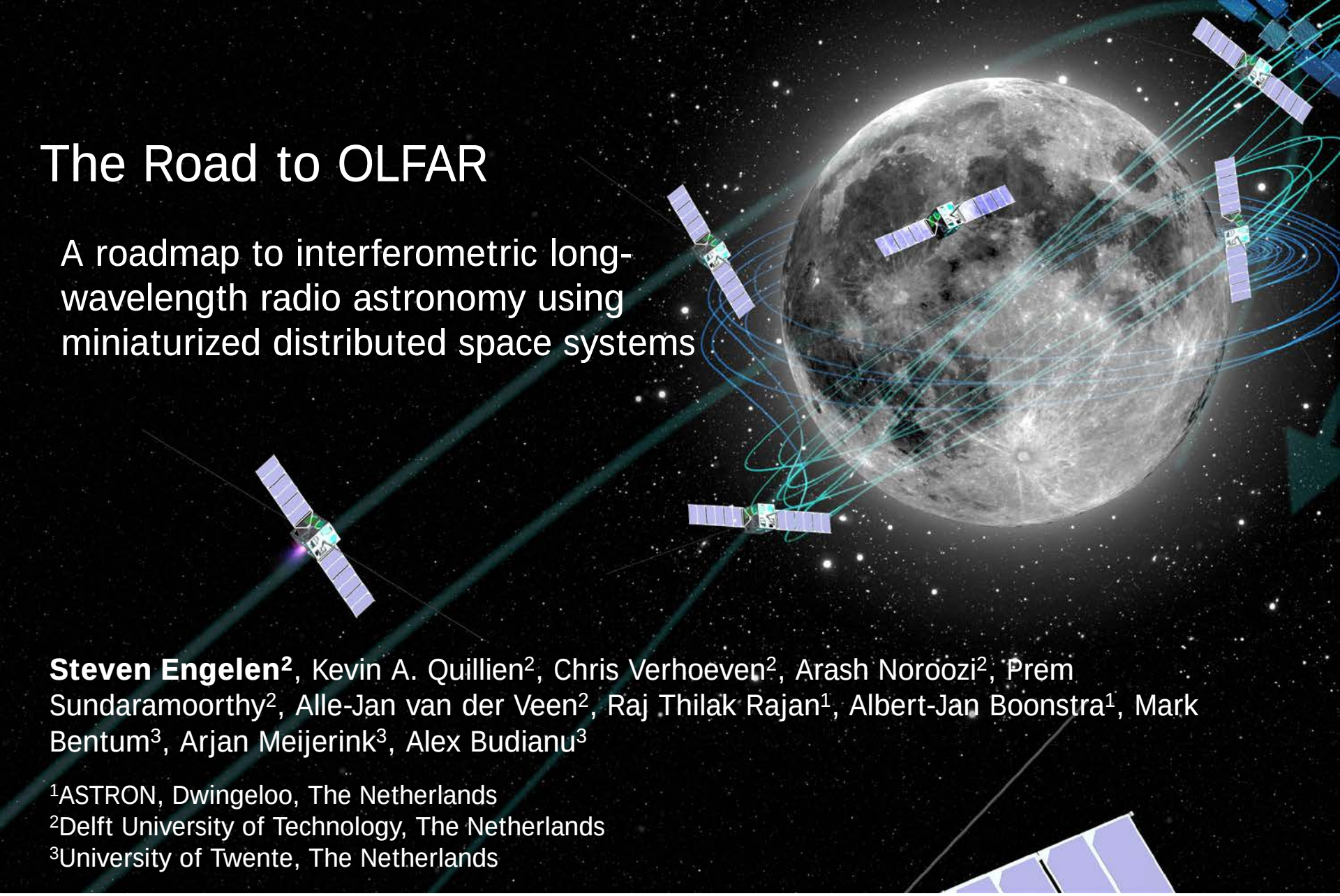
The Road to OLFAR

A roadmap to interferometric long-wavelength radio astronomy using miniaturized distributed space systems



Steven Engelen[2], Kevin A. Quillien[2], Chris Verhoeven[2], Arash Noroozi[2], Prem Sundaramoorthy[2], Alle-Jan van der Veen[2], Raj Thilak Rajan[1], Albert-Jan Boonstra[1], Mark Bentum[3], Arjan Meijerink[3], Alex Budianu[3]

[1]ASTRON, Dwingeloo, The Netherlands
[2]Delft University of Technology, The Netherlands
[3]University of Twente, The Netherlands

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Introduction

Low frequency radio astronomy

LOFAR: Low Frequency Array

- Range: 10-250 MHz
- Distributed sparse array
  - 26 stations on-line
  - 13 under construction
- Targets:
  - Epoch of Reionisation
  - Deep extragalactic surveys
  - Transient sources
  - Ultra high energy cosmic rays
  - Solar science and space weather
  - Cosmic magnetism

LOFAR node

Introduction

Low frequency radio astronomy

- Atmosphere not (fully) transparant below 30 MHz
  - Need for a space segment to augment LOFAR sensitivity at low frequencies
  - Space segment required anyway for

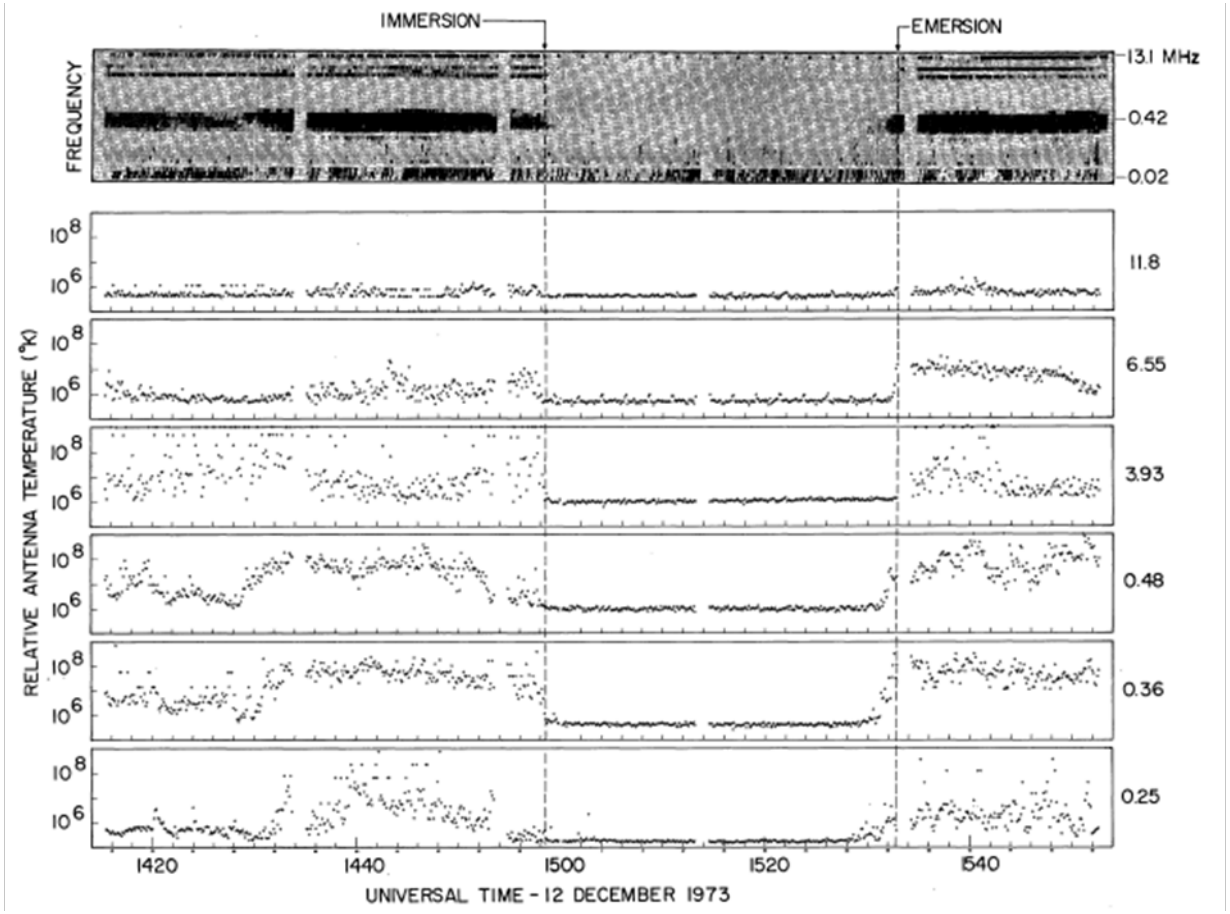
    frequencies below 20 MHz

- NASA launched RAE-1 into Earth orbit (1968)
  - Discovered the ionosphere is highly active
  - Earth emits very strong Kilometric Auroral Emissions

