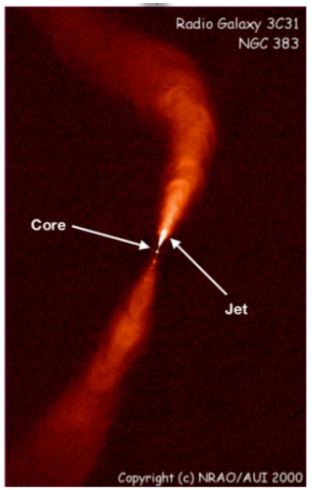
Blackout @IRA

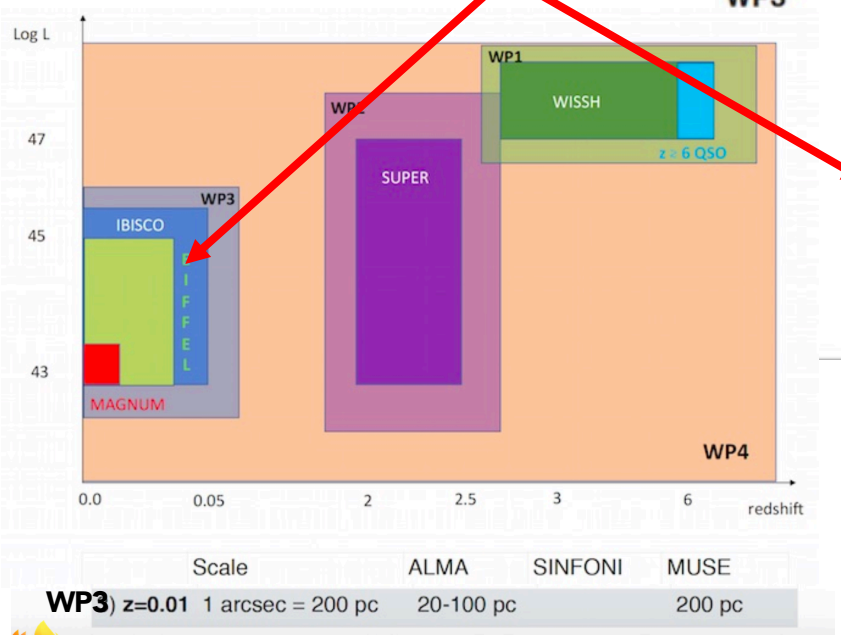
2017PH3WAT
03/11/2019 - 03/11/2022

Isabella Prandoni
IRA-INAF, Bologna

The fueling/feedback cycle in Radio Galaxies



WP3/Task 3.3: The other side of BH accretion: the EIFFEL local radio galaxy sample



WP3	
	Task 3.1 Leader: Cresci, Participants: **PostDoc1 (analysis ALMA and MUSE data)**, Marc Mannucci, Fiore, Piconcelli
	Task 3.2 Leader: Fiore, Participants: **RTD2 (analysis ALMA and MUSE data)**, Malizia, Piconcelli, Cresci, Marconi, Prandoni
	Task 3.3 Leader: Prandoni, Participants: Ruffa, Brusa, Lanzuisi, Fiore, Cresci, Marconi
	Task 3.4 Leader: La Franca, Participants: **RTD4 (BH mass functions)**, Marinucci, Bianchi, Matt, De Rosa, Cappi, Dadina, Malizia, Fiore, Brusa, Lanzuisi, Marconi, Zaino, Middei, Duras

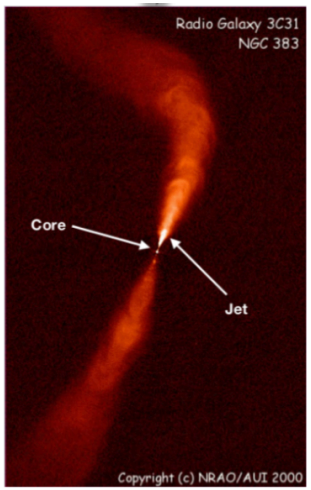
A resolved, multi-phase study (stars, dust, cold & ionized gas, jets, etc.) of inner cores (sub-kpc/kpc scales) of local RGs

→ focus on accretion / (sub-)galaxy scale feedback

The Sample

Radio source	Host galaxy	z	Log $P_{1.4GHz}$ (W Hz^{-1})	FR Type
PKS 0007-325	IC1531	0.025641	23.9	FRI
PKS 0131-31	NGC612	0.029771	25.0	FRI/II
PKS 0320-37	NGC1316	0.005871	22.4	FRI
PKS 0336-35	NGC1399	0.004753	22.5	FRI
PKS 0718-34	—	0.028353	24.6	FRI
PKS 0958-314	NGC3100	0.008813	23.0	FRI
PKS 1107-372	NGC3557	0.010300	23.3	FRI
PKS 1258-321	ESO443-G-024	0.017042	24.0	FRI
PKS 1333-33	IC4296	0.012465	25.4	FRI
PKS 2128-388	NGC7075	0.018479	23.9	FRI
PKS 2254-367	IC1459	0.006011	23.0	FRI*

* *sub-arcsec scale*



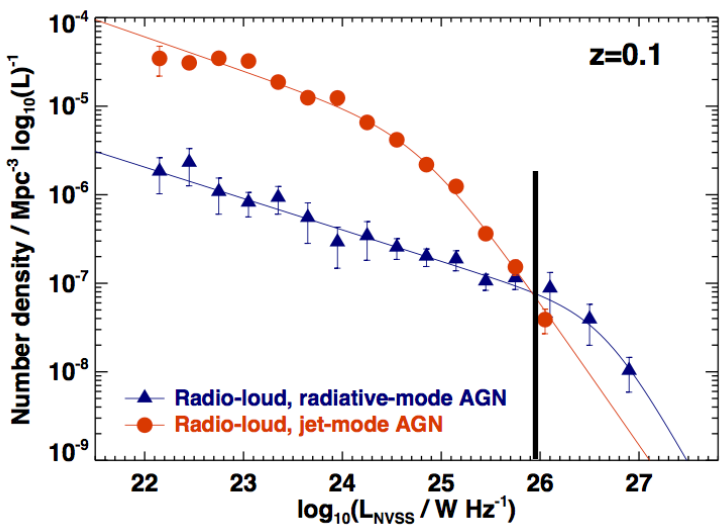
- Parkes 2.7 GHz survey (PKS; Ekers et al. 1989)
  [-17° < Decl. < -40°]
- 11 objects with z<0.03 & E/S0 hosts
- <u>All</u> <u>LERGs</u> (Mostly FRI) [weak/absent low ionization opt. em. lines]
- Diverse environments (different accr. mechanisms)

