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The AGN fueling/feedback cycle in LERGs

A multi-phase study of a sample of local early-type radio galaxies

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In collaboration with: Isabella Prandoni (IRA-INAF), Robert Laing (SKAO), Martin Bureau (Oxford University), Timothy Davis (Cardiff University), Paola Parma (IRA-INAF), Hans de Ruiter (IRA-INAF), Rosita Paladino (IRA-INAF)

AGN 13: Beauty and the Beast
Milano, 11 Ottobre 2018

The HERG and LERG paradigm

Two main class of radio galaxies in the local Universe:

The HERG and LERG paradigm

Two main class of radio galaxies in the local Universe:



High Excitation Radio Galaxies (HERGs):

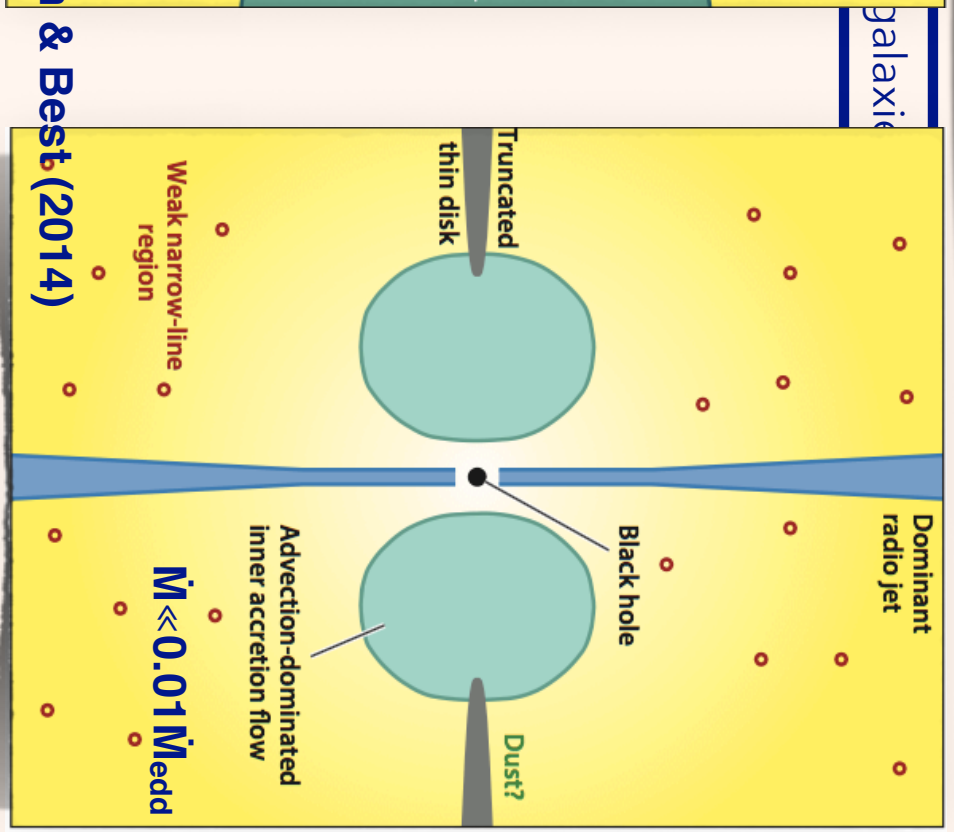
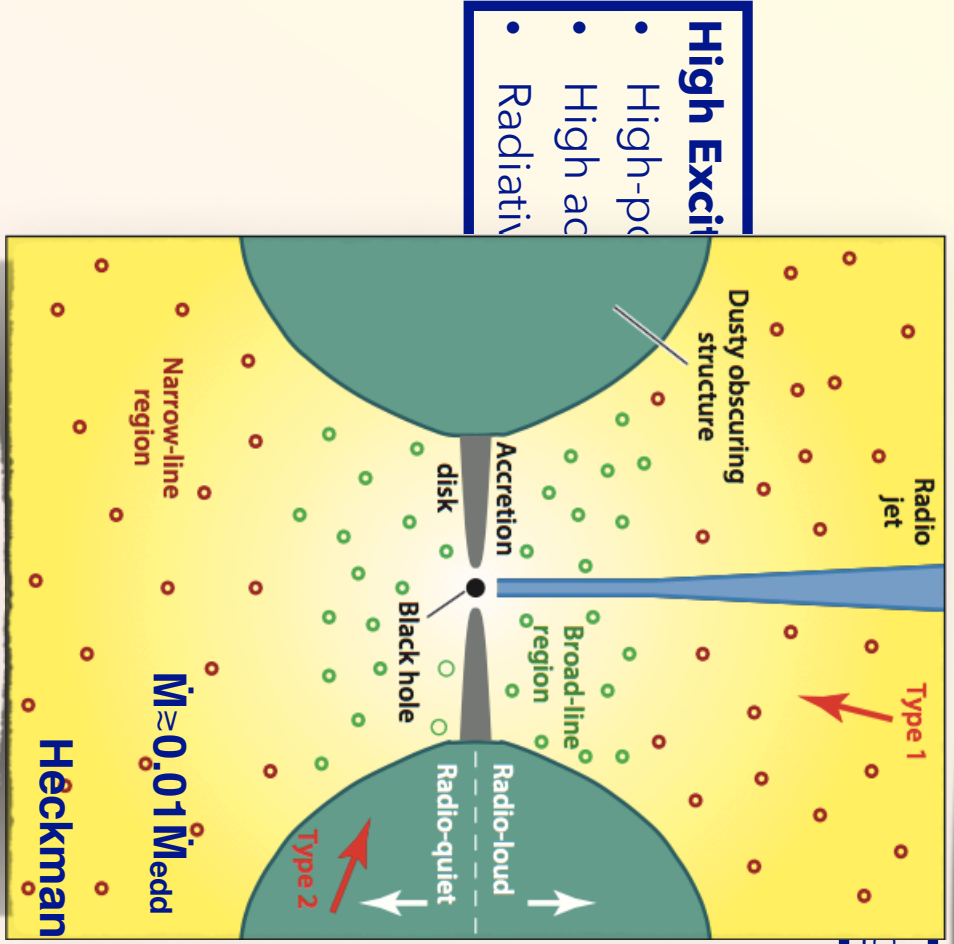
- High-power (FR II)
- High accretion rates ($\dot{M} \geq 0.01 \dot{M}_{\text{edd}}$)
- Radiative-mode AGN



