# The Slow and the Fast: transients with the e-EVN

Zsolt Paragi, Joint Institute for VLBI ERIC

Contribution from Jun Yang (OSO), Zhigang Wen (Urumqi), Yuping Huang (Carleton College), Benito Marcote (JIVE), Aard Keimpema (JIVE) and EVN Users

# The transient parameter space

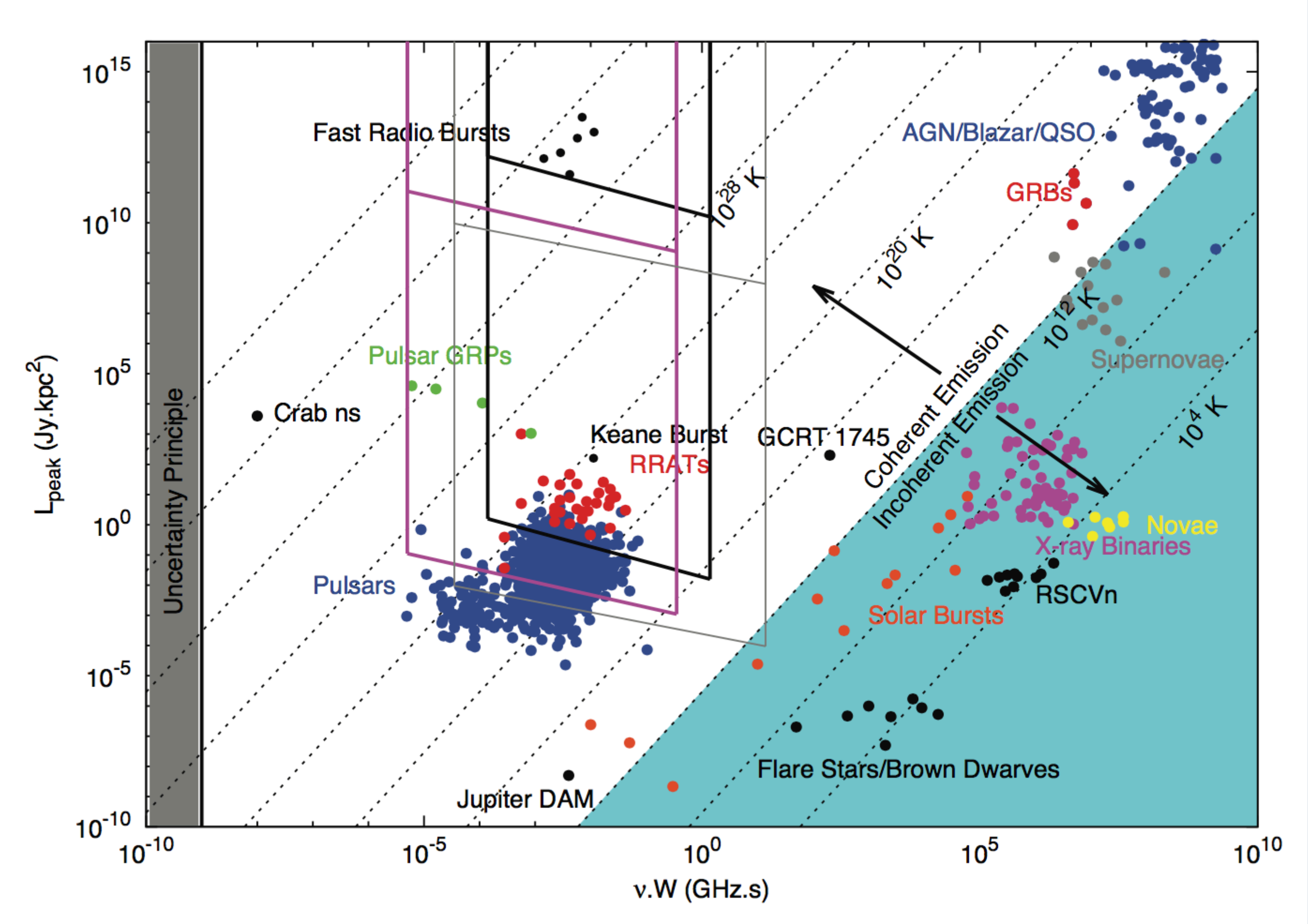
(Beam-formed) sensitivities at 1 kpc and 1 Gpc for:

**Parkes** (black lines)

**SKA1-LOW** (pink)

**SKA1-MID** (grey)

**(EVN ~ SKA1-MID)**




Specific luminosity vs. product of observing frequency and transient duration

*SKA Transient WG - Macquart et al. (2015);*
update of *Cordes, Lazio & McLaughlin 2004*

# EVN => e-EVN


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

# From triggers to (early) results

## e-EVN observations of V404 Cyg in outburst

ATel #7742; *V. Tudose (ISS), Z. Paragi (JIVE), J. C.A. Miller-Jones (ICRAR-Curtin), A. Rushton (Oxford), J. Yang (Chalmers), R. Fender (Oxford), S. Corbel (CEA), M. Garrett (ASTRON/Leiden), R. Spencer (Manchester)*
*on* ***1 Jul 2015; 16:43 UT***
*Credential Certification: Valeriu Tudose (tudose@spacescience.ro)*

Subjects: Radio, Binary, Black Hole, Transient

Referred to by ATel #: 7959

Tweet Recommend 20

Following the outburst of the transient X-ray binary V404 Cyg, we observed the system at 1.6 GHz on 2015 June 23/24 between 22:08-07:58 UT with the European VLBI Network (EVN), using the e-VLBI technique. The participating radio telescopes were Effelsberg, Hartebeesthoek, Jodrell Bank MkII, Medicina, Onsala85, Shanghai, Torun, Westerbork (5 telescopes of the phased-array).

Due to the heavy scattering towards the target, the longer baselines with Shanghai were significantly affected and had to be deleted. Significant variations in the flux density of the source (by a factor 1.5) also influenced the quality of the radio image. However, we clearly detected V404 Cyg as a point-like source (beam FWHM: 30 x 13 mas; PA: 83 deg) with a peak brightness of 166 +/- 5 mJy/beam at the position (J2000):

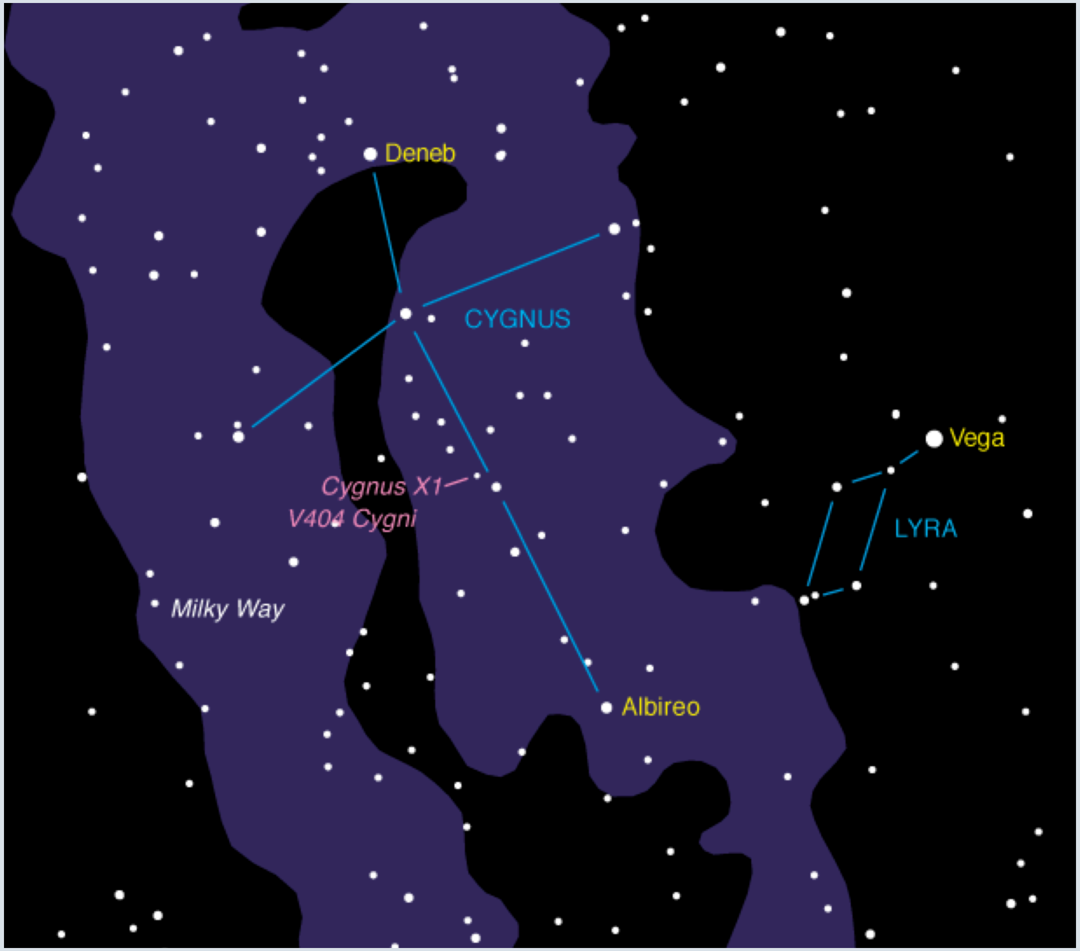
RA: 20h24m03.8183983
Dec: +33d52m01.840768"

We estimate the systematic error in astrometry to be of a few mas due to poorly modeled ionosphere and large line-of-sight scattering.

We do not see any evidence for extended radio emission above a 3-sigma rms noise level of 0.5 mJy/beam, at scales from 5 mas up to 200 mas.

We take the opportunity to note that these observations represent the last occasion on which the MFFE receivers and TADU system were used to form the Westerbork tied array. We thank the "old" Westerbork for the excellent VLBI science it has generated over the last few decades and look forward to the "new" Westerbork system employing the APERTIF Phased Array Feeds.

The European VLBI Network (EVN) is a joint facility of European, Chinese, South African, and other radio astronomy institutes funded by their national research councils. The observations presented here were obtained under the project code ET031A.




**e-VLBI: Delivering the most sensitive VLBI array in a flexible way...**

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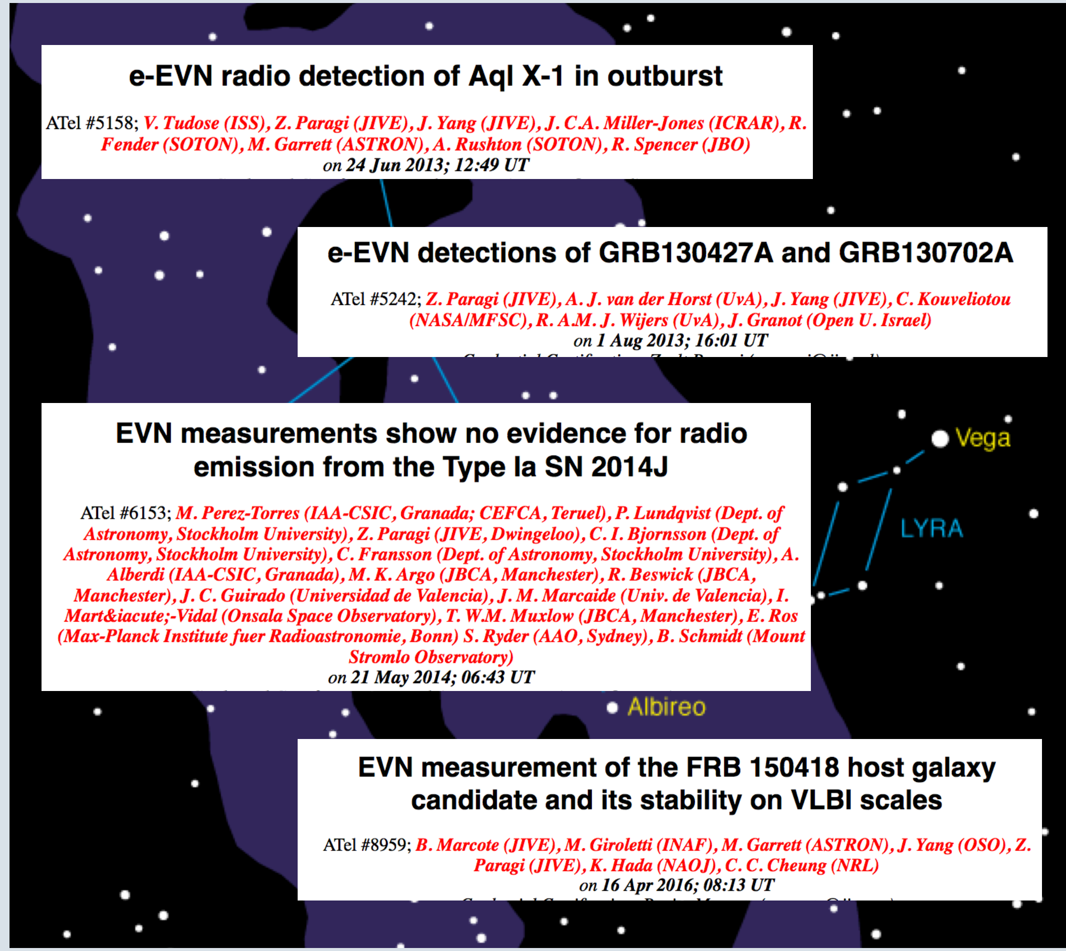



