

# Highlight: ALMA/MUSE

Françoise Combes  
Observatoire de Paris

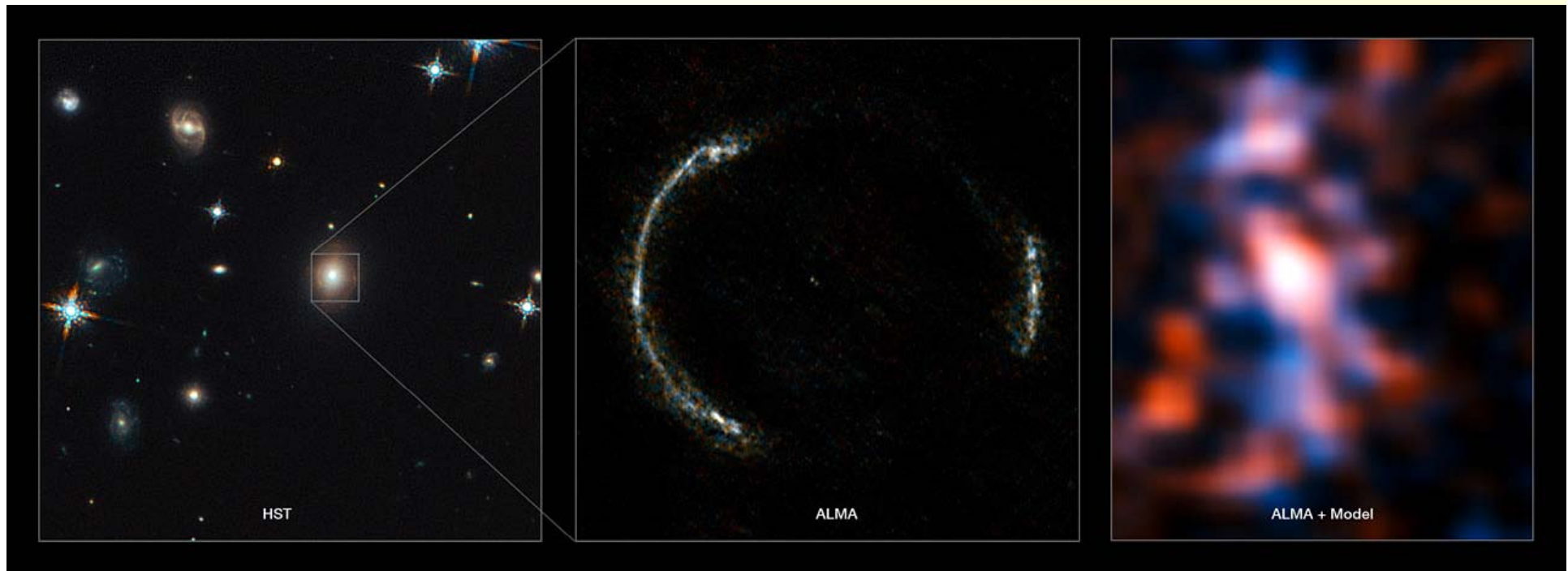
24 November 2016

# SDP.81, at $z=3.042$



Large Baselines → 30mas resolution

Corresponds to 50-100pc on the  $z=3$  galaxy (gain x 3-4 due to lensing)



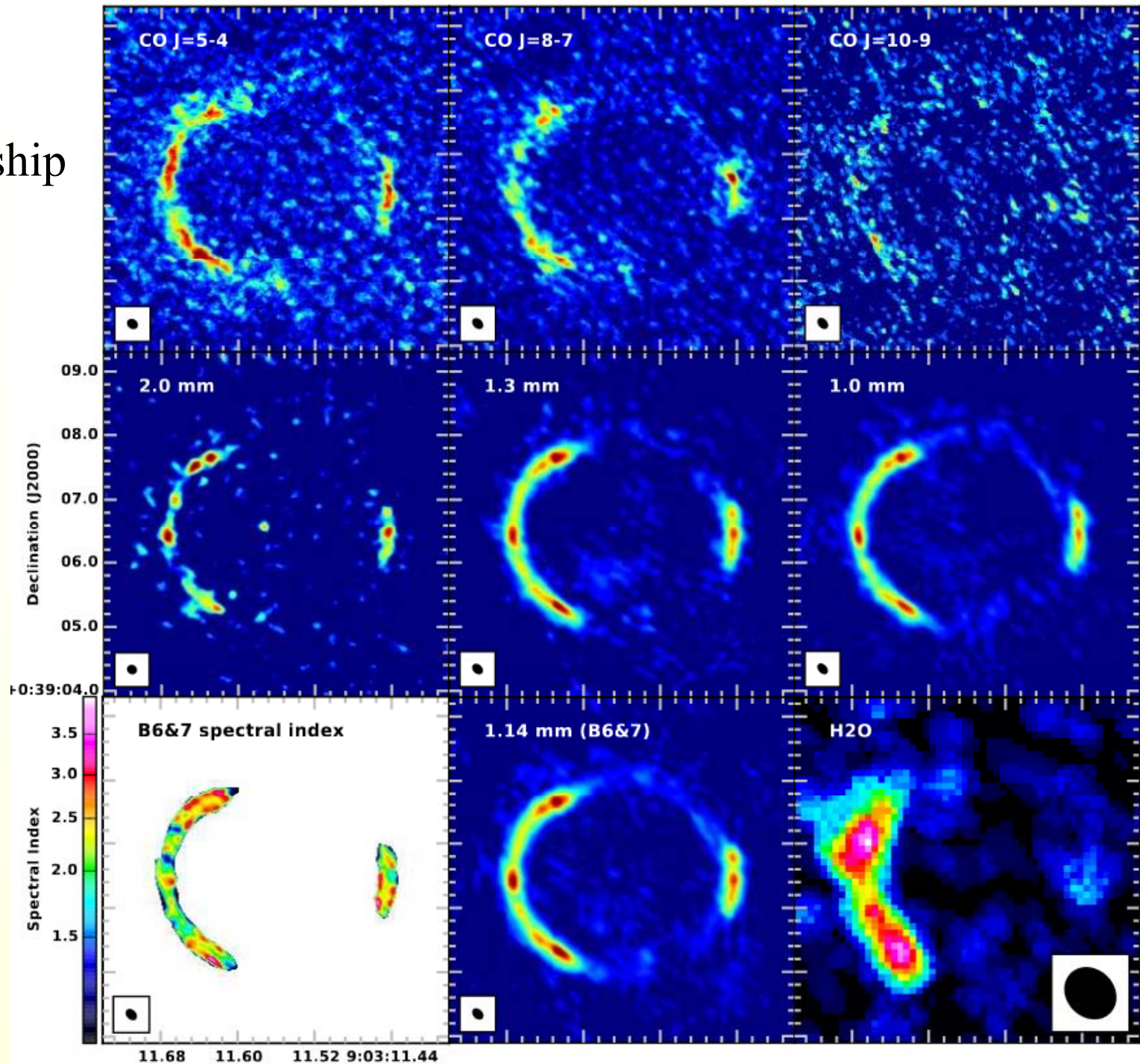
Mass within 1.5kpc,  $3 \times 10^{10}$  Mo, almost entirely gas!

5 different groups have published on this object! >12 papers

*Mol clumps Hatsukade et al 2015, dark structures Hezaveh et al<sup>2</sup> 2016*



ALMA  
Partnership  
2015

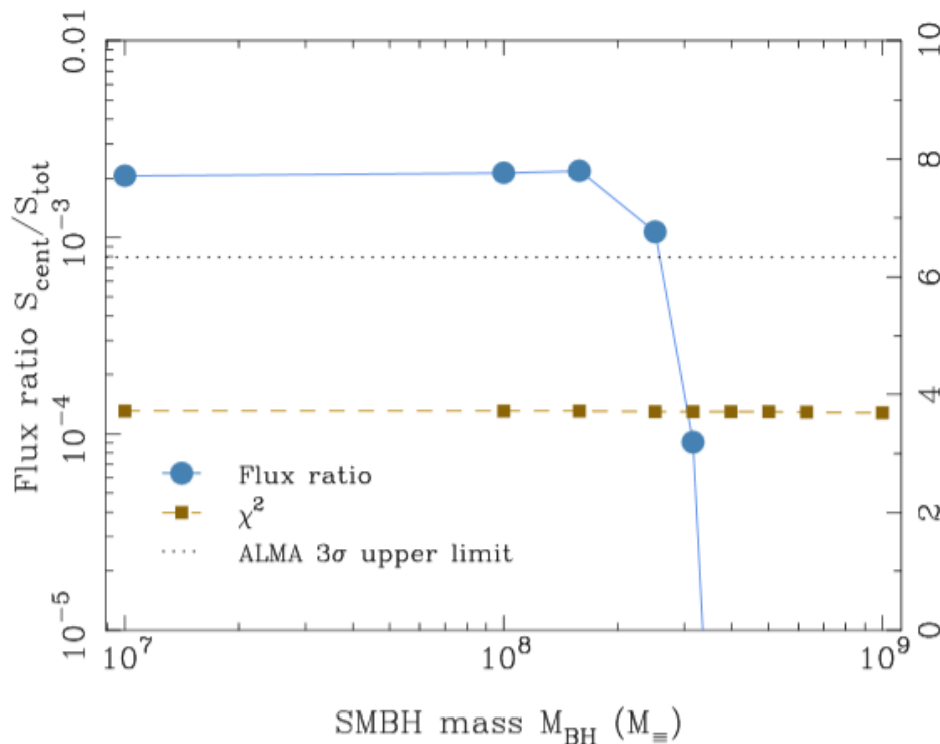


# Black hole in the lens (z=0.3)?

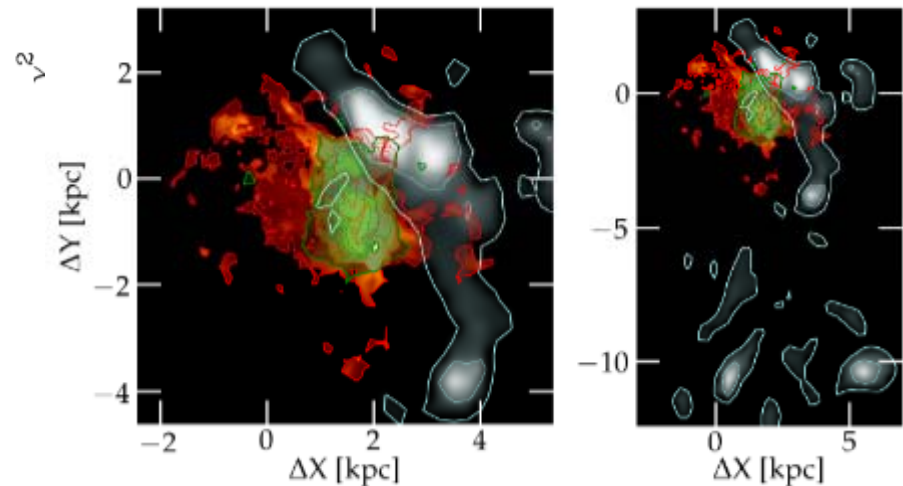
The remote galaxy is composed of tens of <100pc SF clumps, in a 2kpc disk

Ratio between the central image, and the others  $S_{\text{cent}}/S_{\text{tot}}$

