

Using Effelsberg to trigger LOFAR to localise fast radio transients

Sander Ter Veen

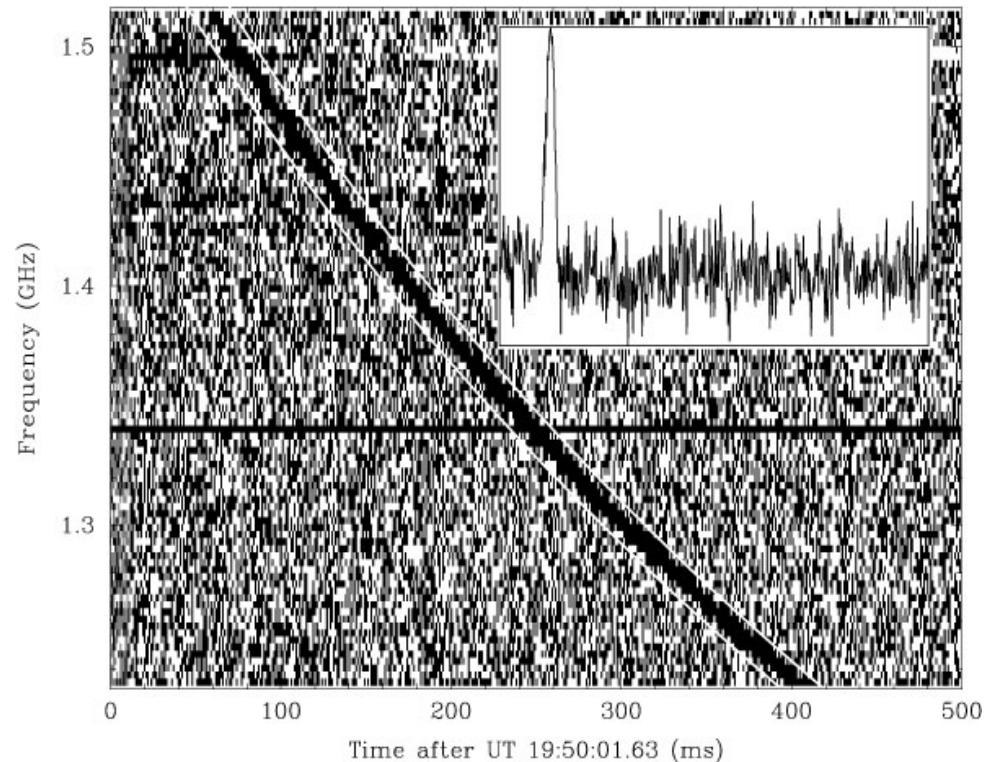
Leon Houben, Emilio Enriquez, Jörg Rachen, Laura Spitler,
David Champion Heino Falcke, Michael Kramer, Emilio
Enriquez

Responsive telescope

- LOFAR is a digital telescope
- Flexible
- Why not use LOFAR to follow-up transients?

My favourite transient: Fast Radio Bursts

- Mysterious highly **dispersed** pulses
- Extragalactic origin?
- Only seen at 1.4 GHz and 800 MHz
 - What is their low frequency emission?
 - Where do they come from?
- No LOFAR detections so far

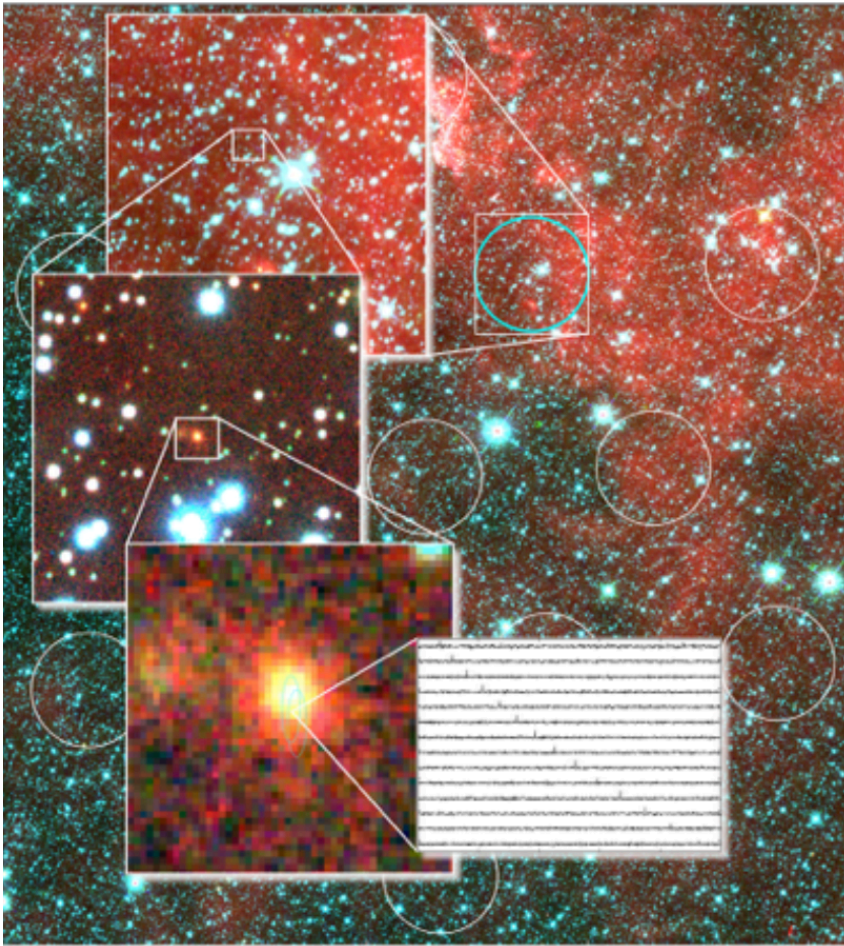


$$S(f) \sim 1/f^2$$

Recent FRB news counterpart?

