NICOLAUS COPERNICUS UNIVERSITY IN TORUŃ

Discovery of new radio transients - short-lived radio-loud AGNs

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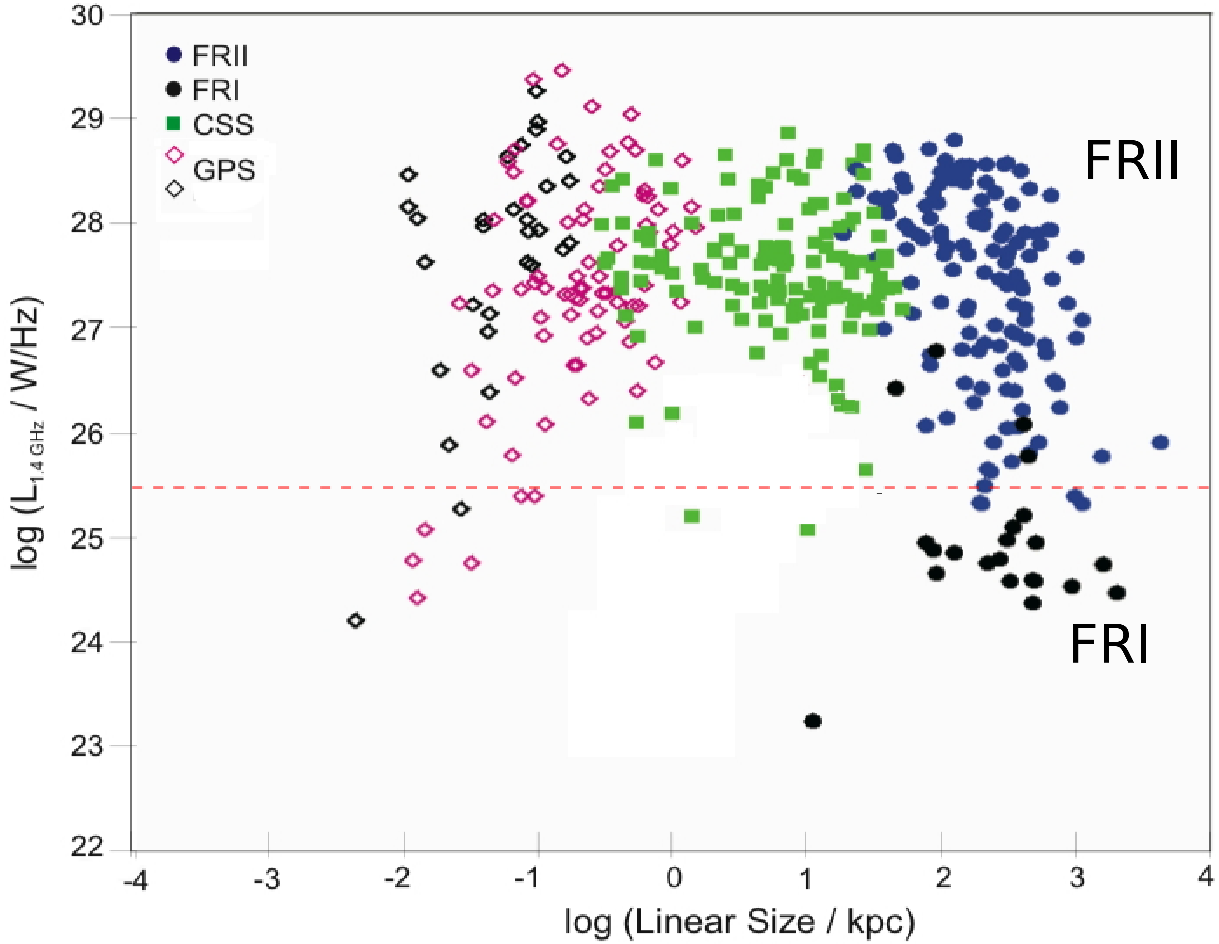
Introduction: AGN evolution

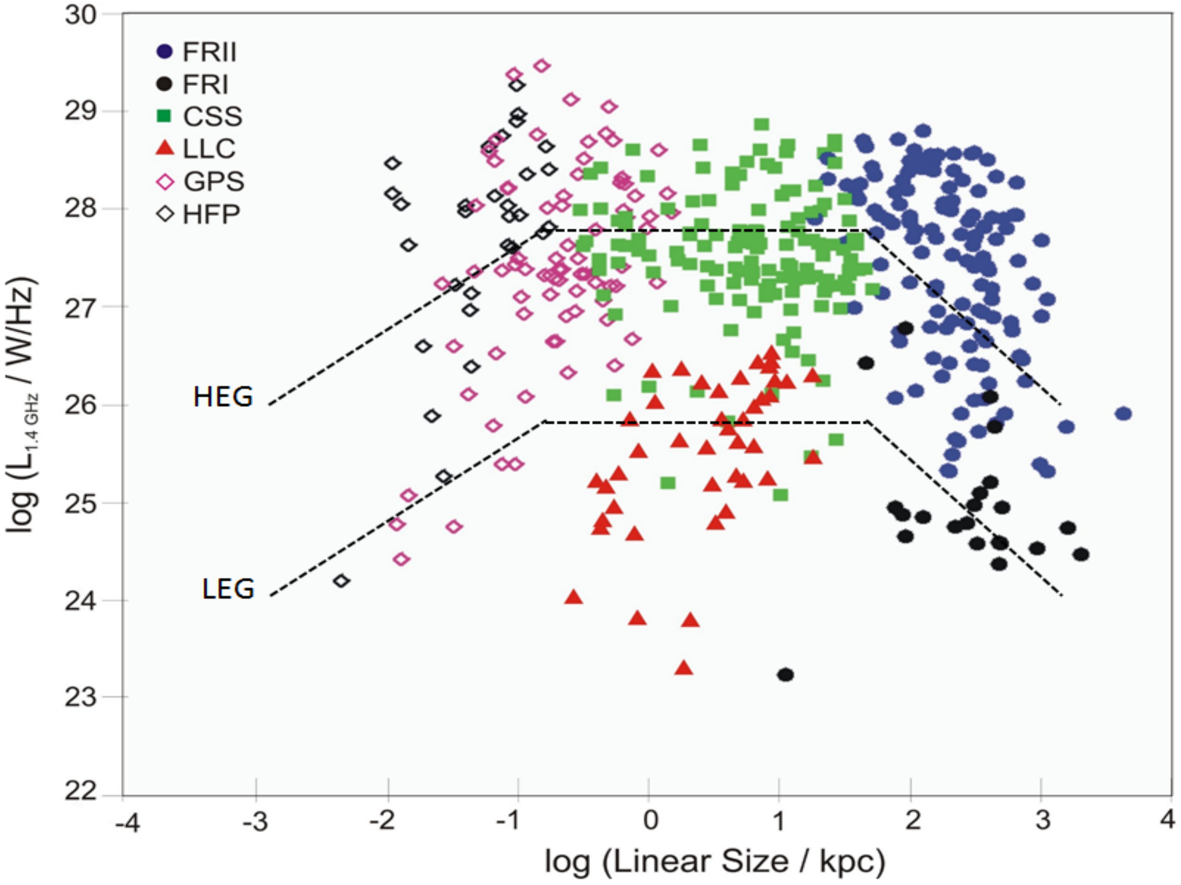


Fanti+1995,
O'Dea & Baum, 1997,
Snellen+2000, Marecki+2003,
Kunert-Bajraszewska+2010,
Turner & Shabala 2015,
Morganti 2017

