An Introduction to EVN data

Jack Radcliffe (SARAO/Pretori

DARA Unit 4 Botswana/Namibia
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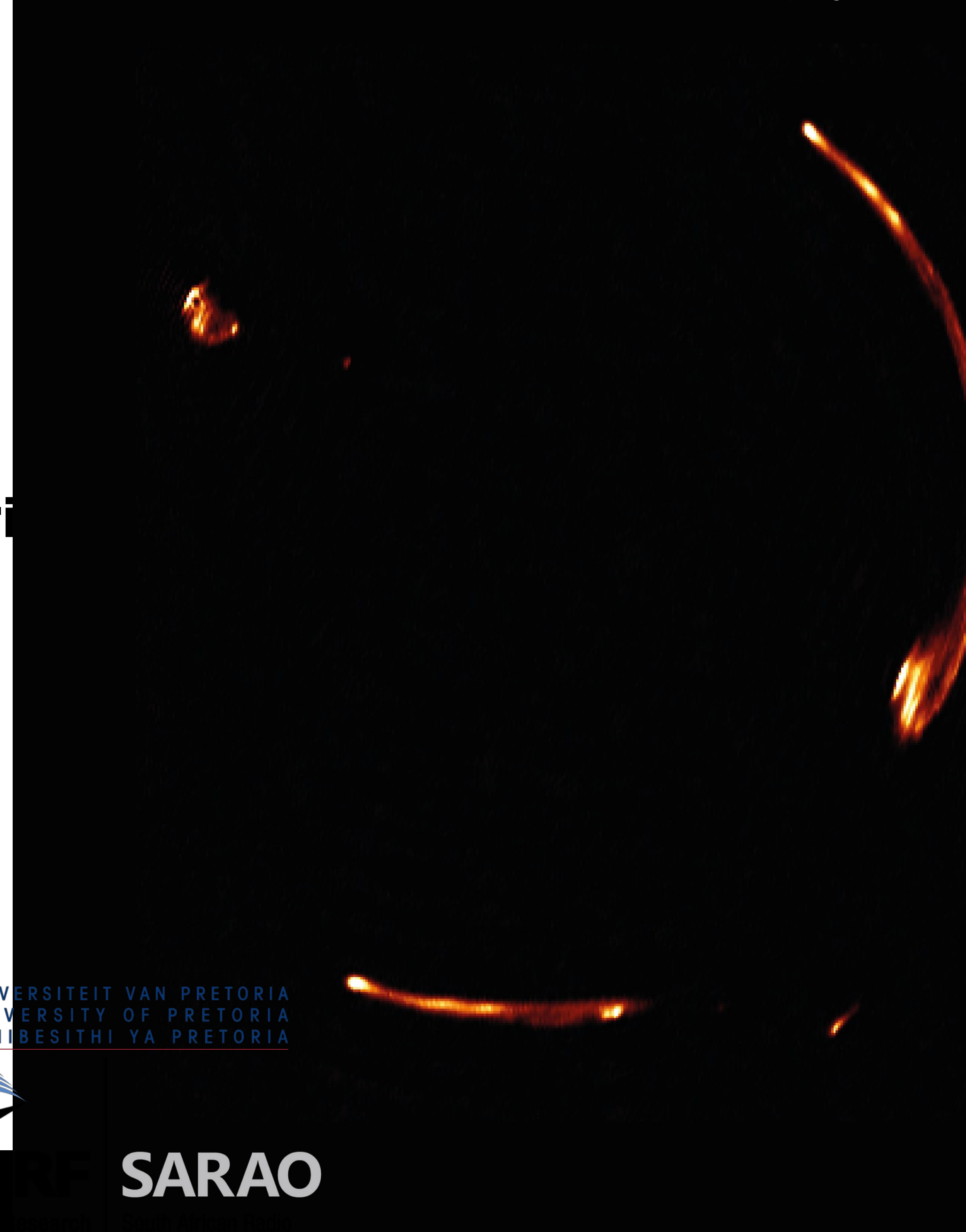

EVN image of J0751+2716 gravitational lens
(Spingola+18)

DARA
DEVELOPMENT IN AFRICA WITH RADIO ASTRONOMY

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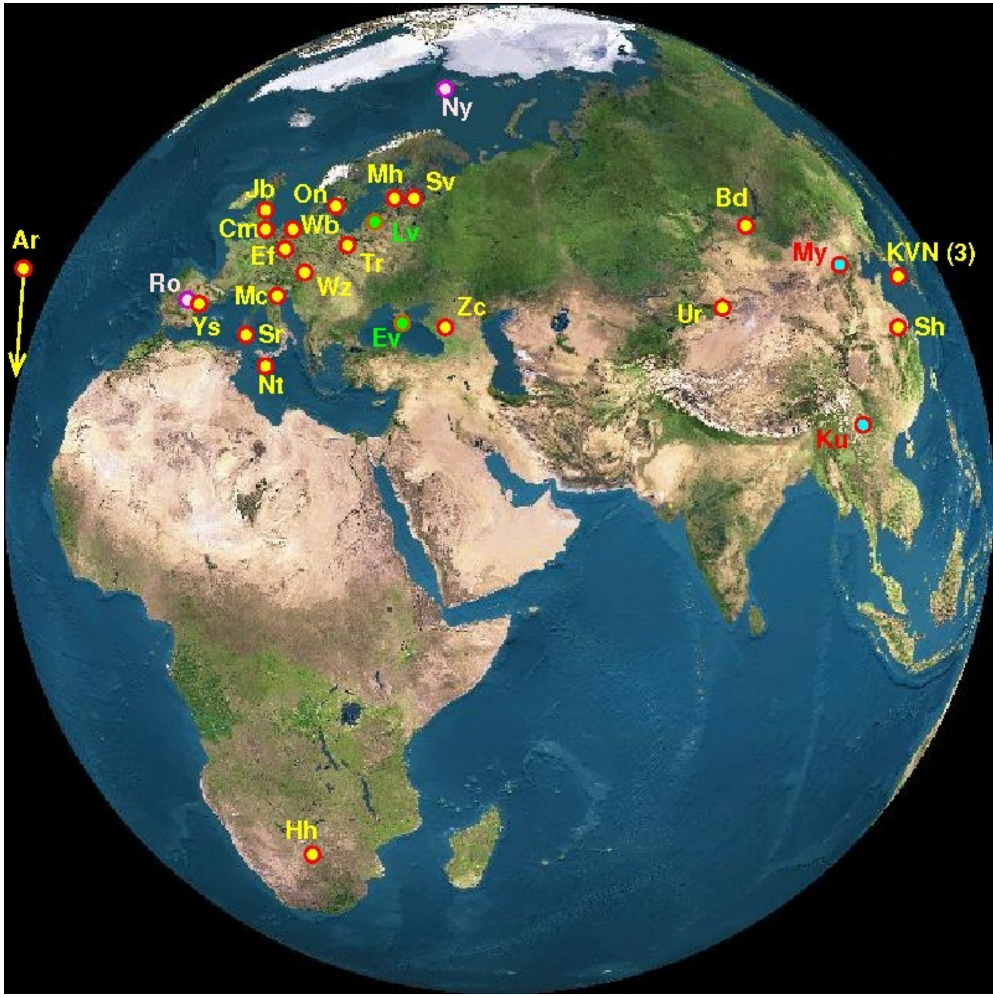
SARAO

What is the European VLBI Network (EVN)?

What is the European VLBI Network (EVN)?

- Array of 12(ish) telescopes but can be more!
- Can include:
    - LBA (Australia)
    - VLBA (USA)
    - EAVN (East Asia)
    - AVN (Africa) soon
- Largest is Effelsberg 100m (occasionally Arecibo 305m)
- Observe from 0.3-43 GHz
- Has the largest collecting area of any parabolic dish array.

