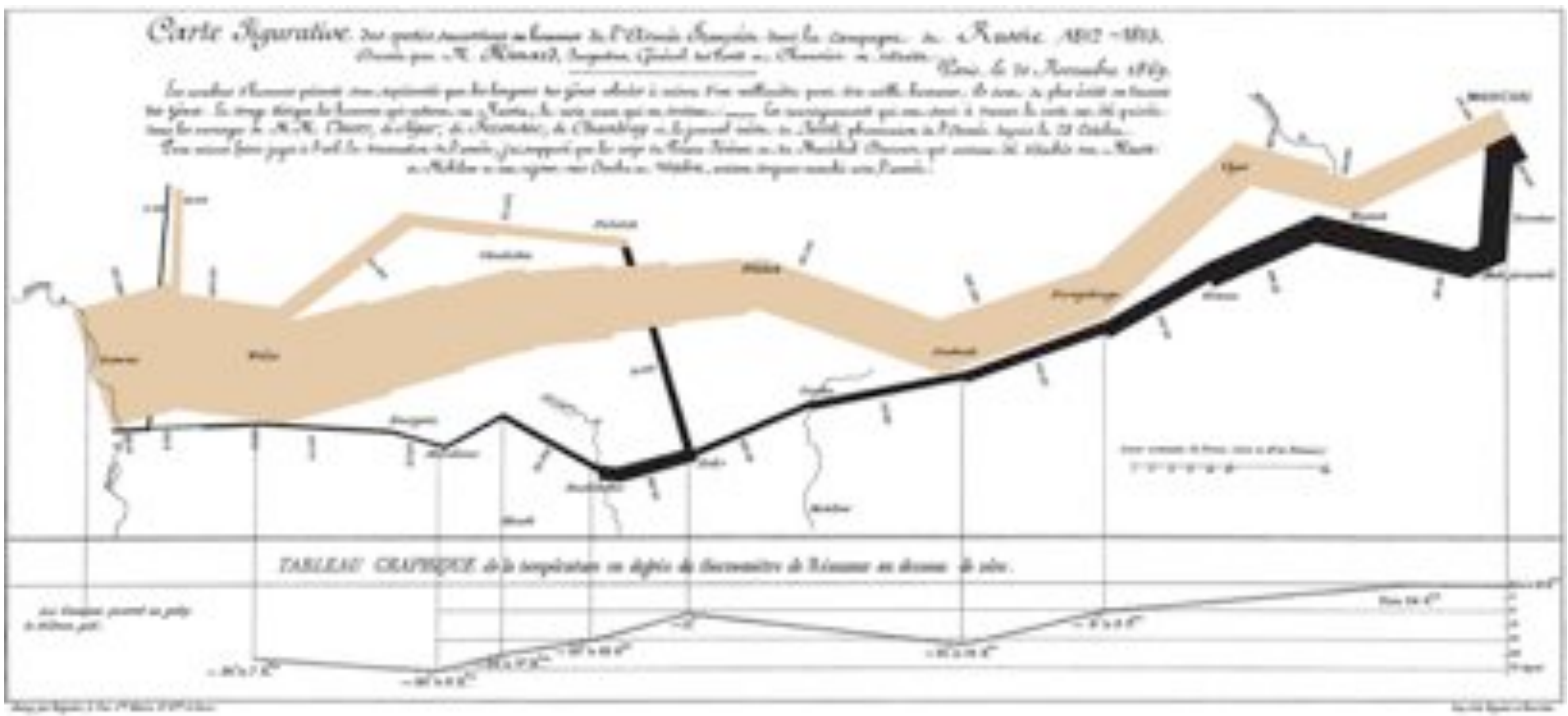
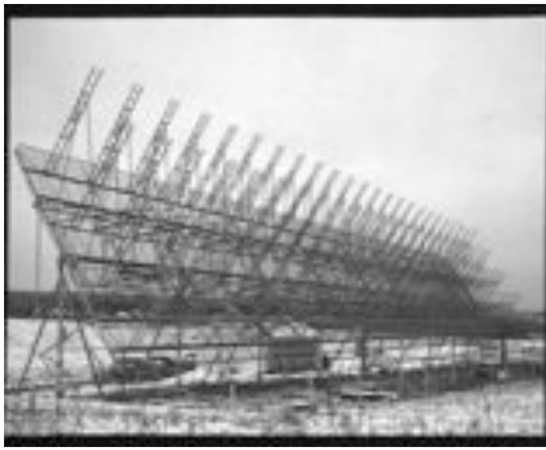
A Low-Frequency Radio Astronomy Battle Plan

