gr-satellites and related experiments

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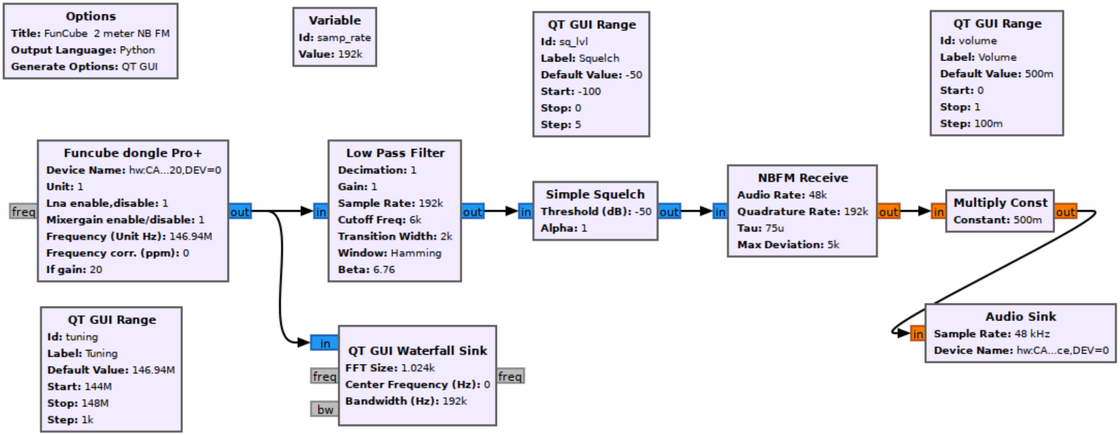
Outline

GNU Radio

- GNU Radio is an open source framework to do DSP for radio.
- It comes with:
  - A GUI application called “GNU Radio companion” where systems can be implemented by dragging and dropping blocks onto a canvas, making a “flowgraph”.
  - A rich library of processing blocks accessible both through GNU Radio companion, and C++ and Python APIs.
  - A “runtime”, that moves data between these blocks.
- In the GNU Radio ecosystem there are out-of-tree modules, which implement new blocks that don’t fit into or exist in the in-tree library.
- There are also full applications that use GNU Radio for their DSP (e.g., GQRX and QRadioLink).

Example flowgraph



gr-satellites

- gr-satellites is a GNU Radio out-of-tree module with a collection of telemetry decoders for Amateur satellites.
- It supports most satellites that transmit on the 145 and 435 MHz Amateur bands: 53 different protocols, and 282 satellites.
- The project started in 2015 with the motivation to create decoders for satellites for which no decoder was publicly available.
- ITU Radio Regulations: “Transmissions between amateur stations [...] shall not be encoded for the purpose of obscuring their meaning” $\Rightarrow$ “open access” for transmissions on amateur radio bands.
- Other goals: education, support to new satellite teams (universities...).
- It can work with recordings and with real-time data from an SDR or conventional radio.

Installing gr-satellites

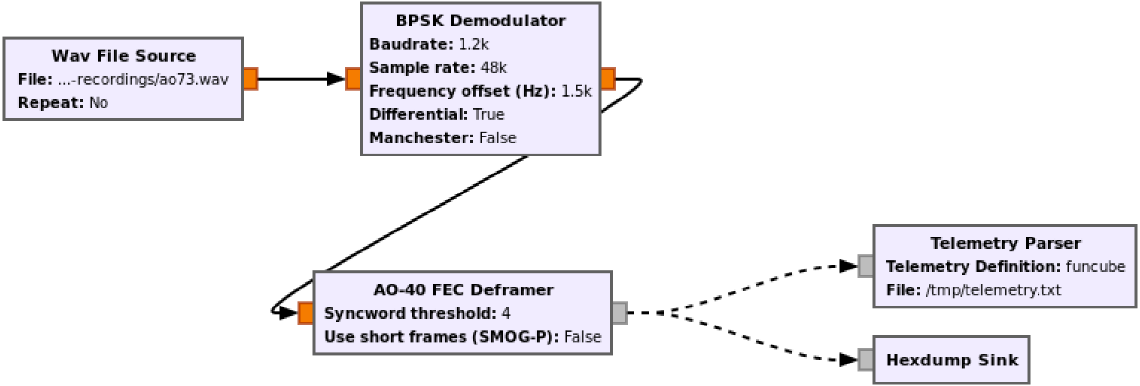
- Source code available at
  `https://github.com/daniestevez/gr-satellites`.
- Radioconda: easy installer for GNU Radio and many related packages for Windows, Mac and Linux.
- Ubuntu PPA for the latest Ubuntu release.
- Also packaged by other Linux distributions.

