OLFAR – Orbiting Low-Frequency Antennas for Radio Astronomy

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Outline

Presentation of a new concept for low frequency radio astronomy in space

- Why low frequencies?
- Why in space?
- Outline of the idea
- Issues

History of Low Frequency astronomy

- Karl Jansky's in 1932
  20.5 MHz (14.5 m) at Bell labs
- Grote Reber continued radio astronomy work at 160 MHz (1.9 m) and observed the Sun, IO, Cygnus-A

History of Low Frequency astronomy

- First radio telescopes operated at long wavelengths with low spatial resolution and very high system temperatures
- Radio astronomy quickly moved to higher frequencies with better spatial resolution $(\theta = \frac{\lambda}{D})$ and lower system temperatures

Low frequency Science

- One of the last unexplored frequency bands.
- Exploring the early cosmos at high hydrogen redshifts, the so-called dark-ages
- Discovery of planetary and solar bursts in other solar systems
- Tomographic view of space weather
- .. the unknown ..
- and for many other astronomical areas of interest

Current low frequency instruments

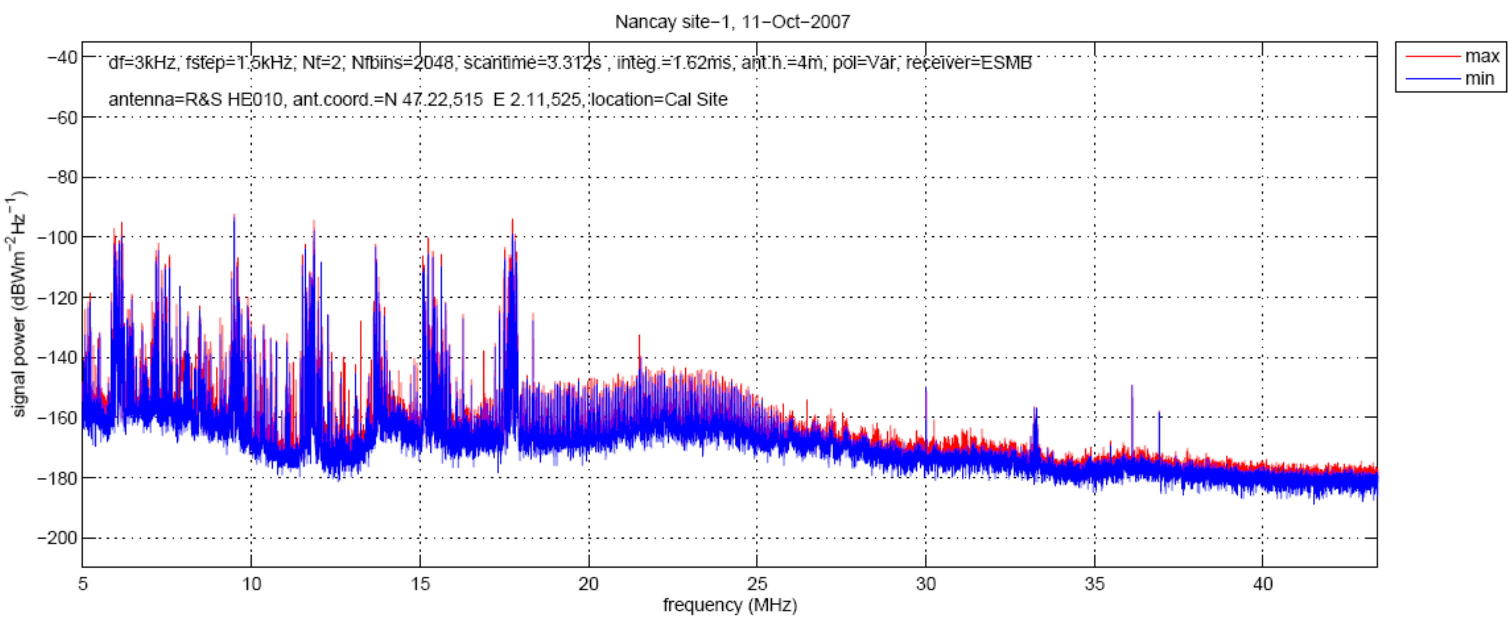
- VLA 74 MHz
- GMRT
- LOFAR
- LWA
- MWA
- … and more

