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Support for LEO-PNT Constellation Data in IGS Data and Product Files

Miquel Garcia-Fernàndez (Rokubun), Raul Orus-Perez (ESA/ESTEC)

with additional contributions from:
Florin Grec (ESA/ESTEC), Rui Sarnadas (ESA/ESTEC)

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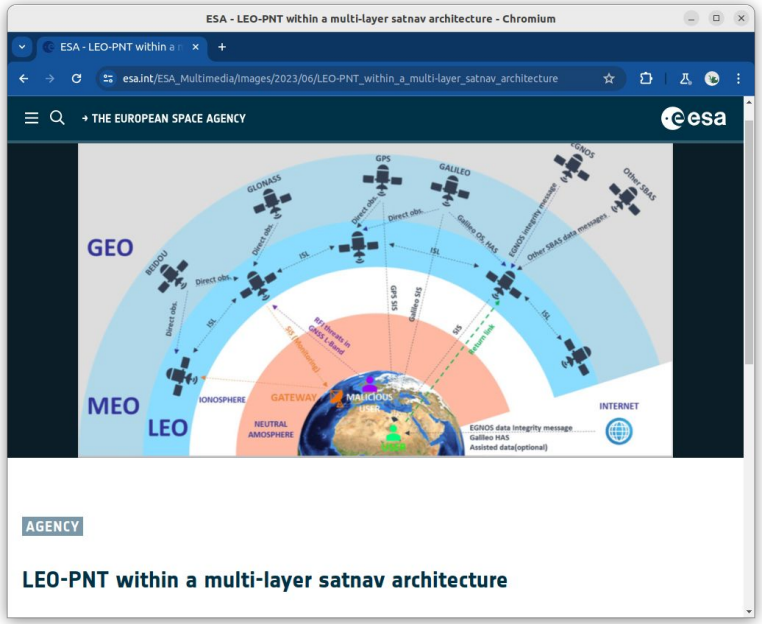
Motivation

- Multi-layer (e.g. LEO) PNT is gaining momentum in the GNSS world
- Institutional: ESA LEO-PNT In orbit demonstration mission, NSSTC/UAE
- Industry (commercial PNT): Xona, Centispace, Trustpoint, Spirent, …
- Industry is already moving forward to advance technology
    - Positioning Engines
    - Research applications

- Need for a standardized format to exchange data!



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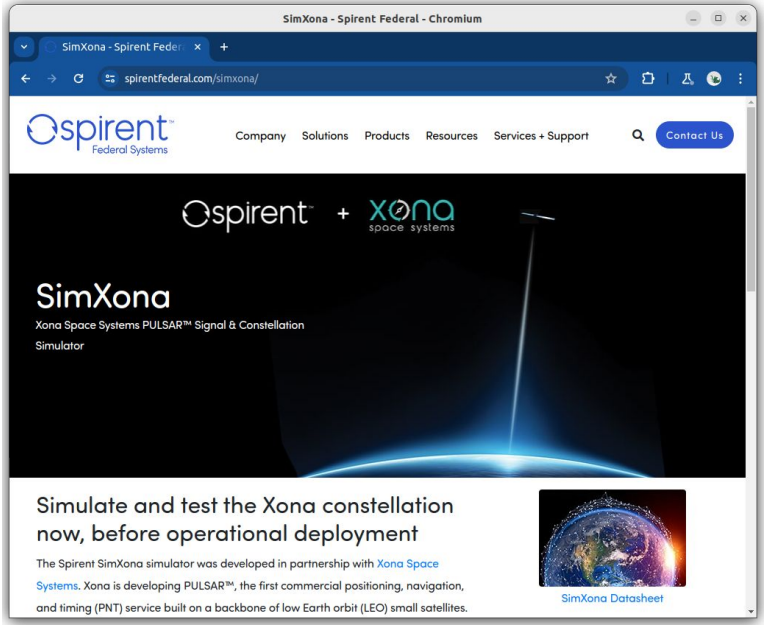