**MBH >  $3 \cdot 10^8 M_{\odot}$  to suppress the central image of SDP.81**



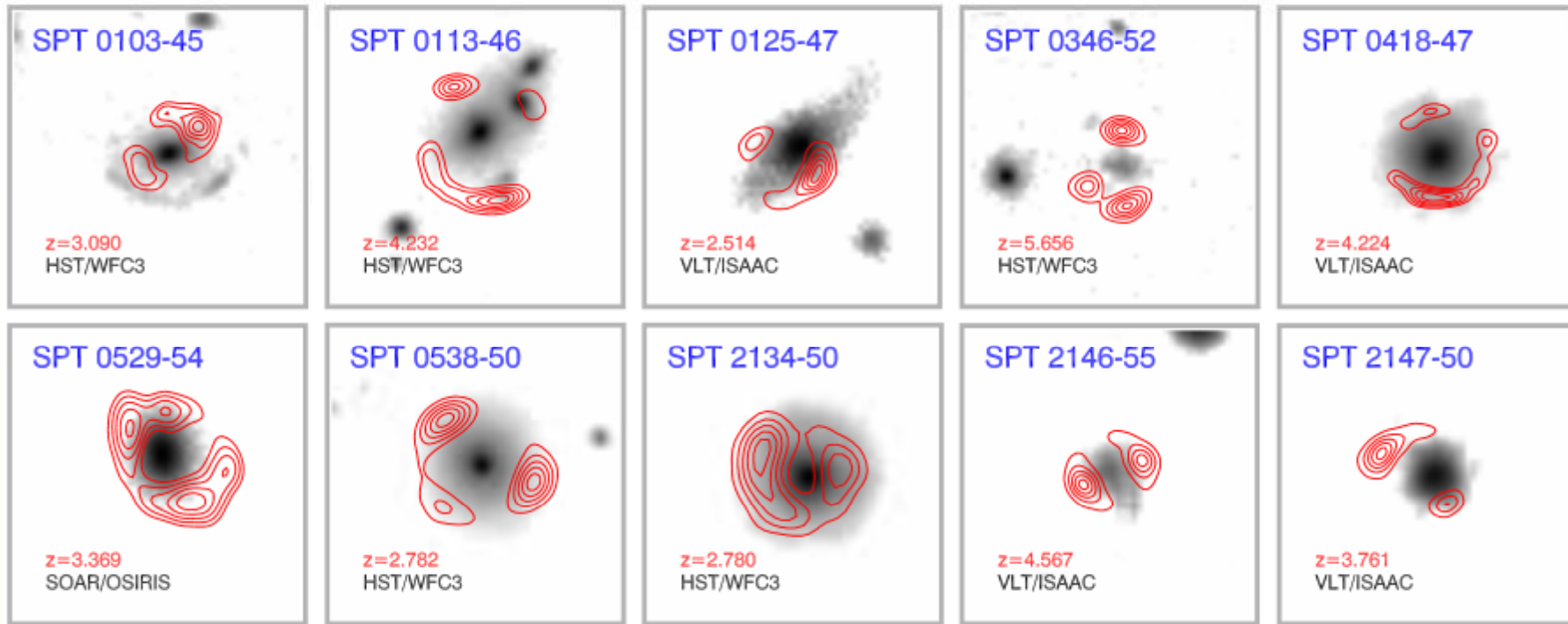
CO, Dust, UV



*Tamura et al 2015*

*Rybak et al 2015*

# ALMA high-z searches



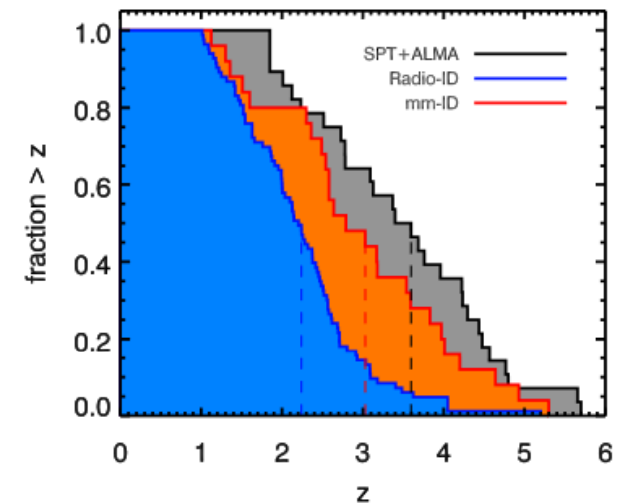
Grey-scale NIR from HST, VLT, SOAR

*Vieira et al 2013 (23/26 detected)*

*10  $z > 4$*

Red=ALMA 870  $\mu\text{m}$  contours, 2min, 0.5''

ALMA-obtained spectro redshift

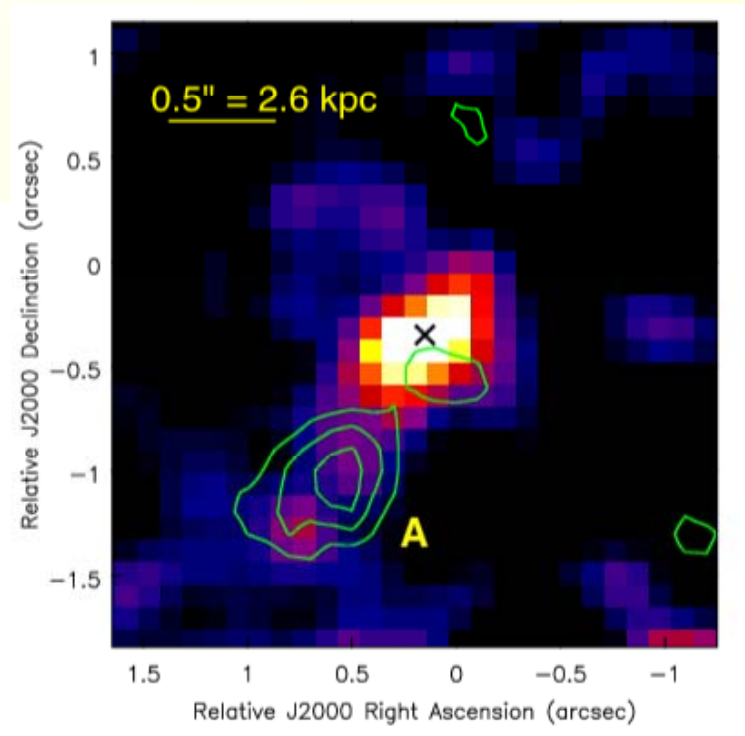
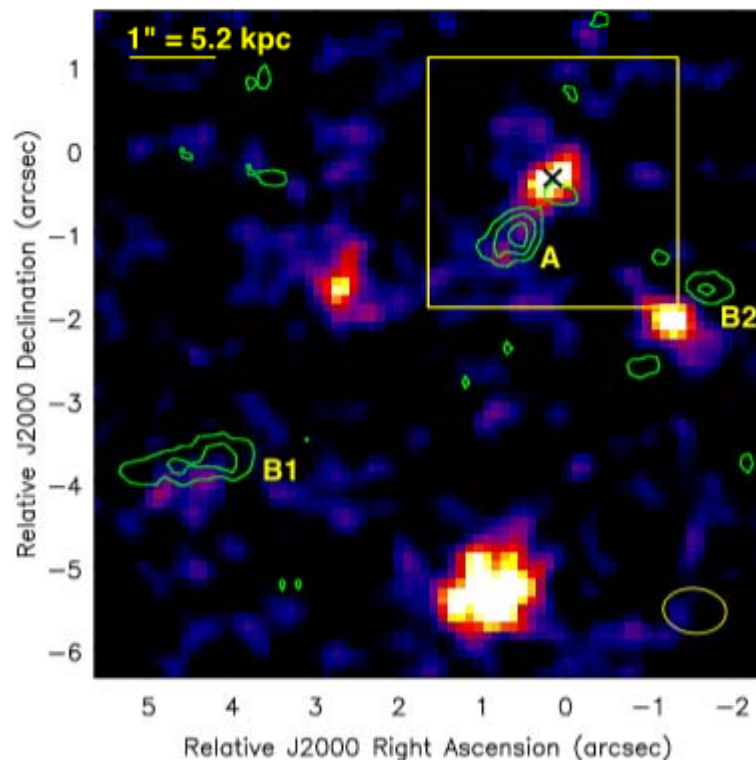


# Galaxies during the EoR

CII line in LBG galaxies at  $z=6.8-7.1$ , with ALMA

SFR = 5-15  $M_{\odot}/\text{yr}$

*Maiolino et al 2015*



CII  
Contours  
Offset from  
the optical  
 $\text{Ly}\alpha/\text{UV}$   
by 4kpc  
Feedback?  
No FIR dust  
Low Z?

*See also Pentericci et al 2016*  
*4 CII detections in the EoR*



# Deep fields: HUDF

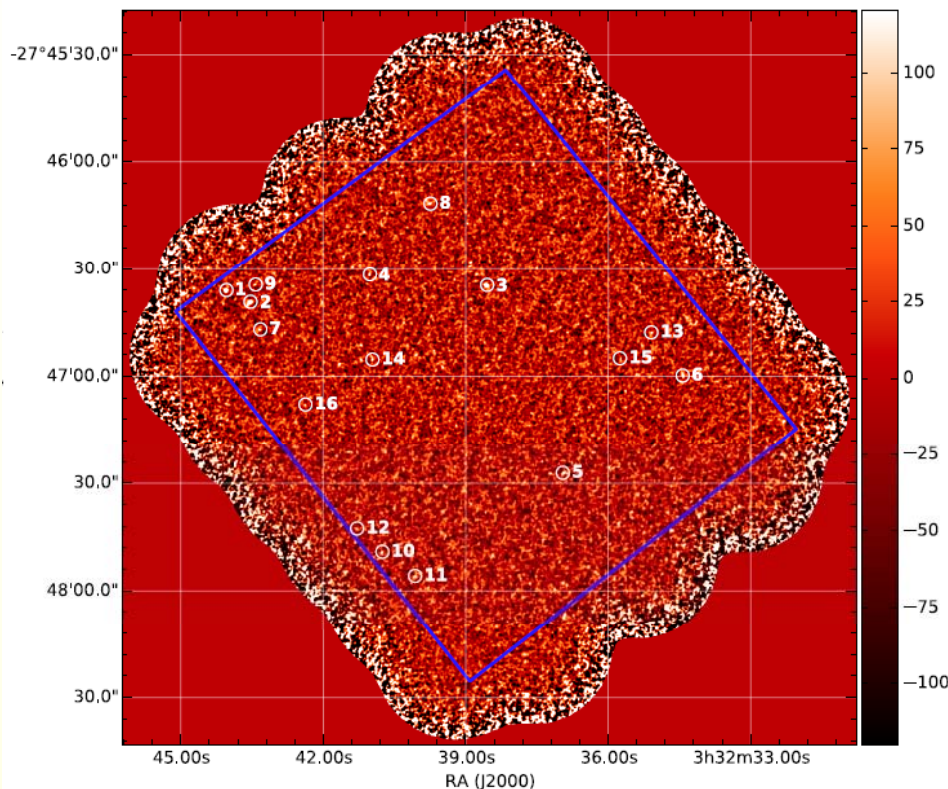
In HUDF 1.3mm, **16 sources detected** (65 expected)  $\langle z \rangle = 2.15$

Only one  $z > 3.5$  The stellar mass is the main criterion  $M^* > 2 \cdot 10^{10} M_{\odot}$

$\sigma \sim 35 \mu\text{Jy}$ ,  $0.7''$  MS:  $\text{SFR} \sim M^*$ ,  $\text{sSFR} = 2.2 \text{Gyr}^{-1}$  SFR (obs/no-obs)=200

*HUDF Dunlop et al 2016*

*Region ~ HUDF (20h)*



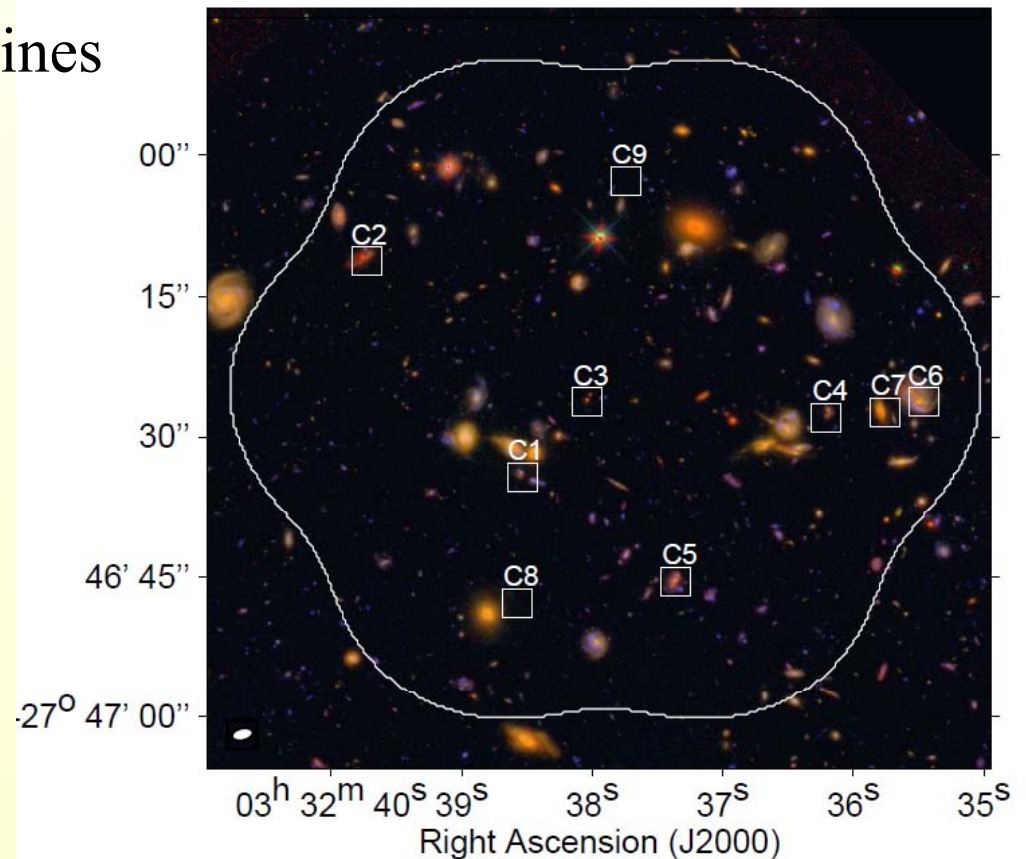
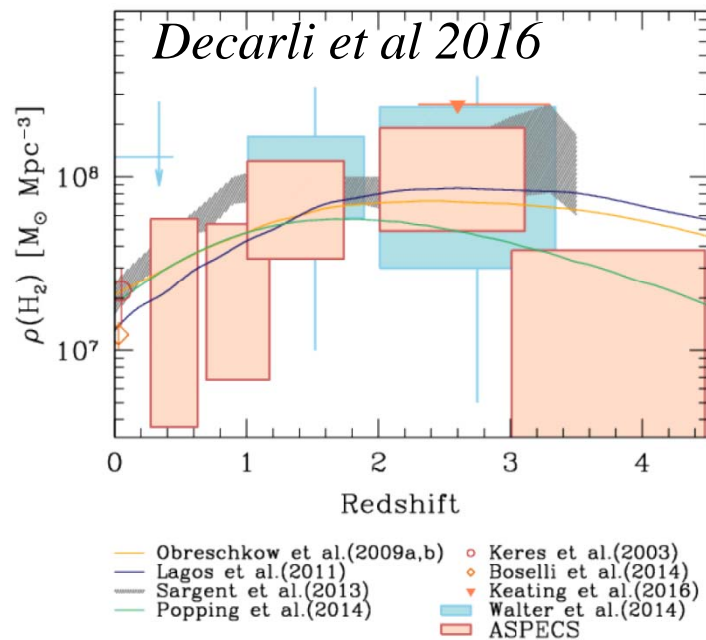
# Deep fields: HUDF ASPECS

