University of Hertfordshire

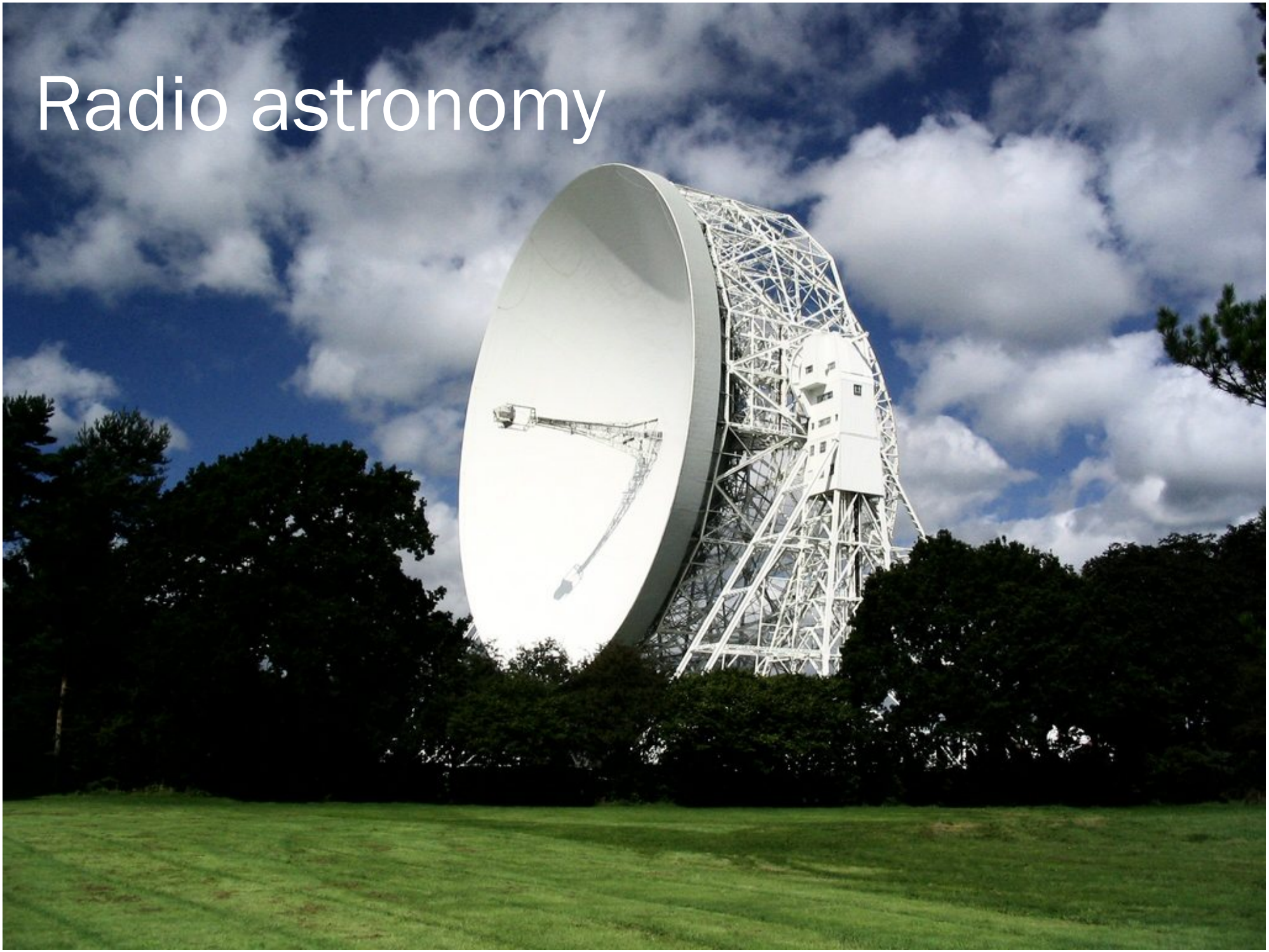
LOFAR

the role of the network in the world's first software telescope

Martin Hardcastle, U. Hertfordshire and LOFAR-UK

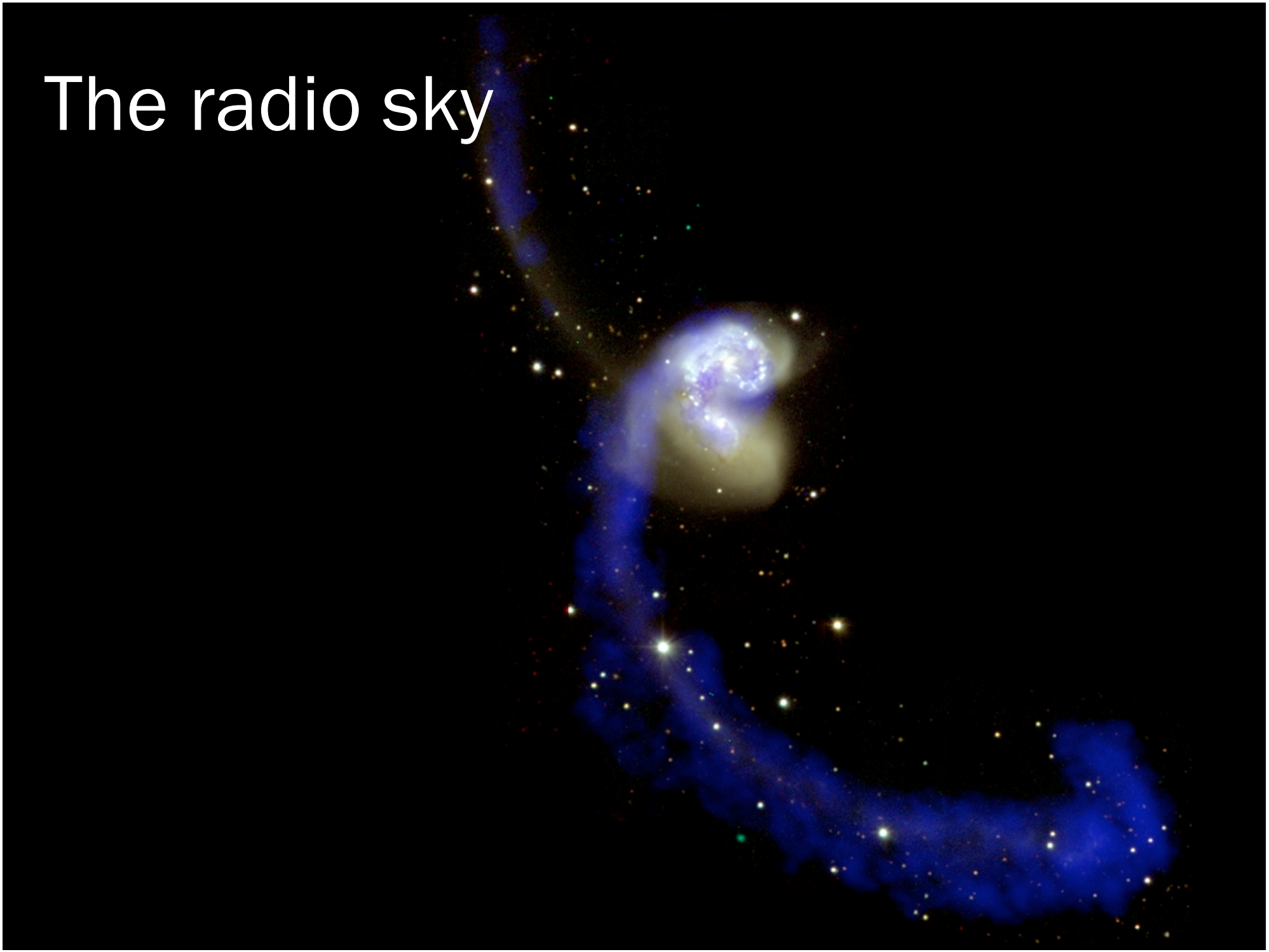
Thanks: Derek McKay-Bukowski, Alan Doo, and the LOFAR-UK collaboration

