LOFAR SCIENCE

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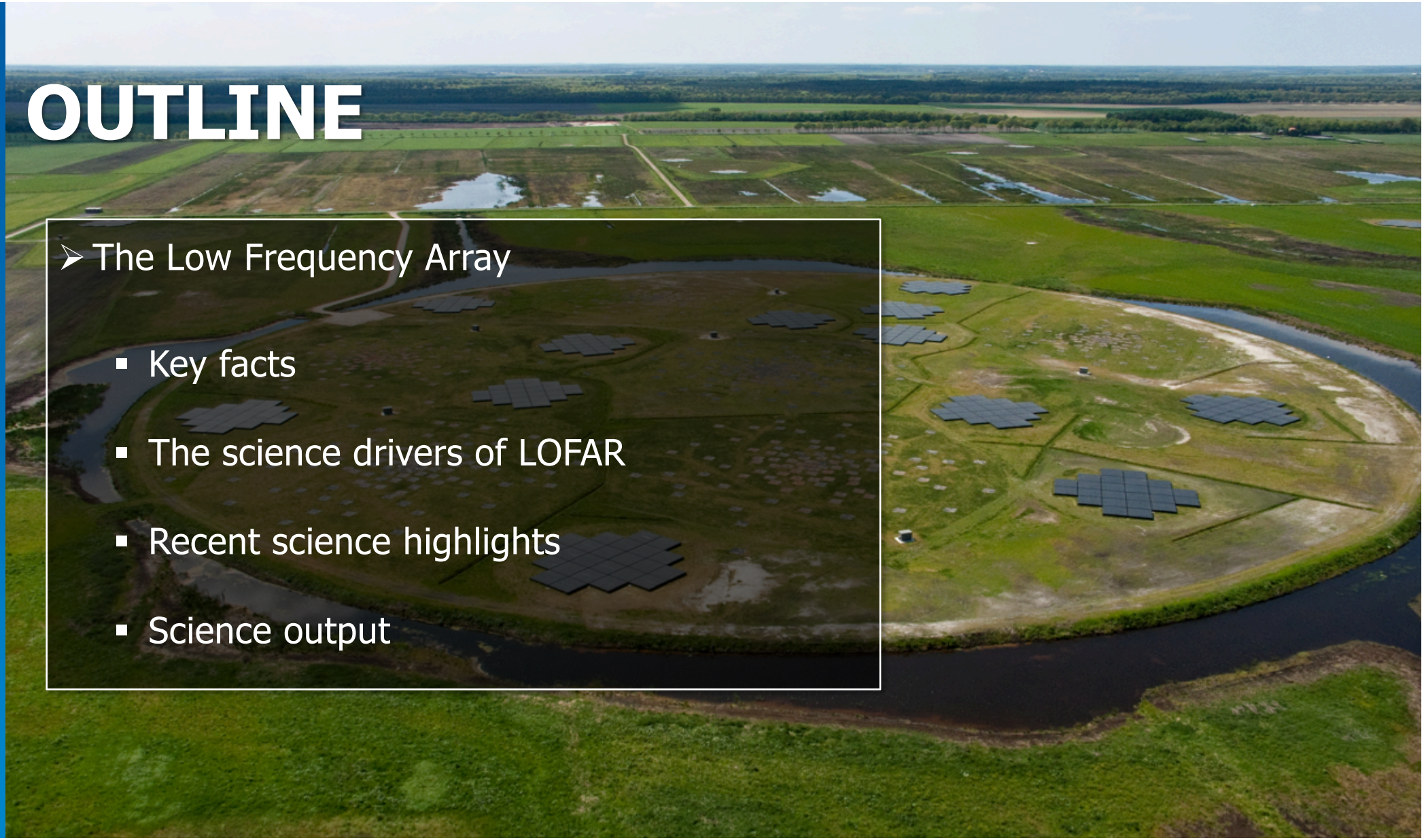
ASTRON
Netherlands Institute for Radio Astronomy

ASTRON, September 17th 2018

LOFAR

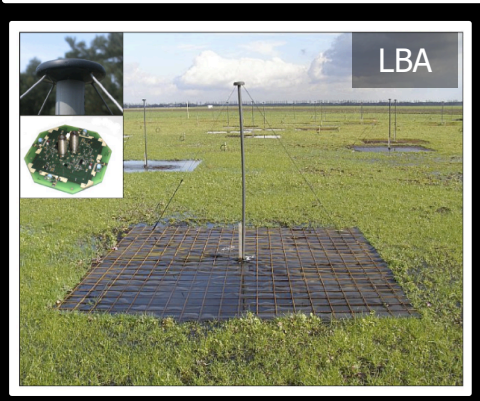


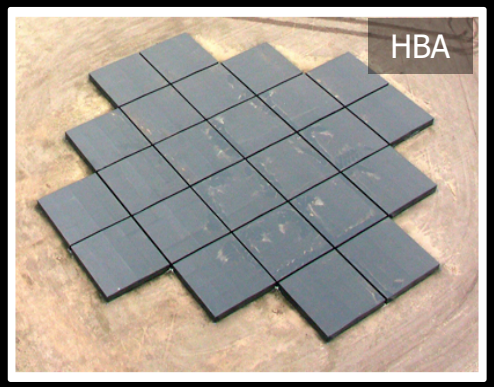
OUTLINE

- The Low Frequency Array
  - Key facts
  - The science drivers of LOFAR
  - Recent science highlights
  - Science output

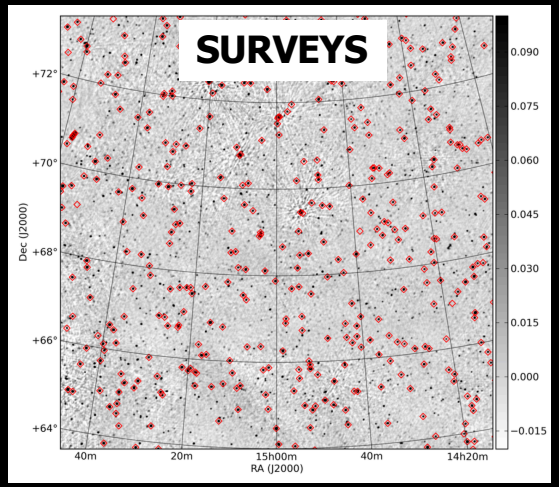
LOFAR: KEY FACTS

- Array of 51 dipole antenna stations distributed across EU
- 10-250 MHz
- Low band antenna (LBA; 10-90 MHz); High Band Antenna (HBA; 110-250 MHz)
- Several observing modes (imaging, BF, BF+IM, TBB)
- Responsive telescope
- 96 MHz bandwidth (multi-beam option)
- Big data: important technological pathfinder for next-gen facilities and data intensive astronomy

