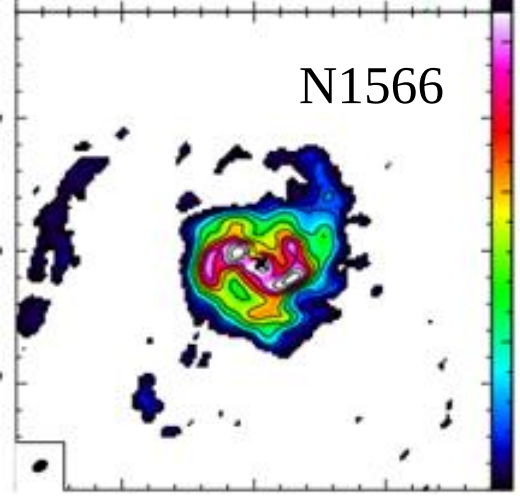
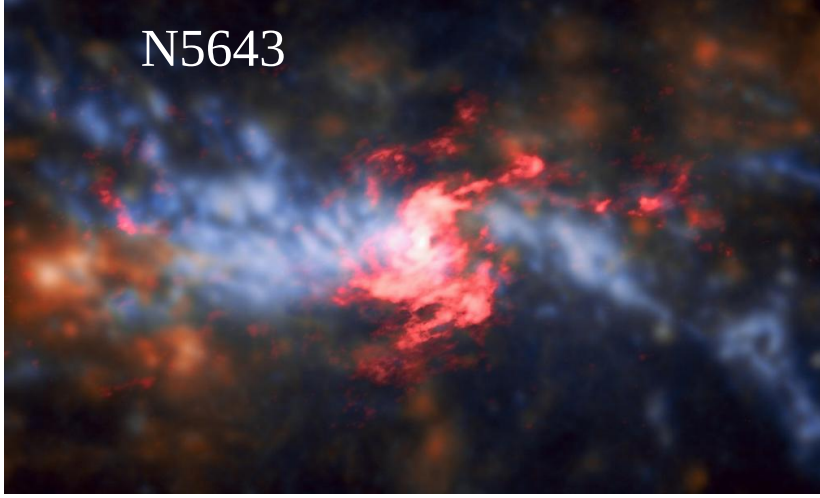
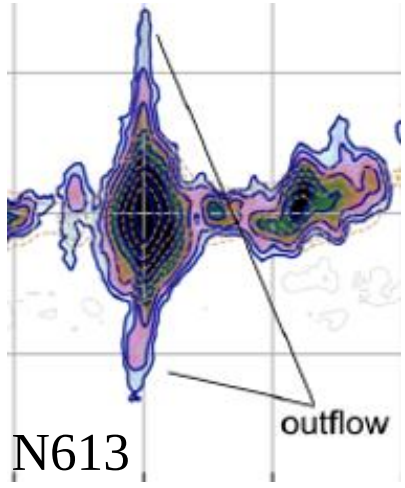
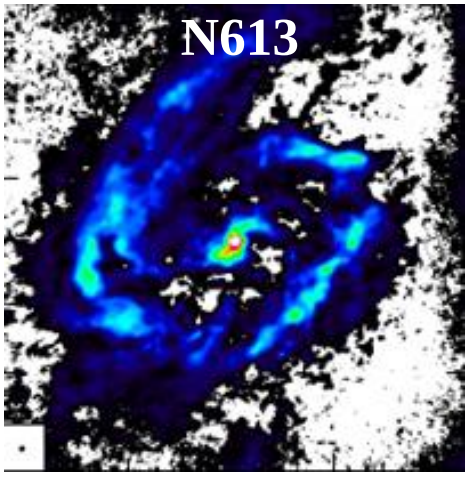




Active Galactic Nuclei and ALMA

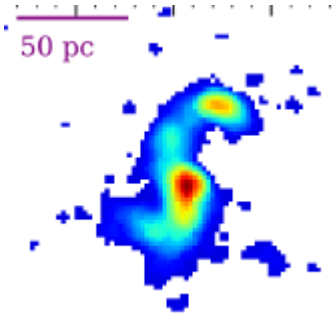




Françoise Combes
Observatoire de Paris

March 2021

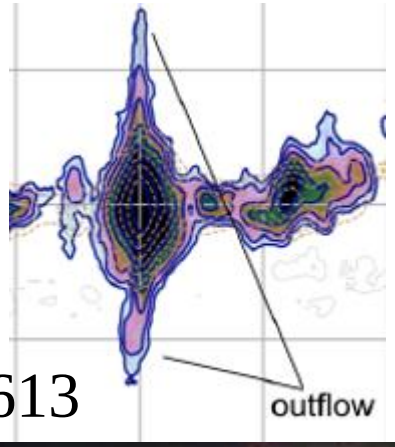
Outline



N1808

➔Feeding the black hole:Angular momentum transfer

Dynamical features: nuclear bars & spirals



N613

➔Molecular outflows

Feedback from the Active Nucleus

➔Molecular tori

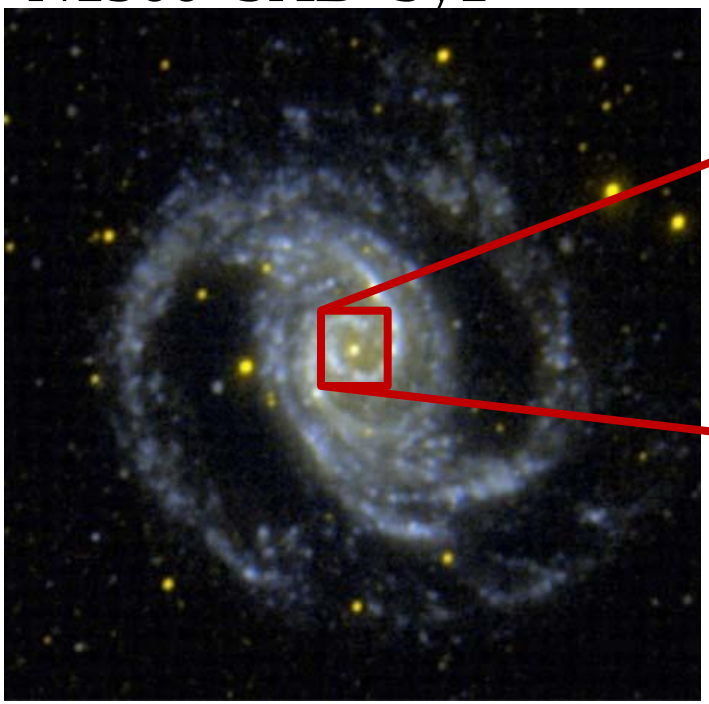
Decoupling, different orientations

➔Mass of the Black Holes

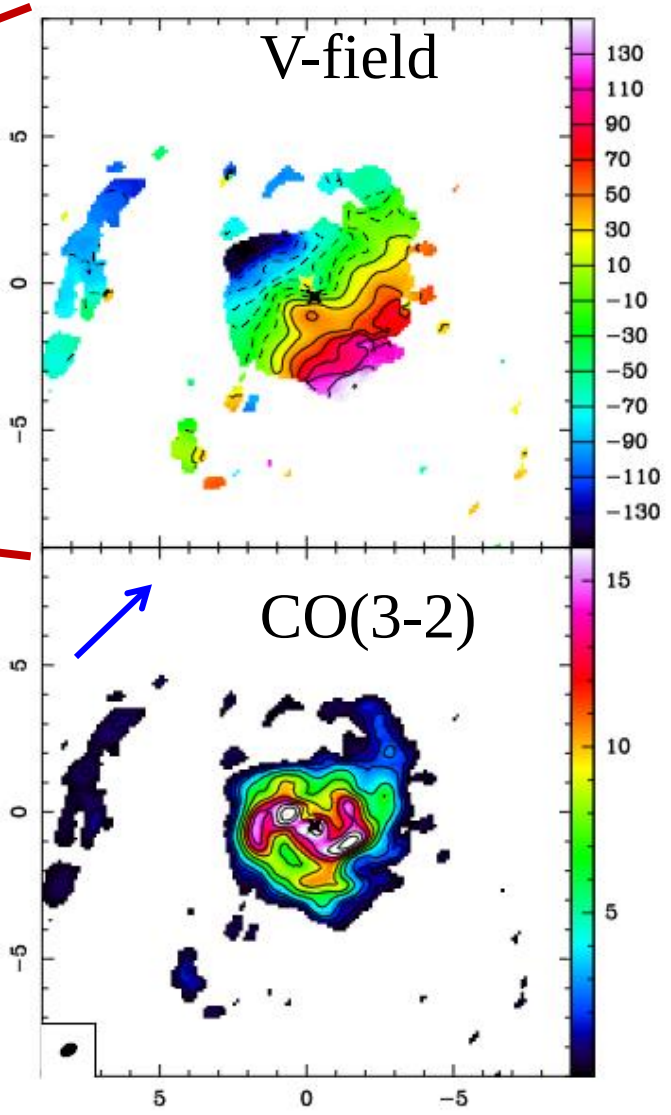
N4258

The barred NGC1566: feeding phase

N1566 SAB Sy1



4 arcmin

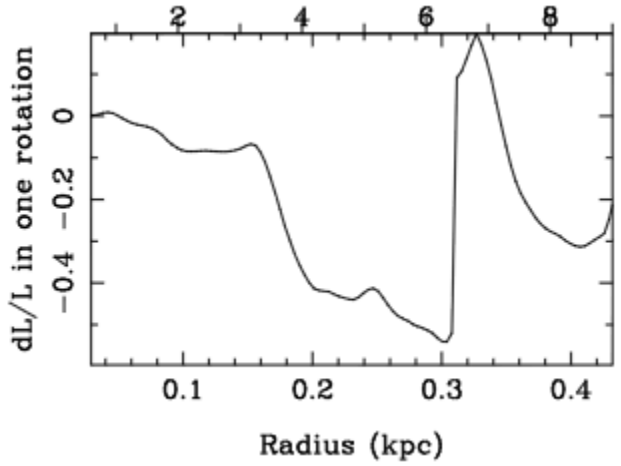


ALMA: mapping inside the nuclear ring

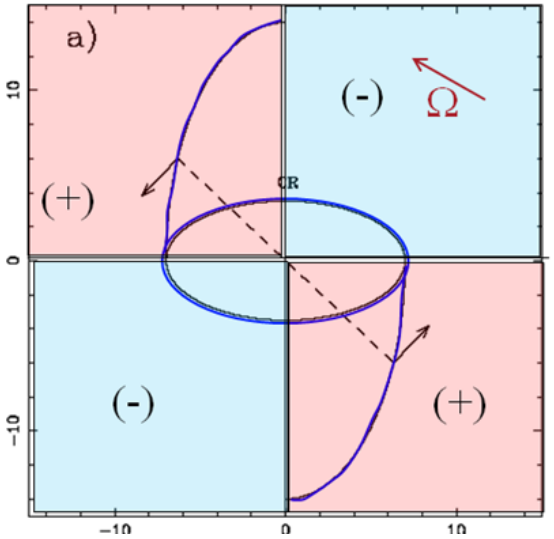
FOV=18 ”

Combes et al 2014

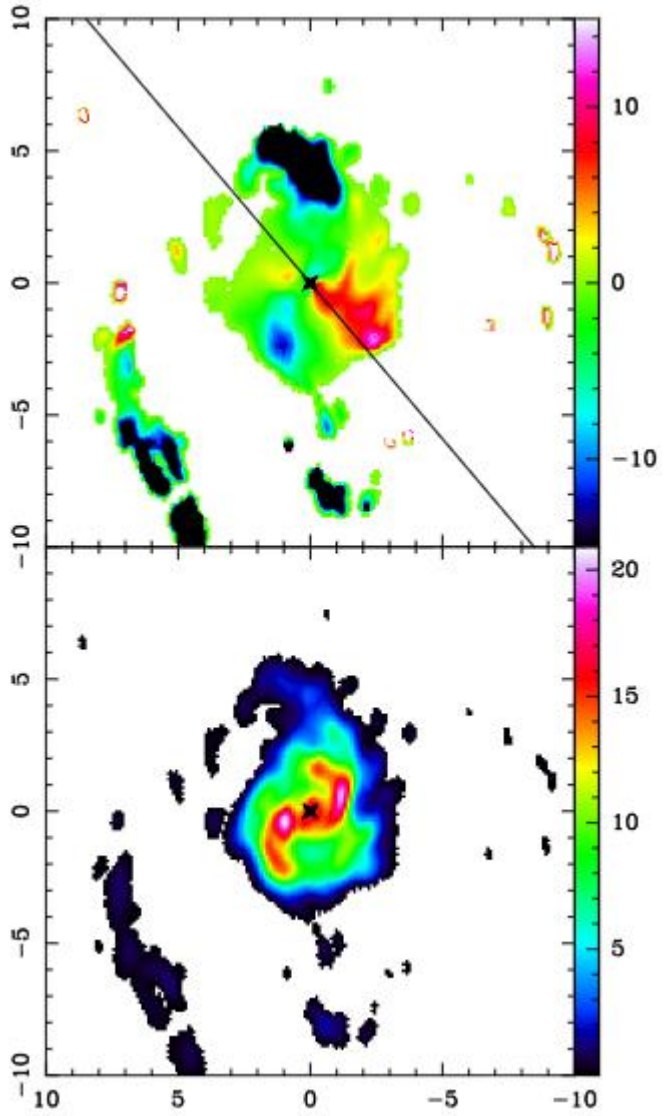
NGC1566: gravitational torques



Gas is driven inwards



Torques on deprojected image



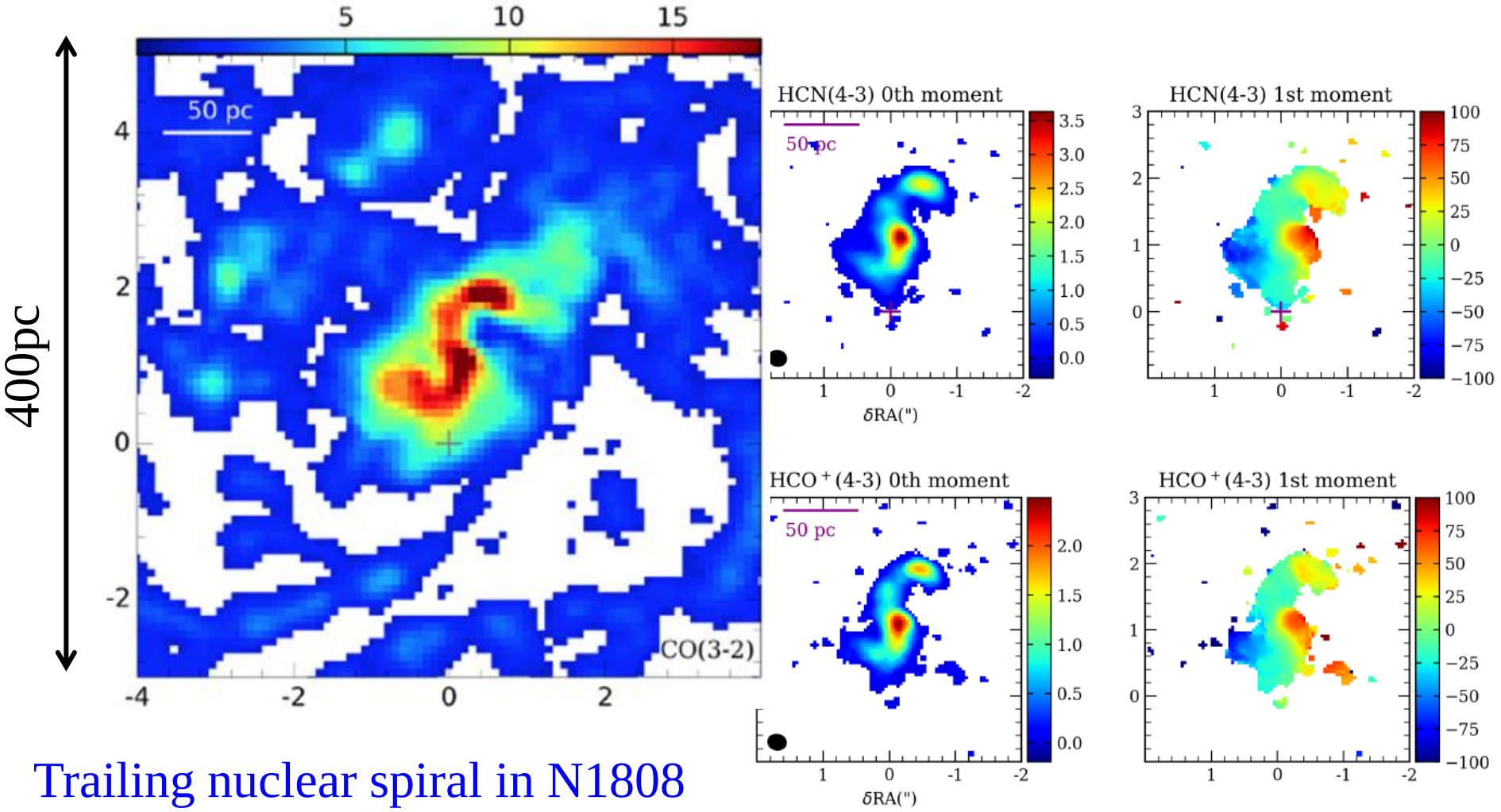
Trailing spiral inside the nuclear ring of the bar