Difficulties with Low Frequency observations on Earth

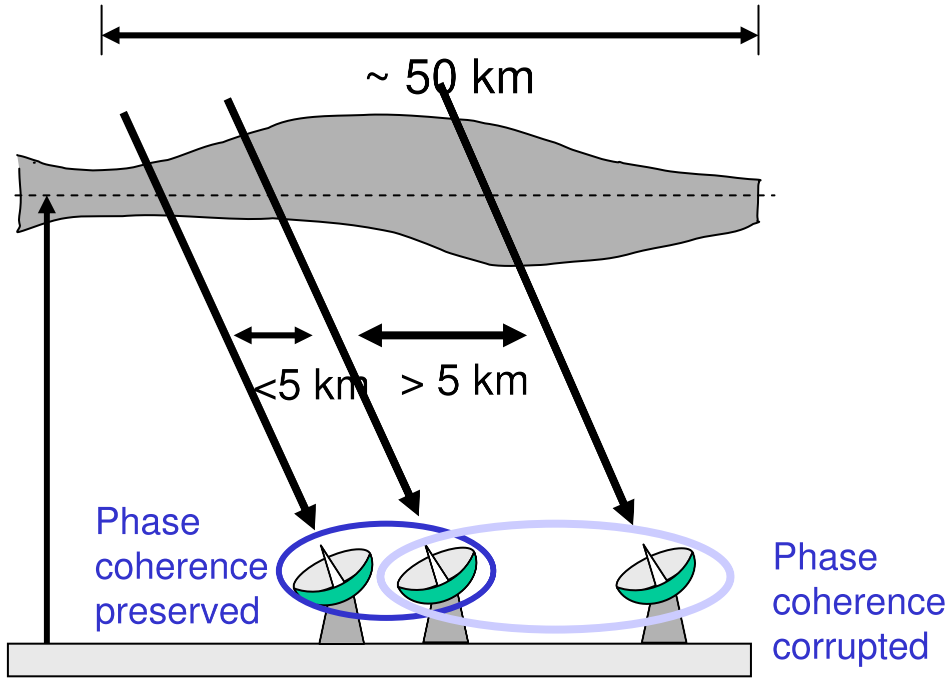
- Interference
  - Severe at low frequencies
- Phase coherence through ionosphere
  - Corruption of coherence of phase on longer baselines
  - Imperfect calibrator based gain calibration
- Isoplanatic Patch Problem:
  - Calibration changes as a function of position

Interference

- Very “crowded” spectrum



Ionospheric Structure

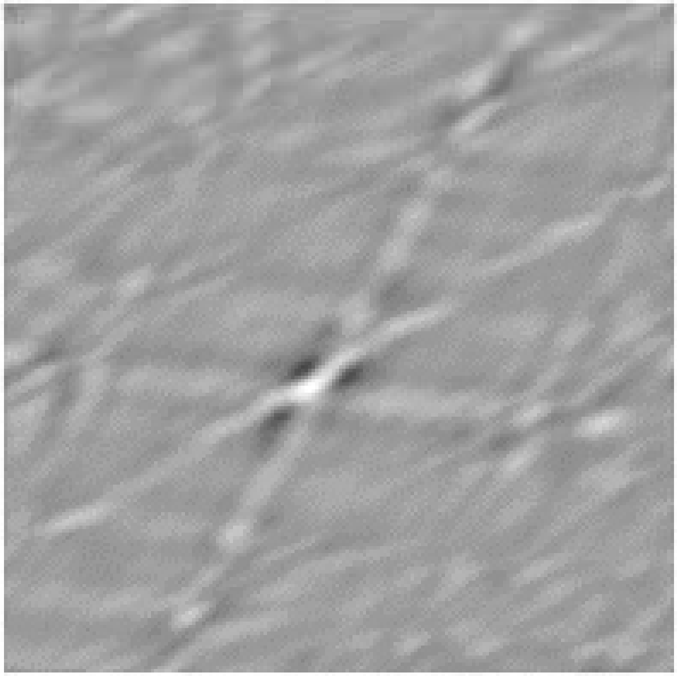


<u>Compared to shorter λ:</u>

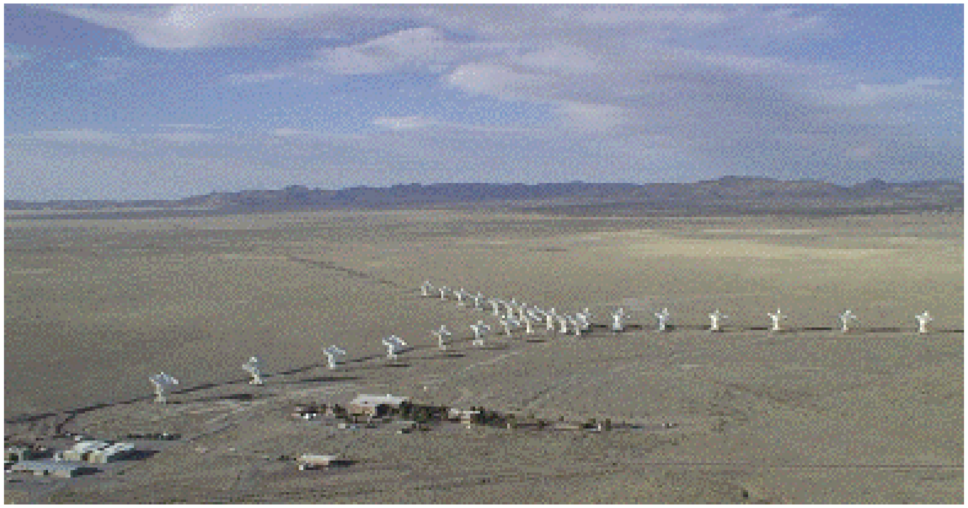
Maximum antenna separation:
< 5 km (vs. $>10^3$ km)

Angular resolution:
$\theta > 0.3°$ (vs. $< 10^{-3}$ °)

