An Overview of the Modern Radio Universe

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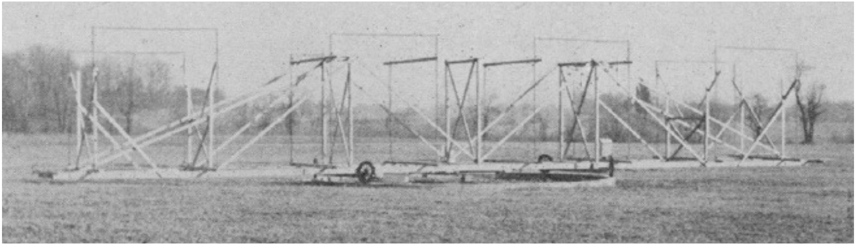
Why is important to observe in radio?

- Astrometry: up to 7 μas nowadays.
- High-resolution imaging
- Map of the gas in the Galaxy (HI)
- High-energy processes: link to X/gamma-ray emission
- Non-thermal processes

Why is important to observe in radio?

Radio astronomy started in the '30s
Observes from 10 MHz to 1 THz
In $\approx$ 80 years: resolution from ~ 10 deg to $\sim \mu$as.
while in optical: from $\sim$ arcmin to ~ 10 mas (Gaia: $\sim 10\mu$as)



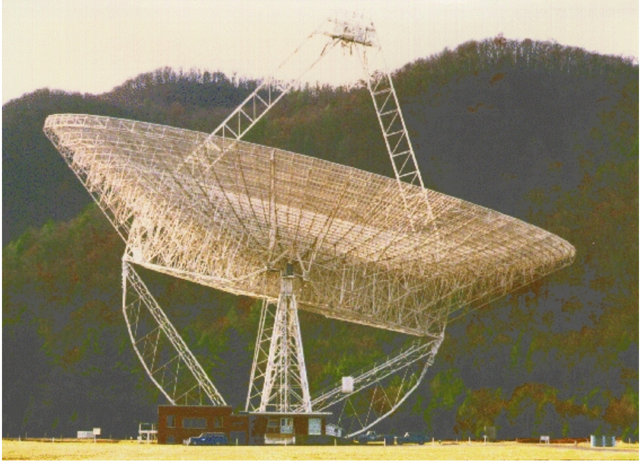
Karl G. Jansky 1932

Why is important to observe in radio?

Effelsberg in Germany $d = 100$ m

Why is important to observe in radio?

Green Bank (GBT) in West Virginia (U.S.A.) $d = 100\ \mathrm{m}$



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Green Bank (GBT) in West Virginia (U.S.A.) $d = 100$ m

Why is important to observe in radio?

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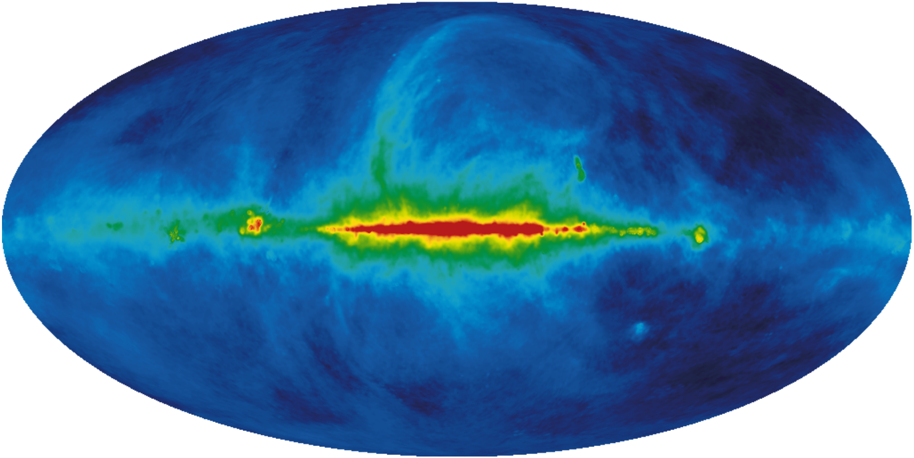
Why is important to observe in radio?

