



Publication Year	2018
Acceptance in OA	2022-07-14T14:17:01Z
Title	The AGN Fueling/Feedback Cycle: A Multiphase Study of a Sample of Local Radio Galaxies
Authors	PRANDONI, ISABELLA
Handle	http://hdl.handle.net/20.500.12386/32490

A Multi-phase study of a Sample of local Radio Galaxies

The feeding/feedback cycle in LERGs



Isabella Prandoni
IRA-INAF, Bologna

*R. Laing (SKAO); M. Bureau (Oxford Univ.); T. Davis (Cardiff Univ.);
R. Paladino (IRA-INAF); P. Parma (IRA-INAF); H. de Ruiter (IRA-INAF)*

PhD Students: I. Ruffa (IRA-INAF); J. Warren (Oxford Univ.)

Focus of the talk

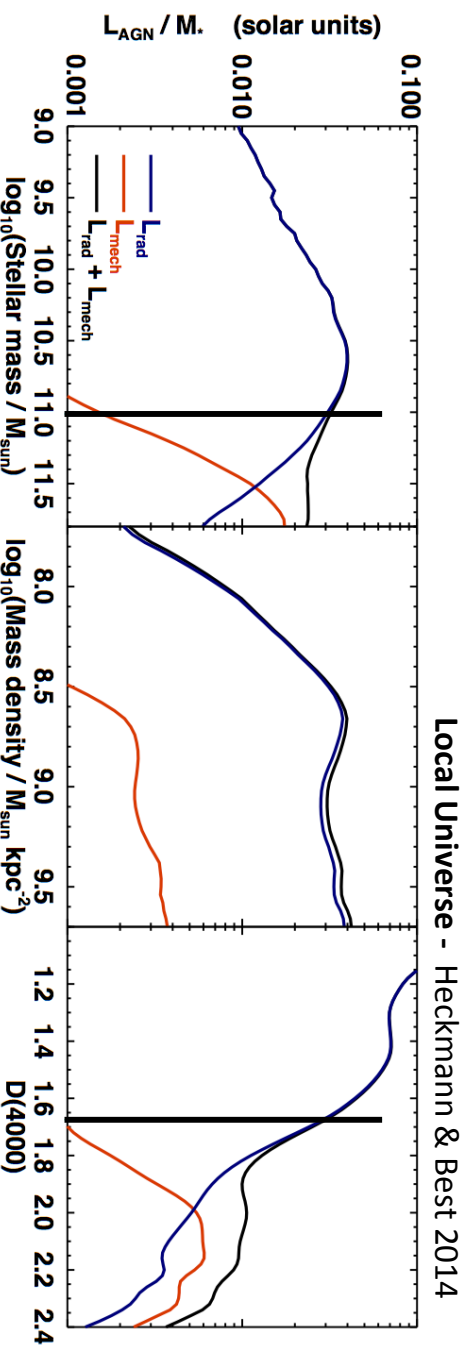
Jet/Radio Mode: $L/L_{\text{Edd}} \leq 0.01$

- moderate radio power
- mostly FRI
- **LERG**
- Hosted by very massive ($M > 10^{11} M_{\text{sun}}$) ETG
- little SF

AGN Fueling: hot gas
(from the X-ray halo)

AGN feedback:
mostly kinetic (radio jets)

- radio jets:**
- relativistic on pc scales (Giovannini+01)
 - sub-relativistic on 1-10 kpc scales (Laing+99)



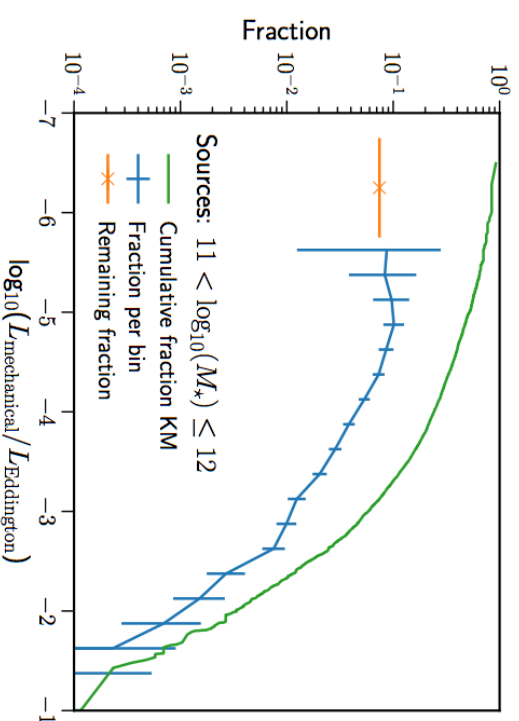
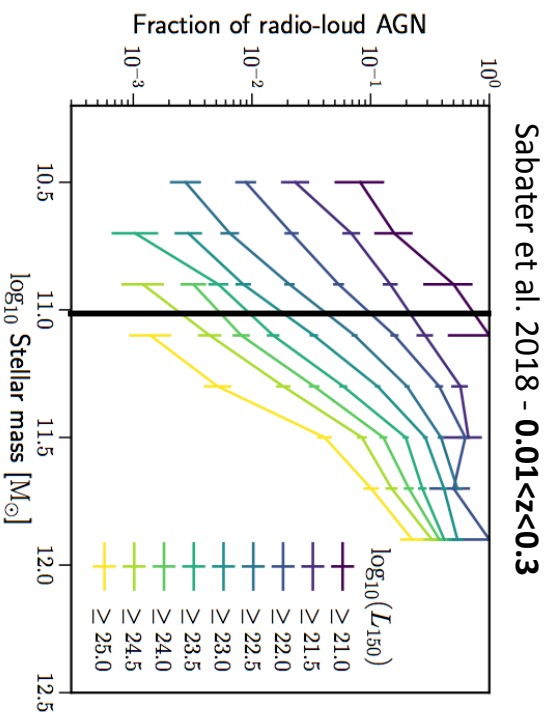
Focus of the talk

Jet/Radio Mode: $L/L_{\text{Edd}} \leq 0.01$

- moderate radio power
- FRI or FRII
- **LERG**
- Hosted by very massive ($M > 10^{11} M_{\text{sun}}$) ETG

Massive galaxies in local Universe
→ 100% RL (always switched on)

Dominant RL-AGN population: $L/L_{\text{Edd}} \sim 10^{-5}$



AGN Fueling: hot gas
(from the X-ray halo)

AGN feedback:
mostly kinetic (radio jets)

radio jets:

- relativistic on pc scales (Giovannini+01)
- sub-relativistic on 1-10 kpc scales (Laing+99)

Our Project

- Better understanding of the feeding/feedback cycle in LERG
- role of LERG in the lifecycle of massive galaxies
- **Statistical approach:** well defined (volume-limited) LERG samples + control samples of RQ early-type galaxies
- **Multi-wavelength (multi-phase) study of LERG (meso scale):**
 - warm ionized gas + stellar component (IFU)
 - molecular gas (single dish and interferometry)
 - detailed radio jet morphology (brightness gradients, deflections, co-spatial heating, outflows)
 - dust (high resolution optical imaging in two bands)

A PILOT SOUTHERN RG 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 *

- 11 objects with $z < 0.03$ & E/S0 hosts
- extracted from Parkes 2.7 GHz survey (PKS; Ekers et al. 1989)
- $[-17^{\circ} < \text{Decl.} < -40^{\circ}]$
- All LERG
- Diverse environs

* *sub-arcsec scale*

The Multi-wavelength dataset



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



2-color 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. in prep.)



Archival + proprietary VLA high res. imaging (Ruffa et al. in prep.)

Adapted from I. Ruffa

The Multi-wavelength dataset



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



2-color 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. in prep.)

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

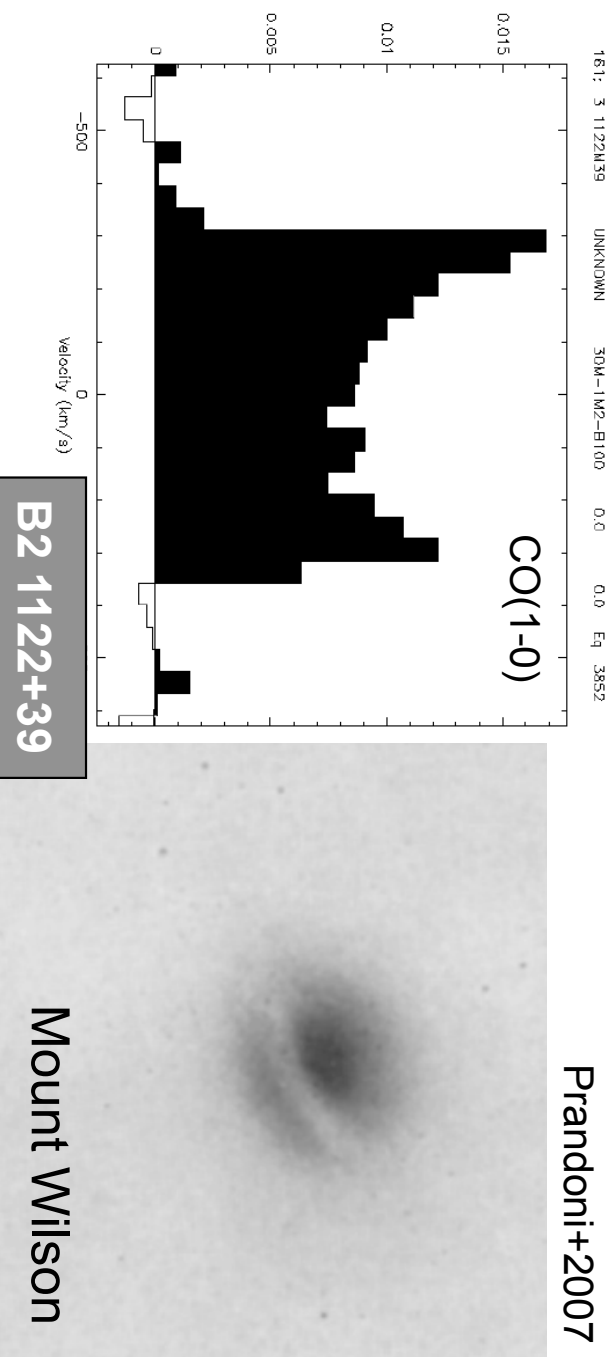


Adapted from I. Ruffa

The Role of Molecular Gas in LERGs - I

- H_2 / dust present in a significant fraction of RQ and RL ETG
- nuclear dust more likely to be found in RL ETG (van Dokkum & Franx 95; de Ruiter *et al.* 2002, Verdoes Kleijn & de Zeeuw 2005)
- Evidence for a relation between CO and dusty disks in ETG cores

→ Is H_2 more abundant in LERG wrt RQ ETG and/or Radio weak AGN?



Master Radio Galaxy Sample

B2: volume limited sample of **23 objects with $z < 0.03$** ;
18 observed in CO [Prandoni+ 2007; Ocana-Flaquer+2010]

3C: volume limited sample of **26 objects with $z < 0.031$**
observed in CO [Lim+ 2003]

UGC: All galaxies with radio jets with $v < 7000$ km/s ($z < 0.0233$)
optical diameter > 1 arcmin
sample of **18 objects** observed in CO [Leon+ 2003]

TANGO: **20 additional sources with $0.031 < z < 0.1$** observed in CO [Ocana-Flaquer
+2010] *no uniform selection criteria*

+ Southern Sample: **11 objects with $z < 0.03$**

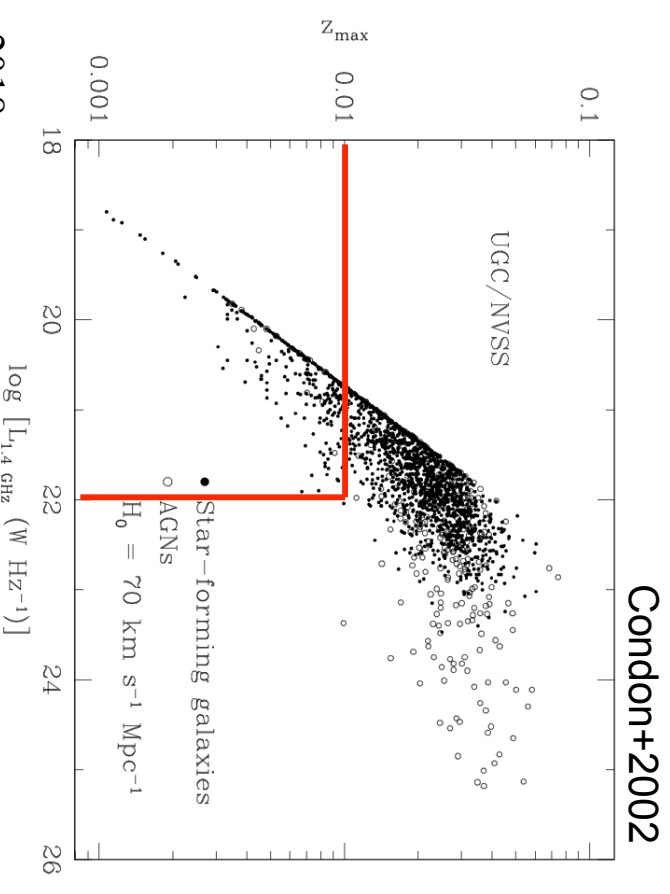
→ **76 distinct Radio Galaxies**

Comparison Sample – ATLAS^{3D}

- 260 early-type galaxies (E/S0) with $D < 42 \text{ Mpc}$ ($z < 0.01$) [Cappellari+11]
- extracted from parent sample with $-6^\circ < \text{Decl.} < 64^\circ$ and $M_K < -21.5$
- SAURON @ WHT
- 259 observed in CO with IRAM [Young+ 2011] → 56 detected

➤ *radio weak AGN* sub-sample:
21 radio detected objects with radio emission classified as AGN-powered based on radio/FIR properties

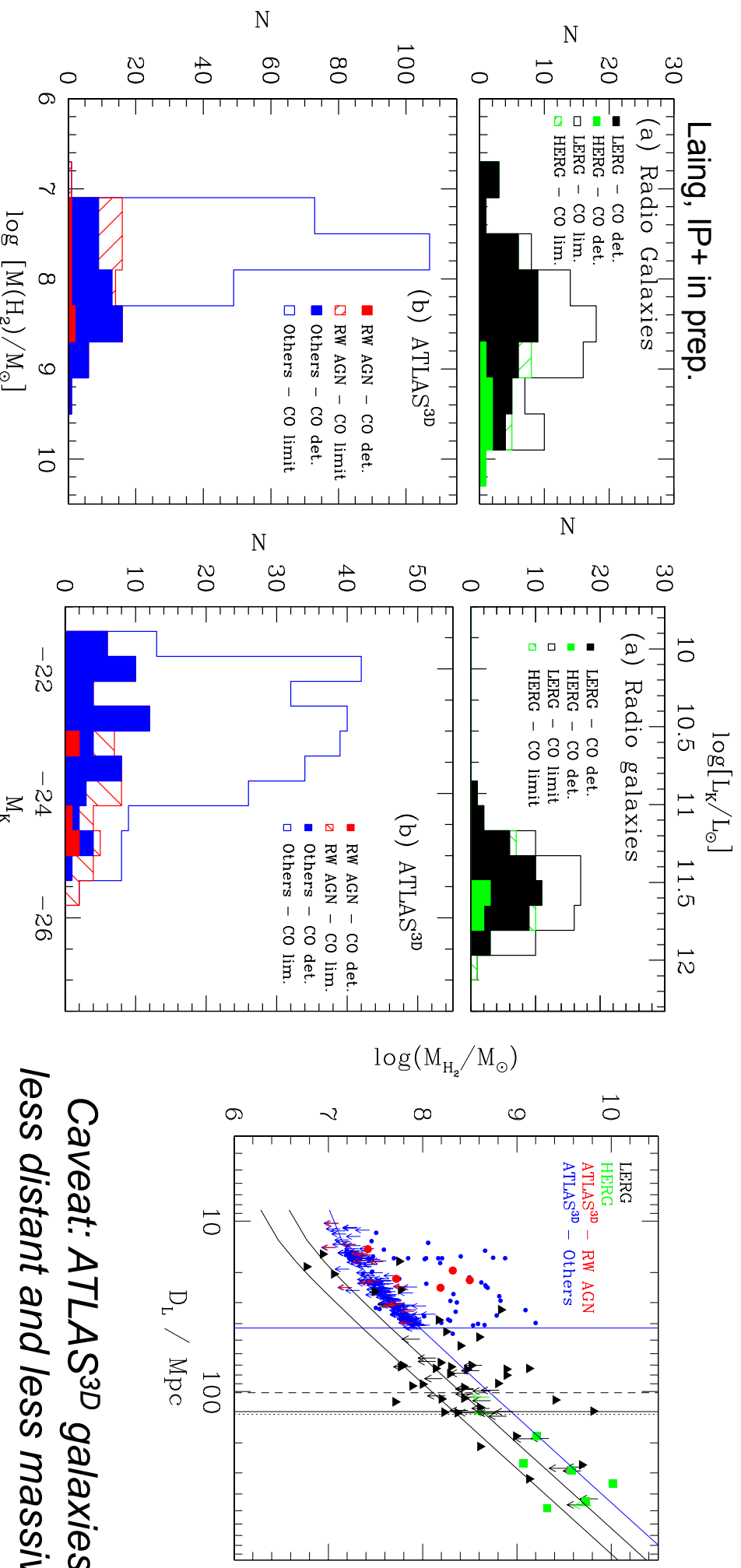
- no large scale jets
- $P < 10^{22} \text{ W/Hz}$



The Role of Molecular Gas in LERGs - I

→ Is H_2 more abundant in LERGs wrt RQ ETG and/or Radio weak AGN?

Laing, IP+ in prep.

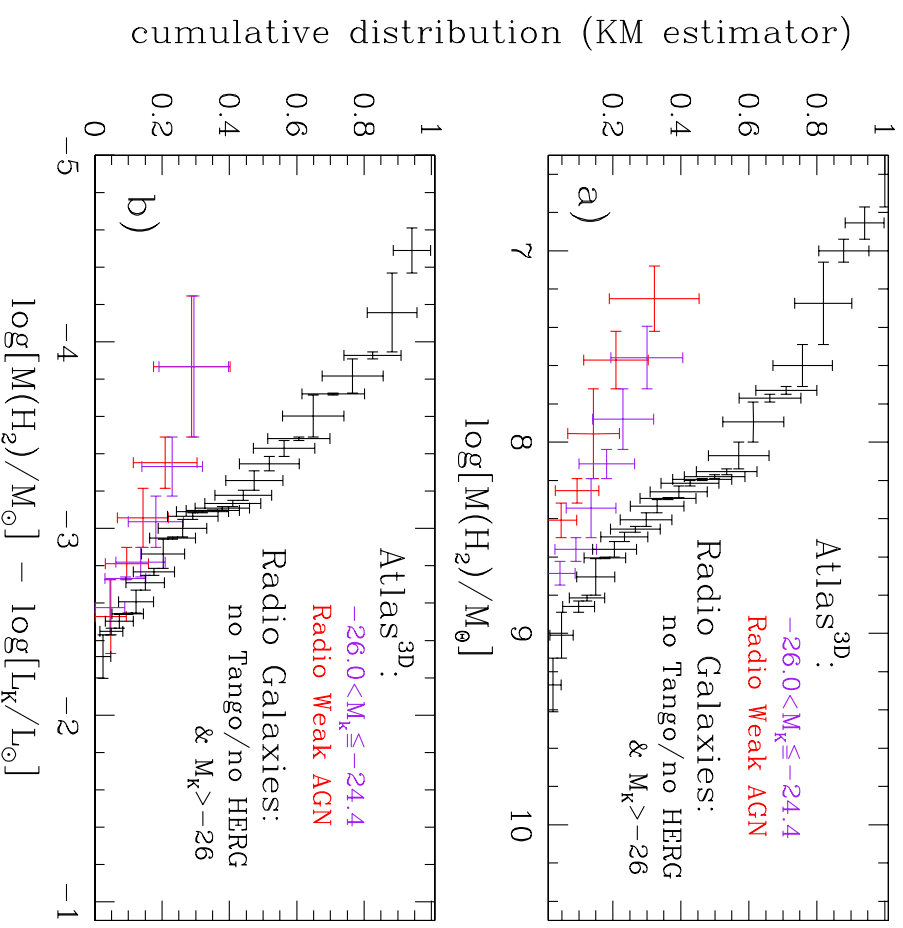
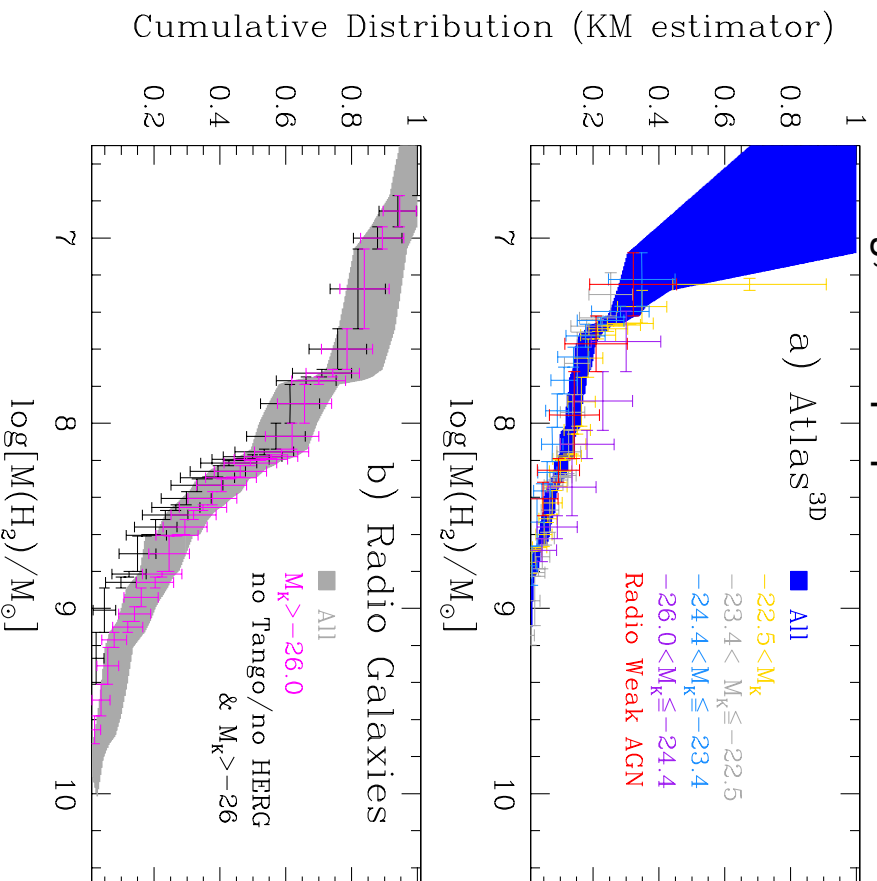


*Caveat: ATLAS^{3D} galaxies
less distant and less massive*

The Role of Molecular Gas in LERGs - I

→ Is H_2 more abundant in LERGs wrt RQ ETG and/or Radio weak AGN?

Laing, IP+ in prep.



The Role of Molecular Gas in LERGs - I

→ Is H_2 more abundant in LERGs wrt RQ ETG and/or Radio weak AGN?

- H_2 seems to be more abundant in LERG than in RQ ETG
- LERG mostly have $\log M(H_2) \sim 7.5 - 8 M_{\text{sun}}$
- radio weak AGN have same molecular mass properties as RQ ETG
- this result seems to be robust against scaling relations and distance selection effects
- this result remain consistent with HERG being richer in H_2

The Role of Molecular Gas in LERGs - II

→ Is the H₂ morphology and kinematics different in RL and RQ ETGs ?

ALMA Cycle 3 Observations for 9 of the 11 RG in the Southern sample:
[typical resolution of 0.6-0.7 arcsec / ~100-250 pc]

Table 5. Main ¹²CO(2-1) integrated parameters. Ruffa, IP+ in prep.

Env.	Target (1)	Line FWHM (km s ⁻¹) (2)	Line FWHI (km s ⁻¹) (3)	SCOΔv (Jy km s ⁻¹) (4)	M _{H2} (M _⊙) (5)
I	IC 1531	260	280	2.0±0.2	(6.4 ± 0.6) × 10 ⁸
P	NGC 612	780	840	273±27	(1.2 ± 0.2) × 10 ¹¹
I	PKS 0718-34	334 ¹	480 ¹	< 0.1	< 3.9 × 10 ⁷
G/P	NGC 3100	345	470	18±1.8	(6.8 ± 0.8) × 10 ⁸
G	NGC 3557	440	484	7.0±0.7	(3.6 ± 0.4) × 10 ⁸
C	ESO 443-G 024	786 ¹	1000 ¹	< 0.1	< 2.1 × 10 ⁷
C	IC 4296 ²	680	880	1.6±0.1	(1.2 ± 0.8) × 10 ⁸
C	NGC 7075	560	640	1.0±0.1	(1.7 ± 0.2) × 10 ⁸
G	IC 1459	492 ¹	640 ¹	< 0.4	< 6.3 × 10 ⁶



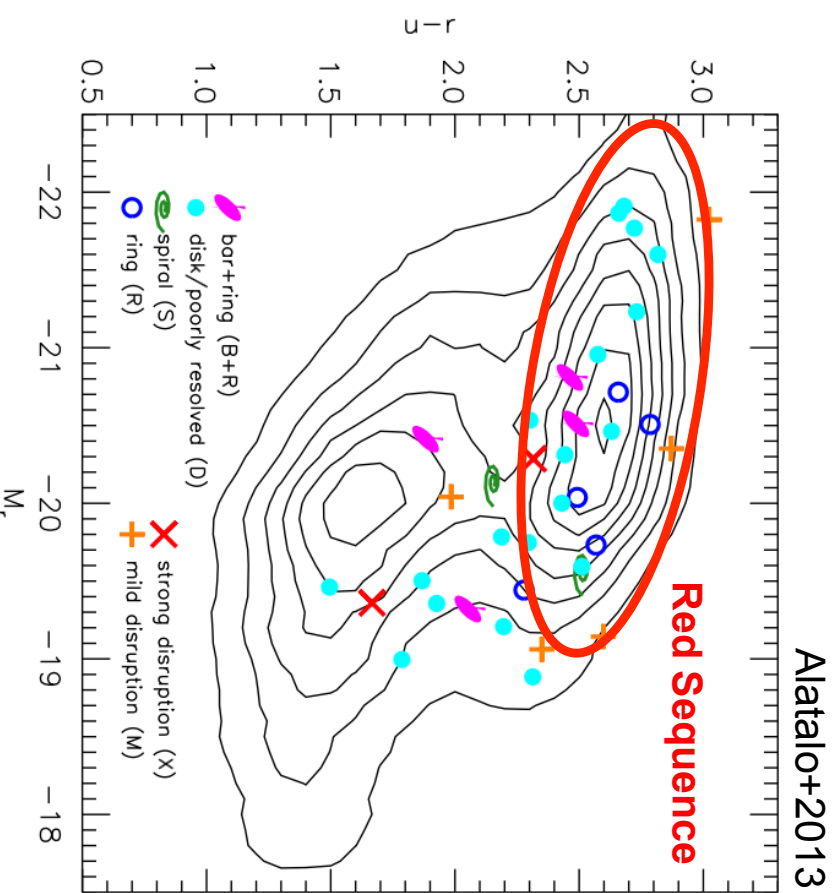
The Role of Molecular Gas in LERGs - II

→ Is the H_2 morphology and kinematics different in RL and RQ ETGs ?

ATLAS^{3D} CO-rich sub-sample (40 objects) observed with CARMA [Alatalo +2013]

50% disks (D)
 15% rings (R)
 10% bars+rings (B+R)
 5% spiral arms (S)
 12.5% mildly disrupted (M)
 7.5% strongly disrupted (X)

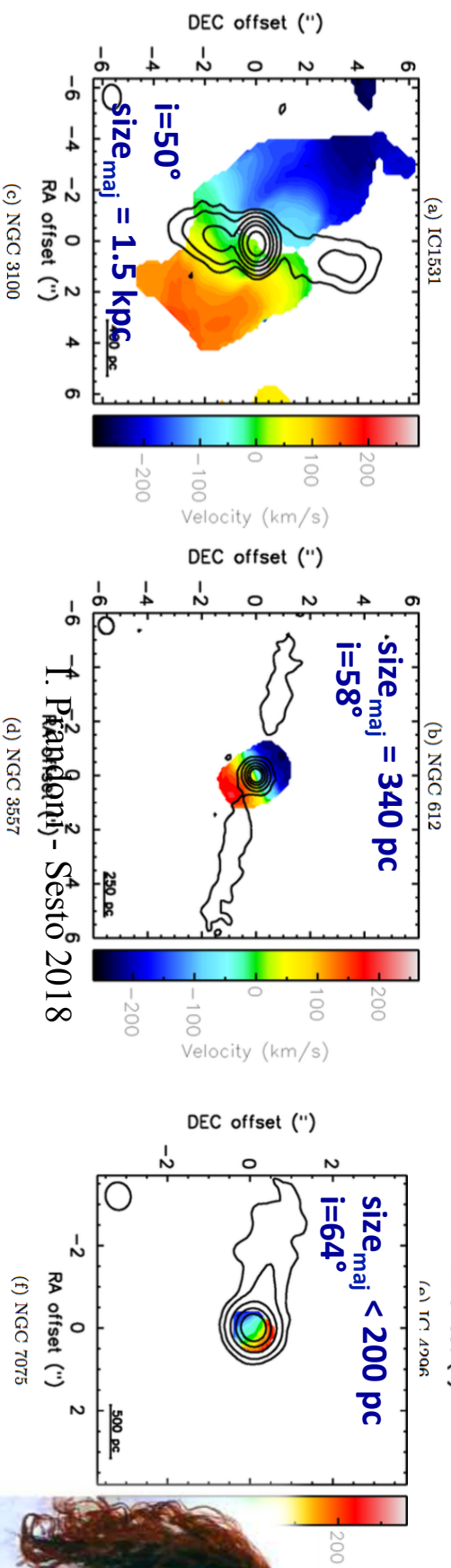
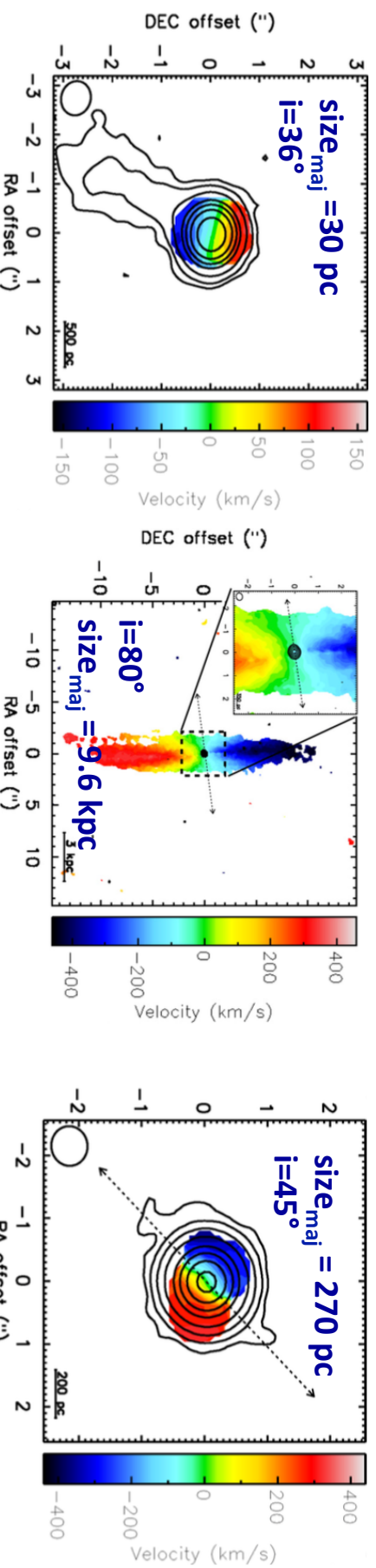
Most massive → disks
 Rings → red sequence



The Role of Molecular Gas in LERGs - II

→ Is the H_2 morphology and kinematics different in RL and RQ ETGs ?

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



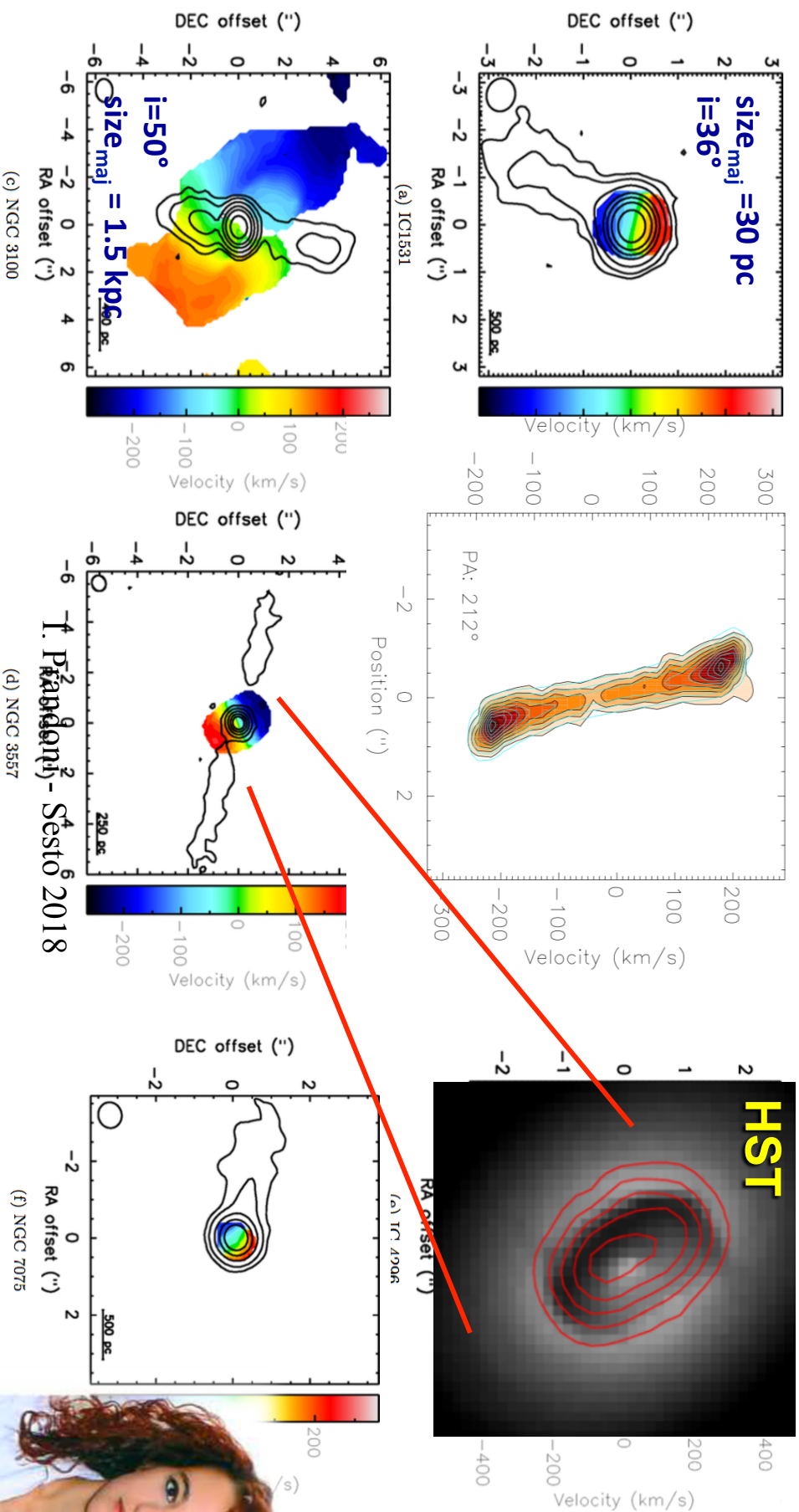
Ruffa, IP+ in prep.



The Role of Molecular Gas in LERGs - II

→ Is the H_2 morphology and kinematics different in RL and RQ ETGs ?

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



Ruffa, IP+ in prep.



The Role of Molecular Gas in LERGs - II

→ Is the H_2 morphology and kinematics different in RL and RQ ETGs ?

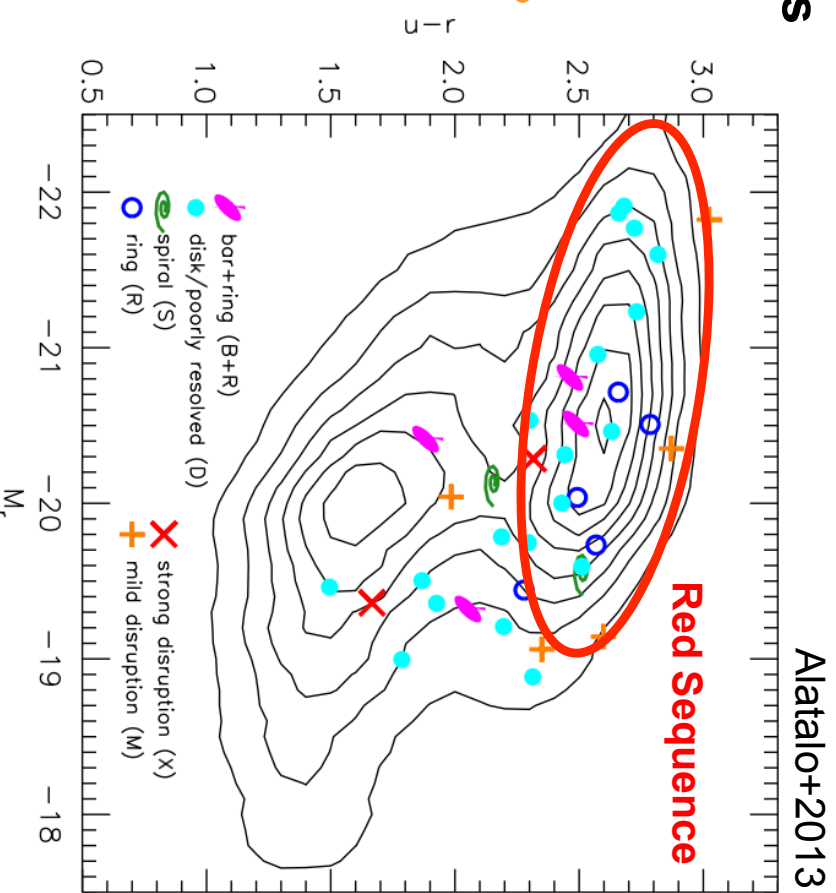
ATLAS^{3D}

50% disks (D)
 15% rings (R)
 10% bars+rings (B+R)
 5% spiral arms (S)
 12.5% mildly disrupted (M)
 7.5% strongly disrupted (X)

Most massive → disks
 Rings → red sequence

6 LERGs

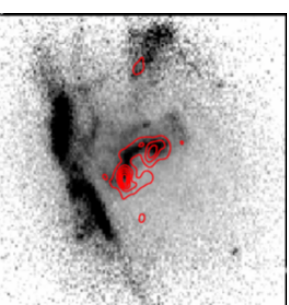
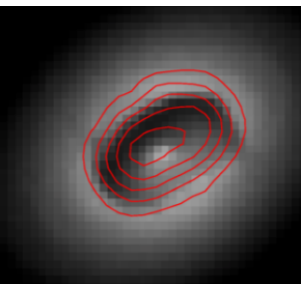
4 ~ 67%
 1 ~ 17%
 1 ~ 17%?



The Role of Molecular Gas in LERGs - II

→ Is the H_2 morphology and kinematics different in RL and RQ ETGs ?

→ No evidence so far... but comparison towards gas-rich galaxies and compact CO structures.



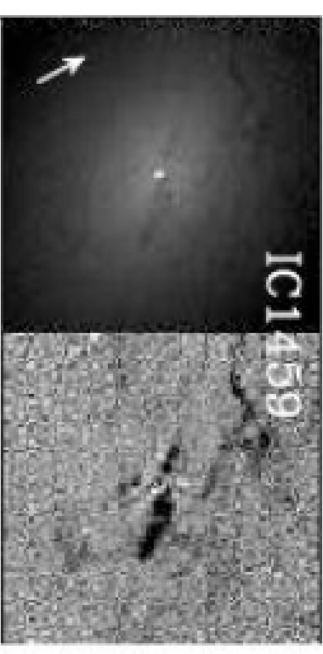
PKS 0336-35



PKS 0320-37



PKS 2254-367



The Role of Molecular Gas in LERGs - III

→ Is the H₂ of internal or external origin?

- 13 (33%) of **ATLAS^{3D}** CO-rich sub-sample show significant (>30°) kinematic major axis misalignment between stellar and gas components
→ external origin

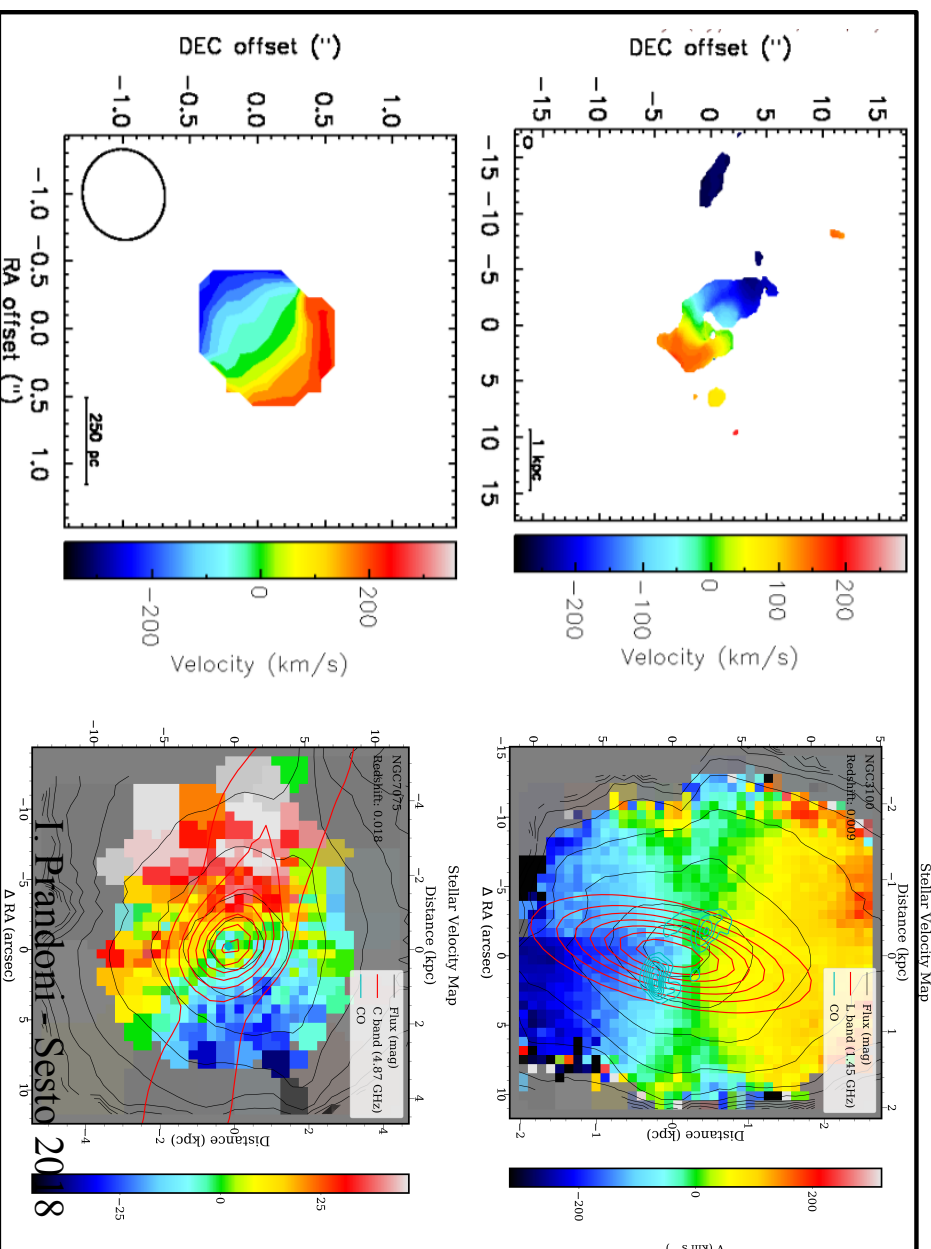
- 2 with other signs of external origin

→ **38% external** [Alatalo+13]

The Role of Molecular Gas in LERGs - III

→ Is the H_2 of internal or external origin?

2 (33%) with kinematic axis misalignments

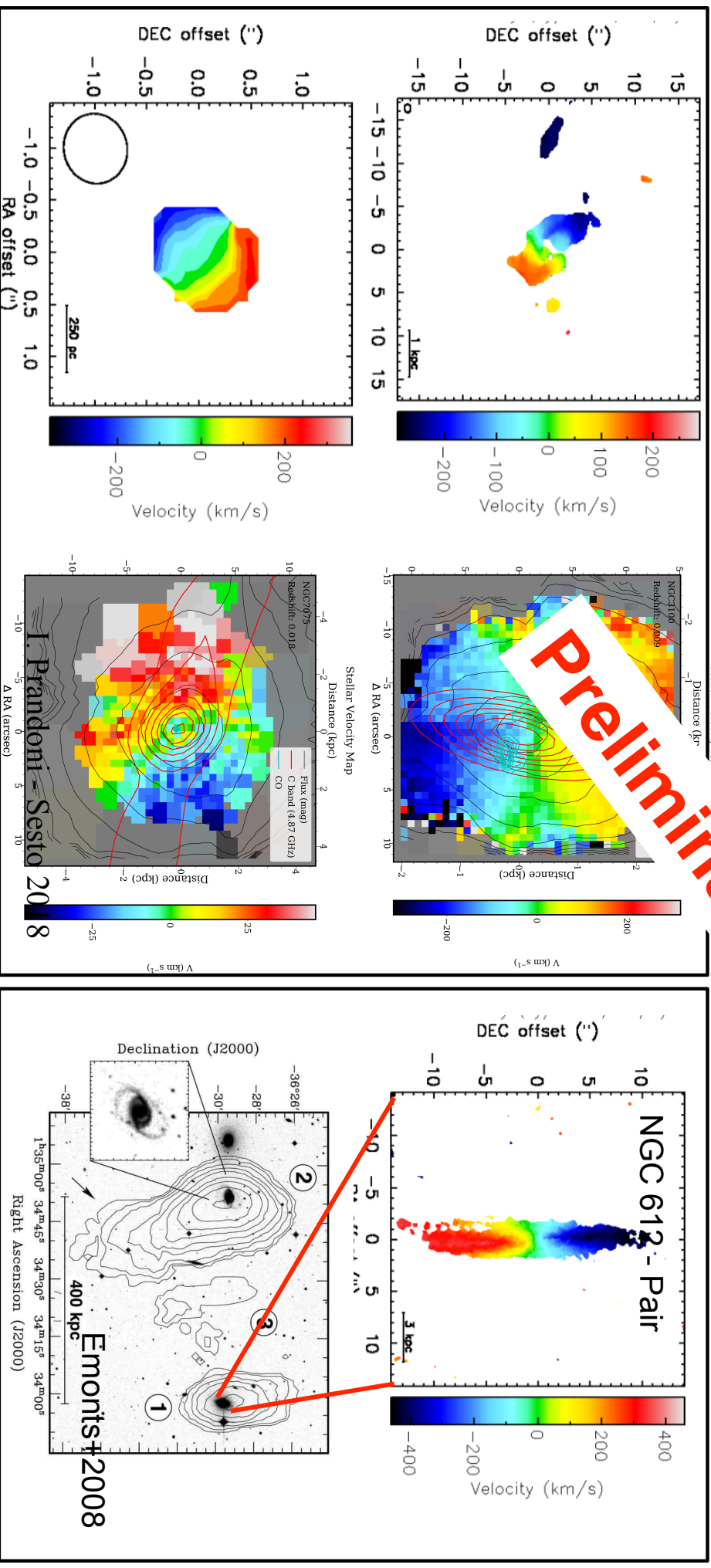


Warren+in prep.

The Role of Molecular Gas in LERGs - III

→ Is the H_2 of internal or external origin?