Why Low Excitation RGs (LERG)

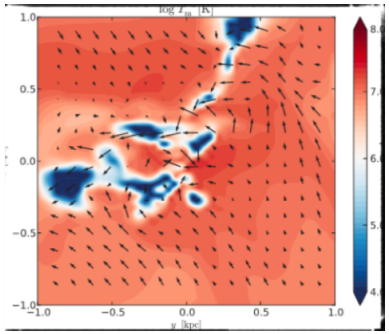
- Dominant RG population in local Universe
- Low Accretion Rates: $L/L_{Edd} \leq 0.01$
- AGN feedback mostly kinetic (jet-mode)
- Hosted by Very massive ($M > 10^{11}\ M_{sun}$) ETG

[Heckmann & Best 2014]

→ shed light on the mechanisms determining the observed properties of massive nearby ETGs

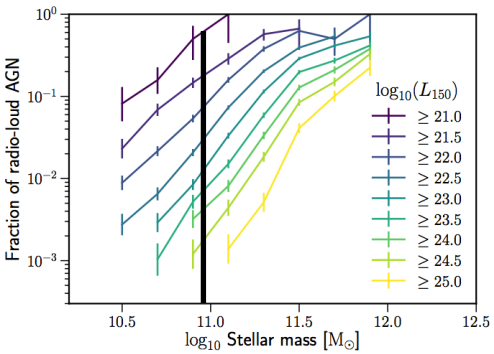


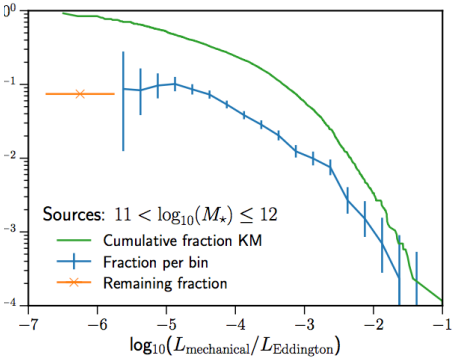
AGN Fueling (hot-mode):
hot gas (from the X-ray halo) through Chaotic Cold Accretion (CCA)



Gaspari+ 2013

Sabater et al. 2018 - **0.01<z<0.3**





Massive galaxies in local Universe:
→ 100% RL (always switched on) *→ Most have L/L_{Edd} ~10^{-5}*

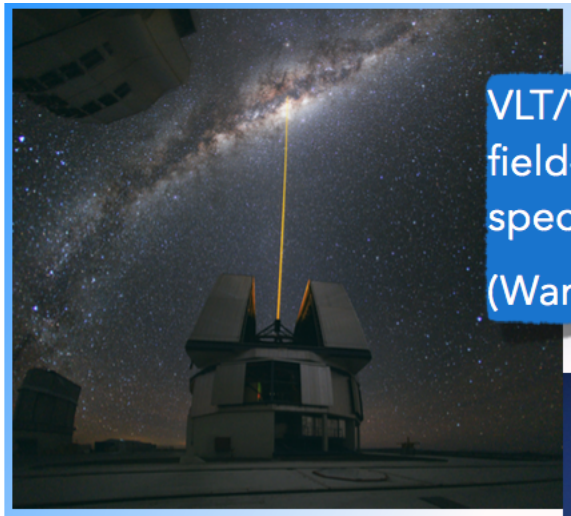
The Project

- Statistical approach: well defined (volume-limited) LERG samples + control samples of RQ early-type galaxies
- Data available:
  - warm ionized gas + stellar component (IFU VIMOS+MUSE)
  - molecular gas (APEX & ALMA)
  - detailed radio jet morphology: jet/CO geometry, brightness gradients, deflections, co-spatial heating, etc. (JVLA+VLA)
  - dust (high resolution optical imaging in two bands, HST),
  - Optical morphology: low SB features, shells, etc. (VST)
  - HI data to probe environment (observations ongoing at ATCA)
- PhD Students: I. Ruffa (2016-2019, Bologna) & J. Warren (2015 – 2018, Oxford)
- Collaborators: *M. Bureau (Oxford), T. Davis (Cardiff), R. Laing (SKAO), R. Paladino (IRA), P. Parma (IRA), H. de Ruiter (IRA)*

  E. Iodice (OAC, VST), HI group OACa (P. Serra, D. Kleiner, F. Maccagni)

  D. Mukherjee (jet simulations), M. Gaspari (gas accretion simulations)

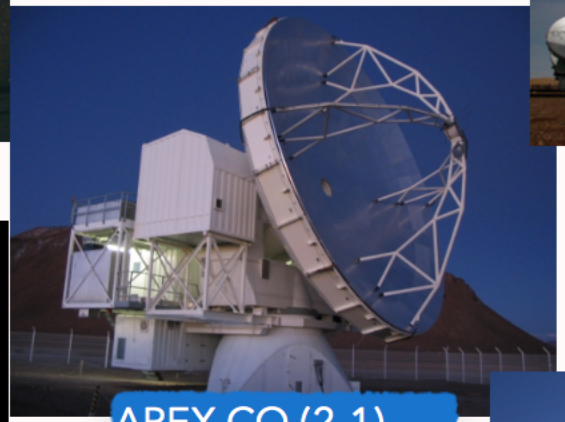
The Multi-wavelength dataset



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

(Warren et al. in prep.)

