Cosmic Rays KSP Update

Clancy James, on behalf of the Cosmic Rays Key Science Project

LOFAR status meeting, 09/03/2011

Overview

- Detecting cosmic rays requires using the transient buffer boards
- CR KSP: Encompasses most TBB-enabled science
- 4 sub-projects:

VHECR (piggyback)

- Detecting 'very high energy' cosmic ray events with individual LOFAR stations

UHEP/NuMoon (stand-alone)

- Searching for 'ultra-high energy' particles (~10^{22} eV cosmic-rays and neutrinos) interacting in the Moon

FRaTs (piggyback)

- Real-time detection of bright, Fast Radio Transients.

LORA (independent)

- LOFAR-Radboud Array (of particle detectors) to confirm cosmic-ray events.

VHECR Mode

- Run a piggyback search for cosmic ray events off any/all LBA observations on an individual station basis.
  - Level 1 trigger: individual dipoles.
  - Level 2 trigger: individual stations.
  - Record TBB time-domain data from all dipoles upon station trigger.
- Status:
  - *observations can be specified from the OTB.*
  - imaging data can be returned simultaneously.
  - *23/02/2011: 8-hour run with CS002, CS024, RS307 .*
  - *TBB data is good!* (fix of CS002 switch worked)
- Bugs/to-do
  - TBBs still sometimes require a 48 V reset.
  - Perform observations on all stations: check for faults/RFI.
  - TBB data-writer must be started manually.
  - Cannot be specified from MoM.

Analysis pipeline works! Example:

- **96-LBA outer antennas, RS307.**
  - 58° fitted elevation (far-field)
  - Left: individual diploe fields.
  - Right: even antennas added in-phase.

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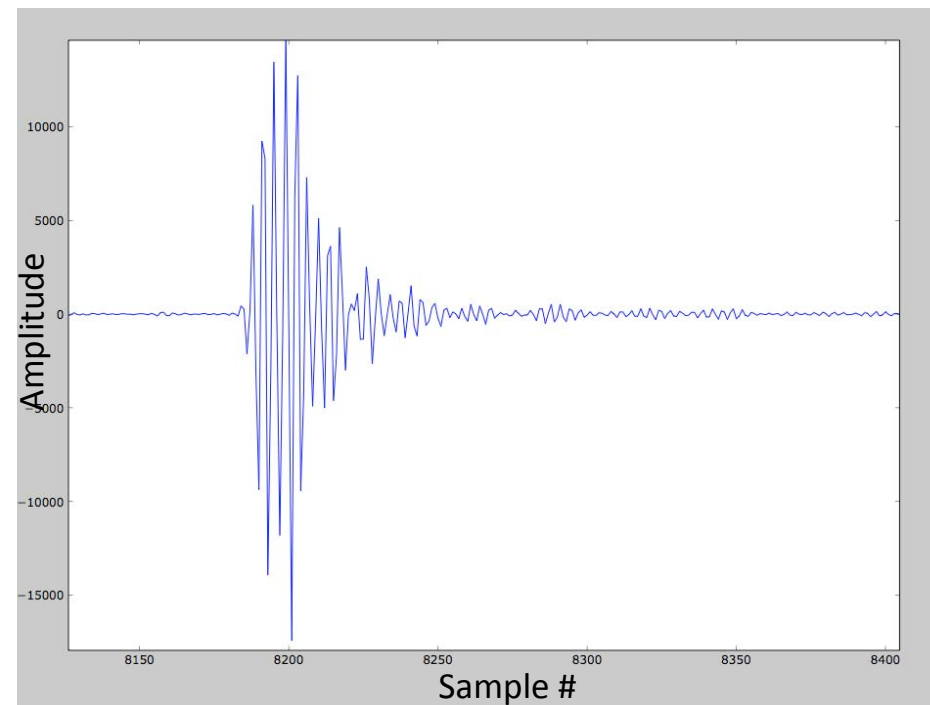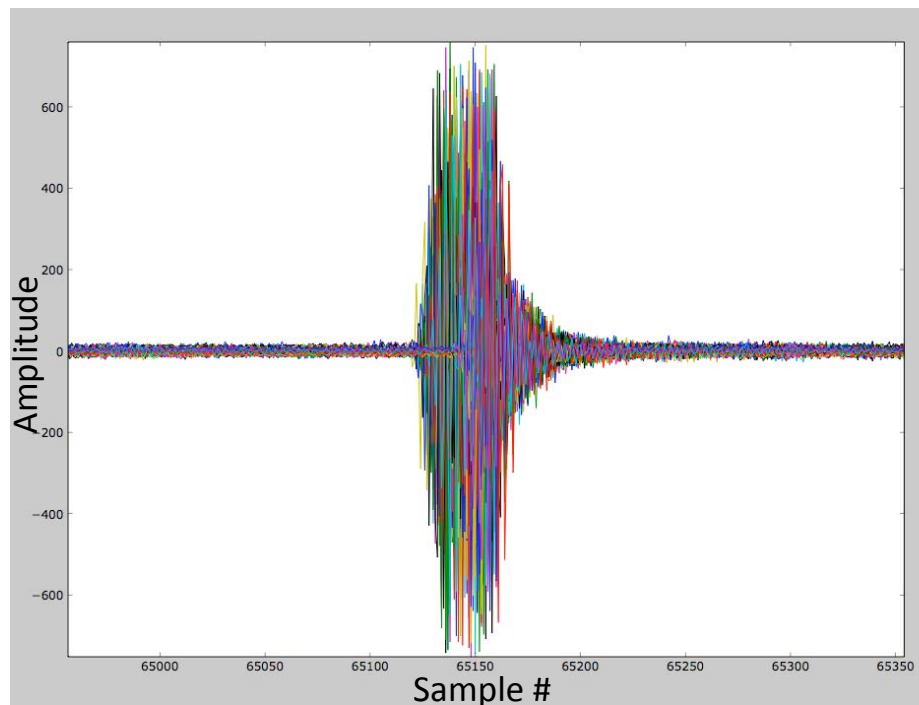