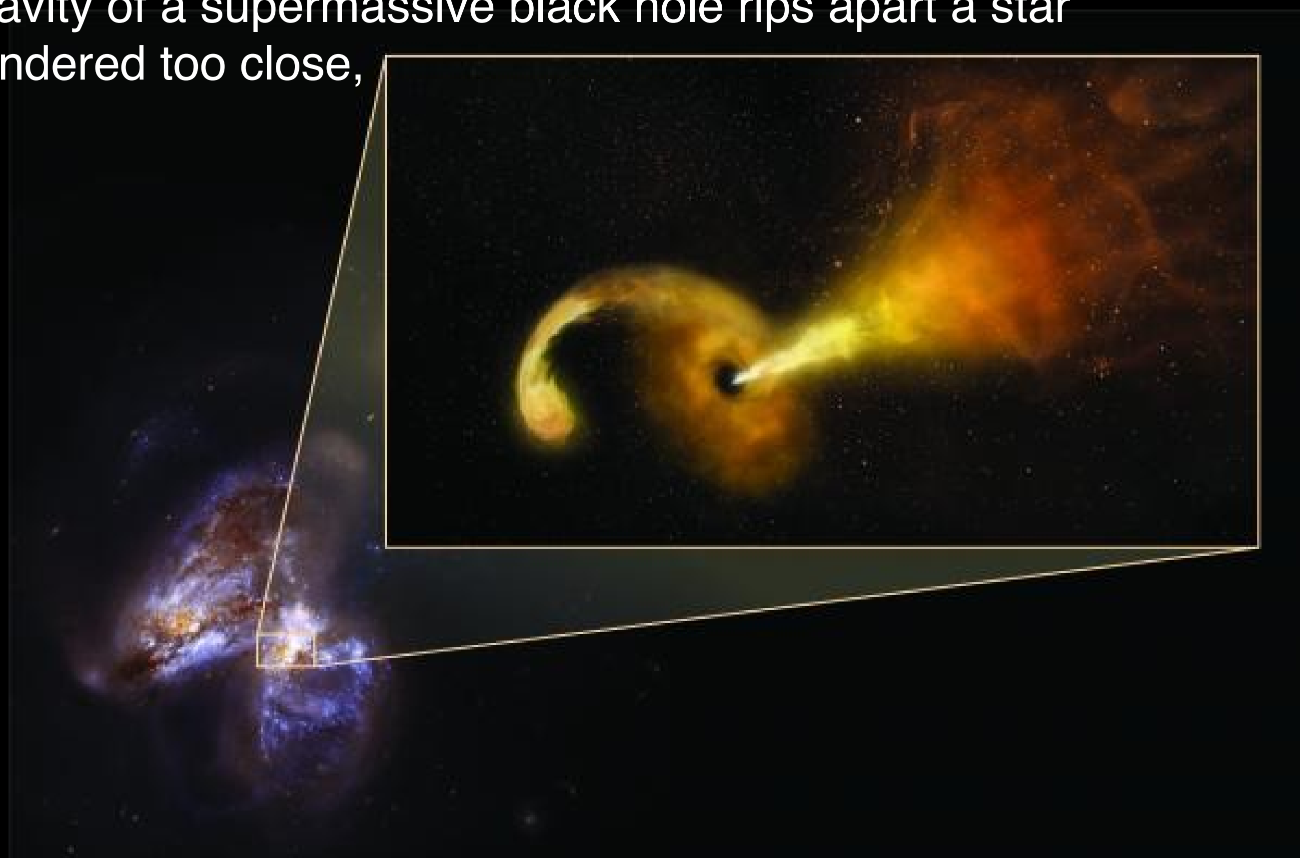


And what is the EVN useful for?

Some science highlights:

Tidal disruption event (TDE)
(Mattila et al. 2018)

- Powerful gravity of a supermassive black hole rips apart a star that has wandered too close,

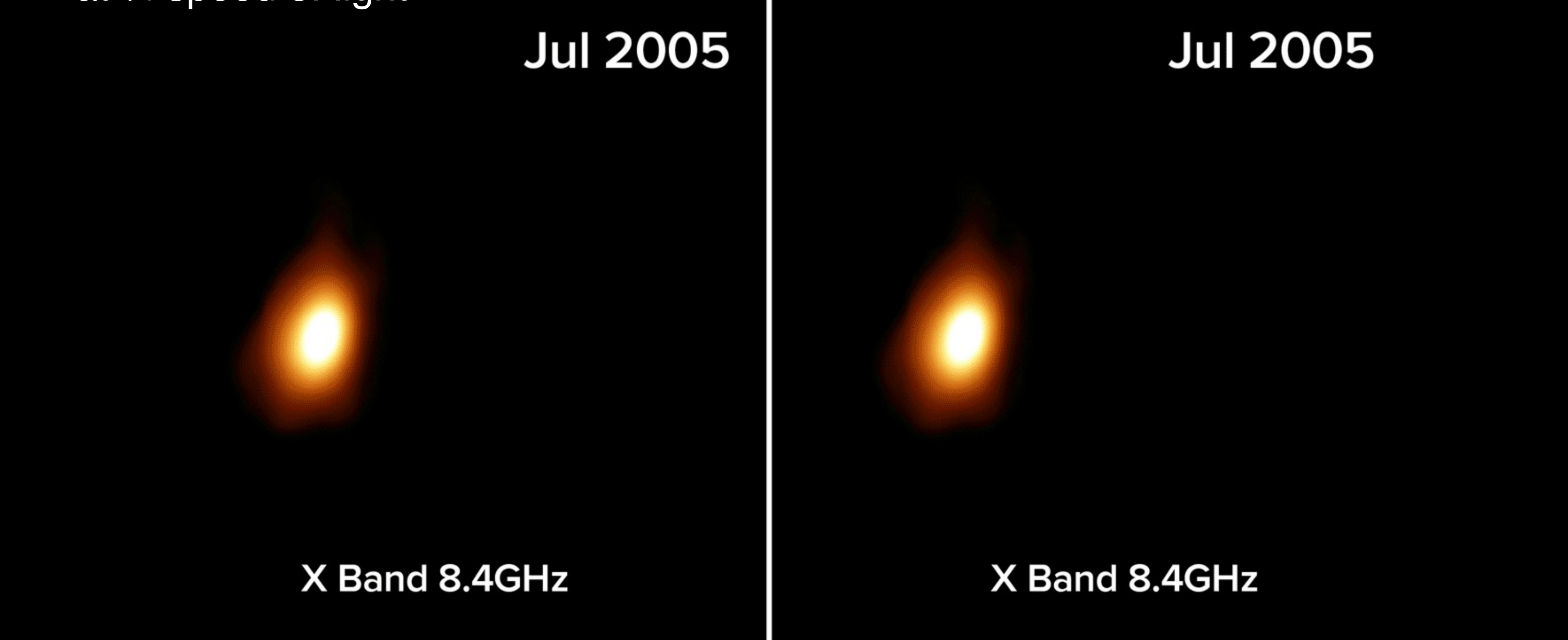


And what is the EVN useful for?

Some recent highlights:

Tidal disruption event (TDE)
(Mattila et al. 2018)

- Radio emission expanding in one direction, forming a jet moving at ¼ speed of light