Low Excitation Radio Galaxies (LERGs):

- Typically low-power (FR I)
- Low accretion rates ($\dot{M} \ll 0.01 \dot{M}_{\text{edd}}$)
- Jet-mode AGN

The HERG and LERG paradigm



(LERGs):
($M \ll 0.01 M_{\text{edd}}$)

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Different accretion rates for different sources of the accreting gas (Hardcastle et al. 2007):

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Different accretion rates for different sources of the accreting gas (Hardcastle et al. 2007):

- Accreting **cold** gas from gas-rich mergers

- Accreting **hot gas from the hot halo?**

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The accretion may occur directly from the hot phase of the IGM (Allen et al. 2006)

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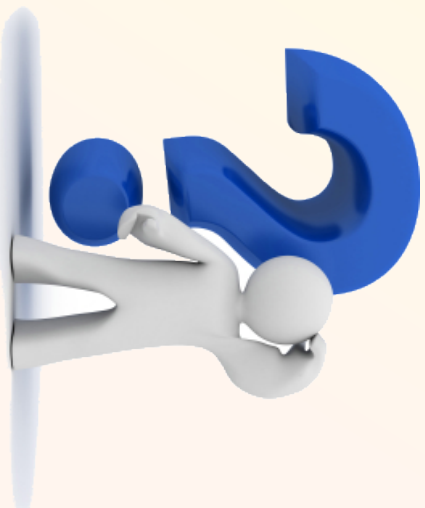
accretion may occur directly from the
phase of the IGM (Allen et al. 2006)

Cold gas often detected in large
amount in LERGs (Prandoni et al. 2007,
2010; Ocaña-Flaquero et al. 2010)

The hot gas may accrete only after chaotic
cooling (CCA model; Gaspari et al. 2013, 2015)

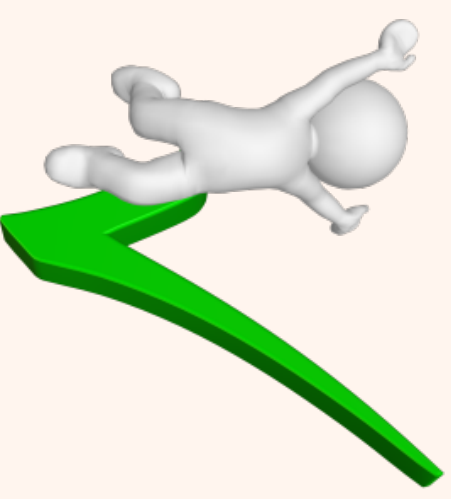
The goal

Investigate the AGN feeding/feedback loop in a sample of 11 nearby LERGs selected from the Southern Parkes 2.7 GHz Survey



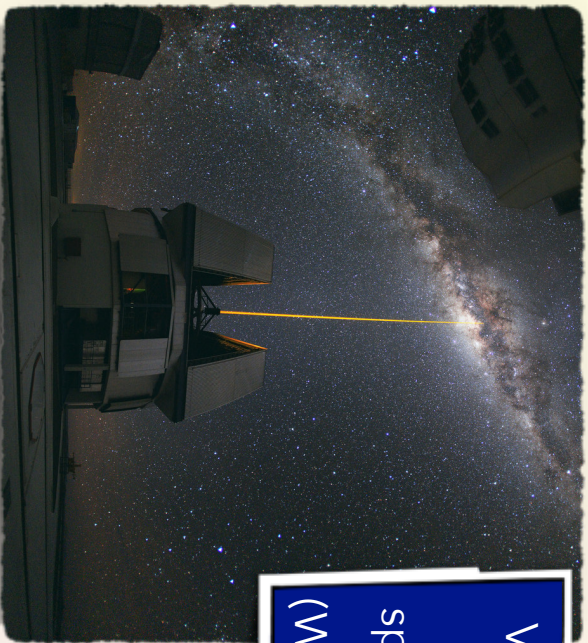
Role of the cold gas in fueling LERGs?
Origin of the gas? Kinematics?
Jets/ gas interaction?

Different galaxy components (stars, warm and cold gas, dust, radio jets) using multi-wavelength data



The dataset

VLT/MIMOS integral-
field-unit (IFU)
spectroscopy + MUSE
(Warren et al., in prep.)



