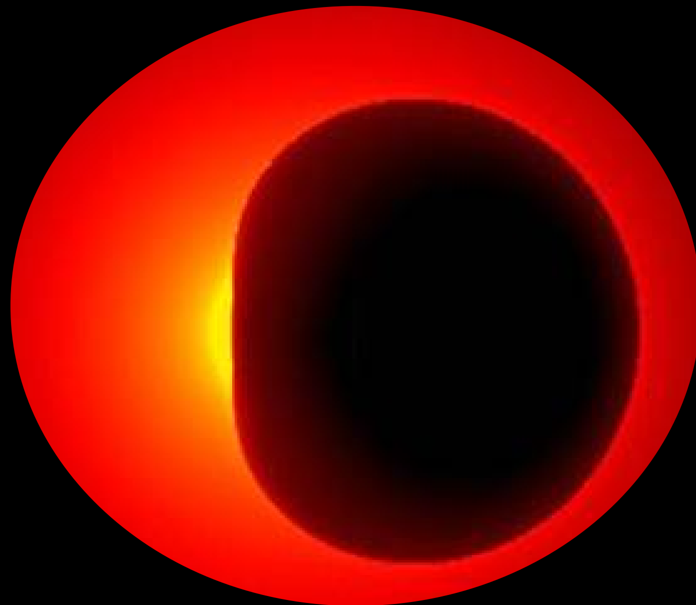
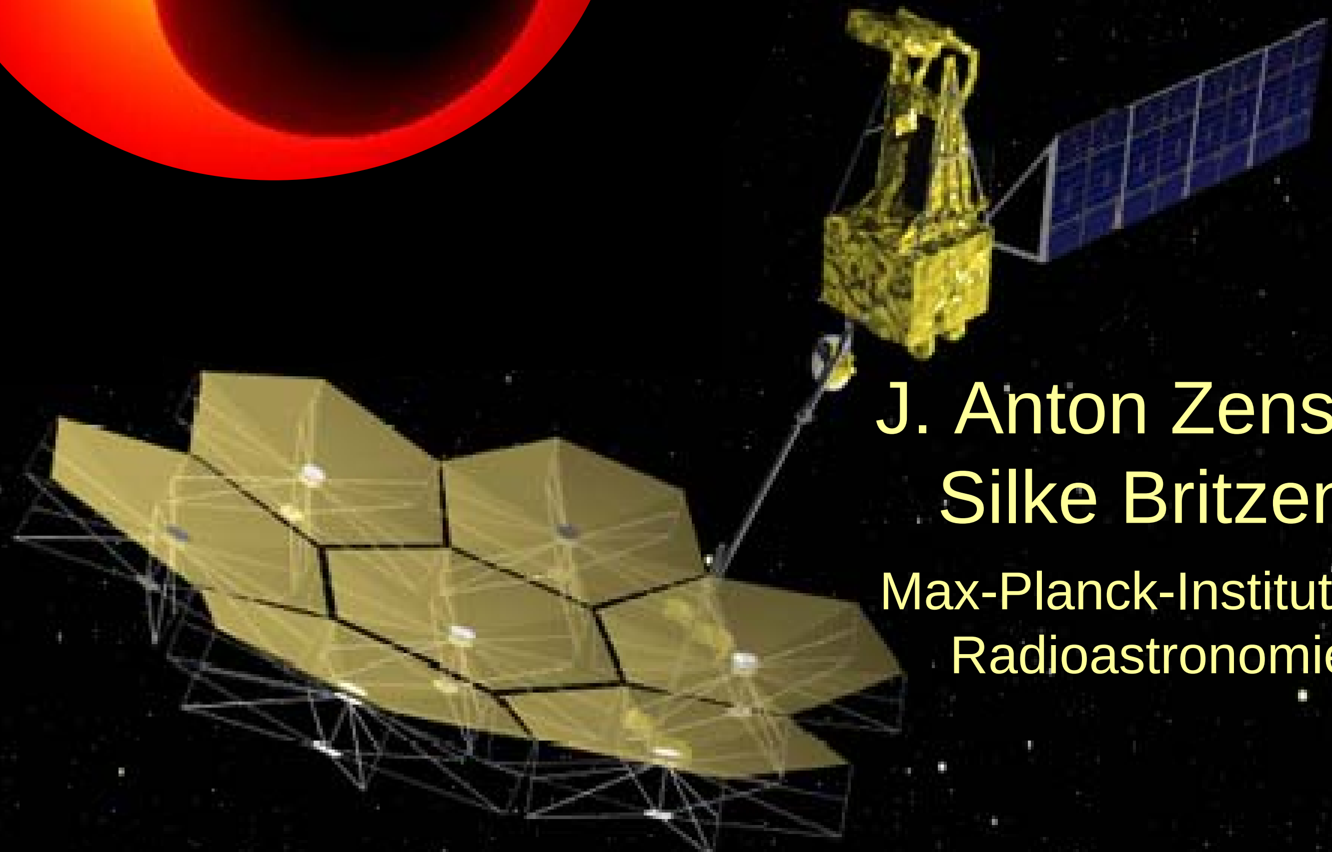
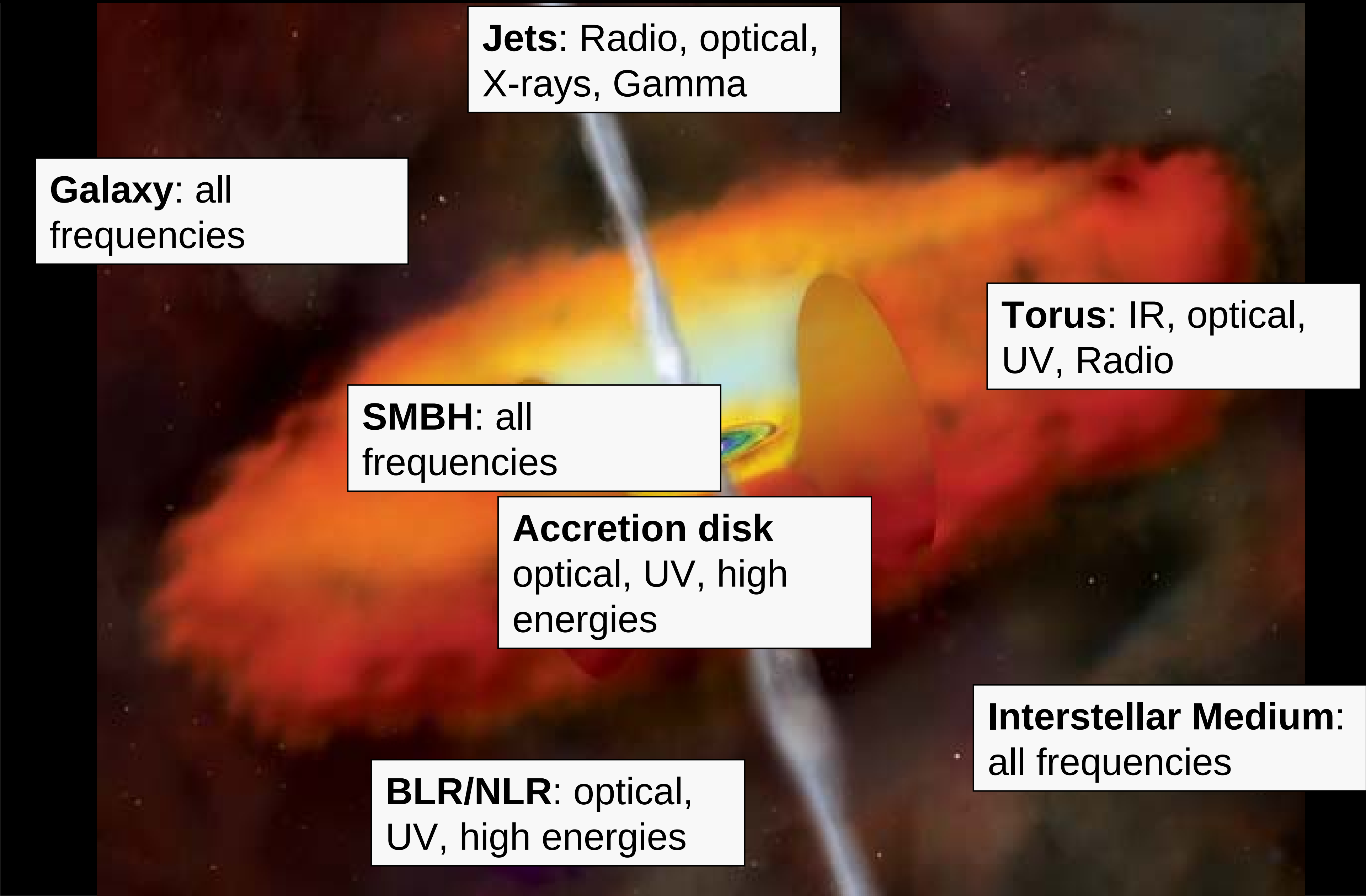


Perspektiven der Radioastronomie im Weltraum

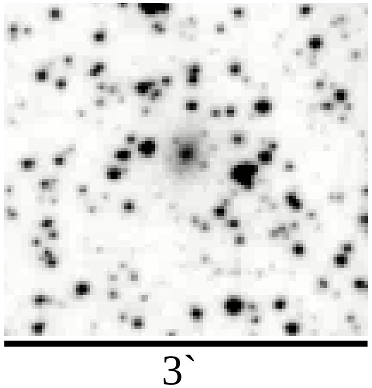


J. Anton Zensus
Silke Britzen
Max-Planck-Institut für Radioastronomie

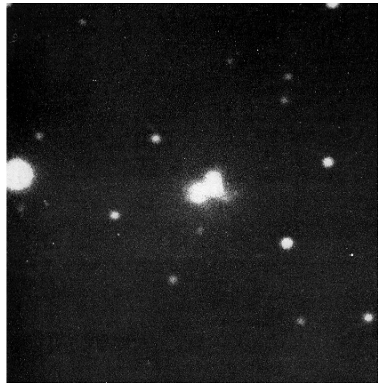
AGN emission



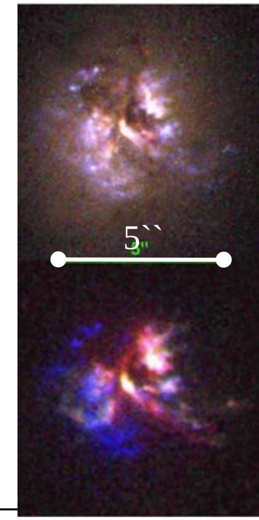
Cygnus A: One Telescope alone is not sufficient !



Palomar 48-inch Schmidt

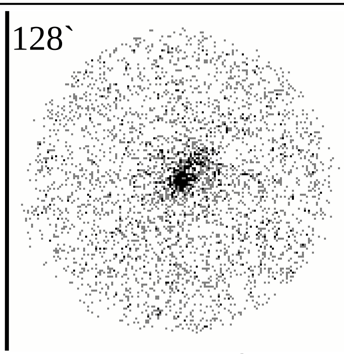


Walter Baade
200" Hale-Reflector

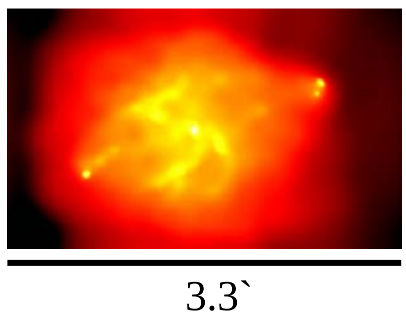


HST

optical

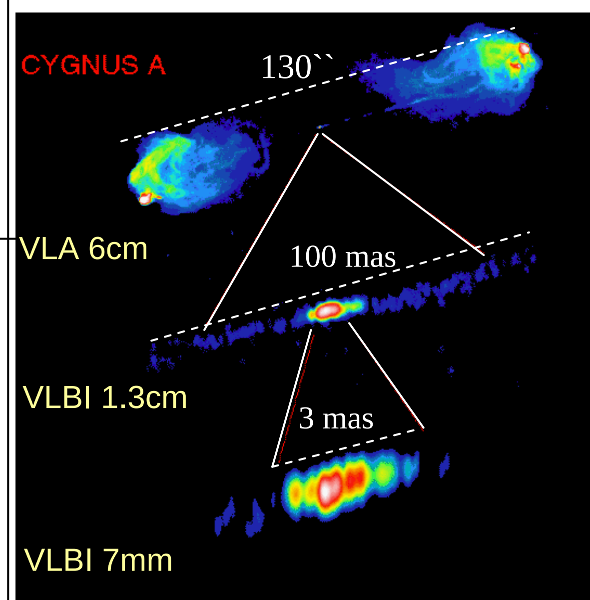


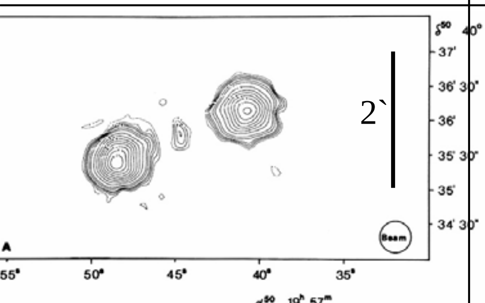
ROSAT, 0.1-2.4keV 1995



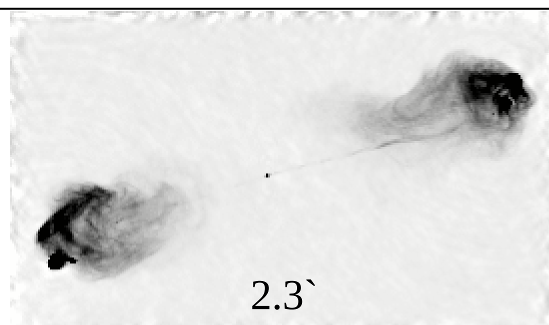
CHANDRA, 0.1-10keV 2003

X-rays





Effelsberg, 8.5 mm, 1976



VLA, 6cm

Radio

State of the Art:

the three largest European mm-telescopes

Effelsberg 100 m (MPIfR)

Plateau de Bure, 6 x 15 m (IRAM, France)

Pico Veleta 30 m (IRAM, Spain)

Baseline lengths (km):

	PdB	PV
EB	658	1700
Pdb		1146

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Cygnus-A

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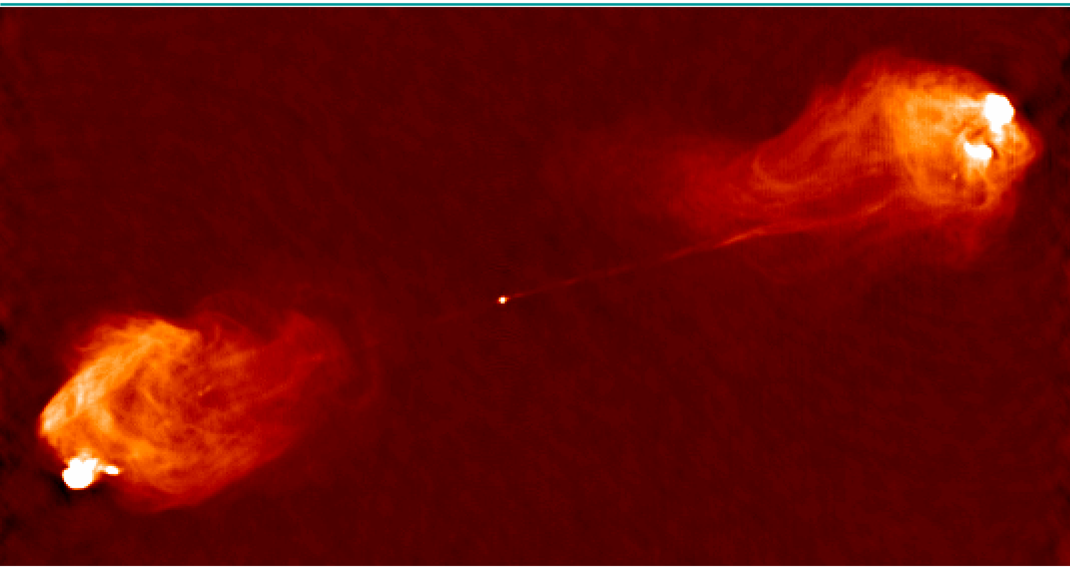
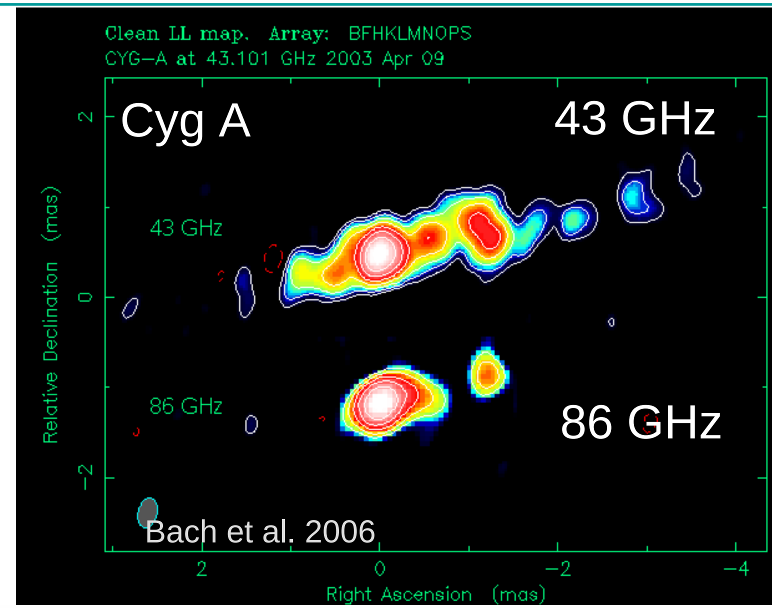
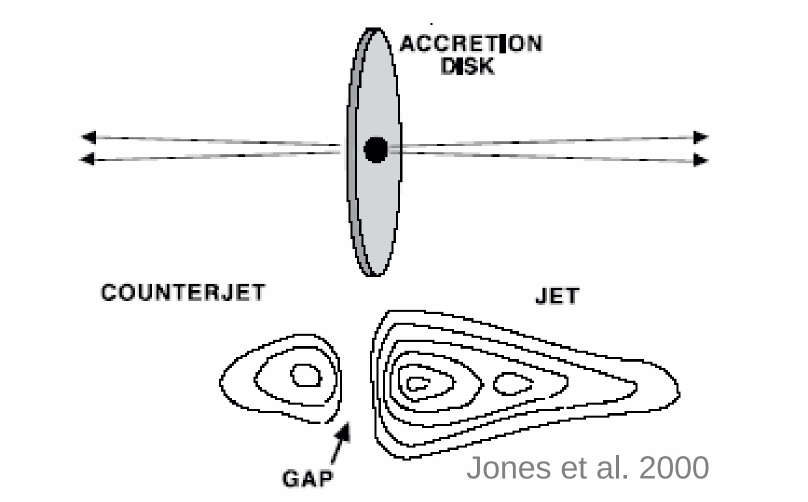
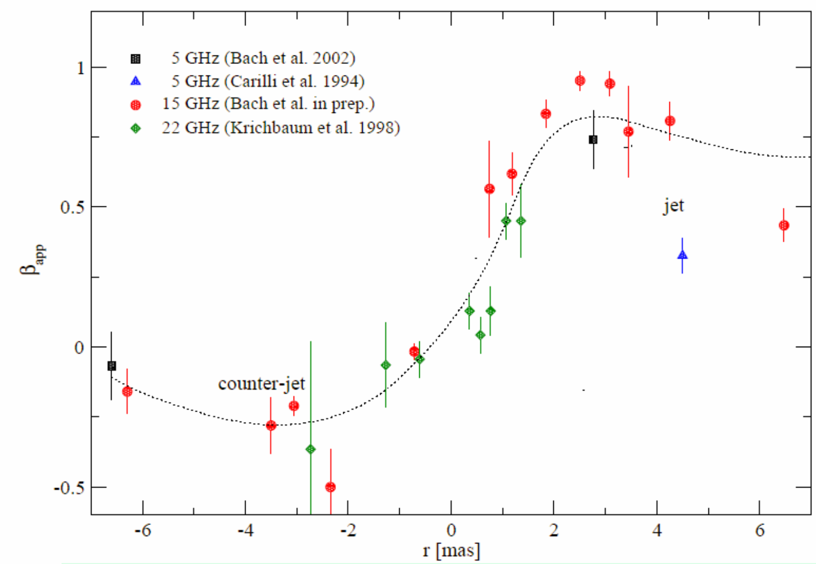


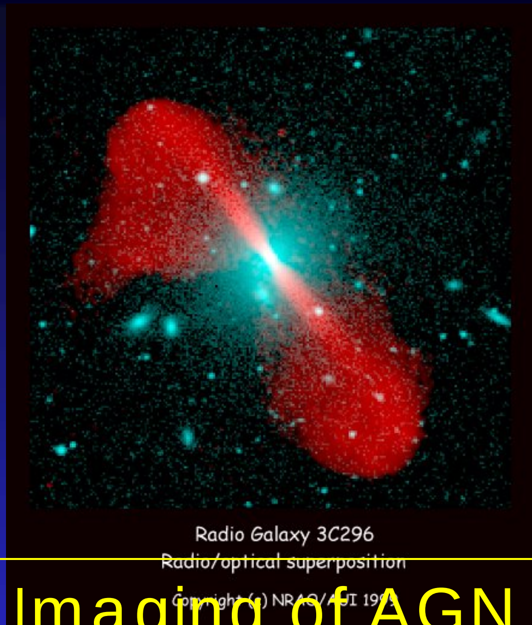


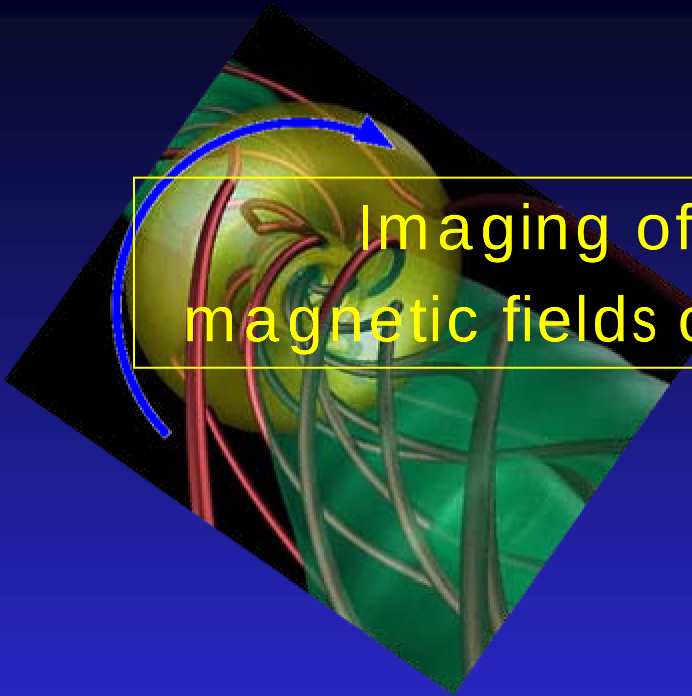


expect large gap for radiative inefficient jet launch



intrinsic jet acceleration from 0.1c – 0.7c

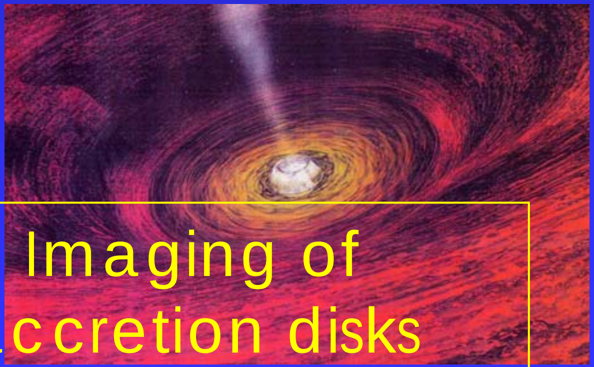


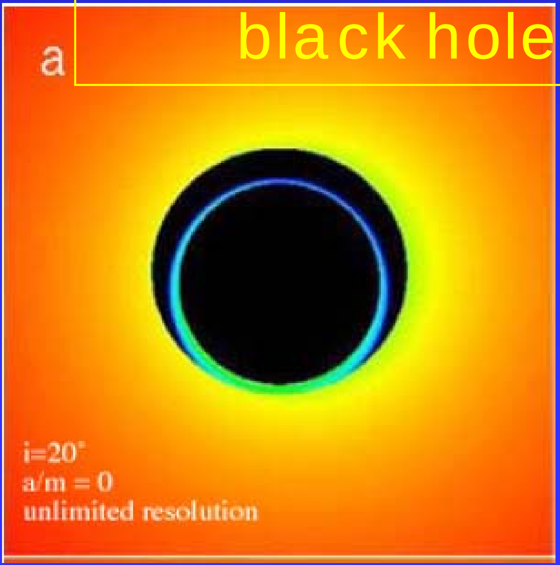


Imaging of
magnetic fields of Jets

Imaging of AGN
jets from the
accretion disks

Shadow of the
black hole



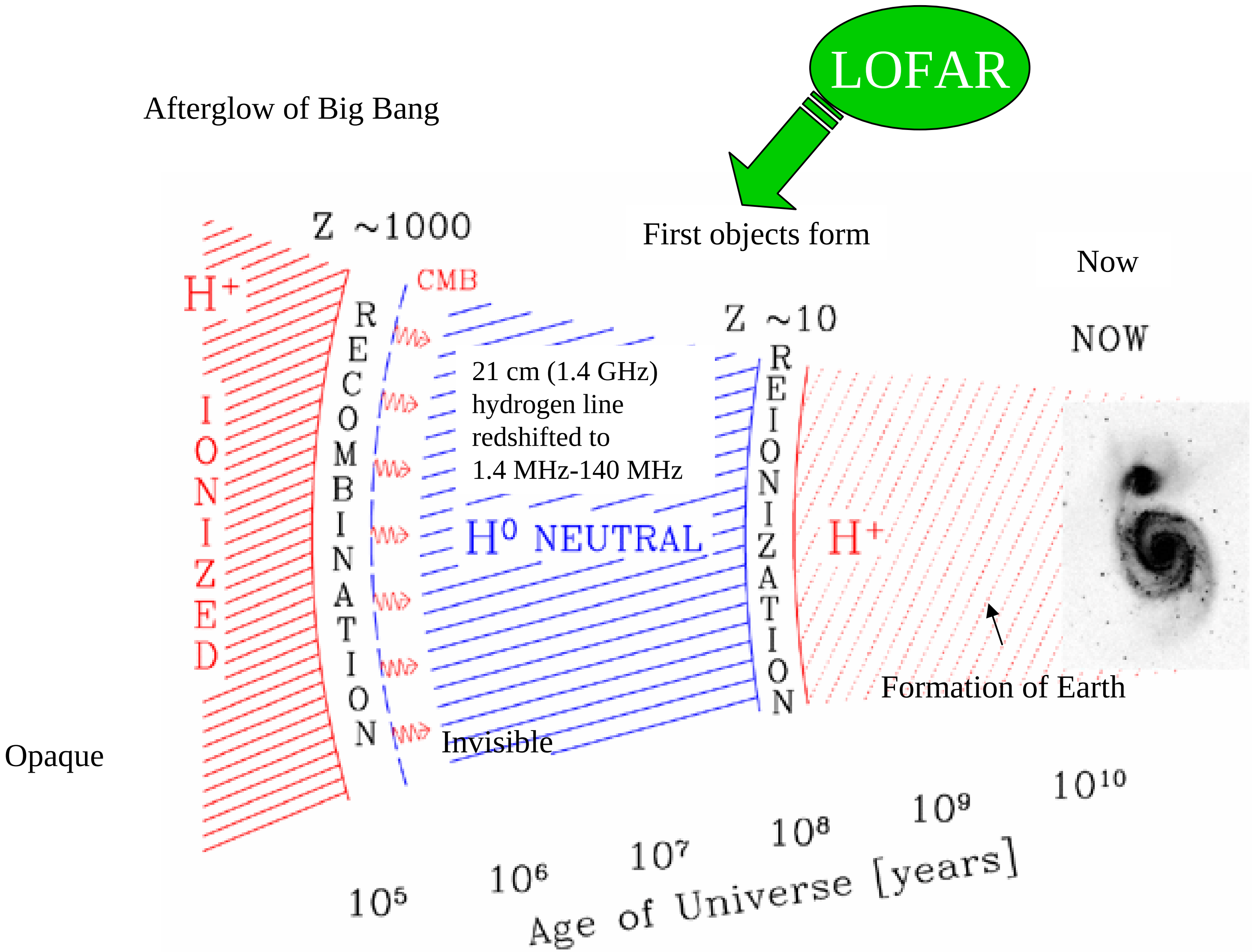


Imaging of
accretion disks
around black holes

Low Frequencies on Earth

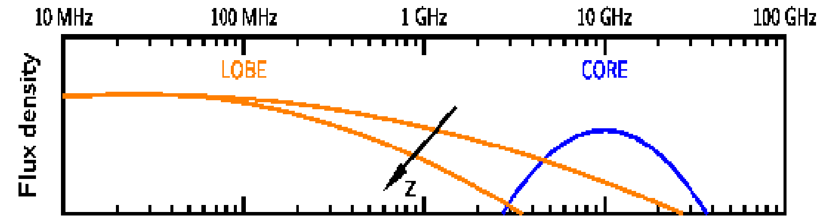
- Telescope the size of the Netherlands plus Germany.
- Pathfinder for the Square-Kilometer Array (SKA).
- Frequencies: 30 - 240 MHz
- Realized as a wide-area sensor network with ~14.000 cheap sensors.
- Two orders of magnitude improvement in resolution and sensitivity
- Main science applications: Big Bang, EOR, astroparticles and transients.
- Current Funding: 74 M€
- German partner consortium formed, first German station in Effelsberg

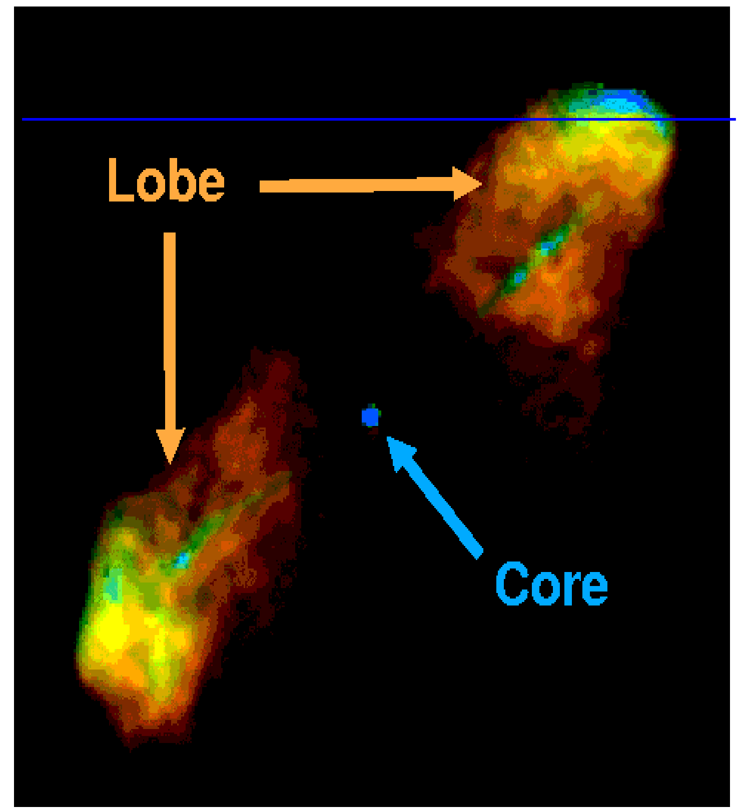
History of the Universe



LOFAR: Search for first quasars

- Quasars produce spectacular radio jets, which reach sizes up to Mpc scales.
- The jets are relativistic plasma beams from the very vicinity of the black hole.
- Complete surveys are best done at low frequencies.
- LOFAR will open up the high-z universe and show the onset of quasar formation.





3C438 courtesy of L Rudnick and M Hardcastle

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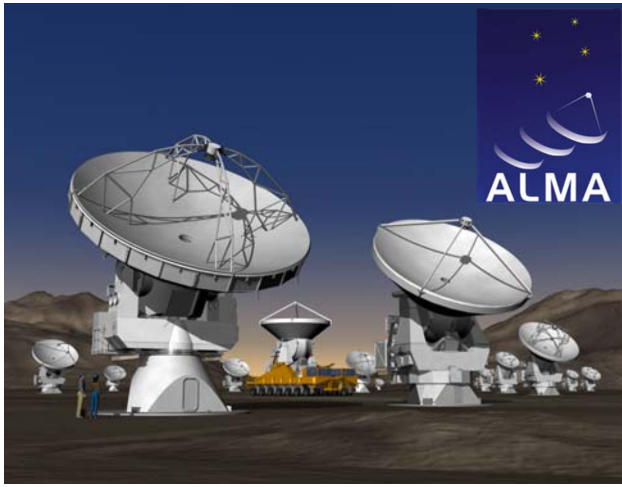
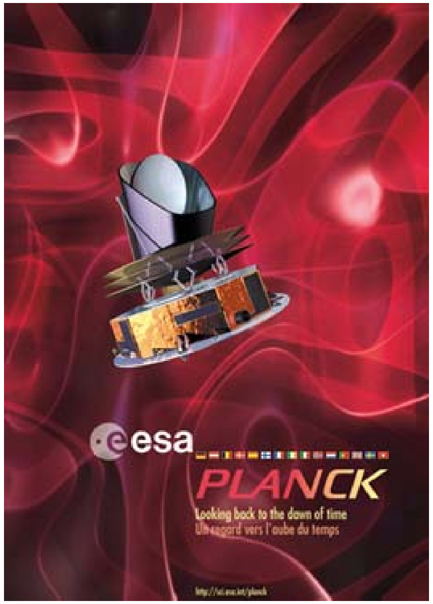
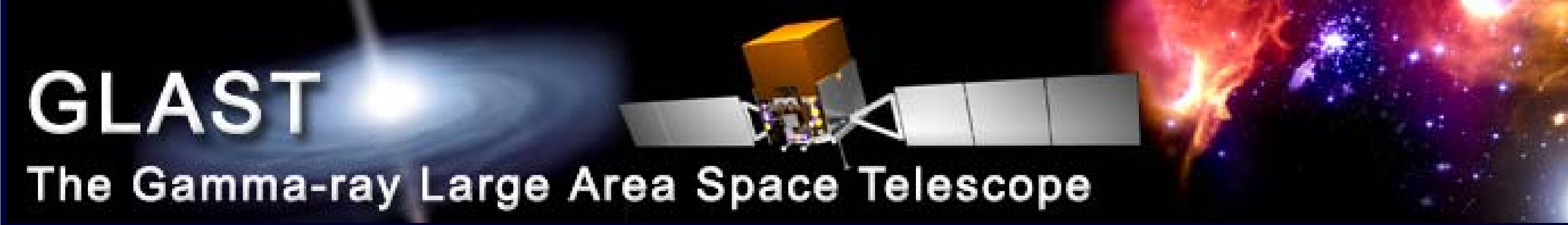
Telescope Perspectives

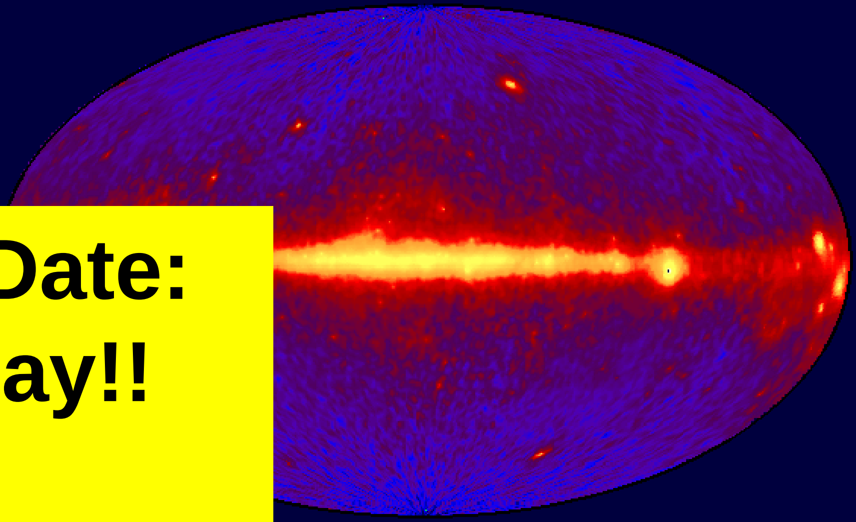
MAX-PLANCK-GESELLSCHAFT





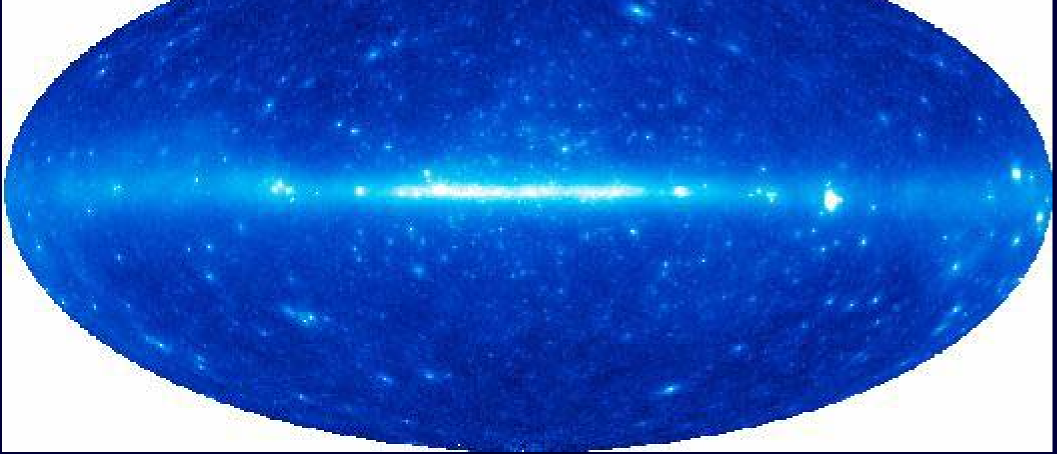


EGRET



Launch Date: Yesterday!!

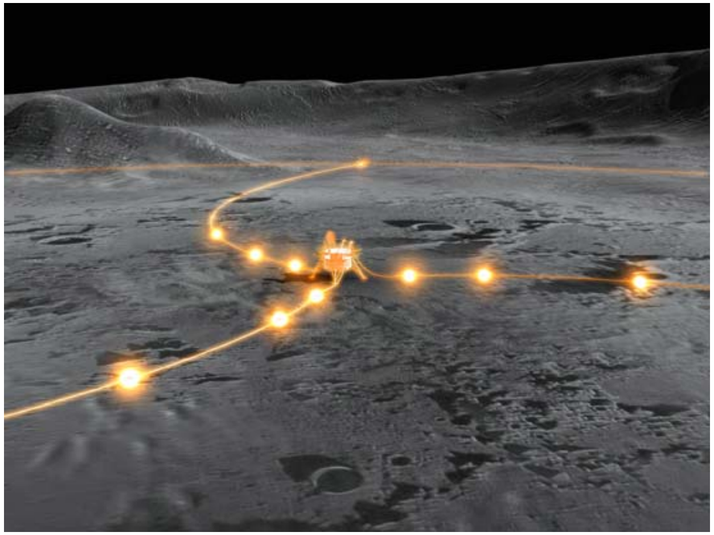
GLAST



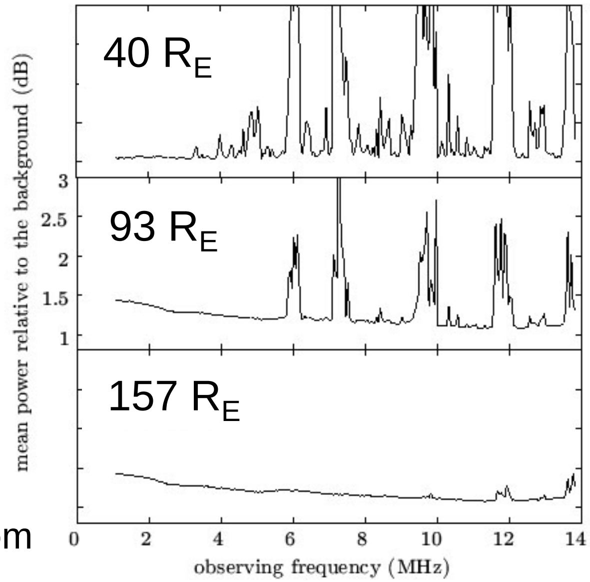
LAT All-Sky Map (E > 100 MeV, 1 year) Simulated,S. Digel

Astronomy from the Moon

- ⇨ The Moon is an attractive location for future astronomical facilities and in particular for a Very Low Frequency radio telescope working at frequencies below 30 MHz.



- ⇨ No atmospheric opacity: the entire EM spectral range is accessible.
- ⇨ Stable ground.
- ⇨ No terrestrial interference.
- ⇨ Cheap and robust, fully robotic technology.
- ⇨ Complementary to LOFAR, SKA, HERSCHEL, PLANCK.



Terrestrial interference at different separations from the Earth, G. Woan from ESA study SCI(97)2

Science with Lunar LOFAR

	Min # of Dipoles	Frequency	Baseline
Solar System	4-10	0-10 MHz	0.1-1 km
Surveys	10-100	1-10 MHz	1-100 km
Neutrinos	10-100	1-10 MHz	10 km
Exoplanets	100-1000	0.1-10MHz	1-10 km
Dark Ages	>1000	10-60 MHz	1-10 km

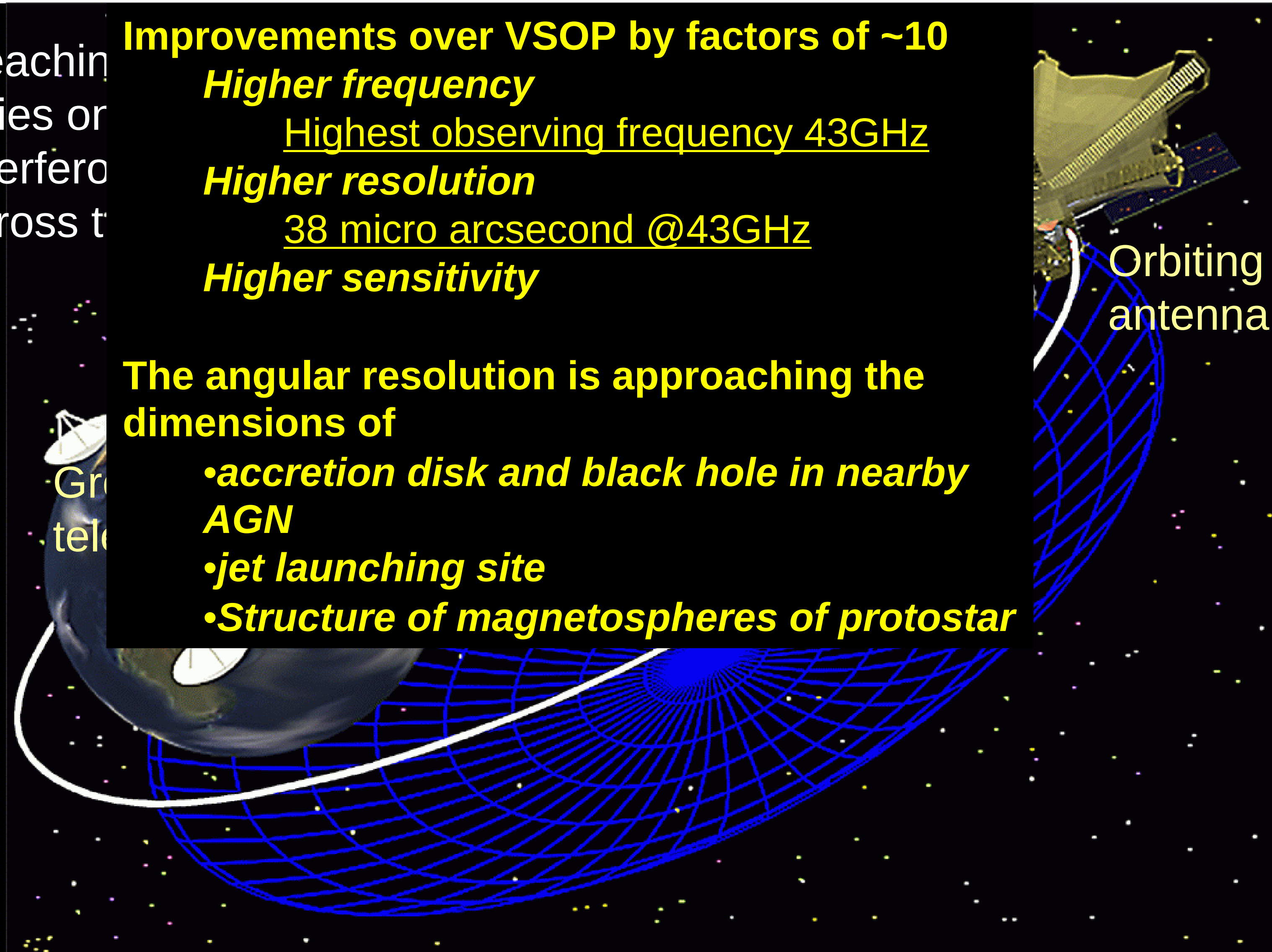
Reachin
relies or
interfero
across t

Improvements over VSOP by factors of ~10

- ***Higher frequency***
  - Highest observing frequency 43GHz
- ***Higher resolution***
  - 38 micro arcsecond @43GHz
- ***Higher sensitivity***

The angular resolution is approaching the dimensions of

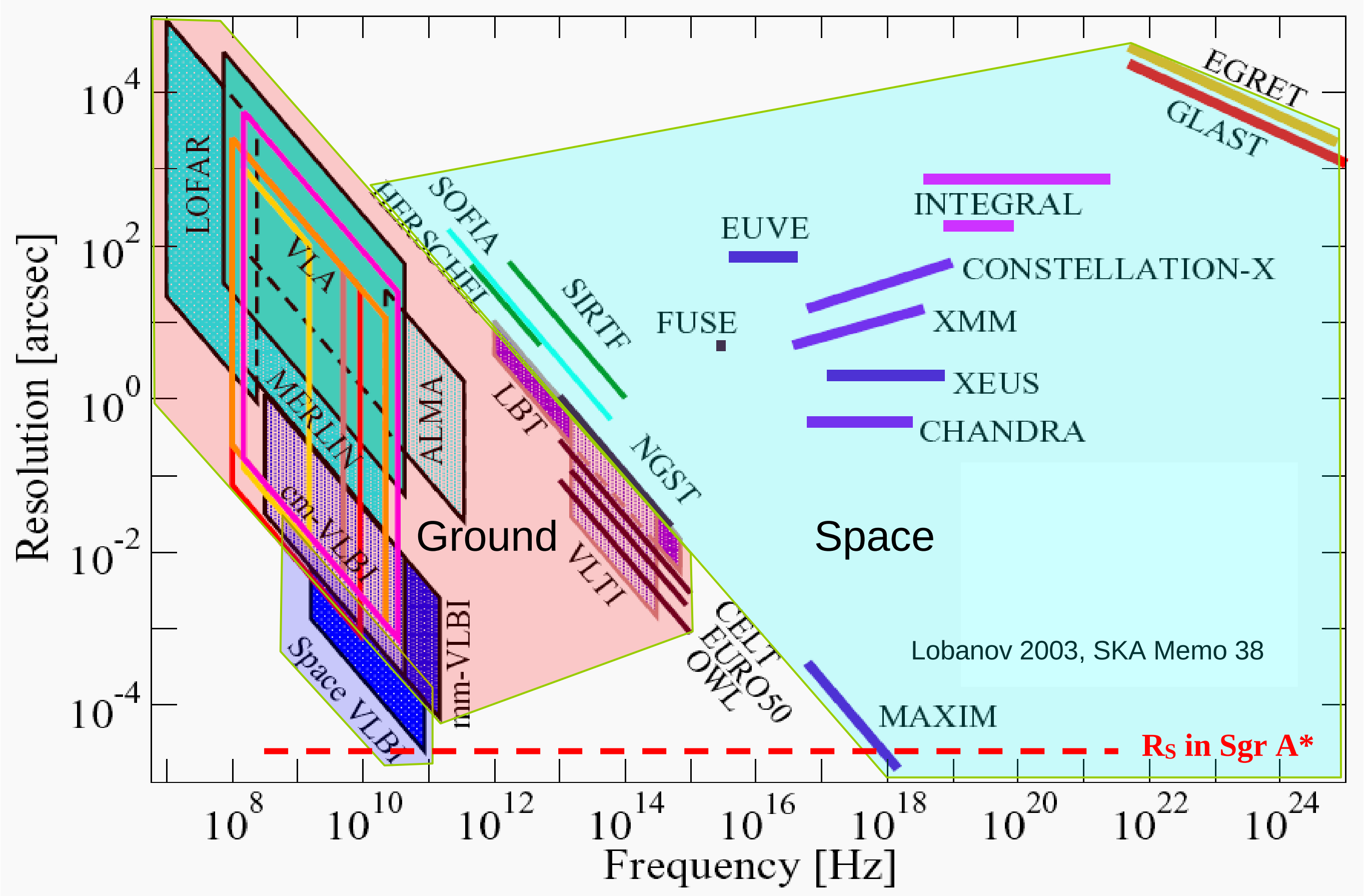
- ***accretion disk and black hole in nearby AGN***
- ***jet launching site***
- ***Structure of magnetospheres of protostar***



Angular Resolution

Interferometer: Sensitivity ∝ sum of the areas of individual elements.
Resolution ∝ largest separation between the elements.

Interferometry offers an effective way to expand the capabilities of astronomical instruments.



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Toward sub-millijansky sources with sub-mas resolution

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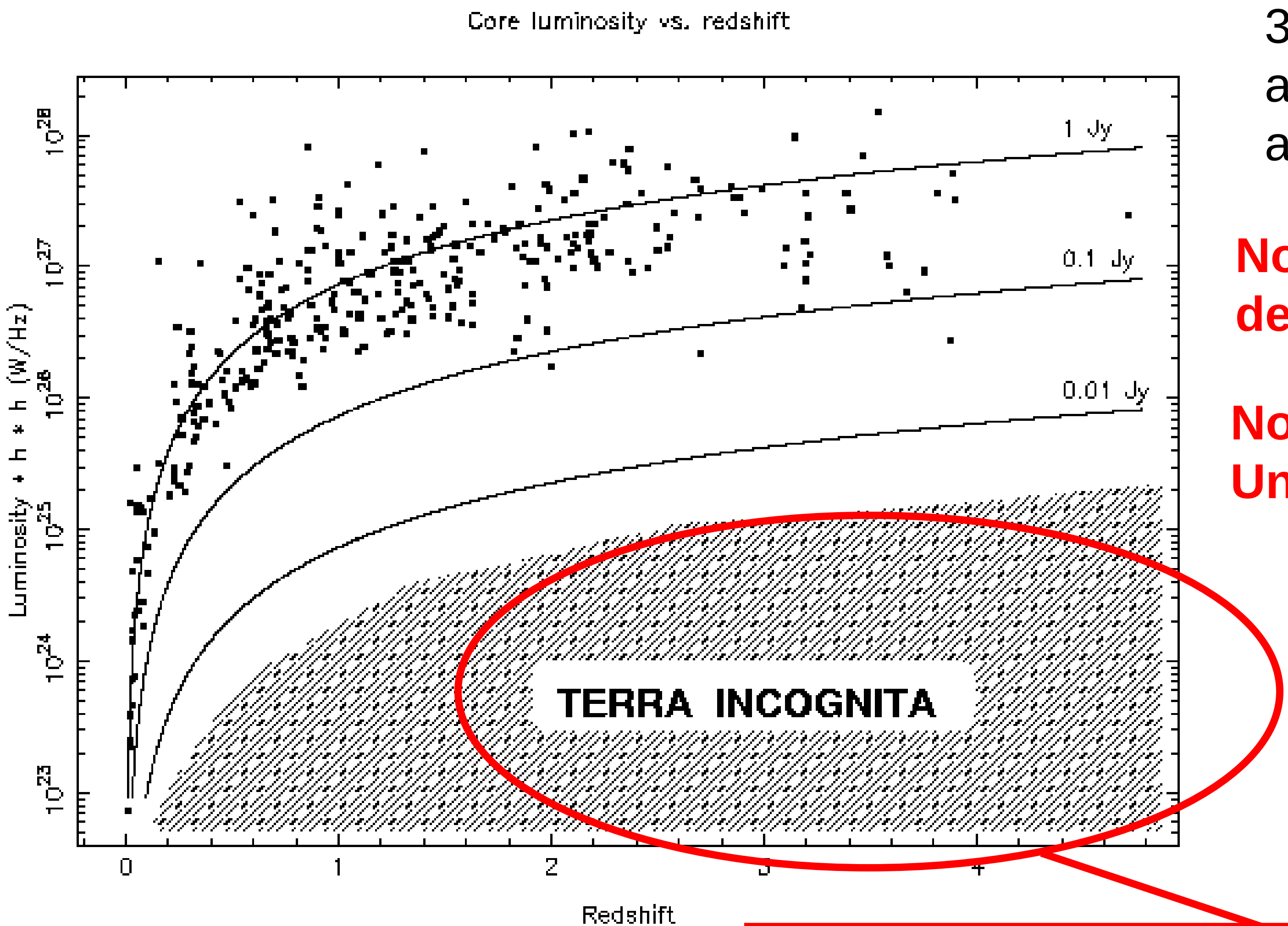


330 AGN imaged at 5 GHz with mas angular resolution

Note 1: de-facto flux density selection!

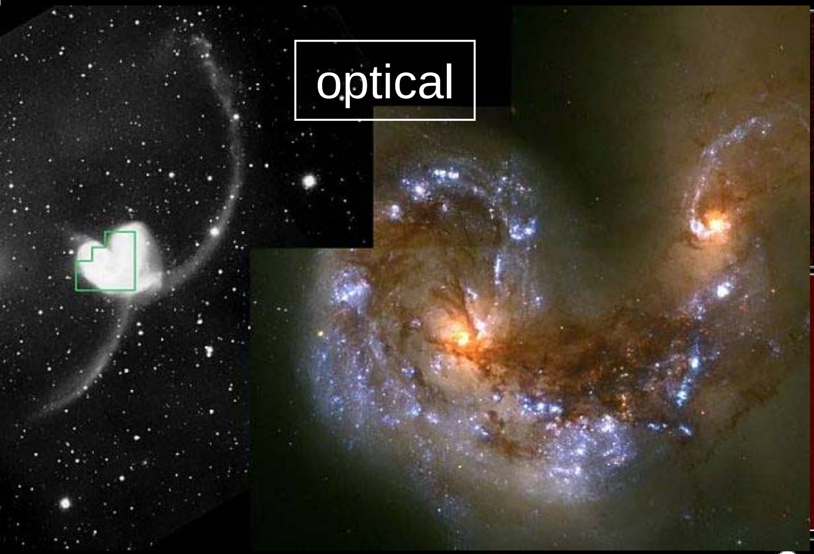
Note 2: most of the Universe is at high z!

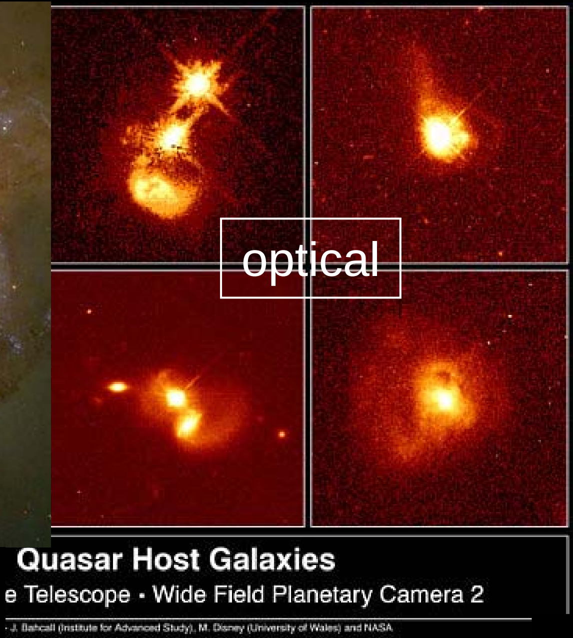
10^4 – 10^5 sources which can be studied at the sub-mas scale by SKA+SVLBI only!

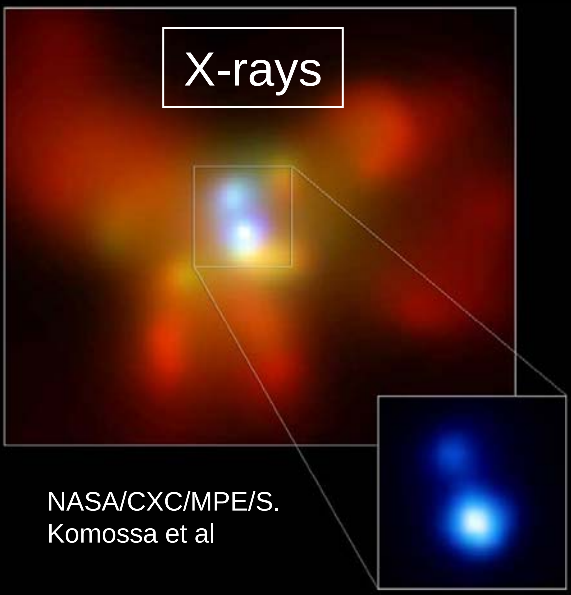
Gurvits, Kellermann, Frey 1999

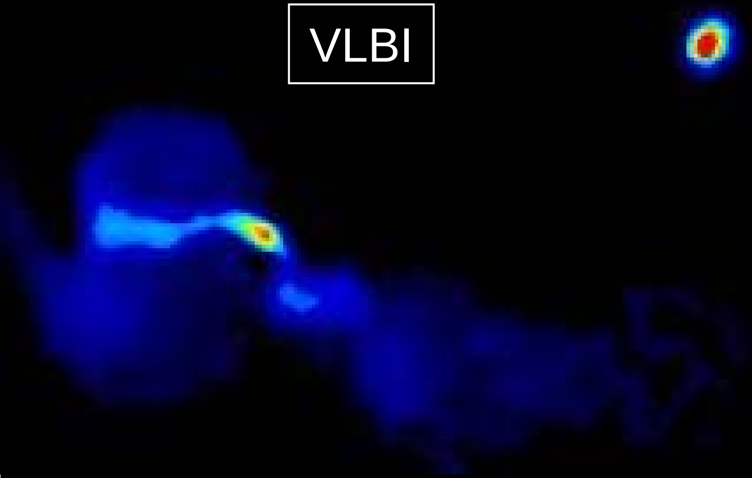
Supermassive Binary Black Holes

in different evolutionary states?

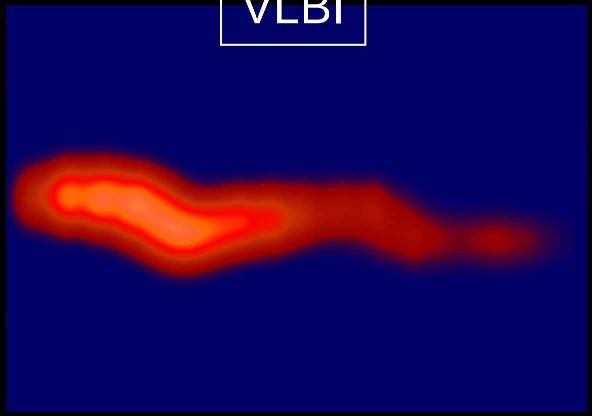




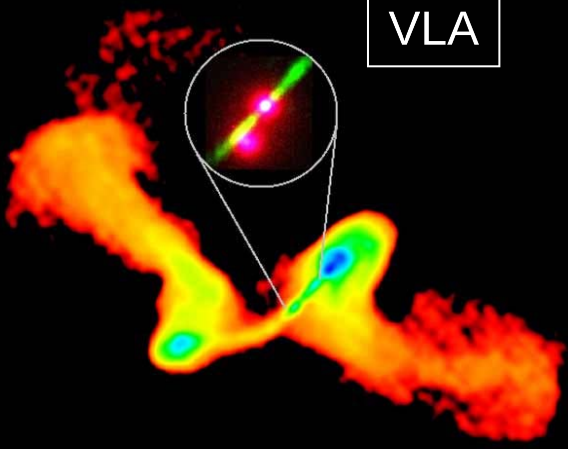




Hardcastle et al. 1996

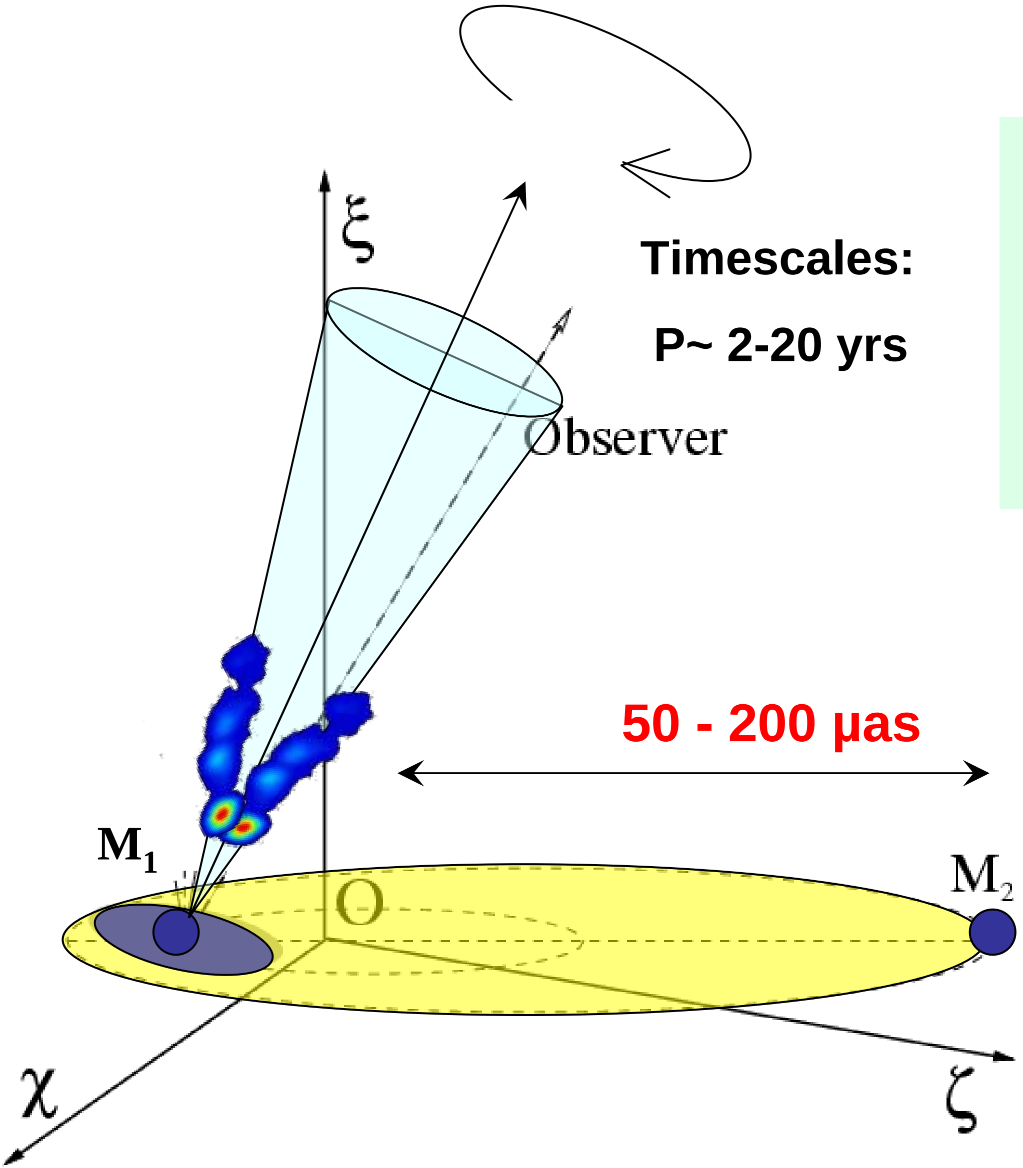


Lobanov & Roland 2004



Murgia et al.

Resolving a Supermassive BBH



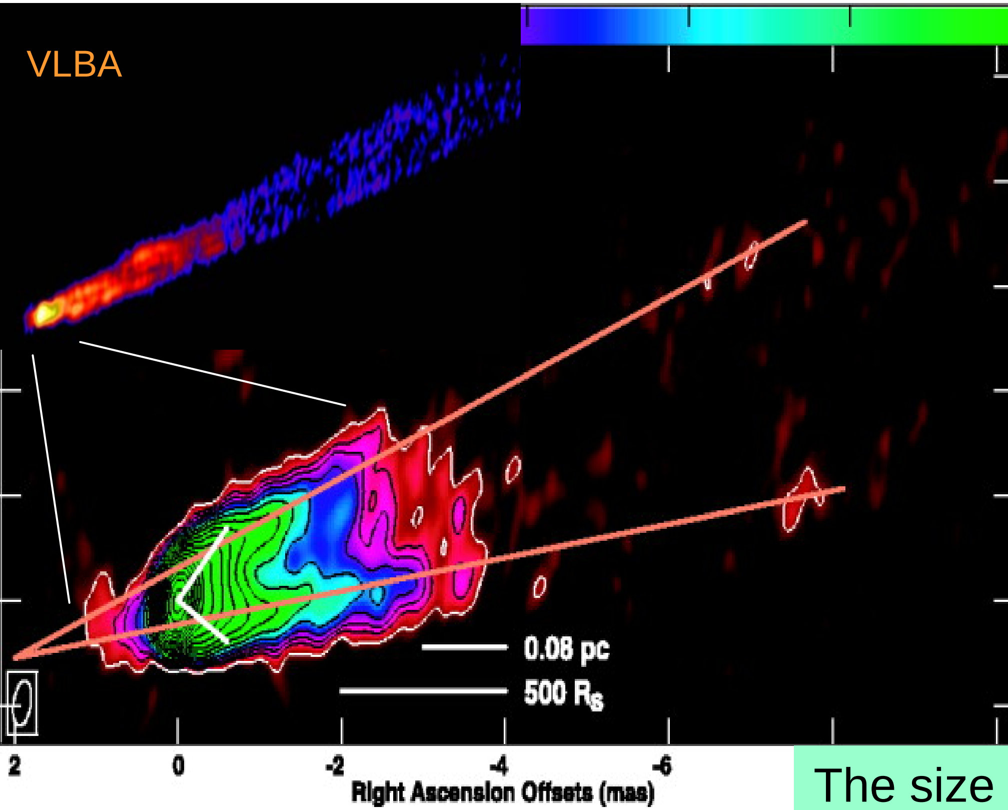
VSOP-2 has resolution of 40 μas which makes it possible to detect the movement on a binary orbit using phase-referencing observations

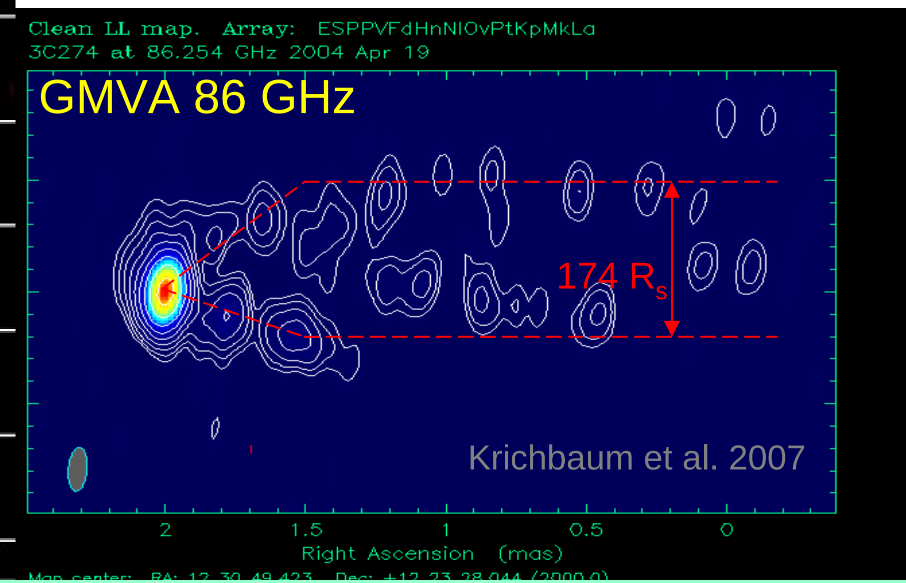
M_1, M_2 – two black holes

O – Center of mass of the binary system

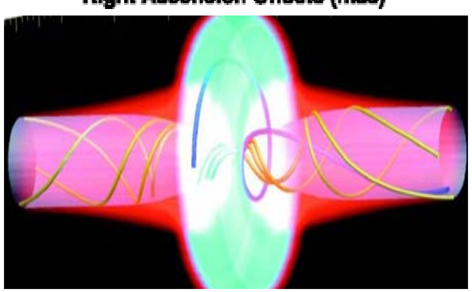
Accretion disk around M_1 inclined at an angle Ω_p

Imaging the jet base in M87





Walker et al. 08
Kovalev et al. 07



The size of the jet base (uniform weighting):

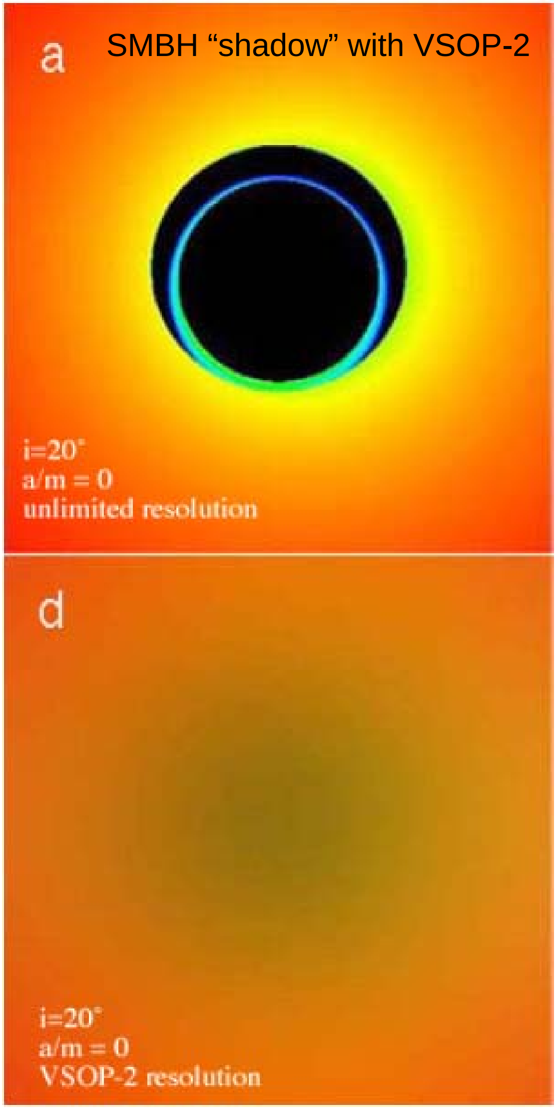
197 x 54 mas = 21 x 6 light days = <u>69 x 19</u> R_s

transverse width of jet at 0.5 mas: ~174 R_s

Perform HDR imaging of M87 with ground and space VLBI at 43 & 86 GHz (spectral index, polarization, RM of jet base, variability).

Science with VSOP-2

- ⇨ VSOP-2 will have a 10 times better sensitivity (0.3 mJy/beam at 8 GHz) and resolution (~40 µas at 43GHz) compared to VSOP.
- ⇨ Main science themes will be expanded to include:
  - – direct imaging of hot (10^9–10^{10} K) material in AGN accretion disks.
  - – imaging of the vicinity of SMBH (M87: a BH "shadow" is ~26 μas).
  - – acceleration, collimation and internal structure of relativistic jets.
  - – imaging magnetospheres and non-thermal radio continuum in protostars.
  - – H_2O masers in protoplanetary disks and accretion disks in AGN.
  - – SiO maser in Asymptotic Giant Branch (AGB) stars.



- Space radio astronomy is a vibrant and rapidly growing field of science and technology opening up new areas of fundamental research.
- Highly complementary to other major future astrophysical facilities such as LOFAR, ALMA, SKA, GLAST, HERSCHEL, JWST, XEUS and ELTs).
- Space VLBI technology charts the ways to future space interferometry instruments.
- European and German astronomical and space research communities are among the prime movers in this field, and they have the best opportunities to remain one the focal points of development in space radio astronomy.