l'Observatoire de Paris

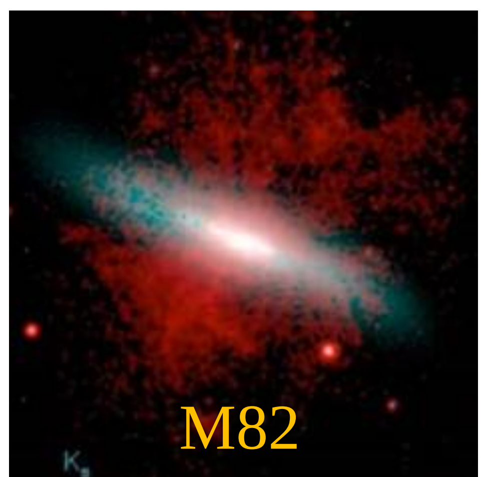
LERMA

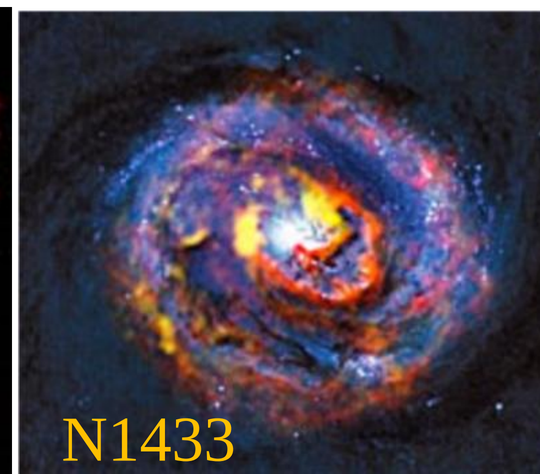
Laboratoire d'Étude du Rayonnement et de la Matière en Astrophysique

Star formation and its triggers

Françoise Combes

Cozumel, April 2016

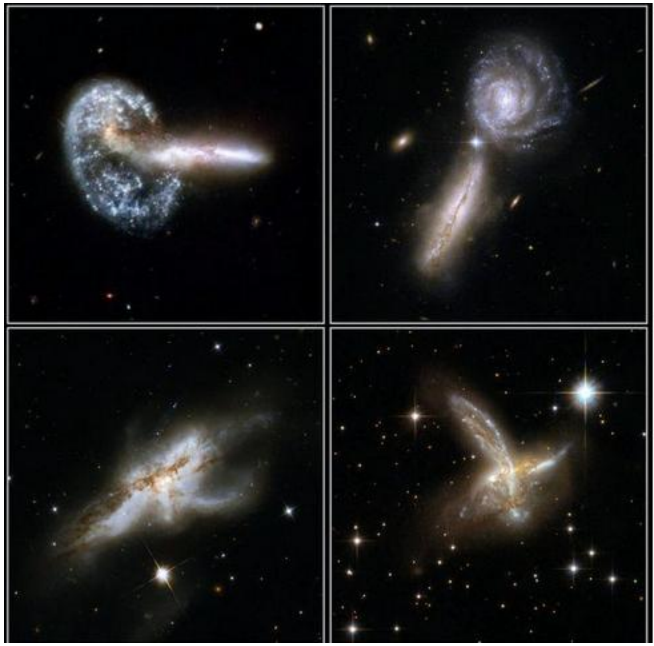




Main Mechanisms

➔**Role of turbulence** **~100pc scale**
Role of feedback from SN, winds.. ><0?
At high z: thick disks, Clumpy galaxies
Double agent: moderates and triggers

➔**Role of bars and spirals in the SFR**
Dynamics at **~1kpc scale**

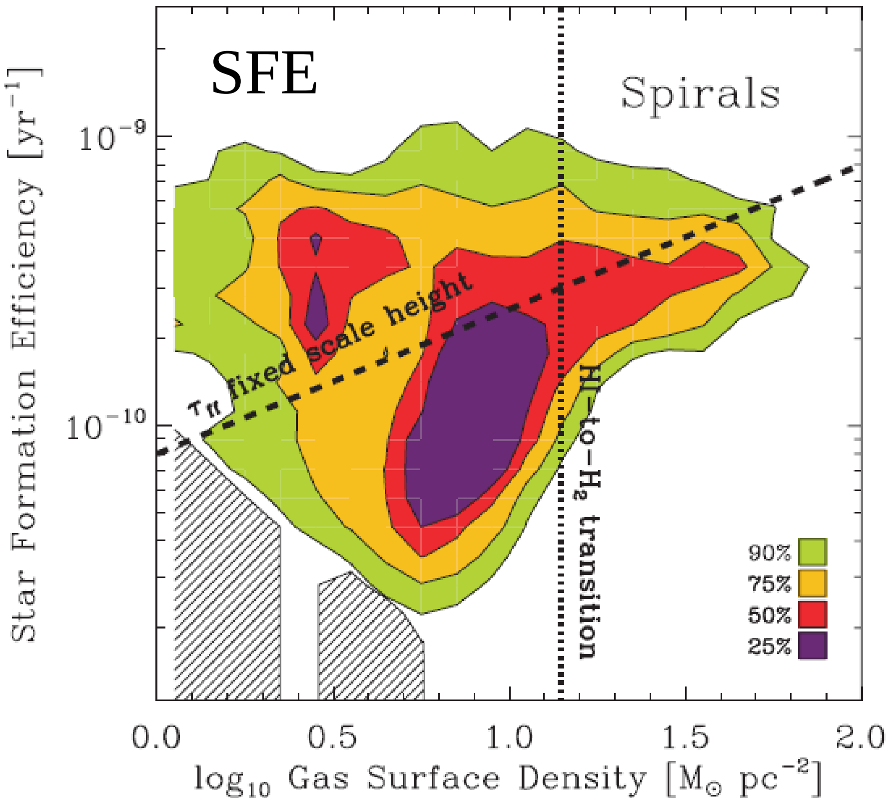


➔**Role of violent events**
Interaction, mergers …. **~10kpc scale**

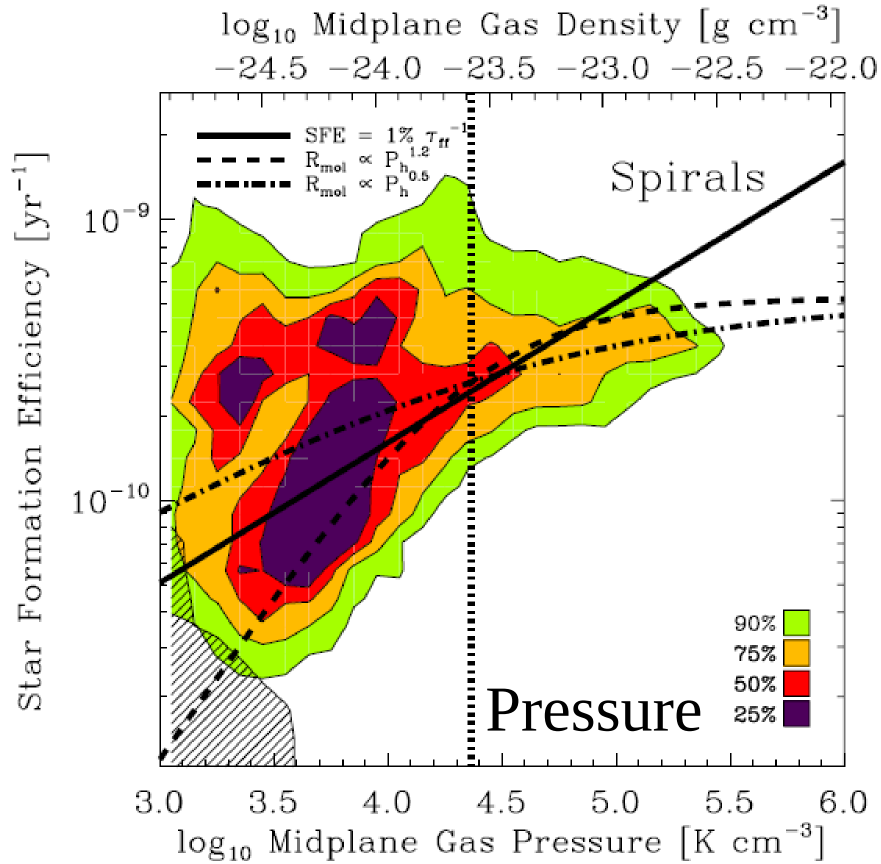
➔**Environment effects**
How SF may be triggered or quenched
in groups and clusters **~100kpc scale**

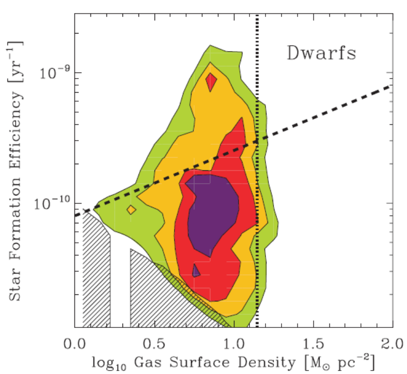
Star formation efficiency, SFE ~ 1/t_{dep}

Leroy et al 2008

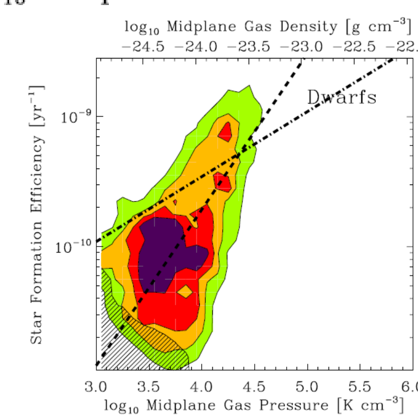


Σ_{gas}

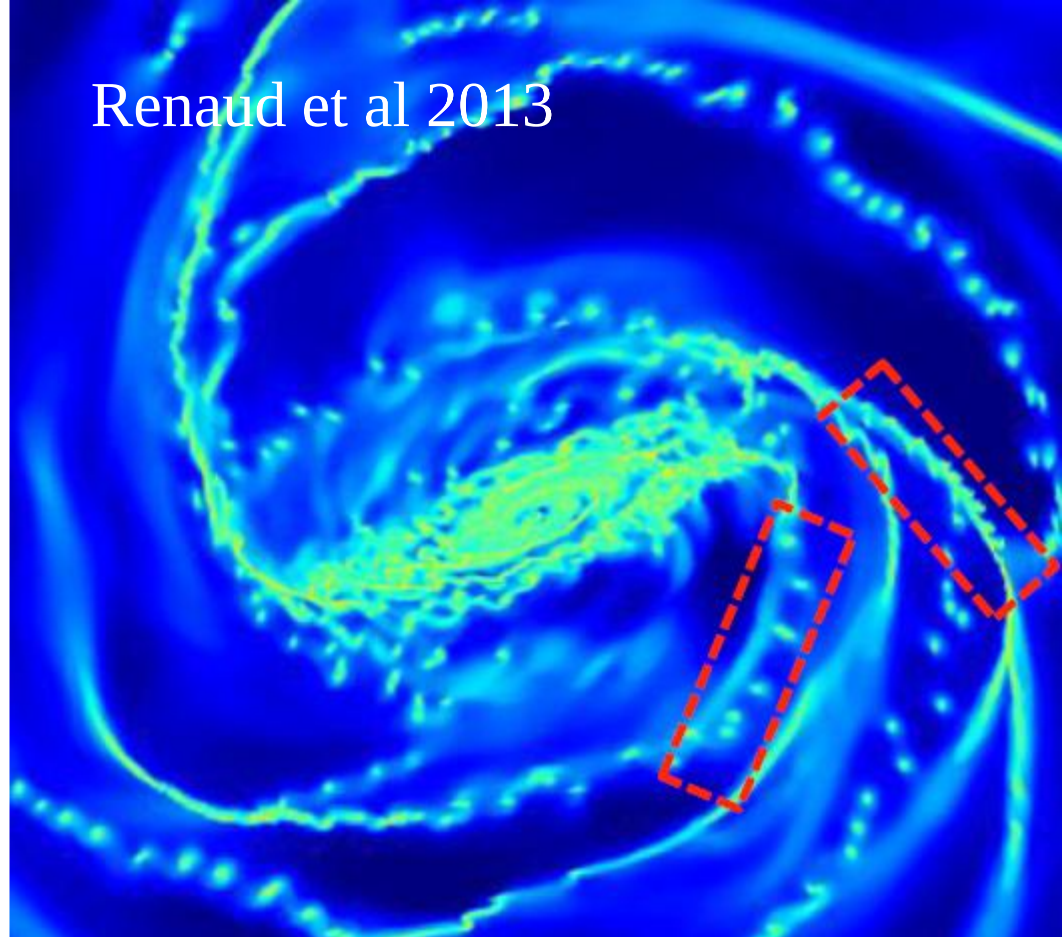




Same for dwarfs

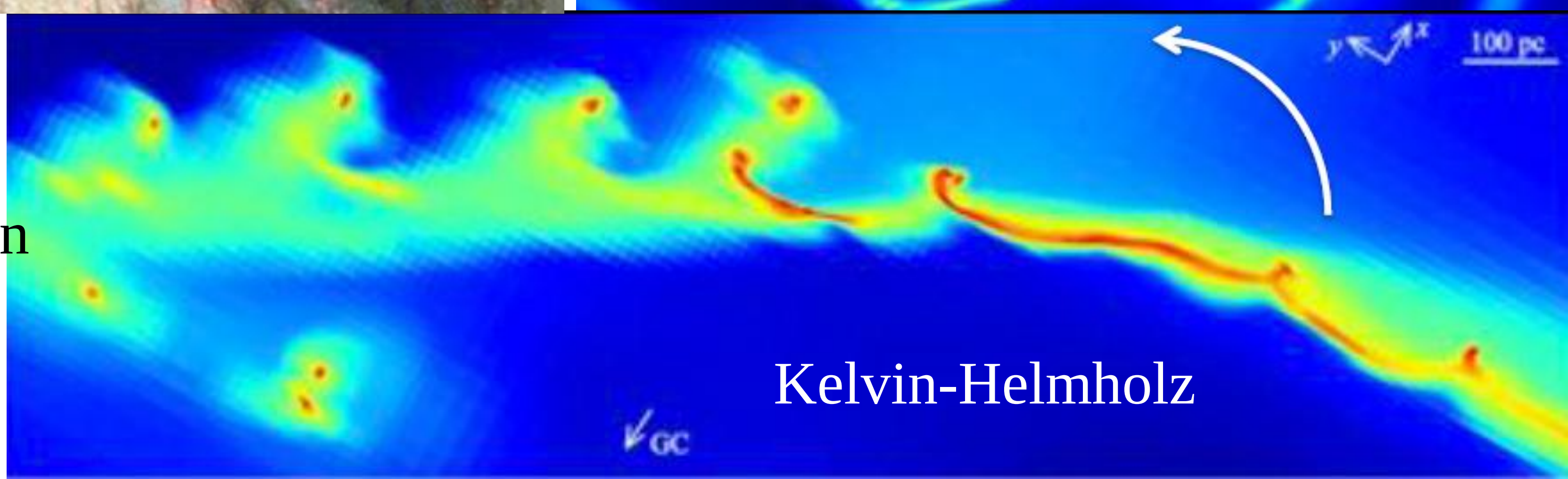


Compression due to spiral arms

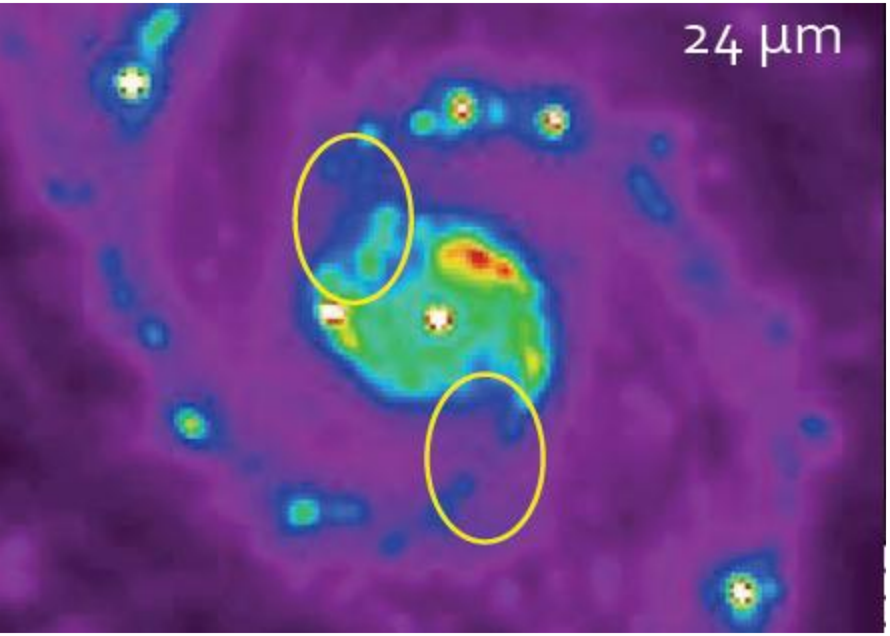


Spurs of star formation

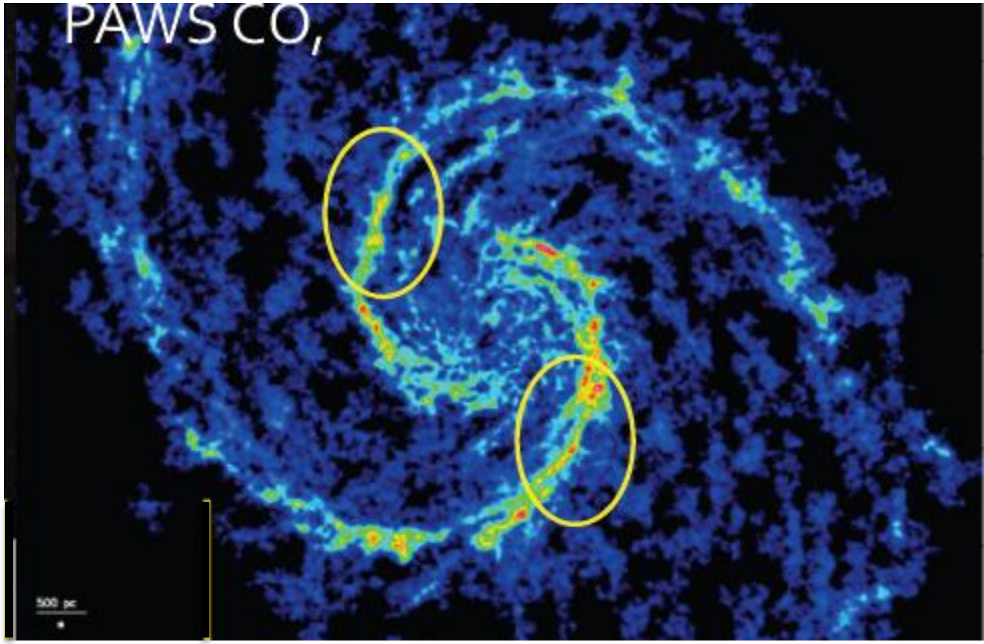
MW simulation



Influence of density waves



Meidt et al (2012)

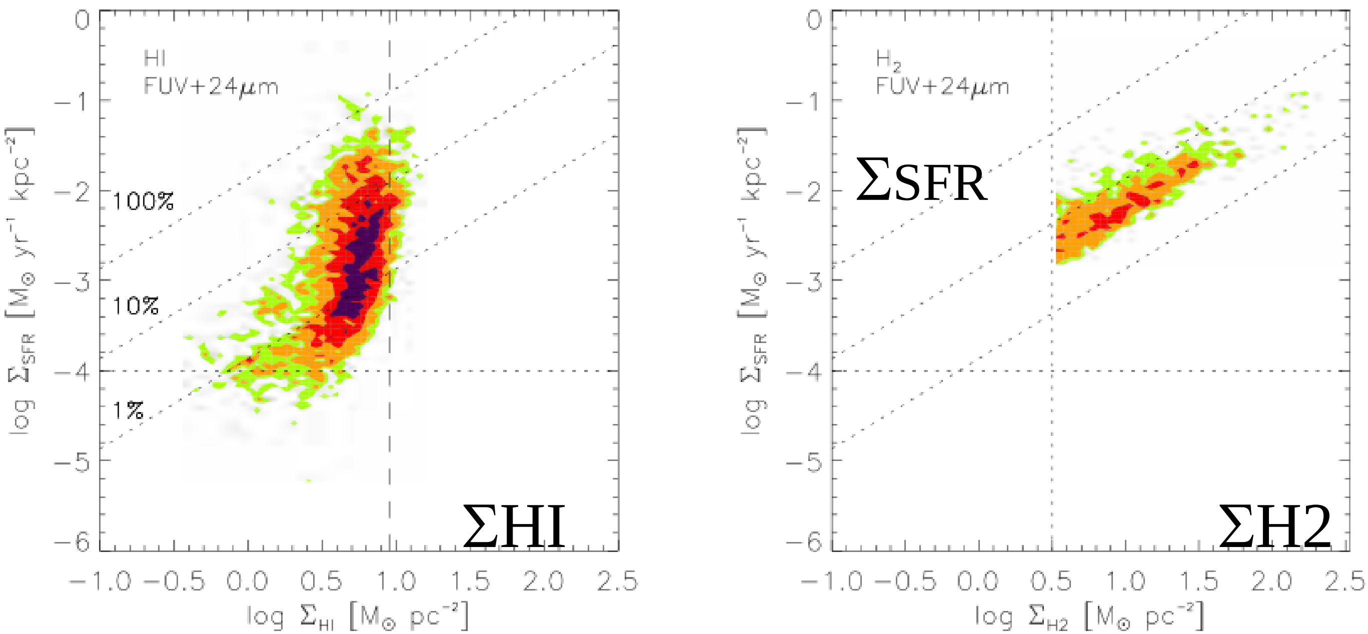


The efficiency of SF is not constant over arms and rings
A way to find Corotation?

Also found in barred galaxies (Reynaud & Downes 1999)

KS law: Essential role of H_2

ΣSFR

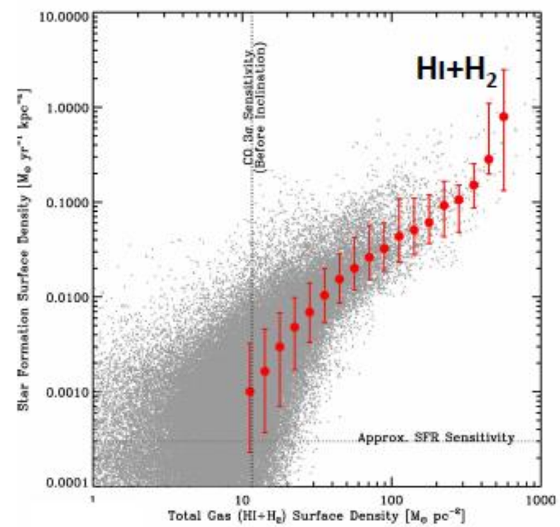


Bigiel et al 2008

Average over 7 galaxies

Confirmed with 38 galaxies, Heracles, Things

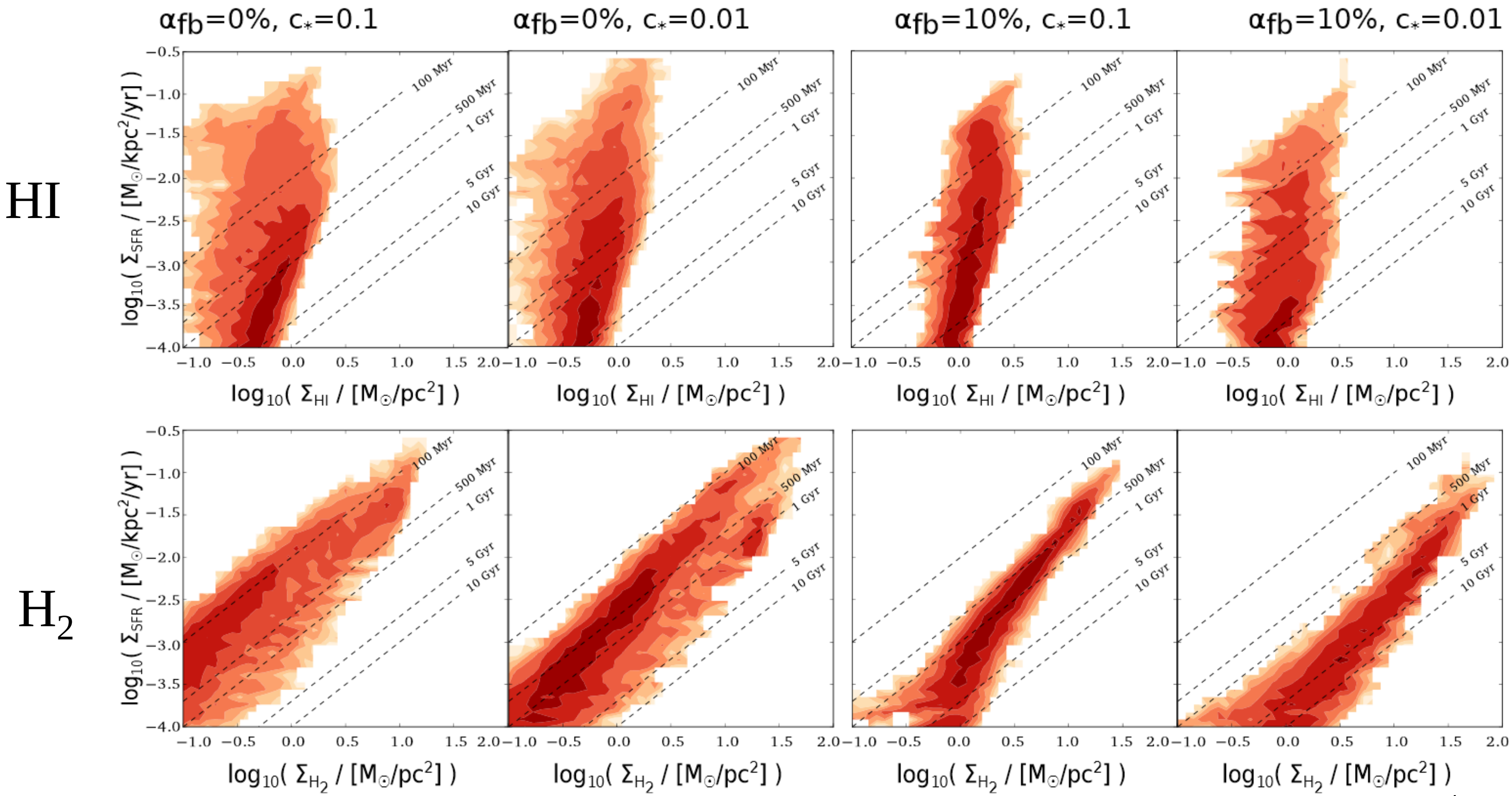
Leroy et al 2013



Disk simulations with H_2 & HI

αfb energy fraction for SN feedback

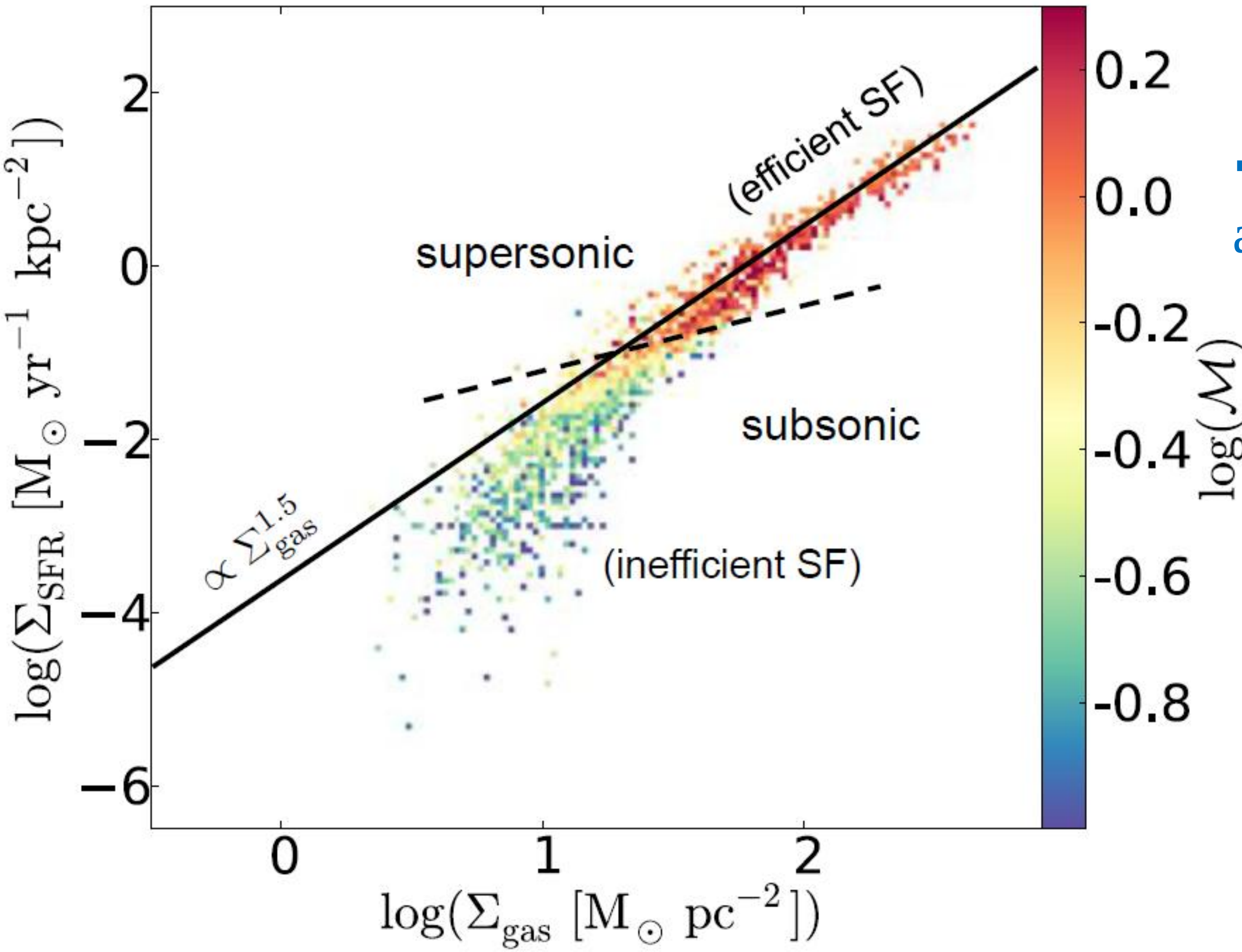
χ UV radiation field, c_* SFE per free-fall time (*Krumholz et al 2009*)



Halle & Combes 2013

Dynamics of the gas: turbulence

Kraljic et al 2014: variations of turbulence within the disk



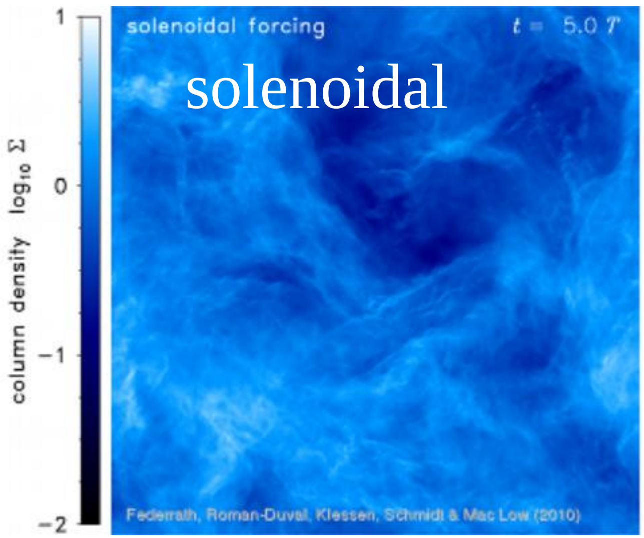
➔Large scatter at low Σ_{gas}

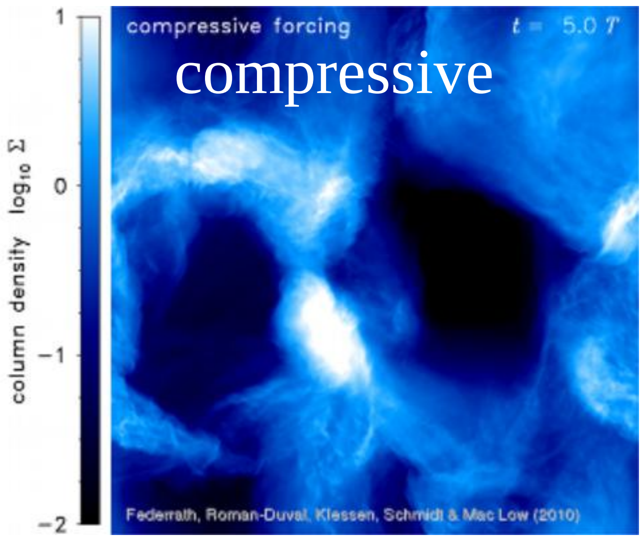
Turbulence: double agent

Turbulence, at ~100pc scale

Solenoidal (**div v=0**)
Compressive (**rot v=0**)
Federrath et al 2008

Turbulence due to gravit. instabilities or feedback, etc..





Compressive forces, 0.1-1kpc scale

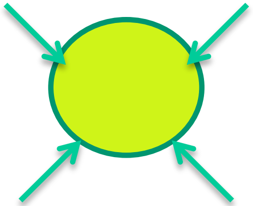
For a density in ρ (r) ~ r $^{-a}$, the force per unit mass is in r $^{1-a}$, thus attraction can increase with distance, if $0 < a < 1$

➔ tidal force is compressive $F_{tid} \sim (1-a)\, r^{-a}$

In particular, for a density=cst (rotation V in r $^{1-a/2}$)

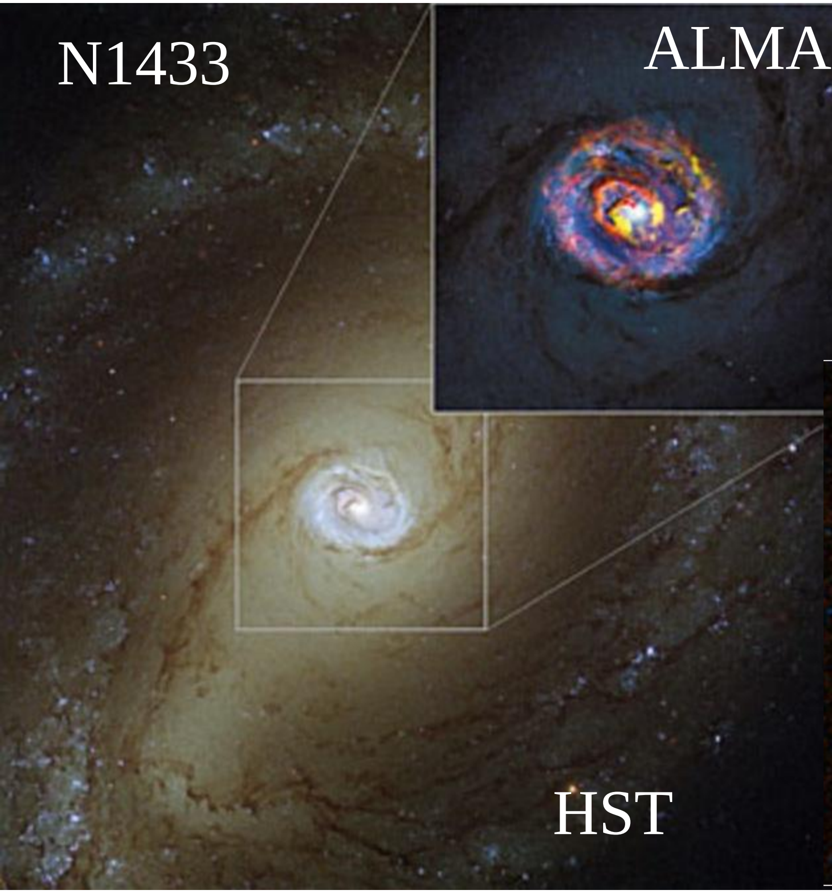
➔**nuclear starburst in galaxies**

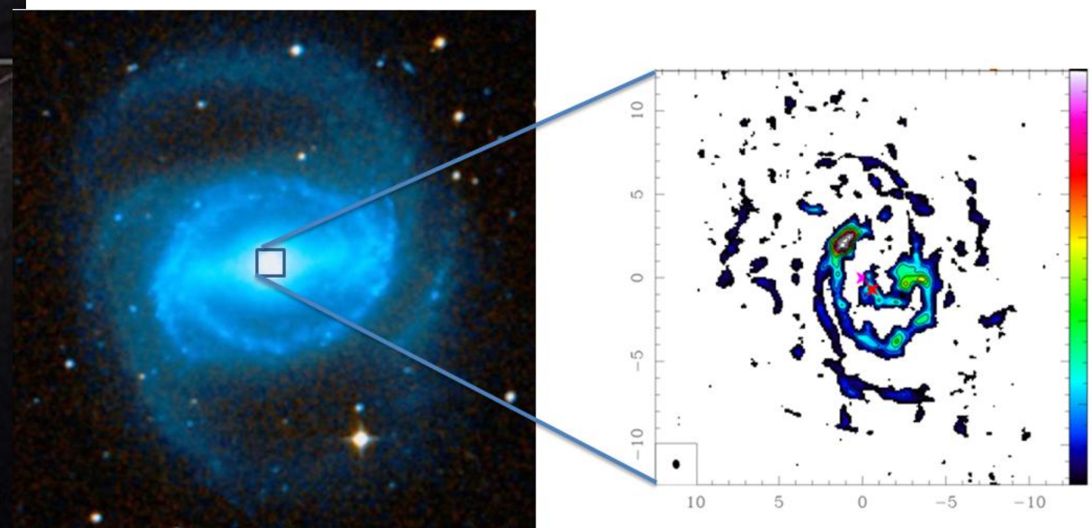
(Emsellem et al 2001, Wozniak et al 2003)



Bars and spiral arms

Gravity torques drive
the gas towards the center,
where it piles up in rings
at Lindblad resonance





Combes et al 2013

The condition of starburst: **accumulating gas in a time short enough that feedback mechanisms have no time to regulate**

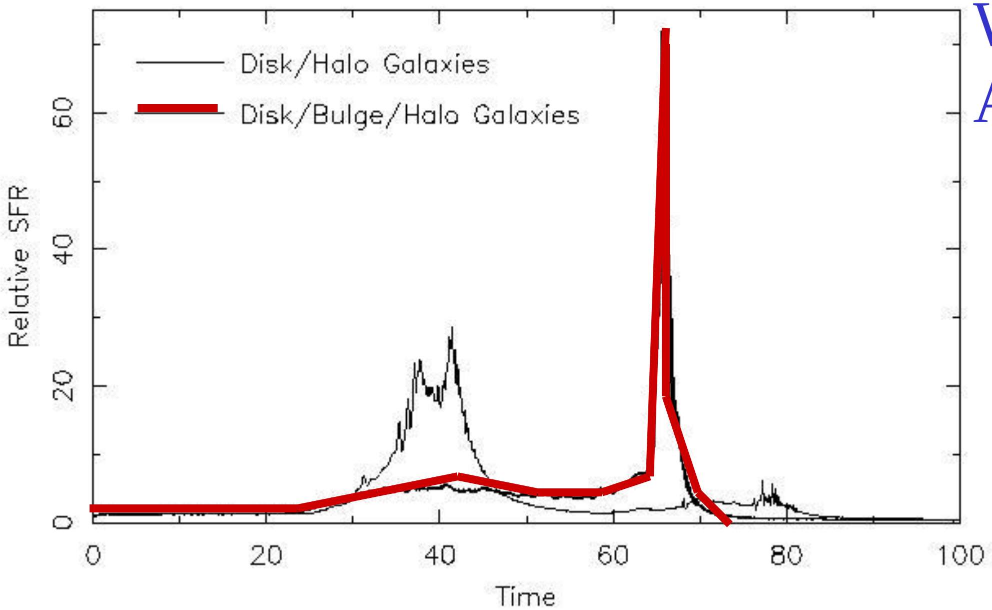
SF triggered by galaxy interactions

Very high impact, according to some simulations!

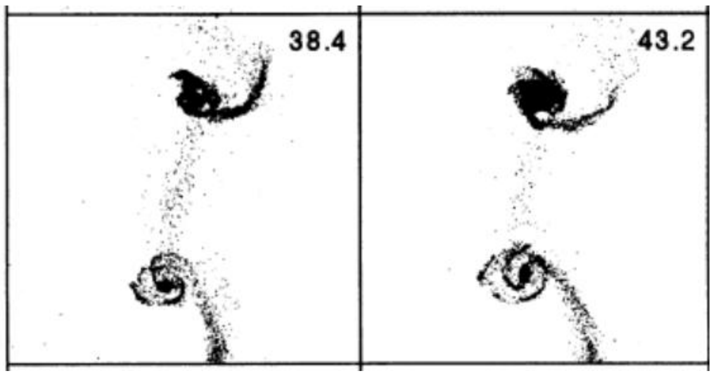
Numerical simulations use recipes, for the sub-grid physics
Katz (1992), Mihos & Hernquist (1994, 96)
Schmidt law with threshold, with **exponent n=1.5**

But not all IG have a starburst!

Results depends on disk stability

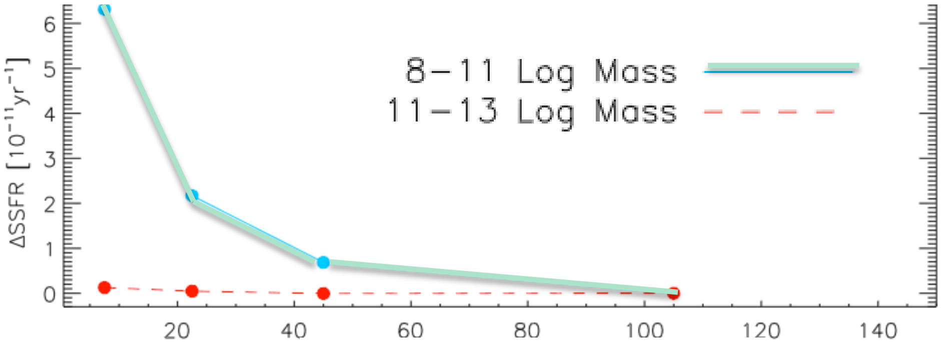


Without bulge, disk more unstable
At the end, the same SFR



Interactions: observations

ΔSSFR



Separation (kpc)

More SSFR in close pairs
5.3 increase in SSFR for low mass (10^{8}-10^{11}Mo) **and a factor of~2.1** for high mass (10^{11}-10^{13} Mo)
Less in cluster environment

As seen in SDSS pairs by
Ellison et al 2008, *Patton et al 2013*
Until 150kpc separation

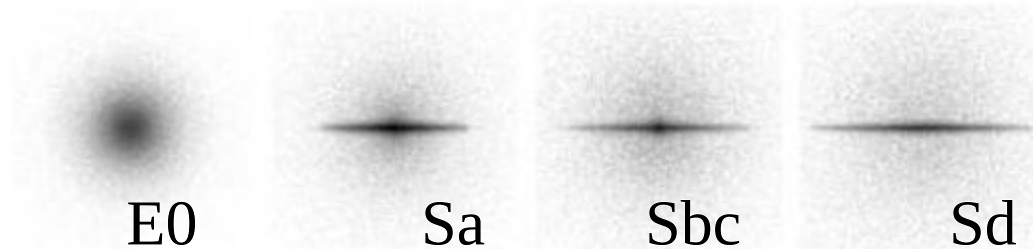
Scott & Kaviraj 2014

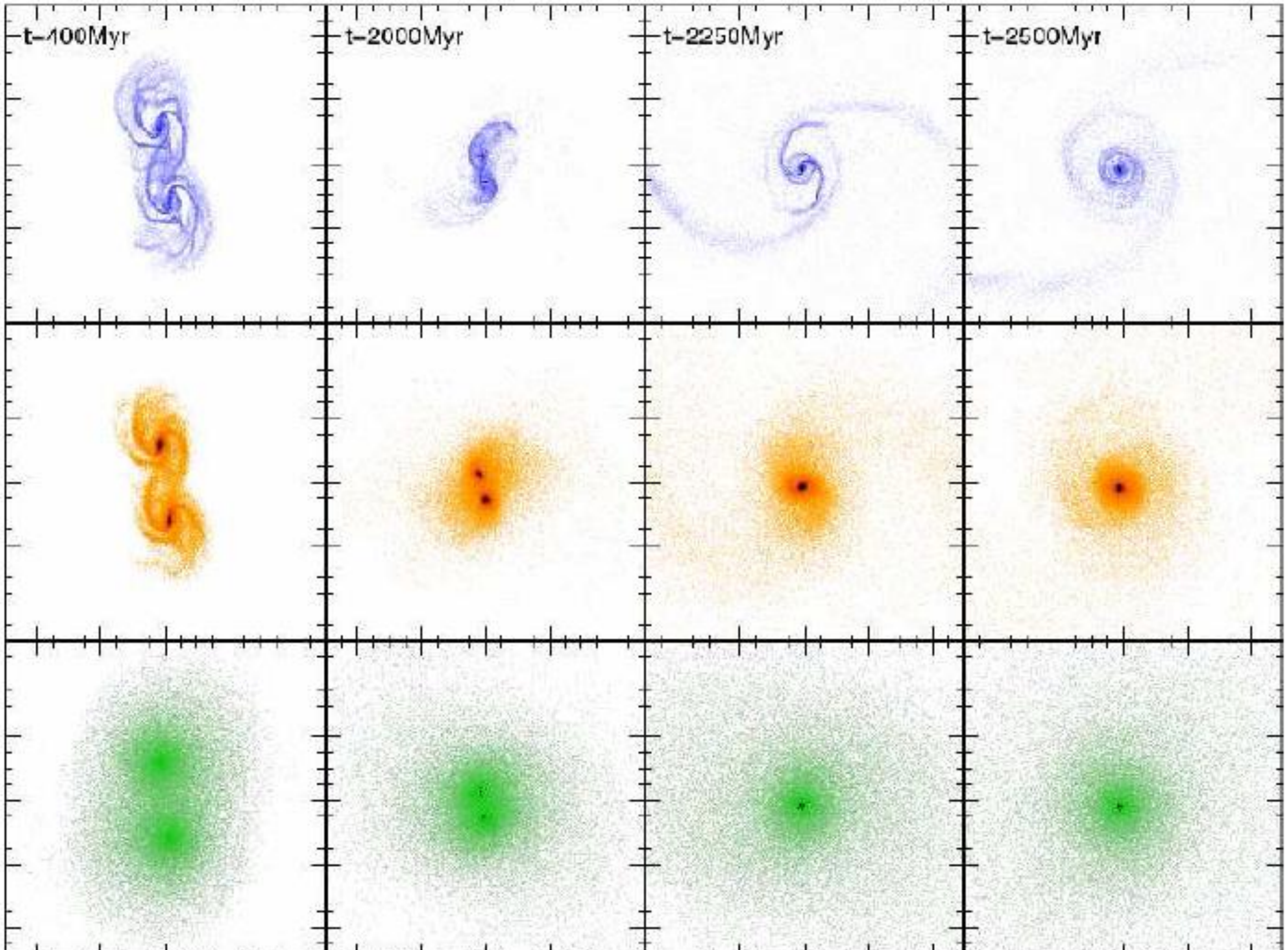
Also SF triggering by interaction at higher z : 0.1 < z < 0.6
accompanied by asymmetries *Patton et al 2005*

At z=1.2 (COSMOS) more triggered SF in low-mass galaxies
(Ideue, Taniguchi et al 2012)

Direct orbit merger gSb gSb

Retrograde orbits produce more starbursts





GALMER
Di Matteo et al 07

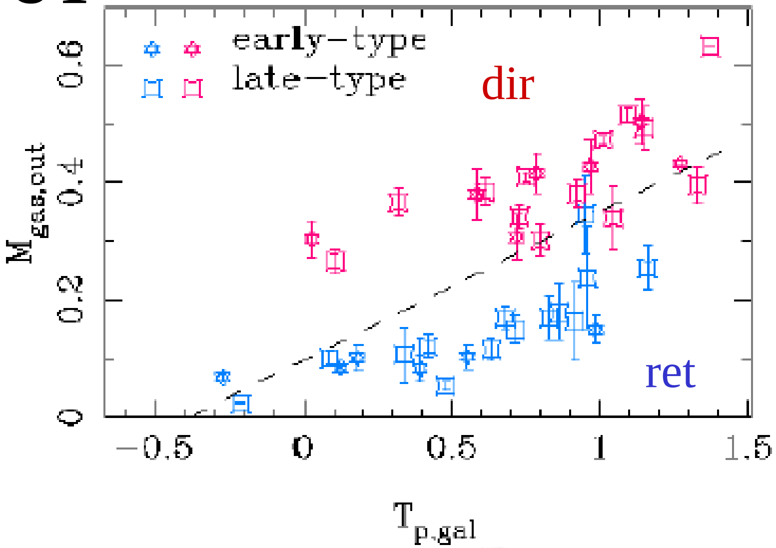
A high trigger in mergers is rare

<10% SF in z=0.6 major mergers for Massive Gal
Robaina et al 2009

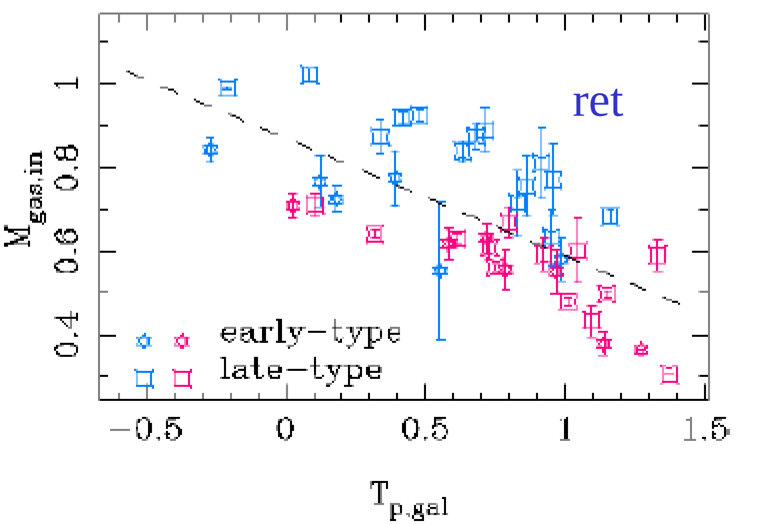
Gas flows IN and OUT

Retrograde keep more gas

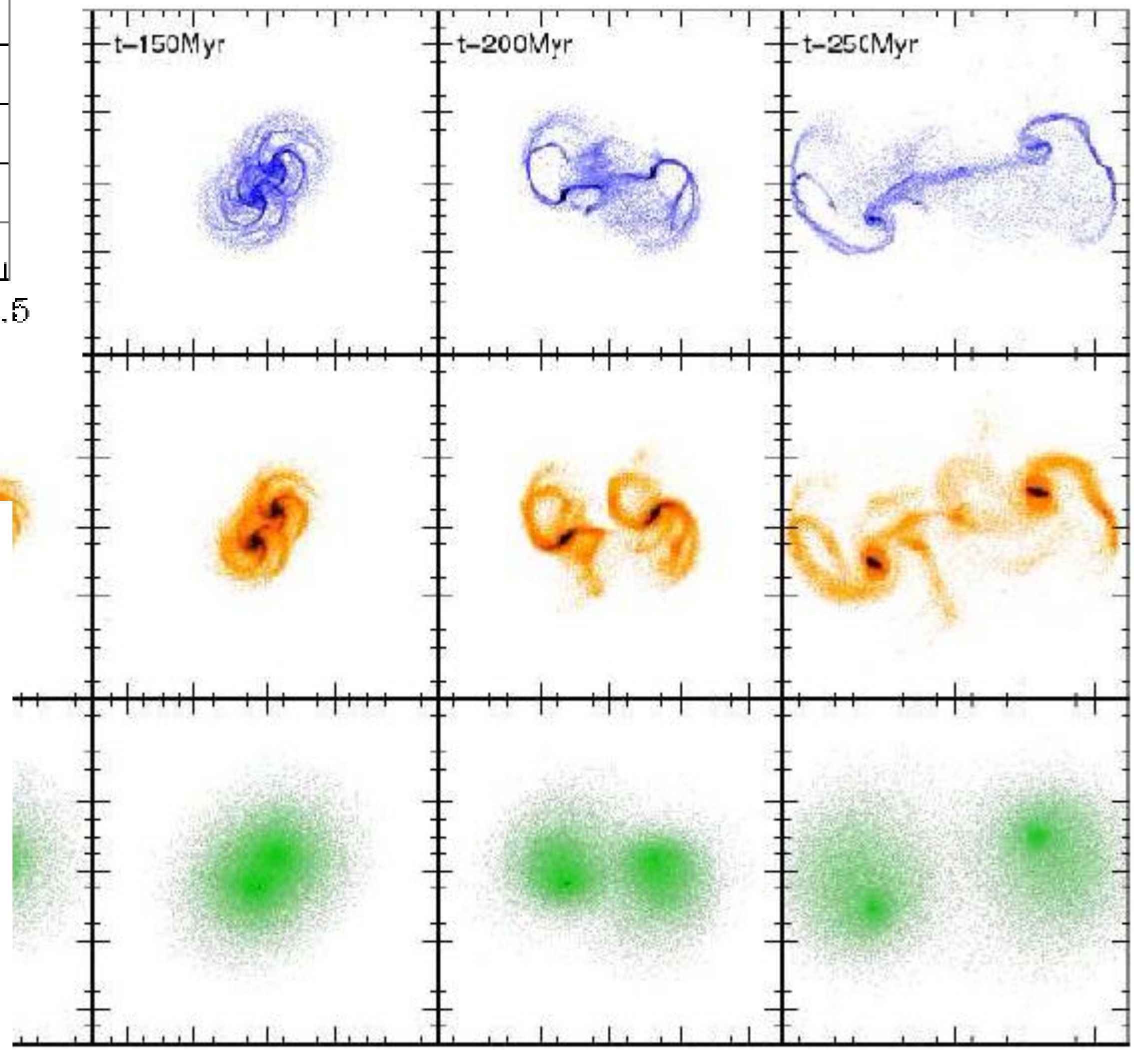
OUT



IN

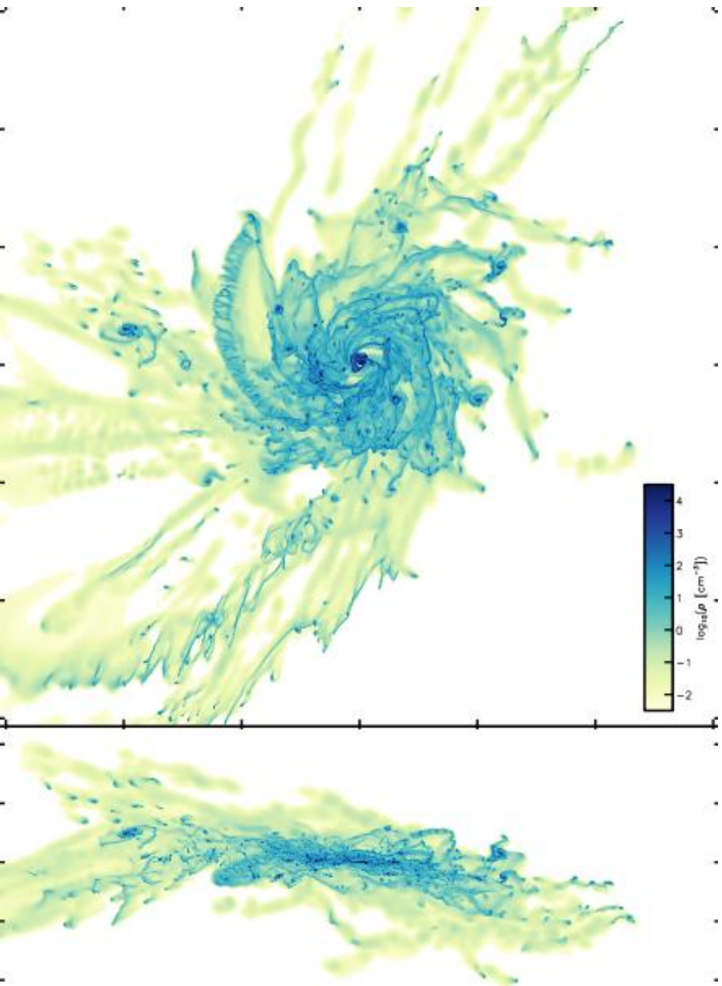


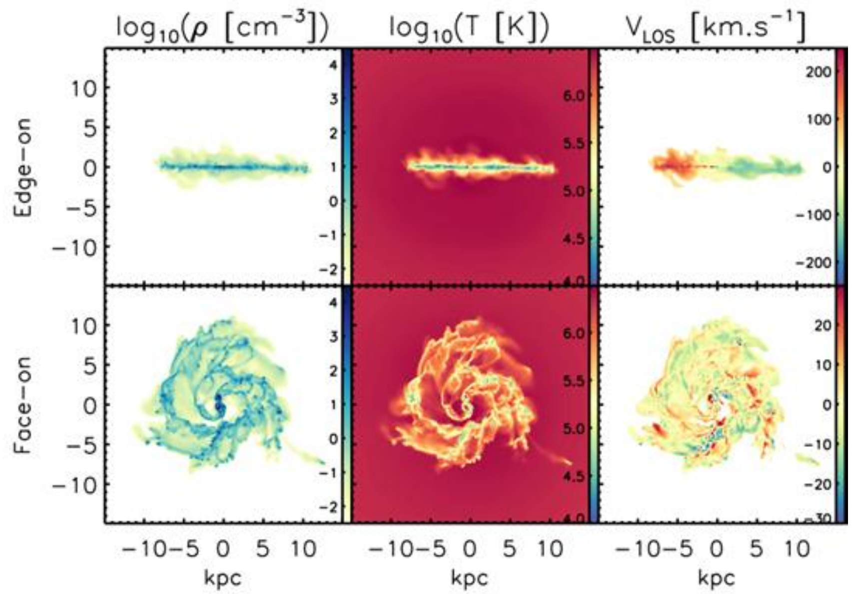
direct orbit flyby gSa gSa



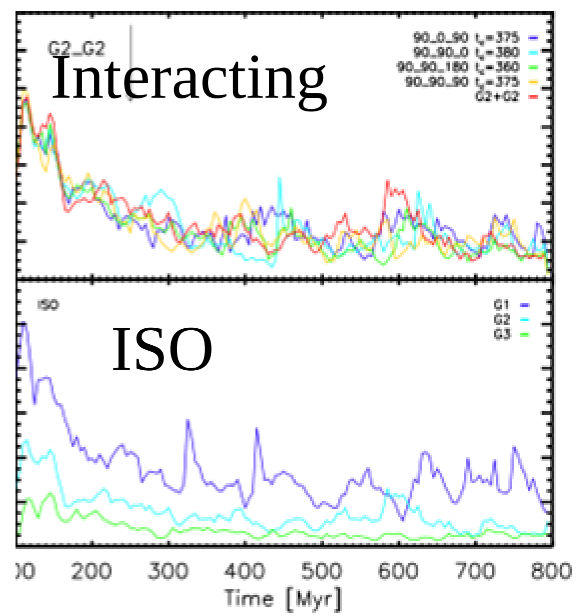
100kpc size

Influence of interaction/merger





High-resolution simulations



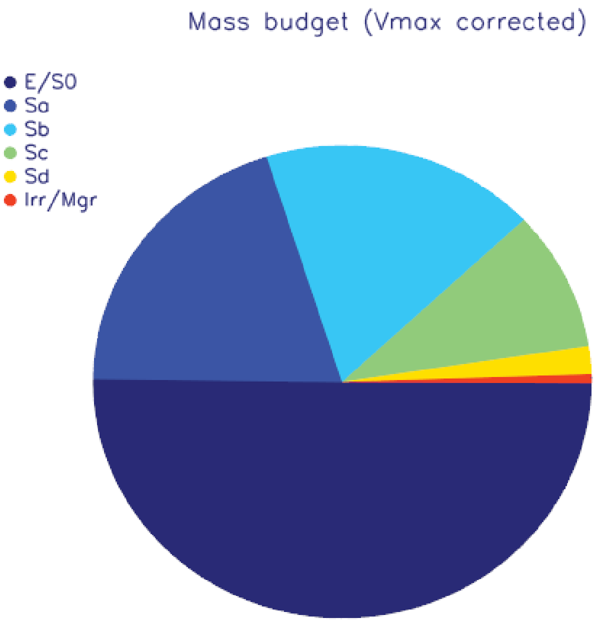
No impact at all

Same SFR for isolated galaxies

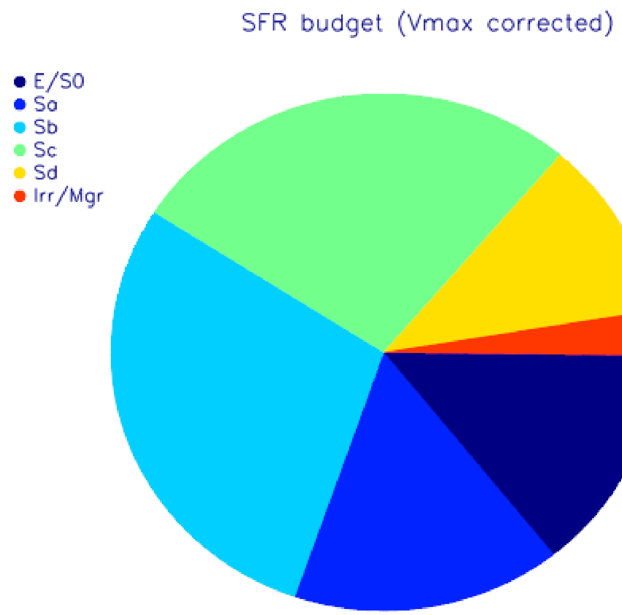
Temperature floor?, EoS? Saturation?

Perret, Renaud et al 2014

Minor mergers are important in global SF



In ETG: 14% of the SFR today
LTG (Sb/Sc) 53%
ETG: SF due to minor mergers
➔ 24% of SF in LTG is due to minor mergers



Fraction of the cosmic SF induced by minor mergers = 35%

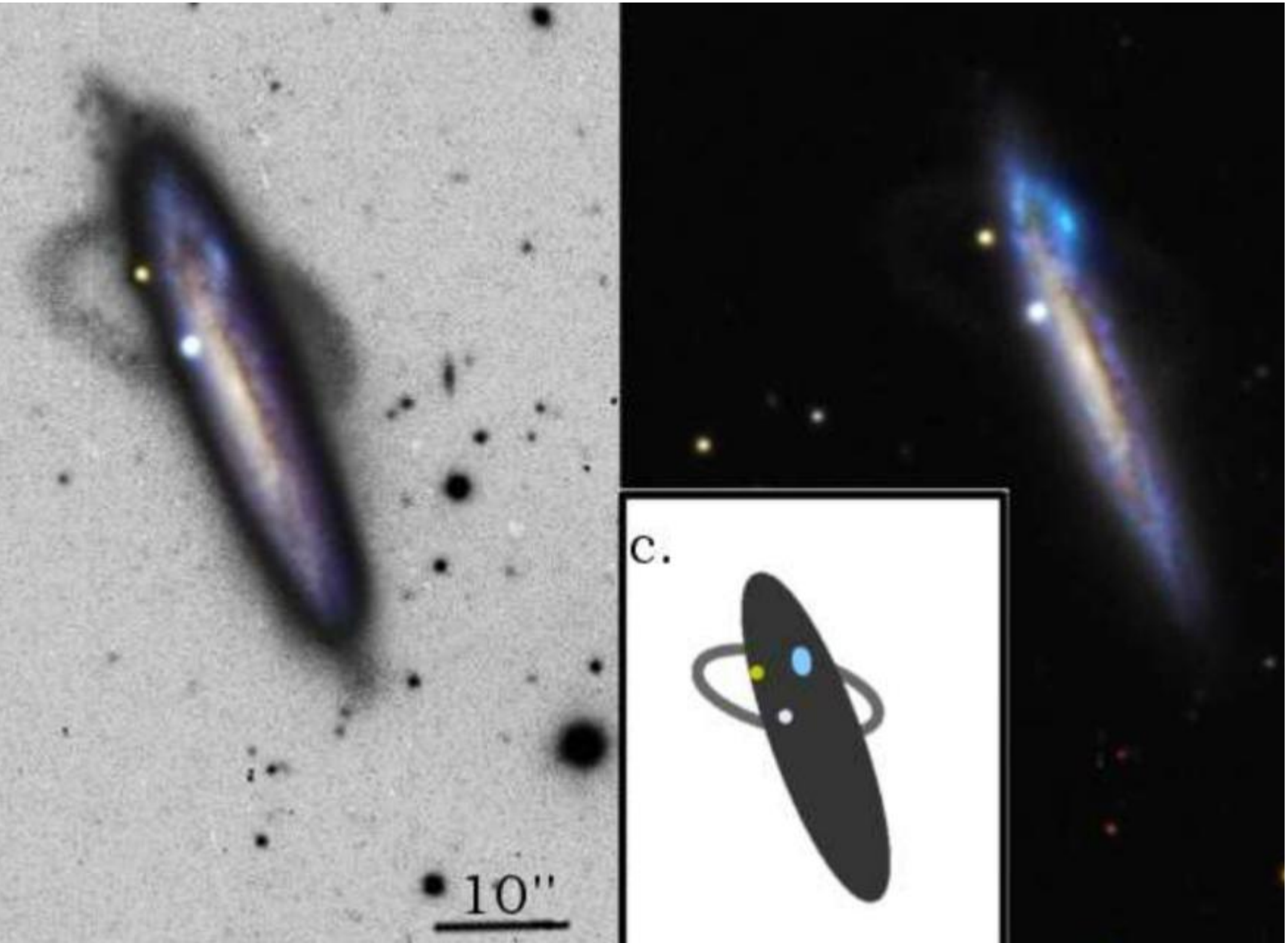
Origin of the bulge and BH growth?

Kaviraj 2014

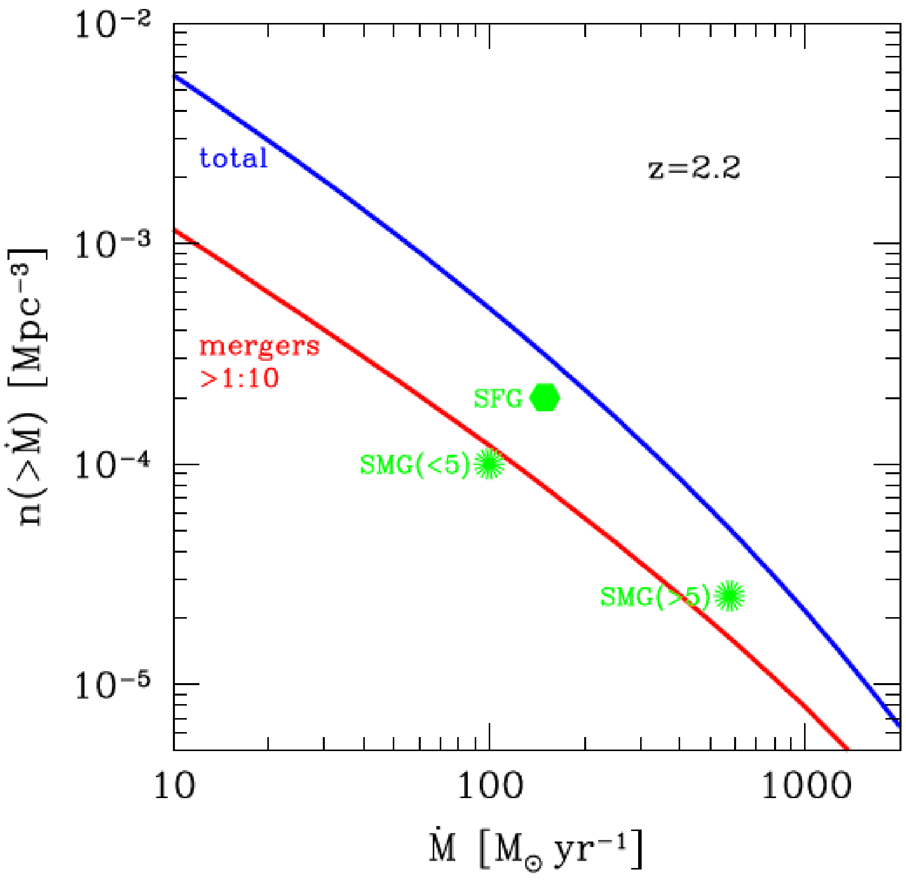
SF trigger minor merger (NGC 5387)

SF trigger in N5387, due to a dwarf merger

Beaton et al 2014

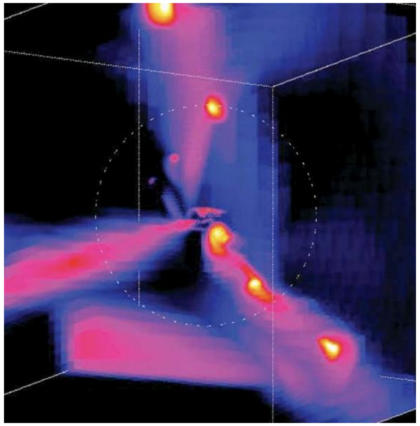


Relative role of gas accretion and mergers



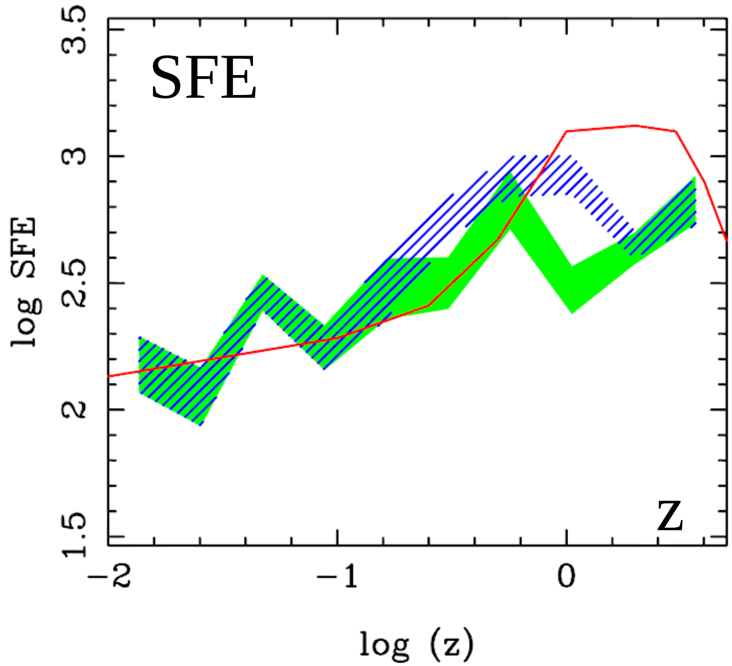
Analysis of results from a cosmological simulation with hydro: most of the SF is due to smooth flows

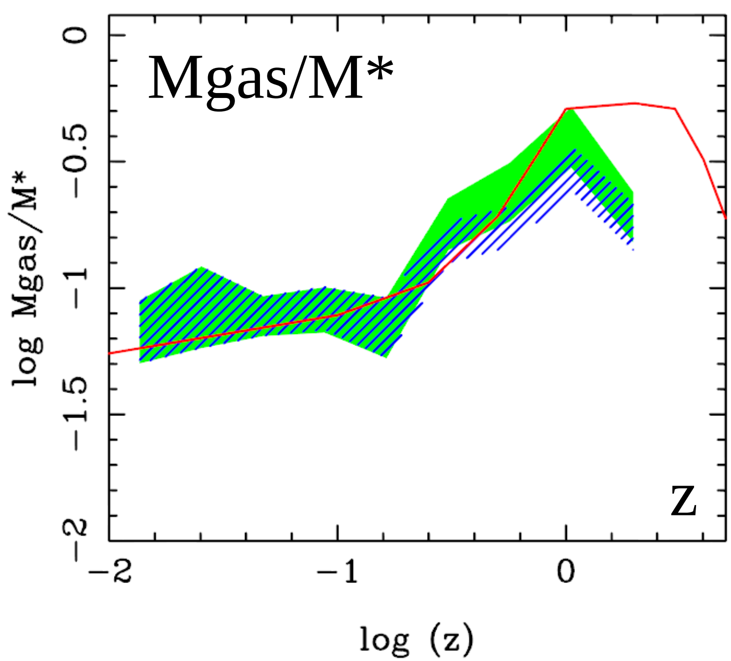
Dekel et al 2009



Fraction of mass acquired from **accretion 77% (mergers 23%)** until z=0 *Lhuillier et al 2011*

Starbursts: evolution with z





Star formation efficiency **and gas fraction**

<z=1>/<z=0>= 2.1 /3.8 (hatched: with upper limits) 3.2 and 2.5

Both contribute, **factor 3±1 increase between z=0 and 1**

SFE should also be increased due to more violent dynamics

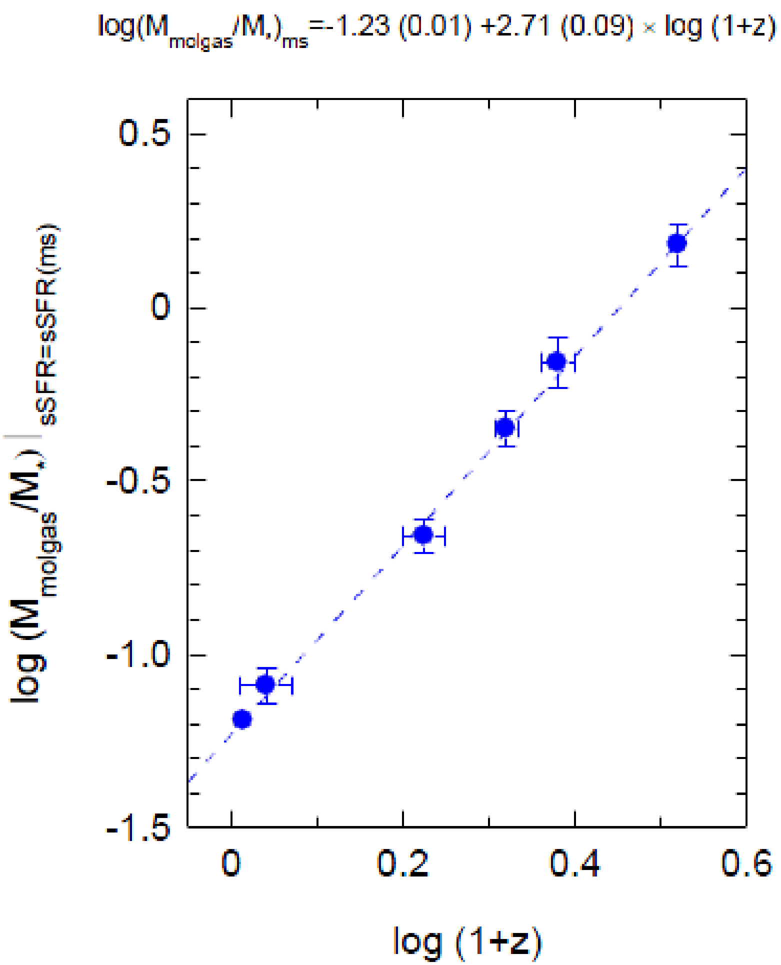
Combes et al 2011, 2013

SFE for main sequence galaxies

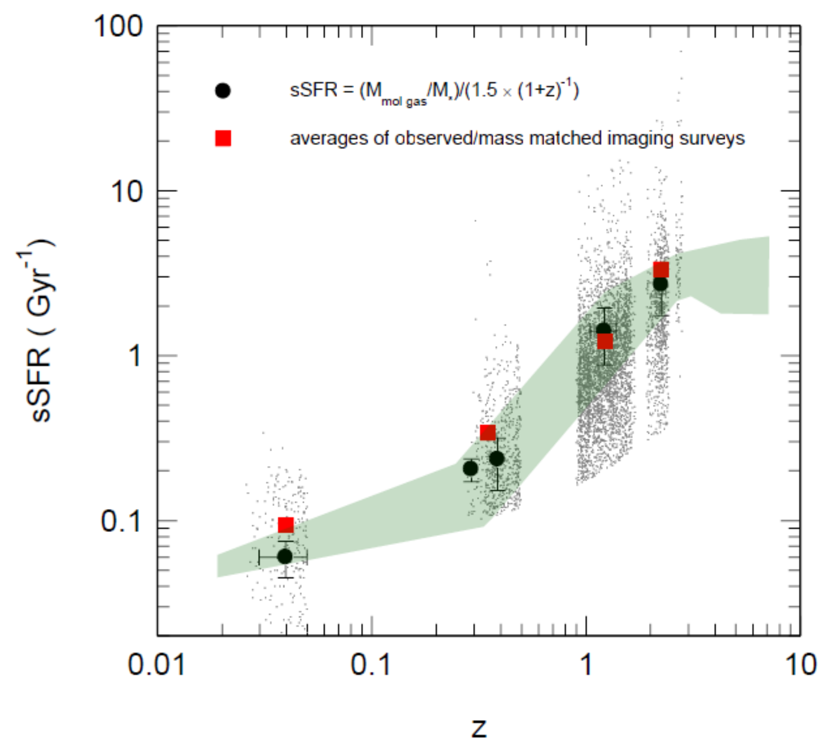
On the Main Sequence, $M_{gas}/M_{*} \sim (1+z)^{2.7}$

tdep=1.5/(1+z) Gyr

➔ SFE increasing with z

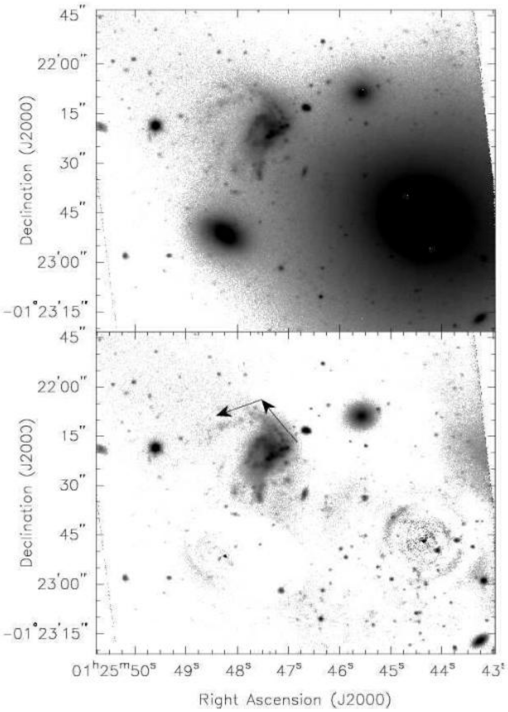


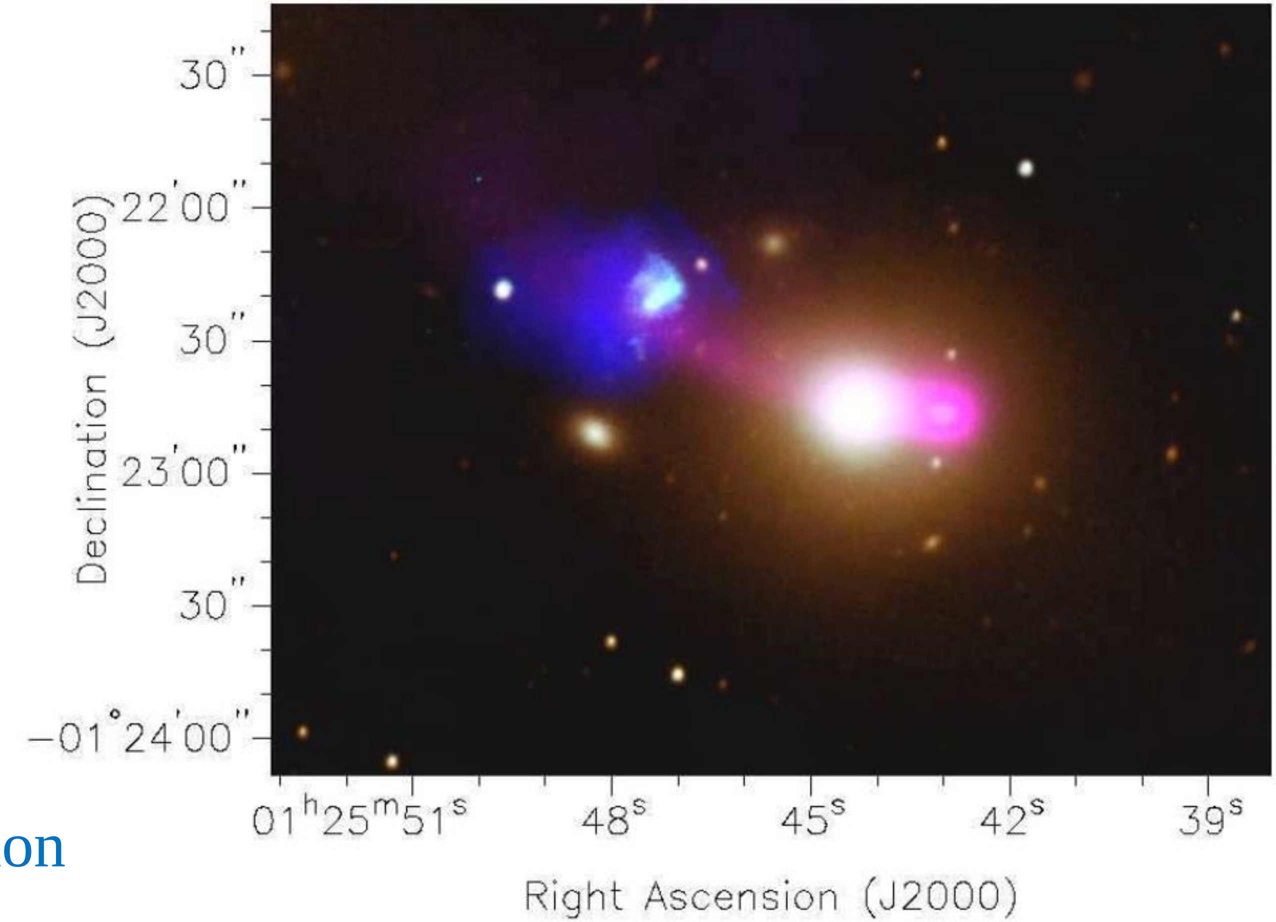
Genzel et al 2014



Tacconi et al 2013

AGN-triggered? Minkowski object





Triggered star formation

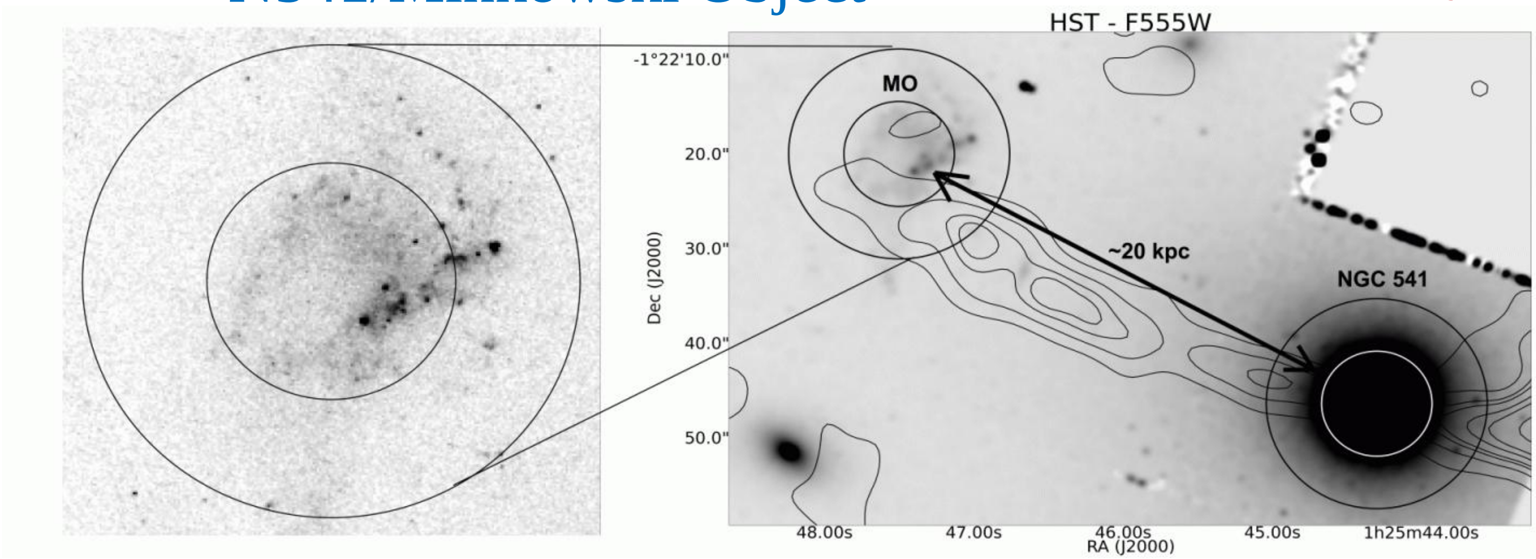
HI: blue, Hα: light blue, Radio cont: purple

Croft et al 2006

Very efficient jet-induced SF

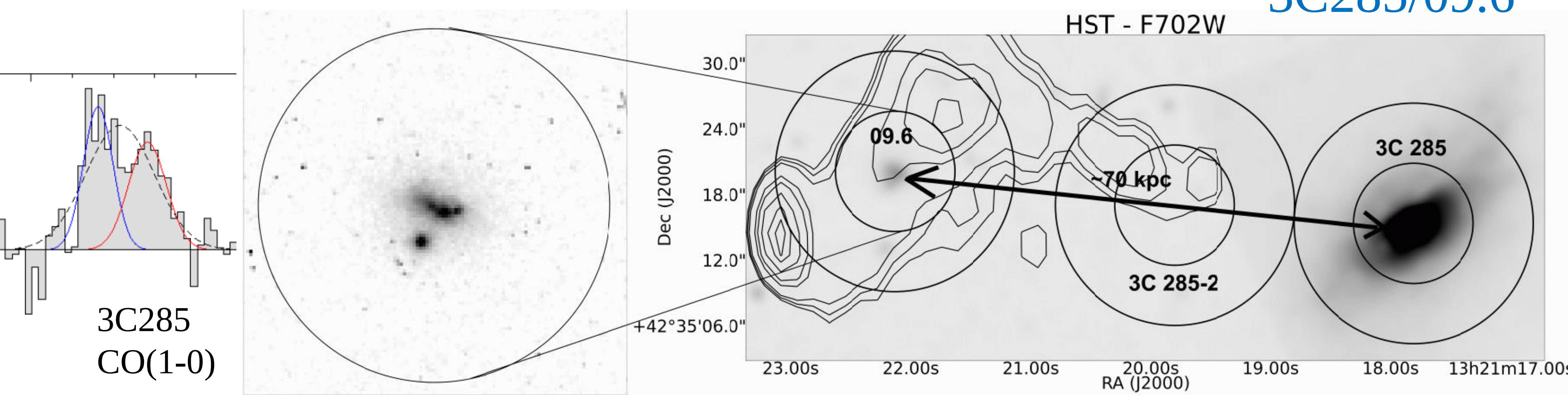
N541/Minkowski Object

CO detected only in the hosts

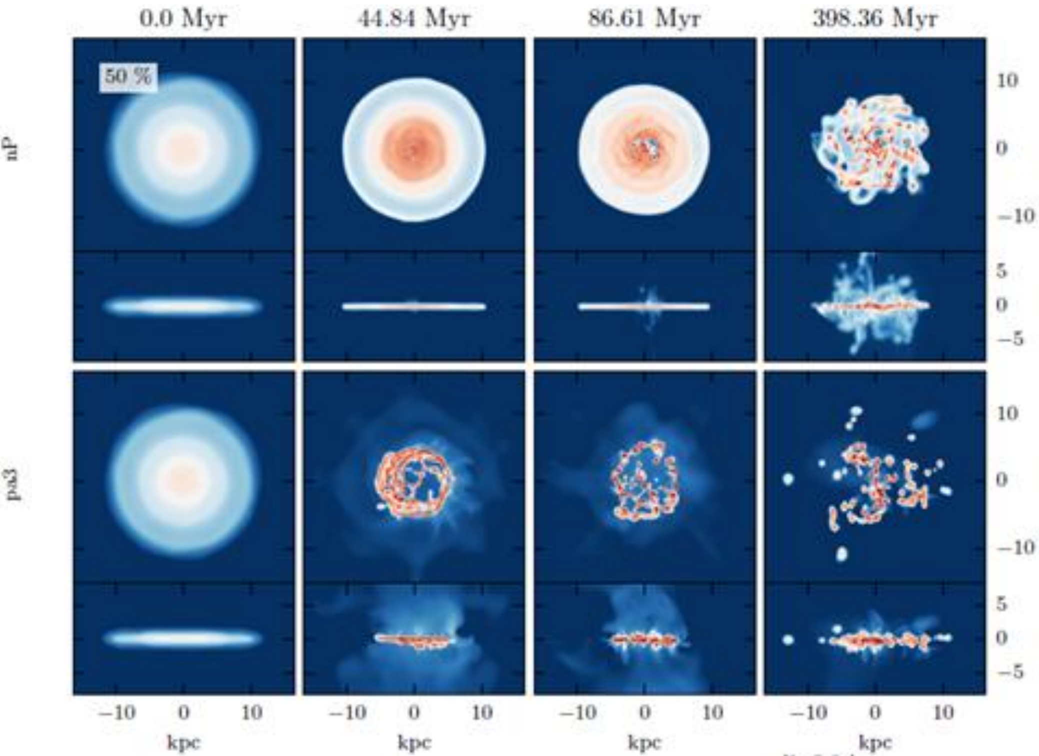


Salome, Salome, Combes 2014

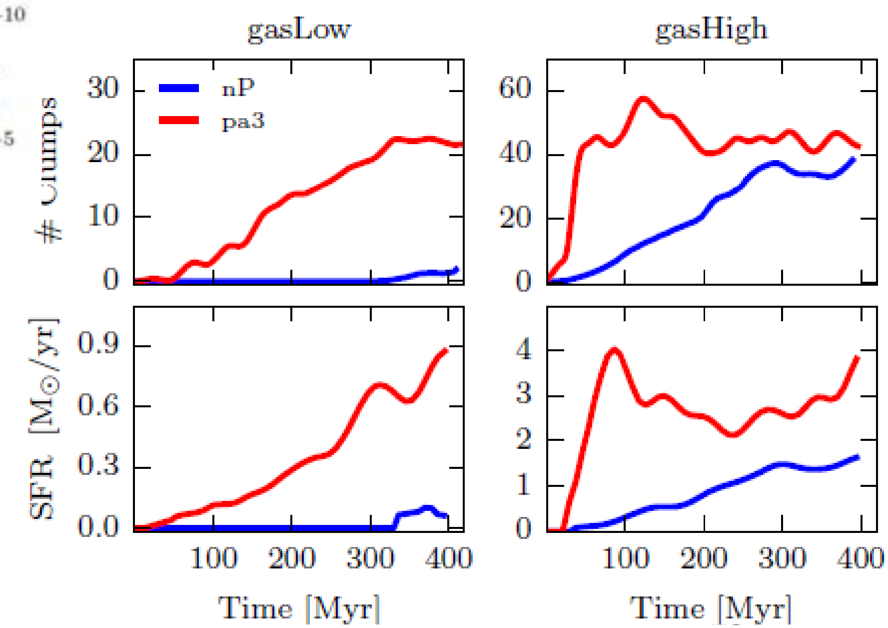
3C285/09.6



AGN-triggered star formation

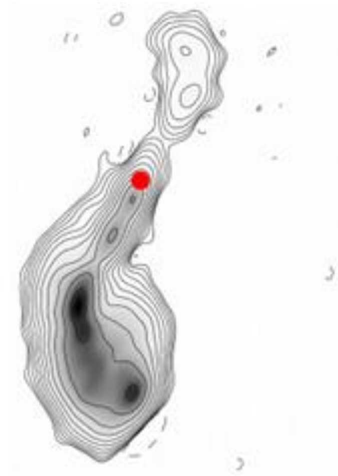


The AGN provides an extra-pressure forming more clumps in the molecular gas



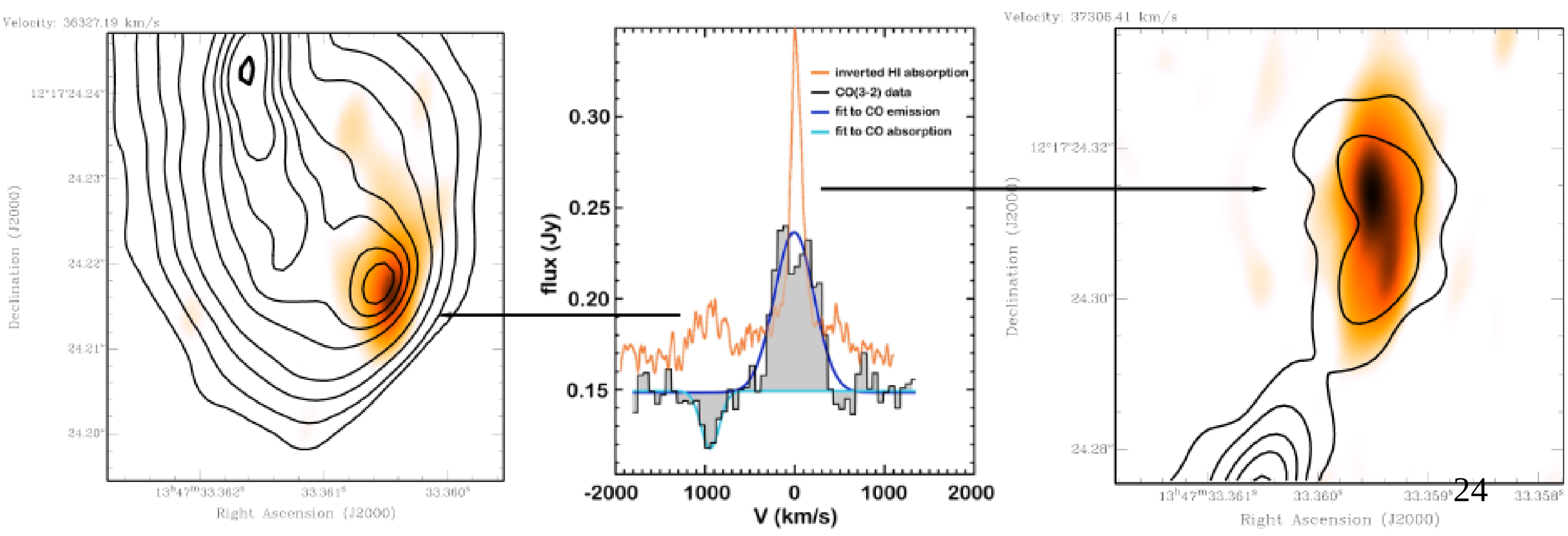
Bieri, Dubois, Silk, Mamon 2015

Positive AGN feedback: Radio jets triggered SF



Young, restarted radio loud AGN 4C12.50

The outflow is located **100 pc from the nucleus** where the radio jet interacts with the ISM
Morganti et al 2013, Dasyra & Combes 2012



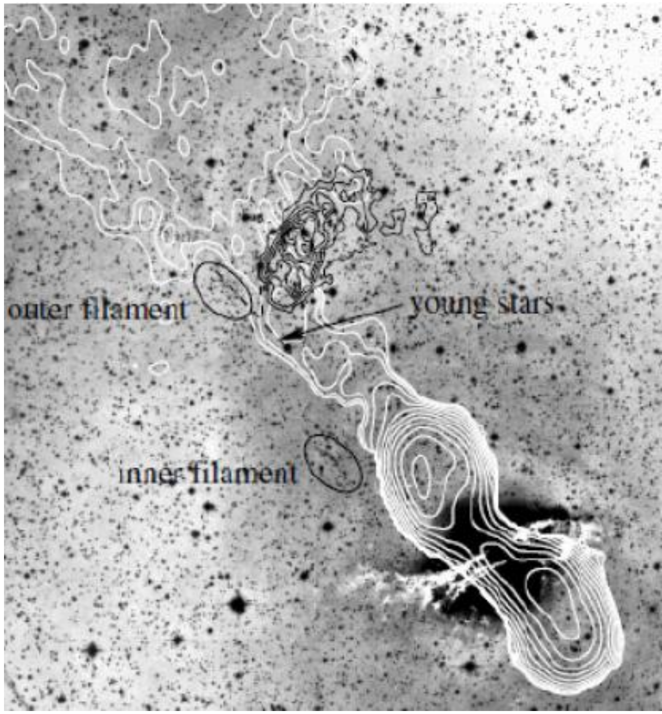
Centaurus A with MUSE

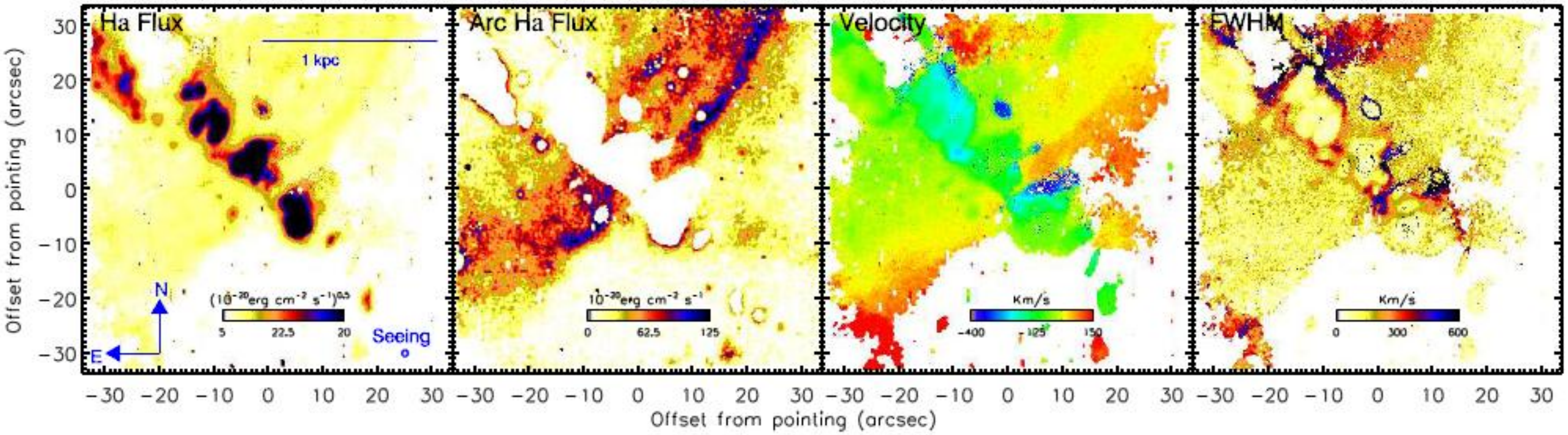
Discovery of arcs perpendicular to the filament
Halpha, [NII], [OIII] and [SII] lines

SF induced by shocks

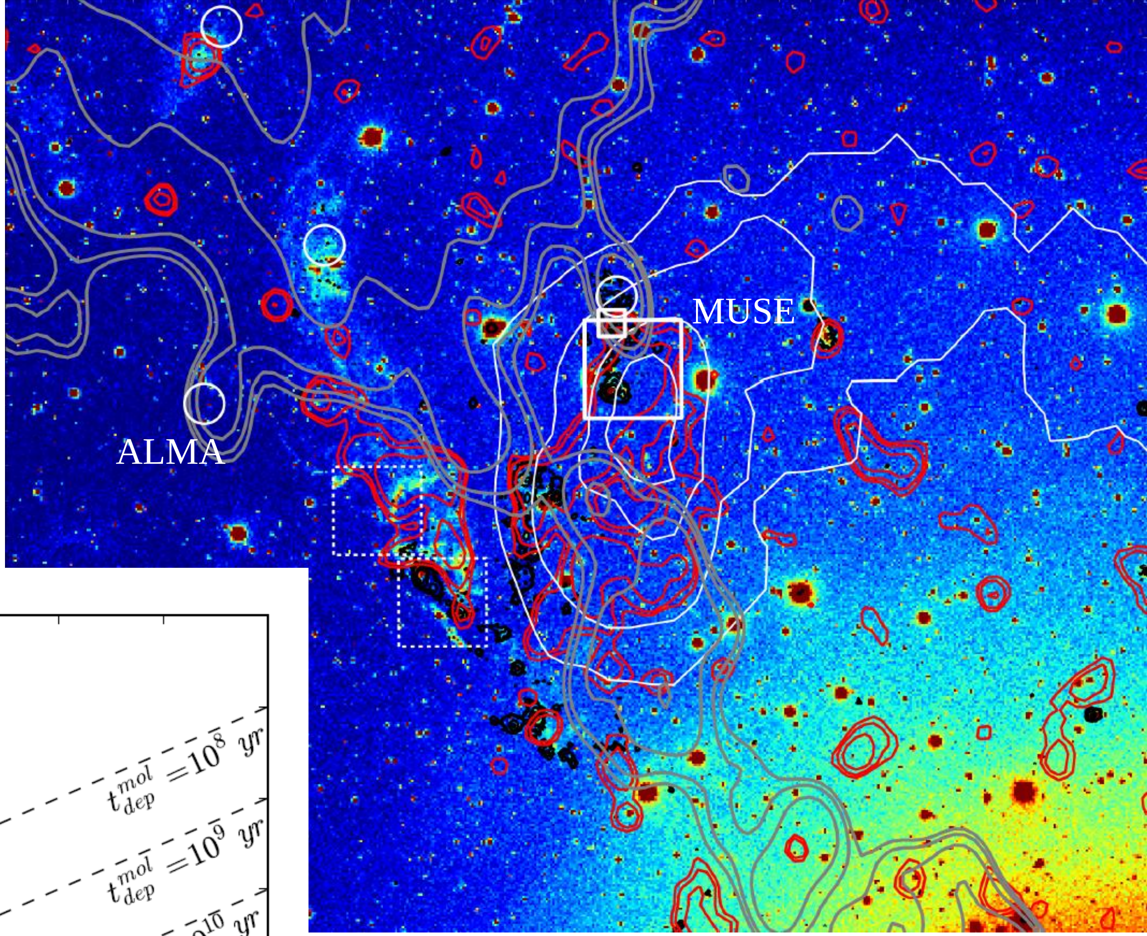
3 arc streams perpendicular to the filament
➔backflow of the AGN jet

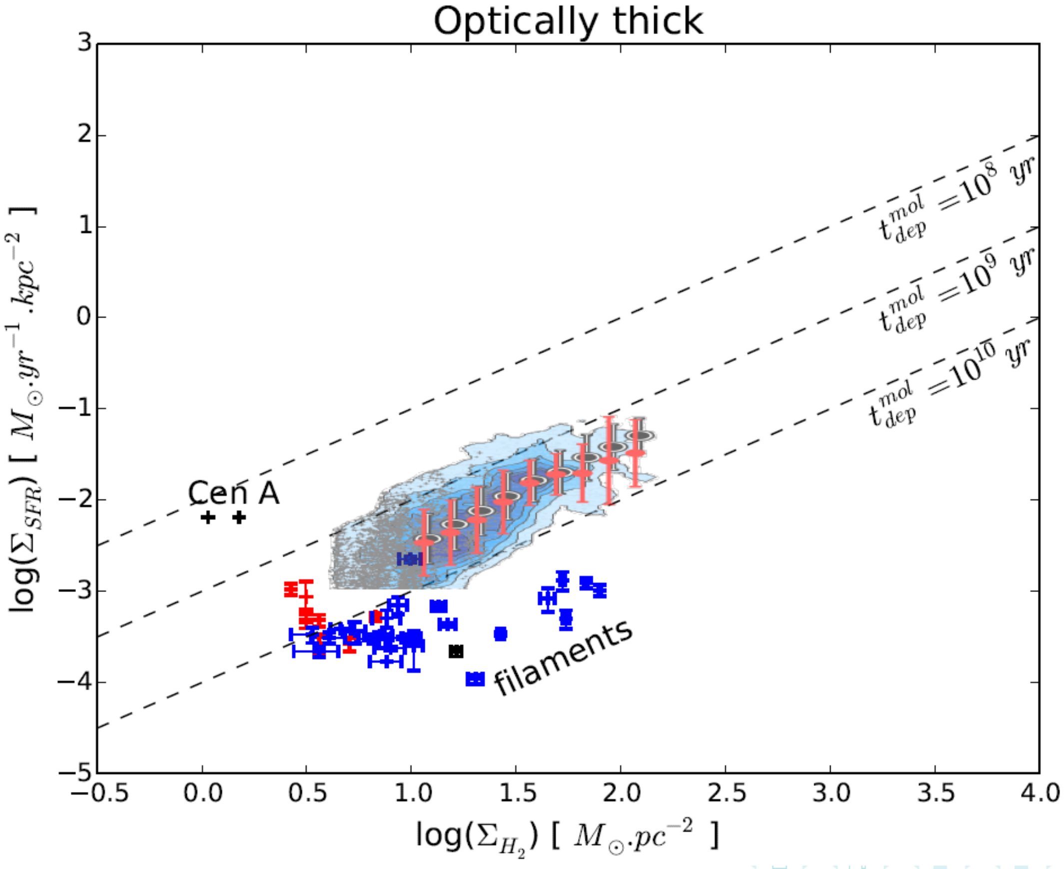
Hamer, Salome, Combes, Salome, 2014





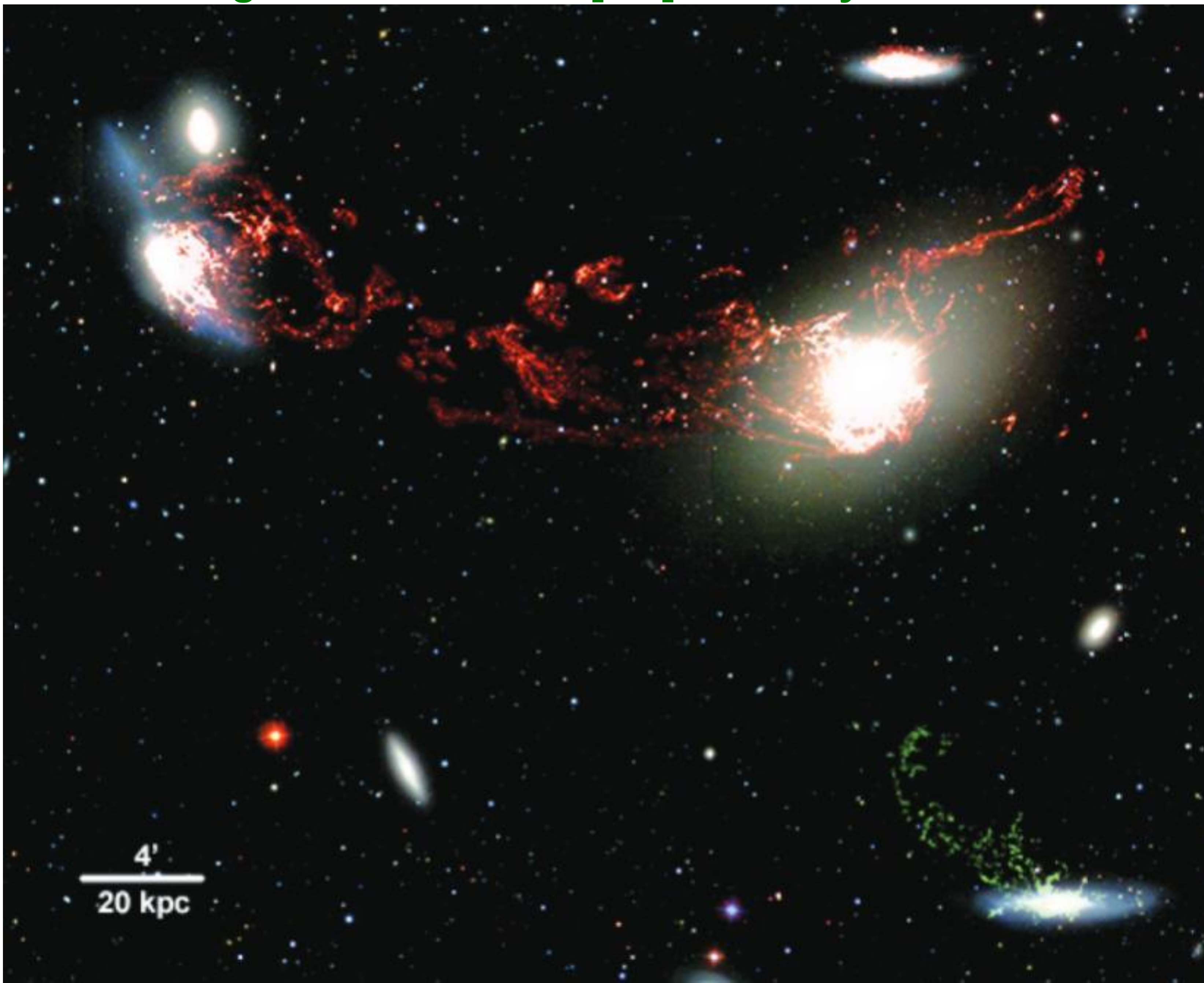
SF efficiency: t(depletion)



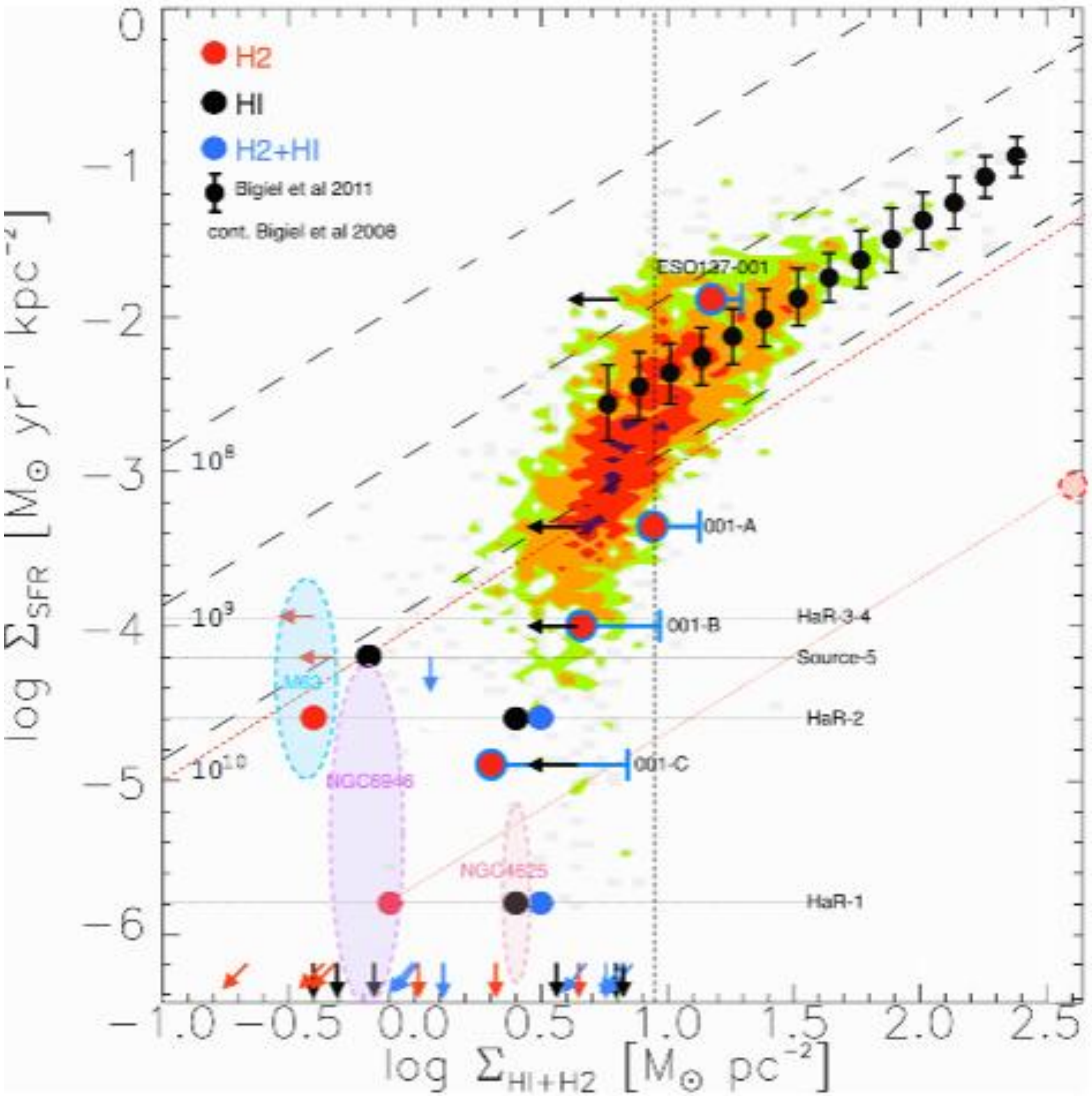


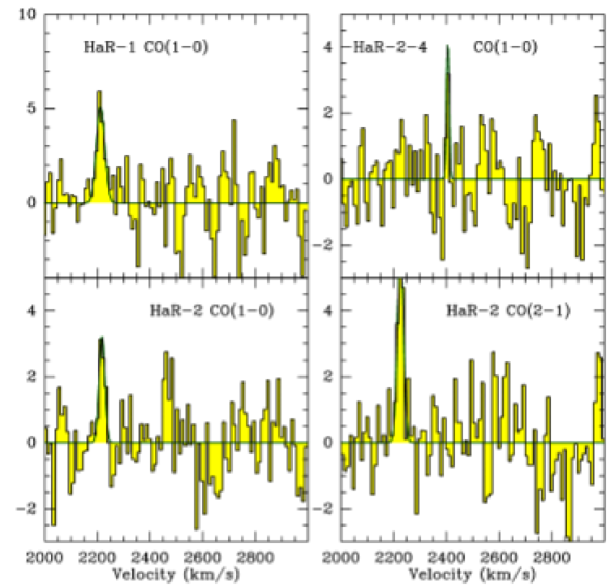
Salome, Salome, Combes, Hamer, Heywood 2016

Virgo cluster: Hα + [NII], Kenney et al 2008



Tidal streams in clusters: Virgo





Verdugo et al 2015

CONCLUSION

➔ Star formation with SFE=cst, but above $\Sigma_{gas} = 9\ M_\odot/pc^2$

➔ Turbulence: solenoidal or compressive, supersonic **~100pc scale**

➔ Density waves, bars and spirals, gas compression **~1kpc scale**

➔ Trigger of galaxy interactions and mergers **~10kpc scale**

➔ Role of environment, AGN feedback (can be positive)
Radio jets, cluster-wide interactions

~100kpc scale