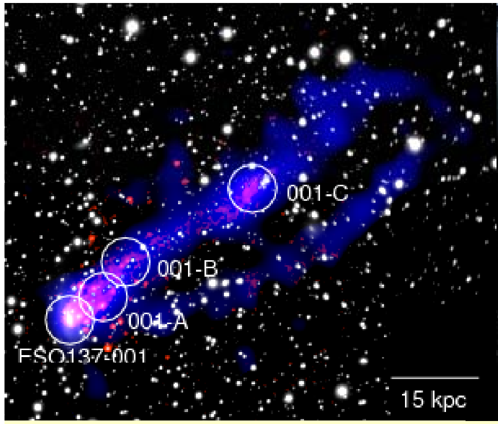


Molecular gas in tidal and ram-pressure stripped tails

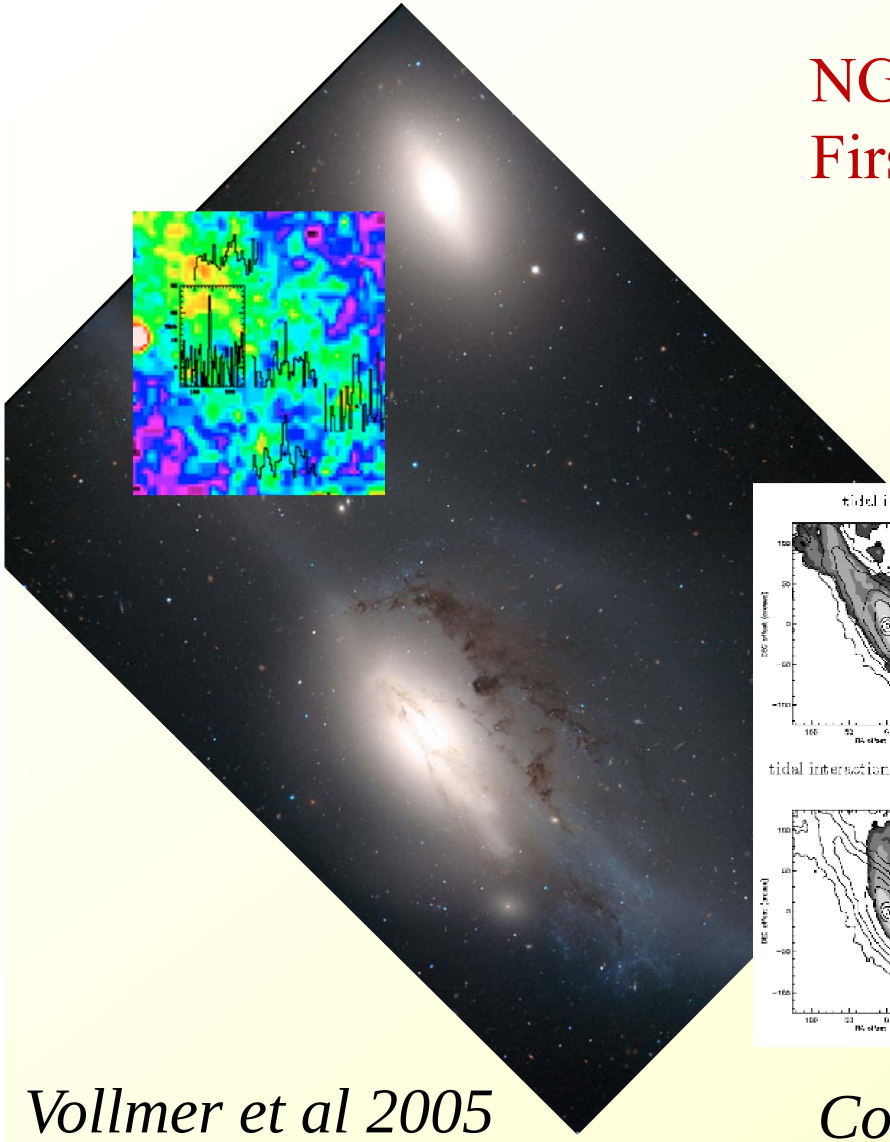
Françoise Combes
Observatoire de Paris

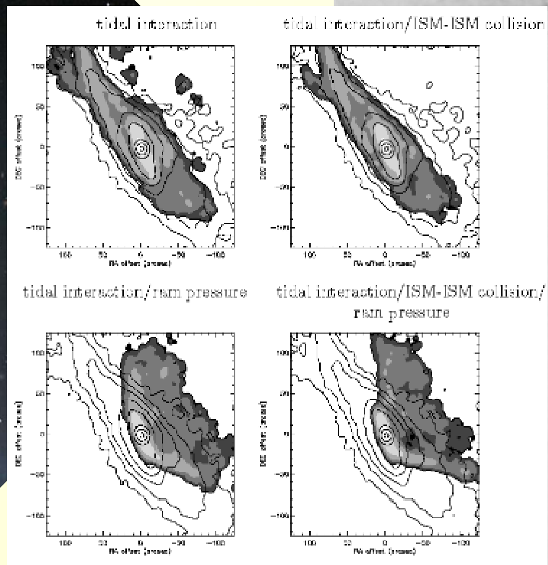
14 December 2016

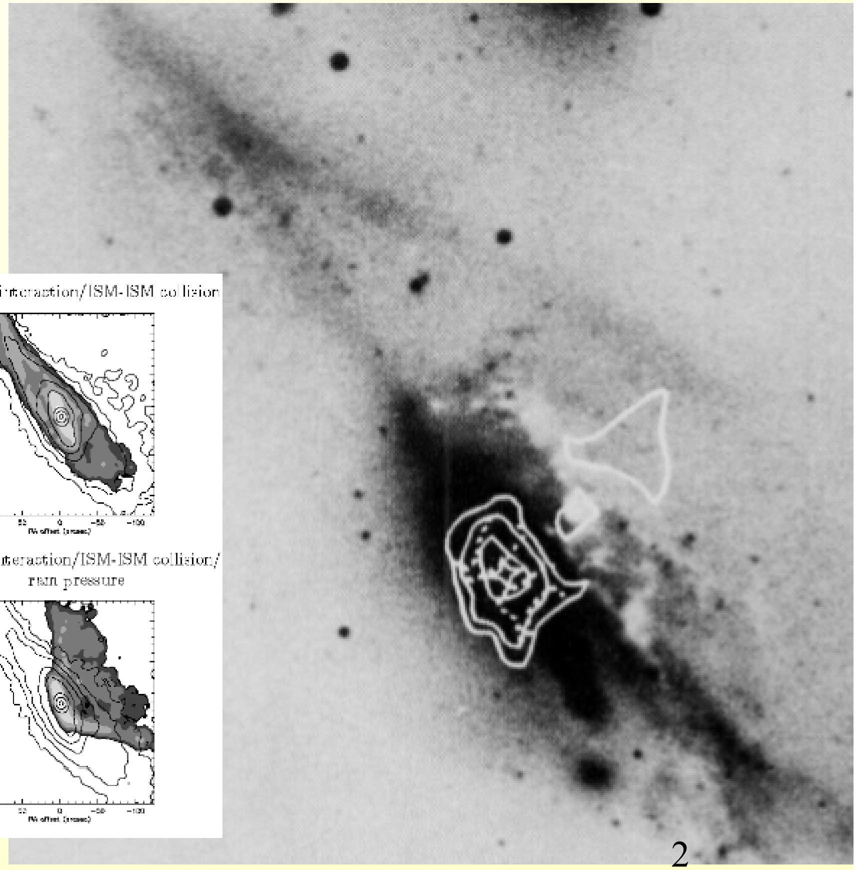
Tides and ram-pressure

Both physical processes are acting, difficult to disentangle

NGC 4438 & 4435 in Virgo
First CO detections outside galaxy disks







Vollmer et al 2005

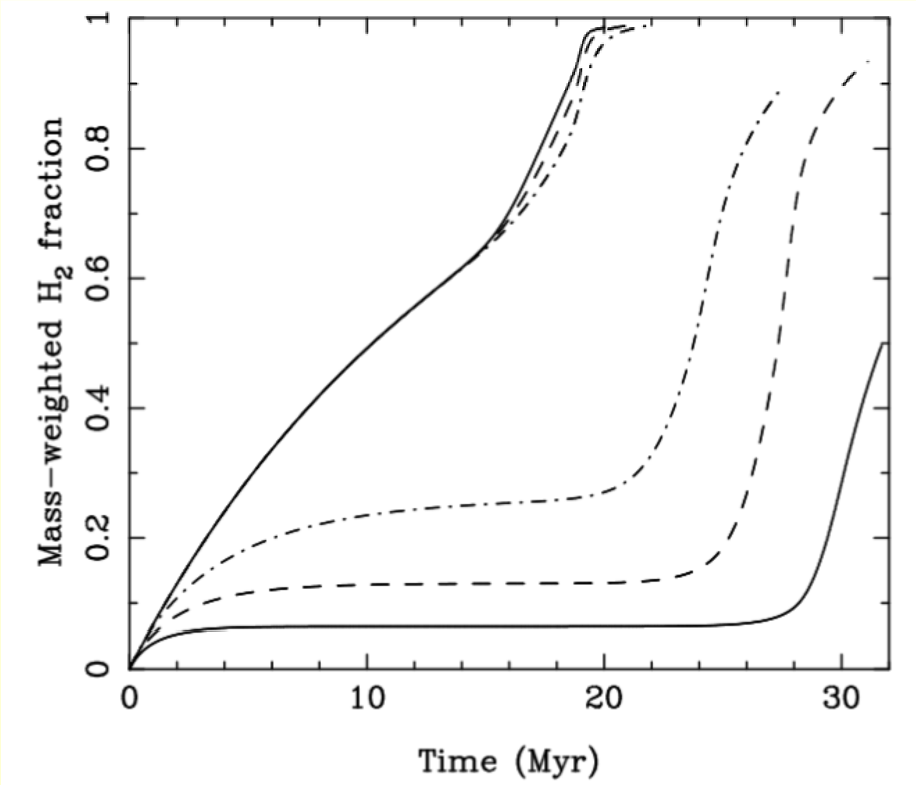
Combes et al 1988

Questions about CO in tails

Molecules should be quickly destroyed in shocks, violent perturbations
Where does the molecular gas come from?

➔Either from the galaxy disk
➔Or reformed in the tail from HI, after destruction?

