LOw Frequency ARray

…a forerunner of SKA

ASTRON – MIT – NRL

Please recall…

Two fundamental features of radio detection:

- **E** is recorded (instead of the energy)
  - *all-sky*, *aperture plane* signal registration is feasible
- Copies of signals come *noise free!*
  - multiple processing of same signal is possible

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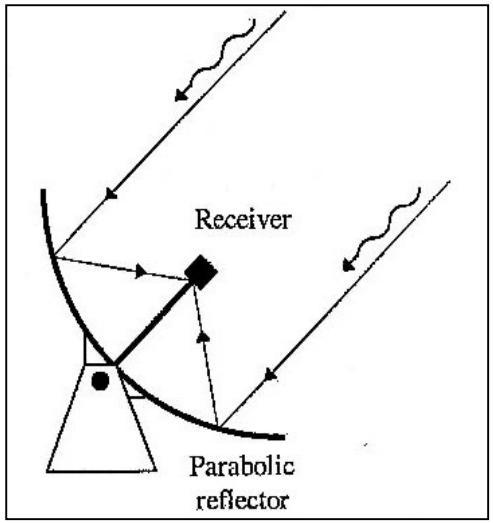
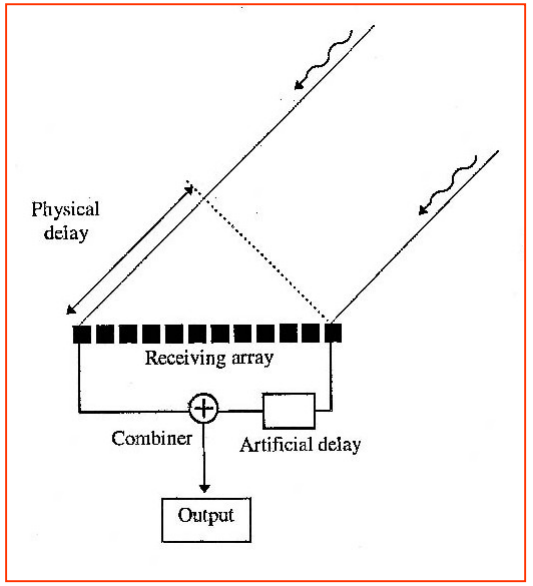


Image plane detection



Aperture plane detection

- *Mechanical* vs *electronic* signal combination
  - electronic signal processing decreasing rapidly in cost
    - *interesting for SKA*
  - new possibilities for wave-front manipulation
    - *adaptive beam shape control*
      - improved calibration, interference suppression
    - *multiple, simultaneous, independent primary beams*

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“Fully electronic” SKA

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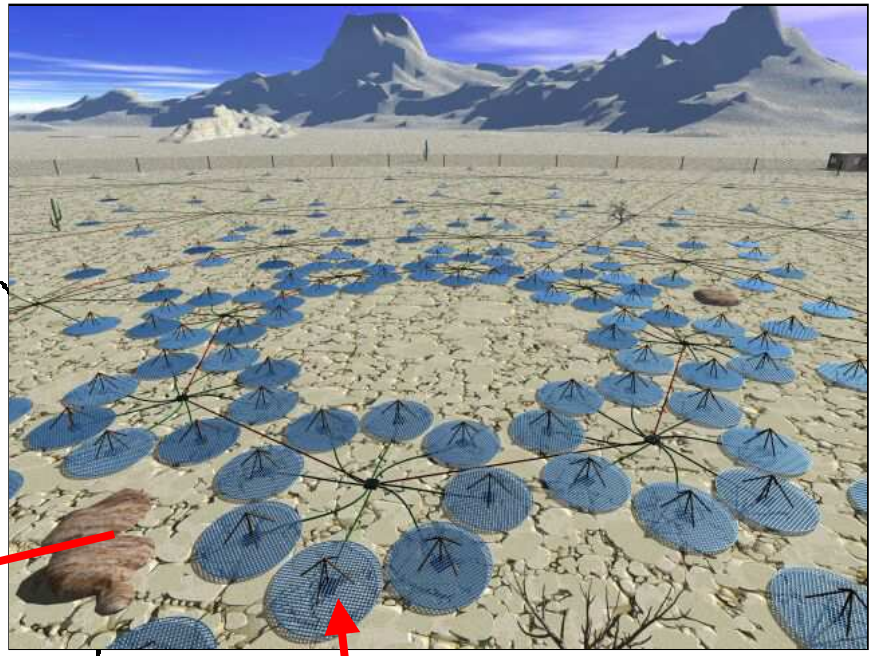
LOFAR antennas

25% of antennas in central core



Station

LOFAR element

LOFAR

LOFAR antennas

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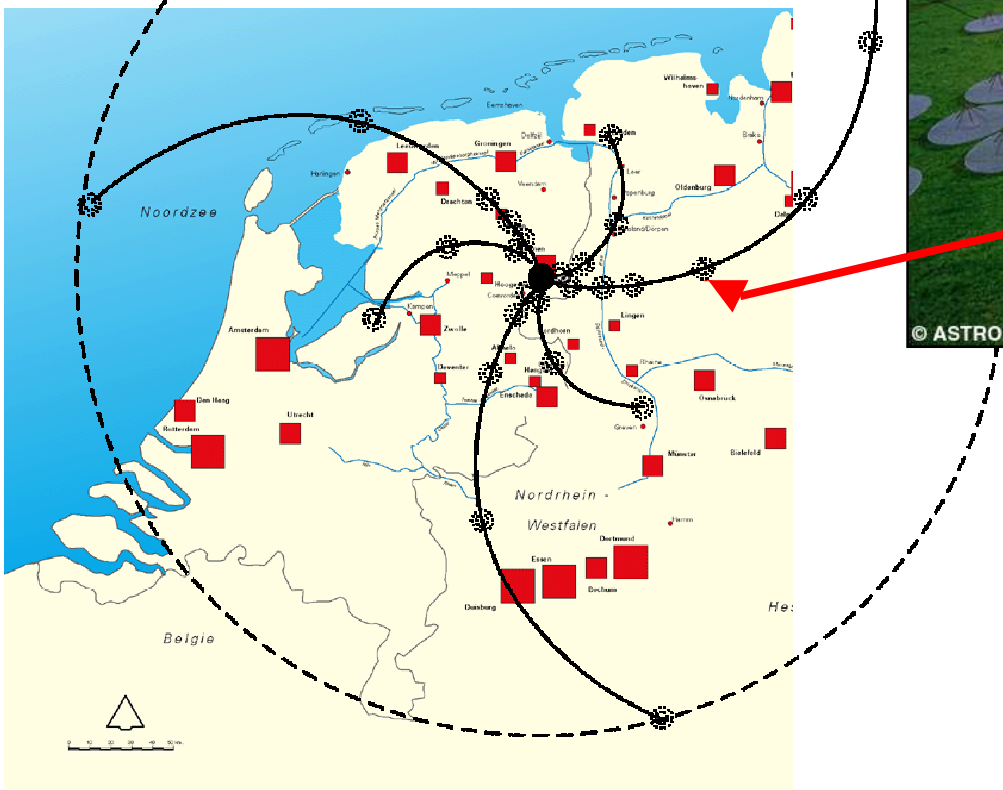

Station

LOFAR element

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LOFAR Specs

- Frequency range — 10 – 240 MHz
- 6 arm log-spiral array configuration — ~ 75 stations
- Arcsec angular resolution
  - total extent ~ 400 km
- Element antennas — 13000 x 2 sets
  - Lo range: active dipoles ($A_{eff} \sim \lambda^2$)
  - Hi range: resonant dipoles (3x3 arrays)
- High capacity fiber links — < 16 Tb/s/fiber
- Beamformer/correlator
  - COTS processor array with custom elements
- Operation over Internet: web-based community
- Up to 8 simultaneous, independent primary beams
- Interference suppression