gr_satellites command line tool

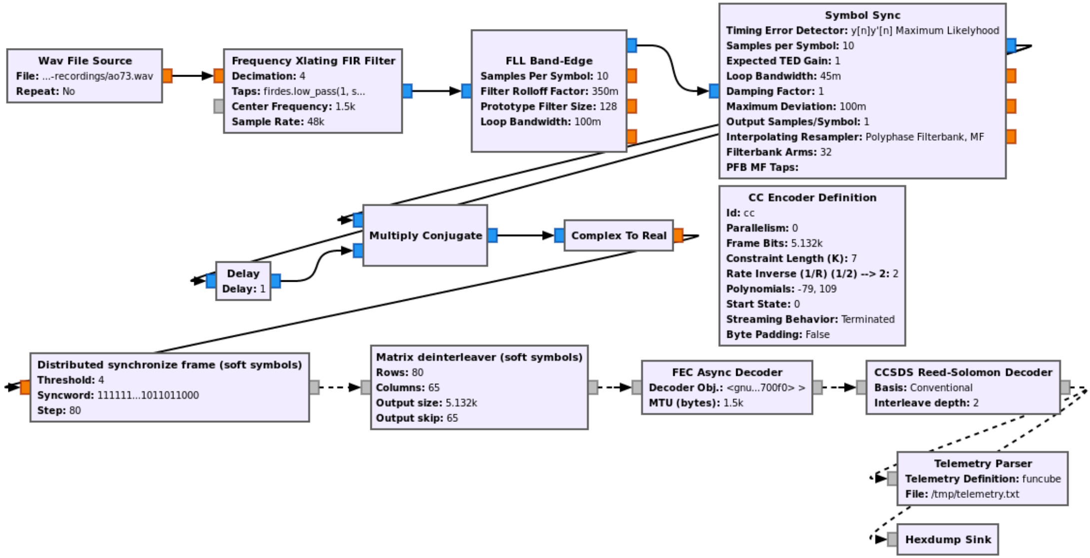
```
$ gr_satellites FUNcube-1 --wavfile satellite-recordings/ao73.wav
-> Packet from 1k2 BPSK downlink
Frame type WO10
----------------------------------------
Realtime telemetry:
----------------------------------------
Container:
    eps = Container:
        photovoltage = ListContainer:
            0
            0
            0
        photocurrent = 0
        batteryvoltage = 8140
...
```

Satellite decoder block

Component blocks



Low level blocks



YAML configuration


```yaml
name: AO-73
alternative_names:
  - FUNcube-1
norad: 39444
telemetry_servers:
  - FUNcube
data:
  &tlm Telemetry:
    telemetry: funcube
transmitters:
  1k2 BPSK downlink:
    frequency: 145.935e+6
    modulation: DBPSK
    baudrate: 1200
    framing: AO-40 FEC
    data:
    - *tlm
```

Outline

Deep space satellite decoding

- I've been interested in decoding deep space satellites since early 2020.
- I've been building GNU Radio decoders for most missions launched since then (see `http://destevez.net`).
- Not officially part of gr-satellites, but re-uses many blocks.
- Amateur DSN:
  - Traditionally, detection of CW carrier.
  - Decoding becoming more common. More missions means more opportunities, and now there are more tools.
- TLEs are no good outside Earth orbit. Other tools are needed: NASA Horizons, GMAT.
- This gives us practical experience for future Amateur payloads and missions outside Earth orbit.
- Huge help by getting observing time on the Allen Telescope Array. Thanks to SETI Institute, BSRC and GNU Radio!