Time-scale or reformation:
A few Myr, depending on density



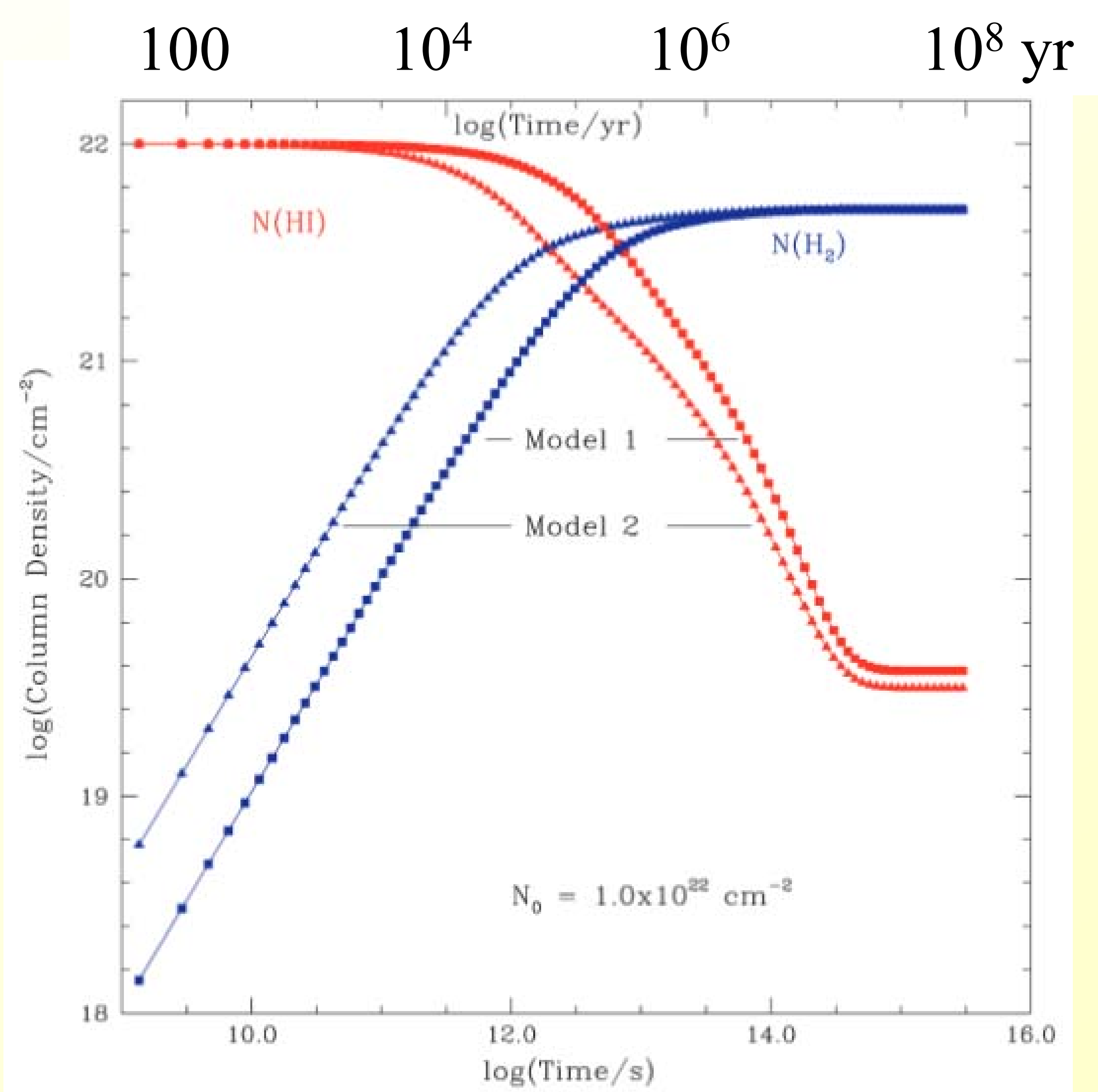
Glover & McLow 2007
Glover & Clark 2012

HI to H_2 transition

Taking into account
Photodissociation
H_2 destruction

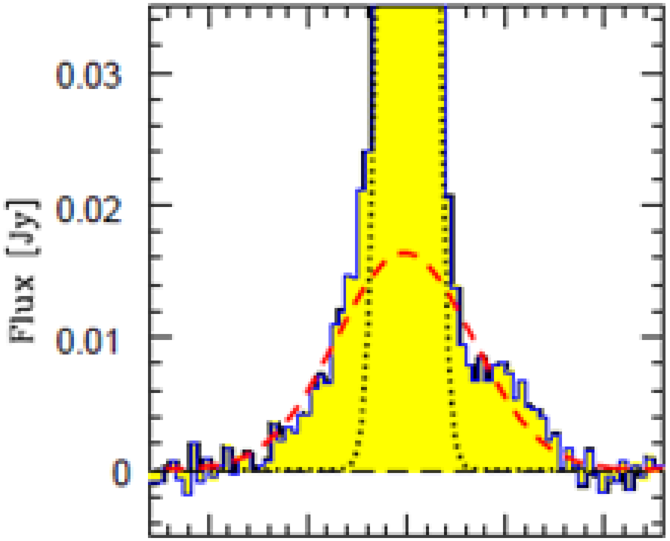
In the dense core
HI-H_2 transition
time-scale is 3 10^4 yr

Model 1: 1.6 $10^4 cm^{-3}$
Model 2: 7.4 10^4 cm^{-3}

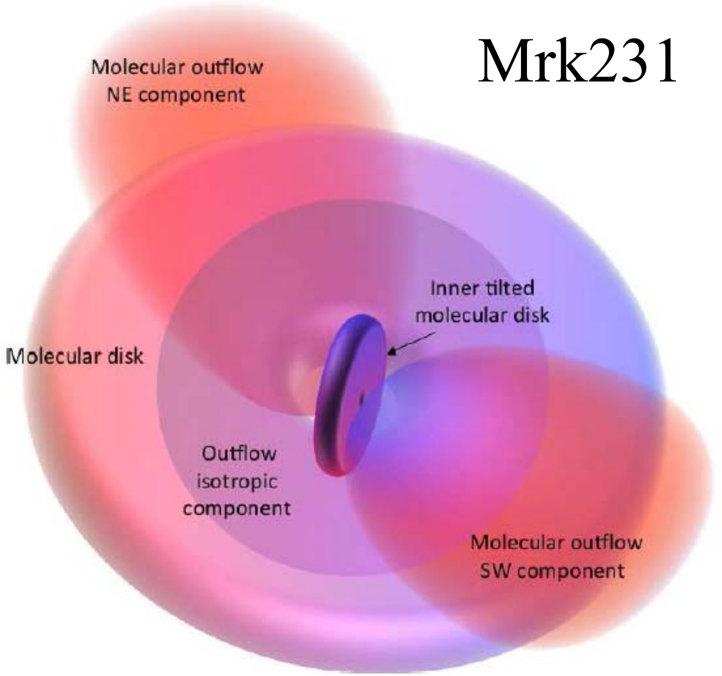


Goldsmith et al 2007

Same question arises in outflows



Mrk231



Gas shock-heated to 10^6-10^7K
Molecules dissociated

Cooling efficient (free-free, metals)
➔Multiphase, with RT instabilities

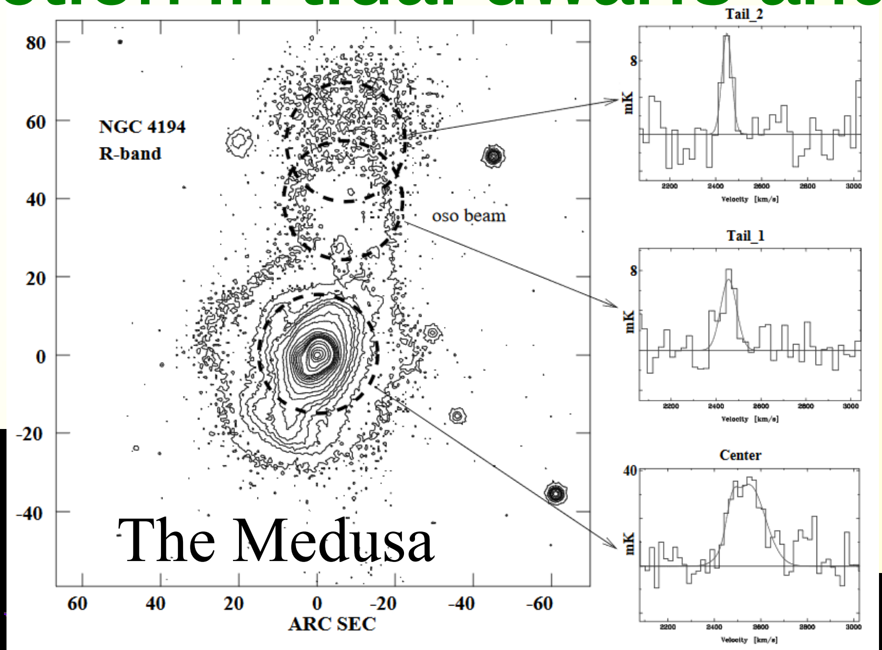
Time-scale for cooling << 1Myr
At kpc scales, ➔SF induced

Mrk 231 Outflow 700Mo/yr
On kpc scale

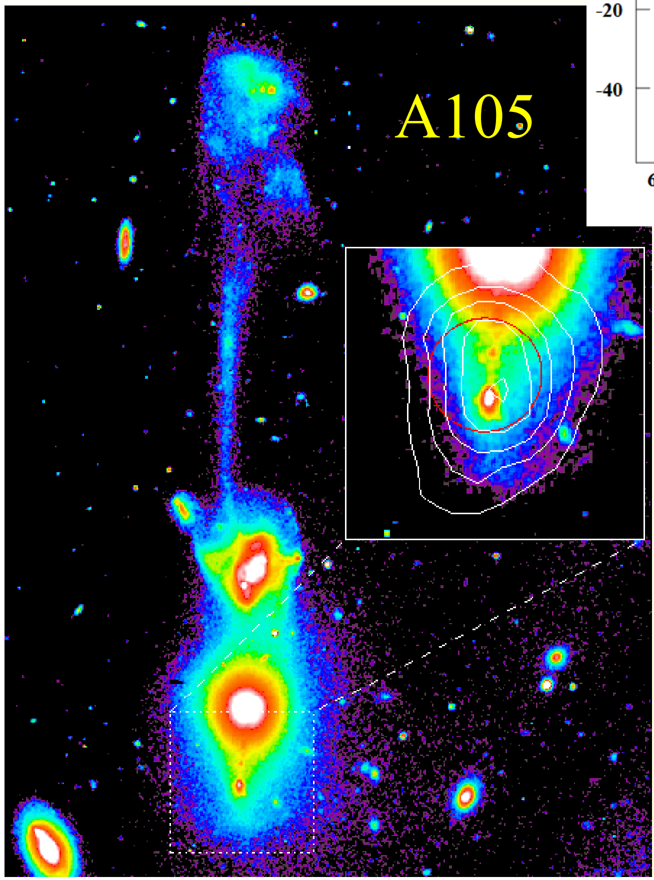
Feruglio et al 2010, 2015

CO detection in tidal dwarfs and tails

Time-scales of
the tail formation
a few 100 Myr

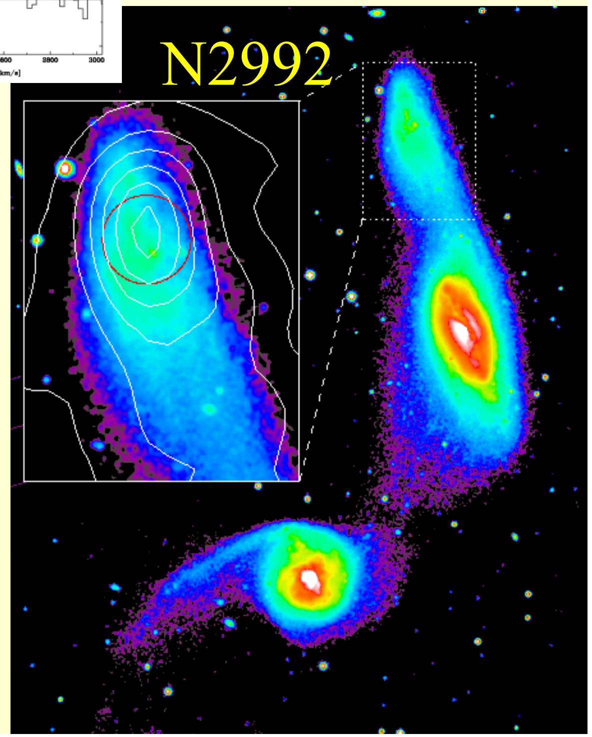


Time-scale of
the bridge
50-100 Myr



Aalto et al 2001

Time to form H_2 clouds
and new stars few 10Myr



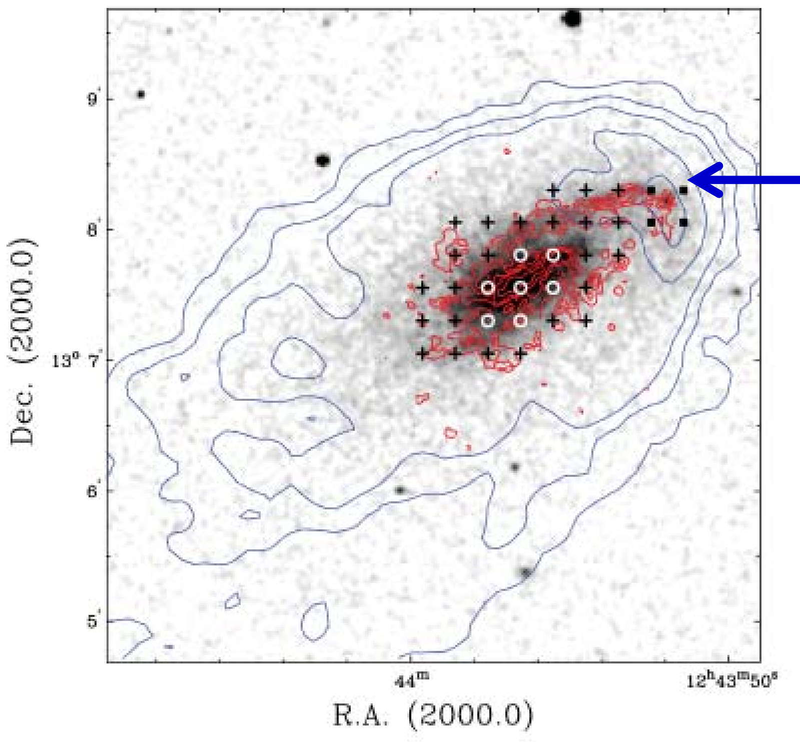
Braine et al 2000

HI to H_2 phase transition

N4654 in Virgo: tidal interaction 500Myr ago, + ram-pressure

Delay in H2 formation? Or problem of projection effect, beams?
Or there exists CO-dark molecular hydrogen (αCO)

