ISSS 2023

Symposium Schedule

THE 6TH INTERNATIONAL SYMPOSIUM ON

SPACE SAILING

JUNE 5-9, 2023

City Tech, CUNY
New York, USA

The 6th International Symposium on Space Sailing (ISSS 2023),
June 5-9, 2023, New York City, USA

ASI Project Helianthus: Solar-Photon Sailcraft for Geostorm Early Warning

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Mission Helianthus Purposes

A. Development of know-how and hardware related to the in-space photon propulsion with **no** rocket add-on;

B. Designing an <u>utilitarian</u> space mission for geostorm early warning with times longer than 100 minutes for the solar <u>fast streams</u> with typical speed about 800 km/s, *as a reference performance*;

C. Geomagnetic-storm <u>yellow-alarm</u> via solar corona imaging by a new class of in-house onboard coronagraphs;

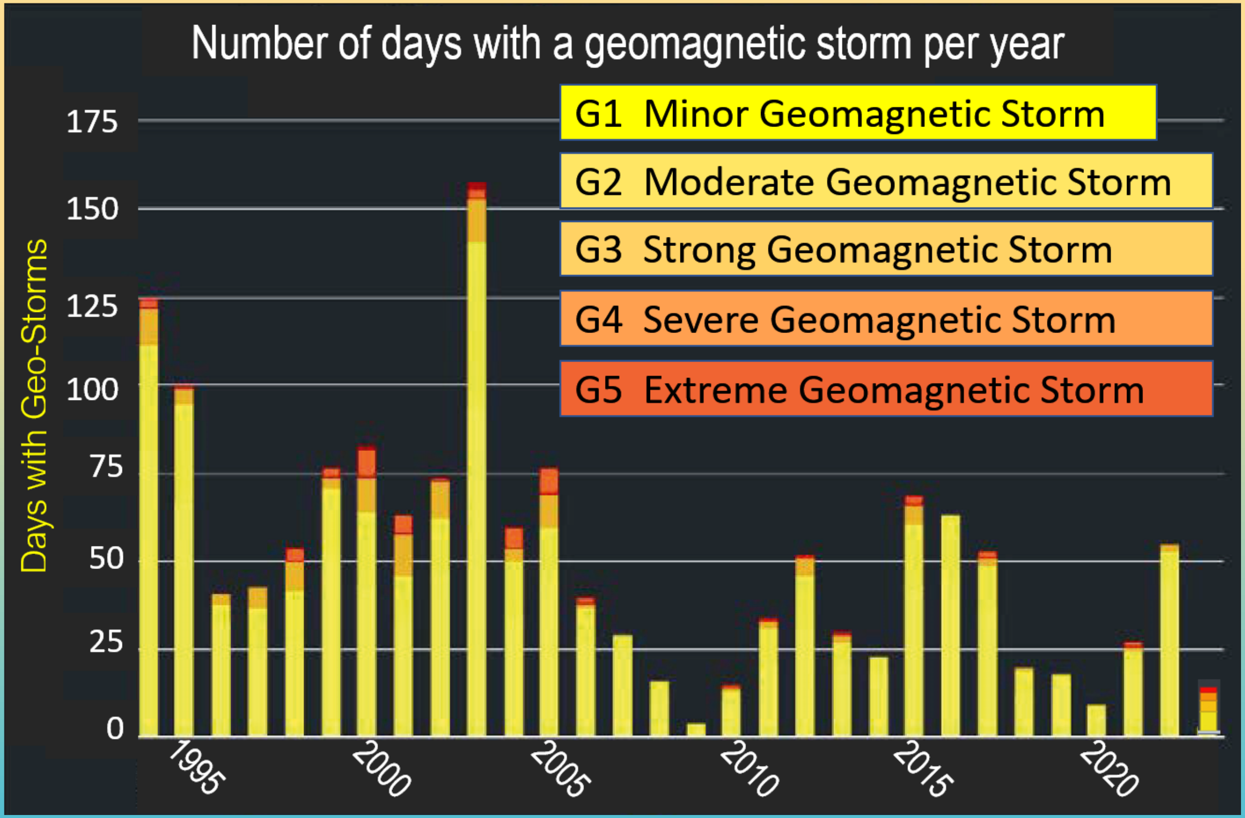
Mission Helianthus Purposes

D. Geomagnetic-storm <u>red-alarm</u> based on the occurrence of both Earthward CME and an ensuing magnetic reconnection in the Earth's magnetopause and magnetotail;

E. <u>Contributing to international geostorm forecasting</u>;

F. Development of very low mass devices also for non-propulsive applications related to ASI's future programs.

Currently, there are international forecasting services for geostorms, based on ground observations, LEO satellites, and mathematical models based on time series.



NOAA rank, Courtesy of Space Weather Live

Helianthus:

Italian Space Agency (ASI)'s main Technology Development Mission for Solar-Photon Sailing

- First Step Duration: Nov. 2019 – Dec. 2022 1/2
- Systems /Subsystems analyzed:
  - Detailed Mission Analysis, including Wrinkles and Earth-Moon disturbance, with preliminary maneuver sequence optimization
  - System/subsystem's loading sharing-out equations
  - CP1 production facility
  - Sail Aluminization and surface analysis
  - Sail Boom Devices (two technological options)

- First Step Duration: Nov. 2019 – Dec. 2022 2/2
  - No-rocket Attitude Sail Control: Electro-Chromic Actuators
  - Onboard Communication System
  - Ground Station Net
  - Electric Power System
  - Scientific Payload

✓ Accurate Sailcraft Acceleration Calculation via the Lightness Vector Formalism;

✓ Preliminary sequence of Synchronization of Helianthus with the Earth-Moon Barycenter (1-year based).

I. ASI Project for Sailcraft Helianthus aims at contributing to international forecasting processes via the observation of - in chronological order - a Solar flare / the ensuing CME, and the *conditions*, if any, that cause *magnetic-reconnection* in *magnetopause* and *magnetotail*. These add to direct entrance of the solar-wind particles from the Magnetosheath into the Earth's Polar Cusps.

II. Ionosphere currents are strongly modified to bring about a geomagnetic storm.

III. Helianthus propulsion system was analyzed for operational-orbit observations of solar disk and solar wind **and** *preliminary* heliocentric transfer orbit.

- Three national universities, two national laboratories, and a private company worked for ASI in this preliminary step.

- Five primary systems and nine main subsystems have been considered in many details for design and feasibility.

- Dept. of Astronautical Engineering at Sapienza University of Rome was given the task of performing the mission analysis.

Here, for length reasons, we summarize only some aspects of the operational-orbit mission analysis.

- Helianthus concept involves the realization of a sailcraft operating on a **sub-L1** orbit to be kept quasi-synchronous with the Earth-Moon Barycenter (EMB) despite both gravitational perturbation and strongly-non-ideal sail optics.

- We need two main reference systems (and a number of auxiliary/intermediate frames) for describing the motion of the sailcraft's center of mass:

1. HIF, derived from the **ICRF**;
2. HOF, with the Z-axis along the sailcraft's orbital angular momentum **H.**

3. The propulsive acceleration is computed with high accuracy by the Lightness Vector Formalism.

Framework:

Classical Dynamics, e.m. Theory, and Quantum Physics (with regard to some aspects of sail's surface metal lattice)

HOF:

$$\mathbf{r} \equiv \mathbf{R} / \|\mathbf{R}\|, \quad \mathbf{V} \equiv \mathrm{d}\mathbf{R}/\mathrm{d}t, \quad \mathbf{h} \equiv \mathbf{R}\times\mathbf{V} / \|\mathbf{R}\times\mathbf{V}\|, \quad \|\mathbf{R}\times\mathbf{V}\| > 0$$

$$\mathbf{x}\text{-axis} \equiv \mathbf{r}, \quad \mathbf{z}\text{-axis} \equiv \mathbf{h}, \quad \mathbf{y}\text{-axis} \equiv \mathbf{z}\times\mathbf{x}$$

HIF:

Translation of the origin of ICRS,

Rotation about the ICRS X-axis by the ecliptic obliquity at J2000.

Time:

T_{eph} of JPL DE430/LE430 *ephemeris file*

$$\boxed{\mathrm{TDB} \equiv T_{eph}}$$

IAU *Resolution at the* XXVI *General Assembly*

(*Prague*, 14–25 *August*, 2006, *Resolution B*3)

Motion Equations 1/3

$$\mathbf{R} \equiv \textit{Helianthus' vector radius in}\ \mathrm{HIF}$$

$$\begin{aligned}
\frac{\mathrm{d}^2\mathbf{R}}{\mathrm{d}t^2} + \frac{\mu_\odot}{R^3}\mathbf{R} &= \boxed{\frac{\mu_\odot}{R^2}\,\Xi^{(\mathrm{HIF})}_{\quad(\mathrm{HOF})}\;\mathbf{L}^{(\mathrm{HOF})}} + \boxed{\sum_{k=1}^{N_{ncb}} \mathbf{P}_k} \\
&= \frac{\mu_\odot}{R^2}\,\Xi^{(\mathrm{HIF})}_{\quad(\mathrm{HOF})} \begin{bmatrix} L_\mathrm{r} \\ L_\mathrm{t} \\ L_\mathrm{n} \end{bmatrix} + \sum_{k=1}^{N_{ncb}} \mathbf{P}_k \\
&= \boxed{\frac{\mu_\odot}{R^2}\left(L_\mathrm{r}\,\mathbf{r} + L_\mathrm{t}\,\mathbf{h}\times\mathbf{r} + L_\mathrm{n}\,\mathbf{h}\right)} + \sum_{k=1}^{N_{ncb}} \mathbf{P}_k \ , \qquad L_\mathrm{r} \geq 0
\end{aligned}$$