- **ALMA Cycle 3 CO(2-1) (Ruffa et al. 2019a,b)**
- **ALMA Cycle 6 multi-species (Ruffa et al. in prep.)**



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

2-color archival HST data (or from ground telescopes, when useful)

Archival + proprietary VLA high resolution imaging (Ruffa et al. submitted)

Proprietary ATCA HI data (PI Prandoni)

Adapted from I. Ruffa

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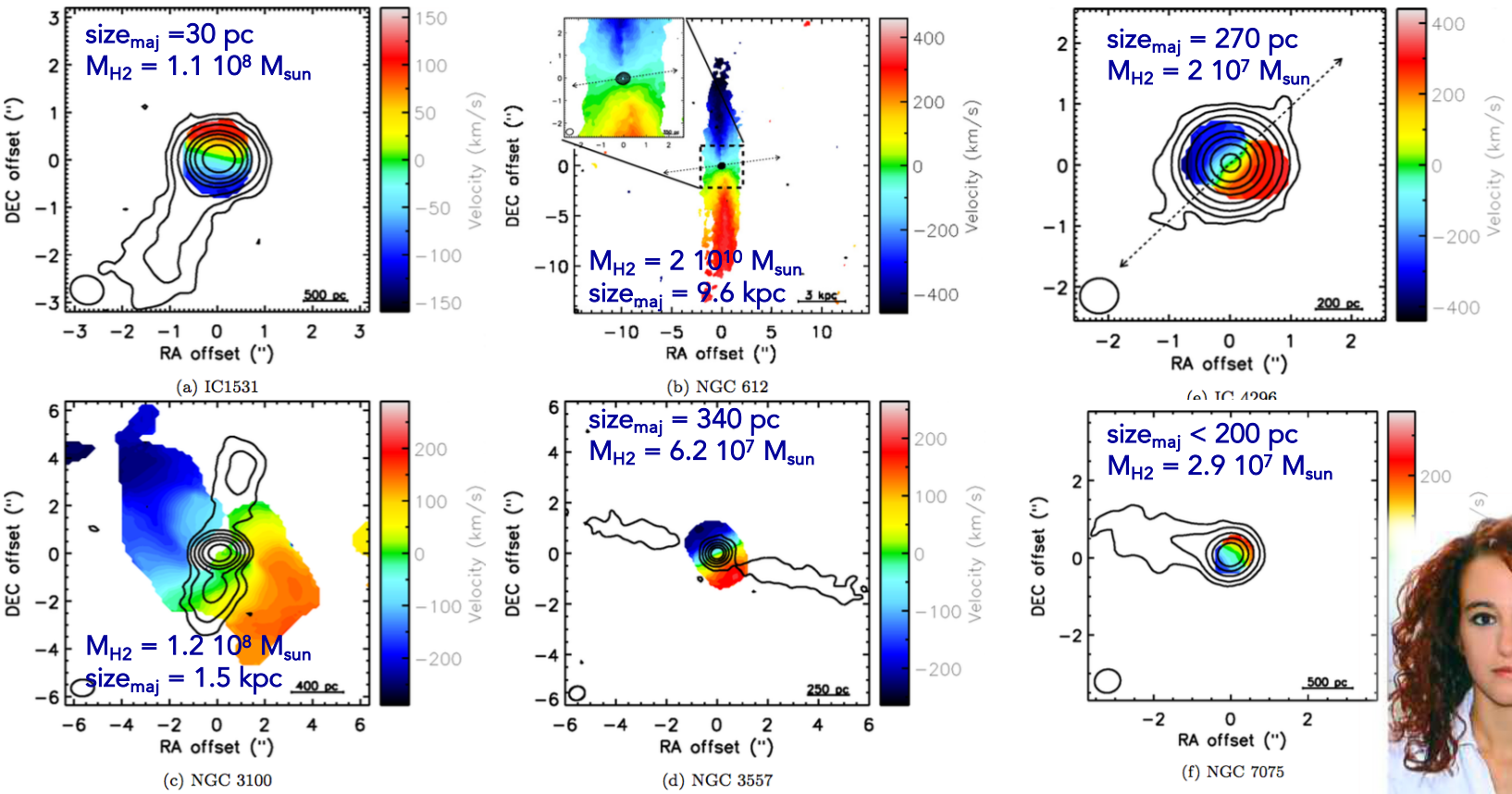
Molecular Gas in LERGs

Ruffa+2019a

ALMA Observations for 9 of the 11 RG in the Southern sample:

- Rotating CO disks on (sub-)kpc scales with large M_{H2} (10^7-10^8 M_{sun})

➔ May explain low accretion rates (see e.g. Okuda+05)

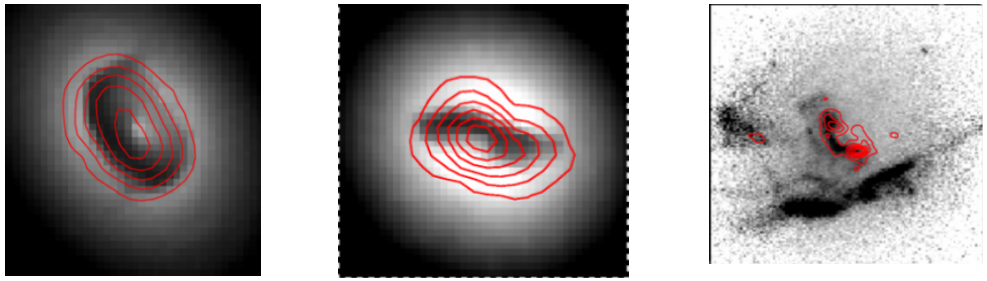


Adapted from I. Ruffa

Molecular Gas in LERGs

Ruffa+2019a

CO and dust always observed to be co-spatial:

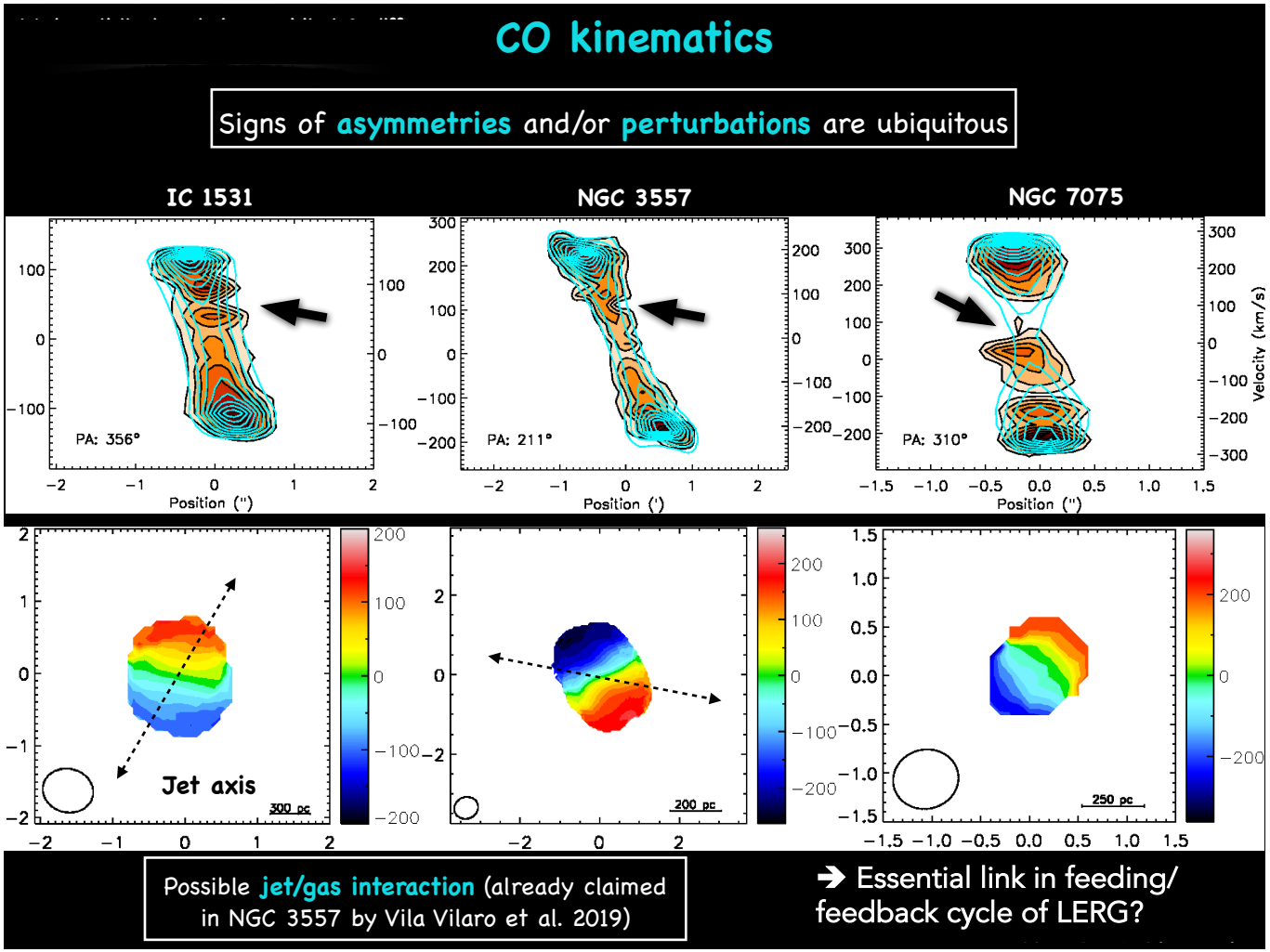


Difficult to reconcile with CCA (gas cooling essentially dustless, Tremblay+18; Temi+18)

➔ Aged gas cooling (dust can reform on Gyr timescales)?
➔ external origin?

