Future Radio Interferometers

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Radio Interferometer Status in 2012

- ALMA
  - Covers much of 80 GHz-1 THz band, with collecting area of about 50% of VLA, for a cost exceeding $1 billion
  - Higher frequencies→infrared
  - More collecting area→too expensive
- EVLA
  - Complete coverage of 1-50 GHz band
  - Lower frequencies are feasible
  - More collecting area might be feasible
  - Longer baselines are feasible
- VLBA
  - Longer baselines from space
  - Higher bandwidth
  - Replace with more collecting area?

Key Science Areas of next 10-20 Years

- Probe epoch of reionization and formation of first galaxies
- Study galaxy evolution over the history of the universe
- Characterize Dark Energy
- Strong gravity
- “Cradle of life”—galaxy, star, planet formation
- Time-domain astronomy

➢ Survey telescopes will become more important, not just telescopes doing individual pointings

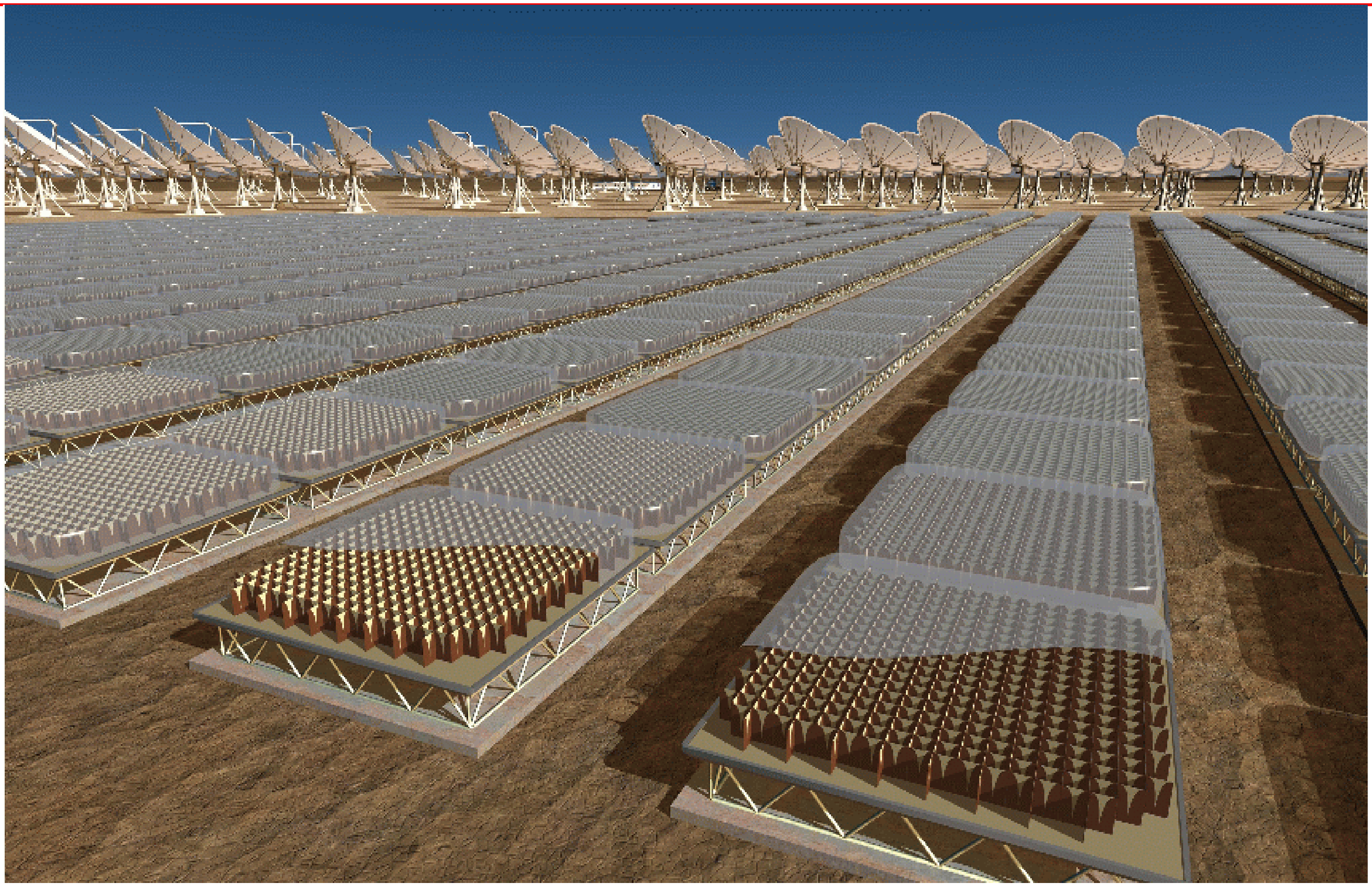
Square Kilometer Array Program

- SKA Program originally aimed at building a meter/cm wavelength telescope with 1 km^2 of collecting area
  - Initially an HI telescope, focused on frequency range near 1 GHz
  - Expanded to multiple telescopes covering frequency range from 100 MHz to 25 GHz, to address five key science areas