NASA HORIZONS

Horizons System

About | App | Manual | Tutorial | Time Spans | News

Horizons Web Application

Save/Load Settings...

1 Ephemeris Type: Observer Table

2 Edit Target Body: **Lucy (spacecraft)**

3 Edit Observer Location: **London England** (0°07′00.1″W, 51°30′00.0″N)

4 Edit Time Specification: Start=**2022-10-08** UT , Stop=**2022-10-09**, Step=**15** (minutes)

5 Edit Table Settings: *custom*

After specifying settings above (items 1 to 5), generate an ephemeris by pressing the "Generate Ephemeris" button below. If you plan
can be viewed by using this link.

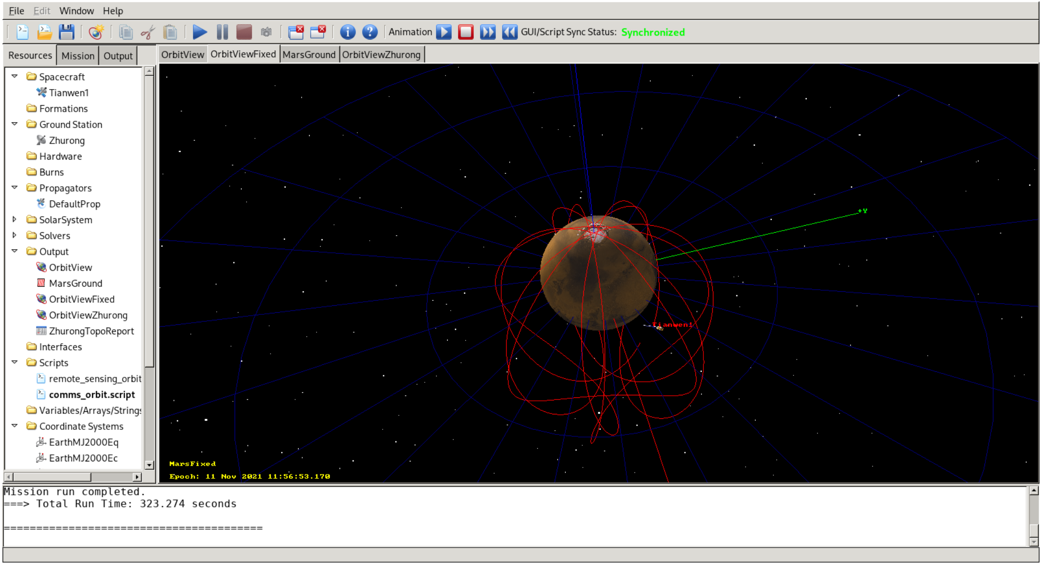
Generate Ephemeris

Home | About | Orbits & Ephemerides | Planets | Planetary Satellites | Small Bodies | Tools | Extras