Example ionosphere



- VLA – 74 MHz



Isoplanatic Patch Problem

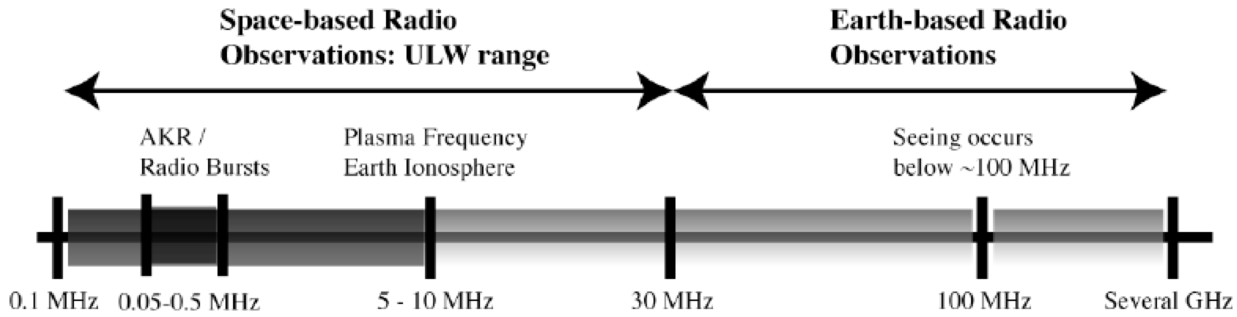
- Standard self-calibration assumes single ionospheric solution across FOV: **φi(t)**
  - Problems: differential refraction, image distortion, reduced sensitivity
  - Solution: selfcal solutions with angular dependence

    $\varphi i(t) \rightarrow \varphi i(t, \alpha, \delta)$

However: computational complex

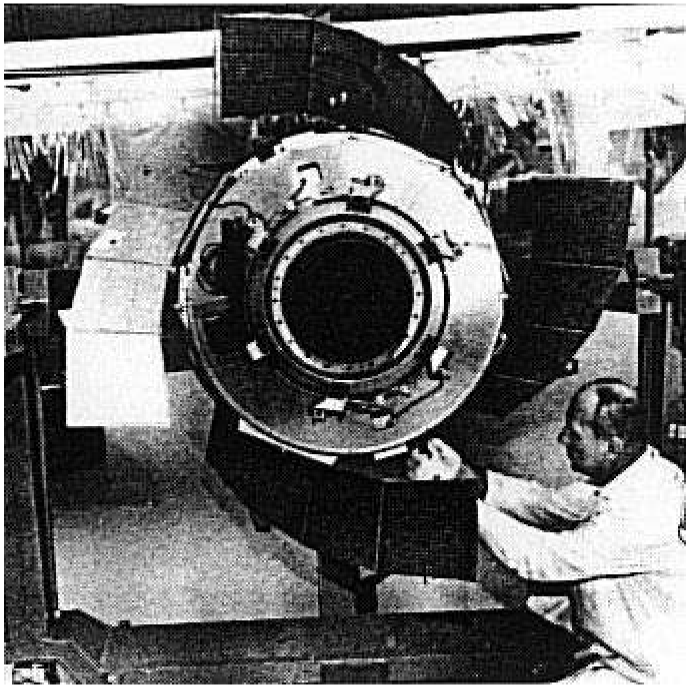
OLFAR

- Want to observe the 0.3 - 30 MHz band (unique)
- So, if the ionosphere is a problem ➔ Space mission
- Aperture diameter of 10 – 100 kilometer ➔ distributed aperture synthesis array (eg. Multiple satellites)
- Autonomous system
- Distributed processing system
- Possible locations: moon-orbit, Earth-Moon L2, L4/5, outer space ..



Previous low frequency missions

- RAE-A (Explorer 38)
  - 1968 July 4
  - 190 kilogram
  - Earth orbit
- RAE- B (Explorer 49
  - 1973 June 10
  - 328 kilogram
  - Moon orbit
  - 25 kHz to 13.1 MHz

