

uGMRT+

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OUTLINE

1. Scientific Motivation

2. Technical Requirements

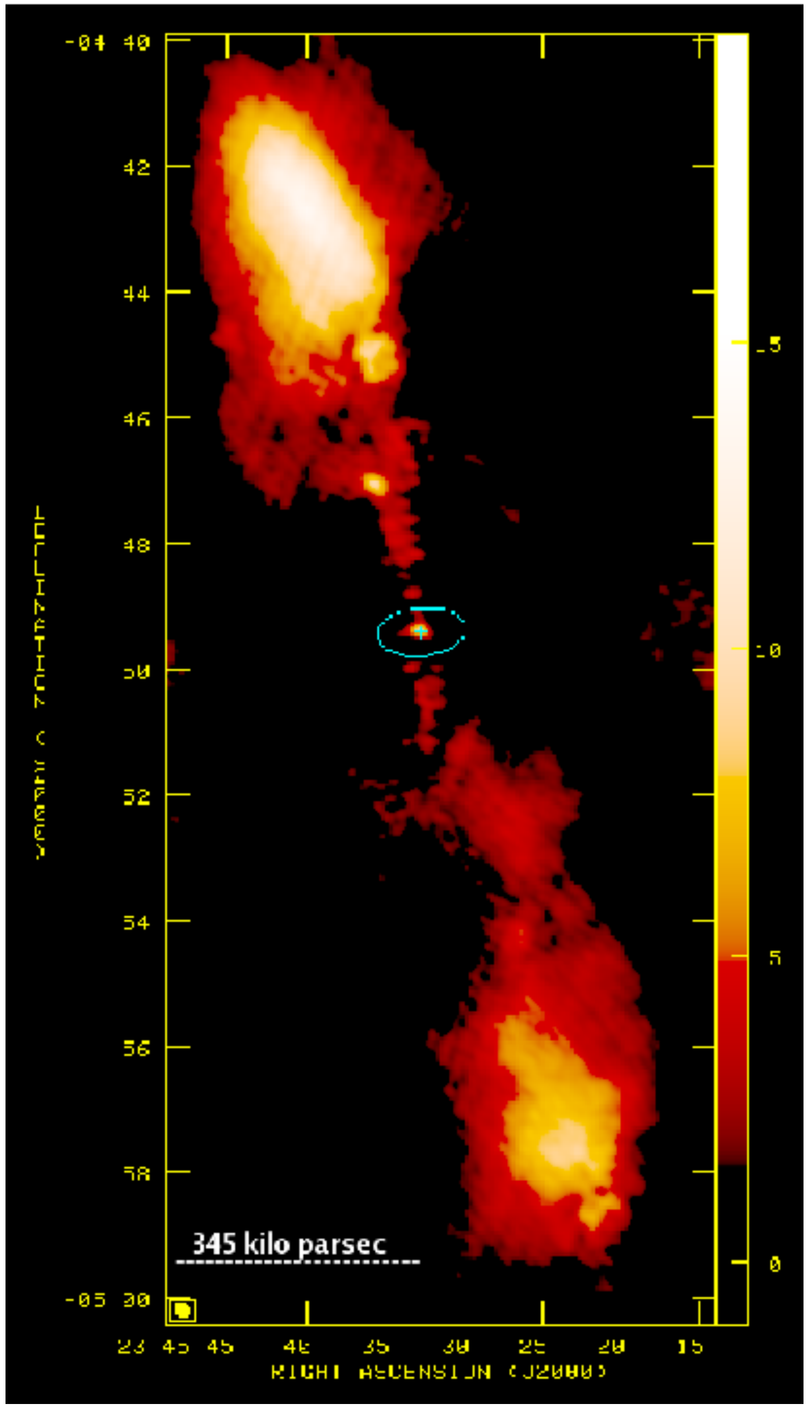
3. Budget

SCIENTIFIC MOTIVATION

JETS

"Radio jets play a major role in the transfer of gravitational energy from black holes and neutron stars back into the surrounding environment, so **anything that expands our understanding of the jet phenomenon subsequently improves our understanding of the universe as a whole.**"

- James Miller Jones, Curtin University



KEY OPEN QUESTIONS :

How do jets get formed?

What collimates the radio jet?

How do jets get accelerated?

What is the shape of jets?

What is the radiative and kinetic power of jets?

What are the magnetic field configurations of jets?

When and how does the jet decelerate and expand as it moves away from the central black hole?