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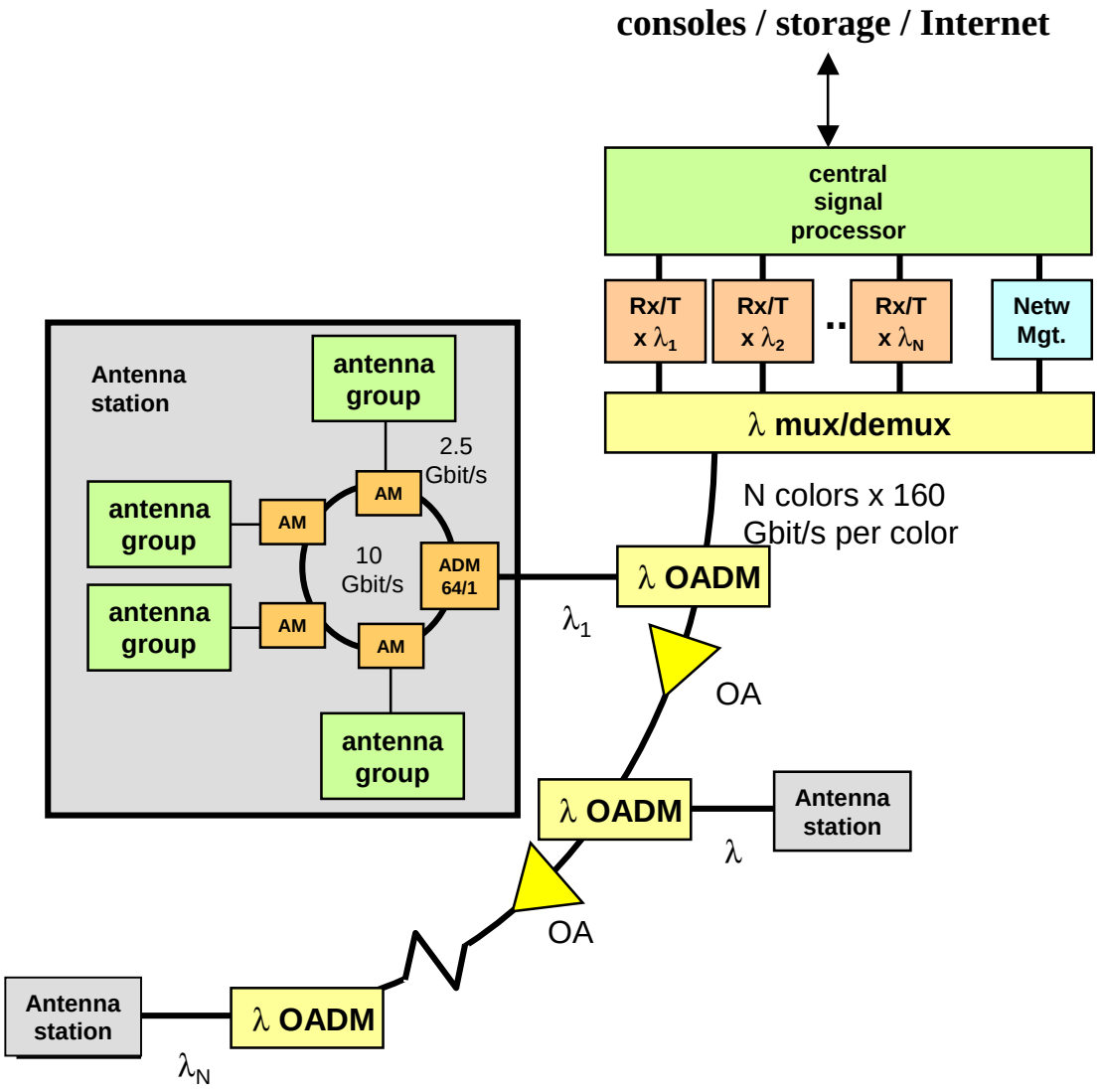
LOFAR DWDM network concept



- λ OADM : flexible wavelength add-drop multiplexer
- ADM, AM: SDH add-drop multiplexer
- OA: optical amplifier

➢ Scalable design to trade BW for cost

Performance Specs

Frequency (MHz)	**A_{eff} (m^2)**	**T_{sys} (K)**	**Sensitivity (mJy)** (1 sec, 4 MHz)	**Resolution (arcsec)**
15	$1.3\ 10^6$	131,000	98	12
30	$3.3\ 10^5$	23,000	68	6.2
75	$5.2\ 10^4$	2450	46	2.5
120	$3.3\ 10^5$	820	2.4	1.5
200	$1.2\ 10^5$	270	2.2	0.9

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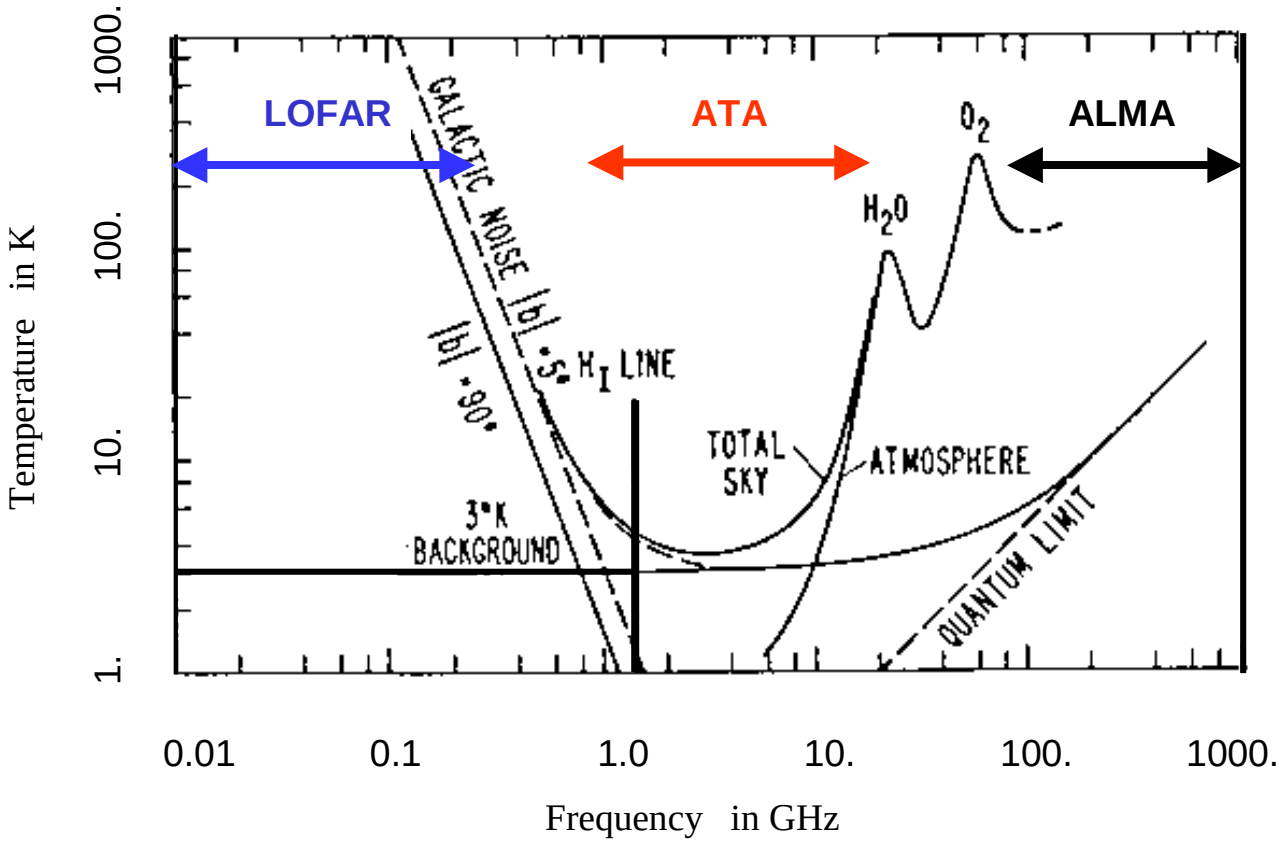
Noise Regimes



