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T320M010 "Satellite control systems"
GNSS Satellites identification using recorded signals

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Task

Identification of “visible” GNSS satellites above Kaunas using submitted signal records of the GNSS satellites (GPS, Galileo or Beidou) (carrier signal restored), which were recorded on October 6, 2020.

1. INTRODUCTION

Satellite navigation systems has become integral part of all applications where mobility plays a important role [1]. These functions will be at the heart of the mobile phone third-generation (3G) networks such as the UMTS. In transportation systems, the presence of 3 receivers will become as common as seat belts or airbags, with all car manufacturers equipping their entry-level vehicles with these devices. As for the past developments, GPS launched a variety of techniques, products and, consequently, applications and services. The milestone of satellite navigation is the real time positioning and time synchronization. For that reason the implementation of wide-area augmentation systems should be highlighted, because they allow a significant improvement of accuracy and integrity performance. WAAS, EGNOS and MSAS provide over US, Europe, Japan a useful augmentation to GPS, GLONASS and Galileo services [2]. GNSS development has an interesting aspect due to its sensitive nature. Considerable events or developments are always subject to a couple of differentiators: technological developments and political decisions. GPS and Glonass in all stages of improvements are strictly related to those differentiators. The approval and startup of the European Galileo program is considered by far the most real innovation. Technological and political decisions in Galileo substantiate that interoperability and compatibility must be reached in the forthcoming years. Such issues are the true GNSS improvement for the benefit of institutions and organizations. GNSS applications in all fields will play a key role, moving its use from the transportation domain to multimodal use, outdoors and indoors. It is expected that GNSS will increase significantly the precision in position domain [3]. The concept of reference system for navigation is essential since all the applications of GNSS are related to the coordinate system used. The main application of GNSS is focused on the potential of to determine the position in the Global reference system any where any time on the Globe in a simple, fast and cost-effective manner. The integration between GNSS and other related technologies such as telecommunications (GSM, GPRS, UMTS), the Geographic Information Systems (GIS) and Inertial Navigation System (INS), has created numerous applications that needs more time to be discussed in details.

1.1. GNSS COMPONENTS

GNSS (Global navigation satellite system) is a term used for constellation of satellites providing signals from space. GNSS receivers determine location by using the timing and positioning data encoded in the signals coming from space.

Global Navigation Satellite System (GNSS) is a space based system of satellites that provide location (longitude, latitude, altitude) and time information in all weather conditions, anywhere on or near the Earth where there is an unobstructed line of sight to four or more GNSS satellites.

Each of them consists mainly of three segments: (a) space segment, (b) control segment and (c) user segment. These segments are almost similar in the three satellite technologies, which are all together make up the GNSS. As of today, the complete satellite technology is the GPS technology and most of the existing worldwide applications related to the GPS technology.
In this project, three GNSS systems global coverage was identified

1.1.1. GPS

(Global Positioning System) is made by US and consists of at least 31 operational satellites around the Earth. It is currently the world's most utilized satellite navigation system.

$$\begin{aligned} L1(t) &= a_1 P(t) W(t)\cos(2\pi f_1 t) + a_1 C/A(t) D(t)\sin(2\pi f_1 t) \\ L2(t) &= a_2 P(t) W(t)\cos(2\pi f_2 t) \end{aligned} \quad (1)$$

The signal broadcast by the satellite is a spread spectrum signal, which makes it less prone to jamming. The basic concept of spread spectrum technique is that the information waveform with small bandwidth is converted by modulating it with a large-bandwidth waveform (HofmannWellenhof et al., 2001). The generation of pseudo random sequence (PRN) in the code is based on the use of an electronic hardware device called tapped feed back shift register (FBSR).

1.1.2. Galileo

GALILEO is Europe’s initiative for a state-of-the-art global navigation satellite system, providing a highly accurate, guaranteed global positioning service under civilian control. Galileo will be not too different from the other GNSS parts (modernized GPs and Glonass [4]. It will provide autonomous navigation and positioning services, but at the same time will be interoperable with the two other global satellite navigation systems; the GPS and GLONASS. A user will be able to take a position with the same receiver from any of the satellites in any combination. By providing dual frequencies as standard, however, GALILEO will deliver real-time positioning accuracy down to the meter range. It will guarantee availability of the service under all, but the most extreme circumstances and will inform users within seconds of a failure of any satellite. This will make it appropriate for applications where safety is vital, such as running trains, guiding cars and landing aircraft. The combined use of GALILEO and other GNSS systems can offer much improved performance for all kinds of users worldwide. GALILEO is expected to be in operation by the year 2008. The first satellite of Galileo system (GIOVE A) has already been lunched in 27th December 2005.

Currently there are 30 satellites in orbit. 24 active and 6 spares, out of the 24 usabe satellities 2 are unavailable and 2 retired which will be observed during this assignment paper.

Satellite Code	SV ID (PRN)	CCSDS ID [hex]	Orbital Slot	Status
GSAT-0101	11	3A5	B05	Usable
GSAT-0102	12	3A6	B06	Usable
GSAT-0103	19	3A7	C04	Usable
GSAT-0201	18	261	not-nominal	Not usable since February 18th, 2021
GSAT-0202	14	262	not-nominal	
GSAT-0203	26	263	B08	Usable
GSAT-0205	24	265	A08	Usable
GSAT-0206	30	266	A05	Usable
GSAT-0207	7	267	C06	Usable
GSAT-0208	8	268	C07	Usable
GSAT-0209	9	269	C02	Usable
GSAT-0210	1	26A	A02	Usable
GSAT-0211	2	26B	A06	Usable
GSAT-0212	3	26C	C08	Usable
GSAT-0213	4	26D	C03	Usable
GSAT-0214	5	26E	C01	Usable
GSAT-0215	21	2C5	A03	Usable
GSAT-0216	25	2C6	A07	Usable
GSAT-0217	27	2C7	A04	Usable
GSAT-0218	31	2C8	A01	Usable
GSAT-0219	36	713	B04	Usable
GSAT-0220	13	704	B01	Usable
GSAT-0221	15	705	B02	Usable
GSAT-0222	33	706	B07	Usable

Table. 1.1. Galileo Reported Constellation Information[5].

1.1.3. BeiDou Navigation Satellite System

Is Chinese GNSS system, which currently consists of 35 satellites in orbit but a total launch of 59. The system can already be used for positioning in Asia-Pacific region.

1.2. TLE

A **two-line element set** (**TLE**) is a data format encoding a list of orbital elements of an Earth-orbiting object for a given point in time, the *epoch*. Using a suitable prediction formula, the state (position and velocity) at any point in the past or future can be estimated to some accuracy. The TLE data representation is specific to the simplified perturbations models (SGP, SGP4, SDP4, SGP8 and SDP8), so any algorithm using a TLE as a data source must implement one of the SGP models to correctly compute the state at a time of interest. TLEs can describe the trajectories only of Earth-orbiting objects. TLEs are widely used as input for projecting the future orbital tracks of space debris for purposes of characterizing "future debris events to support risk analysis, close approach analysis, collision avoidance maneuvering" and forensic analysis.[5]

Originally there were two data formats used with the SGP models, one containing complete details on the object known as the "internal format", and a second known as the "transmission format" that was used to provide updates to that data.

An example TLE

GPS BIIR-2 (PRN 13)

1 24876U 97035A   20280.12410643 .00000017 00000-0 00000-0 0 9992

2 24876 55.4575 179.8355 0044134 58.4891 302.0098 2.00561598170230

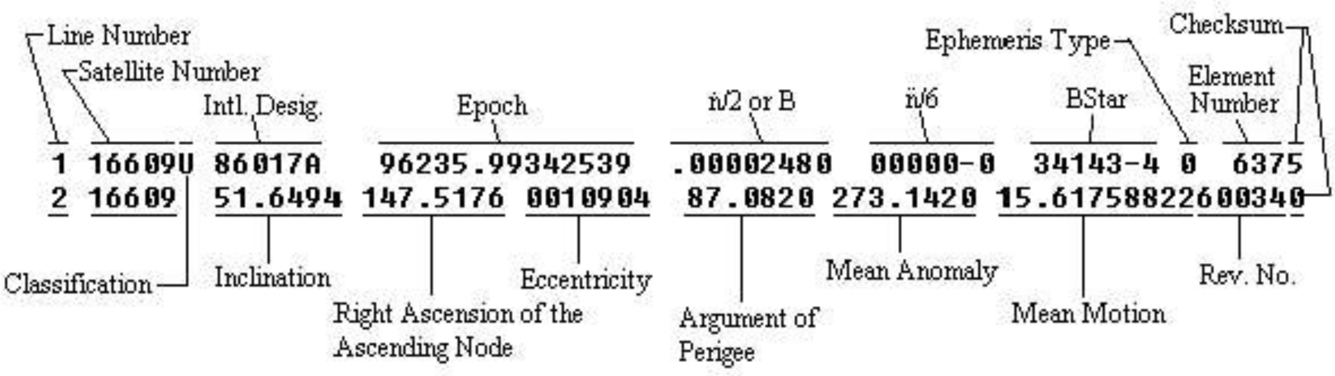

Fig. 1.1. TLE format details

1.3. Coordinate System

The definition of reference coordinate system is crucial for the description of satellite motion, the modeling of observable and the interpretation of results. Reference coordinate system in satellite geodesy is global and geocentric by nature since satellite motion refers to the center of mass of the [3]. In satellite geodesy, two reference systems are required: (a) space-fixed, inertial reference system for the description of satellite motion, and (b) earth-fixed, terrestrial reference system for the positions of the observation stations and for the description of results from satellite geodesy. The positioning with using GNSS depends mainly on knowing the satellite coordinates. The position of the receiver is calculated with respect to the instant position of the satellite. By considering the range vector relation between satellite and receiver, the coordinate of the satellite and receiver should be expressed in the same coordinate system. In satellite geodesy, the two systems are used and the transformation parameters between the space fixed and earth fixed are well known and used directly in the GNSS receiver and post processing software to compute the position of the receivers in the earth fixed system. Terrestrial reference system is defined by convention with three axes, where Z-axis coincides with the earth rotation axis as defined by the Conventional International Origin (CIO). The Xaxis is associated with the mean Greenwich meridian, and the Y-axis is orthogonal to both Z and X axes and it completes the right-handed coordinate system, Fig. 9. One example of the terrestrial reference system is the WGS84.

The basic idea, in geodesy, behind using the reference ellipsoids is that they fit the real shape of the earth. Another example of terrestrial reference frame is the International Terrestrial Reference Frame (ITRF), which is established by Central Bureau of the International Earth Rotation Service (IERS). The ITRF is regularly updated and is more accurate than WGS84, but the difference between WGS84 and ITRF is now in the order of a few centimeters. This difference is mainly due to the difference between the reference stations used by each system when it is realized. Both systems are geocentric and the transformation parameters between them are regularly published by IERS. The representation of position in geocentric Cartesian coordinates (X, Y and Z) has less significance in navigation. Hence, the ellipsoidal representation (longitude, latitude and height above the ellipsoid) are more commonly use for coordinate representation.

The relation between Cartesian coordinate (X, Y, Z) and ellipsoidal coordinates (ϕ, λ, and h) is well known by using the following formulas:

$$
\begin{aligned}
X &= (N+h)\cos\varphi\cos\lambda \\
Y &= (N+h)\cos\varphi\sin\lambda \qquad (2) \\
Z &= (\frac{b^2}{a^2}N+h)\sin\varphi
\end{aligned}
$$

where N is the radius of curvature in prime vertical and is obtained by the following expression:

$$N = \frac{a^2}{\sqrt{a^2\cos^2\varphi + b^2\sin^2\varphi}}, \qquad (3)$$

Here, a, b are the semi axes of the ellipsoid. The Cartesian coordinate of WGS84 is called also ECEF (Earth Centered Earth-Fixed) coordinate system. As mentioned above, the realization of the reference frame depends on the coordinates of ground reference stations. The Galileo Terrestrial Reference Frame (GTRF) is expected to be similar to ITRF, but will be based on the coordinates of the Galileo ground stations. The differences between WGS84, ITRF and the GTRF are expected to be in the order of a few centimeters. The two coordinate systems are compatible, and the accuracy obtained is good enough for most of the applications including navigation. For high precise measurements and for centmetric accuracy between the various systems, the transformation parameters are expected to be published by the geodetic service providers such as IERS.

1.4. Time Reference Frame

There are many time reference systems used and they are based on various periodic processes such as the earth rotation. The major type of this system is UTC.

1.5. Observation Techniques

The basic concept of GNSS is to measure the signal traveling time between artificial satellite and receiver. By multiplying this time by the light velocity (c), we get the range between the satellite and the receiver [4].

$$Range = c.(t_R - t^S) = \Delta t_R^S \cdot c \qquad (4)$$

The time or phase measurement performed by the receiver is based on the comparison between the received signal at the antenna of the receiver and the generated reference signal by the receiver. The two signals are affected by the clocks errors. Therefore, the range measured is not true and it is called pseudorange. Since the signal travels through the atmospheric layers, further noise should be modeled in order to compute the precise range.

1.6. GNSS Positioning Techniques

There are two main types of positioning techniques in GNSS measurements: single point positioning and differential positioning.

1.7. Doppler Effect

What is Doppler effect in satellite? When a radio transmitter is placed in an artificial satellite and its. signal is received on Earth, the frequency registered at the receiver will. seem to vary according to a well defined curve. This is due to the Doppler- Fizeau effect, more frequently called the Doppler effect

Knowing Doppler's shift it is easy to calculate the satellite's relative speed relative to the observer (receiver)

$$Vr = \mathrm{C} * \frac{\Delta \mathrm{F}}{\mathrm{FL1}} \tag{5}$$

$$\Delta F = \frac{Vr * FL1}{C} \tag{6}$$

c- speed of light $3x10^8$m/s

where ΔF satellite's signal Doppler shift KHz;

$F_{L1} = 1575.42x10^6$ Hz L1 band center frequency;

1.8. Identification of "visible" GNSS satellites

In the paper, several methods was used to Identify visible GNSS satellites above Vilnius using submitted signal records of the GNSS satellites (GPS, Galileo or Beidou) (carrier signal restored), which were recorded on October 6, 2020.

1. Orbitron program
2. Matlab and
3. Python

1.8.1. Matlab

Identification of “visible” GNSS satellites above Kaunas using submitted signal records of the GNSS satellites using Orbitron program. 2020-10-06.

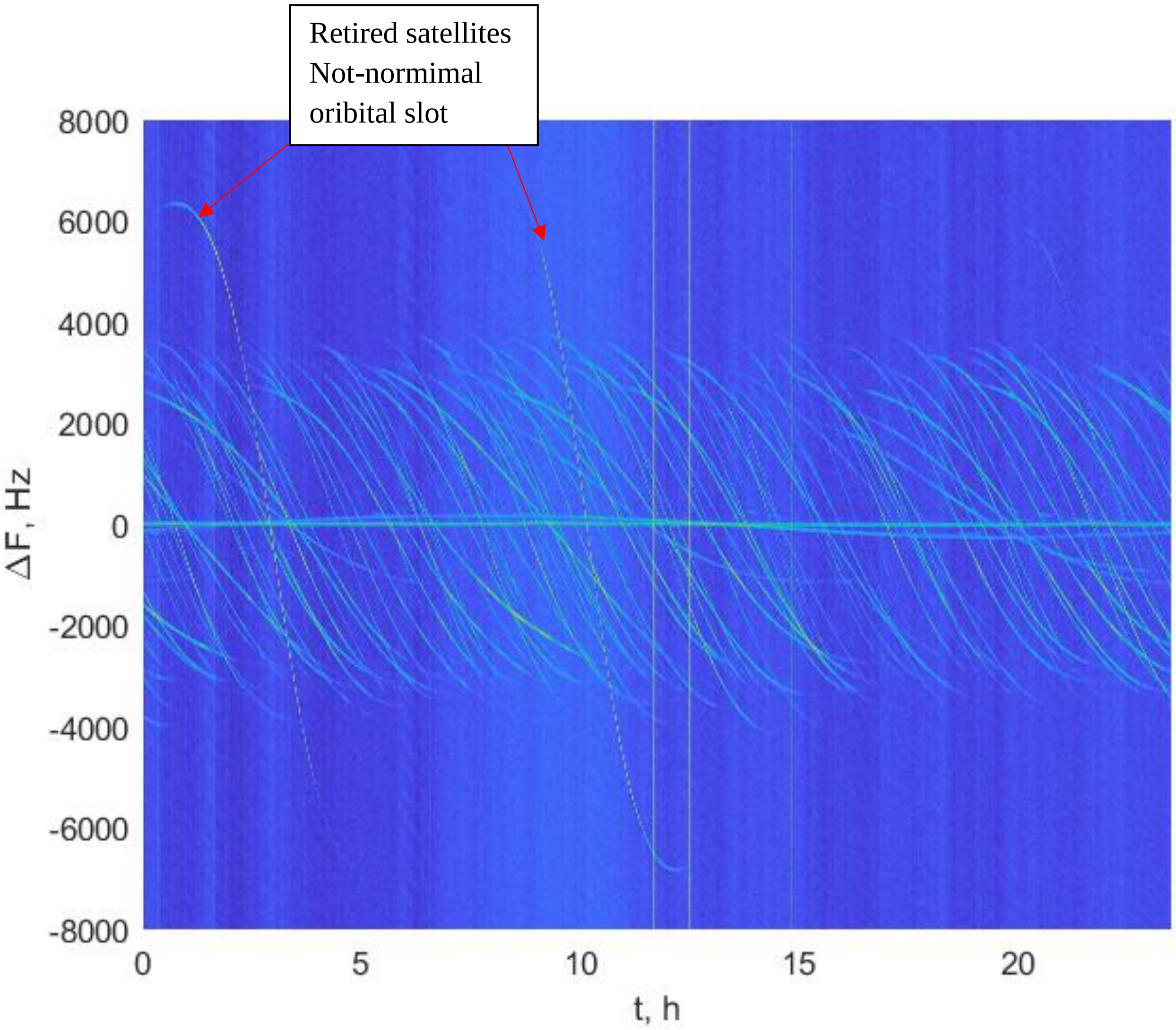

Fig. 1.2.2.1. GNSS satellite signal change in 24 hours

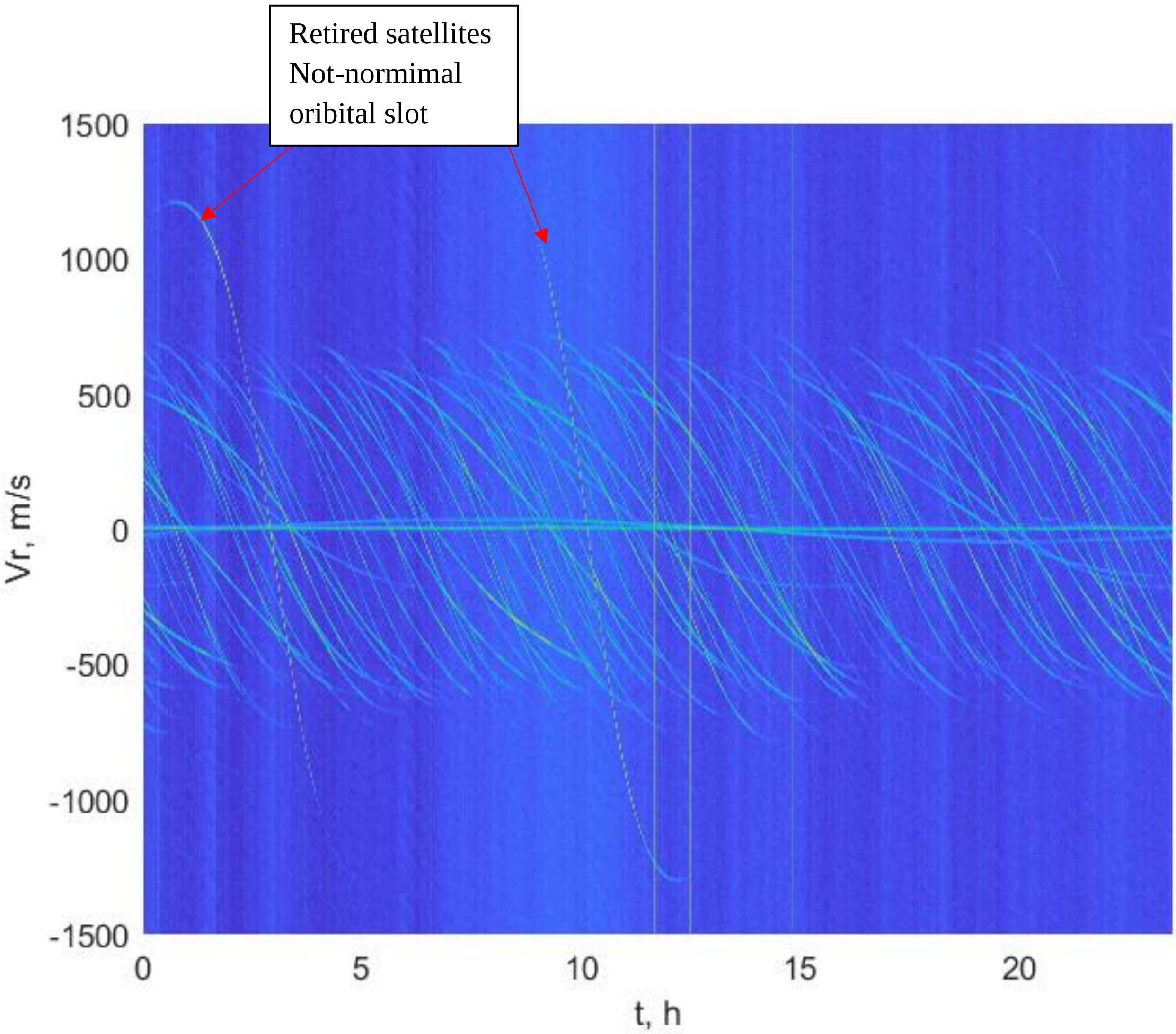

Fig. 1.2.2.2. GNSS satellite relative velocity change in 24 hours

To determine Normalized (by max level) GNSS satellite carrier signal amplitude.

Tx = 9.02 (Analysis time)

```
I=find(t>=Tx);
I=I(1)
```

I = 1624

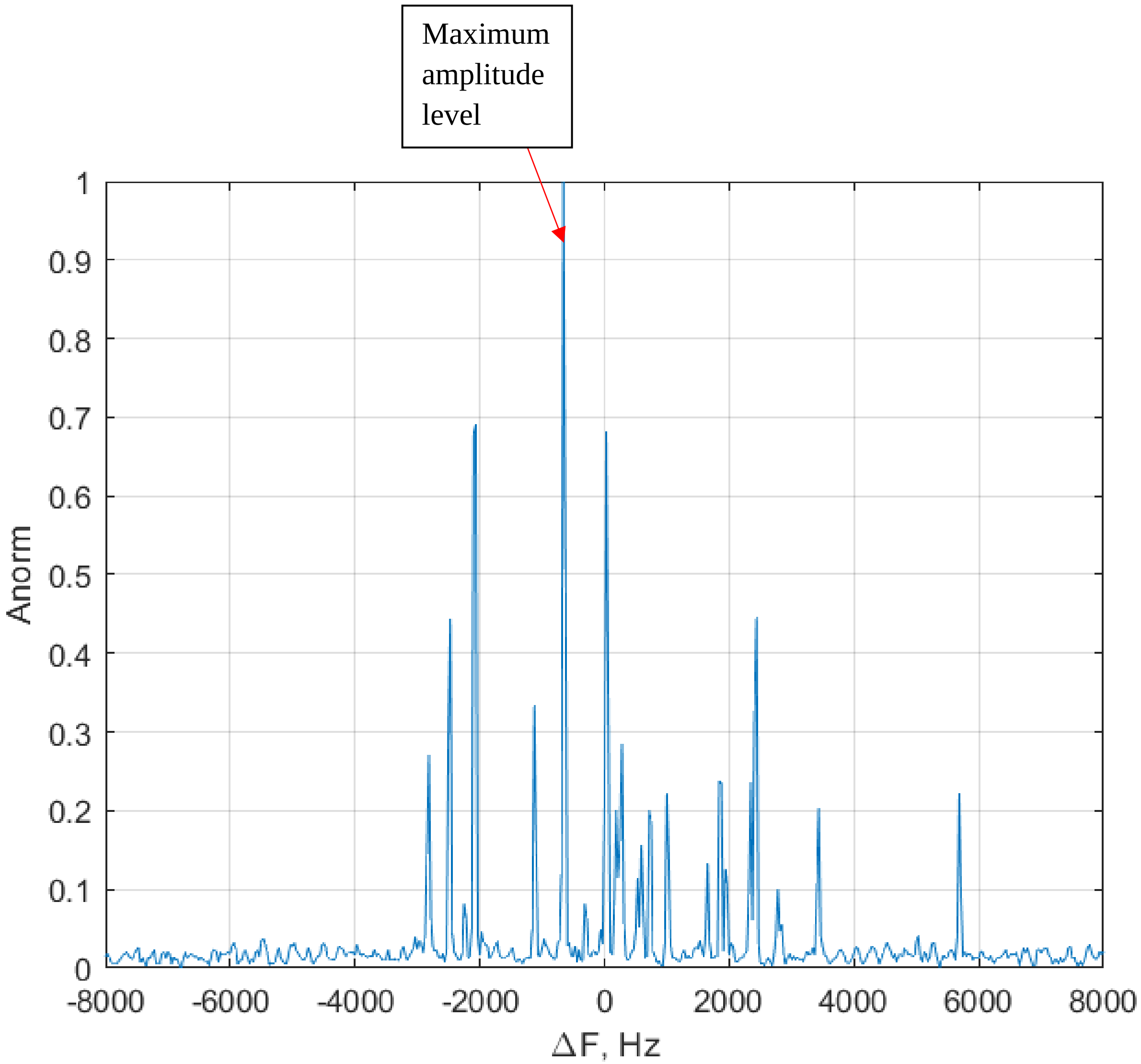

Fig. 1.2.2.3. Normalized (by max level) GNSS satellite carrier signal amplitude and their Doppler shift at time Tx = 9.02hrs UTC

Maximum level of the normalized GNSS satellite carrier signal amplitude and their Doppler shift at time Tx = 9.02hrs UTC is at -657.5Hz.

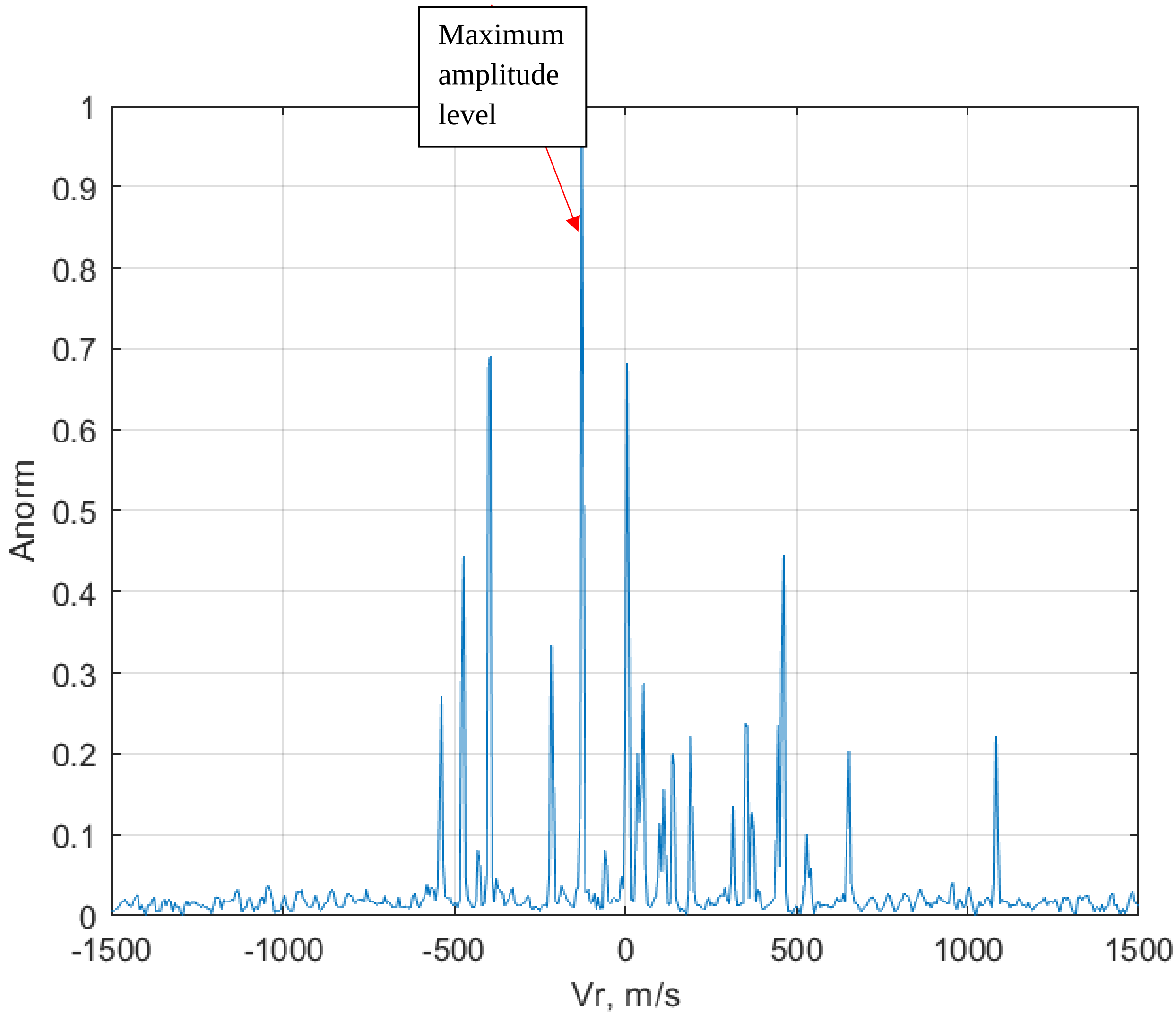

Fig. 1.2.2.4. Normalized (by max level) GNSS satellite carrier signal amplitude and their relative velocity at time Tx = 9.02hrs UTC

Maximum level of the normalized GNSS satellite carrier signal amplitude and their relative velocity at time Tx = 9.02hrs UTC is at -125.205m/s.

Kindly find Matlab code used to identify the Doppler effect and relative velocity in an attached document in moodle.

1.8.2. Orbitron program

Identification of “visible” GNSS satellites above Vilnius using submitted signal records of the GNSS satellites using Orbitron program. 2020-10-06

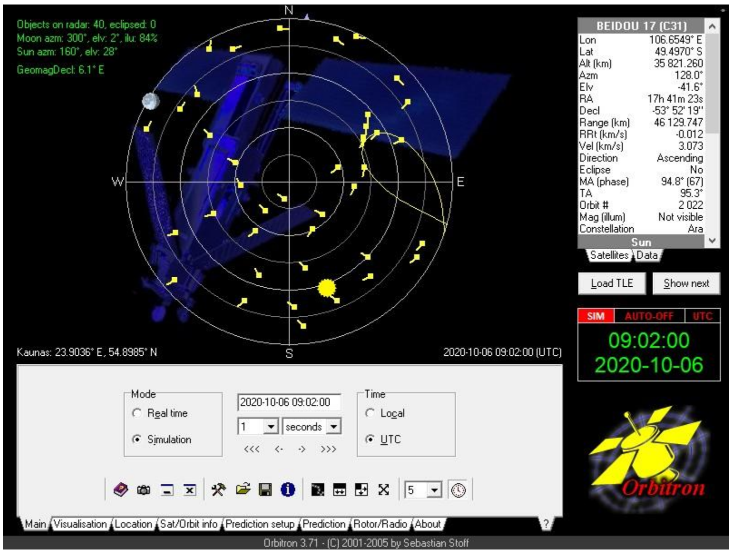

Fig. 1.2.1. Orbitron program view

The TLE file is loaded in the program and the desired time is inputted (2020-10-06) at the simulation part, also the desired location is inputed with the exact coordinate (54.6872 º N, 25.2797 º E) at the location bar, all satellite are selected to be visualized at the radar view.

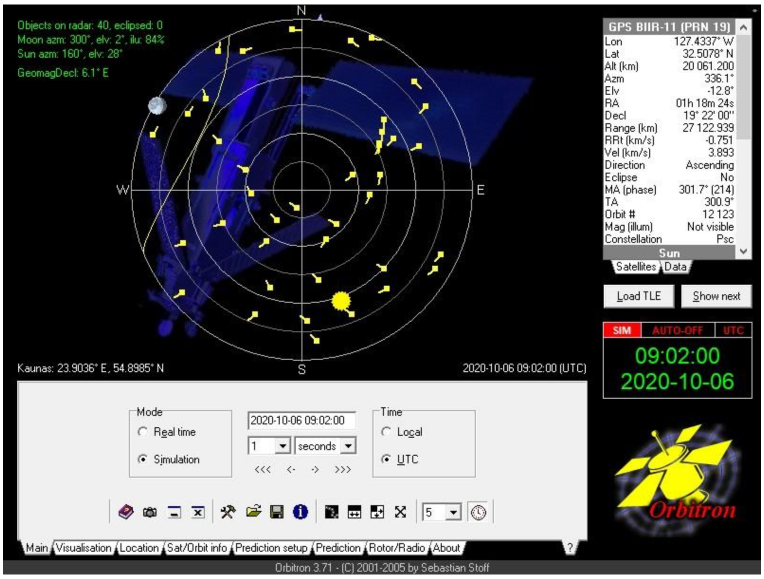

Fig. 1.2.2.1. GPS BIIR (PRN 19) satellite orbital data

As shown in Fig. 1.2.2. Orbital data of GPS BIIR (PRN 19) satellite displays the relative (RRT) (-0.751km/s) at 09:02hrs UTC on 2020-10-06.

From Equ 6. Doppler effect can be calculated.

Doppler effect $\Delta F = \frac{Vr * Fl}{c} = \frac{-0.751 * 1575.42E6}{3E8}$ = -3.944khz

GPS BIIR (PRN 19) satellite was approaching Vilnius at 0.751km/s with 3.944khz frequency.

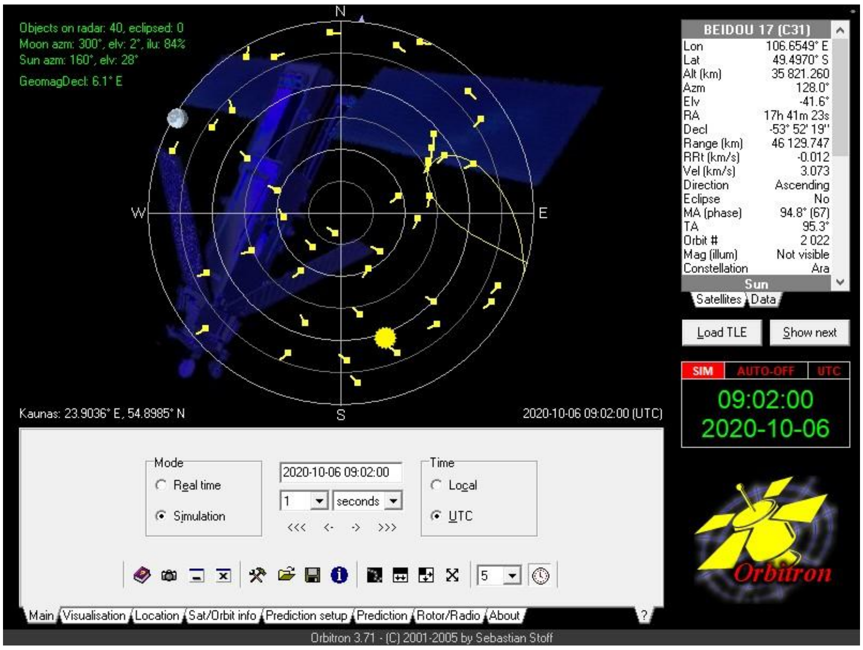

Fig. 1.2.2.2. BEIDOU 17 (C31) satellite orbital data

As shown in Fig. 1.2.2. Orbital data of BEIDOU 17 (C31) satellite displays the relative (RRT) (-0.012km/s) at 09:02hrs UTC on 2020-10-06.

From Equ 6. Doppler effect can be calculated.

Doppler effect $\Delta F = \frac{Vr * Fl}{C} = \frac{-0.012 * 1575.42E6}{3E8}$ = -0.063khz

BEIDOU 17 (C31) satellite was approaching Vilnius at 0.012km/s with 0.063khz frequency.

1.8.3. Python

Identification of “visible” GNSS satellites above Kaunas using submitted signal records of the GNSS satellites using Spyder complier. 2020-10-06.

Skyfield is able to predict the positions of Earth satellites by loading satellite orbital elements from Two-Line Element (TLE) files “ GNSS_2020_10_07.txt“ running them through the SGP4 satellite propagation routine.

Spyder software was used to run the python code

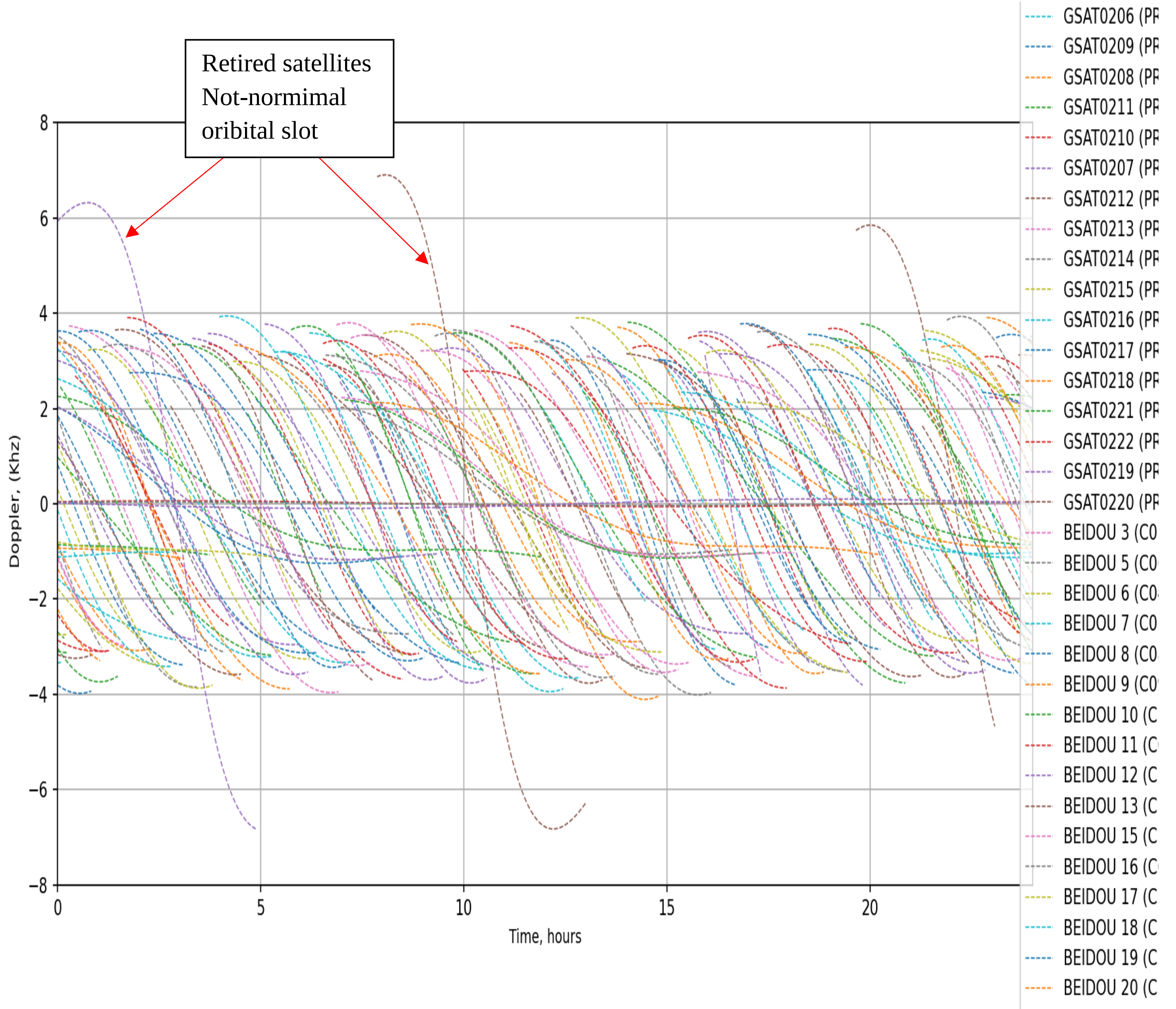

Fig. 1.2.3.1. GNSS satellite signal change in 24 hours

As shown in Fig. 1.2.3.1. GSAT0202 (PRN E14) and GSAT0202 (PRN E14) satellites have high signal frequencies above 6Khz compared to the rest satellite which are below 4Khz. These extreme Doppler shift are unsuccessful galileo satellites which failed to be on the current orbits.

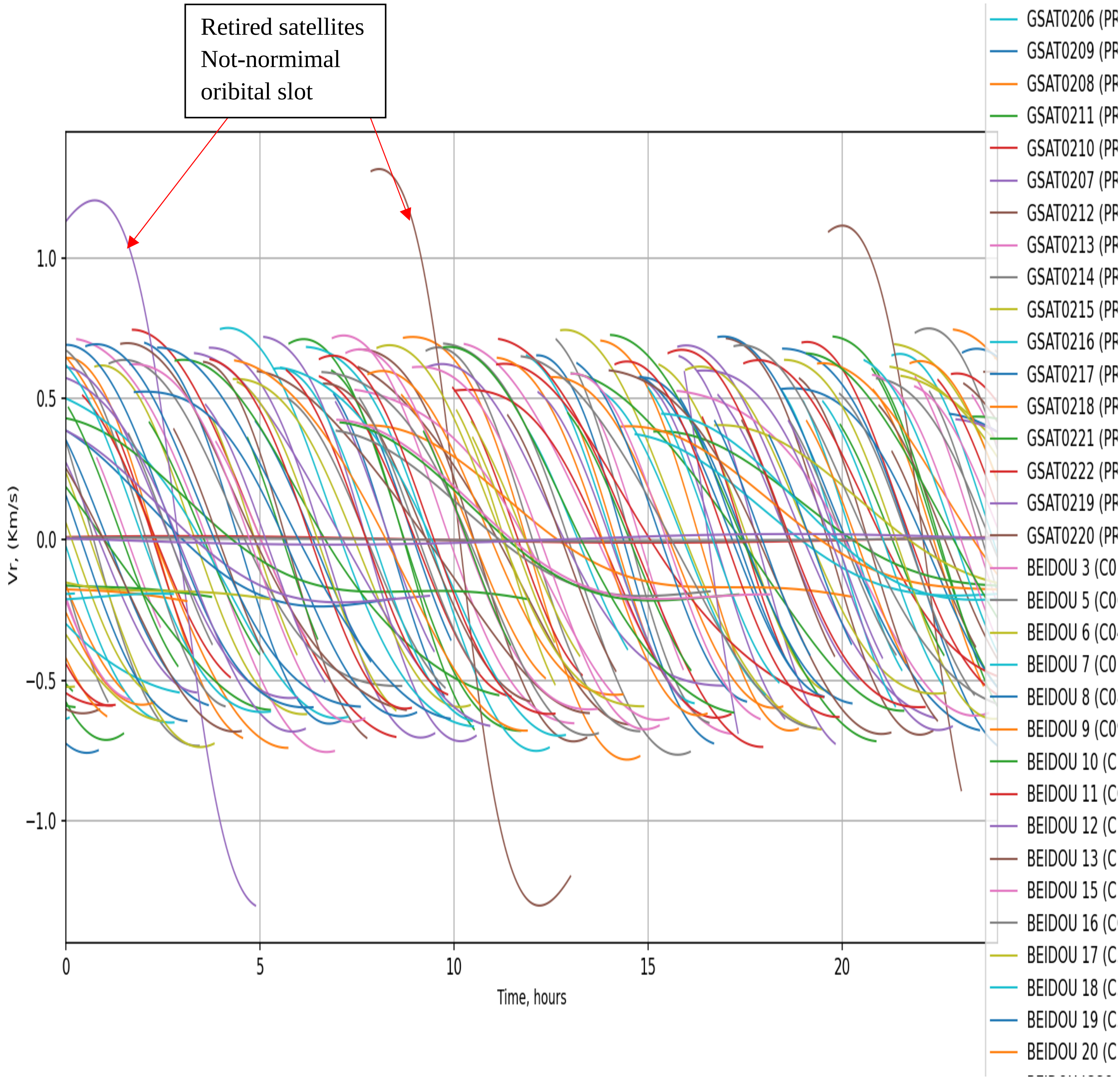

Fig. 1.2.3.2. GNSS satellite relative velocity change in 24 hours

As shown in Fig. 1.2.3.2. GSAT0202 (PRN E14) and GSAT0202 (PRN E14) satellites have high signal frequencies above 1m/s compared to the rest satellite which are below 1m/s. These extreme Doppler shift are unsuccessful galileo satellites which failed to be on the current orbits.

Kindly find Python code used to identify the Doppler effect and relative velocity in an attached document in moodle [6].

Identification of "visible" GNSS satellites above Vilnius using submitted signal records of the GNSS satellites using Orbitron program. 2020-10-06 at specific time 9:02UTC.

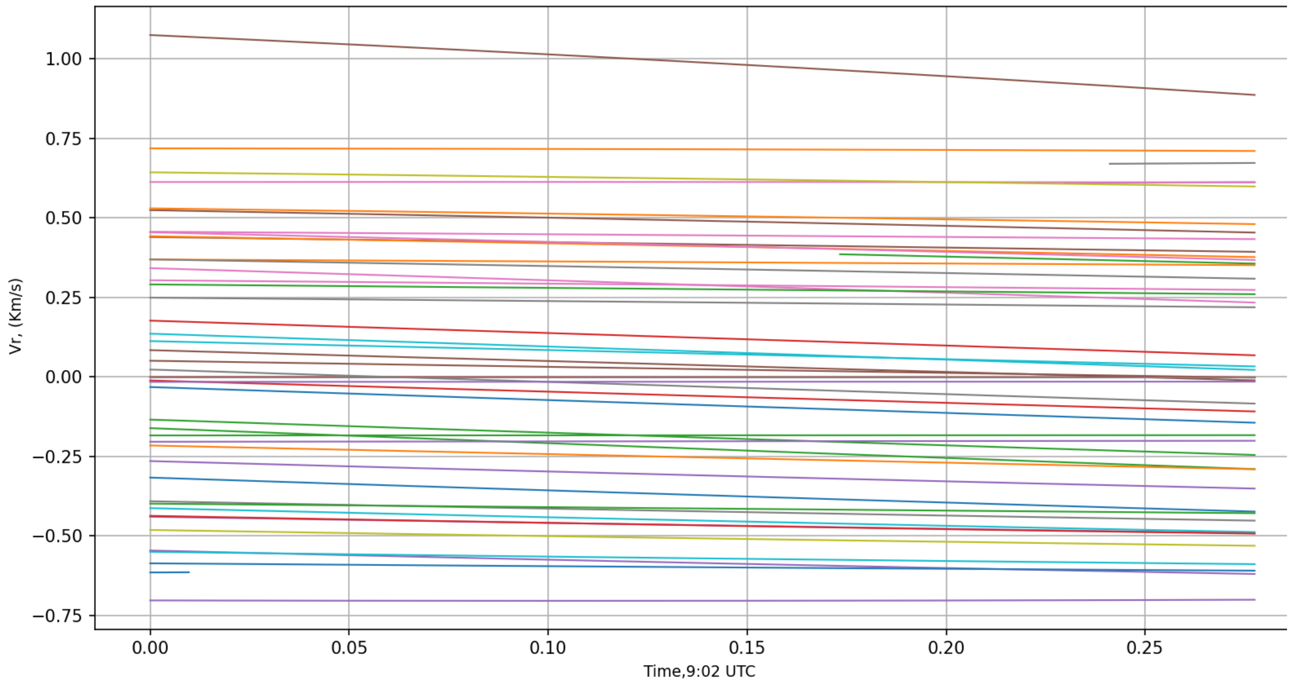

Fig. 1.2.3.3. GNSS satellites relative velocity visible at 9:02UTC

As shown in Fig. 1.2.3.3. Over 45 GNSS satellites were identified at exactly 9:02UTC on 2020-10-06 above Vilnuis. GSAT0202 (PRN E14) satellites was seen to be approaching velocity of above 1km/s

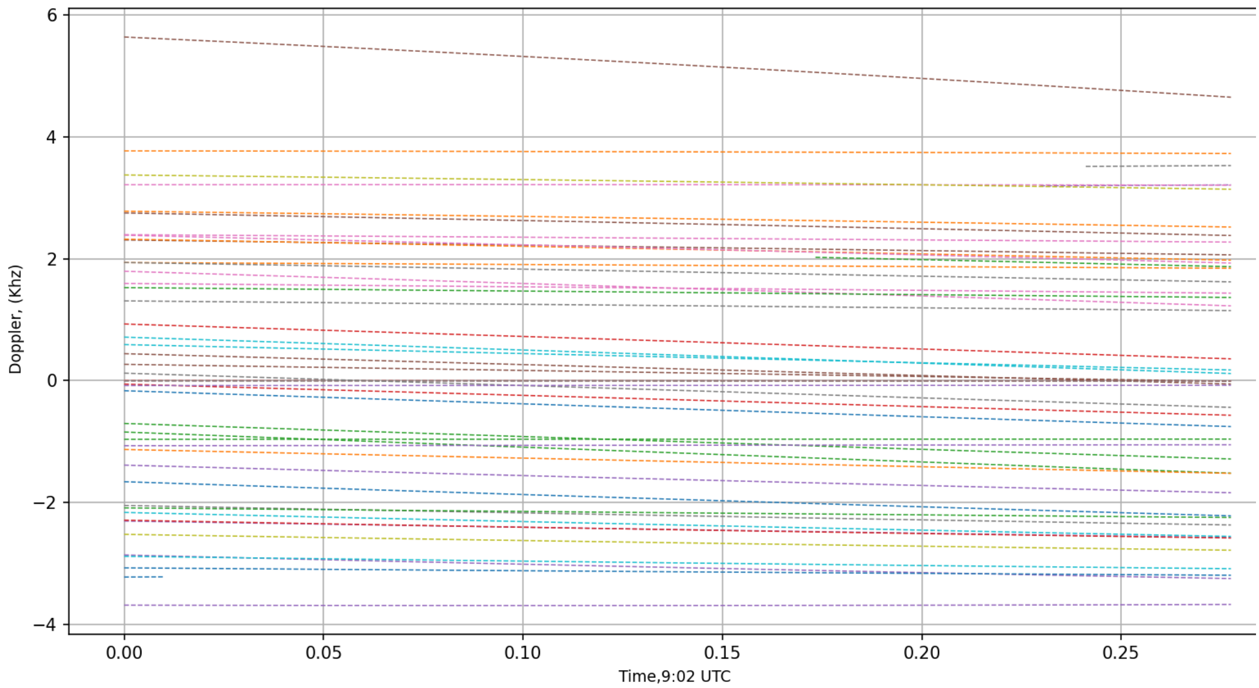

Fig. 1.2.3.4. GNSS satellites Doppler effect visible at 9:02UTC

As shown in Fig. 1.2.3.4. Over 45 GNSS satellites were identified at exactly 9:02UTC on 2020-10-06 above Vilnuis. GSAT0202 (PRN E14) satellites was seen to be approaching frequency of less than 6khz.

1.8.4. Python Code

```
import numpy as np
from scipy.spatial.transform import Rotation as rot
import datetime
from skyfield.api import Loader, EarthSatellite
from skyfield.timelib import Time
from skyfield.api import EarthSatellite, Topos
import skyfield.api
from skyfield.api import load

from skyfield.timelib import Time
import matplotlib.pyplot as plt

TLE_file = "A_GNSS_2020_10_07.txt"
with open(TLE_file, "rt") as f:    # Opening Txt file
  TLE_data = f.read()              # Reading Txt file

TLE_data = TLE_data.split("\n")    # Spliting Txt file

tle = []
for i in range(0, len(TLE_data), 3):    # Txt file has a 318 lines
    name = {}
    tle.append({
        "satellite":EarthSatellite(TLE_data[i+1], TLE_data[i+2], TLE_data[i]),
        "name":TLE_data[i], "1":TLE_data[i+1], "2":TLE_data[i+2],
        })

Time_range = skyfield.api.load.timescale()
Th = Time_range.utc(2020, 10, 6, 9,2, range(0,1000, 1))   # 1000 milli second interval at exactly 9.02 UTC
ts = load.timescale()
Tx = ts.utc(2020, 10, 6, 9, 2, 0 )

Th = Time_range.tt_jd(Th.tt-3/24)


T = (24)*(Th-Th[0])
t = 24
Seconds = 1./24/3600
th = Time_range.tt_jd(Th.tt+Seconds)
my_loc = Topos('54.6872 N', '25.2797 E')      # Vilnius Coordinates
Fre = 1575.42e6                               # GNSS L1 band center frequency
C = 3e8                                       # Speed of light
name = "name"
CL = "Current Velocity"
VL = "Relative Velocity"
doppler = "Doppler Frequency"
```

```
for i in range(len(tle)):
    satellite = tle[i]['satellite']
    rel_pos = (satellite - my_loc).at(Th)     # Initial position
    rel_pos2 = (satellite - my_loc).at(th)    # Position after ine second

    alt, az, distance = rel_pos.altaz()
    I = np.where(alt.degrees < 0)
    D = rel_pos.position.km
    D1 = rel_pos2.position.km
    Dn = np.linalg.norm(D,axis=0)
    Dn1 = np.linalg.norm(D1,axis=0)
    Dis = D -D1
    Vrx = Dn-Dn1                              # Relative velocity
    Doppler = (Fre*Vrx)/C                     # To calculate Doppler shift

    Vrx[I] = None;
    Doppler[I] = None
    tle[i][VL] = Vrx
    tle[i][doppler] = Doppler

for i in range(len(tle)):
    satellite = tle[i]['satellite']
    rel_pos = (satellite - my_loc).at(Tx)     # Initial position
     # Position after ine second

    alt, az, distance = rel_pos.altaz()
    J = np.where(alt.degrees < 0)
    d = rel_pos.position.km

    dn = np.linalg.norm(d,axis=0)

    dis = d
    vrx = dn                          # Relative velocity
    DOppler = (Fre*vrx)/C                     # To calculate Doppler shift


# To Plot Doppler shift against Time

import pylab as plt
from matplotlib.transforms import Bbox
plt.figure(2, dpi = 150)
plt.clf()
for i in range(len(tle)):
  plt.plot(T, tle[i][doppler], linewidth = 0.75, linestyle = 'dashed', label = tle[i-0][name] )

current_handles, current_labels = plt.gca().get_legend_handles_labels()
reversed_handles = list(reversed(current_handles))
```

```
reversed_labels = list(reversed(current_labels))
plt.gca().legend(loc='center left', bbox_to_anchor=(0.98, 0.6))
# Create empty plot with blank marker containing the extra label


plt.xlabel('Time,9:02 UTC ', fontsize=9)
plt.ylabel(' Doppler, (Khz)', fontsize=9)
plt.grid()

# To Relative velocity against Time
import pylab as plt
plt.figure(1, dpi = 150)
plt.clf()
oversize_policy = None     # what there is now
oversize_policy = "hide"   # what is added short term
oversize_policy = "popup"  # for the future

for i in range(len(tle)):
  plt.plot(T, tle[i][VL], linewidth = 1, label = tle[i-0][name] )

current_handles, current_labels = plt.gca().get_legend_handles_labels()
reversed_handles = list(reversed(current_handles))
reversed_labels = list(reversed(current_labels))
plt.gca().legend(loc='center left', bbox_to_anchor=(0.98, 0.6))
# Create empty plot with blank marker containing the extra label



plt.xlabel('Time,9:02 UTC ', fontsize=9)
plt.ylabel(' Vr, (Km/s)', fontsize=9)
plt.grid()
```

CONCLUSION

In this paper, I was able to identify GNSS satellites above Vilnius using different methods and also to identify several satellites by their frequency at a specific time using python program.

The results in this paper demonstrate the identification of satellites at (54.6872 º N, 25.2797 º E) on October 6, 2020 by Doppler shifts in their signal frequencies.

A total of 106 satellites was identified. 30 GPS satellites, 26 Galileo satellites and 50 BEIDOU satellites.

At Tx = 9.02 (Analysis time), I = 1624
As shown in Fig. 1.2.2.4. Maximum level of the normalized GNSS satellite carrier signal amplitude and their Doppler shift at time Tx = 9.02hrs UTC is at -657.5Hz.

As shown in Fig. 1.2.2.4. Maximum level of the normalized GNSS satellite carrier signal amplitude and their relative velocity at time Tx = 9.02hrs UTC is at -125.205m/s.

As shown in Fig. 1.2.3.1 and Fig. 1.2.3.2. GSAT0202 (PRN E14) and GSAT0202 (PRN E14) satellites have high signal frequencies above 6Khz compared to the rest satellite which are below 4Khz. These extreme Doppler shift are unsuccessful galileo satellites which failed to be on the current orbits.

The two extreme Doppler shift satellites are easy to be find out of the hundreds of satellities. The both travel at a faster relative velocity of more than 1km/s compared to the rest identified sarellites.

As shown in Fig. 1.2.3.3. Over 45 GNSS satellites were identified at exactly 9:02UTC on 2020-10-06 above Vilnuis. GSAT0202 (PRN E14) satellites was seen to be approaching frequency of less than 6khz.

As shown in Fig. 1.2.3.4. Over 45 GNSS satellites were identified at exactly 9:02UTC on 2020-10-06 above Vilnuis. GSAT0202 (PRN E14) satellites was seen to be approaching velocity of above 1km/s.

For Obitron software a –ve RRT (relative velocity) indicates that the satellite is approaching, while +ve RRT indicates that the satellite is existing.

For Python code a –ve RRT (relative velocity) indicates that the satellite is existing, while +ve RRT indicates that the satellite is approaching.

Global Navigation Satellite Systems (GNSS) technology has become vital to many applications that range from city planning engineering and zoning to military applications. It has been widely accepted globally by governments and organizations..

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