'cavsiopy'

A Python package to calculate and visualize the pointing direction of the Radio Receiver Instrument on e-POP/Swarm-E and other satellite missions

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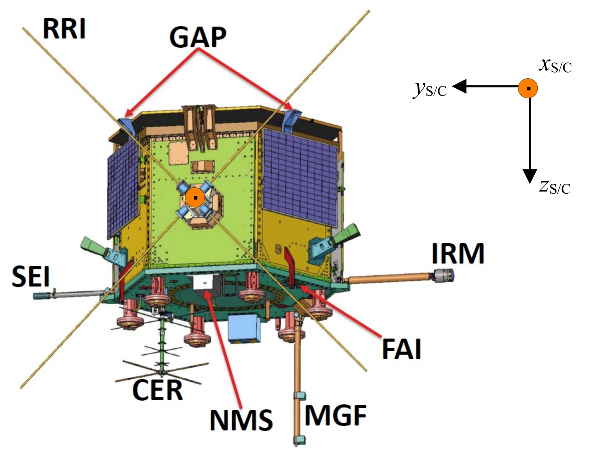
Scope of the problem

- Polarization characteristics of a radio wave observed by an antenna on-board a spacecraft strongly depend on the geometry between the receiving antenna pointing direction and the transmitting source (James, 2003)
- Accurate information about spacecraft orientation/attitude and antenna pointing direction are required
- Determining instrument look direction is not trivial (Acton et al., 2017)
  - Reference frames/coordinate systems lack standardization
  - Software like SPICE Toolkit require steep learning curves

cavsiopy

✓ Open source, light-weight Python package developed at USASK to determine the look direction of the Radio Receiver Instrument (RRI) on e-POP/ Swarm-E

✓ Can be applied to any satellite mission requiring accurate pointing information.



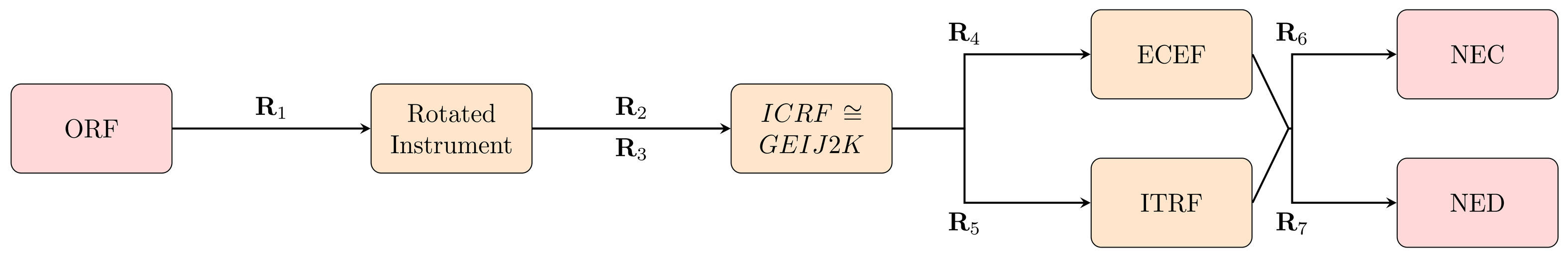
Swarm-E (CASSIOPE)

e-POP scientific suite: 8 instruments

RRI: Radio wave physics

- Orthogonal cross-dipoles
- Dipoles ±45° from $y_{S/C}$ in y-z plane
- Tip-to-tip 6 m.
- Boresight points along the $x_{S/C}$
- Body vector = [1, 0 , 0]