GPS (< 1 kpc) ⇒ CSS (< 15 kpc) ⇒ FRI/FRII (> 15 kpc)

(Kunert-Bajraszewska+2010)

Parallel evolutionary paths



(Kunert-Bajraszewska 2018)

<u>Two parallel evolutionary paths</u>

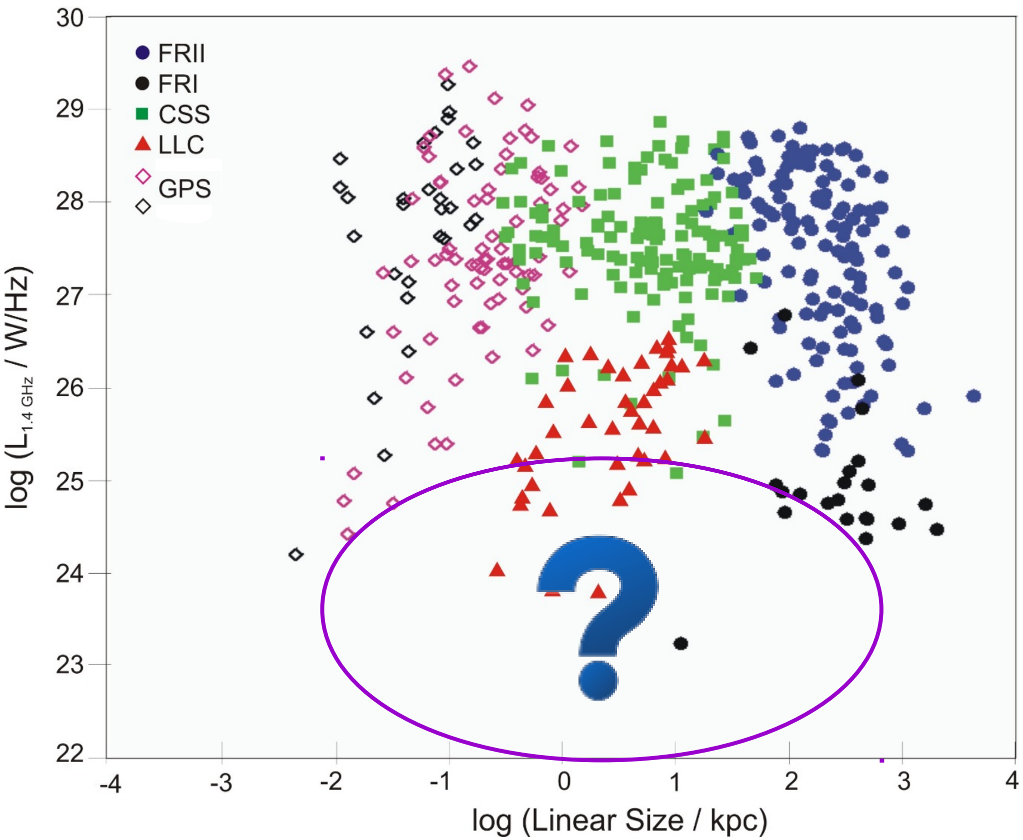
High Excitation Galaxy (HEG):

- evolves more efficiently
- stronger in radio/X-ray
- stronger emission lines

Low Excitation Galaxy (LEG):

- evolves slowly, may never develop large scale structures
- weak in radio/X-ray

What next?



- Radio transients

Stripe 82 Survey

NRAO Caltech

- Low-frequency observations

LOFAR

There is much larger population of faint radio galaxies – our aim is to study weaker and weaker sources

270 sq. deg of SDSS Stripe 82
Dedicated radio transient survey

x - up to three times as deep as **FIRST** *(Faint Images of the Radio Sky at Twenty-Centimeters)*

