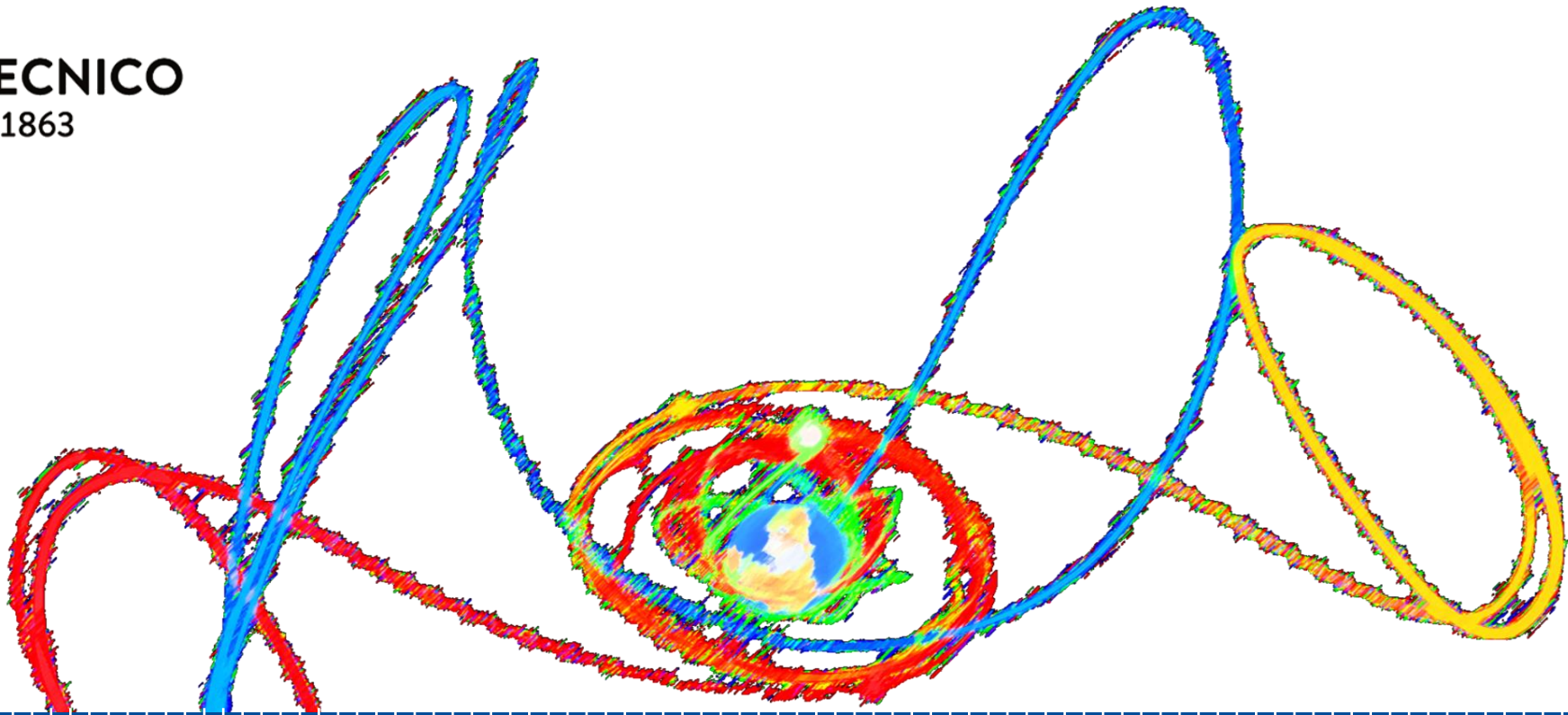




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Orbital Mechanics

Lab Chapter 2: Orbit representation

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Academic year 2022/23

Lab – Orbit representation

■ Ground track

- Definition, angles, geometrical properties
- Repeating ground tracks
- **Exercise 1:** Computation of ground tracks
- **Exercise 2:** Design of repeating ground tracks

■ Orbit representation

- Cartesian and Keplerian elements
- Ephemerides
- SGP models and TLEs
- Online resources
- References
- **Exercise 3:** Ground track from ephemerides data



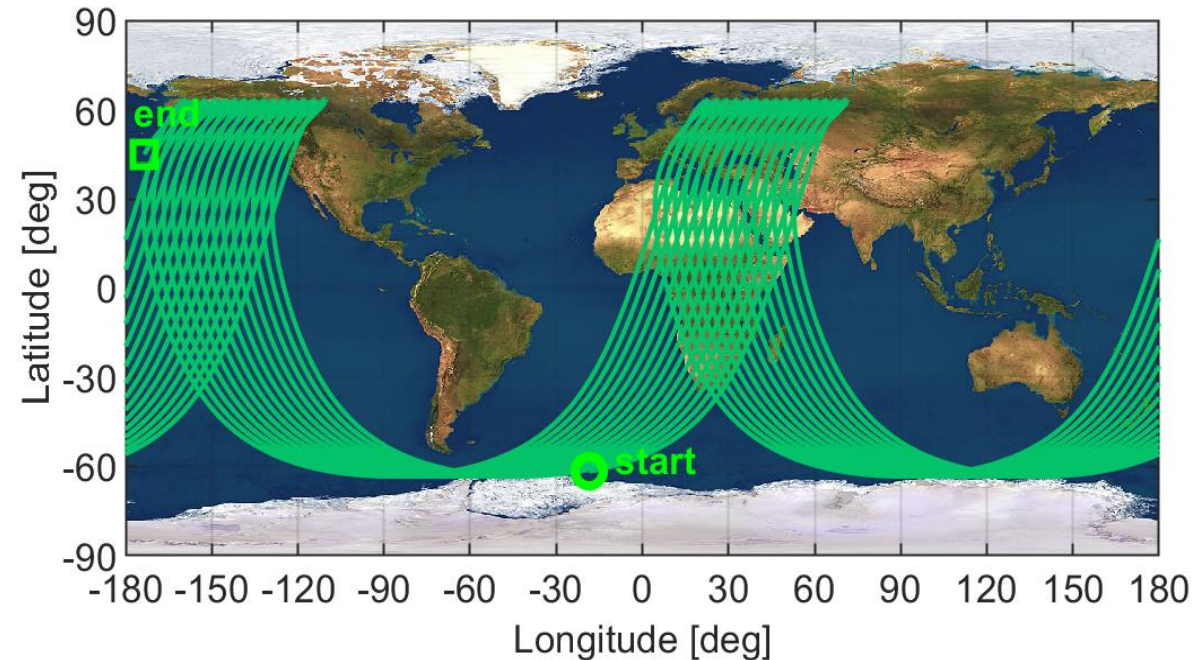
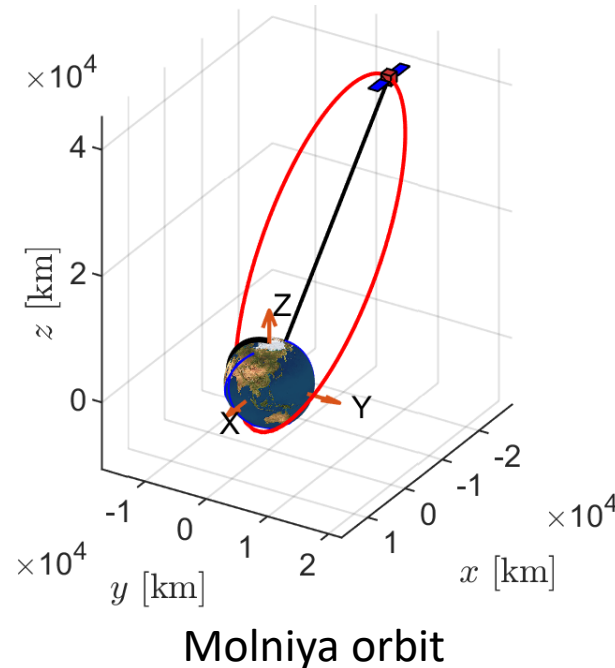
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GROUND TRACK

Definition

Ground track: *Projection of a satellite's orbit onto the Earth's surface [1].*

- Neglecting Earth's oblateness, it can be plotted as the trace left on the planet's surface by the line connecting the centre of the Earth and the satellite as it travels its orbit.
- At each time t , the ground track point is located by its **latitude ϕ** and **longitude λ** relative to the **rotating Earth**.

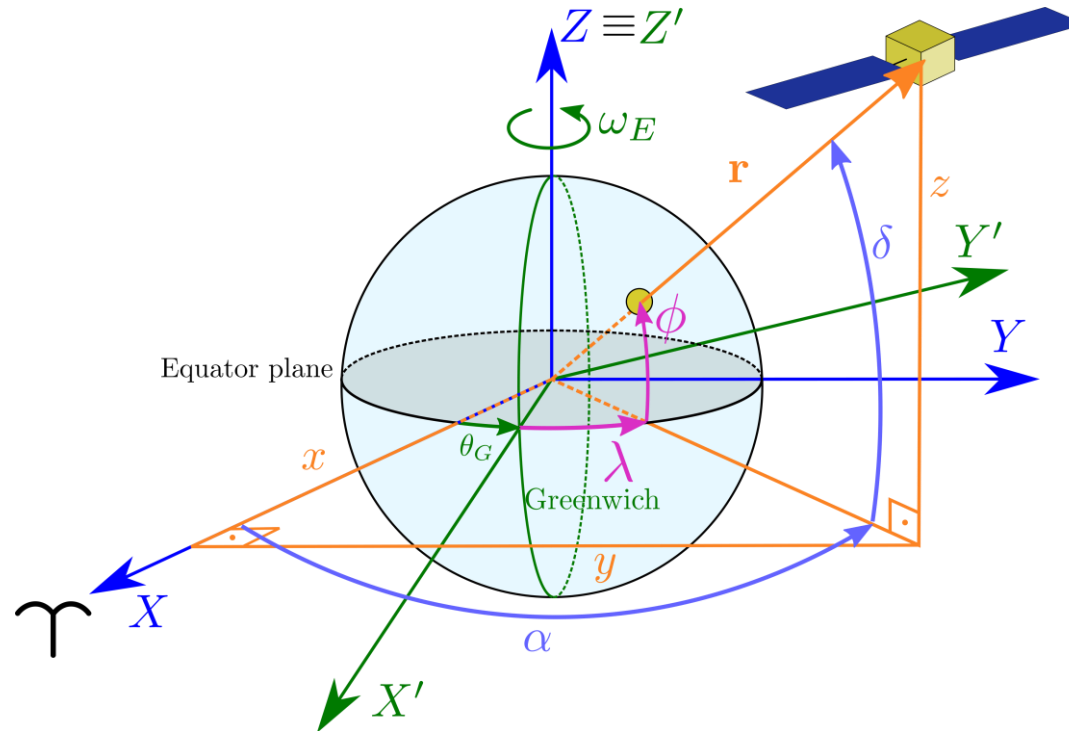


$a = 26600$ km
 $e = 0.74$
 $i = 63.4$ deg
 $\Omega = 50$ deg
 $\omega = 280$ deg
 $f_0 = 0$ deg[‡]
30 orbits
[‡] f denotes true anomaly

[1] Curtis, H. D.. *Orbital mechanics for engineering students*, Butterworth-Heinemann , 2014

