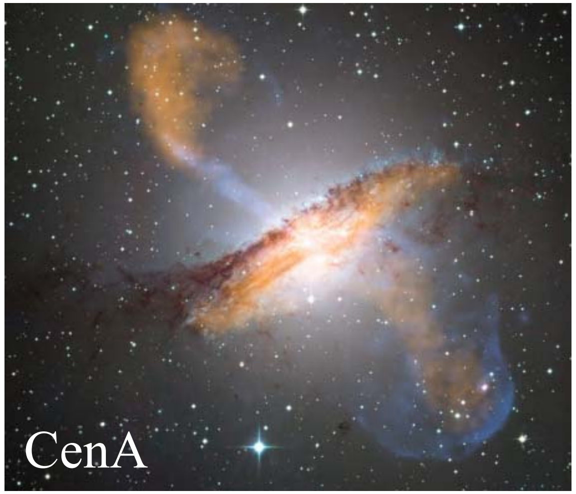
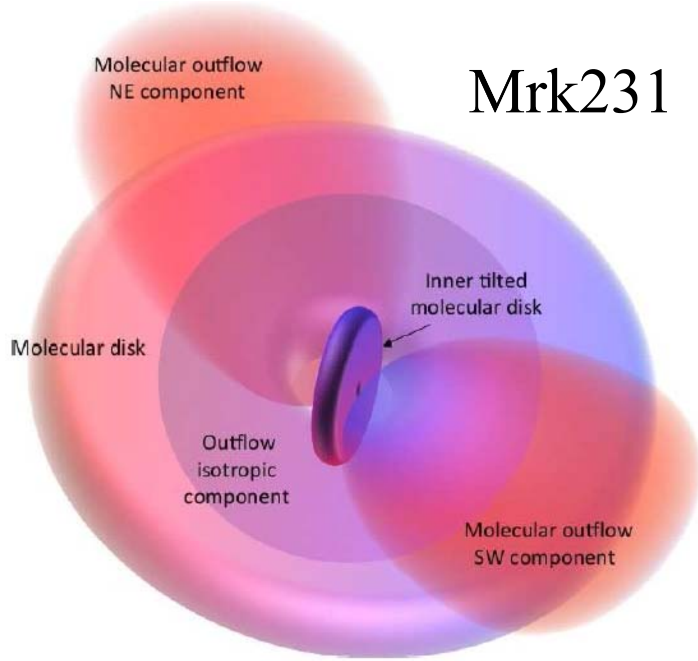
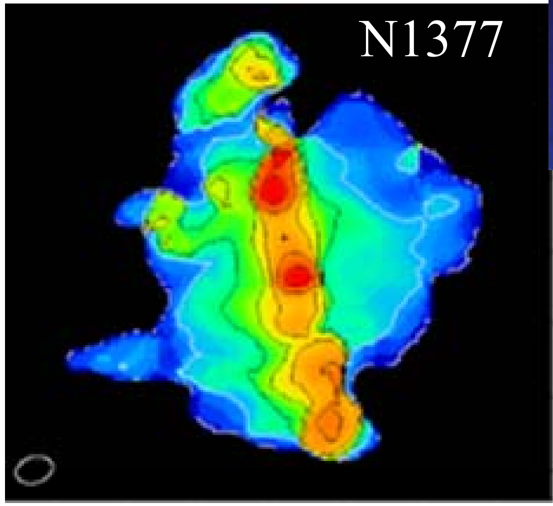
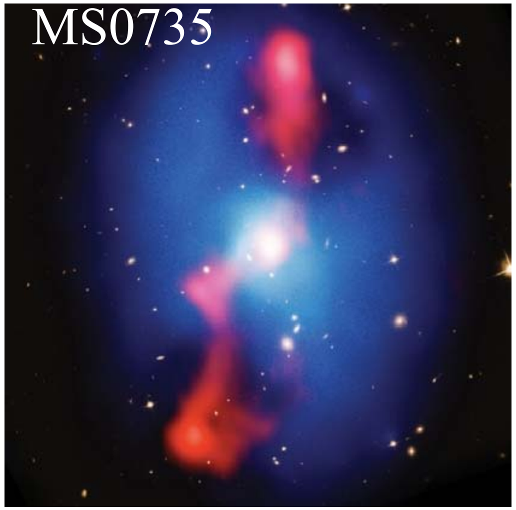




AGN-driven winds at kpc scales

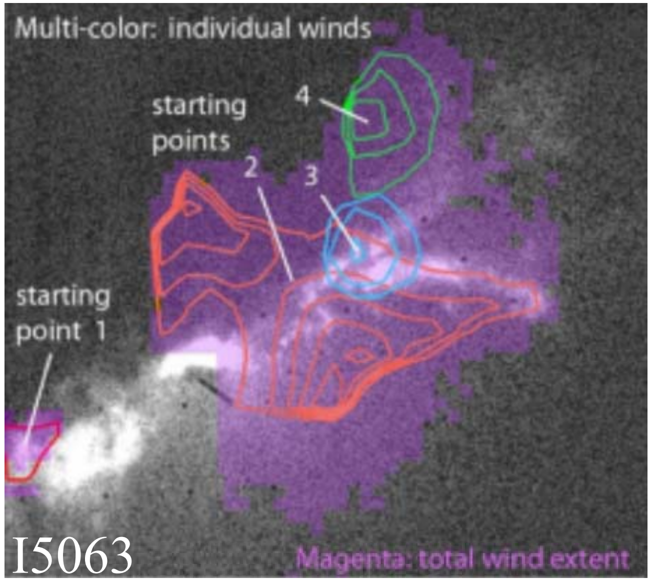




Françoise Combes
Observatoire de Paris

26 June 2017

Outline



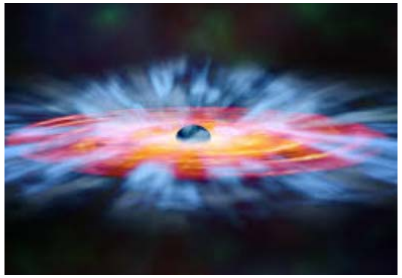
1- Types of AGN feedback

2- Statistics with AGN power

3- Molecular outflows

4- Jet-induced star formation

Two main modes for AGN feedback



Quasar mode: radiative or winds

When L close to Eddington, young QSO, high z

L_{Edd} ~M_{BH}/σ_T ➔ M_{BH} ~$f\, \sigma_T \sigma^4$, f gas fraction

Same consideration with radiation pressure on dust, with σ_d

σ_d / σ_T ~1000, limitation of Mbulge to 1000 M_{BH} ?

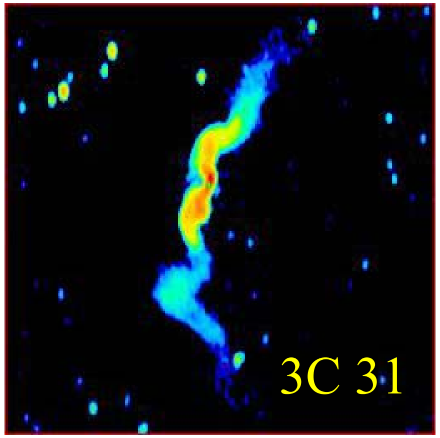
Radio mode, or kinetic mode, jets

When L < 0.01 L_{edd}, low z, Massive galaxies, Radio E-gal

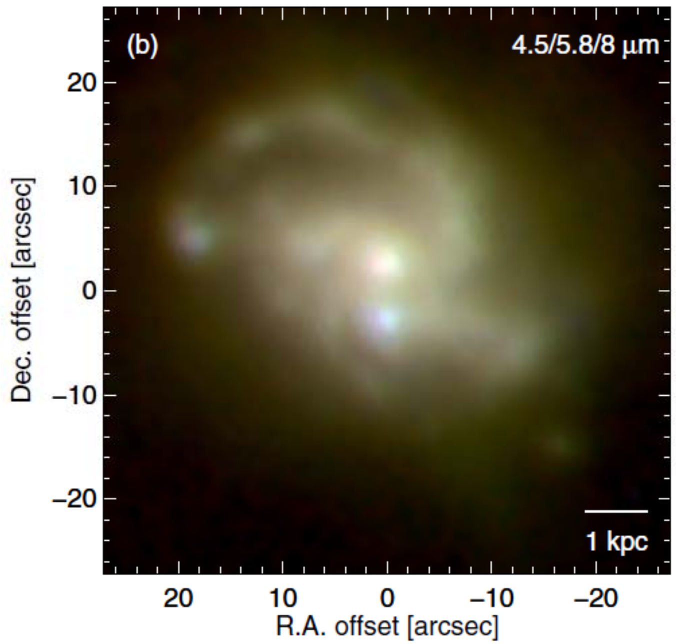
Radiatively inefficient flow ADAF

High frequency of cooling flows in clusters,

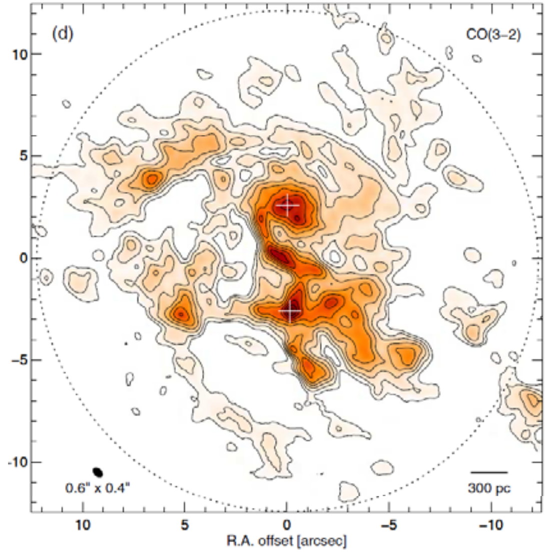
Low-luminosity AGN, Seyferts



Galactic wind quenching

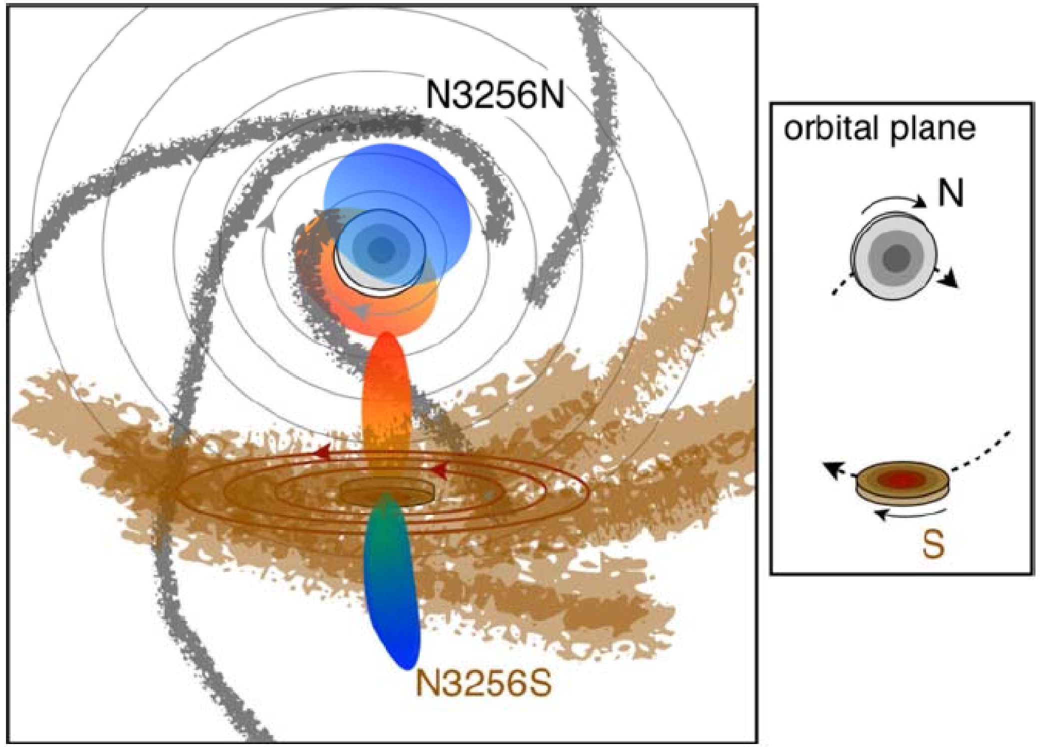


ALMA obs CO(3-2)
Merger-induced
Starburst: N3256
ULIRG z=0.01



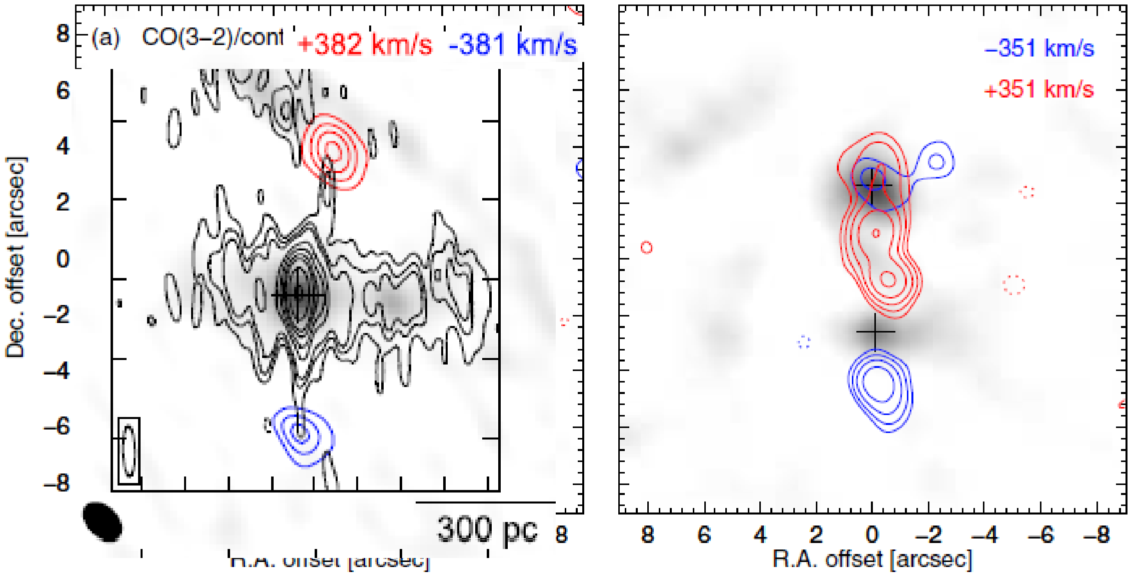
High-velocity wings in both!