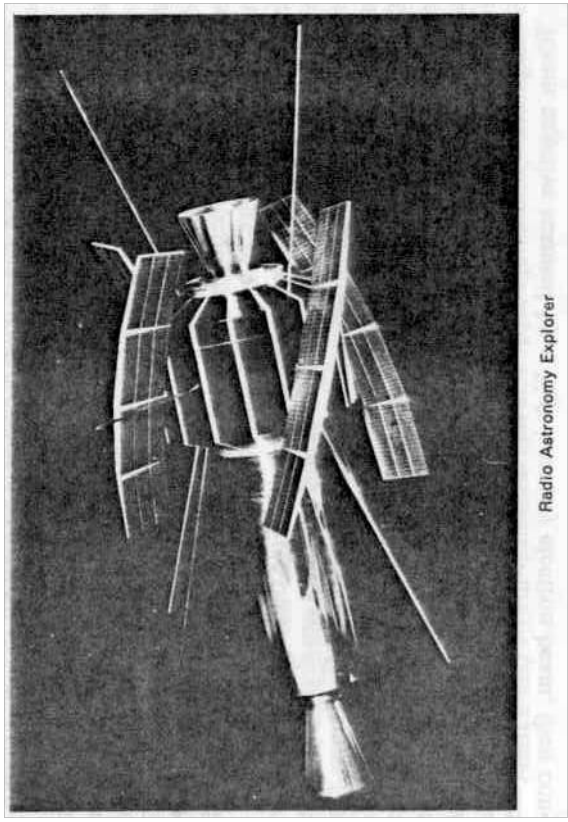
RAE-1

Introduction

Low frequency radio astronomy



Source: J.K. Alexander et al. (1975)



RAE-2

Introduction

Low frequency radio astronomy

- Extremely poor angular resolution: Angular resolution ~30°
- Strong diffuse Galactic emission

RAE-2 observations at 1.3 and 9.18 MHz,

Novaco & Brown,

1978

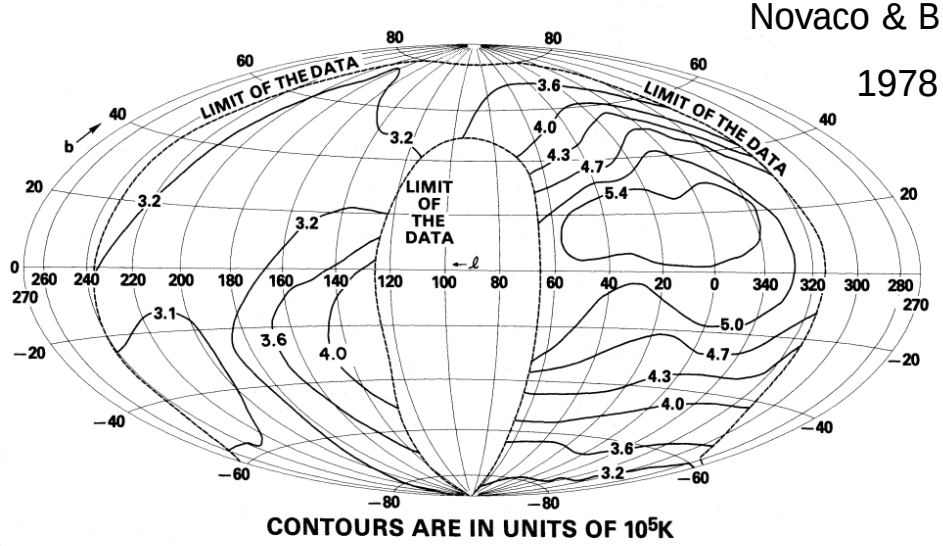


FIG. 3.—Contour map in galactic coordinates of the nonthermal emission observed by *RAE 2* at 9.18 MHz

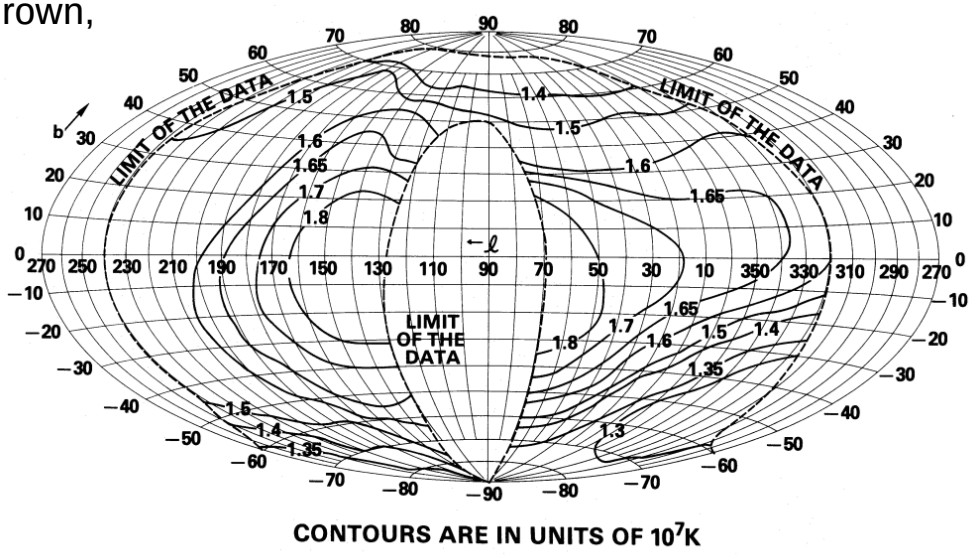


FIG. 8.—Contour map in galactic coordinates of the nonthermal emission observed by *RAE 2* at 1.31 MHz

