VALIDATION PLAN FOR THE E-CALLISTO PRODUCT

A. Csillaghy, FHNW, July 2020

1 Introduction and scope

The purpose of this validation campaign is to evaluate the performance of the actual e-Callisto product as provided in the SSA System. According to our proposal, the entire effort will be divided into two independent campaigns, that we call phases in the following for clarity:

1. The first validation phase will focus on the assessment of the data quality: For a specific observing station, how "good" is the quality of the recorded data? The current interface of the e-Callisto service provides a reliable way to visualise the contents of the raw dynamic spectra in the queried time period. This visualisation as output of the service allows to quickly get information about the solar activity in this period. However, small signals often get lost in the relatively high background that is unfortunately present in many stations. As a result, many signatures of solar activity remain invisible. To correct this negative effect, it is necessary to apply a valid background subtraction before the data are visualised. This background subtracted data allows to identify weak signals and thus provides a way to make first-order comparisons of station signals that allows to classify the data in terms of signal-to-noise ratios. This information can then be used as input to the second phase of the validation campaign.
2. The second validation phase will focus on the availability and on the cross-comparison level of each individual station: How often are individual observing stations available? And how do their observations compare to each other? e-Callisto is a special system compared to more traditional services in the sense that it consists of hundreds of different stations operating independently. Even though the receiver is the same for all stations, the environment in which it operates can be very different. Furthermore, the stations are in general not operating all the (day-) time. In particular, there are a multitude of antennae operating, some are tracking the Sun, and some are fixed. Therefore, each station has an individual level of quality that can vary dramatically from one station to another. For this reason, validation is a crucial step in the setting up of this unique operational system in the radio domain. This campaign is divided in two independent parts that will address the following questions:

The product that is going to be validated consists of solar radio spectrograms of the Sun (S.105b eCallisto Solar radio spectrograms, http://ecallisto.cs.technik.fhnw.ch/prod/latest). Solar radio spectrograms are known to display, among others, signatures of solar radio bursts that are associated to solar flares. An example of such a burst is shown in Figure 1. Clearly, drifting emission is visible, that can be associated with accelerated electrons producing beams of gyrosynchrotron emission while traveling through the solar corona.

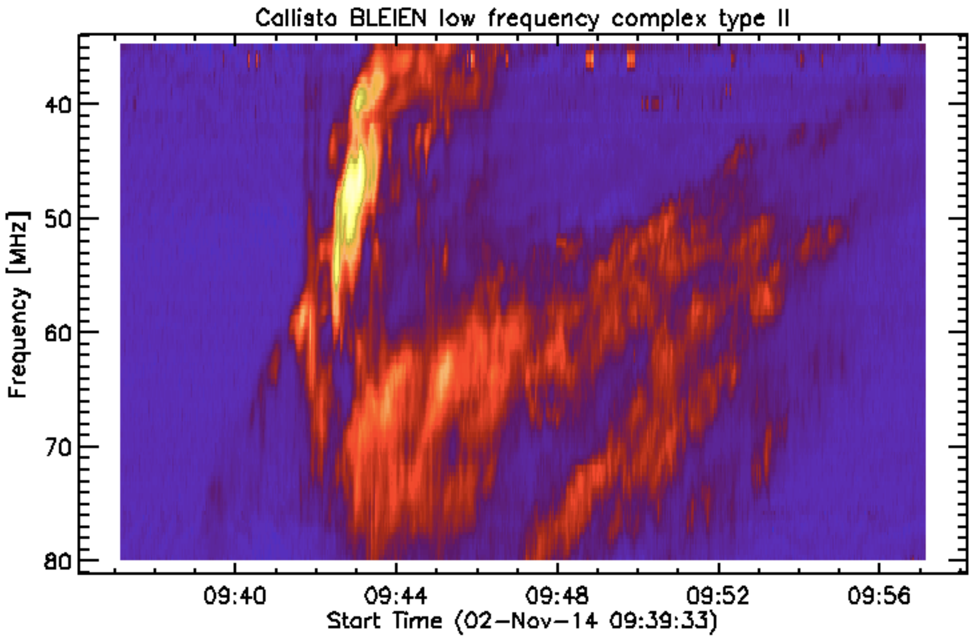

Figure 1: A solar type II radio burst observed with the Bleien Station (Switzerland) of the e-Callisto network.

