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OSSERVATORIO ASTROFISICO DI TORINO

The MOBALES project: a MUse RAdio Loud Emission Snapshot.

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Outline:

✓General introduction on radio galaxies;

✓Our MURALES project: a survey with MUSE of radio galaxies;

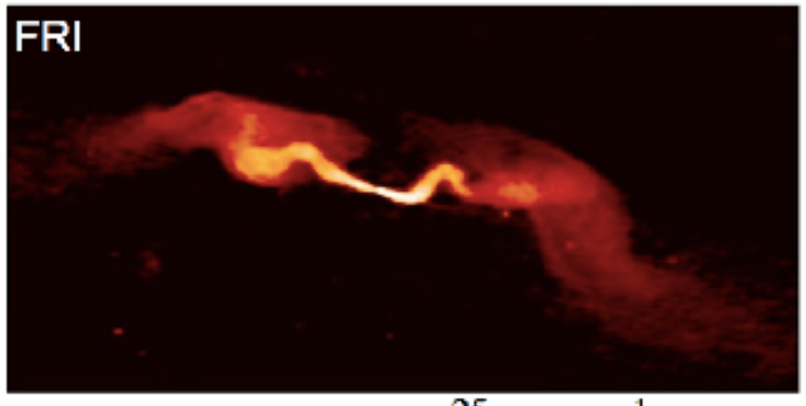
✓Two interesting cases: 3C317 and 3C459;

✓Some results from the survey;

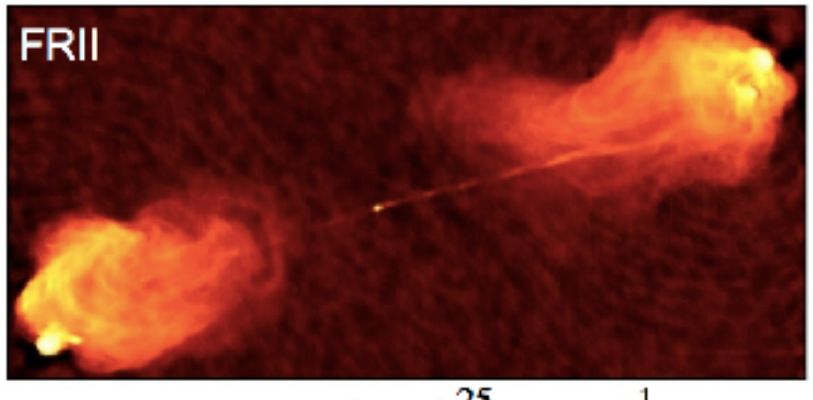
✓ Conclusions

Radio galaxies and radio-loud quasars and blazars as well, are types of active galaxy nuclei that are very luminous at radio wavelengths. The radio emission is due to the synchrotron process.

Classification of radio galaxies based on RADIO morphology (FANAROFF-RILEY CLASSIFICATION 1974)



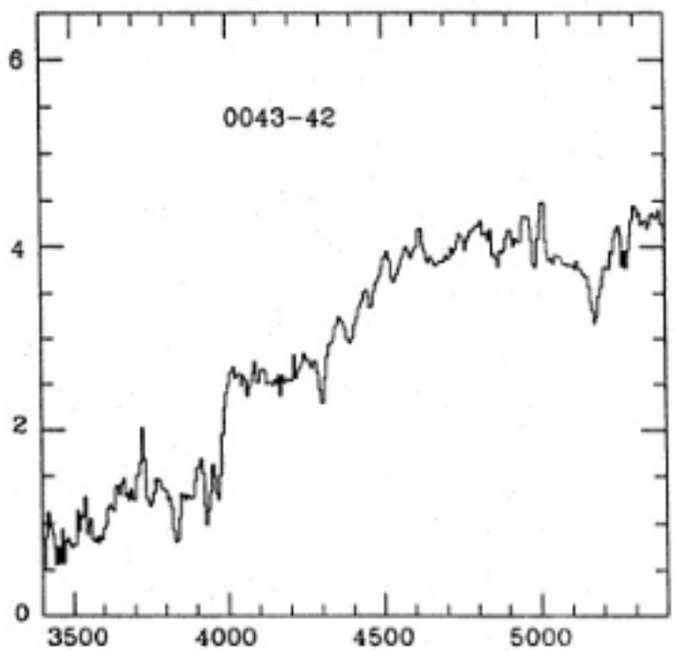
$P_{178Mhz} < 5 \times 10^{25}\ W\ Hz^{-1}$

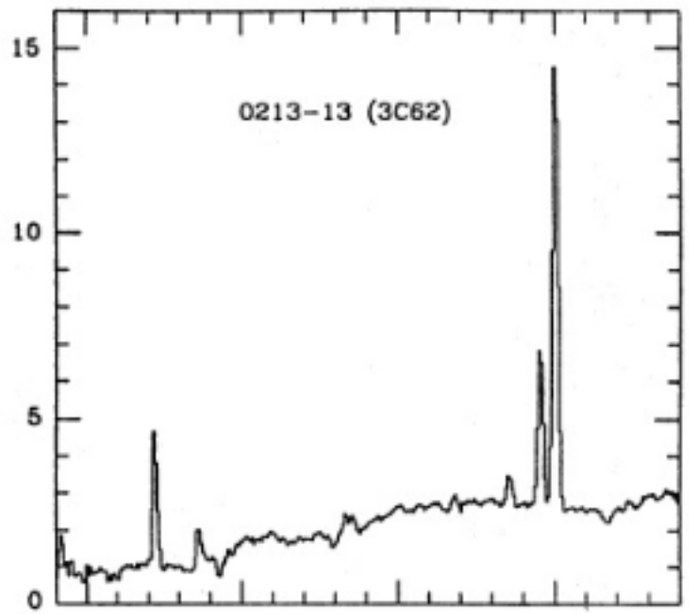


$P_{178Mhz} > 5 \times 10^{25}\ W\ Hz^{-1}$

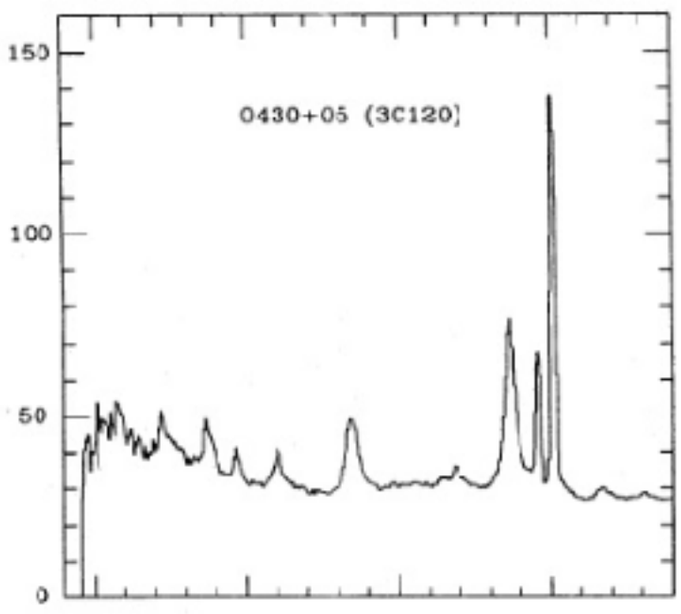
Classification of radio galaxies on OPTICAL SPECTRA

Weak Line Radio galaxies (WLRG) or low excitation radio galaxy (LERGs)





Narrow Line Radio galaxies (NLRG)

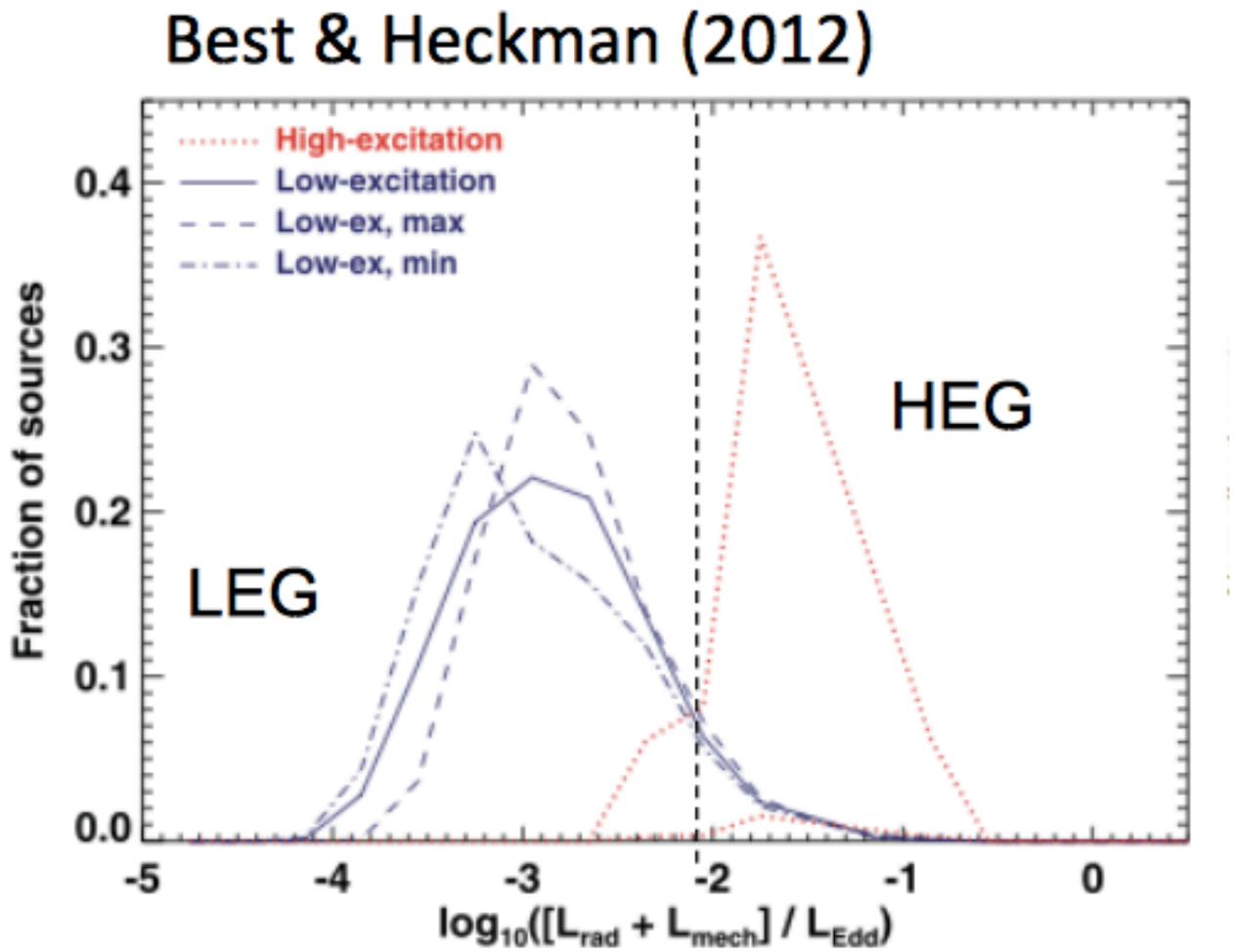


Broad Line Radio galaxies (BLRG)

High excitation radio galaxy (HERGs)

OPEN QUESTION:
The different classifications are related to the environment, to the properties of the central engine, or to something else?…

Transition from WLRG/LEG to SLRG/HEG due to switch between radiatively-efficient accretion disk and radiatively-inefficient accretion flow (RIAF) at fixed Eddington ratio (~1%)



~FR I ~FR II

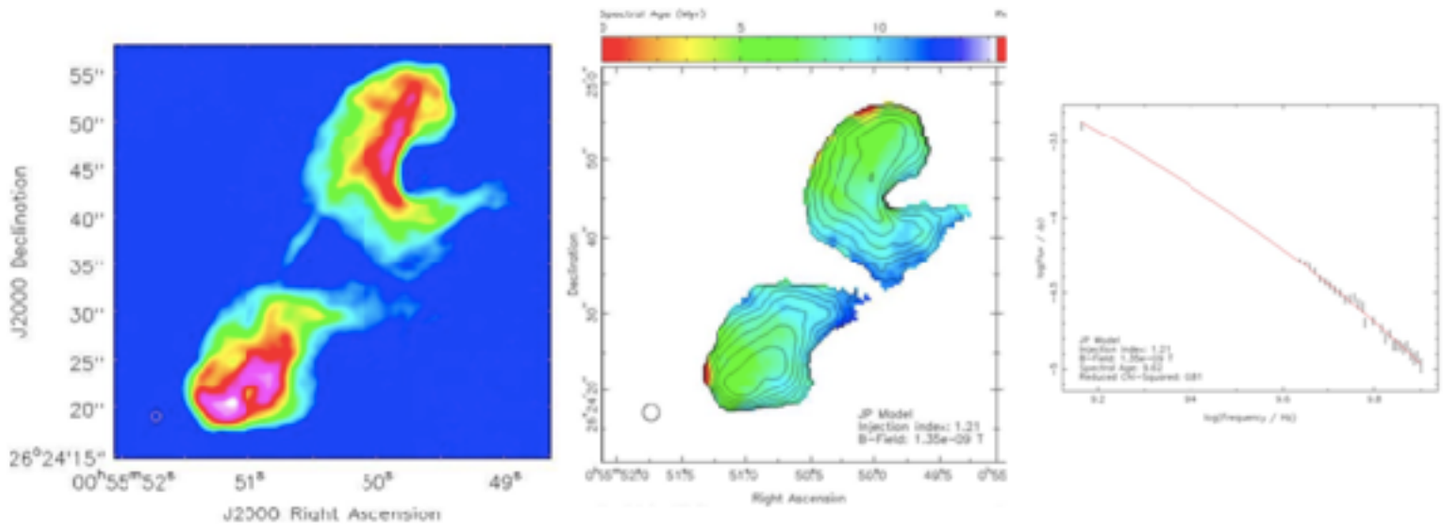
FRI/FRII divide might be related to accretion rate and to the environment

OPEN QUESTION:
what is the radio activity duty cycle?

Her A

Evidences of intermittent radio activity (e.g Brienza et al. 2018, Bruni et al. 2019, Hernández-García et al. 2019..)

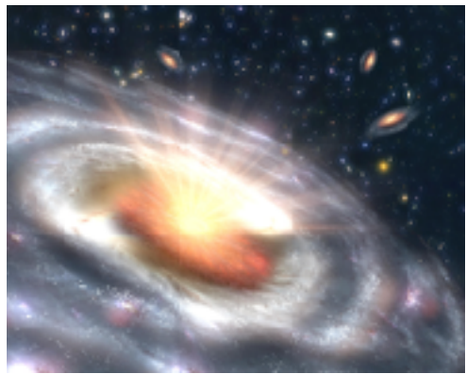
Evidence for recently dead radio galaxies



Harwood et al. (2015)

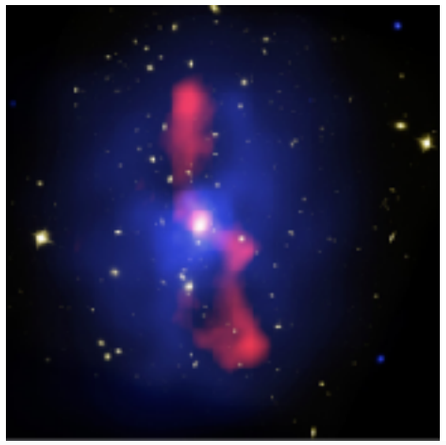
Outflows related to the AGN activity are commonly observed in different bands: X-ray (UFO's) optical, neutral and molecular gas.

OPEN QUESTION: in AGN what is the outflows powering mechanism?



RADIO QUIET: outflows driven by the radiative pressure

RADIO LOUD: outflows driven the mechanical energy of a radio jet(often considered less relevant for driving outflows



Actually, the situation is more complicated:
the classification Radio-Loud vs radio-Quiet is misleading (Jetted vs non jetted AGN)
and disentangling the driving mechanism of gaseous outflows is very complicated

The occurrence and impact of radio jets have been revised in the last years, suggesting that their role should not be underestimated. (Wylezalek & Morganti 2018)

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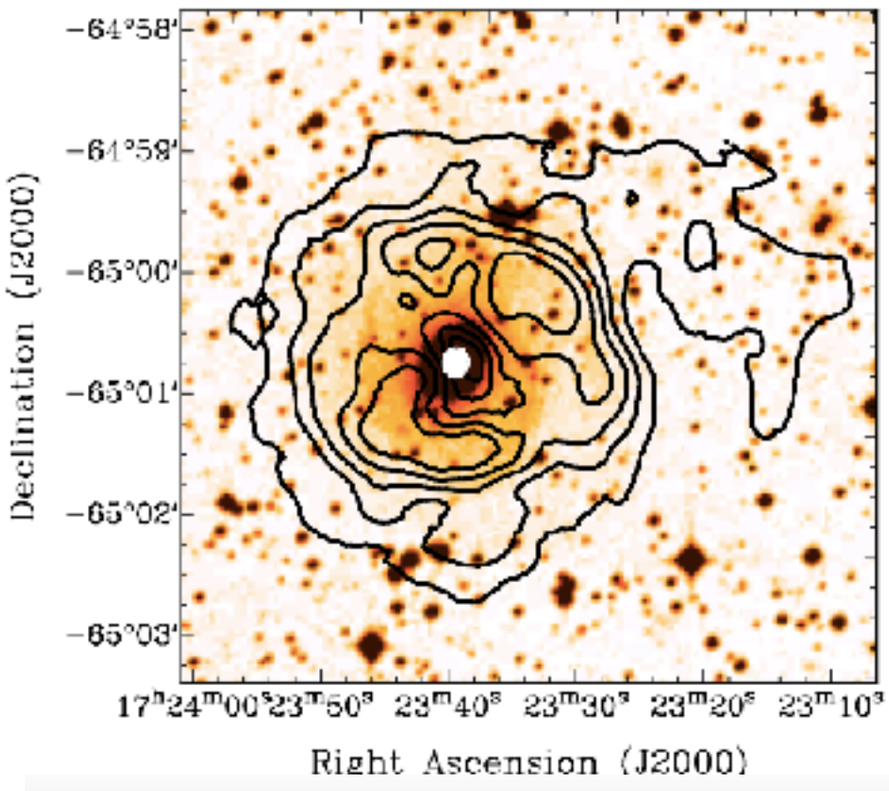
OPEN QUESTION: What triggers the radio activity?

