VLBI survey of nearby infra-red luminous galaxies

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Problem statement:

To find galaxies that have position offset between IR and radio positions.

IR position — marker of the center of stellar mass
radio position — marker of the AGN

Motivation:

An AGN can move from the center of galaxy due to interaction with other galaxies. Therefore, it is a marker of galaxy evolution.

Goal:

minimum: to find at least one offset AGN

maximum: to build statistics of offset AGNs

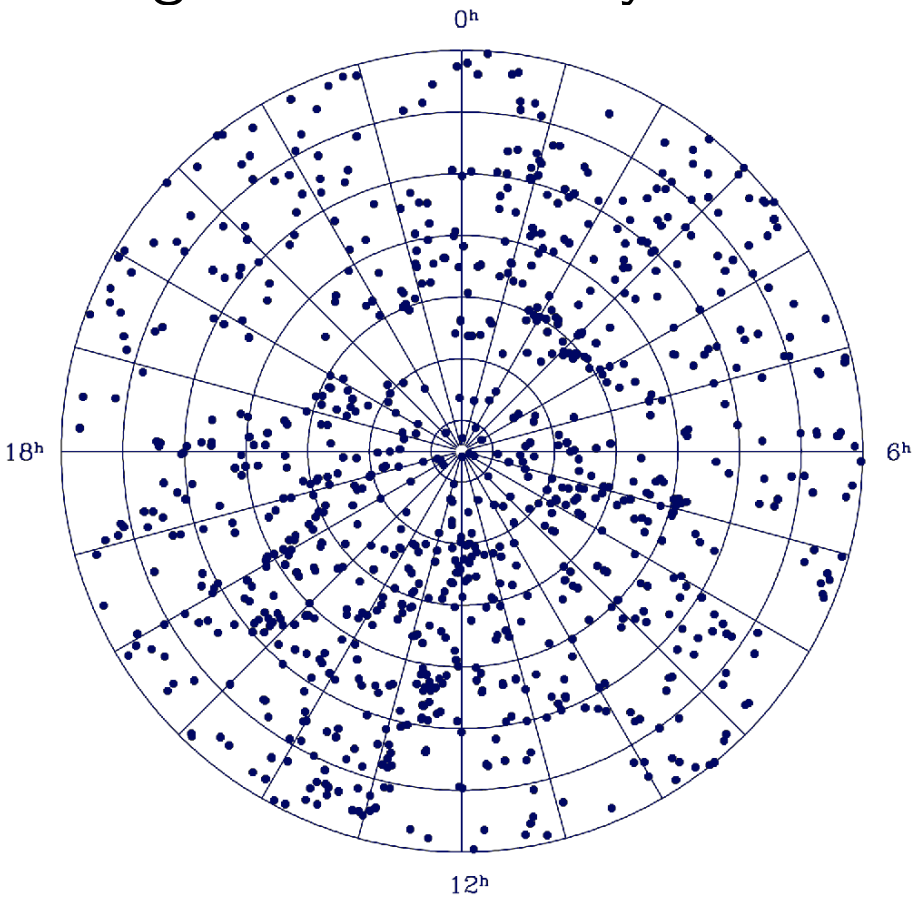
Sample:

2MASS galaxies that

(a) brighter than K20fe $= 12.25$ at $\lambda = 2.2\,\mu m$

(b) have radio emission brighter than 50 mJy at 1.4 GHz according to the NVSS

(c) have $\delta > -30°$



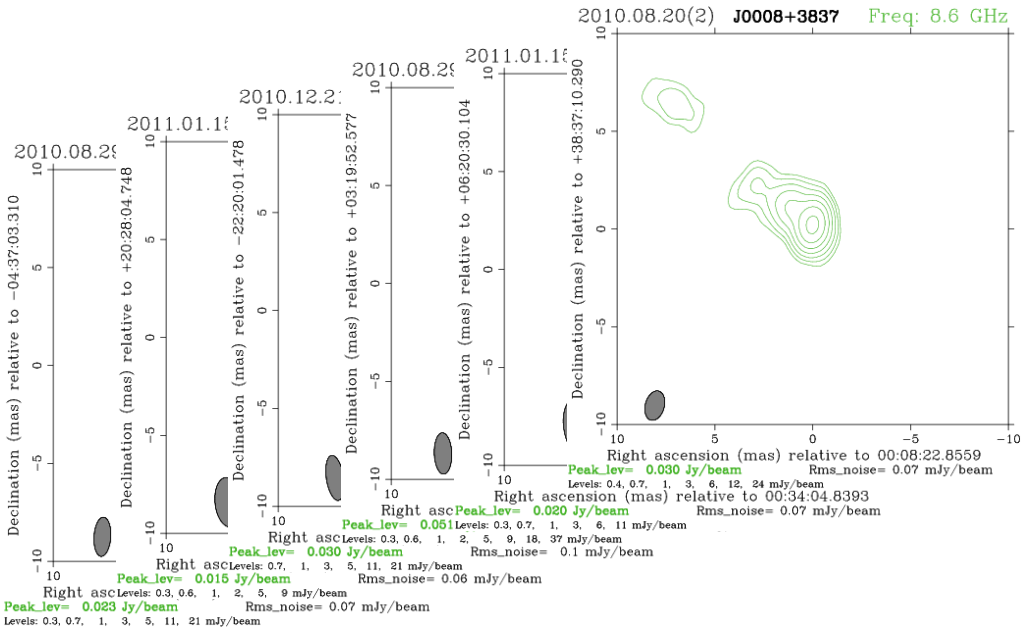
In total, 1504 galaxies over 9 steradian.

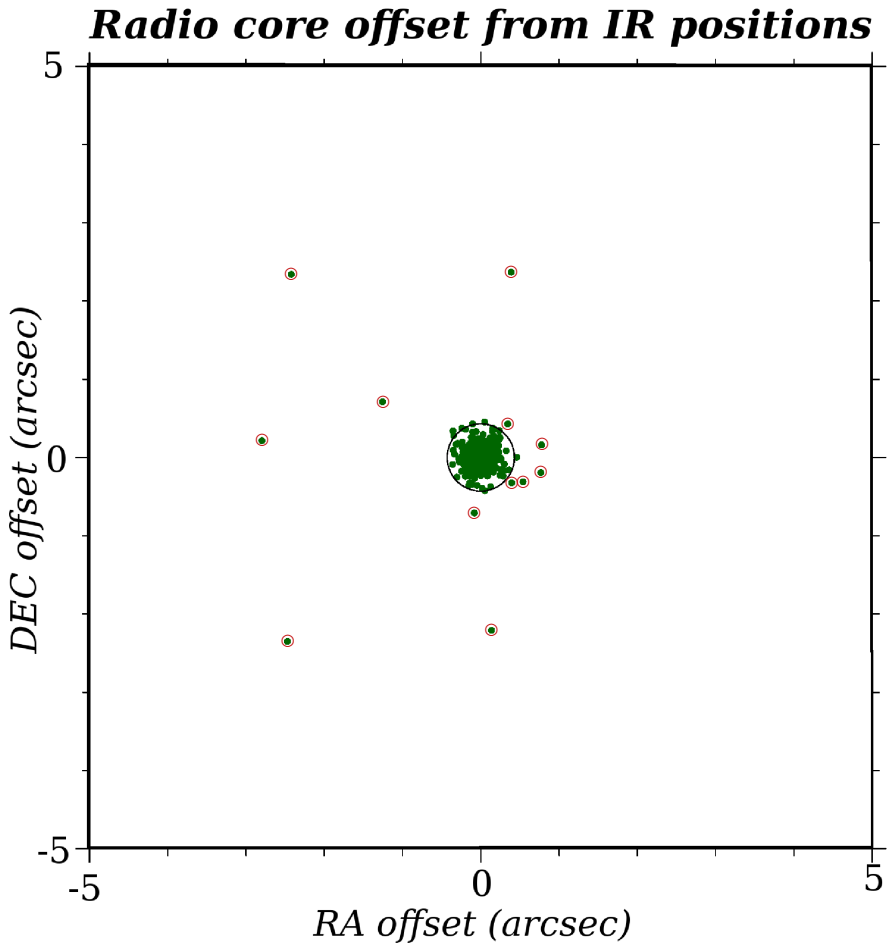
Observations:

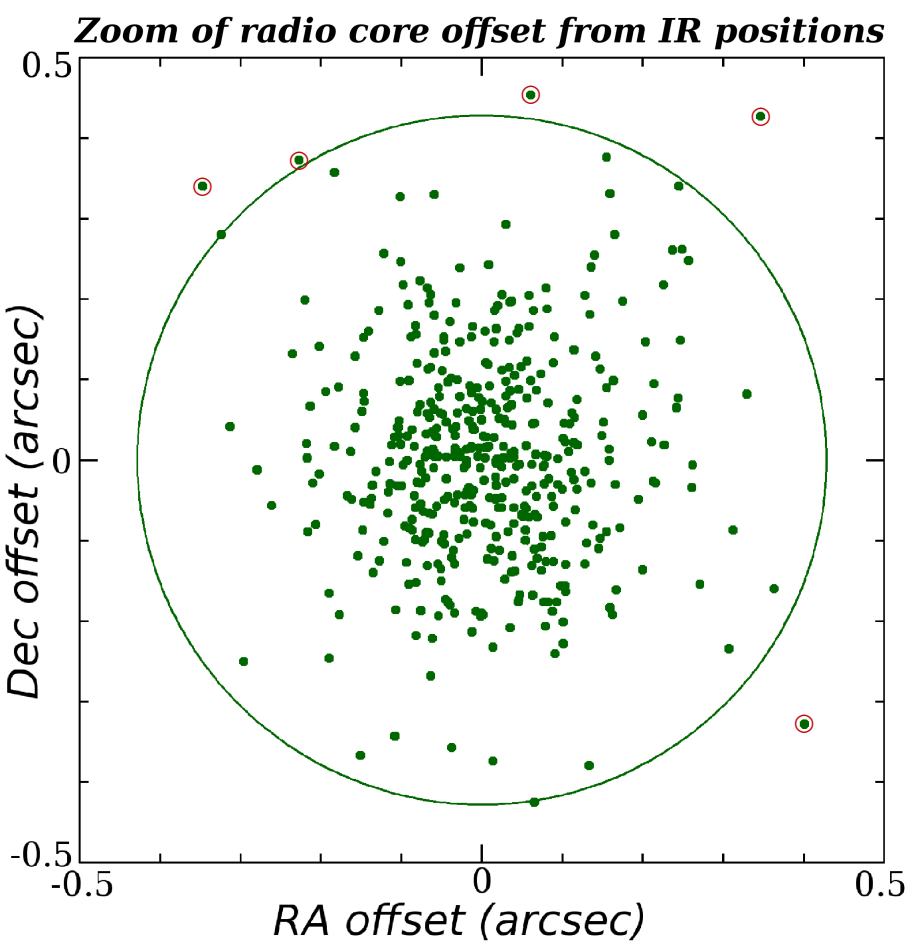
Total # targets:	1415
Time range:	July 2010 through June 2012; 2016
Array:	VLBA
Polarization:	RR
Bit rate:	0.5 Gbps
Int. time:	2 times 360s
Frequencies:	[7.9, 8.9] GHz
FoV:	$1'$ at 80%
Schedule type:	abs and diff astrometry
Scheduling:	fill-in mode
Analysis:	totally AIPSless

Results:

Detection rate:	45%
Total # detections:	642 (including 89 from other surveys)
Detection limit:	8–10 mJy
Position accuracy:	50% percentile: 0.5 mas
Position accuracy:	80% percentile: 1.1 mas
Position accuracy:	95% percentile: 3.8 mas
Images:	2226 images, including calibrators



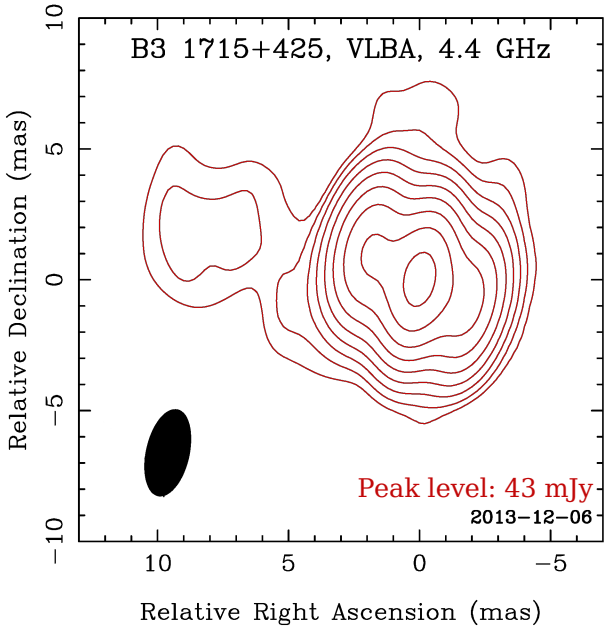


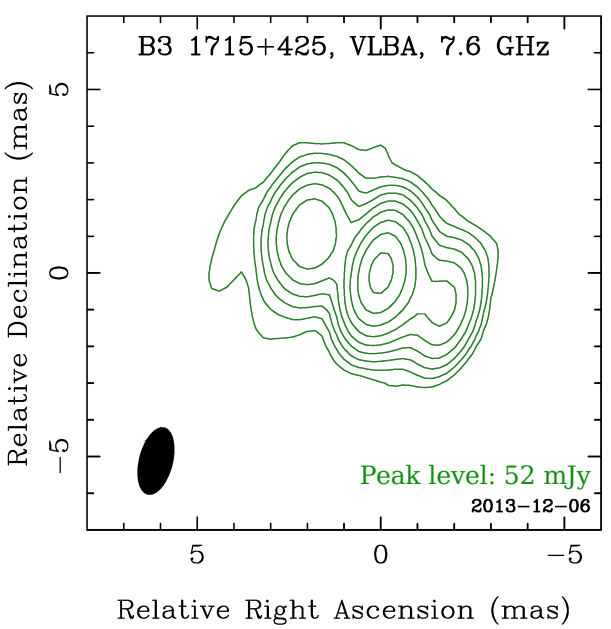


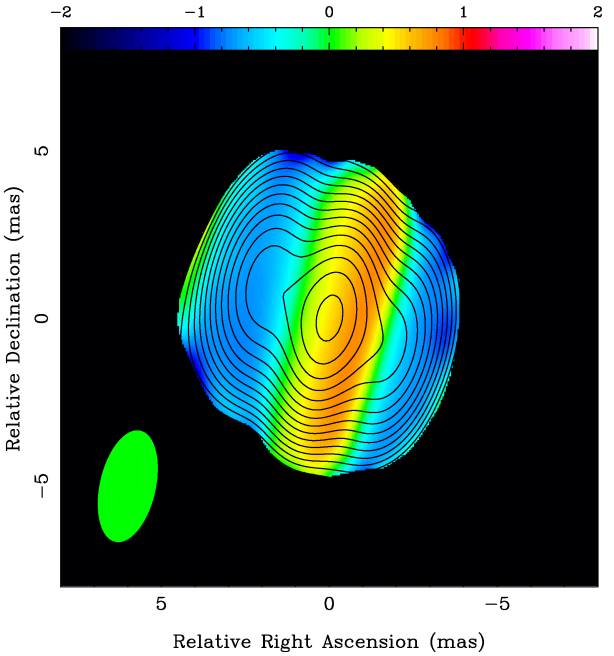
Differences: rms 114 mas; bias: < 10 mas.

