The AGN fueling/feedback cycle in LERGs

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

Ilaria Ruffa
(IRA-INAF/University of Bologna)

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 (FRII)
- High accretion rates ($\dot{M} \gtrsim 0.01 \dot{M}_{edd}$)
- Radiative-mode AGN

Low Excitation Radio Galaxies (LERGs):

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

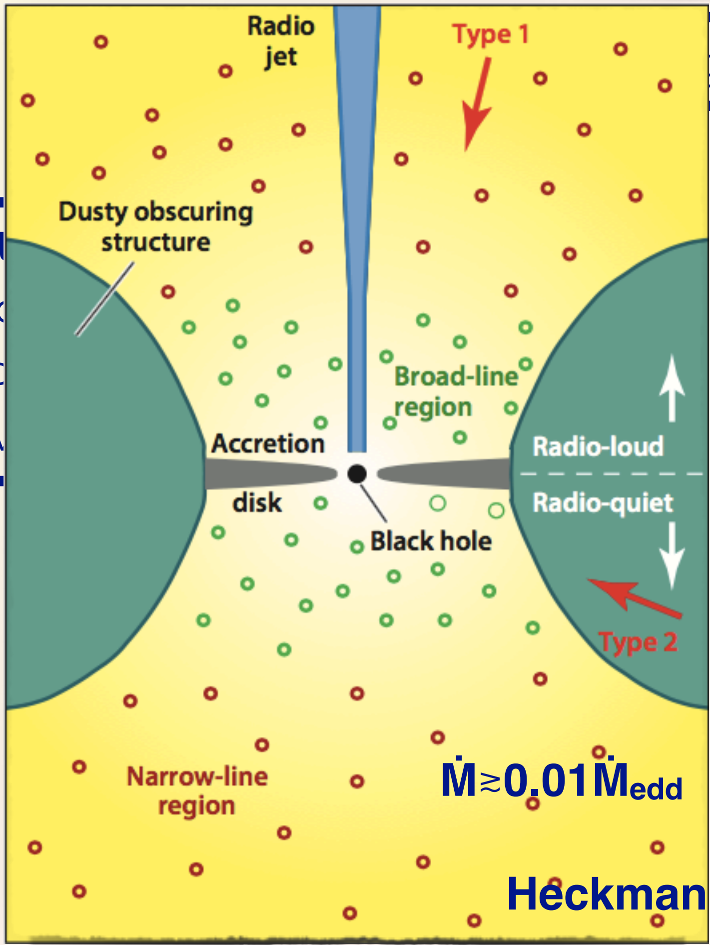
The HERG and LERG paradigm

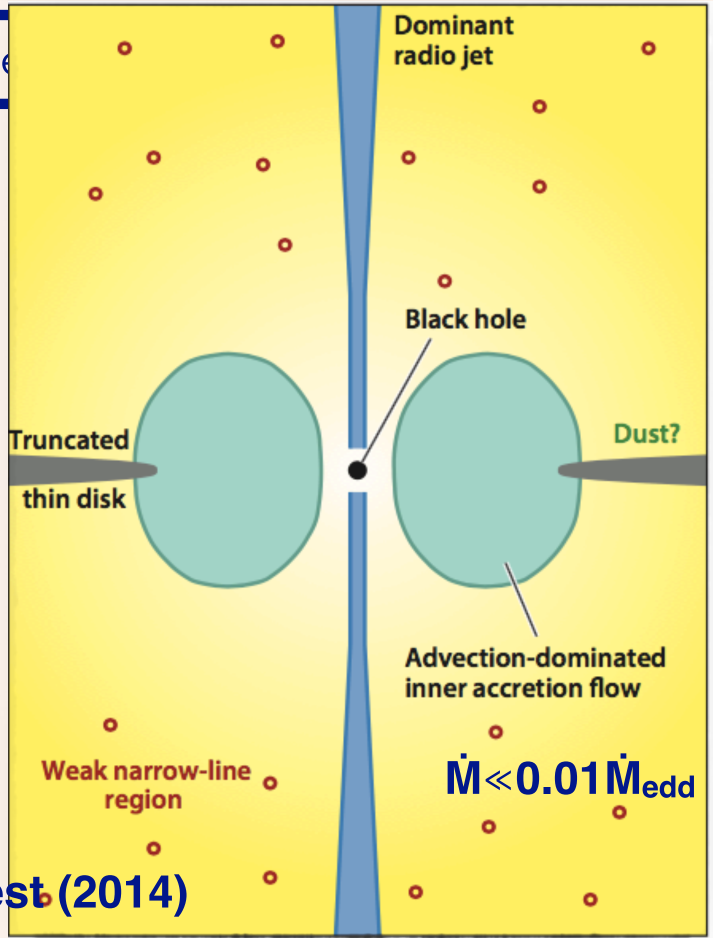
High Excit
- High-p
- High ac
- Radiativ

galaxie

(LERGs):

edd)





