Nr: lzp-2020/2-0121

VARIABILITY OF RADIO GALAXY PERSEUS-A (3C 84), ACCORDING TO DATA OF OBSERVATIONS WITH RT-32 RADIO TELESCOPES IN LATVIA AND UKRAINE.

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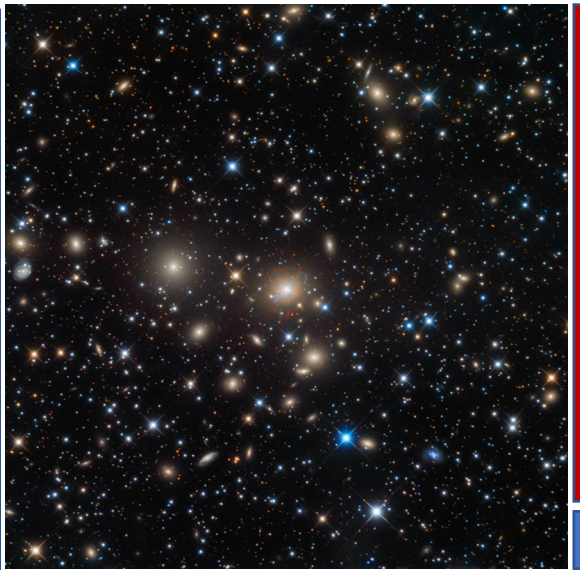
Active galaxy NGC 1275 is the central, dominant galaxy in relatively nearby Perseus cluster of galaxies (Abell 426). NGC 1275 is amazingly powerful source of X-rays and radio emissions. Entire galaxy falls into it, and NGC 1275 engulfs that galaxy's material, that feeding supermassive black hole in its core. It is possible that there is second black hole-satellite in the core, which ensures the precession of source radio-jets (long-term quasi-sinusoidal variability). Filaments of glowing gas, some reaching 20,000 light years in length. Structures ejected from the center of galaxy as result of black hole's activity are supported by magnetic field. The galaxy NGC 1275, also known as the radio source 3C 84 (Perseus A), is over 100,000 light-years across and about 230 million light-years away.

NGC 1275 (credit by NASA, ESA, Hubble ST team)

In November, scientific project, with participation of Ukraine, was won at a competition in Latvia, and funding was received on the topic “Joint Latvian-Ukrainian study of peculiar radio galaxy “Perseus A” in radio and optical bands”.

Observations have begun on radio telescopes RT-32 Zolochiv (Ukraine), and 32-m, 16-m VIRAC (Latvia) as well as with optical telescopes of the observatories Mayaki (Ukraine), Baldone (Latvia), Vihorlat (Slovakia). The first test results have been obtained and work is underway to improve further measurements. Optical B-V-R-I observations showed the presence of day-to-day variability and often noise-like variations during individual nights, also there is low-amplitude microvariability at intra-night timescales.

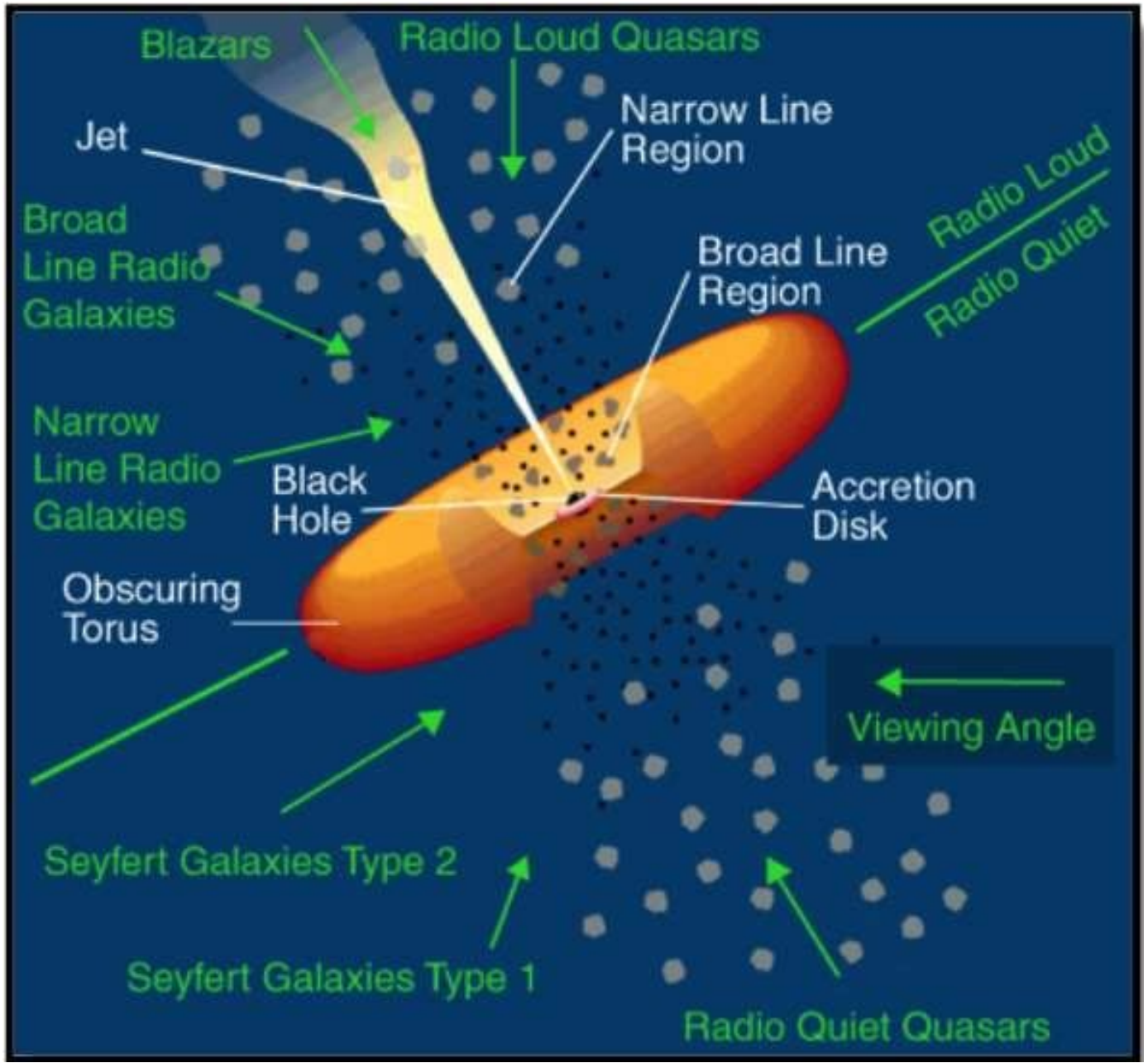


3C 84 is very massive galaxy in a Perseus cluster of many galaxies, in a state of gravitational interaction with its neighbors. Potential candidate for a binary black hole system in the galactic core. 3C 84 has a precession motion of relativistic jets.