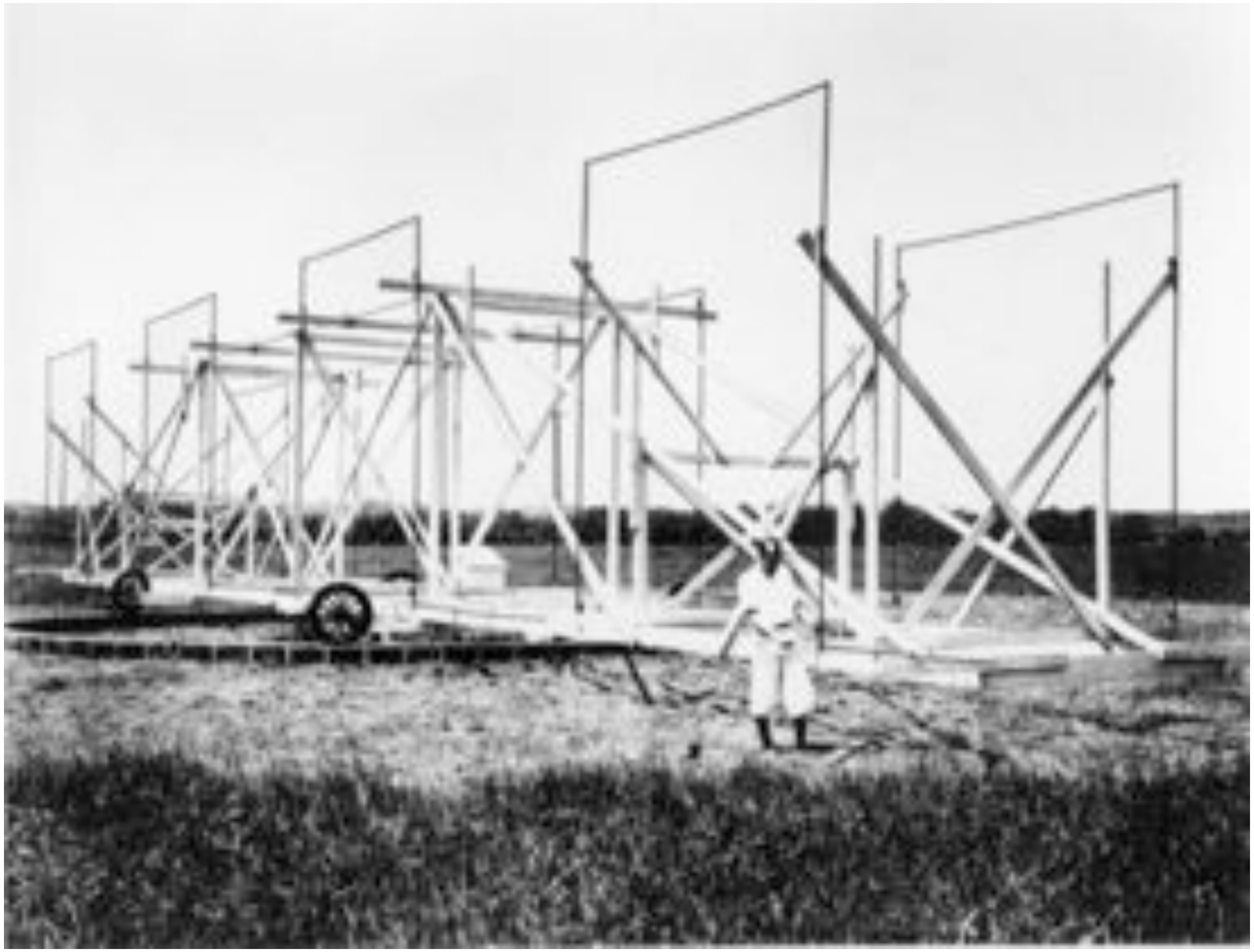
Aaron Parsons



A Brief History of Radio Astronomy < 1 GHz



Bruce Array (Karl Jansky)
20.5 MHz, 1932

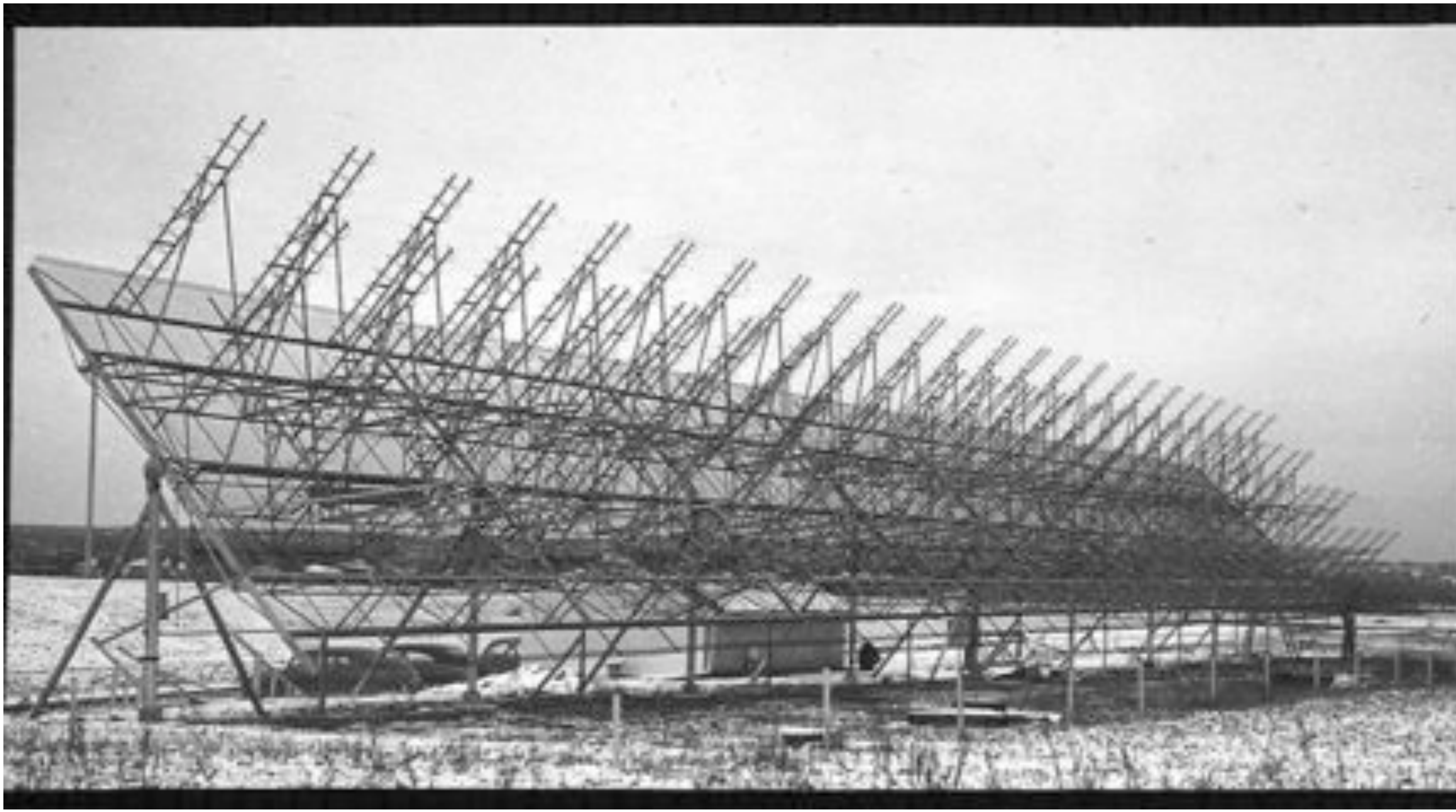


Grote Reber's Backyard
160 MHz, 1937

Mills Cross
85.5 MHz, 1954

MILLS CROSS (CSIRO)

Ohio State's Big Ear
250 MHz, 1954



Shain Cross
19.7 MHz, 1958

Clark Lake
26.3 MHz, 1958

Cambridge Interferometer 45-214 MHz, 1958

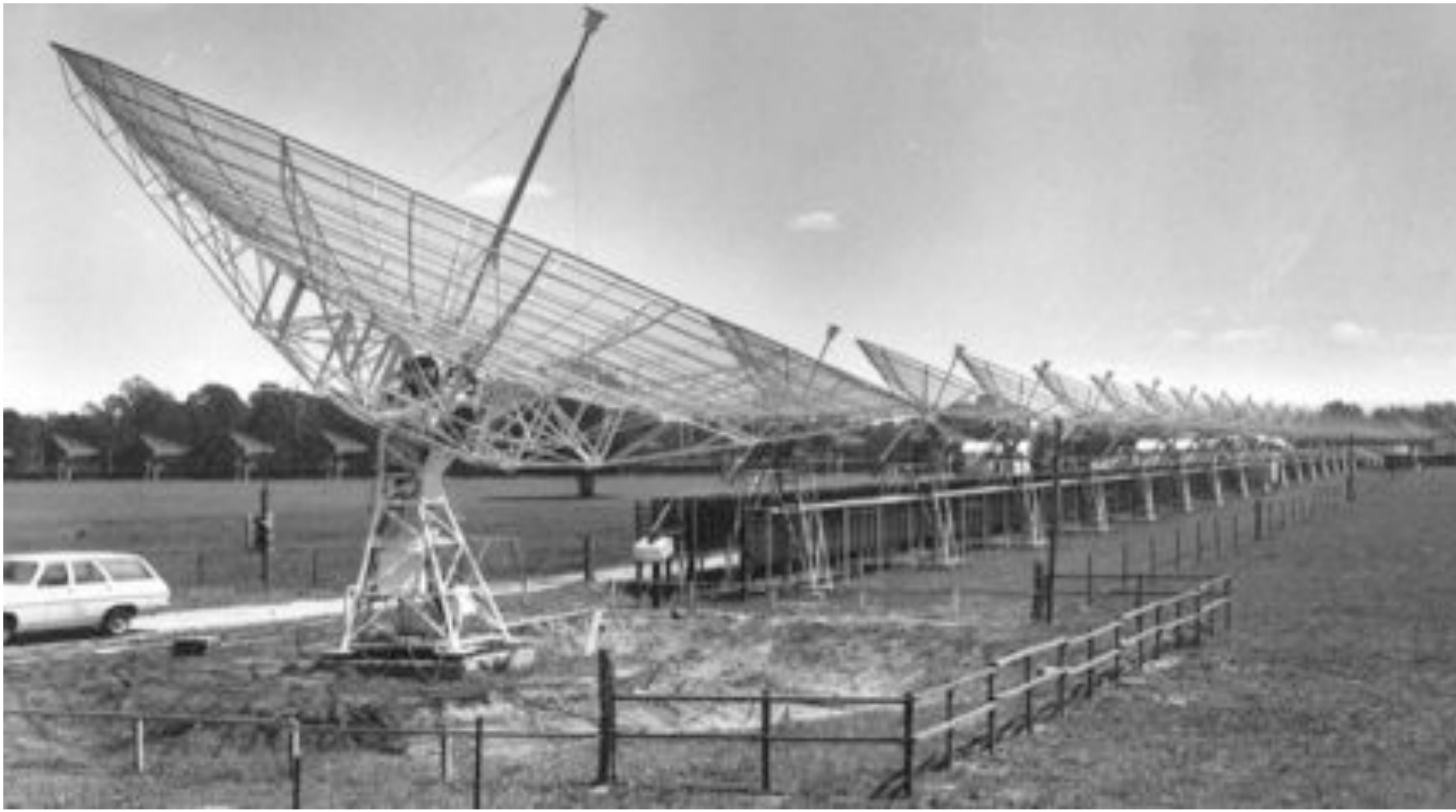
4C Array
178 MHz, 1958

DRAO
22 MHz, 1960

Molonglo Observatory Synthesis Telescope (MOST)