Heckman & Best (2014)

The HERG and LERG paradigm

Two main class of radio galaxies in the local Universe:

High Excitation Radio Galaxies (HERGs):

- High-power (FRII)
- High accretion rates ($\dot{M} \gtrsim 0.01 \dot{M}_{edd}$)
- Radiative-mode AGN

Low Excitation Radio Galaxies (LERGs):

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

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

The HERG and LERG paradigm

Two main class of radio galaxies in the local Universe:

High Excitation Radio Galaxies (HERGs):

- High-power (FRII)
- High accretion rates ($\dot{M} \gtrsim 0.01 \dot{M}_{edd}$)
- Radiative-mode AGN

Low Excitation Radio Galaxies (LERGs):

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

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?**

The HERG and LERG paradigm

Two main class of radio galaxies in the local Universe:

High Excitation Radio Galaxies (HERGs):

- High-power (FRII)
- High accretion rates ($\dot{M} \gtrsim 0.01 \dot{M}_{edd}$)
- Radiative-mode AGN

Low Excitation Radio Galaxies (LERGs):

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

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?**

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

The HERG and LERG paradigm

Two main class of radio galaxies in the local Universe:

High Excitation Radio Galaxies (HERGs):

- High-power (FRII)
- High accretion rates ($\dot{M} \gtrsim 0.01 \dot{M}_{edd}$)
- Radiative-mode AGN

Low Excitation Radio Galaxies (LERGs):

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

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?**

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

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

The HERG and LERG paradigm

Two main class of radio galaxies in the local Universe:

High Excitation Radio Galaxies (HERGs):

- High-power (FRII)
- High accretion rates ($\dot{M} \gtrsim 0.01 \dot{M}_{edd}$)
- Radiative-mode AGN

Low Excitation Radio Galaxies (LERGs):

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

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?**

cretion may occur directly from the se of the IGM (Allen et al. 2006)

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

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

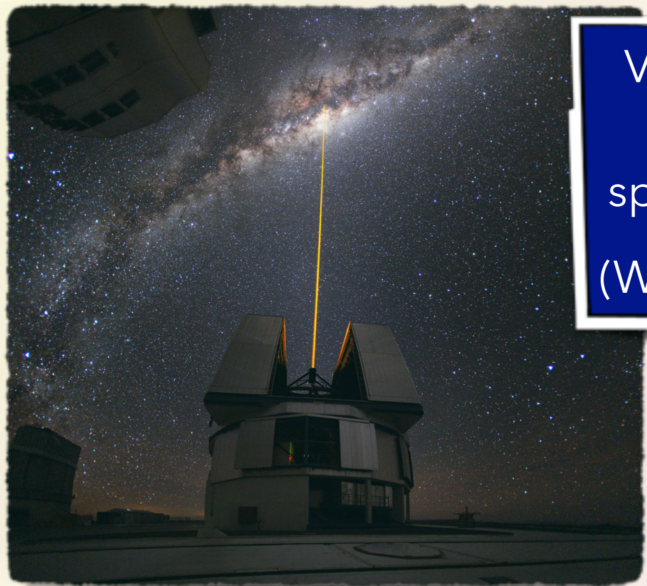
The goal

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

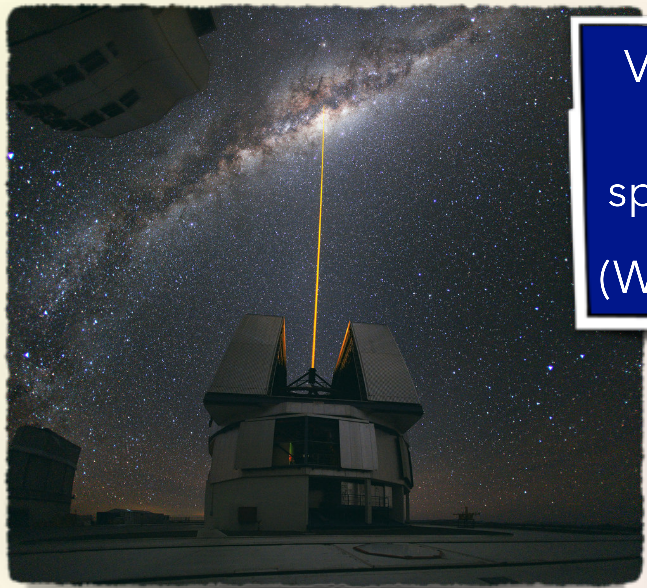
APEX CO (2-1) integrated spectra (Prandoni et al. 2010, Laing et al. in prep.)