Home / Tools / Horizons System

```
Rel. lght bnd GM: 1.3271E+11, 3.9860E+05 km^3/s^2
Atmos refraction: NO (AIRLESS)
RA format       : HMS
Time format     : CAL
RTS-only print  : NO
EOP file        : eop.220923.p221216
EOP coverage    : DATA-BASED 1962-JAN-20 TO 2022-SEP-23. PREDICTS-> 2022-DEC-15
Units conversion: 1 au= 149597870.700 km, c= 299792.458 km/s, 1 day= 86400.0 s
Table cut-offs 1: Elevation (-90.0deg=NO ),Airmass (>38.000=NO), Daylight (NO )
Table cut-offs 2: Solar elongation (  0.0,180.0=NO ),Local Hour Angle( 0.0=NO )
Table cut-offs 3: RA/DEC angular rate (     0.0=NO )
****************************************************************************************************************************************************************
 Date__(UT)__HR:MN     R.A.____(ICRF)____DEC  Azi___(a-app)___Elev    APmag   S-brt             delta      deldot     S-O-T /r     S-T-O  Sky_motion  Sky_mot_PA  RelVel-ANG  Lun_
****************************************************************************************************************************************************************
$$SOE
 2022-Oct-08 00:00  m  13 12 03.59 -06 27 14.7  357.453379 -45.046596    n.a.    n.a.  4.0057467707E+06  -5.4780896    4.8072 /T  175.0606   0.9691535   92.262844   -86.72270
 2022-Oct-08 00:15  m  13 12 04.56 -06 27 15.3    2.735592 -45.042913    n.a.    n.a.  4.0008080022E+06  -5.4966801    4.8011 /T  175.0670   0.9716104   92.657890   -86.72952
 2022-Oct-08 00:30  m  13 12 05.54 -06 27 16.0    7.998525 -44.824349    n.a.    n.a.  3.9958525145E+06  -5.5152291    4.7951 /T  175.0734   0.9702712   93.063668   -86.74900
 2022-Oct-08 00:45  m  13 12 06.51 -06 27 16.9   13.206071 -44.394257    n.a.    n.a.  3.9908803814E+06  -5.5336555    4.7890 /T  175.0798   0.9651364   93.483335   -86.78092
 2022-Oct-08 01:00  m  13 12 07.48 -06 27 17.8   18.325367 -43.759054    n.a.    n.a.  3.9858917495E+06  -5.5518791    4.7829 /T  175.0862   0.9562234   93.920360   -86.82500
 2022-Oct-08 01:15  m  13 12 08.43 -06 27 18.8   23.328431 -42.927799    n.a.    n.a.  3.9808868371E+06  -5.5698204    4.7767 /T  175.0927   0.9435666   94.378635   -86.88092
 2022-Oct-08 01:30  m  13 12 09.37 -06 27 20.0   28.193215 -41.911656    n.a.    n.a.  3.9758659337E+06  -5.5874009    4.7705 /T  175.0993   0.9272173   94.862617   -86.94834
 2022-Oct-08 01:45  m  13 12 10.29 -06 27 21.2   32.904008 -40.723291    n.a.    n.a.  3.9708293987E+06  -5.6045440    4.7643 /T  175.1059   0.9072442   95.377503   -87.02683
 2022-Oct-08 02:00  m  13 12 11.19 -06 27 22.6   37.451275 -39.376287    n.a.    n.a.  3.9657776596E+06  -5.6211748    4.7579 /T  175.1126   0.8837329   95.929458   -87.11597
 2022-Oct-08 02:15  m  13 12 12.06 -06 27 24.0   41.831081 -37.884621    n.a.    n.a.  3.9607112104E+06  -5.6372206    4.7515 /T  175.1194   0.8567864   96.525909   -87.21527
 2022-Oct-08 02:30  m  13 12 12.90 -06 27 25.5   46.044253 -36.262236    n.a.    n.a.  3.9556306094E+06  -5.6526110    4.7449 /T  175.1263   0.8265252   97.175948   -87.32422
 2022-Oct-08 02:45  m  13 12 13.71 -06 27 27.1   50.095450 -34.522712    n.a.    n.a.  3.9505364771E+06  -5.6672788    4.7382 /T  175.1333   0.7930878   97.890875   -87.44225
 2022-Oct-08 03:00  m  13 12 14.48 -06 27 28.8   53.992243 -32.679043    n.a.    n.a.  3.9454294930E+06  -5.6811595    4.7314 /T  175.1405   0.7566308   98.684968   -87.56878
 2022-Oct-08 03:15  m  13 12 15.21 -06 27 30.5   57.744290 -30.743499    n.a.    n.a.  3.9403103932E+06  -5.6941921    4.7244 /T  175.1478   0.7173302   99.576574   -87.70317
 2022-Oct-08 03:30  m  13 12 15.90 -06 27 32.4   61.362638 -28.727558    n.a.    n.a.  3.9351799670E+06  -5.7063194    4.7172 /T  175.1553   0.6753834   100.58970   -87.84475
 2022-Oct-08 03:45  m  13 12 16.55 -06 27 34.3   64.859163 -26.641894    n.a.    n.a.  3.9300390538E+06  -5.7174878    4.7099 /T  175.1630   0.6310109   101.75638   -87.99278
 2022-Oct-08 04:00  m  13 12 17.14 -06 27 36.2   68.246150 -24.496405    n.a.    n.a.  3.9248885390E+06  -5.7276479    4.7024 /T  175.1709   0.5844618   103.12037   -88.14647
 2022-Oct-08 04:15     13 12 17.69 -06 27 38.3   71.535980 -22.300263    n.a.    n.a.  3.9197293509E+06  -5.7367546    4.6947 /T  175.1790   0.5360207   104.74285   -88.30492
 2022-Oct-08 04:30 A   13 12 18.19 -06 27 40.3   74.740920 -20.061983    n.a.    n.a.  3.9145624559E+06  -5.7447674    4.6868 /T  175.1873   0.4860213   106.71185   -88.46712
 2022-Oct-08 04:45 A   13 12 18.63 -06 27 42.5   77.872990 -17.789503    n.a.    n.a.  3.9093888554E+06  -5.7516503    4.6787 /T  175.1958   0.4348689   109.15807   -88.63184
```