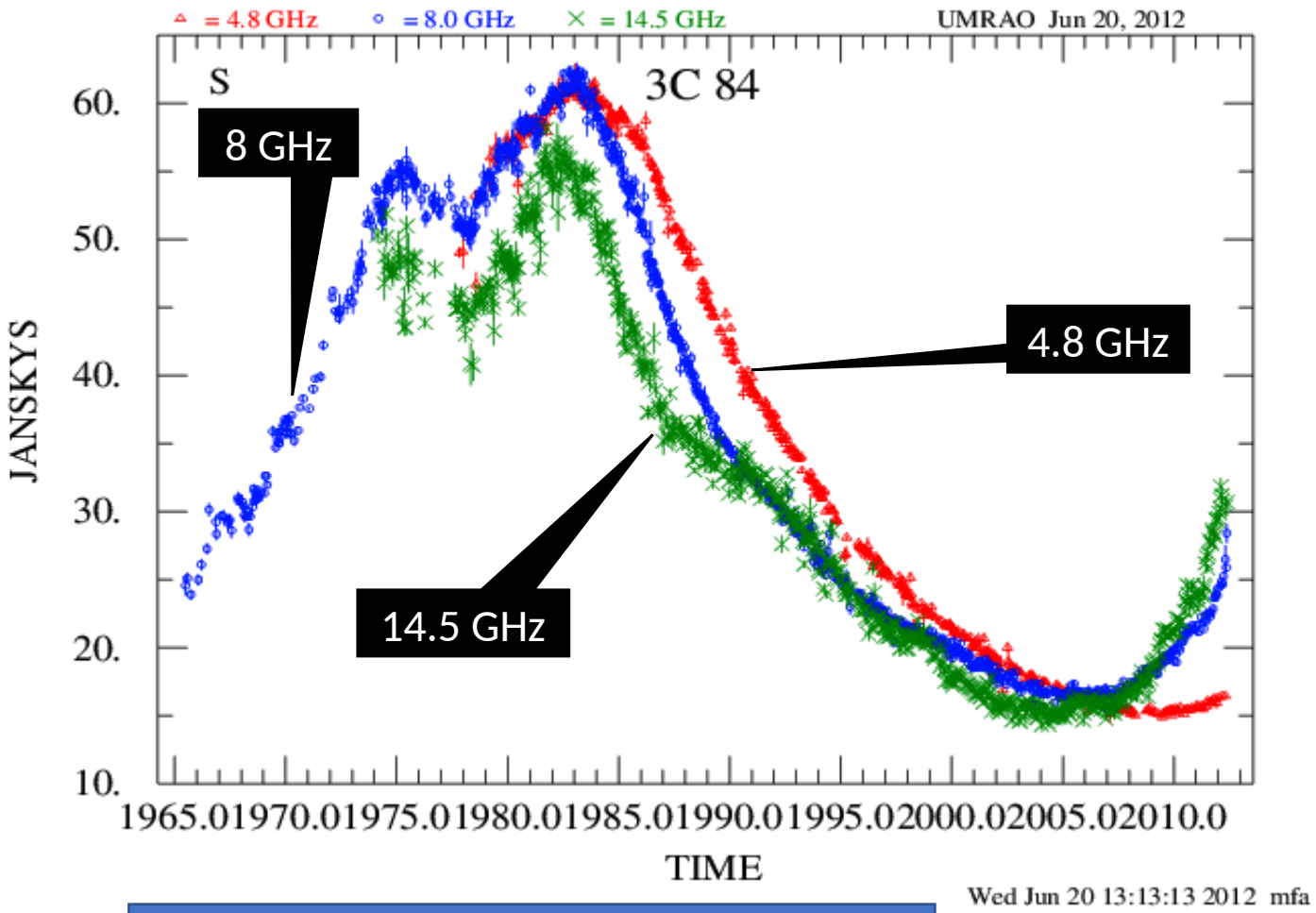
Credit: Leonardo Orazi

Universal Model of the Radio Galaxy

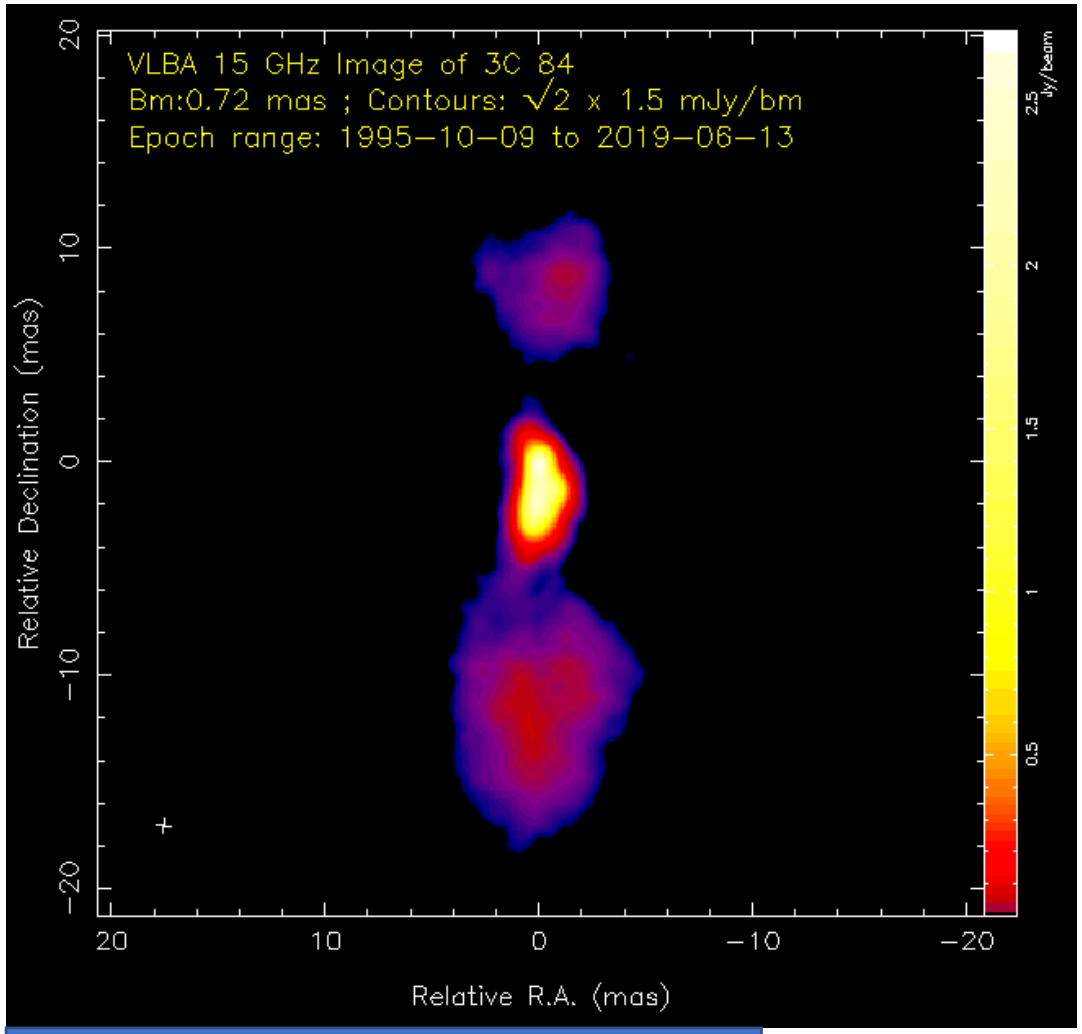
FR-I



FR-II



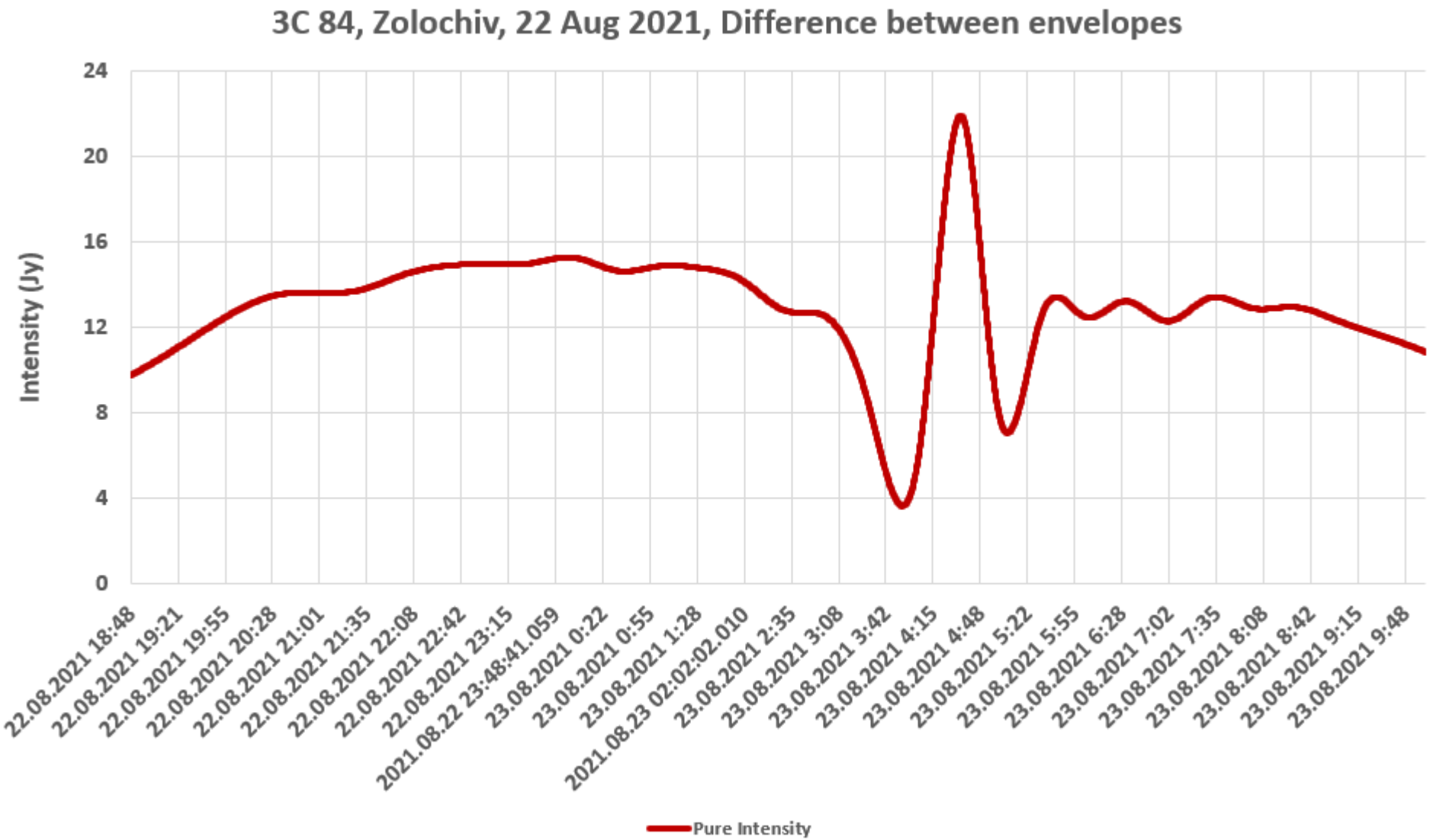
Margo F. Aller et al. 2012, UMRAO team

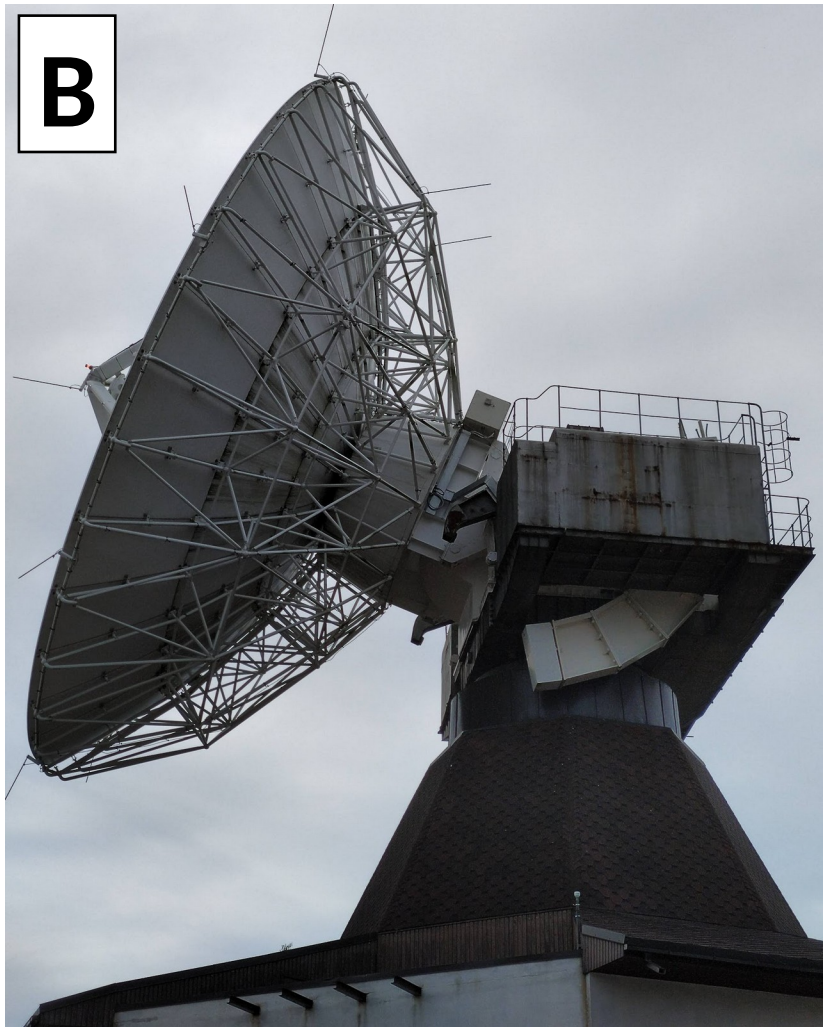


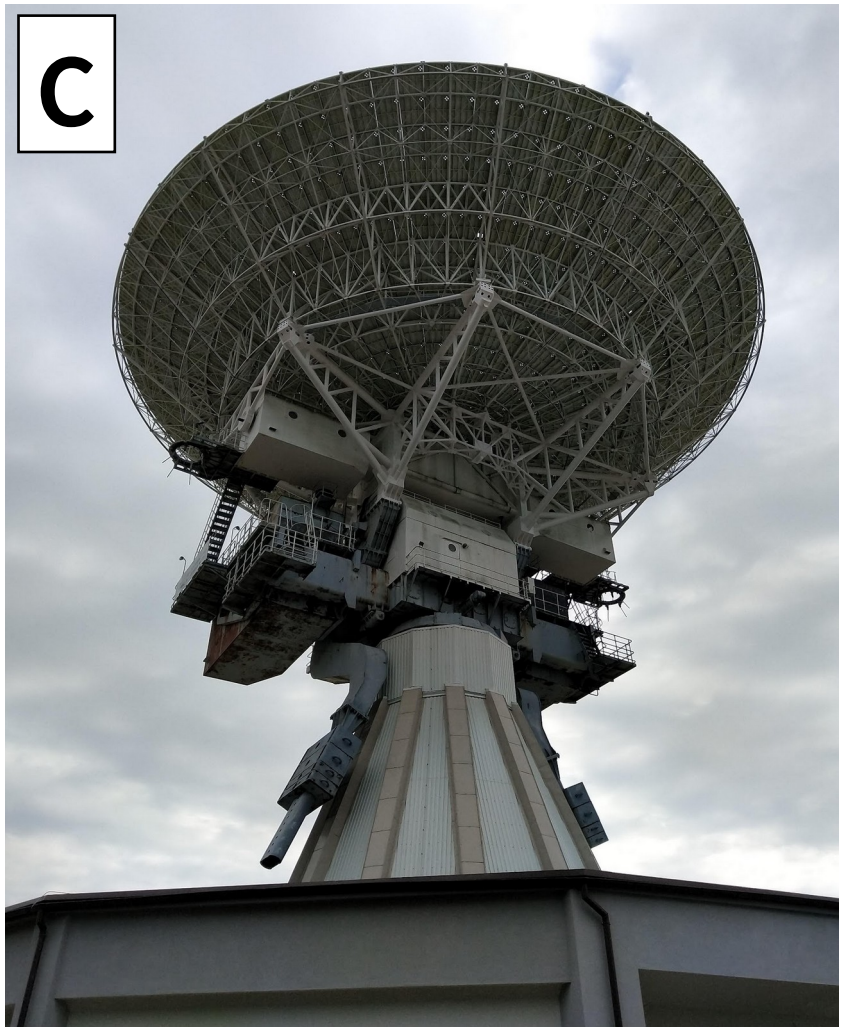
Lister et al. 2018, MOJAVE team

Galaxy 3C 84 (Perseus A) is located in large cluster of galaxies, which gives it special properties. Long-term light curve in radio range has a wave-like appearance (taking into account data to 2019, it is probably a two-peaked form). This is similar to presence of jets precession in radio galaxy (with periods, according to various estimates, from 40 to 90 years). Since the galaxy has fragments from past interactions with another galaxy, there may be a double black hole in active nucleus of 3C 84.

Flux Density of the 3C 84 at 6.6480 GHz

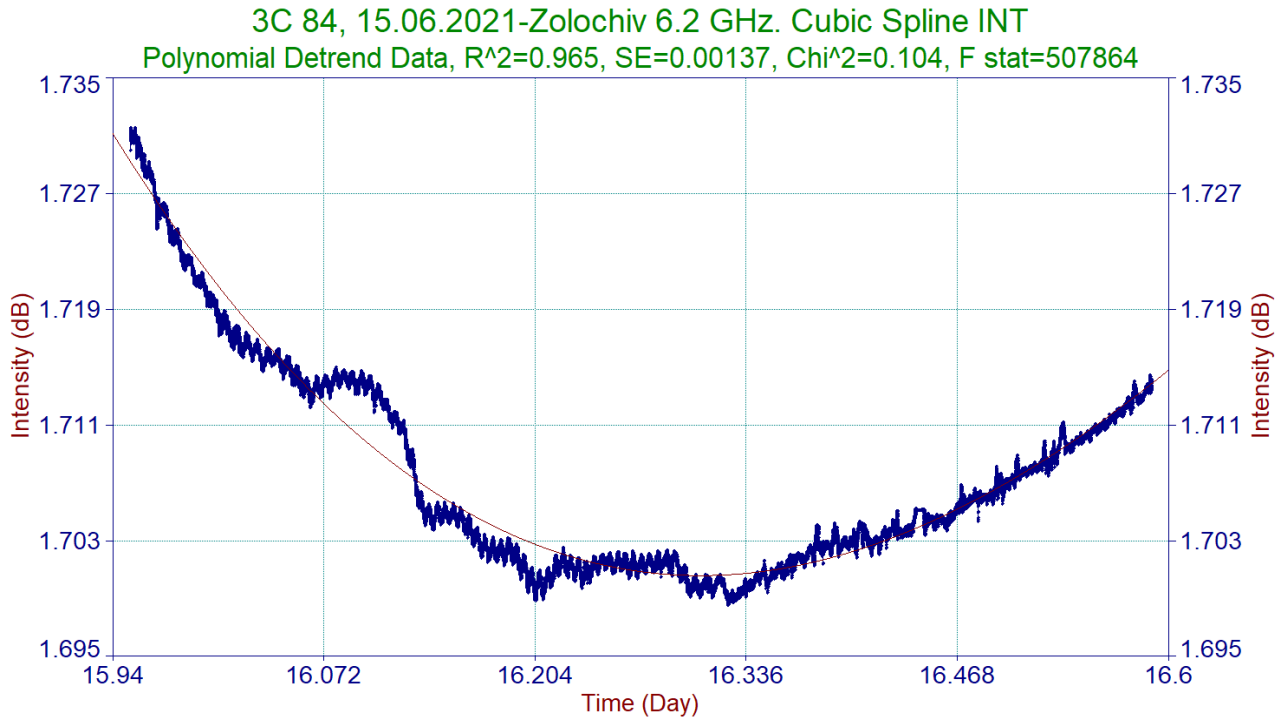


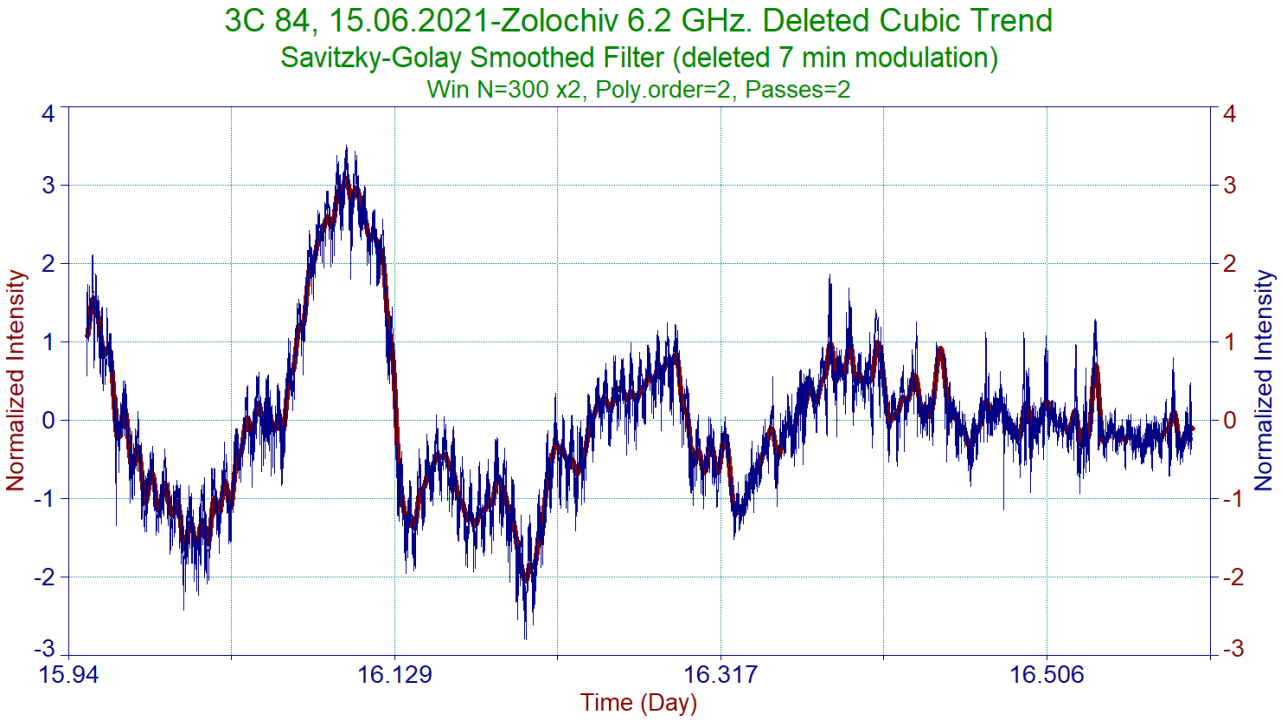




A) – 32-m antenna of National Space Facilities Control and Test Center, Ukraine
B) – 16-m antenna of Ventspils International Radio Astronomy Center, Latvia
C) – 32-m antenna of Ventspils International Radio Astronomy Center, Latvia

Ukrainian antenna operates at frequencies 4.7-6.8 GHz and 20-25 GHz, and equipped with cryogenic receivers (these able to work in “warm” mode) and spectrum analyzer, can conduct observations simultaneously at two frequencies in two circular polarizations. Latvian antennas operate at 5, 6.1, 6.7, 8.7 GHz, are equipped with cryogenic receivers and spectrum analyzers, additionally there is 1.6 GHz uncooled (warm) receiver. Latvian antennas are in the EVN system (European VLBI Network).

