Working schedule for the LOFAR meeting in Brussels

Monday 26 June

[9:00-12:00] Pre-meeting working group
13:00-15:00 (Z room)
15:30-17:30 (Z room)

Tuesday 27 June

9:00-11:30 (Z room)
13:00-15:00 (Neutrino room)
15:30-17:30 (Neutrino room)

evening : group activity

Wednesday 28 June

9:00-12:00 (Z room)
13:00-15:00 (Z room)

Participants:

Name	**Institute**	**In person?**	**When?**
Stijn Buitink	VUB	yes	Monday lunch - Wednesday
Mitja Desmet	VUB	yes	
Tim Huege	KIT	yes	Monday lunch - Wednesday 15:00
Godwin Krampah		yes	
Katie Mulrey	RU	yes	Monday-Friday
Anna Nelles	FAU	yes	Monday evening - Wednesday 15:00
Karen Terveer	FAU	yes	Monday lunch - Friday
Hashjörg Hörandel	RU	yes	Monday-Wednesday
Arthur Corstanje	VUB/RU	yes	Monday - Thursday (maybe Friday)

Nikos Karastathis	KIT	yes	Monday (morning) - Wednesday (but actually arrived in wrong timeslot!)
Jhansi Bhavani Vuta	KU	No	Monday-Wednesday
Boudewijn Hut	ASTRON	Yes	Monday (afternoon) - Tuesday (morning)
Sander Ter Veen	ASTRON	No	Monday-Tuesday, selected sessions (operational, LOFAR2)

Operations

LORA status + plans to get all stations operational
How to continue with digitizer replacement
TBB radio transfer status

Kratos update

Current status
Consistency checks
How close are we to NuRadioReco now?
How to move forward

Cable delays? Causing the amplitude difference in pulse amplitude?
Clock offset calibration
Check amplitude based on Hilbert envelope

LOFAR 2.0 and TBBs

Presentation from Boudewijn
Online pulse finding algorithm

Plans for monitoring and calibration

What do we want to monitor going forward? Daily/weekly cron jobs to understand trigger rate for LORA, how many triggers accepted from ASTRON
Automated simulations?
Monitor radio data over time, keeping log of bad antennas? (Question that sometimes comes up with the footprint plot)
Calibration: do we want to do a calibration in conjunction with AERA (Xmax discrepancy?)
Code from Tomas- we would need to adapt for LOFAR
How to handle missing information (station timing?)

Publications from current analyses

Template synthesis (Mitja)
LORA extension
Jhansi
Nikos

LOFAR 2.0 Extensions

International stations
    joint observations of lunar neutrinos?
- Cosmic rays with single stations?
- Buffers? Need to be included at the first installation
- Only thing operational during the transition to LOFAR 2.0

Observation- beamed data
Open up single station reconstruction

Muons
cross calibration with SKALA
joint calibration campaign with Salla
link towards SKA

testing ground, etc.

Future analyses

Master's Students

Interferometry with LOFAR
Machine learning (Luuk)
Look at "Messy air shower core"
Single station reconstruction
Single station triggering

PhD+

Template synthesis for a specific geometry (RL fit)
R-L analysis SKA (Arthur)

Finish

LORA extension (Katie)
Follow-up issues between LOFAR and Auger
Calibration (same method as AERA) (Karen)
Noise levels (Karen)
Frequency / pulse shape analysis (Nikos?)
Signal backtracking (Jhansi)

Interferometry

Detailed study on physics of Jhansi's work (+ MGMR?)

Gamma rays

Should we think about modeling sources- case for SKA?

Preparation for SKA!

- Trigger studies for scintillators

- Gamma rays
- Standard reconstruction potential
- White paper?

Afternoon discussion

Group1
Discussion of LOFAR 2.0 proposal
Funding / tasks for LOFAR 2.0
Author lists

Group2
Preparation of wiki page to store minutes, presentations, info
Detailed discussion of data access/KRATOS
CR-KSP logo 🙂

ICRC contributions

Arthur - SKA analysis (poster)
Stijn - SKA (talk)
Arthur - sim interpolation (poster)
Mitja - template synthesis (poster)
Nikos
Katie- LOFAR overview (talk)
Katie- cross calibration

Summary

Division of tasks
AOB

Meeting notes

Welcome and operations

LORA and digitisers (Katie)

Currently CS001 is offline for upgrade. Once this is complete, LORA7 will come back online, but the TBBs will not be installed. Next year (March-May) two other stations will be upgraded to LOFAR 2.0 hardware, one core and one remote station. These will have TBBs installed during their upgrade. At some point CS001 will receive the TBBs as well, but these are not high on the priority list.