Archival HST data (or
from ground telescopes,
when useful)



APEX CO (2-1)
integrated spectra
(Prandoni et al. 2010,
Laing et al. in prep.)



ALMA Cycle 3 CO (2-1)
observations (Ruffa et al.,
submitted to MNRAS)

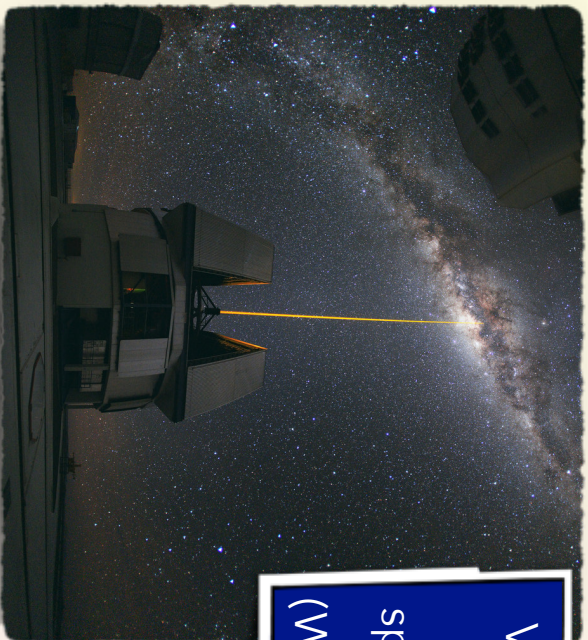


Archival plus proprietary
VLA high-res. imaging
(Ruffa et al., in prep.)



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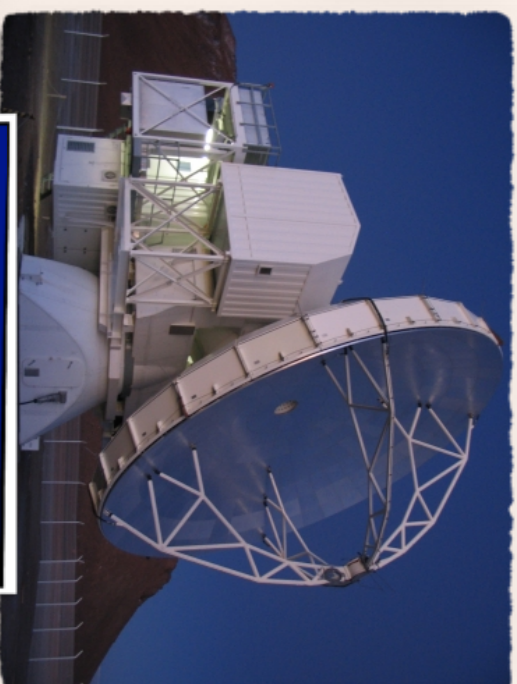
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ALMA observations

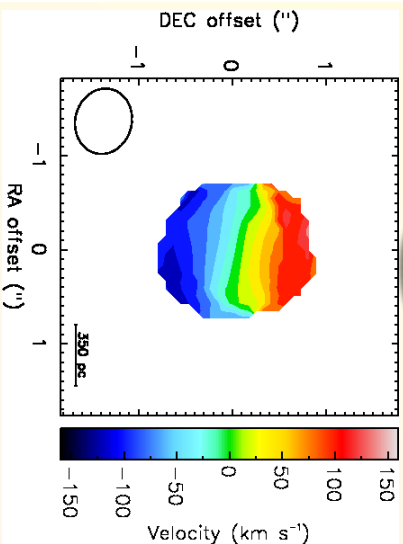
Cycle 3 CO(2-1) and 230 GHz continuum ALMA observations of 9 targets (PI: I. Prandoni). CO (2-1) detected in 6 out of 9 sources (Ruffa et al., submitted to MNRAS)

| Target | Redshift | CO peak (mJy/beam) | SNR | Δv (km/s) | θ_{synth} " (pc) |
|---------------|----------|-----------------------|-----|----------------------|-----------------------------------|
| IC 5131 | 0.0256 | 12.4 | 18 | 20 | 0.7 (360) |
| NGC 612 | 0.0298 | 18.3 | 14 | 20 | 0.3 (180) |
| PKS 0718-34 | 0.0284 | <0.6 | – | 80 | 0.7 (400) |
| NGC 3100 | 0.0088 | 28.3 | 45 | 10 | 0.9 (160) |
| NGC 3557 | 0.0103 | 16.3 | 38 | 22 | 0.6 (130) |
| ESO 443-G 024 | 0.0170 | <0.6 | – | 75 | 0.7 (240) |
| IC 4296 | 0.0125 | 2.0 | 8 | 40 | 0.6 (150) |
| NGC 7075 | 0.0185 | 4.0 | 10 | 40 | 0.6 (230) |
| IC 1459 | 0.0060 | <1.8 | – | 80 | 1.0 (120) |