Molecular Gas in LERGs

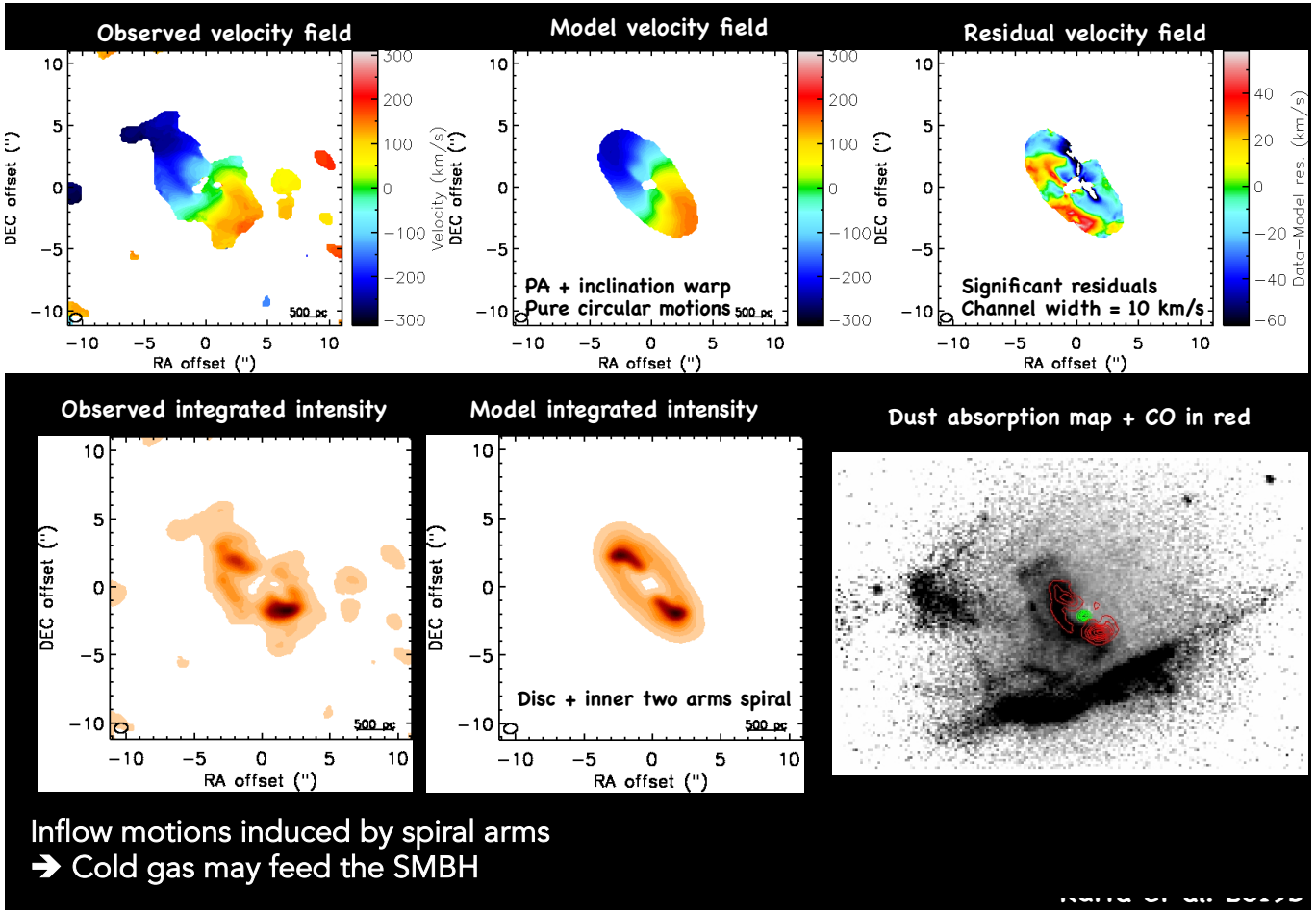
Ruffa+2019b



Adapted from I. Ruffa

The Special case of NGC3100

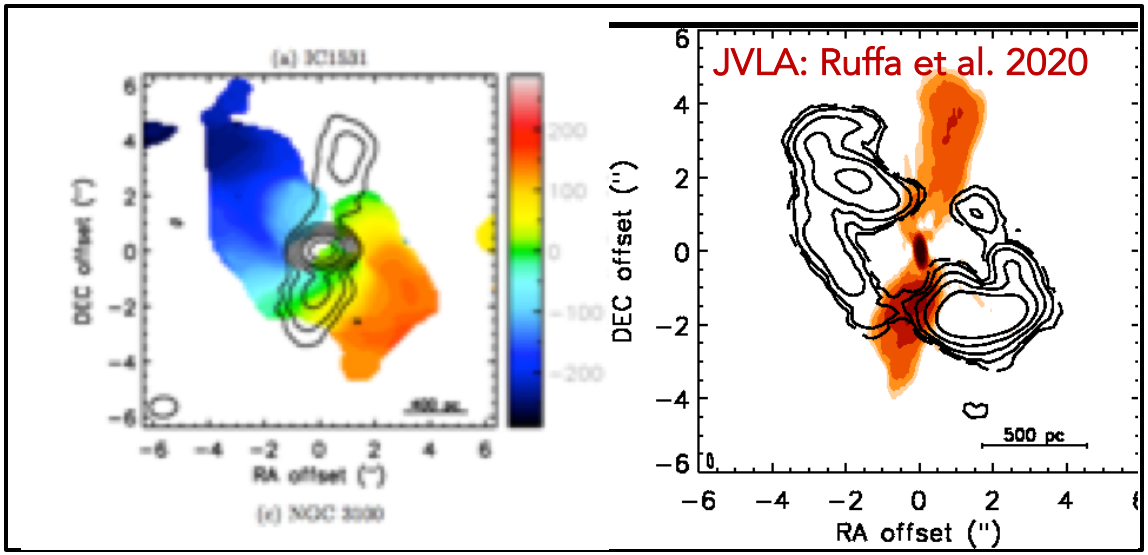
Ruffa+2019b

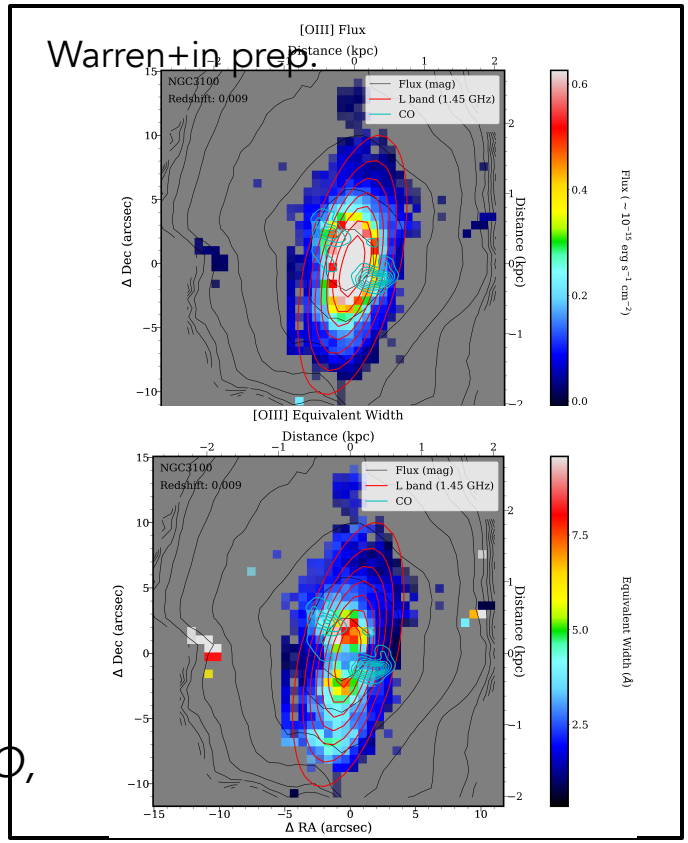


Adapted from I. Ruffa

The Special case of NGC3100

- Molecular Disc disrupted along radio jet axis
- Jets decelerate and expand close to the core and intrisically asymmetric
- Distortion northern jet coincident with that of CO disk
- Combined CO/ warm ionized gas analysis → [OIII] EW enhancement along jet axis





