Thoughts on LOFAR/FASR Synergy

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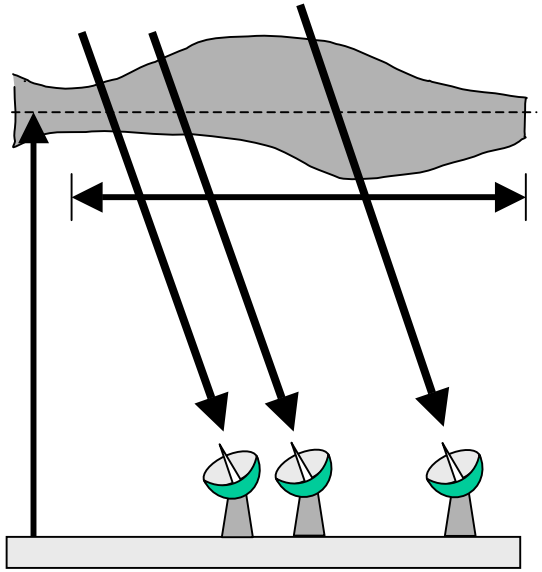
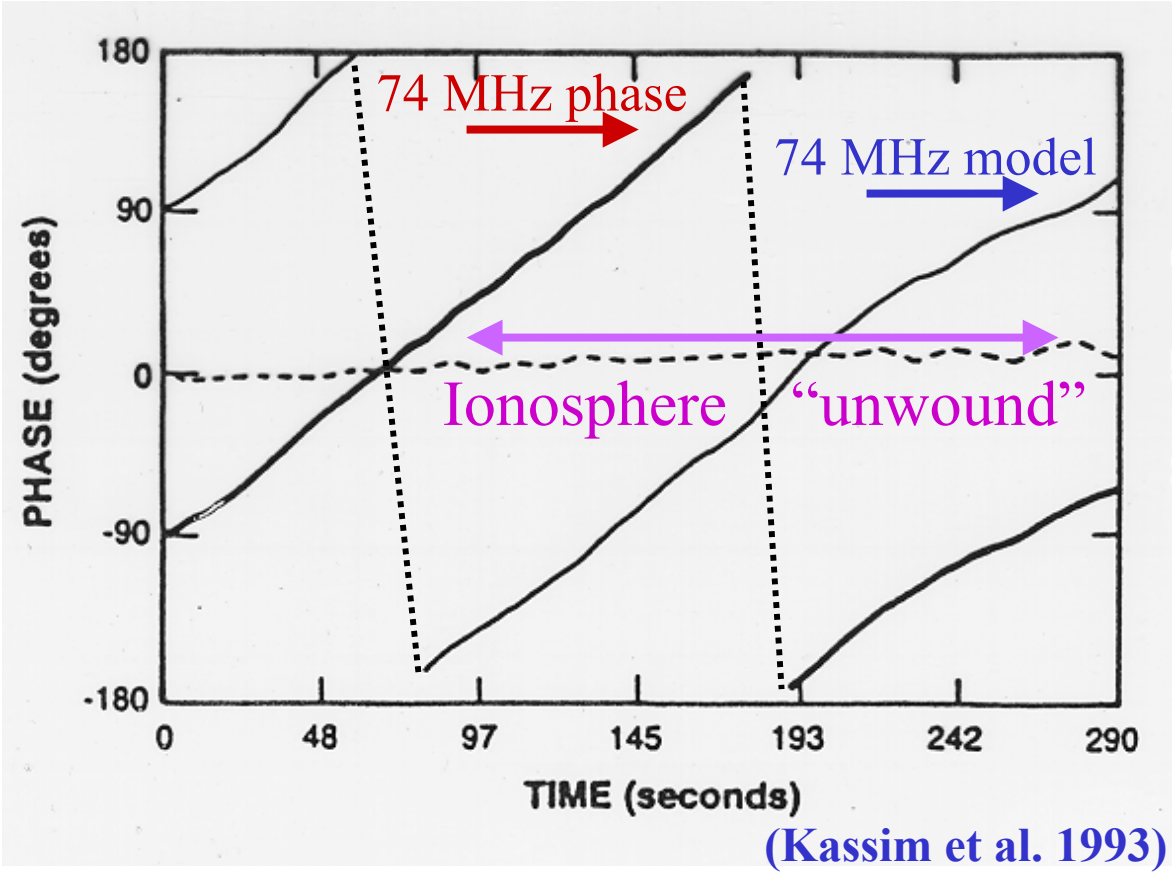
<http://lofar.nrl.navy.mil/>

Ionospheric Waves



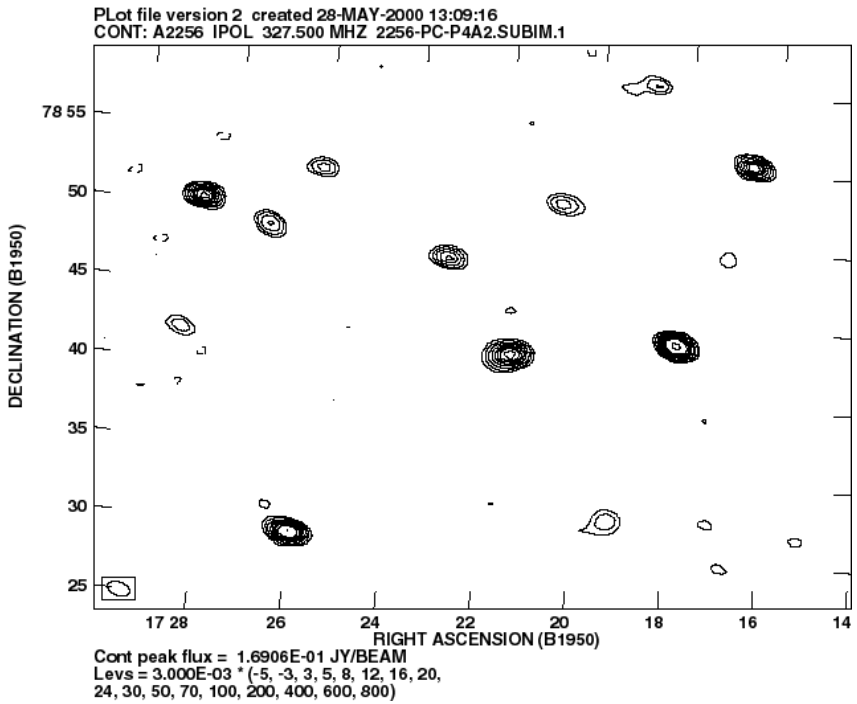


(Kassim et al. 1993)