One nearly edge-on, flow highly collimated ➔ AGN



Sakamoto et al 2014

Two bipolar flows, τ~ 1 Myr



Northern outflow: SF

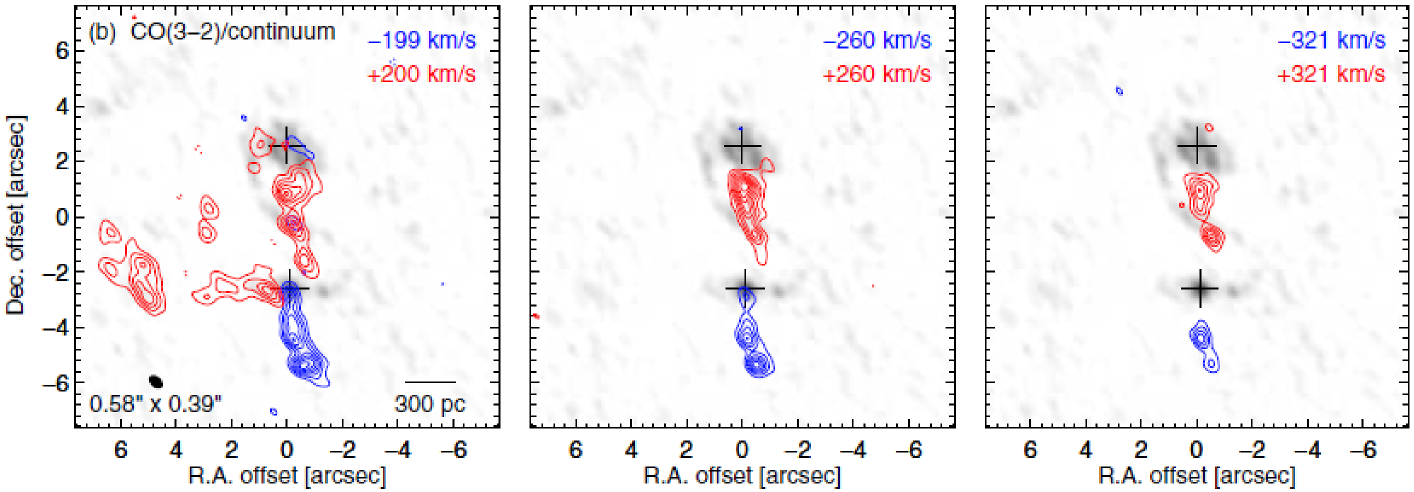
V > 750km/s, 60 Mo/yr

Wide angle

Southern outflow: AGN

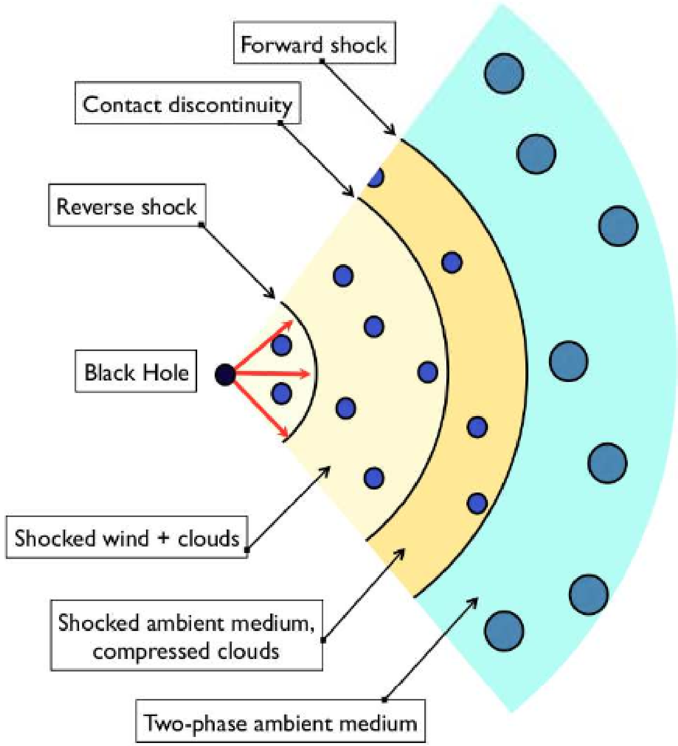
V ~2000km/s out to 300pc

- ➢50 Mo/yr
- ➢Highly collimated



Rate comparable to SFR
➔efficient quenching?

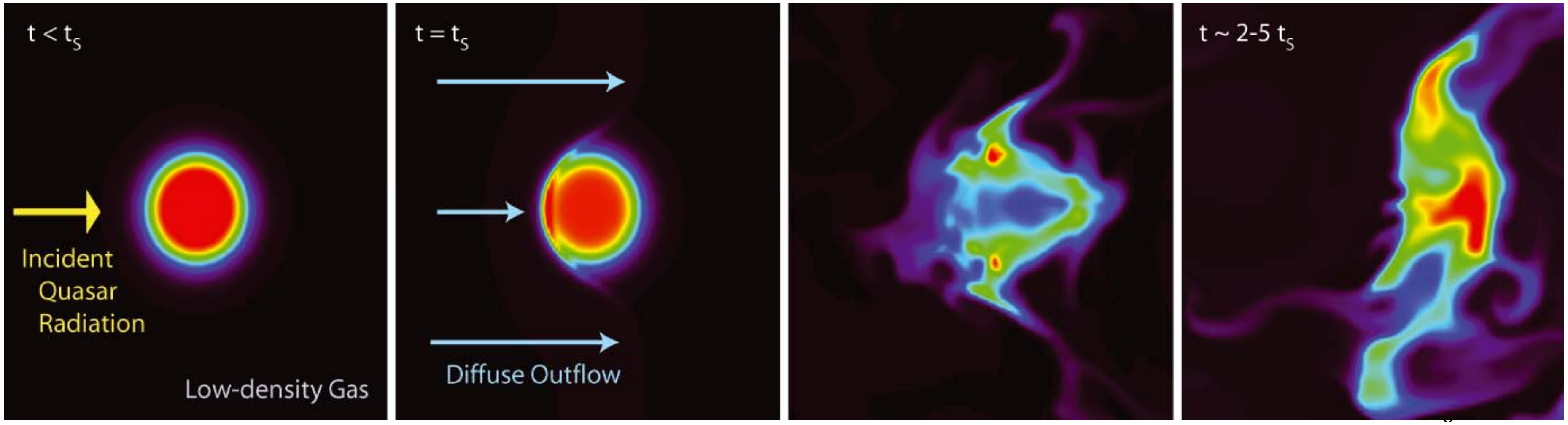
Sakamoto et al 2014



Why so many molecules?

Small dense clouds, the **surface ΔA** is insufficient. A weak wind can disintegrate the clouds, and thus increase their surface

Instabilities Kelvin-Helmholtz ➔ N_H decreases, ΔA increases ➔ + Re-formation of molecules downstream



Hopkins & Elvis 2010

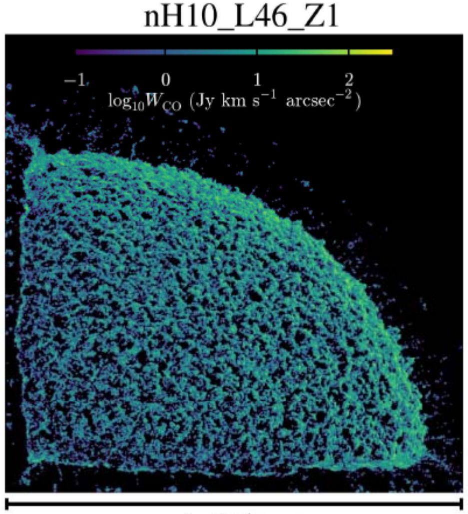
Formation of molecules

Numerical simulations: destroyed clouds do not re-condense

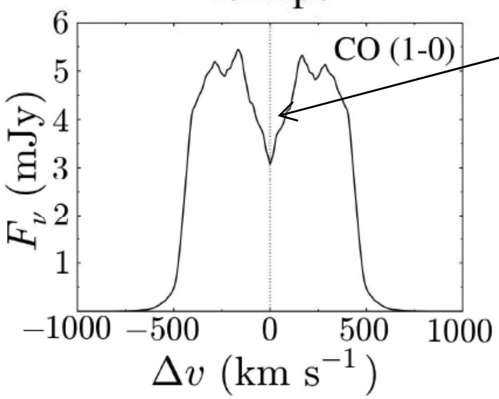
Not enough surface to be entrained *(Ferrara & Scannapieco 2016)*

Dust destruction by sputtering

New simulation, taking into account chemistry, H_2, dust

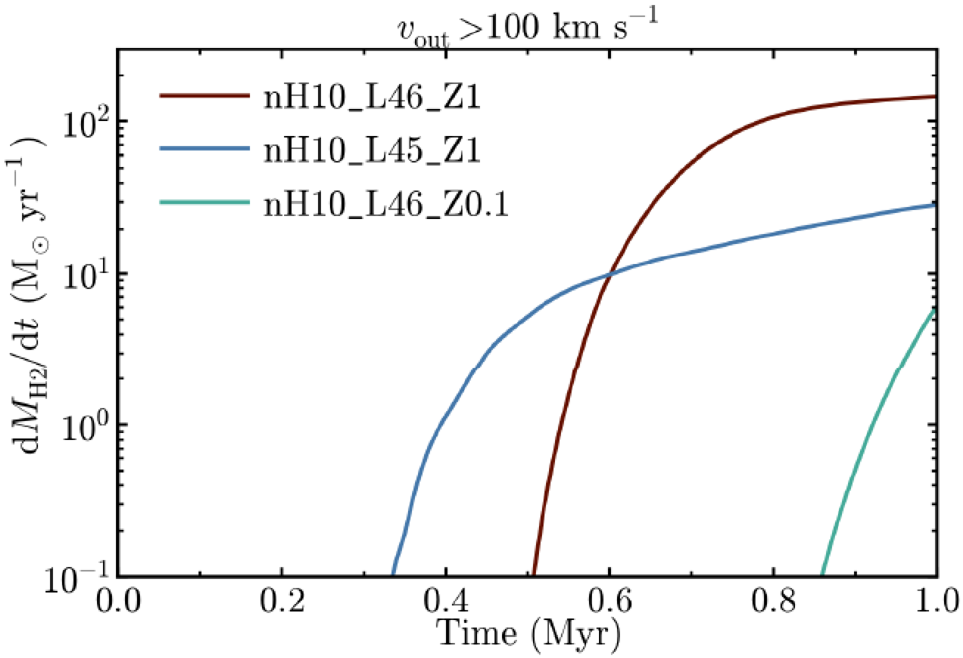


α_{CO} = 0.15 !



