# First light of X-/Ku-band telescope to observe the 2023 and 2024 Solar Eclipses

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## 1. Introduction

There exist plans to observe the annular solar eclipse (ASE) and total solar eclipse (TSE) not only visually by optical telescope or binoculars but also with a small radio telescope in case of bad weather conditions such as fog, clouds, smoke or even snow or rain. Also, for blind people it might be interesting to hear the changing sound of the SAT-Finder when the radio radiation of the sun slowly disappears during the eclipse. The aim was to get a transportable telescope for low cost and components from local store or Amazon-like shops. Here we describe such a low-cost system including some first result while observing the quiet sun in X-/Ku-band.

Figure 1 ~ View of the finalized small radio telescope to observe solar eclipses 2023 and 2024 in X-/Ku-band between 10.610 GHz and 11.245 GHz. It is composed out of a simple, transportable tripod with two attached satellite rotors, one to position in azimuth the other on top to position in elevation. Mounted on the elevation rotor is a horizontal aluminum axis. To this axis there is a satellite dish TRIAX TA 65 with 65 cm (~15 inch) mounted [Triax]. Mounting is such, that the offset angle of the offset dish is compensated in a way that the beam axis is perpendicular to the elevation axis. As a feed there is a wideband LNB from TechniSat WB1 40mm installed with super low noise (according to specification) of 0.1 dB [TechniSat]. Important to mention is the fact, that these LNB have a different local oscillator (LO) of 10.41 GHz which allows to get down in intermediate frequency (IF) to about 200 MHz, ideal for CALLISTO frequency agile spectrometer [Callisto]. This low IF corresponds to a sky frequency of IF + LO = 10.67 GHz which shows low level of interference due to geostationary TV-satellites.

Both rotors are connected via two SAT-coaxial cable to a DiSEqC.controller unit [DiSEqC] which is connected to a standard Windows notebook via USB-cable. Software to control both rotors and thus tracking the Sun is written in Python3.7. This Python script is executing once every minute, triggered by a software tool called ssfree.exe which works quite similar as crontab under LINUX.

For the overall instrument concept, see previous SARA article entitled as: Planning for the 2023 and 2024 Solar Eclipses at VHF, UHF and Ku-band by Christian Monstein and Whitham D. Reeve.

Figure 2 ~ Detail of dish mounting on the elevation axis. Red arrows show slits and bolts to adjust dish-offset in a way, that incoming radiation is perpendicular to the elevation axis. Depending on manufacturer the slits might be extended with a rasp or milling cutter. In this example the dish must be rotated further anti-clockwise to meet the goal. In addition the clamp needs to be rotated by 180° due to the position of the slits.

## 2. Test results

Recent observations of the solar radio radiation in X-band look promising, although without any solar eclipse, just quiet solar radio flux.

