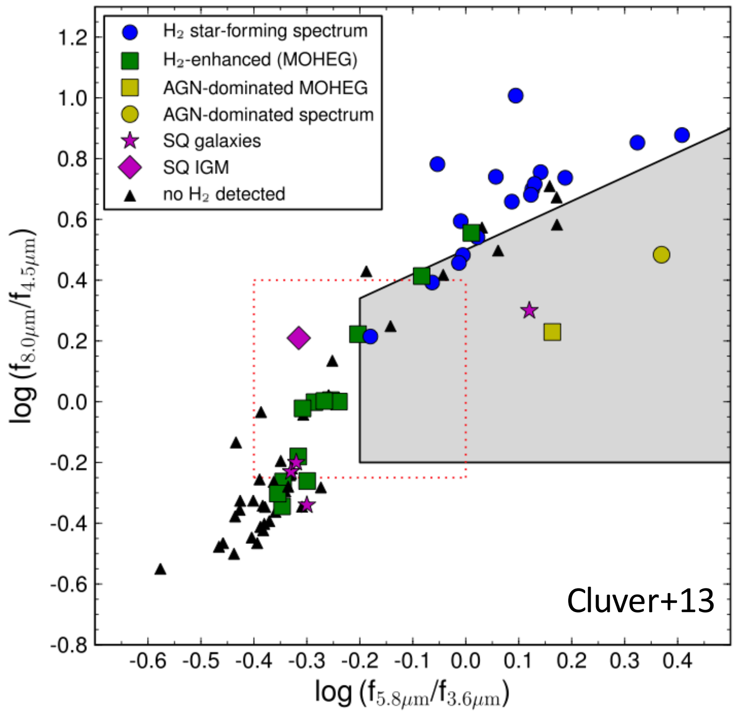




Properties of IR canyon galaxies

- Cayon galaxies lie not in optical green valley but mostly in red sequence (Walker+13)
- Galaxies with enhanced warm H_2 emission (MOHEGs*) indicative of shocks lie preferentially in the gap (Cluver+13)
- Interpretation:
  - Shock or the processes that produce shocks might play a role in the transition.





* MOHEGs = MOlecular Hydrogen Emission-line Galaxies
$L(H_2)/L(7.7\mu m) > 0.04 \Rightarrow$ cannot be achieved by SF

Molecular gas in HCG galaxies

In order to understand the quenching of star formation, **the measurement of the (cold) molecular gas content (traced by CO) is crucial** because it is the fuel of star formation.

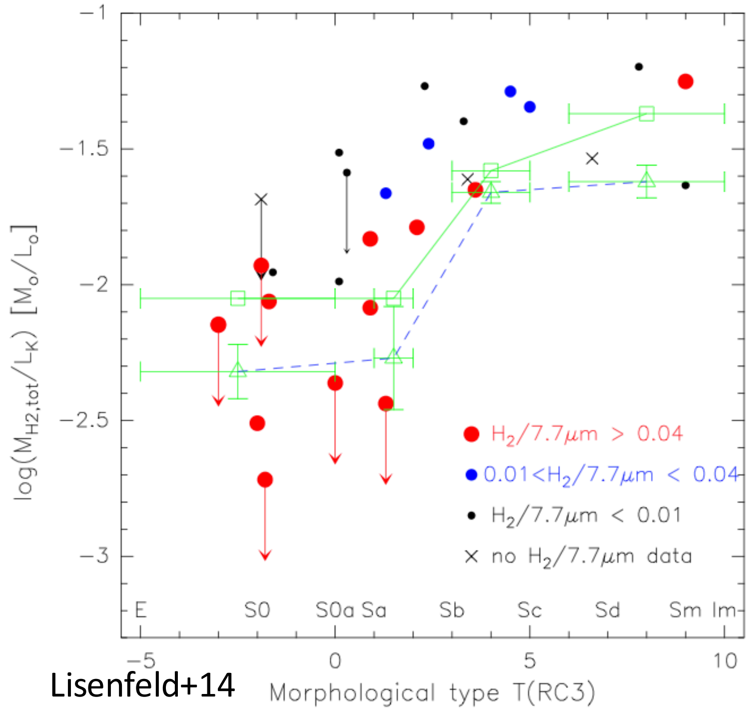
It allows us to answer the question:

Is the decrease in star formation due to a lack of molecular gas or is star formation becoming more inefficient?