Methods



$$R_x = \begin{bmatrix}1 & 0 & 0\\ 0 & cos\alpha & sin\alpha \\ 0 & -sin\alpha & cos\alpha\end{bmatrix} \quad R_y = \begin{bmatrix}cos\beta & 0 & -sin\beta\\ 0 & 1 & 0 \\ sin\beta & 0 & cos\beta\end{bmatrix} \quad R_z = \begin{bmatrix}cos\gamma & sin\gamma & 0\\ -sin\gamma & cos\gamma & 0 \\ 0 & 0 & 1\end{bmatrix} \quad R_{S/C\rightarrow ICRF} = \begin{bmatrix}\vec{x}\\ \vec{y} \\ \vec{z}\end{bmatrix} \quad e = \begin{bmatrix}\vec{e}_{north}\\ \vec{e}_{east} \\ \vec{e}_{center}\end{bmatrix}$$

$$R_1 = R_z(\gamma)\cdot R_y(\beta)\cdot R_x(\alpha) \quad (1)$$
$$R_2 = R_z(\Omega)\cdot R_x(i)\cdot R_z(u)\cdot O \quad (2)$$
$$R_3 = R_{S/C\rightarrow ICRF}(\vec{r}_{icrf}, \vec{V}_{icrf}) \quad (3)$$
$$R_4 = R_z(\mu) \quad (4)$$
$$R_5 = R_M(t)\cdot R_s(t)\cdot N(t)\cdot P(t) \quad (5)$$
$$R_6 = [R_z(-\lambda)\cdot R_y(-\delta-\pi/2)]^T \quad (6)$$
$$R_7 = e \quad (7)$$

$$\vec{z} = (-\vec{r}_{icrf})/|\vec{r}_{icrf}| \quad (8)$$
$$\vec{y} = (-\vec{r}_{icrf}\times\vec{V}_{icrf})/|\vec{r}_{icrf}\times\vec{V}_{icrf}| = (\vec{z}\times\vec{V}_{icrf})/|\vec{z}\times\vec{V}_{icrf}| \quad (9)$$
$$\vec{x} = (\vec{y}\times\vec{z})/|\vec{y}\times\vec{z}| \quad (10)$$
$$\vec{e}_{center} = (-\vec{r}_{itrf})/|\vec{r}_{itrf}| \quad (11)$$
$$\vec{e}_{east} = (\vec{e}_{center}\times[0\ 0\ 1])/|\vec{e}_{center}\times[0\ 0\ 1]| \quad (12)$$
$$\vec{e}_{north} = (\vec{e}_{east}\times\vec{e}_{center})/|\vec{e}_{east}\times\vec{e}_{center}| \quad (13)$$

Requires:

1. Spacecraft position (X, Y, Z) and velocity in GEIJ2K
2. Roll (α), pitch (β) and yaw (γ) angles
3. Spacecraft position in geographic lat, long, alt
4. Instrument body vector