Radio astronomy



The radio sky

The radio sky



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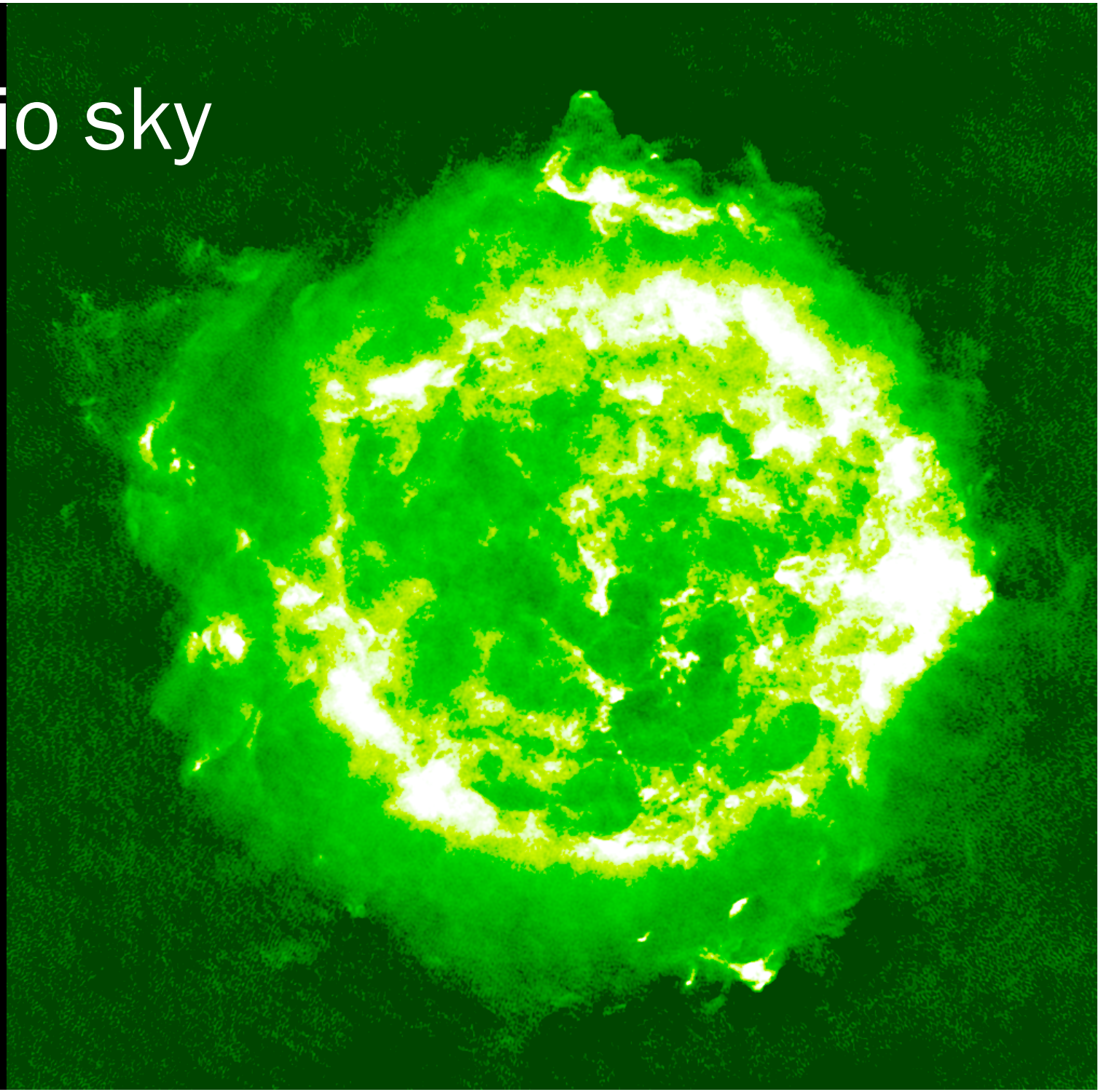
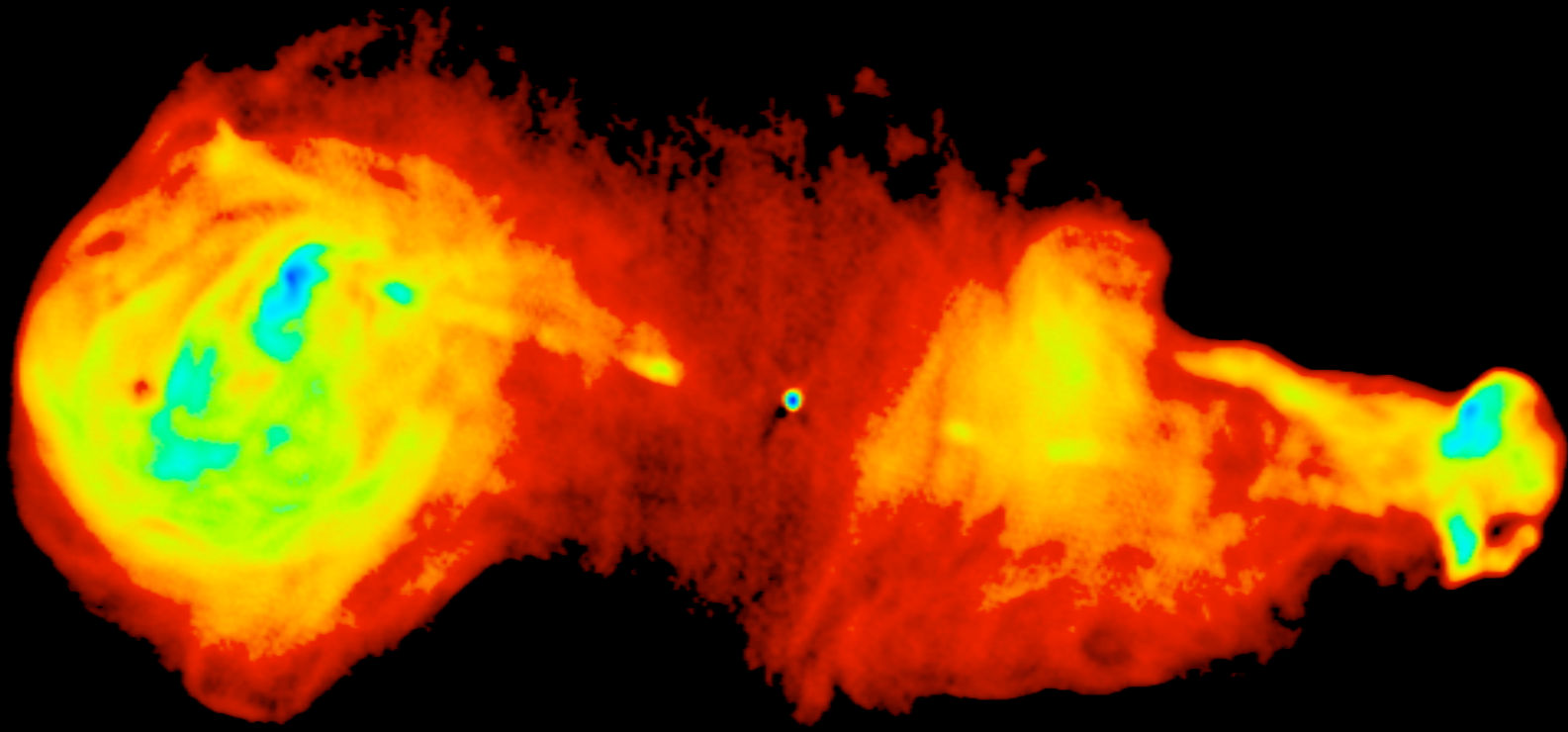


The radio sky



Radio interferometry

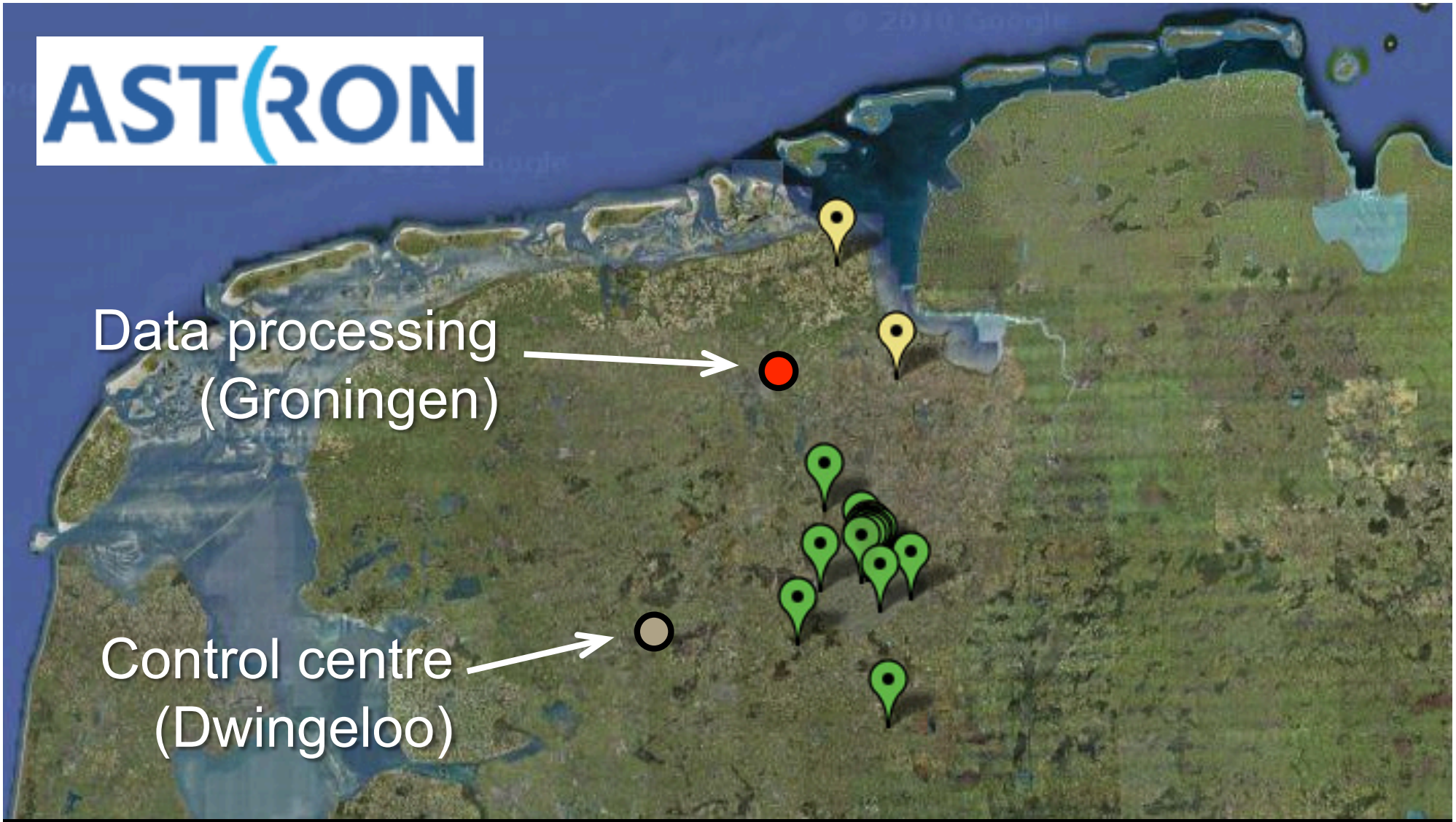
VLBI


Cambridge/MERLIN UK
Effelsberg (DE)
Jodrell Bank (UK)
Onsala Space Obs (SE)
WSRT (NL)
Torun (PL)
DSN Robledo (ES)
Noto (IT)
Medicina (IT)

Why LOFAR?