Catch #1: J1717+4226 (B3 1715+425, ZwCl 8193)

Distance radio/IR: 2".397
Observations: 2008.03.08 (2.2/8.6 GHz), 2013.12.06 (4.3/7.6 GHz)
Kiloparsec-scale spectrum index (1.4/4.8 GHz): 0
Parsec-scale spectrum: -0.26 ± 0.07 (2.2/8.6 GHz); $+0.24 \pm 0.13$ (4.3/7.6).

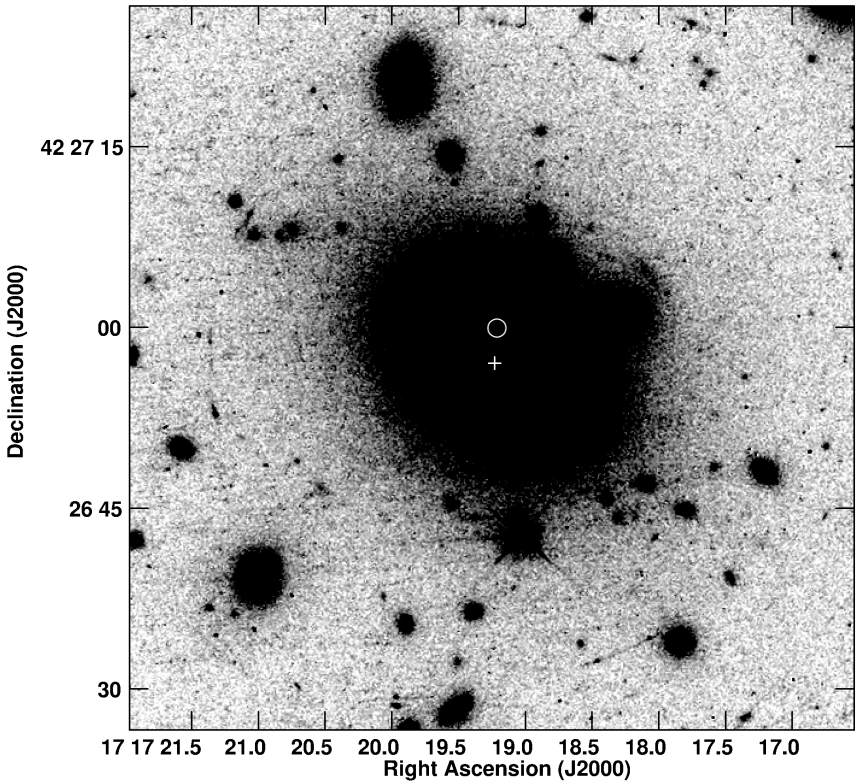


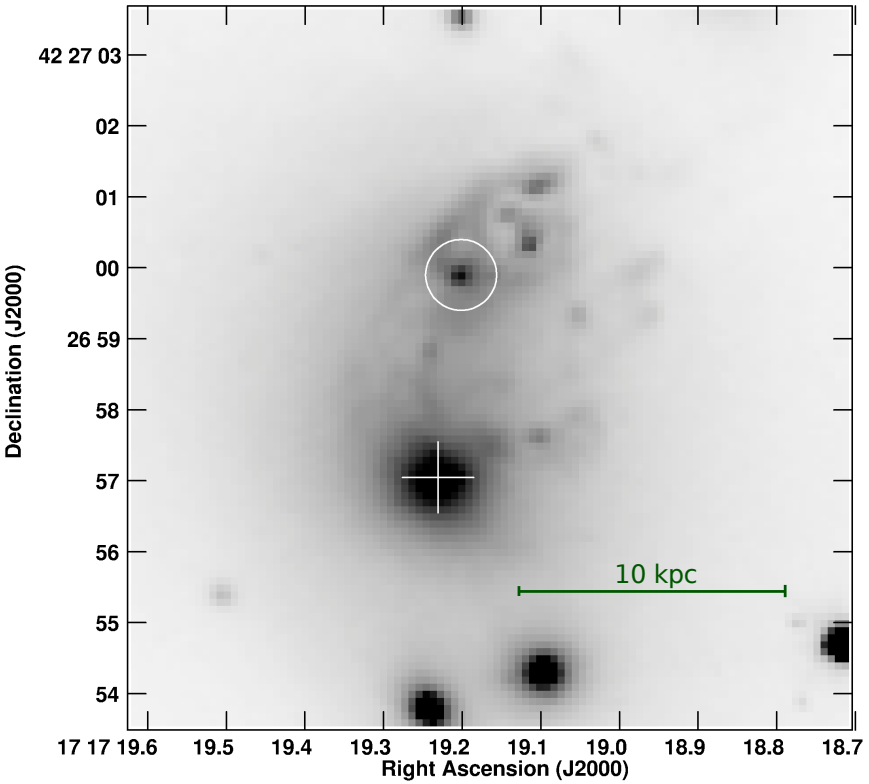




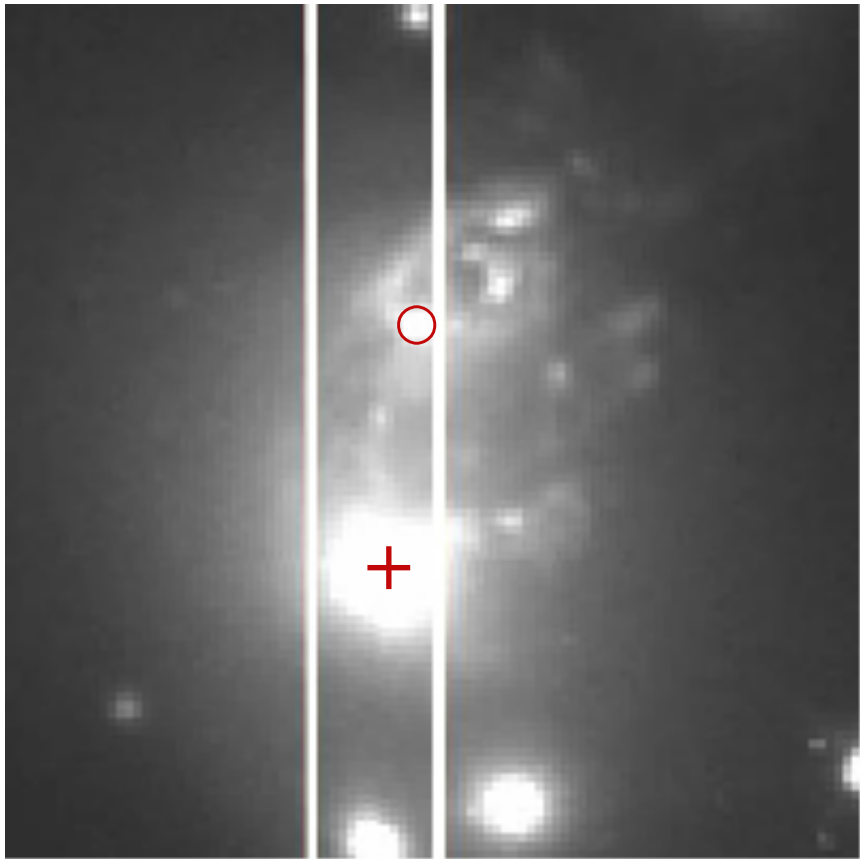
Spectral index ($S \sim +f^{\alpha}$).