HI in blue, CO in red (CARMA)

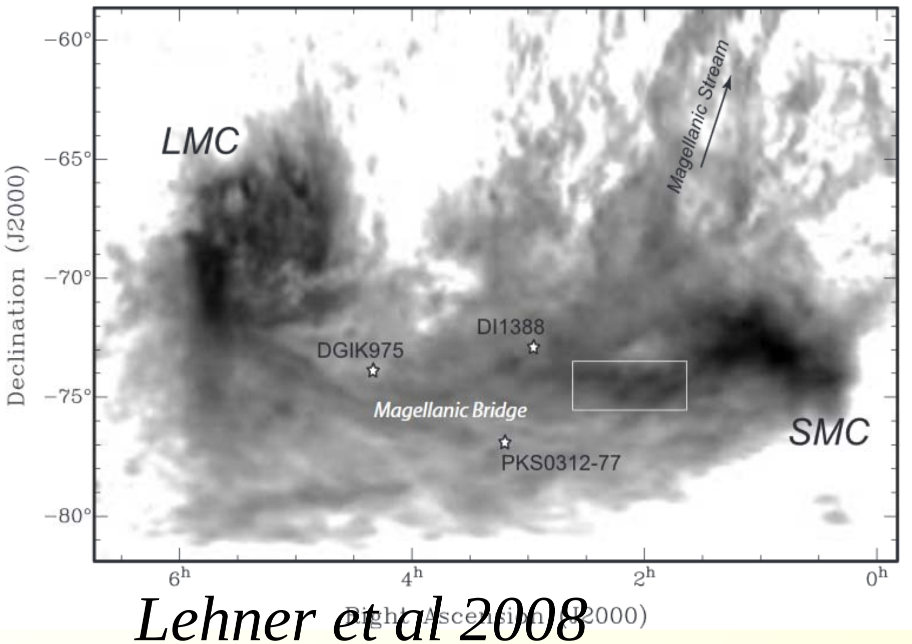


25 Mo/pc² of HI, without H_2,
Low metallicity gas dragged
out towards NW?

High efficiency of star formation

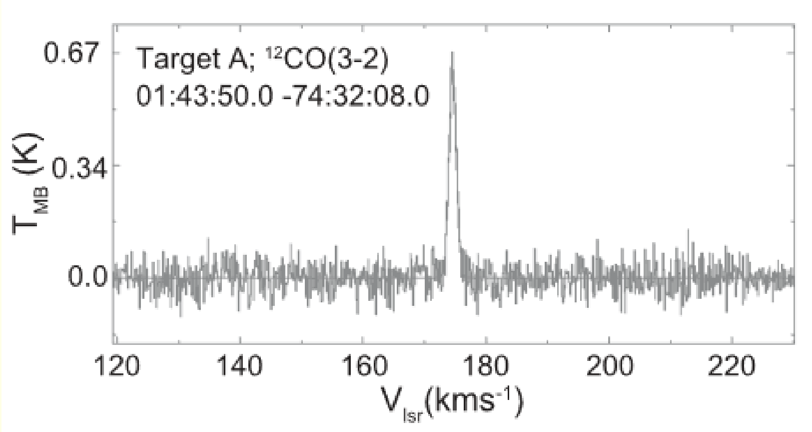
Chung & Kim 2014

Magellanic bridge LMC-SMC



Lehner et al 2008

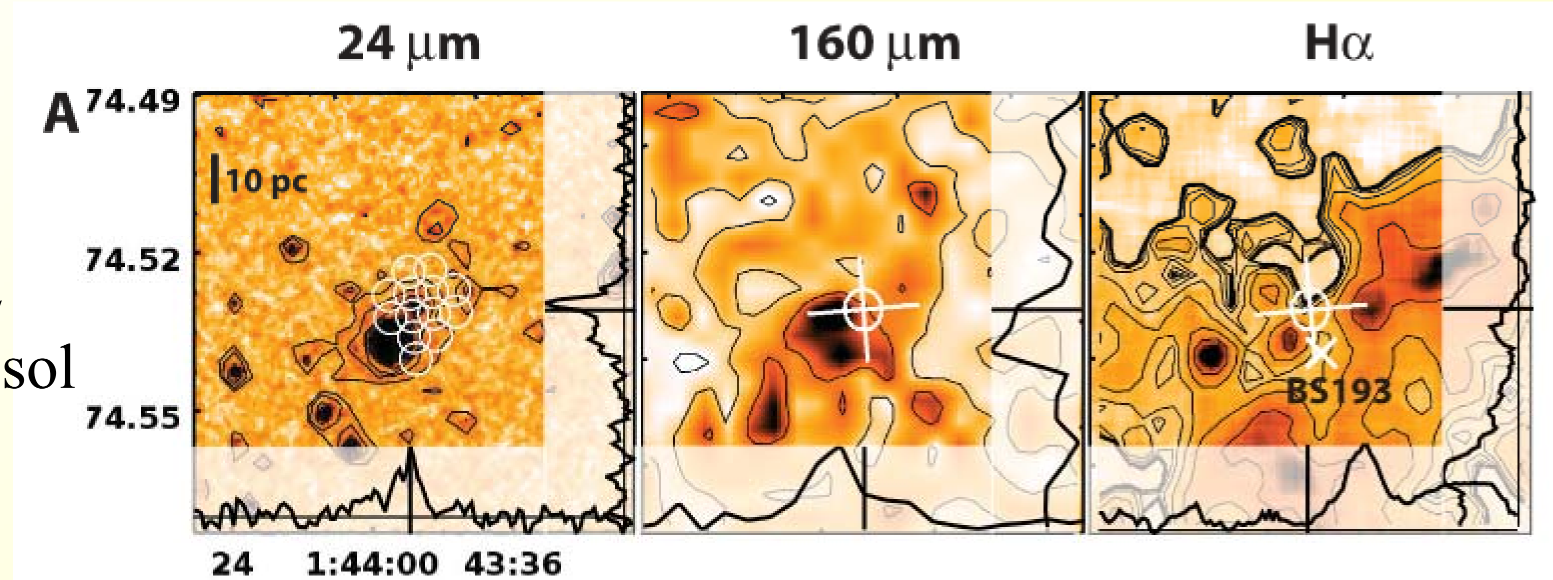
CO32/CO10 high, star formation in the tail: **warm and dense gas**