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

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

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

The dataset



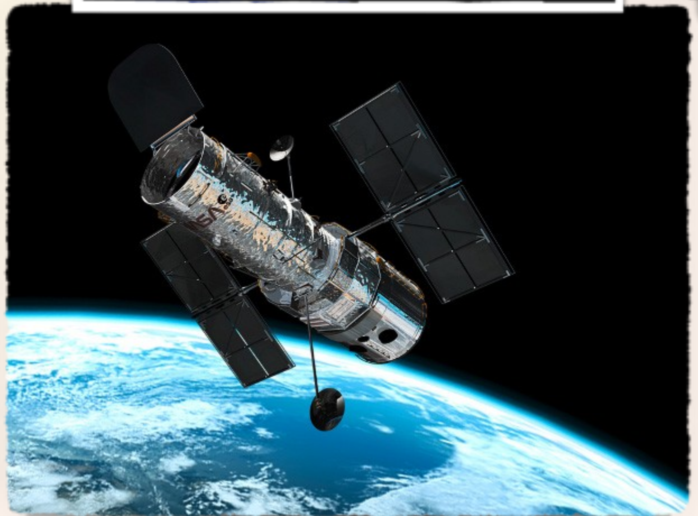
VLT/VIMOS integral-field-unit (IFU) spectroscopy + MUSE

(Warren et al., in prep.)

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 HST data (or from ground telescopes, when useful)



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

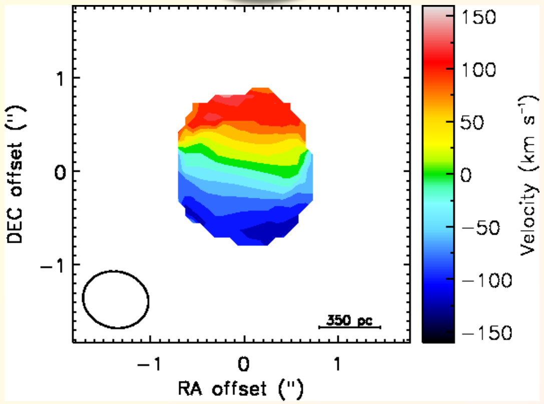
ALMA observations

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	$\Delta\nu$ (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)

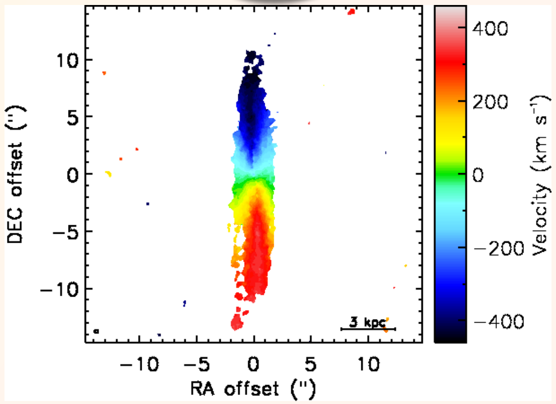
CO(2-1) detections

IC 1531



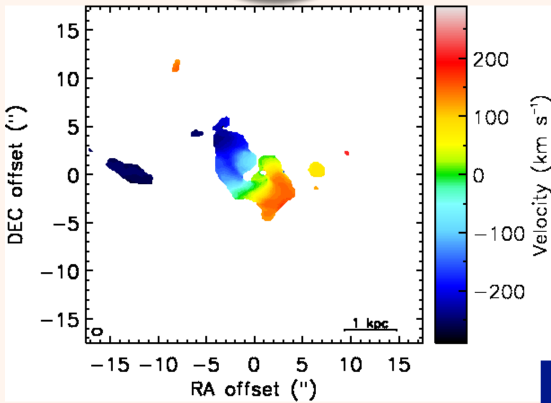
Size = 250 pc
M_{H2} = 1.1 x 10^8 $M_\odot$

