Studying the late stages of radio galaxy evolution with LOFAR

Marisa Brienza
Raffaella Morganti, Leith Godfrey
and many more!

Heinz+2016

AGN REMNANTS represent only few % of the sources in radio catalogues

(e.g.Giovannini+1988, Parma2007, Murgia+2011,Mullin+2008)

ARE WE MISSING THEM ?

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AGN REMNANTS represent only few % of the sources in radio catalogues

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ARE THEY EVOLVING FASTER THAN EXPECTED ?

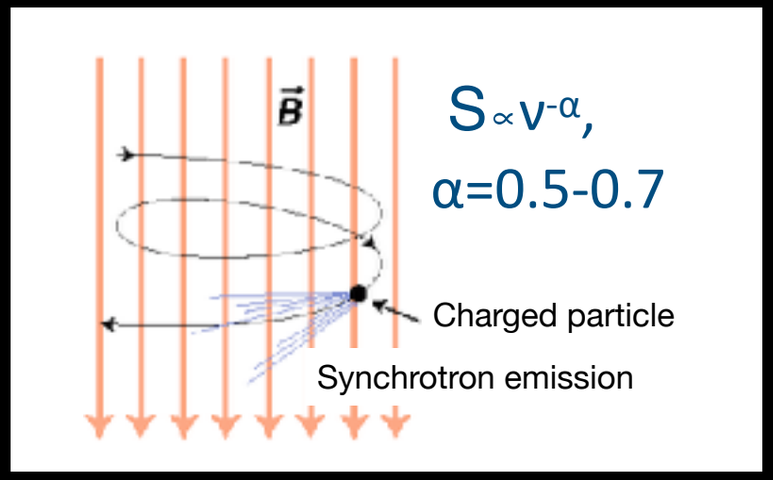
HOW?

LOFAR

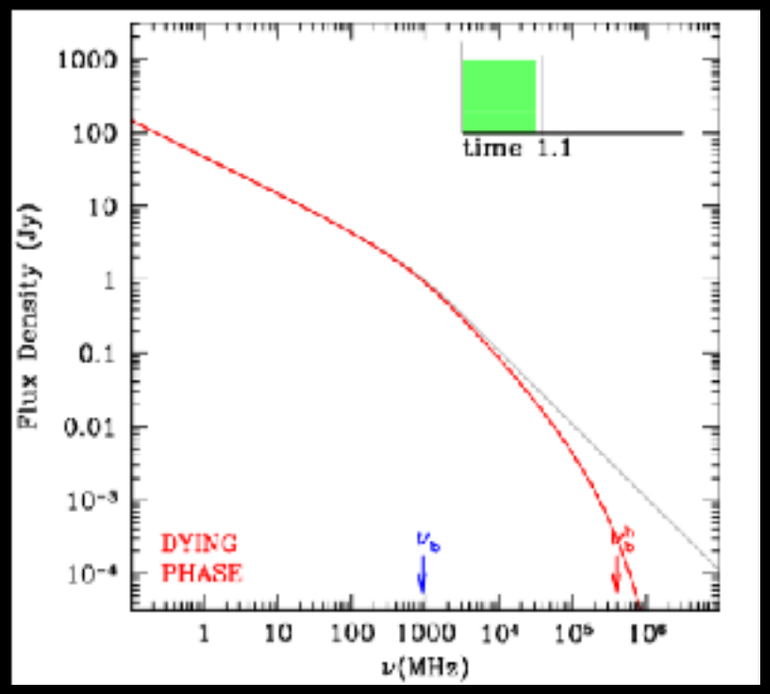

Birr
Onsala
Dutch stations
Norderstedt
Chilbolton
LOFAR Core (NL)
Potsdam
Baldy
Borówiec
Jülich
Effelsberg
Tautenburg
Łazy
Unterweilenbach
Nançay
LOFAR
ASTRON
Netherlands Institute for Radio Astronomy