Sky noise dominates for LOFAR

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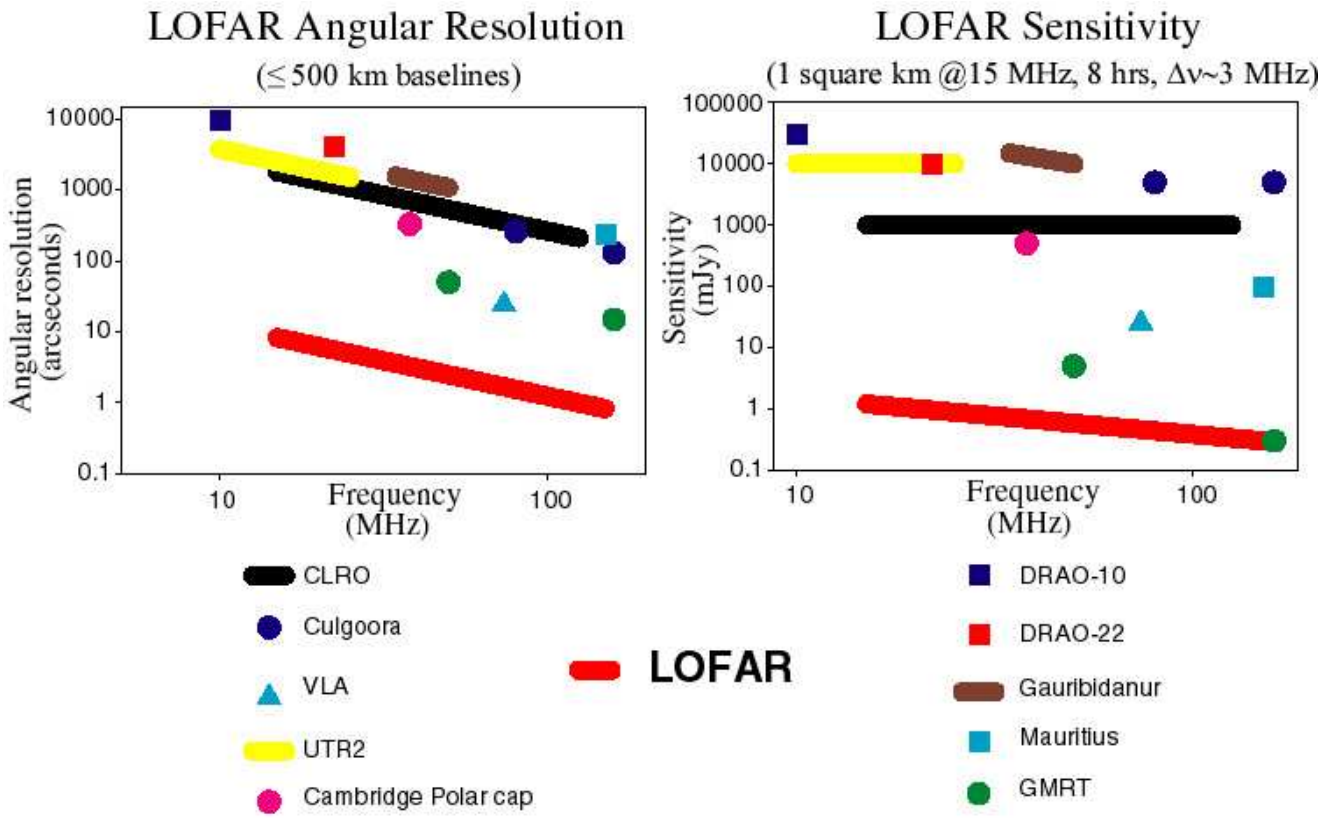
Comparisons



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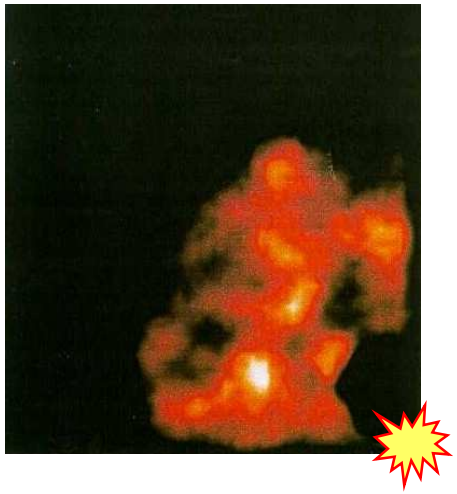
LOFAR Science



- Sky Survey at high (few arcsec) resolution
  - 30 - 50 MHz
  - high redshift Universe, galactic astronomy
- Transient signals
  - new science (coherent processes)
  - signal replay buffer
- Detection of re-ionization signal
  - warm atomic hydrogen at z • 7 (21cm → ~2m)
- Cosmic rays
  - LOFAR , γ-rays map same electrons in Galaxy, with/without **B**, HI
  - high energy (• 10^{17} eV) particle events in Earth's atmosphere
- Solar, space, atmospheric physics
  - passive imaging of Sun, IPS imaging of solar wind
  - radar imaging of Sun

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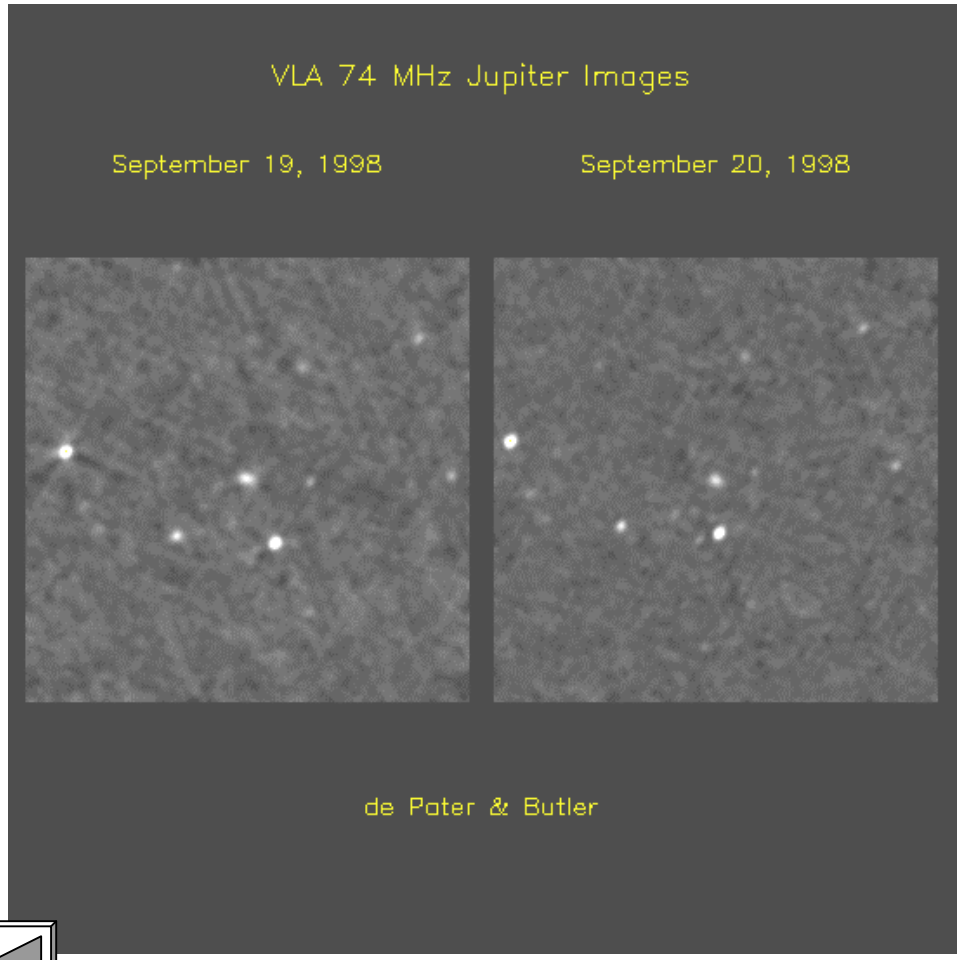
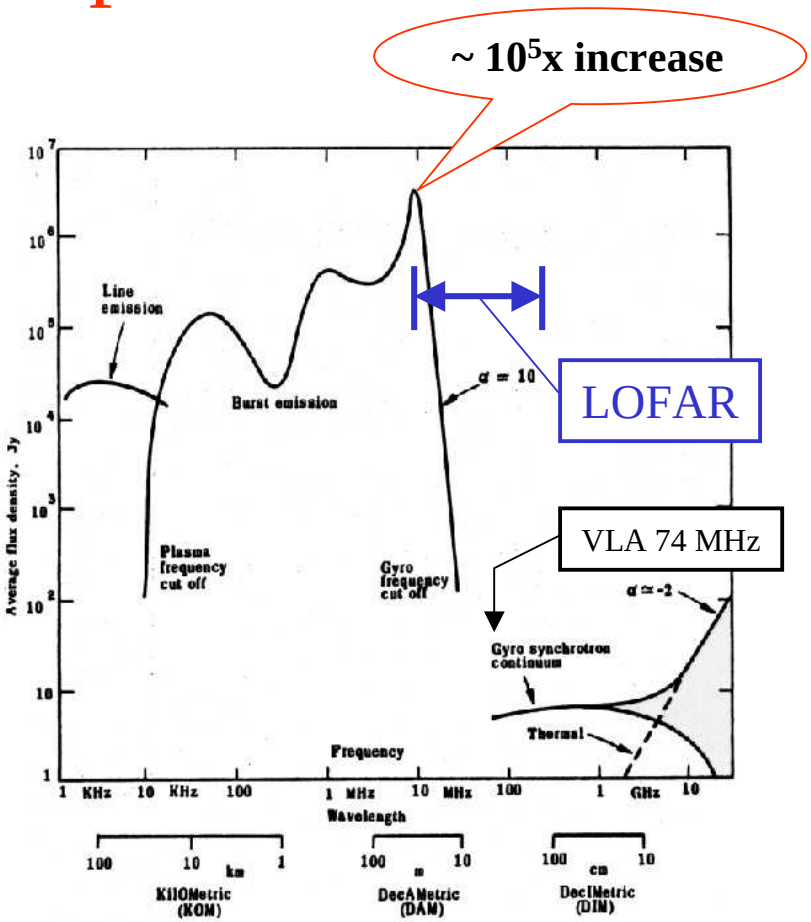
Coherent emission processes





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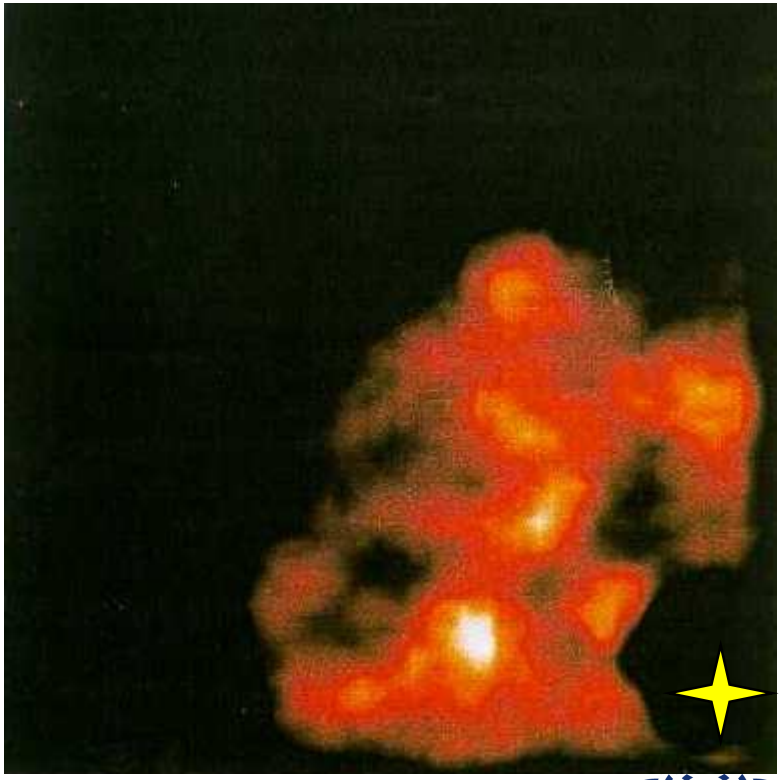
Re-ionization

- First objects
  - warm IGM locally
  - provide Ly-α field
- Ly-α photons couple thermal, 21cm radiation fields
- Predicted freq ~ 130 MHz
- Signal $\delta T / T \sim 5 \times 10^{-5}$ on arcmin scales



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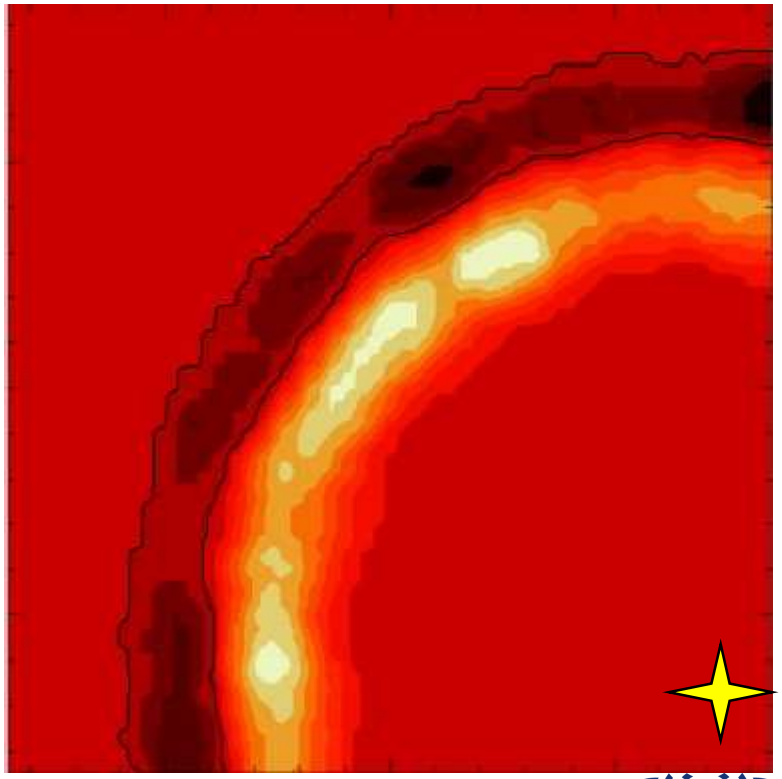

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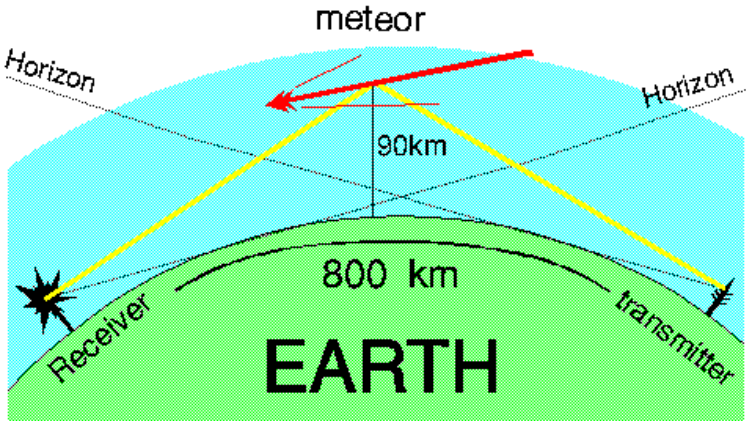
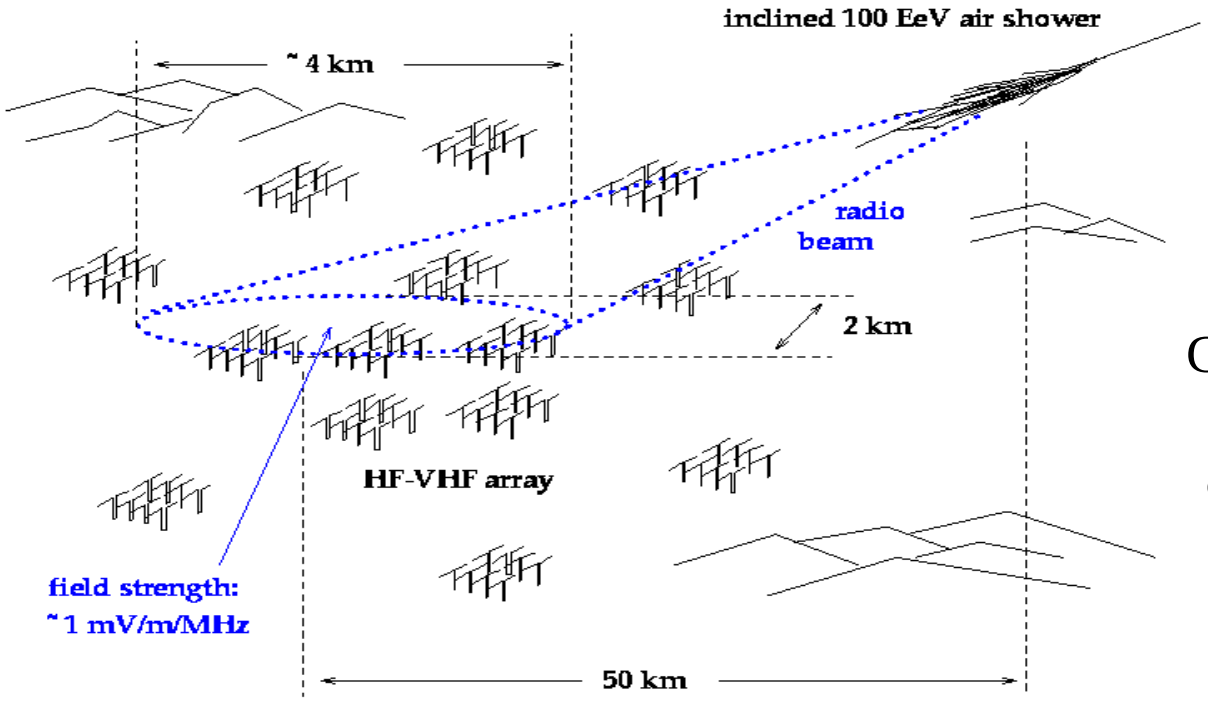
Detecting particles in Earth's atmosphere



Meteor events using radar



Cosmic Ray events using intrinsic coherent emission (MJy in nsec)

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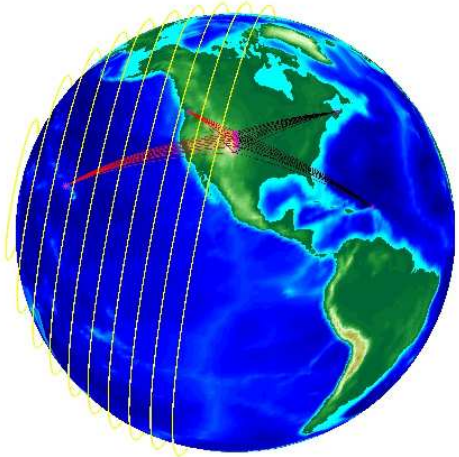
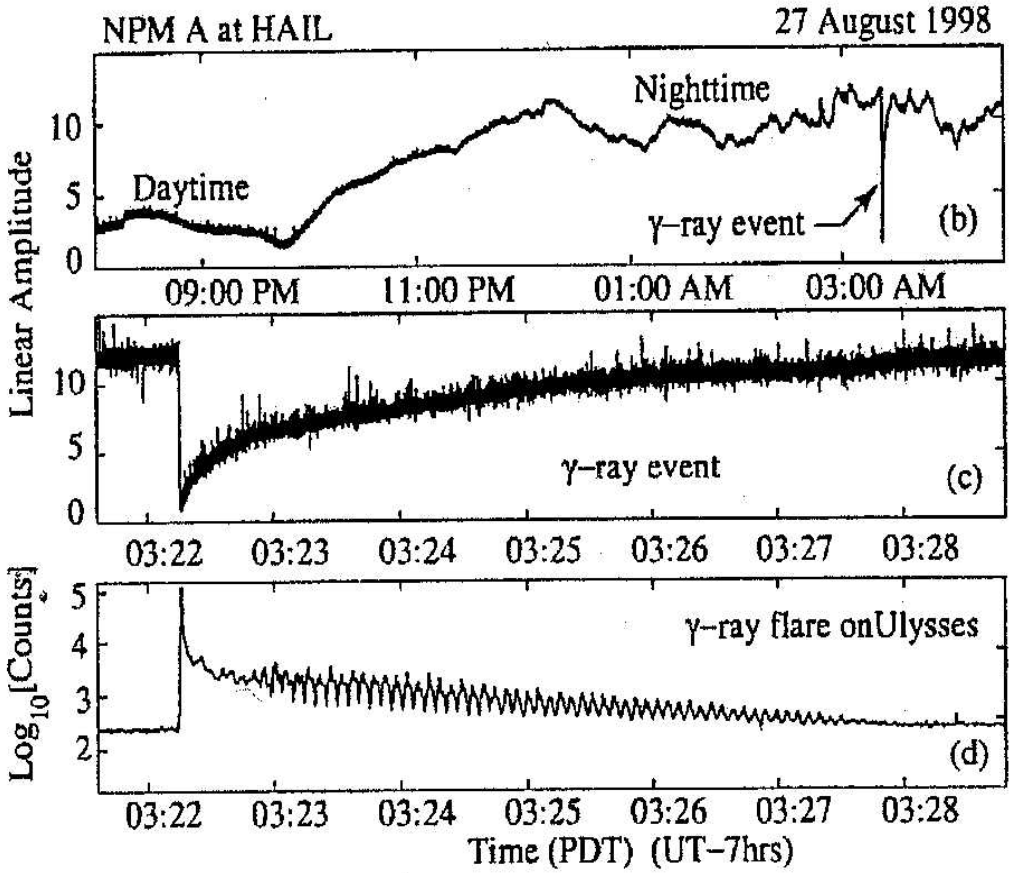
Ionosphere as γ-ray detector

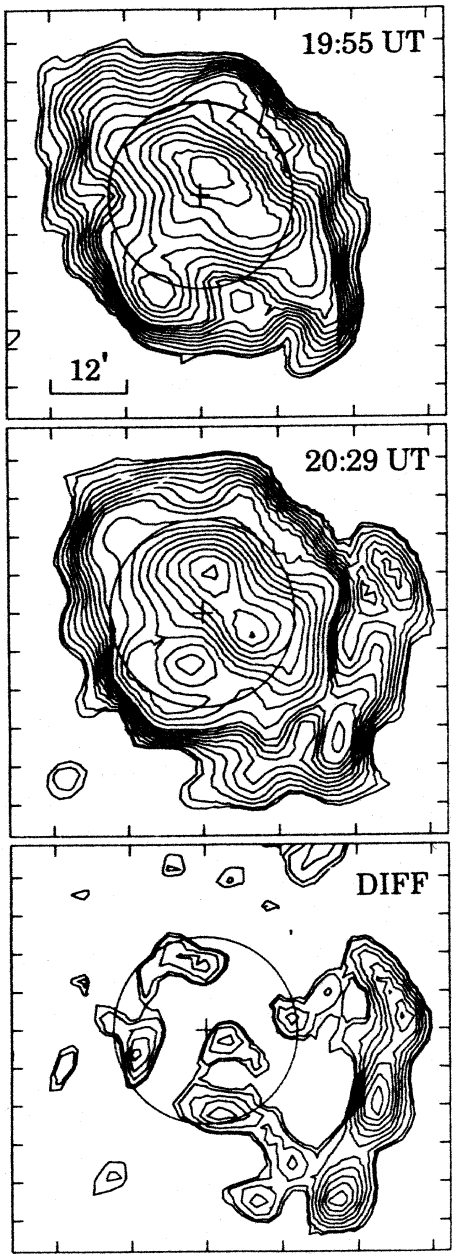
- Magnetar event 1998
  - affected Short Wave signal reflection from ionosphere

Direction of burster

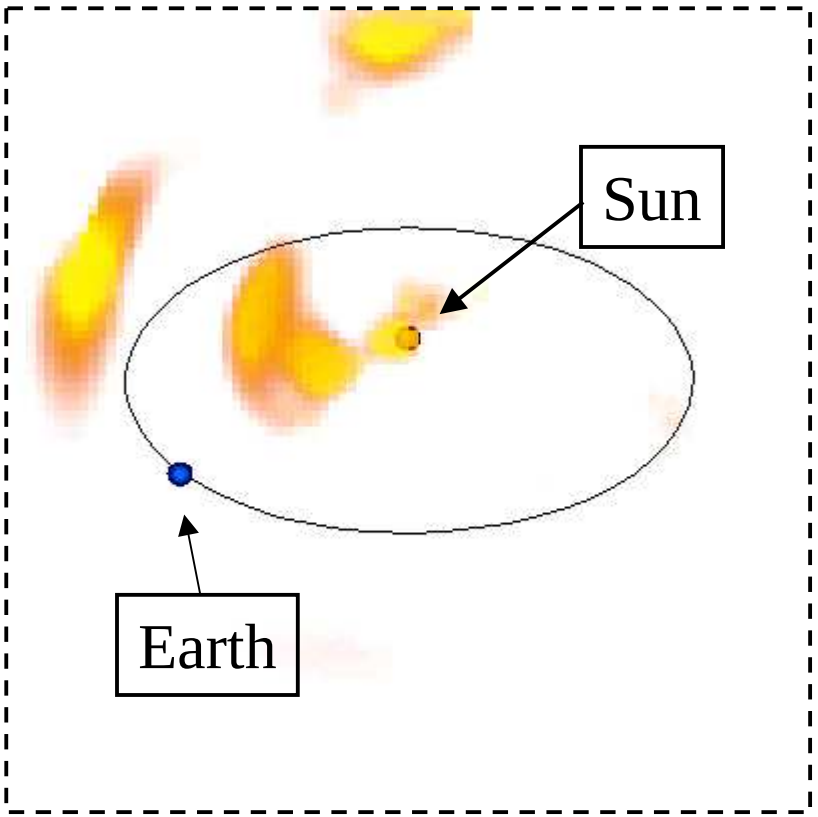




Coronal Mass Ejections and Space Weather



Continuum



Solar Wind observed via
Radio Source Scintillation

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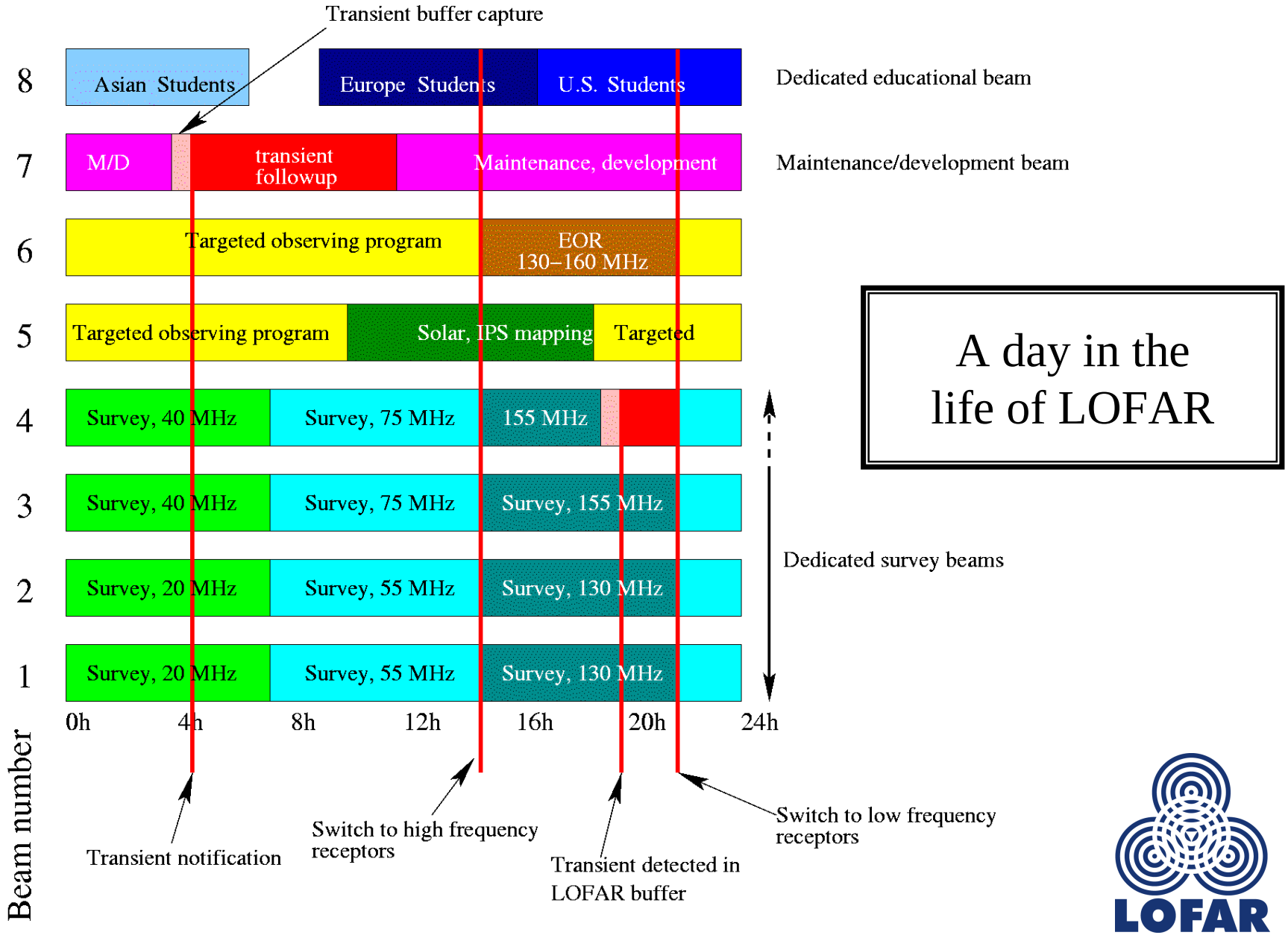

A day in the life of LOFAR

LOFAR

Project planning

- Schedule
  - 2003 begin construction
  - 2006 begin observations
    - during solar minimum, quiet ionosphere for deep Sky Survey
- WBS, costing, risk analysis, etc
  - 1st version in 2000, review 3Q 2001
- Engineering Consortium
  - ASTRON, MIT, NRL
  - *US$ 15M* committed (2Q 2001)
  - *US$ 70M* total required
- Science Consortium
  - enquiries from > 20 university and institute based groups
  - diverse scientific interests, research cultures

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LOFAR related talks/posters

• Jaap Bregman	Technical concept
• Joseph Lazio et al.	Progress at NRL
• Kjeld van der Schaaf, Marco de Vos	Central processing
• Roger Capallo	Large array processing
• Dion Kant, Sylvain Alliot	Scalable processor designs
• Marco de Vos	System software
• Jan Noordam	Calibration issues
• Shep Doeleman	Simulation of large N array
• Jan Noordam	Array configurations
• Willem Baan	Siting Studies
• Albert Jan Boonstra, Willem Baan	RFI Mitigation
• Dion Kant	LOFAR Lo antenna

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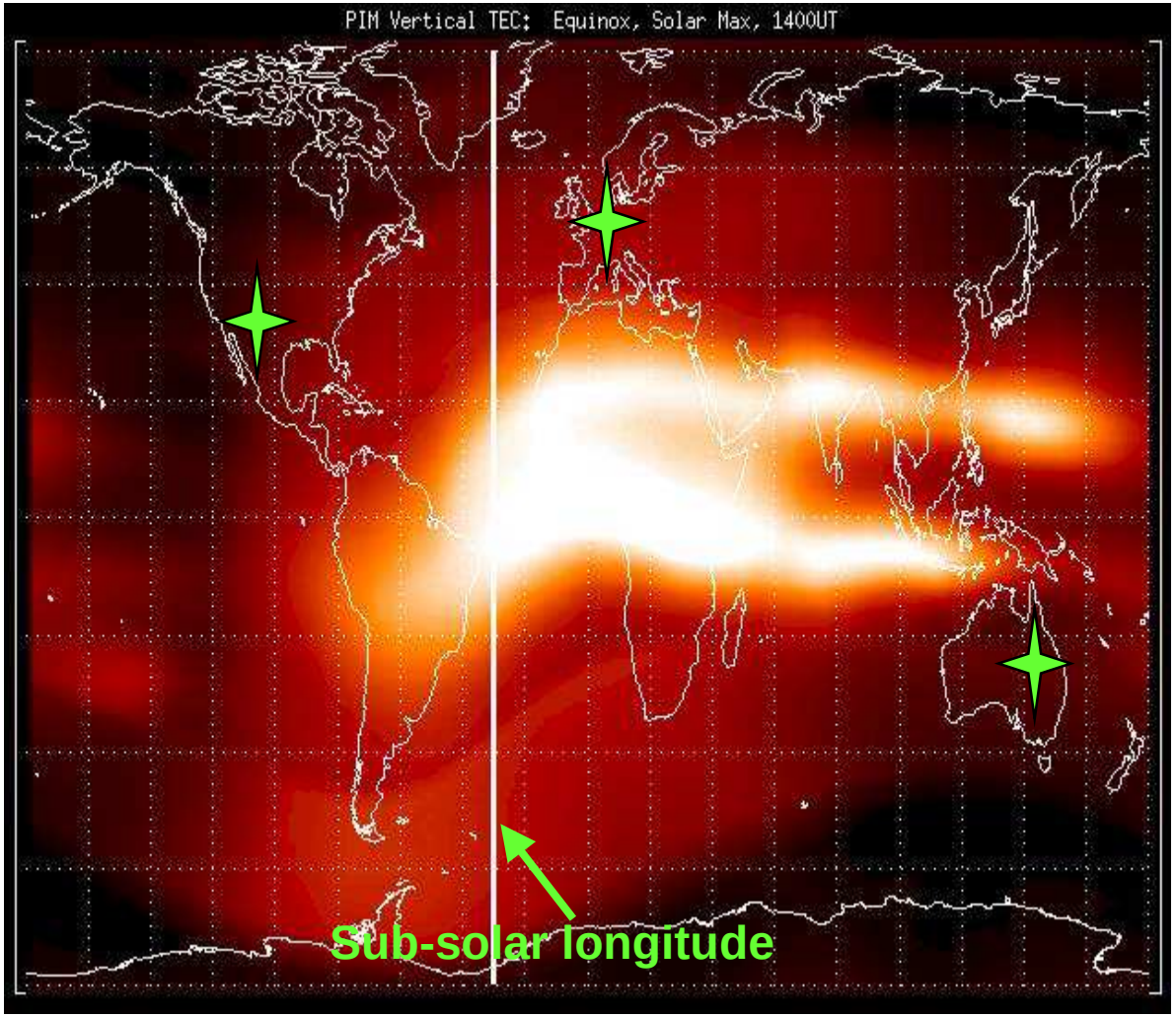
Model by Bob Campbell



Total Electron Content pattern in ionosphere
follows magnetic equator during day

Siting:

Mid-latitudes are preferred:

avoid magnetic equator and auroral rings

Australia
Netherlands
Texas

Cost could prove decisive

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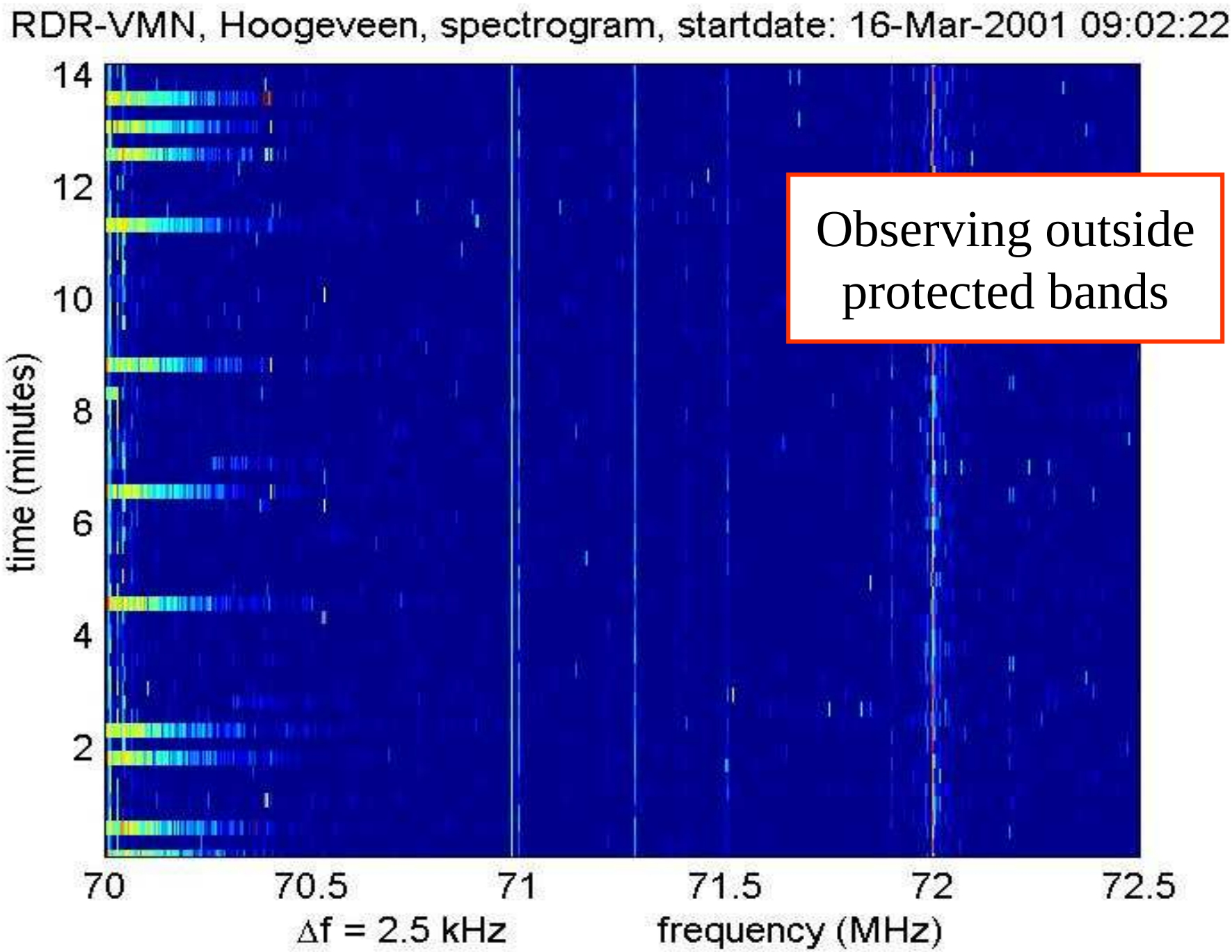
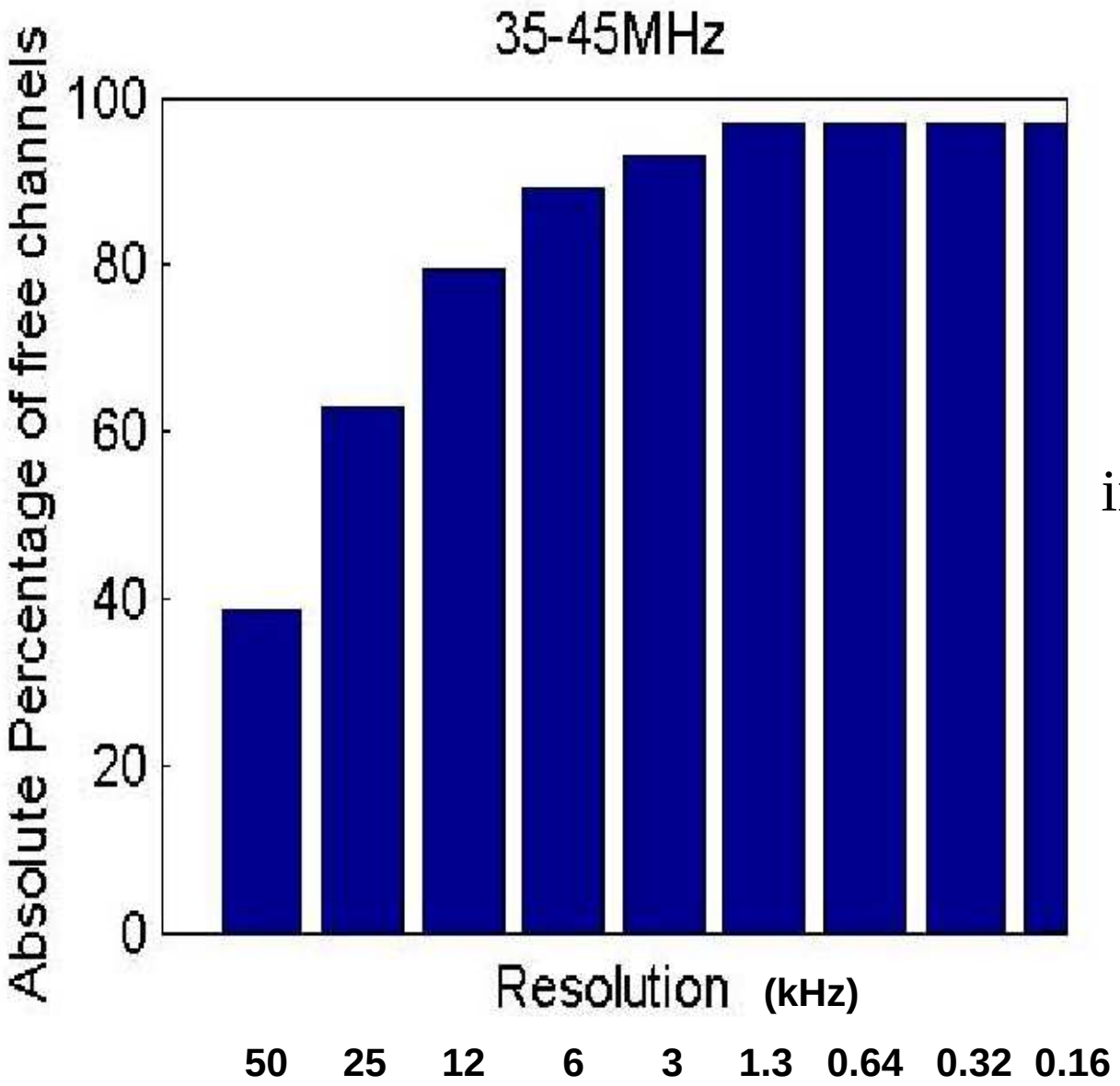