Motion Equations 2/3

$$E = \tfrac{1}{2}V^2 - (1-L_\mathrm{r})\frac{\mu_\odot}{R} = -(1-L_\mathrm{r})\frac{\mu_\odot}{2a}$$

$$\|\mathbf{H}\|^2 \equiv (1-L_\mathrm{r})\mu_\odot\, p\,,$$

$$e = \sqrt{1 + 2E_{(sail)}\left(\|\mathrm{H}\|/\mu_\odot\right)^2} = \sqrt{1-p/a}$$

$$\dot{\mathbf{H}} = \mathbf{R}\times\ddot{\mathbf{R}} = \frac{\mu_\odot}{R}\left(L_\mathrm{t}\,\mathbf{h} - L_\mathrm{n}\,\mathbf{h}\times\mathbf{r}\right)$$

$$\mathbf{H}\times\dot{\mathbf{H}} = \frac{\mu_\odot}{R}\,\mathrm{H}\;L_\mathrm{n}\,\mathbf{r}$$

$$\mathbf{H}\cdot\dot{\mathbf{H}} = \mathrm{H}\,\dot{\mathrm{H}} = \frac{\mu_\odot}{R}\,\mathrm{H}\;L_\mathrm{t}$$

$$\dot{\mathrm{H}} = \frac{\mu_\odot}{R}\,L_\mathrm{t}$$

$$\frac{d^2}{dt^2}\mathbf{R} \equiv \ddot{\mathbf{R}} = \frac{\mu_\odot}{R^2}\left[-(1-L_\mathrm{r})\mathbf{r} + L_\mathrm{t}\,\mathbf{h}\times\mathbf{r} + L_\mathrm{n}\,\mathbf{h}\right]$$

$$L_\mathrm{r} \geq 0$$

$$E = \tfrac{1}{2}V^2 - (1-L_\mathrm{r})\frac{\mu_\odot}{R}$$

$$\frac{d}{dt}E = \frac{\mu_\odot}{R^2}\mathbf{V}\cdot\mathbf{h}\times\mathbf{r}\,L_\mathrm{t} + \frac{\mu_\odot}{R}\frac{d}{dt}L_\mathrm{r} = \frac{\mathrm{H}}{R^2}\frac{d}{dt}\mathrm{H} + \frac{\mu_\odot}{R}\frac{d}{dt}L_\mathrm{r}$$

Motion Equations 3/3

$\mathbf{L}^{(\mathrm{HOF})} \equiv \mathbf{L}$

- The Lightness Vector **L** and its time rate are necessary and sufficient control quantities for describing and optimizing a sailcraft trajectory from the dynamical viewpoint.

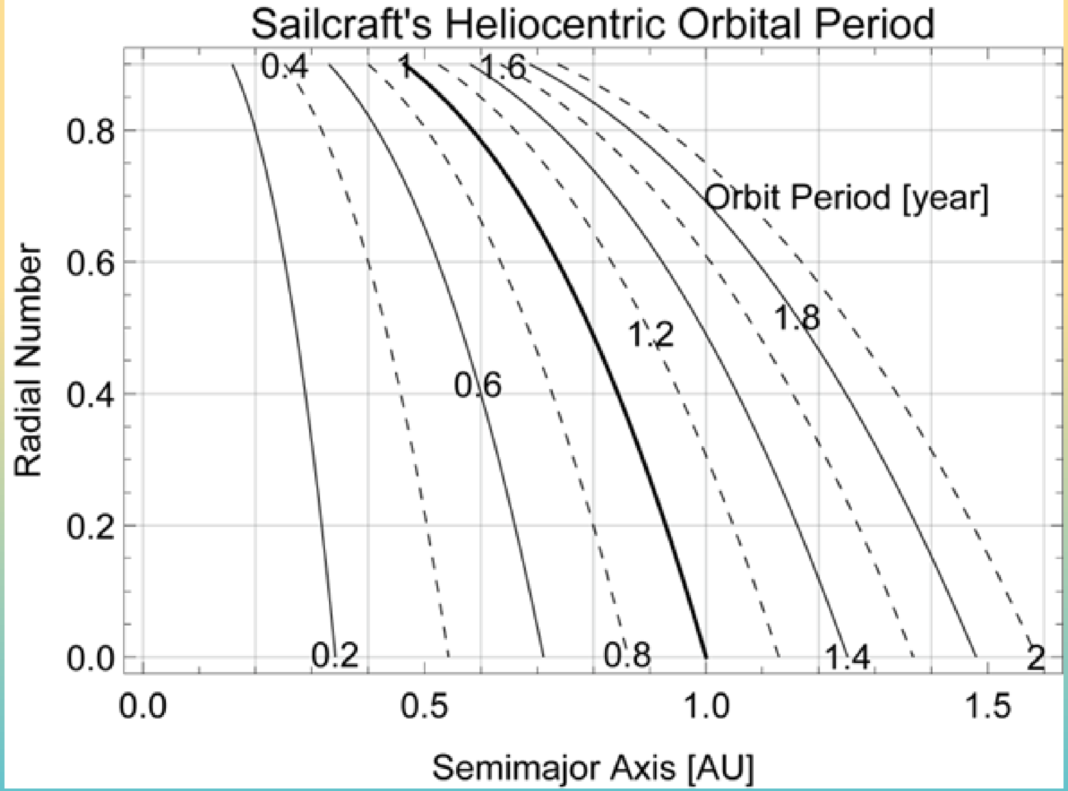
- Therefore, we will state the current problem and proceed to the computation of **L** in the context of the electromagnetic theory, the physics of the metal lattice, and the sail interaction with the Solar Total Irradiance (TSI) and the Solar Spectral Irradiance (SSI).

- There is also an interaction with the solar-wind plasma, which was computed years ago outside the project Helianthus.