The System

OLFAR – A Nano-Satellite Swarm for Radio Astronomy (1)

OLFAR system requirements

• Frequency range	0.3-30 MHz
• Number of nodes	>10, scalable
• Maximum baseline between nodes	100 km
• Spectral resolution	1 kHz
• Processing bandwidth	100 kHz
• Snapshot integration time	1-1000 s, depending on deployment location
• Instantaneous bandwidth	> 1 Mhz
• Survey sensitivity	< 65 mJy
• Deployment location	High Earth orbit, Lunar orbit, Lunar L2, Earth leading/trailing

The System

OLFAR – A Nano-Satellite Swarm for Radio Astronomy (2)

Why a nano-satellite swarm?

- Swarm:
  - A single monolithic satellite is impossible (100 km baseline)
  - Very high redundancy, low node complexity, high expandability, high autonomy
  - Propellant usage is less, or even non-existent due to lack of precise control
  - Radio interferometers ***prefer*** a random positioning of the antennas (in order to fill the U-V-W matrix more rapidly)
- Nano-satellites:
  - Cost driven (>10 elements required)
  - Basic functionality: They are radio receivers (technically feasible)
  - Access to modern, industrial components: very high performance and efficiency
  - Not without challenges though (long range, high bandwidth)

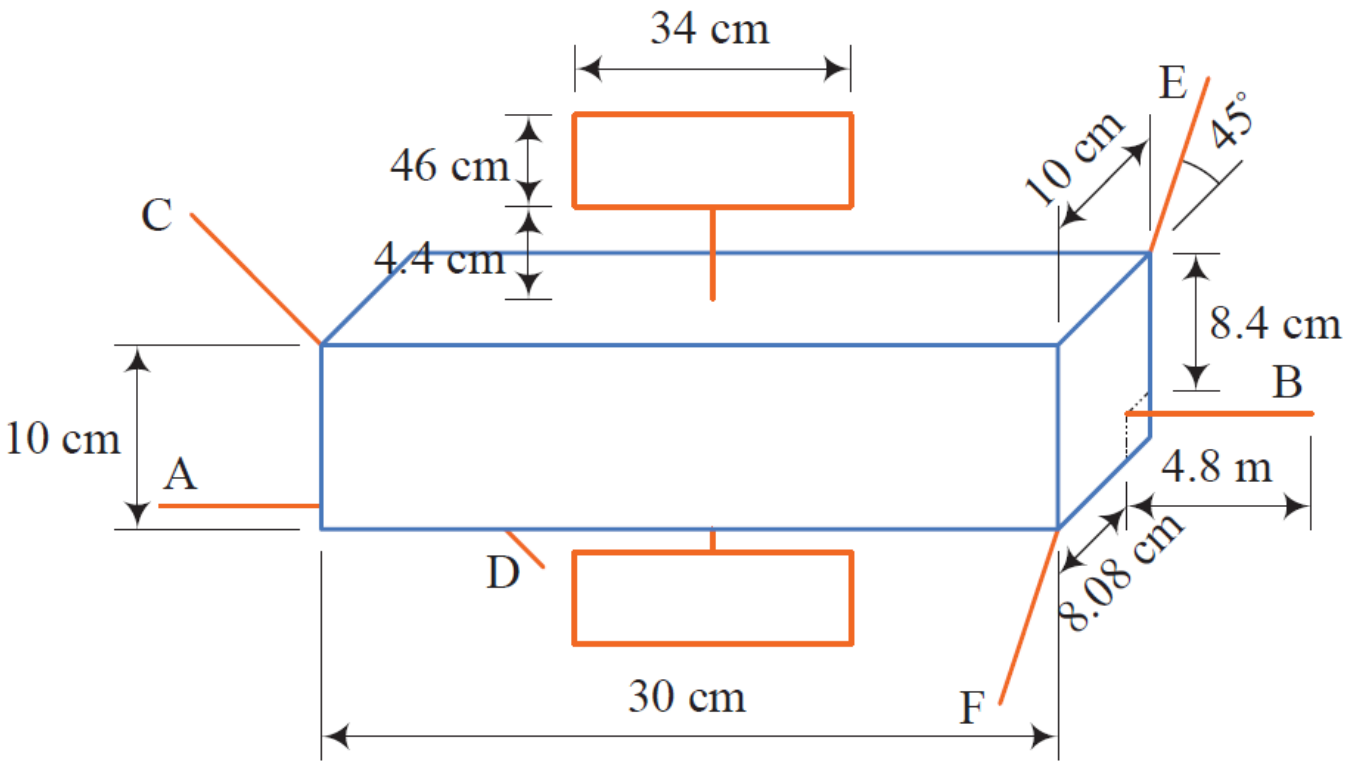
The System

Current status

- Solved issues:
  - Accurate timing/ time synchronisation and relative positioning
  - Storage and deployment of long antennas
  - Radio astronomy with a very small ground-plane
  - High bandwidth inter-satellite communication strategies
  - Large area, low cost solar panels, with integrated down-link antennas
  - Swarm reliability assessments
  - Orbital analysis for lunar orbit cases and transfer orbits. Lagrange orbits underway.

