# VLBI science in the EVN - now and in the future

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# Outline

- Description of the EVN
- Science with the EVN
- Summary

# Description of the EVN

- The European VLBI Network (EVN) was formed in 1980
  - MPIfR (Germany), IRA (Italy), ASTRON (The Netherlands), OSO (Sweden), JBO (UK)
- Today it includes 15 major institutes, including the Joint Institute for VLBI in Europe (JIVE)
  - The primary mission of JIVE is to operate and further develop the EVN correlator. JIVE is also involved in supporting EVN users and operations of EVN as a facility
- EVN has no central funding.
  - Institutes contribute to the operation of JIVE

EUROPEAN VLBI NETWORK

JOINT INSTITUTE FOR VLBI IN EUROPE

# Description of the EVN

- The overall policy of the EVN is set by the EVN Consortium Board of Directors (CBD)
- Technical aspects of EVN operations are considered by the Technical and Operations Group (TOG)
- The EVN is an open facility and encourages proposals from the entire astronomical community
- Proposals are submitted to the EVN Programme Committee (EVN PC) 3 times/year

# The EVN PC

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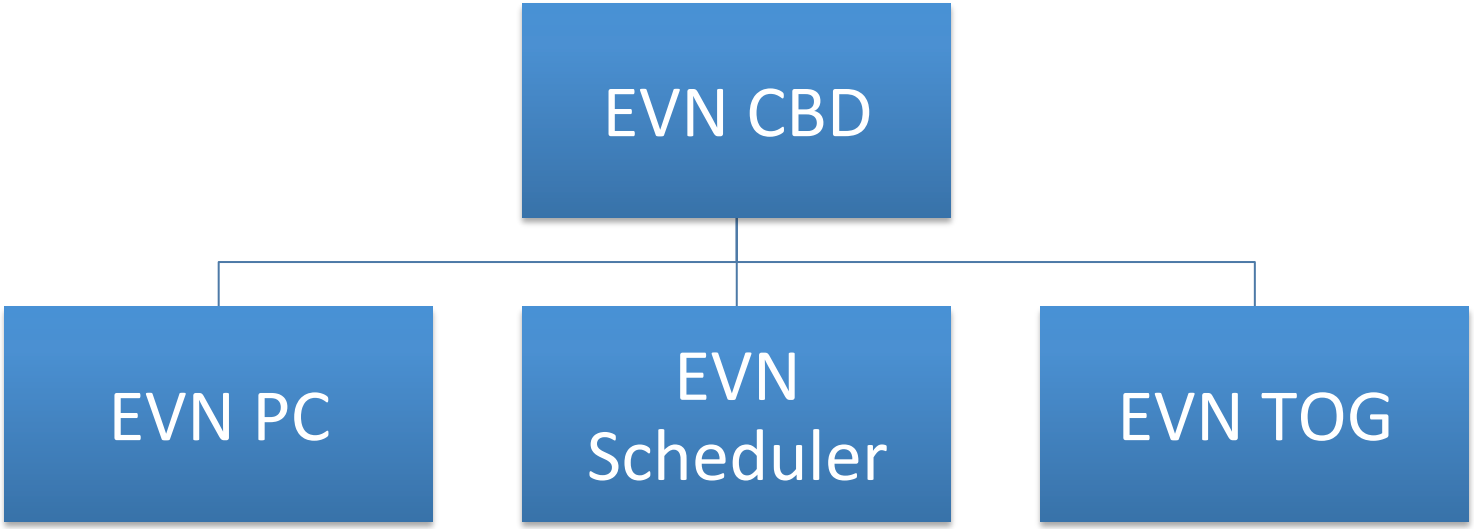
# Description of the EVN

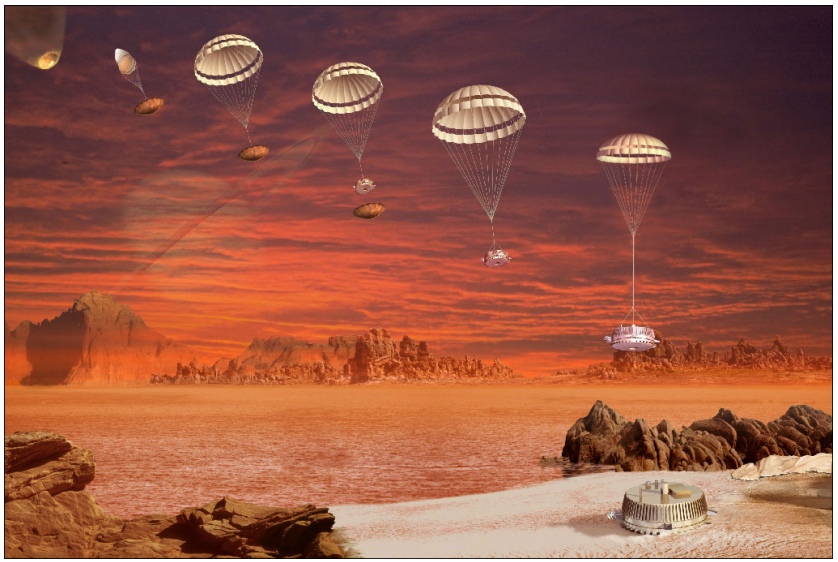
- The EVN observes during:
  - 3 EVN sessions (3x3 weeks)
  - 10 e-VLBI sessions (10x24 hours)
  - Target of Opportunity
  - Out of Session
- The scheduling is done by the EVN Scheduler
- The VLBI friends performs the observations

# Description of the EVN



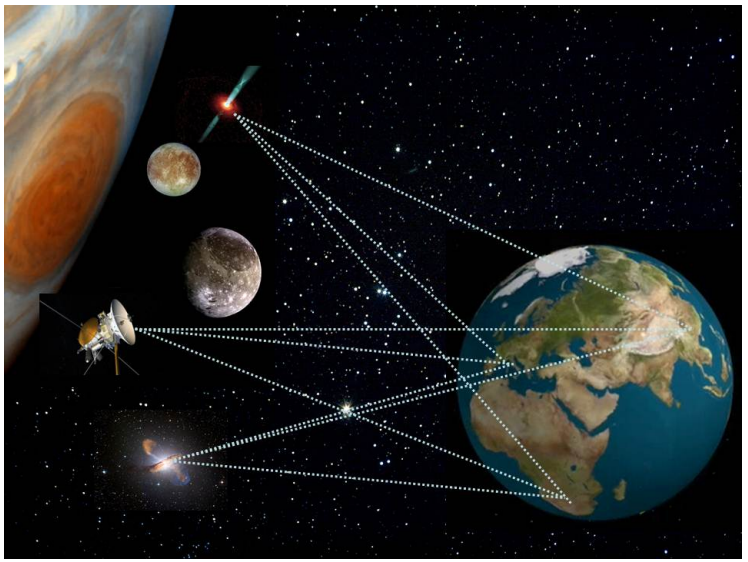
# Planetary science

## Huygens/Titan



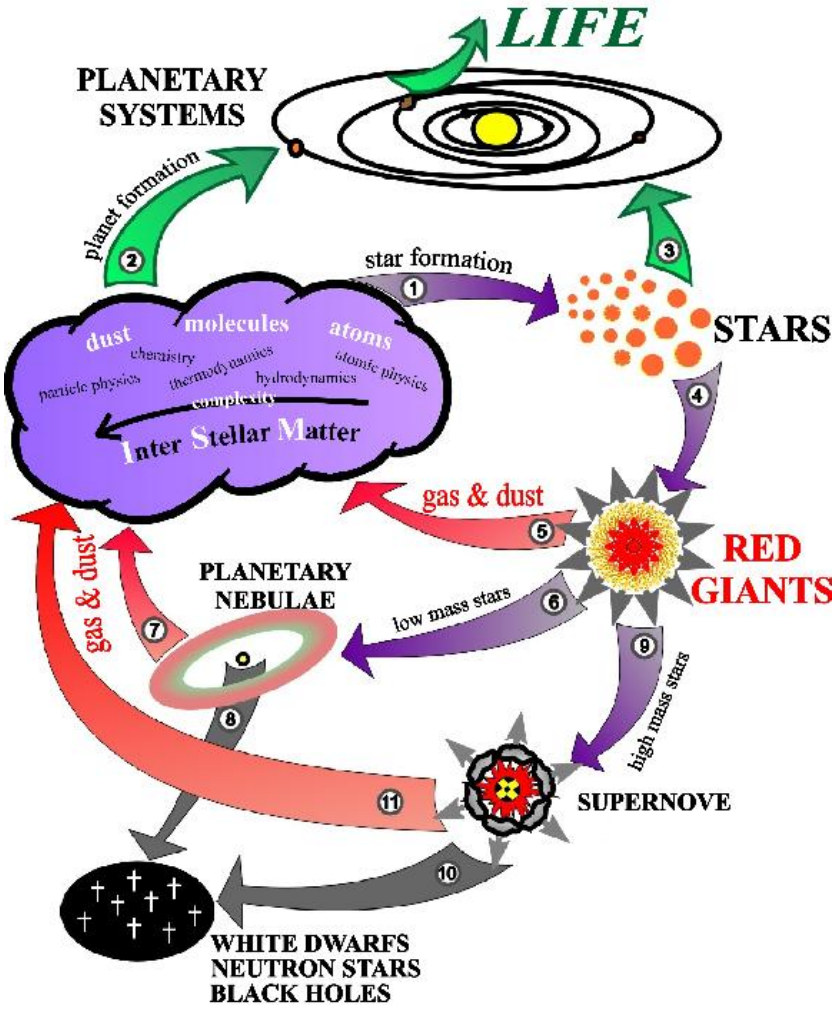
Gurvits et al.

## JUICE-PRIDE/Jupiter

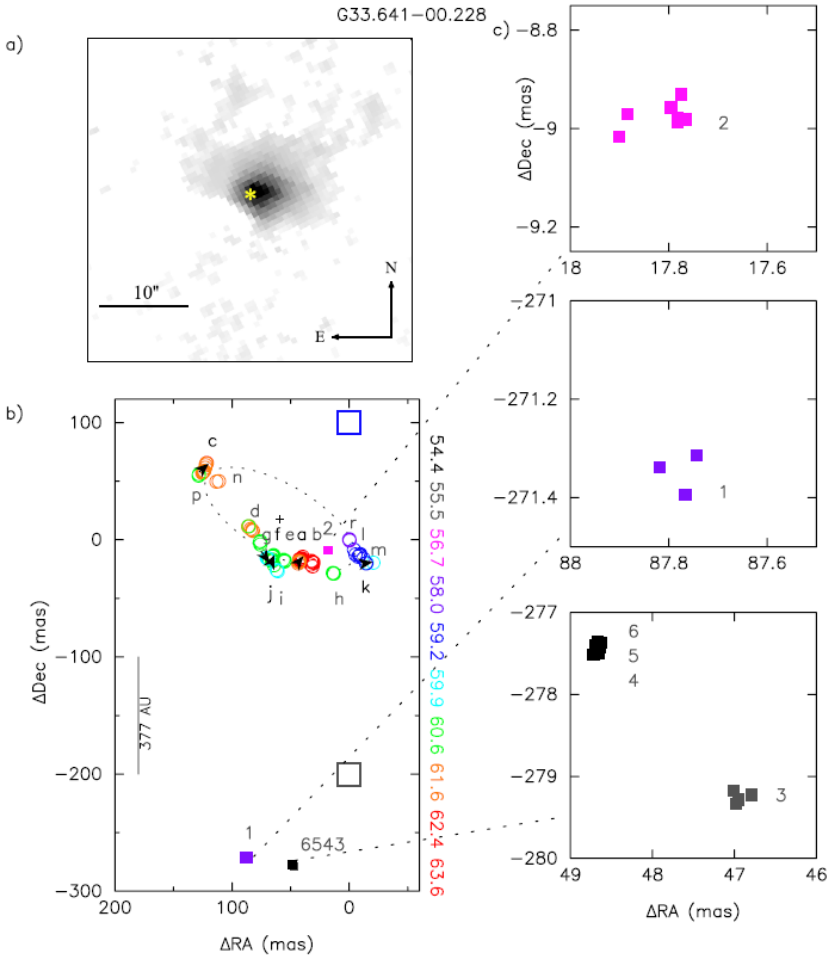


Gurvits et al.

# Stellar evolution



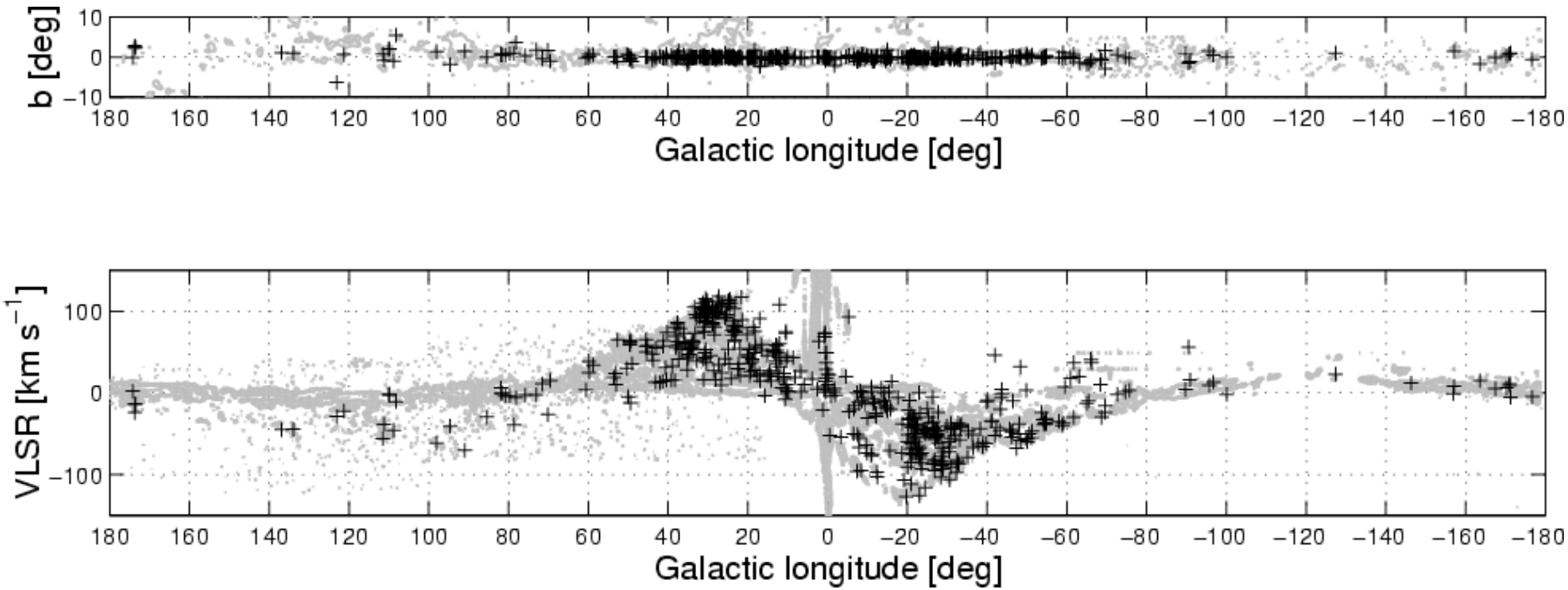
# High mass star formation




Bartkiewicz et al. 2012

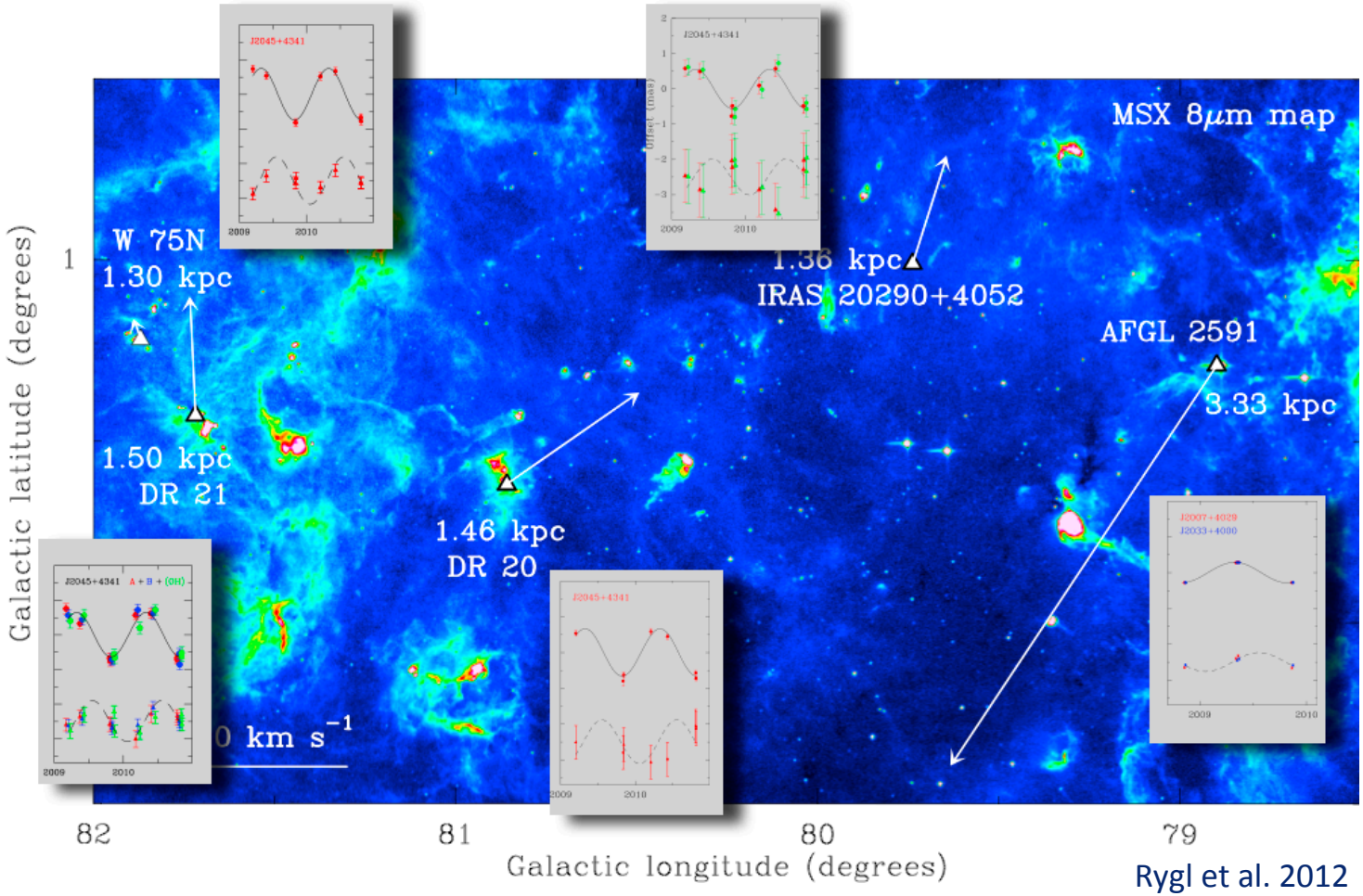
- The EVN has pioneered the high resolution study of Galactic methanol masers utilising its sensitivity, wide-field imaging polarisation capability, and astrometric accuracy
- This allows detailed modelling of the rotating disk of methanol masers around the high-mass protostar
  - a) Spitzer GLIMPse image + 22 $H_2O$ maser
  - b) Distribution of 6.7 GHz methanol masers (open circles, coloured by velocity)
    22 GHz $H_2O$ masers (EVN - closed squares, VLA – open squares)
  - c) Zoomed areas showing details of water maser positions

# Distribution of methanol masers



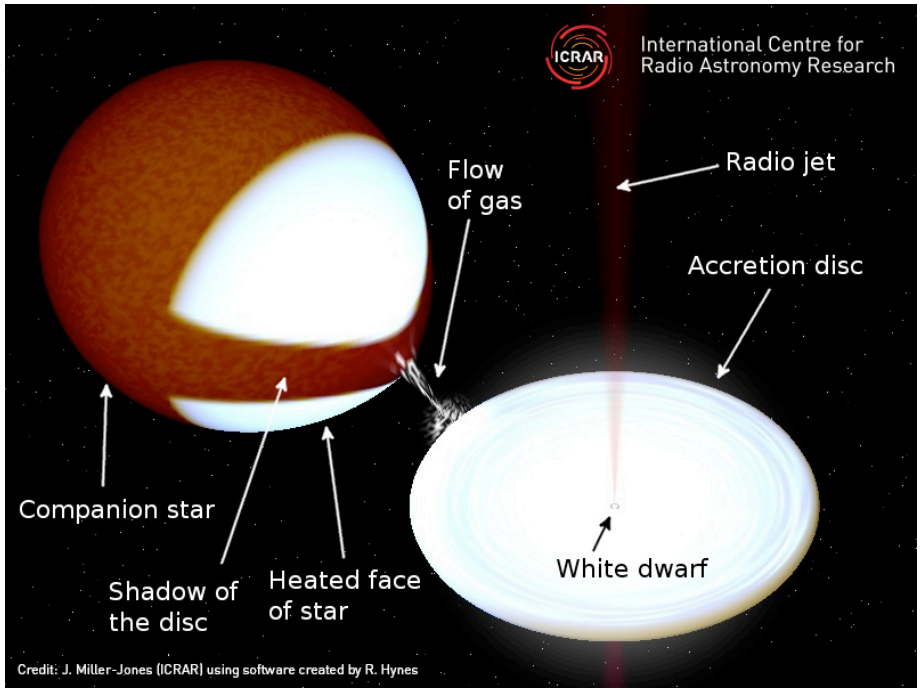

- Many sources could be observed with the AVN!

# Structure of the Milky Way




Rygl et al. 2012

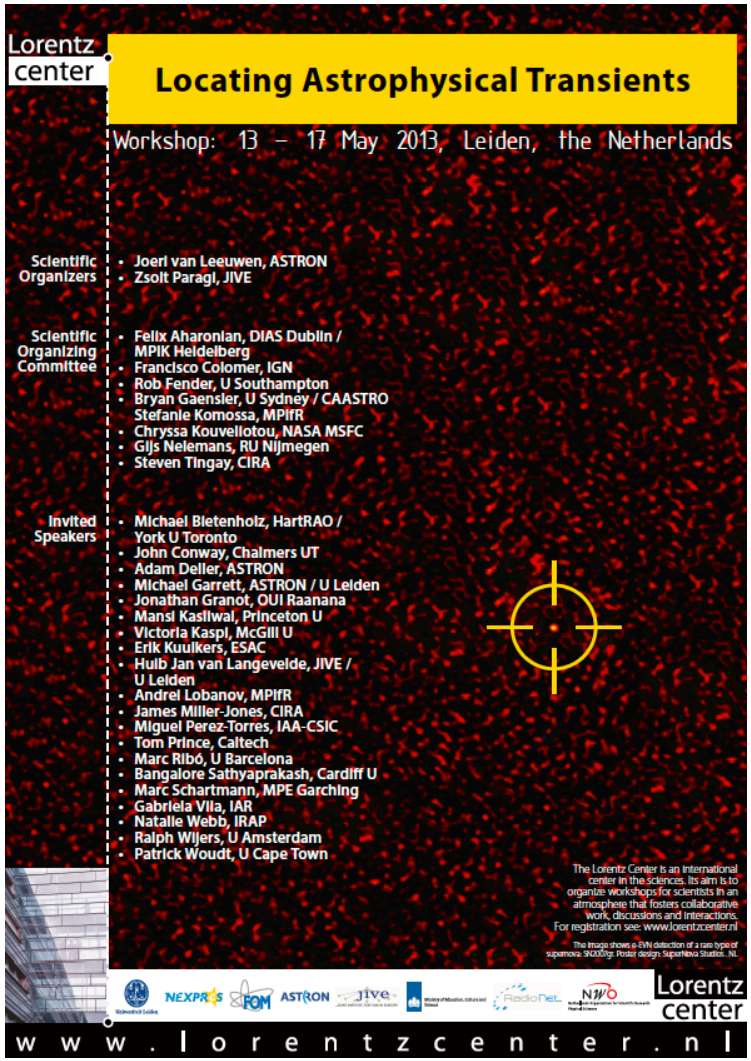
# The dwarf nova SS Cygni




J. Miller-Jones et al. 2013

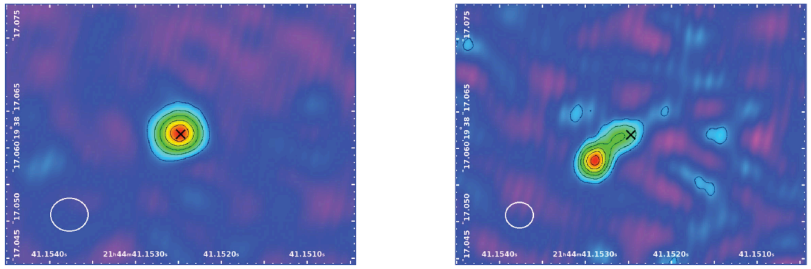
- SS Cygni – a challenge to our understanding of accretion disc theory?
- VLBI data places SS Cygni substantially closer, 114 pc, than HST data , 159 pc
- This reconciles the source behaviour with our understanding of accretion disc theory in accreting compact objects

# 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
- EXPReS/NEXPReS (EC-projects)
- New exciting science!

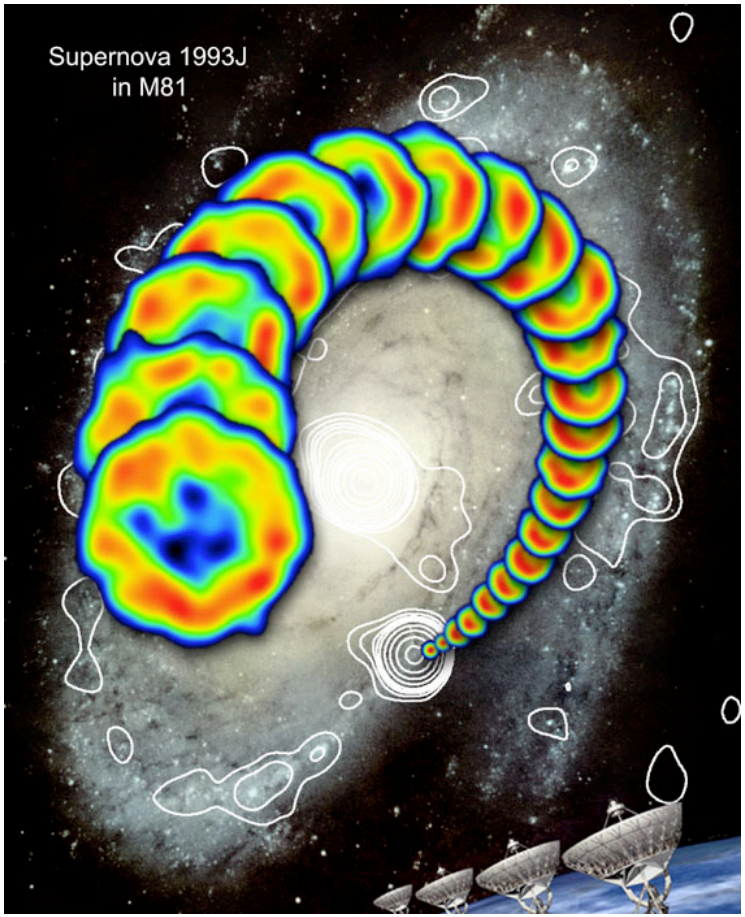
# e-VLBI - rapid turn-around



R.E. Spencer et al. 2013

- e-EVN observations on two successive days of the neutron-star X-ray binary Cyg X-2.
- The cross in both panels is the position of the peak flux of the first day image, showing that a jet has been launched, probably related to a mini-flare on the first day.
- The combination of EVN and X-ray data during this event helps constrain theoretical models of processes in the neutron-star/ accretion-disk environment.