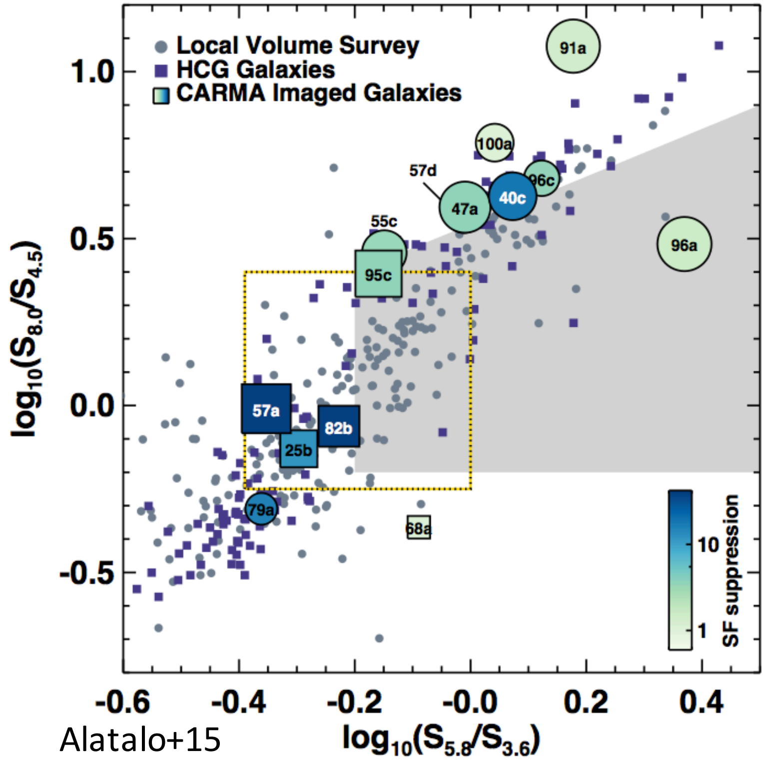
Molecular gas in HCG galaxies

- Previous studies of molecular gas in HCG:
  - No lack of molecular gas in HCG galaxies (Leon+98, Verdes-Montenegro+98, Martinez-Badenes+10)
  - Indications that MOHEG galaxies have lower molecular gas content than non-MOHEG (Lisenfeld+14)
  - Indications of supression of SF in HCG galaxies in the Spitzer IR canyon (Alatalo+15).

- Still missing:
  - Larger sample
  - Systematic consideration of IR data ➔ WISE data is helpful