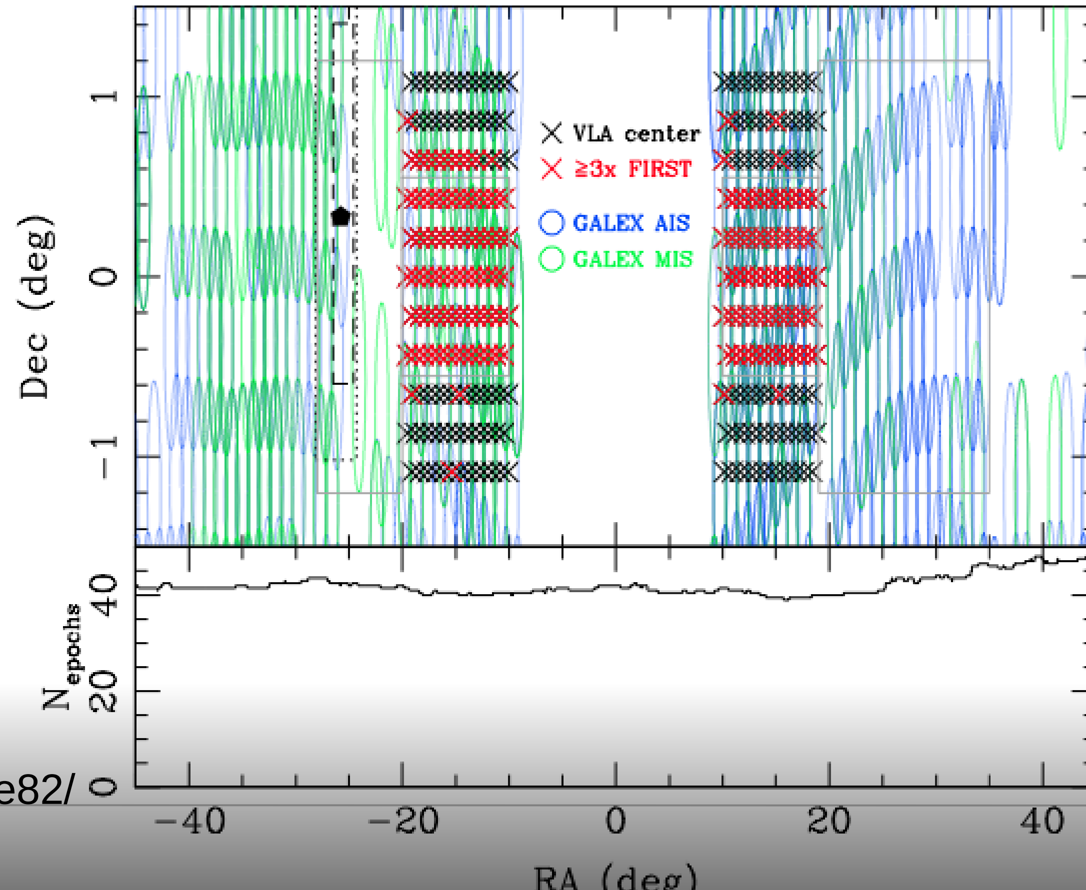
x – even deeper

Galaxy Evolution Explorer (GALEX) – near and far UV

covered by SDSS

VLA, 2–4 GHz, A and B configs
5 epochs (2012–2015)
80 uJy (RMS) per epoch

PI: Gregg Hallinan
Data release: Mooley et al. (2016, 2018 in progress)



http://www.tauceti.caltech.edu/stripe82/

The Caltech-NRAO Stripe 82 Survey (CNSS)

Stripe 82 - 270 deg^2 of sky on the celestial equator

(142 new sources from <u>pilot survey only</u>):

- flaring AGNs (shocks in the jet)
- candidates for tidal disruption events
- candidates for stellar explosions
- flare stars
- active binary star systems

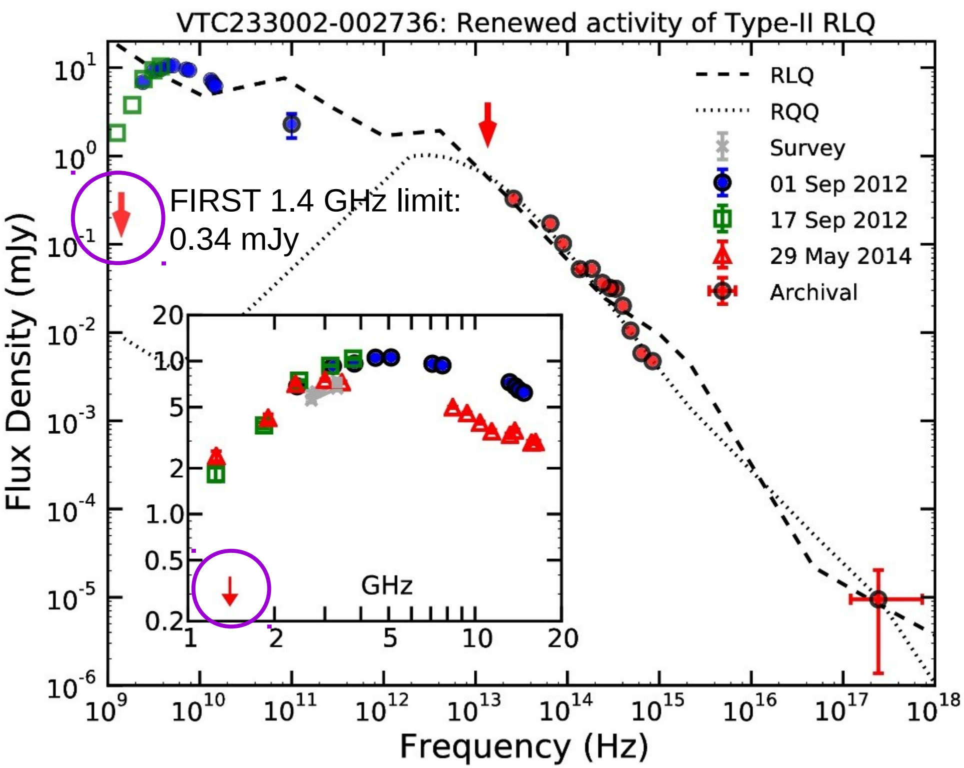
and ...

<u>Distinct population of AGN not detected as radio sources in any of the previous surveys of Stripe 82.</u>

<u>Sources are newly born – 3-6 years old!</u>

detection at mJy-level, GPS spectra typical for young AGNs

The Caltech-NRAO Stripe 82 Survey (CNSS)



This source suddenly appears in 2012!

Type II quasar – we look closer to the accretion disk.

GPS spectrum transitioning into a flat spectrum source.

radio-quiet → radio-loud

Mooley+2016

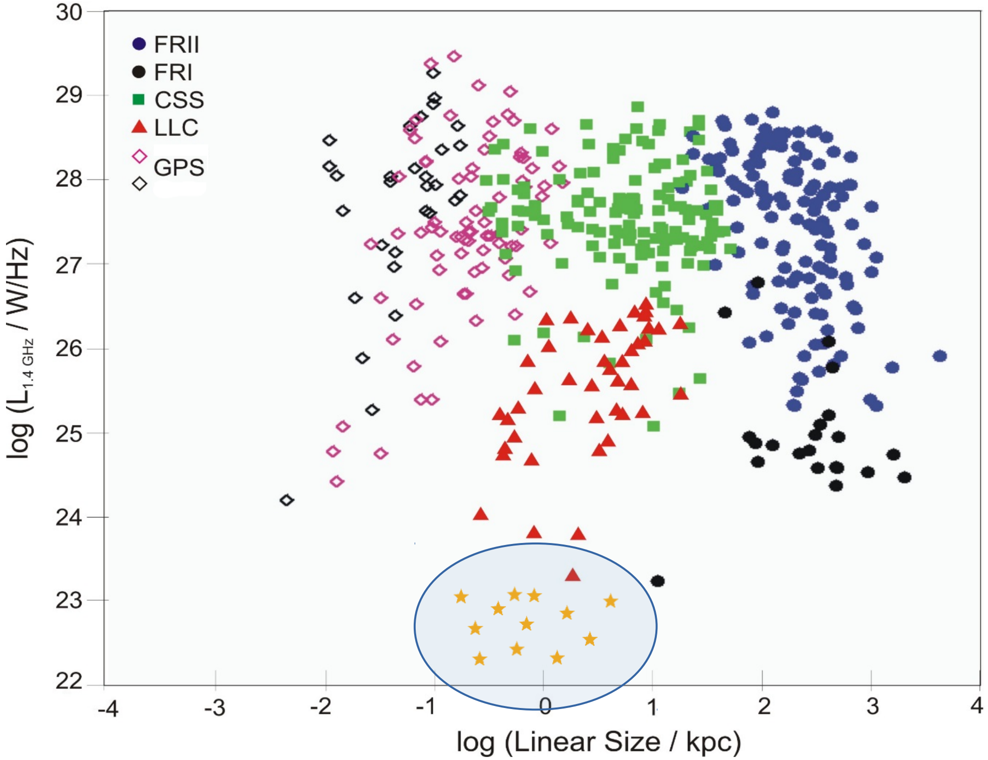
Conclusion: **VTC233002 is due to renewed jet-activity from a type-II QSO.**

