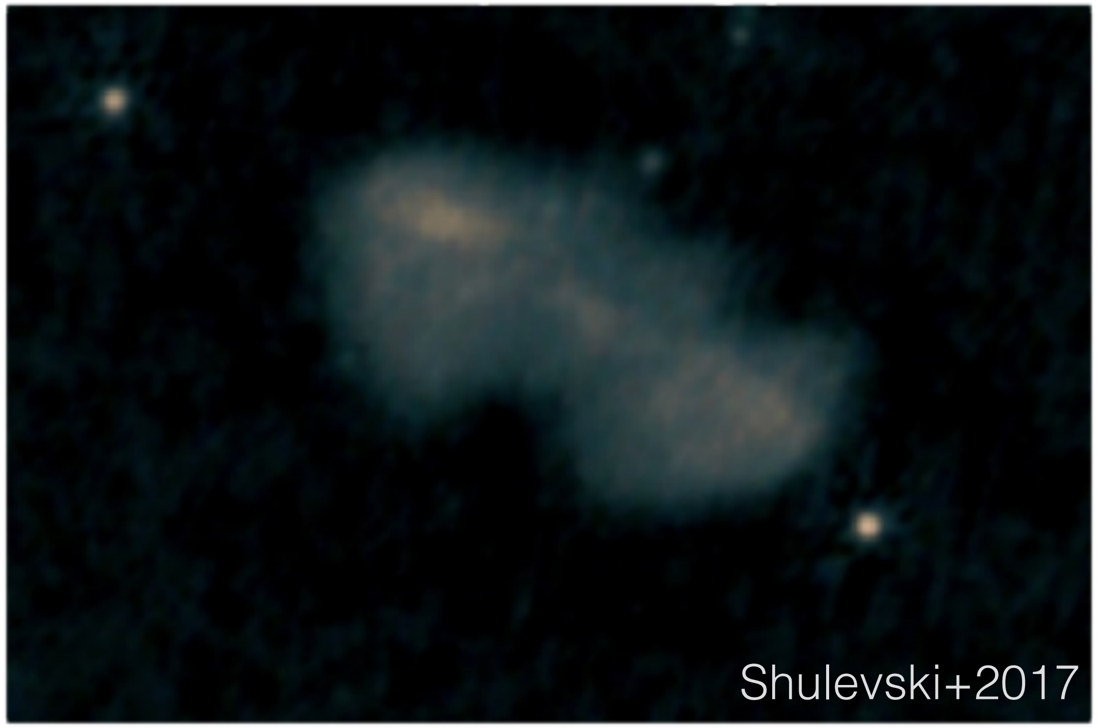
Search and modelling of remnant radio galaxies in the LOFAR Lockman Hole

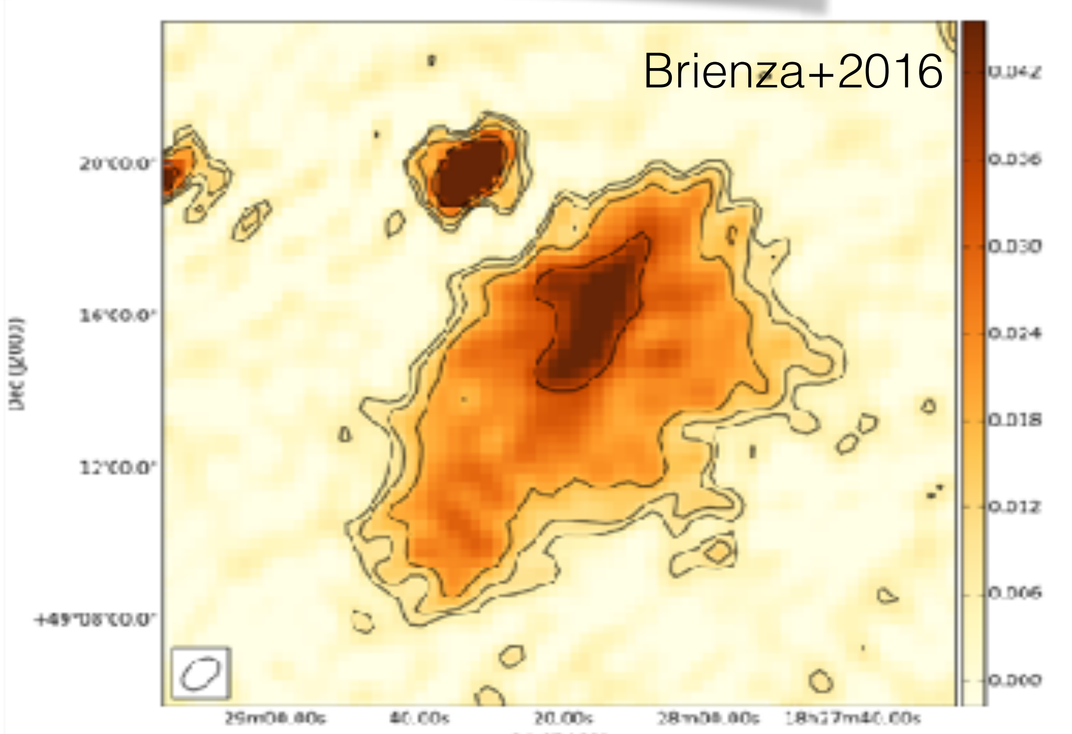
Marisa Brienza

L. Godfrey, R. Morganti, I. Prandoni, J. Harwood, E. Mahony,
M. Hardcastle, T. Shimwell, M. Murgia, A. Shulevski, H. Rottgering