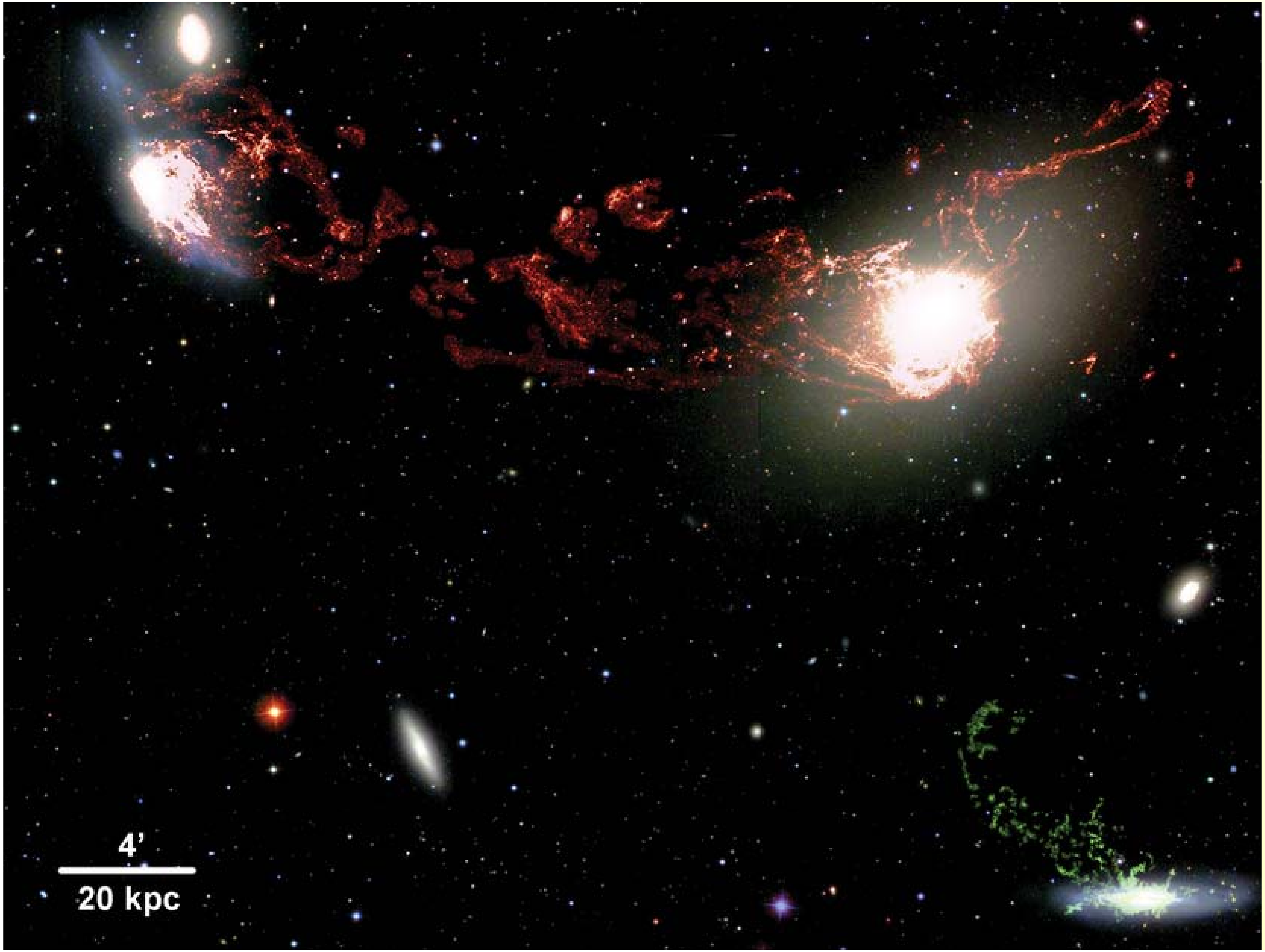
E. Muller et al 2014

ASTE

6pc resol

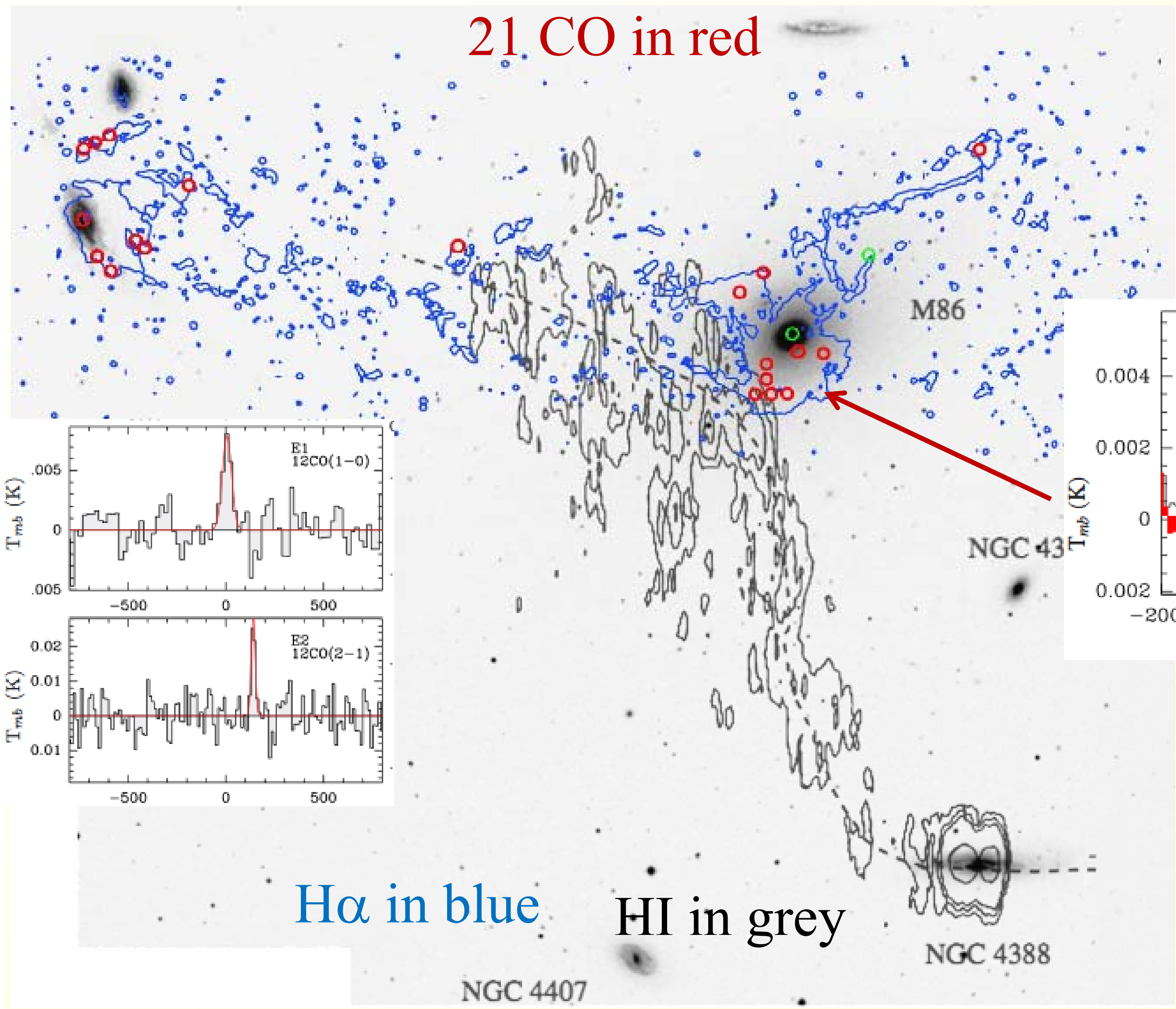


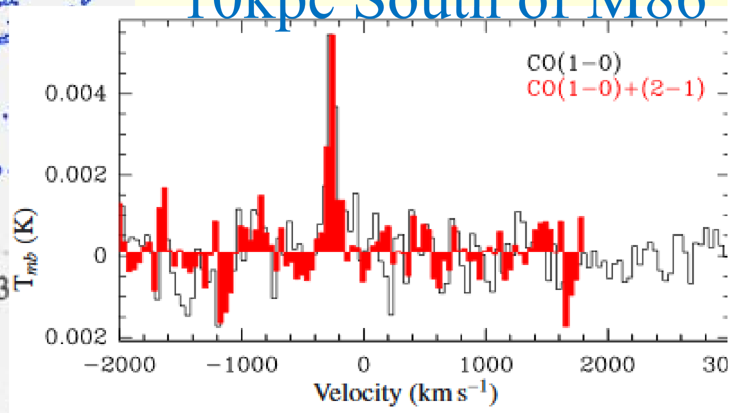
Giant Hα tail in Virgo



Kenney+ 2008

Tail around M86 : H2 gas in hostile environment





10^7K ICM
Survival during
100 Myr?

