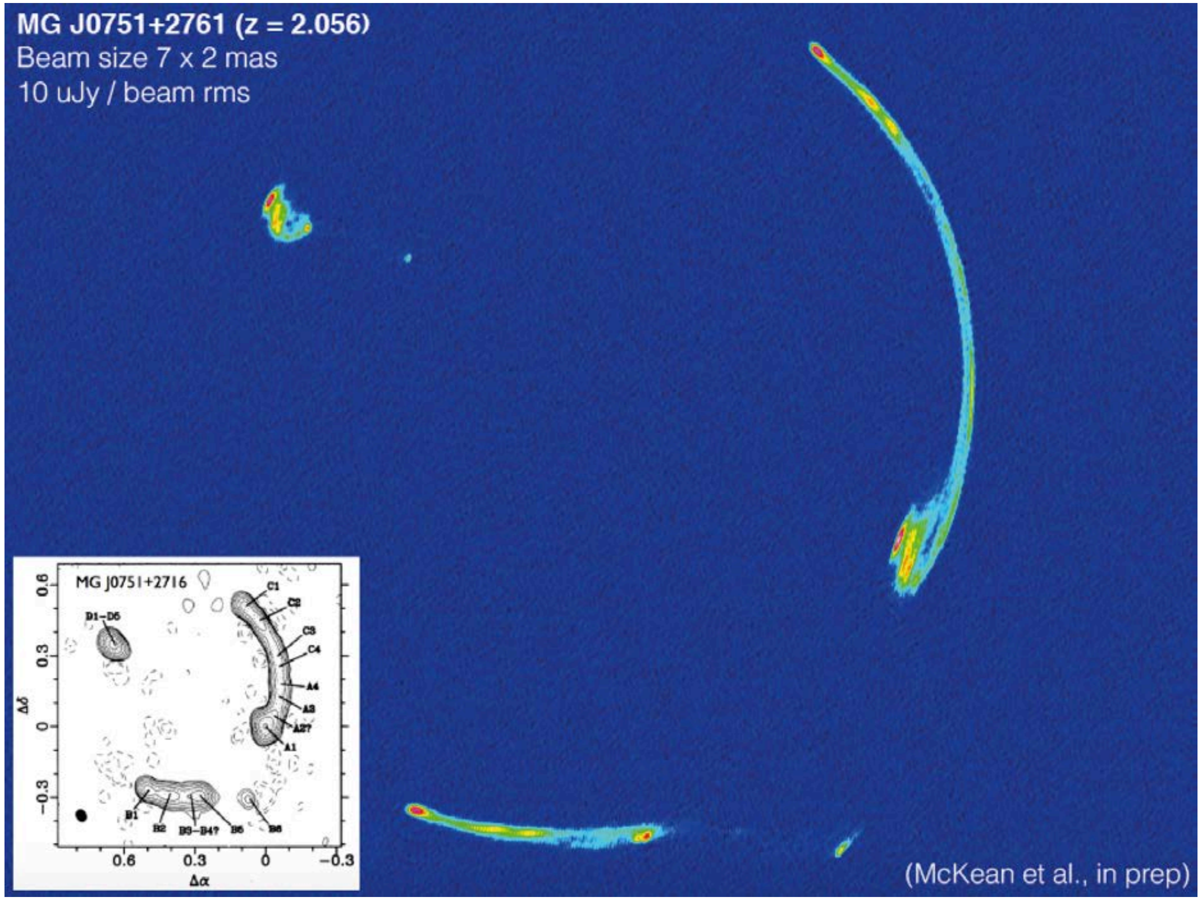
Science highlights from the EVN and SKA



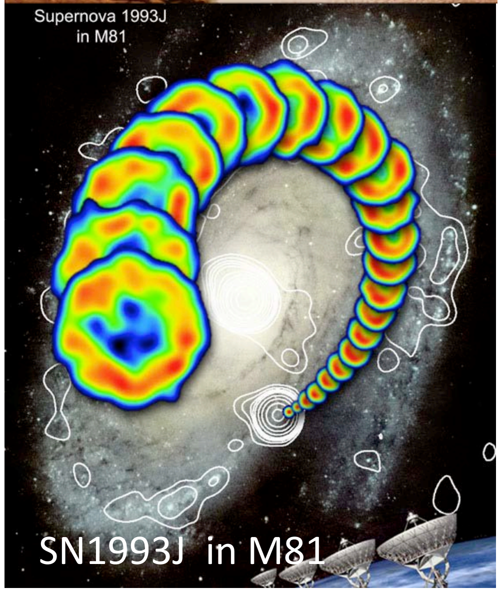
Michael Lindqvist, Onsala Space Observatory

VLBI science

VLBI continuum observations typically observe high brightness temperature radio emission from synchrotron processes

Radio spectral lines are observable in maser emission (OH, H_2O, SiO) and in absorption against bright continuum sources (mainly in HI, OH, and H_2CO)

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



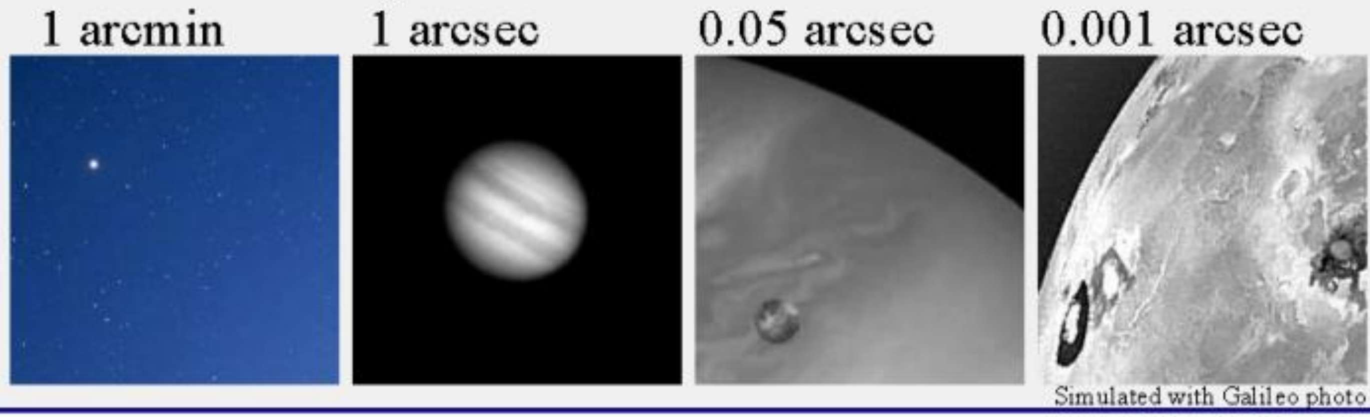
THE QUEST FOR RESOLUTION

Resolution = Observing wavelength / Telescope diameter

Angular Resolution	Optical (5000A)		Radio (4cm)	
	Diameter	**Instrument**	**Diameter**	**Instrument**
1′	**2mm**	**Eye**	**140m**	**GBT+**
1″	**10cm**	**Amateur Telescope**	**8km**	**VLA-B**
0.″05	**2m**	**HST**	**160km**	**MERLIN**
0.″001	**100m**	**Interferometer**	**8200km**	**VLBI**

Atmosphere gives 1″ limit without corrections which are easiest in radio

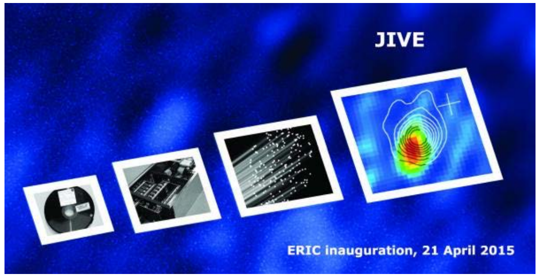
Jupiter and Io as seen from Earth



Description of the EVN

- The European VLBI Network (EVN) was formed in 1980. Today it includes 15 major institutes, including the Joint Institute for VLBI ERIC, JIVE

- JIVE operates the EVN correlator. JIVE is also involved in supporting EVN users and operations of EVN as a facility. JIVE was officially established as an European Research Infrastructure Consortium (ERIC) in 2015.



