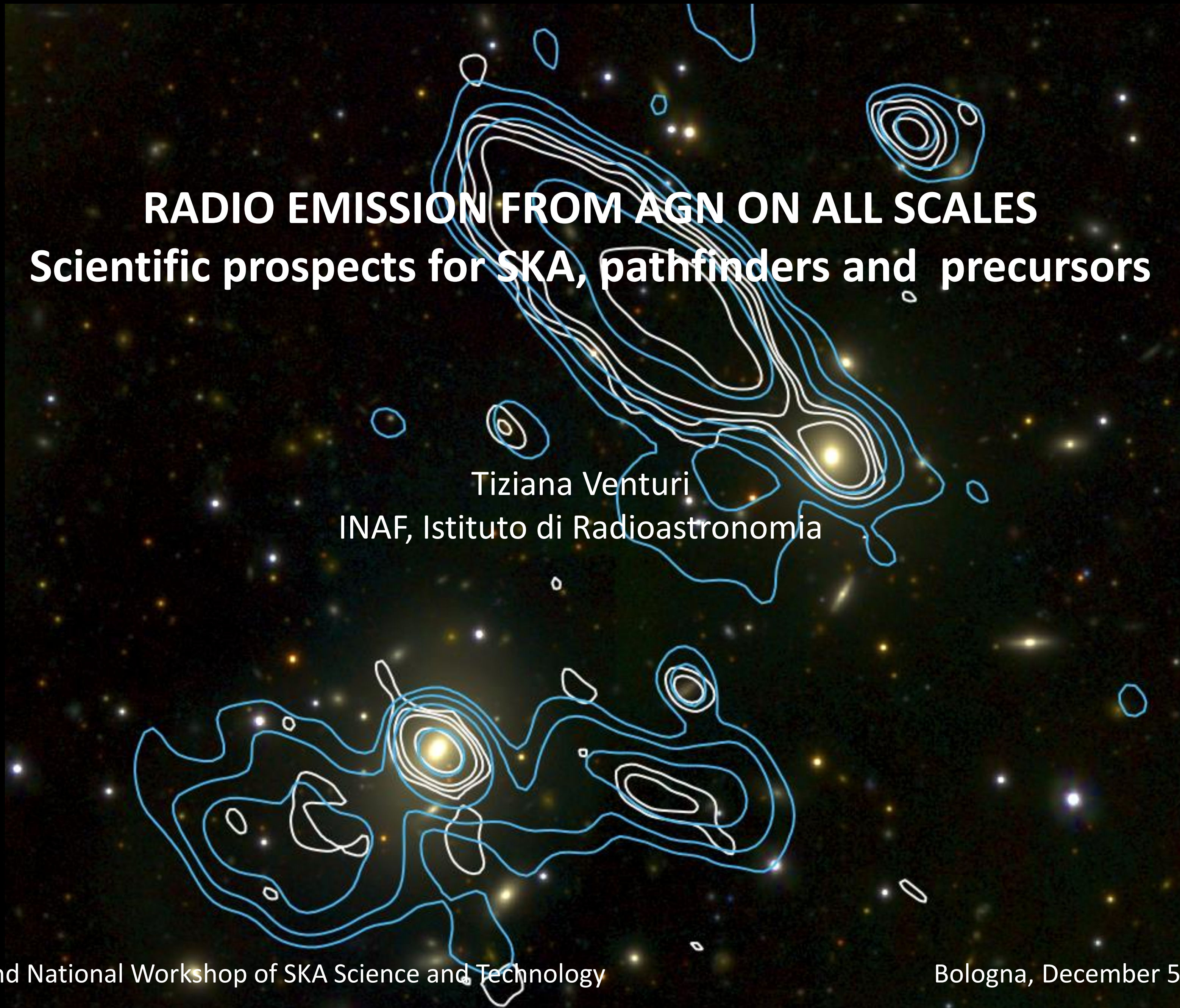
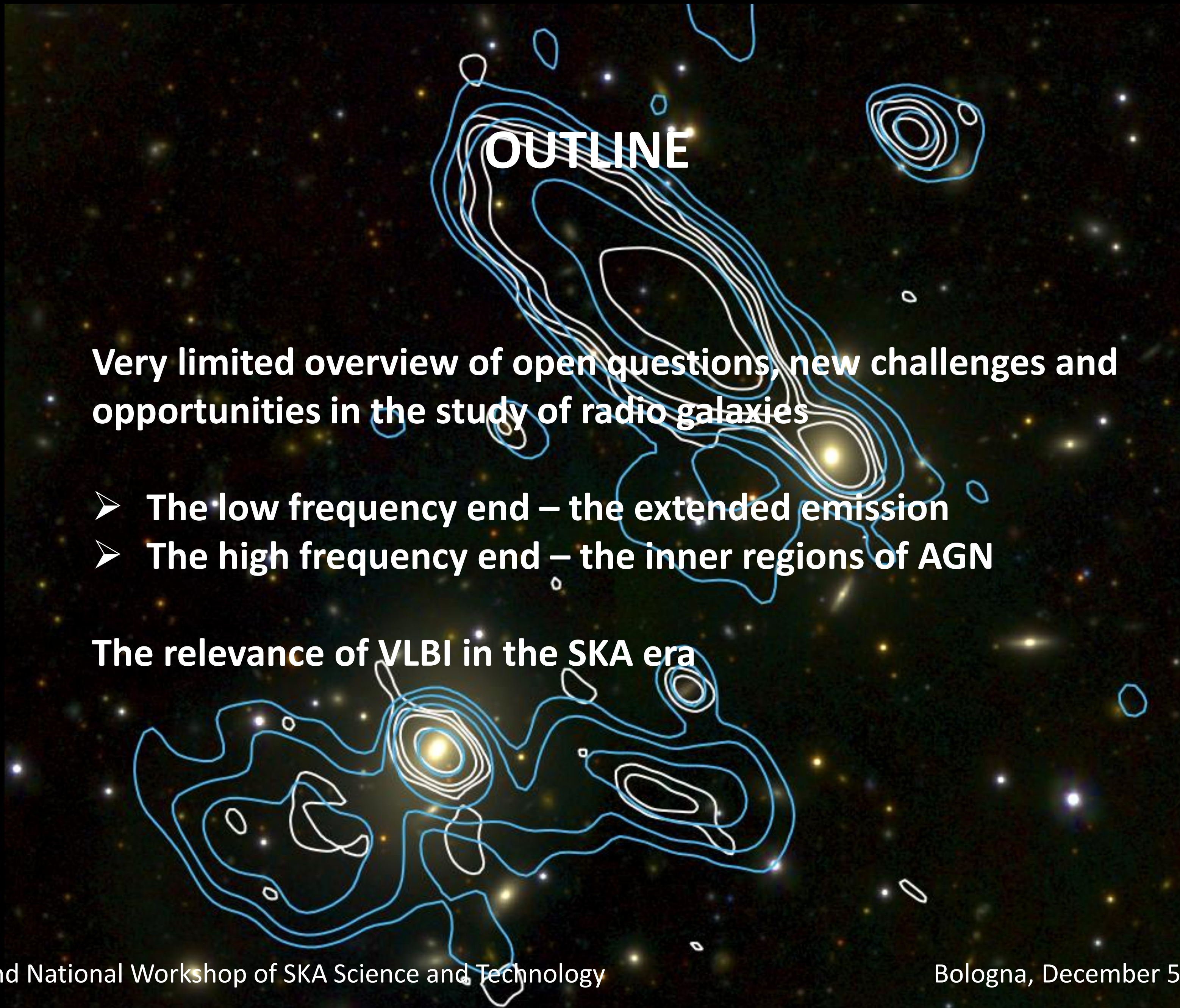


RADIO EMISSION FROM AGN ON ALL SCALES
Scientific prospects for SKA, pathfinders and precursors

Tiziana Venturi
INAF, Istituto di Radioastronomia

Second National Workshop of SKA Science and Technology

Bologna, December 5th, 2018

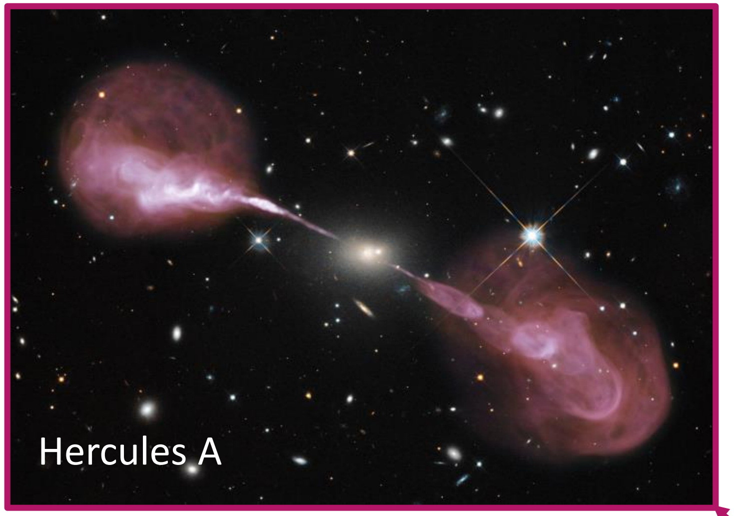


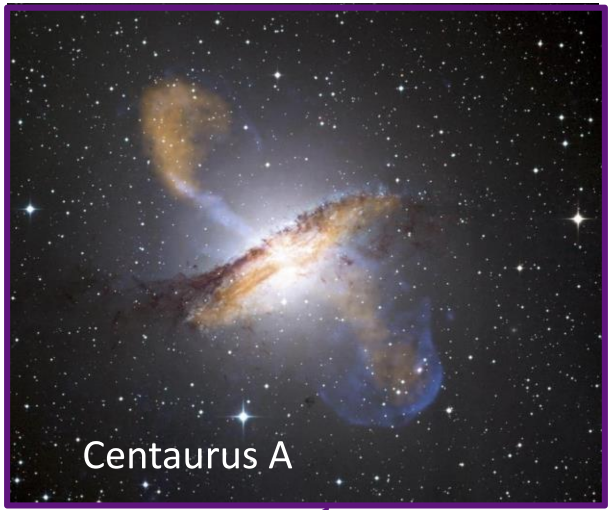
OUTLINE

Very limited overview of open questions, new challenges and opportunities in the study of radio galaxies

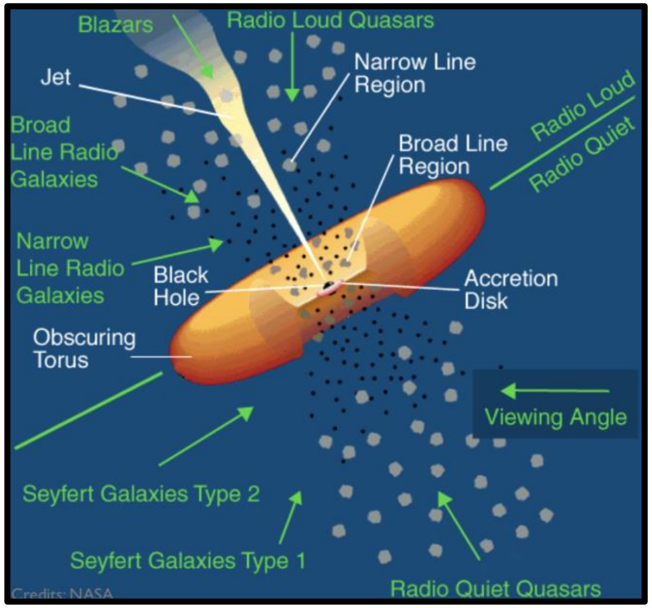
- The low frequency end – the extended emission
- The high frequency end – the inner regions of AGN

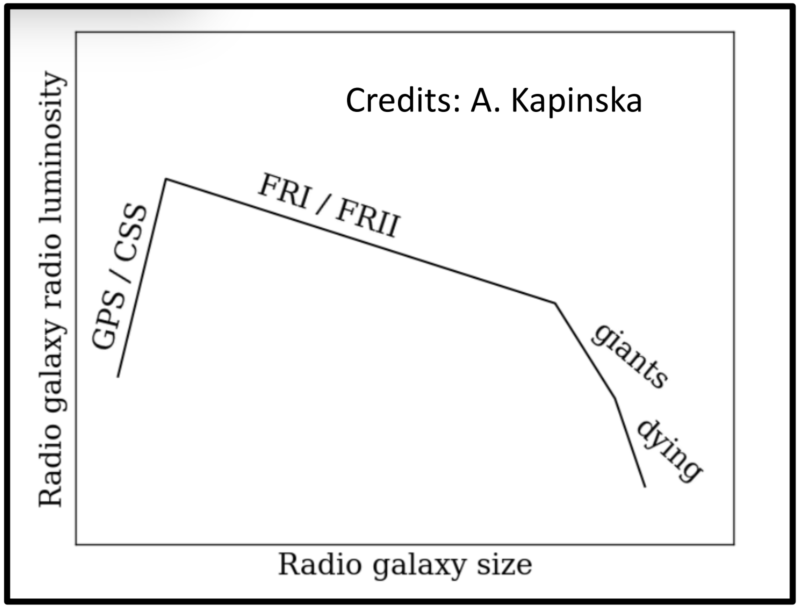
The relevance of VLBI in the SKA era



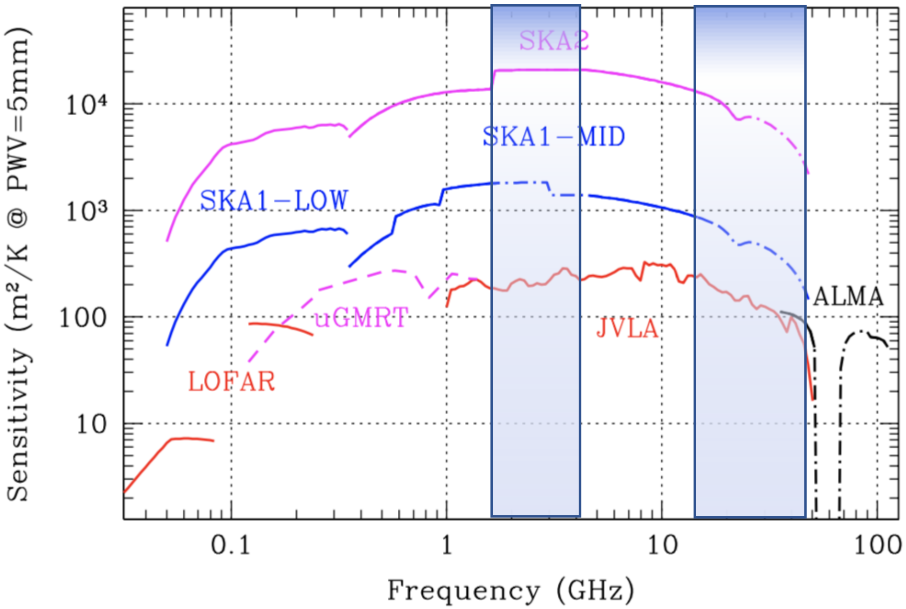


Science space: Radio galaxies – FRII and FRI – and their nuclear regions





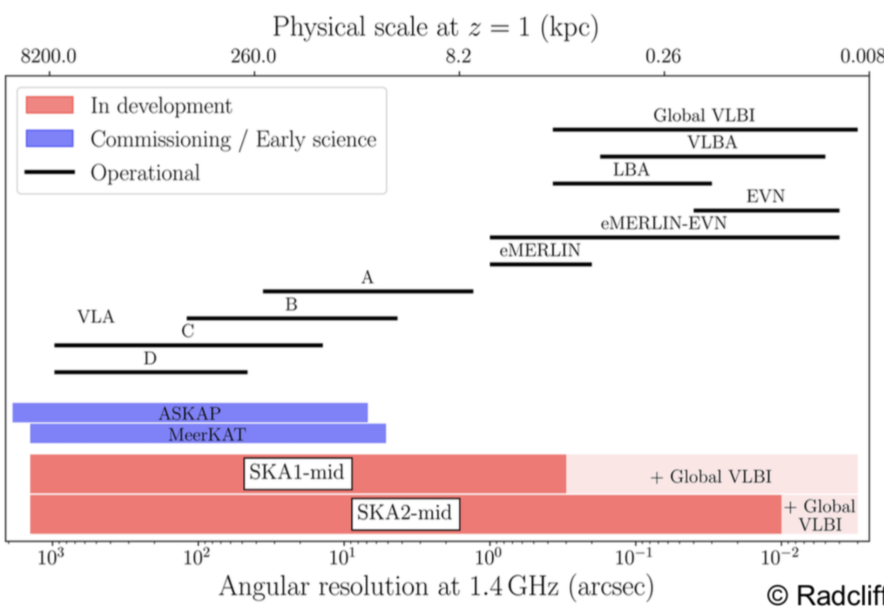
Parameter space

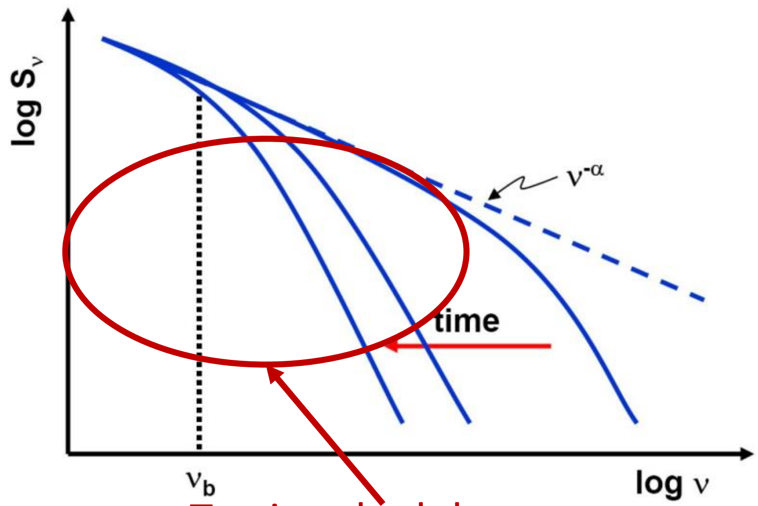


ν_{min} (MHz)	ν_c (MHz)	ν_{max} (MHz)	σ_L (μJy/Bm)	σ_C (μJy/Bm)	θ'_{min} (")	θ_{min} (")	θ_{max} (")	θ'_{max} (")
50	**60**	**69**	11050	163	16.4	23.5	1175	3290
69	**82**	**96**	3261	47	11.9	17.0	850	2379
96	**114**	**132**	1841	26	8.6	12.3	614	1719
132	**158**	**183**	1258	18	6.2	8.9	444	1244
183	**218**	**253**	973	14	4.5	6.4	321	899
253	**302**	**350**	794	11	3.3	4.6	232	650

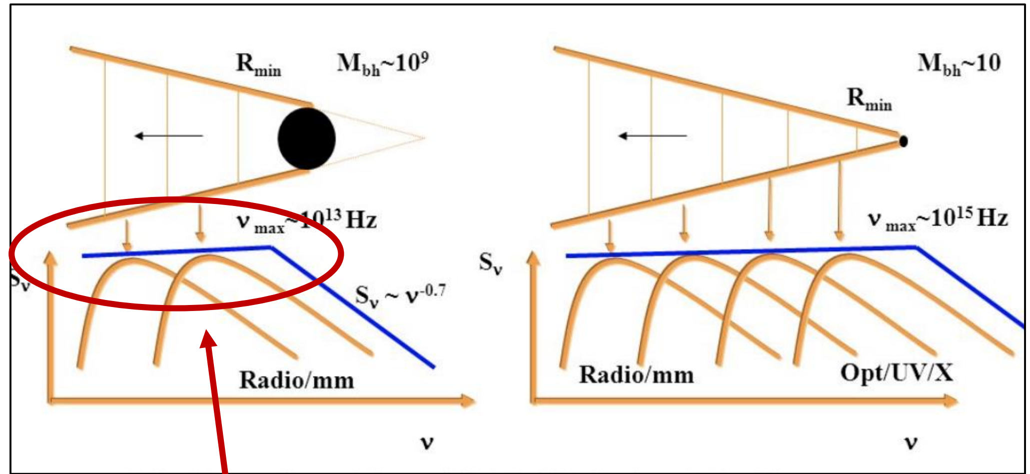
SKA-TEL-SKO-0000000 2017-10-06

ν_{min} (GHz)	ν_c (GHz)	ν_{max} (GHz)	σ_L (μJy/Bm)	σ_C (μJy/Bm)	θ'_{min} (")	θ_{min} (")	θ_{max} (")	θ'_{max} (")
0.35	**0.41**	**0.48**	1176	16.8	1.015	2.031	270.8	541.6
0.48	**0.56**	**0.65**	560	8.1	0.745	1.489	198.6	397.2
0.65	**0.77**	**0.89**	303	4.4	0.546	1.092	145.6	291.2
0.89	**1.05**	**1.21**	186	2.7	0.400	0.801	106.8	213.5
1.21	**1.43**	**1.65**	137	2.0	0.294	0.587	78.3	156.6
1.65	**1.95**	**2.25**	113	1.6	0.215	0.431	57.4	114.9
2.25	**2.66**	**3.07**	99	1.4	0.158	0.316	42.1	84.2
3.07	**3.63**	**4.18**	109	1.6	0.116	0.232	30.9	61.8
4.18	**4.94**	**5.70**	95	1.4	0.085	0.170	22.7	45.3
5.70	**6.74**	**7.78**	89	1.3	0.062	0.125	16.6	33.2
7.78	**9.19**	**10.61**	85	1.2	0.046	0.091	12.2	24.4
10.61	**12.53**	**14.46**	85	1.2	0.034	0.067	8.9	17.9
14.46	**17.09**	**19.72**	91	1.3	0.025	0.049	6.6	13.1
19.72	**23.31**	**26.89**	116	1.7	0.018	0.036	4.8	9.6
26.89	**31.78**	**36.67**	121	1.8	0.013	0.026	3.5	7.0
36.67	**43.33**	**50.00**	209	3.2	0.010	0.019	2.6	5.2



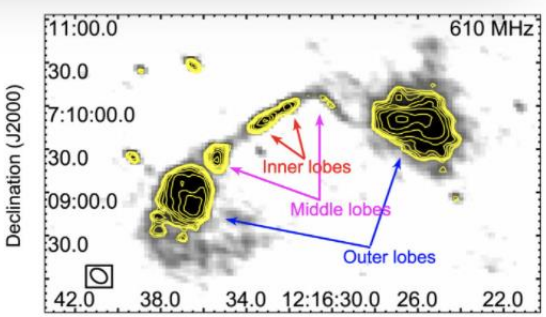


Tracing the lobes

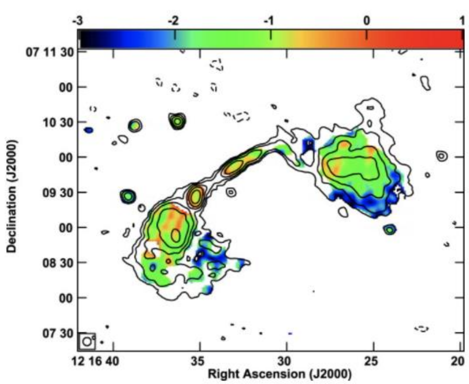


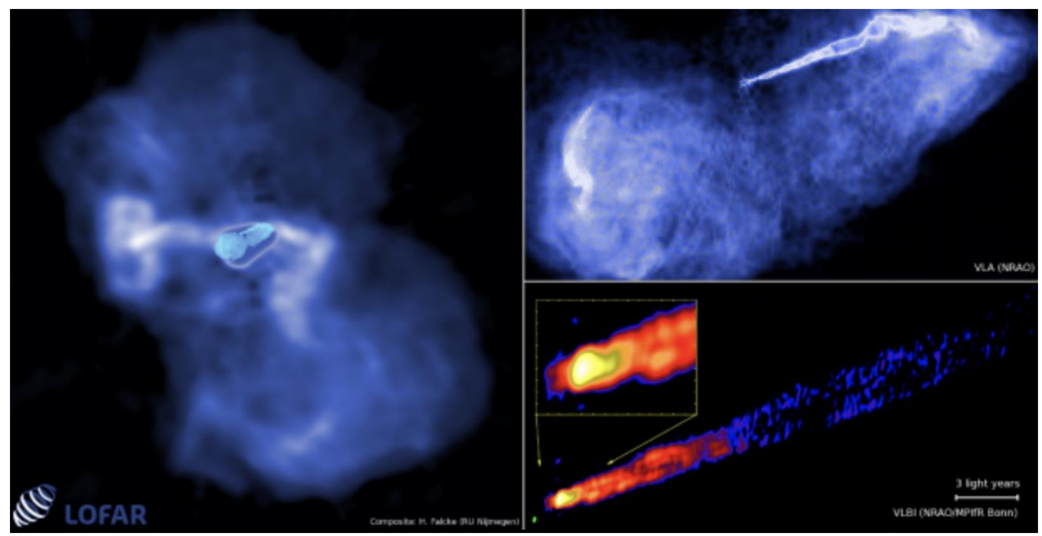
Tracing the core

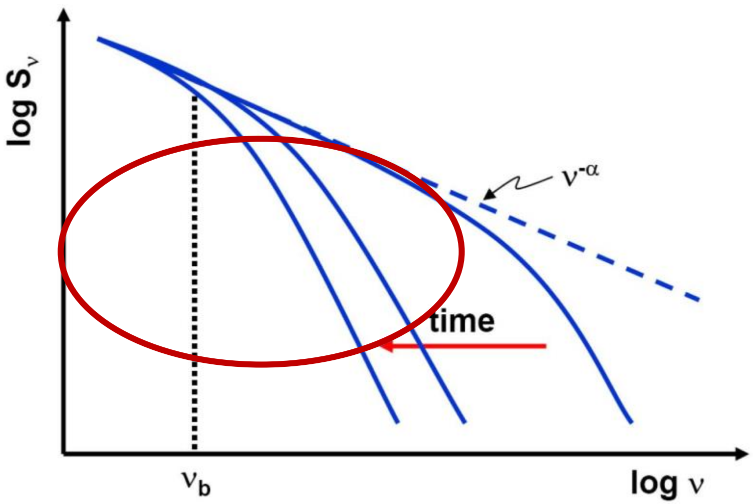
Falcke 2018



Singh et al.2016







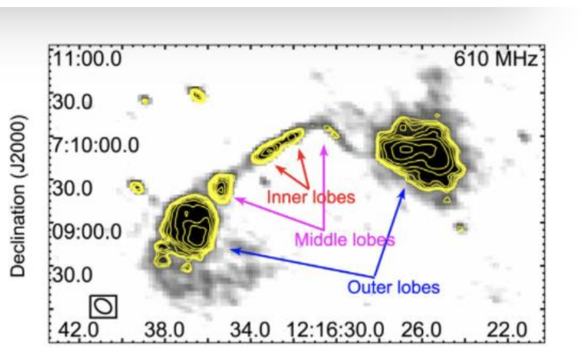
Tracing the lobes

High resolution and high sensitivity imaging at low frequencies (LOFAR, uGMRT)

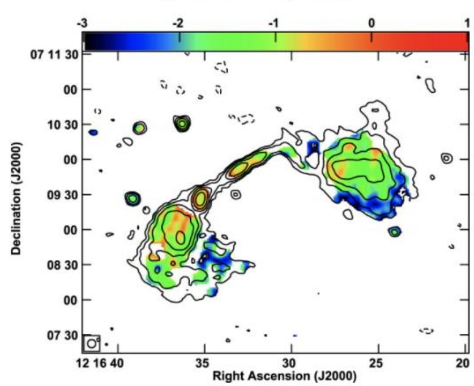
Revision of the size in radio galaxies
Old radio emission

Life cycles of radio galaxies
Restarted emission

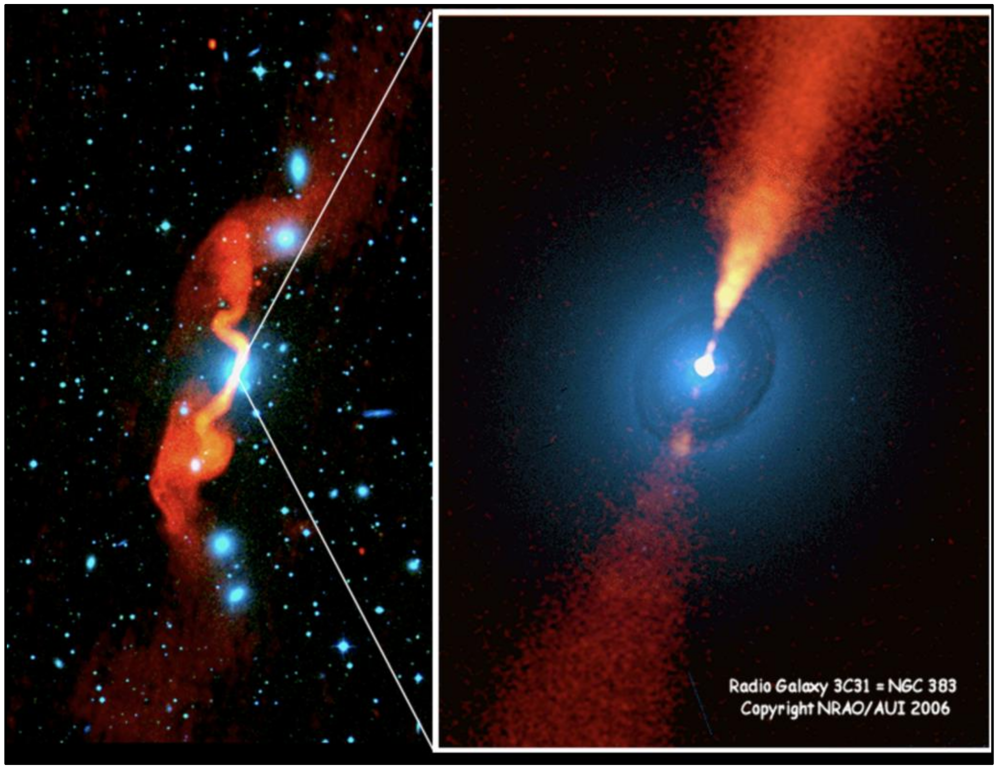
What triggers the radio activity?
Which is the interplay between the jets and lobes in radio galaxies and the ICM?