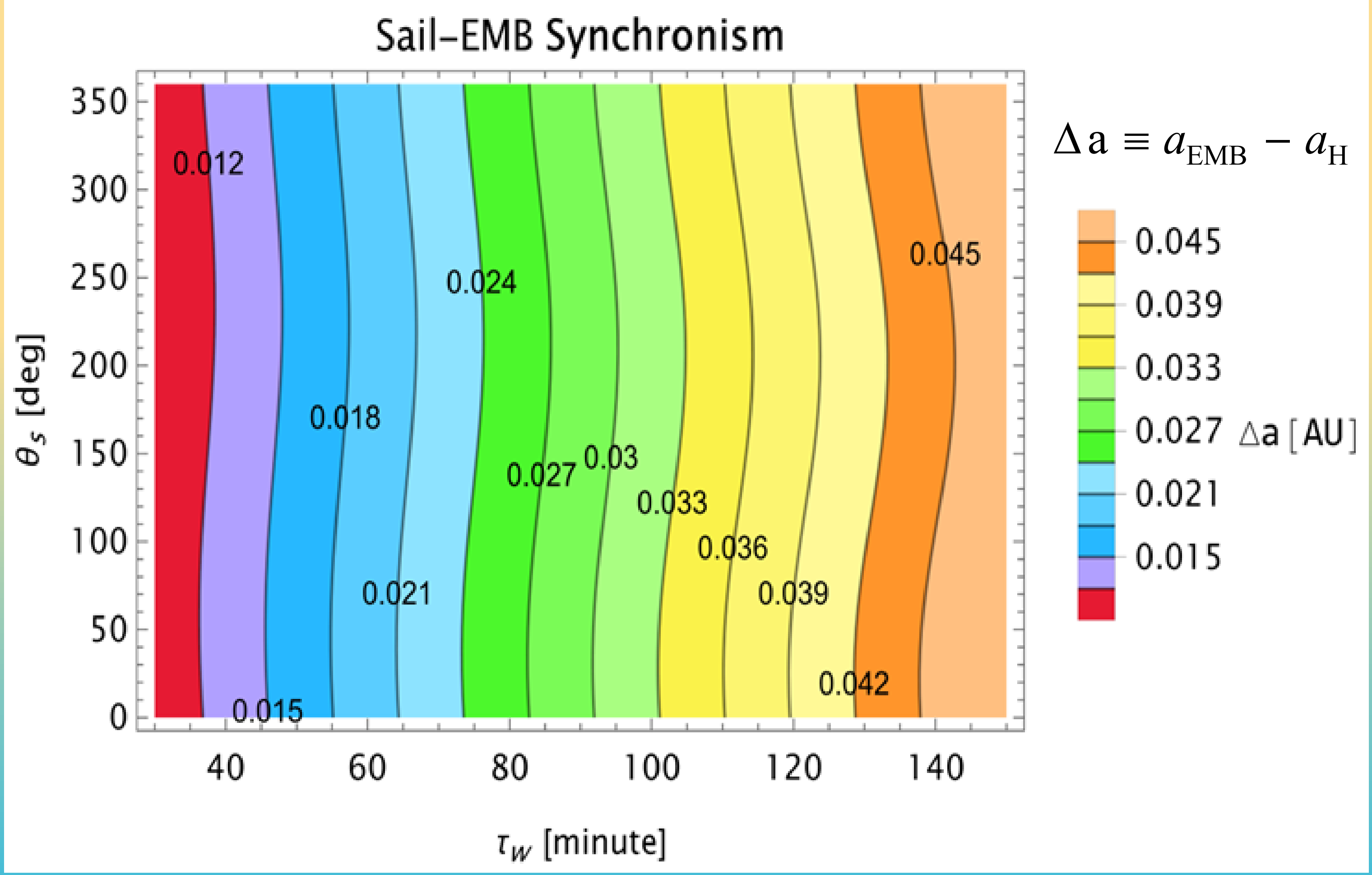
Ideal EMB-Synchronism

nominal radial number L_r

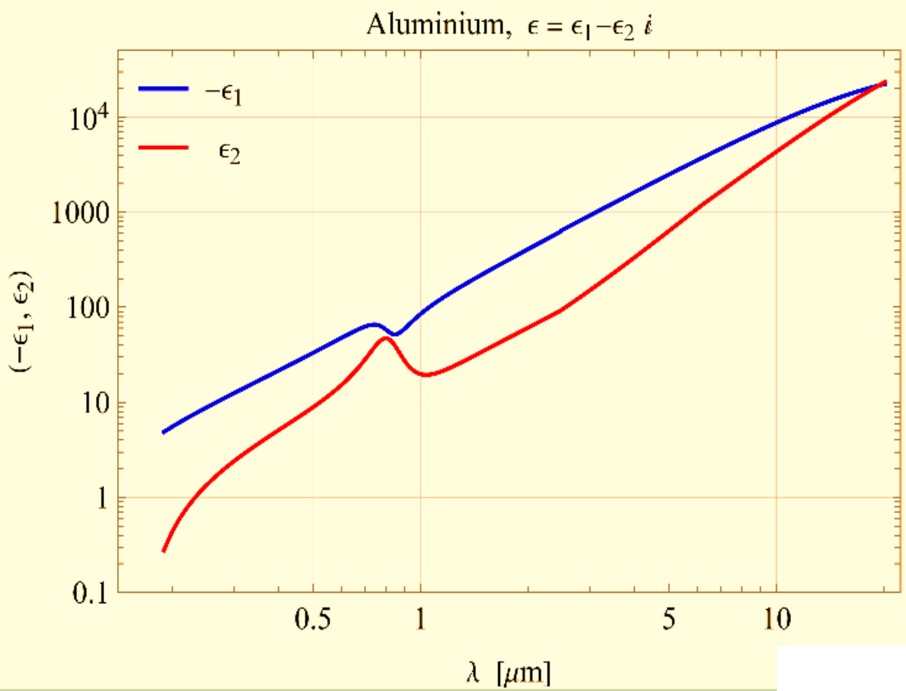
$$\mathbf{L} \cdot \mathbf{r} = 1 - \left(a_H / a_{EMB}\right)^3$$

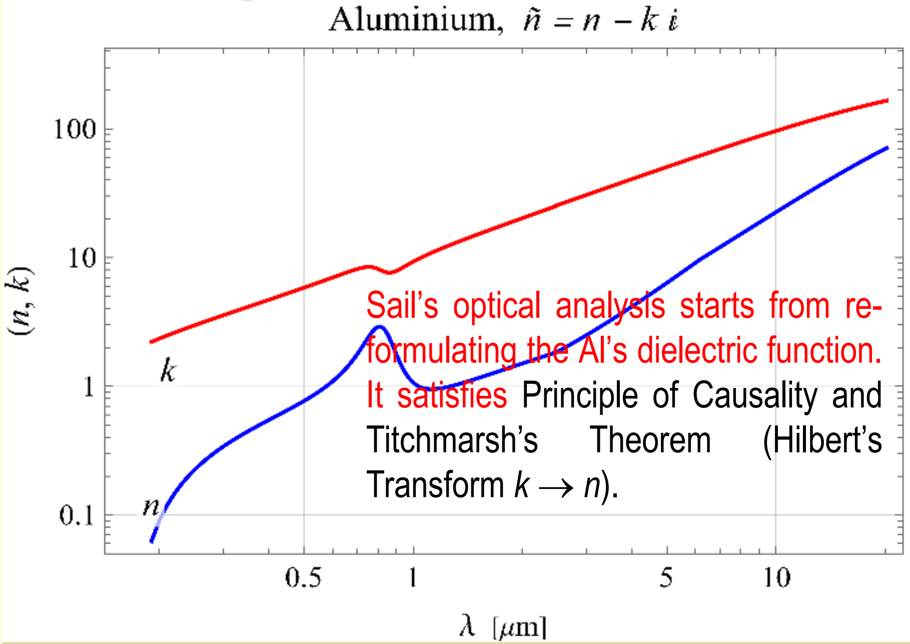


Contours of the surface function of the semiaxis difference, the station orbit phase, and the early warning time for **fast streams** ($\upsilon = 800$ km/s)



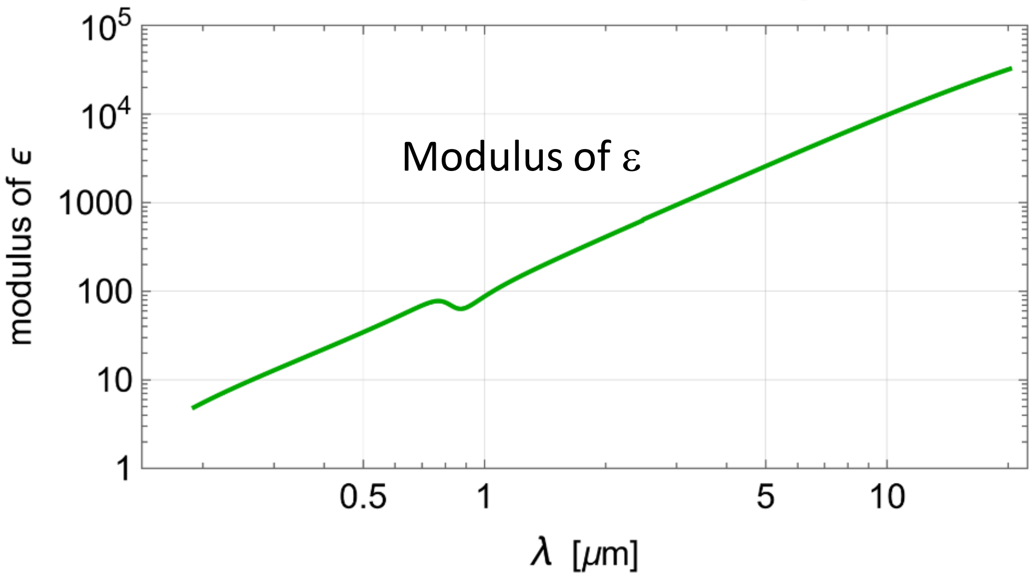
Dielectric Function and Refraction’s Complex Index of *Al*





Sail’s optical analysis starts from re-formulating the Al’s dielectric function. It satisfies Principle of Causality and Titchmarsh’s Theorem (Hilbert’s Transform $k \rightarrow n$).

Aluminium, $|\epsilon|$ *vs* wavelength



A.R. Forouhi and I. Bloomer. *Optical dispersion equations for metals applicable to the Far-IR through EUV spectral range.* Journal of Physics Communications, Volume 5, Number 2, 2021

e.m.-theory-compliant acceleration functions

(in order of logical calculation):

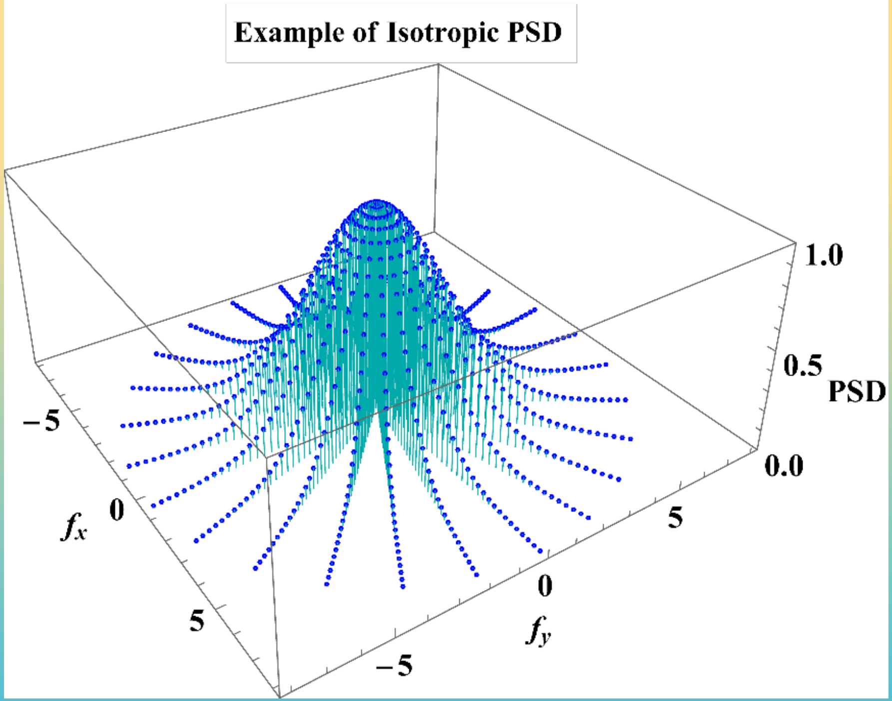
Translational-Acceleration Contributions $\left(\tilde{\mathbf{L}}\right)$

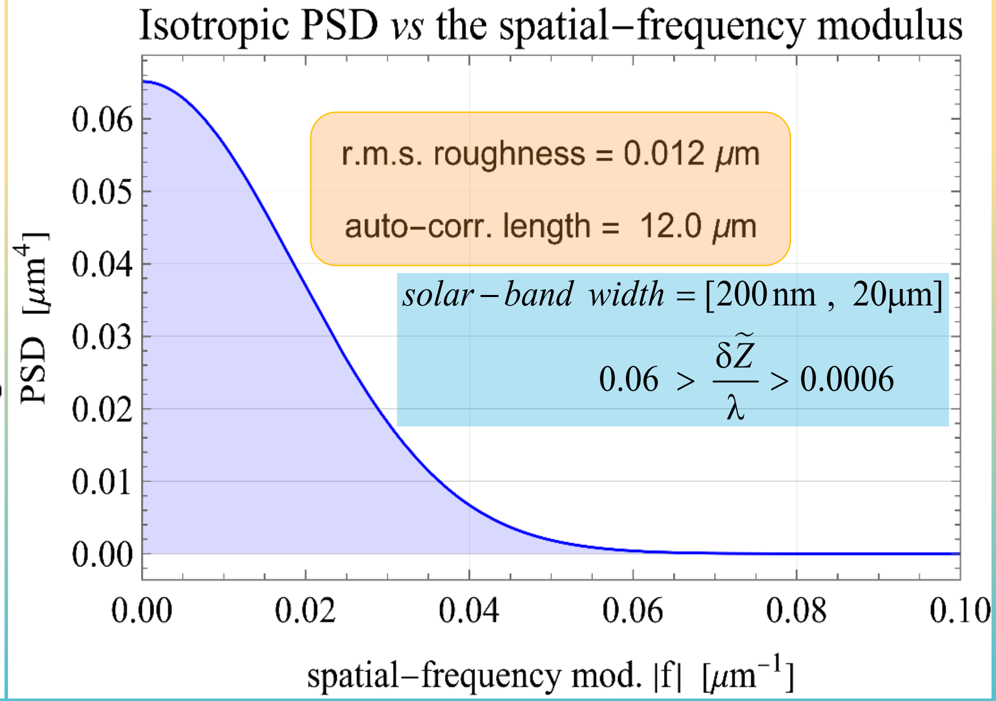
1. **Intrinsic Absorption**
2. **Roughness-Induced Absorption**
3. **Diffuse Reflection (two components)**
4. **Specular Reflection**
5. **Temperature-Induced**
6. **Wrinkles (two components)**
7. **Averaged TSI** → **TSI’s time series**