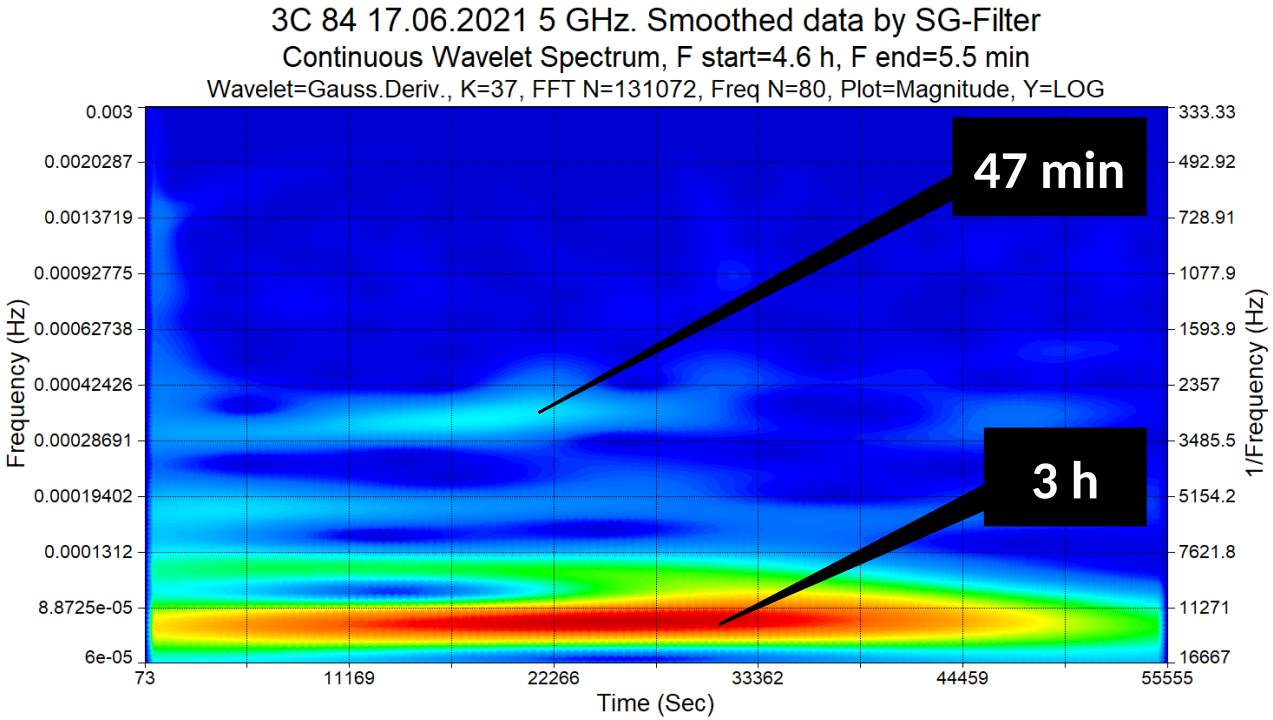


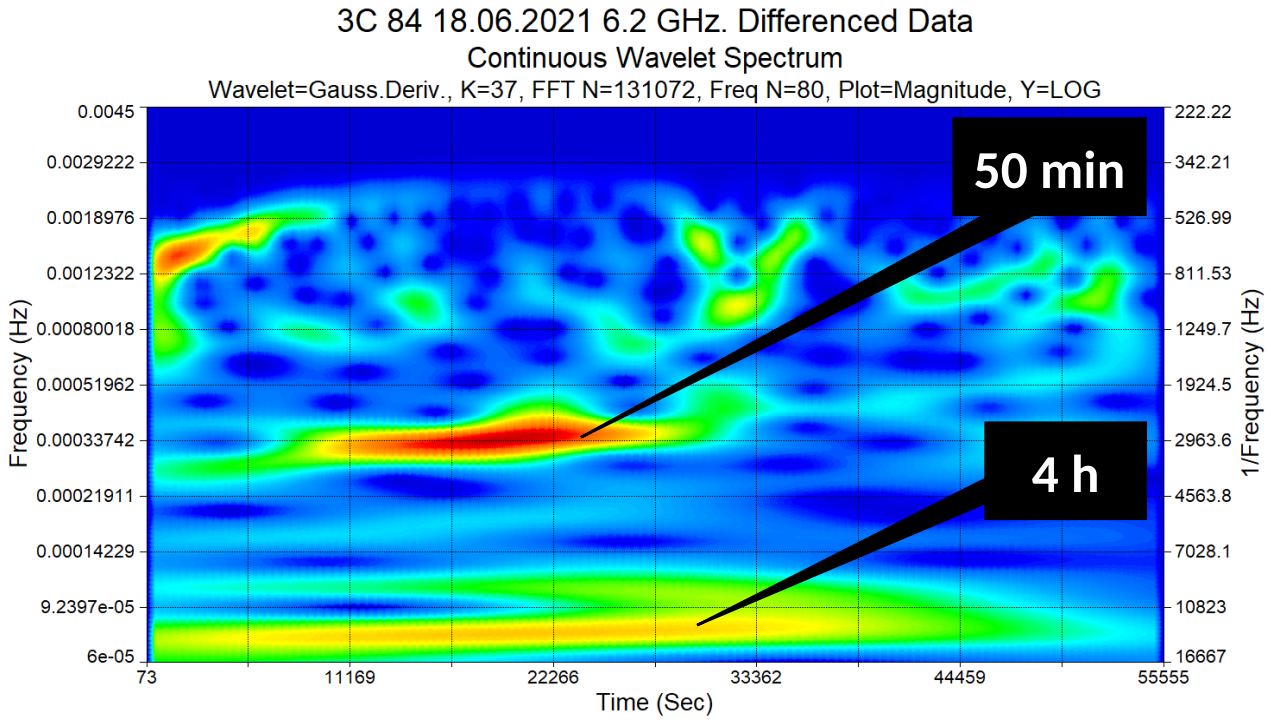


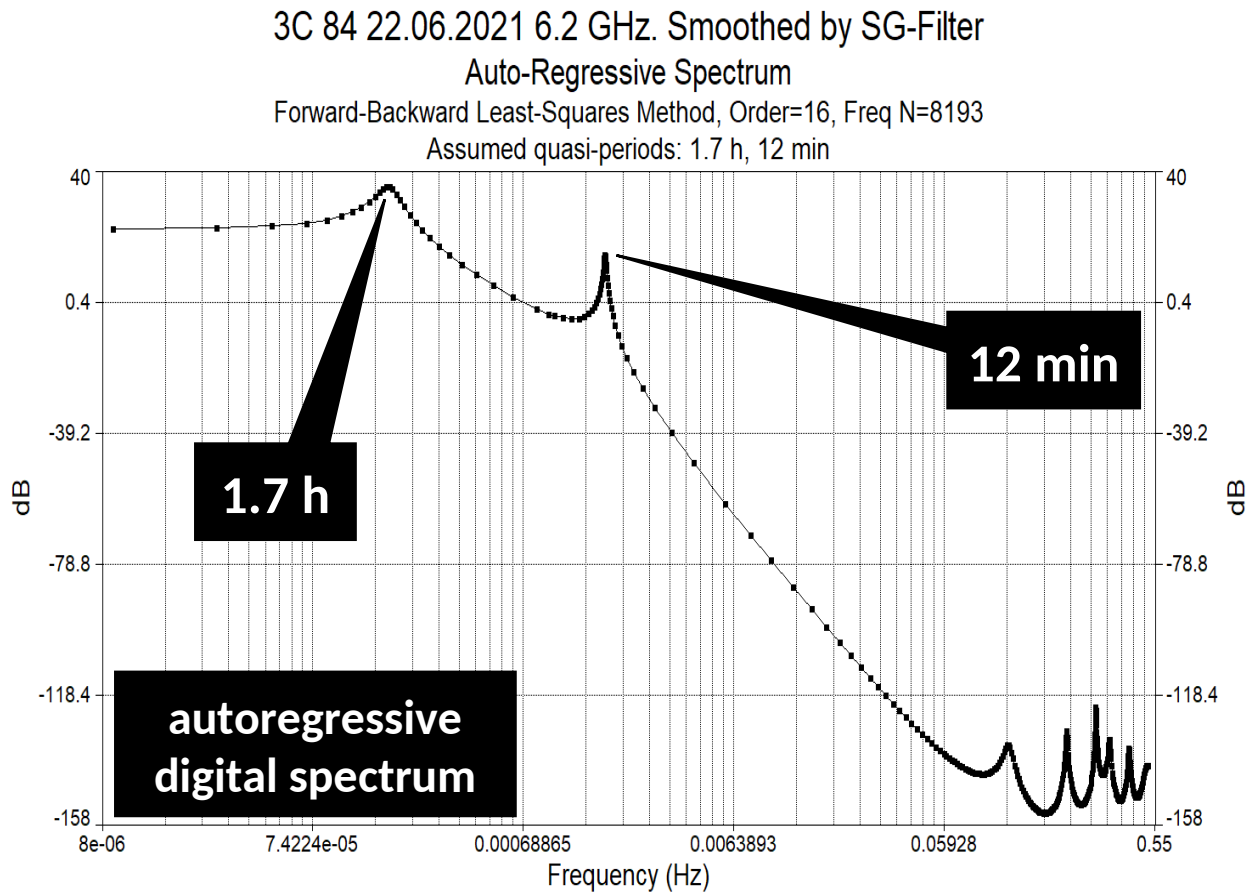
For almost all data from the Zolochev antenna, the dependence, radio-flux vs antenna elevation, is described with high accuracy by a 3-degree polynomial. In the next, this polynomial is subtracted and radio-data is aligned.

Further, the observational data are interpolated by cubic spline, and smoothed by polynomial filter, to remove RFI noise and artifacts, associated with high-frequency vibration of the Zolochiv's antenna in some of its positions. The data for analysis, typically has sampling rate of 1 Hz (one measurement per second). This makes it possible to very accurately record the light curve during each observation session.

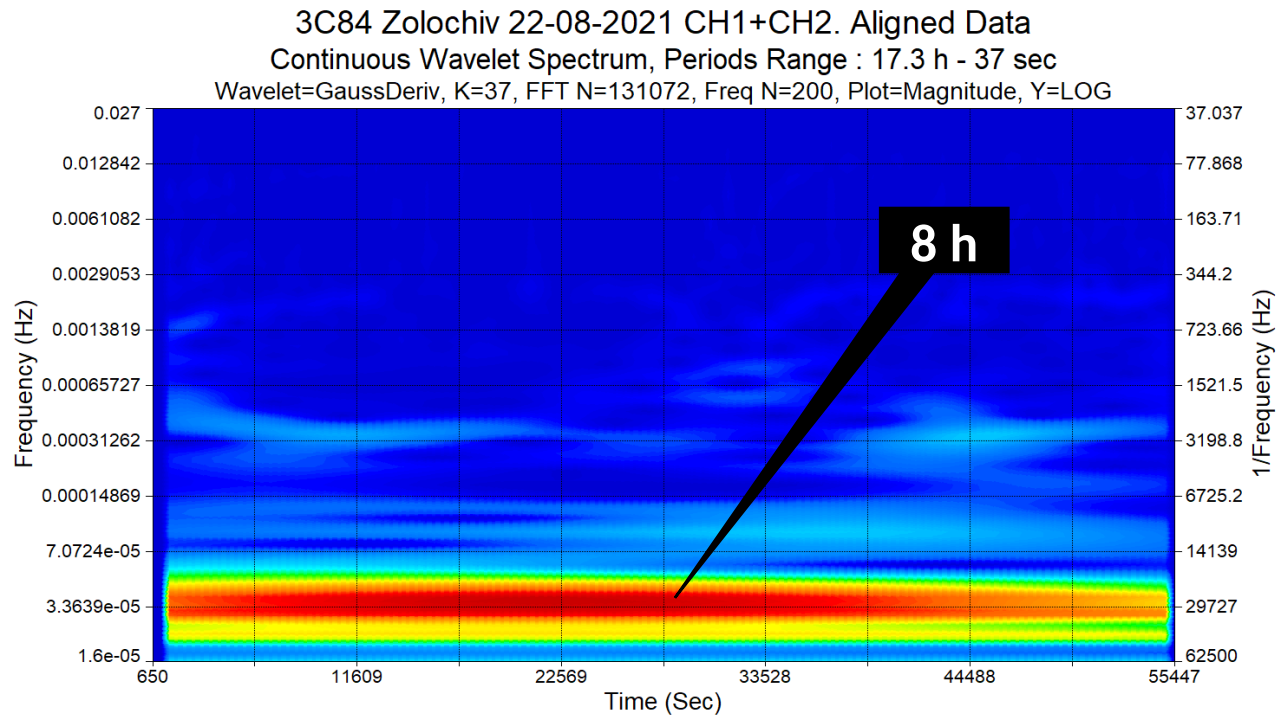
After that, time-frequency spectrograms were built to study distribution of quasi-periods of flux variations over time.

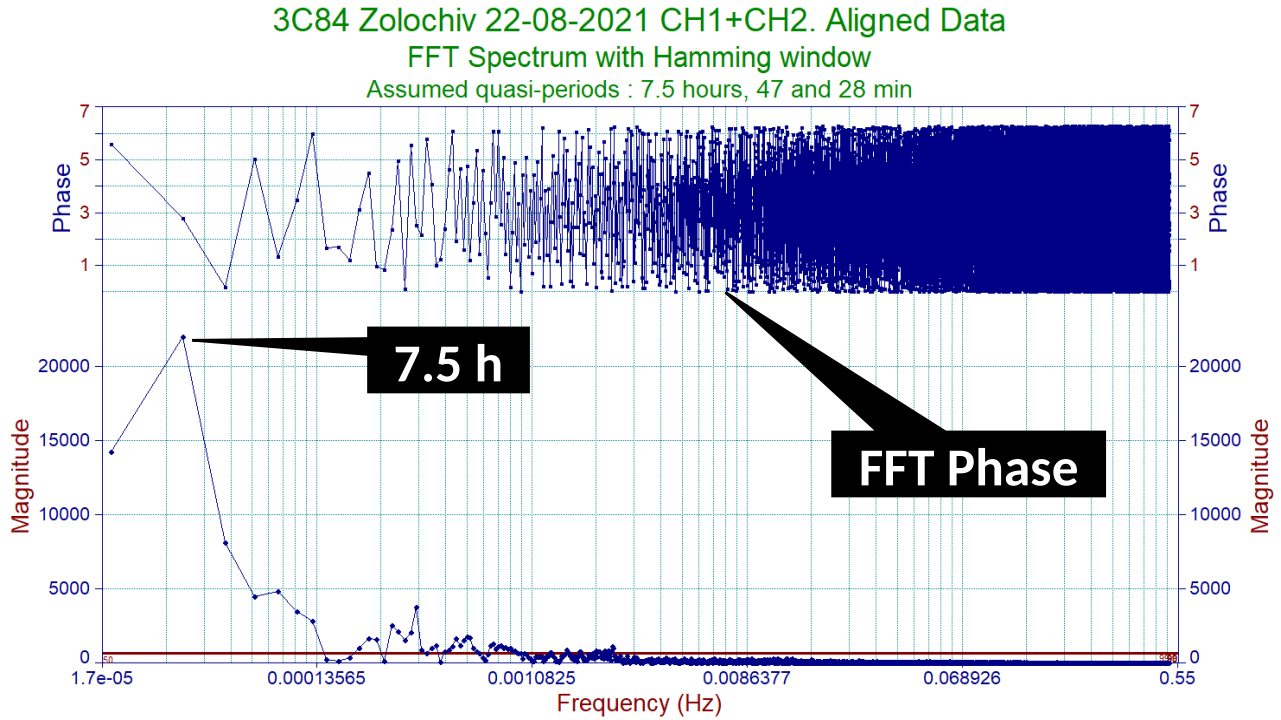


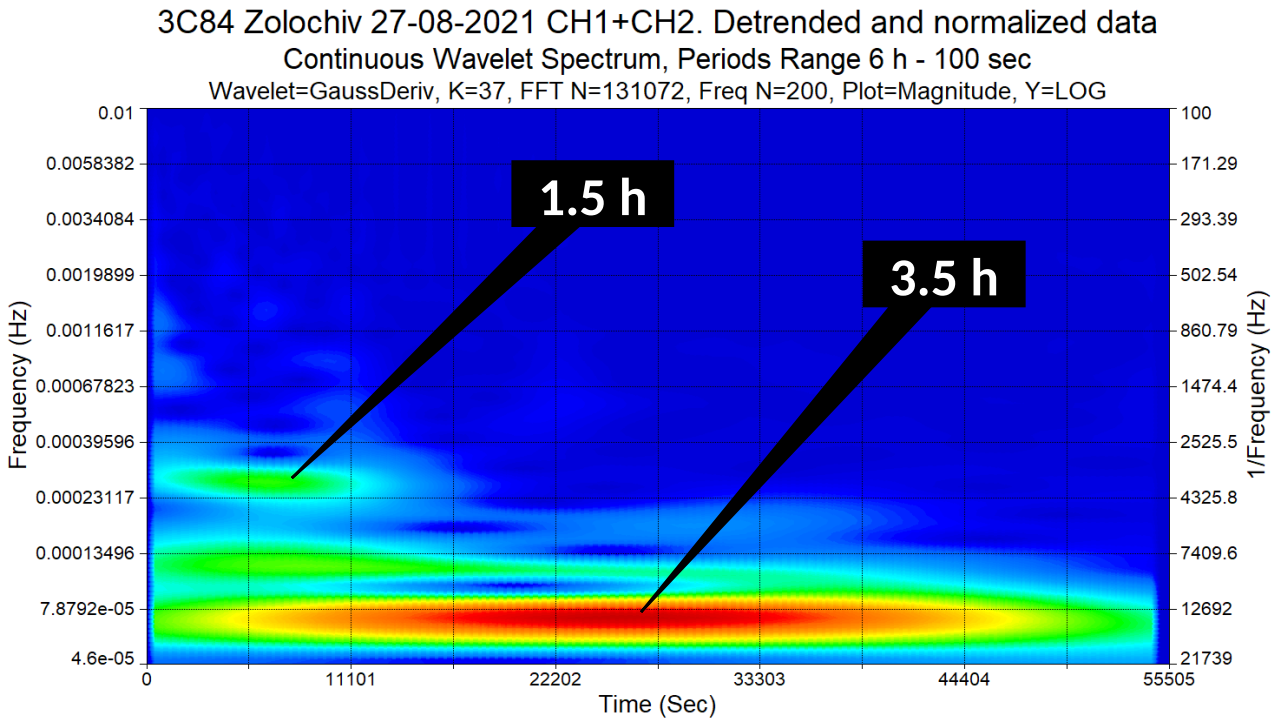


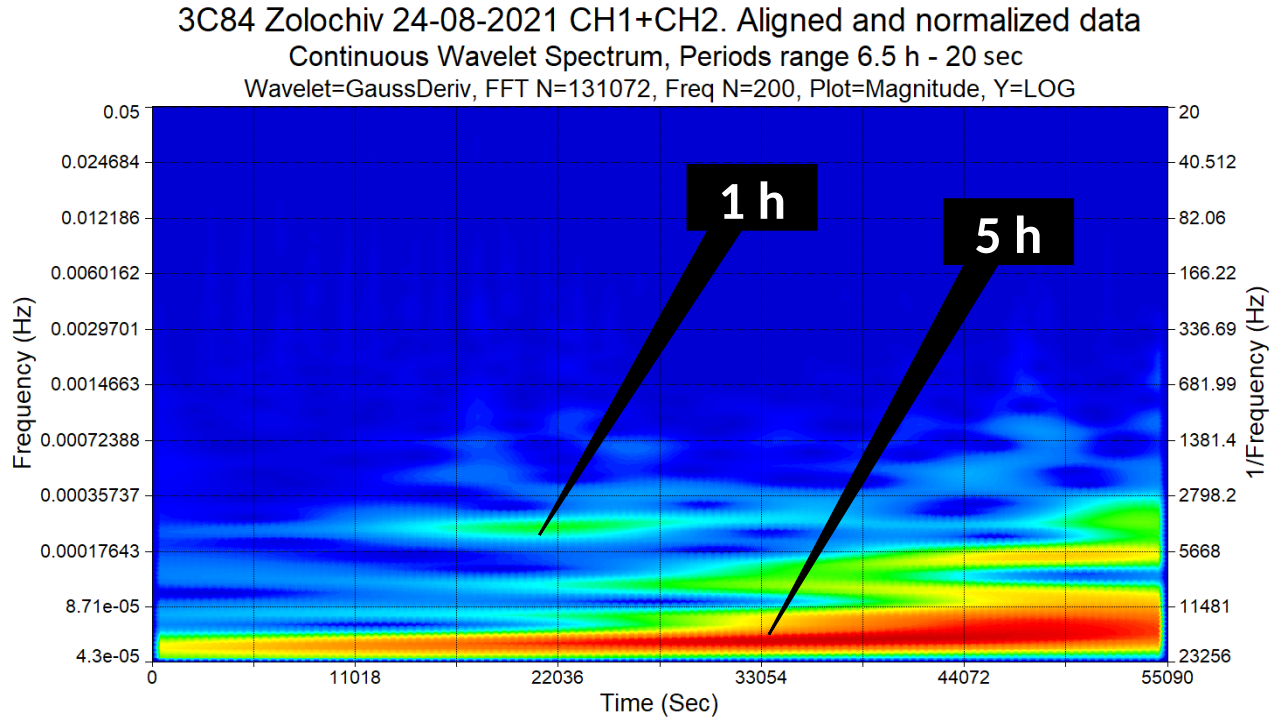


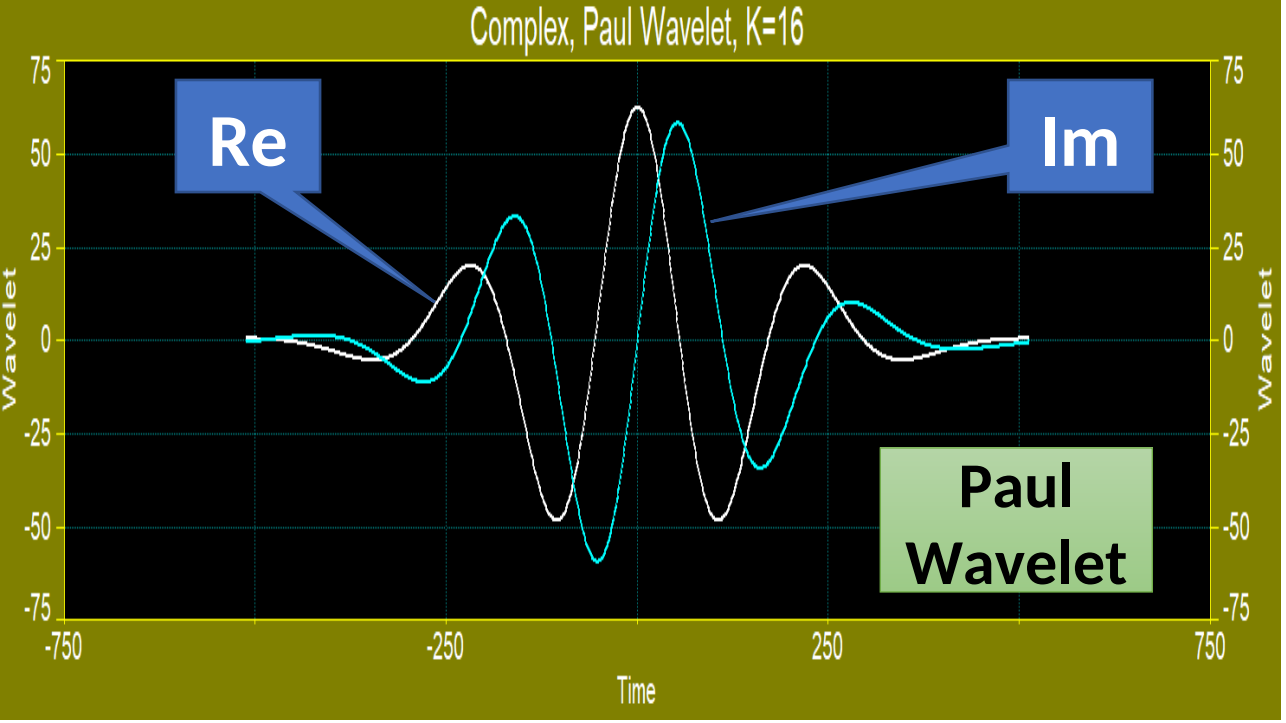
In the radio galaxy 3C 84, variations in non-noise appearance are often observed. Their characteristic times are quite different, so let's highlight the main ones. Most often, there is variation with characteristic time 3 - 4 hours. Variation with quasi-period from 45 to 60 minutes is also clearly visible. This fluctuation is usually limited in time and shorter than typical observation sessions. Less often, variations of 1.5 - 2 hours are observed.


3C84 Zolochiv 22-08-2021 CH1+CH2. Aligned Data
Continuous Wavelet Spectrum, Periods Range : 17.3 h - 37 sec
Wavelet=GaussDeriv, K=37, FFT N=131072, Freq N=200, Plot=Magnitude, Y=LOG
8 h
Frequency (Hz)
1/Frequency (Hz)
Time (Sec)
0.027
0.012842
0.0061082
0.0029053
0.0013819
0.00065727
0.00031262
0.00014869
7.0724e-05
3.3639e-05
1.6e-05
37.037
77.868
163.71
344.2
723.66
1521.5
3198.8
6725.2
14139
29727
62500
650
11609
22569
33528
44488
55447

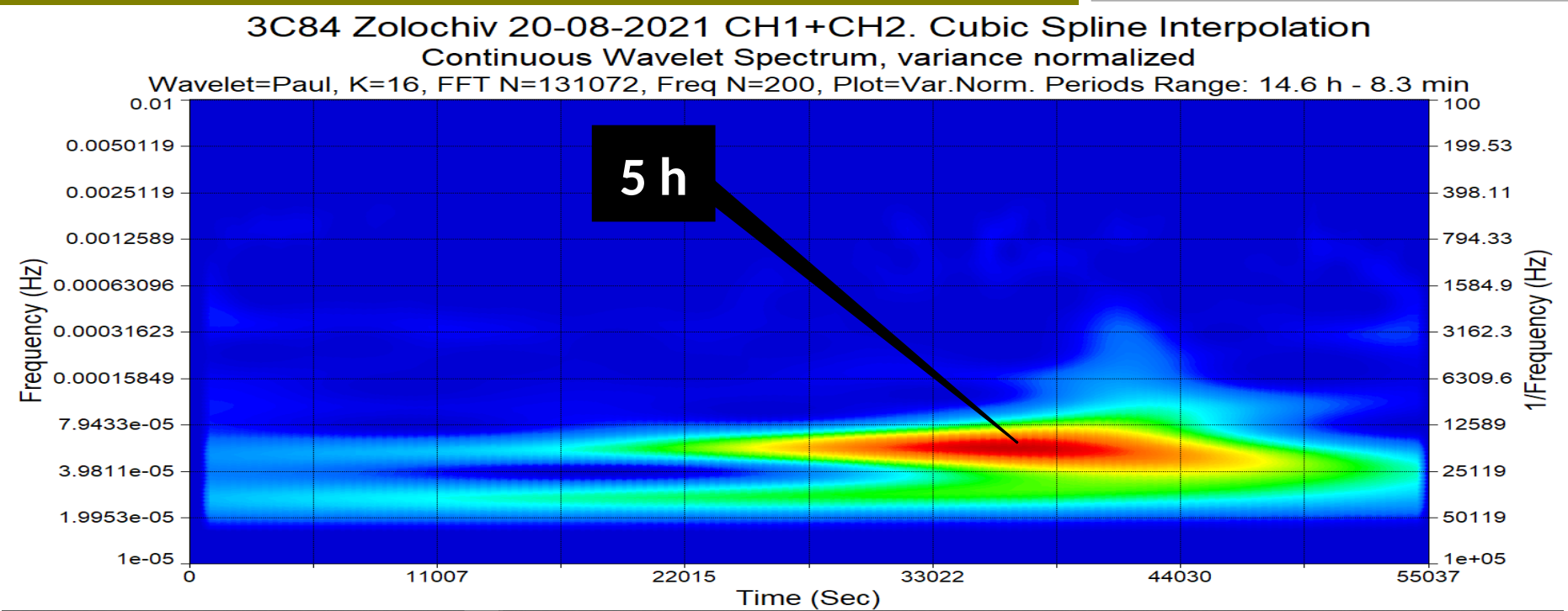

3C84 Zolochiv 22-08-2021 CH1+CH2. Aligned Data
FFT Spectrum with Hamming window
Assumed quasi-periods : 7.5 hours, 47 and 28 min
7.5 h
FFT Phase
Phase
Magnitude
Frequency (Hz)
7
5
3
1
20000
15000
10000
5000
0
1.7e-05
0.00013565
0.0010825
0.0086377
0.068926
0.55


3C84 Zolochiv 27-08-2021 CH1+CH2. Detrended and normalized data
Continuous Wavelet Spectrum, Periods Range 6 h - 100 sec
Wavelet=GaussDeriv, K=37, FFT N=131072, Freq N=200, Plot=Magnitude, Y=LOG
1.5 h
3.5 h
Frequency (Hz)
1/Frequency (Hz)
Time (Sec)
0.01
0.0058382
0.0034084
0.0019899
0.0011617
0.00067823
0.00039596
0.00023117
0.00013496
7.8792e-05
4.6e-05
100
171.29
293.39
502.54
860.79
1474.4
2525.5
4325.8
7409.6
12692
21739
0
11101
22202
33303
44404
55505


3C84 Zolochiv 24-08-2021 CH1+CH2. Aligned and normalized data
Continuous Wavelet Spectrum, Periods range 6.5 h - 20 sec
Wavelet=GaussDeriv, FFT N=131072, Freq N=200, Plot=Magnitude, Y=LOG
1 h
5 h
Frequency (Hz)
1/Frequency (Hz)
Time (Sec)
0.05
0.024684
0.012186
0.0060162
0.0029701
0.0014663
0.00072388
0.00035737
0.00017643
8.71e-05
4.3e-05
20
40.512
82.06
166.22
336.69
681.99
1381.4
2798.2
5668
11481
23256
0
11018
22036
33054
44072
55090

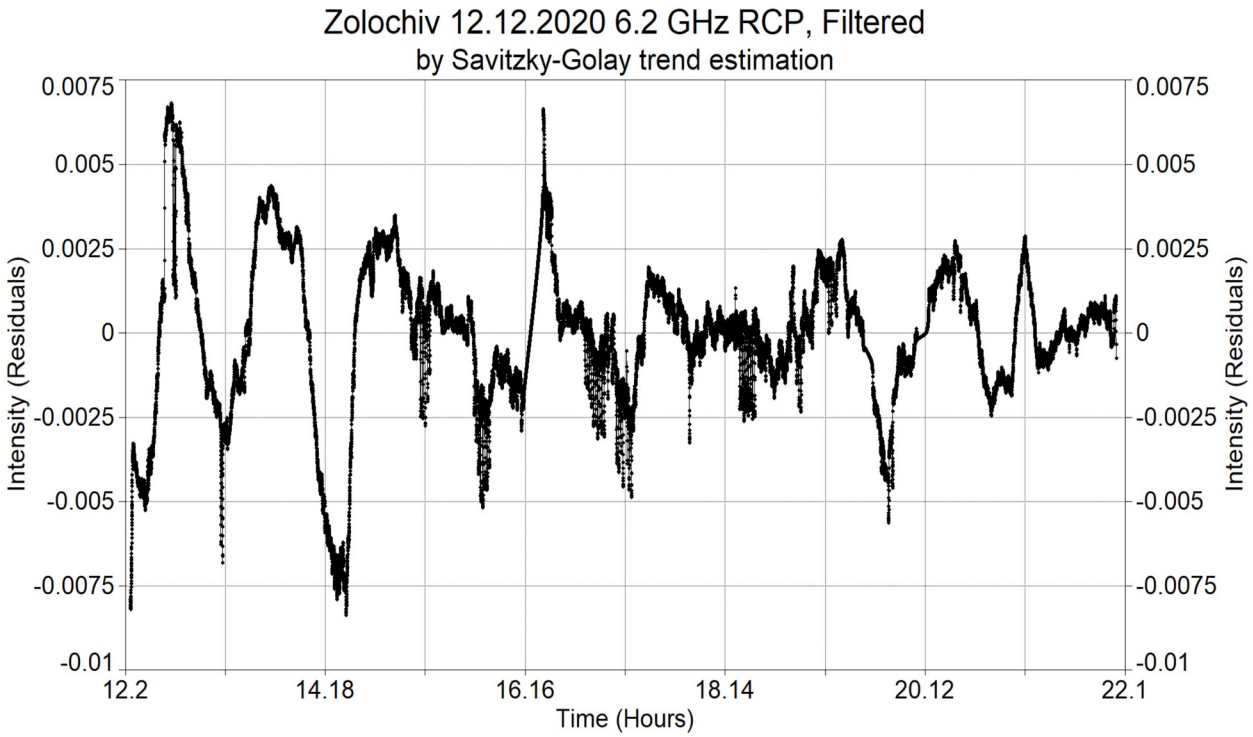


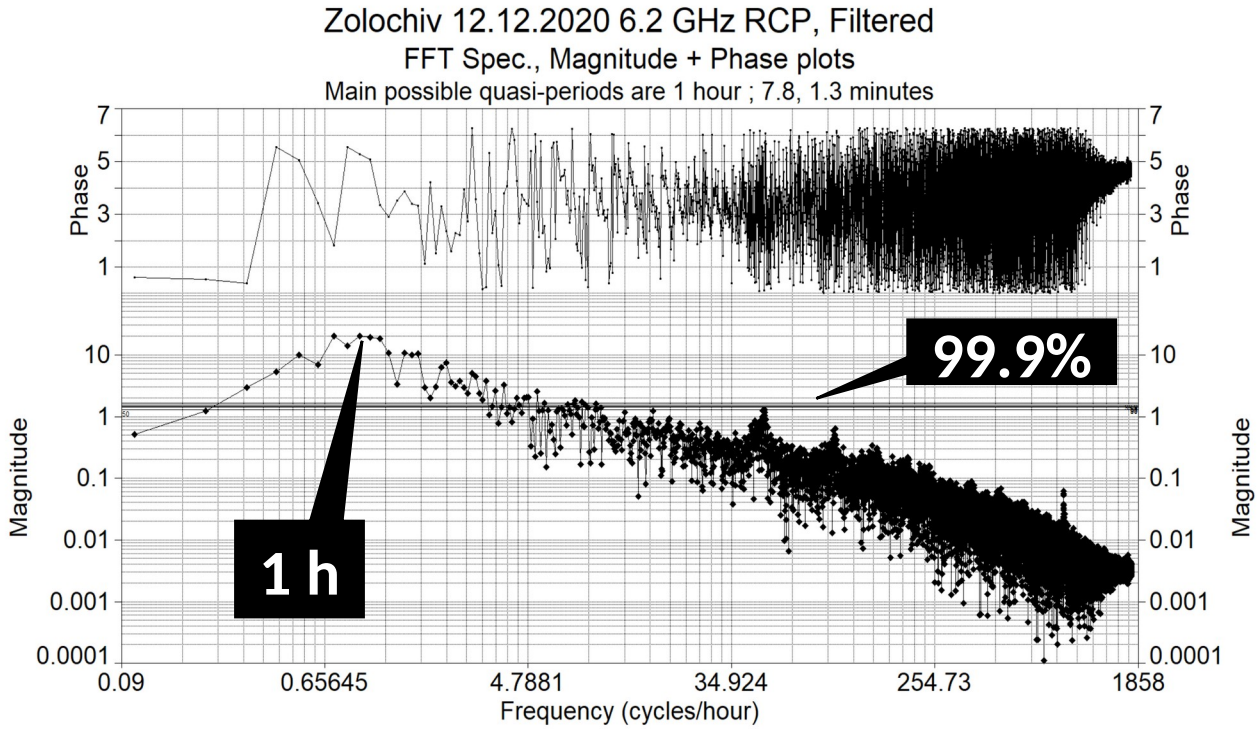
The many-month observations on Zolochiv (Ukraine) and VIRAC (Latvia) telescopes show very close results on presence weak quasiperiodic variations in flux of radio galaxy 3C 84 (Perseus A). Characteristic times of these variations most often are in interval 3 - 5 hours, less often 7 - 8 hours. Multiple observations of calibration radiosources show absence of such flux variations, which confirms result. The next step is to make sure these variations are not close-periodic ionospheric acoustic gravity waves.



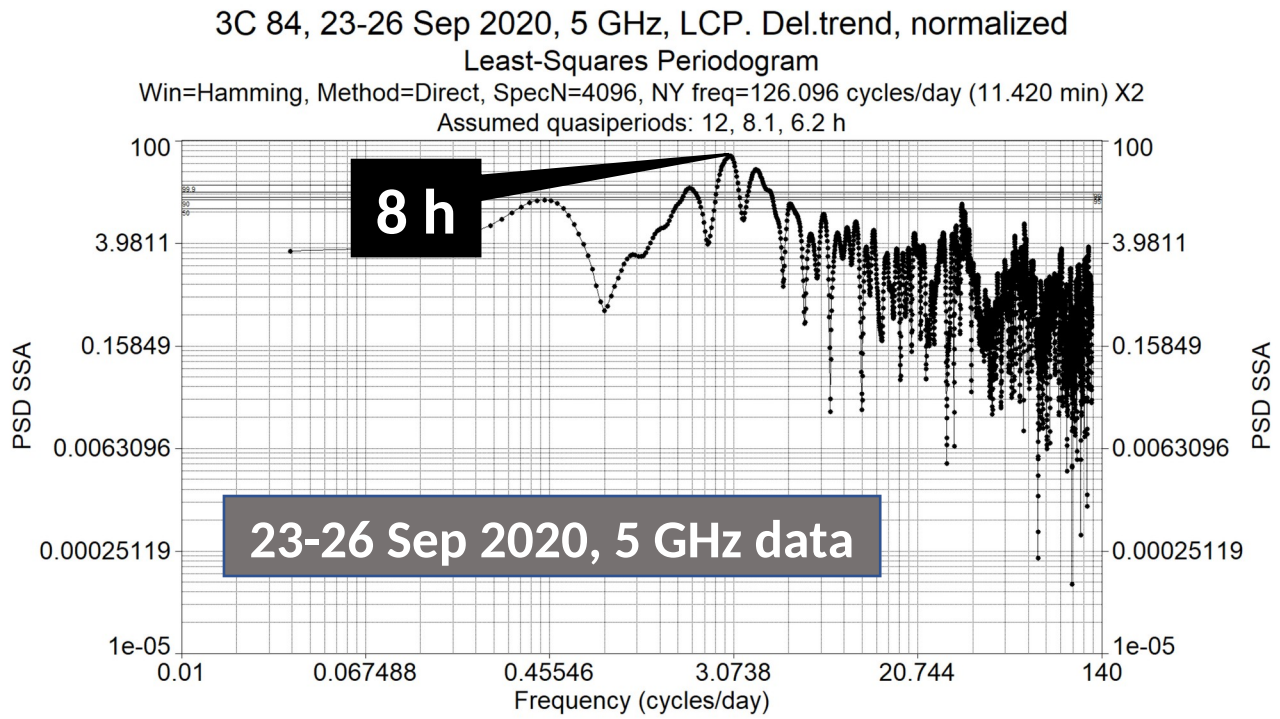
The use Paul wavelet, in some days with interference, that complicates determination of main quasiperiod, allows to more accurately determine localization spectral maximum of quasi-harmonic component of 3C 84 radio galaxy signal. In this example, quasi-period about 5 hours was quite clearly seen.

Perseus A, flux density fluctuations with a period about 1 hour are especially interesting; in our research, these variations were observed at all frequencies, from 5 to 8.8 GHz, in Zolochiv and Ventspils. The nature of these fluctuations in radio flux is not yet understood, and requires additional verification by the cross-spectral method. However, it is safe to say that variations close to 1 hour did not caused to random or regular interference.





Consider an example of a 3C 84 record, December 12, 2020. A typical "wave-like" shape of the light curve is visible, and a period of about 1 hour is clearly highlighted in the amplitude-phase FFT spectrum, above 99.9% confidence level.



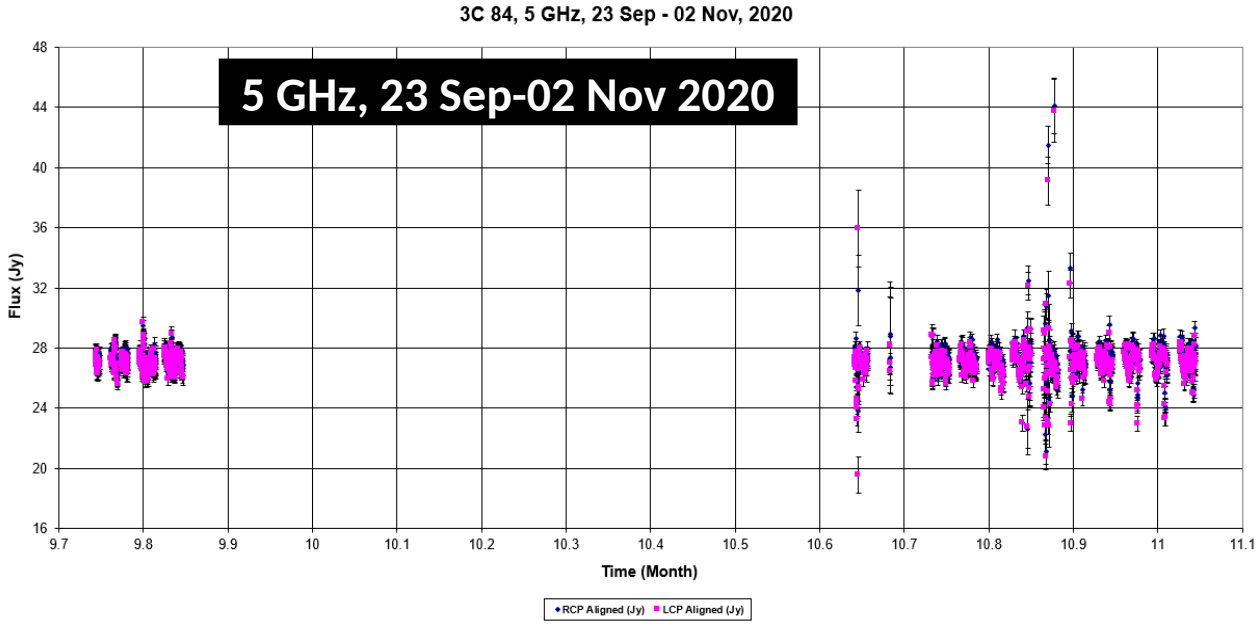
This result obtained in our work is very interesting, but it requires careful verification on quasi-simultaneous observations, lasting at least three days. If a correlated signal with a period of about 8 hours will received on the both 32-m antennas of Ukraine and Latvia, then it is very likely that it will not be a harmonic of the 24 hour period associated with the solar-diurnal ionospheric disturbance.

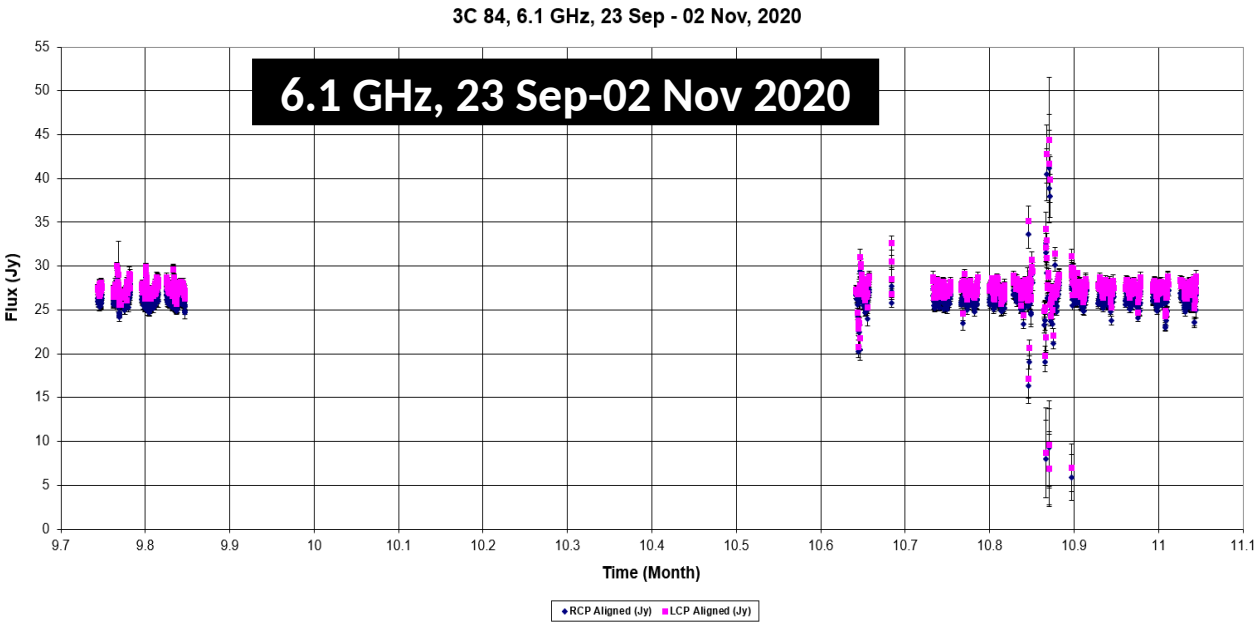
The timescale of radio flux variations, close to 8 hours, were observed earlier, for example, for quasar 3C 454.3 (Gorshkov, AG 2018); however, in the case of quasar 3C 454.3, there was noticeable lag between maxima of light curves from telescopes at large distances (delay in time), which means that oscillations may have been caused by signal propagation environment.

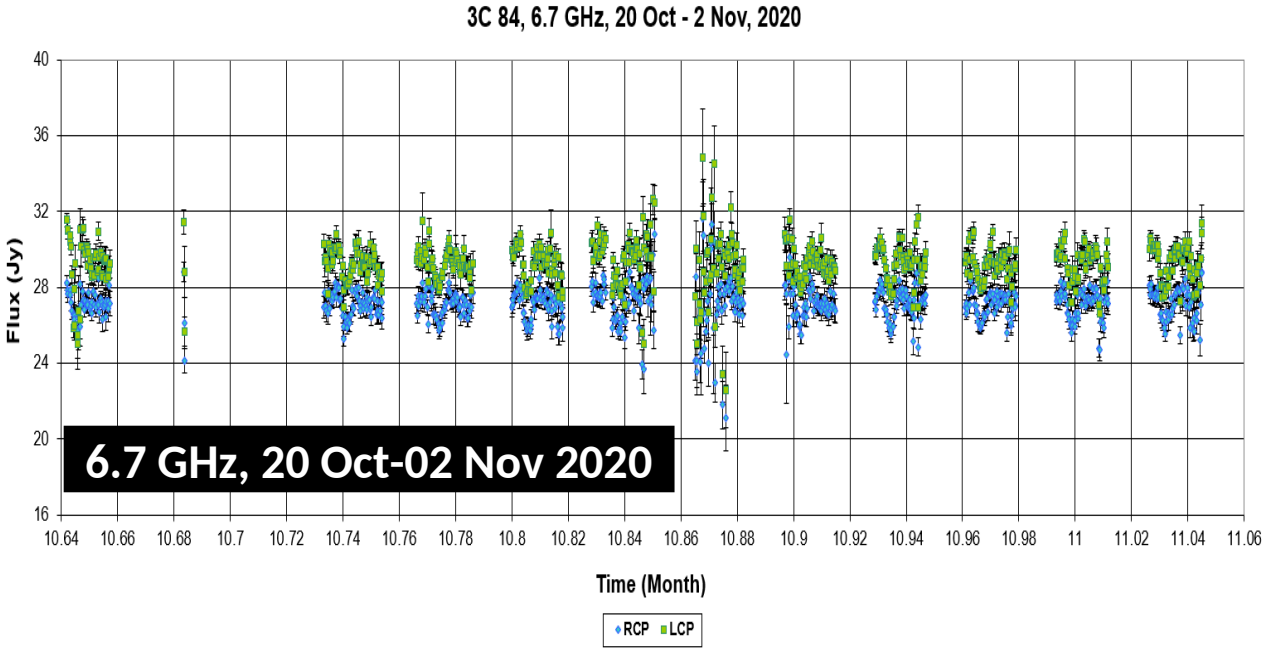
It should be noted that no day-to-day variability was observed. Perhaps this is due to a certain "phase of stability" of the radio source, which is observed even in the optical range, in 2020 - 2021. In order to check this, an attempt was made to make continuous daily observations of 3C 84 in Latvia for more than a month. The data has not yet been processed.

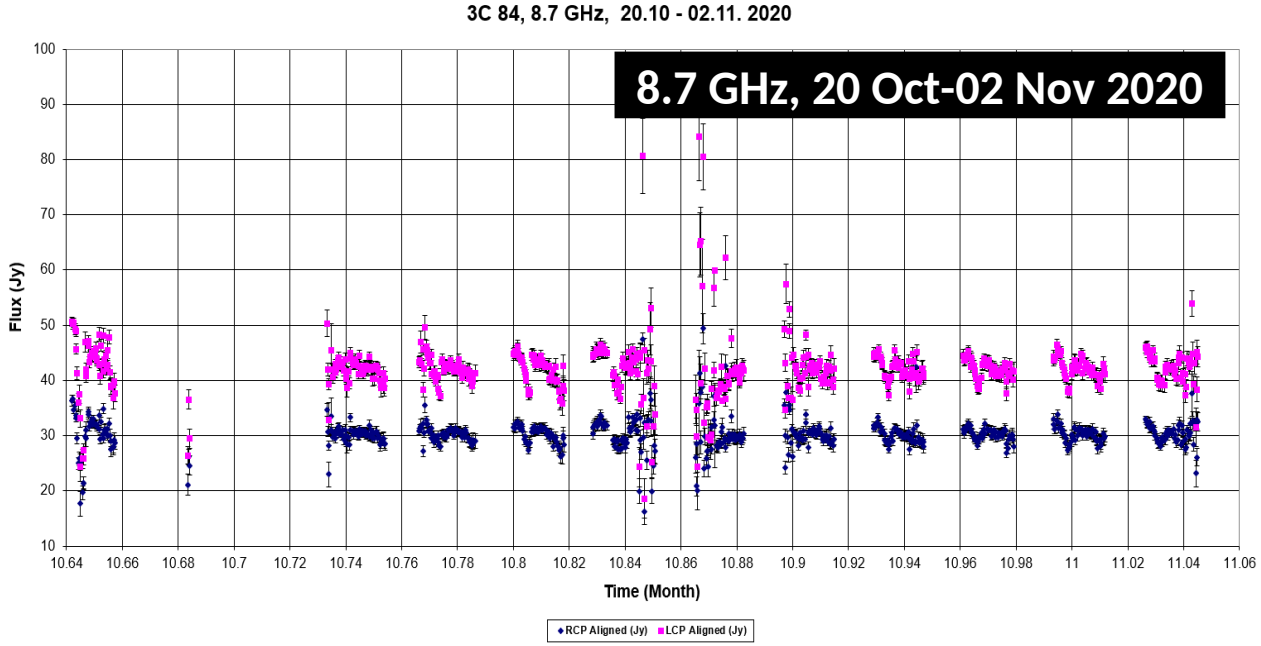
The presence a clear cyclicity with period about 8 hours, at frequencies 5, 6.7, 8.7 GHz, on the data obtained in VIRAC, Latvia at close time intervals, shows that there is cyclicity in signal from the galaxy 3C 84. However, picture is spoiled by the fact that at a frequency 6.1 GHz, for the same observation time, detected cycle is 6 hours in the right and left circular polarizations. It is possible that there was some distortion at 6.1 GHz.

Consider light curves of the radio galaxy 3C 84 in radio range, obtained by radio telescope of VIRAC, Latvia, at different frequencies.

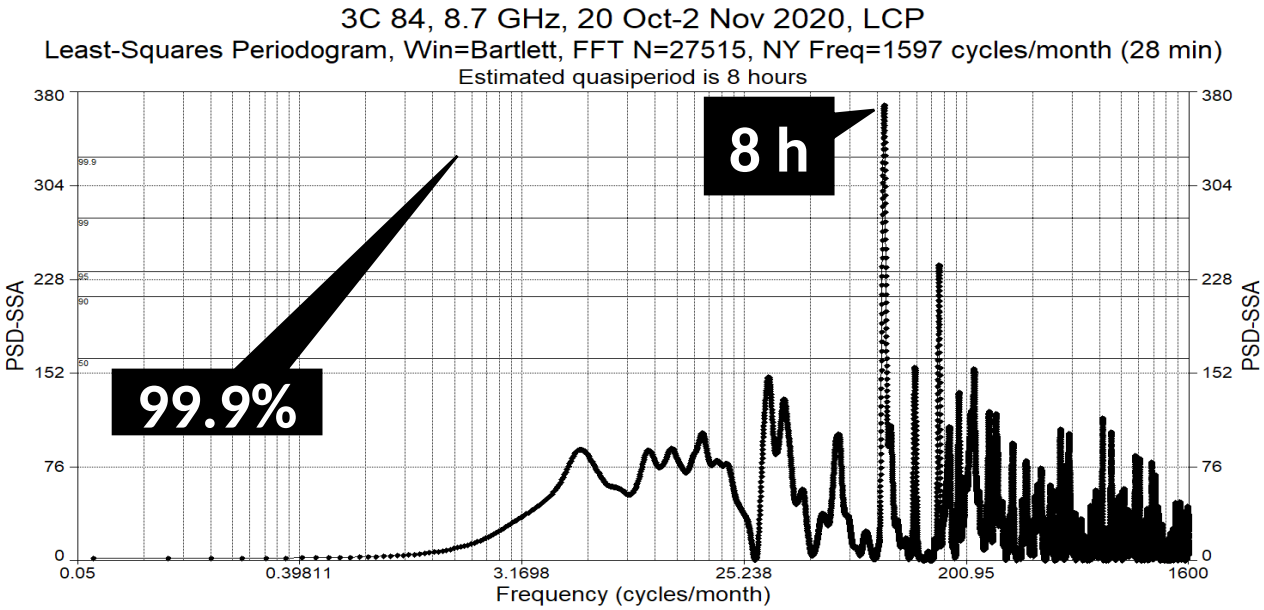


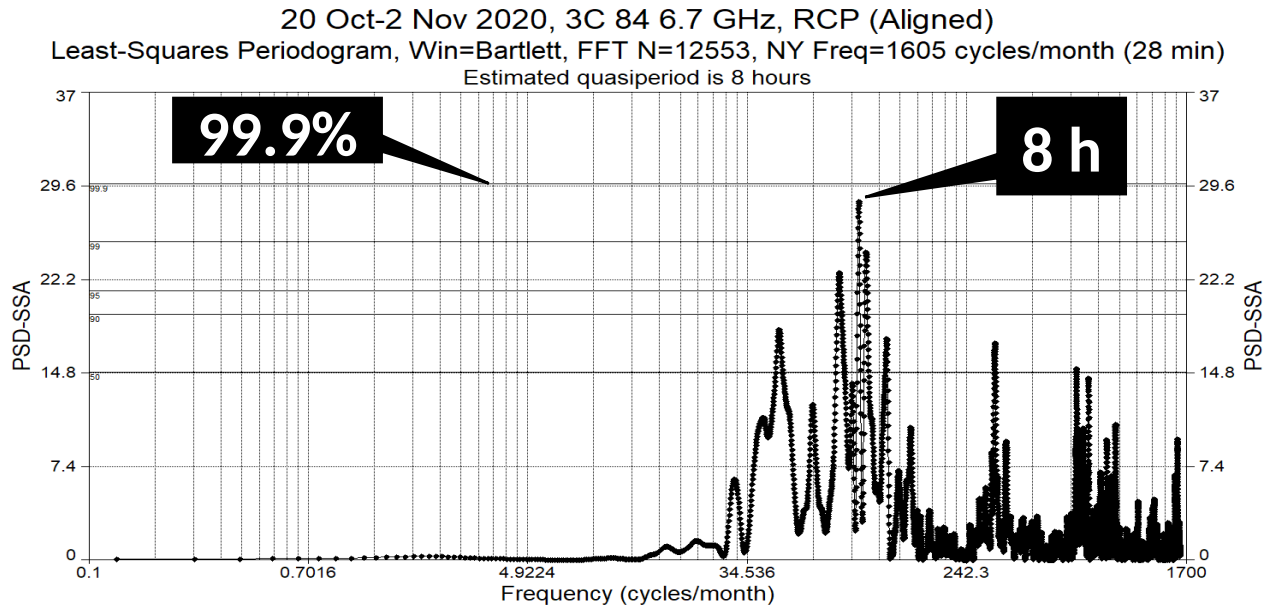


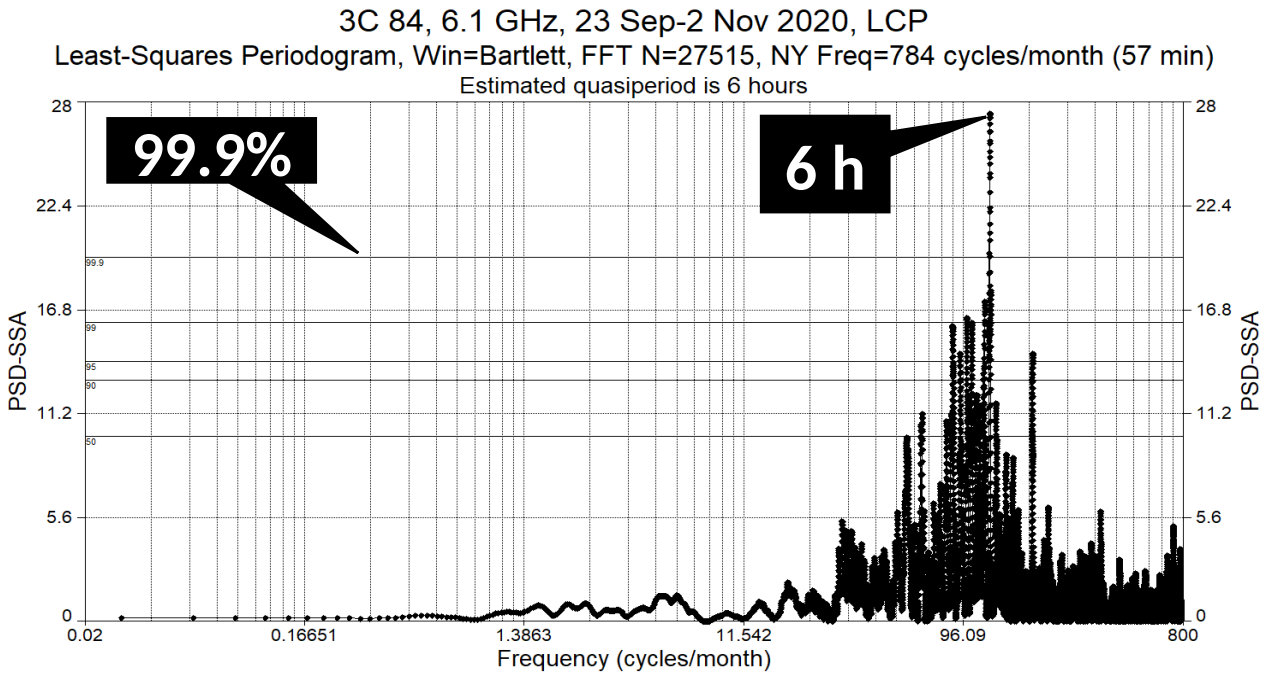


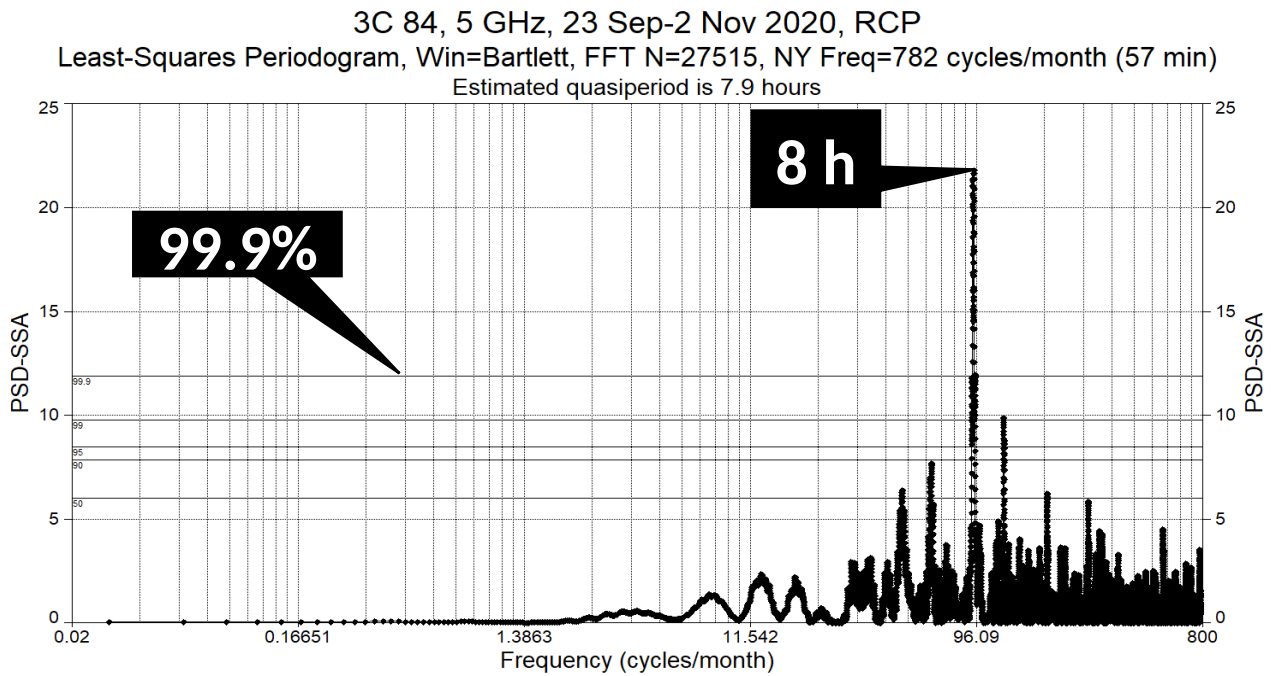


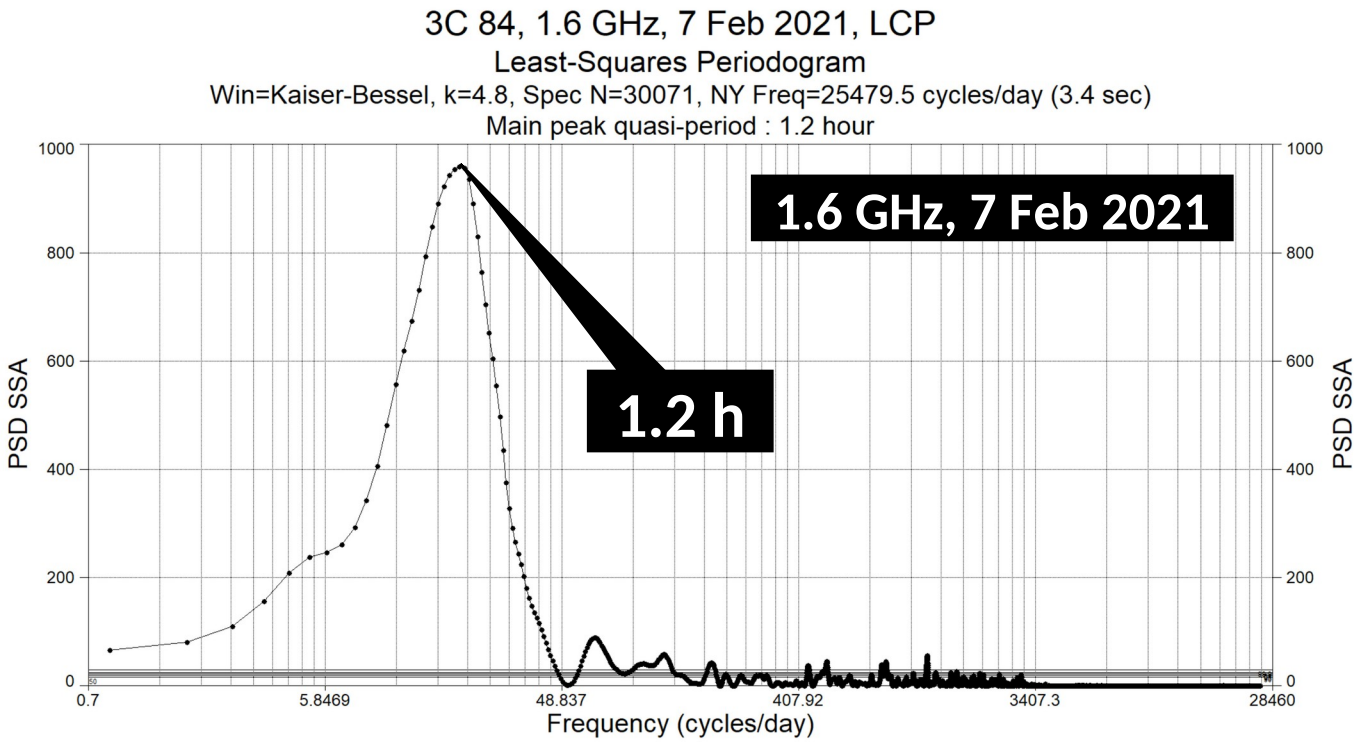
Consider the periodograms of raw observations (only outliers points of radio interference were removed) performed in VIRAC, Latvia, during September, early November 2020.



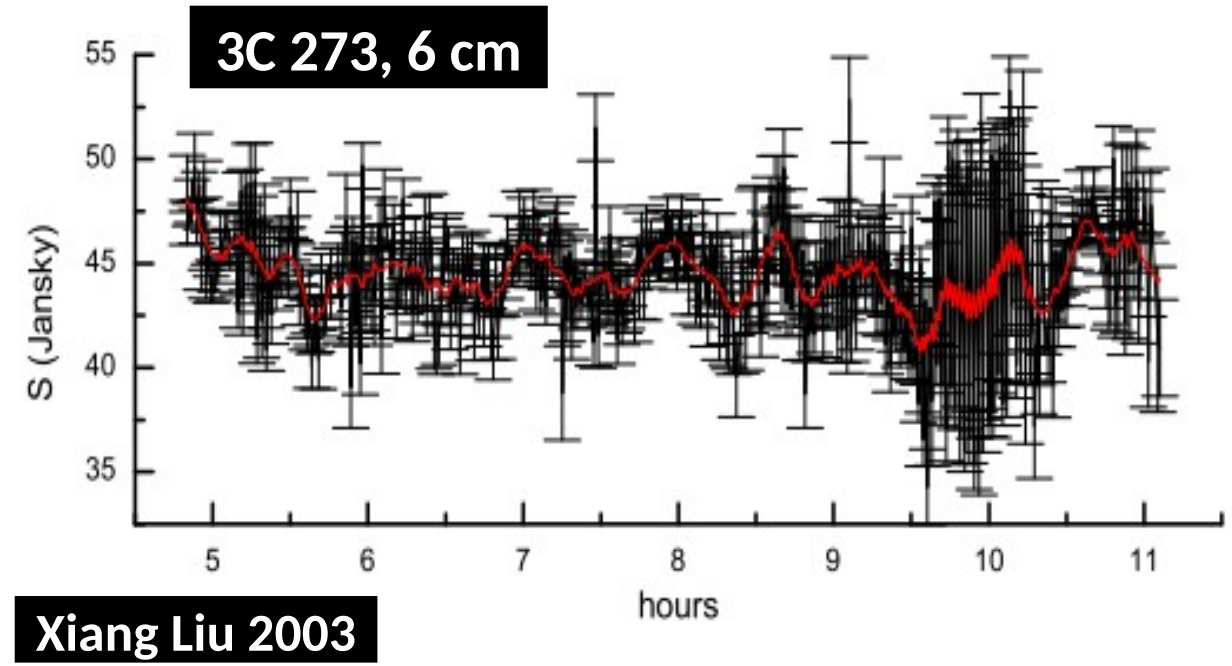


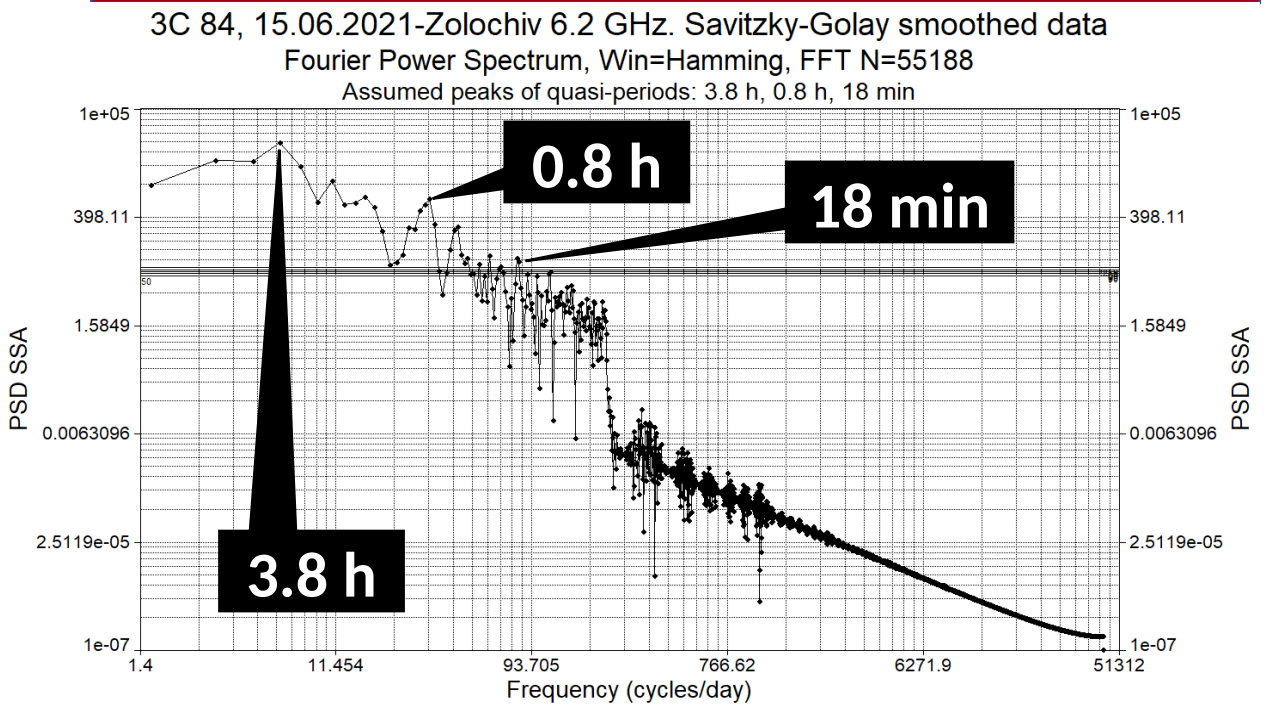




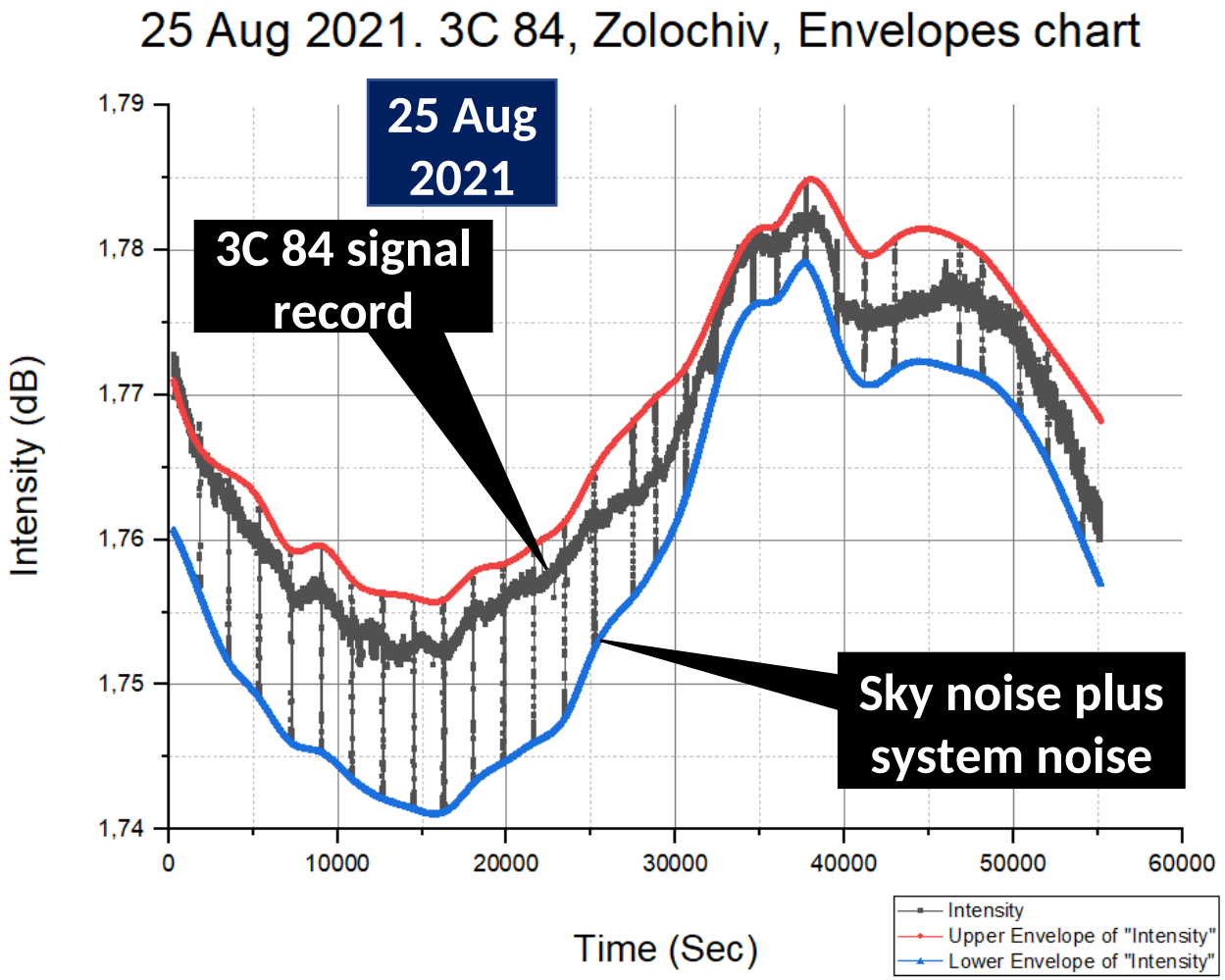


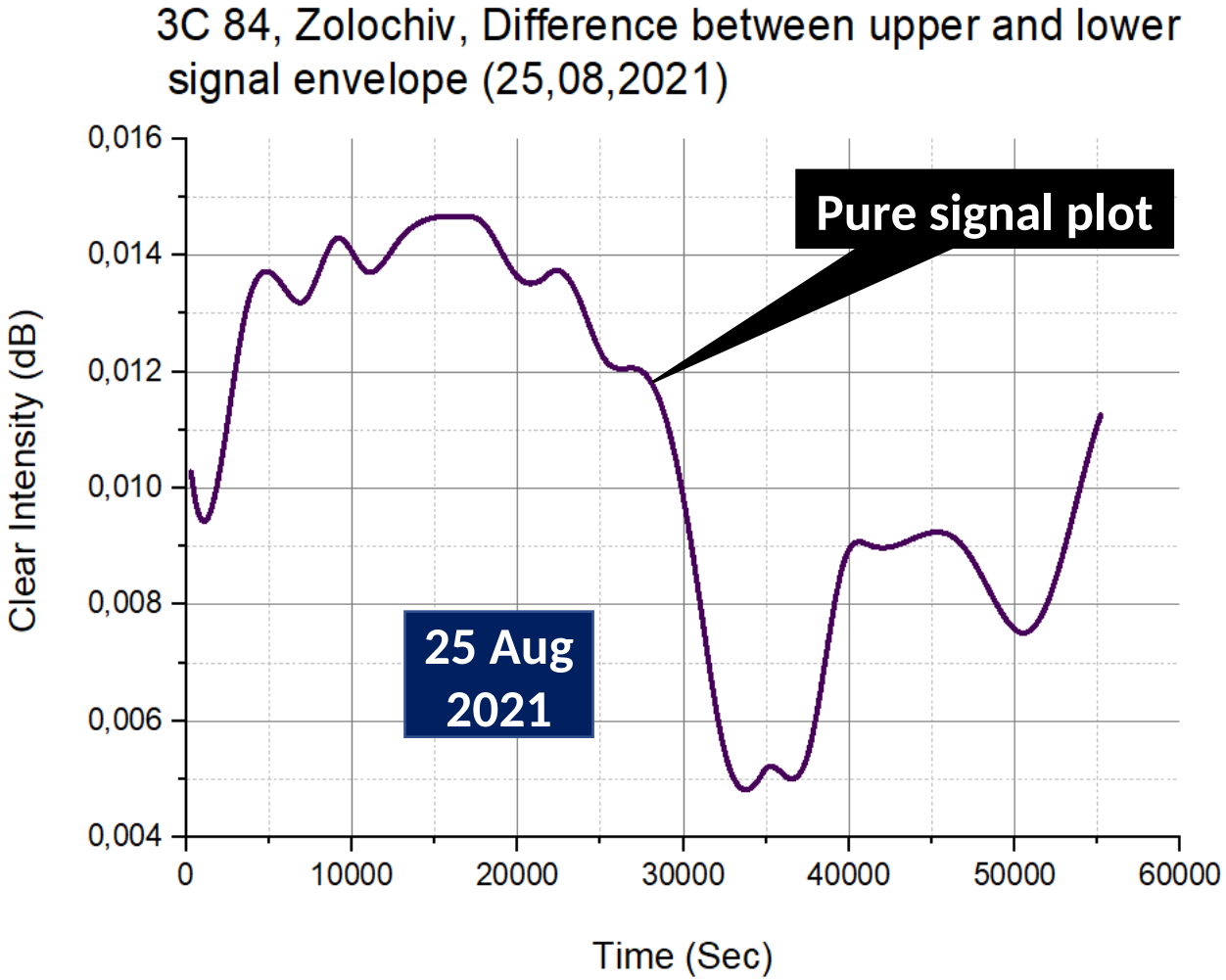
As shown in the plot on the left, clear variability with quasiperiod about 1 hour (according to VIRAC, Latvia) appears even at frequency 1.6 GHz. This is quite strange. Unless these are manifestations of planetary ionospheric waves. It is known that small acoustic gravity waves in mid-latitude ionosphere often have periods 50 - 100 minutes (Chinmaya Nayak, Erdal Yigit 2018). However, variability of the quasar 3C 273 with characteristic time of irregular variations about 1 hour (Xiang Liu 2003) was found from the observations in Urumqi, China.



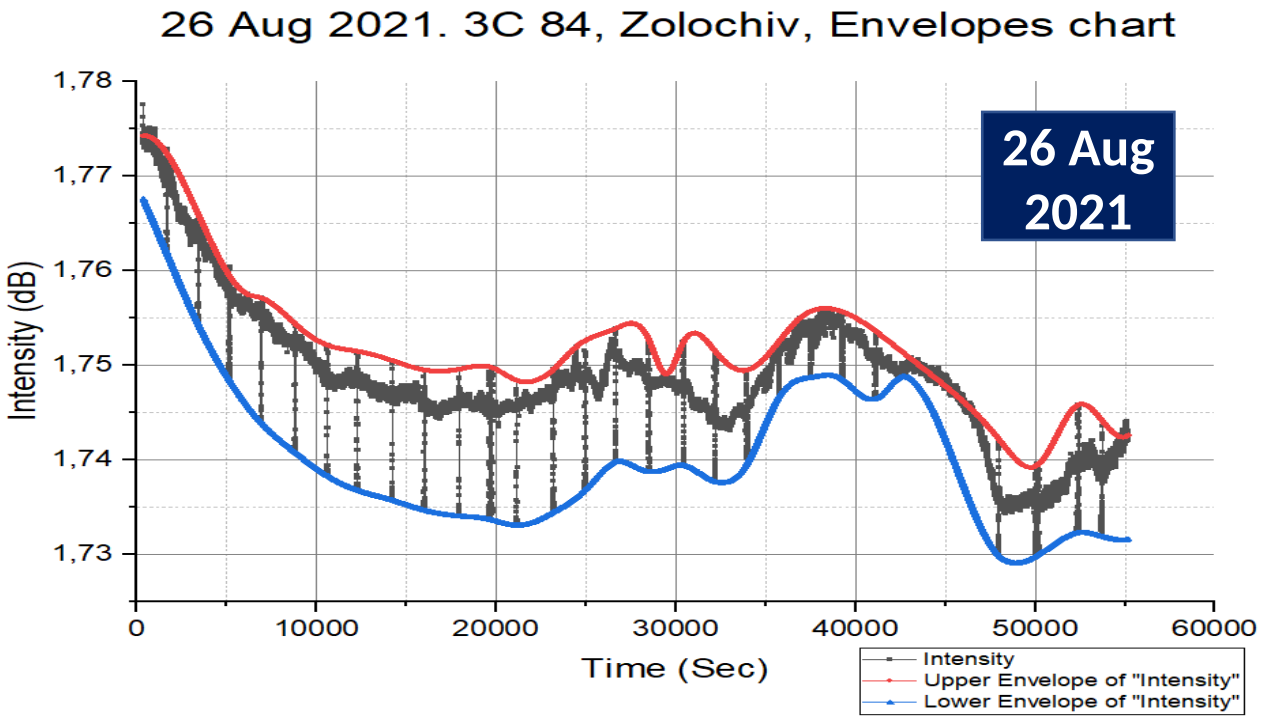


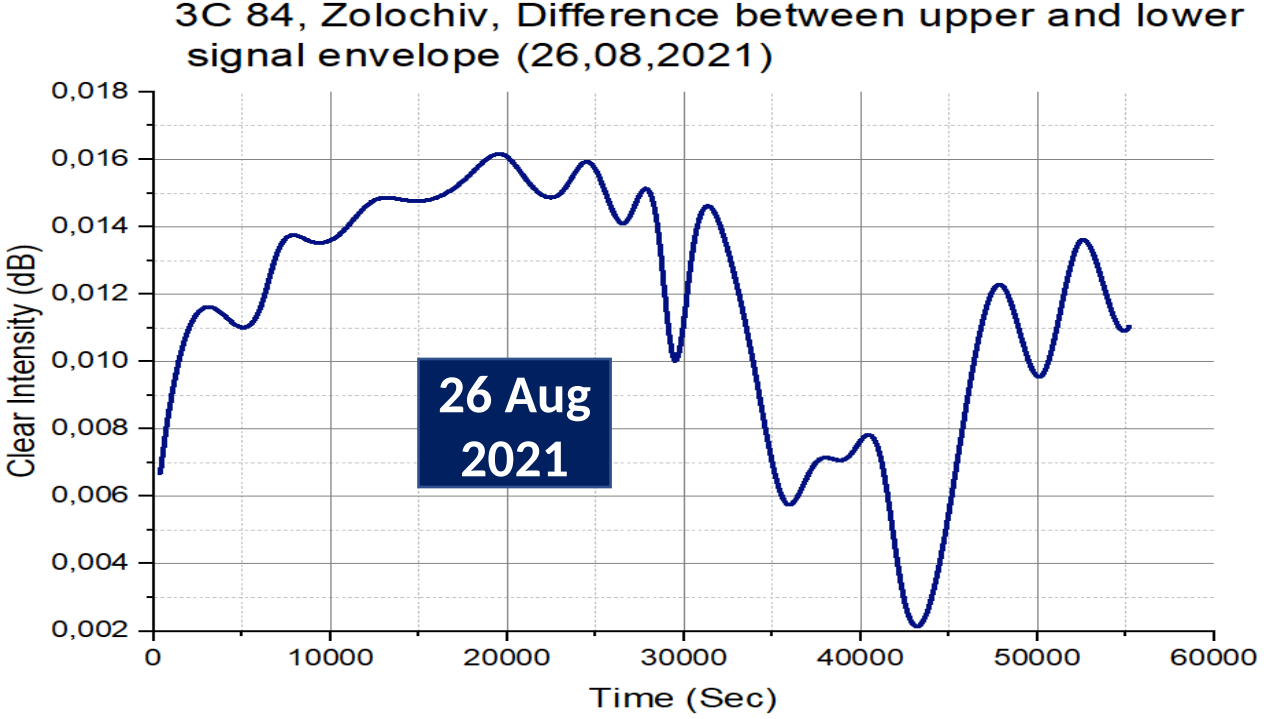
Confirmation of intra-day variability in the radio galaxy Perseus-A (3C 84) using a scanning of radio source, the experiment was done with the Zolochiv antenna.

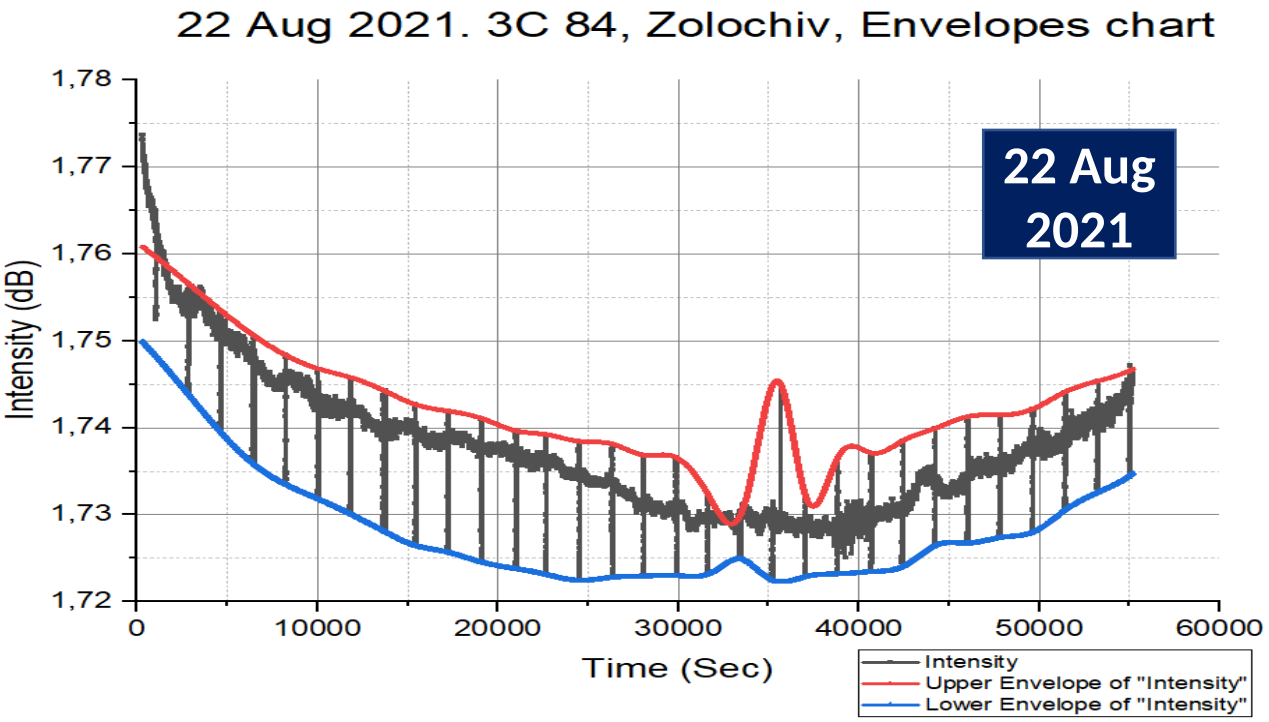


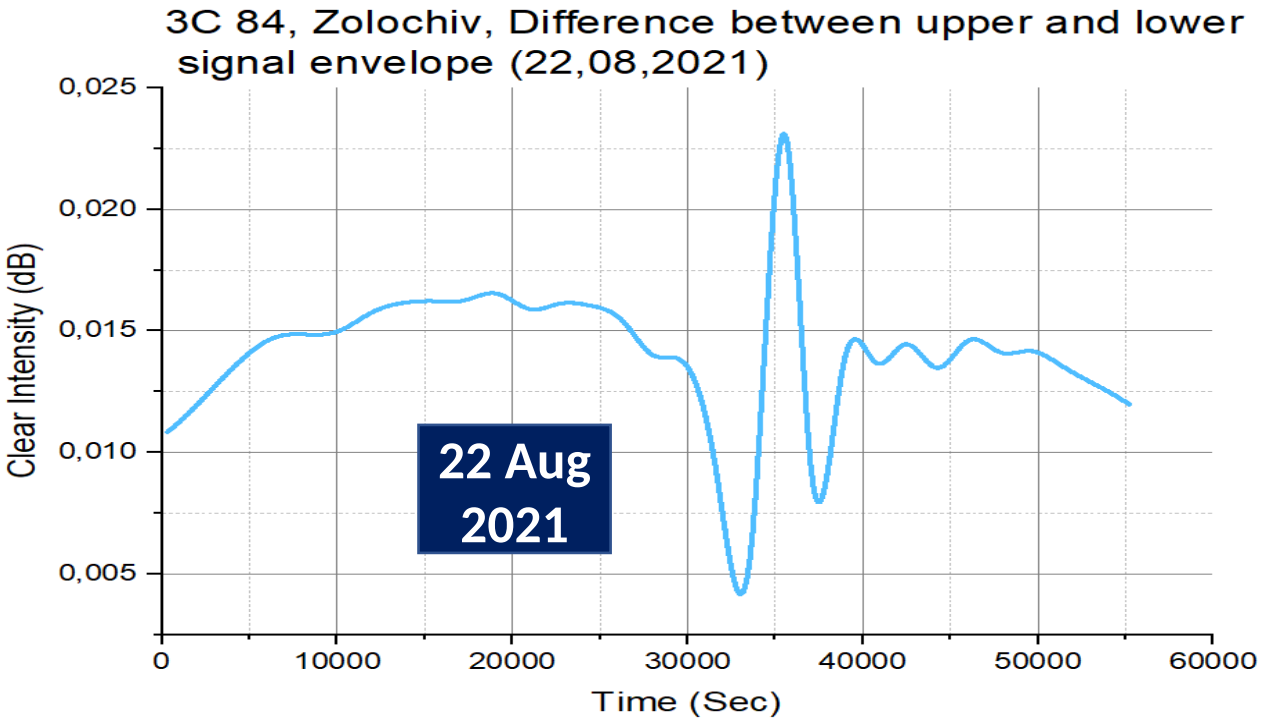


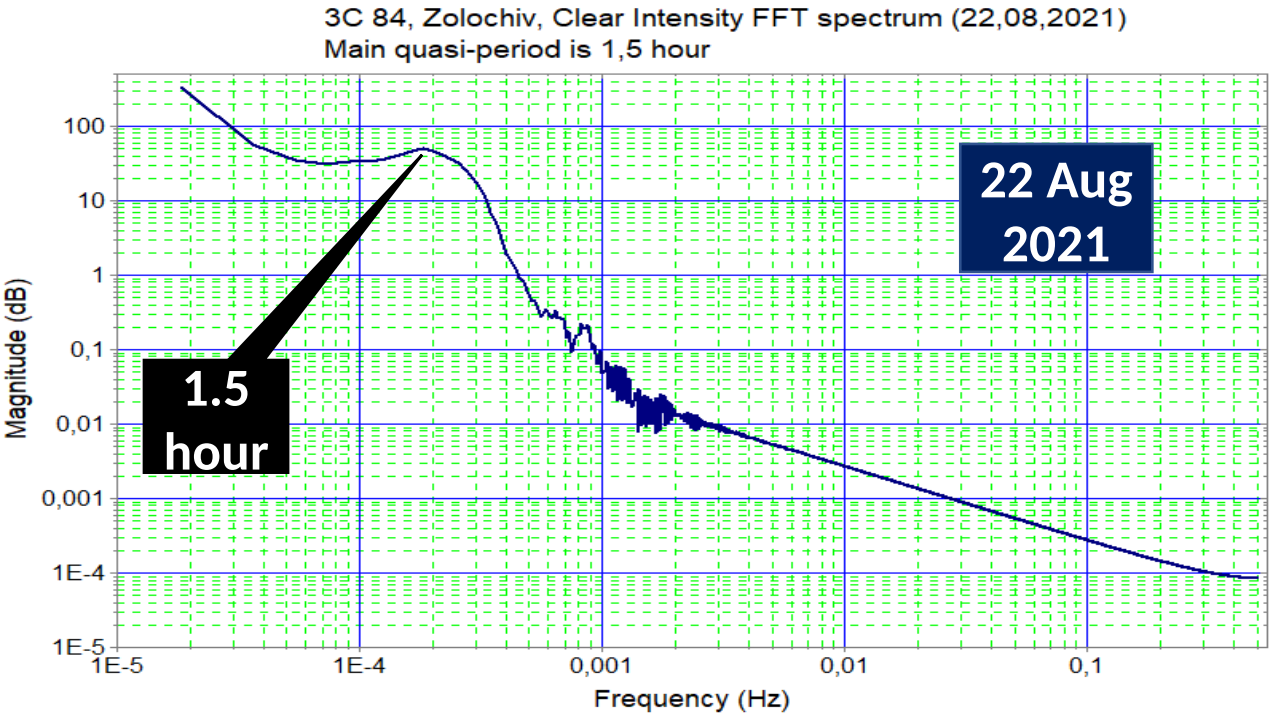
As result of scanning 3C 84 source, lower pulses correspond to sky noise plus noise of receiving equipment, and upper pulses are result of slight "non-hit" of beam to 3C 84. Then, using cubic spline with fixed knots, two signal envelopes were constructed, and difference between upper and lower envelopes was “pure" signal from 3C 84 radio source, cleaned from noise and trend dependence of flux from angle of antenna elevations.

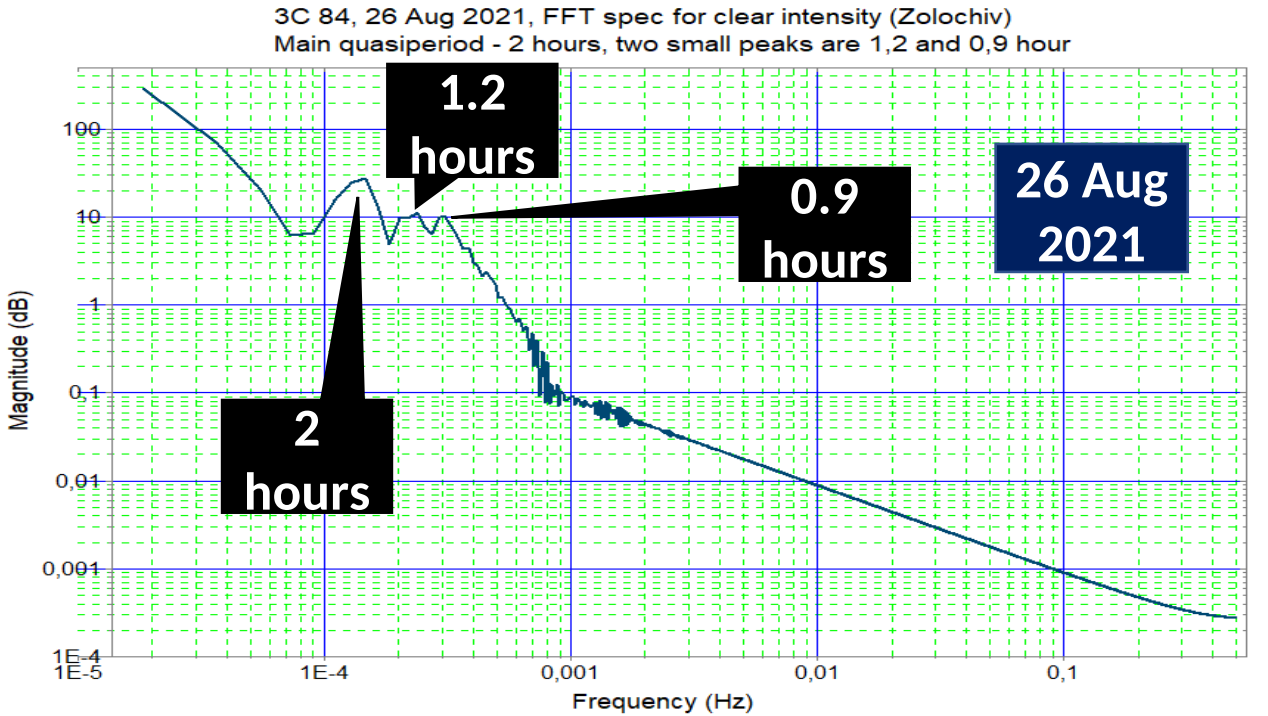

26 Aug 2021. 3C 84, Zolochiv, Envelopes chart
Intensity (dB)
Time (Sec)
26 Aug 2021
Intensity
Upper Envelope of "Intensity"
Lower Envelope of "Intensity"

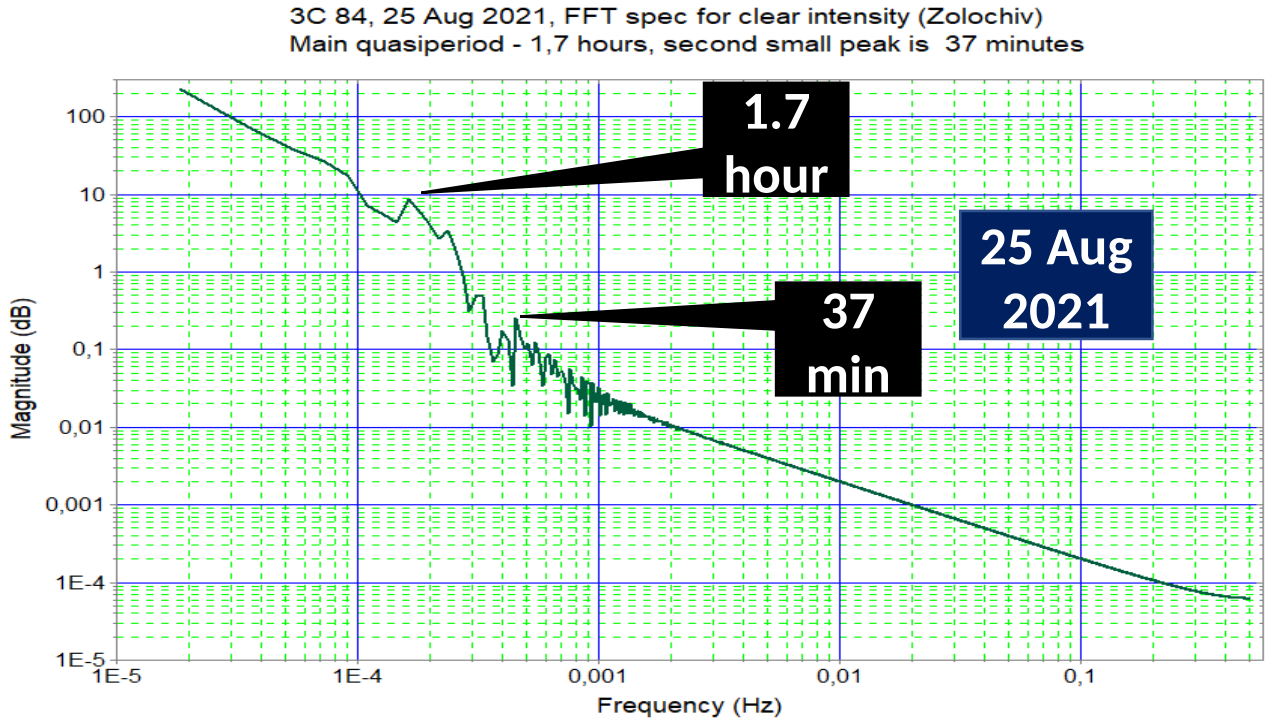

3C 84, Zolochiv, Difference between upper and lower signal envelope (26,08,2021)
Clear Intensity (dB)
Time (Sec)
26 Aug 2021

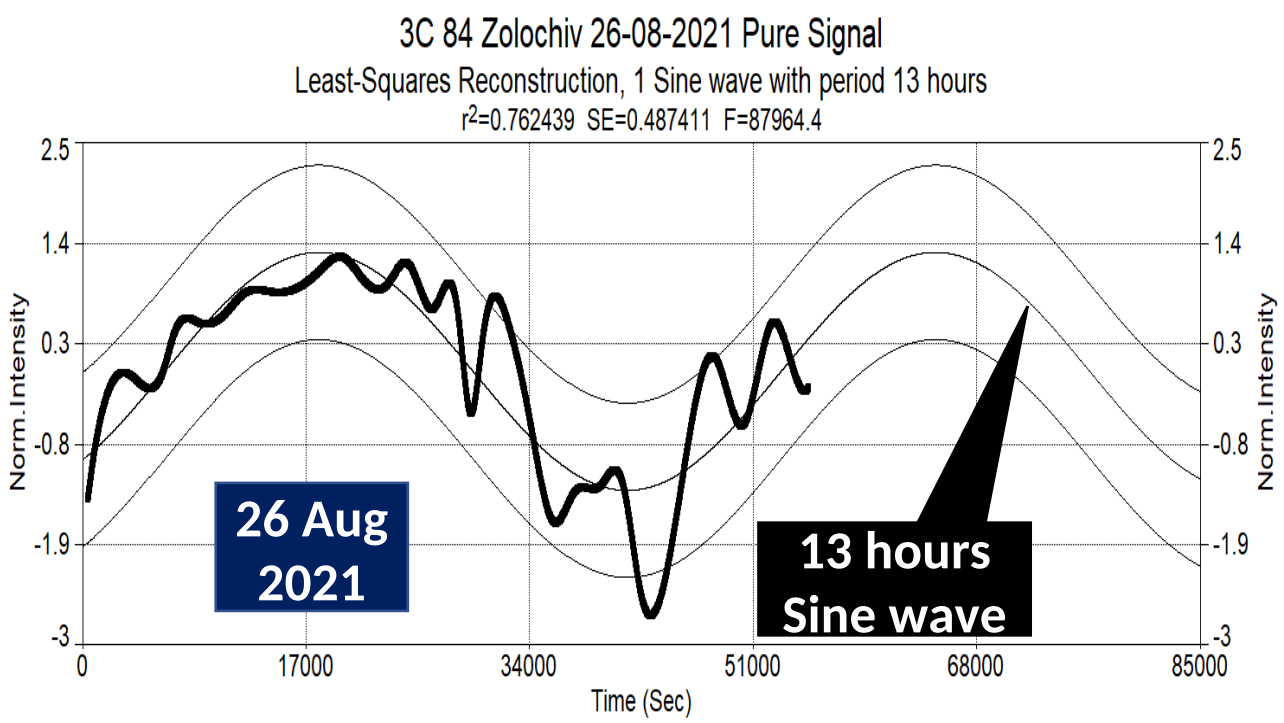

22 Aug 2021. 3C 84, Zolochiv, Envelopes chart
Intensity (dB)
Time (Sec)
22 Aug 2021
Intensity
Upper Envelope of "Intensity"
Lower Envelope of "Intensity"


3C 84, Zolochiv, Difference between upper and lower signal envelope (22,08,2021)
Clear Intensity (dB)
Time (Sec)
22 Aug 2021


3C 84, Zolochiv, Clear Intensity FFT spectrum (22,08,2021)
Main quasi-period is 1,5 hour
22 Aug 2021
1.5 hour
Magnitude (dB)
Frequency (Hz)
100
10
1
0,1
0,01
0,001
1E-4
1E-5
1E-5
1E-4
0,001
0,01
0,1


3C 84, 26 Aug 2021, FFT spec for clear intensity (Zolochiv)
Main quasiperiod - 2 hours, two small peaks are 1,2 and 0,9 hour
1.2 hours
0.9 hours
26 Aug 2021
2 hours
Magnitude (dB)
Frequency (Hz)
100
10
1
0,1
0,01
0,001
1E-4
1E-5
1E-4
0,001
0,01
0,1


3C 84, 25 Aug 2021, FFT spec for clear intensity (Zolochiv)
Main quasiperiod - 1,7 hours, second small peak is 37 minutes
1.7 hour
25 Aug 2021
37 min
Magnitude (dB)
Frequency (Hz)
100
10
1
0,1
0,01
0,001
1E-4
1E-5
1E-5
1E-4
0,001
0,01
0,1


3C 84 Zolochiv 26-08-2021 Pure Signal
Least-Squares Reconstruction, 1 Sine wave with period 13 hours
r²=0.762439 SE=0.487411 F=87964.4
26 Aug 2021
13 hours Sine wave
Norm.Intensity
Time (Sec)
2.5
1.4
0.3
-0.8
-1.9
-3
0
17000
34000
51000
68000
85000

conclusions

1) Studies of variability of the radio galaxy 3C 84 (Perseus-A), performed with radio telescopes in Latvia and Ukraine, have shown presence of intra-day radio variability (IDV), at all available radio frequencies, from 1.6 GHz to 8.8 GHz.
2) Characteristic time of observed flux variations is not constant in different observation sessions, and usually varies from 8 to 5 hours, sometimes variations with characteristic time from 3 to 4 hours prevail.
3) The most interesting are low-amplitude flux variations with characteristic times about 1 hour. They were confidently observed in both Zolochiv and VIRAC. Even at frequencies 8.7, 8.8 GHz.
4) Using method of scanning the 3C 84 radio source in Zolochiv, influence of intrinsic noise of receiving system, as well as background noise of the sky, was removed, however, in resulting “clean” signal, presence of cyclic flux variations with characteristic times about 1.7 and 1.5 hours was confirmed.
5) This confirmed correctness of previous observations, and fact, those flux variations of the 3C 84 source, were actually observed, and not effect of background noise and radio-interference. It is possible, that rapid variations about 1 hour were caused by ionospheric effects, in particular acoustic-gravity waves, which often have periods about 1 hour. Variations with characteristic times 8 - 3 hours were observed in Ukraine and Latvia, despite distance between antennas is about one thousand kilometers. Perhaps this is consequence of interstellar scintillations in the direction of Perseus-A.

! Thank you for your attention !