- The EVN operates an "open sky" policy

- No standing centralised budget for the EVN - distributed European facility

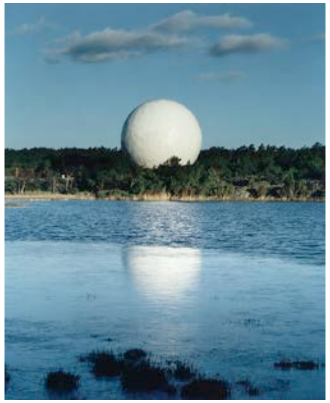
The network

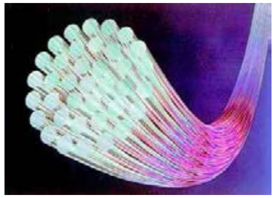
Image by Paul Boven (boven@jive.nl). Satellite image: Blue Marble Next Generation, courtesy of Nasa Visible Earth (visibleearth.nasa.gov).

EVN and e-VLBI

From tape reel to intercontinental light paths

- Pieces falling into place around 2003:
  - Introduction of Mark5 recording system (game changer) by Haystack Observatory
  - Emergence of high bandwidth optical fibre networks



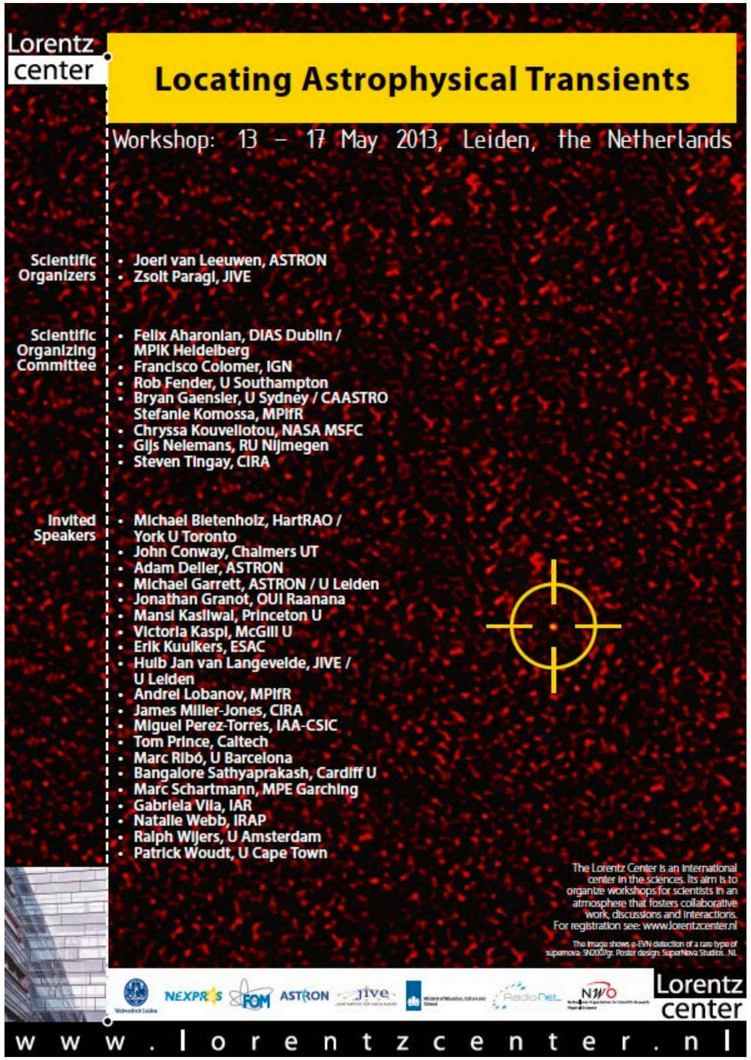


e-VLBI

Hot science

- The development of e-VLBI has been spearheaded by the EVN
- In this way, the EVN/JIVE is a recognized SKA pathfinder

e-VLBI - rapid turn-around



- e-VLBI has made rapid turn-around possible
  - X-ray, γ-ray binaries in flaring states (including novae)
  - AGN γ-ray outbursts — locus of VHE emission
  - Other high-energy flaring (e.g., Crab)
  - Outbursts in Mira variables (spectral-line)
  - Just-exploded GRBs, SNe
  - Binaries (incl. novae, XRBs) at specific orbital/ outburst phases

Current status

- **Call for proposals:** 3 times per year: (February 1, June 1, October 1)
- **Wavebands:** 90, 18, 6, 5, 3.6, 1.3, 0.7 cm
- **Not a full time array, the EVN observes during predefined "sessions":**
  - **70 days per year**
  - **Target of Opportunity**
  - **Out-of-Session**
- **Disk recording and/or e-VLBI**
- **Automated trigger e-VLBI** (tracking new source within 10 minutes)
- **Data correlated using the software correlator at JIVE**
- **Collaborations:** EVN+NRAO, EVN+RadioAstron, EVN+LBA
- ***Advice during proposal preparation etc:*** *Zsolt Paragi (zparagi@jive.eu)*

Current status

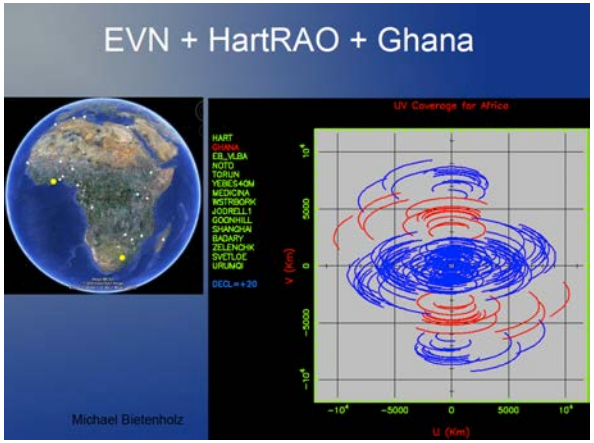
Maximum Angular Resolution in milliarcseconds

Array	90 cm	18 cm	6 cm	3.6 cm	1.3 cm	0.7 cm
EVN	-	15	5	3	1	0.6
EVN (inc. SH/Ur)	30	5	1.5	1	0.3	0.15
EVN+VLBA	19	3	1	0.7	0.25	0.13

- The angular size of the largest structure detectable (mappable) depends on the length of the shortest (projected) baseline (Eb-Wb)
- The largest detectable angular size is about 0.1" at 18 cm
- Larger angular scale-size? Consider joint EVN+eMERLIN

Enhancing EVN capabilities

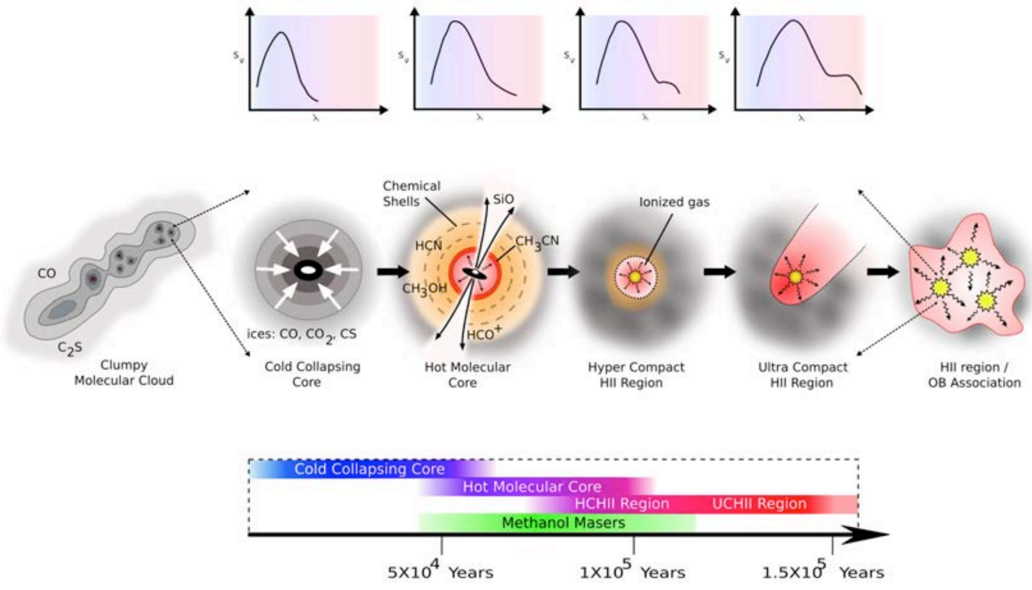
- **New telescopes and collaborations**
  - African VLBI Network (AVN), FAST, MeerKAT, …
  - SKA1 (*there will be VLBI with the SKA1*)



Most important – you!

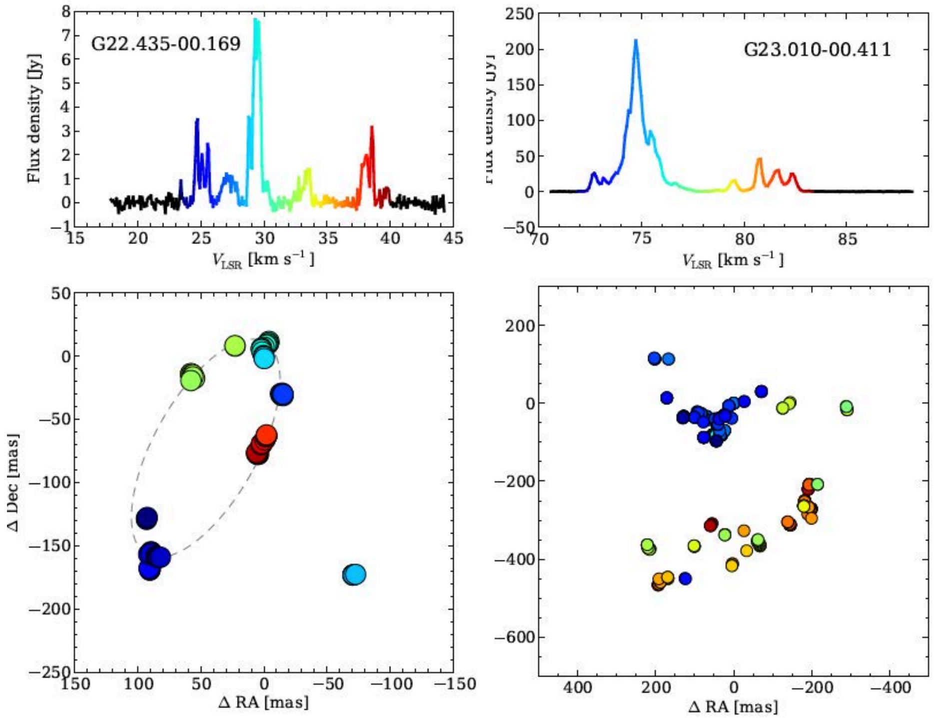
High mass star formation

- 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
- Methanol masers at 6.7 GHz are well known tracers of high-mass star-forming regions
- The EVN has pioneered the high resolution study of galactic methanol masers



C. Purcell

High mass star formation

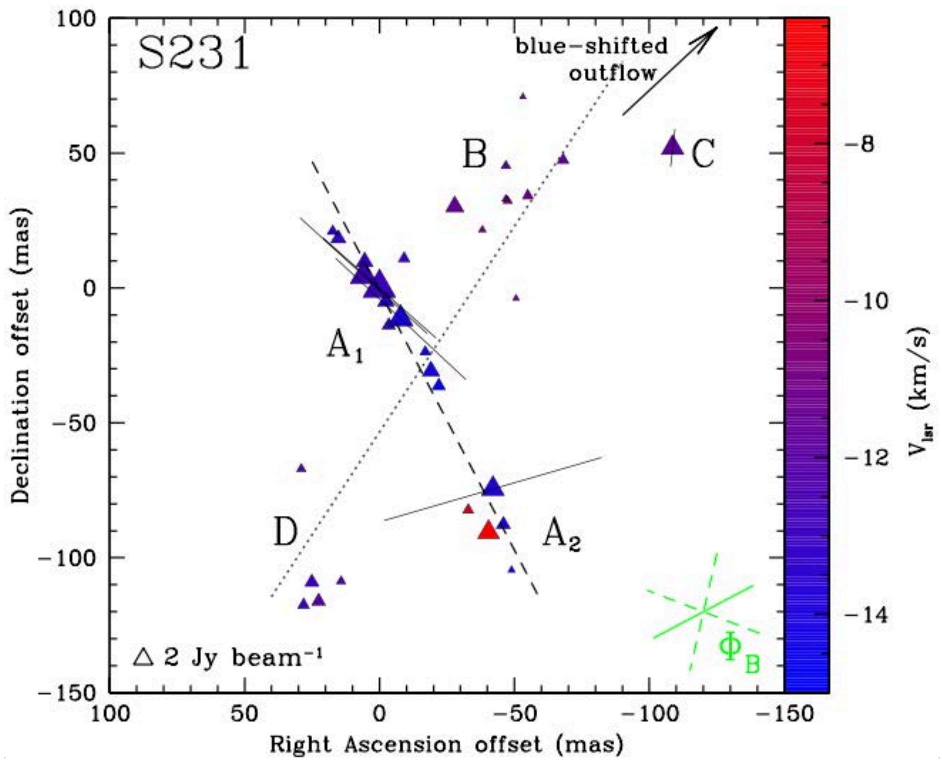


Bartkiewicz et al. (2016)

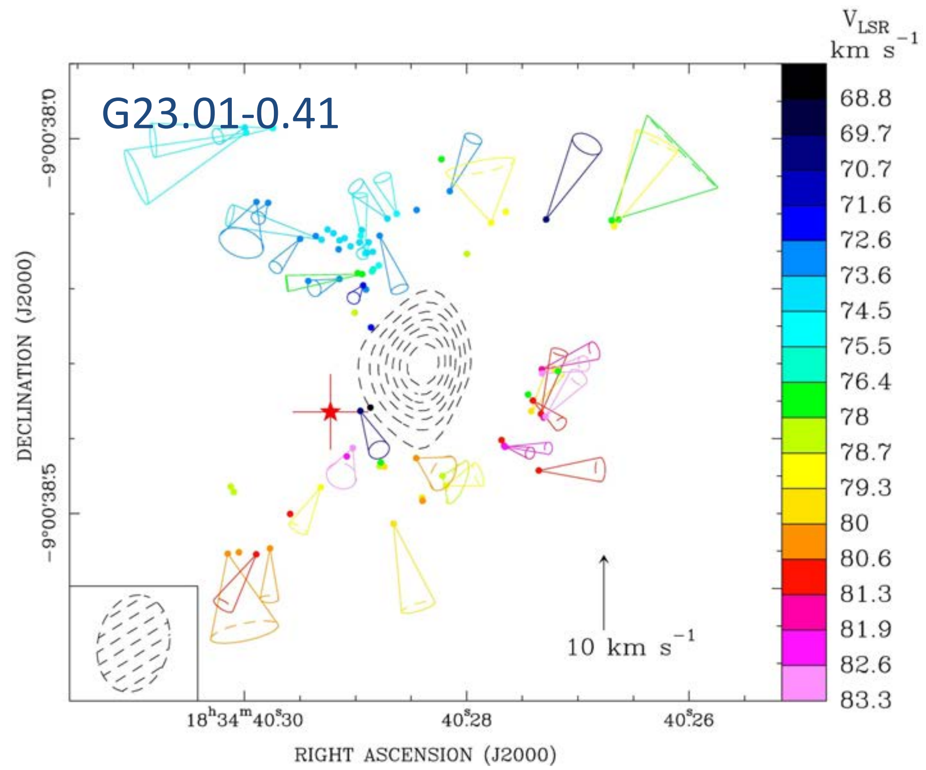
- Bartkiewicz et al. have in a series of papers collected a database of 63 source for detailed studies

Source structure	#
Simple	1
Linear	13
Ring-like	11
Arched	5
Paired	4
Complex	29

High mass star formation

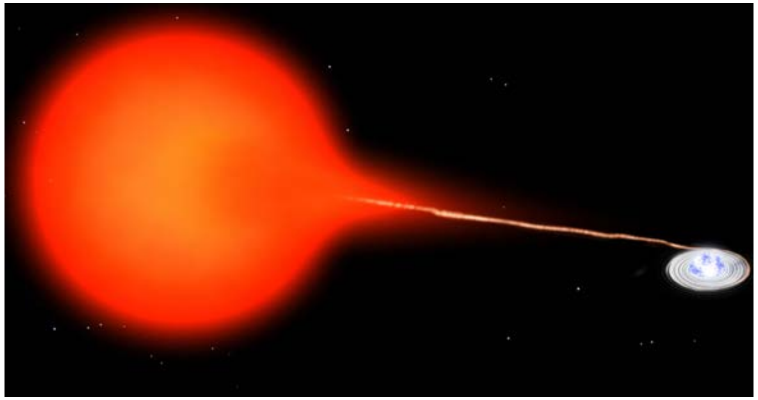


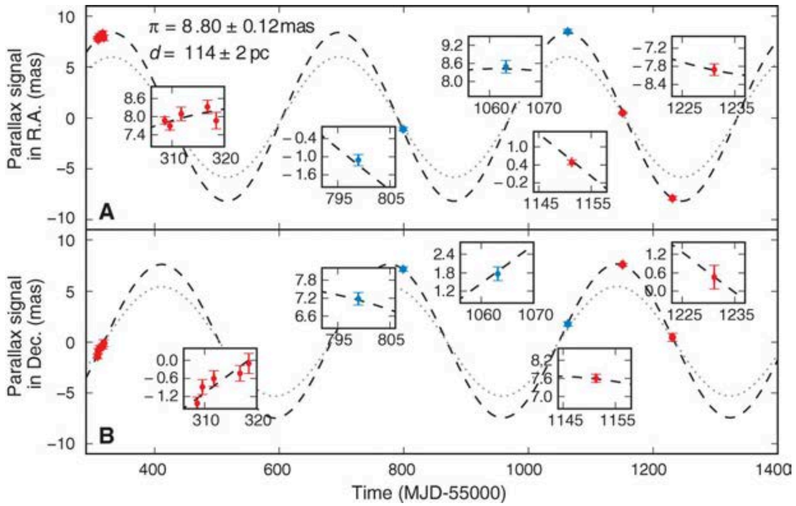
The magnetic field around the YSOs is preferentially oriented in the same way as the molecular outflows, Surcis et al. (2013, 2015)



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. (2013)

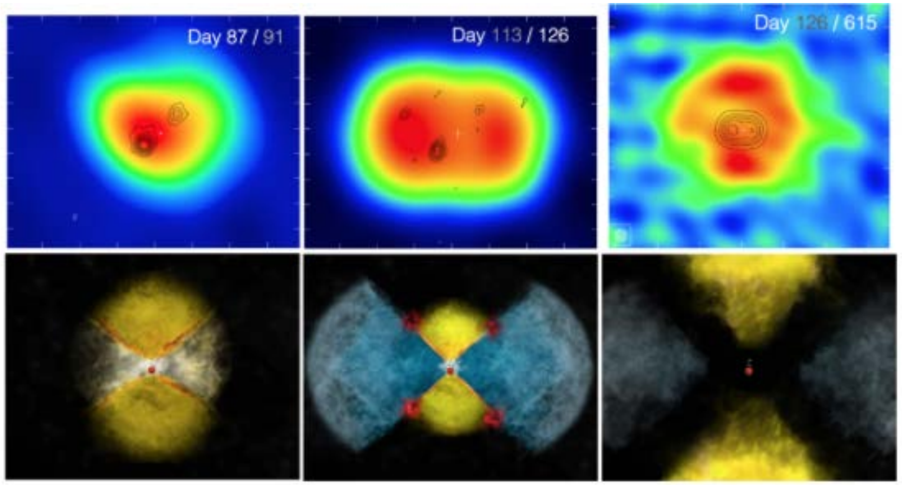
The dwarf nova SS Cygni





- 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

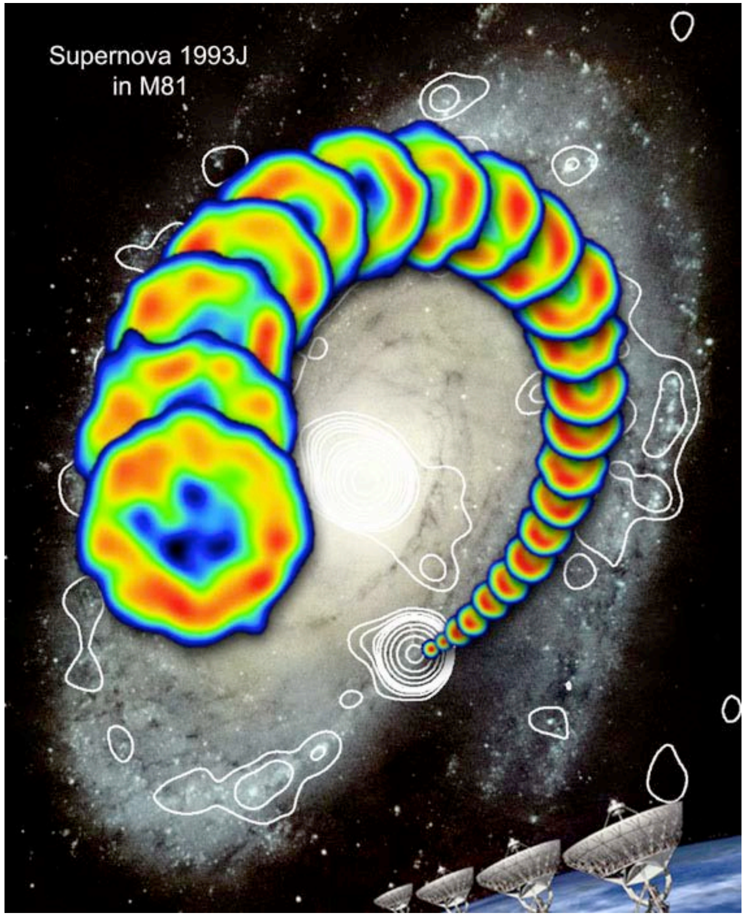
The γ-ray-emitting nova V959 Mon



Chomiuk et al. (2014)

- Why does it emit γ-ray?
- γ-rays are typically produced in really fast, violent shocks, and novae weren't supposed to have such energetic blasts
- VLBI data showed that the nova explosion is elongated like an hourglass
- The fast moving material in the hourglass plows into really dense, slow-moving material
- This interaction gives the violent shocks needed for gamma-ray production

Supernova 1993J in M81



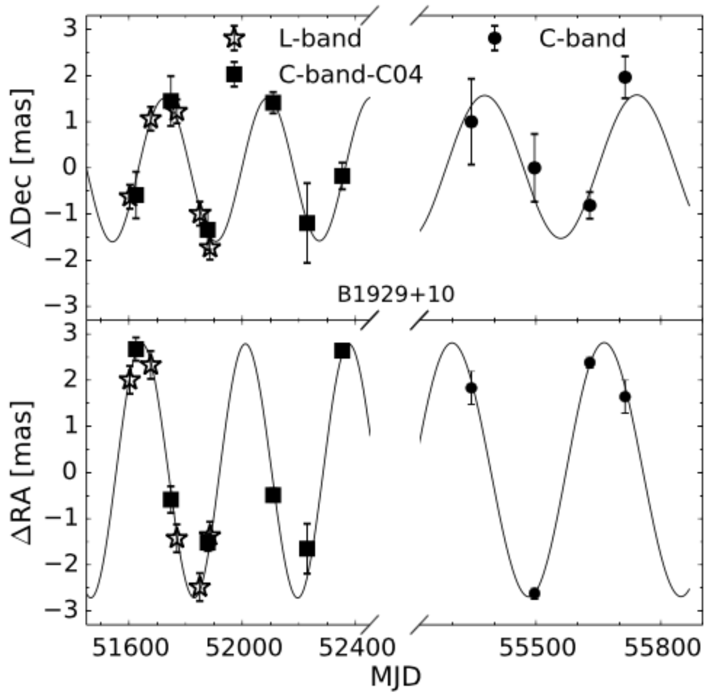
Bartel et al.; Marcaide et al.

- SN 1993J is a textbook example where one can trace the physical and structural evolution of an supernova, an exploding star
- From 1993 it has been the subject of intense studies

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

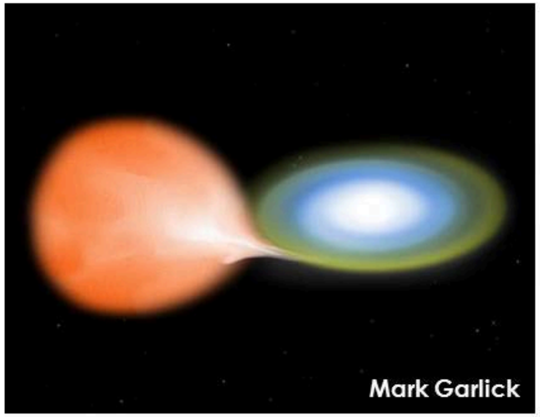


Kirsten et al. (2015)

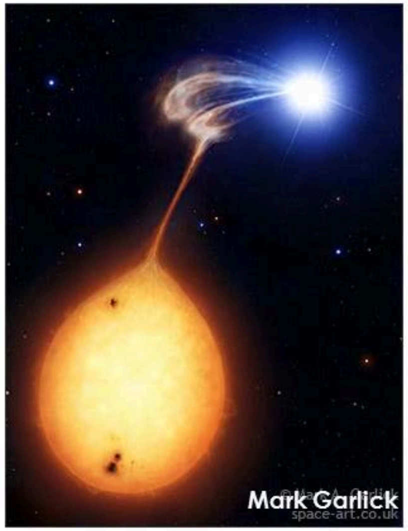
- Based on the new astrometry, extending for more than 10 years, they rule out previously proposed common origin scenarios

The annual parallax of cataclysmic binary system AM Herculis using e-VLBI

- A Polar is a highly magnetic type of cataclysmic variable (CVs) binary star system.
- Like other cataclysmic variables (CVs), they contain two stars: an accreting white dwarf (WD), and a low-mass donor star (usually a red dwarf) which is transferring mass to the WD.
- Polars are distinguished from other CVs by the presence of a very strong magnetic field in the WD.



Non-Magnetic CVs



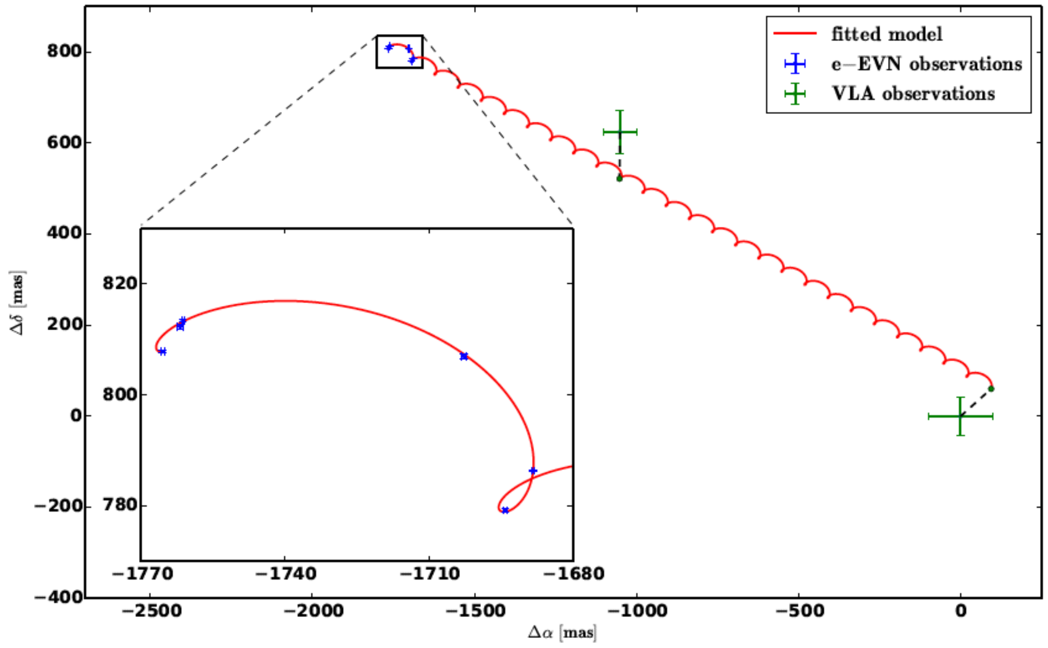
Polars

The annual parallax of cataclysmic binary system AM Herculis using e-VLBI

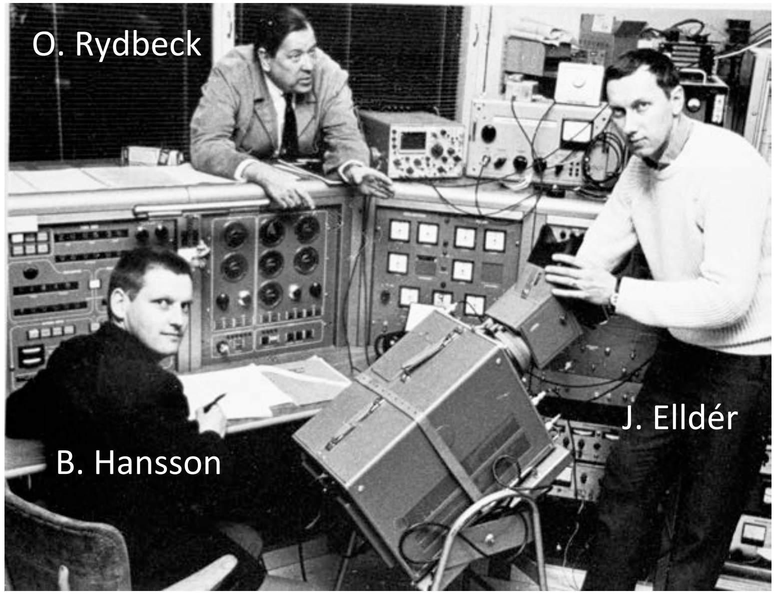
- Gawronski et al. (2016) used the e-EVN for a more precise distance estimate for AM Her

- With the addition of two archival VLA observations, they arrive at:
  d = 88.5 ± 2.8 pc

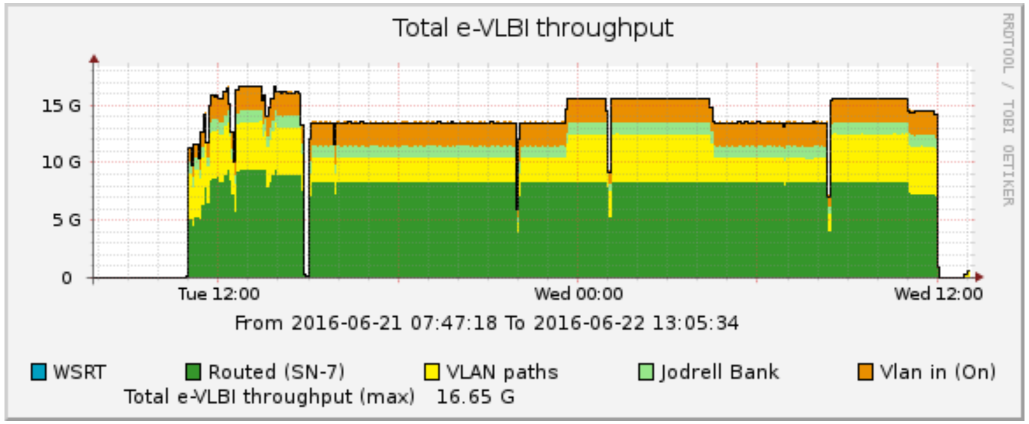
- The precise estimation is crucial in better understanding of physical parameters of these interesting stellar systems