GPS spectrum is indicative of a young jet.

the sudden appearance - enhanced accretion proces

the flattening of the spectra index – cessation of the accretion episode and/or interaction with the ISM

12 new radio transients

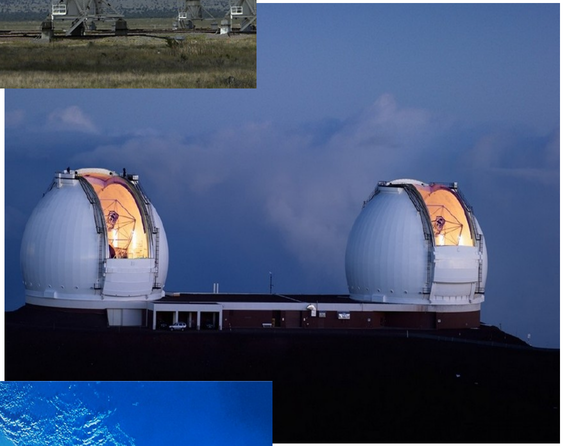


Source	S_{3GHz}	S_{5GHz}	$S_{7.5GHz}$	(mJy)
VTC221650	2	2	8.6	
VTC221812	7.2	13.4	8.9	
VTC223041	3.1	3.1	3.3	
VTC233001	5.4	6.1	5	
VTC013815	2.3	2.3	1.3	
VTC015411	3.6	3.6	3.3	
VTC020827	4.2	4.2	3.5	
VTC030533	2	5	4.1	
VTC030925	10.7	13.3	9.7	
VTC031833	3	5.1	2.7	
VTC034526	2.7	7.8	9.0	

- Sources peak at few GHz

- Wide observational campaign of 12 new sources – MHz to X-ray
- Preliminary results

Observational status



VLBA – 4.5GHz and 7.5GHz radio morphology

VLA – monitoring changes in the spectra from 0.2 to 20 GHz

XMM-Newton/Chandra – environmental study, X-ray emission from compact AGNs

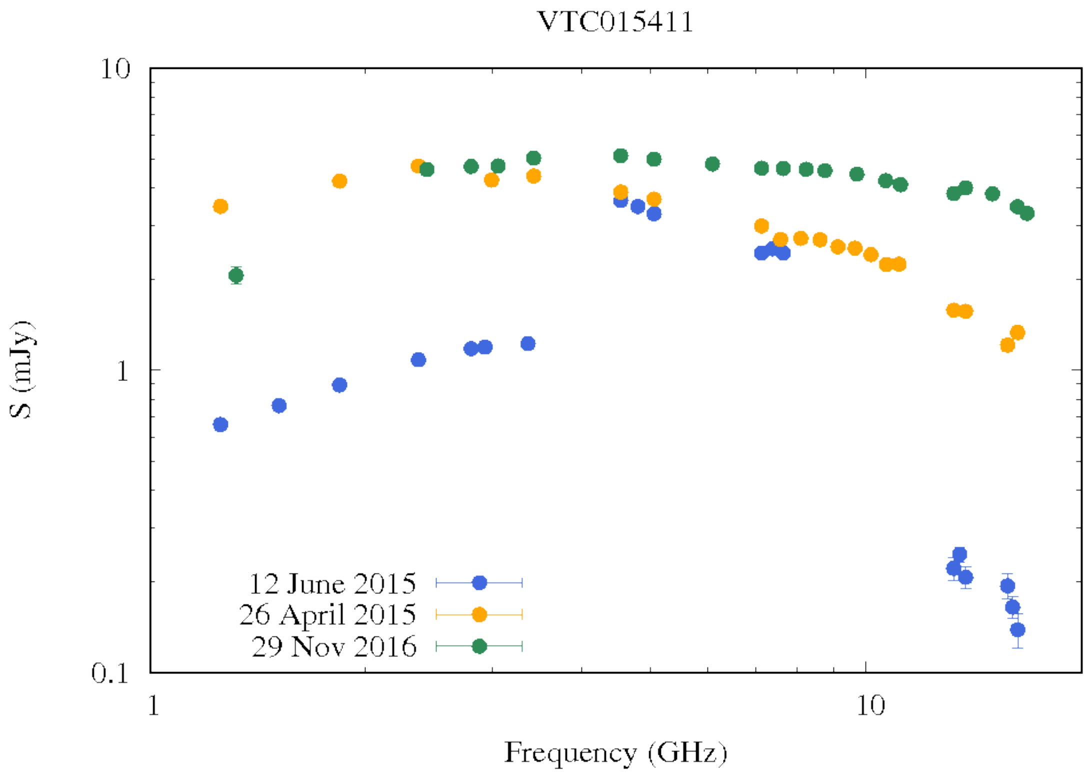
SDSS/BOSS – photometry and spectroscopy

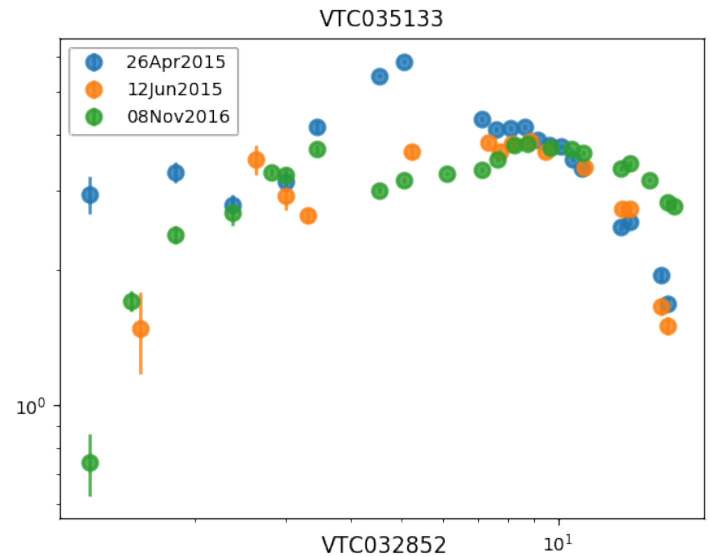
LOFAR – looking for an extended emission from previous phases of activity
<u>observations completed</u>

