Very Long Baseline Interferometry

Ilse van Bemmel (JIVE)

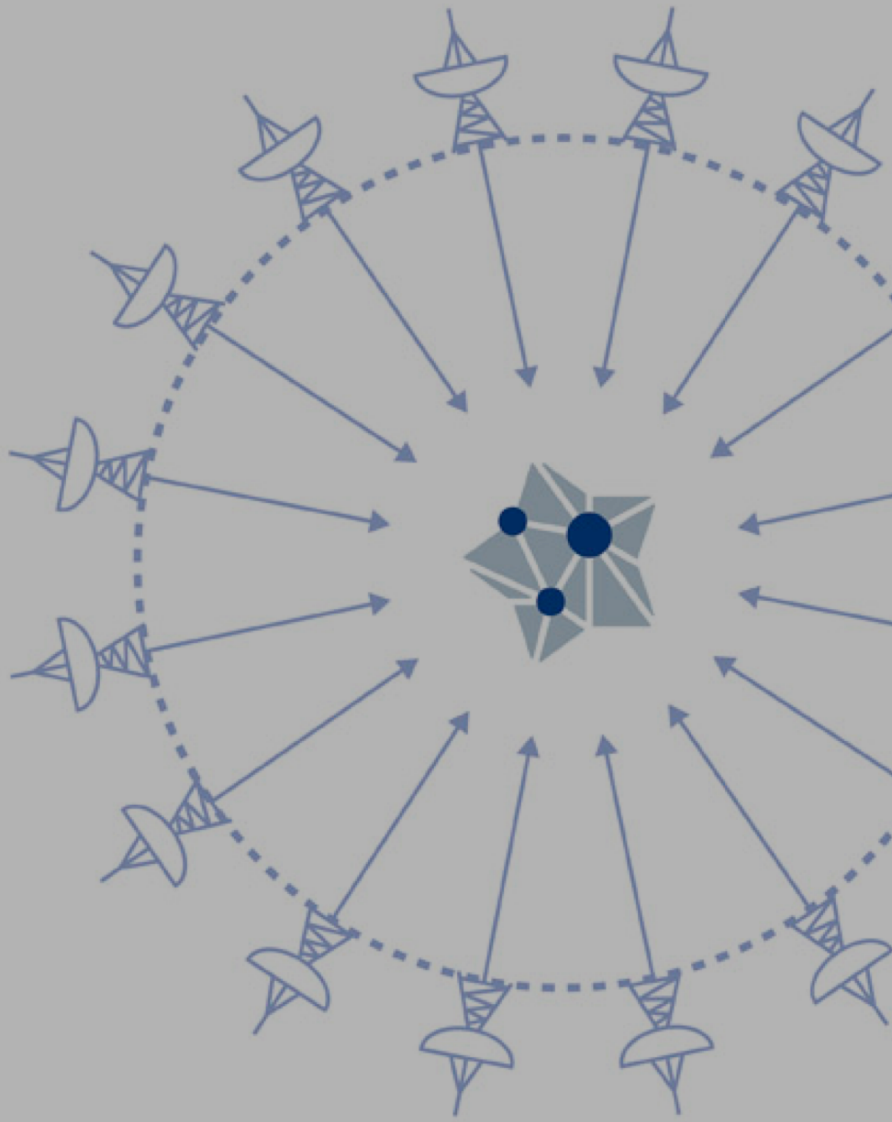
Overview of VLBI lectures

- Three sessions today:
  1. Lecture on VLBI basics
  2. Interactive tutorial part 1: calibration
  3. Interactive tutorial part 2: imaging

- Advanced sessions tomorrow:
  1. High frequency VLBI and the rPicard pipeline (T9B)
  2. Hydrogen absorption line VLBI experiments (T9C)

This lecture

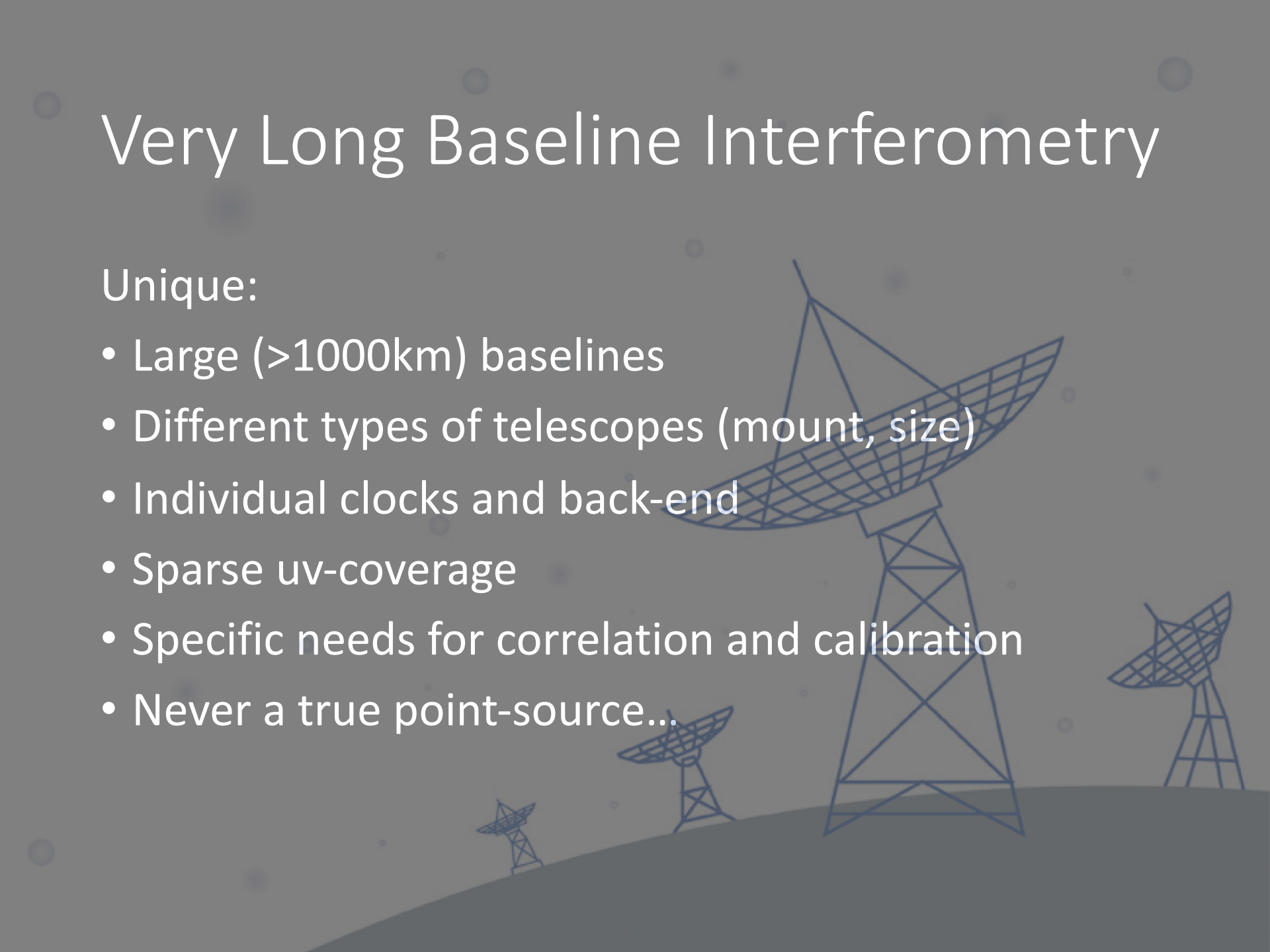
- What, why, how
- VLBI instruments
- Science cases
- VLBI specifics
- Ongoing development



Very Long Baseline Interferometry

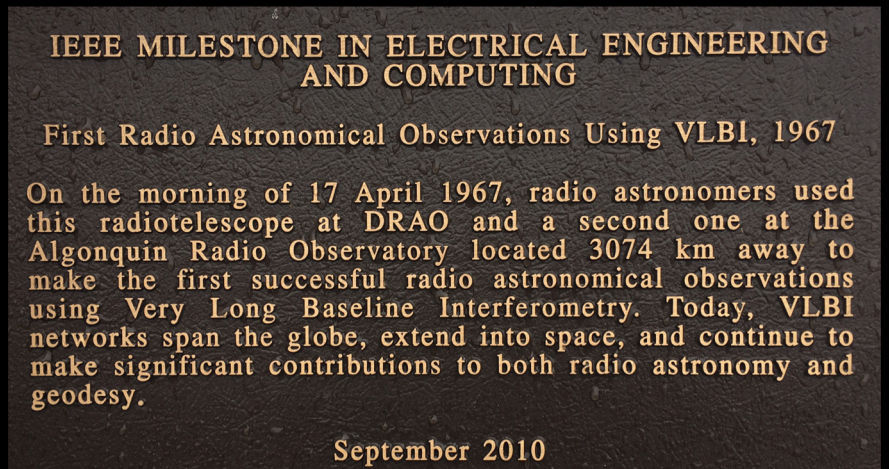
Unique:

- Large (>1000km) baselines
- Different types of telescopes (mount, size)
- Individual clocks and back-end
- Sparse uv-coverage
- Specific needs for correlation and calibration
- Never a true point-source…



History

- Just over 50 years old
  - Canada to US
  - Transatlantic US to Onsala
- First VLBI networks late 1970's
  - European VLBI Network ~1980
- JIVE established ~25 years ago



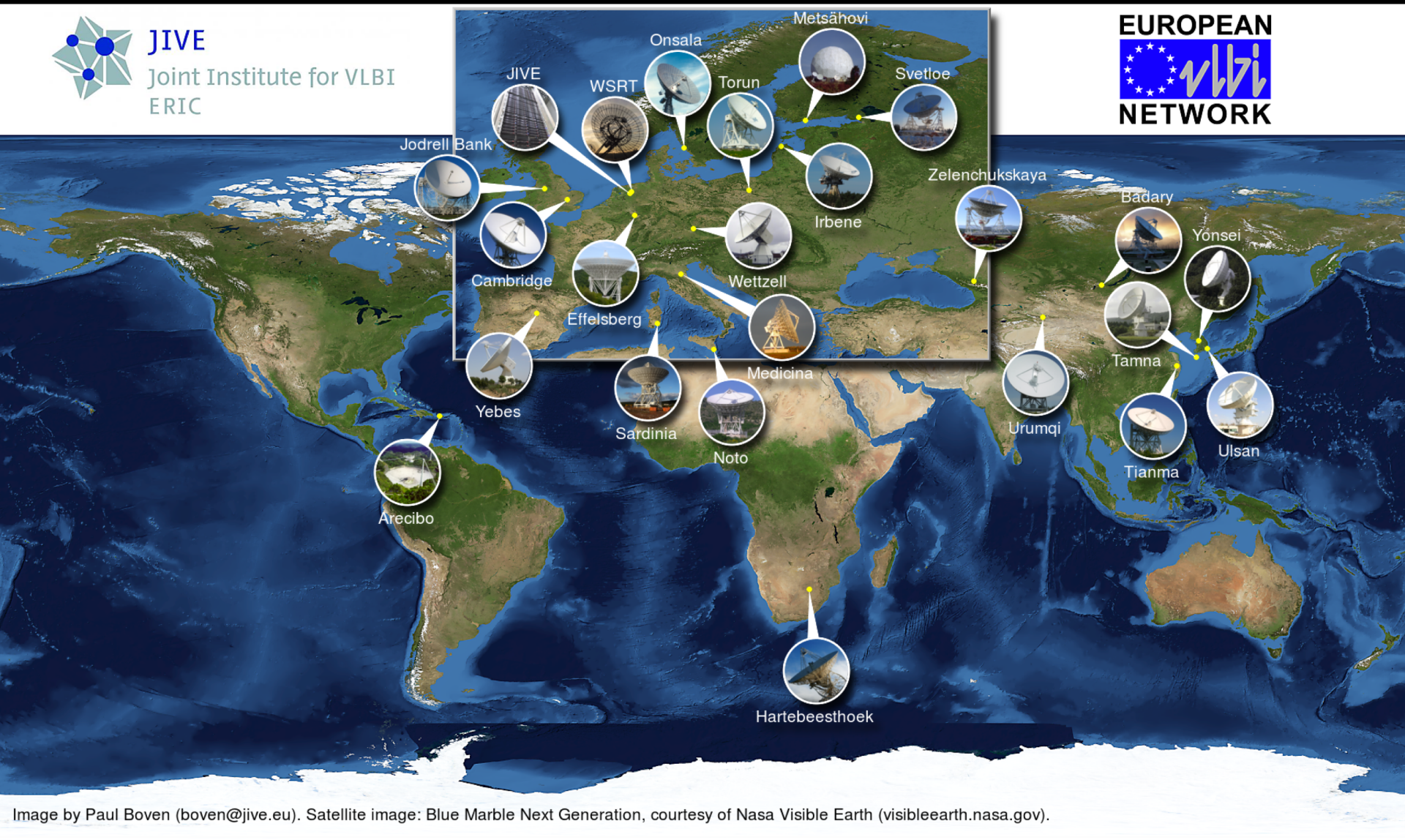
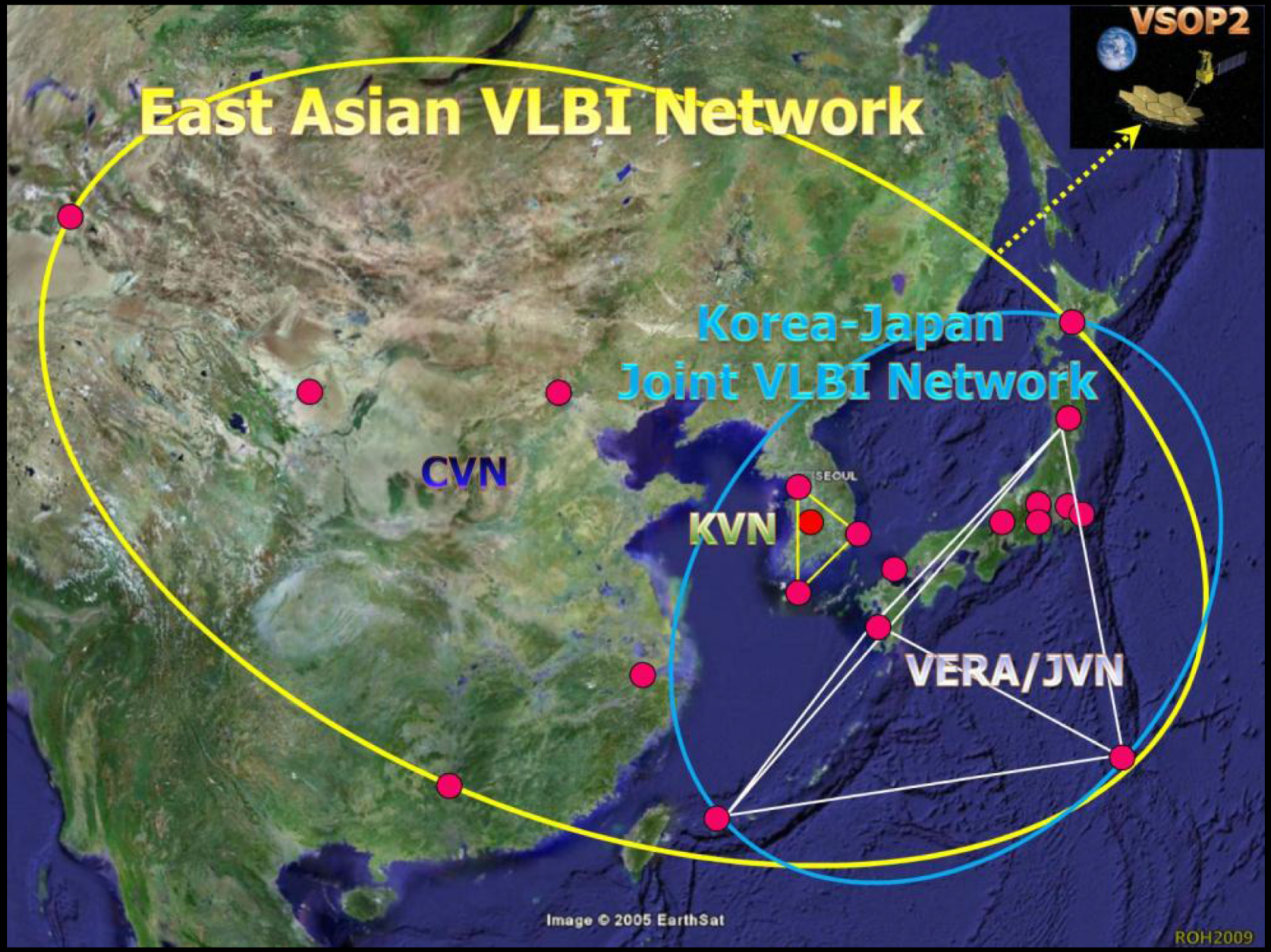
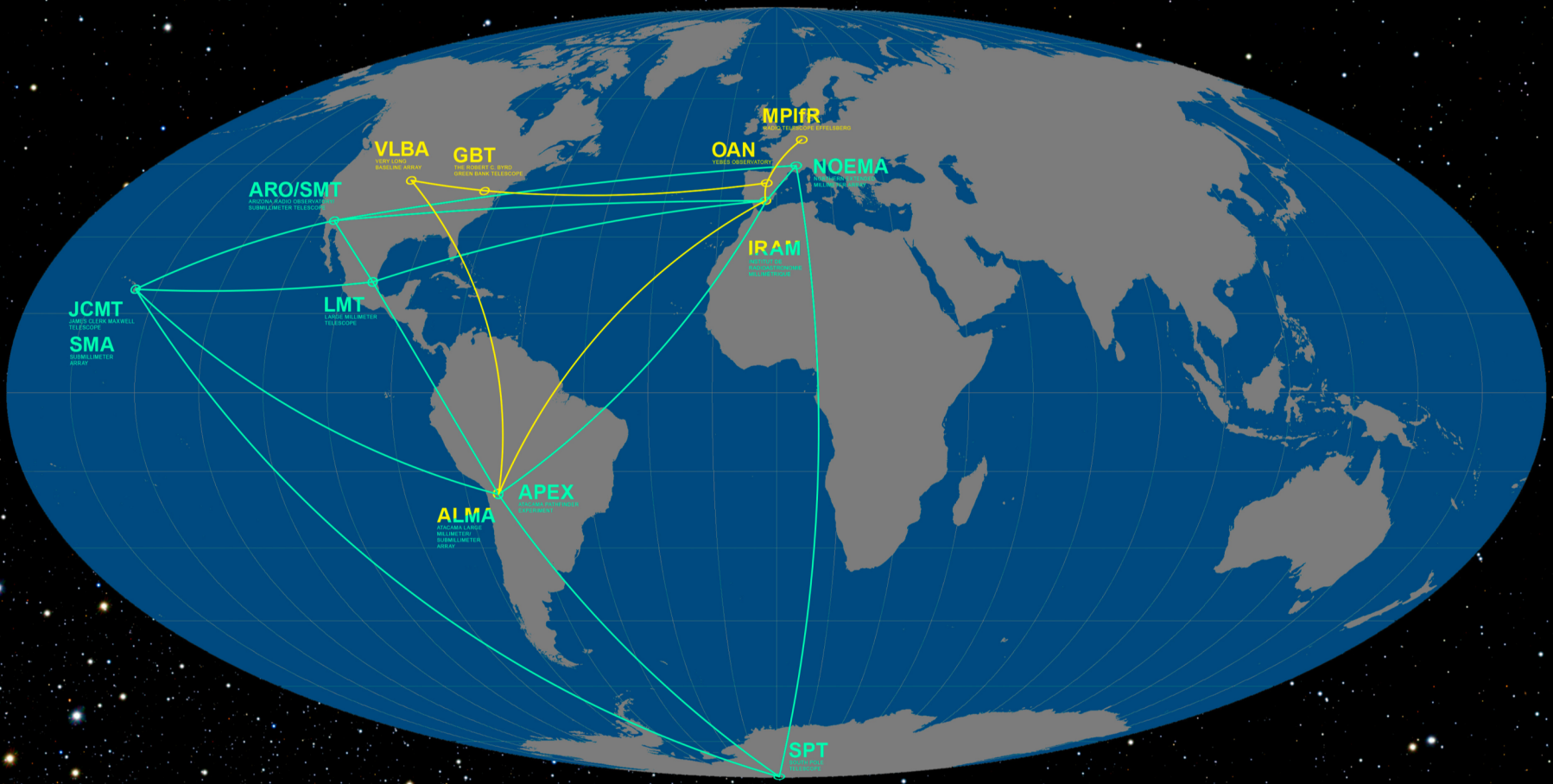


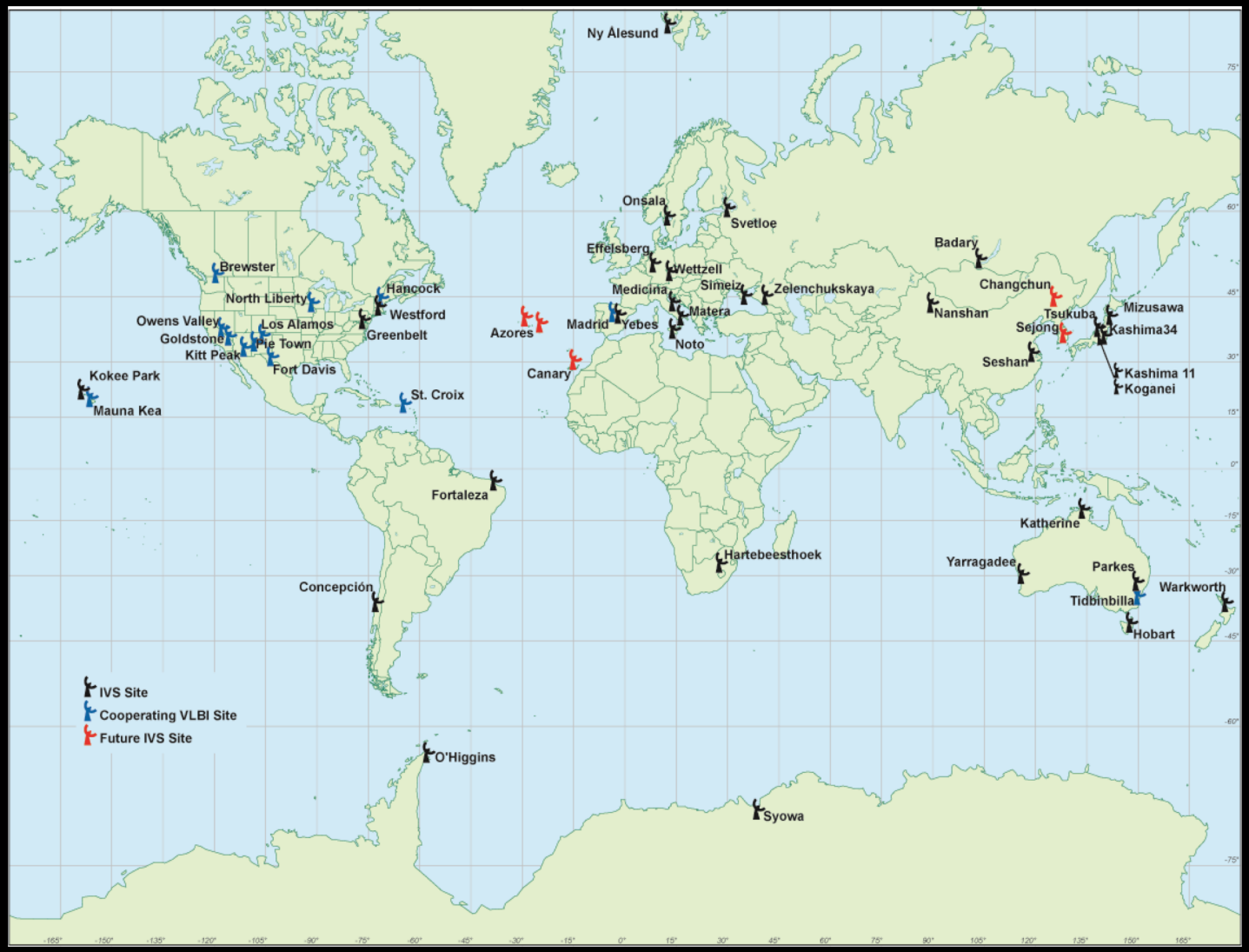
Image by Paul Boven (boven@jive.eu). Satellite image: Blue Marble Next Generation, courtesy of Nasa Visible Earth (visibleearth.nasa.gov).


The Very Long Baseline Array (VLBA)
Brewster, Wash.
Pie Town and
Los Alamos, N.M.
Owens Valley, Calif.
Kitt Peak, Ariz.
Fort Davis, Texas
North Liberty, Iowa
Hancock, N.H.
Mauna Kea, Hawaii
St. Croix, V.I.
1,000 km
1,000 miles


East Asian VLBI Network
VSOP2
Korea-Japan
Joint VLBI Network
CVN
SEOUL
KVN
VERA/JVN
Image © 2005 EarthSat
ROH2009

Event Horizon Telescope



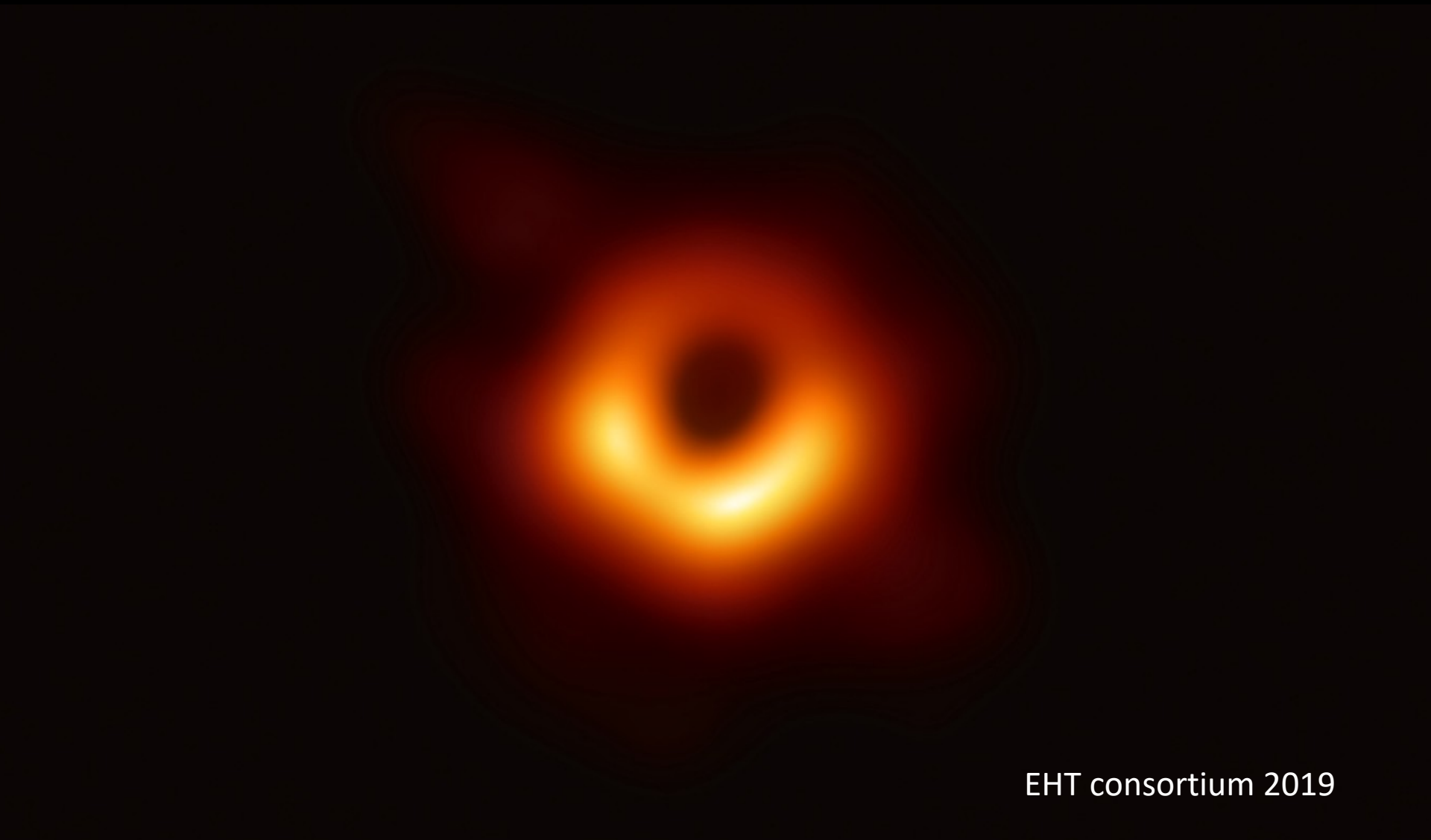

Ny Ålesund
Onsala
Svetloe
Effelsberg
Wettzell
Badary
Changchun
Brewster
Hancock
North Liberty
Medicina
Simeiz
Zelenchukskaya
Nanshan
Tsukuba
Mizusawa
Owens Valley
Los Alamos
Westford
Greenbelt
Azores
Madrid
Yebes
Matera
Sejong
Kashima34
Goldstone
Pie Town
Kitt Peak
Fort Davis
Noto
Seshan
Canary
Kashima 11
Koganei
Kokee Park
Mauna Kea
St. Croix
Fortaleza
Katherine
Hartebeesthoek
Yarragadee
Parkes
Warkworth
Concepción
Tidbinbilla
Hobart
IVS Site
Cooperating VLBI Site
Future IVS Site
O'Higgins
Syowa

Science cases

Compact and bright objects

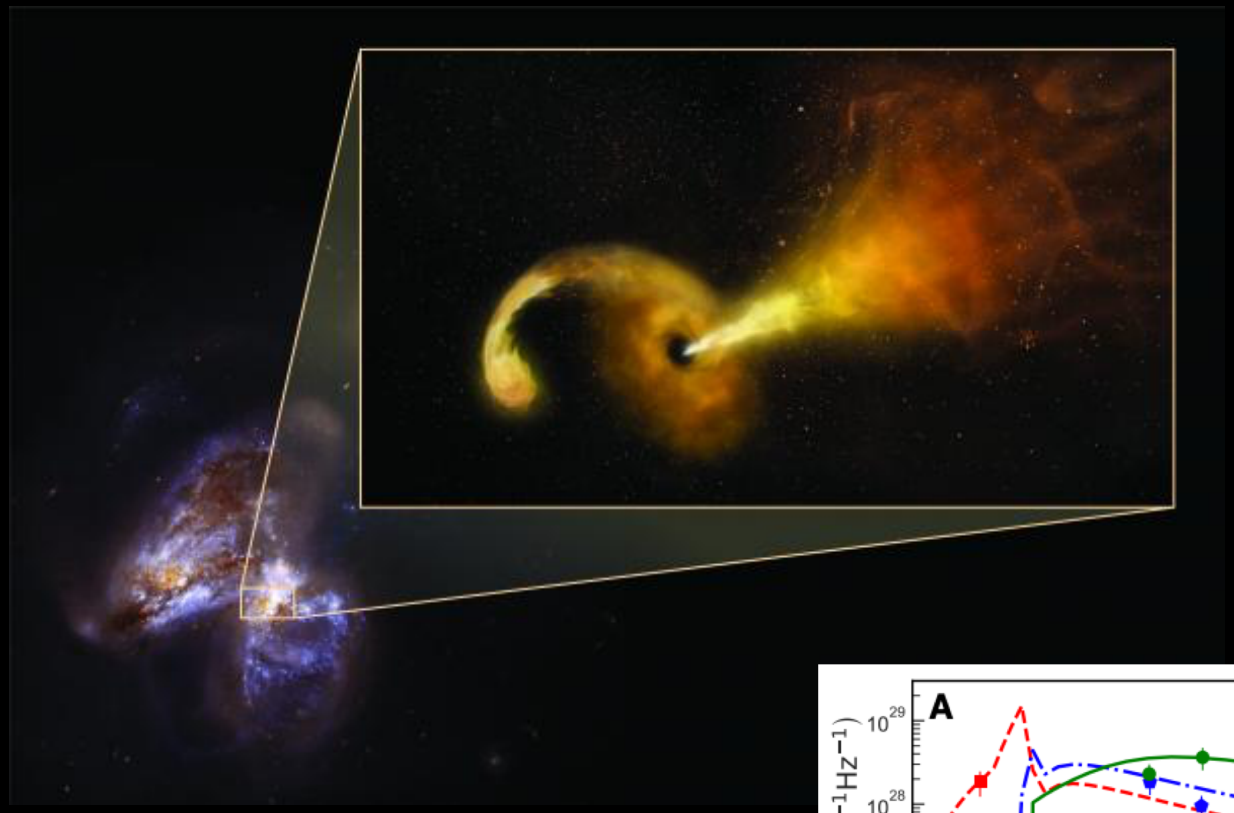
- Accretion and jets from supermassive black holes
- Stellar evolution
- Transients
- Astrometry
- Geodesy
- Space-craft tracking

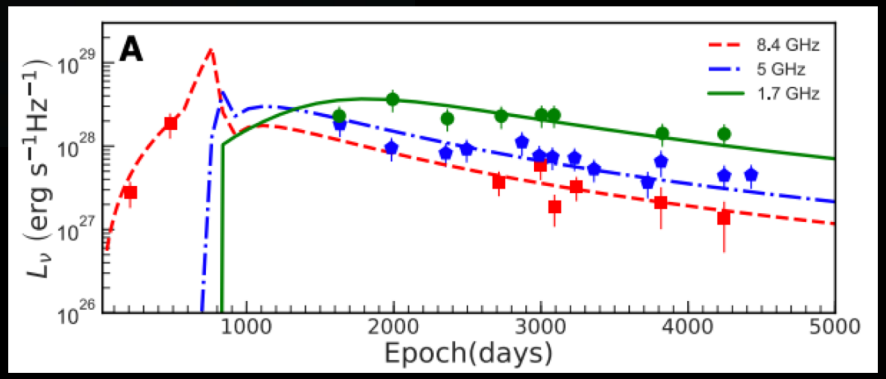
Recent highlights of VLBI



EHT consortium 2019

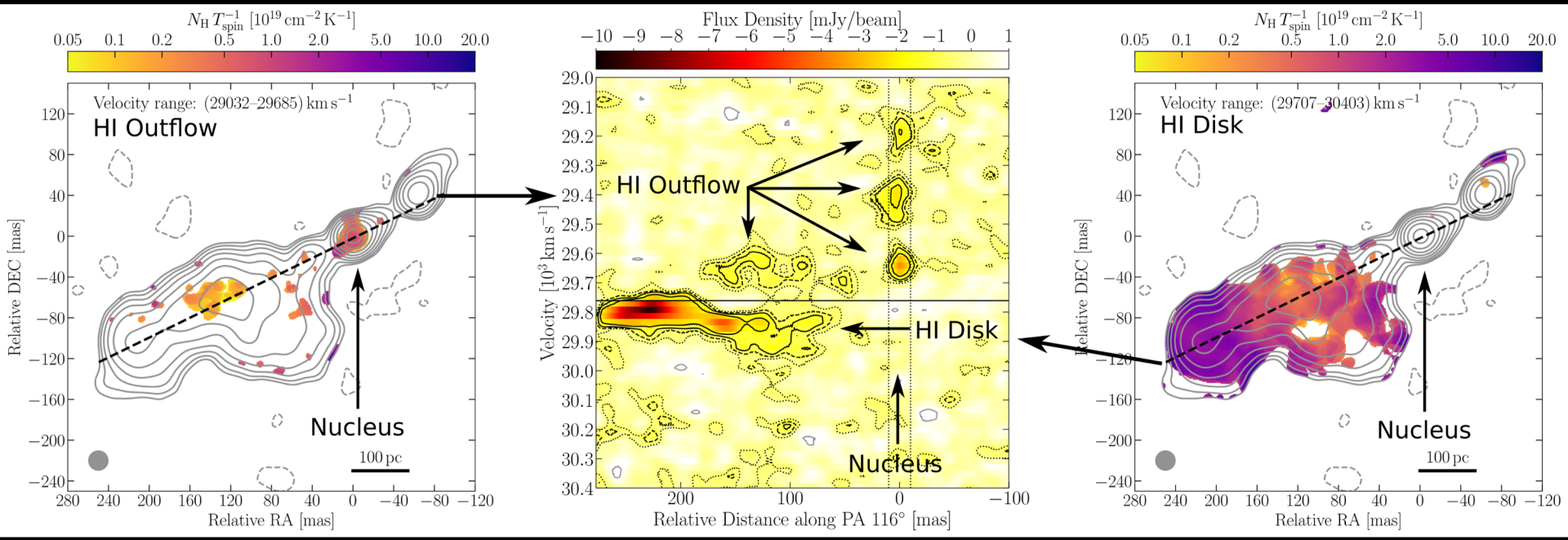
Recent highlights





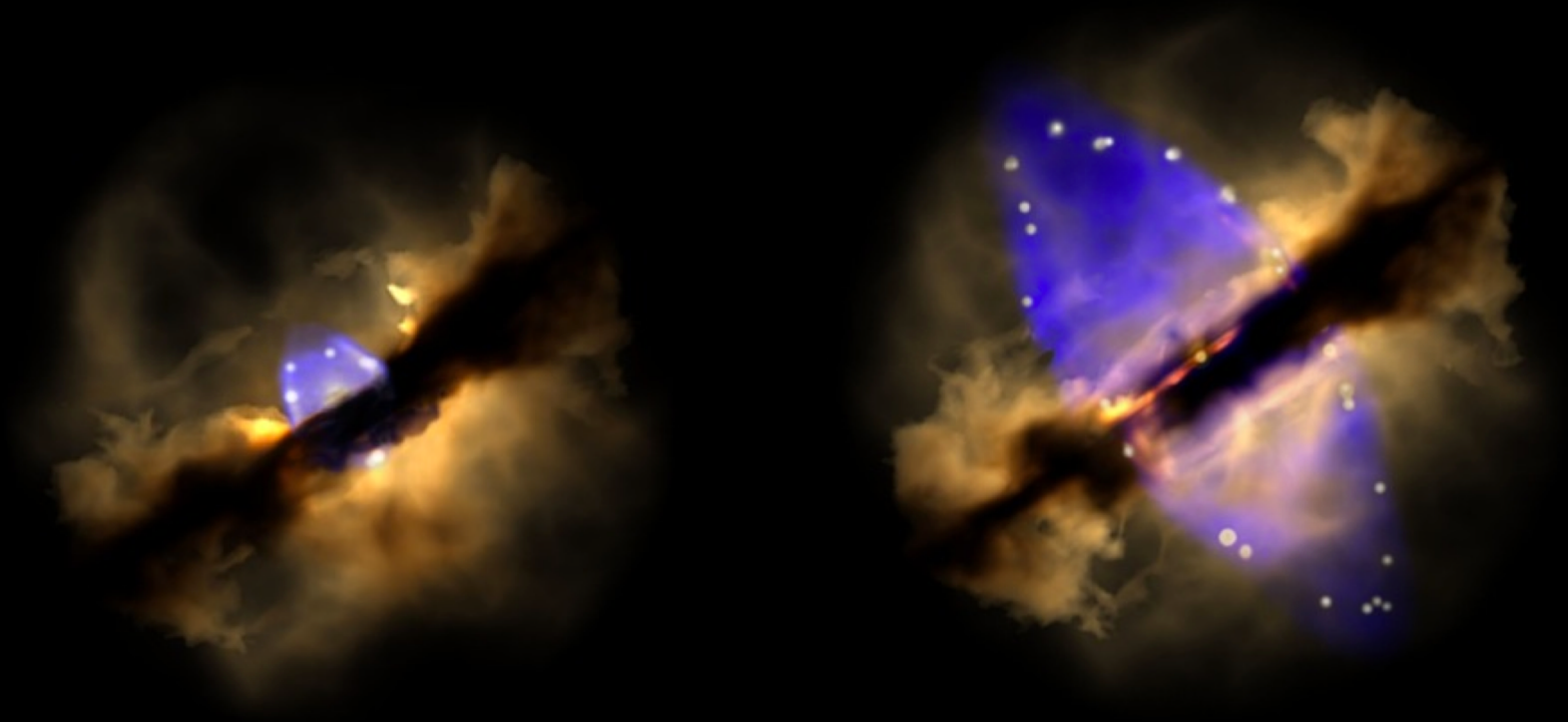
Mattila+ 2018

Recent highlights



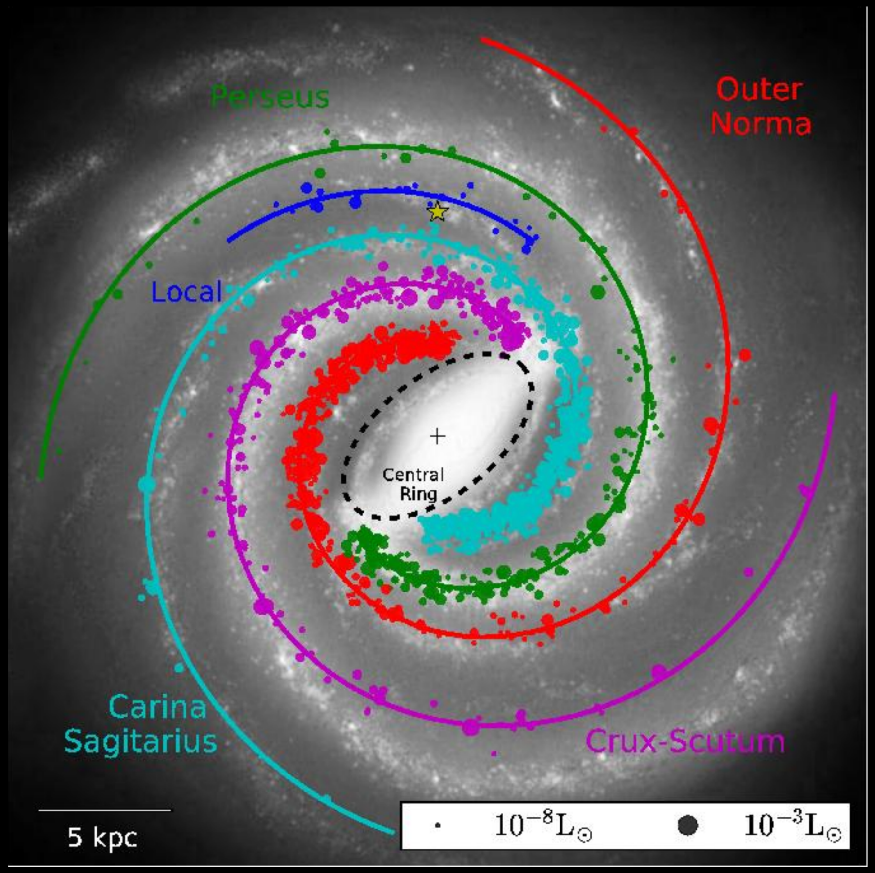
Schulz+ 2018, Morganti+ 2018

Recent highlights



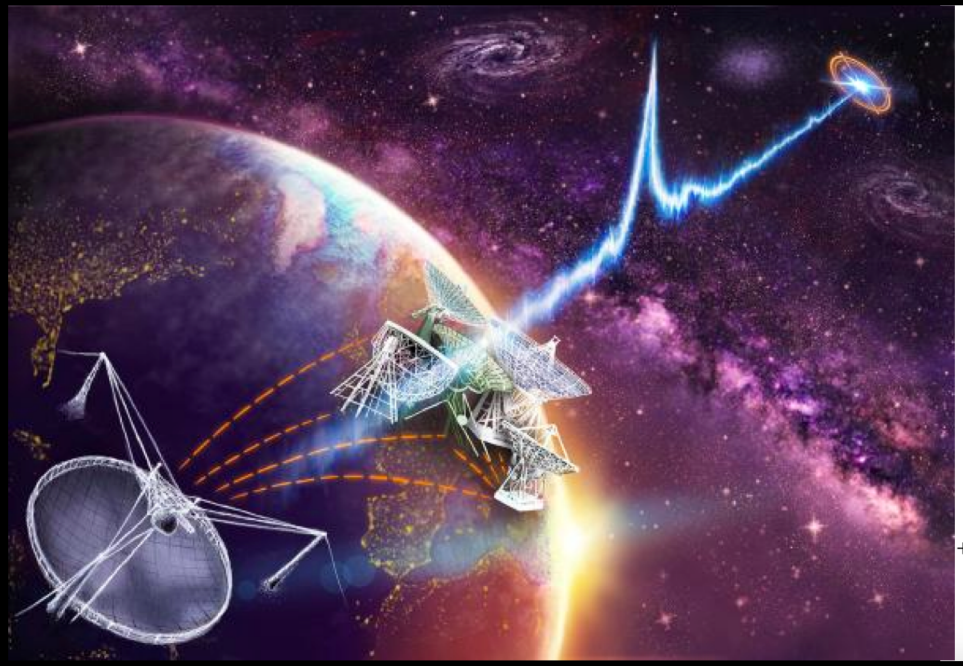
Carrasco-González+ 2015

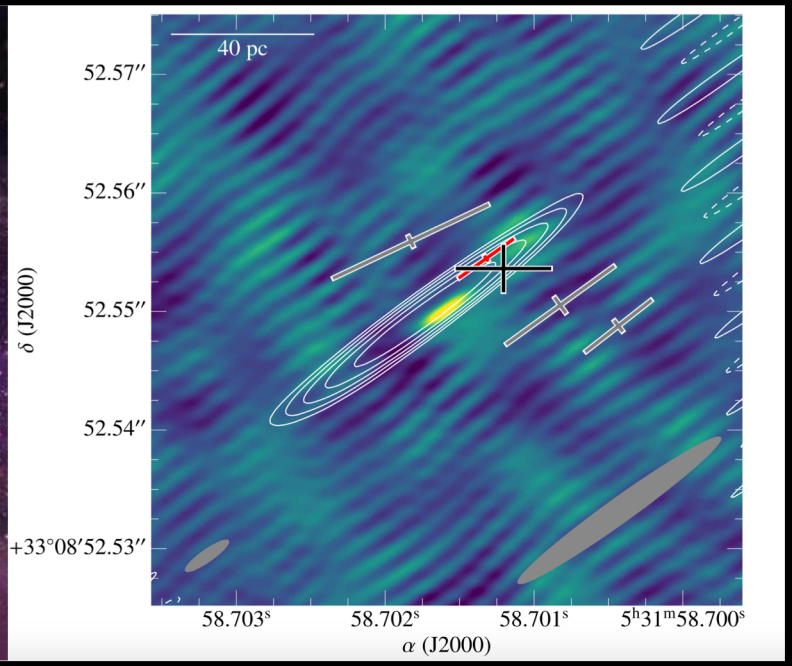
Recent highlights



Quiroga+ 2017

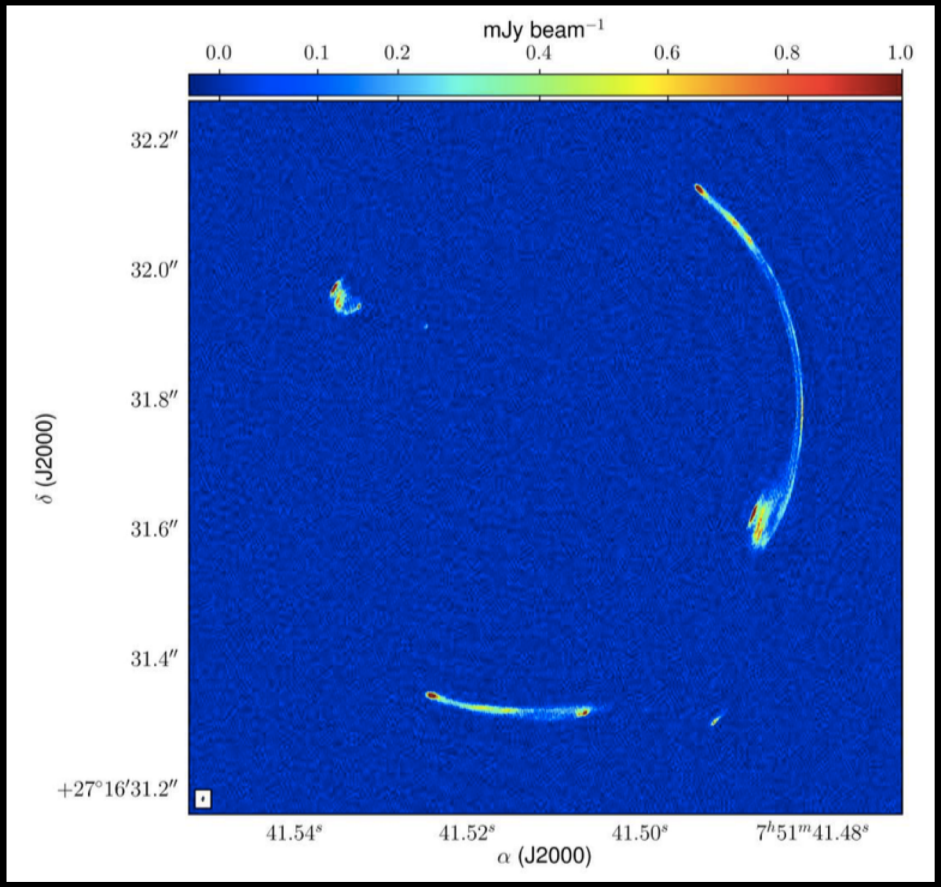
Recent highlights





Chatterjee+ 2017, Marcote+ 2017

Recent highlights



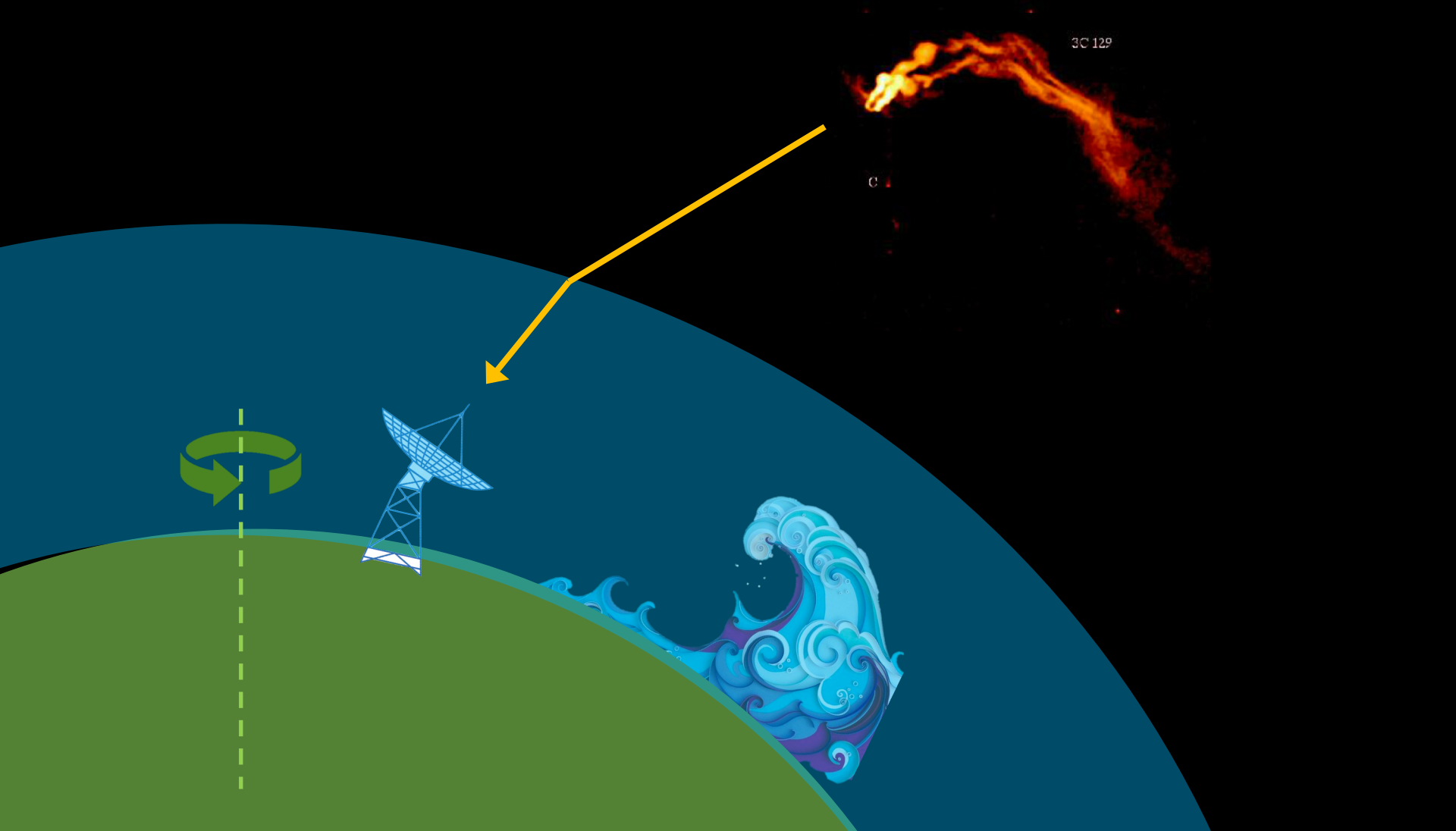
Spingola+ 2018

VLBI specifics

Data acquisition

Inspection

Correlator model



Parallactic angle & mount type

Polarization

- Circular polarization back-end
- Linear polarization back-end

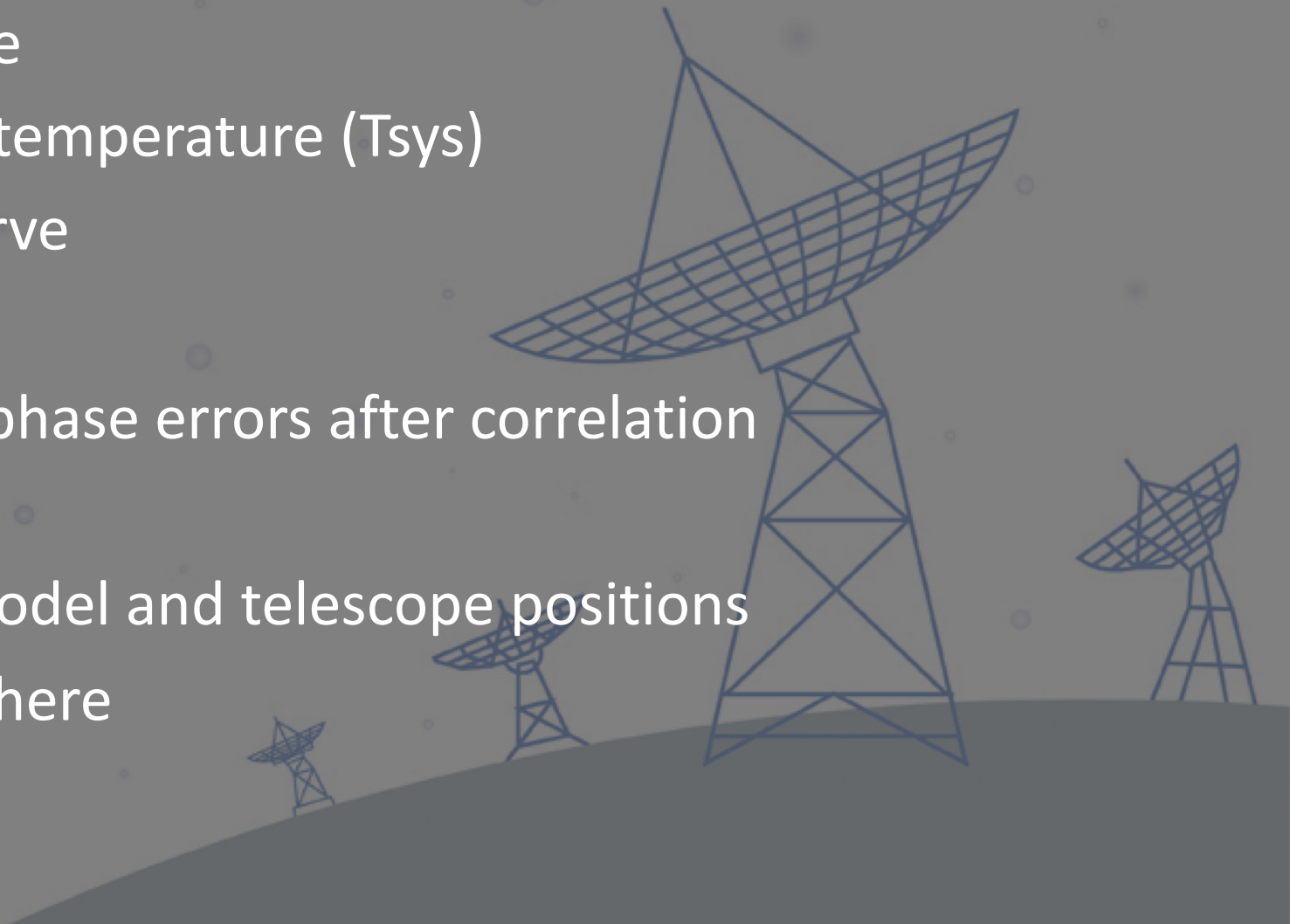
Calibration

Amplitude

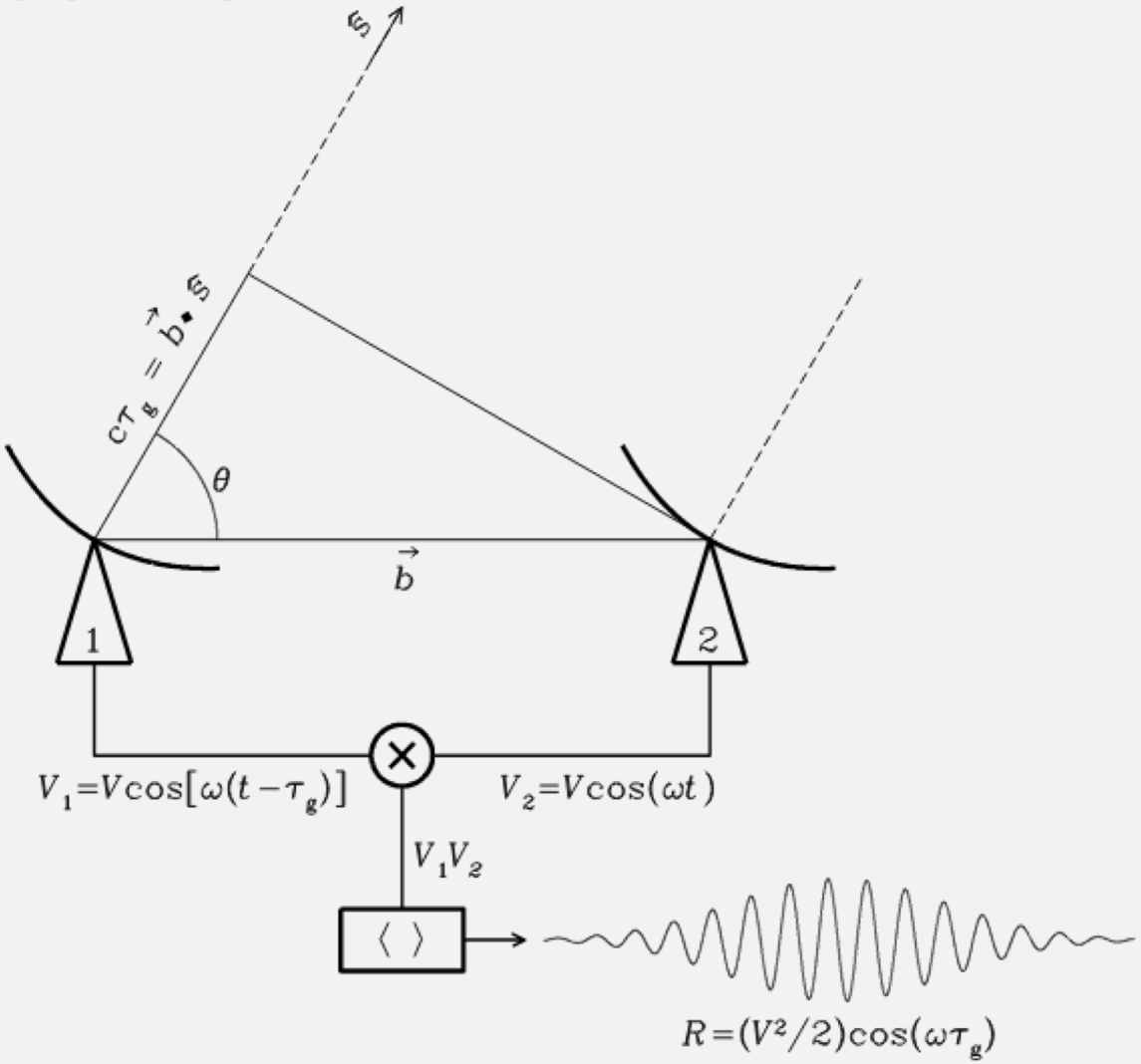
- System temperature (Tsys)
- Gain curve

Residual phase errors after correlation

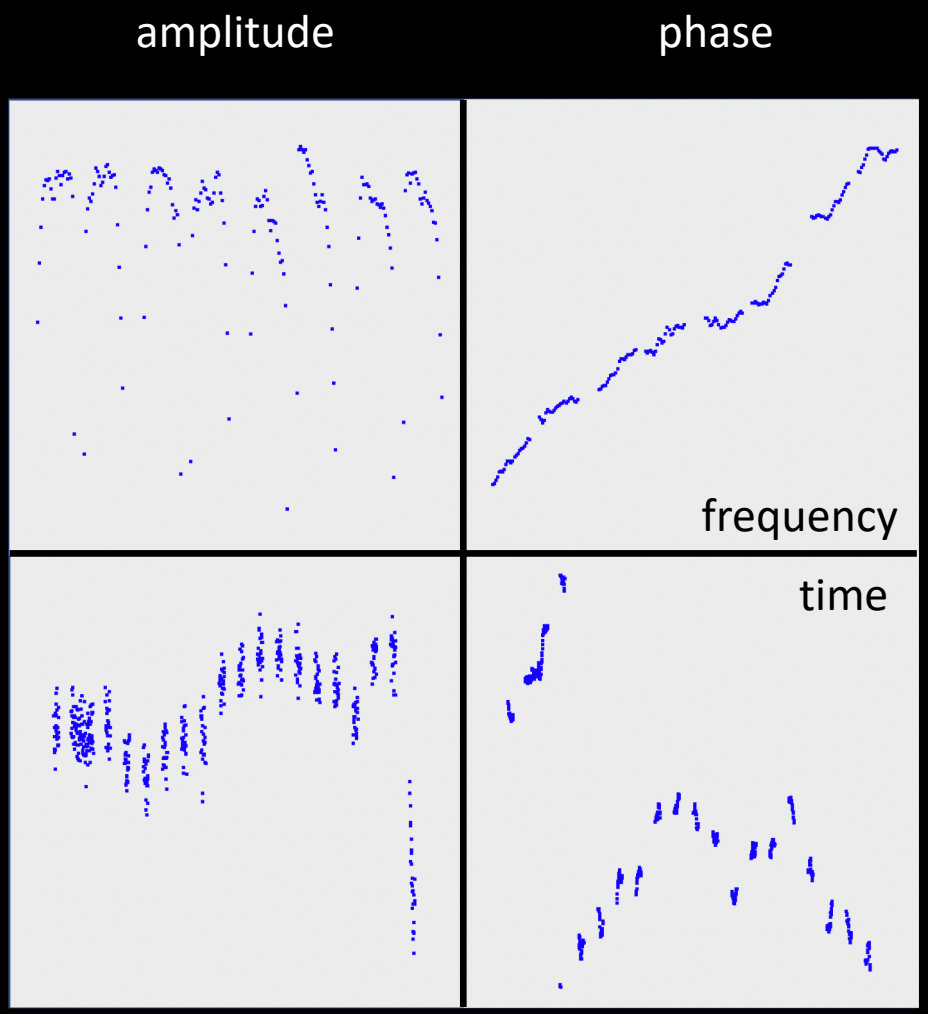
- Clock
- Earth model and telescope positions
- Atmosphere



Phase center

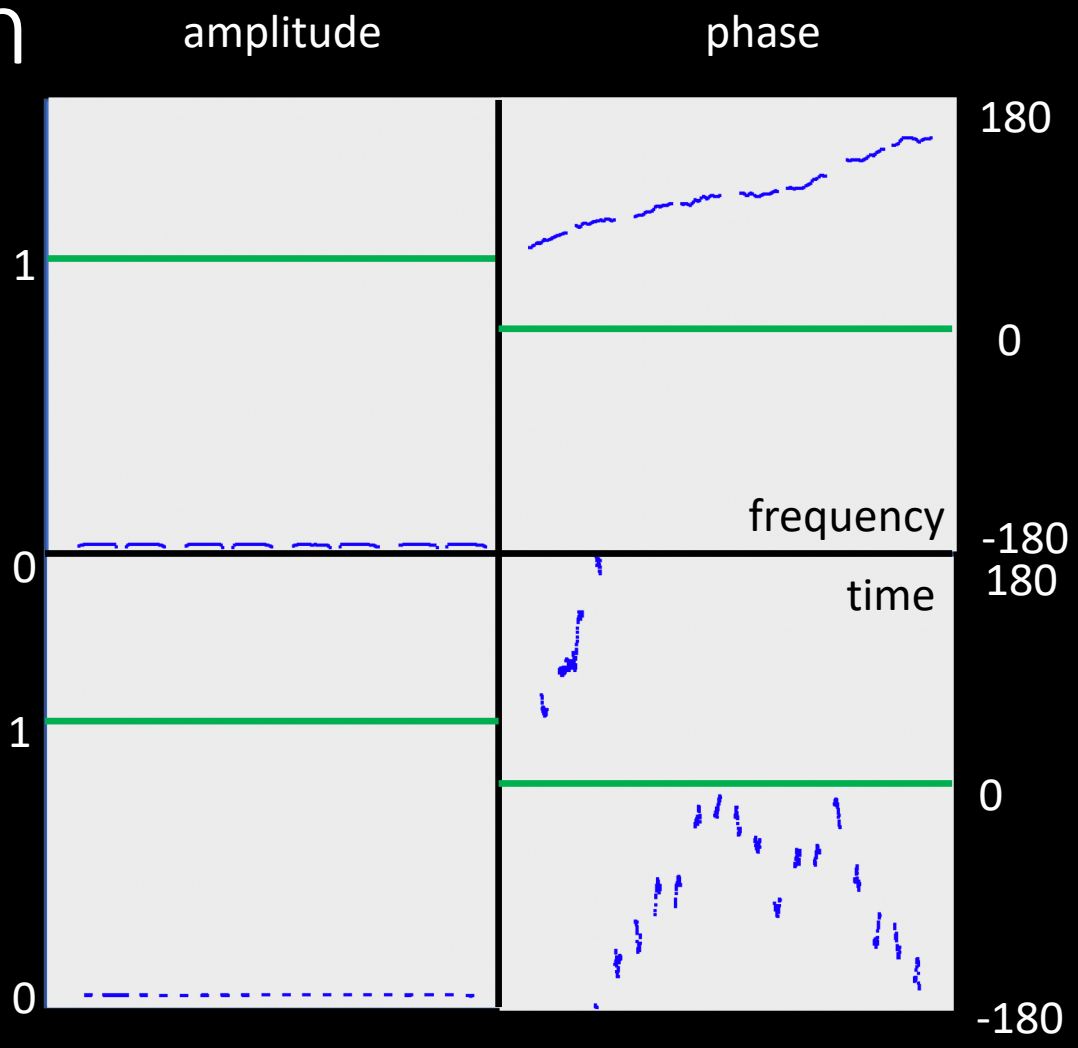


Calibration



One baseline, one polarization

Calibration



One baseline, one polarization

System temperature

Convert correlator units to flux scale:

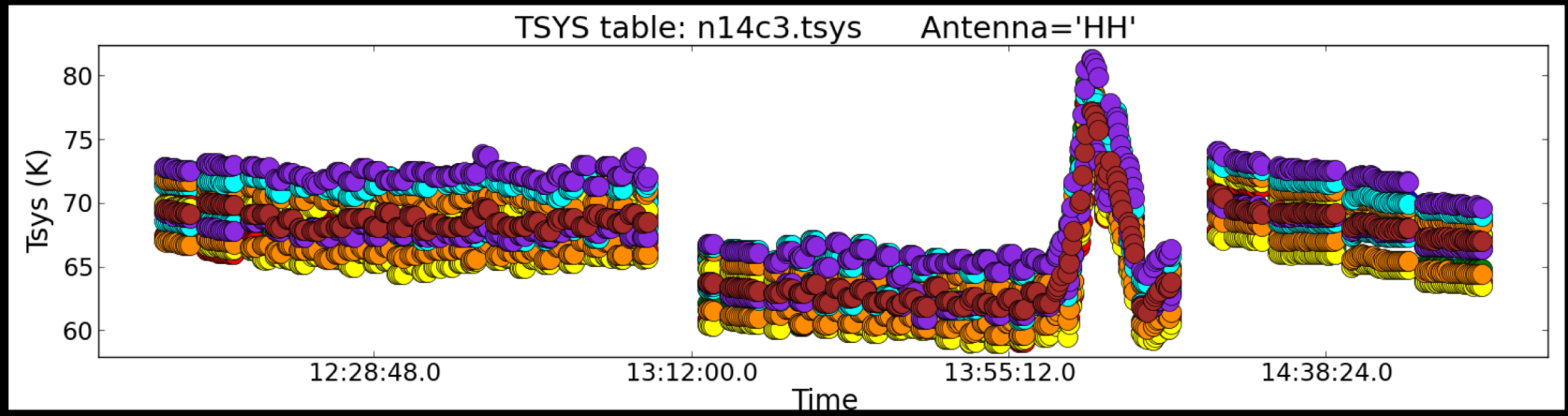
System Equivalent Flux Density

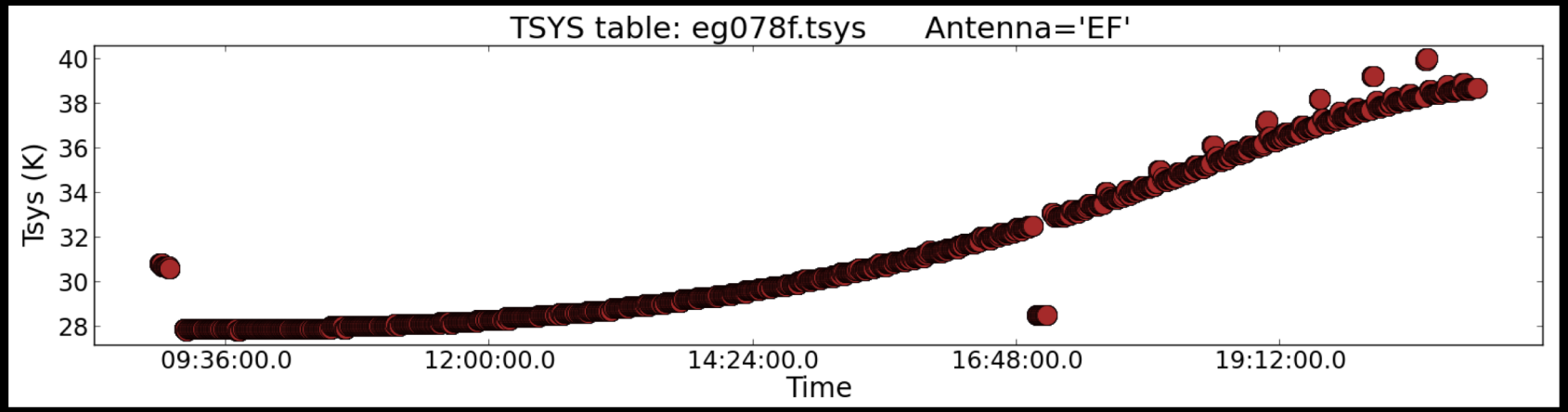
$$\mathrm{SEFD}\ [\mathrm{Jy}] = \frac{2k_B T_{\mathrm{sys}}[K]}{\eta_{\mathrm{A}}\, A_{\mathrm{eff}}}$$

η_{A} : efficiency

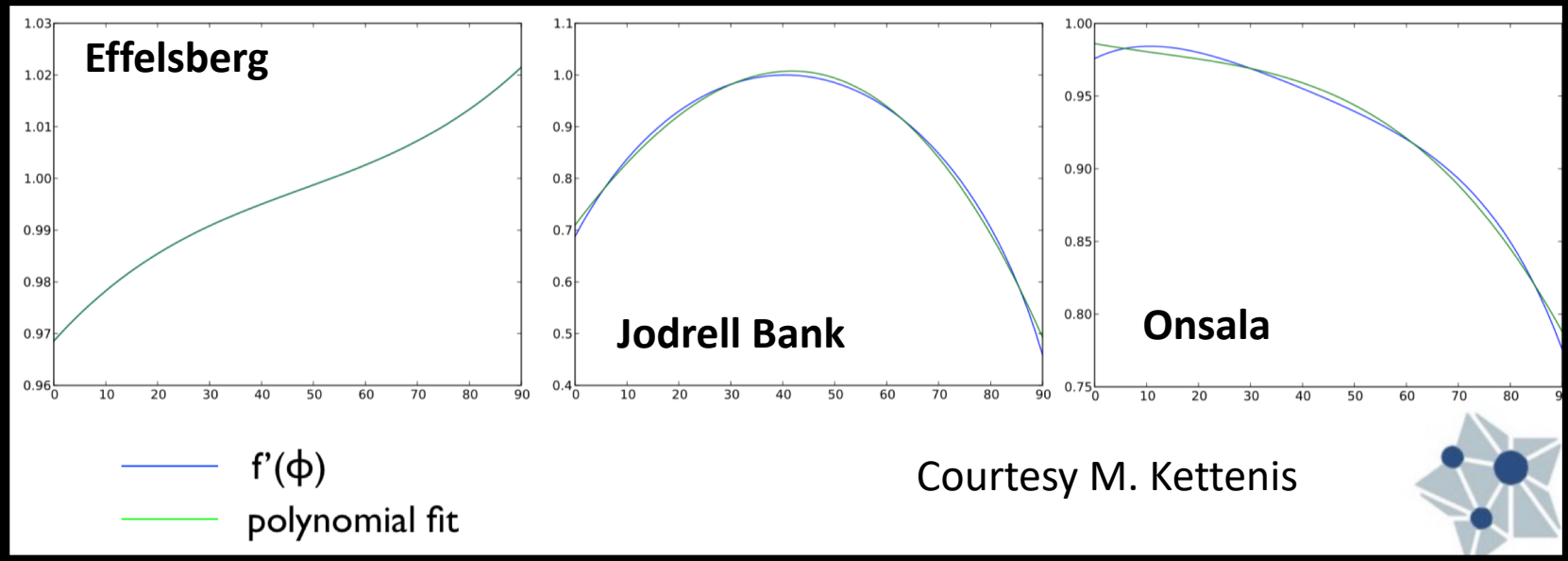
A_{eff}: effective antenna area

System temperature





Gain curves


Gain
Effelsberg
Jodrell Bank
Onsala
f'(ϕ)
polynomial fit
Courtesy M. Kettenis

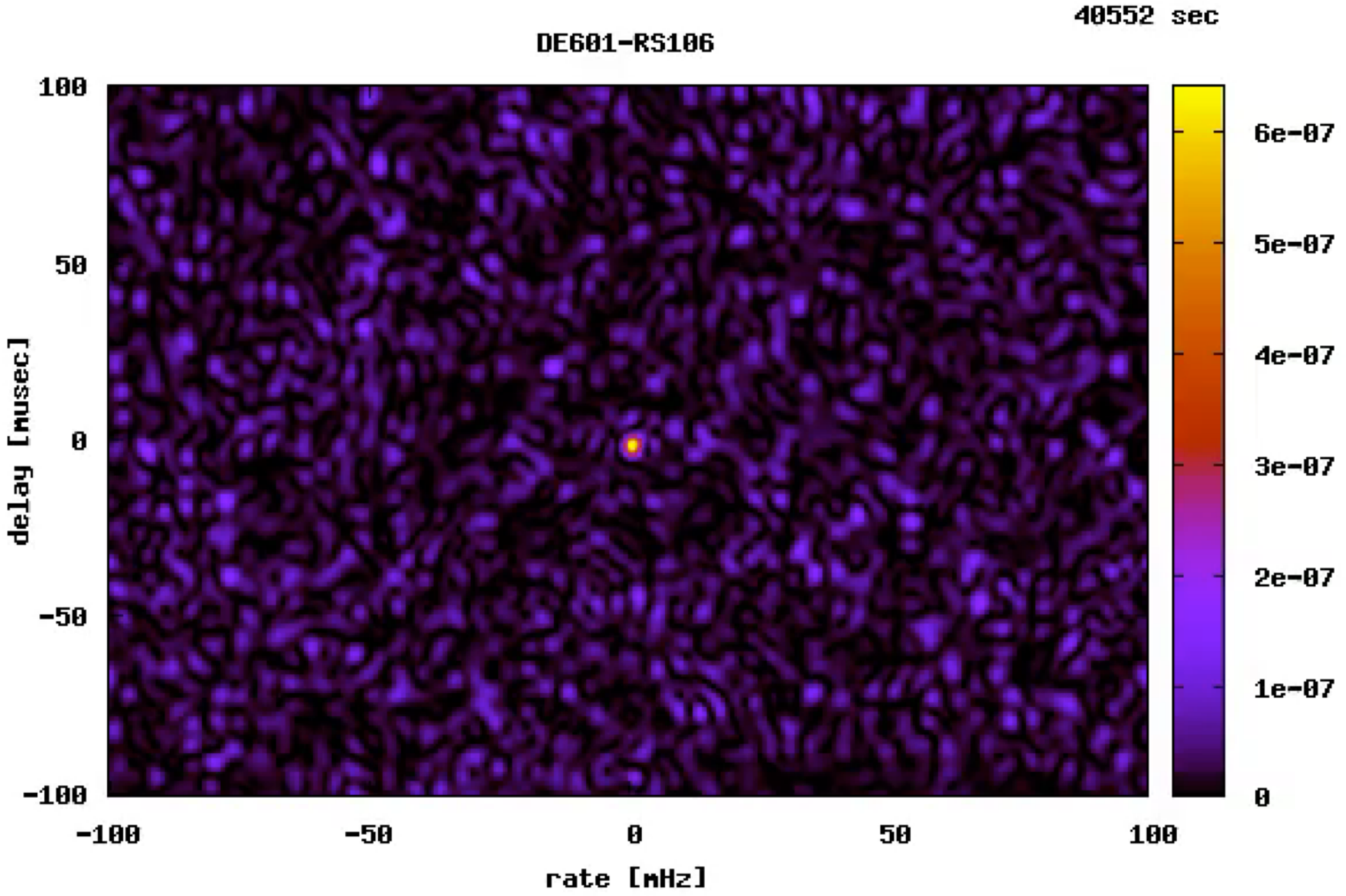
Calibration

- Amplitude: Tsys and gain curve

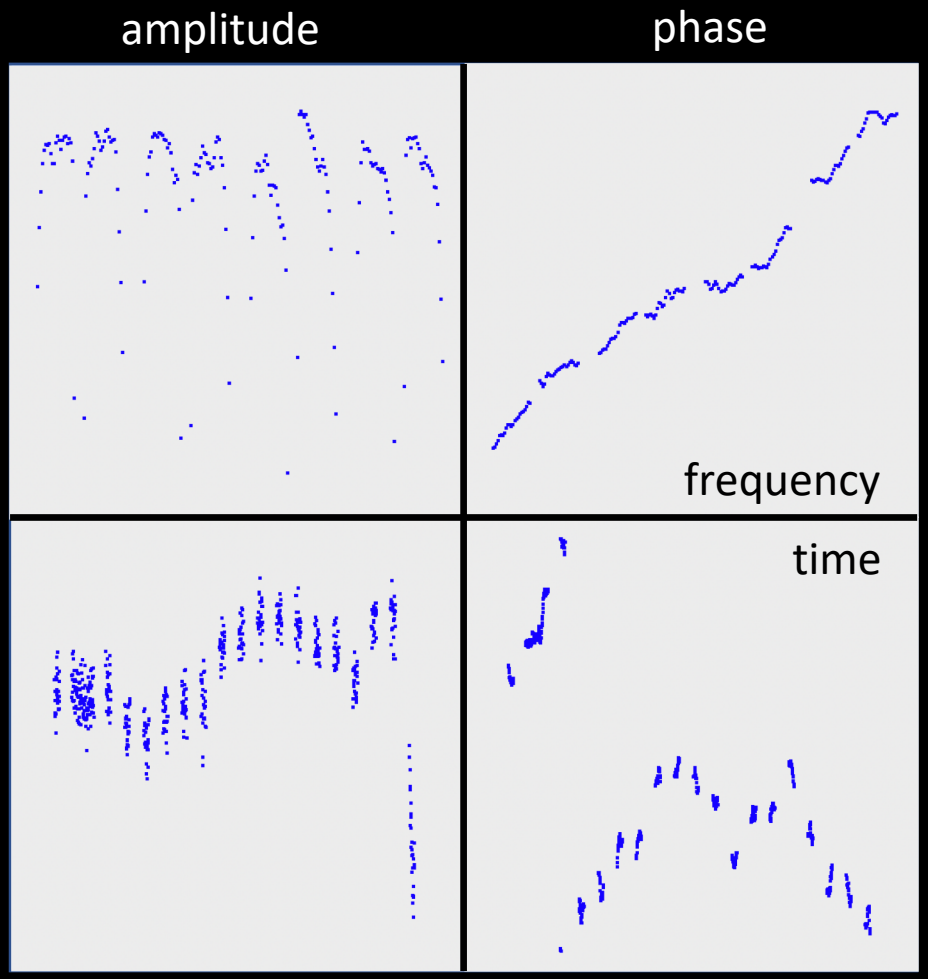
- Phase
- Delay
- Rate

$$\phi_{t,\nu} \approx \phi_0 + \frac{\partial \phi}{\partial \nu}\Delta\nu + \frac{\partial \phi}{\partial t}\Delta t$$

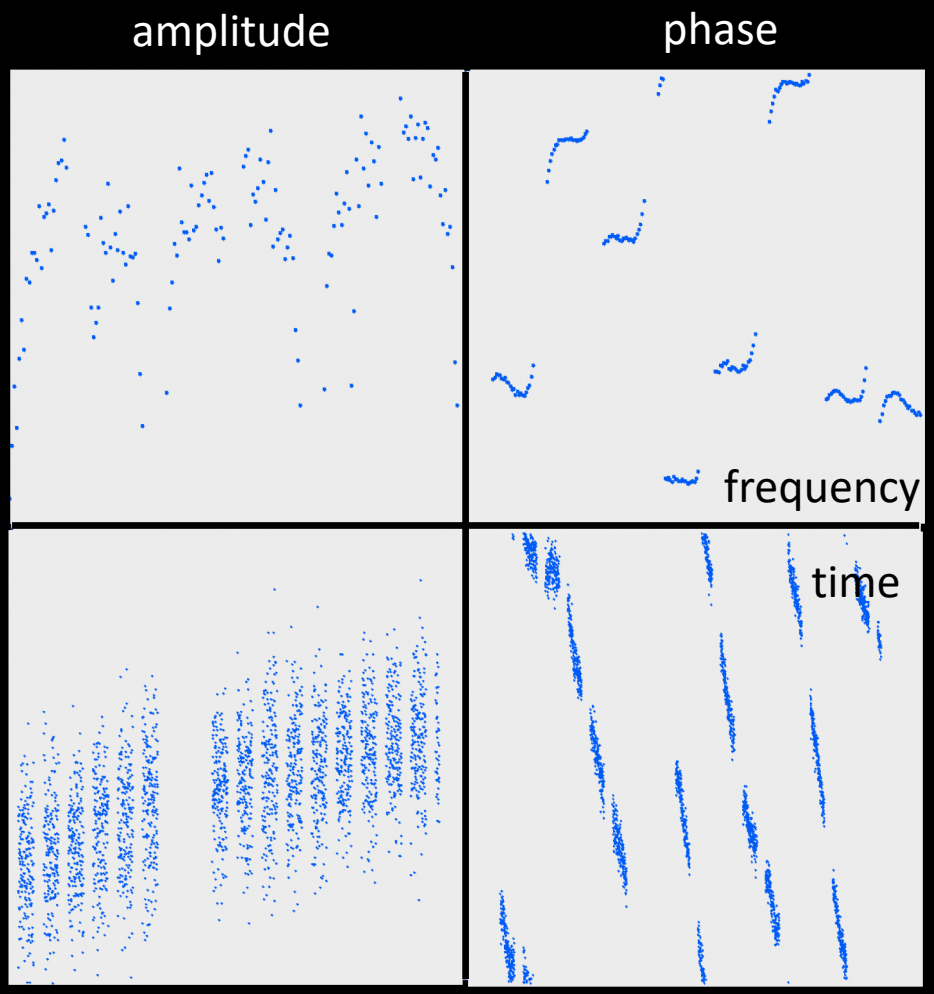
- Higher order terms: dispersive delay, acceleration


40552 sec
DE601-RS106
100
50
0
-50
-100
delay [musec]
-100
-50
0
50
100
rate [mHz]
6e-07
5e-07
4e-07
3e-07
2e-07
1e-07
0

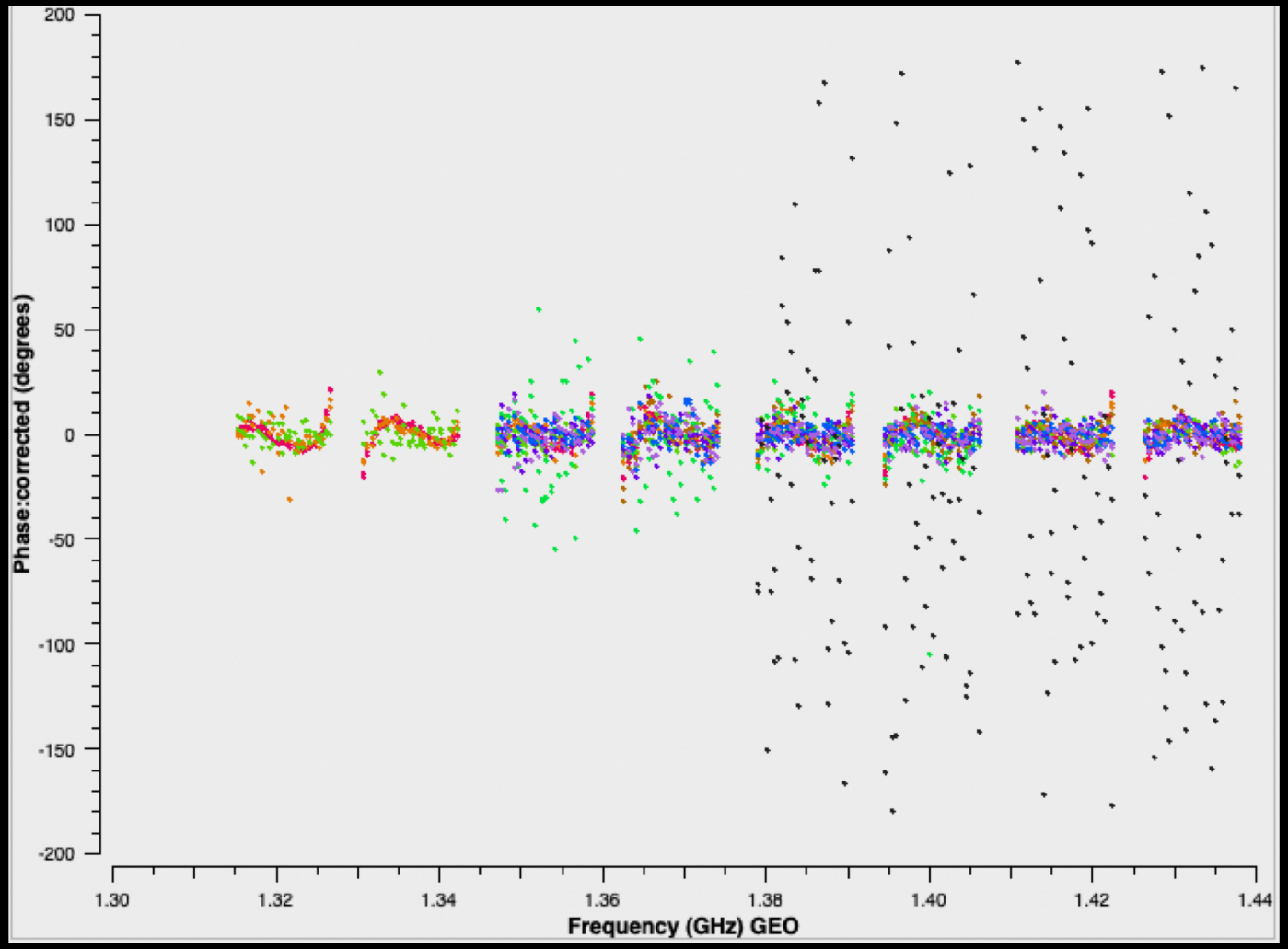
Fringe fit



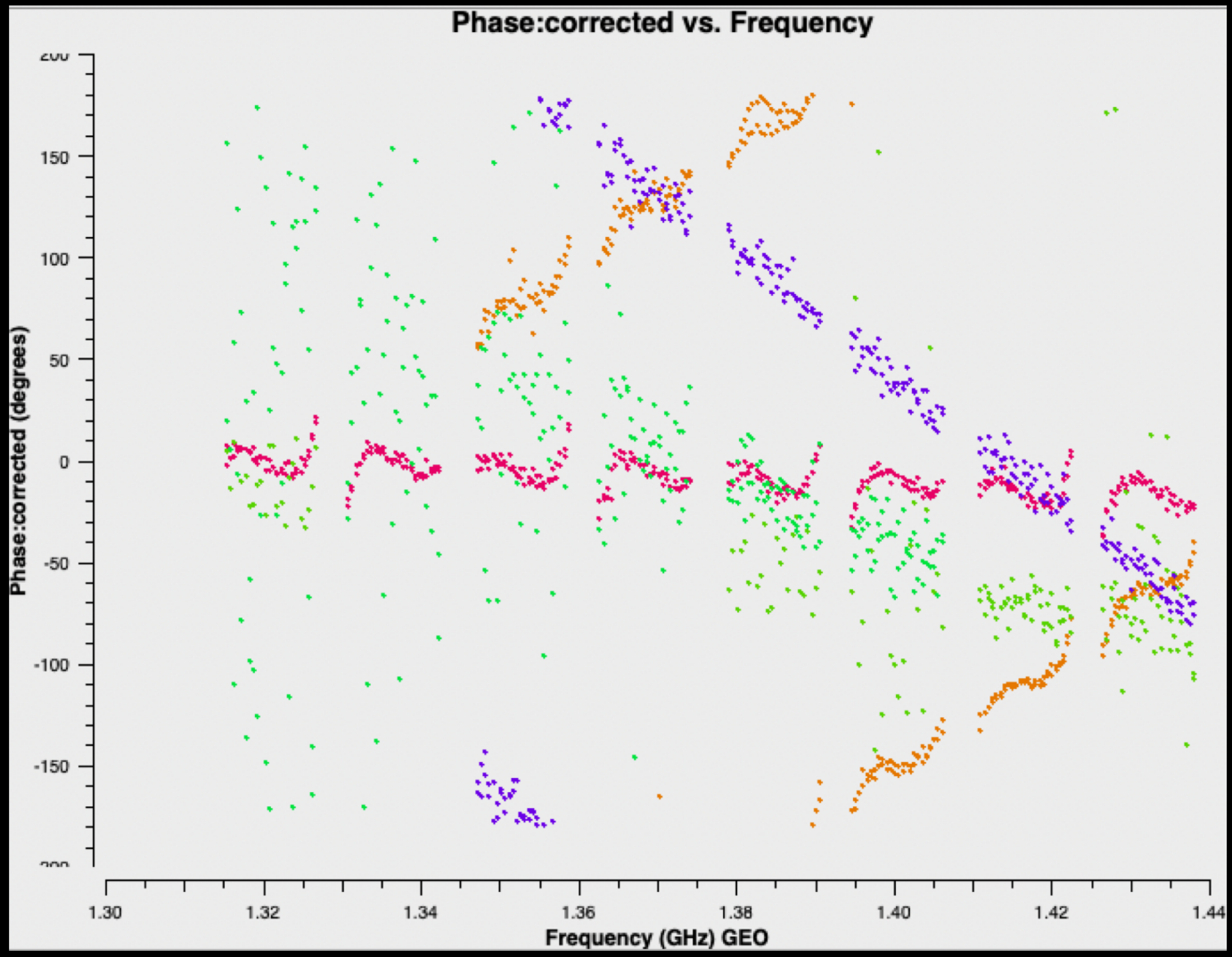
Fringe fit



Fringe fit


Phase:corrected (degrees)
200
150
100
50
0
-50
-100
-150
-200
1.30
1.32
1.34
1.36
1.38
1.40
1.42
1.44
Frequency (GHz) GEO

Fringe fit

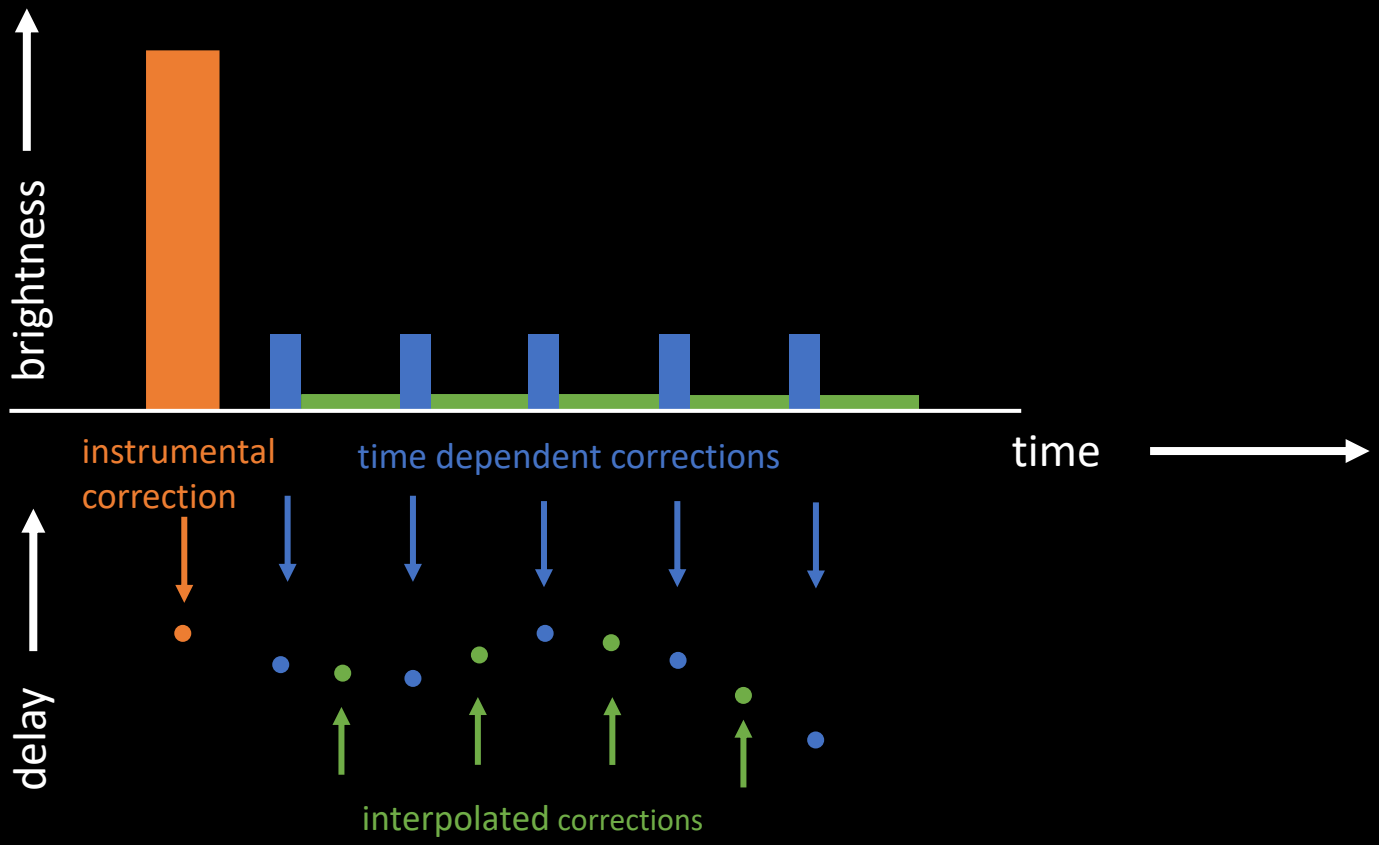

Phase:corrected vs. Frequency
Phase:corrected (degrees)
150
100
50
0
-50
-100
-150
1.30
1.32
1.34
1.36
1.38
1.40
1.42
1.44
Frequency (GHz) GEO

Complications

- No point sources in VLBI
- Very fast phase wrapping in time
- Target too faint to calibrate on

- What to do?