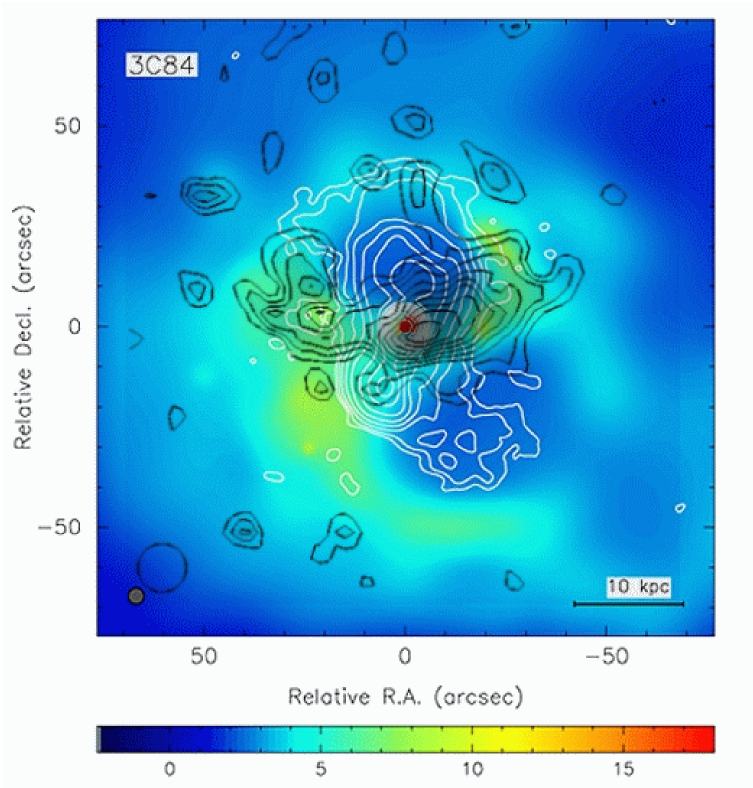
Dip is an artifact of boundary

H_2 flow of 140 Mo/yr



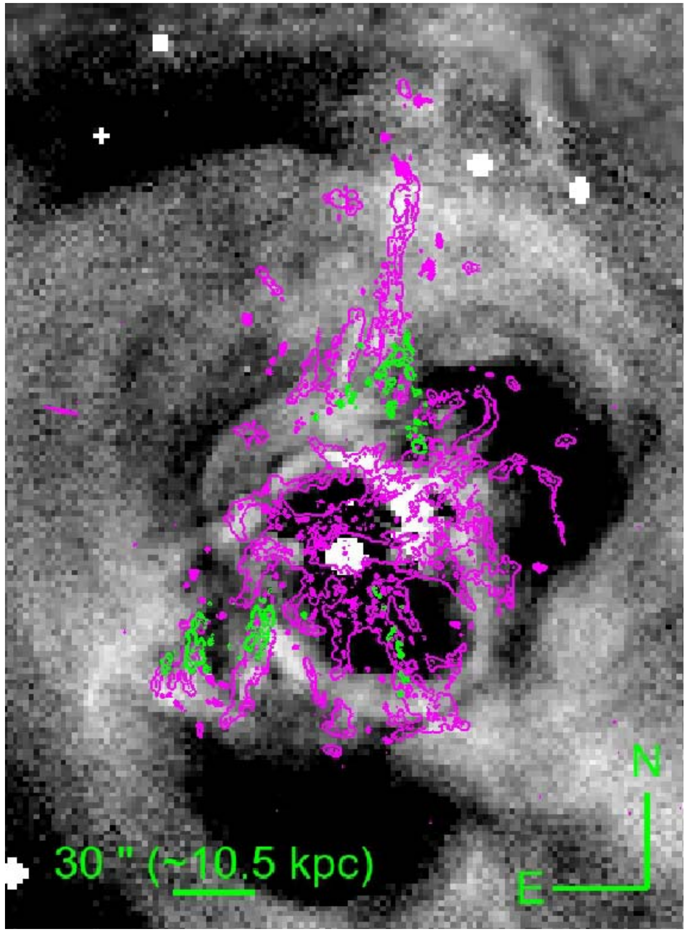
Richings & Faucher-Giguère 2017

Gas flow in cool core clusters

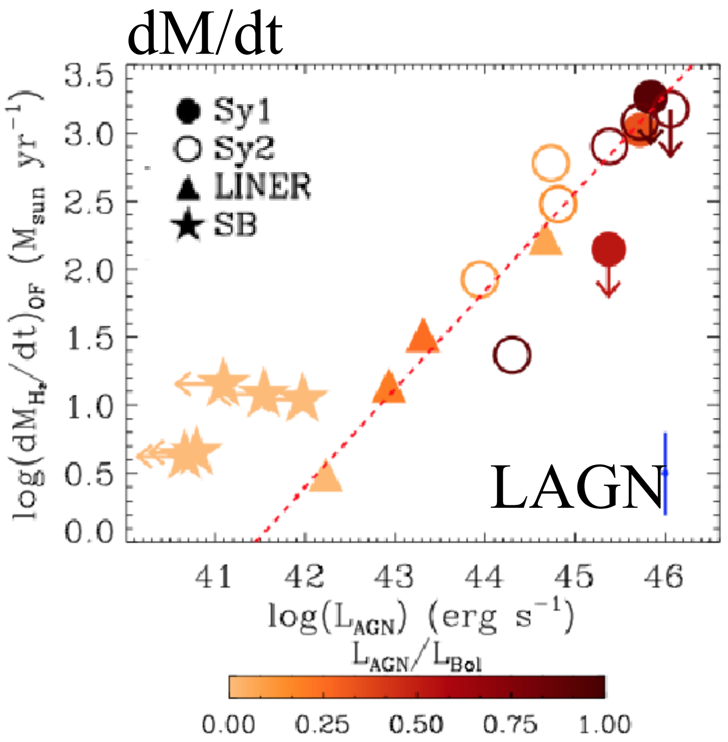


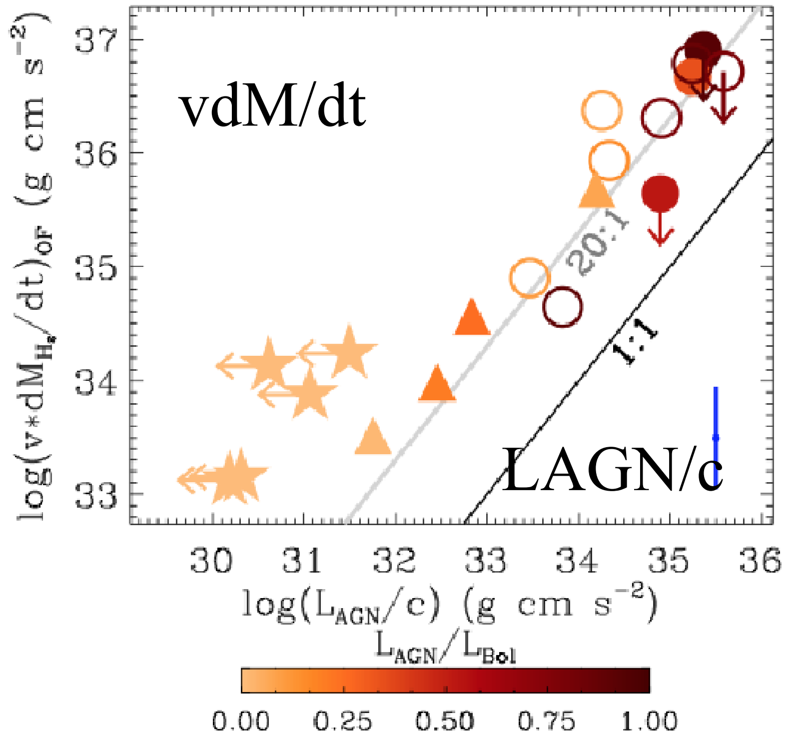
Molecular gas
Salomé et al 2006

Star formation (green)
Canning et al 2014



Outflow rates vs AGN power





For AGN-hosts, the outflow rate
Correlates with the AGN power

Cicone et al 2014

vdM/dt ~20 L_{AGN}/c

➔**energy-driven outflows**

(Zubovas & King 2012)

Ionized gas outflows more frequent

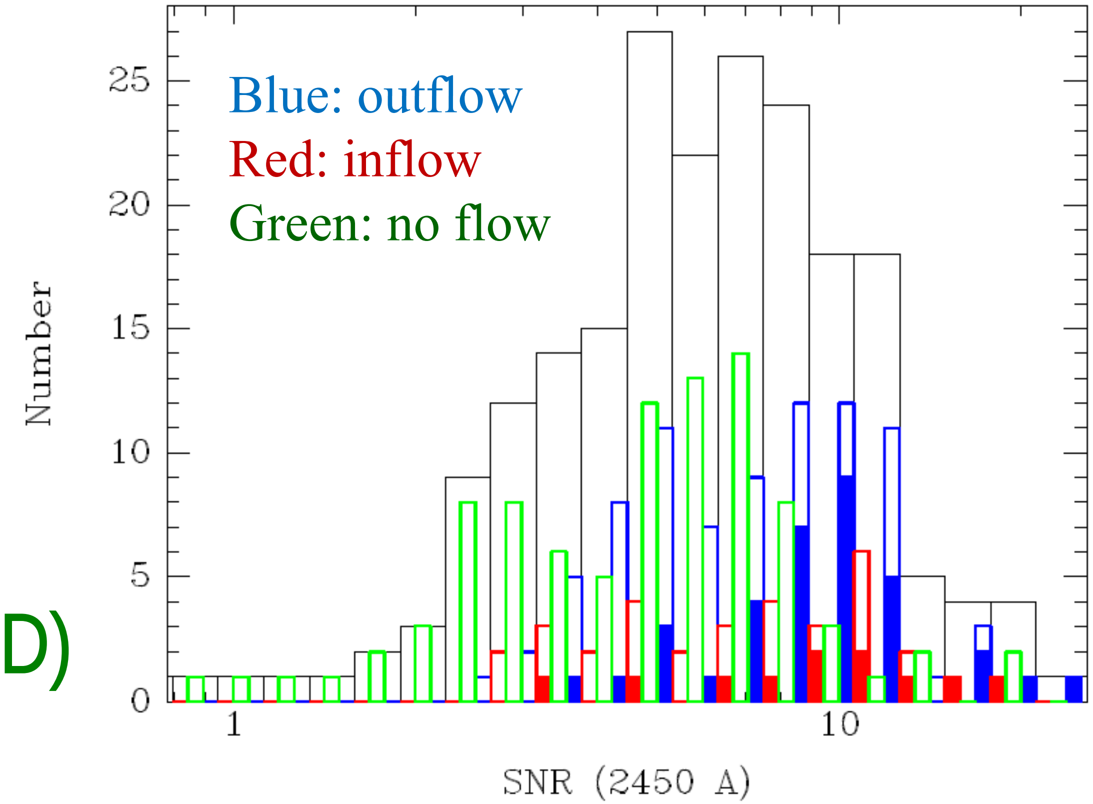
Statistics on 200 galaxies **0.4 < z <1.4** *(Martin C. et al 2012)*
2% of the FeII absorption outflow at 200Km/s, **20%** at 100km/s
Depends on the star formation rate *(FeII, MgII, Keck)*

Inflow or outflow

➔Collimated
Angle smaller at large V

Atomic gas (abs Na I D)

Rupke et al 2005

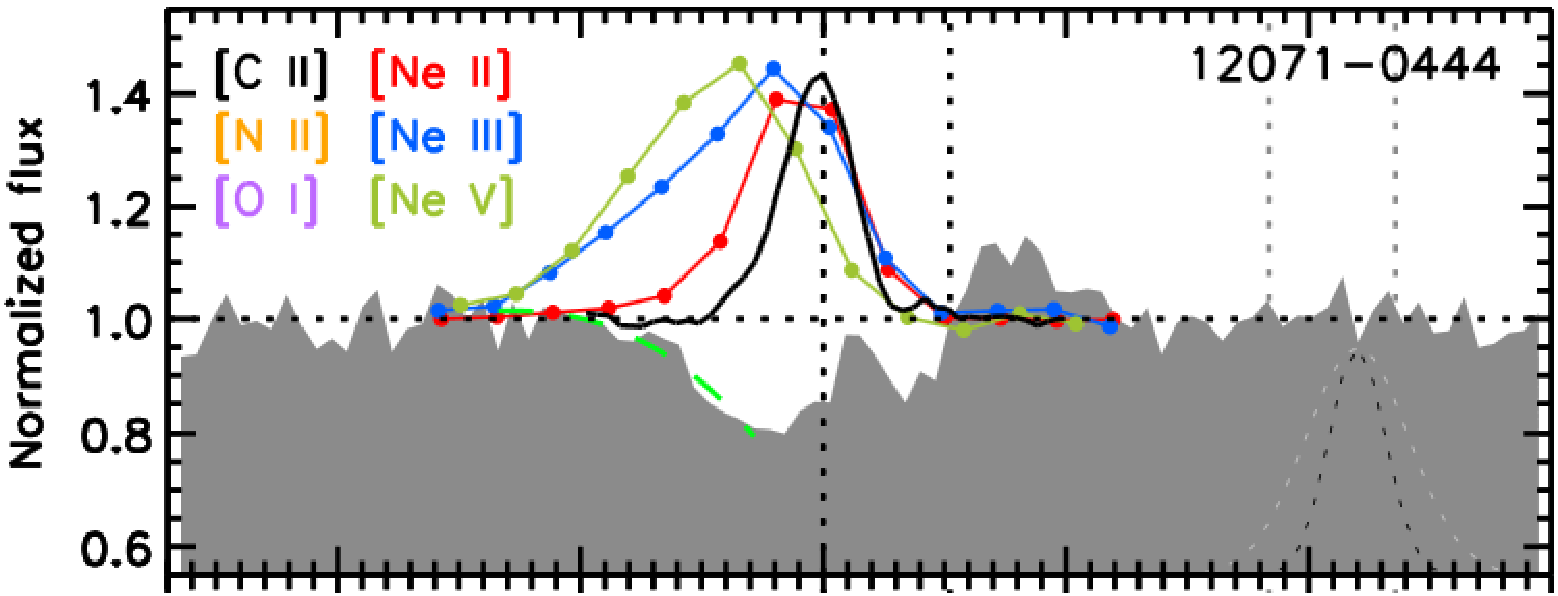


Molecular winds seen by Herschel

Absorption lines **blueshifted in 70% of objects** (43 nearby ULIRGs)
➔Outflow with a large angle (145°) *Veilleux et al 2013*