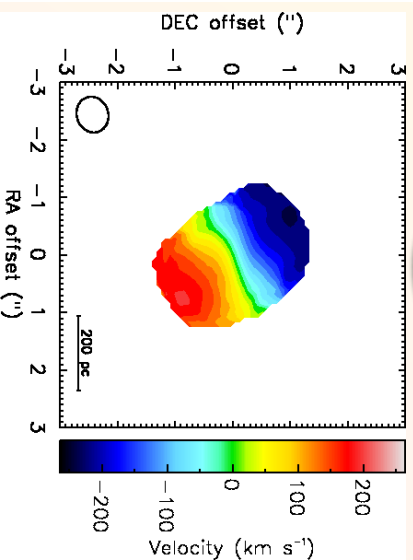
CO(2-1) detections

IC 1531



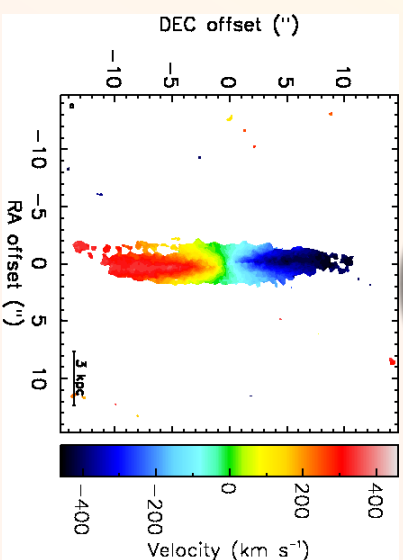
Size = 250 pc
 $M_{\text{H}_2} = 1.1 \times 10^8 M_{\odot}$

NGC 3557



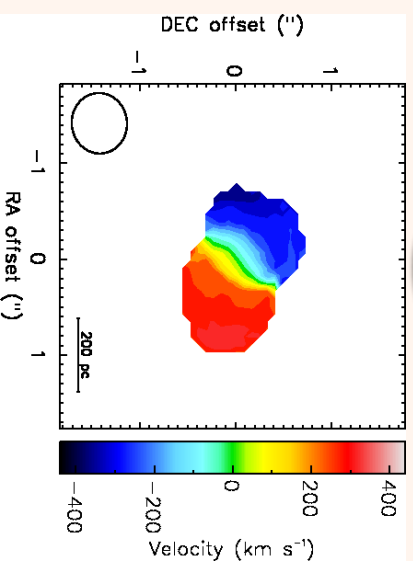
Size = 300 pc
 $M_{\text{H}_2} = 6.2 \times 10^7 M_{\odot}$

NGC 612



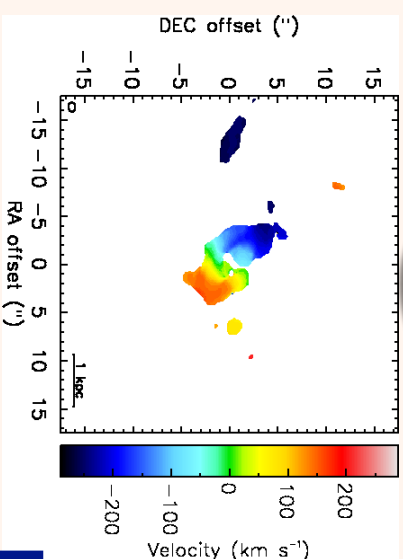
Size = 9.6 kpc
 $M_{\text{H}_2} = 2.0 \times 10^{10} M_{\odot}$

IC 4296



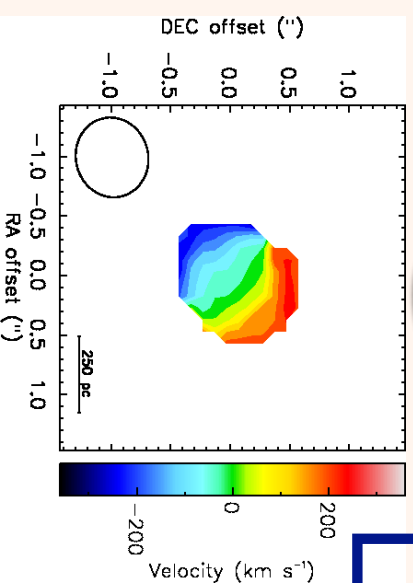
Size = 200 pc
 $M_{\text{H}_2} = 2.0 \times 10^7 M_{\odot}$

NGC 3100



Size = 1.6 kpc
 $M_{\text{H}_2} = 1.2 \times 10^8 M_{\odot}$

NGC 7075

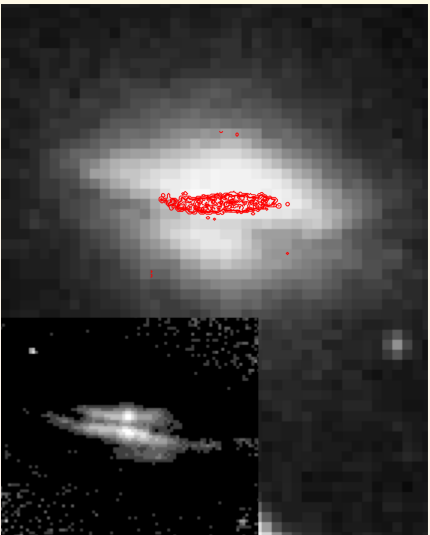


Size < 200 pc
 $M_{\text{H}_2} = 2.9 \times 10^7 M_{\odot}$

- Rotating CO discs
- Large molecular gas masses
- Sizes from ≈ 200 pc to 9.6 kpc
- Signs of asymmetries and/or warping in some cases