Keane et al. Nature 2016/02
Afterglow with ATCA

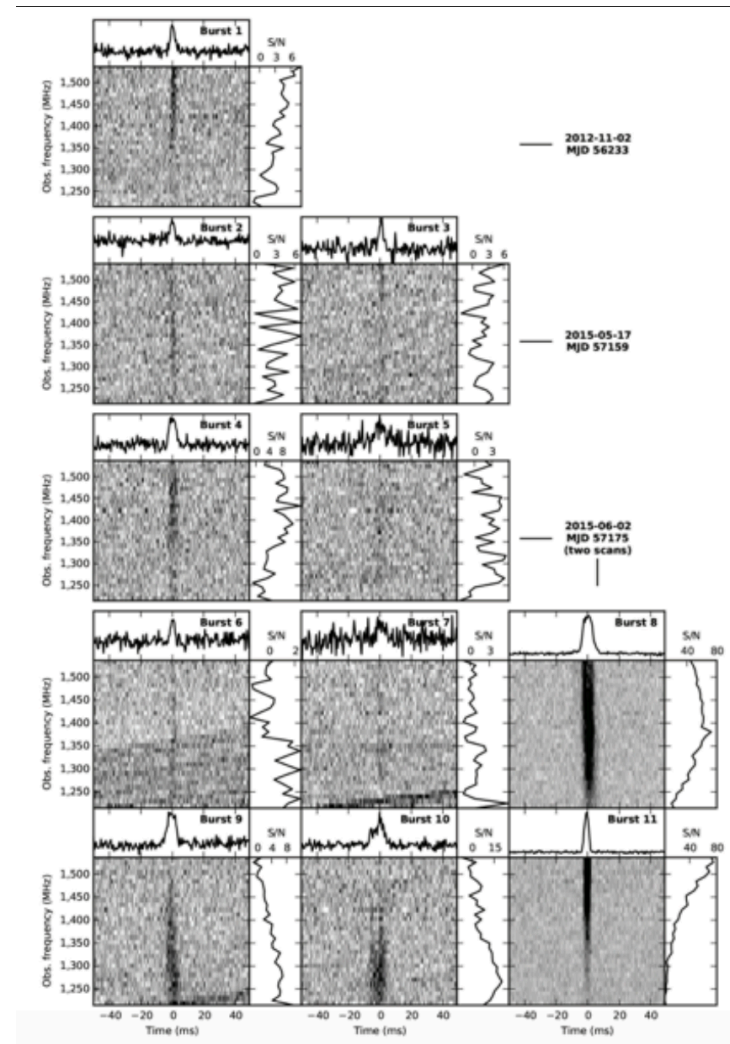
Or is it just an AGN? VLA measurements
Williams et al. Arxiv.



Recent FRB news

Repeating FRB!

- L. Spitler et al. (Nature 2016/03) report on 10 more bursts from FRB 121102
- First repeating FRB!



Direct localisation?
LOFAR detection?

Commissioning test:
Transient Buffer Boards triggered from Effelsberg detection



Effelsberg 100m telescope
High freq detection

LOFAR
Low frequency observation
Localisation



Current rapid response capabilities at low frequencies



LOFAR

- ~30 minutes
- High spatial resolution
- Capability:
 - Imaging and/or beam formed

MWA

- ~10 seconds
- Low spatial resolution
- Capability:
 - Imaging

Current rapid response capabilities at low frequencies



LOFAR

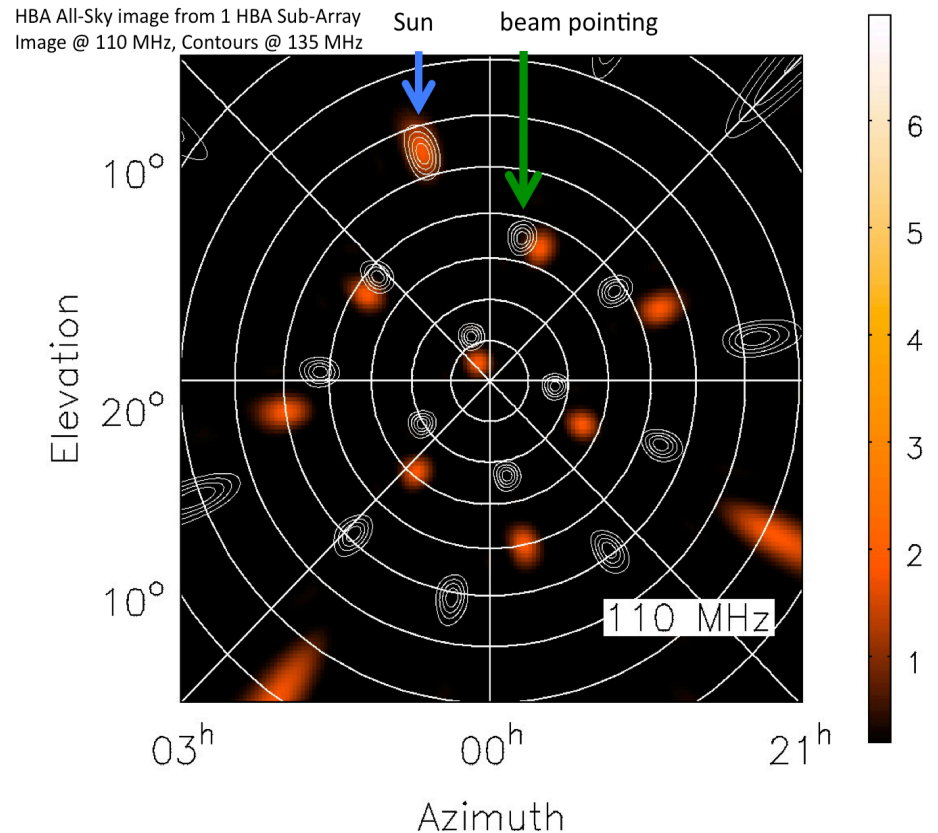
- -5 seconds
- High spatial resolution
- Capability:
 - Imaging and/or beam formed
 - **Transient Buffer Boards**

MWA

- ~10 seconds
- Low spatial resolution
- Capability:
 - Imaging

Transient Buffer Board

- Memory for each LOFAR dipole / tile
- 5 seconds full bandwidth all antennas
- Subband mode, change bandwidth for buffer duration (**not working**)
- Frozen and read-out on an interesting signal
- All-sky capability
- Full timeresolution
- Dual polarisation

