

*The*



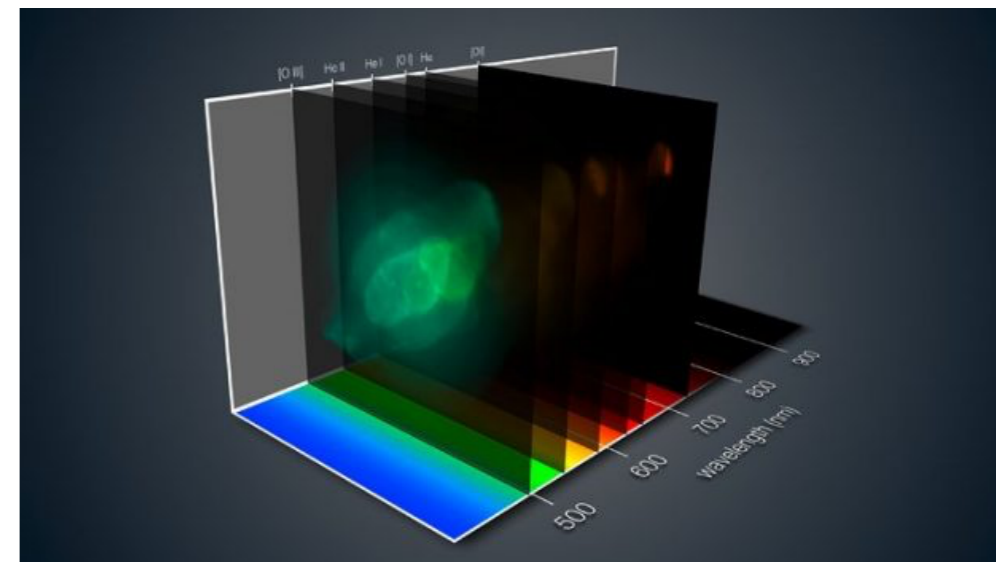
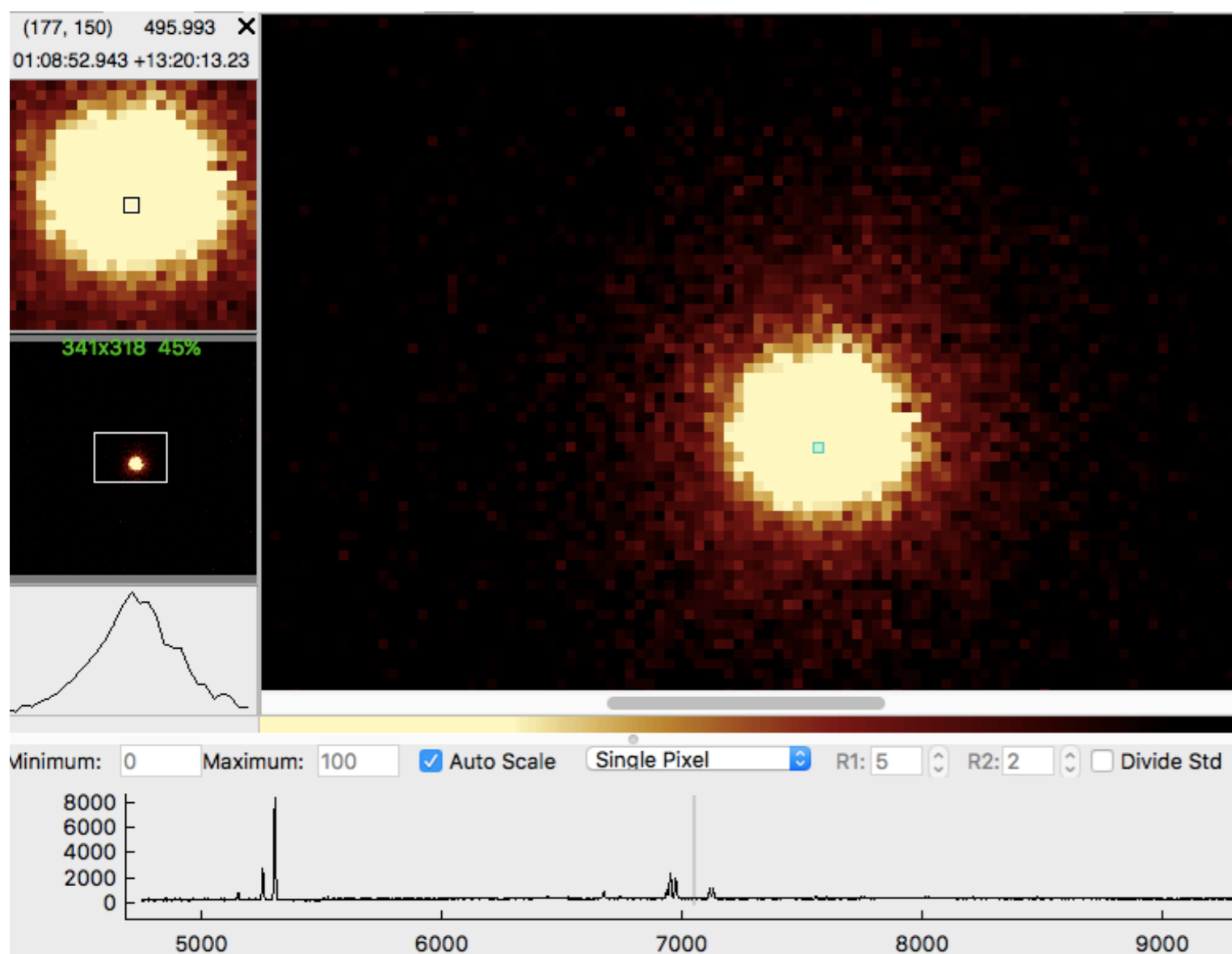
*project: a MUse Radio Loud Emission Snapshot.*

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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

$R = 1750@465\text{nm}$  to  $3750@930\text{nm}$

Wavelength range = 480-930nm



## THE PROJECT:

MURALES is a Muse Radio Loud Emission lines Snapshot survey. We have been awarded in of ~30 hours of observations with the integral field MUSE at VLT to observe 40 radio galaxies in a snapshot mode (~20 minutes on source). Half of the sample has been already observed and analysed.

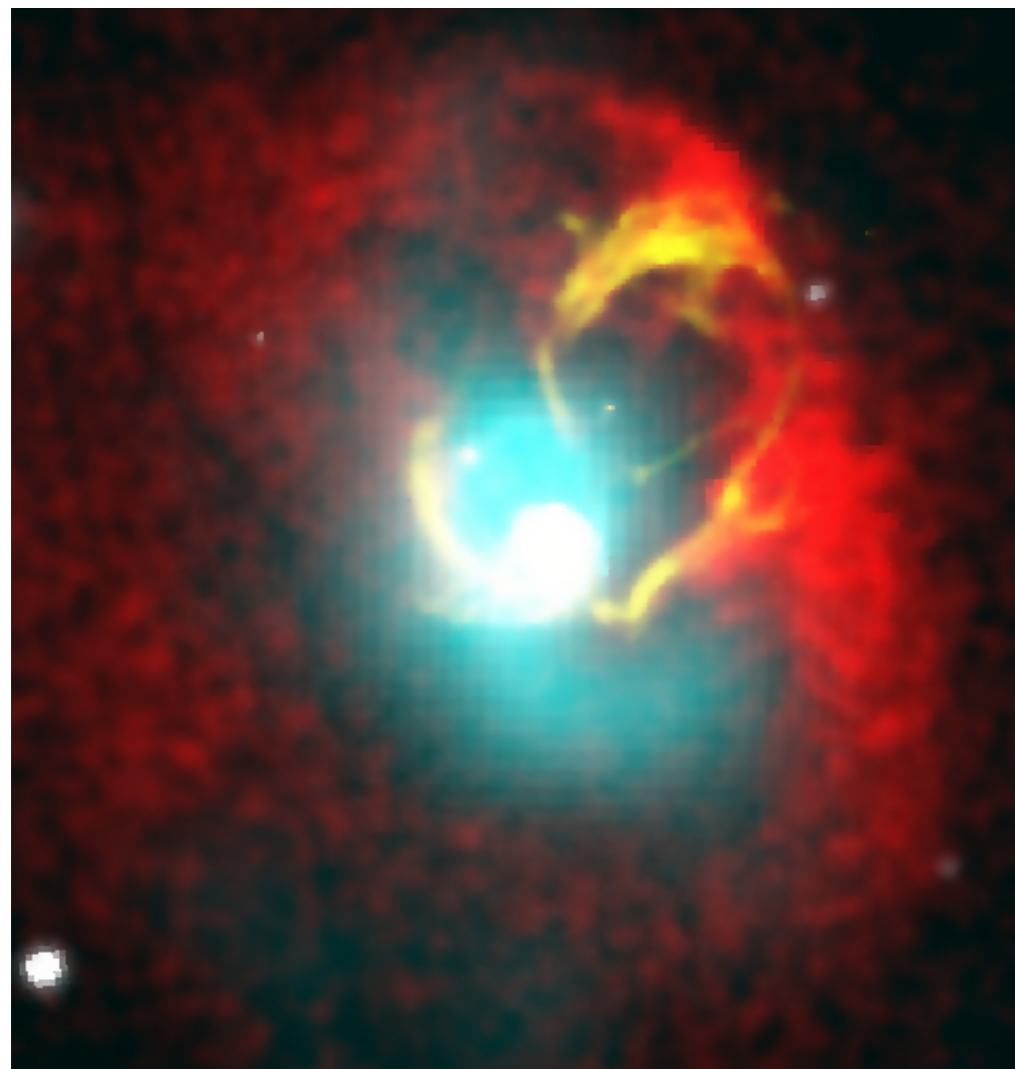
## THE SAMPLE:

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.