NGC 612



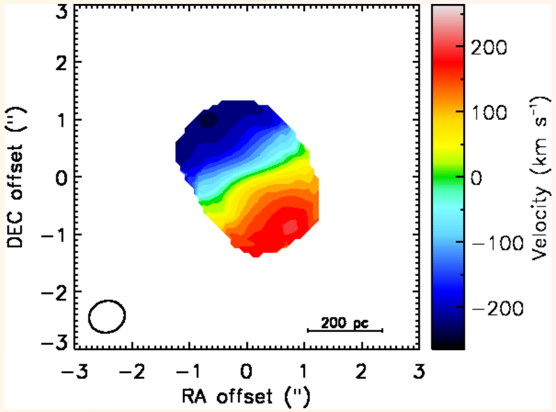
Size = 9.6 kpc
M_{H2} = 2.0 x 10^{10} $M_\odot$

NGC 3100



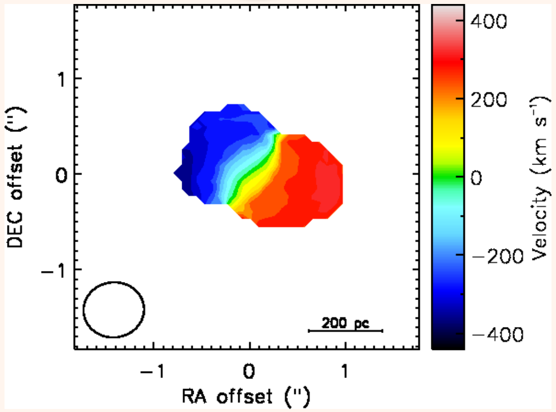
Size= 1.6 kpc
M_{H2} = 1.2 x 10^8 $M_\odot$

NGC 3557



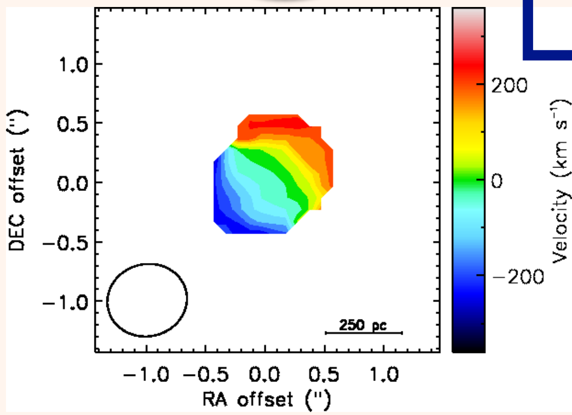
Size = 300 pc
M_{H2} = 6.2 x 10^7 $M_\odot$

IC 4296



Size = 200 pc
M_{H2} = 2.0 x 10^7 $M_\odot$

NGC 7075



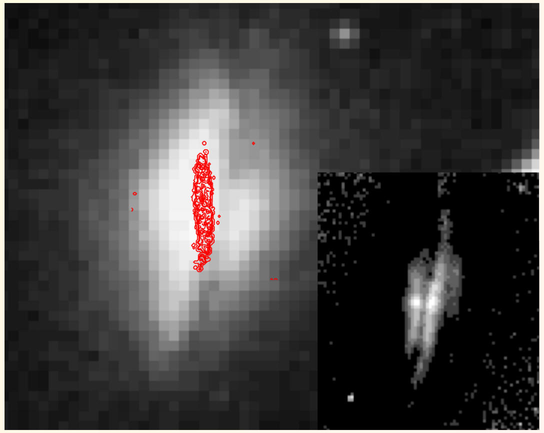
Size < 200 pc
M_{H2} = 2.9 x 10^7 $M_\odot$