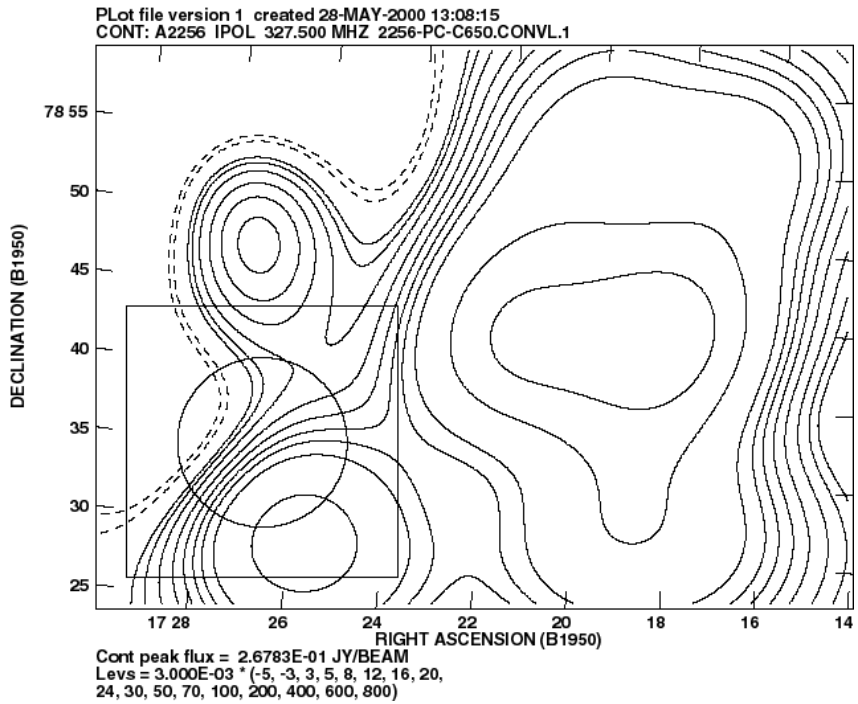
- Ionospheric waves introduce rapid phase variations
  ~ 1° s^{-1} for A-configuration (35 km) VLA
- Disrupt phase measurements and limit coherence times
- 1980s: Self-calibration predicted to remove ionospheric effects from LF data
- 1990: NRL-NRAO propose to "break ionospheric barrier" with 74 MHz VLA