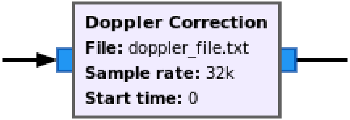
GMAT



File Edit Window Help
Animation
GUI/Script Sync Status: Synchronized
Resources
Mission
Output
OrbitView
OrbitViewFixed
MarsGround
OrbitViewZhurong
Spacecraft
Tianwen1
Formations
Ground Station
Zhurong
Hardware
Burns
Propagators
DefaultProp
SolarSystem
Solvers
Output
OrbitView
MarsGround
OrbitViewFixed
OrbitViewZhurong
ZhurongTopoReport
Interfaces
Scripts
remote_sensing_orbit
comms_orbit.script
Variables/Arrays/Strings
Coordinate Systems
EarthMJ2000Eq
EarthMJ2000Ec
+Y
Tianwen1
MarsFixed
Epoch: 11 Nov 2021 11:56:53.170
Mission run completed.
===> Total Run Time: 323.274 seconds
==

Doppler correction block

- New block added to gr-satellites in July.
- Can correct Doppler using data from a text file (produced with HORIZONS, GMAT, or anything else).



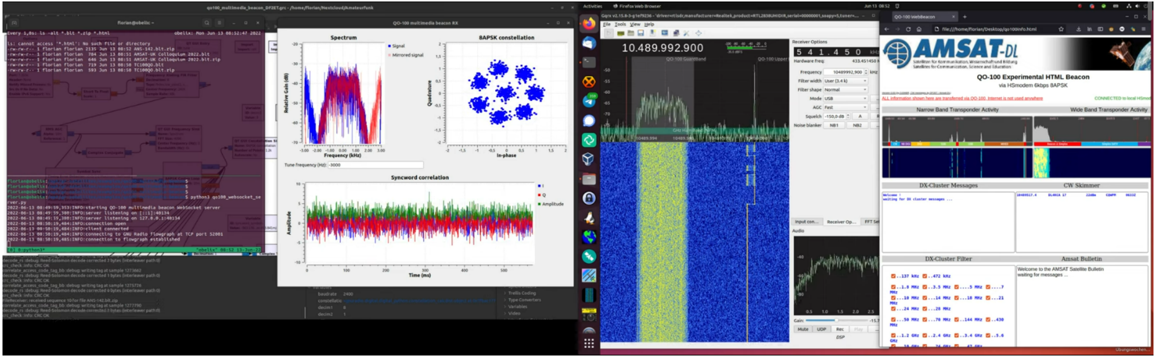
- Was tested with the Allen Telescope Array, by detecting Voyager-1 with a single 6.1 metre dish.
- It seems possible to detect Voyager-1 even with a smaller dish by integrating several hours worth of data!