➔ influence on the dynamics

also in N613, N1808

Audibert et al 2020

Beam 0.08” =4pc



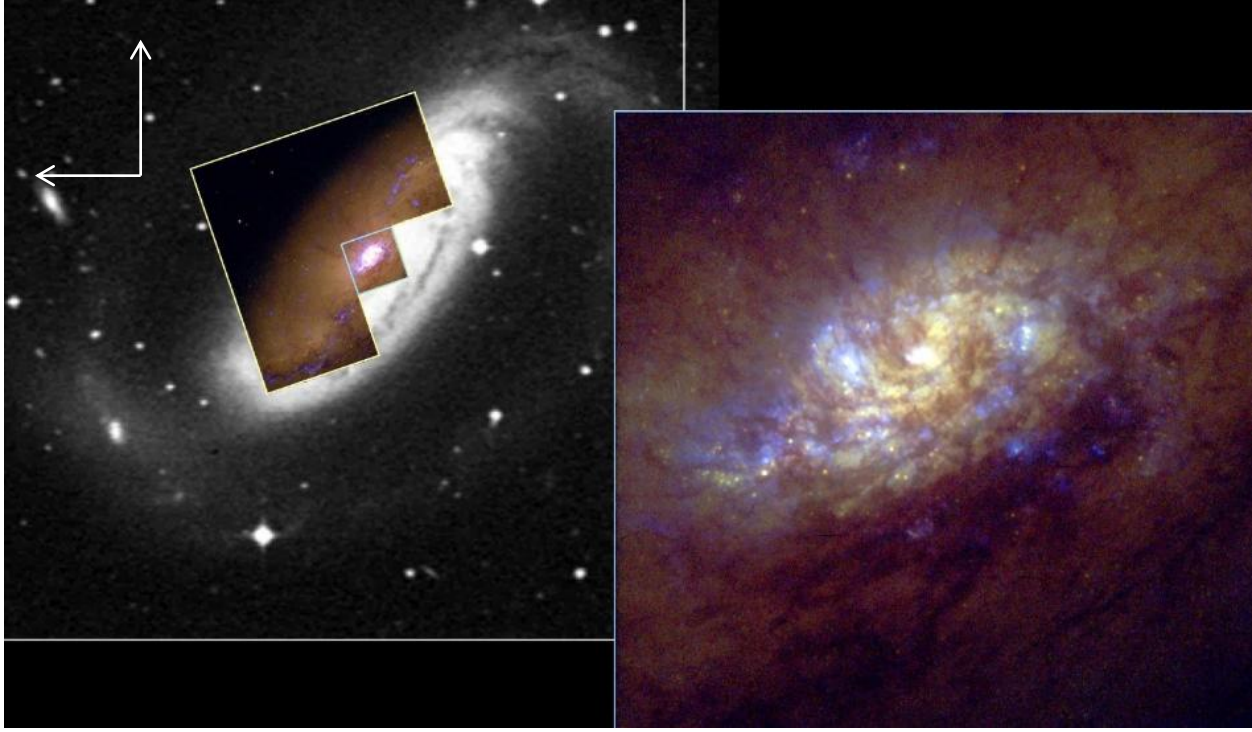
Trailing nuclear spiral in N1808

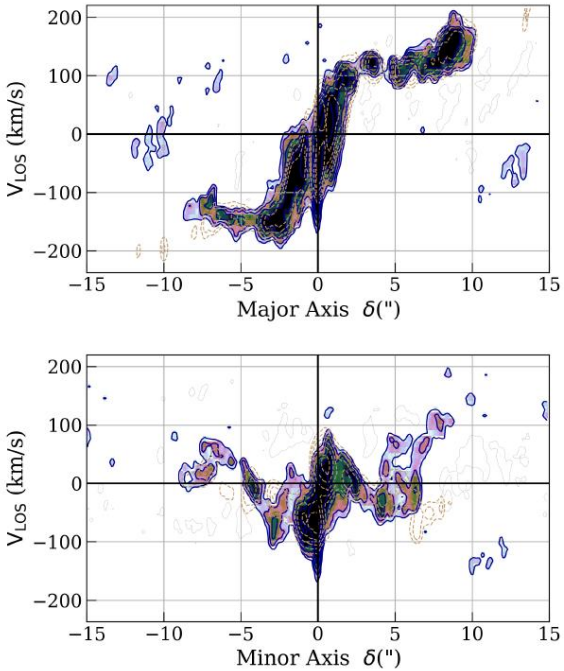
➔ Fueling the black hole

NGC 1808

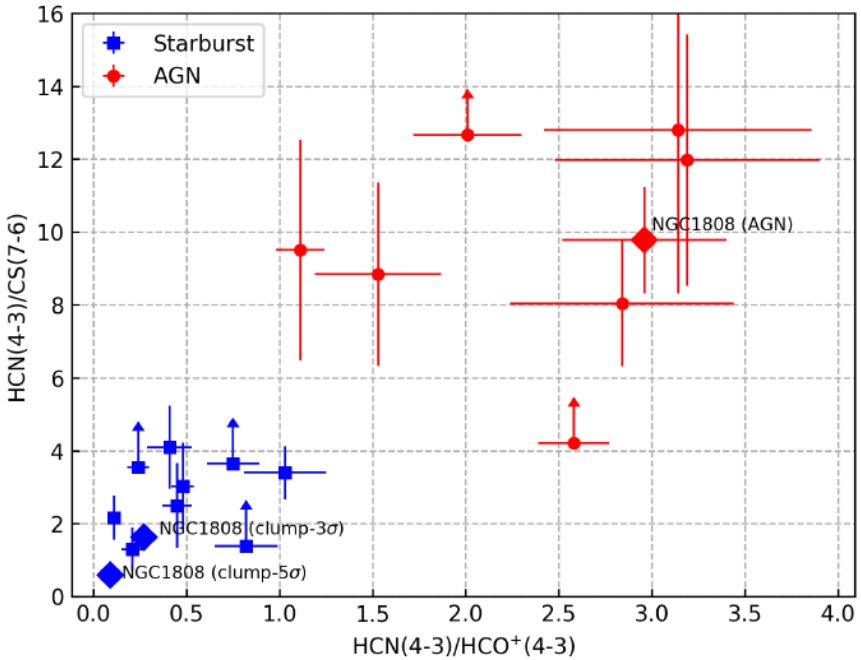
No outflow
close to the center

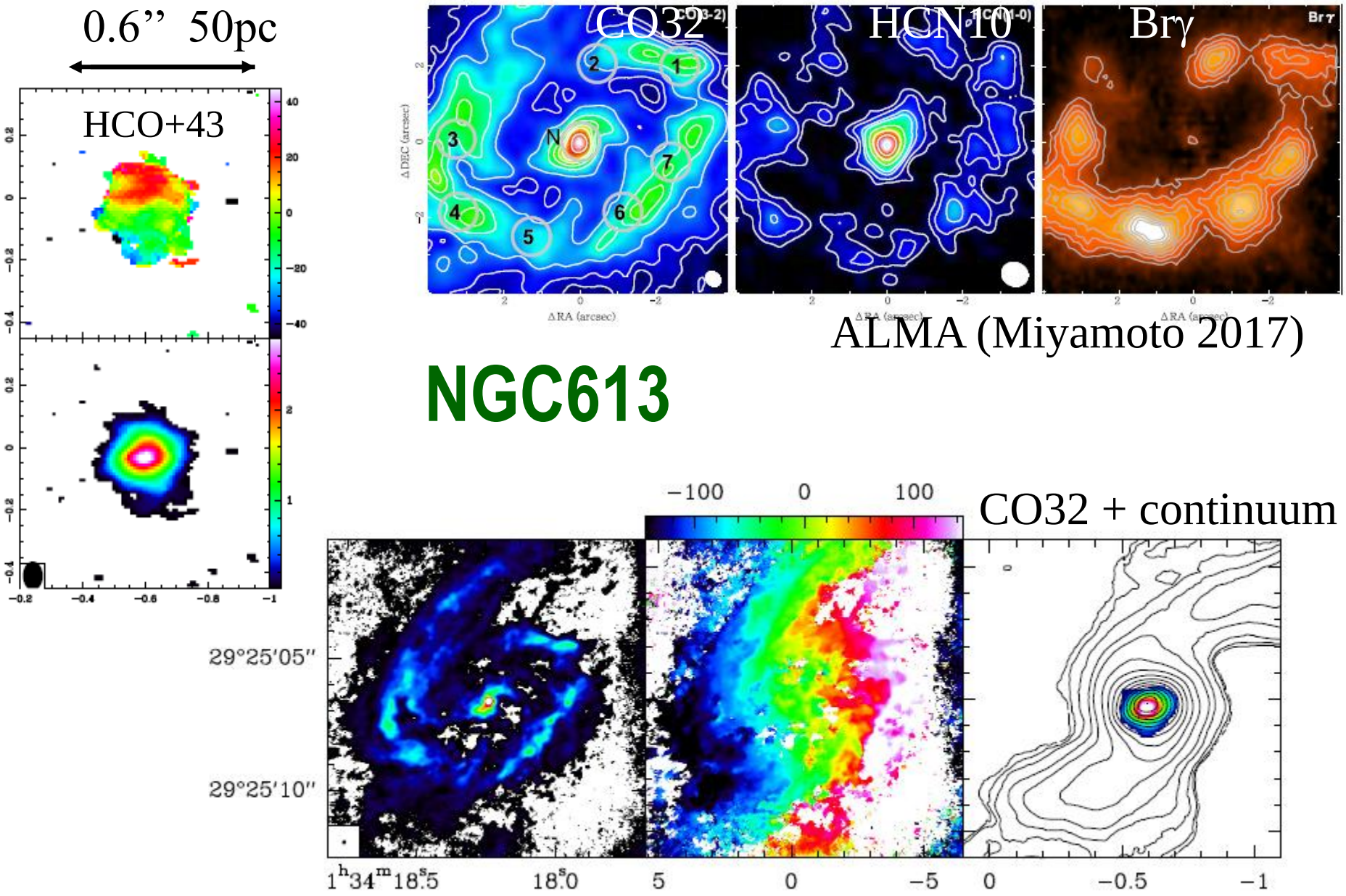
But outflow at
larger scale
➔ Due to starburst





CO(3-2)

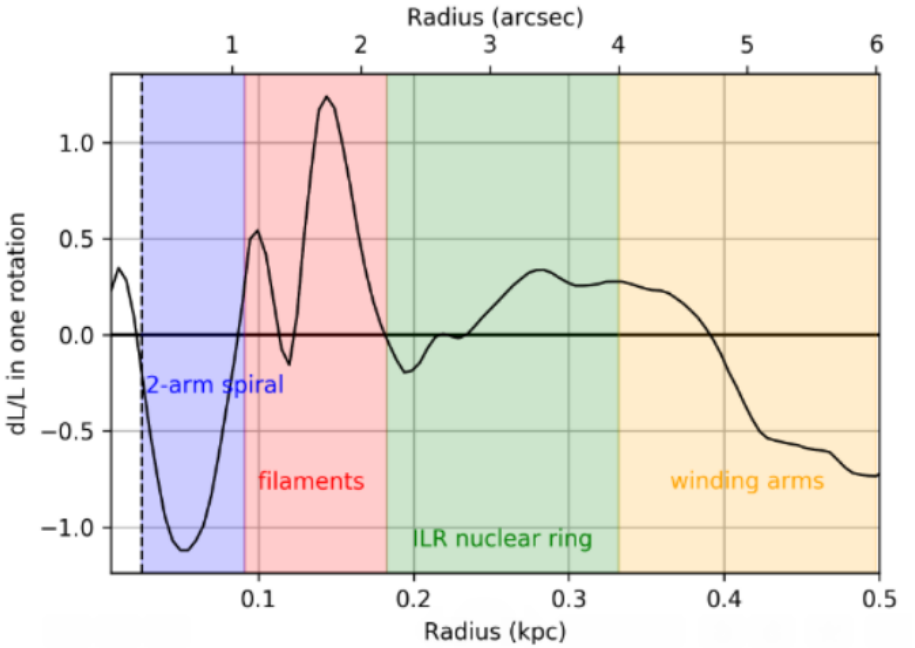




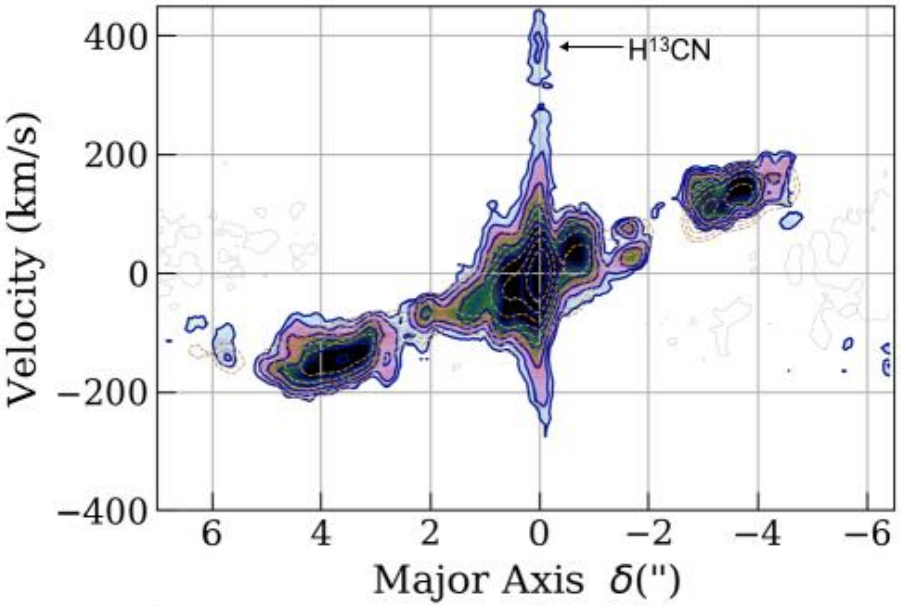
With 0.09” x 0.06” resolution (5pc): nuclear spiral +torus