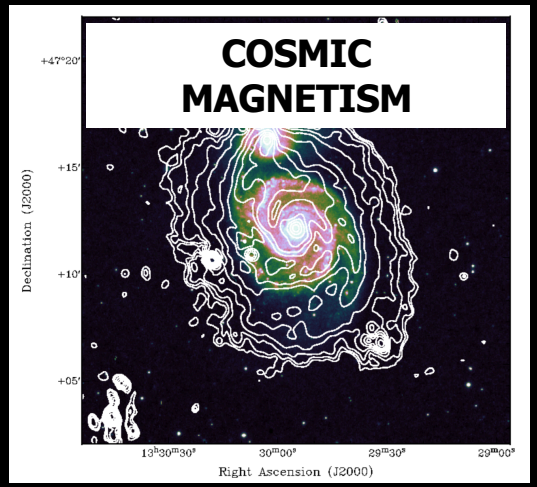




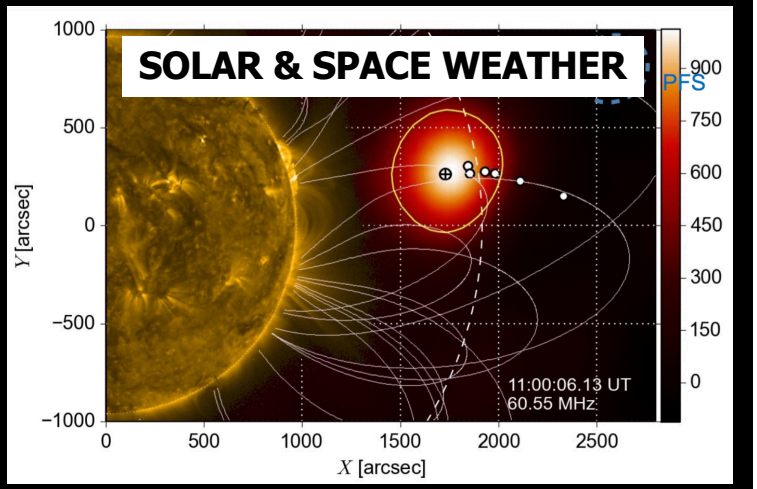
SURVEYS



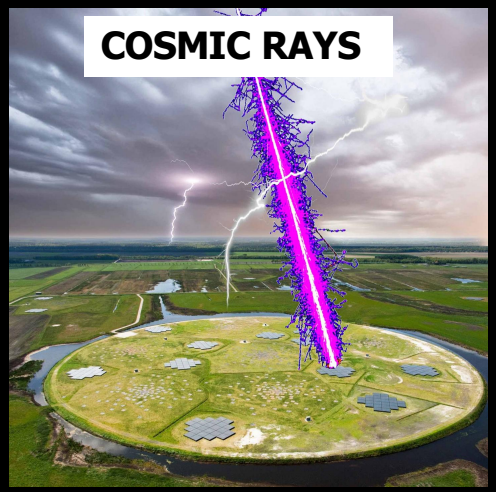
COSMIC MAGNETISM



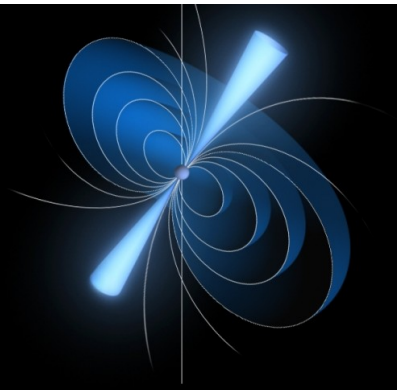
SOLAR & SPACE WEATHER



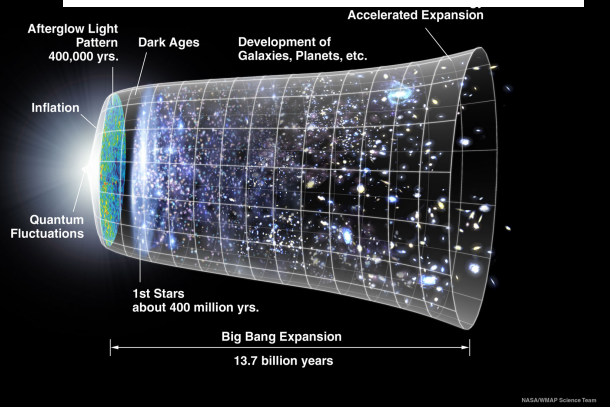
COSMIC RAYS



TRANSIENTS & PULSARS



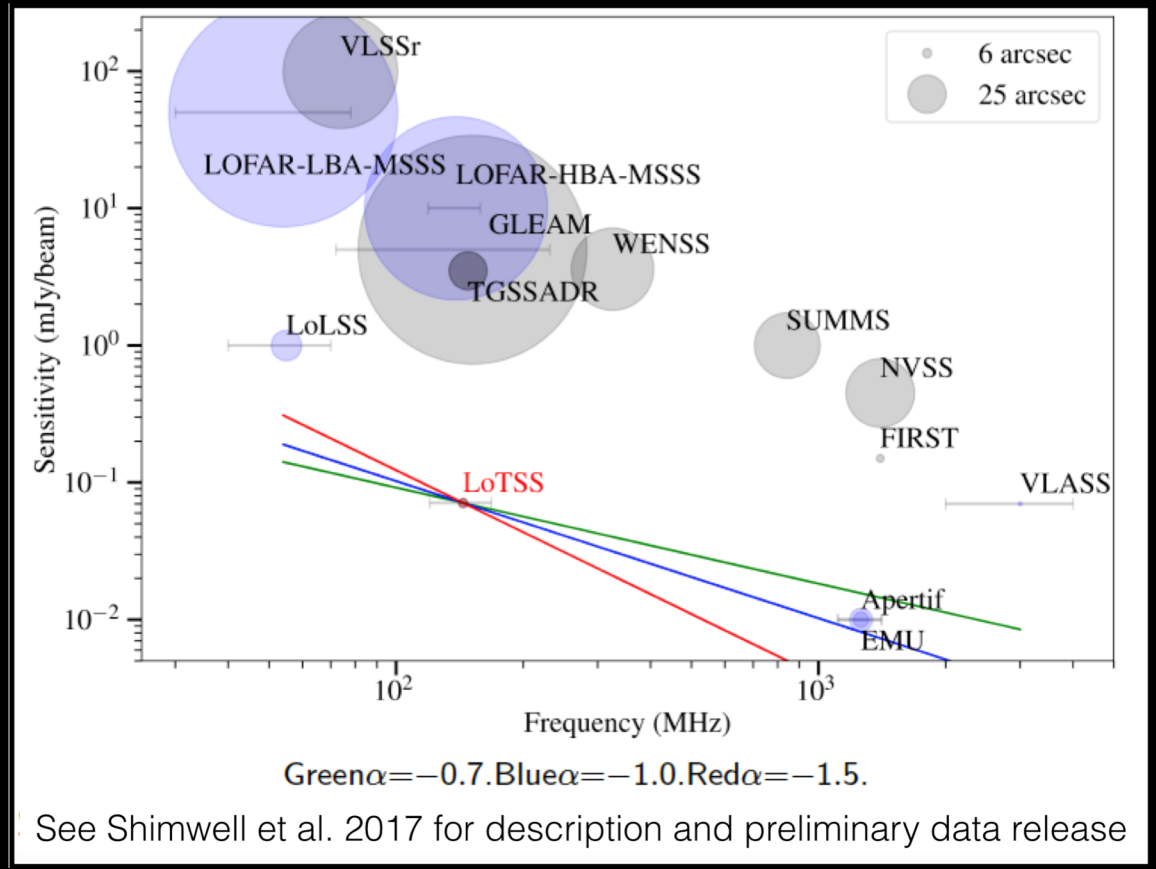
EPOCH OF REIONIZATION



International membership from countries all over the World

Constribute development and commissioning resources

SURVEYS: THE LOFAR TWO-METRE SKY SURVEY (LoTSS)

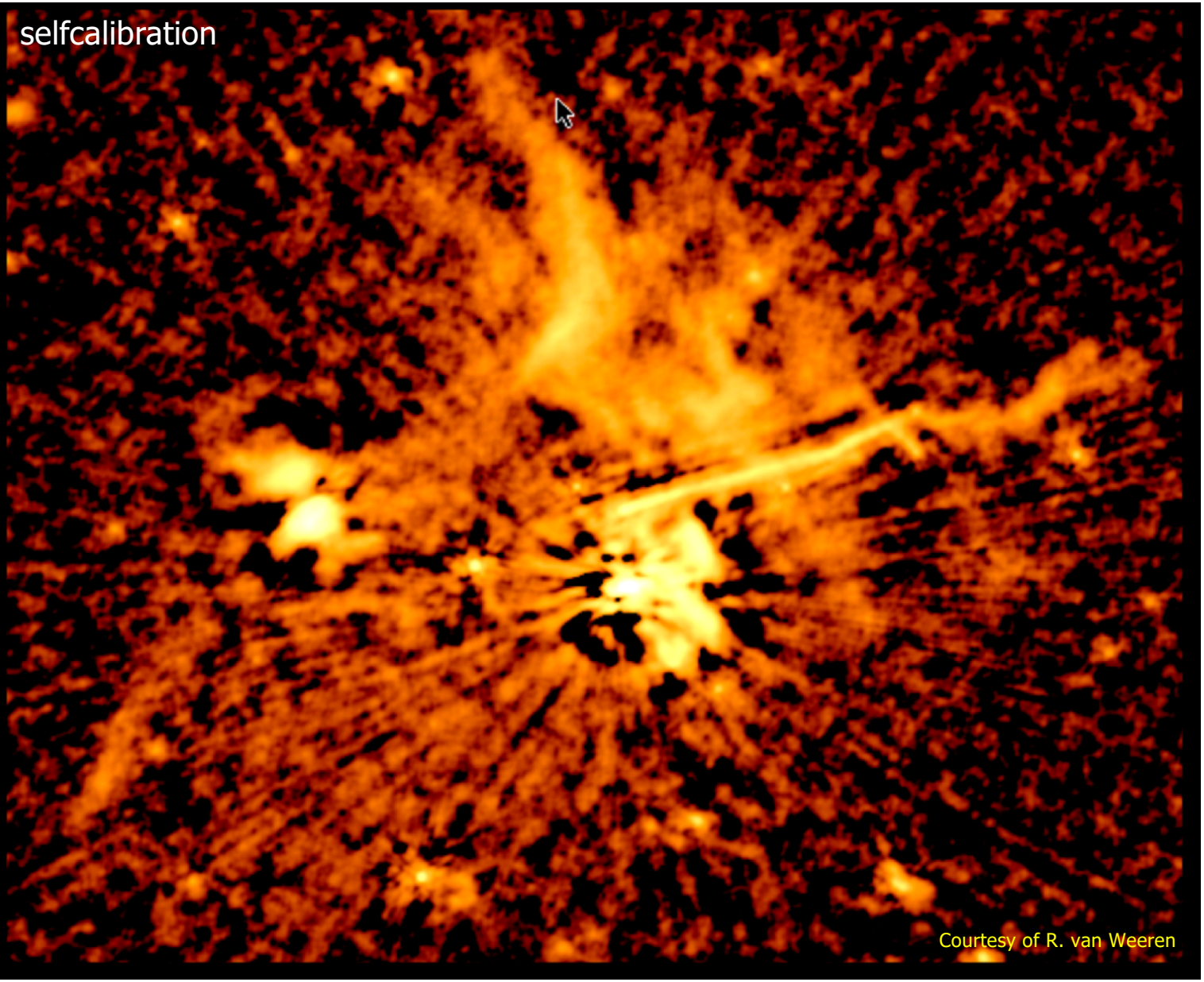


- High-redshift radio galaxies: formation and evolution of massive galaxies, rich clusters and massive black holes
- Galaxy clusters: origin and evolution of magnetic fields and relativistic electrons
- Determining the cosmic star-formation history of the Universe
- serendipitous discoveries
- How? Produce high fidelity images of the entire Northern sky with a resolution of 5" and sensitivity of 100μJy/beam at most declinations.
- Will not be surpassed as a norther sky survey for the foreseeable future

See Shimwell et al. 2017 for description and preliminary data release

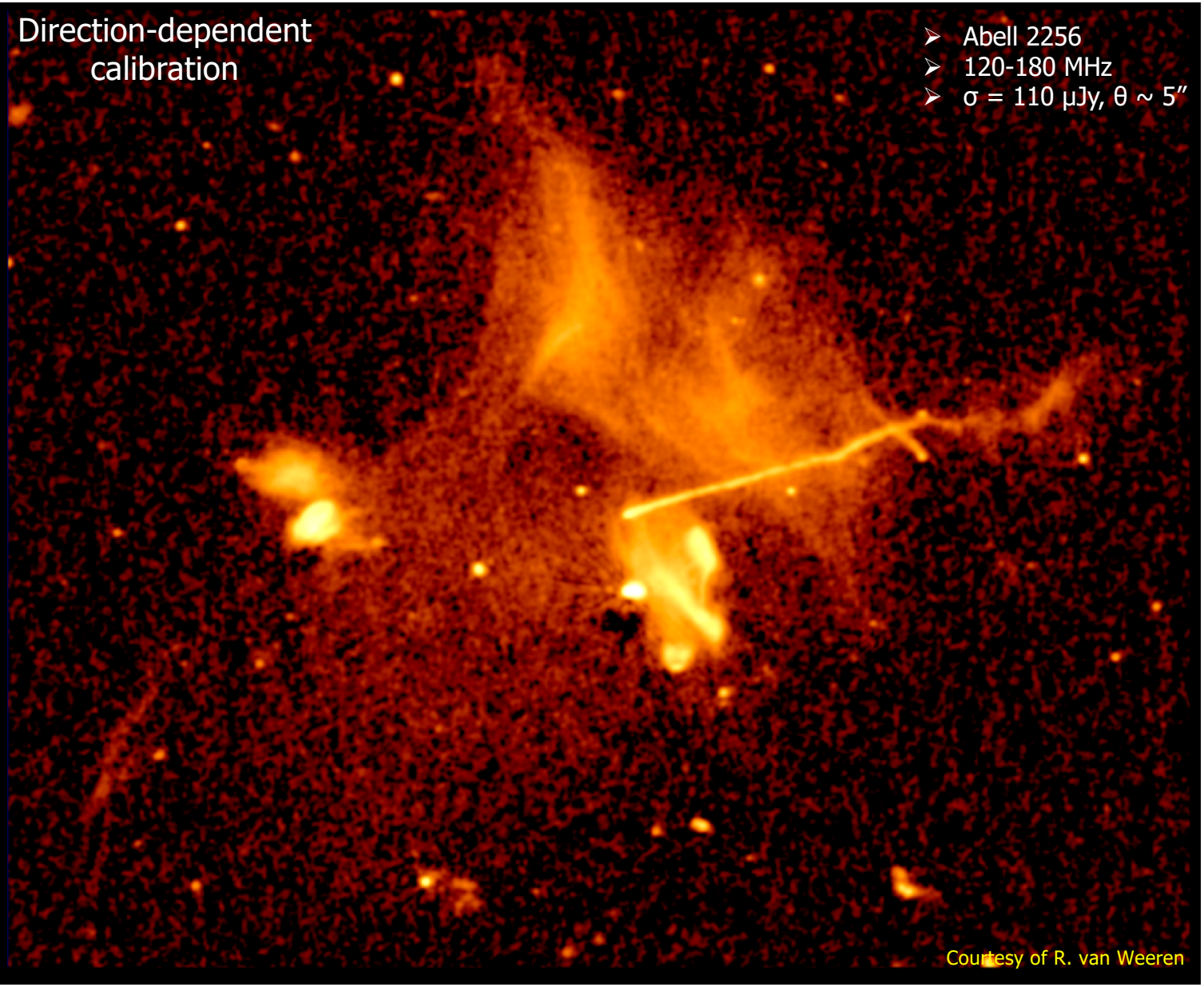
SURVEYS

more in lecture L7 by Shimwell, van Weeren, Mevius (Wednesday)



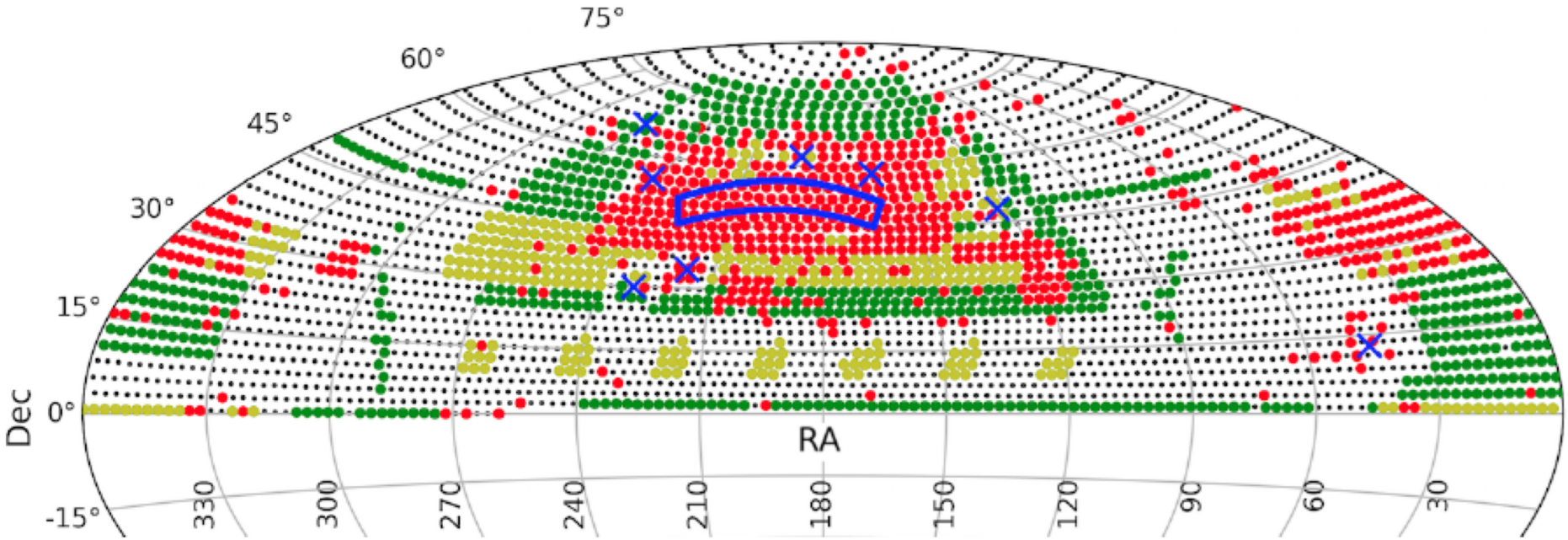
SURVEYS

You will also do it by Friday!