Thinking about the future, we might want to think about replacing the mini PCs used to control the (Auger) digitisers with Raspberry Pi's, as these are cheaper and more flexible to work with. This would speed up the replacement of the LORA digitisers. Katie is looking for (wo)manpower to help with making this happen! We can get some inspiration for other experiments (such as RET and RNO-G) as well as ICRC in a few weeks.

To summarise the digitizer part: Katie kindly agreed to go to the field! Write threshold changing into the digitizer software.

An update about the TBB data transfer (Sander)

TBB files are dumped, then the metadata is added, after which the files are grouped. This is done using a manual procedure that has to be activated once per month. At the moment, about 50% of all the events have been processed. A colleague has been identified in order to help Sander with ingesting the missing data in the next weeks (Katie follows this up in the next few weeks).

Currently there are issues with missing metadata in the files. A short term solution could be to fix these during our own read-in of the files, but that is not optimal. For now, Sander will add them to the TAR files marked as "BROKEN" such that we have the data and we can still decide at a later point what to do with them.

(We are discussing the previous LOFAR in person meeting and wondering if Tim was left out on the previous edition)

LOFAR 2.0 and TBBs (Boudewijn)

There are a lot of ideas for LOFAR 2.0, much more than can be realised. During the current preparation phase it is a matter of identifying the most important features we want to build. This

discussion has been ongoing with Brian, for the lightning case. Now we need to see how closely the CR case aligns with the lightning one.

The first step is to define the Minimum Viable Product (MVP), the minimum requirements for the system to work for our science case. Brian has done this for LIFT (lightning for LOFAR). He made a (long) list of requested features, ranked by importance.

Katie went over the CR case together with Boudewijn in order to identify the major differences. From this, they concluded the CR science case requires (a) all antennas in a station to be sampled and (b) a piggyback mode for continuous observation. In the current MVP, we would be still limited to one trigger per hour in piggyback mode. We would like to increase this, but there is a risk of overloading the network. We will probably have to look at the load on the network during the first months of LOFAR 2.0 and evaluate at that point. For this we would also like a "smart" trigger to reduce the amount of unuseful data to be saved.

The TBBs will need to be installed on all the Dutch stations, this is planned for 2025. For the CR trigger interface, we will not need to read out all the stations every time (need the ability to select which ones to read out). In July-August the review of the current firmware architecture will be held, at which the cost of the current MVP will become clear.

Communicate with Brian to make sure we are buying the right buffers and who pays.

TBB pulse finding (Katie)

Applying a finite response filter to TBB trace in real time, then trigger on the Hilbert envelope of the result. Using a bandpass filter (in time domain) with 32 taps gives a remarkably good result, with a pulse that sticks out of the noise as much as the offline analysis result. To use this for triggering, simply checking for a signal above threshold could be enough. For the lightning case a more involved algorithm is required however. All the details are still up in the air though, the number of taps, the roll bandwidth,... can all be further optimised.

The (notch) filters on the antennas will be slightly different for LOFAR 2.0. We might want to account for this in our analysis pipeline, as well as these realtime bandpass filters.

KRATOS current status (Mitja)

Use Singularity to run PyCRTools on COMA (ask Sander if he can process one event on his VM?). We need to find the source of mismatch after calibration. *Mitja has too many tasks to go through. Help.*

Anna will kindly organise a meeting at ICRC with the NuRadioReco developers to see what the options are for integrating the LOFAR software.

Katie will finish writing LORA processing software and find 5-10 good events from the old pipeline that can be used for analyses.

Find a day in September to sit together and work on the software.

Publications from current analyses

Study the Xmax sensitivity with respect to pulse shape (Nikos)

Before Christmas, Nikos was comparing data to simulations by correlating the pulses with each other. However, this basically only proves that we understand our antenna model well. An interesting study that could be used in the future is to make correlation maps of the antennas. This could help us identify antennas which are consistently off and even test new antenna models. Could also try this with the AARTFAC antenna model which includes each antenna individually (with mutual coupling).

Next, he looked at a set of starshaped simulations. He studied every antenna separately, by treating one simulation as data and comparing it with all other simulations. For each comparison, he used the correlation factor to find and compare pulses. Plotting the sum of correlation factors against the Xmax of the simulation produces an inverted parabola, with a peak close to the real Xmax. However, these results do not include noise and no antenna model. The correlation factors are way too high, so it will probably not work in the real world. But it still shows the characteristics from your antenna, so it might still be a good test for that.

However, this was all in the time domain. The information in the frequency domain is better to work with. The idea is to calculate the fraction of the total energy fluence contained up to a certain frequency (fluence up to freq / fluence up to 350 MHz). For every comparison, this produces two curves, one reference and one simulation. The defining metric he uses is then to look at the area between the curves. Plotting the difference in area against the Xmax gives again a parabola, with a minimum close to the true Xmax.

To benchmark this method, he picked 148 events with different energy and zenith angles. The simulation sets are a mix of proton and iron showers. The resulting plot shows a slight negative bias, however some fits are clearly off. When the Xmax is really at the edge at the set of simulations you have, the parabola fails completely. For this study it would be better to only select points close to the real Xmax, following the standard LOFAR reconstruction procedure.

Tim worries that the amplitude does play a role in this metric, but Nikos is not sure it does. If this is true, then we are basically using the information we already have (as this is the same dependency we use for our standard Xmax reconstruction). As the area is normalised to the total fluence, it would be weird that the amplitude indeed enters in somewhere. Showing it in an equation would be helpful though. In further discussions we concluded that the method is fine (it does not use information on the signal strength)

Something else that needs to be added is realistic noise (Karen).

Update on the NuMoon experiment (Godwin)

“A small and quick update on the Numoon experiment”
By the end of the week a paper on the simulated effective aperture for the NuMoon experiment will (hopefully) be published, after a final plot is added.

The choice of stations to use for the observations was guided by having a spherical beam when beamforming. The complete LOFAR HBA DAQ is simulated using a GPU simulation pipeline, from simulating an Askaryan pulse to applying the impulse response and filters in order to get a measured pulse. An important factor here is polyphase filtering, which reduces the timing resolution of the measurements from nanoseconds to microseconds. This is reversed in software, in order to retrieve the original time resolution. After removing the polyphase filter, Godwin filters the trace from RFI using a fit to the spectral energy density and looking at where the data comes above the fit.

For the observation, Godwin got 1min of data for 6 stations (due to disk space constraints). This data was cleaned, by removing the polyphase filter and also removing the ionosphere dispersion. Pulses coming from the horizon look very similar in all beams, while for the centre of the moon this is very different.

To design a trigger, Godwin used the P5 value (other values were tried but this one worked the best). When plotting the standard deviation across the beams against the n40 value, simulations from the horizon and the Moon split neatly into two regions. When looking at the data, there were some outliers. These were the result of strong signals in only one station, which rules them out as being a real signal.

Intermezzo to interrogate Boudewijn and Sander about why Godwin does not have access to the node on DragNet which contains his data. Sander will try to knock on Jason’s door to fix this.

Once Godwin has access to all his data, he can do a more thorough study about the LOFAR background. Also on his to-do list is to put upper limits on the ultra-high energy neutrino flux. With LOFAR 2.0, Jason will monitor a couple hours of raw data for all stations. If we have a good trigger algorithm, we use this to get data for a background analysis.

There is some talk about a Belgian LOFAR station in the future. With a single station the beam would be larger, but with the country privilege we could use the station to record every week. Adding the German LOFAR station(s), which we happen to have access to, could improve this study already significantly.

LOFAR 2.0 extensions

International stations

To continue the brainstorming about using international stations, the timeline for the potential Belgian station is very much undetermined. Talks to find interested partners are TBA.

Science cases for single (international) stations include lunar neutrinos and cosmic rays. These stations will be the only ones operating once the transition to LOFAR 2.0 is started. So we can start these analyses already now. One nice thing about the international stations is that we access the backend.

Another idea for an international station would be to test gamma ray searches, by beamforming the LBAs. There is rack space to add particle detectors and “Bavaria is closer by than Australia”. Other ideas would be to install SALLA4 antennas to test them, as well as the grounding planes.

A Latvian colleague (Jesus A. Cazares) Anna and Katie spoke with at the LOFAR family meeting was really interested in using TBBs and using the station for CR studies. The only issue was that he didn’t know how to work with them. Brian was appointed as his contact person for this.

Developing a radio-only trigger could also be a nice project during the LOFAR 2.0 upgrade. This can be used for low-energy shower search, by beamforming a patch on the sky. Planes passing through these beams can be used as a calibration signal.

Before the LOFAR 2.0 upgrade, the network will already be upgraded. The international links might be down for a while.

Anna will figure out how everything works on the backend and ask for 1 minute of beamformed data from a German station, to already get some background data for analysis.

What’s new with LOFAR 2.0

First of all we will have much more statistics, thanks to the 24/7 observations. Next to that, we will be able to go to lower energies using the hybrid trigger.

Another idea would be to also request the beamformed HBA data if the beam pointed in the same direction as the LORA reconstructed direction. This would need to happen within a couple of hours though. However, what could we really do with this data?

Thinking about the proposal that is coming up, we need to emphasise our team, infrastructure and data storage solutions. ASTRON only provides 18 months of storage, longer term needs to be specified and probably self-hosted.

Katie has benevolently agreed to start work on the LOFAR 2.0 proposal.

Future analyses

Reconstruction of Xmax based on backtracking of radio signals (Jhansi)

The central idea is to associate a point of emission along the shower axis for each antenna, assuming the signal travels perpendicular to the shower front. By splitting the signals in the geomagnetic and charge-excess contributions, she managed to reconstruct the wave fronts for each component separately, as well as the total shower front.

By multiplying the total fluence in an antenna with the distance to the associated emission point squared, you get something that resembles a longitudinal profile. Using this to reconstruct the Xmax, you obtain a value which is not too far off from the true Xmax. However a bias dependent on the true Xmax seems to be present in the simulation data. The zenith angle also seems to have some kind of an impact, although this is not immediately clear.

Some things that need to be done are to use the GDAS parameters to calculate the slant depth instead of the standard one, as well as checking for duplicate events. For the future, she wants to test different array configurations (size of the array, as well as antenna spacing). Applying the method with an irregular (i.e. LOFAR-like) array would be a nice test.

One simple argument why this method works, is a toy model where you assume the emission on the Cherenkov cone is emitted at Xmax. Hence, tracking the radiation back to the emission point should arrive at Xmax. However, this does not explain why the rest of the shower profile should be so similar.

Testing this in data, using some of the golden LOFAR events, could be a good idea to show in a publication. Perhaps we can use this opportunity to make some of our events public? This will probably require KRATOS to be ready for release.

Reconstructing air showers for LOFAR with IFT (Karen)

The goal is to use Information Field Theory (IFT) to reconstruct air shower parameters. IFT is a Bayesian theory that exploits correlations to reconstruct signals. Combining models for the prior distributions of the electric field signals, the detector response and noise, you obtain a posterior distribution on the air shower signals. The most likely signal can then be reconstructed from given data by maximising the posterior. Implementing this will be done in Python, using the NIFTy package.

This approach sits in between using neural networks (which are black boxes) and handmade reconstruction algorithms (which are time intensive). It is used for RNO-G to find the most likely electric field associated with a signal, to circumvent the problem of having to unfold the detector response, which blows up the noise at high frequencies.

Low-hanging fruit

A. LORA extension

Once the other LORA stations are installed and we have about a year worth of data, we can write an “easy” paper on this.

B. R-L analysis for LOFAR

Using template synthesis, we can generate the antenna signals for showers with different (Xmax, L, R) points. Currently this is restricted to a single geometry, but we can try to do some steepest descent approach in this parameter space for a certain event. For the SKA setup Arthur has already a large set of CoREAS simulations, which can be used to test the template synthesis approach with.

Mitja and Arthur will prepare the simulations for this.

C. Small analyses to be done

We should keep a list of small(ish) analyses that are still to-do on the wiki (see this afternoon), in order to have stuff to distribute as student thesis projects. For this we would need some processed events publicly available, such that the students can start to work on this. These should be the best few events, of which we believe the results from PyCRTools.

Higher hanging fruit

A. Some kind of SKA white paper

Collect all the SKA analyses in a single place, with less work and scrutiny than a full (set of) publication(s). Something like this was started some time ago, but it became obsolete and as a result the work on it has stopped. However we must be careful that we don’t give the impression that LOFAR is finished, we have to balance the SKA with LOFAR 2.0 science cases and show how they can be complementary.

Who do we need to convince at this point? *Let the haters hate, we will build this thing*

Stijn is boldly going to lead this effort.

B. Gamma ray detection with LOFAR/SKA

Beamforming radio antennas to look at gamma rays, at lower energies. This becomes possible with SKA because of the high antenna density, beamforming can give a factor of 16 in signal-to-noise. Another factor of 4-6 can be achieved using matched filtering.

The hardest part of this would probably be triggering. Stijn will investigate this in the coming months and read the SWGO white paper, to understand whether this can be put into the proposal he is writing. He will focus on the particle detector triggering however, as that is what he is asking money for. Radio triggering will be investigated later, together with Arthur.

This would be a unique selling point of SKA, and might convince some sceptical people of investing in this project. Something to keep in the back of our minds is that SKA will be in somewhat direct competition with SWGO, as that would sit at the same latitude as SKA. That project is not funded at the moment however, so we can probably do it first.

ICRC proceedings

Don't forget our internal deadline for the proceedings: 10th of July. Katie will make an Overleaf version of this for ease of use.

Internal deadline for posters: 18th of July
Overview talk draft: 5th of July

SKA analysis and Fourier interpolation (Arthur)

Finishing two posters in 12 working days is difficult, especially if there are also proceedings to be written up. Anna can help with the latter, she is the "master in condensing papers" and therefore she proposes to help make the interpolation proceedings. The best thing is to focus on the proceedings, as these will be read by the conference attendees. Worst case the poster can be a summary of the figures from the paper.

What about the author list? This will be the LOFAR-CR list (see later) and Clancy.

Template synthesis (Mitja)

Everyone (except Jörg) is super hyped for a Patreon page and the merchandising! *Next steps are a LOFAR CR song and dance, to present at the next LOFAR family meeting.*

Area difference in Xmax reconstruction (Nikos)

The proceedings will start with the LOFAR Xmax reconstruction, and highlight how there might be more information hidden in the pulse shape apart from the signal strength. This is most easily analysed in the frequency domain, in which the area metric can be used. A good plot to show here is a comparison of pulse spectra together with their metric curves to show how the area reflects how similar they are (perhaps two, one with a small and one with a large difference).

The benchmarking needs to be improved, and he should find a way to present the result better. Comparing the bias to the zenith angle is interesting, but this plot takes up a lot of space and

does not provide that much information. The analysis needs to be redone for the 30-80 MHz case, although the result will probably have to be condensed into one number.

LOFAR overview talk (Katie)

Katie will show nothing new, she will focus on how we move forward and what we will do with LOFAR 2.0 (triggering, going beyond Xmax,...). She will also use this opportunity to highlight posters and other work from working group members.

Do we want to comment on the ongoing efforts to solidify the AERA and LOFAR results? Yes, but we need to be careful about what we claim. Simply listing out the things that have been checked would be a good idea, as well as saying that we haven't found any obvious causes for the discrepancy. Both groups are sharing their raw data and analysis with each other, which is important!

The author list (ominous music starts playing…)

We can do it per institute (with a list curated by each of them), or individually. Whatever we do, we should revisit this about every semester to check if it's still up to date. The most recent version of the author list is on the pulse interpolation paper. Nikos's name is misspelt, this should be fixed asap! We will put this on the Gitlab wiki page.

Stijn will contact Gia to know if she wants to still be on the list. Krishna can be removed. Hershal's work is still very relevant to our publication in the short term, but we will reevaluate this next year. What about the lightning people, like Brian's PhD student? They should be included as well, Stijn will email Brian about this.

About master students, who join for one year, we should evaluate if they have contributed to the work.

Our next workshop will be in the week 08/04/2024 - 12/04/2024

Original topic list:

- Current status of data collection, working LORA stations, data transfer
- Plan for monitoring / maintenance
- Station timing?
- Future analyses, where do we want to go with LOFAR?
- LOFAR2.0 Transient Buffer plans (added by Boudewijn Hut, ASTRON)
- Extensions (muons?, cross calibration with SKALA?, joint calibration campaign with Salla?) link towards SKA, testing ground, etc.
- Publications from current analyses / other analyses we need to do
    - Template synthesis (Mitja)
    - LORA extension
    - Analysis Jhansi
    - R-L analysis (Arthur)
    - Interferometry
    - Look at “Messy air shower core”
    - Follow-up Energy scale issues between LOFAR and Auger
- Authorlist policy
- Meeting minutes / wiki / upload of talks
- KRATOS working group probably stays an extra day or two to make progress there
- ICRC contributions
- Large Program Proposal for LOFAR 2.0
- Making TBB data products useful for students (and station owners)