CII+dust  $6 < z < 8$ , 14 CII candidates, more than 60% spurious, 2 blind  
Dust only on the stack, SFR = 3 Mo/yr

1mm  $\sigma \sim 13 \mu\text{Jy}$   $\langle z \rangle = 1.6$ ,  $M_{\text{gas}}$  lower than CO-derived by a factor 2

*Aravena et al 2016, 1/6th of the HUDF (30h)*

10 sources detected in some CO lines  
 $\sim$ less than 5 spurious



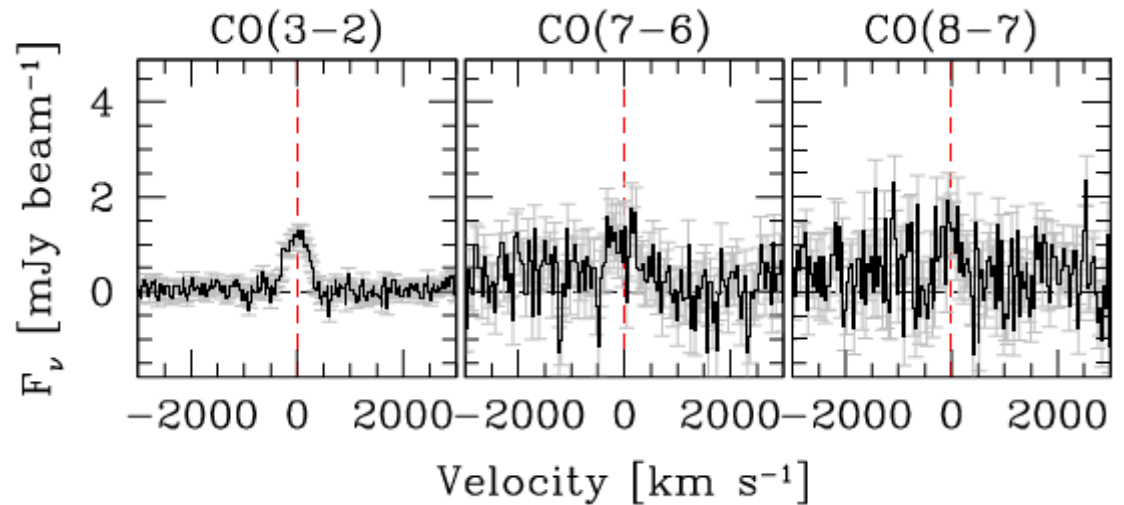
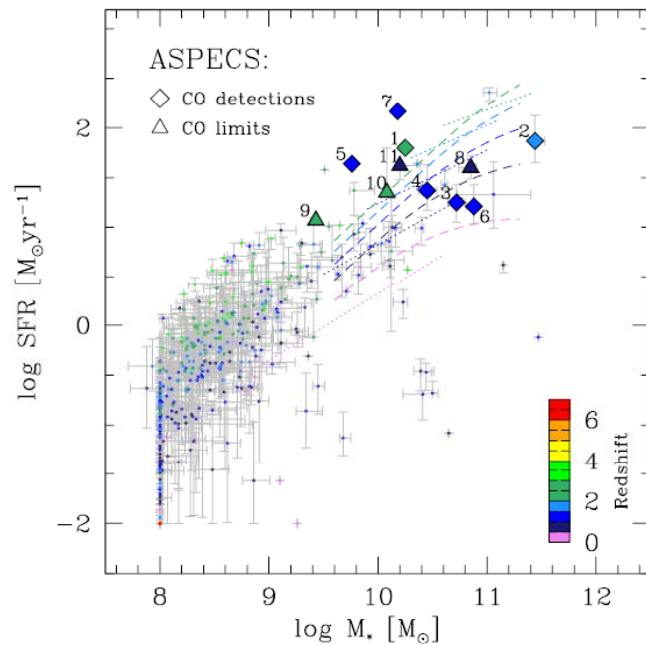


# CO lines in HUDF-ASPECS

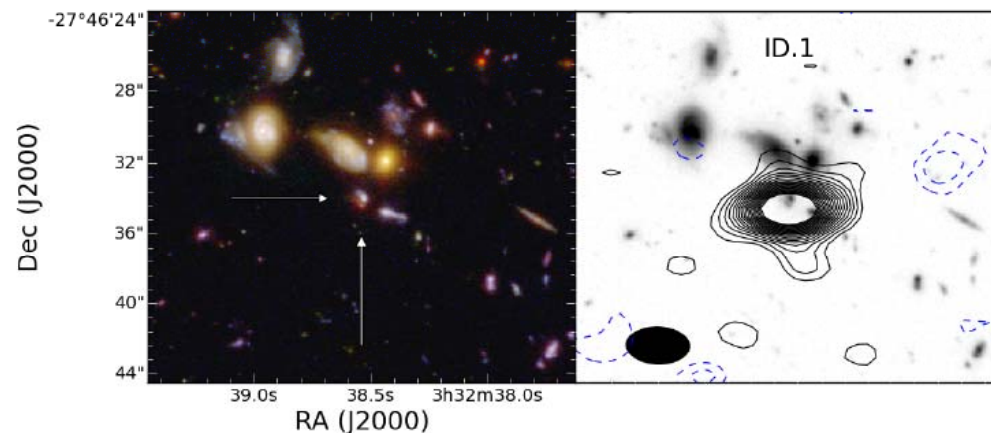
1 arcmin<sup>2</sup>, 1302 galaxies, 56 with spectro-z, 11 with  $L_{\text{IR}} > 10^{11} L_{\odot}$

7 « detected » at different levels

CO excitation less than in starbursts,  $\rightarrow$  MS,  $t_{\text{dep}} \sim 1$  Gyr



*Decarli et al 2016*

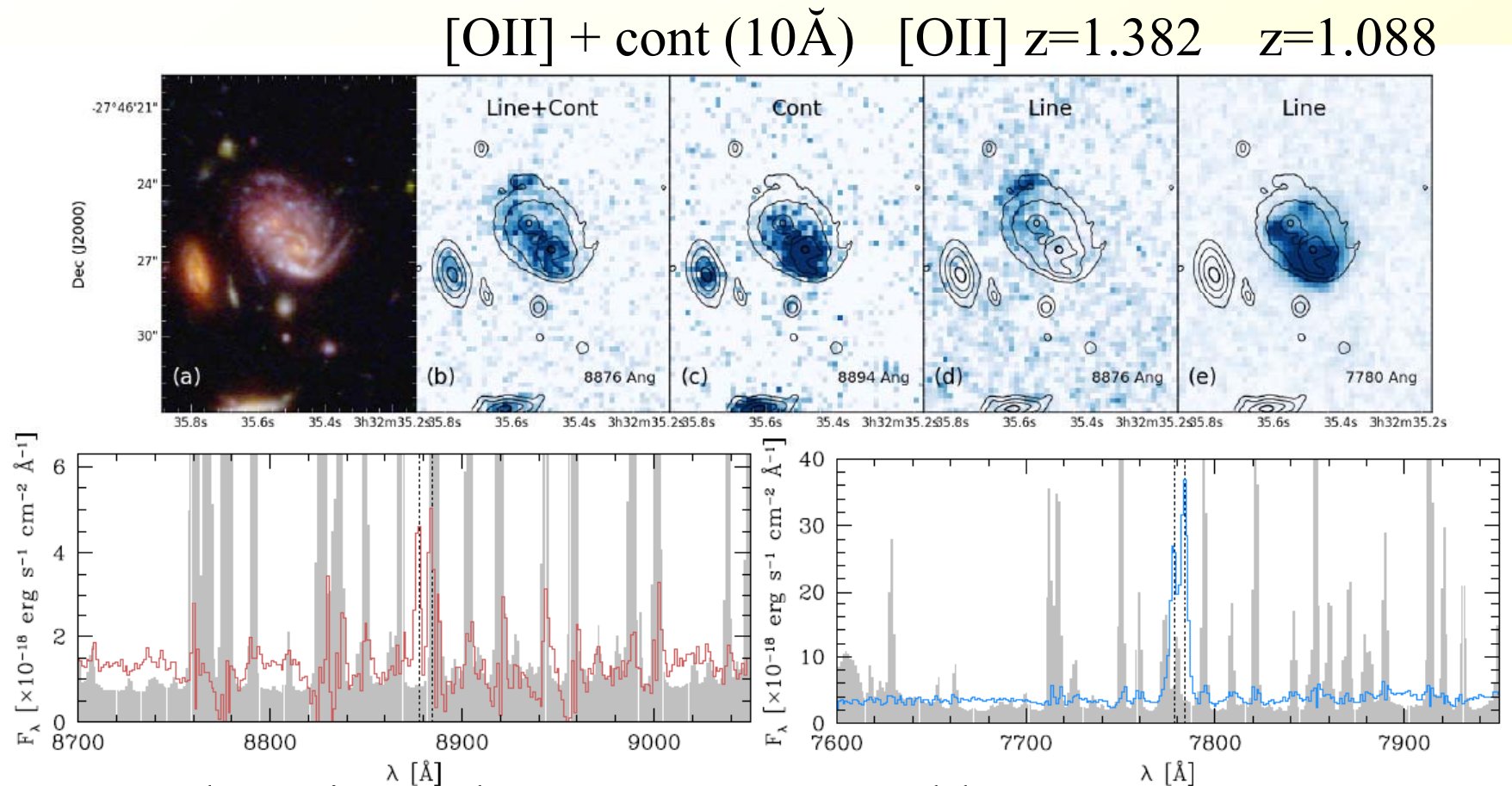


$z=2.5$

9

# MUSE in the HUDF-ASPECS

Several galaxies confusing along the los

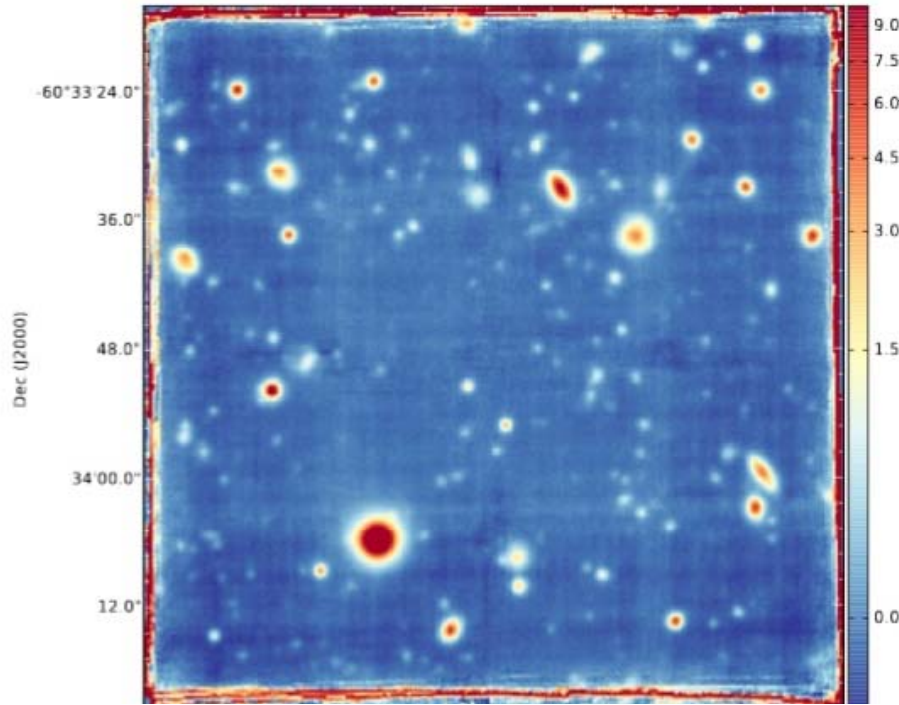


Grey=sky noise, red [OII]

