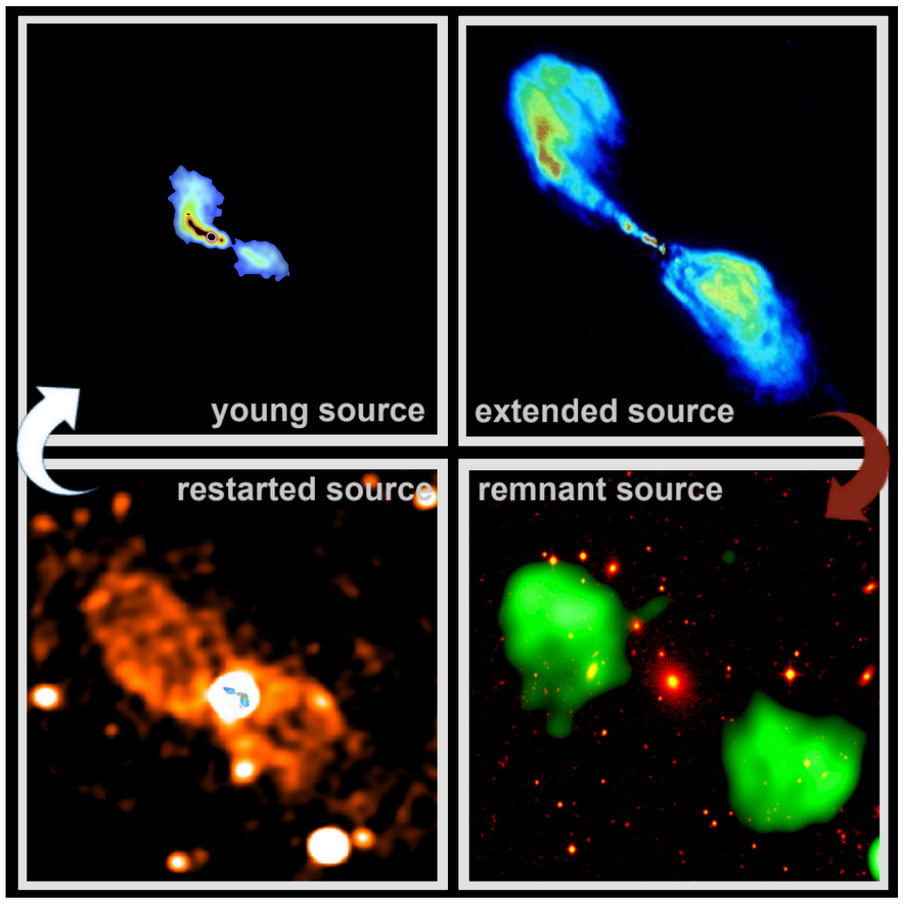
Jets evolution and duty cycle

Marisa Brienza



BOLOGNA & FRIENDS

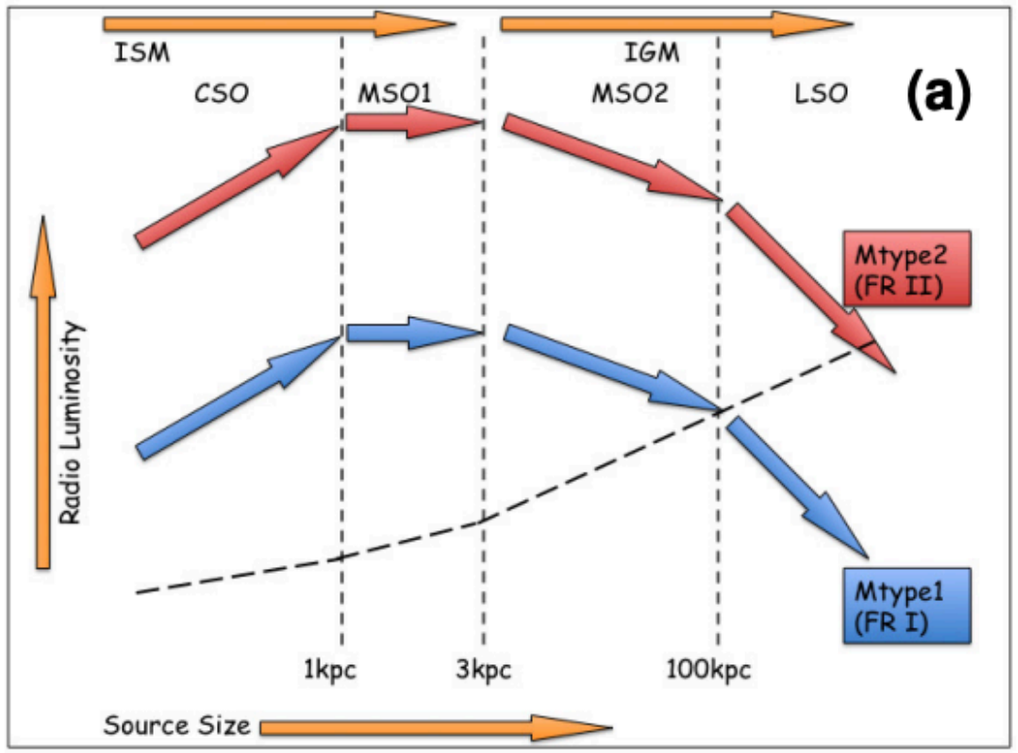
1-2 March 2023

INAF/IRA Bologna

Jets evolution

P-D diagram

An & Baan 2012

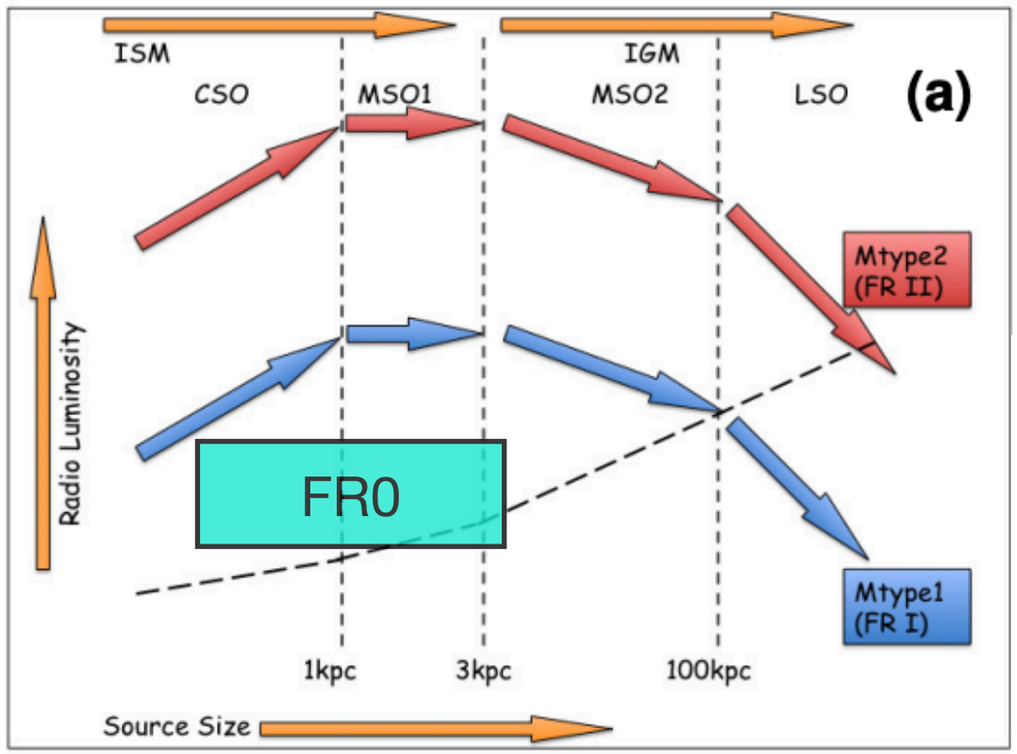


Jet power ->

Jets evolution

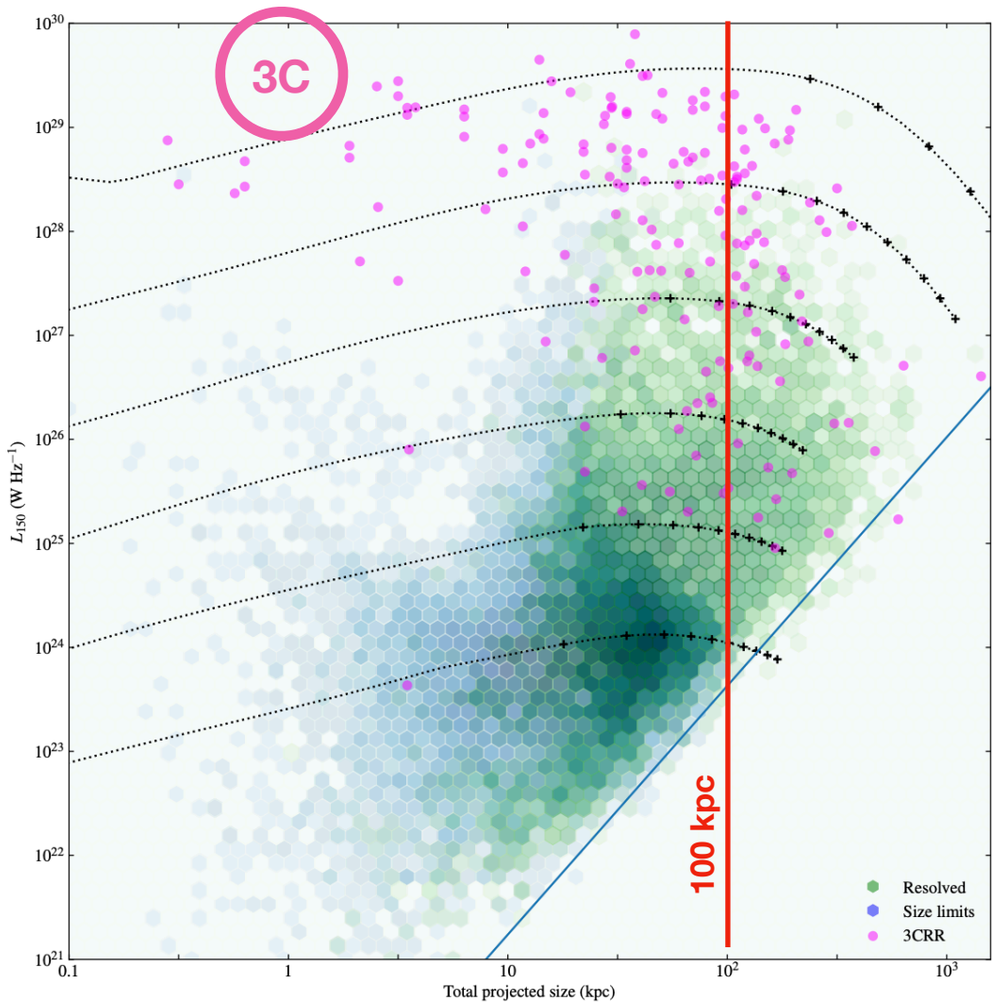
P-D diagram

An & Baan 2012



Jet power ->

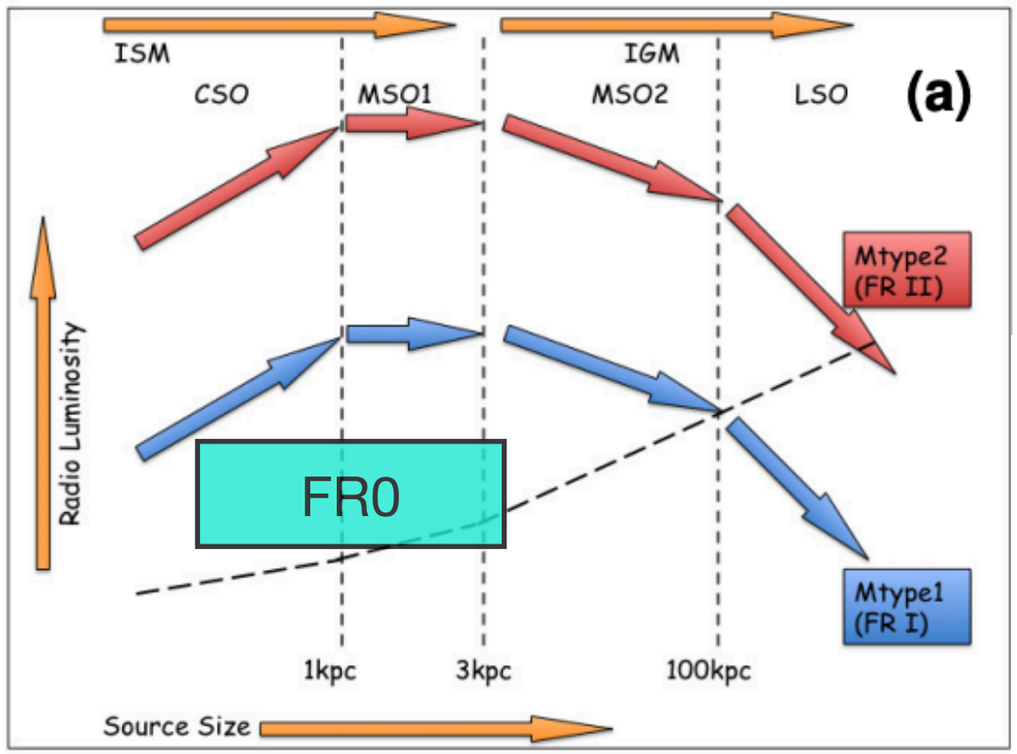
Hardcastle+2019 from **LoTSS DR1 @ 144 MHz**



Jets evolution

P-D diagram

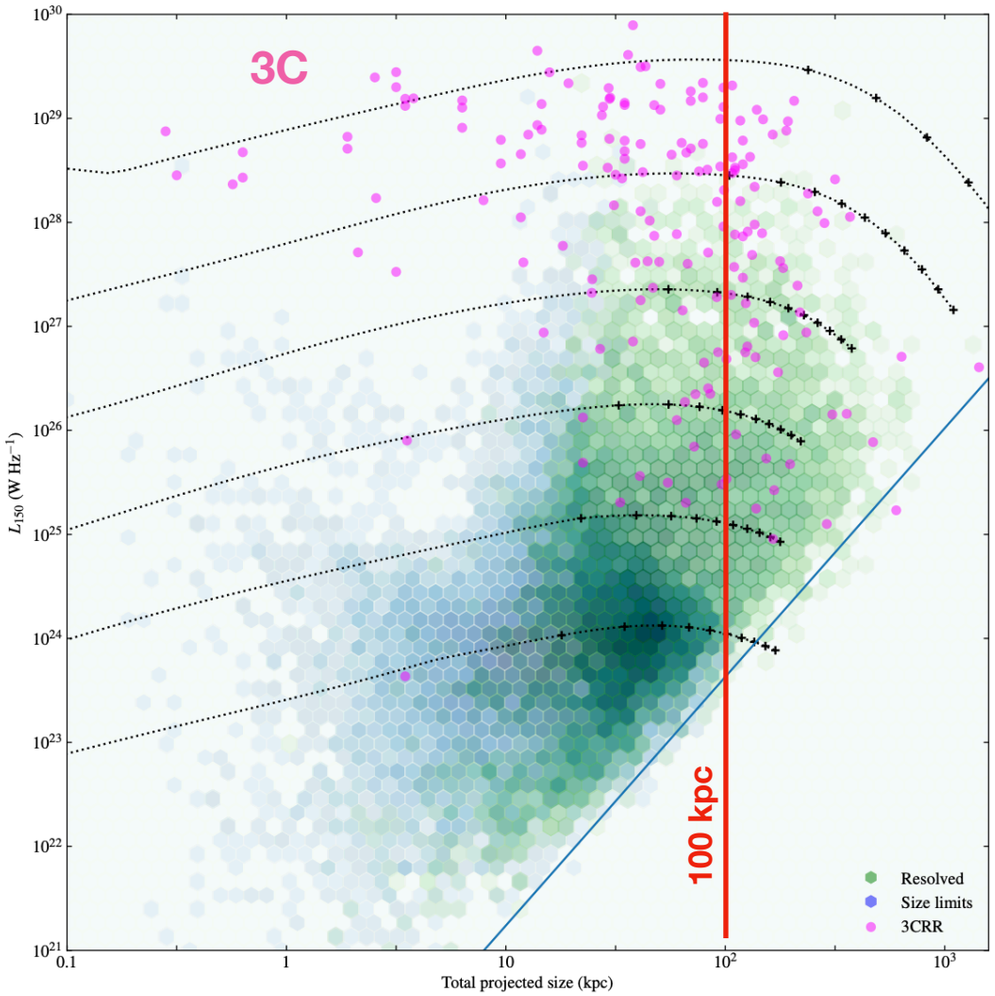
An & Baan 2012



Jet power ->

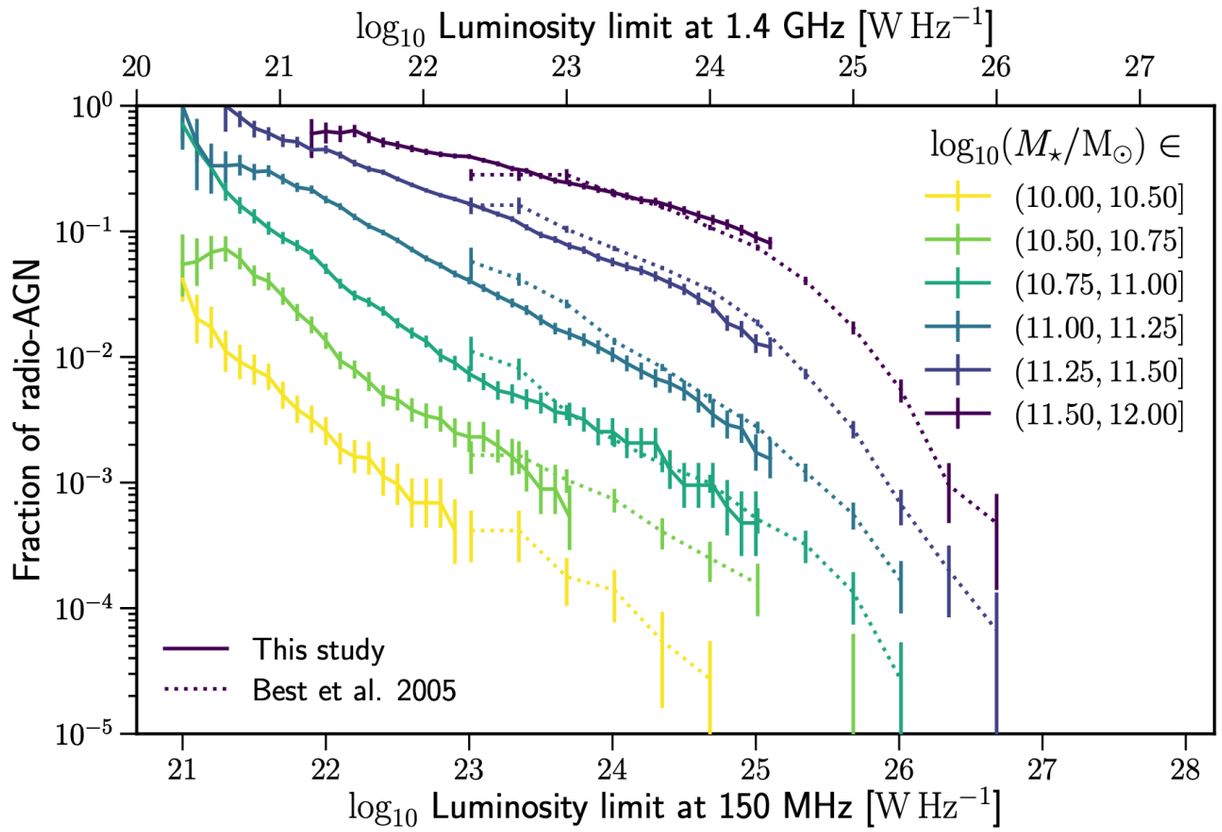
- BH spin
- Accretion
- Duty cycle
- Host mass
- Environment

Hardcastle+2019 from **LoTSS DR1 @ 144 MHz**



Jets vs host

(in the nearby universe)



SAMPLE