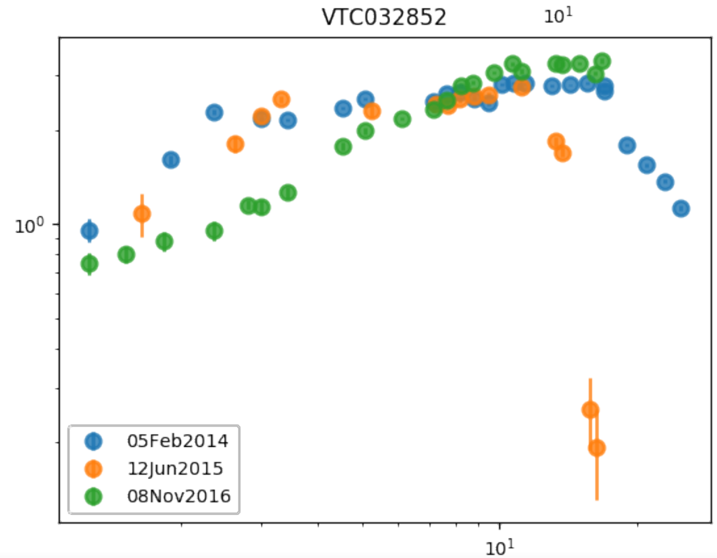
GMRT – very low frequency, sunchrotron self-absorption properties
<u>observations completed</u>

Preliminary results - evolving VLA spectra

Subsequent observations show evolution of sources – changes of flux density, movement of the peak and spectral flattening.