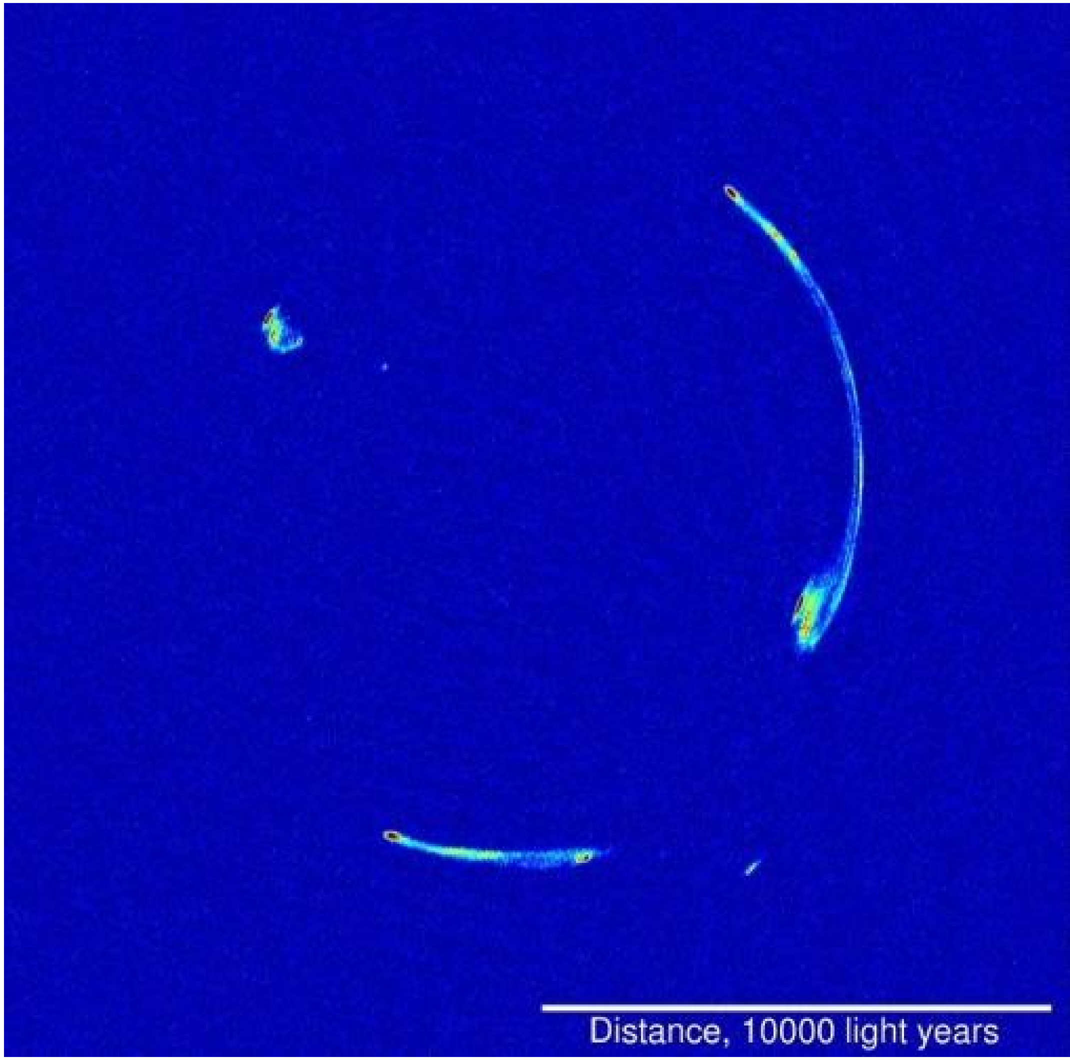


And what is the EVN useful for?

Some recent highlights:

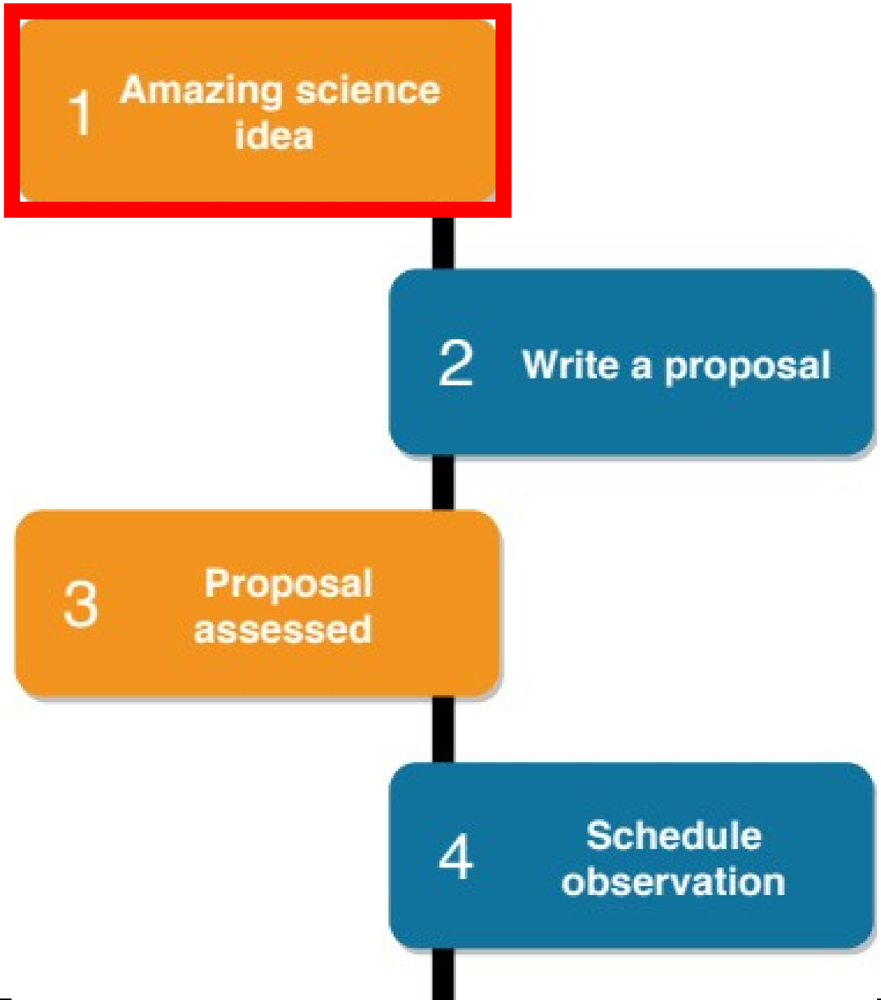
Gravitational lensing
(Spingola et al. 2018)

- Gravitational lensing allows us to observe the faintest sources.
- Radio emission bent by the gravitational field of a massive object (the lens) located between the source and the Earth, allows us to infer about both the distant source and the lens.
- Composition of dark matter across the lens, found to be clumpy and uneven.



The road from proposal to science

How do we get our EVN data (or any radio data)?

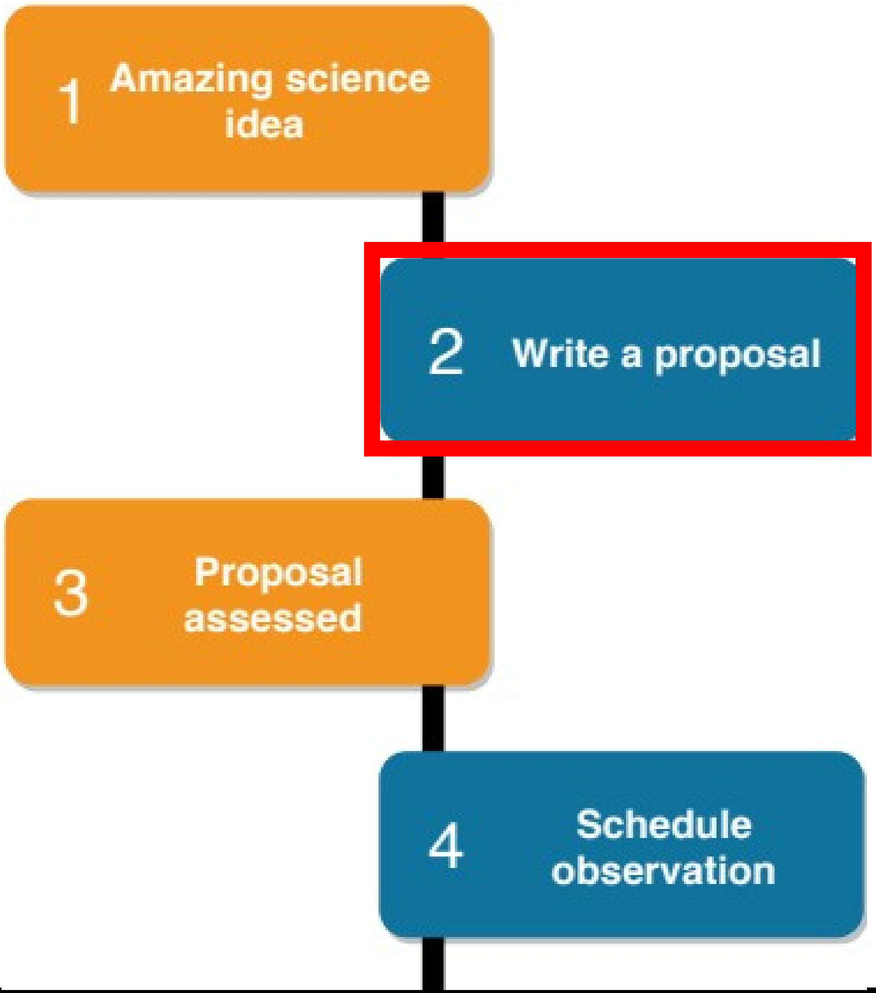


1. Start with a great science idea

- Inspiration can come from previous observations.
- Outline what telescope is suitable
- We will talk more about this process more in later lectures!