Ground Track

Angles for the ground track



$$\theta_G(t) = \theta_G(t_0) + \omega_E (t - t_0)$$

Declination

$$\delta = \arcsin \frac{z}{r}$$

Right ascension

$$\alpha = \begin{cases} \arccos \frac{x}{r \cos \delta} & \frac{y}{r} > 0 \\ 2\pi - \arccos \frac{x}{r \cos \delta} & \frac{y}{r} \leq 0 \end{cases}$$

or alternatively

$$\alpha = \text{atan2}(y, x)$$

Longitude

$$\lambda = \alpha - \theta_G$$

Latitude

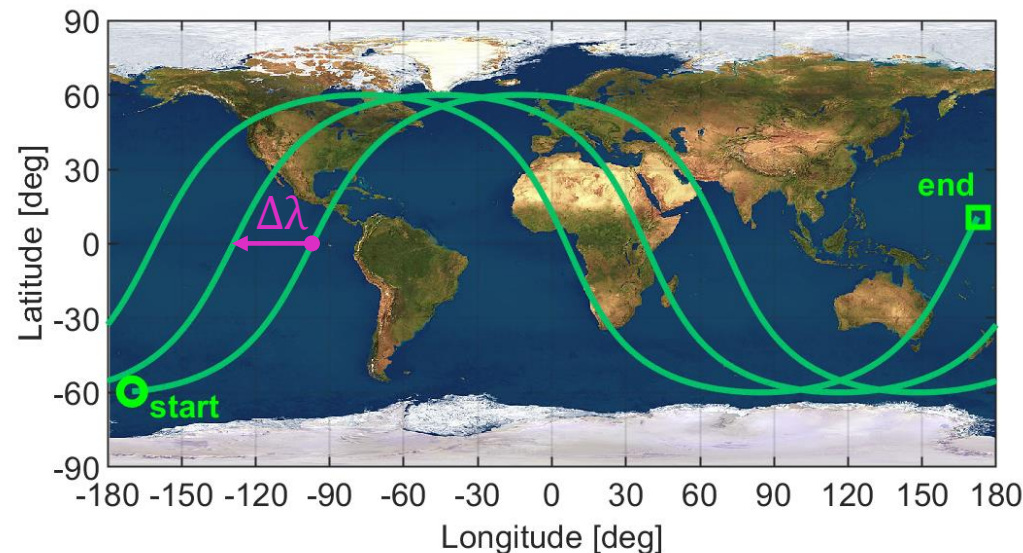
$$\phi = \delta$$

Geometrical properties

- For each orbital revolution, the ground track presents 2 *equator crossings*, one maximum in latitude, and one minimum in latitude.
- For the unperturbed two-body problem, the orbit remains constant. However, **the ground track advances westward** by an angle $\Delta\lambda$ equal to Earth's rotation during one orbital period T of the satellite:

$$\Delta\lambda = T \omega_E$$

Earth's rotation velocity (eastwards): $\omega_E = 15.04 \text{ deg/h}$



$a = 8350 \text{ km}$
 $e = 0.19760$
 $i = 60 \text{ deg}$
 $\Omega = 270 \text{ deg}$
 $\omega = 45 \text{ deg}$
 $f_0 = 230 \text{ deg}$
3.25 orbits

Repeating ground tracks

- A ground track will repeat itself after k revolutions of the satellite and m rotations of the planet if the total ground track drift $k\Delta\lambda$ is equal to the corresponding planet rotation $m2\pi$:

$$k \Delta\lambda = m 2\pi \Rightarrow \frac{\Delta\lambda}{2\pi} = \frac{m}{k} \quad \text{with } k, m \in \mathbb{N}$$

- Substituting $\Delta\lambda = T\omega_E$ and operating, we see that this is equivalent to imposing that *the ratio of the satellite's orbital period T and Earth's rotational period $T_E = 2\pi/\omega_E$ is a rational number*:

$$\frac{T}{T_E} = \frac{m}{k} \quad \text{with } k, m \in \mathbb{N}$$

- Or expressed in terms of the satellite's mean motion $n = 2\pi/T$ and Earth's rotation velocity ω_E :

$$\frac{\omega_E}{n} = \frac{m}{k} \quad \text{with } k, m \in \mathbb{N}$$

Repeating ground tracks

- Therefore, **repeating ground tracks can be obtained by choosing an orbit with a period T such that:**

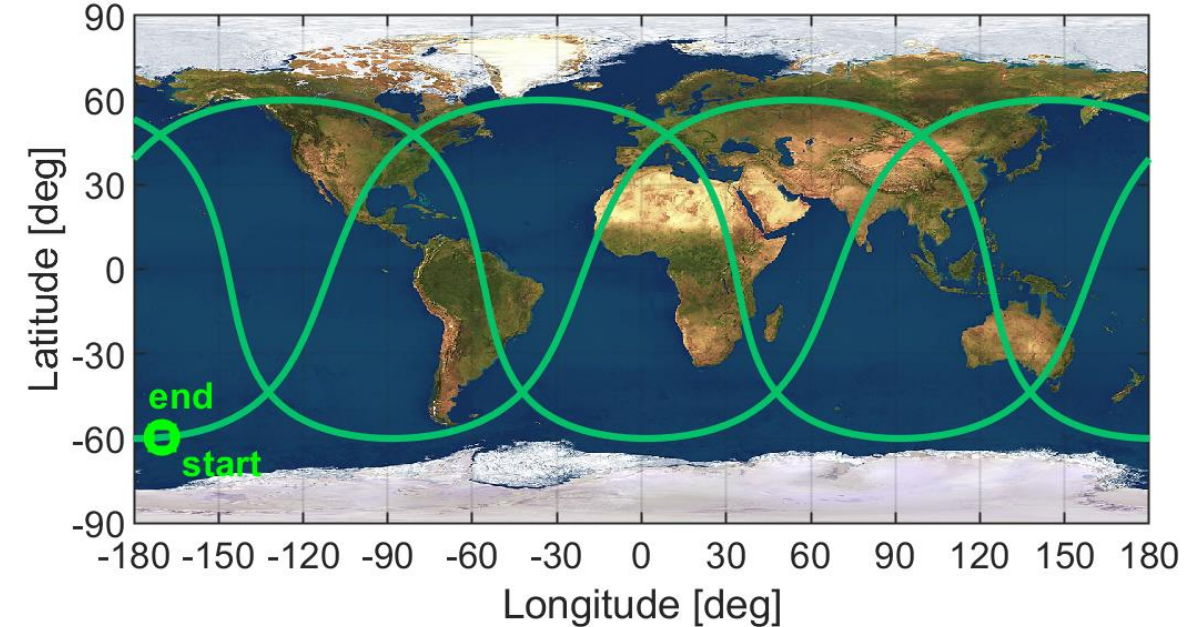
$$T = T_E \frac{m}{k} = \frac{2\pi}{\omega_E} \frac{m}{k}$$

- Or equivalently, with a mean motion n such that:

$$n = \omega_E \frac{k}{m}$$

- Keep in mind that period T and mean motion n only depend on the semimajor axis a :

$$n = \frac{2\pi}{T} = \sqrt{\frac{\mu}{a^3}}$$



$$a = 16733.65 \text{ km}$$

$$e = 0.19760$$

$$i = 60 \text{ deg}$$

$$\Omega = 270 \text{ deg}$$

$$\omega = 45 \text{ deg}$$

$$f_0 = 230 \text{ deg}$$

$$k = 4$$

$$m = 1$$

Exercise 1: Computation of ground tracks

Exercise 1: Computation of ground tracks

1. Implement a function `groundTrack` that computes the ground track of an orbit

- **Inputs:**

- State of the orbit at the initial time (either in Cartesian or Keplerian elements)
- Longitude of Greenwich meridian at initial time
- Vector of times at which the ground track will be computed
- Other inputs that you consider useful (e.g., ω_E , μ , t_0)

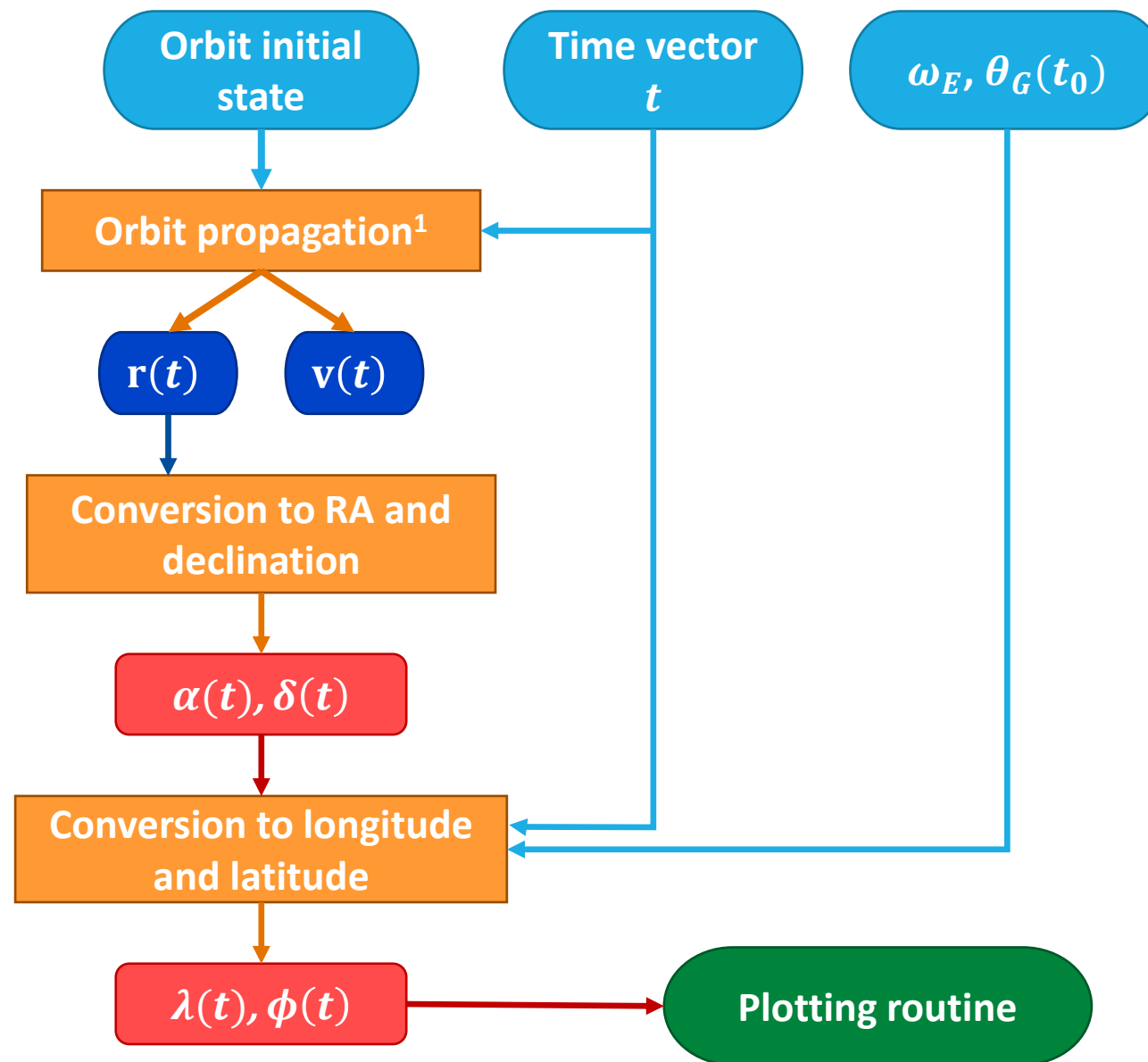
- **Outputs:**

- `alpha`: right ascension in Earth Centred Equatorial Inertial frame
- `delta`: declination in Earth Centred Equatorial Inertial frame
- `lon`: longitude with respect to rotating Earth (0 deg at Greenwich meridian)
- `lat`: latitude with respect to rotating Earth

Exercise 1: Computation of ground tracks

Flow diagram

For numerical orbit propagation¹, you can reuse the code from [Chapter 1](#).