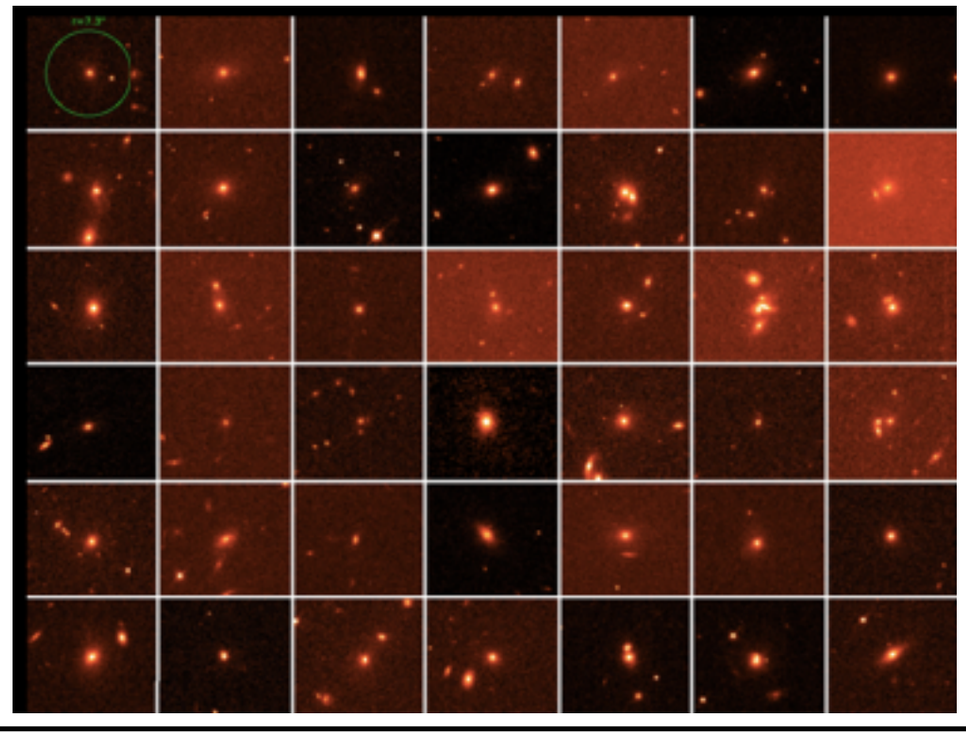
Accretion of cold gas?



HI emission (contours) superposed to a band I image of PKS B1718–649 (Maccagni et al. 2017)

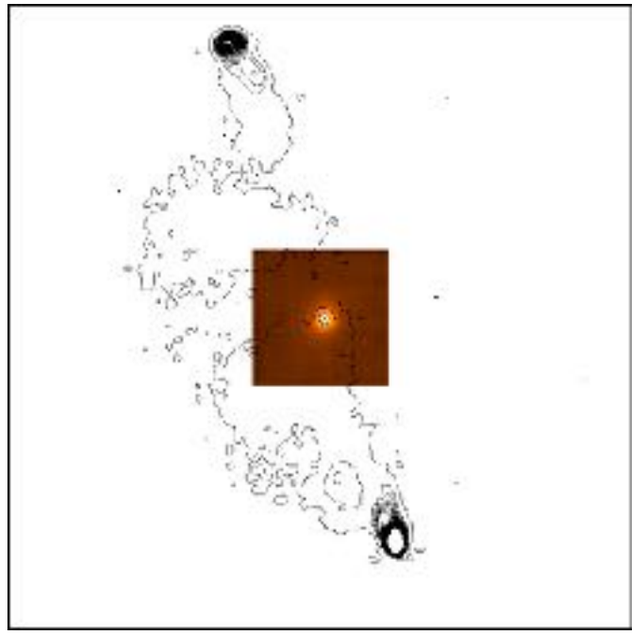
Mergers?

Most radio galaxies at z>1 are associated with major mergers (Chiaberge et al. 2016) and jets are very frequent in merging galaxies, (Sabater et al. 2013, Ramos Almeida et al. 2013)



THE PROJECT:

MURALES is a Muse Radio Loud Emission lines Snapshot survey. We have been awarded in cycle 99B (2017) of 19.5 hours of observations and 11 hours in cycle 102 (2019) with the integral field MUSE at VLT to observe 40 radio galaxies in a snapshot mode (~20 minutes on source).



THE SAMPLE:

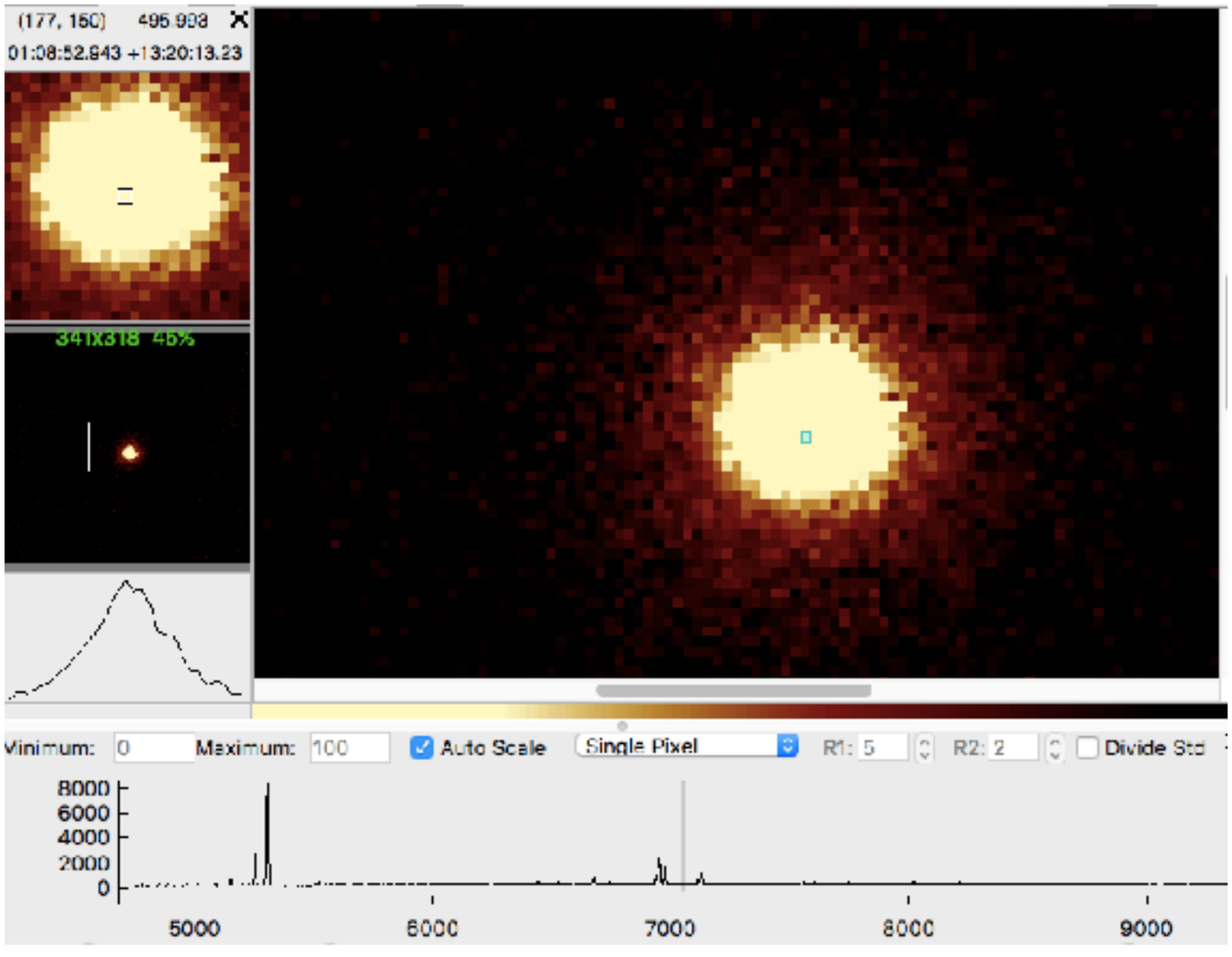
We selected all the 3C radio galaxies (40 targets) visible from the Southern Hemisphere in the observing semester at z<0.3., both FRI and FRII radiogalaxies.

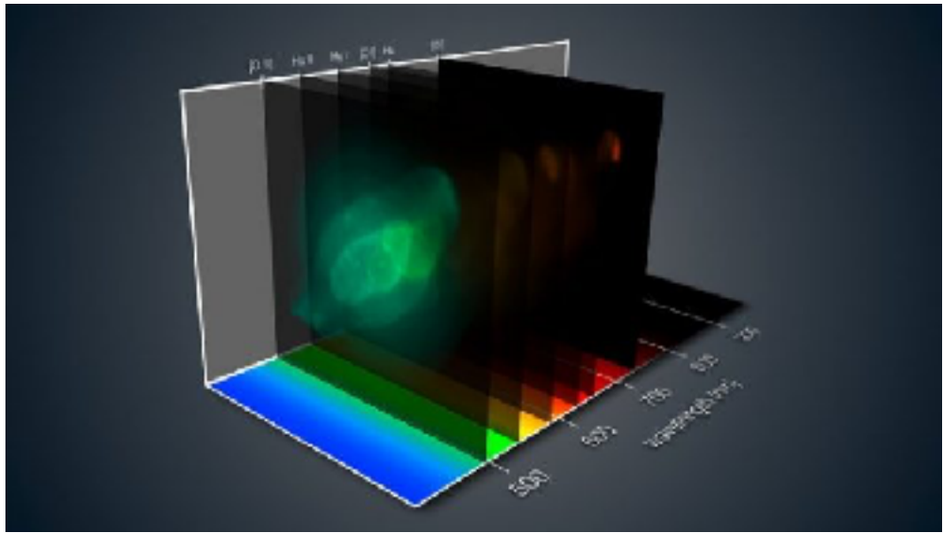
THE AIM:

We want to explore the gas kinematics, its relationship with the relativistic outflow and its ionization mechanism, unveiling jet-triggered star forming regions. This will enable us to explore quantitatively the so-called feedback process, i.e. the exchange of energy between these radio loud AGN and their environment.

What is MUSE?

MUSE is the integral field spectrograph at VLT operating in the optical band.





Credits: ESO/J. Walsh

muse

Overview of the instrument:

Resolution: 0.2 arcsec/pixel

FoV: 1x1 arcmin

R = 1750@465nm to 3750@930nm

Wavelength range = 480-930nm

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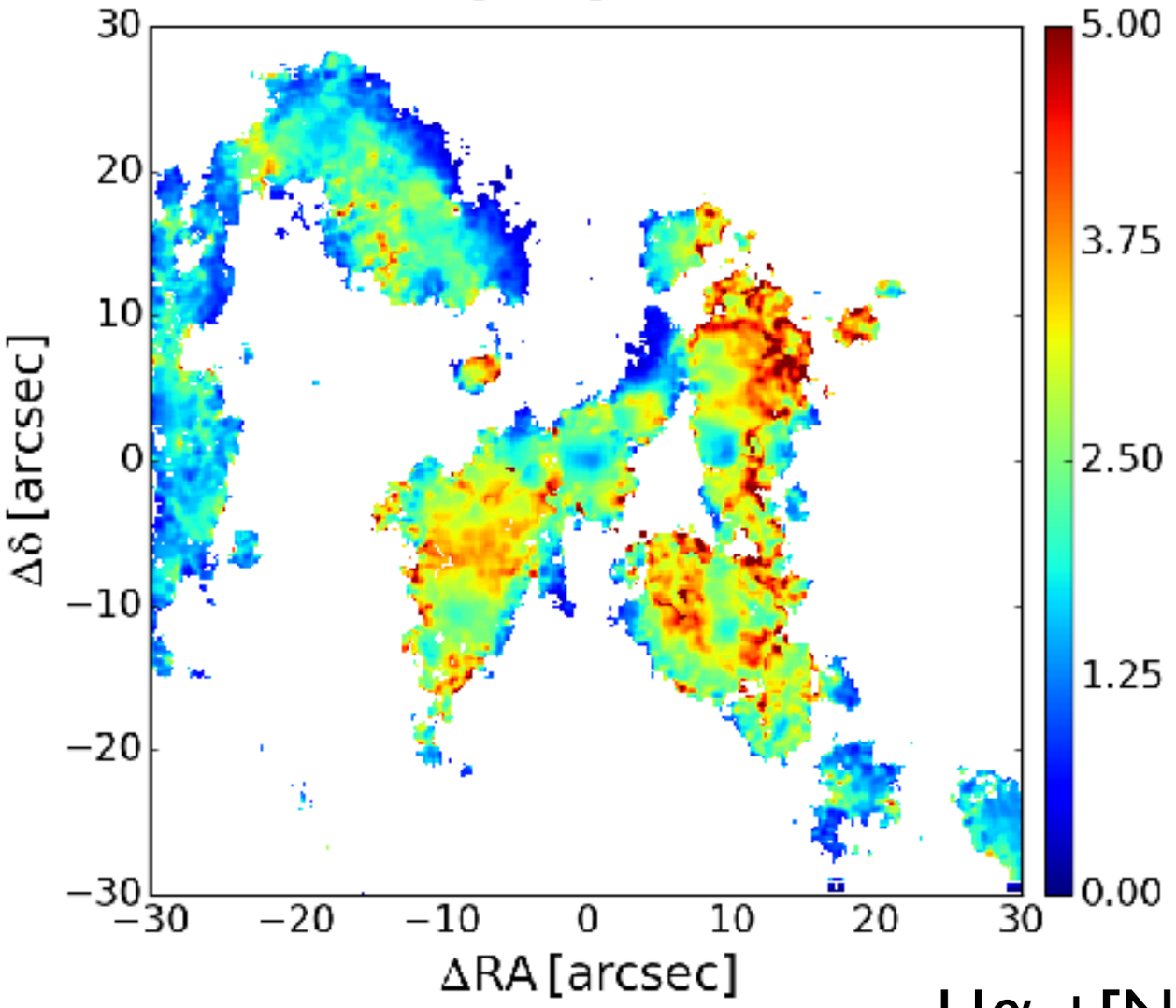
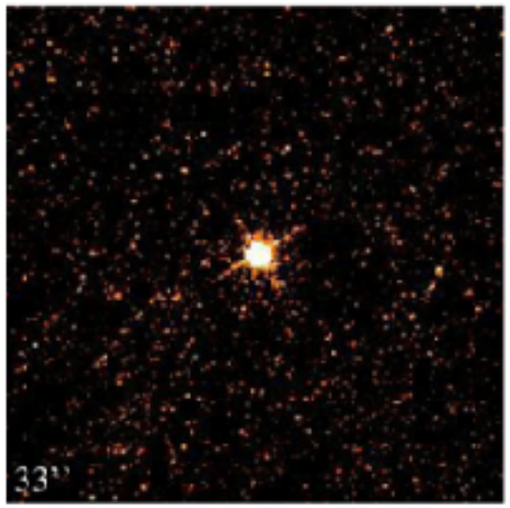
3C227

[OIII]/Hα



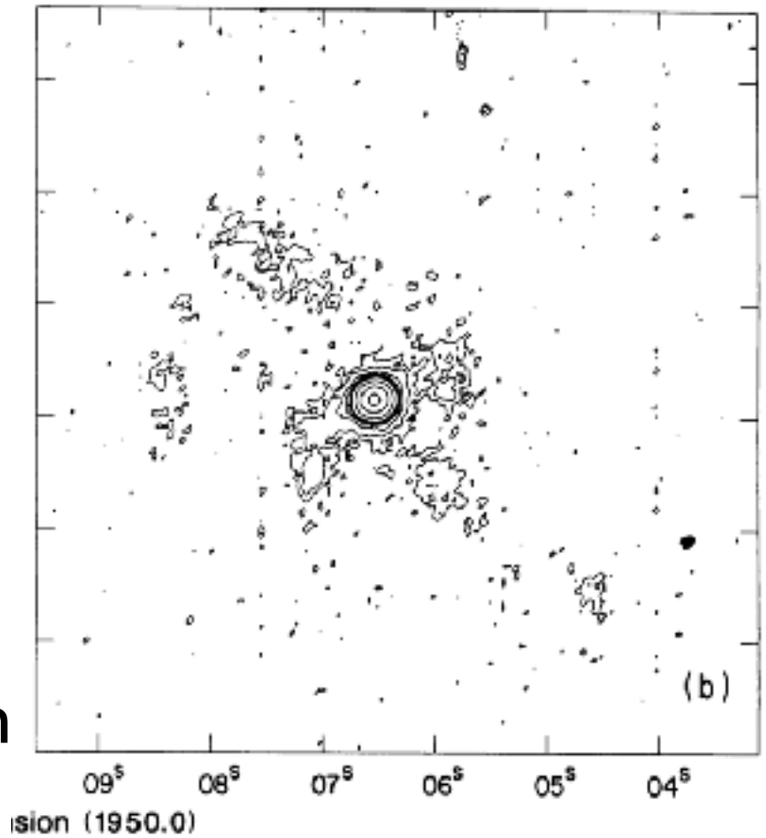
FoV 104 kpc

Hα (from HST)
Baldi et al. 2018

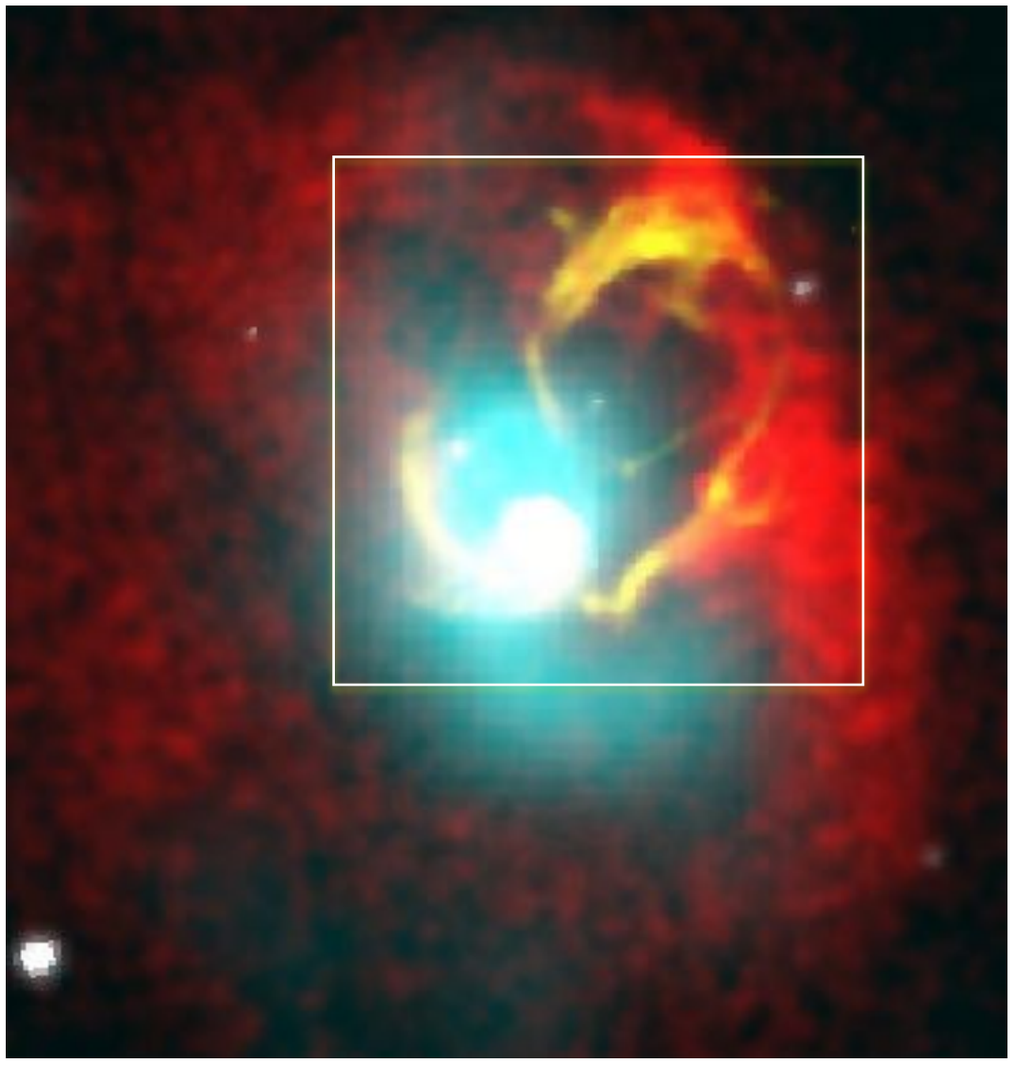


Hα

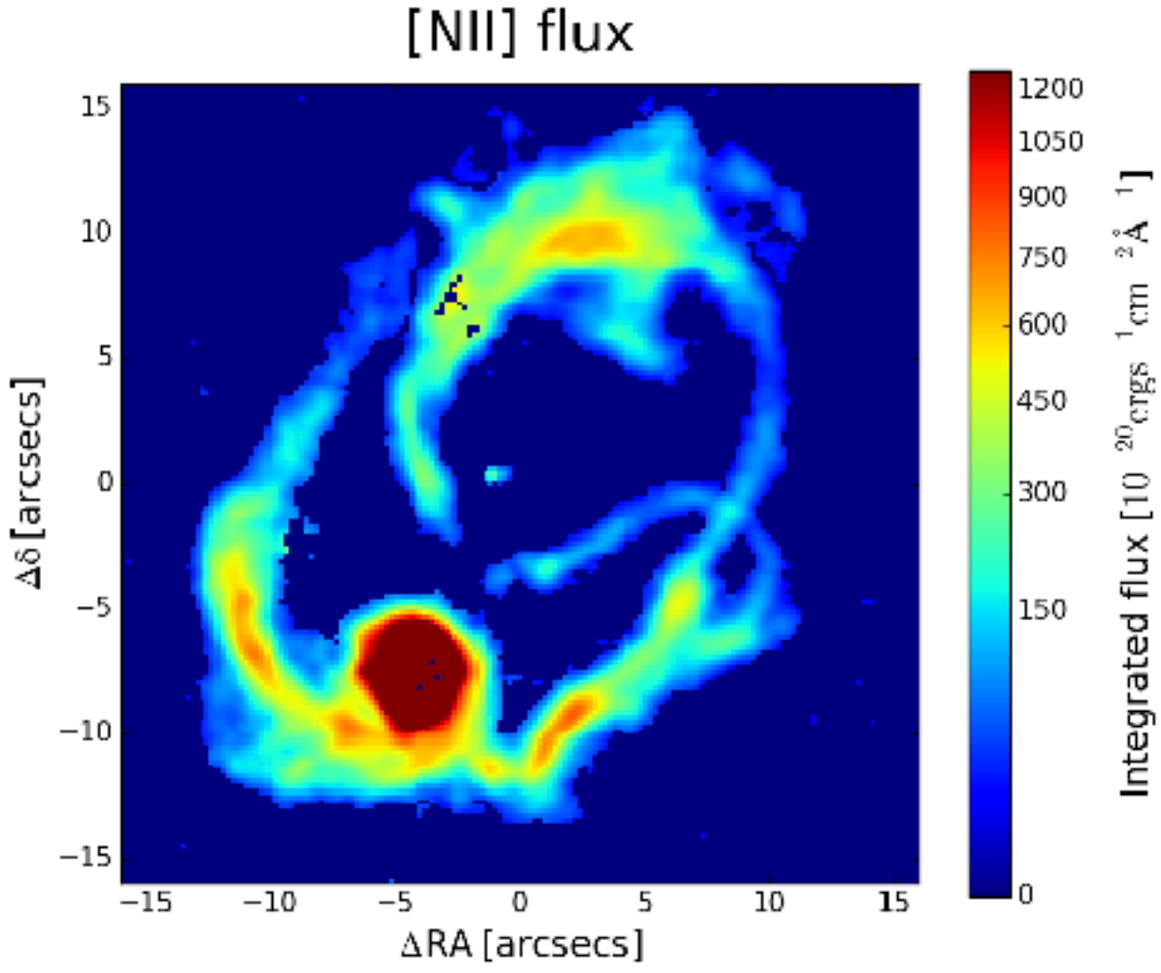
Hα +[NII] emission
Baum et al. 1988



Our pilot case: 3C317 in Abell 2052

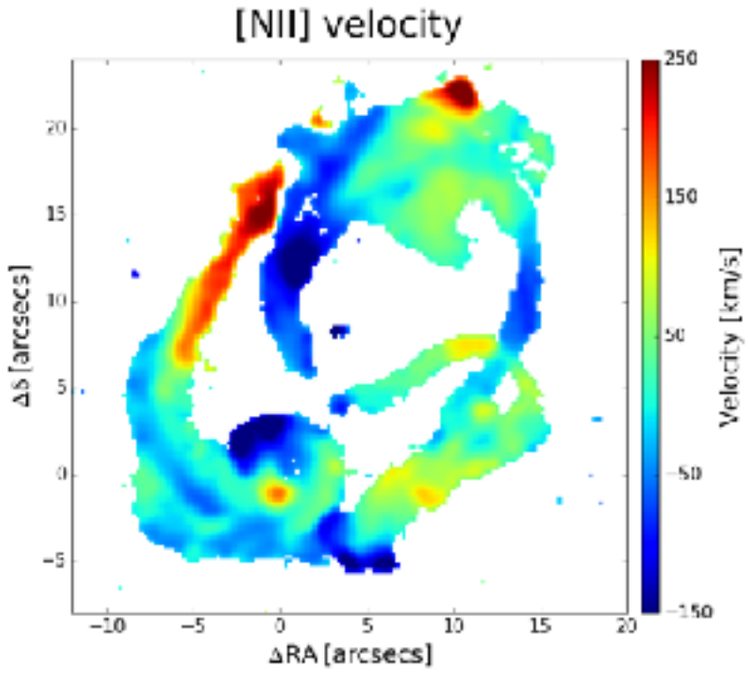


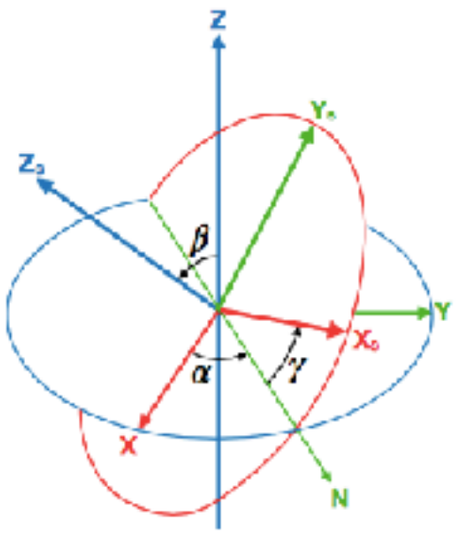
A2052. Red: X-ray; cyan: radio; white: continuum; yellow: line emission.

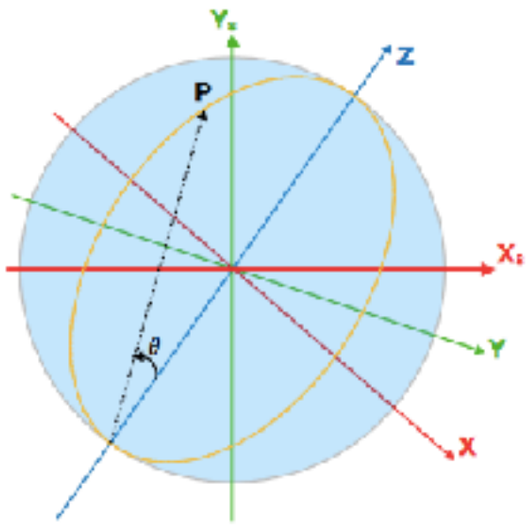


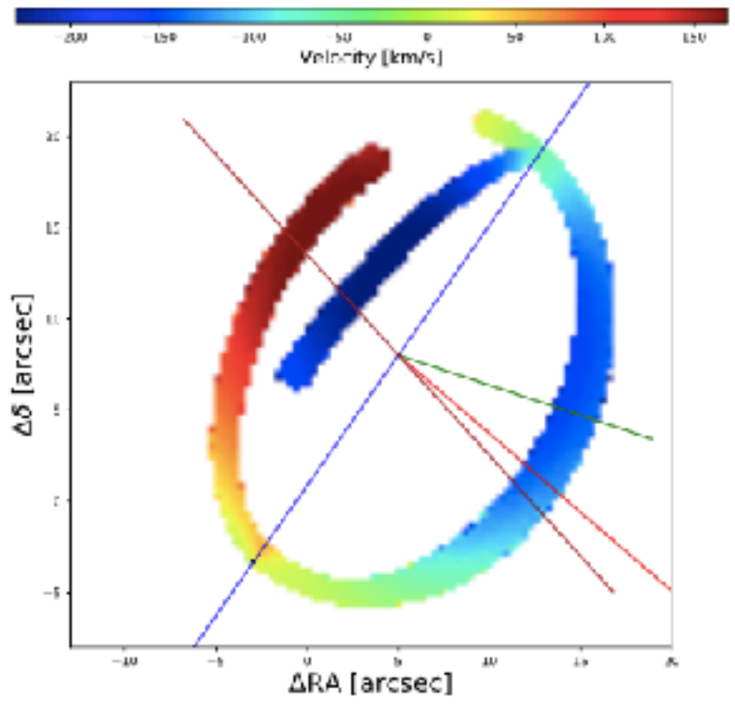
We can reproduce the velocity map the toy model of an expanding bubble

The maximum observed speed is 265 km s−1 (SUB-SONIC: Cs=~500 km s−1 for an external gas temperature of 10^7 K)