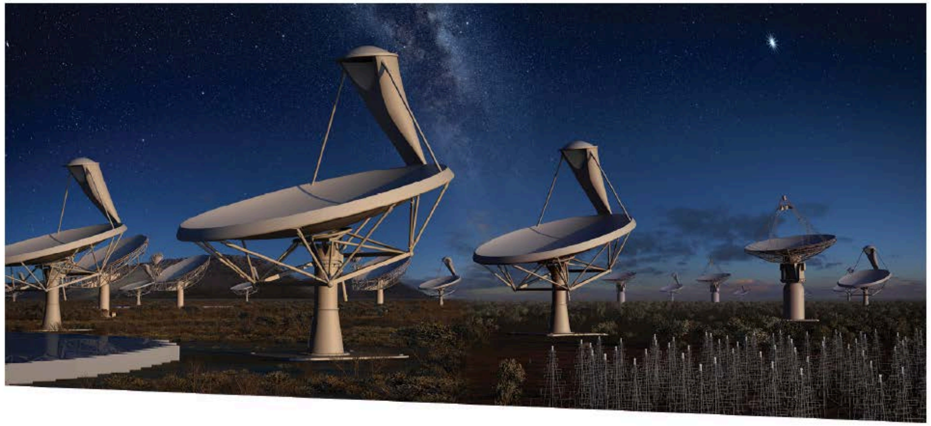


From the 60's via e-VLBI to the SKA

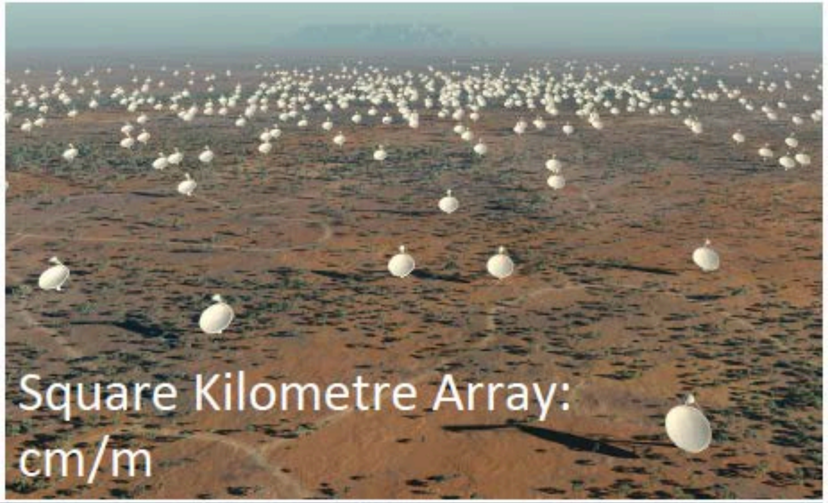


First transatlantic VLBI, Onsala, Sweden, 1968





SKA



Exploring the Universe with the world's largest radio telescope

SKA

2 sites; 2 telescopes

1 Observatory

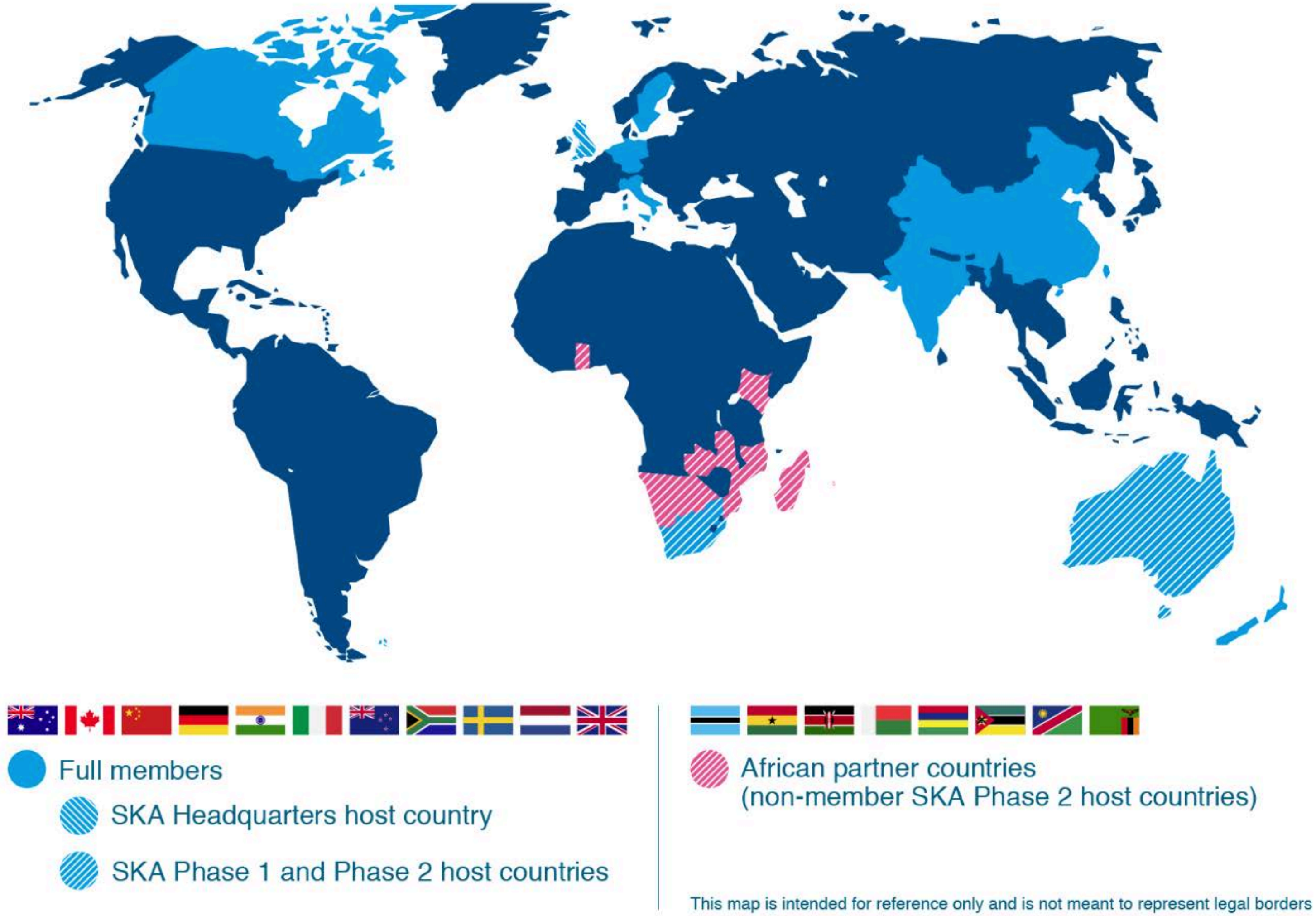
Phase 1

Construction: 2018 – 2023

Construction cost: € 650 M

Operations cost: ~ € 75 M/yr

Participating Countries



The SKA Organisation

- SKA Organization established as U.K. "Company Limited by Guarantee" (2011 December 14) to design SKA
- Sweden joined June 2012
- The expectation is that the SKAO will smoothly transition into the final 'SKA Observatory' which is planned to be an Inter-governmental Organisation

Australia
Canada
China
India
Italy
The Netherlands
New Zealand
South Africa
Sweden
United Kingdom

SKA1-MID, Karoo, South Africa

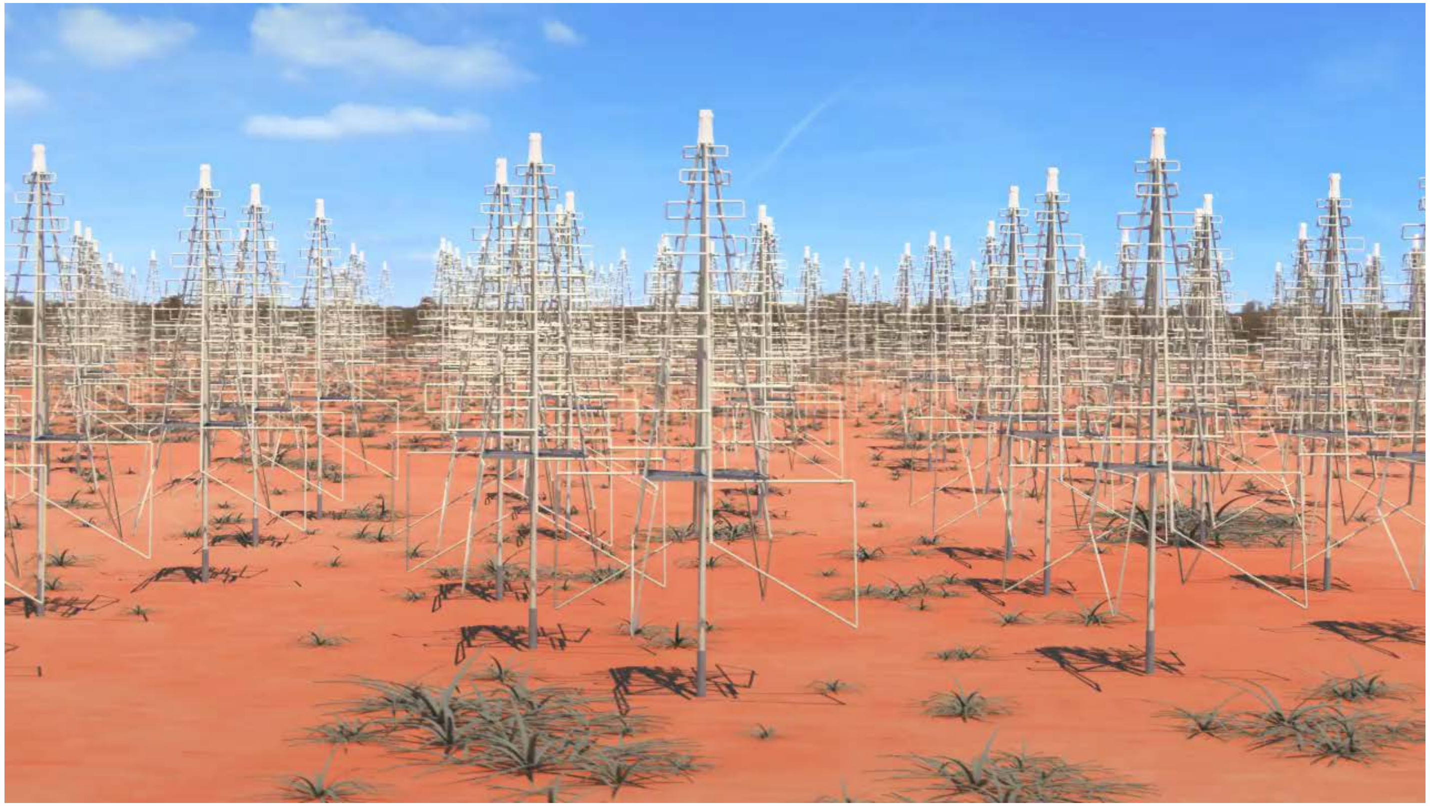
133 SKA1 + 64 MeerKAT dishes. Max baseline ~ 150 km.