Only **10% of redshifted absorption**:
➔Accretion from filaments, plane geometry

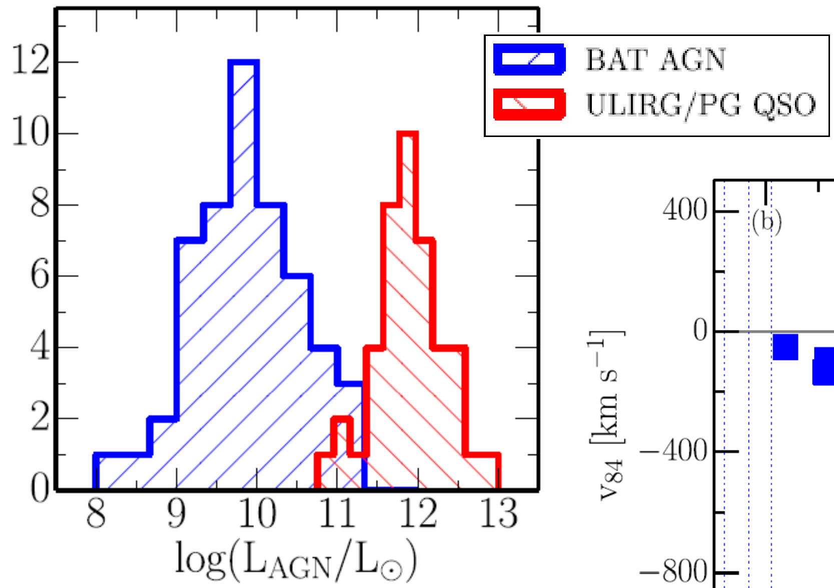
Vmax ~-1000km/s, Vmoy -200km/s, increases with L_{AGN}

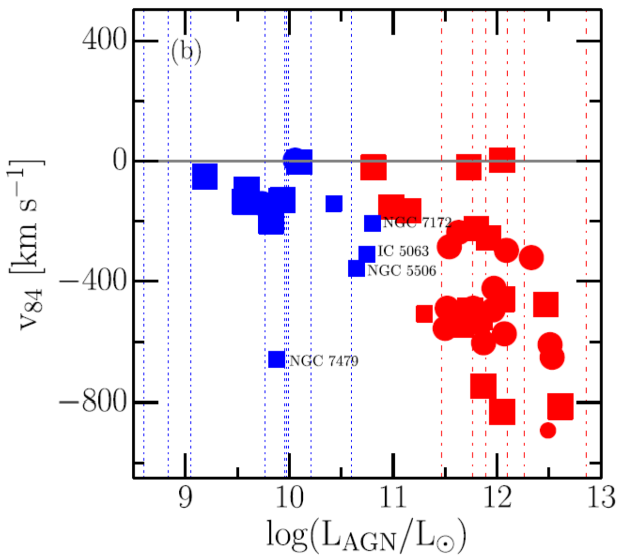


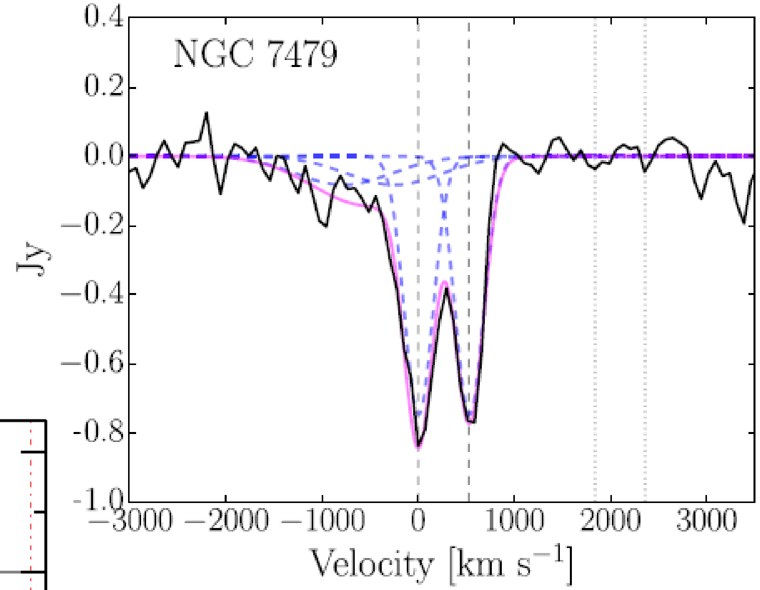
Statistics in 52 local AGN (< 50Mpc)

10-100 lower Luminosities than ULIRG, QSO *(Stone et al 2016)*
OH 119μm detected in 42, abs in 17: outflow in 4, inflow in 7
➔24% outflow, 40% inflow

➔ AGN-driven outflows require a QSO

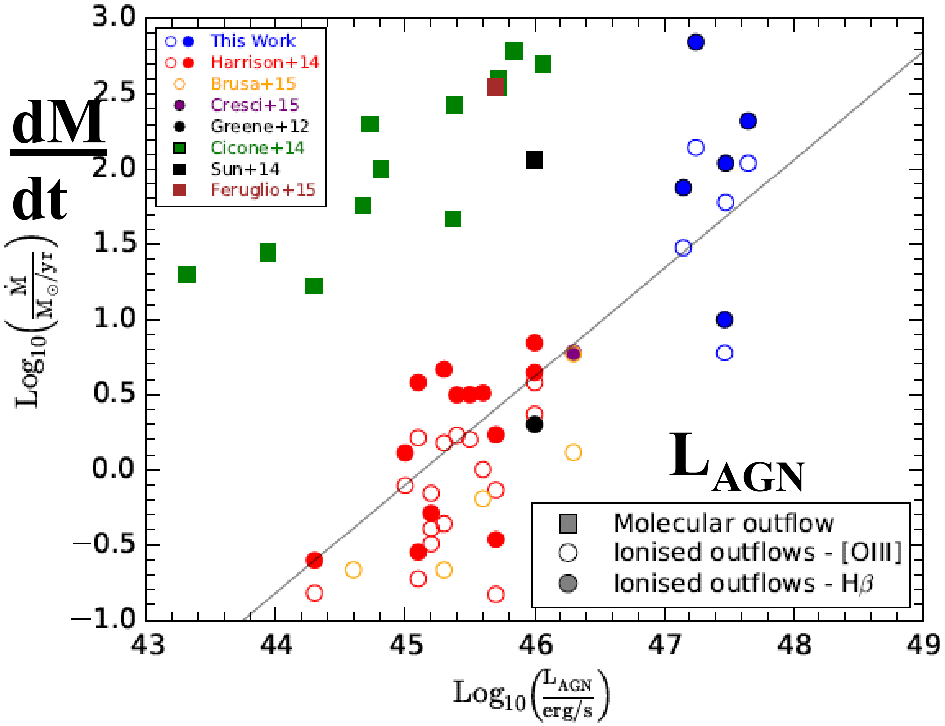






84% of velocities
< -300km/s

Molecular vs ionized outflows



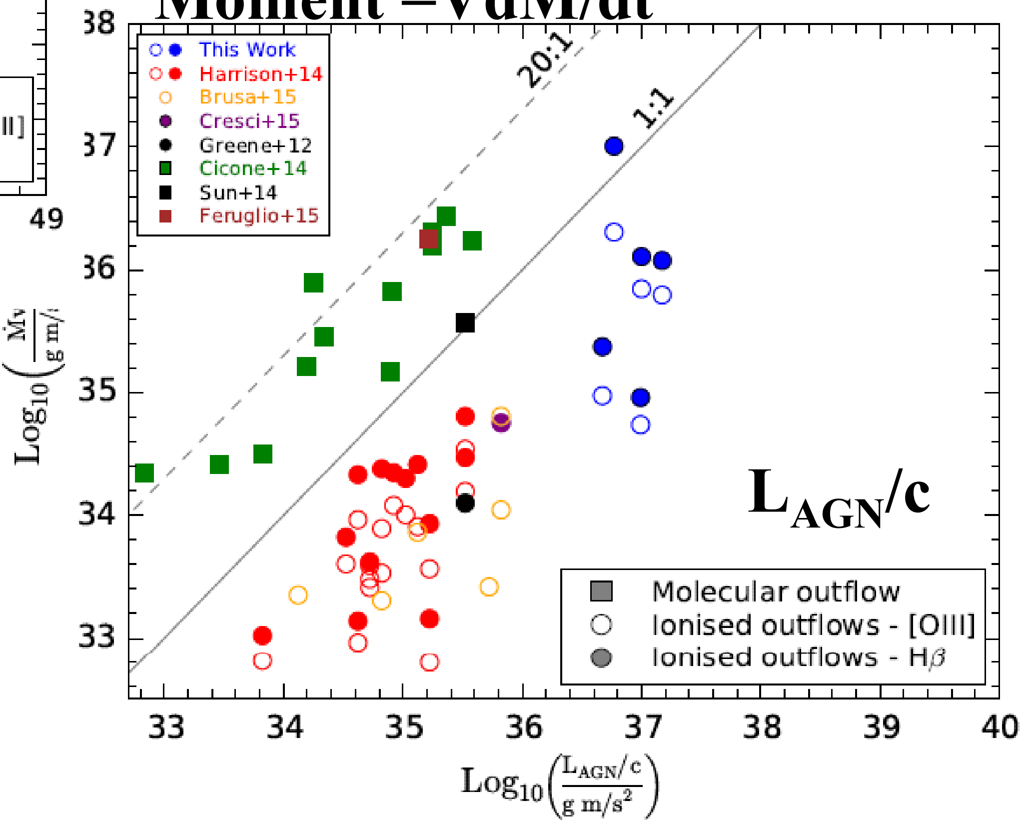
6 QSO at z=2.4

Carniani et al 2015

Only one object in common

AGN varies in amplitude

Moment =VdM/dt



Kinetic power of ionized gas

<0.1% LAGN

Molecular gas outflow

50x ionized gas outflow

Different acceleration mechanisms

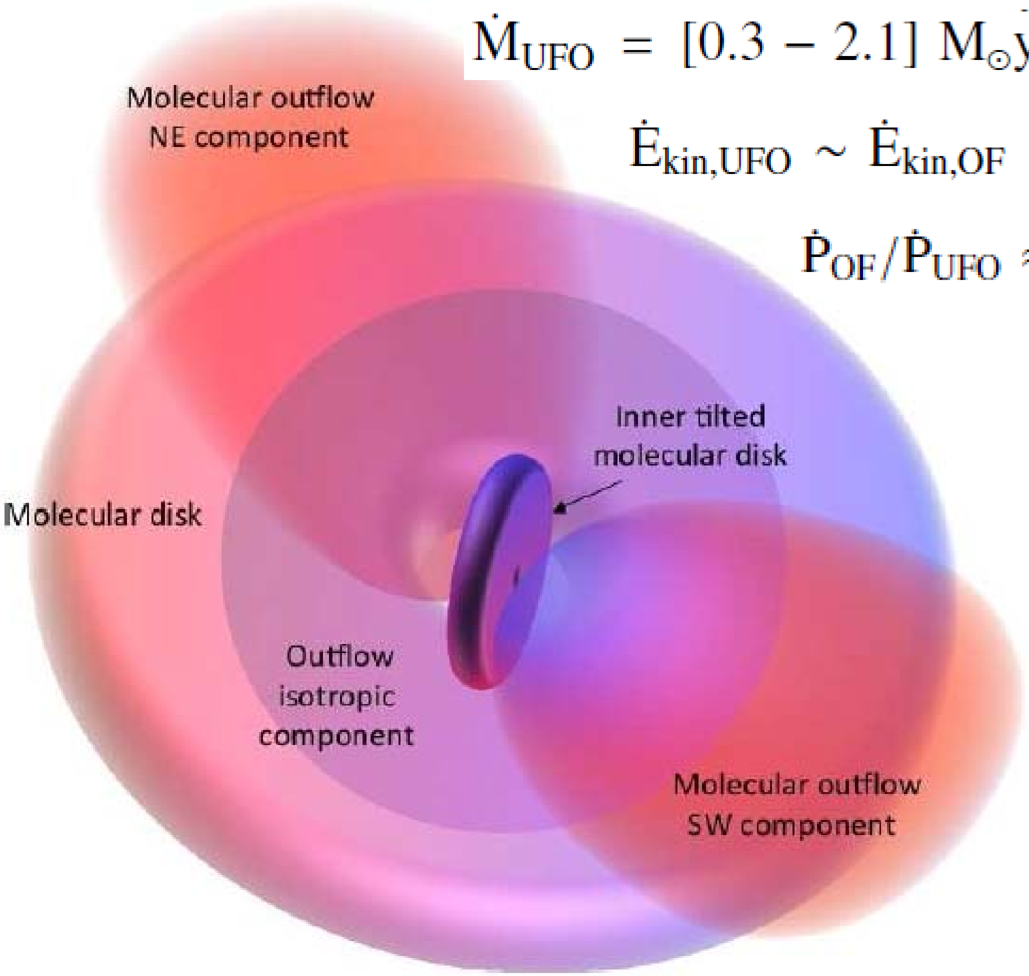
UFO+ molecular outflow Mrk231

V_{UFO} = 20 000 km/s
1kpc in molecules, 3kpc in atomic gas
(Rupke & Veilleux 2011) **Loading factor η > 2.5**