MH_2 =2 10^7Mo
10kpc South of M86

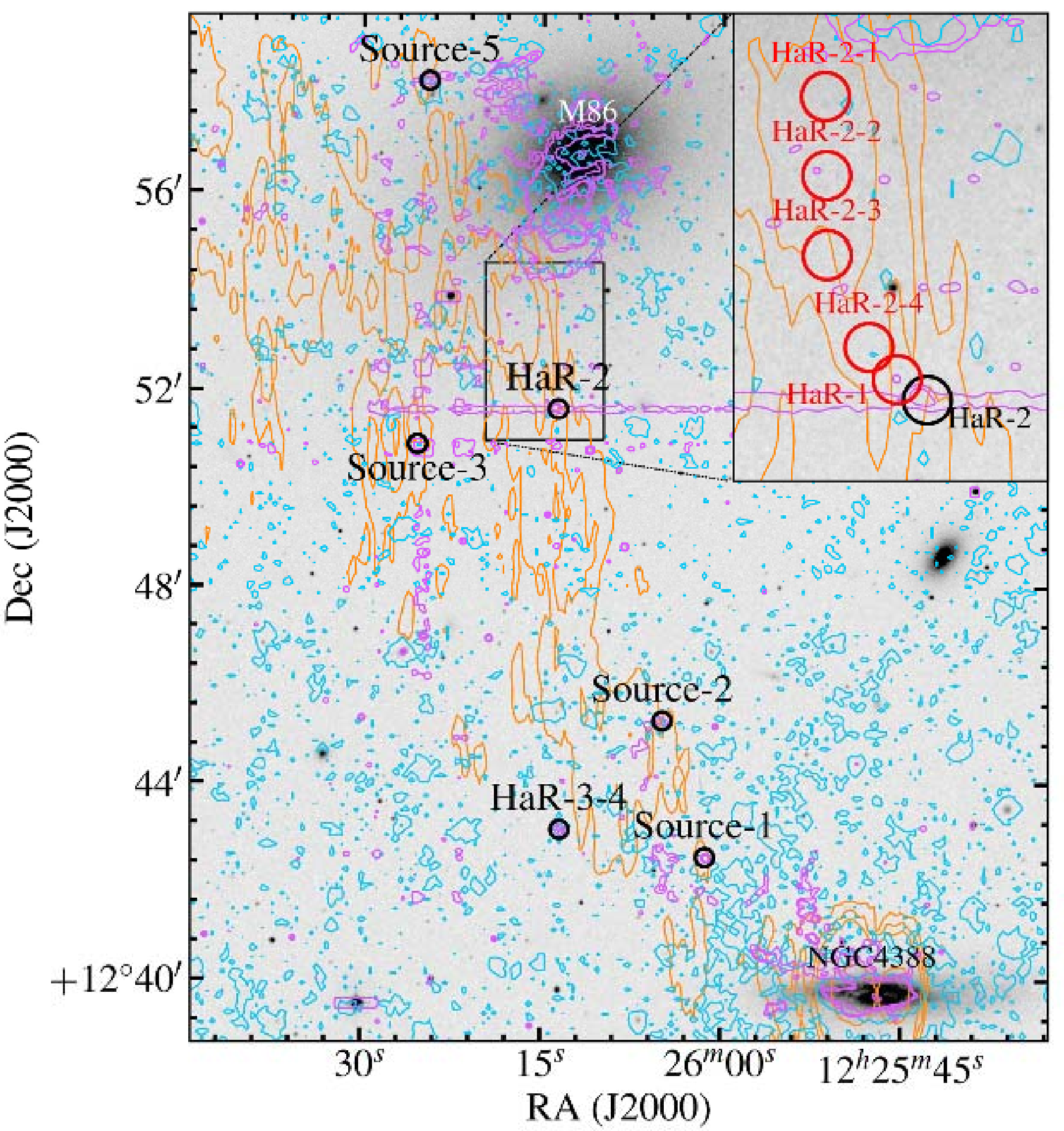
MH_2 =7 10^6Mo
10kpc NE M86

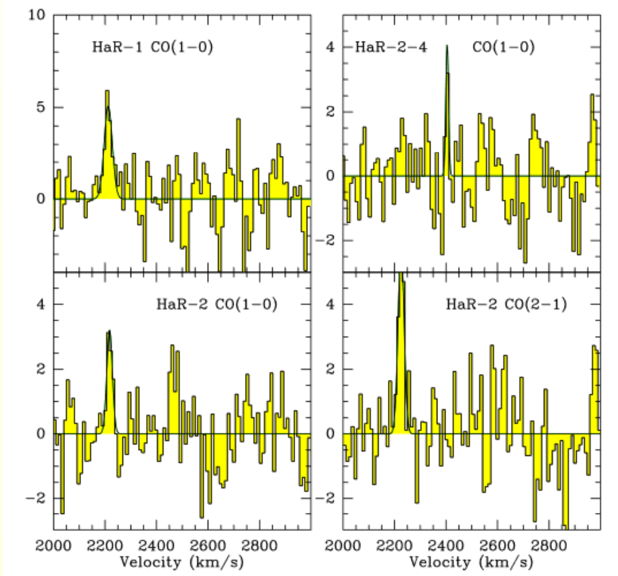
In situ formation
Or tail from N4438

Dasyra et al 2012

Tidal tail N4388 – M86

At 100kpc distance, 2 10^6Mo of H_2



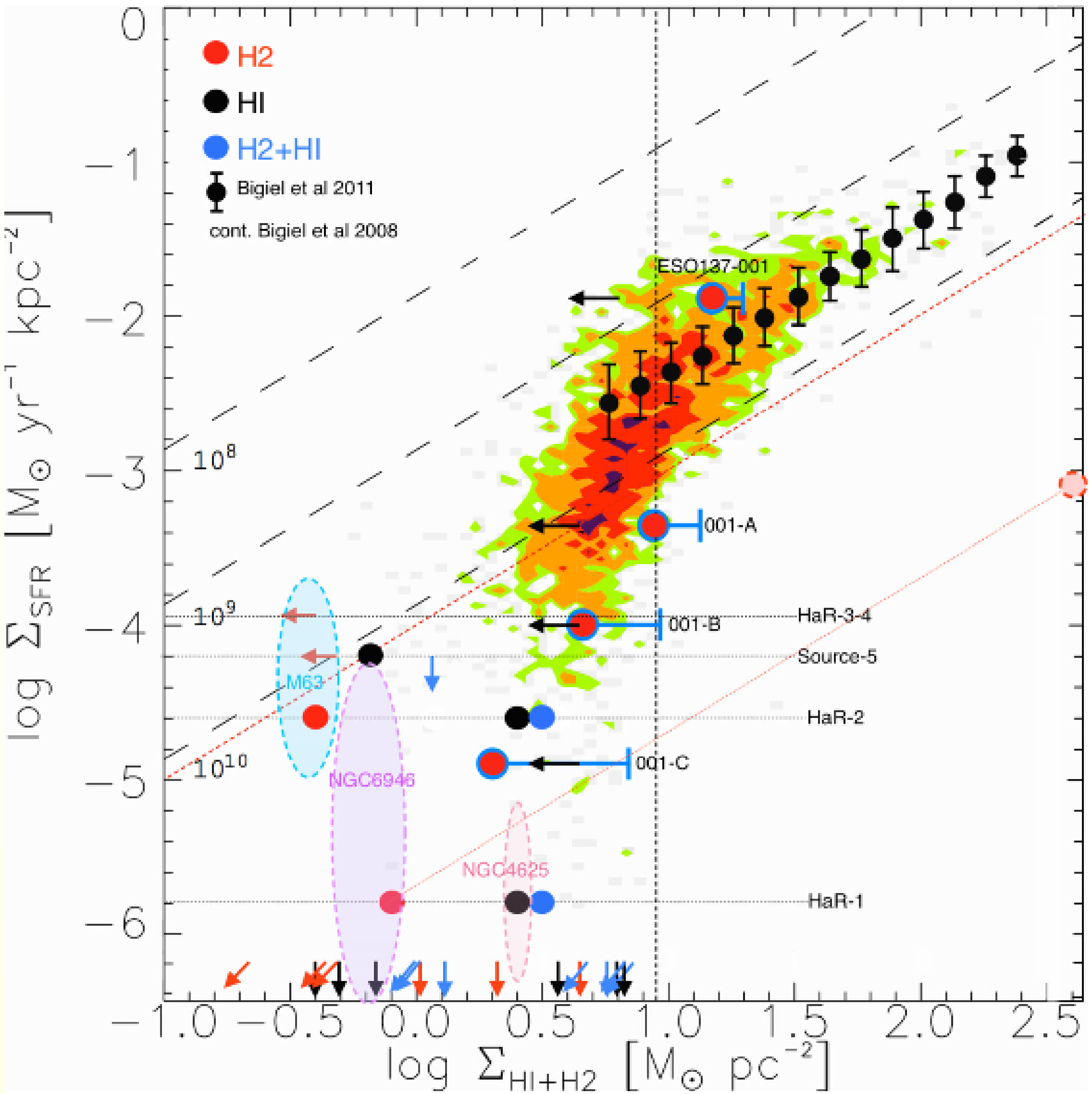


➔Formation in situ of H_2
Star formation enrich the ICM
Low SFE, tdep ~500Gyr

Verdugo et al 2015

Star formation efficiency

Comparison with XUV disks



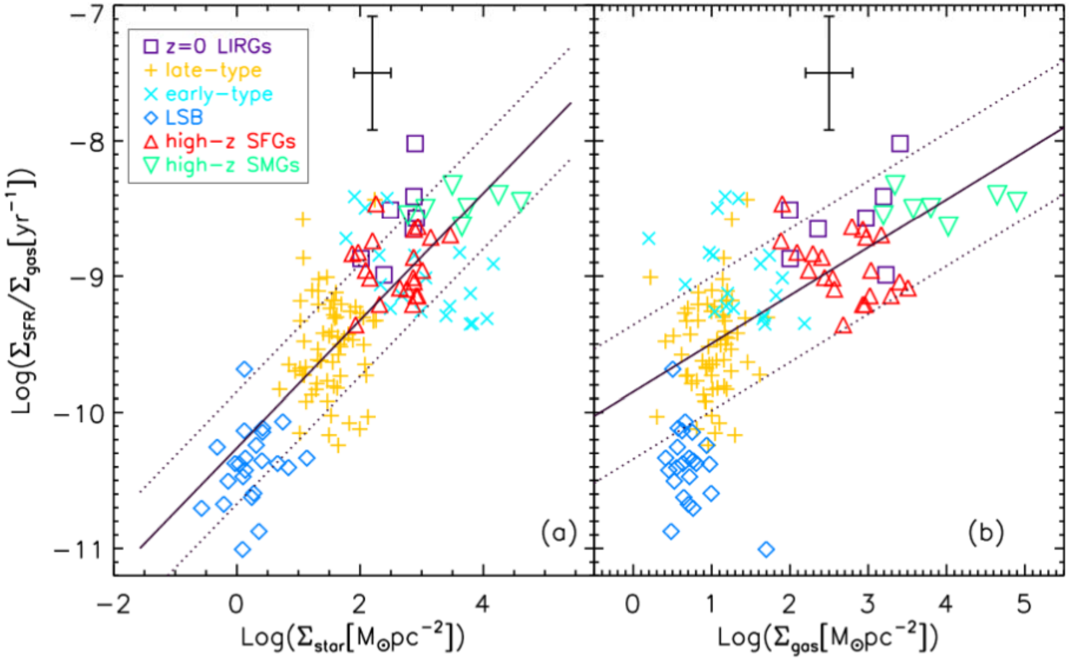
Gas in tails, and far from disks have not enough pressure from stars

And the gas surface density is not enough for fast HI to H_2 transition

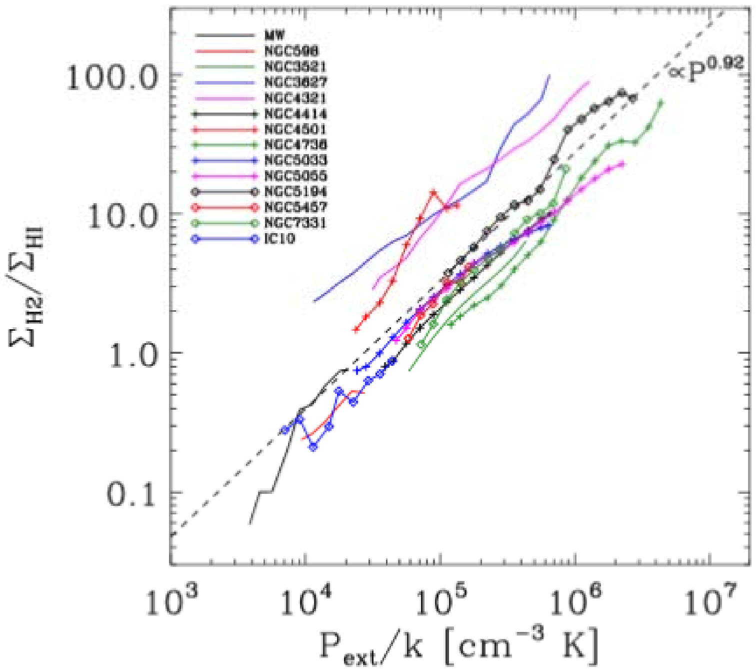
Verdugo et al 2015

Importance of pressure

The surface density of stars
is very important for
the SF effeiciency



Shi, Helou et al 2011



The HI to H_2 transituon
is favored by external pressure

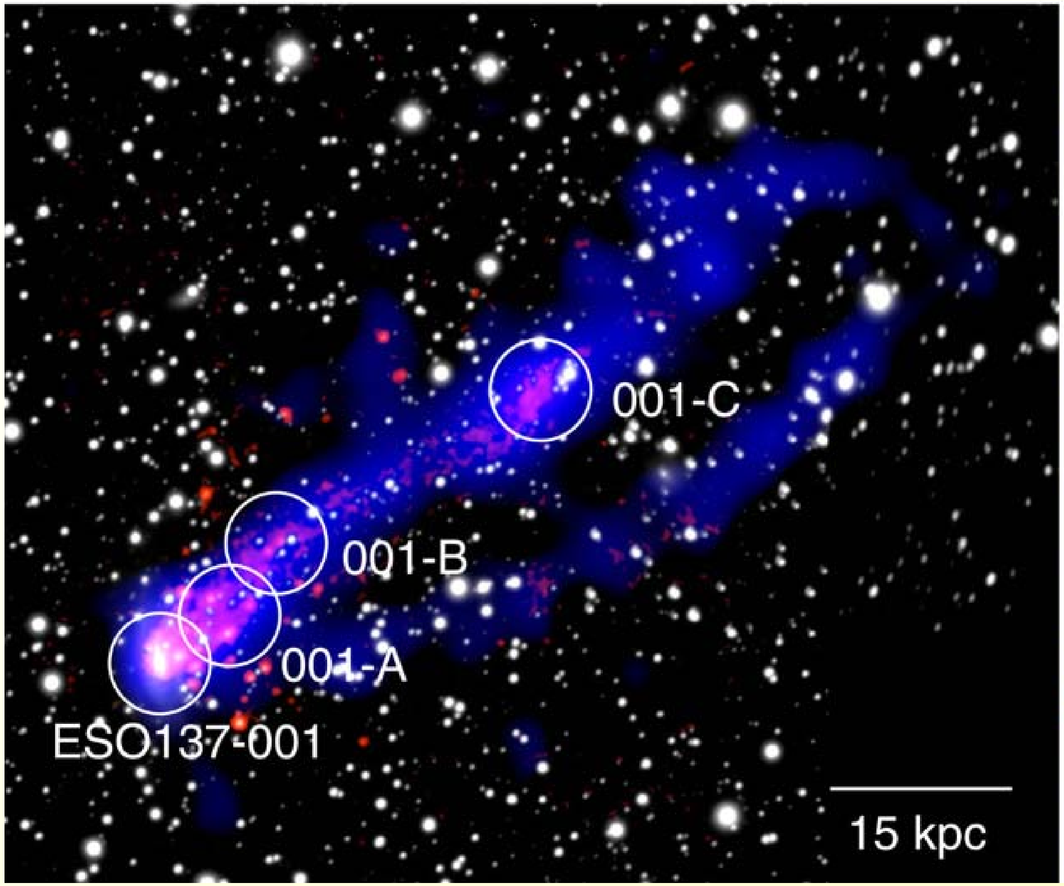
Blitz & Rosolowsky 2006

Environmental quenching

Ram pressure in clusters: **in general slow**:

In Virgo, HI deficient, but not H_2 (Kenney & Young 1989)

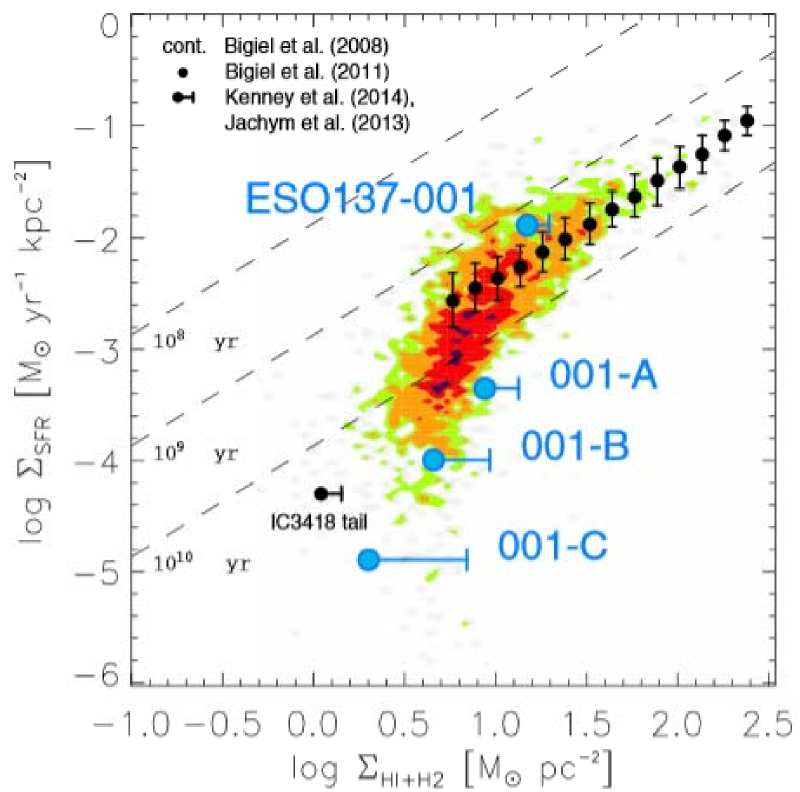
but **can be fast** in exceptional cases: ESO137-001