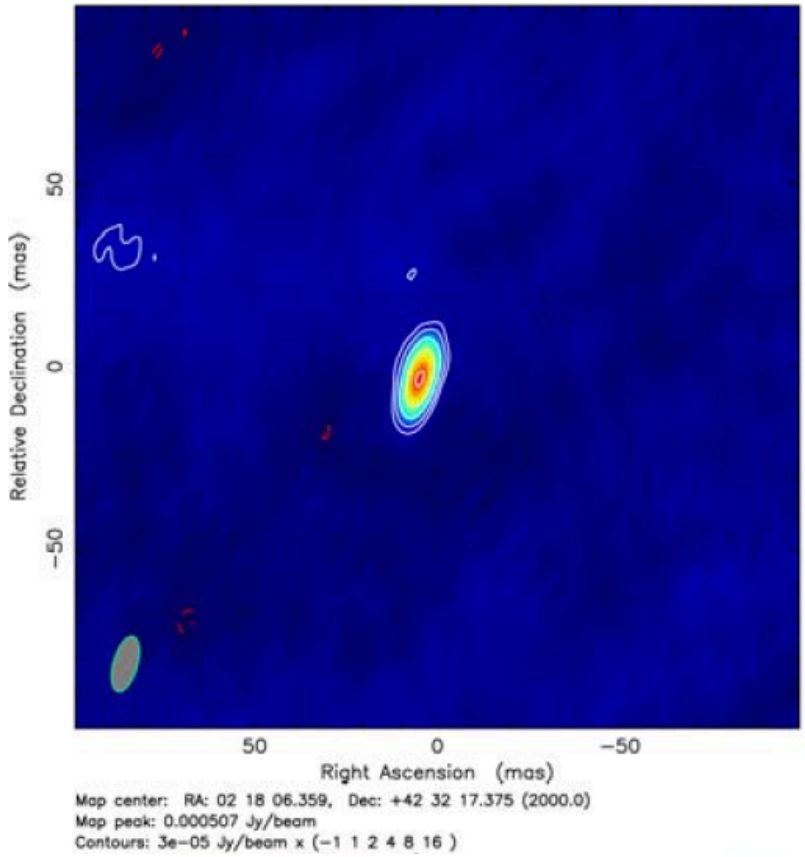
# Supernova 1993J in M81




N. Bartel et al., J.M. 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

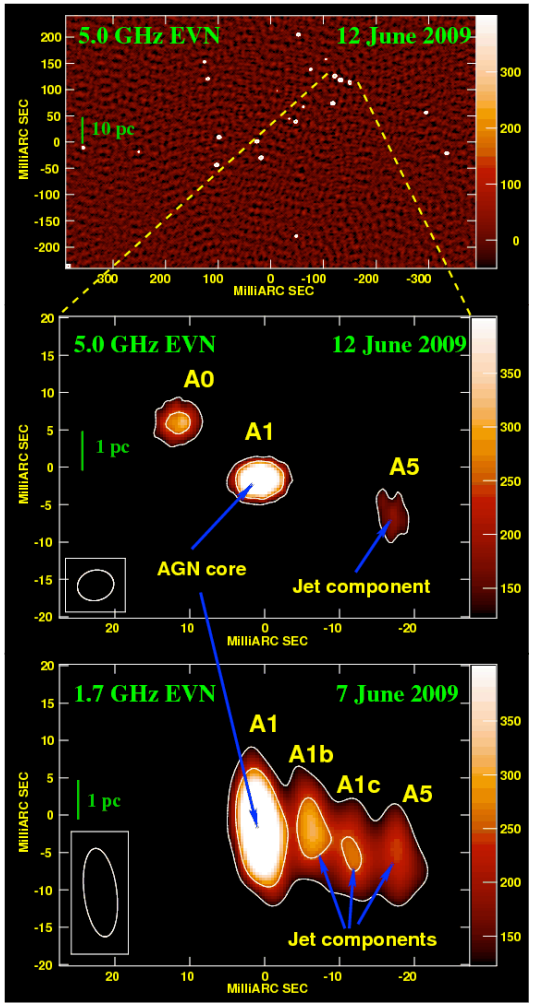
# The X-ray millisecond pulsar PSR J0218+4232




D. Chen et al. 2013

- The EVN software correlator at JIVE (SFXC) provides features that were never available on the MkIV, such as pulsar gating/binning
- VLBI astrometry of pulsars can yield the positions, proper-motions, and trigonometric parallaxes of the pulsars
- It has been suggested that X-ray ms pulsars are natural navigation beacons for deep-space satellites carrying small X-ray detectors!

# Multi-epoch EVN observations of Arp299-A

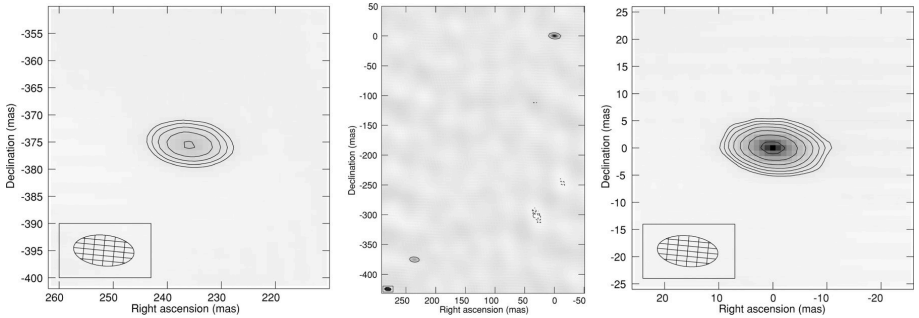



M.A. Pérez-Torres et al. 2010
M. Bondi et al. 2012

- Arp299-A is a luminous infrared galaxy at a distance of 45 Mpc
- The galaxy has been monitored with the EVN
- 26 compact sources (8 new) are detected in a region of about, 150 x 110 pc
- The data is consistent with them being a mixed population of core-collapse SNe and supernova remnants (SNR).
- They also conclude that A1 is the long-sought AGN in Arp 299-A.