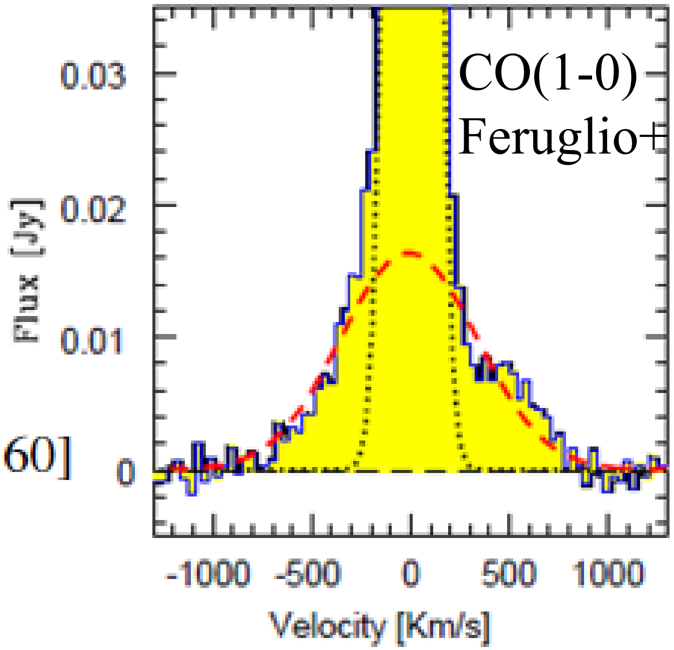
$$\dot{M}_{UFO} = [0.3 - 2.1]\ M_{\odot} yr^{-1}$$

$$\dot{E}_{kin,UFO} \sim \dot{E}_{kin,OF}$$

$$\dot{P}_{OF}/\dot{P}_{UFO} \approx [30 - 60]$$



+HCN
Aalto +12

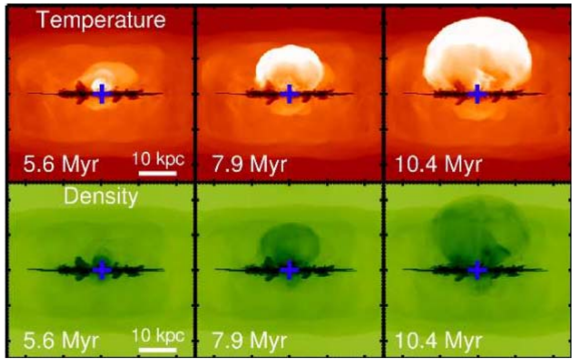


+ Radio jet in the N
+ SB wind in the S
Ejected gas 10^7-10^8Mo
Outflow of 700Mo/yr

Feruglio et al 2015

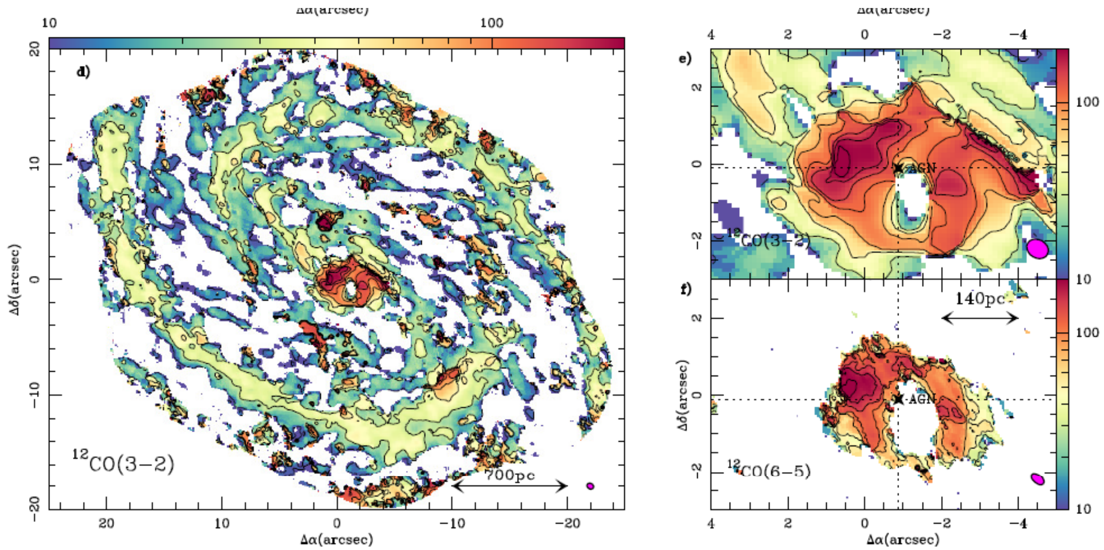
How much coupling?: jet in the plane of N1068

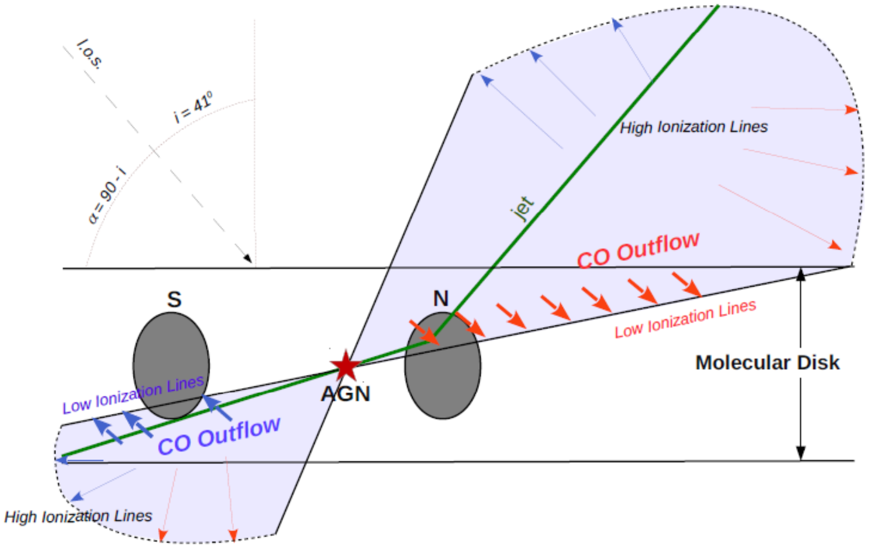
AGN wind simulated



Gabor & Bournaud 2014:

No quenching effect



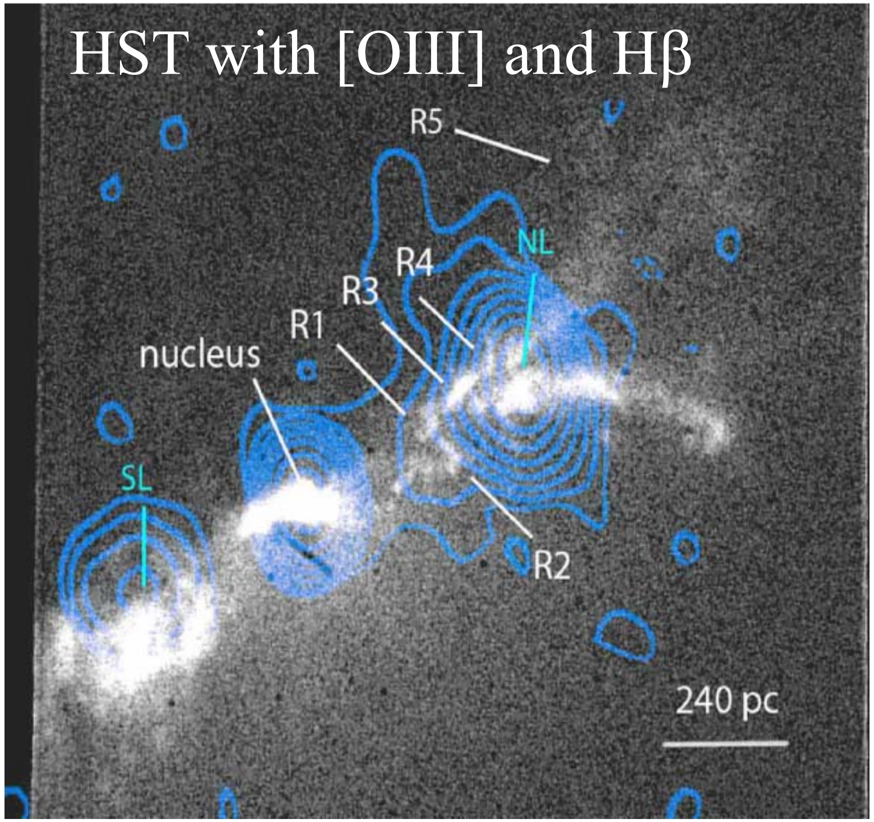


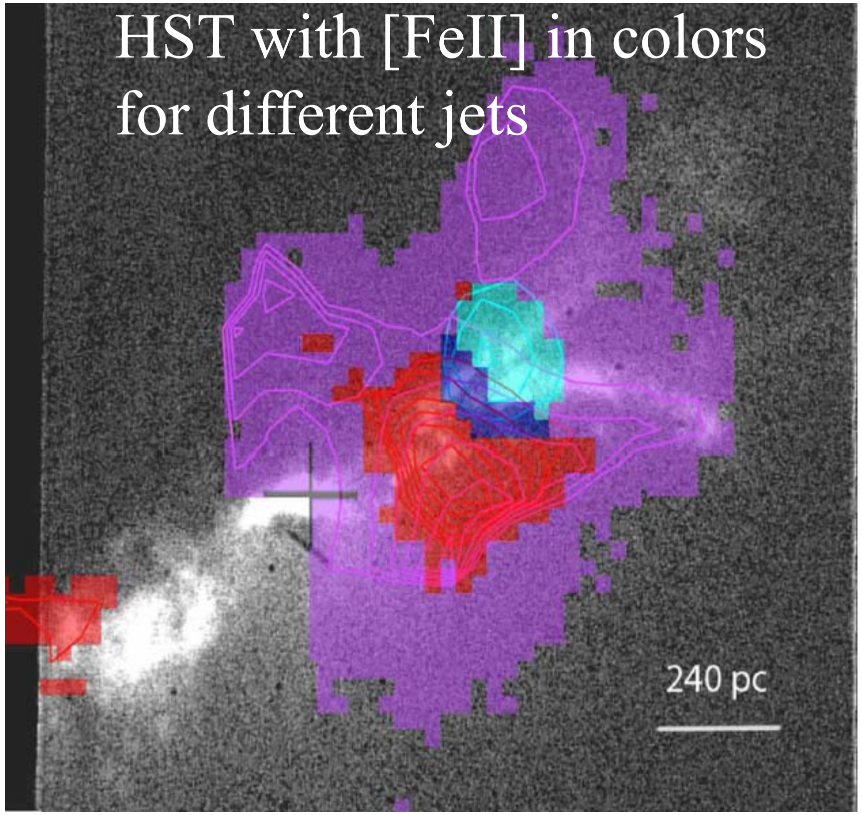
Outflow of 63Mo/yr
About 10 times the SFR in this CMD region

Garcia-Burillo et al 2014

IC5063: multiple winds along the jet

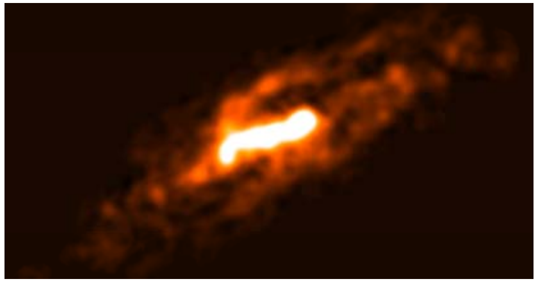
VLT SINFONI, NIR H_2, Fe lines
Blue and Red-shifted lines in 4 points, where the jet is diverted