**e-VLBI: Delivering the most sensitive VLBI array in a flexible way…**

# Triggering timescales for e-VLBI

| Transient | Early trigger | Typical duration |
| --- | --- | --- |
| cataclysmic variables | | |
| RS CVn | hours | $\sim$1 day |
| classical and gamma-ray novae | within a week | months |
| "faint and fast" sub-class | 1 day | days-weeks (no known radio detection) |
| dwarf novae | hours | $\sim$1 day |
| "gap transients" | | |
| Ca-rich | days | 100 days (no known radio detection) |
| SN2002bj, PTF10bhp-like (.Ia) | hours | days (no known radio detection) |
| supernovae | | |
| Type Ia | days | years (no known radio detection) |
| Type Ib/c | days | months |
| Type II | days | years |
| gamma-ray bursts | | |
| short-GRB afterglows | hours to days | days |
| long-GRB afterglows | hours to days | weeks to years |
| prompt GRB emission | minutes | ? |
| X-ray transients | | |
| supergiant fast XRT | ? | no known radio detection |
| black hole X-ray binaries | hours–days | days–weeks |
| neutron star X-ray binaries | hours | days |
| isolated stellar-mass BH | ? | no known example |
| (super-)massive black holes | | |
| flaring AGN | $\sim$1 month | years |
| tidal disruption events | weeks | months–years |
| short radio transients ($t < 2$s) | | |
| Lorimer bursts prompt emission | real-time | 1–10 ms |
| Lorimer bursts afterglow | minutes | no known example |
| NS–NS mergers | minutes | no known example |

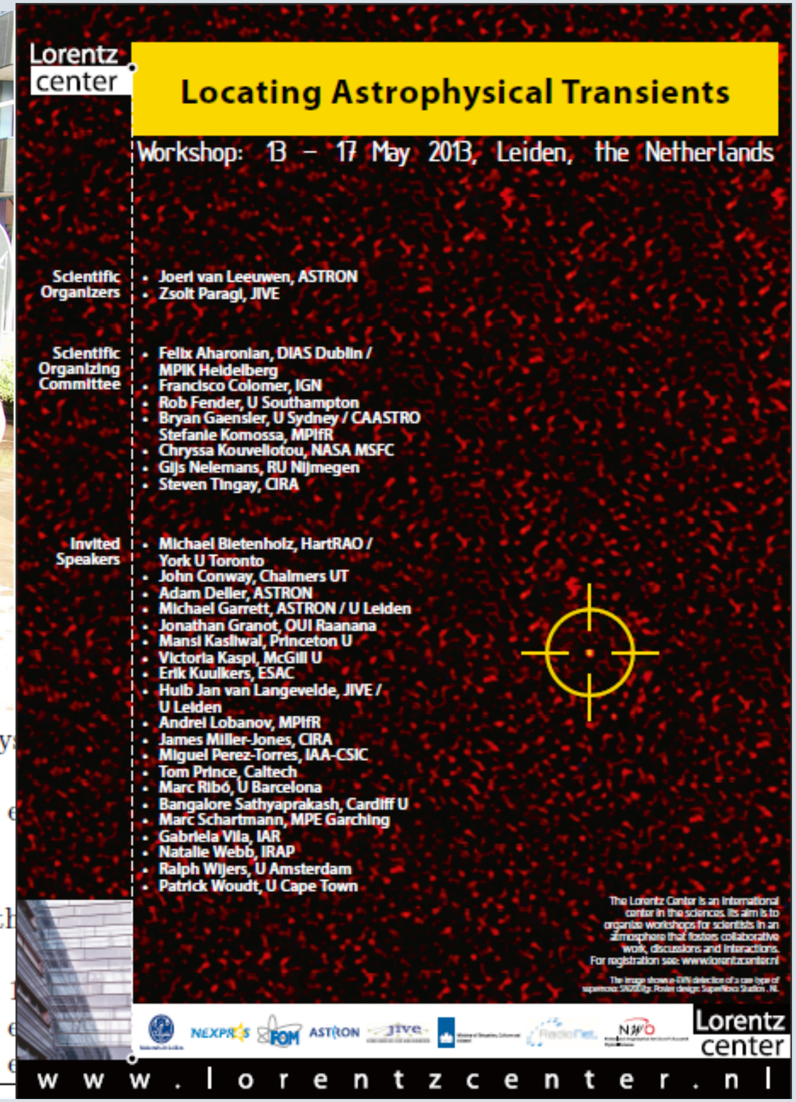
From the final report of the *Locating Astrophysical Transients* workshop, Lorentz Center, Leiden, 2013

**… on various timescales**

# Triggering timescales for e-VLBI

| | | |
|---|---|---|
| black hole X-ray binaries | hours–days | day |
| neutron star X-ray binaries | hours | |
| tidal disruption events | weeks | month |
| short radio transients ($t < 2$s) | | |
| Lorimer bursts prompt emission | real-time | |
| Lorimer bursts afterglow | minutes | no known e |
| NS–NS mergers | minutes | no known e |

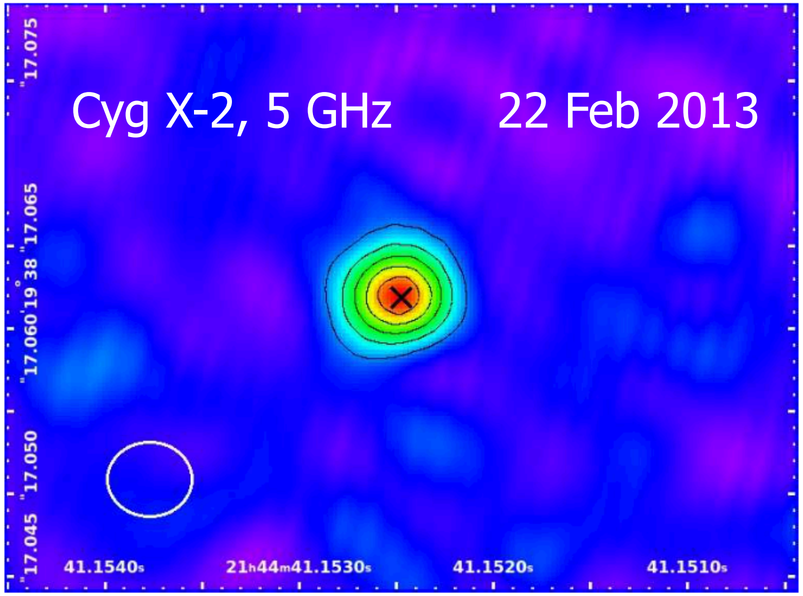
- **Special discussion on automated triggering**
- **Highlighting fast radio burst (FRB)**

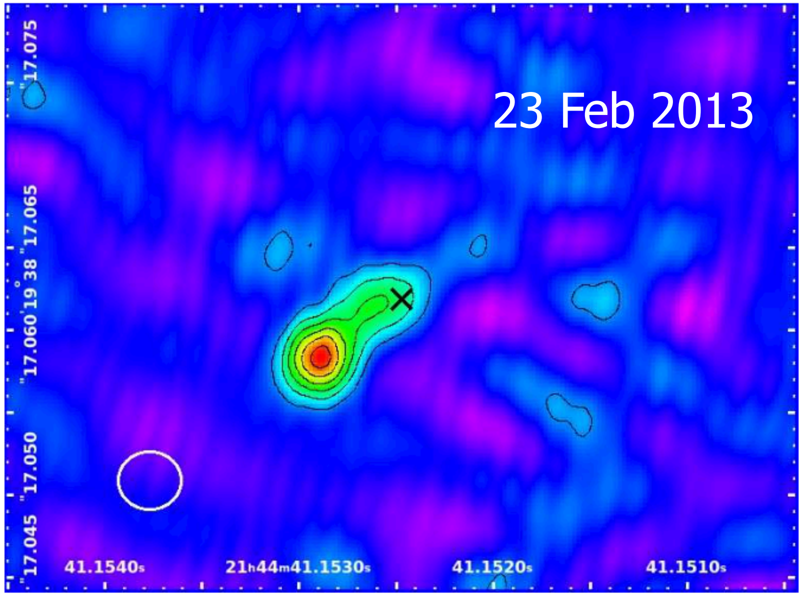


# “SLOW” transients

>2 seconds

# “Microquasars”




- A luminous low-mass X-ray binary
- Simultaneous Swift observations show the source on the Horizontal Branch of the Z-track
- Jet ejection after a flare, β~0.3

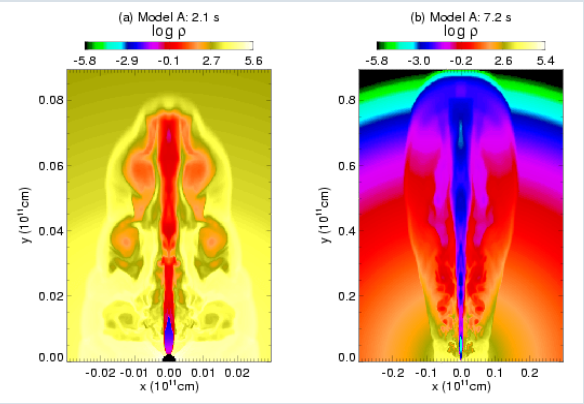
*Spencer et al. (2013)*

**(Note the HMXB Cyg X-3 is has a huge flare these days, and being observed with an ad-hoc “EVN-lite”)**

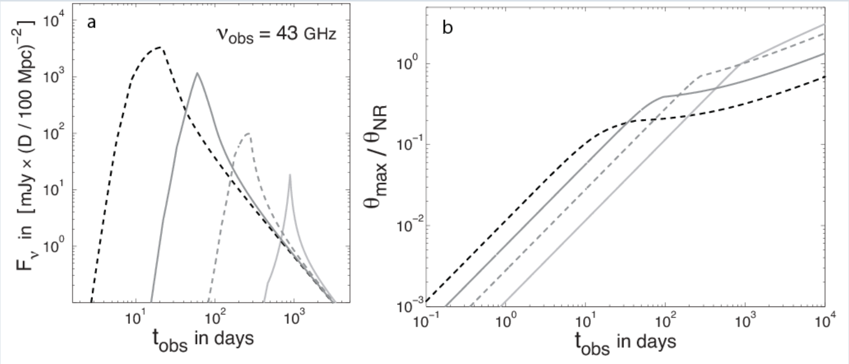
# Core-collapse SNe & GRB afterglows

## Relativistic SNe, long-GRBs

- Death of massive stars: Collapsar model
- VLBI confirmed for only GRB030329 *(Taylor et al. 2004, …)*
- **(SKA-)VLBI: model independent probe of expansion for (all) "radio-loud" long-GRBs**

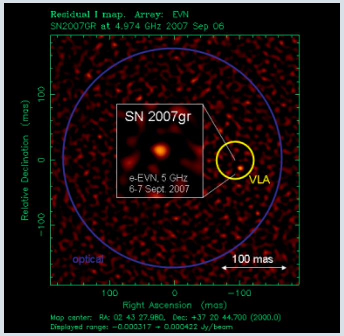


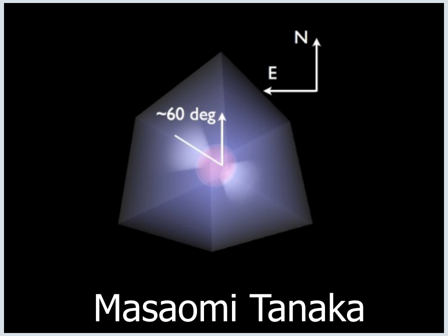

*Woosley (1993)*
*MacFadyan & Woosley (1999)*

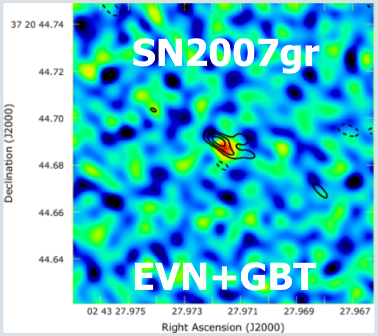



*Granot & Loeb (2003)*

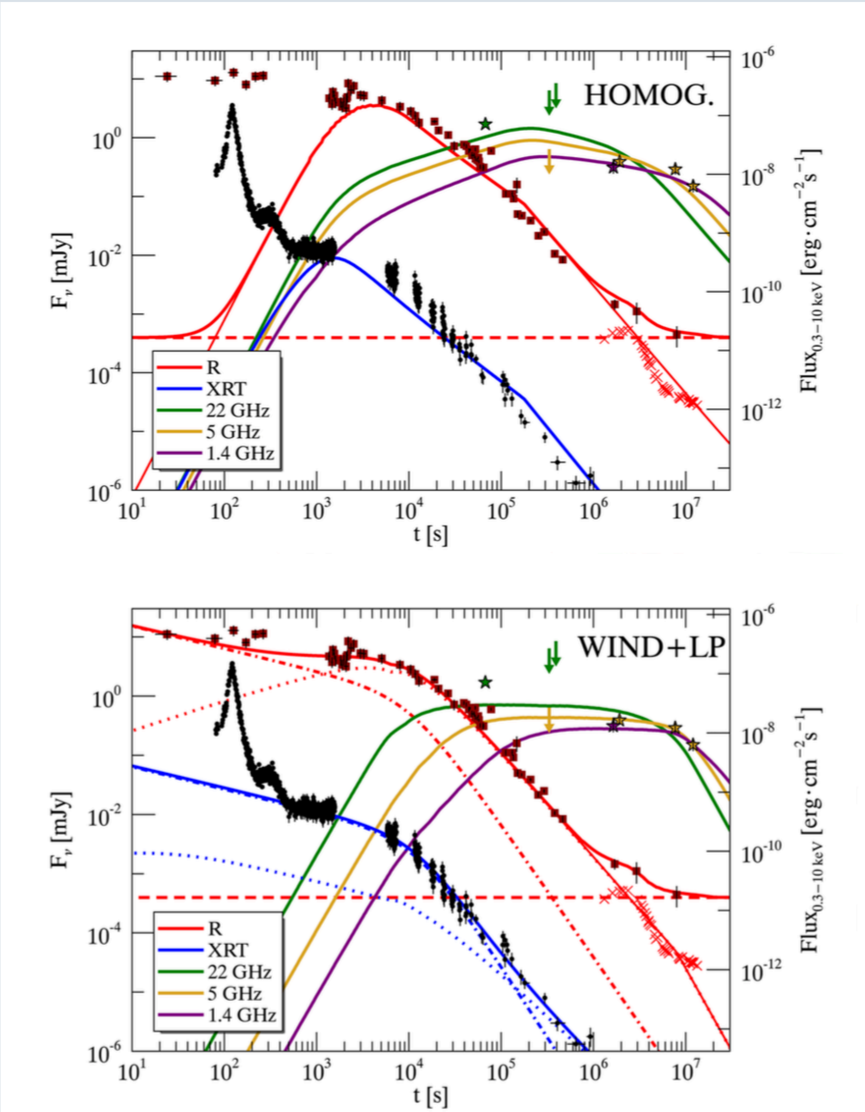
- Mildly relativistic jets in the more powerful Ib/c SNe - no model-independent evidence yet, in spite of claims by *Paragi et al. (2010)*

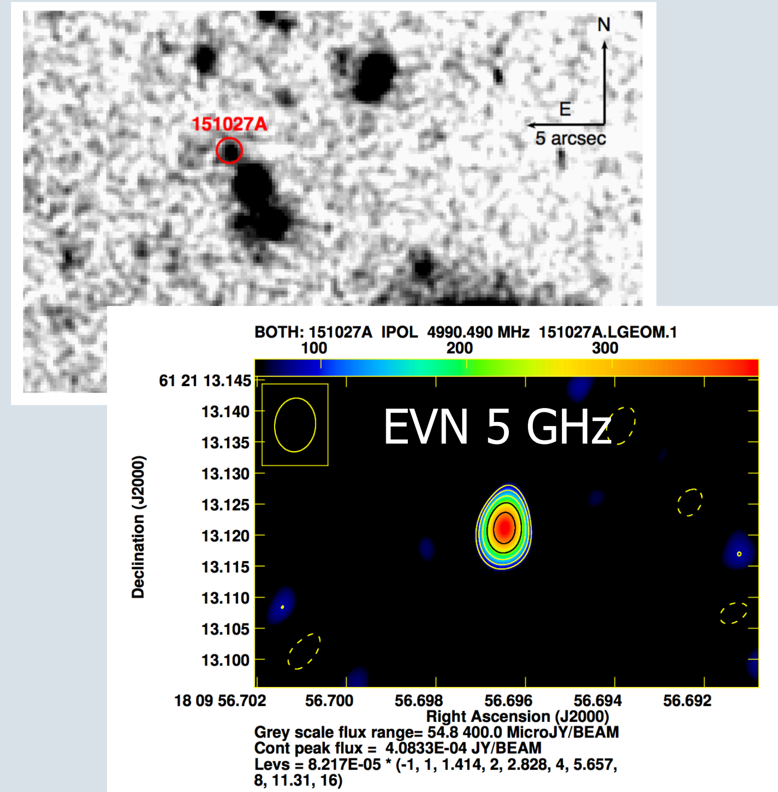


# GRB151027A: the 999th Swift GRB

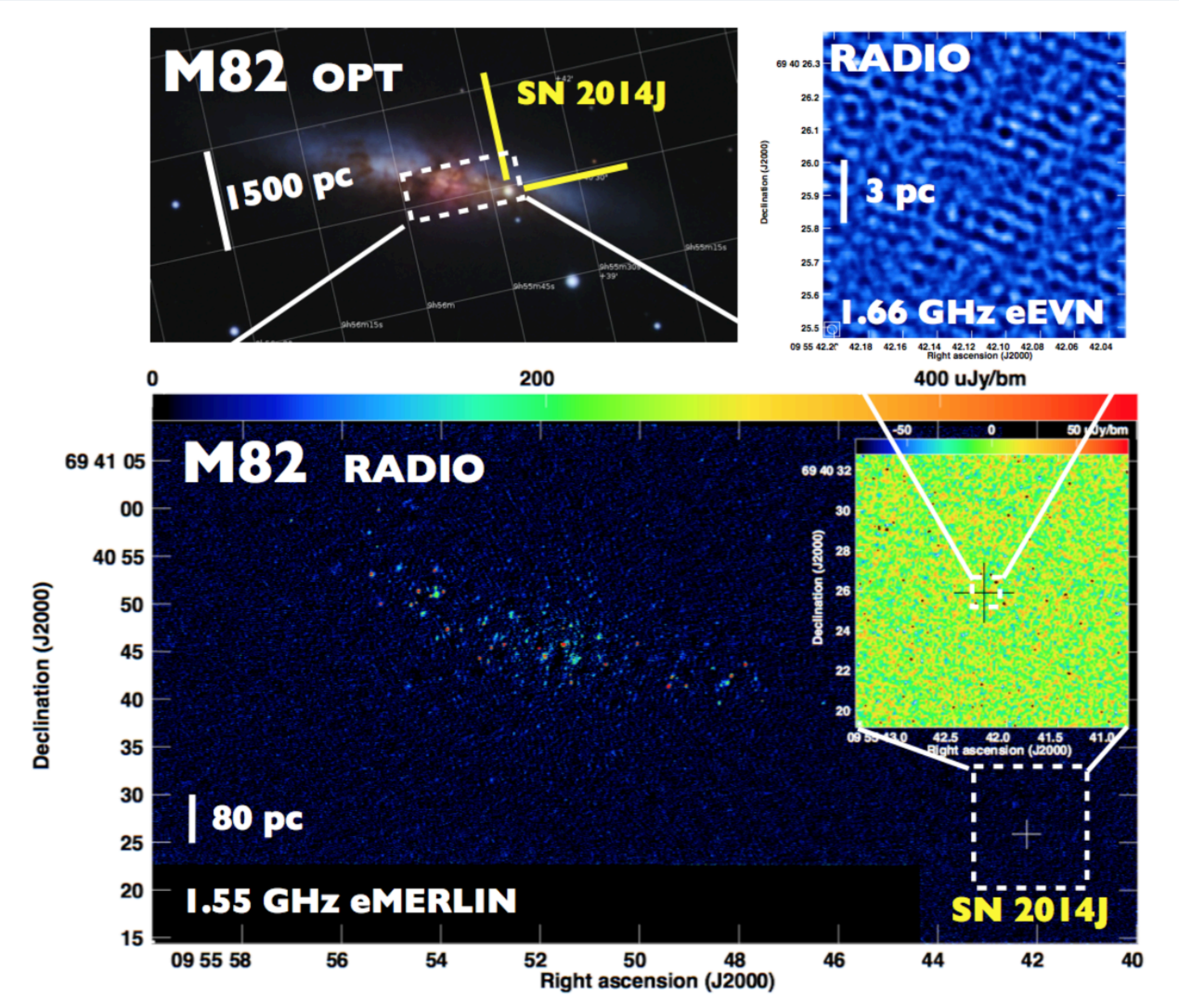



Even if unresolved with VLBI, radio/multi-band data give constraints on environment (and thus possible progenitors).

*Nappo et al. (2016)*

# Thermonuclear (Type Ia) supernovae




SN2014J EVN/e-MERLIN:

Deep radio limits point to double-degenerate progenitors in SN Ia

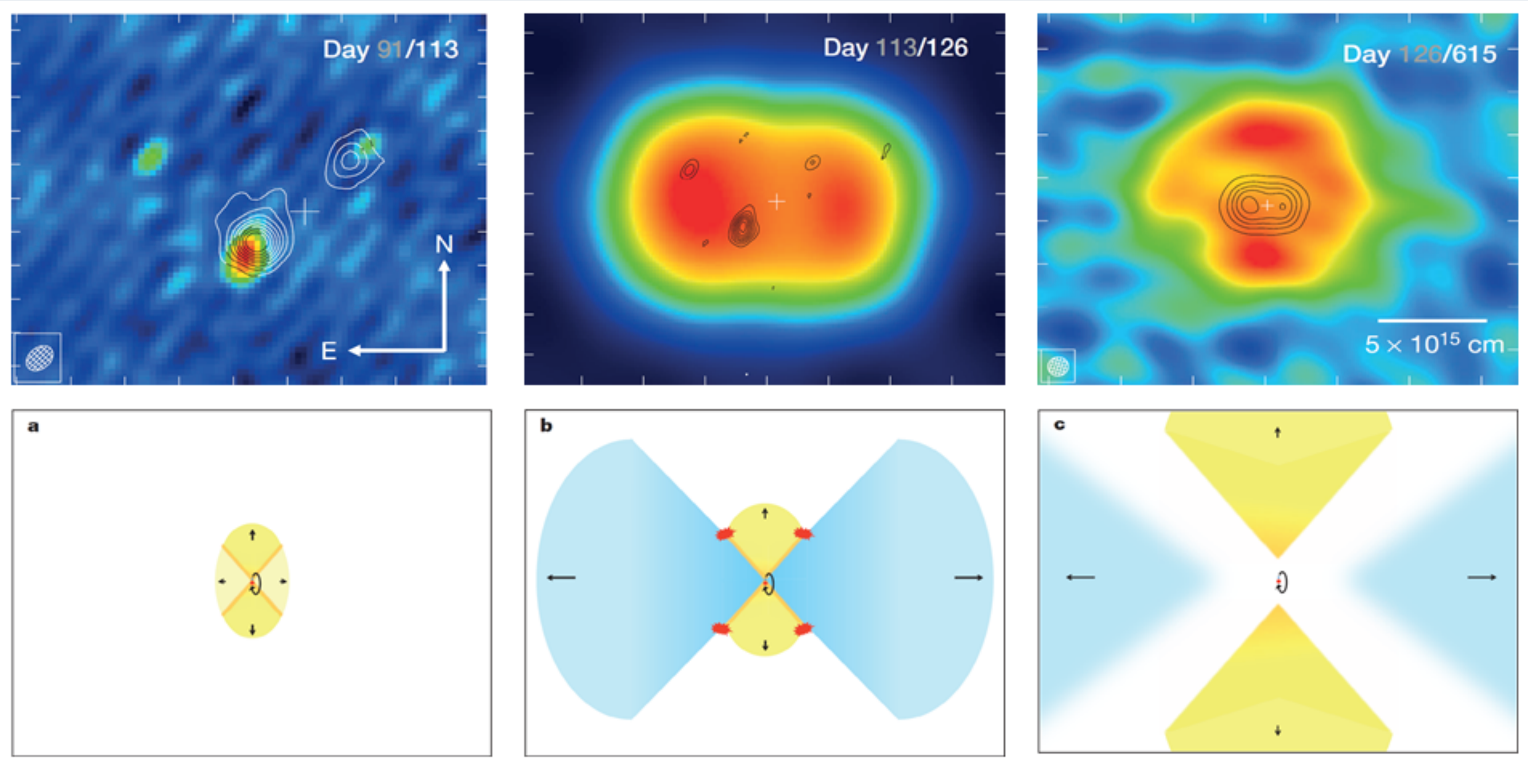
*Pérez-Torres et al. (2014)*

# Classical novae: V959 Mon

- Fiona Healy, previous session

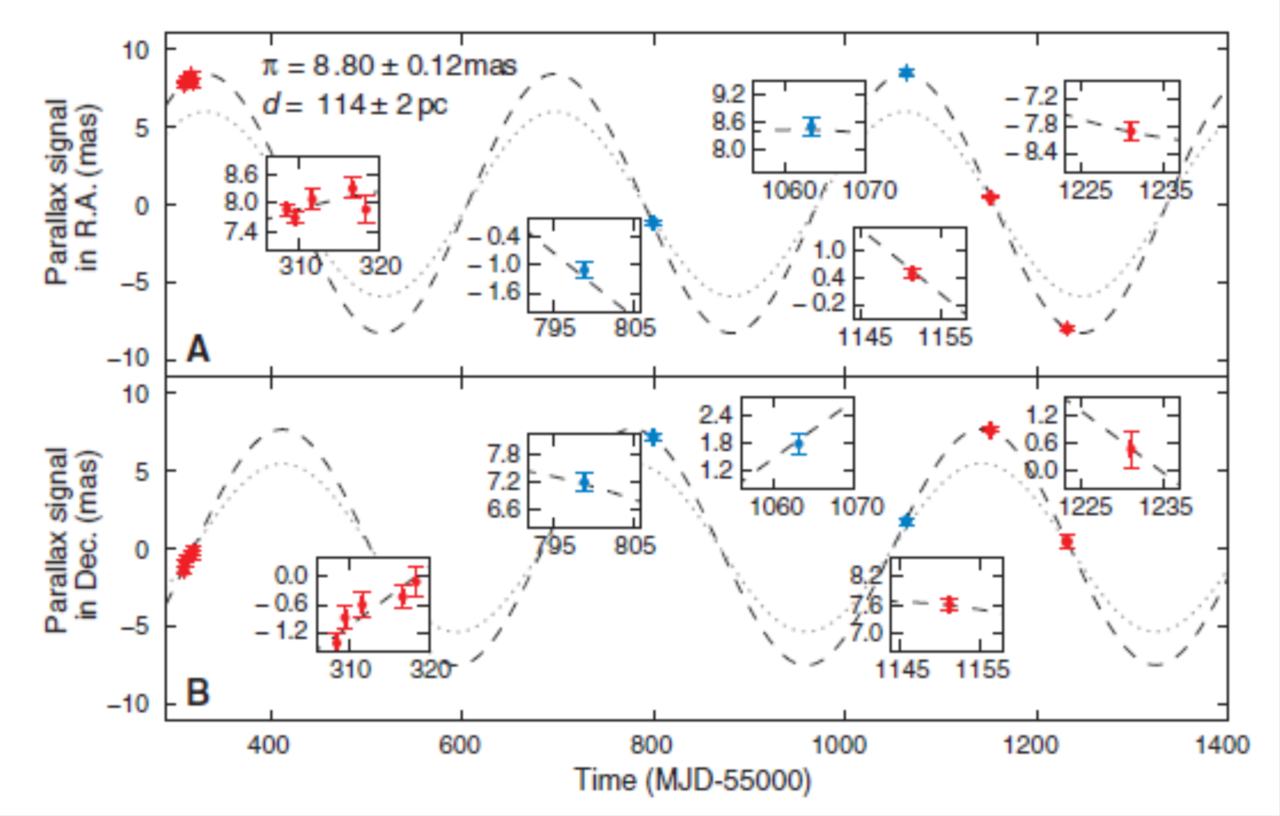
*Chomiuk et al., Nature, 514, 339, 2014*

**e-EVN, JVLA, VLBA, e-Merlin**



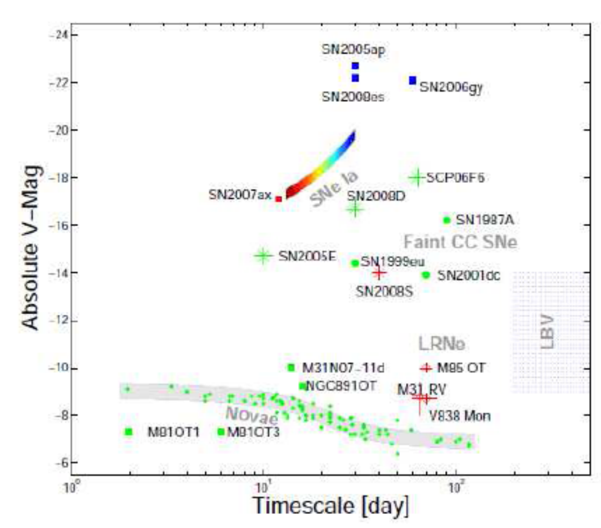
# Dwarf novae

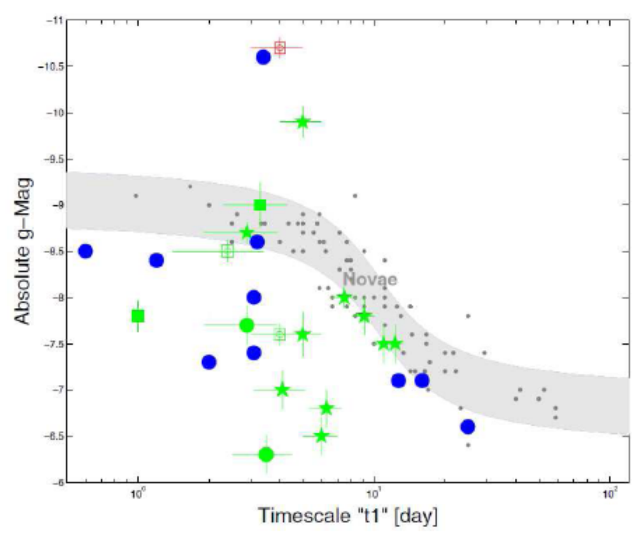
SS Cyg dwarf nova: triggered observations for parallax measurements (VLBA/e-EVN)




*Miller-Jones et al., Science, 340, 950, 2013*

# Novae-SNe transient space



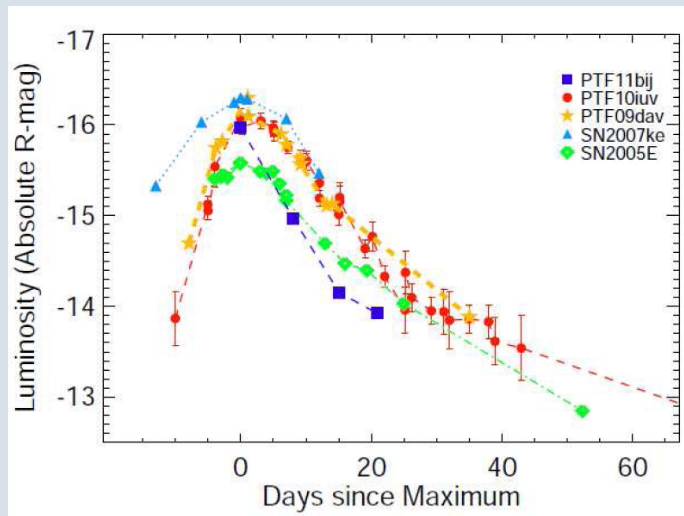

- Gap transients (left)
- Fast/faint class of classical novae (right)

**It is worth exploring a broader transient space in the radio as well!**

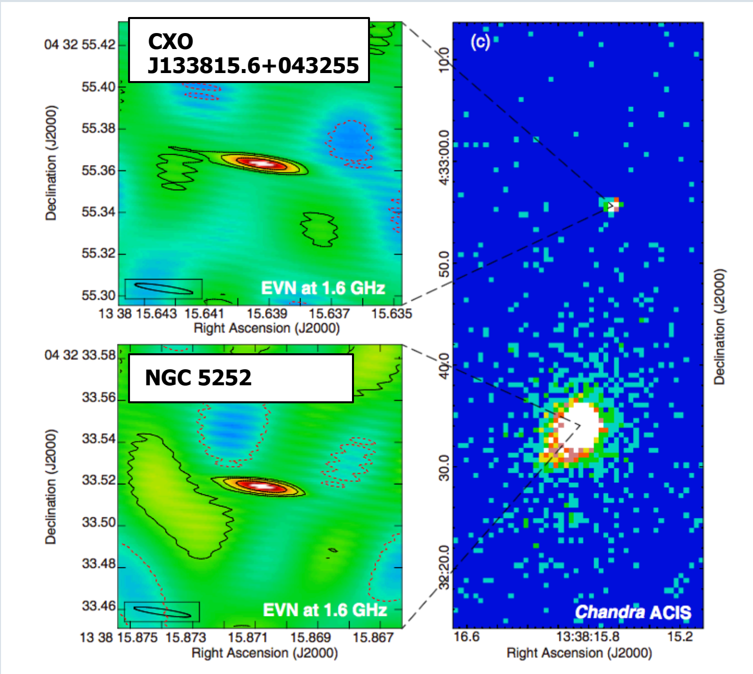
*Kulkarni and Kasliwal (2009), PTF/LSST white paper*

- Ca-rich gap transients
- Fainter/faster than SNe

*Kasliwal et al. (2012)*

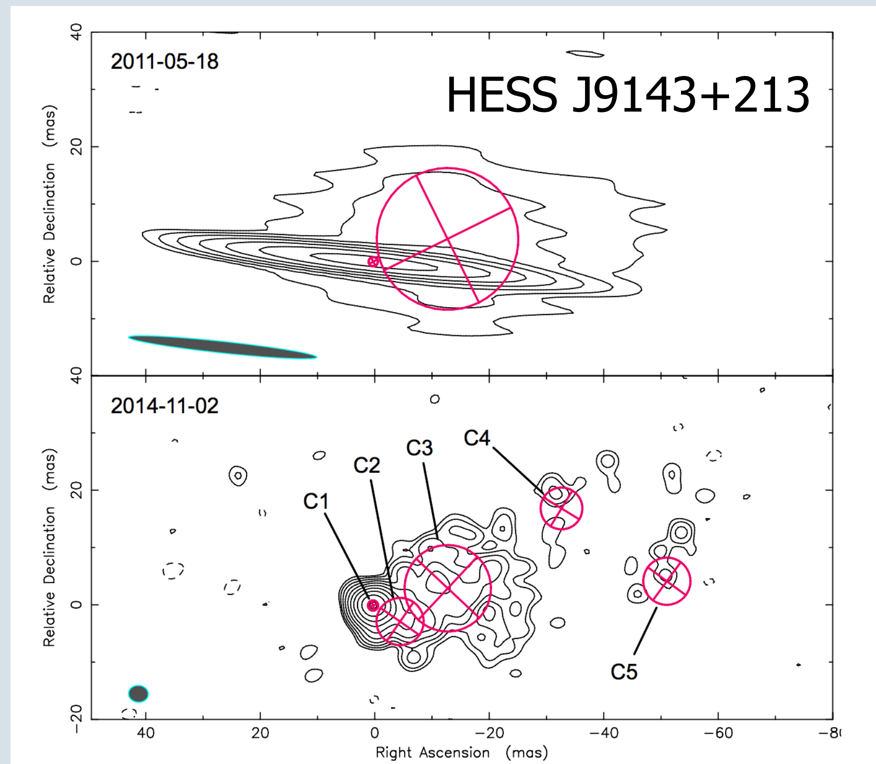


# Unidentified ‘ULX’ & TeV sources




CXO J133815.6+043255 off-nuclear IMBH candidate “ULX” in Seyfert gx. NGC 5252 – *Kim et al. (2015)*

EVN: evidence for pair of SMBH – *Yang et al. (2016)*




Unidentified TeV source HESS J1943+213: PWN or extreme BL Lac?

AGN activity revealed by EVN

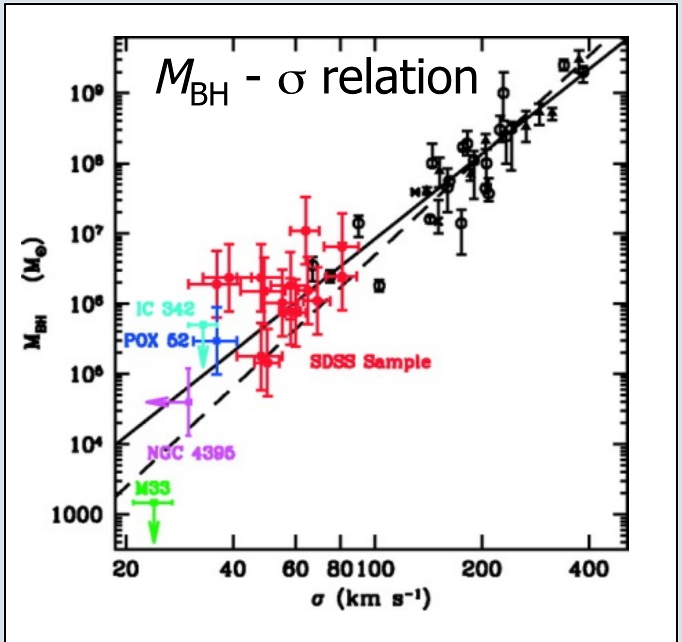
*Akiyama et al. (2016)*
*Straal et al. (2016)*

# Why Tidal Disruption Events are important?

- **They may give a clue on the massive BH population ($M_{BH}$<$10^6$ $M_\odot$)**

To understand supermassive BH formation we must now the BH demographics – but massive BH below ~$10^6$ $M_\odot$ are hard to find.

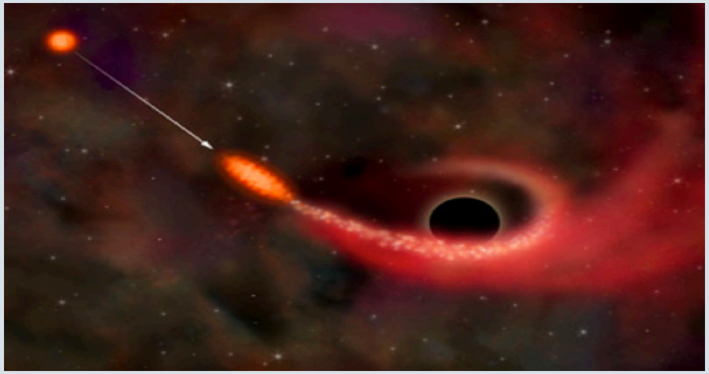
Where are the left-over seed BH required by structure formation models? How do they grow?



Barth, Greene & Ho (2005)

- **We can study jet formation in a pristine environment**

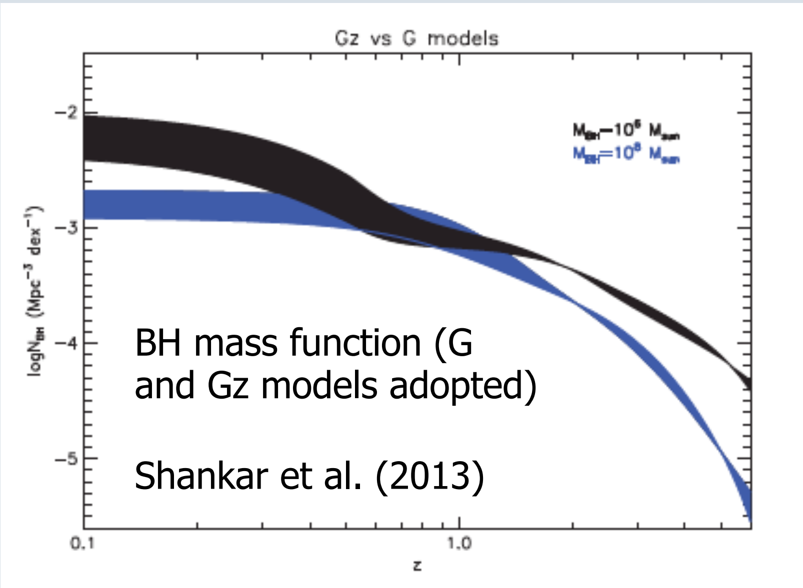
Also relevant for AGN feedback. VLBI will have a crucial role in this, since milliarcsecond resolution is needed.

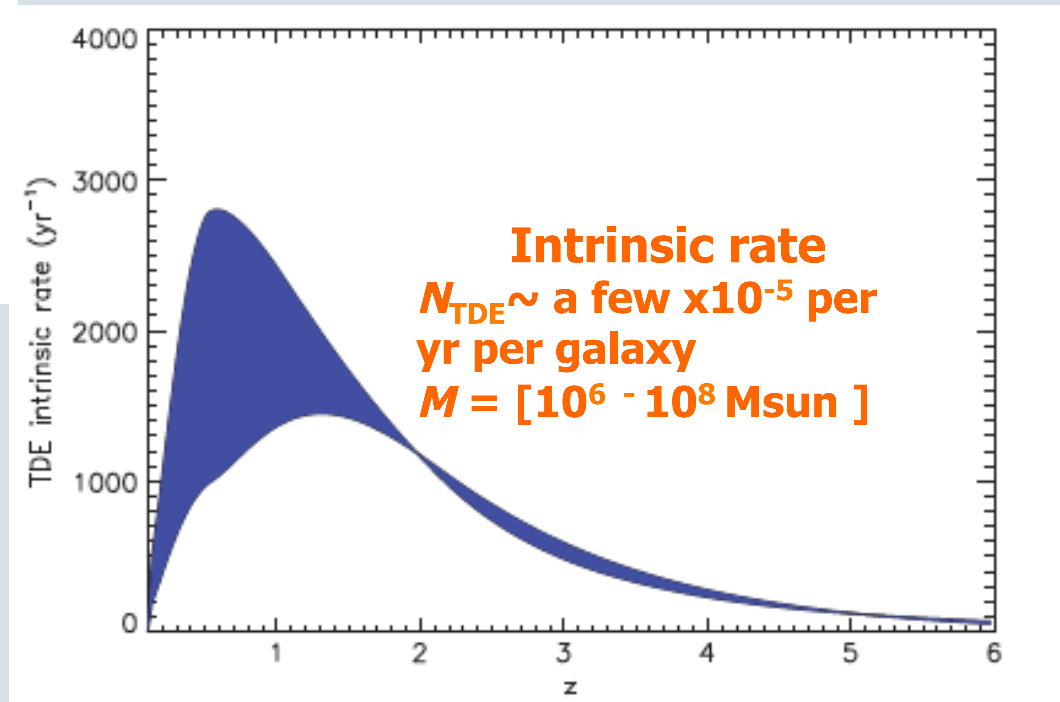


# What is the expected TDE rate?

Take Swift J1644+5734 as prototype for predictions in the X-ray and radio bands: Donnarumma et al. (2015)

$$R(z) = \int_{M_{\rm min}}^{M_{\rm max}} \phi(M, z) V(z) N_{\rm tde} dM,$$



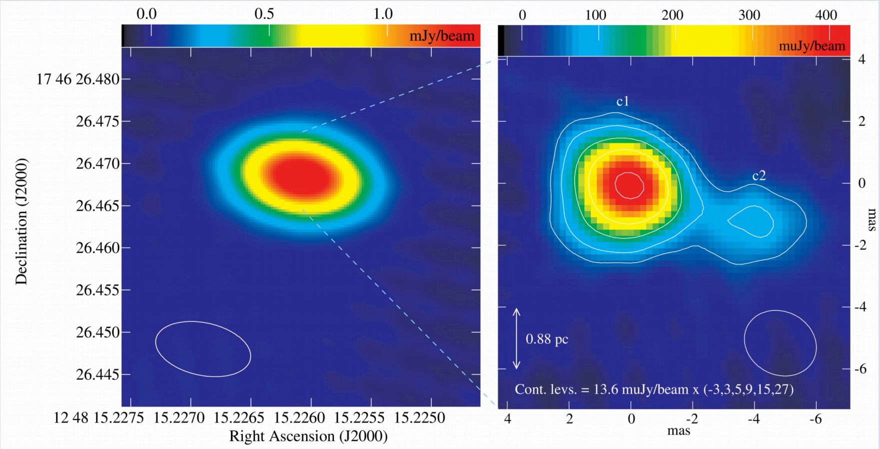

From intrinsic to jetted TDE rate: rescaling R(z) by a factor $(2\,\Gamma)^{-2}$

**Must understand jet efficiency and measure Lorentz factors in TDE**

# TDE with the EVN

- **Transient in Arp299B: origin unclear – TDE?**
  - **Talk by M.A. Pérez-Torres yesterday**
- **ASASSN-14LI: relativistic jet in thermal TDE?**
  - **Talk by Cristina Romero-Canizales yesterday**
- **Swift J1644+5734**
  - **Next talk by Jun Yang**

**ASASSN-14LI**

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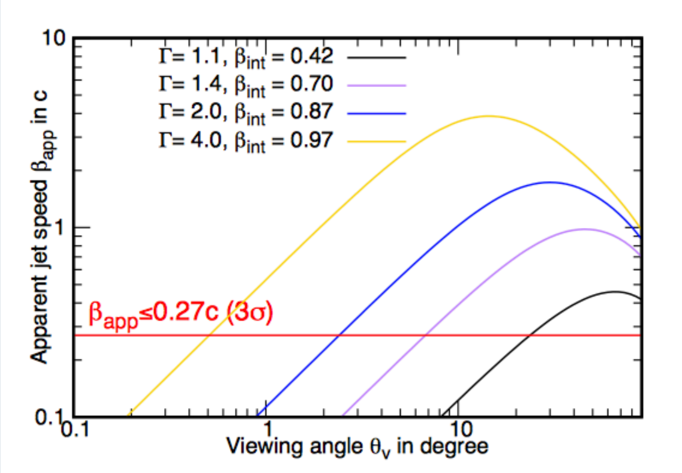


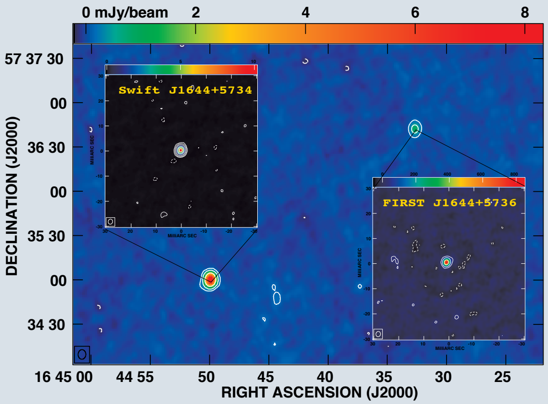

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(Beam-formed) sensitivities at 1 kpc and 1 Gpc for:

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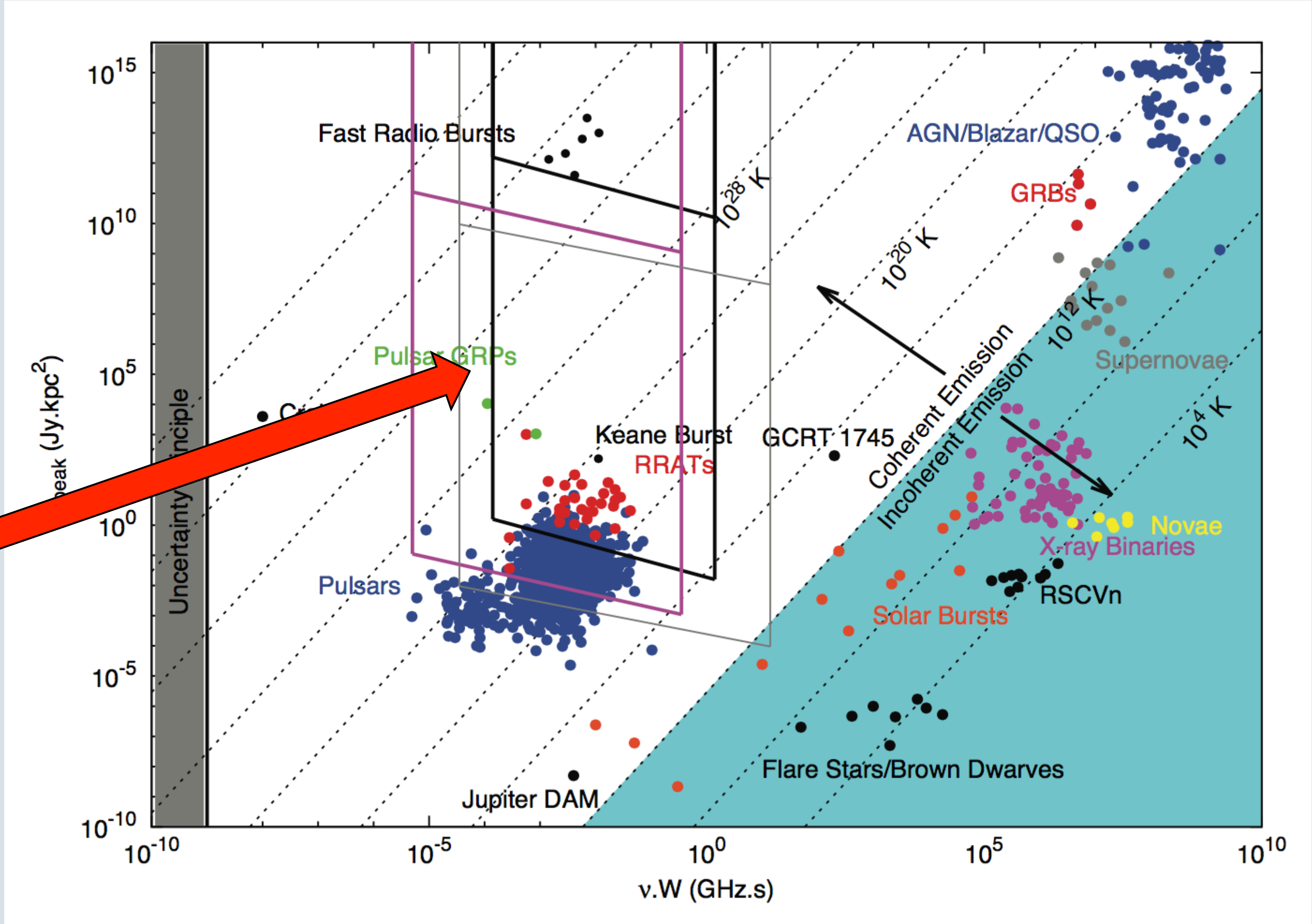
**SKA1-MID** (grey)

**Can the EVN contribute here?**




Specific luminosity vs. product of observing frequency and transient duration

*SKA Transient WG - Macquart et al. (2015);* update of *Cordes, Lazio & McLaughlin 2004*

# “FAST” transients

< 2 seconds

# Fast Radio Bursts (FRB)

- Highly dispersed, non-repeating ms-transient signals, indicating cosmological origin, >1 Jy

*Lorimer et al. (2007), Science, 318, 777*
*Keane et al. (2011), MNRAS, 415, 3065 - Galactic???*
*Thornton et al. (2013), Science, 241, 53 – 4 FRBs; +1 in PhD thesis*
*Spitler et al. (2014), ApJ, 790, 101 – Arecibo!*
*Bourke-Spolaor & Bannister (2014), ApJ, 792, 19*
*Petroff et al. (2015), MNRAS, 447, 246 – real-time*
*Ravi, Shannon, Jameson (2015) – real-time (Carina Dwarf gx?)*
*Masui et al. (2015) – GBT!*
*Keane et al. (2016) – real-time follow-up, candidate counterpart*
*Spitle et al. (2016) – Arecibo FRB repeating!*

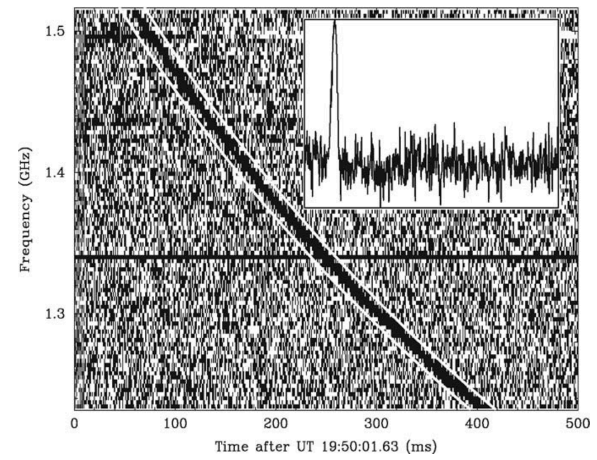
- Not to be confused with *Perytons*, dispersed signals of local origin

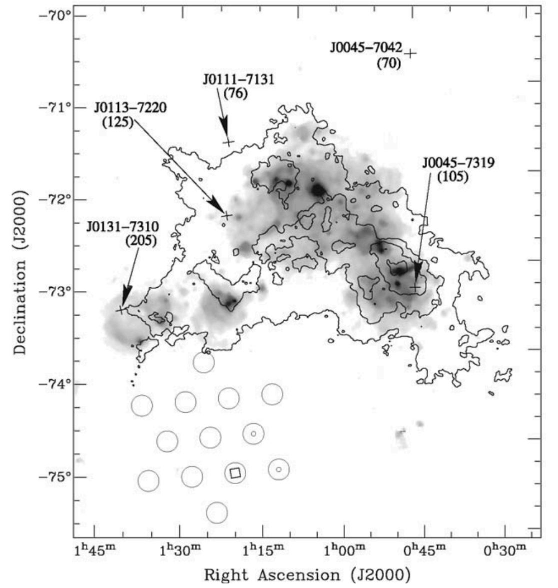
*Bourke-Spolaor et. al. (2011), ApJ, 727, 18*
*Petroff et al. (2015), MNRAS, 451, 3933*

- Initial even rate of ~>10^4/sky/day recently reconsidered to ~10^3-10^4/sky/day

*Rane et al. (2015), arXiv:1505.00834*

**To date, there is still no LOFAR, MWA or VLA detection (reported)!**



# The origin of FRBs

Dispersion measures well in excess of Galactic values. A number of possible explanations, just a few:

- 'Blitzar': collapsing supramassive neutron stars

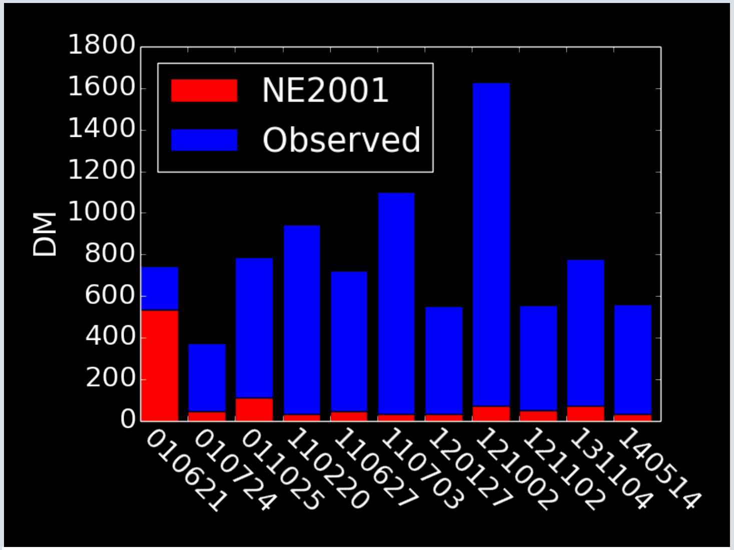
*Falcke & Rezzola et. al. (2011), A&A, 562, A137*

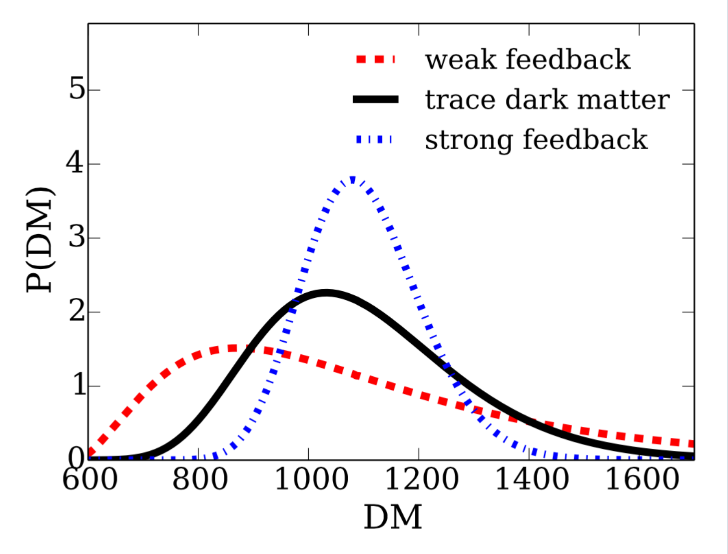
- Nearby flare stars; DM due to coronal plasma effects

*Loeb,* Shvartzvald, Maoz *(2014), MNRAS, 439, L46*
*Maoz et al. (2015), MNRAS, 454, 2183*

If extragalactic, they are important for cosmology:

- To weigh the missing barions *(McQuinn 2014)*
- To measure intergalactic magnetic field and determine dark energy equation of state *(Gao, Li & Zhang 2014; Zhou et al. 2014)*



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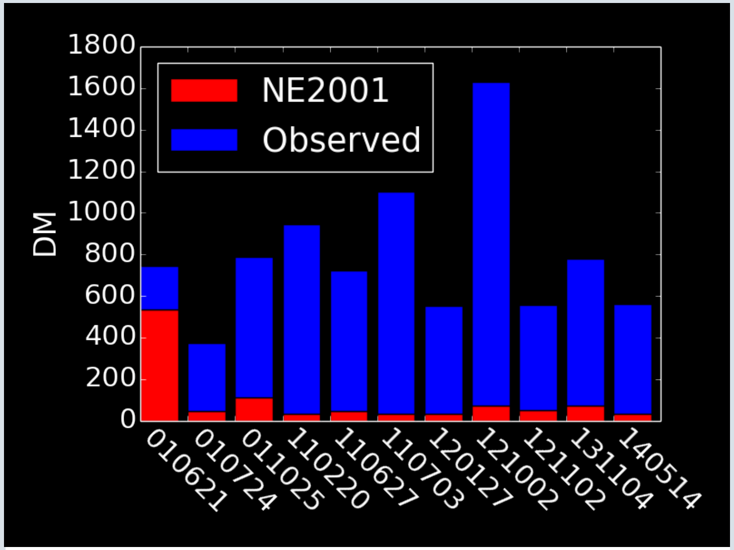
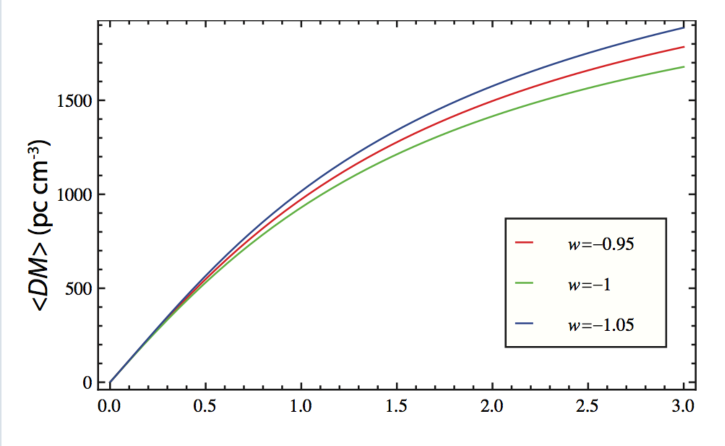
**Localization needed to prove extragalactic origin!**