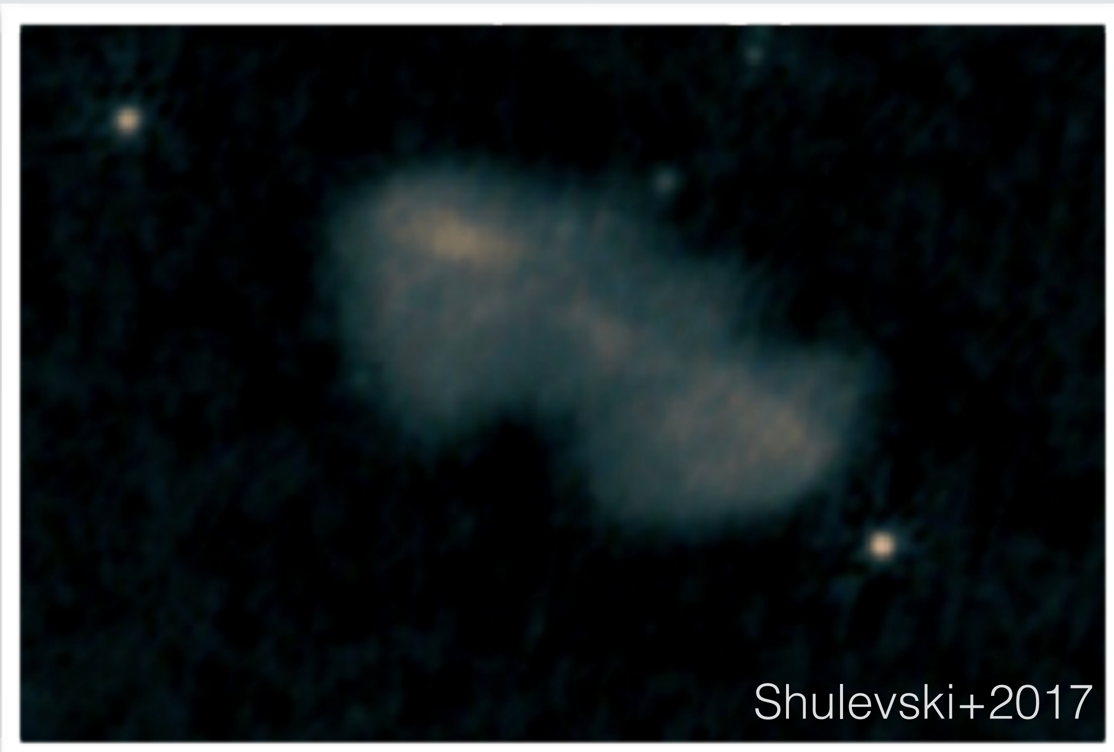
submitted to A&A

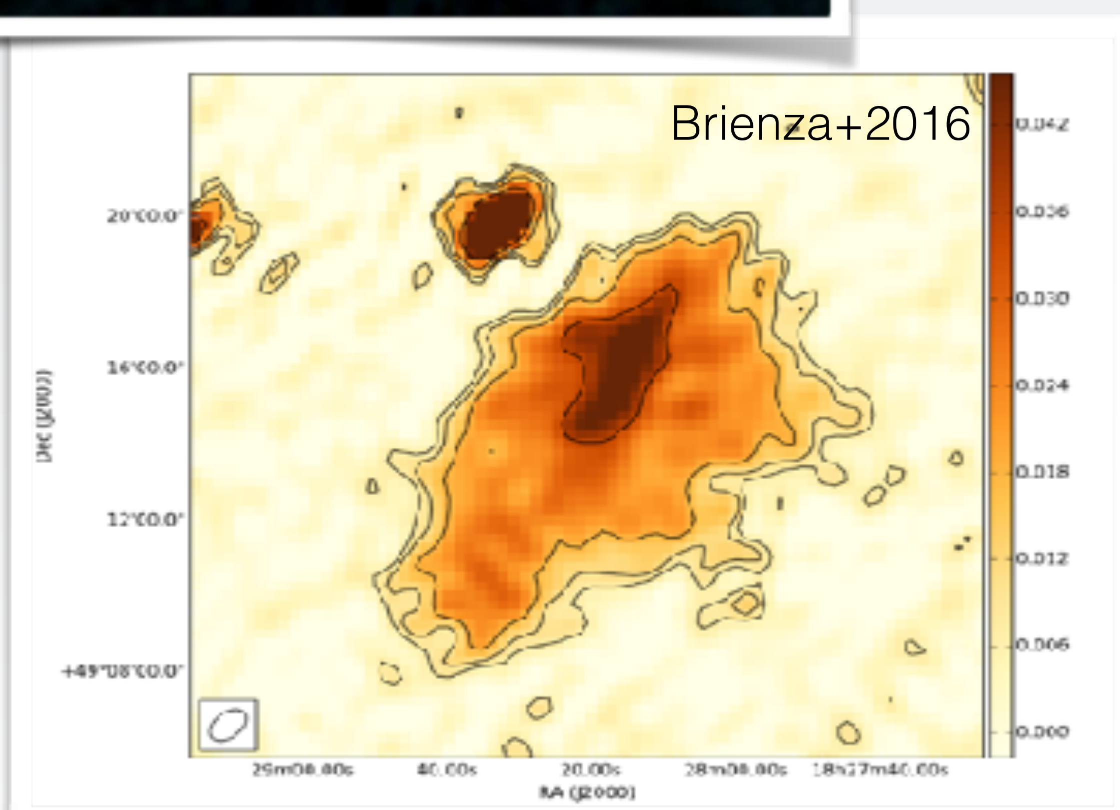
What?