- LOFAR – the LOw Frequency ARray.
- Low frequencies (30-200 MHz):
  - Mostly unexplored
  - High redshift universe – look back in time
- But:
  - Fighting with human-generated interference
  - Need long baselines for resolution
  - Sensitivity requires many telescopes and high bandwidth => lots of data

- 8 international stations
  - 5 × Germany, 1 × France, 1 × Sweden, 1 × UK



- Heart of the facility
  - ASTRON (Dwingeloo, Exloo, Groningen)

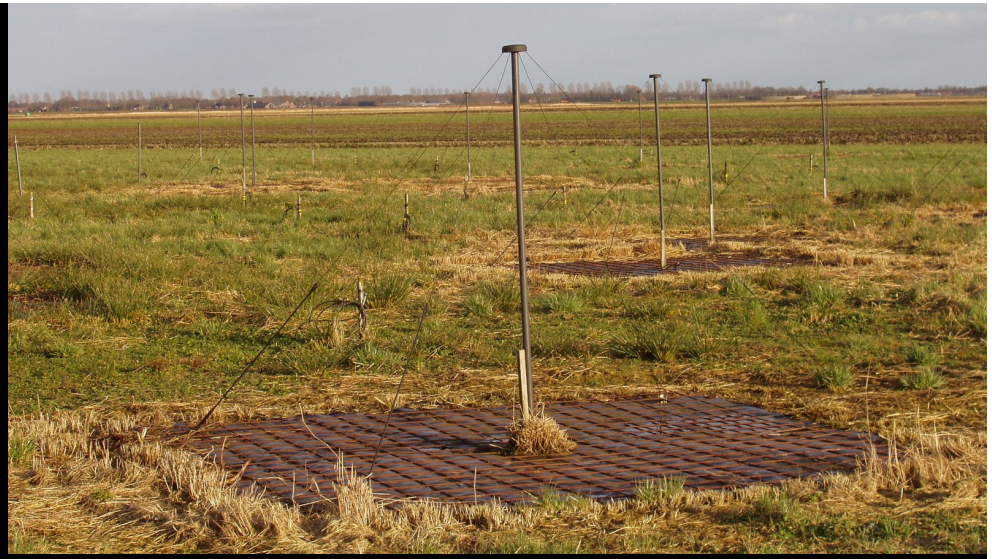
- Main Antenna Array near Buinen/Exloo
  - 24 core stations, 16 remote stations

- At the heart of this is the Superterp
  - The equivalent of 6 core stations

- Core station
  - 96 LBA + 2×24 HBA

- LBA (Low Band Array) 30-80 MHz
  - Angled dipole, ground plane, LNAs

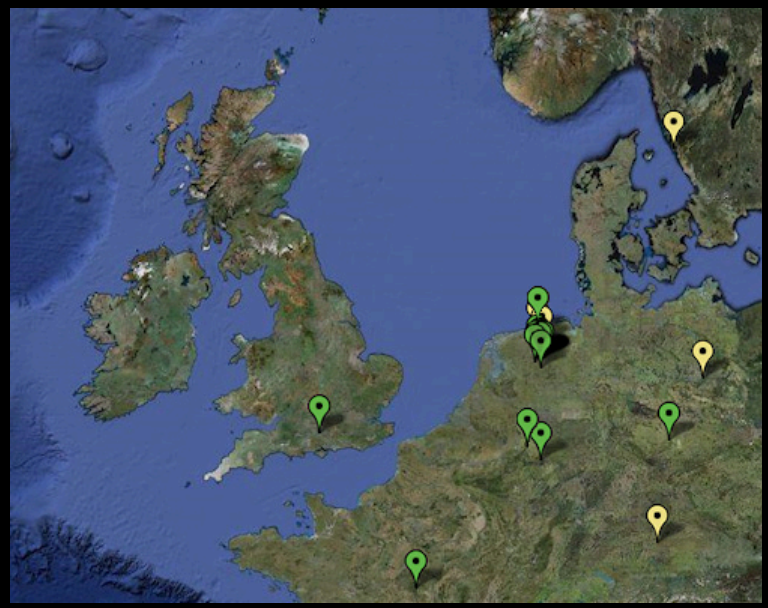
LOFAR design



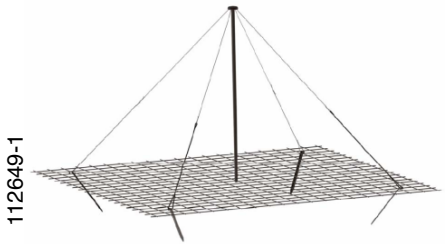
- Cheap, simple components:
- But lots of them (around 5000 LBA antennas)
- No moving parts
- Pointing done in software
- Hardware is dumb, software is clever.
- Many small antennas combined to make one station.

LOFAR-UK

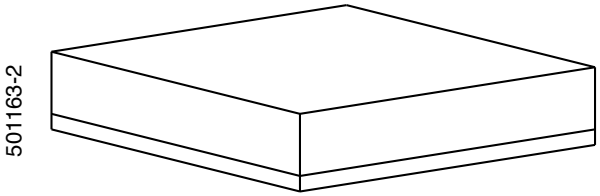
- Why a UK station?
  - Long baselines => science
  - Strong UK tradition of radio astronomy
  - Pathway to future (SKA)
- Largest astronomy collaboration in the UK
  - (funds from 22 universities + funding from STFC)
- Everything must be cheap!