¹ **Orbit propagation:** prediction of a body's orbital characteristics at a future date given the current orbital characteristics.

Exercise 1: Computation of ground tracks

Exercise 1: Computation of ground tracks

2. Plot the ground track for the following orbits:

1. $a = 8350$ km, $e = 0.1976$, $i = 60$ deg, $\Omega = 270$ deg, $\omega = 45$ deg, $f_0 = 230$ deg (from [1], Example 4.12)
In Cartesian coordinates: $\mathbf{r}_0 = [-4578.219, -801.084, -7929.708]$ km, $\mathbf{v}_0 = [0.800, -6.037, 1.385]$ km/s
2. Molniya orbit with $a = 26600$ km, $e = 0.74$, $i = 63.4$ deg, $\Omega = 50$ deg, $\omega = 280$ deg, $f_0 = 0$ deg
In Cartesian coordinates: $\mathbf{r}_0 = [3108.128, -1040.299, -6090.022]$ km, $\mathbf{v}_0 = [5.743, 8.055, 1.555]$ km/s
3. Three circular LEO with altitude 800 km, $\Omega = 0$ deg, $\omega = 40$ deg, $f_0 = 0$ deg, and different inclinations:
 - $i = 0$ deg $\mathbf{r}_0 = [5493.312, 4609.436, 0.000]$ km, $\mathbf{v}_0 = [-4.792, 5.711, 0.000]$ km/s
 - $i = 30$ deg $\mathbf{r}_0 = [5493.312, 3991.889, 2304.718]$ km, $\mathbf{v}_0 = [-4.792, 4.946, 2.856]$ km/s
 - $i = 98$ deg $\mathbf{r}_0 = [5493.312, -641.510, 4564.578]$ km, $\mathbf{v}_0 = [-4.792, -0.795, 5.656]$ km/s

Data:

μ_{\oplus} and R_{\oplus} from `astroConstants.m` (identifiers 13, and 23, respectively)

$\omega_E = 15.04$ deg/h $\theta_G(t_0) = 0$ deg

[1] Curtis, H. D.. *Orbital mechanics for engineering students*, Butterworth-Heinemann , 2014

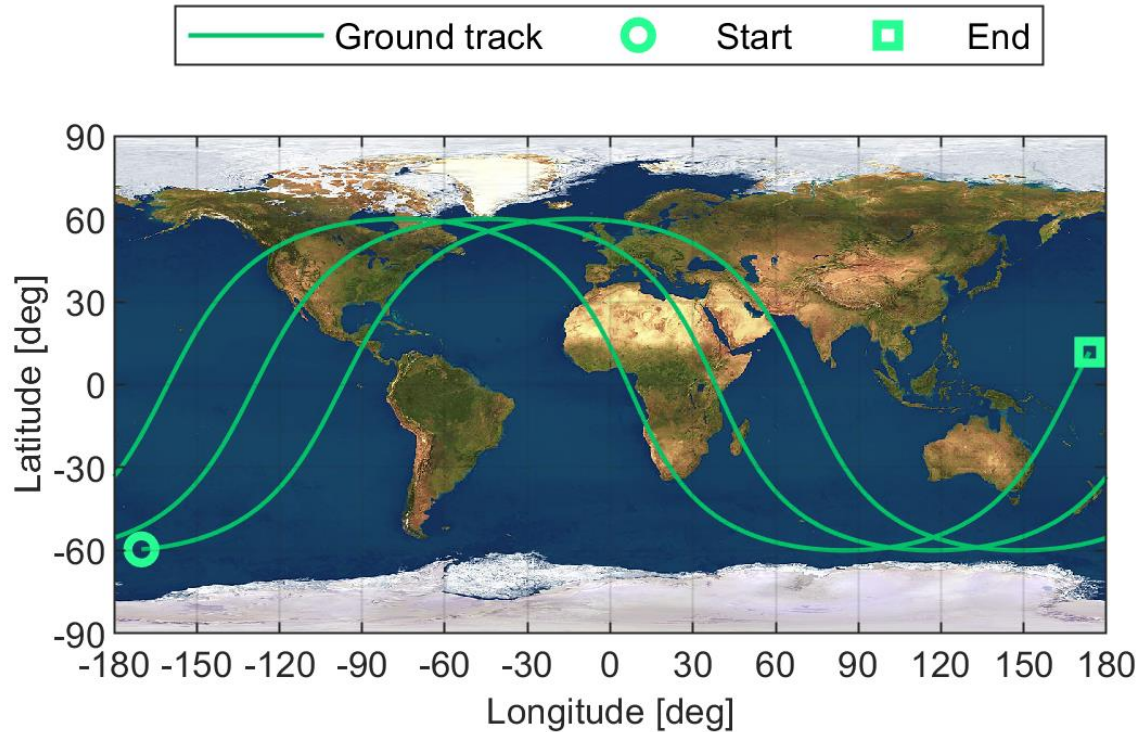
Exercise 1: Computation of ground tracks

Hints

- **Radians** are more convenient for calculations, while **degrees** are better for graphical representation.
- **Longitude λ** has to be reduced to the 360 deg angular range chosen for the ground tracks (e.g., $[-180, 180]$ deg or $[0, 360]$ deg). Consequently, the ground track plot will be discontinuous in λ at the boundaries of the angular range.
To avoid having horizontal lines connecting the points before and after the discontinuity:
 - Easiest way is to change the plot style, removing the line connecting the data points and using a marker for each point instead. That is, setting 'LineStyle' to 'none' and 'Marker' to '.' (high number of points required to get a continuous path).
 - If instead you want to keep the line connecting the data points, you can introduce NaN values in your data arrays separating the points before and after the discontinuity. Matlab does not connect the data points that include NaN values.
- If you want, you can add Earth's surface as background, using function `imread` to load the image as a matrix of colored pixels, and function `image` to plot it.
 - Check the **documentation center** for detailed information on how to use them.
- Don't forget to *adjust the limits for the plotting regions, to label the axes, and to add a legend* if more than one line is represented.

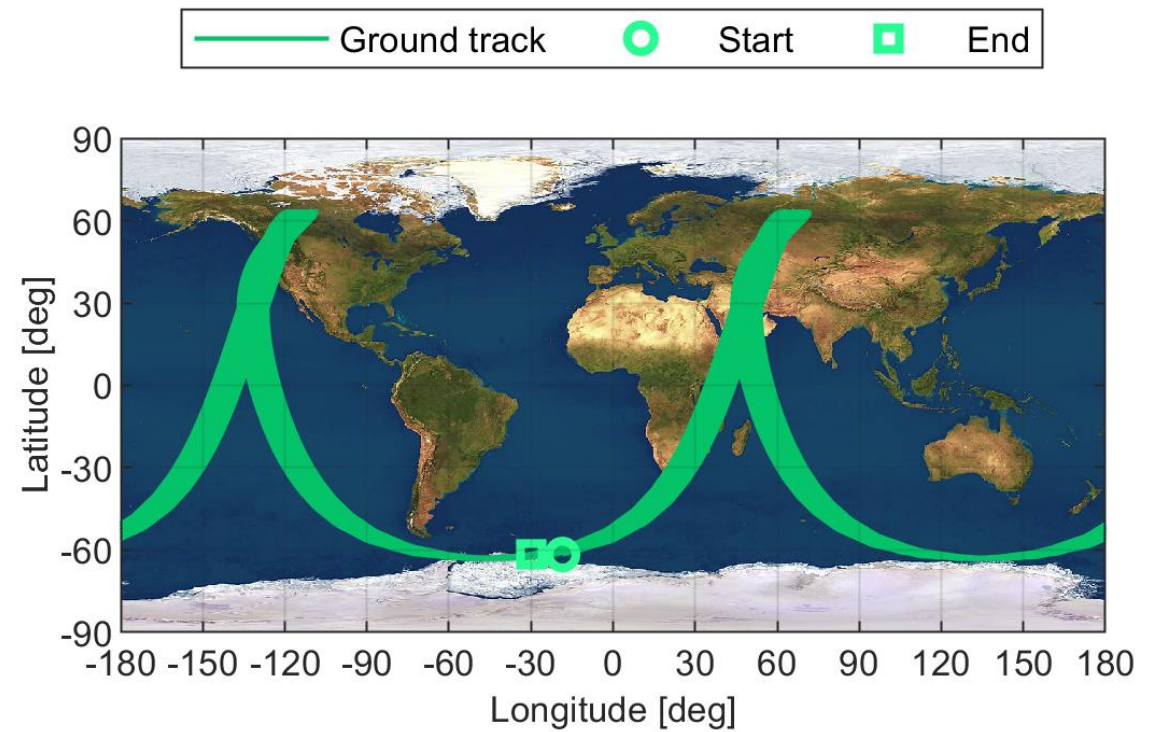
Exercise 1: Computation of ground tracks

Sample solutions



Case 1

$a = 8350$ km, $e = 0.19760$, $i = 60$ deg
 $\Omega = 270$ deg, $\omega = 45$ deg, $f_0 = 230$ deg
 $\theta_G(t_0) = 0$ deg, 3.25 orbits



Case 2

$a = 26600$ km, $e = 0.74$, $i = 63.4$ deg
 $\Omega = 50$ deg, $\omega = 280$ deg, $f_0 = 0$ deg
 $\theta_G(t_0) = 0$ deg, 30 orbits

