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eVLBI
Networks Bringing Radio Telescopes Together

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CSIRO

With Thanks

UTAS

Curtin University of Technology

aarnet Australia's Academic and Research Network

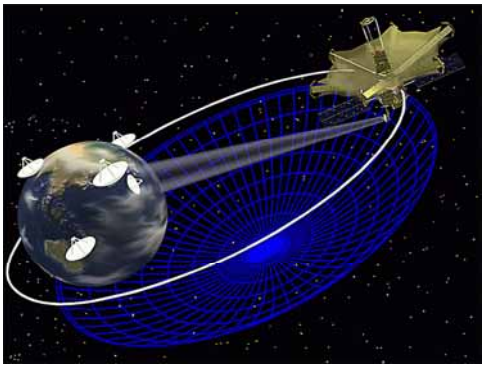
Introduction to Radio Astronomy

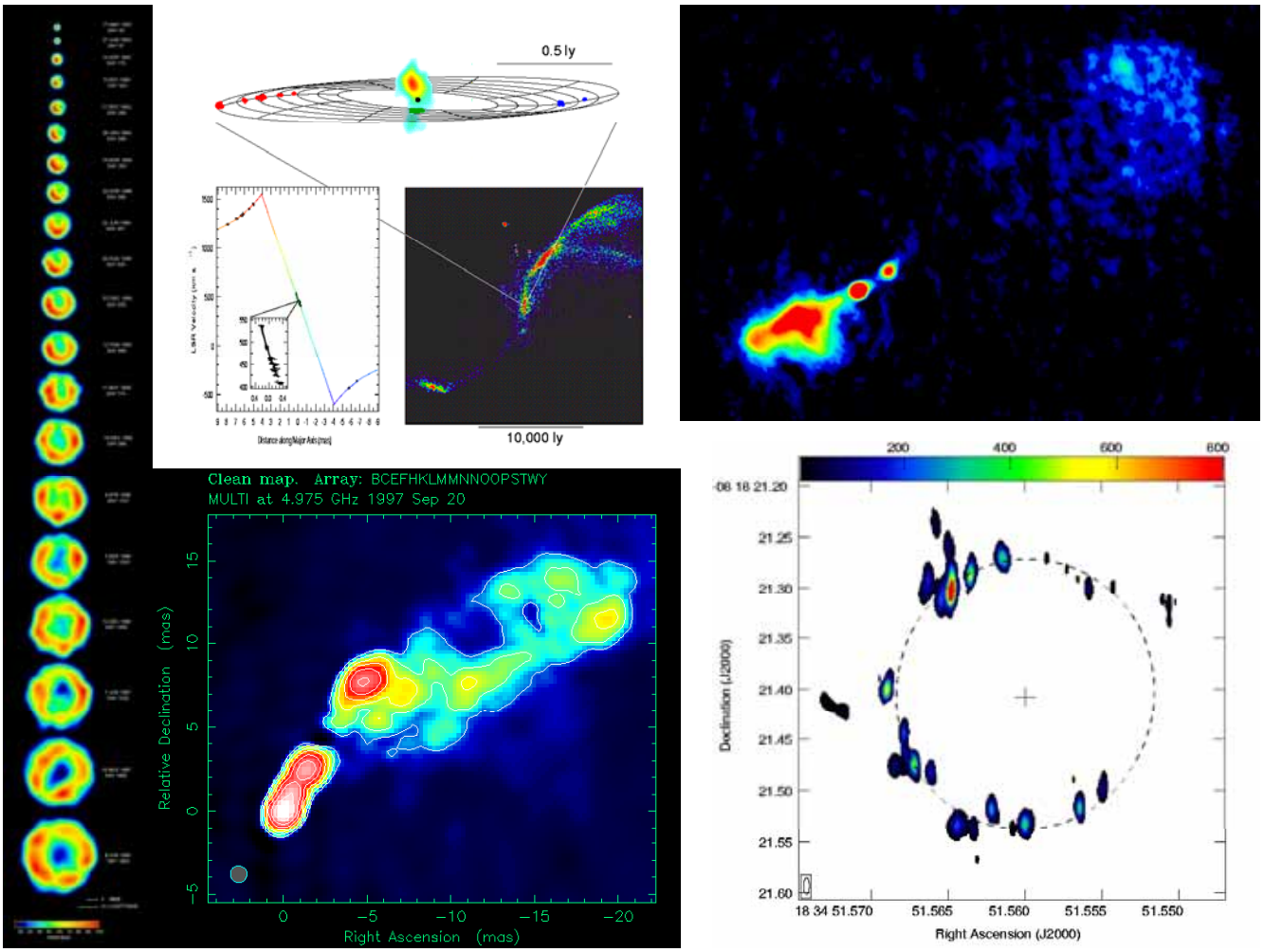
- Radio Astronomy encompasses long wavelength electromagnetic radiation (light!) up to about 300 GHz
  - Typically 10 MHz - 300 GHz (30m – 1mm)
- Astronomical radio signals weak so telescopes need to be large
- Detail (resolution) depends on size of telescope
  - Need many km to give same detail as optical telescopes