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

Ruffa et al., submitted to MNRAS

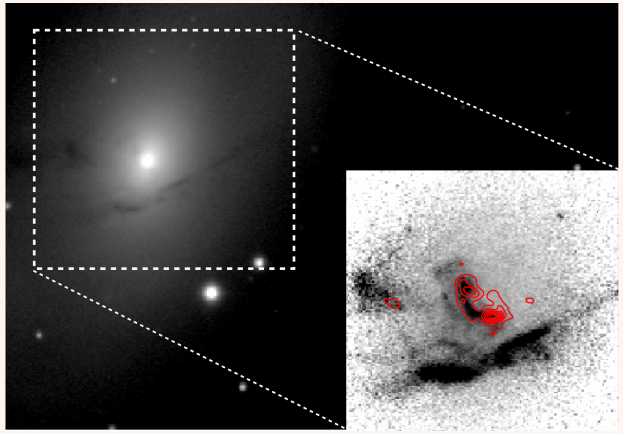
Dust and molecular gas

NGC 612



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

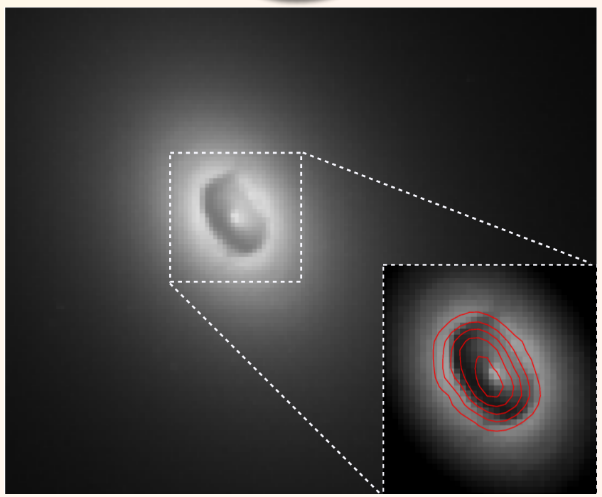
NGC 3100



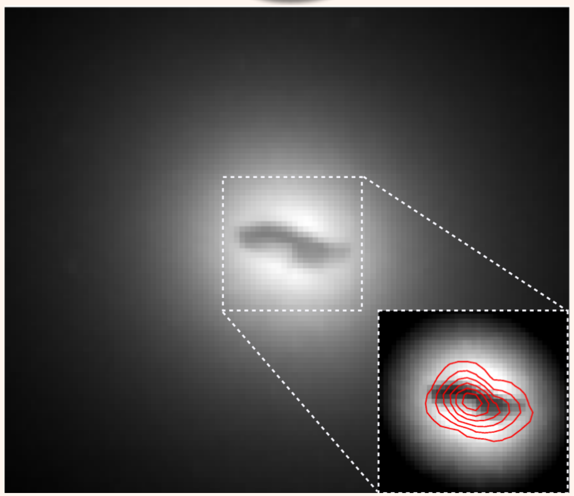
Las Campanas Obs. image (300-400 nm). Resolution = 0.77 arcsec.