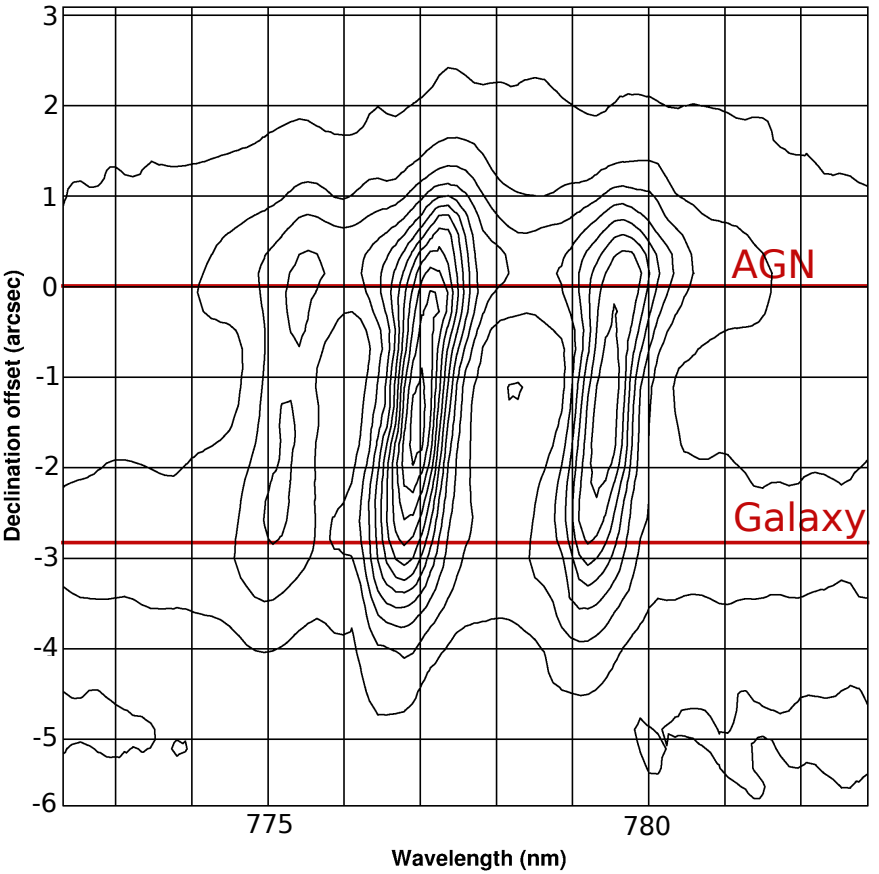
Hubble image of J1717+4226 at λ 606 nm





Spectrum of J1717+4226 centered on the H_α and N II lines





Spectrum from 3.6 m Apache Point Observatory telescope. Redshift of emission lines:

+ Near the background galaxy: z = 0.18215
○ Near the AGN: z = 0.18271 The difference: **140 km/s**.

Spectrum of J1717+4226 (*continued*)

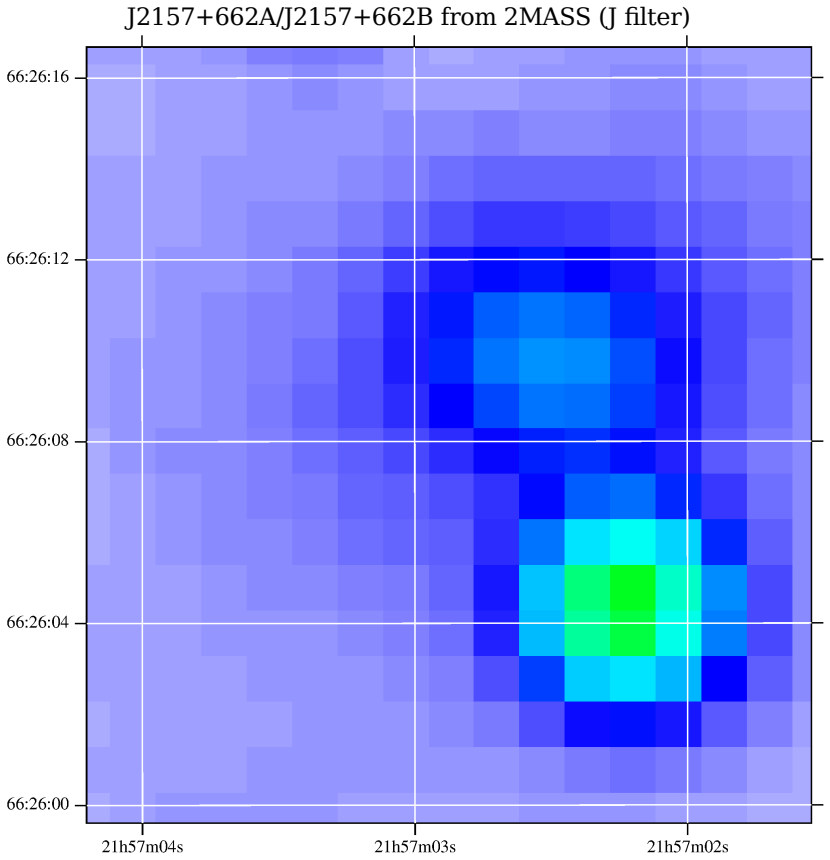
Redshift of emission lines:	0.1827
Redshift of absorption line:	0.1754
Difference:	1860 km/s
Escape velocity:	3000 km/s
FWHM of emission line	320–480 km/s

