# Remnant radio galaxies in the LOFAR Lockman Hole

**Marisa Brienza**

Raffaella Morganti, Leith Godfrey, et al.

Heinz+2016

# Why studying remnant radio galaxies?

- Radio galaxy evolution and dynamics
- Timescales of jet active and inactive phase
- AGN radio feedback
- Potentially provide seed particles for cluster halos and relics

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BETTER SELECTION

?

BETTER LUMINOSITY EVOLUTION MODELS

BETTER SELECTION

?

# Low Frequency Array

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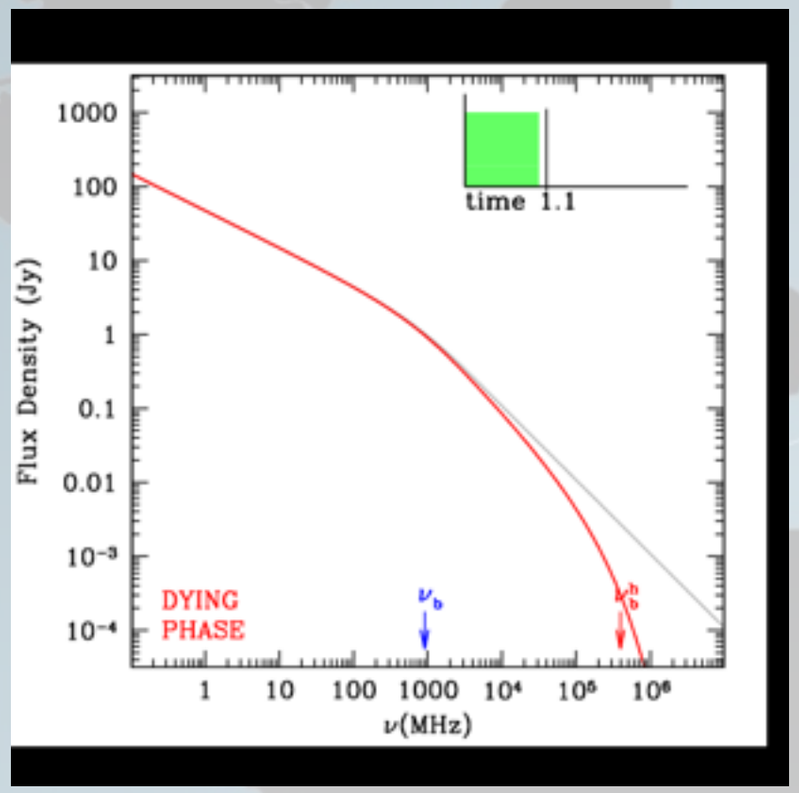
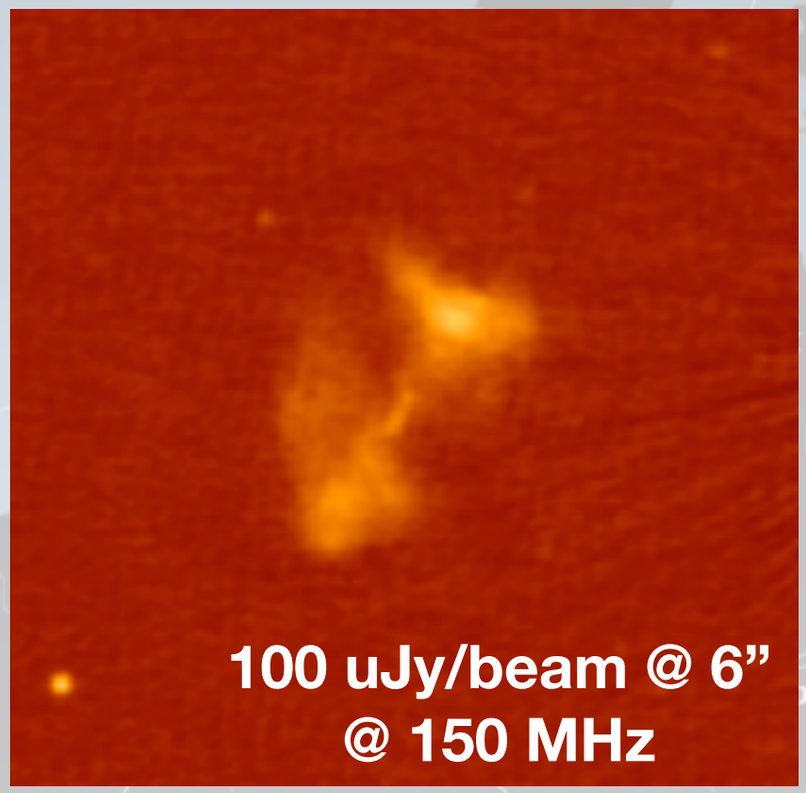
LOW FREQUENCY