Combes et al 2019

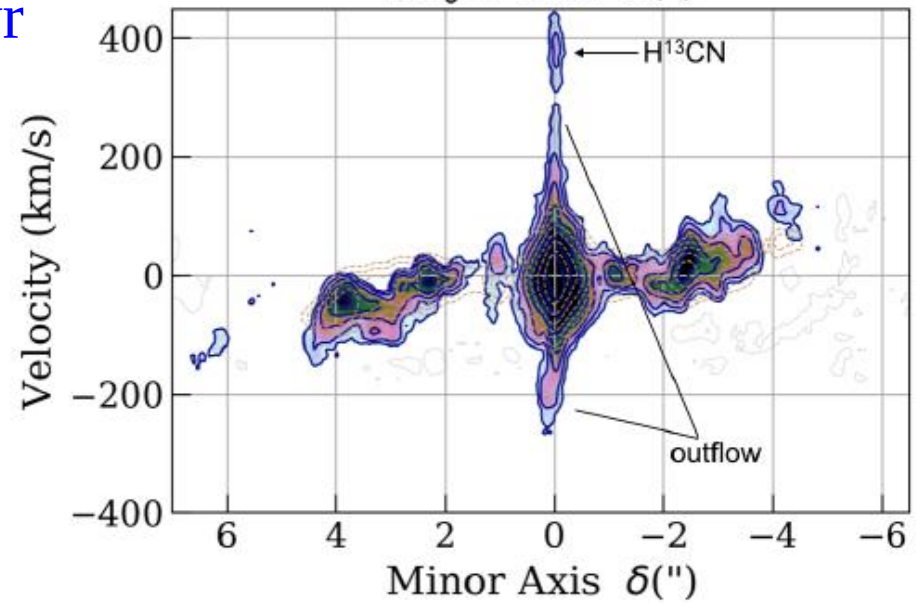
Average gravity torque



NGC 613: Outflow



The gas infalls in 1 rotation~10Myr

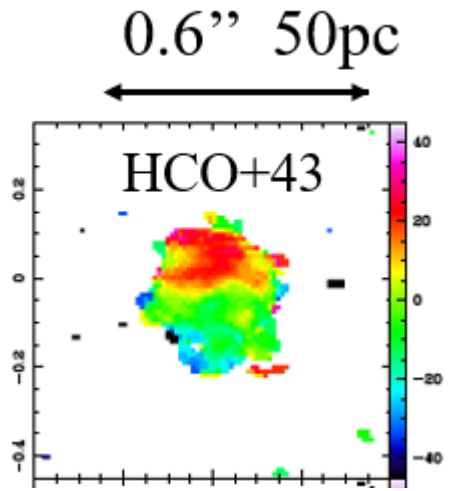


$M_{out} = 2\ 10^6\ M_\odot$

$\dot{M}_{out} = 15\ M_\odot$ /yr

Audibert et al 2019

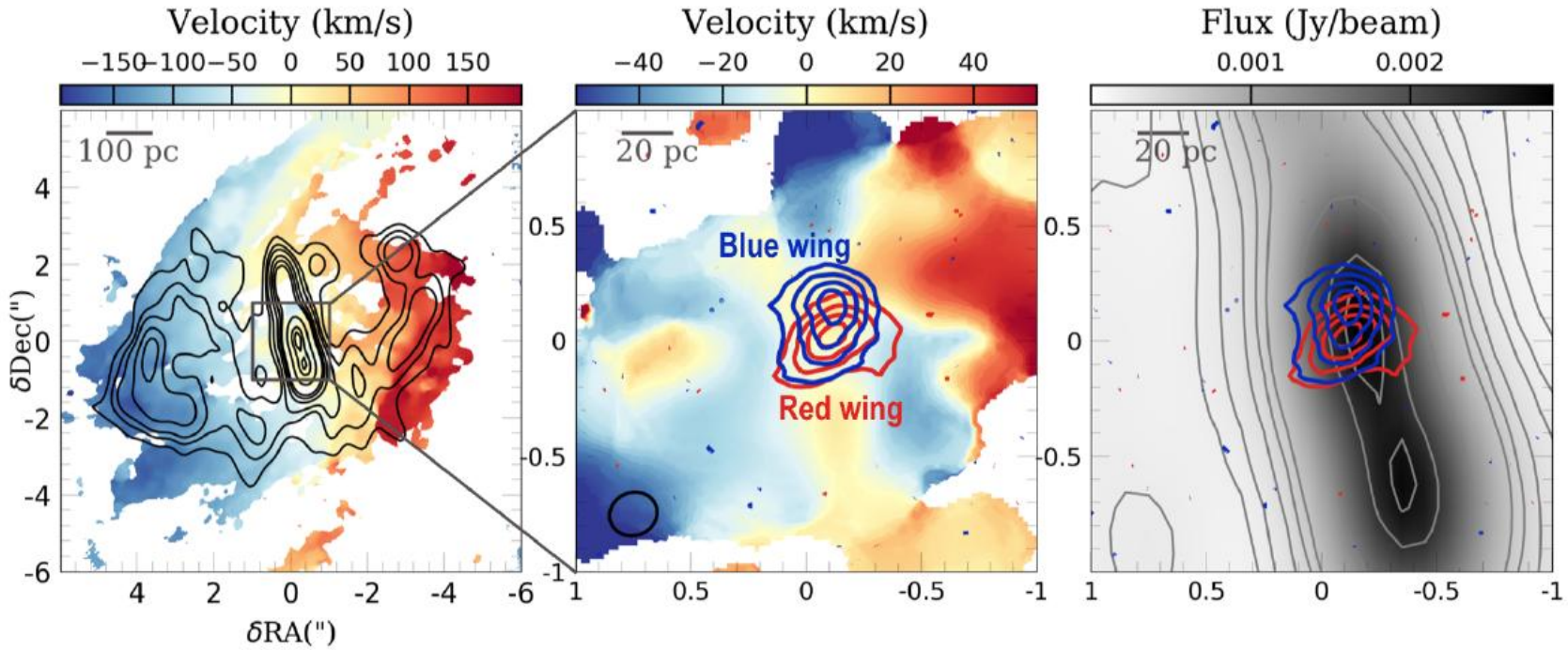
Flow parallel to the radio jet



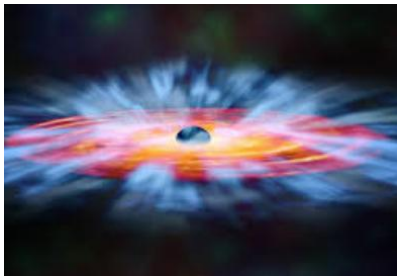
The molecular torus is R=14pc =0.17”

Difficult to disentangle with the outflow, of size R_{out}=23pc=0.28”, V_{out}=300km/s

But reverse sense!



Two main modes for AGN feedback



Quasar mode: radiative or winds

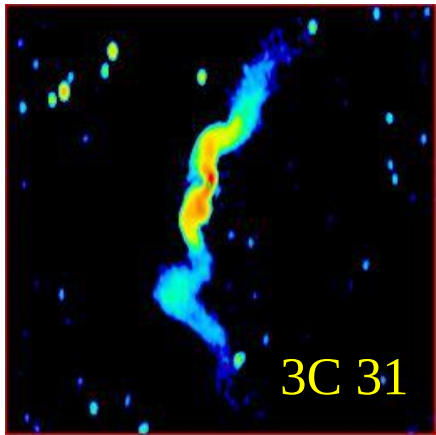
When Luminosity close to Eddington, young quasars, high redshift

Radio mode, or kinetic mode, jets

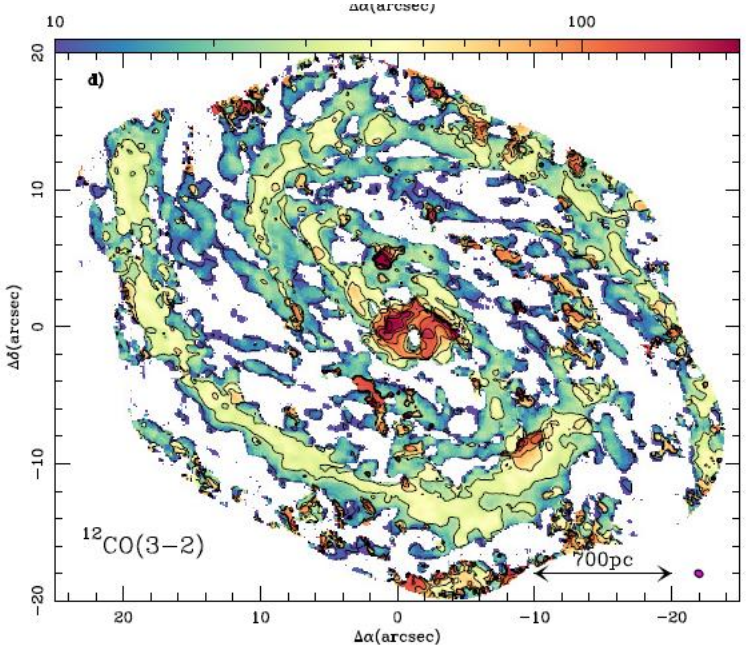
When Luminosity < 0.01 L_{edd}, low redshift

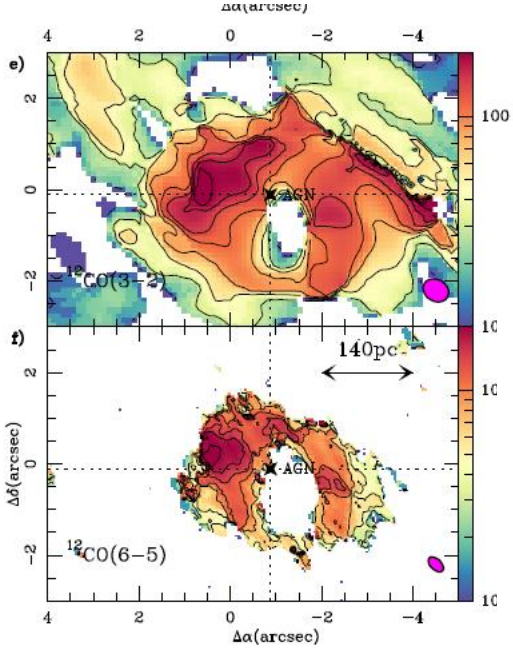
Massive galaxies, Radio galaxies, ellipticals

Radiatively inefficient flow



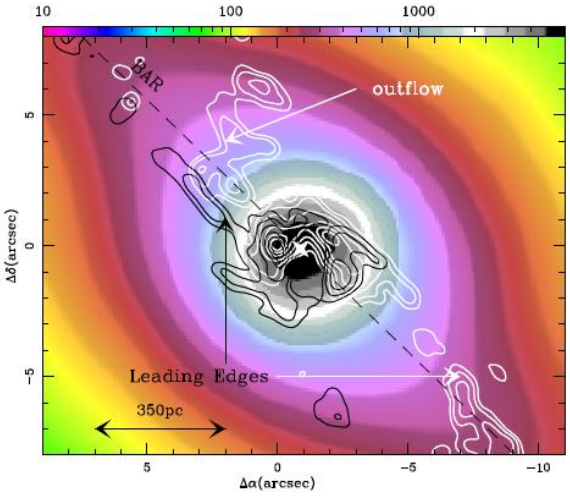
Off-centered nucleus and outflow in NGC1068