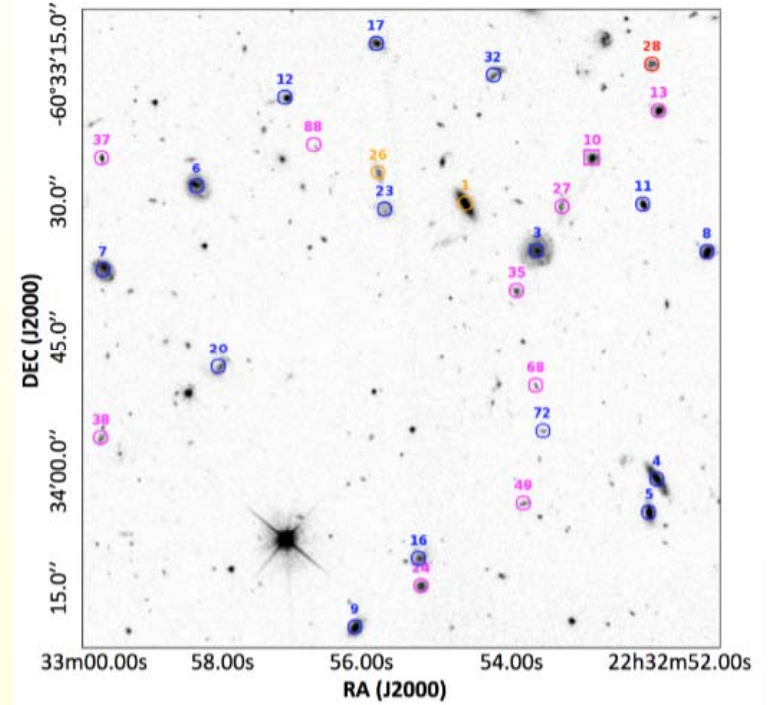
*Decarli et al 2016*

blue [OII]

z=1.382 & 1.088 compatible with  $^{10}\text{CO-z}$

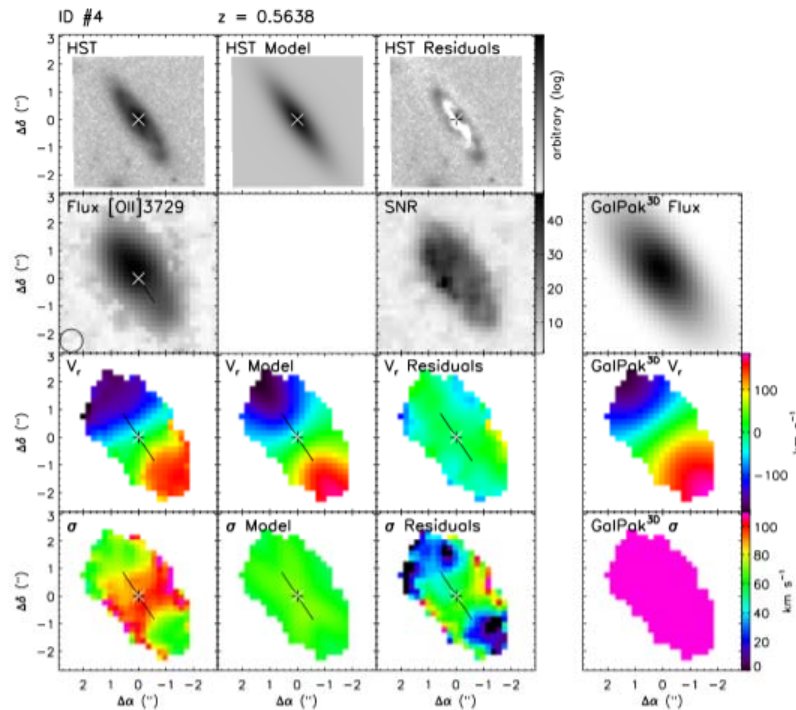


*Bacon et al 2015*



*Contini et al 2016*

# MUSE HUDFS

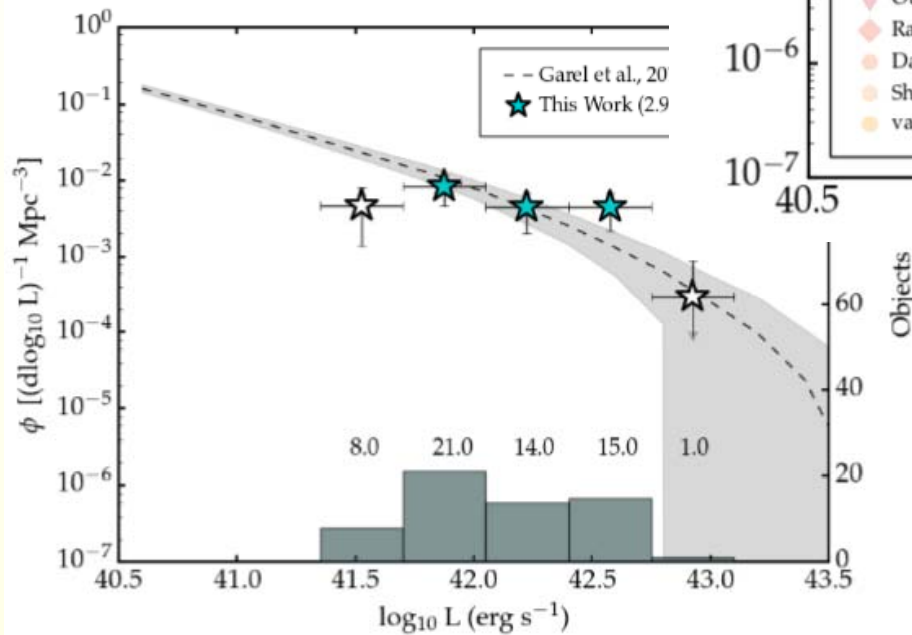
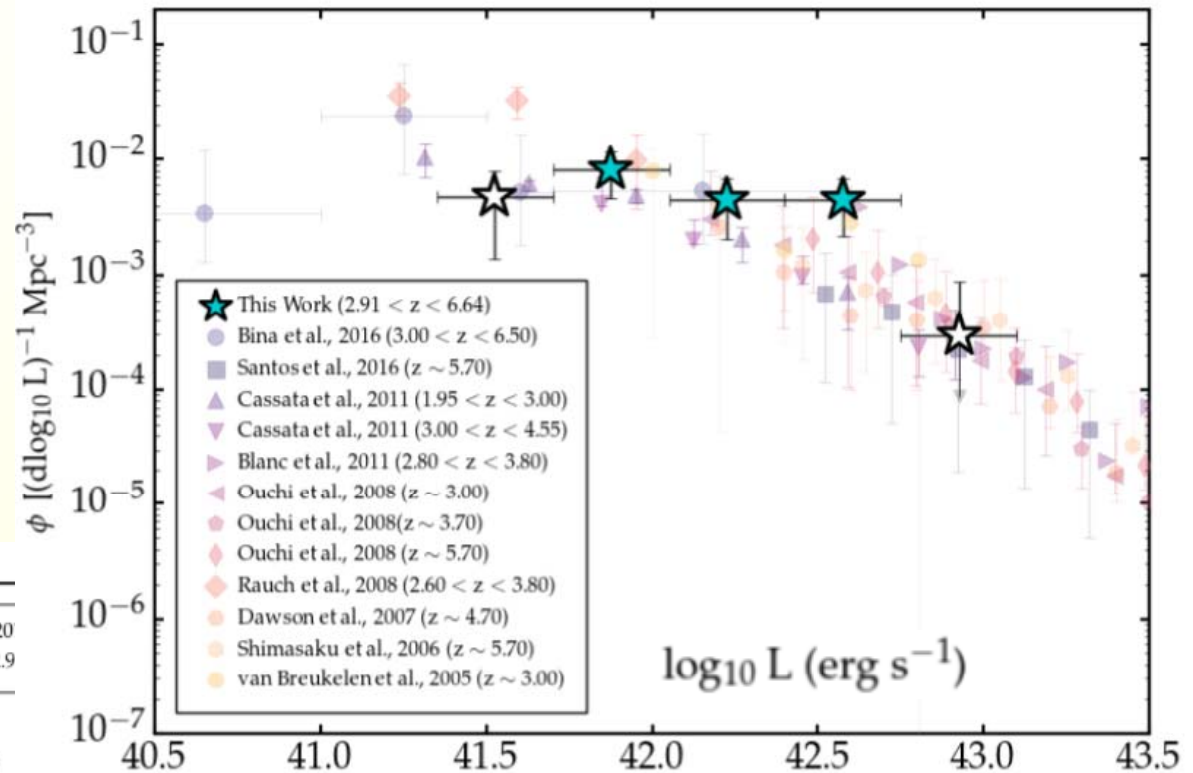


28 galaxies  $0.2 < z < 1.4$   
 20%  $V/\sigma < 1$ , 30% close pairs  
 90%  $M_* < 10^{9.5} M_{\odot} \rightarrow$  gas disks



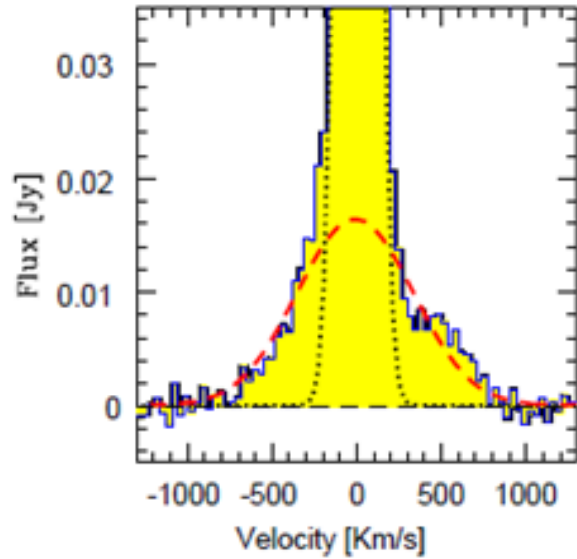
# Ly $\alpha$ Luminosity function HUDFS

*Drake et al 2016*



Ly $\alpha$  could be underestimated  
Here the correction brings to  
2-3 higher than literature

# AGN feedback

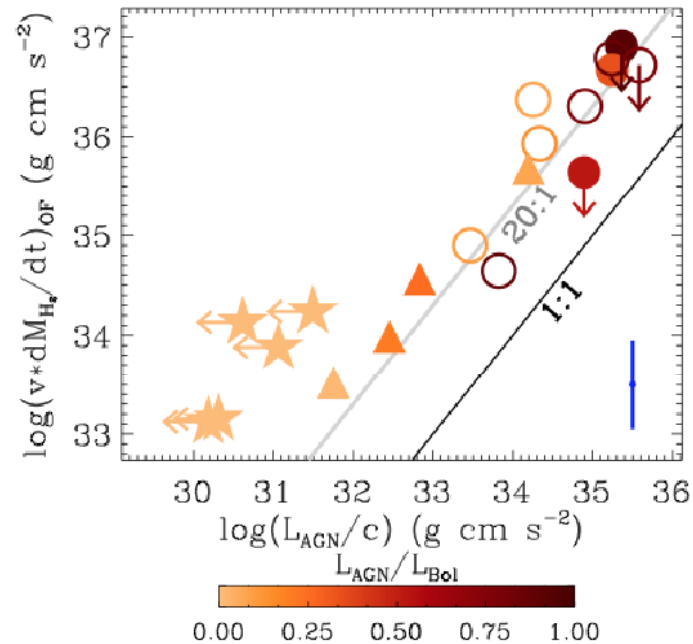
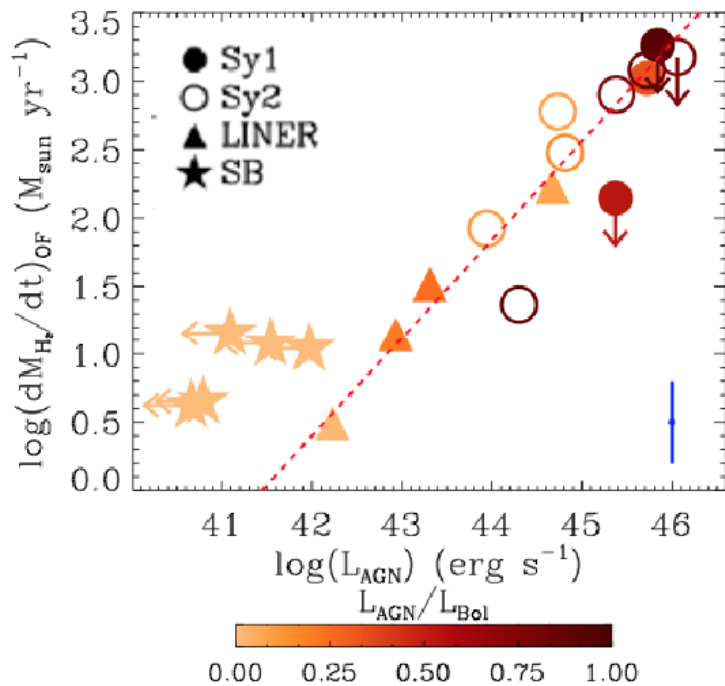