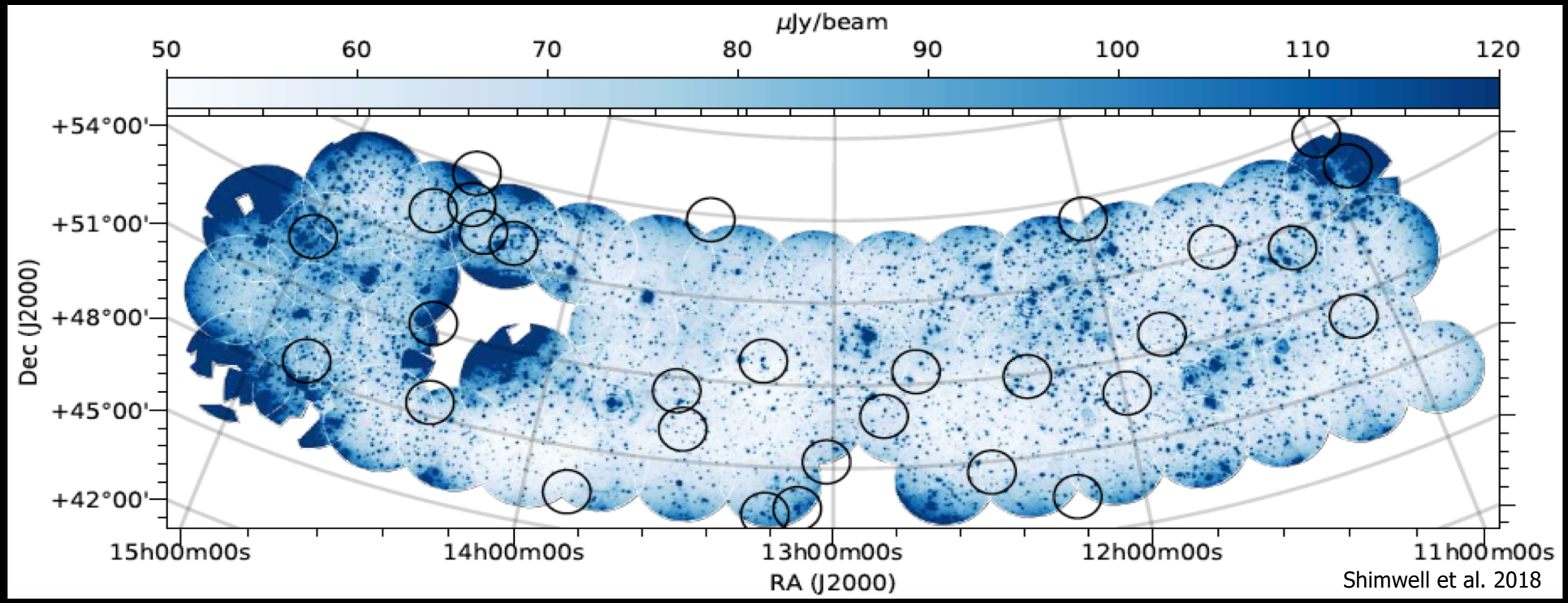
SURVEYS

Since Cycle 2: 30% of the Northern Sky observed -> 4000 observing hours.



Red observed, **yellow** observed in next 6 months, **green** observed in next 2 years.

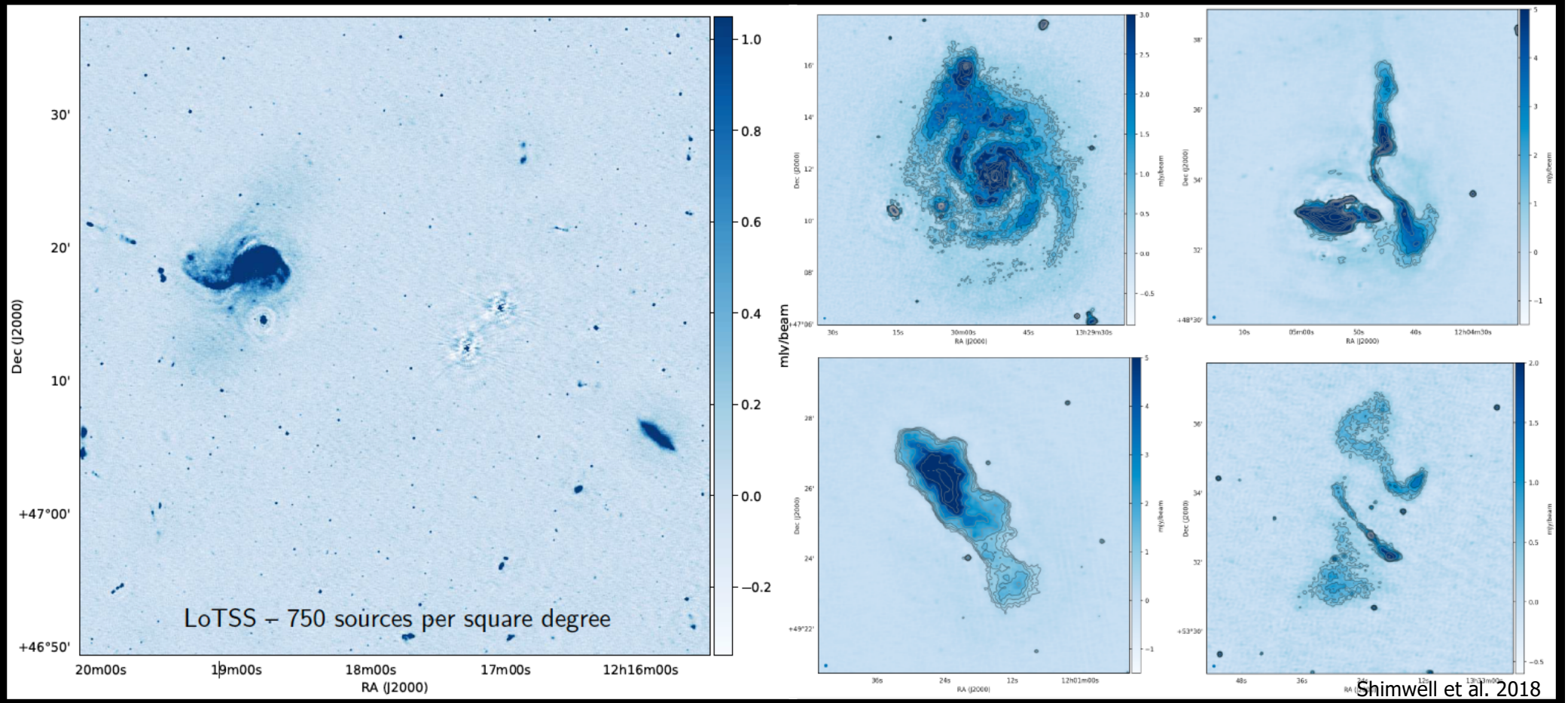
SURVEYS



First full quality data release: 6" resolution images with a sensitivity of 71μJy/beam that covers 424 square degrees in the HETDEX Spring Field region.

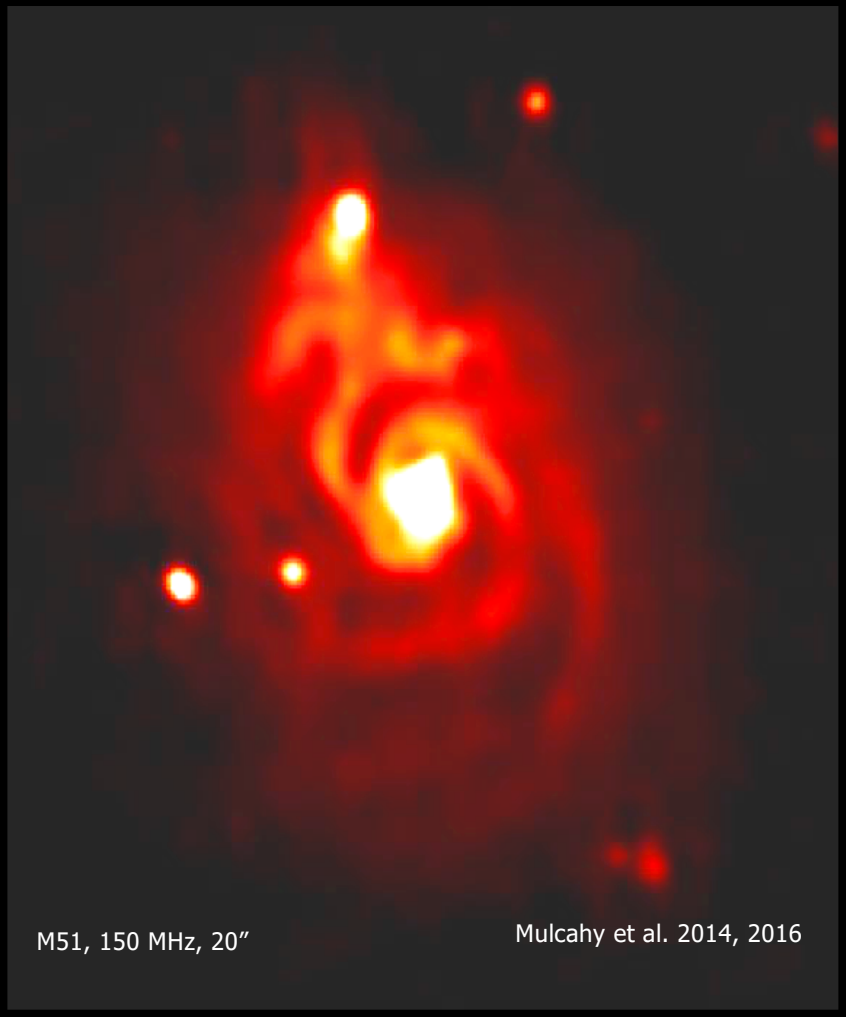
The catalogue contains 325,694 radio sources (Shimwell et al 2018, in press), 225,457 optical identifications (Williams+submitted) and 158,284 photometric redshift estimates (Duncan+ submitted)