Shulevski+2017


Brienza+2016
0.042
0.036
0.030
0.024
0.018
0.012
0.006
0.000

What?





Why?

- dynamics of radio lobes of radio galaxies
- radio galaxy duty cycle
- radio galaxy feedback
- origin of cluster halos and relics in cluster

… to put new constraints on this phase
of the radio galaxy evolution
we need new **BIGGER SAMPLES**

… to put new constraints on this phase of the radio galaxy evolution we need new **BIGGER SAMPLES**

How do we find them?

- ☆ STEEP SPECTRAL INDEX (e.g. Parma+2007, Dwarakanath+2009, Sirothia+2009, VanWeeren+2009)
- ☆ SPECTRAL CURVATURE (Murgia+2011)
- ☆ MORPHOLOGY (e.g. Saripalli+2009)
- ☆ LOW CORE PROMINENCE (e.g. Giovannini+1988, Hardcastle+2016)

Lockman Hole
LOFAR 150 MHz
average flux limit 5sigma=1.5mJy
15” beam
~6000 sources
Mahony+2016

Lockman Hole

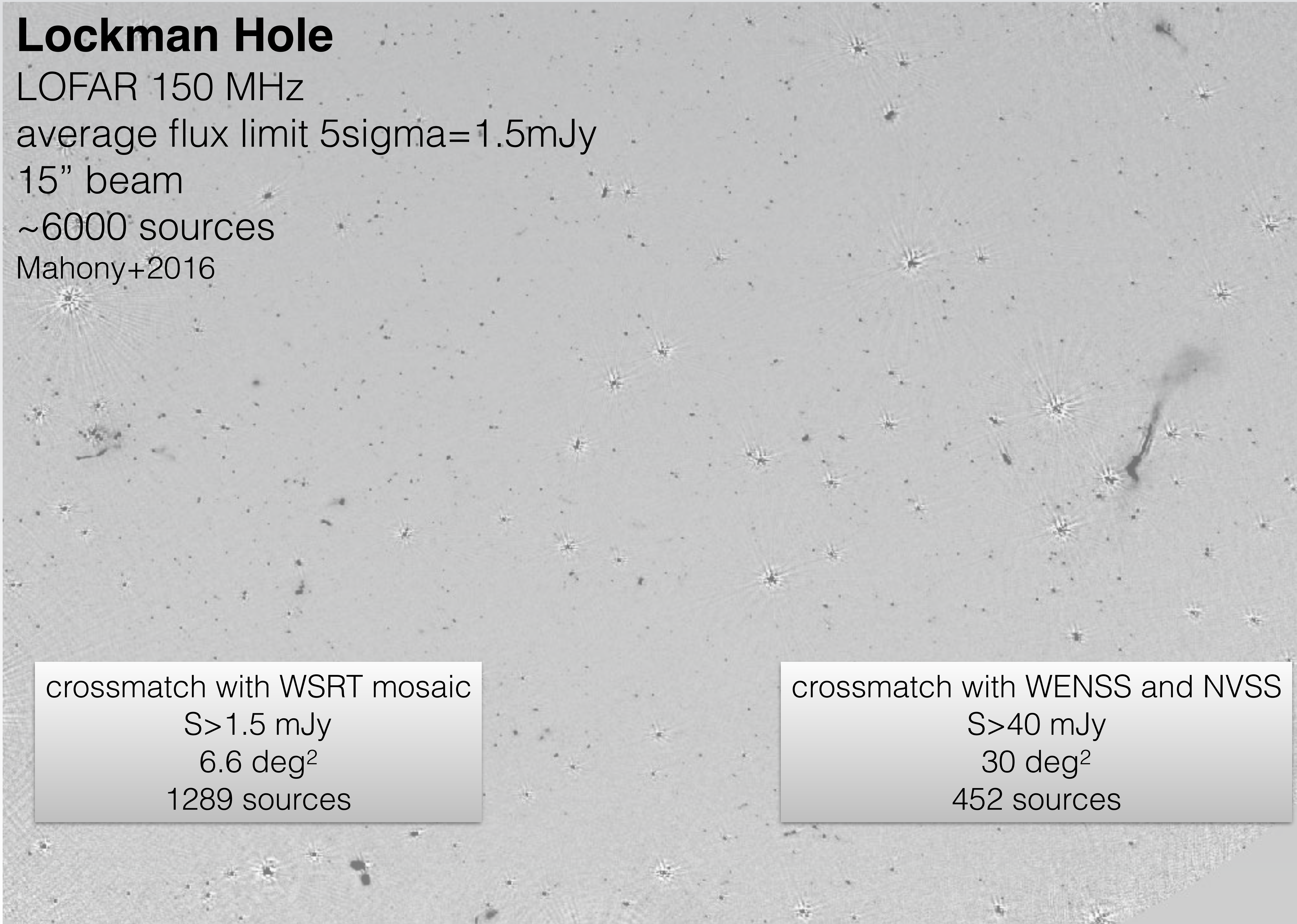
LOFAR 150 MHz

average flux limit 5sigma=1.5mJy

15” beam

~6000 sources

Mahony+2016



crossmatch with WSRT mosaic
S>1.5 mJy
6.6 deg^2
1289 sources

crossmatch with WENSS and NVSS
S>40 mJy
30 deg^2
452 sources

SPECTRAL INDEX

alpha(150-1400) >1.2

LOFAR-WSRT <6.6%

LOFAR-NVSS <4.1%

SPECTRAL CURVATURE

LOFAR-WENSS-NVSS

0.5<alpha(150-325)<1

alpha(325-1400)>1.5

6 SOURCES

Search for remnants in the Lockman Hole

MORPHOLOGY

relaxed,

low surface brightness,

no compact feature in FIRST 5''

size > 60''