*Ferruglio et al 2010*

## Molecular outflow in Mrk 231

AGN and also nuclear Starburst,  $10^7$ - $10^8 M_{\odot}$   
 Outflow  $700 M_{\odot}/\text{yr}$

$$dM/dt \sim 20 L_{\text{AGN}}/c$$

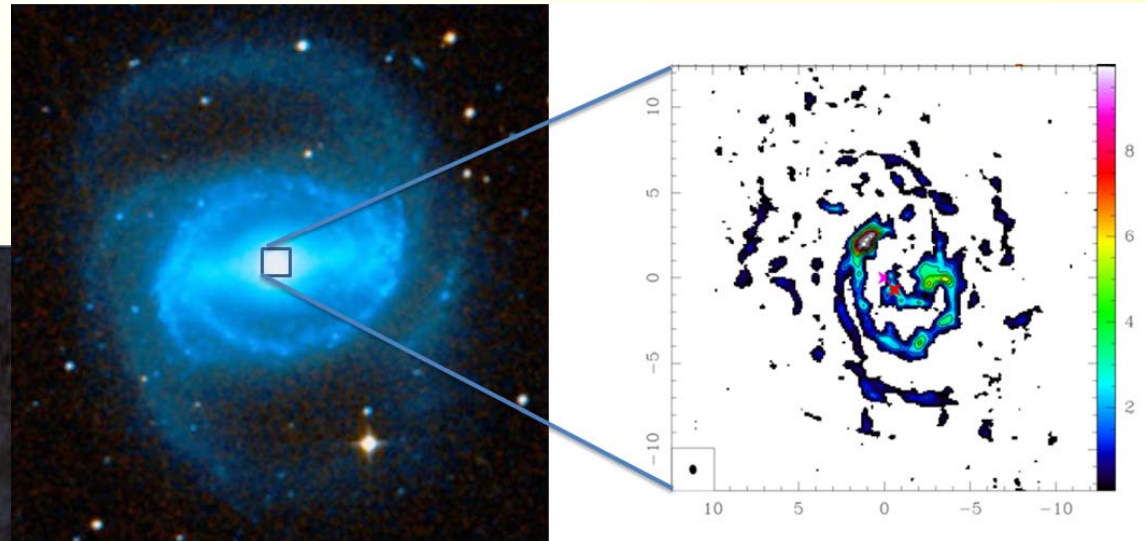


*Cicone et al 2014*

# Fueling in low-luminosity AGN

NGC 1433: Sy 2 barred spiral, the « Lord of the Rings »

**The smallest molecular  
AGN-driven outflow**

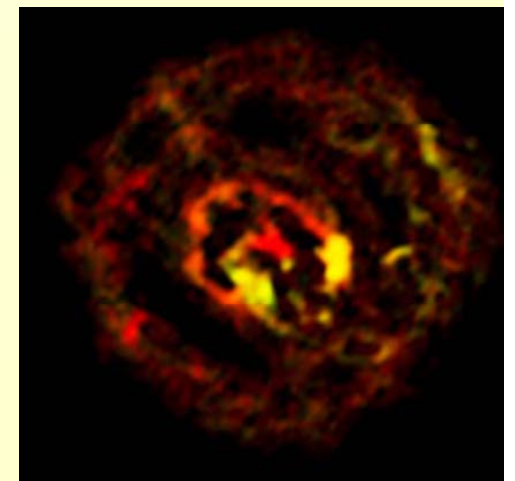


CO(3-2) with ALMA (Cycle 0)

Beam =  $0.5'' = 24\text{pc}$

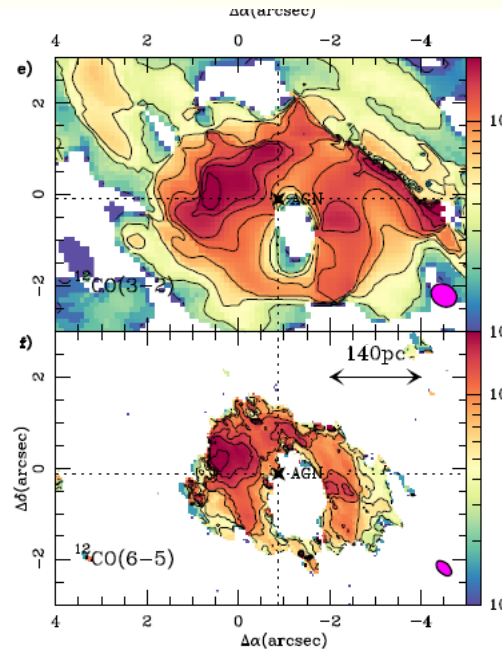
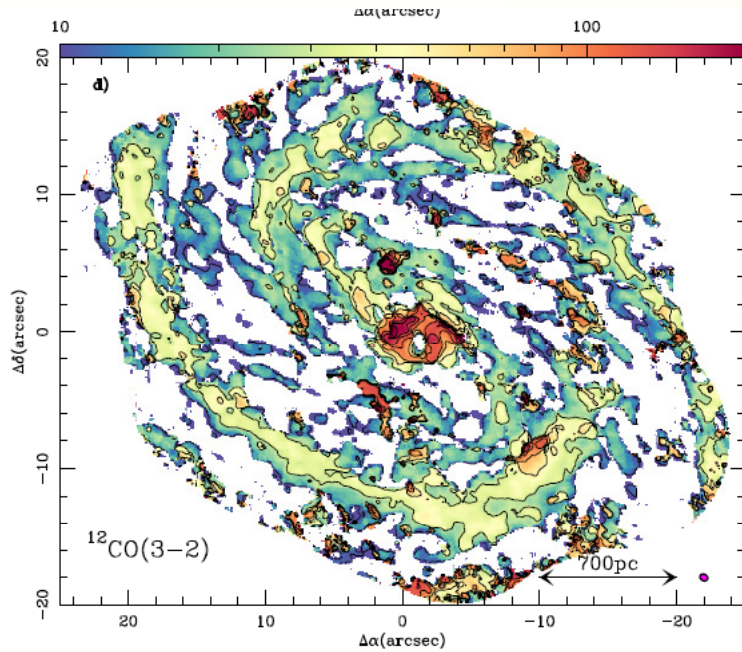
Flow of  $60\text{pc}$  size

*Combes et al 13*

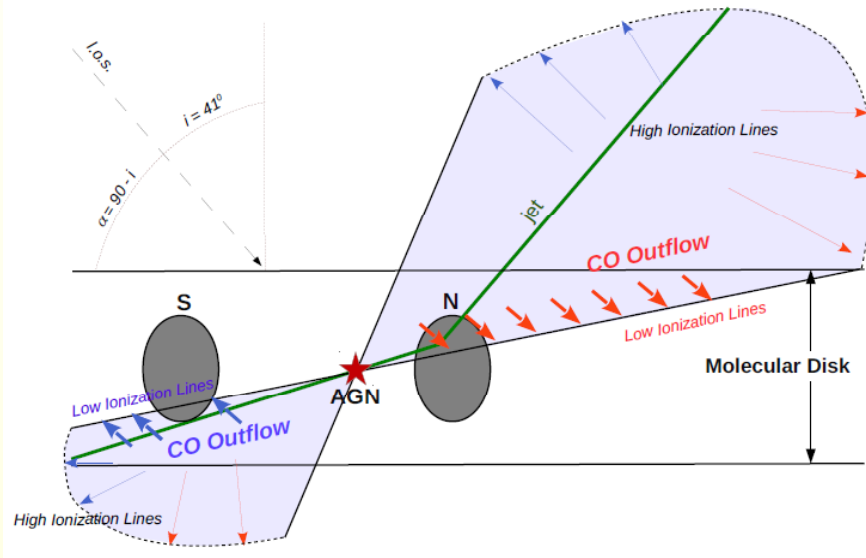
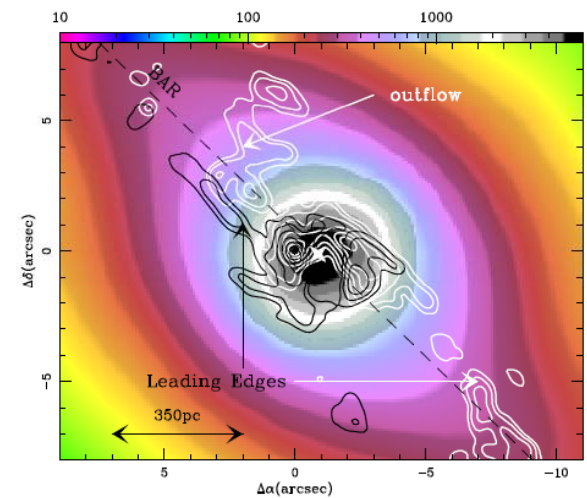




# Off-center AGN and outflow in N1068



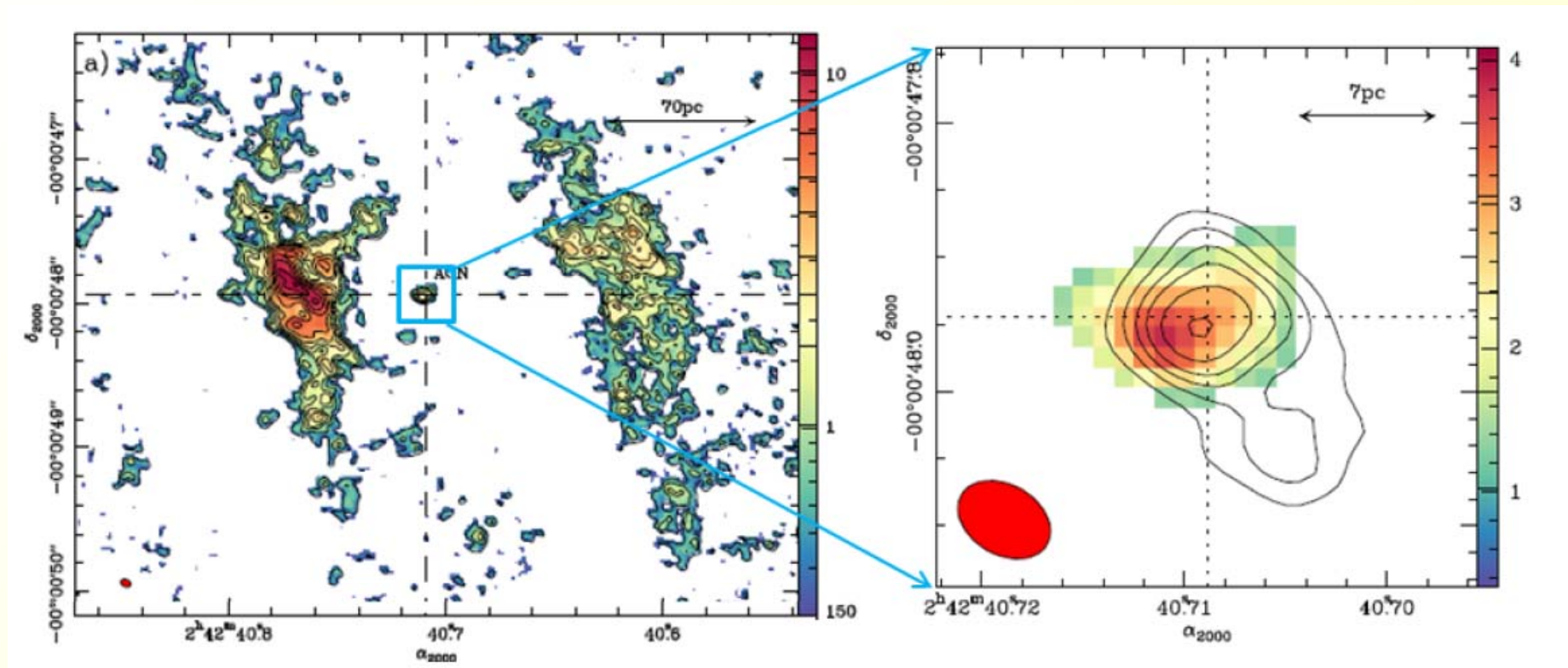
Black  $V=-50\text{km/s}$   
White  $V=50\text{km/s}$



Outflow of  $63\text{M}_\odot/\text{yr}$   
About 10 times the SFR in  
this CMD region