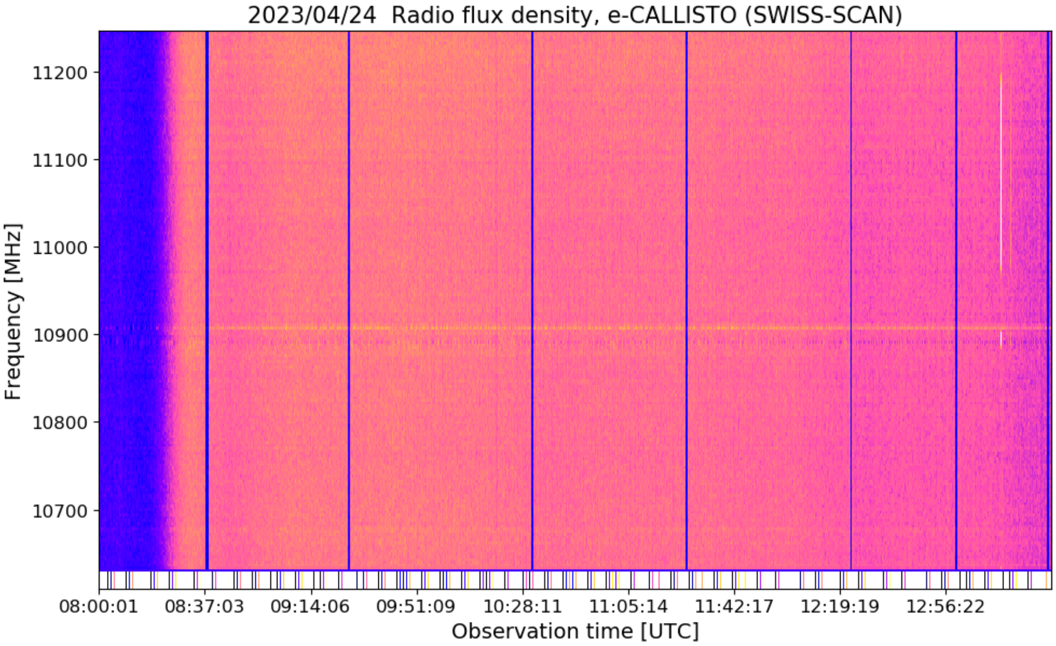


Figure 3 ~ Dynamic radio spectrum of the quiet sun between 10.6 GHz and 11.3 GHz between 08:00 UT and about 13:00 UT. Blue color denotes to cold sky (no solar radiation). Blue vertical lines show manual testing of cold sky to verify baseline of the spectrometer. Reddish color shows quiet sun radio flux.

Dynamic spectrum is stored as FIT-files (Flexible Interchange Transport System) on local disc of the control computer. Time resolution is 0.25 seconds while integration time per spectral pixel is 1 ms. Radiometric bandwidth is 300 KHz. Intensity resolution is reduced to 8 bits to save storage space. Since Callisto contains a logarithmic detector the dynamic range is given by 10*log[(2^8)^2] = 48.1 dB. Using some Python scripts, we can extract single spectra from the dynamic spectra, as shown in figure 4.