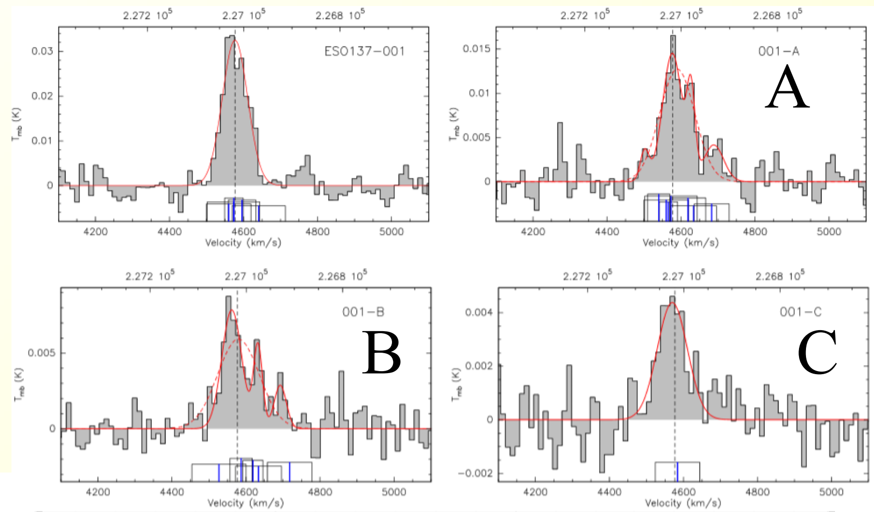


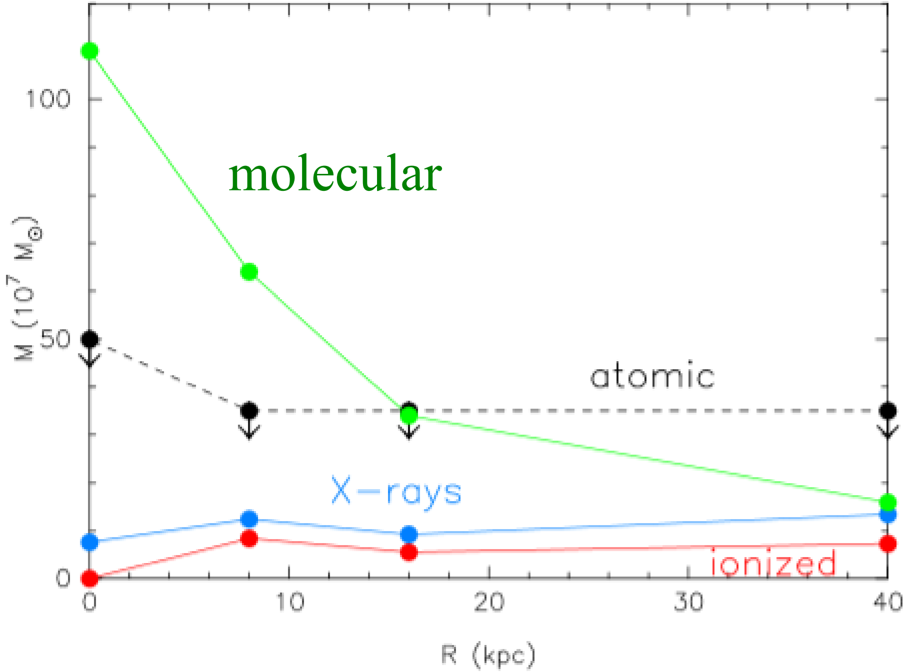
Jachym et al 2014

Norma cluster

Ram-pressure quenching



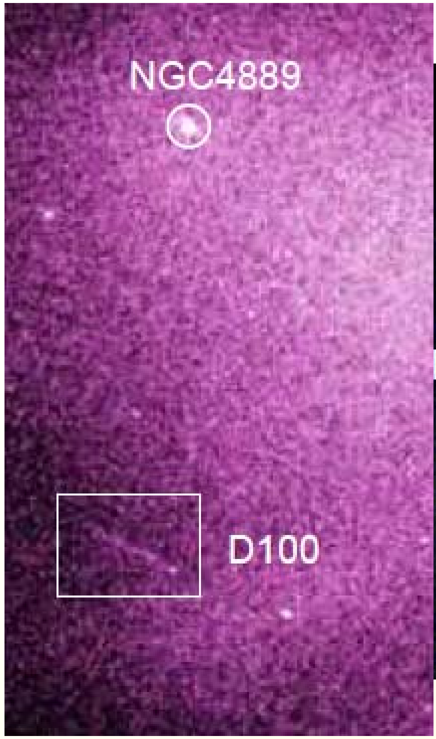


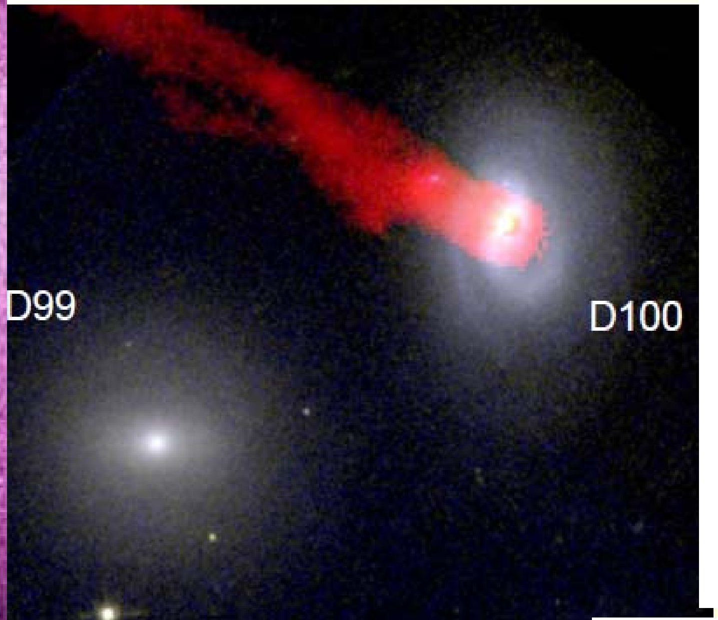


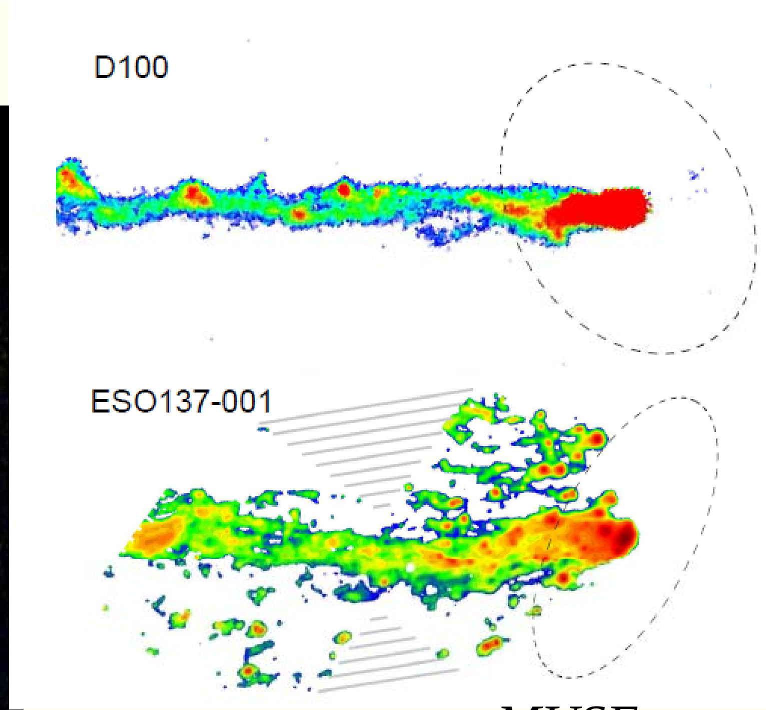
Tail of 80kpc in X-ray gas,
40kpc in CO
$M(H_2)$ in C =1.5 10^8Mo