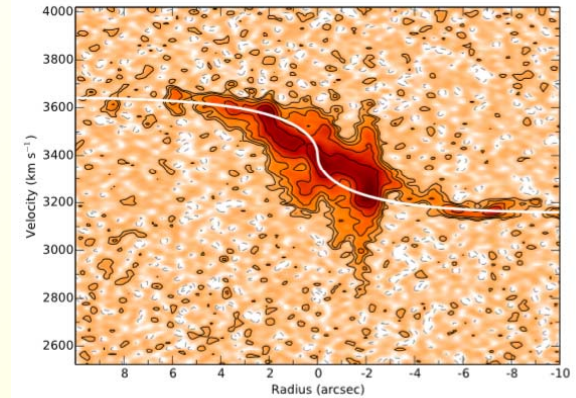
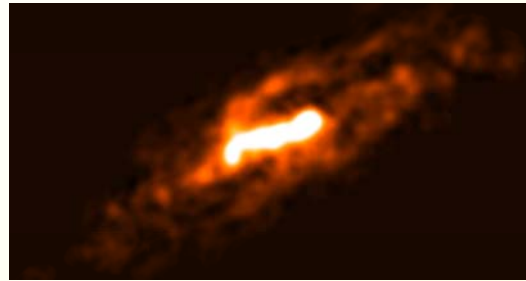
15  
ALMA, Garcia-Burillo et al 2014

# NGC 1068: detection of the torus (7pc)



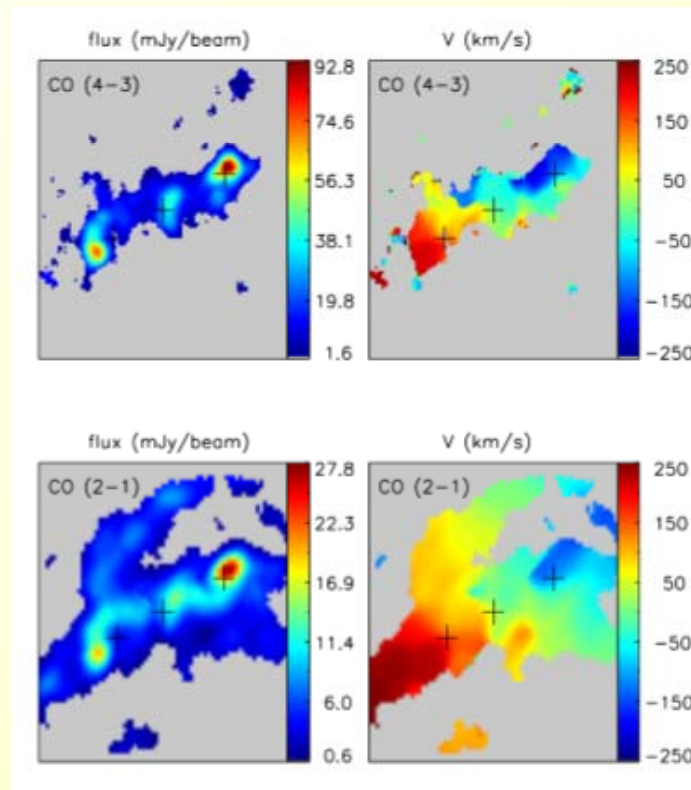
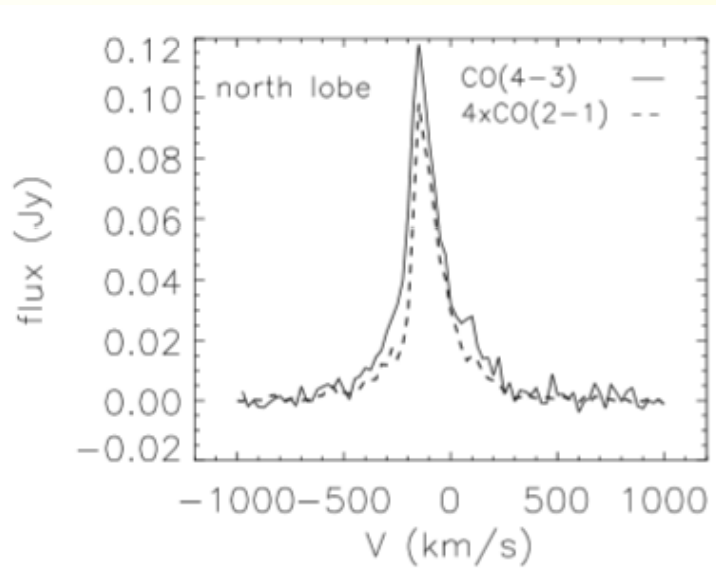
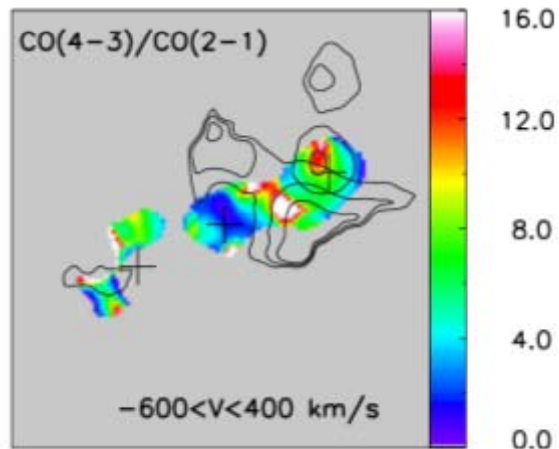
Garcia-Burillo et al (2016)

# Radio mode: molecular flow IC5063



*Morganti et al 2015*

Some of the gas optically thin in the flow?