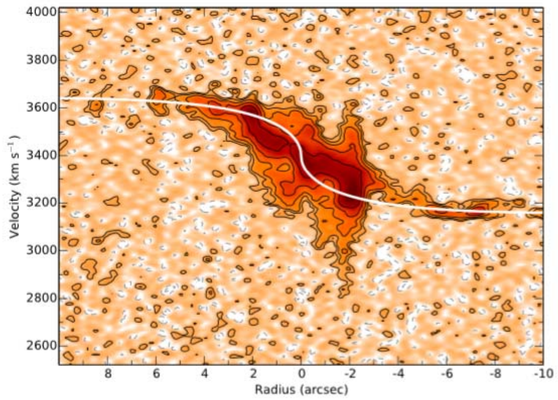




Dasyra et al 2015

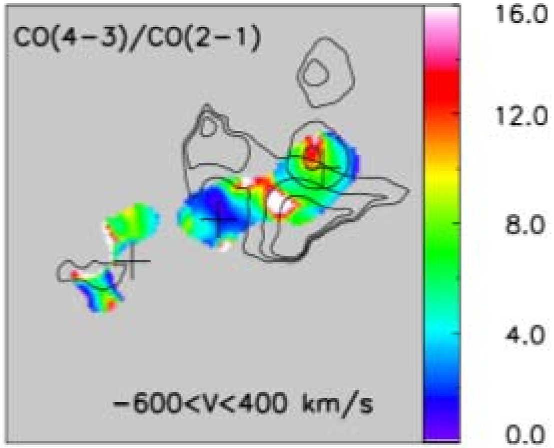
Radio mode: molecular flow IC5063

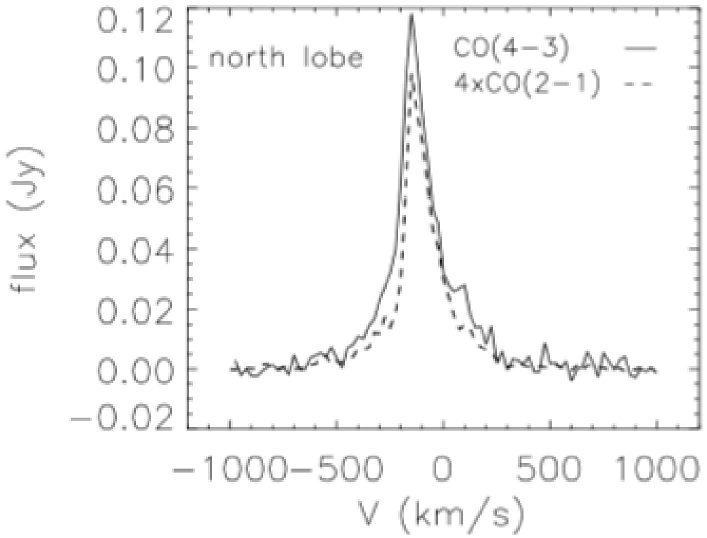


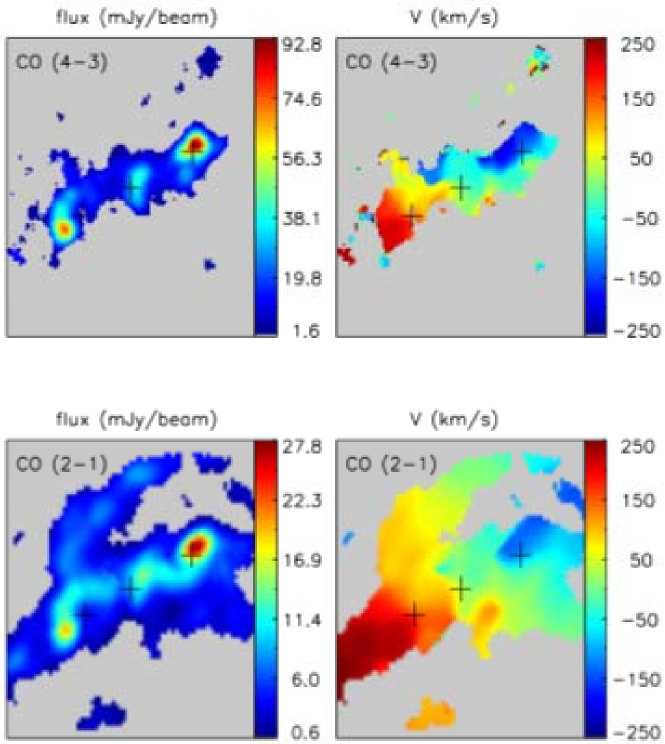


Morganti et al 2015

Some of the gas optically thin in the flow?





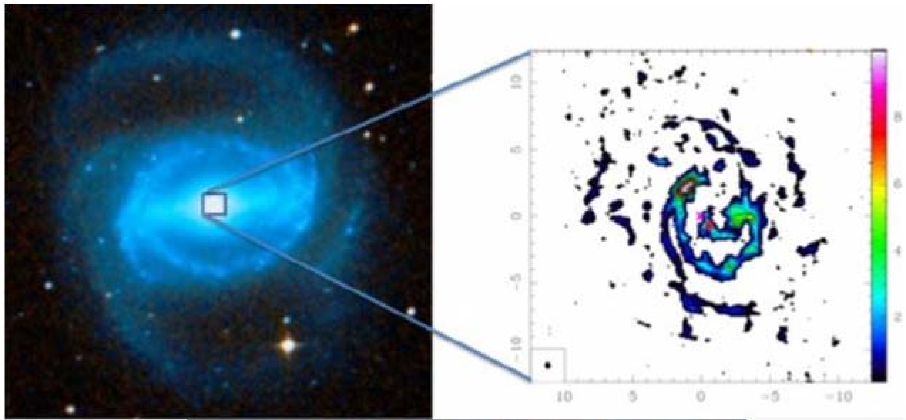


CO(4-3)

CO(2-1)

Dasyra et al 2016

BH feedback in low-lum AGN



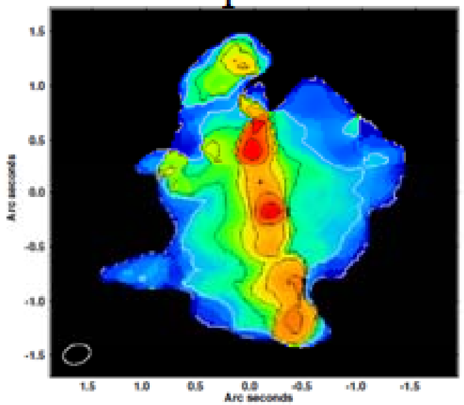
The smallest outflow detected
AGN feedback
V=100km/s, 7% of the mass
$M_{BH} = 4\ 10^6 Mo$
Flow momentum $=10\ L_{AGN}/c$

Combes et al 2013

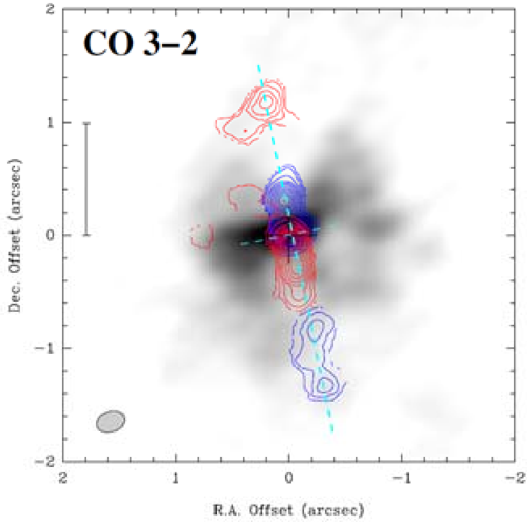
N1433
CO(3-2)
ALMA
On HST

N1377 precessing jet

Dispersion



Beam 0.2 arcsec



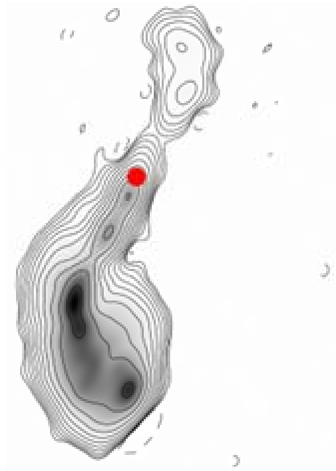
Aalto et al 2015

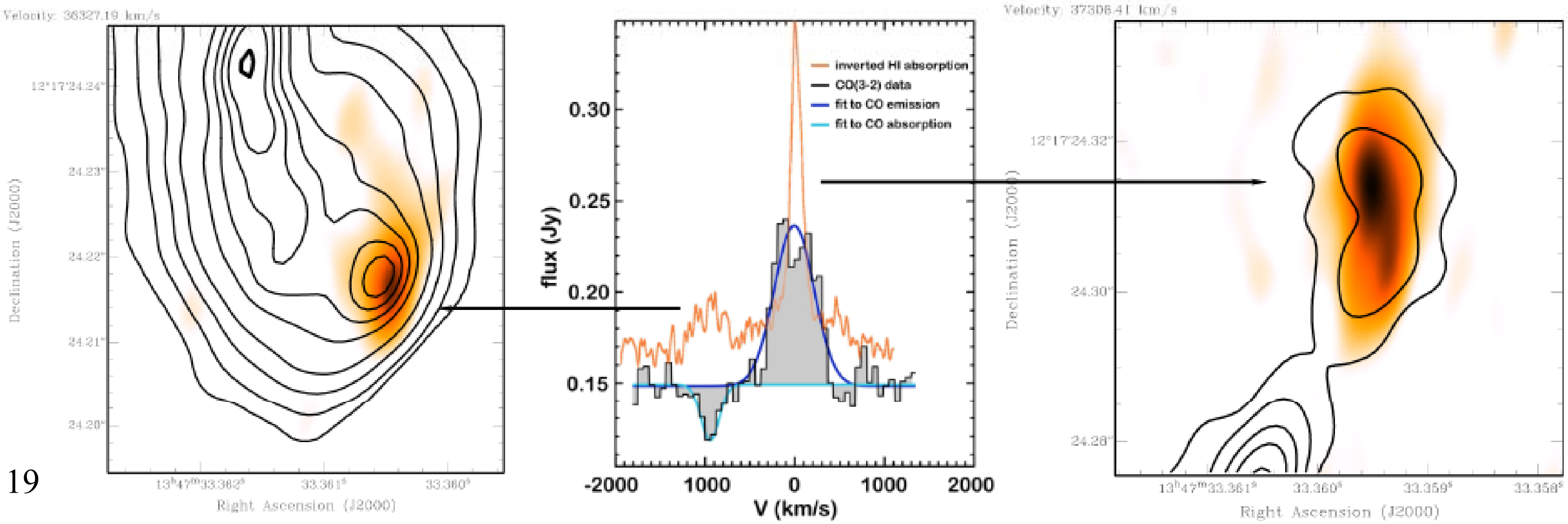
Positive AGN feedback: jet-induced star formation

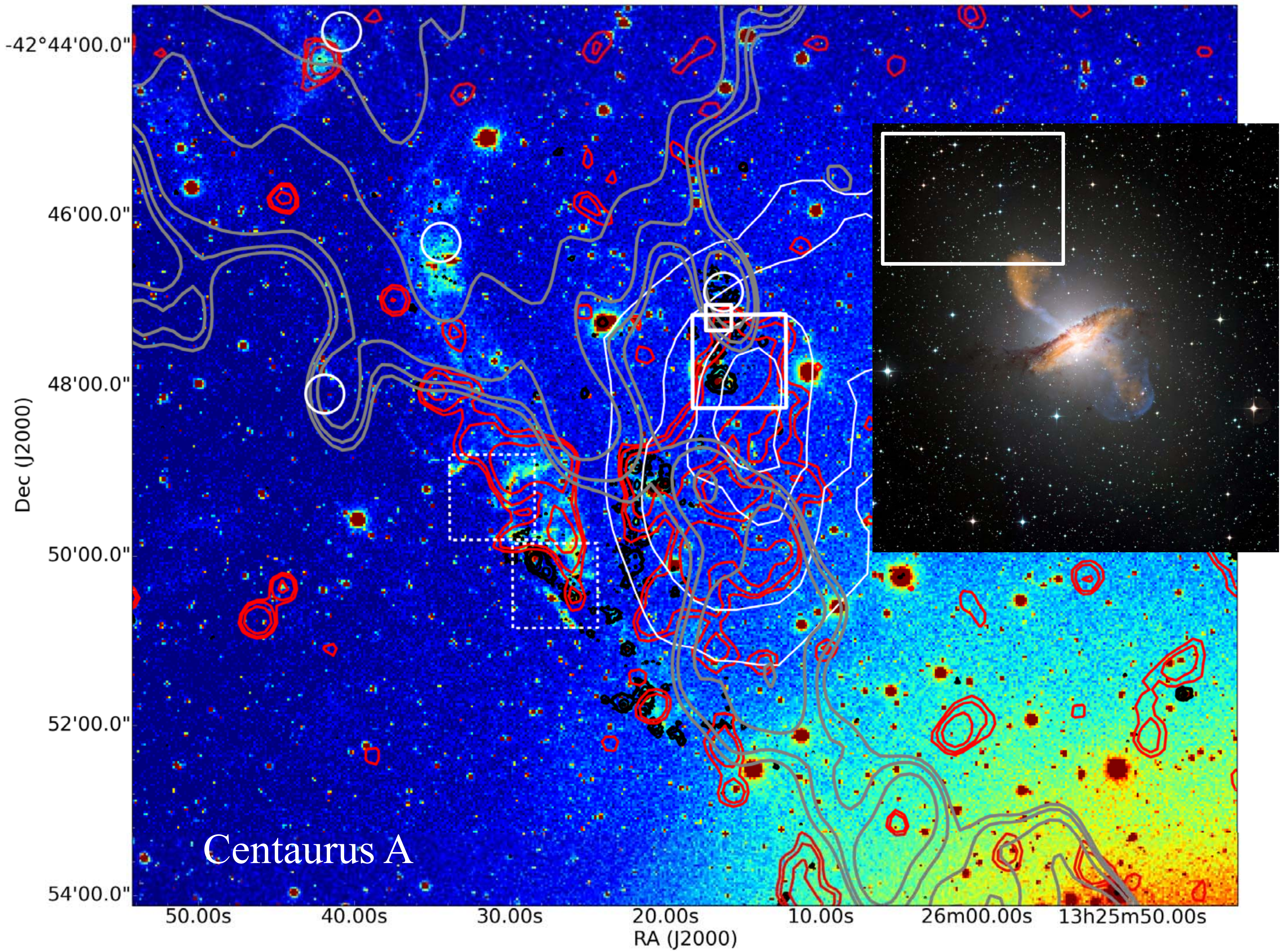
AGN radio source 4C12.50: young or rejuvenated

The gas flow starts at 100 pc from the nucleus
Where the jet interacts with the gas medium