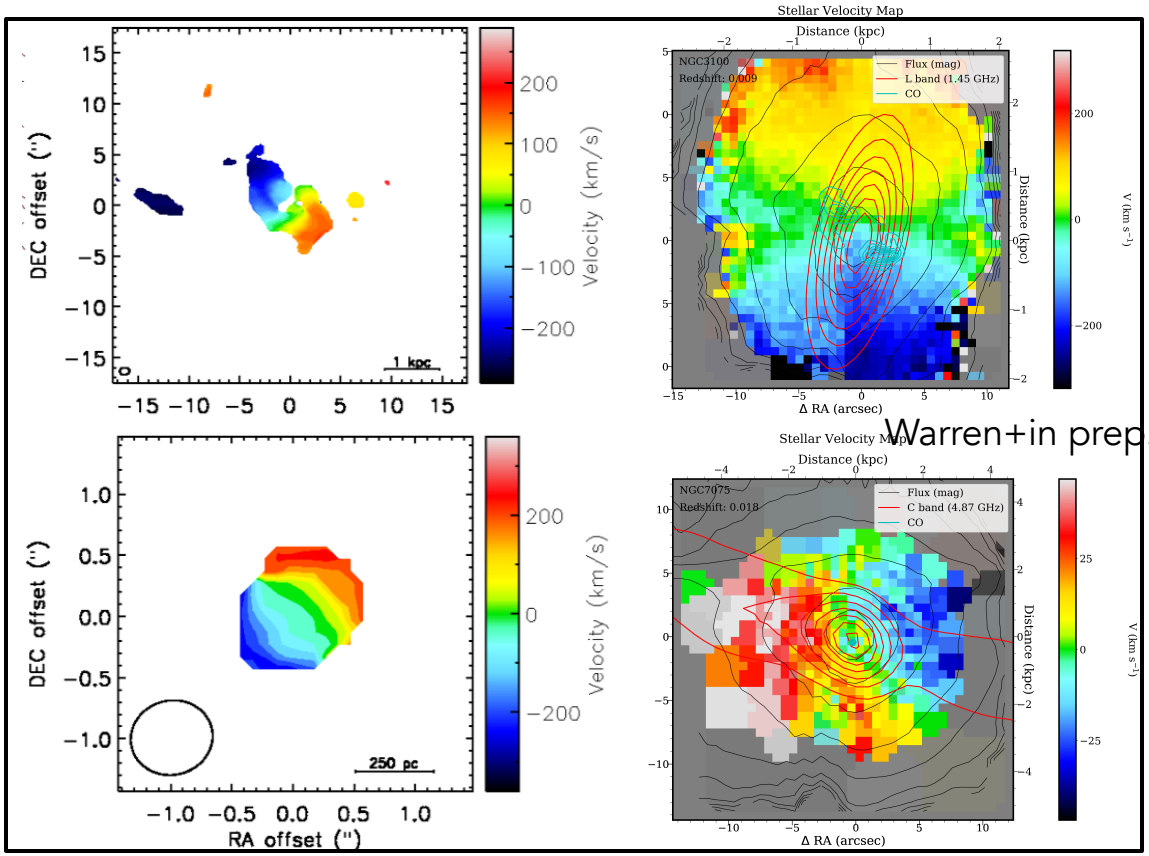
➔ *Evidence of feedback?*

➔ ***Preview:*** *Cycle 6 ALMA multi-line (CO(1-0); CO(3-2), SiO, HNCO, HCO+) follow-up*

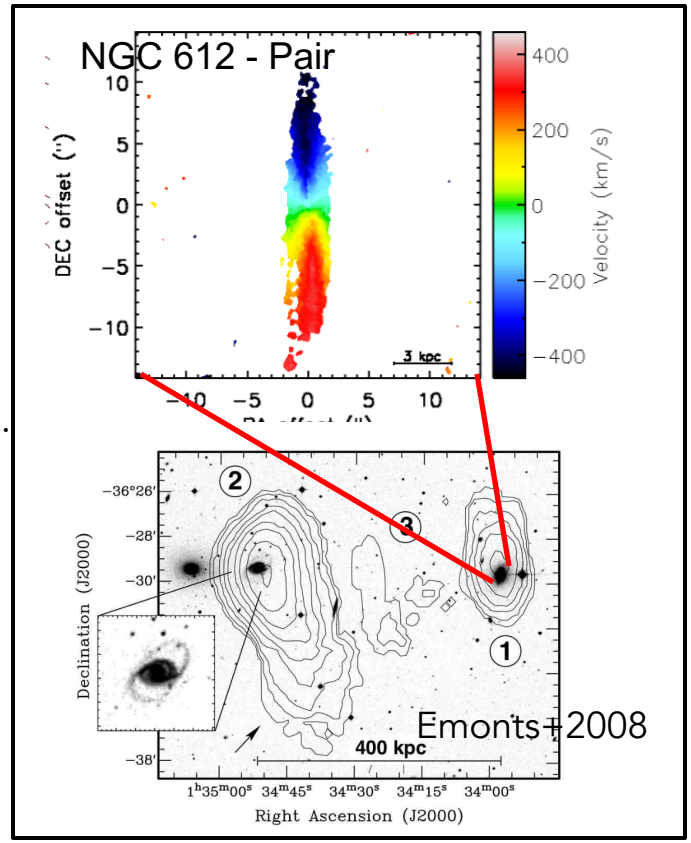
Origin of Molecular Gas in LERG

➔ Is the H_2 of internal or external origin?

