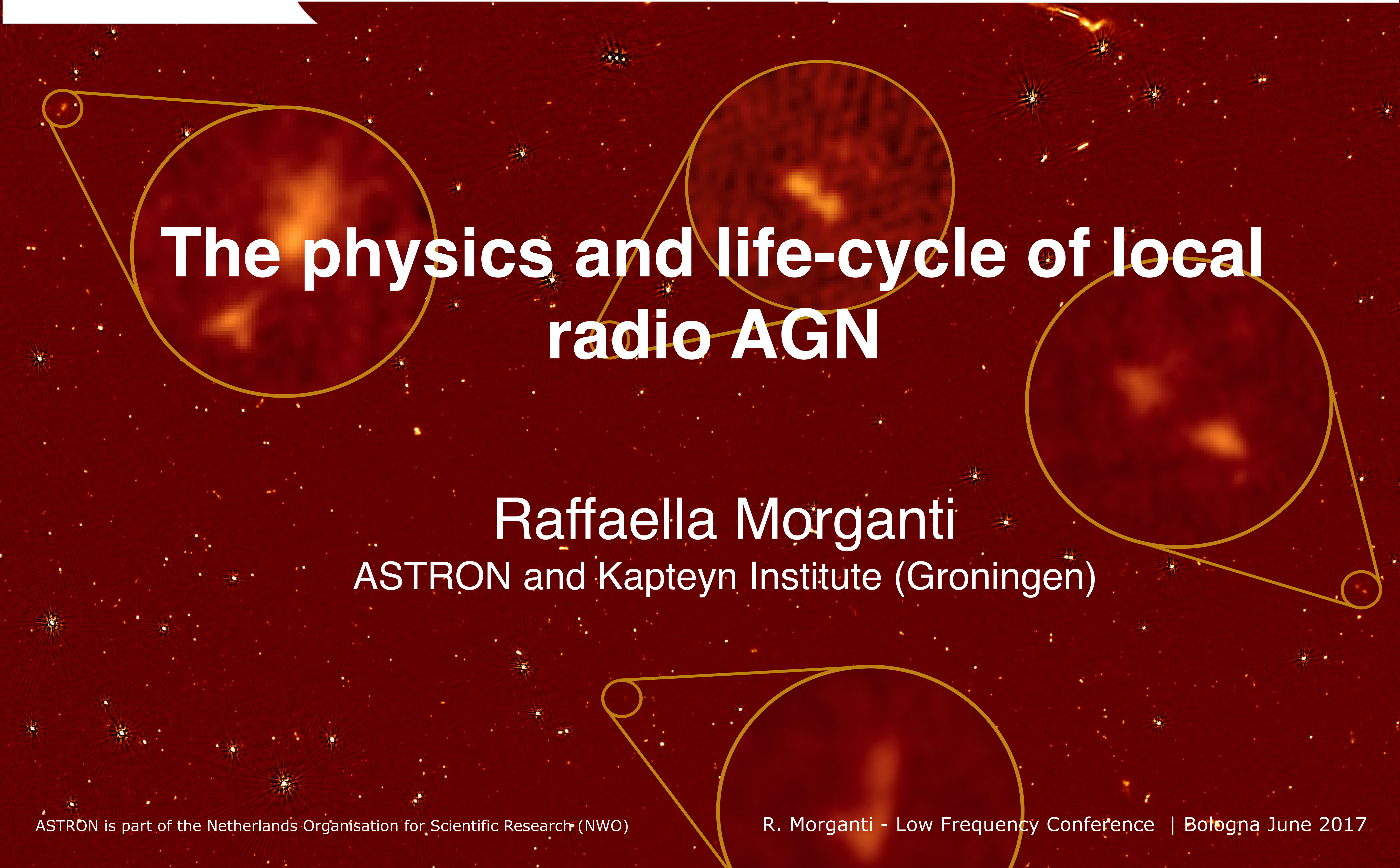
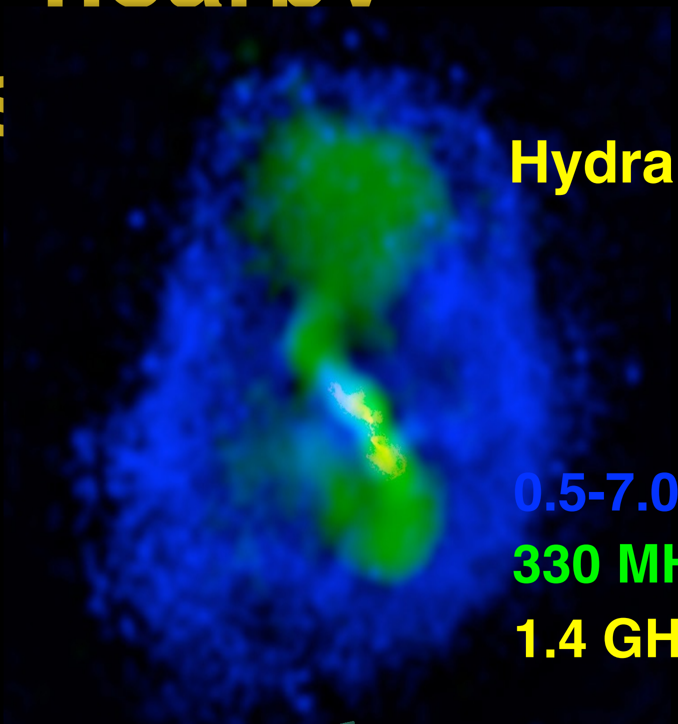
Netherlands Institute for Radio Astronomy



The physics and life-cycle of local radio AGN

Raffaella Morganti
ASTRON and Kapteyn Institute (Groningen)

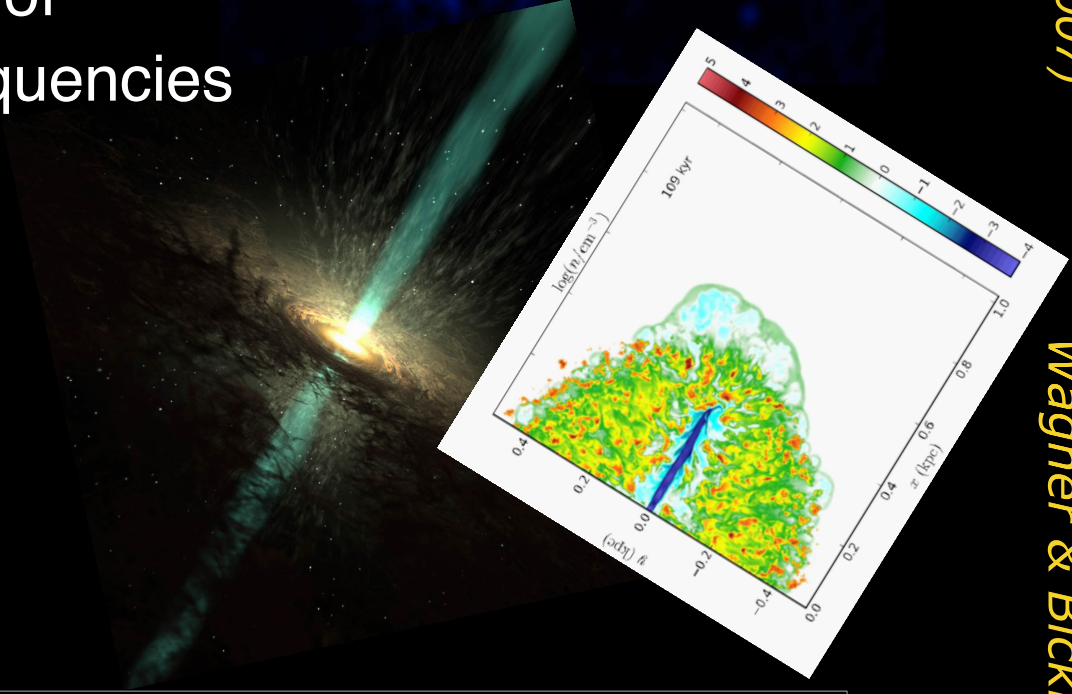
Low frequencies for the study of nearby AGN: physics and impact of thes



Lane et al. (2004), Wise et al. (2007)

Radio jets/lobes affect their surrounding medium on different scales:
from tens of pc to many hundred kpc
e.g. cavities and outflows

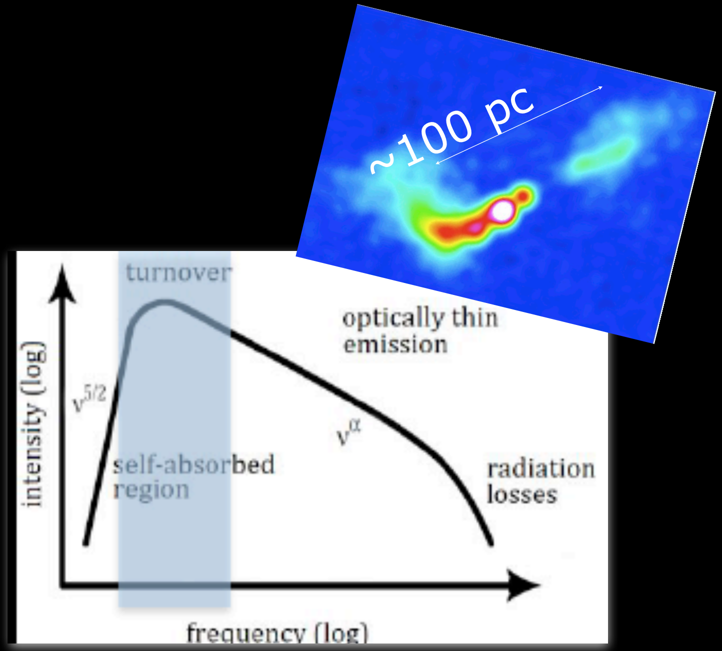
Amplitude of their impact depends on a number of parameters that we can explore at low radio frequencies



Wagner & Bicknell 2011

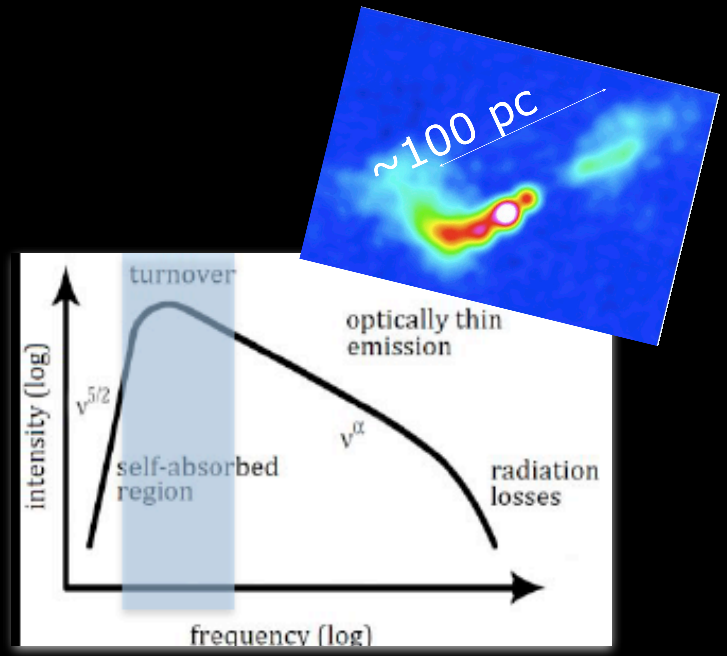
Low frequencies: energetics and the life-cycle
➔ occurrence of remnants and comparison with mock catalogues
➔ restarted radio sources