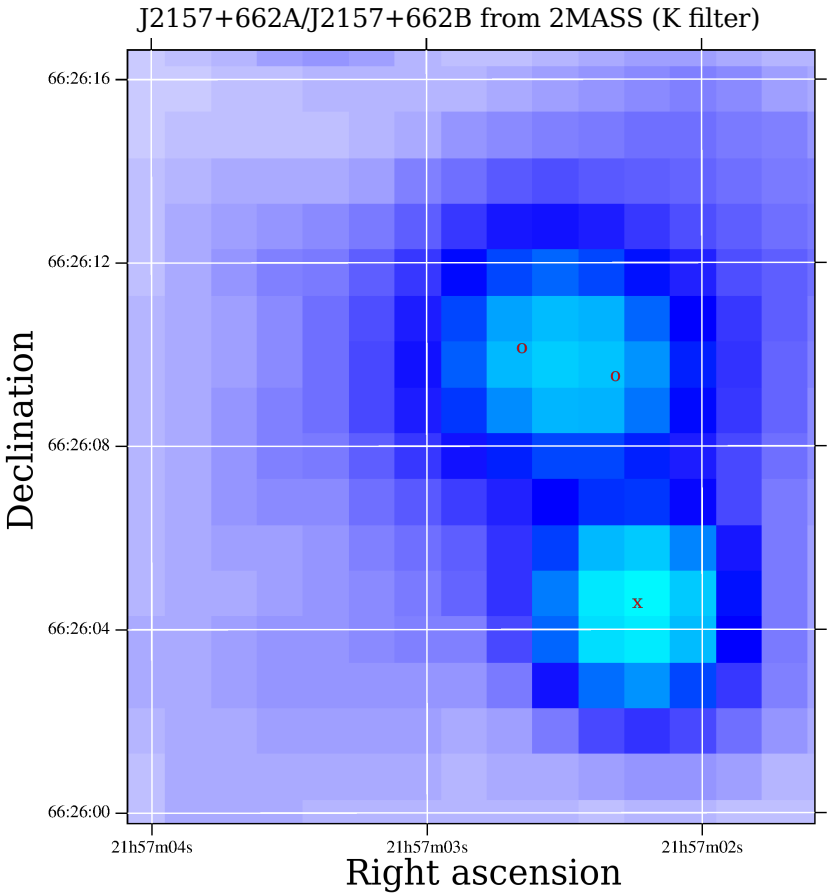
Interpretation:

Normal galaxy fell to ZwCl 8193, was tidally stripped and is rapidly moving away from ZwCl 8193.

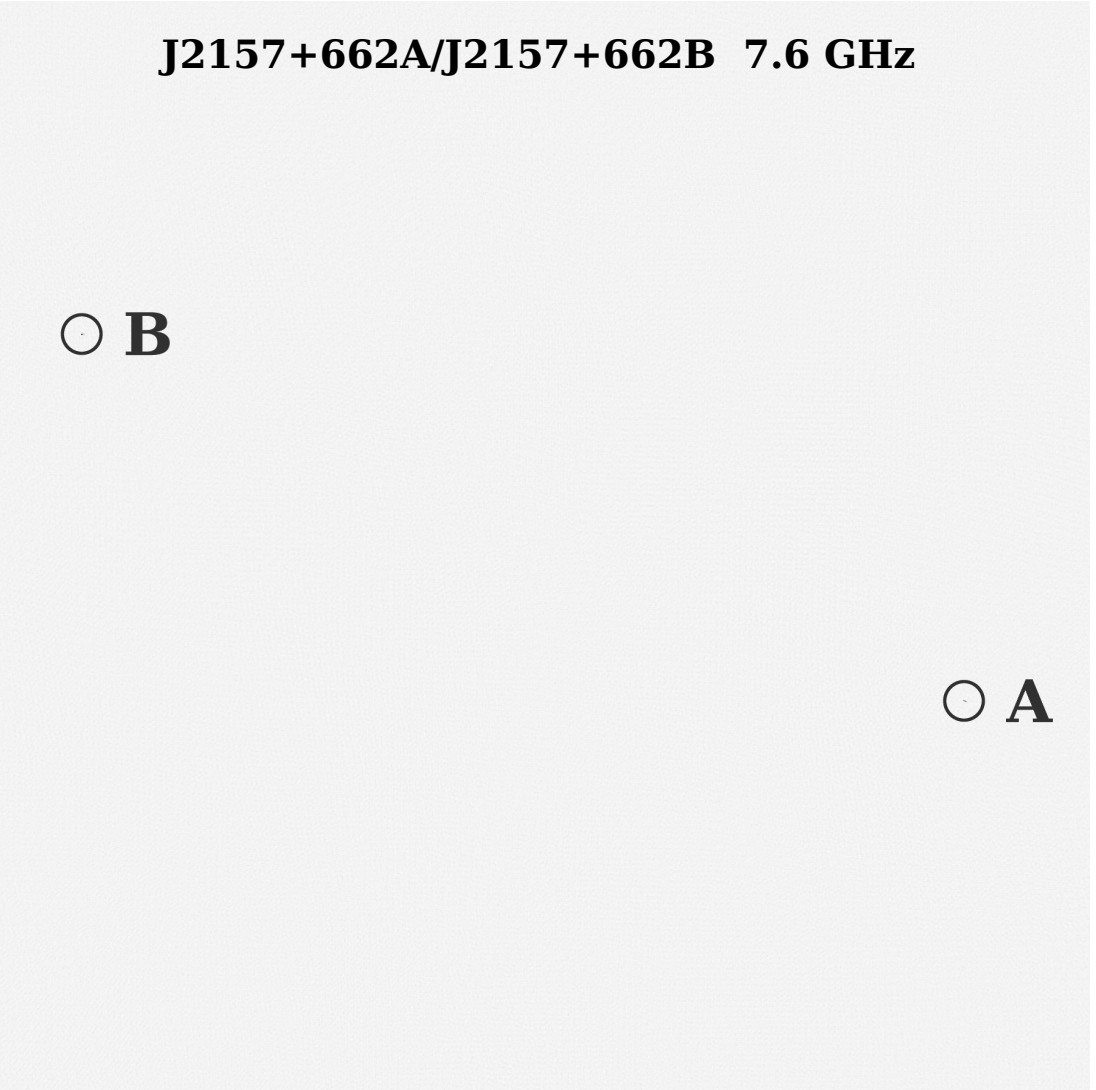
Mass J1717+4226 is $< \ 6 \cdot 10^9 \ M_\odot$.

Catch #2:


J2157+662A/J2157+662B from 2MASS (J filter)
66:26:16
66:26:12
66:26:08
66:26:04
66:26:00
21h57m04s
21h57m03s
21h57m02s


J2157+662A/J2157+662B from 2MASS (K filter)
66:26:16
66:26:12
66:26:08
66:26:04
66:26:00
Declination
21h57m04s
21h57m03s
21h57m02s
Right ascension

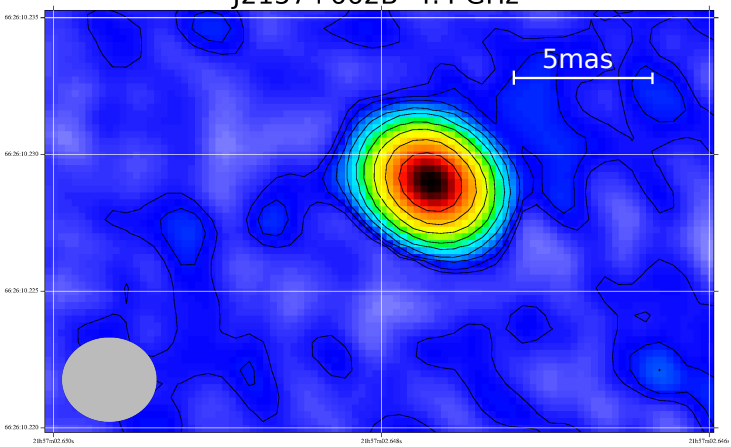
VLBA image:



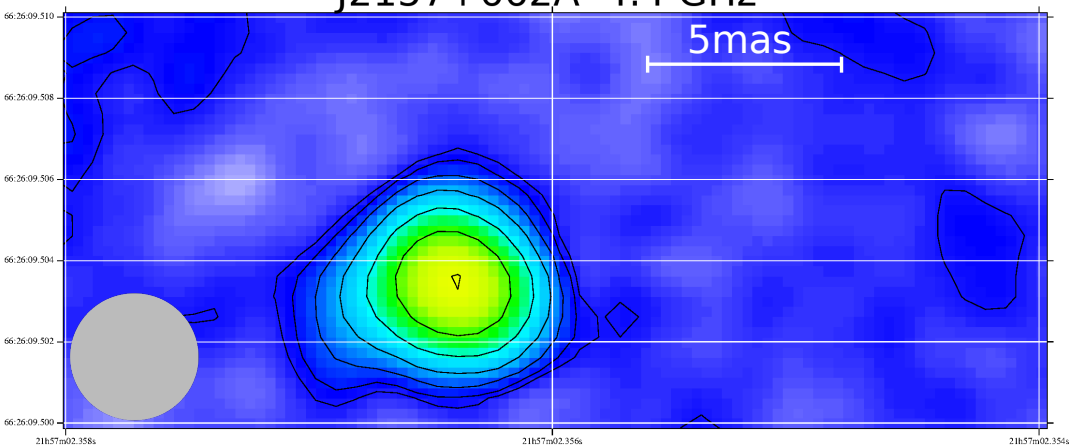
Distance A/B: 1”.8894 (2.1 kpc)

VLBA images:

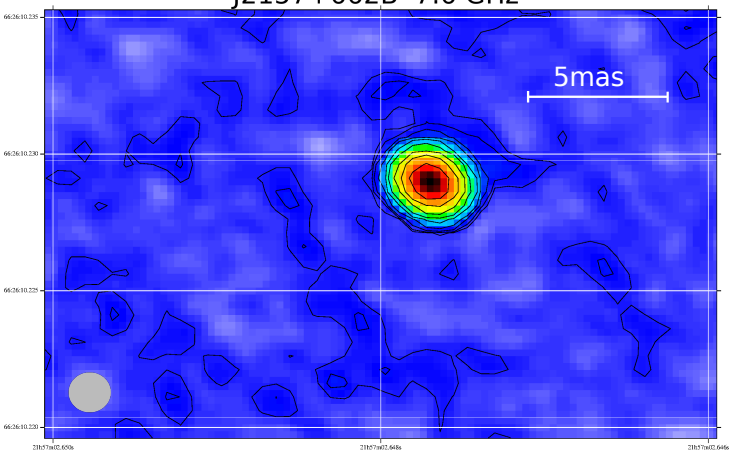
J2157+662B 4.4 GHz



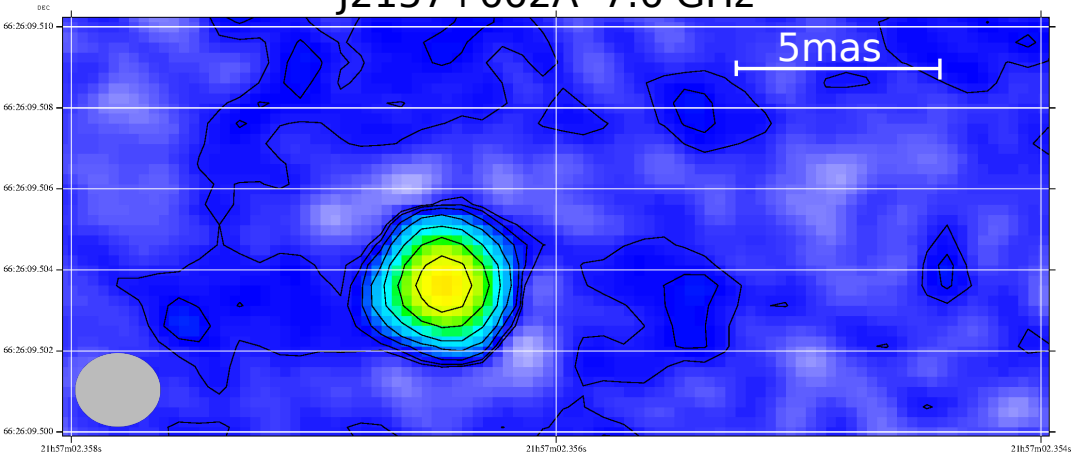
J2157+662A 4.4 GHz



J2157+662B 7.6 GHz



J2157+662A 7.6 GHz



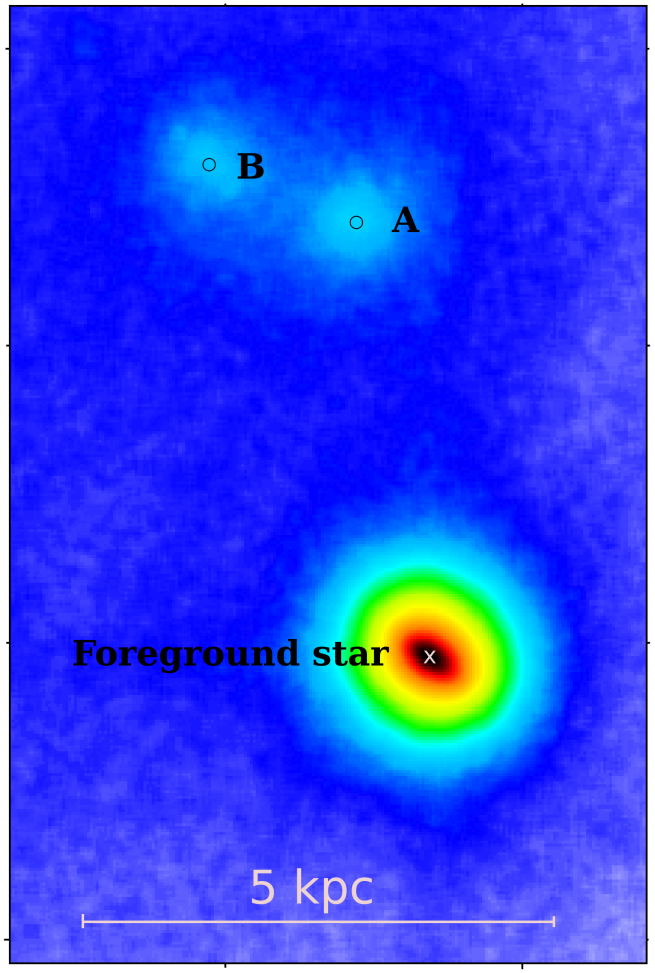
VLBA flux densities (in mJy)

		J2157+662B	J2157+662A
		$F_{\rm tot}$	$F_{\rm tot}$
2013.07.21	C	45.1	4.4
2013.12.06	C	29.2	13.1
2015.11.18	C	29.7	5.2

		J2157+662B	J2157+662A
		$F_{\rm tot}$	$F_{\rm tot}$
2013.07.21	X	56.4	12.2
2013.12.06	X	40.9	10.6
2015.11.18	X	35.4	6.2

Adaptive optic image:

J2157+662A/B from ROBO-AO



Possible interpretations:

1. Double AGNs at 2.1 kpc
2. Gravitational lens

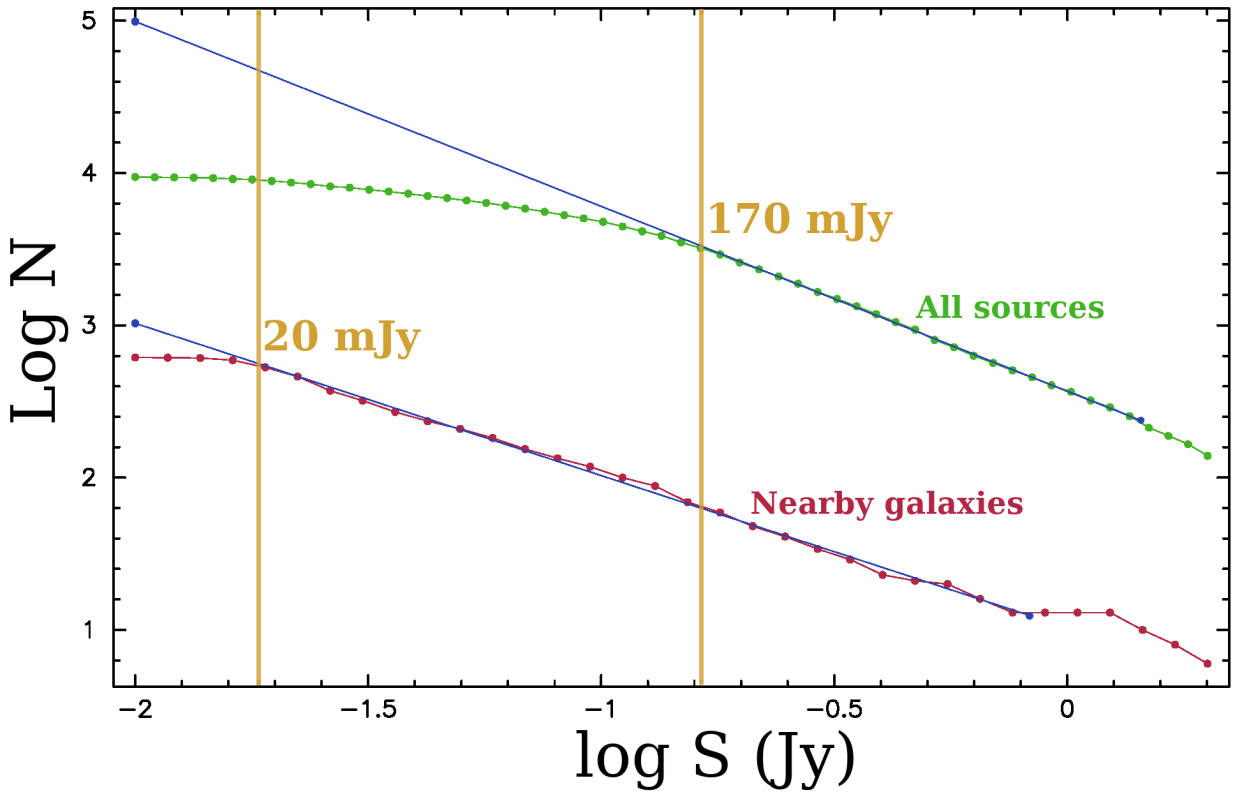
Redshift 0.0584 is from absorption lines.

No emission line is detected.

Robo-AO is the first autonomous laser adaptive optics system currently in the commissioning phase at the the 2.1-m telescope at Kitt Peak National Observatory, AZ, USA.

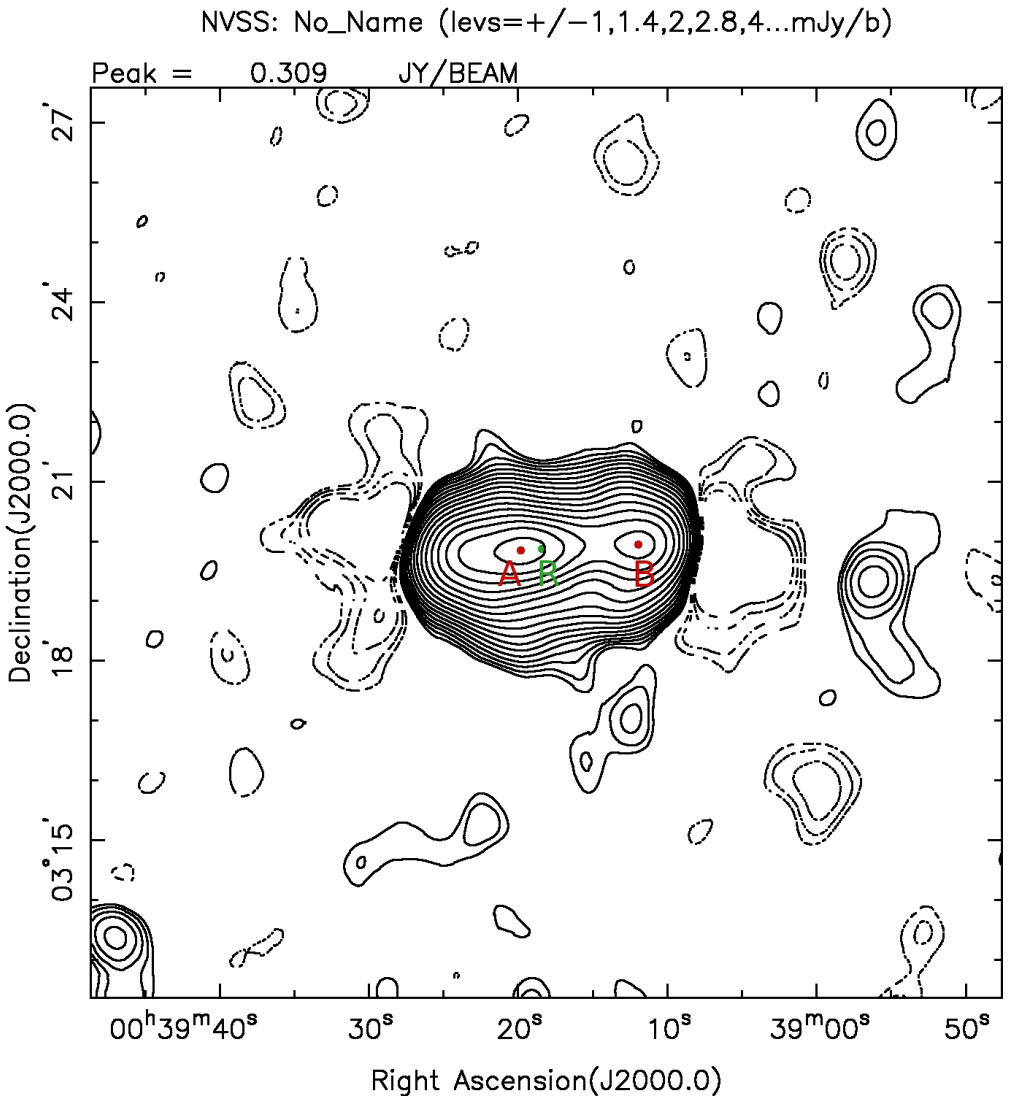
Preliminary population analysis

Total # sources:	1504	
# sources observed:	1444	96%
# sources processed:	1321	88%
# sources detected:	642	43%
# sources detected brighter 20 mJy:	527	35%



All sources: **Slope -1.23** **Completeness 170 mJy**
Nearby galaxies: **Slope -1.00** **Completeness 20 mJy**