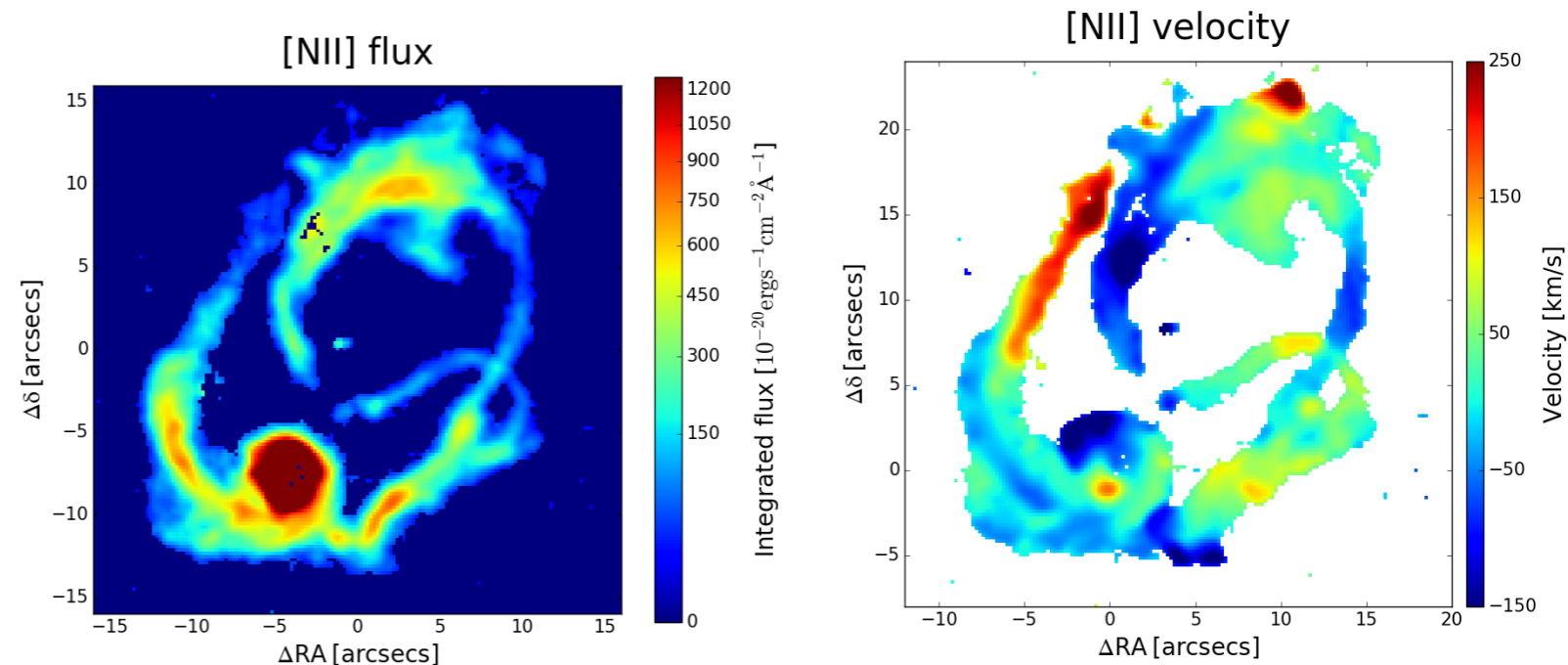
## THE AIM:

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.

## 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.

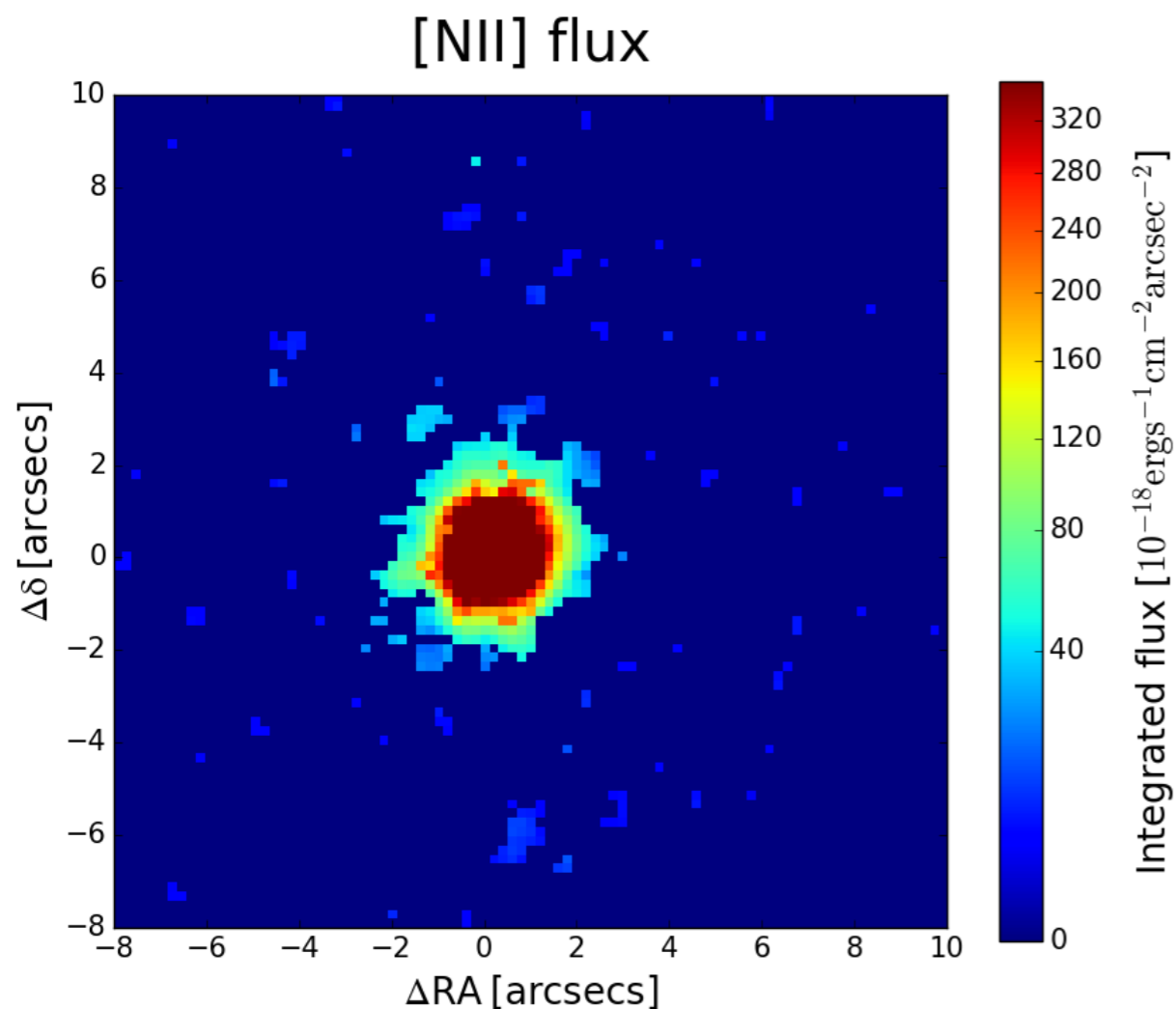


### MAIN RESULTS:

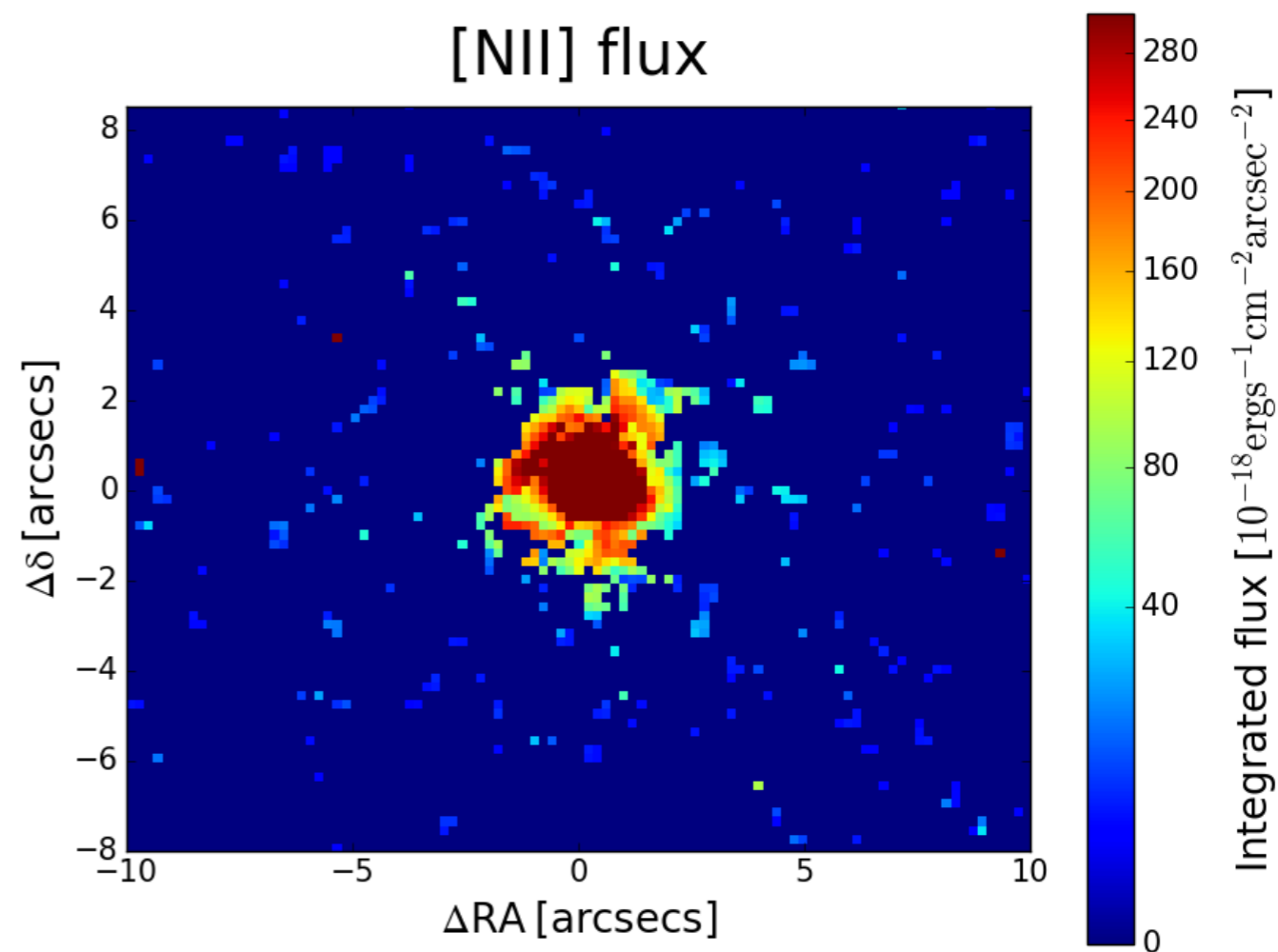
- ✓ We observe a network of emitting line filaments enshrouding the Northern cavity.
- ✓ In the filaments the gas is dense (up to  $270 \text{ cm}^{-3}$ ) and makes up part of a global quasi spherical outflow driven by the radio source.
- ✓ We obtain a direct estimate of the expansion velocity of the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