Life of a radio galaxy

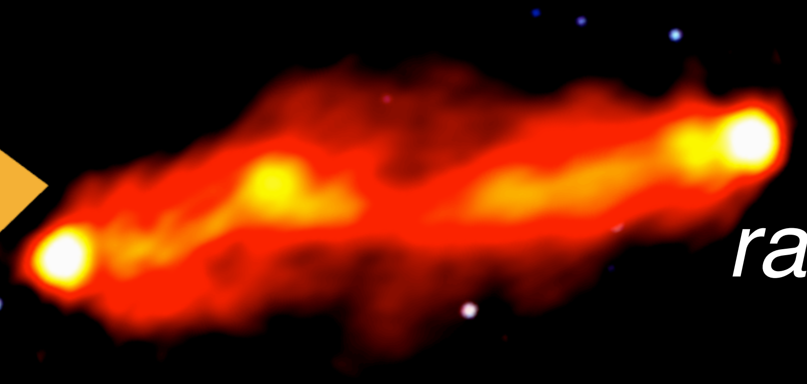


Younger radio galaxies

Life of a radio galaxy

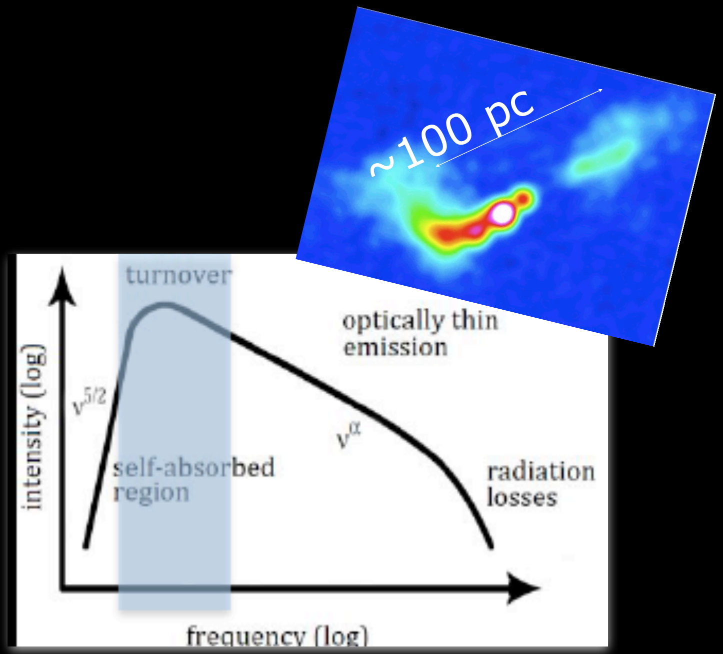


Younger radio galaxies

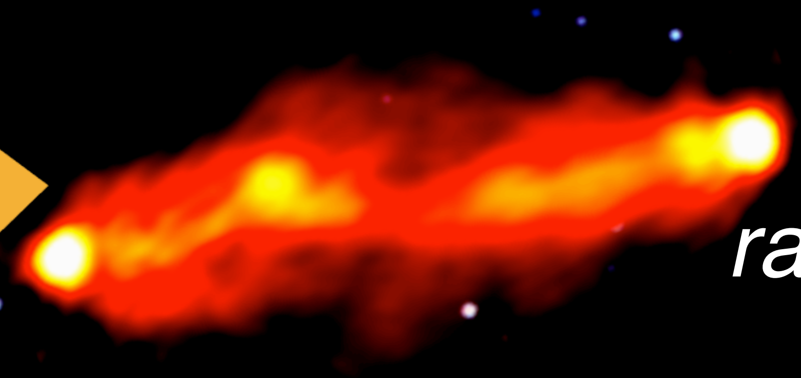


“Adult” radio galaxies

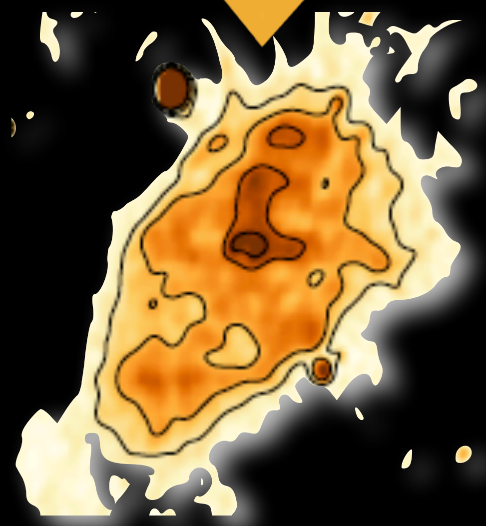
Life of a radio galaxy



Younger radio galaxies

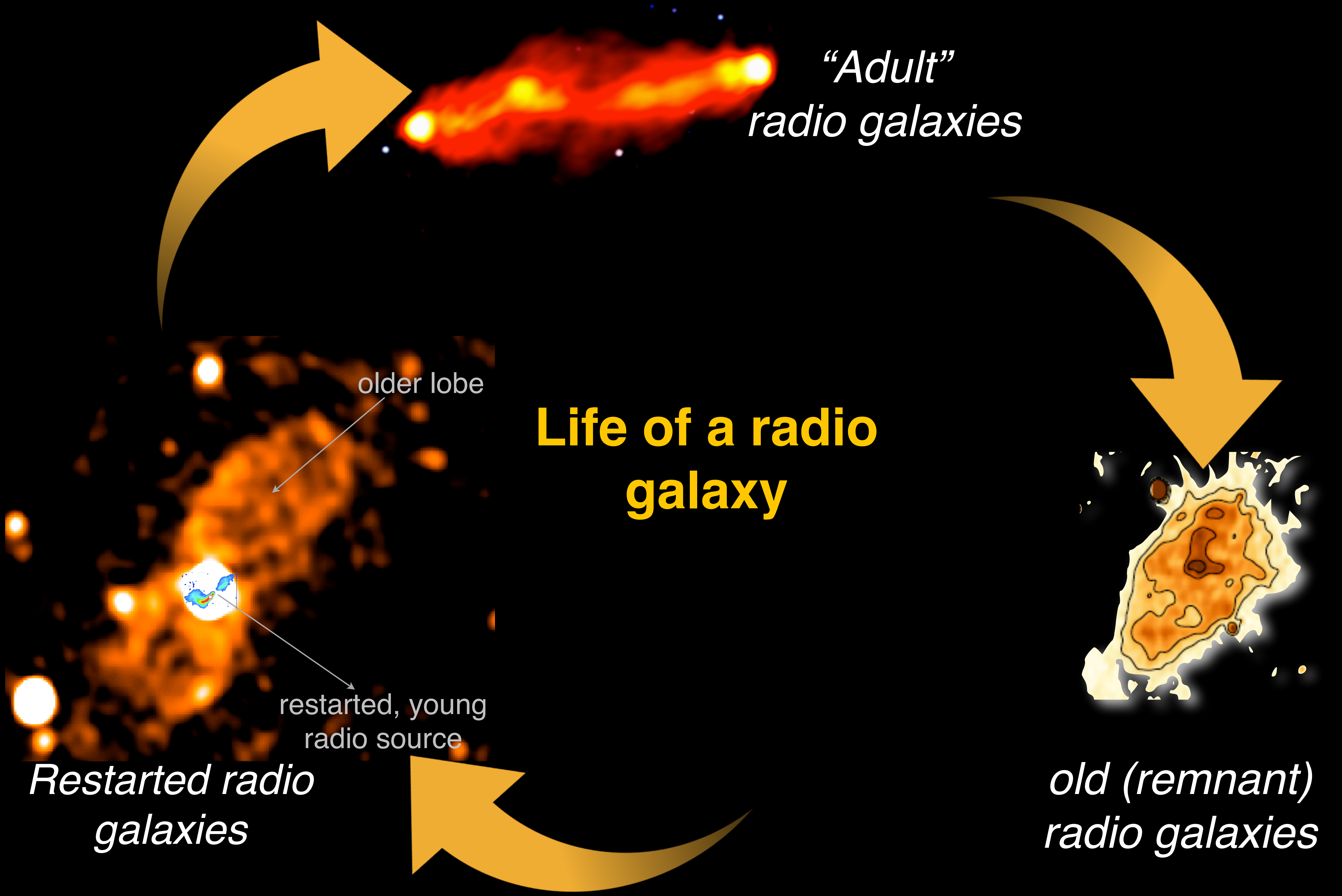


“Adult” radio galaxies



old (remnant) radio galaxies

Life of a radio galaxy



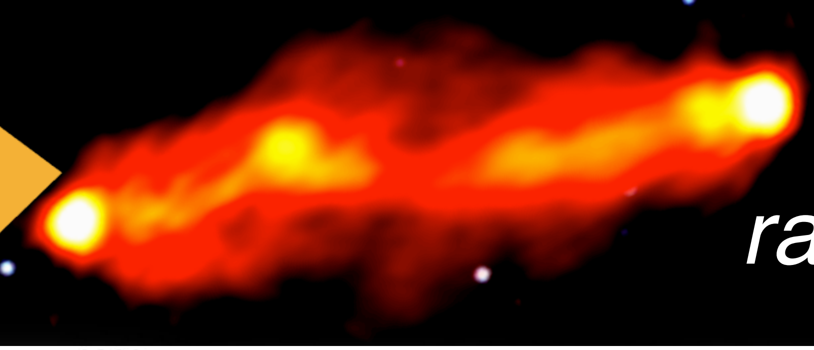
"Adult"
radio galaxies

old (remnant)
radio galaxies

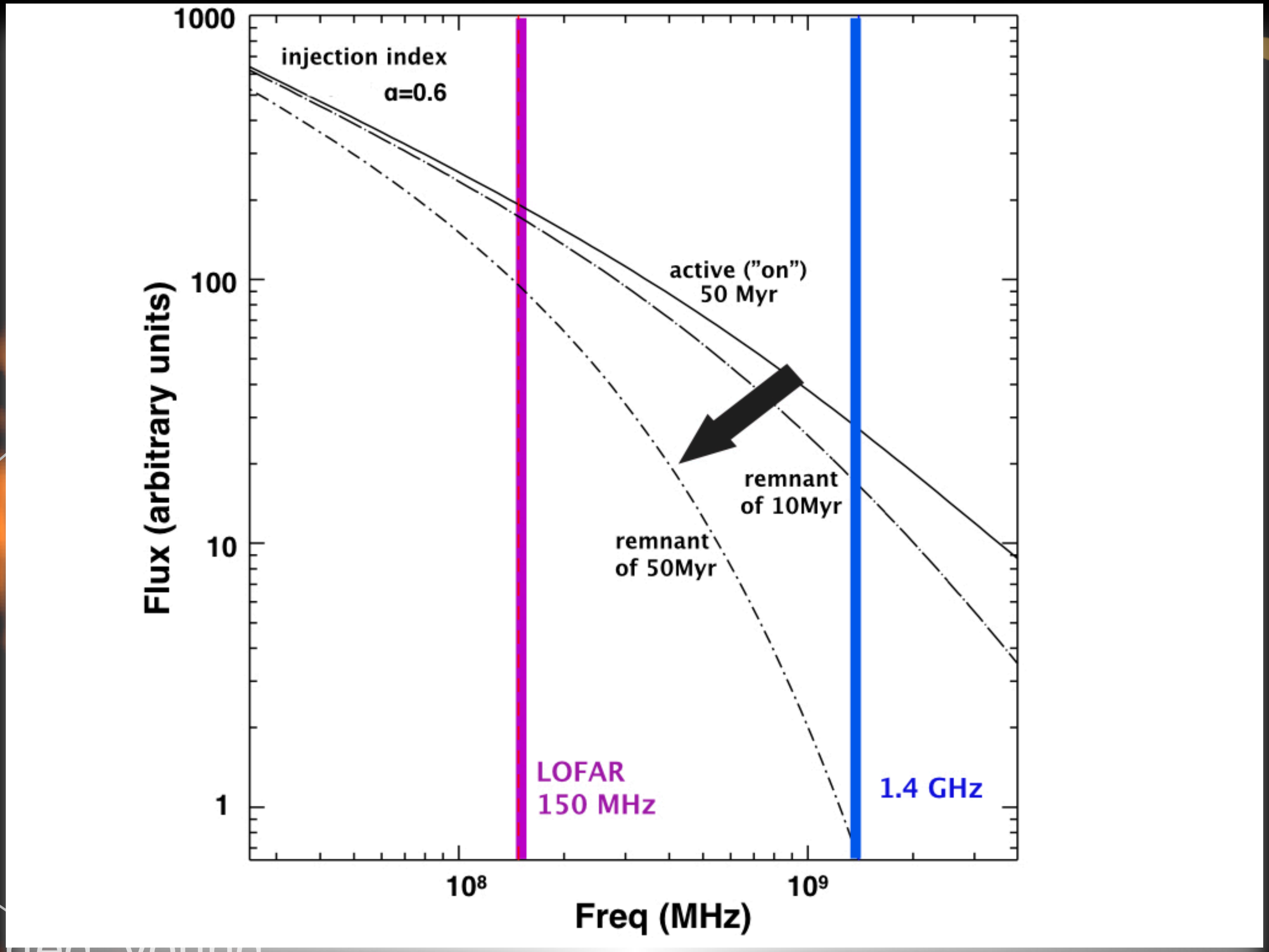
Restarted radio
galaxies

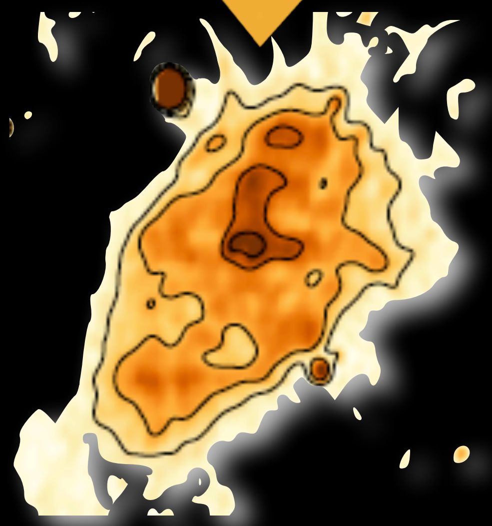
older lobe

restarted, young
radio source



"Adult"
radio galaxies





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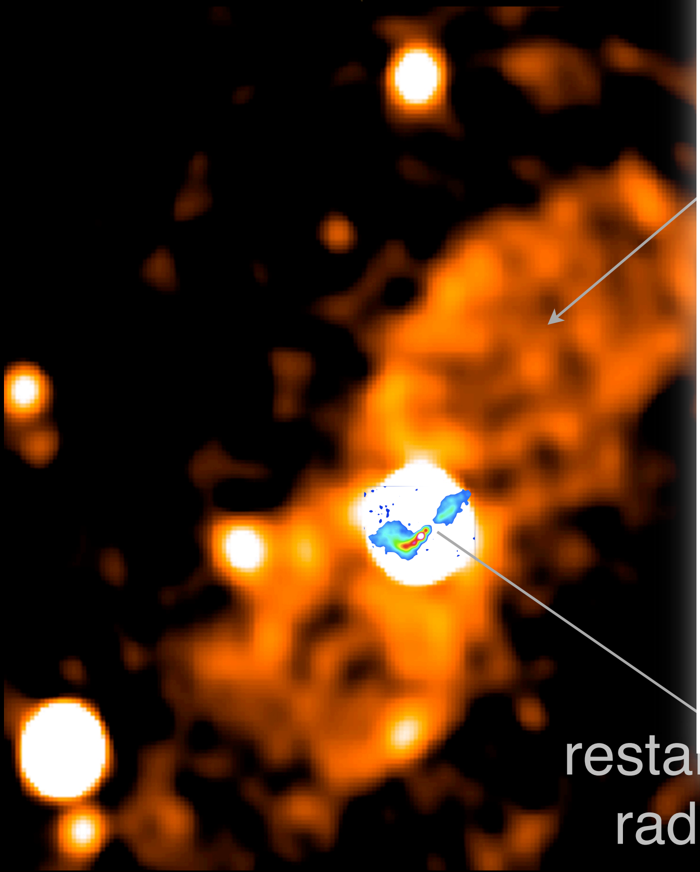
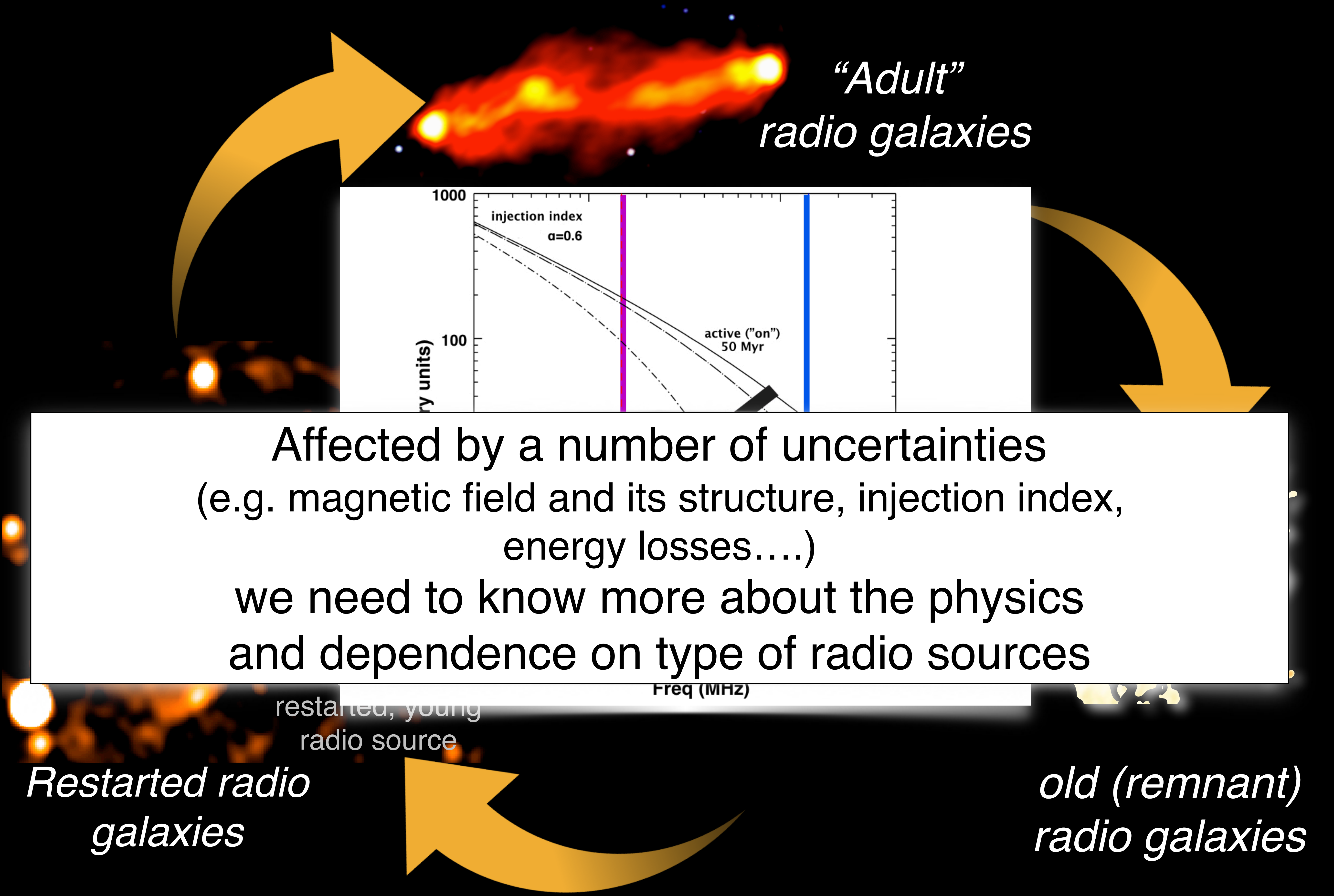


Restarted radio
galaxies



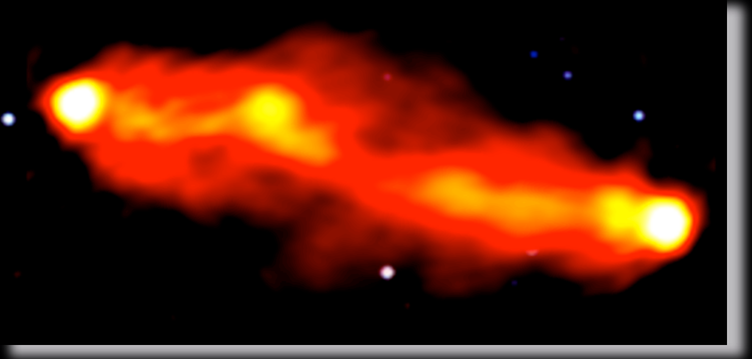
"Adult"
radio galaxies

Affected by a number of uncertainties
(e.g. magnetic field and its structure, injection index, energy losses….)
we need to know more about the physics
and dependence on type of radio sources

Restarted radio galaxies

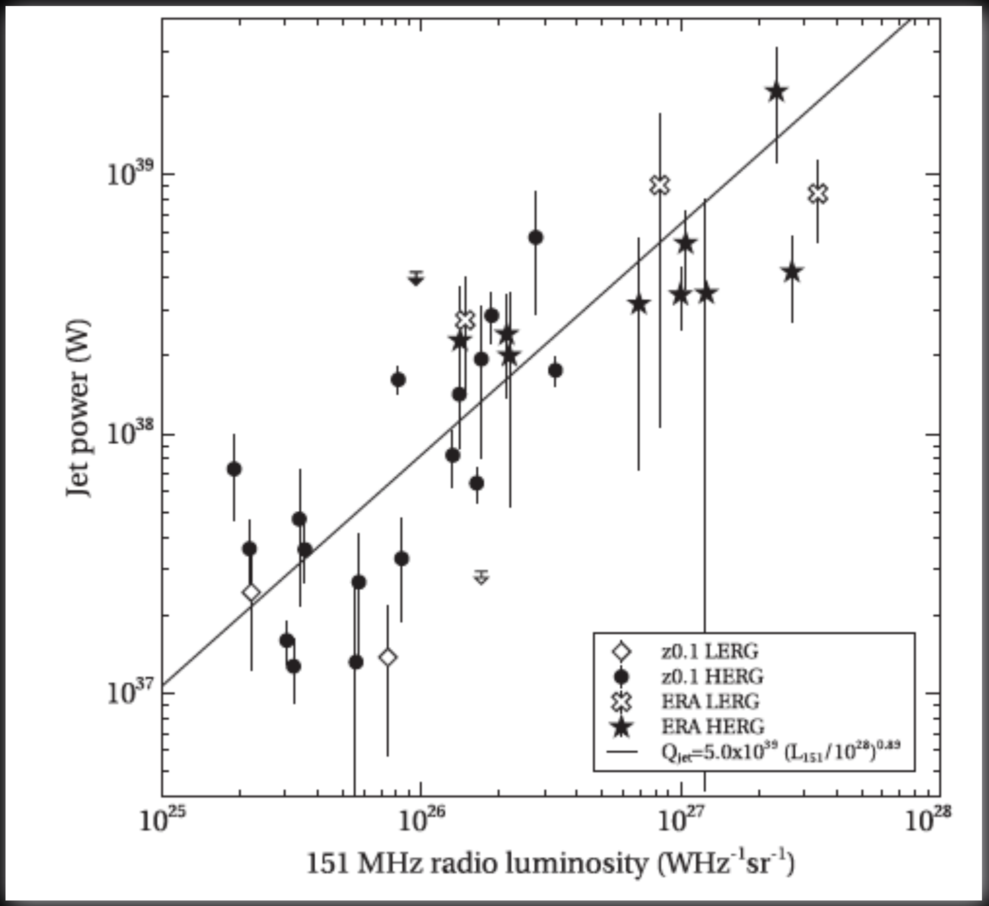
old (remnant) radio galaxies

High power radio sources

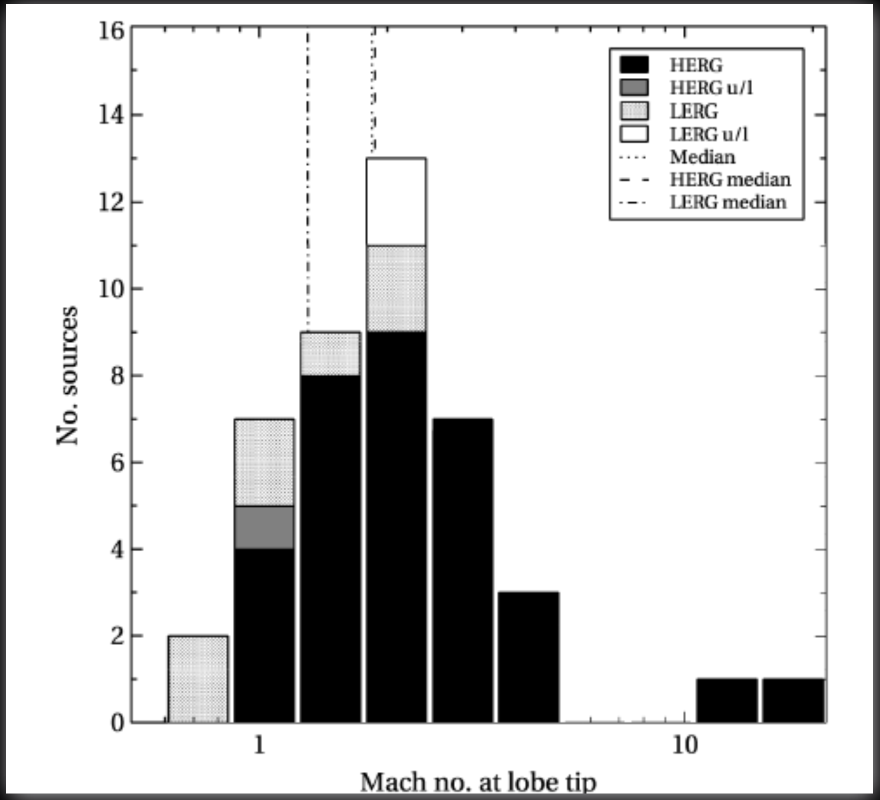


Energetics and magnetic field: internal conditions (via X-ray inverse Compton) **and** environmental information (specifically external pressure) ➔ linked to low frequencies ➔ electron dominated, relatively small deviation from equipartition, overpressure compared to external pressure

- *we can now use radio properties alone to estimate internal energy of FRII* ➔ to use for survey data!