SURVEYS



Shimwell et al. 2018

COSMIC MAGNETISM

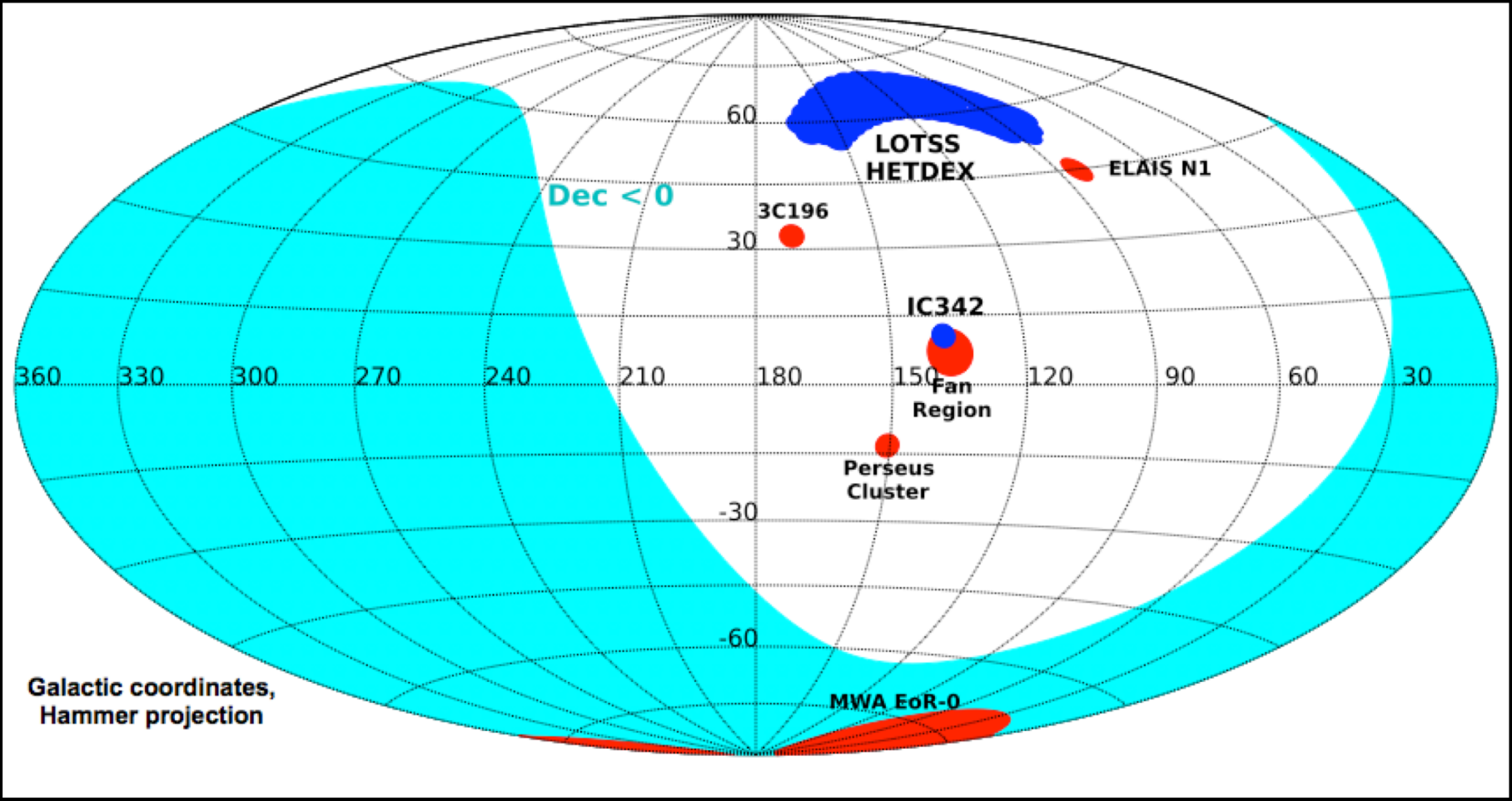


M51, 150 MHz, 20″ Mulcahy et al. 2014, 2016

- Magnetic fields are ubiquitous in the Universe – their origin, evolution and structure still remain open fundamental problems
- Due to its wide bandwidth at low frequency, LOFAR can:
  - Provide info on spectral properties of the synchrotron radiation
  - Trace magnetic fields far away from CR acceleration sites
  - Trace weak magnetic fields through Faraday rotation studies (RM synthesis)

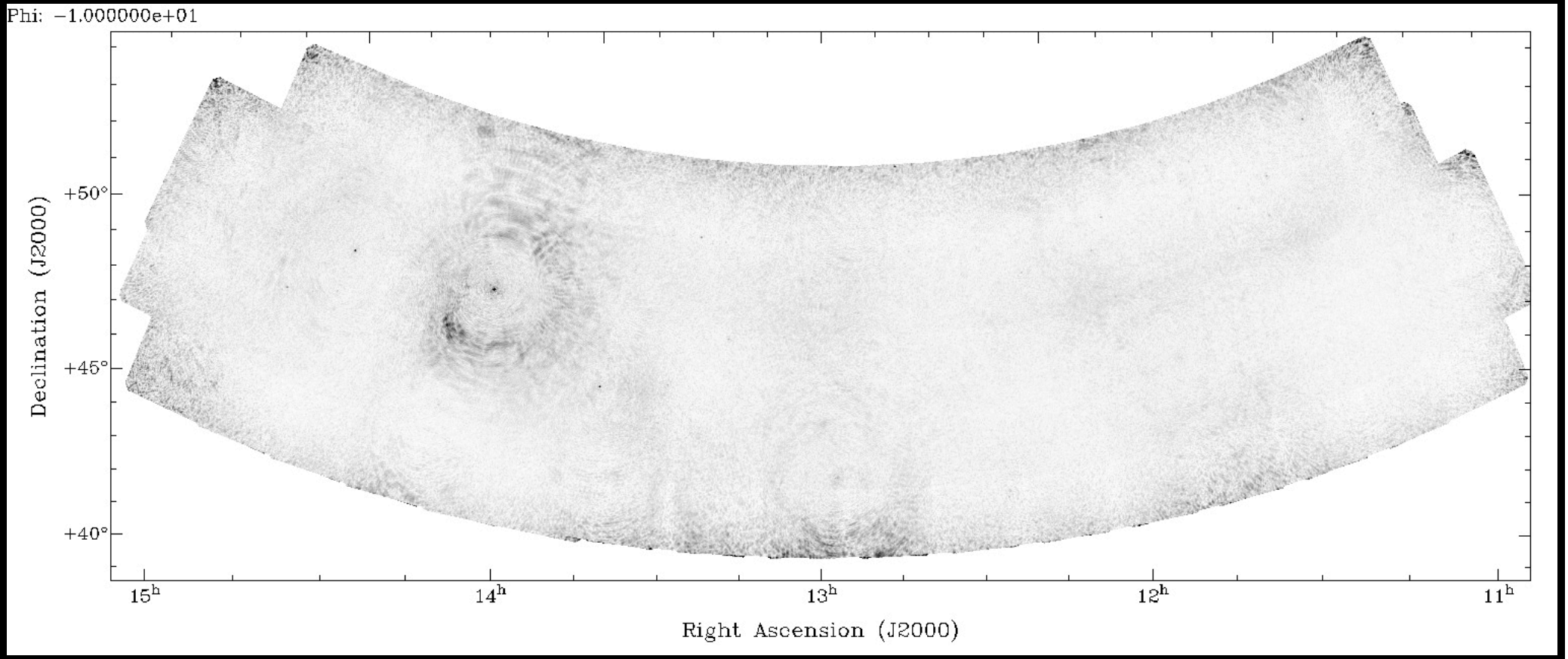
See lecture L14 by M. Iacobelli on Friday