Exercise 1: Computation of ground tracks

Sample solutions

Case 3

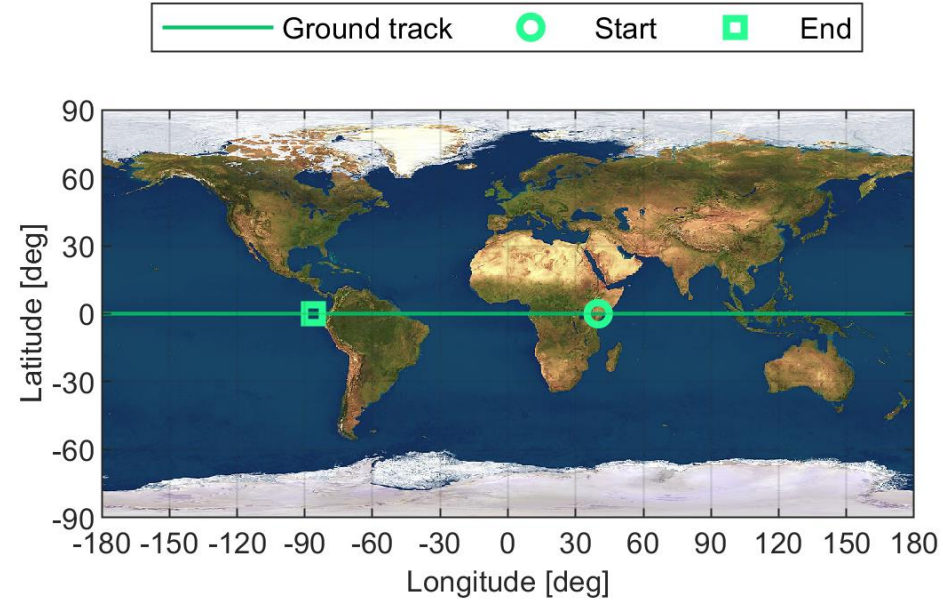
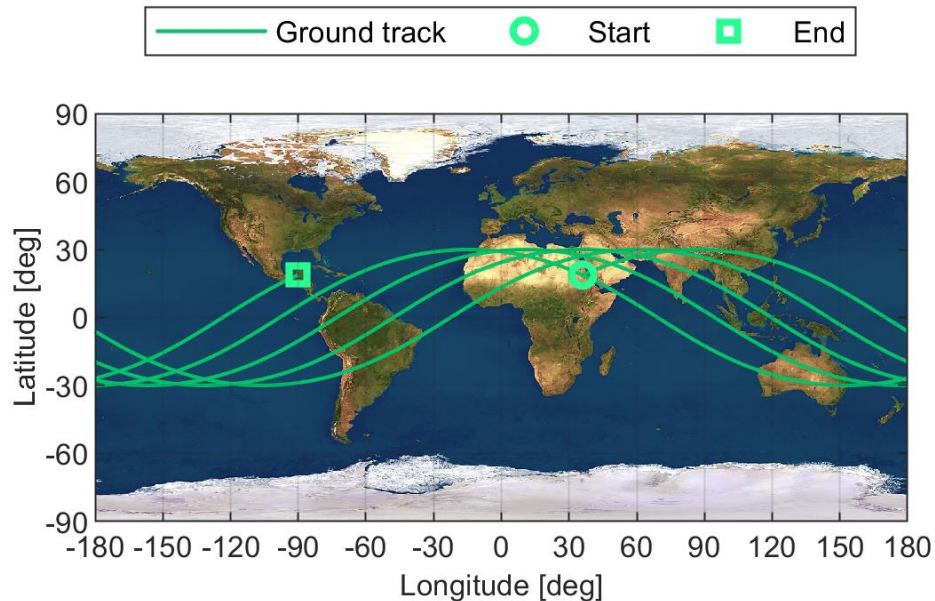
$$a = 7171.010 \text{ km}, e = 0$$

$$\Omega = 0 \text{ deg}, \omega = 40 \text{ deg}, f_0 = 0 \text{ deg}$$

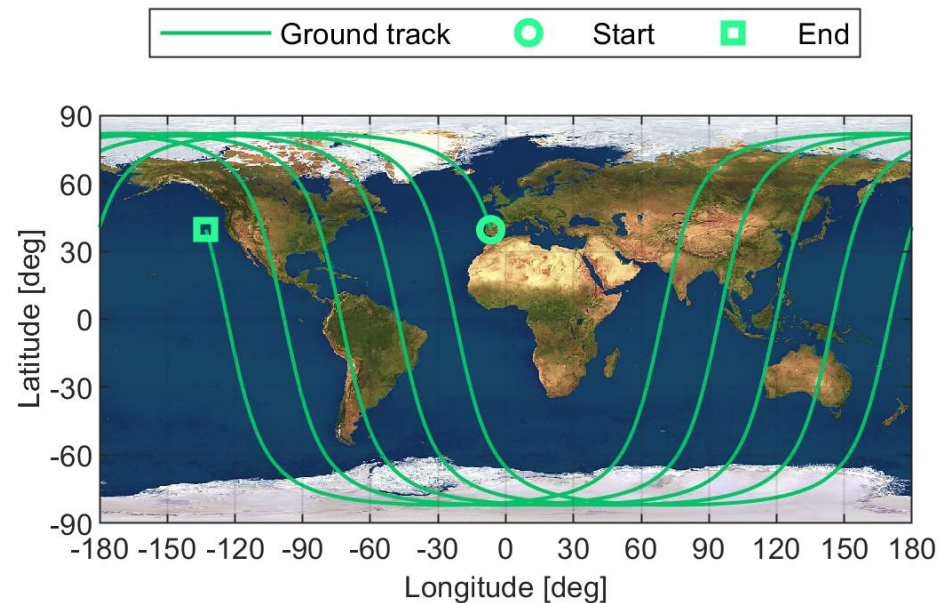
$$\theta_G(t_0) = 0 \text{ deg}$$

5 orbits

$i = 30 \text{ deg}$



$i = 0 \text{ deg}$



$i = 98 \text{ deg}$

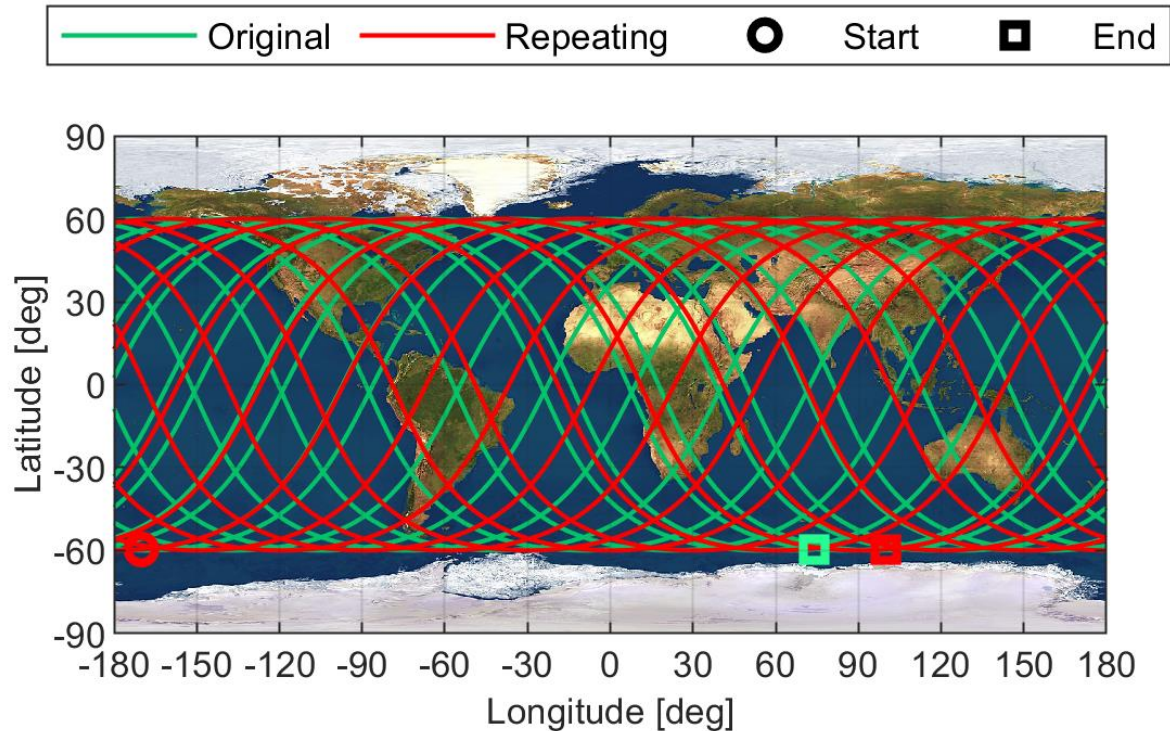
Exercise 2: Design of repeating ground tracks

Exercise 2: Design of repeating ground tracks

1. Implement a function that computes the required a for a repeating ground track with k satellite revolutions and m Earth revolutions.
2. Modify the semimajor axis of the orbits in [Exercise 1](#) to get repeating ground tracks with:
 - **Case 1:** $k = 12, m = 1$
 - **Case 2 (Molniya orbit):** $k = 2, m = 1$
 - **Case 3 (circular LEOs):**
 - For $i = 0$ deg: $k = 20, m = 2$
 - For $i = 30$ deg: $k = 29, m = 2$
 - For $i = 98$ deg: $k = 15, m = 1$
3. Compute the semimajor axis for a GEO (with $e = 0, i = \Omega = \omega = 0$ deg, $f_0 = 20$ deg). Remember that satellites in GEO remain stationary over a point of the equator, so $m = k = 1$.
4. Plot each repeating ground track together with the original one and compare them

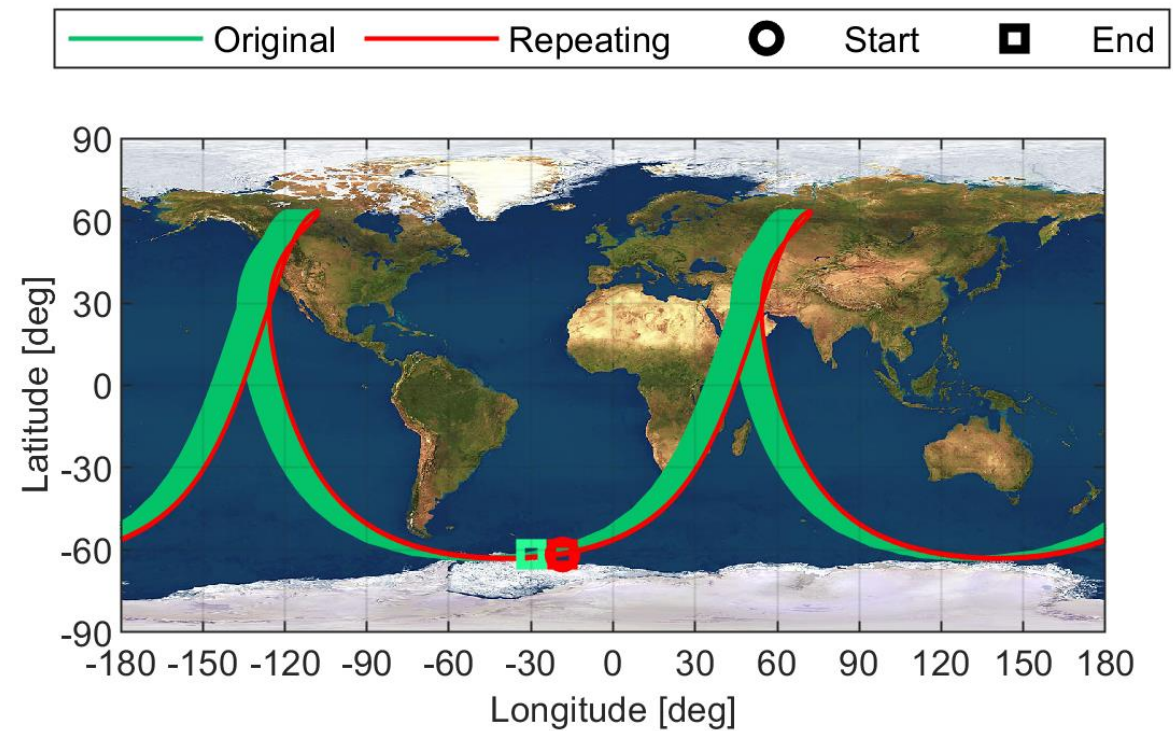
Exercise 2: Design of repeating ground tracks

Sample solutions



Case 1

$a = 8350 \text{ km}$, $e = 0.19760$, $i = 60 \text{ deg}$
 $\Omega = 270 \text{ deg}$, $\omega = 45 \text{ deg}$, $f_0 = 230 \text{ deg}$
 $\theta_G(t_0) = 0 \text{ deg}$, 15 orbits
 $a_{\text{rep}} = 8044.702 \text{ km}$, $k = 12$, $m = 1$