Morganti et al 2013, Dasyra & Combes 2012

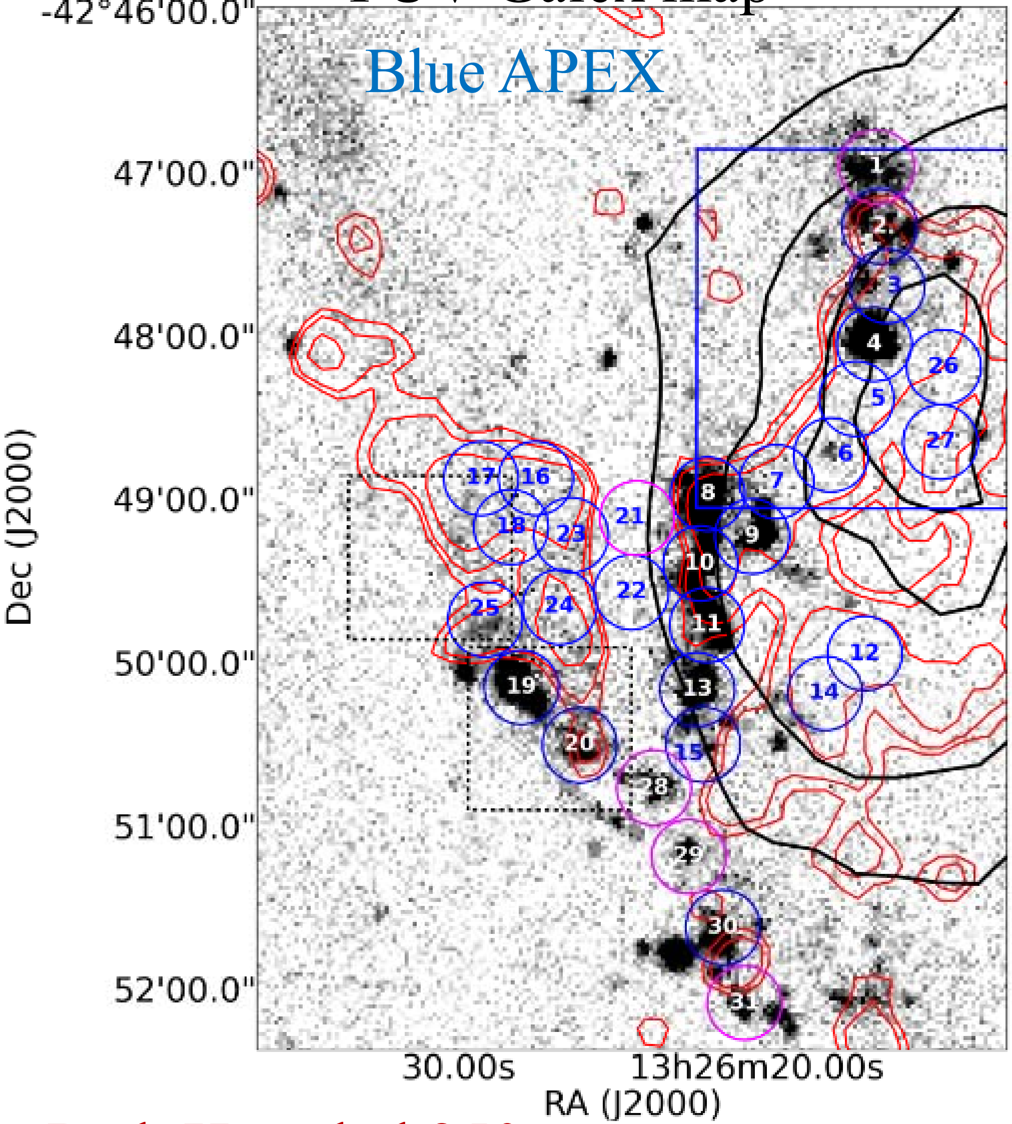


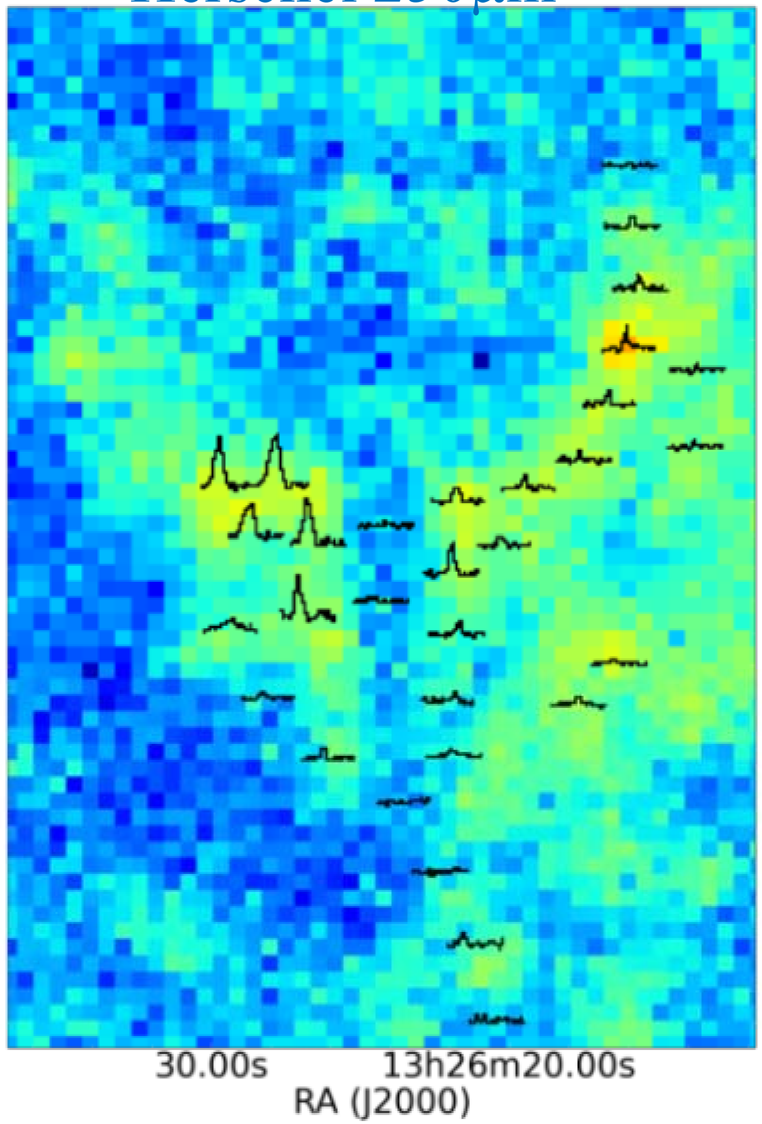




-42°44'00.0"
46'00.0"
48'00.0"
50'00.0"
52'00.0"
54'00.0"
Dec (J2000)
50.00s
40.00s
30.00s
20.00s
10.00s
26m00.00s
13h25m50.00s
RA (J2000)
Centaurus A