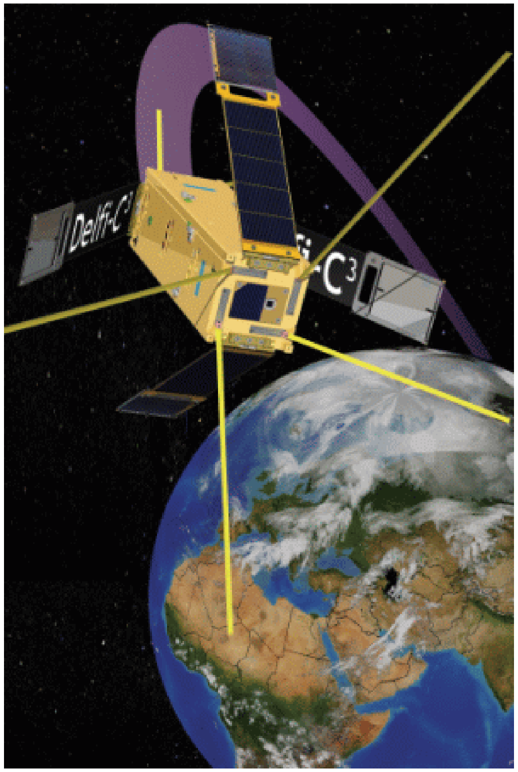


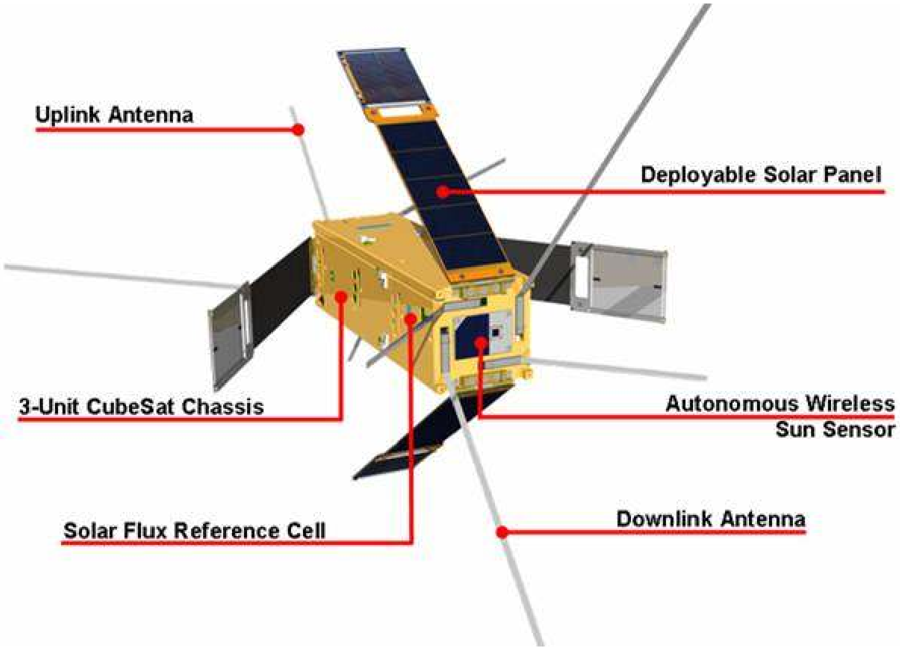
Basic idea

- Nano satellites
- Formation flying
- Deployable antenna for the frequency band between 1 and 30 MHz
- Ultra-low power receivers
- Intra-satellite communication
- Autonomous distributed processing
- Using diversity techniques for downlink

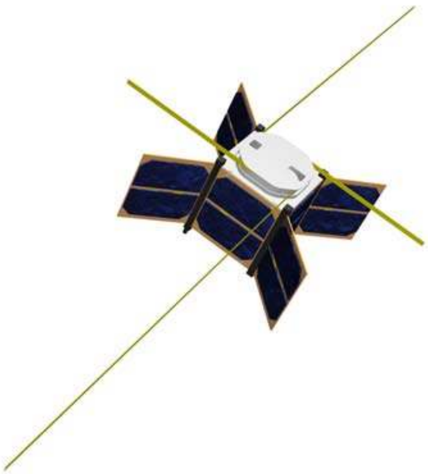
OLFAR

Example – Delfi-C3 Cubesats





Cubesat



- Nanosatellite
- 1..3 kg
- 10x10x10 cm
- Approx. 1 ..3 W of power

- Payload for other missions

OLFAR system specifications

Preliminary OLFAR system specs	
Frequency range	at least 1-10 MHz, preferably 0.3 - 30 MHz
Antennas	dipole, tripole
Number of antennas / satellites	$\geq$ 50
Maximum baseline	between 60 and 100 km
Configuration	Formation flying, investigate 2D and 3D
Spectral resolution	1 kHz
Processing bandwidth	t.b.d. 100 kHz?
Spatial resolution at 1 MHz	0.35 degrees for 60 km aperture
Snapshot integration time	1 to 1000 s, dependent on deployment location
Sensitivity	confusion limited
Instantaneous bandwidth	to be determined
Deployment location	Earth orbit, moon orbit, moon far side ?, L2 point

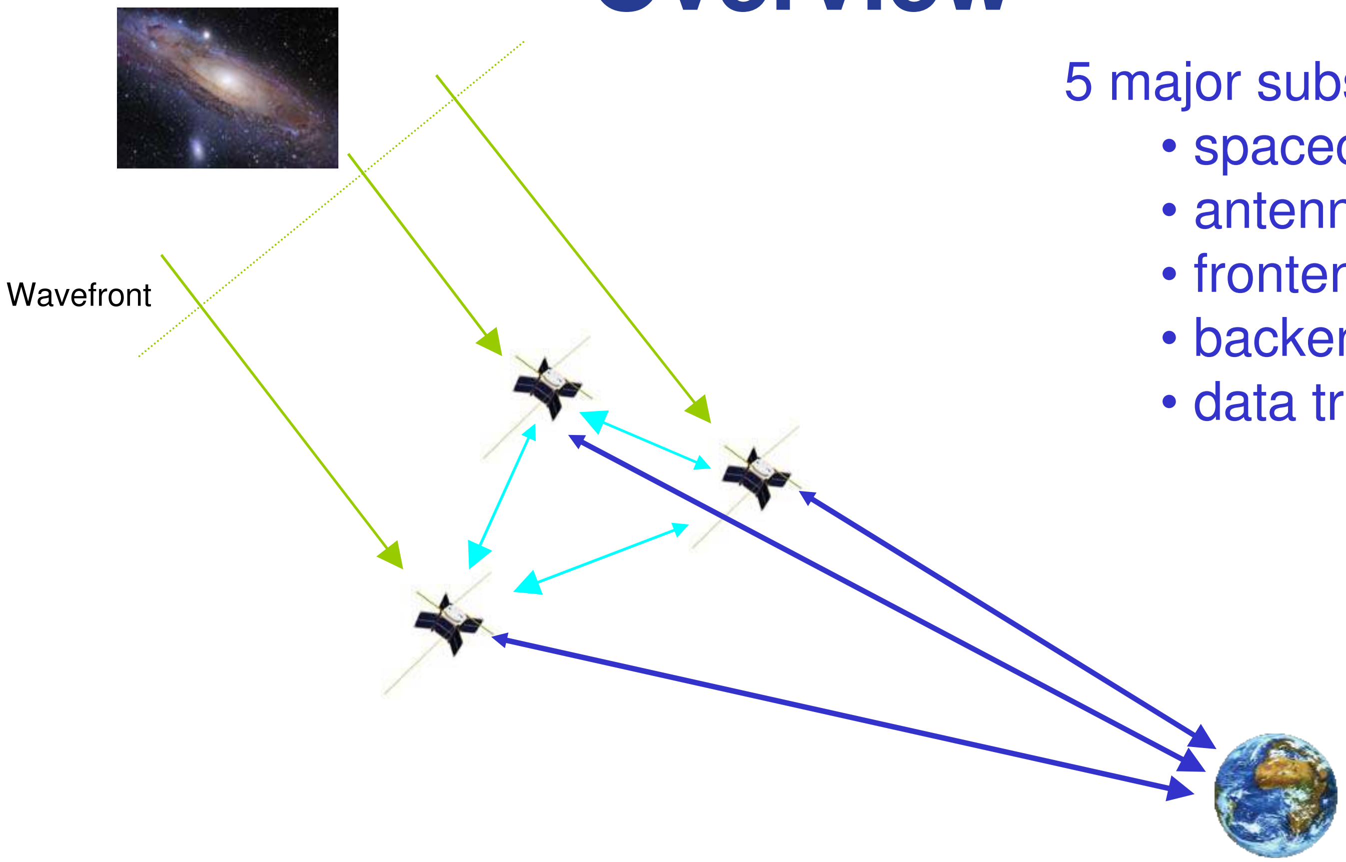
Program

- DARIS – Distributed Aperture Array for Radio Astronomy in Space (ESA/ESTEC funded project)
  - Concept study started
- OLFAR project – Funding for phase-A currently under review (Dutch Science and Technology Funds)

How many satellites?

Topic	Requirements					
	Freq. (MHz)	Res.	Baseline (km)	Expected signal	N (Antennas	t_{exp} (5σ)
Extragalactic surveys	10	1’	0.1-100	≈ 65 mJy	300	2 yr
Galactic surveys						
Solar system	0.1-10	degrees	0.3-30	10 000 K	10-100	yr
Origin cosmic rays	0.1-30	1”	$(3\text{-}30)\times10^3$	155 000K	100 000	100 d
Transients						
Solar/Planetary bursts	0.1-30	degrees	0.5-200	MJy	1-100	min-hours
Extrasolar planets	0.5-30	$\lesssim$1’	$\gtrsim$35-1000	10 mJy	10^4-10^5	15 min
Ultra-high energy particles	10-100	N/A	0-5	100 MJy	1-00	N/A (Bursts)
Meteoritic impacts						