- 33,504 SDSS galaxies in the LoTSS area with 0.01< z <0.3 and 32% detected by LoTSS
- After SFGs-AGN separation **2121 AGN** identified

Sabater+2019

ETGs

10^{12} Msun

↑

$6x10^{10}$ Msun

	$\overline{M}_K$	Detected	Compact		Extended	$\log \overline{L}_{150}$
			Detected	Total		
-26.0< M_K <-26.5	-26.22	100%	55%	55%	45%	22.47
-25.5< M_K <-26.0	-25.67	91%	63%	57%	34%	21.97
-25.0< M_K <-25.5	-25.17	70%	74%	52%	18%	21.45
-24.5< M_K <-25.0	-24.70	64%	84%	54%	10%	21.02
-24.0< M_K <-24.5	-24.26	42%	86%	36%	6%	20.69
-23.5< M_K <-24.0	-23.74	43%	86%	37%	6%	20.58

SAMPLE

- **620 most massive galaxies** in the nearby universe from SDSS (Mk<-25, recession velocity < 7,500 km/s) with LoTSS counterpart

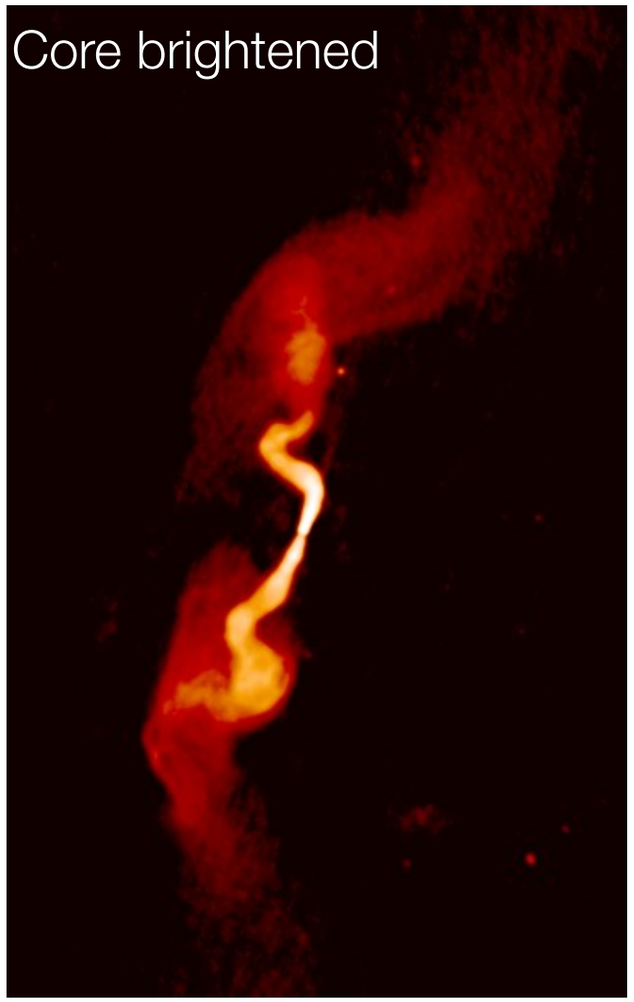
Capetti, Brienza+ 2021, 2023 (in prep)

Environment matters!