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

3C15



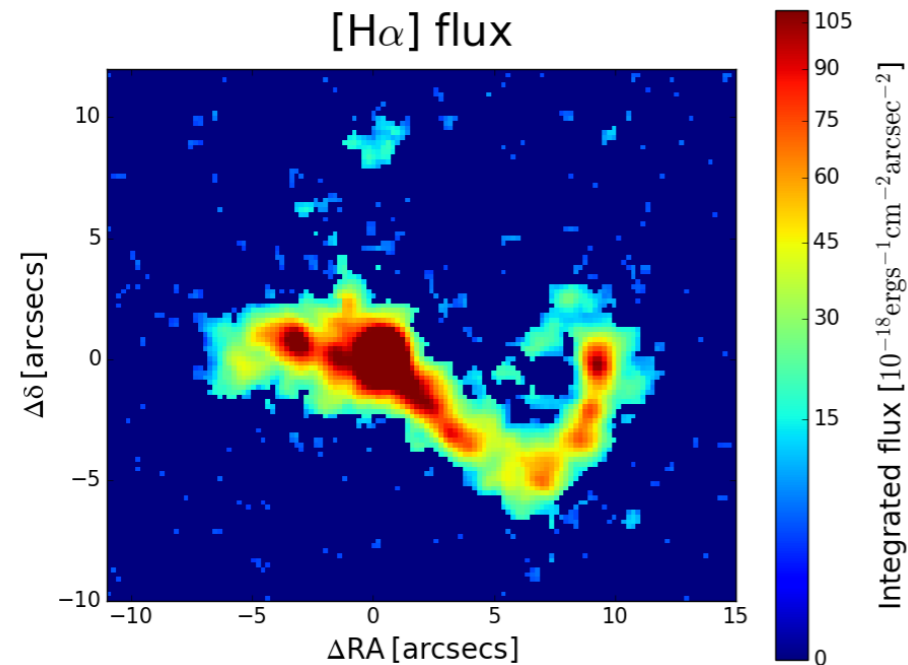
3C29



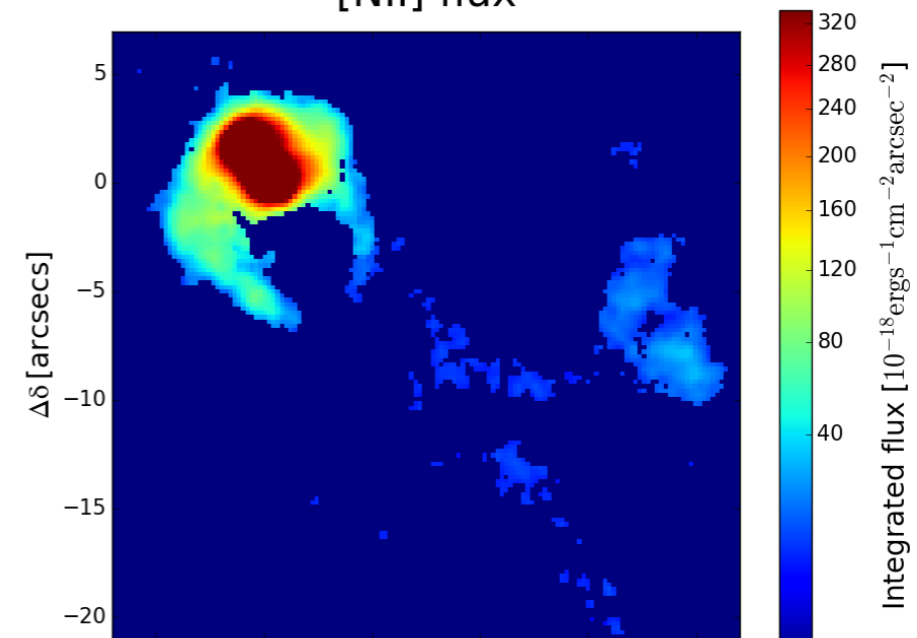
Instead, in the FRII sample we find cavities...

[NII] flux

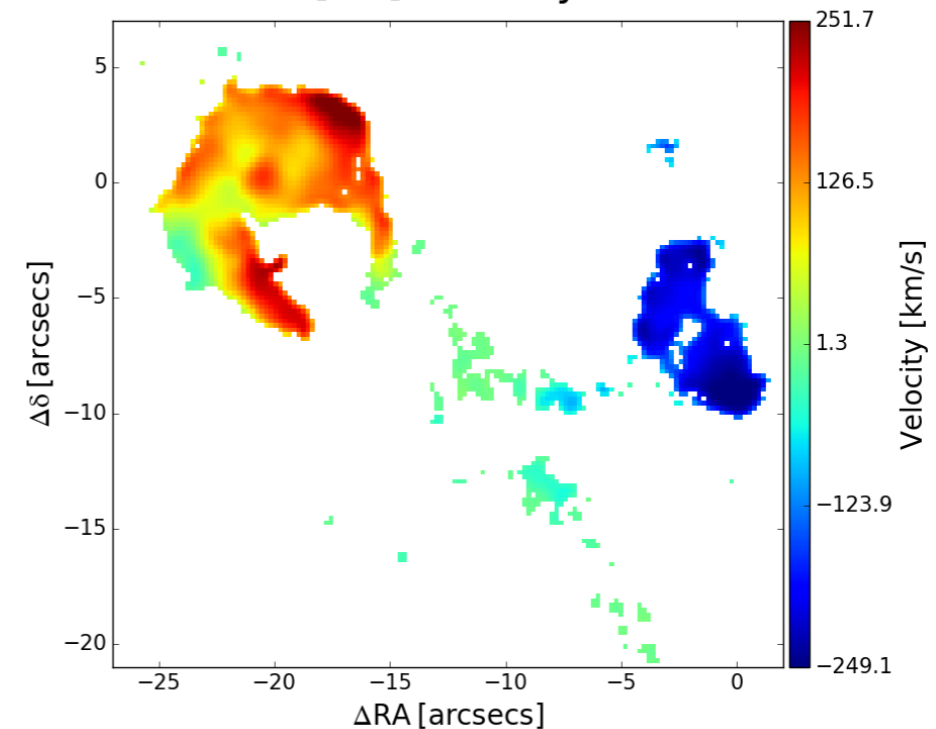
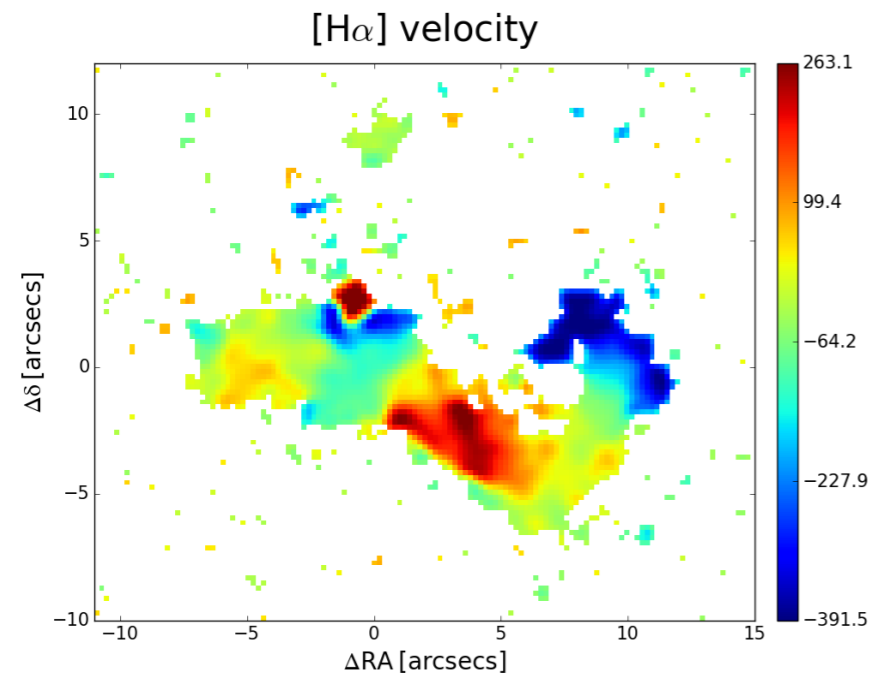
3C63