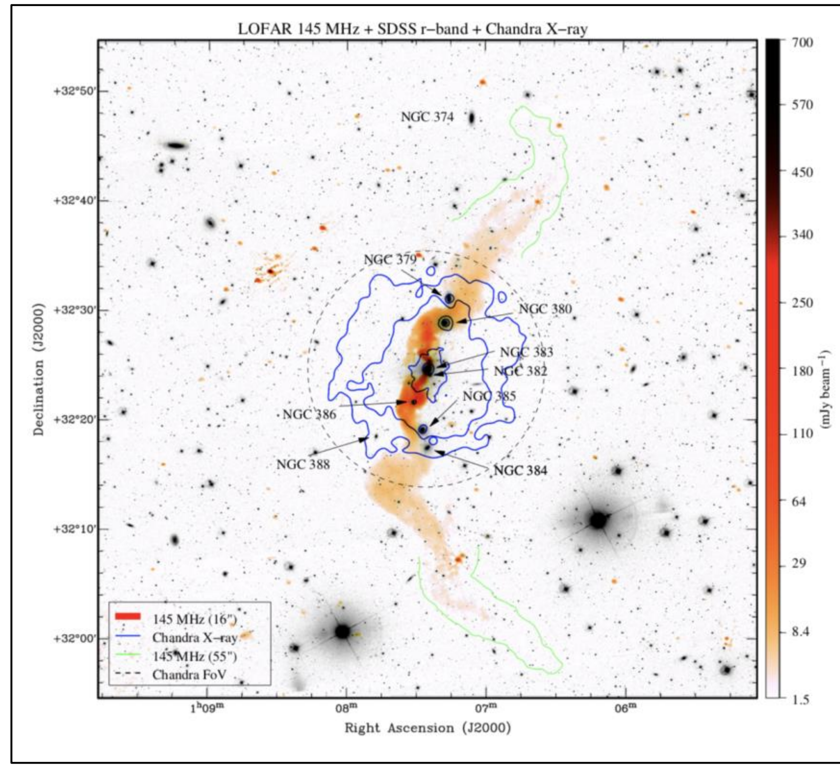


Singh et al.2016



The case of 3C31

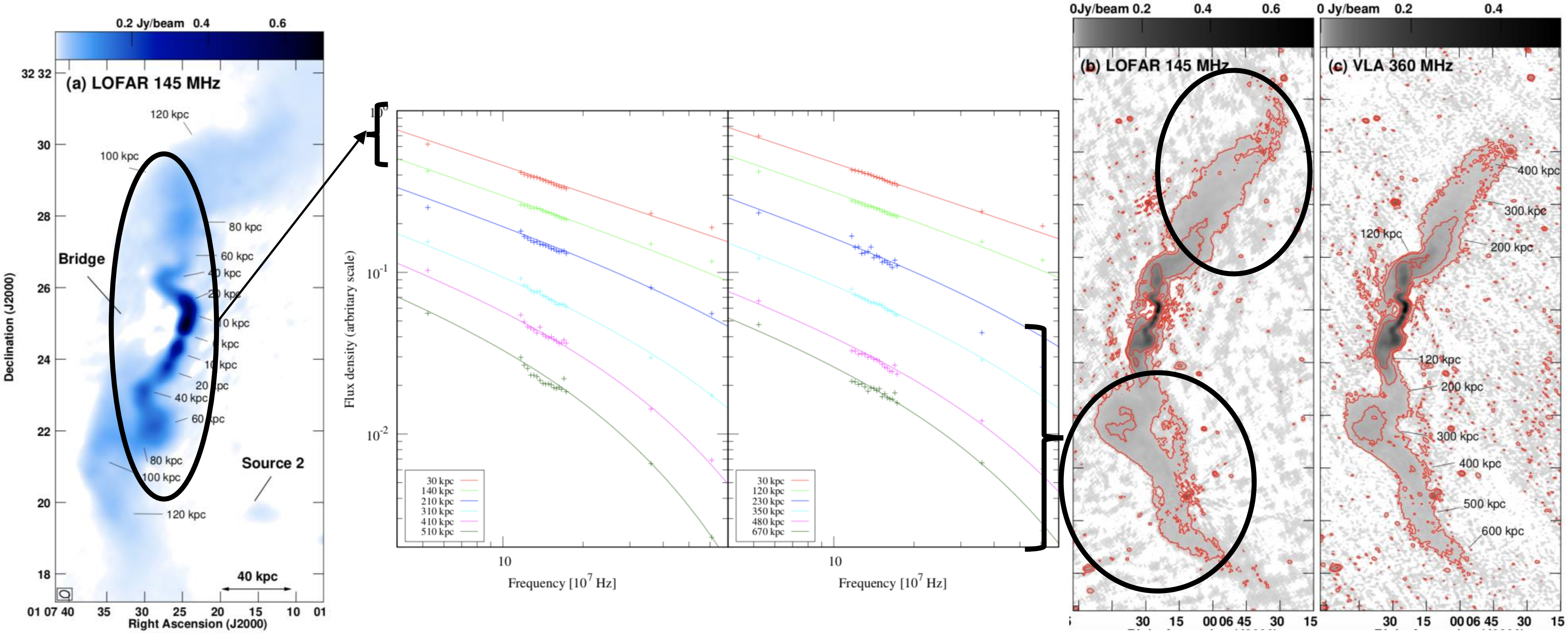




Heesen et al. 2018

The case of 3C31

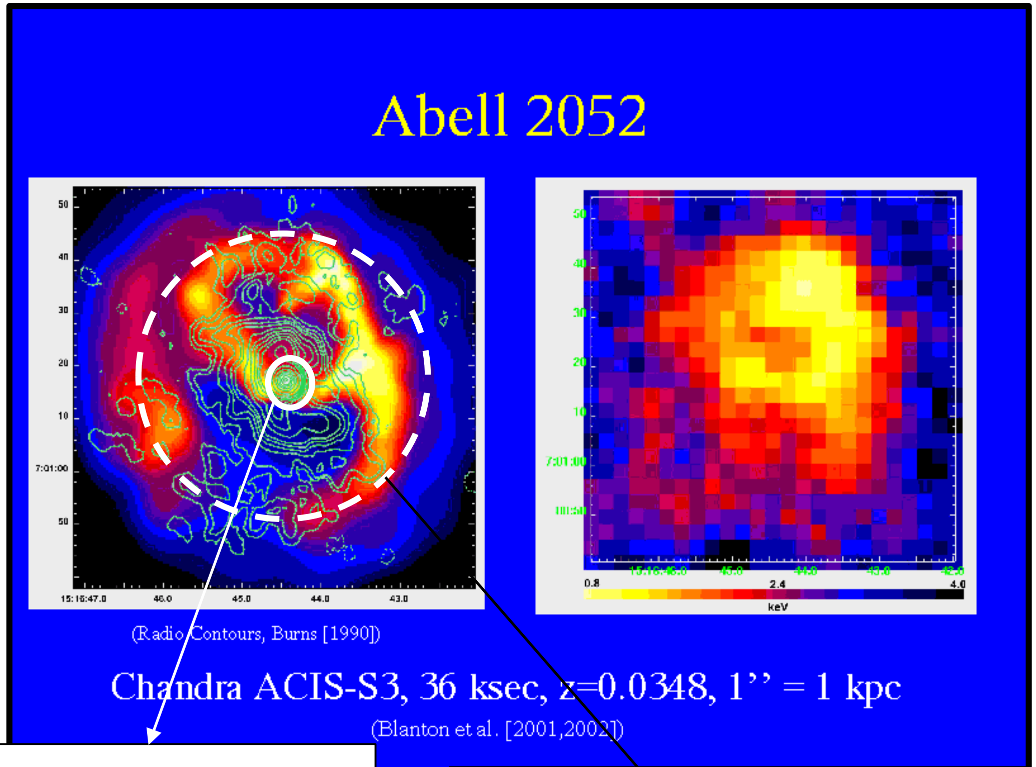
Heesen et al. 2018



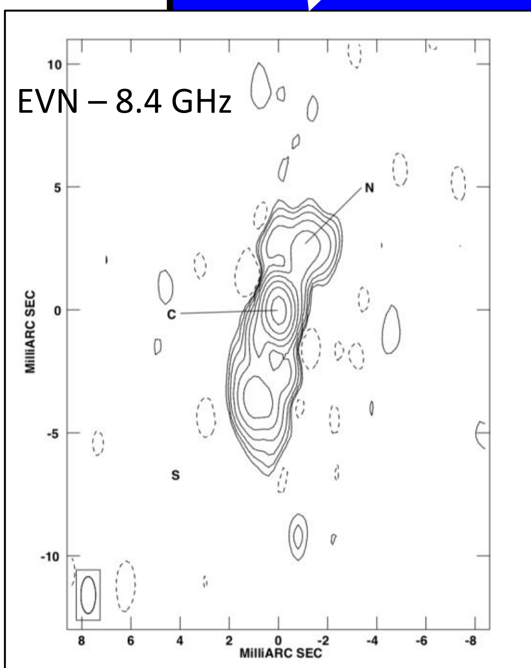
- A nearby (z=0.0169) giant radio galaxy (~ 1 Mpc) at low radio frequencies
- Estimated radiative age ~ 200 Myr
- Implications on the expansion on the ICM

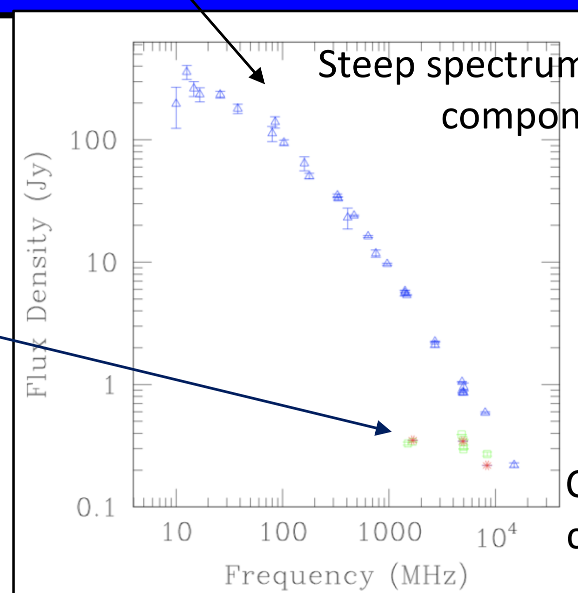
Few cases of restarted activity known so far

They seem more common in dense environments (galaxy clusters and group centres)



Major role of high sensitivity & high resolution low frequency imaging combined with VLBI observations

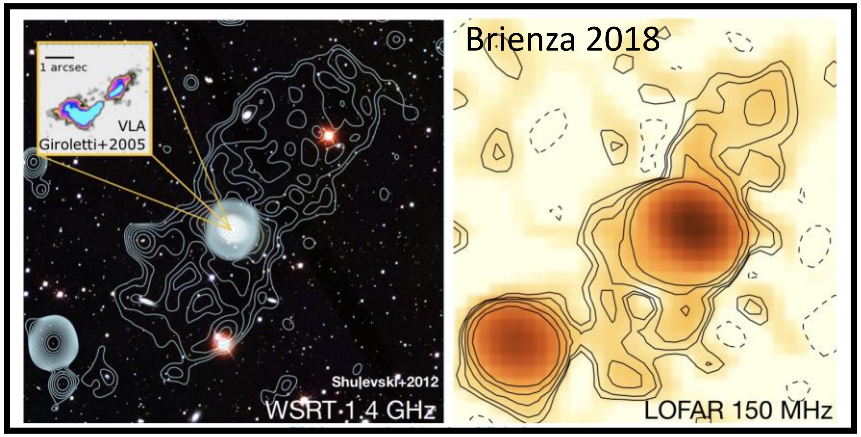




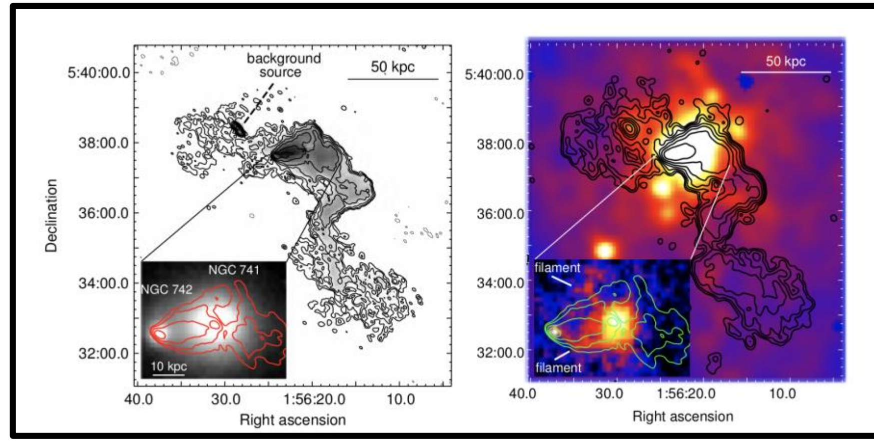
CSS nuclear component

Venturi et al. 2004

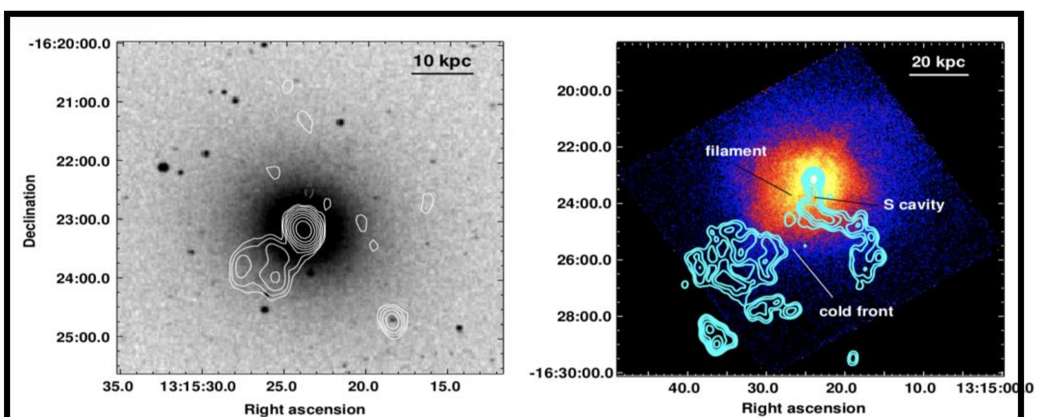
Increasing the statistics on remnant emission from radio galaxies and restarted activity



Restarted activity in B2 0258+35 - The addition of LOFAR to previous studies (Brienza 2018)



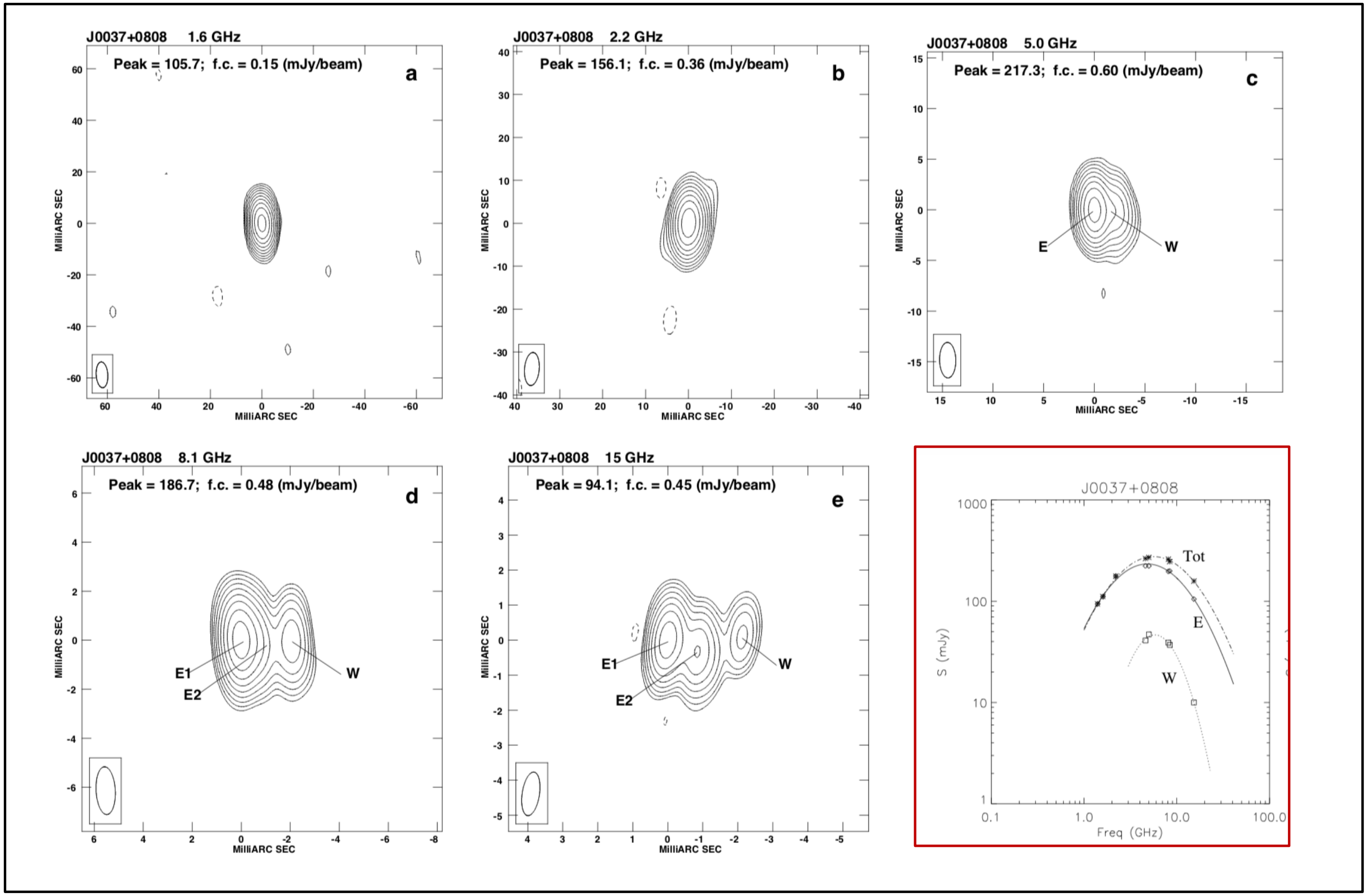
Restarted activity in the galaxy group NGC742 from multiband GMRT imaging (Giacintucci et al. 2011)



Multiple bursts of radio emission in NGC5044 at the centre of a galaxy group from multiband GMRT imaging (Giacintucci et al. 2011)

Potentials of the new broad band receivers

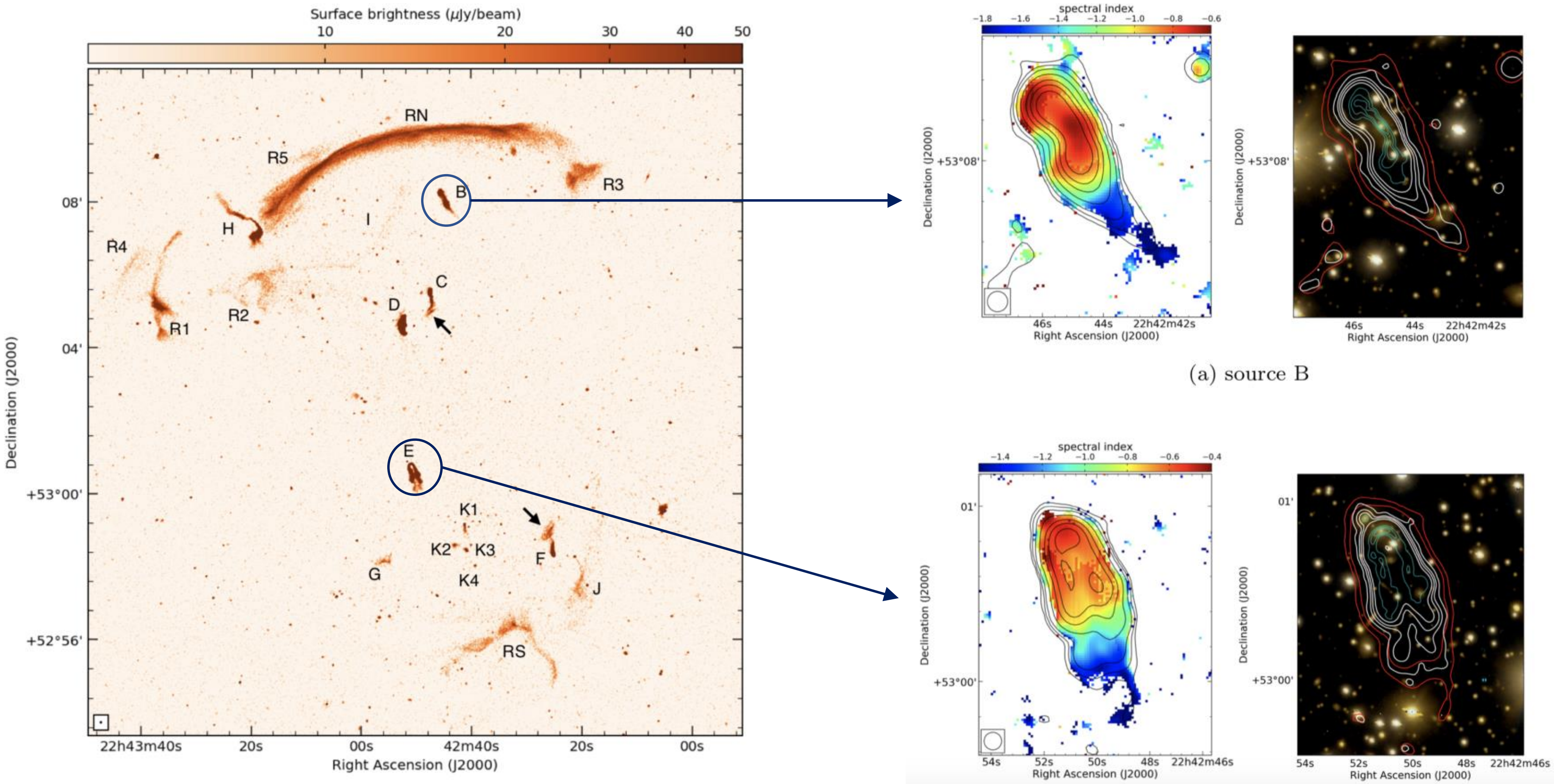
- Simultaneous spectra for compact radio sources and nuclear components of radio galaxies



Orienti & Dallacasa 2014

Potentials of the new broad band receivers

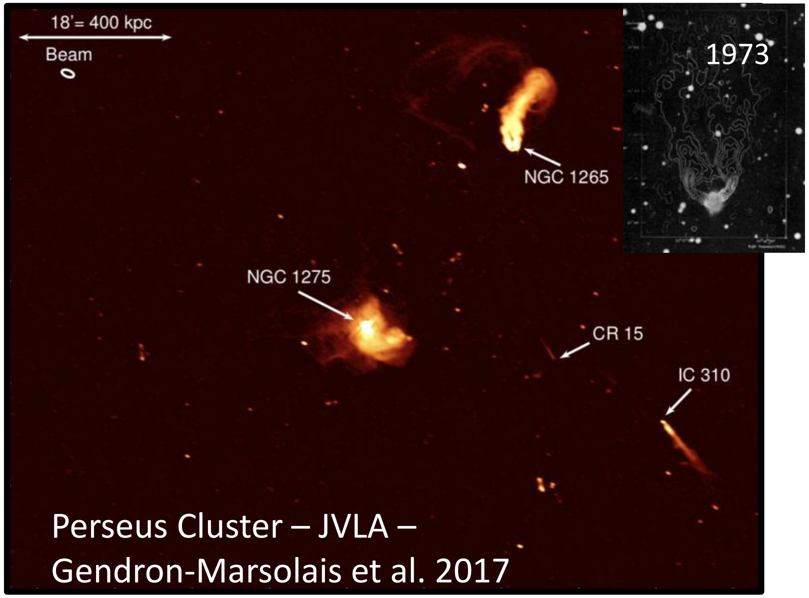
- Simultaneous spectral imaging with unprecedented resolution
- Impressive sensitivity at high angular resolution

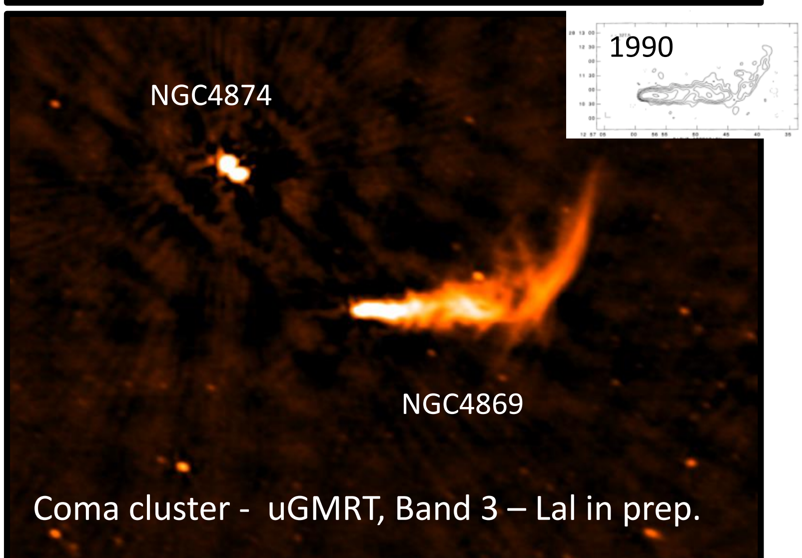


The Sausage cluster – JVLA 2-4 GHz band – rms 2.3 microJy/b

Di Gennaro et al. 2018

Where AGN science and galaxy cluster science meet



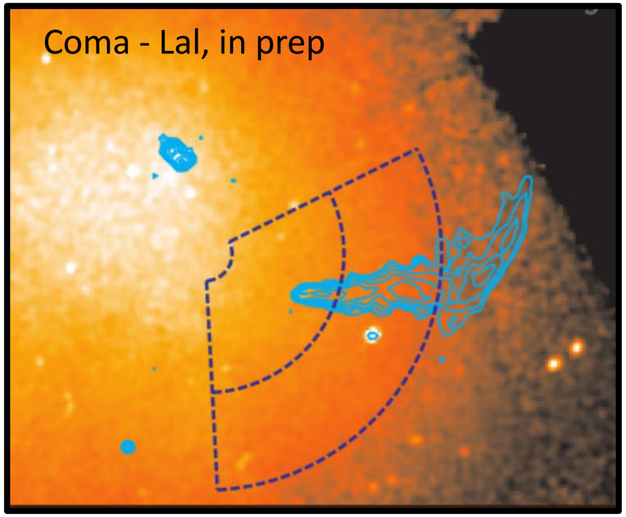


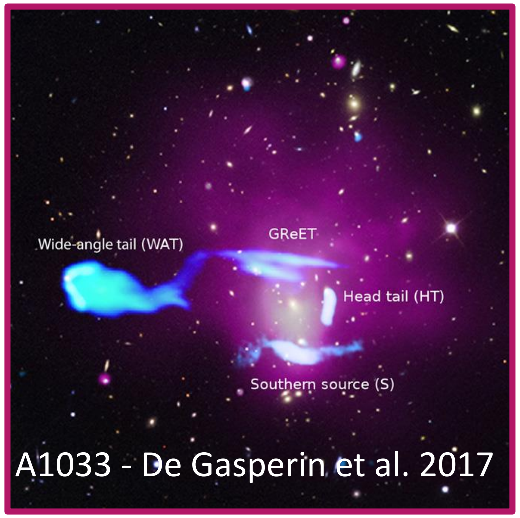
The quality of the present low frequency observations show impressive tails of emission from cluster radio galaxies

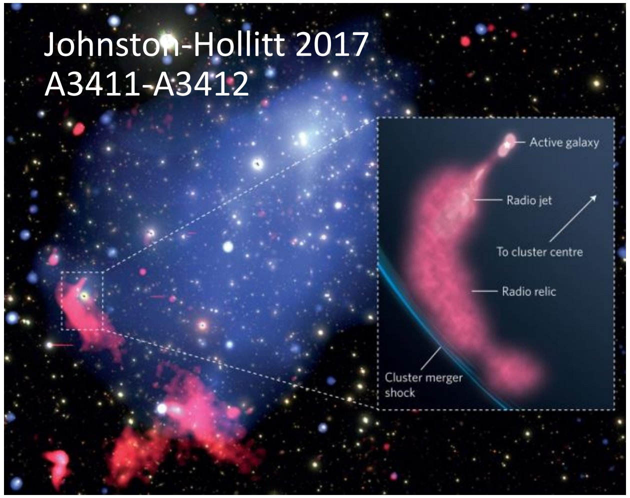
- Radio plasma and ICM interaction
- Trajectories of galaxies in their motion within the cluster

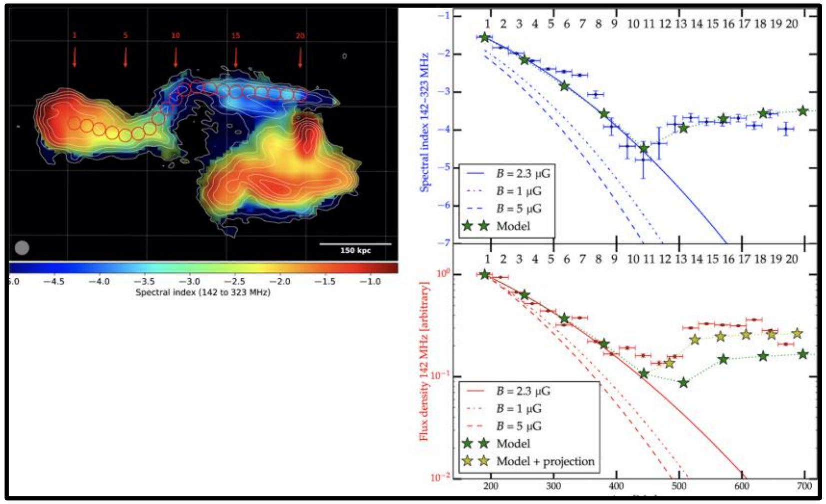
Where AGN science and galaxy cluster science meet

Clear connection between tailed radio galaxies and radio features in galaxy clusters







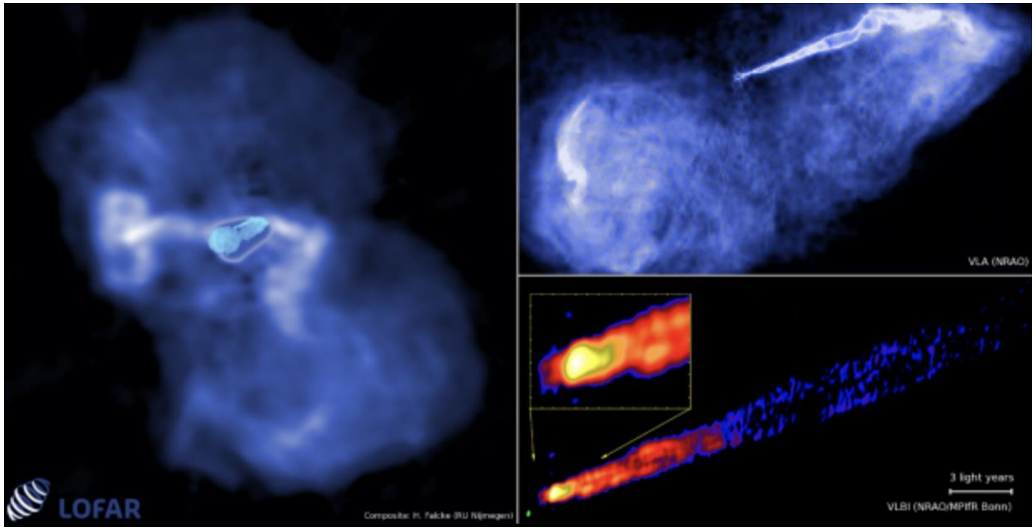


Tracing the core

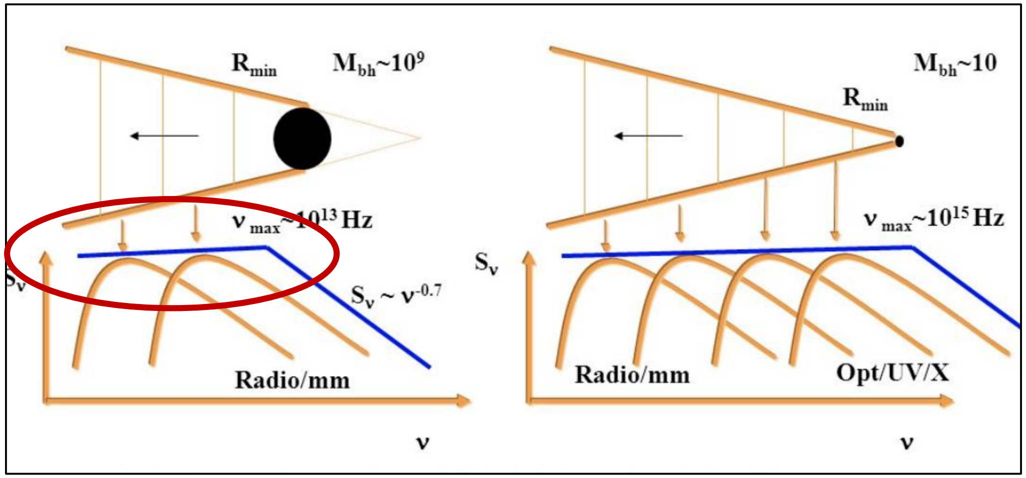
High sensitivity imaging at high frequencies and mas angular resolutions

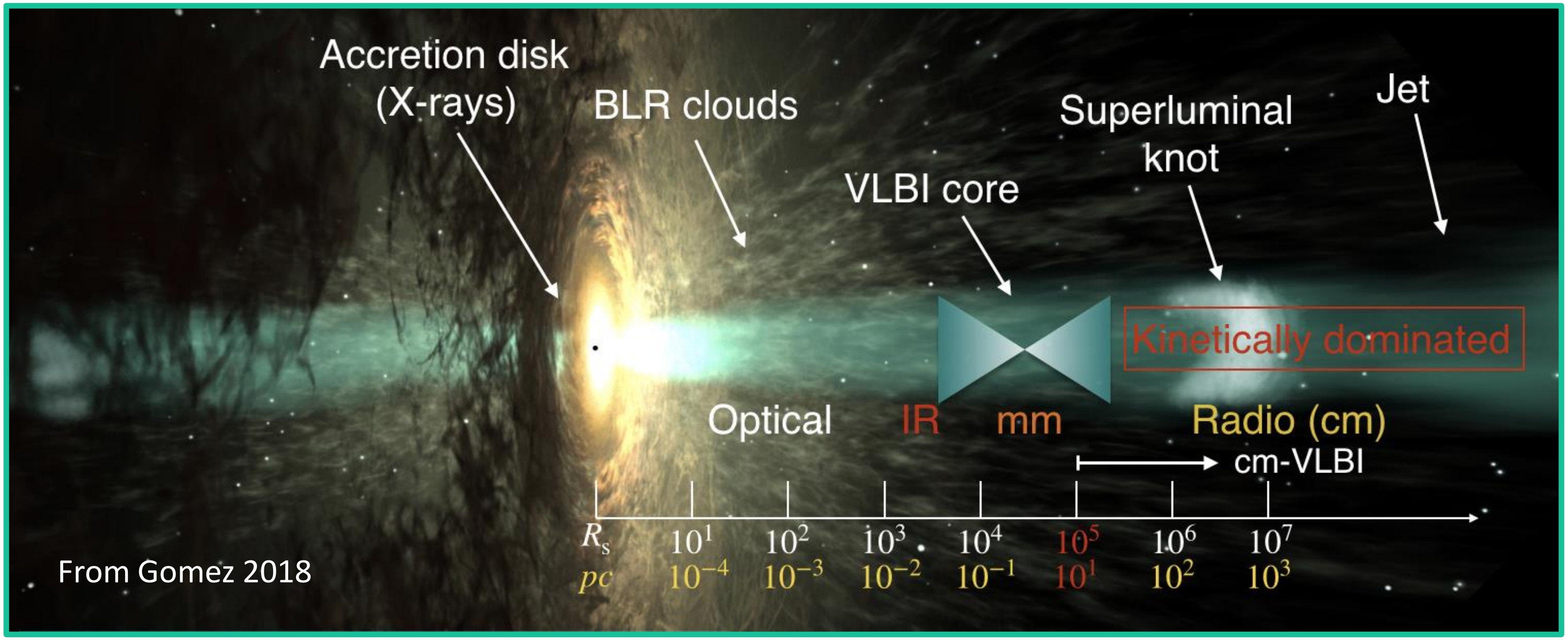
Peering into the innermost regions of AGN

Despite the huge progress in theory, simulations and observing capabilities many questions are still open

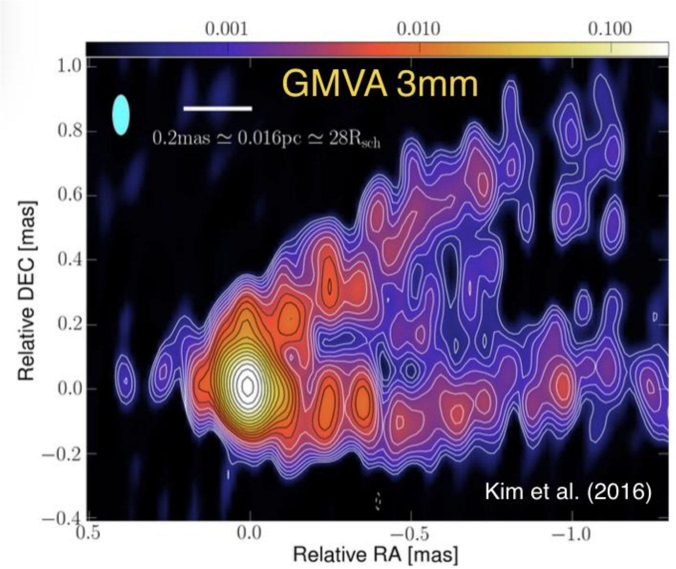


Falcke 2018





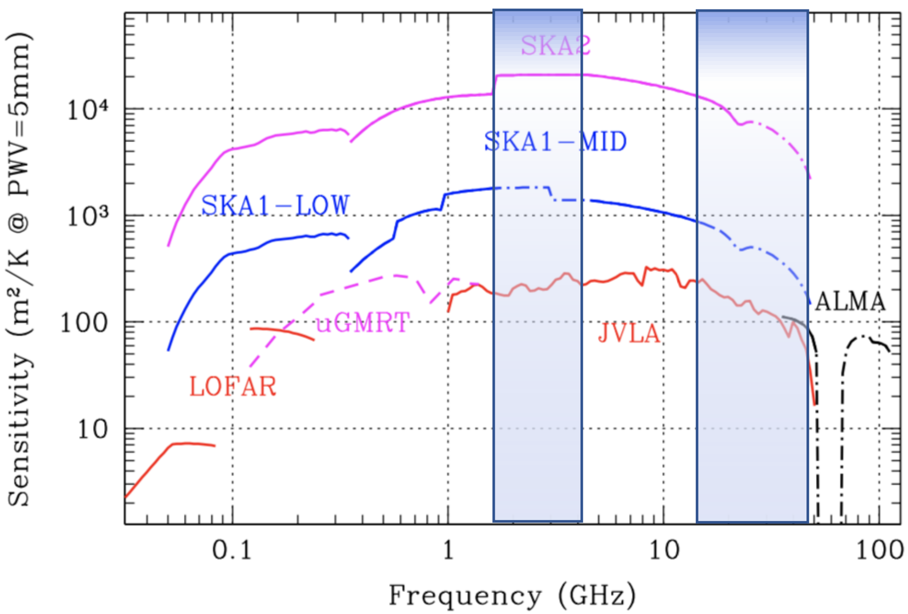
- Which is the launching mechanism for the jets?
- What is the core?
- Where does recollimation occur, and how?
- What determines the accretion mechanism and the jet power?

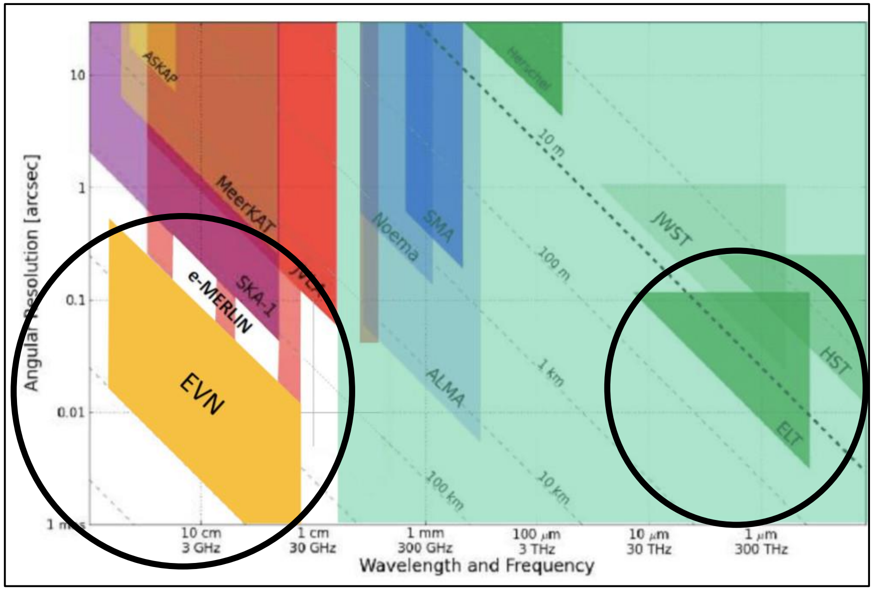


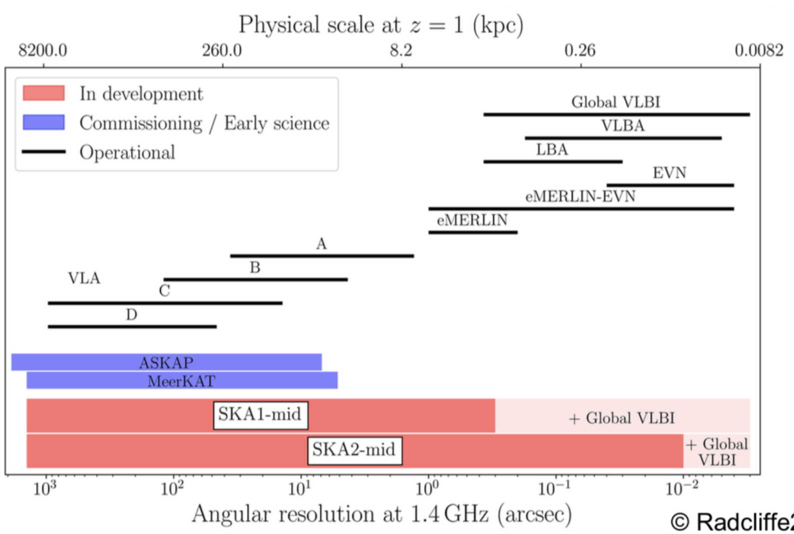
Very Long Baseline Interferometry Science

Science Goal	SWG	Objective	SWG Rank
1	*CD/EoR*	Physics of the early universe IGM - I. Imaging	1/3
2	*CD/EoR*	Physics of the early universe IGM - II. Power spectrum	2/3
3	*CD/EoR*	Physics of the early universe IGM - III. HI absorption line spectra (21cm forest)	3/3
4	*Pulsars*	Reveal pulsar population and MSPs for gravity tests and Gravitational Wave detection	1/3
5	*Pulsars*	High precision timing for testing gravity and GW detection	1/3
6	*Pulsars*	Characterising the pulsar population	2/3
7	*Pulsars*	Finding and using (Millisecond) Pulsars in Globular Clusters and External Galaxies	2/3
8	*Pulsars*	Finding pulsars in the Galactic Centre	2/3
9	*Pulsars*	Astrometric measurements of pulsars to enable improved tests of GR	2/3
10	*Pulsars*	Mapping the pulsar beam	3/3
11	*Pulsars*	Understanding pulsars and their environments through their interactions	3/3
12	*Pulsars*	Mapping the Galactic Structure	3/3
13	*HI*	Resolved HI kinematics and morphology of ~10^10 M_sol mass galaxies out to z~0.8	1/5
14	*HI*	High spatial resolution studies of the ISM in the nearby Universe.	2/5
15	*HI*	Multi-resolution mapping studies of the ISM in our Galaxy	3/5
16	*HI*	HI absorption studies out to the highest redshifts.	4/5
17	*HI*	The gaseous interface and accretion physics between galaxies and the IGM	5/5
18	*Transients*	Solve missing baryon problem at z~2 and determine the Dark Energy Equation of State	=1/4
19	*Transients*	Accessing New Physics using Ultra-Luminous Cosmic Explosions	=1/4
20	*Transients*	Galaxy growth through measurements of Black Hole accretion, growth and feedback	3/4
21	*Transients*	Detect the Electromagnetic Counterparts to Gravitational Wave Events	4/4
22	*Cradle of Life*	Map dust grain growth in the terrestrial planet forming zones at a distance of 100 pc	1/5
23	*Cradle of Life*	Characterise exo-planet magnetic fields and rotational periods	2/5
24	*Cradle of Life*	Survey all nearby (~100 pc) stars for radio emission from technological civilizations.	3/5
25	*Cradle of Life*	The detection of pre-biotic molecules in pre-stellar cores at distance of 100 pc.	4/5
26	*Cradle of Life*	Mapping of the sub-structure and dynamics of nearby clusters using maser emission.	5/5
27	*Magnetism*	The resolved all-Sky characterisation of the interstellar and intergalactic magnetic fields	1/5
28	*Magnetism*	Determine origin, maintenance and amplification of magnetic fields at high redshifts - I.	2/5
29	*Magnetism*	Detection of polarised emission in Cosmic Web filaments	3/5
30	*Magnetism*	Determine origin, maintenance and amplification of magnetic fields at high redshifts - II.	4/5
31	*Magnetism*	Intrinsic properties of polarised sources	5/5
32	*Cosmology*	Constraints on primordial non-Gaussianity and tests of gravity on super-horizon scales.	1/5
33	*Cosmology*	Angular correlation functions to probe non-Gaussianity and the matter dipole	2/5
34	*Cosmology*	Map the dark Universe with a completely new kind of weak lensing survey - in the radio.	3/5
35	*Cosmology*	Dark energy & GR via power spectrum, BAO, redshift-space distortions and topology.	4/5
36	*Cosmology*	Test dark energy & general relativity with fore-runner of the 'billion galaxy' survey.	5/5
37	*Continuum*	Measure the Star formation history of the Universe (SFHU) - I. Non-thermal processes	1/8
38	*Continuum*	Measure the Star formation history of the Universe (SFHU) - II. Thermal processes	2/8
39	*Continuum*	Probe the role of black holes in galaxy evolution - I.	3/8
40	*Continuum*	Probe the role of black holes in galaxy evolution - II.	4/8
41	*Continuum*	Probe cosmic rays and magnetic fields in ICM and cosmic filaments.	5/8
42	*Continuum*	Study the detailed astrophysics of star-formation and accretion processes - I.	6/8
43	*Continuum*	Probing dark matter and the high redshift Universe with strong gravitational lensing.	7/8
44	*Continuum*	Legacy/Serendipity/Rare.	8/8

Several good reasons for SKA-VLBI operations

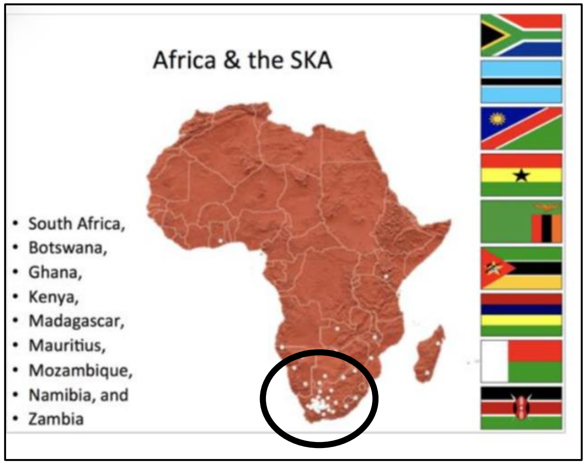


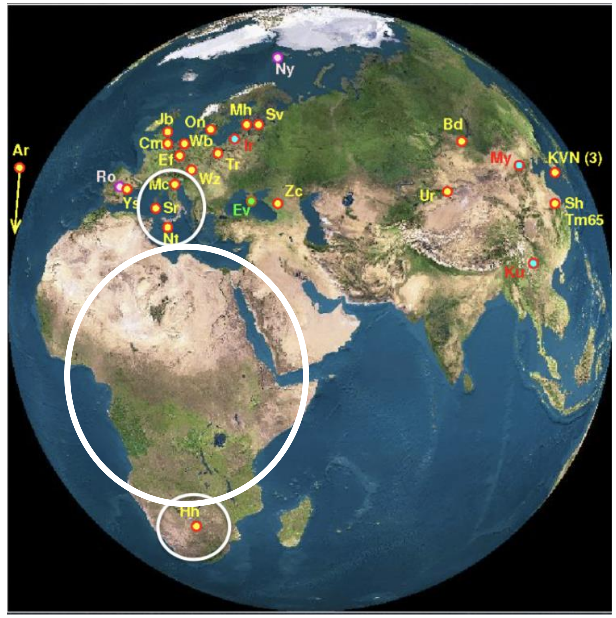


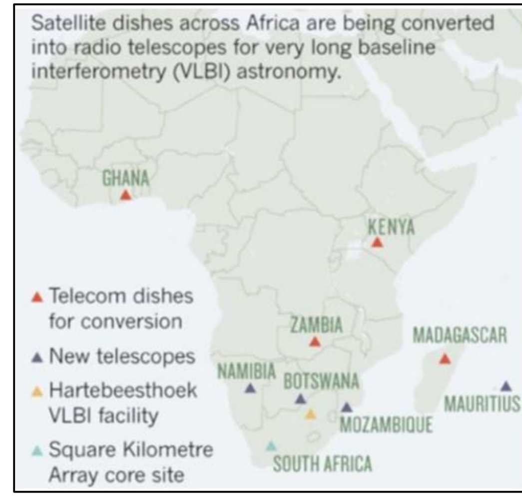


- ✓ A large part of the AGN science would remain unaddressed without SKA-VLBI operations
- ✓ Several major SKA science goals would strongly benefit from VLBI
- ✓ Synergy with E-ELT requires milliarcsecond resolution

VLBI in the SKA-mid1 era



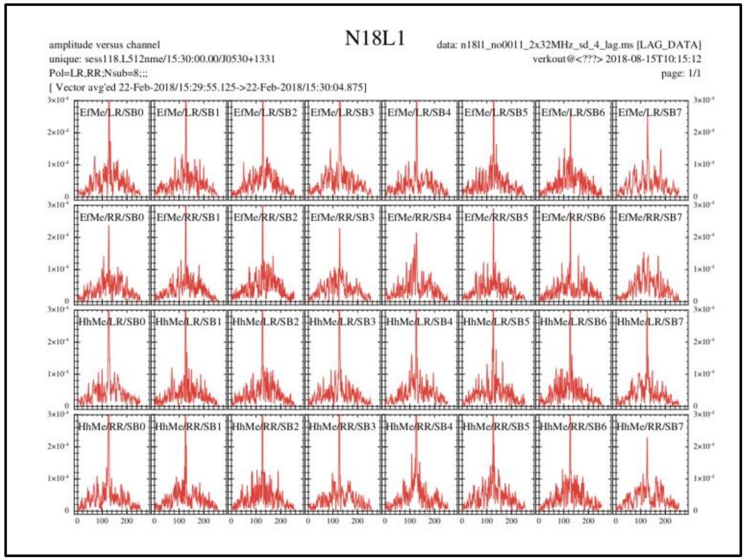




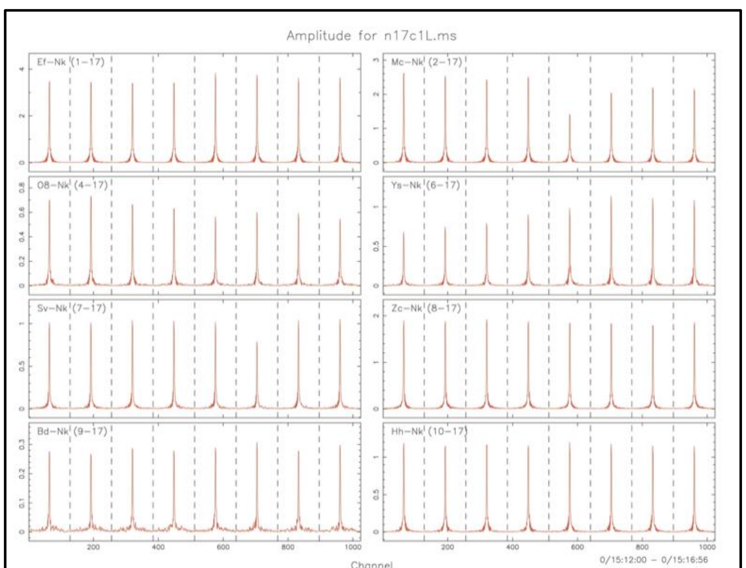
To ensure successful milliarcsecond follow-up of SKA-mid1 sources, and synergy with the E-ELT, the full completion of the African VLBI Network is necessary to ensure the **broadest portion of the sky accessible to all instruments**, and the **best u-v coverage for VLBI** ➡ **Special role of the Italian VLBI Network to ensure continuity between EVN and AVN**

VLBI in the SKA-mid1 era

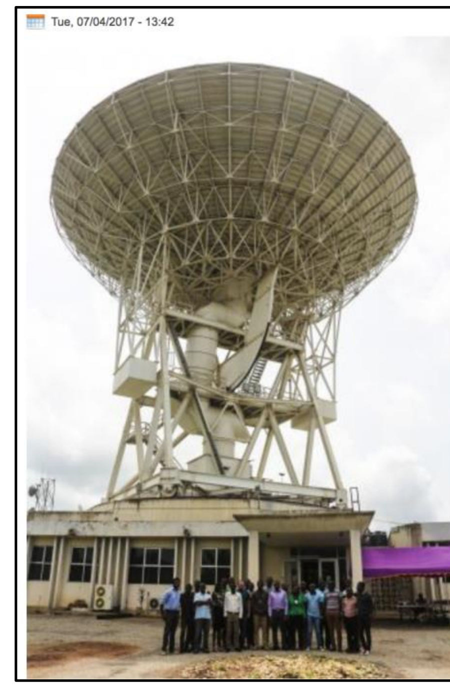
Integration of the antenna in Ghana and of MeerKAT ongoing



First successful fringe test between EVN antennas and MeerKAT in Session 1-2018

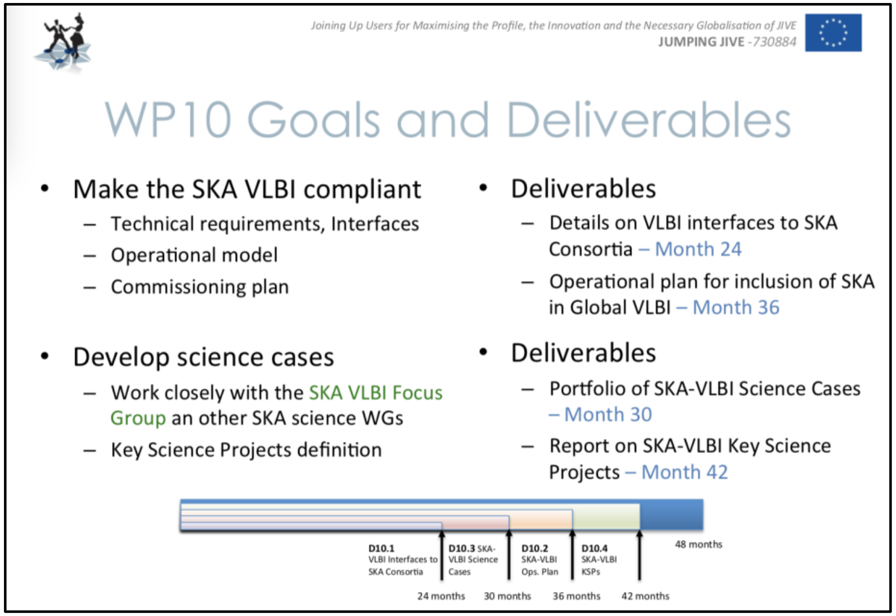


First successful fringe test between EVN antennas and Ghana in April 2017
(JIVE Press release 07/04/2017)

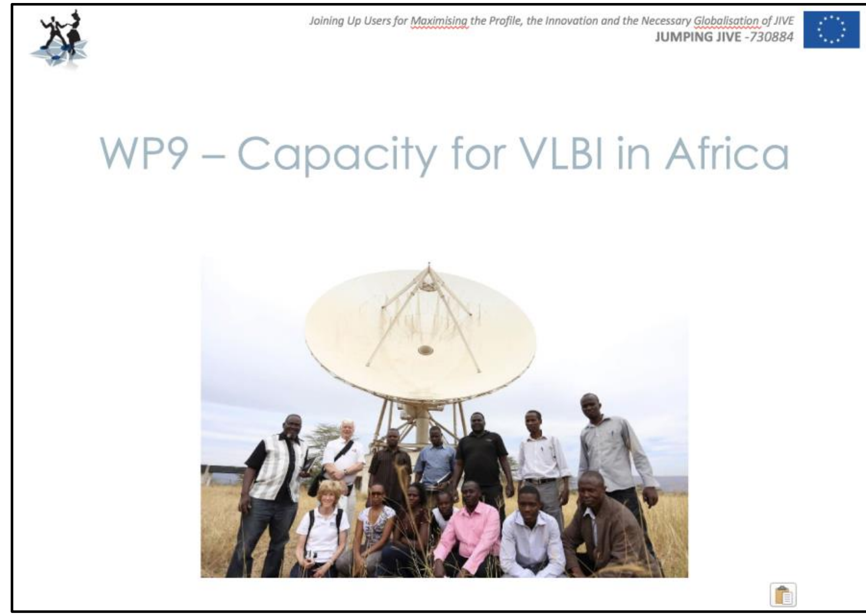


VLBI in the SKA-mid1 era

- Focus of one of the WP in the EC-H2020 JUMPING JIVE project (INAF is a partner)



Slide from Paragi 2018
JJ Mid-Term Review



Slide from Beswick 2018
JJ Mid-Term Review

- Progetto di Grande Rilevanza MAECI-NRF RADIO SKY 2020 (PIs Venturi/Vaccari)

SUMMARY and CONCLUSIONS

- ✓ **New potentials in our understanding of radio galaxy evolution are emerging from SKA pathfinders and precursors**
- ✓ **The radio galaxy science and galaxy cluster science are progressing hand in hand**
- ✓ **SKA1-mid will complement the current low frequency interferometers in terms of polarization performances**
- ✓ **The study of radio galaxies would strongly benefit from SKA Band 5 and SKA-VLBI operations**

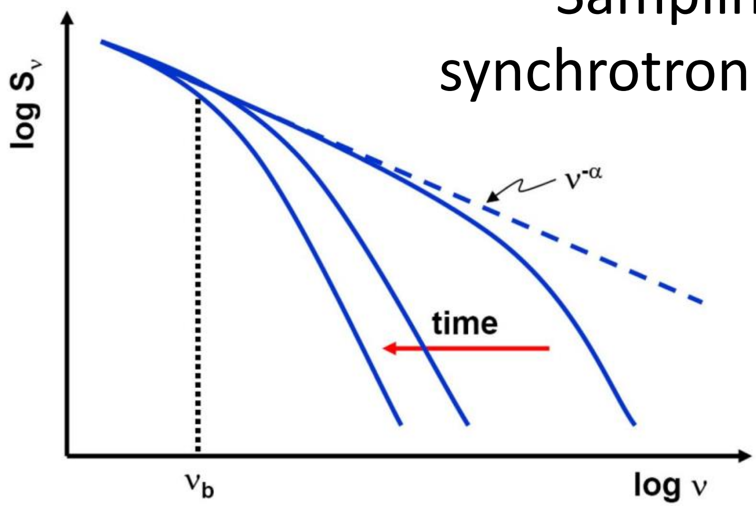
SKA-VLBI operations will be essential:

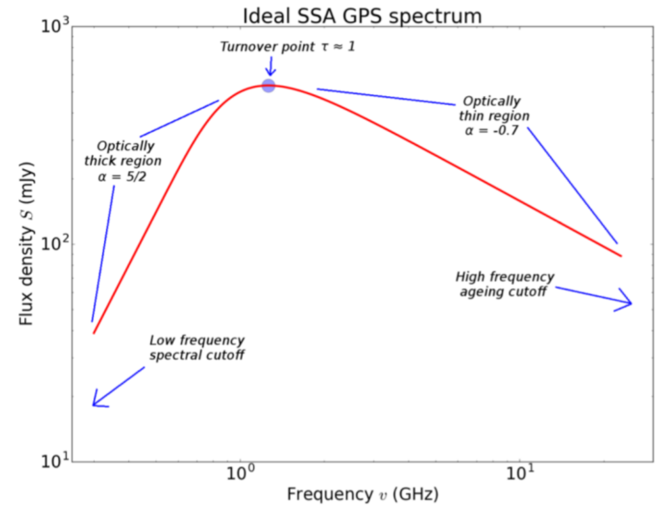
- ➢ **In several of the main scientific goals of the SKA**
- ➢ **For a full exploitation of the synergy between SKA and E-ELT**

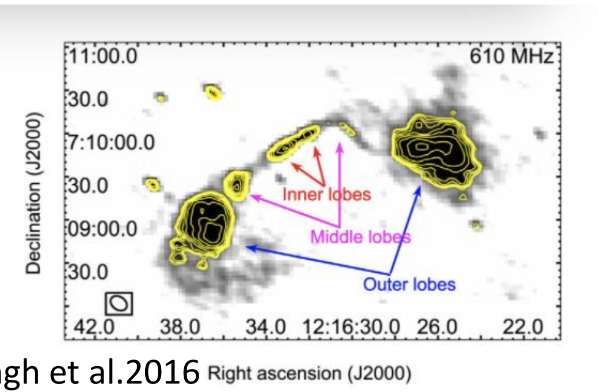
- ❖ **Efforts for SKA-VLBI operations in the SKA1 era are in progress and INAF can play a major role**

THANK YOU FOR YOUR ATTENTION

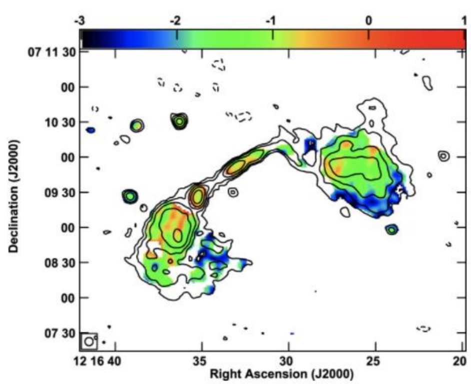
Sampling the synchrotron spectrum







Singh et al.2016



Orienti & Dallacasa 2014