Low Angular Resolution: Limits Sensitivity Due to Confusion

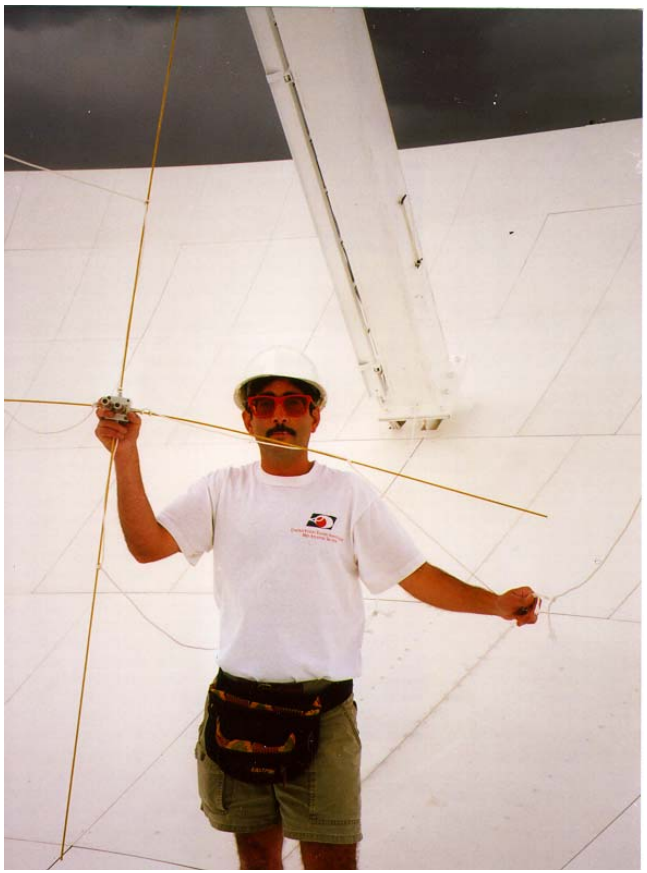
θ ~ 1', rms ~ 3 mJy/beam



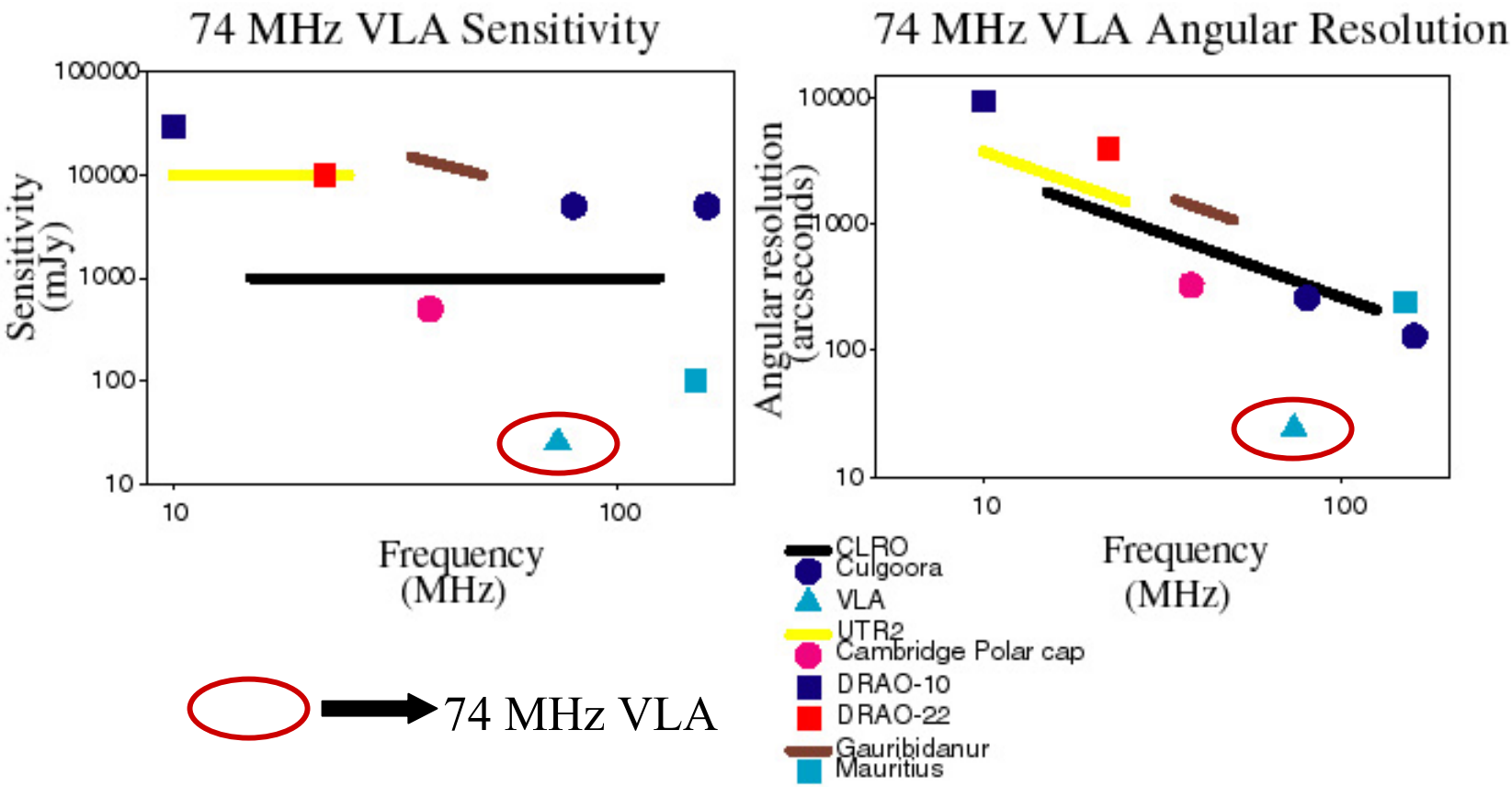
θ ~ 10', rms ~ 30 mJy/beam



74 MHz Receiving System: Dipoles

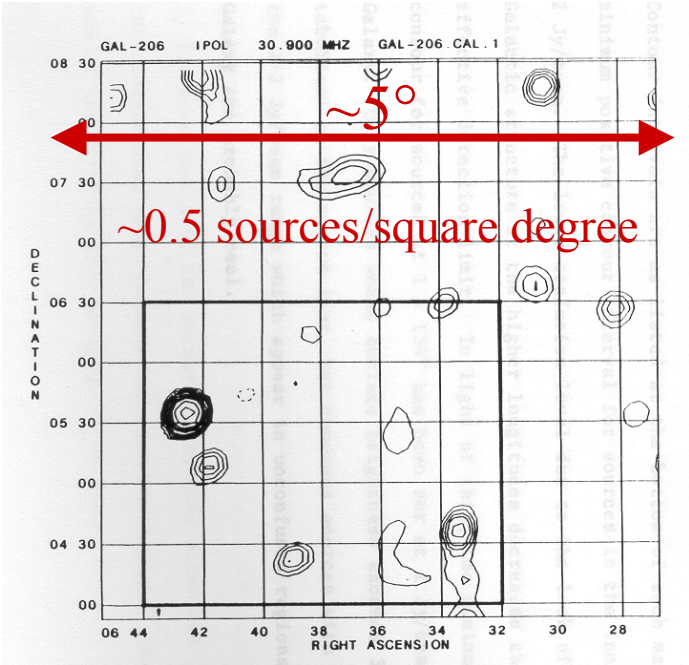


74 MHz VLA: Significant Improvement in Sensitivity and Resolution



Comparison of Low Frequency Capabilities (past vs. present)

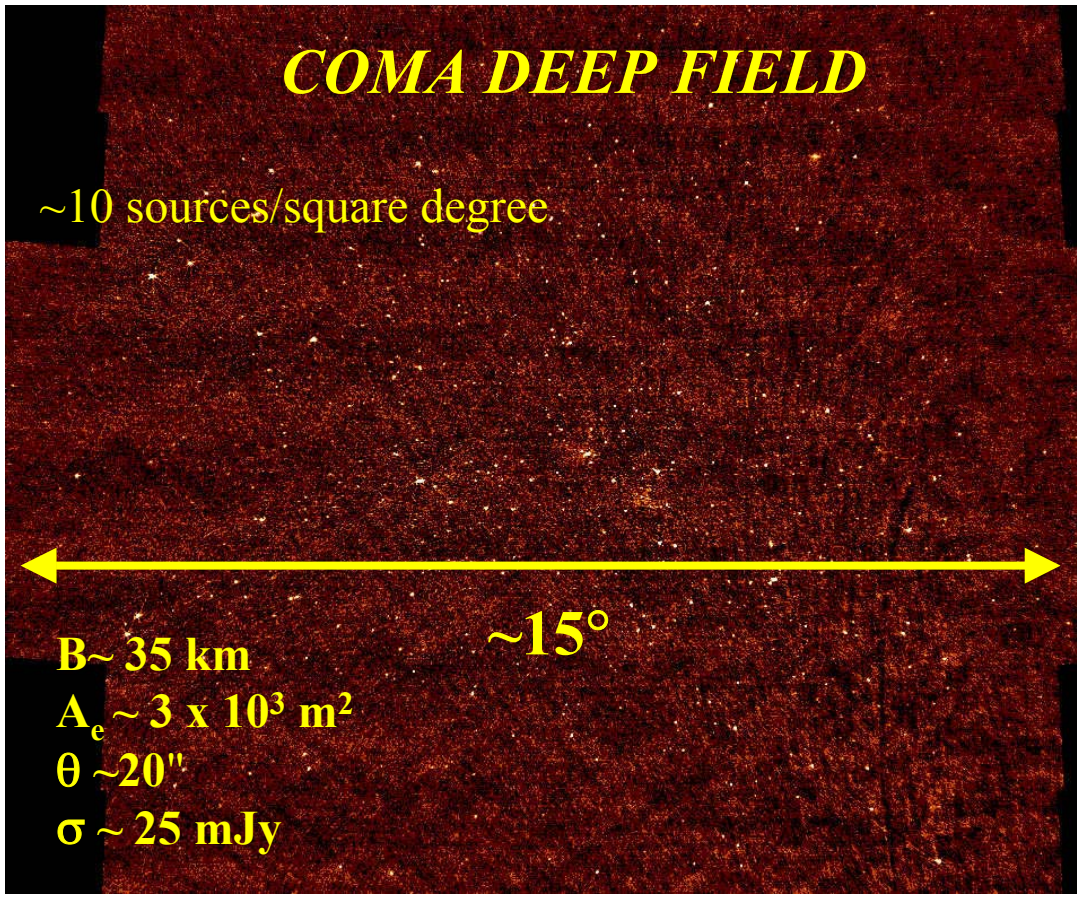
Clark Lake (30 MHz)



Kassim 1989

- B ~ 3 km
- A_e ~ 3 x 10^3 m^2
- θ ~ 15' (900")
- σ ~ 1 Jy

VLA (74 MHz)



Enßlin *et al*. 1999

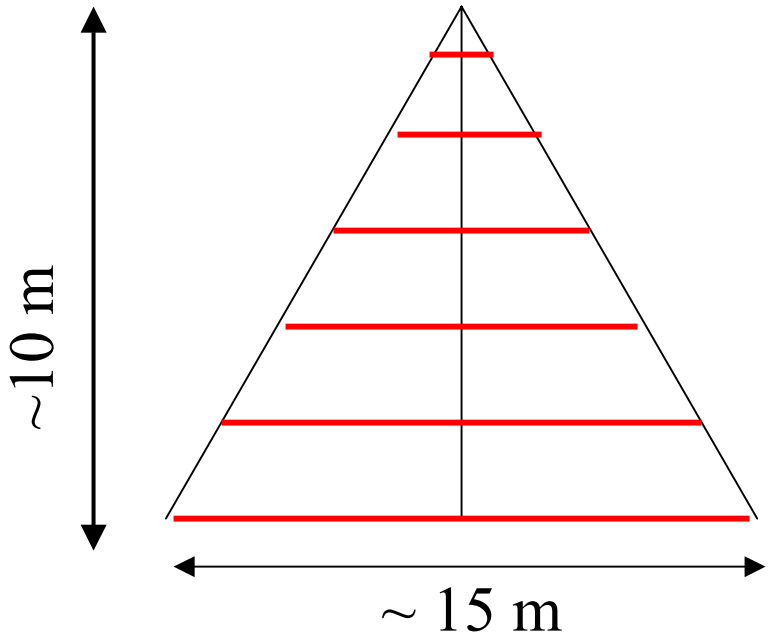
LOFAR Concept

(presented to Astronomy Decade Committee)