Arecibo in Puerto Rico $d = 300\ \mathrm{m}$

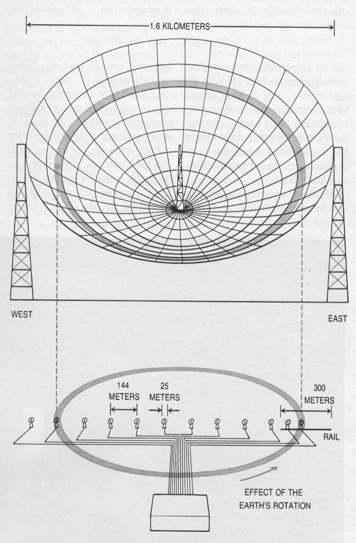
HASLAM 408 MHz



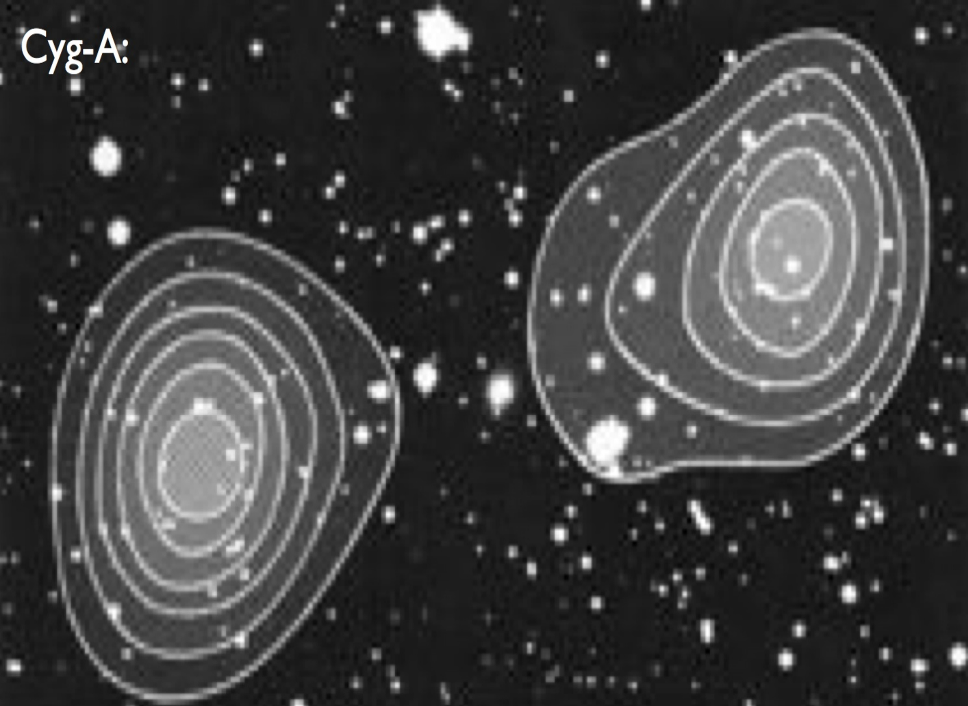
Interferometric Arrays

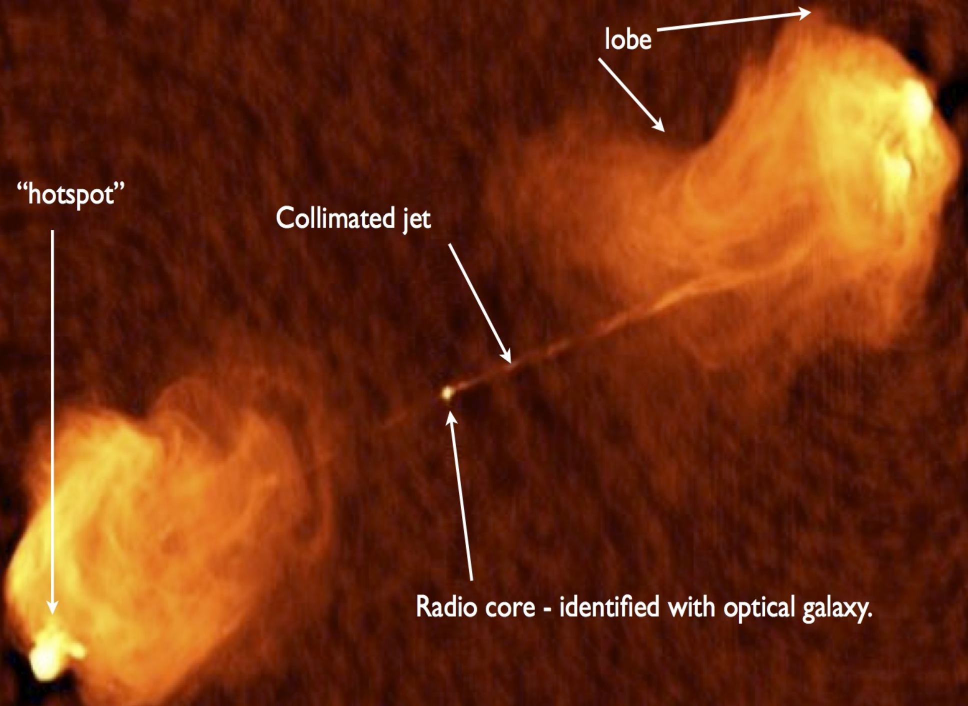
One of the most important step forward in radio observatories:
interferometry

- Combining the coherent signal from many antennas
- Resolution $\sim$ largest distance between antennas
- Many "medium" antennas instead of one big antenna



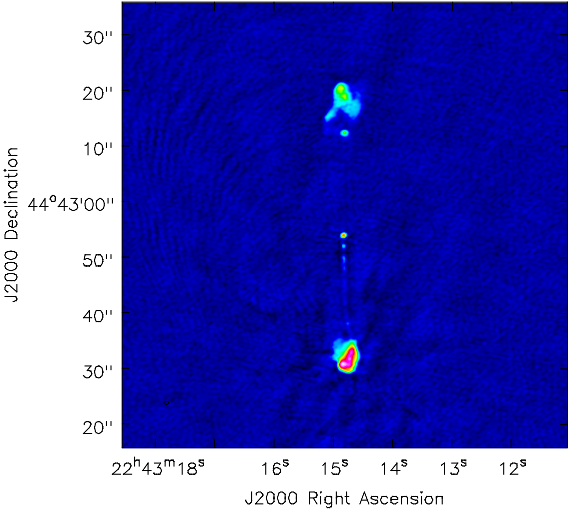
Cyg-A:




lobe
"hotspot"
Collimated jet
Radio core - identified with optical galaxy.