RDR-VMN, Hoogeveen, spectrogram, startdate: 16-Mar-2001 09:02:22
14
12
10
8
6
4
2
time (minutes)
70
70.5
71
71.5
72
72.5
Δf = 2.5 kHz
frequency (MHz)
Observing outside protected bands



1 kHz LOFAR spectral resolution is chosen for interference excision

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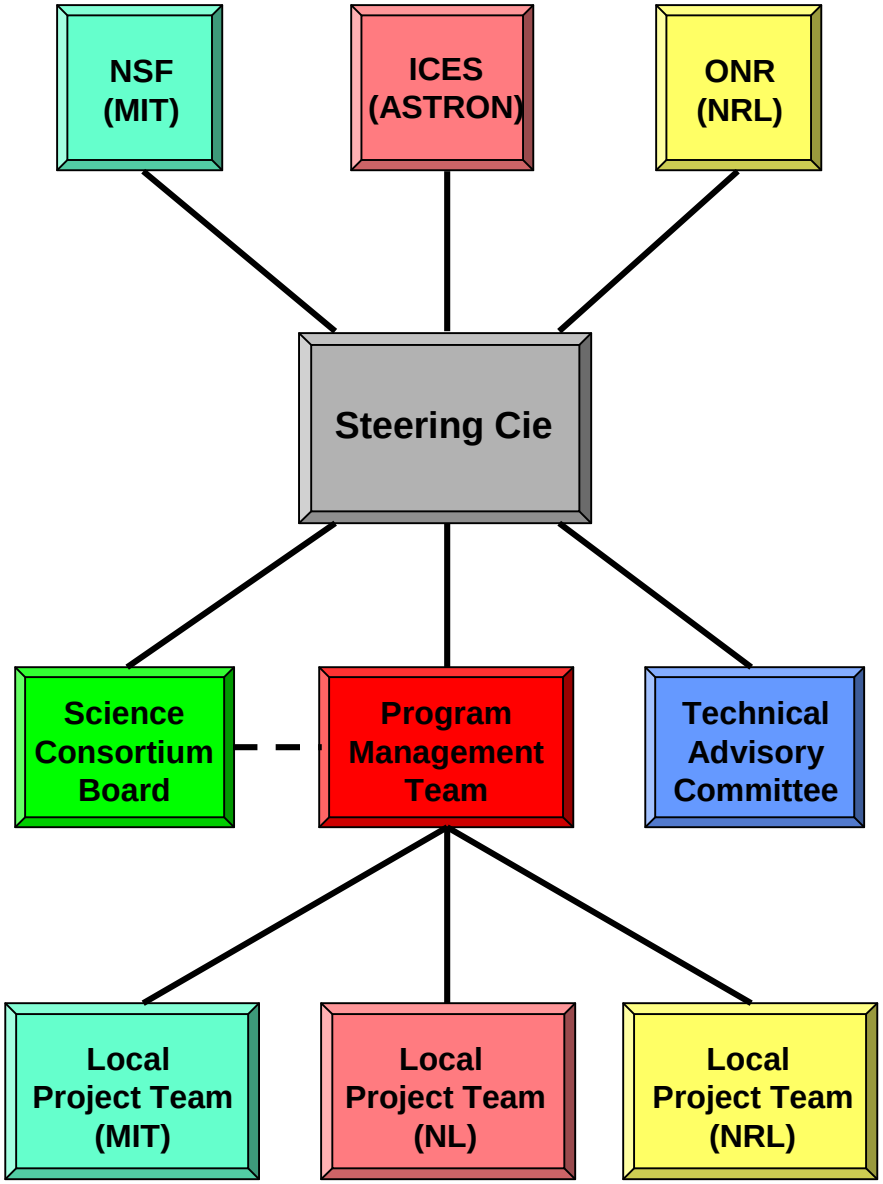

Management Structure

- 3 funding agencies in 2 countries
  - 3 institutes: ASTRON, MIT, NRL
  - funding to Local Project Teams
  - "no-exchange-of-funds"
- Joint Steering Committee
  - Institute directors
- Engineering Consortium
  - Joint Program Mgt Team
  - coordinates Local Project Teams
  - system engineering
- Science Consortium
  - community involvement
  - through Science Consortium
  - research, training and outreach
- Independent reviews

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