LÖFÅR

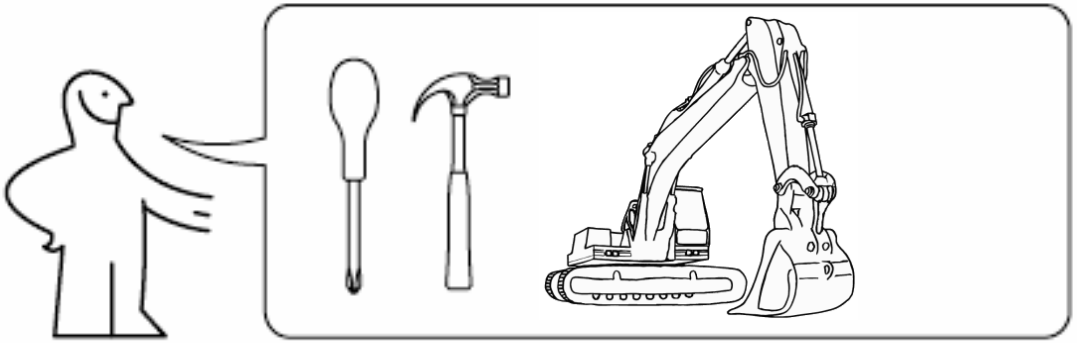


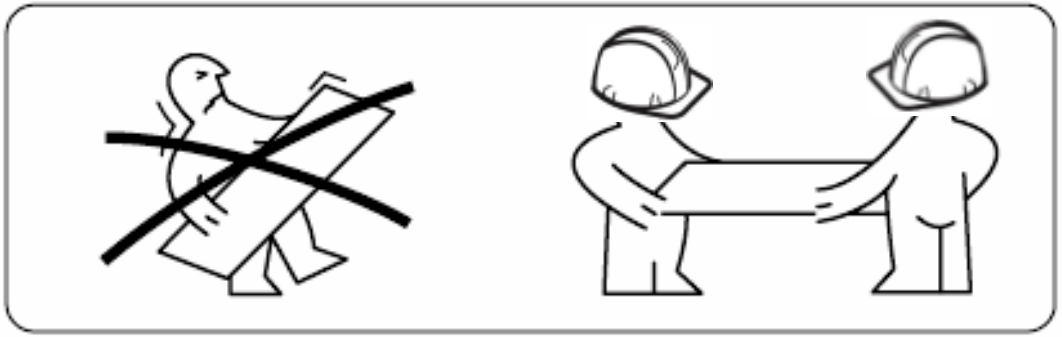
96x

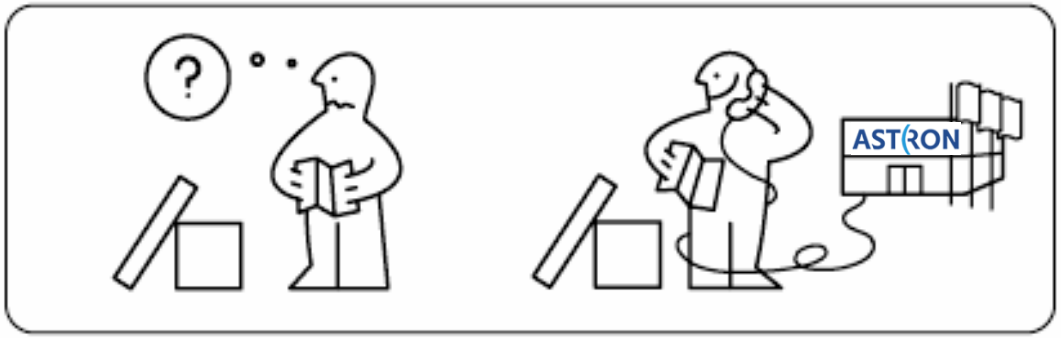


96x

1x



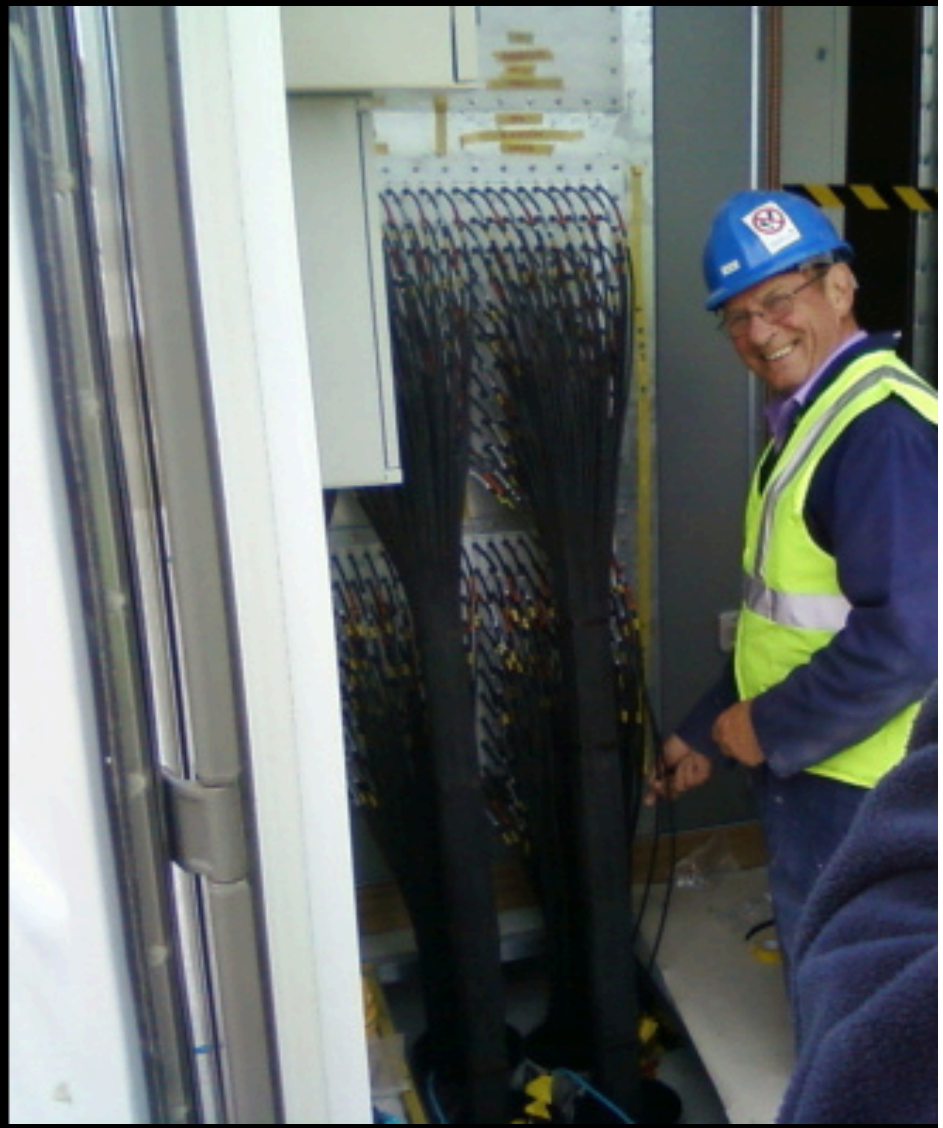




Derek McKay-Bukowski

LOFAR-Chilbolton

Connecting it up



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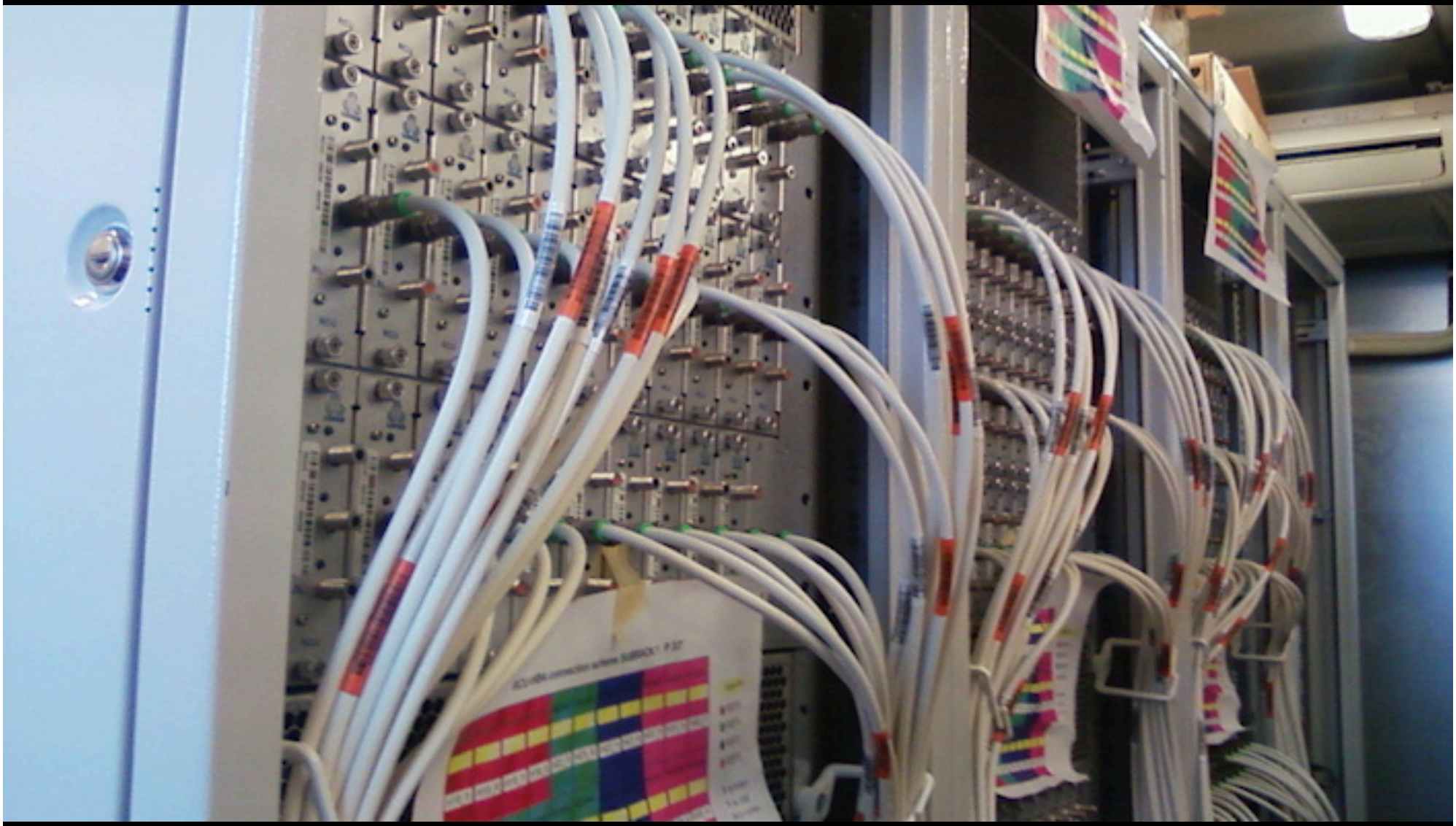


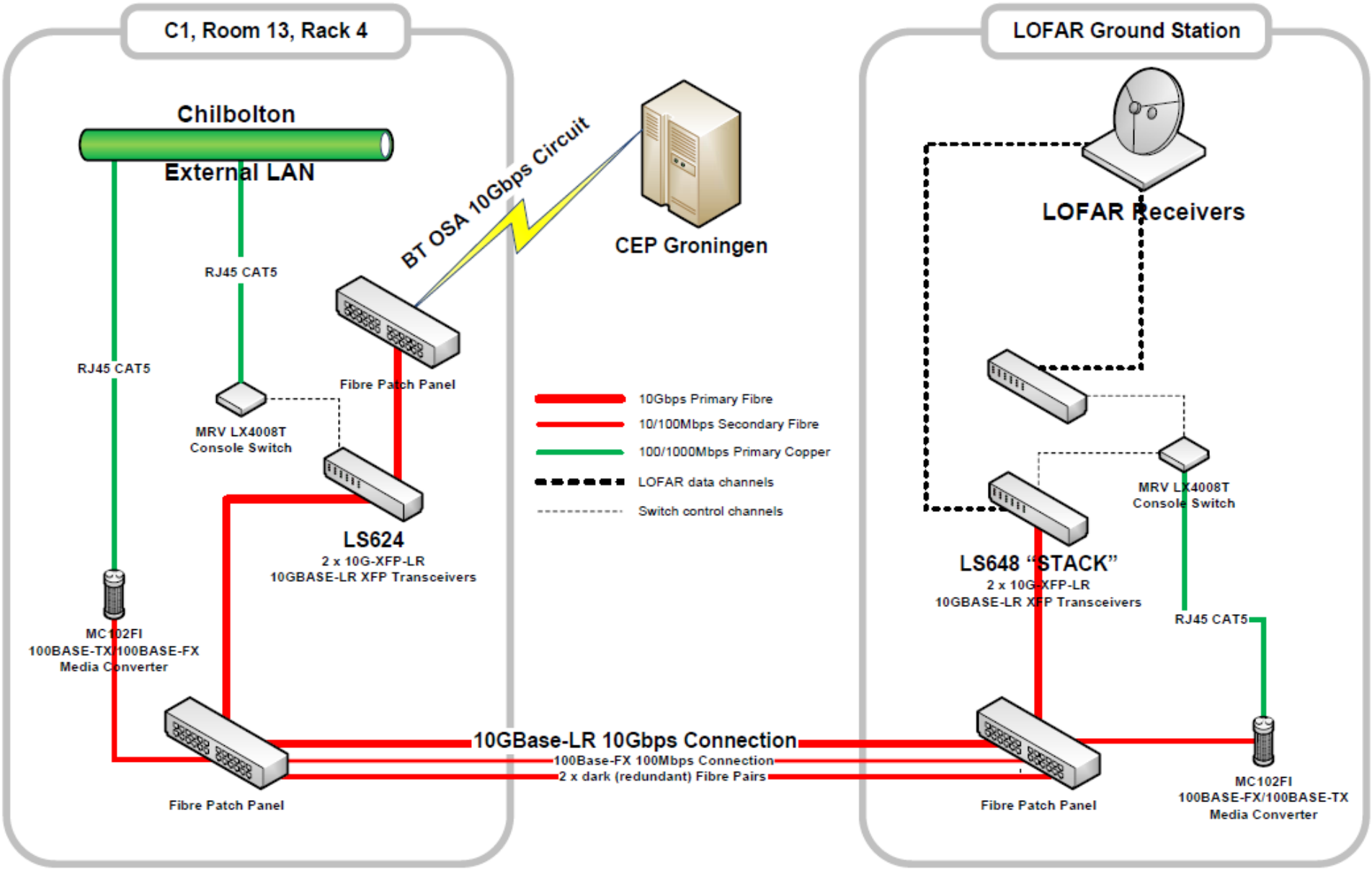
Networking: the hard part

- The signal from the individual antennas is combined and digitized in the RF cabinet.
- This generates about 2 Gb/s of data: in unusual circumstances up to 3 Gb/s.
- Data from all stations must be returned to the central processing facility in Groningen.
- Control data must also be sent and received from ASTRON.

Signal path

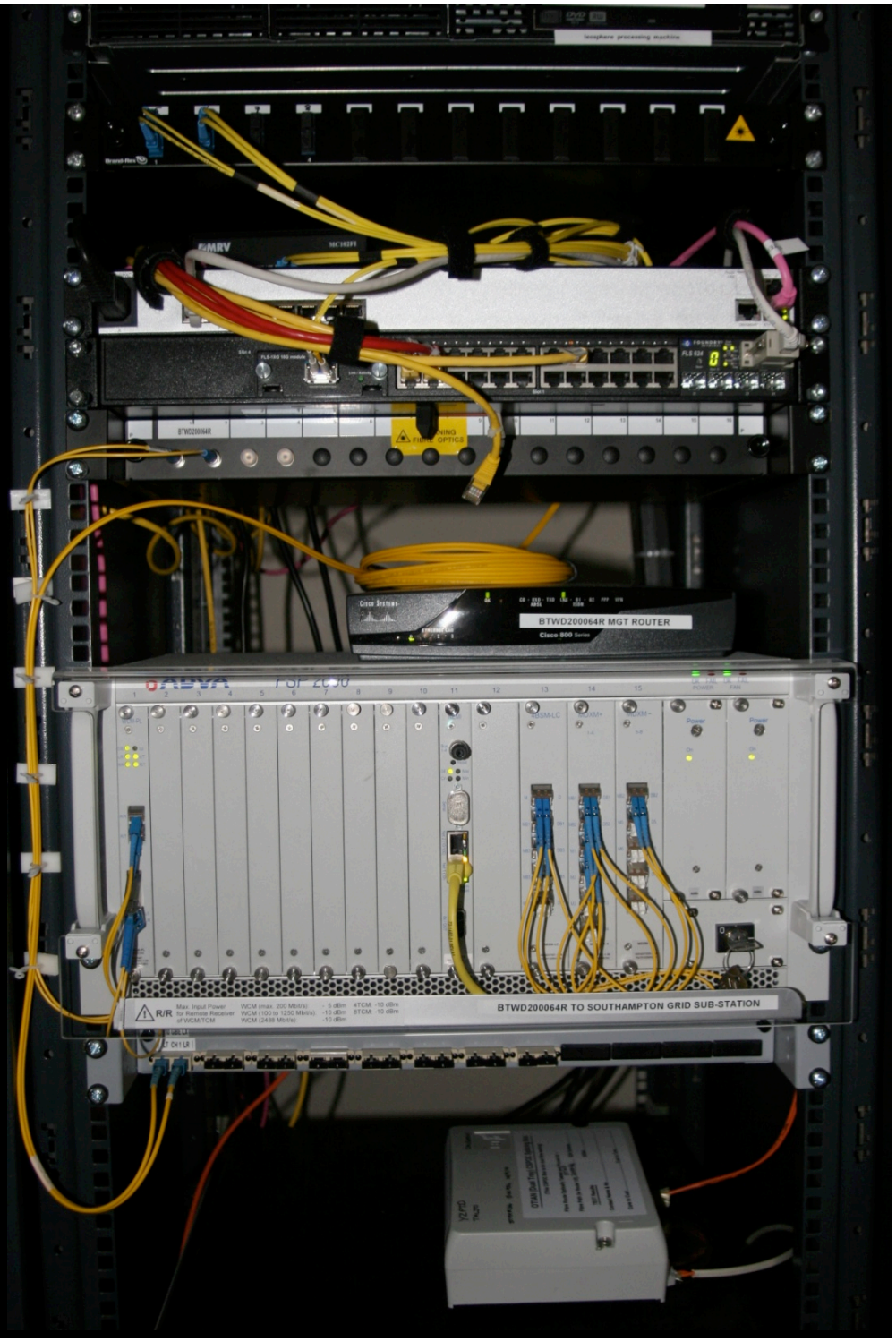
+-> Start at UK608 RF-container
--> Chilbolton main building NTE (local fibre)
--> Southampton (LeNSE/BT)
--> London Docklands (JANET/Telecity)
--> Brussels (GEANT/DANTE)
--> Amsterdam (GEANT/DANTE)
--> Dwingeloo (Surfnet)
--> Assen (Surfnet)
--> Groningen (Surfnet)
--> Zernikecomplex van de Rijksuniversiteit Groningen
--+ CEP (Blue-Gene/P)

Chilbolton / LOFAR Ground Station Networking Interface Overview



Networking (Chilbolton end)

- Data joins JANET at Southampton
- ‘lightpath’ takes us all the way to Groningen – no switching/routing.
- Conceptually all the stations form a single WAN, talking UDP over ethernet, with up to 10 Gb/s dedicated bandwidth.



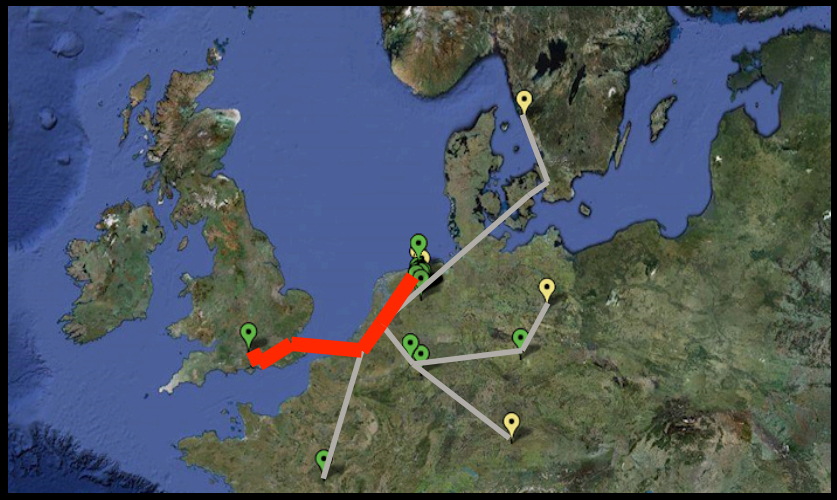
- Data ingest and storage
  - Linux cluster with infiniband links as front end

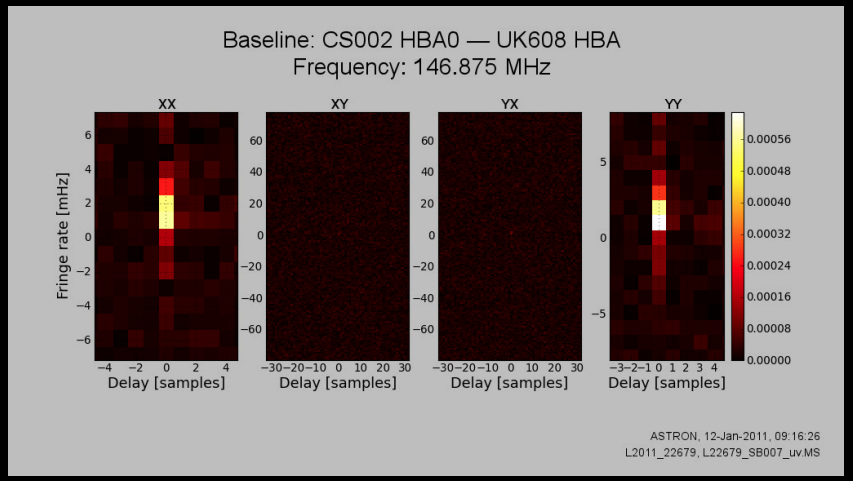
- Blue Gene/P
  - Currently 40th largest supercomputer in the world

- Long-term archive
  - Groningen (Netherlands) and Jülich (Germany)

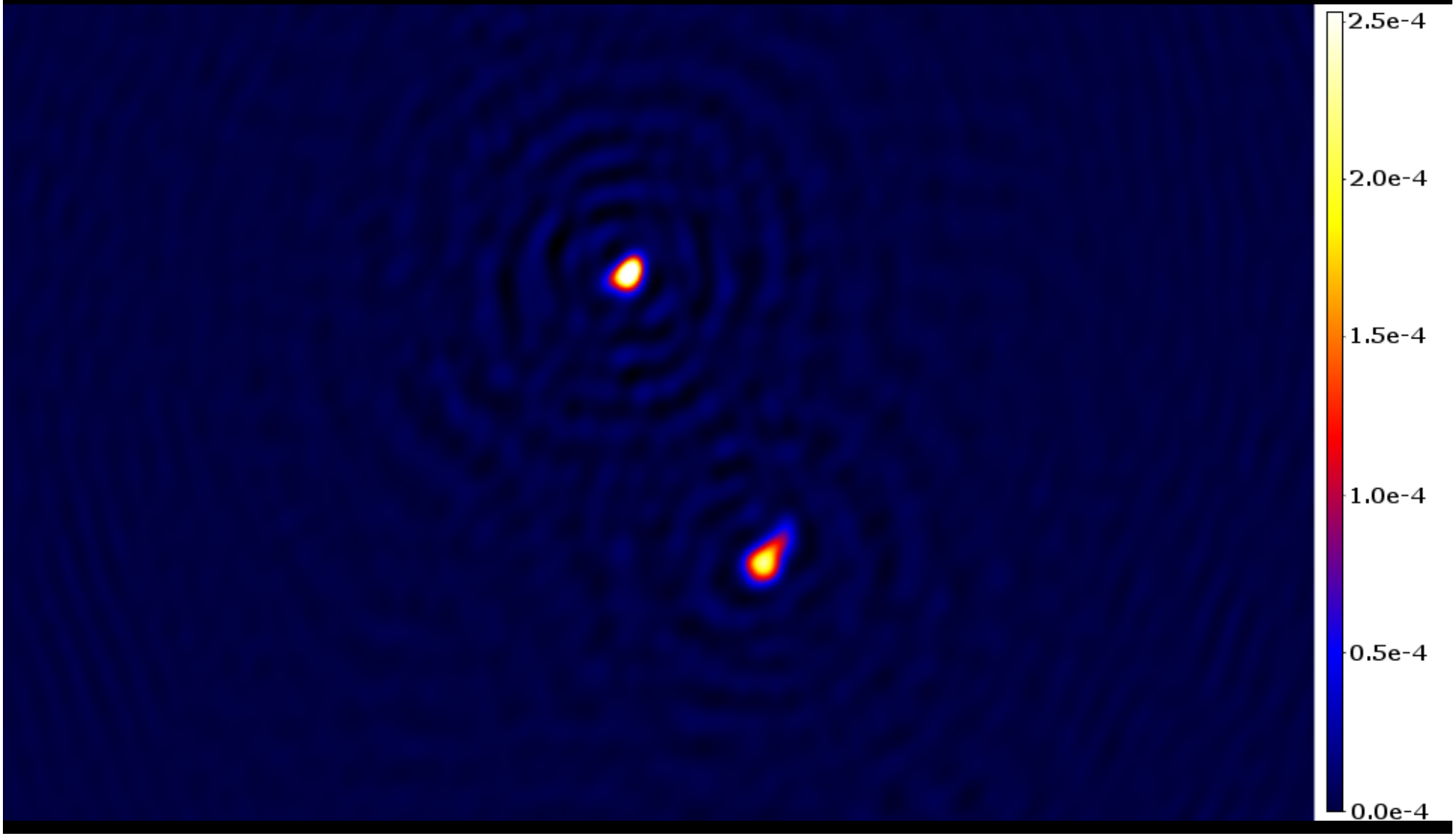
So does it work?