(figs courtesy of Arthur Corstanje)

RFI (esp RS307)

- Real-time trigger includes cut on elevation (pass: >30°).
- Pulse trains: antennas trigger on different peaks.
- Fitted elevation distorted: get past the cut!
- Need to (re-)implement a counter to overcome this.
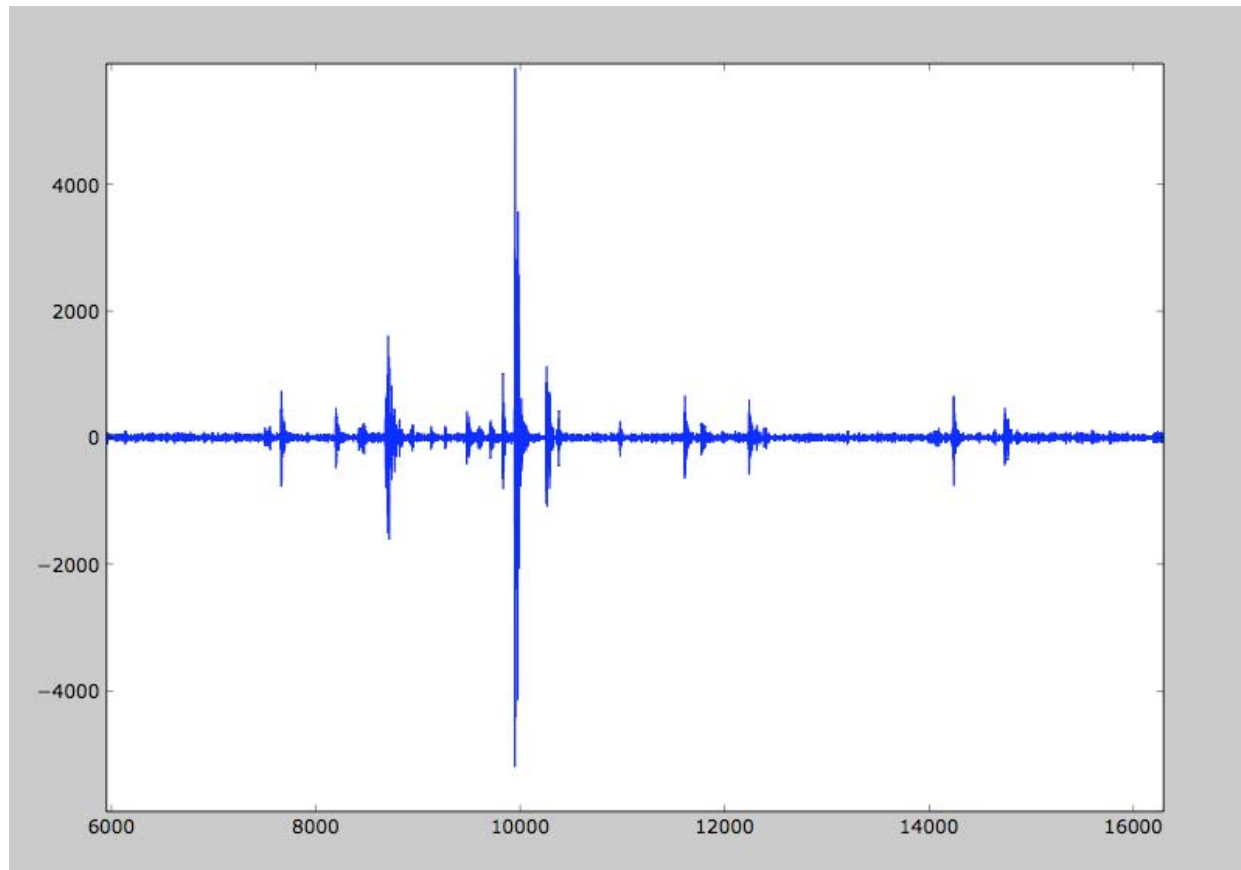


(fig. courtesy of Arthur Corstanje)

Arrival-direction reconstruction

- Observations 23/02/2011
  - Specified in the OTB.
  - RS307, CS002, CS024.
  - 8 hr stable run.
  - 2994 triggered events.

- Analysis:
  - Red: trigger times only.
  - Blue: using triggered data.
  - Use cuts based on pulse shape.
  - Fits for near- and far-field.



(figs courtesy of Arthur Corstanje)
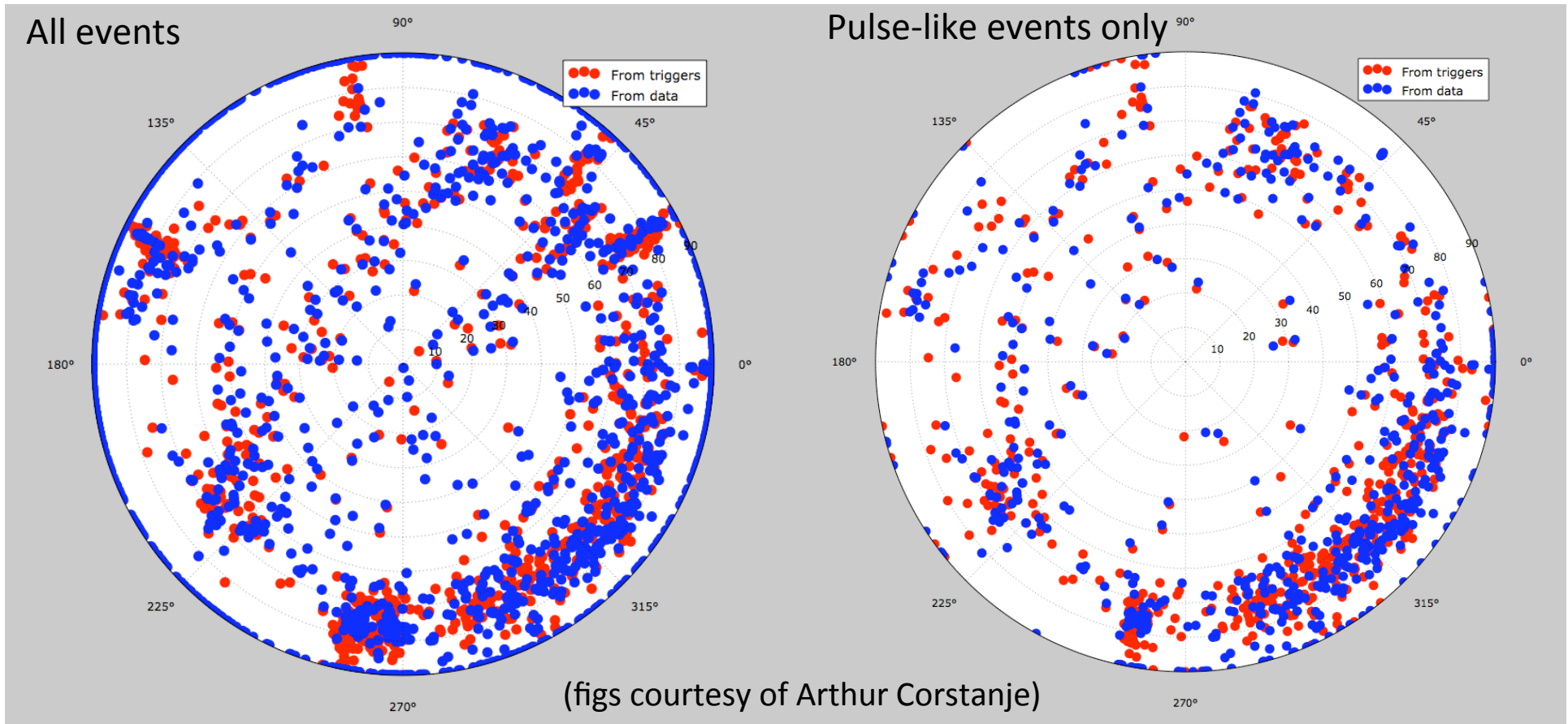
LORA