Lisenfeld+14



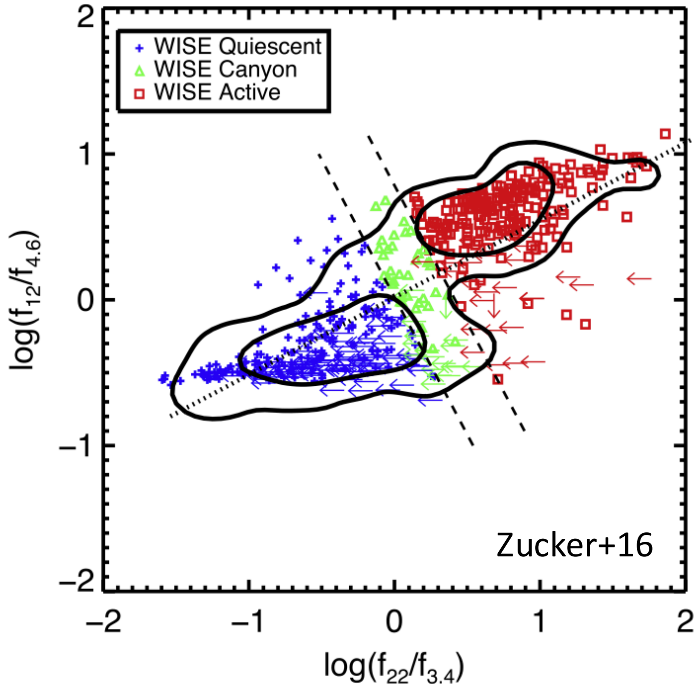
Alatalo+15

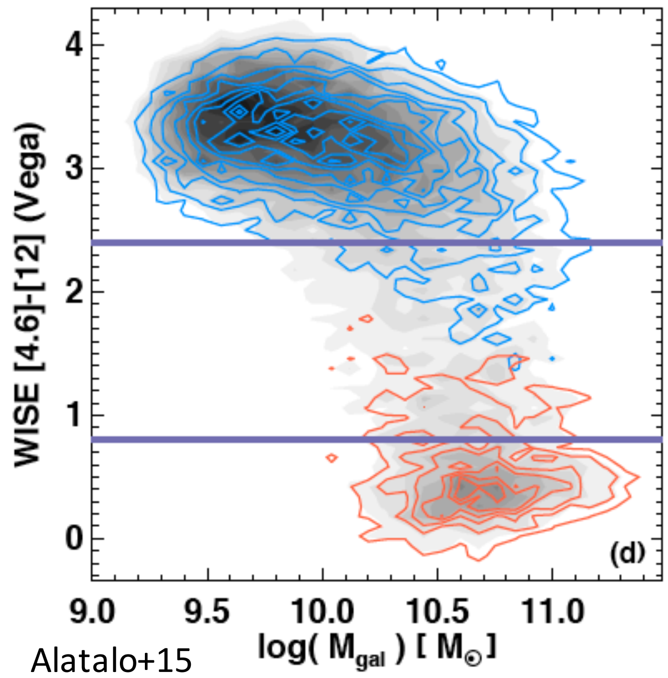
Present work

- We use sample of Zucker et al. (2016) which derived WISE fluxes for 652 galaxies in 163 compact groups.
- We use classification of Zucker+16 in active/quiescent/canyon galaxies.
- We also classify galaxies that are in the IRTZ (Alatalo+15)

Goal:

- Compare molecular gas fraction and star formation efficiency of
  - Active galaxies
  - Quiescent galaxies
  - Transitioning galaxies