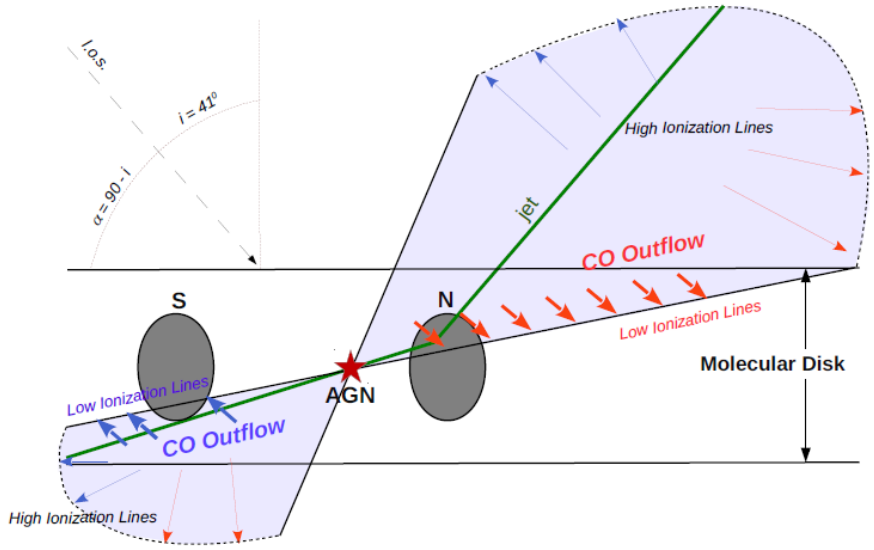




Black V=-50km/s

White V=50km/s





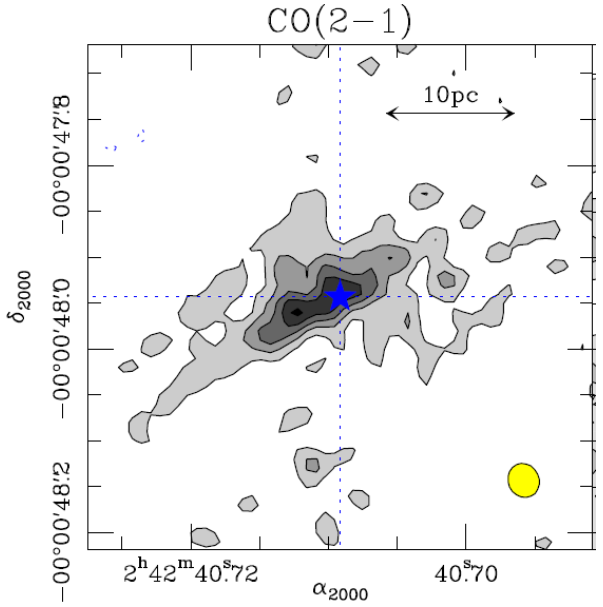
Outflow of 63$M_{\odot}$/yr

10x the star formation rate in this region

Garcia-Burillo, Combes, Usero et al 2014

Detection of molecular tori

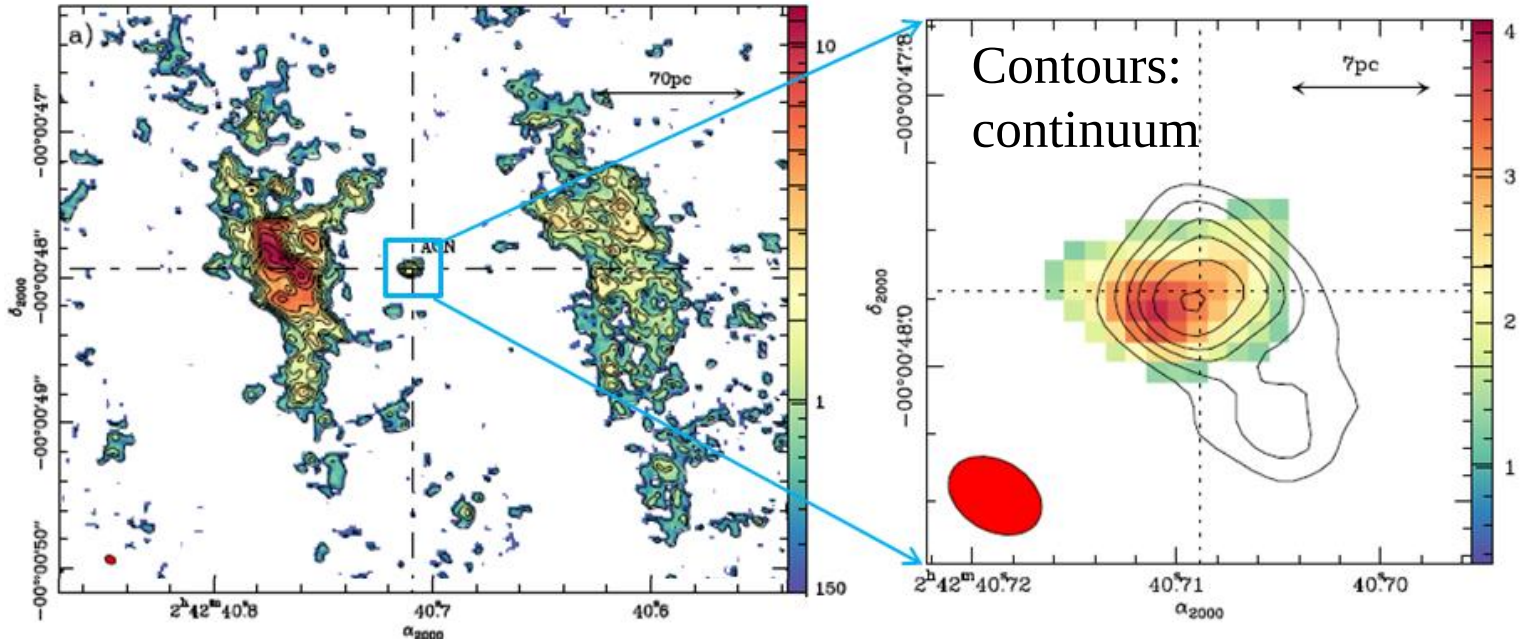
Garcia-Burillo et al 2019



ALMA CO(6-5) and 432μm dust emission

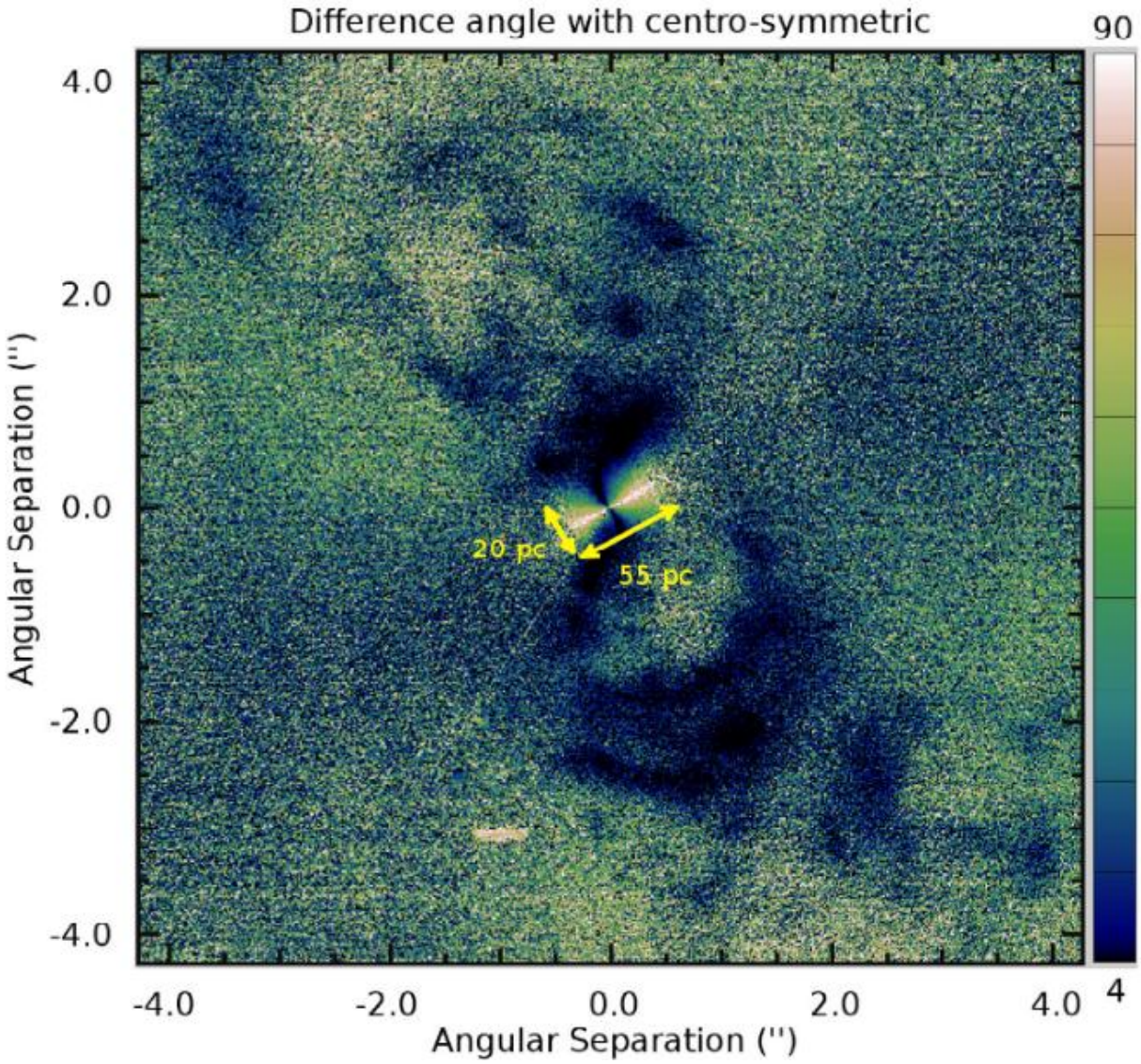
➔Torus of 7-10pc in diameter in NGC1068

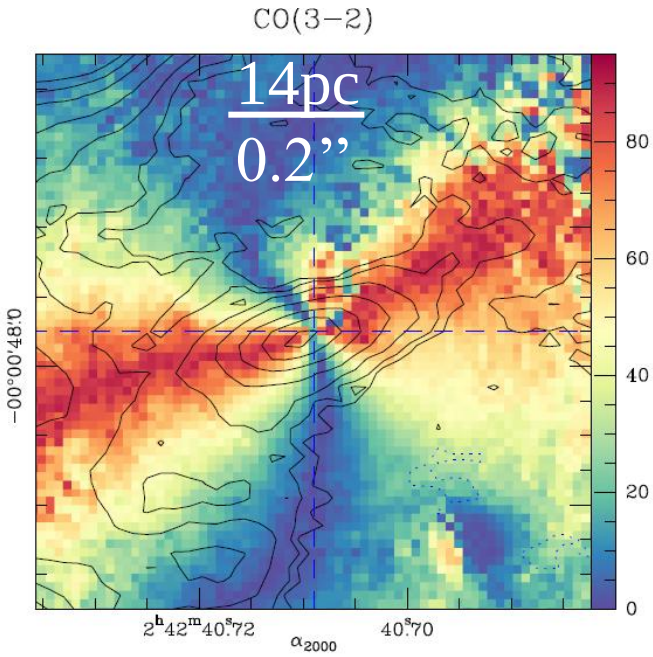
More inclined than the H_2O maser disk



Garcia-Burillo, Combes, Ramos-Almeida et al 2016, **R=3.5pc torus**

Molecular torus inside a polar dusty cone



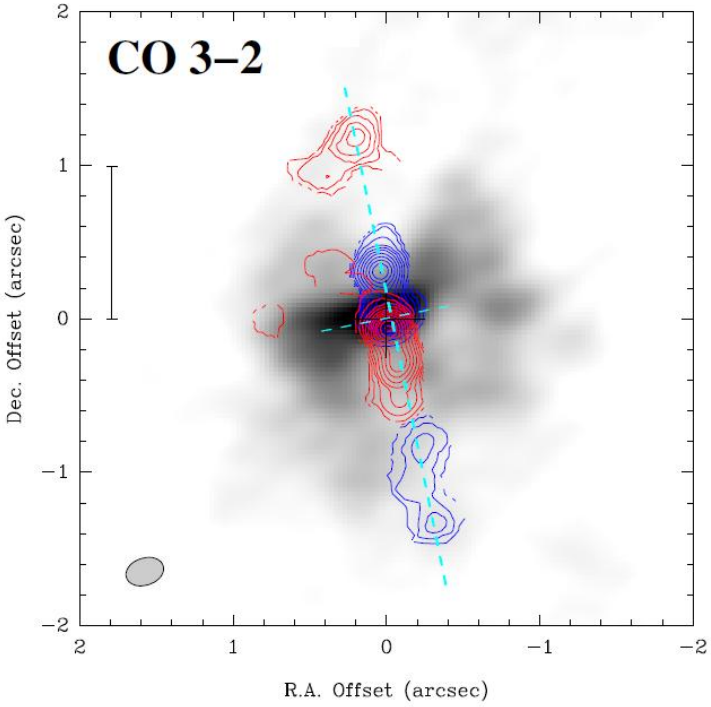


Garcia-Burillo et al 2019

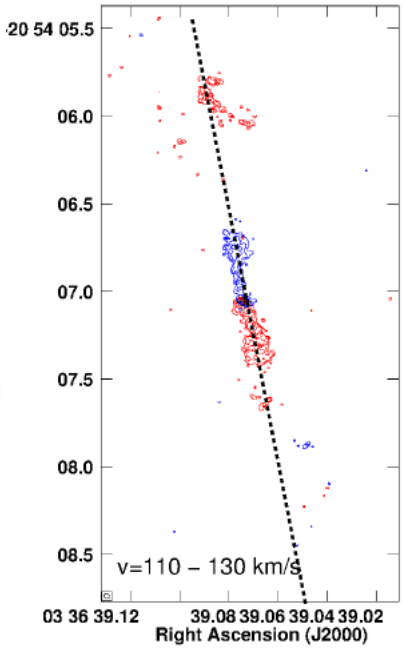
1”=70pc, *Gratadour et al 2015* *SPHERE NIR*

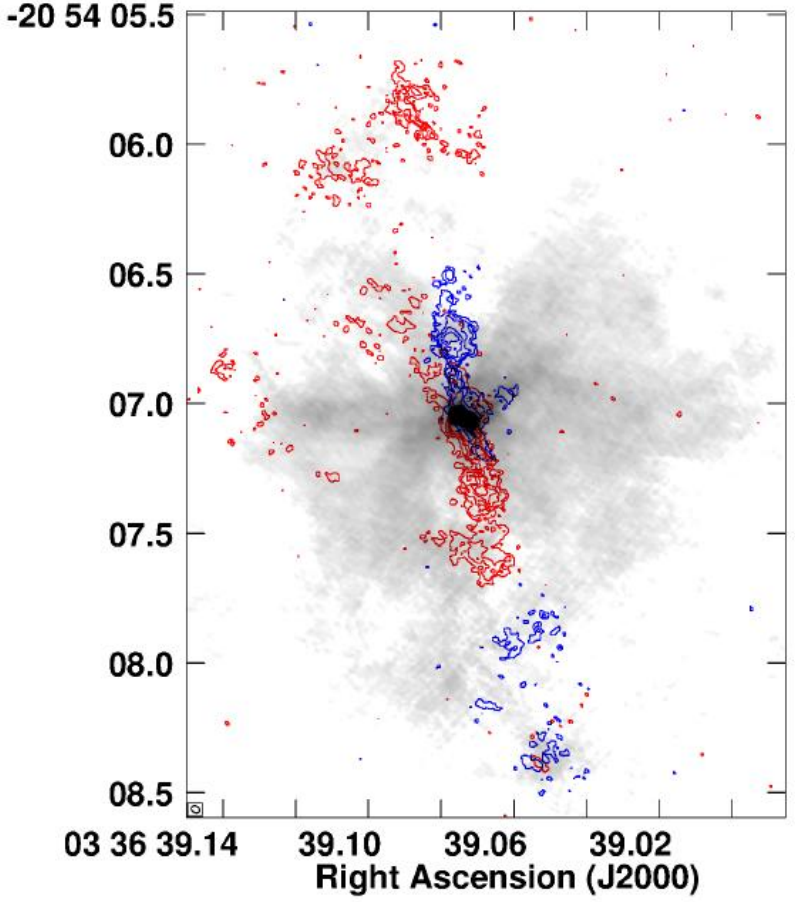
Radio mode in NGC1377

Beam 0.2”

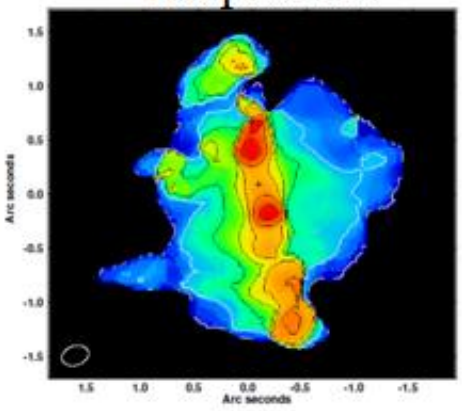


The most radio quiet galaxy!