Two main use cases will be addressed for the validation of this product:

- The first use case is the determination of the speed of the accelerated electron beams. This speed can be derived from the drift time visible in the radio emission (see also Figure 1).
- The second use case is the provision of such spectrograms as complementary information for analysis of events observed by instruments on spacecraft that look at the same events, but in different wavelengths. Such observations are provided among others by Solar Orbiter or Parker Solar Probe. The e-Callisto products can "track" the time evolution of the accelerated particles back to their origin in the solar corona.

The user can get to this product by first querying on the SSA website the user interface for an appropriate time interval. He or she can then first visualize the data products available for this time period, which are provided either as images or raw data FITS files. She or he can then download the FITS files for further processing locally with an appropriate python software, such as the solar radio spectrograms software included in SunPy.

The performance requirements for the mentioned use cases are as follows:

1. **Phase 1: Data quality**: How clearly can the radio emission originating from the Sun be distinguished from background noise or radio frequency interferences? This is more difficult to assess and can be done in several complexity levels. The most basic level that will be used for the validation campaign is assessing the signal to noise ratio (SNR) of the observations.
2. **Phase 2: Station availability and cross-comparisons**: How often is a specific observing station that is part of the network available? This can be measured by the ratio of recording time vs. the number hours of sunshine for that particular station. And how good to simultaneous observations compare to each other? This can be assessed by comparing (cross-correlating) background-subtracted signals from different stations.

The information that should be communicated to the users as result of the campaign will be, on the one hand, the reliability of the station in form of “stars”, analog to hotel qualifications. 5 stars will designate the best stations. The results of queries will be sorted along these stars: if two stations record a radio burst simultaneously, the best station will be used as the query result.

1.1.1 Test product assessment

The e-callisto Network is a large collection of ~150 observing stations distributed across the world. They all use the same CALLISTO radio spectrometer. C. Monstein describes on the e-Callisto website the instrument as follows:

> The CALLISTO spectrometer is a programmable heterodyne receiver designed in 2006 by Christian Monstein [...]. CALLISTO is an artificial word, composed as 'Compound Astronomical Low frequency Low cost Instrument for Spectroscopy and Transportable Observatory'. The main applications are observation of solar radio bursts for astronomical science, education, outreach and citizen science as well as RFI-monitoring. The instrument natively operates between 45 and 870 MHz using a modern, commercially available broadband cable-TV tuner CD1316 having a frequency resolution of 62.5 KHz. The data obtained from CALLISTO are FITS-files with up to 400 frequencies per sweep. The data are transferred via a RS-232 cable to a computer and saved locally. Time resolution is 0.25 sec at 200 channels per spectrum (800 spectral pixels per second). The integration time is 1 msec and the radiometric bandwidth is about 300 KHz. The overall dynamic range is larger than 50 dB. For convenient data handling several IDL-, PERL- and Python-routines were written.

All CALLISTO spectrometers together form the e-Callisto network. Many CALLISTO instruments have already been deployed worldwide. Therefore, the e-Callisto network is able to continuously observe the solar radio spectrum 24h per day through all the year. Data from individual instruments are automatically uploaded by FTP to the central server at FHNW.

Instrument deployment including education and training of observers was financially supported by SNF, SSAA, NASA, Institute for Astronomy and ETH Global, formerly known as North-South Center of ETH Zurich and a few private sponsors.

2 Assessment of available reference/ground-truth data

The reference ground truth information for the first validation test – availability of the station – is implicit: if the Sun should be visible from the station, then the station should provide data for that time period.

The reference data for testing SNR is two-fold. First, the data should be compared to observations from a larger instrument. We consider currently a radio spectrometer operated at the Nancay radio station, ORFEES, as reference. Of course, ORFEES has visibility only over Europe. Therefore, starting from this reference, the station testing needs to be organized in such a way that the reference can be transferred to stations at more western longitudes, eventually reaching those that observe while the reference station is in the night.

The data availability from ORFEES is limited. However, we can use the available data to determine which time intervals should be used in the e-Callisto database.

There are many uncertainties, biases and limitations in solar radio spectral observations. However, we believe that ORFEES is the best instrument that can be used for our campaign in terms of data availability and quality.

2.1.1 Selection of validation methods

This section is aimed at relating the proposed validation campaign with the "Validation Guidelines" document SSA-SWE-ESCDEF-TN-5401 that drives our approach to the campaign.

- The type of product to be tested is a **measurement.**
- The class of product to be tested is **spectral-time domain.**
- The validation methods that are applicable for the type and class of product tested in this campaign are the following:

1. Station availability: Over the entire database, for each station, compute the factor

$$\frac{\text{number of observed hours}}{\text{number of sunshine hours}}$$

   Obviously, the number of sunshine hours for a specific location must be computed from an ephemeris as a function of the geolocation. Horizon and obstacles on the ground might also play a role in the station availability. This information will also be included in the model.

2. Data quality: For each station, go through a selected radio burst list observed by the reference station, retrieve the data, and compute the signal to noise ratio. To do this, a background must first be subtracted. The data from the reference station and the e-Callisto station are then compared for the overlapping frequencies. This result in a score that can be mapped into a $[0..1]$ interval, where 0 means no observation and 1 means perfect agreement with the reference station. Note that it is important to make these computations on real observations of radio bursts. The stronger the burst, the better the assessment can be performed.

Using the two scores computed in (1) and (2), compute a suitable combination of both scores, and divide the range into 5 intervals, each interval corresponding to a number of "stars".

2.1.2 Selection of test time period(s)

For computing the station availability score, the entire time of operation of the station will be used. This is not to confound with the operation time of the entire network.

For computing the signal to noise ratio, intervals containing solar activity will be preferred.

3 Planning

The general idea is to compute three station scores that will rank the quality of the observations. The scores will be added together and the best score will rank the best station.

This campaign phase has already started and will last until June 2021. The campaign is led by André Csillaghy, the programming is done by Simon Beck (senior) and Delberin Ali (junior).

The detailed planning of the validation campaign will be as follows:

1. First validation phase: quality assessment based on the background subtraction

The steps that will be followed are:

- Test of the currently available background subtraction function in SunPy;
- Extension of the standard background subtraction functions with windowing capabilities;
- Addition of the new functionality to the SunPy package;
- Development of the testing framework for computing background subtracted e-Callisto spectrogram;
    - Original plan was : make a BIG spectrogram for 1 day (join_many)
    - Now: don't do the BIG spectrogram, but use bgk subtract on each single file:
    - Main program:
        - Test / dev: only 1 month. When accepted → run over entire db
        - For each file in the repository:
            - Read file
            - Subtract background
            - Remove RFI (could be better, see with Kushtrim)
            - Compute std dev & mean → store this in the db
            - Optionally save spectrogram → create a new directory
        - For each std dev in db:
            - Group by station and then average std dev
        - Order the station : lowest std wins
    - (at this point: merge request:
        - Documentation
        - Integrate with actual version, update our version with the online version and test)

- Computation of the SNR for each spectrogram;
- Aggregation of the results by time and observing station;
- Visualization of the results;
- Computation of the first "station score" assessing the quality of the data, including calibration of the results.

2. Second validation phase: station availability and cross-comparison

The steps that will be followed are:

- Extraction of the daily operating times of each individual station from the observational data;

- Comparison with the (seasonal changing) maximum possible observation time;
- Determining a second station score for the availability time;
- Cross correlation of the spectrograms for stations that have observational overlap;
- Determination of a cross correlation coefficient and ranking the station according to this score;
- Determination of a third station score assessing the best overlaps of signal;
- Test and calibration of this third score, and decision whether this can be used in practice.