The LOFAR TBB imager

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Cosmic Rays Key Science Project

TBBs?

- Transient Buffer Boards
- Ring buffers that store up to ~1.3 s of raw voltage data for all antennas
- When an interesting signal is detected this buffer is saved to disk
- Zero information loss gives maximum flexibility in offline processing

Why do we need a TBB imager?

- TBB raw voltage data cannot be processed directly with the standard LOFAR imaging pipeline
- But we need imaging capabilities to:
  - check source positions;
  - characterize our background spatially;
  - create nice images for outreach.

TBB imaging pipeline

- Python based
- Low level functions implemented in C++
- Imaging optimized for multicore systems

$$T_{\mathrm{computing}} \propto N_{\mathrm{Cores}}^{-1} \text{ if } N_{\mathrm{Pixel}} > N_{\mathrm{Cores}}$$

- In the future distributed memory clusters and possibly GPU hardware acceleration.

Imaging by tied array beamforming

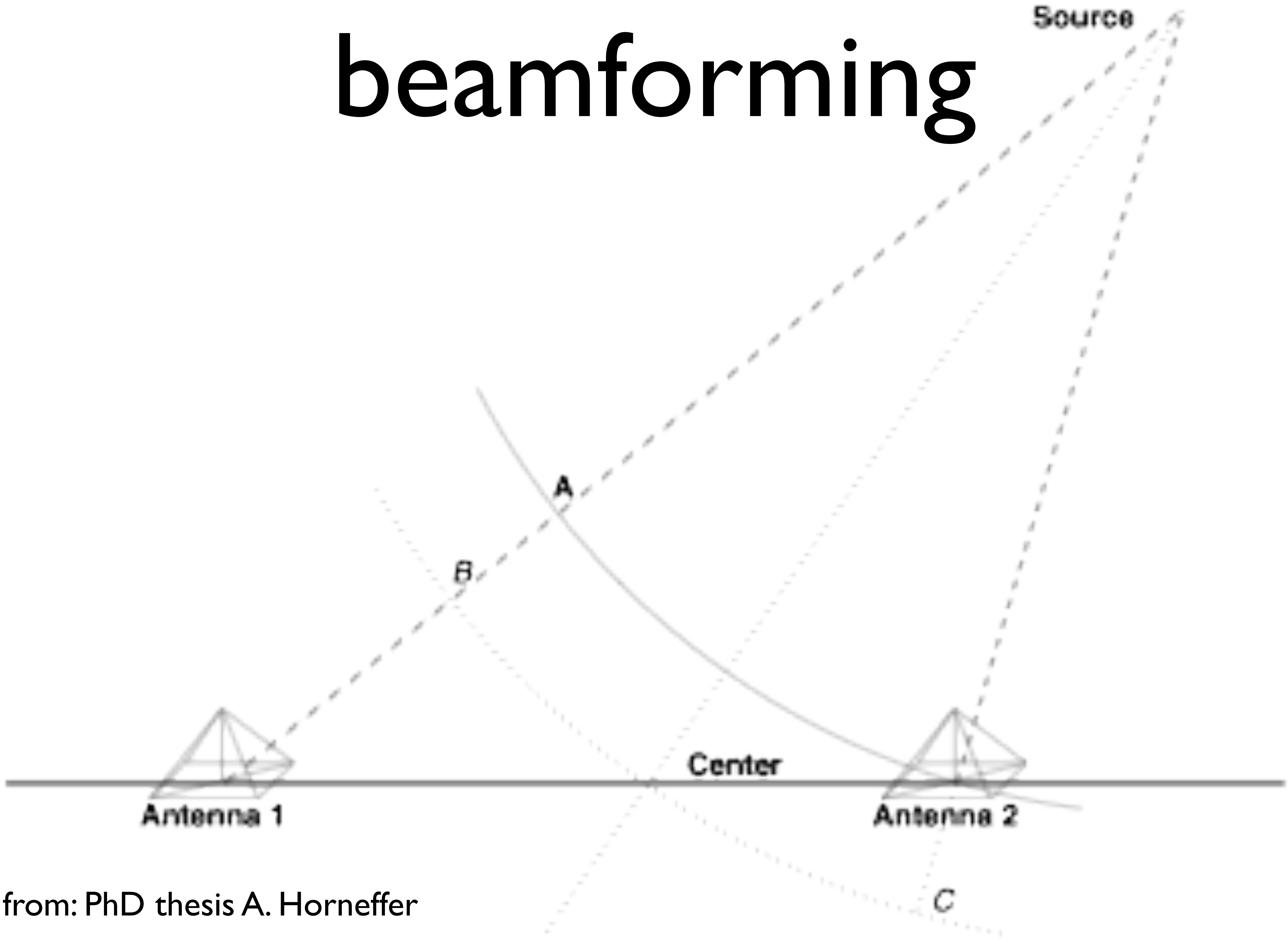


Image from: PhD thesis A. Horneffer

Two methods

$$P(\vec{\rho})[\omega] = |S(\vec{\rho})[\omega]|^2 = \left| \sum_{i=1}^{N_{\mathrm{Ant}}} \omega_i(\vec{\rho})[\omega] s_i[\omega] \right|^2$$

$$P(\vec{\rho})[\omega] = \langle |S(\vec{\rho})[\omega]|^2 \rangle = \frac{1}{N_{\mathrm{Blocks}}} \sum_{k}^{N_{\mathrm{Blocks}}} |S_k(\vec{\rho})[\omega]|^2$$

$$\Rightarrow T_{\mathrm{computing}} \propto N_{\mathrm{Pixel}} * N_{\mathrm{Block}} * N_{\mathrm{Ant}}$$

$$= \langle |S(\vec{\rho})[\omega]|^2 \rangle = \sum_{i,j}^{N_{\mathrm{Ant}^2}} \mathbf{W}_{ij}(\vec{\rho})[\omega] * \langle \mathbf{C}_{ij}[\omega] \rangle$$

$$\Rightarrow T_{\mathrm{computing}} \propto N_{\mathrm{Pixel}} * N_{\mathrm{Ant}}^2 + N_{\mathrm{Block}} * N_{\mathrm{Ant}}^2$$

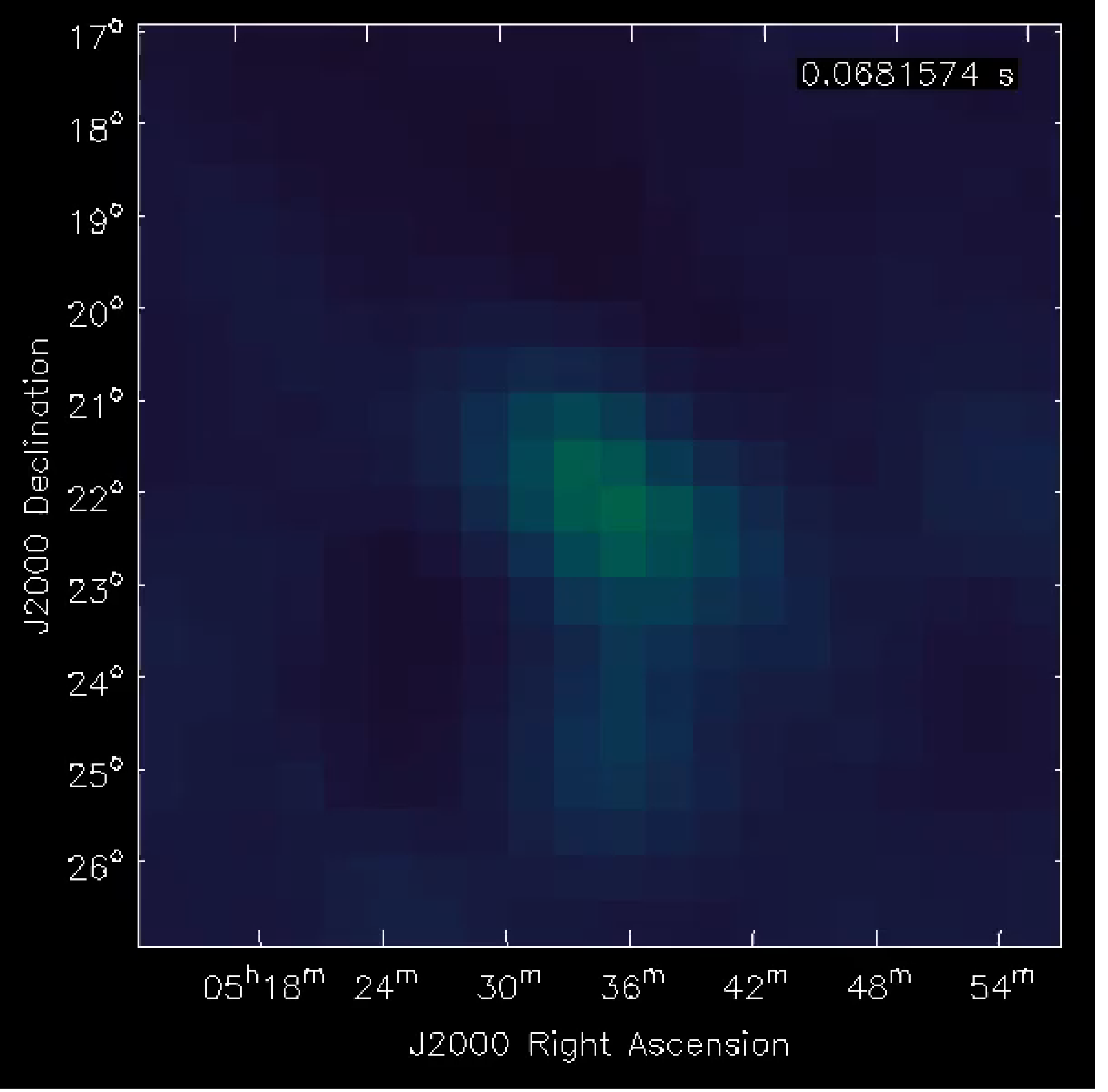
Equations from: Ph.D. thesis A. Horneffer