VLA in Socorro (U.S.A.) 27 antennas of 25 m each one up to 36 km

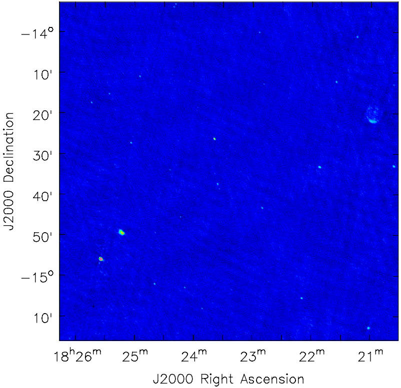
VLA

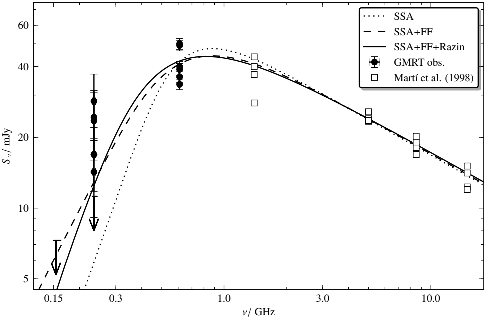


HD 215227 field. 1-hour observation at 2.3 GHz

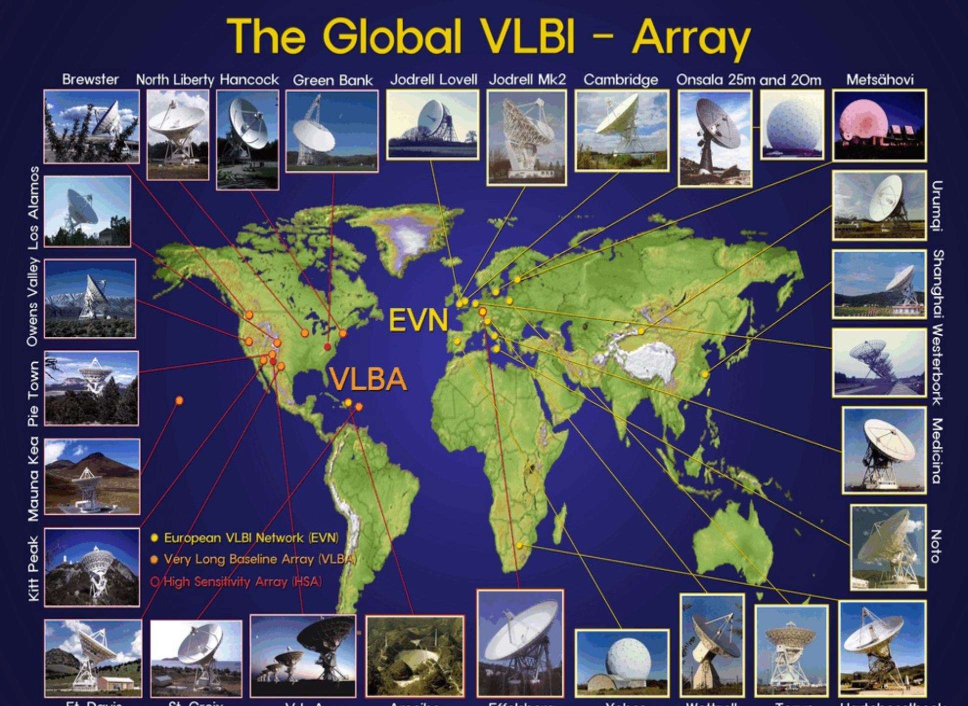
GMRT in India **30 antennas of 45 m each one up to 25 km**