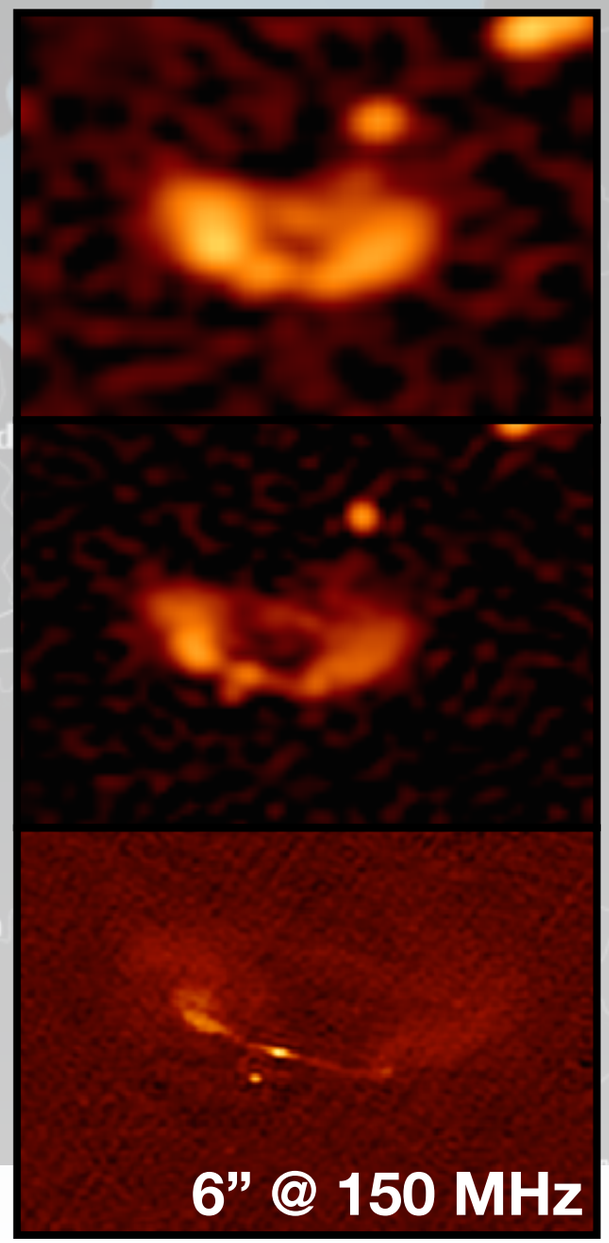



$S \propto \nu^{-\alpha}$

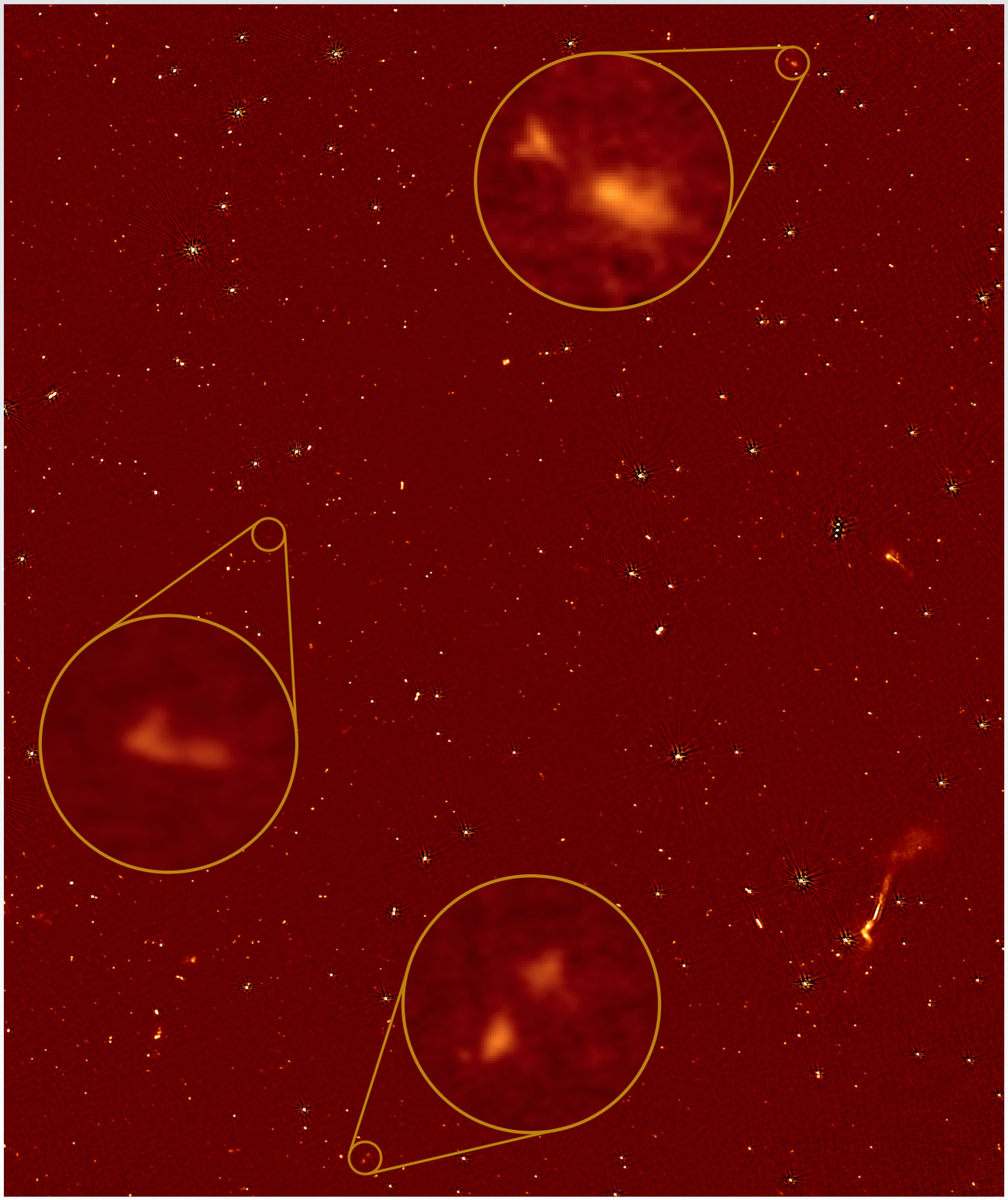
HIGH SENSITIVITY




RESOLUTION



# The LOFAR Lockman Hole at 150 MHz



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**

# Selecting remnant radio galaxies

## COMPLEMENTARY CRITERIA

- ULTRA-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+1989, Mullin+2008, Hardcastle+2016)

# Selecting remnant radio galaxies

## COMPLEMENTARY CRITERIA

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  (e.g. Parma+2007, Dwarakanath+2009, Sirothia+2009, VanWeeren+2009)
  → **LOFAR-NVSS**
  **$\alpha$(150-1400)>1.2**

- SPECTRAL CURVATURE
  (Murgia+2011)
  → **LOFAR-WENSS-NVSS**
  **$\alpha$(1400-327)-$\alpha$(327-150)>0.5**

- MORPHOLOGY
  (e.g. Saripalli+2009)
  → **Amorphous in LOFAR with no compact components in FIRST**

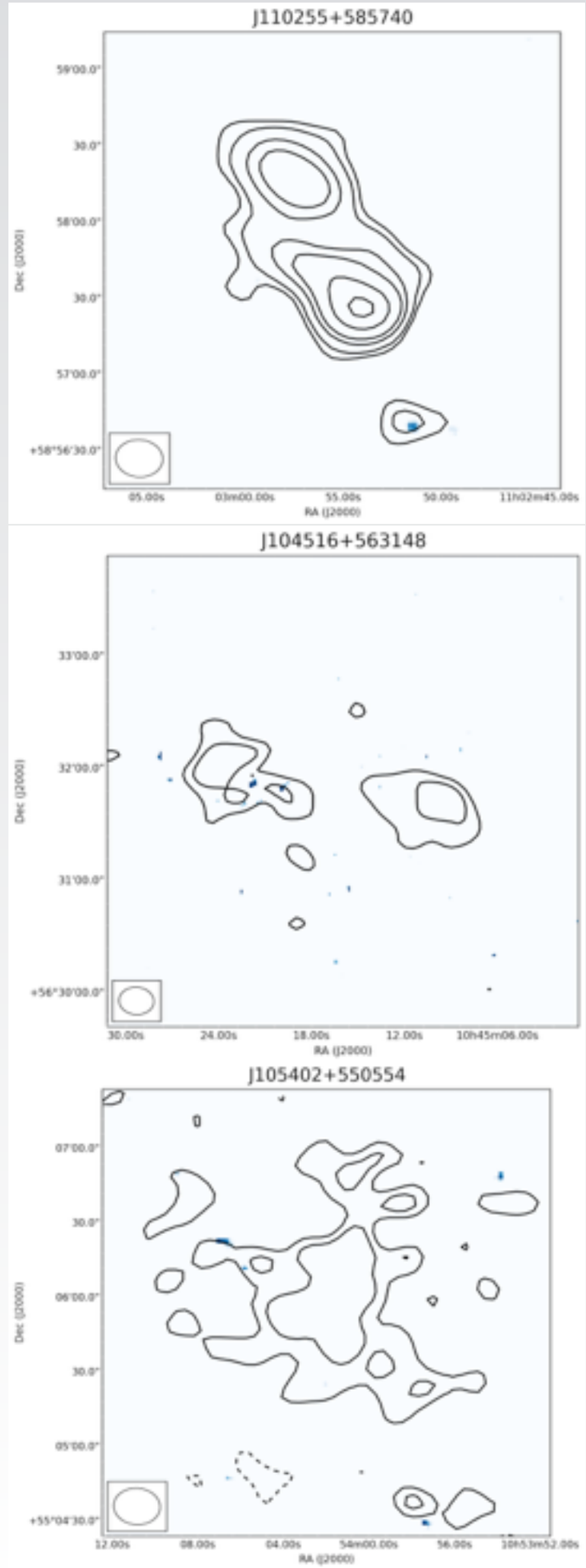
- LOW CORE PROMINENCE
  (e.g. Giovannini+1989, Mullin+2008, Hardcastle+2016)
  → $\frac{S_{core,FIRST}}{S_{tot,LOFAR}} \ll$

# 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.




LOFAR contours + FIRST color map

# BETTER LUMINOSITY EVOLUTION MODELS

# Monte Carlo simulations of radio galaxies

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, external density profile, geometry, minimum and maximum energy)

+

## RADIATIVE EVOLUTION

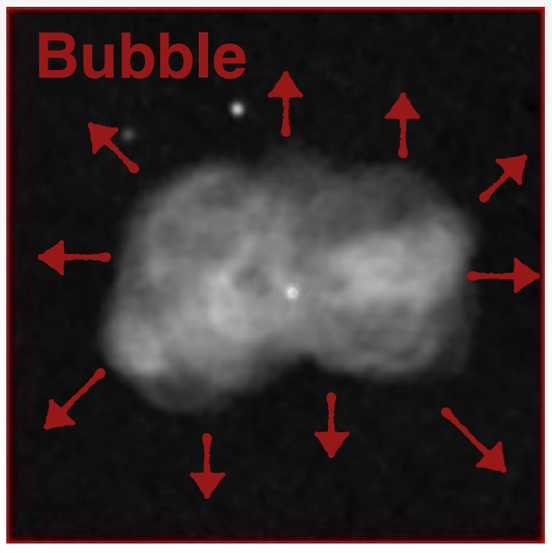
Synchrotron + Inverse compton
( Komissarov & Gubanov 1994 +
Tribble1994 = gaussian magnetic field distribution)