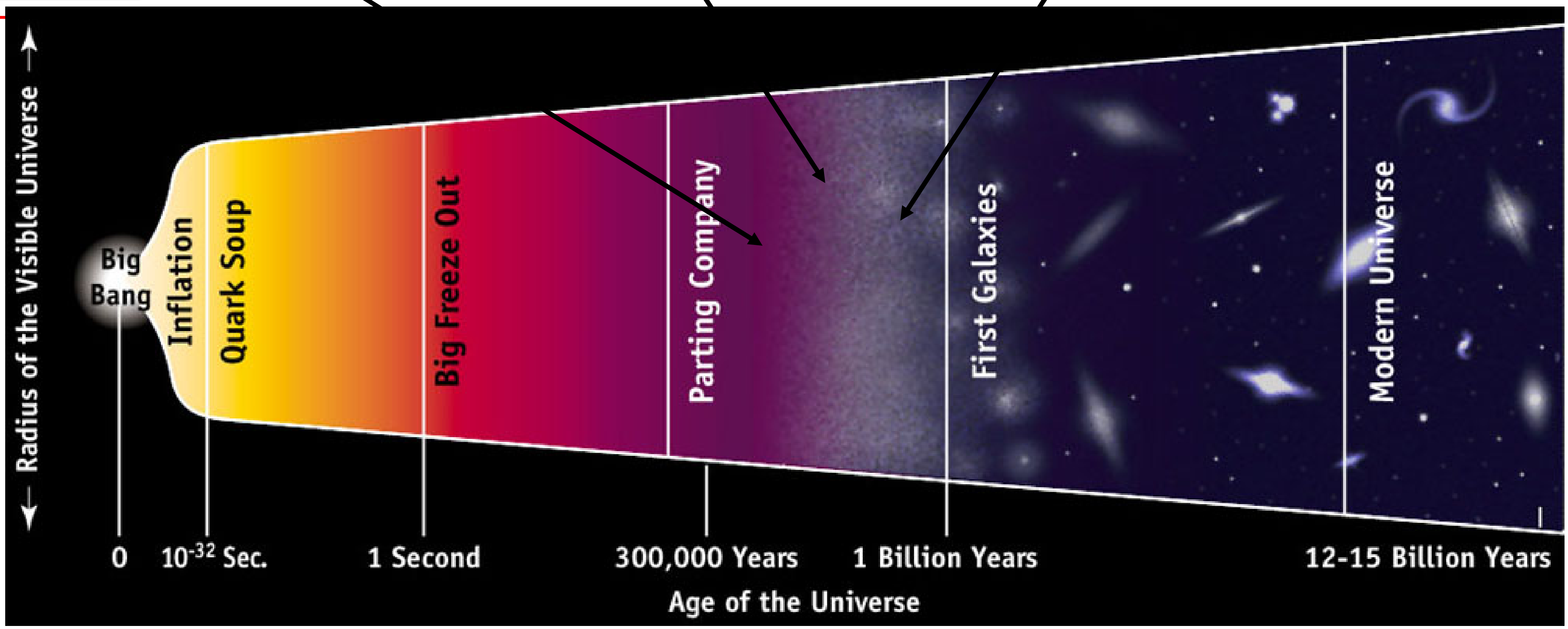
SKA Components

- SKA-low
  - ~80-300 MHz, primarily Epoch of Reionization
- SKA-mid
  - ~300 MHz-few GHz, primarily galaxy evolution (HI telescope) and Dark Energy; also gravity
  - Note: 1 km^2 is nearly 6000 15m dishes!!
- SKA-high