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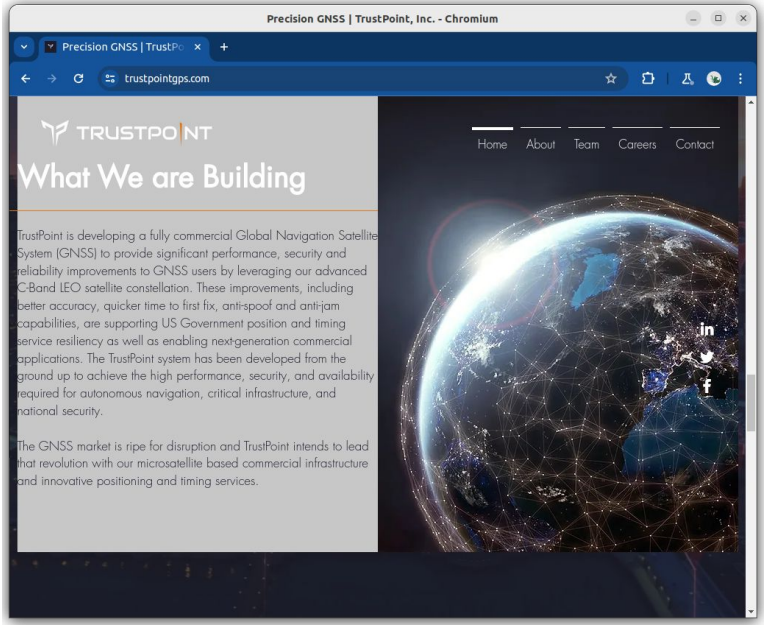

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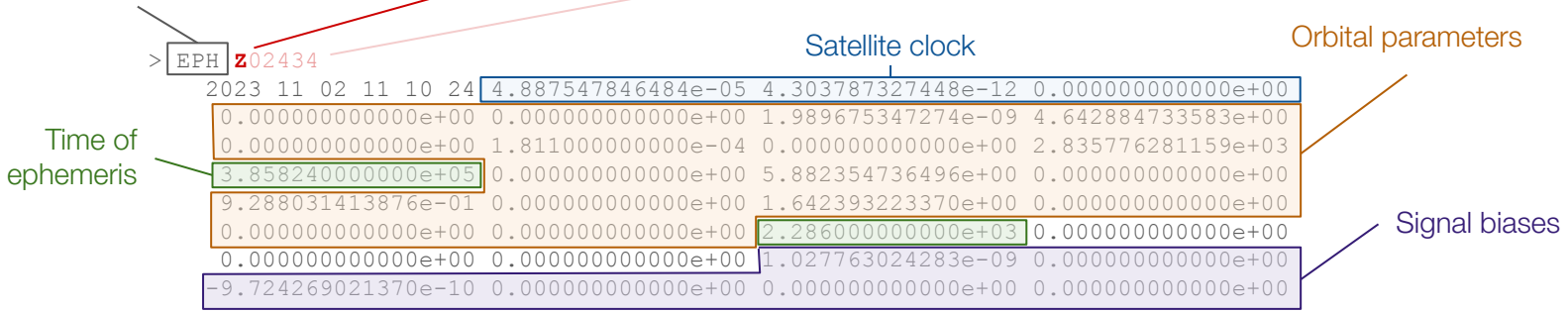
RINEX Navigation

- “Easiest to adapt” in RINEX version 4
- Needs agreement on constellations to include as well as fields for each constellation (e.g. signal biases)

LEO constellation type	Constellation	LEO satellite id
L	Generic LEO-PNT constellation	custom
P	Xona	NORAD id
Y	Geely	NORAD id
X	Starlink	NORAD id
O	Oneweb	NORAD id
V	Spire	NORAD id
Z	Centispace	NORAD id

Rinex 4 “EPH” allows arbitrarily long Sat ID descriptor (no need to place it in the data block

NORAD id (5 digit) could be used. Mega-constellations may reach thousand satellites (e.g. Starlink)



RINEX Observation

- Critical **limitation**: 2-digit for Satellite ID

- Needs to maintain **consistency** with proposed extension for RINEX NAV (5-digit satellite ID)
- After several iterations, opted to add a “breaking change” where the parser will have to check first letter to select the appropriate parser (e.g. decide how to parse satellite ID, necessary fields, …).