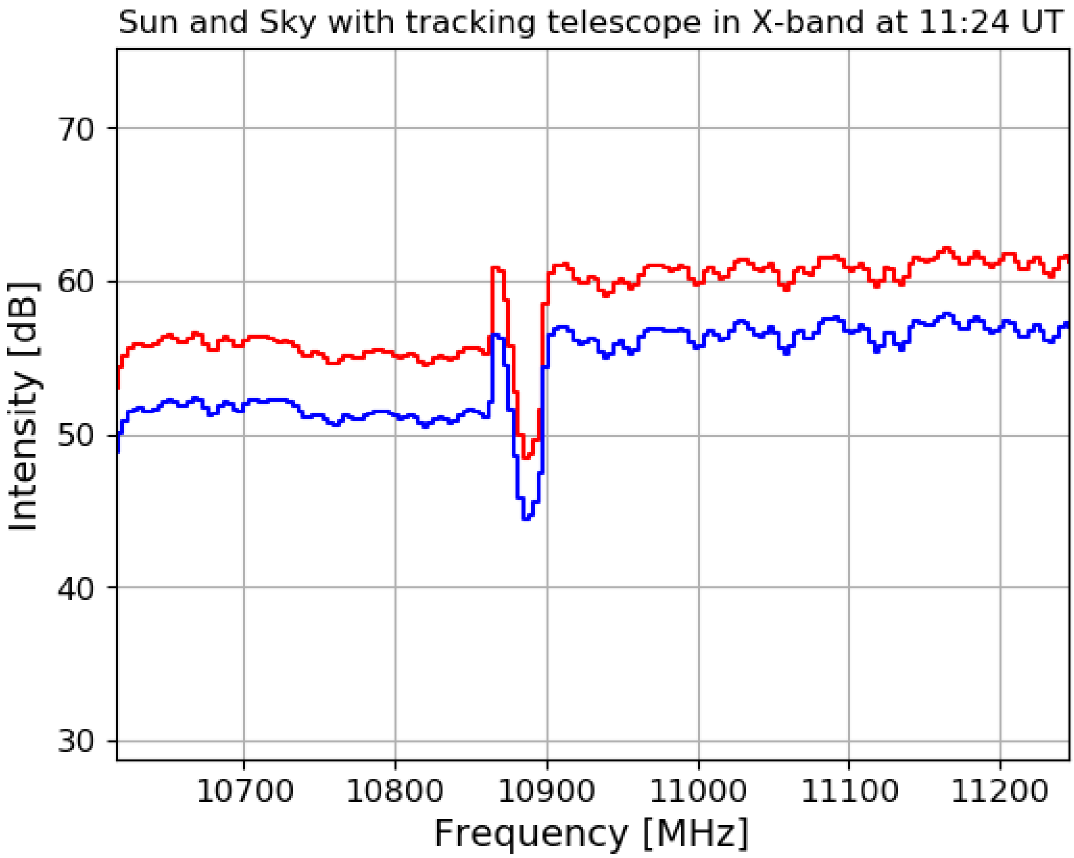


Figure 4 ~ Single spectra around noon. Red plot shows radiation from the sun while the blue plot shows radiation from the cold sky which we call reference or background radiation. Wiggle around 10.9 GHz is due to internal receiver switching inside Callisto spectrometer at an IF of 450 MHz.

Spectra from sun(hot) and cold sky (cold) allow to estimate the so-called Y-factor [Y-factor] a quality measure of a radio telescope, see figure 5.

Interesting the fact that the Y-spectrum is quite constant over the whole frequency range which can be observed with CALLISTO. Variations are less than +/- 0.5 dB. Based on another Python script we can also extract light-curves from the dynamic spectrum as shown in figure 6. Sun-rise is about 08:30 UT when the sun pops up behind my neighbor’s home on the east-side. Then flux is quite constant till about 12UT when the sun is hidden behind a hazelnut tree. After 13:30 the sun disappears behind the home of my neighbor in the west.