Diffuse-Reflection **BRDF** (Rayleigh-Rice Vector Scattering Theory)

$$\left(\Lambda_{\lambda}^{\square}\right)_{a\to b} = \frac{16\pi^{2}}{\lambda^{4}}\left[\cos\left(\vartheta_{\odot}\right)\cos\left(\vartheta_{(re)}\right)\right]\ \mathbb{S}_{2}^{(iso)}\left(f^{2}\right)\ Q_{a\to b}$$

$$a = \perp\ ,\ \parallel \qquad\qquad b = \perp\ ,\ \parallel$$





1/4

$$\tilde{\mathbf{L}} = \frac{1}{2}\frac{\left\langle\sigma_{(cr)}\right\rangle}{\sigma_0}\left(1+\frac{\delta A}{A_0}\right)\cos\left(\tilde{\vartheta}_\odot\right)\left[\begin{array}{l} 2\cos\left(\tilde{\vartheta}_\odot\right)\mathcal{R}^{(spec)}\,\tilde{\mathbf{n}} \\ + \varpi\left(\sin(\bar{\beta})\,\mathbf{n}_0 + \cos(\bar{\beta})\,\mathbf{X}_s{}^{(\mathrm{HOF})}\right) \\ + \left(\mathcal{A}^{(tot)} + \mathcal{R}^{(diff)}\right)\mathbf{u} \\ + \mathcal{A}^{(f)}_{\vartheta_\odot}\,\dfrac{\bar{\chi}^{(f)}\mathcal{E}^{(f)} - \bar{\chi}^{(b)}\mathcal{E}^{(b)}}{\mathcal{E}^{(f)} + \mathcal{E}^{(b)}}\,\tilde{\mathbf{n}} \end{array}\right]$$

$$\left\langle\sigma_{(cr)}\right\rangle \equiv \left\langle\sigma_{(cr)}\right\rangle_{cycle-24}\ , \qquad \left\langle\sigma_{(cr)}\right\rangle \to \sigma_{(cr)}\left(\mathrm{TSI}(t)\right)$$

$$\mathbf{u} \equiv \mathbf{X}^{(\mathrm{HOF})} \neq \mathbf{X}_{sail}{}^{(\mathrm{HOF})}\ ,$$

$$\tilde{\mathbf{n}} = \mathbf{n}_0 + \delta\tilde{\mathbf{n}}\ , \qquad \tilde{\vartheta}_\odot \equiv \mathit{equivalent\ incident\ angle}: \quad \cos(\tilde{\vartheta}_\odot) = \cos(\vartheta_\odot) + \delta\tilde{\mathbf{n}}\cdot\mathbf{u}$$

$$\mathbf{L}^{(total)} \equiv \mathbf{L} = \widetilde{\mathbf{L}} + \mathbf{L}^{(\mathrm{SAC})}(\vec{\mathbb{P}}, \widetilde{\mathbf{L}}) + \mathbf{L}^{(\mathrm{booms})}$$

$$\mathbf{L}^{(\mathrm{SAC})} \equiv \widetilde{\mathbf{L}}'s \;\; modification \; due \; to \; the \; Sail \;\; Attitude \; Control$$

$$\mathbf{L}^{(\mathrm{booms})} = \widetilde{\mathbf{L}}'s \;\; modification \; due \; to \; the \; booms = \vec{f}\left(general \;\; booms \;\; config\right)$$

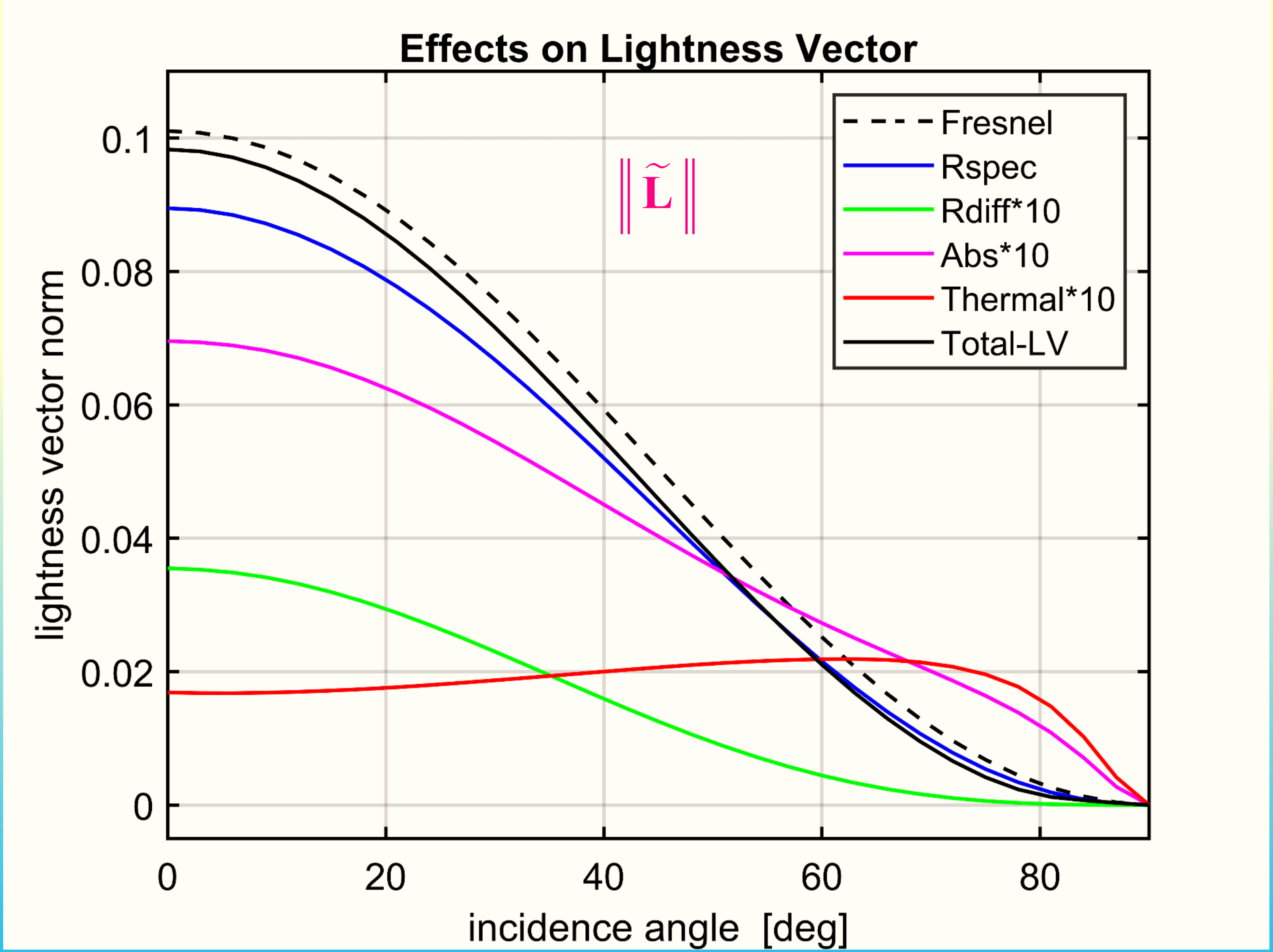
$$\Rightarrow$$

$$\boxed{\mathbf{L}_l^{(total)}} \cong \widetilde{\mathbf{L}}_l + \sum_{k=1}^{K} \frac{\partial \mathbf{L}^{(\mathrm{SAC})}{}_l}{\partial \mathbb{P}_k} d\mathbb{P}_k + \sum_{j=1}^{3} \frac{\partial \mathbf{L}^{(\mathrm{SAC})}{}_l}{\partial \widetilde{\mathrm{L}}_j} d\widetilde{\mathrm{L}}_j, \quad l = 1..3$$

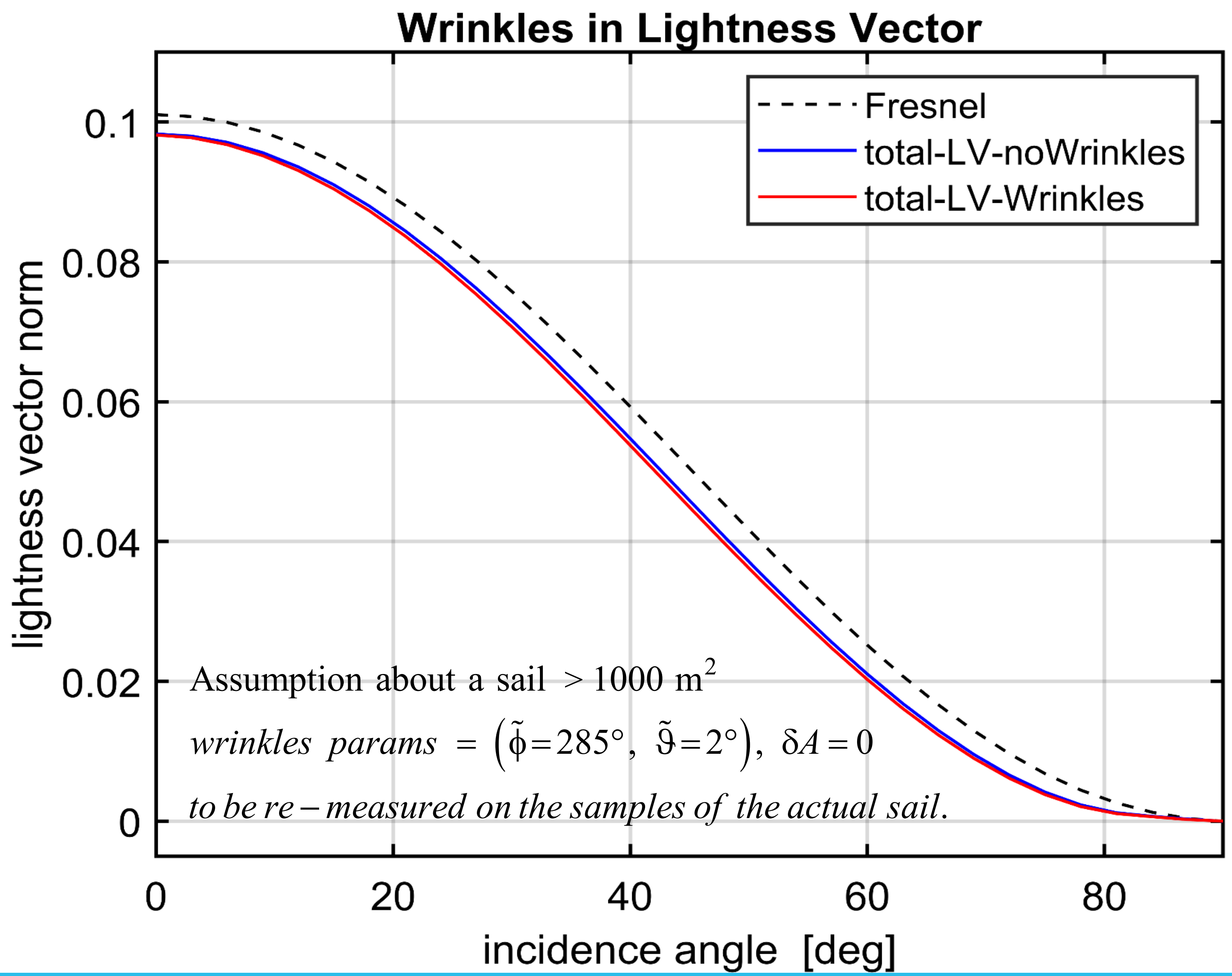
$sign(\mathbf{L}^{(\mathrm{SAC})}{}_l)$, $l = 1..3$, *depends on the*

working mode of the electrochromic (*aka electro – optic*) *materials*

3/4


Effects on Lightness Vector
$\|\tilde{\mathbf{L}}\|$
Fresnel
Rspec
Rdiff*10
Abs*10
Thermal*10
Total-LV
lightness vector norm
0.1
0.08
0.06
0.04
0.02
0
0
20
40
60
80
incidence angle [deg]

4/4



Assumption about a sail $> 1000\ \mathrm{m}^2$

$\textit{wrinkles params} = \left(\tilde{\phi} = 285°,\ \tilde{\vartheta} = 2°\right),\ \delta A = 0$

to be re – measured on the samples of the actual sail.

Helianthus' Standard Sail

$$L_0^{(\mathcal{F})}\Big|_{\sigma_0=14.59\,\mathrm{g/m^2}} = 0.0983153$$

$$\left\|\mathbf{L}(t_0)\right\|_{\sigma_0=14.59\,\mathrm{g/m^2}} \equiv L_0 = 0.0978923$$

$$accel(t_0) = 0.61161\,\mathrm{mm/s^2}$$

$$\Delta L_0 / L_0^{(\mathcal{F})} = -0.0043$$

$$\sigma_0 = 14.59\ \mathrm{g/m^2} \qquad m_0 = 20.34\ \mathrm{kg}$$

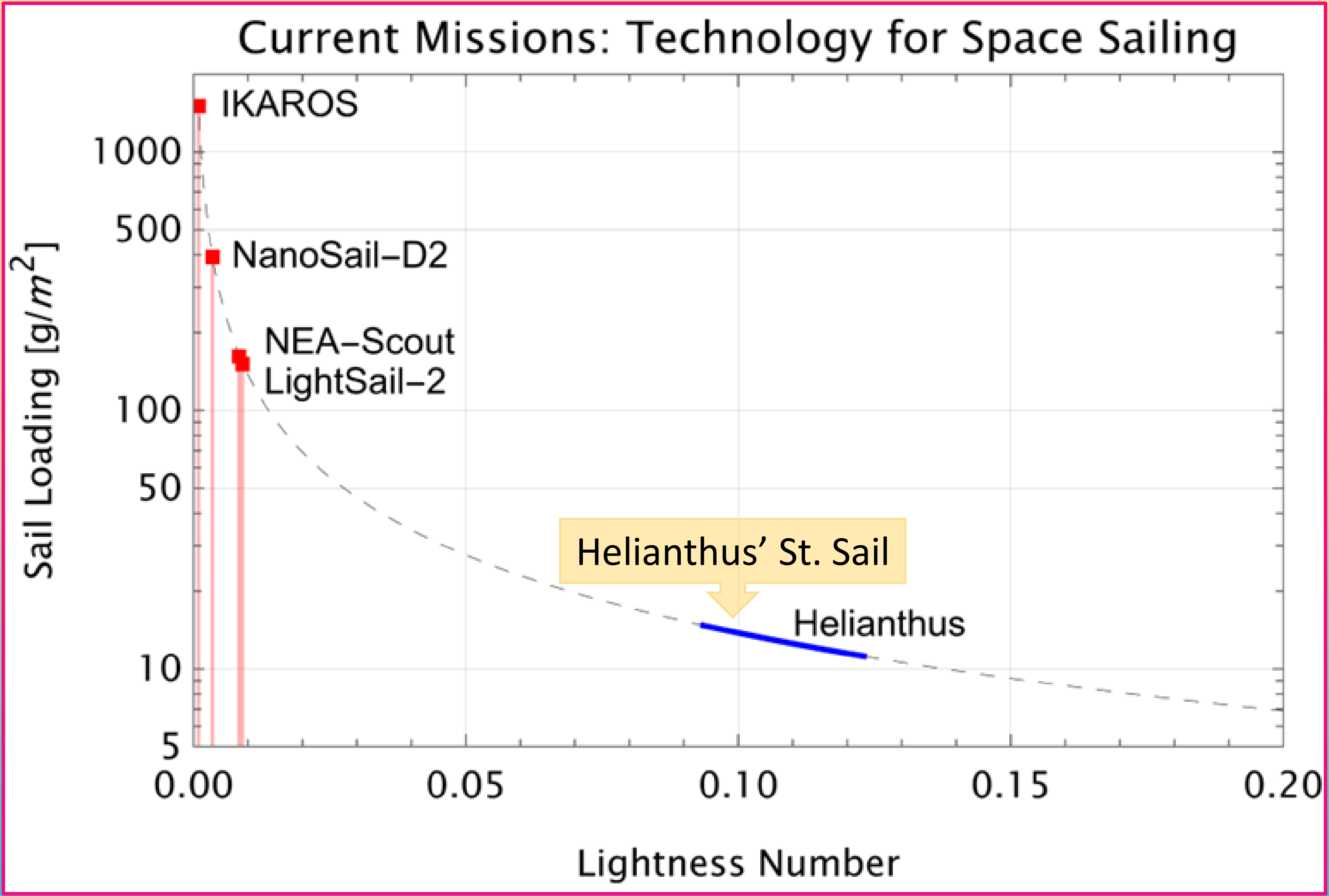
$$m_{P/L} = 5.0\ \mathrm{kg} \qquad A_0 = 1394.34\ \mathrm{m^2}$$

$$a_{\mathrm{EMB}} - a_{\mathrm{H}} = 0.03401\ \mathrm{AU} \Rightarrow \frac{a_{\mathrm{EMB}} - a_{\mathrm{H}}}{\mathrm{dist(EMB,\ L1)}} = \mathbf{3.4}$$

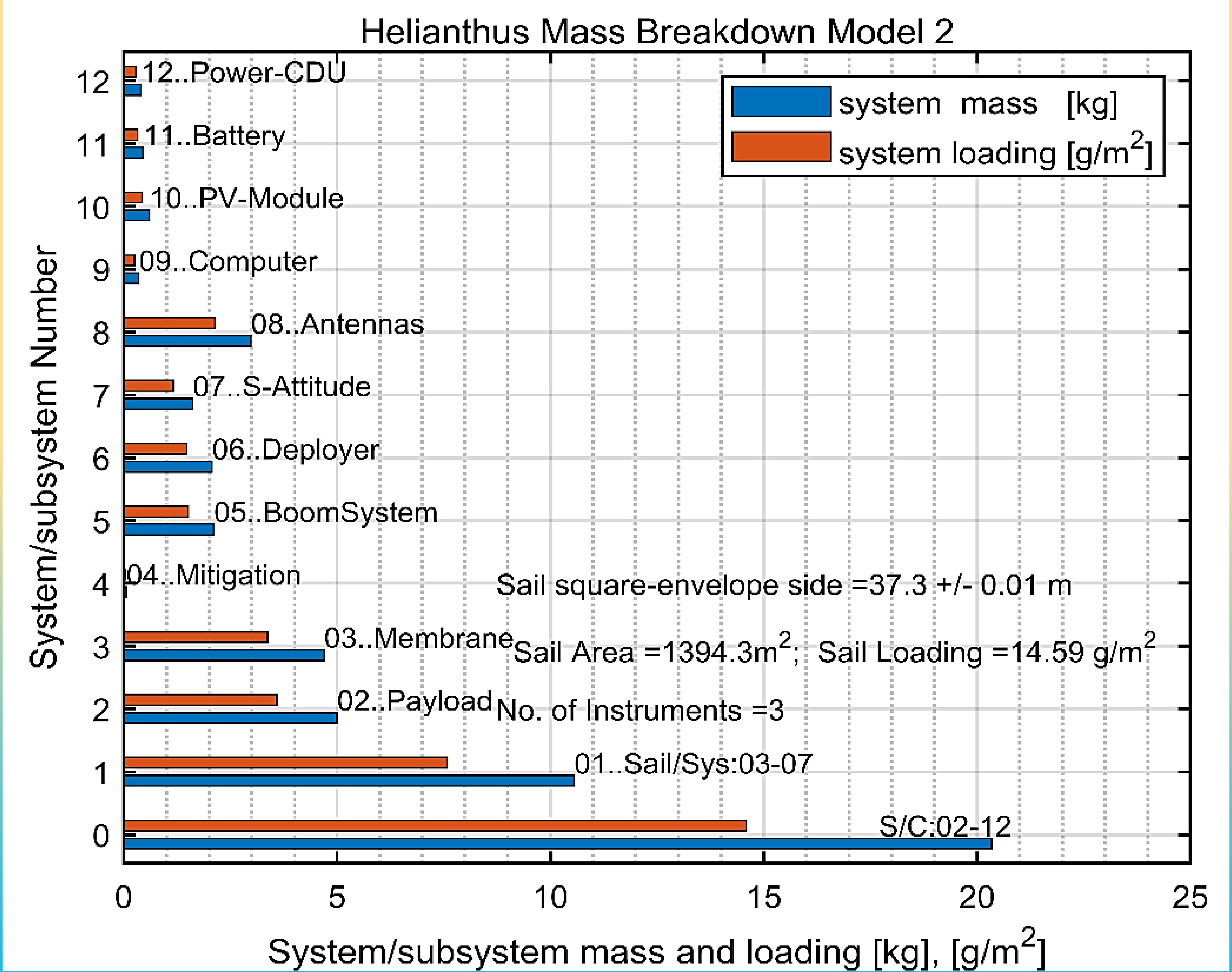
$$\langle \tau_w \rangle_{800\mathrm{km/s}} = 106\ \mathrm{min} = \mathbf{3.4}\langle \tau_w \rangle_{\mathrm{ACE}}$$

This is the reference set of values about which all of the next-sail design parameters are described and carried out by expansion.

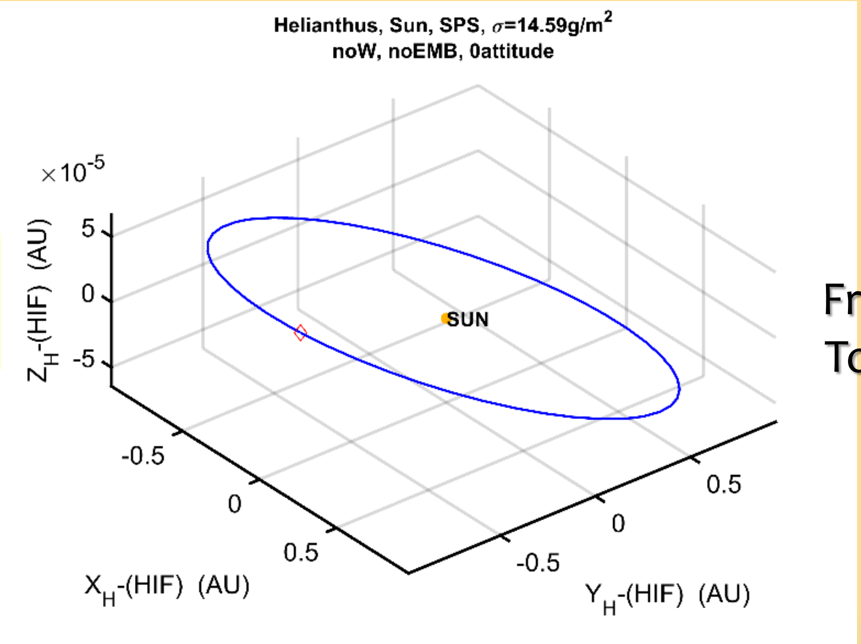
$$\langle L\rangle\,\sigma \;-\; \left\langle \sigma_{(cr)} \right\rangle \underset{\uparrow\ \text{thrust efficiency}}{\eta(\mathcal{P})} \;=\; 0$$



Helianthus’ St. Sail


Helianthus Mass Breakdown Model 2
12..Power-CDU
11..Battery
10..PV-Module
09..Computer
08..Antennas
07..S-Attitude
06..Deployer
05..BoomSystem
04..Mitigation
03..Membrane
02..Payload
01..Sail/Sys:03-07
S/C:02-12
system mass [kg]
system loading [g/m^2]
Sail square-envelope side =37.3 +/- 0.01 m
Sail Area =1394.3m^2; Sail Loading =14.59 g/m^2
No. of Instruments =3
System/subsystem Number
0
1
2
3
4
5
6
7
8
9
10
11
12
System/subsystem mass and loading [kg], [g/m^2]
0
5
10
15
20
25

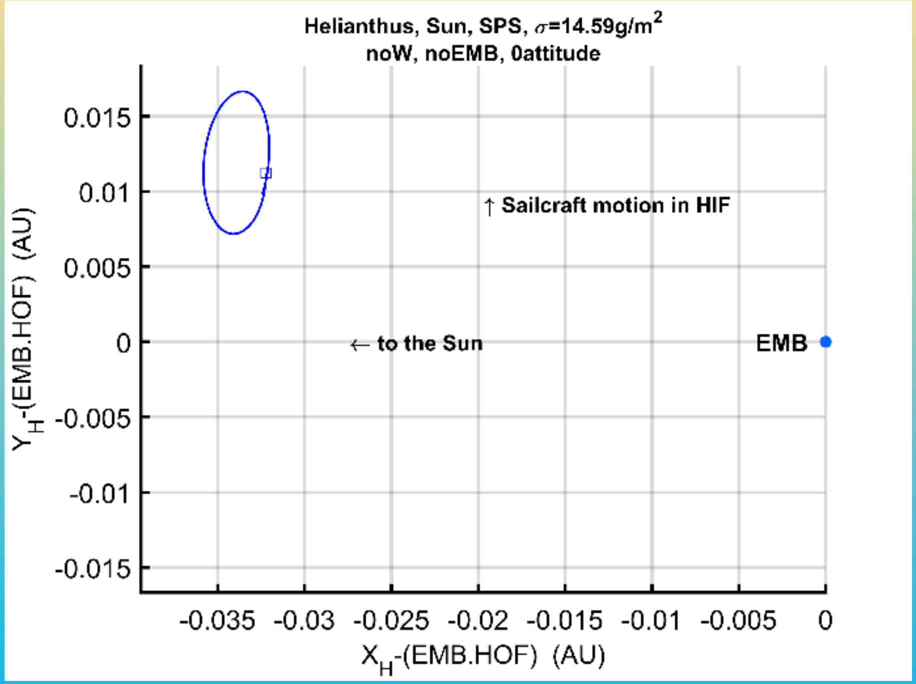
Helianthus' reference **ideal** orbit.

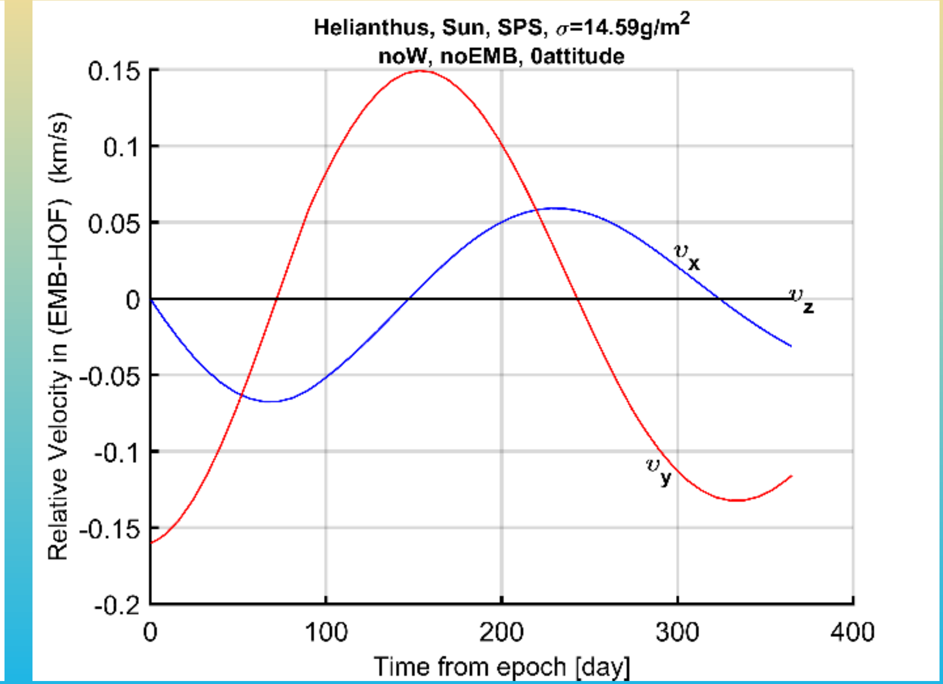


Time frame:

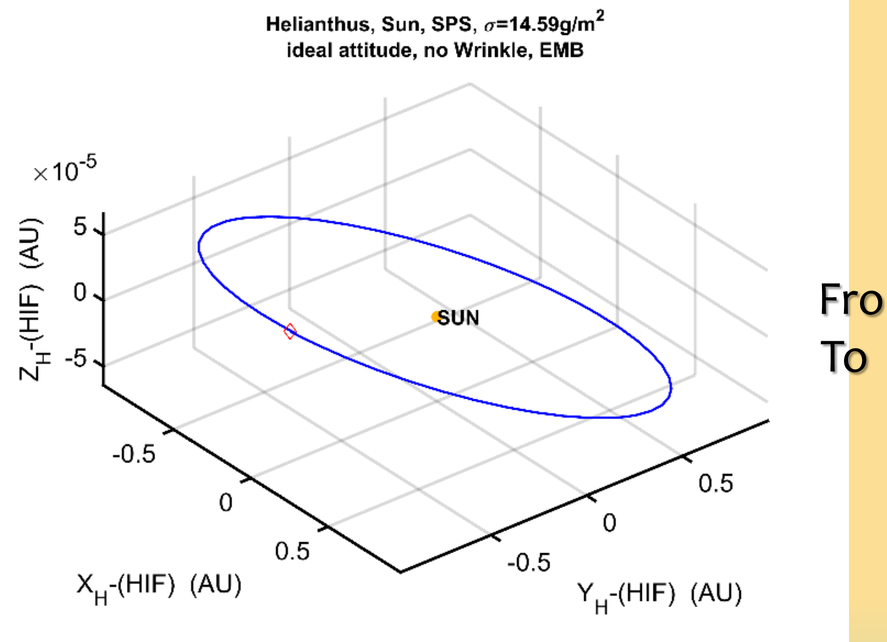
From 2030.07.05 12:00:00

To 2031.07.05 12:00:00

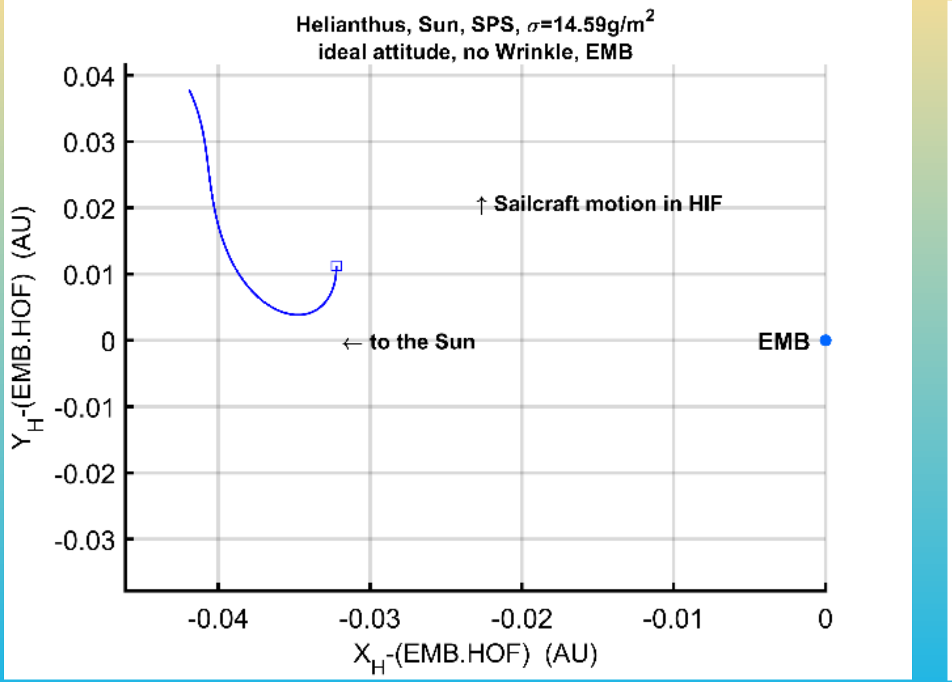


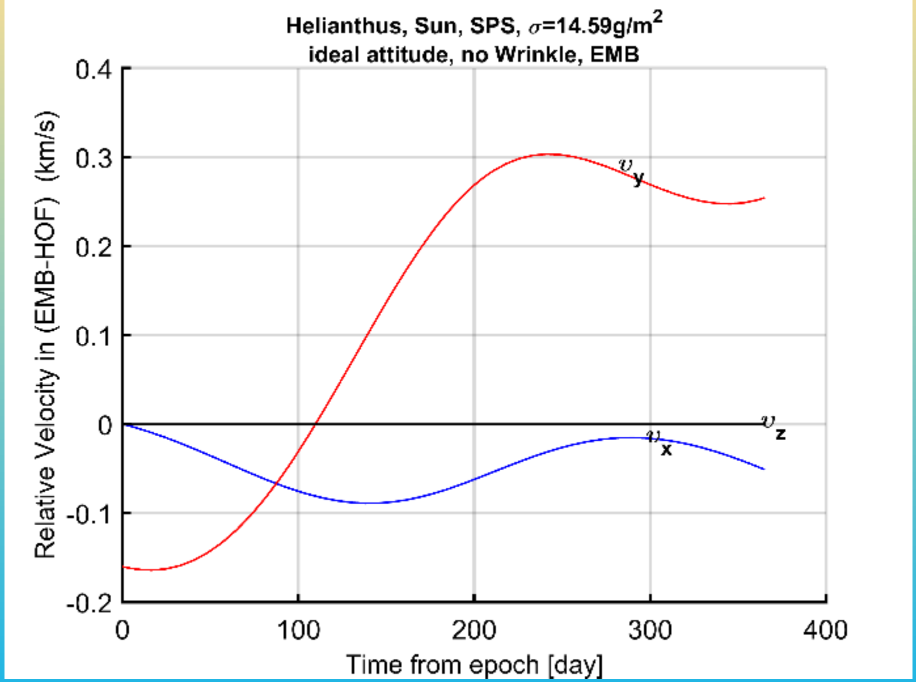


Helianthus' reference orbit perturbed by EMB.