BCGs more likely to host radio-loud AGN for a given mass (e.g. Best+2007)

Jets evolution …

FRII vs FRI



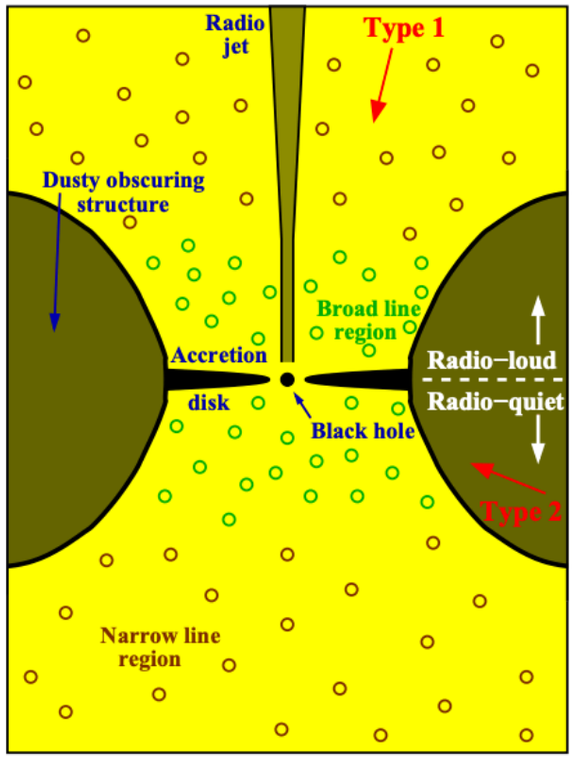
Jets at least moderately relativistic up to the hotspots

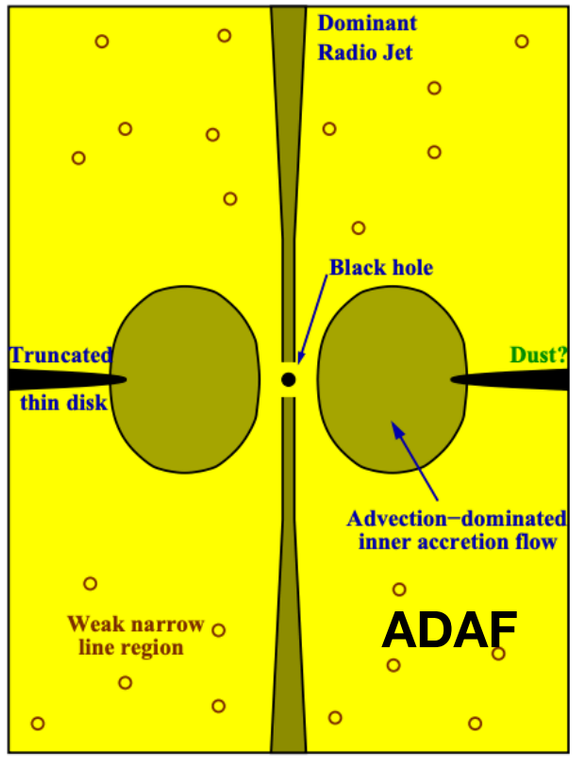
Jets decelerate and become sub-relativistic on kpc-scales

Jets evolution …

FRII vs FRI

Best&Heckman2014





High Excitation Radio Galaxies (HERGs):
- High accretion rates ($\dot{M} \gtrsim 0.01 \dot{M}_{edd}$)
- Accreting cold gas (mergers)
- Radiative-mode AGN

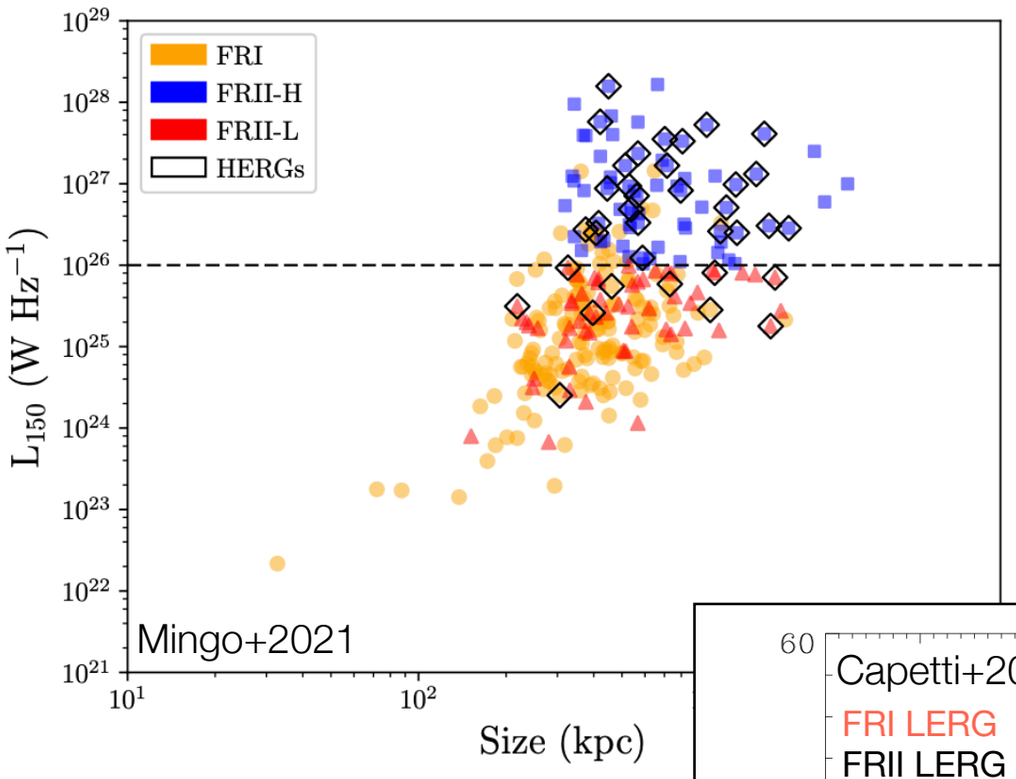
mostly FRII

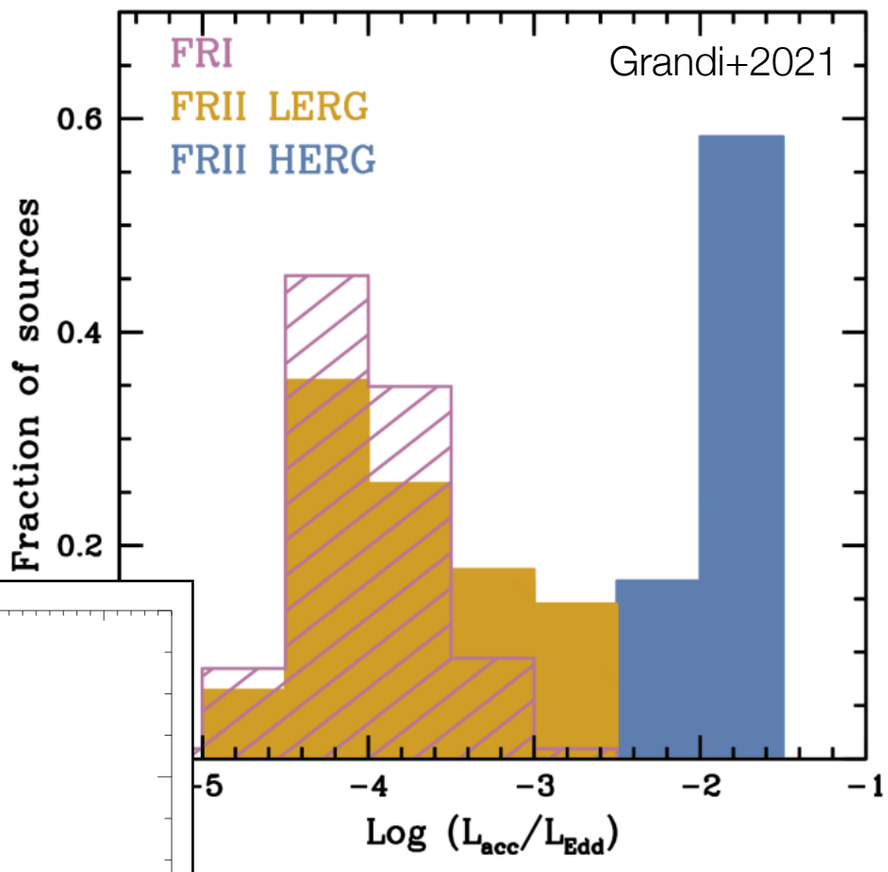
Low Excitation Radio Galaxies (LERGs):
- Low accretion rates ($\dot{M} \ll 0.01 \dot{M}_{edd}$)
- Accreting hot gas (from halo)
- Jet-mode AGN

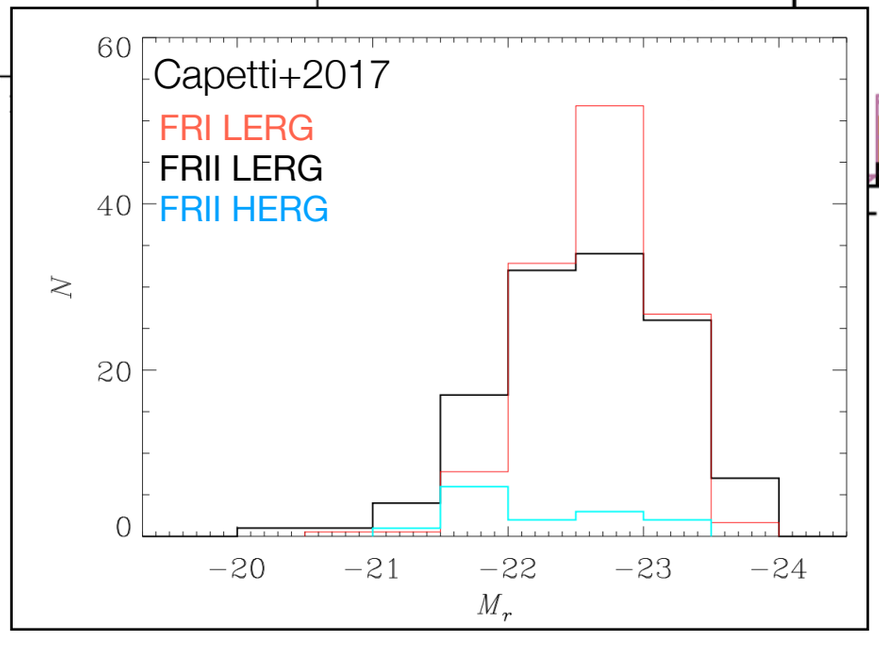
mostly FRI

Jets evolution … HERG/LERG vs FRII/FRI
Not so simple!

The **correspondence** between the morphological classification of FR I and FR II and the separation in radio power **disappears** when including sources selected at low radio flux densities





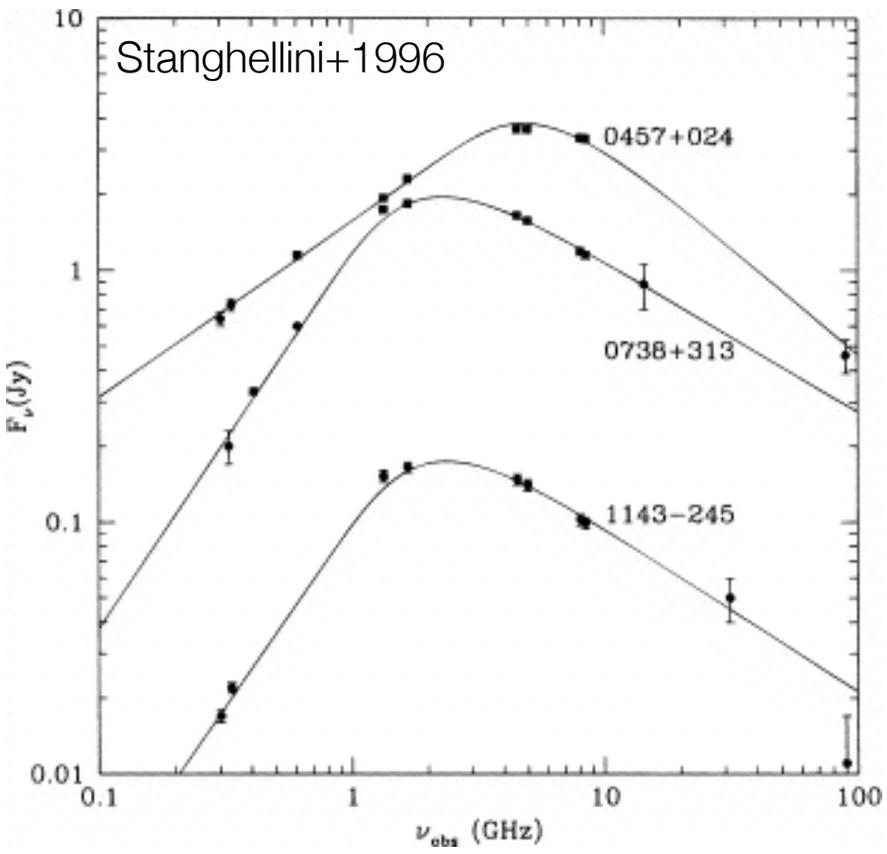


Is there an evolutionary track between FRII and FRI?

Are FRII-LERGs a **transition** between FRII-HERG and FRI?

Jets evolution … Peaked spectrum vs FRII/FRI

(O'Dea+2021, Orienti+2015 for recent reviews)



Peaked spectrum = optically thick plasma

Size $\propto \nu_{peak}^{-1}$

- 1-20 kpc
- L1.4>10^25 W/Hz
- Low variability
  (consistent with evolution)

Young

Small because they are still in an early stage of their evolutionary path, and will develop into FR I/II sources

SOURCE EXCESS

?

Short duty cycle

Frustrated

Jets evolution … FR0 vs FRI/FRII/Peaked sources

Dominated by compact nuclear emission & low radio power

Baldi & Capetti 2009, 2010, Baldi+2015, 2019, Ghisellini+2011, Sadler+2014, Torresi+2019, Capetti+2020,2021, Garofalo & Singh, 2019 and many others)

Indistinguishible from FRI under different points of view :

- OPTICAL EMISSION (LERG)
- HOST PROPERTIES
- X-ray PROPERTIES

BUT…

- Factor 30 more CORE DOMINATED
- Jets on scales few pc - kpc
- Less dense environment

Young? Short duty cycle? Frustrated? Different nuclear engine?

5x FRI abundance

STATIONARY MODEL

Intrinsic different physical conditions:

- Smaller BH mass
- Lower magnetic field
- BH spin (low spinning prograde)
  -> lower bulk Lorentz factors
- Less hadronic flow

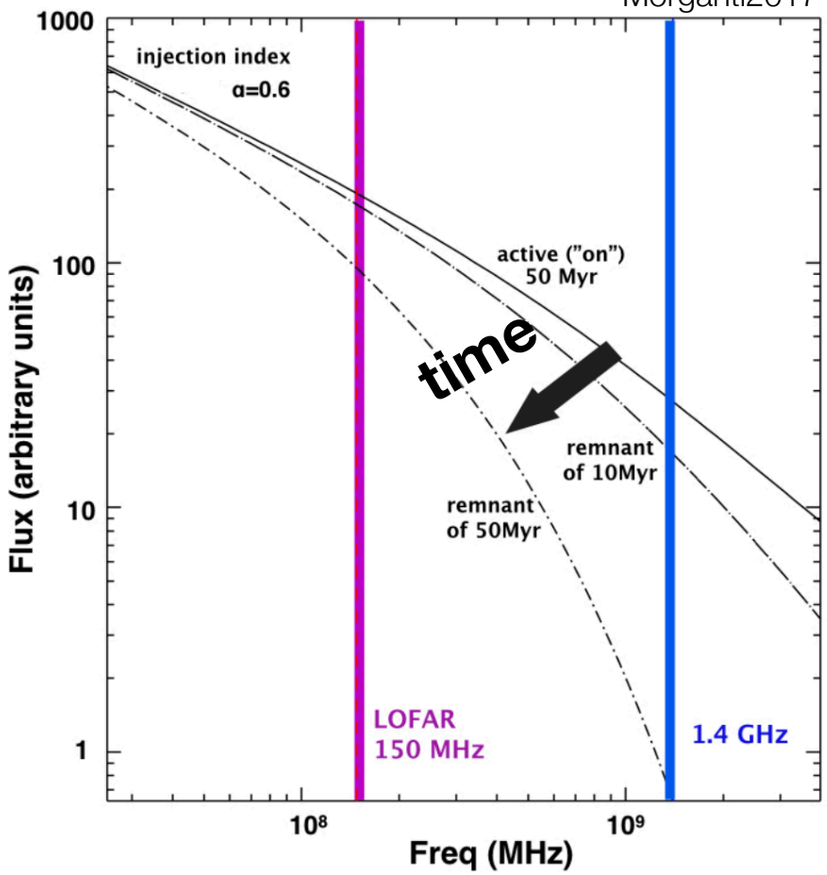
DYNAMICAL MODEL

- Occasional fuelling/intermittent activity /low BH mass -> instable jet (not clear why different from FRI)

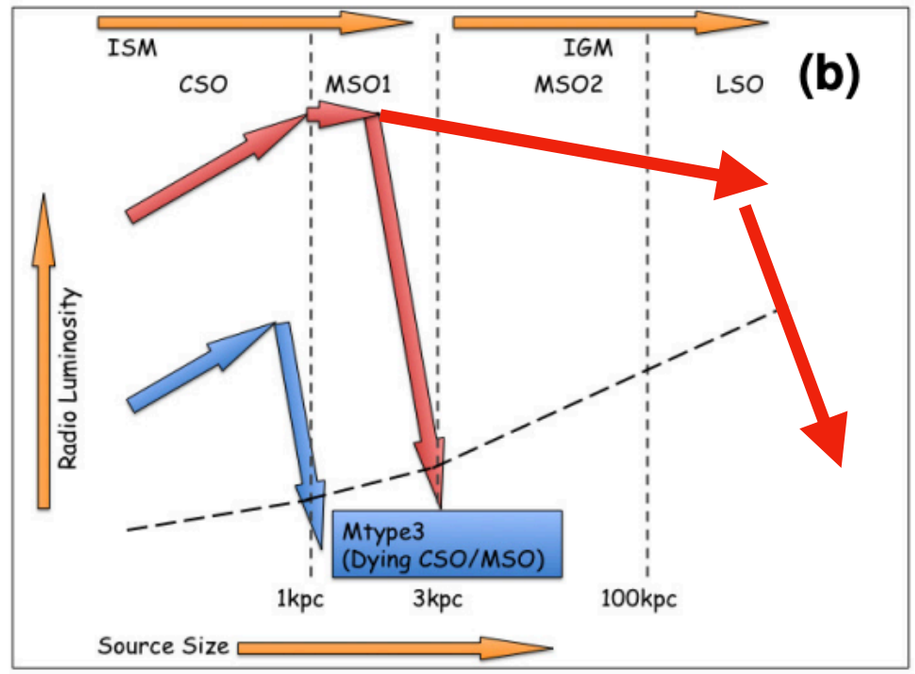
- Different physical conditions during a transition phase from FRII to FRI

Jets switch off: remnant radio galaxies

Morganti2017



An & Baan 2012



Synchrotron + IC losses

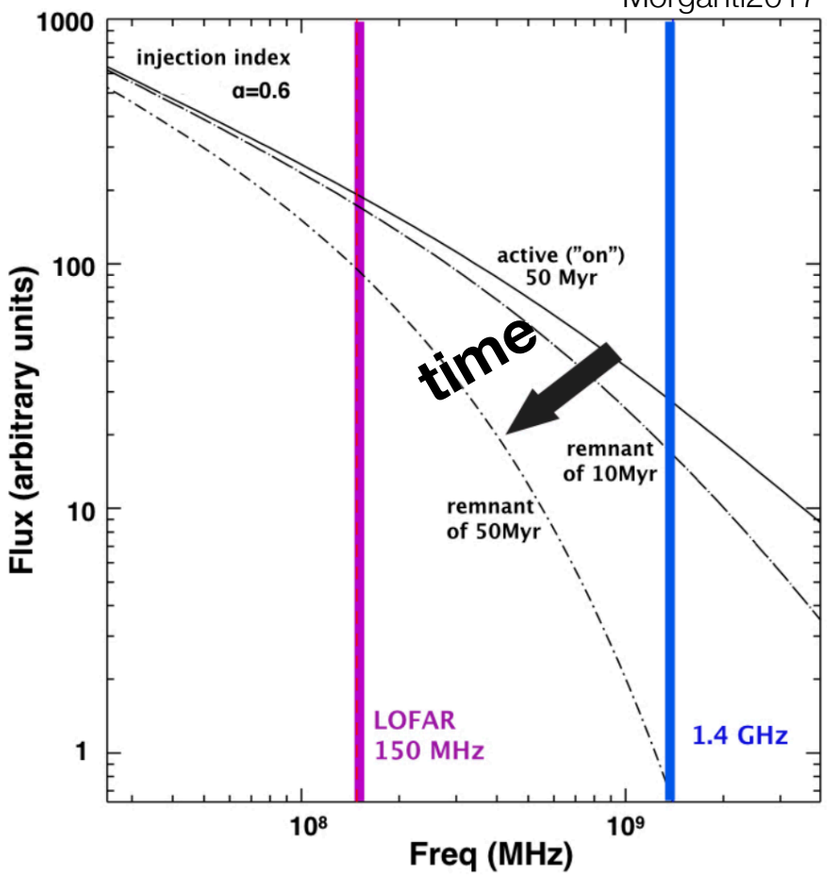
+

Adiabatic expansion

(depends on how much overpressured)

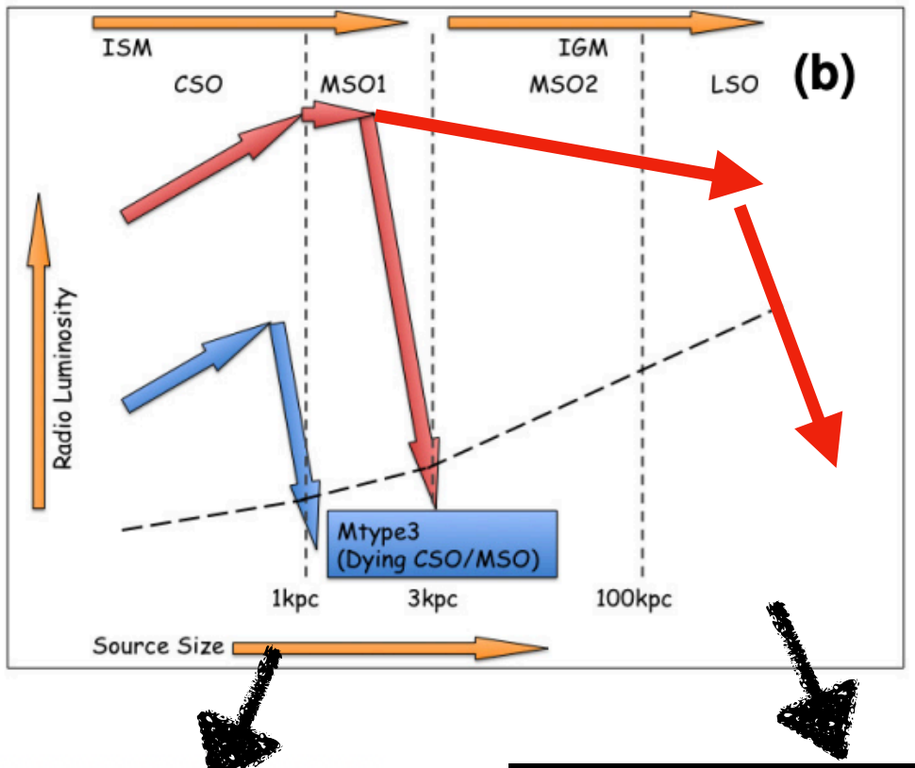
Jets switch off: remnant radio galaxies

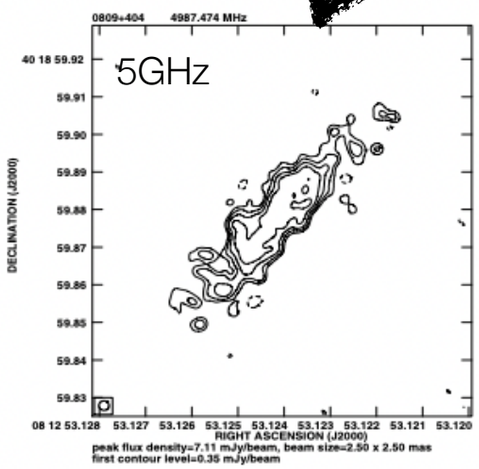
Morganti2017



Synchrotron + IC losses
+
Adiabatic expansion
(depends on how much overpressured)

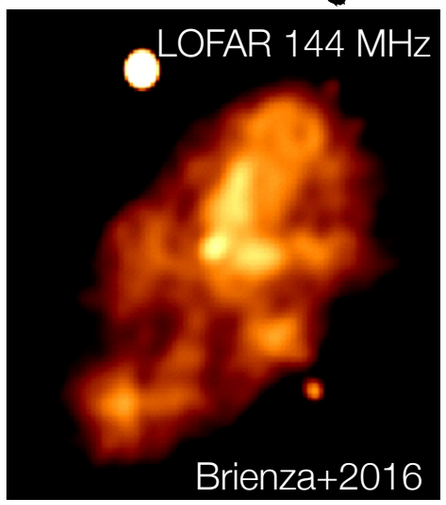
An & Baan 2012





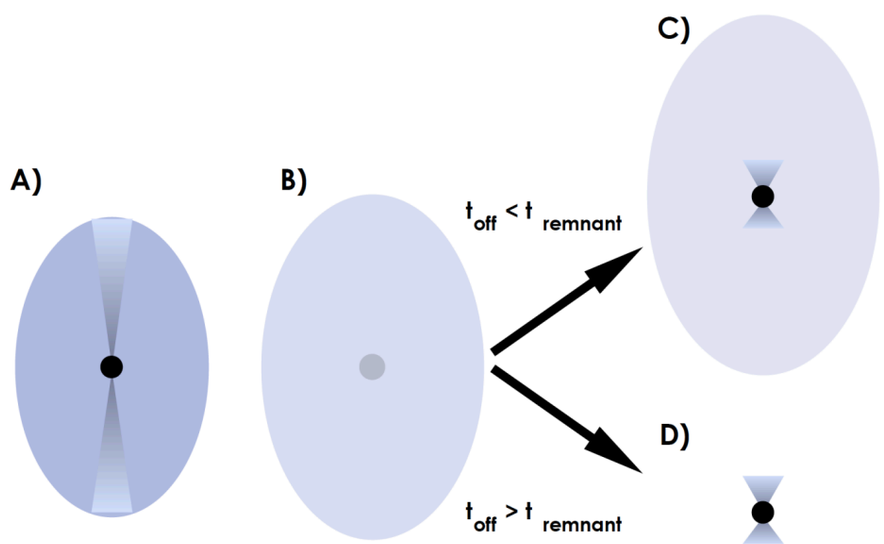
0809+404, Kunert-Bajraszewska+2006

BUT ALSO..
Callingham+2015
Orienti+2010, 2021
Giroletti+2003
Kunert-Bajraszewska+2005



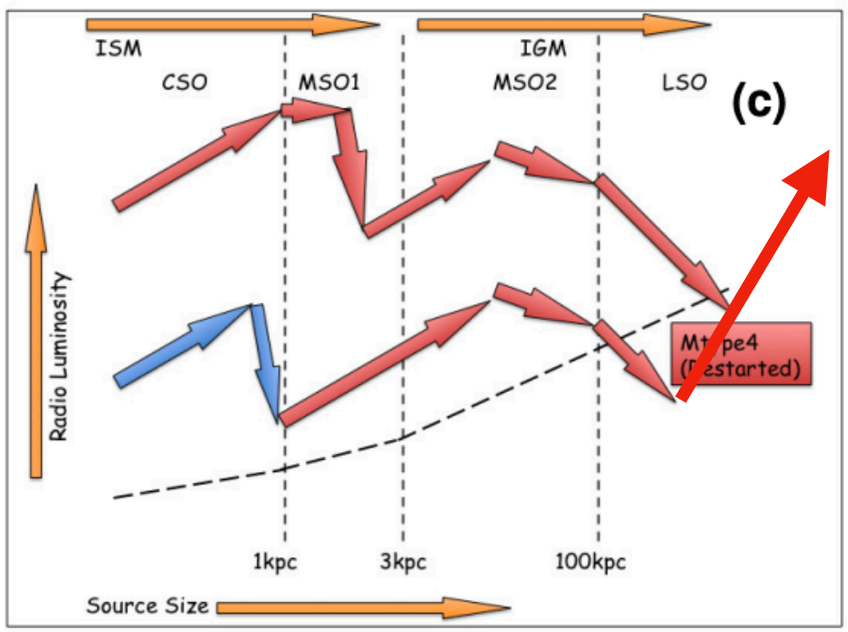
BUT ALSO..
Murgia+2011
Parma+2007
Saripalli+2012