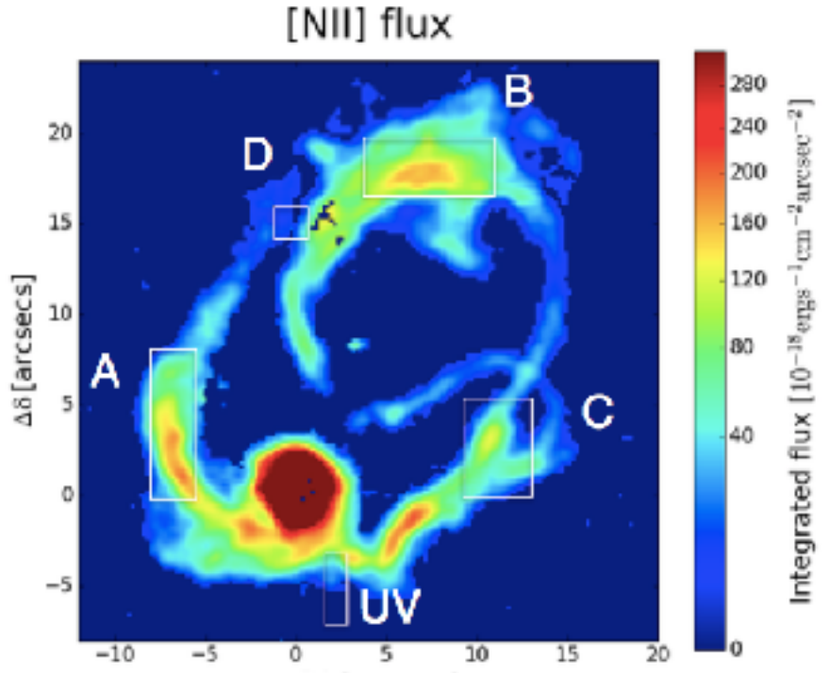


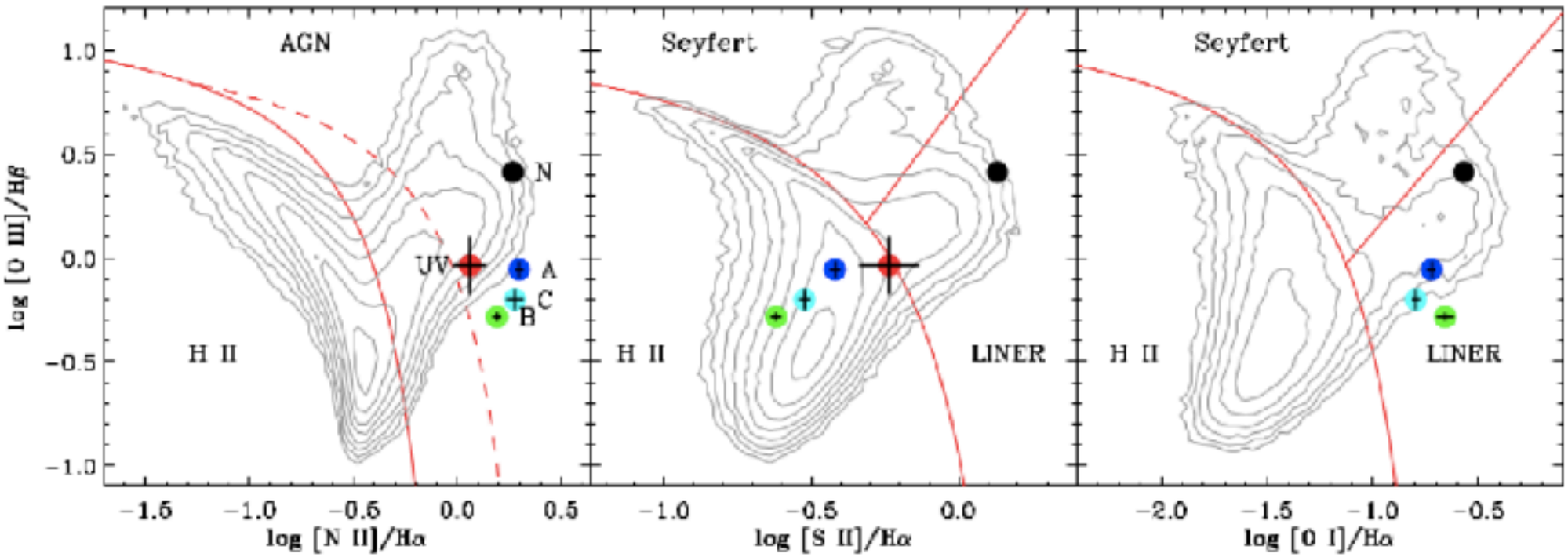




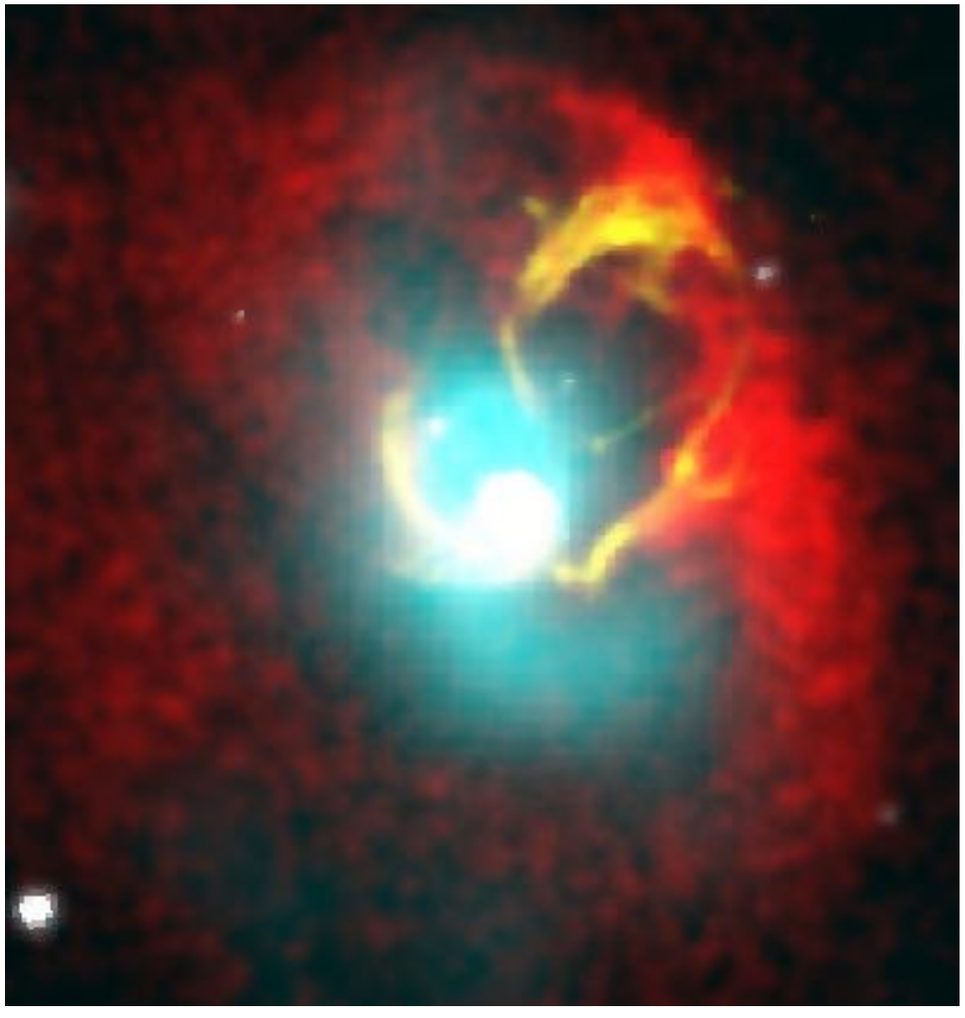
The emission line ratios rule out the AGN or young stars as the dominant sources of ionization of the gas.

Possible alternatives: ionization due to slow shocks (Dopita & Sutherland 1995) or collisional heating from cosmic rays (Ferland et al. 2008, 2009; Fabian et al. 2011)





Balmaverde et al. A&A 612, A19 (2018))



A2052. Red: X-ray; cyan: radio; white: continuum; yellow: line emission.

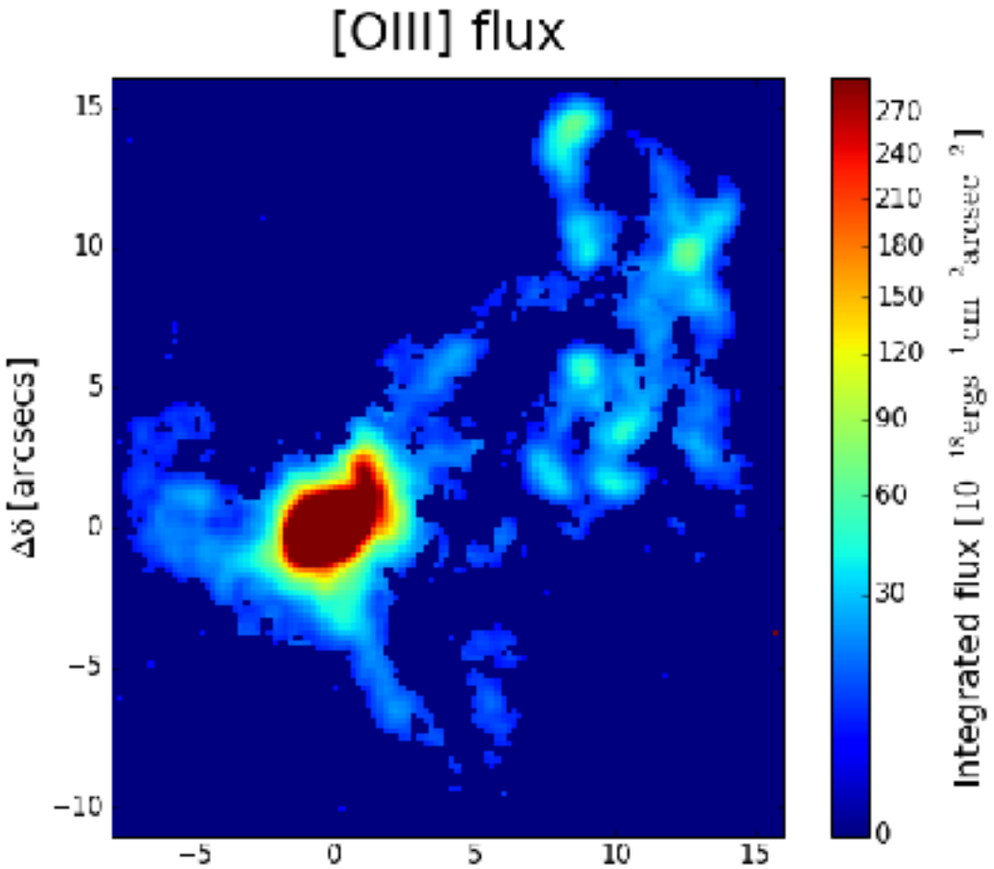
MAIN RESULTS:

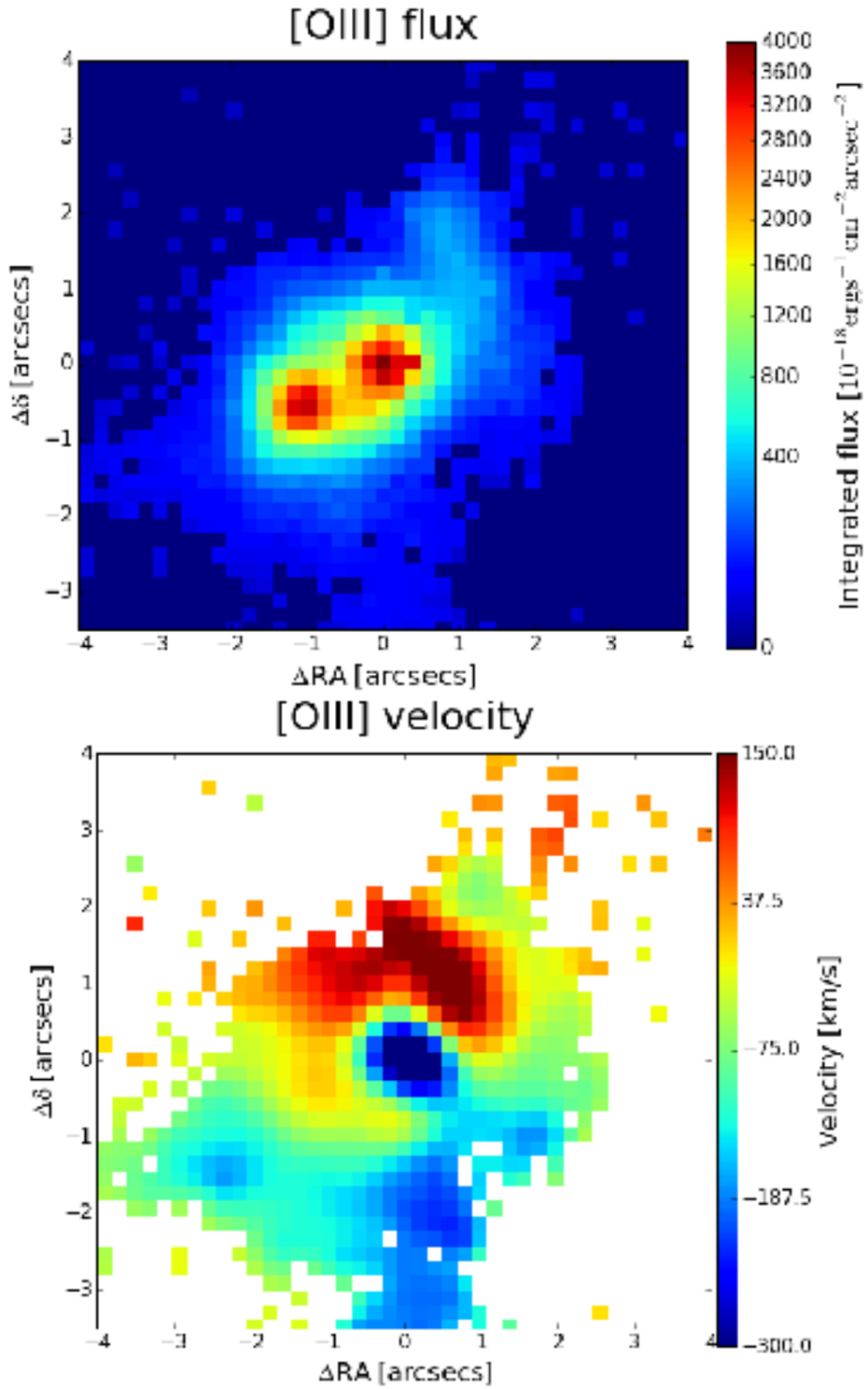
✓We observe a network of emitting line filaments enshrouding the Northern cavity.

✓In the filaments the gas is dense (up to 270 cm-3) and makes up part of a global quasi spherical outflow driven by the radio source.

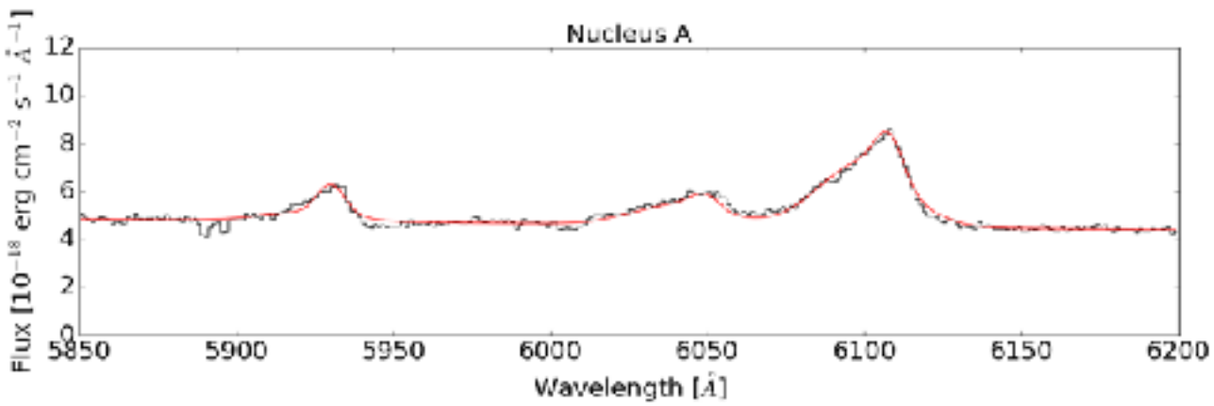
✓We obtain a direct estimate of the expansion velocity of the cavities (265 km s-1).

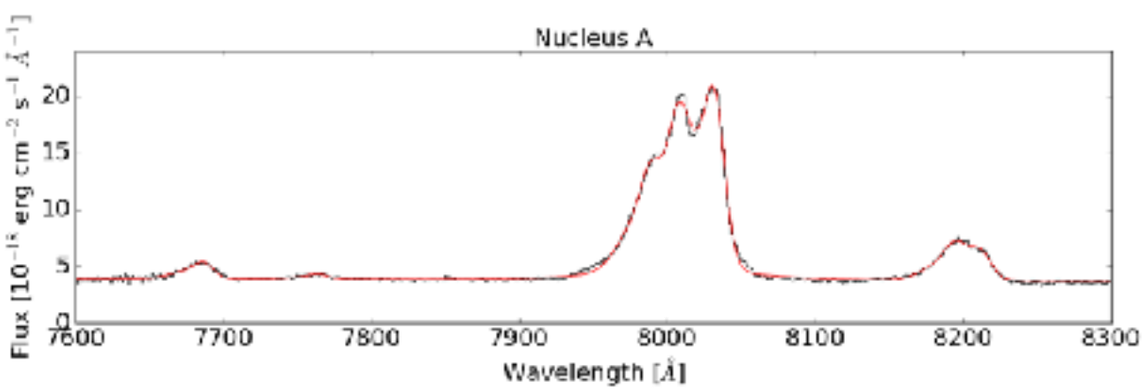
A binary black holes in 3C459?...

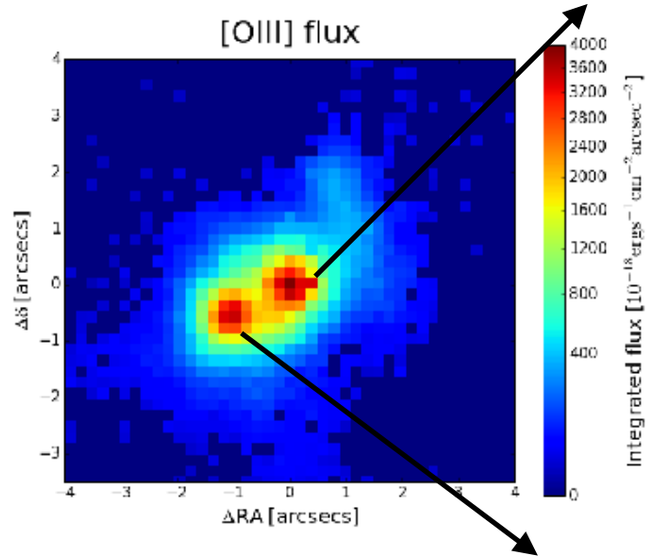




- ✓ The central emission line region is dominated by two compact knots: the first cospatial with the radio core, the second located 1.2 (5.3 kpc) to the SE.
- ✓ The two regions have velocity (Dv~300 km/s), line widths, and line ratios.