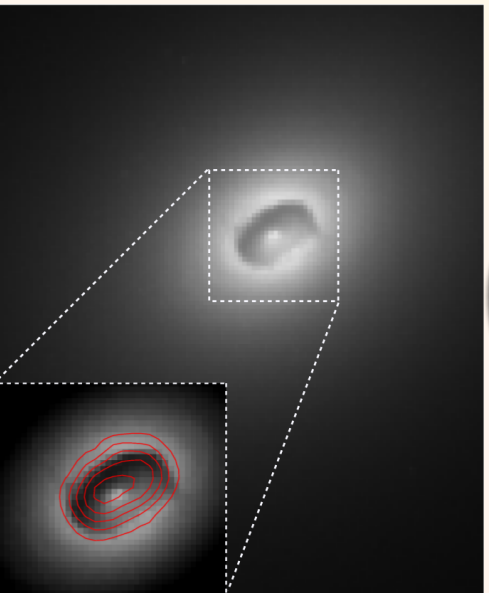
Dust and molecular gas

NGC 612



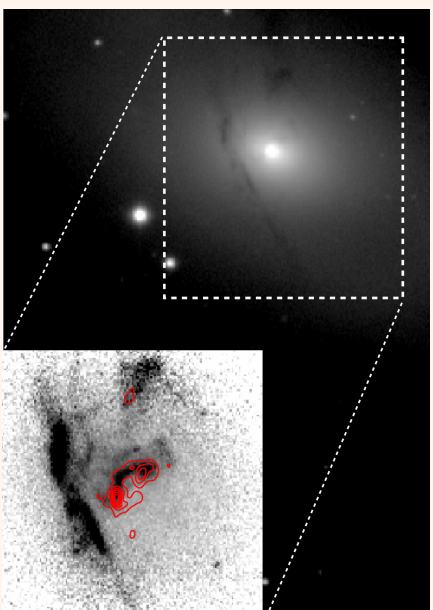
UK Schmidt Telescope image (468 nm).
Resolution = 1.7 arcsec. B-I color map
adapted from Veron-Cetty & Veron (2001)

NGC 3557



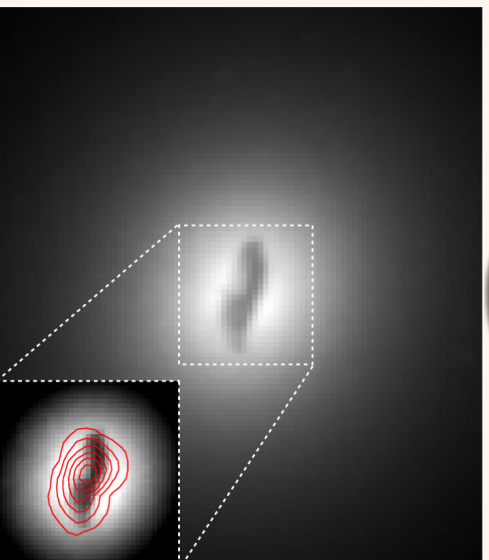
Archival HST images in the F555W filter. Resolution: 0.1 arcsec/pixel. CO moment 0 contours in red

NGC 3100



Las Campanas Obs. image (300-400
nm). Resolution = 0.77 arcsec.

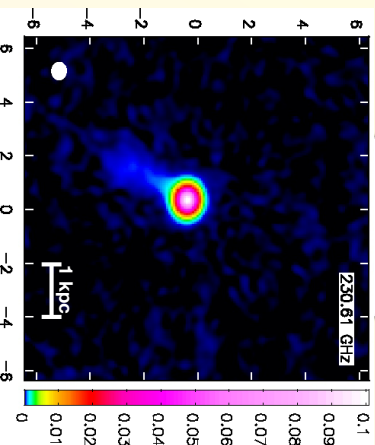
IC 4296



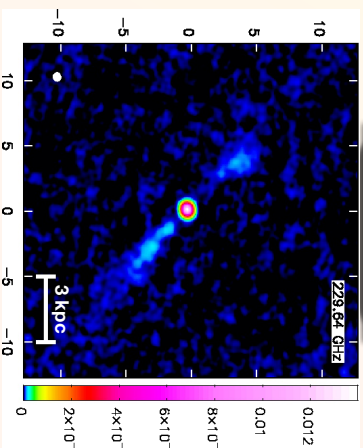
- Evidences of dust and molecular gas co-spatiality