Jets restart: restarted radio galaxies

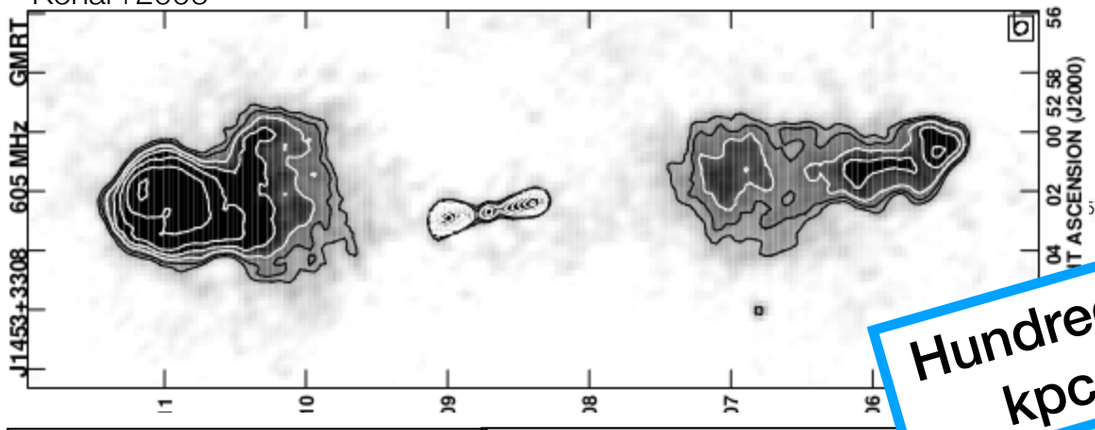


Jurlin+2020

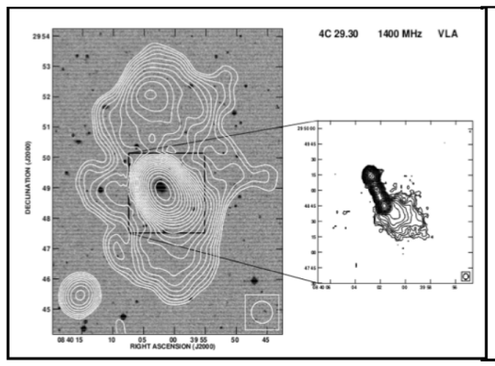
An & Baan 2012



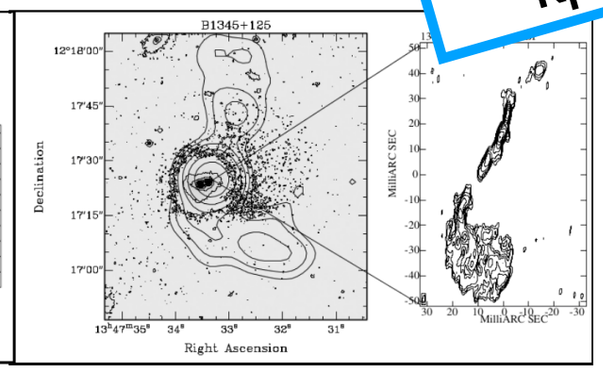
Konar+2006



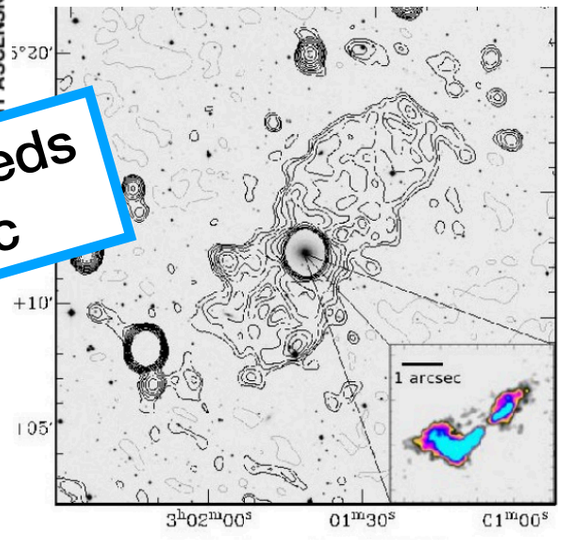
Hundreds kpc



Jamrozy+2007

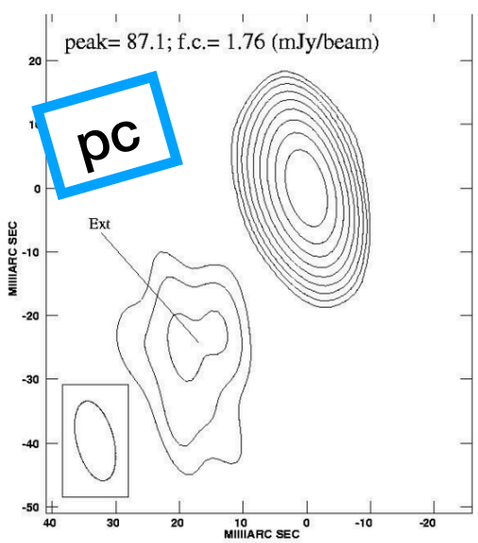


Stnghellini+2005



Shulevski+2012

J1511+0518



Orienti,Dallacasa+2008

Remnants and restarted in the SKA era

Great progress (especially on large scales)!

High sensitivity and spatial resolution at low (<1GHz) frequencies

LOFAR

Individual sources

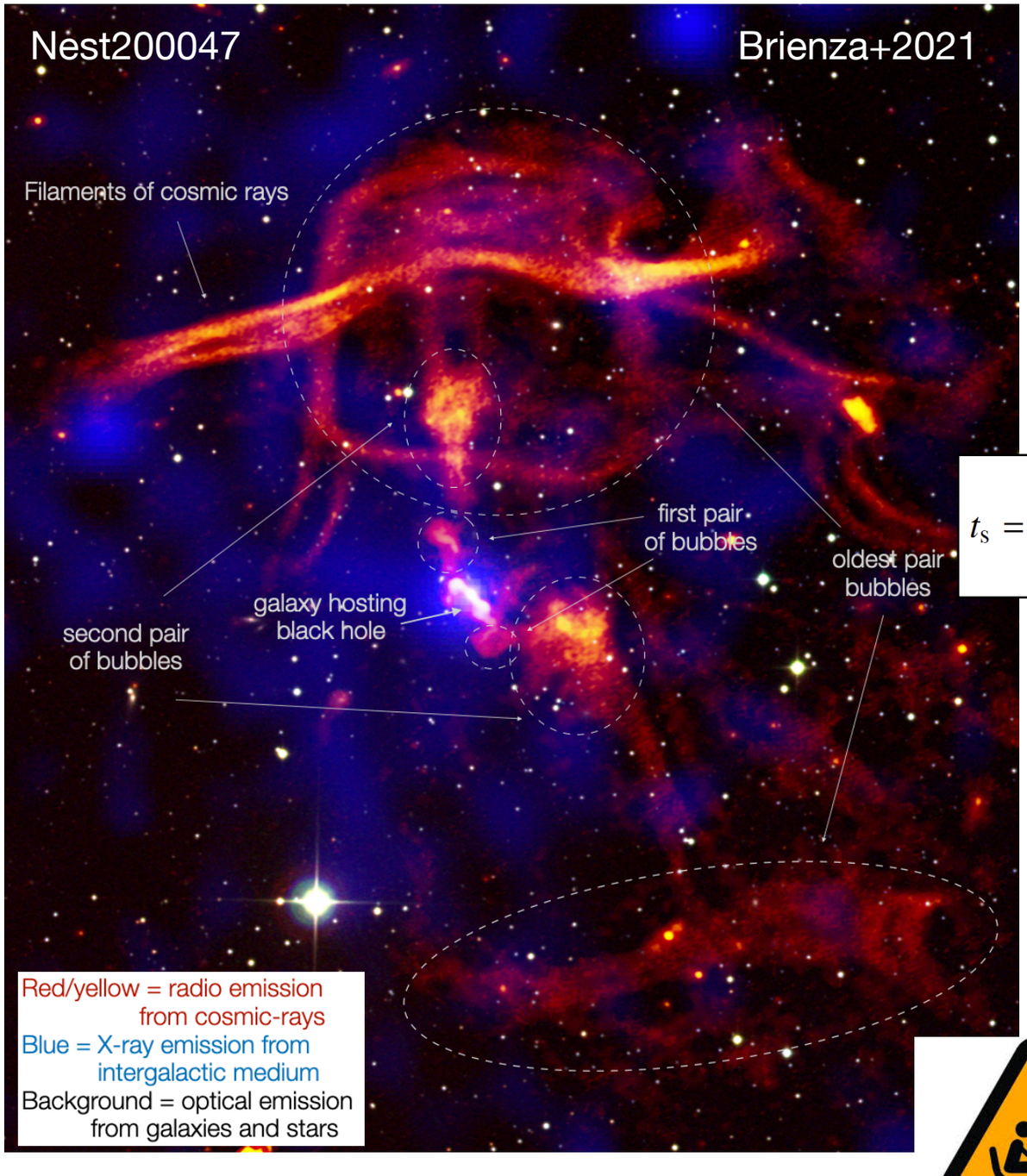
e.g.
Brienza+2016
Hurley-Walker+2015
Tamhane+2015
Duchesne&Jhonston-Hollit+2019
Randriamanakoto+2020
Lal+2021

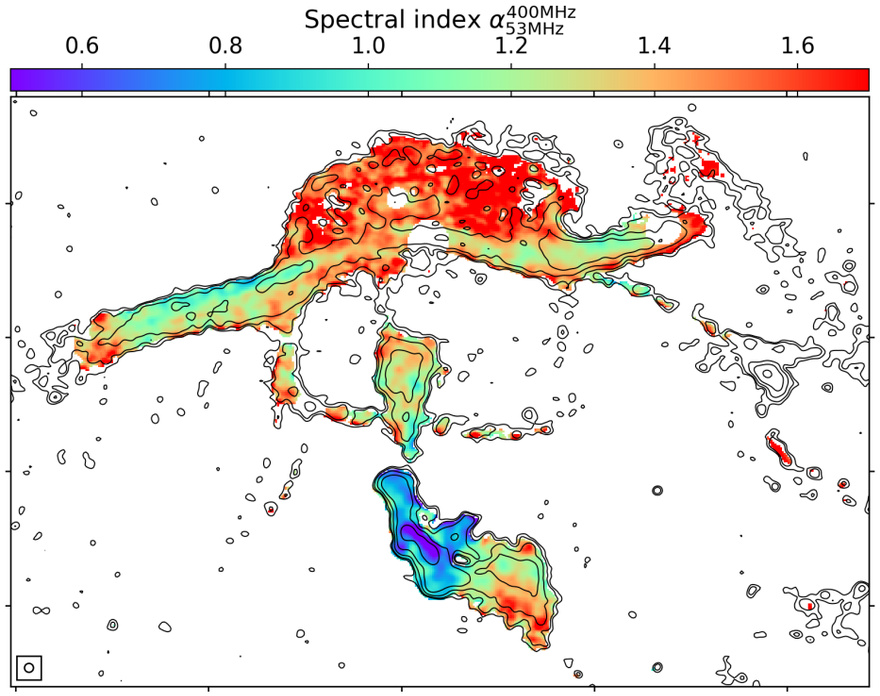
Samples!

e.g.
Godfrey+2017
Brienza+2017,
Mahatma et al. 2018
Jurlin+2020, 2021
Quici+2021

Individual sources

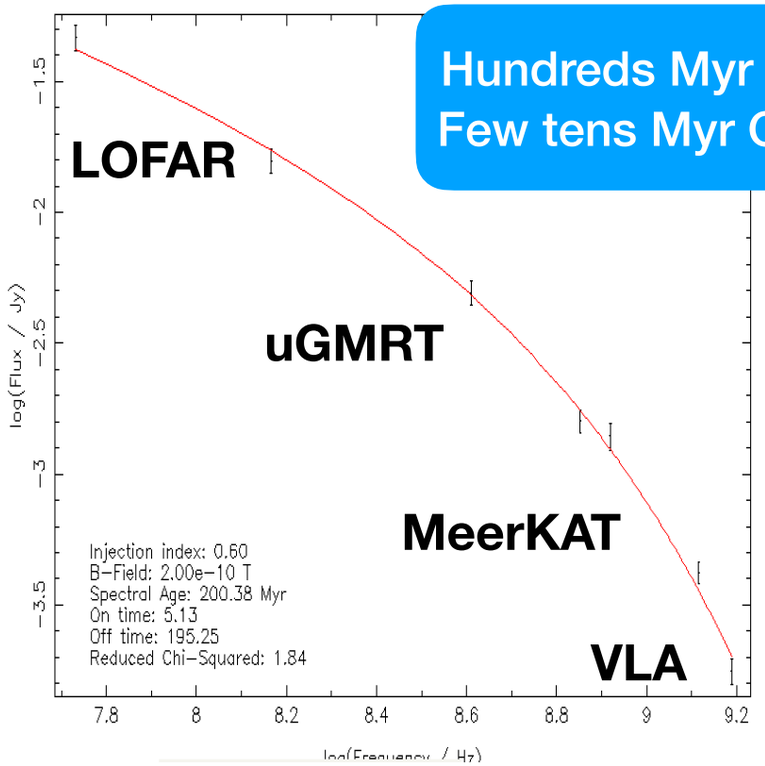
Remnants and restarted in the SKA era





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

Radiative evolution models (Jaffe&Perola1974, Komissarov&Gubanov1994)



Hundreds Myr ON
Few tens Myr OFF

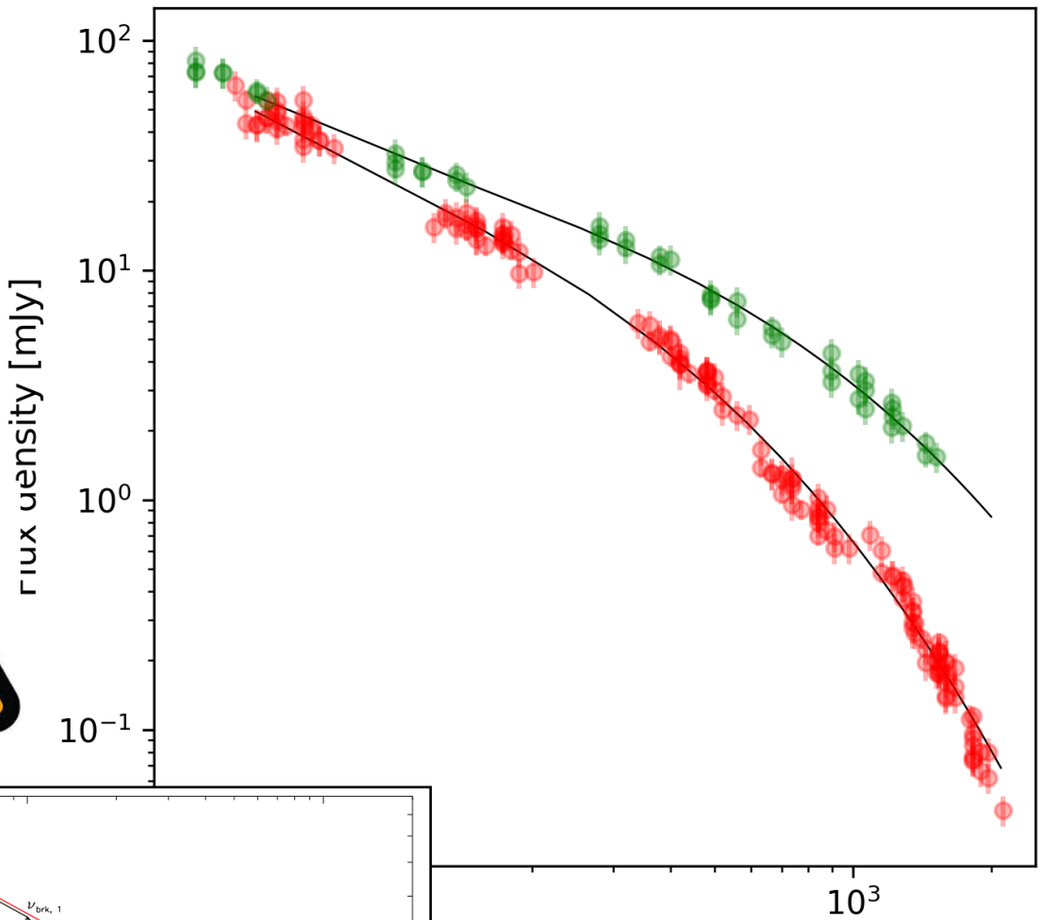
Individual sources

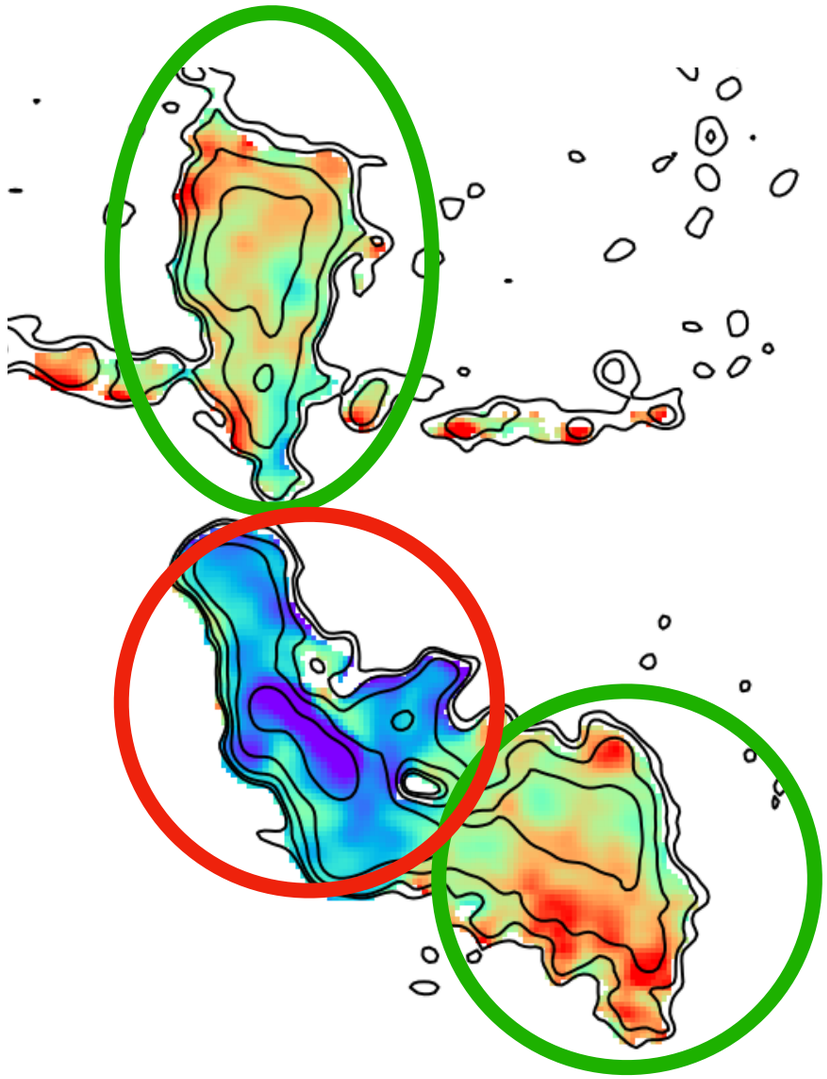
Remnants and restarted in the SKA era

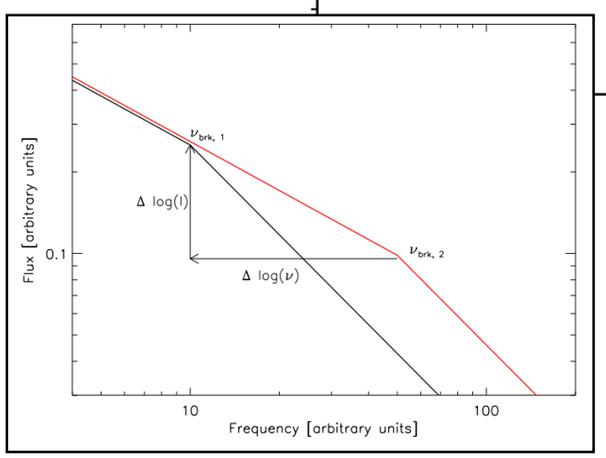
Global spectrum

Katz-Stone+1997
Van Weeren+2012
Shulevski+2015,2017

54+144+400+700+815+1280+1518 MHz







Different injections! Particles accelerated differently in different outbursts

SHIFT= different ages & density & B

Samples

Remnants and restarted in the SKA era

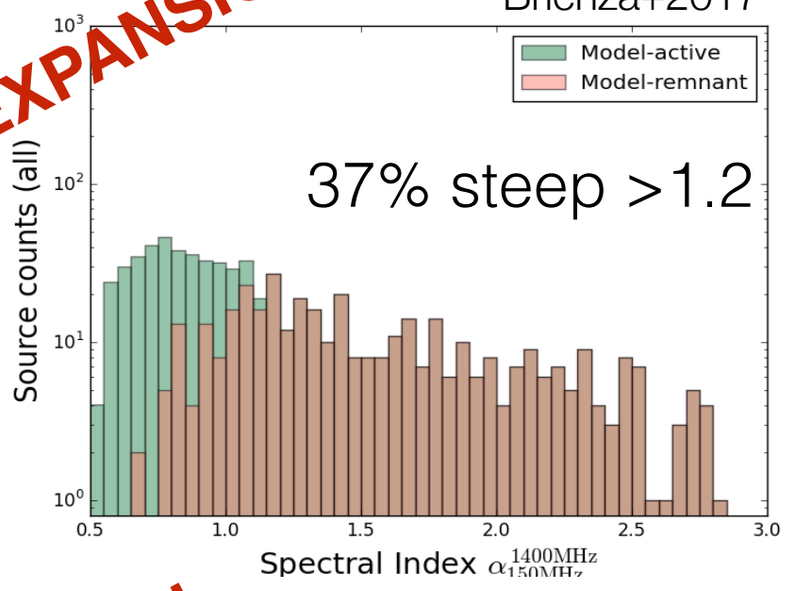
Godfrey+2017
Brienza+2017,
Mahatma et al. 2018
Jurlin+2020, 2021
Quici+2021