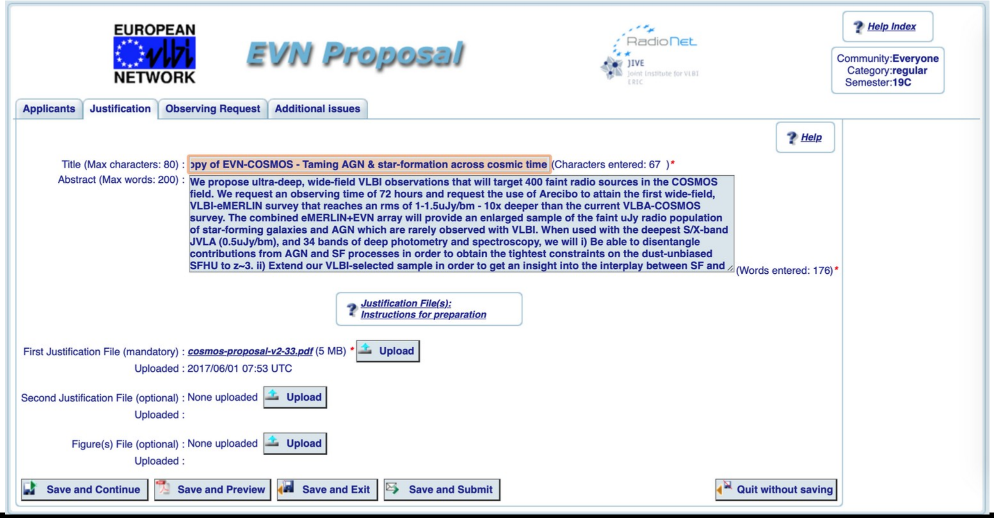
The road from proposal to science

How do we get our EVN data (or any radio data)?



2. Proposal writing

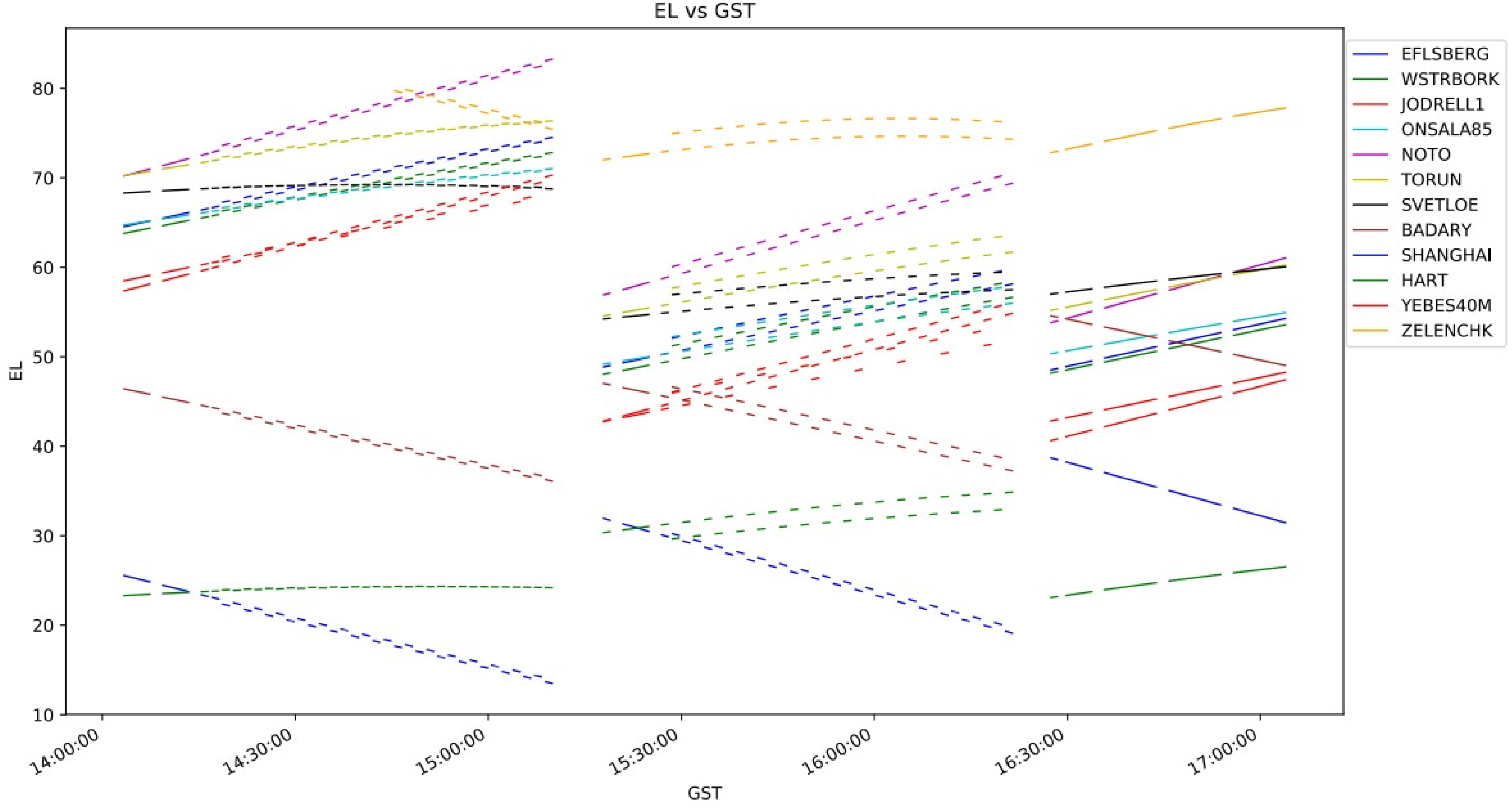
- Need to outline science case and observing strategy (we will do an exercise on this.
- Calls for proposals normally 1-3 times per year
- EVN uses Northstar GUI to do this:



The road from proposal to science

How do we get our EVN data (or any radio data)?