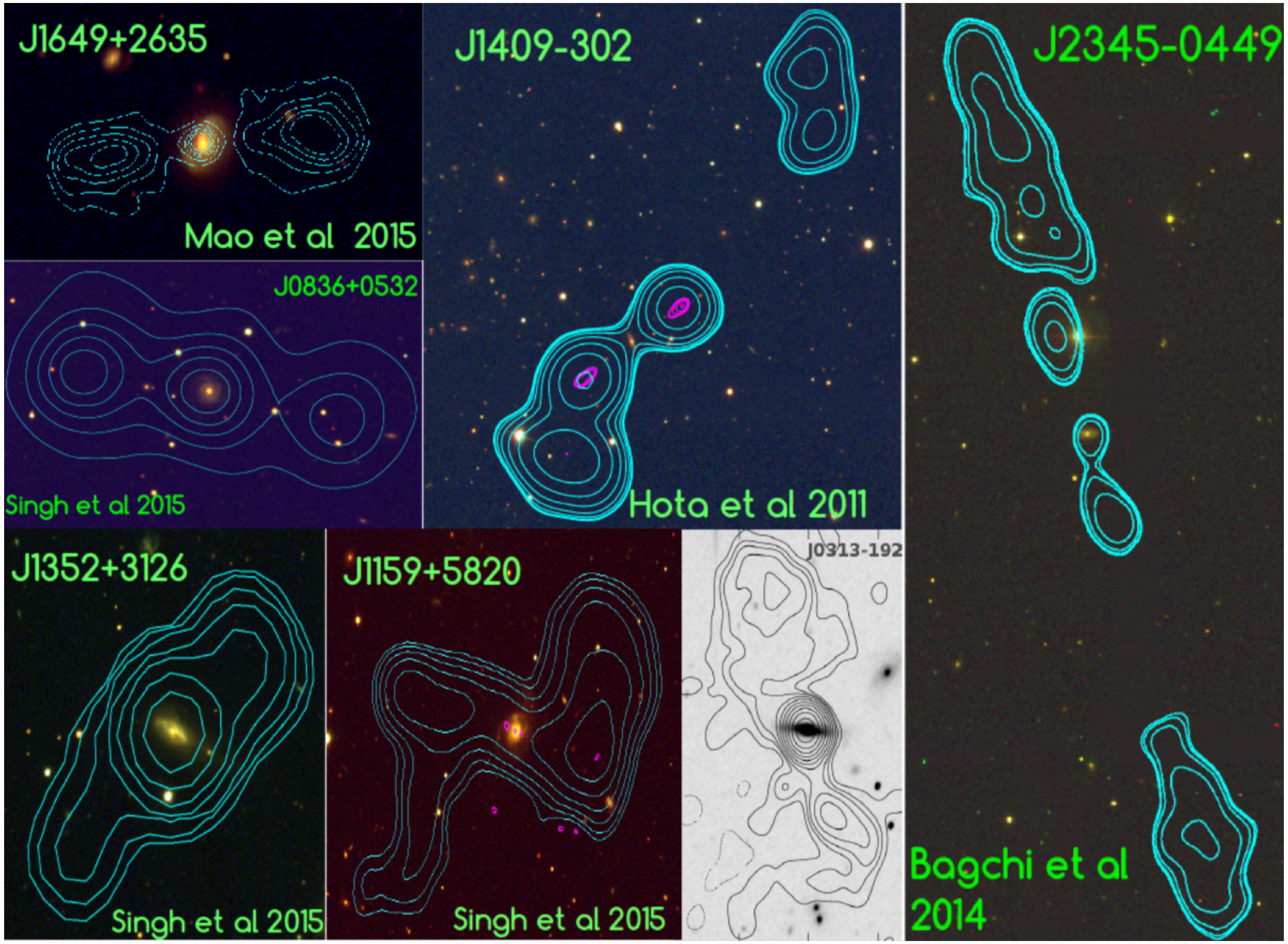
How do all of these vary as accretion flow properties (e.g. the accretion geometry) change?

Science Question 1 : Active galactic nuclei

Previous idea : Most powerful radio galaxies and radio loud quasars/blazars all originate in bulge dominated elliptical galaxies! Spiral galaxies never produce large-scale radio jets.

New Excitement : Bagchi et al. (2014) and many more later GMRT led studies found Megaparsec jets in Seyferts!! But we know very handful of them and hence do not have enough material to dig into the physics of these objects.

What extra is needed : We need even better low frequency imaging sensitivity. Right now GMRT is playing a major role. uGMRT+ will double the detection rate with higher sensitivity, and resolve jet structures with the significantly higher baseline.

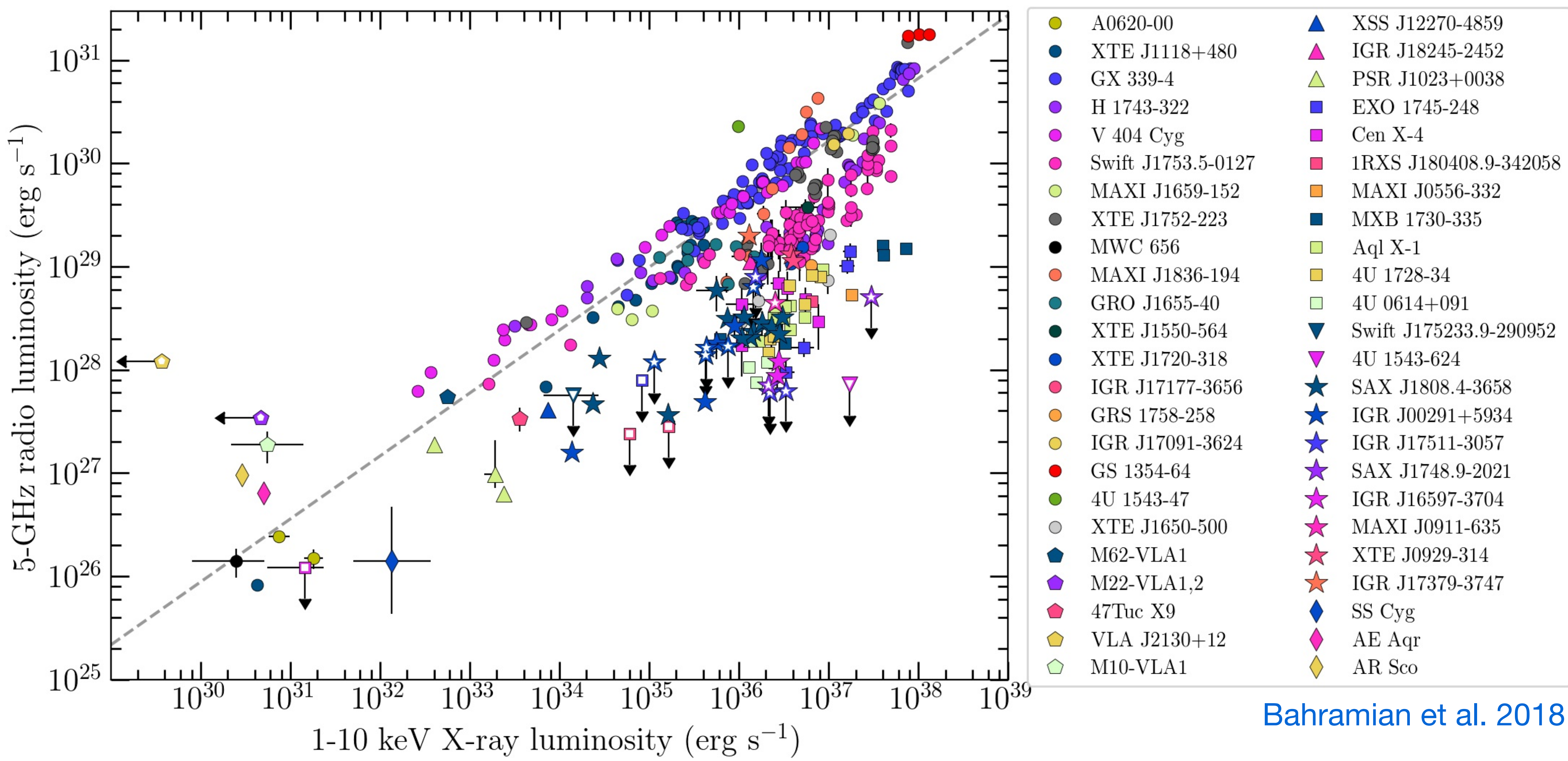


Credit : Bagchi

Science Question 2 : Stellar-mass black holes (BHXRB)

Question 1 : During an outburst, the radio emission of a BHXRB is strongly correlated with the X-ray luminosity (interpreted as relation between accretion rate and outflow in compact jets). This correlation was extended to the Fundamental Plane of Black Hole Activity in AGN (Merloni et al. 2003).

But with better coverage, many sources deviated from the standard FPBHA, following a radio-quiet branch and challenging the simple picture presented of disk-jet connection in accreting black holes across all masses. We need many more detections of these radio-quiet BHXRBs to understand uniformity of jets in all black holes.



Bahramian et al. 2018

Question 2 : Currently it is not clear how BHXRBs behave in quiescence. With the highly sensitive uGMRT+, we can finally check if the radio/X-ray correlation extend towards the lowest luminosities.

Science Question 3 : Neutron Stars (NSXRB)

Why interesting :

In contrast to the BHXRBs, the NSXRB accretor has a surface and a stellar magnetic field!

The status till now :

- NSXRB are radio quiet compared to BHXRB counterparts (e.g. Fender & Kuulkers 2001).
- **Previous idea :** Only neutron stars with very weak magnetic fields can emit jets. So we had assumed that strong magnetic fields ($> 10^{12}$ G) inhibit the formation of jets.
- **New excitement (van den Eijnden et al. 2019, Nature)** : jet-spewing, highly magnetized, neutron star called Swift J0243.6+6124 (probably also in, magnetic NSs GX 1+4 and Her X-1)
- **Where are we failing :** The current facilities lack the sensitivity needed.

What the proposed telescope can bring :

- Better sensitivity
- Higher frequency coverage
- Better spatial resolution
- Better coverage of the northern sky

What questions we can answer :

- Which classes of NSXRBs launch jets?
- Which system parameters enable/prevent jet launching, how is magnetic field important?
- How the accretion-outflow connection differs from the BHXRBs?

Science Question 4 : White Dwarfs (Cataclysmic variables, CV)

Why interesting :

- Unlike BHXRBs and NSXRBs, White dwarfs (CVs) are non-relativistic!
- Magnetic field strength of CVs (10^6 G) insufficient to channel accretion flow from the disk.

The status till now :

- Most CVs are faint at radio frequencies (on the order of 10s to 100s of μJy at 300 pc).
- **Previous idea :** CVs were thought to not launch jets, and used to constrain jet-launching models in compact accretors (e.g Soker & Lasota 2004).
- **Körding et al. 2008** : Accretion-outflow cycle observed in XRBs could be mapped to CVs
- **New excitement (eg. Mooley et al. 2017) :** discovered jet in the CV SS Cyg and few more CV
- **Where are we failing :** Need high sensitivity to determine the spectral indices and put strong constraints on the polarization fraction or determine the spatial extent of the emitting region

What the proposed telescope can bring :

- Better sensitivity, polarization information
- Spatial resolution to conclusively determine if CVs are producing jet
- Better coverage of the northern sky

What questions we can answer :

- What is the impact of the magnetic field strength of the white dwarf on jet emission?
- How does relativity and strong gravity play a role on jet formation?

Science Question 5 : Galactic clouds

What question we want to answer:

What is the physical nature of molecular gas prior to the formation of stars, and what processes play important roles in exciting star formation?

Why interesting :

To Study the molecular clouds of the milky way (or nearby galaxies) using sub-mm waveband (expected star formation clouds are below 10 K) and resolve the structure with a larger angular resolution.

What new things we can do :

Calculate the mean magnetic orientations of the molecular clouds and compare it to the Galactic plane (from Polarization vector we can measure the magnetic field of these clouds).

Science Question 6 : SETI

The possibility of discovery of biological extraterrestrial life in exoplanets, like signatures of methane emissions, over the next 10 years is extremely high.

There are three factors when searching for alien life:

1. do they exist
2. will they transmit to us
3. and at what frequencies.

But, if they have extremely powerful radars or high electronics system radiation, we may be able to detect these signals using a highly sensitive telescope.

Aliens may transmit over a wide bandwidth. Since hydrogen is the predominant component of our universe, one possibility is that they may transmit at the frequency that is emitted by neutral hydrogen. It radiates at a unique frequency of 1,400MHz, that is 21cm wavelength. In order to increase the sensitivity for reception of the signal, they may transmit over a very narrow bandwidth, say 1Hz or 0.5Hz.

We need to develop a suitable back-end electronics and software system of radio telescope for such signals.

Science Question 7 : European VLBI Network

The European VLBI Network (EVN) :

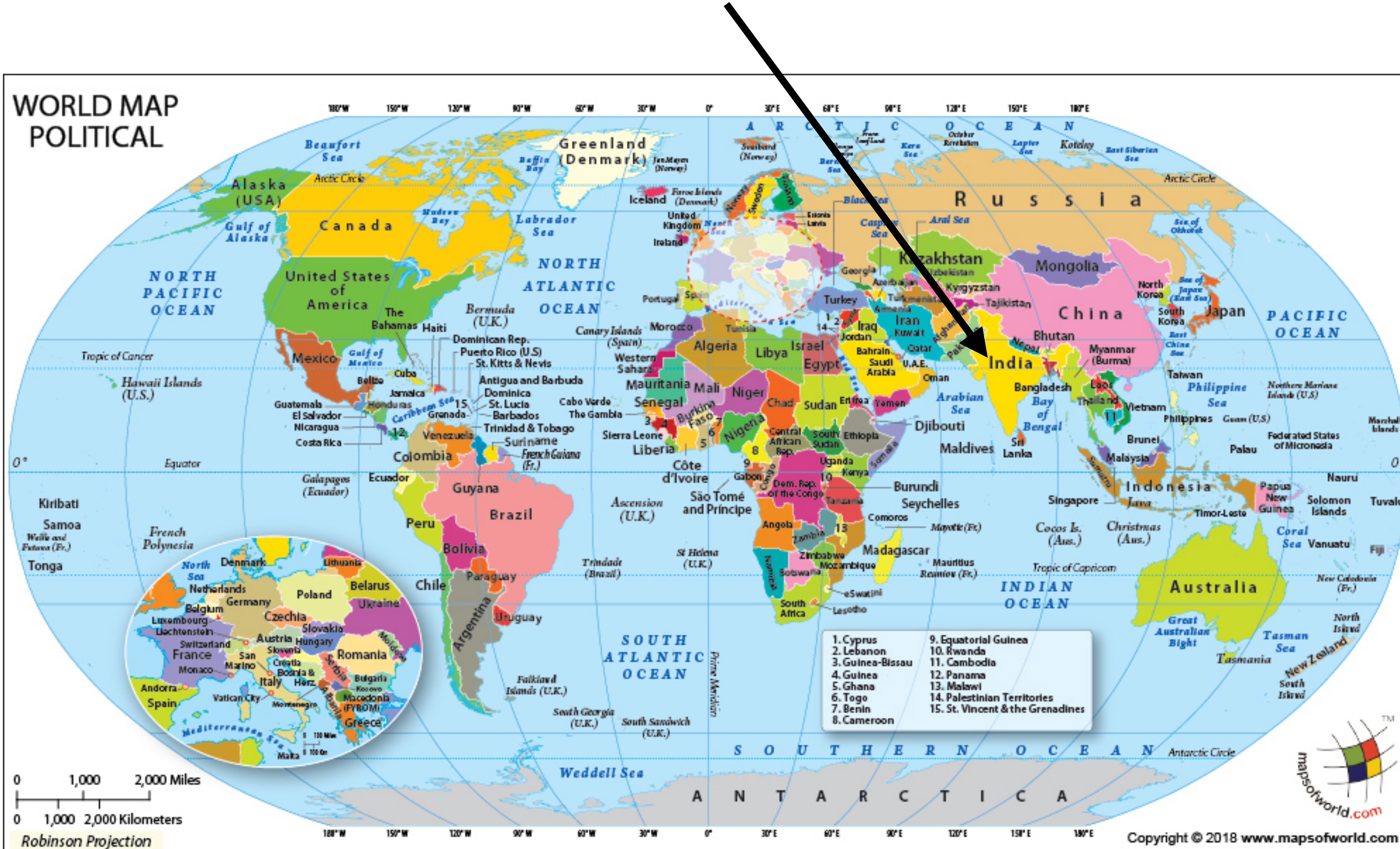
- network of radio telescopes in Europe, Asia, South Africa and Puerto Rico
- performs very high angular resolution observations of cosmic radio sources
- most sensitive VLBI array in the world, and the only one capable of real-time observations.

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

Missing : Huge gap in the UV-coverage, no antenna in the middle-east & Indian subcontinent.
We provide : Intermediate baselines for EVN, a better UV-coverage

TECHNICAL REQUIREMENTS

LOCATION


WORLD MAP
POLITICAL
Greenland (Denmark)
Alaska (USA)
Canada
United States of America
Mexico
NORTH PACIFIC OCEAN
NORTH ATLANTIC OCEAN
SOUTH ATLANTIC OCEAN
PACIFIC OCEAN
INDIAN OCEAN
ARCTIC OCEAN
SOUTHERN OCEAN
Russia
Kazakhstan
Mongolia
China
India
Japan
Iran
Iraq
Turkey
Egypt
Libya
Algeria
Sudan
Chad
Niger
Mali
Nigeria
Brazil
Colombia
Venezuela
Peru
Bolivia
Argentina
Chile
Paraguay
Uruguay
Guyana
Suriname
Indonesia
Australia
Madagascar
Angola
Zambia
Tanzania
Kenya
Ethiopia
Somalia
Saudi Arabia
Yemen
Oman
Pakistan
Afghanistan
Nepal
Bhutan
Bangladesh
Myanmar (Burma)
Thailand
Vietnam
Malaysia
Sri Lanka
Maldives
Philippines
Papua New Guinea
New Zealand
Tasmania
Iceland
United Kingdom
Ireland
Portugal
Spain
France
Germany
Poland
Ukraine
Belarus
Romania
Greece
Italy
Morocco
Western Sahara
Mauritania
Senegal
Liberia
Côte d'Ivoire
South Africa
Namibia
Botswana
Mozambique
Zimbabwe
Hawaii Islands (U.S.)
Kiribati
Samoa
Tonga
French Polynesia
ANTARCTICA
Weddell Sea
Arabian Sea
Bay of Bengal
Tropic of Cancer
Equator
Tropic of Capricorn
Arctic Circle
Antarctic Circle
Prime Meridian
0 1,000 2,000 Miles
0 1,000 2,000 Kilometers
Robinson Projection
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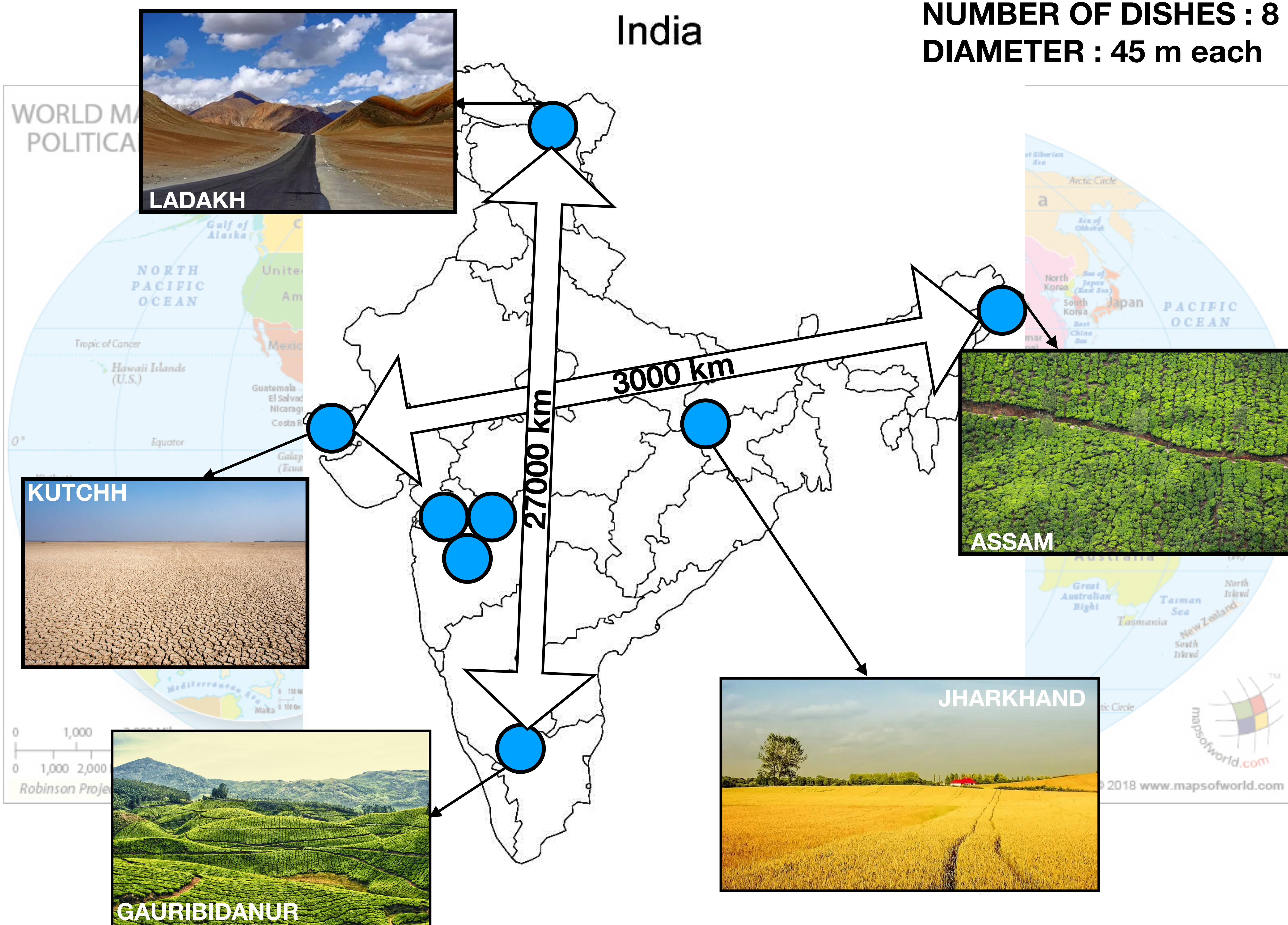
LOCATION

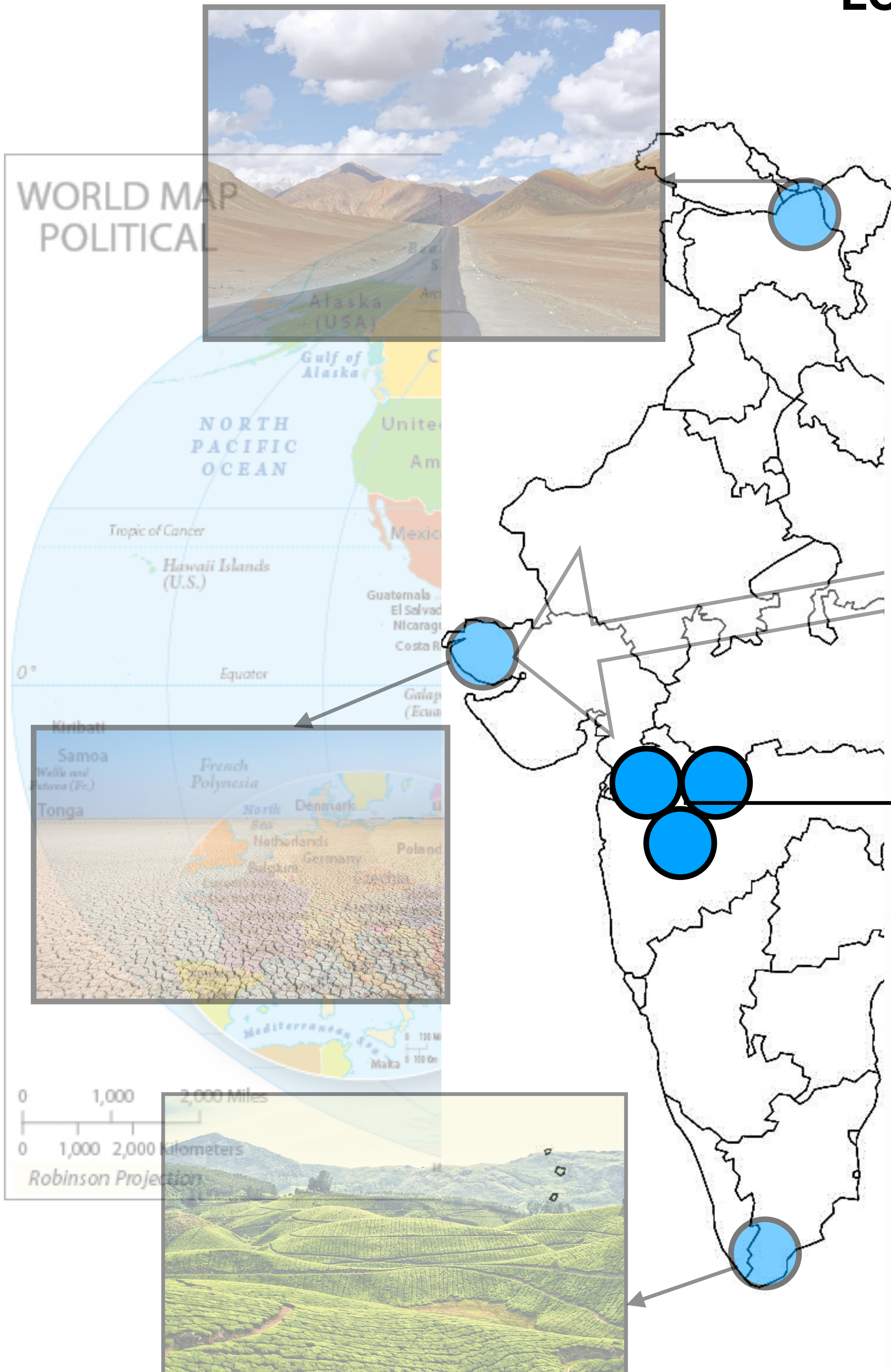
India

NUMBER OF DISHES : 8
DIAMETER : 45 m each

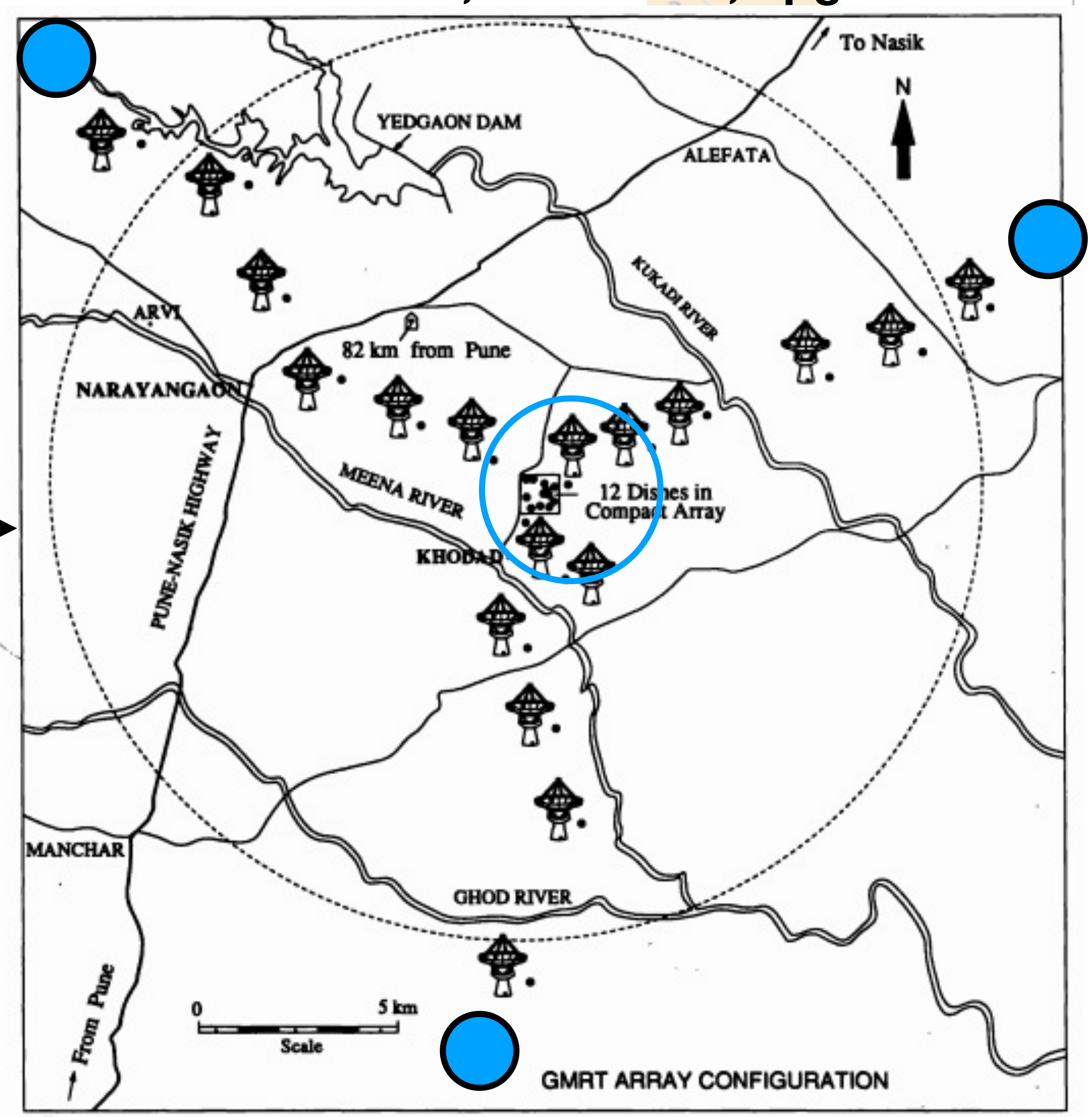


LOCATION

India



GMRT : 30 dishes, 45 m each, upgradable



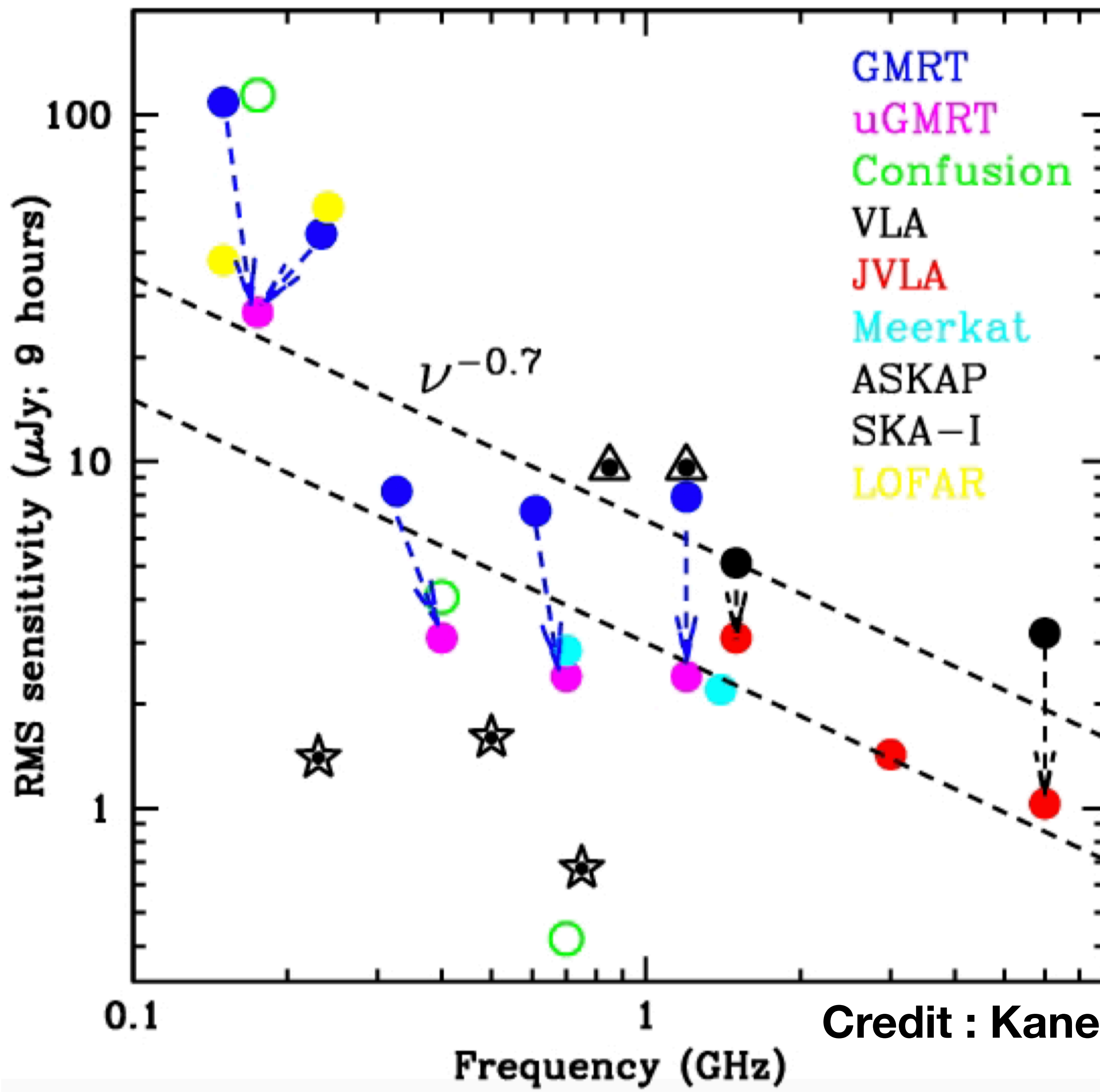
SCIENCE & TECHNICAL REQUIREMENTS

Frequency Coverage:

- 580-640 MHz : wide bandwidth receiver
- 1.4 GHz- 5 GHz : ultrawide bandwidth receiver
- 15 GHz : single receiver

Continuum Sensitivity:

0.2 μJy/bm RMS
for a 1 hour observation
at 15 GHz



Credit : Kanekar

SCIENCE & TECHNICAL REQUIREMENTS

Angular Resolution : For a 3000 km maximum baseline the angular resolution is

$$\theta = \frac{20}{\nu_{\mathrm{GHz}}}\ \mathrm{mas}$$

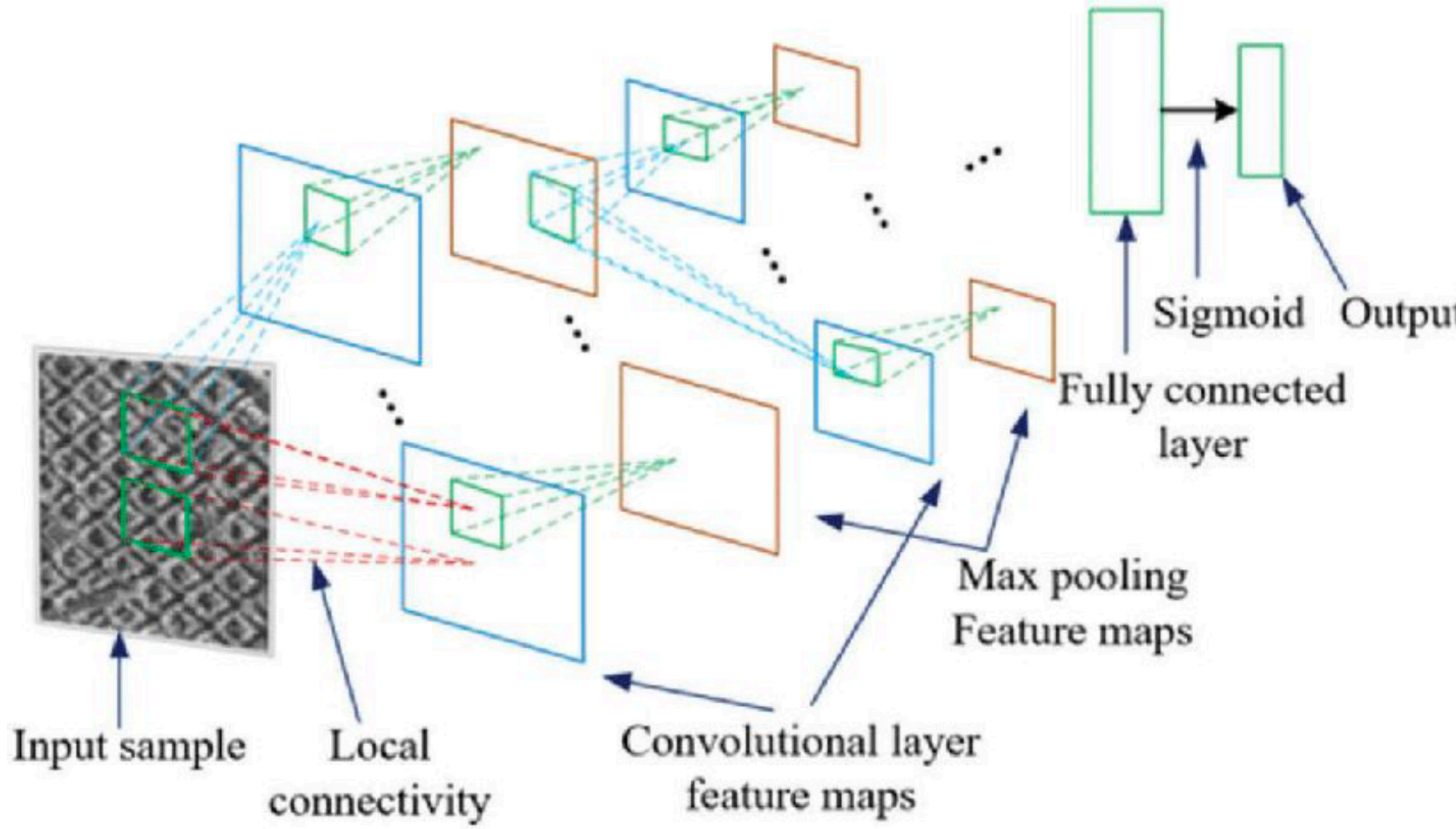
For 15 GHz, we will get an angular resolution of 1.3 mas!!!!

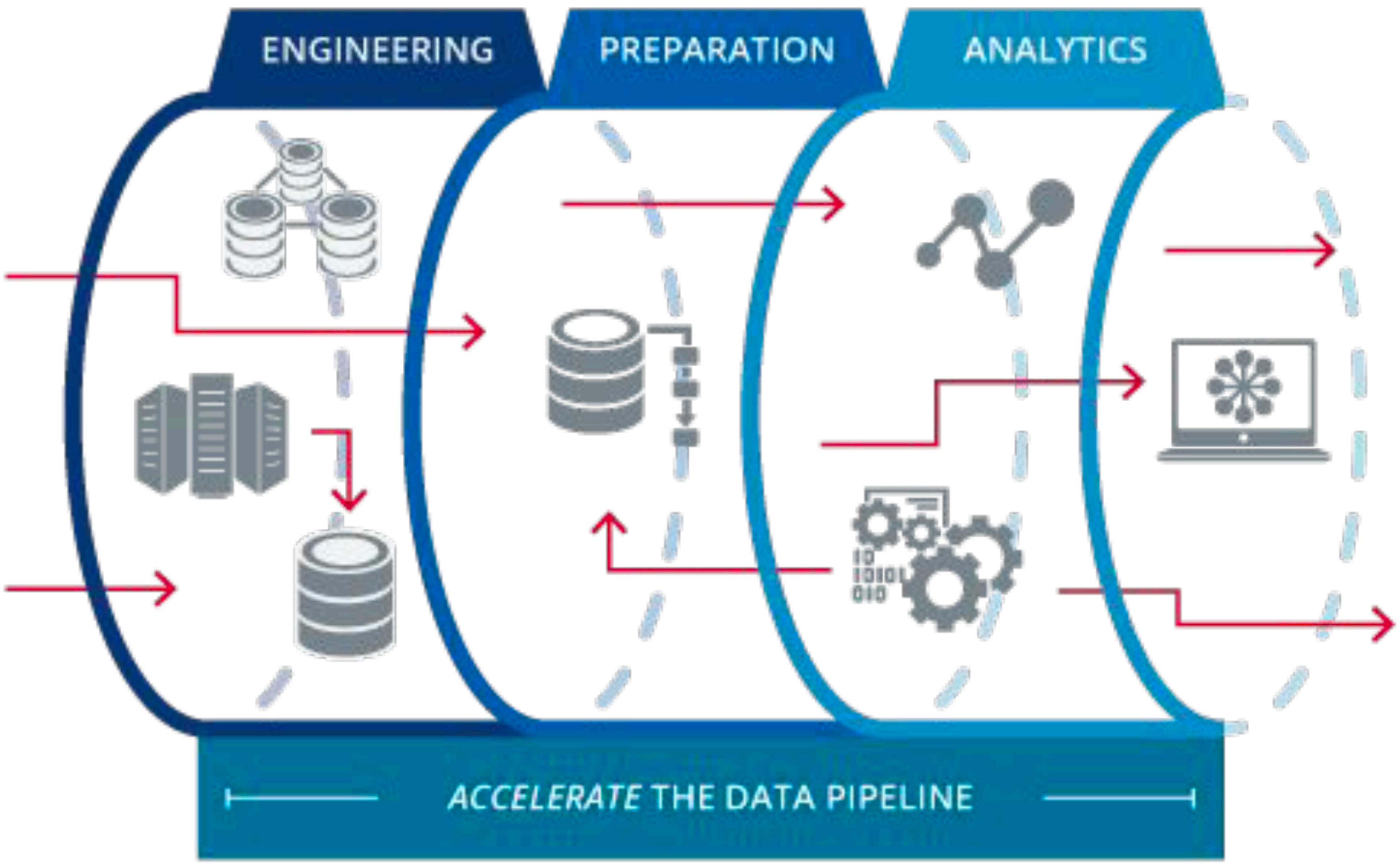
Surface Brightness Sensitivity : The array shall provide high-surface brightness sensitivity over the full range of angular scales recoverable with the instrument.

Science Ready Data Products : The primary data product delivered to users shall be calibrated images and cubes. Uncalibrated/“raw” visibilities shall be archived to permit reprocessing.

BUDGET and MORE

Image Reconstruction Algorithm: Convolutional Neural Nets





1. Data Rate
2. Storage
3. Computing power
4. Total Hardware costs
5. Software Required
6. Total Software Required
7. Data products
8. Analysis and publishing

BUDGET

50 million Euros

Total Budget

1. Land, Taxes and Other Formalities 10%
2. Skilled Labour 35%
3. Instrumentation, Electricity, Software, Hardware and Computing Power 40%
4. Maintaining costs 10%
5. Education,Research and outreach 5%

Cost Feasibility

50 million euros

= 400 Crore

rupees

1. The whole GMRT project was done for 150 crore rupees
2. We have enough funds to do state of the art research and expand our network to the islands - Andaman and Nicobar and Lakshadweep
3. It ensures functionality of the telescope without further funding for at least a decade.
4. The collaboration with existing GMRT allows room to cut down costs on resource management and adds flexibility to invest into latest hardware and software.

Timeline

Phase 1

1. Technical and Mechanical Design
2. Commissioning the new sites
3. Upgrading the GMRT
4. Developing the reconstruction algorithm for the telescope
5. Building the data pipeline
6. Integration of instruments and software systems
7. Calibration of the telescope
8. Testing the telescope
9. Risk management to avoid any natural disasters
10. Building research problems with studfents and scientists for simulations

Phase 2

1. Data Management and storage on clouds and servers
2. Proposal based data collection at data rates
3. Prediction of good weather to collect data
4. Data analysis tools and user interfaces for quick visualisations
5. Maintenance costs of disturbances in the signal to ensure good efficiency

THANK YOU

Extra Slide

SKA will use around 3000 **dishes**, each 15 m in **diameter**
VLA has 27 independent antennas, each of which has a **dish diameter** of 25 meters
GMRT consists of 30 fully steerable parabolic dishes, of 45 m **diameter** each.