The

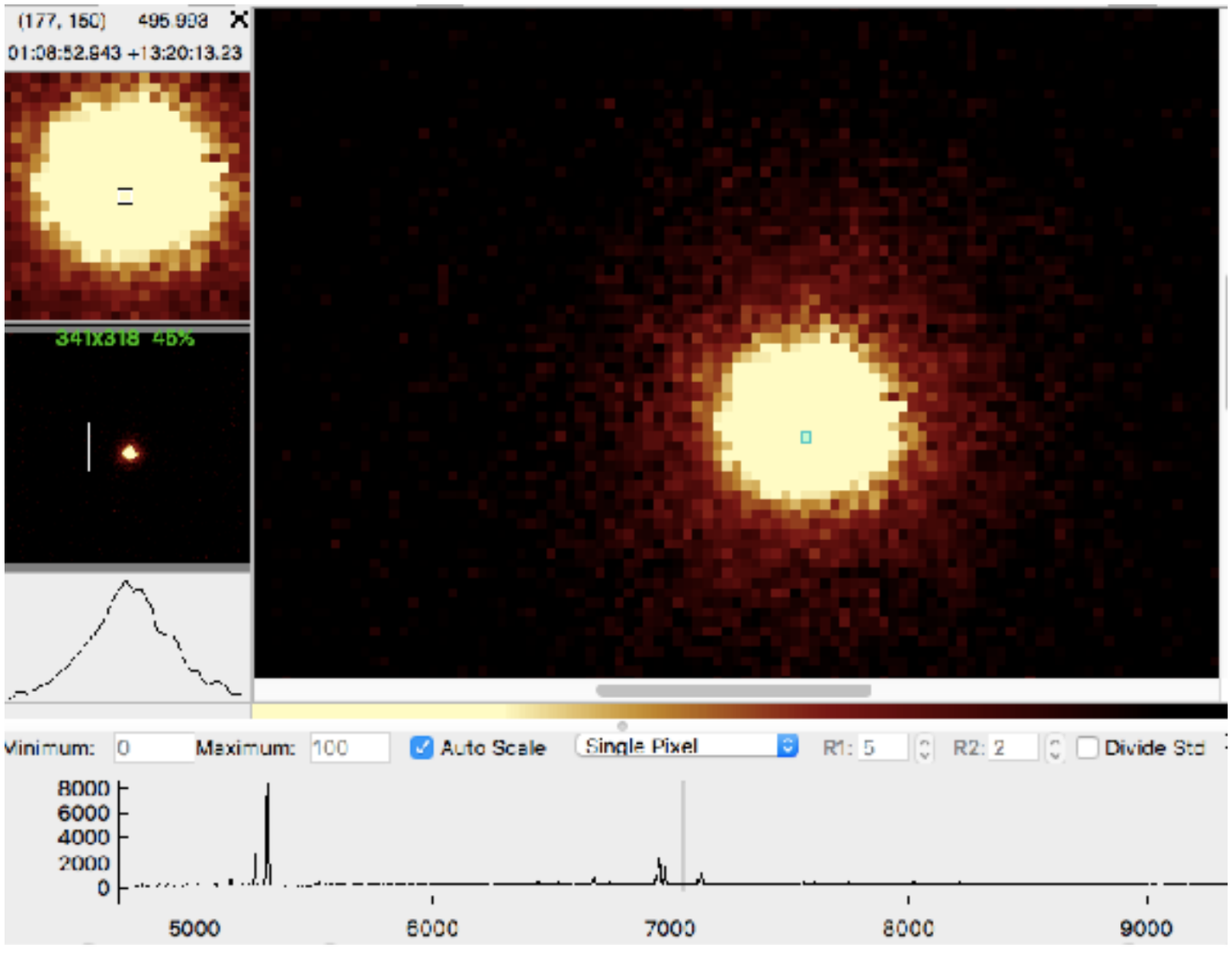
project: a MUse RAdio Loud Emission Snapshot.

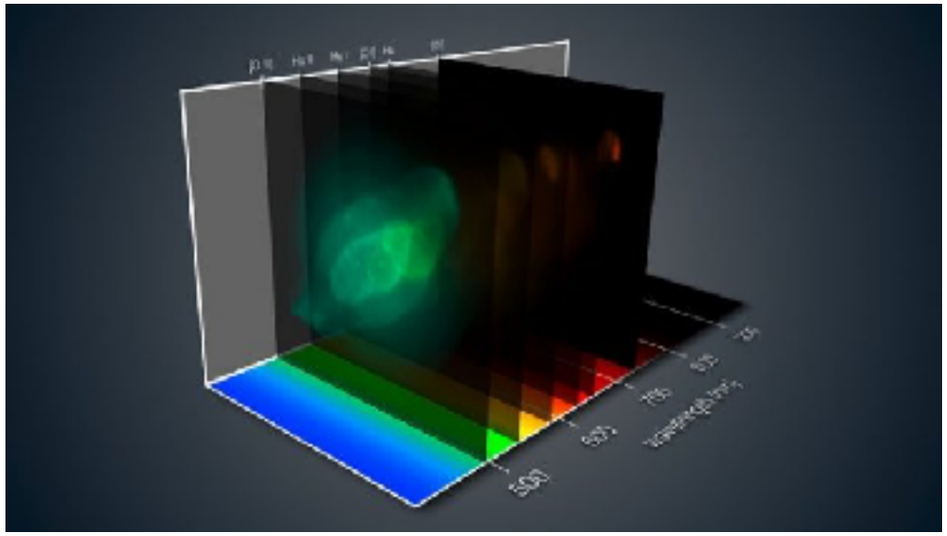
Barbara Balmaverde
INAF - Osservatorio Astronomico di Brera (Italy)

Co-I: **Alessandro Capetti**, Alessandro Marconi, Giacomo Venturi, M. Chiaberge, **R.D. Baldi**, S. Baum, R. Gilli, P. Grandi, E. Meyer, G. Miley, **C. O'Dea**, W. Sparks, E. Torresi, and G. Tremblay

What is MUSE?

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





Credits: ESO/J. Walsh

Overview of the instrument:

Resolution: 0.2 arcsec/pixel

FoV: 1x1 arcmin

R = 1750@465nm to 3750@930nm

Wavelength range = 480-930nm

The MURALES Survey

THE PROJECT:

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

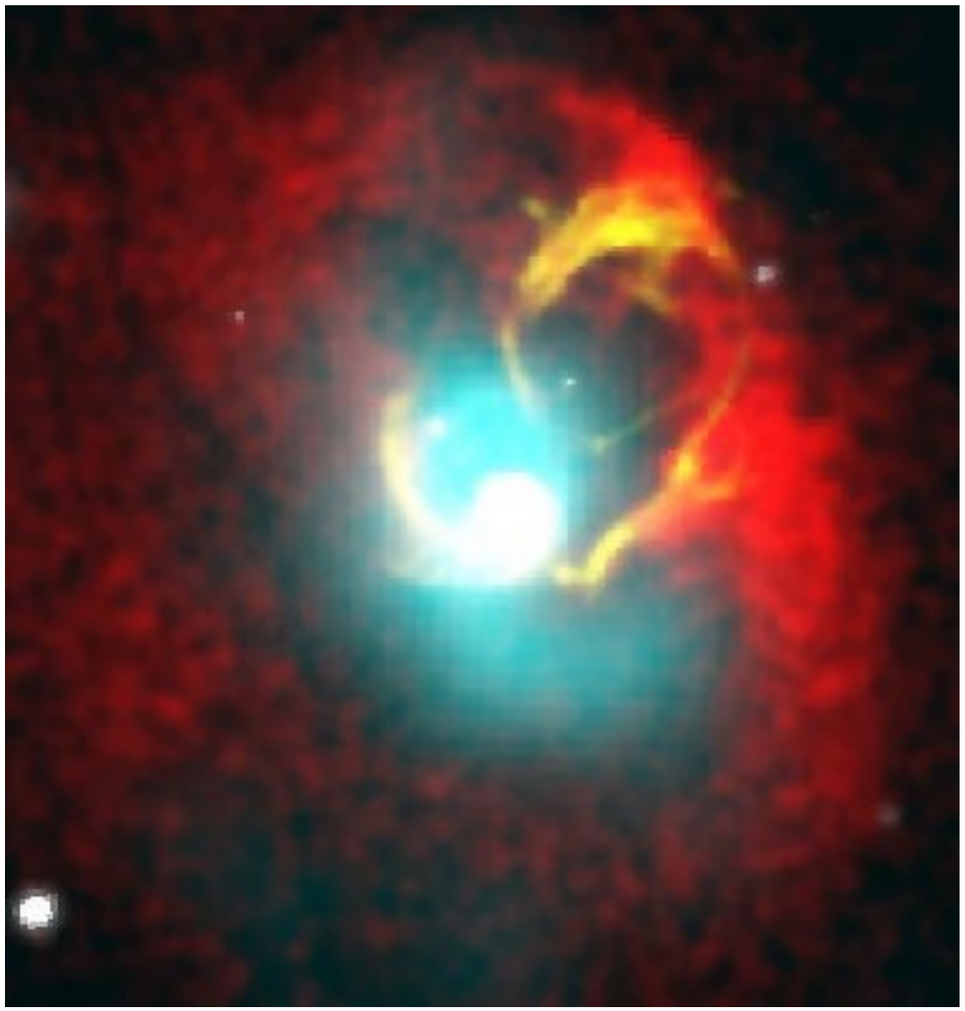
THE SAMPLE:

We selected all the 3C radio galaxies (20 targets) visible from the Southern Hemisphere in the observing semester ($\delta < 20^{\circ}$) at $z<0.3$., both FRI and FRII radiogalaxies.