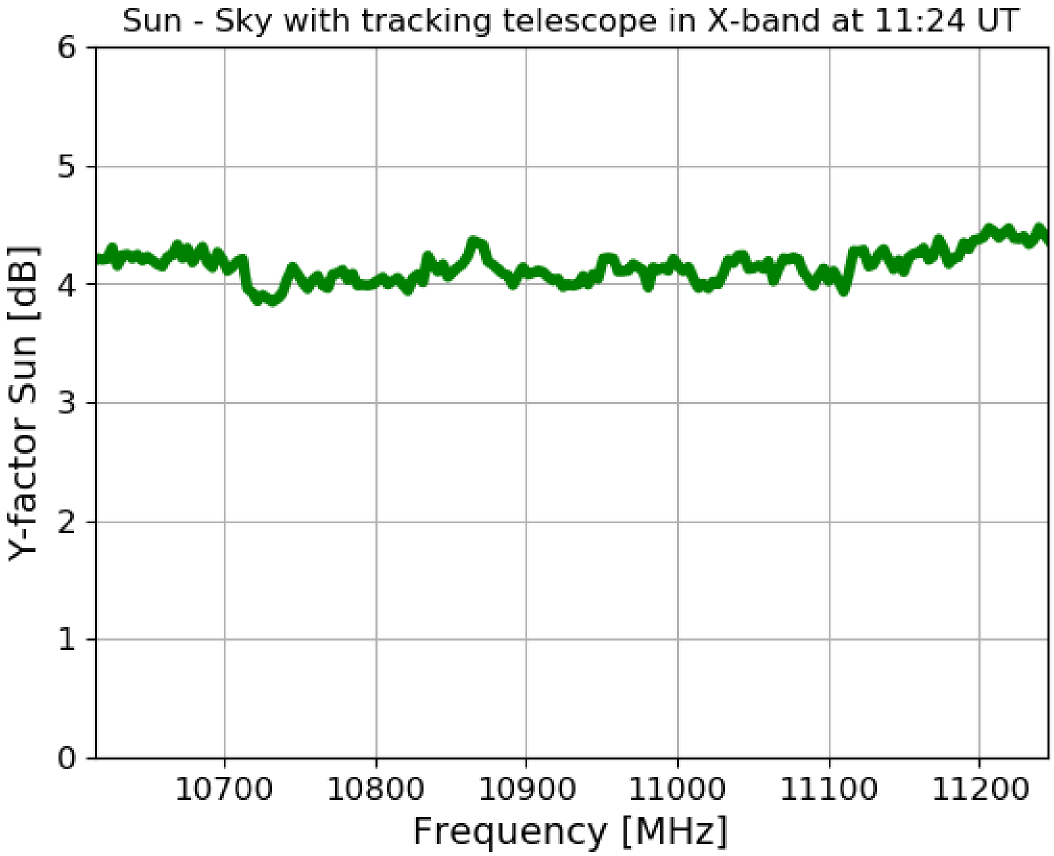


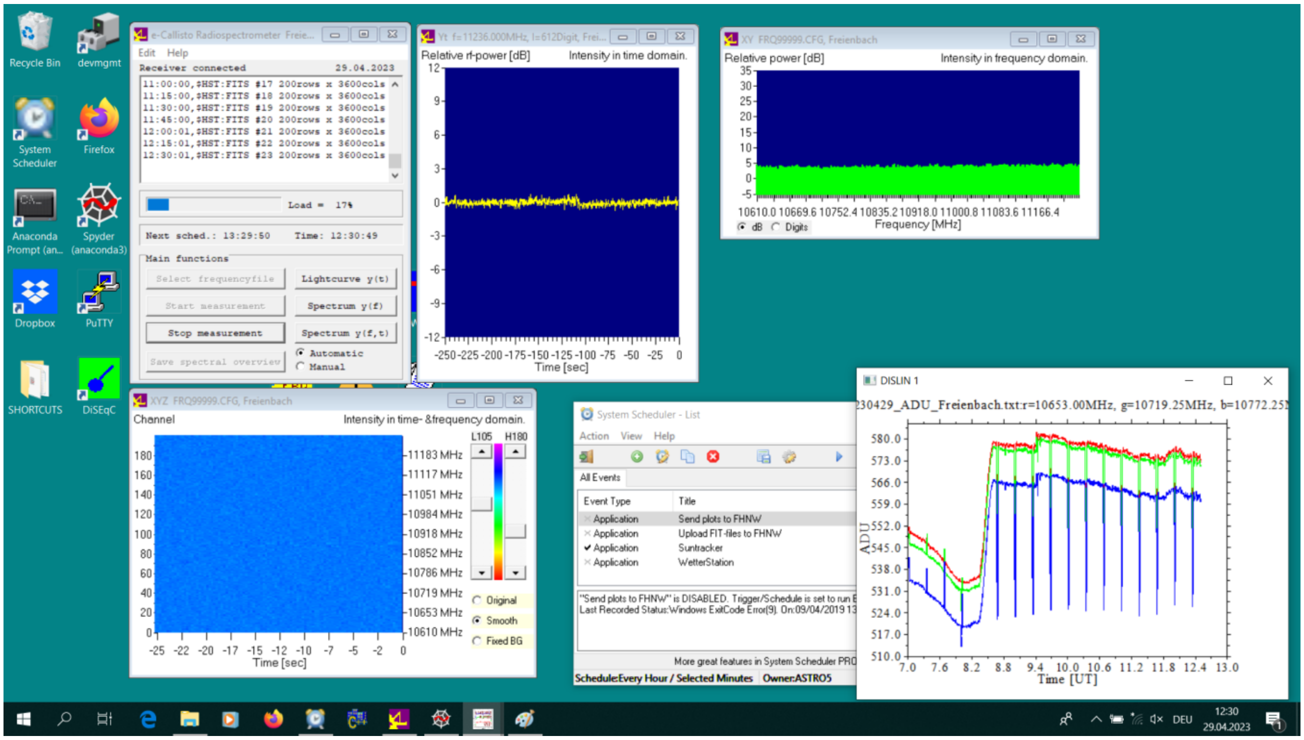
Figure 5 ~ Y-factor calculated from observations shown in figure 4. Y = Hot – Cold, expressed in dB.