FRACTION OF REMNANTS with respect to the active radio galaxy population 10-15%

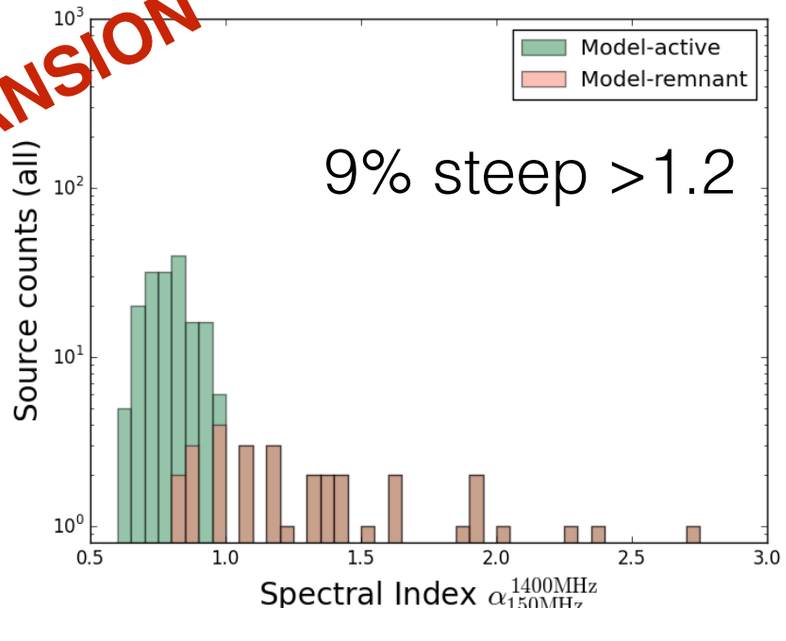
Constraining RG evolution models

NO EXPANSION

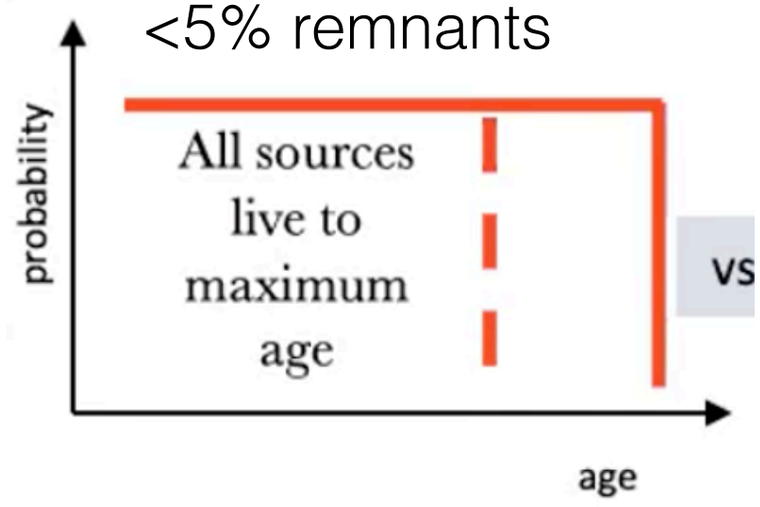
Brienza+2017

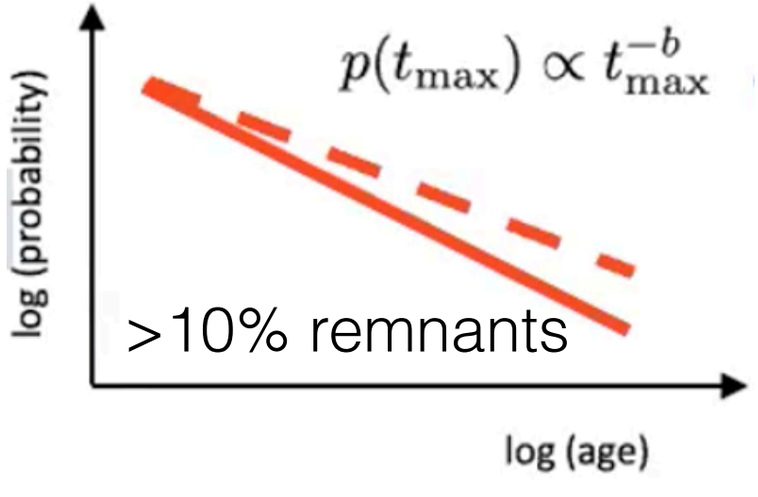


EXPANSION



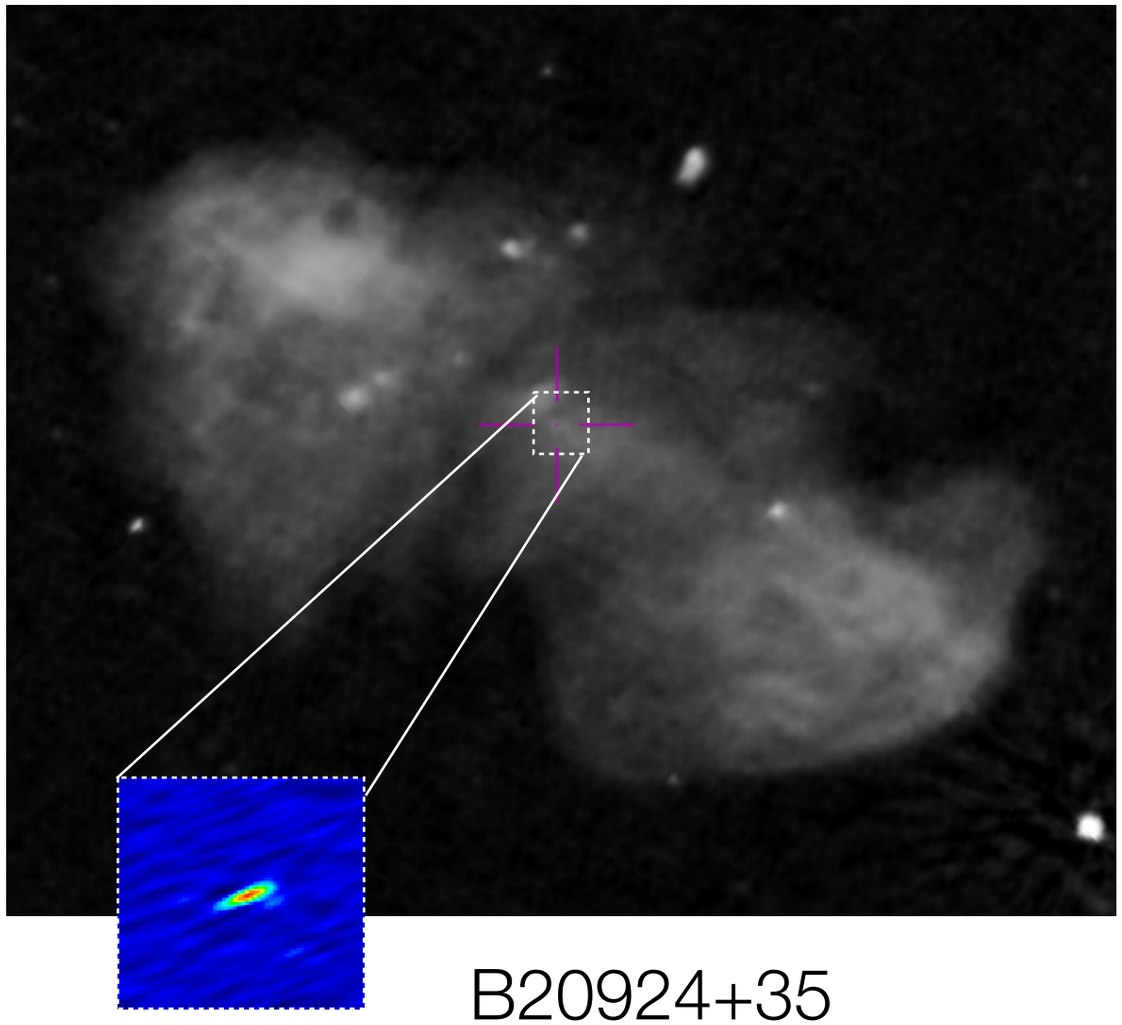
Shabala+2020





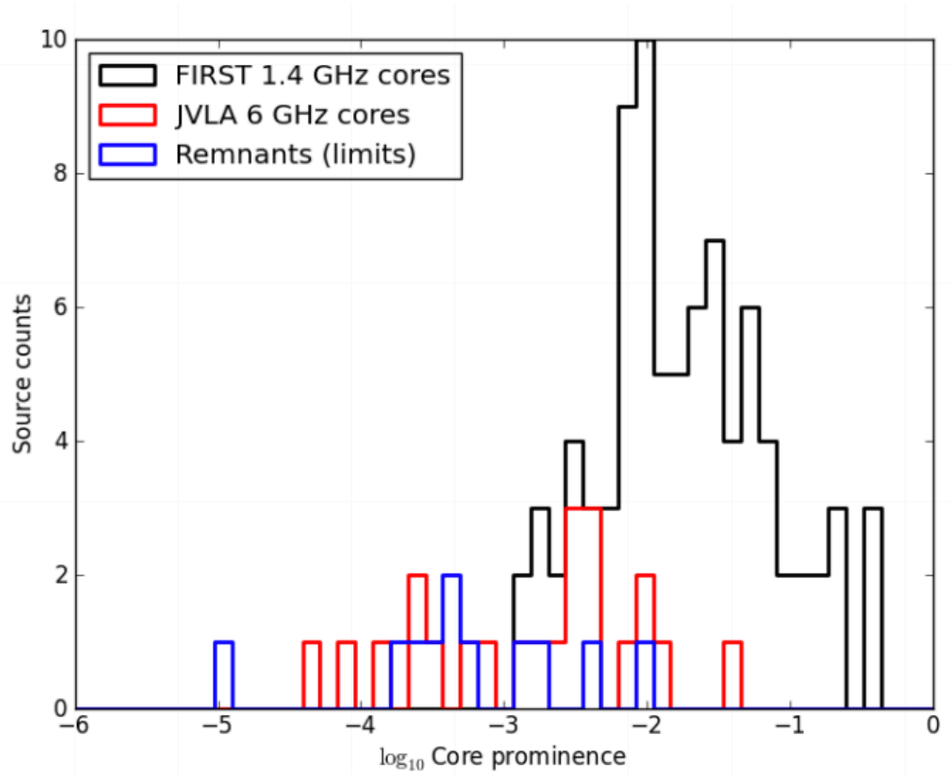
Samples

Remnants and restarted in the SKA era



B20924+35

Shulevski+2015, Brienza+



Mahatma+2020

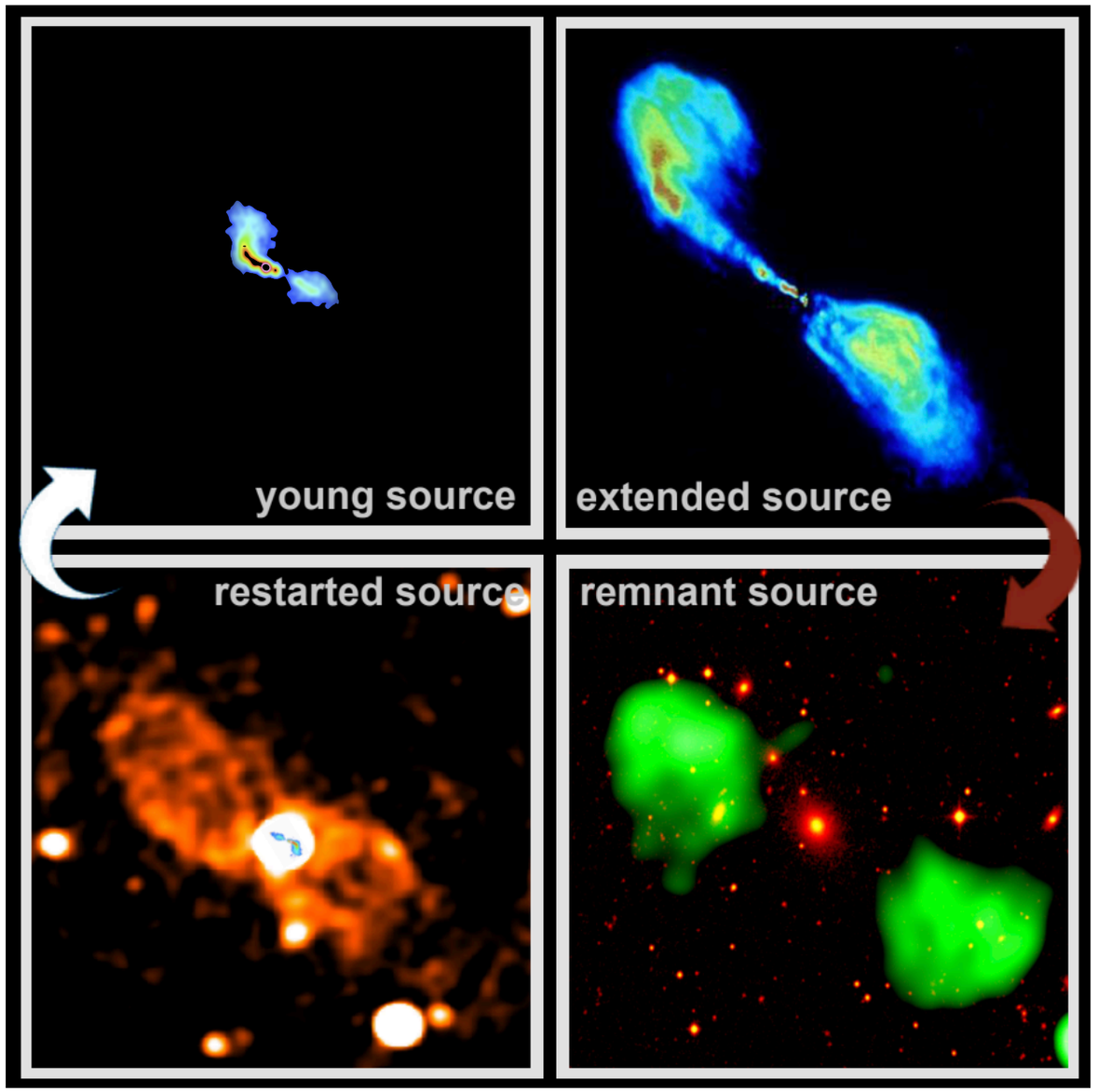
But also ..

Jurlin+2021

Quici+2022

Remnants often have weak cores!

Thank you!


young source
extended source
restarted source
remnant source