Outline

QO-100 multimedia beacon

- New digital beacon on the QO-100 NB transponder since May.
- Uses a 2.4kbaud 8APSK modem ($\sim$6.2kbps) by Kurt Moraw DJ0ABR.
- Added a decoder to gr-satellites with some custom blocks.
- The multimedia beacon transmits an HTML webpage and some real-time data (waterfall, DX cluster, CW skimmer) that is sent to the webpage using websockets. Implemented a Python script for that.
- Some help from Florian Wolters DF2ET testing and putting all together with an RTL-SDR and GQRX.
- `https://github.com/daniestevez/gr-satellites/tree/main/examples/qo100-multimedia-beacon`

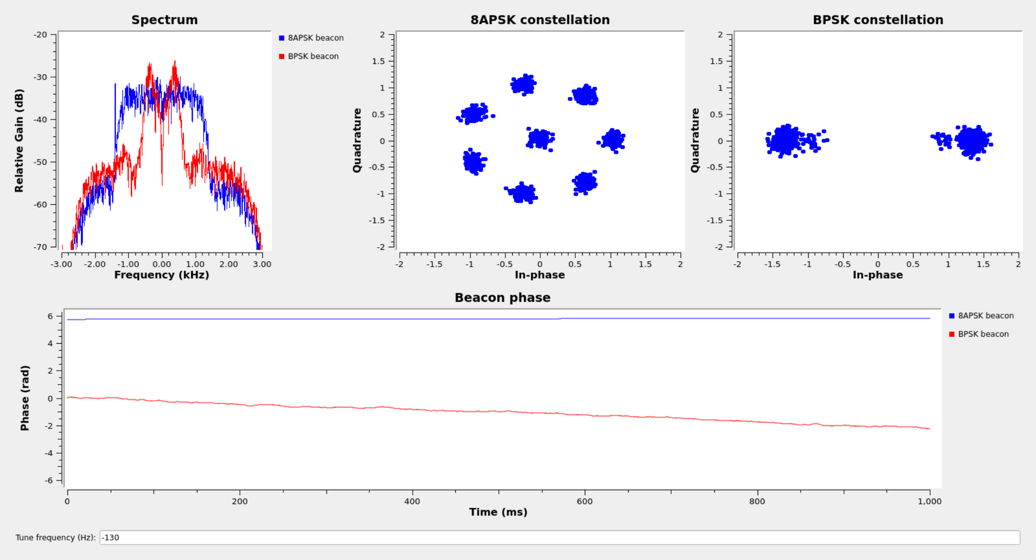
gr-satellites QO-100 multimedia beacon decoder + GQRX + RTL-SDR