Bands: 2 (0.95–1.76 GHz), 5 (4.6–13.8 GHz), 1 (0.35–1.05 GHz)

SKA1-LOW, Murchison, Australia

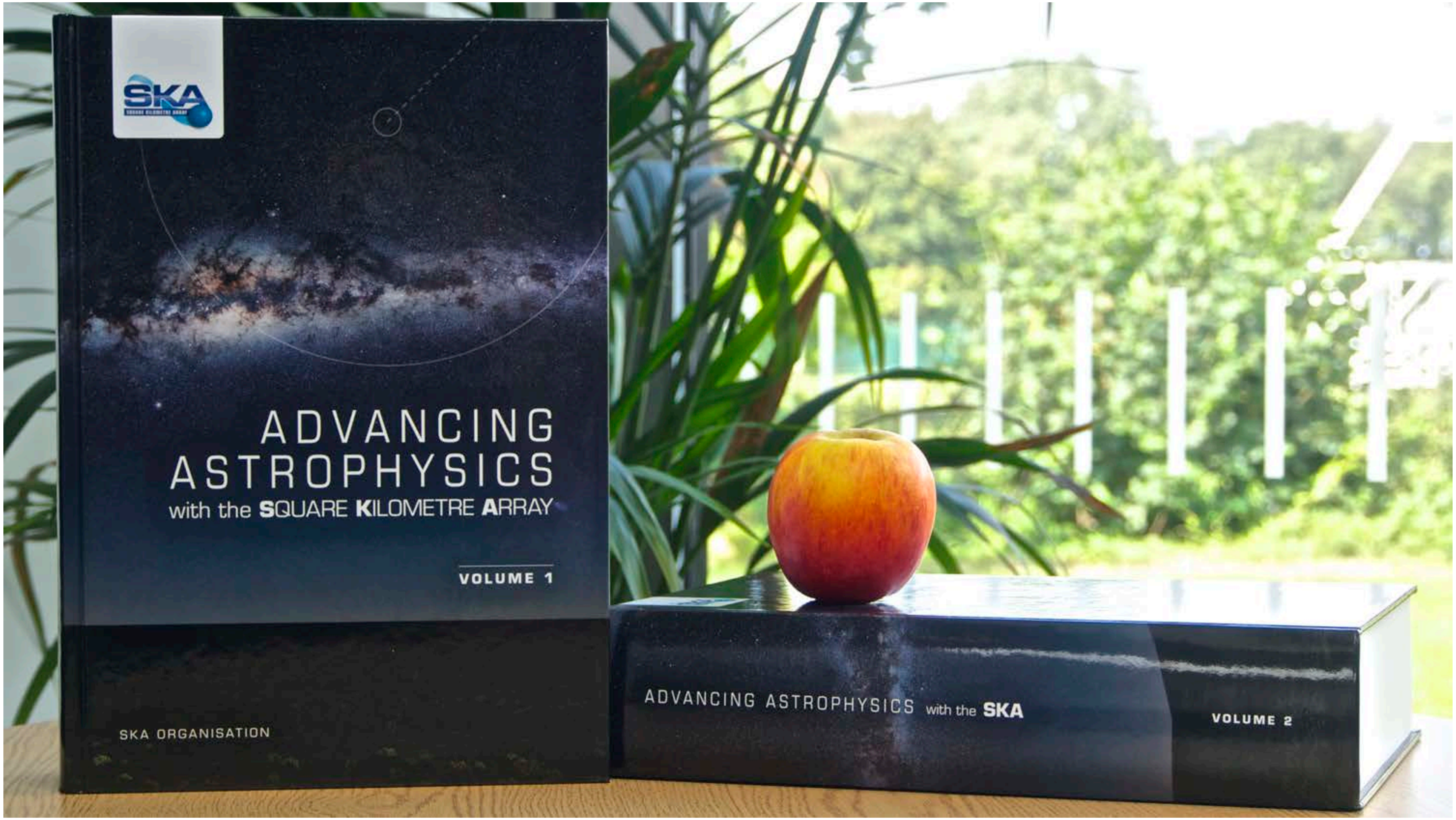
130,000 dipoles (512 stations x 256 antennas); 50–350 MHz

~ 80 km baselines; large areal concentration in core



SKA headline science

SKA Science book 2015



SKA Science examples

- Pulsar Wind Nebulae in the SKA era, Gelfand et al.
- Transient Astrophysics with the Square Kilometre Array, Fender et al.
- Incoherent transient radio emission from stellar-mass compact objects in the SKA era, Corbel et al.
- Core-collapse and Type Ia supernovae with the SKA, Pérez-Torres et al.
- Thermal radio emission from novae & symbiotics with the Square Kilometre Array, O'Brien et al.
- Protoplanetary disks and the dawn of planets with SKA, Testi et al.
- Maser Astrometry with VLBI and the SKA, Green et al.
- Complex organic molecules in protostellar environments in the SKA era, Codella et al.
- Very Long Baseline Interferometry with the SKA, Paragi et al.

OH masers in the Milky Way and Local Group galaxies in the SKA era, Etoka et al

- From SKA deep surveys at 18 cm they predict the discovery of more than 20.000 sources of stellar and interstellar origin throughout the Galaxy.
- They list many applications, including the determination of magnetic field strengths from polarisation measurements, studies of stellar kinematics using the precisely determined radial velocities, and distance determinations from VLBI astrometry.
- For the first time, larger numbers of OH masers will be detected in Local Group galaxies.

EVN in the SKA era

- The two instruments are complementary because the angular resolution of the EVN is better
- EVN also observes at shorter wavelength not available to SKA1
- Very-high-sensitivity VLBI observations will be possible using SKA1-MID acting as a single phased-up element
- Interest in the EVN will increase further in the SKA era as there will be increasing demand for follow-up VLBI observations at high resolution

EVN will still be unique in the SKA era

Thank you for your attention! Any questions?