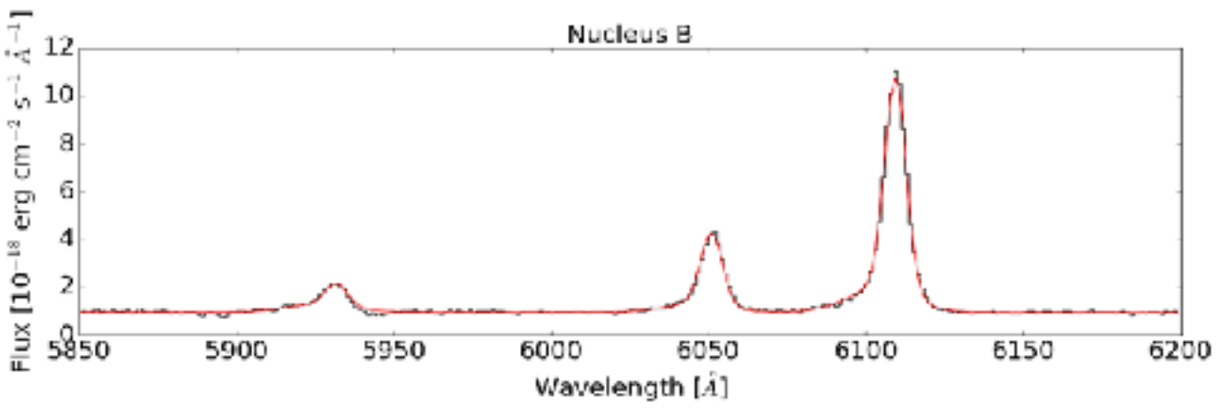


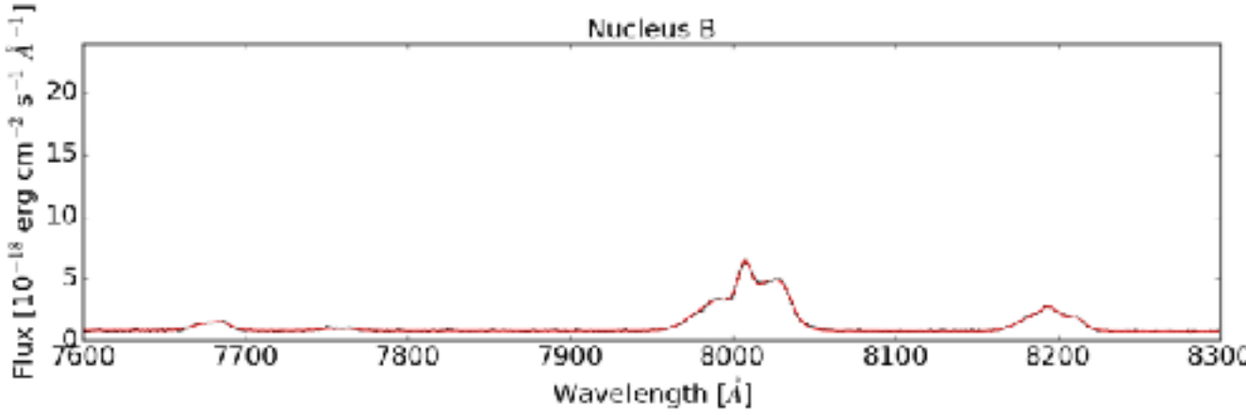




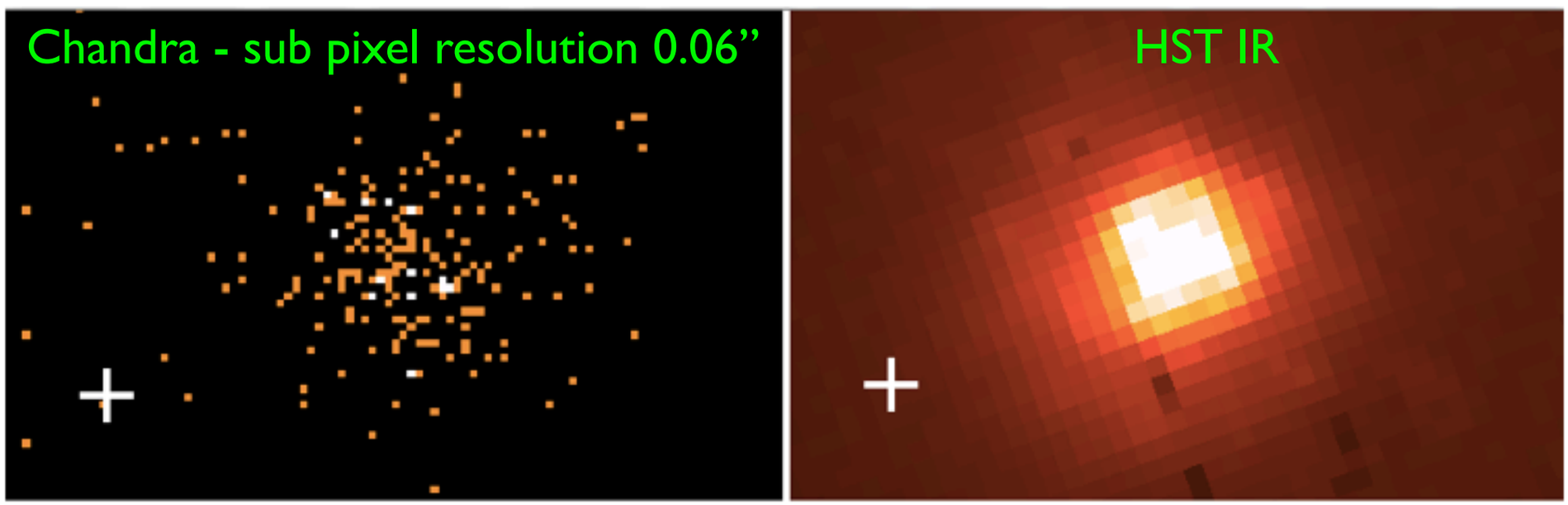
MAIN RESULTS:

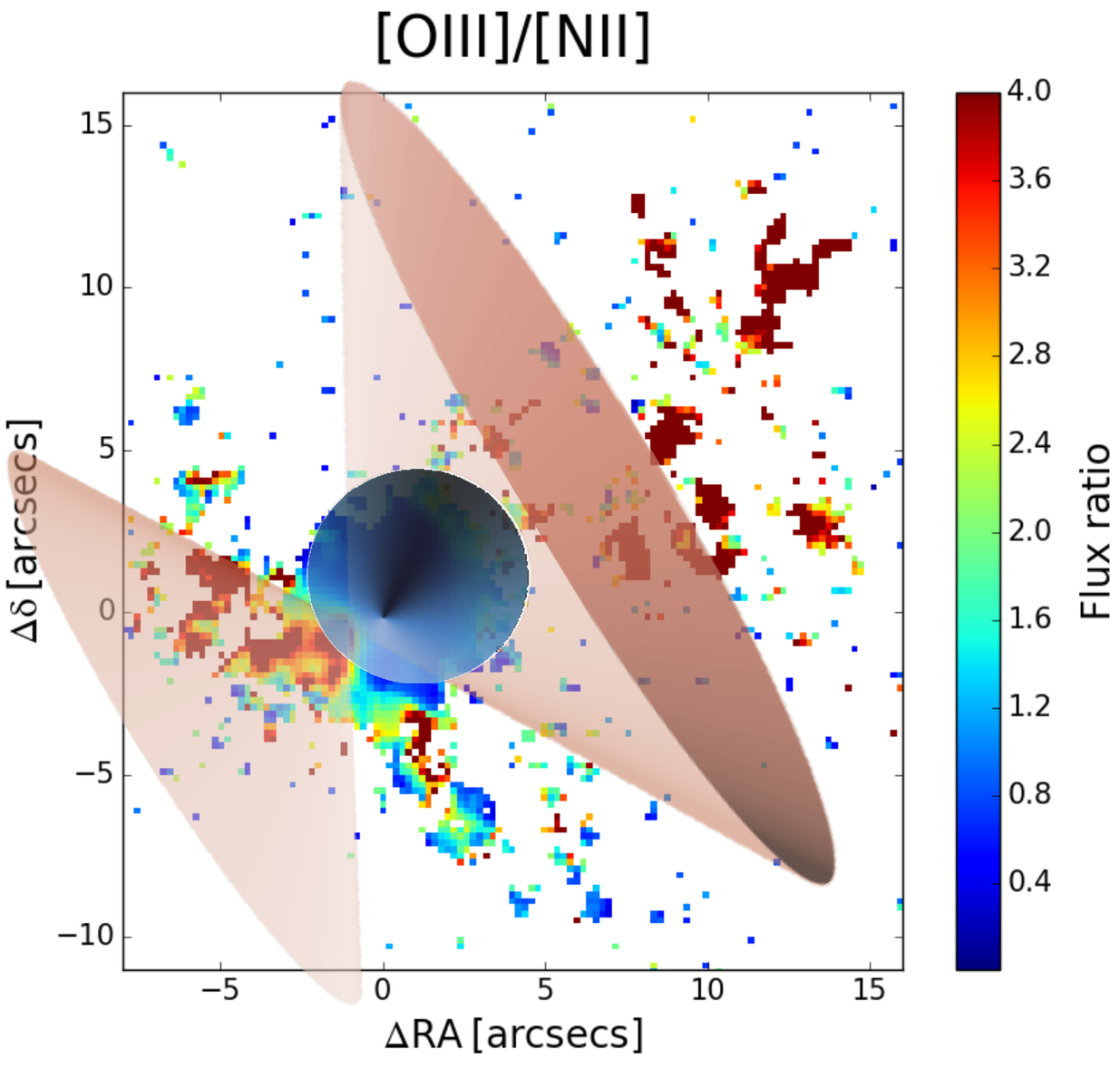
✓The emission line ratios in the two knots are different.
✓A QSO spectrum highly absorbed?
✓The [OIII] luminosity of N2 is ~ 5 × 10^8 L sun





A binary black holes in 3C459?...



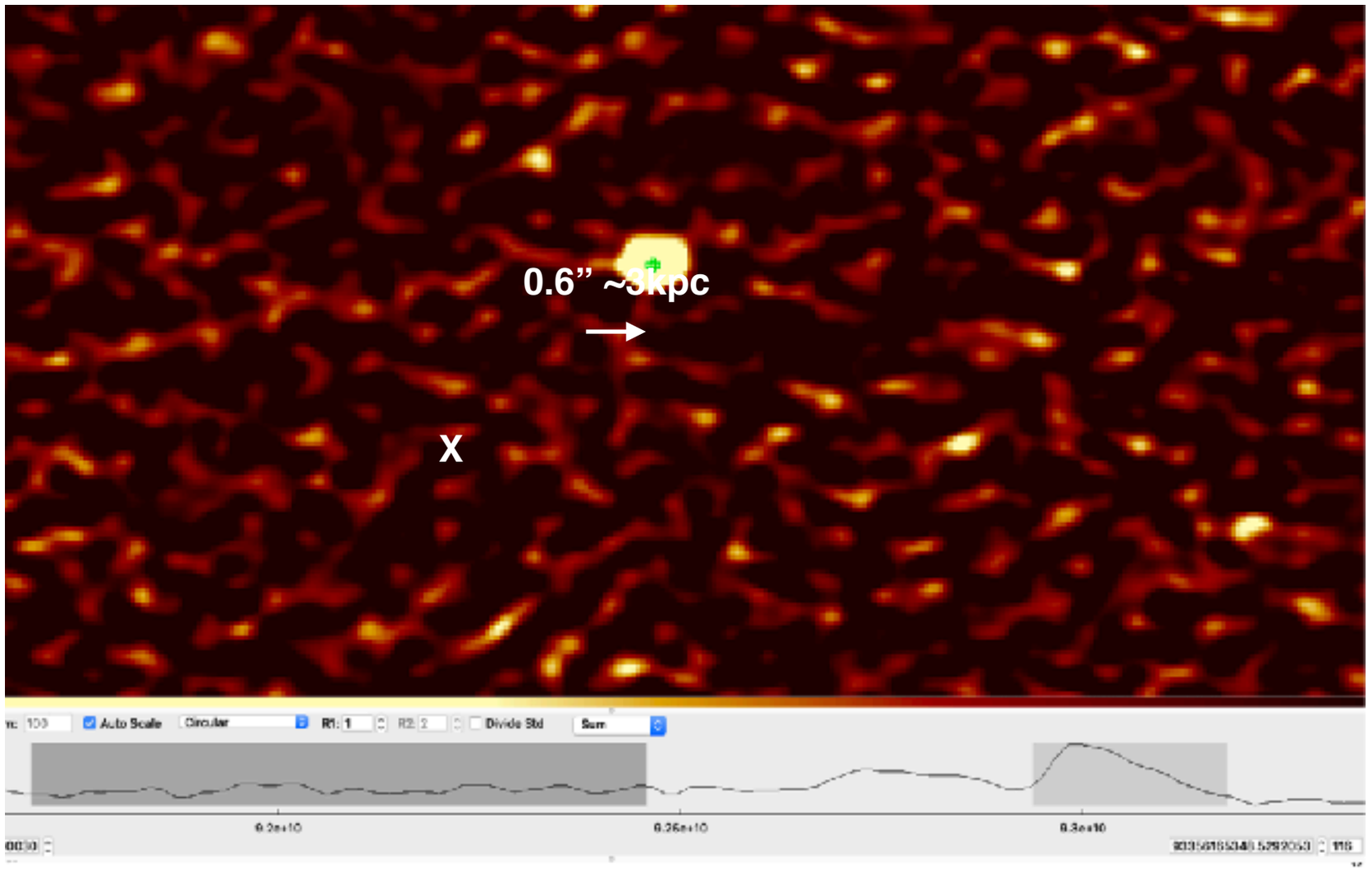


MAIN RESULTS:

- ✓A gas ionization map shows a full biconical shape, centered at the putative Seyfert nucleus, further supporting this interpretation.
- ✓The secondary AGN must be highly obscured, since we do not detect any emission in the Chandra and H-band HST images but it is very luminous in [OIII]

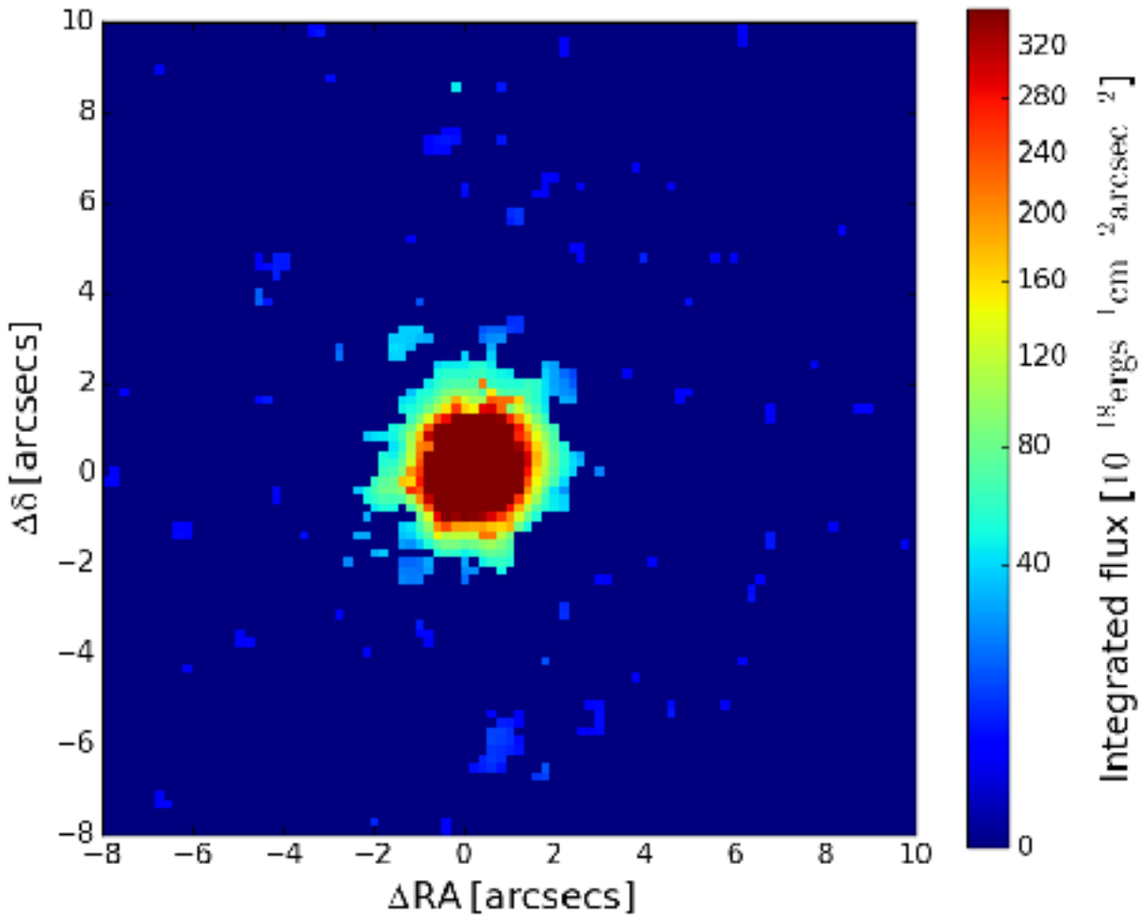
Balmaverde et al. 2018A&A...619A..83B.