Dispersion



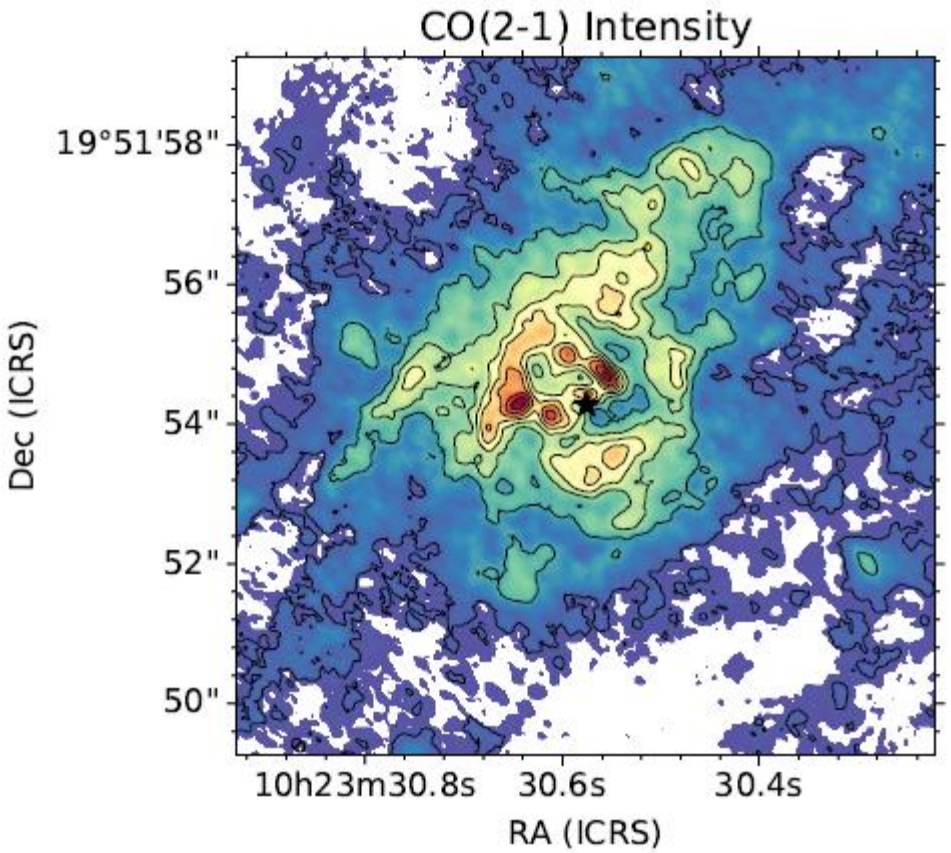
MH_2 in the cone 10^8 $M_\odot$

In the jet 10^7 $M_\odot$

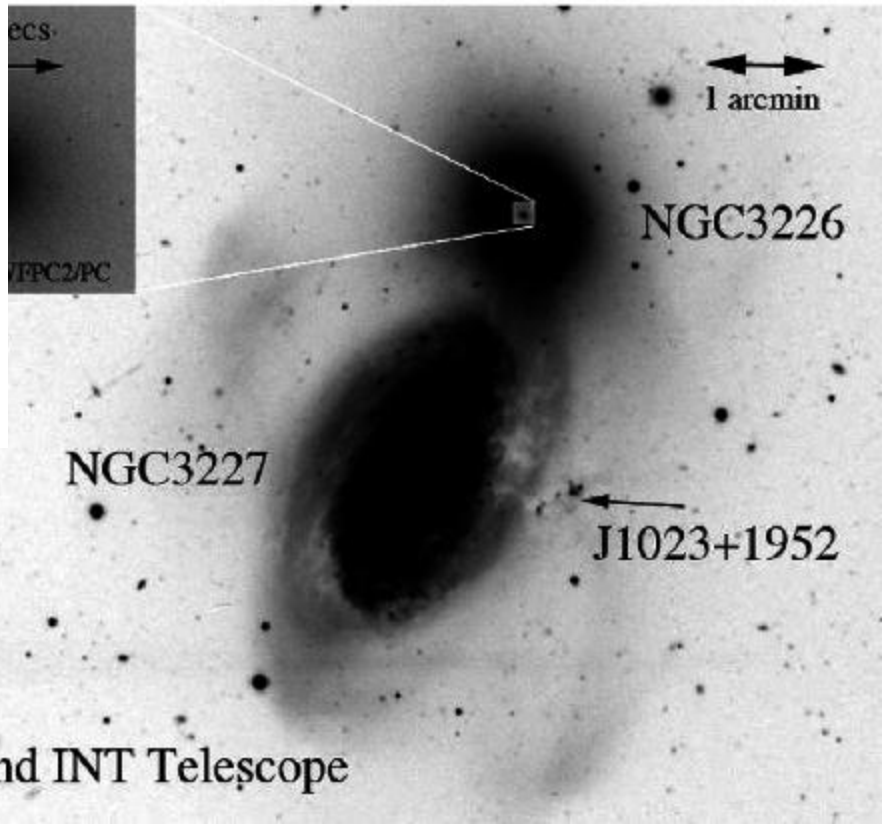
Aalto et al 2016, 2019

Outflow in NGC 3227

Alonso-Herrero et al 2019



CO21, CO32 ALMA, ~10pc
Streaming motions
+ outflow



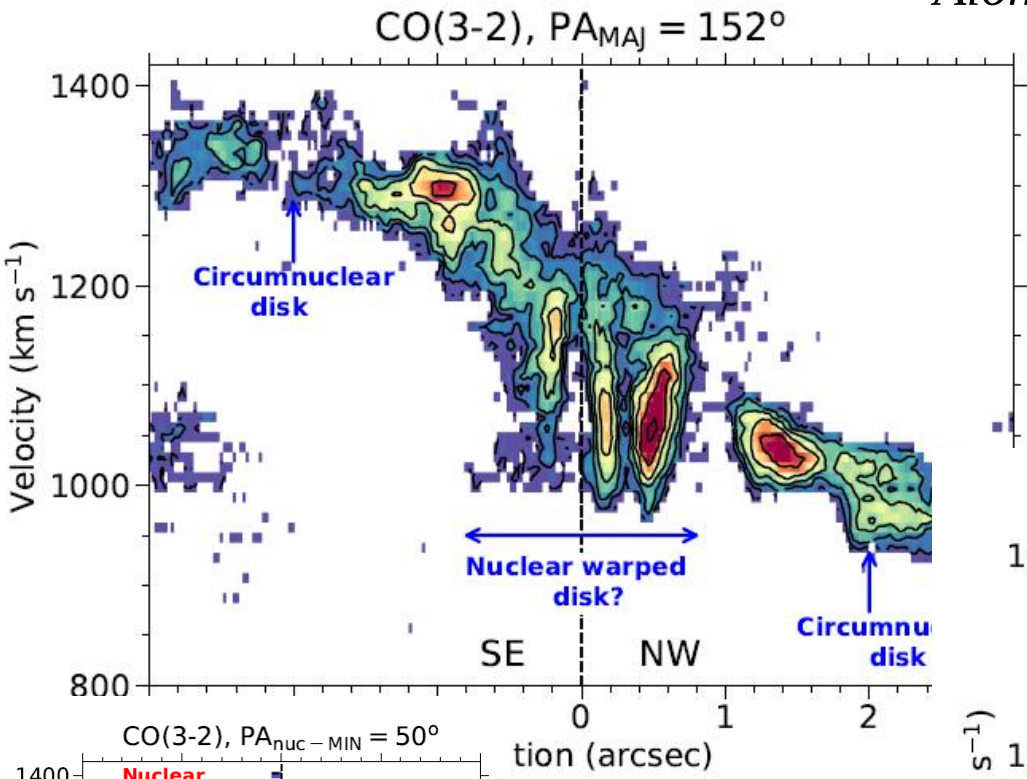
5 $M_{\odot}$/yr of outflow

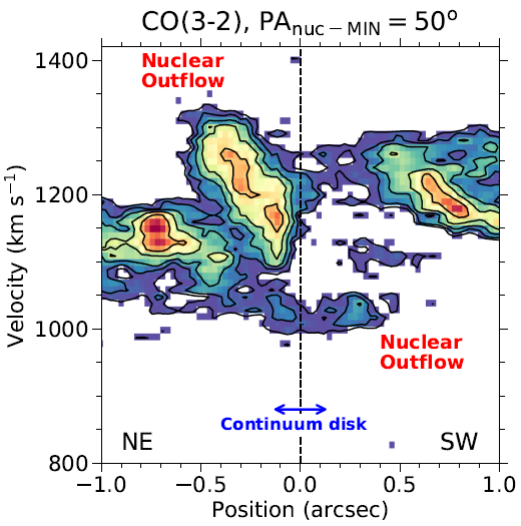
No evidence of a compact torus

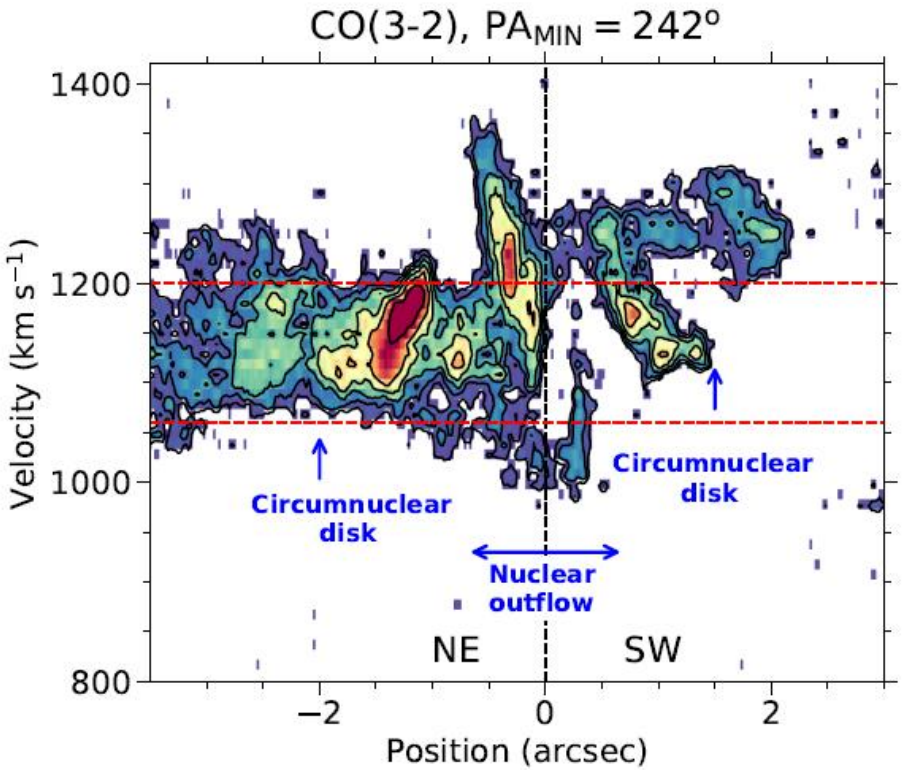
Evidence of an outflow

N3227,

Alonso-Herrero et al 2019

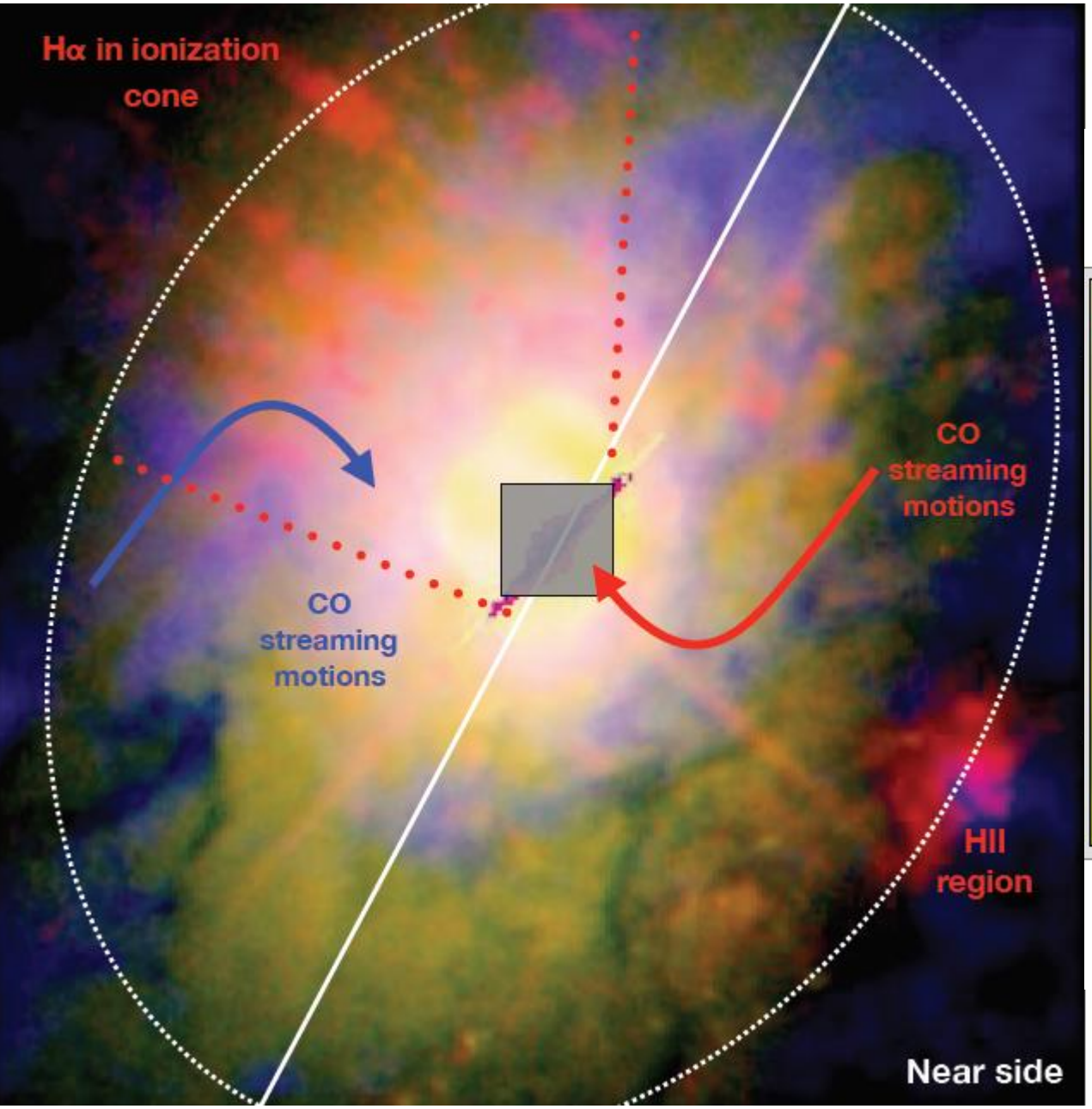


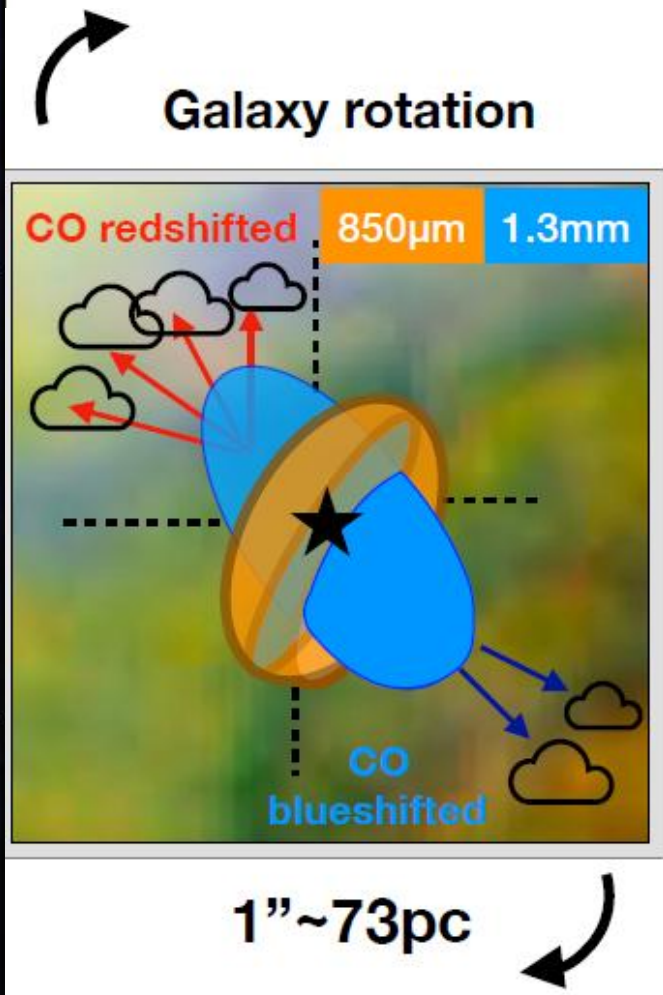


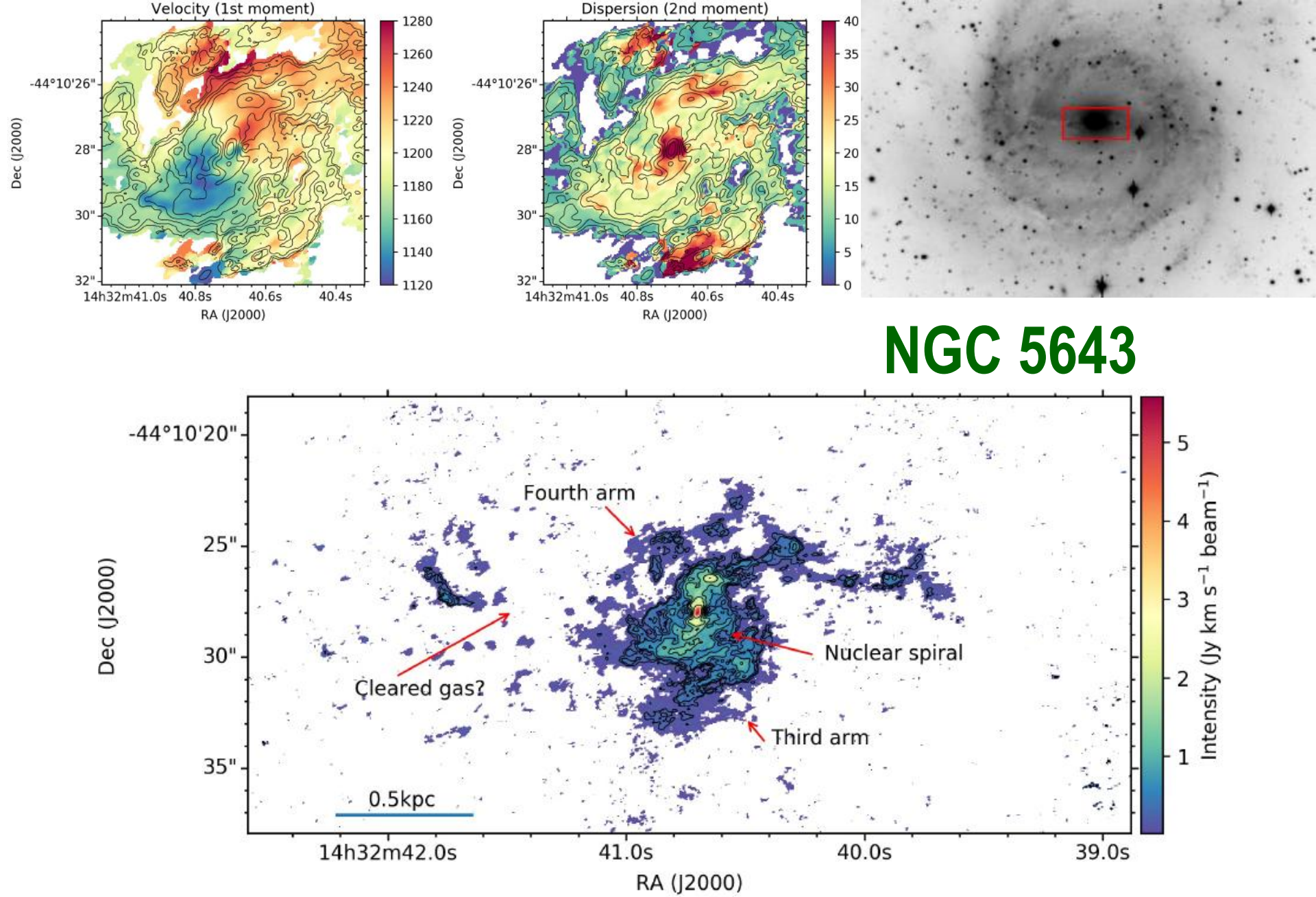


N3227,

Alonso-Herrero et al 2019







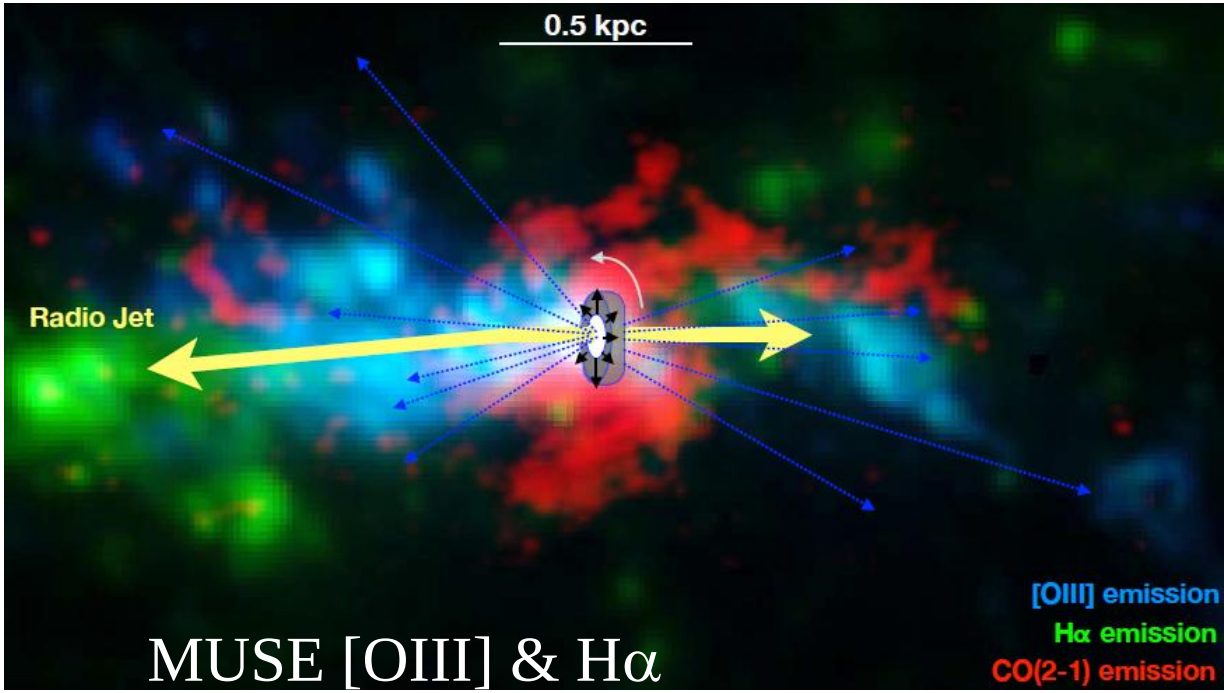