Ineson et al. 2017, Croston et al. 2017

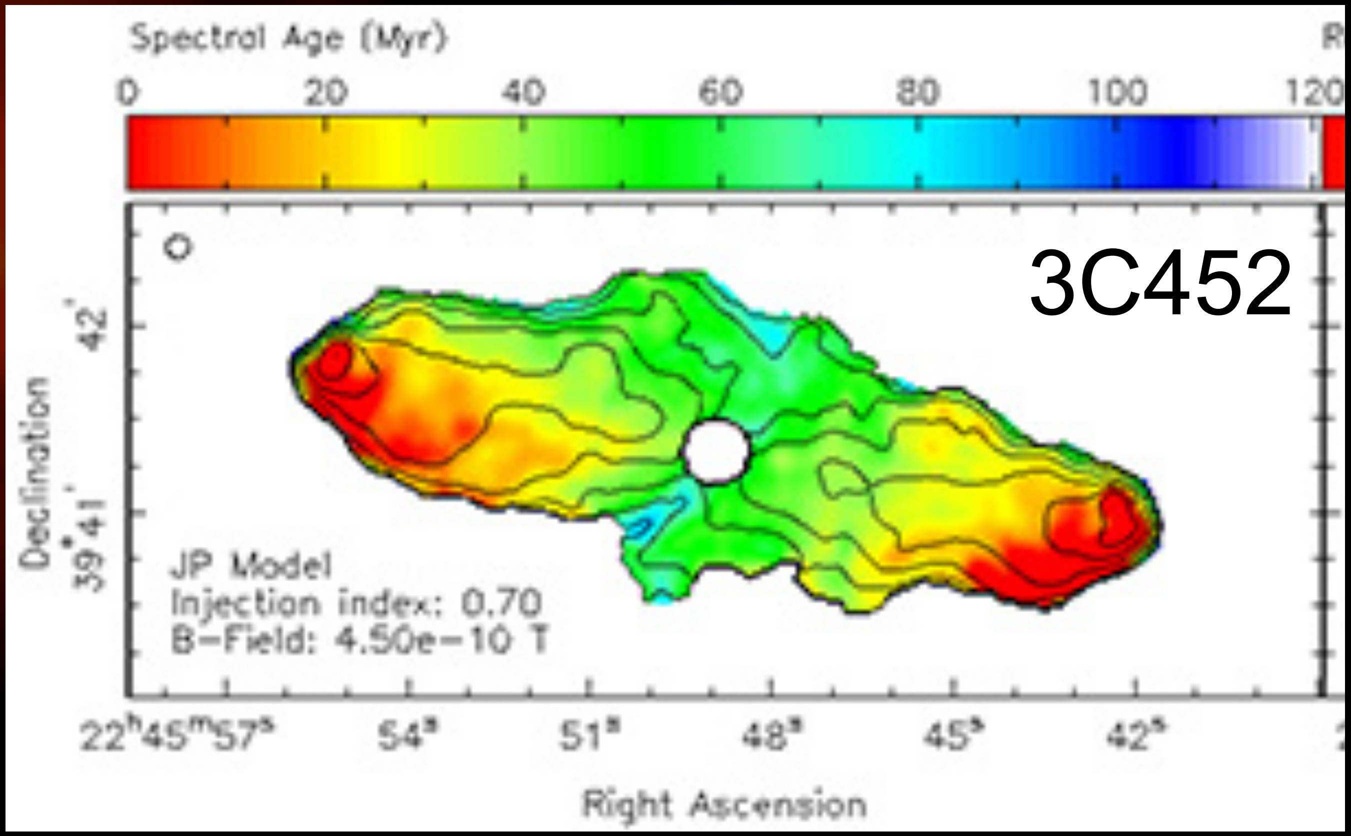


Need for resolved studies to trace injection index…

Better constrained spectrum at low frequencies.
Injection index (as derived from the lobe emission) remains **steeper** than classically assumed values even when considered on well resolved scales at low frequencies ➔ greater amount of energy is contained in the low-energy electron population than previously thought.

Harwood et al. 2015, 2016

3C452 LOFAR 150 MHz - Jeremy Harwood



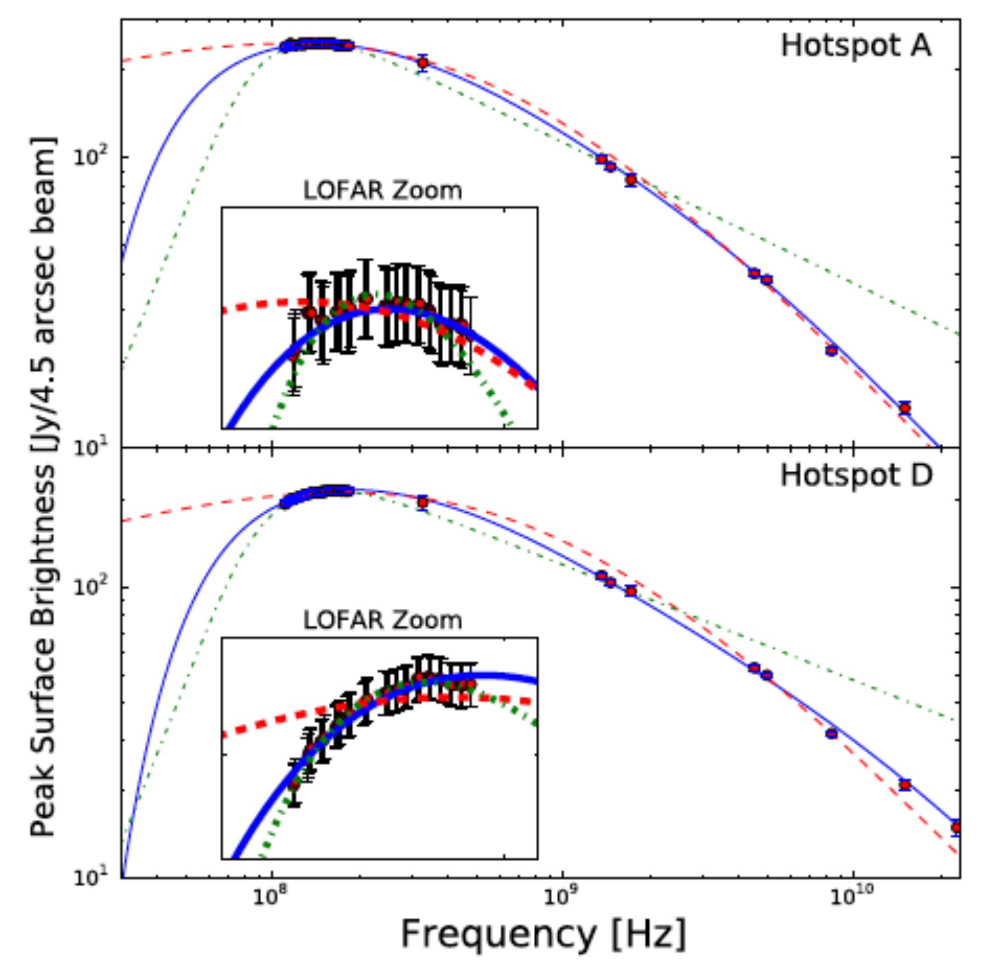
absorption of hotspot emission and/or non-homogeneous and additional acceleration mechanisms

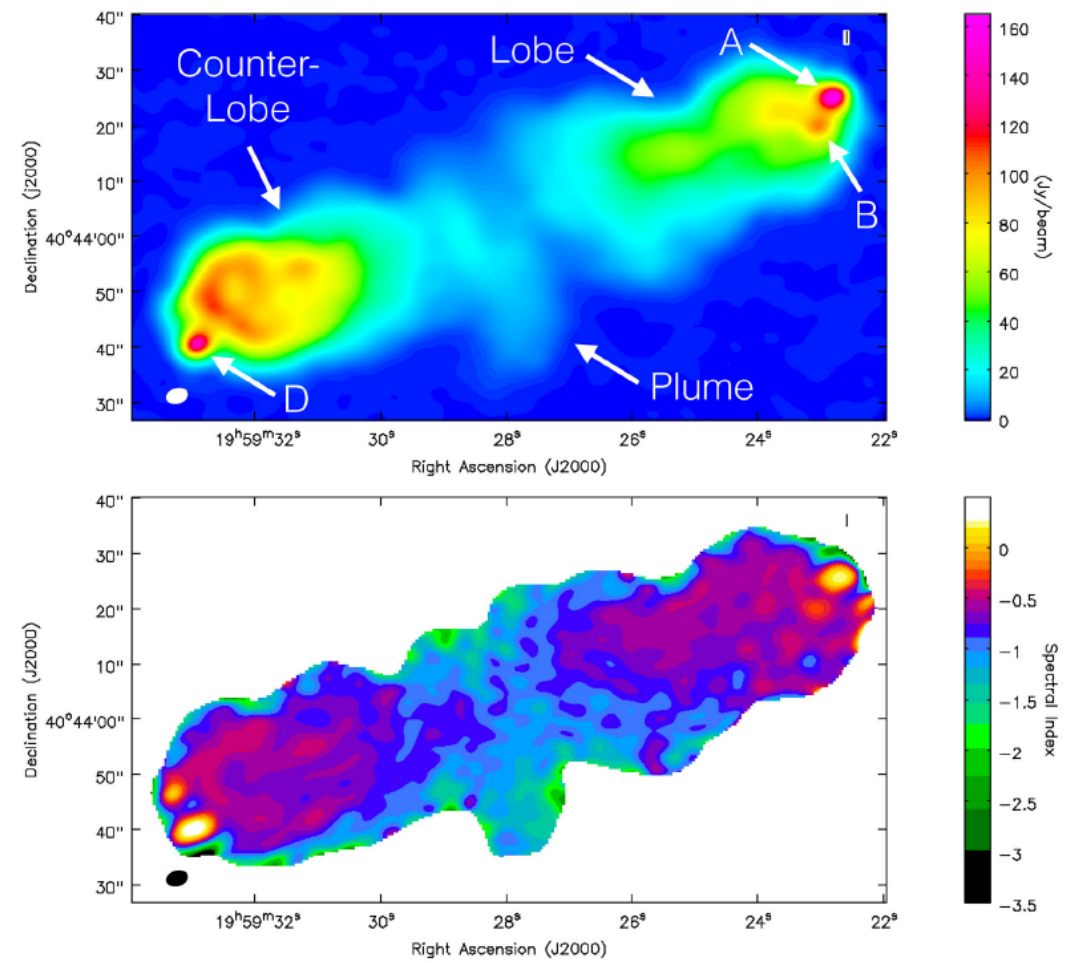
See talk of Harwood

High spatial resolution is important: hot-spots in Cygnus A for nearby AGN

- on the small scales, cutoff in spectrum and/or absorption

McKean et al. 2016





Low-energies cutoff model with low energy tail (dashed red)
➔ doesn't reproduce the observations

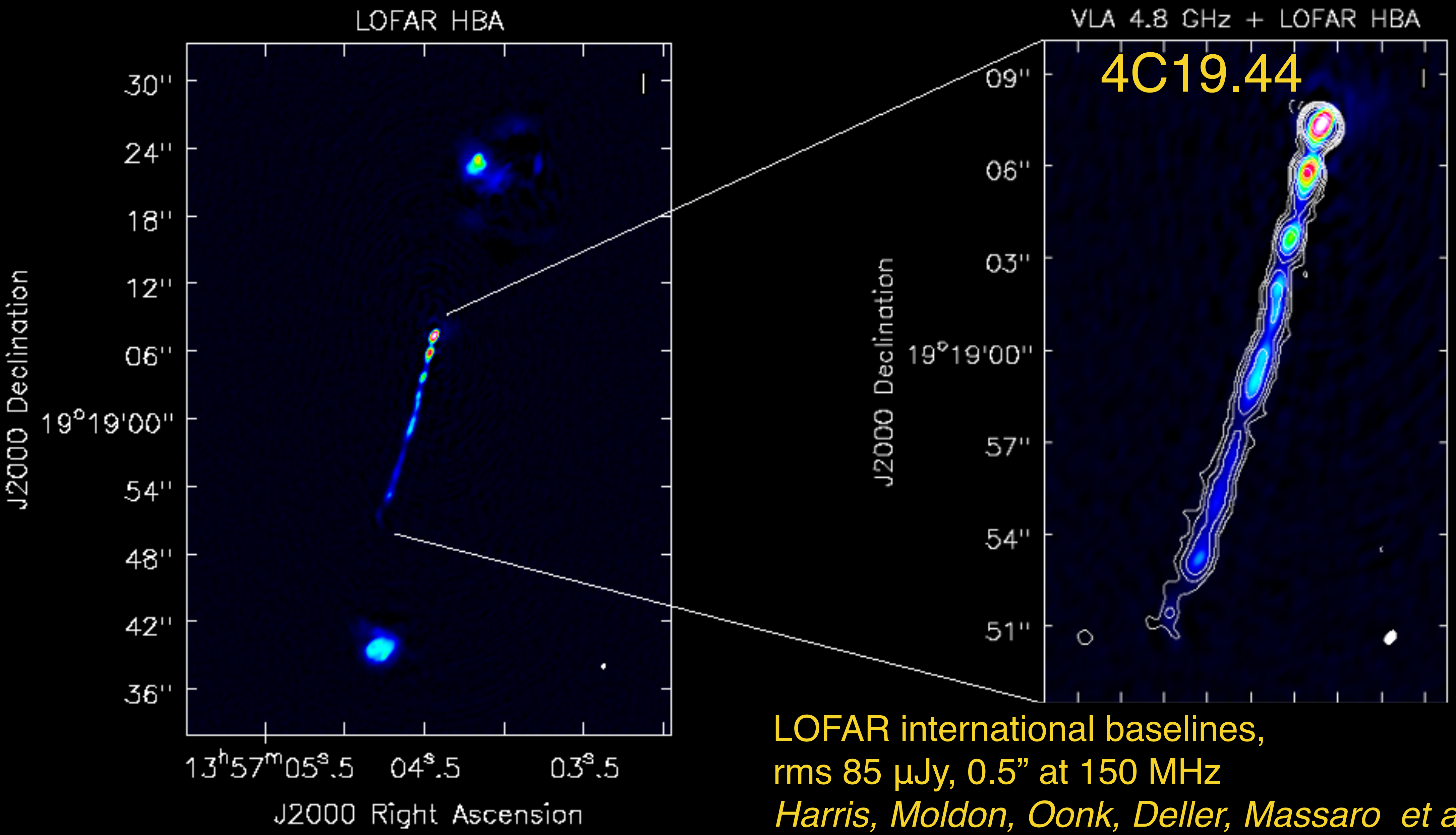
Free-free absorption (solid blue. => but high-density thermal material

High spatial resolution is important: emission processes of the X-rays knots in radio jets

Dan Harris's dream…

✓ Origin of X-ray and radio emission in jets: separate synchrotron component? Or is it IC/CMB emission from a jet with significant (e.g. $\Gamma \approx 10$) bulk velocity on kpc scales?

➔ use LOFAR international baselines to test this



LOFAR international baselines,
rms 85 µJy, 0.5" at 150 MHz
Harris, Moldon, Oonk, Deller, Massaro et al.

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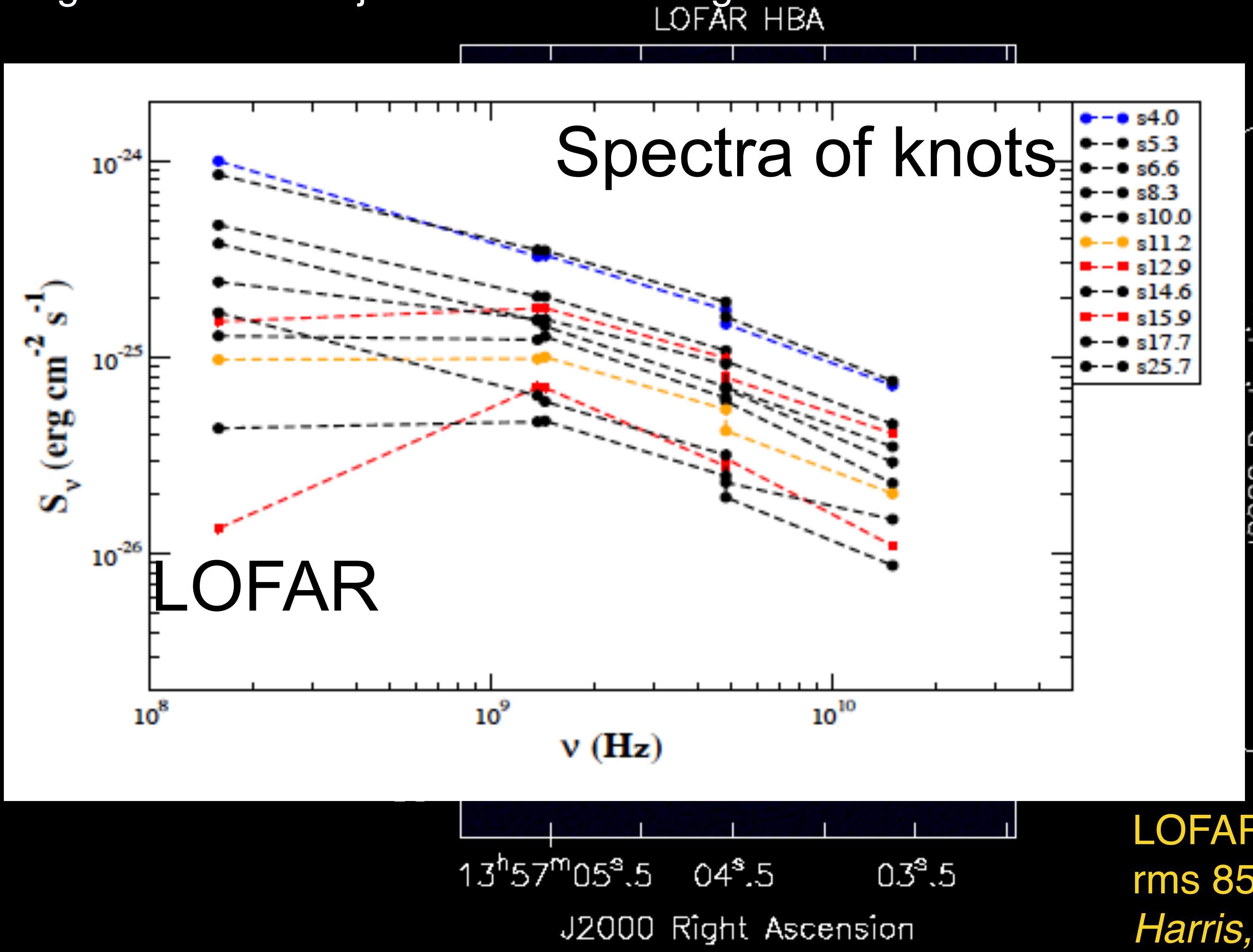
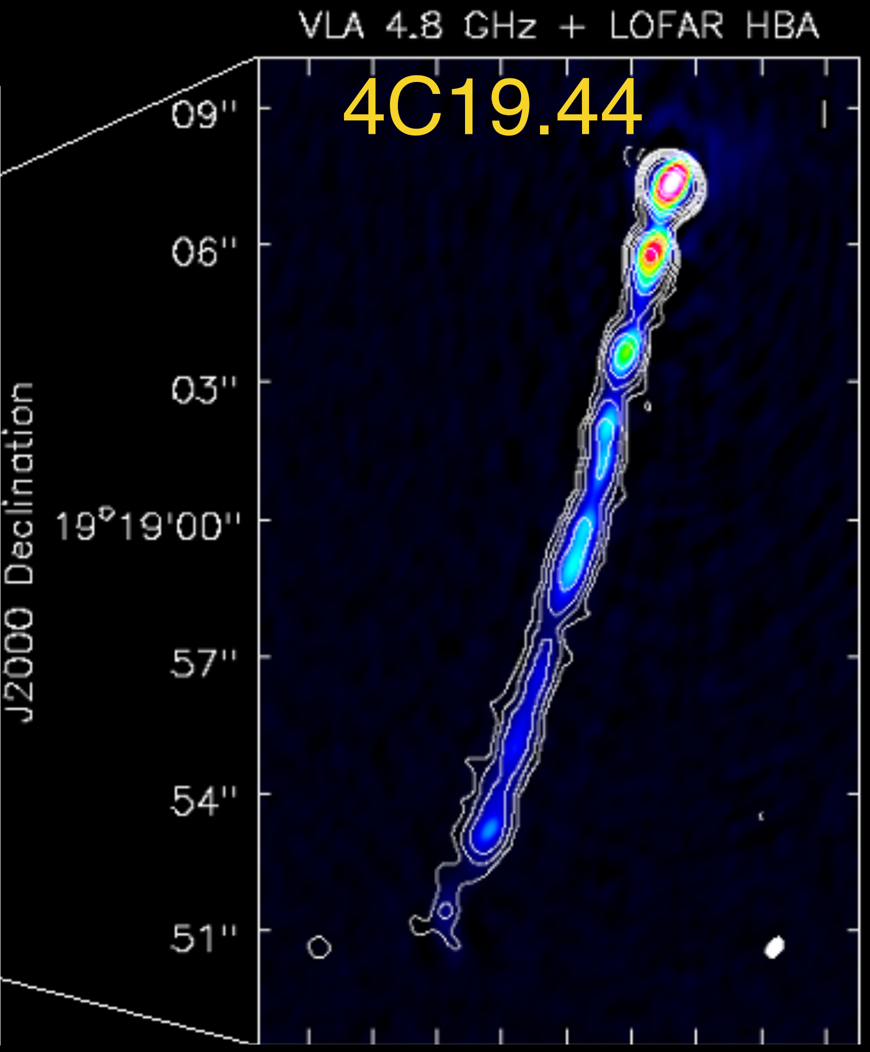
➔ use LOFAR international baselines to test this

✓ Low frequency curvature found: indicate a spectral break or even a low energy cutoff of the electron spectrum ➔ the IC/CMB model would require more extreme beaming parameters: larger Γ and smaller angle between the jet and the line of sight.