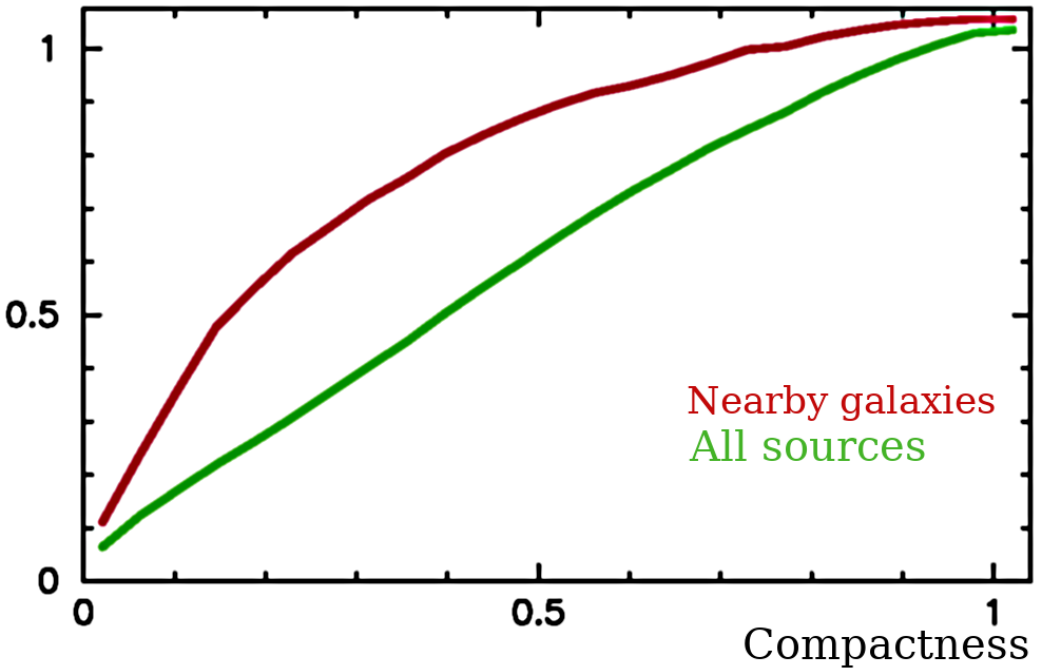
Caveats of association NVSS/VLBI: J0039+0319



A–**R** offset: $26''$. **R** is within 0".2 of the IR galaxy.

Compactness analysis ($S_{\rm VLBI}/S_{\rm NVSS}$)

Cumulative distribution of the compactness:



Using completeness and completeness distribution, we can compute mathematical expectation of # detections above 20 mJy.

Total # observations:	1321	
Predicted # detections:	805	
Observed # detections:	527	65%

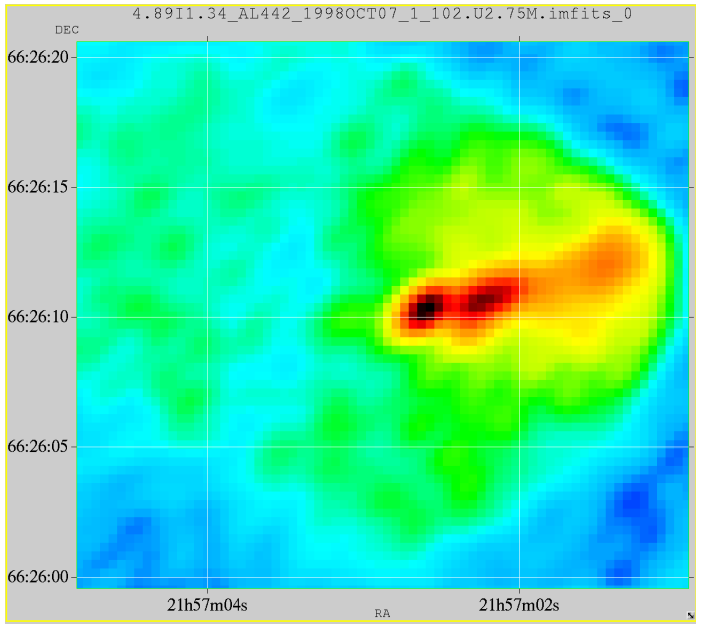
Summary

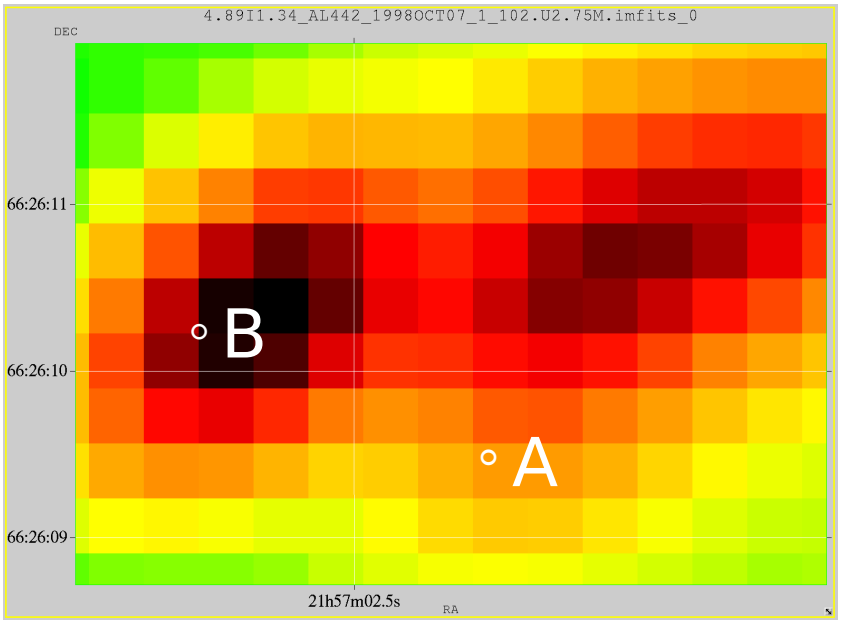
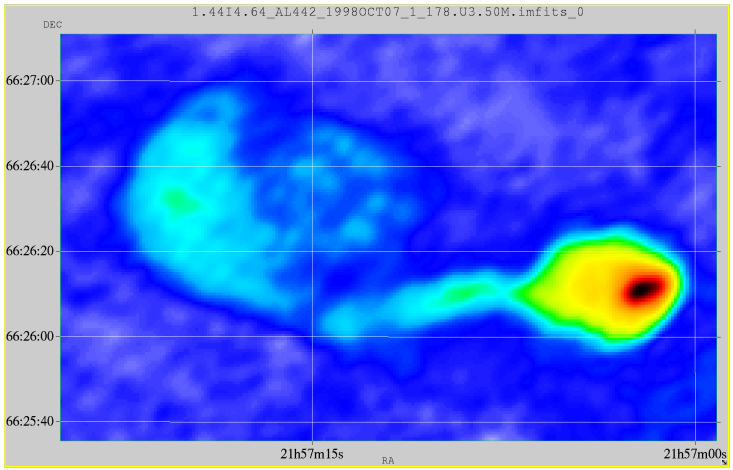
- 1445 nearby IR galaxies have been observed with VLBA;
- Detection rate is 45%;
- Several offset IR/VLBI galaxies have been found;
- Catch #1: a stripped naked galaxy in a cluster **http://arxiv.org/abs/1606.04067v1**;
- Catch #2: a pair of radio sources $1''.89$ apart;
- LogN–LogS curves of the nearby sample has a different slope;
- There are two populations in the nearby galaxy sample: with and without an AGN with parsec scale emission inside.

Project web-site: **http://astrogeo.org/v2m**

Archive VLA images:

4.8 GHz:





1.4 GHz: