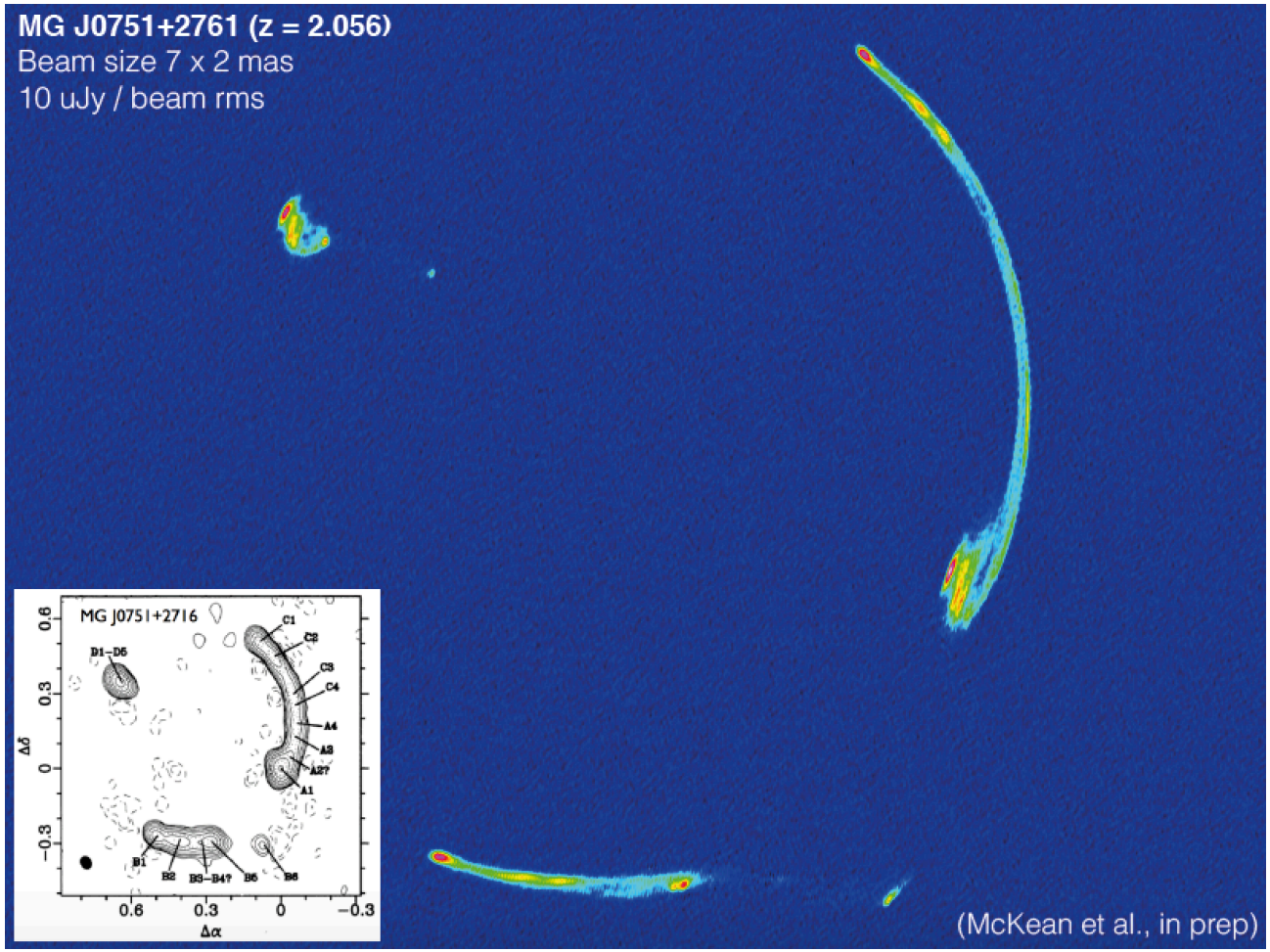
Science with the EVN



Michael Lindqvist, Onsala Space Observatory

Outline

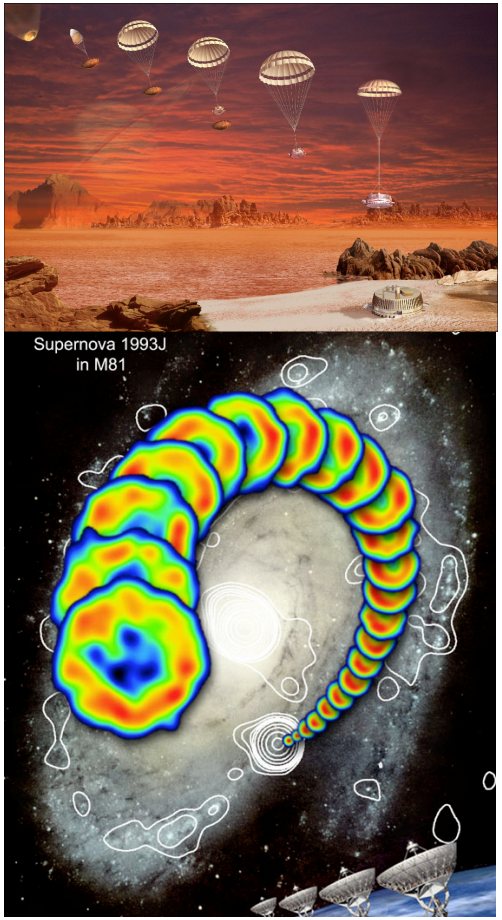
- Introduction
- The European VLBI Network
- Science examples
- Summary

VLBI science is varied

- **Continuum:** high brightness temperature radio emission from synchrotron processes

- **Spectral lines**: maser emission (OH, CH_3OH, H_2O and SiO) and in absorption against bright continuum sources (mainly in HI, OH and H_2CO)

  - Radio jet & black hole physics
  - Radio source evolution
  - Astrometry
  - Galactic and extra-galactic masers
  - Gravitational lenses
  - Supernovae and gamma-ray-burst studies
  - Nearby and distant starburst galaxies
  - Nature of faint radio source population
  - HI absorption studies in AGN
  - Space science VLBI

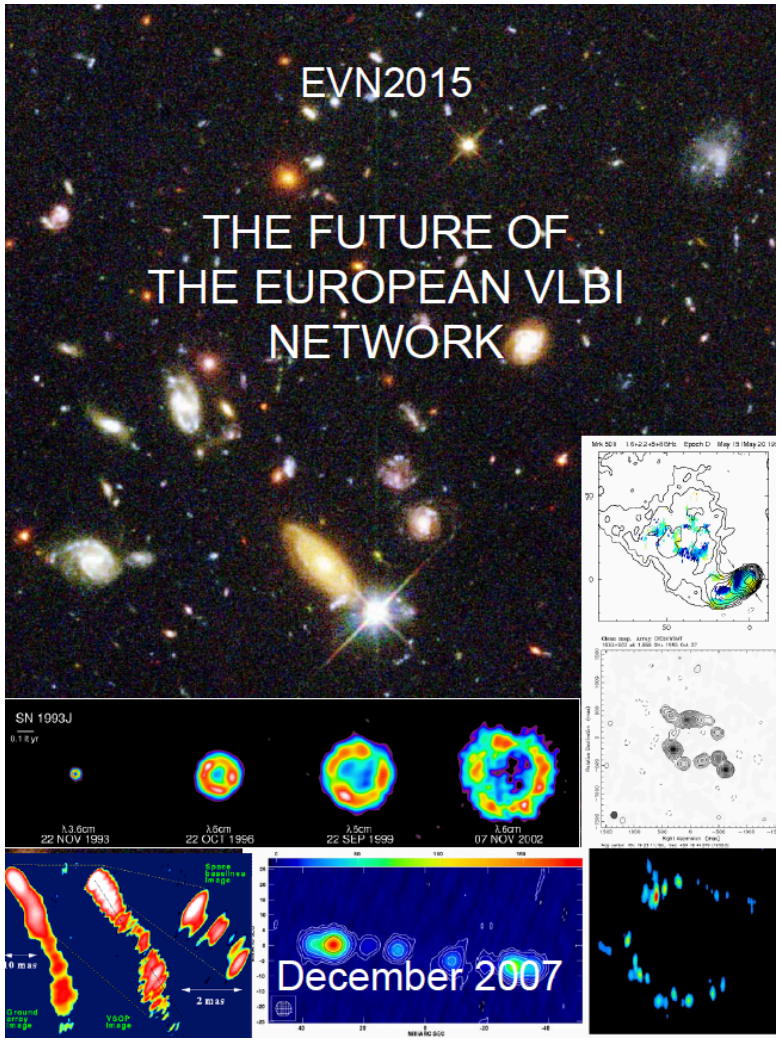


EVN - Current status & new opportunities

- **EVN is a classical example of a distributed European facility**
  - NO central budget
  - Its annual operating costs are estimated to be of the order of 5 M€
  - The capital investments are several hundreds of M€
- **Call for proposals:** 3 times per year: (February 1, June 1, October 1)
- **Maximum data rate (disk):** 2 Gbps (4 Gbps, …, 32 Gbps)
- **Out-of-Session, EVN+LBA, automated trigger eVLBI**
- **New telescopes and collaborations:** Kunming, AVN, FAST, MeerKAT, SKA
- **e-VLBI/e-transport:** Disk recording & e-VLBI simultaneously
- **Next generation receivers, backends and recording systems**
- **Next generation correlators:** UniBoard / SFXC

So, …, we have the technique to update the EVN,…but…

Difficult to predict the future



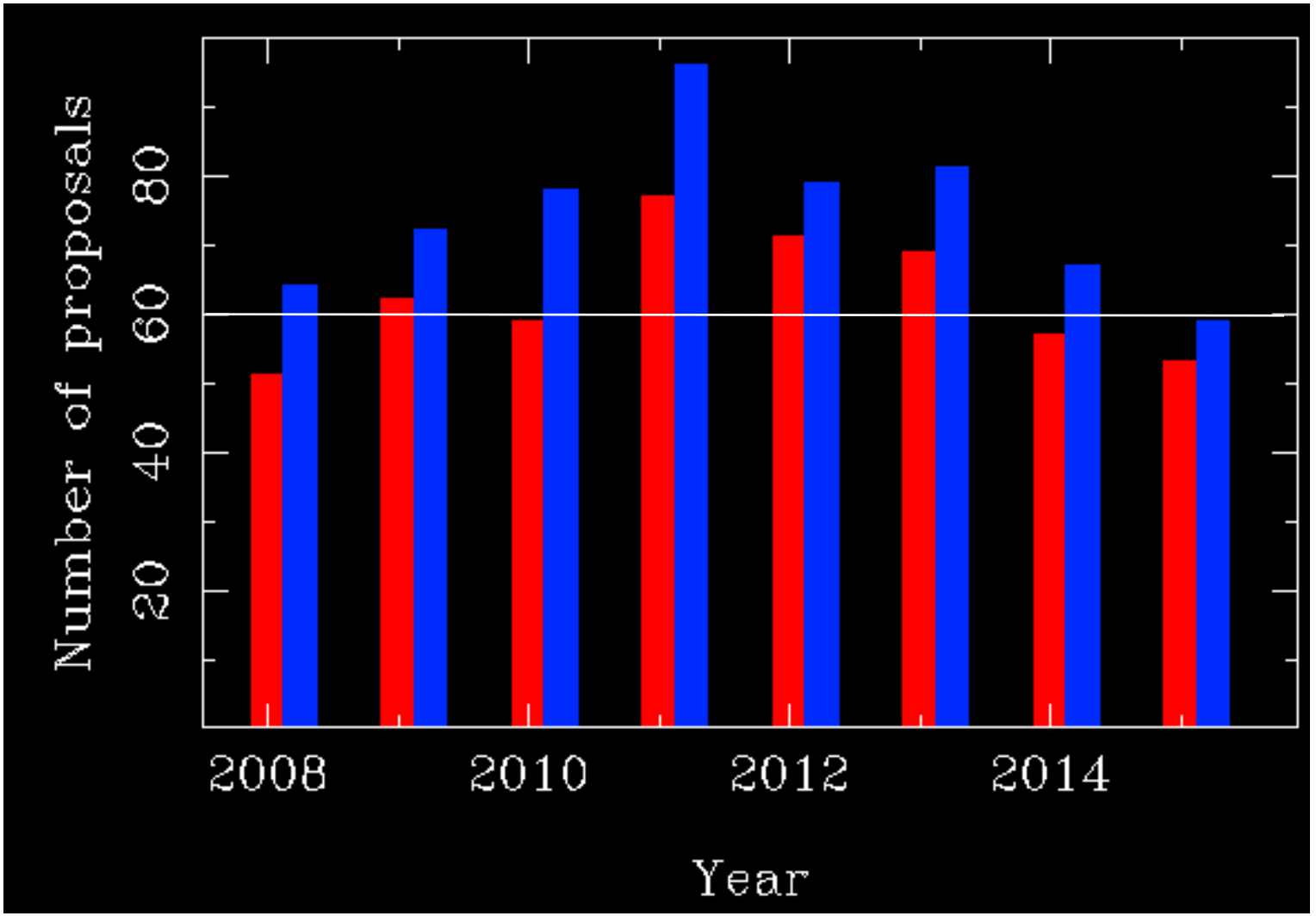
The operational performance of the European VLBI Network depends on the effective collaboration of national observatories, the large collecting areas available at those observatories, and its success in incorporating the advances in technology.

Target-of-opportunity capability and e-VLBI operation will contribute to robust and flexible operational procedures. Seamless EVN-MERLIN integration as the short baseline core of EVN can be achieved by adding EVN antennas to MERLIN and connecting the e-Merlin telescopes into the EVN correlator at JIVE.

The increased correlation capability at JIVE of up to 256 Gb/s per radio telescope for routine operations with 32 stations will facilitate innovative research with EVN2015.

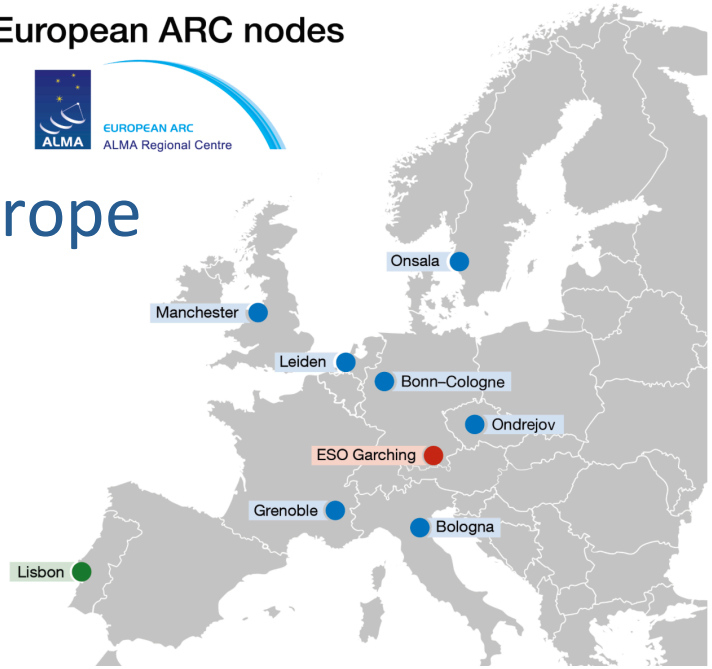
Most important – the users!

Proposal trends over 8 years



More users/proposals

- We don't lack projects to schedule, but rather media
  - ✓ Especially when we have moved to 2 Gbps…
- Funding agencies - non EVN institutes
- Non-experts using the VLBI/EVN
- User support is very important: JIVE
- ALMA Regional Centres Nodes in Europe
- Visibility & Outreach
- Papers, papers, papers…

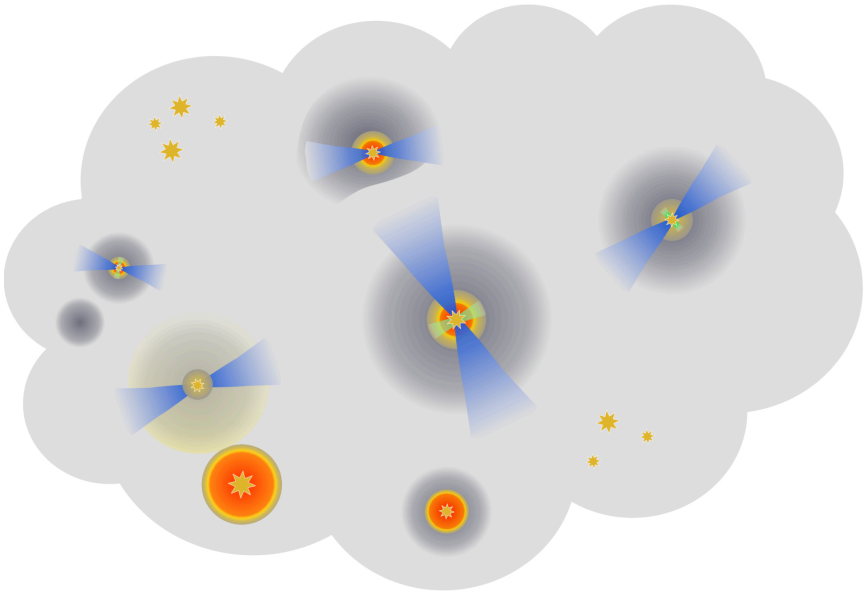


What do the users want?

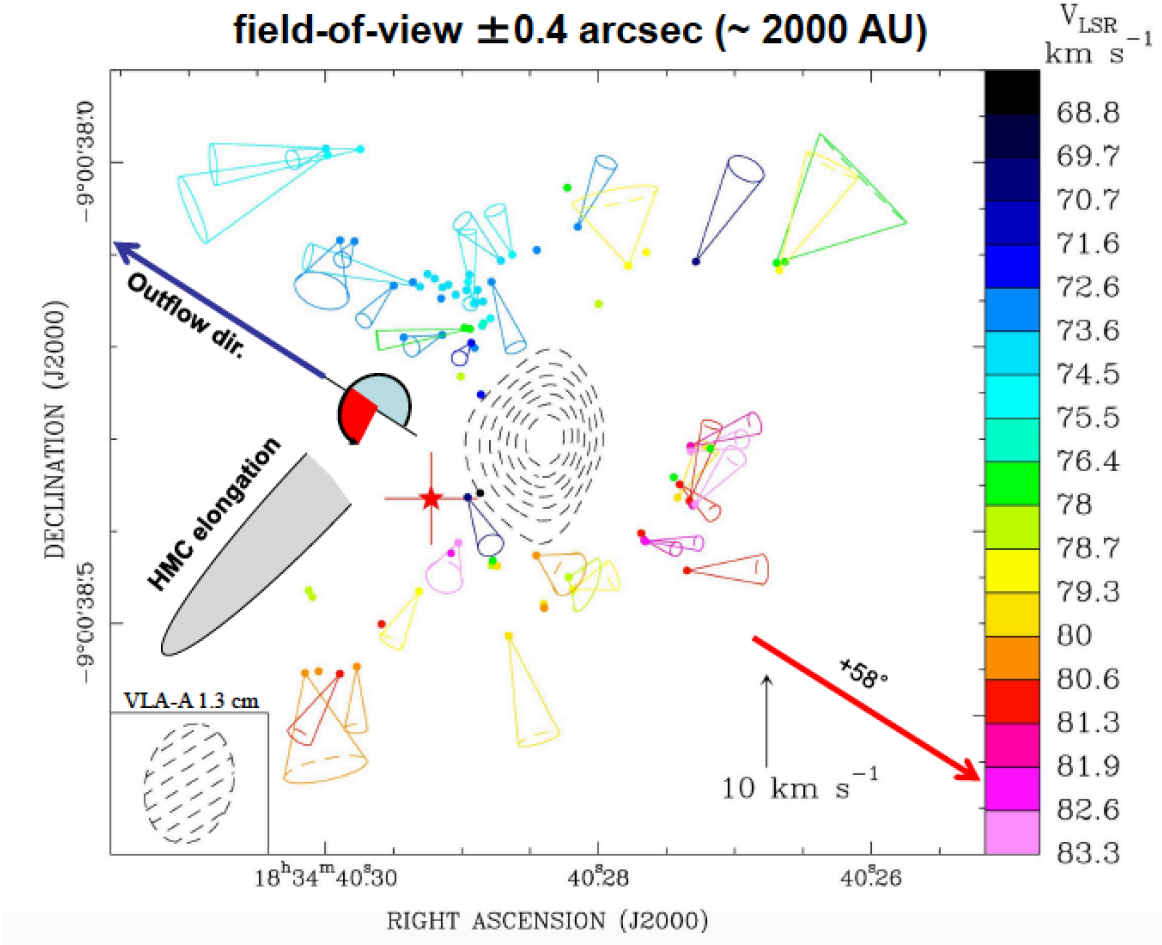
Average rank	In which direction should the EVN develop?
2.73	Improved uv-coverage (more telescopes, more short spacings)
3.50	Increased bandwidth to improve sensitivity
4.57	Improved calibration in general (phase, amplitude, bandpass, polarization)
4.60	Improved resolution (more long baselines)
4.73	Frequency agility for spectral index imaging
6.06	Real-time e-VLBI capabilities for more telescopes
6.34	Extended observing time to be able to carry out big surveys
6.42	Real-time e-VLBI capabilities for a larger fraction of observing time
6.71	Improved astrometry
6.89	Larger field of view

High mass star formation

- We do not know how massive stars form!
- Theoretical simulations and observations at different angular resolutions have shown that magnetic fields have a central role in massive star formation.
- Like in low-mass star formation, the magnetic field in massive young stellar objects can either be oriented along the outflow axis or randomly.
- The EVN has pioneered the high resolution study of galactic methanol masers utilising its sensitivity, wide-field imaging polarisation capability, and astrometric accuracy

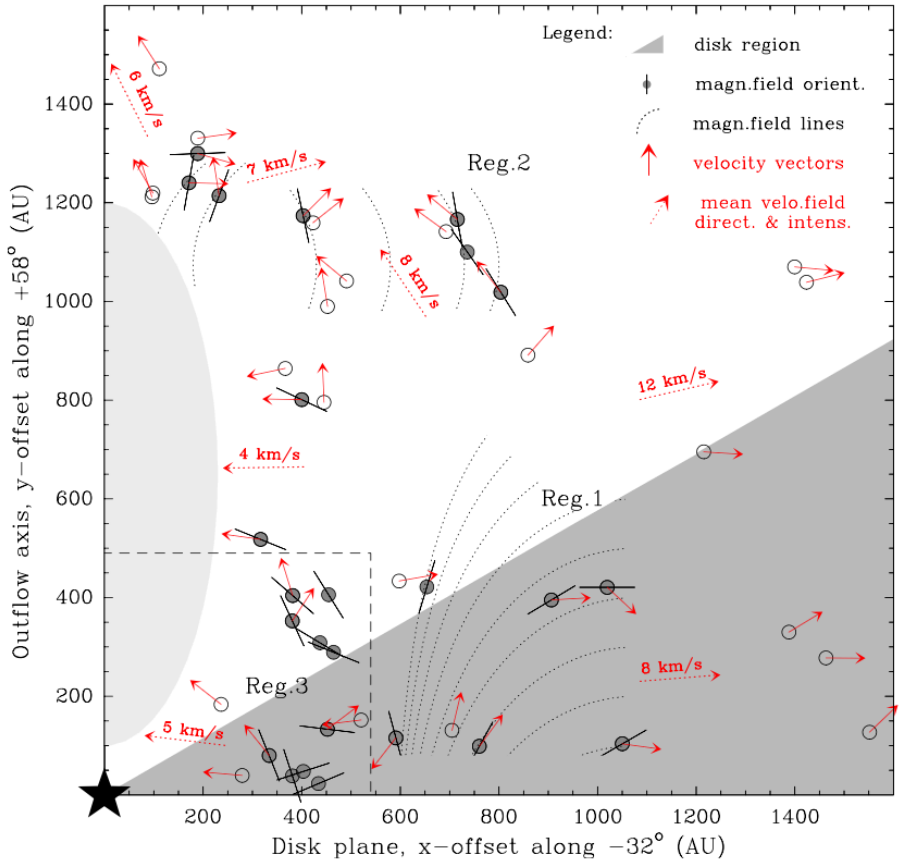


G23.01-0.41 - a high-mass star-forming region



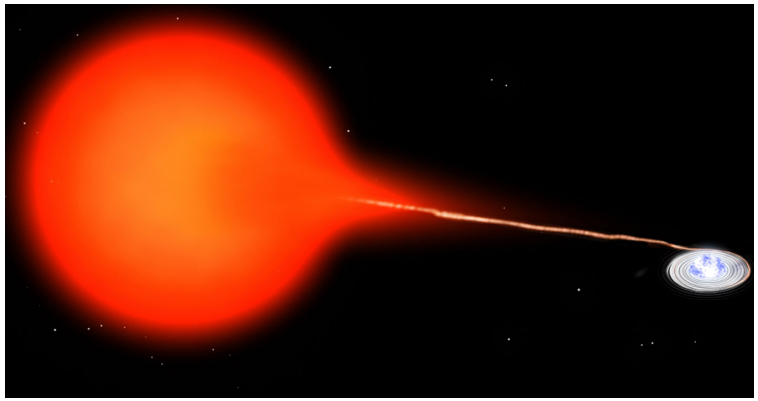
3D gas kinematics (cones) from the 6.7 GHz CH_3OH masers within ~ 2000 AU from the dust continuum peak (red star), Sanna et al. (2010, 2013)

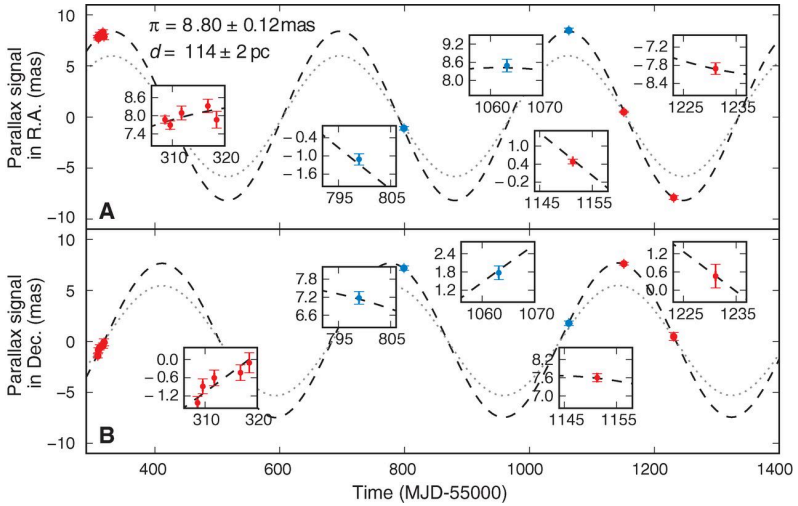
G23.01-0.41 - a high-mass star-forming region



Sanna et al. (2015) provide a first detailed picture of the gas dynamics and magnetic field configuration within a radius of 2000 AU of a massive YSO, G023.01-0.41

The dwarf nova SS Cygni



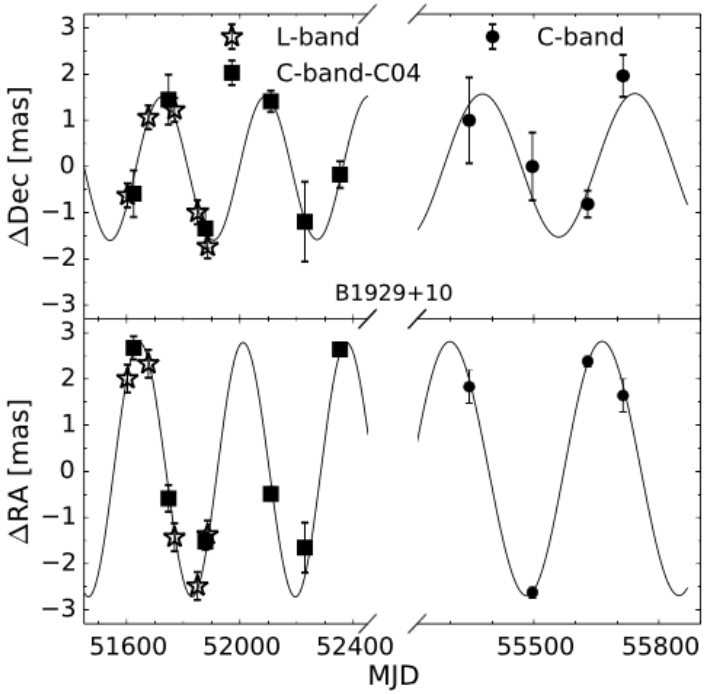


- SS Cyg is perhaps the prototype dwarf nova, the outbursts result from changes in the rate at which matter moves through the disk onto the white dwarf
- Using VLBA and the EVN, Miller-Jones et al., (2013) were able to accurately measure the distance to SS Cyg
- VLBI data places SS Cyg substantially closer, 114±2 pc, than HST data, 159±12 pc
- The new distance measurement has solved the puzzle of SS Cygni's brightness, it fits the theories after all

Birth locations of pulsars

- Typical transverse velocities of isolated pulsars are of the order of several hundred km/s
- Progenitor O- and B-stars are at most several tens of km/s
- The discrepancy is explained by an asymmetry in the SN explosion that gives a kick to the pulsar, accelerating it to the observed velocities
- Due to the different time scales, direct associations between SN-remnants and pulsars are rare

B1929+10

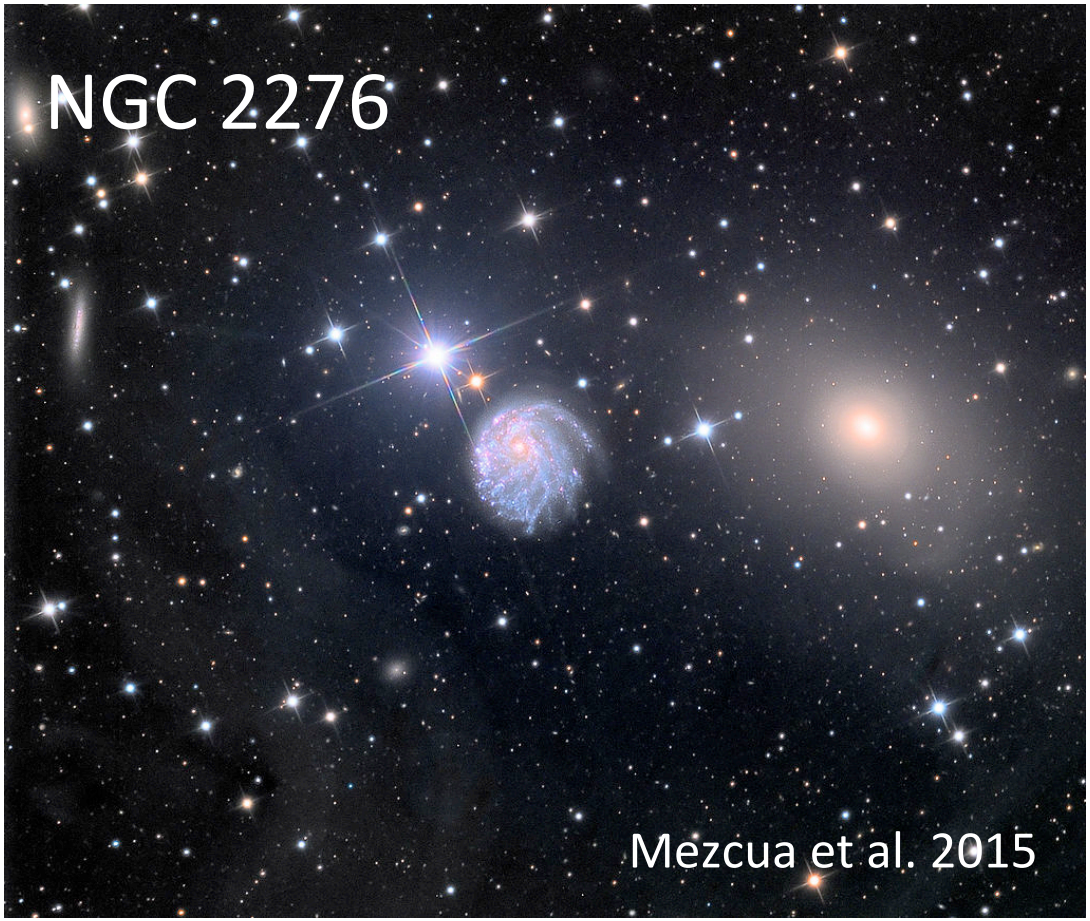


Kirsten et al. (2015)

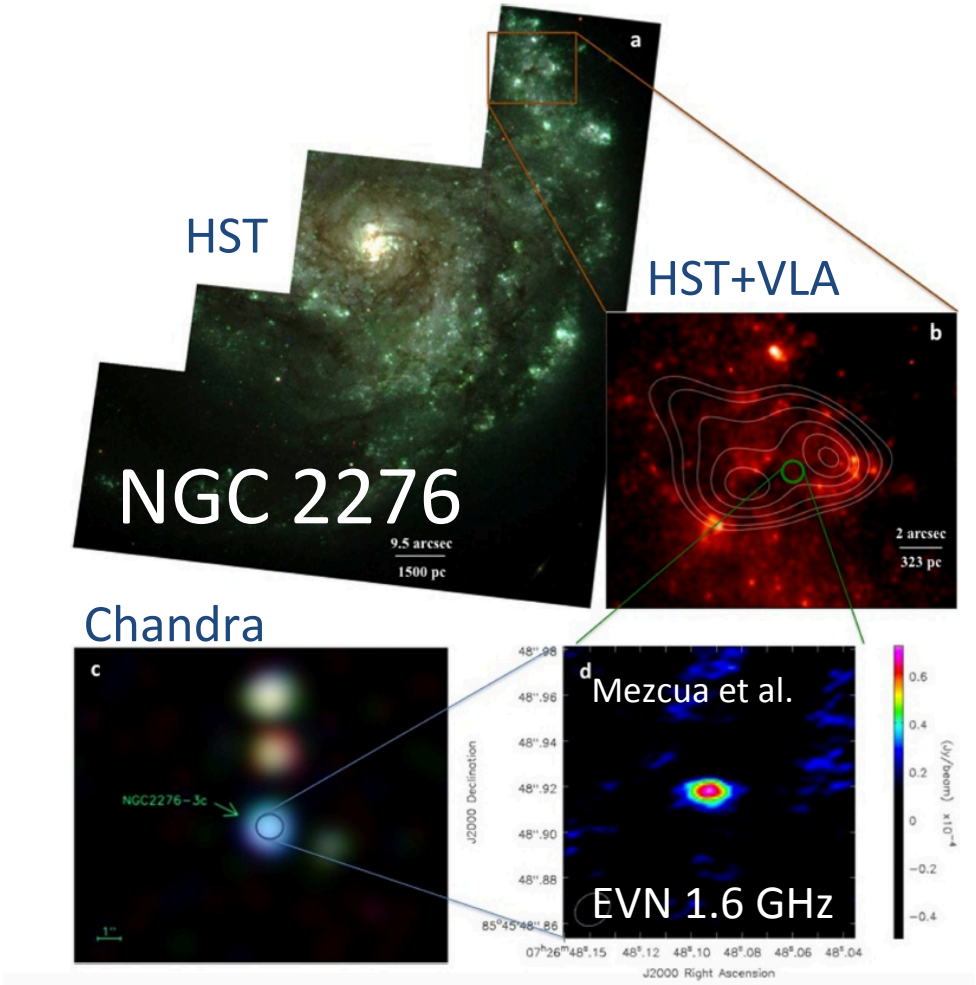
- Based on the new astrometry they rule out previously proposed common origin scenarios