  - Few GHz to 25-50 GHz, primarily cradle of life (star and planet formation, galaxy formation)
- "Top-down" or "bottom-up" approach??

Hypothethical SKA



"Dark Ages," Reheating, and "Epoch of Reionization"



(Next several slides from
Jacqueline Hewitt, MIT)

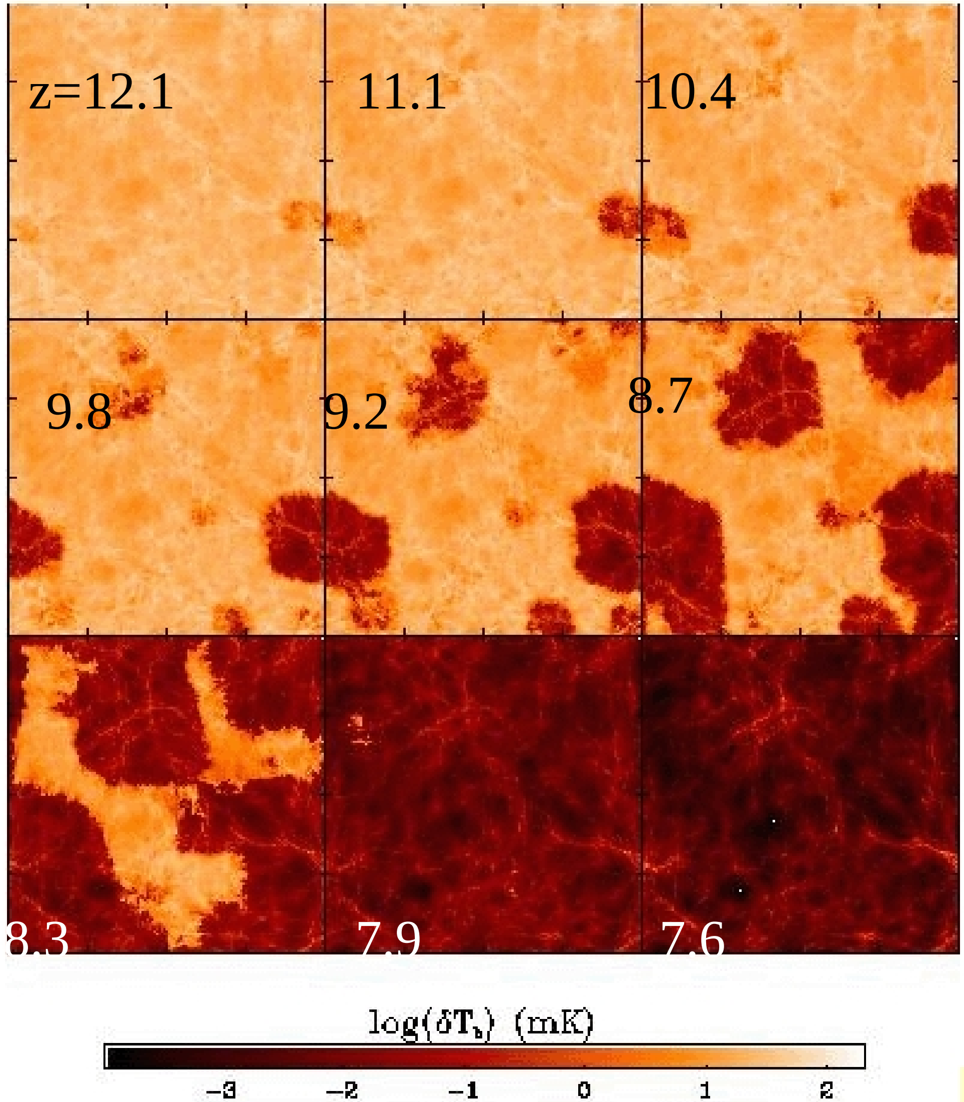
Credit: www.kheper.net/cosmos/universe/universe.html

Reionization of Universe

Bandwidth = 100 kHz
Box size = 10/h comoving Mpc

Fluctuations are about 10 mK

Furlanetto, Sokasian, Hernquist 2004



Challenges to EOR Detection

- Sky noise—systematics, collecting area
- Foregrounds—systematics, stability
- RFI—data excision
- Ionospheric fluctuations—time-dependent calibration
- Field of view larger than isoplanatic patch—direction-dependent calibration
- Flat sky approximation fails—efficient 3-D imaging algorithms

Require high speed computation to address - affordable only now

First-Generation EOR Experiments: Arrays
Resolution is ~few arcminutes or better

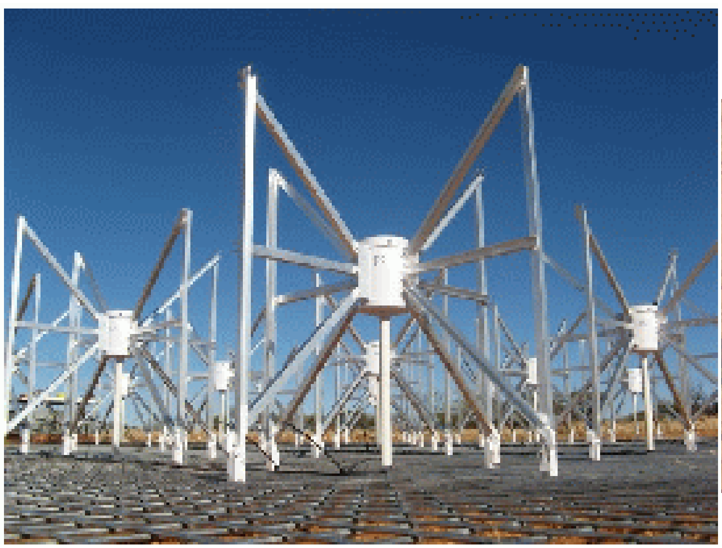
Expt	Freq MHz	Red-shift	Area (sq m)	FOV (deg)	N (sta-tions)	Status
GMRT Core	100-200	6-13	24,000		15	RFI Mitigation
21CMA	50-200	6-27	25,000		80	Complete
LOFAR Core	30-90 110-230	17-46 6-11	15,000	2 X 4 beams Dual-pol	40	Constr.
MWA	80-240	5-17	8000	35 Dual-pol	500	Constr.
PAPER	130-200	6-10	~500	90 Dual-pol	~100 (to grow?)	Proto-typing

Note: reflects LOFAR descope in early 2008

LOFAR High-Band Antenna (110-230 MHz)

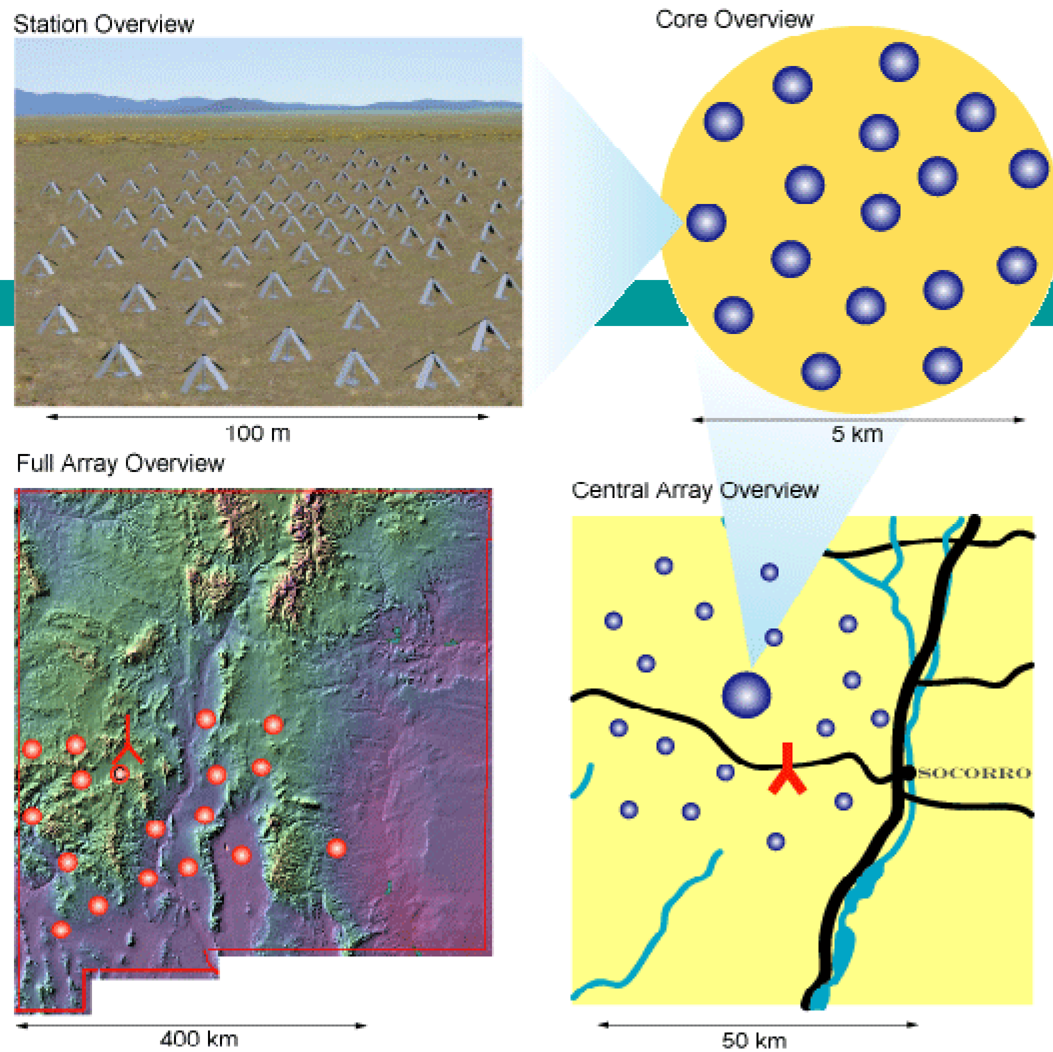
Murchison Widefield Array

- Will be 500 tiles of 16 antennas in Western Australia
- 32 tiles currently deployed



Long Wavelength Array

- LWA is being developed by Southwest Consortium (UNM, NRL, LANL, UTex)
- Radio galaxies, SNe, transients, ionosphere



Mid-frequency (~1 GHz) Telescopes

- For survey telescopes, the Figure of Merit for performance becomes survey speed, not just point-source sensitivity
- Raw point-source sensitivity: How low is the detection threshold in a fixed period of time?

$$\mathbf{FOM \sim \Delta\nu\ A_{eff}/T_{sys}}$$

- Survey speed: How much volume can be surveyed to a given flux level in a fixed period of time?

$$\mathbf{FOM \sim \Delta\nu\ (N_{FoV}\Omega_{FoV})\ (A_{eff}/T_{sys})^2}$$

- Optimizing for number of sources, or transient sources, gives different Figures of Merit

Practical Figure of Merit

Practical FOM ~ (Technical FOM)/Cost

- Cost equation depends on antenna price, cost of reducing system temperature, cost of adding field of view, cost of data processing, power costs, etc.
  - E.g., in the limit of tens of thousands of small antennas (maximizing field of view), dominant cost may be the cost of the power required to do all the data processing!

SKA Demonstrator Telescopes

- Data transport and processing: **EVLA, e-MERLIN, and low-frequency arrays**
- Inexpensive collecting area: **Allen Telescope Array (ATA), MeerKAT**
- Wide fields of view: **Australian SKA Pathfinder (ASKAP), low-frequency arrays, focal plane arrays on single dishes**
- Science pathfinders:
  - SKA-high: **EVLA, e-MERLIN, ATA**
  - SKA-mid: **ATA, MeerKAT, ASKAP, Arecibo/ALFA**
  - SKA-low: **MWA, LWA, LOFAR, PAPER**

Mid-frequency Telescopes-1

- Allen Telescope Array, Northern California
  - 42 6m antennas, hope to grow to 350
  - Single-piece hydroformed dishes
  - Single-frequency feed, 0.5-11 GHz
  - SETI searches
  - Time-domain astronomy
  - 2-4 beams in sky

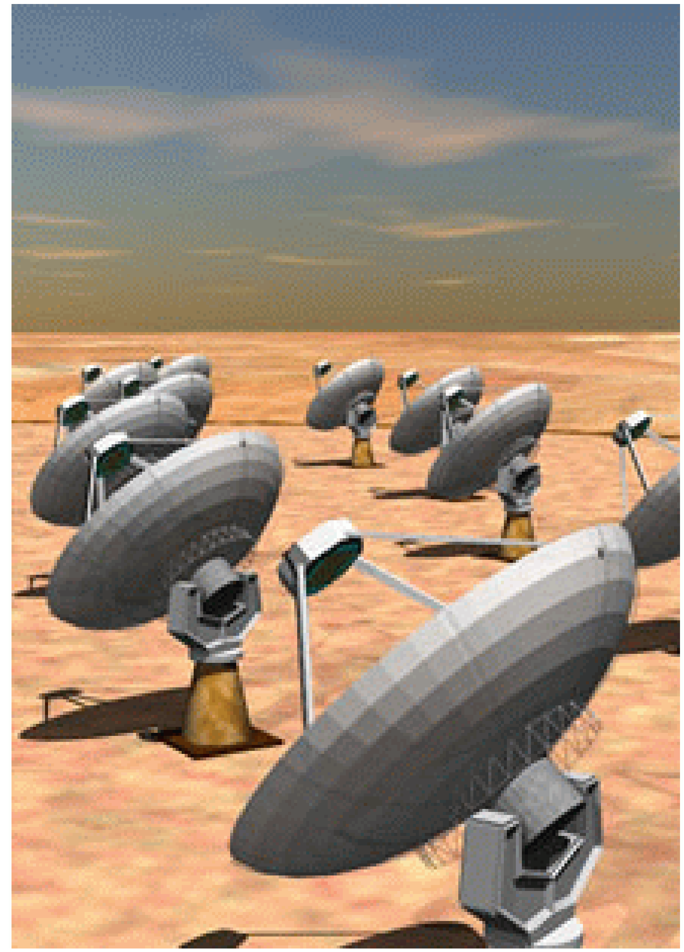
ATA Photos

Mid-frequency Telescopes-2

- MeerKAT, South Africa
  - 20-80 12m antennas
  - Single-pixel feed, 700-1700 MHz
  - Composite dishes
  - Completion in 2012?
  - Prototype 15m composite dish shown here

Mid-frequency Telescopes-3

- ASKAP, Western Australia
  - 30-45 12m dishes
  - Focal plane arrays
  - 3-axis dish—primary reflector rotates with the sky in order to keep sidelobes fixed
  - 700-1800 MHz
  - Completion in 2012?



SKA Timeline/Specs Summary

- Phase I—Build ~10% of SKA collecting area in 4 yr (finish in 2016) at cost of ~300M€
  - Wildly optimistic in technology/funding forecast
- Phase II—Build "complete" SKA at frequencies up to 10 GHz (finish in 2020) with total sunk cost (including Phase I) of 1500M€
  - Inadequate contingency, already descoped
- Phase III—SKA-high deferred indefinitely

Predictions

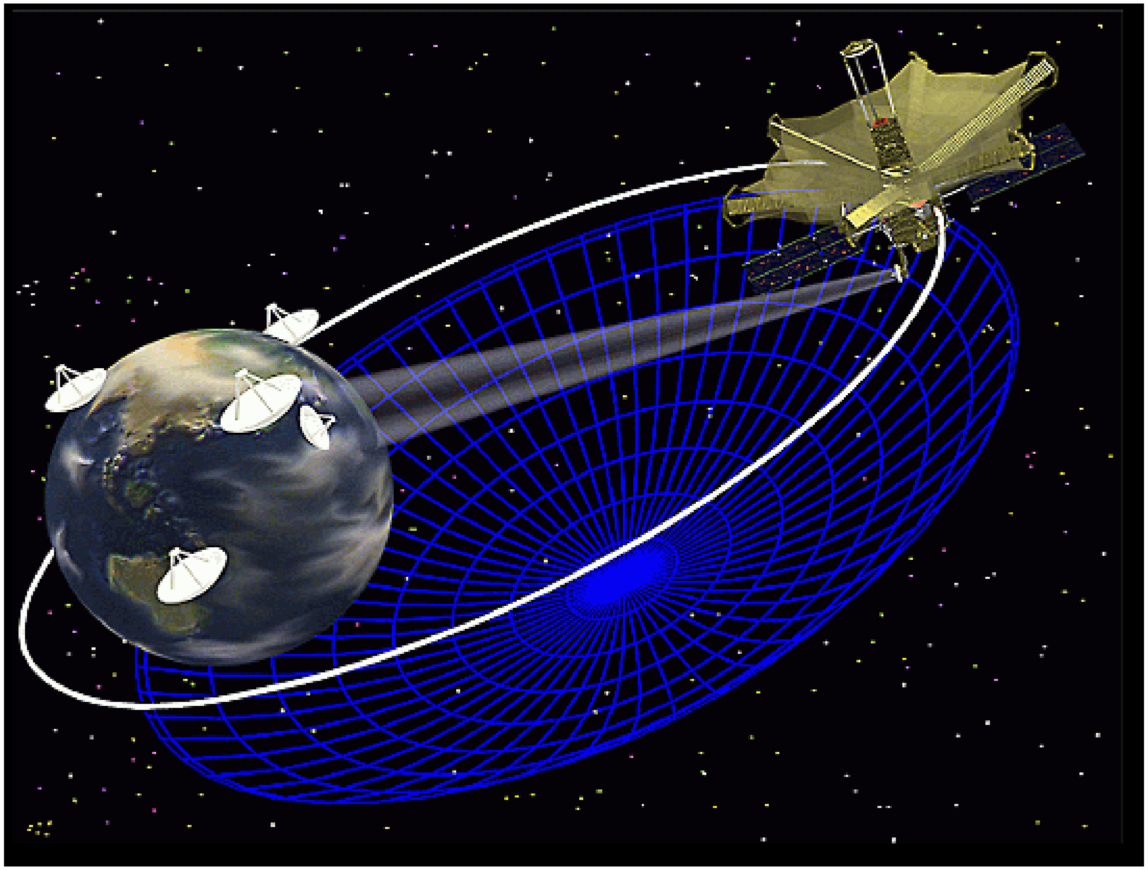
- Low-frequency arrays may detect Epoch of Reionization within a few years
  - If successful, possible development of much more collecting area by 2020
- Mid- and high-frequency "SKA" will become an umbrella term embracing efforts to add significant collecting area for cm-wave radio interferometry
  - This will be an activity spanning several decades

Space VLBI

- Angular resolution is not necessarily limited by the diameter of the Earth
- First Space VLBI demonstrations in the 1980s
- First dedicated Space VLBI mission, VSOP, was launched in 1997, operating at 1.6 and 5 GHz

Space VLBI Concept

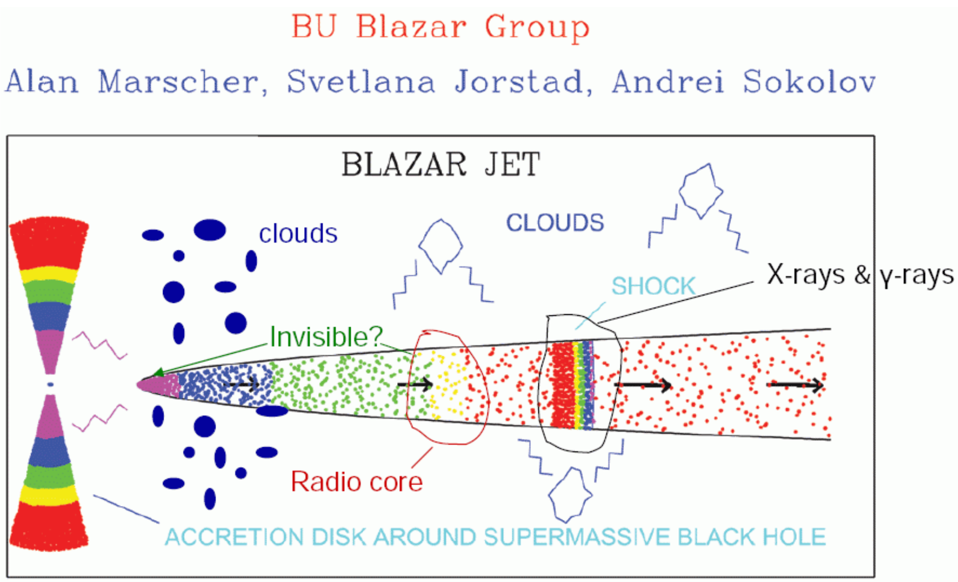
- Use spacecraft orbit to synthesize an aperture larger than the Earth
- Imaging is difficult with one spacecraft



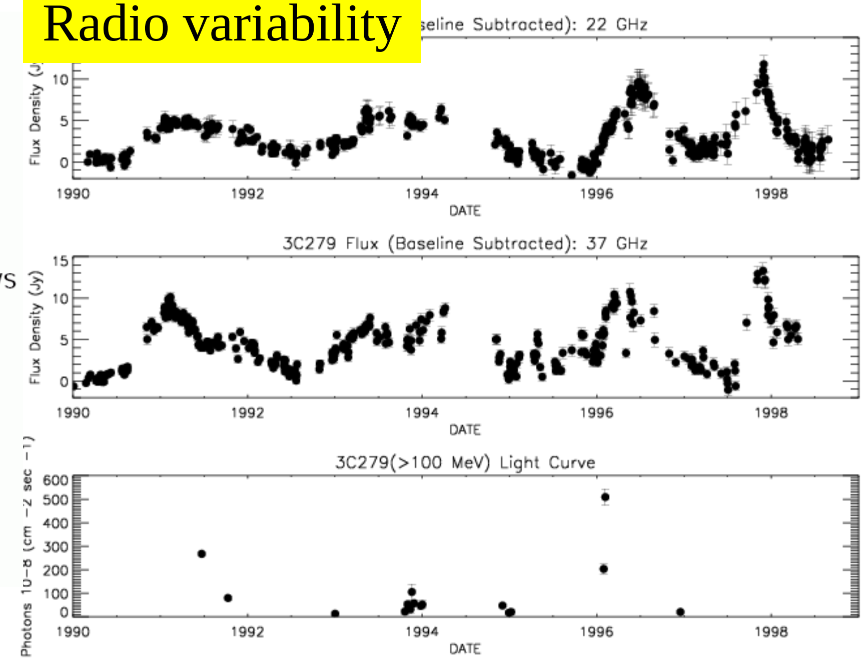
VSOP-2

- Japanese-led mission approved for launch in 2012
- Apogee height of 25,000 km gives 30,000 km baselines
- 9-meter space telescope operating at 8, 22, and 43 GHz
- Key science: gamma-ray blazars, water megamasers

Gamma-ray blazars



Radio variability



Gamma-ray variability

- Blazars are active galaxies with relativistic jets pointing at us
- Extreme variability
- Source of gamma-ray emission?

VSOP-2 + GLAST

- GLAST launched yesterday
- Combine with VSOP-2 imaging in 2013 to model gamma-ray production

http://www.youtube.com/watch?v=MmIVn2TrJcU