- Inspired by 74 MHz VLA, which demonstrates major breakthrough in sensitivity and angular resolution:
  - Reflects impact of self-calibration, ability to emerge from confusion
- Fully electronic, **broad-band antenna array**
- Basic element is an active dipole receptor: $\Delta\nu \sim 10$–240 MHz
  - Low frequency limit: ionospheric absorption, scintillation
  - High frequency limit: λ^2 collecting area, better to use dishes above this
- "Stations" (dishes) are 160 m in size, comprised of 256 receptors
  - Good primary beam definition, low sidelobe levels
- **Large aperture**: baselines $\leq$ 500 km (no limit on baseline length)
  - Good angular resolution, low confusion
- **Large collecting area**: $\geq 10^6$ m^2
  - 2–3 orders of magnitude improvement in resolution & sensitivity
  - 8"@15 MHz, 0.8"@150 MHz; < 1 mJy@15 MHz, < 300 μJy@ 150 MHz
- Multiple beams: new approach to astronomical observing

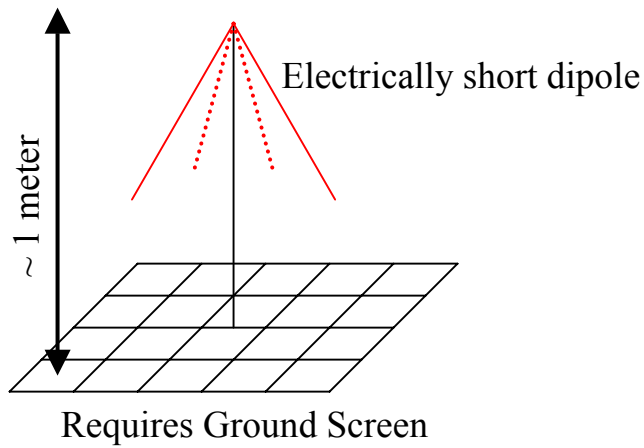
Antenna Design

- Conventional approach: Log-Periodic Array
  - Pro: well studied, good frequency & sky coverage
  - Con: large



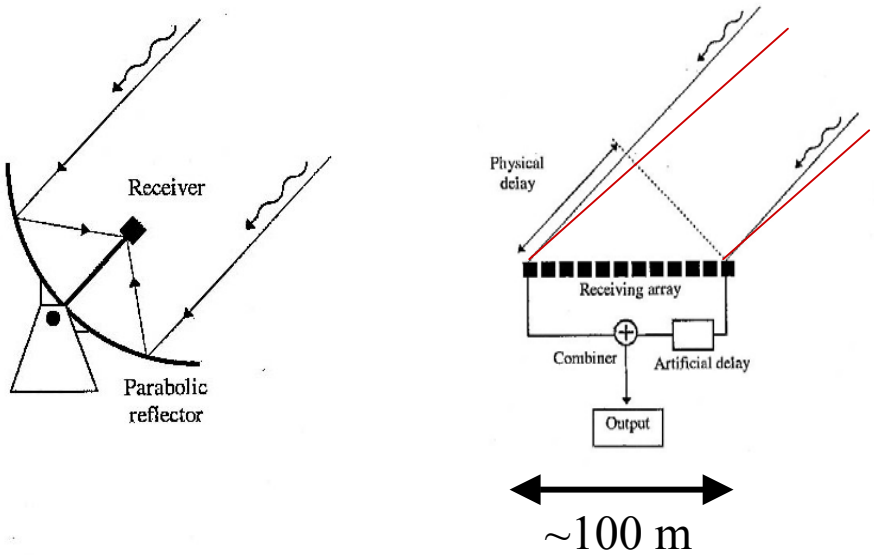
- New-technology approach: "Active" Dipoles
  - Pro: small
  - Con: impedance matching, sensitivity, sky coverage, ground plane, strong inter-element coupling

    NRL testing underway

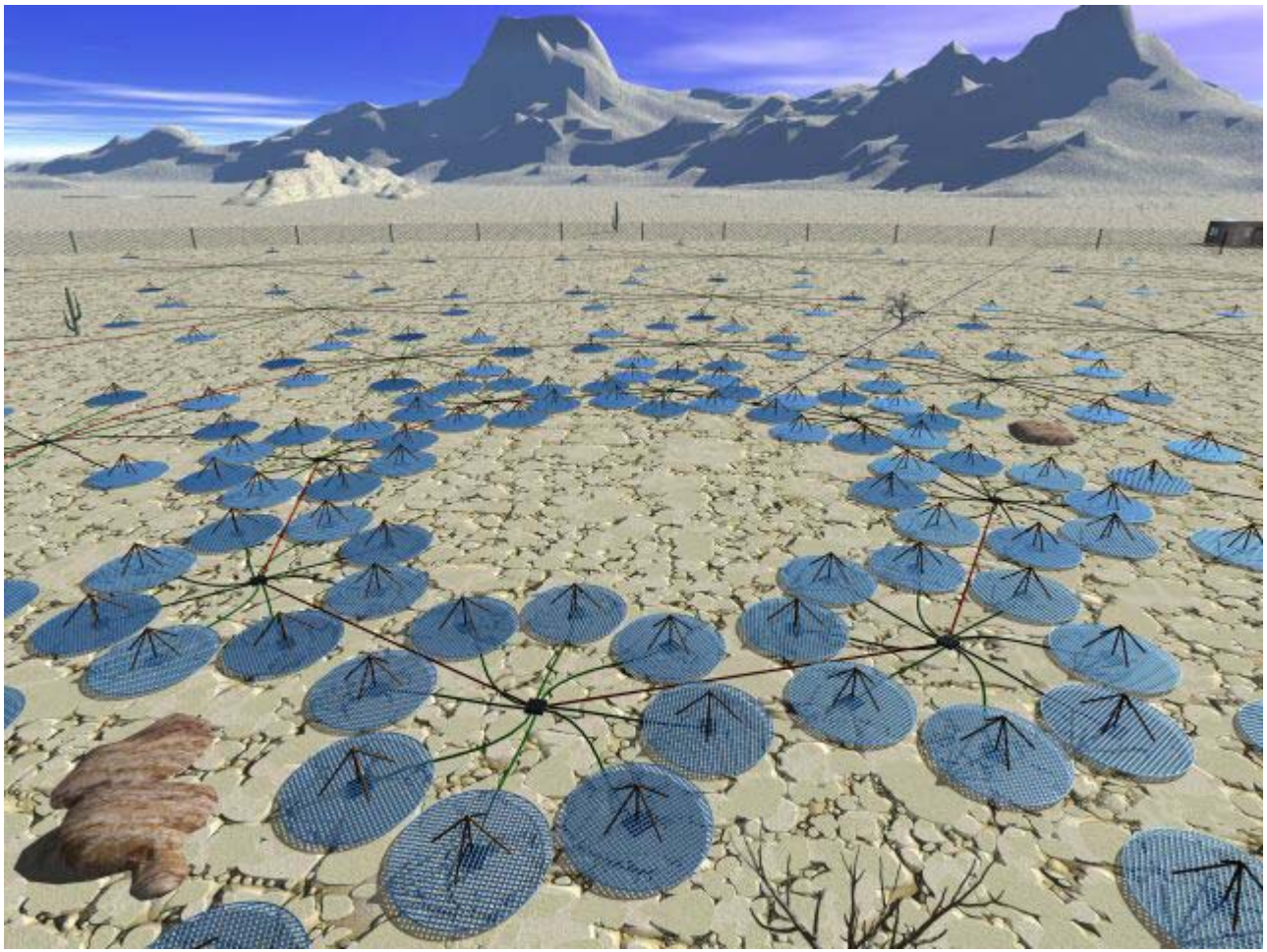


Station Design

- Consists of 256–1000 broad-band wire antenna elements
- Phased array will deliver one signal that looks like the signal from a single VLA antenna
  - Plug & play philosophy for VLA integration
  - Will serve as prototypes for LOFAR lower frequency antennas



High Sensitivity Station: LOFAR Prototype

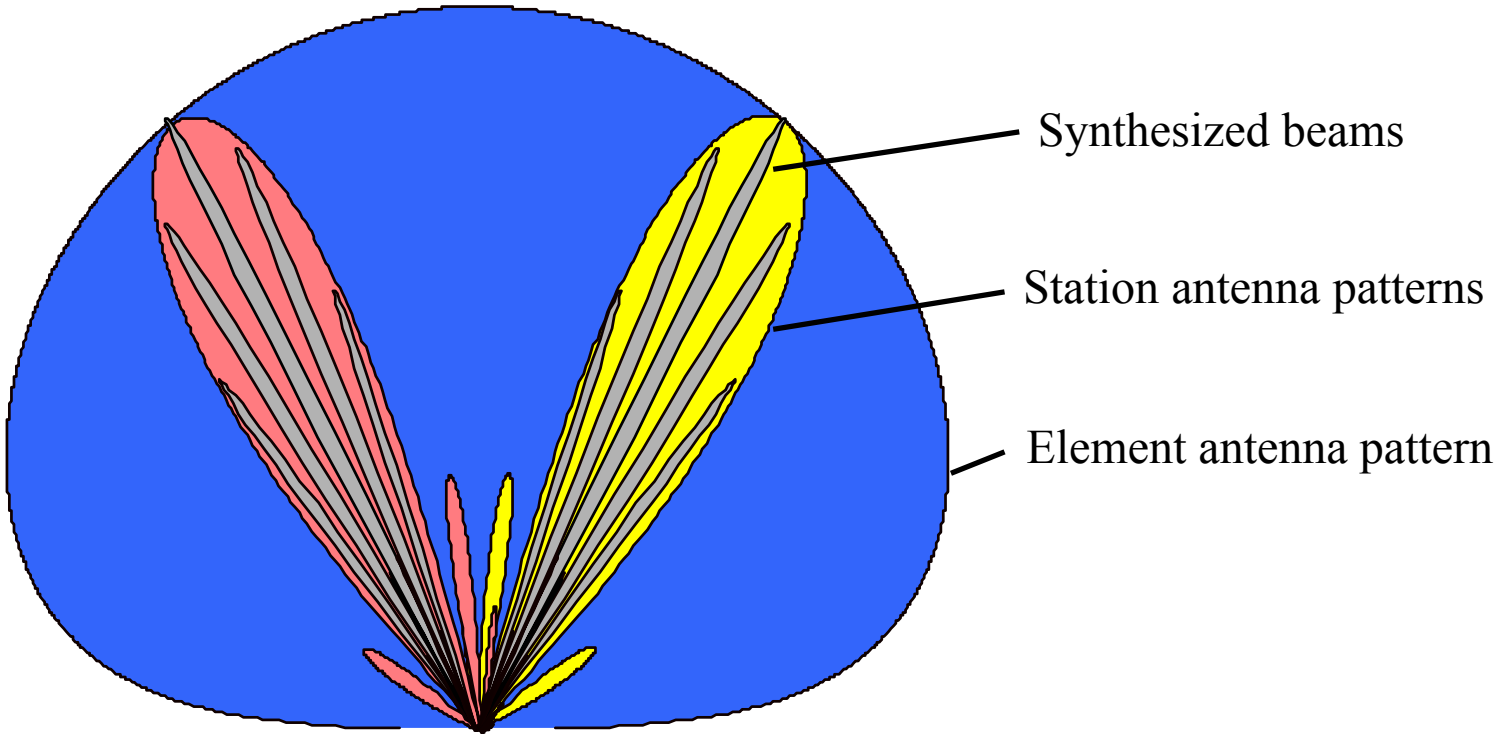


Analogous to one VLA antenna but with > 10x the sensitivity

~ 100 meter diameter

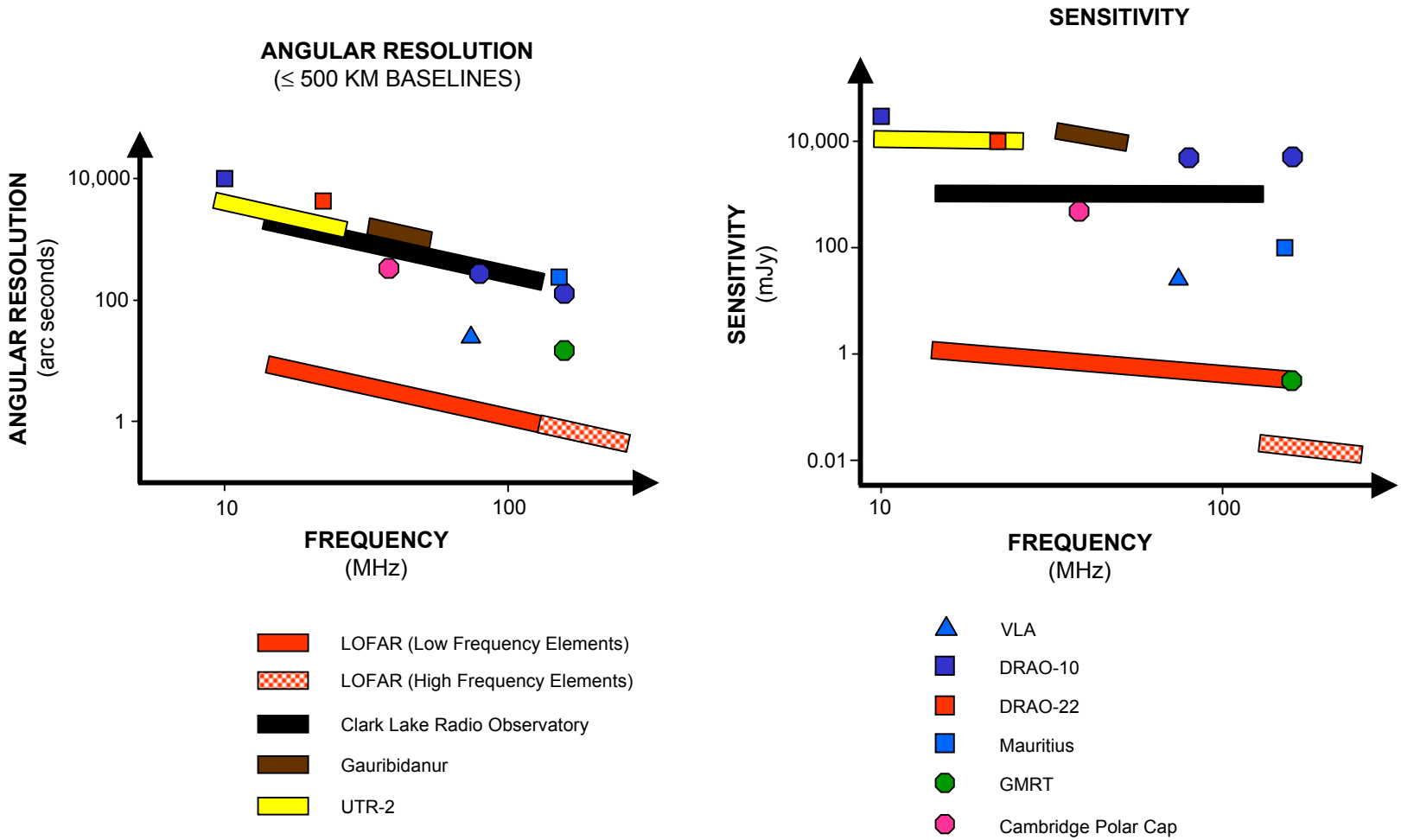
@74MHz:
VLA antenna ~ 125 m^2
LWA Station ≥ 1500 m^2

New Technology Electronic Arrays: Fast, Flexible, Multibeamed



Multiple, independent beams $\Rightarrow$ speed and flexibility
$\Rightarrow$ multiple, simultaneous science programs

Opening A New Window On The Universe



Key LOFAR Science Projects

- High Redshift Universe
  - unbiased sky surveys, select highest *z* galaxies
  - trace Galactic & intergalactic **B** fields, infalling shocks around clusters
  - Epoch of Reionization: detect and map spatial structure
- Cosmic Ray Electrons and Galactic Nonthermal Emission

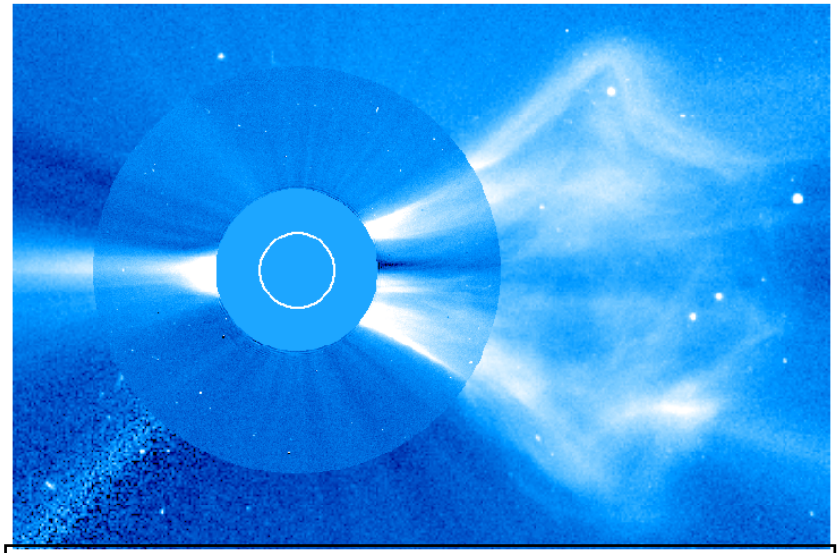
  map 3D distribution & spectrum, study propagation: clues for expected origin & acceleration in SNRs?
- Bursting and Transient Universe
  - broad-band, all-sky monitoring for variable/transient sources (GRBs, etc …)
  - search for coherent emission sources; e.g., stars, quasars, exoplanets
- **Solar-Terrestrial Relationships**
  - **study fine-scale ionospheric structures**
  - **image Earth-directed CMEs (as radar receiver)**
  - **plan for dedicated solar beam**

LOFAR science plan was recommended by the NAS Astronomy Survey Committee in the Decadal Report.

Broad Range of Scientific Applications

- Steep spectrum clusters and fossil galaxies, including polarization studies using background sources
- Surveying (Galactic & extragalactic), studies of variable source populations
- Galactic center mapping, transient source monitoring
- Pulsars - detecting, finding new steep spectrum fast pulsars
- Supernova remnants and their interaction with pulsars and the ISM
- Thermal absorption from low density, ionized gas in ISM
- Recombination lines, emission and absorption lines from the cool ISM (carbon clouds)
- **Propagation and scattering, in the solar wind, the IPM, the Galaxy, and towards extragalactic sources**
- **Steep spectrum emission from Flare Stars, Binary Star systems**
- **Passive emission from solar flares, storms, CMEs, quiet sun**
- **Solar and Planetary radar**
- Tracking Ionospheric TIDs, real-time ionospheric modelling from self-cal solutions
- Magnetospheric, ionospheric sounding

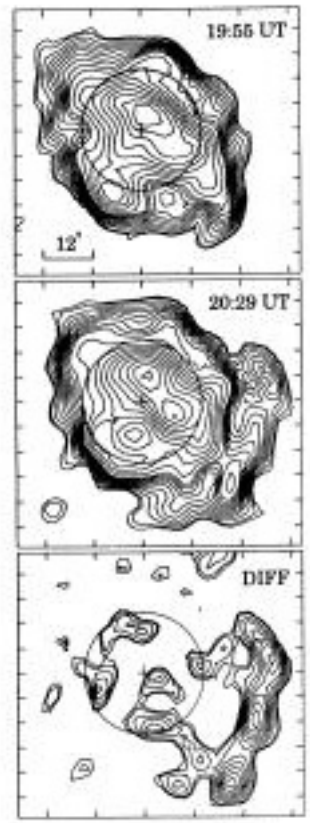
Coronal Mass Ejections



Coronal Mass Ejections (CMEs) are both significant science problems for solar physics and significant dangers for DoD and commercial space missions.

LOFAR could map out the structure of CMEs and determine space velocities to predict their impacts.

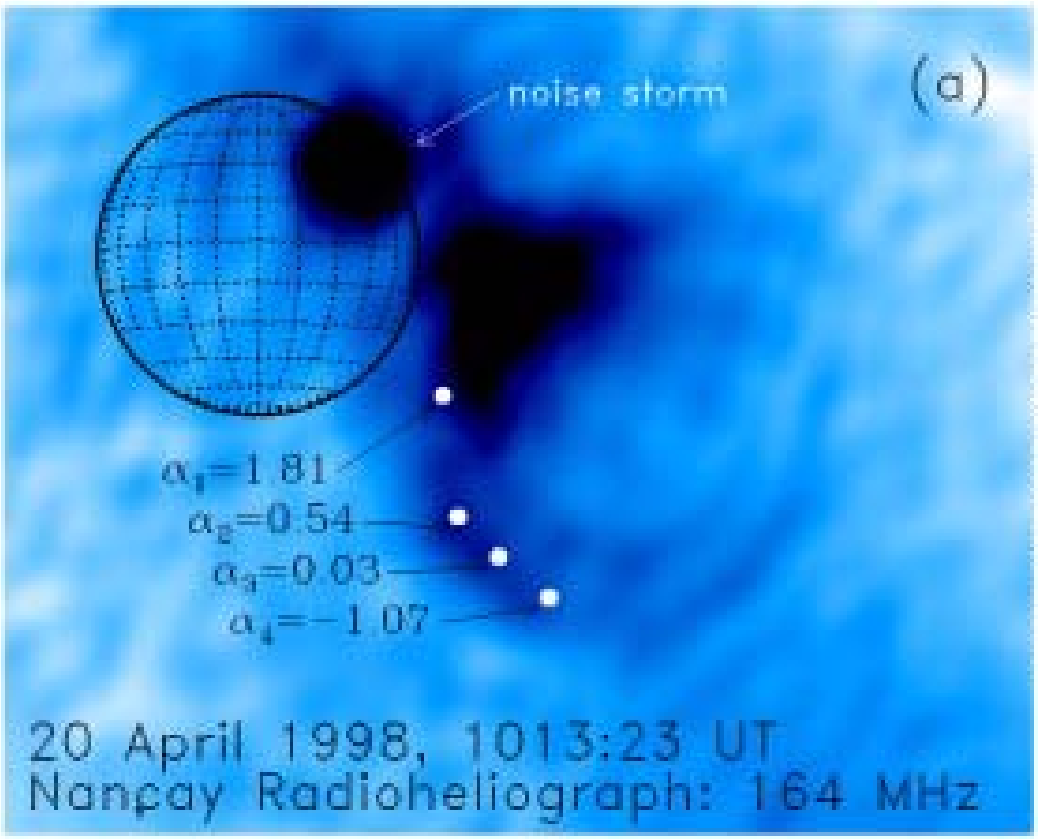
Although LOFAR is a passive instrument, it could also be used in combination with a suitably located radar transmitter to completely probe the density structure and space velocity.

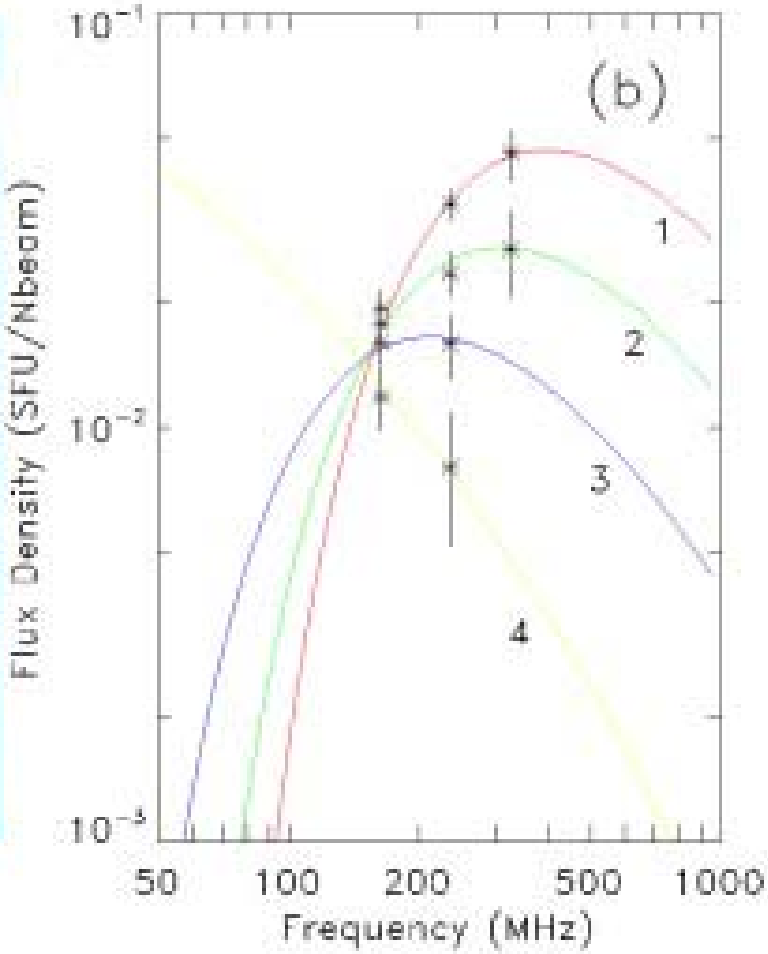


Clark Lake
(73.8 MHz)