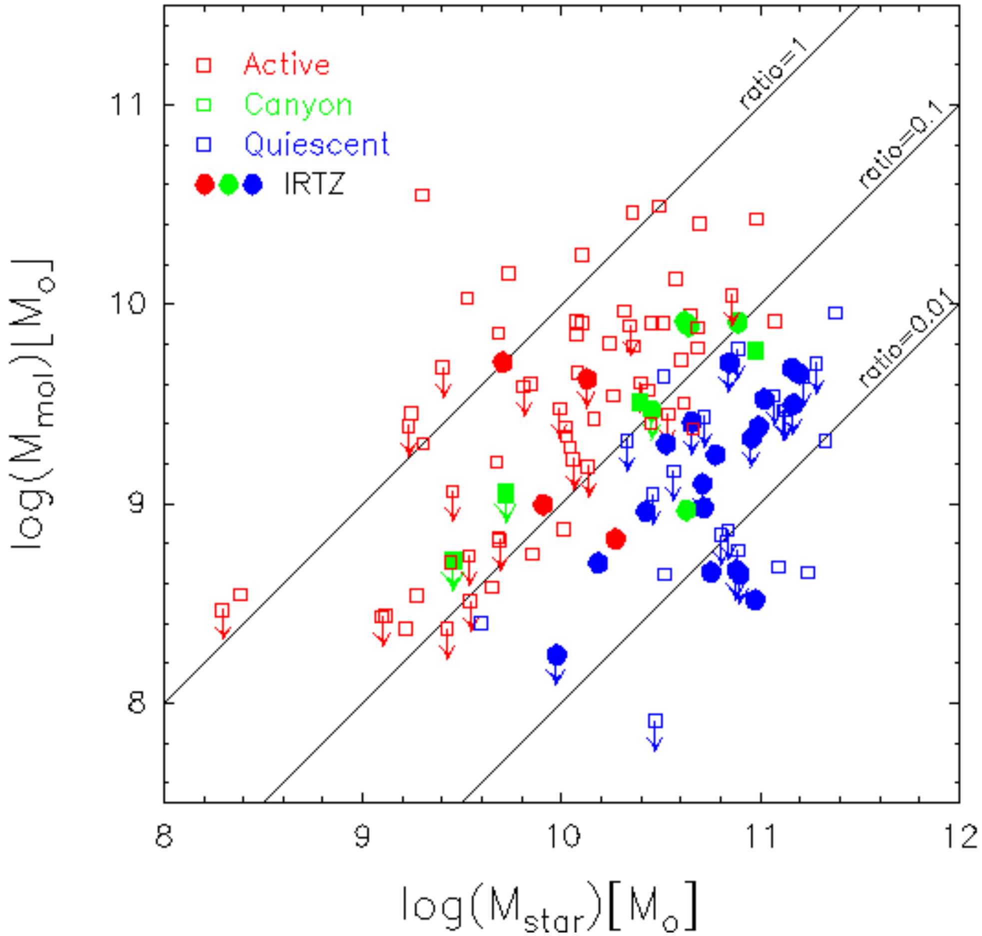
The method

- WISE data allows us to calculate SFR and stellar mass:
  - SFR from W4 (22μm) (Lee+13): **$SFR = 10^{-9} L_{W4}$ [Mo yr^{-1}]**
  - M_{star} from W1 + W2 (3.4μm and 4.6μm) (Jarrett+13): **$\log(Mstar/L_{W1}) = -0.246-2.100(W1-W2)$**

- Molecular gas from the literature (Leon+98, Verdes-Montenegro+98, Martinez-Badenes+10, Lisenfeld+14)
  - Observed mainly with IRAM 30m, also with FCRO, Kitt Peak
  - CO data for 139 galaxies (77 detections)

- Need to homogenize the single dish CO data (different beams+different fractions of the disks are probed)(Lisenfeld+11)
  - Extrapolated molecular gas mass from the <u>central pointing to the entire disk</u> with the (observationally founded) assumption of expontial distribution of CO and $r_{e,co} = 0.2\ r_{25}$ (Leroy+10,Regan+01, Nishiyama & Nakai 2001, Young+95).
  - This aperture correction is mostly between 1 and 2 (mean 1.7, maximum factor 6)
  - Extrapolated molecular gas mass agrees well with measurements by CARMA for 13 galaxies in common (Alatalo+15)

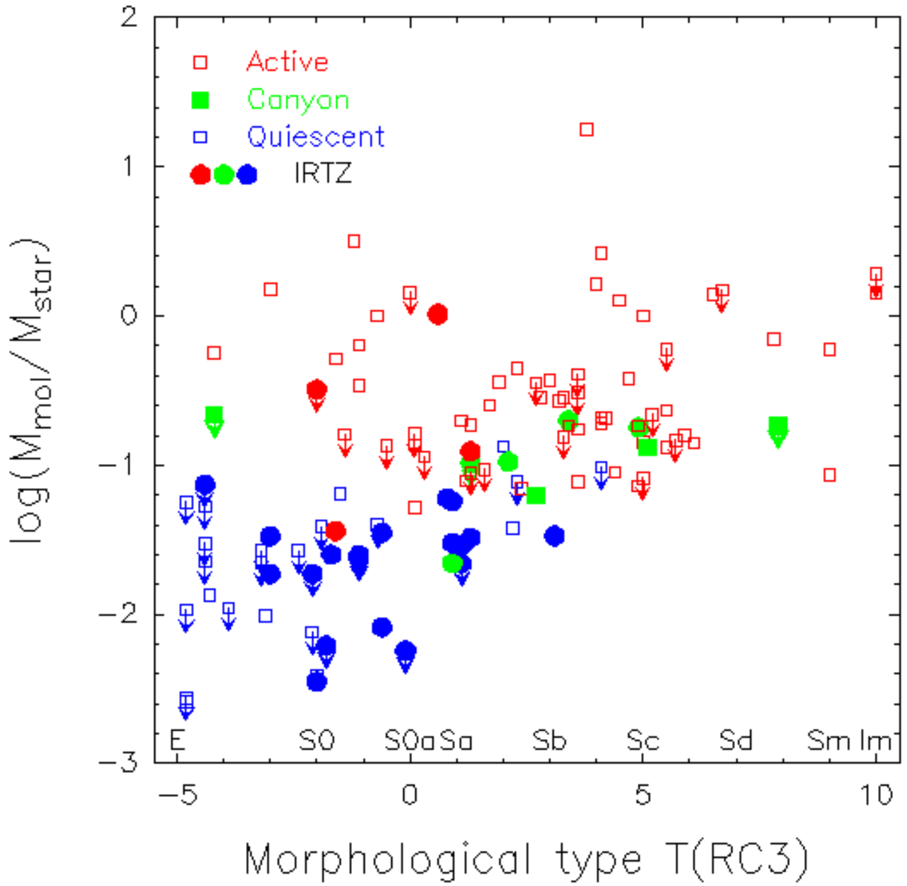
Molecular gas mass



Stratified distribution: For a given Mstar, the molecular gas mass is:

- Highest in **active galaxies**
- Lowest in **quiescent galaxies**
- In between in **canyon galaxies**
- In between, but more to the quiescient side, **IRTZ galaxies**

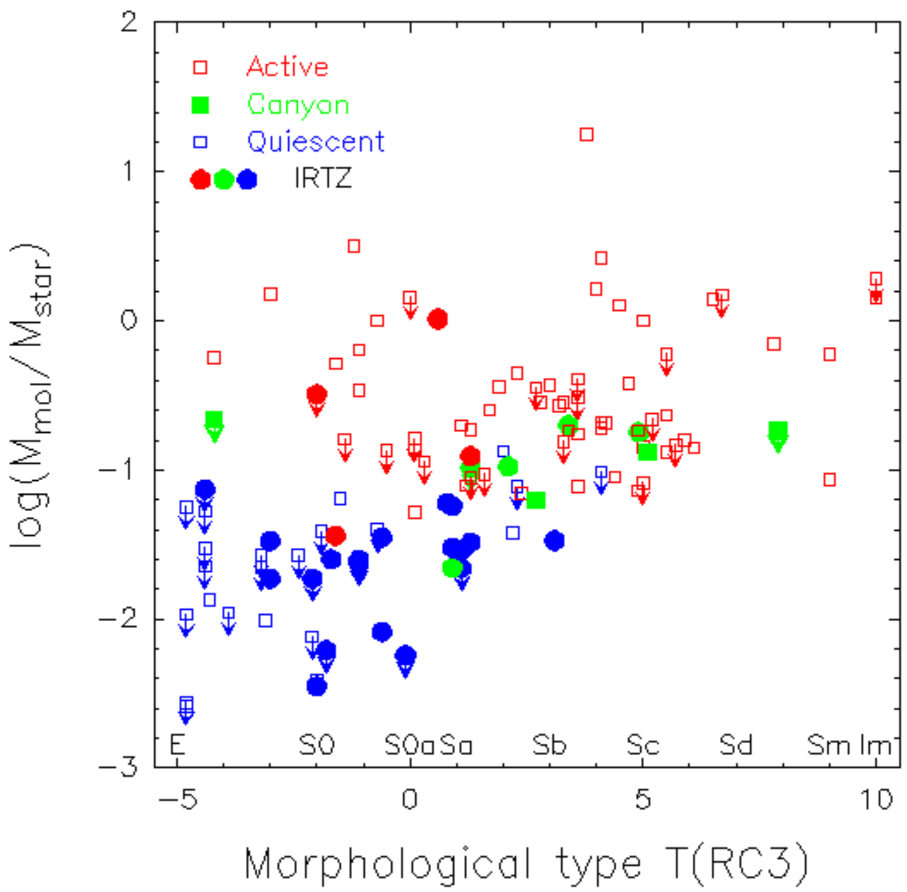
Molecular gas fraction



Class	$\langle M_{mol}/M_{star} \rangle$ (all)	$\langle M_{mol}/M_{star} \rangle$ (late-types)
Active	-0.64±0.07	-0.67±0.07
Canyon	-1.06±0.14	-1.09±0.14
IRTZ	-1.90±0.10	-1.31±0.08
Quiescent	-2.06±0.09	-1.55±0.13

- Canyon late-type galaxies have $\langle M_{mol}/M_{star} \rangle$
  - factor 2.5 (3σ) below active galaxies
  - factor 2.5 (2σ) above quiescent galaxies
- IRTZ late-type galaxies have $\langle M_{mol}/M_{star} \rangle$
  - factor 4 (5σ) below active galaxies (for entire sample and for spirals)
  - Marginally above quiescent galaxies