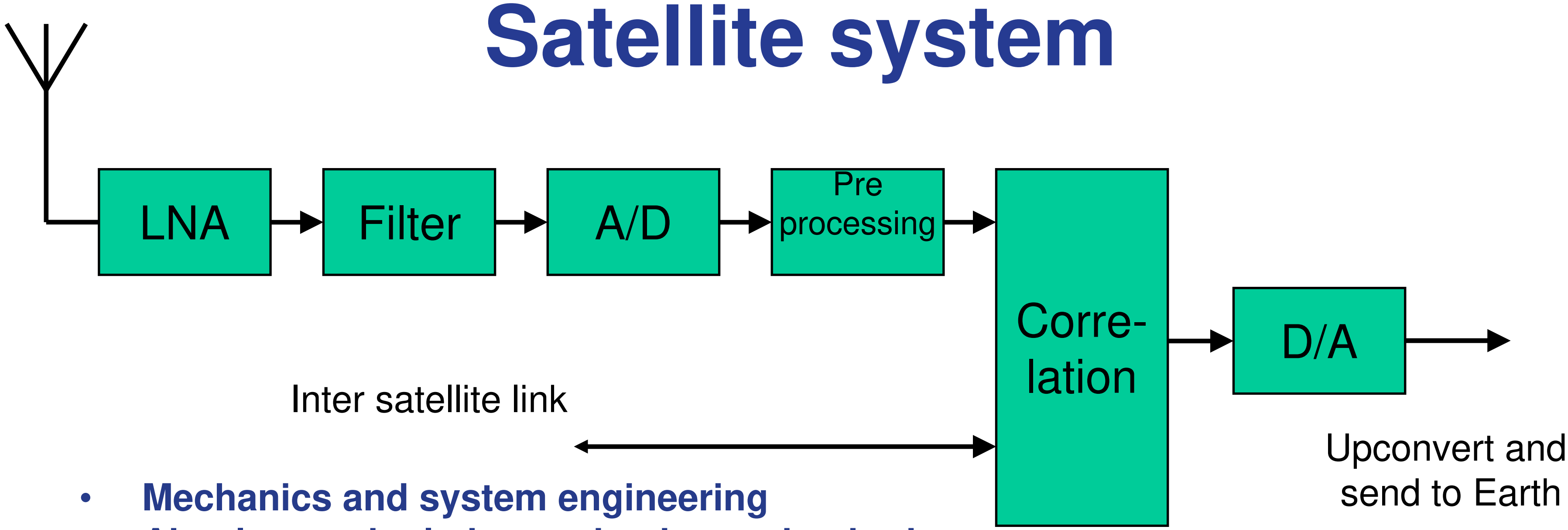
Overview



5 major subsystems:

- spacecraft
- antenna design
- frontend
- backend
- data transport

Satellite system



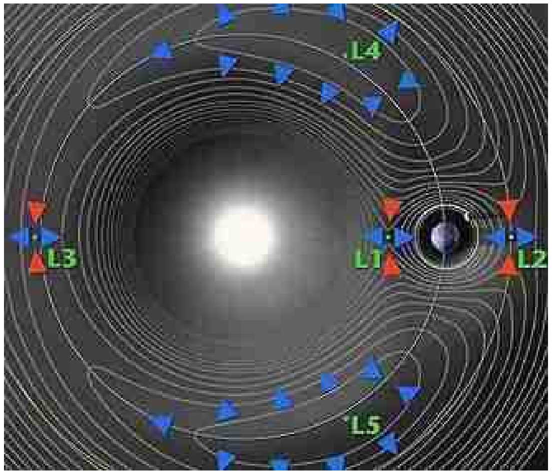
- Mechanics and system engineering
- Absolute and relative navigation and attitude
- Inter-satellite link
- Active antenna system for low-frequency radio astronomy
- Sensors for relative attitude determination
- Star trackers for absolute attitude determination
- Constellation maintenance
- Correlation software and hardware
- Overall observation control

Some system aspects

- Antenna design for 1-30 MHz band
- Active LNA
- Receiver – filtering, sampling,
- Timing, clocking (local and global)
- Localization
- Digital signal processing
  - RFI mitigation
  - Filtering
  - Subband sampling
  - Distributed correlation, tied-array calculations
- Data transport
  - Between individual nodes
  - Corrrelated and/or tied array data to datacente
- Datahandling
  - LOFAR as receptor
  - Storage
  - Post-processing
  - Calibration

Locations

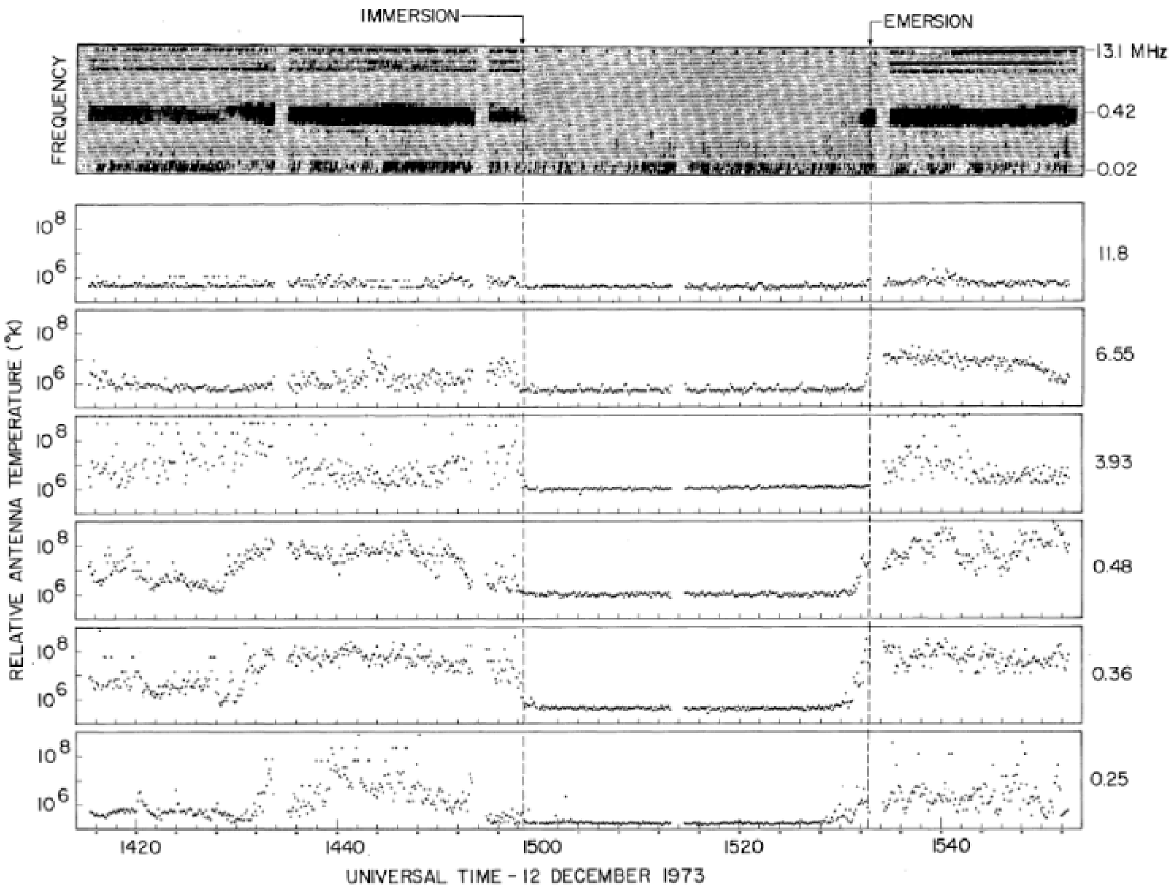
- Earth orbit
- Moon orbit
- L2
- Outer space