Negative peaks which were manually introduced by moving the telescope to a fixed position on the sky at azimuth 180° and elevation 45° which is indicated to as Sky or cold sky or background describe the instrument baseline.

Callisto spectrometer does not only provide FIT-files, in parallel there is also a so-called light-curve file written onto disc with reduced time resolution but improved sensitivity. Improved sensitivity is given by a longer integration time of 20 ms which reduces noise. This type of plot as shown in figure 7 is meant to be sent to a website for real-time monitoring of the observation and the instrument itself.

## 3. Control system

The control system is based on a standard notebook currently running under Windows 8 but, applications also do their job under Win 10 and Win 11 as well. One application to control both rotors is written in Python and is executed once every minute, triggered by system scheduler ssfree.exe, For experimenting the script is executed in Anaconda and Spyder. Connection to the DiSEqC-interface is done via USB-cable. The second application is called Callisto.exe and control CALLISTO spectrometer and stores data as FIT-files on local disc. This application is written in C++ and works under all available windows operating system 95, 98, XP, 2000, Vista, 8, 10 and 11. In addition, a so-called light curve is also saved on the same or any mounted drive system, see figure 8 below. Worth to be mentioned is the requirement that he computer provides precise date and time for tracking system. Beam size of the antenna (FWHM) is in the order of 3° so any error in longitude, latitude or time will make it impossible to track the sun over several hours.



```
Receiver connected                     29.04.2023
11:00:00,$HST:FITS #17 200rows x 3600cols
11:15:00,$HST:FITS #18 200rows x 3600cols
11:30:00,$HST:FITS #19 200rows x 3600cols
11:45:00,$HST:FITS #20 200rows x 3600cols
12:00:01,$HST:FITS #21 200rows x 3600cols
12:15:01,$HST:FITS #22 200rows x 3600cols
12:30:01,$HST:FITS #23 200rows x 3600cols
Load = 17%
Next sched.: 13:29:50     Time: 12:30:49
```

● Automatic
○ Manual

● dB ○ Digits

○ Original
● Smooth
○ Fixed BG

| Event Type | Title |
|---|---|
| ✗ Application | Send plots to FHNW |
| ✗ Application | Upload FIT-files to FHNW |
| ✓ Application | Suntracker |
| ✗ Application | WetterStation |

"Send plots to FHNW" is DISABLED. Trigger/Schedule is set to run E
Last Recorded Status:Windows ExitCode Error(9). On:09/04/2019 13

Schedule:Every Hour / Selected Minutes Owner:ASTRO5

12:30
29.04.2023

Figure 6 ~ Screen photo from Windows notebook depicting spectrometer- and drive control software.

Figure 7 ~ DiSEqC control unit. Left: backside with F-connector for two satellite rotors and USB-connector. Right image: Front panel with LED and power switch.

## 4. Conclusions

The current setup has demonstrated that one can build a cheap small radio telescope to observe electromagnetic radiation in X-/Ku-band. Given the observed Y-factor of about 4…5 dB should be fine to demonstrate a drop to be observed in signal intensity by a solar eclipse which allows to 'observe' the eclipse even during heavy rain, clouds or smoke in the air.

There are several constrains which have to be considered. First of all, satellite rotors as used in this present system allow only angular deviation of +/-77°, some only +/-68° which reduces observation time unless the telescope is re-aligned after a few hours of observation. On the other hand, this solution, based on satellite rotos is quite cheap, compared to a professional tracking system. Not to neglect is the fact that all axis must be aligned very precisely. Firstly, the ground must be completely flat and horizontal, the azimuth axis must be perfectly vertical and the elevation axis must be perfectly horizontal again. And most challenging is the positioning/mounting of the offset dish with its unknow offset angle, usually in the order of 22° … 25°. The only solution I found was using a torch hanging vertically on a string above the center of the telescope. The radiation falls then onto 5 mirrors glued onto the satellite dish, reflecting the light towards the LNB, see figure 10. Later, when the telescope is used to observe the sun these mirrors allow to visually check if the light is still centered on the plastic cover of the LNB. If this not the case then at least on of the axis (azimuth, elevation of offset) is out of order and requires re-adjusting. A rough adjusting can be performed visually while fine-adjust is best done by observing the light curve on the computer monitor at the highest frequency. Highest frequency is most sensitive to any mis-alignment. It was found out that tracking period must be at least once per minute, otherwise light-curves show a saw-tooth like structure. Ideal would be a tacking system which permanently tracks the sun but, this a cost-factor of 2…3 above the satellite rotor version which provides an angular resolution of 1/16°.

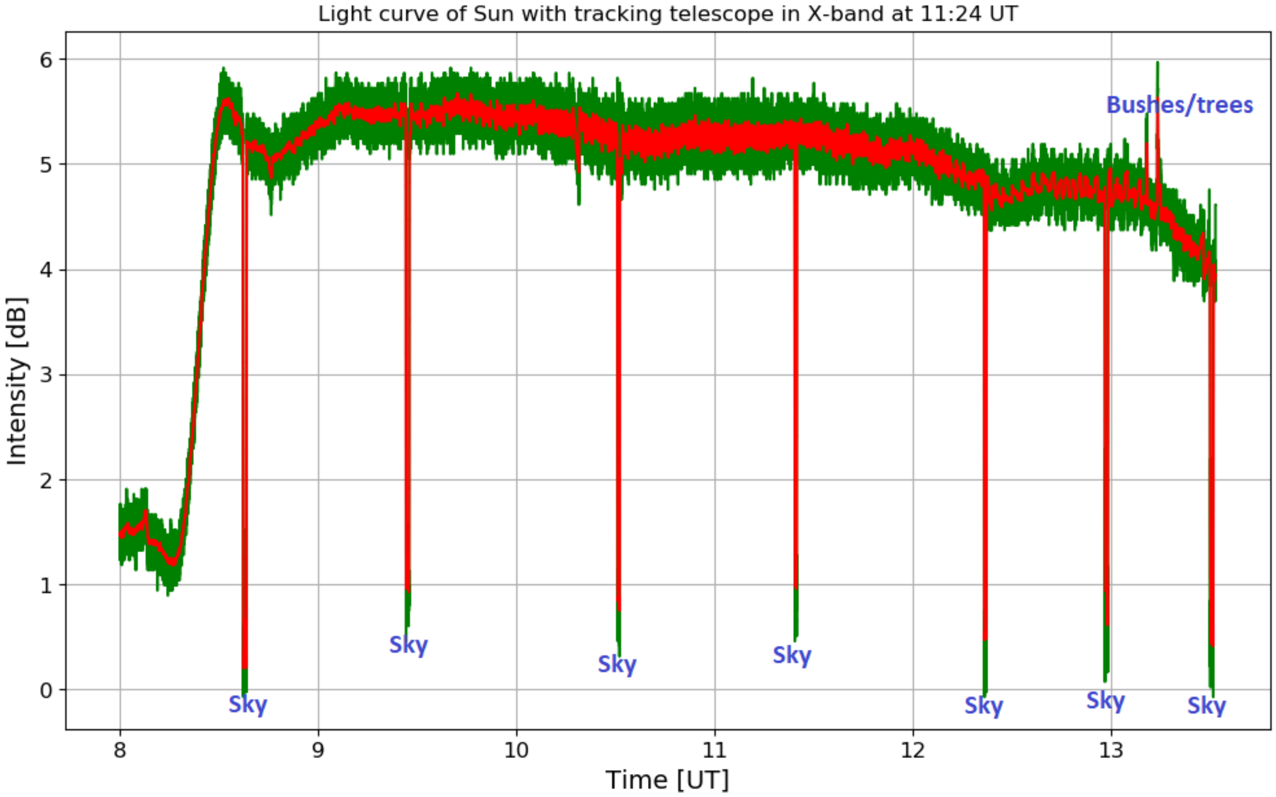


Figure 8 ~ Extracted light curve from FIT-file at around 11 GHz. Green plot shows observed and averaged (over 8 frequency channels) data converted into dB while the red plot is a Gaussian filtered version of the same trace.

Not to forget minimum precision requirements in geographic coordinates as well as date and time. To allow perfect alignment and positioning longitude and latitude must be more precise than +/-0.02° and timing error of the computer must be smaller than +/-5 seconds (UT-time). The current Python tracking script also requires current air-pressure and temperature to compensate refraction when the source (sun) is at low elevation. During observation one should also take care about thermal heat of LNB and spectrometer. It is recommended, that at least the spectrometer is on a place without direct sunlight. If one can reduce heating of the LNB this would also help to keep the baseline and instrument gain more constant.

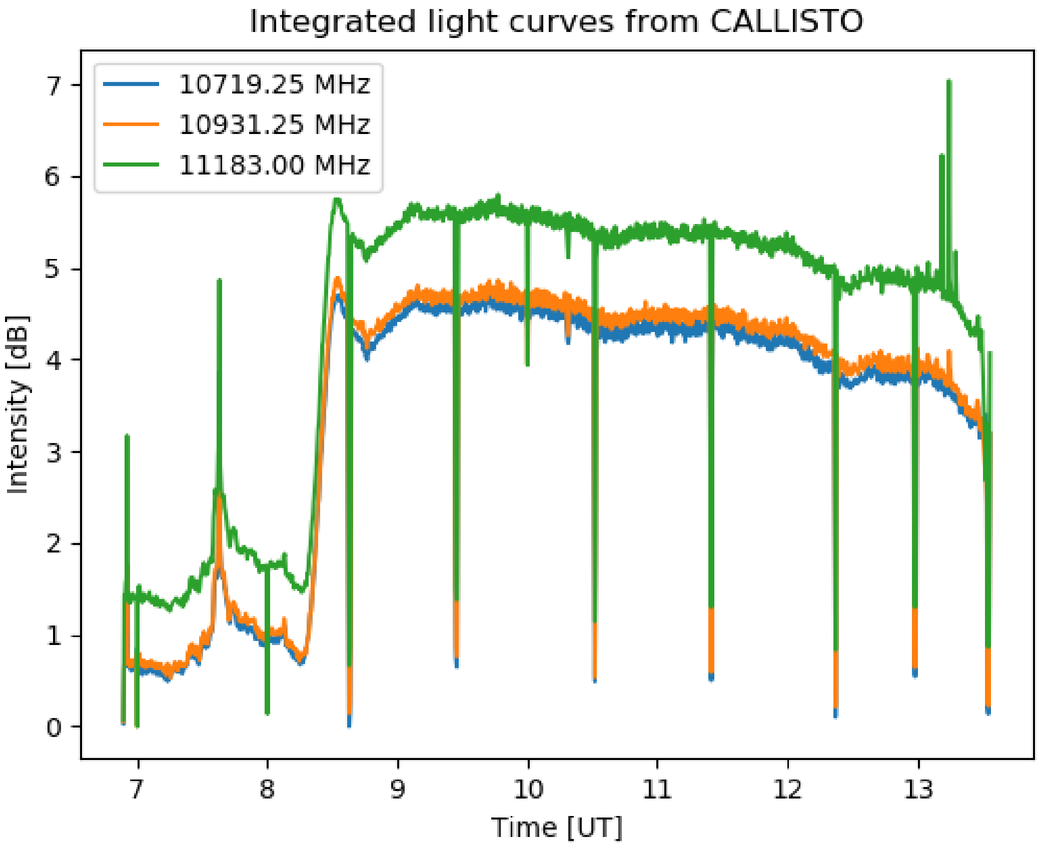


Figure 9 ~ Extracted light curves (here at 3 frequencies) from the light-curve text-file with larger integration time. Negative peaks again show the background at a fixed sky-position. Positive peak around 13:20 UT is given when the telescope points to the geostationary path of TV-satellites while tracking the sun.

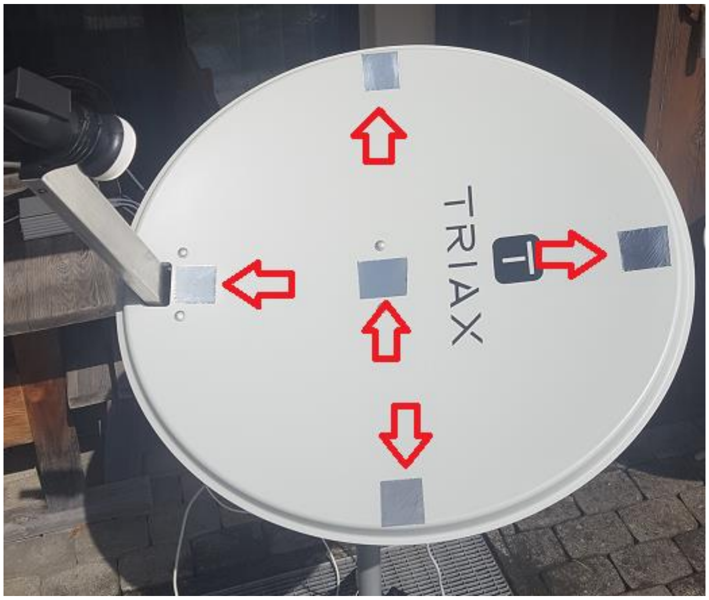


Figure 10 ~ Satellite dish with 5 glued aluminum mirrors (red arrows) which shall reflect vertically light from above onto the cover of the LNB. This alignment of course needs to be performed in the night or in a room without additional light source. It was found out that the best source was a torch with blue LEDs, offered as ultraviolet torch on Amazon. But their blue part is good enough to adjust the offset of the dish.

## 3. References

[TechniSat ] https://www.technisat.com/de_CH/WIDEBAND-LNB/352-2751-11567/?article=0007/8840
[Callisto] https://e-callisto.org/index.html
[DiSEqC] http://www.e-callisto.org/Hardware/Diseqc/Doku%20Diseq_V07.pdf
[Triax] https://triax.com/shop/en_nord/catalog/category/view/s/satellite-dishes/id/3342/
[Y-factor] https://deepai.org/machine-learning-glossary-and-terms/y-factor

Christian Monstein is a native of Switzerland and lives in Freienbach. He obtained Electronics Engineer at Konstanz University, Germany in 1978. Christian is a SARA member and is licensed as amateur radio operator, HB9SCT. He has 20 years of experience designing test systems in the telecommunications industry and is proficient in several programming languages including C++, IDL and PYTHON. He has worked at ETH-Zürich on the design of frequency agile radio spectrometers, FFT-spectrometers, radio receivers and noise calibration transmitters as payload on a drone. He also has participated in the European Space Agency (ESA) space telescope Herschel (HIFI), European Southern Observatory (ESO) project MUSE for the VLT in Chile. Recently, he was involved in the radio astronomy project 'BINGO' in Uruguay / Brazil and in 'HIRAX' in South Africa. He is still responsible (PI) for the hardware and software associated with the e-CALLISTO Project. He plays also the role of a coordinator of SetiLeague in Switzerland and he was representing Switzerland within Committee on Radio Astronomy Frequencies (CRAF). He is a member of the ISWI steering committee at UN Office for Outer Space Affairs in Vienna (UNOOSA) and has been nominated as a member of ITU. He is also a member of Scientific Committee on Solar-Terrestrial Physics (SCOSTEP) as well as a member of Committee on Space Research (COSPAR).