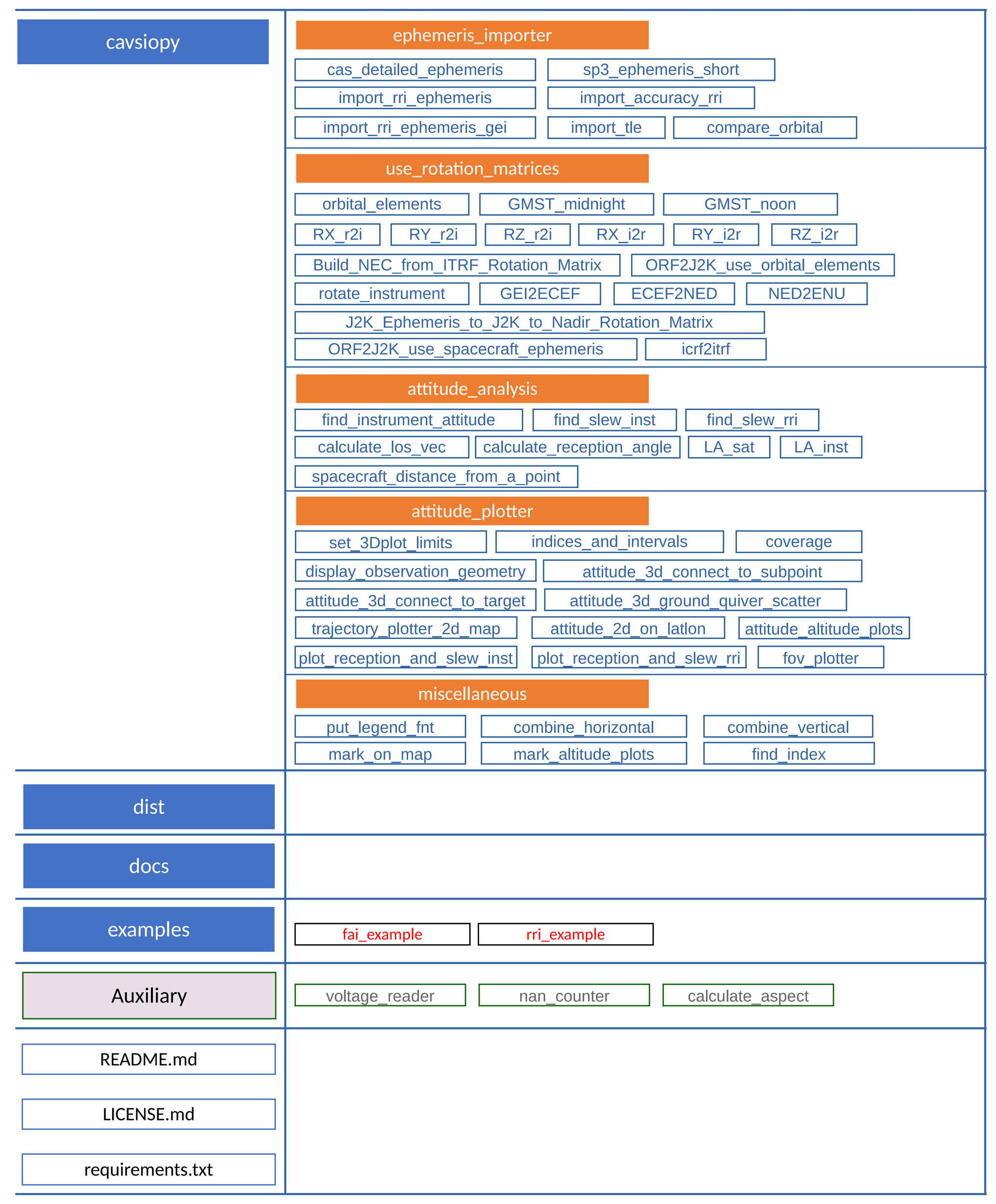
➢ First three are provided in ephemeris files of spacecraft

➢ Fourth item can be determined w.r.t body-fixed frame of spacecraft

Supports transformations between

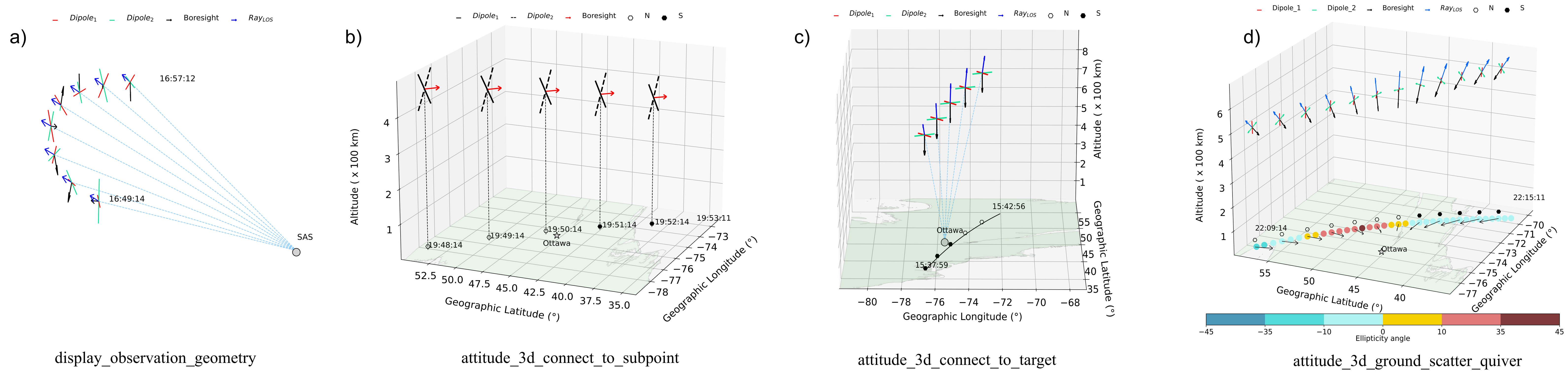
- Spacecraft orbital frame (ORF)
- Geocentric Equatorial Inertial J2000 (GEI J2K) / International Celestial Reference Frame (ICRF)
- Earth Centered Earth Fixed (ECEF)
- International Terrestrial Reference Frame (ITRF)
- Geodetic North-East-Down (NED)
- Geocentric North-East-Center (NEC)