230 GHz continuum emission

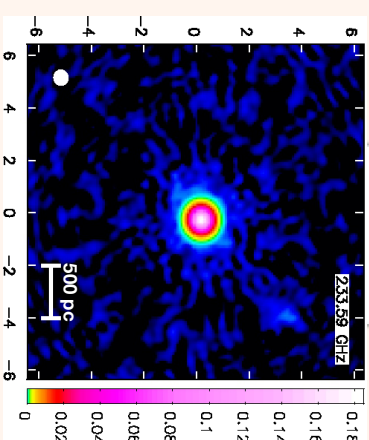
IC 1531



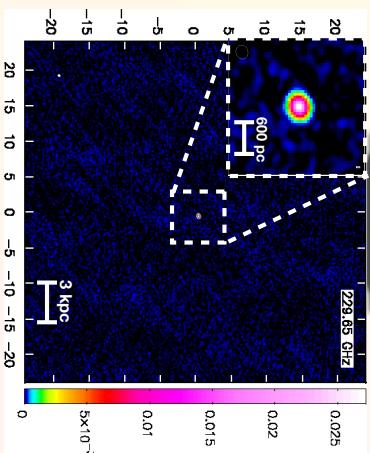
PKS 0718-34



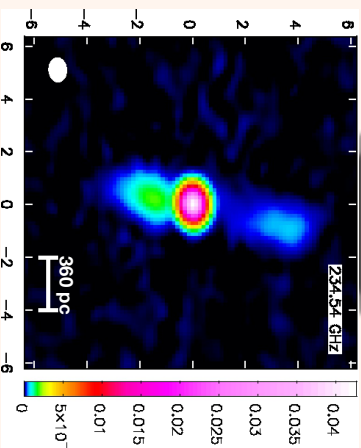
IC 4296



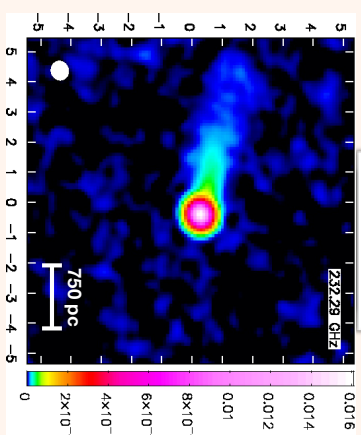
NGC 612



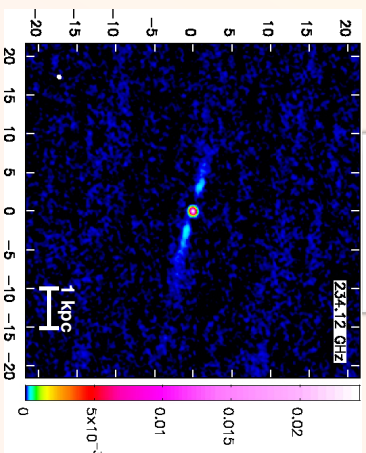
NGC 3100



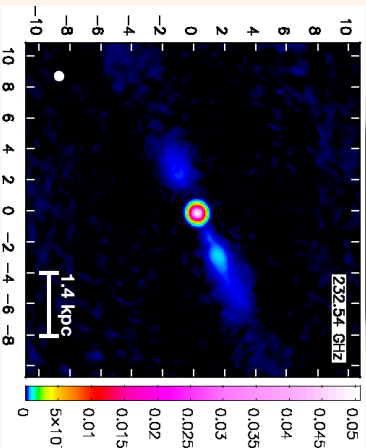
NGC 7075



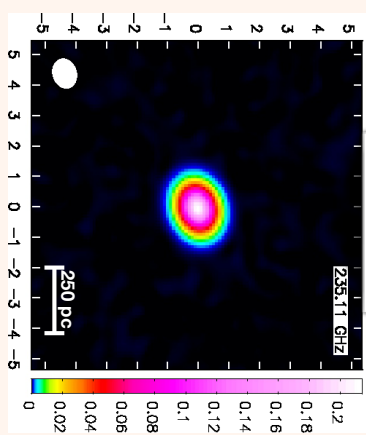
NGC 3557



ESO 443-G 024



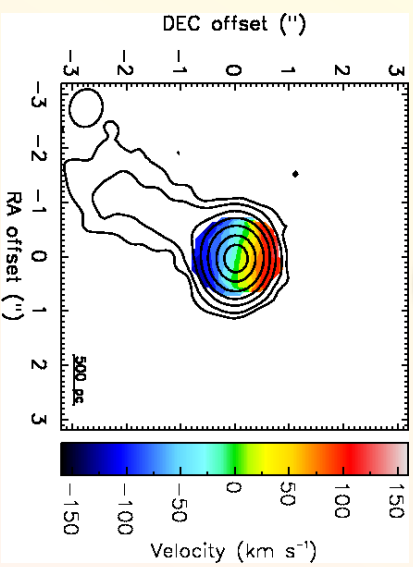
IC 1459



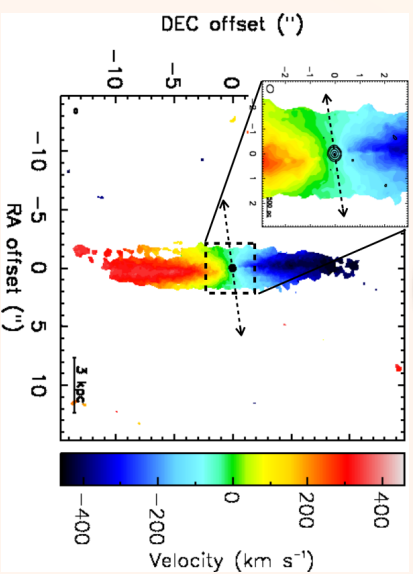
- All the sources detected in continuum
- Six of them show extended emission from the jets, perfectly matching that visible in the archival radio images (1.4-10 GHz)