2 (33%) with kinematic axis misalignments + 512) → 50%

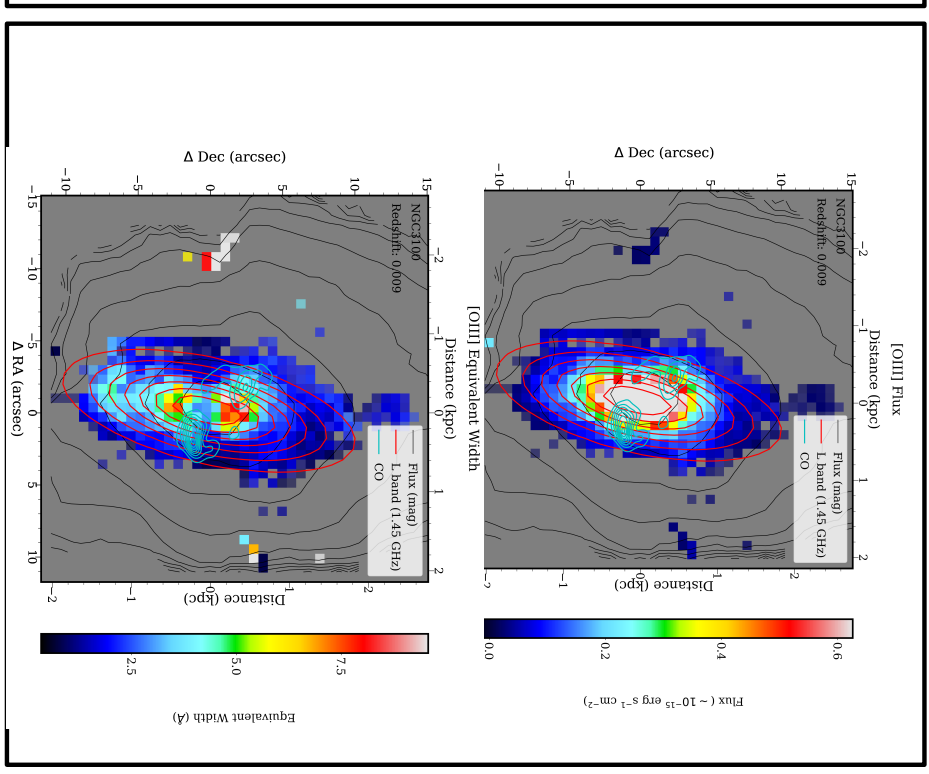
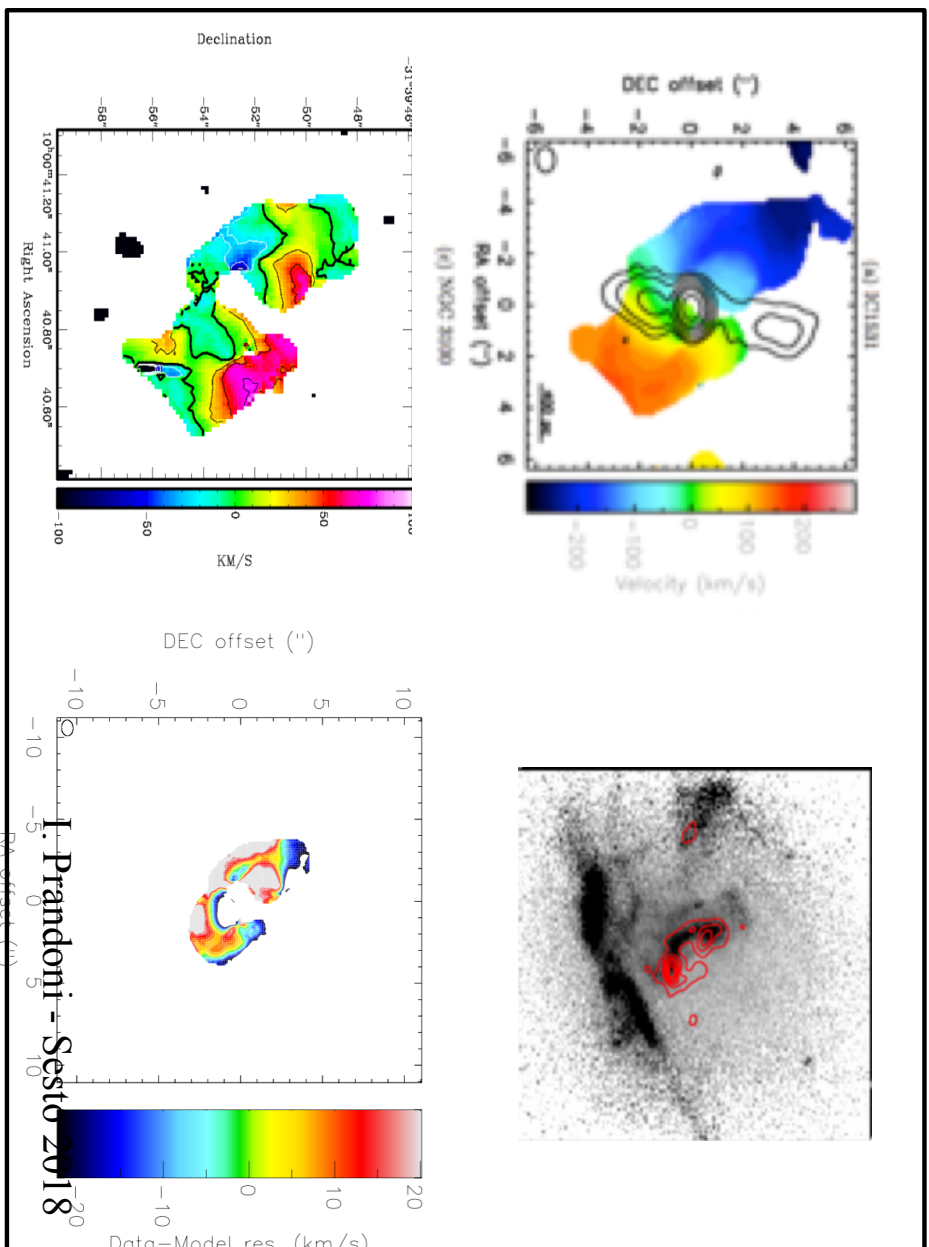


Preview: The case of NGC 3100

→ *Evidence of feeding/feedback?*

- Detailed modeling of CO kinematics
- Combined CO/ warm ionized gas analysis

Ruffa, Davis+ in prep.



Warren+in prep.

Summary

- H_2 is more abundant in LERG than in RQ ETG
- H_2 is more abundant in LERG than in radio weak (no large scale radio jets)

Based on our ongoing multi-phase study of a pilot LERG sample (11 sources):

- H_2 morphology and kinematics similar in LERG and gas-rich RQ ETGs
- H_2 disks are very frequent in cores of LERGs (rings also present)
- LERG seem to have smaller disks/rings (sub-kpc) than gas-rich RQ ETGs
- H_2 is of external origin in at least 33-50% of LERG (similar fractions for gas-rich RQ ETGs)
- NGC 3100: detailed kinematic modeling → tentative evidence of H_2 radial inflows (AGN feeding?)
- NGC 3100: link between disrupted CO morphology and presence of OIII emission along radio jet (AGN feedback in action?)

Open Questions

- *Are the many observed sub-kpc/kpc scale H_2 disks in LERGs in agreement with CCA?*
- *Can the various evolutionary phases of CCA (see Lakhchaura talk) explain what we observe?*
- *Can gas/stars misalignments be explained in CCA?*
- *How the environment fit in?*
- *Are LERG statistically important for galaxy-scale feedback?*