Hickson Compact Groups: Galaxy evolution on steroids, a CARMA and *Herschel* view

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CARMA Symposium, 2013

Hickson Compact Groups

"By *compact group*, we mean a small, relatively isolated system of typically four or five galaxies in close proximity to one another."

Hickson 1997 ARA&A 35, 357

High fraction of E/S0

Evidence of tidal interactions

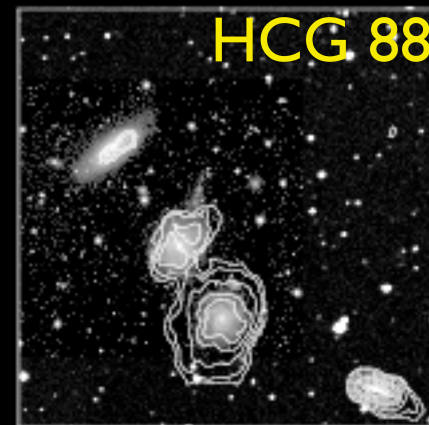
High density, low σ_v

Generally deficient in H I

HCG 31

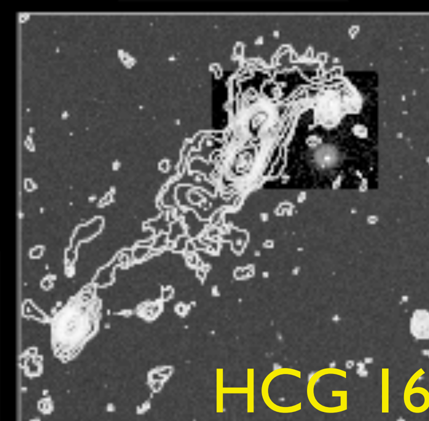
Hickson Compact Groups

Phase 1:
low level of interaction

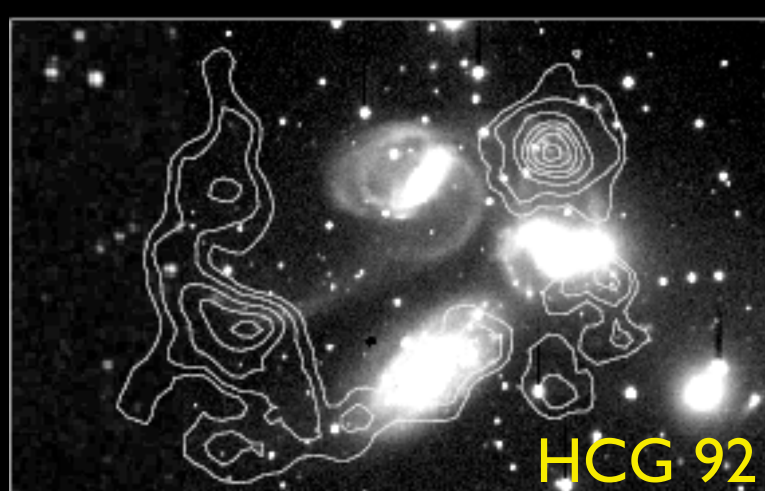


H I is still found in individual galaxy disks

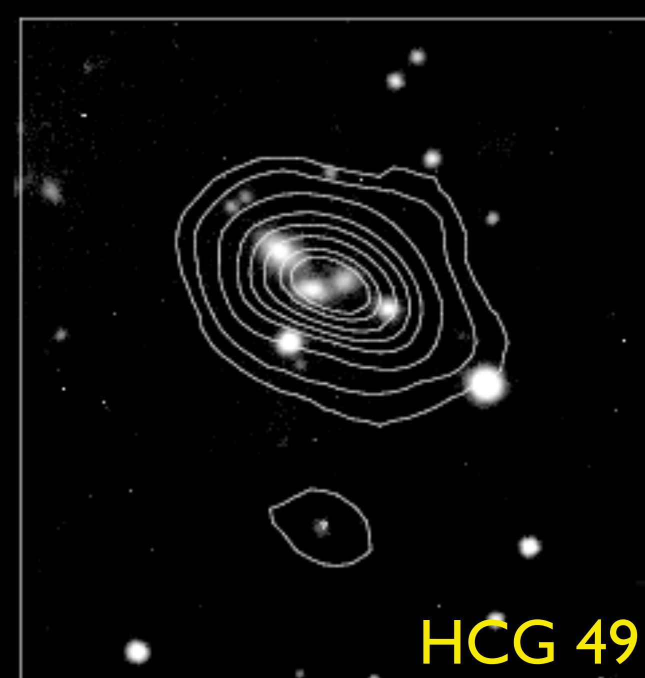
Phase 2:
more interaction



H I is disturbed, visible in tidal tails



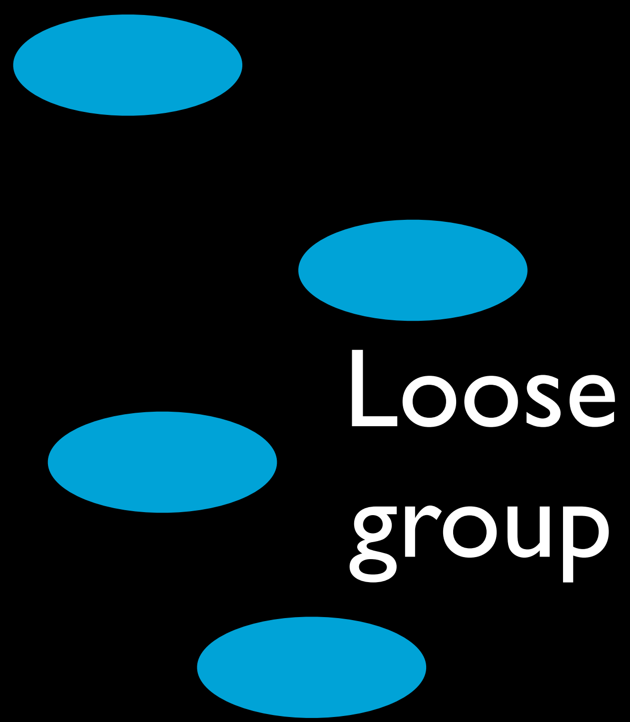
Phase 3:
advanced group stage



H I no longer in individual galaxies. Possibly now outside group or in common envelope

Verdes-Montenegro et al. 2001

HCG: evolutionary cycle



Hickson et al. 1997, Verdes-Montenegro et al. 2001, Johnson et al. 2007, Bitsakis et al. 2011a, 2011b

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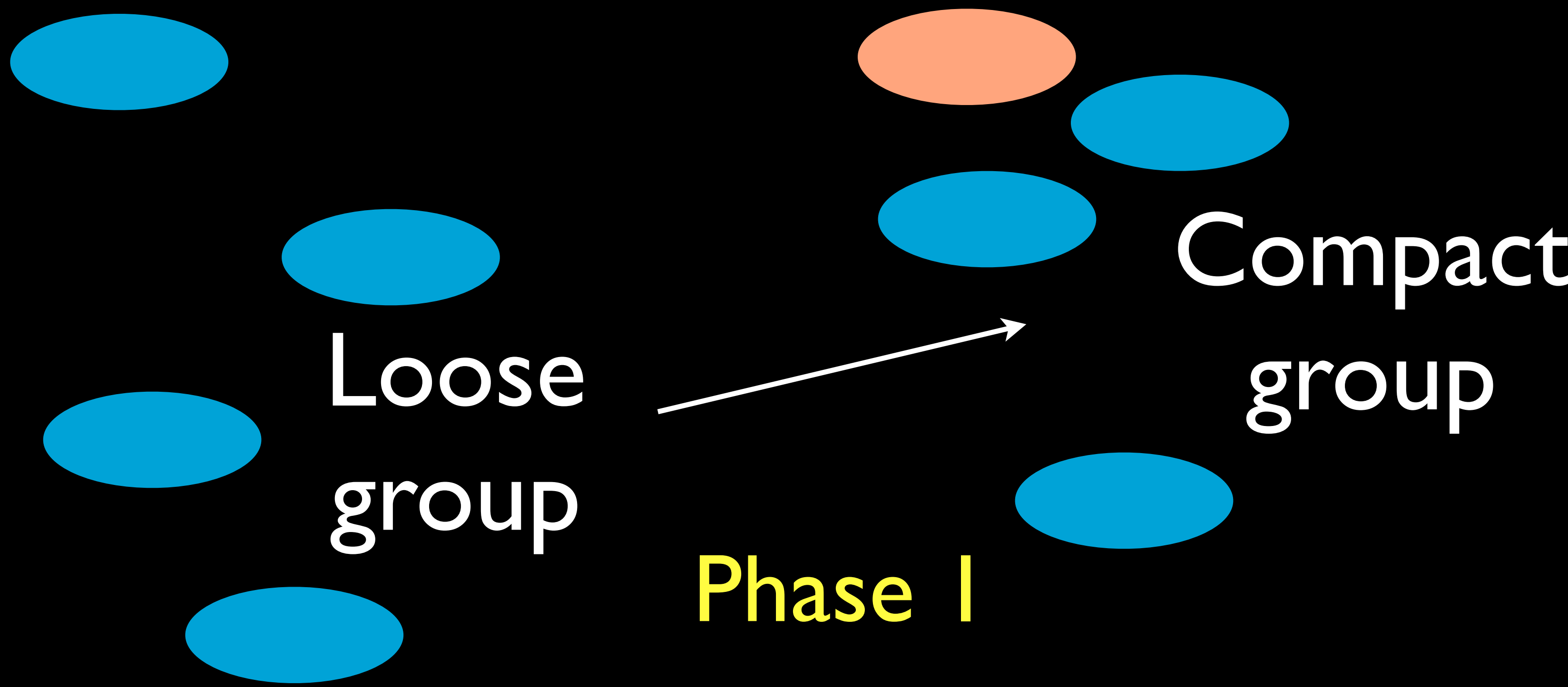

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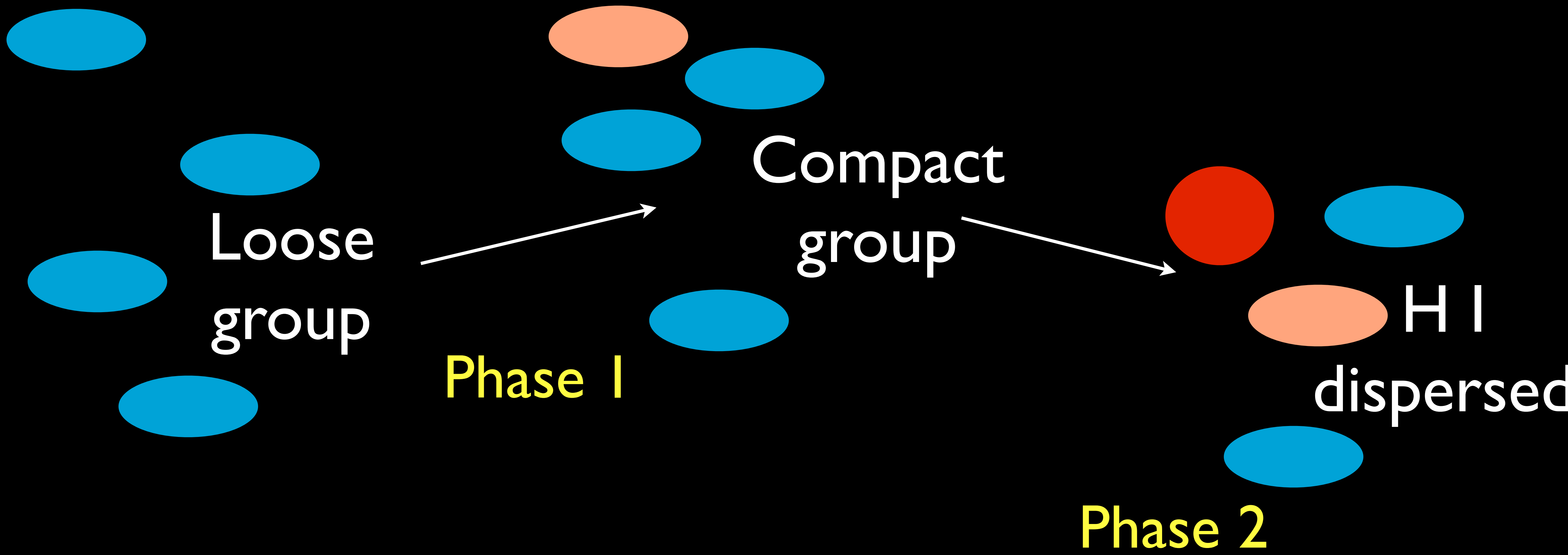