- Connect individual telescopes together to synthesis larger telescope - Interferometry

VLBI: Very Long Baseline Interferometry

- Typical radio-astronomy interferometry have sizes up to a few 10s km
  - Connected via optical fiber, realtime processing
- VLBI uses radio telescopes separated by 100's and 1000's km
  - Including one space based telescope
- More than 50x more detail than the Hubble space telescope




0.5 ly
10,000 ly
Clean map. Array: BCEFHKLMMNNOOPSTWY
MULTI at 4.975 GHz 1997 Sep 20
Relative Declination (mas)
Right Ascension (mas)
200
400
600
800
Declination (J2000)
Right Ascension (J2000)

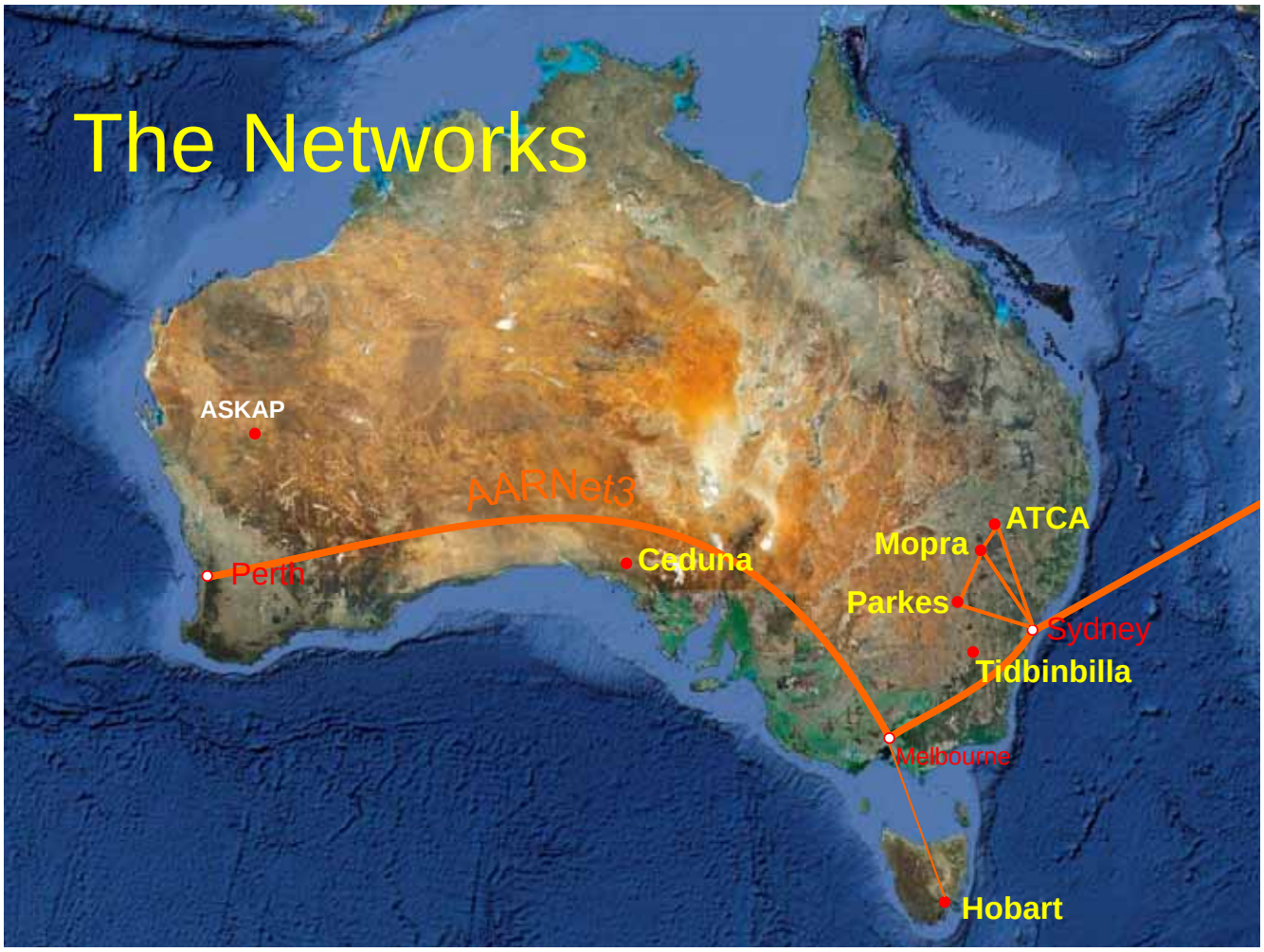

The LBA
ASKAP
Ceduna
ATCA
Mopra
Parkes
Sydney
Tidbinbilla
Hobart

VLBI: Data Transport
What's the bandwidth of a truck full of tapes?

- Traditionally VLBI data recorded onto magnetic tape and physically transported to central processing site
- More recently tapes have been replaced with commercial HDD
- Currently record up to 11 TB/telescope/day
- Want to expand data rates by an order of magnitude or more
  - State-of-the-art systems 160 Gbps/telescope
  - Almost 2 Petabytes/telescope/day

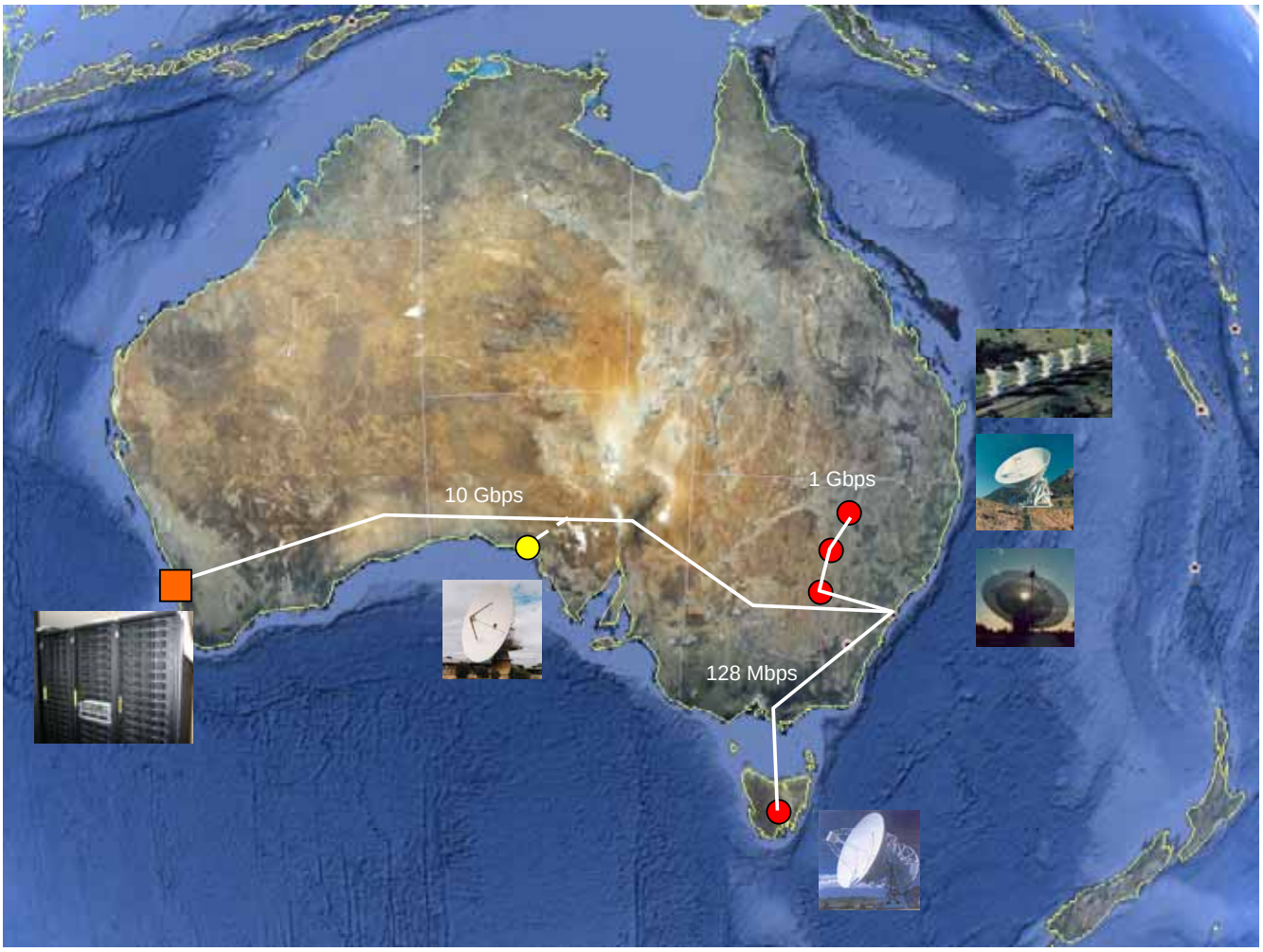
eVLBI

- Replace physical transport with networks
- All ATNF telescopes and Hobart connected to AARNet3 backbone at 1 Gbps
- Data transfer handled for us by fine folk at ARCS
- Also transfer some data to Germany for specialized processing
  - Eliminates long term problem with compatibility of physical medium
- Transferring large amounts of data over the network is problematic – no good solution



Realtime eVLBI

- Disk based recording gives months of latency between observing and supplying data to astronomer
  - Problematic for time critical observations
- Eliminate any disk recording – process data in realtime with no (disk) buffering - eVLBI
- Requires sufficient network bandwidth to transfer data with no delay
  - Average bandwidth is not enough – need sustained bandwidth

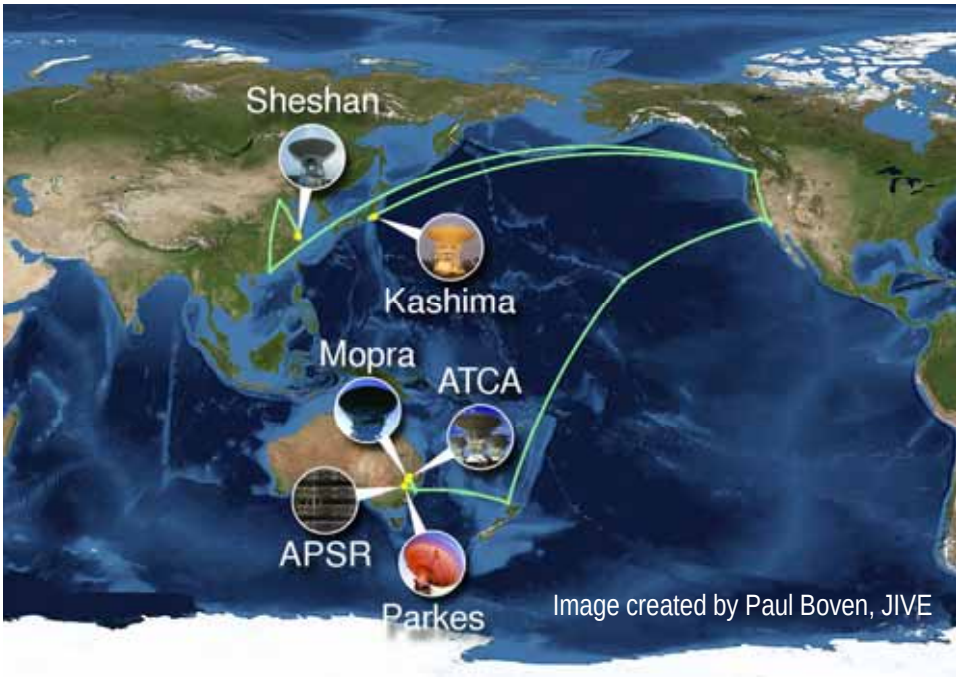


EXPReS

- 1x1 Gbps lightpaths Australia-Netherlands
- 3x512 Mbps VLBI data

e-APT

- 622 Mbps lightpaths from Japan & China
- 4x512 Mbps eVLBI



World eVLBI

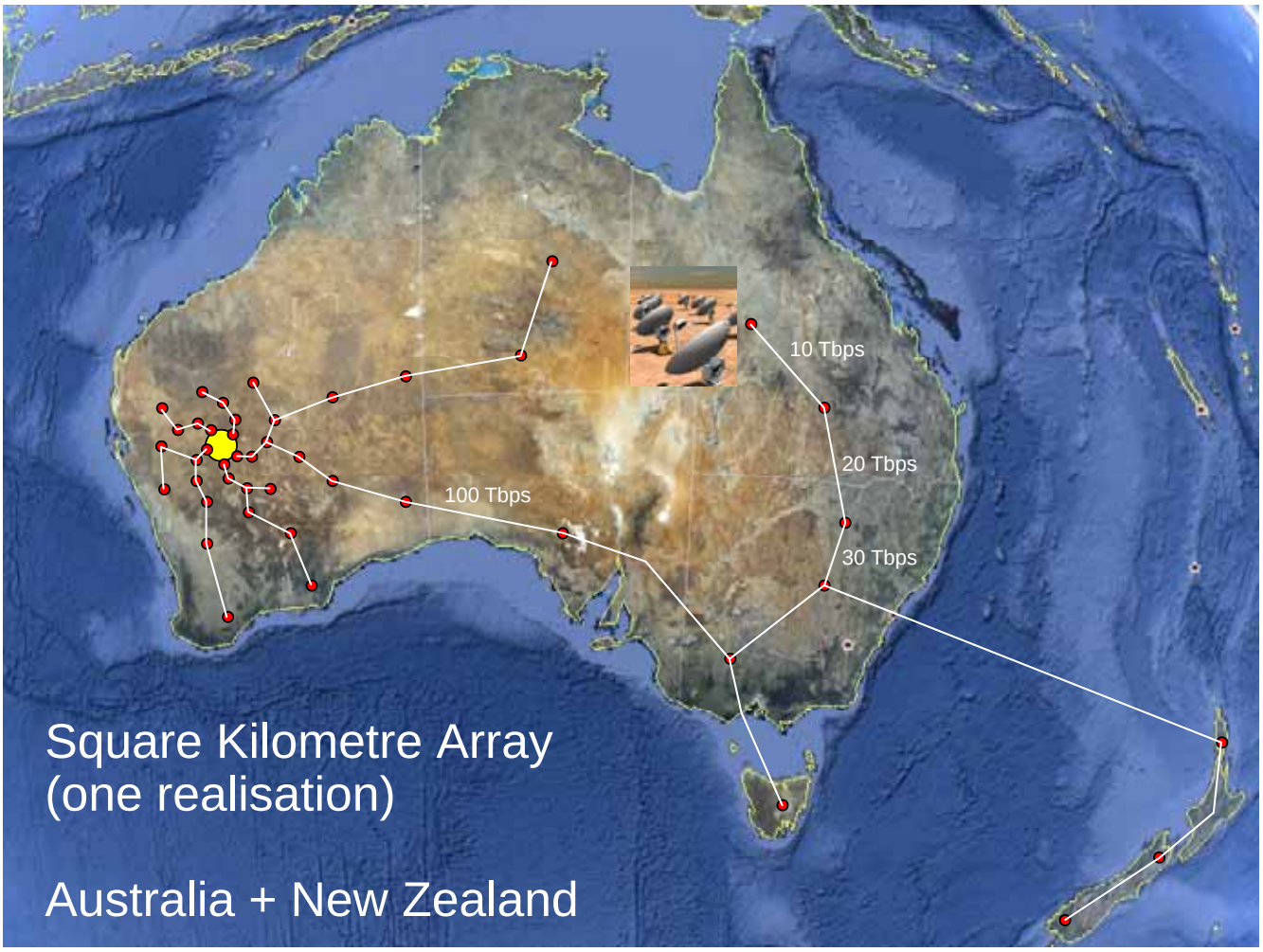
e-VLBI telescopes and connections in the world. Image by Chris Phillips (ATNF) and Paul Boven (JIVE). Satellite image Blue Marble Next Generation, courtesy of Nasa Visible Earth (visibleearth.nasa.gov).

eVLBI Technology

- Use a mixture of dedicated and shared networks
- TCP works well within private ATNF networks
- Need UDP on shared networks
  - Low level packet loss
- Data transfer using mix of “reliable UDP” software and gridFTP

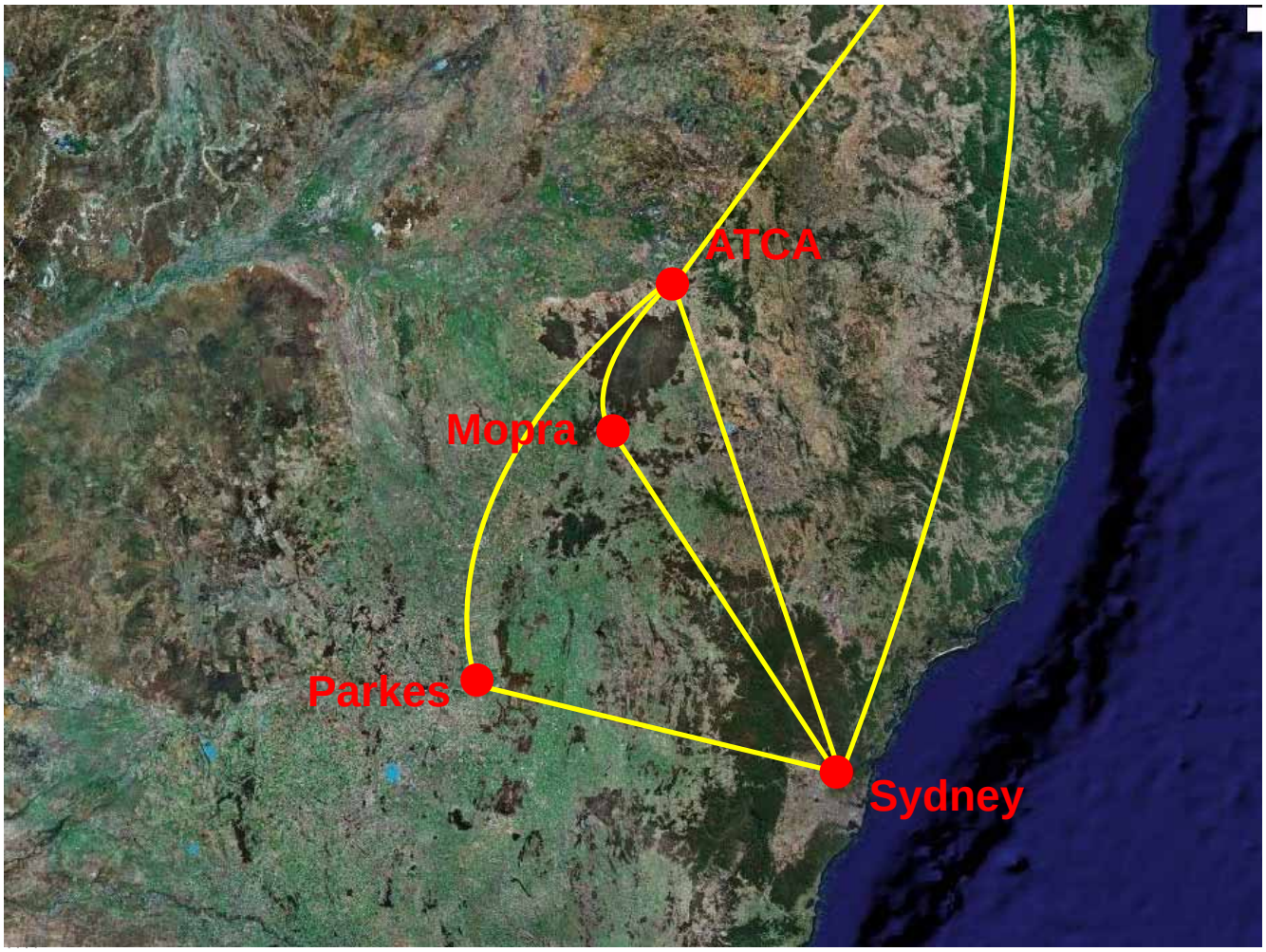
Future - SKA

Square Kilometre Array



Demo

Realtime eVLBI



Uitsmijter

- This work depends critically on the AARNet infrastructure
  - Would not be possible relying on commercial providers
- Transferring bits around, and effectively using the networks, is much harder than it should be
- “Security Nazis” make life overly difficult
  - Limiting effective use of networks

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Thank you

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Resolution

Resolution = Observing wavelength / Telescope diameter

Angular Resolution	Optical (5000A) Diameter	Optical (5000A) Instrument	Radio (4cm) Diameter	Radio (4cm) 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

1 arcmin 1 arcsec 0.05 arcsec 0.001 arcsec

Simulated with Galileo photo