- Design considerations:
  - RFI from Earth
  - Constellation control (absolute and relative position)
  - Downlink to Earth
  - …

OLFAR

Shielding by the moon



Antenna systems

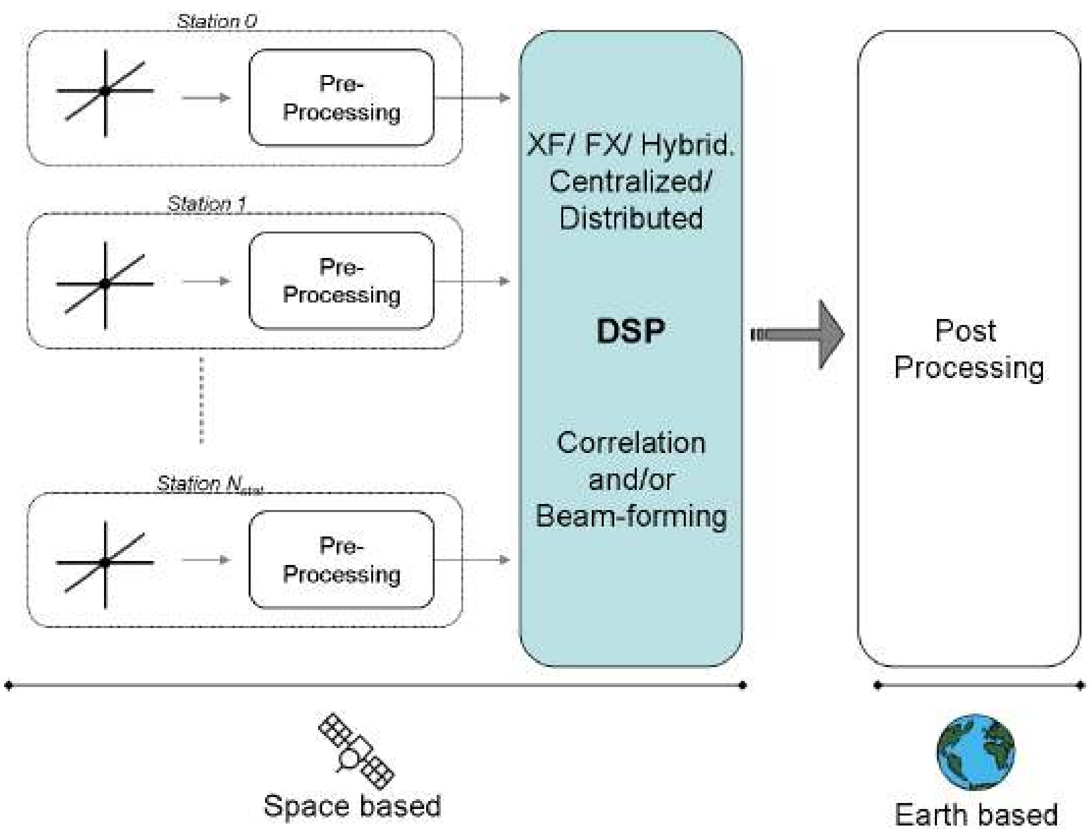
- Astronomical observing antenna
  - 0.3 – 30 MHz ➔ Wavelengths: 10 - 1000 meter !
  - Aperture
- Inter satellite link
  - Data rates (raw data – bandwidth of 100 kHz with 8 bits and all-to-all satellites is ~200 Mbps per satellite)
- Down link
  - Data rate is ~ 20 Mbps in case of correlation in space.
  - Possible use of diversity techniques

Formation flying

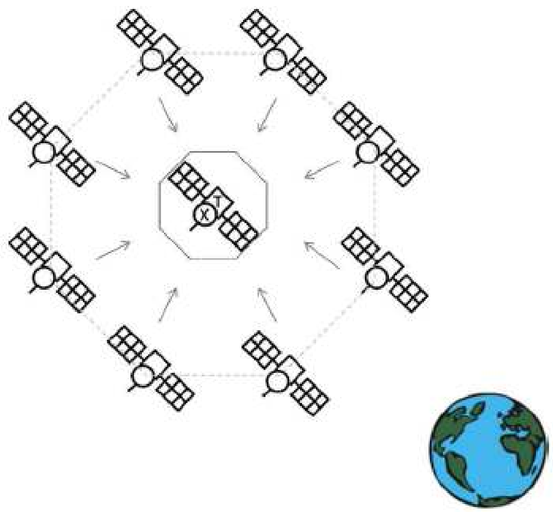
- Constellation must be limited to approx. 100 kilometers.
- Individual satellites can move slowly (as long as stable within integration time).
  - Constraint: given the integration time and the accuracy of 1/20th of the wavelength within the integration time.
- 5 years of operation

- This is currently under research (we consider L2 and moon orbit at this moment).

Data processing



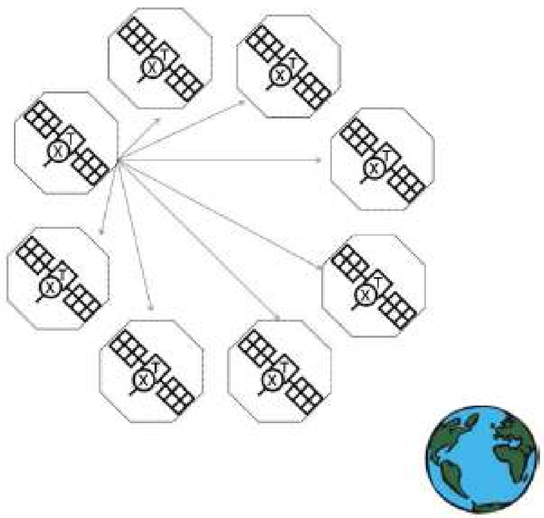
Signal processing



Centralized correlation, centralized downlink

- Correlation:
  - Distributed
  - Centralized
- Downlink
  - Distributed
  - Centralized

Signal processing



Distributed correlation,
Distributed downlink

- Correlation:
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  - Distributed
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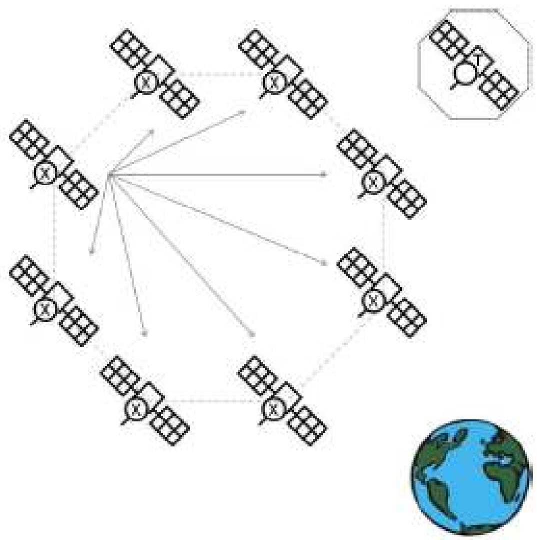
Signal processing



Distributed correlation,
Centralized downlink

- Correlation:
  - Distributed
  - Centralized
- Downlink
  - Distributed
  - Centralized

Example

- If case of 50 satellites
- 8 bit sampling
- Bandwidth of 10 MHz
- Integration time of 1 second

➔ Communicaton in bits/sec:

	Intersatellite	*Downlink*
Distributed correlation		
Distributed Transmission	235,2E+6	359,99E+3
Centralized Transmission	235,2E+6	18,0E+6

Planning

- 2009: concept study, start
- After that – detailed system design with focus on main issues:
  - Virtual distributed system and nano satellite architecture
  - Radio architectures for the communication in distributed arrays in space
  - distributed autonomous signal processing
- 2010/11: astronomical receiver in Delfi-N3xt
- 2013: flightunits available

Conclusions and future work

- OLFAR is a new concept of a low frequency radio telescope in space using small satellites.
- Correlation must be done in space.
- Distributed processing with centralized downlink transmission is the preferable option.
- Inter satellite link is the communication challenge.
- In 2010/2011 experiments with Delfi-N3xt.

Future work:

- Simulate the constellations in Moon Orbit en L2
- Virtual distributed system and nano satellite architecture
- Radio architectures for the communication in distributed arrays in space
- Distributed autonomous signal processing

Partners

ASTRON

Universiteit Twente
de ondernemende universiteit

TU Delft
Technische Universiteit Delft

Radboud Universiteit Nijmegen

EADS astrium

ISIS

Dutch Space
an EADS Astrium company

AEMICS

National Semiconductor

AXIOM IC TWENTE

SystematIC
Electronic and IC Design

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