Case 2

$a = 26600 \text{ km}$, $e = 0.74$, $i = 63.4 \text{ deg}$
 $\Omega = 50 \text{ deg}$, $\omega = 280 \text{ deg}$, $f_0 = 0 \text{ deg}$
 $\theta_G(t_0) = 0 \text{ deg}$, 30 orbits
 $a_{\text{rep}} = 26563.020 \text{ km}$, $k = 2$, $m = 1$

Exercise 2: Design of repeating ground tracks

Sample solutions

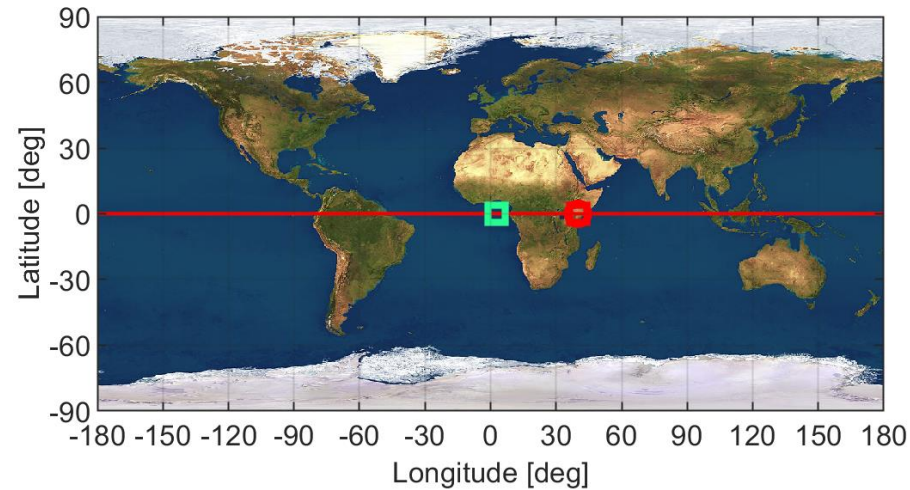
Case 3

$a = 7171.010$ km, $e = 0$
 $\Omega = 0$ deg, $\omega = 40$ deg, $f_0 = 0$ deg
 $\theta_G(t_0) = 0$ deg
30 orbits

$i = 30$ deg

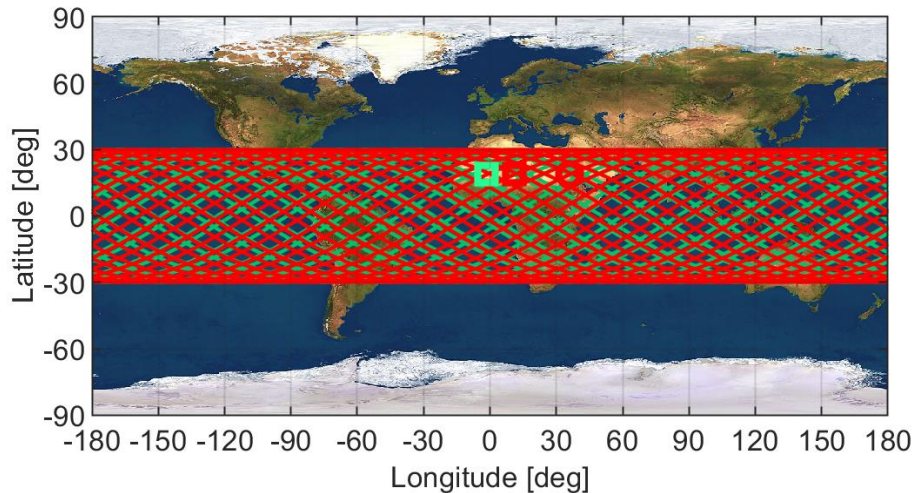
$a_{\text{rep}} = 7091.185$ km, $k = 29$, $m = 2$

Original Repeating Start End

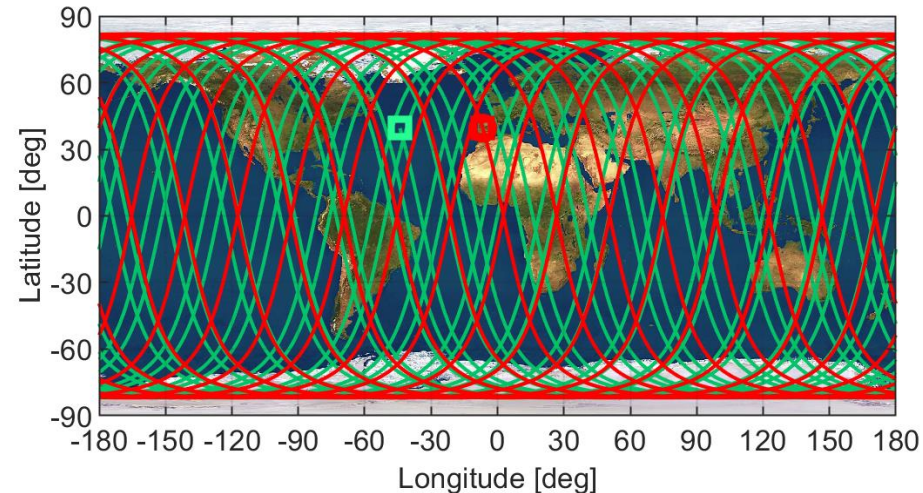


$i = 0$ deg
 $a_{\text{rep}} = 9084.425$ km
 $k = 20$, $m = 2$

Original Repeating Start End



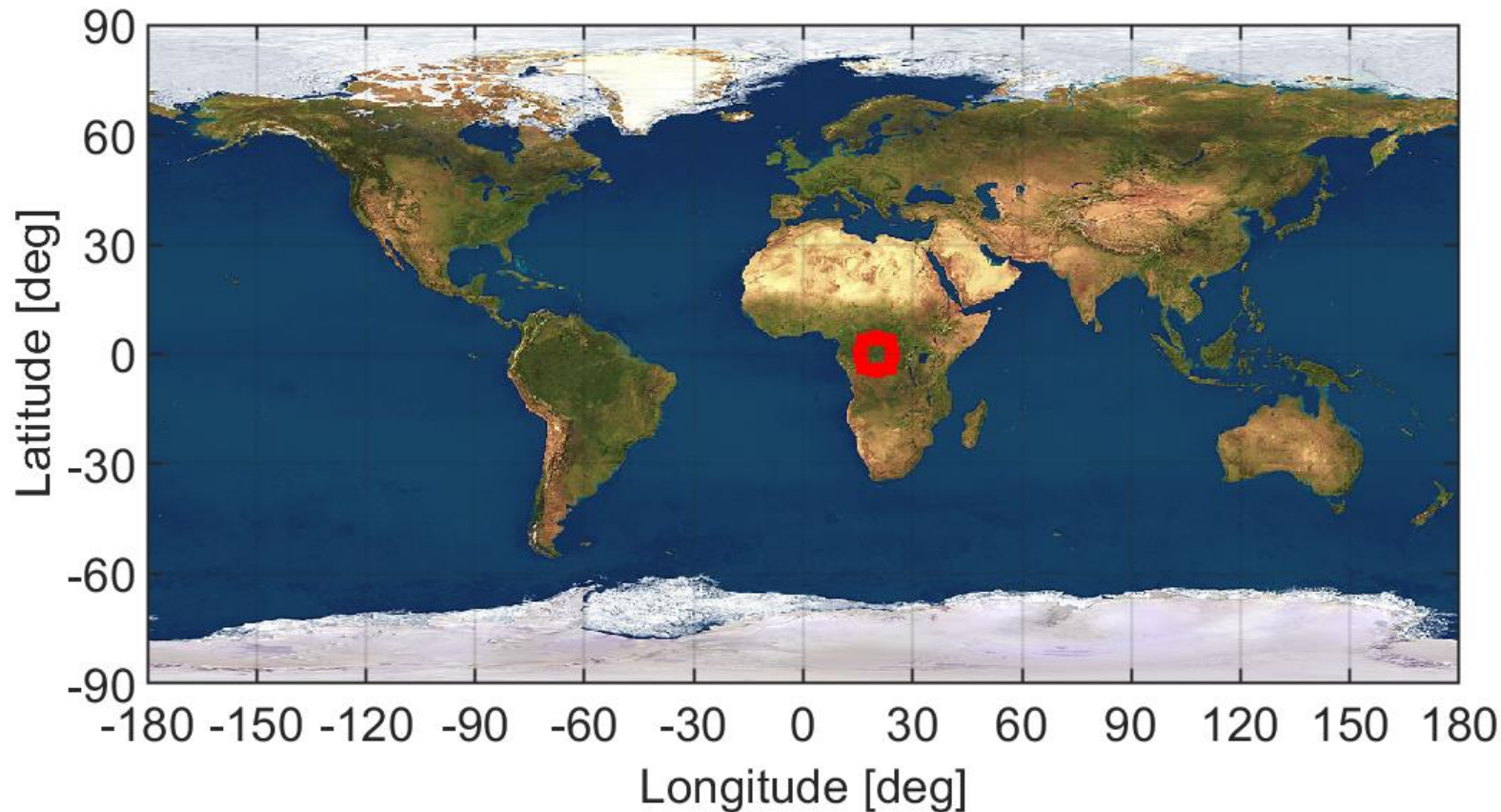
Original Repeating Start End



$i = 98$ deg
 $a_{\text{rep}} = 6932.714$ km
 $k = 15$, $m = 1$

Exercise 2: Design of repeating ground tracks

Sample solutions



GEO

$a_{\text{rep}} = 42166.167 \text{ km}$, $e = 0$, $i = 0 \text{ deg}$
 $\Omega = 0 \text{ deg}$, $\omega = 0 \text{ deg}$, $f_0 = 20 \text{ deg}$
 $\theta_G(t_0) = 0 \text{ deg}$, 500 orbits



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ORBIT REPRESENTATION

Cartesian and Keplerian elements

Basic orbit representation

- The most common representations for the state of an orbiting body are the **Cartesian coordinates** and the **Keplerian elements** [1]:
 - **Cartesian coordinates** $\mathbf{s} = [\mathbf{r}, \mathbf{v}]$. Position \mathbf{r} and velocity \mathbf{v} at a given time t .
 - **Keplerian elements** $\alpha = [a, e, i, \Omega, \omega, M]$. Based on a geometric description of the conic:
 - a and e give the geometry of the planar conic.
 - i , Ω , and ω give the orientation of the conic in space (Euler angles).
 - M (or equivalently, true anomaly f) gives the object's position in the orbit. M and f are related through Kepler's equation.
- It is possible to convert between both [1]:
 - You will need to create your own `kep2car` and `car2kep` functions for the labs.
 - **Be careful with singularities at $e = 0$ and $i = 0$ deg.**
 - **Test your functions converting a set of elements back and forth and checking if you recover the original value: $\mathbf{s} \rightarrow \alpha \rightarrow \tilde{\mathbf{s}} = \mathbf{s}$.**

[1] Curtis, H. D.. *Orbital mechanics for engineering students*, Butterworth-Heinemann , 2014

Osculating orbit and singularities

■ Strictly, **Keplerian elements are defined for Keplerian orbits (2BP)**

- $[a, e, i, \Omega, \omega]$ constant, M changes in time. That is, the orbit remains constant, and the body moves along it.
- In the presence of perturbations (e.g., drag, Moon, etc.), the orbit changes slowly in time.