+

## DYNAMICAL EVOLUTION

Luo&Sadler2011 (pressure limiting case)

ON


Adiabatic expansion

OFF

or

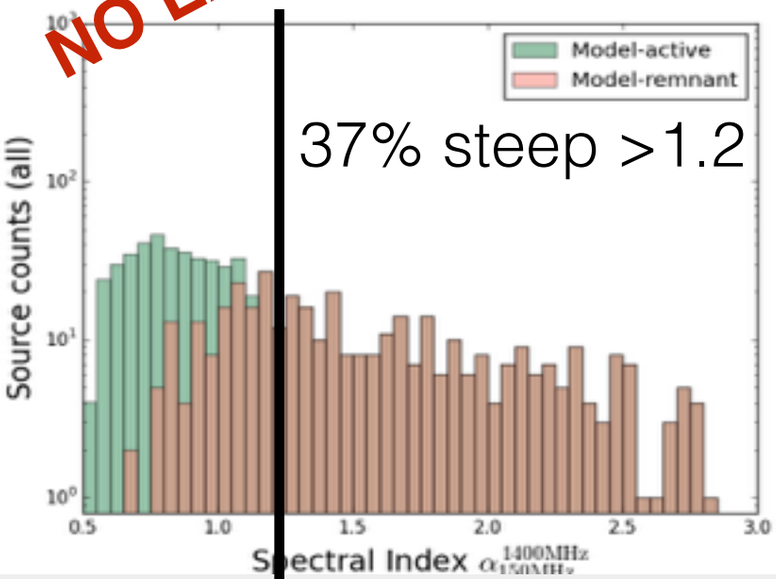
jet driven speed
<
bubble speed (0.5cs)

# Results from simulations

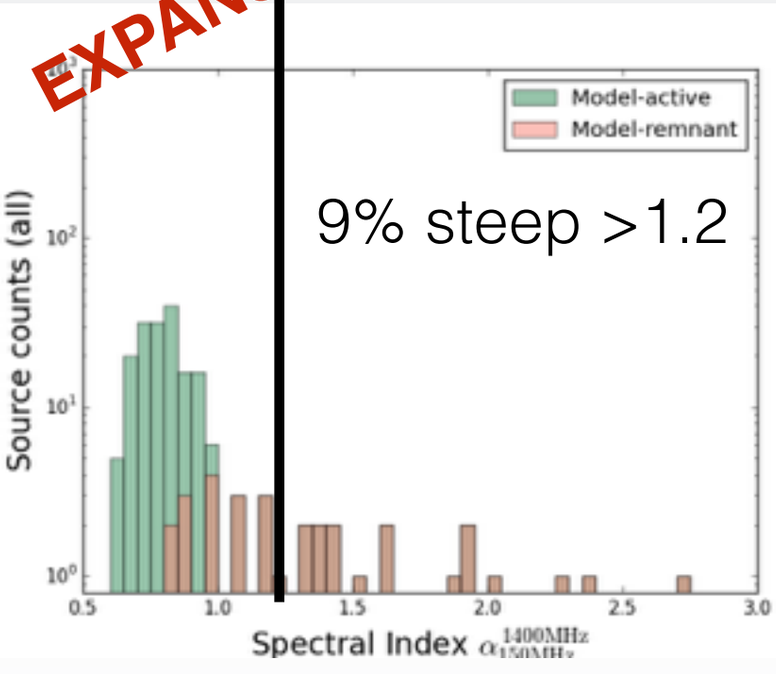
Dynamical evolution models are required to reproduce the observed fraction of ultra-steep spectrum remnants in the Lockman Hole field (<15%). When only the radiative evolution is included, the number of ultra-steep spectrum remnants is largely overpredicted.