3C442

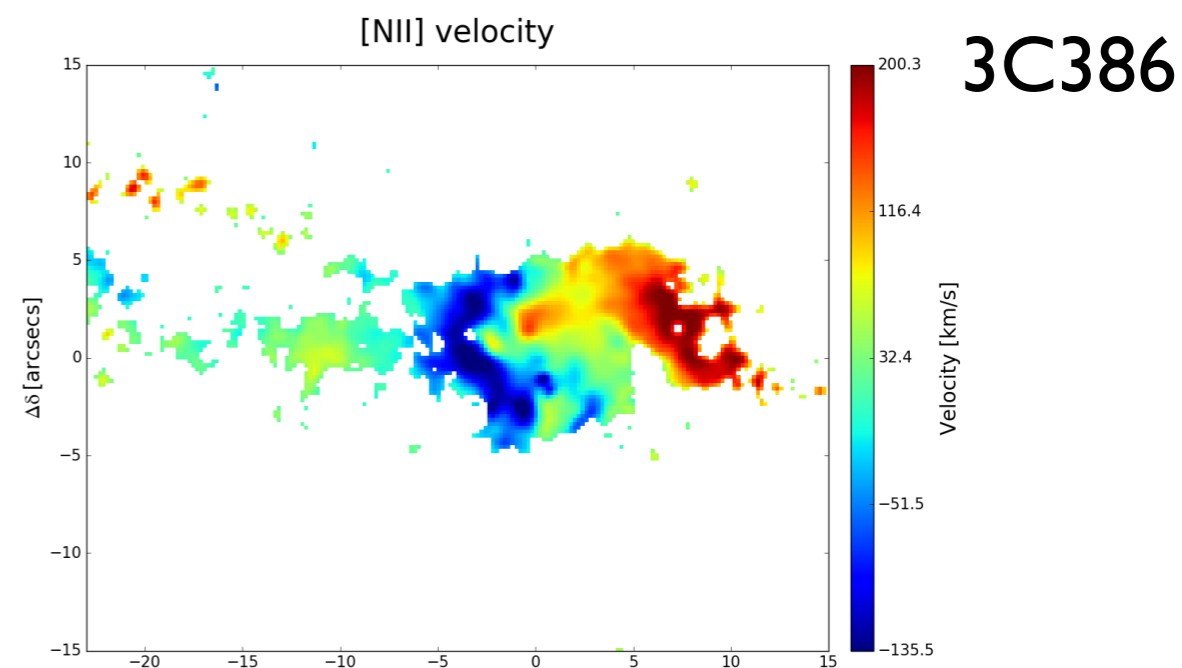
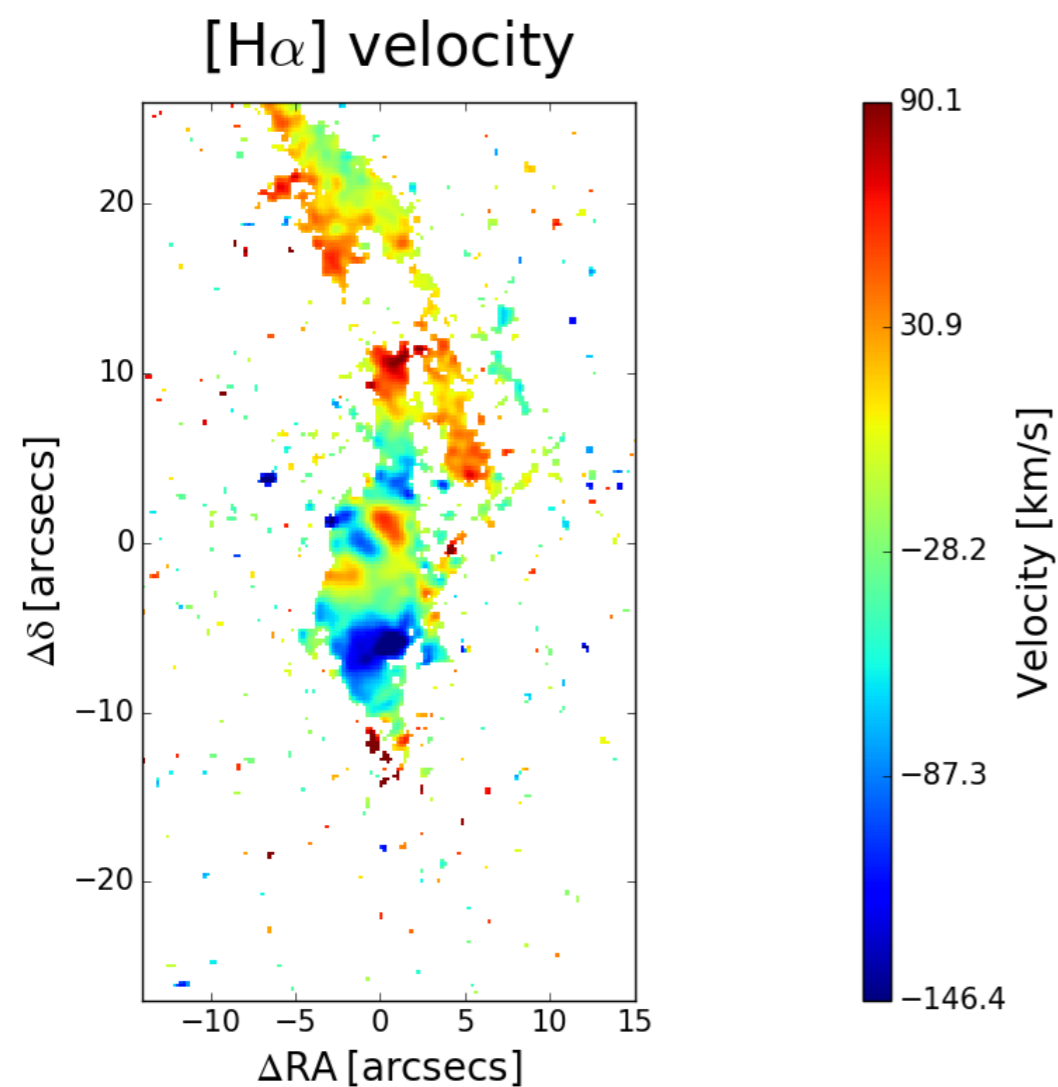


[NII] velocity

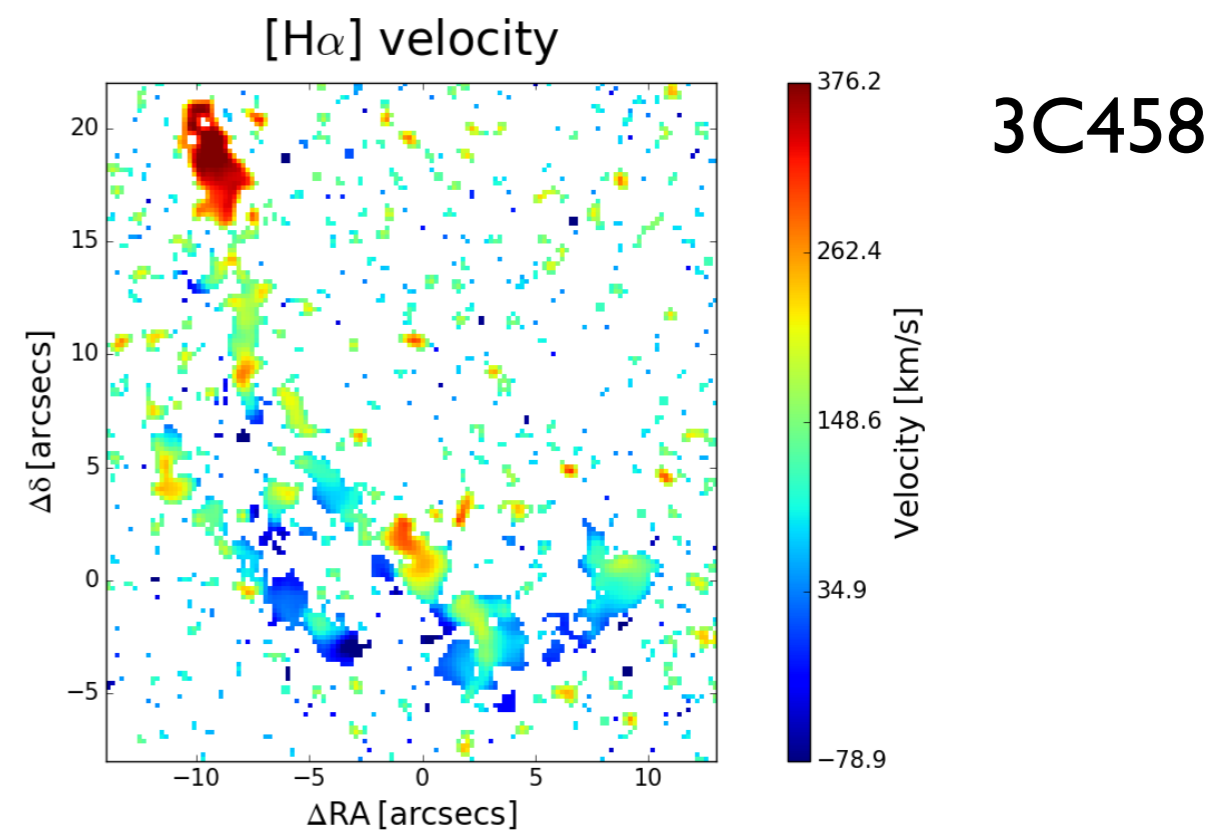


## Filaments...

3C353

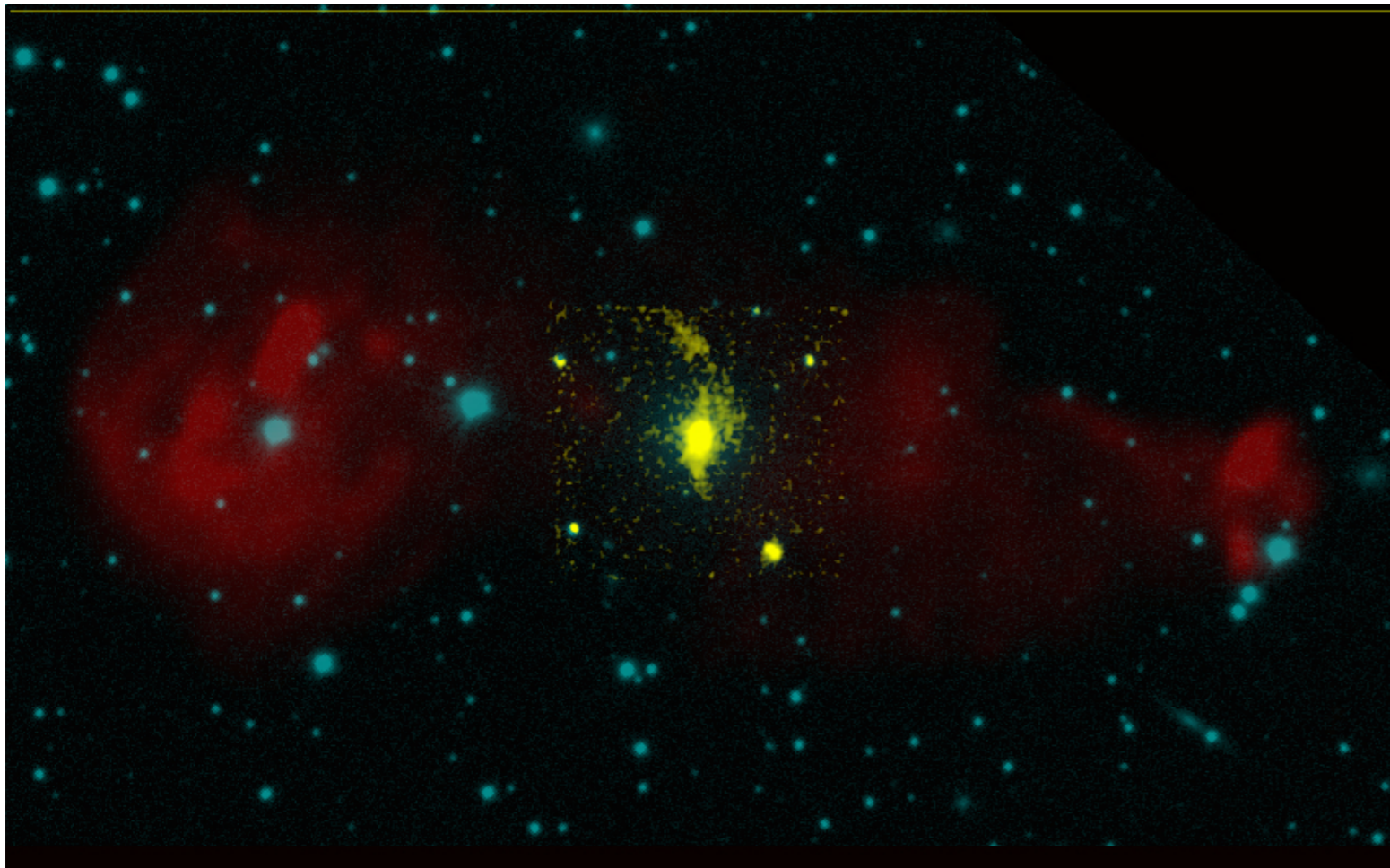


3C386



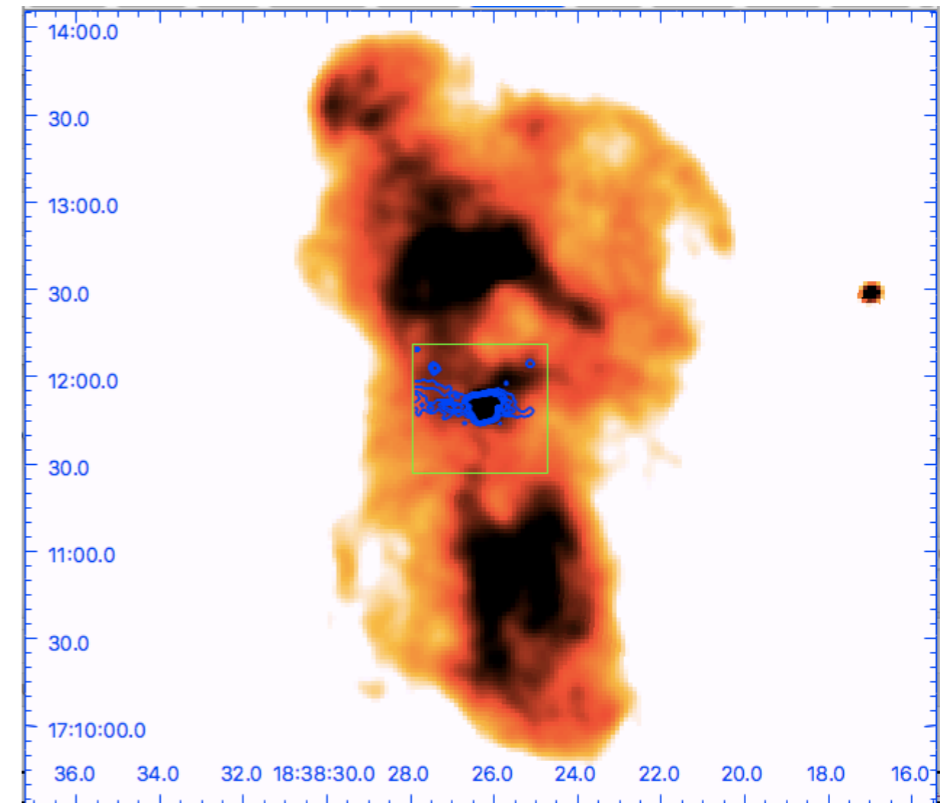
3C458

## Filaments...



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

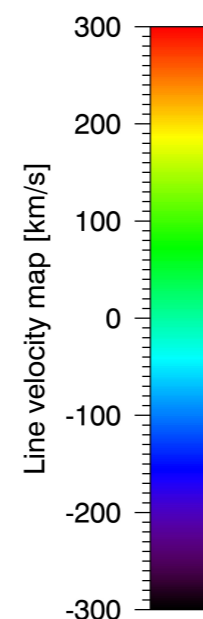
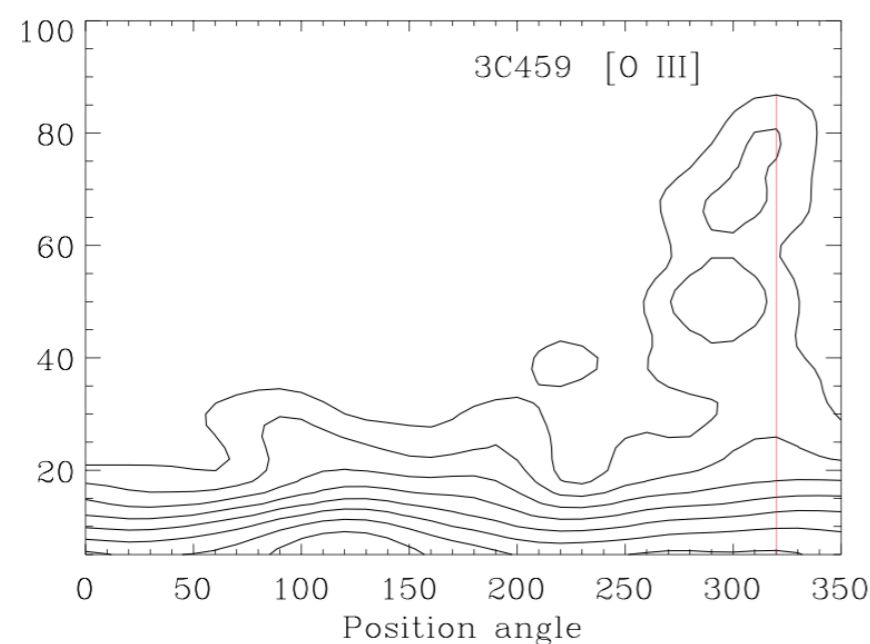
**3C386** (right; Radio: red, Line: blue)



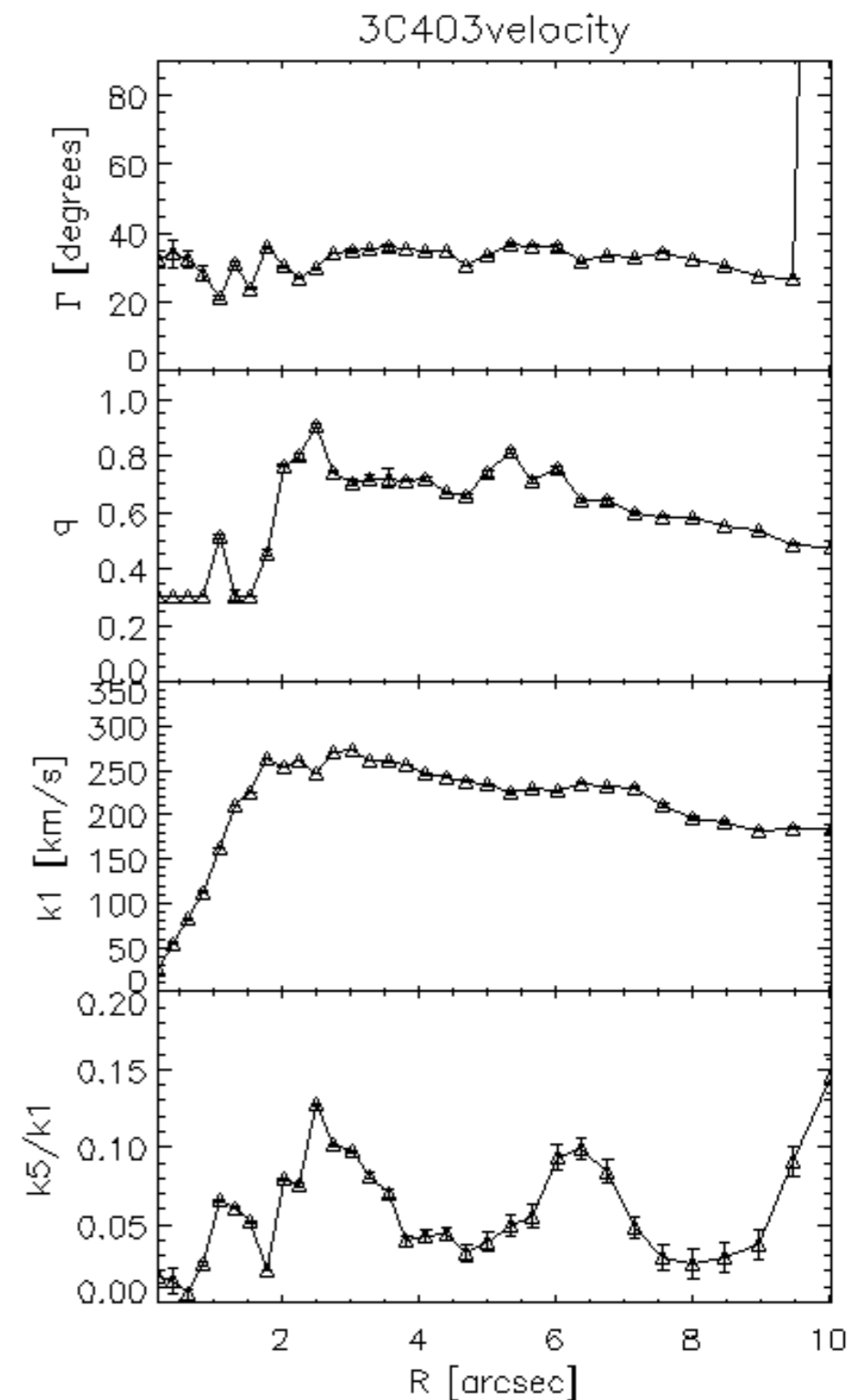
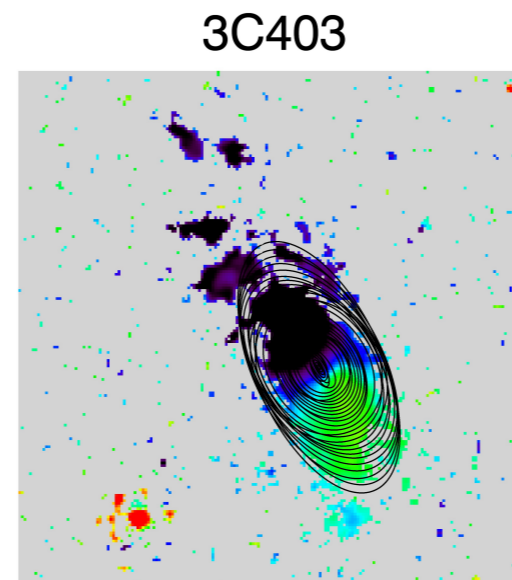
## How to describe the filaments?