Advantages of imaging through beamforming

- Keep full time resolution
- Faster for short integration times
- All-sky images (curved images in general) which are not directly possible through visibility function

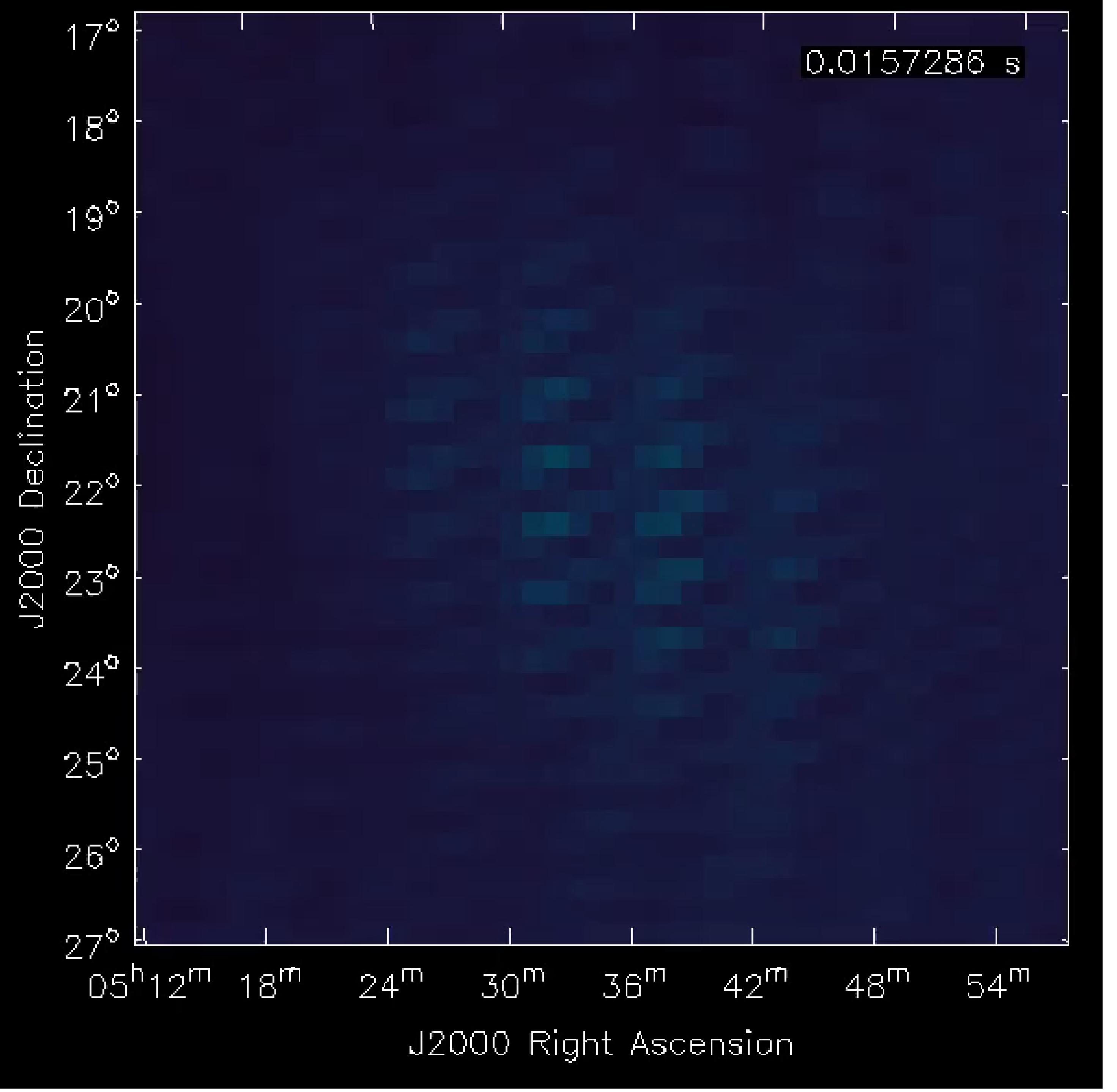
Currently implemented

Imaging with incoherent dedispersion



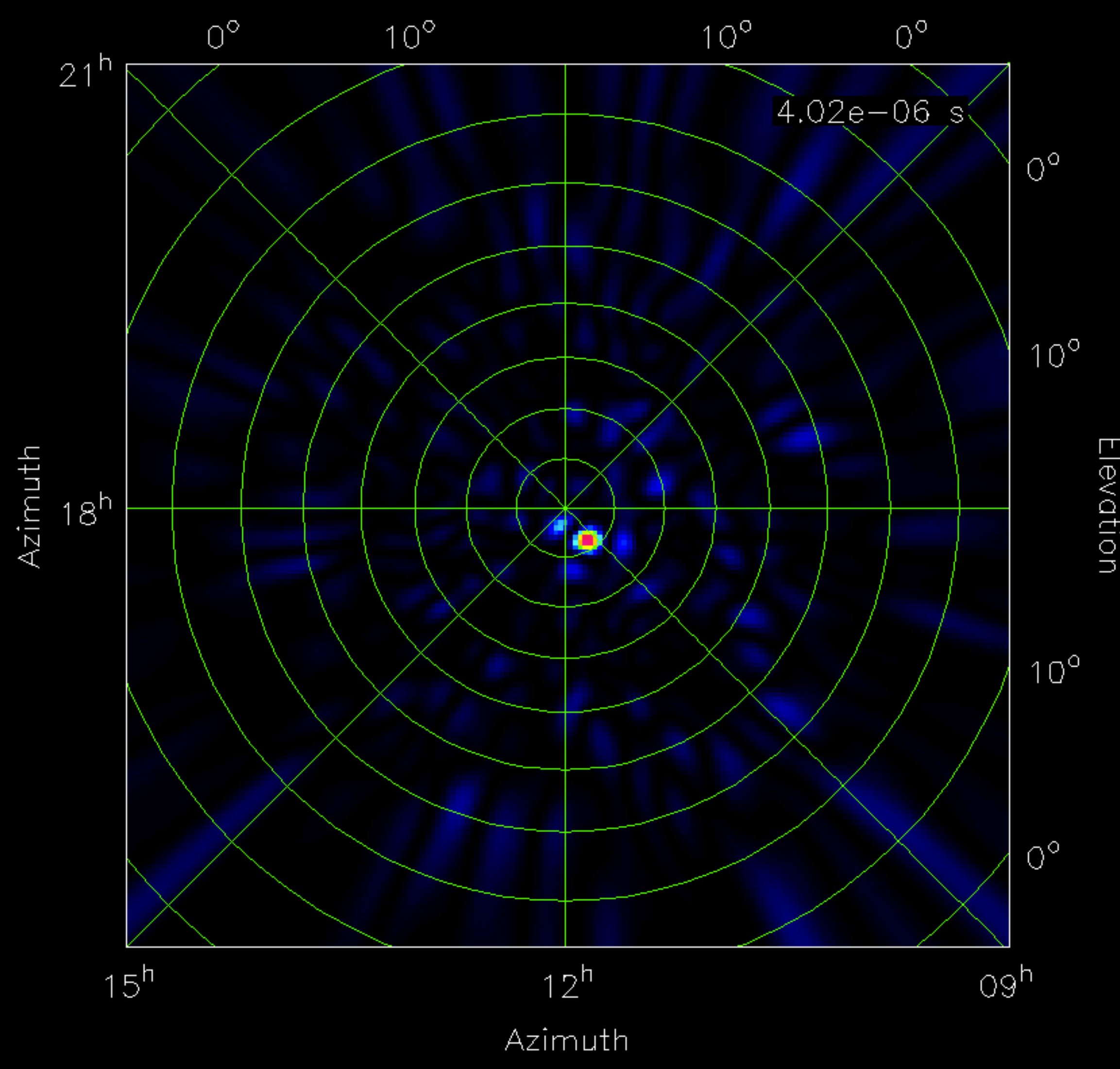
Crab giant pulse imaged from LOFAR CS002 TBB data

Multi-station imaging

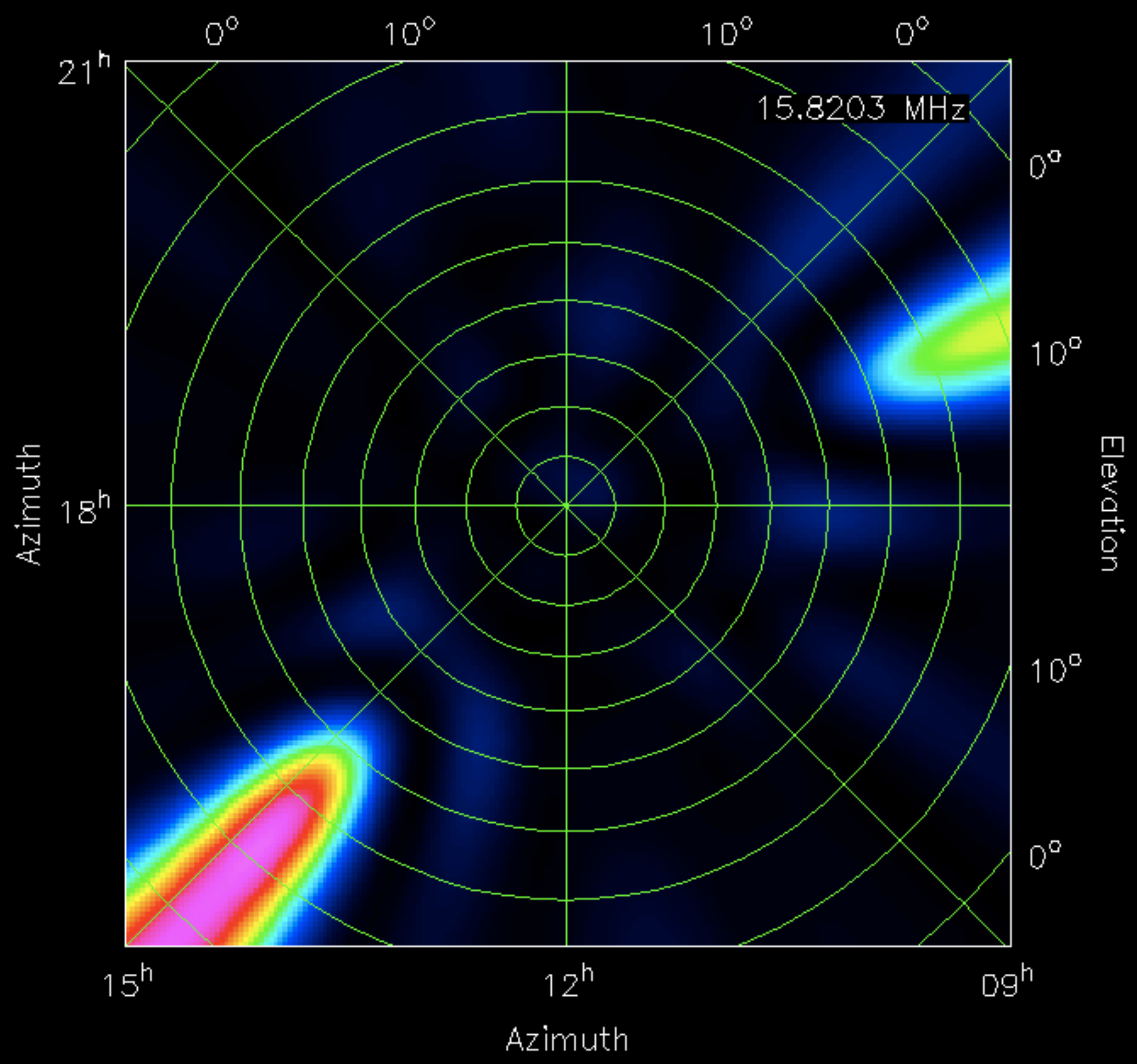


Crab giant pulse imaged with TBB data from two and four LOFAR core stations respectively

All sky imaging

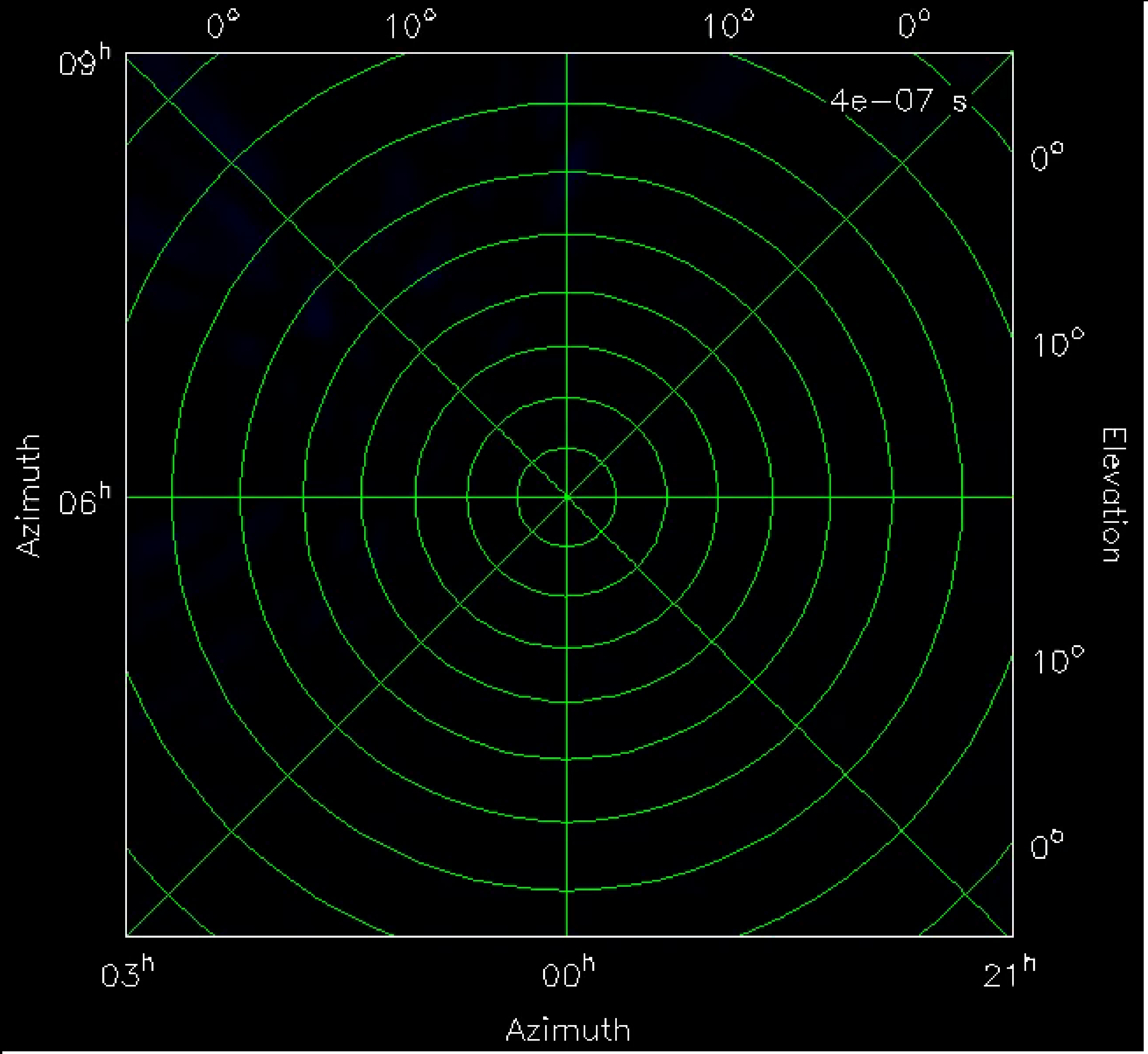


Localizing single pulses



And finding RFI sources

Maximum time resolution imaging



Cosmic ray detection imaged with data from CS002

What we have now

- Support for any WCS specified coordinate system and projection
- Multi station imaging
- Maximum time resolution (5ns) imaging
- Optional frequency or time integration
- Incoherent dedispersion
- Optimized for multicore shared memory systems

Work in progress

- 3D imaging
- Calibration
- Image cleaning
- Speed, speed and more speed...

Conclusion

- Can make images of LOFAR TBB data
- Maximum flexibility, including generating all sky images to exclude pulsed RFI sources
- High time resolution to capture Fast Radio Transients