408,843 MHz, 1960

Fleurs Synthesis Telescope
29.9 MHz, 1963



Medicina (Northern Cross)
408 MHz, 1964

Cambridge One-Mile Telescope 408 MHz, 1964

Culgoora Heliograph
80,160 MHz, 1967

Interplanetary Scintillation Array
81 MHz, 1967

Ooty Radio Telescope
326.5 MHz, 1970

Westerbork (WSRT)
120-> MHz, 1970

Effelsberg
408-> MHz, 1972

Clarke Lake Teepee-Tee
25-75 MHz, 1974

Gauribidanur Radio Obs.
34.5 MHz, 1976

Ratan-600
610 MHz, 1977

Nancay’s RDN
10-100 MHz, 1978

Cambridge Low-Frequency Synthesis Telescope (CLFST)

151 MHz, 1980

… (15 years) …

GMRT
38-610 MHz, 1995

Mauritius Radio Telescope
151.5 MHz, 1998

Green Bank Telescope (PF1 Rxs) 290-> MHz, 2000

VLSS (on the VLA)
74 MHz, 2004

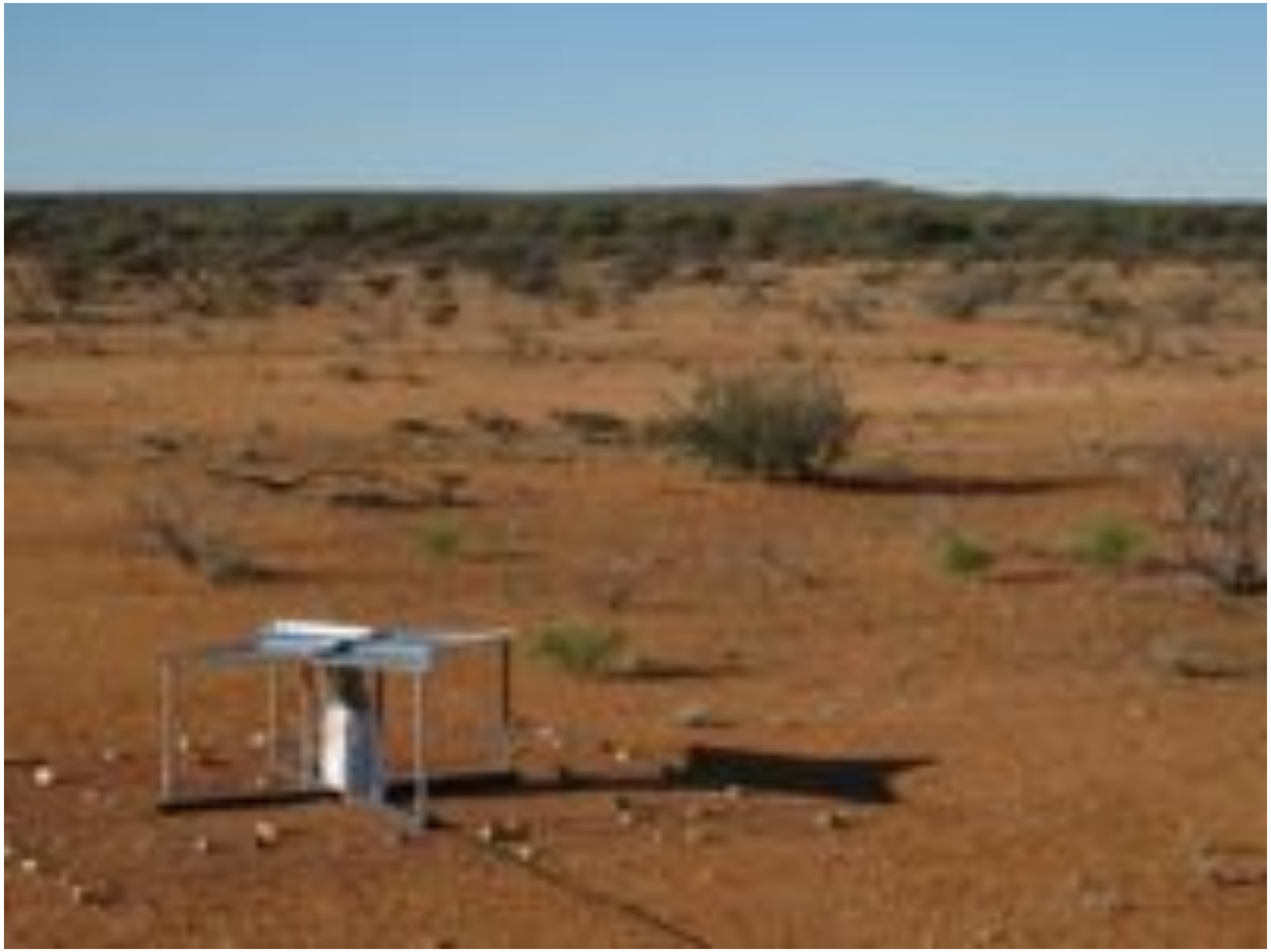
Deuterium Array
327 MHz, 2004

21cmA/PaST
50-200 MHz, 2004

CoRe
114-228 MHz, 2005

ATA
500-> MHz, 2007

EDGES
100-200 MHz, 2009



LWA, + LEDA
10-88 MHz, 2011

LOFAR
10-240 MHz, 2011

MWA-32
100-200 MHz, 2011

PAPER-64, South Africa
100-200 MHz, 2011

Omniscope-16
100-200 MHz, 2011

Zero-Spacing Interferometer
~50-100 MHz, 2011

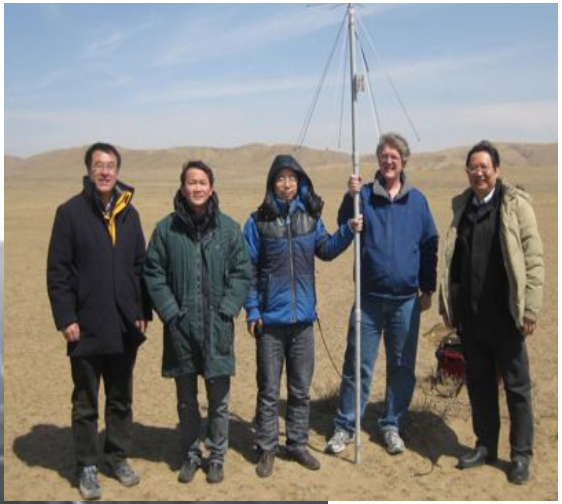
BAOBAB-4
600-900 MHz, 2012

The Near Future

- PAPER-128/256
- MWA-128
- BAOBAB-32
- LWA @ OVRO?
- and …

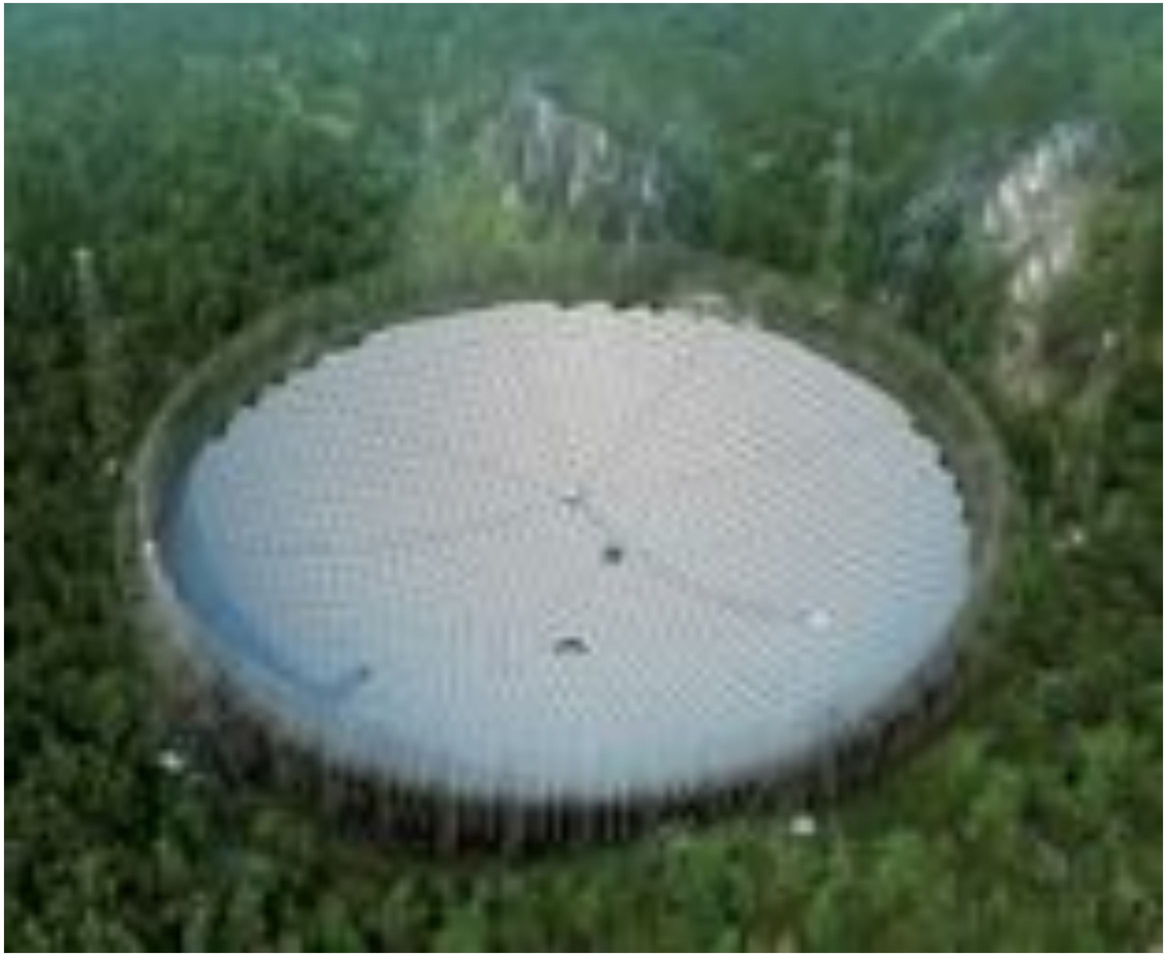
CRT/Tainlai
~750 MHz, ?

Tainlai/CRT
~750 MHz, ?

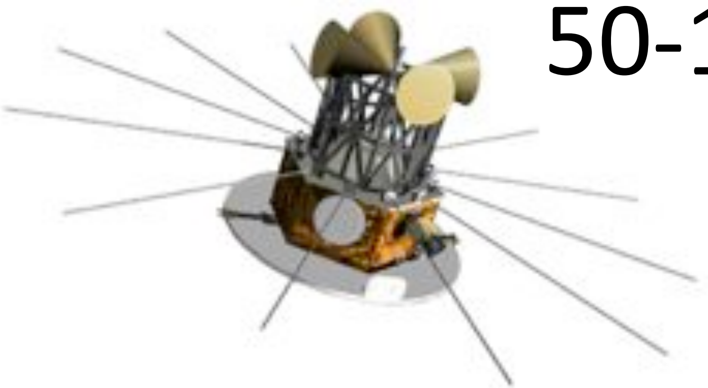


Five-hundred meter Aperture Spherical Telescope (FAST)

300-> MHz, ?



Dark Ages Radio Explorer
50-100 MHz, ?



The Farther Future

- SKA-low
- Hydrogen Epoch of Reionization Array (HERA)

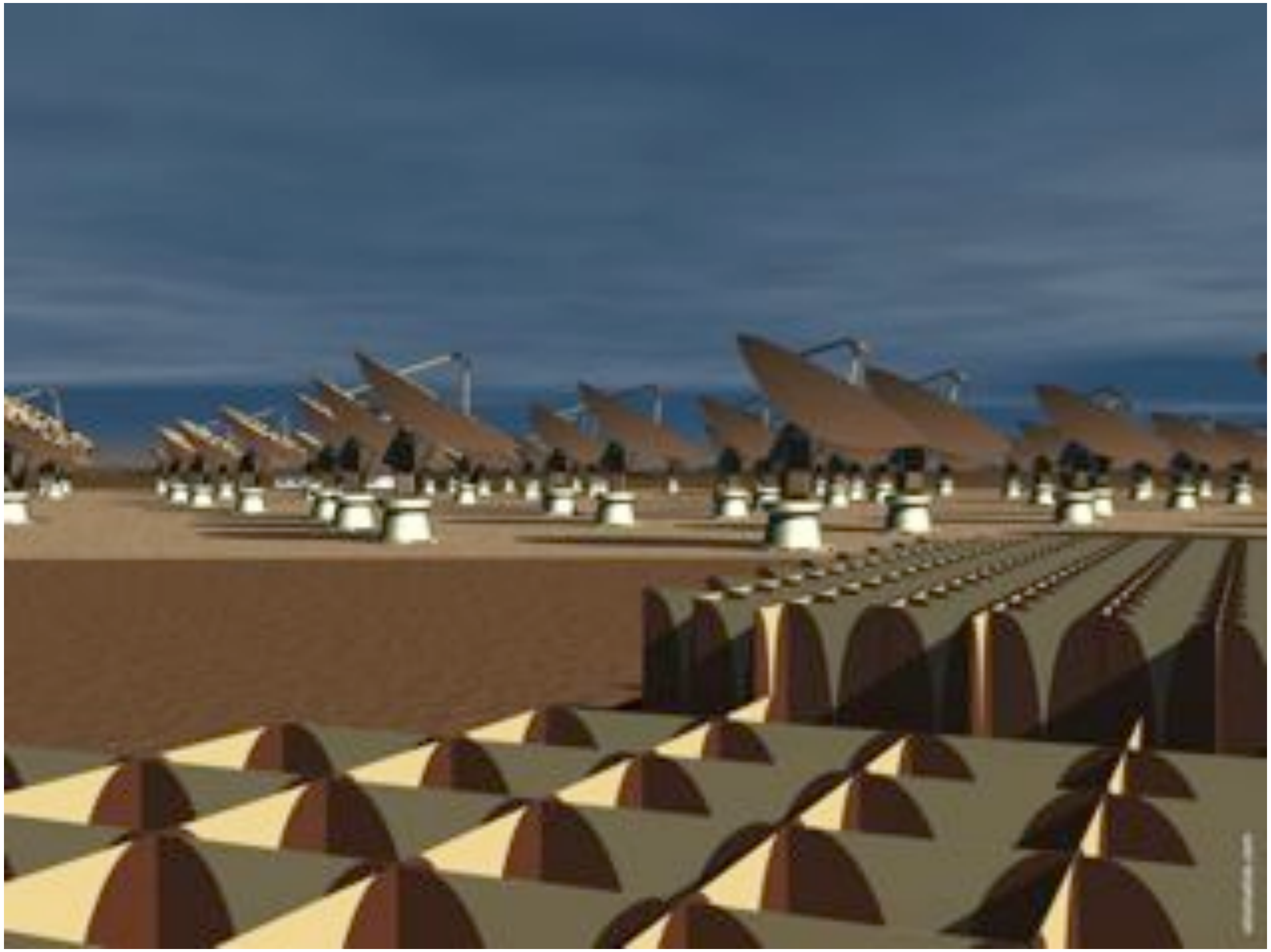
TABLE II: **HERA II Characteristics Table**[†]

Antenna Array	*Value*	*Units*
Main and Effective Aperture Size	20 ($\propto \lambda^2$)	m^2
Size of Array Elements	25	m^2
Number of Array Elements	5000	—
Total Collecting Area	10^5	m^2
Angular Resolution	3 ($\propto \lambda$)	arc-minute
Field of View	30 ($\propto \lambda$)	degrees
Wavelength range	1.5 - 3.8 (200-80)	m (MHz)
Driving Wavelength for Accuracy	1.5 (200)	m (MHz)
Required Surface Accuracy (ground screen)	0.1	m
Number of Reflecting Surfaces	1	—
Total Moving Mass (Earth)	6×10^{24}	kg

[†] Double entries for PAPER, MWA telescopes

SKA-low?

SKA-low?



SKA-low?

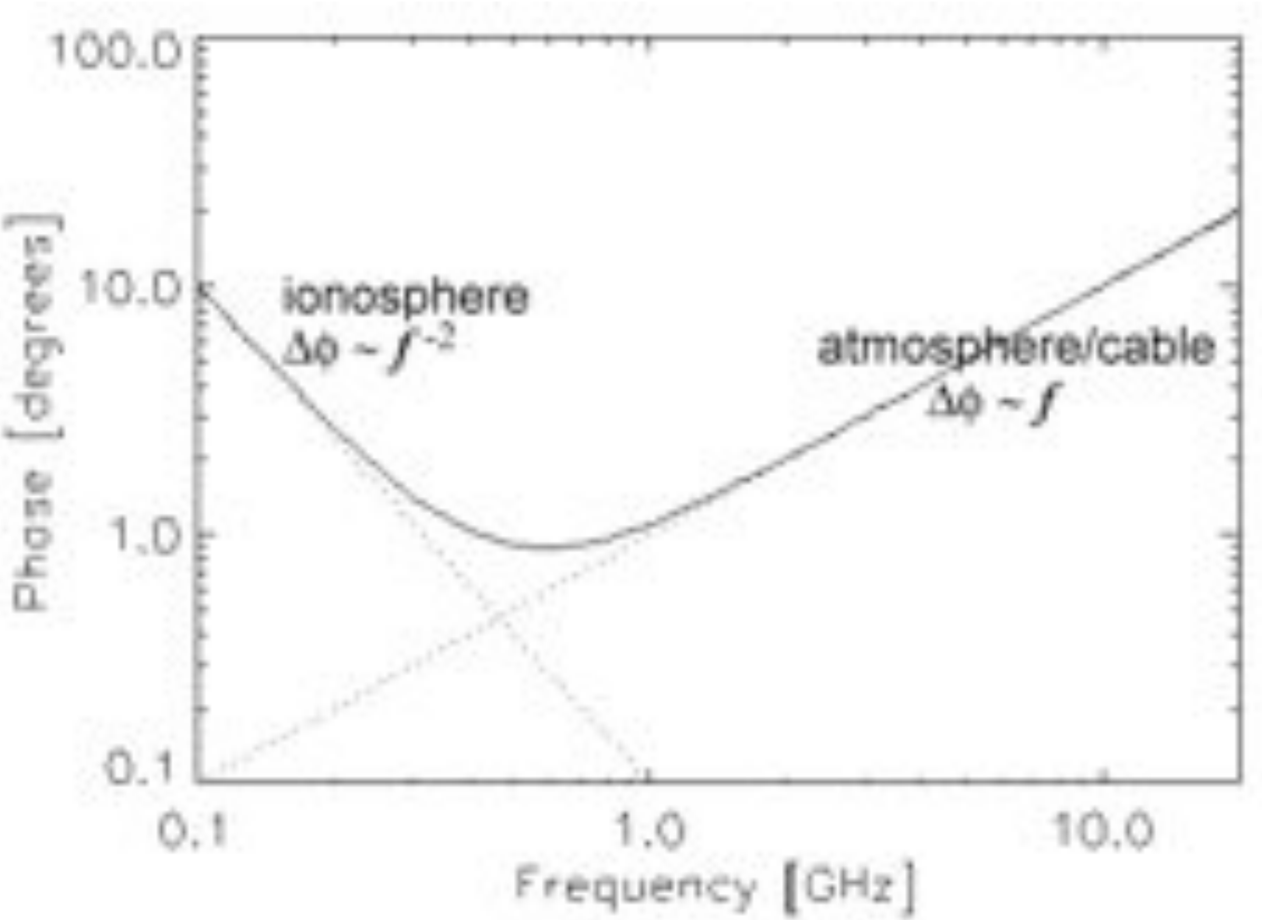
SKA-low?

SKA-low?

1932-2012: What Stands Out?

- 1937-54: Gap
  - Reason: war (what is it good for?)
- 1954-64: 1 telescope per year
  - Reason: Low level of investment to play a new science game
- 1964-80: Gradual decline in activity
  - Reason: higher ante, moving on to greener (higher) pastures
- 1980-95: Nothing
  - Reason: staying in greener (higher) pastures
- 1995-2000: A few new telescopes
  - Reason: advancing technology making low frequency cheap
- 2004: Boom
  - Reason: HI jumps out of L-Band (EoR), see 1954
- 2005-2010: Slow going
  - Reason: reinventing everything (low frequency is hard)
- 2011: Boom v2
  - Reason: figuring it out

Where are the Fields Greenest?



Where are the Fields Greenest?

Weinreb (1980)

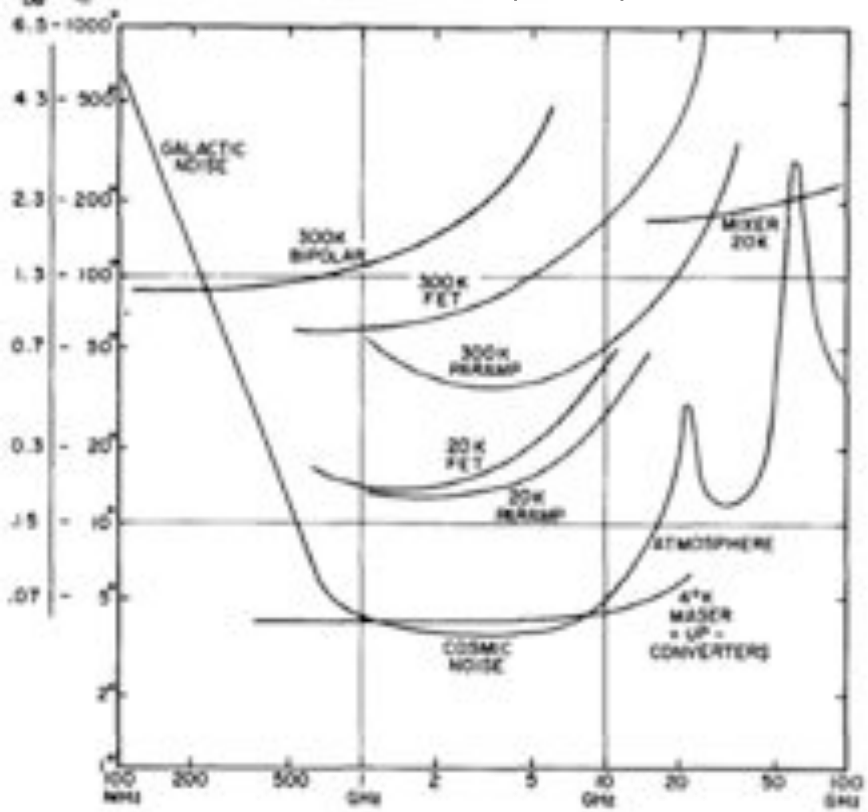
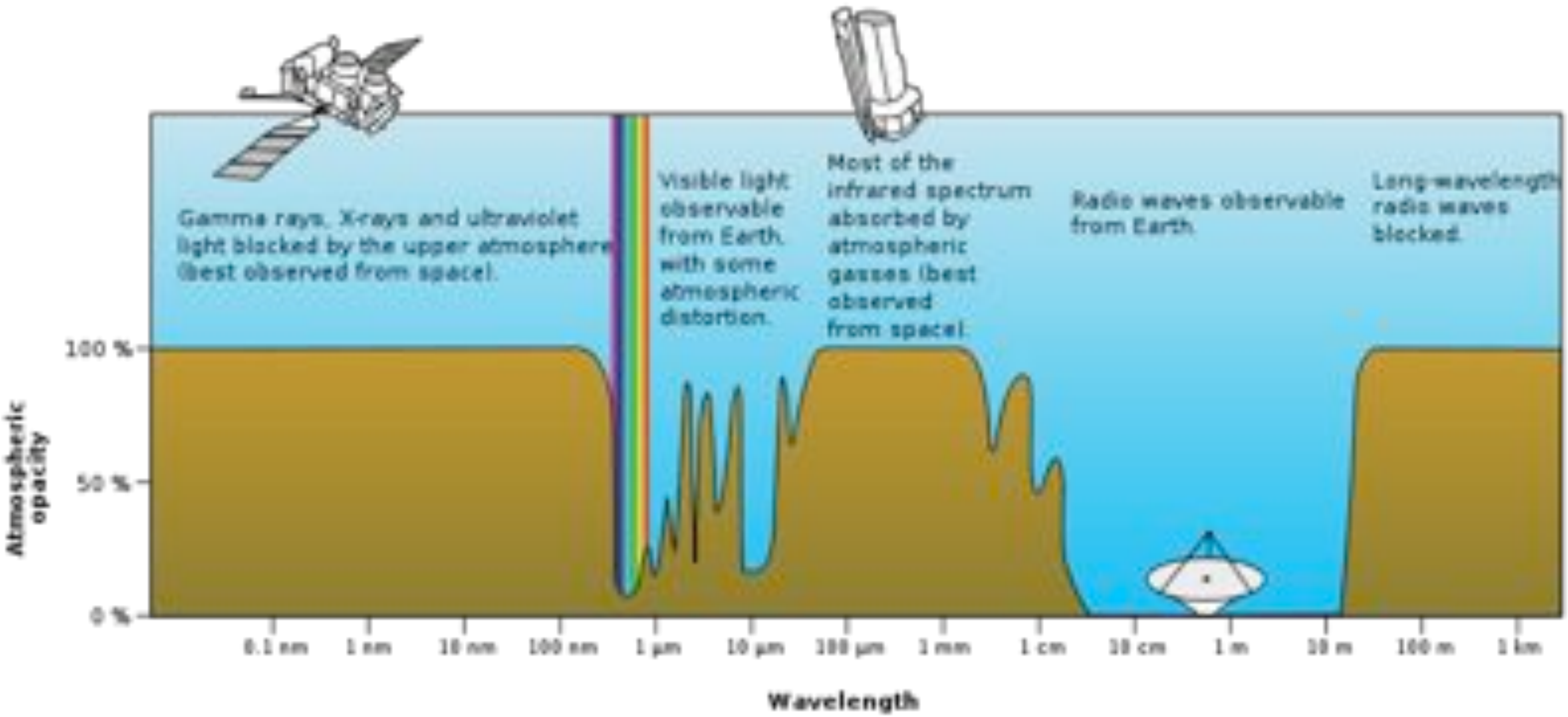


Fig. 1. Noise figure 10 log F, and noise temperature $T_n = 290°(F-1)$, versus frequency for various 1980 state-of-the-art low-noise devices.

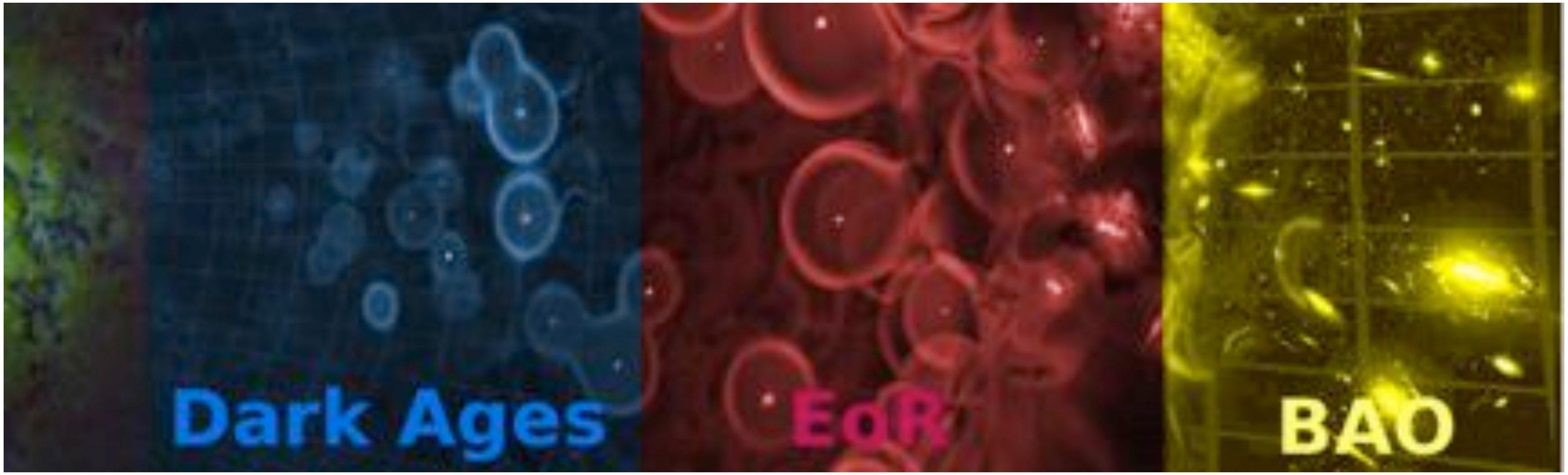
Opacity vs. Wavelength



2012-?: Where do we go from here?

- Lessons from history:
  - Technology-driven, build-it-because-you-can progress (e.g. 1954) doesn't keep a field healthy
  - Science-driven progress (e.g. CMB) can be stable over decades
  - Existing telescopes can be upgraded to broaden their science appeal.
  - Advancing technology can defunctify long lead-time projects (e.g. the computer revolution)

Radio Astronomy @ >= 21cm

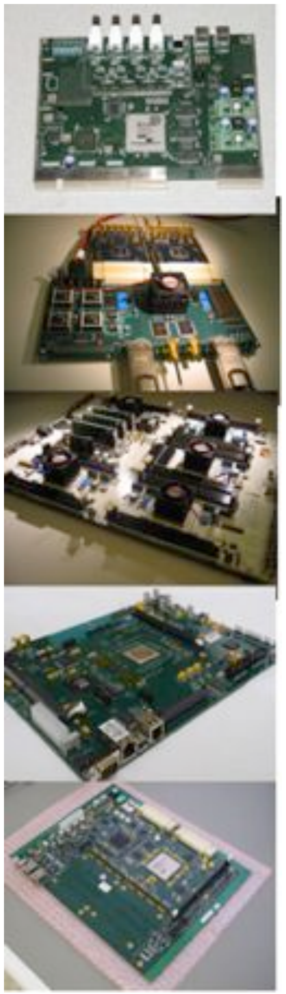


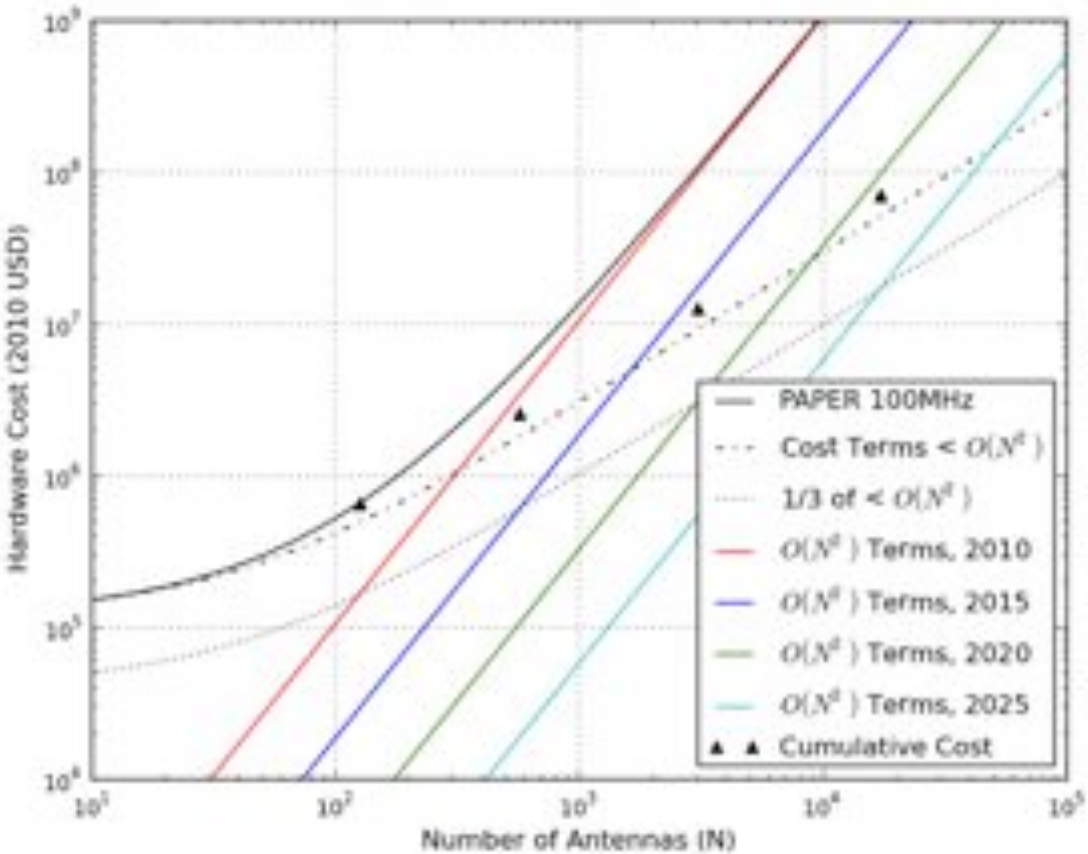
z = 100 to 20
15 to 70 MHz

z = 20 to 5
70 to 240 MHz

z = 5 to 0
240 to 1400 MHz

Costing Telescope Buildout



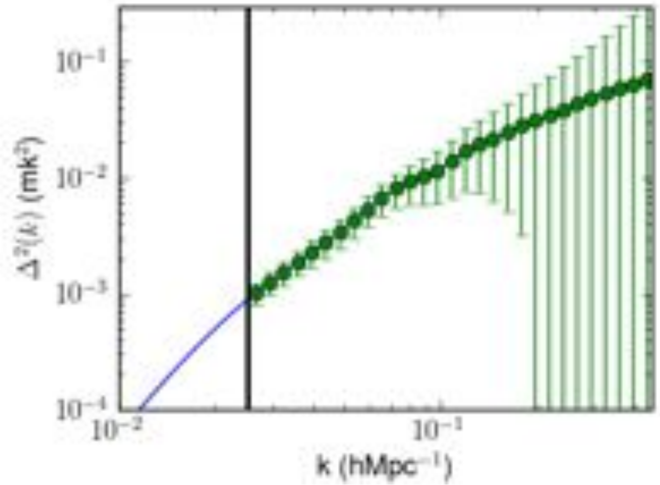


2012-?: Where do we go from here?

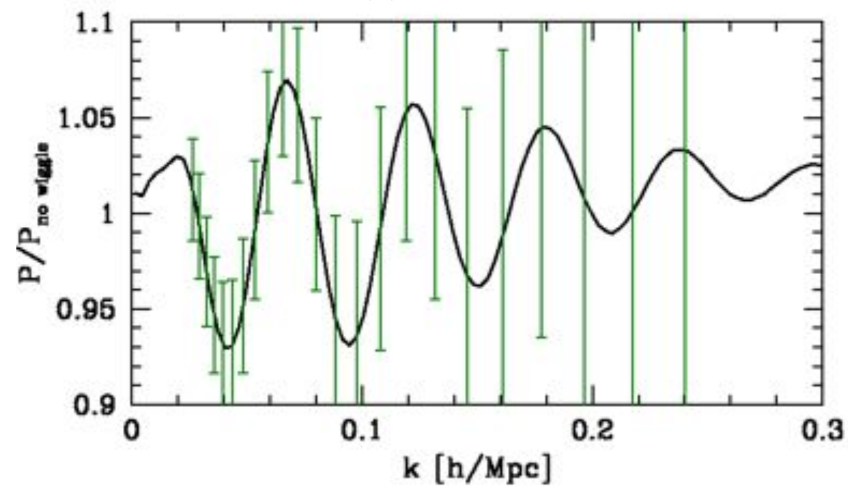
- Divining the future:
  - Metal and computers are cheap; people are not
    - Low-cost telescopes = easy-to-build designs (e.g. CASPER)
  - Annual telescope operations = 10% Total construction cost
    - NSF has too many mouths to feed; get in, get science, get out
  - The days of building university-based observatories are waning
    - Experiment != observatory
  - It's better to be first then best than later and worse
    - Agility and improvement are important tools for harsh funding environments

BAOBAB Science

- Integrate over HI in galaxies post-reionization (z = 0.5 to 1.5)
- Measure power spectrum
- Nail down BAO peaks vs. redshift
- Learn about expansion at the onset of the Dark Energy-dominated epoch



Top: 30 days with BAOBAB-32 will result in high-significance detection of HI power spectrum
Bottom: 60 days with BAOBAB-128 will measure BAO peaks, return 1-3% errors on H(z)



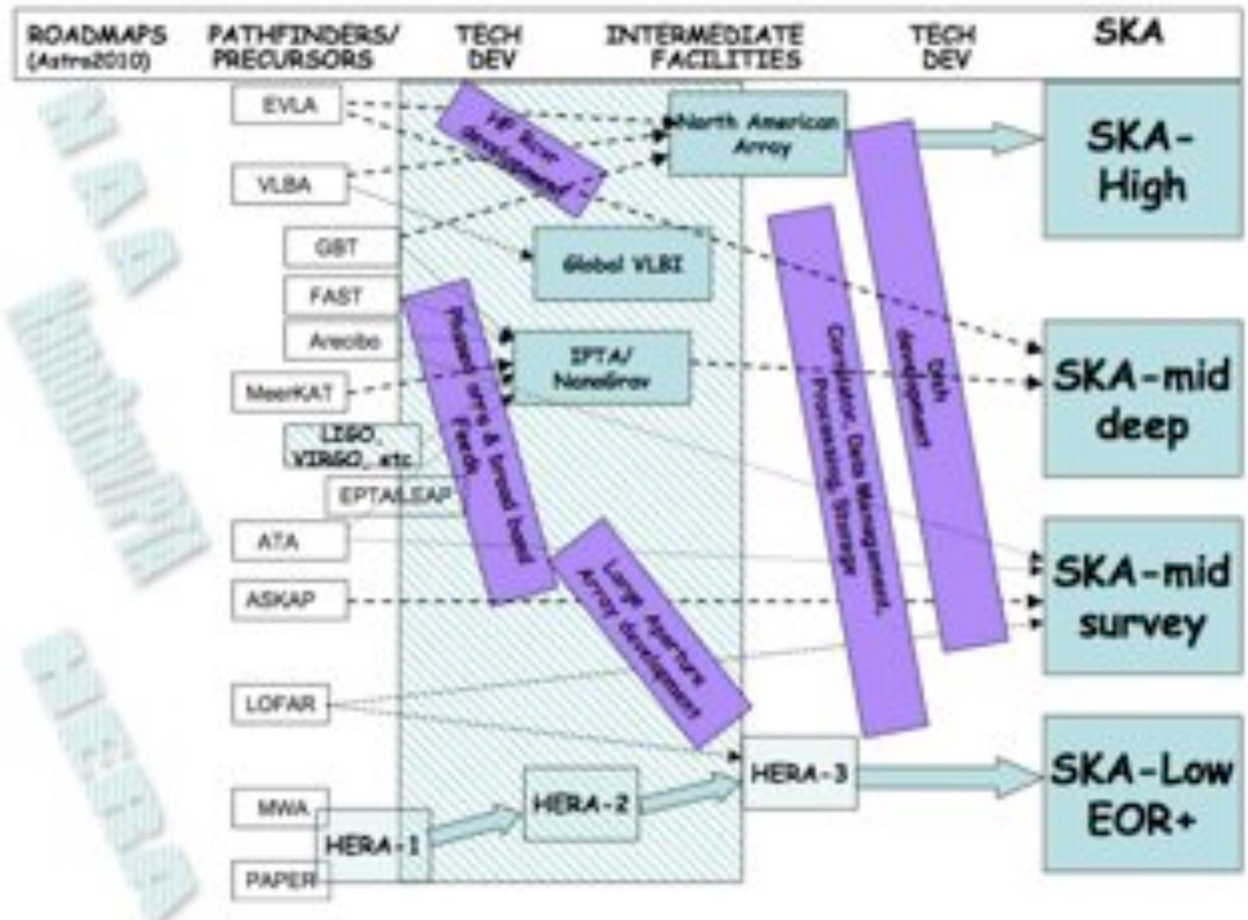
Some Active Players

- Facility
  - LOFAR
  - GMRT
- Dark Ages (Global)
  - CoRe
  - EDGES 2
  - LWA/LEDA
  - DARE
- Dark Ages (Pspec)
  - LWA/LEDA?
- EoR (Global)
  - EDGES 1
- EoR (Pspec)
  - LOFAR
  - MWA
  - PAPER
  - GMRT
- BAO (Radio Galaxy)
  - ASKAP/WALLABY
- BAO (Pspec)
  - Tainlai/CRT
  - CHIME
  - BAOBAB
  - GBT

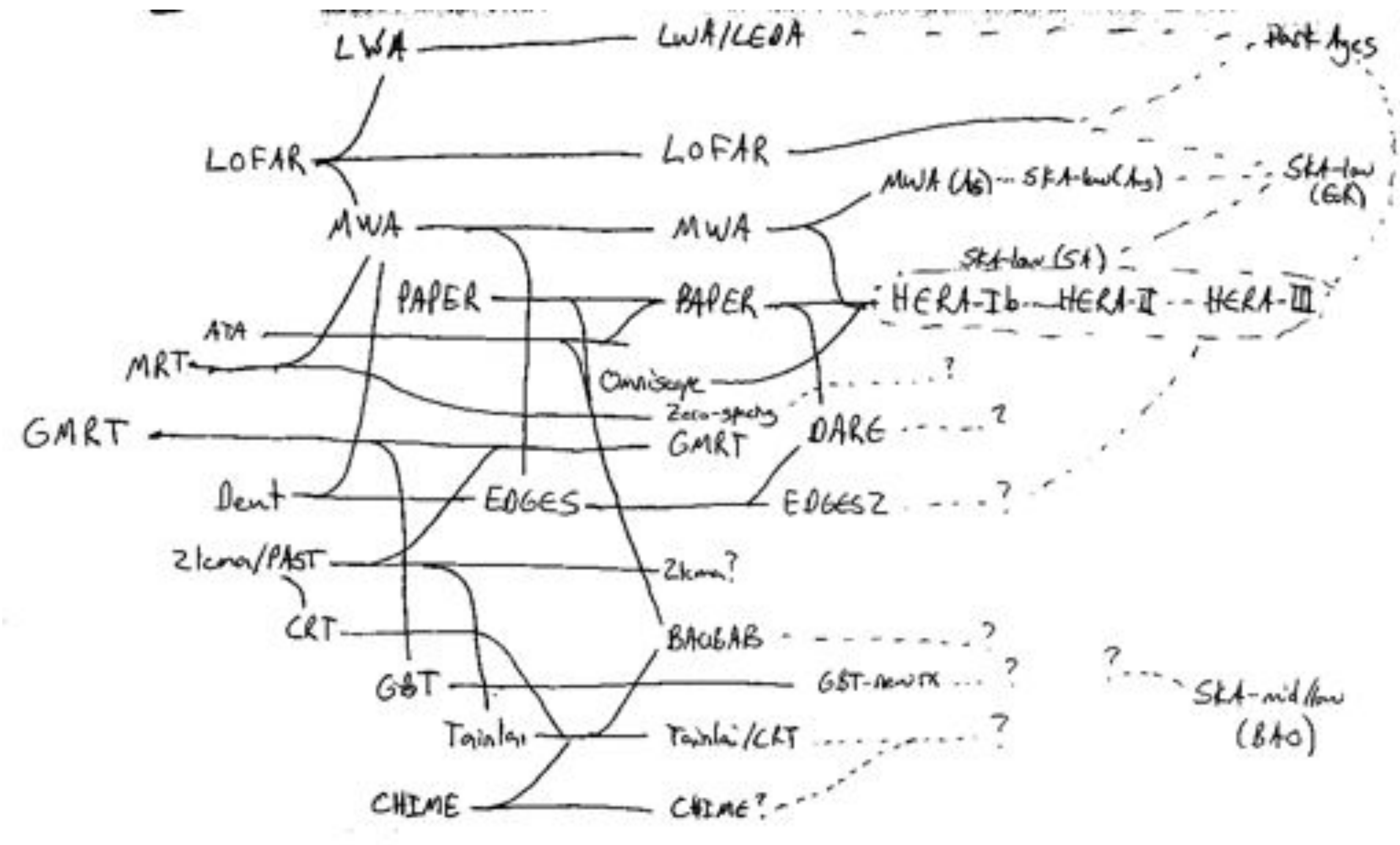
?

- Facility
  - SKA-low
- Dark Ages (Global)
  - ?
- Dark Ages (Pspec)
  - SKA-low?
- EoR (Global)
  - ?
- EoR (Pspec)
  - SKA-low?
  - HERA
- BAO (Radio Galaxy)
  - SKA-low/mid
- BAO (Pspec)
  - SKA-low?
  - ?

Last Year’s Playbook (AUI)



This Year's Playbook



The Sky (as we know it)