2 (33%) with kinematic axis misalignments + 1 (NGC612) ➔ 50%



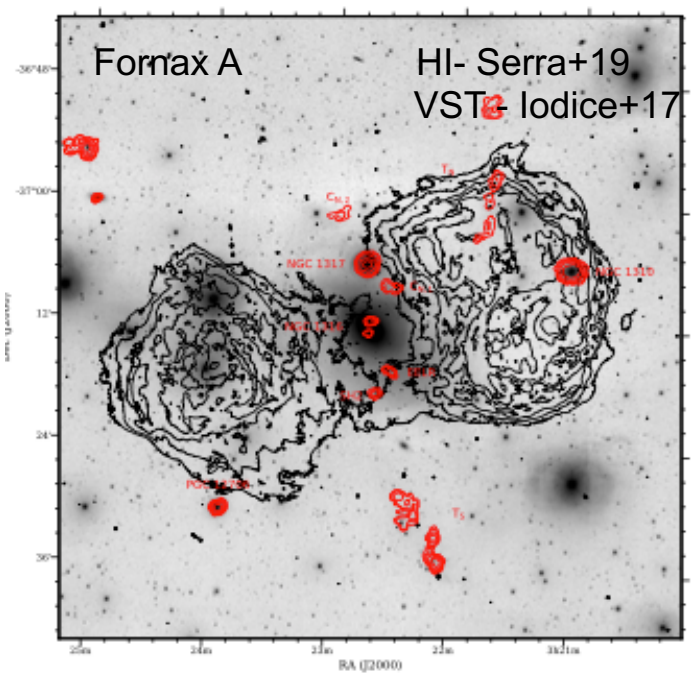
Warren+in prep.