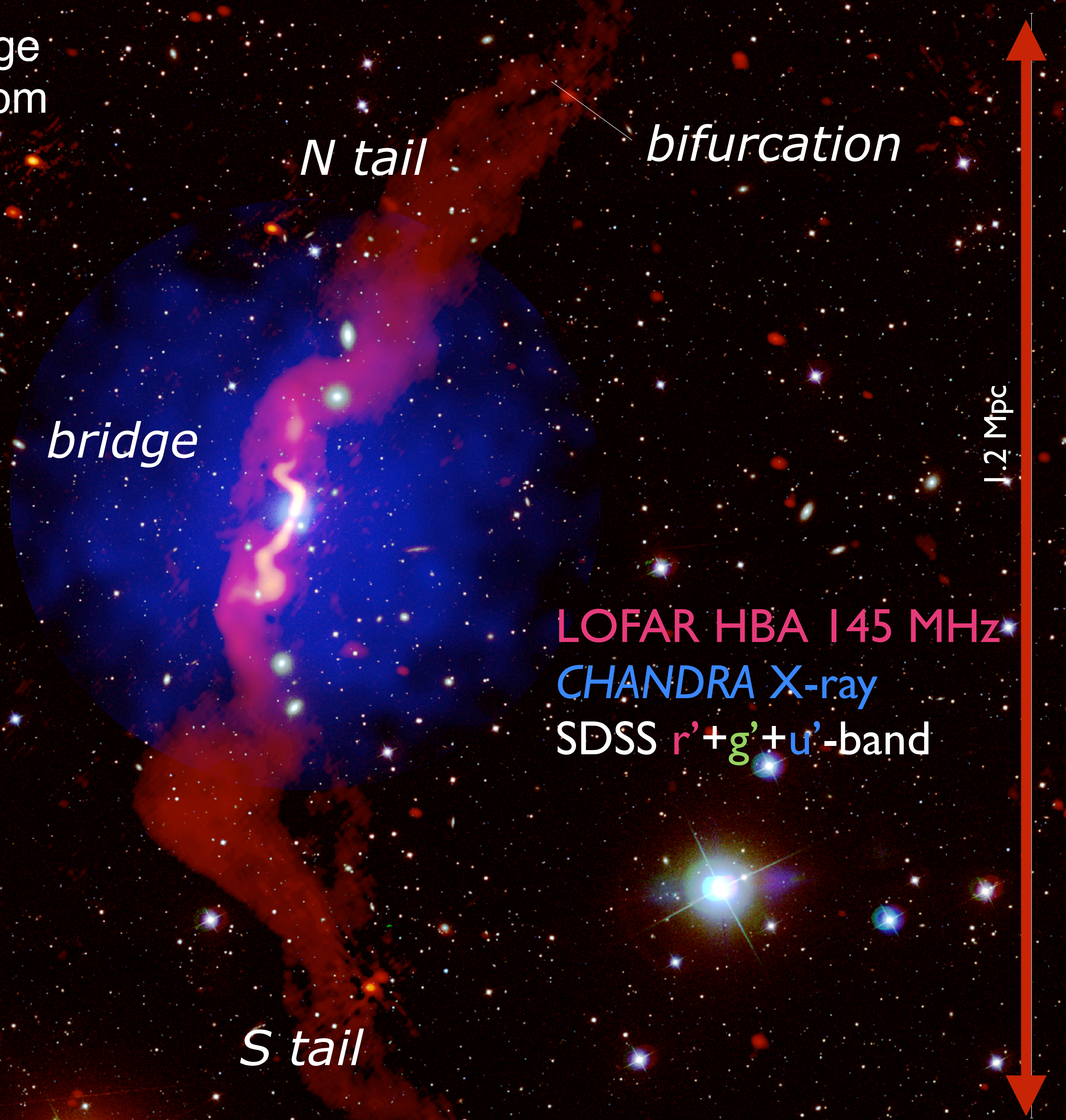


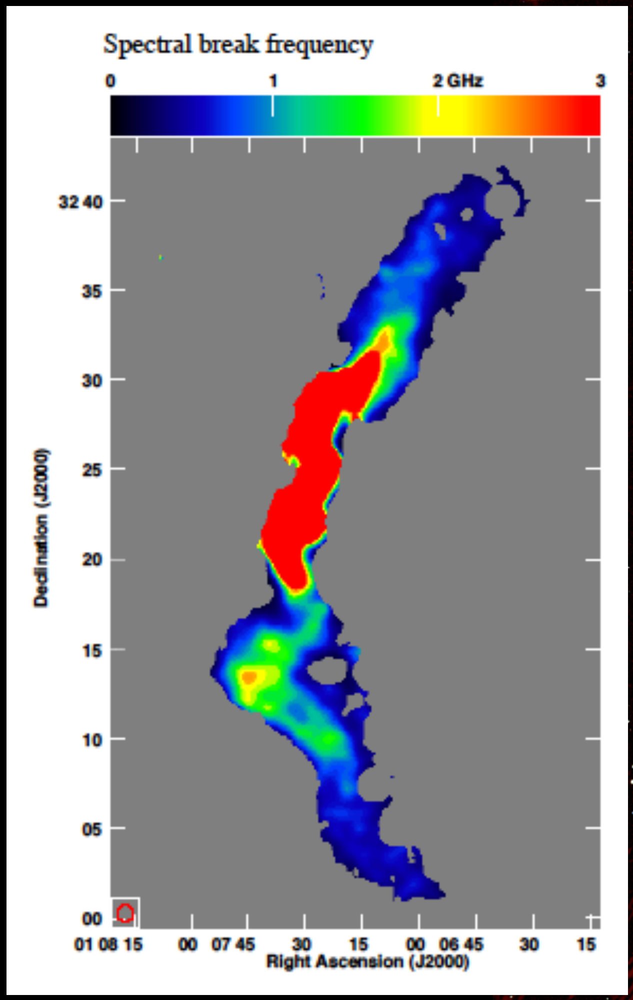
LOFAR international baselines,
rms 85 μJy, 0.5" at 150 MHz
Harris, Moldon, Oonk, Deller, Massaro et al.

Lower power radio sources: the case of the (FRI) radio galaxy 3C31

- ✓Combine LOFAR, GMRT, VLA
  ➔ importance of frequency coverage
- ✓Spectral break decreases with distance from the core
- ✓Strong entrainment/adiabatic losses
  ➔ deceleration of the flow
- ✓B ~3μG in the tails, Mach number ~ 5
  ages ~200 Myr

Heesen et al. 2017





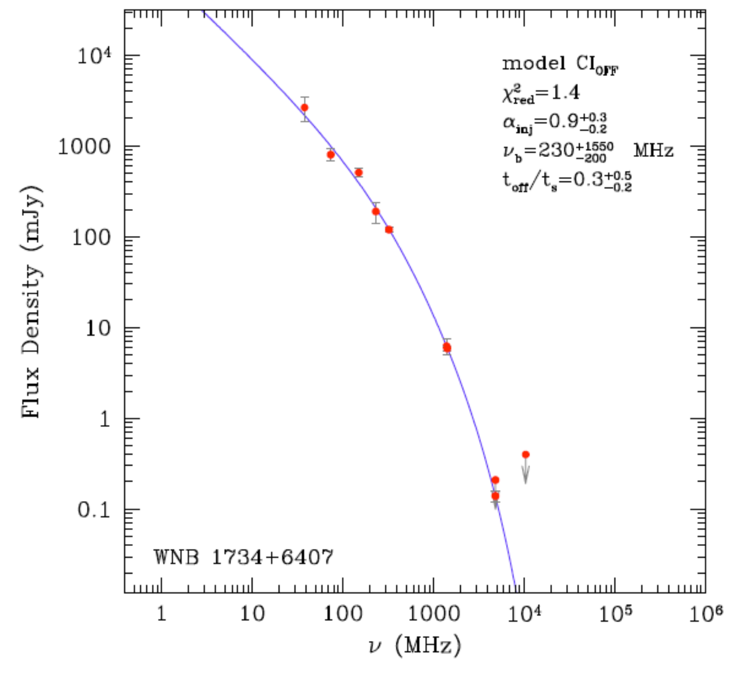
Understanding the life-cycle of radio AGN

See also talk of J. Callingham on “young” radio sources

Low frequencies and AGN remnants

Approachs so far:

➜ Results from selection on steep spectrum (spectral curvature) ➜ minority outside clusters ➜ remnant phase short or similar to active phase (Parma et al. 2007, Dwaraknath & Kale 2009, van Weeren et al. 2011, Murgia et al. 2011)



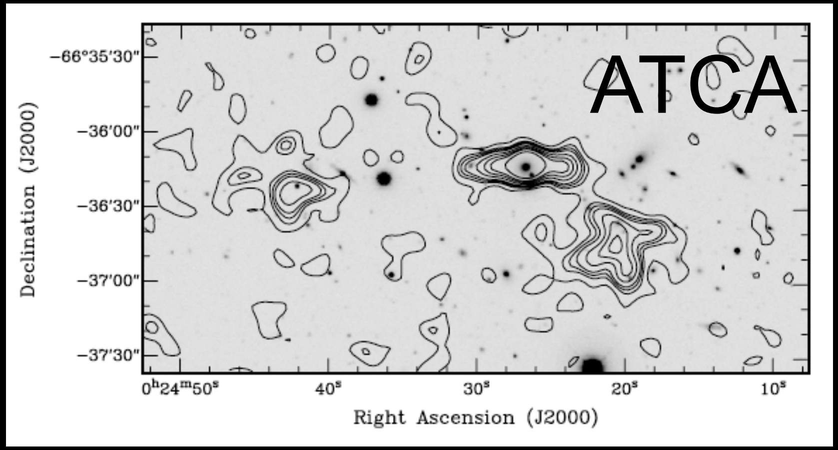
Murgia et al. 2011

General expectation ➔ deep low frequency radio surveys will reveal an abundance of steep spectrum remnant radio galaxies

➜ Results from morphology (no spectral info available) ➜ important the sensitivity to low surface brightness: e.g. Saripalli et al.

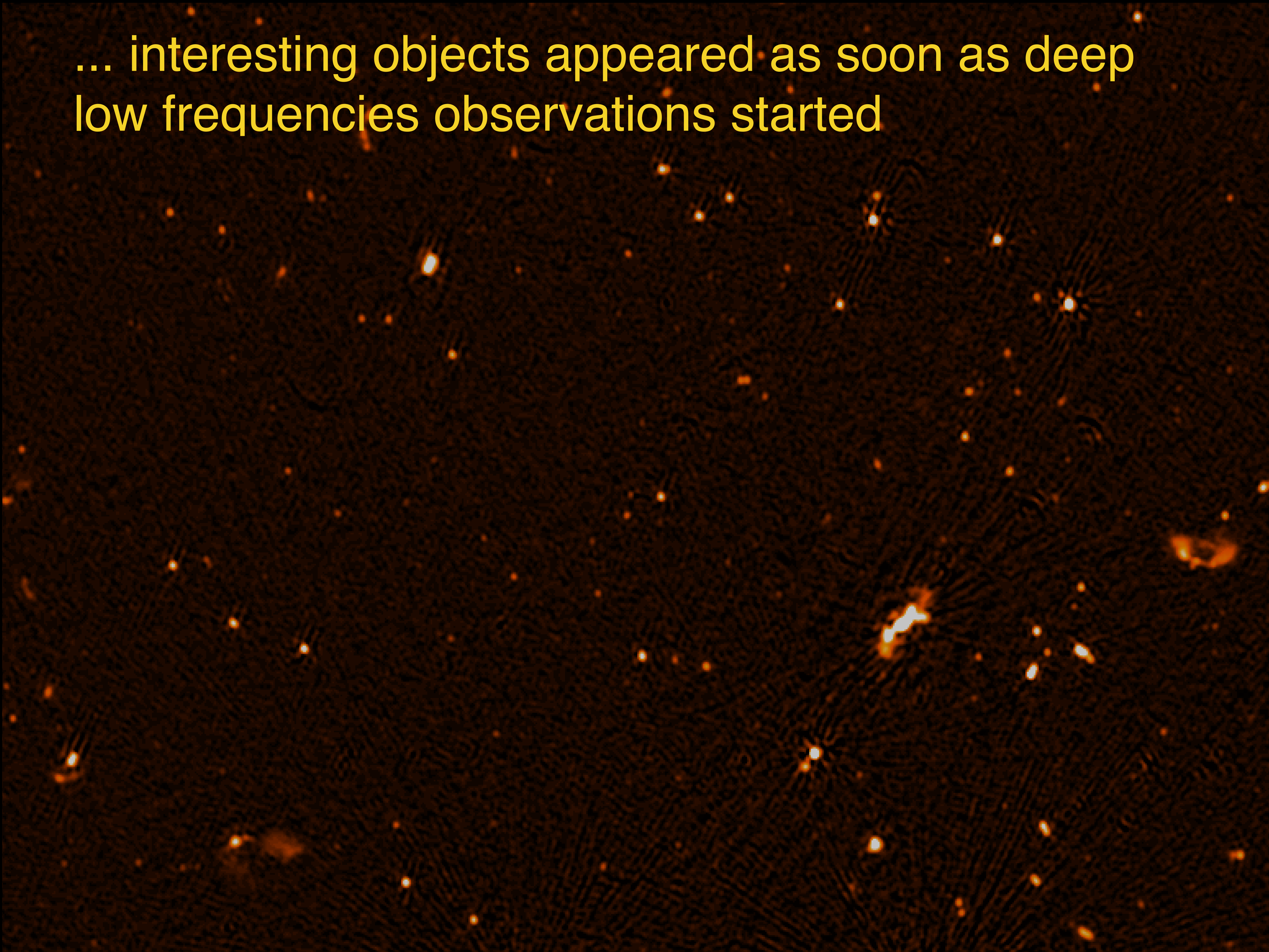
➜ episodic activity: active phase followed by a brief dying phase

and restarting activity ➜ *remnants rare, restarted not so rare*



Saripalli et al.

... interesting objects appeared as soon as deep low frequencies observations started



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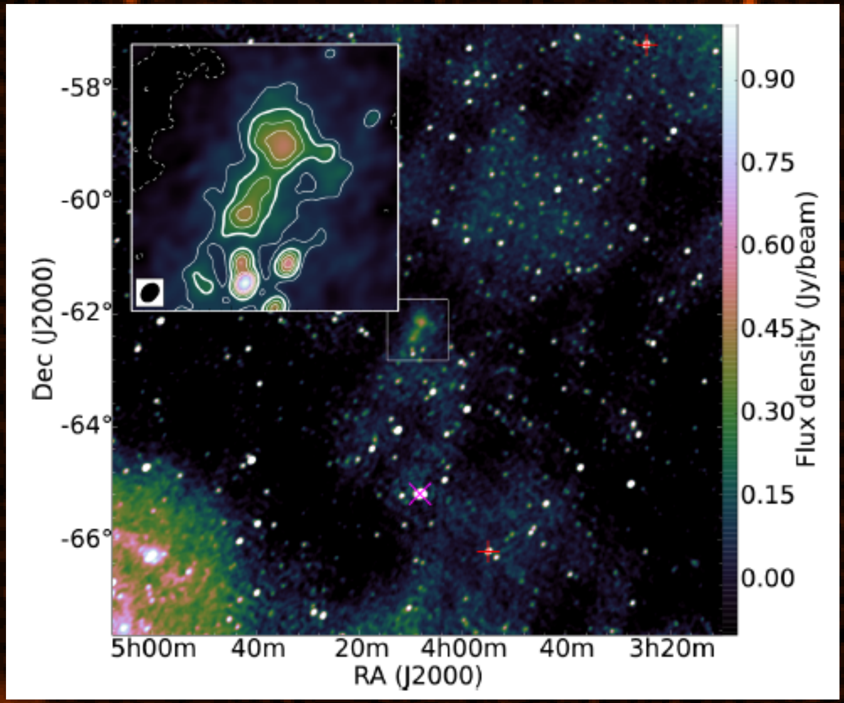


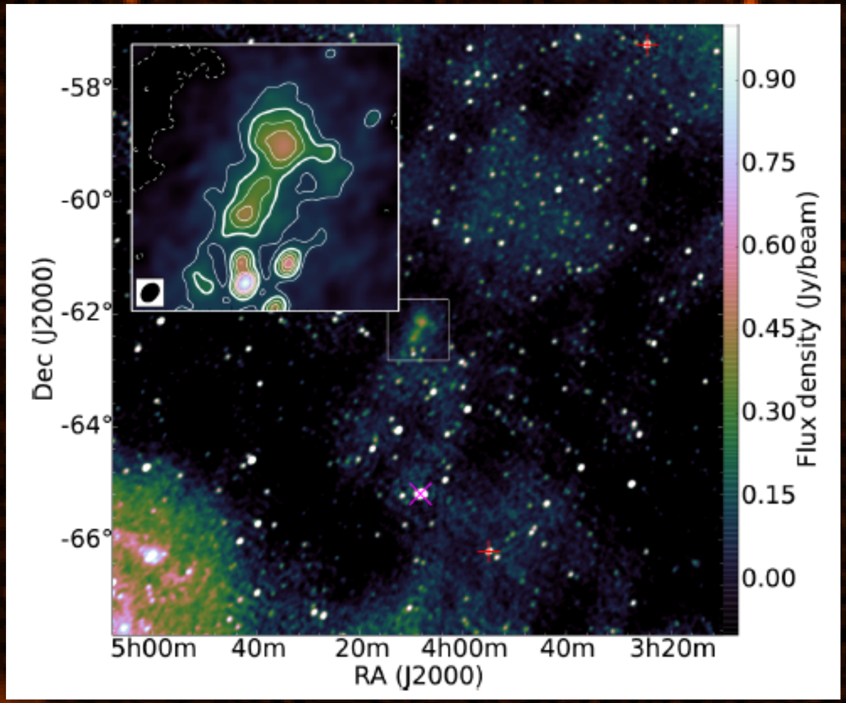
Hurley-Walker et al. 2015

NGC 1534 Galaxy with prominent dust-lane hosting a giant (dying) radio structure

... interesting objects appeared as soon as deep low frequencies observations started

“Blob1”, Brienza et al. 2016

Serendipitous, field 3C380



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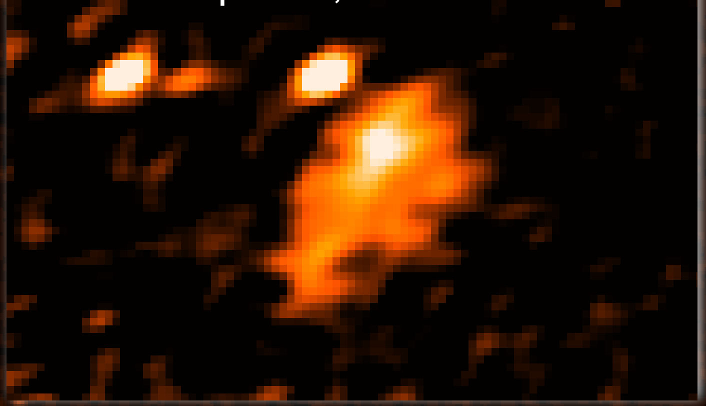
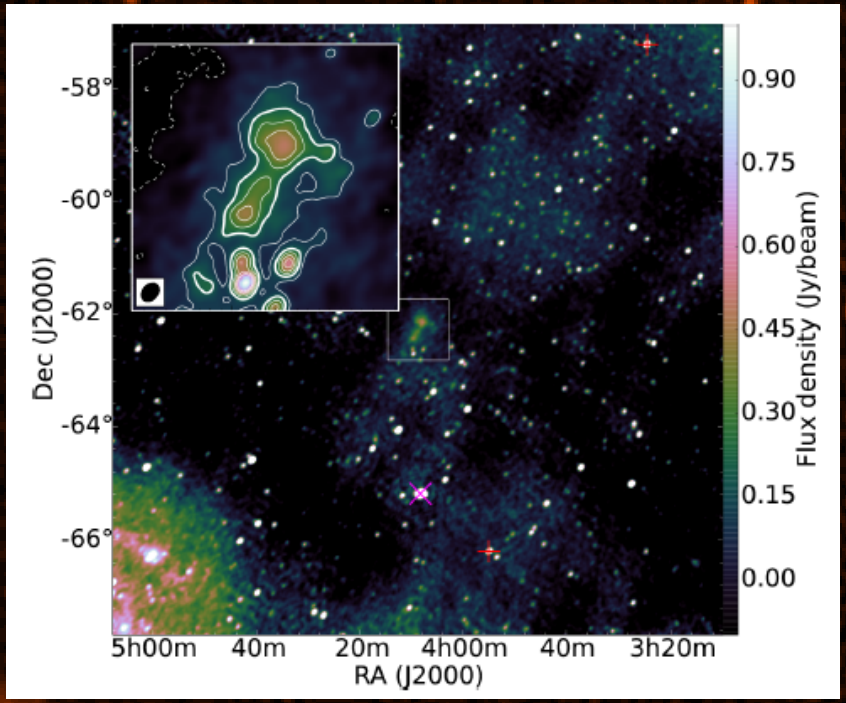


Serendipitous candidate remnant (field J1431+14), Shulevski et al.