Jets and CO discs

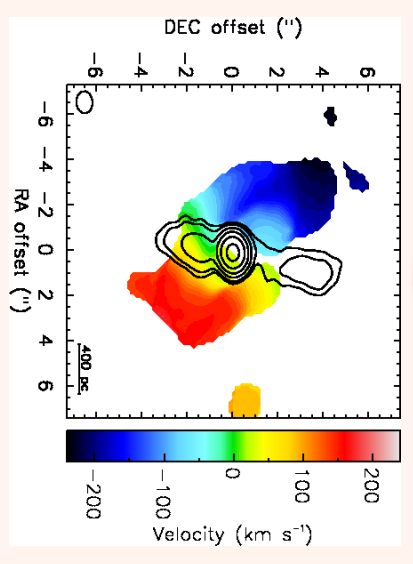
IC 1531



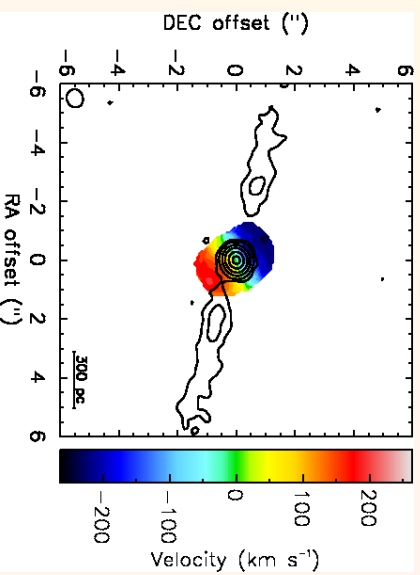
NGC 612



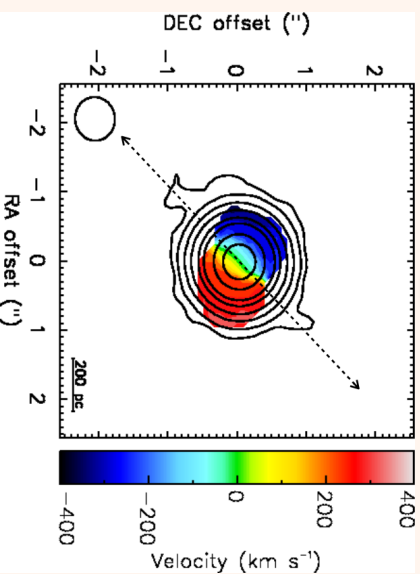
NGC 3100



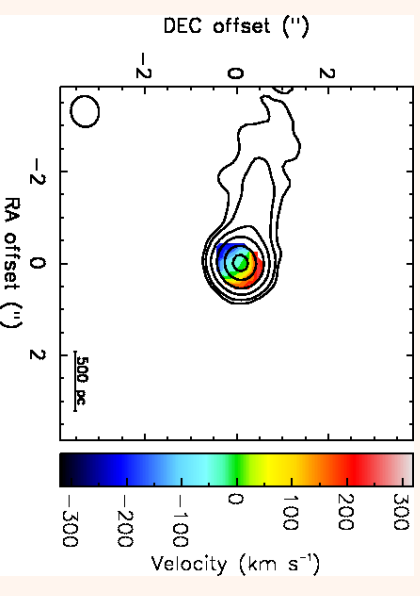
NGC 3557



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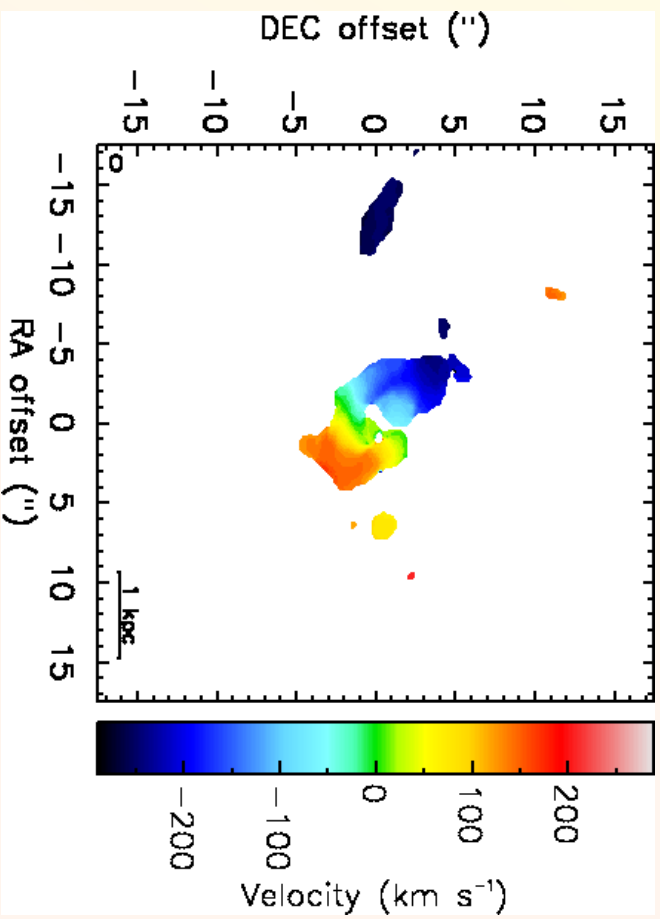
NGC 7075



