High resolution images of extragalactic jets with the International LOFAR

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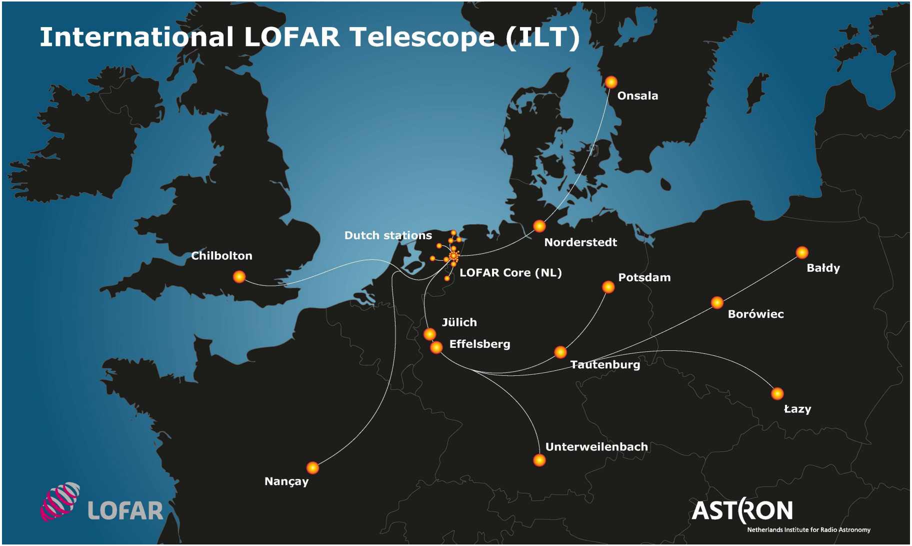
ASTRON Netherlands Institute for Radio Astronomy

LOFAR STATUS MEETING
ASTRON, November 26, 2014

International LOFAR

Future International LOFAR



Baselines between international stations

	CS001	DE601	DE602	DE603	DE604	DE605	FR606	SE607	UK608
CS001	0	266	581	396	419	226	700	594	602
DE601	266	0	390	344	476	53	490	833	590
DE602	581	390	0	277	455	440	690	990	959
DE603	396	344	277	0	186	372	800	714	920
DE604	419	476	455	186	0	487	957	556	1005
DE605	226	53	440	372	487	0	498	807	552
FR606	700	490	690	800	957	498	0	1292	495
SE607	594	833	990	714	556	807	1292	0	1110
UK608	602	590	959	920	1005	552	495	1110	0

$$\left[\frac{\theta}{\mathrm{rad}}\right] \approx \frac{\lambda}{B}$$

$$\left[\frac{\theta}{\mathrm{arcsec}}\right] \approx 206.3 \left[\frac{B_{\mathrm{max}}}{\mathrm{k}\lambda}\right]^{-1}$$

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International LOFAR resolution

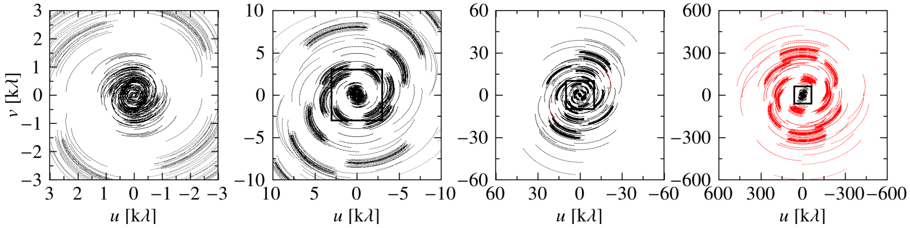


Figure : uv coverage for a typical 4-hr observation of a source at declination $+48°$ with a single subband centred at 140 MHz. Only one visibility every 160 seconds is shown. The rectangles in the last three panels show the area covered by the previous panel. Visibilities corresponding to baselines with international stations are plotted in red.

International LOFAR resolution

International station Beam and LOFAR synthesized beam (FWHM) as a function of frequency.