14 SOURCES

CORE PROMINENCE

S(tot)/S(core)<10^{-4}

size > 40'' & S>90mJy

+NO CORE in FIRST

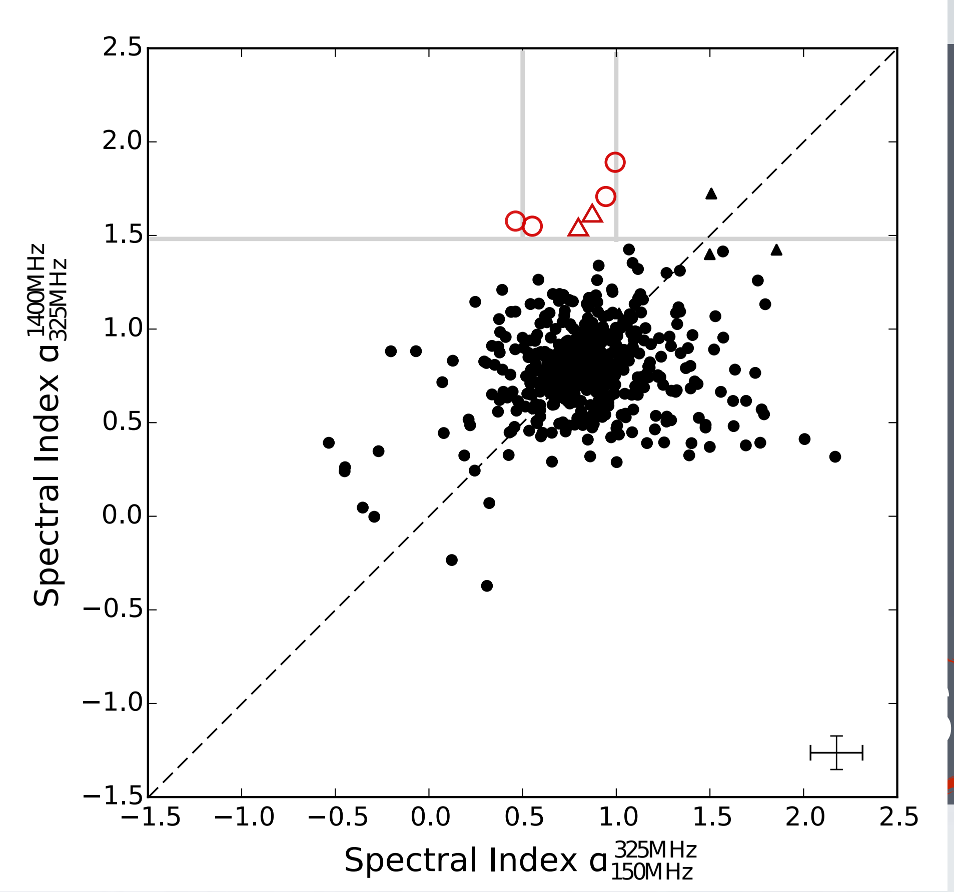
10 SOURCES

SPECTRAL INDEX

alpha(150-1400) >1.2

LOFAR-WSRT <6.6%

LOFAR-NVSS <4.1%



Search for remnants in the Lockman Hole

MORPHOLOGY

relaxed,

low surface brightness,

no compact feature in FIRST 5''

size > 60''

14 SOURCES

CORE PROMINENCE

S(tot)/S(core)<10^{-4}

size > 40'' & S>90mJy

+NO CORE in FIRST

10 SOURCES

SPECTRAL INDEX

alpha(150-1400) >1.2

LOFAR-WSRT <6.6%

LOFAR-NVSS <4.1%

SPECTRAL CURVATURE

LOFAR-WENSS-NVSS

0.5<alpha(150-325)<1

alpha(325-1400)>1.5

6 SOURCES

Search for remnants in the Lockman Hole

MORPHOLOGY

relaxed,

low surface brightness,

no compact feature in FIRST 5''

size > 60''