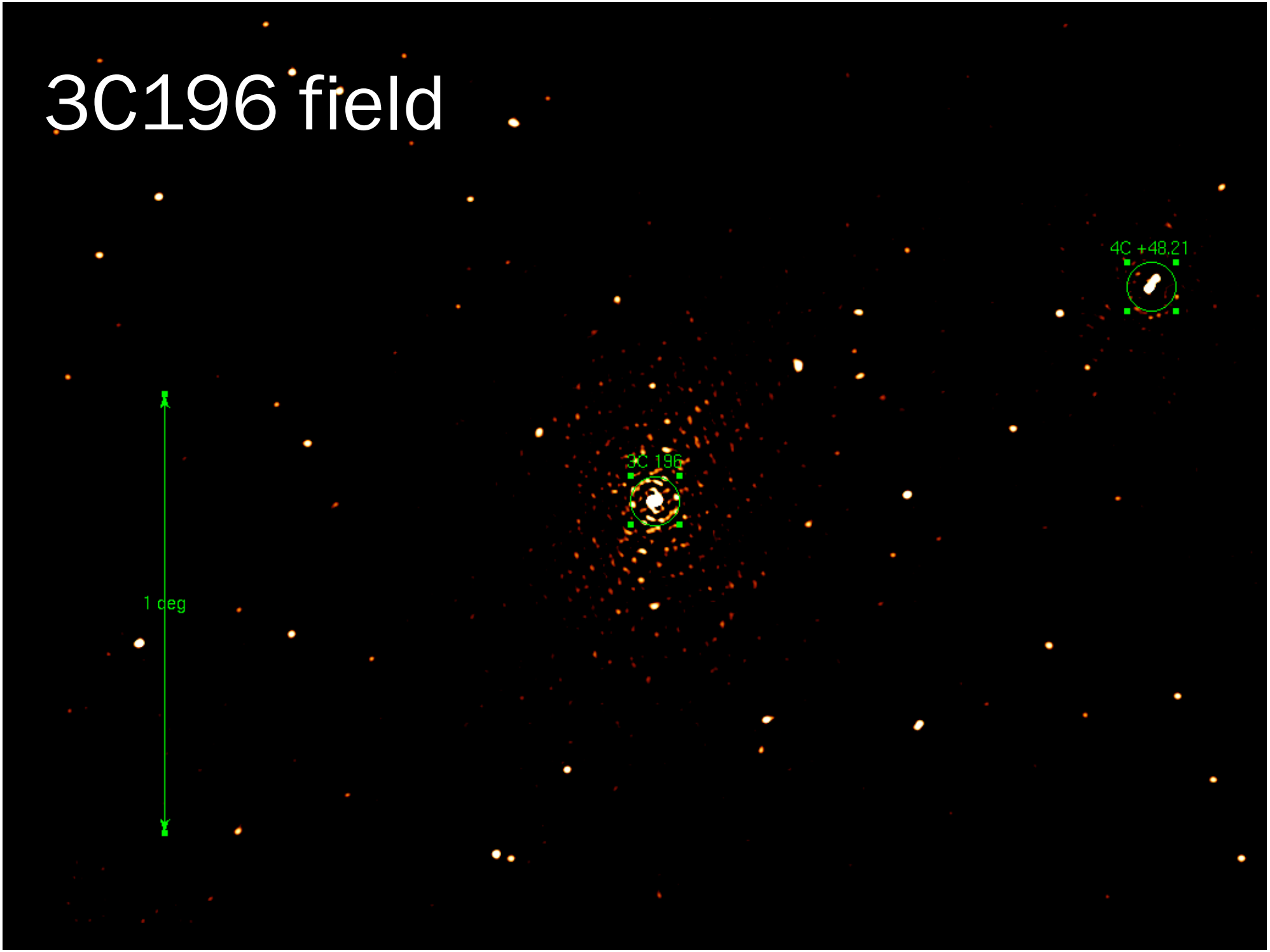
- Yes!
- First ping 10th Dec.
- First fringes (interference patterns meaning both telescopes are seeing the same objects) 11th Jan.
- First image 18th Jan...