Intermediate-mass black holes

- Intermediate-mass black holes; the missing link
- IMBHs could form either from the
  - ✓ death of very massive and short-lived stars
  - ✓ direct collapse of a pre-galactic gas disc
  - ✓ the collapse of dense stellar clusters
- Difficult to find them

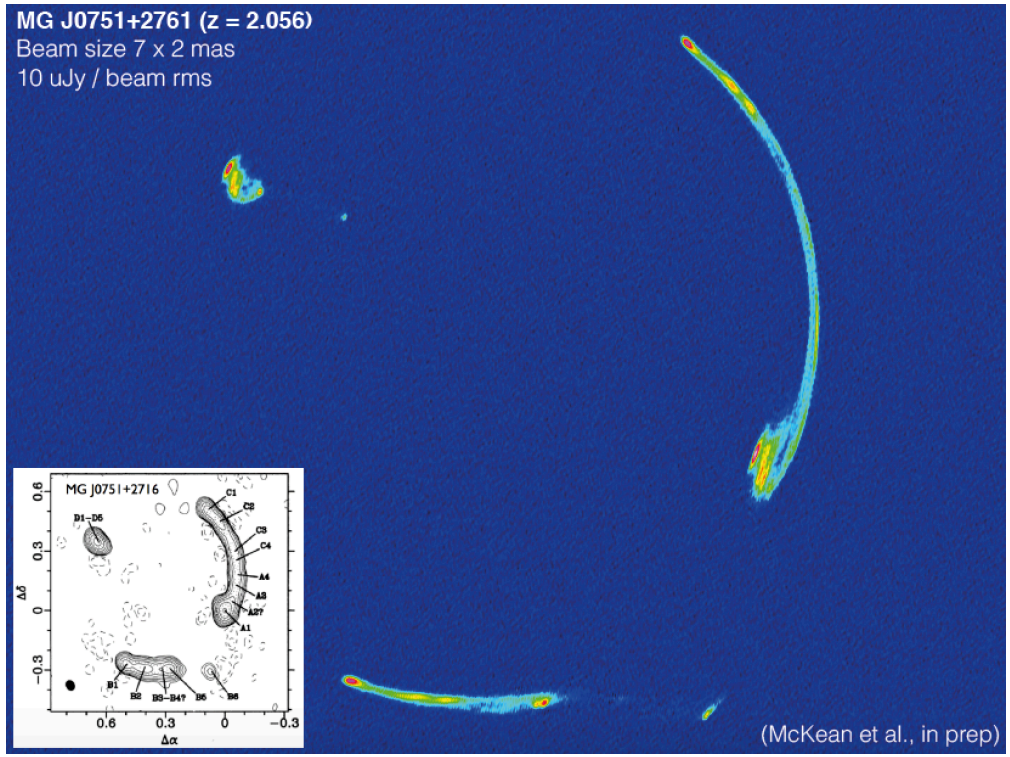


Intermediate-mass black holes



- The spatial coincidence of the EVN source with the location of unresolved, hard X-ray emission is one of the most compelling signatures of an accreting BH.
- Formed in situ? Nucleus of an accreted stripped dwarf galaxy?
- The mass is estimated to be 5×10^4 M_{sun}

Cosmology



McKean et al. in prep.

- Image gravitationally lensed radio jets in order to detect dark matter substructure
- Use deviations in the brightness distribution of gravitationally lensed arcs as tracers of sub-haloes around lensing galaxies
- Important for CDM models of galaxy formation

Summary

- Development can come either bottom-up (new technology looking for astronomical uses) or top -down - (defining astronomical problems first and finding technical solutions afterward). EVN does both.

- Communication and scientific interaction between engineers and scientists involved in the development and operation of radio astronomical instruments, such as the EVN, is very important

- EVN is making use of and drive technical progress

- The future for the EVN is looking bright (but we need more non-experts) also when we enter the SKA era

The EVN is producing excellent science

Thank you for your attention! Any questions?