14 SOURCES

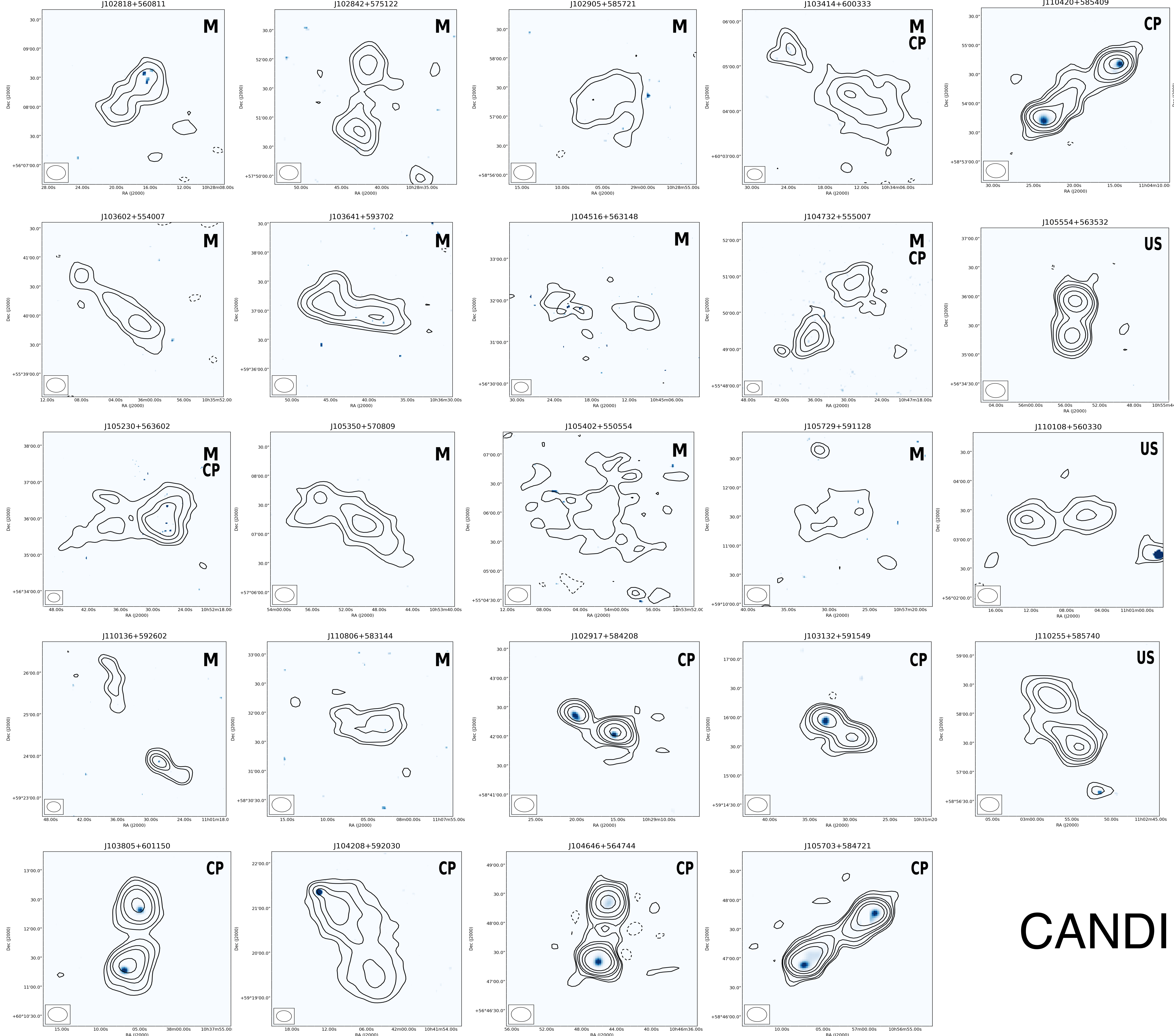
CORE PROMINENCE

$S(tot)/S(core)<10^{-4}$

size > 40'' & S>90mJy

+NO CORE in FIRST

10 SOURCES


J102818+560811
M
J102842+575122
M
J102905+585721
M
J103414+600333
M
CP
J110420+585409
CP
J103602+554007
M
J103641+593702
M
J104516+563148
M
J104732+555007
M
CP
J105554+563532
US
J105230+563602
M
CP
J105350+570809
M
J105402+550554
M
J105729+591128
M
J110108+560330
US
J110136+592602
M
J110806+583144
M
J102917+584208
CP
J103132+591549
CP
J110255+585740
US
J103805+601150
CP
J104208+592030
CP
J104646+564744
CP
J105703+584721
CP
RA (J2000)
Dec (J2000)

CANDIDATES

RESULTS FROM THE SELECTION

We have selected 24 remnant radio galaxy candidate that likely trace different phases of the remnant evolution

USS (150-1400)
21 sources = 4.1%
3 with size>40” (<1%)

SPC
6 sources but all have alpha>1.2
and are unresolved
NEED FOR 5GHz!

Morphology
14 sources
<50% have USS

LOW CP
10 sources
<10% have USS

NEED FOR RADIO FOLLOW UP AND OPTICAL ID TO CONFIRM THE CANDIDATES

PREDICTING THE FRACTION OF REMNANT RADIO GALAXIES IN THE LOCKMAN HOLE

Create MOCK CATALOGUES of radio galaxies with Monte-Carlo simulations based on observed source properties and analytical radiative and dynamical evolution models of radio sources

Directly compare the empirical catalogue with the mock catalogue by applying the same flux density cut and compare the results by applying the same spectral selection criteria.

SKADS Simulated Skies (S3) simulations (Wilman et al. 2008) ~70% FRI

+

~60% lobed FRI (Parma+96)

= ~40% of the LH sample

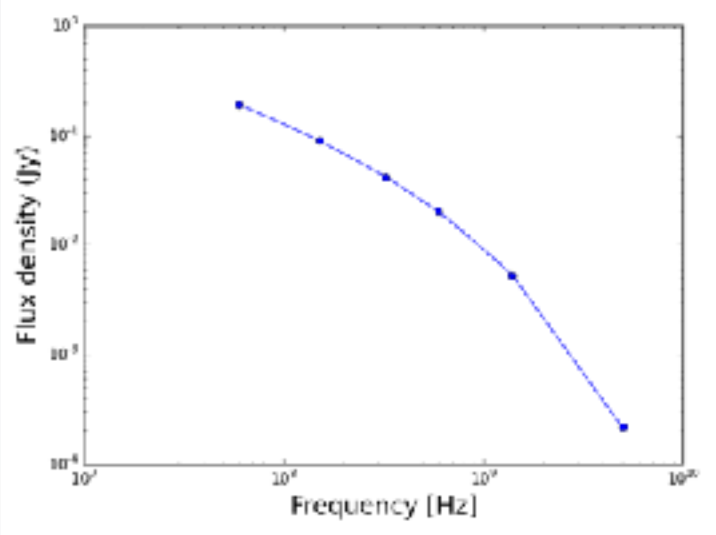
NUMBER OF FRI REMNANTS < 0.066/0.43 =15%