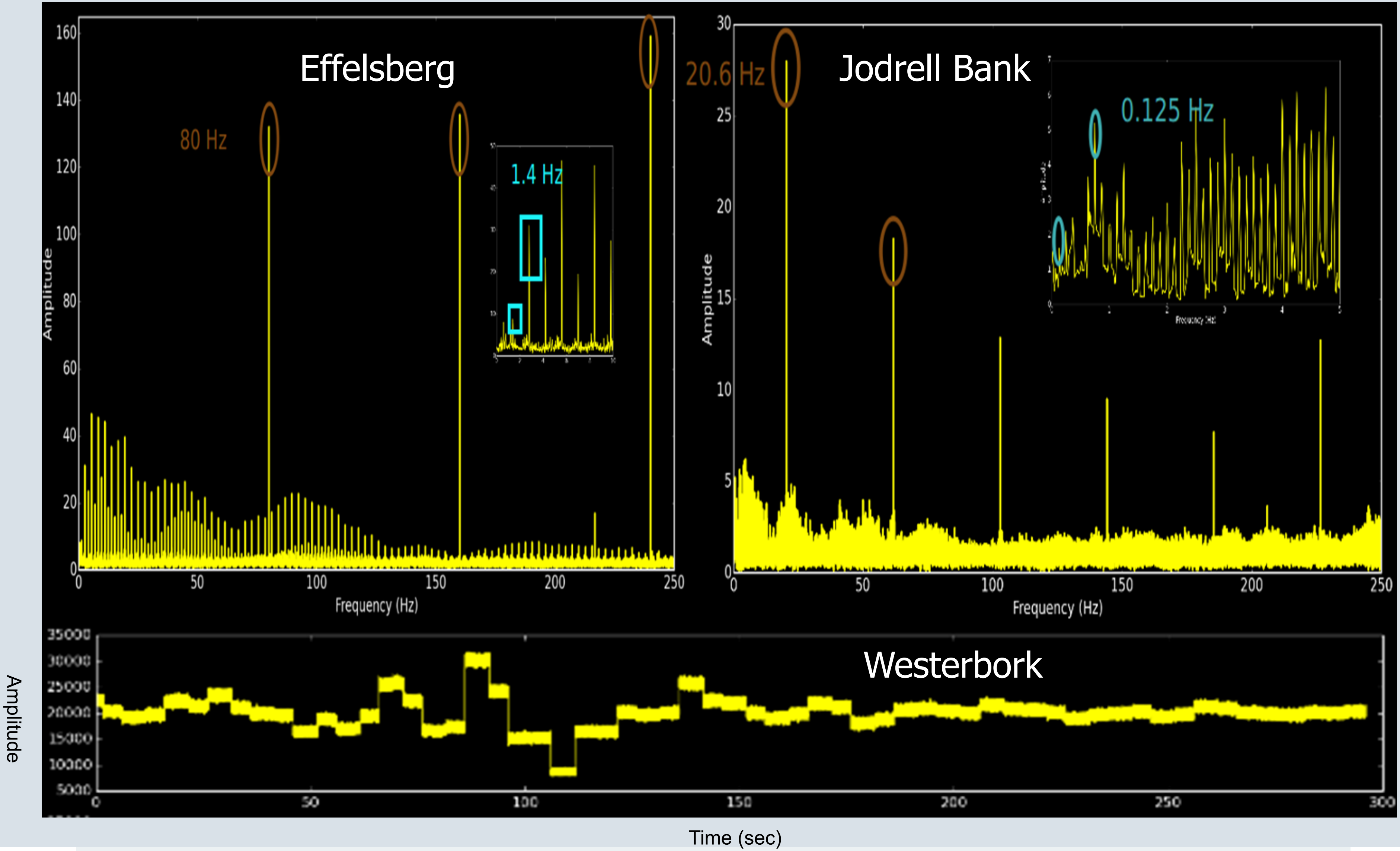


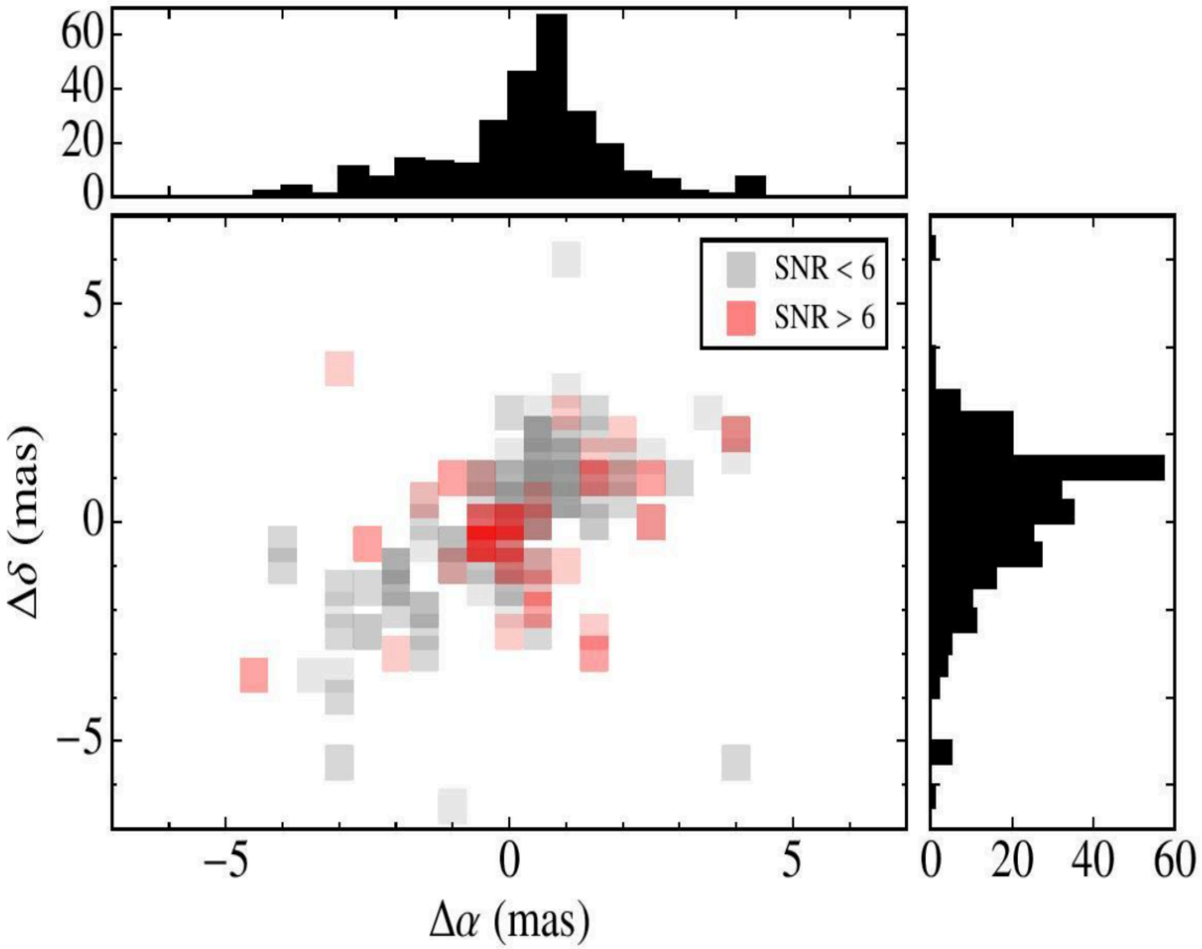
# How to localize?

- **Image candidate “afterglow”**
  - **See talk by Benito Marcote**
- **Direct VLBI detection**
  - **Took some data on test pulsars and RRAT**

# The ‘real EVN’ – RFI, calibration, gain control…

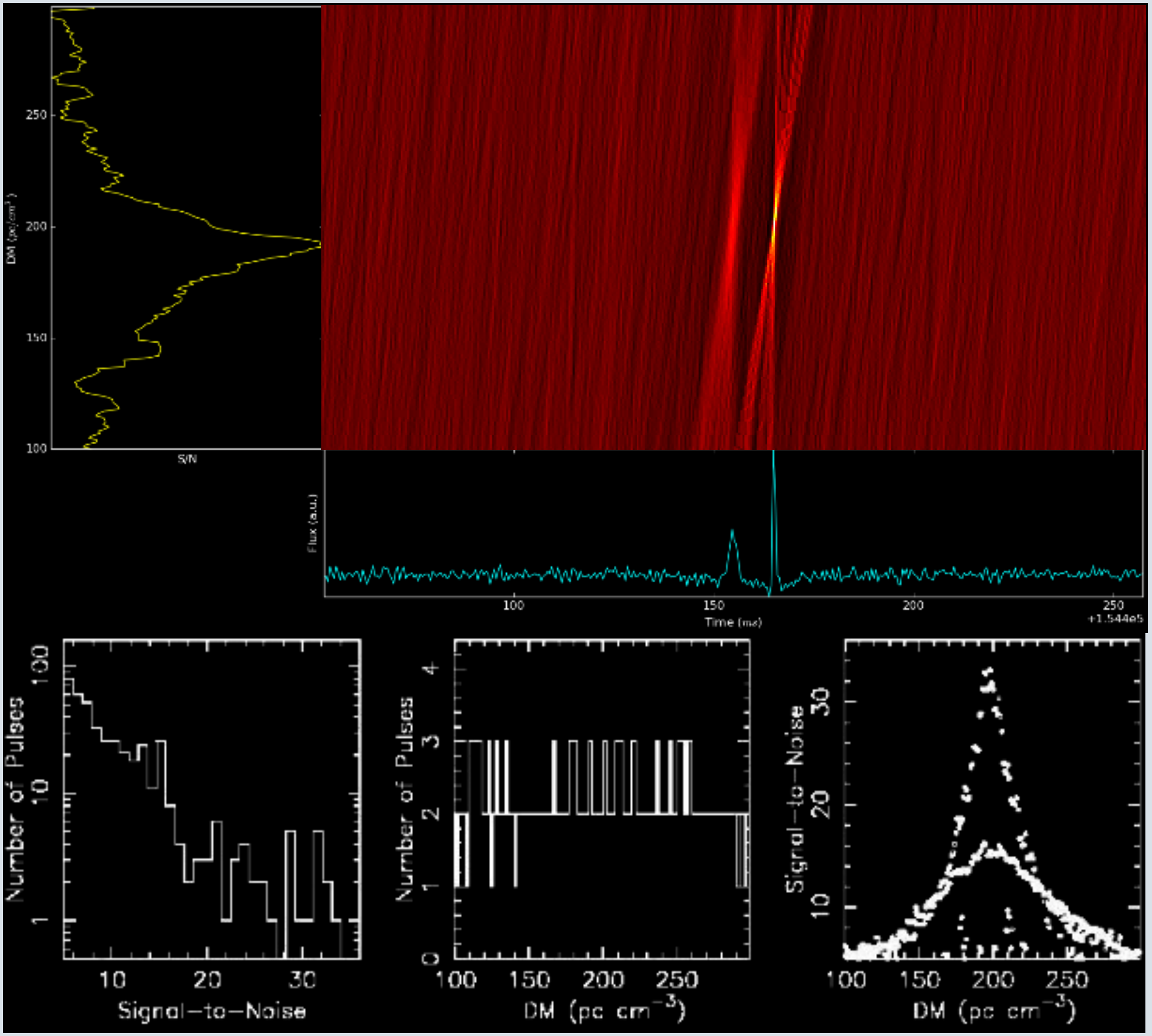


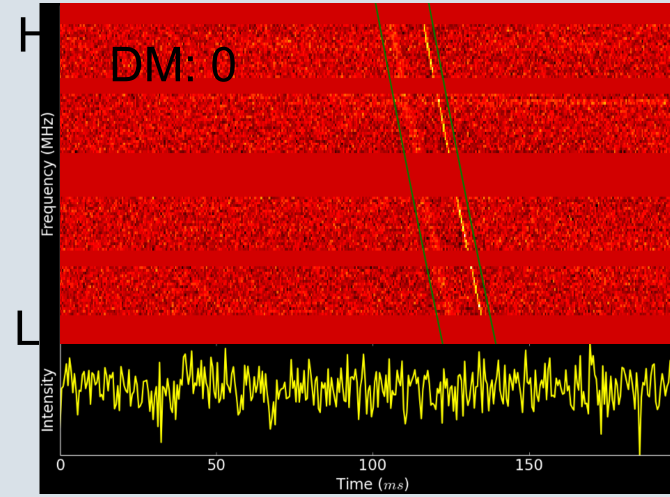
# Test pulsar localisation: B0525+21

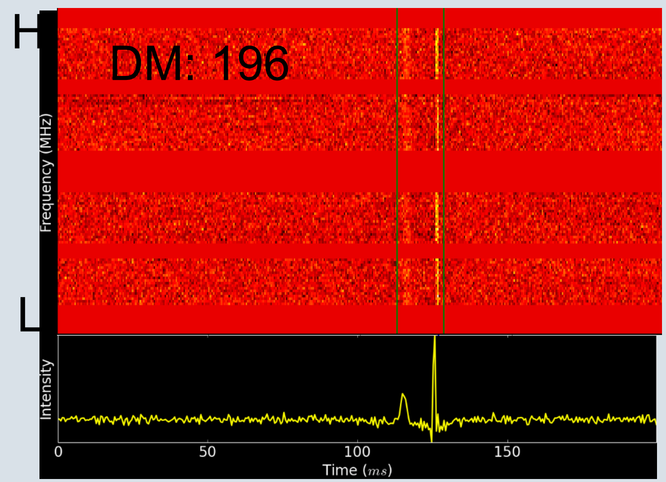



Histogram of single pulse position deviations
(Image credit: Benito Marcote, JIVE)