- Evidences of dust and molecular gas co-spatiality

NGC 3557



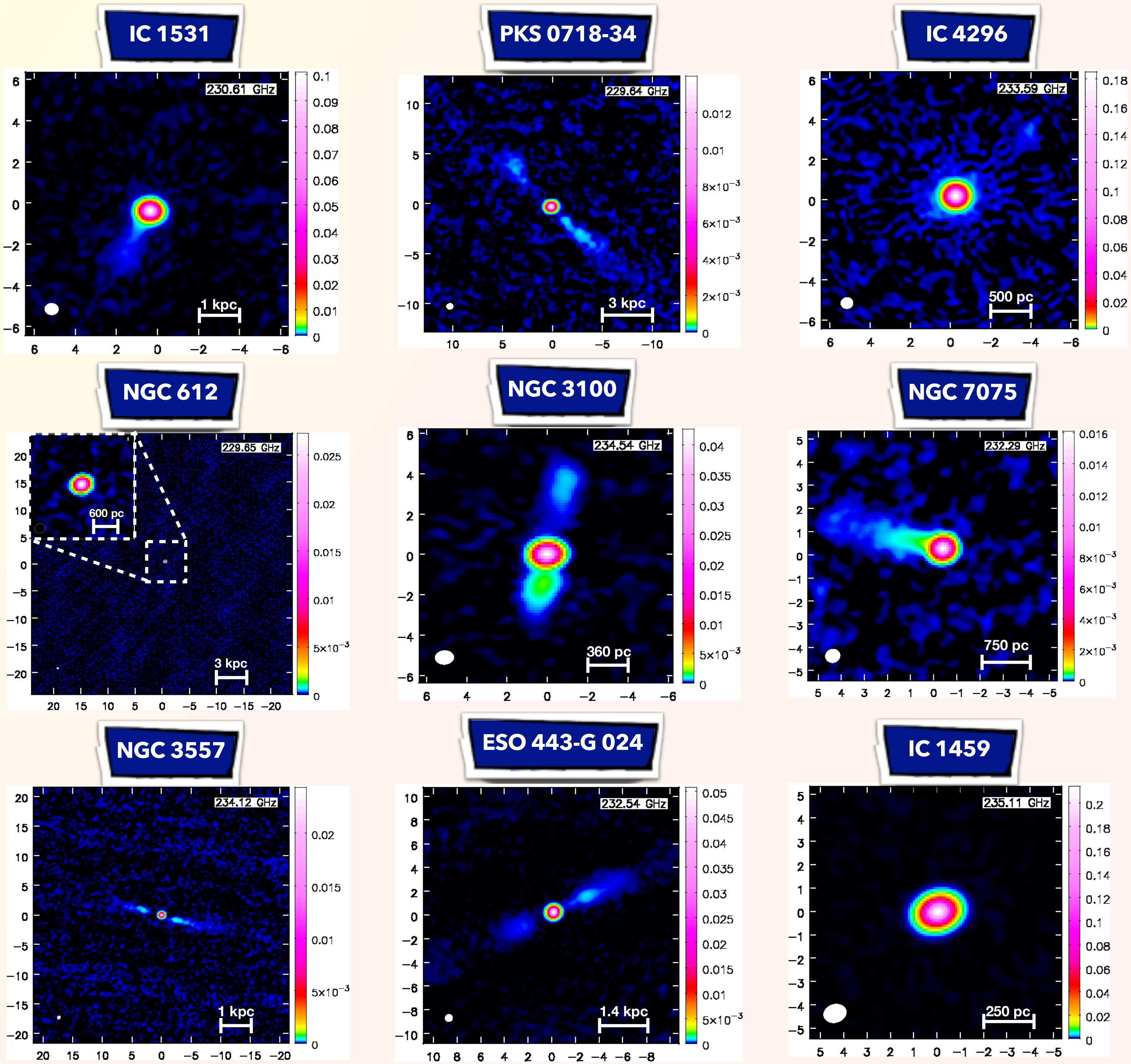
IC 4296



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

Ruffa et al., submitted to MNRAS

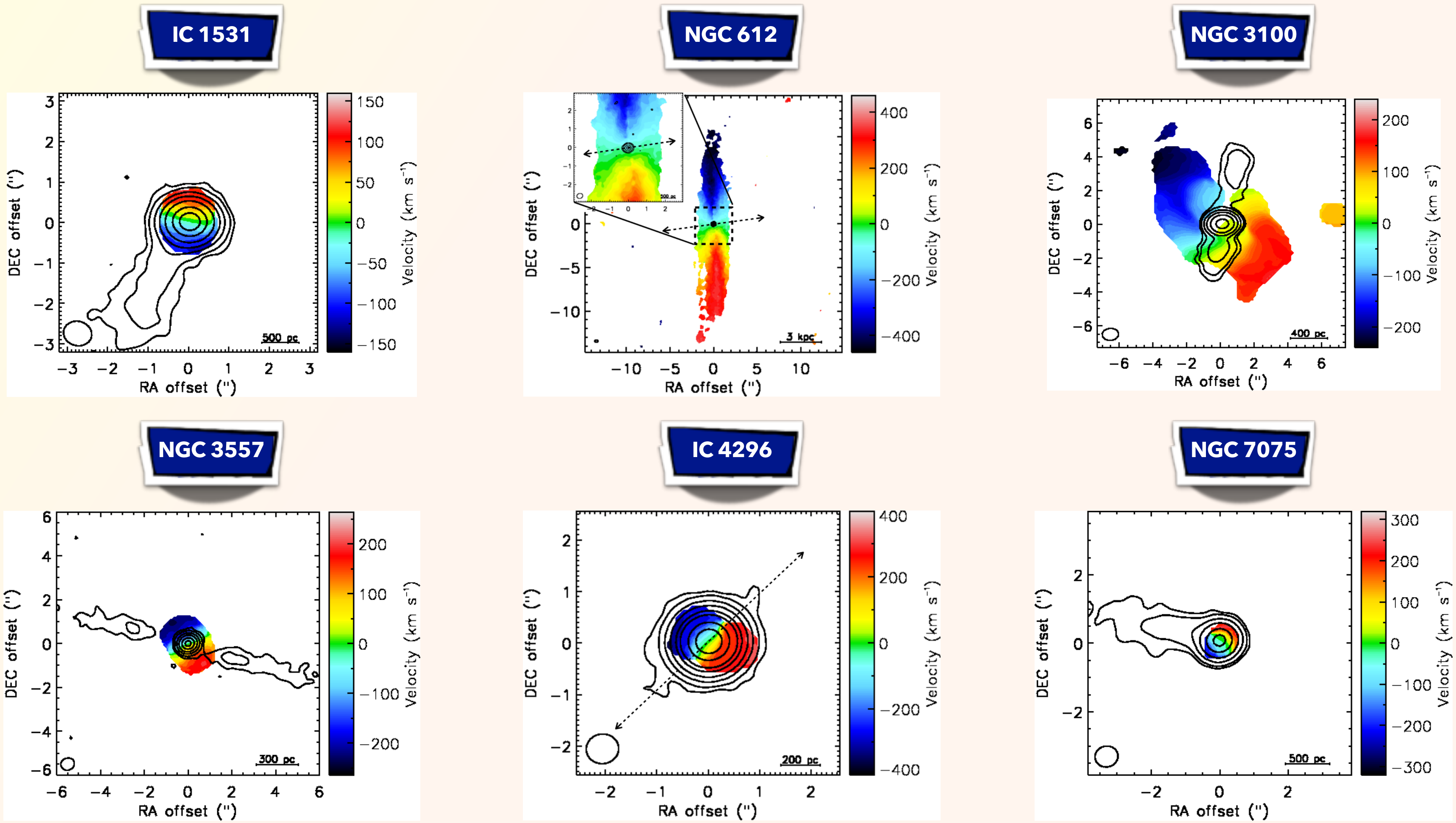
230 GHz continuum emission



- 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)

Ruffa et al., submitted to MNRAS