Generating MOCK CATALOGUES …

– set the number of sources to be generated (several thousands)

– set the values of the fixed parameters of the model and sample the other parameters from the corresponding probability distributions

- jet power
- redshift
- active time
- observation time
- magnetic field
- external environment
- injection index



– for each source, given its set of parameters, calculate the model radio galaxy spectrum using numerical integration of equations by Godfrey et al. (2017 submitted)

– apply a flux density cut consistent with the deepest available observations (1.5 mJy) so that all sources below the threshold are rejected

– derive flux densities at the observed frequencies and compute relevant spectral indices

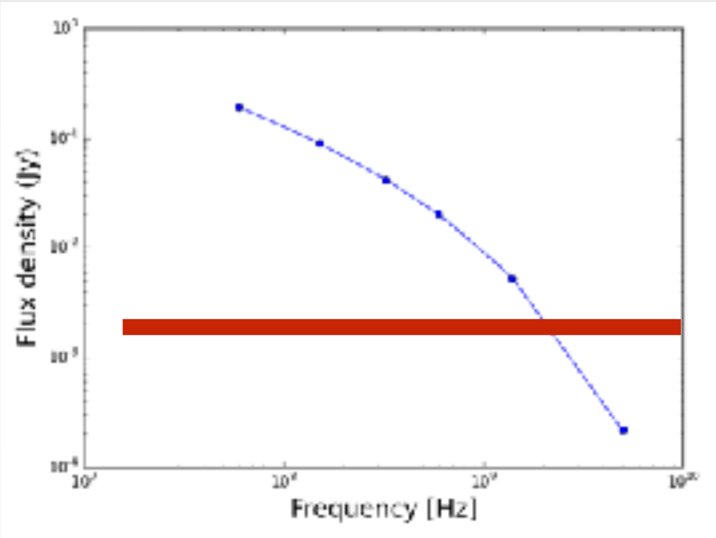
Generating MOCK CATALOGUES …

– set the number of sources to be generated (several thousands)

– set the values of the fixed parameters of the model and sample the other parameters from the corresponding probability distributions

- jet power
- redshift
- active time
- observation time
- magnetic field
- external environment
- injection index

– for each source, given its set of parameters, calculate the model radio galaxy spectrum using numerical integration of equations by Godfrey et al. (2017 submitted)



– apply a flux density cut consistent with the deepest available observations (1.5 mJy) so that all sources below the threshold are rejected

– derive flux densities at the observed frequencies and compute relevant spectral indices

SIMULATIONS

1 RADIATIVE EVOLUTION ONLY

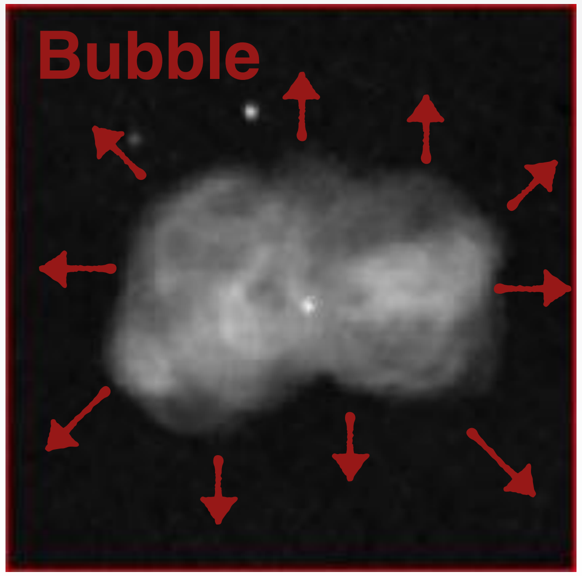
Synchrotron + Inverse compton
(Komissarov & Gubanov 1994 + Tribble1994 = gaussian magnetic field distrib)

2 RADIATIVE EVOLUTION

+ DYNAMICS

Luo&Sadler2011
(pressure
limiting case)

ON



Adiabatic expansion

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

RESULTS FROM THE SIMULATIONS

Number of sources in the sample ($S_{150MHz} > 1.5mJy$)	Radiative evolution	Radiative + Dynamic evolution
Total*	1609	1665
Active ($t_{obs} < t_{on}$)	1073 (66%)	1317 (79%)
Remnants ($t_{obs} > t_{on}$)	536 (33%)	329 (20%)
Ultra-steep spectrum ($t_{obs} < t_{on}$ and $\alpha_{150}^{1400} > 1.2$)	387 (24%)	165 (10%)
Ultra-steep spectrum ($t_{obs} < t_{on}$ and $\alpha_{150}^{5000} > 1.2$)	444 (28%)	321 (19%)

Simulation with radiative+dynamical model gives consistent results with observations

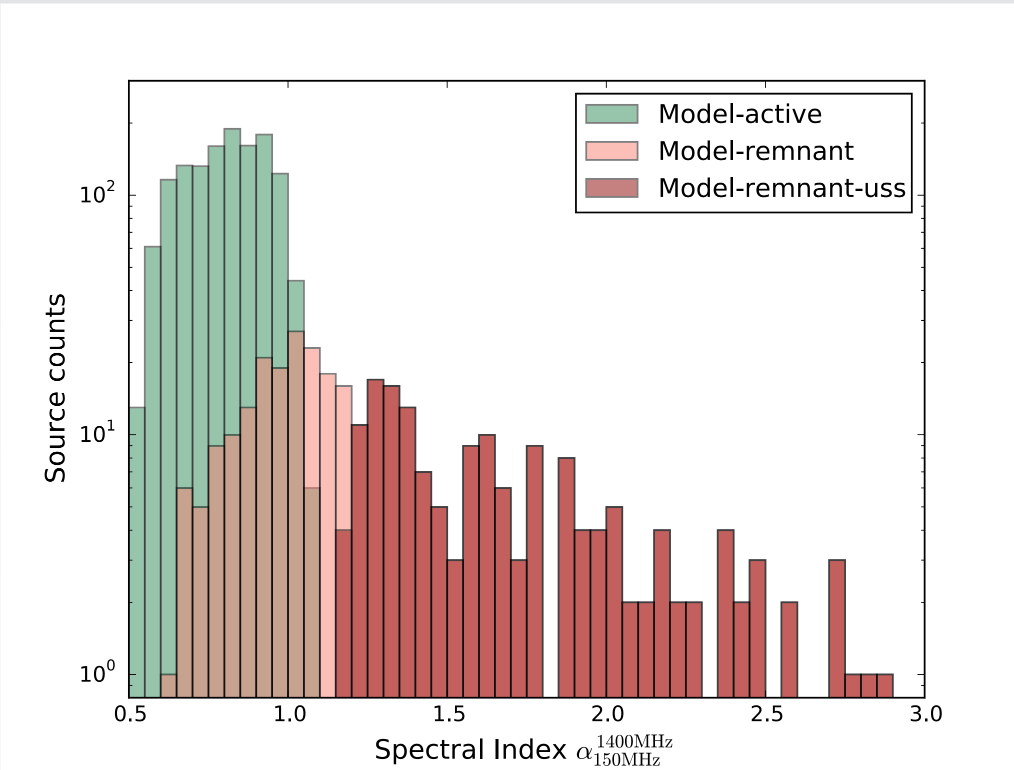
By neglecting adiabatic cooling, and magnetic field evolution radiative ages over-estimate the remnant age