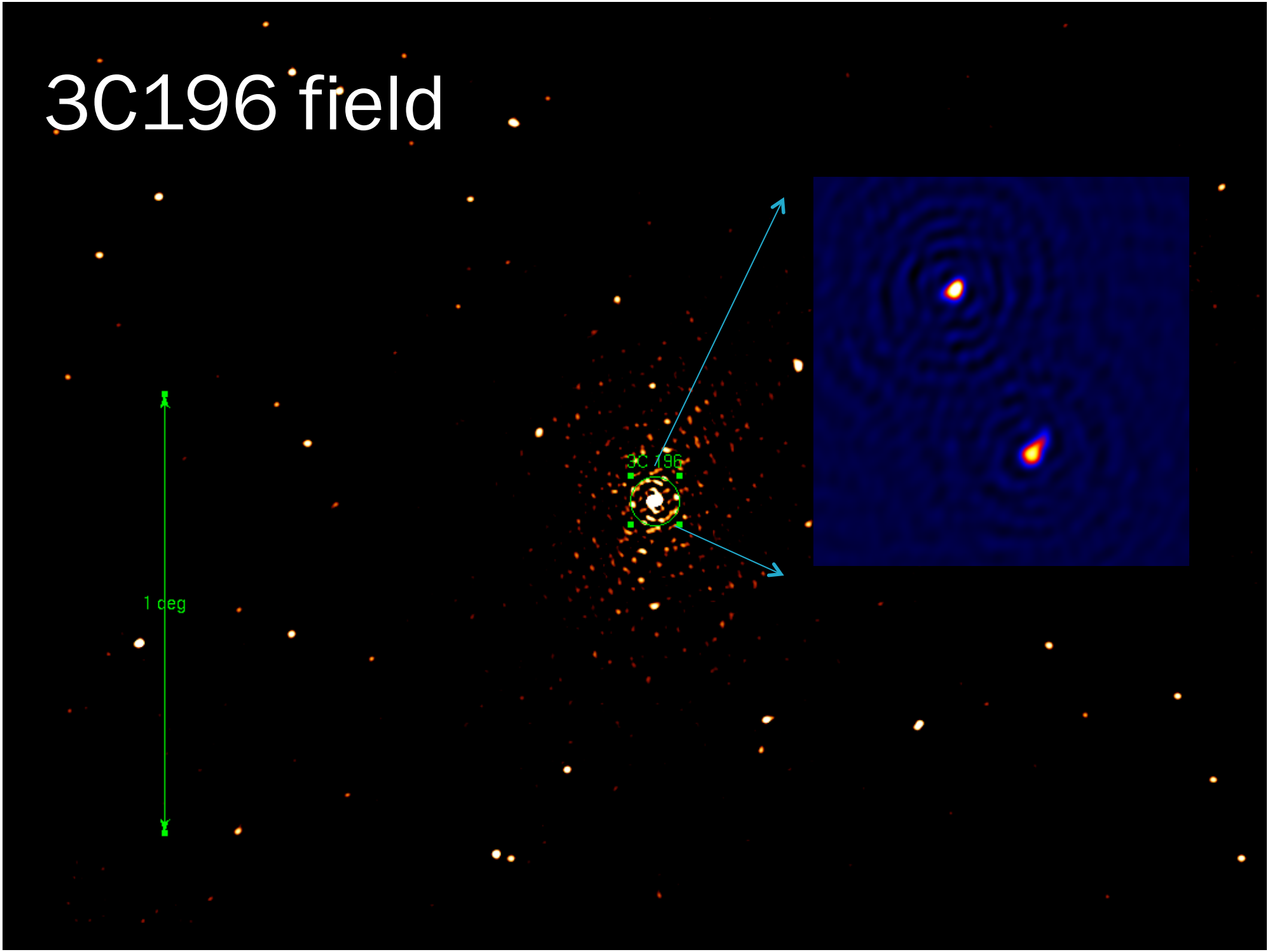


First light image – quasar 3C196



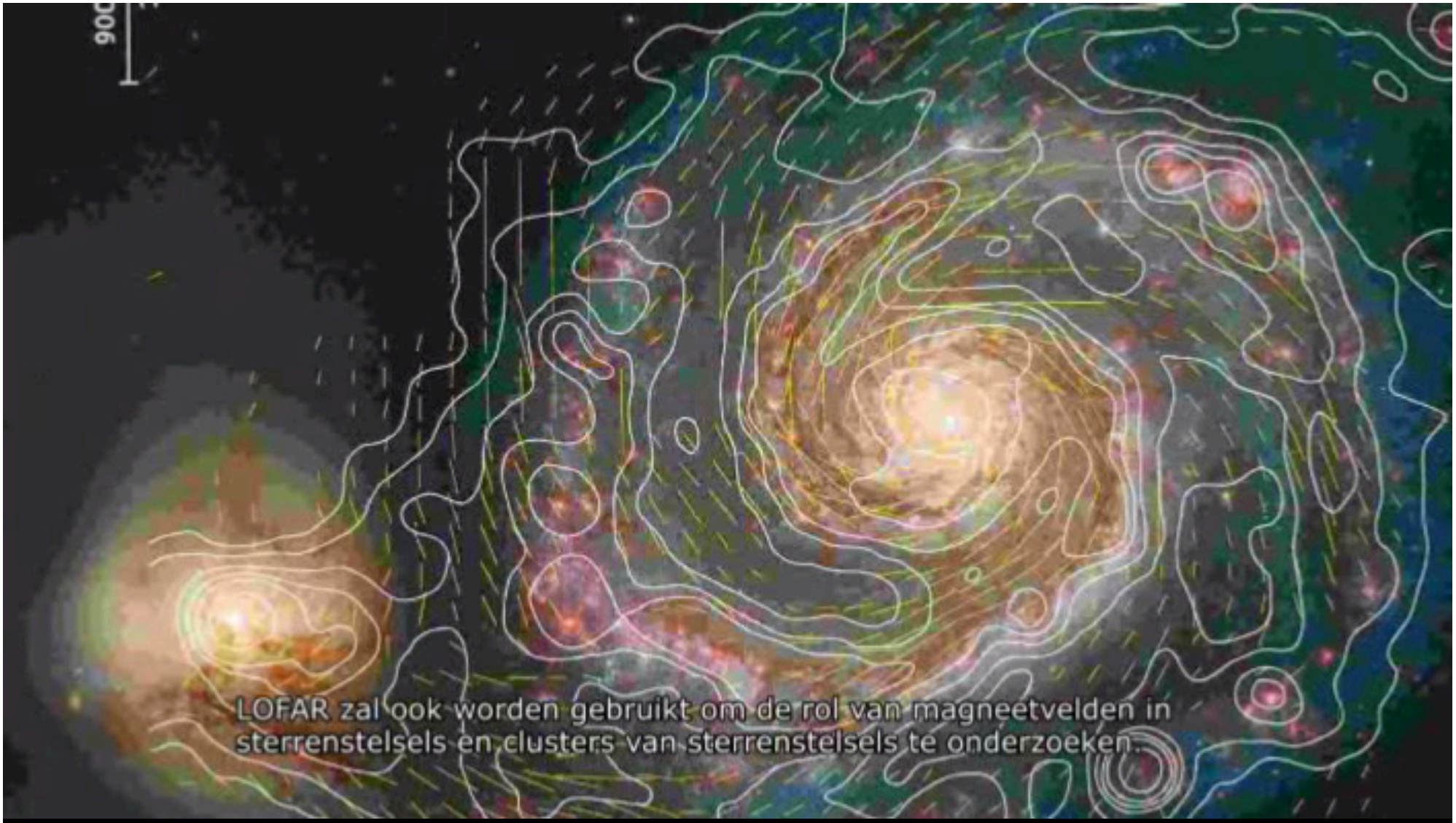

3C196 field
4C +48.21
3C 196
1 deg

3C196 field



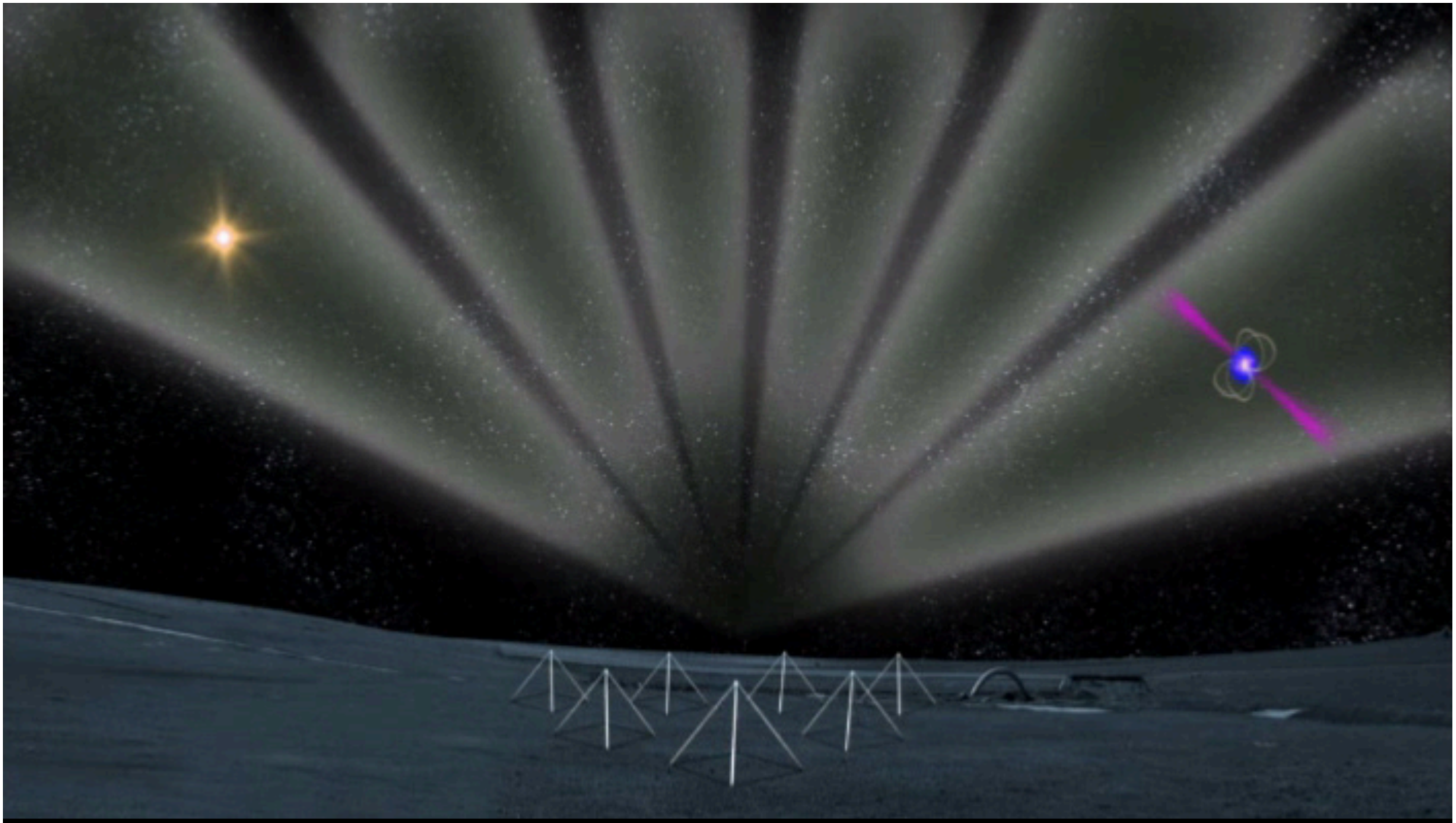
What next?

- Still a lot of commissioning to do...
- Then on to science?
- Astronomy... and beyond!

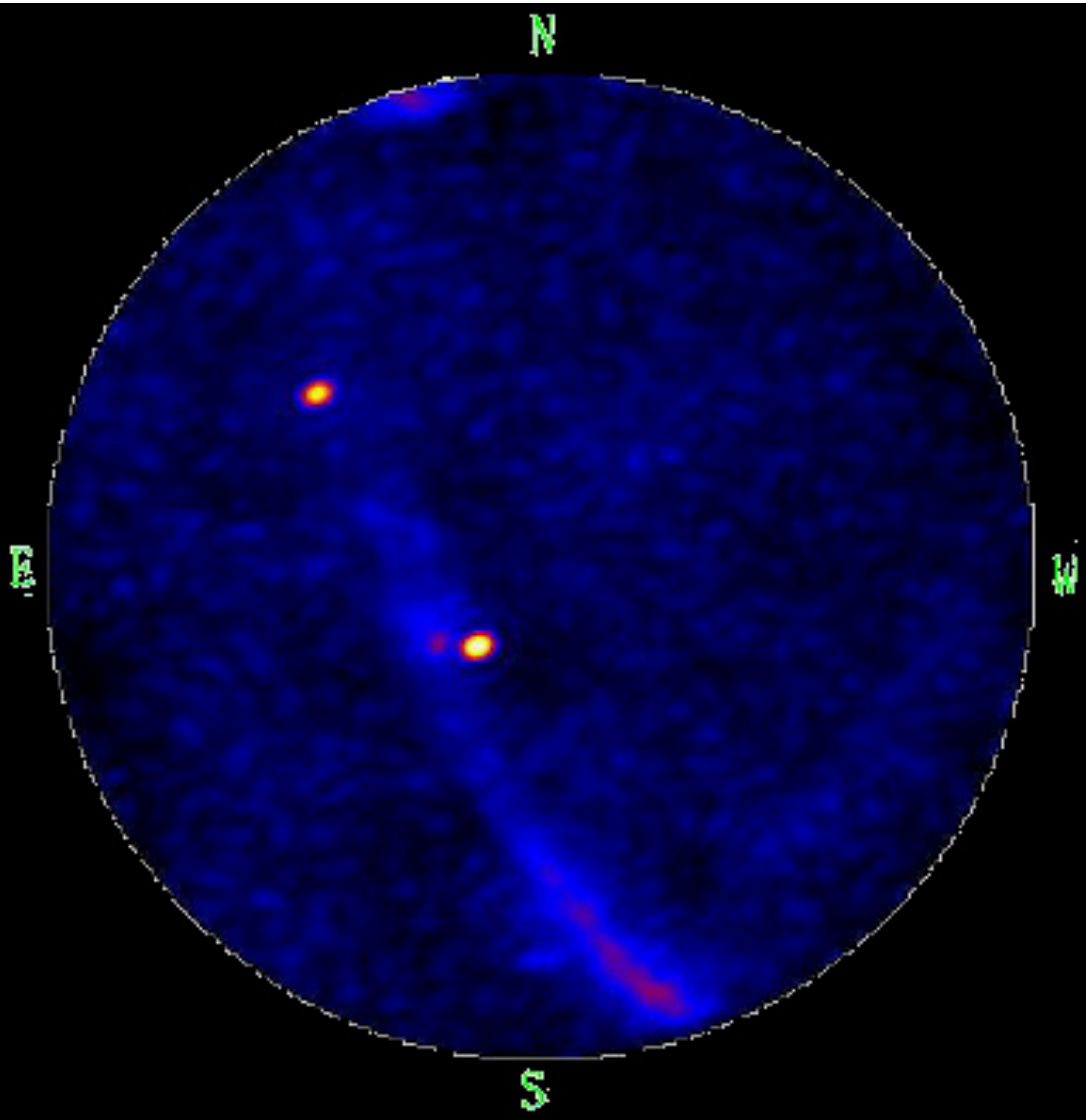


- Conventional radio astronomy
  - Galaxy dynamics, magnetism, clusters, AGNs, etc.