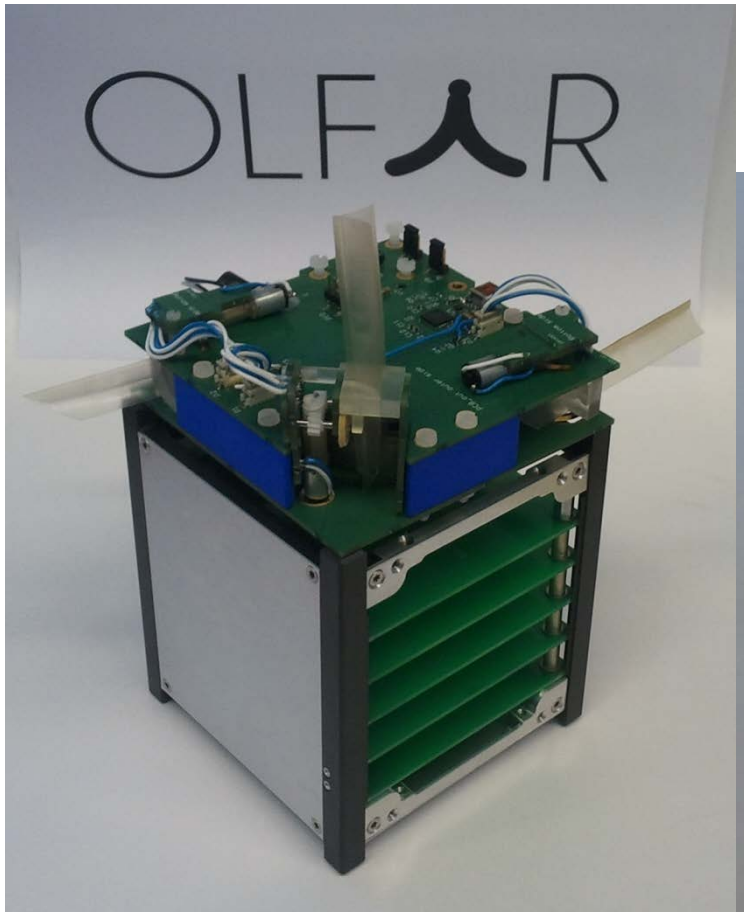
The System

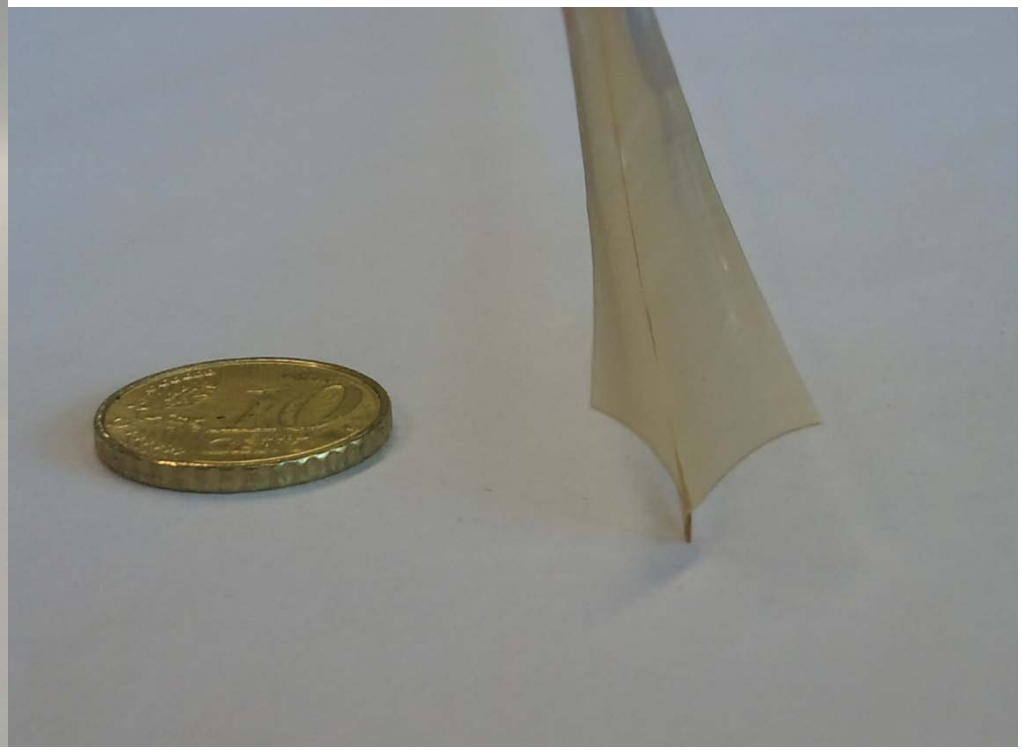
Current status