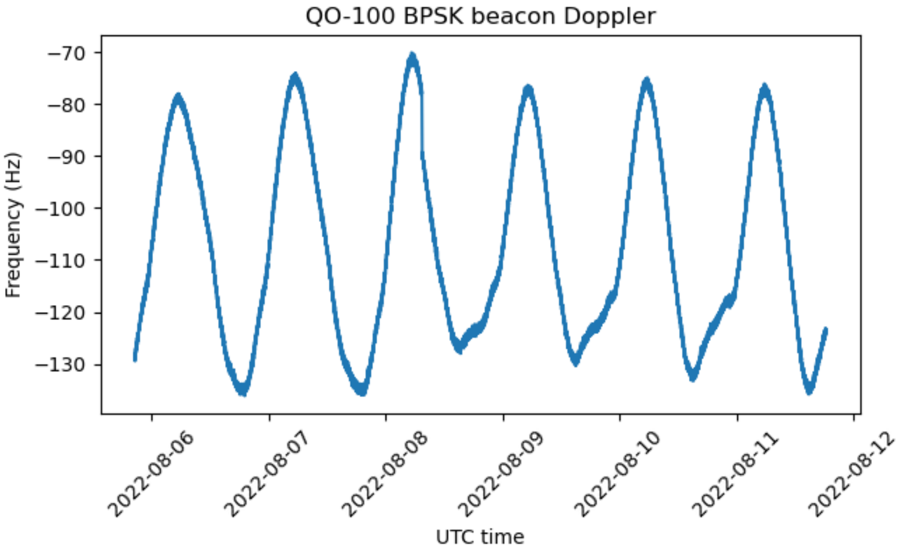
Phase measurement of the QO-100 beacons

- GNU Radio and gr-satellites can be used to measure the phase of the BPSK and 8APSK QO-100 beacons.
- The phase difference between the beacons gives the time of flight (distance) between the transmitter in Bochum, the satellite, and the receiver (plus some unknown constant offset).
- In practice, we can use the Doppler difference of the beacons to do orbit determination.
- Requires calculating all the frequency errors due to the SDR. Done examples for the LimeSDR and Pluto.

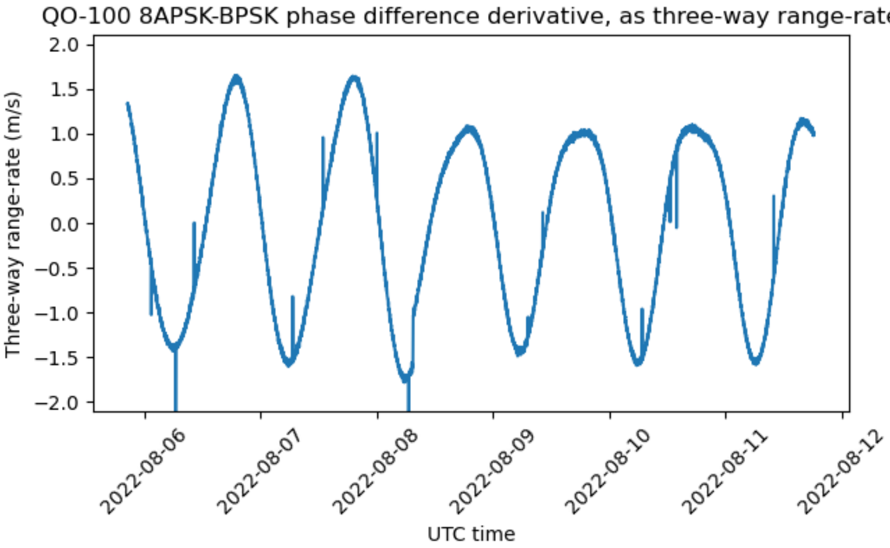
Measurement of the QO-100 beacon phases



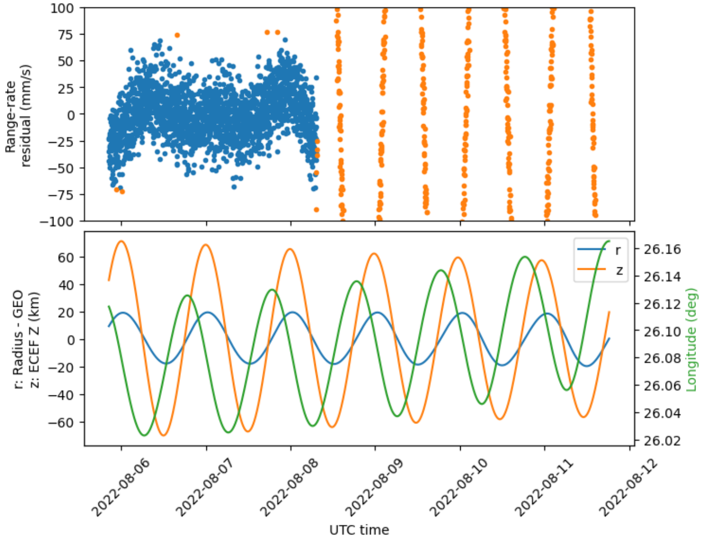
Doppler of one beacon (has spacecraft LO effects)



Doppler difference of two beacons (no spacecraft LO effects!)



Orbit determination



More stations needed

- Having only one stations doesn't give very good results.
- It is difficult to tell if the satellite is going “up” or south.
- Interested people, do get in touch!