# RRAT J1819-1458

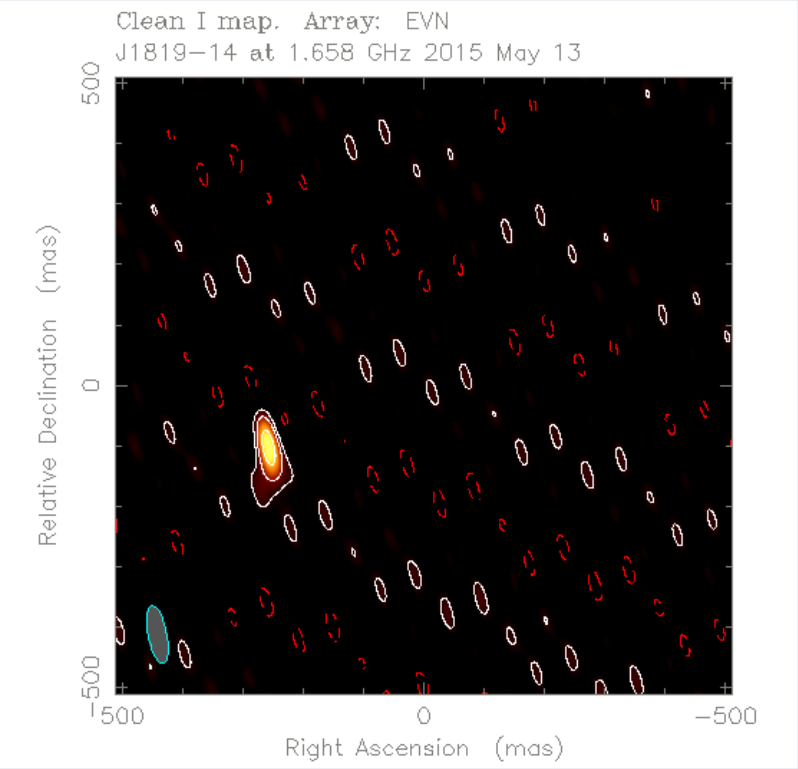


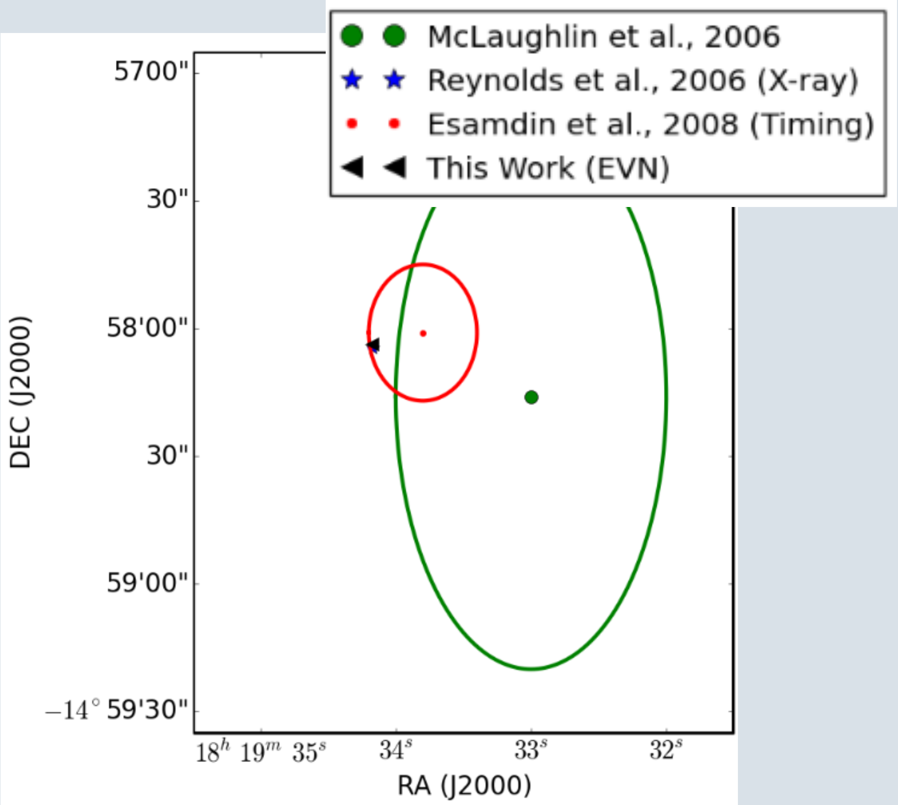



# Successful EVN localization!

**Single pulse e-EVN image of RRAT J1819-1458**
(note this mode of observation requires buffering/recording VLBI voltage data)



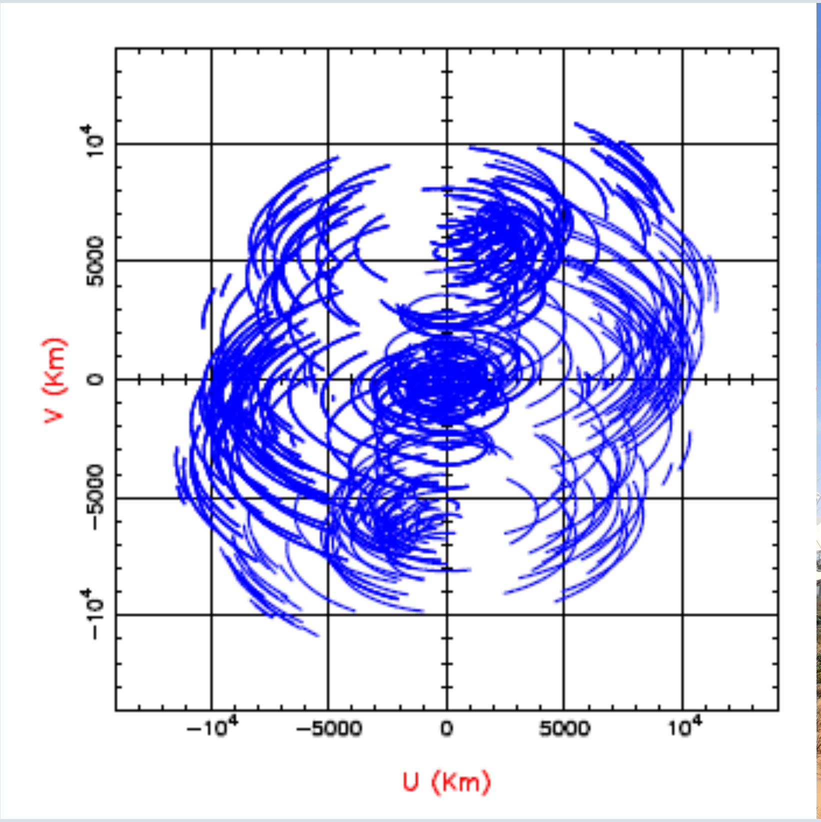

LOCATe team + students at JIVE (some updates are expected soon)

# Concluding remarks

- EVN sensitivity and resolution is highly important for a number of transient phenomena
- The flexibility offered by the e-EVN is great for transient science
- There may be a great role for the EVN in the developing field of fast transient research
- EVN combined with SKA1-MID will be a powerful tool for transients *(SKA-VLBI, Paragi et al. 2015)*

***SKA-VLBI working group associate membership is open for everybody!***

# VLBI with the Square Kilometre Array



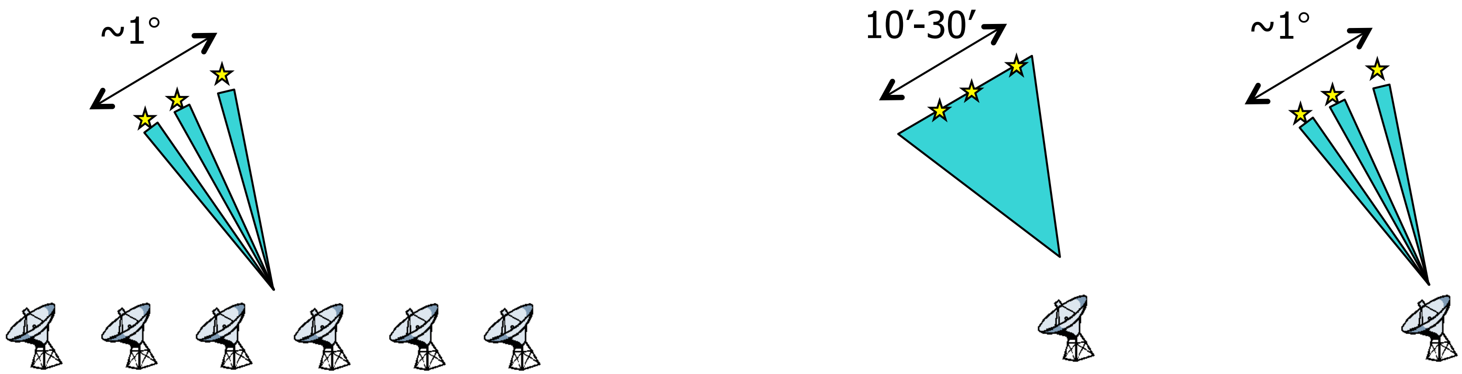


**Ultra-sensitive VLBI allowing access to the Galactic Centre and the southern sky**

*"Very Long Baseline Interferometry with the SKA", Paragi et al. 2015, SKA Science book*

# How to do SKA-VLBI (Phase I.)

Use in-beam calibrators / fast switching




SKA1-MID: phased array core; form multiple beams

Matching resources: 30-100m telescopes

**Real-time or "e-shipping" transfer to data processor centre (e.g. JIVE)**

- SKA1-MID baselines up to ~200 km
- SKA-VLBI baselines up to ~10000 km

→ a range of angular scales, but, a limited number VLBI phase-centres

- Full SKA goal: all angular scales, mas imaging of the full FoV

# SKA-VLBI for synchrotron transients

Being sensitive to tiny displacements/structural variations allows to measure the following very accurately:

- **Source expansion / apparent jet speed**
- **Proper motion**
- **Parallax (distance!)**

**Faint synchrotron radio transients in the Local Universe (like TDE)**

- $d \leq 200$ Mpc corresponds to $z \sim 0.05$
- For 1 mas (typical global VLBI) resolution at 5 GHz, the corresponding linear size is 1 parsec @ $z$=0.05
- Within 200 Mpc, relativistically expanding source can be resolved within ~a few weeks with SKA1-VLBI:
  100 μJy source, SNR>100 in 1h => size >~0.05 mas detectable, using
  $\zeta_{min} \sim 0.6 \times SNR^{-0.5}\ \zeta_{beam}$ *(Martí-Vidal, Pérez-Torres & Lobanov 2012)*
- Within 200 Mpc, relativistic, collimated ejecta can be resolved with SKA1-VLBI within ~a week !
  100 μJy source, proper motion measured in the ~1 μas regime,
  $\zeta_{min} \sim \zeta_{beam} / (2 \times SNR)$