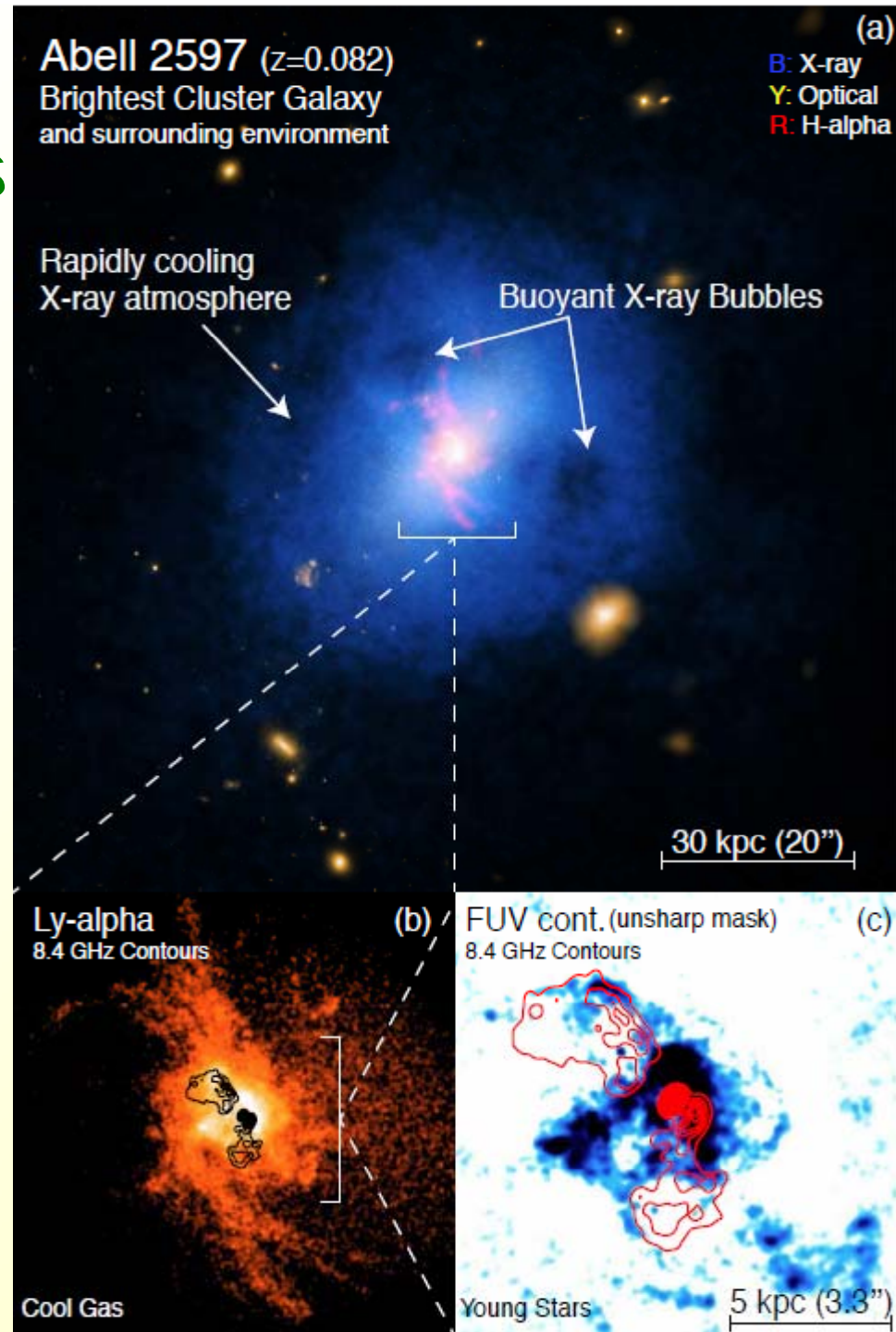
*Dasyra et al 2016*



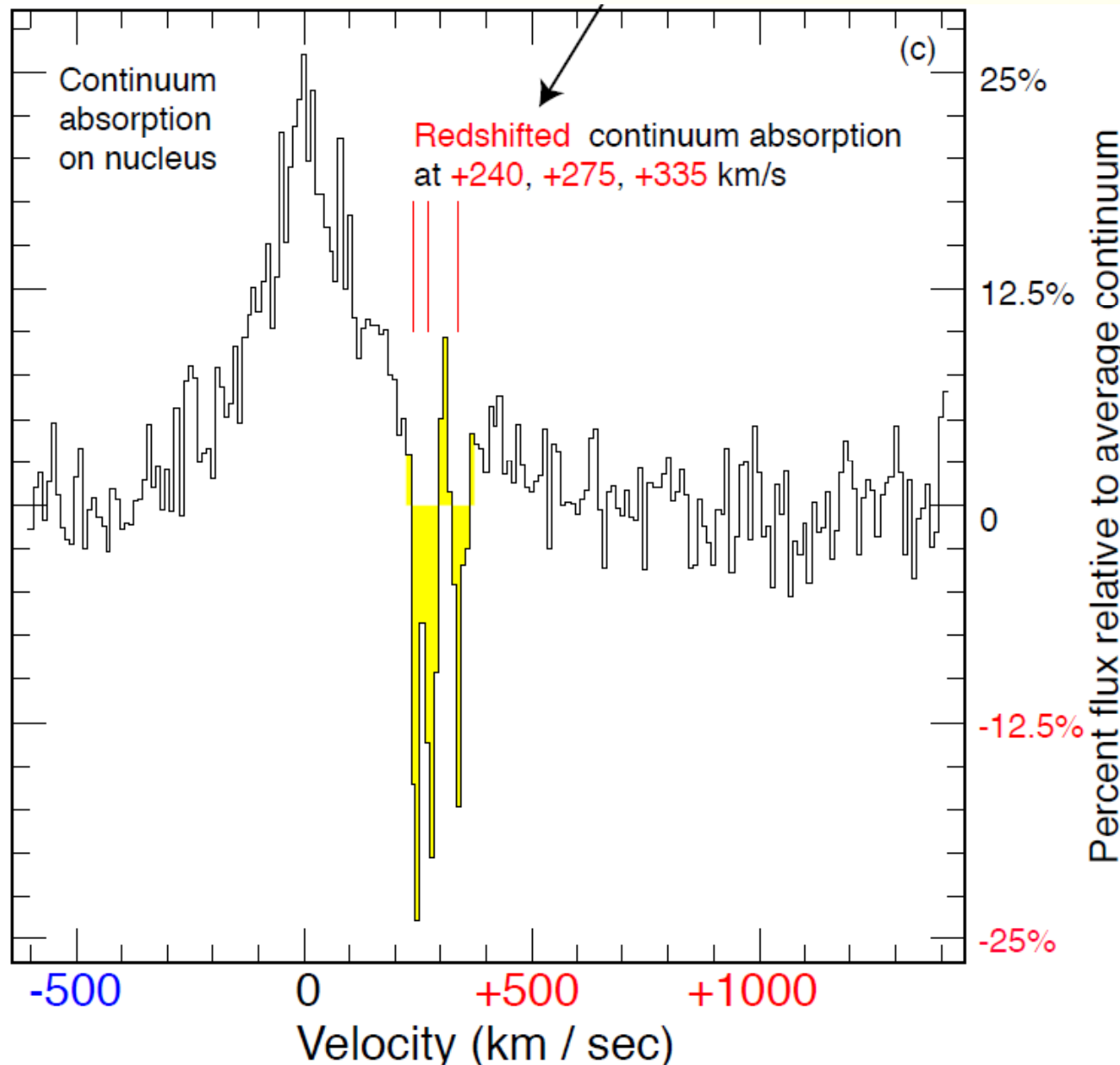
# ALMA: cooling flows

Abell 2597  
Central Galaxy  
with radio jets  
and optical filaments

*Tremblay et al 2016*



# ALMA: cold gas in cool core clusters



Abell 2597 ALMA  
CO(2-1) absorption  
in front of the  
AGN synchrotron

Red-shifted only  
Dense clouds  
fueling the AGN

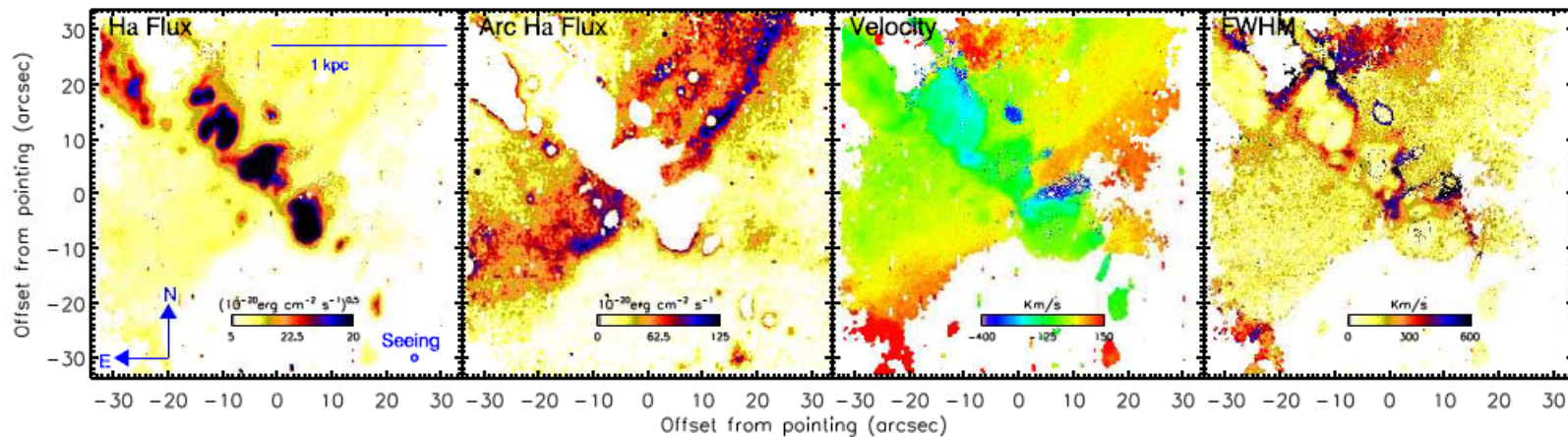
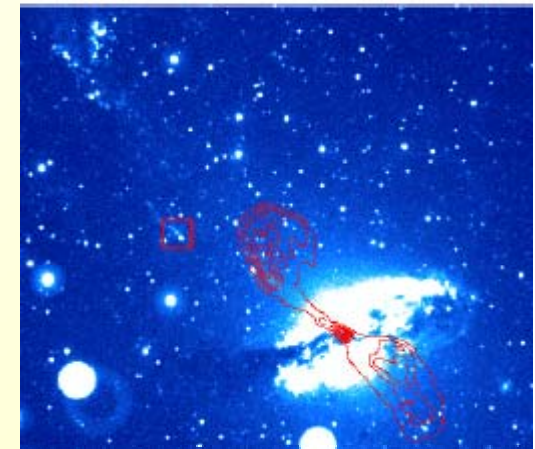
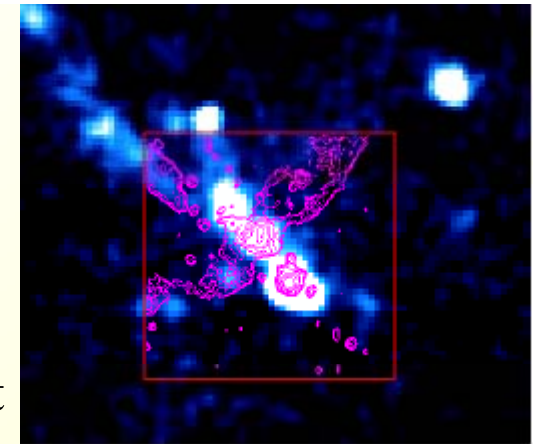
*Tremblay et al 2016*

# Centaurus A with MUSE

Discovery of arcs perpendicular to the filament  
H $\alpha$ , [NII], [OIII] and [SII] lines  
clumpy structures inside the diffuse medium along the radio-jet

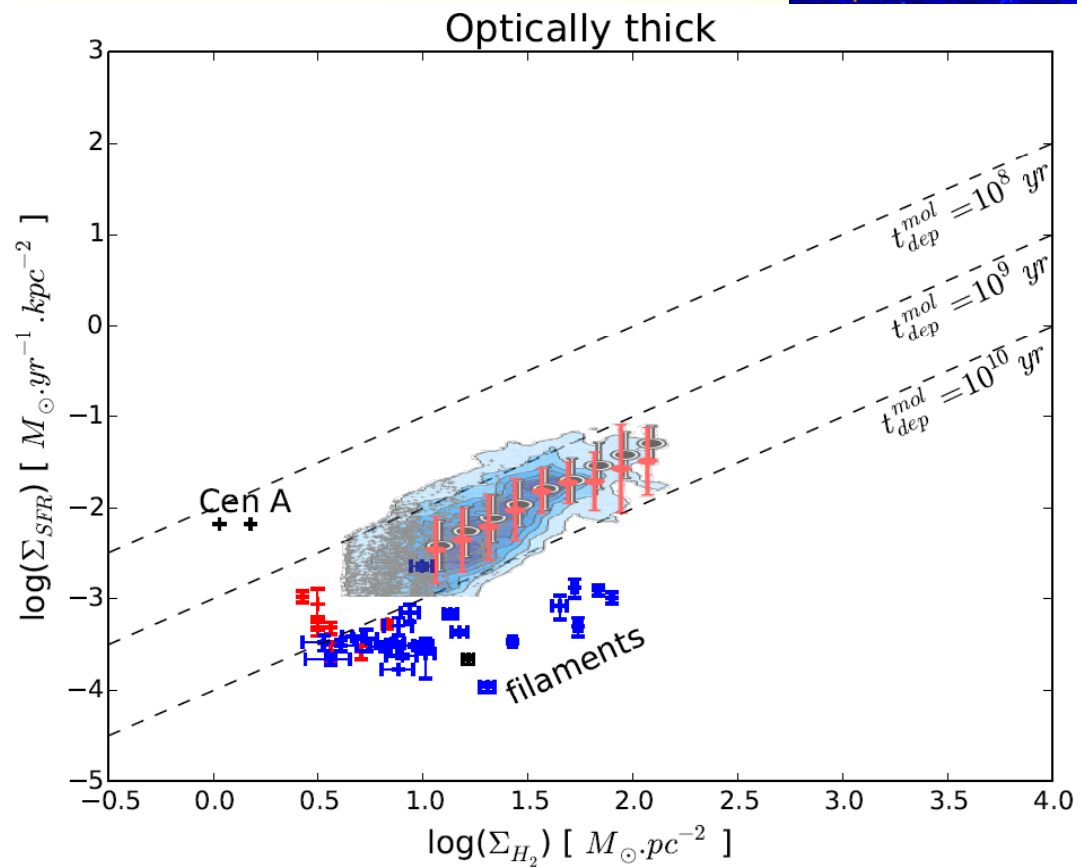
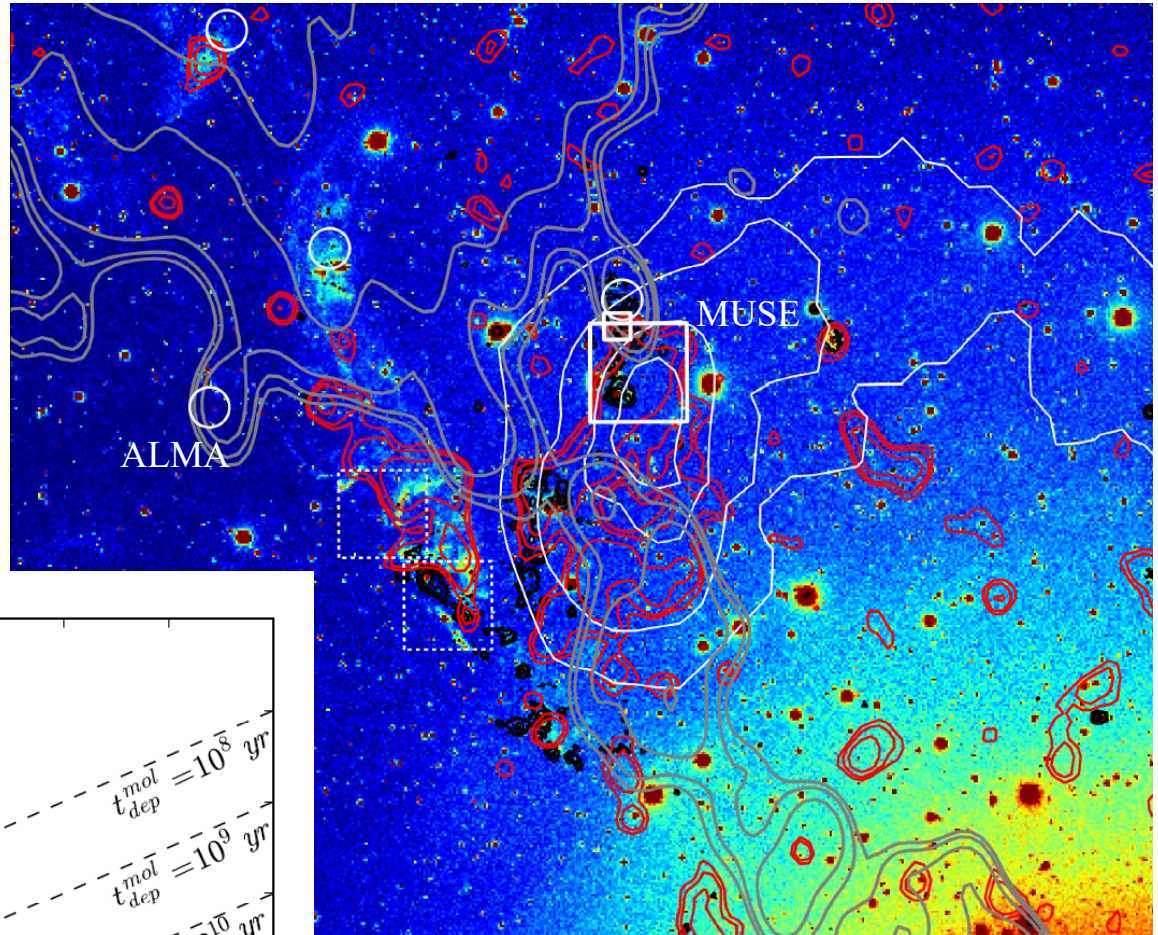
→ Neutral material swept by a backflow of the AGN jet  
outburst and ionised through slow shocks

*Hamer, Salome, Combes, Salome, 2014*





# SF efficiency: $t(\text{depletion})$



*Salome, Salome, Combes,  
Hamer, Heywood 2016*

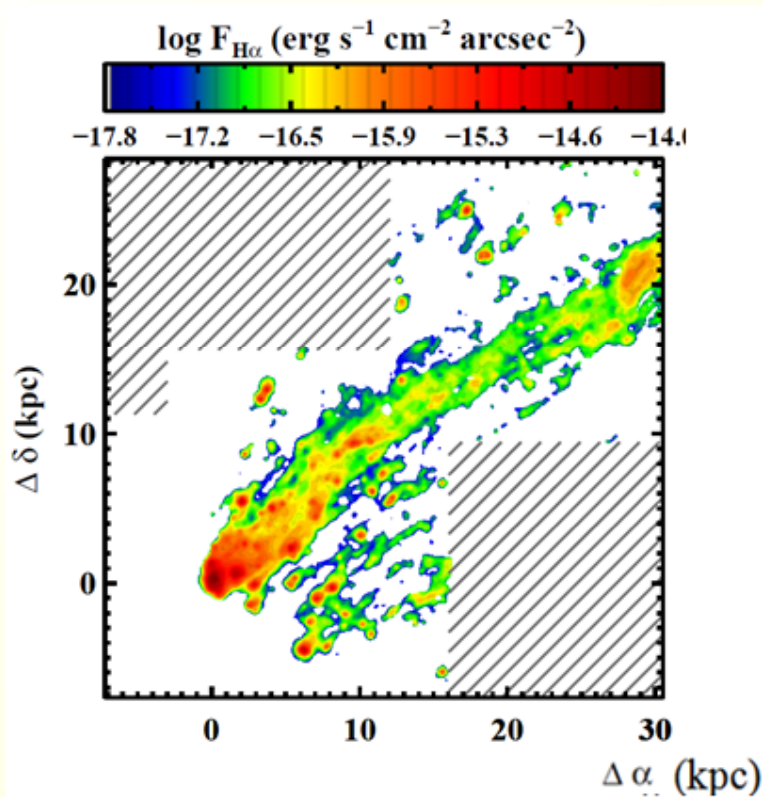
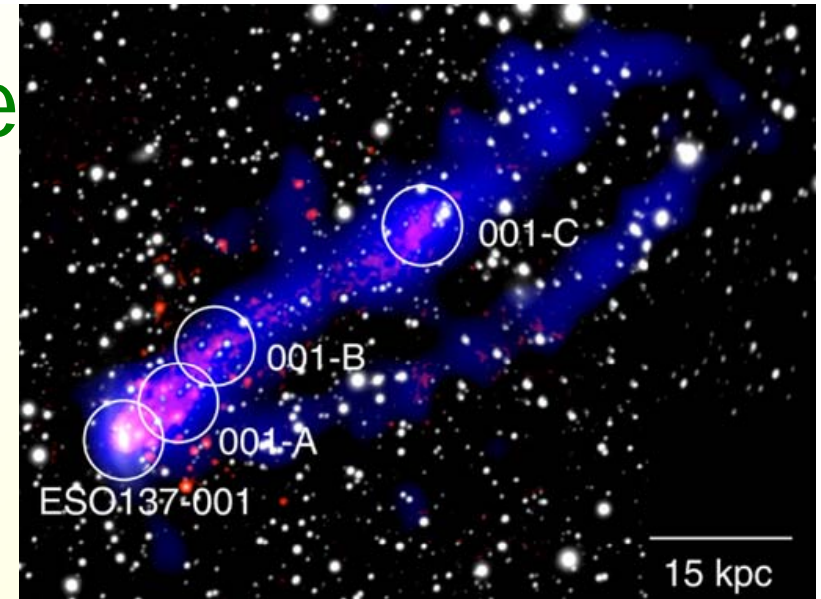
# HalpHa MUSE: ram-pressure

Outer parts stripped first:

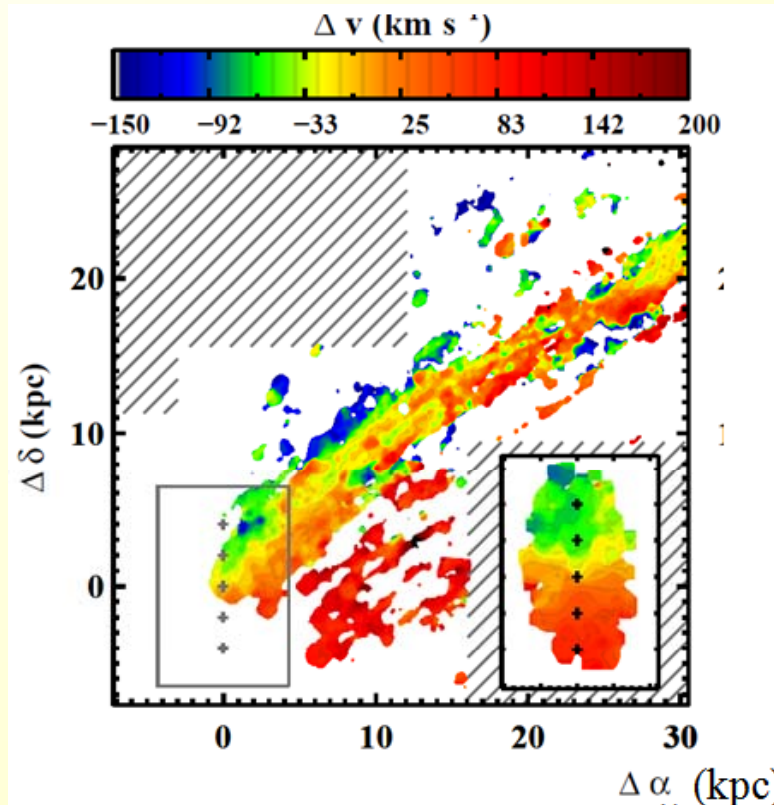
Now only the center

Transition from laminar to turbulent

> 6.5 Myr



*Fumagalli et al 2014*



Jachym  
et al 14  
H<sub>2</sub> gas  
dominant



# MUSE discovery of « cold » atomic gas illuminated by quasars

Blind survey for giant Ly- $\alpha$  nebulae around **17 bright RQQ** at  $3 < z < 4$

All QSO have 100-320kpc Ly- $\alpha$  nebulae

*Borisova et al 2016*

→ **Ubiquitous**, like the Slug nebula,

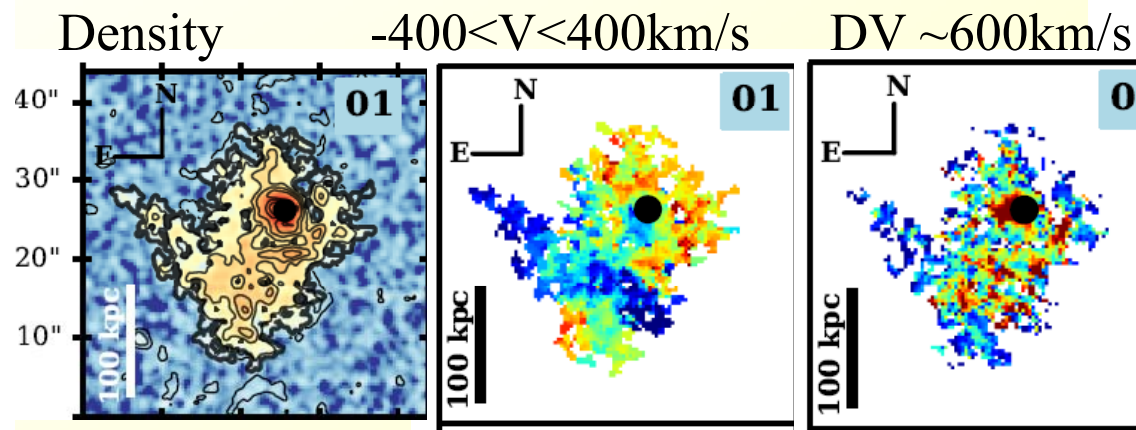
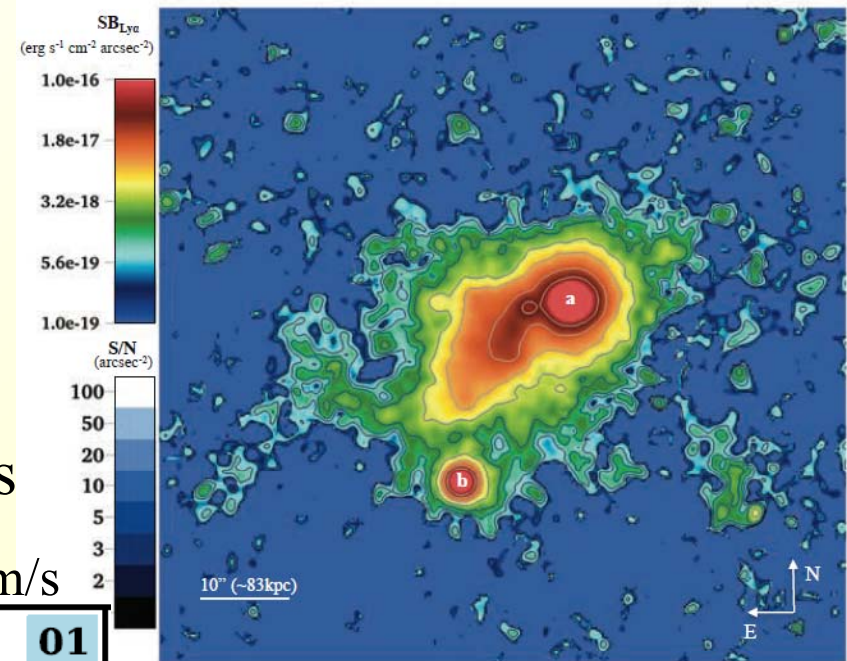
Fluorescence of gas up to 500kpc

at  $z=2$ ,  $10^{12}$ Mo filament

*Cantalupo et al 2014*

Also absorption lines in front of the QSO

→ 60% filling factor of “cold” dense gas



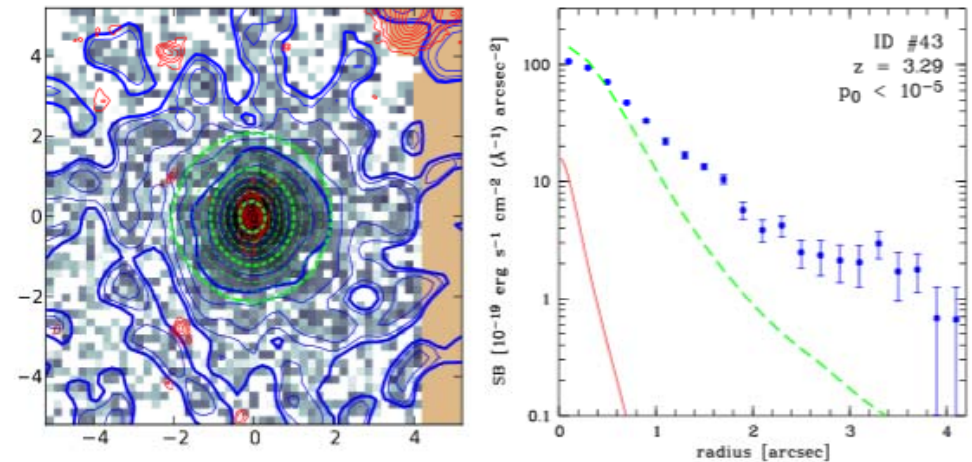
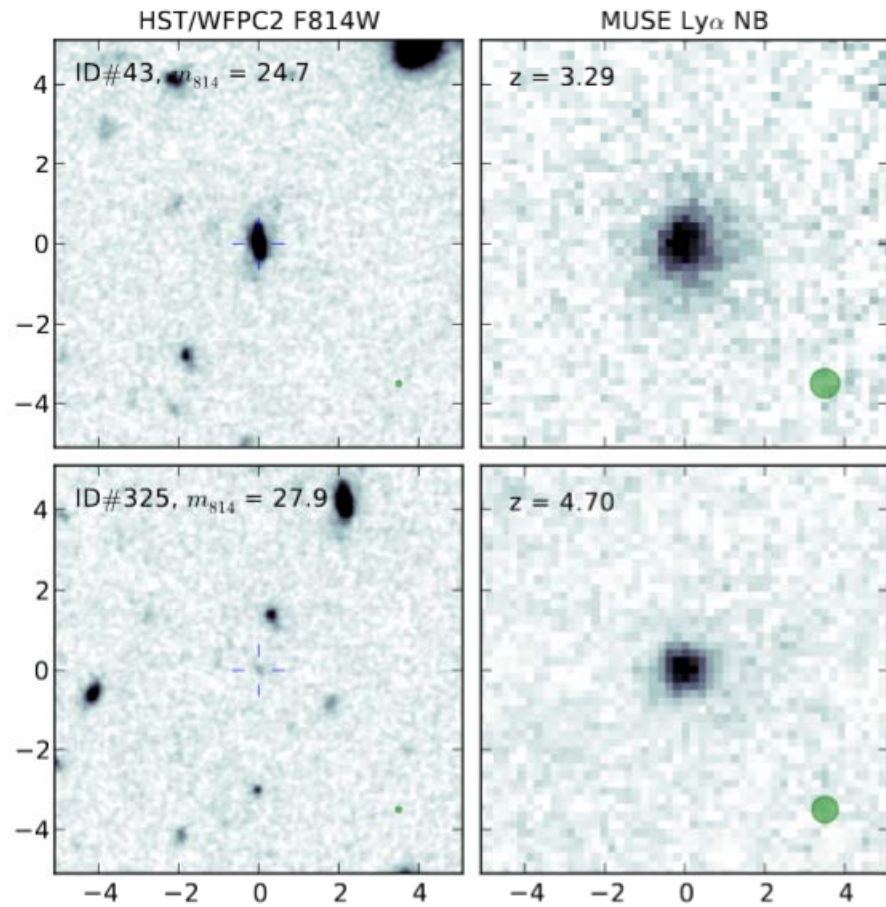
*Borisova et al 2016*



# Extended Ly $\alpha$ haloes around galaxies

Galaxies between  $3 < z < 6$  Ly $\alpha$  more extended than UV continuum

Extension of a few kpc



# SUMMARY

- HUDFS: ALMA & MUSE, still small numbers, but already surprises: most of the SFR is not dust-obscured low CO excitation
- High-z galaxies, evolution of cosmic star formation, Gas mass fraction increases by  $\sim 10$ ,  $t_{\text{dep}} \sim (1+z)^{-1}$
- AGN feedback, negative and positive, molecular outflows (ALMA)
- Ram-pressure tails, polar rings with MUSE
- Illumination of cold gas in filaments with MUSE