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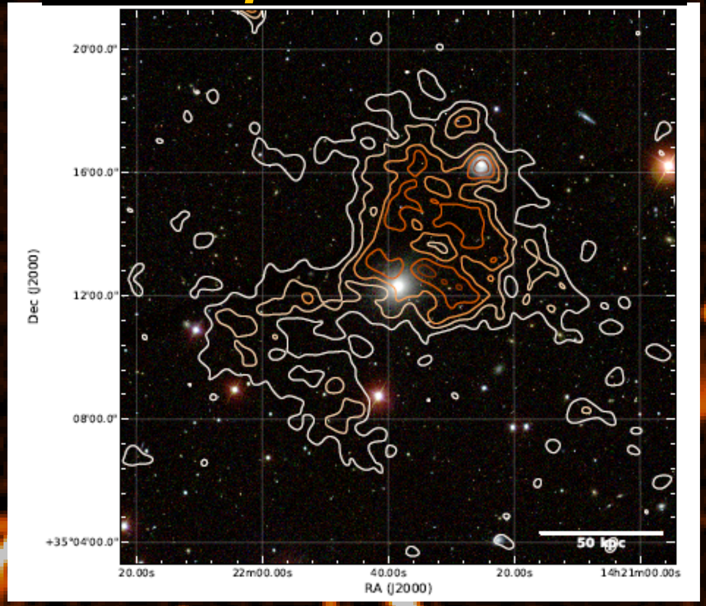
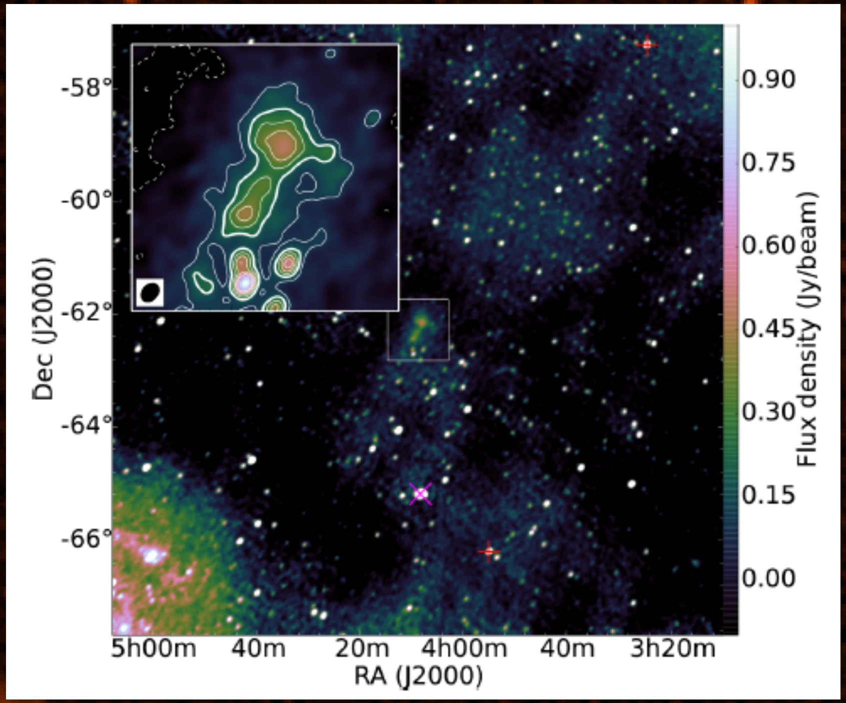
De Gasperin et al. 2012



Candidate remnant,
Bootes field
van Weeren et al. 2014



Hurley-Walker et al. 2015
NGC 1534 Galaxy with prominent dust-lane hosting a giant (dying) radio structure

A systematic search of AGN remnants

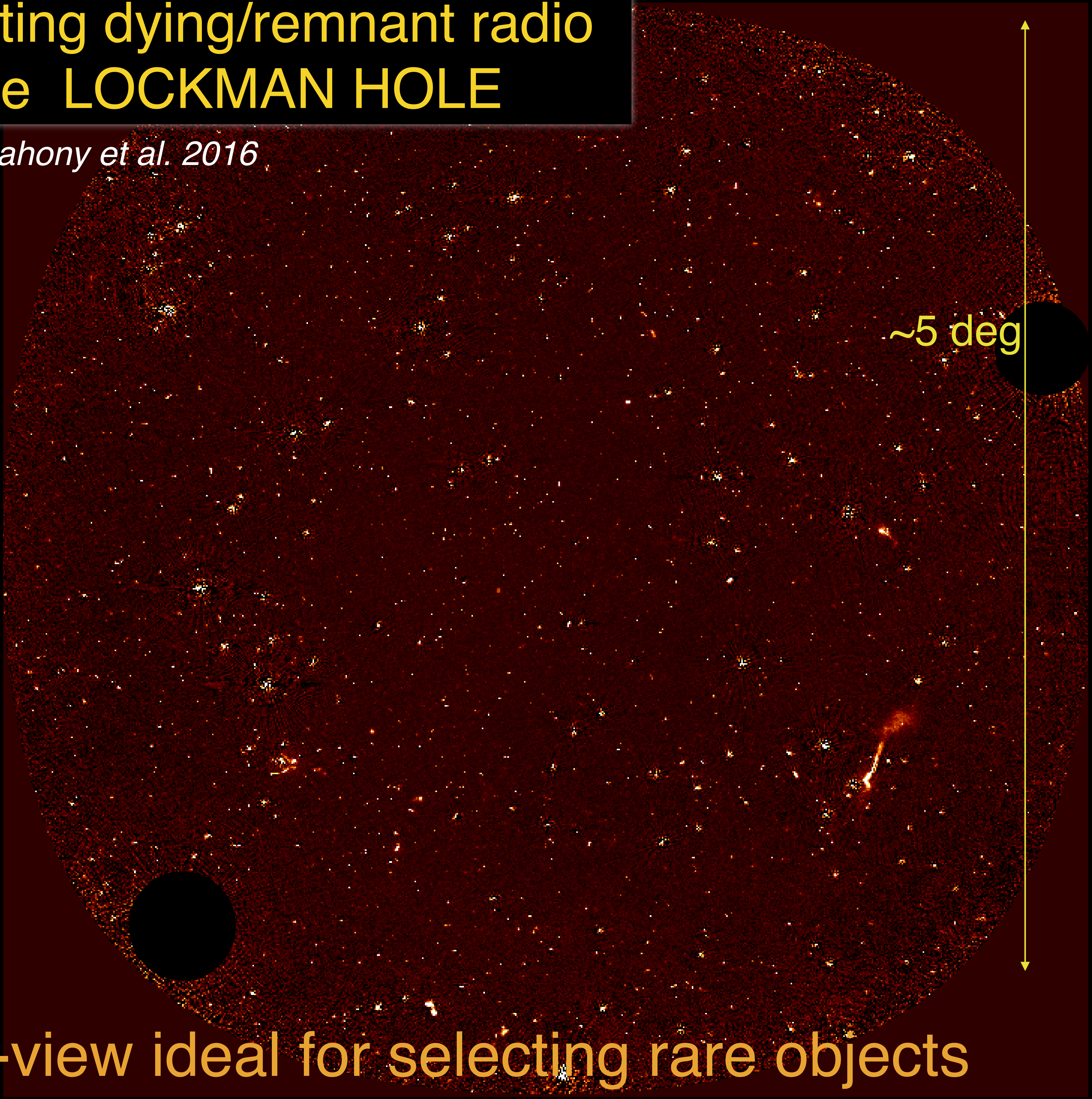
We can now select from
spectral index AND morphology
from the same datasets

See also poster of Marisa Brienza

Pilot study: selecting dying/remnant radio galaxies in the LOCKMAN HOLE

LOFAR image @ 150 MHz, Mahony et al. 2016

- HBA observation (110-180 MHz)
- 70 MHz bandwidth (300 subbands)
- 10 hrs int. time
- 14”x18” resolution
- rms~0.15 mJy
- about 6000 sources



Large field-of-view ideal for selecting rare objects

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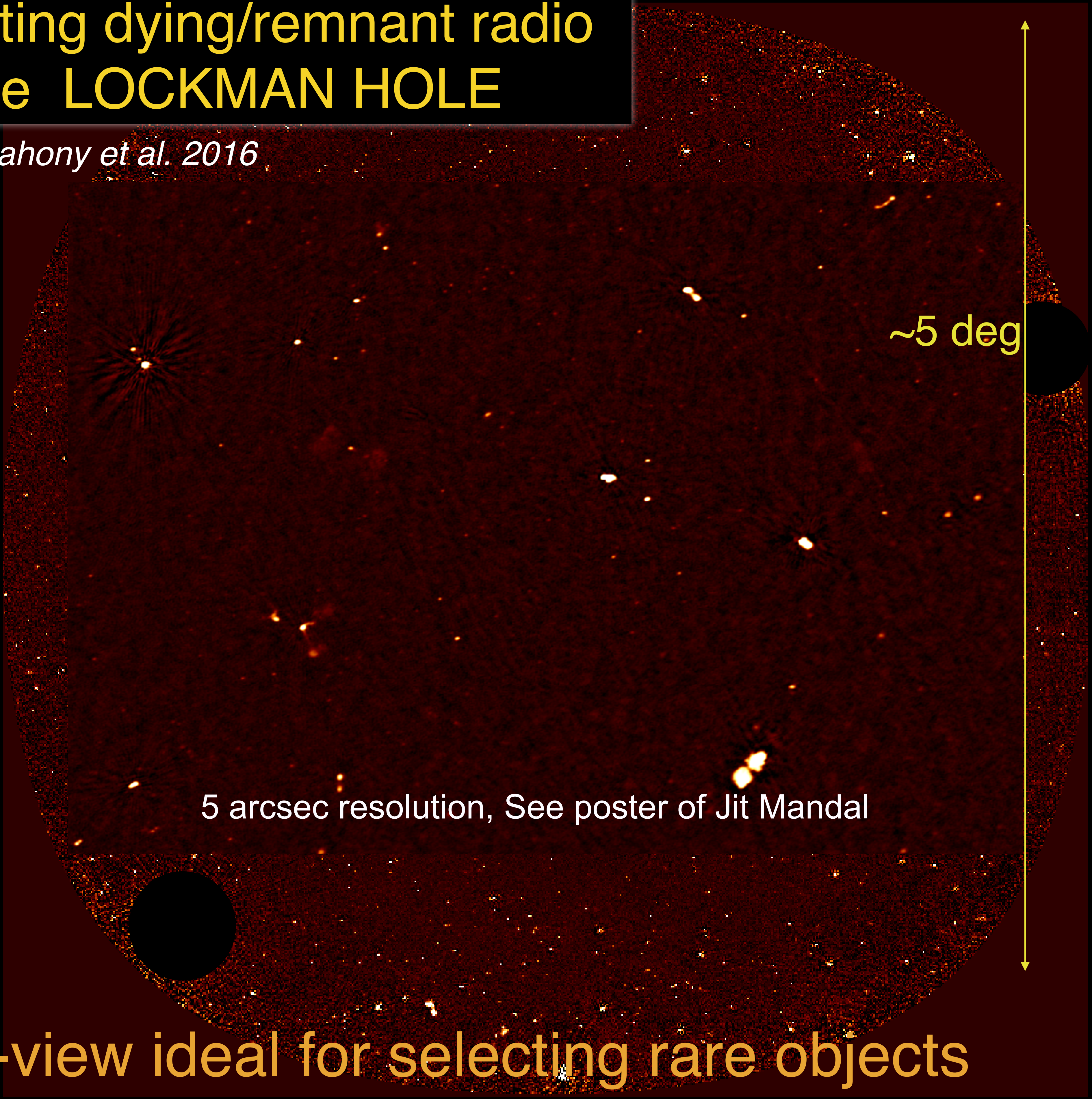
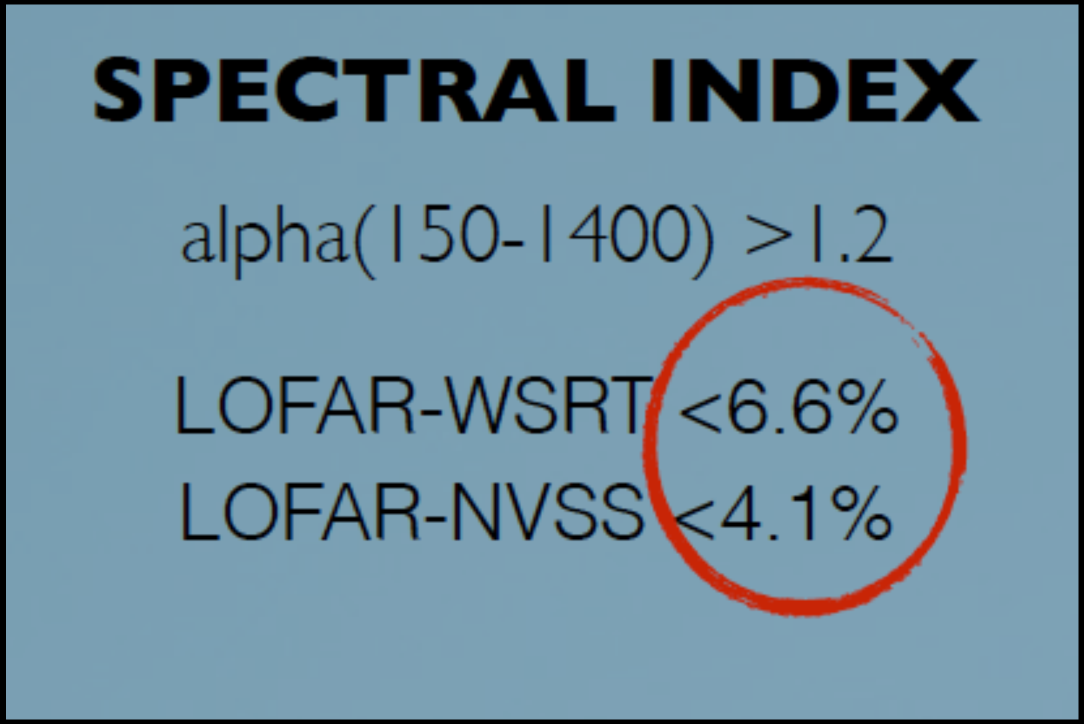


5 arcsec resolution, See poster of Jit Mandal

Large field-of-view ideal for selecting rare objects



SPECTRAL INDEX

alpha(150-1400) >1.2

LOFAR-WSRT <6.6%
LOFAR-NVSS <4.1%

Despite the increased sensitivity of LOFAR, steep spectrum remnants remain RARE

↓

Rapid luminosity evolution after the central engine has stopped?