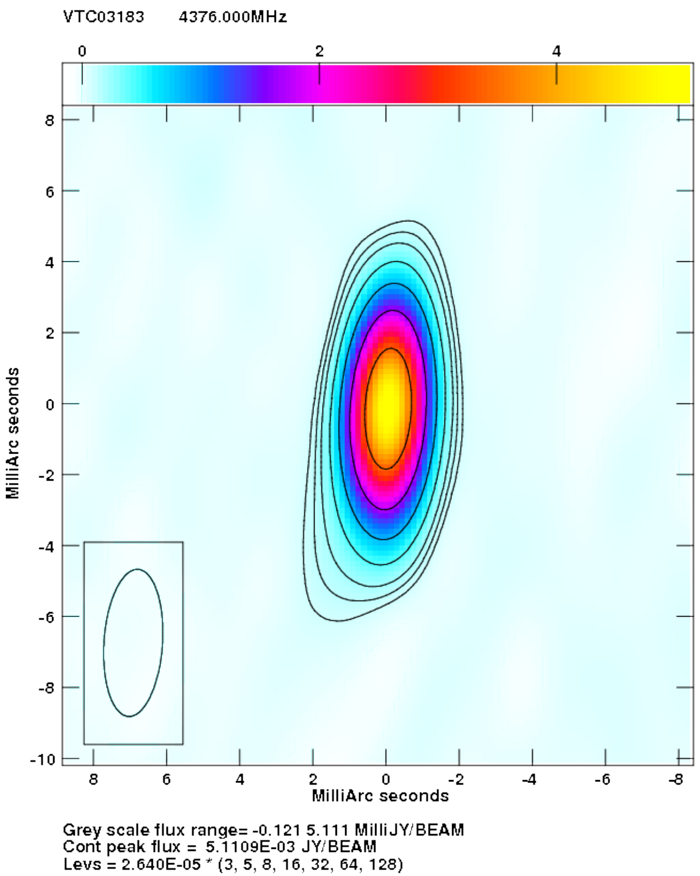


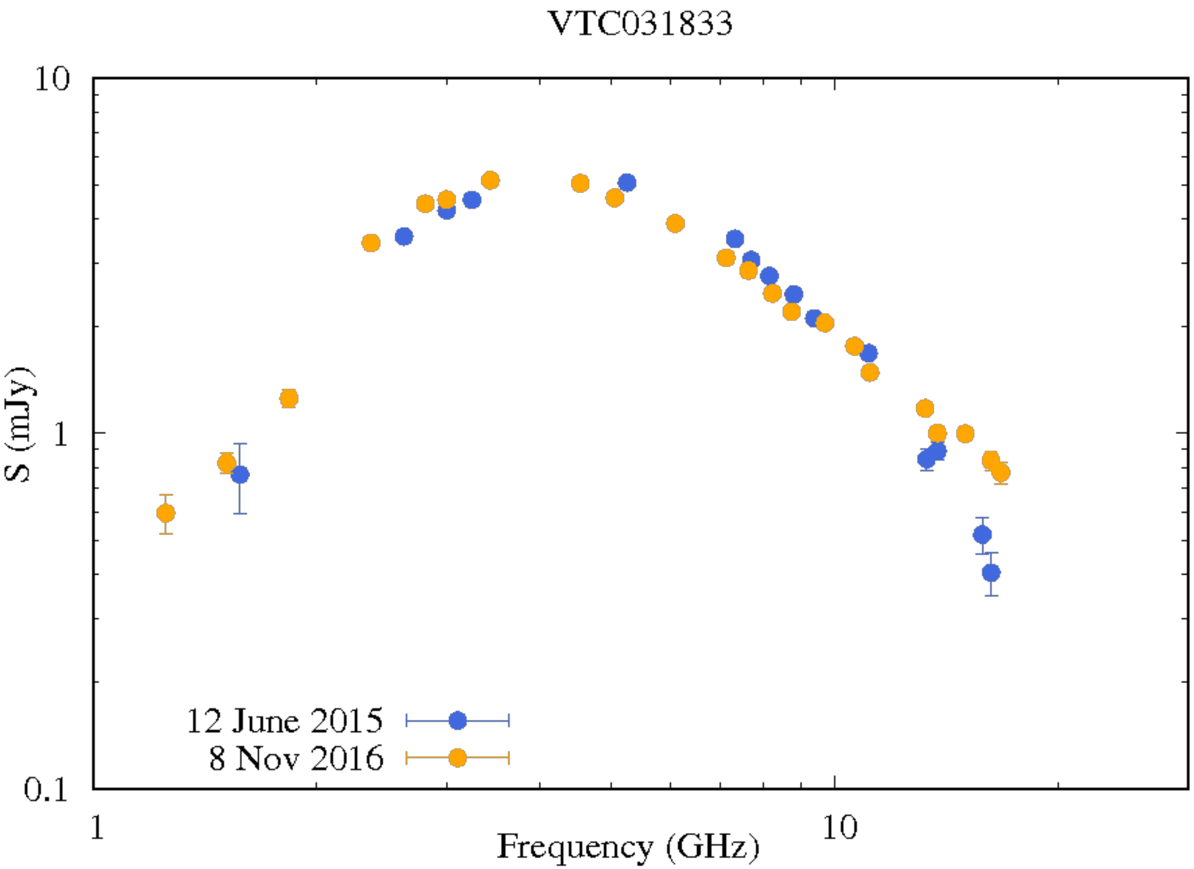




Mooley et al. in prep (CNSS), Wolowska et al. in prep

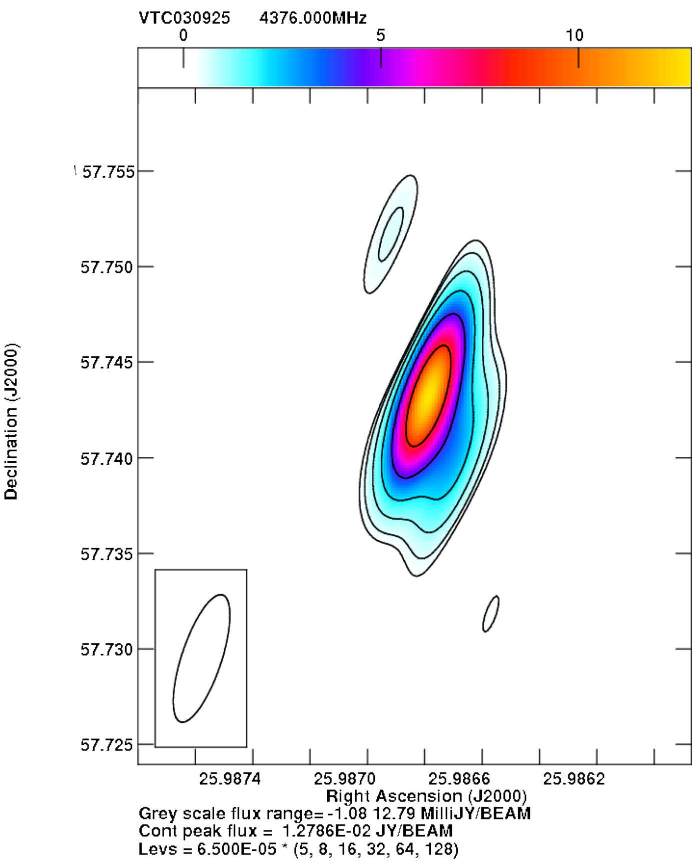
Preliminary results - VTC031833

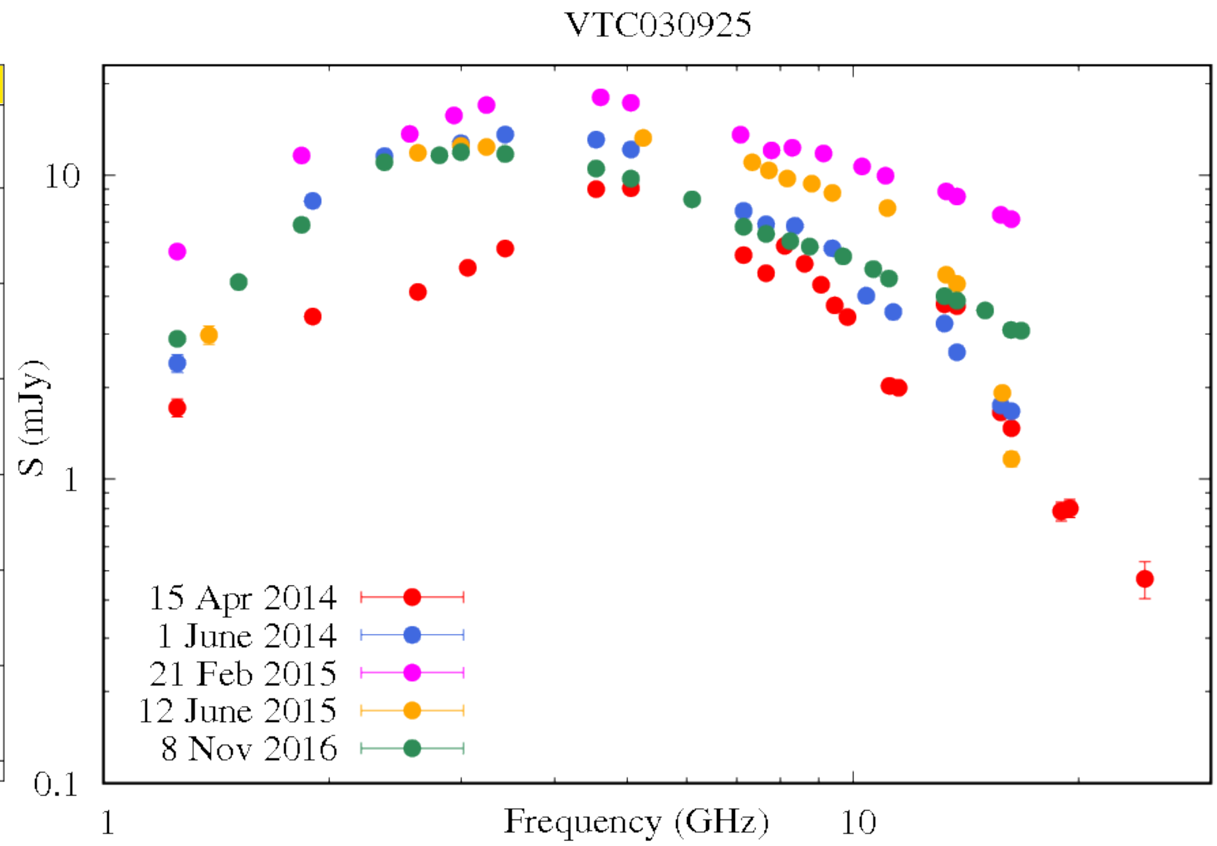




- VTC031833+00 discovered in 2015.
- Source peaking at 5GHz with a flux density of 5.1 mJy.
- Peak seems to slightly move towards lower frequency, when comparing the spectrum from June 2015 and the 2016 spectrum.
- That process could be due to propagating of the jet and its interaction with the circum-nuclear material in the host galaxy.

Preliminary results - VTC030925

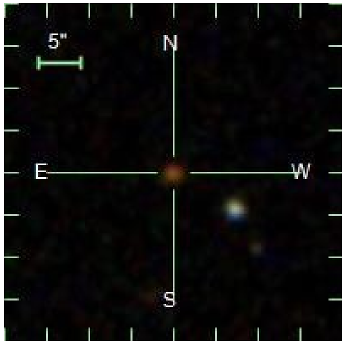




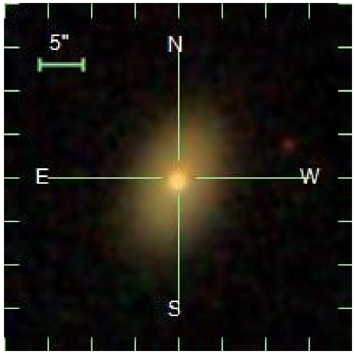
- First observed in April 2014
- Peaks at ~5GHz
- Flattening of the spectrum consistent with map – visible presence of a jet (observations – 22 March 2016)

Preliminary results – suggested optical types (SDSS)