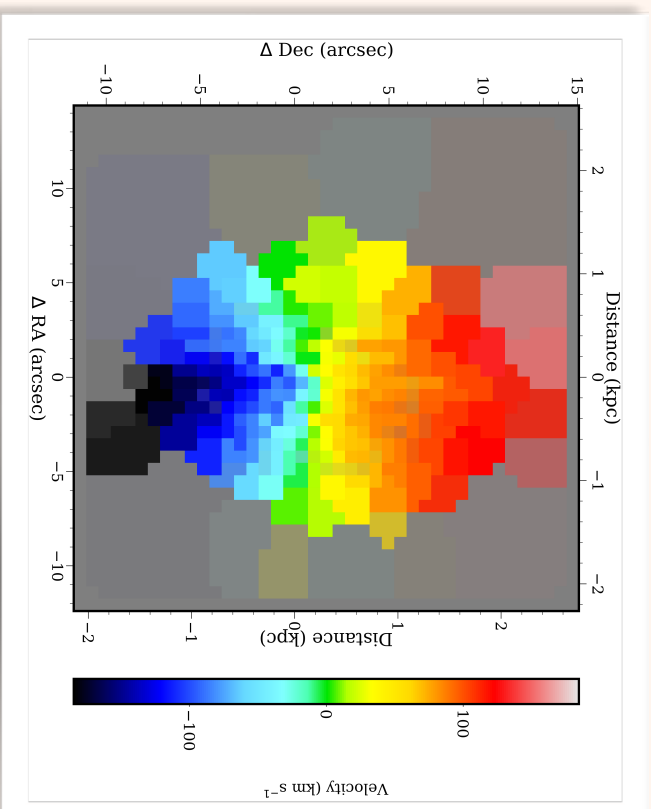
- CO disc/jet axes aligned (in projection) in four cases (NGC 612, NGC 3100, IC 4296, NGC 7075)
- Significant misalignments in NGC 3557 and IC 1531

- Assuming dust/CO co-spatiality: consistence with results of de Ruiter (2002), de Koff (2000)
- Origin of the misalignment?

The case of NGC 3100



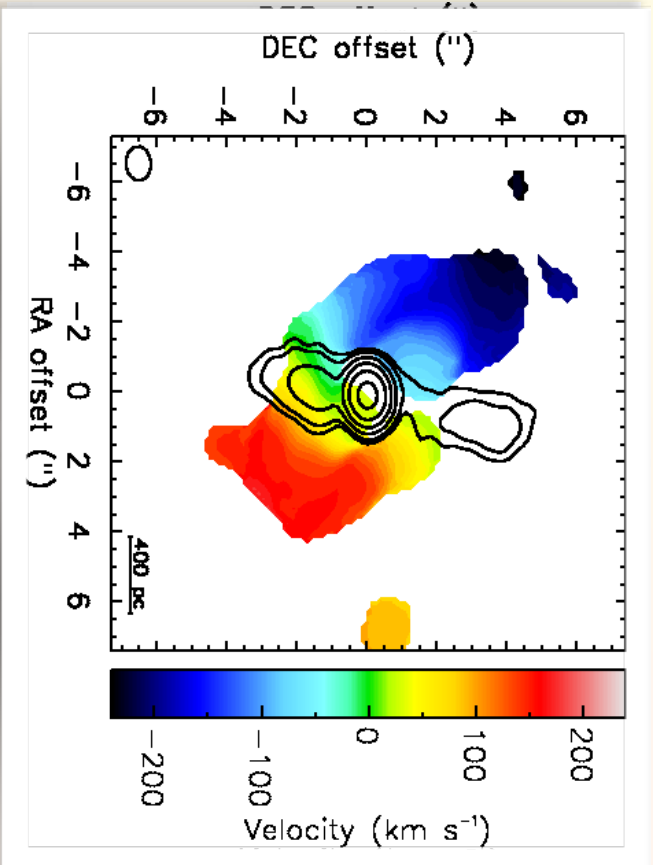
Ruffa et al., submitted to MNRAS



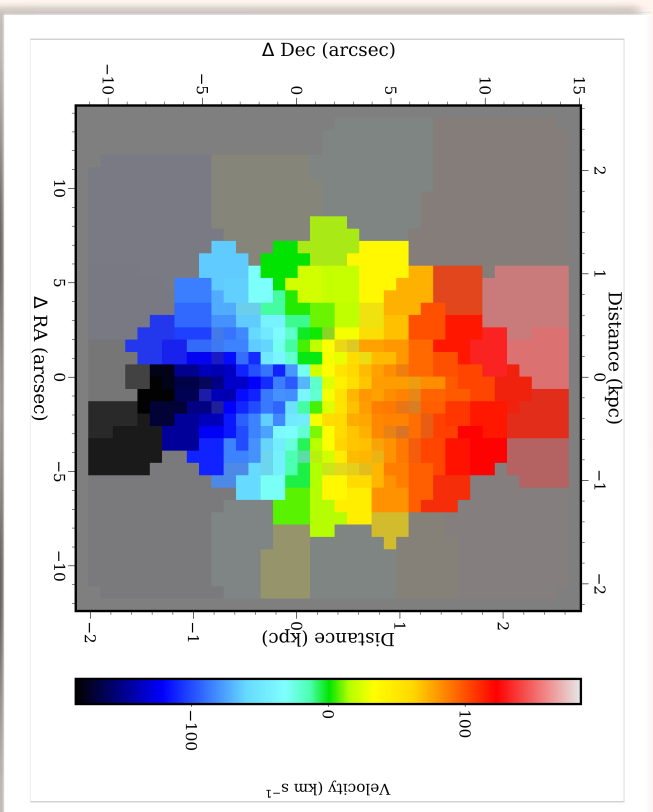
Warren et al., in prep.

- Possible external origin
- Best candidate for a jet/ISM interaction
- Requested (and obtained) 10 hours ALMA observations (PI: I. Ruffa) of different molecular transitions in NGC 3100

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Future perspectives

- Detailed analysis of the kinematics of the six CO(2-1) detections (Ruffa et al., in prep)
- Detailed analysis of the radio jets using recently acquired high-resolution JVLA 10 GHz continuum data (Ruffa et al., in prep)
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Work in progress



**Thank
You**