- 5 'stations' x 4 detectors in the LOFAR superterp

- Each detector: sees high-energy secondary particles from cosmic ray interactions in the atmosphere.

- Goal: give 100% confirmation of VHECR events + energy calibration.

- Status:
  - All detectors deployed Feb 2011*
  - CS 005 station operating remotely
  - Fine calibration pending
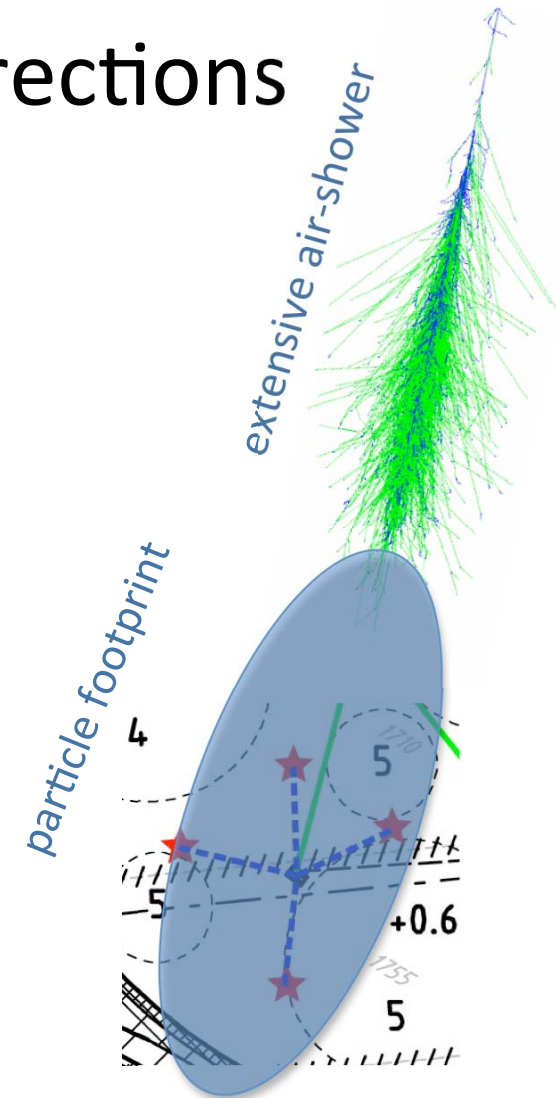 - Other stations need network switches

- We can take data remotely!
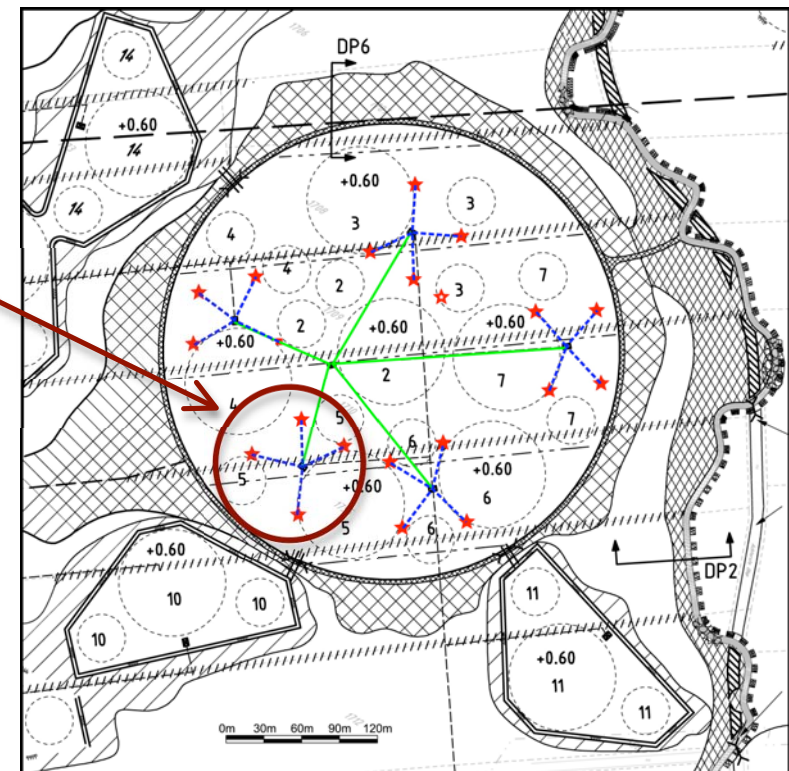
*Thanks to Jan Nijboer, Menno Norden, and Klaus Stuurwold

Reconstructed arrival directions

- 60 hr run mid-February

- 1628 4-fold coincidences

- 4 stations + timing => arrival direction

θ - φ plot

90
45
Zenith
135
180
0
0.2 0 40 60
225
315
270

Horizon
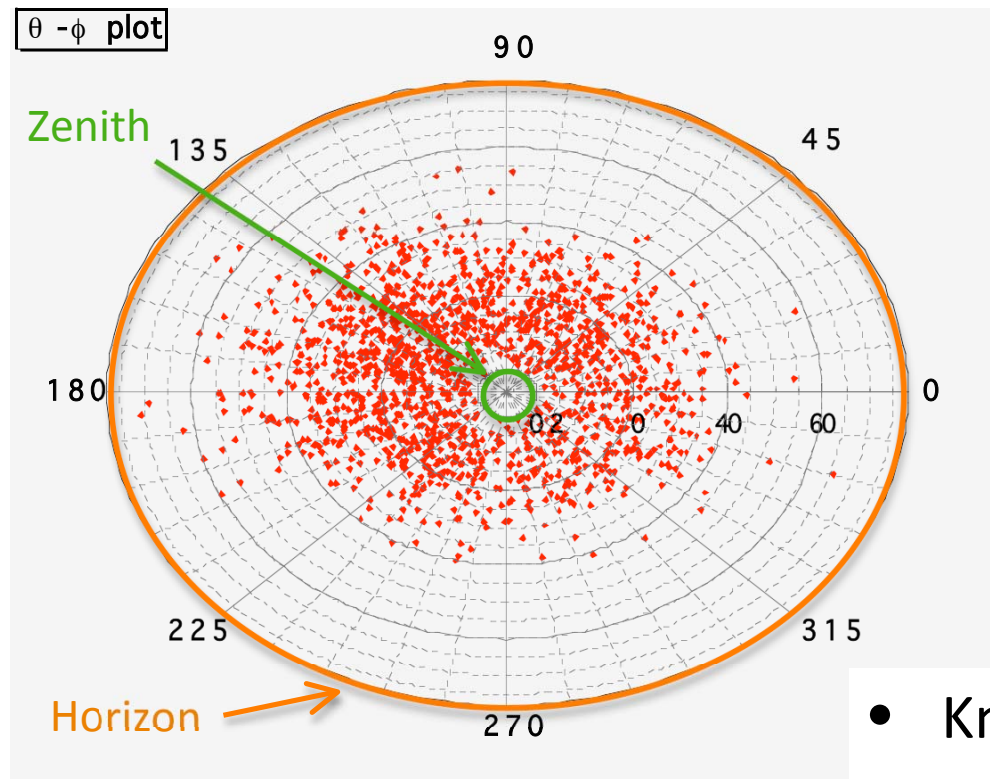
(fig courtesy of Satyendra Thoudam)

extensive air-shower

particle footprint

- Known isotropy distorted by:
  - Non-uniform detector geometry
 - Uncalibrated timing offsets

Next step: LORA+VHECR

- Simultaneous LORA+VHECR on same stations.
- Match arrival directions & times: detect very-high energy cosmic rays.
- This is running as we speak! (so keep speaking?)

Technical Stuff: TBBs and Triggering

- Someone wants to trigger and return TBB data (e.g. FRaTs)
- How do you get to the data? *CR KSP and ASTRON must solve this jointly.*
- Method 2010:
  - Log onto each RSP board at each station.
  - Start up an imperfect data-writer manually.
  - Send TBB start/stop/send data commands to each RSP board.
- Recent Improvements:
  - TBB control handles all start/stop/dump commands (P. Donker)
  - Plan for MAC handling of 'trigger requests' ~finalised.
  - Plan for MoM/scheduler management of piggyback modes ~finalised.
- Next steps:
  - We need the LCCG to assign a priority for getting these plans implemented (because it takes valuable developer time).
  - Adapt beamformed data-writer to handle TBB hdf5 data (who?).
 - Until this is done, we still have to use 'hacked' methods.

FRaTs: Fast Radio Transients

- Analyse dynamic-spectrum data in quasi-real-time for strong dispersed pulses.

- Trigger and return TBB data.

- Act as motivation to develop real-time triggering

- Piggyback off pulsar Christmas observations:
  - Level 1: threshold on power in each sub-band.
  - Level 2: require coincidence between sub-bands.
  - Level 3: anti-coincidence with DM 0/other beams.

    Not implemented!

- Outcomes:
  - Many false triggers!
  - No TBB data dumped.
  - Detected PSR B0834+05

- Next steps:
  - Parallelise code.
  - Implement level 3 trigger.
  - Run automatically.
  - Improve sensitivity.

(courtesy Sander ter Veen)
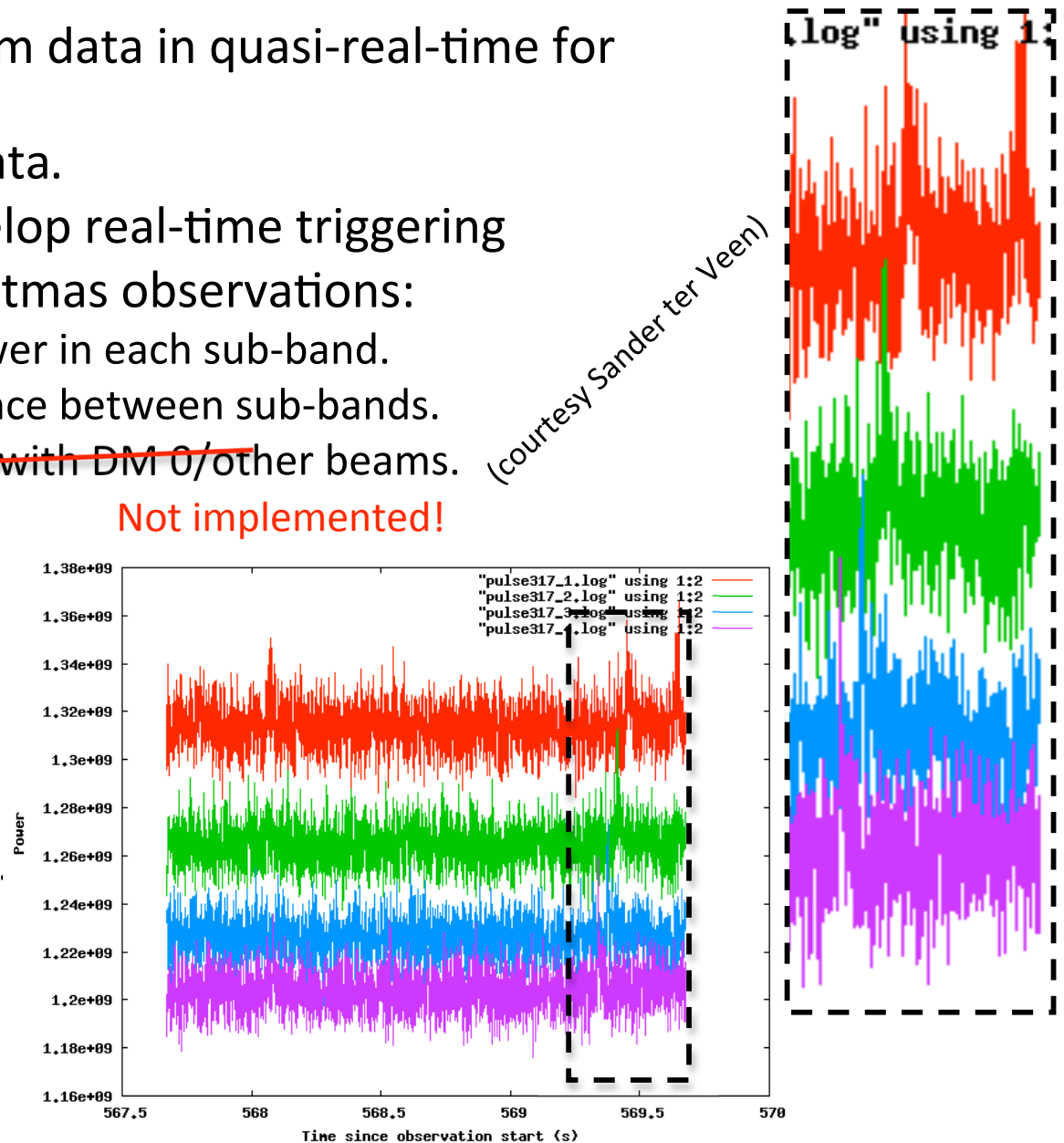
UHEP Mode/NuMoon
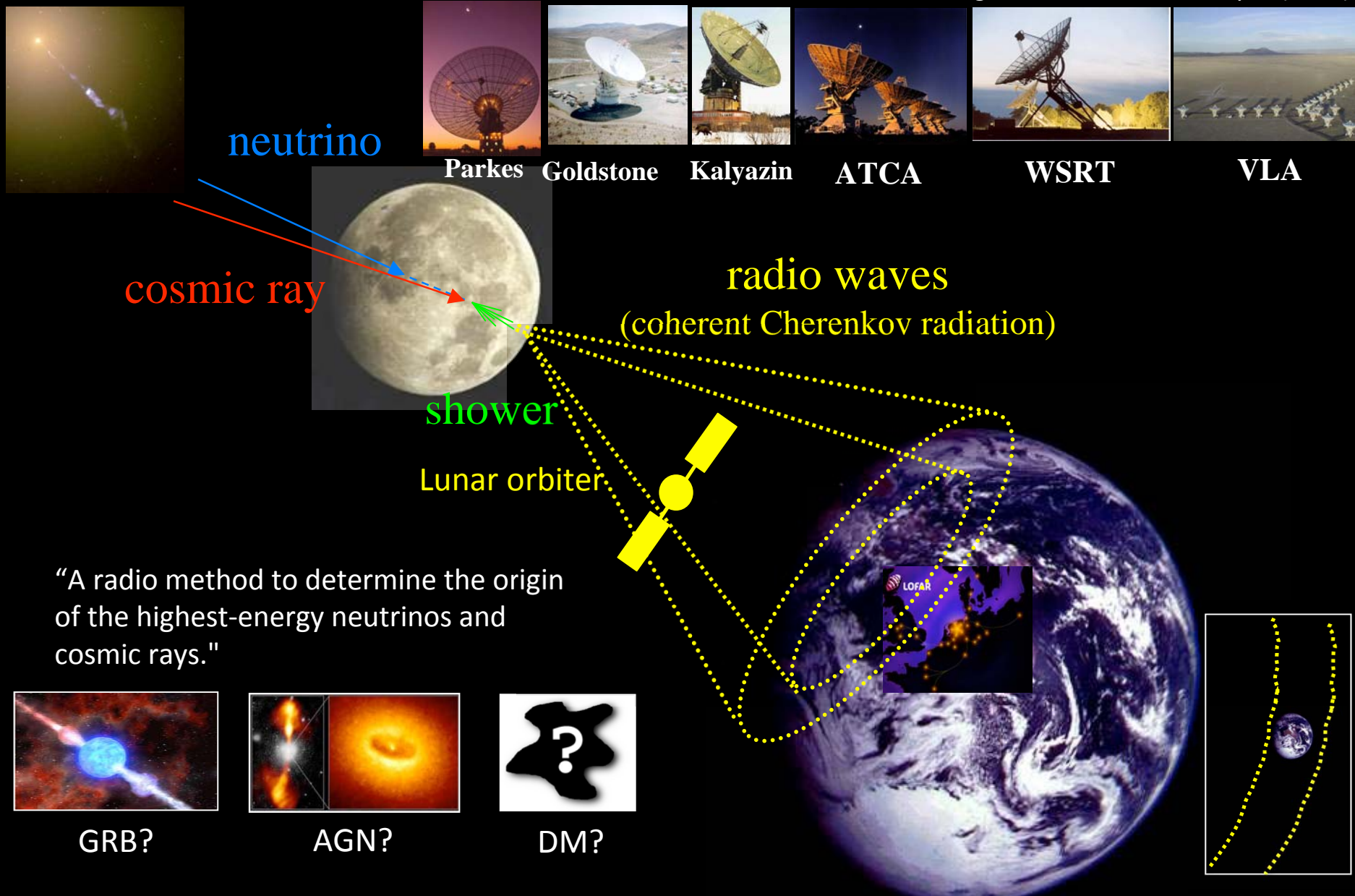
neutrino

cosmic ray

Parkes **Goldstone** **Kalyazin** **ATCA** **WSRT** **VLA**

radio waves
(coherent Cherenkov radiation)

shower

Lunar orbiter

LOFAR

"A radio method to determine the origin of the highest-energy neutrinos and cosmic rays."
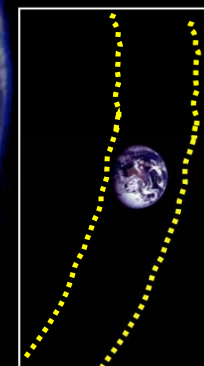
GRB?   AGN?   DM?

UHEP/NuMoon

- Ultra-high energy particle mode:
  - Dedispersed tied-array beams track the Moon looking for band-limited impulses and trigger TBBs.
  - Very technically challenging.
  - Implementation > (>>?) 1 year away.
  - Other groups working on many aspects, e.g. ionospheric calibration, tied beamforming, coherent dedispersion, triggering etc.
- Progress:
  - Determining optimal trigger algorithm (paper in progress)
  - Sensitivity to cosmic rays:
    - Prediction of sensitivity to cosmic rays by James *et al.*
    - Calculation by ter Veen *et al.* confirmed this.
- UHEP mode targeting both cosmic rays and neutrinos

The elephant in the room

- The current TBBs are not be long enough to capture UHEP-triggered pulses due to trigger dead-time.

- No TBB data = reduced sensitivity + inability to discriminate vs RFI.

- Reduced science vs increased cost: exact tradeoff will not be known until preliminary (non-TBB) UHEP observations have begun.

Offline Analysis

- 'cr-tools' analysis suite.
  - Developed for TBB data
  - Depends on common libraries, e.g. for hdf5.
  - Designed to work within LOFAR framework
  - Vulnerable to software shenanigans
  - (was down for 16 days due to DAL move)
- Pipelines:
  - v1 VHECR pipeline completed (< 1 processor/station).
  - v1 LORA pipeline completed.
  - LORA+VHECR combined: to start soon.
  - NuMoon: not for a long time!
  - FRaTs/dynamic spectrum: v1 in progress.
  - All-sky-imaging: optimised v2 complete.

VHECR: top-level

- Specifying VHECR through MoM: have a 'TBB piggyback' button.
- Settings:
  - Turn TBB piggyback off.   [initial default]
  - Allow piggyback observations.   [eventual default]
  - Set TBBs to time-domain data, but no piggyback.
  - Set TBBs to sub-band data, but no piggyback.
  - Choose my specialised TBB template I have created earlier.
- Scheduler will add appropriate TBB piggyback settings based on other observation parameters.
  - Initially, VHECR only.
  - Eventually: FRaTs, VHECR multistation ('HECR'), others…
- Very close to being able to implement this

Trigger Handling

- Next steps: