SKA&CTA synergies

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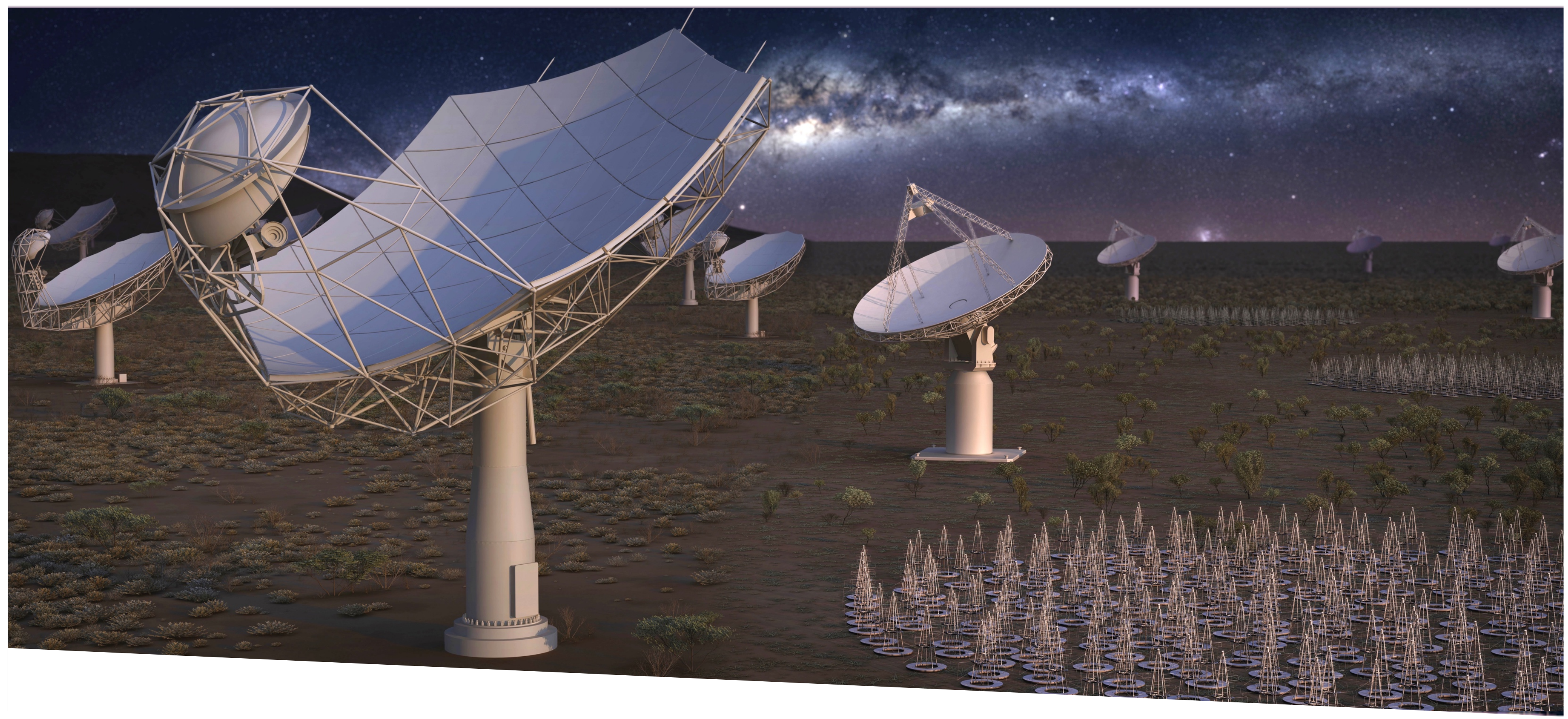
Outline



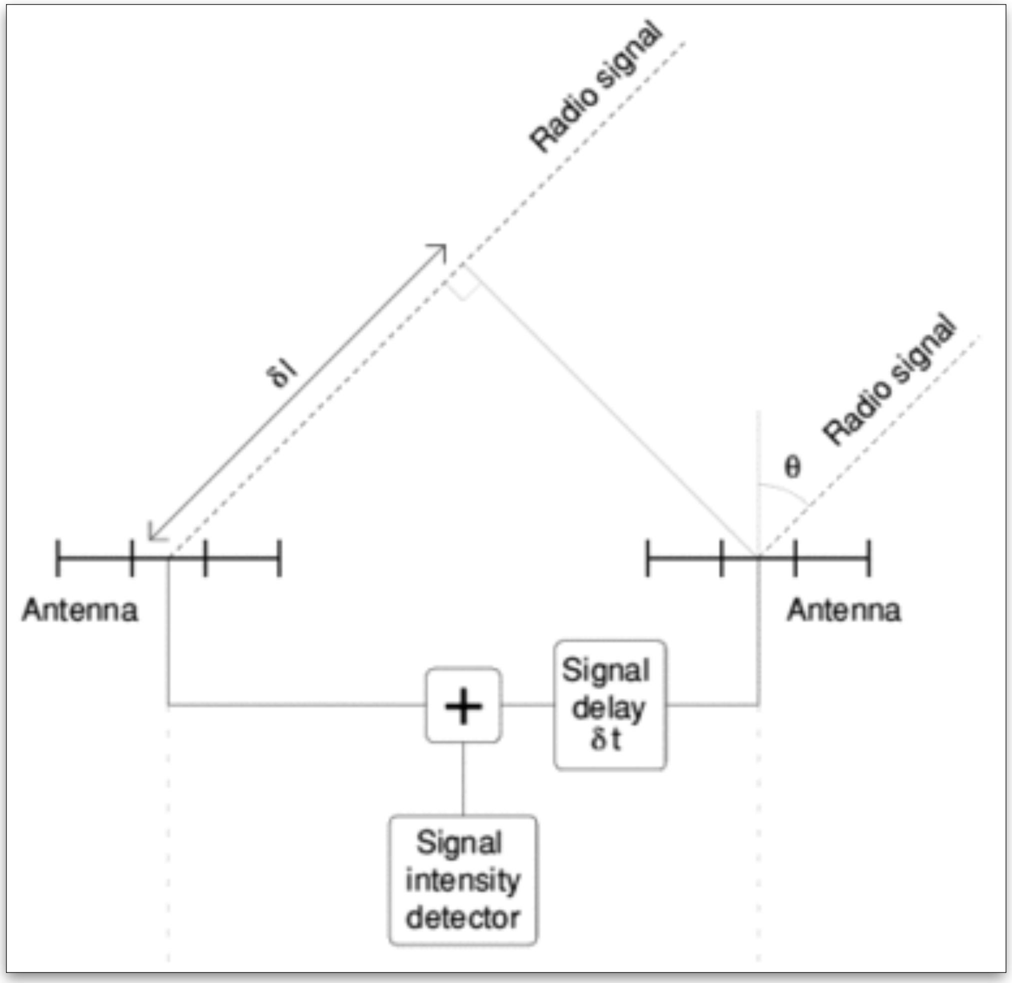
- What is the SKA?
- SKA and CTA: differences and similarities
- SKA-CTA synergies

Exploring the Universe with the world's largest radio telescope

- The Square Kilometre Array (SKA), with a total collecting area of 1,000,000 m^2, will be **the largest radio telescope *array* ever constructed**
- HQ in UK, instrument split between South Africa and Australia
- Italy is one of the founding members of the SKA organisation

A radio *array*

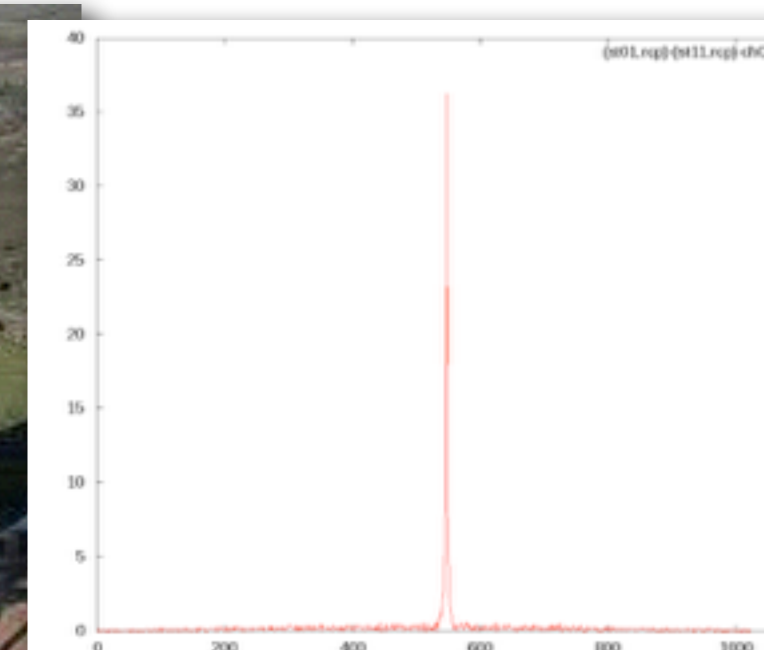
- radio telescopes angular resolution $\theta \sim \lambda / d$ is limited by λ (~arcmin even with d=100m)
- interferometry can synthesise a much larger aperture, where $\theta \sim \lambda / B$, with B=separation between interferometer elements



- adding more telescopes (realising $N(N-1)/2$ pairs) and exploiting Earth rotation, rich spatial information can be reconstructed (also helping sensitivity)
- VLBI (*Very Long Baseline Interferometry*) reaches up to B~10000km (and longer with satellites!), and θ<1 mas

Current arrays: the European VLBI Network, a SKA *pathfinder*

- a VLBI consortium of independently built and operated radio telescopes in Europe, extending to Asia, Africa, America
- Includes some of the largest apertures in the world (Arecibo, Effelsberg, Lovell, **Sardinia**); yet only ~0.03 km^{-2}
- *Development to transmit data with fast optical fibre links and correlating in real time*



Current arrays: SKA *precursors*

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- Interferometers on SKA sites, eventually integrated in SKA1
  - MeerKAT (SA): 64x16m dishes, 1-1.75 GHz, 4km radius; pulsars, HI, and more
  - ASKAP (Aus): 36x12m dishes with Phased Feed Array providing 30deg^2 field of view in 0.8-1.7 GHz
  - MWA (Aus): fully operational, aperture array, 80-300 MHz

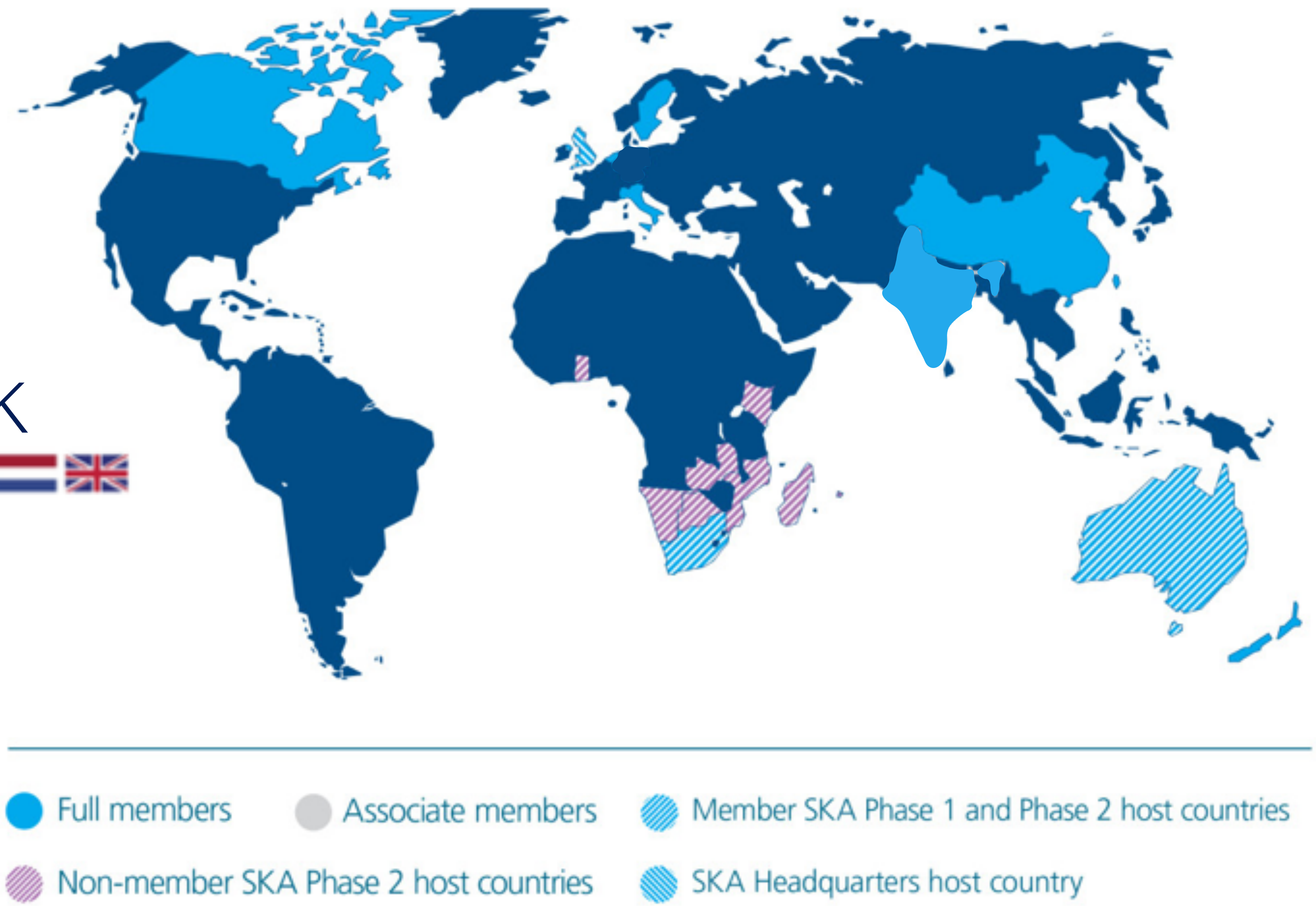
SKA science drivers

Credits: R. Braun, SKA Science director

SKA organisation:
10 countries, more to join

- Australia, Canada, China, India, Italy, Netherlands, New Zealand, South Africa, Sweden, UK

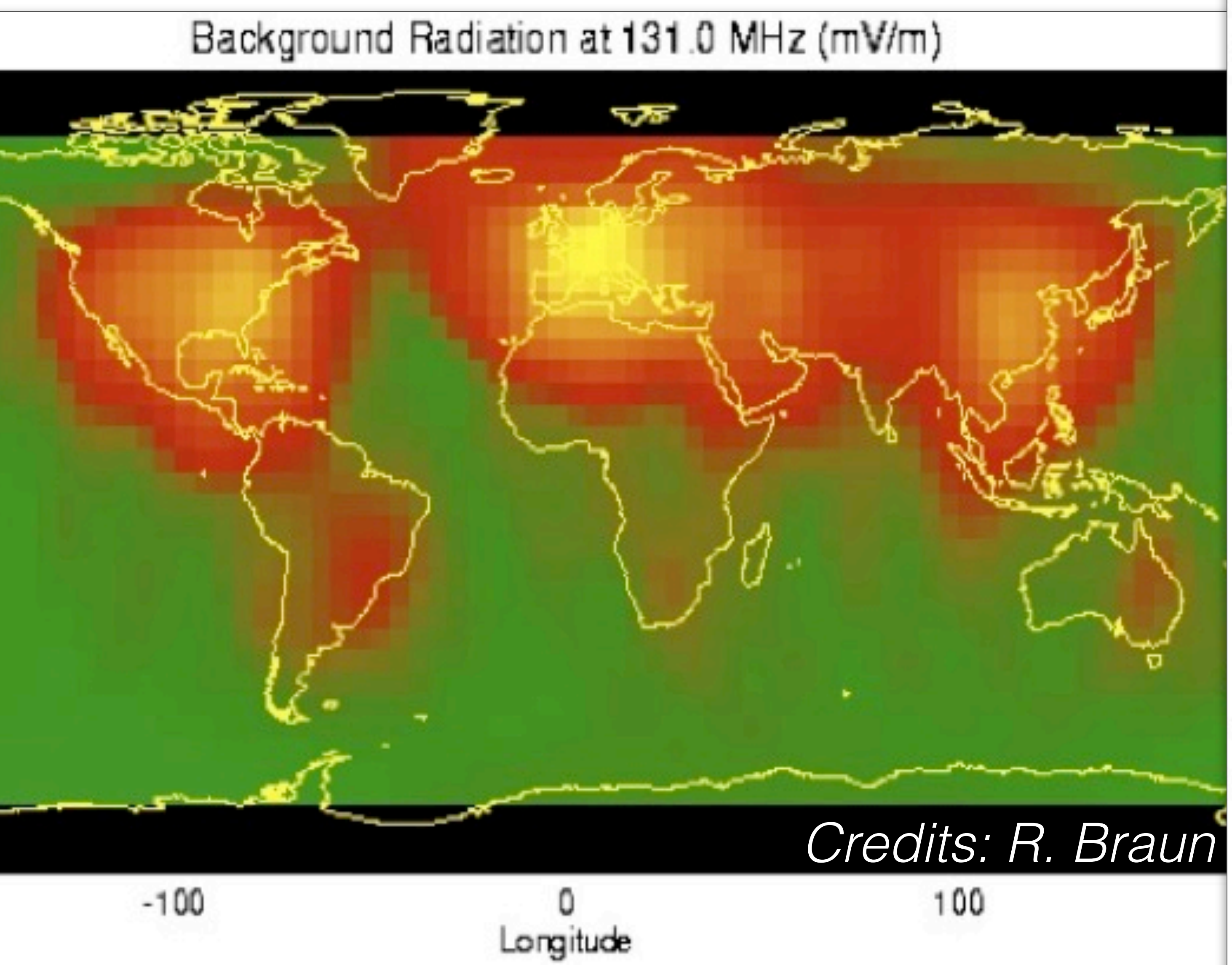
- France, Germany, Japan, Korea, Spain, USA, …
(Brazil, Russia, …)

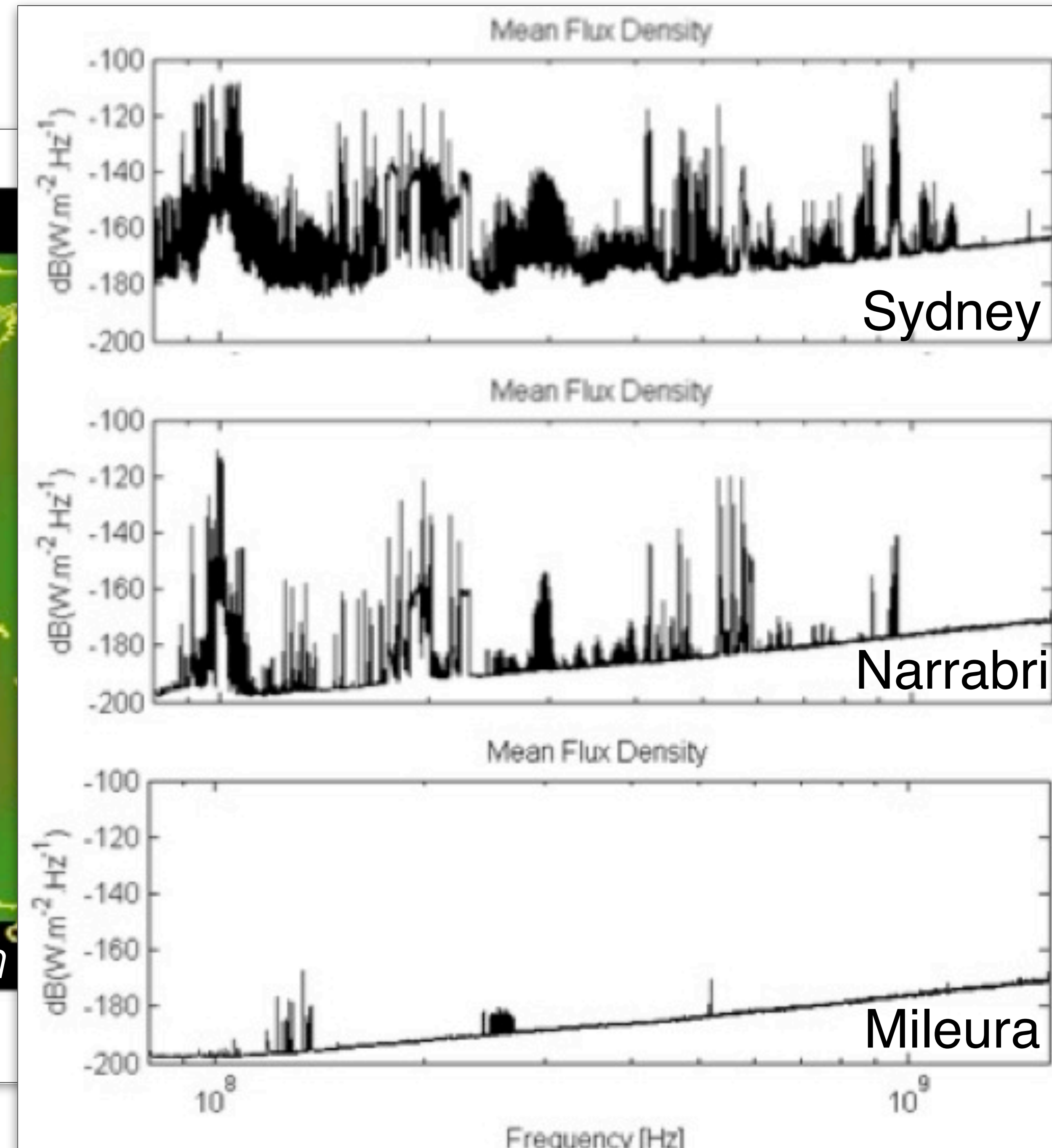


SKA design

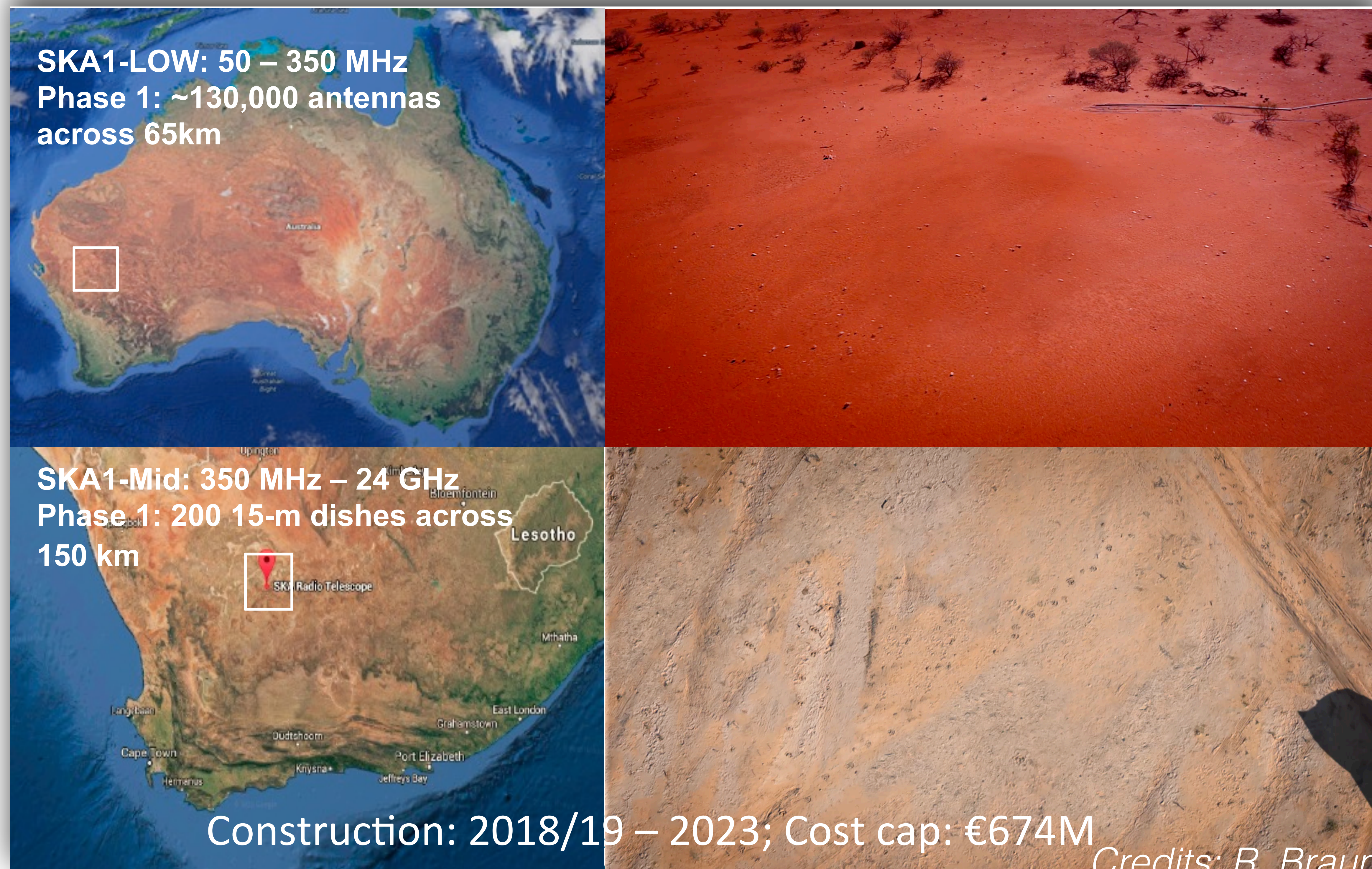
- 2 phases
  - SKA1: construction 2018-203
  - SKA2: detailed design >2018
- SKA1: dual site, dual scope (frequency & design)
  - **SKA1-low: Australia, dipoles, 50-350 MHz**
  - **SKA1-mid: South Africa, dishes, 0.3-3 GHz**

Essential for site: radio frequency interference (RFI)



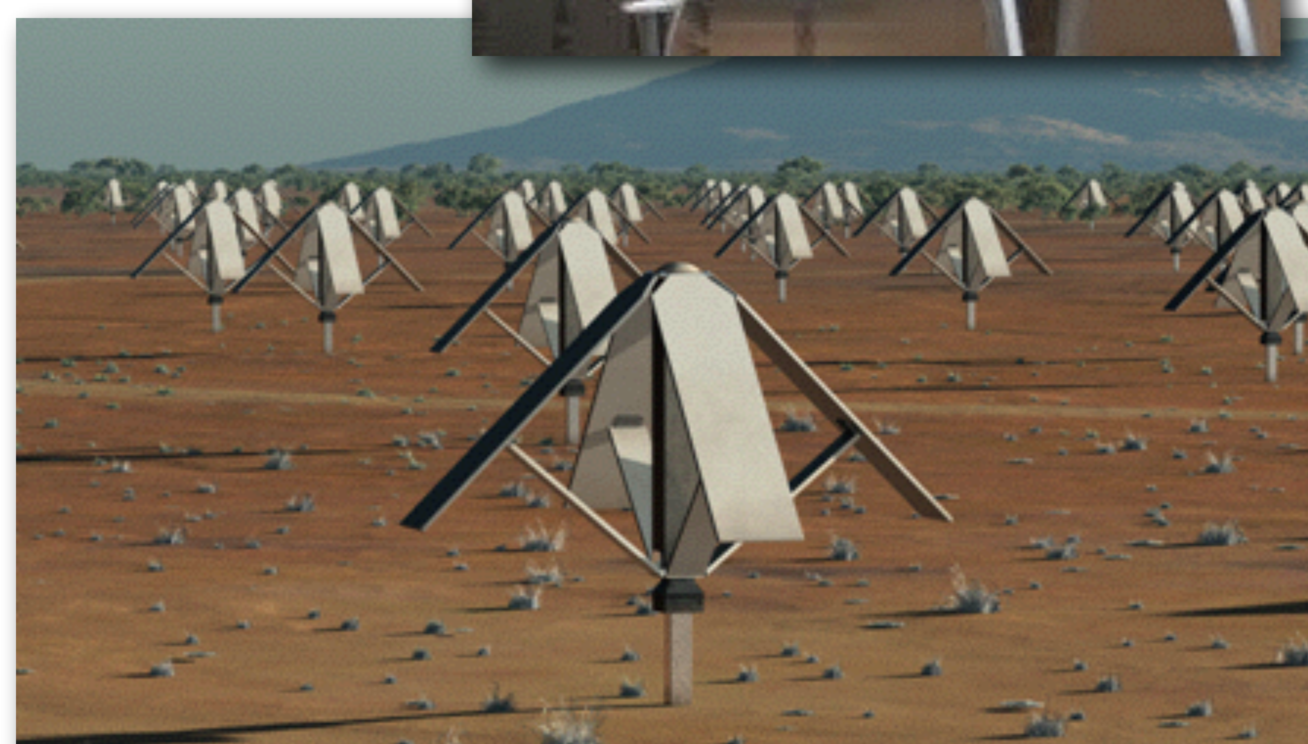


SKA sites in AUS & RSA



SKA1-low

- Location: Australia
- Main driver: **highly redshifted 21 cm HI line** from the Epoch of Reionisation and earlier
    - pulsars, magnetised plasma, extrasolar planets
- ~250000 **dipoles**
- **50-350 MHz**
- 1 km radius core
- 45 km maximum baseline
- 20 deg^2 field of view



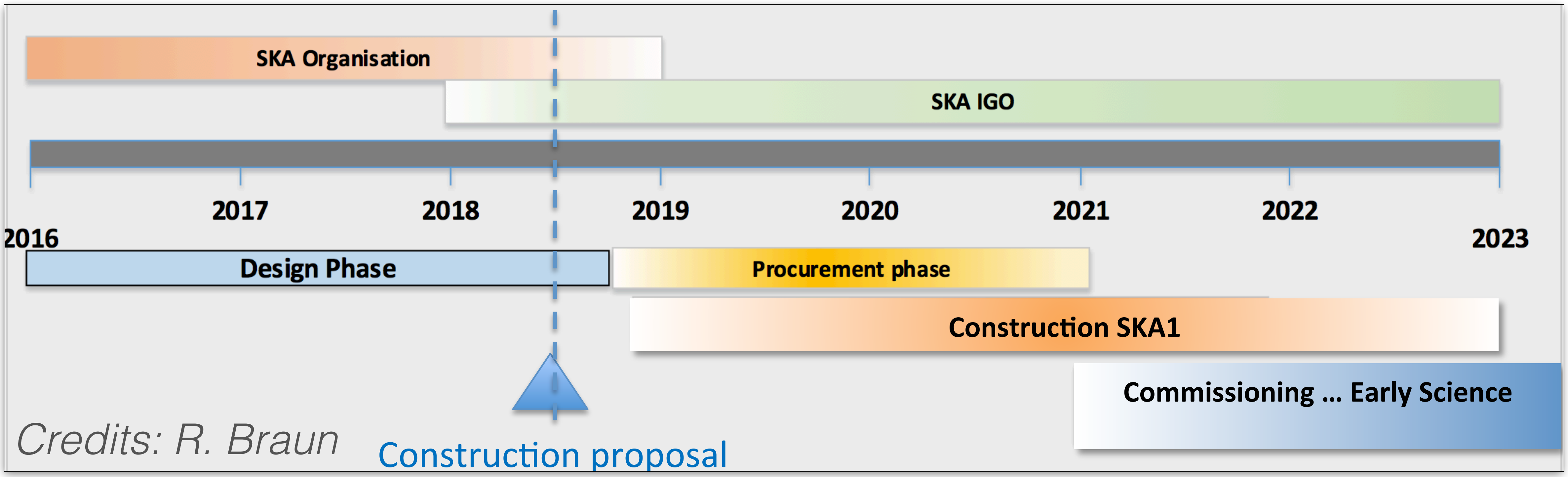
SKA1-mid

- Location: South Africa
- Drivers: **pulsars**, nearby to mid-z **HI line**, high sensitivity **continuum** sources
- ~250 15m **dishes**, incorporating Meerkat dishes
- **0.35-3 GHz**; ready for additional receivers
- ~100 km maximum baseline, but VLBI capable