Molecular gas fraction

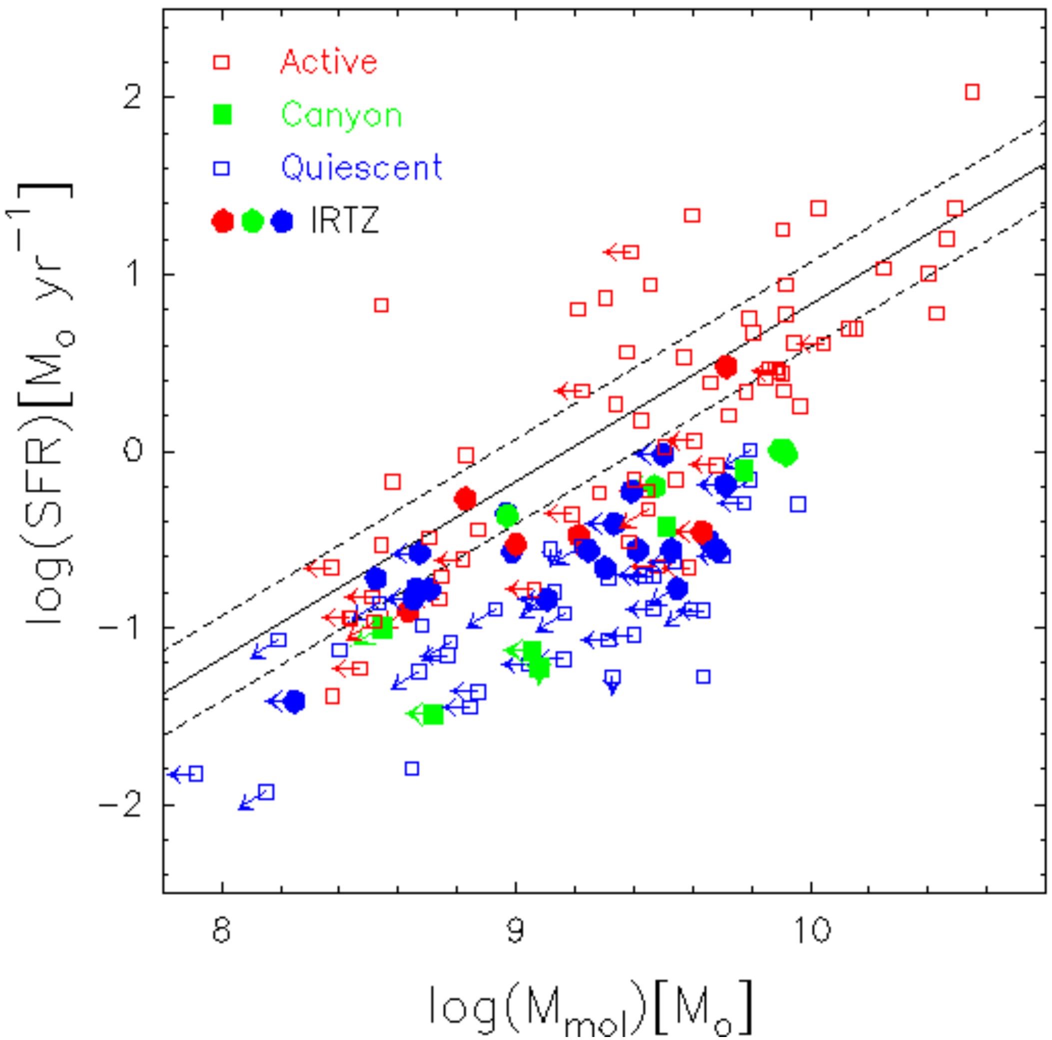


Class	$<M_{mol}/M_{star}>$ (all)	$<M_{mol}/M_{star}>$ (late-types)
Active	-0.64±0.07	-0.67±0.07
Canyon	-1.06±0.14	-1.09±0.14
IRTZ	-1.90±0.10	-1.31±0.08
Quiescent	-2.06±0.09	-1.55±0.13

- Canyon late-type galaxies have $<M_{mol}/M_{star}>$
  - factor 2.5 (3σ) below active galaxies
  - factor 2.5 (2σ) above quiescent galaxies
- IRTZ late-type galaxies have $<M_{mol}/M_{star}>$
  - factor 4 (5σ) below active galaxies (for entire sample and for spirals)
  - Marginally above quiescent galaxies