Brienza et al. 2017

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

Brienza et al. 2017

MORPHOLOGY

relaxed,
low surface brightness,
no compact feature in FIRST 5''
size > 60''

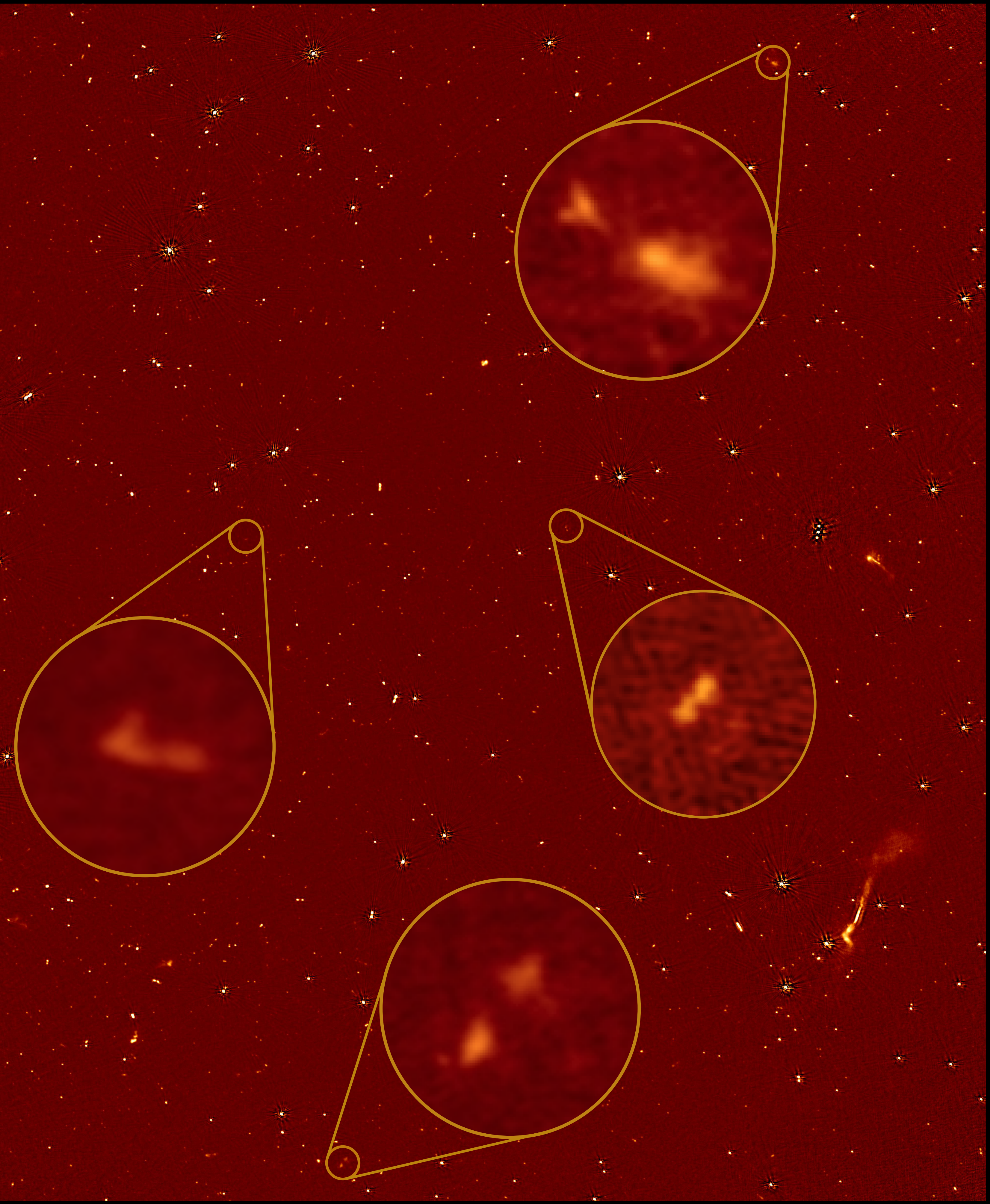
14 SOURCES

CORE PROMINENCE

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

size > 40'' & S>90mJy
+NO CORE in FIRST

10 SOURCES



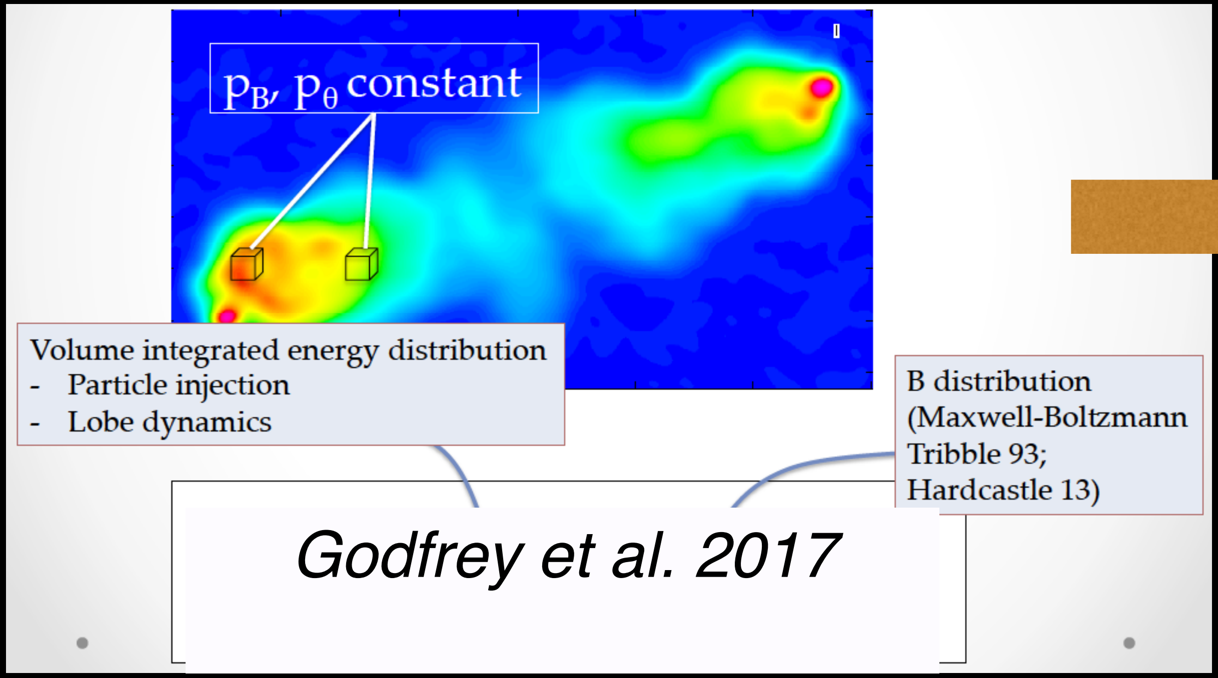
Complementary selection via morphology: high quality LOFAR images allow this

Amorphous, low surface brightness,
no core (or very weak)

➔ *only a minority have steep low-frequency spectrum!*

Brienza et al. 2017

Simulating the populations of active and remnants



Godfrey et al. 2017

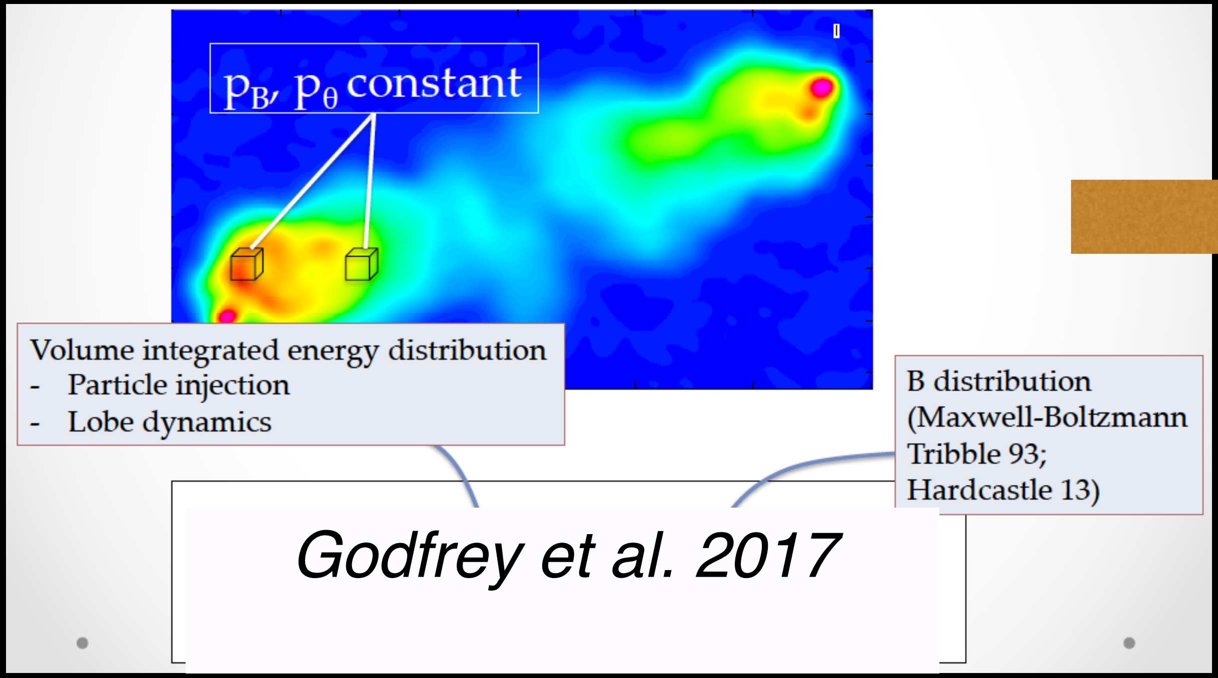
Trace spectral evolution in active and remnant phases

Estimate synchrotron flux density ➔ select sources based on realistic flux limit

Powerful sources ➔ Godfrey et al. 2017
http://arxiv.org/abs/1706.05909

Low power sources ➔ Brienza et al. 2017

Simulating the populations of active and remnants



Godfrey et al. 2017

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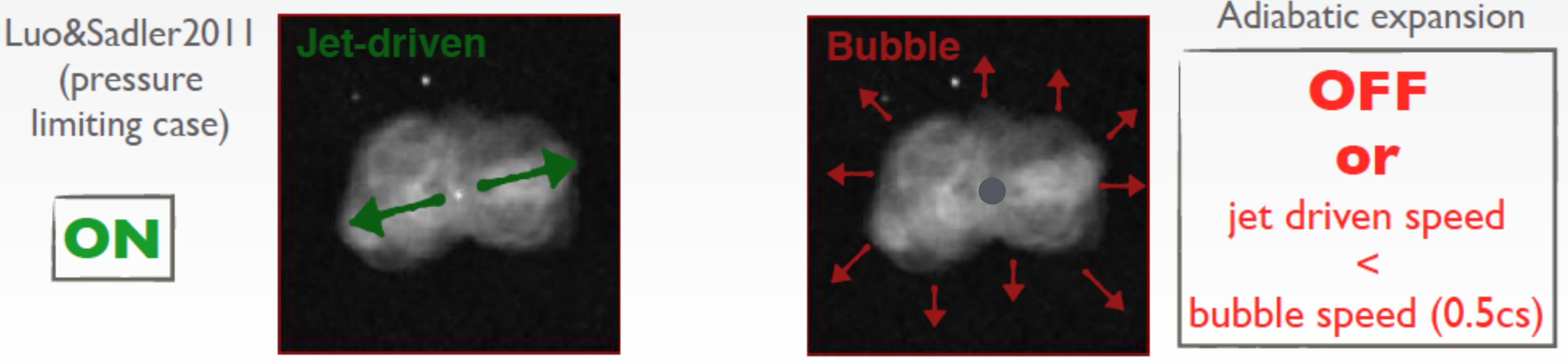


Mock catalogues to directly compare the predictions with the observations (applying the same flux cut)

Monte Carlo simulations: model parameters (z, t_on etc.) are sampled from probability distribution…

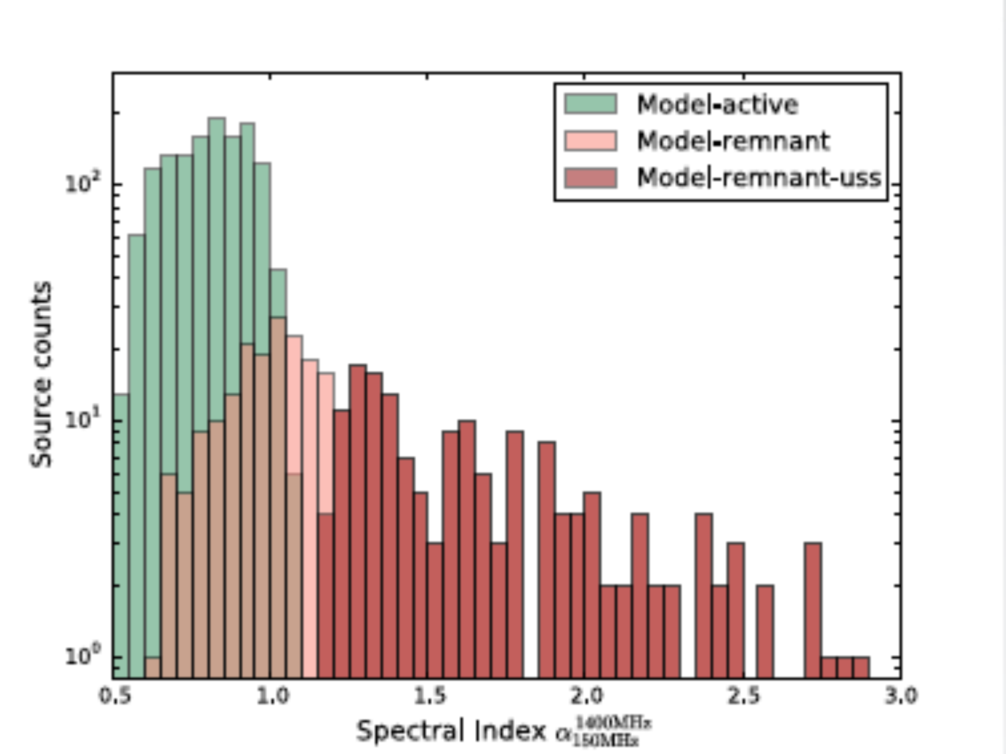
See poster from Marisa Brienza

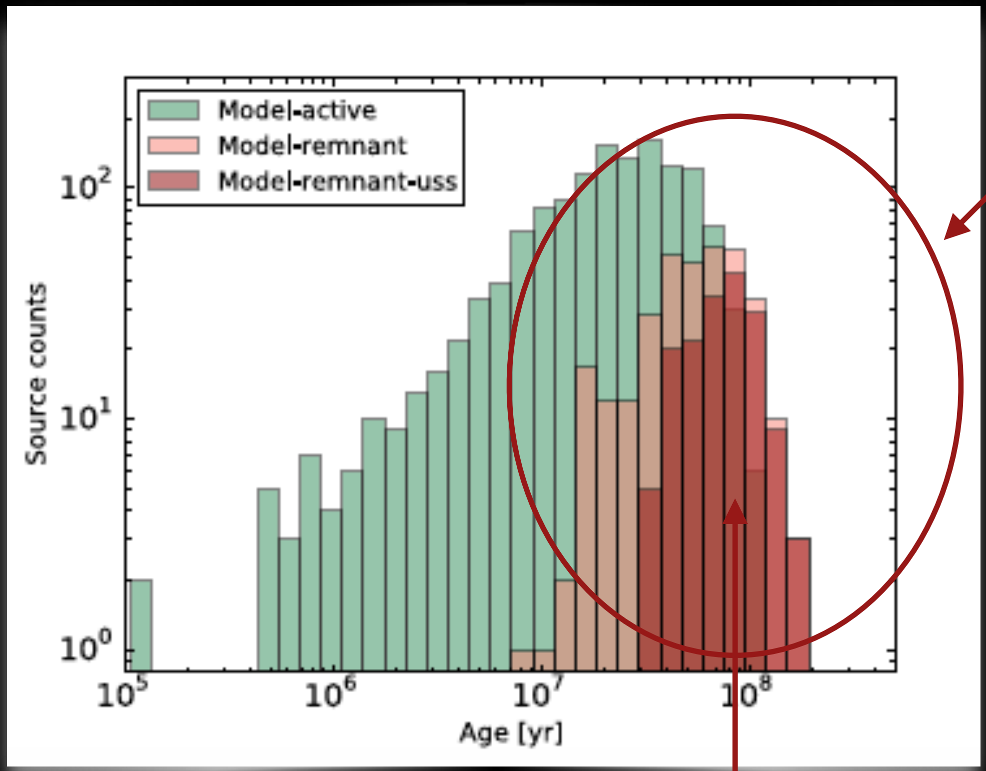
Only radiative loses do not reproduce observed number of remnants: need adiabatic expansion

Radio lobes are still overpressure (with respect to the ambient medium) when reaching the *off* phase ➔ expansion continue ➔ fast evolution, dimming of the remnant emission

Remnants selected based on their steep, low frequency spectrum ➔ older remnants in the sky (**ages > 10^8 yrs**)

Most of the remnants are younger, i.e. in the phase shortly after the switching off (i.e. **a few x 10^7 yr**) low frequency spectrum not yet ultra steep





Remnants

~20%

~10%

Remnants ultra steep spectrum - older

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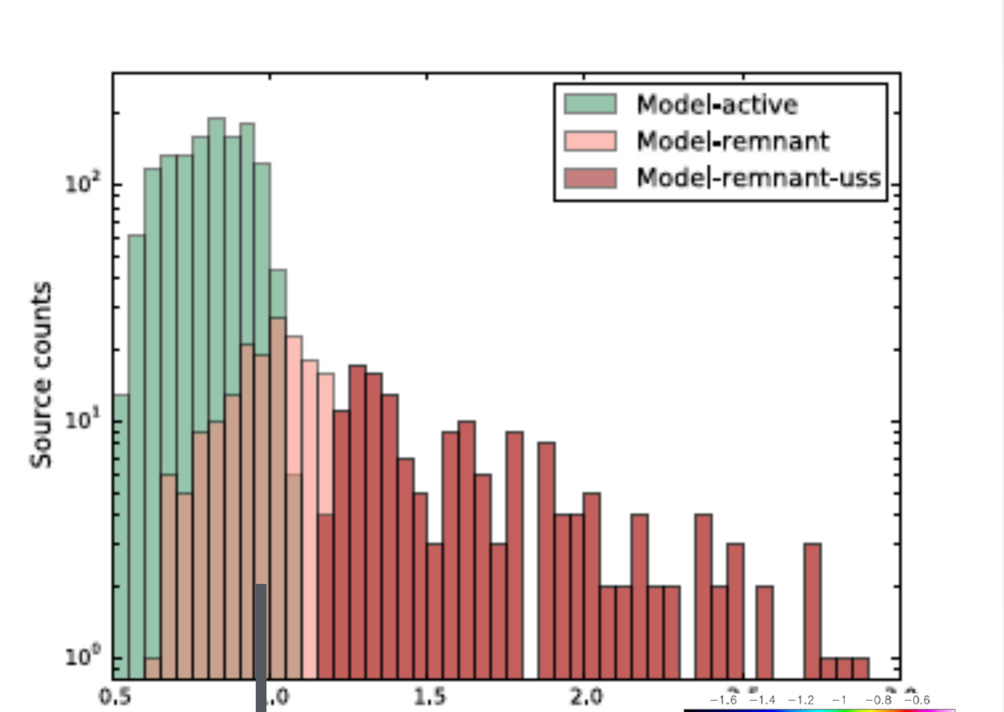
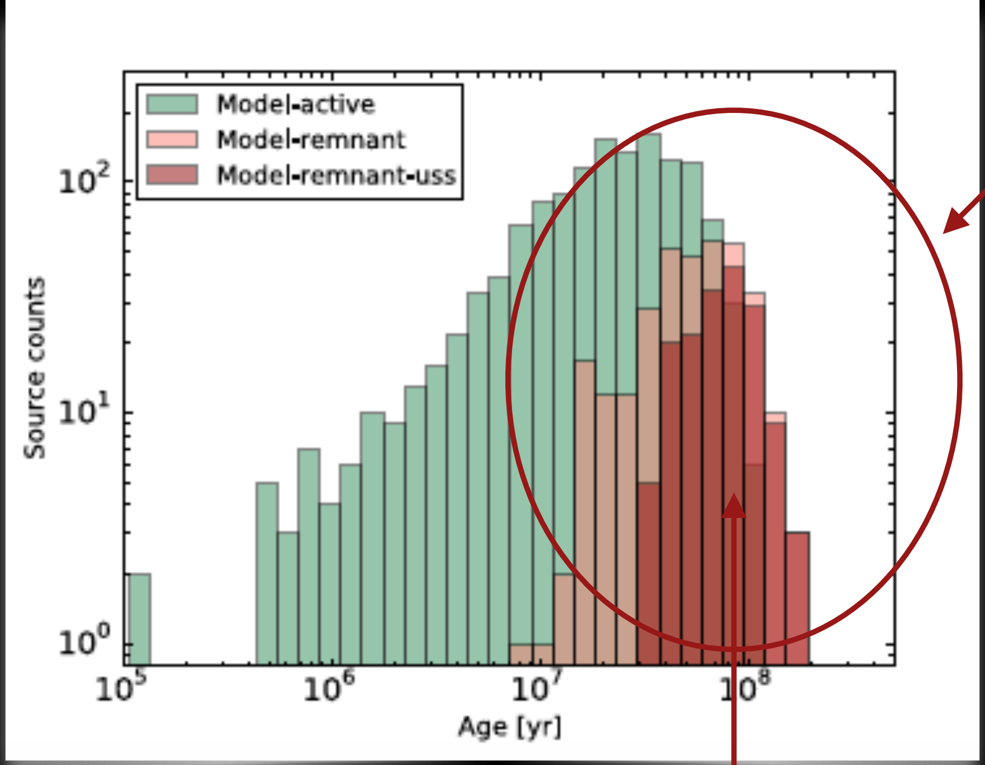
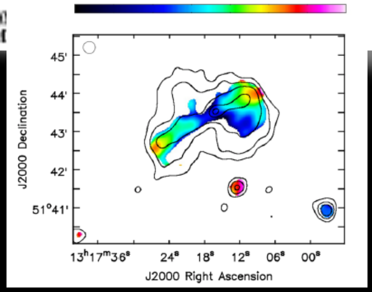




Remnants

~20%



Example in the poster of Savini?