The System

Current status





The System

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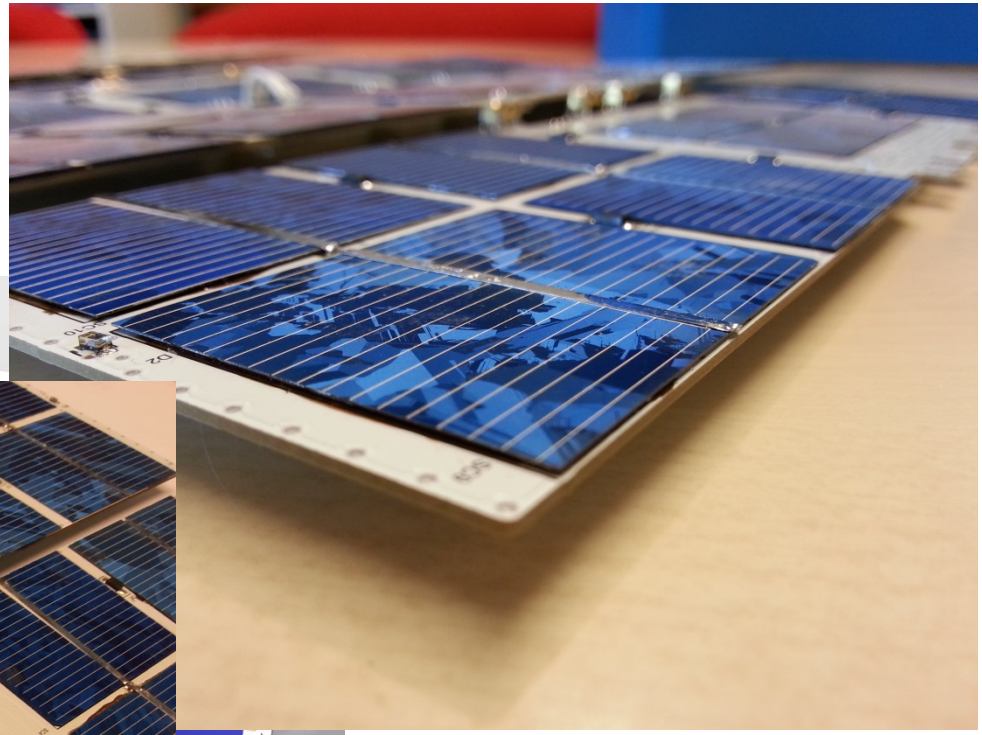
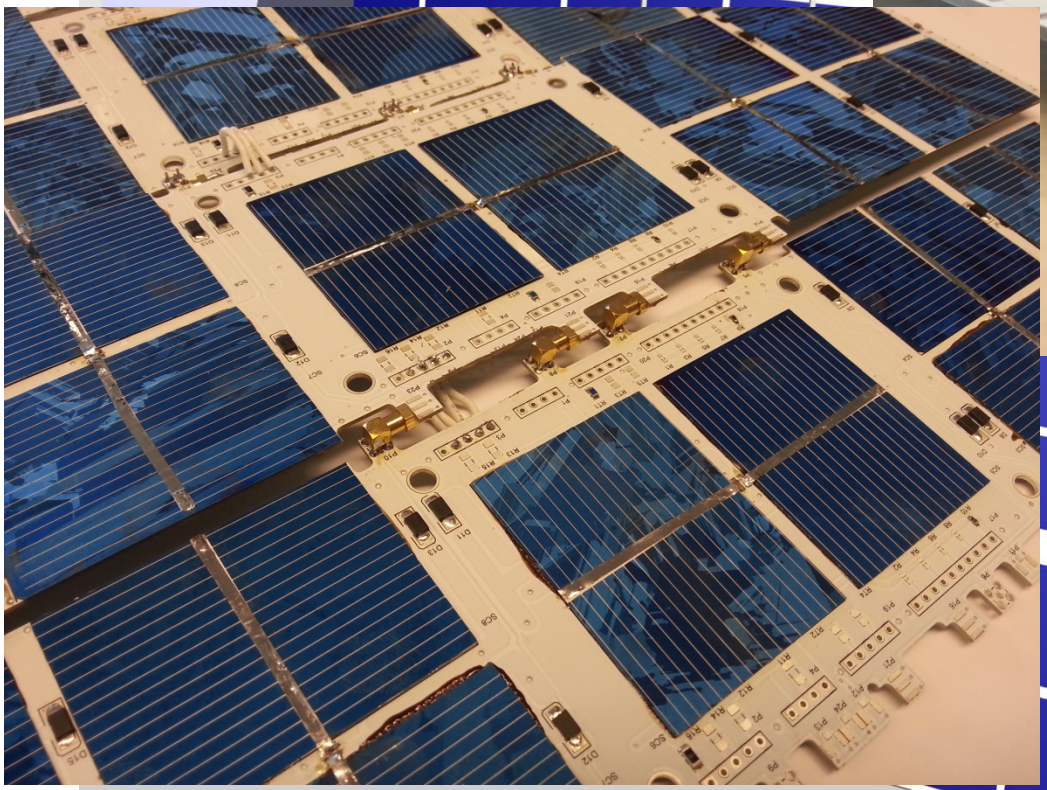
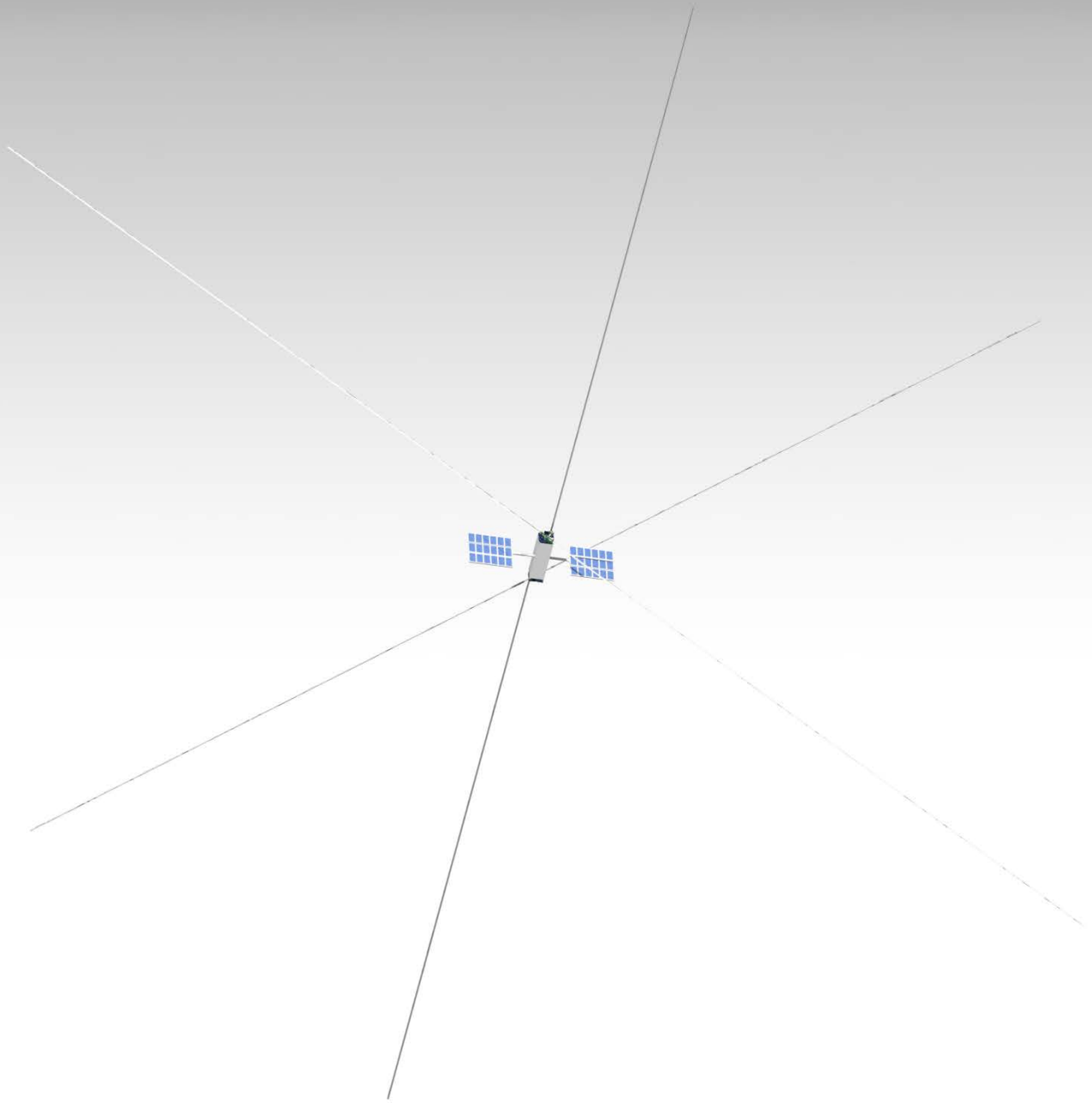