2. Proposal writing - Key: We should ensure that the sources are visible!



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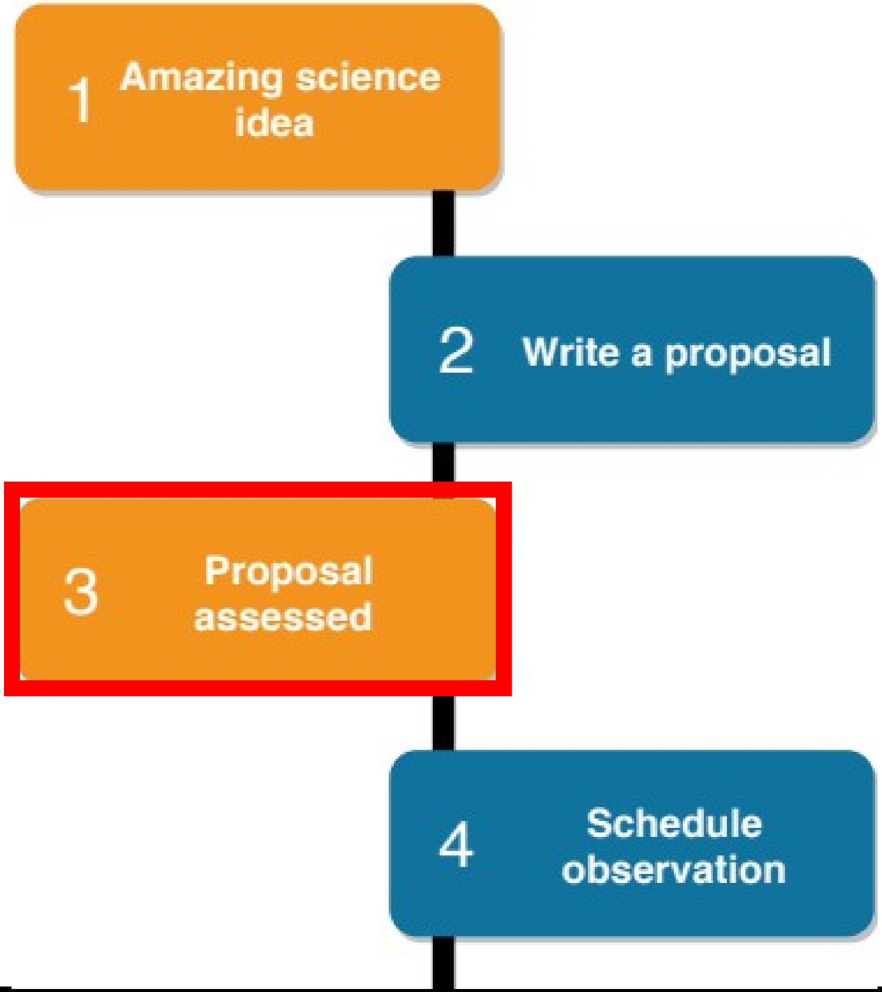
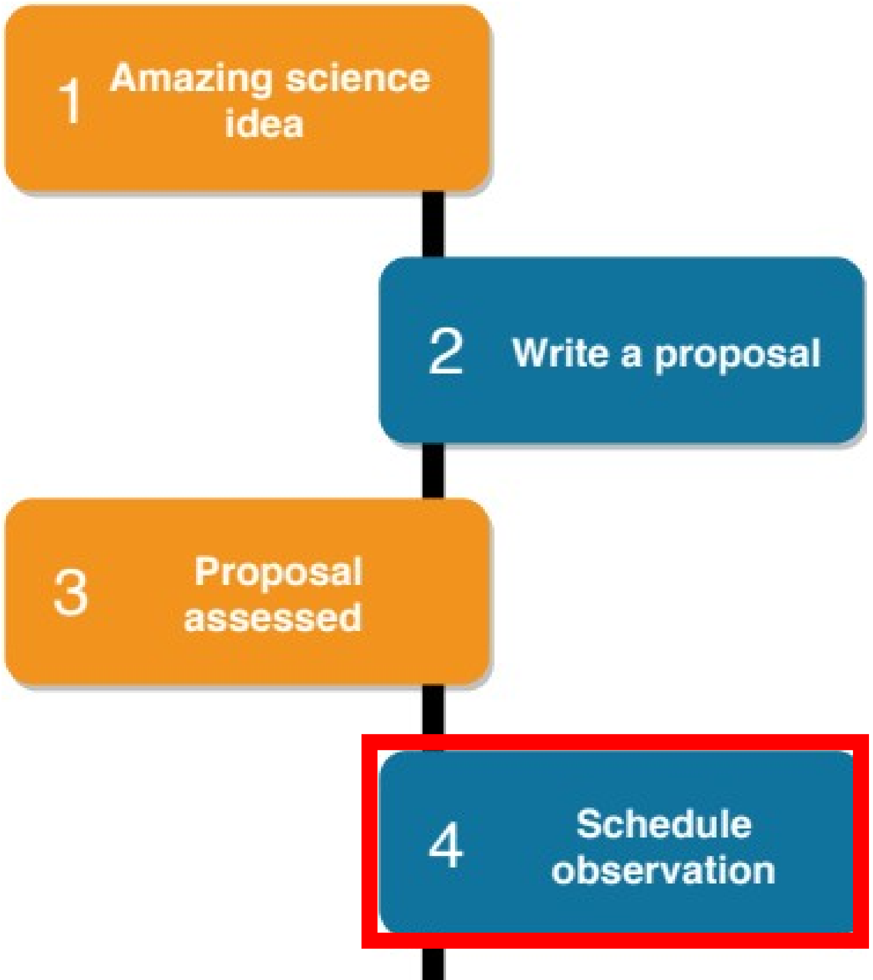


3. Proposal gets assessed

- The time allocation committee (TAC) decides who will use the telescope.
- Only limited amount of time per proposal call so only the strongest get all the time.

The road from proposal to science

How do we get our EVN data (or any radio data)?



4. If successful, schedule observation

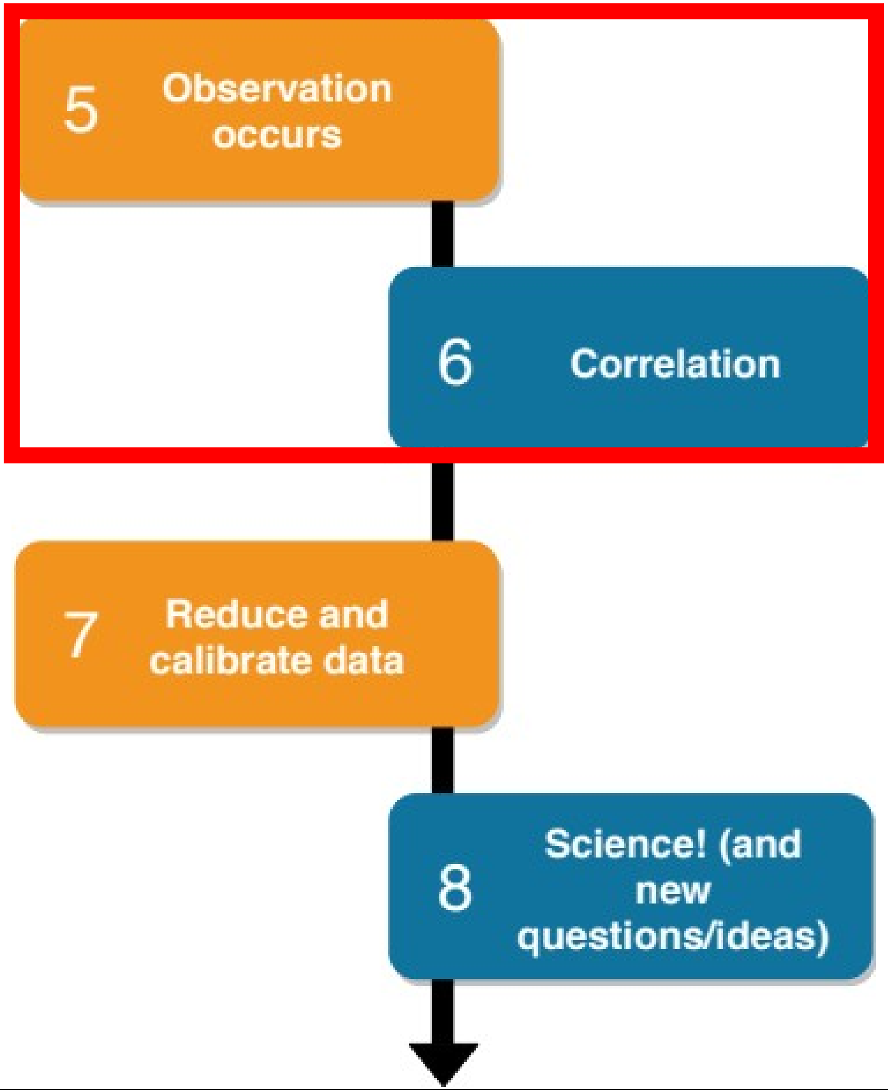
- Need to decide calibration strategy

Typical (simple strategy):

1. Observe bright source with known flux density for flux scale calibration (or fringe finding in VLBI!).
2. Go to phase calibrator (reasonably bright – usually ~100 mJy at least).
3. Go to source (which might be too faint to observe in real time).
4. Back to phase calibrator (time set by frequency, observing conditions, etc).
5. Repeat 3 and 4 until reach desired noise.
6. Usually finish on gain cal.

Explained more in calibration lecture!