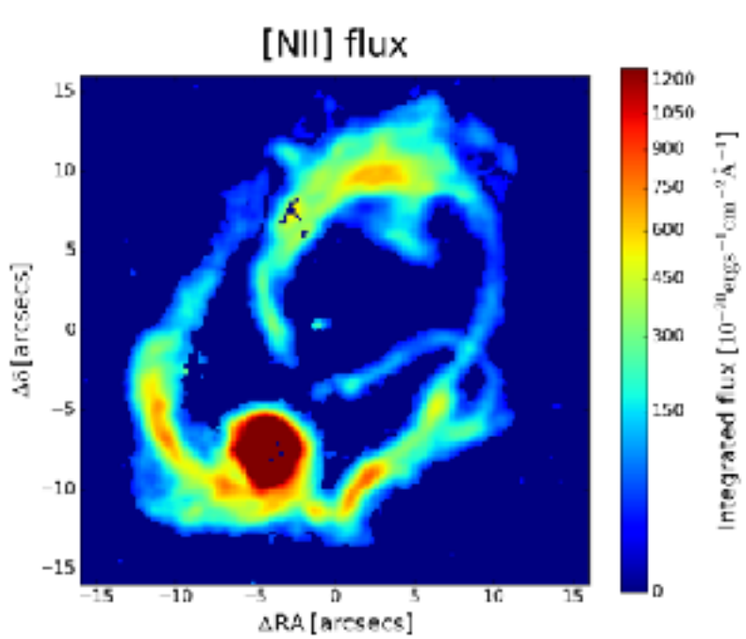
THE AIM:

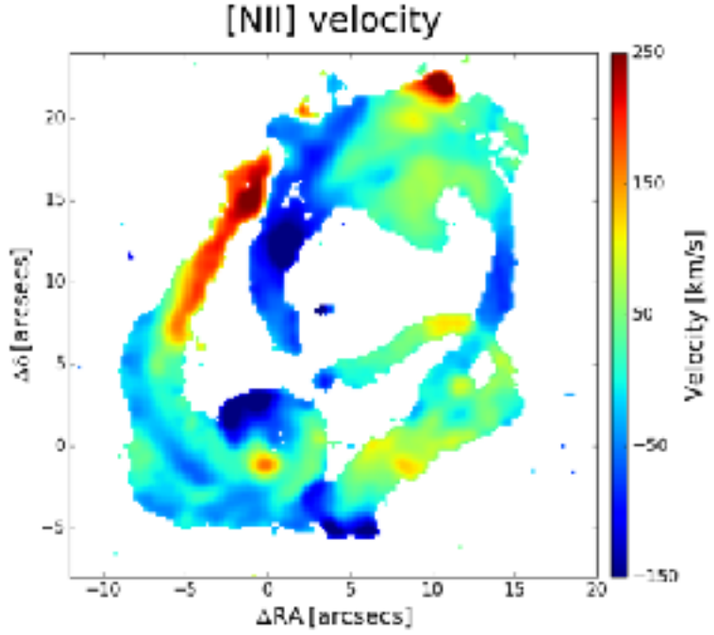
We want to explore the gas kinematics, its relationship with the relativistic outflow and its ionization mechanism, unveiling jet-triggered star forming regions. This will enable us to explore quantitatively the so-called feedback process, i.e. the exchange of energy between these radio loud AGN and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

Our pilot case: 3C317 in Abell 2052 (Balmaverde et al. 2018- arXiv:1801.05435)



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



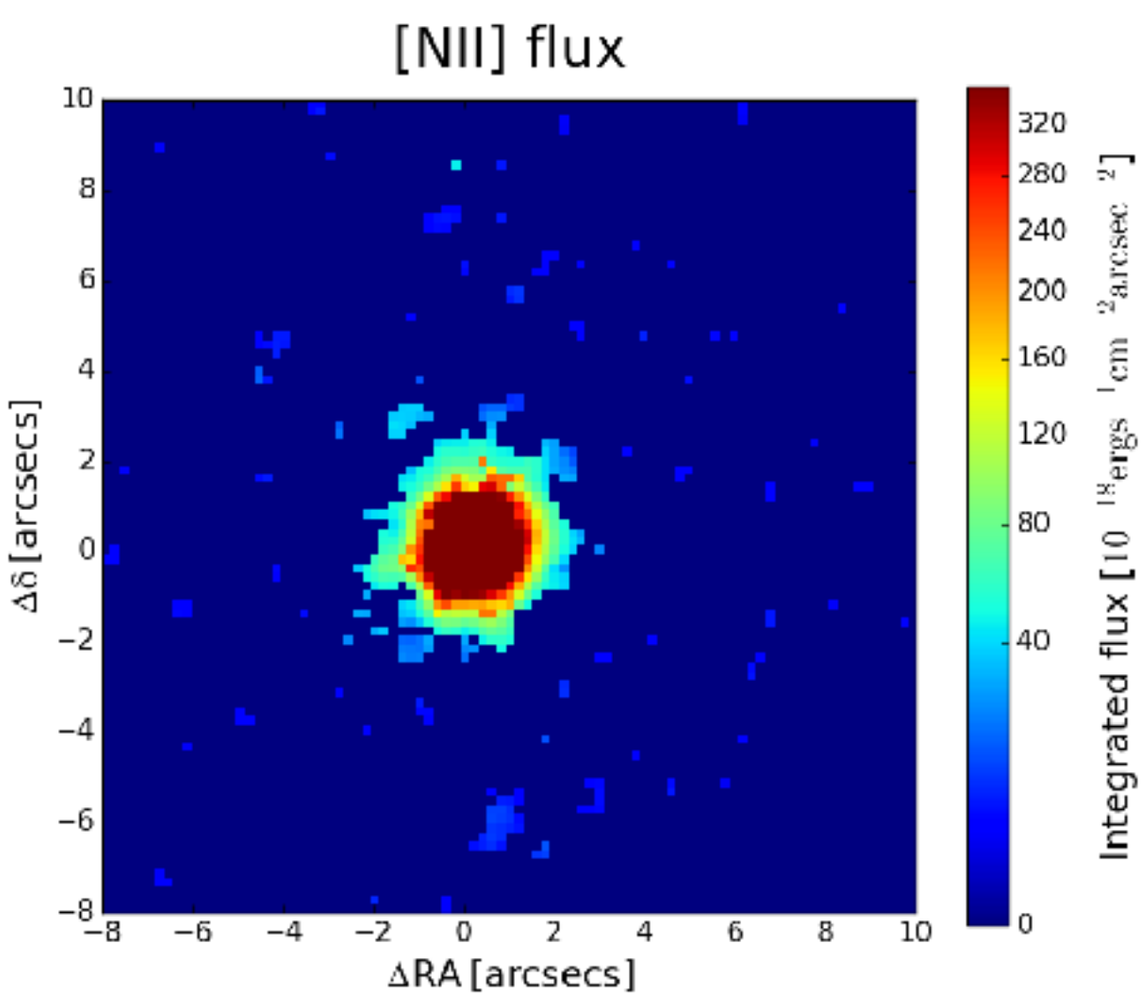


MAIN RESULTS:

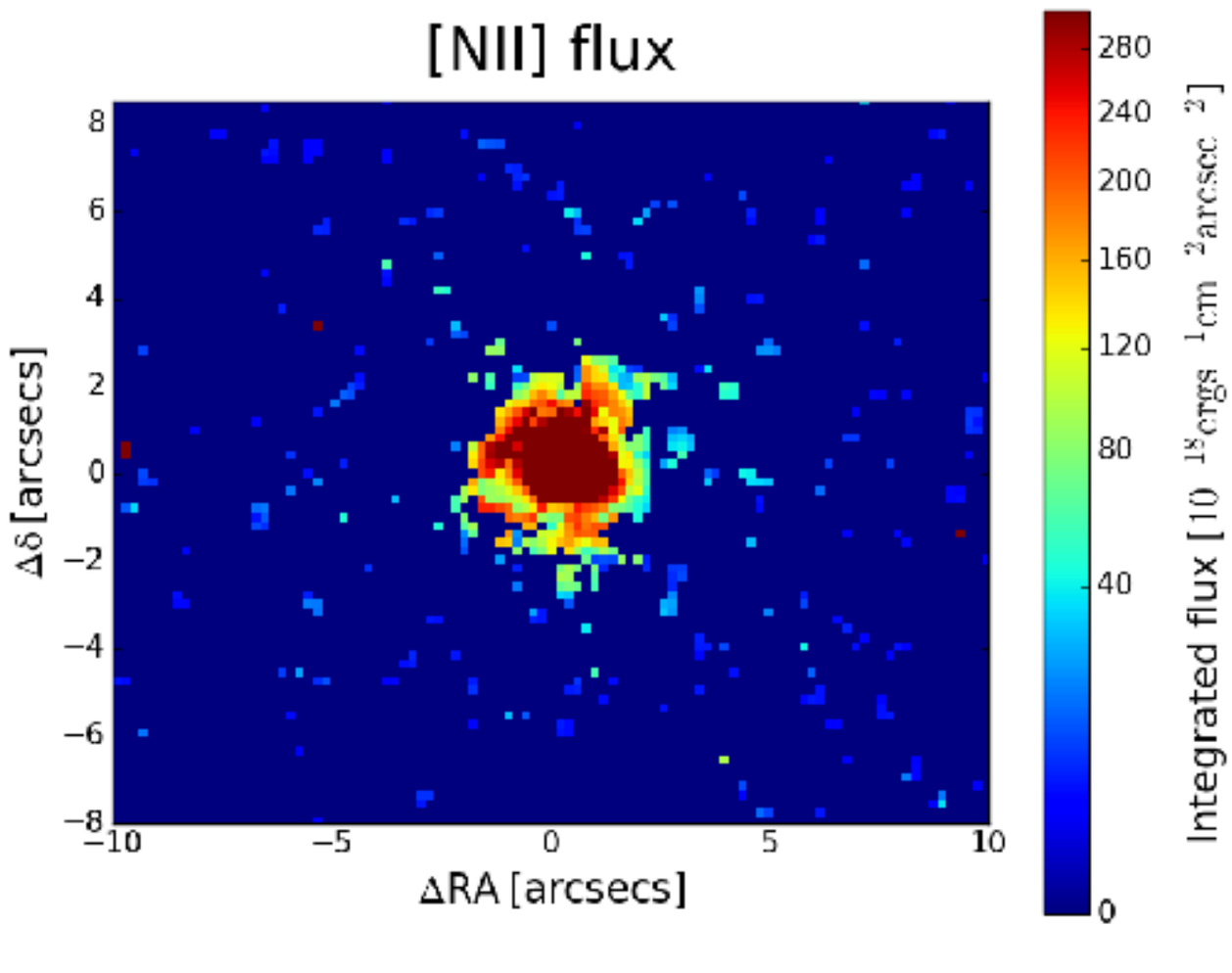
- ✓ We observe a network of emitting line filaments enshrouding the Northern cavity.
- ✓ In the filaments the gas is dense (up to 270 cm-3) and makes up part of a global quasi spherical outflow driven by the radio source.
- ✓ We obtain a direct estimate of the expansion velocity of the cavities (265 km s-1).