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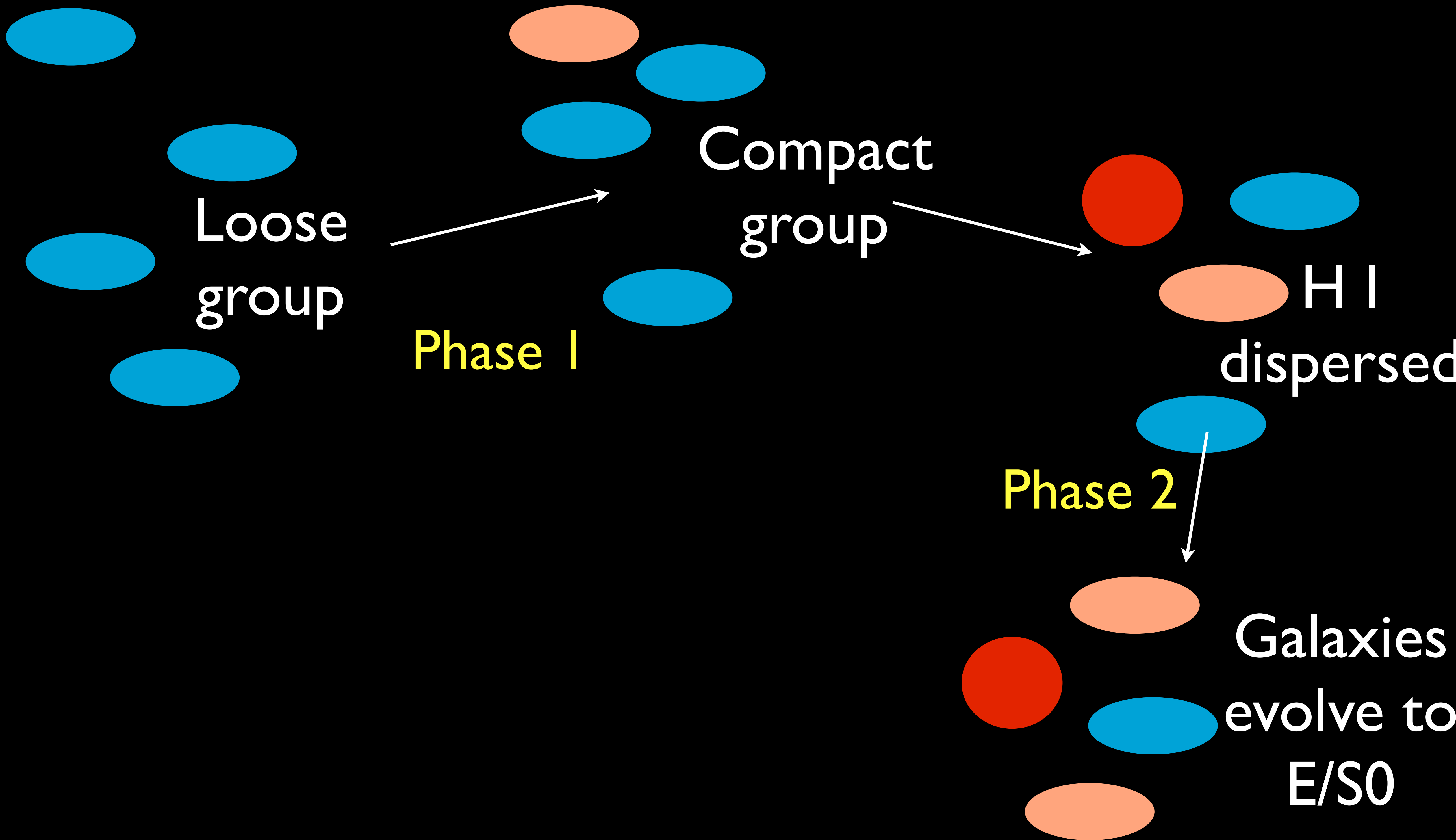

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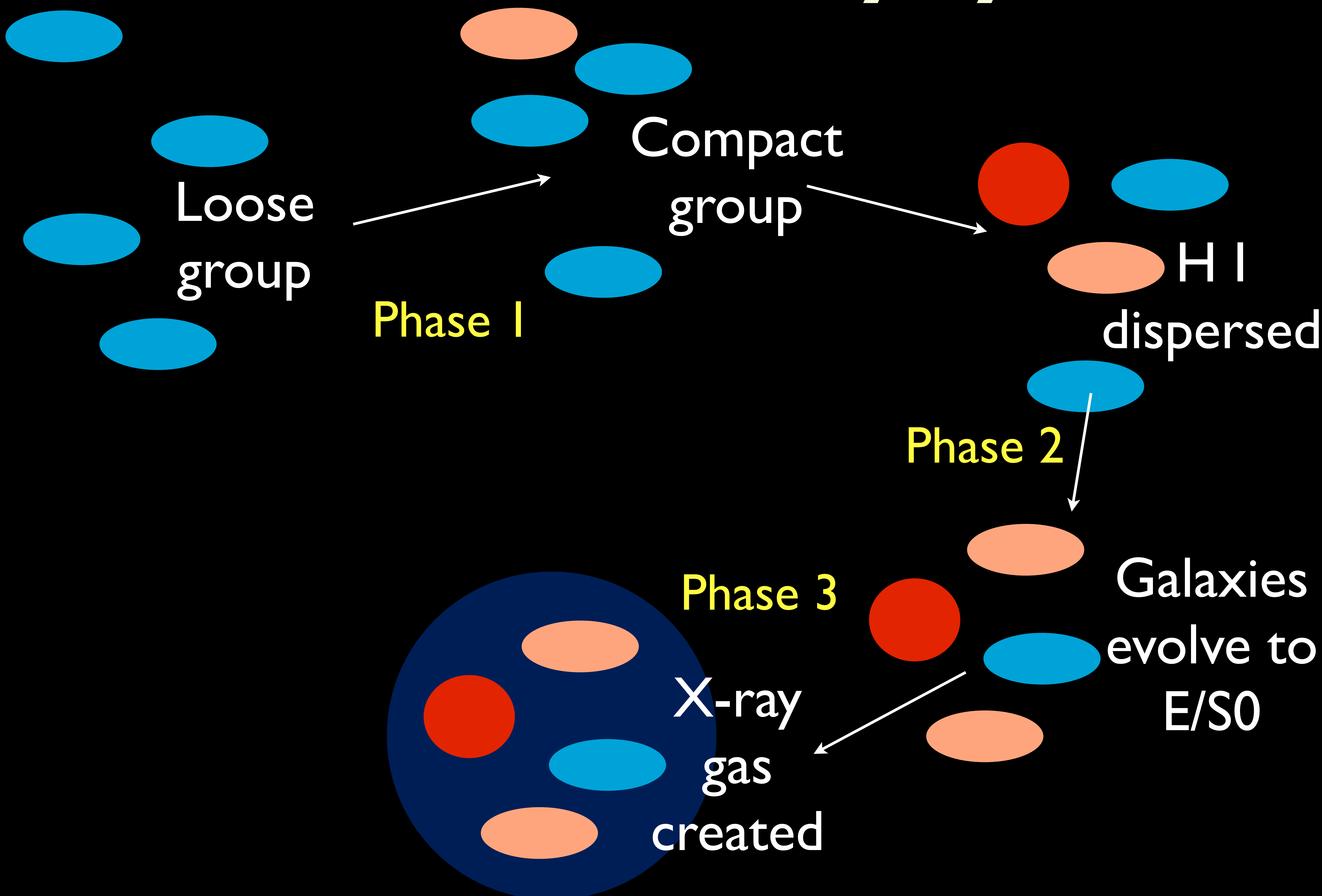

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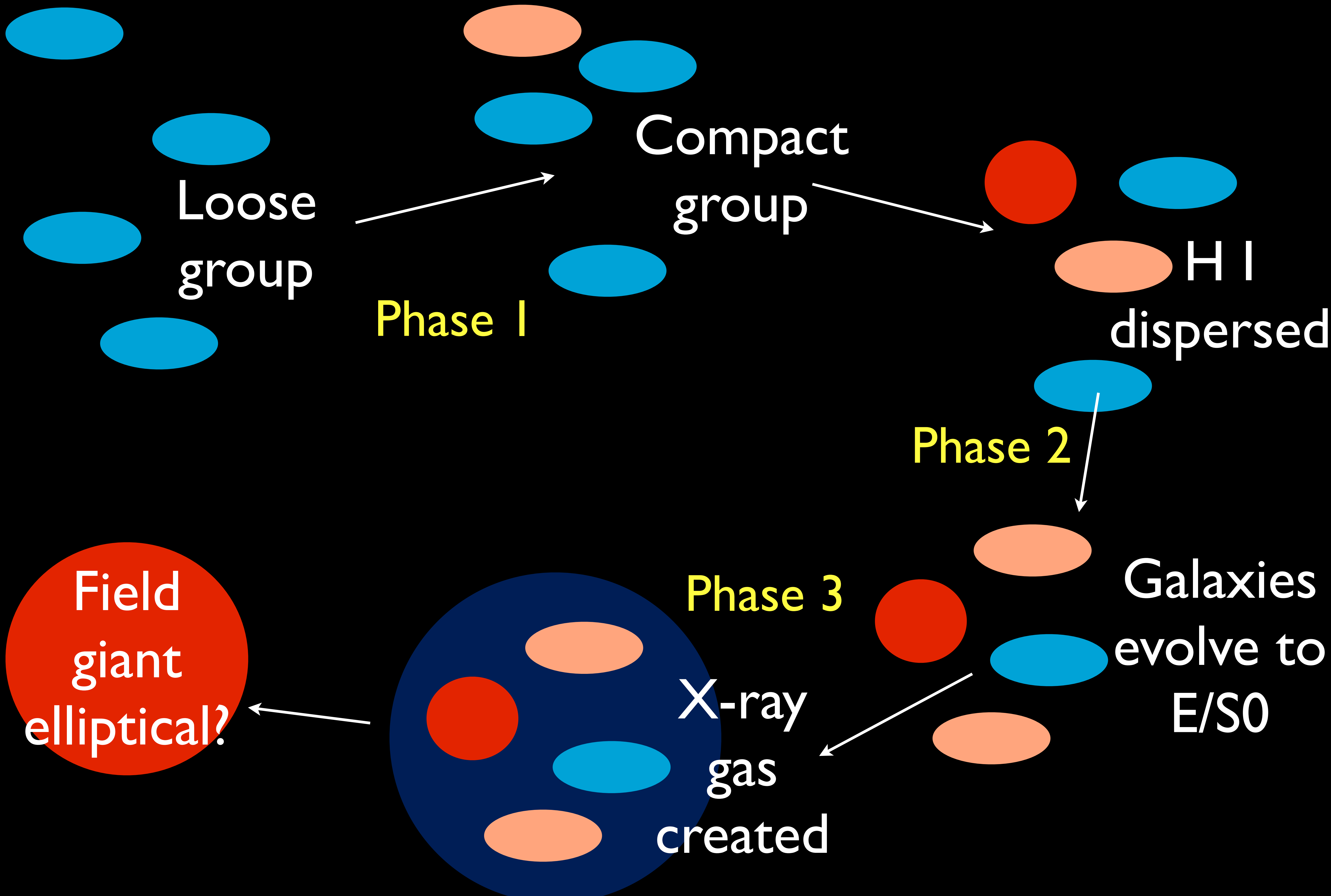


Hickson et al. 1997, Verdes-Montenegro et al. 2001, Johnson et al. 2007, Bitsakis et al. 2011a, 2011b