Modules and Functions

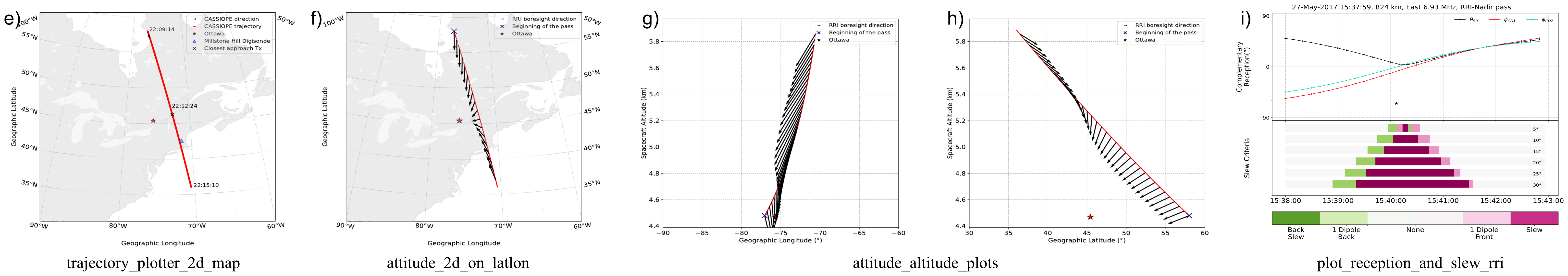


'cavsiopy' GitHub repository and contents

Example figures from 'cavsiopy' attitude_plotter module



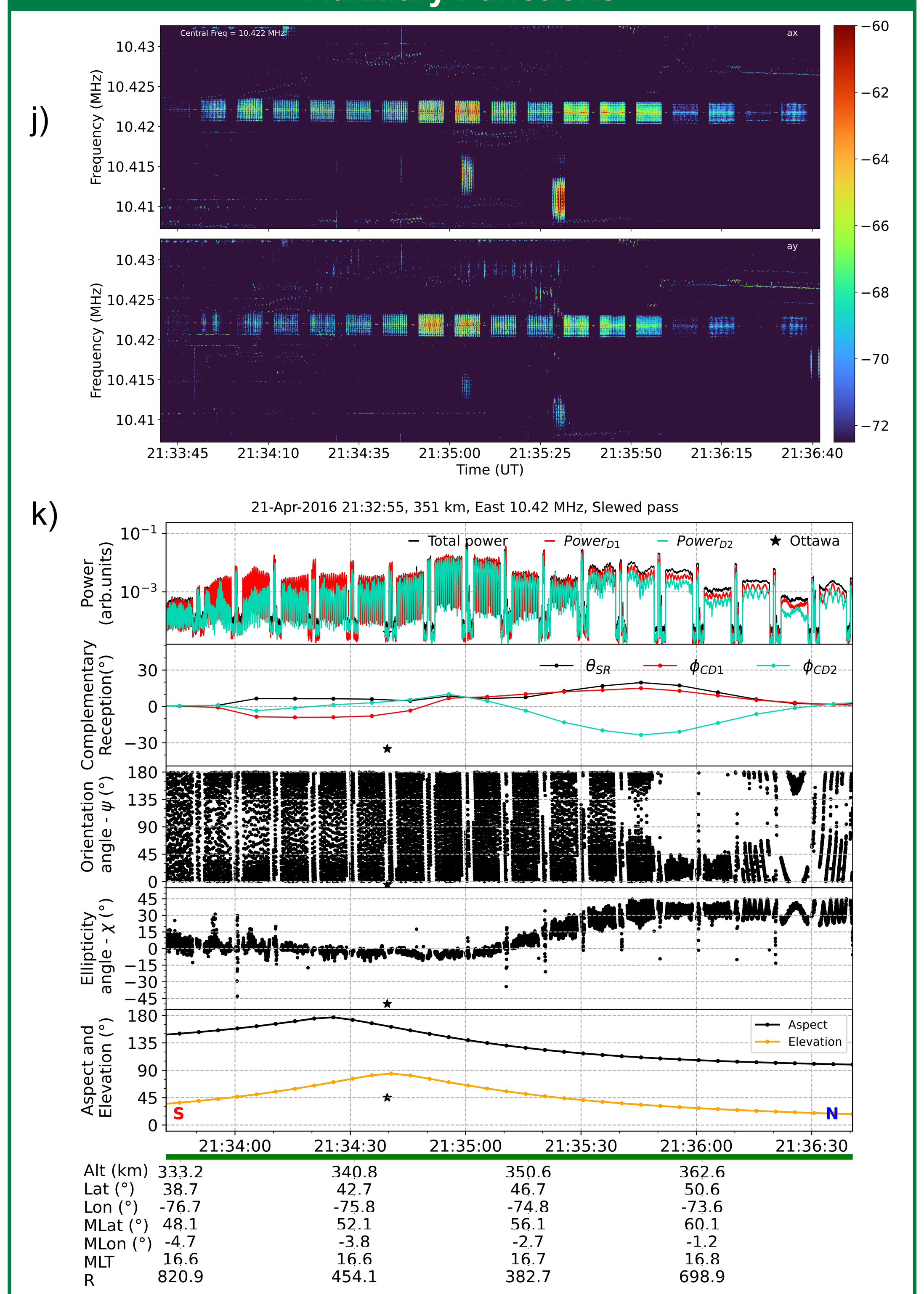
Example plots for different attitude modes typically used in RRI observations: number of vectors, plotted parameters, colors, look-view of the plots are fully customizable. Functions specified below plots are used generally a) to display geometry for any kind of attitude, and when instrument b) points along ram, c) points downwards, and d) is in slew mode



e, f, g, h) 2D plots for a slew-to target pass , and i) time series plots for determining slew modes for an RRI-nadir (RRI looking down) pass

e) spacecraft trajectory, f) spacecraft trajectory and instrument attitude overlaid on map, g) longitude vs altitude, h) latitude vs. altitude plots, and i) top: complementary reception angles, bottom: slew mode

Auxiliary Functions



j) Induced complex voltages, and k) in-situ observed polarization characteristics of radio waves from NRCan Ottawa Tx at RRI

Dependencies, Documentation, Installation

Dependencies:	Github: https://github.com/icebearcanada/cavsiopy	Installation (coming soon):
astropy, spacepy, pysofa, numpy, matplotlib, cartopy	Documentation: https://cavsiopy.readthedocs.io/en/latest/	pip install cavsiopy conda install cavsiopy

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e-POP/Swarm-E data from e-POP data portal: https://epop-data.phys.ucalgary.ca

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Summary: Capabilities of 'cavsiopy'

✓ Determining the attitude of spacecraft axes

✓ Finding the look direction of an instrument on-board a spacecraft

✓ Calculation of the look angles of the spacecraft (elevation and azimuth)

✓ Calculation of the look angles of the instrument

✓ Calculation of the distance between the spacecraft and a designated point on the ground

✓ Calculation of the line-of-sight direction vector from target to spacecraft

✓ Visualization of spacecraft and instrument direction in 2D and 3D

References

Acton, C., Bachman, N., Semenov, B., Wright E. (2017). A look toward the future in the handling of space science mission geometry, Planetary and Space Science, https://doi.org/10.1016/j.pss.2017.02.013

H. G. James; High-frequency direction finding in space. Rev Sci Instrum 1 July 2003; 74 (7): 3478–3486. https://doi.org/10.1063/1.1581396

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