Osculating orbit: *Keplerian orbit that the object would have around the central body at a particular time instant if perturbations were absent.*

Osculating elements: *Keplerian elements of the osculating orbit. They evolve in time.*

■ Keplerian elements have 2 singularities:

- **Zero inclination:** The line of nodes is not defined. Ω can take an arbitrary value, the angle of the apse line with the X axis is $\Omega + \omega$.
- **Circular orbit:** The line of apses is not defined. ω can take an arbitrary value, the angular position of the body with the line of nodes is $\omega + f$.

Locating objects in space

- *A table of the coordinates of celestial bodies as a function of time is called an **ephemeris** [1].*
 - Can be provided in the form of a look-up table, polynomial fittings, TLEs, etc.
 - Computed from astronomical observations and precise orbit propagation.
 - Importance of the **reference time** (epoch of the ephemeris).
- We will make an overview of one of the most common sources of ephemerides: the **Simplified General Perturbation (SGP)** models and the **Two-Line Elements (TLE)**.
- Other ephemerides will be used in future labs (Matlab functions available in WeBeep).

[1] Curtis, H. D.. *Orbital mechanics for engineering students*, Butterworth-Heinemann , 2014

Overview

- **Simplified General Perturbation (SGP) models:**
 - Analytical methods for propagating the orbital state of a satellite or debris, **taking as input some ad-hoc mean elements**.
 - They include expressions for the **secular (linear), long-periodic and short-periodic (oscillatory) evolutions**, depending on the perturbations included.
- The US Air Force began development of their SGP model series in the 1960s:
 - Five different models: SGP, SGP4/SDP4, and SGP8/SDP8.
 - SGP/SGP4/SPG8 for close-Earth objects (period < 225 minutes), SDP4/SDP8 for deep-space objects (period ≥ 225 minutes).
 - Most used one is SGP4/SDP4.
 - **Mean elements** distributed as **Two-Line Element (TLE) sets**.
 - SGP4/SDP4 was documented in Spacetrack Report #3, to promote compatibility in the operational community.

Two-line elements

- **NORAD (North American Aerospace Defense Command)** provides the TLEs for SGP4/SDP4.
 - TLEs for SGP/SGP8/SDP8 can be derived from them (some fields are included only for this purpose).
- TLEs are computed from observations and orbit determination procedures.
 - Exact data and models used are classified information.
 - A single TLE allows to propagate the orbital state for a **limited time range** around the TLE epoch (accuracy degradation).
- Data is stored in two different lines (hence the name):
 - Originally in 80-column punch cards.
 - Currently in 70-column ASCII files.
 - They are made publicly available through Space-Track, but not all objects can be queried (e.g., classified satellites are excluded).
- **The orbital elements in the TLEs are averaged mean values, not the osculating elements at the epoch of the TLE. Do not use them directly.**

Simplified General Perturbation models

Two-line elements – Line 1

1 20580U 90037B 19341.79883884 .00000350 00000-0 10277-4 0 9996
2 20580 28.4681 153.8207 0002675 174.2378 205.9686 15.09309002426911

Column	Description
01	Line number
03-07	Satellite number
08	Classification (U=Unclassified)
10-11	International Designator (last two digits of launch year)
12-14	International Designator (launch number of the year)
15-17	International Designator (piece of the launch)
19-20	Epoch year (last two digits of year)
21-32	Epoch (day of the year and fraction portion of the day)
34-43	First time derivative of the mean motion
45-52	Second Time Derivative of Mean Motion (decimal point assumed)
54-61	BSTAR drag term (decimal point assumed)
63	Ephemeris type
65-68	Element number
69	Checksum (Modulo 10)

Simplified General Perturbation models

Two-line elements – Line 2

1 20580U 90037B 19341.79883884 .00000350 00000-0 10277-4 0 9996
2 20580 28.4681 153.8207 0002675 174.2378 205.9686 15.09309002 426911

Column	Description
01	Line Number of Element Data
03-07	Satellite Number
09-16	Inclination [deg]
18-25	Right Ascension of the Ascending Node [deg]
27-33	Eccentricity (decimal point assumed)
35-42	Argument of Perigee [deg]
44-51	Mean Anomaly [deg]
53-63	Mean Motion [rev/day]
64-68	Revolution number at epoch [rev]
69	Checksum (Modulo 10)



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NORAD GP Element Sets	
Current Data (GP)	Supplemental Data (SupGP)
Special Data Request (GP)	Special Data Request (SupGP)
Library	
Publications	
Software Repository	
Computers & Satellites Columns	
"Frequently Asked Questions: Two-Line Element Set Format"	
"More Frequently Asked Questions"	
"A New Way to Obtain GP Data (aka TLEs)"	
"How to Perform SupGP Queries"	
Special Event Coverage	
NEW: Artemis 1 Mission	
Long March-5B Rocket Body (48275) Reentry of 2021 May 9	
ORS-3 Launch of 2013 Nov 20	
Dnepr Launch of 2013 Nov 21	
Breeze-M Rocket Body (38746) Breakup	
Iridium 33/Cosmos 2251 Collision	
USA 193 Post-Shootdown Analysis	
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Assessing Threatening Encounters in Space	
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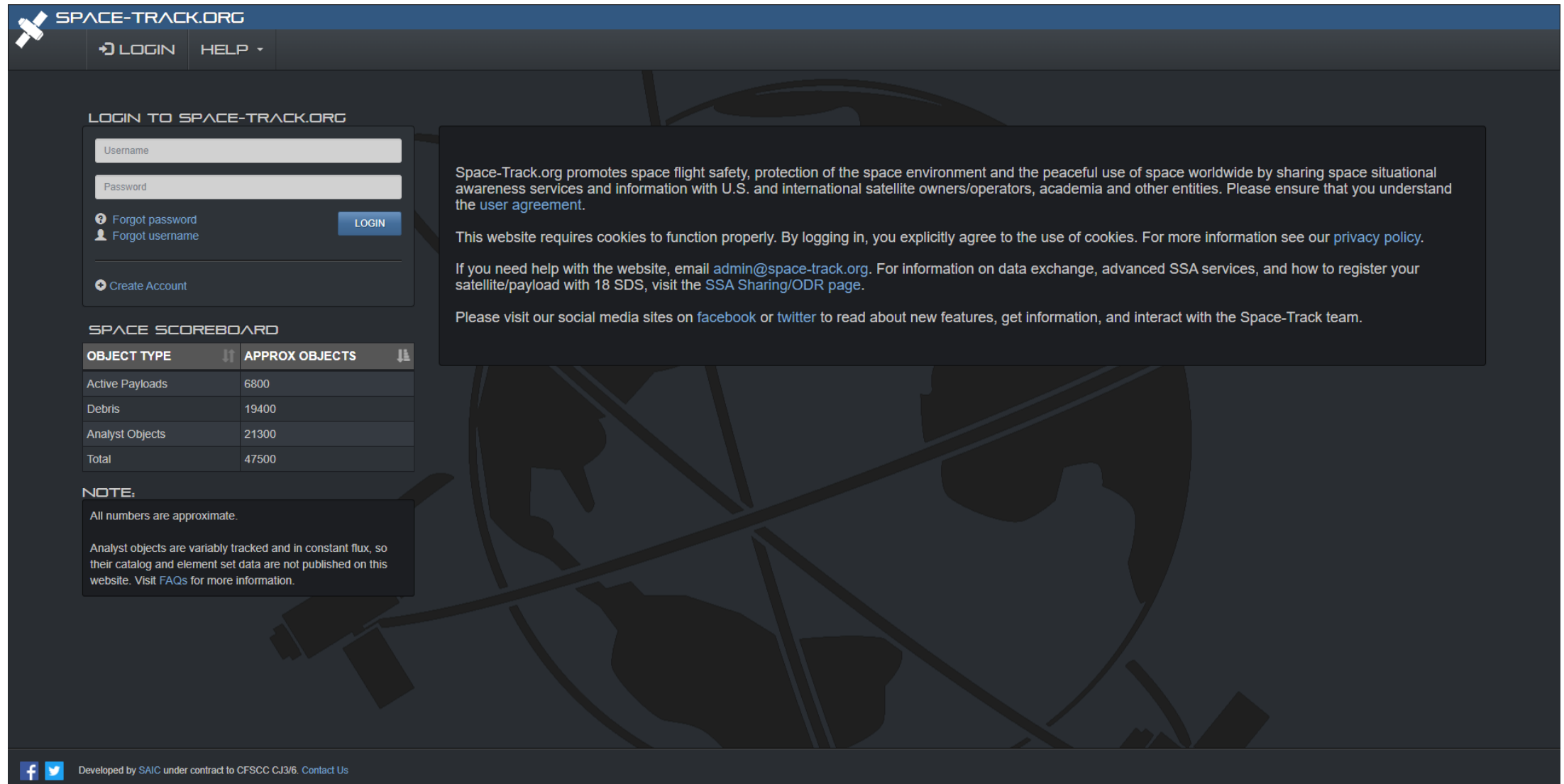
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<https://celestrak.com/>

- Created and maintained by **Dr. T.S. Kelso**.
 - Originally introduced in 1985 to make TLEs electronically available (NASA was providing them as printed bulletins).

- Contains a lot of **useful information**:
 - Current TLEs for non-classified satellites, organized by types of satellites/missions.
 - Historical TLEs archive for selected objects.
 - Satellite catalogue (SATCAT).
 - Documentation and Q&A (including a detailed description of TLEs).
 - Software.
 - Others: GPS data, space weather data, etc.



The image shows a screenshot of the Space-Track.org website. The header features the Space-Track.org logo and navigation links for LOGIN and HELP. The main content area is divided into three sections: a login form, a space scoreboard, and a note. The login form includes fields for Username and Password, links for 'Forgot password' and 'Forgot username', a LOGIN button, and a 'Create Account' link. The space scoreboard is a table with two columns: 'OBJECT TYPE' and 'APPROX OBJECTS'. The note section states that all numbers are approximate and that analyst objects are variably tracked. A large, semi-transparent overlay box is positioned in the center-right of the page, containing text about the website's mission, cookie policy, contact information, and social media links. The footer includes social media icons for Facebook and Twitter, and text indicating the website was developed by SAIC under contract to CFSCC CJ3/6.

SPACE-TRACK.ORG

LOGIN HELP

LOGIN TO SPACE-TRACK.ORG

Username

Password

[Forgot password](#) [Forgot username](#) [LOGIN](#)

[Create Account](#)

SPACE SCOREBOARD

OBJECT TYPE	APPROX OBJECTS
Active Payloads	6800
Debris	19400
Analyst Objects	21300
Total	47500

NOTE:

All numbers are approximate.

Analyst objects are variably tracked and in constant flux, so their catalog and element set data are not published on this website. Visit [FAQs](#) for more information.

Space-Track.org promotes space flight safety, protection of the space environment and the peaceful use of space worldwide by sharing space situational awareness services and information with U.S. and international satellite owners/operators, academia and other entities. Please ensure that you understand the [user agreement](#).

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If you need help with the website, email admin@space-track.org. For information on data exchange, advanced SSA services, and how to register your satellite/payload with 18 SDS, visit the [SSA Sharing/ODR](#) page.