Freq. (MHz)	λ (m)	St. Beam (deg)	PSF ($''$)
15	20.0	19.4	3.30
30	10.0	9.7	1.65
60	5.0	4.8	0.82
120	2.5	2.6	0.41
150	2.0	2.1	0.33
200	1.5	1.6	0.25
240	1.2	1.3	0.21

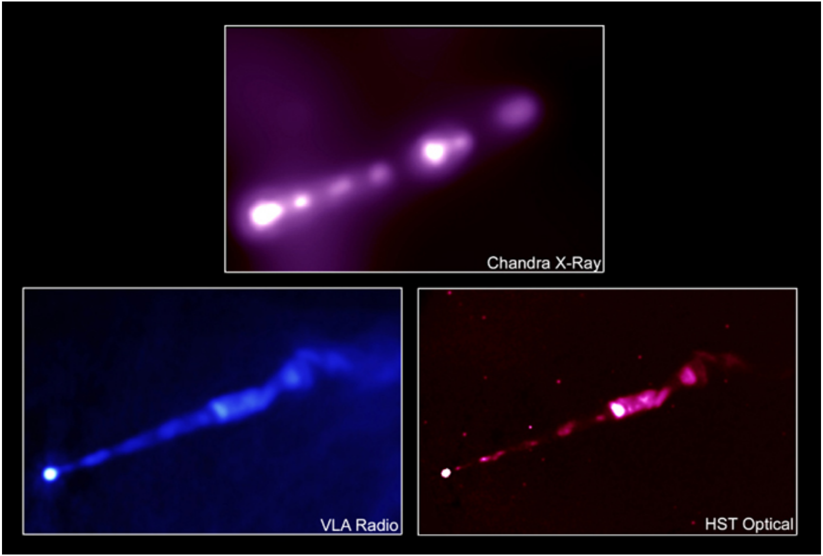
Matching resolution with other instruments

Matching with other instruments. 0.7arcsec resolution corresponds to:

- 3 km baselines @ 45 GHz (VLA C array)
- 9 km baselines @ 15 GHz (VLA B array)
- 27 km baselines @ 4.5 GHz (VLA A array)
- 100 km baselines @ 1.4 GHz (E-MERLIN)
- 1200 km baselines @ 120 MHz (Intl. LOFAR)

For each resolution we are sensitive to different parts of the source, so matching resolutions are needed for spectral analysis.

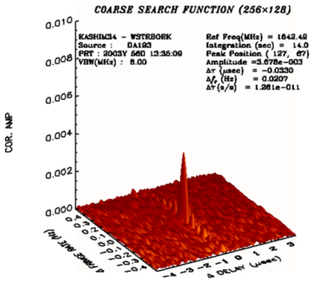
Matching resolution at other energy ranges



LOFAR Long Baselines calibration

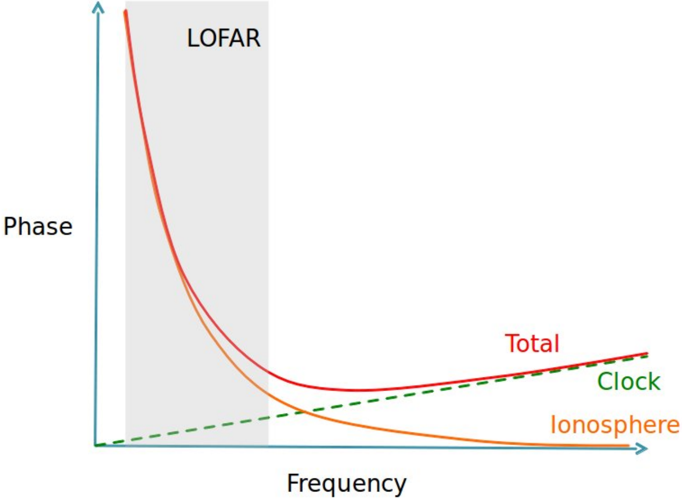
Phase calibration

- Time-variable delay offsets at each station.
- Solving directly for phases would require short time, narrow bandwidth: bad sensitivity.
- We can use "VLBI" tools to coherently combine more data: delay/rate search.
- We need to solve for [phase, phase delay, phase rate] simultaneously for each [station, time range, frequency range].



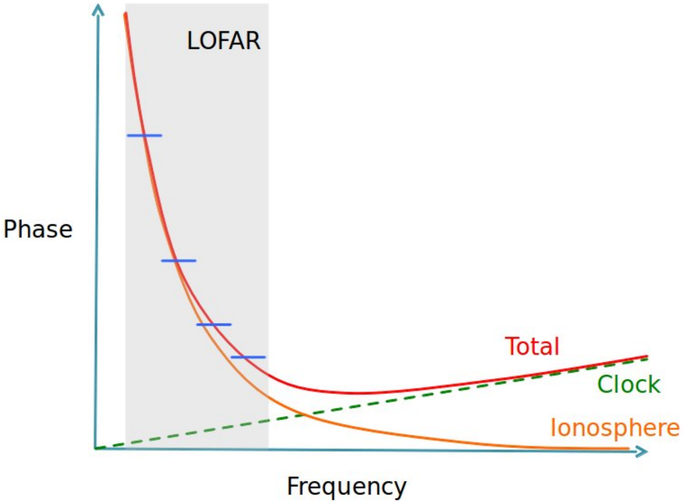
Phase calibration

- The phases change very fast because of the high delays at low ν.
- The ionospheric delay is dispersive, depends on the frequency.



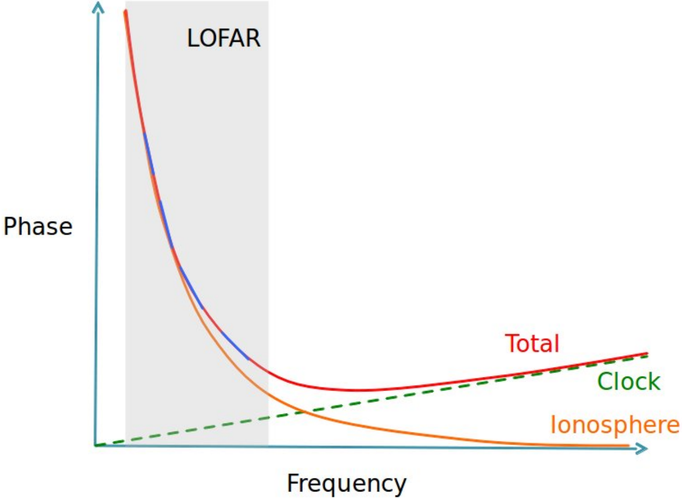
Phase calibration

- Standard phase calibration does not include changes across the band.
- Strong decorrelation occurs as more bandwitdh is added.



Phase calibration in AIPS

- Solving for non-dispersive delay we can include more bandwidth.
- Solving for dispersive delay for an even wider band is not possible yet.



Calibration strategy

We need different types of calibrators:

- Dutch array calibrator.
  - Very bright and well-known sources. 3C196, 3C84.
  - Known flux density to set scale.
  - Can be several degrees away.
  - Apply normal LOFAR calibration techniques (BBS, NDPPP).
- Primary calibrator.
  - Compact source.
  - Moderately bright (above 50 mJy on the longest baselines).
  - Separations of $\sim$degrees.
  - Fringe-fitting in AIPS (non-dispersive delay, using $\sim$3 MHz 'subbands').
  - We determined that there is ~ 1 suitable primary calibrator per square degree.
- Secondary calibrator.
  - Relatively faint source (5–10 mJy).
  - Close to target $\sim$ arcmin.
  - Normal phase calibration (residual delays are small).

Amplitude calibration

- What we need:
  - Compact source.
  - Has to be bright.
  - With known and stable flux density.
- What we have:
  - Low-resolution catalogues provide flux density at very different scales.
  - Most sources are resolved, and we don't know its structure.
  - No catalogue of compact sources.
  - Compact and bright regions of potential calibrators, usually AGN, are expected to change with time.
- What to do?
  - Instrumental gains within LOFAR could be tracked with time. This option is currently being commissioning with the COBALT correlator.
  - Self-calibrate a bright calibrator to find its small-scale structure, and bootstrap its flux density between the short and long baselines
  - Good compact sources are pulsars, which should show the same flux density at short and long baselines (link).

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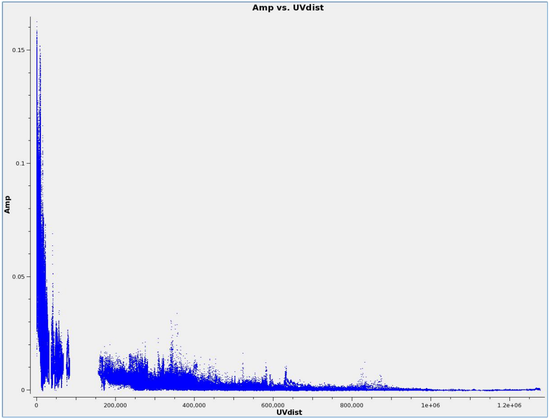
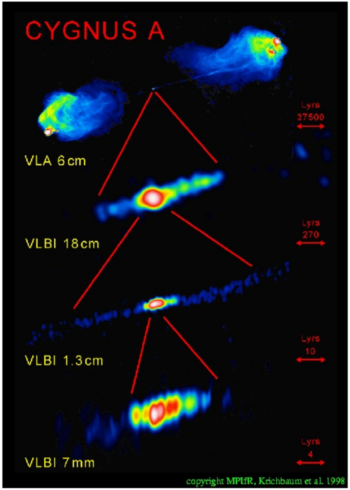
The curse of resolution

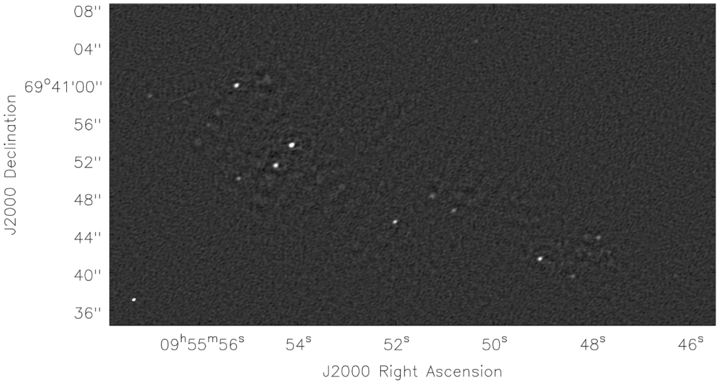




LOFAR Long Baselines are already here!

M82: Varenius et al.

- Observations with International LOFAR at 118 MHz and 154 MHz.
- Resolutions of about 0.35 and 0.3 arcsec.
- Close to thermal noise: 0.30 mJy/beam and 0.15 mJy/beam.



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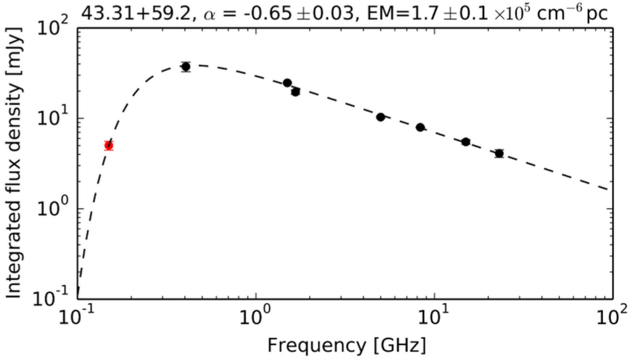
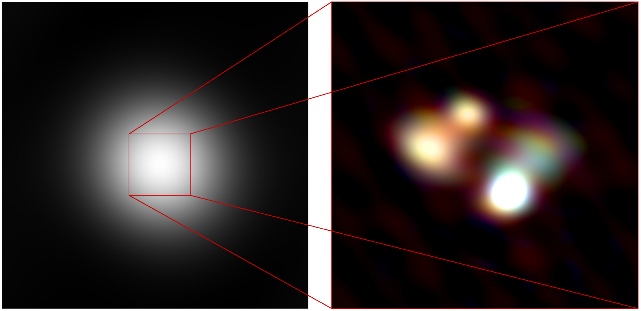


3C196 at 30–80 MHz

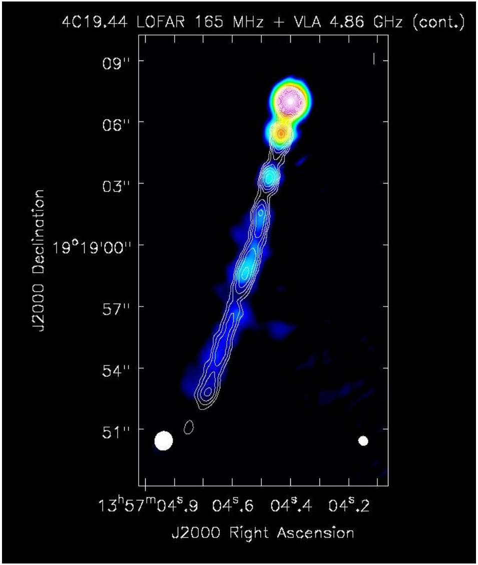
- High resolution images also possible below 100 MHz.
- Calibration of long-baselines LBA data is complicated.
- Dutch stations: $30''$.
- When including just 3 International Stations: $1.5''$



Olaf Wucknitz, 2010

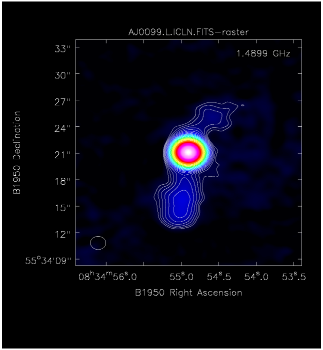
Jet acceleration in 4C19.44

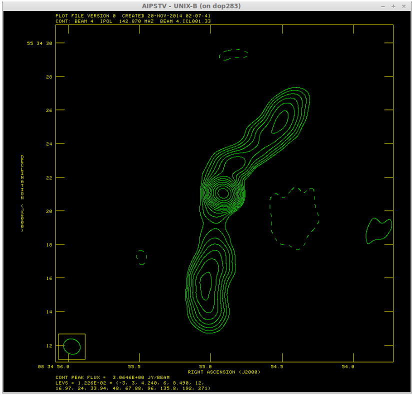
- Preliminary image done with only 3 MHz (1/16 of total)
- Similar resolution as VLA and *Chandra* observations.
- Testing the IC/CMB Model for X-ray Emission on knots along the quasar jet.



kpc structure of 4C55.16

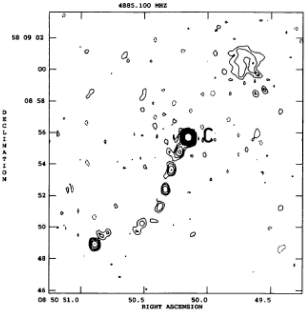
- It is a radio galaxy at the centre of a cool core cluster of galaxies.
- Monitored in the MOJAVE project.
- Study of the source morphology at kpc scales and jet bending.

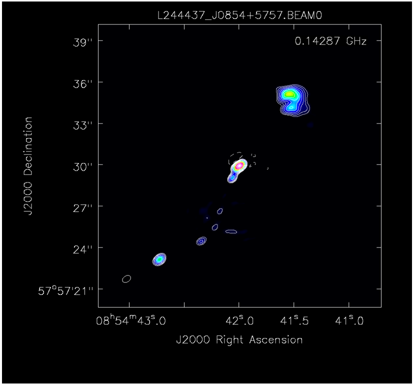




Hotspots in 4C58.17

- Monitored in the MOJAVE project.
- Very preliminary images show hotspot correspondence with higher frequencies.



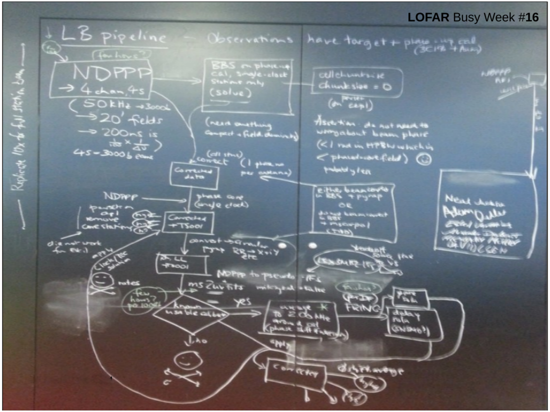


Opening International LOFAR to not specialized observers

Long baseline group

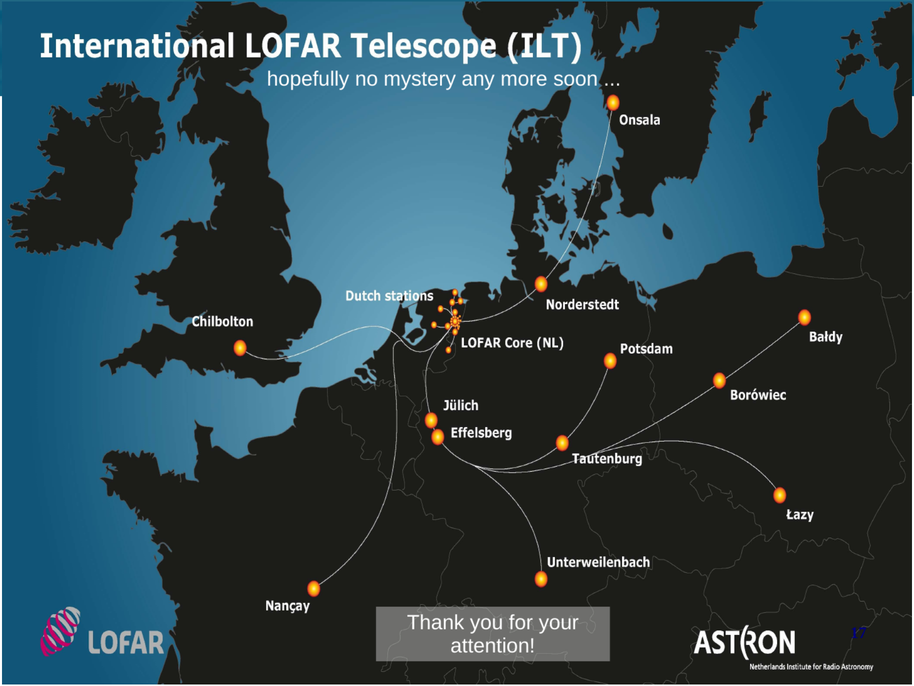
- Calibrating long-baseline data requires special procedures and techniques.
- The long-baseline group has been working to understand the data, the calibration approach and the instrument.

John Conway
Adam Deller
Alexander Drabent
Tobias Carozzi
Neal Jackson
Anna Kapinska
John McKean
Javier Moldon
Leah Morabito
Eskil Varenius
Olaf Wucknitz
Philippe Zarka



Making long-baseline observations possible

- Testing and developing calibration and imaging strategies.
- Finding primary calibrators for long baseline observations.
  - The LOFAR long baseline snapshot calibrator survey.
  - LOBOS: the LOFAR Long-Basline calibratOr Survey.
- Developing the long-baseline pipeline.
  - Provide a FITS file that can be directly processed in AIPS.
  - Calibrate and phase-up the core stations, filter stations, convert to circular polarization, shifting to different phase centers, combining subbands and forming FITS file.
  - Saves PI from dealing with 10+ TB datasets
- Future.
  - Go to lower frequencies.
  - Supercharged calibration, using all available bandwidth simultaneously to solve for dispersive delay and dispersive delay rate.


International LOFAR Telescope (ILT)
hopefully no mystery any more soon ...
Onsala
Dutch stations
Norderstedt
Chilbolton
LOFAR Core (NL)
Potsdam
Bałdy
Borówiec
Jülich
Effelsberg
Tautenburg
Łazy
Unterweilenbach
Nançay
Thank you for your attention!
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