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

NO EXPANSION



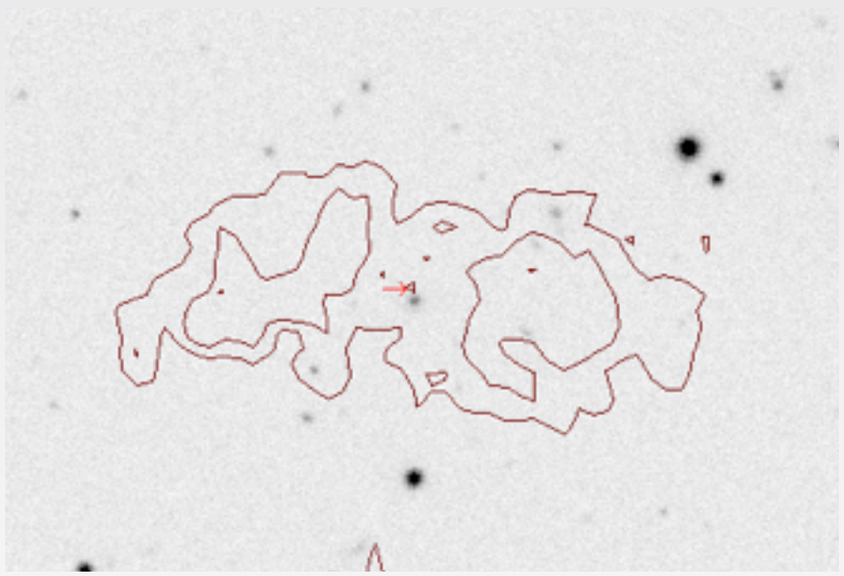

EXPANSION

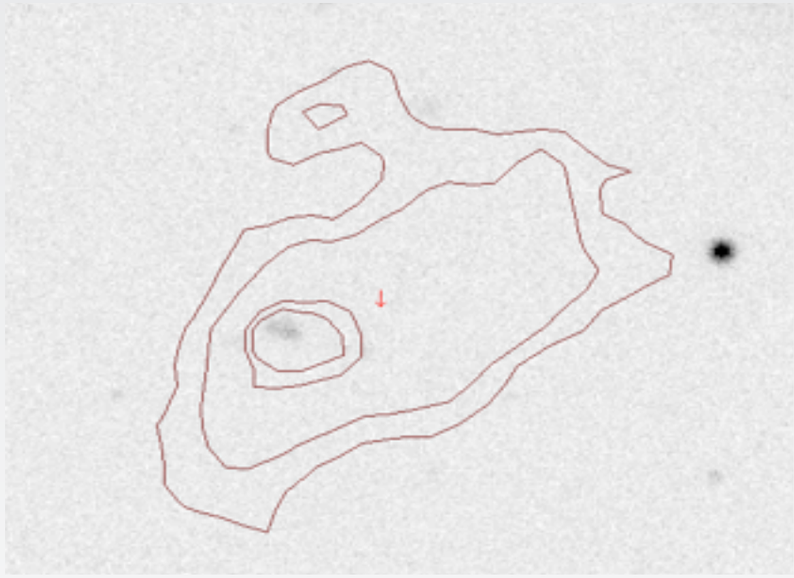



**α>1.2**

# Next steps …

**1** Optical identifications to derive physical properties i.e. radio power, size, environment + follow up observations





**2** Search expansion to HETDEX field covered by the LOFAR Two-metre Sky Survey (LoTSS, Shimwell+2017) to obtain a bigger sample

# Take away messages!

**REMNANT RADIO GALAXIES ARE INTERESTING TO UNDERSTAND THE EVOLUTION OF RADIO GALAXY AND PROVIDE CONSTRAINTS TO THE AGN JET TIMESCALES**

- The fraction of remnants is low also at low frequency (<10-15%) = luminosity evolution of radio plasma after the jets switch off is fast!
- Simulations based on radiative and dynamical models predict a remnant fraction that is consistent with observations
- Not all remnants have ultra-steep spectra! Different selection criteria can likely identify sources at different stages of their evolution

Brienza et al. 2017, A&A, 606, A98
FOR MORE DETAILS!

Brienza+2016

Shulevski+2016

Shulevski+2017

# Thank you!

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