LOW FREQUENCY

Low frequency to detect the oldest populations of emitting particles

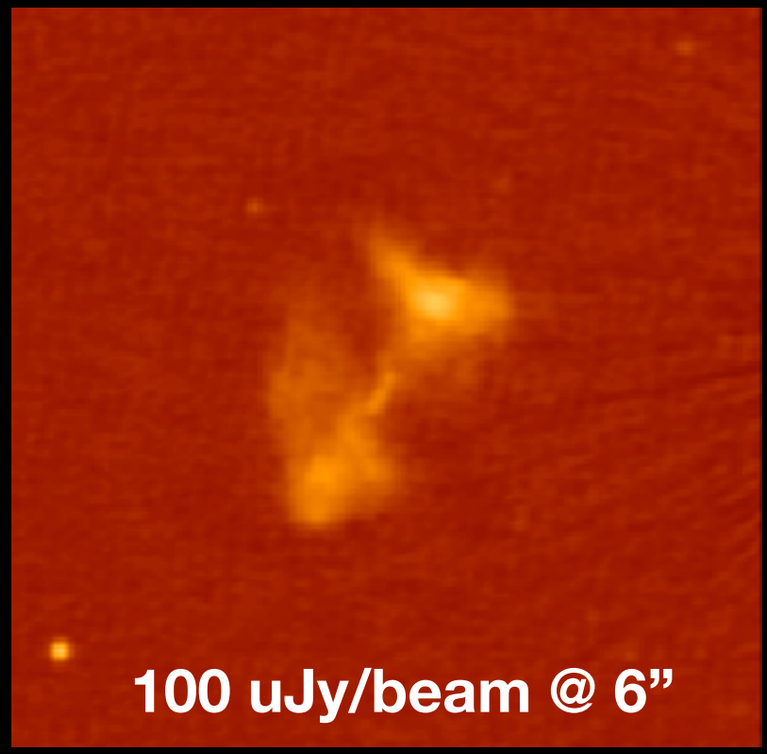


$$t_s = 1590 \frac{B_{eq}^{0.5}}{(B_{eq}^2 + B_{CMB}^2)\sqrt{\nu_b(1+z)}},$$



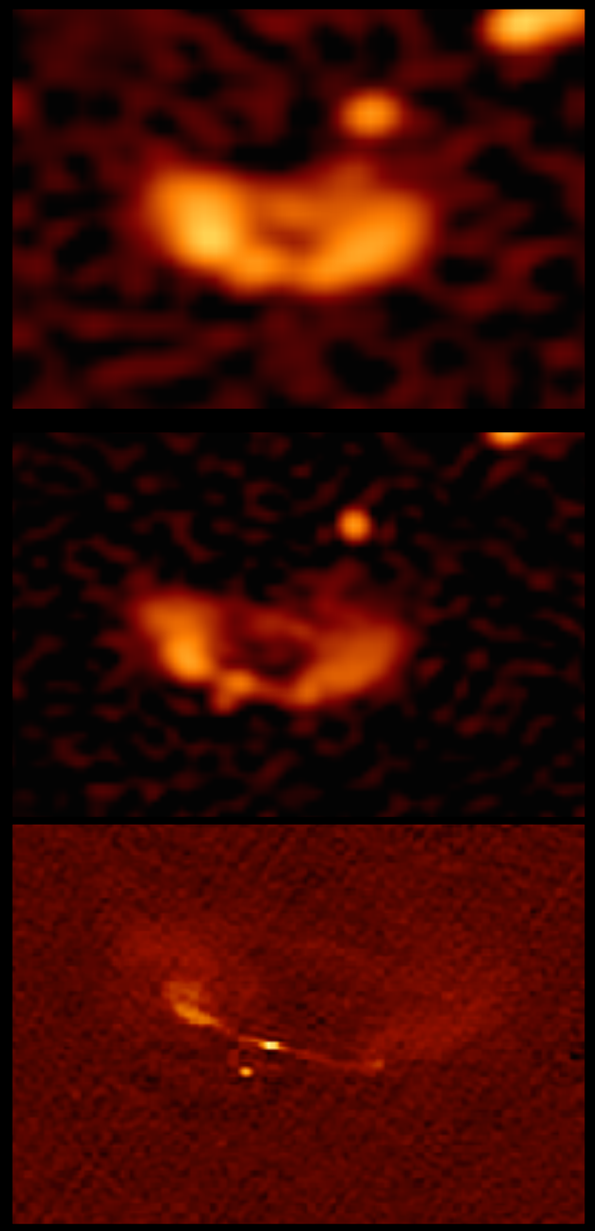
HIGH SENSITIVITY

to detect low surface brightness emission



UV-COVERAGE

get high resolution and sensitivity to large scales at the same time

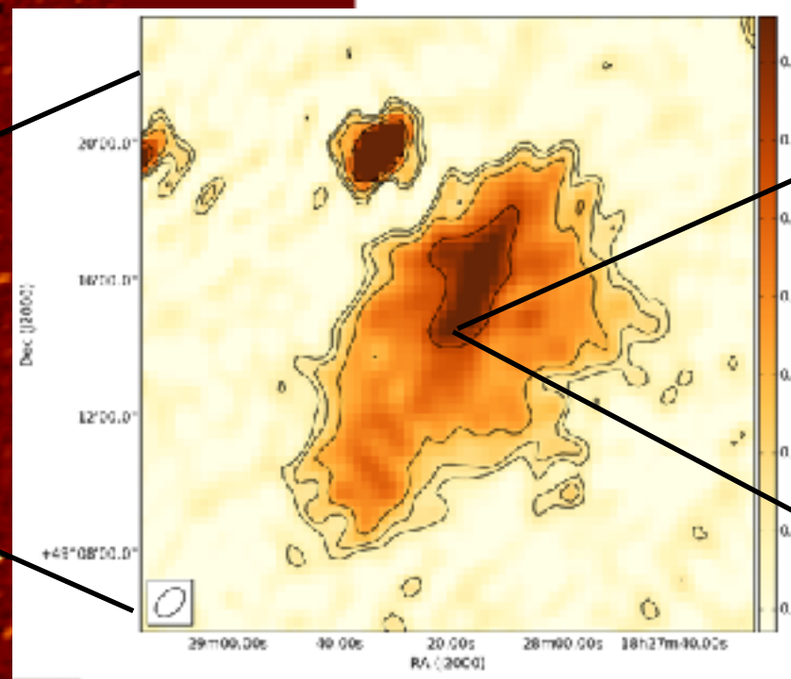


LOFAR discovery of a 700-kpc remnant radio galaxy at low redshift

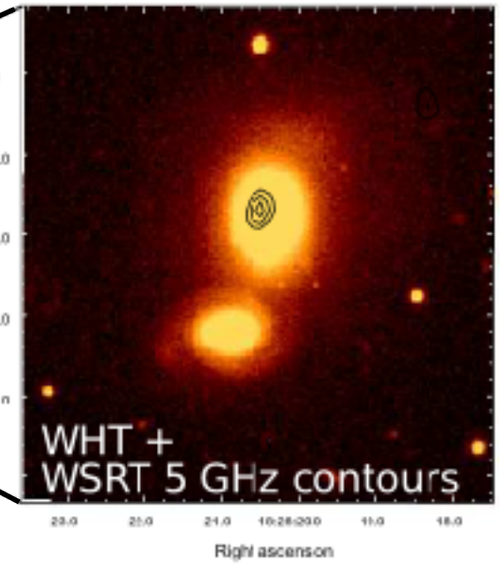
Brienza+2016,A&A,585, A29

LOFAR 150 MHz

3C380

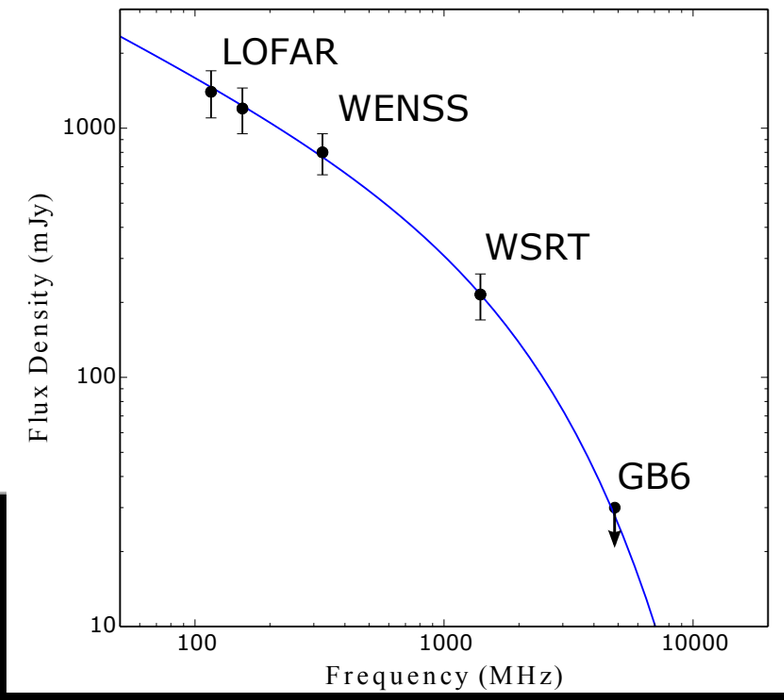


z=0.05



core prominence
L_core/L_source
=1e-4

no ultra-steep
spectral index
at MHz frequencies
but sudden
steepening above
1.4 GHz!



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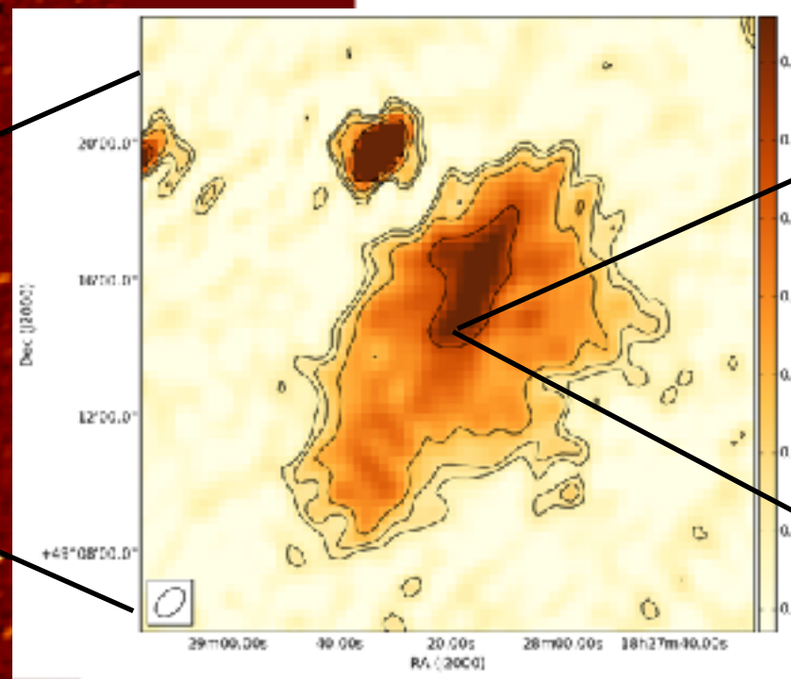

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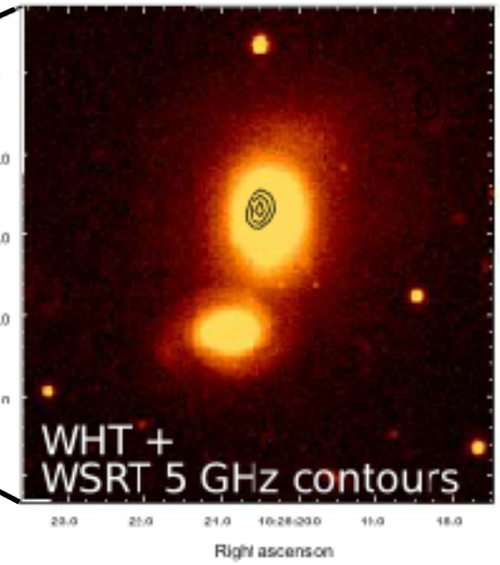

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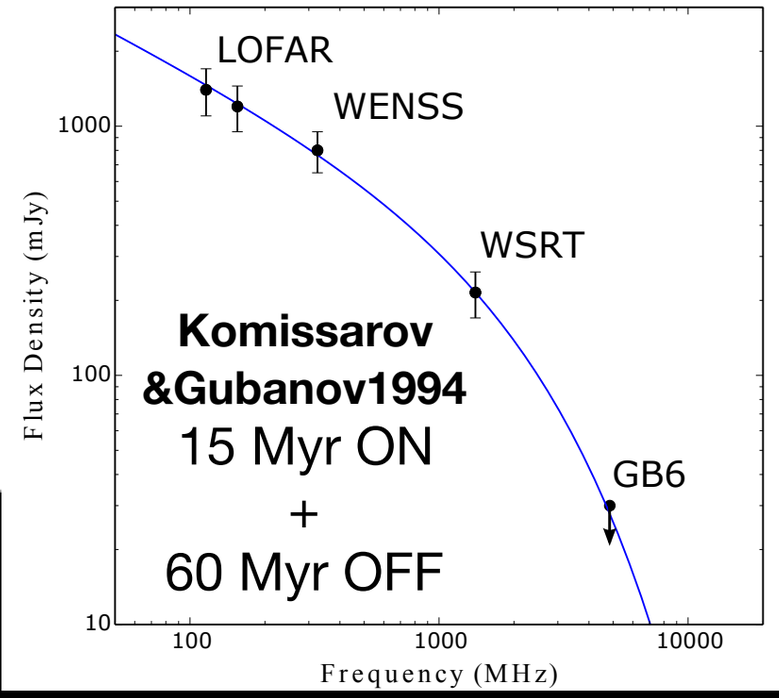
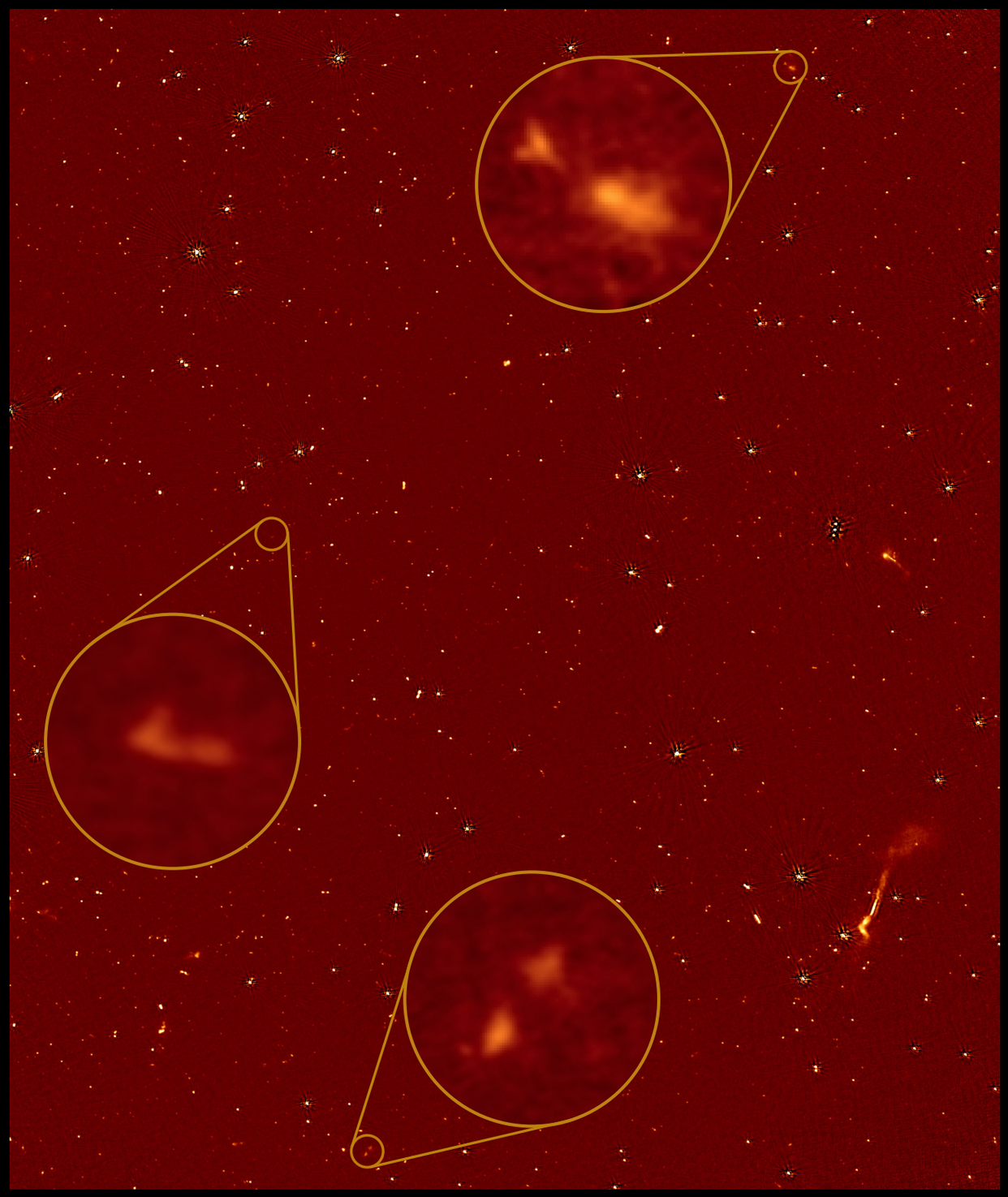


BETTER SELECTION

?

Search for remnants in the LOFAR Lockman Hole at 150 MHz

Brienza+2017,A&A,606, A98



HBA observation
(110-180 MHz)

70 MHz bandwidth
(300 subbands)

35 deg^2

10 hrs int. time

14”x18” resolution

rms~0.75 mJy

about 6000 sources

Mahony et al. 2016

ULTRA-STEEP SPECTRAL INDEX

LOFAR-NVSS
α(150-1400)>1.2

(e.g. Parma+2007, Dwarakanath+2009, Sirothia+2009, VanWeeren+2009)

SPECTRAL CURVATURE

LOFAR-WENSS-NVSS
α(1400-327)-α(327-150)>0.5

(Murgia+2011)

COMPLEMENTARY SELECTION CRITERIA

MORPHOLOGY

relaxed,
low surface brightness,
no compact feature at
1400 MHz, size > 60”

(e.g. Saripalli+2009)

CORE PROMINENCE

LUMINOSITY CORE
LUMINOSITY EXTENDED
< 0.005
size > 60”

(e.g. Giovannini+1989, Mullin+2008, Hardcastle+2016)

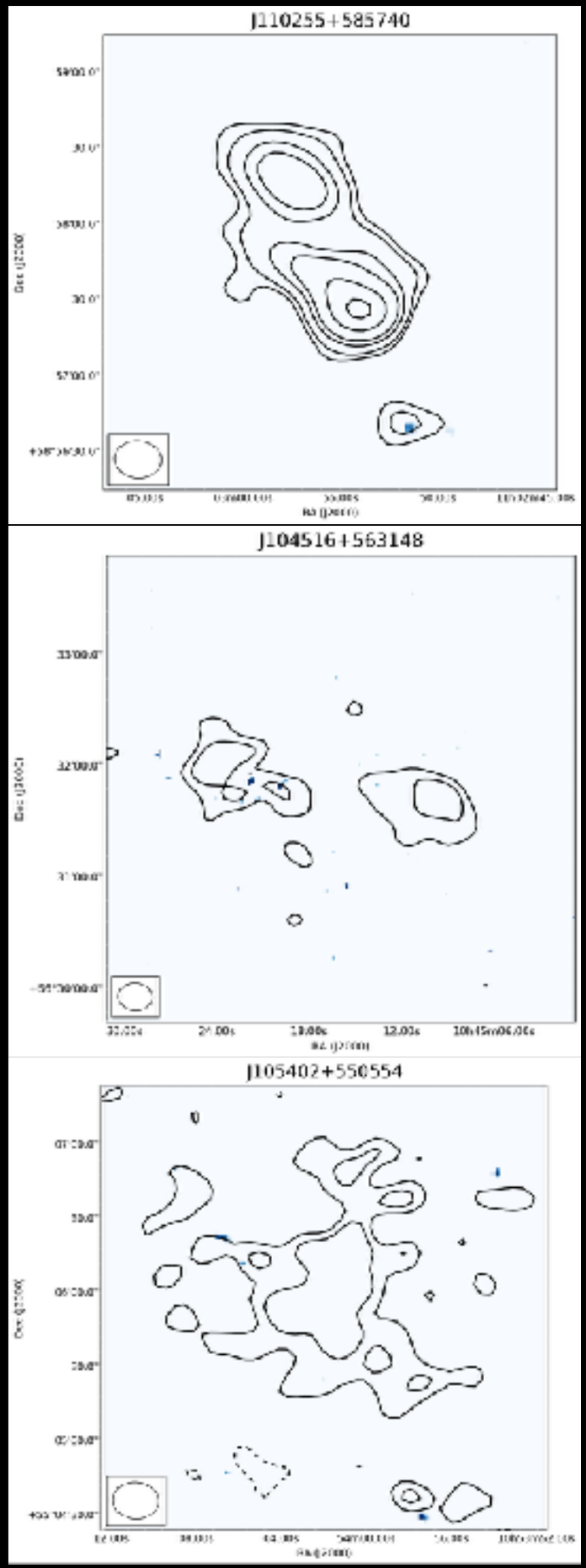
Results from the selection

23 remnant radio galaxy candidates selected

By using low frequency and multiple selection criteria **the fraction of remnant radio galaxies remains low!**

Only a fraction of the remnants selected morphologically (<46%) and with low core prominence (10%) **have ultra-steep spectra** with α(1400-150)>1.2 confirming that remnants can have different spectral properties (depending on the phase of their evolution) and thus the need for extra selection criteria.

CONFIRMED BY Mahatma+17!