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

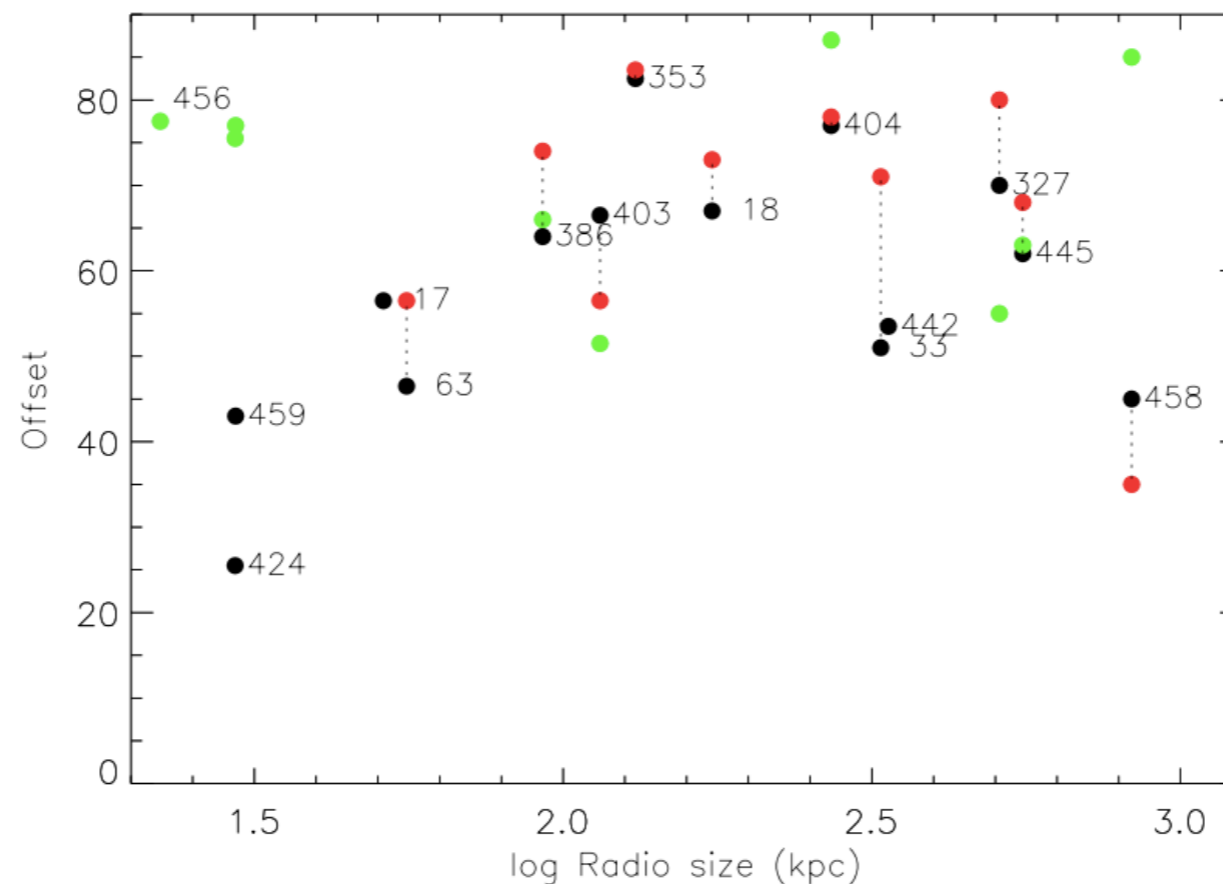


### Kinematic analysis on inner scales

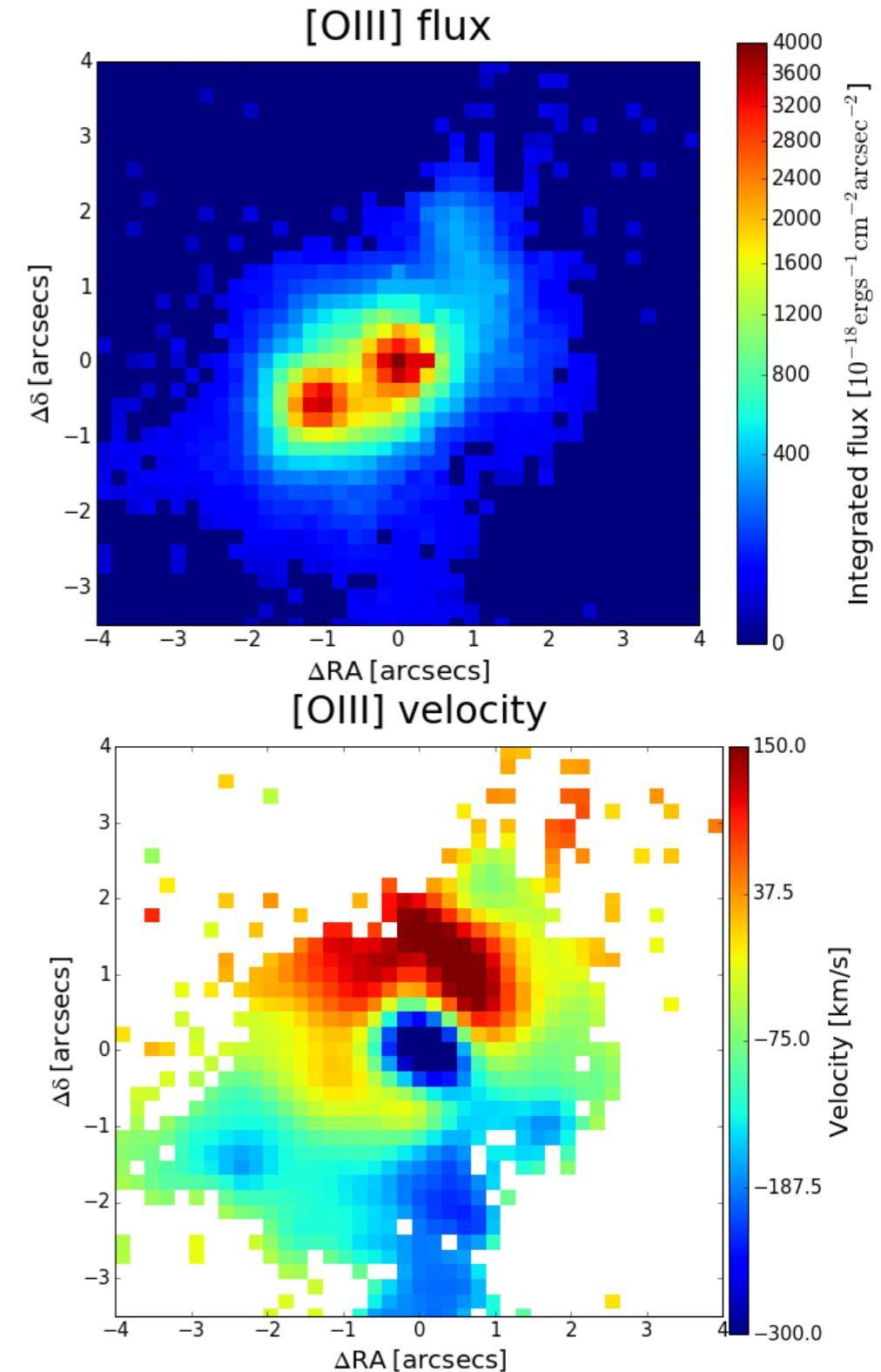
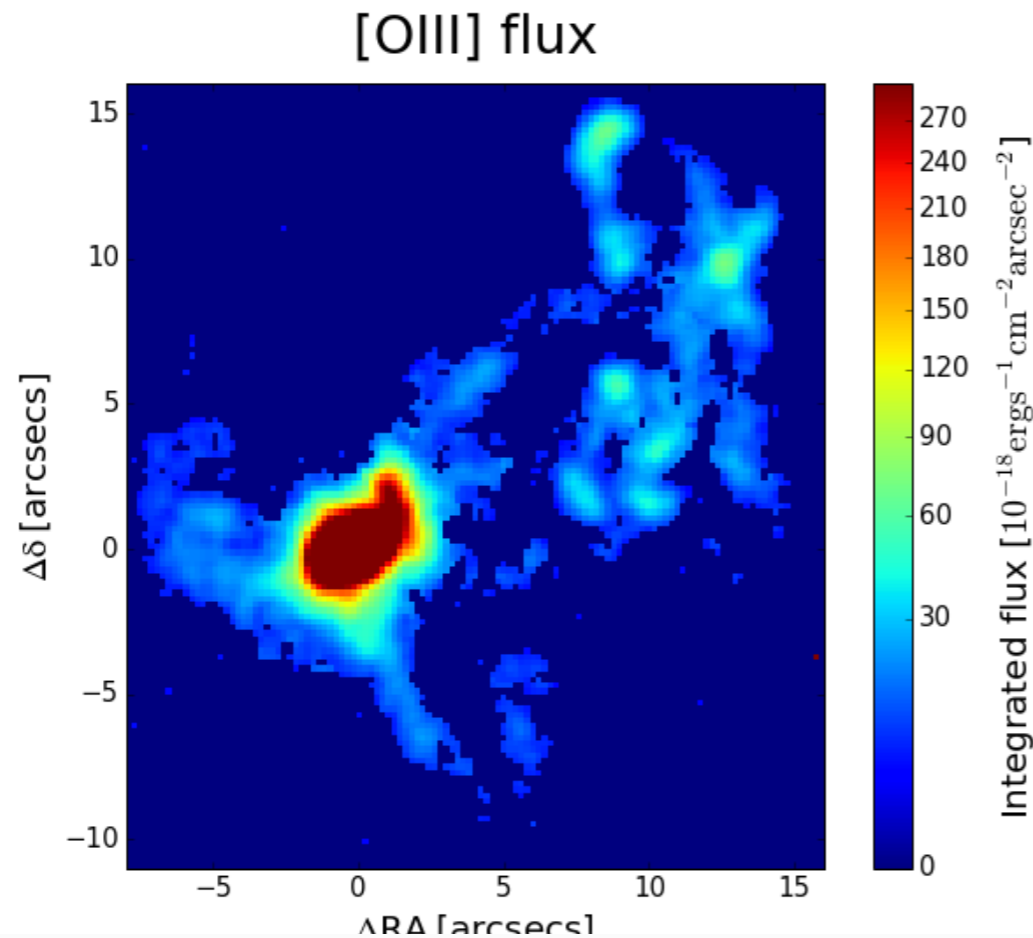


**MAIN RESULTS:**

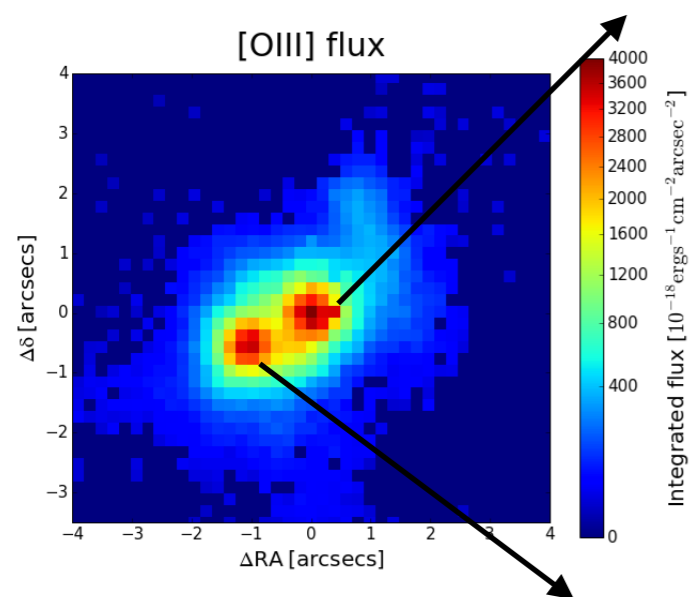
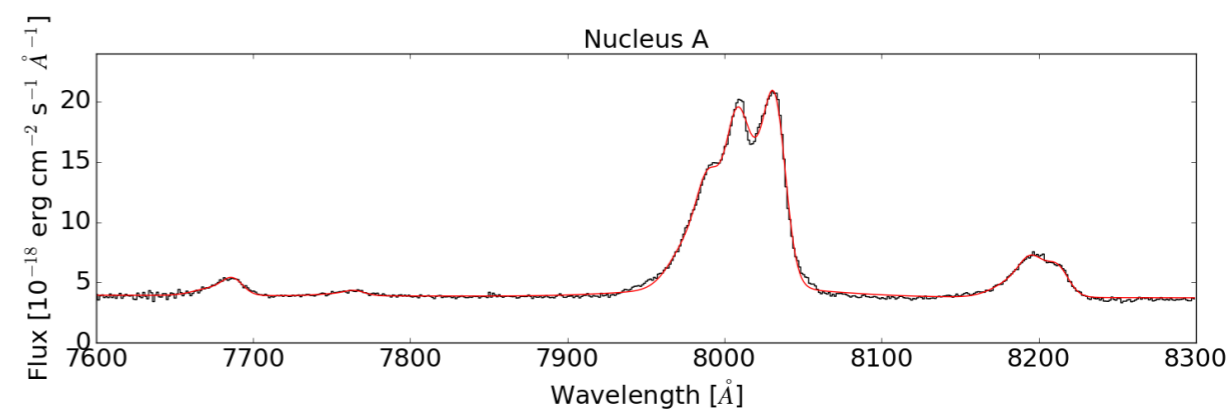
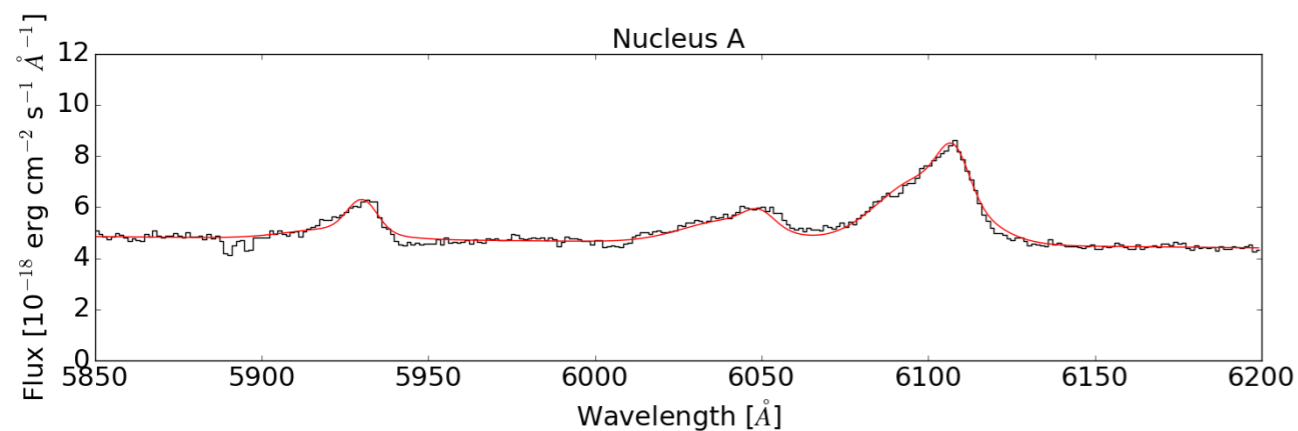
- ✓ We observe in all but one of the 15 FR II radio-galaxies observed extended filamentary structures.
- ✓ These filaments are extended for several tens of kpc, are preferentially oriented perpendicularly to the radio jets.
- ✓ The geometrical connection between the structure of ionized gas and the radio 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?...

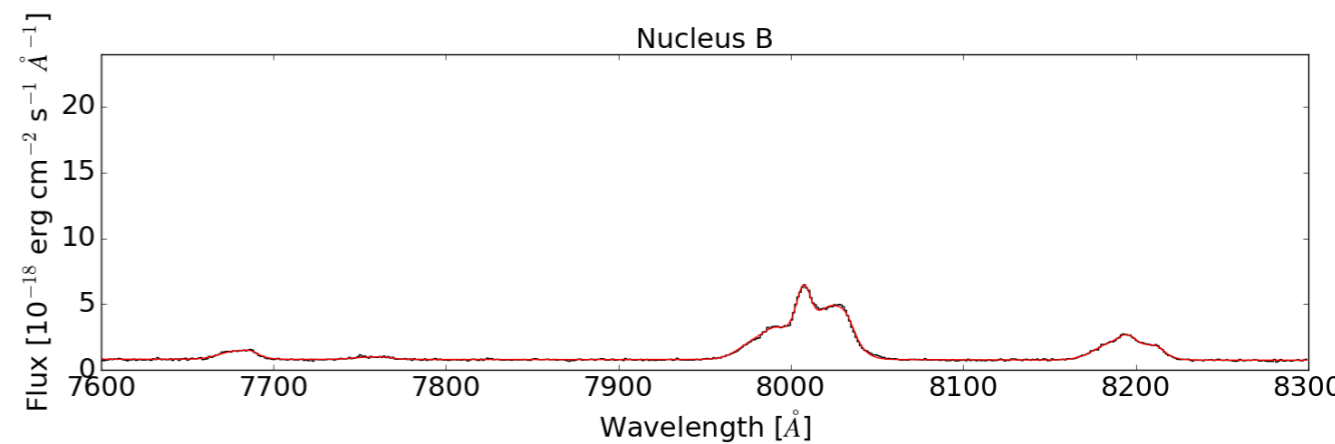
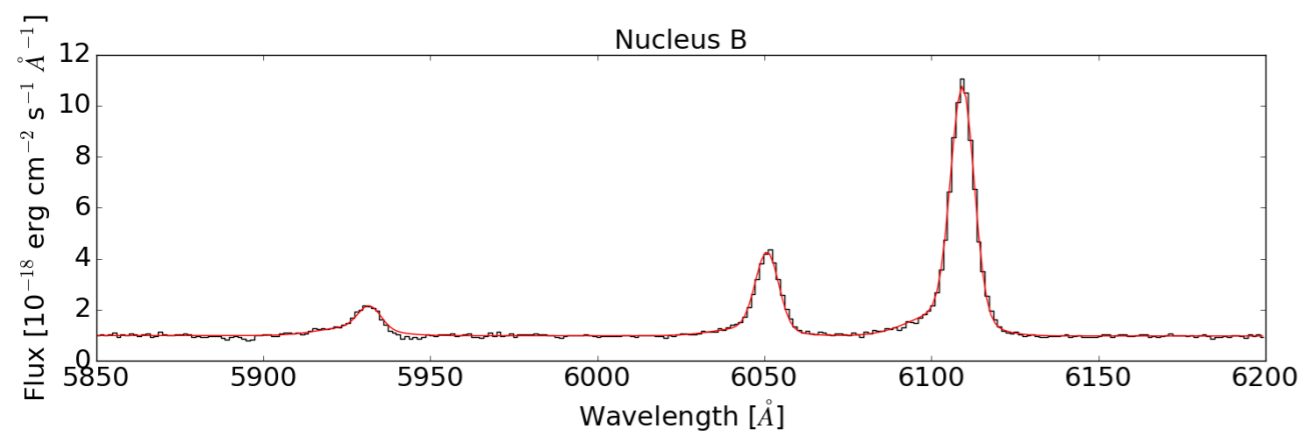


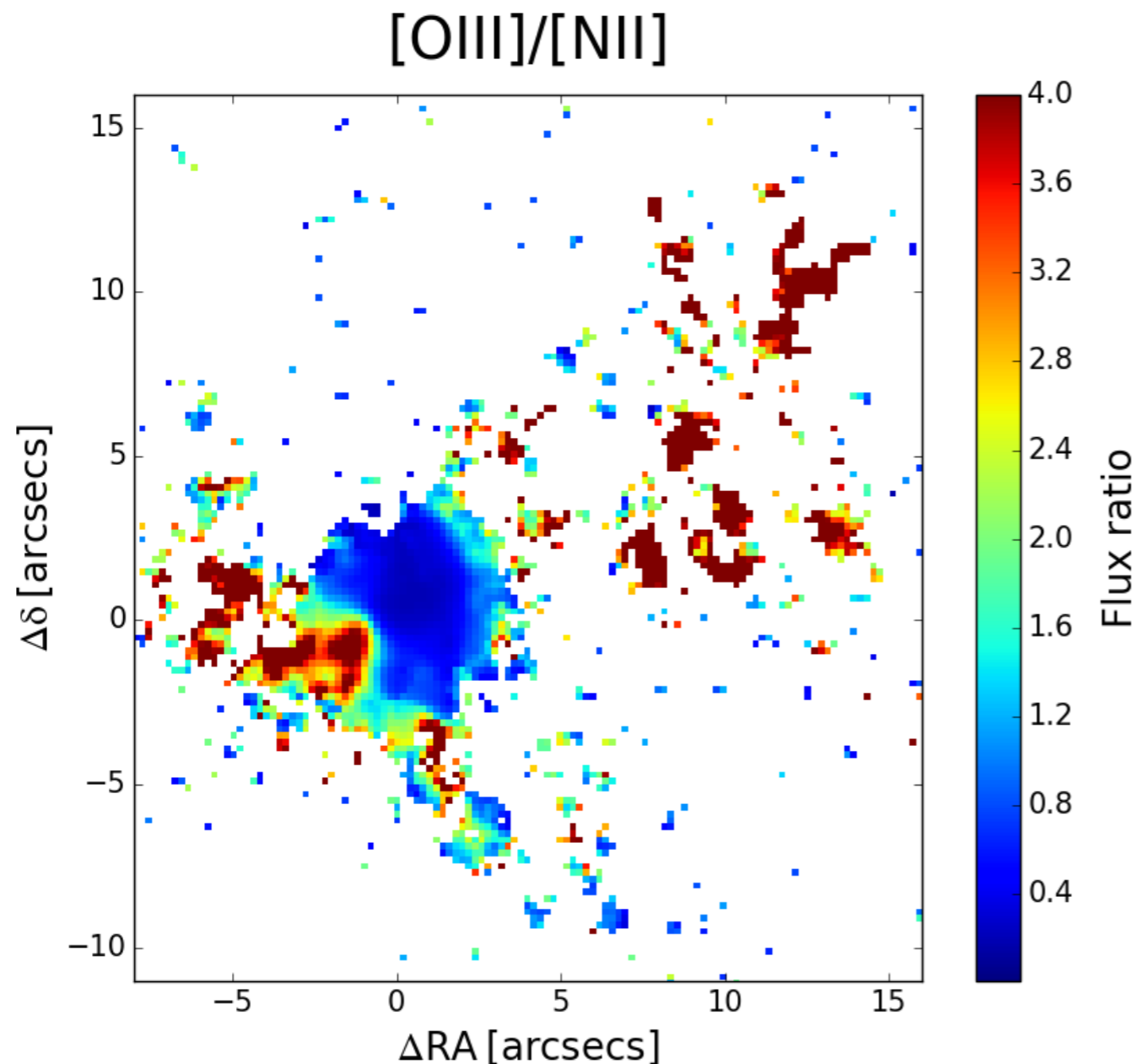
- ✓ The central emission line region is dominated by two compact knots: the first cospatial with the radio core, the second located 1.2 (5.3 kpc) to the SE.
- ✓ The two regions have velocity ( $Dv \sim 300 \text{ km/s}$ ), line widths, and line ratios.