Rapid Evolution

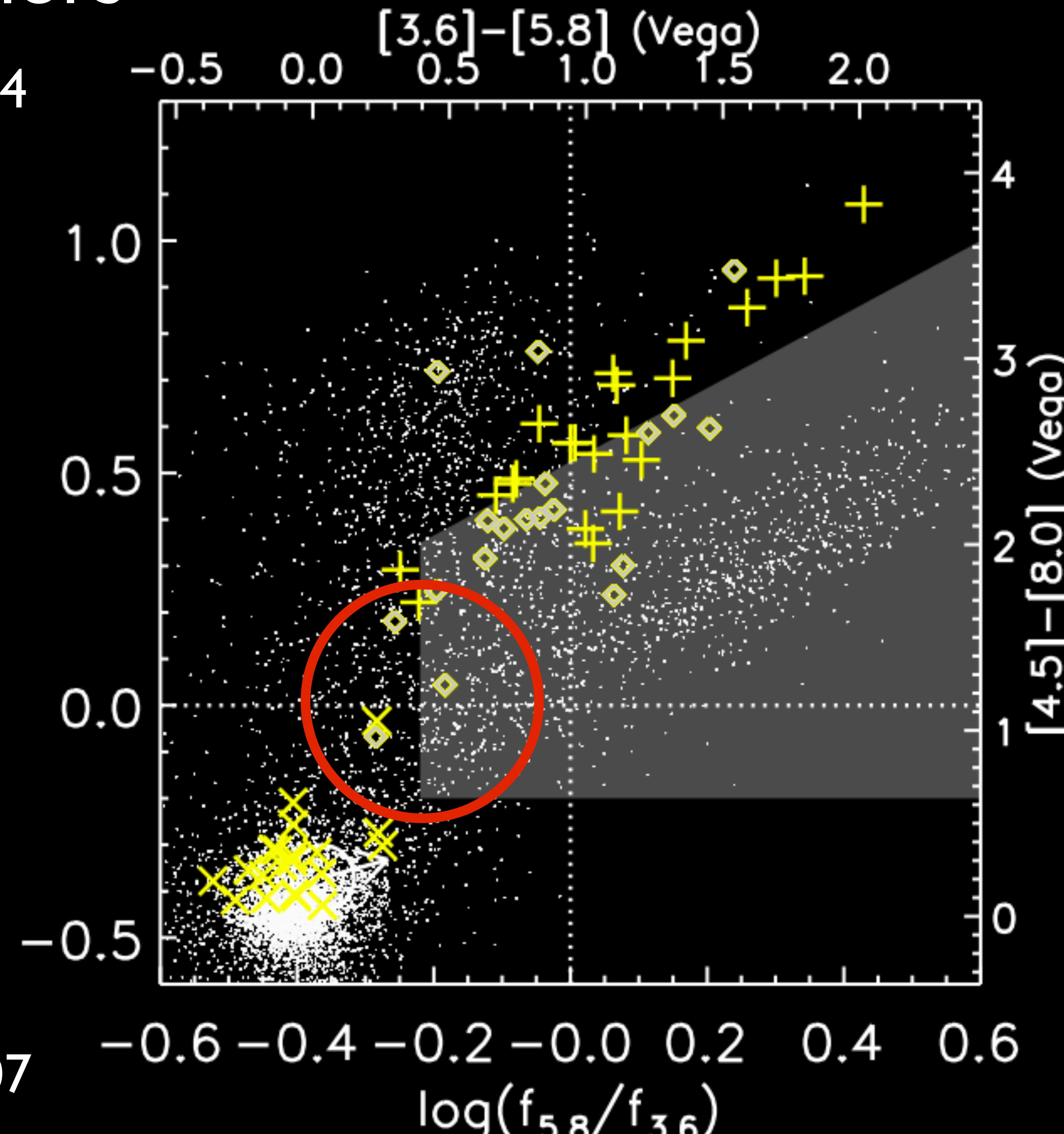
HCGs have bimodal IR colors

Color-color plot from Lacy et al. 2004
Lower left: red ETGs
Upper right: blue starformers

HCGs show bimodality between red colors (X) and blue colors (+) with very few in the gap

This gap is not as obvious in underlying population

=> rapid evolution in HCGs



Johnson et al. 2007

MoHEGs

MoHEG = Molecular Hydrogen Emitting Galaxy

$$H_2/7.7\mu m \text{ PAH} \geq 0.04$$

H_2 emission in MoHEGs is too strong to be energized solely by photon-dominated regions (PDRs).

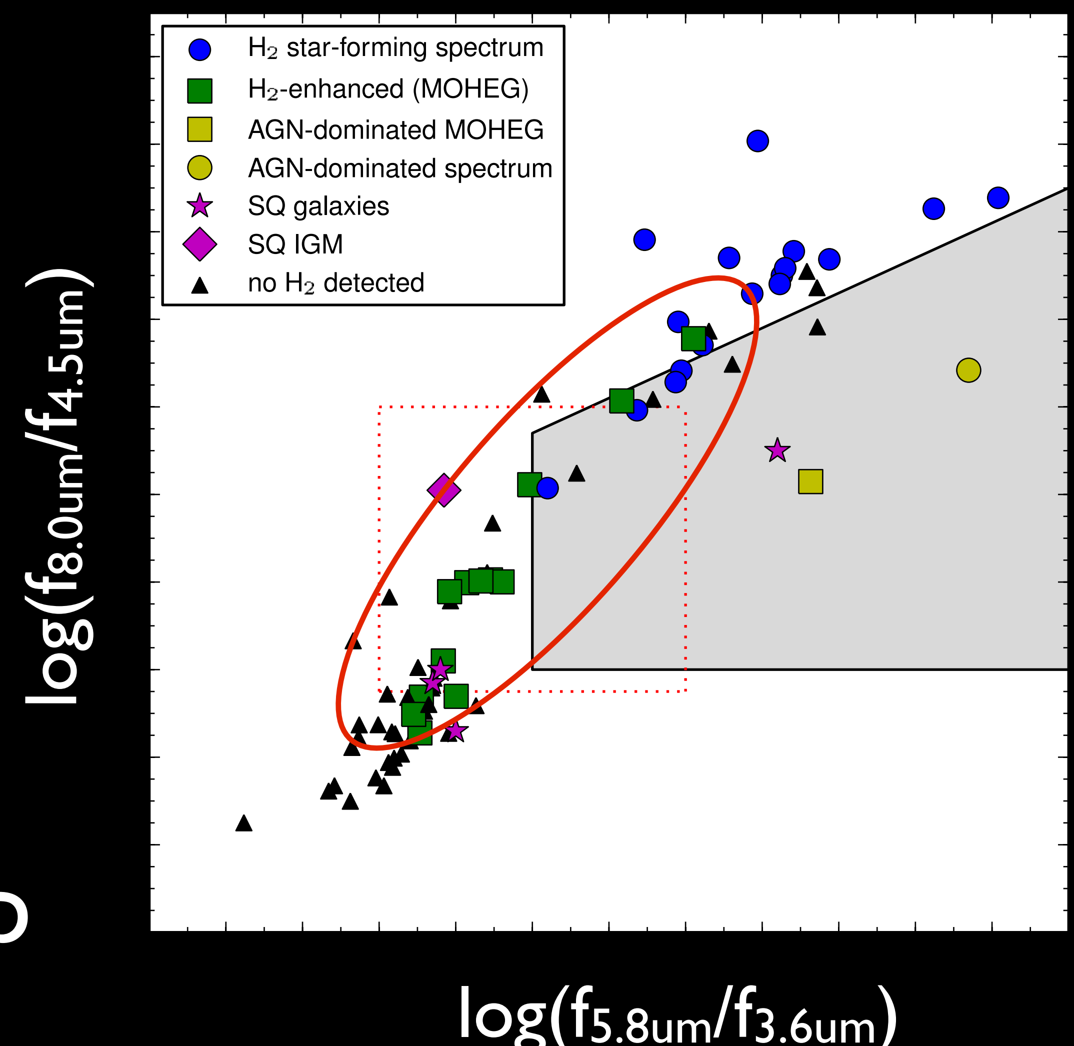
Ogle et al. 2004

Cluver et al. (2013) investigated 23 HCGs with *Spitzer* IRS

14 of those galaxies are considered MoHEGs

Those 14 tend to sit in the IR gap

Cluver et al. 2013



HCGs: CO results (30m)

CO in HCGs (in general)

CO/FIR properties "surprisingly similar" to isolated galaxies

20% of HCG spirals appear CO deficient, related to H I deficiency?

25% detection rate of ETGs (same as ATLAS^{3D}; Young et al. 2010)

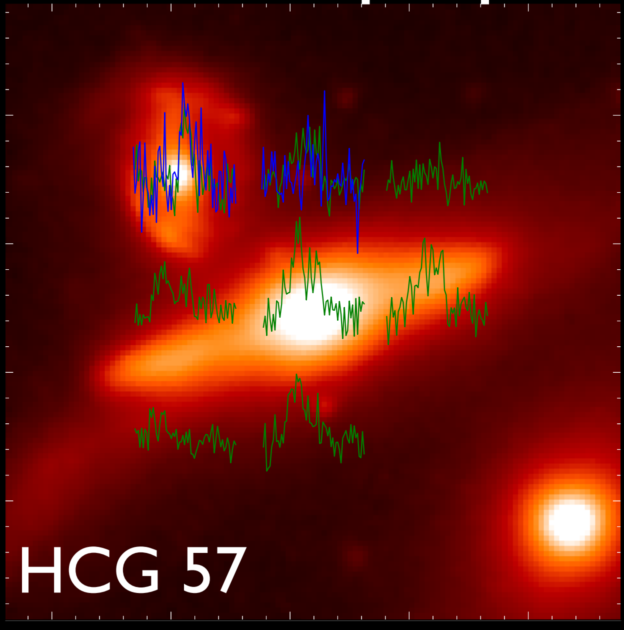
Verdes-Montenegro et al. 1998
Martinez-Badenes et al. 2012

CO in MoHEGs

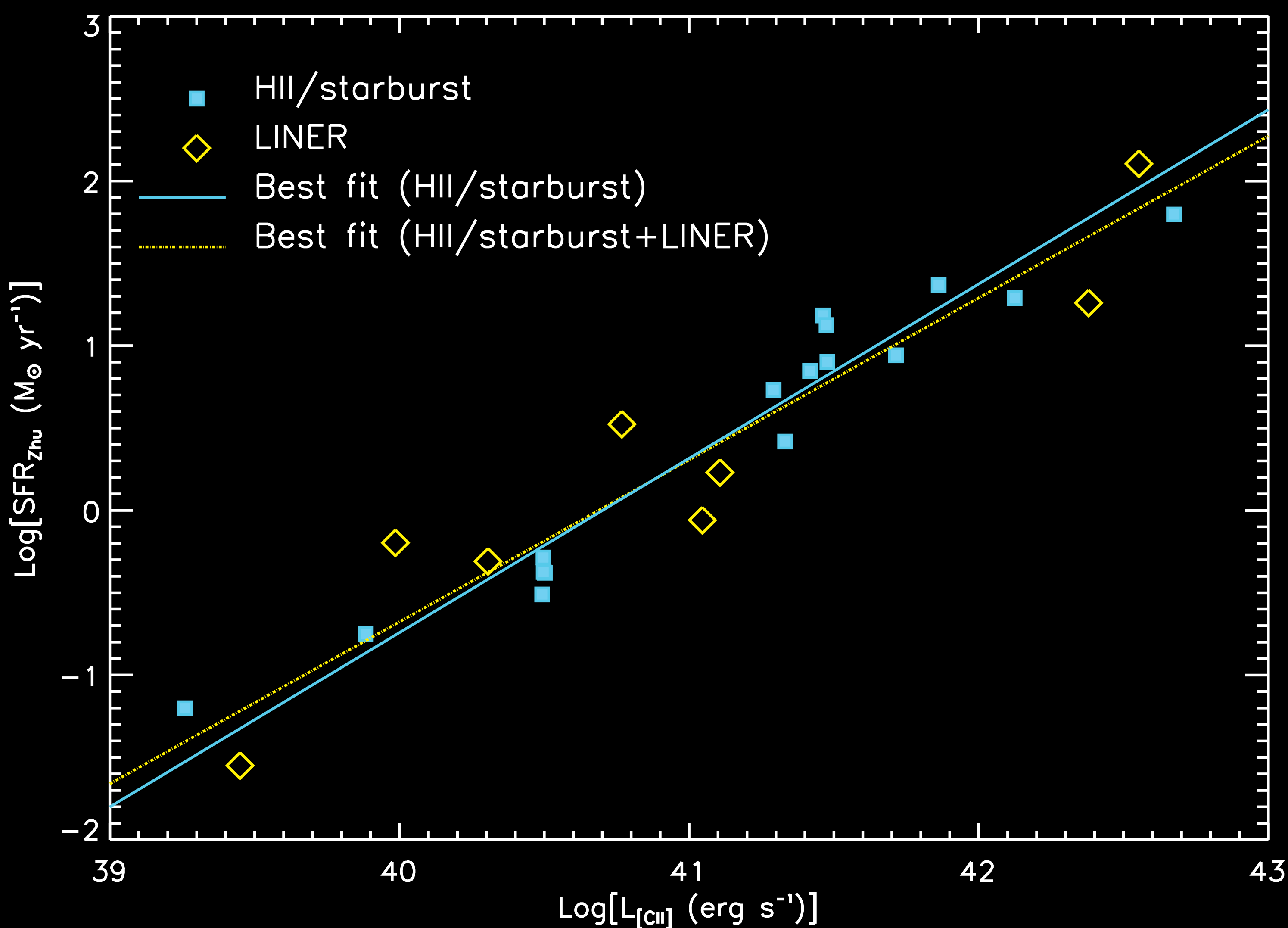
CO/FIR properties also similar to isolated galaxies, though $M(H_2)/L_K$ is low

Broad line wings seen in CO of some MoHEGs, higher than can be explained solely with rotation