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

3C15

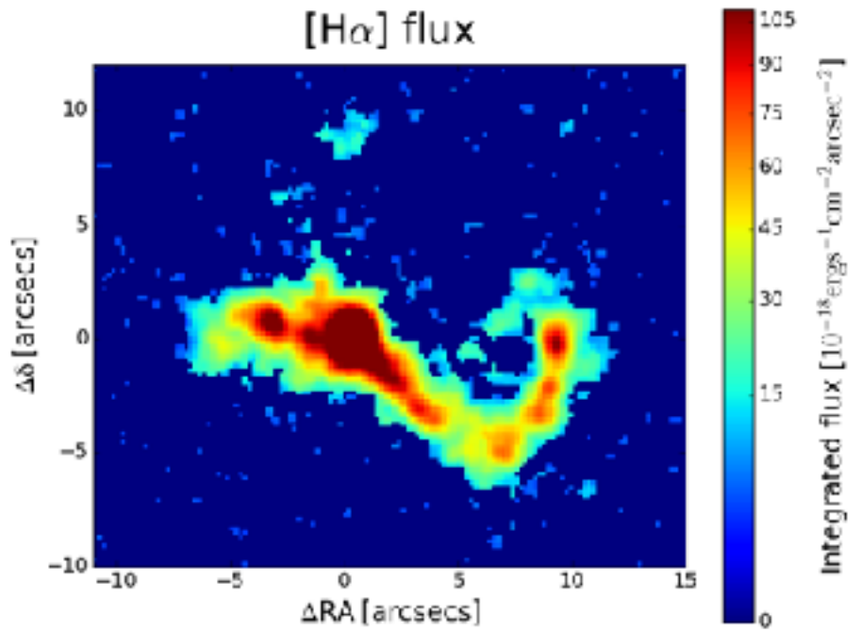


3C29

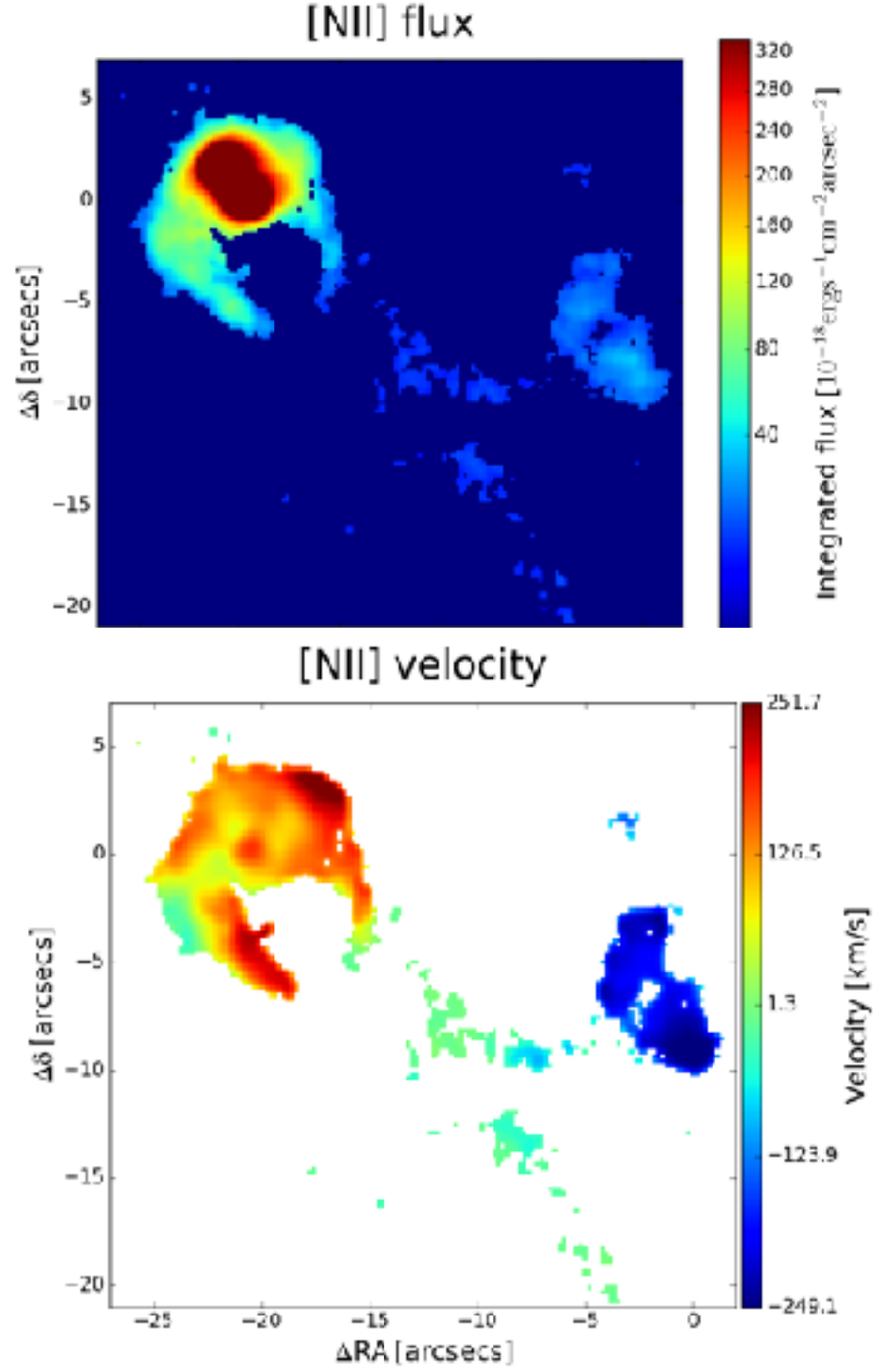


Instead, in the FRII sample we find cavities…

3C63

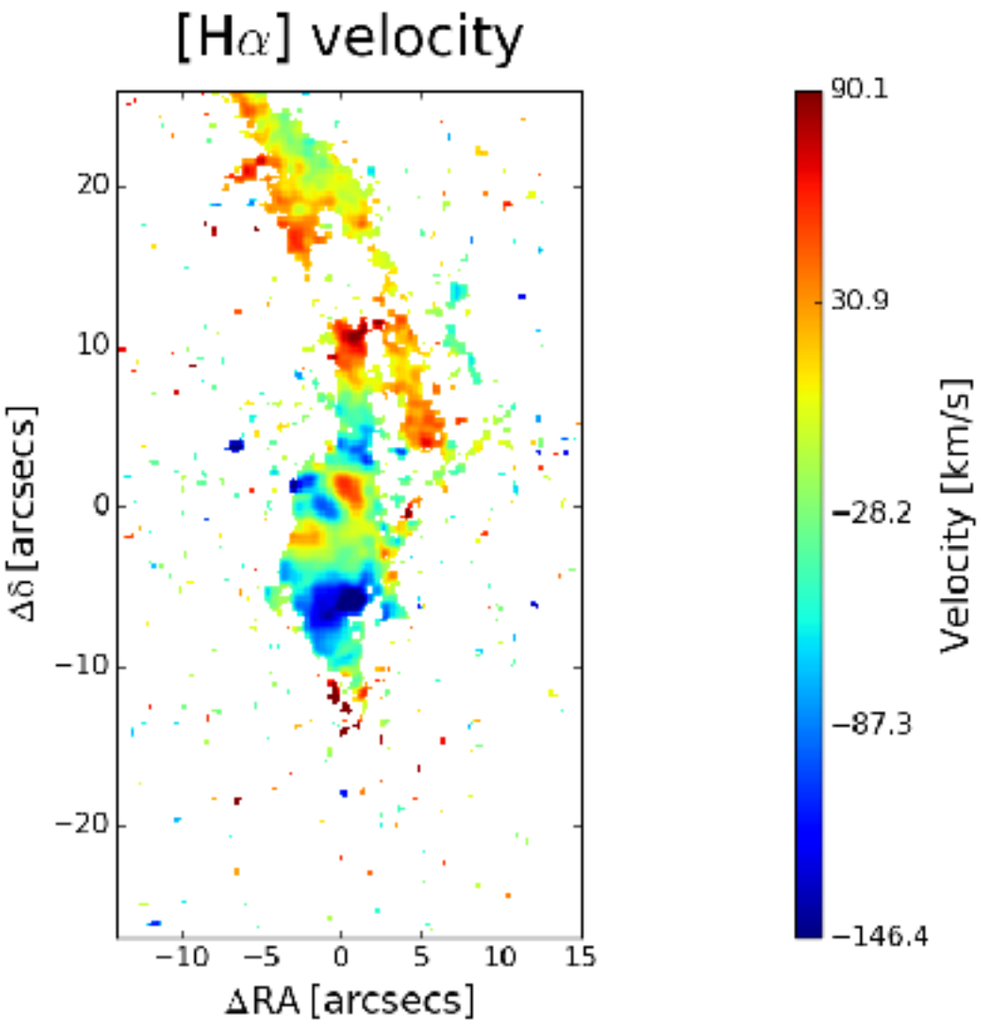


3C442

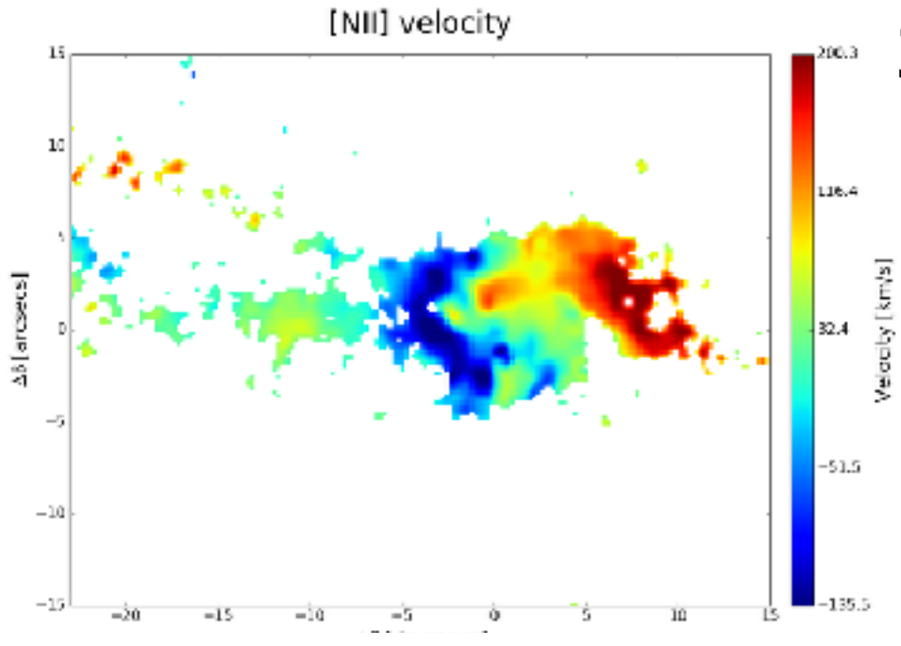


Filaments…

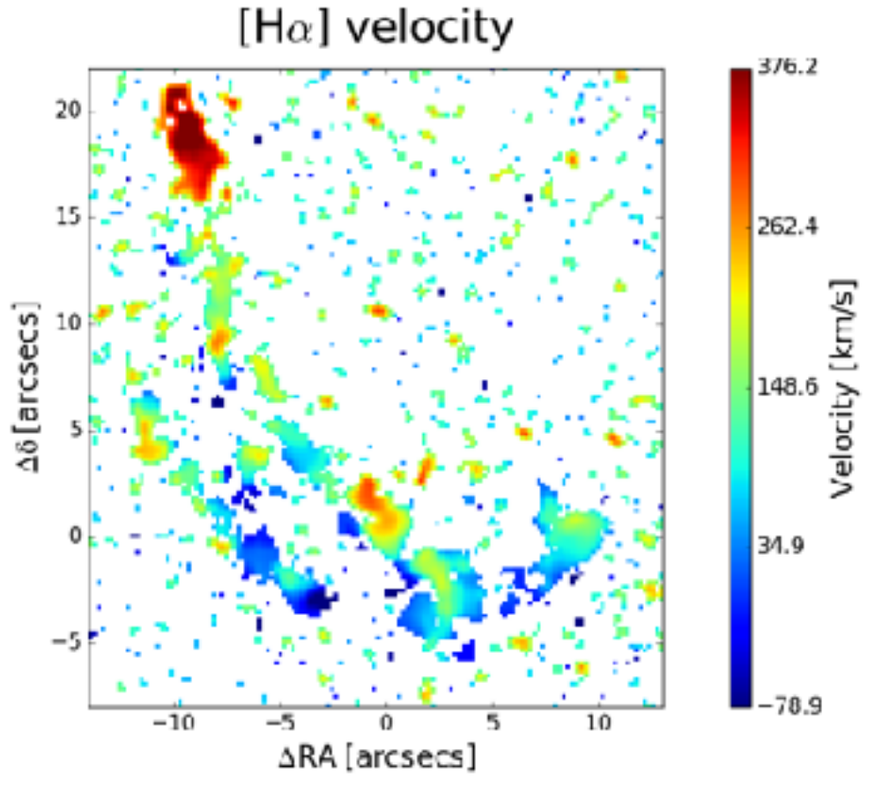
3C353



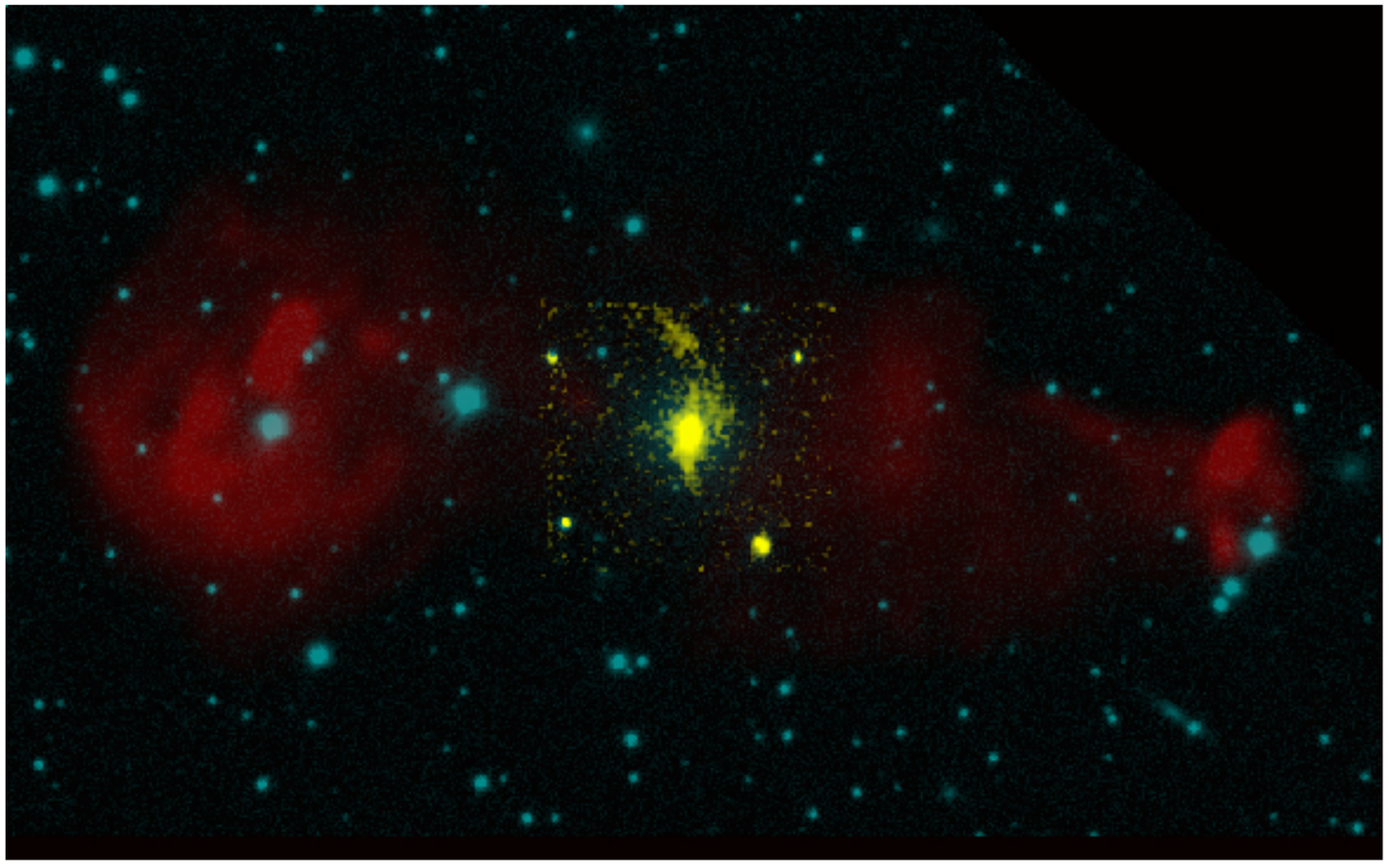
3C386

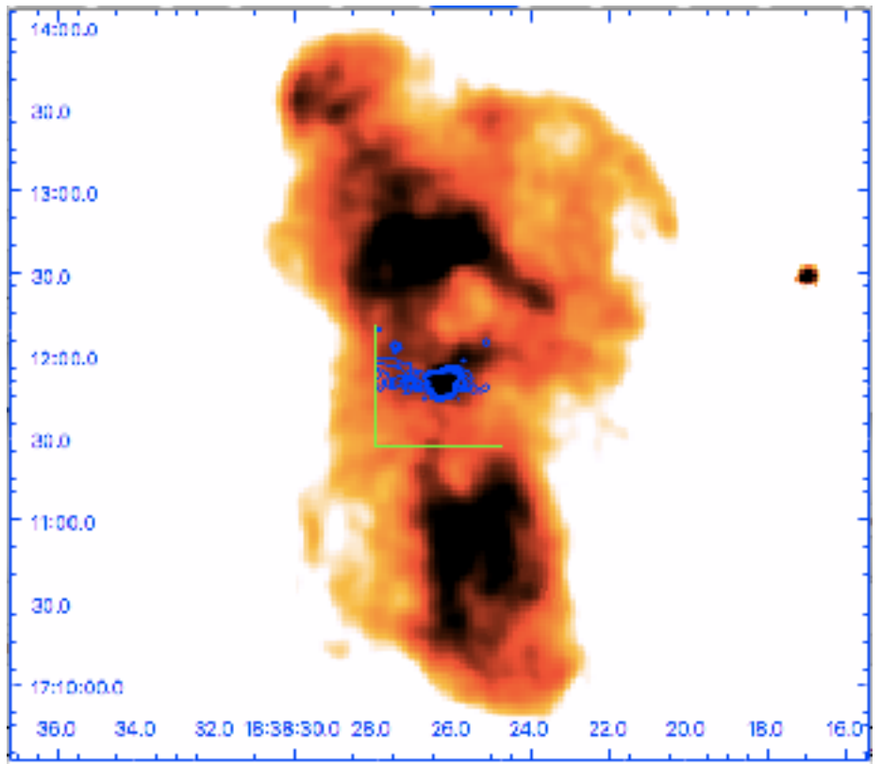


3C458



Filaments…





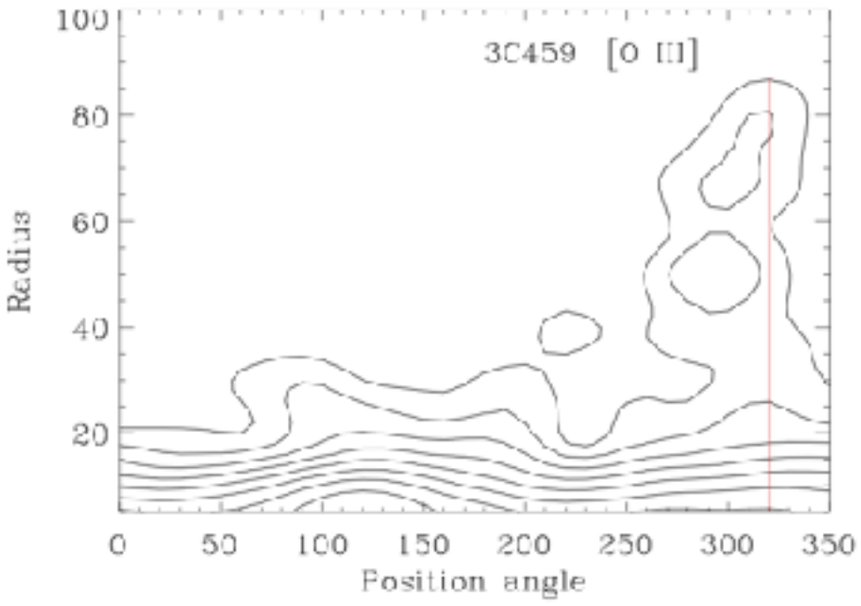
3C353 (left; Radio:red, Continuum: cyan, Line: yellow)

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

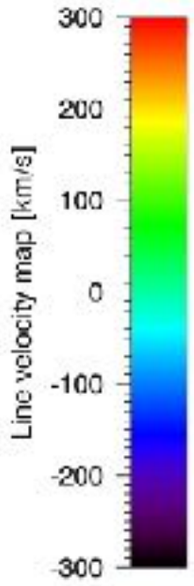
How to describe the filaments?

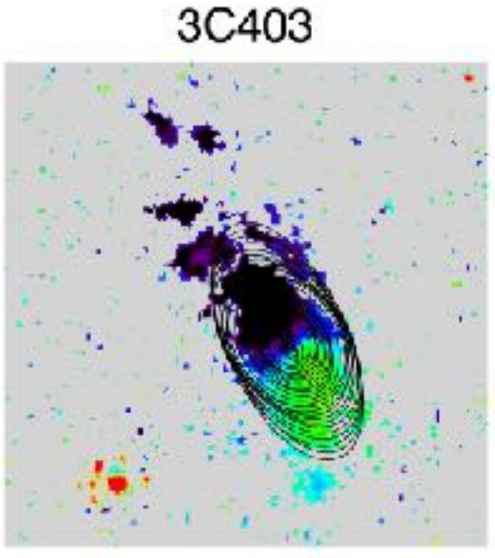
We used the software "kinemetry" (Krajnovic+05) to measure the "kinematic" PA of the emitting line disk, determining the best fitting ellipses along which the profiles of the velocity can be extracted assuming a cosine law. We measure instead the direction of the filaments measuring the brightness in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

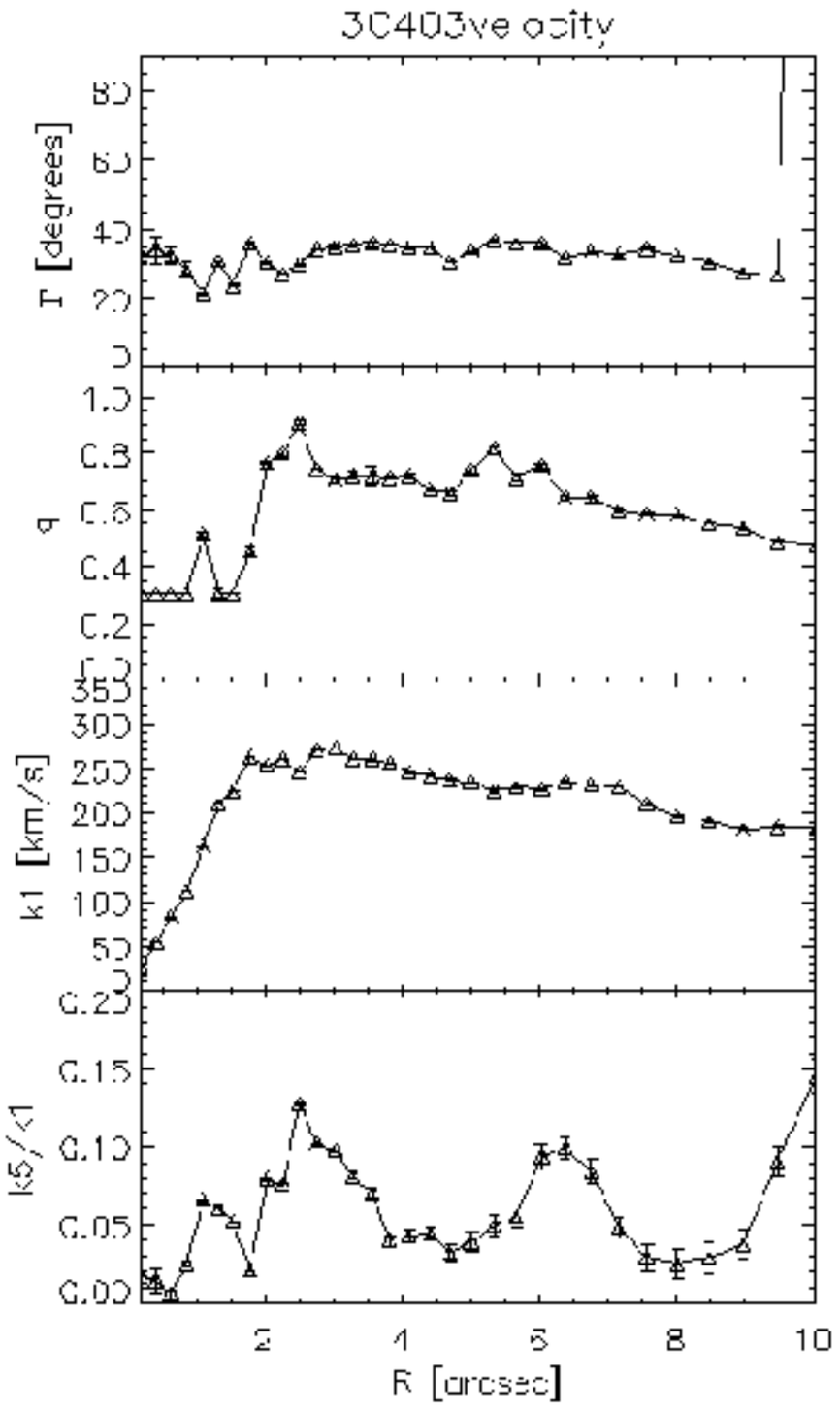
Morphological analysis on extended scales



Kinematic analysis on inner scales







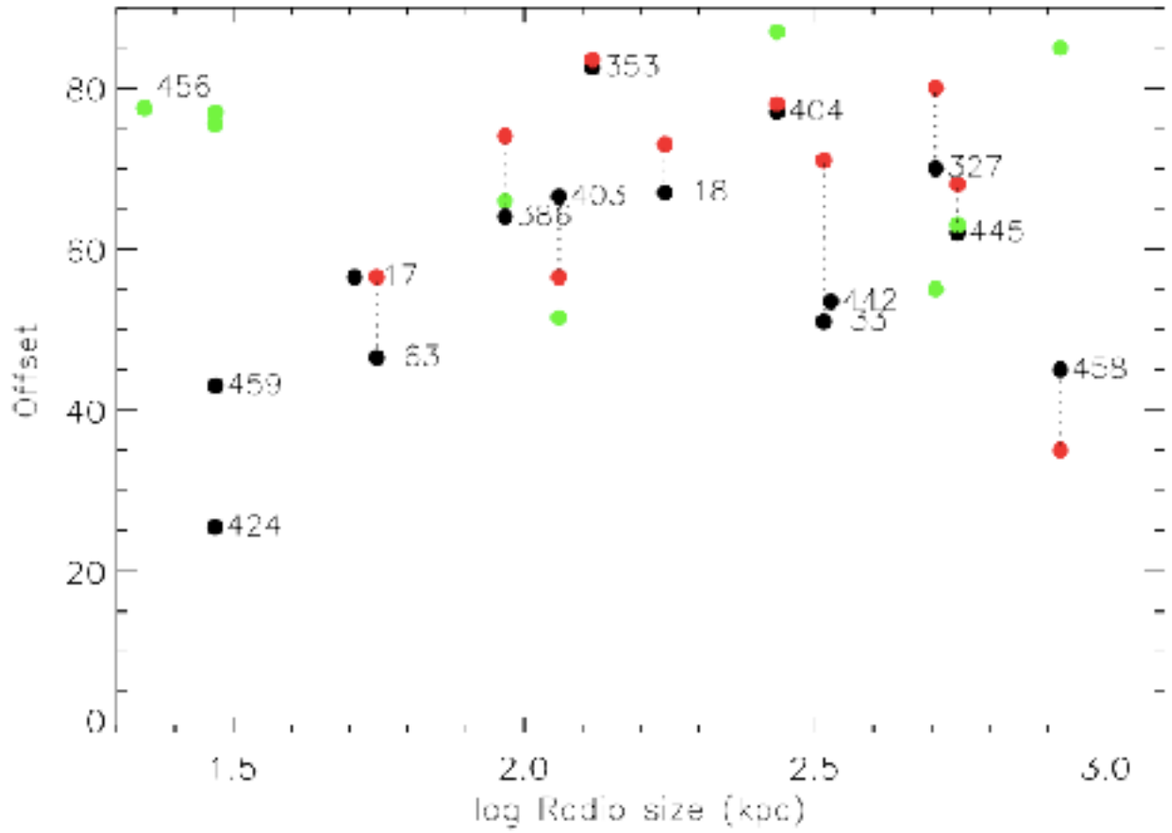
MAIN RESULTS:

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

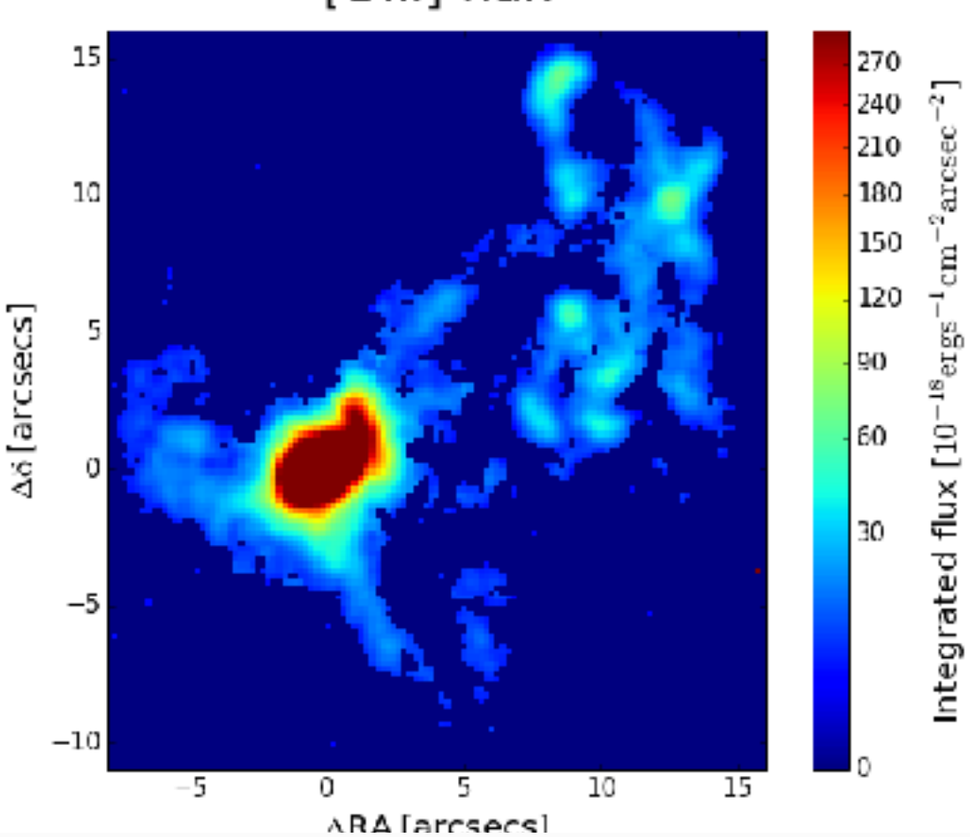
✓ These filaments are extended for several tens of kpc, are preferentially oriented perpendicularly to the radio jets.

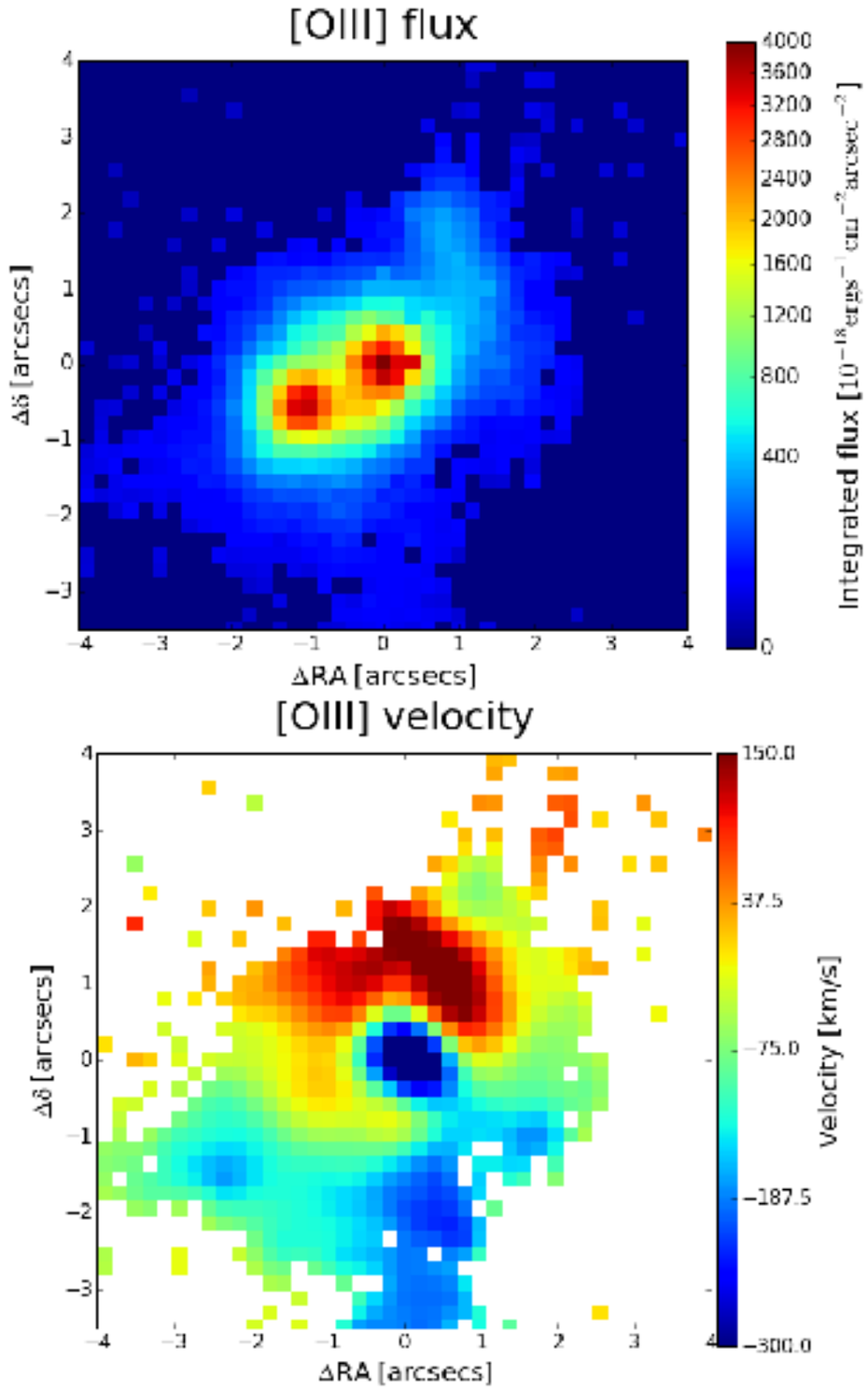
✓ The geometrical connection between the structure of ionized gas and the radio jets supports the connection between mergers and nuclear activity.

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



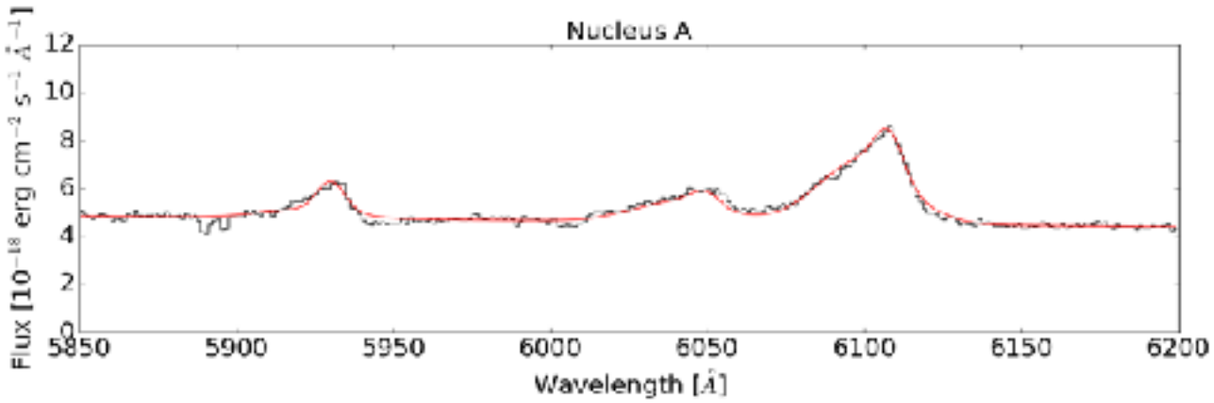
A binary black holes in 3C459?...

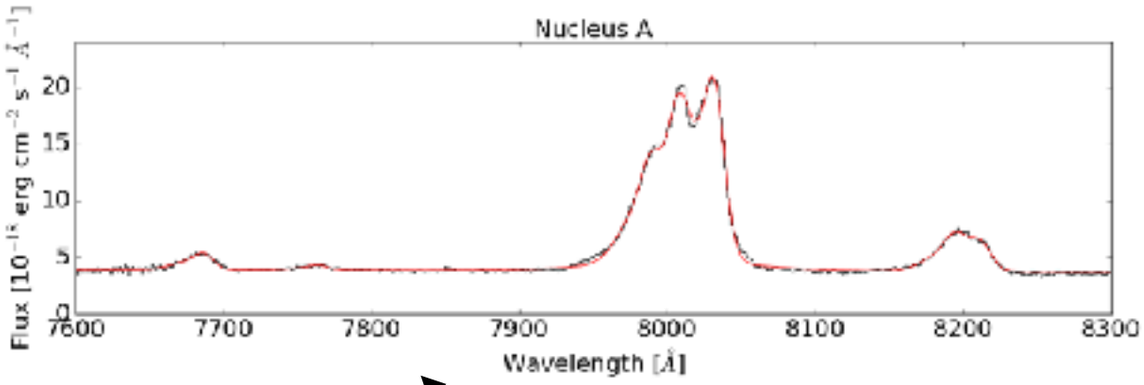


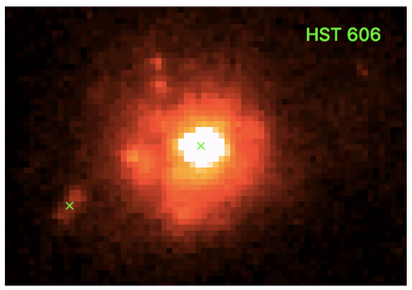


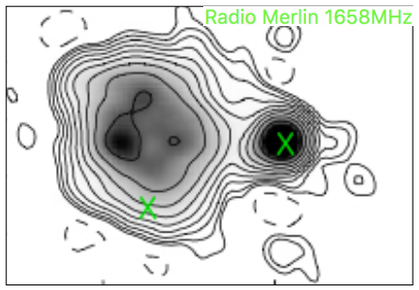
- ✓ The central emission line region is dominated by two compact knots: the first cospatial with the radio core, the second located 1.2 (5.3 kpc) to the SE.
- ✓ The two regions have velocity (Dv~300 km/s), line widths, and line ratios.

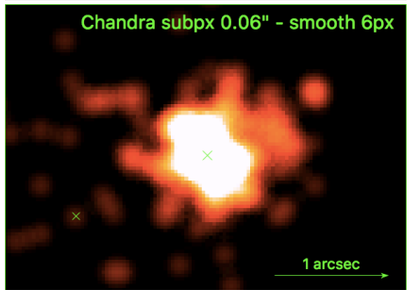
The eMORALZS Survey

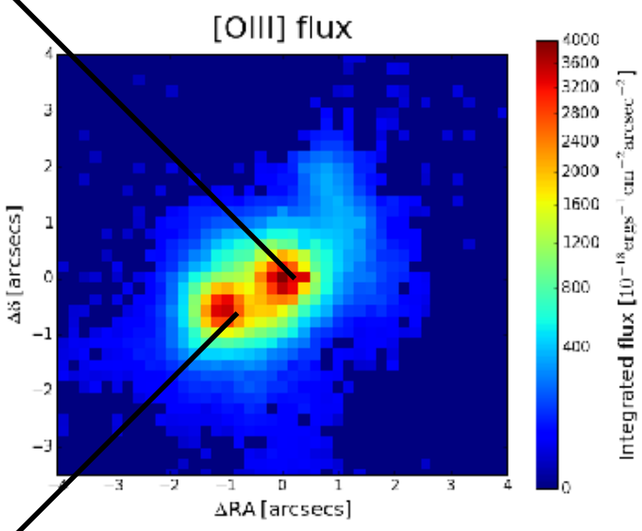


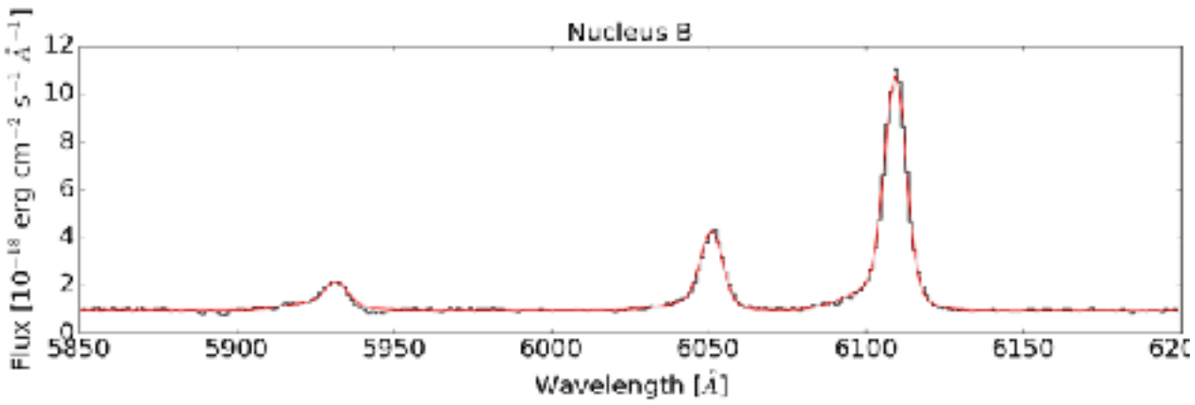


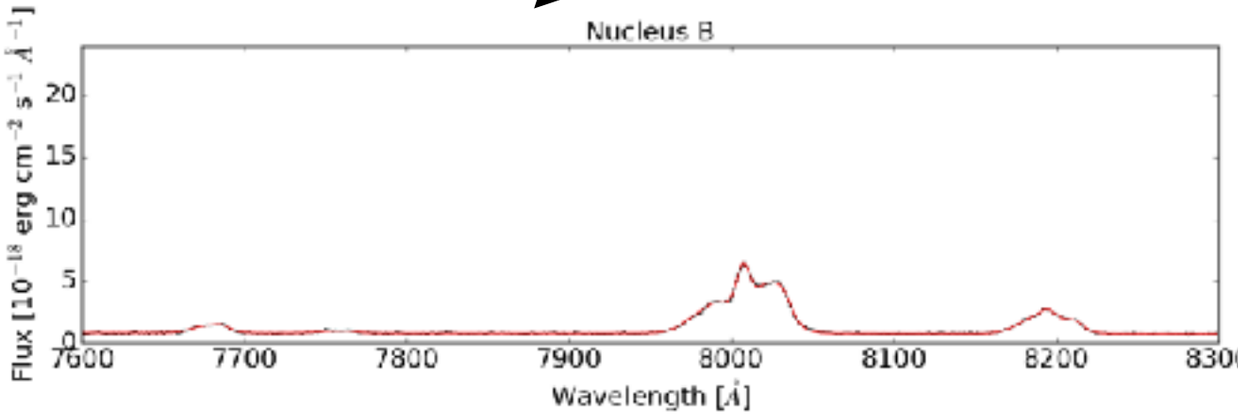


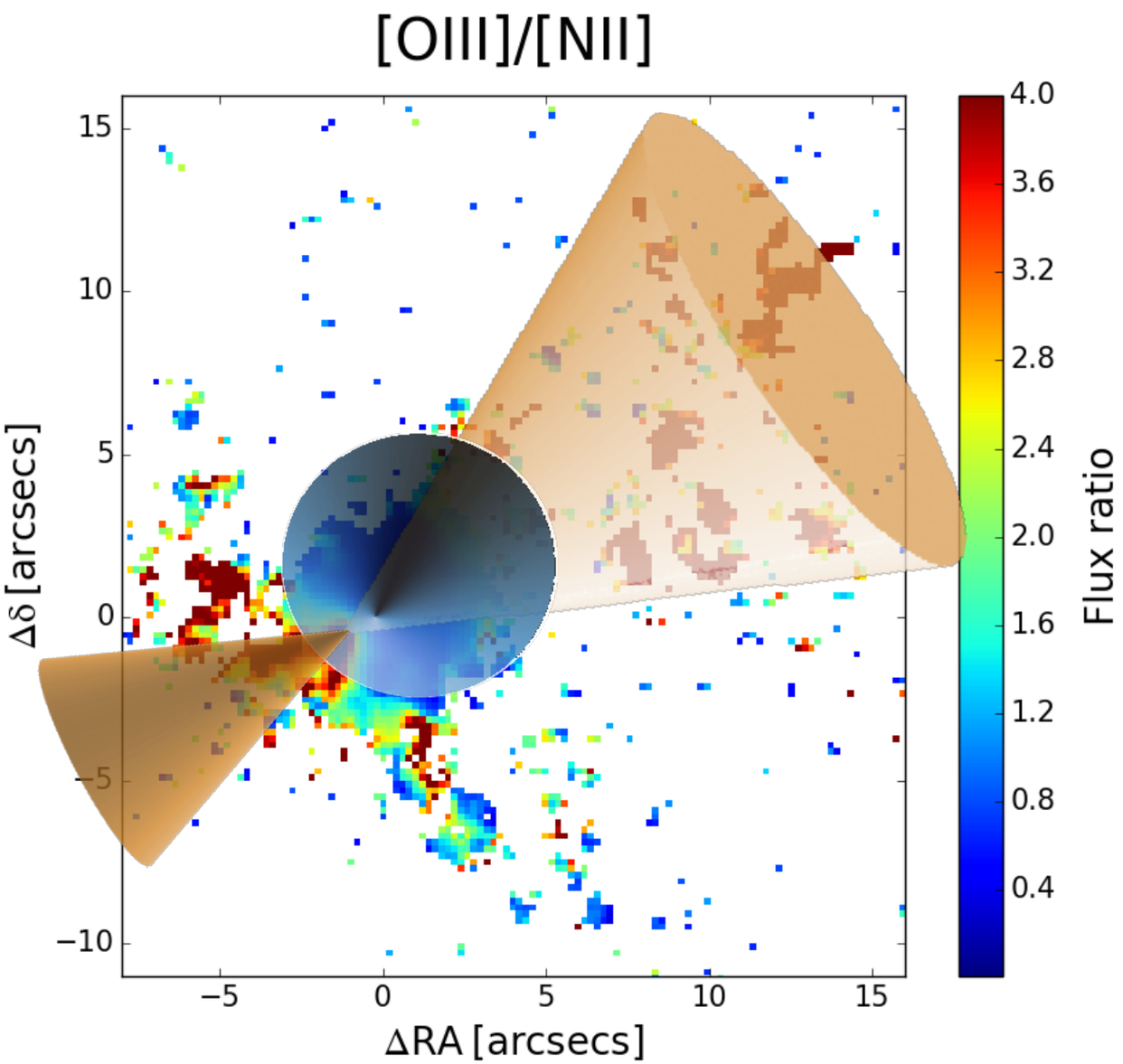












MAIN RESULTS:

✓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.

Balmaverde et al. 2018 in preparation.

Summarizing…

For the project MURALES we have observed with MUSE 20 3C radio galaxies at z<0.3.