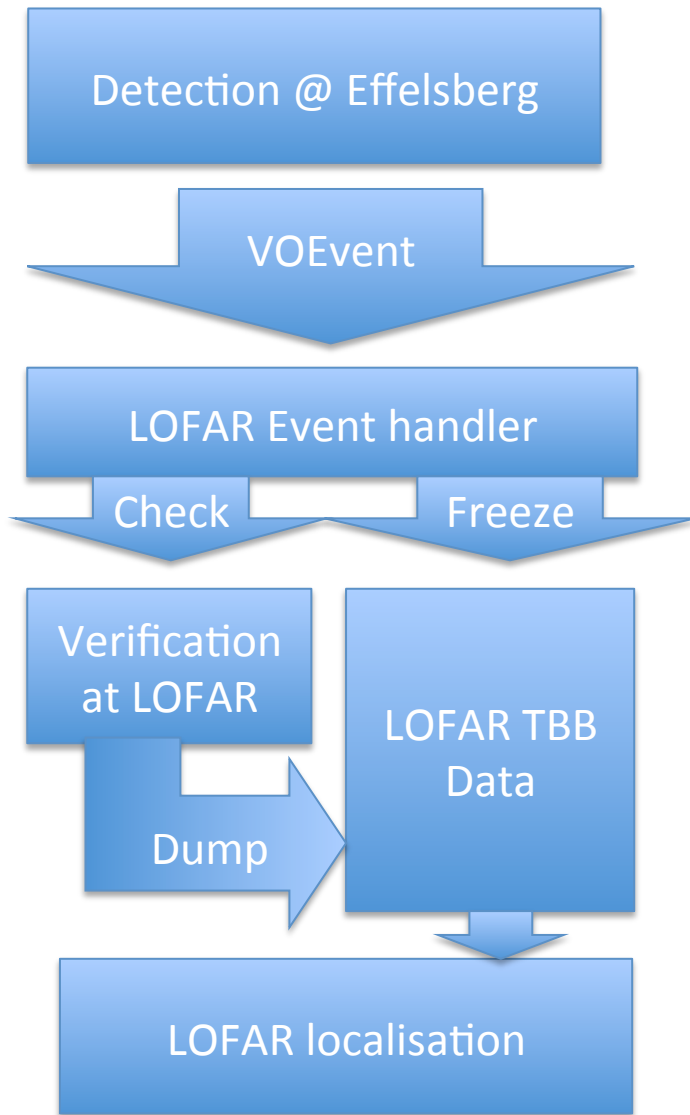


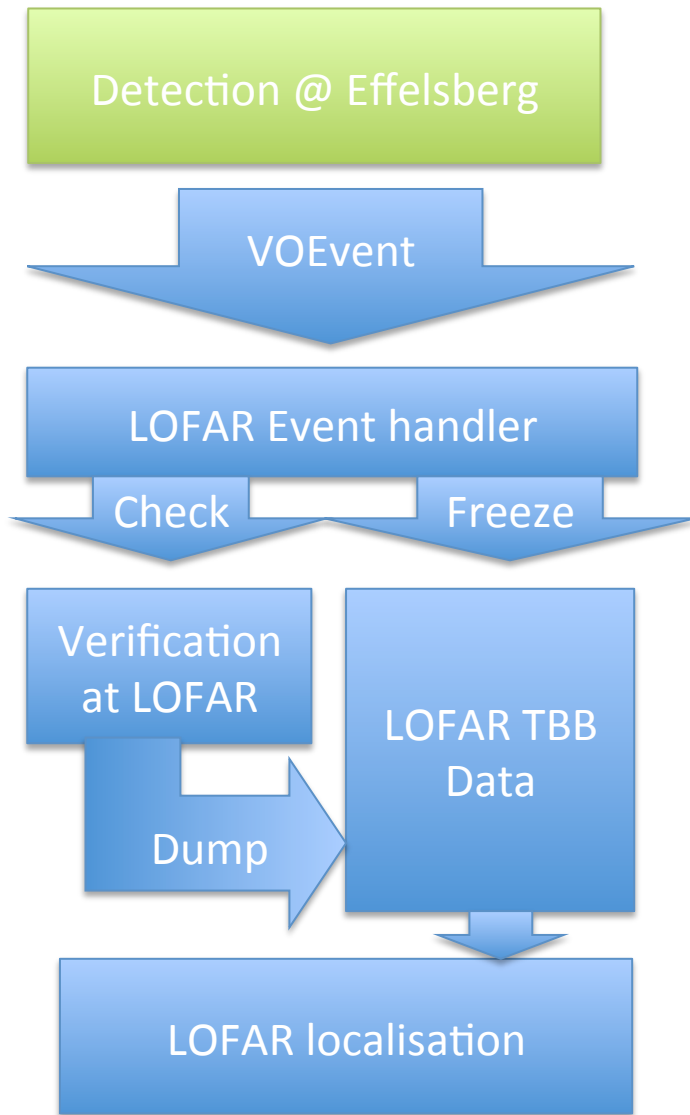
Delay times [s] from 1.3 GHz

DM	250 MHz	190 MHz	150 MHz	110 MHz
141	9	15.9	25.7	48.2
500	32	56	91	170
1000	64	112	182	340

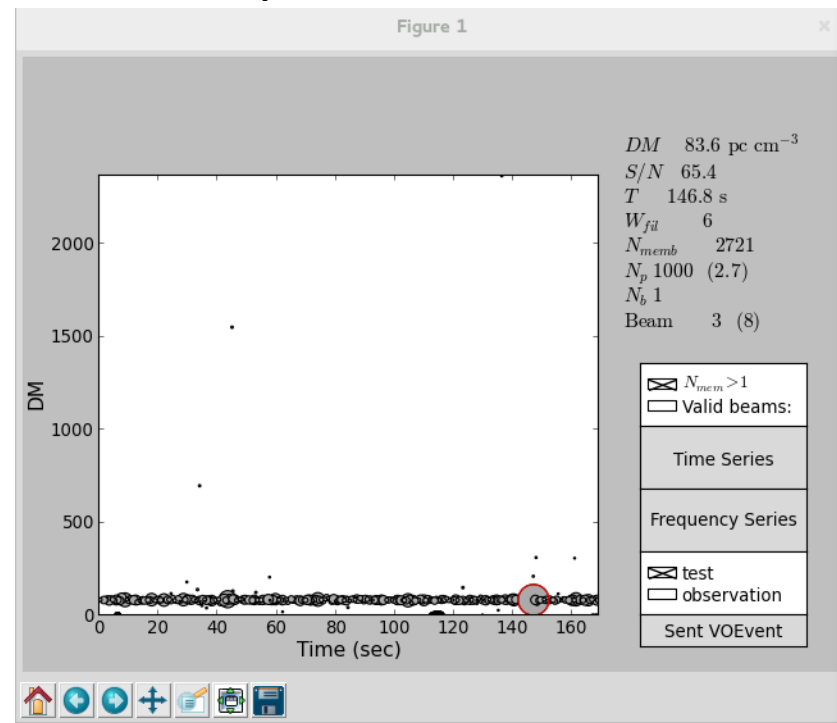
Bandwidth [MHz] in 5 seconds buffer

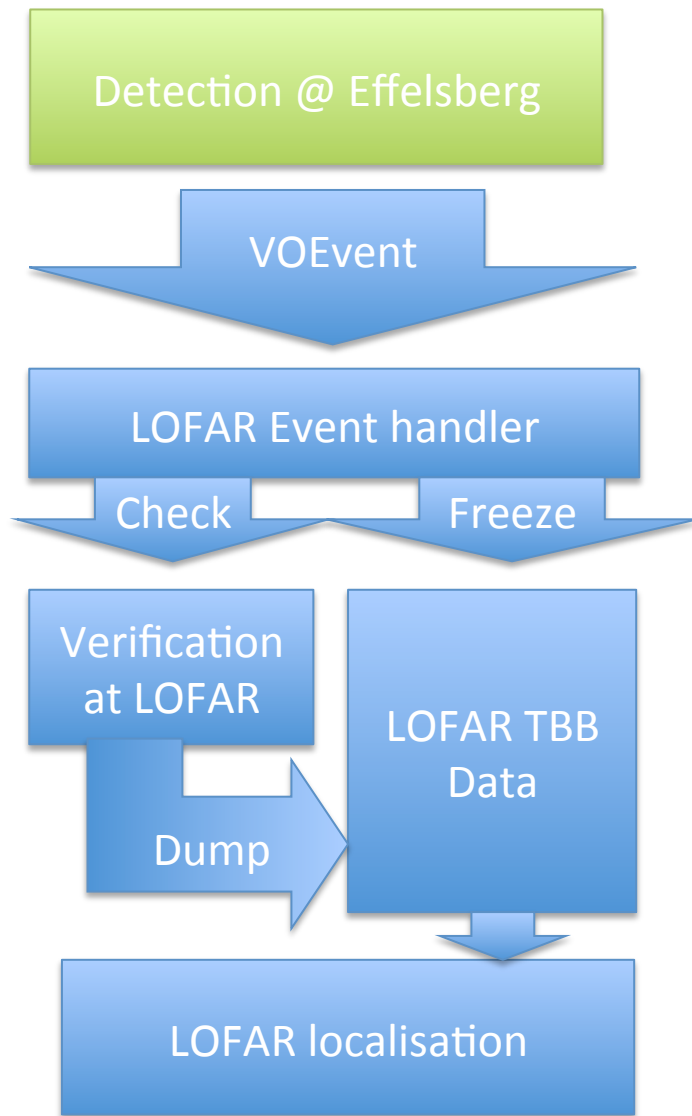
DM	250 MHz	190 MHz	150 MHz	110 MHz
141	40+	25	15	6
500	17	8	4	2
1000	9	4	2	1



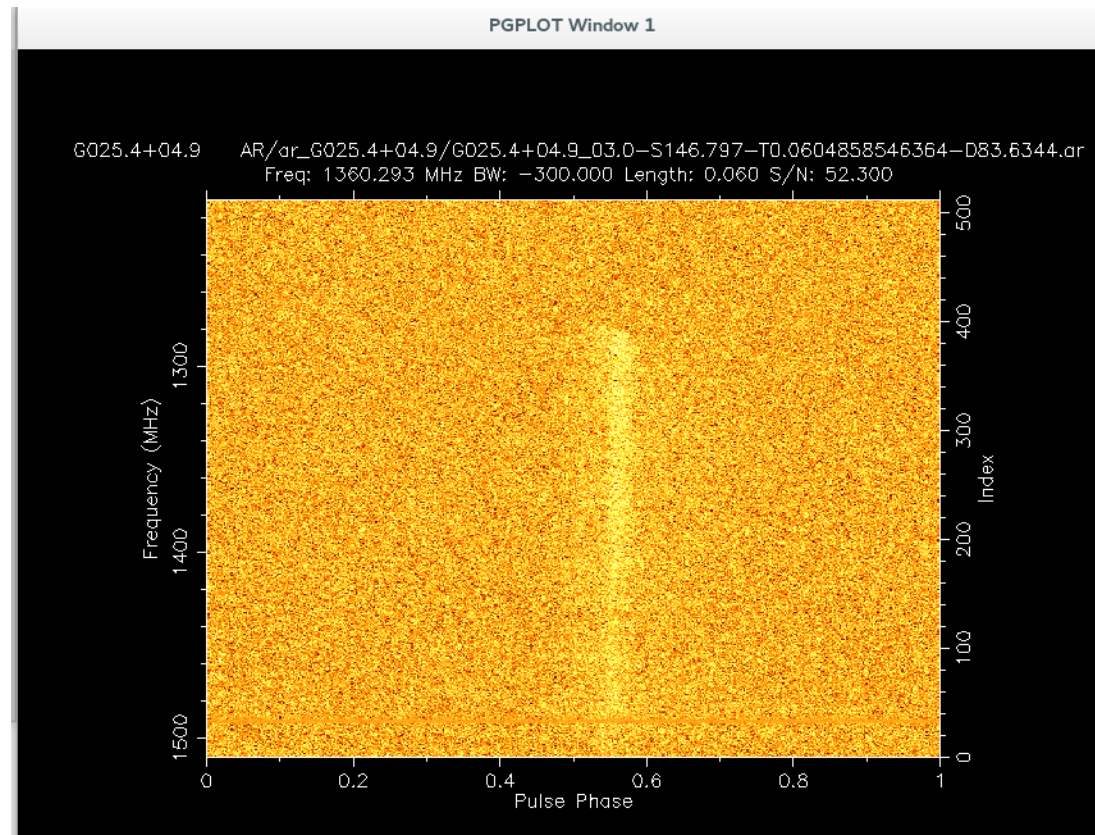


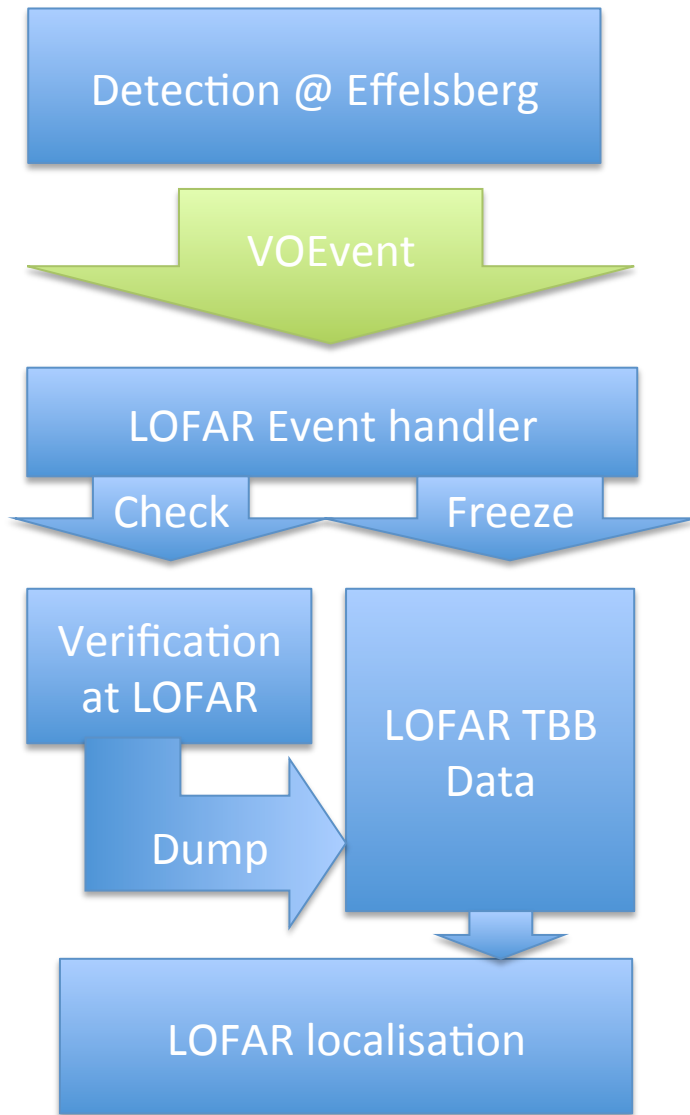
- Running Heimdall, same software that detected Parkes FRBs
- Early test stages
- Manual verification of triggers
- Testing on B2111+46
- $DM=141 \text{ pc cm}^{-3}$





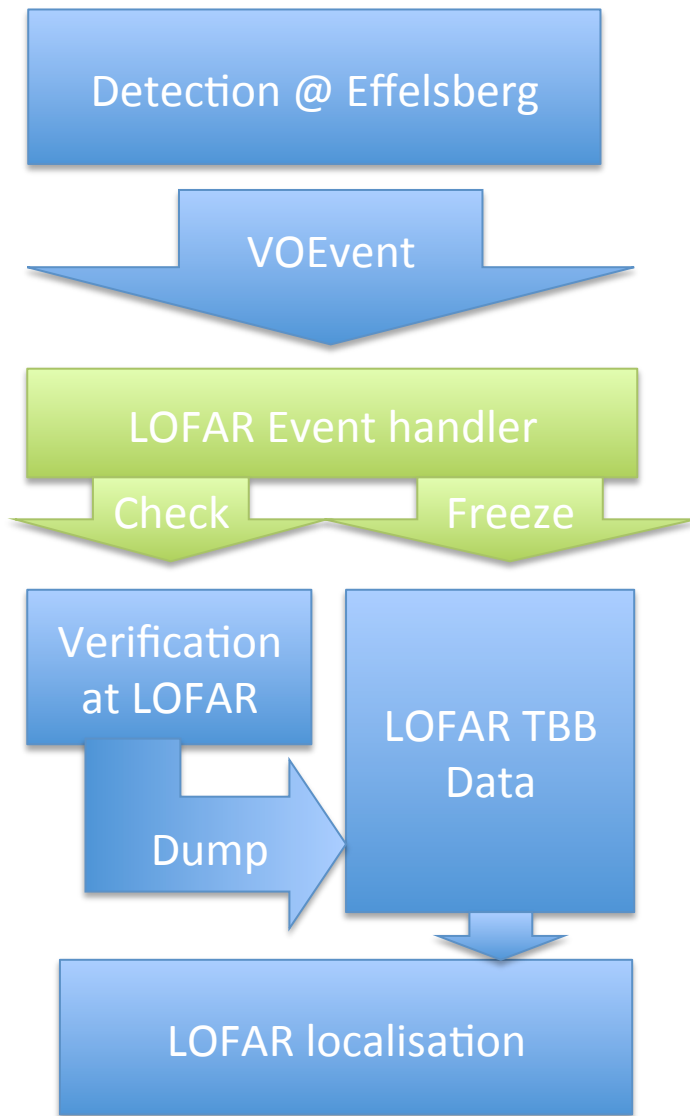
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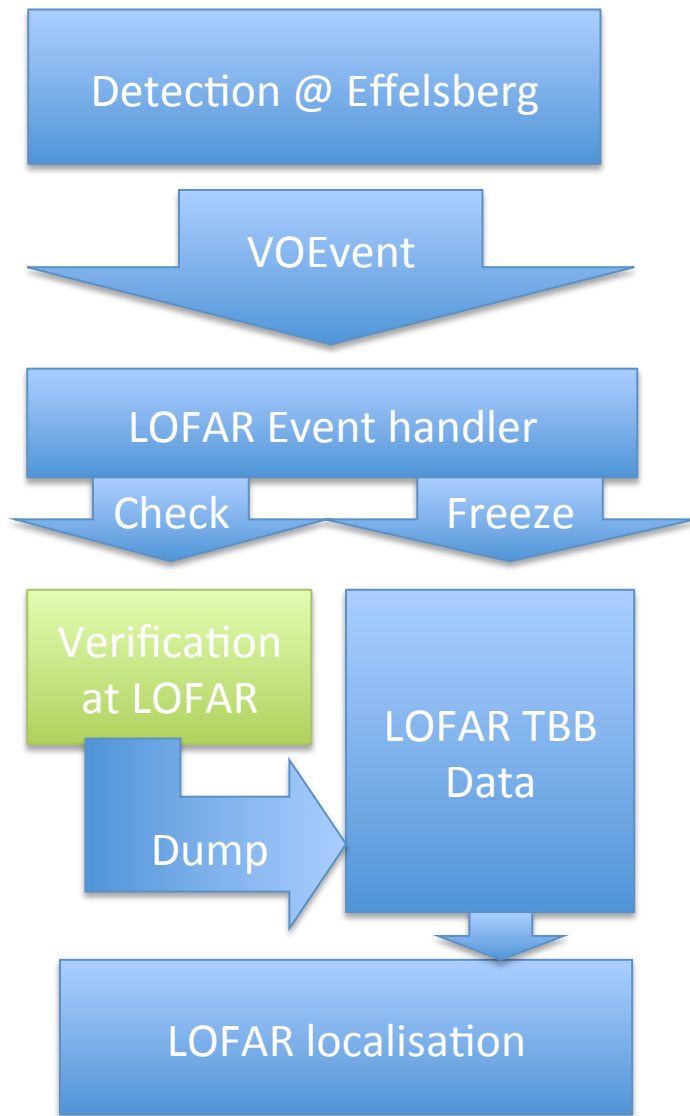


- VOEvent

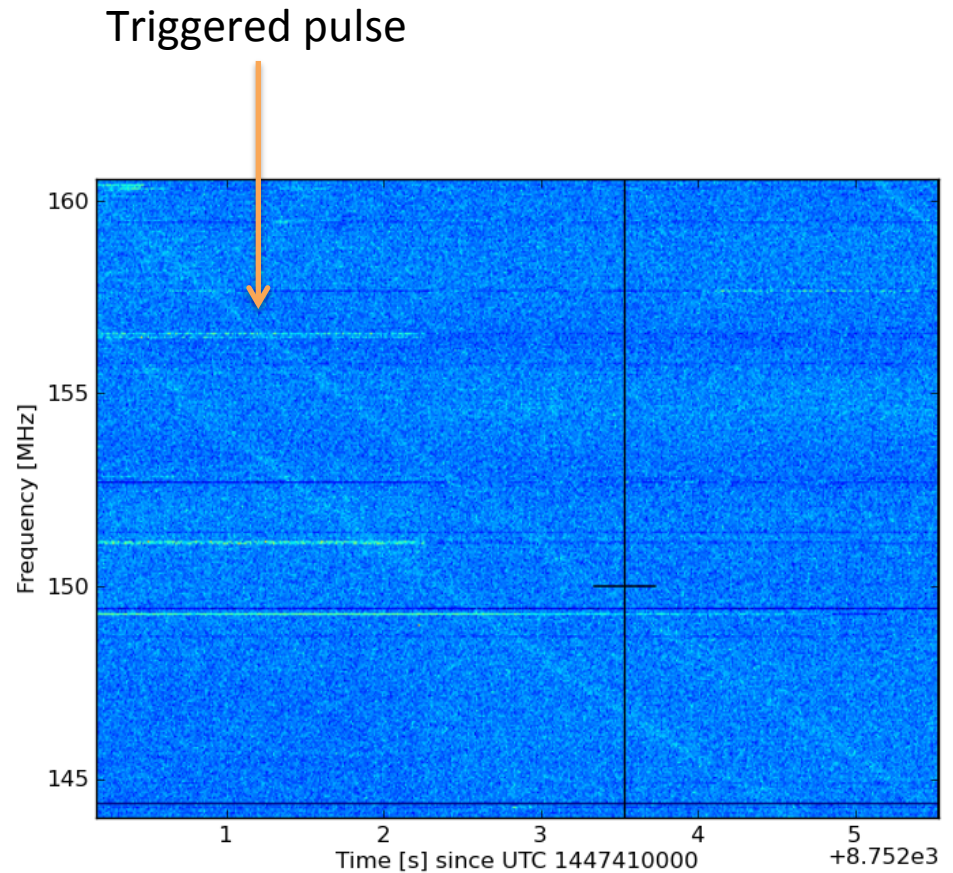
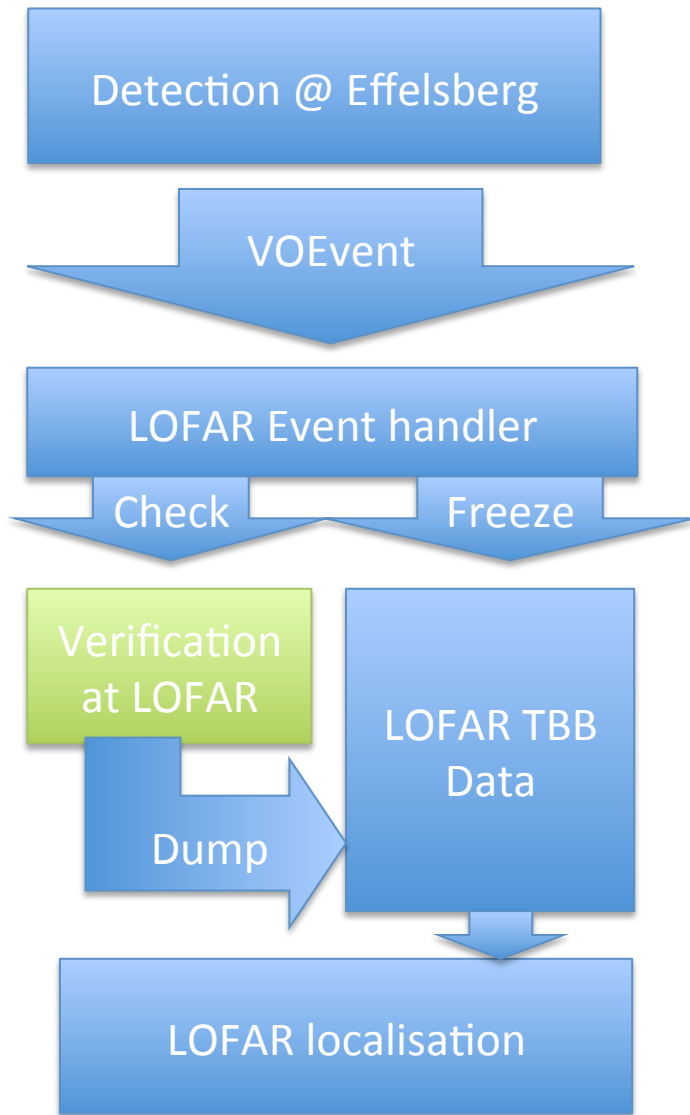
- Communication between observatories for transient follow-up
- XML message with default and custom parameters
- Send event time, DM, SNR, observing frequencies **and errors**
- Position and beamsize
- Determine stop time based on these parameters
- LOFAR broker subscribed to Effelsberg broker

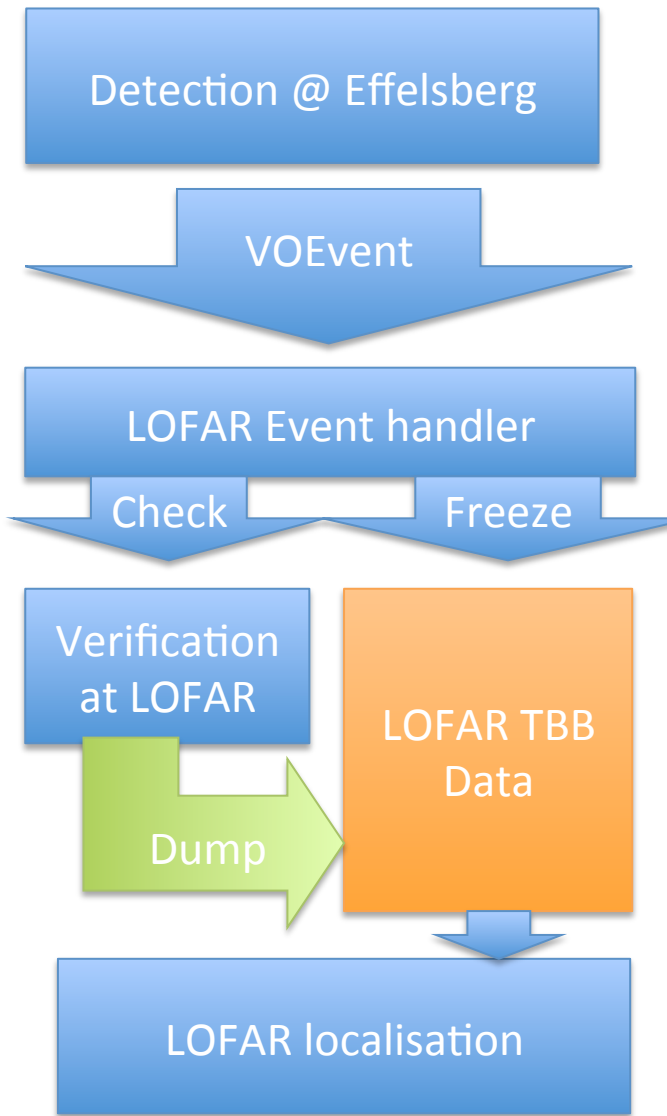


- Calculate time the burst would arrive at LOFAR
- Determine if position is within tile-beam
- Send stop (freeze) command to bufferboards
- Delay time total: 27-36 seconds
 - Calculation Effelsberg (10-12 seconds)
 - Manual verification (20-25 seconds)
 - Communication to LOFAR (10 milliseconds)
 - LOFAR trigger (10 milliseconds)
 - Record time: 16 seconds

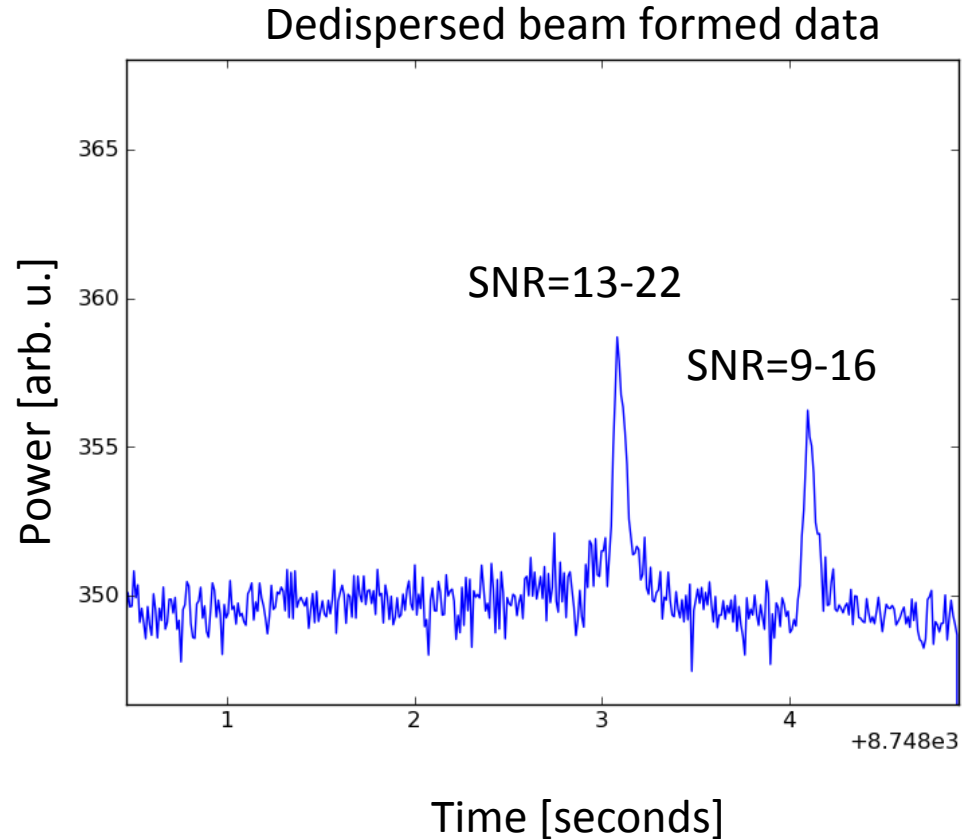


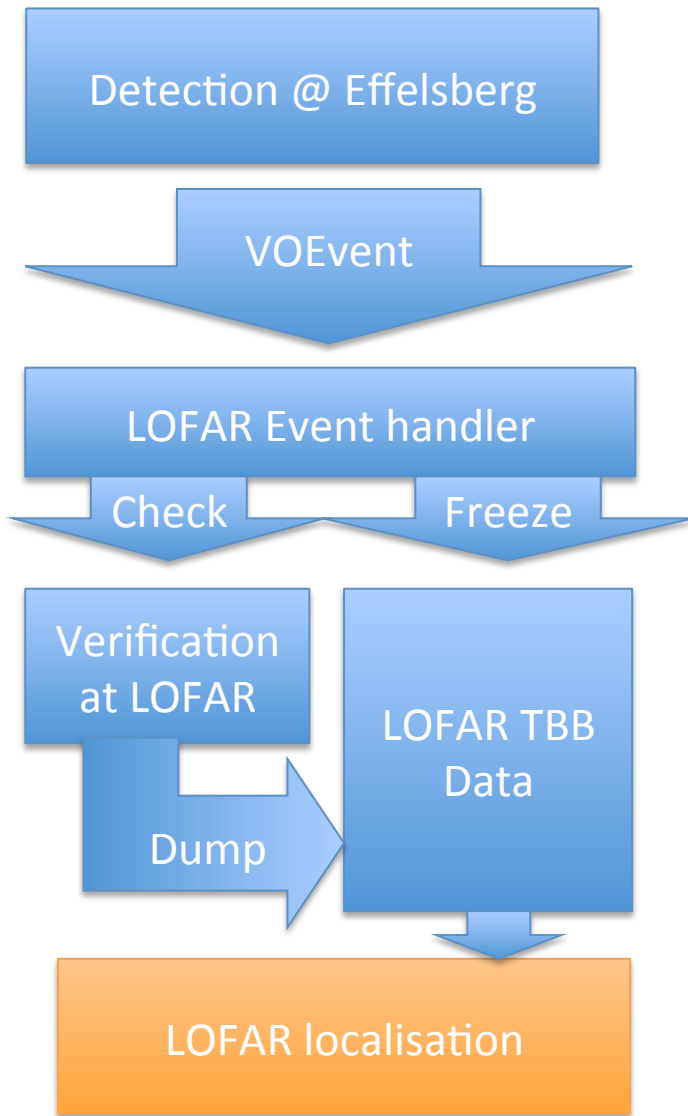
- Simultaneous beam formed observations with LOFAR
- Use LOFAR observation to check if pulse is visible
- Check offset between expected / actual time of arrival
 - Offset of 0.1 seconds
 - Time stamp at Effelsberg needs to be verified



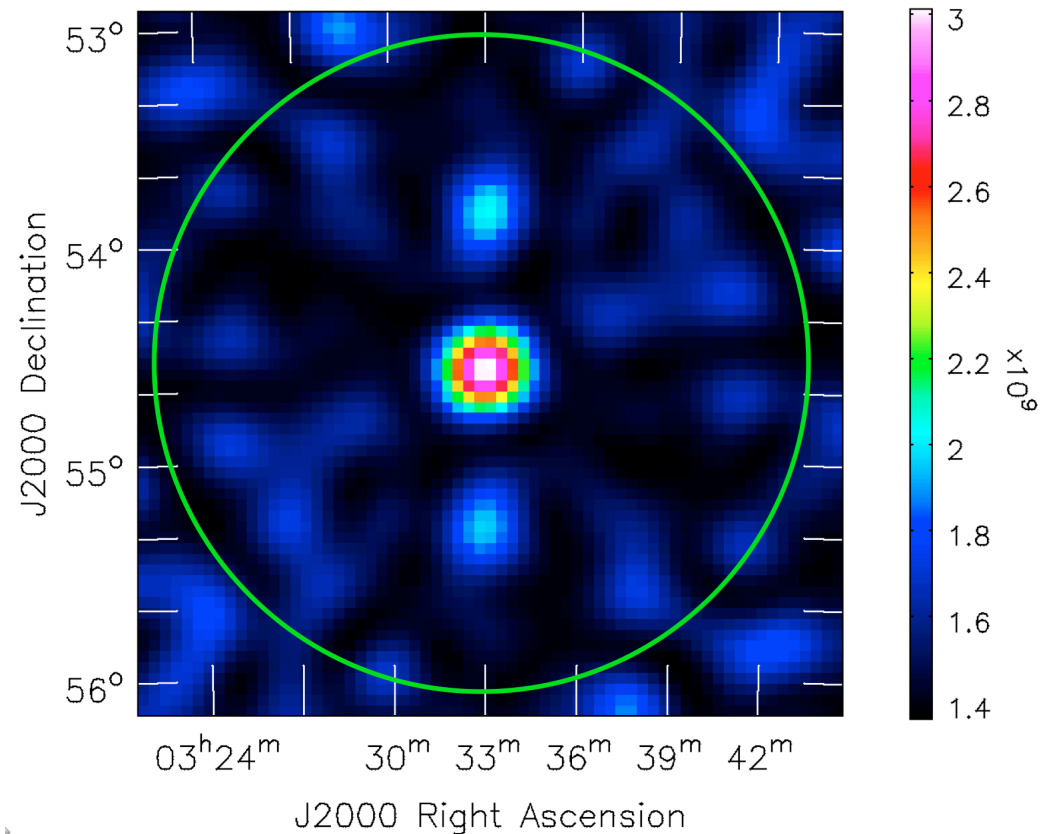


Data taken for two events
 TBB data analysis ongoing
 From beamformed observation SNR
 too low for single station detection





- Data analysis ongoing
- Example from B0329+54
 - Superterp only image



Conclusions

- Taken TBB data triggered by the Effelsberg telescope from a pulsar pulse
- First time LOFAR acts as a responsive telescope
- Same pulse detected by LOFAR and Effelsberg
- TBB analysis ongoing
- Next step: Simultaneous observations of repeating FRB