## MAIN RESULTS:

- ✓ The emission line ratios in the two knots are different.
- ✓ A Seyfert-like spectrum highly absorbed?

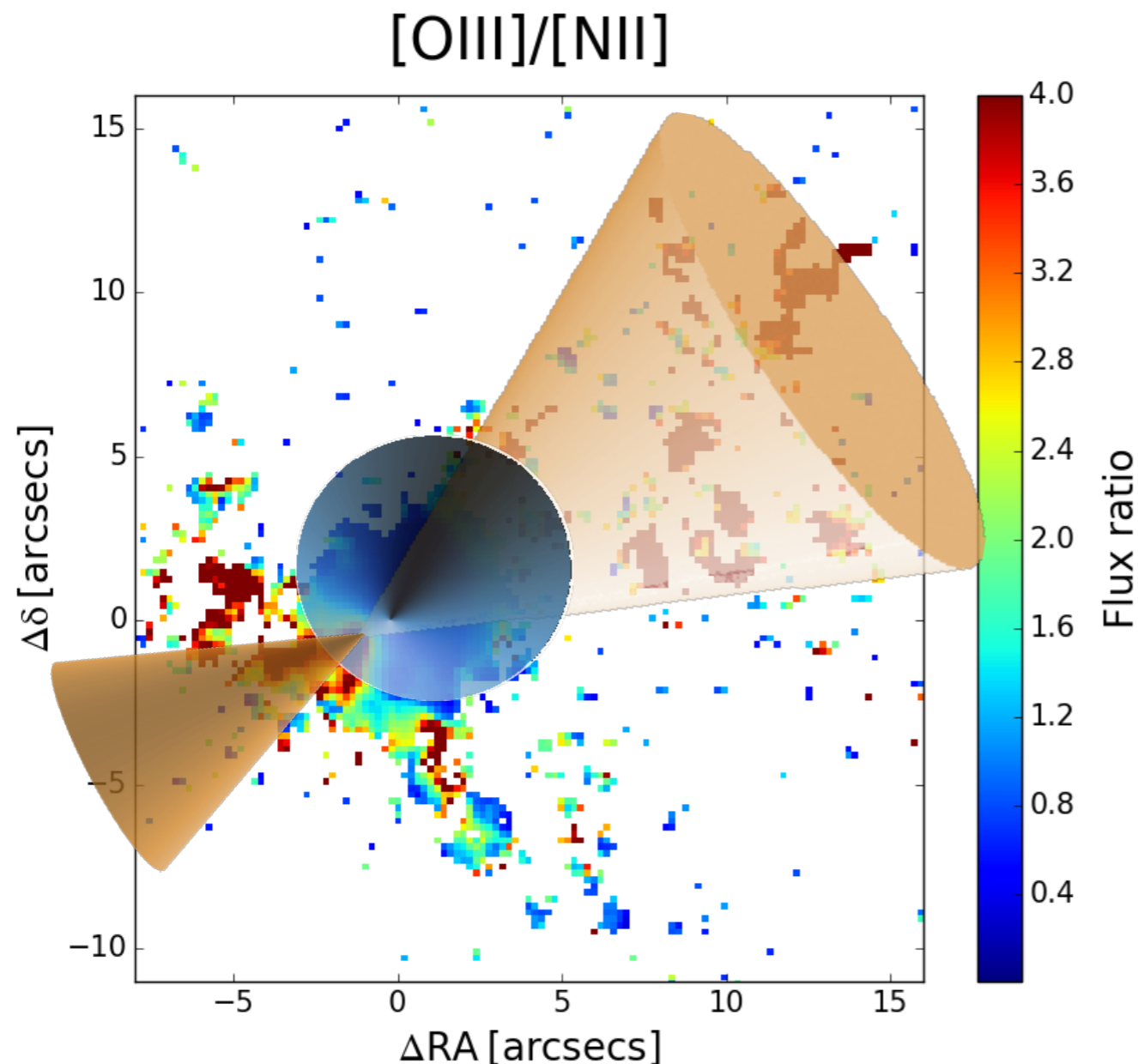




### MAIN RESULTS:

- ✓ 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. (2018arXiv180904083B)



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## Summarizing...

For the project MURALES we have observed with MUSE 20 3C radio galaxies at  $z < 0.3$ . The observations of other 20 radiogalaxies are on-going.

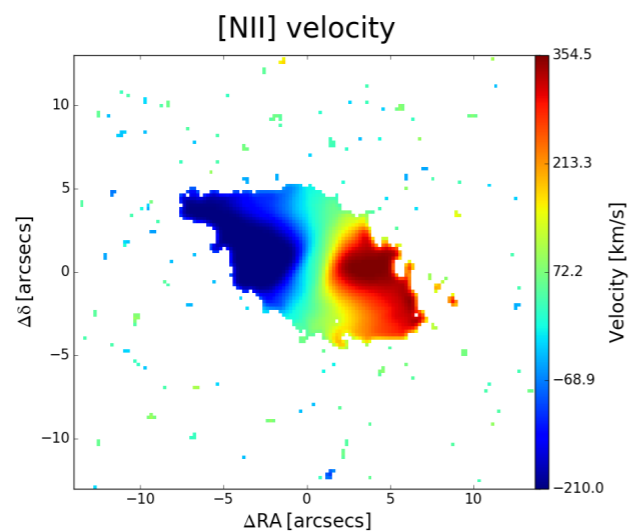
The line emission images of unprecedented depth revealed the widespread presence of filamentary structures extending several tens of kpc in all but one FR II (the FR I are preferentially compact), oriented almost perpendicularly to the radio jets, likely the remnants of the gas rich mergers which triggered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

## For the future...

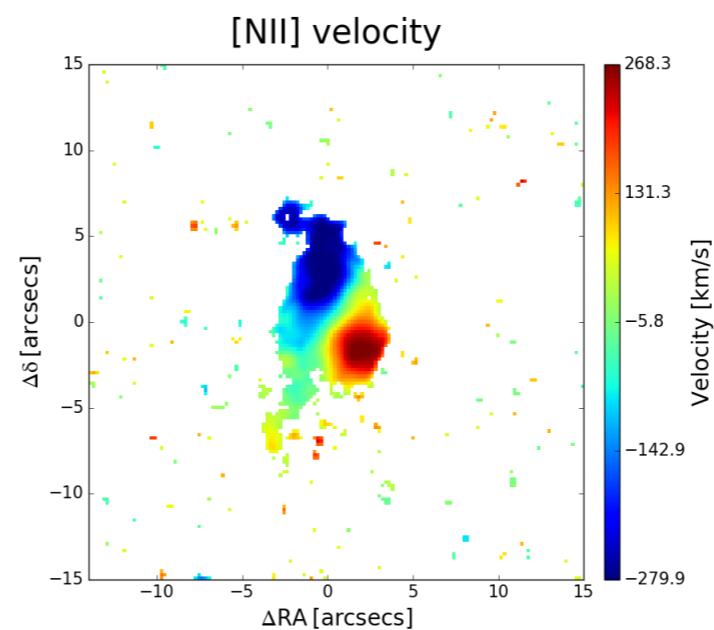
The ionized gas structures revealed by MUSE could be only the tip of the iceberg of a much larger amount of colder (atomic and molecular) gas. We have therefore proposed a pilot study to map the **H I emission** in the three nearest FR II radio galaxies of the MURALES sample **with VLA** (VLA/18B-084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

We have obtained time to confirm with **VLA** and **ALMA** the presence of a binary BH in 3C459.

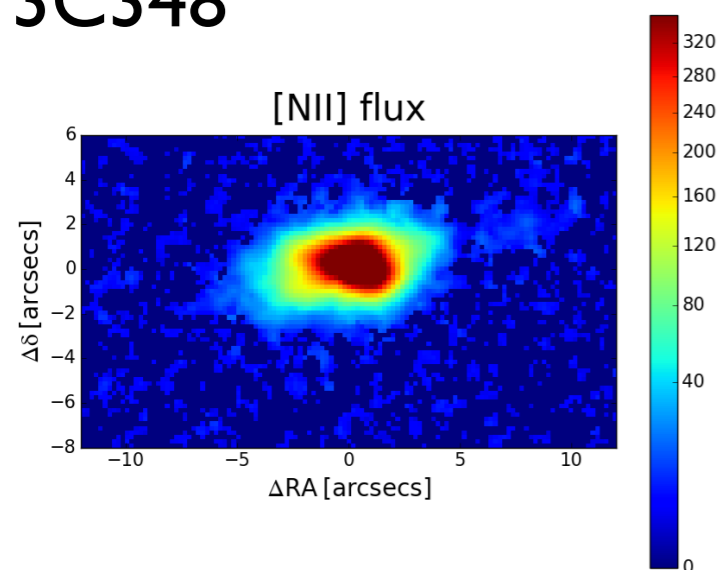
3C33



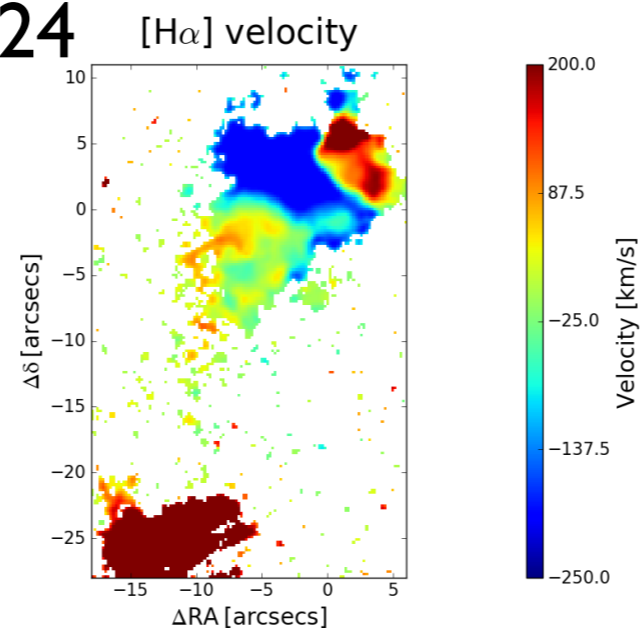
3C327



3C348



3C424



3C353