The road from proposal to science



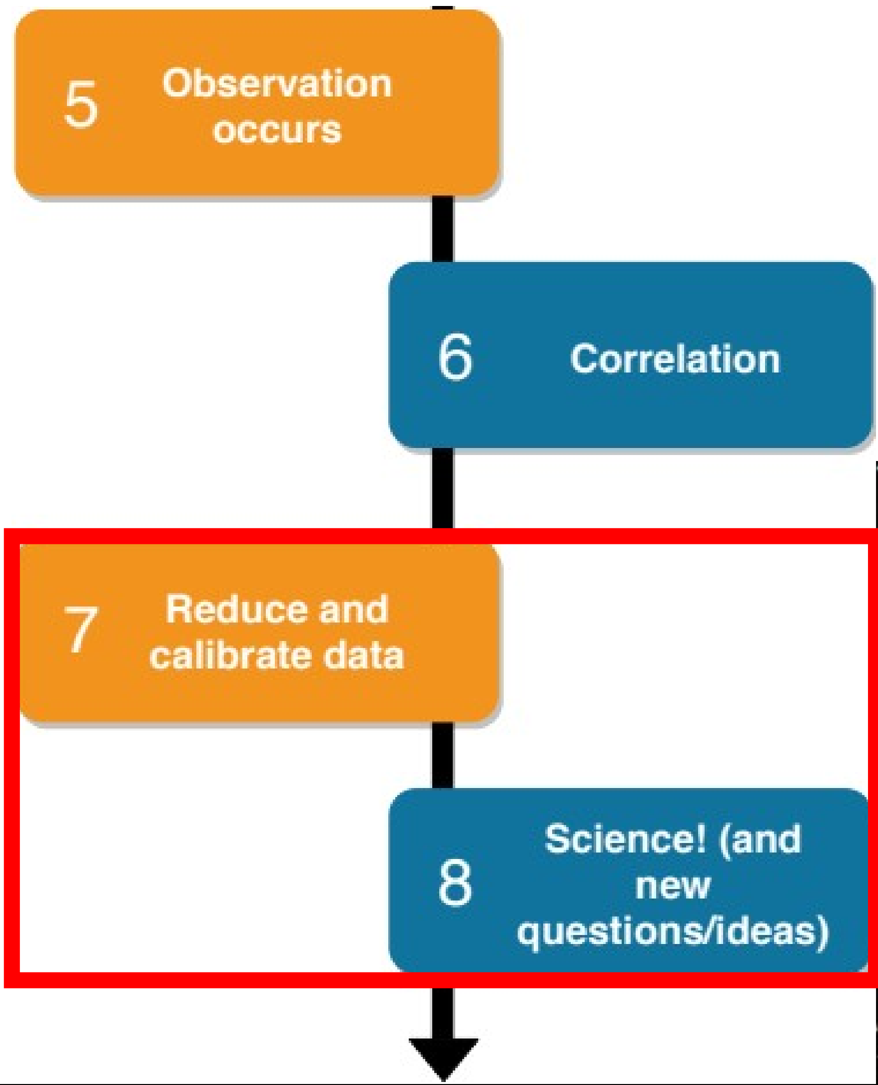
5. Observe

- VLBI observations done for you typically

6. Correlation

- For EVN data, most data recorded at each telescope onto computer disk packs
- Shipped to JIVE correlator (now possible to get all the data over the internet in select cases; e-VLBI)

The road from proposal to science

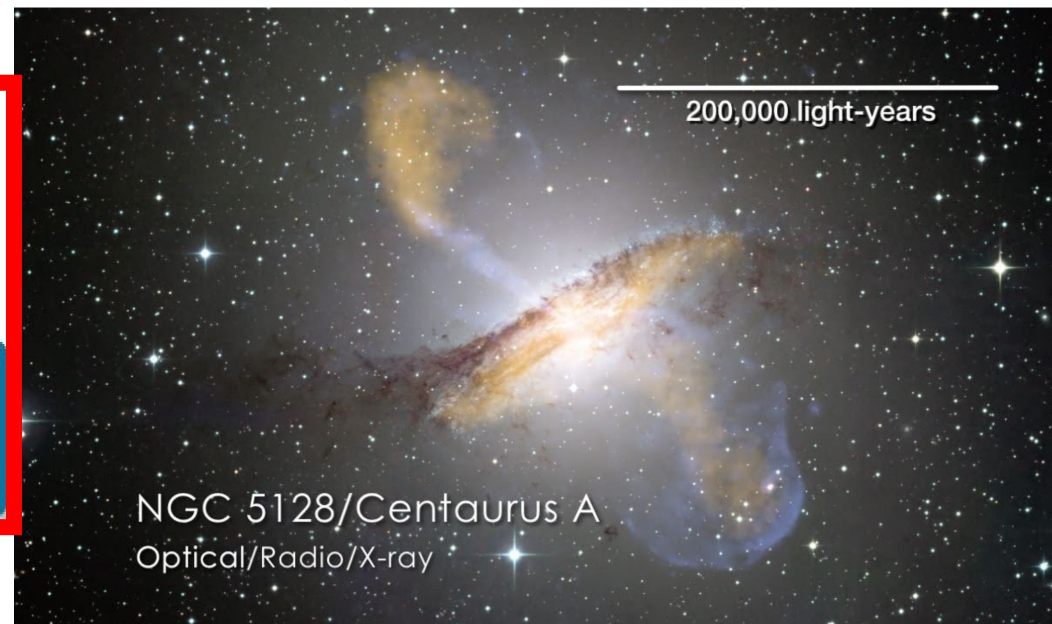


7. Reduce your data

- What you will mainly learn in this unit

6. Science

- Analyse your data and extract your science!
- Open new questions and possible new observations.



EVN data reduction workshop – the data

N14C3 – Network Monitoring Experiment (NME)

Not acquired through typical proposal means

- EVN is a ad-hoc array, telescopes are set up differently across the year so set-up issues can occur e.g. the polarizations need to be the right way round.

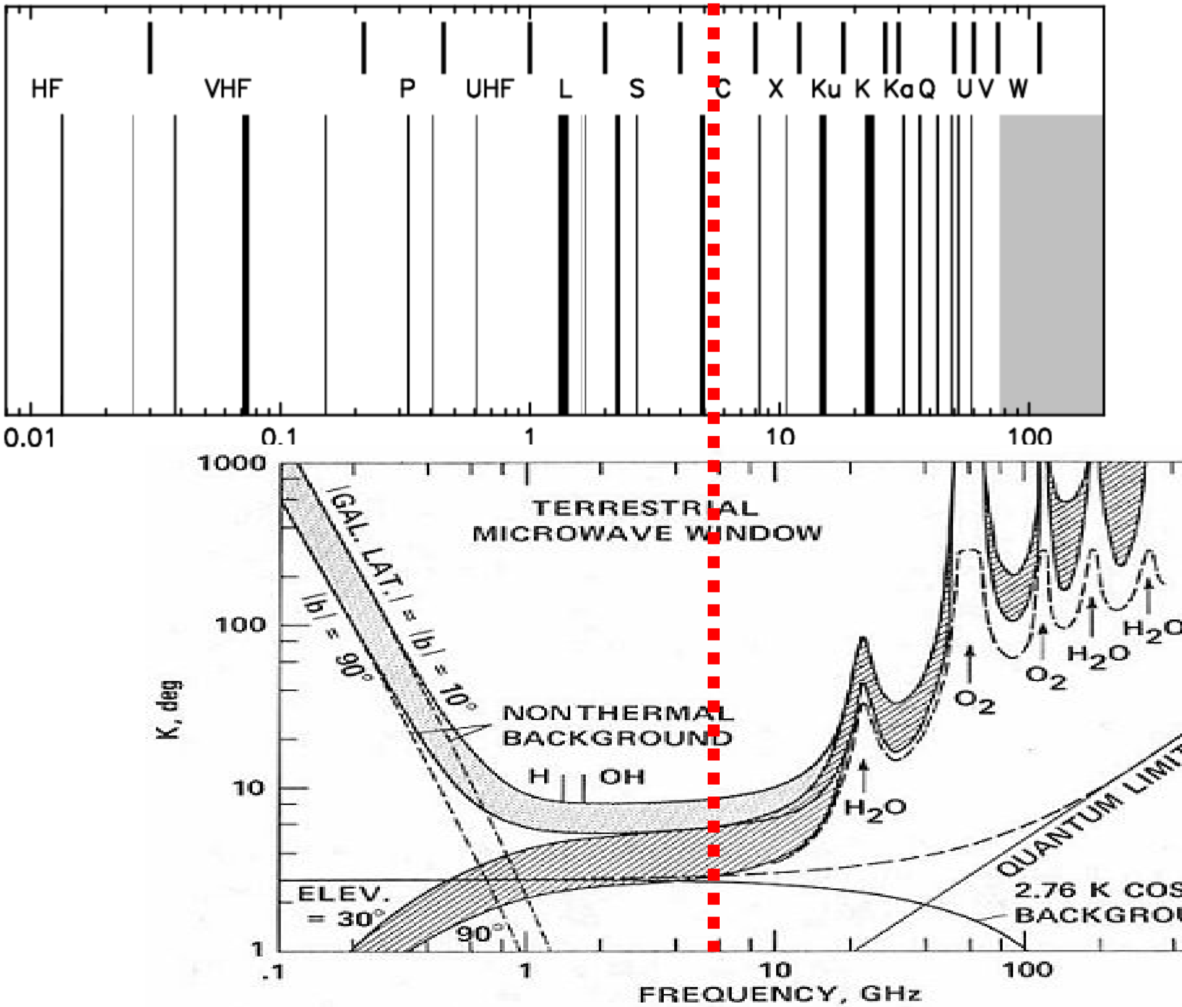
- To test these, and identify problems before proposers get their data, a short observation is used to test the array

- These NMEs are short (~few hour) observations which are useful to evaluate performance of the array.