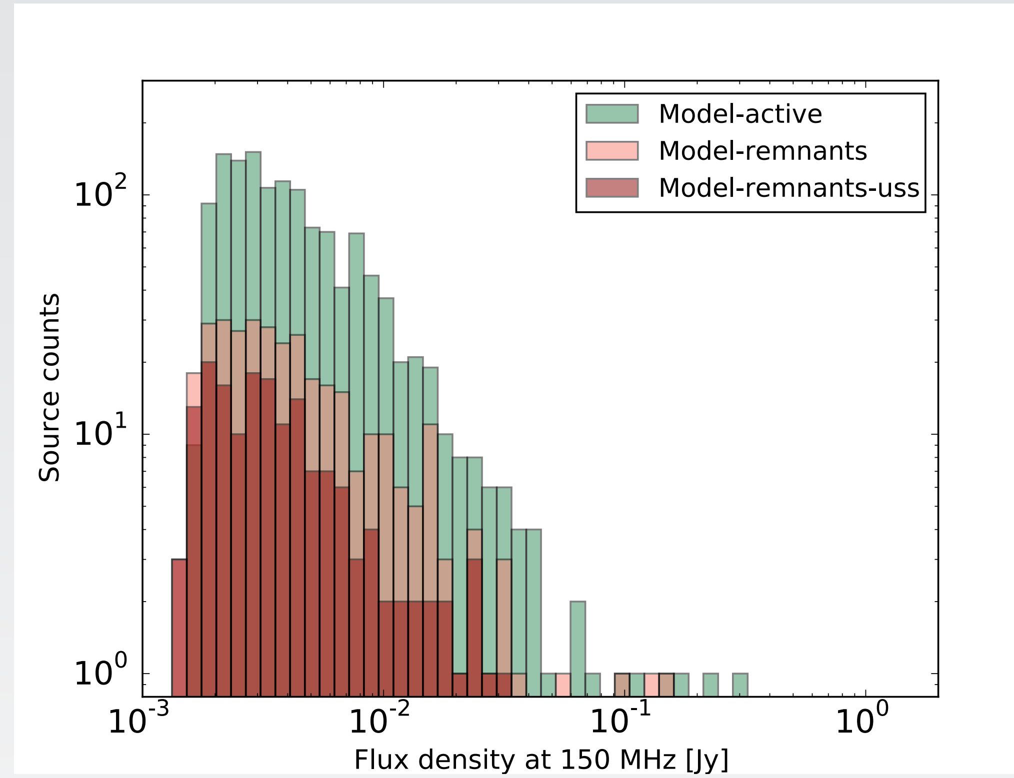
Remnants with alpha(150-1400)>1.2

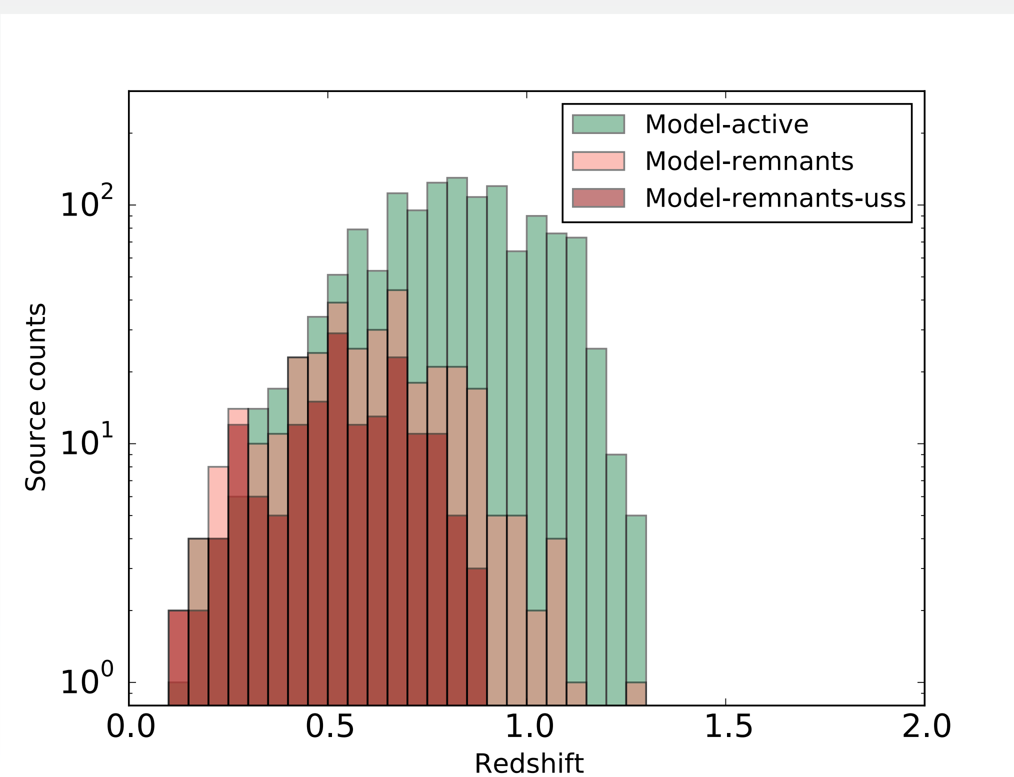
represent only a fraction of the entire FRIs remnant radio galaxy population (~50%) and represent the oldest tail of the age distribution.

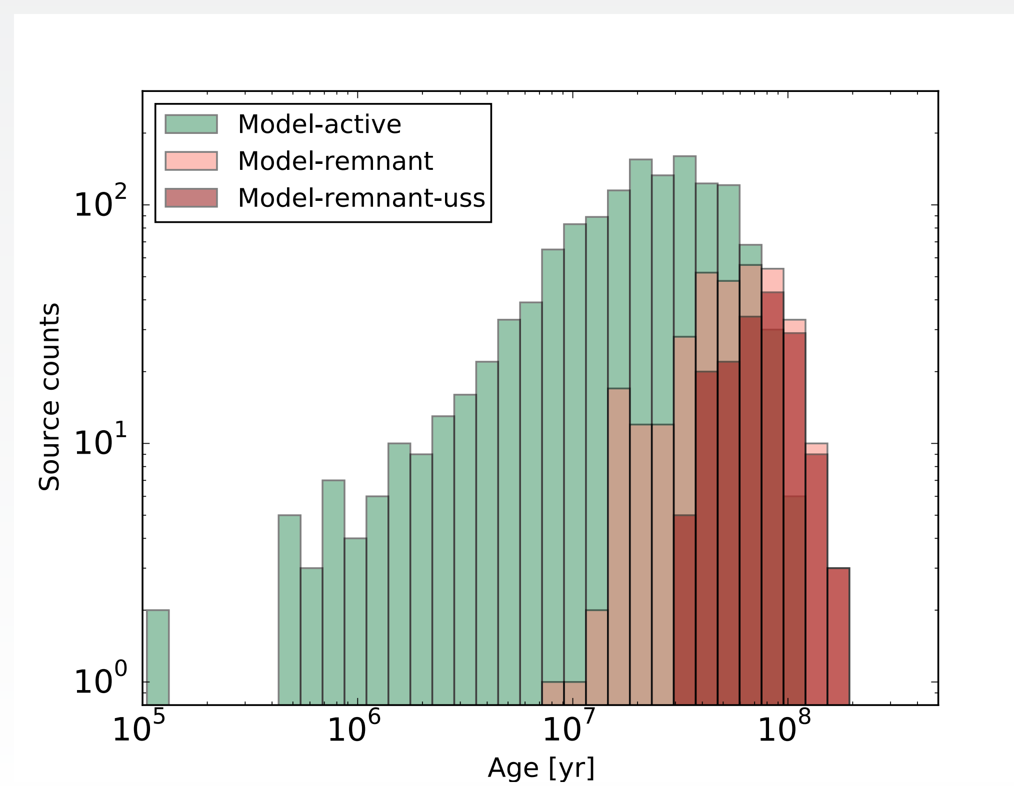
When introducing **5GHz observations** the fraction of remnants is almost entirely recovered. Otherwise **morphological criteria** are essential for a complete selection

RESULTS FROM THE SIMULATIONS









CONCLUSIONS

Observations show that NOT ALL remnant sources have USS spectra in the range 150-1400MHz

Simulations with radiative+dynamical models give consistent results with observations for the USS fraction

Simulations predict that using alpha(150-1400) we can only recover <50% of remnants

5-GHz observations are necessary to recover the entire remnant population or morphological criteria need to be used in a complementary way