SKA2 - early view

- Increase total collecting area
  - 1,000,000 m^2
- Improve angular resolution (longer baselines)
  - $\sim$1 mas
- Extend frequency coverage (additional receivers)
  - 20 GHz

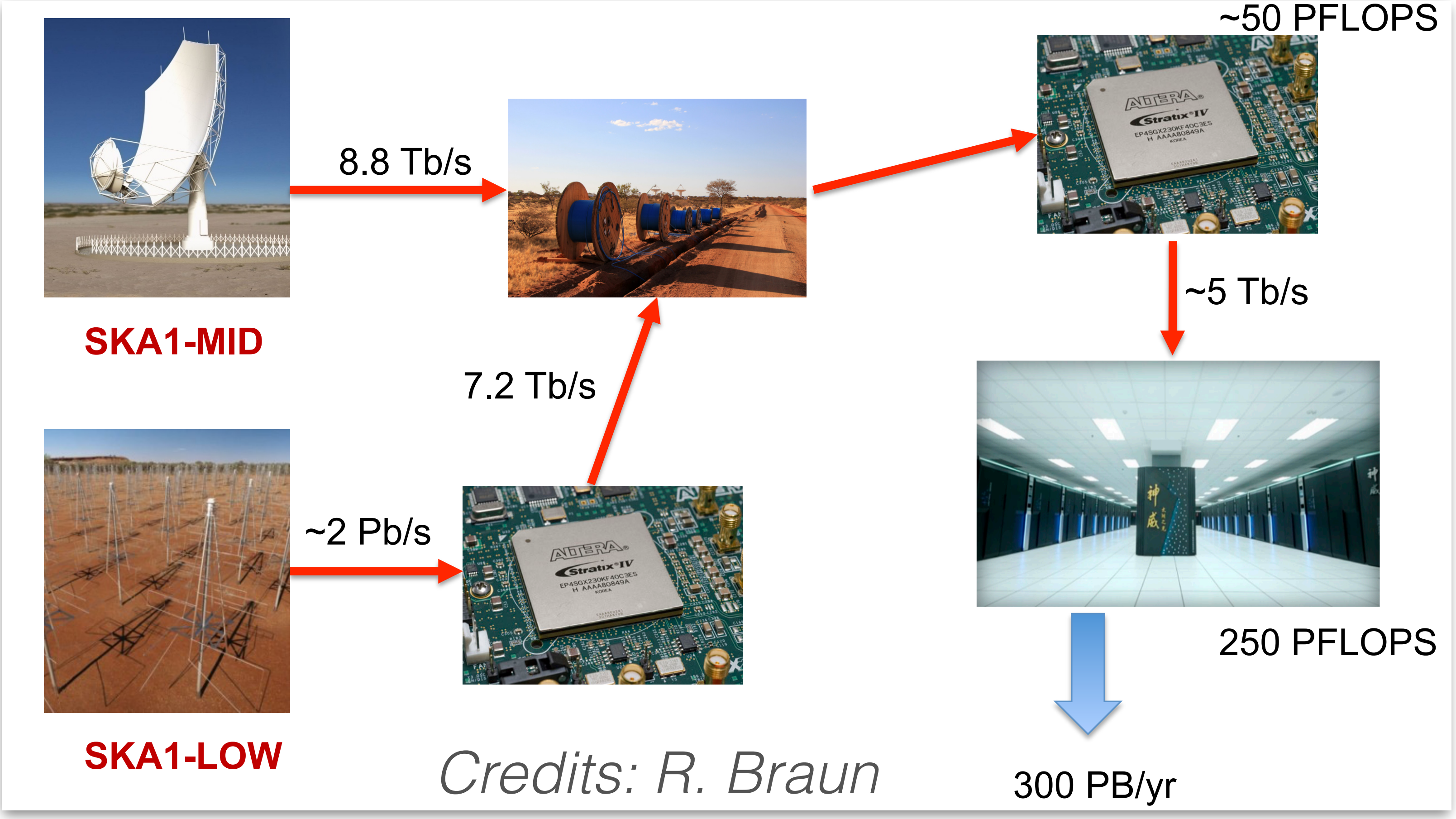
SKA1 timeline



- Preliminary Design Reviews completed
- Critical Design Review scheduled
- Inter-Governmental Organisation formal negotiations in progress
- Cost Control Plan to retain transformational science in essentially all areas at cost-cap (170M€ design, 670M€ construction)

SKA-CTA similarities

- International projects involving large teams of scientists and engineers
- Order of magnitude improvement with respect to existing instrumentation
- Dual site projects
- Big (huge!) computational challenges: data rates, analysis, storage

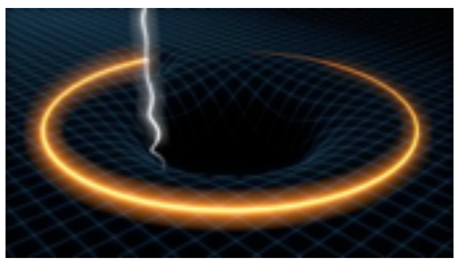


SKA-CTA differences

- SKA sites are both in the southern hemisphere (JVLA/ngVLA, LOFAR, VLBI will continue to play important roles in the northern hemisphere) & SKA sites have completely different designs from each other
- Traditional (~century) radio astronomy features: high duty cycle, great sensitivity, many sources, spectral lines, wide field of view and large survey speed
- For many classes, CTA will allow study of individual cases at extreme energies, SKA will perform population studies: complementary approach and plenty of room for synergy

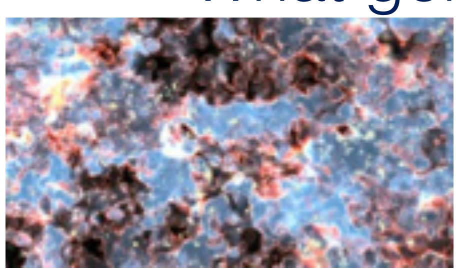
SKA Key Science Projects

- **Galaxy evolution, cosmology and dark energy**
  - How do galaxies evolve? What is dark energy?

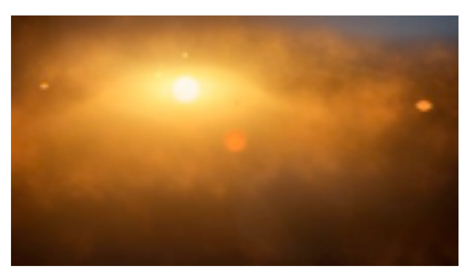


- **Strong-field tests of gravity using pulsars and black holes**
  - Was Einstein right about gravity?

- **The origin and evolution of cosmic magnetism**
  - What generates giant magnetic fields in space?



- **Probing the Cosmic Dawn**
  - How were the first black holes and stars formed?
- **The cradle of life**
  - Are we alone?



- **Flexible design to enable exploration of the unknown**

A rich radio Universe

- More mature technology (around for a century, and useful for telecommunication)
- Lower energy photons
- Various types of radio emission:
  - thermal (free-free)
  - non-thermal (synchrotron: relativistic particles in magnetic fields)
  - coherent emission (eg pulsars)
  - spectral lines (redshifted)

CTA-SKA synergies

- Main areas of synergy with CTA:
  - cosmic rays - eg in supernova remnants (talks by Duranti, de Palma)
  - astroparticle physics - dark matter from gamma rays, dark energy and cosmology from matter dipole etc. (Morselli, Roncadelli)
  - star formation history - continuum emission in radio and EBL absorption in VHE gamma rays
  - particle acceleration, primarily in blazars but also other extragalactic and galactic jets (GRBs, radio galaxies, binaries, etc.), galaxy clusters (talk by G. Brunetti), etc.

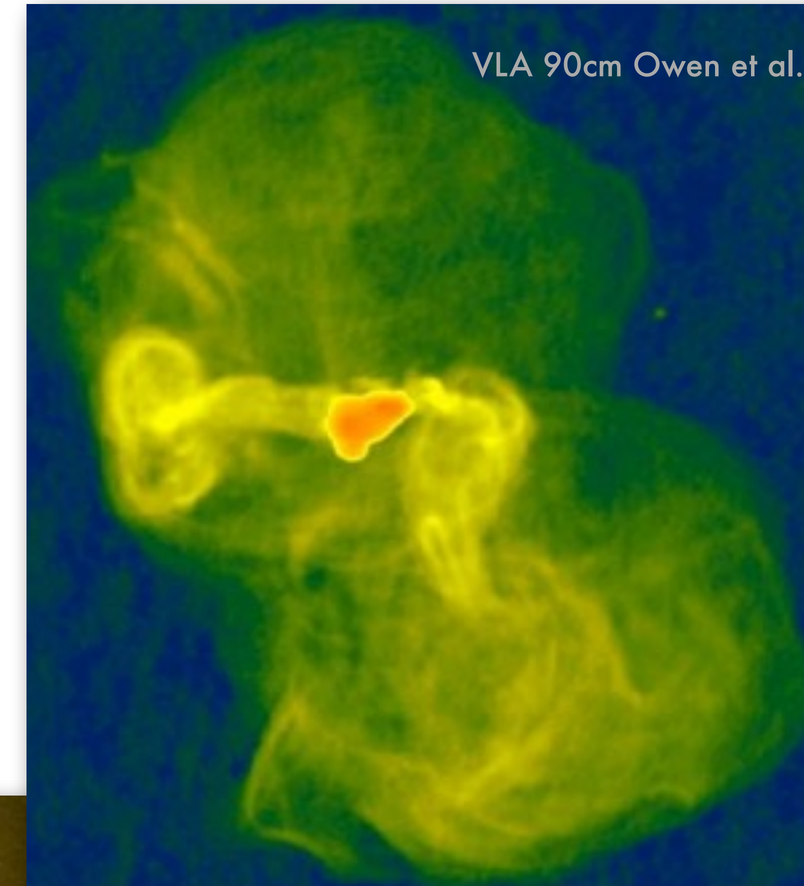
CTA-SKA & jets

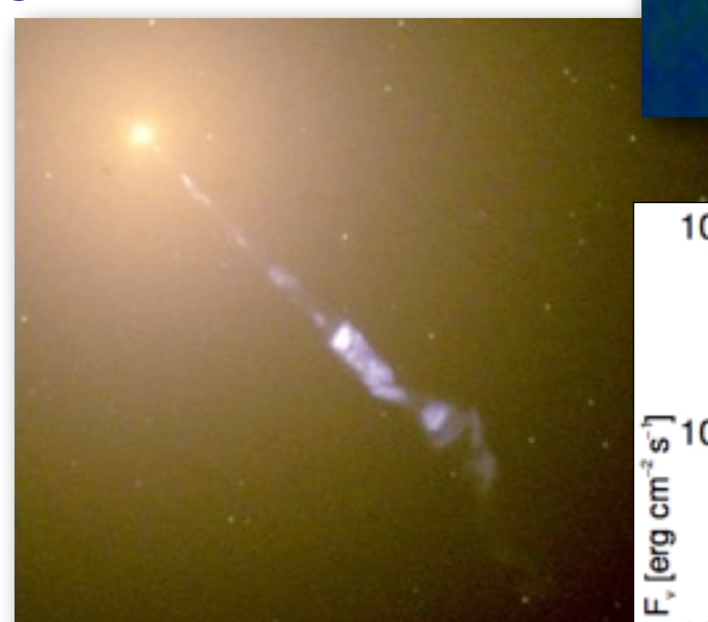
(also Tavecchio's talk)

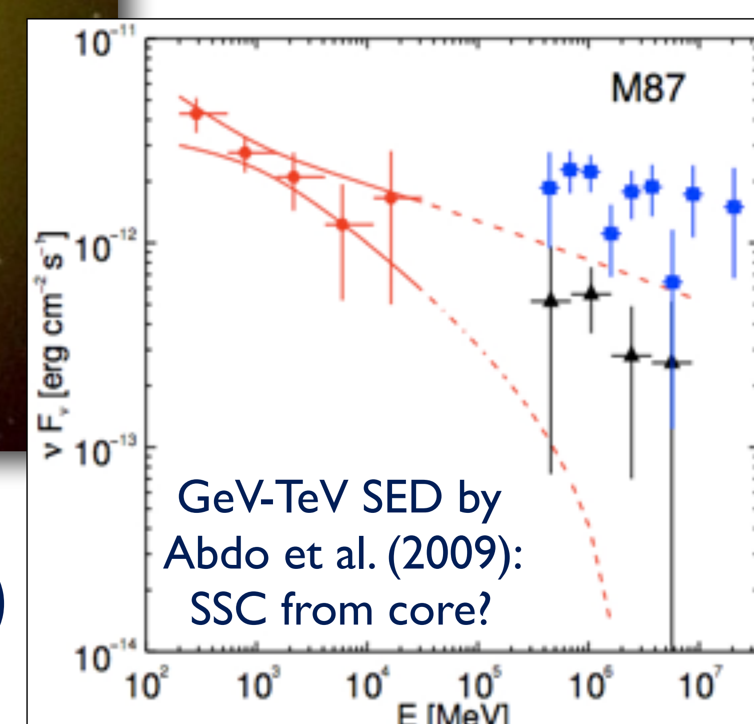
- Radio waves and gamma rays are both emitted by non-thermal processes
- Can be used complementarily to constrain different parts of the particle energy distribution and different physical parameters (magnetic fields, ambient photon density, emission region size…)
- Where are the gamma rays produced? near the black hole or further downstream? blazars vs radio galaxies
- How are the gamma rays produced? leptonic vs hadronic processes

Jets in radio galaxies: M87

- An unremarkable guy ($P_{0.4}=10^{25}$ W Hz^{-1}) in a very remarkable location (d=16 Mpc)
- M_{BH}~$6x10^9$ M_{sun}, 1mas=0.081pc=140R_s
- kpc scale jet resolved in optical and X-rays
- gamma-ray emission detected
  - by Fermi (MeV/GeV, non variable)
  - by Cherenkov telescopes, with flares in 2005, 2008, ...
- Probably our best laboratory for jet studies: nearby, bright, with massive black hole (EHT)



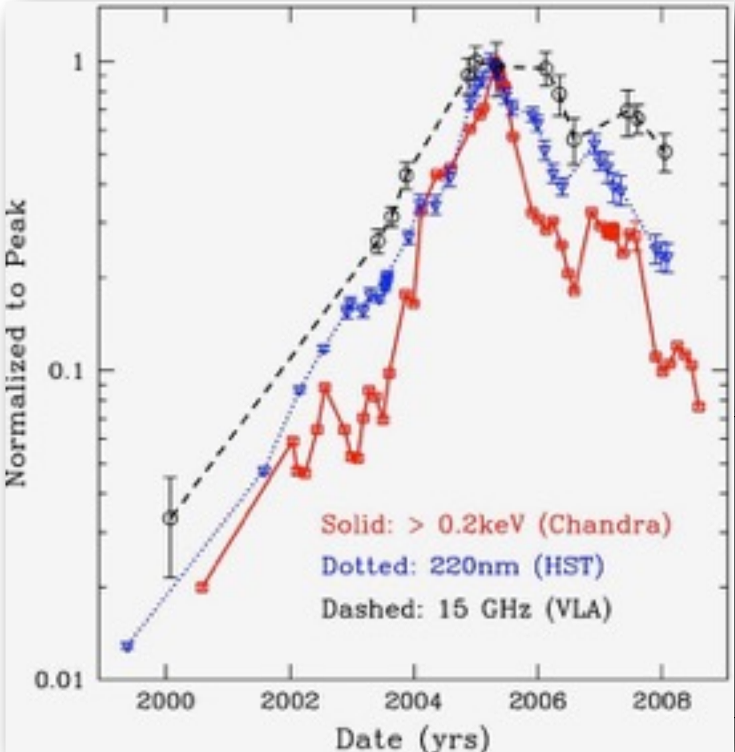




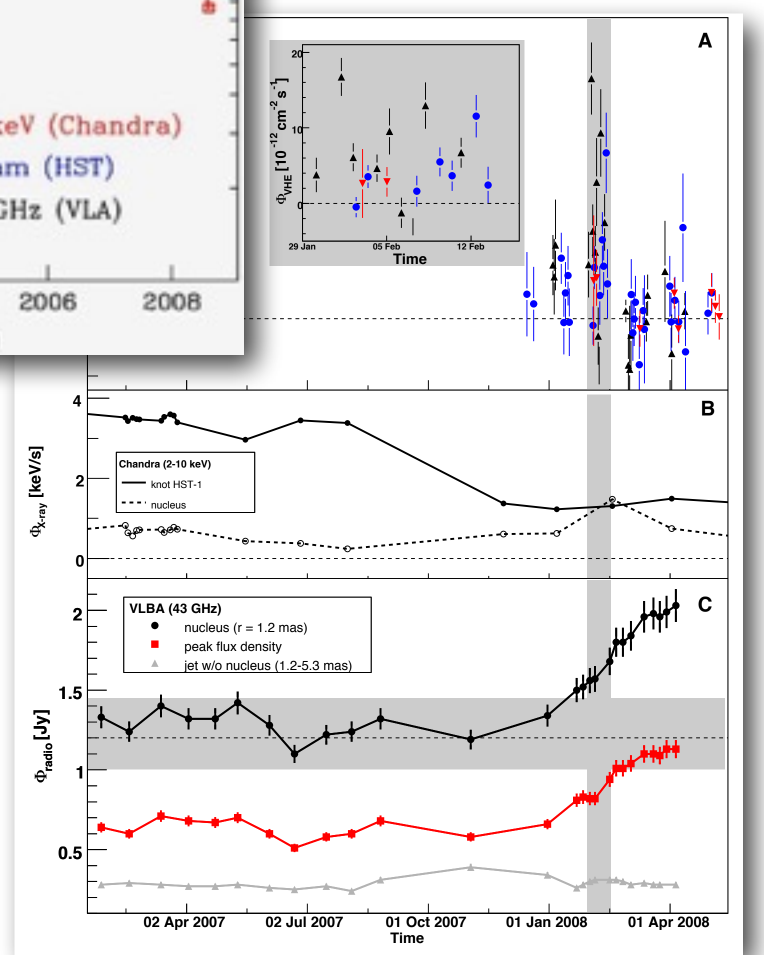
M87 radio-VHE connection

core 900 mas ~ 70 pc HST-1

- VHE observations reveal rapid flares but cannot resolve the emission - radio can!
- HST-1
  - jet knot ~70 pc downstream
  - superluminal motion
  - major optical, X-ray, and radio flare around 2005 VHE activity
- Core
  - very compact, as required by VHE variability time scale
  - radio flux density increase simultaneous to 2008 VHE event

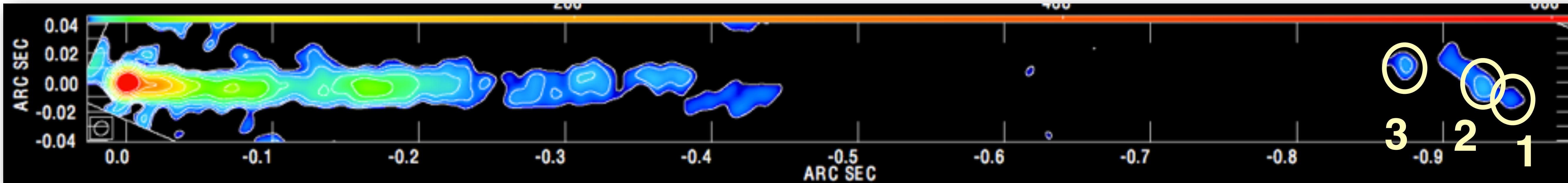


Harris et al. 2009

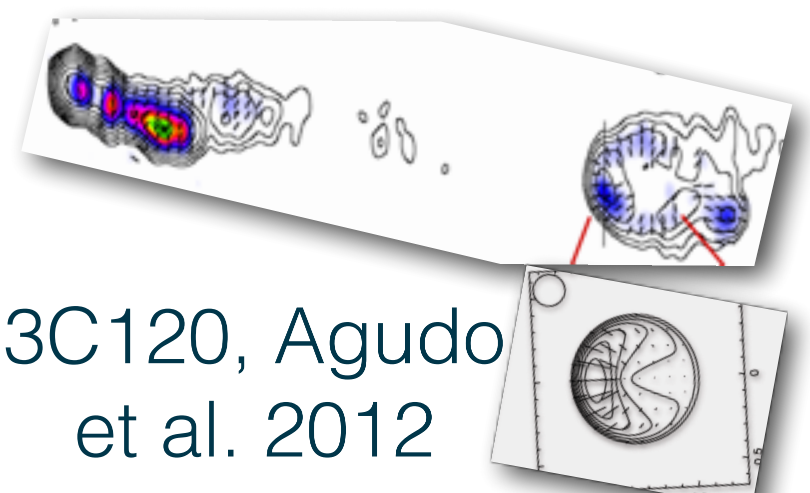


Acciari et al. 2009

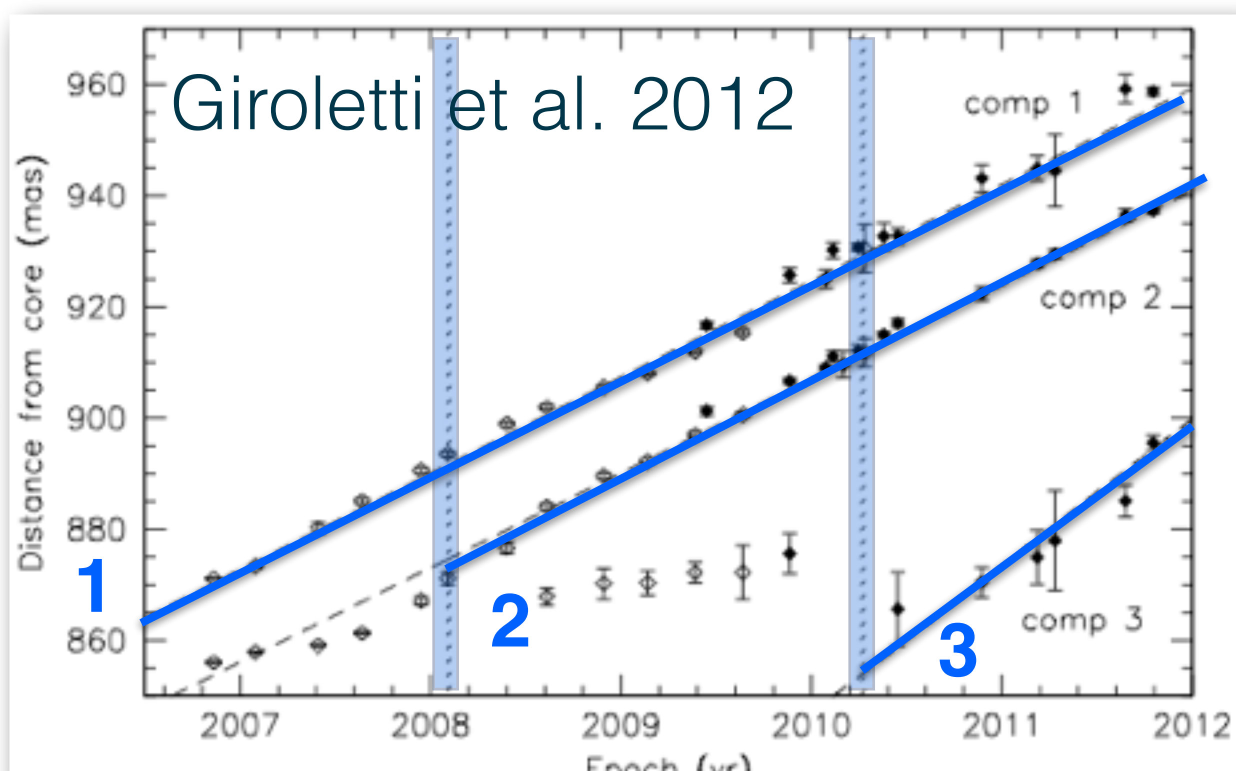
M87 radio-VHE status



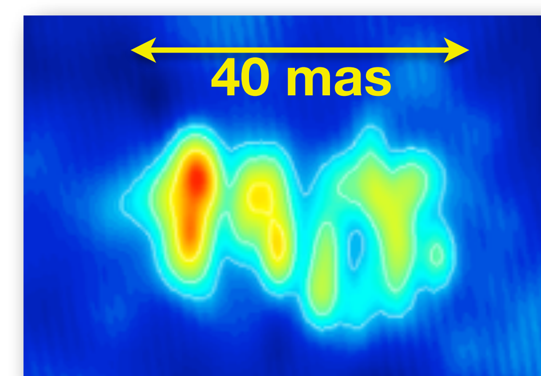
Data from a long&dense monitoring with the eEVN reveal ejection of superluminal components within the jet knot HST-1 is temporally associated to 2008, 2011 VHE events.



3C120, Agudo et al. 2012



v=(4.1+-0.1)c
δ=1.5-4.0

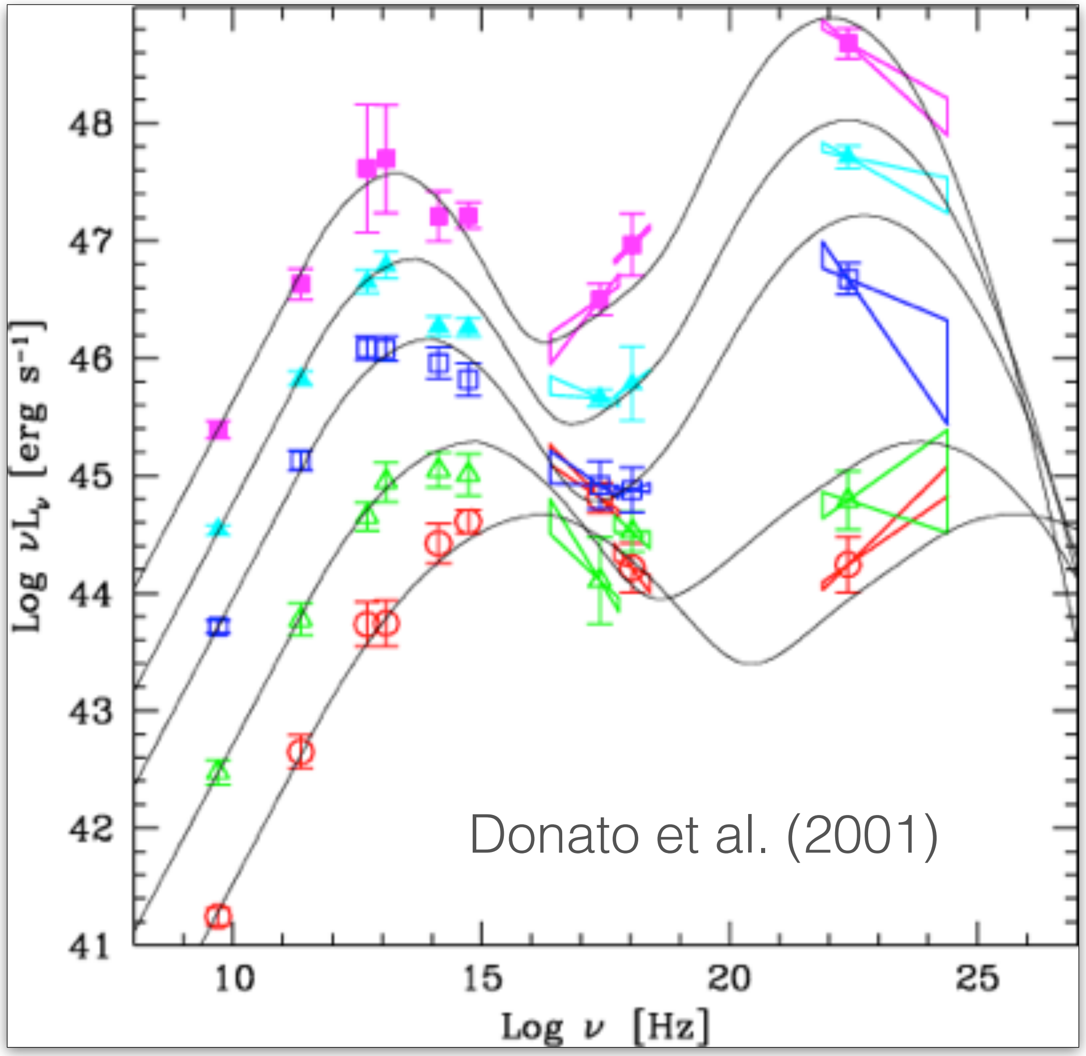


more on SKA-CTA & jets

- Association of VHE activity and radio features (flares, component ejection, **polarisation** and RM sign reversals, …) is currently highly speculative due to very limited gamma-ray event statistics
- CTA will reveal many more flares but radio follow-up will become challenging
  - at present, dedicated campaigns are difficult to organise and have to focus on very few objects
- SKA1_MID will be the ideal partner, in particular with VLBI-mode enabled
- **both for extragalactic and galactic (binary) jets**

TeV blazars

- Despite much debate on its origin (physics, bias, or both), there is evidence for a trend between increasing peak frequency and decreasing luminosity in blazars



- This means that most CTA blazars will be faint radio sources
- SKA will be useful to study them - and to recognise them in the first place (out of the plethora of other faint radio sources): polarisation, spectral index, variability…

More topics…

- SKA great sensitivity and field of view: great machine for discovering and following up **transients**
- **GRBs**: SKA1 can detect and monitor the light curve and spectra of many afterglows
  - detailed understanding of any CTA detected GRB (Bissaldi's talk)
  - connection to search for high-freq (10-1000 Hz) **GW** progenitor systems (Patricelli's talk)
  - population study, including **off-axis afterglows**
- **GW**; directly detect low-freq (~nHz) GW through **pulsar** timing

Take home notes

- Despite being at the opposite ends of the EM spectrum, radio and gamma rays have a deep physical connection
- SKA will be the largest radio telescope array ever constructed
- expect synergy in the field of acceleration, star formation history, astroparticle physics, transients, and unknown!

…meanwhile, let's get as much as possible from the current instruments!