Ideal for tutorial purposes as data has a size of ~3GB smallcompared to some radio data sets >10s TB

N14C3 – the observations

- Observation on 22 Oct 2014 for 3 hours.
- Targeted 5 sources (including fringe-finders, phase calibrators and target sources)
- Observed at C-band (~5GHz)
- Sweet spot for VLBI as:
    - Receivers are sensitive
    - Sky noise is low (see right)
    - and limited impact from atmosphere!



N14C3 – the observations

EVN OBSERVATORIES	TELESCOPE Code	Diameter(m)
Jodrell Bank (UK)	Jb-1 Lovell	76
	Jb-2 Mk2	25
Cambridge (UK)	Cm	32
Westerbork (NL)	Wb	25
Effelsberg (DE)	Ef/Eb	100
Medicina (IT)	Mc	32
Noto (IT)	Nt	32
Sardinia (IT)	Sr	65
Onsala (SE)	On-85	25
	On-60	20
Sheshan(Shanghai,CN)	Sh	25
Tianma(Shanghai,CN)	Tm65 (T6)	65
Nanshan(Urumqi,CN)	Ur	25
Torun (PL)	Tr	32
Metsaehovi (FI)	Mh	14
Yebes (ES)	Ys	40
Arecibo (USA)	Ar	305
Hartebeesthoek (SA)	Hh	26
	Ht	15
Wettzell (DE)	Wz	20
Svetloe (RU)	Sv	32
Zelenchukskaya (RU)	Zc	32
Badary (RU)	Bd	32

- 12 antennas used (highlighted in yellow)
- Data recorded on disc
- measurements recorded separately.
  - Used to set the flux-scale of your observations (i.e. you know how bright something is in reference to a ‘standard’.
- Gain-elevation curves also separately available.
  - Takes into account differing volume of atmosphere looking through) which affects gain.
- Data correlated at JIVE, stored in FITS IDI format.

N14C3 – observing strategy

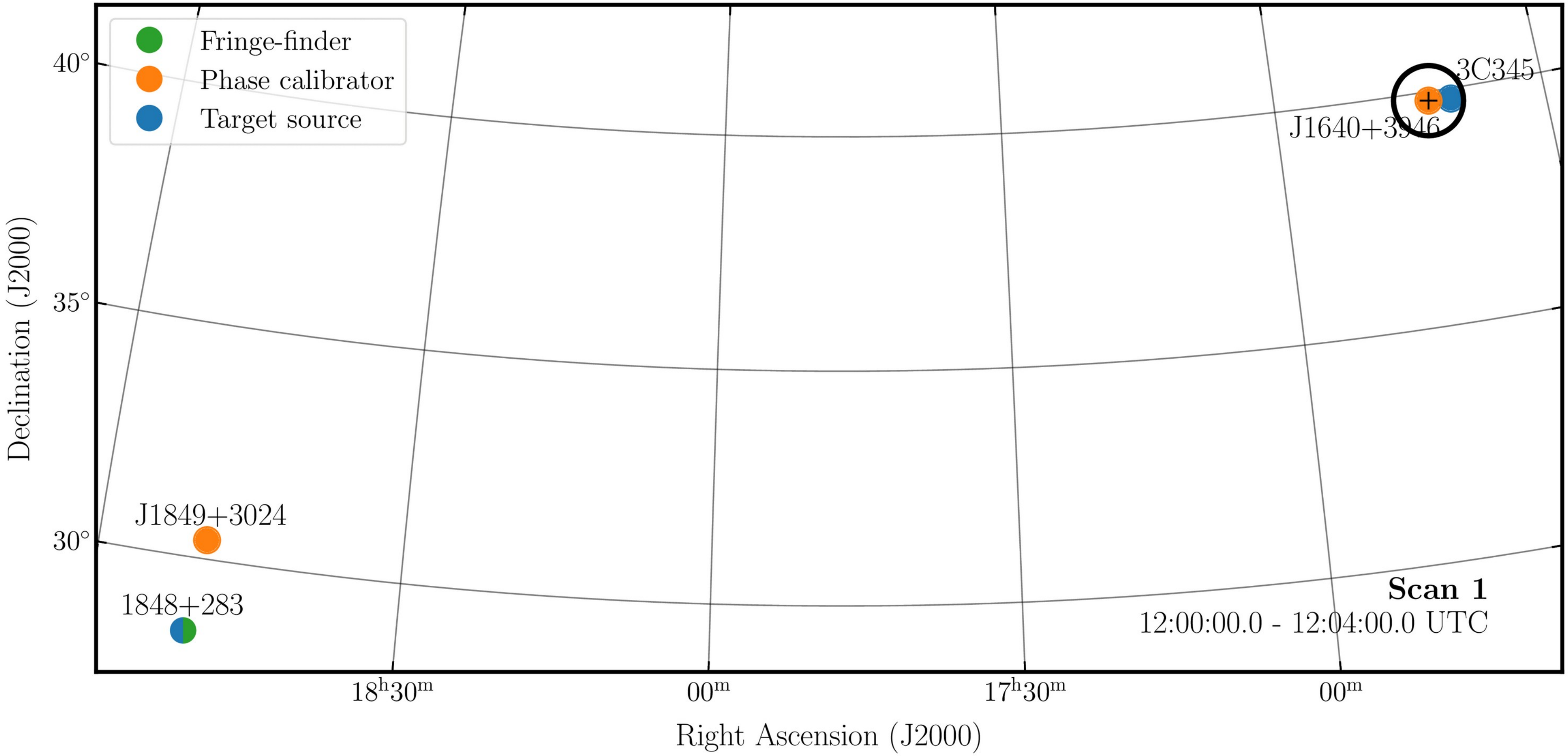
Observations are set-up so that you can calibrate your data!

Key requirements:

- Fringe-finder source – ultra-bright source used to find delays (geometric) during correlation.
- Phase calibrator – bright, compact source near to target source to track approximate phase (+ amp) induced by atmosphere & instruments vs time & frequency.
- Flux calibrator – used to set the flux scale (can be standard source, or noise diode which provides a measurement)