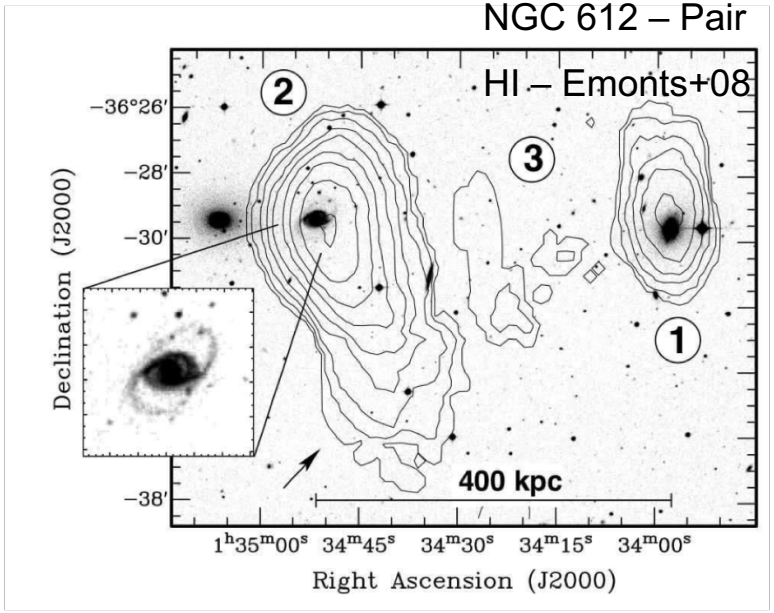


Emonts+2008

Origin of Molecular Gas in LERG

Analysis of environment: isolated/pairs/groups/clusters





➔ HI follow up to probe CCA vs external accretion against environment

Observations ongoing (May 2020 – Feb. 2021): PI Prandoni

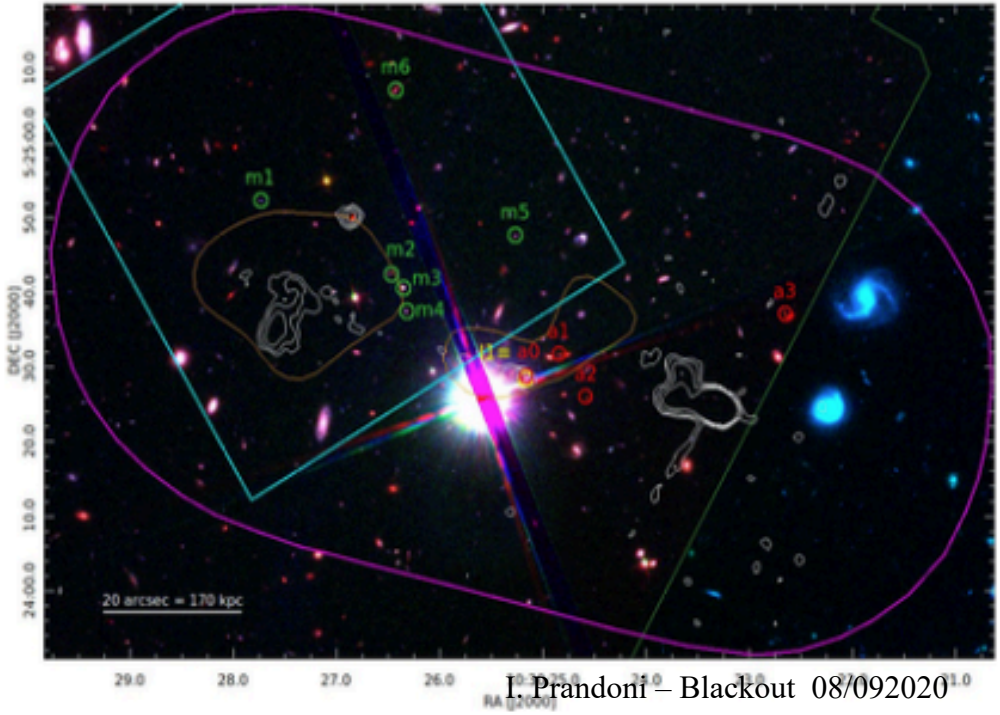
Preview: Other Ongoing Projects - I

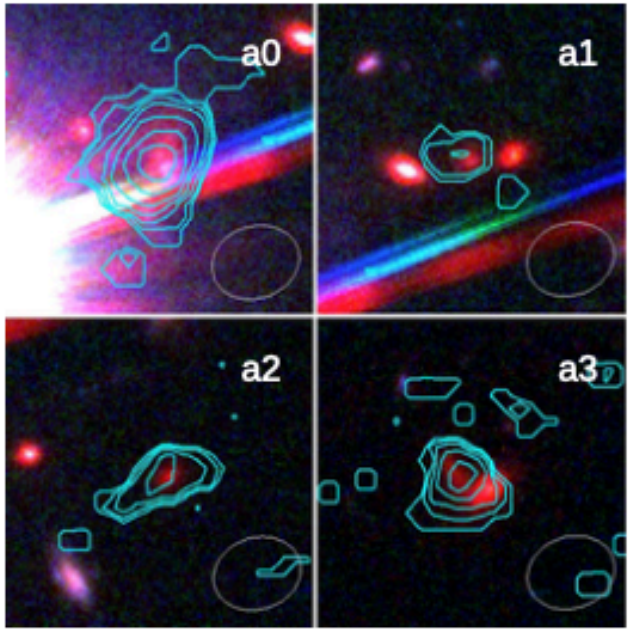
J1030 Field Collaboration: Discovery proto-cluster at z~1.7 with positive large-scale feedback induced by FRII RG (Gilli+19):

- Q. D'Amato (PhD 2018-2021): : JVLA + ALMA follow-up

➔ ALMA: 3/4 new protocluster members + large reservoirs of H_2 gas in FRII (M_{H2}~ 2 10^{11} M_{sun})

D'Amato+2020





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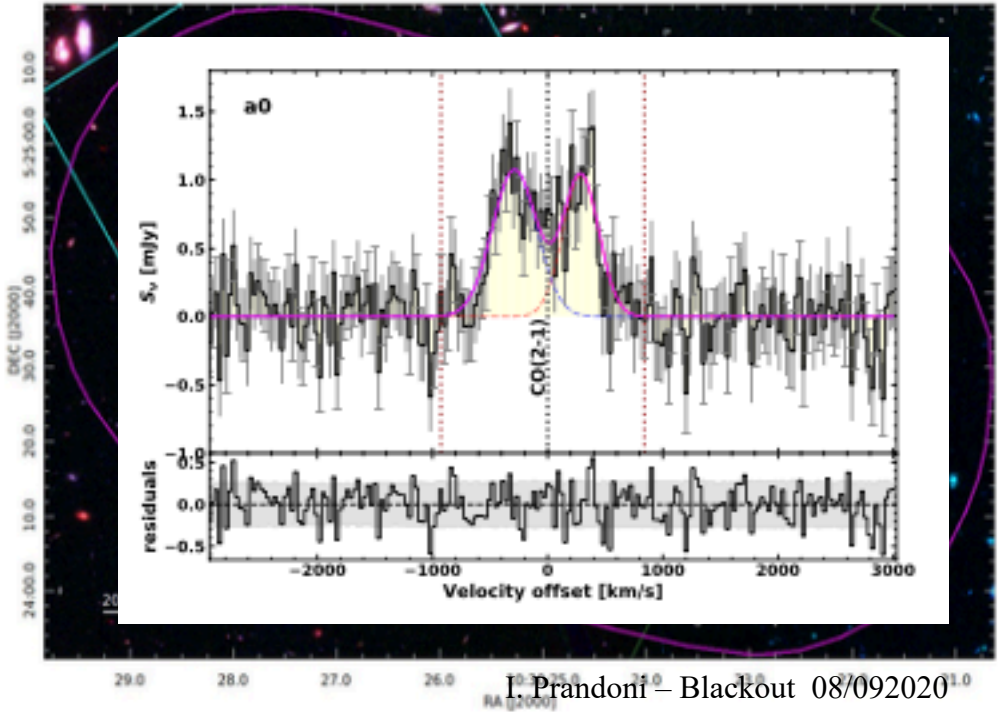

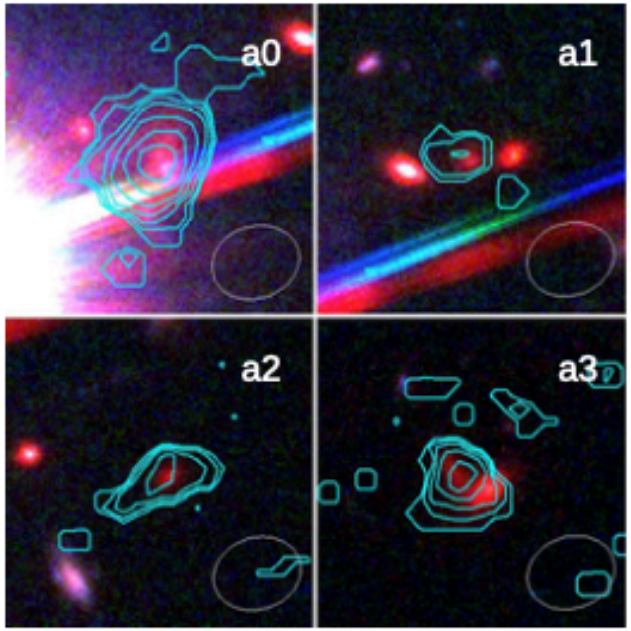

Summary

Three main projects ongoing:

a) *Local sample of LERG (z<0.03)→ multi-phase study of galaxy cores (Ruffa+19a,b; Ruffa+20; Ruffa et al. in prep.).*
   Collaborators at IRA: I. Prandoni, R. Paladino, P. Parma, I. Ruffa
   Next future:
   - *HI component on larger scales (obs. ongoing)*
   - *Jet/gas simulations (D. Mukherjee; CINECA computing time)*

b) *J1030 Field Collaboration (OAS/IRA/UniBO)→ JVLA+ALMA follow-up*
   Collaborators at IRA: Q. D'Amato PhD; I. Prandoni, M. Massardi, E. Liuzzo
   - *Focus on radio feedback in proto-cluster at z~1.7 (D'Amato+20)*

c) *GAMA selected AGN sample in G23 (z<0.4):* link between radio jets and outflows in RE AGN → ASKAP + GAMA surveys: Pilot study in G23 (Prandoni+ in prep.)
   Collaborators at IRA: I. Prandoni, L. Marchetti, M. Vaccari

PRIN Funding → research support (man power from different resources)