AGN and Radio Galaxy Studies with LOFAR and SKA

Andrei Lobanov

MPIfR, Bonn

AGN/RG Science

- **AGN/RG drivers for LOFAR and SKA**: astrophysical masers, nuclear regions of AGN, physics of relativistic and mildly relativistic outflows, kinetic feedback from AGN, radio halos and radio relics, supermassive black holes and galaxy evolution.

Telescope	Freq.Range [MHz]	N stns.	Bmax [km]	Resolution [arcsec]	Main AGN/RG science drivers
LOFAR	30 – 240	55+	*600*	0.4 – 3.4	SNR, extended outflows, feedback, relics
MeerKAT$_{Low}$	580 – 2500	87	60	0.4 – 1.8	BH, extended flows, masers, lobes, nuclear gas
MeerKAT$_{High}$	8000 – 14500	87	60	0.07 – 0.12	SN, BH, outflows, lobes
ASKAP	30 – 240	45	8	5.0 – 11.0	SNR, relics, lobes, extended outflows
SKA$_{Low}$	70 – 700	550	300	0.7 – 6.8	SNR, extended flows, lobes, relics, nuclear gas
SKA$_{Mid}$	700 -- 3000	550	300	0.1 – 0.7	SN, BH, outflows, nuclear gas, megamasers
SKA$_{High}$	3000+	550	3000	0.001-0.004	SN, relativistic flows, BH, non-thermal cont.

Galaxies and Their Nuclear Regions

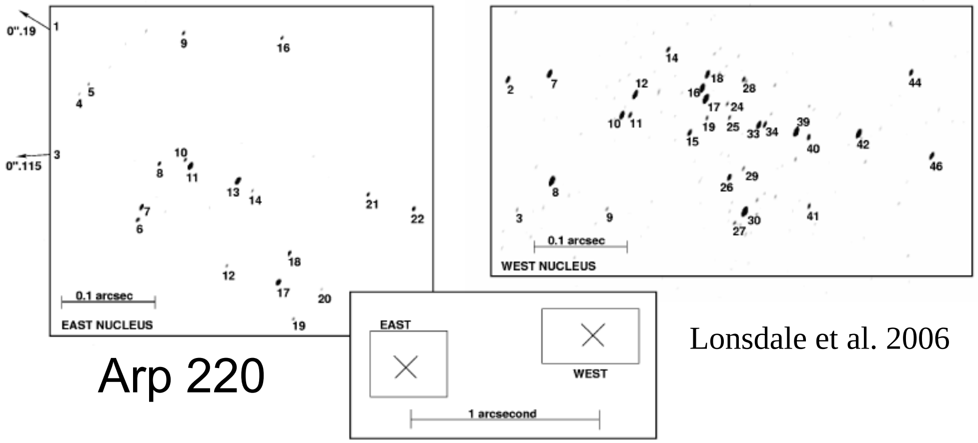
Supernova Science

A. Lobanov

MAX-PLANCK-GESELLSCHAFT

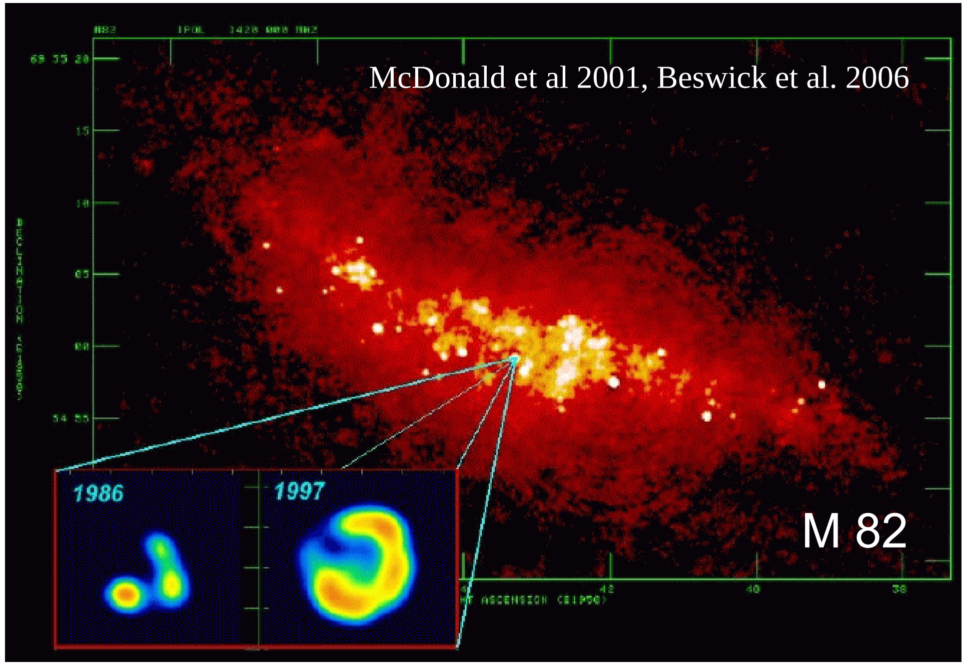
- ❑ Radio observations are an effective tool to detect and monitor extragalactic SN/SNR – giving a good estimate of SFR and helping assess the connection between AGN and star formation.

- ❑ These measurements rely on highly sensitive, long baselines. LOFAR and SKA would detect weaker SN/SNR in a much wider range of galaxies.



Arp 220

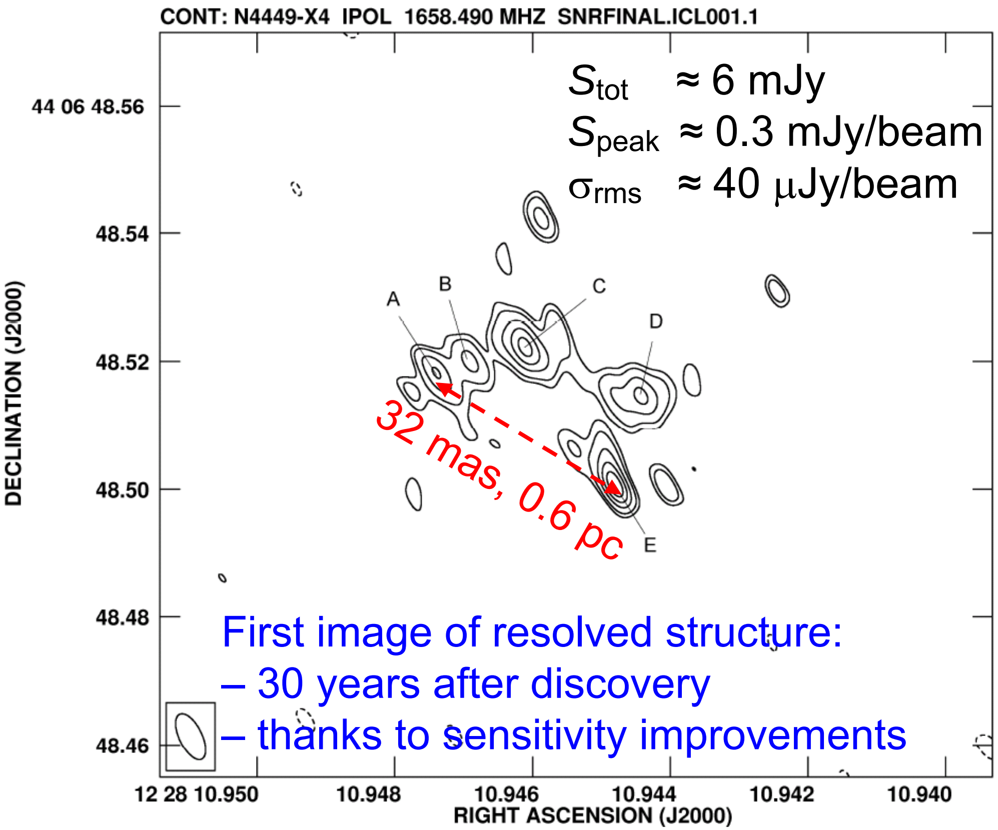
Lonsdale et al. 2006



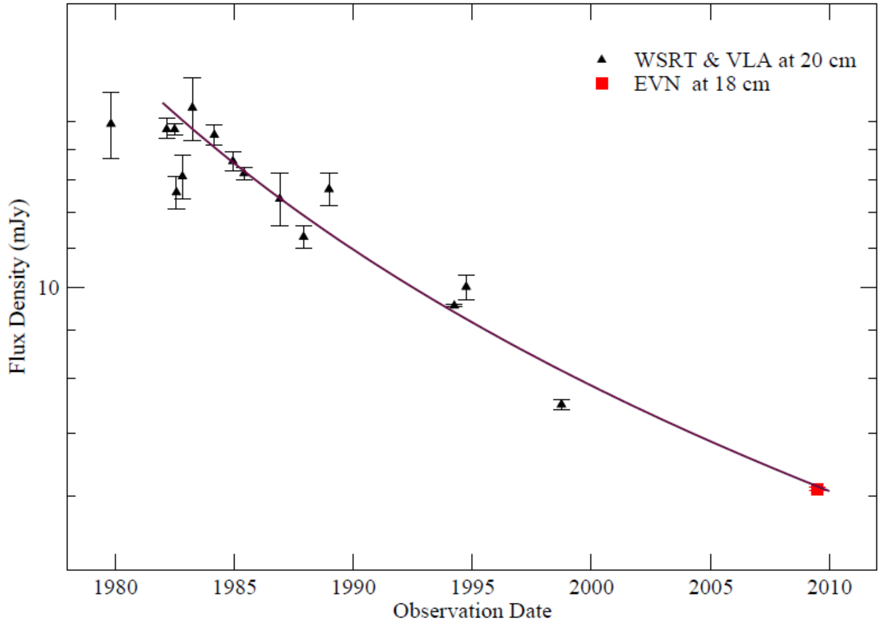
McDonald et al 2001, Beswick et al. 2006

Supernova Evolution

❑ Combination of high resolution and superb brightness sensitivity would enable much longer tracing of evolving supernova shells and supernova remnants, yielding essential information about their ages and galactic environment.



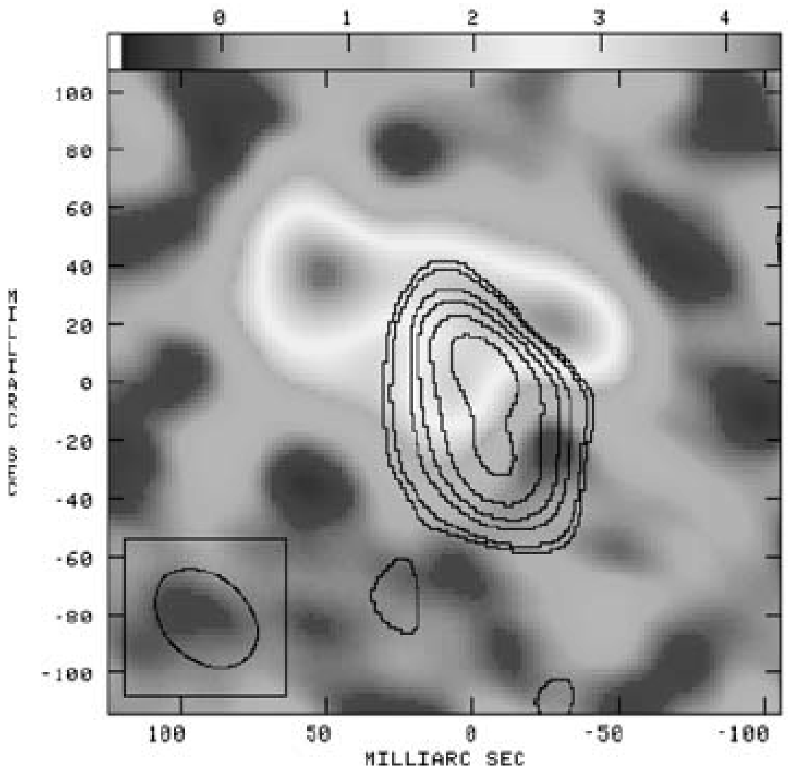
SN in NGC 4449: found, lost, and recovered



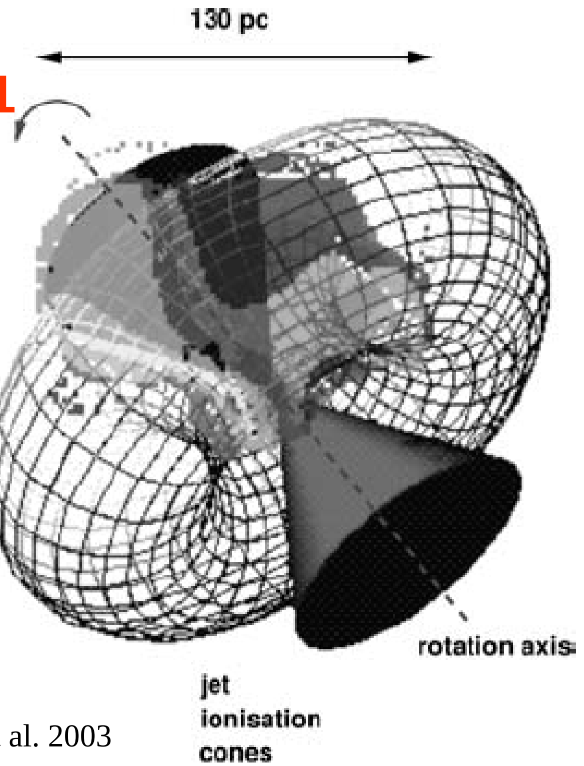
Mezcua & Lobanov 2010

OH Megamasers

- Detected towards IR luminous galaxies; 10^3 – 10^6 times larger than brightest Galactic masers; most distant ~ z=0.3.
- SKA_{Mid} at a mas resoultion would broaden the study.



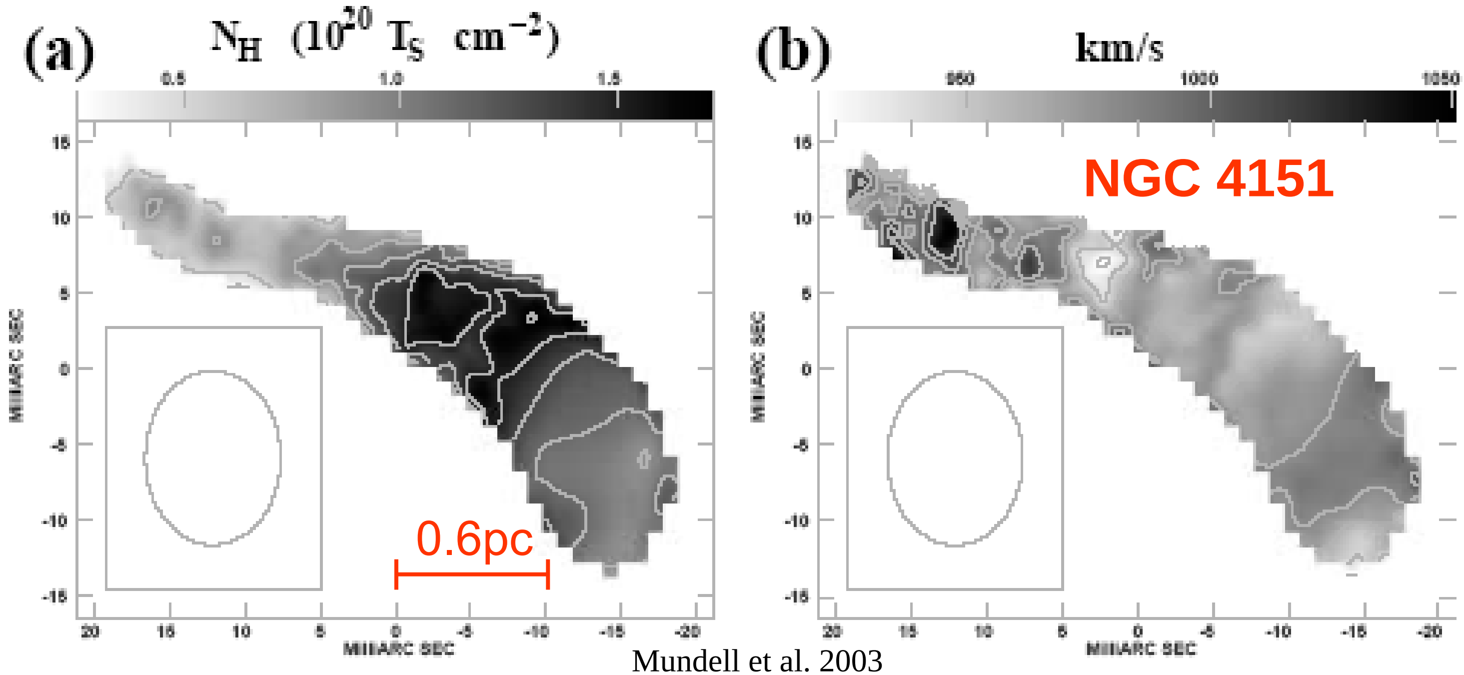
Mrk 231



Kloeckner et al. 2003

Nuclear Absorption

- Absorption due to several species, most notably HI, CO, OH, HCO^+
- HI and OH absorption toward compact continuum sources is an unique tool to probe nuclear regions on parsec scales -- still beating the resolution and accuracy of optical integral field spectroscopy studies.
- Studies of the nuclear absorption will benefit from highly sensitive baselines provided by using SKA alone or together with VLBI arrays.



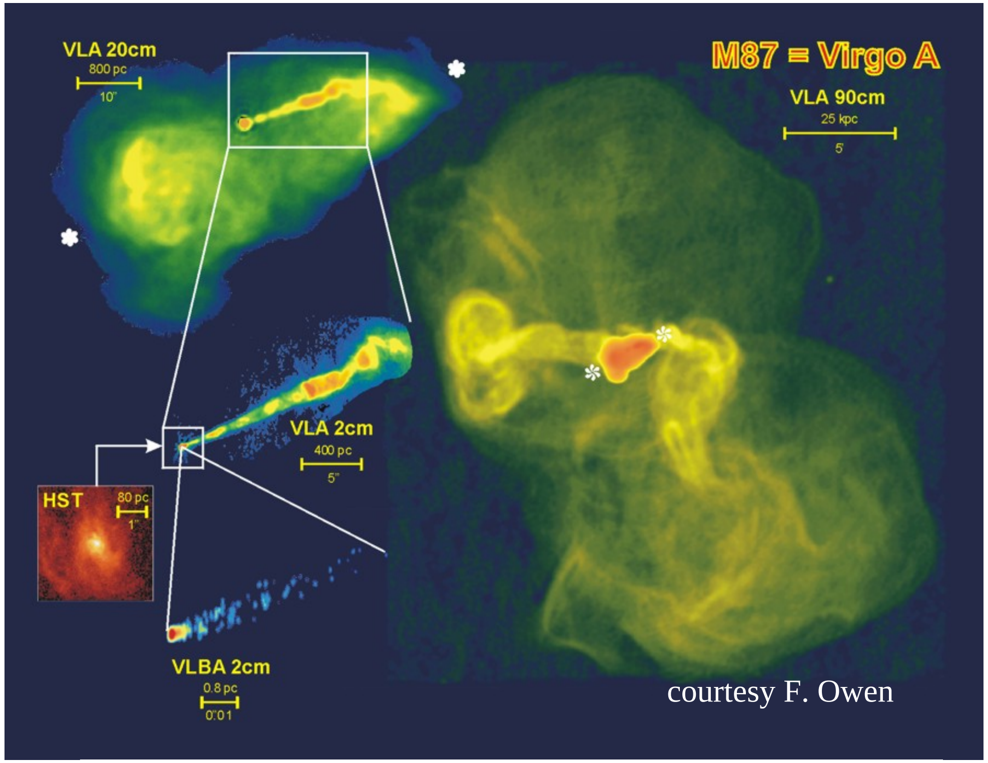
Mundell et al. 2003

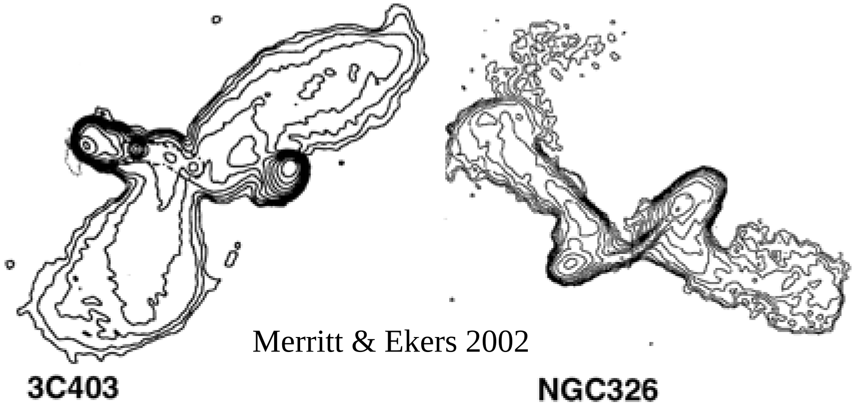
Collimated Outflows

Extragalactic Radio Sources

A. Lobanov

- Probing physical conditions in low-energy tail of outflowing plasma
- Mildly relativistic and sub-relativistic components of outflows.
- Stratification of the outflows and interaction with ambient medium. Kinetic feedback.
- Strongly evolved plasma in extended lobes, cavities and halos produced by jets
- AGN relics and duty cycles; tracers of BBH and BH mergers.





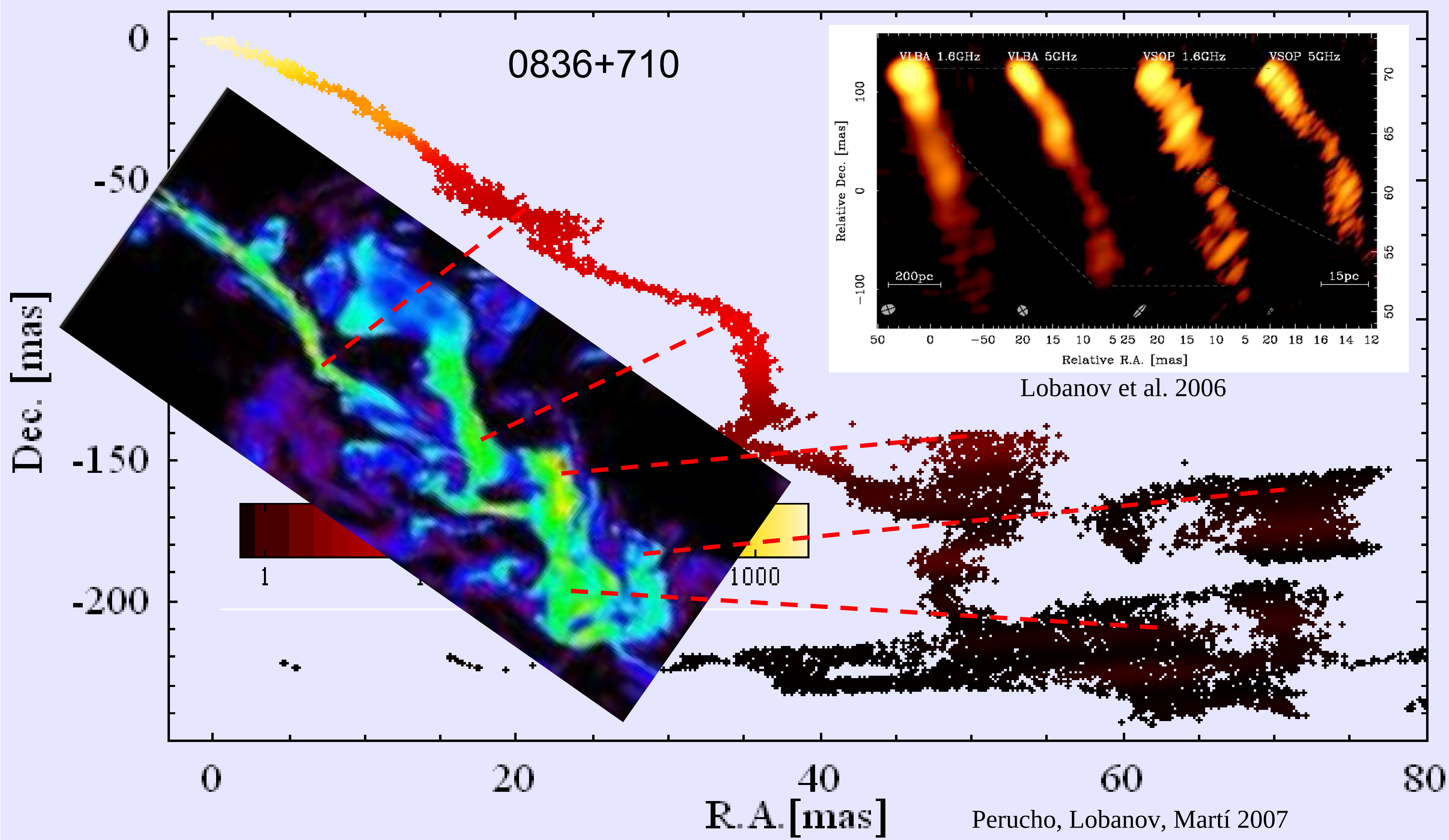
Merritt & Ekers 2002

Jet Disruption

A. Lobanov

MAX-PLANCK-GESELLSCHAFT

- ❑ High-resolution observations in 0.7–3 GHz range will enable detailed studies of instability, disruption and kinetic energy dissipation in jets.

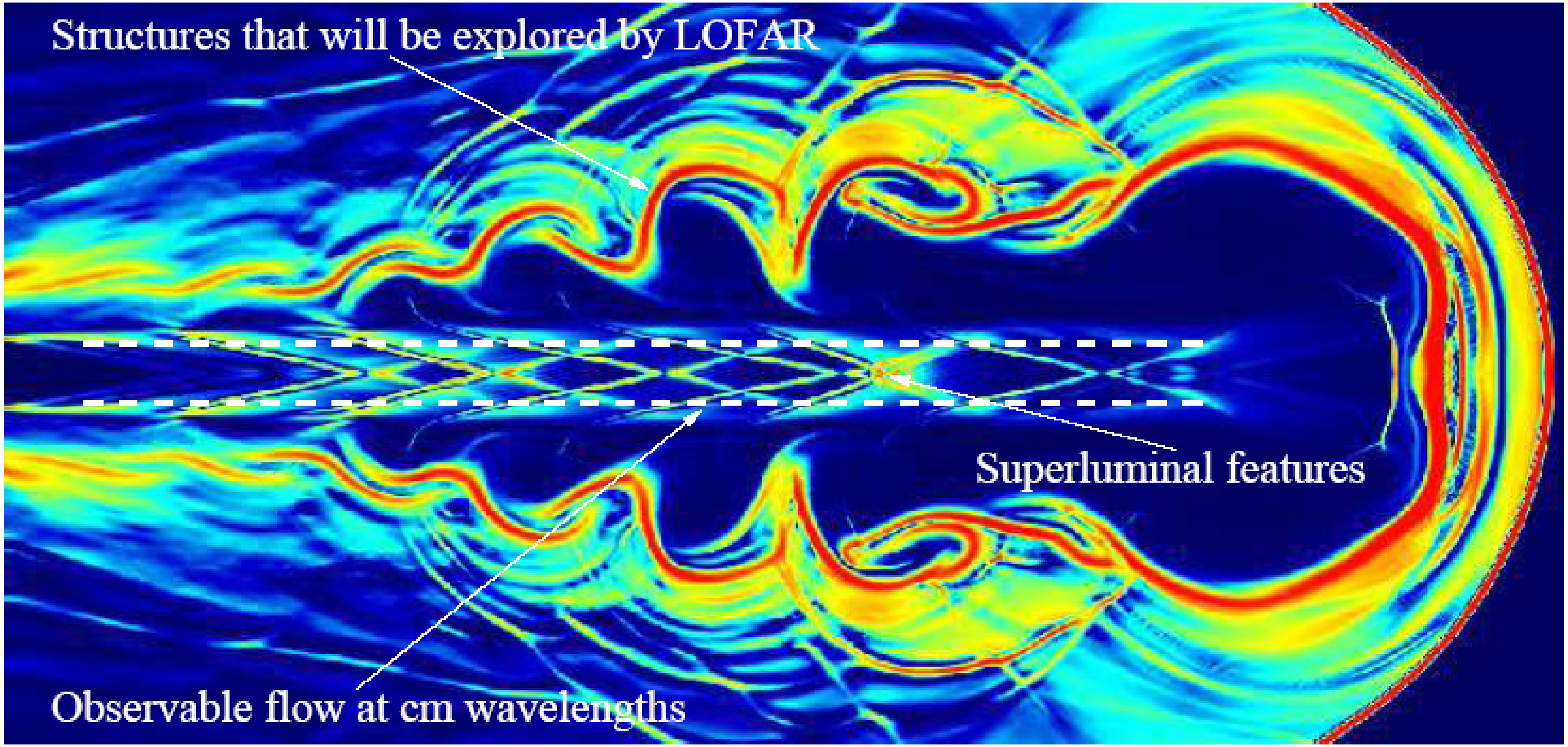


Lobanov et al. 2006

Perucho, Lobanov, Martí 2007

Extended Jets

- Steep spectrum in the outer layers of outflows requires observations at low frequencies to study flow dynamics and interaction with ambient medium

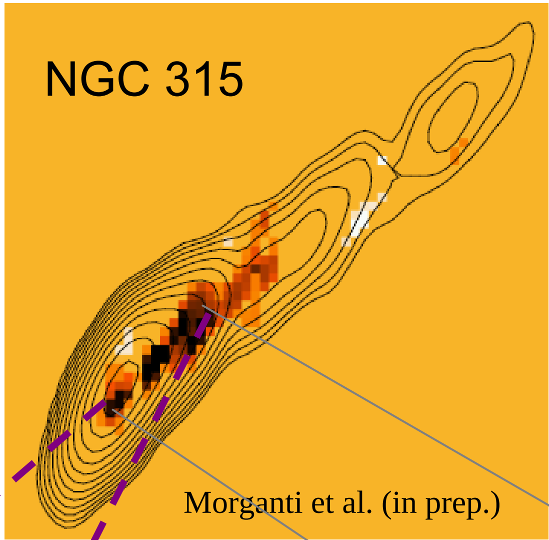


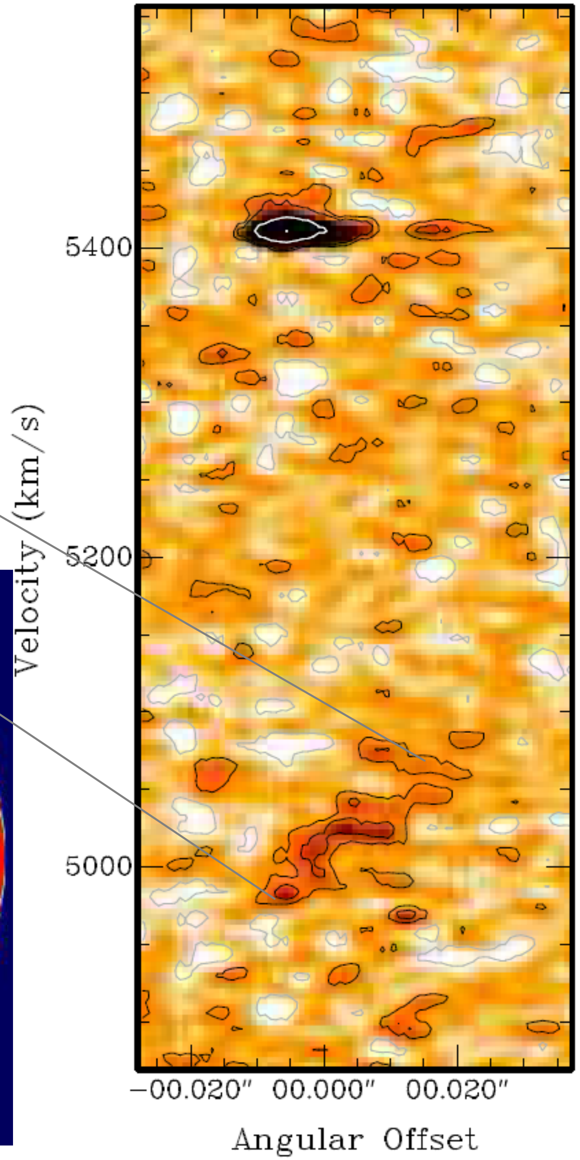
Duncan & Hughes 1994

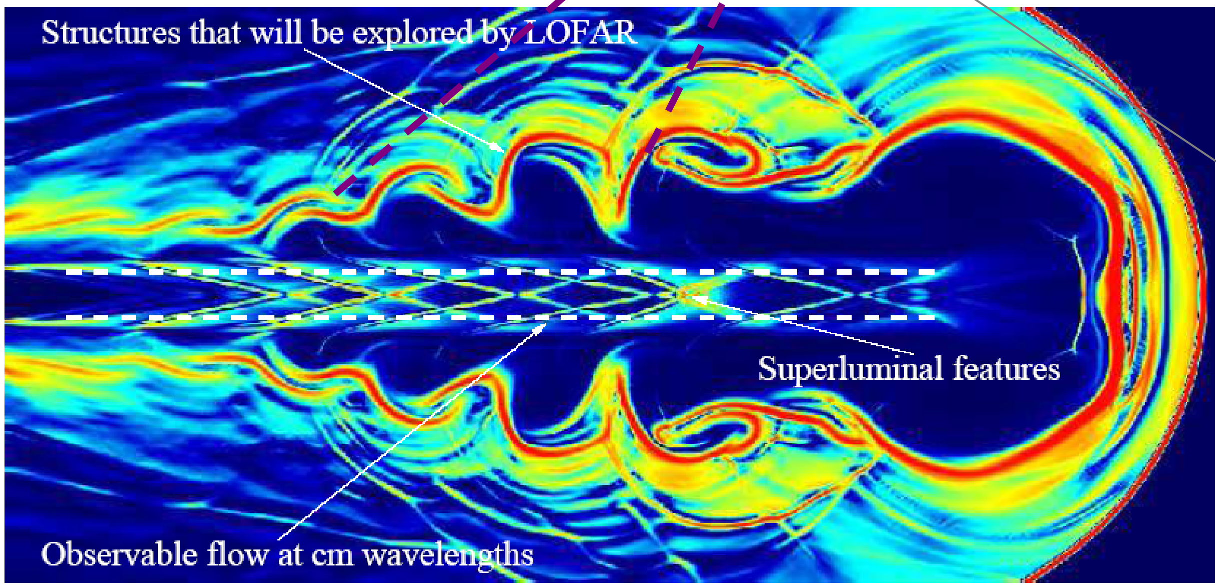
Instability and Entrainment

A. Lobanov

- ❑ Mass entrainment can be traced at present only indirectly, e.g. via peculiar velocity field of absorption of radio continuum by neutral hydrogen



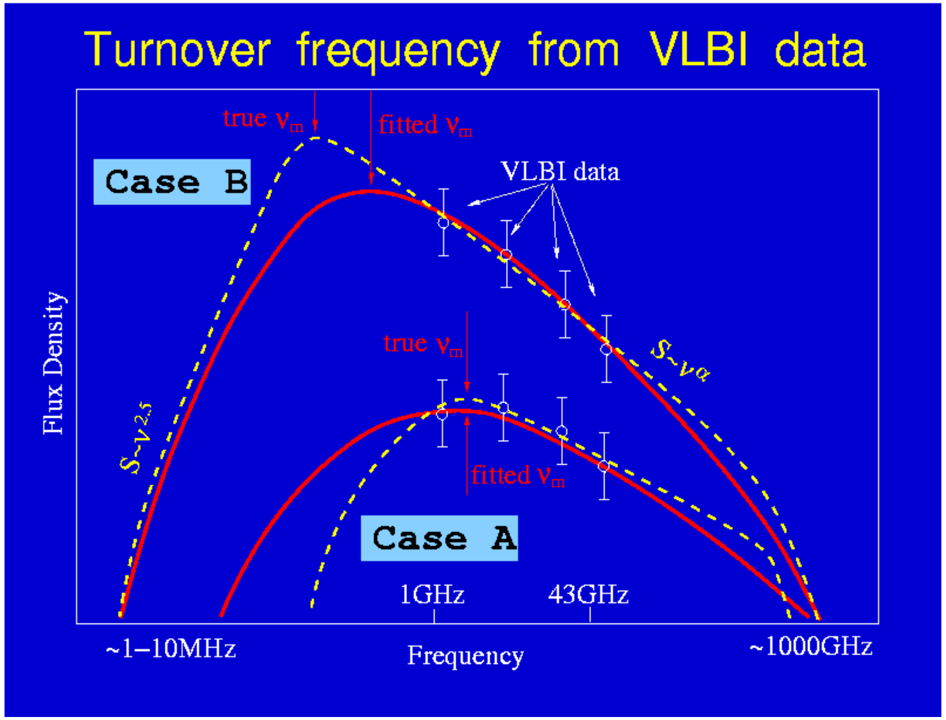


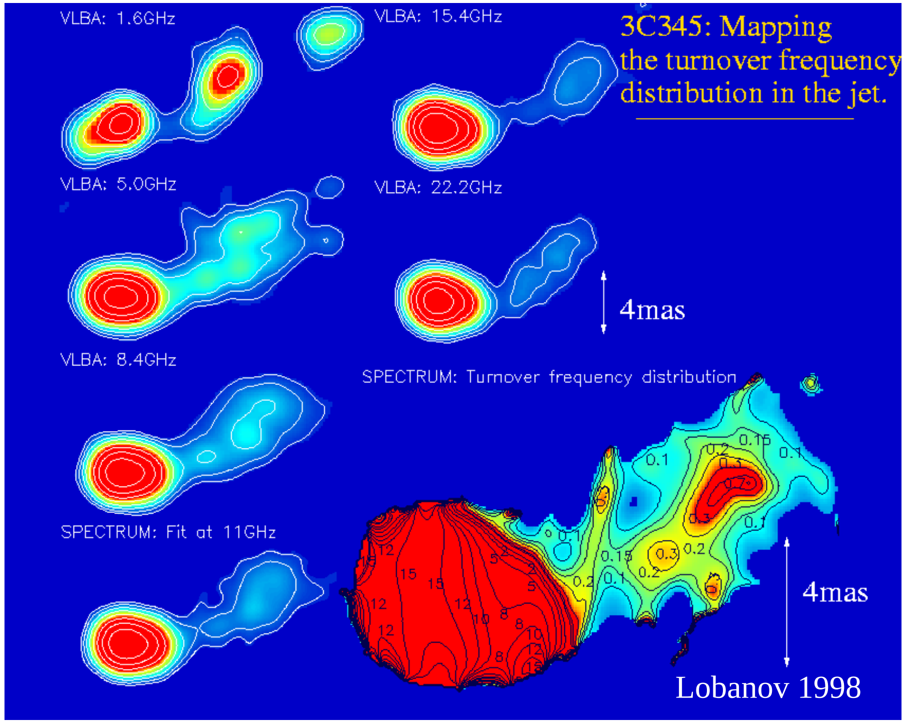


Plasma Diagnostics

A. Lobanov
MAX-PLANCK-GESELLSCHAFT

- Distribution of the spectral turnover: a tool to detect patterns induced by plasma instabilities and obtain two-dimensional distribution of particle density and magnetic field in the flows.
- Low frequency observations are the only way to enable imaging the spectral turnover in extended jets

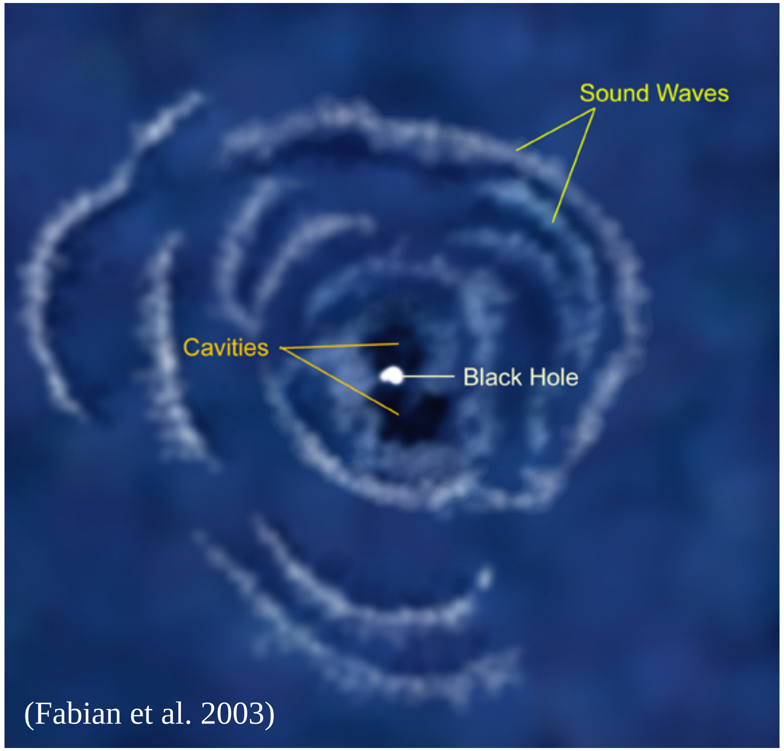




AGN Feedback and Activity Cycles

AGN Feedback

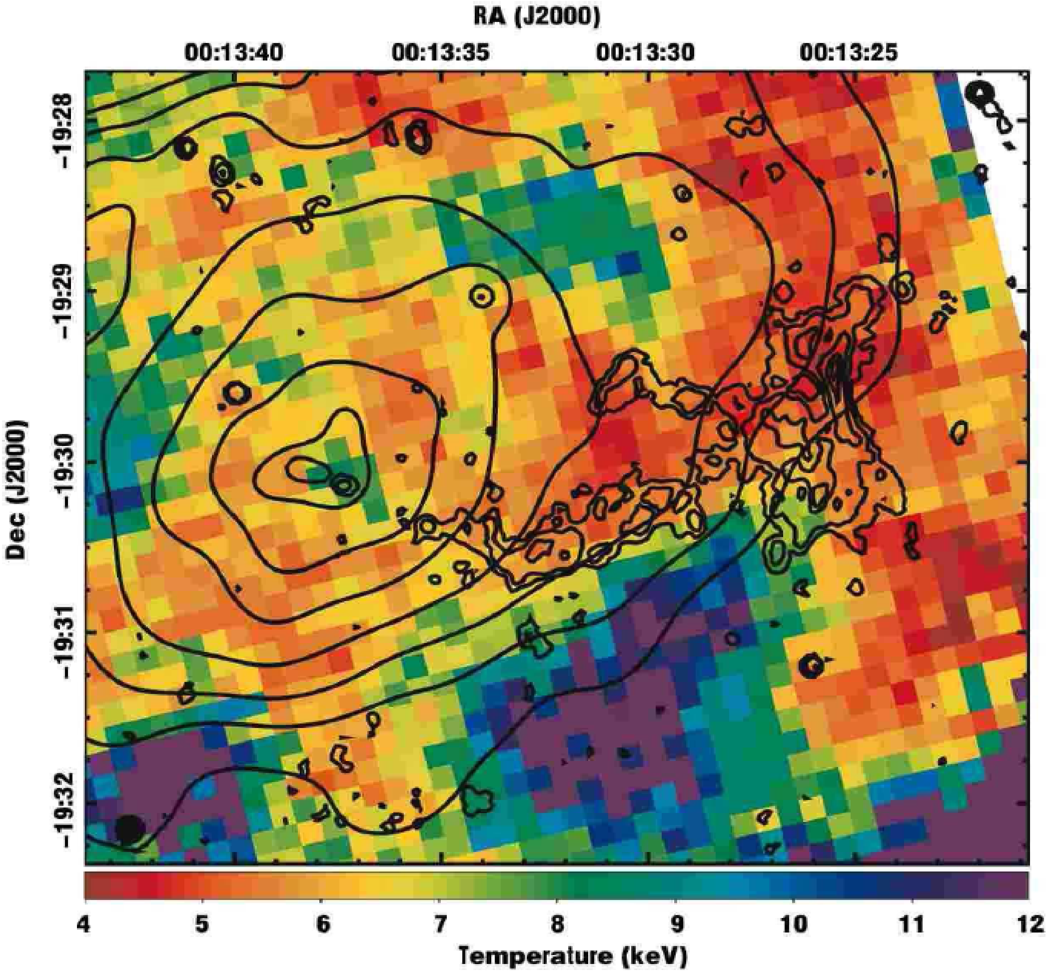
- Kinetic output of AGN $\geq 0.01\ M_{bh}\ c^2$ – jets, BAL outflows (Elvis 2000, Begelman 2004). Collimated outflows may be prime contributors to AGN feedback (Heinz & Sunyaev 2003, Heinz et al. 2005)
- Radiative feedback from AGN influences strongly SMBH growth (Di Matteo et al. 2004, Sazonow et al. 2005)
- Both kinetic and radiative components of the feedback can be highly anisotropic.
- A large fraction of ionizing continuum can be produced in jets (Arshakian et al. 2005, Popovic et al. 2007)
- Shocks and ripples in the IGM caused by the AGN in Perseus A (Fabian et al. 2003)



(Fabian et al. 2003)

Interactions with IGM

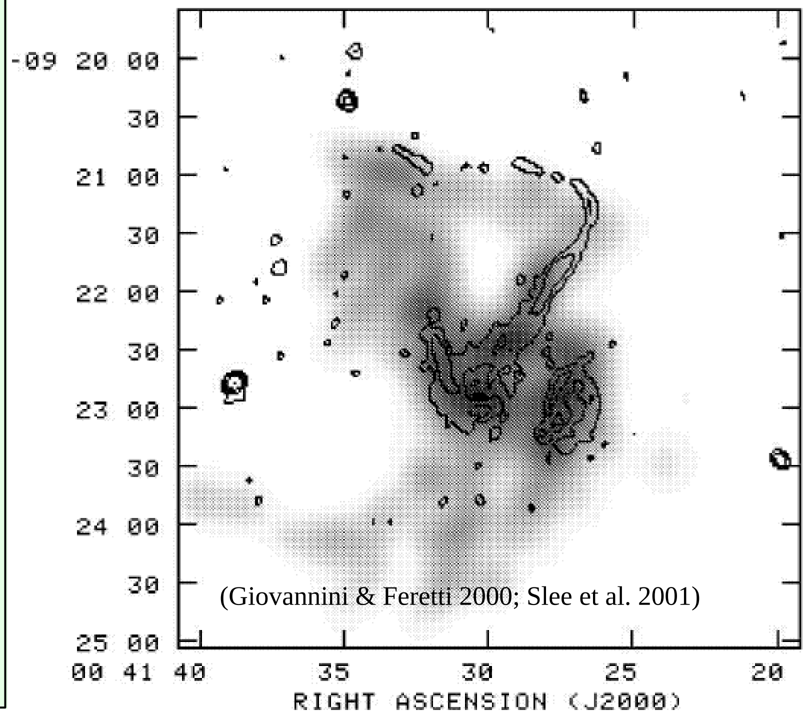
- Combination of X-ray data and observations with LOFAR and SKA_{Low} will give a complete account of the dynamics and energetics of interactions between extragalactic outflows and IGM



Juett et al. 2007

Radio Relics and AGN Cycles

- Every galactic merger induces two major episodes of nuclear activity (first contact and final coalescence of the merging galaxies; Springel et al. 2004).
- LOFAR and SKA_{Low} will detect relics for up to 10^8 years after the end of an active phase in a galactic nucleus.
- Ages of relics measured with LOFAR and SKA_{Low} would provide a good census for AGN cycles and merger rates.
- Measurements of radio power in relics and outflows will give estimates of the kineitc feedback and total energy released into the IGM.



(Giovannini & Feretti 2000; Slee et al. 2001)

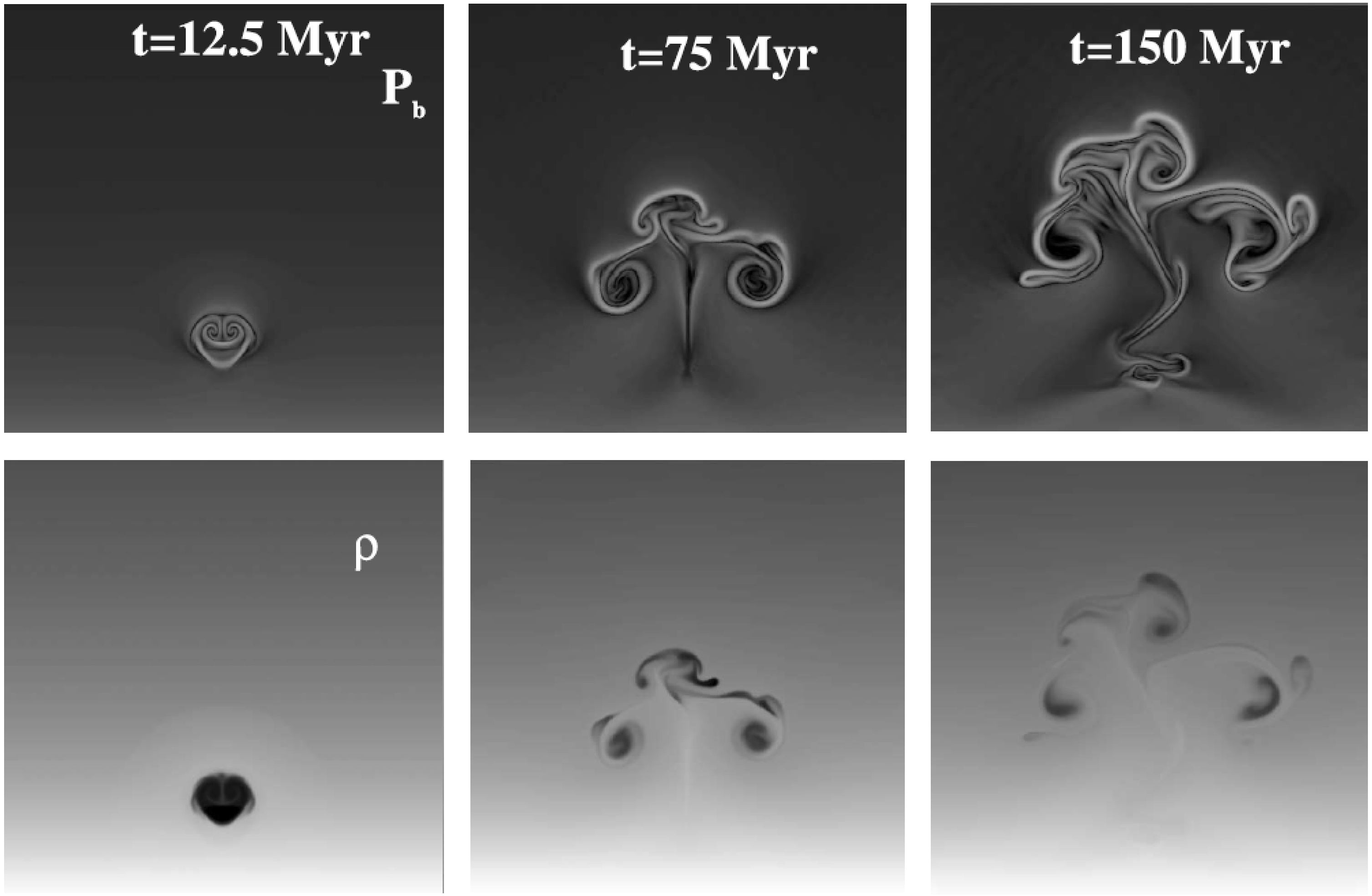
Max-Planck-Institut für Radioastronomie

Tracing the Relics History

A. Lobanov

MAX-PLANCK-GESELLSCHAFT

- LOFAR and SKA_{Low} will extend the history record of radio relics by a factor of 100.



Jones & De Young 2005

Black Holes and Galactic Mergers

Mergers and AGN

- Most powerful AGN are produced by galactic/SMBH mergers (Haehnelt & Kauffmann 2002, Di Matteo et al. 2004)

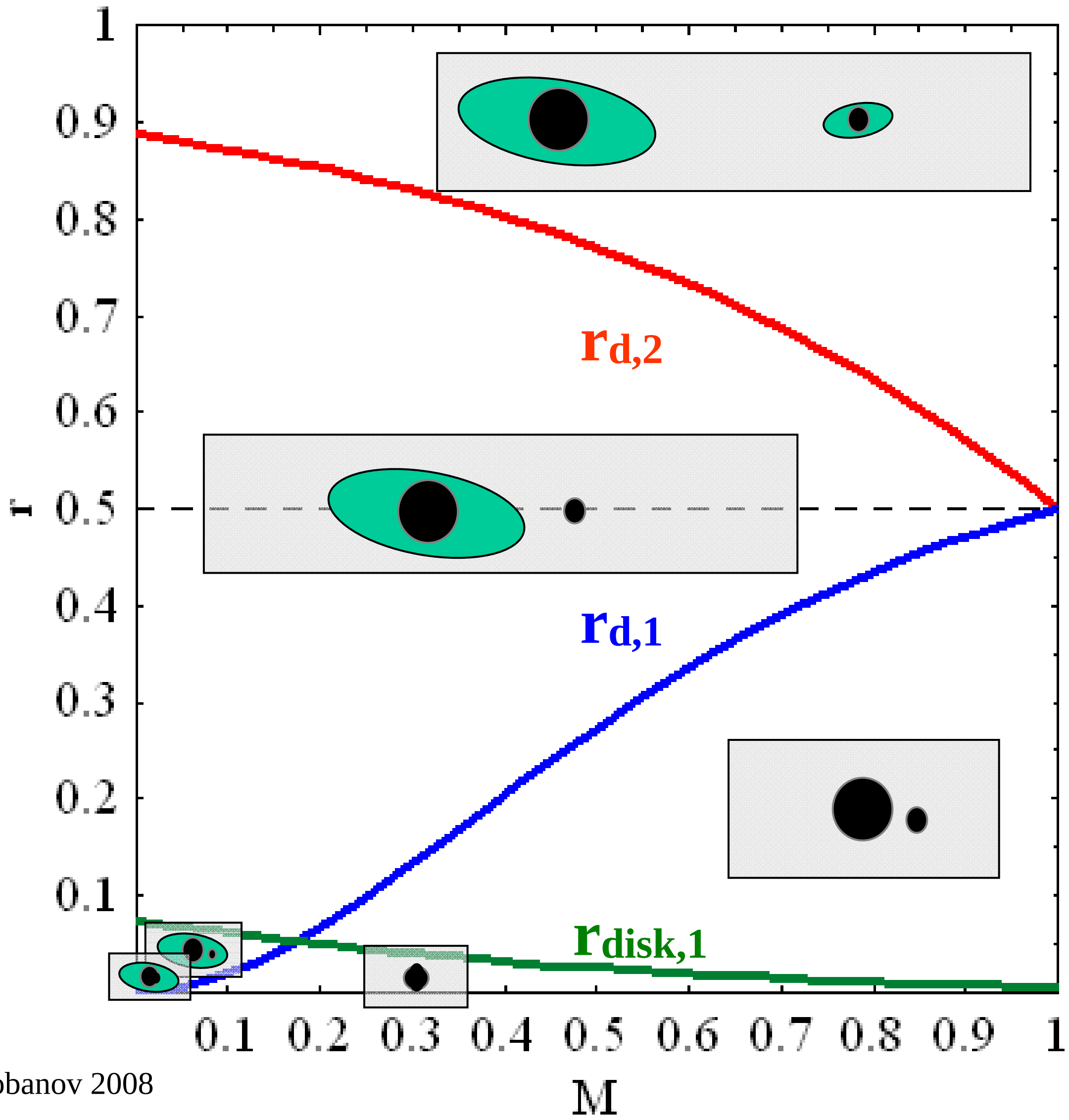
- Activity is reduced when a loss cone is formed and most of nuclear gas is accreted onto SMBH (Dokuchaev 1991, Merritt 2003). Having a secondary SMBH helps maintaining activity of the primary.

- Evolution of nuclear activity can be connected to the dynamic evolution of binary SMBH in galactic centers (Lobanov 2008)

- Secondary black holes in post-merger galaxies – a needle in a haystack... or rather in many haystacks.

Why Are They Not There?

- Accretion disks around BBH companions can be disrupted during merger.
- Simultaneous activity in both BBH companions is then restricted almost exclusively to wide pairs, before forming a gravitationally bound orbit.
- Direct detections of secondary SMBH in post-merger galaxies are the best way to the evolution of black holes and galaxies together.

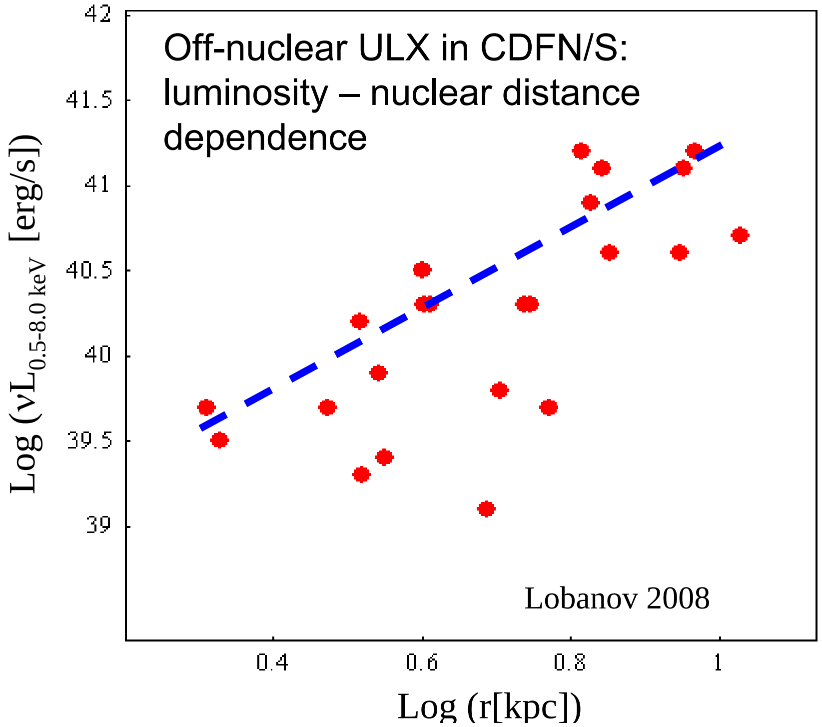


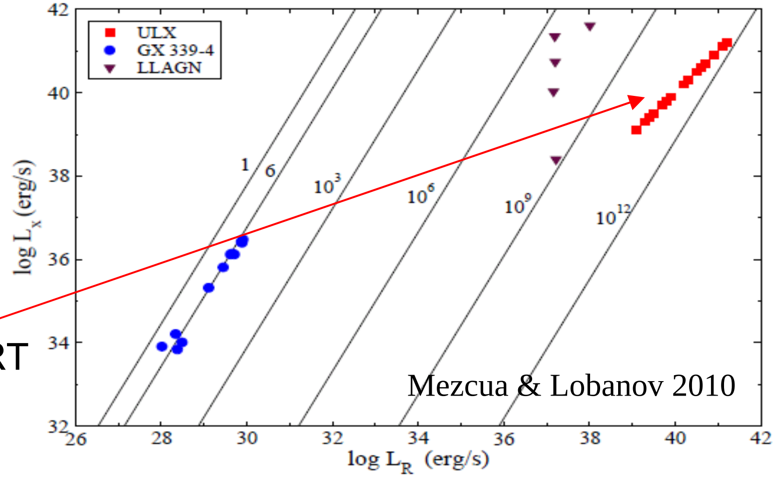
Lobanov 2008

Secondary BH in ULX?

- Some of the secondary BH may be "disguised" as ULX objects – accreting at ~10^{-5} of the Eddington rate.

- They are not detected in deep radio images at present. SKA will be essential for detecting and classifying these objects (using brightness temperature and spectral index criteria).





Upper limits on black hole masses of the CDFN/S off-nuclear ULX – from existing deep radio images with MERLIN and GMRT

Summary

- LOFAR and SKA would address a number of important astrophysical areas of study:

  – studying supernovae, providing a good account of starburst activity in galaxies;
  – using megamasers and nuclear absorption to probe the nuclear gas in galaxies;
  – understanding in detail the physics of (ultra- and mildly-relativistic) outflows and their connection to the nuclear regions in galaxies;
  – searching for radio emission from weaker AGN and secondary black holes in post-merger galaxies;
  – measuring the full kinetic power of collimated outflows and relative contributions from kinetic and radiative feedback from AGN
  – detecting relics of past activity in AGN and enabling full assessment of evolutionary duty cycles in the nuclear activity in galaxies