ALMA CO(3-2), Beam 0.2'' = 20pc

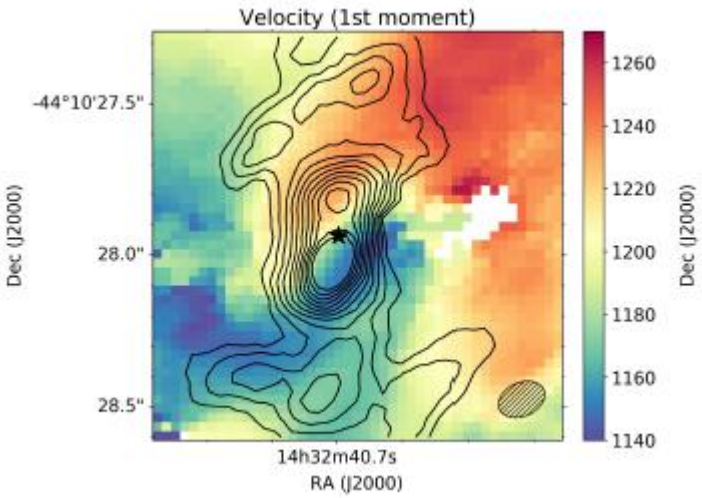
Alonso-Herrero et al 2018

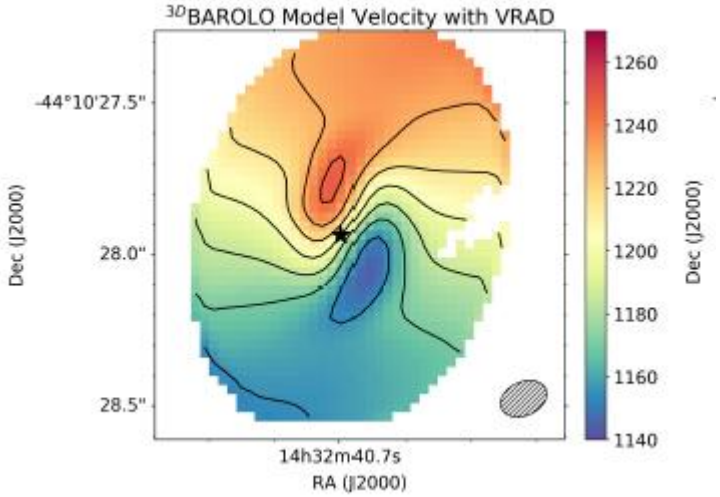
NGC5643

Molecular outflow detected
Nuclear disk
R~13pc, almost N-S

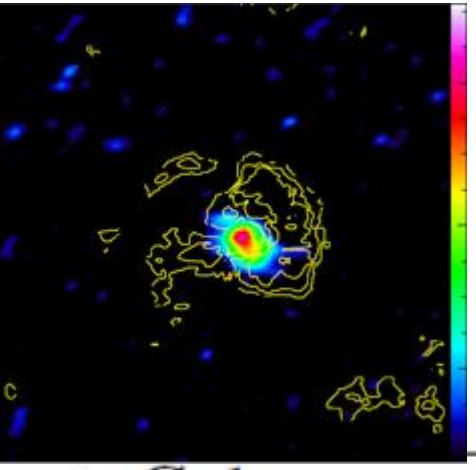
Decoupled from the main disk

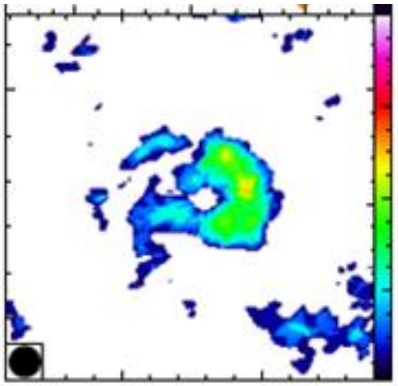


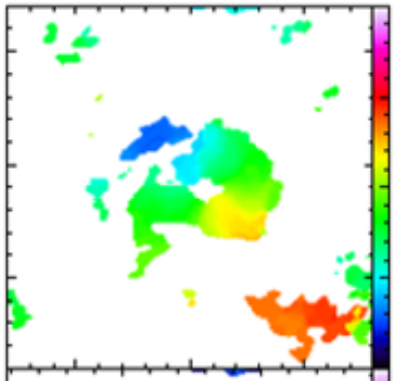




Frequency of « molecular tori » : 7/8



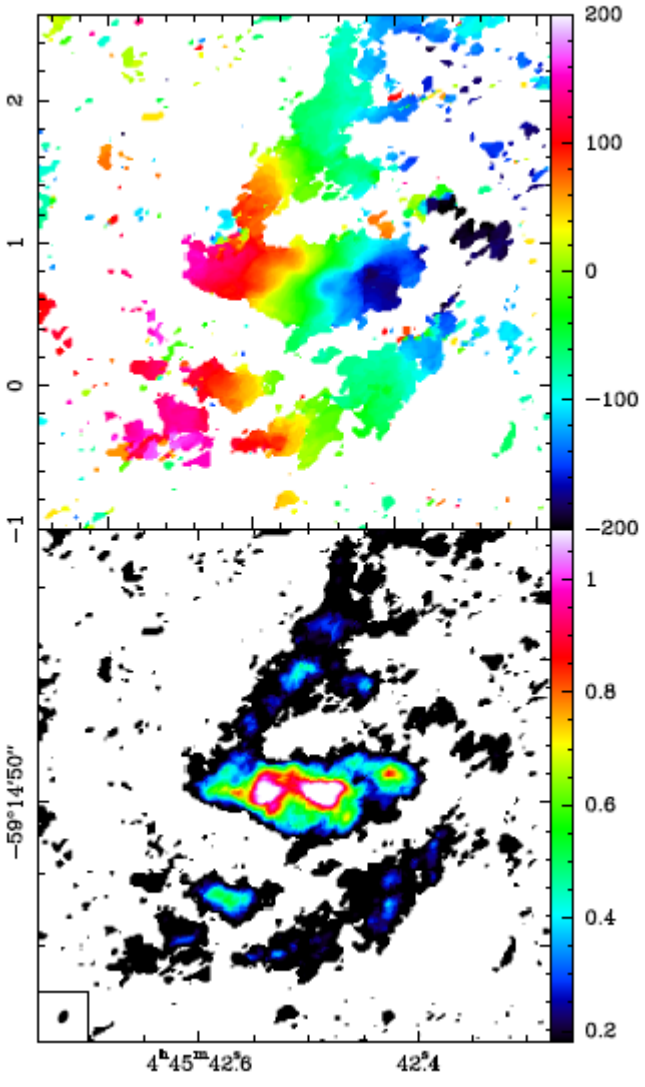




NGC 1365

Galaxy	Radius (pc)	$M(H_2)^a$ 10^7 $M_\odot$	inc(°) torus	$inc(°)^b$ gal
NGC 613	14±3	3.9±1.4	46±7	36
NGC 1326	21±5	0.95±0.1	60±5	53
NGC 1365	26±3	0.74±0.2	27±10	63
NGC 1433	–	–	–	67
NGC 1566	24±5	0.88±0.1	12±12	48
NGC 1672	27±7	2.5±0.3	66±5	28
NGC 1808	6±2	0.94±0.1	64±7	84
NGC 1068	3.5	0.01	80	24