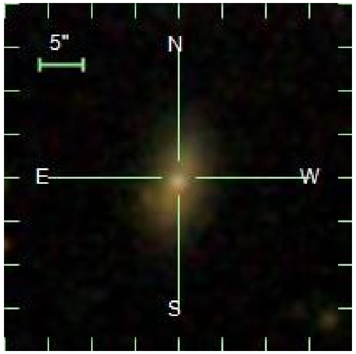
VTC221650



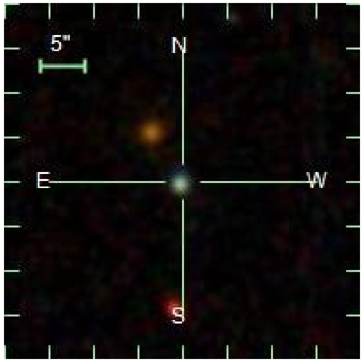
VTC015411



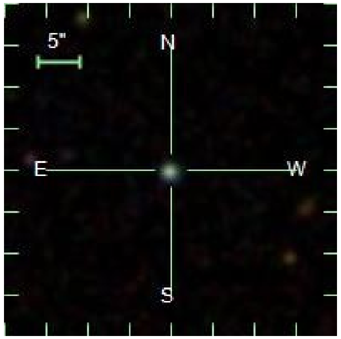
VTC030925



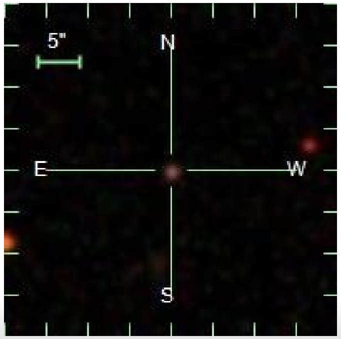
VTC020827



VTC013815

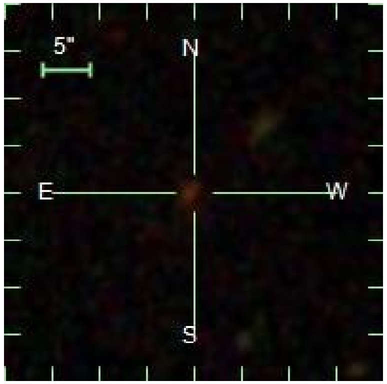


VTC233001



VTC221650: Type 2 AGN
VTC221812: Seyfert type 1 (Mrk 231-like)
VTC223041: ?
VTC233001: Seyfert type 1 (Mrk 231-like) to Type 1.8
VTC013815: Seyfert type 1.5-1.8
VTC015411: Type 2 AGN
VTC020827: Type 1 QSO
VTC030533: Type 2 AGN
VTC030925: Type 2 QSO
VTC031833: ?
VTC034526: Type 2 QSO

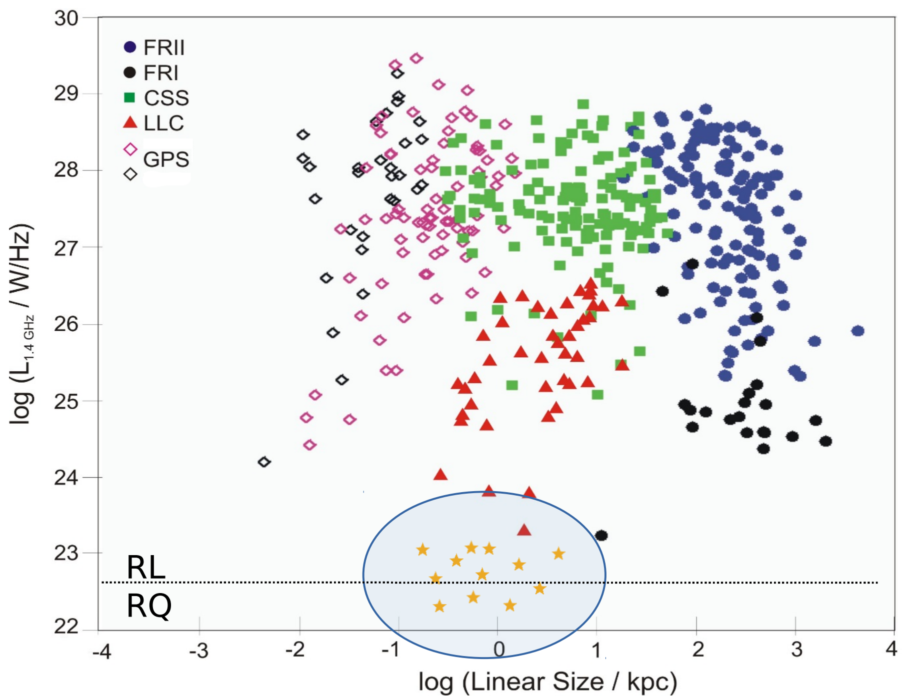
VTC034526



Type-II objects:

- central nucleus obscured by a molecular-dust torus
- direction of view is close to the plane of the disk
- **no Doppler enhancing**

Preliminary results – radio loudness parameter



Preliminary estimations

Source	$\log R_1$↓	$\log R_2$
VTC221650	1.13	1.82
VTC221812	?	?
VTC223041	1.85	2.79
VTC233001	1.31	2.56
VTC013815	1.02	1.83
VTC015411	-0.88	-0.01
VTC020827	0.96	2.07
VTC030533	1.72	2.40
VTC030925	-0.26	1.08
VTC031833	1.65	2.58
VTC034526	0.86	1.68