COSMIC MAGNETISM



Courtesy of C. Van Eck

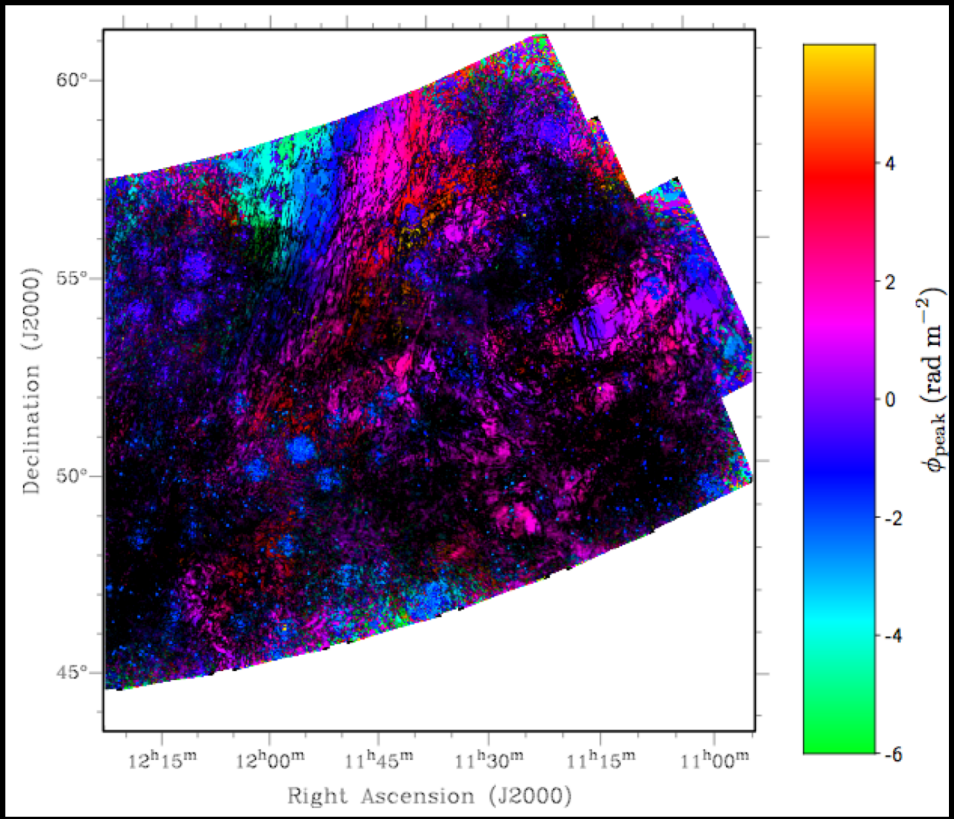
COSMIC MAGNETISM

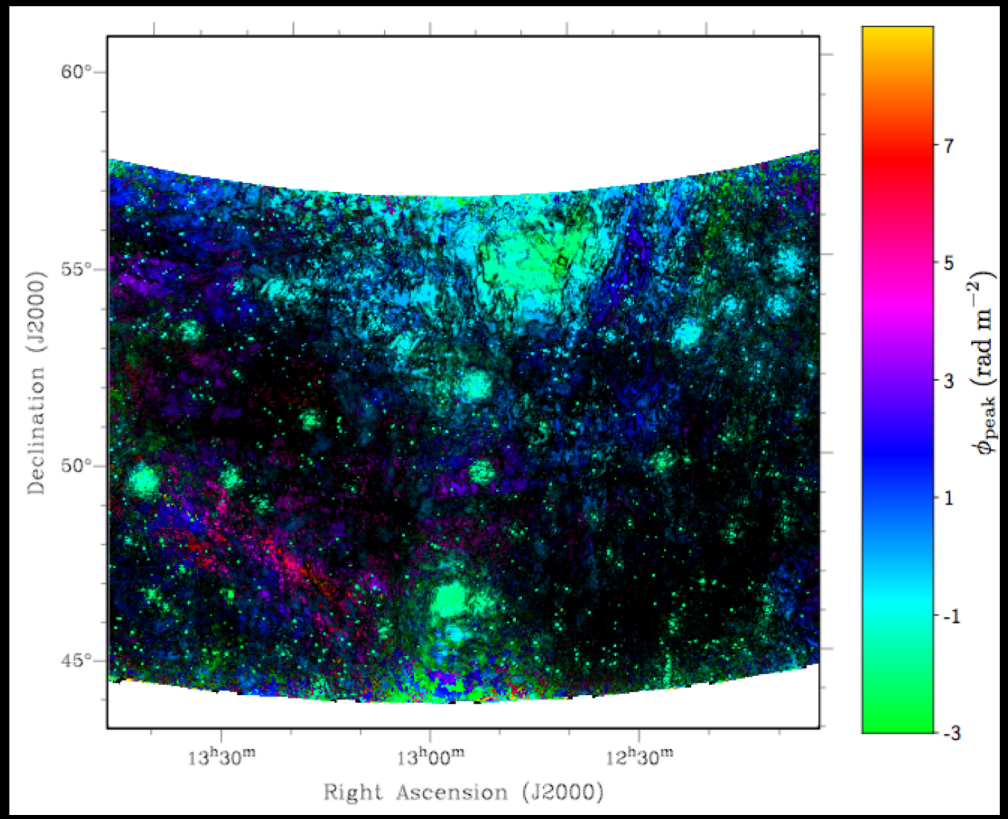


60 LOTTS observations – 570 deg^2

Courtesy of C. Van Eck

COSMIC MAGNETISM



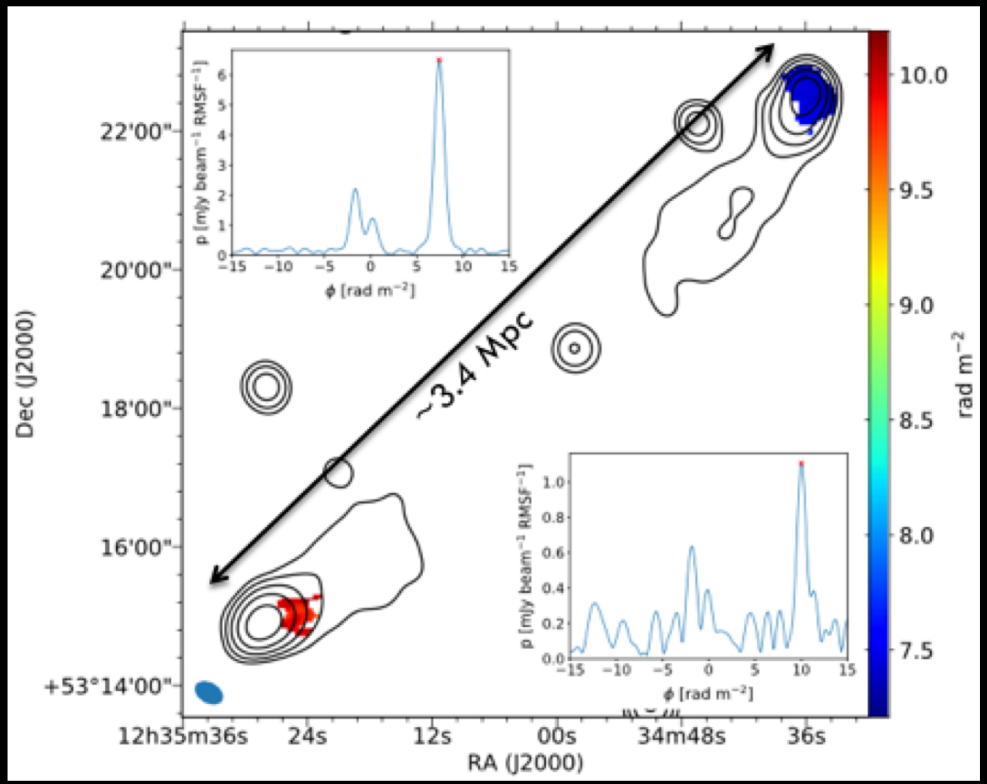


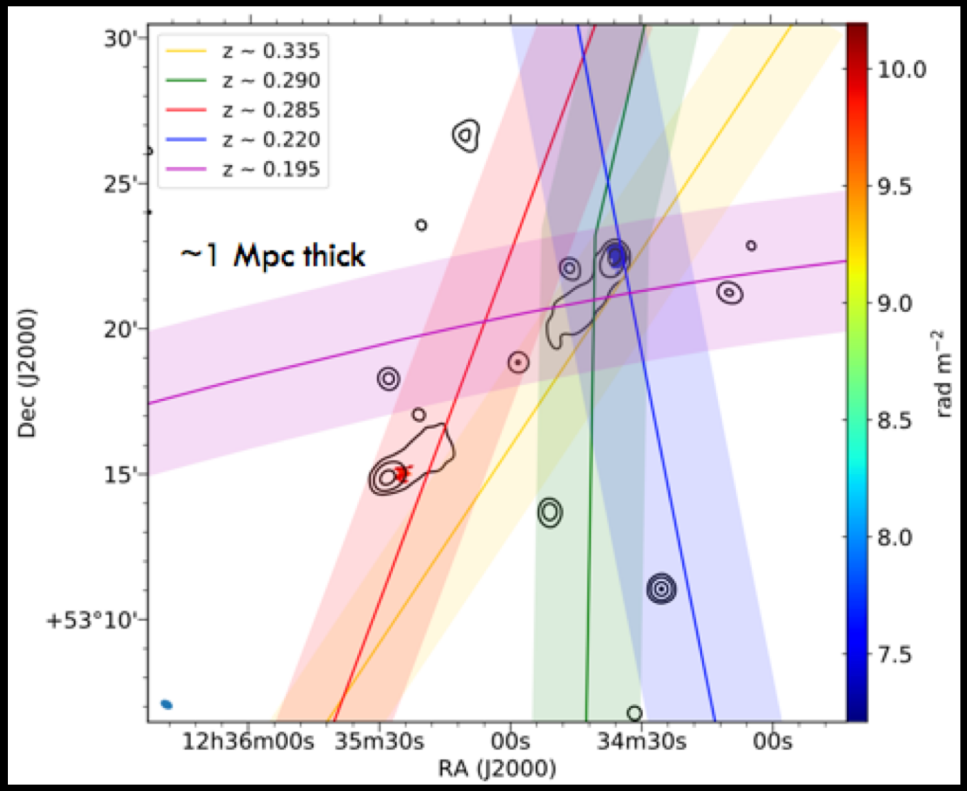
Color -> Faraday Depth of the peak
Brightness -> Polarized intensity

Courtesy of C. Van Eck

COSMIC MAGNETISM

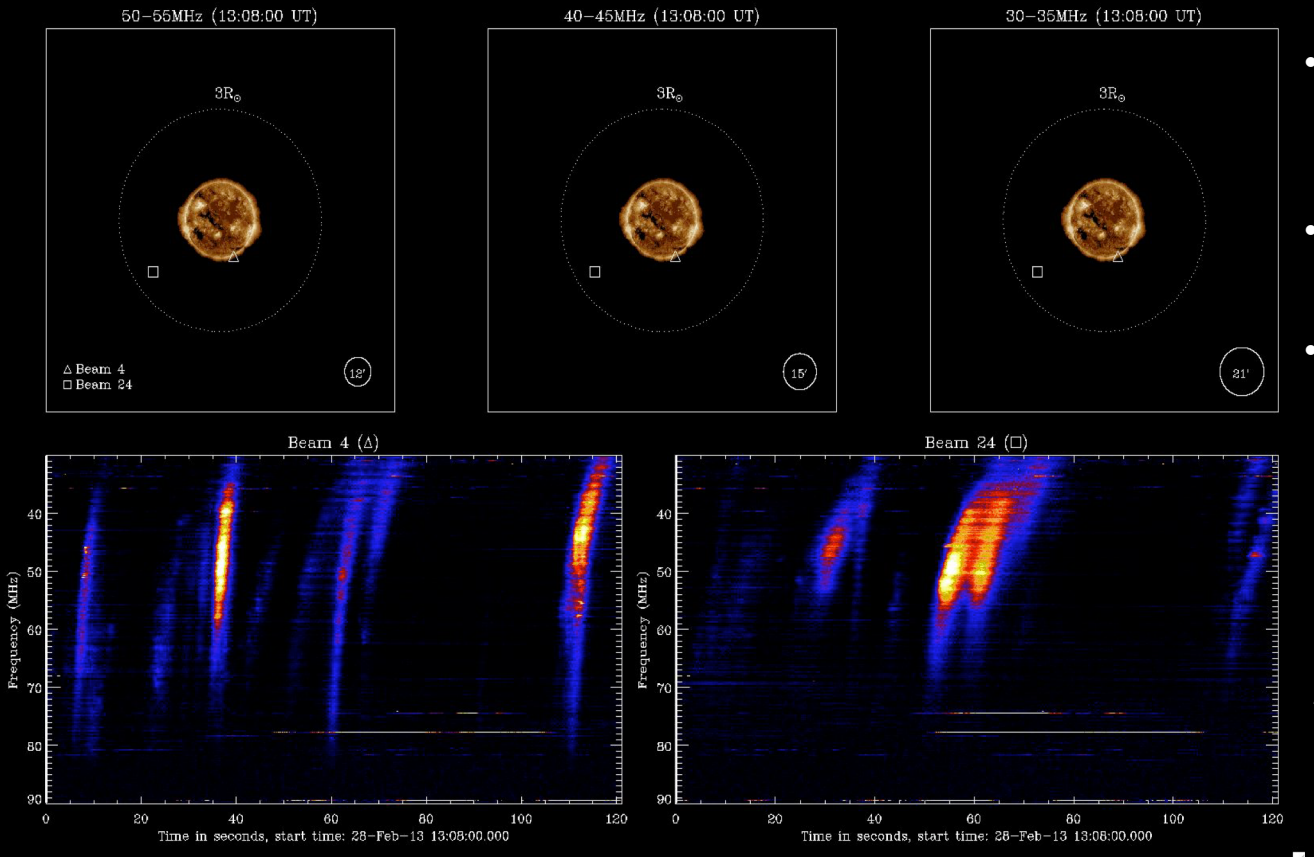
Probing magnetic fields in intergalactic filaments: excess of 2.5 rad/m^2 on 3.4 Mpc scales in Giant Radio Galaxy





Courtesy of S. O' Sullivan

SOLAR PHYSICS AND SPACE WEATHER



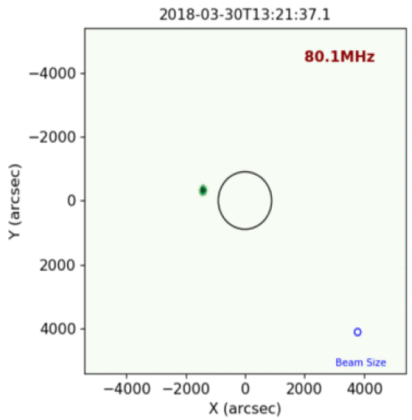
- Thermal radiation of the quiet Sun interspersed with intense radio bursts (flares and CMEs)
- LOFAR: dynamic spectroscopic radio imager
- Several type I-II-III radio bursts detected since 2011

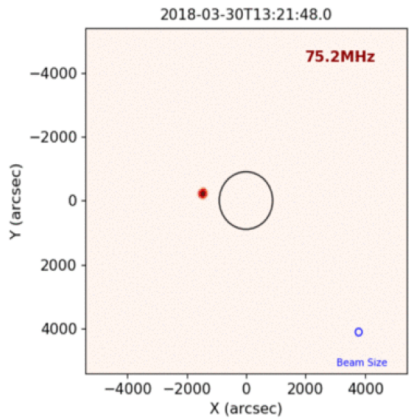
See lecture L15 by Zucca on Friday

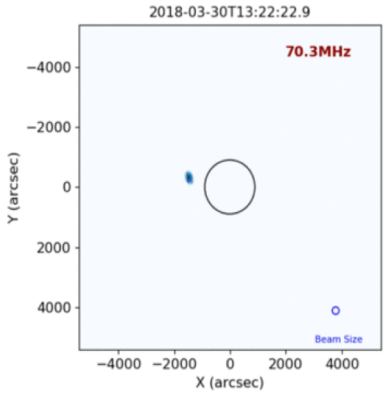
LOFAR tied array imaging of the Sun: electrons escaping the solar corona

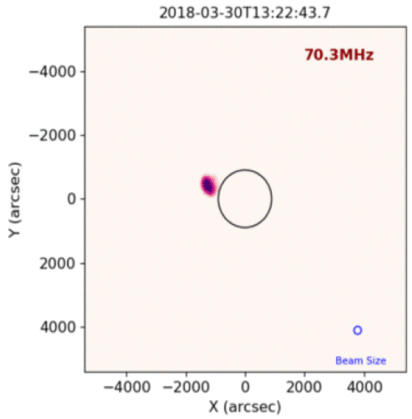
Courtesy Morosan, Gallagher, Zucca, Fallows, Carley and the Solar KSP

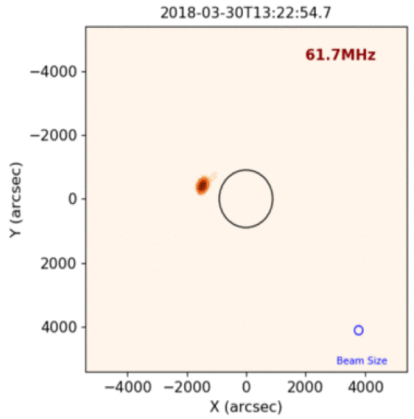
SOLAR PHYSICS AND SPACE WEATHER

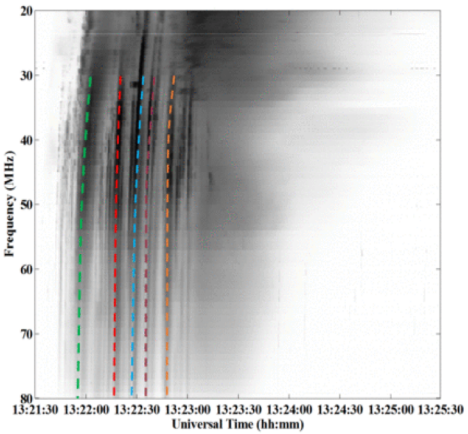










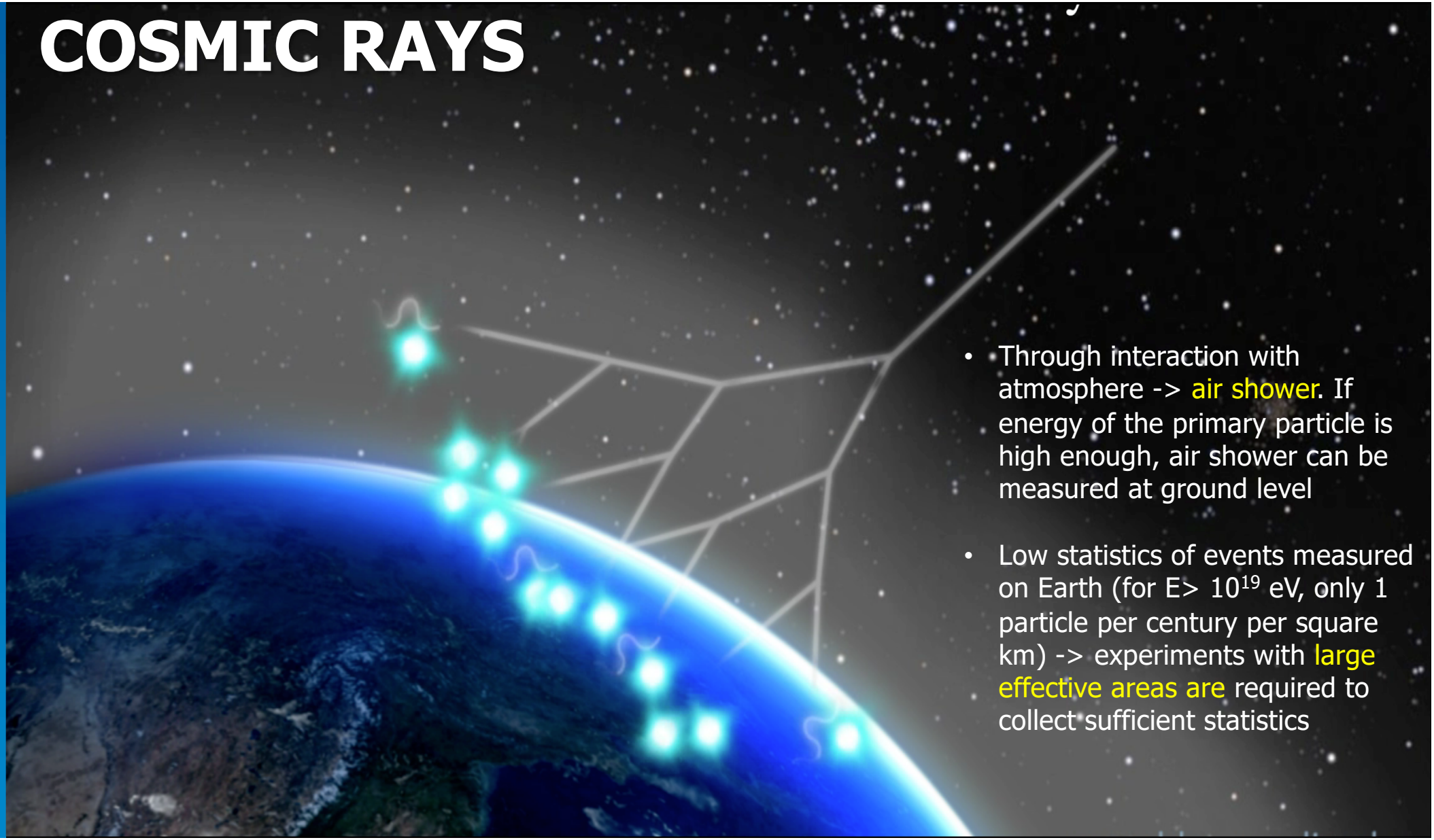


Interferometric images of type III bursts

See lecture L15 by Zucca on Friday

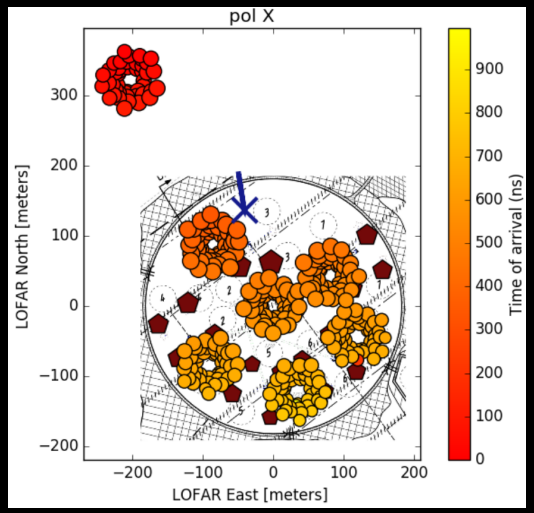
Kumari & Zucca in prep.

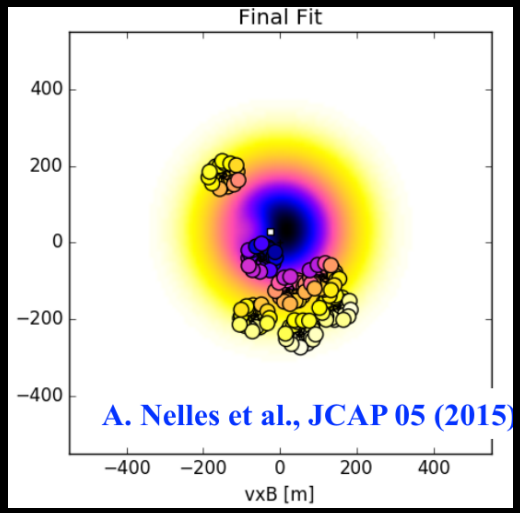
COSMIC RAYS

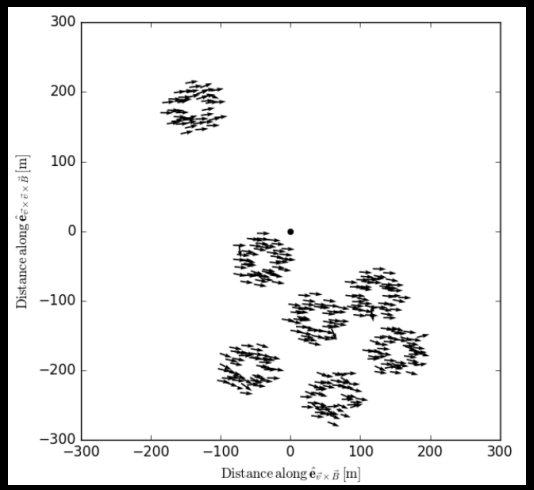


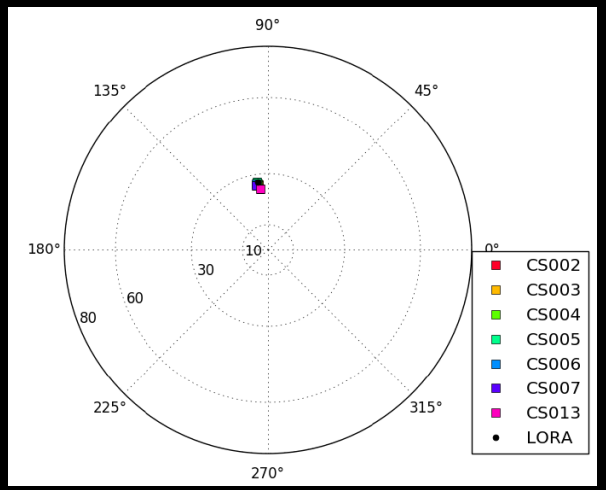
- Through interaction with atmosphere -> air shower. If energy of the primary particle is high enough, air shower can be measured at ground level
- Low statistics of events measured on Earth (for E> 10^{19} eV, only 1 particle per century per square km) -> experiments with large effective areas are required to collect sufficient statistics

COSMIC RAYS





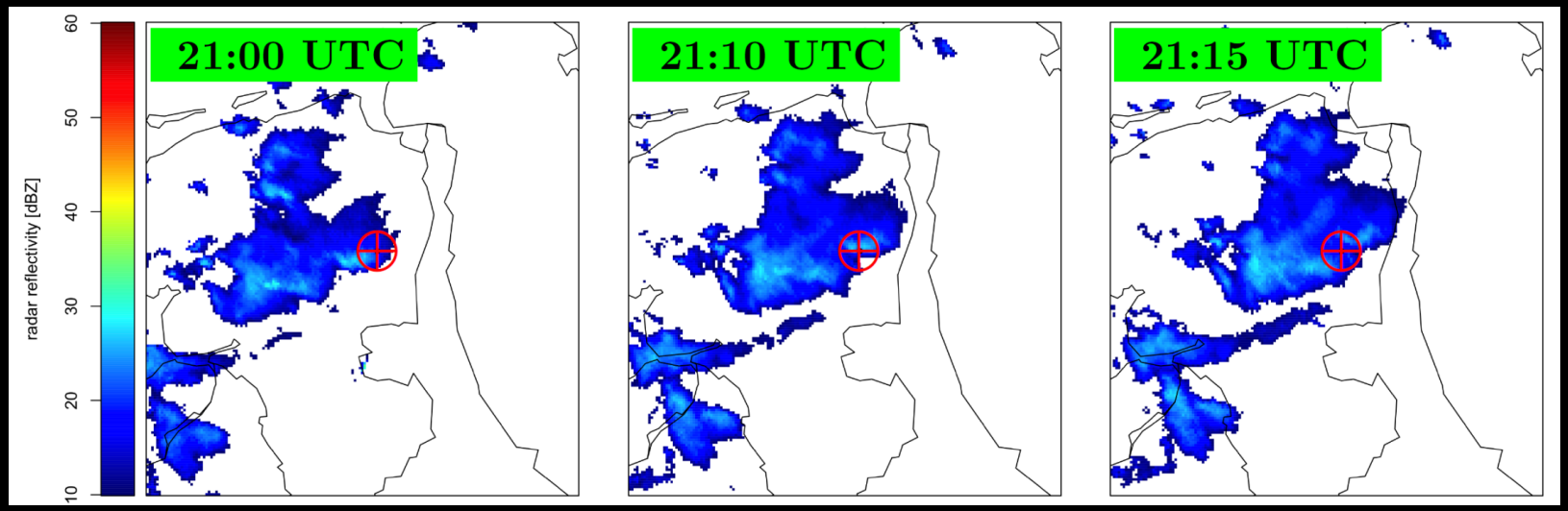


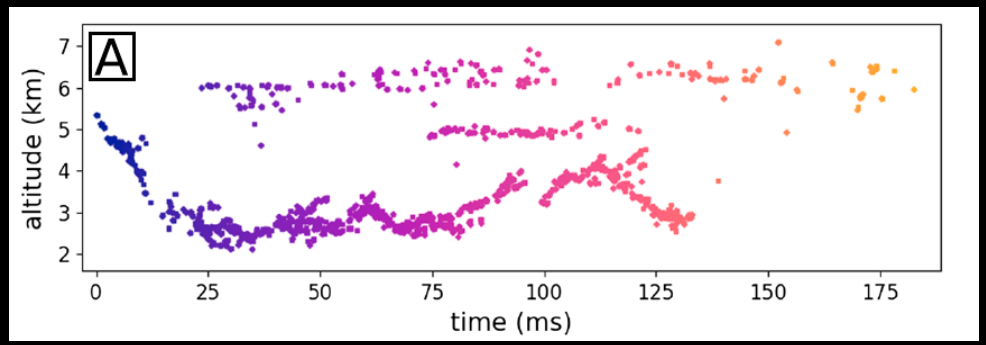


- Cosmic-ray events reconstruction between 10^{16} – 10^{18} eV -> acceleration and propagation mechanisms
- Distribution of radio footprint allows to reconstruct arrival direction, energy and mass composition of the primary particle.
- Best and most precise CR composition measurements to date (Buitink et al., Nature, 2016).
- Good reconstruction of polarization direction

Courtesy of L. Rossetto

COSMIC RAYS





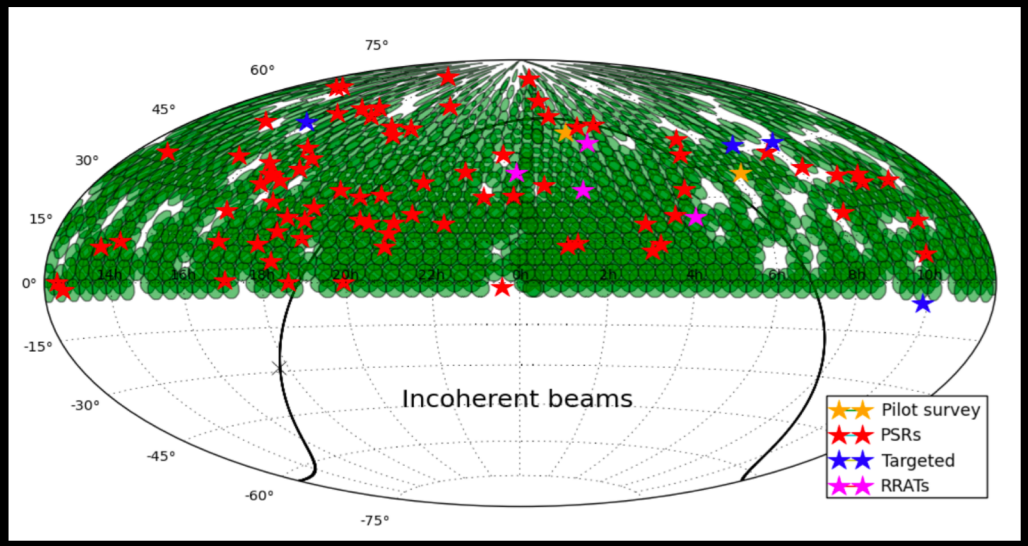
B. Hare et al. Journal of Geophysical Research (2018) 123
T.N.G. Trinh et al. Submitted to Journal of Geophysical Research (2018)

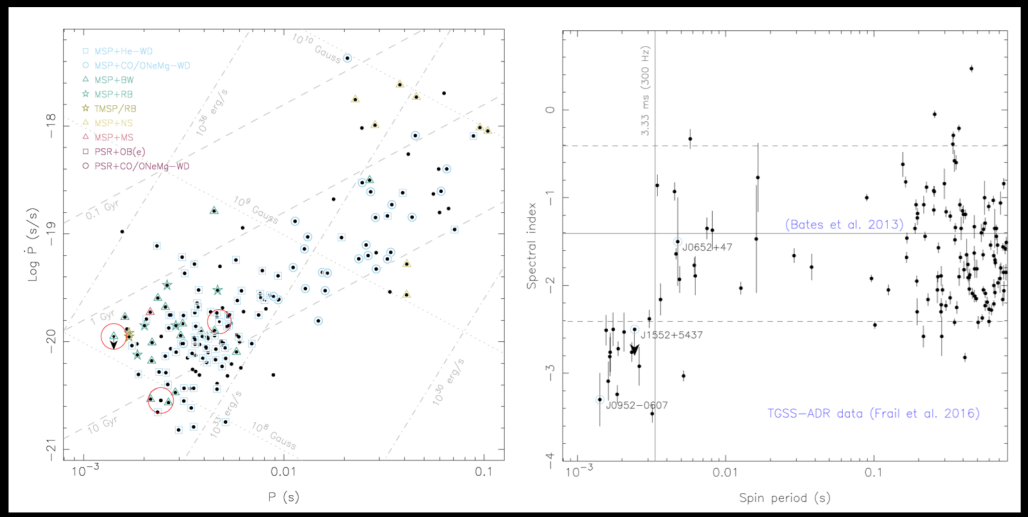
Routine for mapping thunderstorm and lightning events:

- reconstruction of the on-sky position of the electric discharge
- mapping the electric fields within clouds during thunderstorms, and characterizing their influence on cosmic-rays radio emission

Courtesy of L. Rossetto

TRANSIENTS & PULSARS



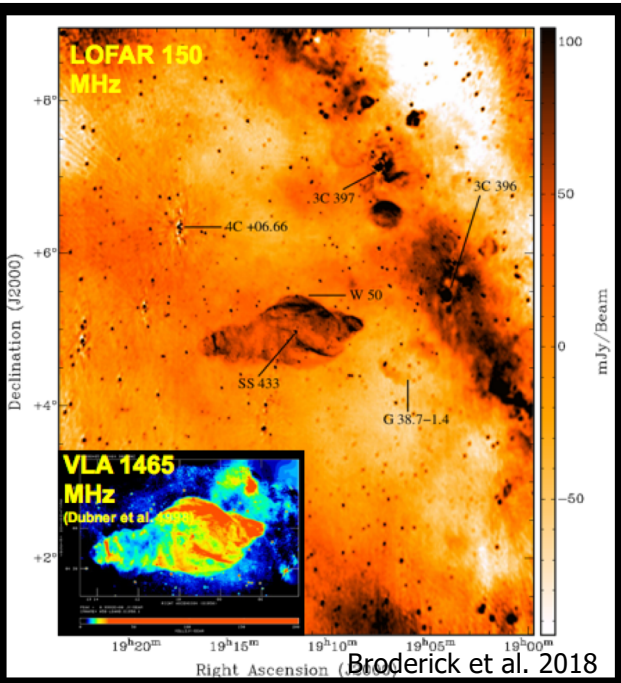


- LOTAAS – LOFAR Tied Array All-Sky Survey - deepest low frequency pulsars survey ever performed:
  - Discover exotic pulsar systems to test gravity, constrain the physics of dense matter, and probe the pulsar emission mechanism
  - Characterize the low-frequency transient radio sky on sub-second timescales
  - Almost completed!
  - 85 pulsars discovered so far
  - One of the most successful pulsars surveys in the last decade
- Discovery of 3 MSPs with LOFAR, including the fastest MSP in the Galactic field (PSRJ0952-0607)
- J0250+58: slowest PSR ever: 23.5 s period!

Courtesy of C. Bassa, V. Kondratiev and C. M. Tan

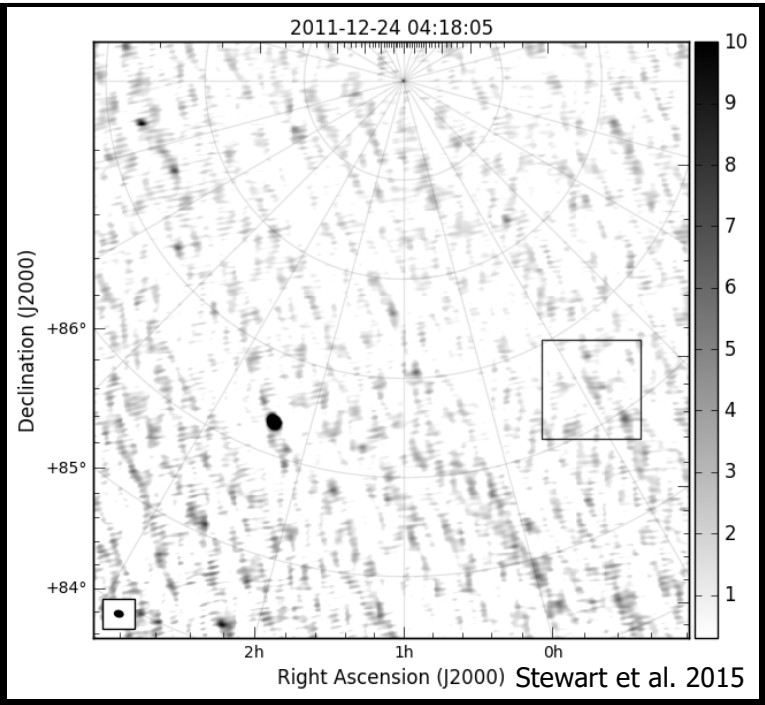
See beamformed lectures on Thursday

TRANSIENTS & PULSARS



Broderick et al. 2018

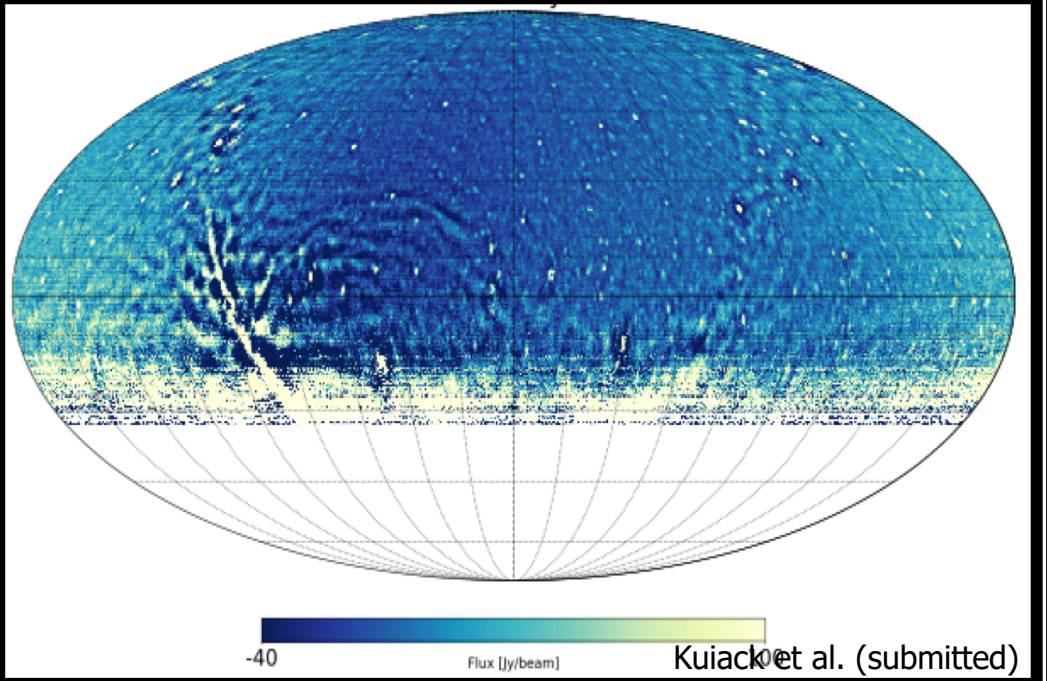
- W 50 morphology in excellent agreement with higher-frequency maps. 150-MHz integrated flux ~ 210 Jy.
- Most complete detection of radio shell of SNR G 38.7-1.4.
- SS 433 marginal variability at 150 MHz; rise corresponds to extended flaring activity at GHz frequencies.



Stewart et al. 2015

- Detection of first LOFAR transient event (LBA)
- 400 h monitoring data of NCP (single LBA sub-band in MSSS).
- ILT J225347+862146: ~20 Jy at 60 MHz. Estimated time-scale of event ~4 min
- Flare star? (Scattered) FRB with unusually steep radio spectrum ($\alpha < -4.7$)?

TRANSIENTS & PULSARS

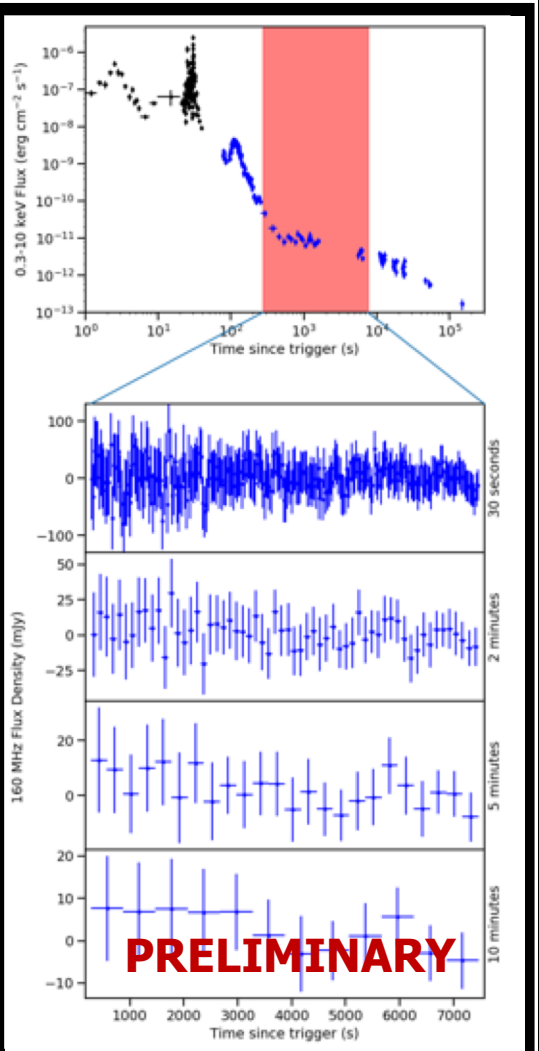


Kuiack et al. (submitted)

- AARTFAAC: Amsterdam-ASTRON Radio Transients Facility And Analysis Center
- New AARTFAAC source catalogue at 60 MHz

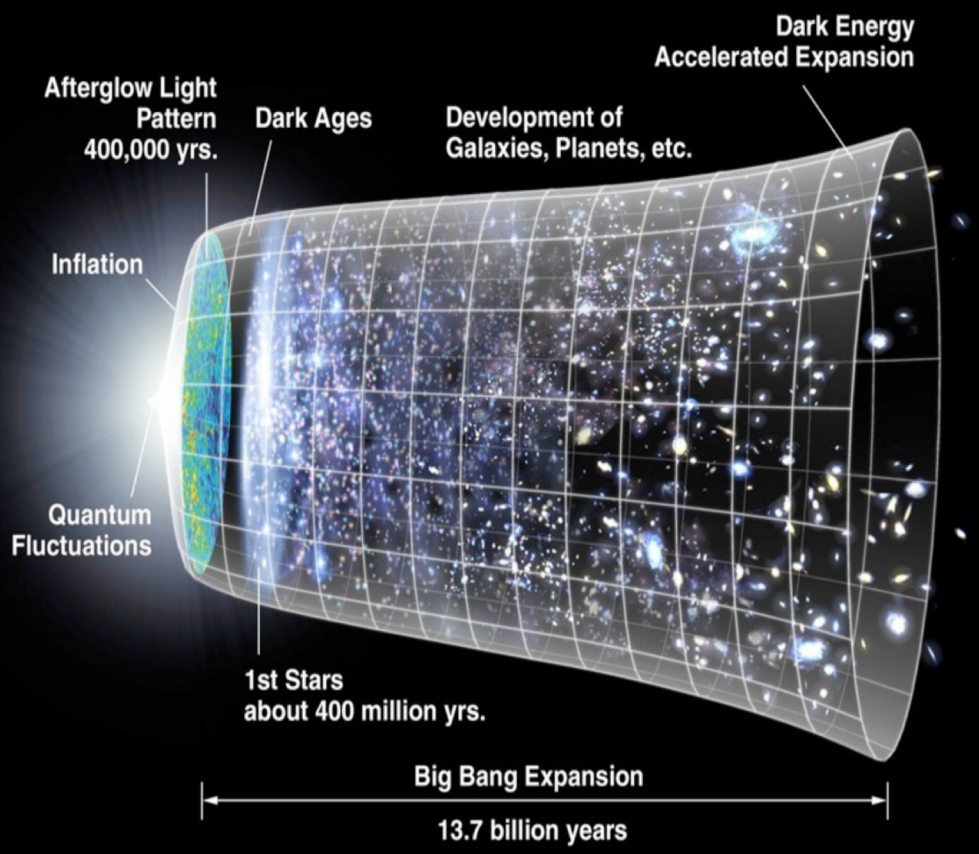
LOFAR Rapid Response Observations of GRB 180706A

- Observations started within 5 minutes of the GRB
- top: X-ray light curve of the gamma-ray burst (GRB) detected by Swift Observatory. Red box: timescale of the LOFAR observations
- bottom: LOFAR light curve at the position of the GRB at 4 different timescales
- No emission was detected placing the deepest limits on this to date



Rowlinson, Gourdji et al. (in prep.)

EPOCH OF REIONIZATION



- When was the Universe reionized ?
- How (fast) did reionization proceed ?
- Which objects were responsible ?
  stars/galaxies , QSOs, or …

Redshifted HI to frequency mapping

z =6.7 ⇒ 185 MHz

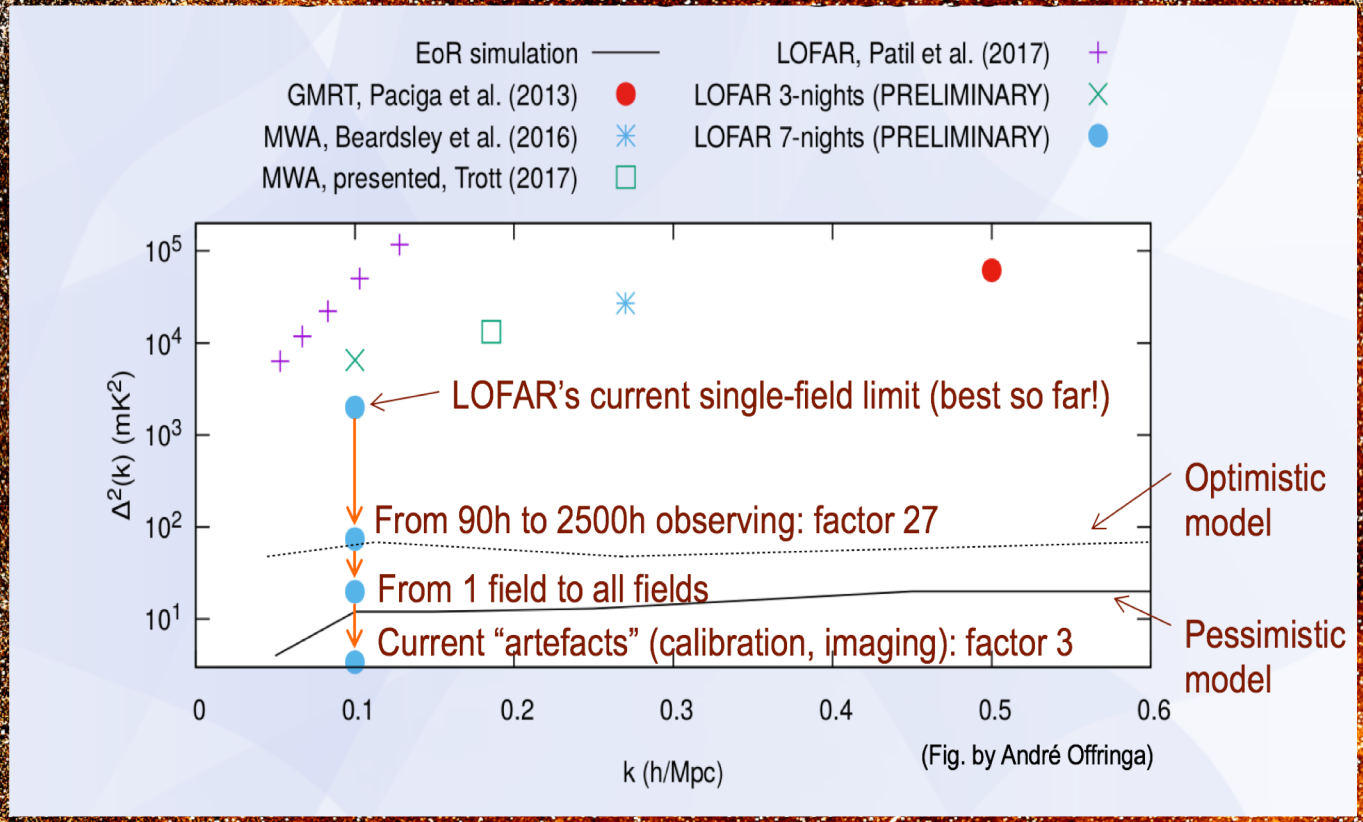
z = 8.5 ⇒ 150 MHz

z = 11.4 ⇒ 115 MHz

Goal: Detect cosmological 21cm signal (z~6-10) from the Epoch of Reionization

⇒ 1.5 Pbytes and 10^{21}-10^{22} FLOP to extract signal!

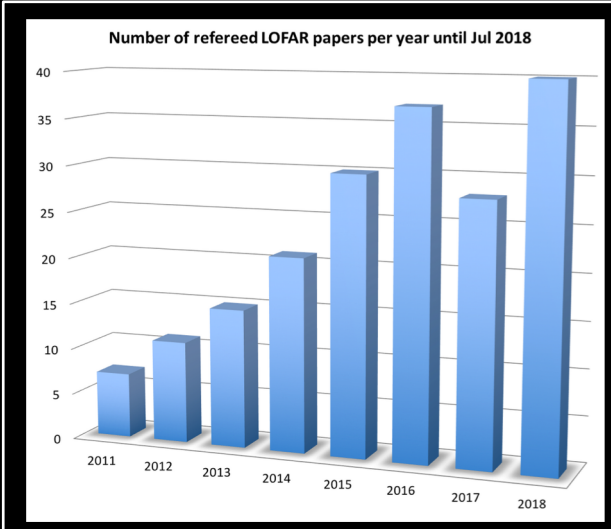
EPOCH OF REIONIZATION

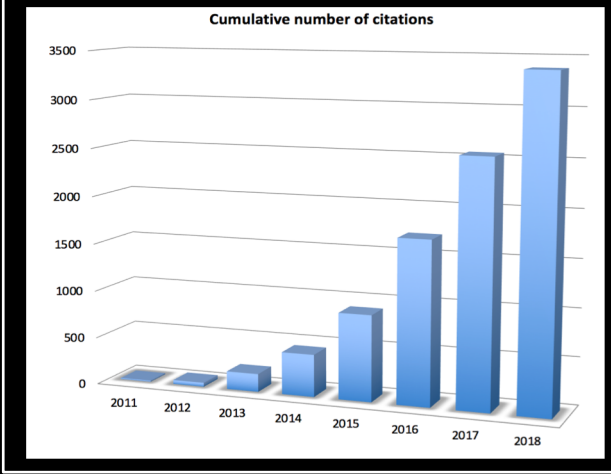


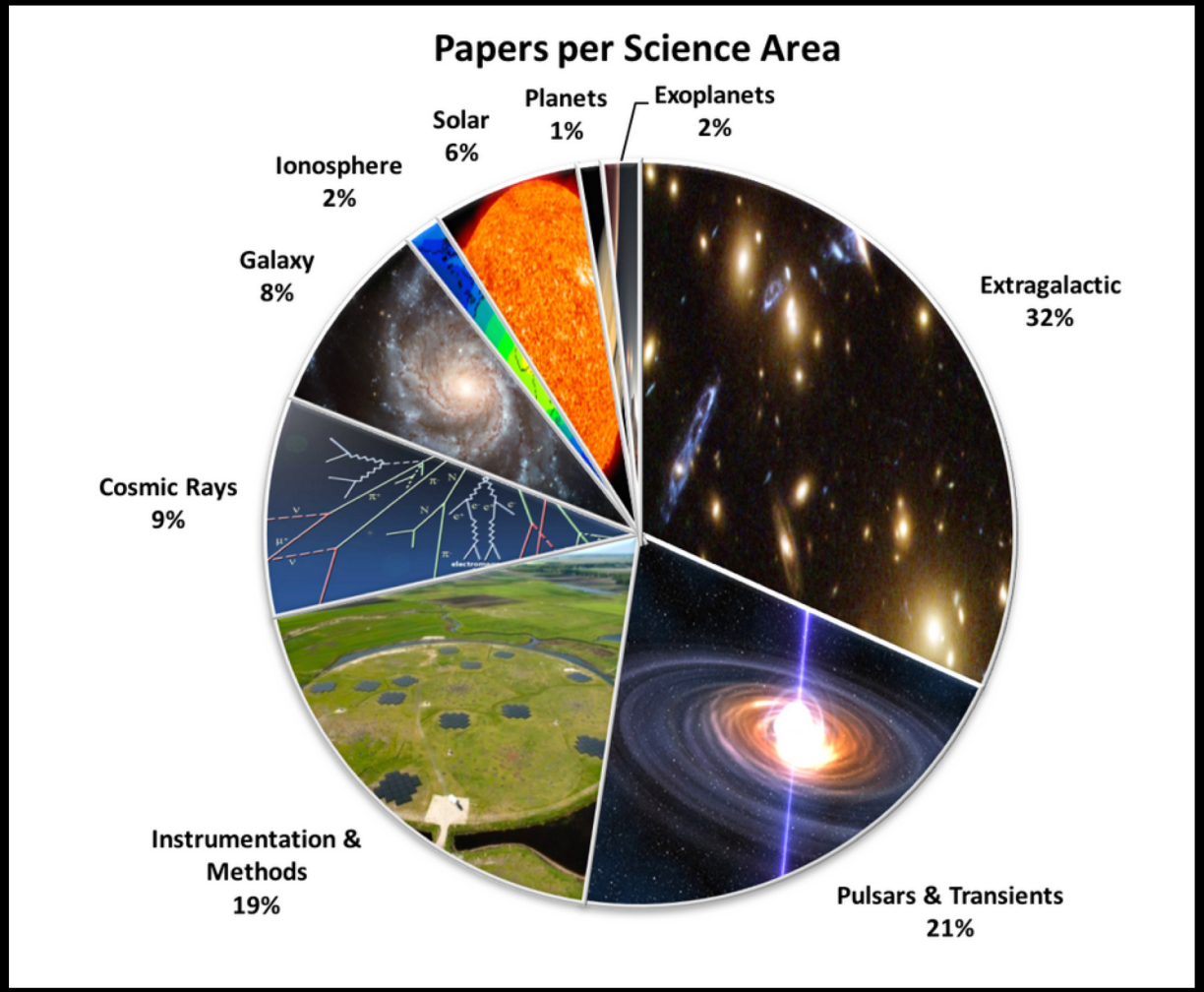
LOFAR is currently ***the best telescope*** to detect EoR signals:

- High sensitivity
- The only low-frequency telescope with high (arcsec) resolution
- The LOFAR team has published the current world-leading upper limit

LOFAR SCIENCE OUTPUT







SUMMARY

- LOFAR is generating great scientific data
- LOFAR provides several unique scientific capabilities
- NEW EXCITING DISCOVERIES ARE THERE FOR YOU TO MAKE!!!