OBSERVATION DATA FILE - DATA RECORD DESCRIPTION (LEO)	
DESCRIPTION	FORMAT
EPOCH record	
- Record start identifier : ">"	A1
- Epoch:	
- year (4 digits)	1X,I4
- month, day, hour, min (2 digits)	4(1X,I2.2)
- sec	F11.7
- Epoch flag [*]	2X,I1
- Number of satellites in current epoch	I3
- (reserved)	6X
- receiver clock offset (seconds, optional)	F15.12
[*] EPOCH FLAG follow the same definition as RINEX 4.0	
OBSERVATION record for LEO-PNT satellites [**]	
- Satellite number (LEO system dependent, e.g. NORAD ID)	A1,I5
- m fields of observation data in the same sequence as given in the "SYS / # / OBS TYPES" header record	m(F14.3,
- LLI | each obs.type (same seq	I1,
- Signal strength | as given in header)	I1)
[**] Observation records for MEO GNSS are the same as RINEX 4	

RINEX Observation

- Example

```
     4.99           OBSERVATION DATA    M (MIXED)           RINEX VERSION / TYPE
rdd 76.46.1-r1      Rokubun             20240613 105750 UTC PGM / RUN BY / DATE
SIM                                                         MARKER NAME
                                                            MARKER NUMBER
                                                            MARKER TYPE
                                                            OBSERVER / AGENCY
                    argos               76.46.1-r1          REC # / TYPE / VERS
                                                            ANT # / TYPE
        0.0000        0.0000        0.0000                  APPROX POSITION XYZ
        0.0000        0.0000        0.0000                  ANTENNA: DELTA H/E/N
  2023    11    01    19    52   17.0000000     GPS         TIME OF FIRST OBS
  2023    11    01    20    13   57.0000000     GPS         TIME OF LAST OBS
G    4 C1C L1C D1C S1C                                     SYS / # / OBS TYPES
E    4 C1C L1C D1C S1C                                     SYS / # / OBS TYPES
z    4 C1C L1C D1C S1C                                      SYS / # / OBS TYPES
                                                            END OF HEADER

> 2023 11 01 19 52 17.0000000  0 15
E13  25878172.51301 135990714.41801      -2235.82001
E21  24723841.81401 129924665.65301      -2178.18601
E26  23323688.40101 122566809.80701       -375.24701
E31  26757149.28001 140609768.50701       2545.19701
E33  25223059.64801 132548073.07601       1626.59801
G05  22952763.20301 120617584.73401       3596.63401
G06  22062030.79501 115936754.33601      -2652.35101
G11  20540902.96801 107943173.65301       -851.69301
G12  20392939.80101 107165621.96401        475.05801
G19  23163152.88101 121723189.95101      -2373.50601
G20  20884593.55701 109749279.88701       1663.99601
G24  24918715.92301 130948736.00901      -2767.12401
G25  22080762.26401 116035188.87301       2581.21401
G29  25095906.90201 131879880.88601       2656.54601
z47817   3913093.12601  20563443.16801     27481.19301
```

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SP3 format

- Problem statement: Similar than RINEX, 2-digit satellite ID
- Required modifications will have larger impact:
  - Satellite block in header
  - Satellite ID in PV rows
- Example: LEO orbit for Spire's LEMUR satellites.
  - ID specified in the file name:
    `leoOrb_2021.004.125.16_0001.0001_sp3`
  - Uses **`L99`** inside the file (single satellite). Only 8 satellites would fit in each row of the satellite header block, instead of 17.

```
#cV2021  1  4  8 16 53.00000000     478       IGS08 FIT UCAR
## 2139 116213.00000000    60.00000000 59218 0.3450578703705
+    1   L99  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
+          0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
+          0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
+          0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
+          0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
++         0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
++         0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
++         0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
++         0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
%c     cc GPS ccc cccc cccc cccc cccc ccccc ccccc ccccc ccccc
%c cc cc ccc ccc cccc cccc cccc cccc ccccc ccccc ccccc ccccc
%f 00.0000000 00.000000000 00.00000000000 00.000000000000000
%f 00.0000000 00.000000000 00.00000000000 00.000000000000000
%i 0000 0000 0000 0000 000000 000000 000000 000000 000000000
%i 0000 0000 0000 0000 000000 000000 000000 000000 000000000
/*
/*
/*
/*
*  2021  1  4  8 16 53.00000000
PL99   5524.274281   3163.274083  -2698.438729 999999.999999
VL99 -17743.894636 -27918.462889 -69221.257287 999999.999999
```

Open questions

- Should we go for a RINEX format specific to LEO systems only (rather than mixing it with currently existing GNSS MEO systems?
- Reference signal for satellite clock in RINEX Nav? (dual freq. Iono-combination? Which signals?)
- Description of orbital parameters in LEO orbit (larger perturbations): Increase update rate (allowed by the format), increase grade of sine/cosine coefficients (may require update of the format, … Alternatively, should we use GLONASS- /SBAS- like ephemeris (XYZ)
- How to assign letters for satellite constellation. Any limitations?
- Signal biases in RINEX Nav: To be defined on a per-constellation basis. Number of frequencies and channels (data? pilot?...). Example: Xona frequencies are public, but not its signal structure.

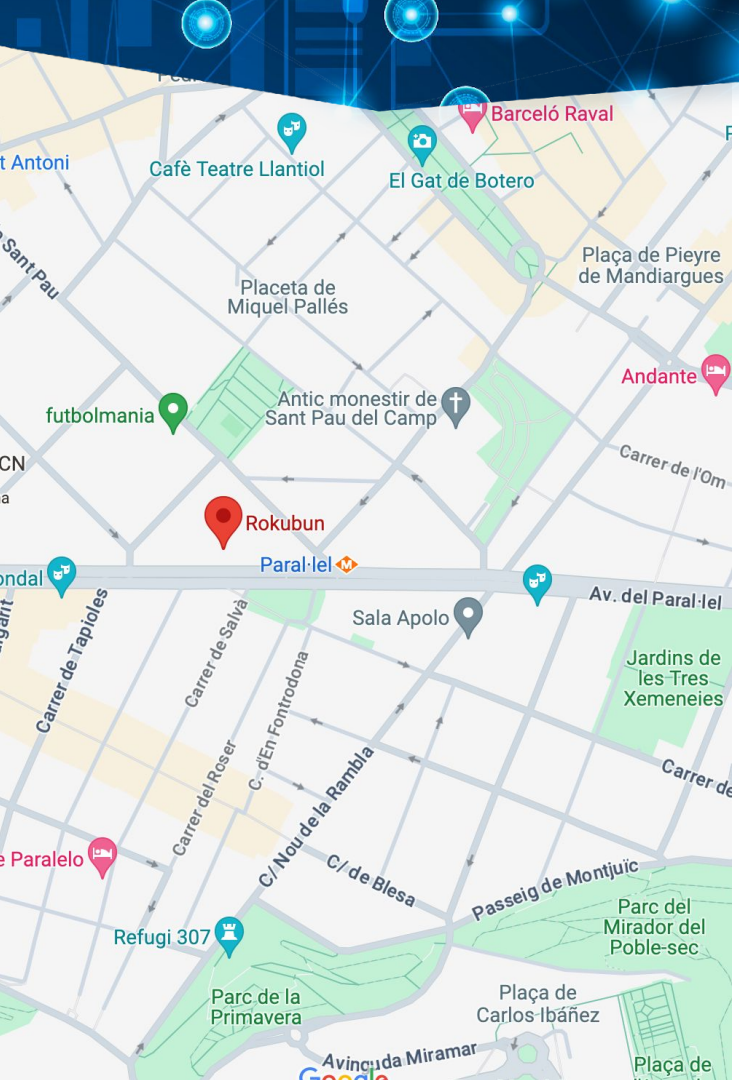
Conclusions

Extension of RINEX and SP3 format proposed

- RINEX format is widely used not only in academia, but also in industry
- Development of Multi-layer PNT positioning engines (and other processing tools) are already underway
- Satellites for LEO-PNT already in place
- ESA's LEO-PNT missions in-orbit before 2027
- Therefore, standardization is important to foster development and knowledge exchange.

Ongoing and next steps:

- Gather feedback from relevant stakeholders (academia, receiver manufacturers, simulation, …) to address open questions.
- Github repo with format proposal: https://github.com/rokubun/rinex_leo (access upon request)



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Thank you!

Av Paral·lel 88 1st floor, 08015
Barcelona
+34 93 599 21 54
miquel.garcia@rokubun.cat
www.rokubun.cat