Jets and CO discs

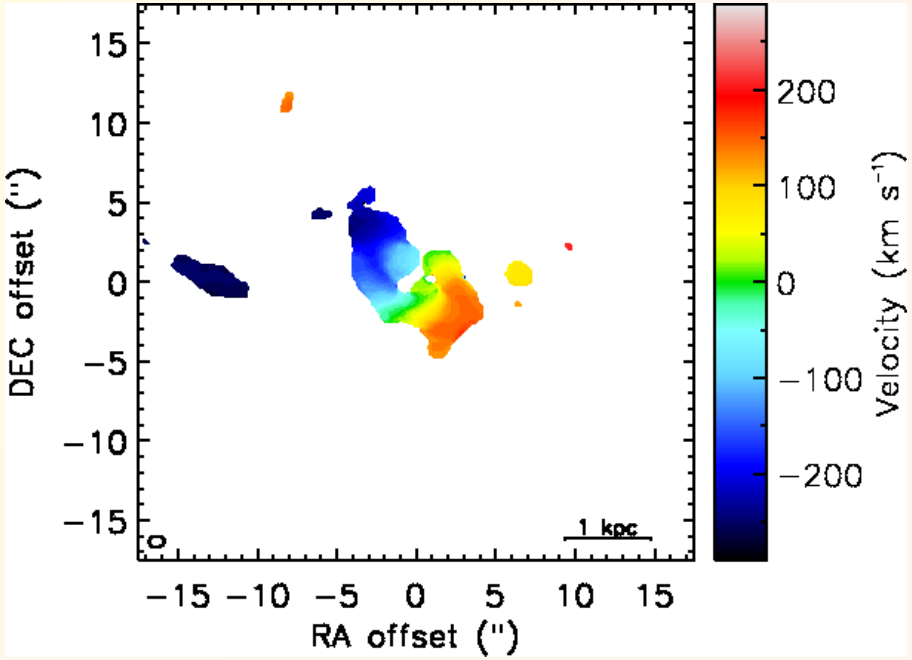


- CO disc/jet axes aligned (in projection) in four cases (NGC 612, NGC 3100, IC 4296, NGC 7075)
- Significant misalignments in NGC 3557 and IC 1531

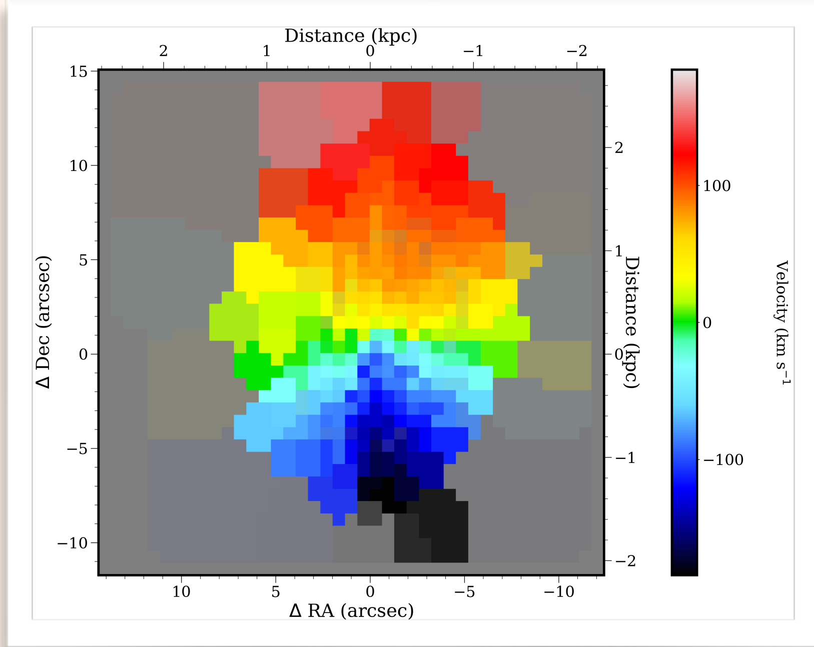
- Assuming dust/CO co-spatiality: consistence with results of de Ruiter (2002), de Koff (2000)
- Origin of the misalignment?