Open Items

Orbital location

Reason for space mission is RFI situation

- Actual RFI levels unknown
- Type/properties of RFI unknown
- RFI in different orbits unknown

⇒Orbital location cannot be fixed
⇒Bandwidth requirements depend on on-orbit RFI mitigation

- Lunar orbit perfect, except for integration times

⇒Very hard to do

Open Items

Imaging with a satellite swarm

OLFAR is to form a radio telescope

- No known methods for 3D imaging have ever been proven
- Current ideas are all very computationally intensive and require huge inter-satellite bandwidth

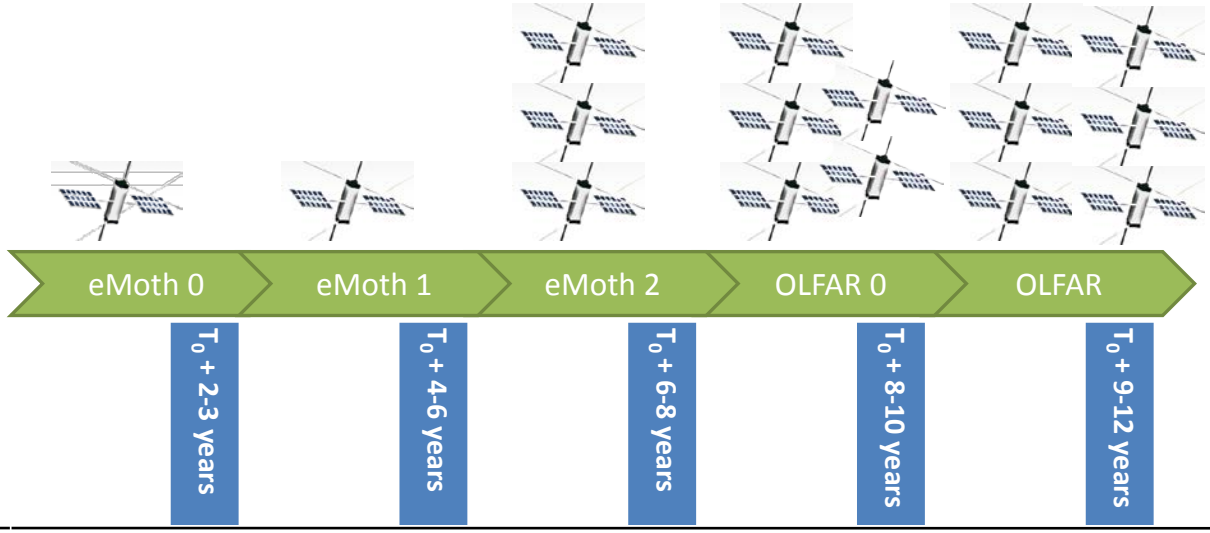
- Swarm autonomy is still in the research stage
- Satellite swarms have never been built

⇒OLFAR will require precursor missions to act as pathfinders

Roadmap

Pathfinders should prove/investigate:

- Technology demonstrators for advanced nano-satellites
- Operation in relevant environment (past Van Allen belts)
- (autonomous) Orbit and swarm maintenance and control
- RFI properties in potential deployment locations
- (autonomous) Interferometry in space



Conclusions

- Key milestones to reach the goal of Low Frequency Radio Astronomy from space have been identified
- Quite some technological challenges still ahead
- Pathfinder missions required to reduce development risk for OLFAR
- Gradual build-up of OLFAR is possible, reducing risk and initial cost