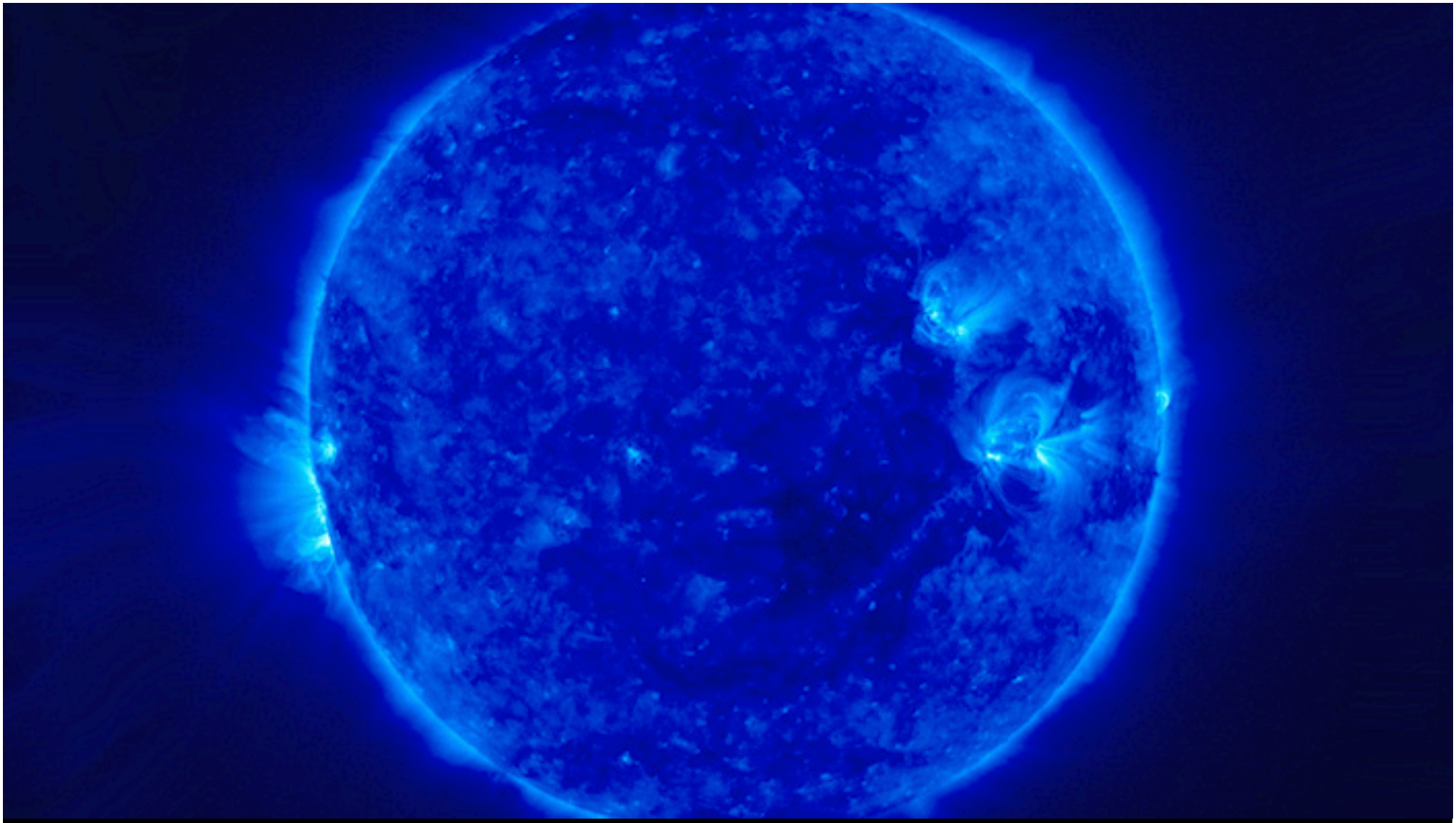
- Cosmology (Epoch of Re-ionisation)
  - Possible at VHF, with huge collecting area



- High time-resolution
  - Radio transients, pulsars, (radar pulses, SETI, etc.)



- LOFAR all-sky image
  - Effelsberg station, Nov’2009, 60 second exposure



- Solar physics
  - High-time and spatial resolution studies

- Cosmic rays
  - Trigger-mode and post-observation beam forming

- Ionospheric studies
  - Also radar, space situational awareness, etc.

- Lightning
  - Event trigger statistics, direction and time resolution

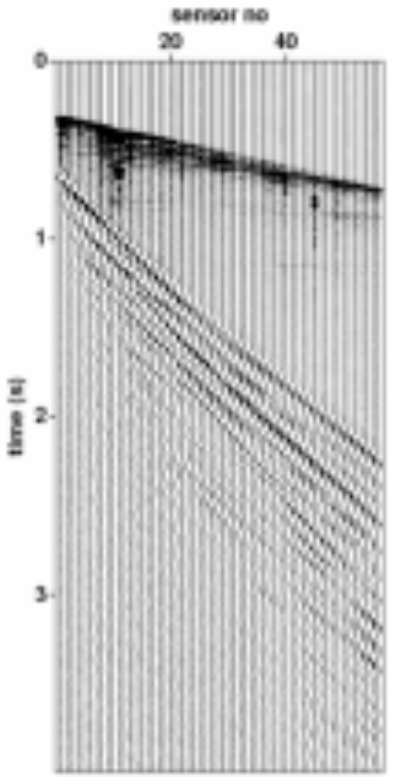
- Agriculture
  - Thermistors, distrometers, tracking, etc.


Geofoons en infrageluidsensoren zijn op veel LOFAR stations in Nederland te vinden.

- Geophones

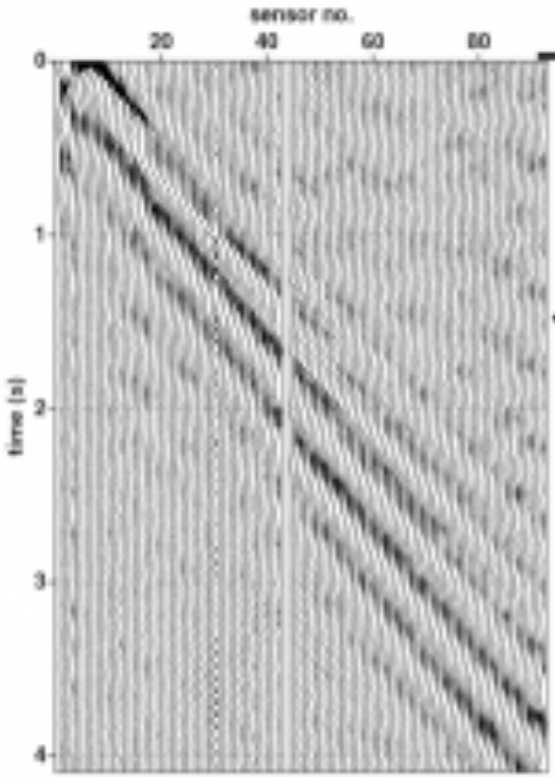
- Geophones, precision seismography

Seismic record from dynamite:

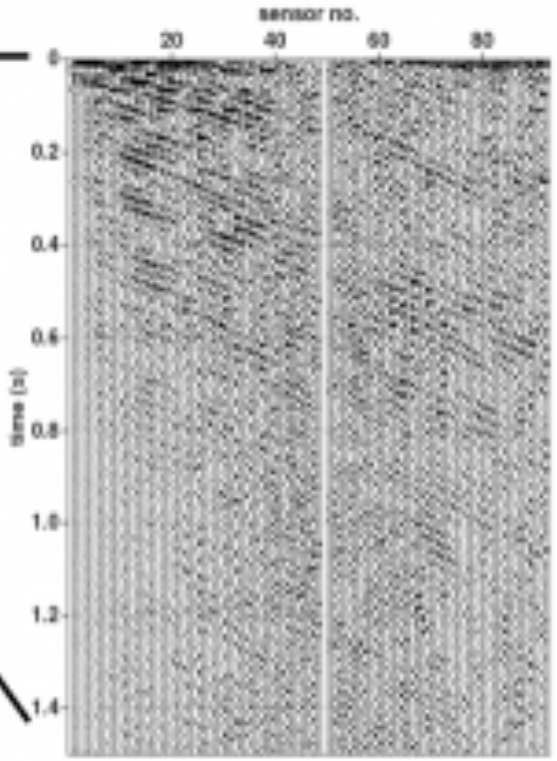


Seismic records from correlated noise:

Low-frequency surface waves:



High-frequency reflected/refracted waves:



- First LOFAR seismic results
  - Dutch geological and petrochemical research

- Infrasound arrays
  - Supersonic monitoring, NTBT.

- Combined geo-sensors
  - Traditional geophysics: seismology, vulcanology

The end

Thanks: Derek McKay-Bukowski, Alan Doo, and the LOFAR-UK collaboration