N14C3 – observing strategy

- Starts at 12:00 - ends at 15:00



N14C3 – correlation

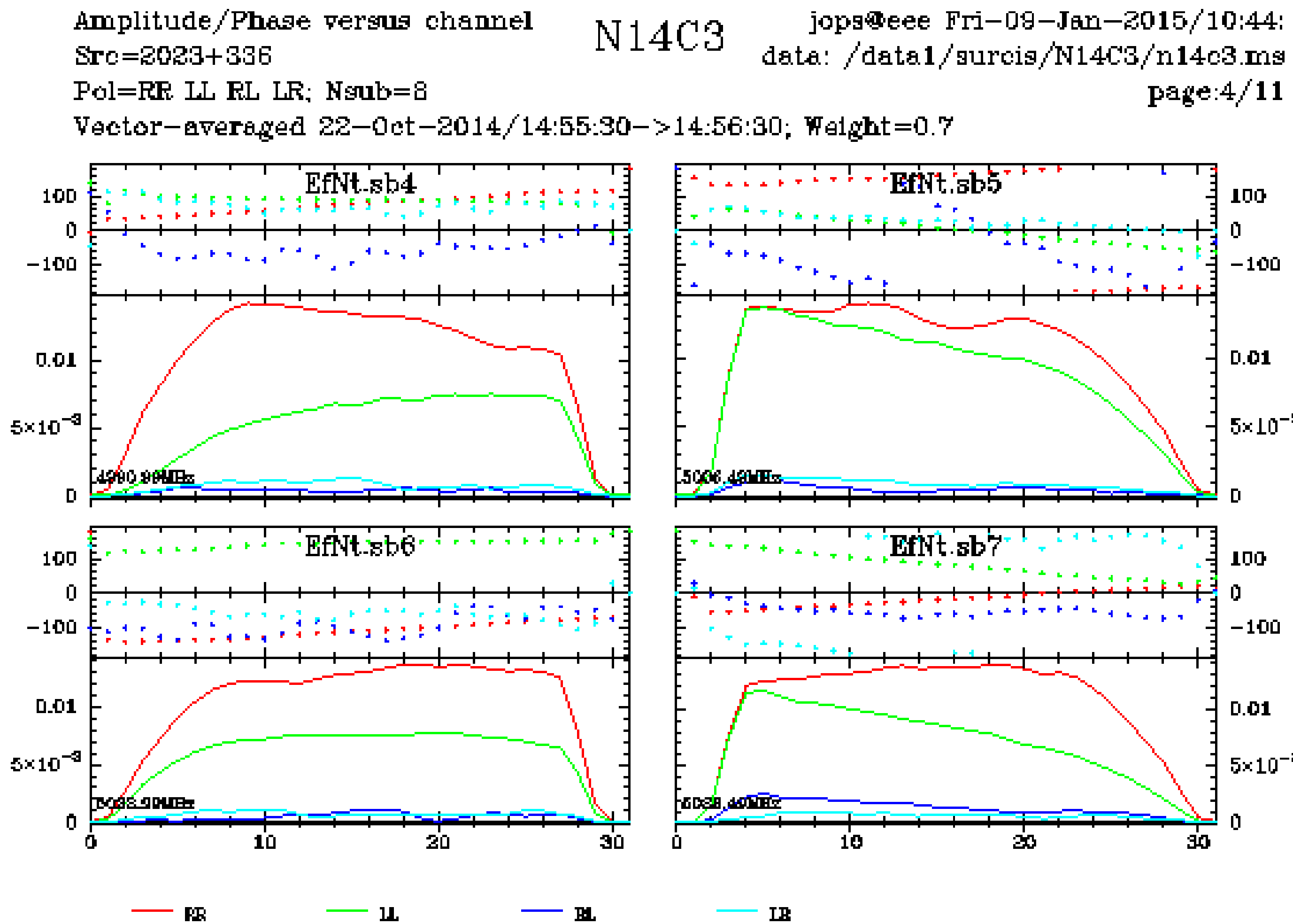
- Data correlated at JIVE using SFXC correlator.
- During correlation delay is adjusted to ensure 'fringes' on bright source known as ‘fringe finder’
  - i.e. timing corrected to provide constructive interference
- Long scan at start of phase reference cycle provides additional refinements.
- Residual delay errors are likely!

$$\tau_{\mathrm{obs}} = \tau_{\mathrm{geom}} + \tau_{\mathrm{rot}} + \tau_{\mathrm{str}} + \tau_{\mathrm{tropo}} + \tau_{\mathrm{iono}} + \tau_{\mathrm{insts}} + e_{\mathrm{noise}}$$

  - Source orientation wrt. position of telescope, Earth rotation
  - Source structure
  - Atmospheric refraction
  - Instrumental electronic path effects

N14C3 – phase vs frequency (delay)

- Fringe finders used to calculate delay corrections (refine further with calibration
- These data are pretty good!
- Very important to correct before averaging (otherwise decorrelate)



N14C3 – manual calibration strategy: I

- Apply and gain-elevation curves
  - Provides approximate flux scale by using SEFDs (emission in Jy equivalent to system temperature)
- Inspect and remove radio frequency interference (RFI)
- Inspect brightest source
- Select ~2 min good data to derive instrumental delays.
  - Corrects for antenna induced delays ~ constant over observation)
  - Short period to avoid time-variable decorrelation
  - Assume clock errors constant, apply correction to all data
- Fringe-fit to derive phase, rate (phase vs time derivative), and delay (phase vs frequency) on both phase cals

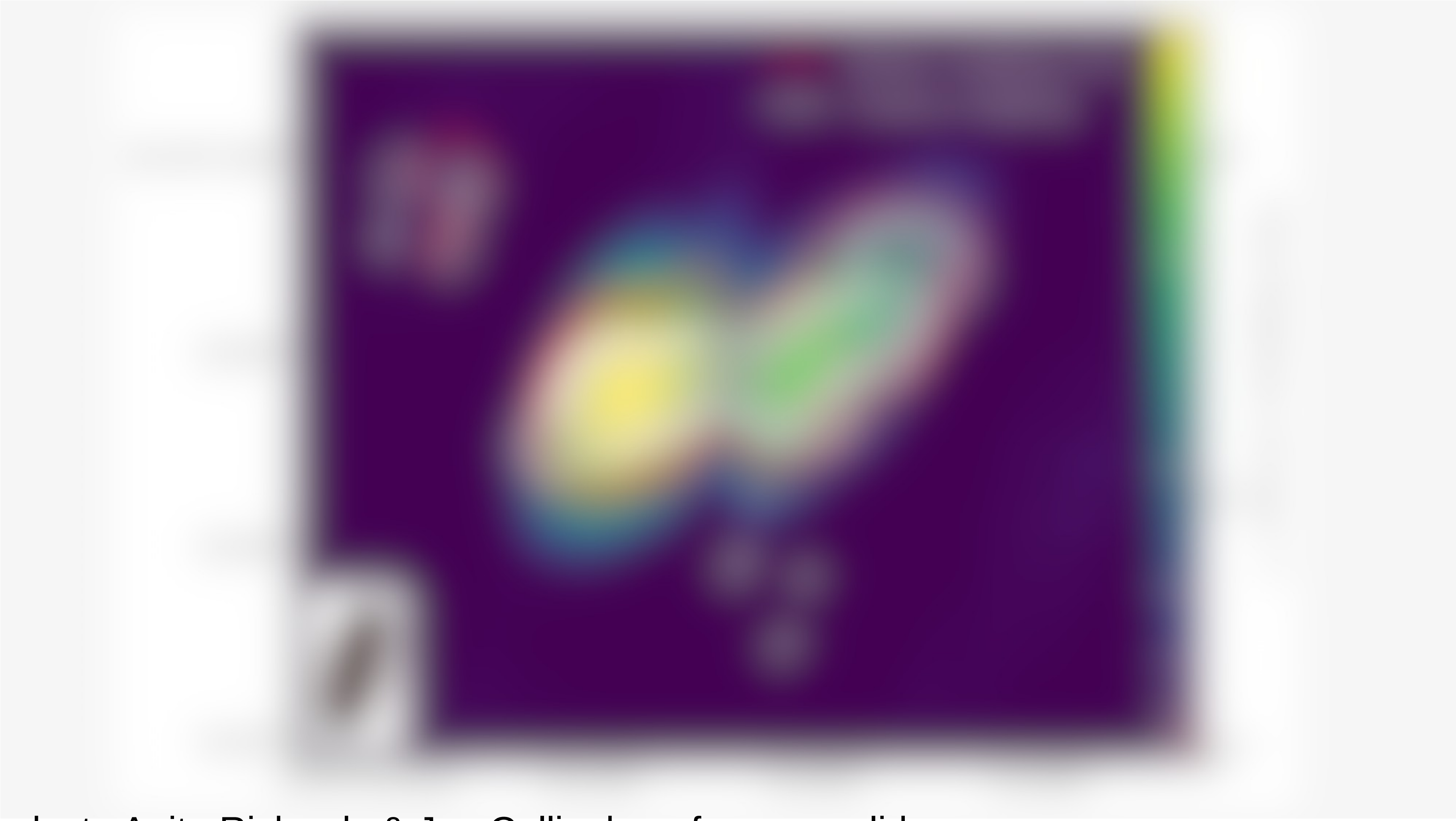
N14C3 – manual calibration strategy: 2

- At several stages, apply parallactic angle correction, i.e. compensate for different effects on L and R feeds as Alt-Az antennas rotate on the sky
- Flag brightest source first, flag other sources as calibration is applied (easier to see bad data)
- Check amplitude v. uv distance for signs of resolution
- Split out each phase-ref – target pair
- Bandpass amplitude and phase are calibrated to allow averaging of all channels

N14C3 – manual calibration strategy: 3

- Apply calibration to phase ref and image
- Use image as model for phase, delay & amp calibration of phase-reference
- If very resolved, repeat until good model is achieved
- Apply phase and amplitude solutions derived from the phase ref to the target (bandpass solutions already applied)
- Image target
- Self calibrate target (if bright enough)
- Do some science! (in the real world)

The result – you have to wait and see!



Thanks to Anita Richards & Joe Callingham for some slides