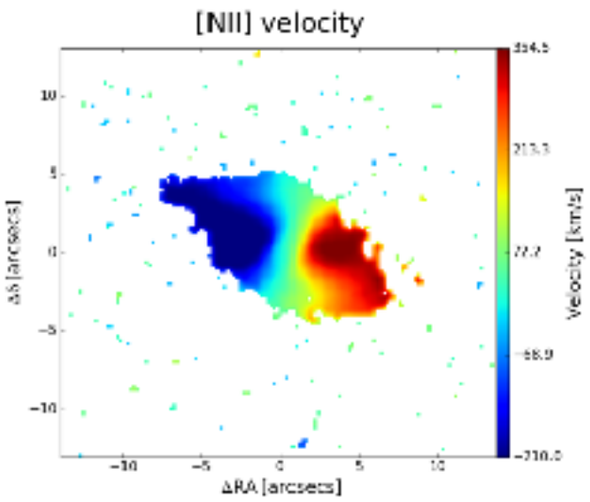
The line emission images of unprecedented depth revealed the widespread presence of filamentary structures extending several tens of kpc in all but one FRII (the FRI are preferentially compact), oriented almost perpendicularly to the radio jets, likely the remnants of the gas rich mergers which triggered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

For the future…

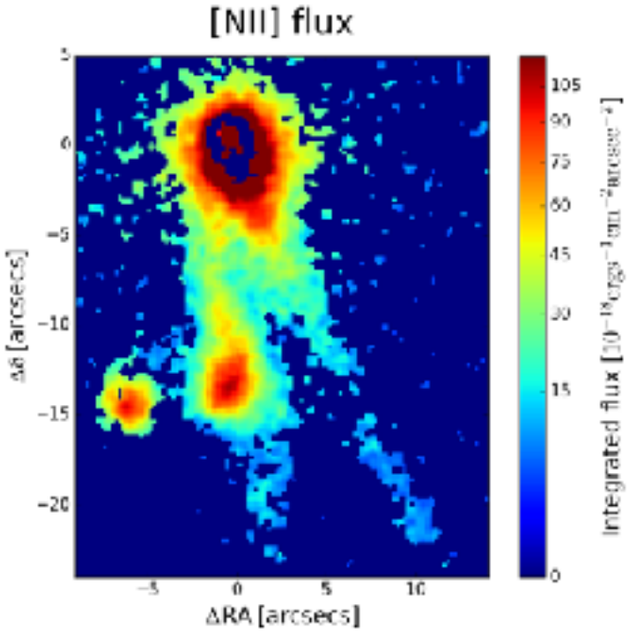
We will propose to observe all the remaining 20 3C radio sources at z<0.3 and δ < 20 degree with VLT/MUSE have a complete and unbiased sample, to constrain the occurrence of merging signatures in FRII radio galaxies.

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)

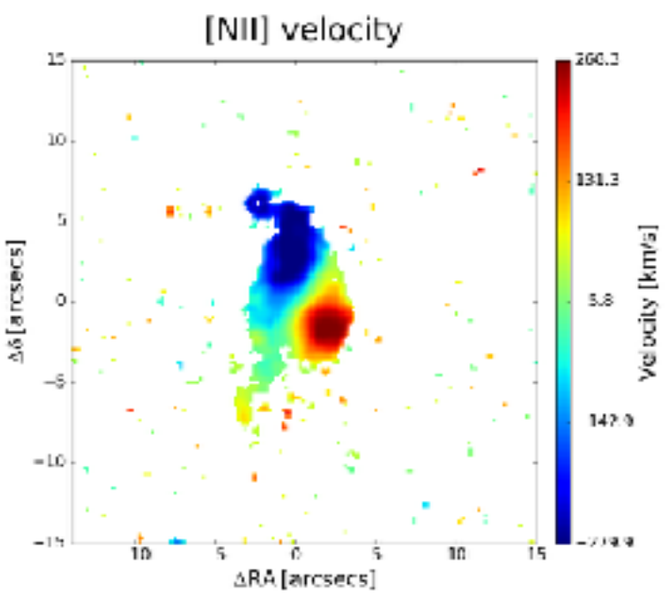
3C33



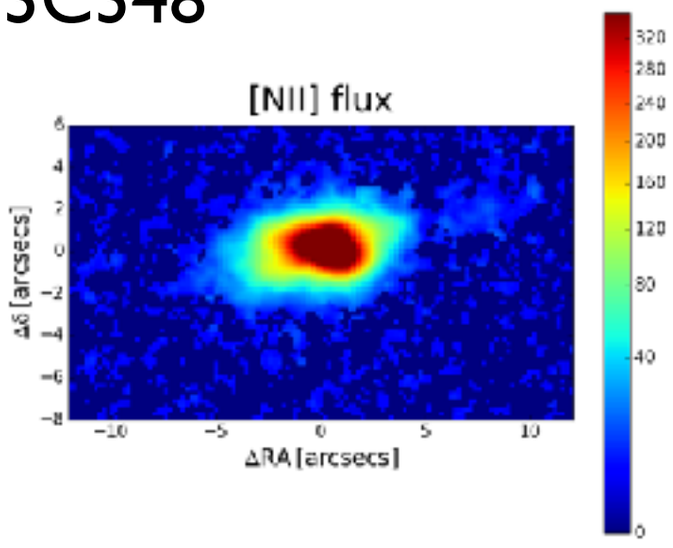
3C318.1



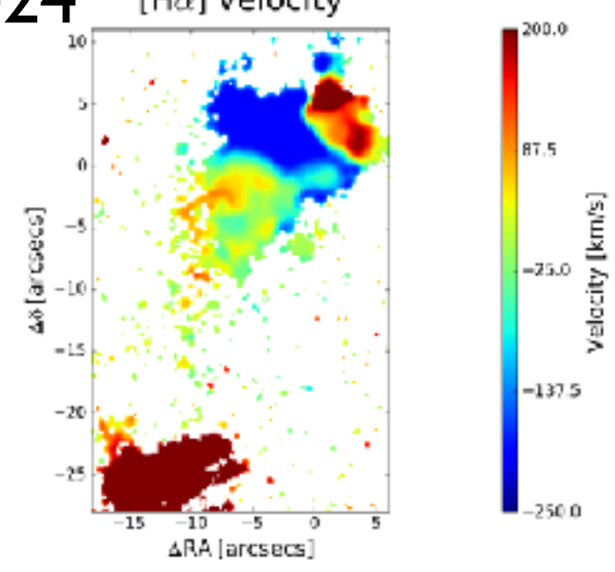
3C327



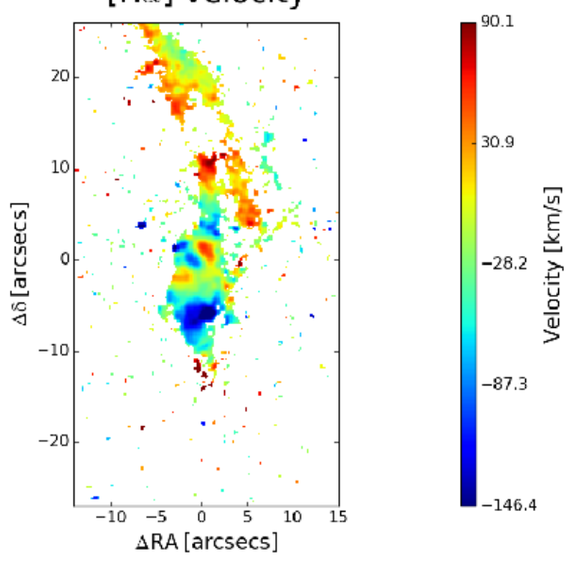
3C348



3C424



3C353



ADDITIONAL MATERIAL

Log of the observations

Name	RA	DEC	z	Release Date	Exp.Time	Type
3C015	00:37:04.15	-01:09:08.1	0.074	2017-06-30	1624	LEG
3C017	00:38:20.5	-02:07:41	0.22	2017-07-20	1200	FR2 / BLO
3C018	00:40:50.51	+10:03:27.7	0.19	2017-06-30	1200	FR2 / BLO
3C029	00:57:34.88	-01:23:27.6	0.045	2017-07-20	1200	FR1 / LEG
3C033	01:08:53.21	+13:20:14.5	0.06	2017-06-30	1200	FR2 / HEG
3C040	01:26:00.95	-01:20:42.4	0.018	2017-07-22	1200(+600 sky)	FR1 / LEG
3C063	02:20:54.20	-01:56:52.0	0.175	2017-07-21	1200	HEG
3C318.1	15:21:52.18	+07:42:29.7	0.04	2017-06-22	1200	?
3C327	16:02:27.40	+01:57:55.5	0.10	2017-06-22	1200	FR2 / HEG
3C346	16:51:08.1	+04:59:33s	0.155	2017-07-20	2766 (mosaic)	ELEG
3C353	17:20:28.49	-00:58:47.1	0.03	2017-06-29	1200	FR2 / LEG
3C386	18:38:34.98	+17:11:47.9	0.017	2017-06-03	1200(+600 sky)	?
3C403	19:52:16.14	+02:30:24.4	0.06	2017-06-30	1200	FR2 / HEG
3C403.1	19:52:30.50	-01:17:21.0	0.05	2017-06-30	1800	LEG
3C424	20:48:12.12	+07:01:17.5	0.13	2017-06-30	1200	LEG
3C442	22:14:47.22	+13:50:27.2	0.03	2017-06-30	1200(+600 sky)	LEG
3C445	22:23:49.57	-02:06:13.1	0.05	2017-06-30	1200 (X2?)	FR2 / BLO
3C456	23:13:38.11	+00:10:33.6	0.23	2017-06-30	1200	FR2 / HEG
3C458	23:12:52.09	+05:16:50.6	0.289	2017-07-22	1200	FR2 / HEG
3C459	23:16:35.26	+04:05:19.3	0.22	2017-07-22	1200	FR2 / BLO
3C075N*	02:57:41.57	+06:01:29.0	0.023			FR1
3C270*	12:19:23.2	+05:49:31	0.007			FR1 / LEG
3C273*	12:29:06.69	+02:03:12.3	0.16			BLO
3C274*	12:30:49.4	+12:23:28	0.004			FR1 / LEG
3C317*	15:15:44.5	+07:01:18	0.034			LEG
3C346*	16:43:48.49	+17:15:50.6	0.16			FR2

Offset Position angle radio-emitting line gas