GMRT

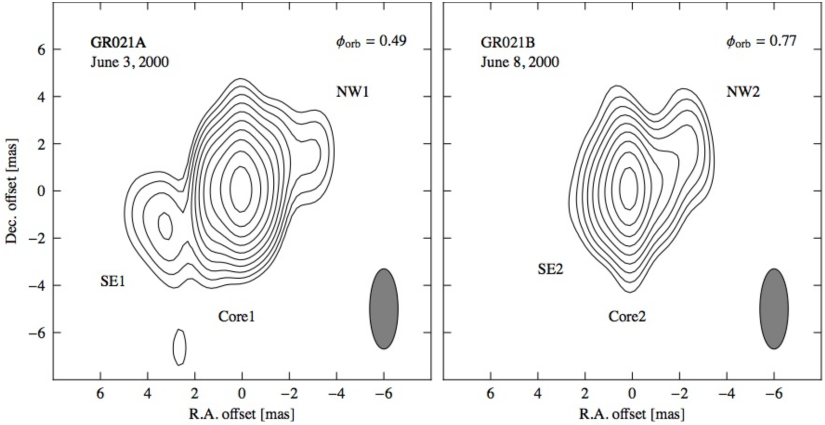




LS 5039 field. 5-hour observation at 150 MHz

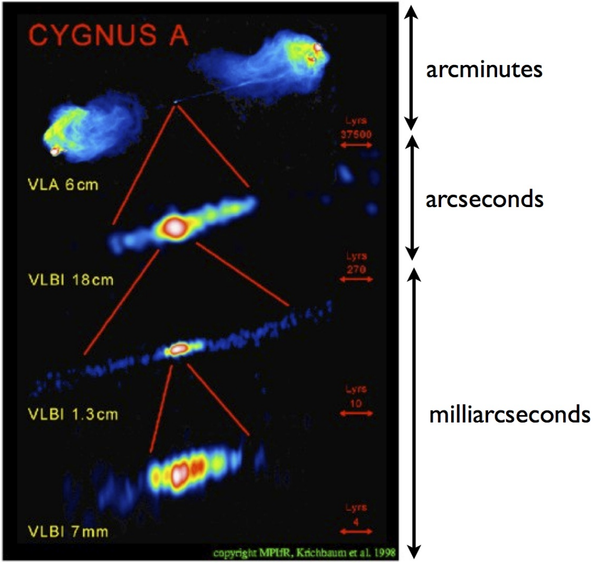

The Global VLBI - Array
Brewster
North Liberty
Hancock
Green Bank
Jodrell Lovell
Jodrell Mk2
Cambridge
Onsala 25m and 20m
Metsähovi
Urumqi
Shanghai
Westerbork
Medicina
Noto
Los Alamos
Owens Valley
Pie Town
Mauna Kea
Kitt Peak
EVN
VLBA
European VLBI Network (EVN)
Very Long Baseline Array (VLBA)
High Sensitivity Array (HSA)
Ft. Davis
St. Croix
V L A
Arecibo
Effelsberg
Yebes
Wettzell
Torun
Hartebeesthoek

VLBI



LS 5039 (Moldón 2012)

VLBI


CYGNUS A
VLA 6cm
VLBI 18cm
VLBI 1.3cm
VLBI 7mm
Lyrs
37500
Lyrs
270
Lyrs
10
Lyrs
4
copyright MPIfR, Krichbaum et al. 1998
arcminutes
arcseconds
milliarcseconds

New Generation Radio Telescopes

VLA LBA VLBA VLBI EVN . . .

$\Downarrow$

ALMA LOFAR SKA Radioastron . . .

New Generation Radio Telescopes

VLA LBA VLBA VLBI EVN ...

$\Downarrow$

ALMA LOFAR SKA Radioastron ...

and more beautiful names!

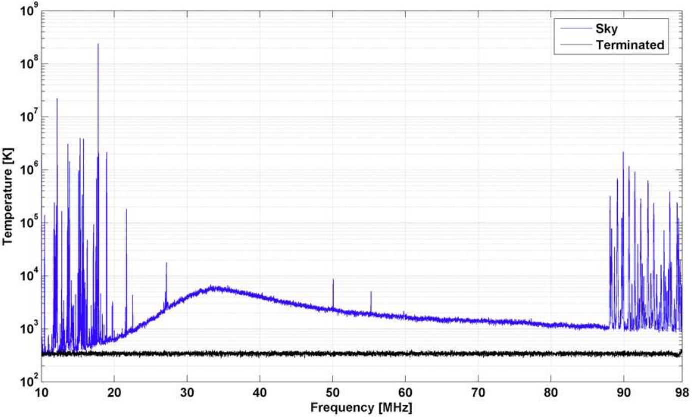
New Generation Radio Telescopes

Observing at low frequencies (below 1 GHz)

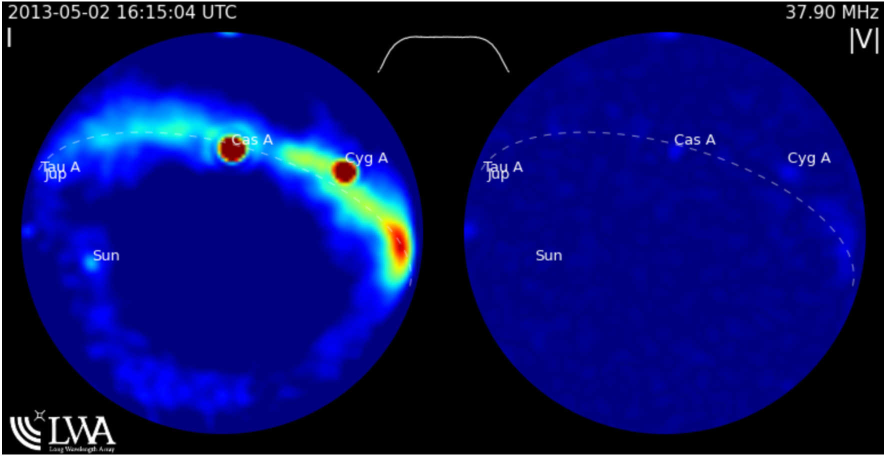
- Most sources have a higher luminosity
- Only non-thermal processes
- Ionospheric problems. . .
- Much lower cost per antenna

New Generation Radio Telescopes

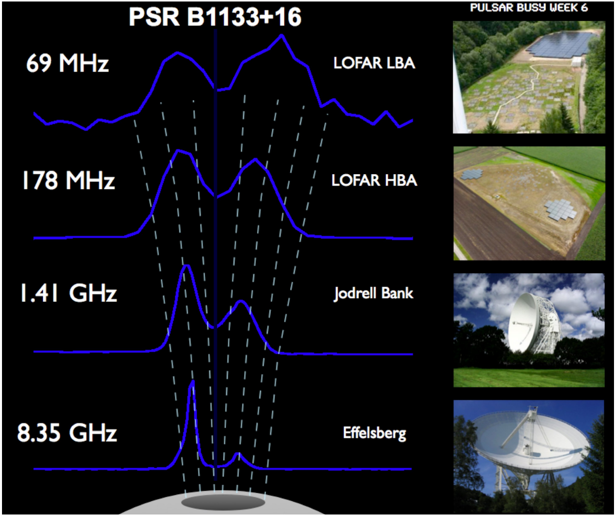
There is also more problems: (LWA spectrum)



New Generation Radio Telescopes



New Generation Radio Telescopes



LOFAR

The Low Frequency Array

LOFAR

Observes in the 10–250 MHz range

- LBA: 10–80 MHz
- HBA: 110–250 MHz

Core in The Netherlands

Also Germany, U.K., France, Sweden

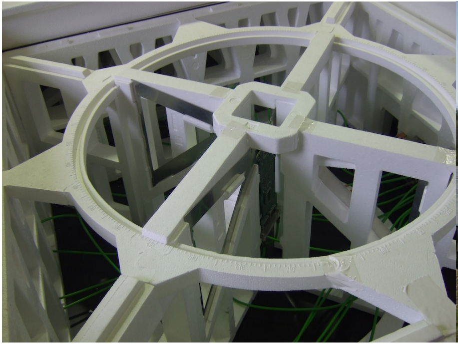
$\sim$ 45 stations (48 HBA & 96 LBA)

Baselines up to 1 500 km ($\lesssim$ arcsec)

Pointing purely by software

First large-scale interferometer at low frequencies

LOFAR: High Band Antennas



LOFAR: Low Band Antennas

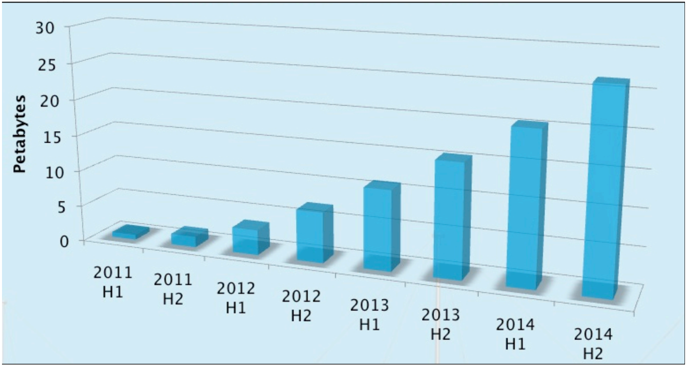
LOFAR

There are a lot of science to which LOFAR can contribute. . .

- Transients
- Pulsars
- Planets, exoplanets
- Sun (Space Weather)
- Cosmic Rays
- Epoch-of-Reionization
- Cosmic magnetism
- Galactic structure and ISM
- Wide imaging surveys
- Clusters and halos
- AGNs and radio galaxies
- And more. . .