Lisenfeld et al. 2013, in prep



The complexities of [C II]



de Looze et al. 2011

[C II] traces:

PDRs

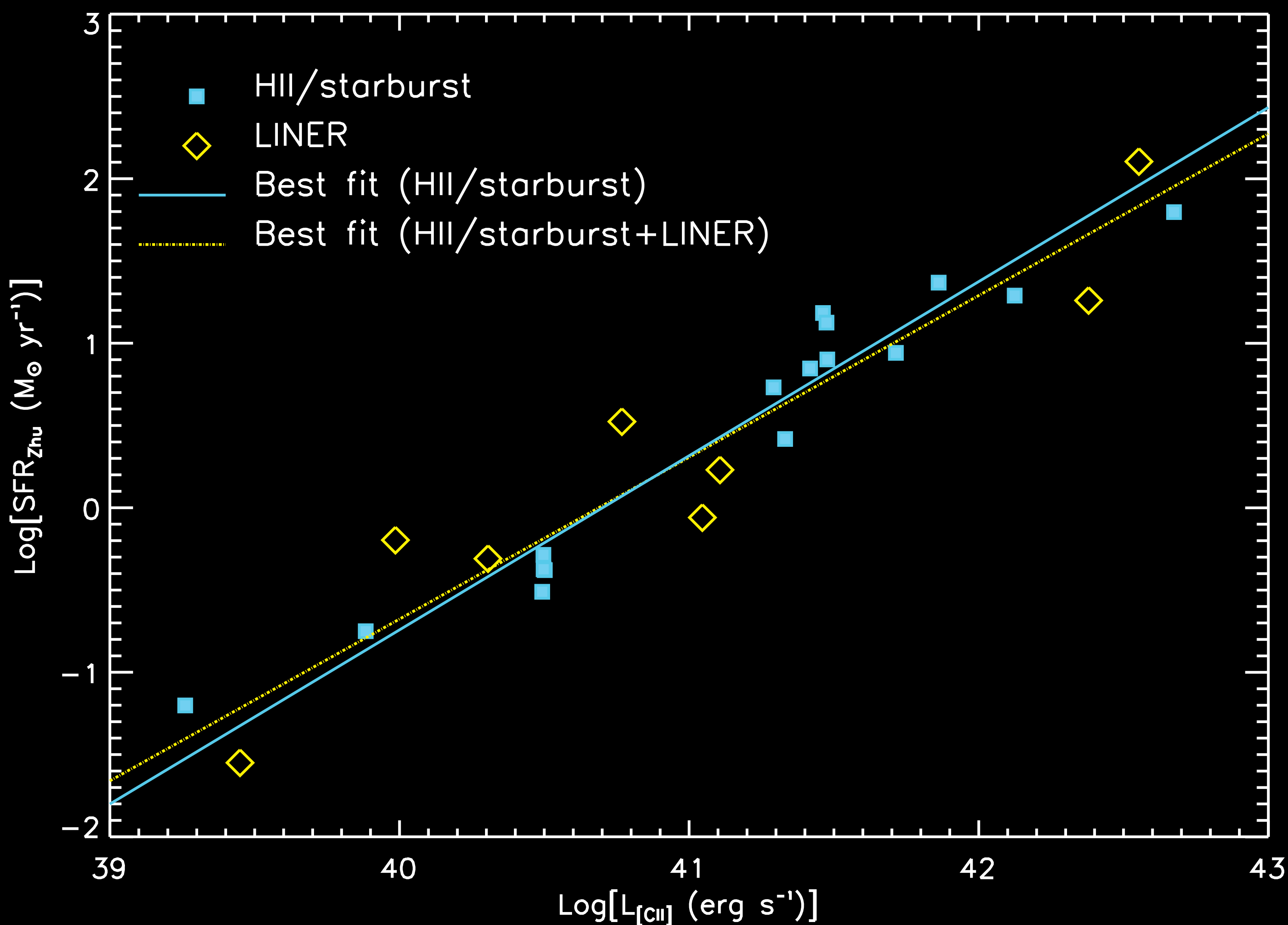
Crawford et al. 1985, Tielens & Hollenbach 1985, Wolfire et al. 1989, Hollenbach, Takahashi & Tielens 1991, Stacey et al. 1991, Bakes & Tielens 1998

H II regions and Diffuse neutral/ionized ISM

Wolfire 1995, Nakagawa et al. 1998

[C II] is a reliable tracer of star formation *in normal non-interacting galaxies*.

The complexities of [C II]



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H II regions and Diffuse neutral/ionized ISM

Wolfire 1995, Nakagawa et al. 1998

X-ray heating?

Appleton et al. 2013

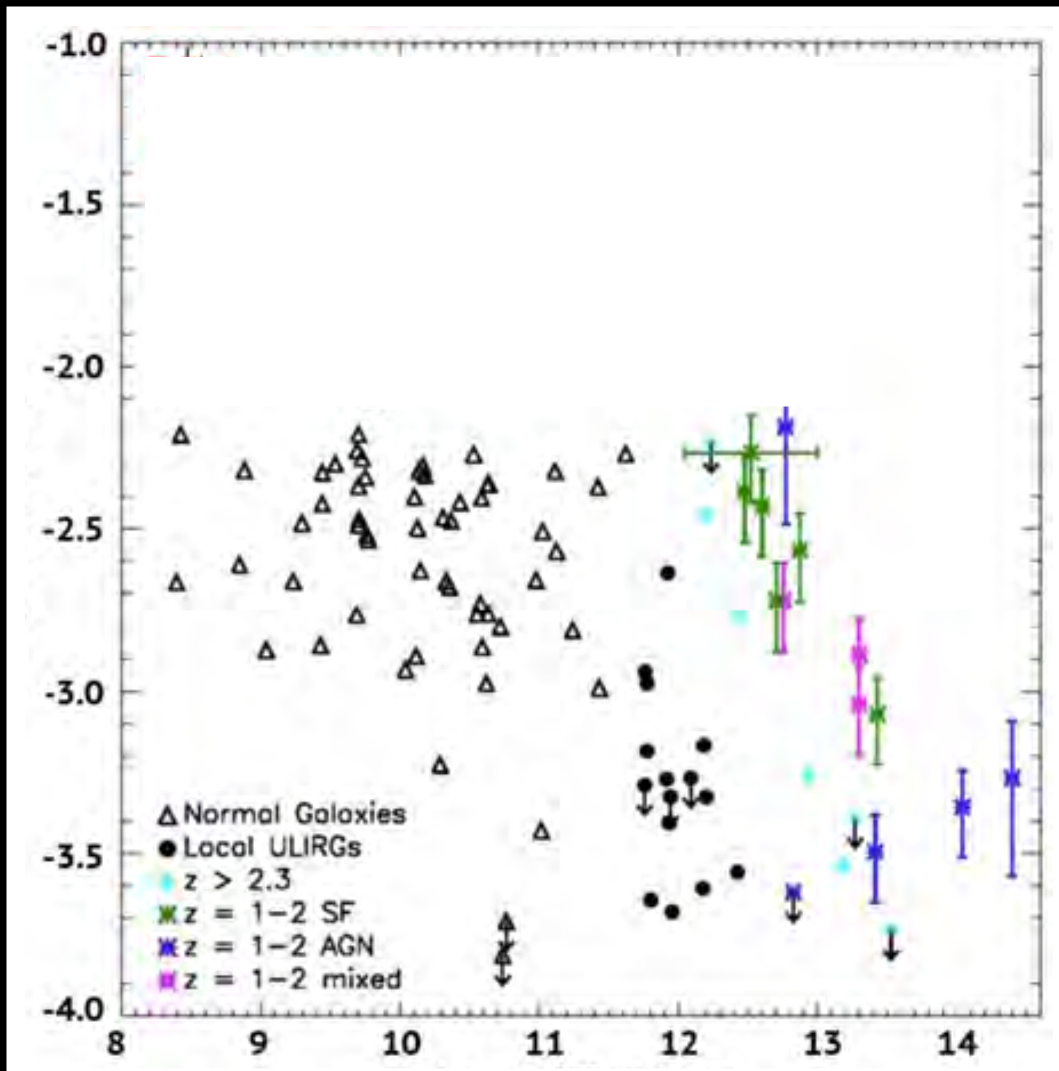
Cosmic rays

Nesvadba et al. 2010, Ogle et al. 2010, Appleton et al. 2013

Shocks

Appleton et al. 2013, Lesaffre et al. 2013

Shock excitation of [C II]

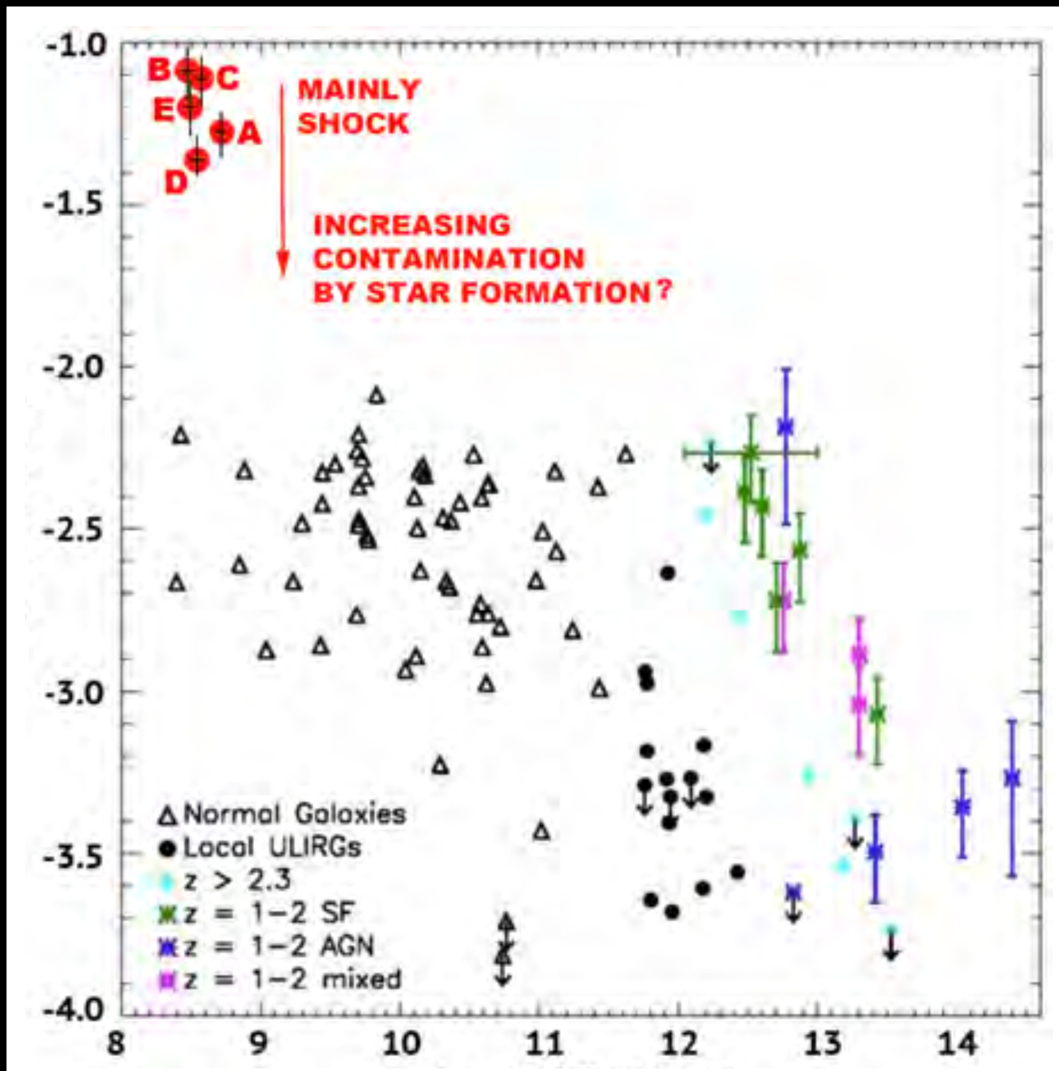


log([C II]/L_{FIR})

log(L_{FIR}/L_{sun})

In normal galaxies, [C II] traces emission associate with SF, and leads to a reliable relation. In turbulent galaxies, this relationship appears to break down

Shock excitation of [C II]



log([C II]/L_{FIR})

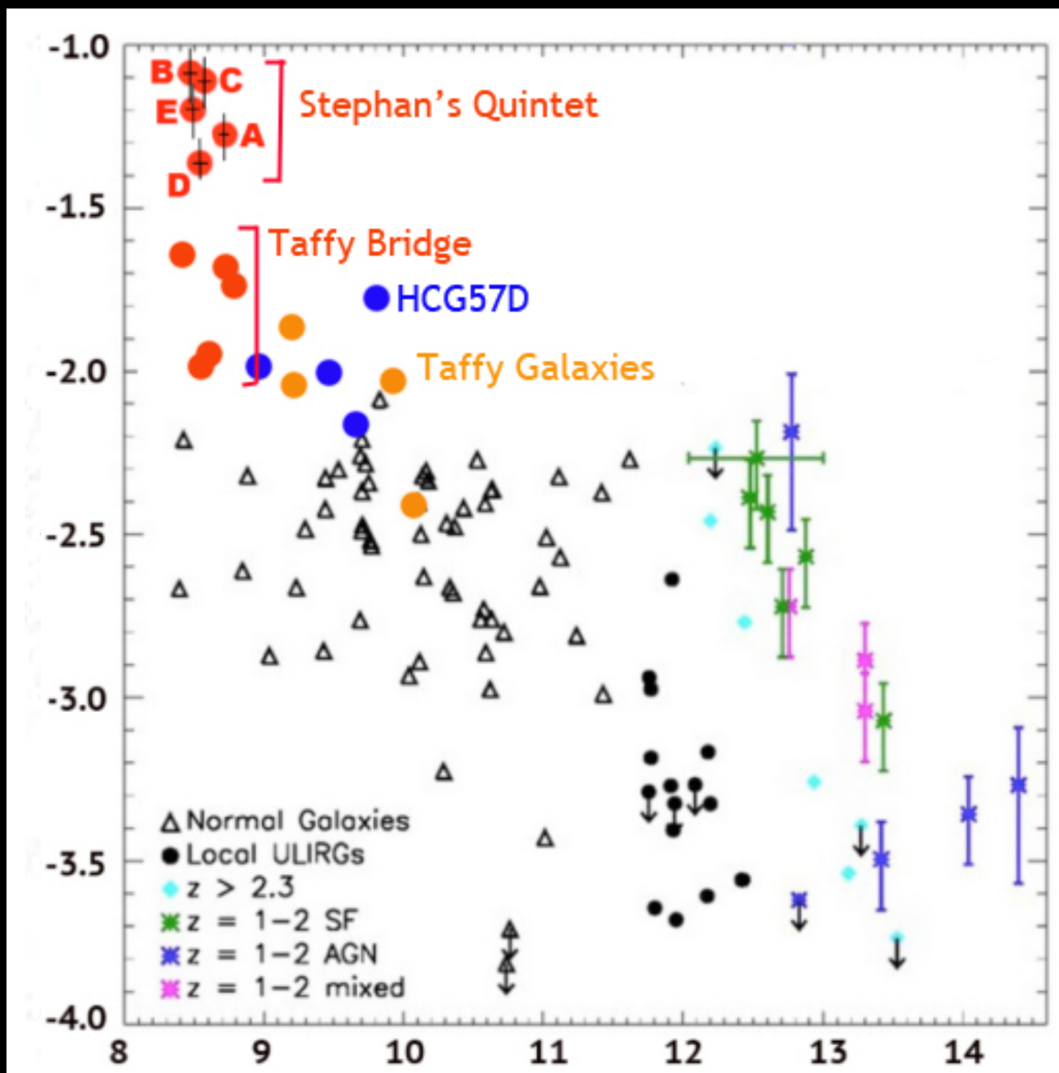
log(L_{FIR}/L_{sun})

Stephan's Quintet Appleton et al. 2006, Cluver et al. 2010, Appleton et al. submitted

Stephan's Quintet (HCG 92)

In normal galaxies, [C II] traces emission associate with SF, and leads to a reliable relation. In turbulent galaxies, this relationship appears to break down

Shock excitation of [C II]



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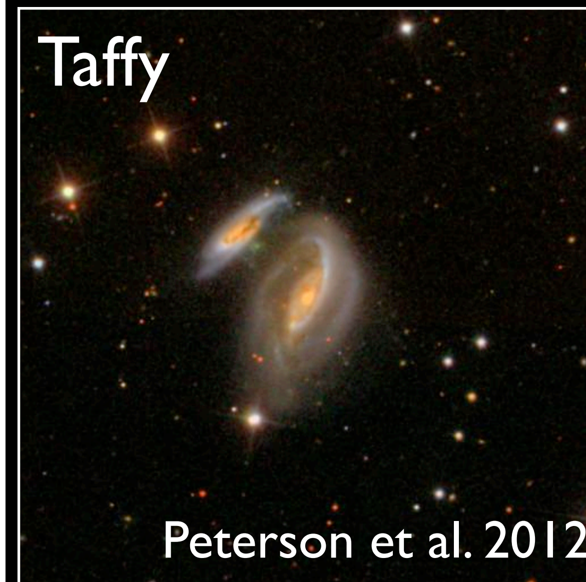

HCG 57

Stephan's Quintet (HCG 92)

Stephan's Quintet Appleton et al. 2006, Cluver et al. 2010, Appleton et al. submitted

Taffy bridge Peterson et al. 2012

Taffy galaxies Peterson et al. 2012; Peterson et al. in prep

HCG 57 Alatalo et al. in prep

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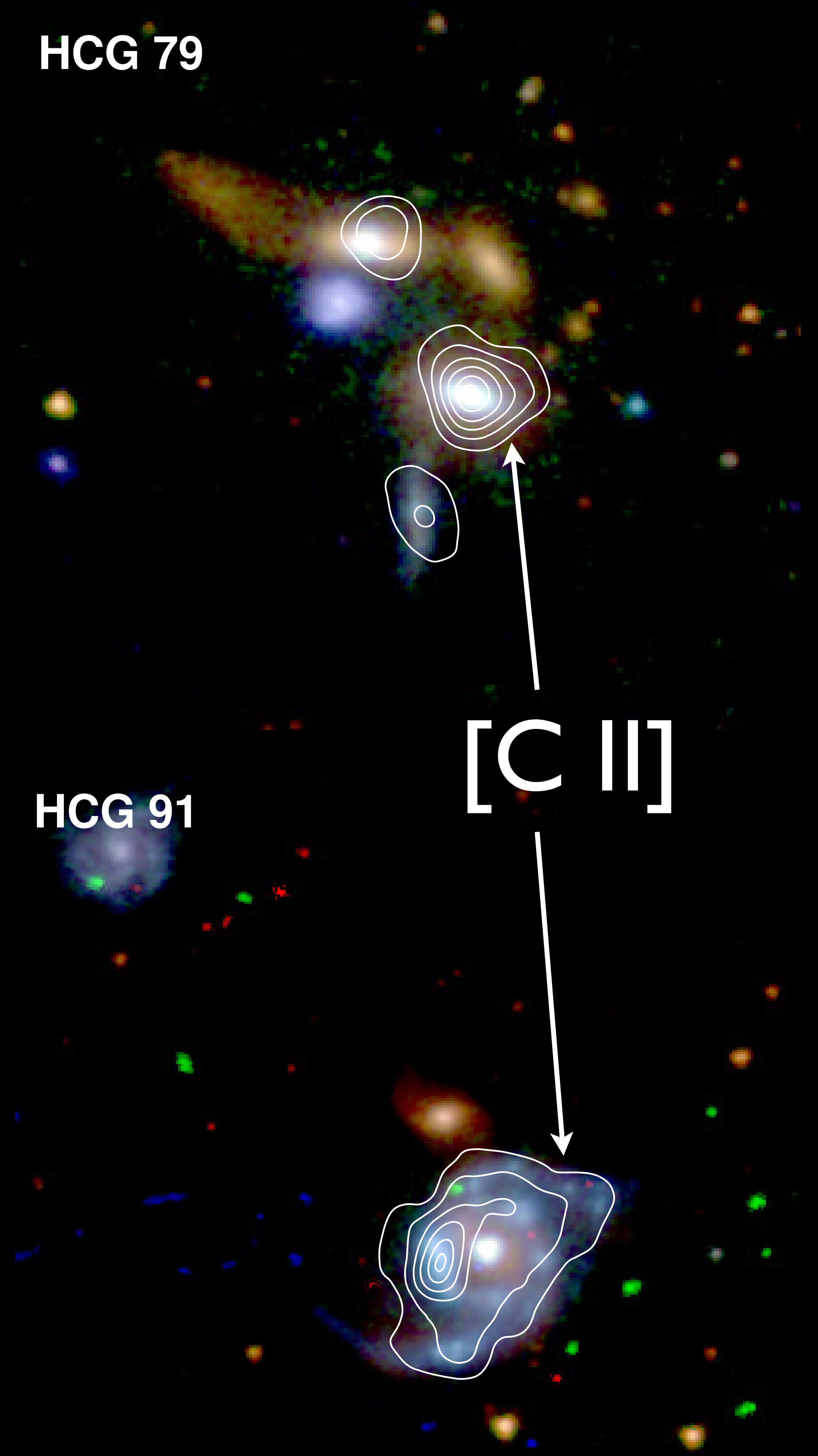
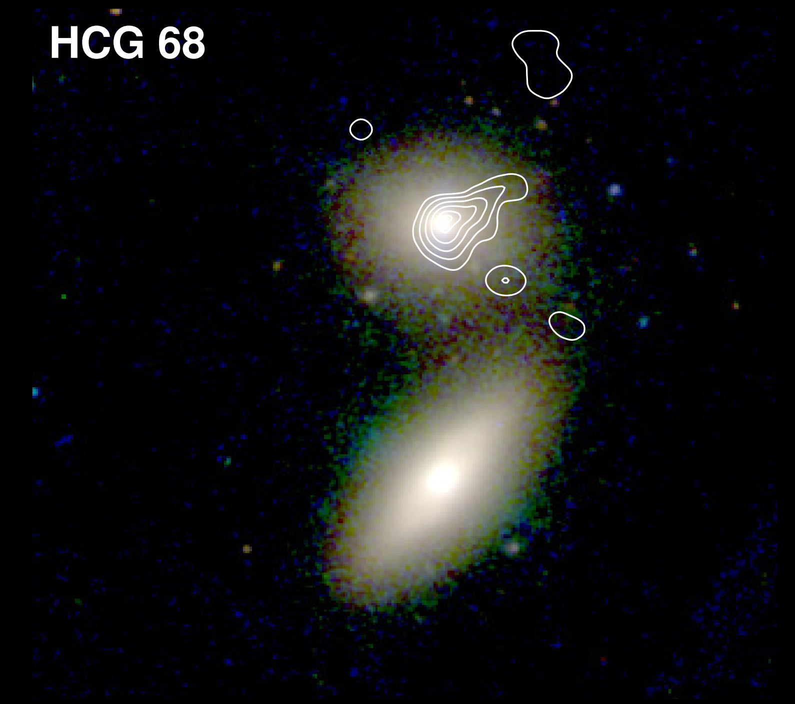
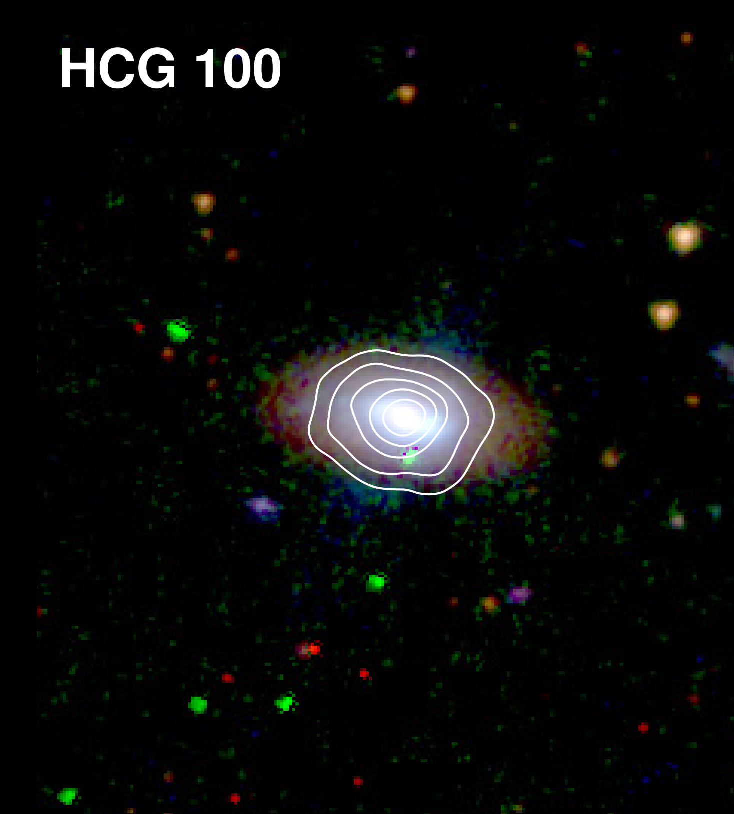
Herschel [C II] results



Preliminary:
[C II] mom0 mapped for 11 MoHEG systems

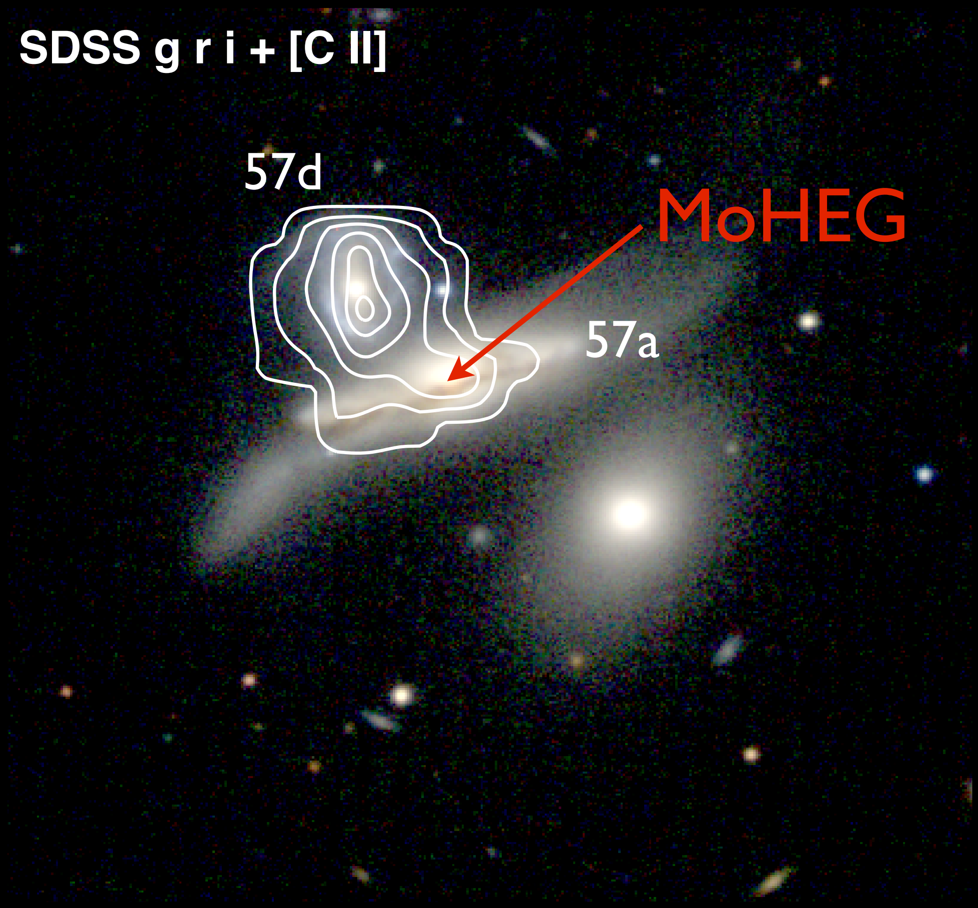
9/11 of these systems have also been detected in CO (Lisenfeld et al. in prep)





Spitzer RGB - 3.6, 5.8, 8.0um, respectively. Alatalo et al, in prep

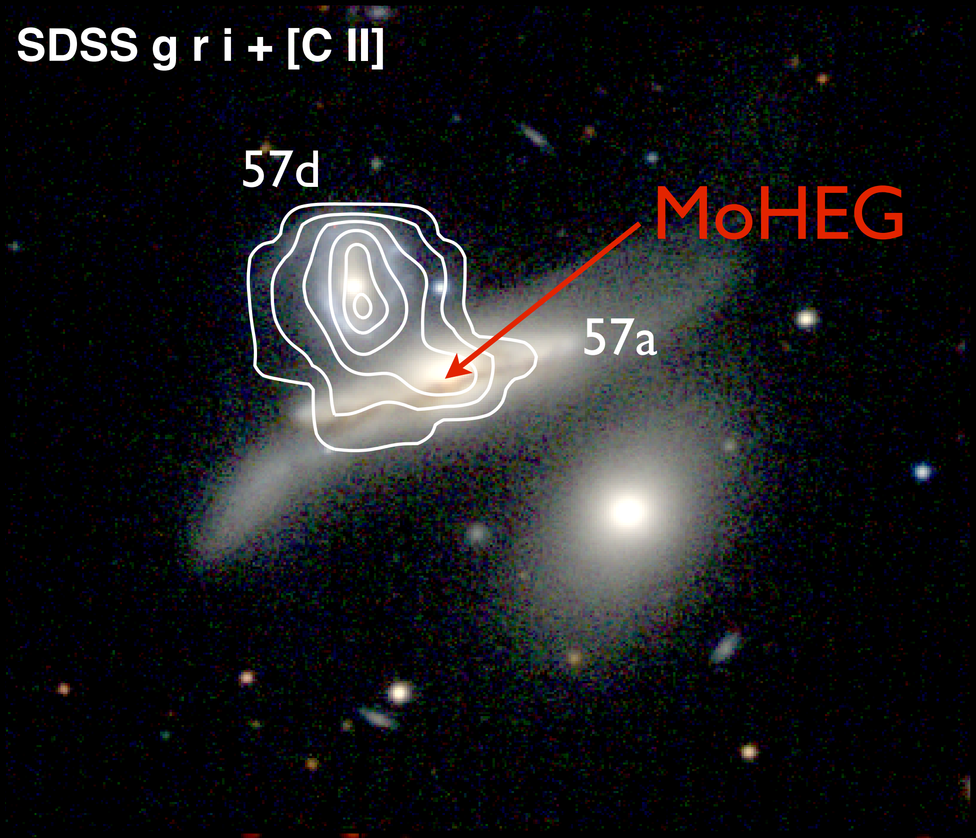
Results: [C II] and CO in HCG 57



HCG 57d brighter in [C II] and bluer in optical than 57a

HCG 57a is the MoHEG

Results: [C II] and CO in HCG 57

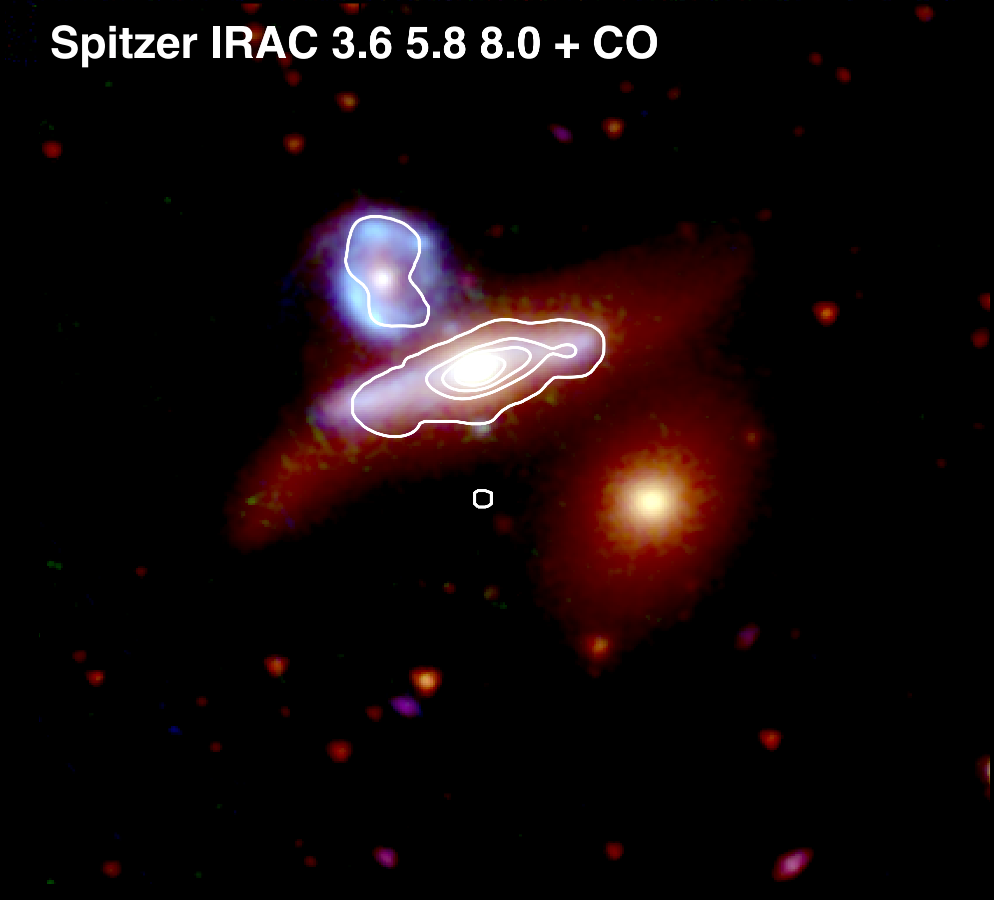


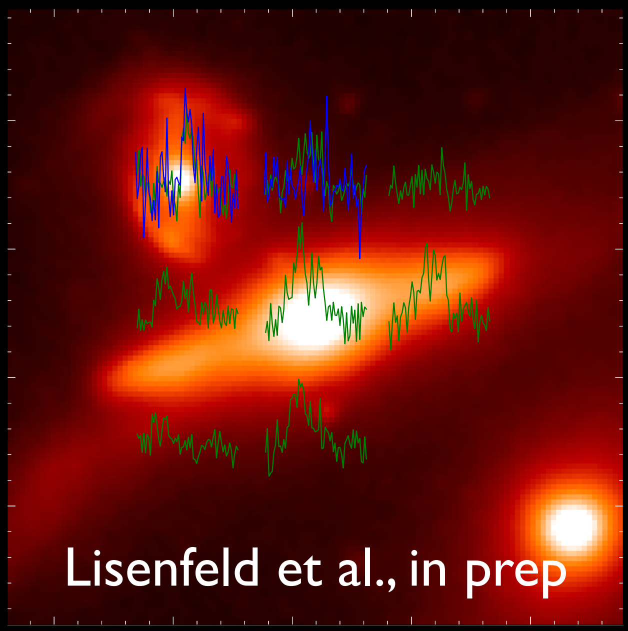
HCG 57d brighter in [C II] and bluer in optical than 57a

HCG 57a is the MoHEG

HCG 57d is also bright in PAH emission (blue)

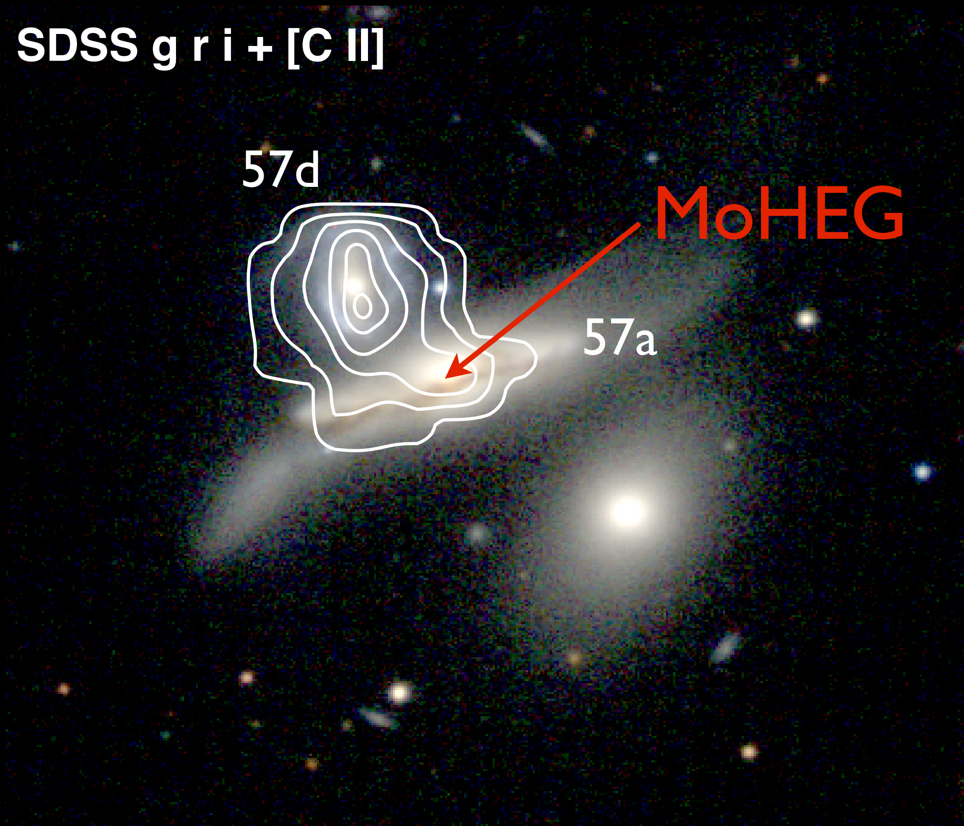
HCG 57a is much brighter in CO despite the PAH and [C II] emission in HCG 57d

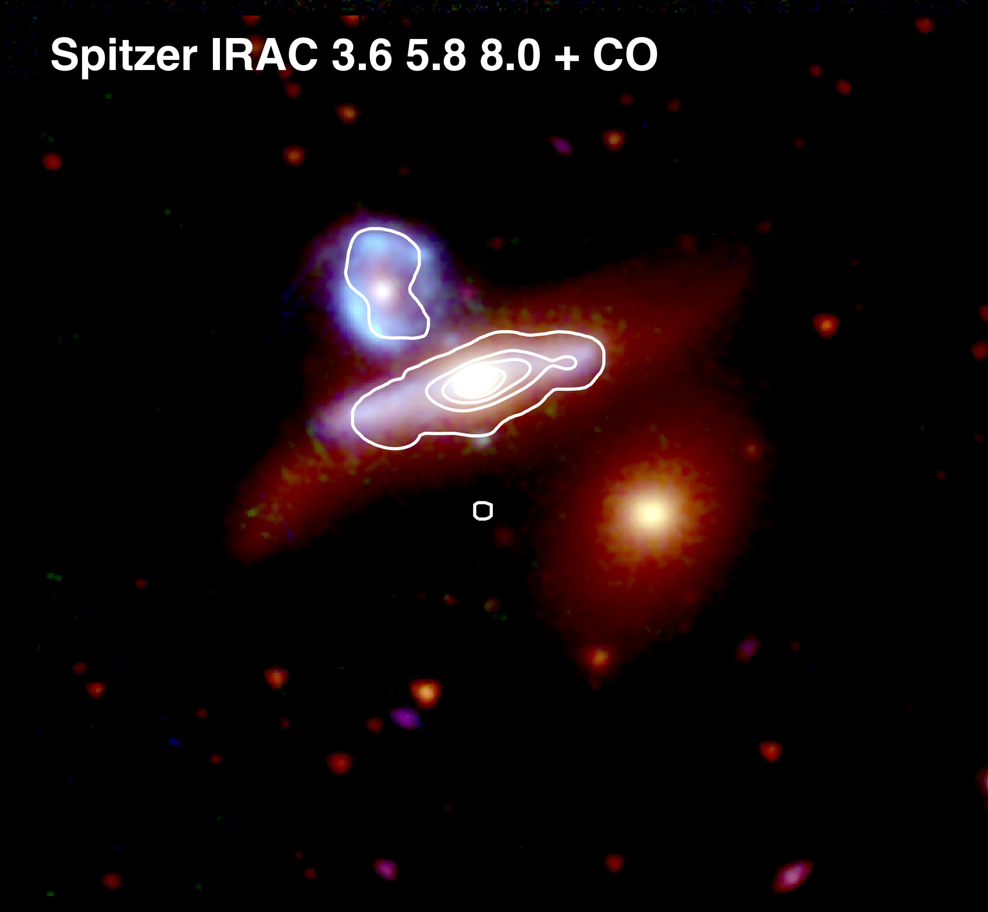




CARMA recovers 65% of the single dish in HCG 57d, possibly a diffuse molecular component?

Results: [C II] and CO in HCG 57



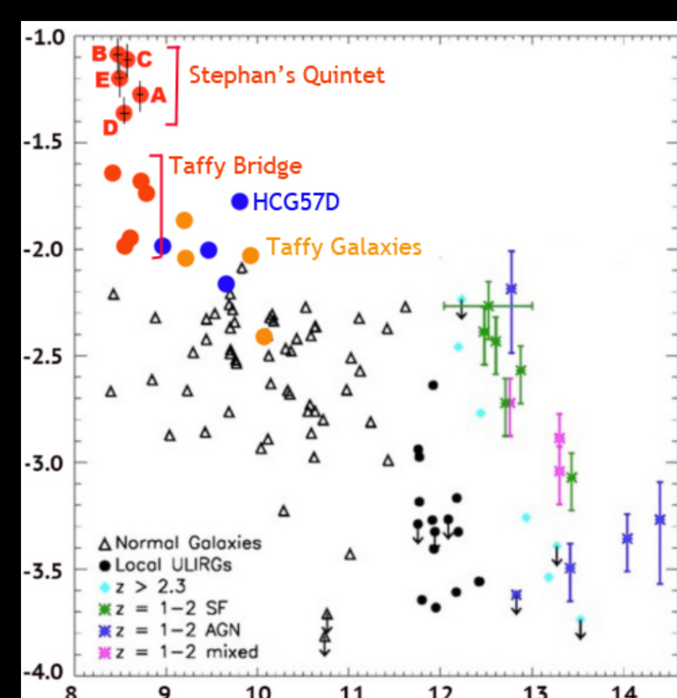


HCG 57d brighter in [C II] and bluer in optical than 57a

HCG 57a is the MoHEG

HCG 57d is also bright in PAH emission (blue)

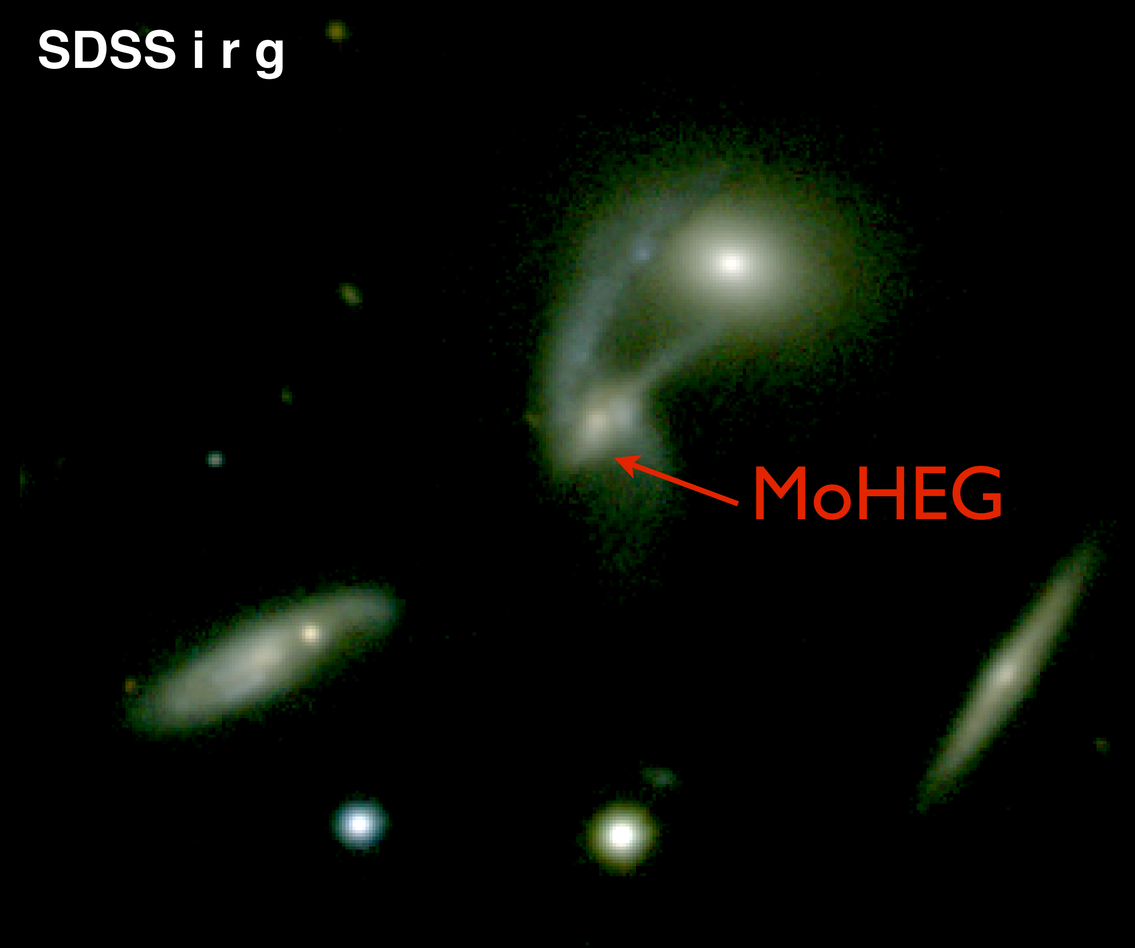
HCG 57a is much brighter in CO despite the PAH and [C II] emission in HCG 57d



CARMA recovers 65% of the single dish in HCG 57d, possibly a diffuse molecular component?

Clearly, in HCG 57, CO and [C II] do not trace one another (as expected in SFR/PDRs), and HCG 57d has an enhanced [C II]/L_{FIR}

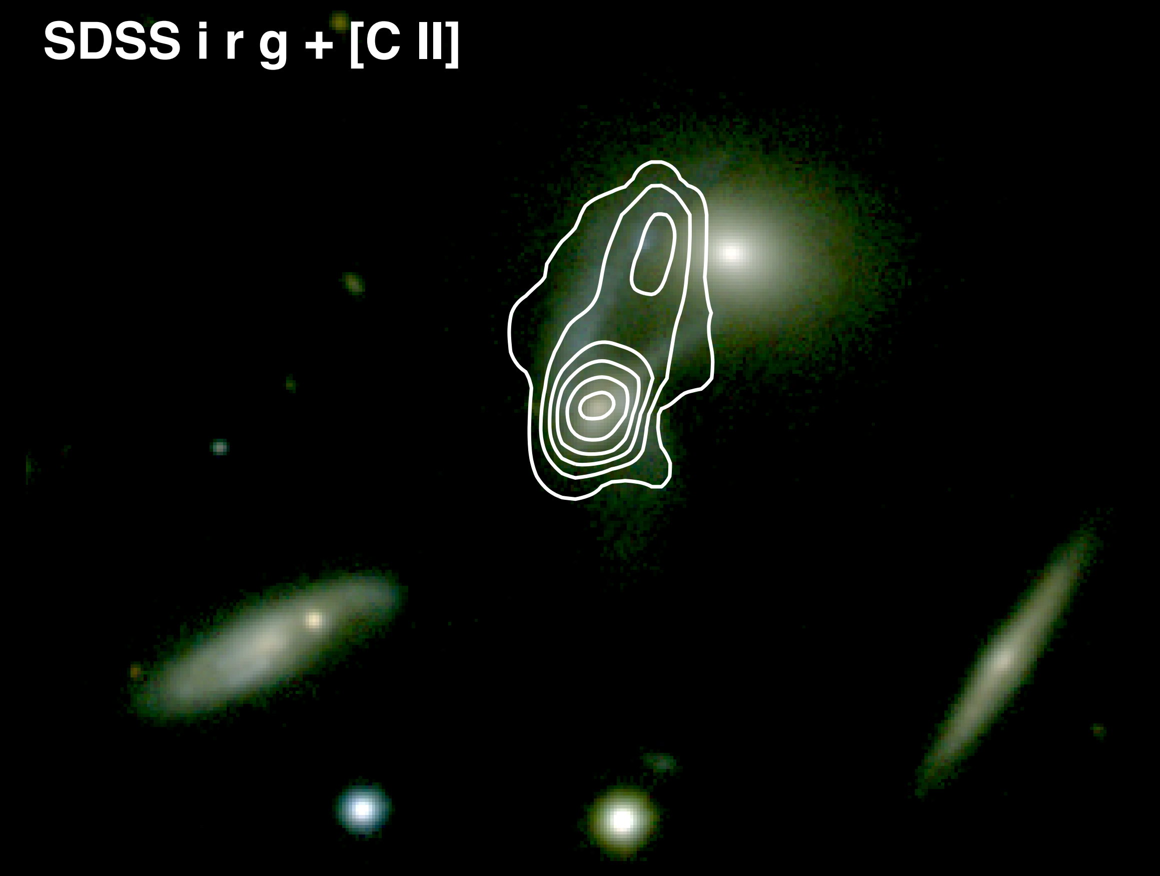
Results: [C II] and CO in HCG 95



Preliminary (CARMA data arrived last week)

HCG 95c is the MoHEG (H_2/PAH = 0.07)

Results: [C II] and CO in HCG 95



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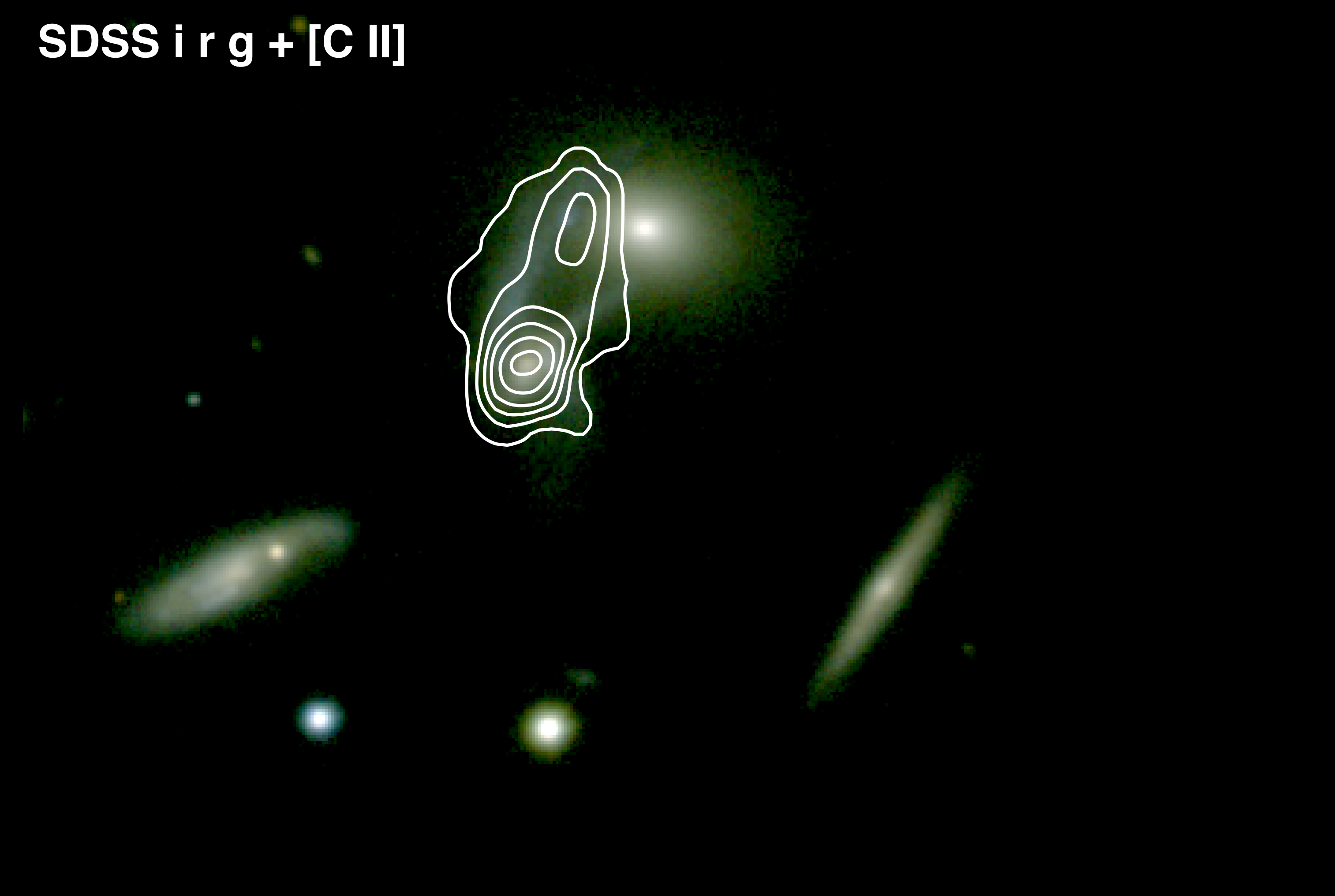
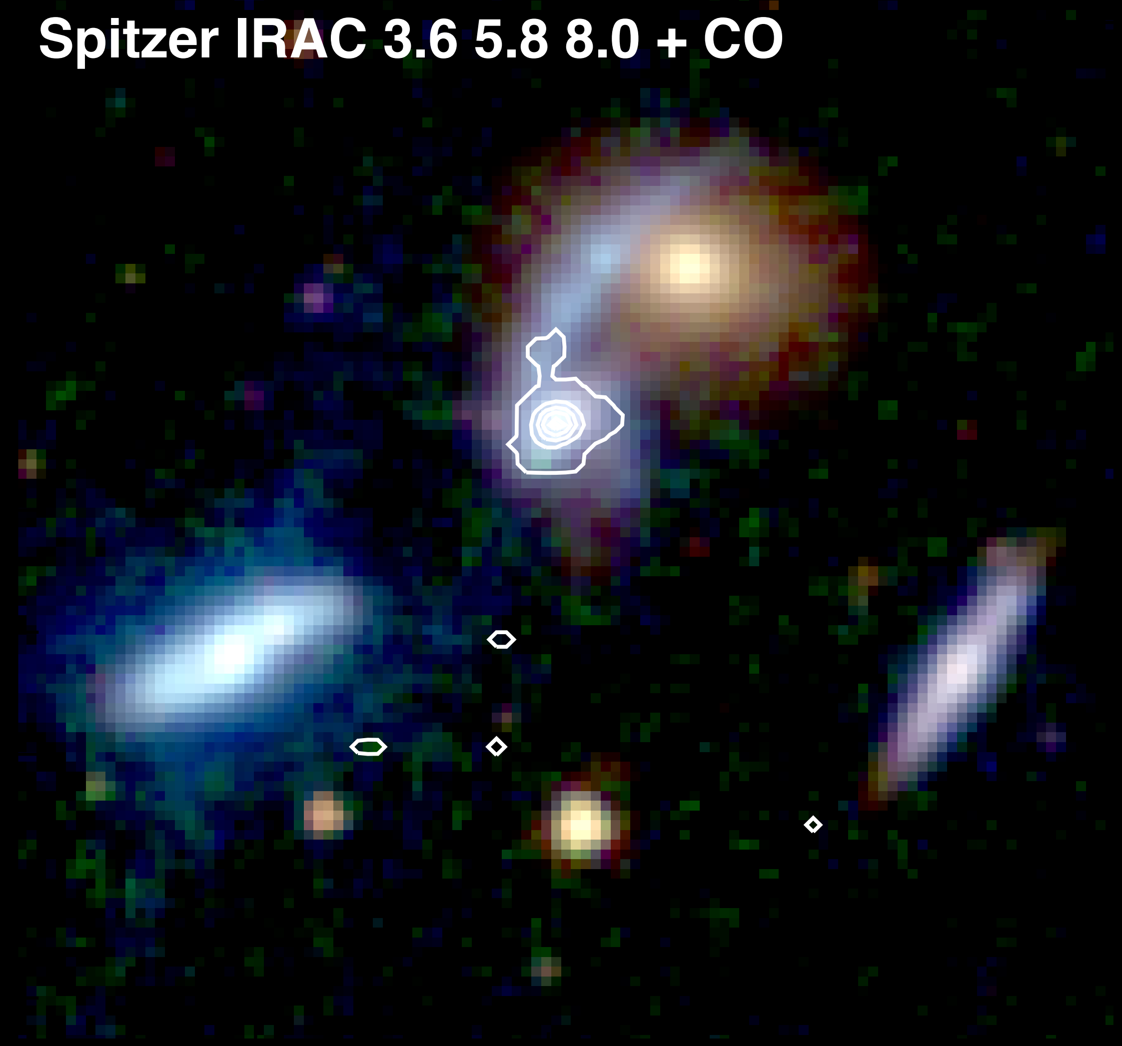
[C II] seen in the interacting / tidal tail galaxies

Results: [C II] and CO in HCG 95





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HCG 95c is the MoHEG (H_2/PAH = 0.07)

[C II] seen in the interacting / tidal tail galaxies

CO strongest where [C II] strongest, with hints of CO in the tidal tail, and bluest (strong PAH) feature

Summary

HCGs are perfect laboratories to study galaxy evolution

Their H I, and ETG fraction allow for a quick identification along their evolutionary cycle

Galaxy evolution within HCGs is rapid

MoHEG galaxies within HCGs have been shown to be the rare transition objects and appear to be driven by shocks

Herschel [C II] and CARMA CO provide a synergistic dataset to study these MoHEGs

The end

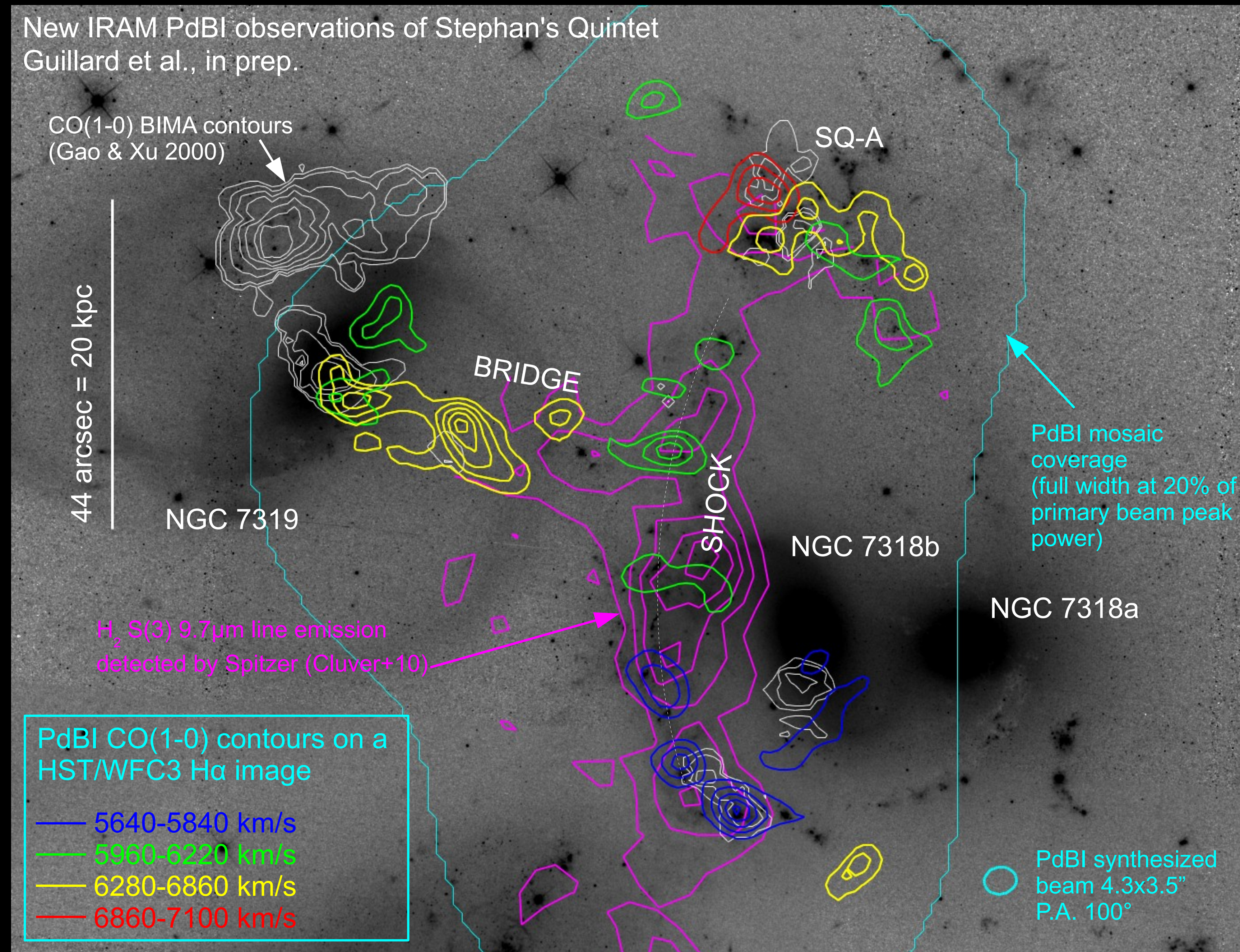
Herschel + CARMA = 

The case for resolved maps

Cluver et al. (2013) H_2 in HCGs identified interesting sources, but where is the interaction taking place?
[C II] can also identify shock-enhanced regions, and Herschel PACS can map (and has mapped 11 HCGs)

Lisenfeld et al. have shown that MoHEGs appear to have normal SF efficiency, but are the sites of shock activity in these MoHEGs also normally forming stars?
Comparing CO maps to [C II]/L_{FIR} enhancements shows if shocks lead to inefficiency

Lisenfeld also detected high velocities unexplained by rotation alone.
CO maps can identify the sites of the broad wings - be they AGNs (like NGC 1266 or NGC 1377; Alatalo et al. 2011, Aalto et al. 2012) or bow shocks (like SQ, Guillard et al. in prep)



IS [C II] reliably related to SF even in these extreme shock-enhanced systems?
[C II] and CO maps can be directly compared, and will allow for a lot of insight into the [C II] emission mechanism. Possibly helping future high-z ALMA [C II] studies normalize their detections.