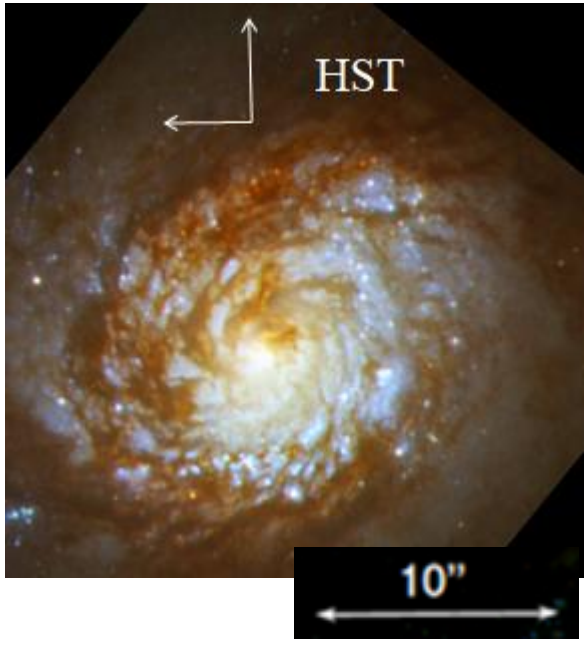
NGC 1672



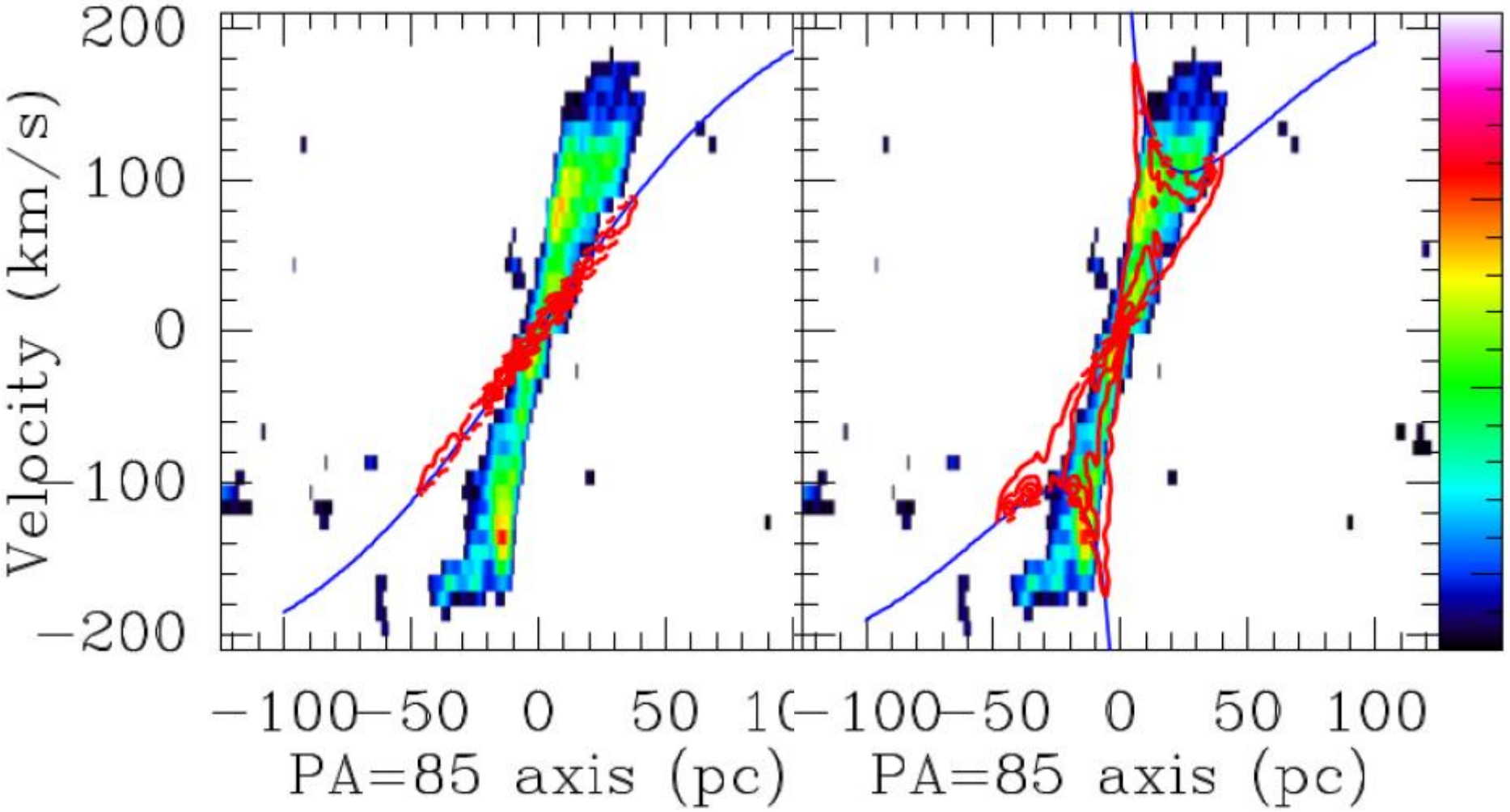
1 arcsec = 55pc

In an almost face-on galaxy

Edge-on torus

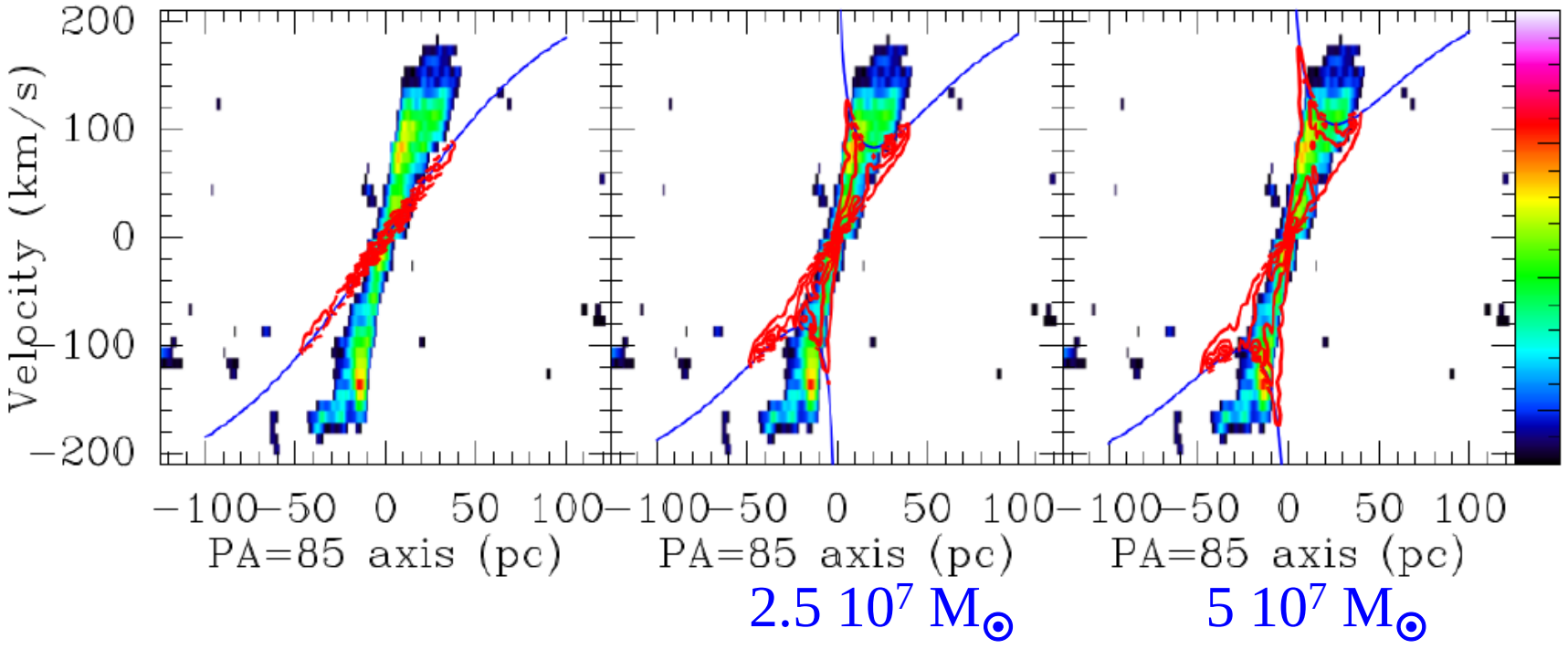


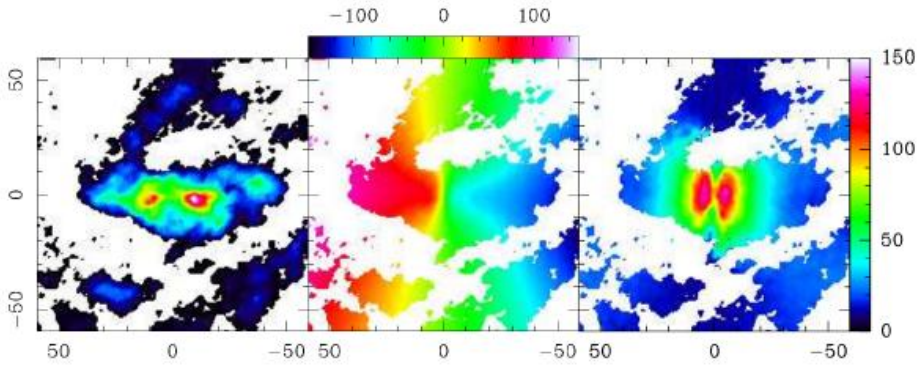
N1672: Black hole mass



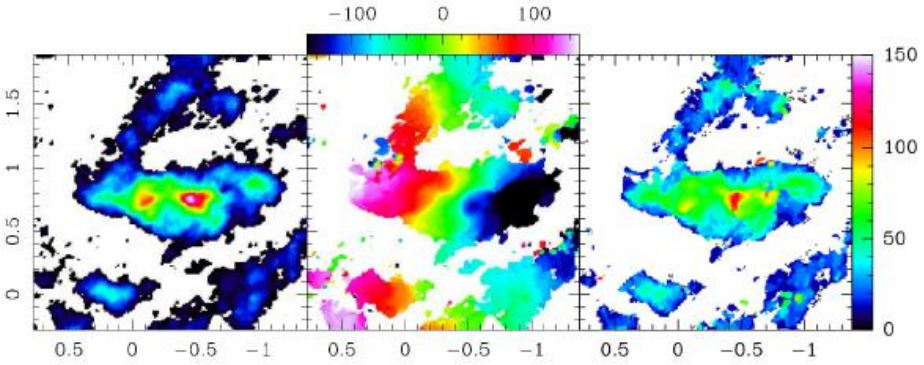
Without BH

With BH, of
$M = 5\ 10^7\ M_\odot$





Intensity V σ

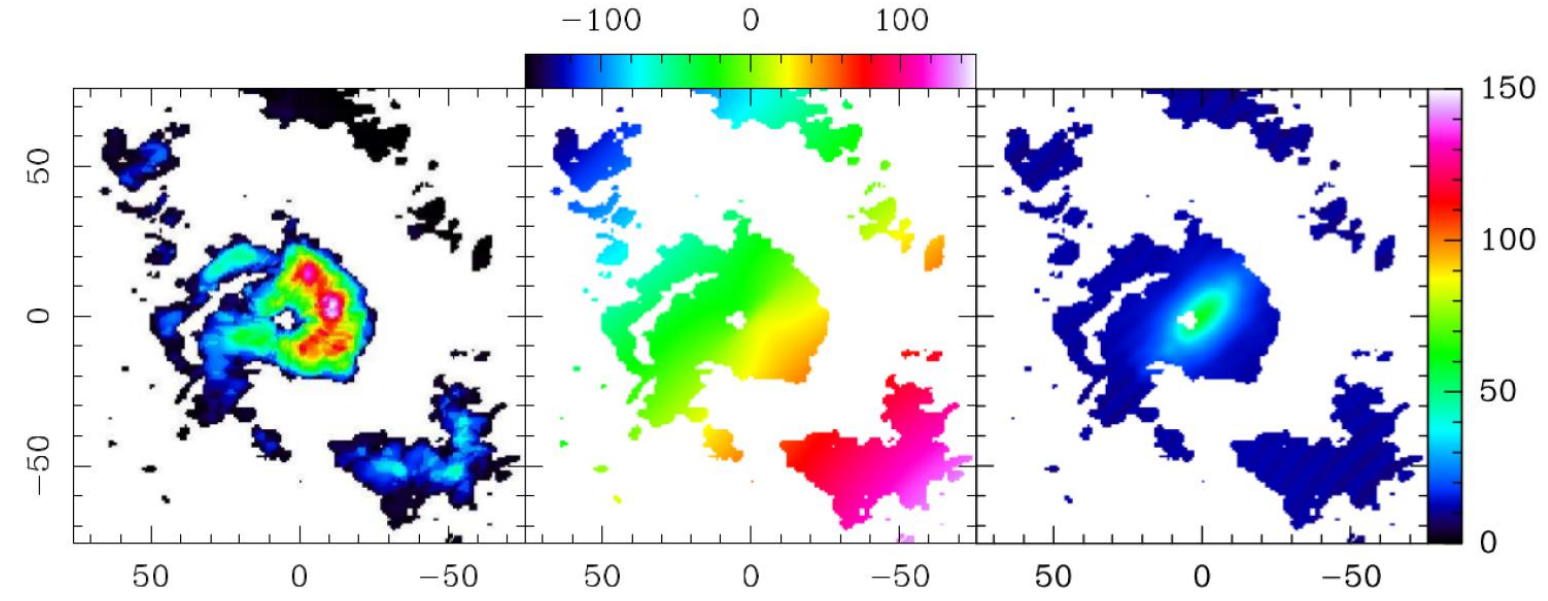


Intensity V σ

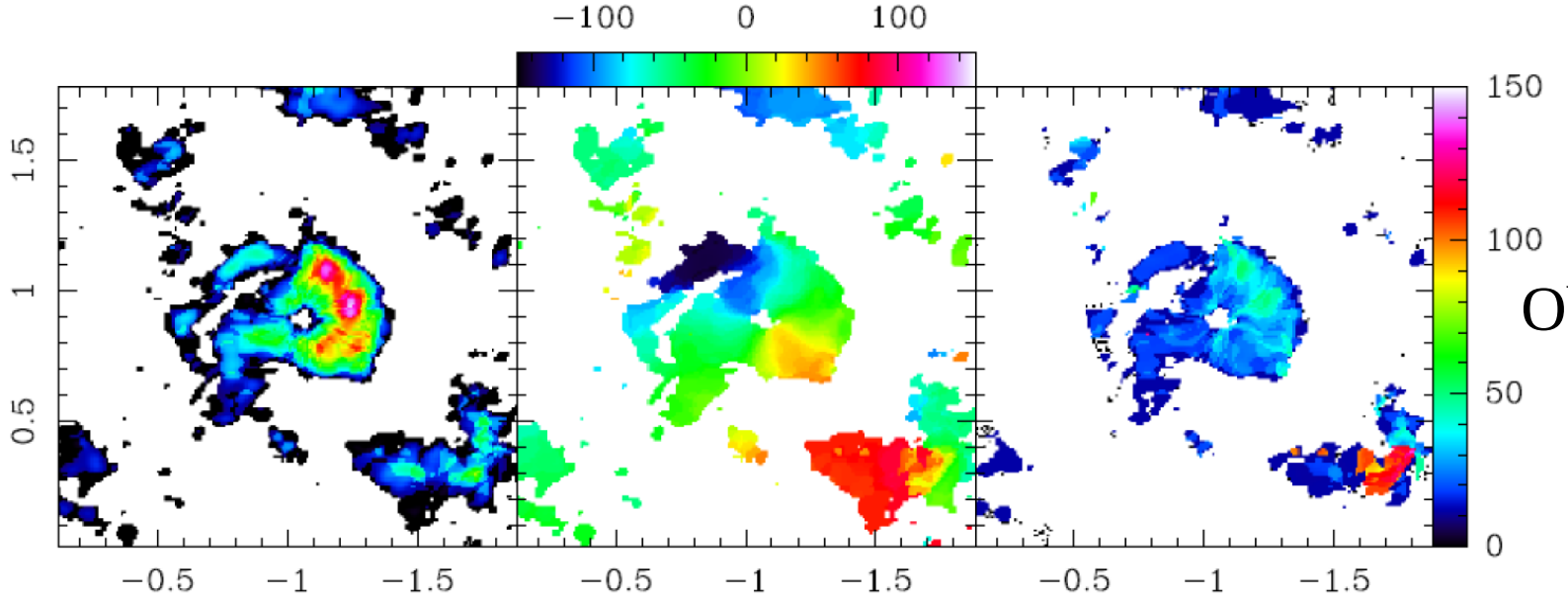
Model

Observations

Modelisation of NGC 1365



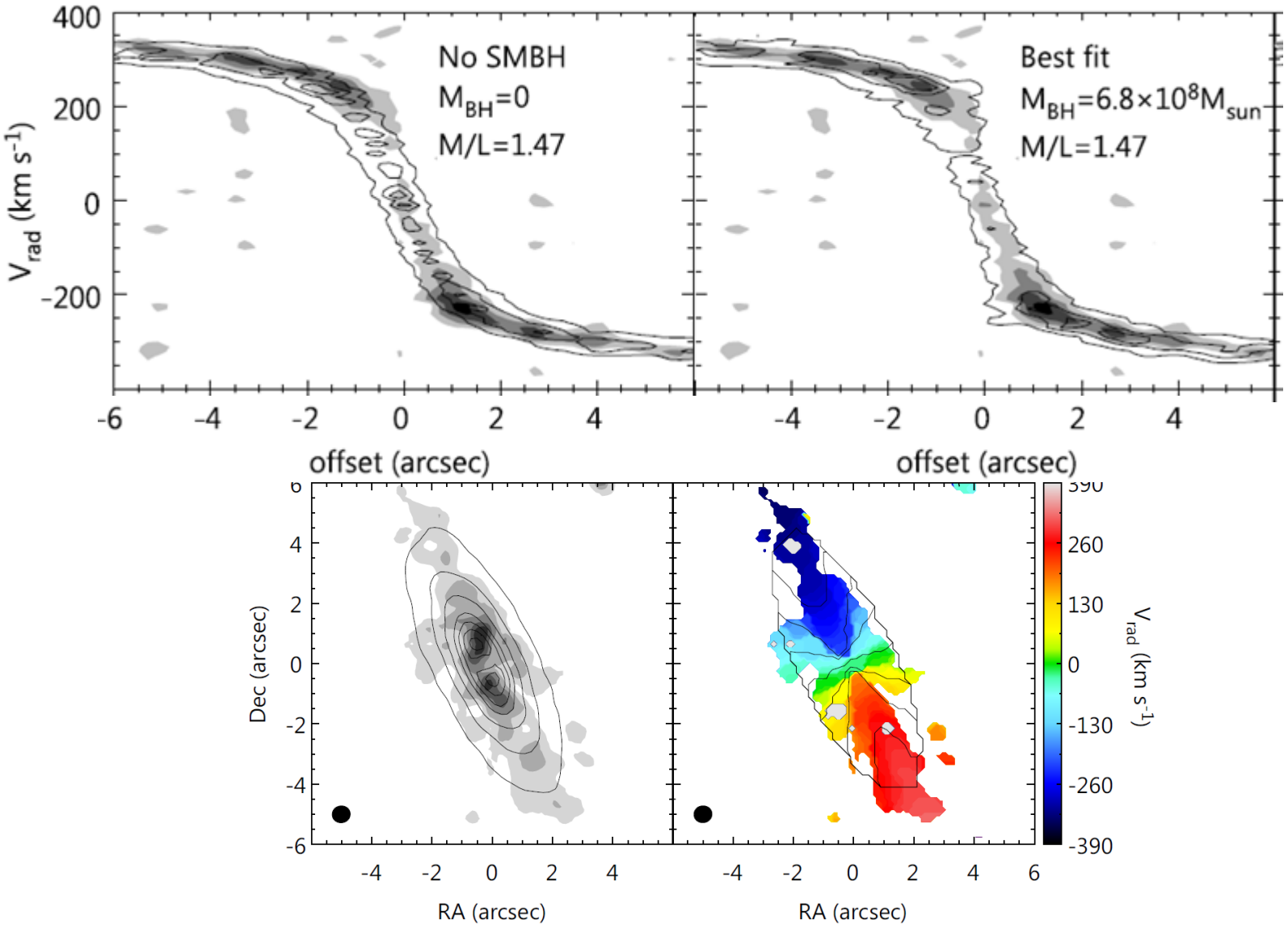
Model



Observed

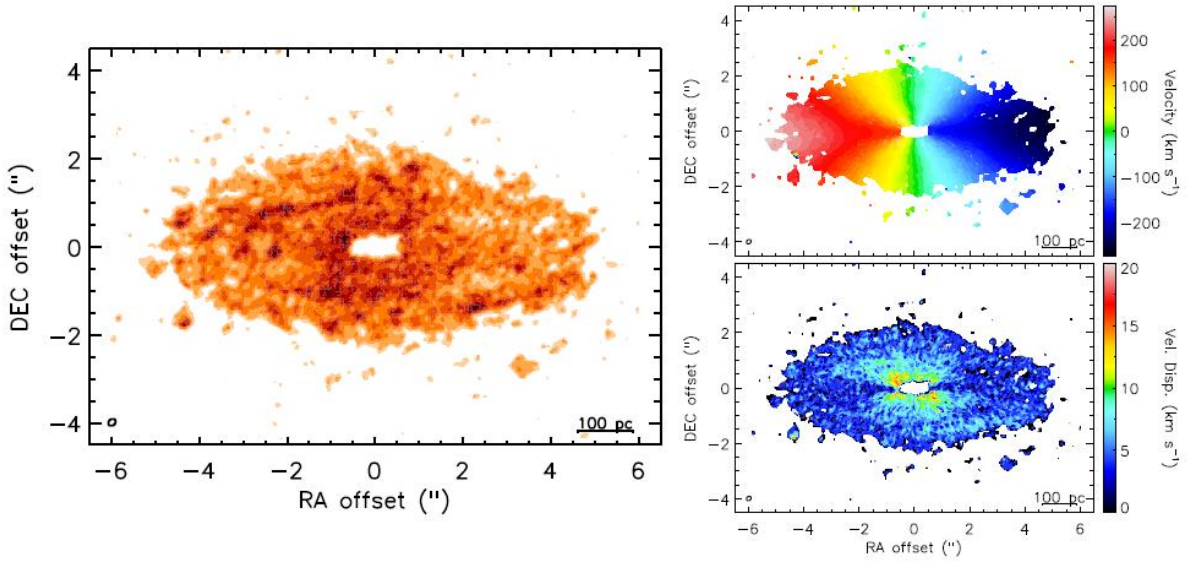
WISDOM project: NGC 3665 *Onishi et al 17*

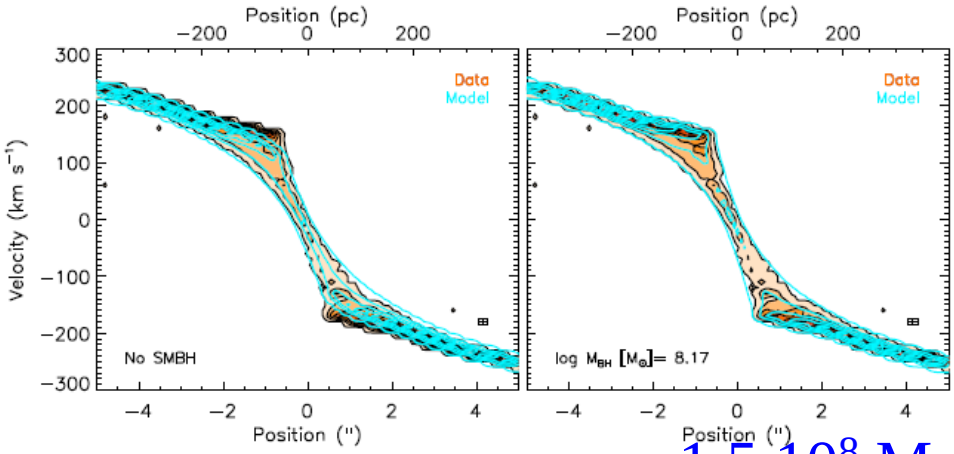
CO(2-1) , Beam 0.60x0.56” = 100x93pc 1” =167pc



WISDOM project: NGC 4429 *Davis et al 17*

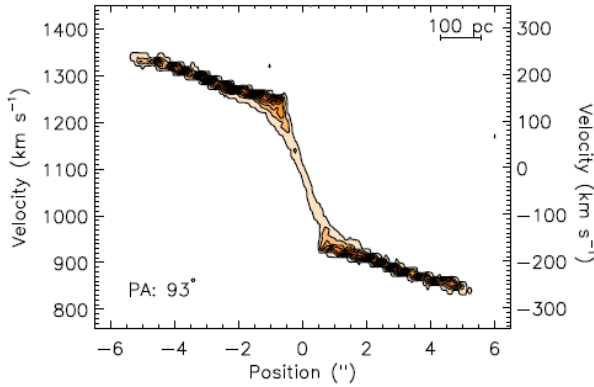
CO(3-2) , Beam 0.18x0.14” = 14x 11pc D=16.5Mpc 1” = 80pc

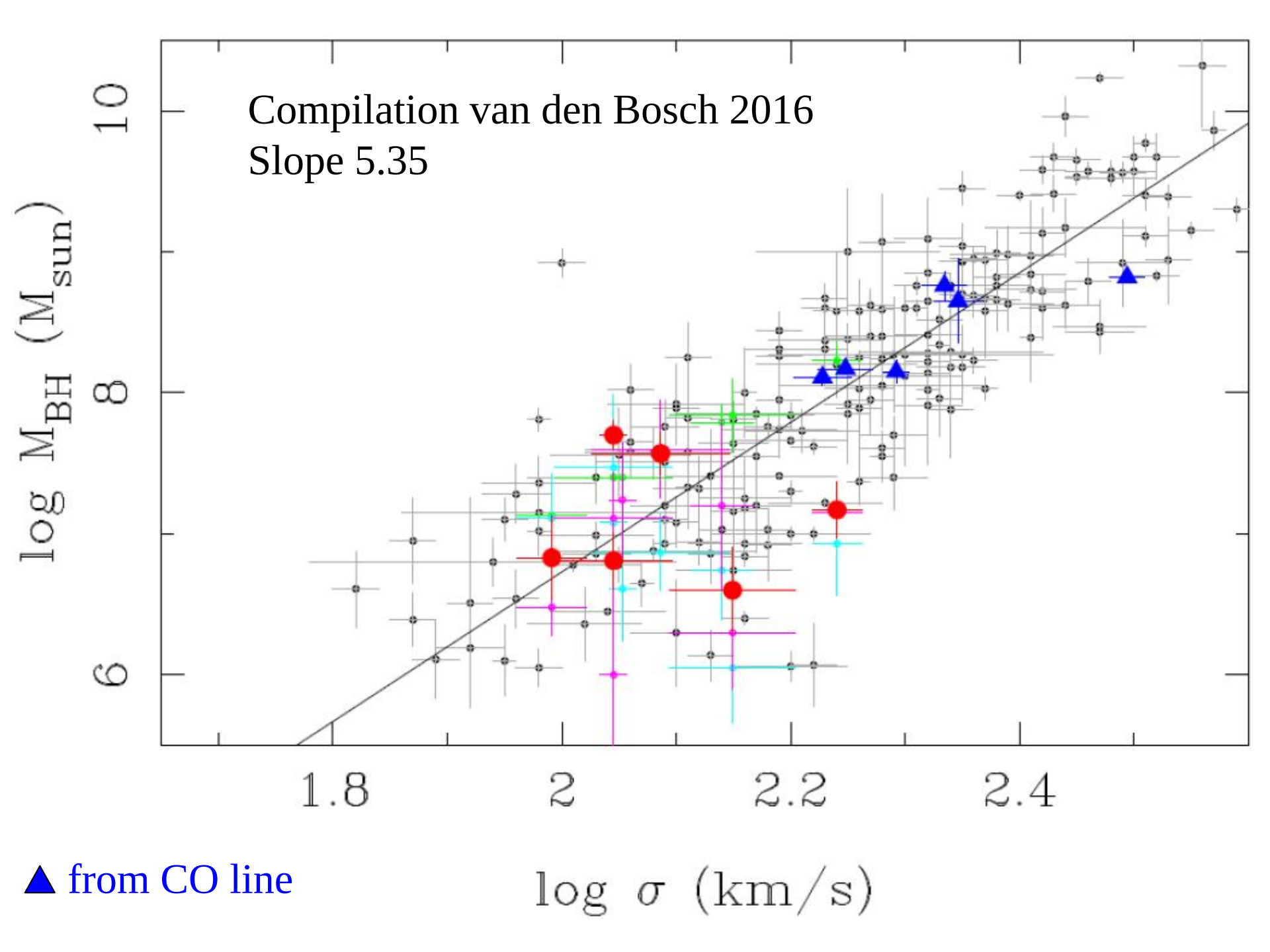




No BH

1.5 10^8 $M_\odot$
Best Fit

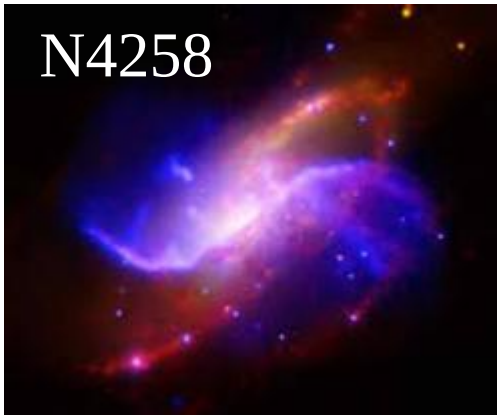



Compilation van den Bosch 2016
Slope 5.35
log M_BH (M_sun)
10
8
6
1.8
2
2.2
2.4
log σ (km/s)
▲ from CO line

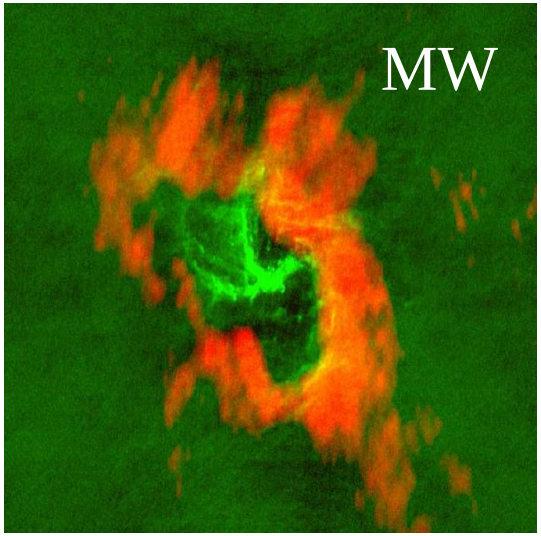
Non-alignment with host disk

Like in the MW, the nuclear disks are not aligned with the galaxy,

In NGC 4258, the H_2O maser disk ~0.2pc misaligned by 119° from the galaxy disk, the jet is in the plane

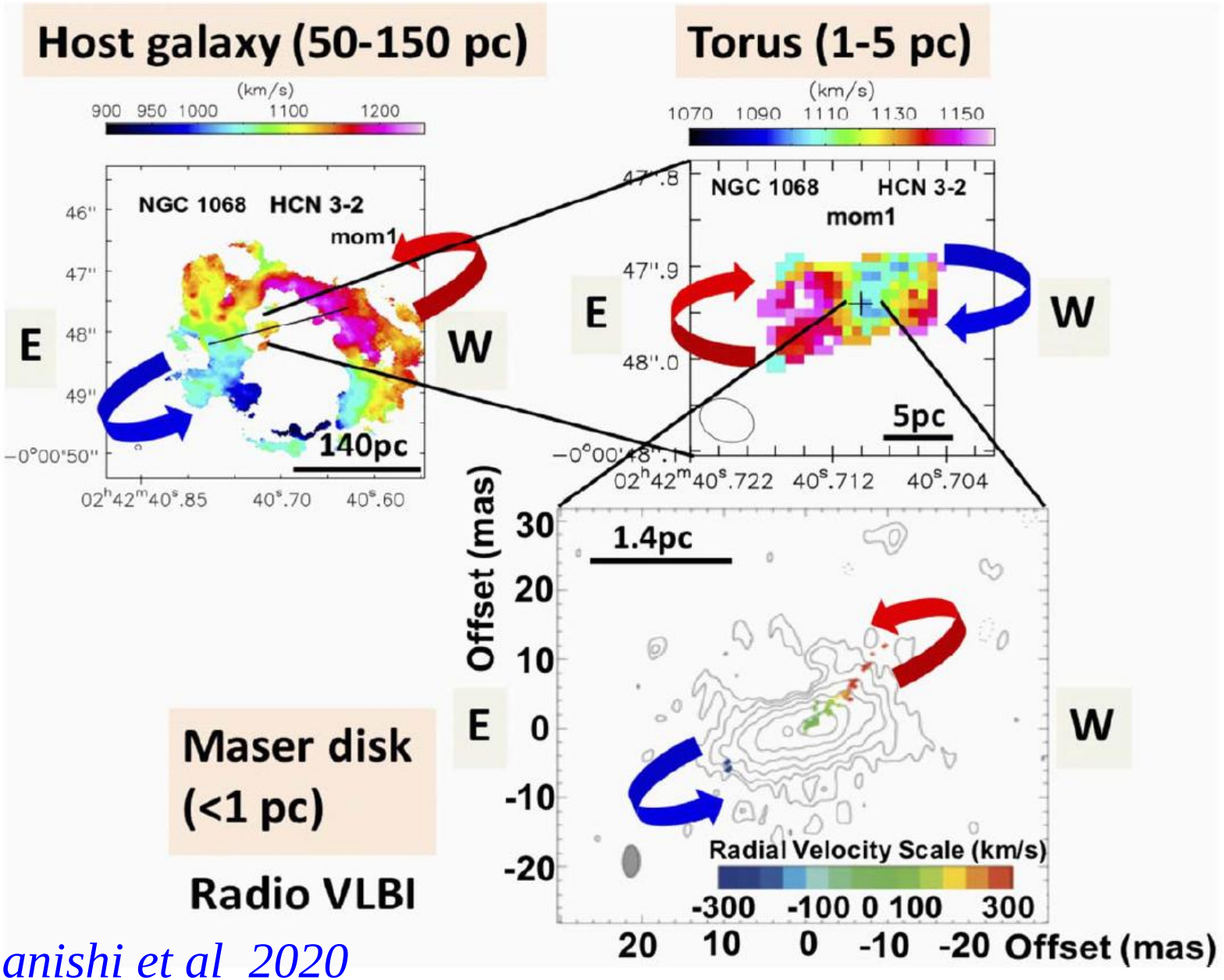


Circumnuclear ring
2-3pc in radius
HCN in orange
Ionized gas in green
Inclination of 20° /plane



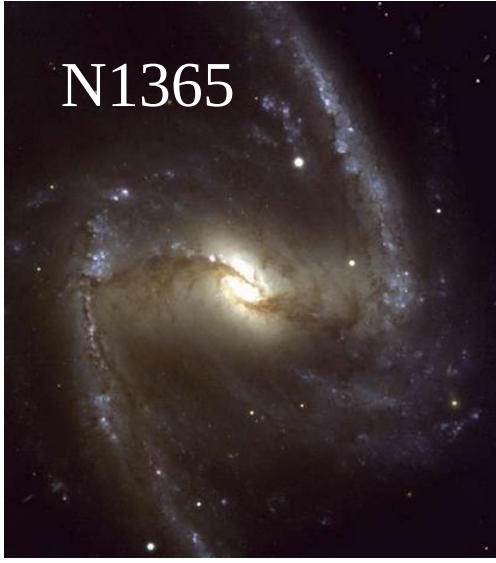
Mini-spiral $60M_\odot$
Cavity $200M_\odot$
CNR $10^6 M_\odot$
$7\ 10^4$ cm^{-3}
300K

Accretion in counter-rotation in NGC 1068



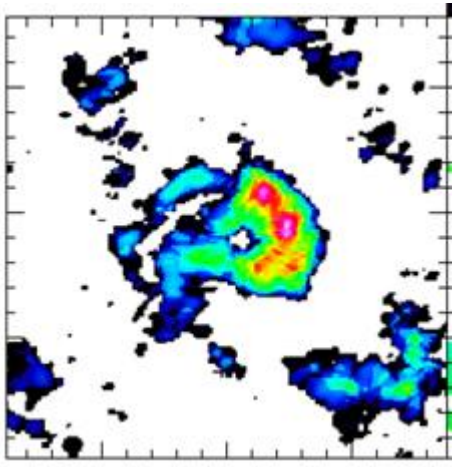
Imanishi et al 2020

SUMMARY



➔ **Fueling: Primary bar** drives gas to ring➔ **100pc**
Then nuclear bar from 100pc to 10pc

N1365 torus



➔ **Feedback: outflows** due to Active Nucleus
Radio jets or winds (or both)

➔ **Molecular tori: decoupling** between small scales and large scales **due to accretion, different dynamical time-scales**

ALMA