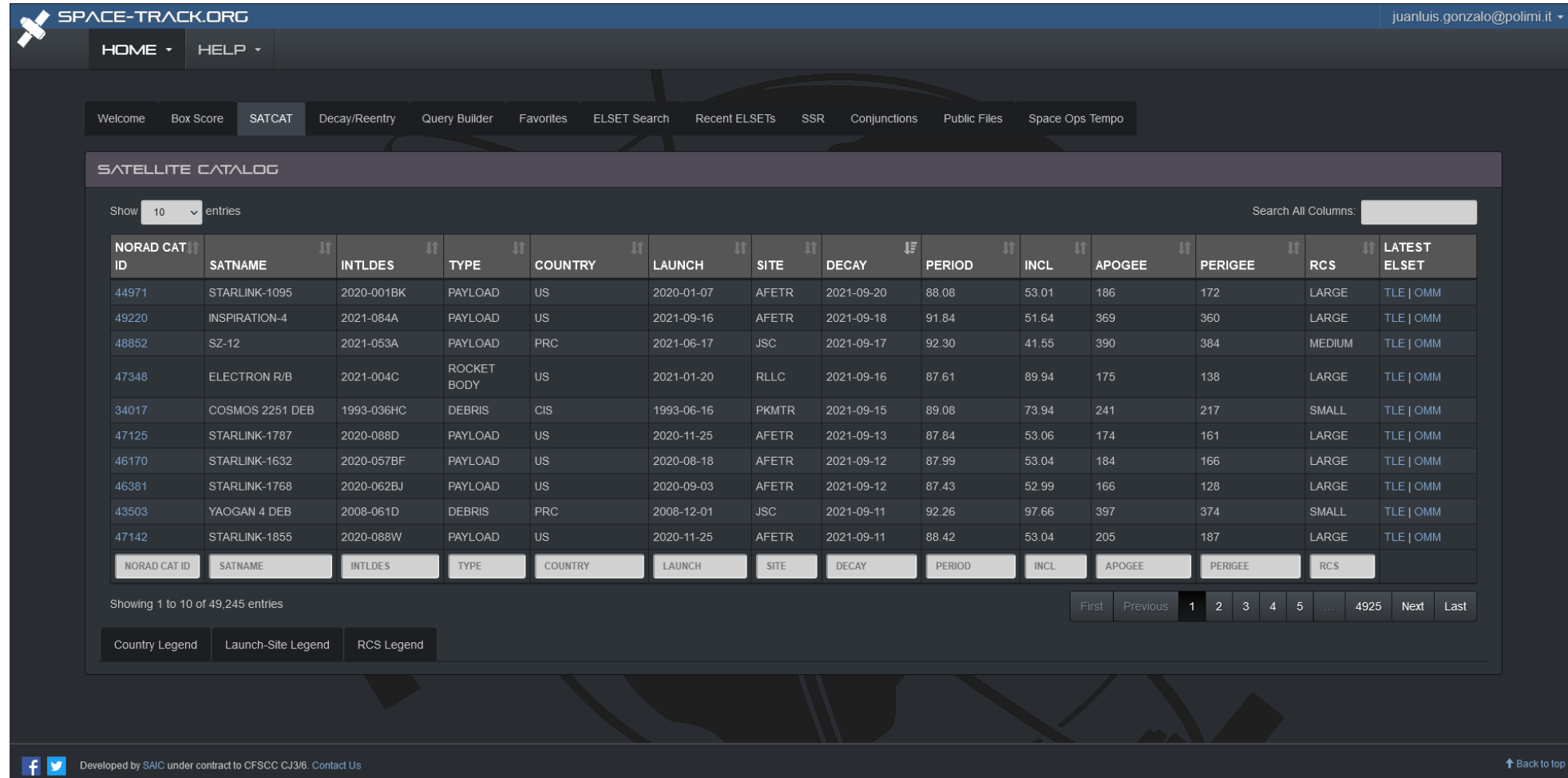
Please visit our social media sites on [facebook](#) or [twitter](#) to read about new features, get information, and interact with the Space-Track team.

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■ TLE information published by USSPACECOM/NORAD:

- Objective: *promoting a safe, stable, sustainable, and secure space environment through Space Situational Awareness information sharing.*
- Includes a Windows/Linux implementation of SGP4.
- API for automatic queries.
- Information about decay/reentry of satellites.
- Information about conjunctions (close approaches) between space debris.
- Requires an account.
 - You should have no problem in getting an account using your university email.

- Satellite catalog (SATCAT) can be filtered, ordered and queried for different fields.



SPACE-TRACK.ORG juanluis.gonzalo@polimi.it

HOME ▾ HELP ▾

Welcome Box Score **SATCAT** Decay/Reentry Query Builder Favorites ELSET Search Recent ELSETs SSR Conjunctions Public Files Space Ops Tempo

SATELLITE CATALOG

Show 10 entries Search All Columns:

NORAD CAT ID	SATNAME	INTLDES	TYPE	COUNTRY	LAUNCH	SITE	DECAY	PERIOD	INCL	APOGEE	PERIGEE	RCS	LATEST ELSET
44971	STARLINK-1095	2020-001BK	PAYLOAD	US	2020-01-07	AFETR	2021-09-20	88.08	53.01	186	172	LARGE	TLE OMM
49220	INSPIRATION-4	2021-084A	PAYLOAD	US	2021-09-16	AFETR	2021-09-18	91.84	51.64	369	360	LARGE	TLE OMM
48852	SZ-12	2021-053A	PAYLOAD	PRC	2021-06-17	JSC	2021-09-17	92.30	41.55	390	384	MEDIUM	TLE OMM
47348	ELECTRON R/B	2021-004C	ROCKET BODY	US	2021-01-20	RLLC	2021-09-16	87.61	89.94	175	138	LARGE	TLE OMM
34017	COSMOS 2251 DEB	1993-036HC	DEBRIS	CIS	1993-06-16	PKMTR	2021-09-15	89.08	73.94	241	217	SMALL	TLE OMM
47125	STARLINK-1787	2020-088D	PAYLOAD	US	2020-11-25	AFETR	2021-09-13	87.84	53.06	174	161	LARGE	TLE OMM
46170	STARLINK-1632	2020-057BF	PAYLOAD	US	2020-08-18	AFETR	2021-09-12	87.99	53.04	184	166	LARGE	TLE OMM
46381	STARLINK-1768	2020-062BJ	PAYLOAD	US	2020-09-03	AFETR	2021-09-12	87.43	52.99	166	128	LARGE	TLE OMM
43503	YAOGAN 4 DEB	2008-061D	DEBRIS	PRC	2008-12-01	JSC	2021-09-11	92.26	97.66	397	374	SMALL	TLE OMM
47142	STARLINK-1855	2020-088W	PAYLOAD	US	2020-11-25	AFETR	2021-09-11	88.42	53.04	205	187	LARGE	TLE OMM

Showing 1 to 10 of 49,245 entries

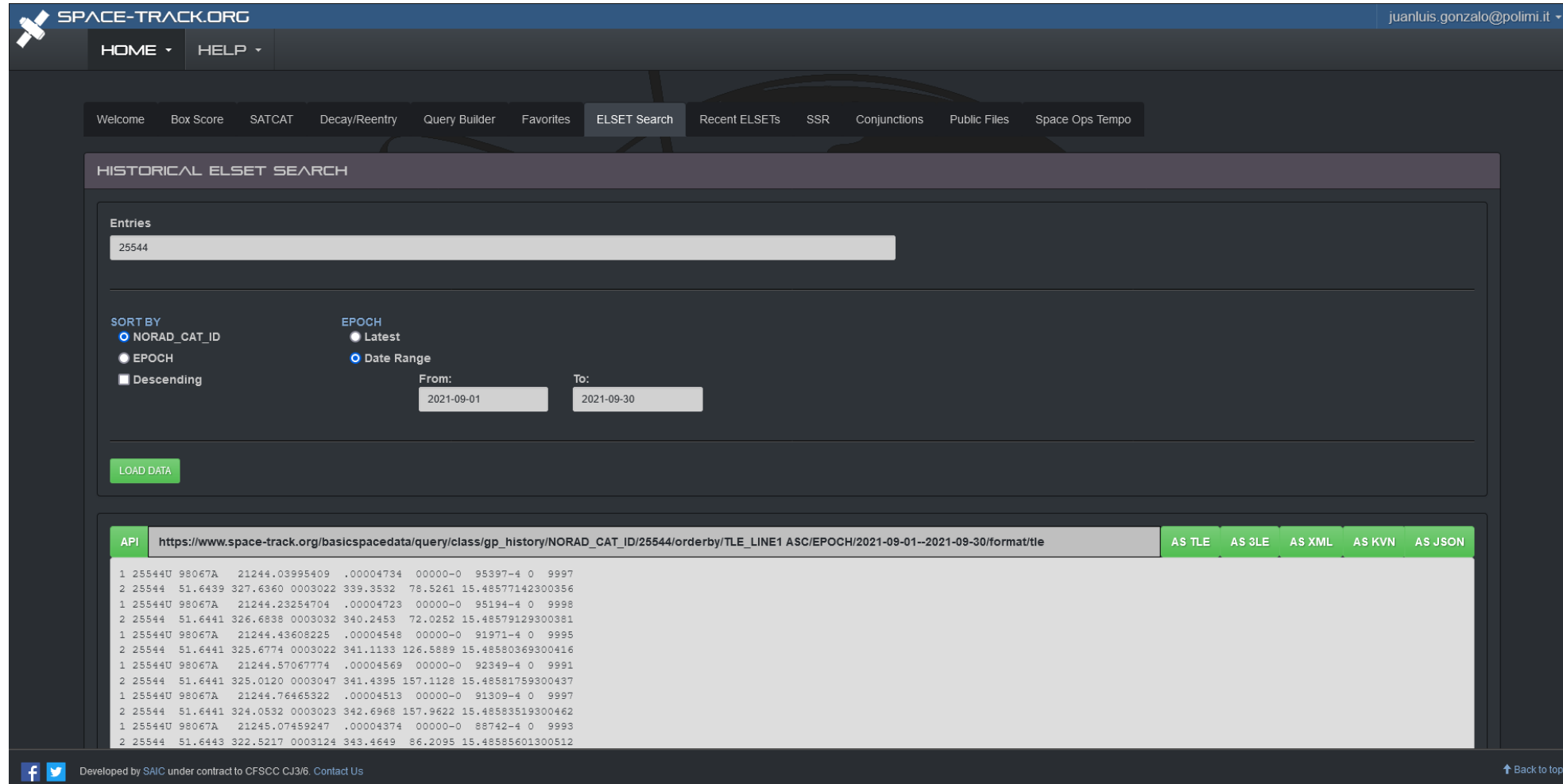
Country Legend Launch-Site Legend RCS Legend

First Previous 1 2 3 4 5 ... 4925 Next Last

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Back to top

- Search of historical element sets (TLEs, 3LEs, Keplerian, ...) for given satellites and epoch ranges.



The screenshot shows the Space-Track.org website interface for the ELSET Search function. The top navigation bar includes links for HOME, HELP, and a user profile (juanluis.gonzalo@polimi.it). The main menu features various search and data tools, with 'ELSET Search' currently selected. The 'HISTORICAL ELSET SEARCH' section contains a search input field with the value '25544'. Below the input field, there are sorting options: 'SORT BY' with radio buttons for 'NORAD_CAT_ID' (selected), 'EPOCH', and a 'Descending' checkbox; and 'EPOCH' with radio buttons for 'Latest' and 'Date Range' (selected). The 'Date Range' section includes 'From:' and 'To:' date pickers, both set to '2021-09-01' and '2021-09-30' respectively. A green 'LOAD DATA' button is located below the search parameters. At the bottom, there is a table of search results with columns for API, URL, and output format (AS TLE, AS 3LE, AS XML, AS KVN, AS JSON). The table displays a list of satellite data entries, including NORAD IDs, epoch numbers, and orbital parameters.

API	URL	AS TLE	AS 3LE	AS XML	AS KVN	AS JSON
1	25544U 98067A 21244.03995409 .00004734 00000-0 95397-4 0 9997					
2	25544 51.6439 327.6360 0003022 339.3532 78.5261 15.48577142300356					
1	25544U 98067A 21244.23254704 .00004723 00000-0 95194-4 0 9998					
2	25544 51.6441 326.6838 0003032 340.2453 72.0252 15.48579129300381					
1	25544U 98067A 21244.43608225 .00004548 00000-0 91971-4 0 9995					
2	25544 51.6441 325.6774 0003022 341.1133 126.5889 15.48580369300416					
1	25544U 98067A 21244.57067774 .00004569 00000-0 92349-4 0 9991					
2	25544 51.6441 325.0120 0003047 341.4395 157.1128 15.48581759300437					
1	25544U 98067A 21244.76465322 .00004513 00000-0 91309-4 0 9997					
2	25544 51.6441 324.0532 0003023 342.6968 157.9622 15.48583519300462					
1	25544U 98067A 21245.07459247 .00004374 00000-0 88742-4 0 9993					
2	25544 51.6443 322.5217 0003124 343.4649 86.2095 15.48585601300512					



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Horizons Web Application

[Save/Load Settings...](#)[Set Defaults](#)

1

Ephemeris Type:

2

[Edit](#) Target Body: **user-specified TLEs**

3

[Edit](#) Coordinate Center: **Geocentric** [code: 500]

4


[Edit](#) Time Specification: Start=**2011-09-18** TDB , Stop=**2011-10-14**, Step=**1** (days)

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 to use one of the "batch" modes to access Horizons, the batch-file corresponding to the settings above can be viewed by using [this link](#).

[Generate Ephemeris](#)



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Site Manager: Ryan Park
Site Design: Alan B. Chamberlin, Javier Roa Vicens
URS Clearance: CL#21-4165

<https://ssd.jpl.nasa.gov/horizons/>

- NASA/JPL HORIZONS is a **solar system data and ephemeris computation service**:
 - Maintained by the Solar System Dynamics Group of the Jet Propulsion Laboratory (JPL).
 - Provides access to key solar system data.
 - Computes highly accurate ephemerides for solar system objects (1,134,533 asteroids, 3,760 comets, 205 planetary satellites, 8 planets, the Sun, L1, L2, select spacecraft, and system barycenters).
 - **Few Earth-orbiting objects are included in the database**, but **users can provide their own set of TLEs** (i.e., we can use it as a SGP4 implementation).
 - Full access through remote command-line interface or email (submitting batch-style input files).
 - **A web interface is available (providing nearly all capabilities).**

<https://ssd.jpl.nasa.gov/horizons/>

- Settings for the web interface
 - **Ephemeris type:** Osculating Orbital Elements or Vector Table.
 - **Target body:** Select a satellite from the database, or provide up to 750 sets of SGP4/SDP4 TLEs in standard form (option “Specify a target using TLEs” in the dropdown menu).
 - **Coordinate Center:** Geocentric (code 500) for Earth-orbiting objects.
 - **Time Specification:** Initial time, final time, and step size. Remember that the earliest initial time and latest final time are limited by the available data (particularly, each set of TLEs only allows to propagate a few days before and after its epoch).
 - **Table Settings:** Available options depend on the Ephemeris type. Remember to choose adequate reference frame (ICRF), reference plane (equatorial), and units (km and km/s). To import the results into Matlab and other tools, it is strongly recommended to set output to CSV format.
 - **Generate Ephemeris:** Click to generate and visualize the ephemeris. The results can then be downloaded as a plaintext file clicking on “Download Results”.

- **CelesTrak** (TLEs and other resources):
<https://celestrak.com/>
- **Space-Track** (satellite/debris catalogue and TLEs):
<https://www.space-track.org/>
- **NASA/JPL's HORIZONS** (ephemerides for solar-system bodies and user-provided TLEs):
<https://ssd.jpl.nasa.gov/horizons/>
- References about SGP4/SDP4 and TLEs (accessible in CelesTrak):
 - F.R. Hoots, "Spacetrack report no. 3, models for propagation of NORAD element sets", *Department of Commerce, National Technical Information Service*, 1980.
 - D. Vallado, P. Crawford, Hujsak, R., and Kelso, T.S., "Revisiting Spacetrack Report #3," *AIAA/AAS Astrodynamics Specialist Conference*, Keystone, CO, 21-24 August 2006.

Exercise 3: Ground track from ephemerides data

Exercise 3: Ground track from ephemerides data

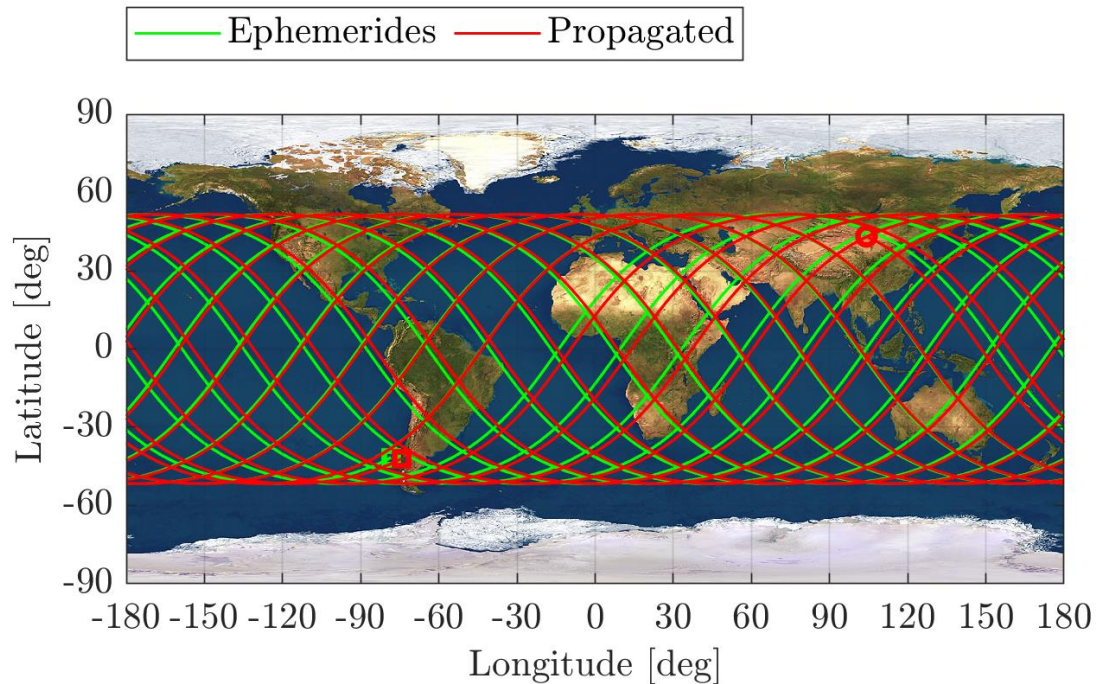
1. Select a satellite or debris from **CelesTrak** or **Space-Track**, and download at least one TLE
 - Space-Track database has more objects and historical data, but you will need an account to use it.
 - In CelesTrak it is easier to find the current TLEs of satellites organized by mission kind.
2. Use Horizons' SGP4 to propagate the orbit from the TLEs
 - Generate the ephemerides in either Cartesian coordinates or Keplerian elements.
 - **Remember:** each TLE allows for a limited propagation time before and after its epoch. If you need longer propagation times, you need to provide Horizons' SGP4 with more TLEs.
3. Download the ephemerides from Horizons and import the resulting datafile in Matlab
 - In Matlab's file explorer right click on the file and select "Import Data..." to open the interactive import wizard. You will have to select the data delimiter (e.g., comma), the range of rows to import, and the output type (e.g., Numeric Matrix). The imported data will appear as a new variable in your Workspace.
 - You can also import the data from your scripts or functions using functions like `importdata` or `readmatrix` (check the documentation!).

Exercise 3: Ground track from ephemerides data

Exercise 3: Ground track from ephemerides data

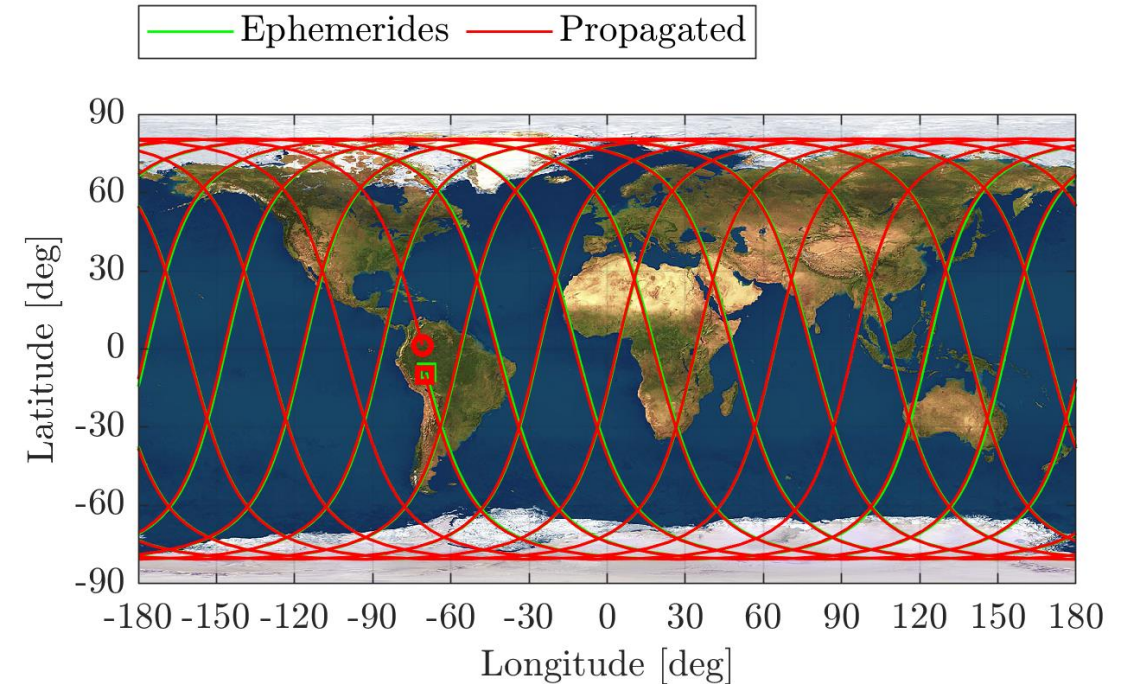
4. Compute the ground track from the downloaded ephemerides, using the codes you developed for **Exercise 1**
 - If you downloaded the ephemerides as Keplerian elements, convert them to Cartesian coordinates.
 - Compute longitude and latitude at each provided time epoch.
 - Plot the ground track.
5. Propagate the orbit from the initial states of the downloaded ephemerides and compute the ground track
 - Plot the resulting ground track together with the one computed at point 4.

Exercise 3: Ground track from ephemerides data



International Space Station

Epoch: 00:00 05/10/2022 – 00:00 06/10/2022



Fengyun 1C debris

Epoch: 00:00 05/10/2022 – 00:00 06/10/2022