ALMA PROPOSAL "Dancing with the stars: a binary black hole in the nucleus of 3C459": 5hr

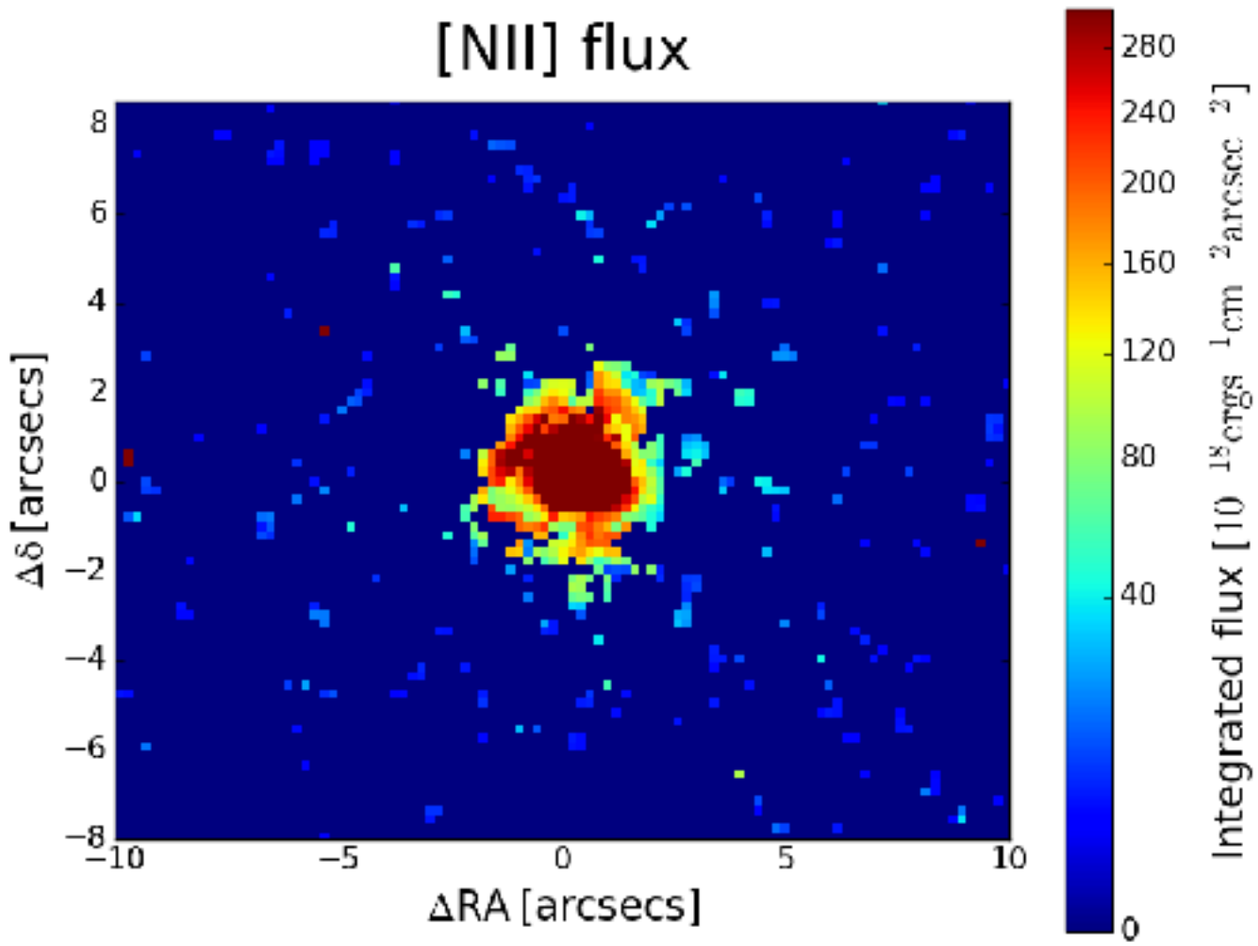


What did we observe? FRI/LEG are preferentially compact…

3C15

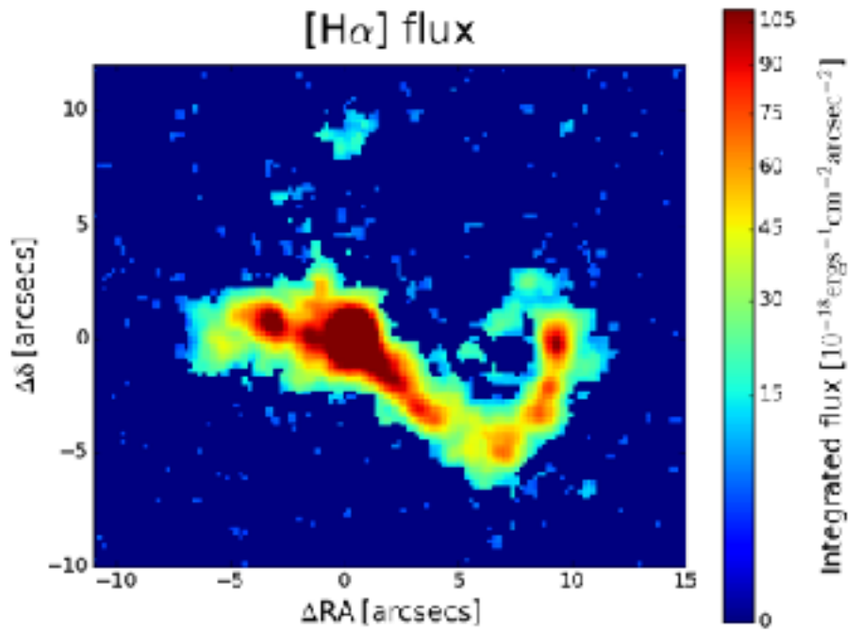


3C29

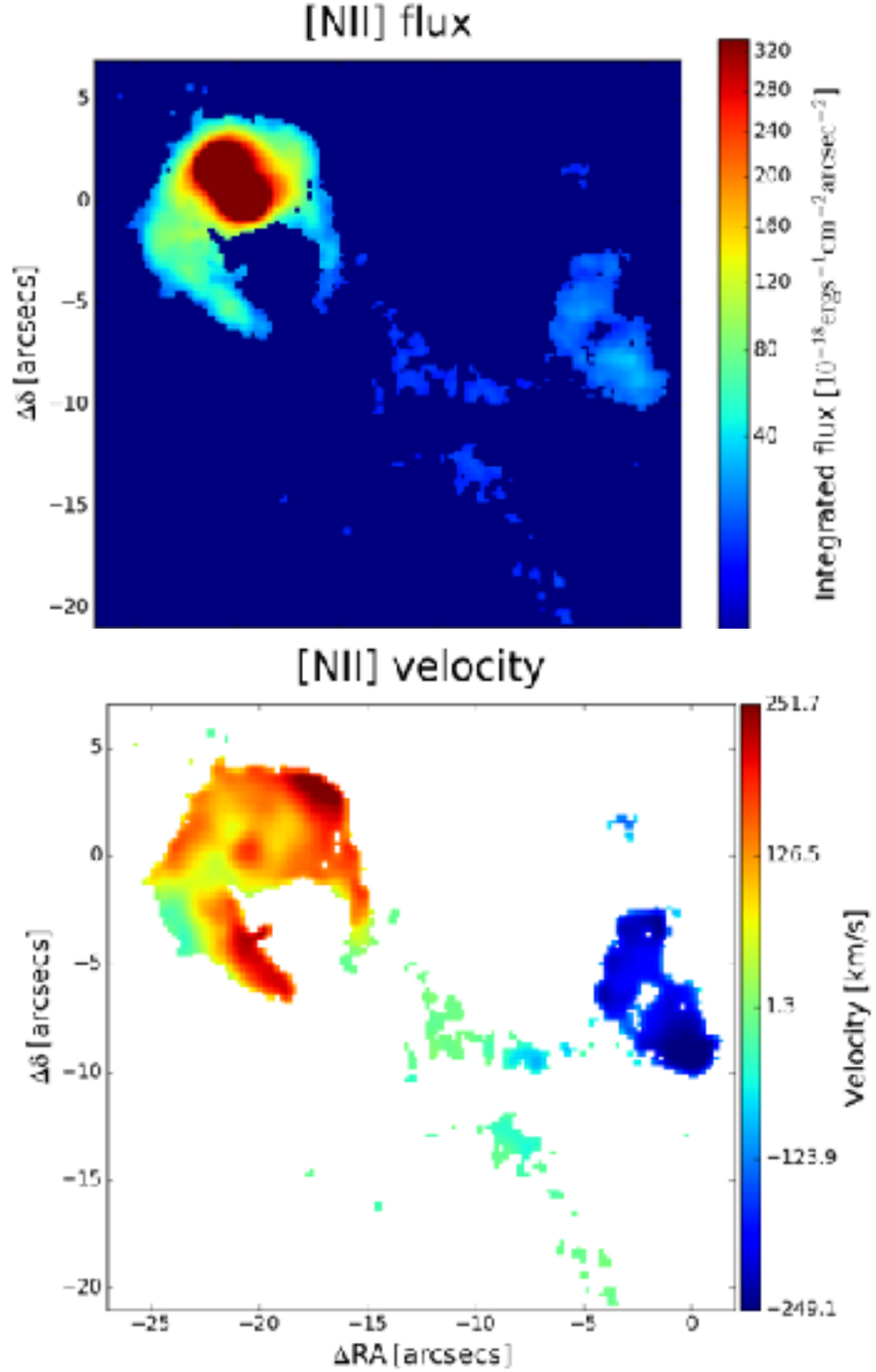


Instead, in the FRII sample we find cavities…

3C63



3C442



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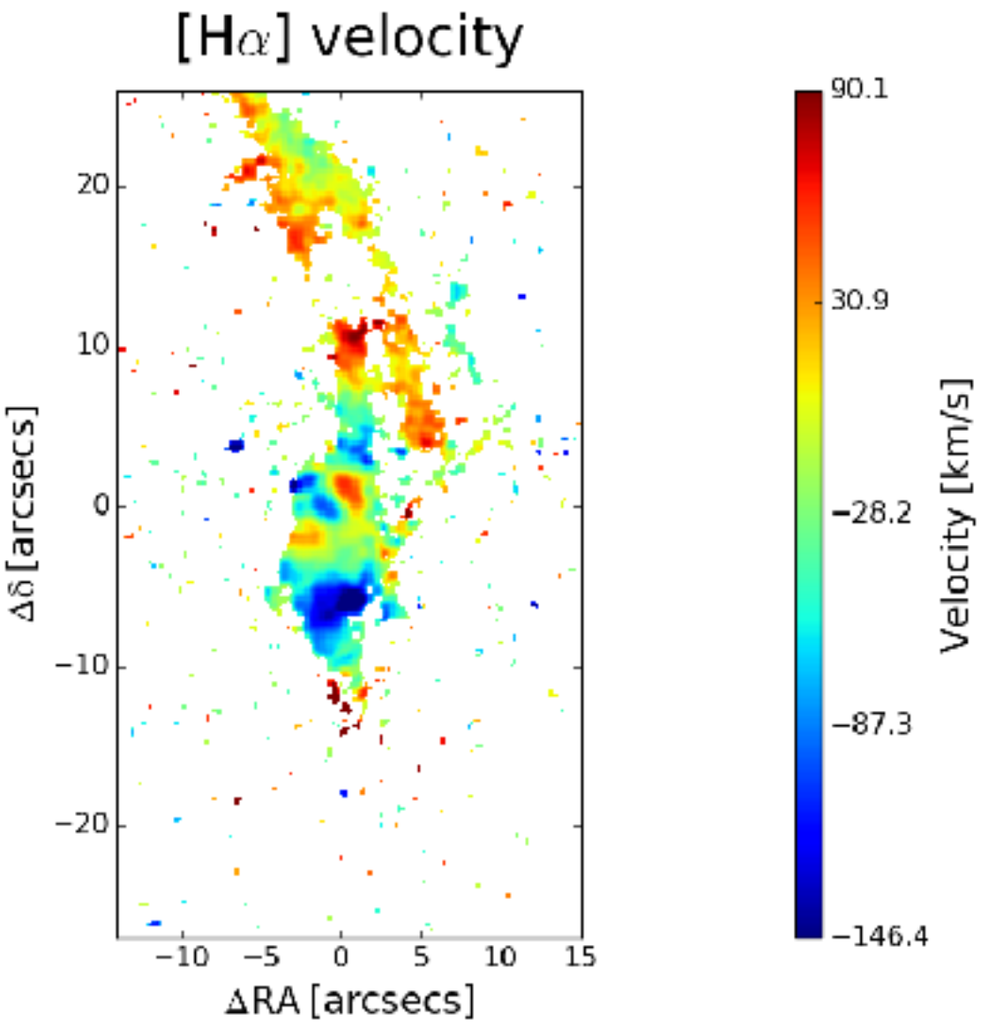
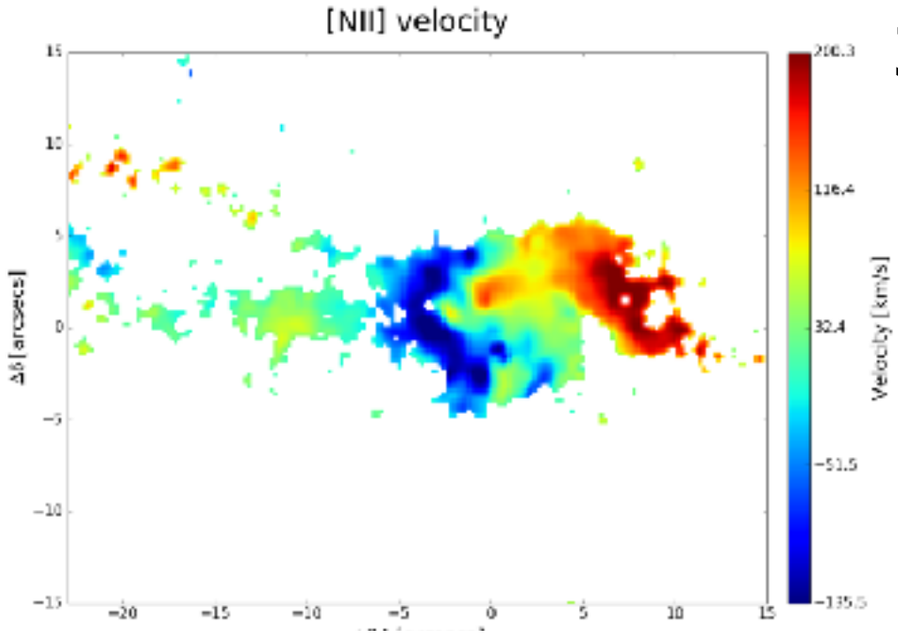
Filaments…

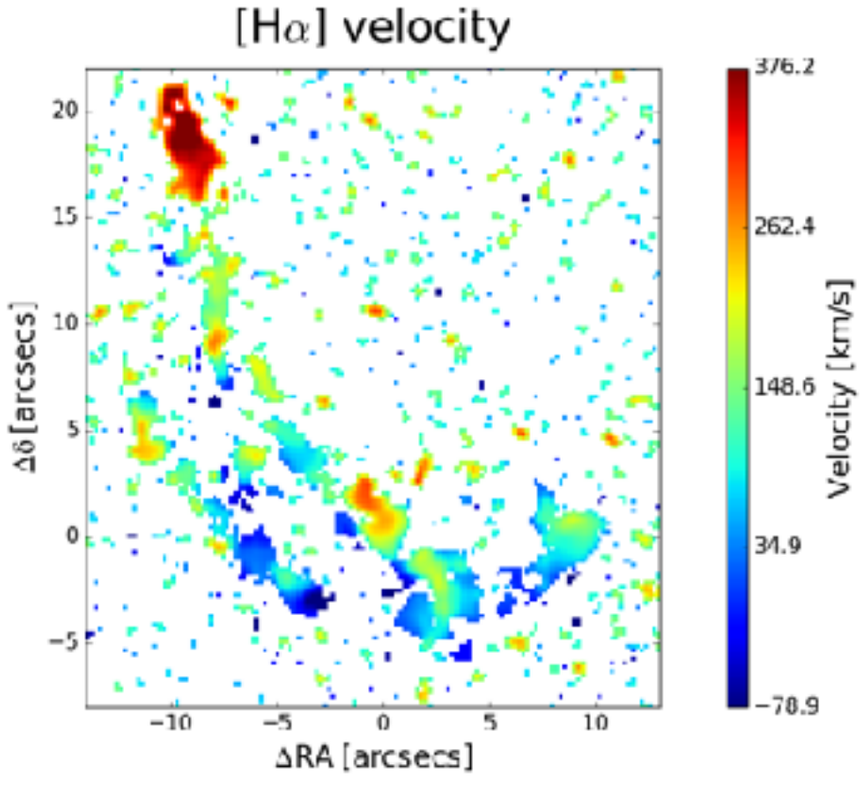
3C353



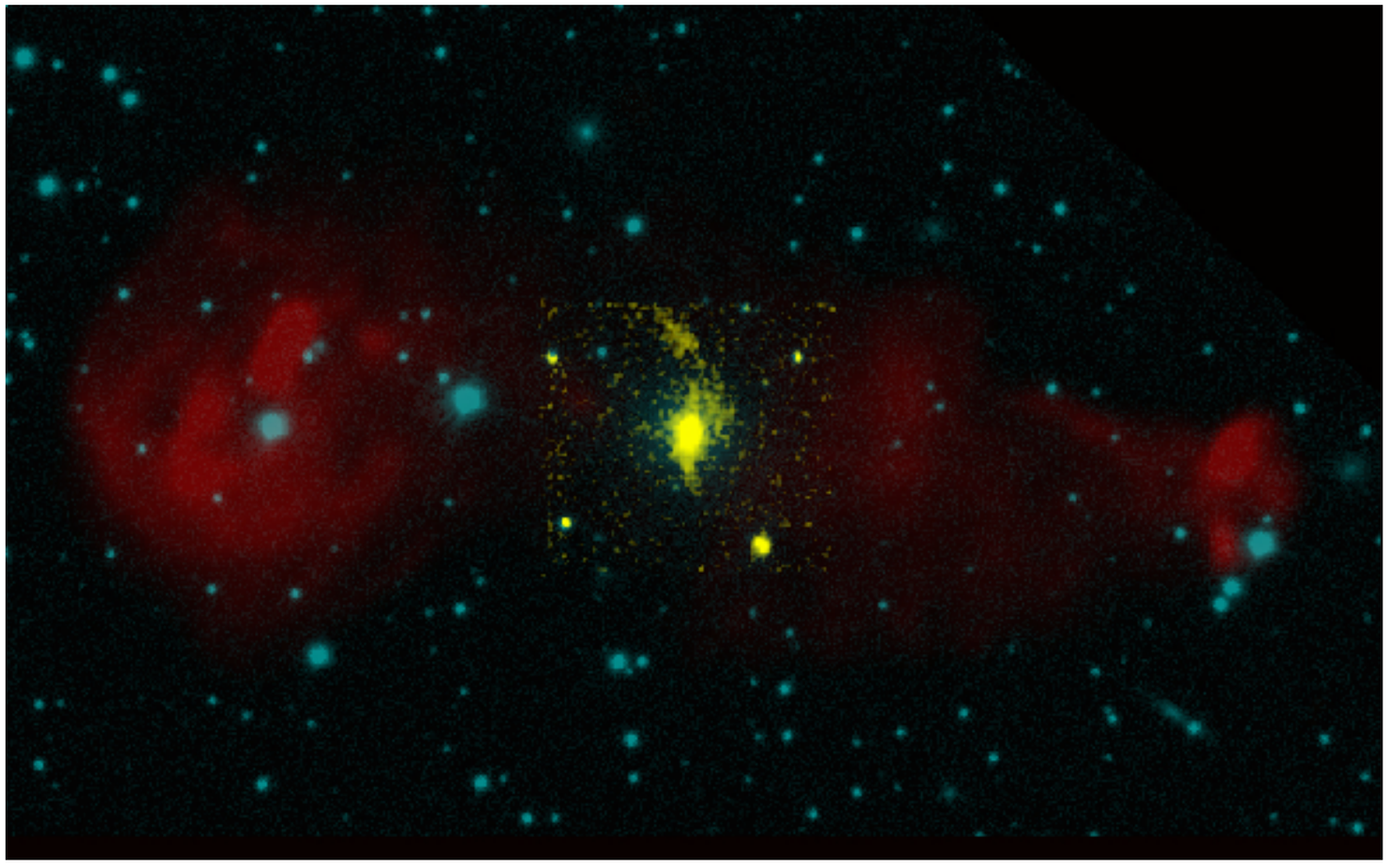
3C386

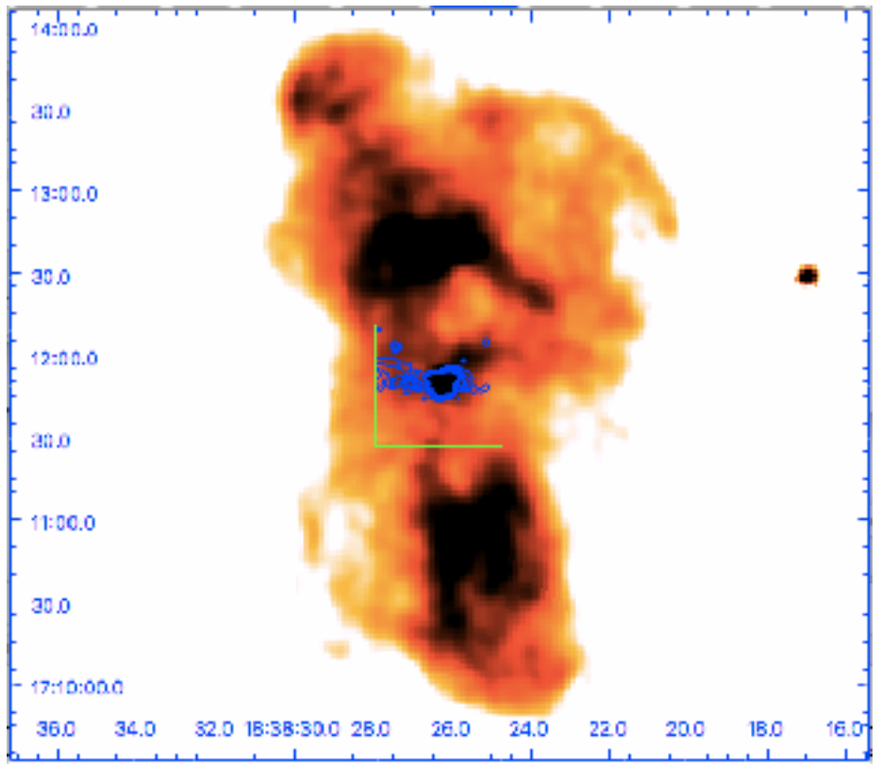


3C458



Filaments…





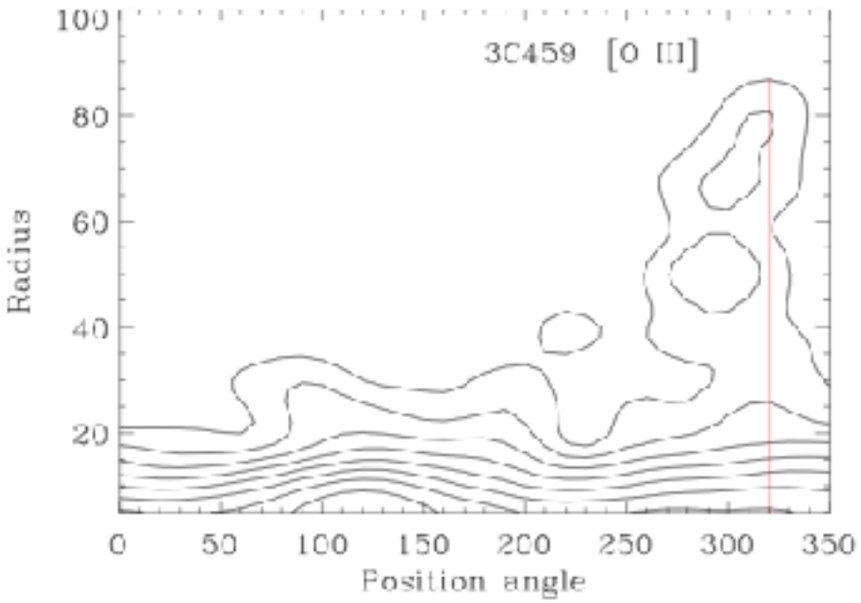
3C353 (left; Radio:red, Continuum: cyan, Line: yellow)

3C386 (right; Radio: red, Line: blue)

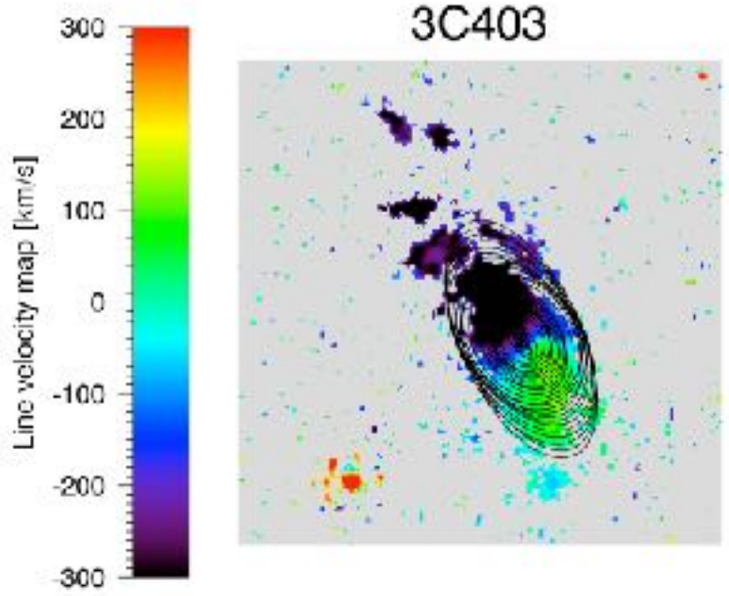
How to describe the filaments?

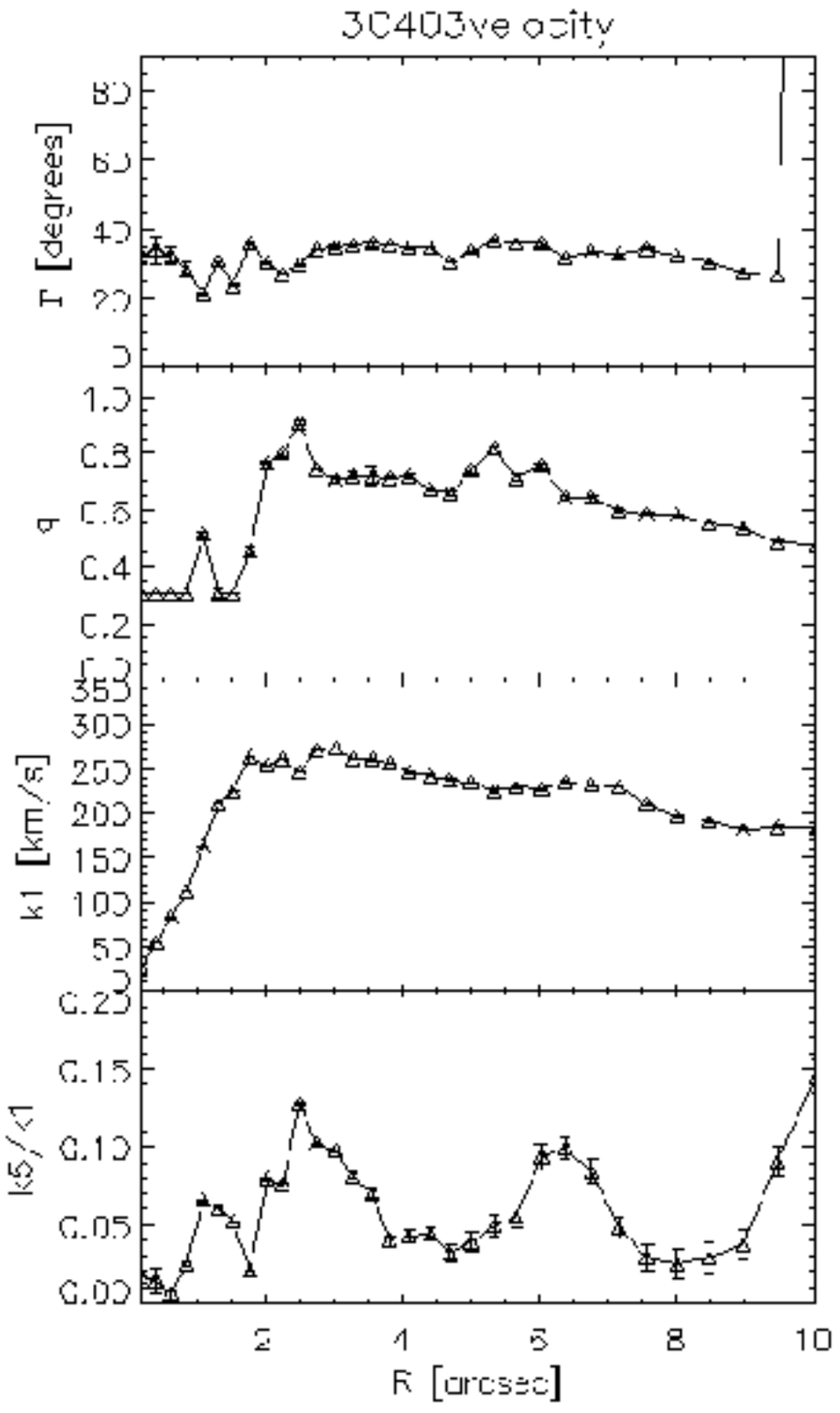
We used the software "kinemetry" (Krajnovic+05) to measure the "kinematic" PA of the emitting line disk, determining the best fitting ellipses along which the profiles of the velocity can be extracted assuming a cosine law. We measure instead the direction of the filaments measuring the brightness in polar angles.

Morphological analysis on extended scales



Kinematic analysis on inner scales





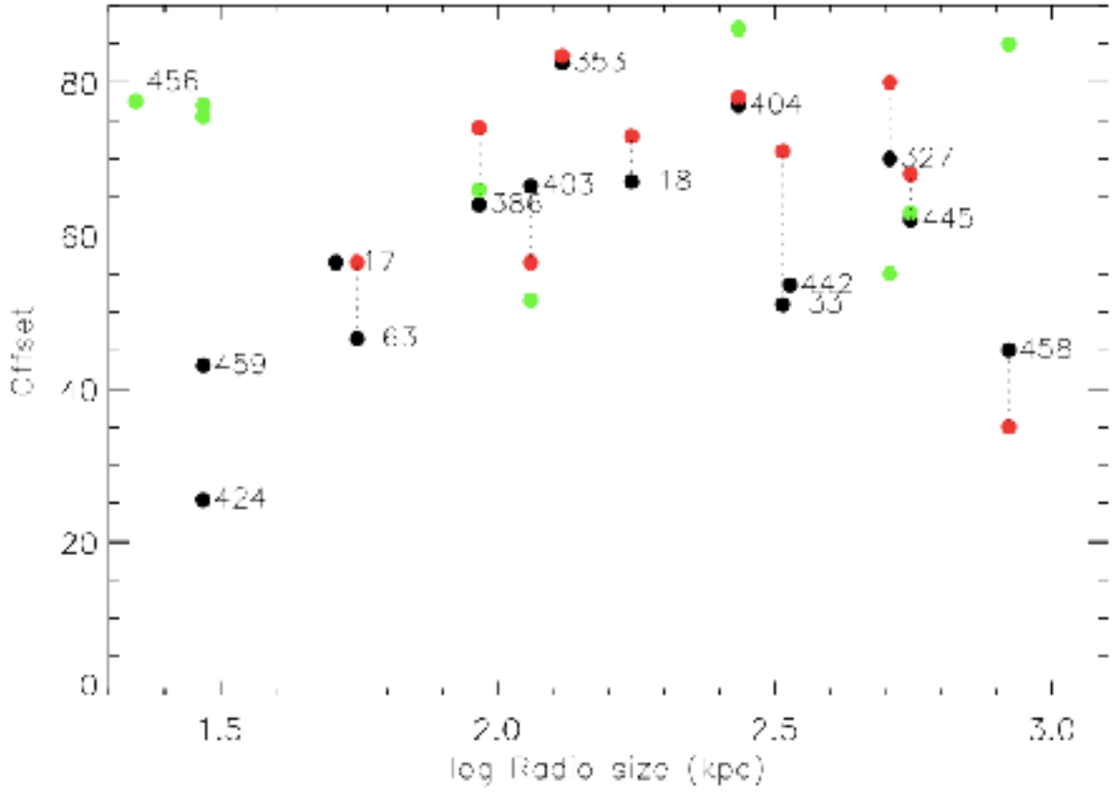
MAIN RESULTS:

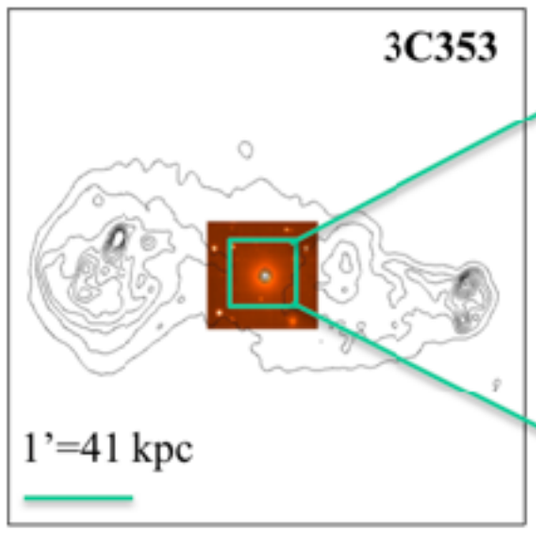
✓ We observe in all but one of the 15 FR II radio-galaxies observed extended filamentary structures.

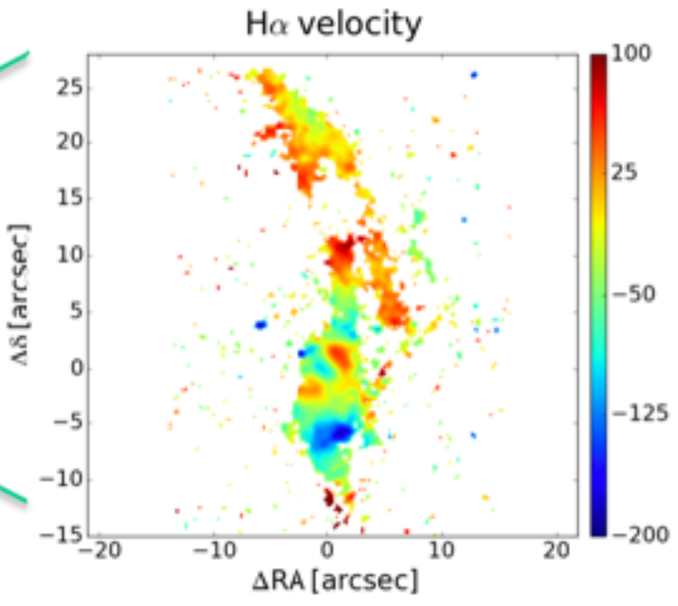
✓ These filaments are extended for several tens of kpc, are preferentially oriented perpendicularly to the radio jets.

✓ The geometrical connection between the structure of ionized gas and the radio jets supports the connection between mergers and nuclear activity.

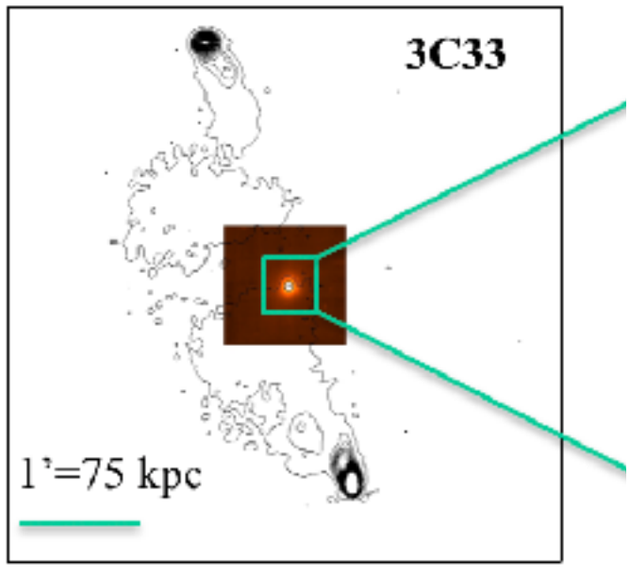
✓ The BH at sub-pc radii knows about the orientation of the gas at 10-100 kpc scales!

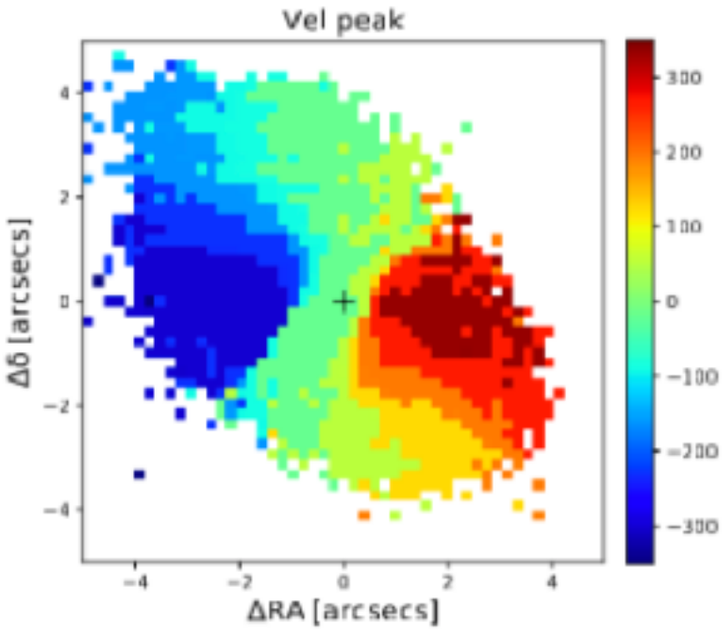


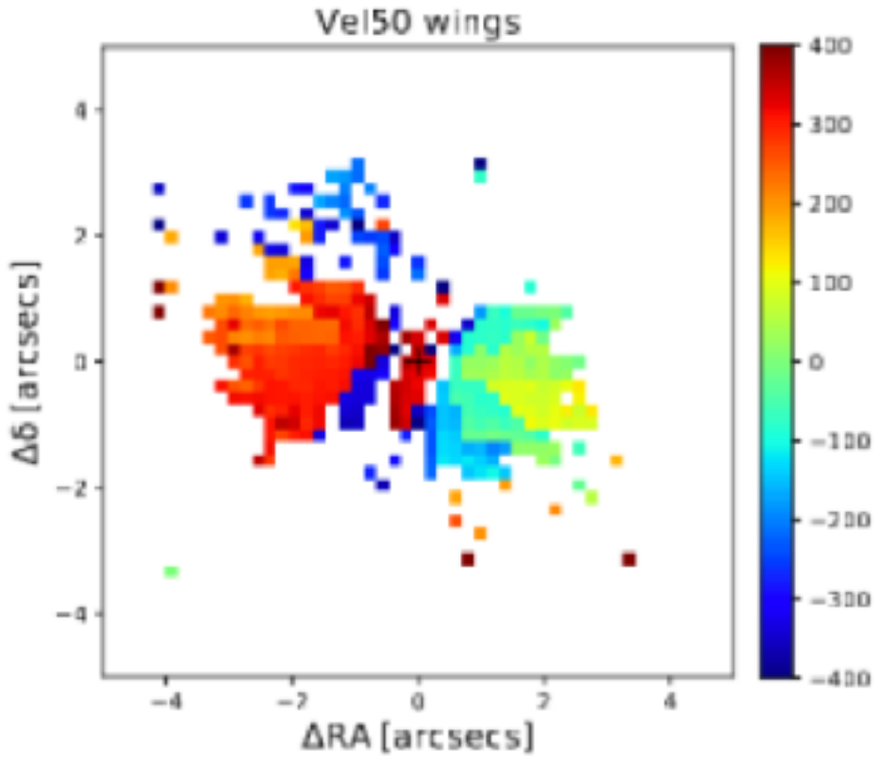


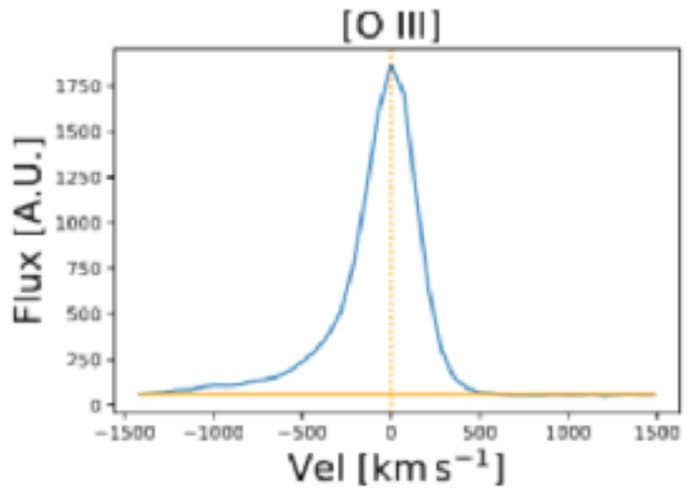


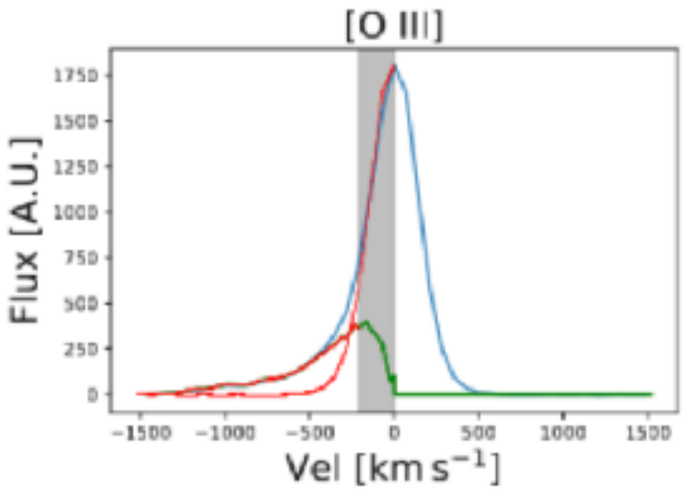
Searching for nuclear outflows

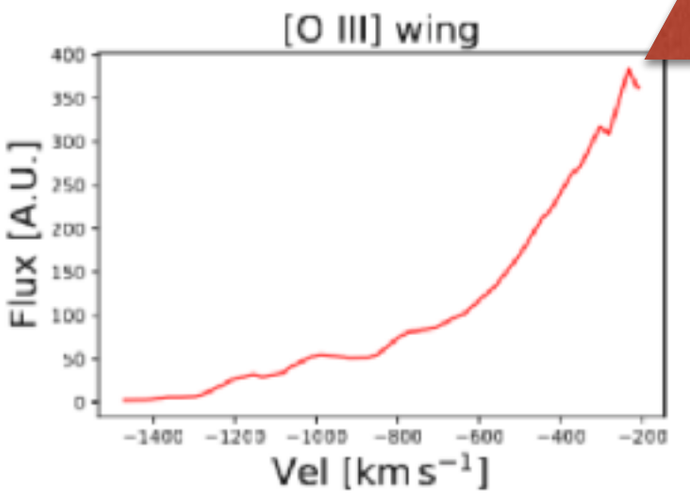












Giovanna Speranza's master thesis

Summarizing…

For the project MURALES we have observed with MUSE 40 3C radio galaxies at z<0.3.

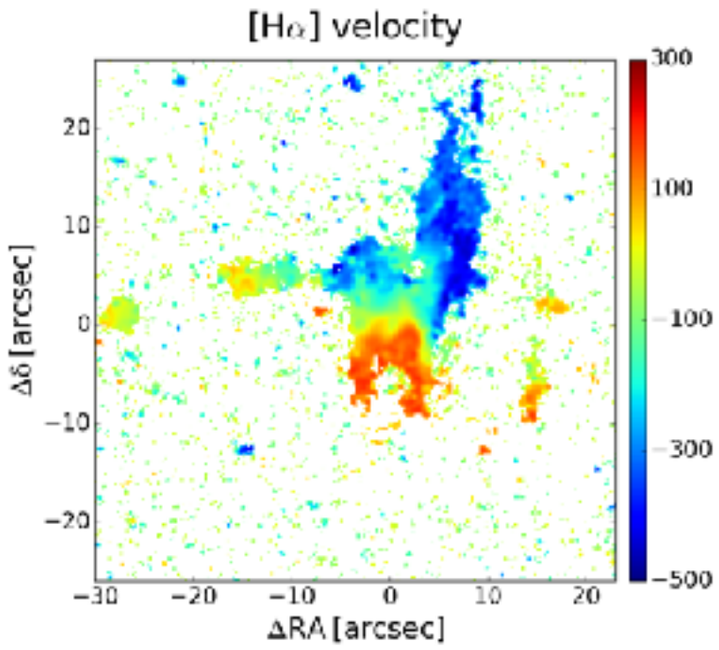
The line emission images of unprecedented depth revealed the widespread presence of filamentary structures extending several tens of kpc in all but one FRII (the FRI are preferentially compact), oriented almost perpendicularly to the radio jets, likely the remnants of the gas rich mergers which triggered the AGN.

For the future…

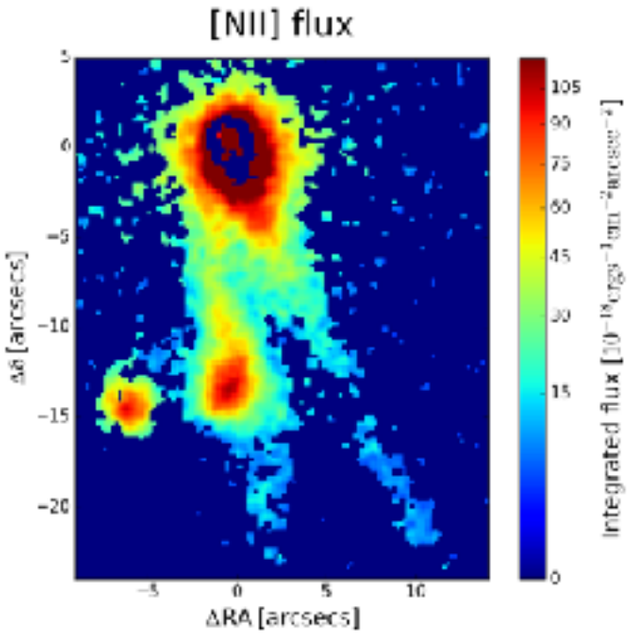
We will propose to observe other 3C radio sources at z>0.3 with VLT/MUSE have a complete and unbiased sample up to higher redshift

The ionized gas structures revealed by MUSE could be only the tip of the iceberg of a much larger amount of colder (atomic and molecular) gas. We have therefore proposed a pilot study to map the H I emission in the three nearest FR II radio galaxies of the MURALES sample with VLA (VLA/18B-084 - Balmaverde, Capetti, Morganti, Oosterloo) and an ALMA proposal to observe CO(1-0) in 3C459

3C79



3C318.1



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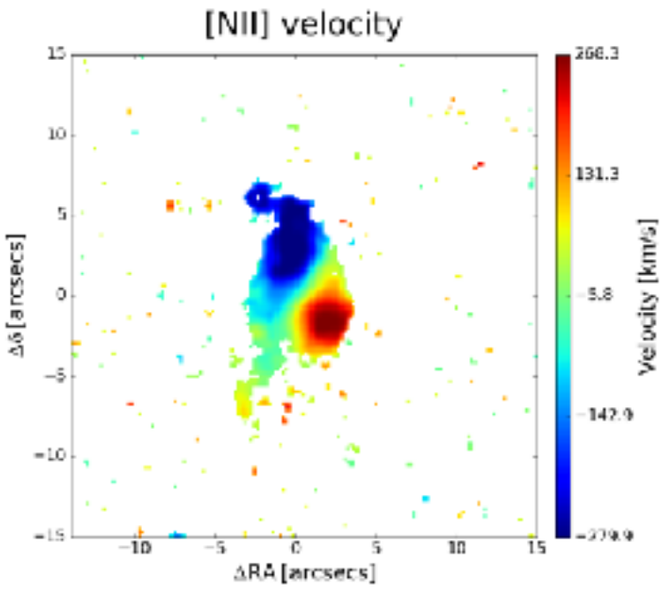

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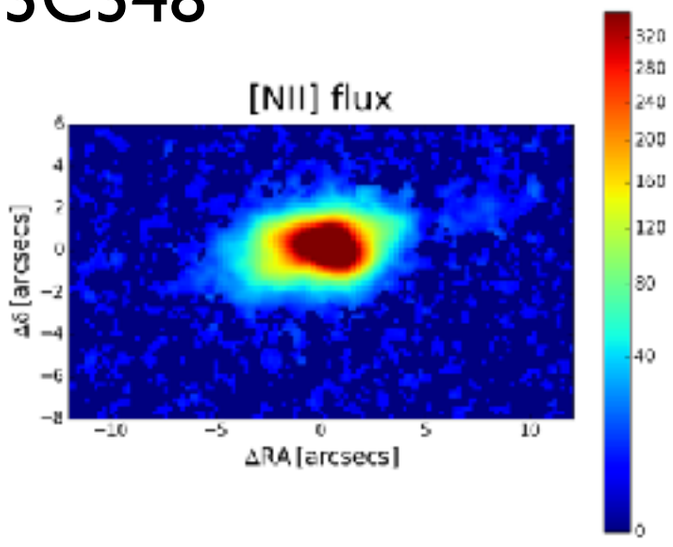

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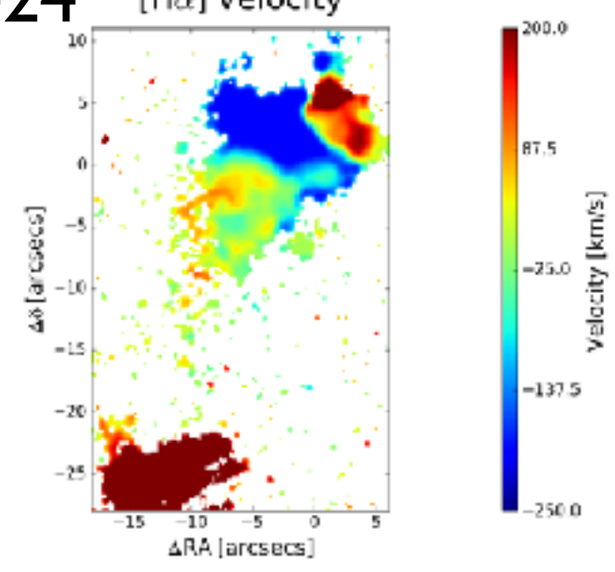

3C272