HI, ionized and H_2 gas in the shell





Red: Herschel 250μm

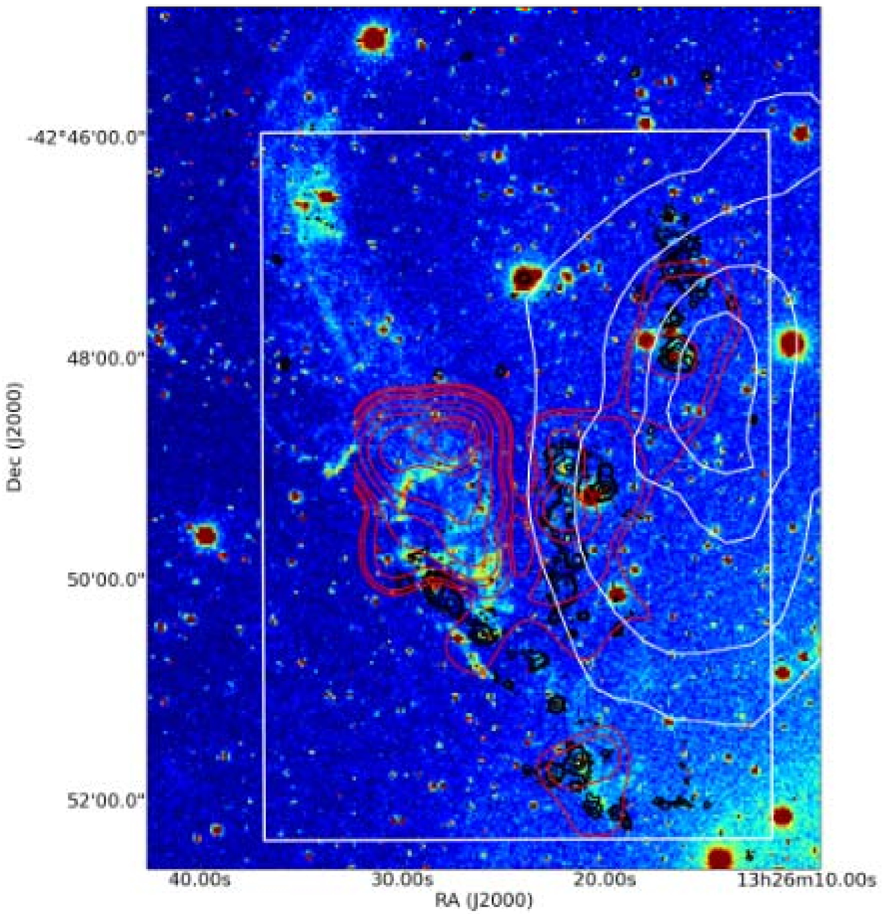
Salome et al 2016

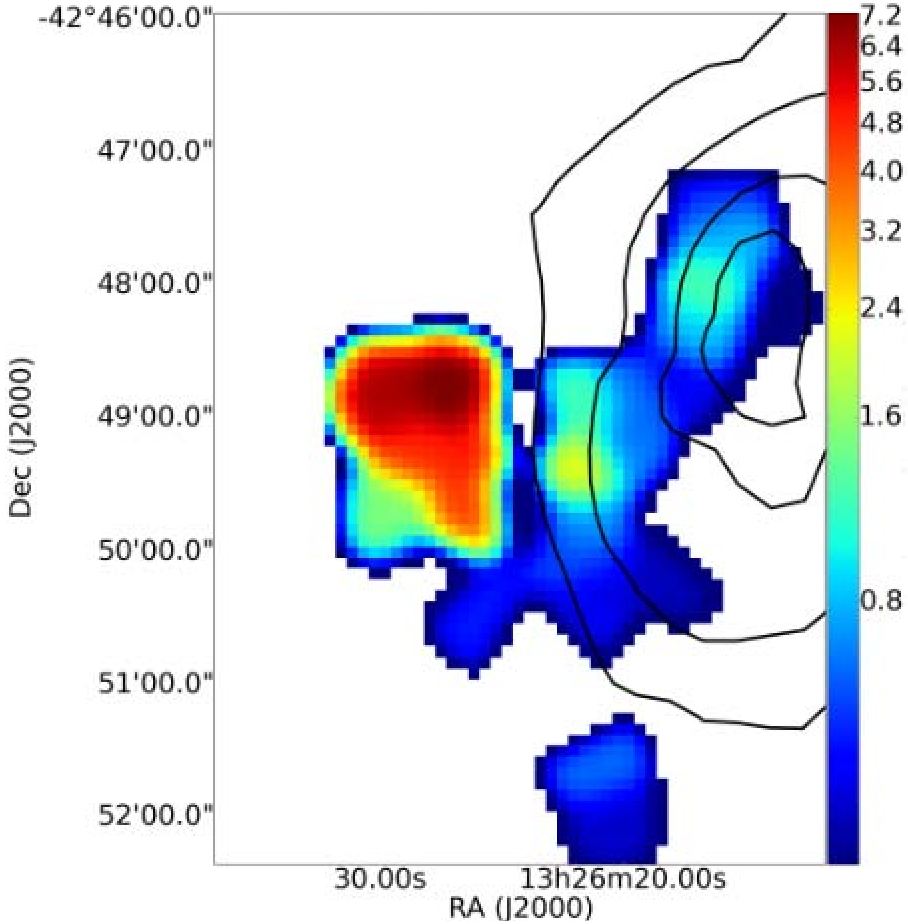
Molecular gas in the shell

H_2 dominant at E, while HI at W

Hα map

Salome et al 2016

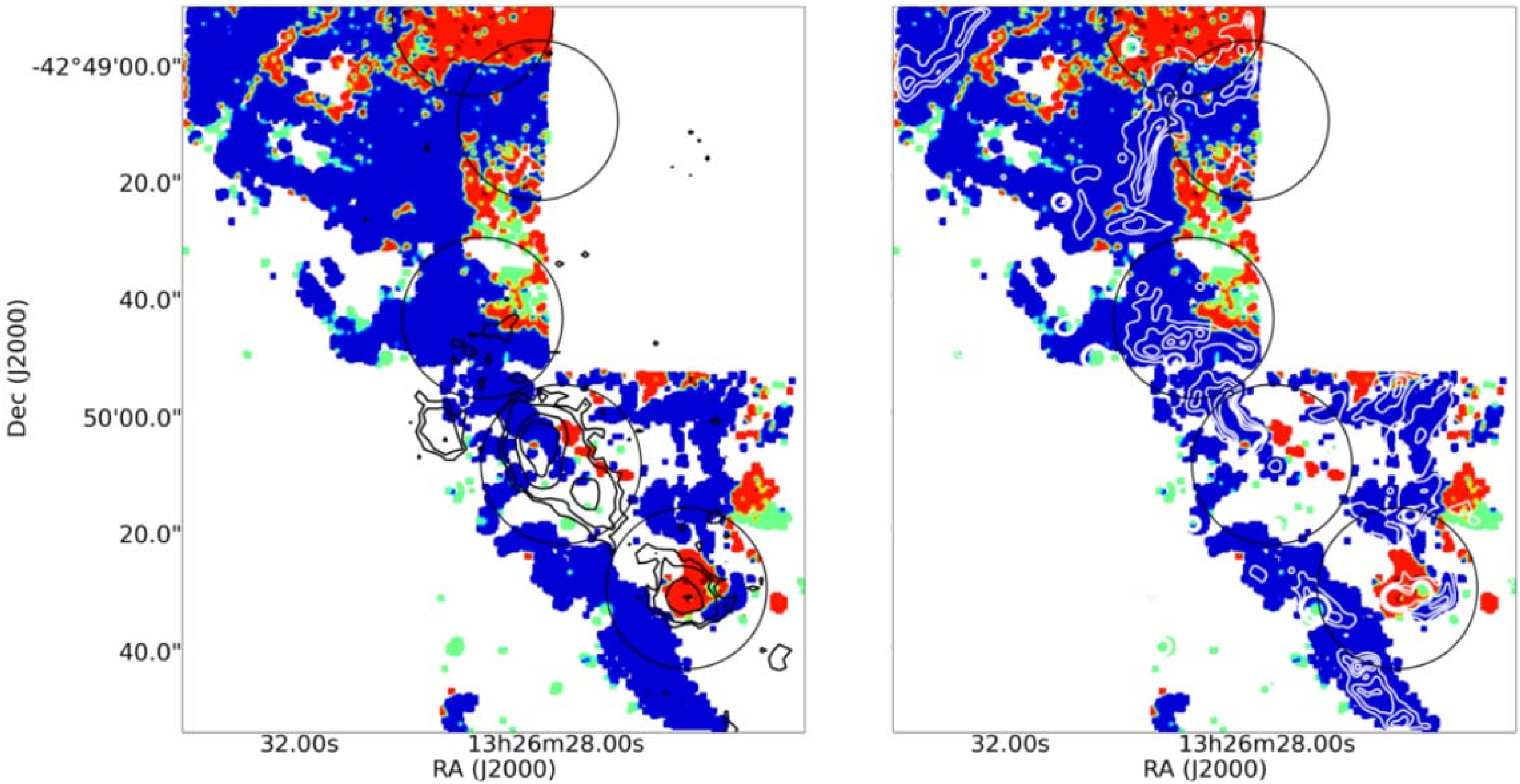




Red: CO, White: HI, **FUV-Galex: black**   CO21, HI contours

Ionised gas excitation -MUSE

Blue: AGN/shocks   Green: Star formation Red: Composite

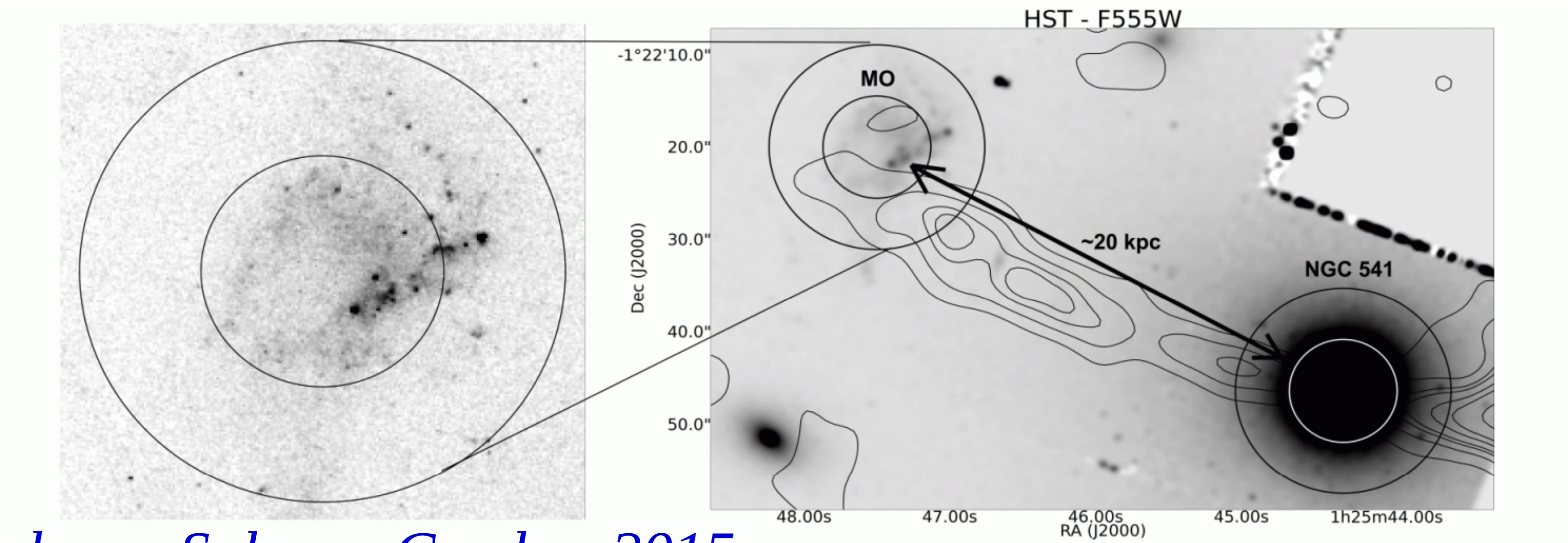


From BPT diagram (Salome et al 2016)

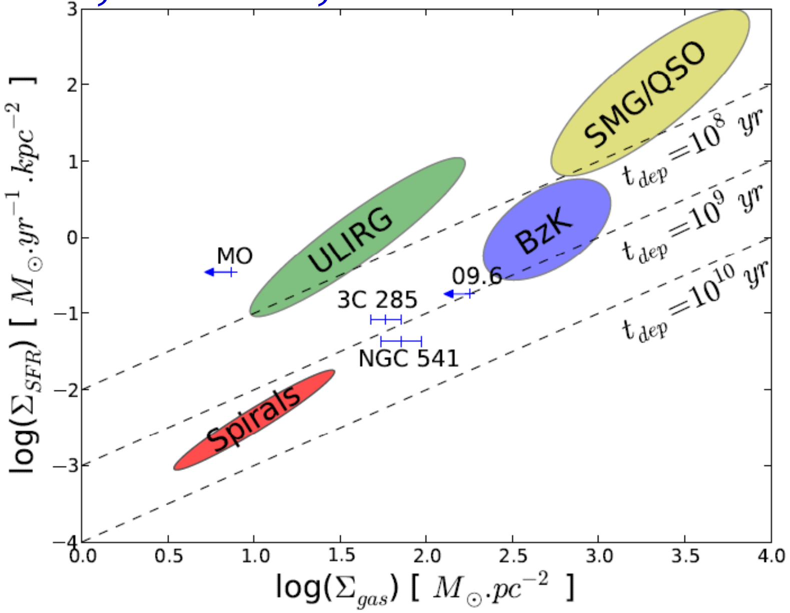
Cases of jet-induced SF

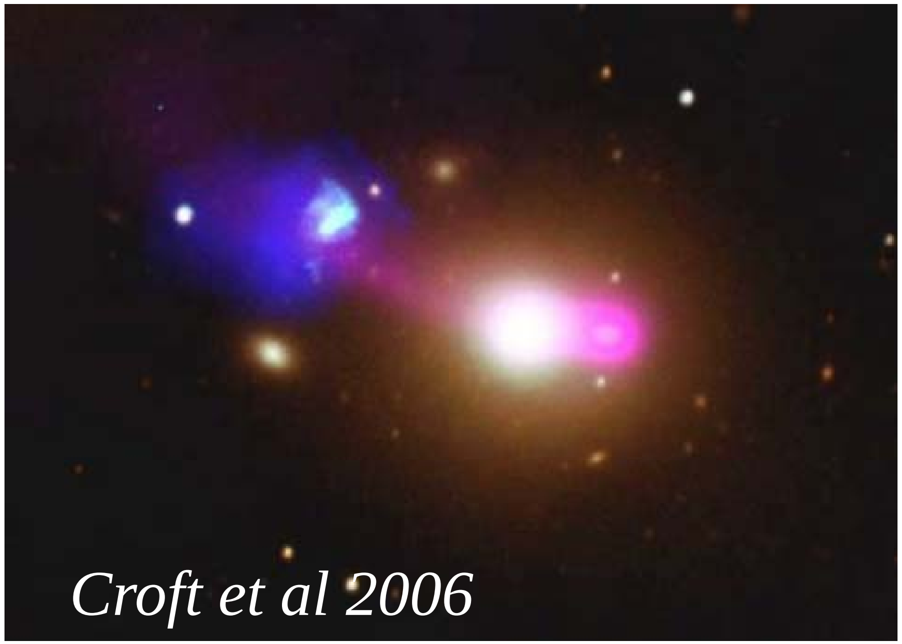
N541/Minkowski Object

CO detected only in the host



Salome, Salome, Combes 2015

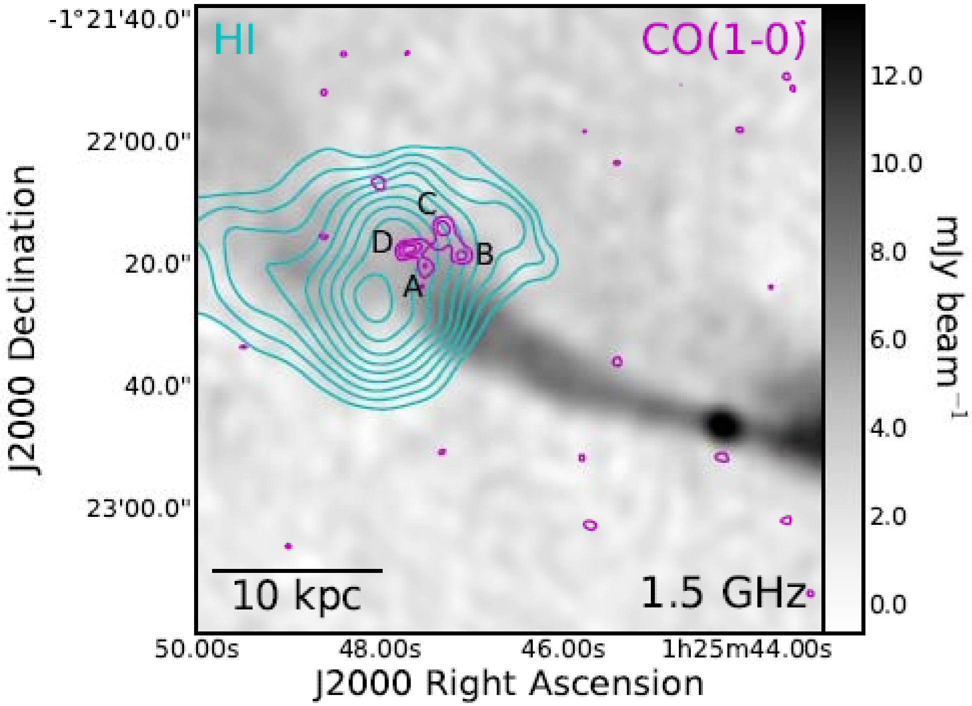


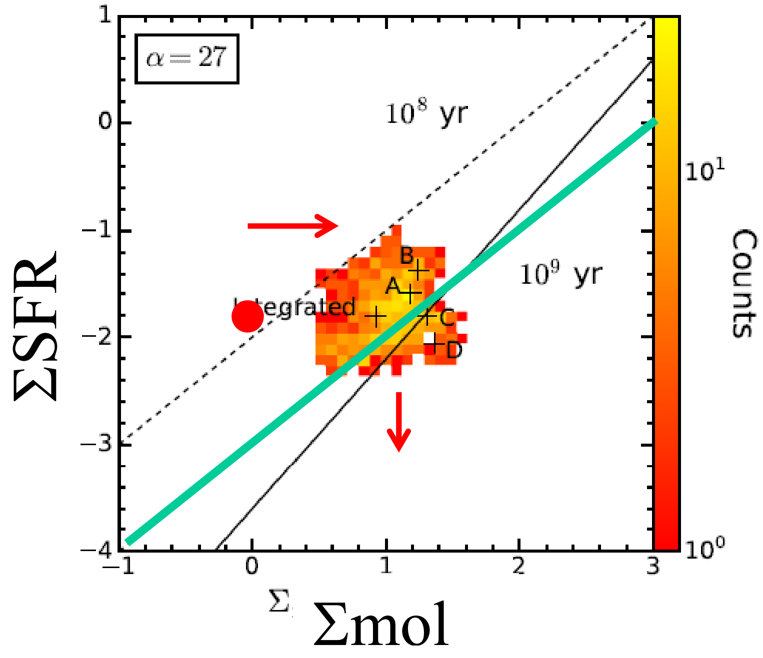


Croft et al 2006

CO detection by ALMA

Compatible with the IRAM upper limit





Lacy et al 2017

When taken into account metallicity effects on CO-to-H2 conversion and excitation by shocks (less SFR)
➔ Low SF efficiency

Summary

2 types of AGN feedback: galactic winds, and radio jets
-- more easy to see the radio mode

AGN driven winds: rare in low-luminosity objects

Molecules are destroyed, but then clouds re-condense

Molecular outflows: loading factor between 1 and 10
Energy conserving

AGN positive feedback, SF triggering by the radio jet
but low efficiency