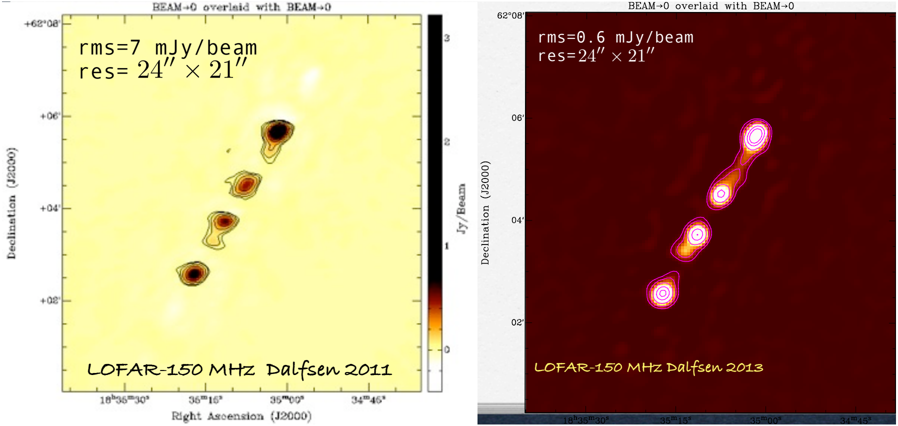
LOFAR

LOFAR can observe the almost all sky at the same time
Many pointings simultaneously
The only restriction is. . . the *disk space!* ($\sim$ 1 TB/hr)



CEP1: 24 x 24 TB & CEP2: 100 x 21TB $\Rightarrow$ $\sim$ 3 PB

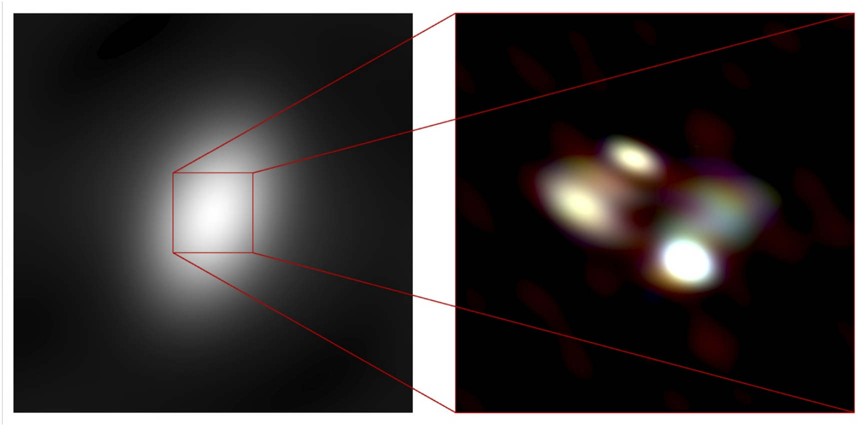
Quasar B1834+620 at 150 MHz (Orru's talk at LOFAR Dalfsen II)



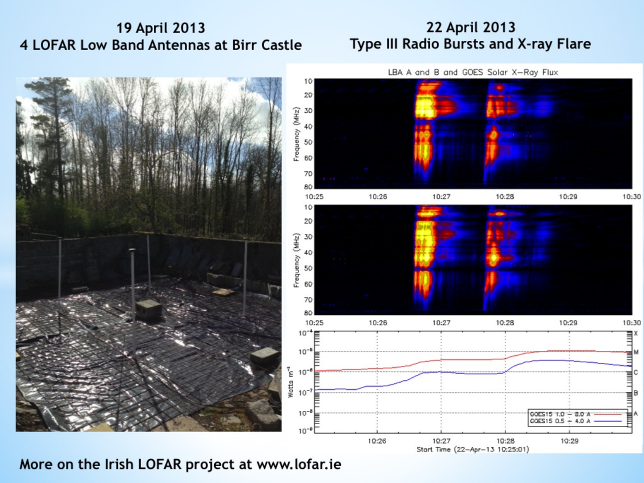
LOFAR

3C196 at 30–80 MHz (Wucknitz's talk at LOFAR Dalfsen II)

NL only: $35'' \times 22''$ beam NL+DE: $1.5'' \times 0.9''$ beam

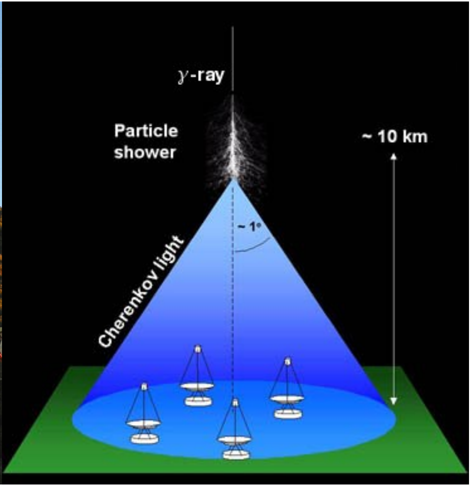


Solar radio bursts (Ireland station)



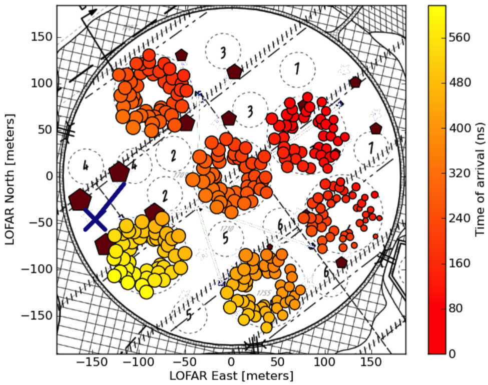
Cosmic Rays

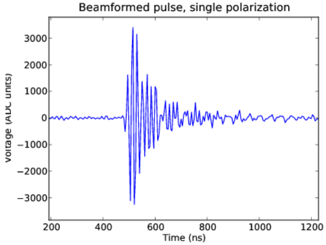
MAGIC (Major Atmospheric Gamma-ray Imaging Cherenkov Telescopes)

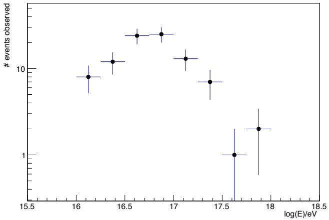


Cosmic Rays

With LOFAR you can also detect air showers...





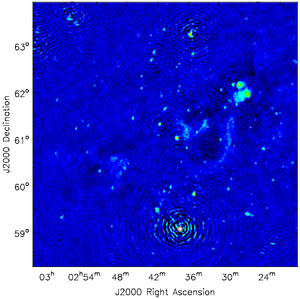


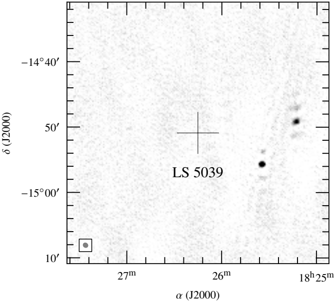
Events from July 2012 to June 2013

Nelles et al. 2013

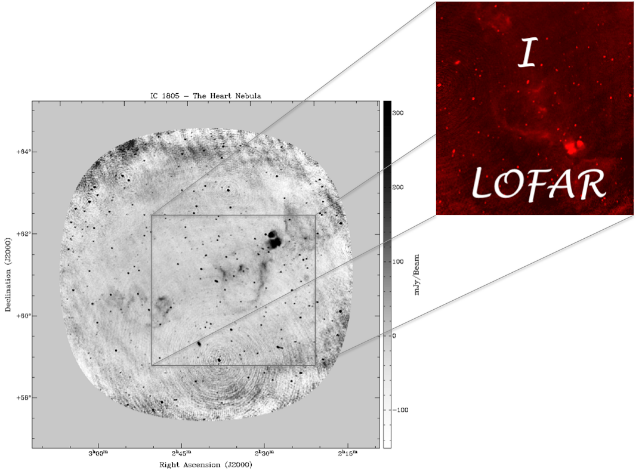
Using LOFAR for Gamma-Ray Binaries

- LOFAR is the first radio observatory at low frequencies with enough resolution and sensitivity
- At these frequencies we should detect the emission present at larger scales away from the system
- We have two LOFAR observations during commissioning stage: LS 5039 & LS I +61 303





Using LOFAR for Gamma-Ray Binaries




The Old Ones
The New ones