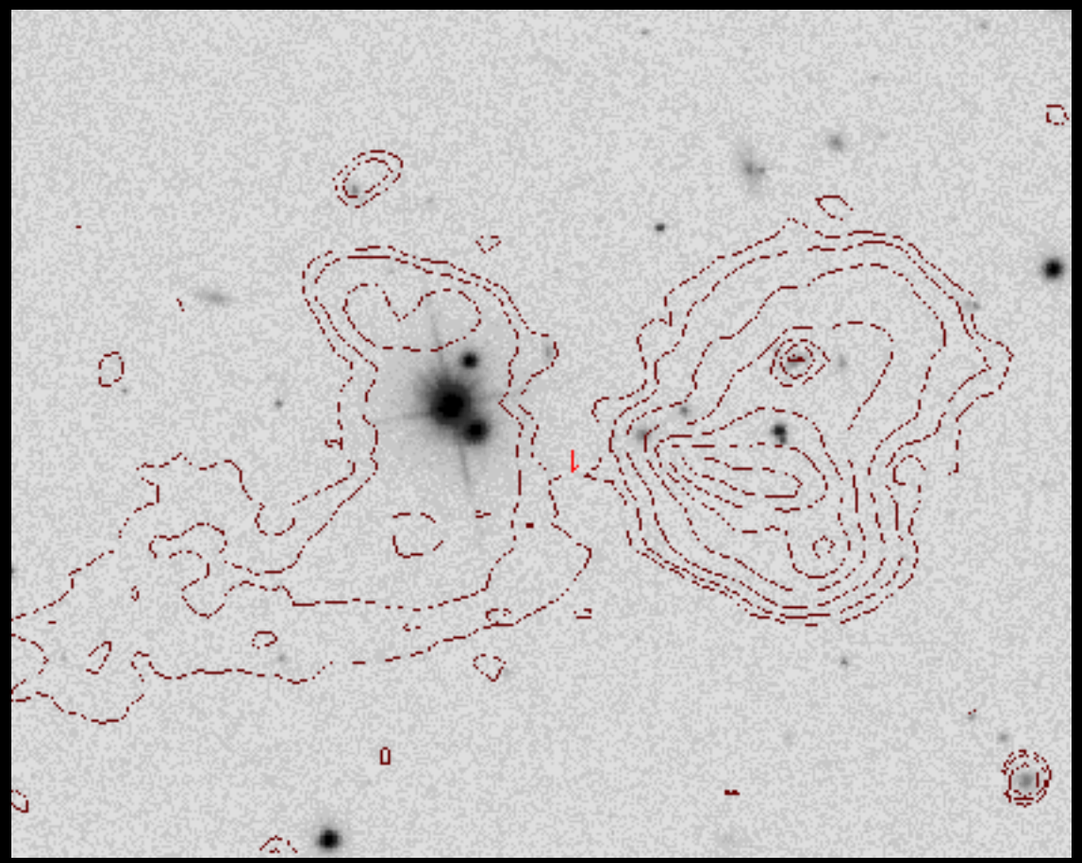


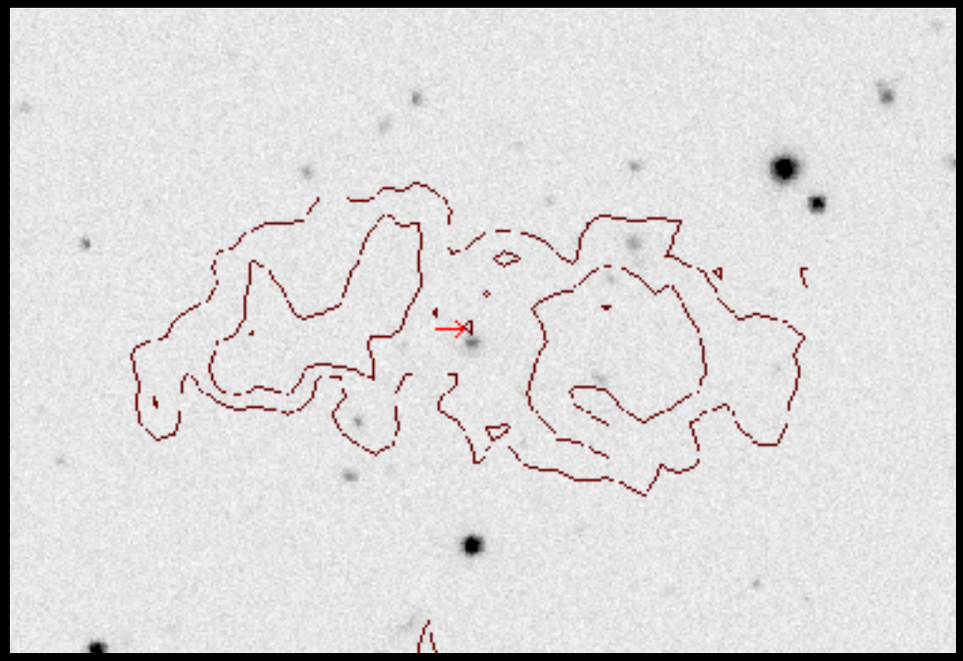
LOFAR contours + FIRST color map

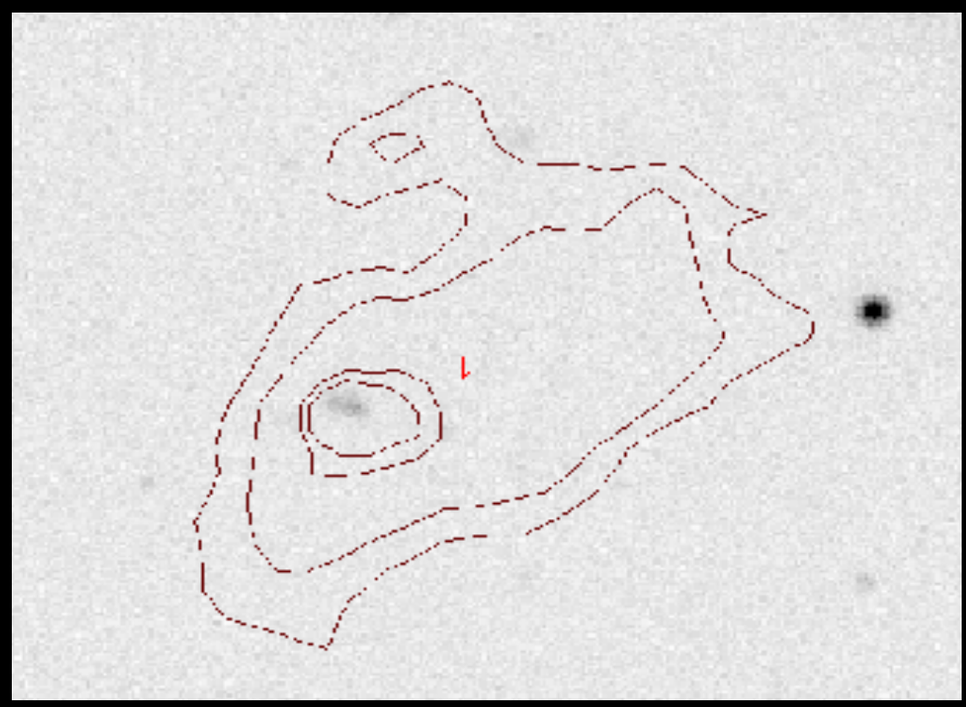
Optical counterparts for remnant radio galaxies

Not an easy job! (Nika Jurlin et al. in prep)

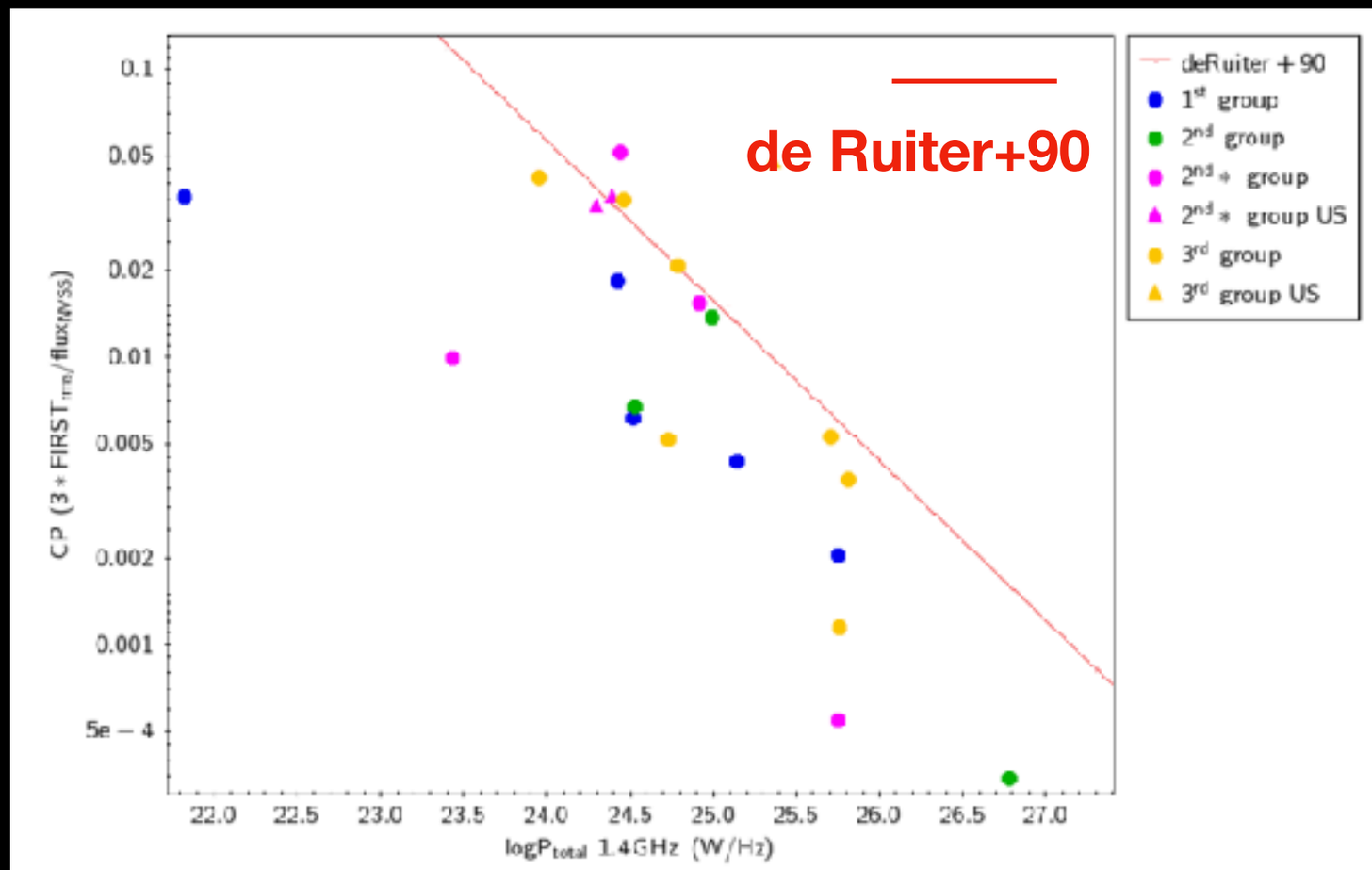
With the 6” map (Mandal+2018) we have found optical counterparts in SDSS or SERVS for ~90% of the sources & rejected 2 candidates



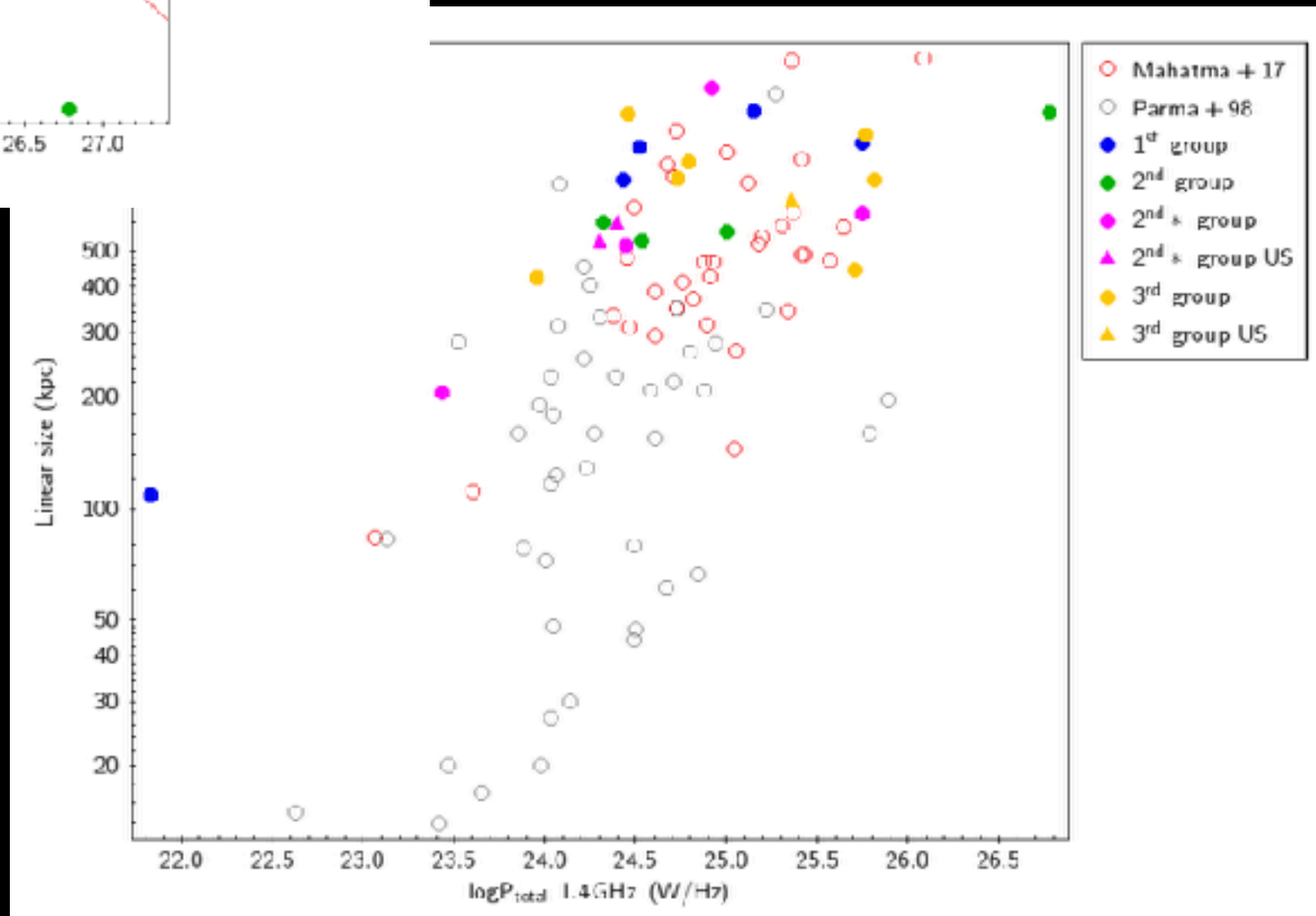




CP vs Power at 1.4 GHz



Power at 1.4 GHz vs Size



BETTER LUMINOSITY EVOLUTION MODELS

?

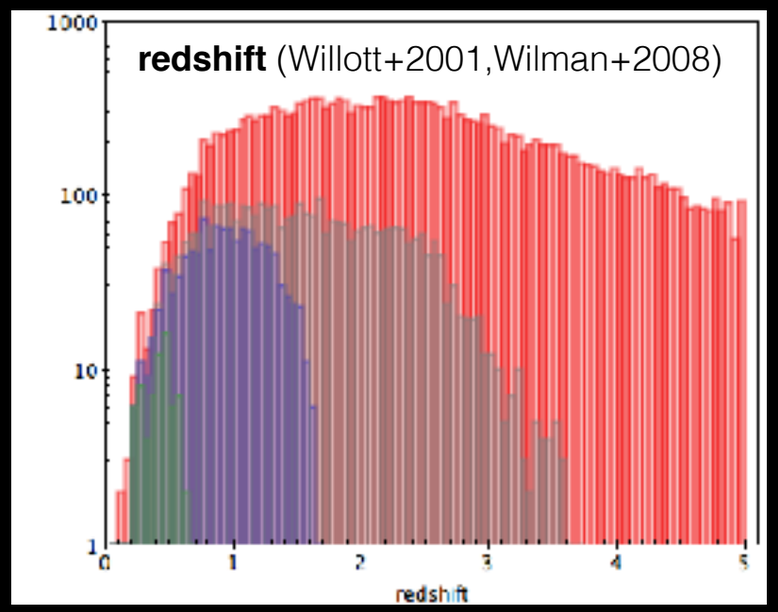
Monte Carlo simulations of low power radio galaxies

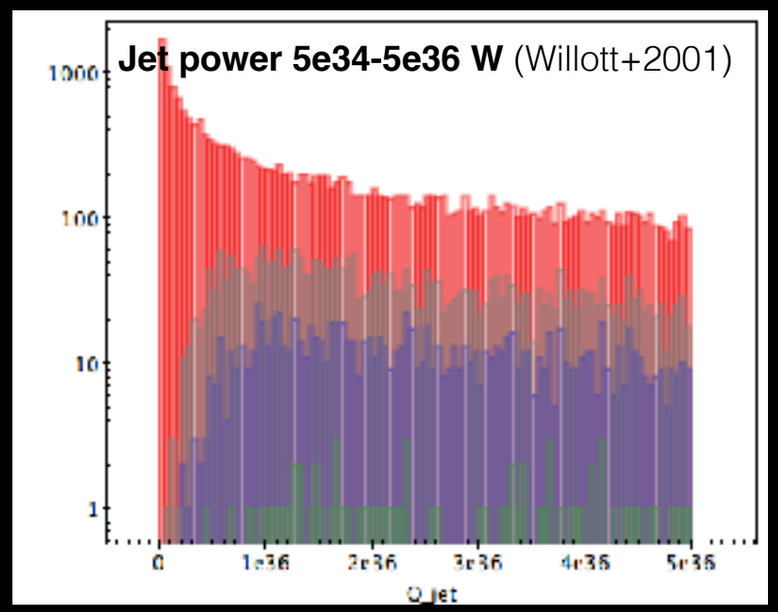
based on Godfrey, Morganti, Brienza 2017 (for high power RG)

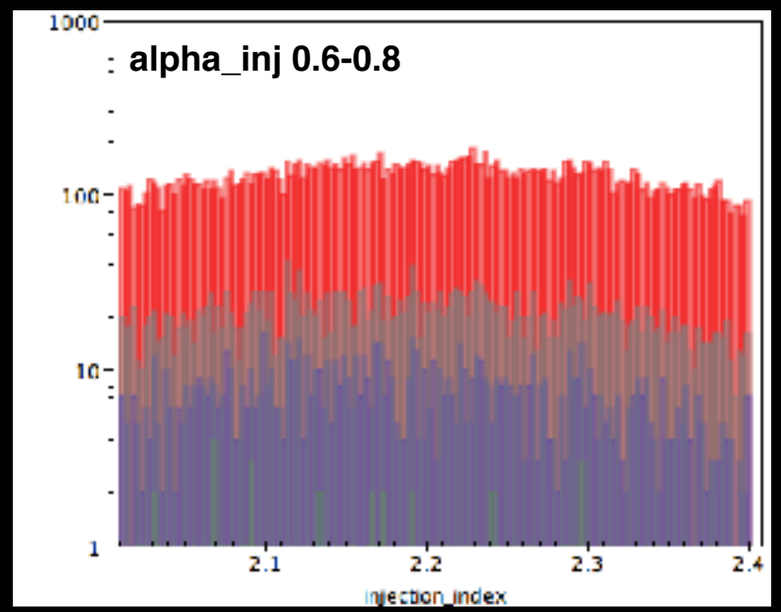
SKADS Simulated Skies (S3) simulations (Wilman et al. 2008) predict 70% low power RG at 1mJy flux limit (limit of the Lockman Hole)

→ **MOCK CATALOGUES** of low power radio galaxies to compare with observed radio catalogues in the Lockman Hole

Simulations based on empirical radio galaxy parameters (z, Qjet, alpha, t_{on}, age, density profile of external gas, geometry, minimum and maximum energy)







reproduced the spectrum using…

RADIATIVE EVOLUTION

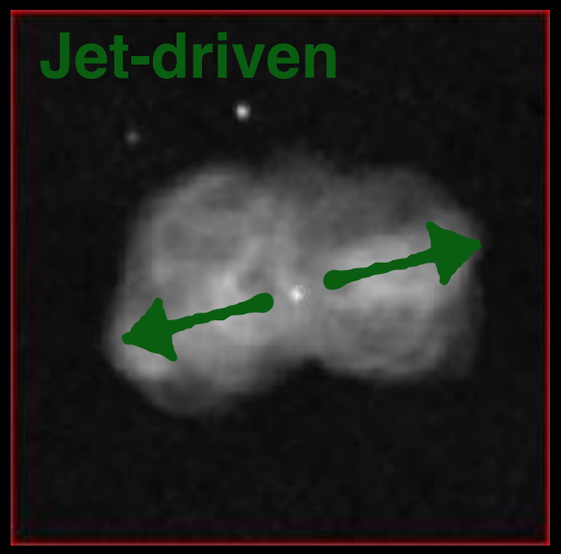
Synchrotron + Inverse compton
(Komissarov & Gubanov 1994 +
Tribble1994 = gaussian magnetic field distribution)

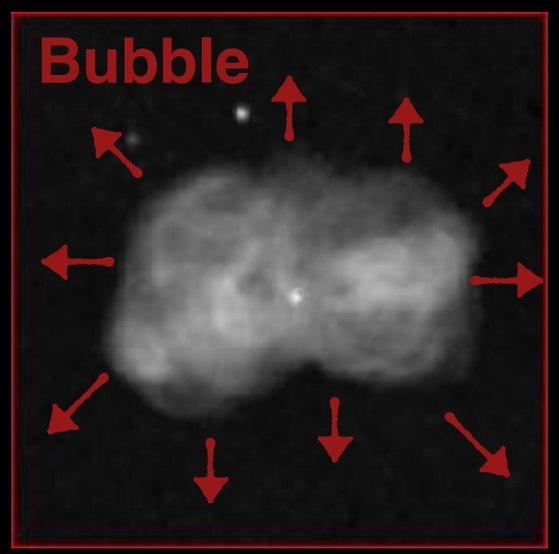
+

DYNAMICS

Luo&Sadler2011
(pressure
limiting case)

ON





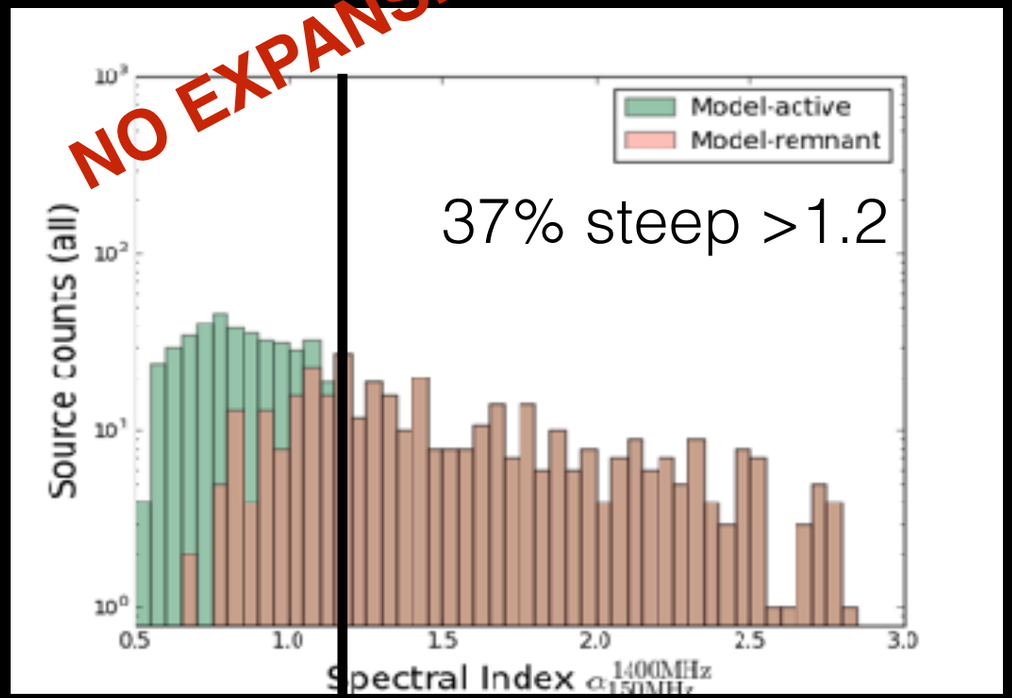
Adiabatic expansion

OFF
or
jet driven speed
<
bubble speed (0.5cs)

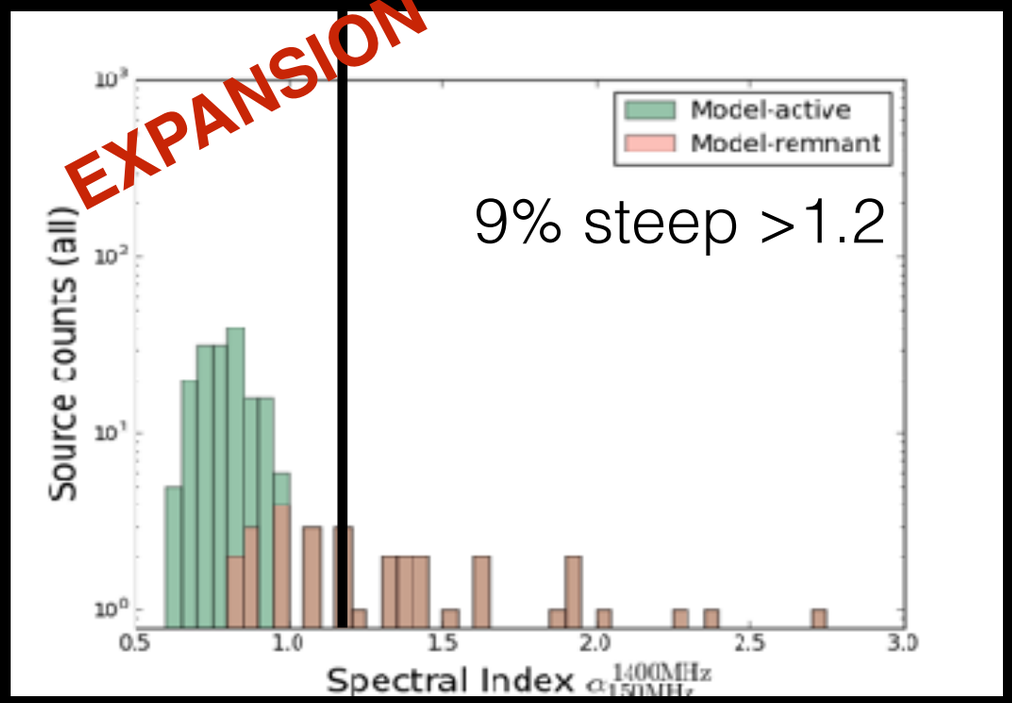
applied same flux density cut as in the LOFAR Lockman Hole

Results from simulations

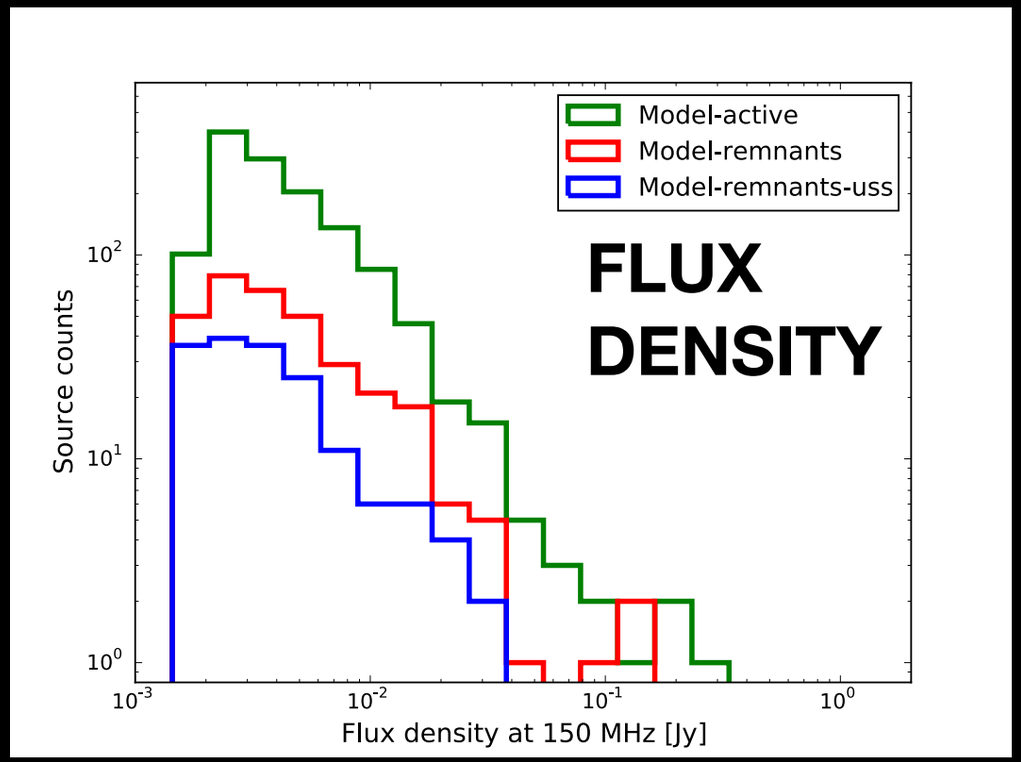
Dynamical evolution models are required to reproduce the observed fraction of ultra-steep spectrum remnants in the Lockman Hole field (<15%). When only the radiative evolution is included, the number of ultra-steep spectrum remnants is largely overpredicted.

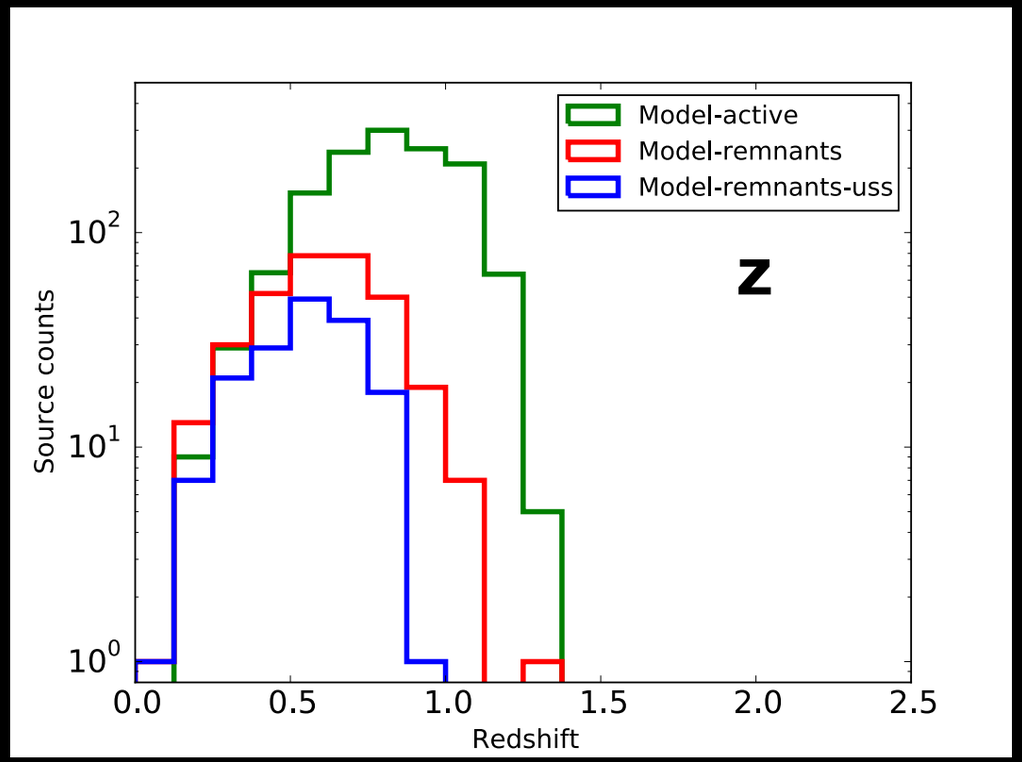


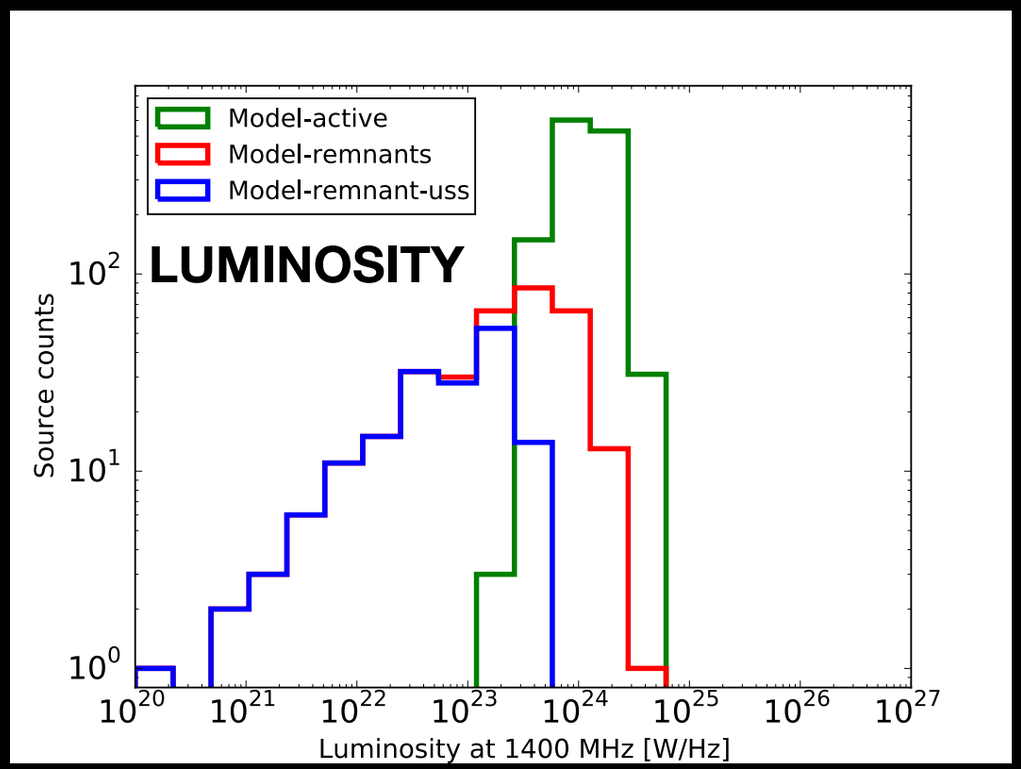
Ultra-steep spectrum remnants represent only a subset of the entire population when frequencies higher than 1400 MHz are not included in the selection and they are biased towards old ages, confirming the need to include frequencies >1400 MHz or additional selection methods in order to collect the entire population

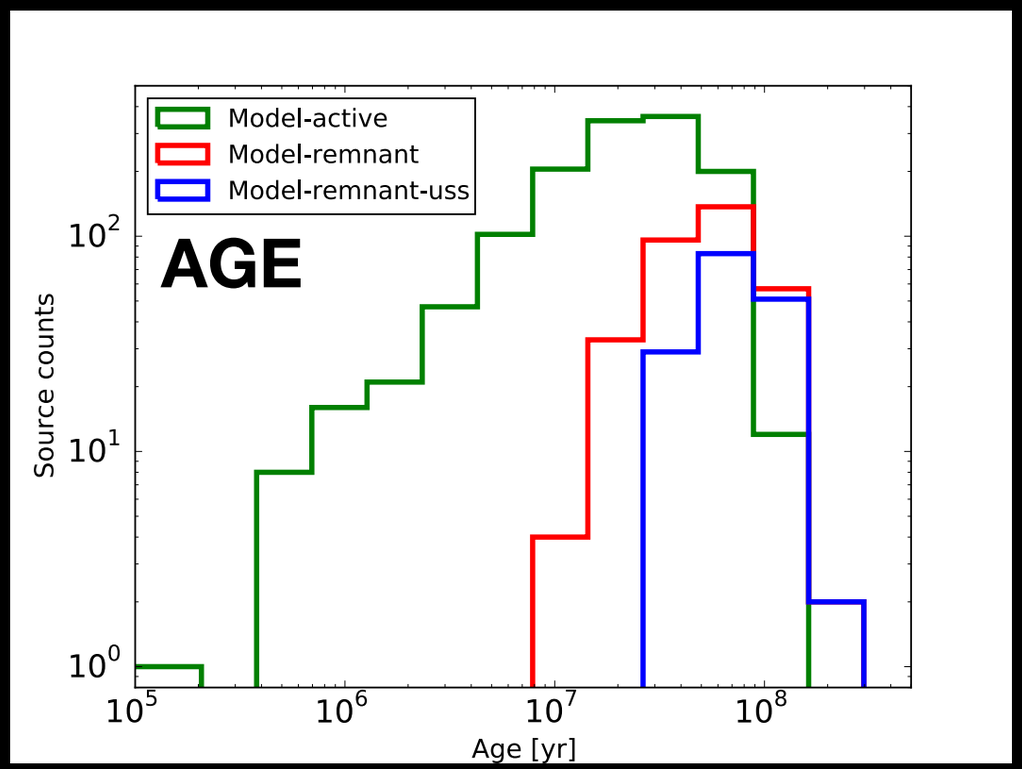


more interesting plots ..





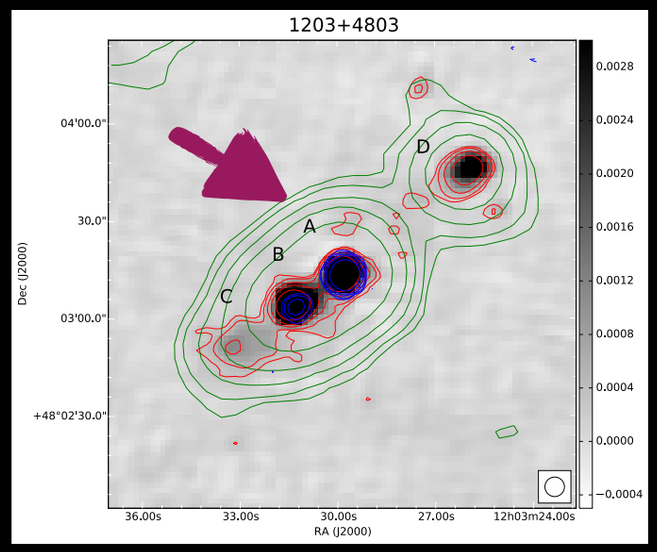


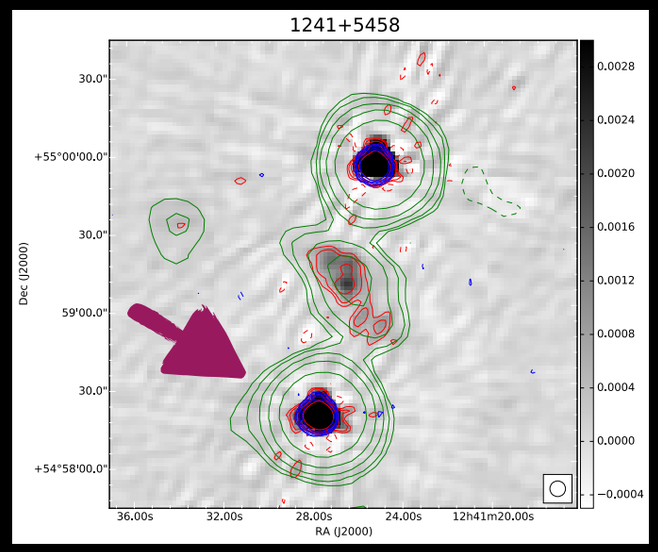


Search for extended emission in LoTSS at 150 MHz around known compact radio galaxies (GPS/CSS/HFP)

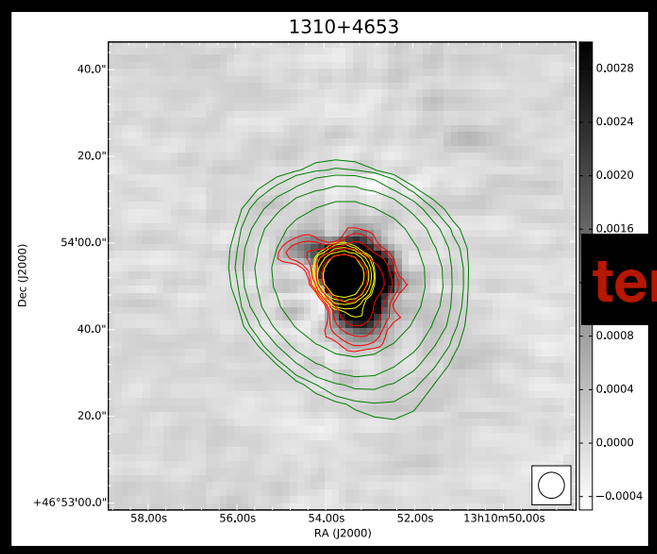
2-4/18 (<15-30%) candidates showing new diffuse emission at low frequency, comparable to detection rate at 1.4 GHz (Stanghellini et al. 1990,2005)

remnants disappear before the start of the new episode of jet activity!

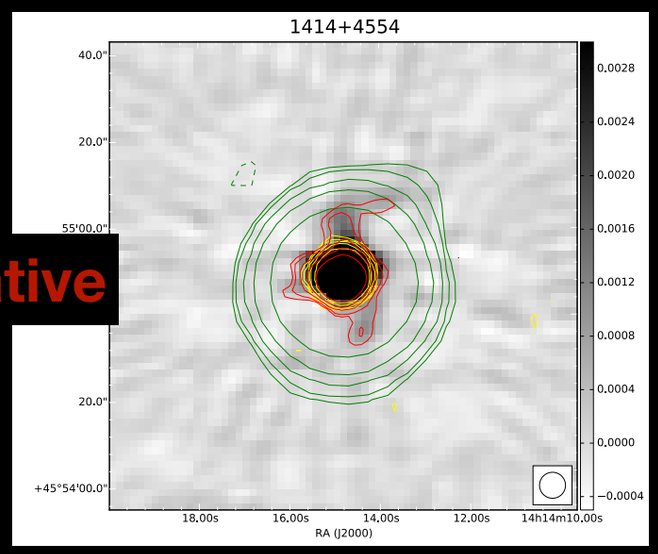




FIRST 1400 MHz
LOFAR 150 MHz



tentative



FIRST 1400 MHz
LOFAR 150 MHz

CONCLUSIONS

ARE WE MISSING THEM ? ARE THEY EVOLVING FASTER THAN EXPECTED

- Not all remnants have ultra-steep spectra at MHz freq! Different selection criteria can identify sources at different stages of their evolution

- The fraction of remnants is low also at 150 MHz (<10-15%) and even using complementary criteria for the selection

→ luminosity evolution of radio plasma after the jets switch off is fast and anyway faster than the jet reactivation!

- Mock catalogues manage to reproduce the low fraction of remnants when using evolutionary models based on both radiative losses and adiabatic expansion

FUTURE WORK

- VLA observations to confirm remnant candidates
- selection of bigger samples in the LoTSS survey
- expand Monte Carlo simulations