Jachym et al 2014

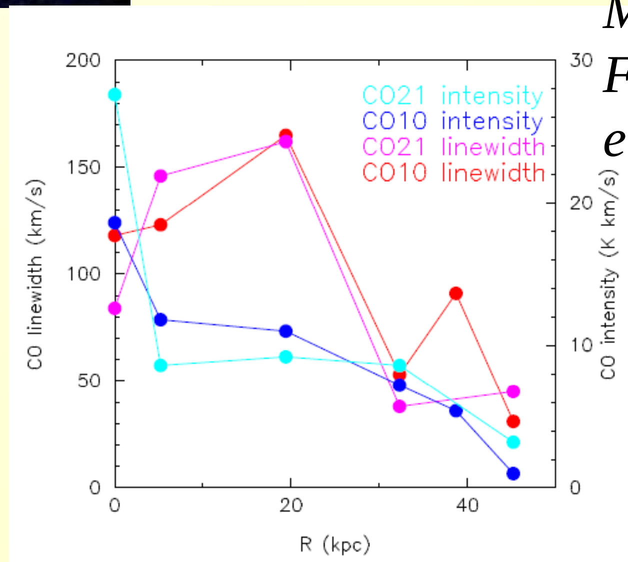
Ram-pressure in Coma







MUSE Fumagalli et al 2014



D100 tail: thinner
Last stage of stripping
CO detected along, until 45kpc

Jachym et al 2016

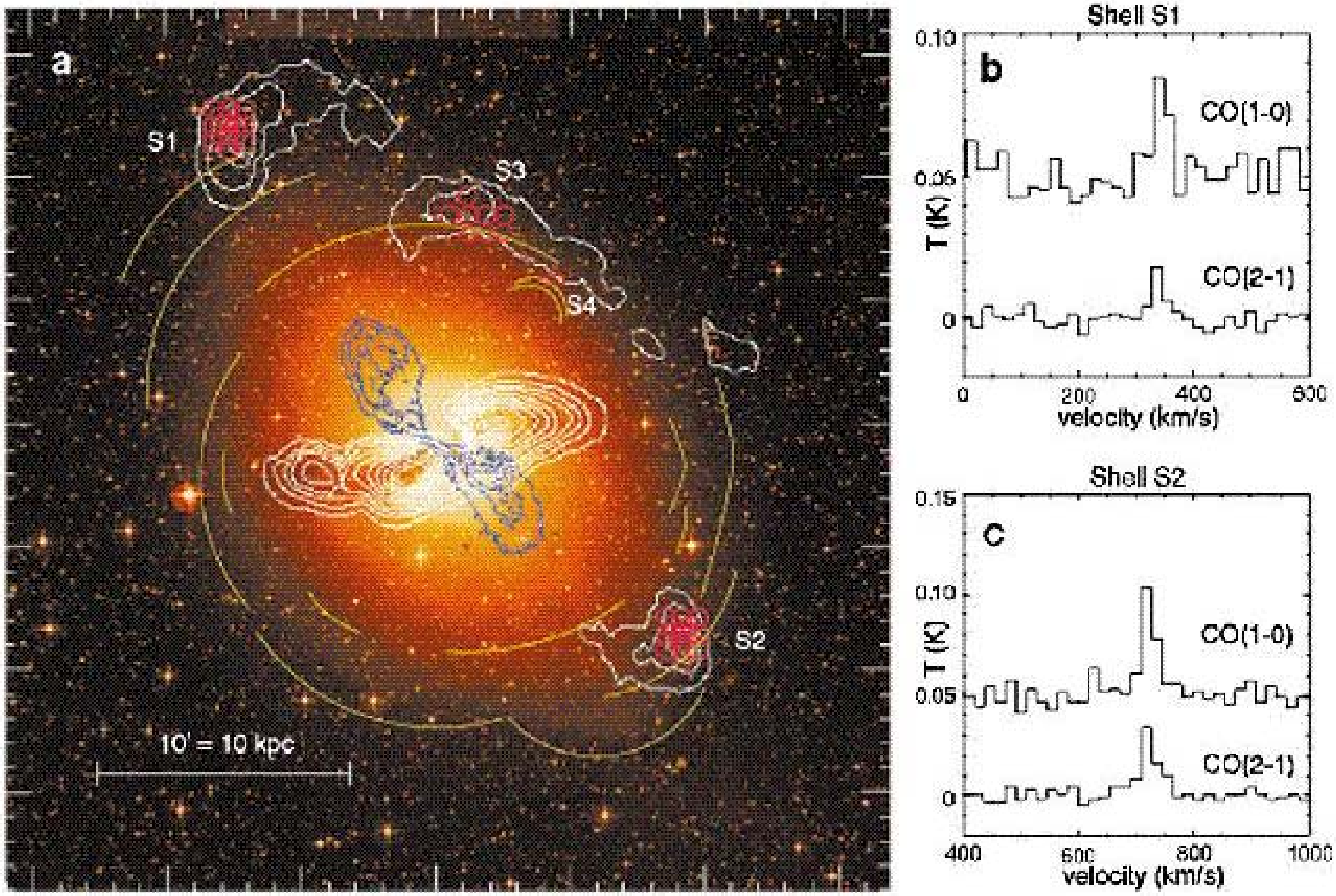
Molecular gas in shells

Yellow: stellar shells

White: HI

Blue: Radio jets

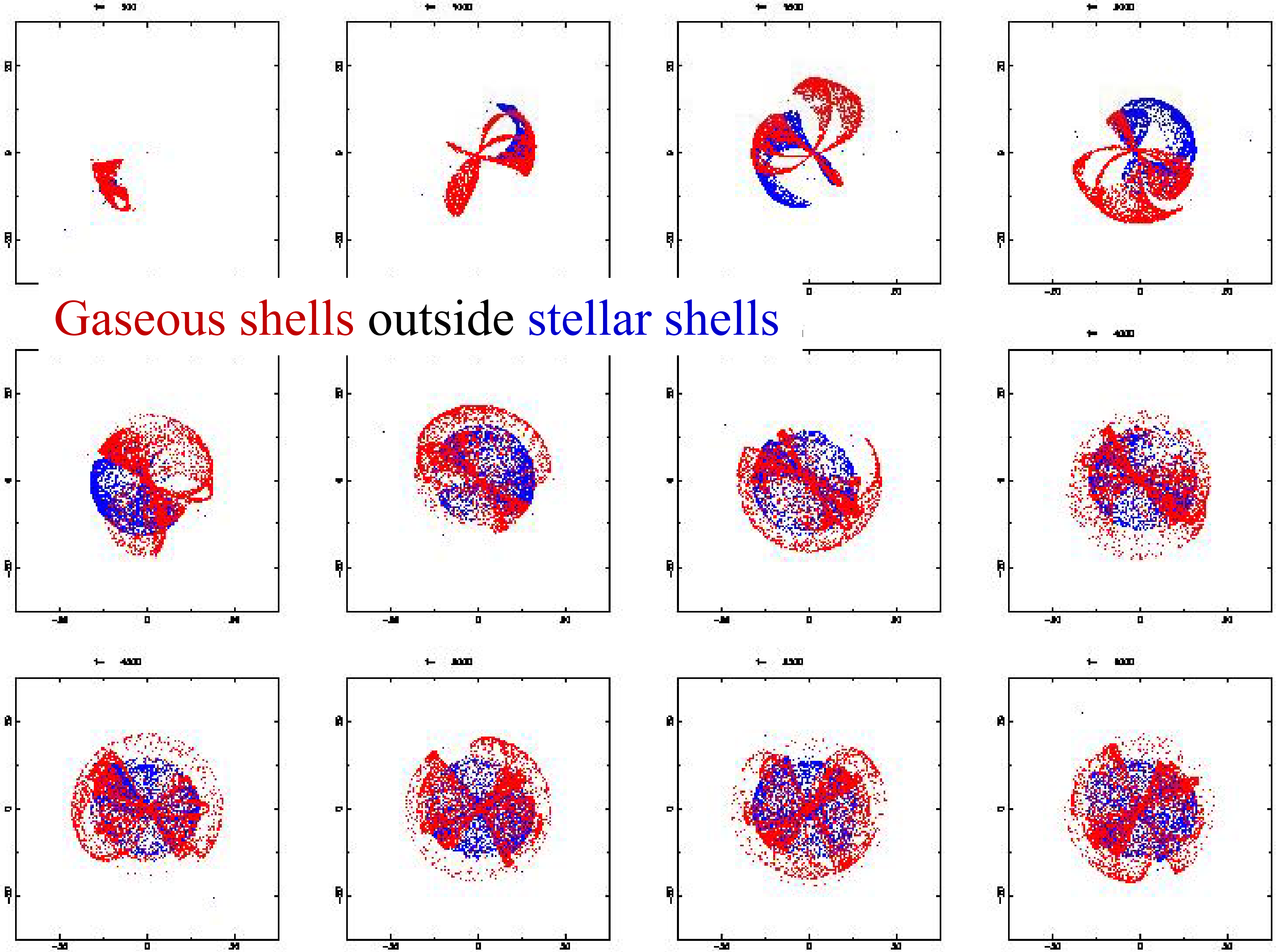
Red CO obs



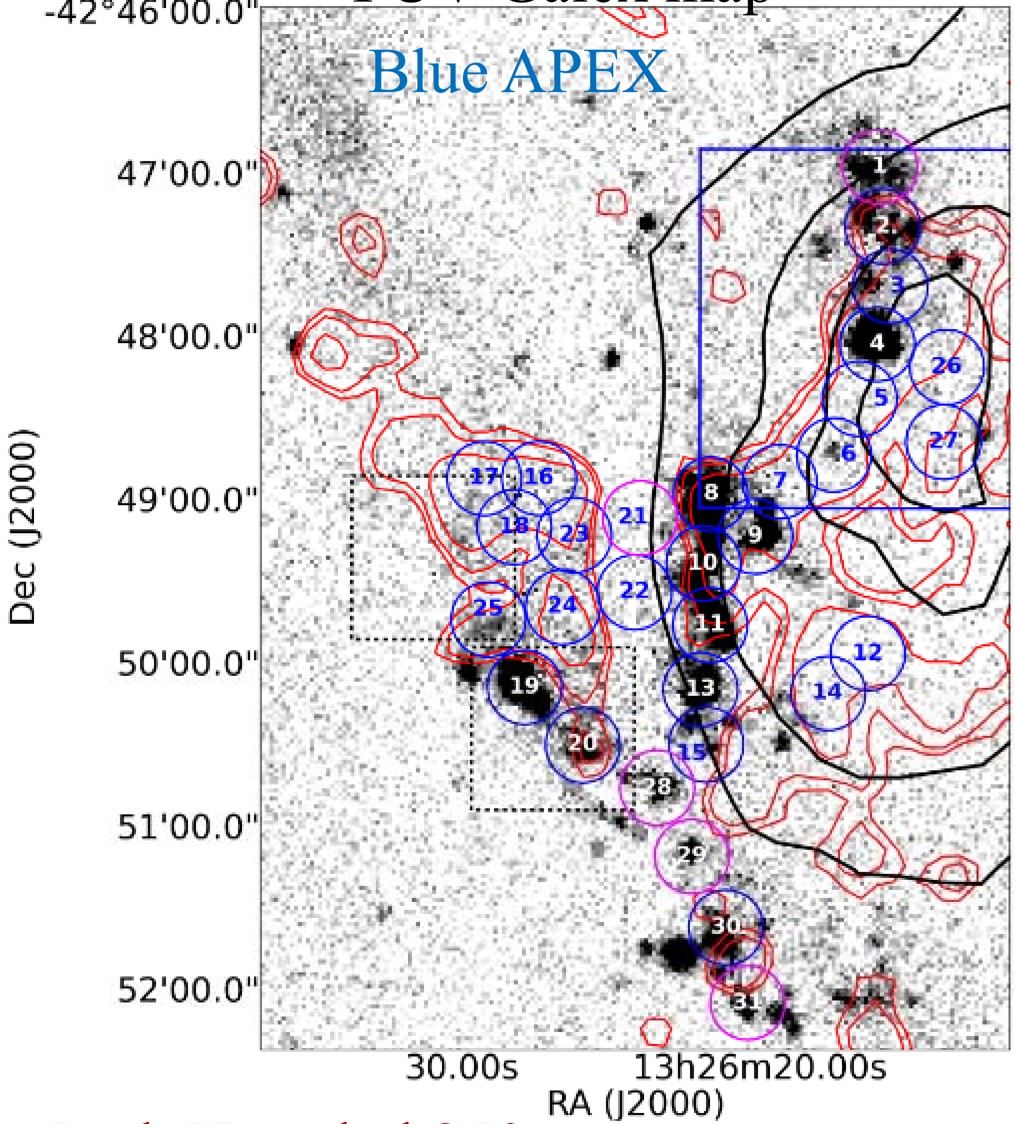
Charmandaris et al 2000

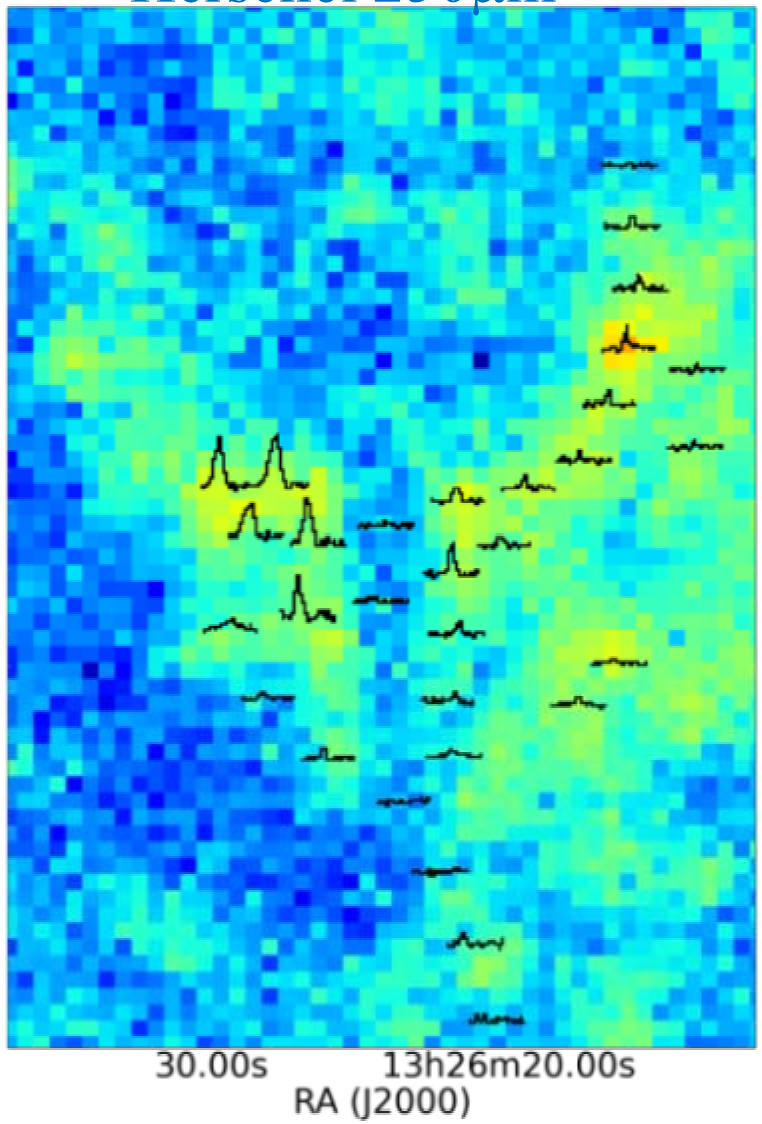
Gas is less bound, and stripped earlier in the interaction than stars

➔ Suffers less dynamical friction.