~10%

Remnants ultra steep spectrum - older

Evolution of the remnants

(adiabatic losses continue after the source is switched off)

only the older one have very steep spectrum

➔ combining spectral index and morphology we start to understand the evolution of radio sources

Evolution of the remnants

(adiabatic losses continue after the source is switched off)

only the older one have very steep spectrum

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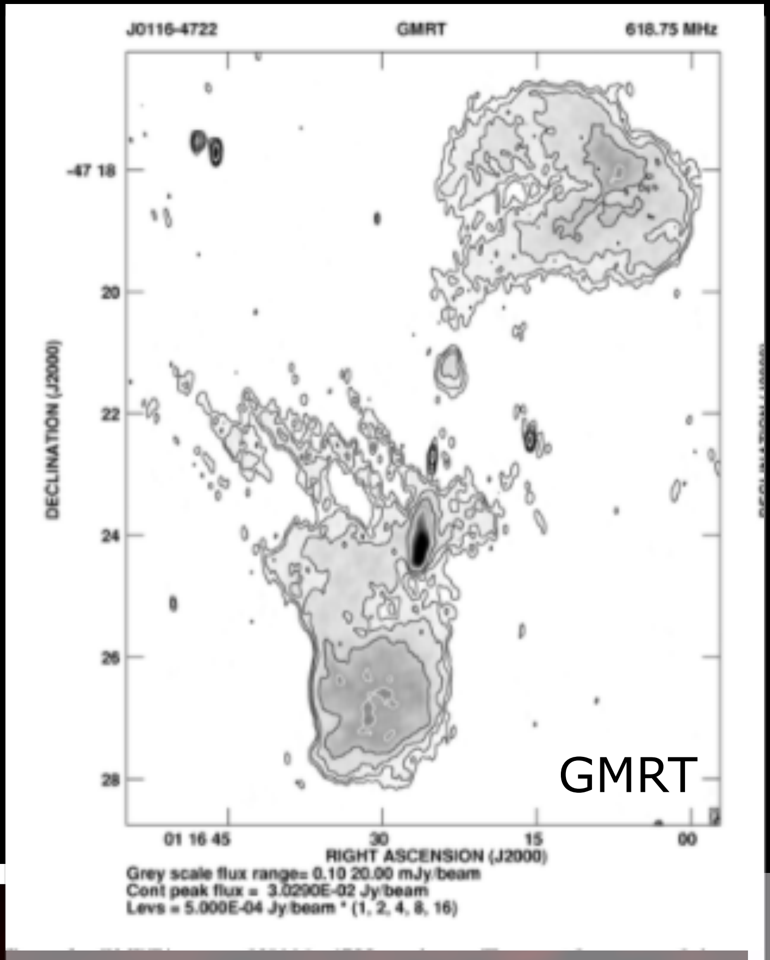
⬇

…how about restarted radio sources?

The restarting life of powerful radio AGN

Double-double radio galaxies

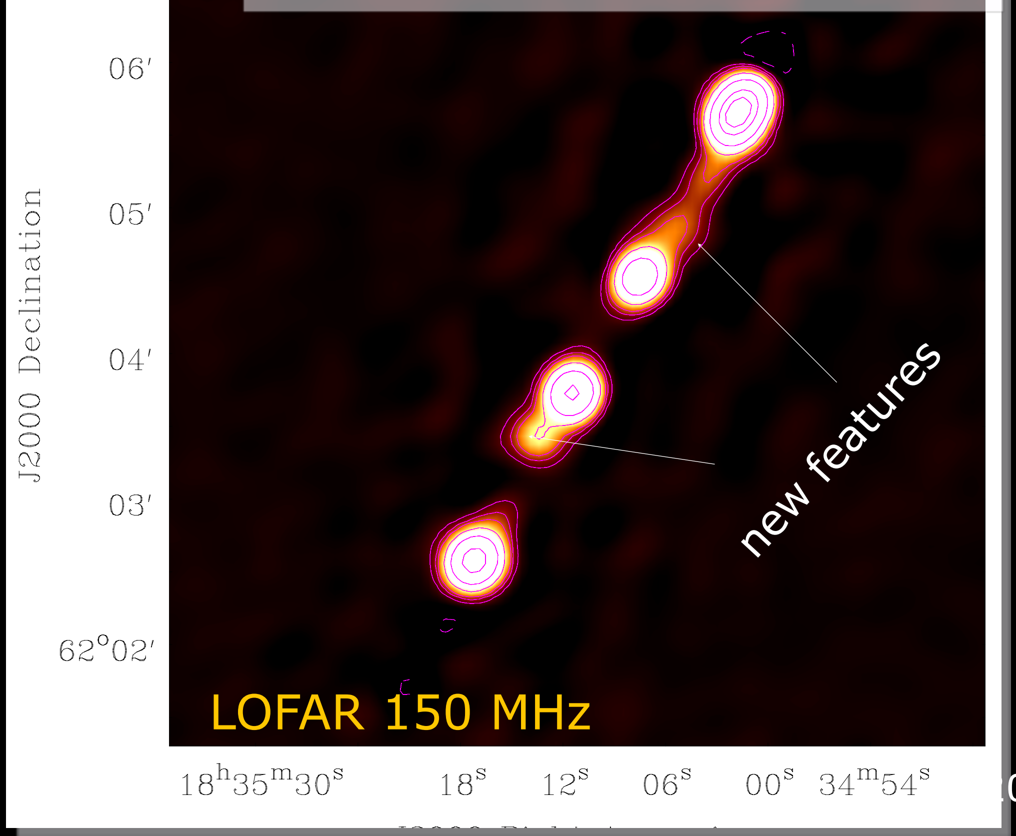
Konar et al. 2015



➜ selected from morphology

➜ fast cycle (e.g. 20 Myr ON a few Myr OFF, *Konar & Hardcastle 2013, Schoenmakers et al.*)

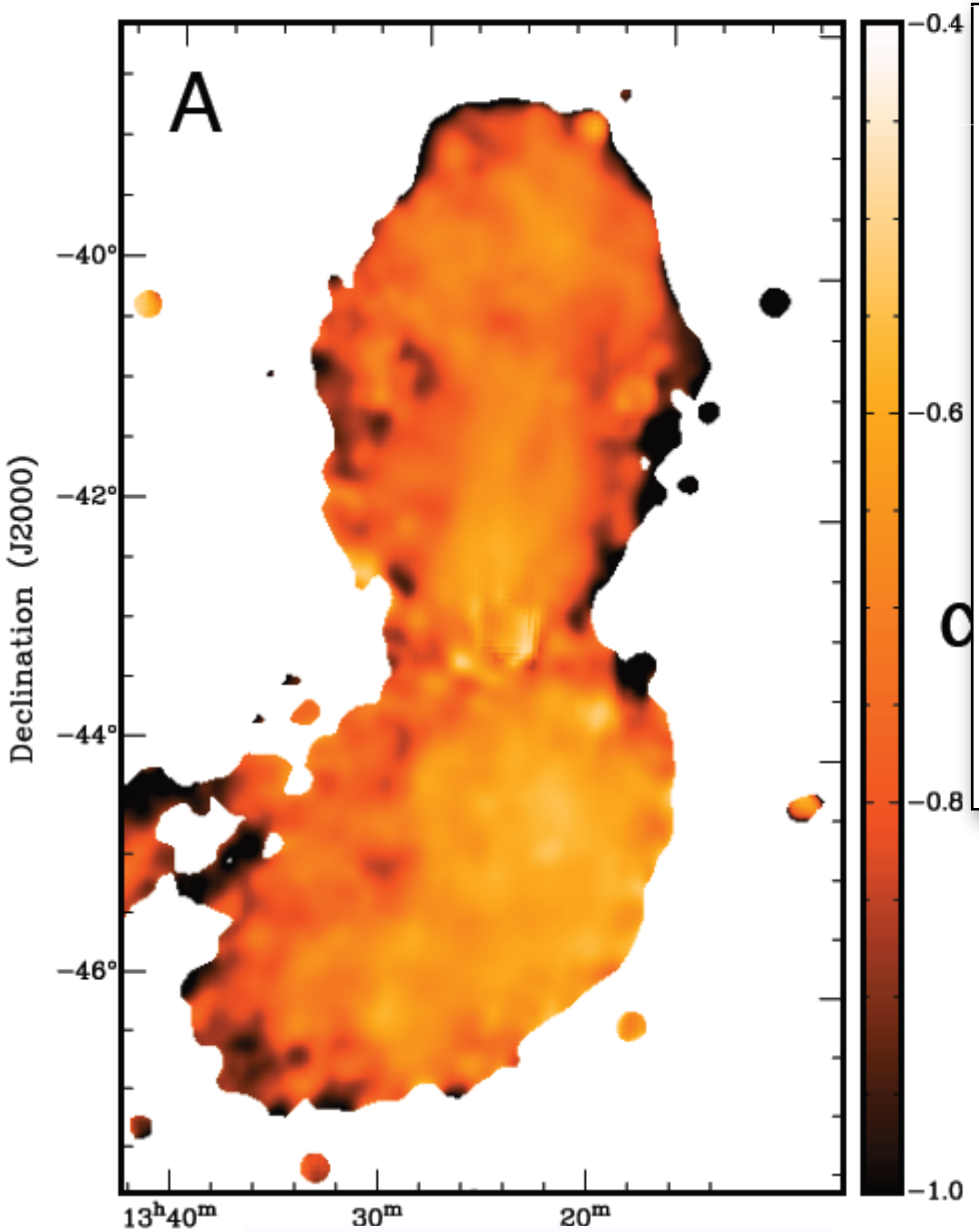
Orru` et al. 2015



- Outer lobes still fed.
- Inner lobes: mix new/older electrons.
- Detection of a low brightness feature that point from the inner lobes
- towards the outer lobes: remnant emission of an intermediate burst.

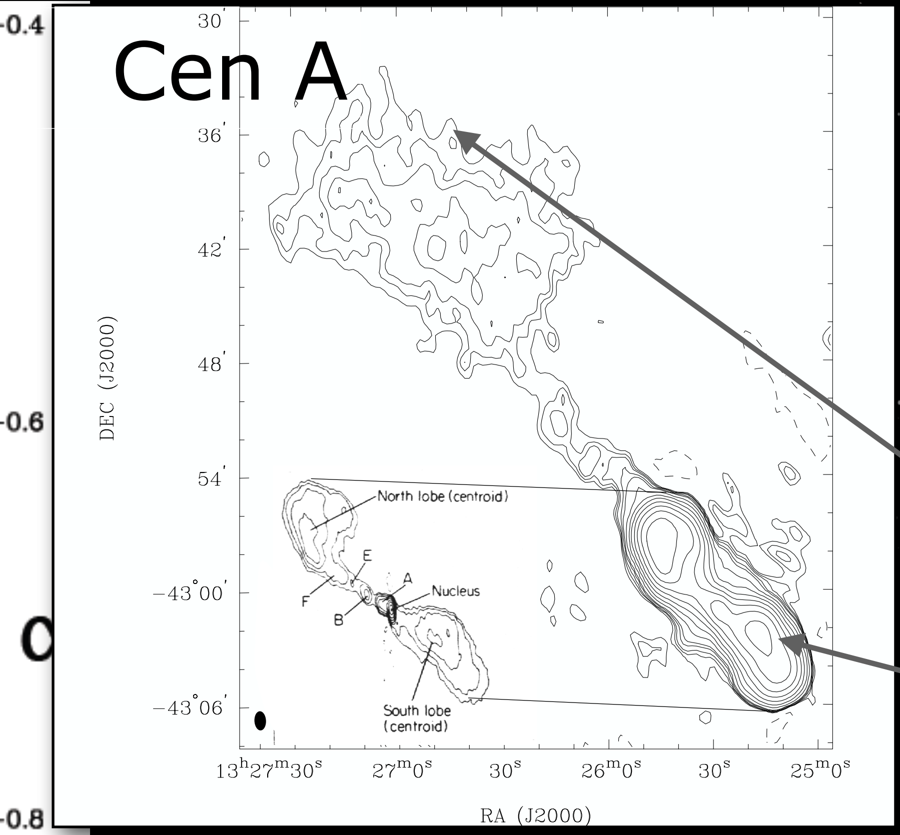
The restarting life of a lower power radio AGN

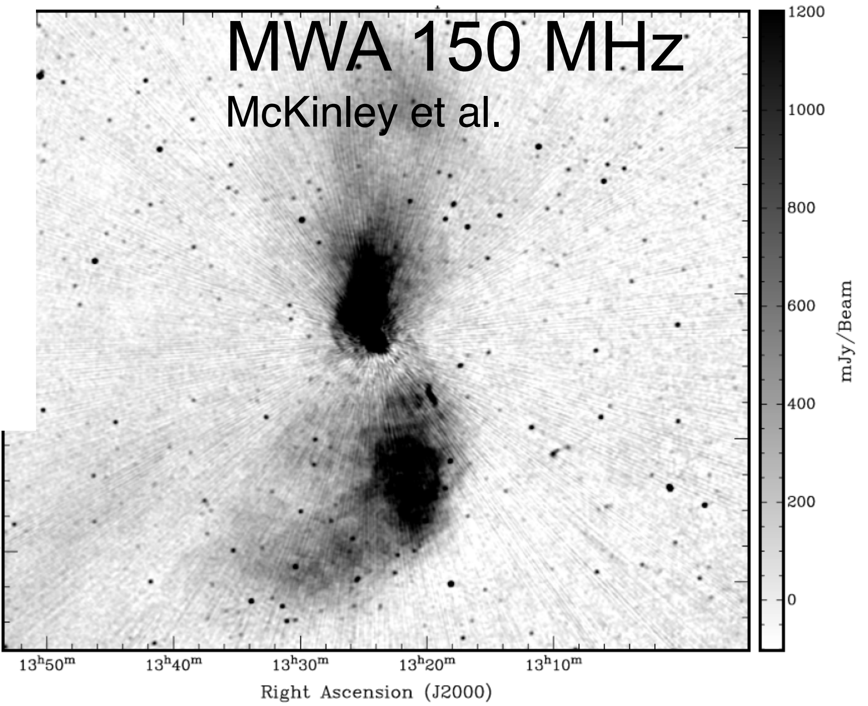
Restarted: does not mean that the old, low-surface brightness lobes are dead!

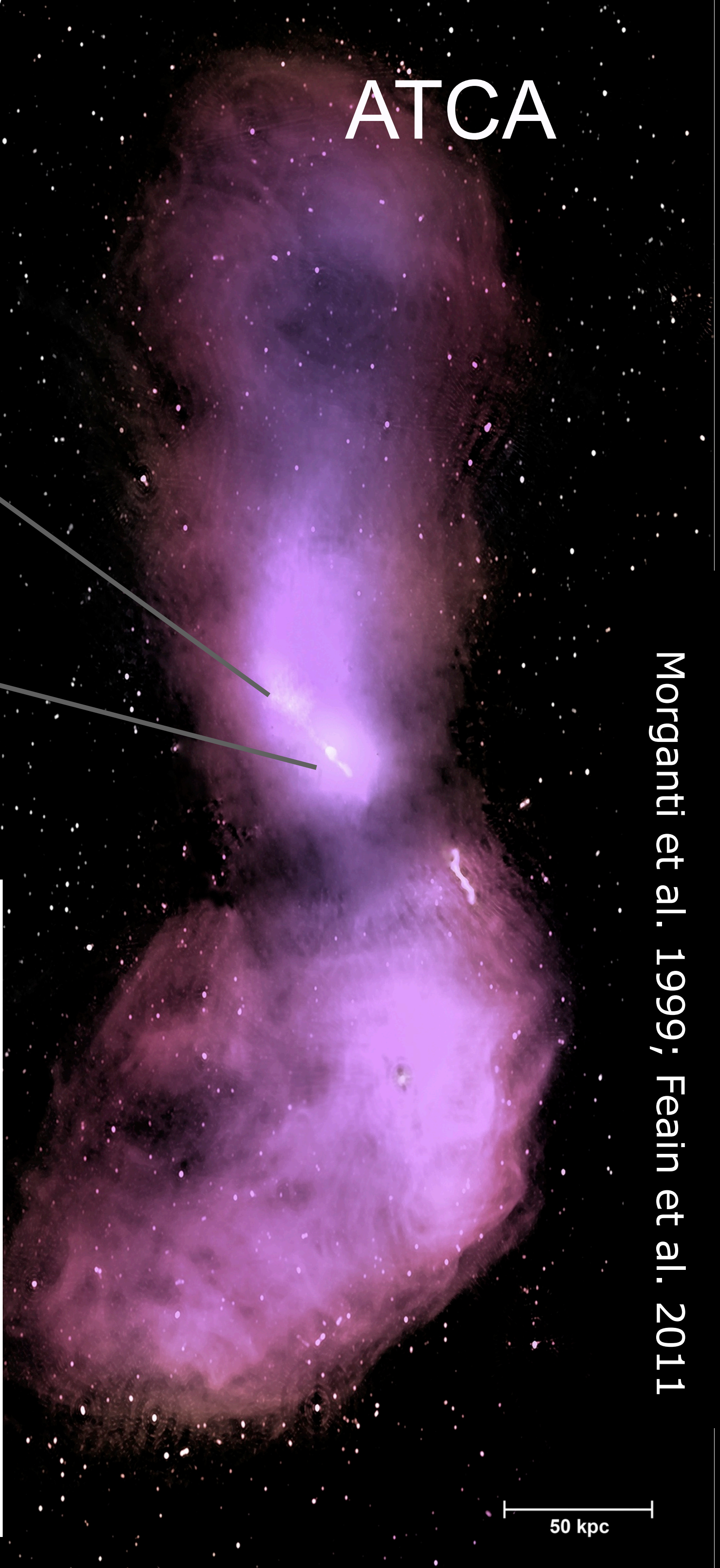


spectral index -
154 MHz and 2.3 GHz

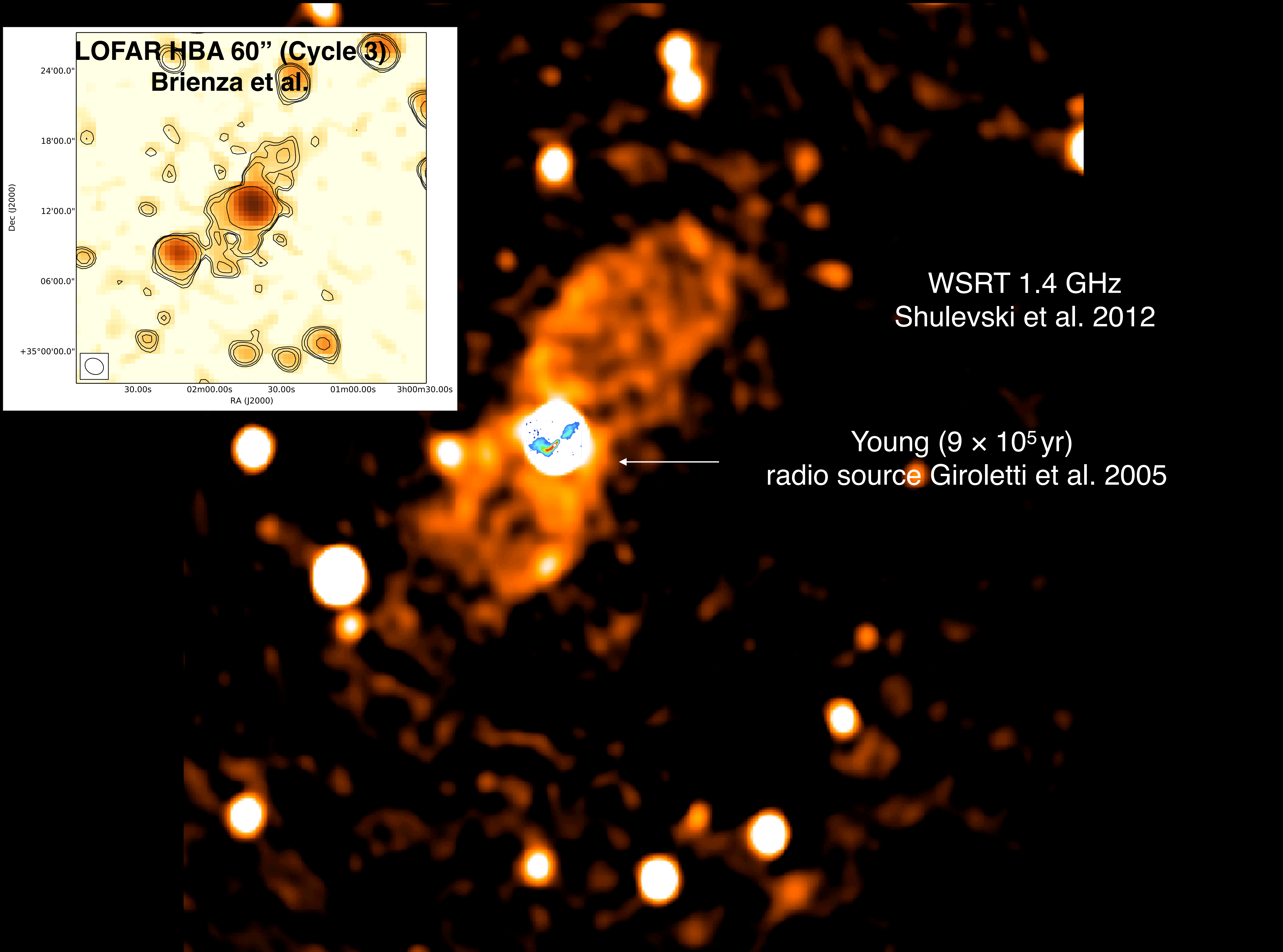
McKinley et al.