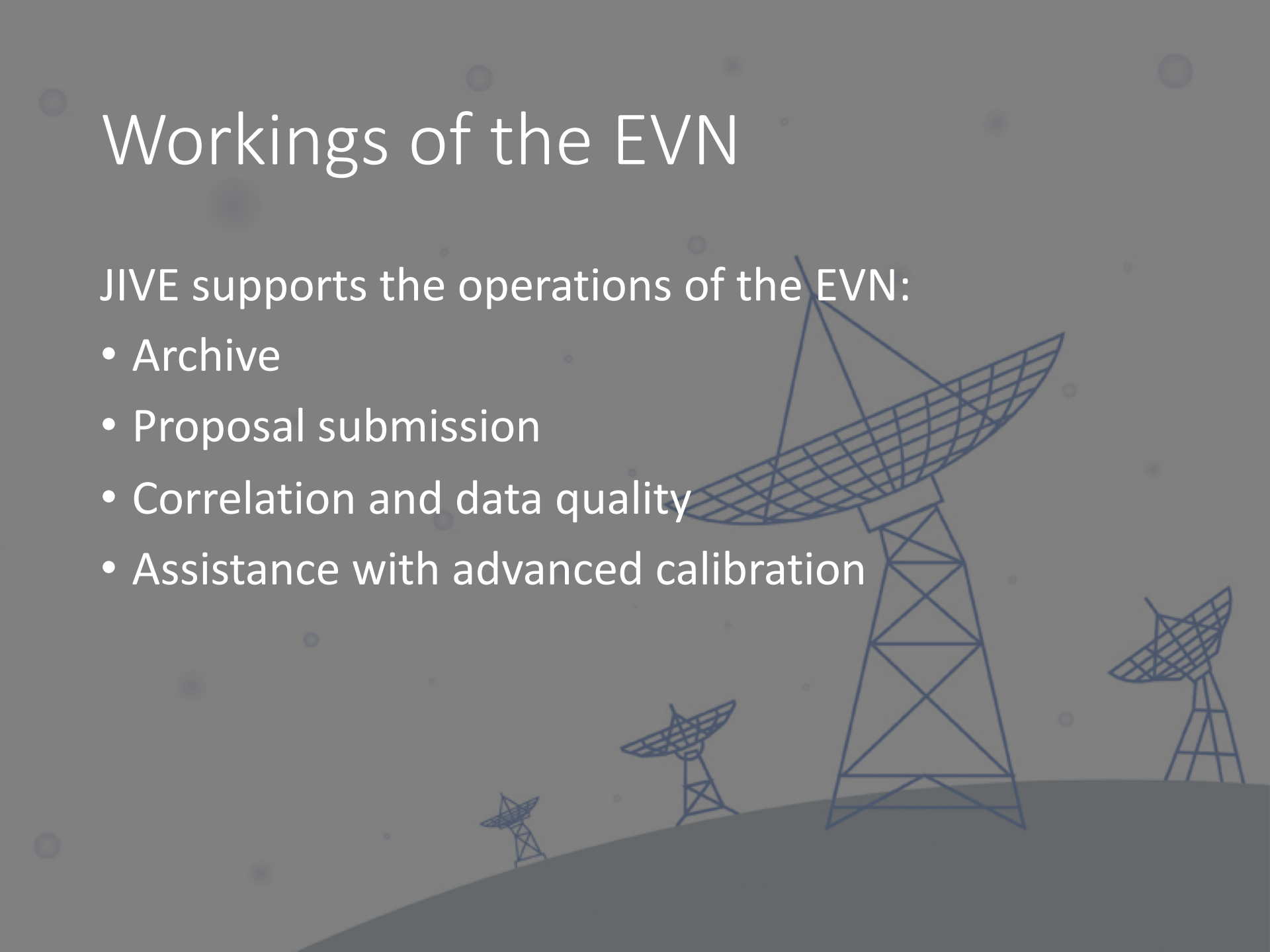
Phase referencing



Workings of the EVN

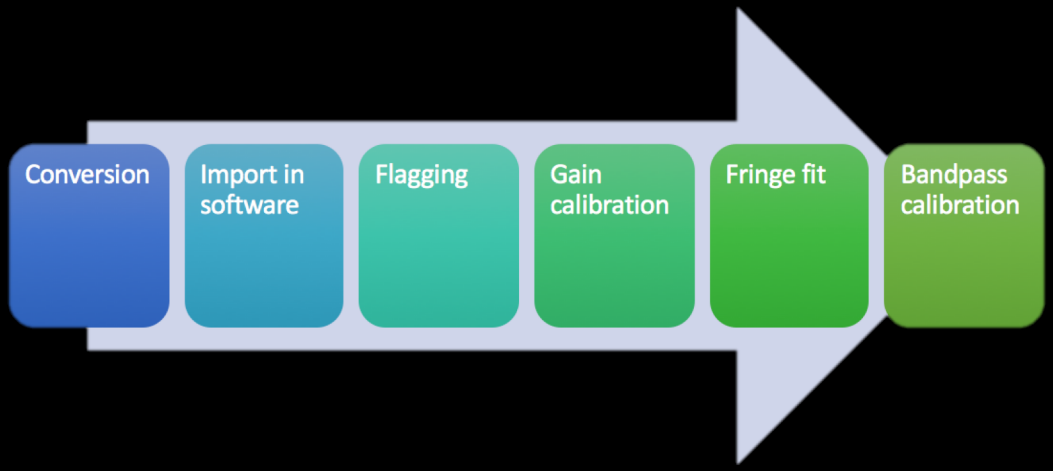
JIVE supports the operations of the EVN:

- Archive
- Proposal submission
- Correlation and data quality
- Assistance with advanced calibration



Software development

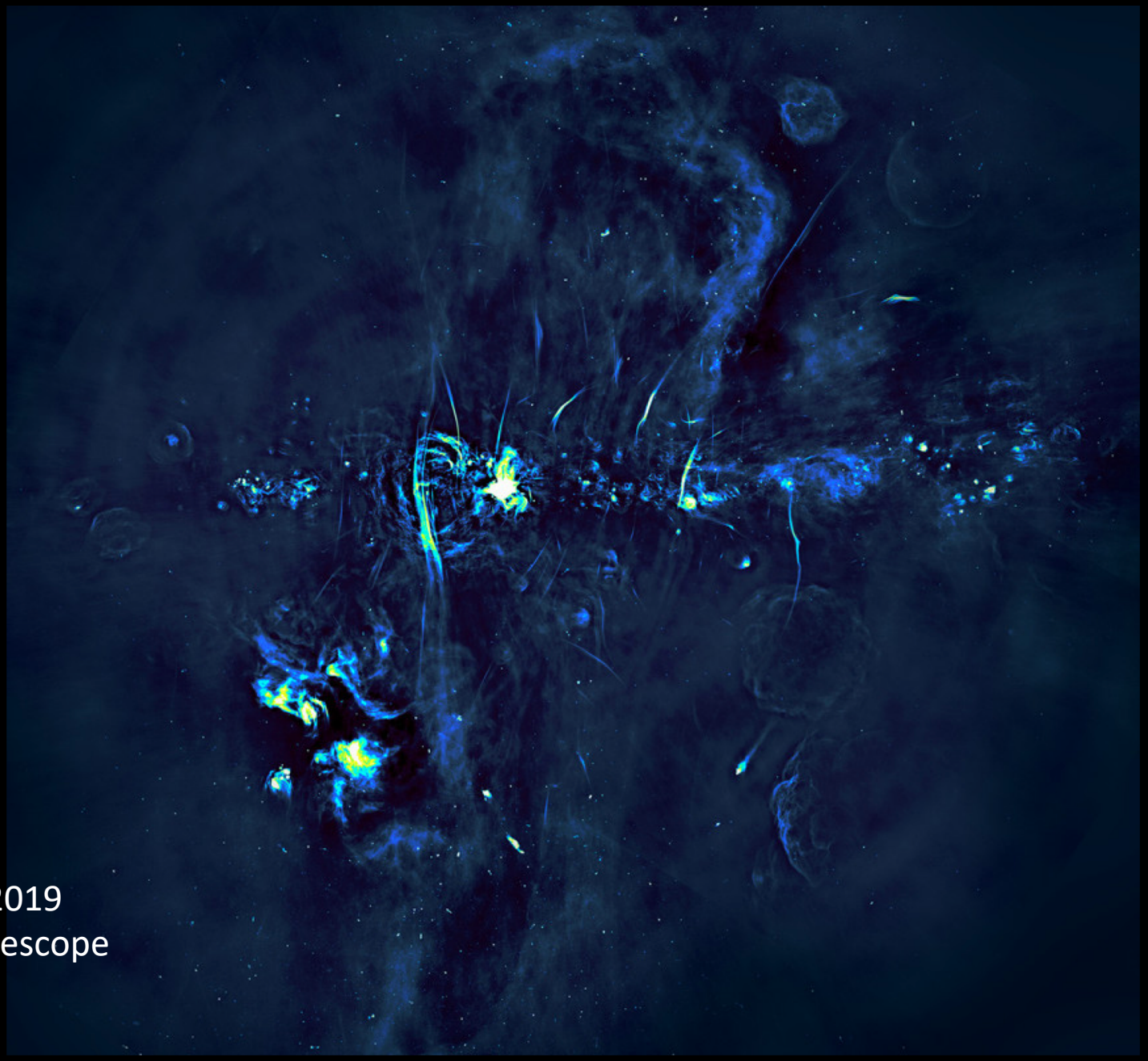
- CASA now ready for VLBI
- Pipeline development:
  - ALMA
  - VLA
  - EHT
  - rPicard
  - (VLBA and EVN)



CASA

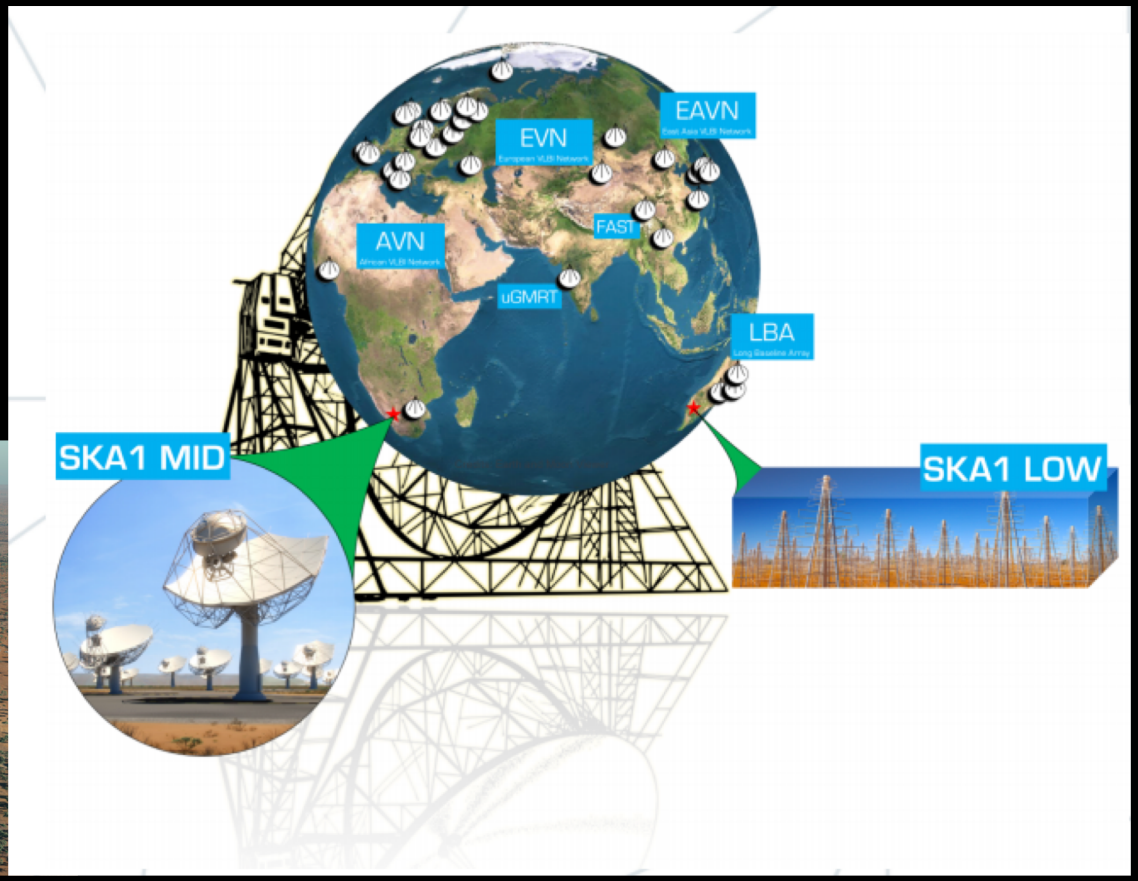
Future of VLBI

- Advancing into Africa
- Combining arrays of different sizes
- Advancing technology
- Accessibility
- Space-VLBI ideas



Heywood+ 2019
MeerKAT telescope

Square Kilometre Array



Next: try for yourself