# The search for dual SMBH

SDSS J1425+3231



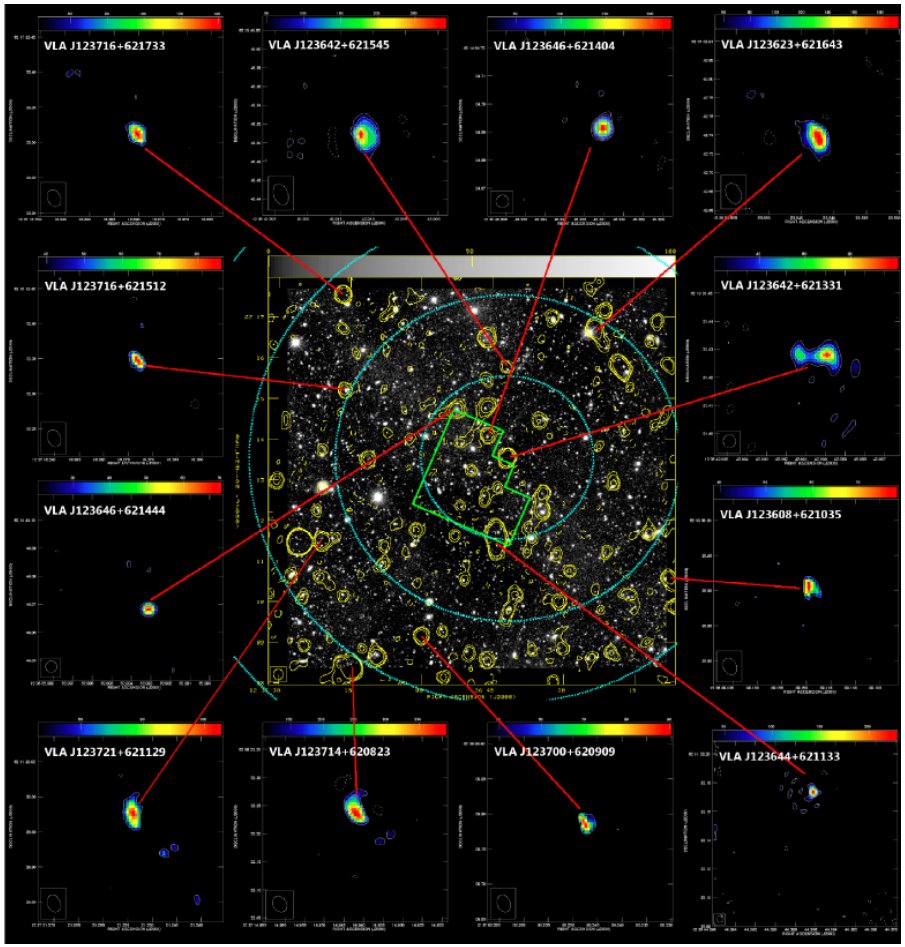

S. Frey et al., 2012

SDSS J1536+0441

M. Bondi et al., 2010

- Most major galaxies harbour supermassive black holes (SMBHs) in their centre.
- Hierarchical structure formation models involve interactions and mergers in which the host galaxies and their central SMBHs grow together
- In this scenario, one may expect to see some dual SMBH systems as the snapshots of the corresponding evolutionary phases of the merger process

# Starburts or AGN in faint sources at high redshift?




S. Chi et al., 2013

- The aim of the project is to determine the nature of the faint radio source population in the Hubble deep field north and its flanking fields
- Separate faint AGN and starburst galaxies
- Around 25% of star-forming galaxies of various types harbour faint AGN
- EVN can do even better now
  - sensitivity and multiple phase centres

# What do the user 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 |

# Enhancing EVN capabilities

- Observations at 4 Gbps (and beyond)
- New telescopes and collaborations (SRT, AVN, KVN, China)
- High speed connectivity to, KVAZAR, China, …
- Better frequency agility
- Improve flexibility (transients, ToO)
- eMERLIN+EVN at 1 Gbps
- Sub-arrays, more observing time with smaller telescopes
- Next generation correlators, new possibilities

# Summary

- EVN is producing excellent science
- EVN will complement the SKA
- Participate in VLBI-meetings
  - EVN symposia, EVN TOG-meetings, Interferometry schools, IVS TOW-meetings, VLBI Technical Workshops
- Looking forward to a scientific and technical collaboration with AVN!