CMEs: Synchrotron Emitting Sources

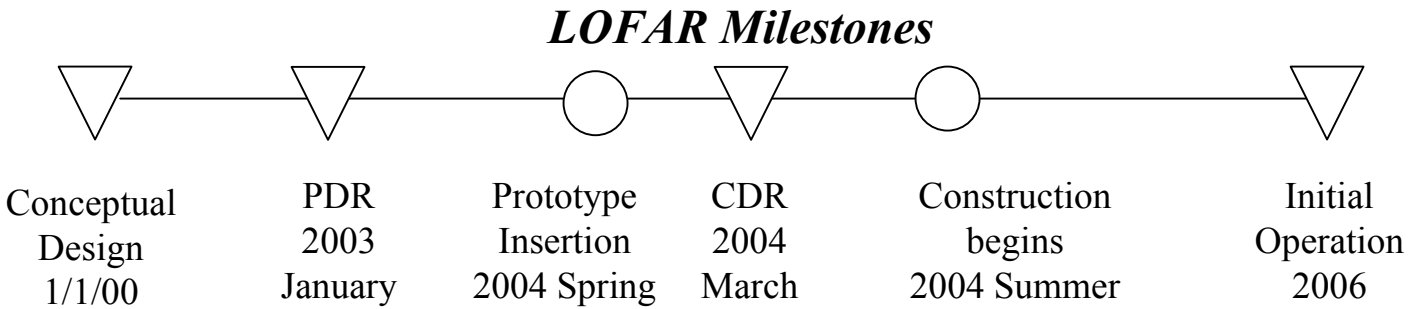
Nancay Image at 164 MHz





Bastian et al 2001

LOFAR Consortium: NRL-ASTRON-MIT/HO



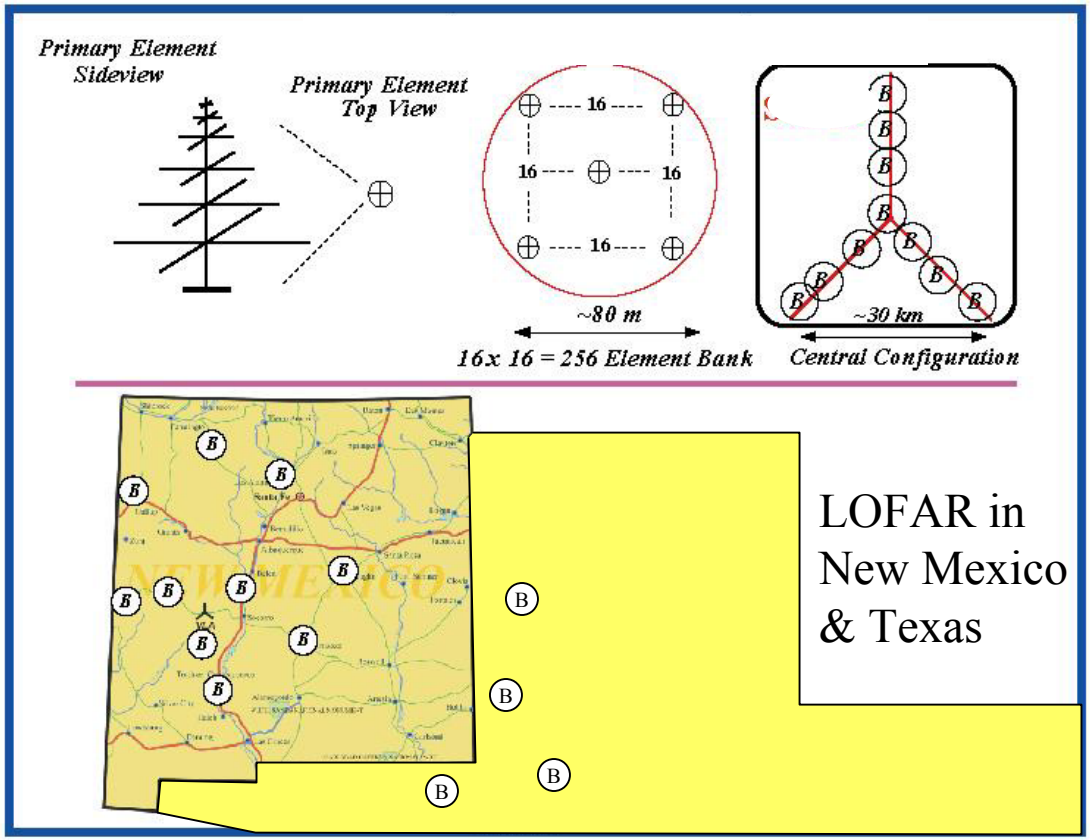
- LOFAR Consortium on track to build LOFAR within this decade
  - seeking new partners
- Science Consortium forming – Call to Participate Issued February 2002
  - Help us set up a LOFAR "solar working group" which can promote fruitful exchange of information between our two projects – see http://lofar.nrl.navy.mil & http://www.lofar.org

Site Selection Scheduled for 12/02

(Competition will be intense)

- Netherlands
  - Pros –
    - Local government funding
    - Massive infrastructure
    - National political/financial support
  - Cons –
    - Scarce land
    - Expected high RFI
    - High northern latitude
- Western Australia
  - Pros –
    - GC overhead
    - Ample land; government interest
    - Low RFI/Radio Quiet Zone plans
  - Cons –
    - Isolated
    - Little infrastructure
    - Long travel
    - Ill-defined local support
- Western US
  - Pros
    - Reasonable RFI
    - Ample land; reasonable infrastructure
    - Low northern latitude
  - Cons
    - Local support just organizing
    - Local funding undetermined

LOFAR in the SW?



- As a location for LOFAR, the SW US offers:
  - Initial capability near existing VLA-hosted system
  - Eventual expansion within New Mexico and Texas
    - Might coordinate with EVLA -II and New Mexico Array
    - Share site, infrastructure, operational costs
  - SW Consortium forming

University Radio Astronomy Renaissance

- LOFAR will be built by the academic community; run by the academic community.
  - Many opportunities for direct, hands-on involvement by students and faculty.
- Multi-beam capability provides greater access.
  - Current plan includes dedicated student beam.
- LOFAR will be a world class facility complementing other major observatories.
  - Coordination with high-energy, optical, cm λ, and gravitational communities.

Opportunities for Cooperation

- Scientific
  - Joint research projects – immediate exploitation of new VLA system
  - Graduate student exchange; already underway
  - Postdoc positions
  - Faculty participation
- Technical
  - Engineering support for joint hardware development
  - Student involvement with NRL HF station prototyping
- Infrastructure
  - Assistance with site characterization studies (e.g., RFI)
  - Characterization of potential site support (land, roads, politics, money)
  - Characterization of communication links (e.g., fiber)
  - Synergy with development for other projects (e.g., EVLA, SKA)

LOFAR/FASR Synergy

- Develop common tools for simulation studies
  - System, configuration, etc …
- Advantage of Co-Location
  - Scientific
    - A LOFAR dedicated solar beam would continuously monitor the sun, with observations below 100 MHz acting as a trigger for FASR follow-ups
    - **LOFAR could "calibrate out" the ionosphere for FASR**, since LOFAR will see a myriad of background sources of known positions
  - Technical
    - Shared site characterization (e.g. RFI surveying), shared infrastructure, etc …
- Shared technologies
  - Active antenna technology
  - After the antennas, much overlap: correlator, transmission, etc …
  - Common need for high DR, RFI resistent systems
  - Common need for high time resolution
    - For LOFAR: transients and pulsars
- High Data Rates
  - Common massive data management, visualization, manipulation techniques

SUMMARY

(http://www.lofar.org & http://www.lofar.nrl.navy.mil)

- LOFAR will open one of the last and most poorly explored regions of the EM spectrum below 240 MHz
  - Sophisticated, multi-beam, multi-frequency electronic array which will herald revolutionary new approach to astronomical observations
  - **Science plan recommended by National Academy of Sciences Astronomy Survey Committee in the new Decade Report**
- Key science drivers:
  - High Z Universe, Epoch of Reionization, Cosmic Rays, Bursting & Transient Universe
  - **Solar-Terrestrial Relationships**: study fine-scale ionospheric structures, image Earth-directed CMEs
    - **One beam dedicated for solar use**
    - **Co-location seals success of LOFAR as solar instrument – does LOFAR help FASR?**
  - Lots of "regular science" too
  - **Serendipity: new discoveries likely in unexplored regime**