⇒ Galaxy transformation is accompanied by a decrease in molecular gas

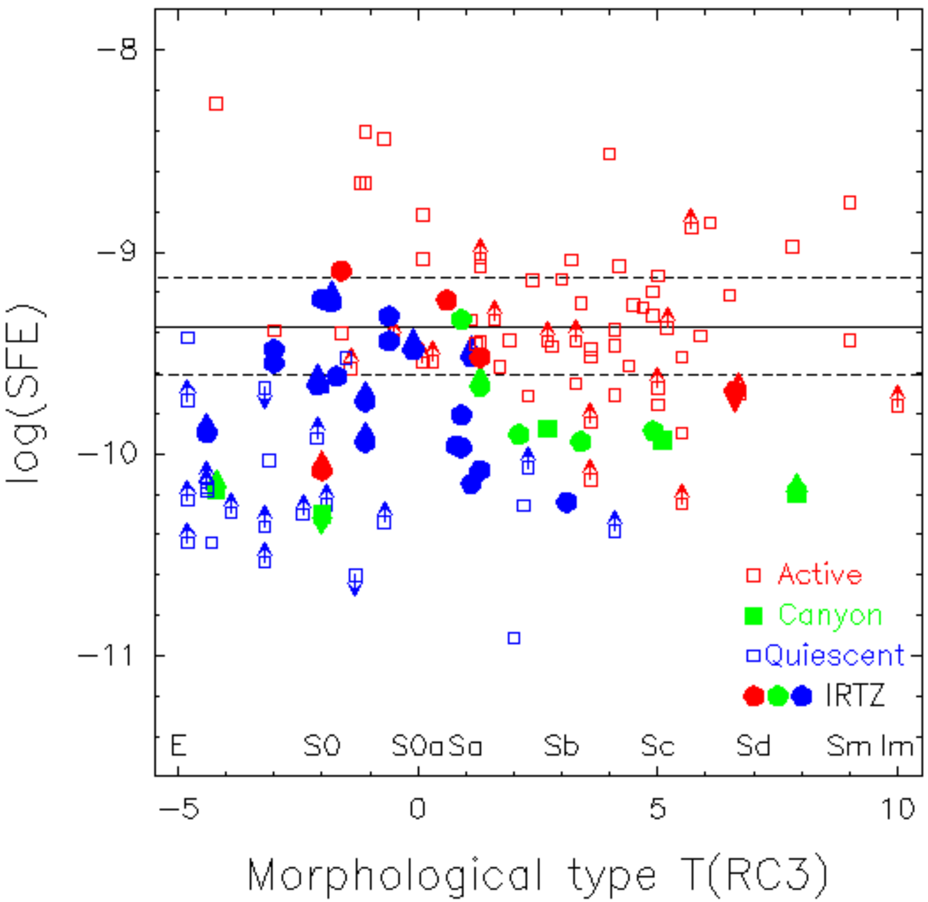
Molecular gas and star formation rate



Canyon/IRTZ galaxies lie below relation followed by

- active HCG galaxies
- "field" spiral galaxies (full+ dashed lines, Bigiel+11).

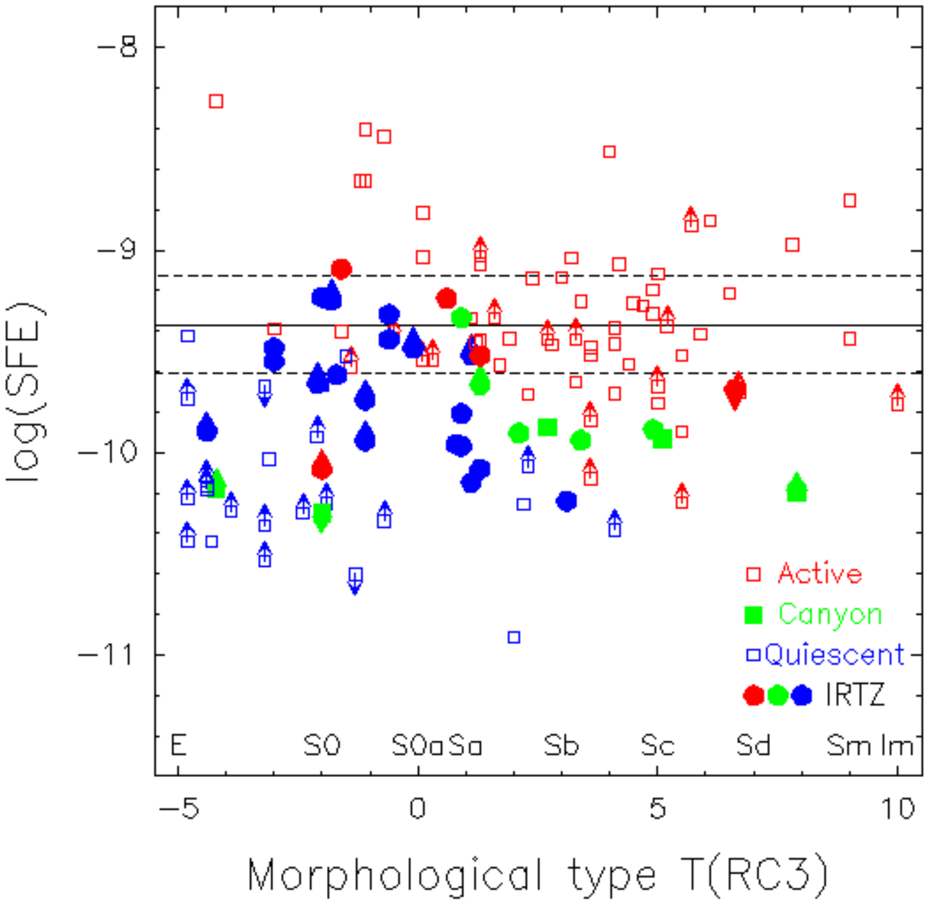
Star formation efficiency (SFE = SFR/M_{mol})



Class	<SFE> (all)	<SFE> (late-types)
Active	-9.17±0.05	-9.26±0.05
Canyon	-9.74±0.10	-9.74±0.10
IRTZ	-9.53±0.07	-9.76±0.08
Quiescent	-9.67±0.07	-10.06±0.11

- Canyon late-type galaxies have <SFE>
  - Factor 5 (5σ) below active galaxies
  - Marginally above quiescent late-type galaxies
- IRTZ late-type galaxies have <SFE>
  - Factor 3 (4σ) below active galaxies
  - Marginally above quiescent galaxies

Star formation efficiency (SFE = SFR/M_{mol})



Class	<SFE> (all)	<SFE> (late-types)
Active	-9.17±0.05	-9.26±0.05
Canyon	-9.74±0.10	-9.74±0.10
IRTZ	-9.53±0.07	-9.76±0.08
Quiescent	-9.67±0.07	-10.06±0.11

- Canyon late-type galaxies have <SFE>
  - Factor 5 (5σ) below active galaxies
  - Marginally above quiescent late-type galaxies
- IRTZ late-type galaxies have <SFE>
  - Factor 3 (4σ) below active galaxies
  - Marginally above quiescent galaxies

$\Rightarrow$ In transitioning galaxies the molecular gas is not able to form stars efficiently

What does this tell us about the evolutionary pathways?

- The data shows that the transition of galaxies in HCGs goes along with:
  1. Loss of molecular gas.
  2. Remaining molecular gas is not able to form stars efficiently

- Possible scenarios (consistent with e.g. Bitsakis+2011, Cluver+2013, Alatalo+2015):
  1. In HCG gas is being removed from galaxies and accumulates in intergroup medium (IGM). This is seen in HI (Verdes-Montenegro+01); **but the molecular gas is affected as well.**
  2. What supresses star formation?
     - Most likely turbulent energy injection which perturbes molecular gas: This has been identified as most likely process in several HCG galaxies:
       – Stephan's Quintet (Appleton+02,Guillard+09,12)
       – Enhanced warm H_2 emission indicative of shocks(Cluver+13)
     - Possible processes are:
       – Collisions with neighboring galaxies (as in HCG 57a+d, Alatalo+14)
       – Collision with IGM (Stephan's Quintet).

Summary

- IR color allow to classify galaxies in HCG in active, quiescent and transitioning (canyon or IRTZ galaxies)
- Molecular gas observations show that **canyon/IRTZ** galaxies have a:
  - **lower molecular gas fraction**
  - **lower SFE**

  than active galaxies.
- These results are consistent with scenarios where galaxy transition goes along with **loss of gas (also molecular!)** and the **perturbation of the gas.**