HI, ionized and H_2 gas in the shell





Red: Herschel 250μm

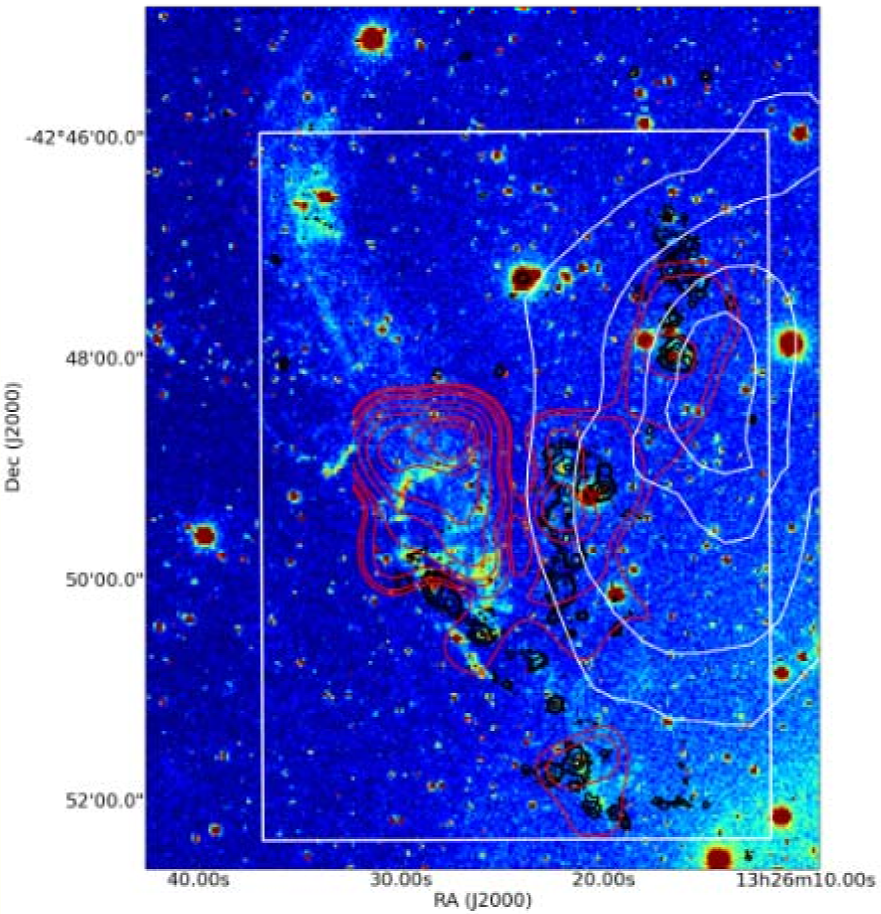
Salome et al 2016

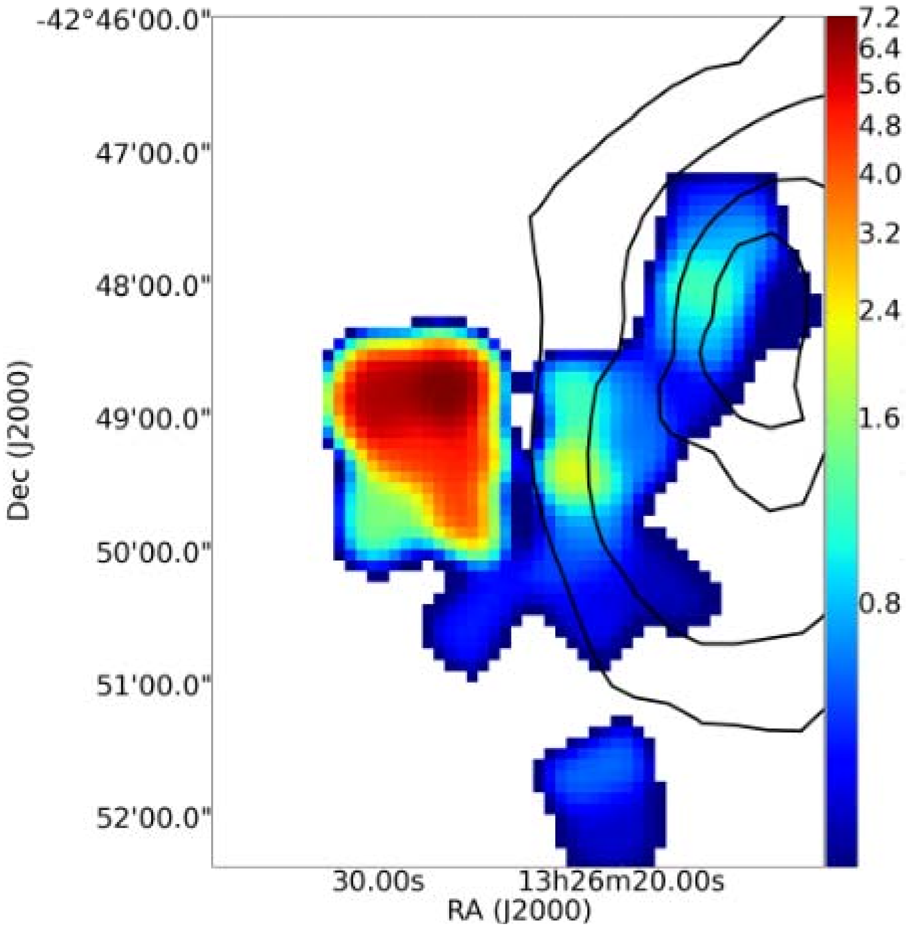
Molecular gas in the shell

H_2 dominant at E, while HI at W

Hα map

Salome et al 2016

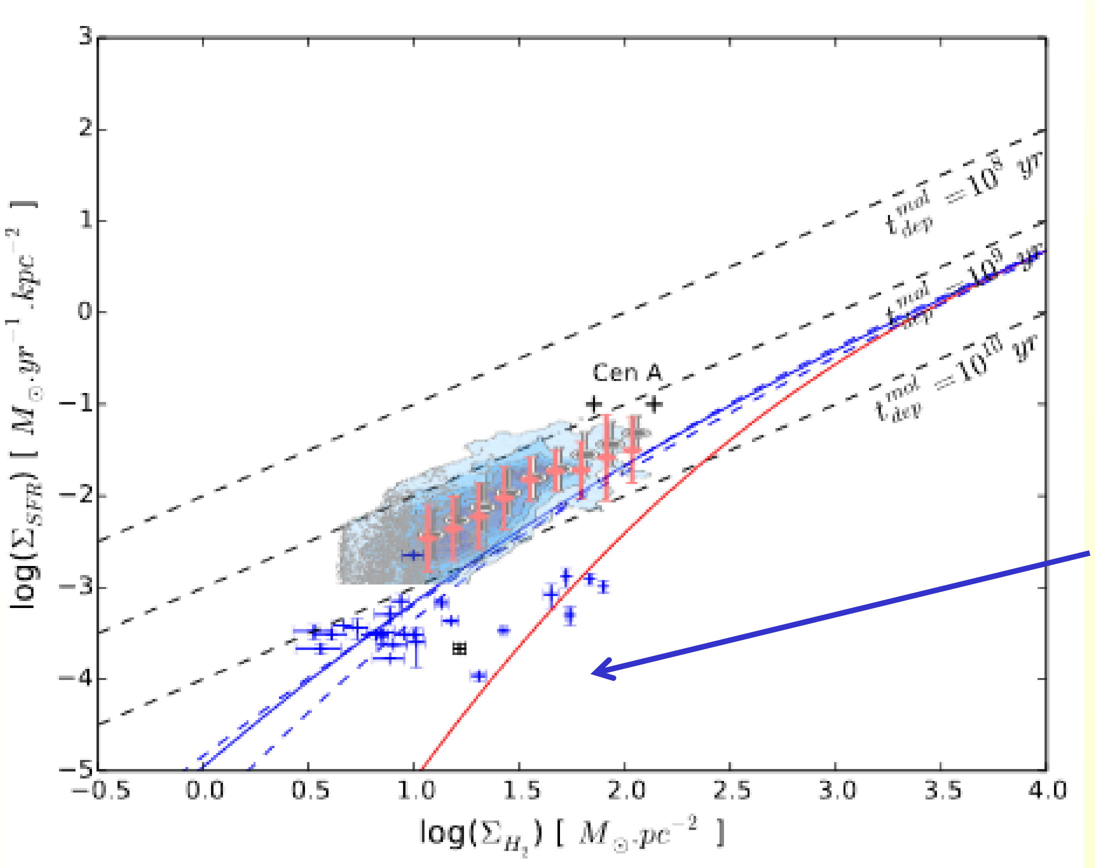




Red: CO, White: HI, **FUV-Galex: black** CO21, HI contours

Star formation triggering

The radio jet effectively triggers star formation in the shell along the jet ➔ positive AGN feedback



However, the SF efficiency is lower than in disks

➔Not enough pressure

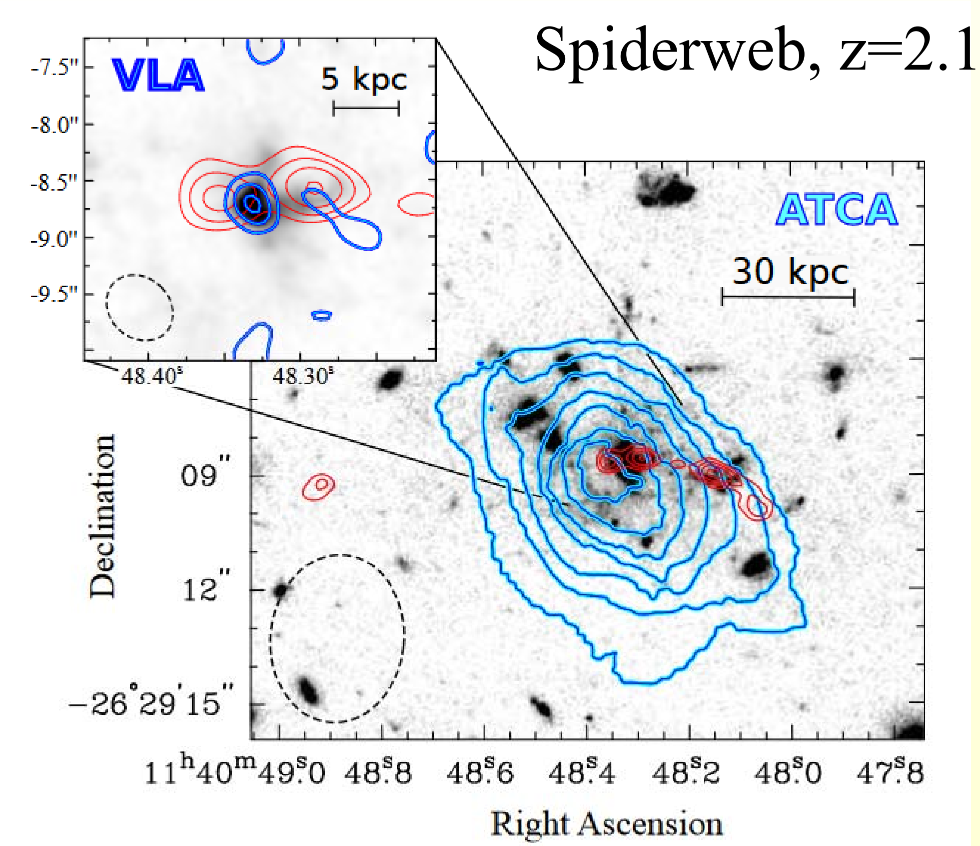
➔Tdep larger than a Hubble time

Salome et al 2016

High-z CO extensions

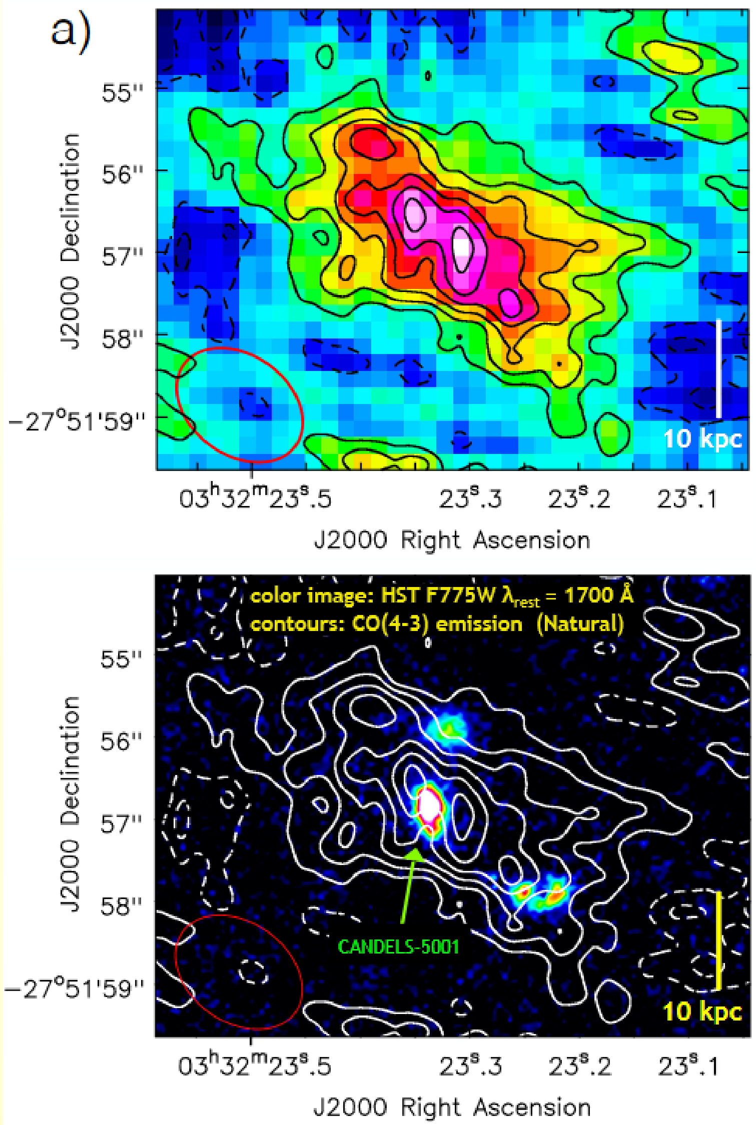
Even more easy at high z?
Denser gas?

Spiderweb, z=2.1



Emonts et al 2016

z=3.47



Ginolfi et al 2016

Conclusions

Molecular gas detected in the tails, either tidal or ram-pressure

For tides: metallicity problems
For ram-pressure: survival of molecular clouds, in 10^7K ICM?
(but see also cooling flows, e.g. Perseus)

Star formation in tails also, clumpy molecular gas

HI to H_2 phase transition: either spontaneous (instabilities)
Or triggered by AGN

High-z cases, Lyα blobs, Cluster BCG

A lot to do with ALMA

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Ram pressure stripping and galaxy evolution

SOC: Pavel Jachym, Elke Roediger, Ming Sun, Jeff Kenney et al.