Ruffa et al., submitted to MNRAS

The case of NGC 3100



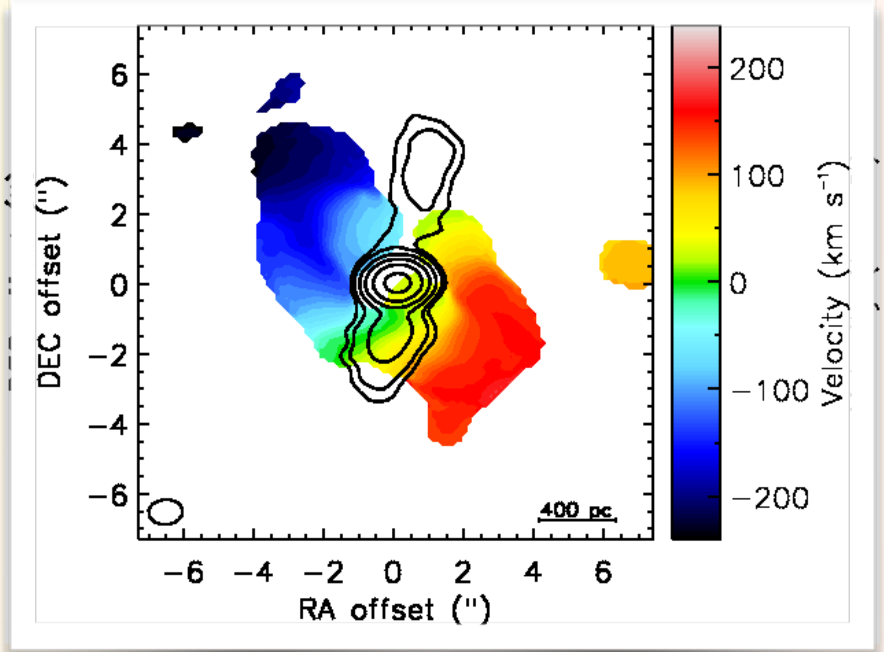
Ruffa et al., submitted to MNRAS



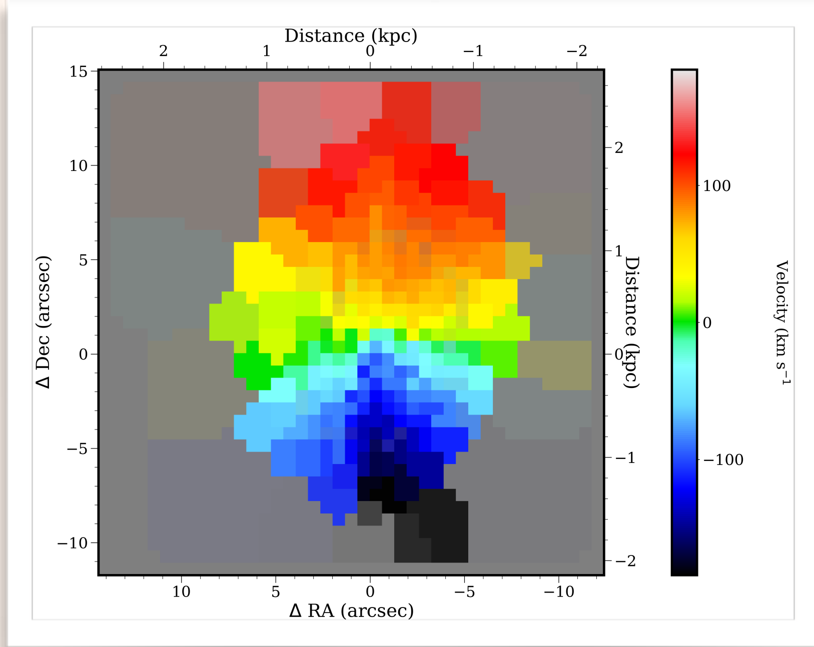
Warren et al., in prep.

- 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

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

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)
- Detailed comparison with optical VIMOS/IFU data (Warren et al., in prep)

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)
- Detailed comparison with optical VIMOS/IFU data (Warren et al., in prep)

Work in progress


Thank
You