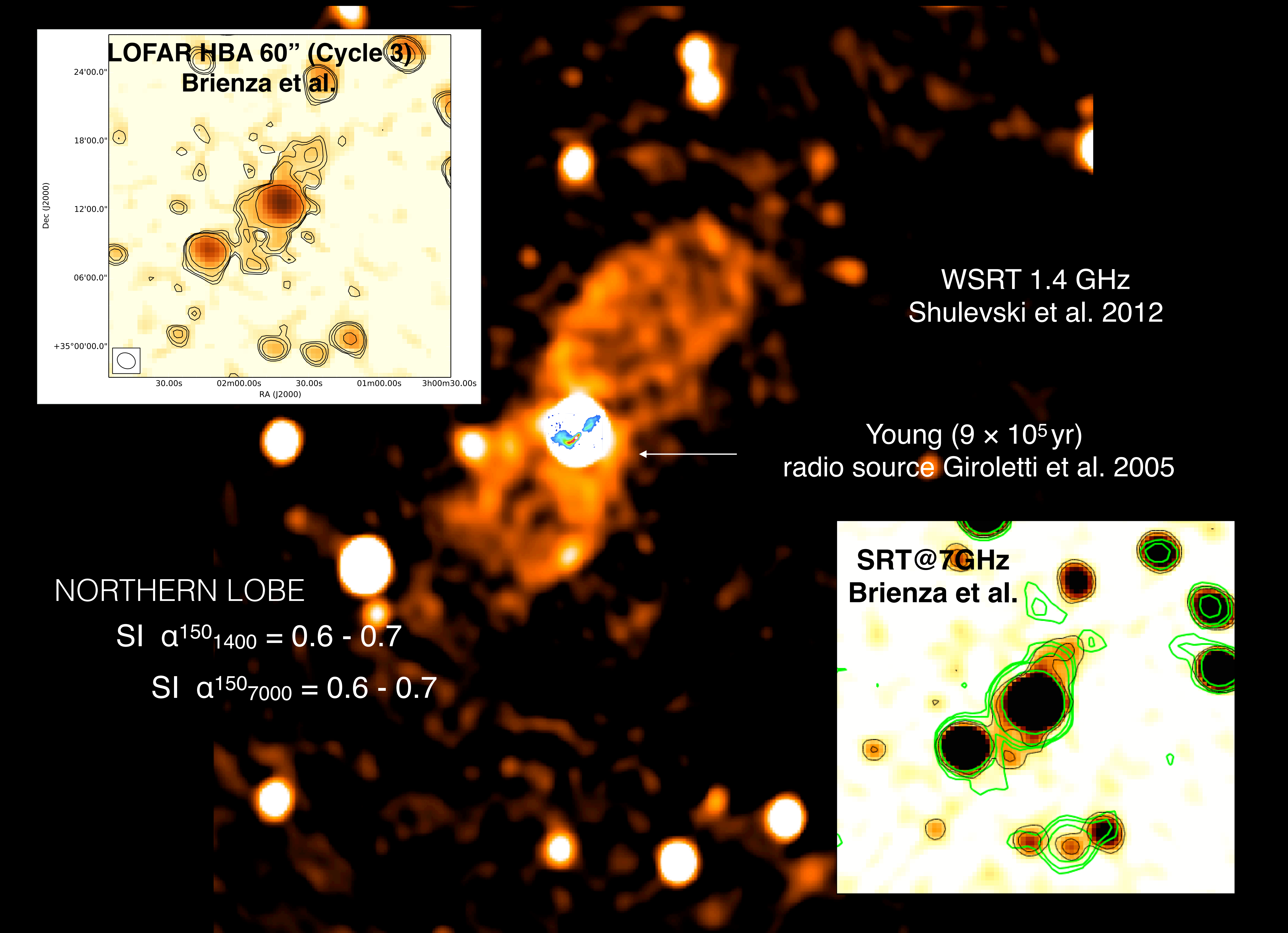
Morganti et al. 1999; Feain et al. 2011



LOFAR HBA 60” (Cycle 3)
Brienza et al.

WSRT 1.4 GHz
Shulevski et al. 2012

Young (9 × 10^5 yr)
radio source Giroletti et al. 2005



LOFAR HBA 60" (Cycle 3)
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Shulevski et al. 2012

Young (9×10^5 yr)
radio source Giroletti et al. 2005

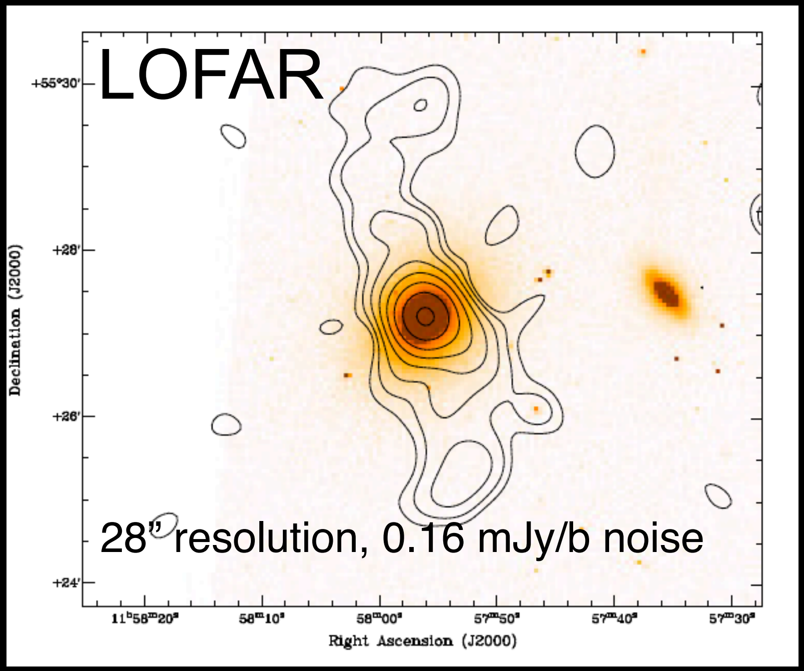
NORTHERN LOBE

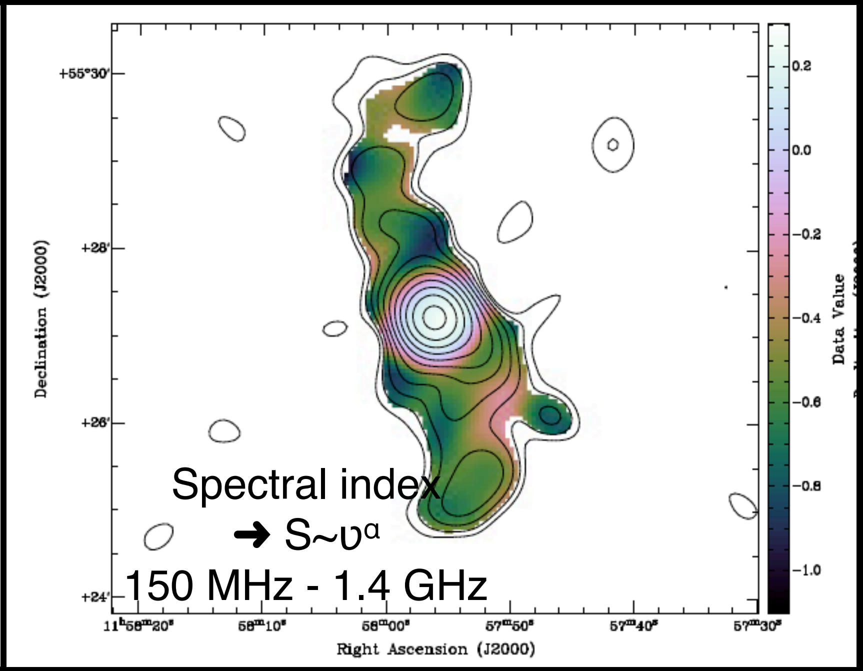
SI $\alpha^{150}_{1400} = 0.6 - 0.7$

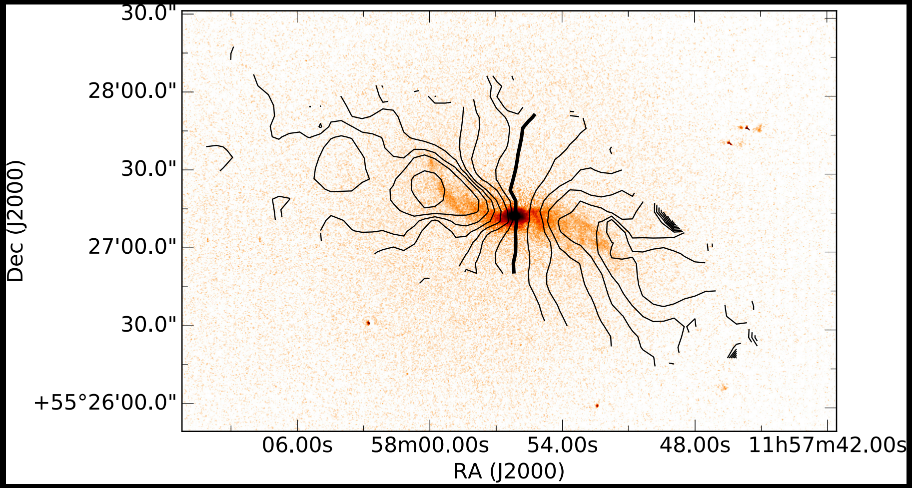
SI $\alpha^{150}_{7000} = 0.6 - 0.7$

SRT@7GHz
Brienza et al.

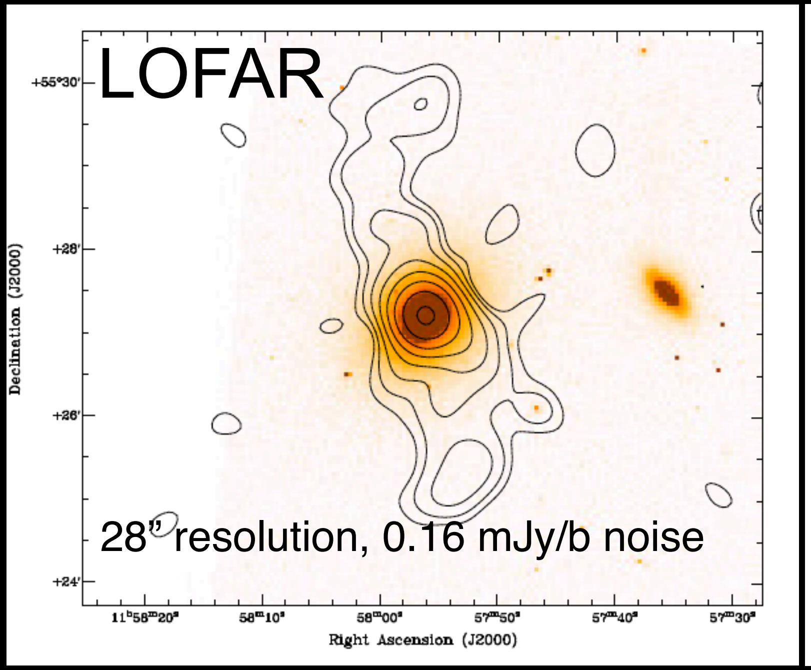
Sridhar et al. in prep

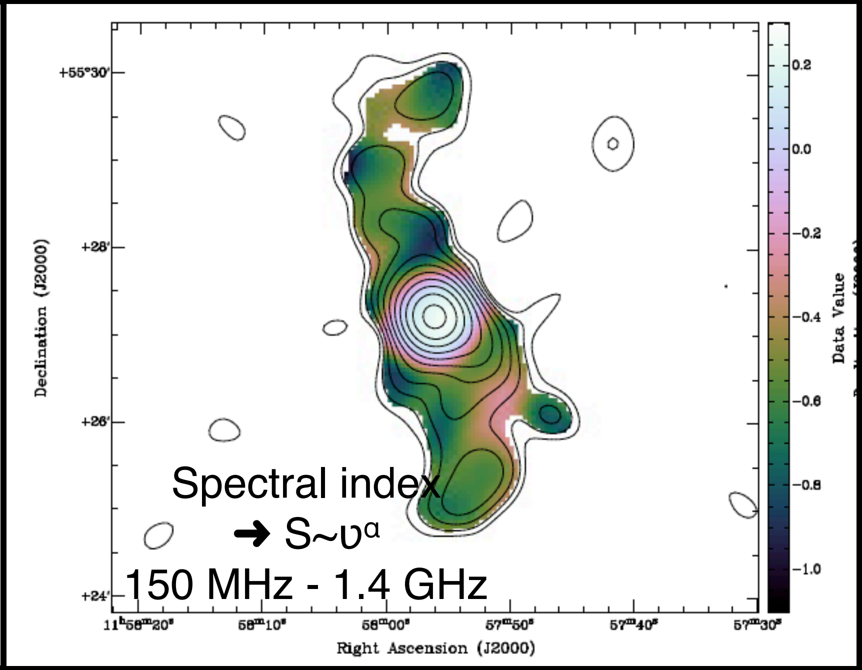


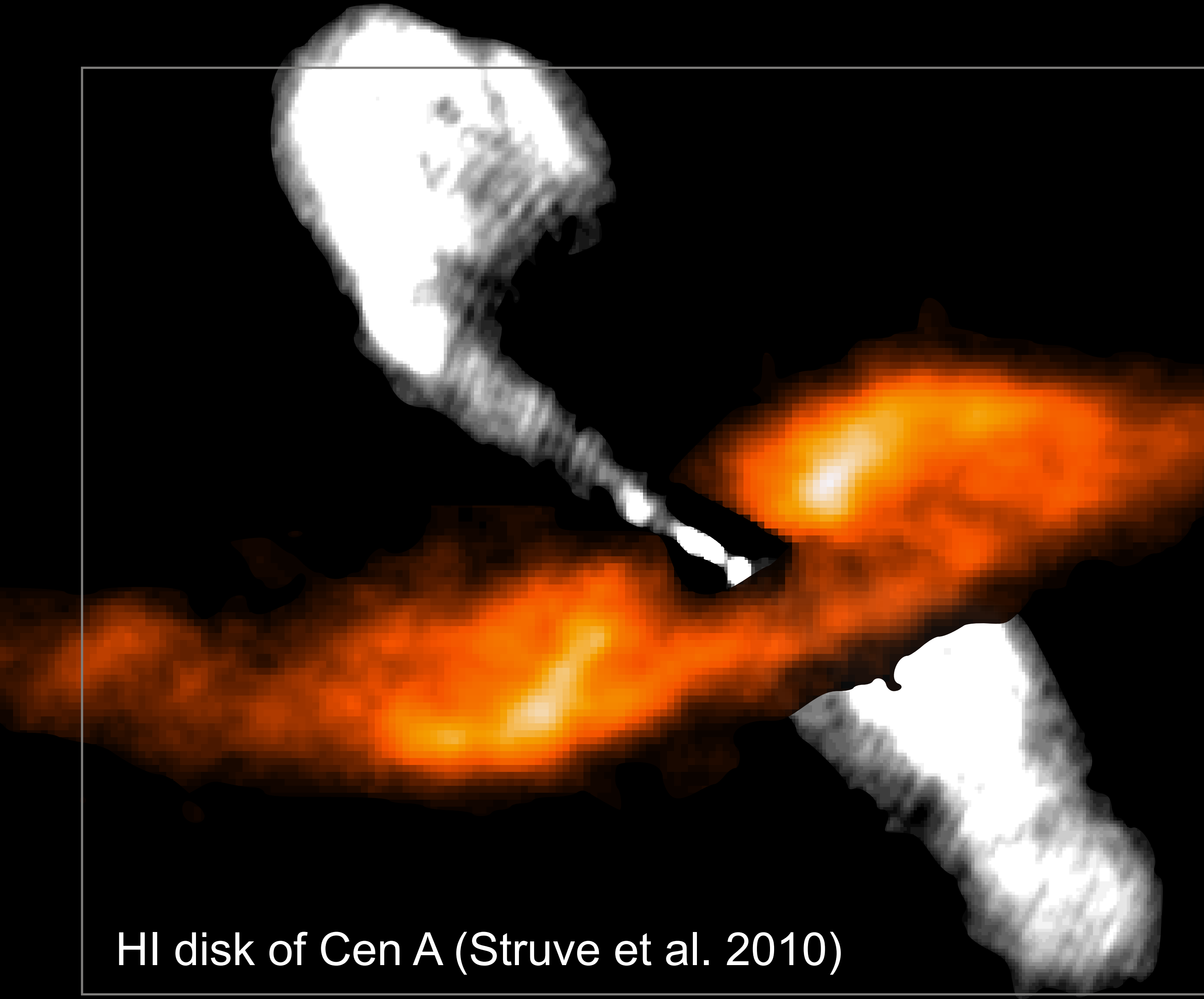




Sridhar et al. in prep







expected a possible connection with the presence of gas (HI and molecular)

HI disk of Cen A (Struve et al. 2010)

Low radio frequencies: a powerful way to study AGN life-cycle and AGN physics

We have started to address key questions for radio AGN energetics (magnetic field, particle content, injection index, low freq cutoff, absorption)

Statistics is also building up
High spatial resolution and image fidelity are very important

- Number of ultra steep spectrum (USS) does not increase going at lower fluxes, but AGN remnants can be identified e.g. from the morphology
- Numbers remnants explained by simple models: USS represent the older one while the morphology allows to trace intermediate stages after the switching off, not all USS.
- Restarted radio sources: not all diffuse, low surface brightness emission is signature of AGN remnants ➔ cases of low level activity, uncollimated jets etc.
- Connection with the presence of gas for re-triggering the AGN: link to HI surveys of Apertif, ASKAP, MeerKAT

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