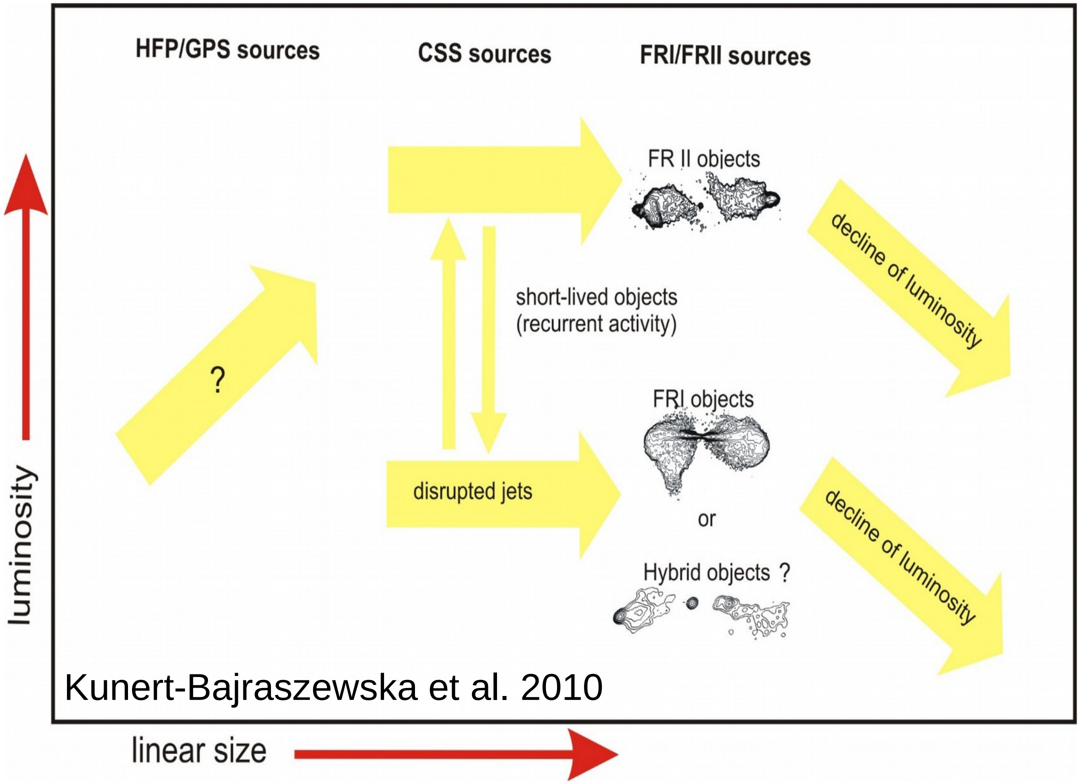
R_1 – with upper limit (0.5 for FIRST)

R_2 – after radio activity ignition

- According to classical division - sources are on the border of radio loudness.
- Sources show poorly developed jets (similar to RQ objects, Ulvestad et al. 2005 or „FR0” sources, Baldi+ 2015).
- Radio-loud and radio-quiet or jetted and not-jetted? (Padovani, Nature Astronomy, Volume 1, 2017)

Preliminary results: Variability timescales and new scheme

Assuming 20 years for an enhanced accretion episode and given the fact that $50deg^2$ of the sky has ~2000AGNs with flux density >3mJy, we can estimate the period of **occurence of such episodes as ~40 000 years** (Kunal et al. 2016).



Kunert-Bajraszewska et al. 2010

That suggests that some young radio-loud AGNs have short-lived jets operating on timescales of 10^4 –10^5 years

(Reynolds & Begelman 1997;
Czerny et al. 2009;
Kunert-Bajraszewska et al. 2010)

'Young' GPS or CSS source means ongoing episode of the accretion disk outburst

LOFAR

The lifespan 10^4-10^5 years means that not all GPS and CSS sources will be able to develop large scale morphologies.

Many will fade away being middle-aged.

Thus faint diffuse emission should be present on arcsecond scales in some young AGNs.

If found - such extended emission could mean That the CSS/GPS sources are recurrent, with the extended emission originating from a previous phase of activity, or that the parsec scale jets have been smothered and jet propagation halted on scales of tens of parsecs.

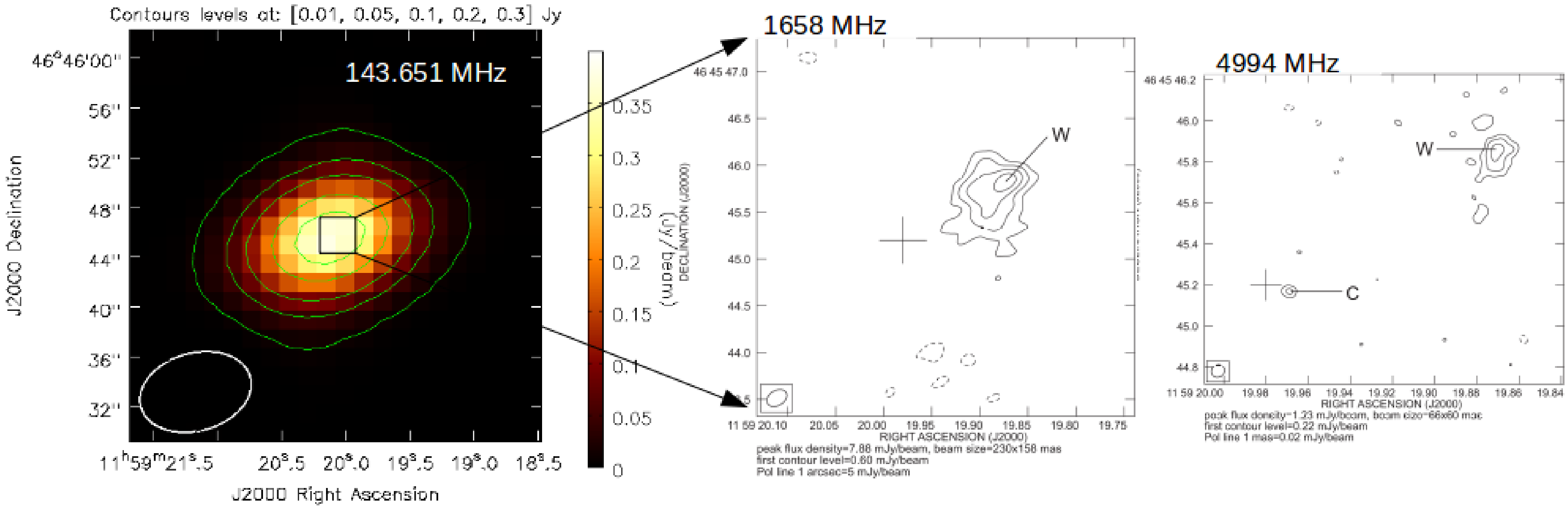
Another indications come from study of the low frequencies - GPS sources peaking above 5GHZ display also a convex spectrum at lower frequencies implying that some AGN go through multiple epochs of activity (Calingham et al. 2017).

LOFAR

LOFAR capabilities are ideal to determine how common this steep spectrum extended emission is, and enable us to study different phases of evolution of radio sources.
<u>We expect much larger population will be discovered.</u>

LOFAR

MERLIN (2010 sample)



Only Dutch stations. We need international baselines!

<u>History of phases of activity written in diffused emission regions</u>

We have already observed 3 sources – to be analyzed.

Summary

The analysis of newly-born AGNs has just begun - we will discover more and more sources of this type.

We have discovered **twelve new radio transients** on timescales of 5-20 years, largely associated with renewed AGN activity:

- sources that crossed the RQ/RL border few years ago
- peaking at a few GHz
- with fast evolving radio spectra.
- Have poorly developed, probably weak jets.

We are looking for extended emission around young AGNs that could originate from previous phase of activity – LOFAR.

Thanks to the wide observational campaign, we will be able to collect the whole EM spectrum and follow the evolution of radio activity from its very beggining.


Thank you!