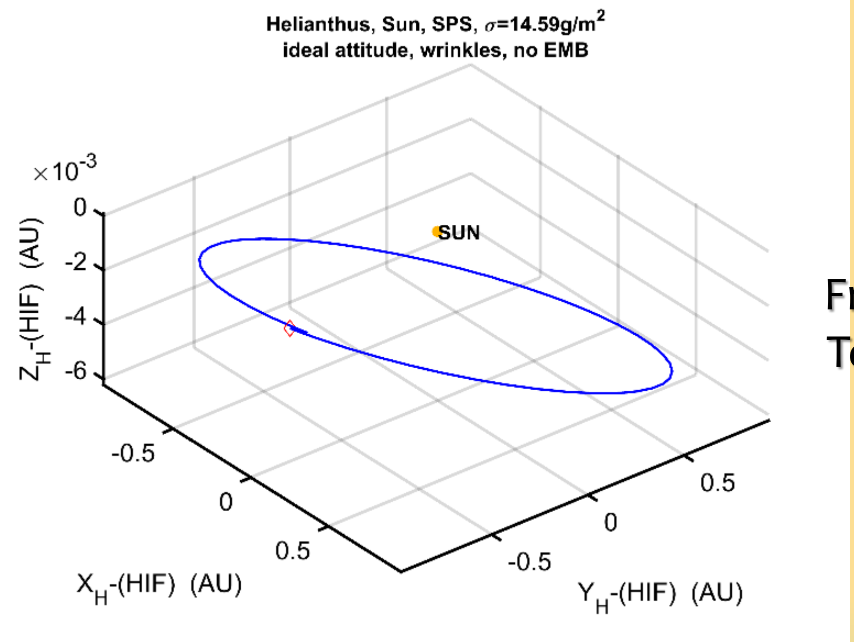


Time frame:
From 2030.07.05 12:00:00
To 2031.07.05 12:00:00

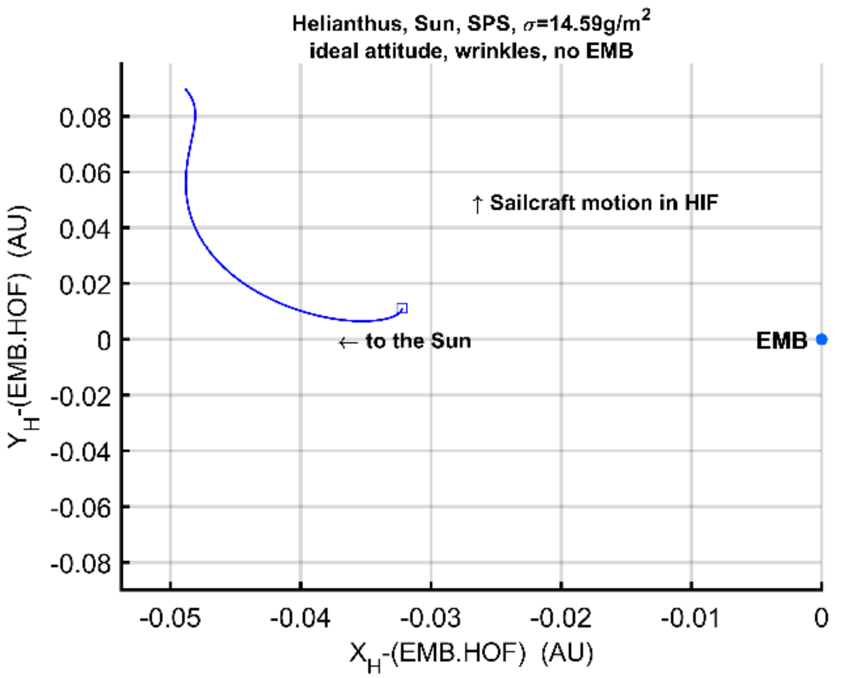


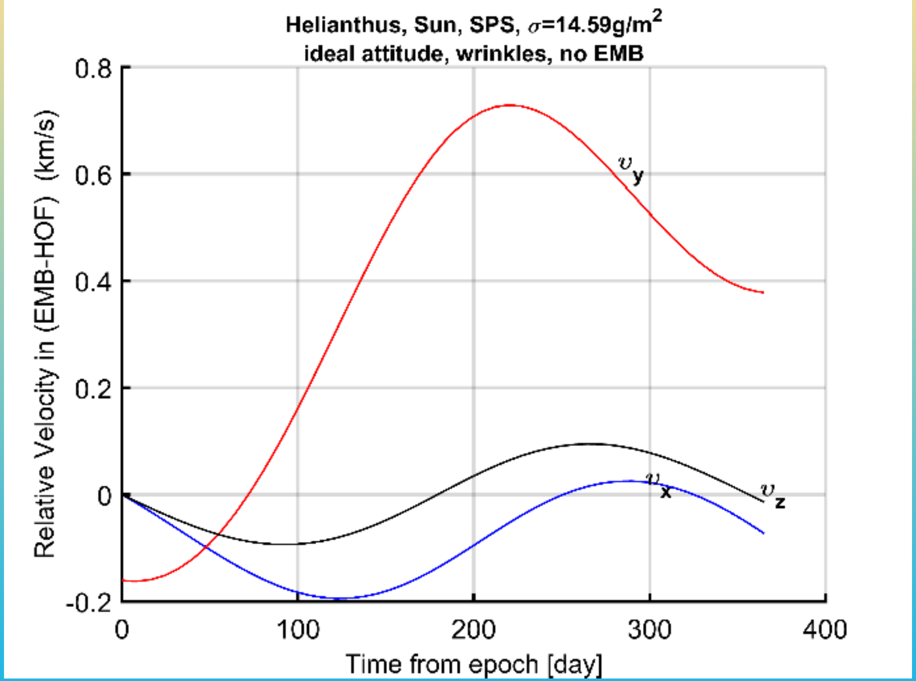


Helianthus' reference orbit perturbed by **wrinkles only.**

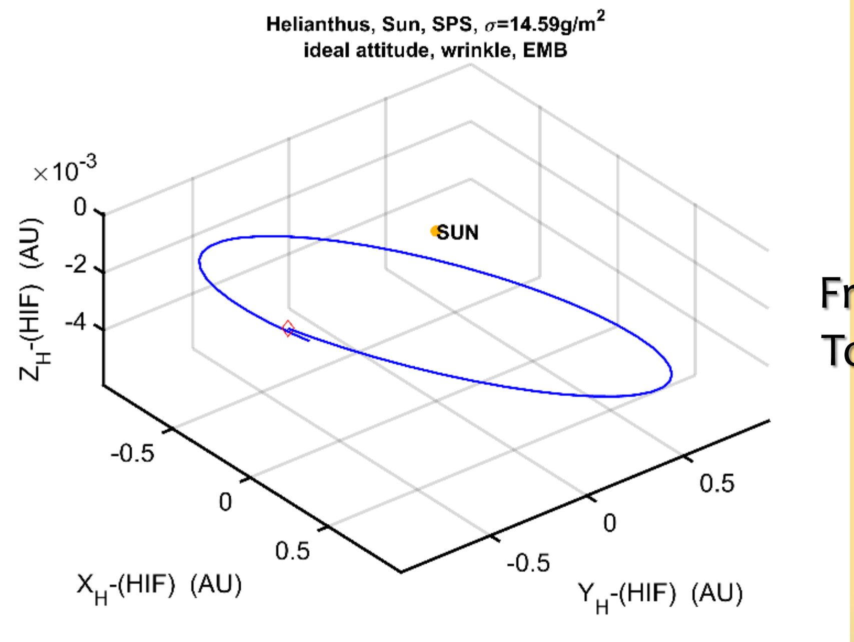


Time frame:
From 2030.07.05 12:00:00
To 2031.07.05 12:00:00

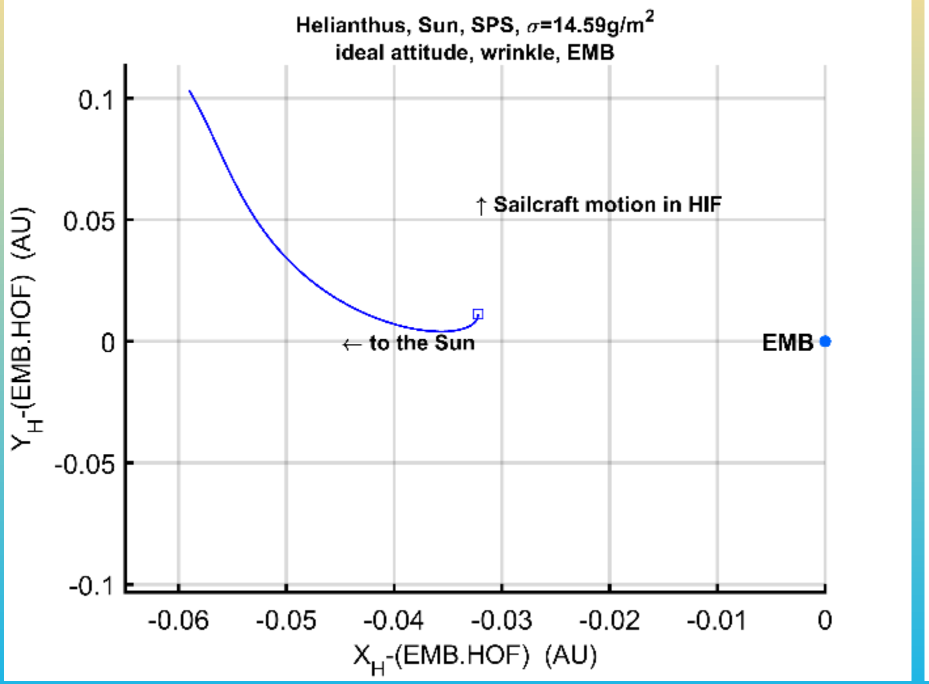


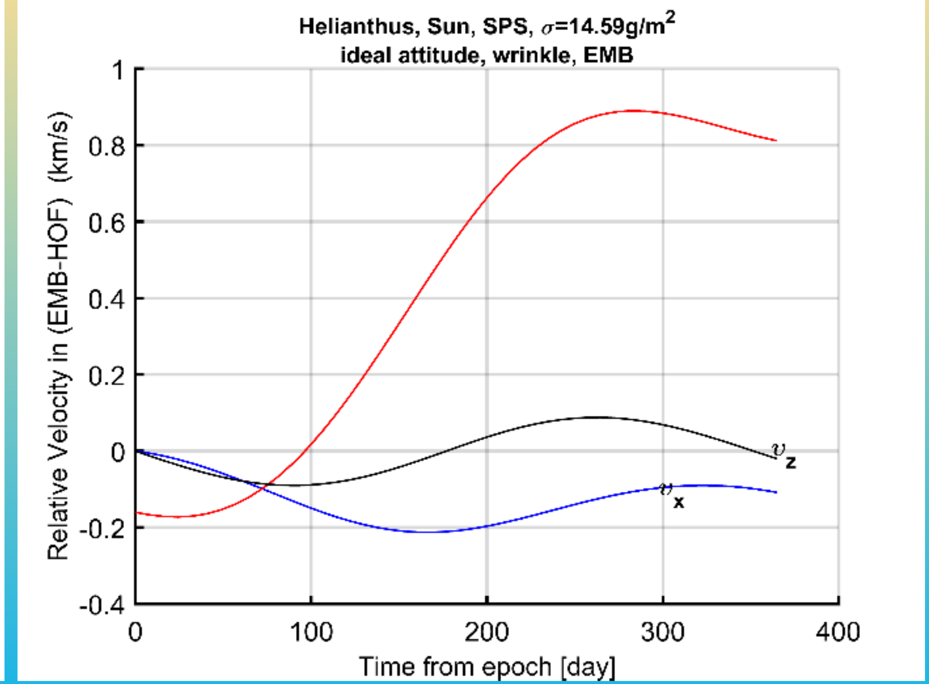


Helianthus’
reference orbit
perturbed by
EMB + wrinkles.



Time frame:
From 2030.07.05 12:00:00
To 2031.07.05 12:00:00





The numerical propagation tells us that there is no way for obtaining an EMB-synchronous by *spontaneous* orbit. Therefore, let us build the following vector performance:

$$\mathbf{J}_{\Delta\mathbf{S}} = \begin{bmatrix} \sum_{k=1}^{N_m} \left\| \boldsymbol{\rho}^{\square}_{(k)}(t_k) - \boldsymbol{\rho}^{\square}(t_0) \right\| \cdot \vec{\xi}_1 \\ \sum_{k=1}^{N_m} \left\| \boldsymbol{\upsilon}^{\square}_{(k)}(t_k) - \boldsymbol{\upsilon}^{\square}(t_0) \right\| \cdot \vec{\xi}_2 \\ \left| \sum_{k=1}^{N_m} \Delta t_k - 2\pi \right| \cdot \varsigma \\ \left\| \boldsymbol{\rho}^{\square}(t_f) - \boldsymbol{\rho}^{\square}(t_0) \right\| \cdot \vec{\xi}_3 \\ \left\| \boldsymbol{\upsilon}^{\square}(t_f) - \boldsymbol{\upsilon}^{\square}(t_0) \right\| \cdot \vec{\xi}_4 \end{bmatrix}$$

$$\equiv \begin{bmatrix} \mathbf{J}'_{\Delta\mathbf{S}(N_m)} \\ \mathbf{J}'_{\Delta\mathbf{S}(t_f)} \end{bmatrix}$$

$\boldsymbol{\rho}^{\square}(t) \equiv$ H-position relative to EMB at t

$\boldsymbol{\upsilon}^{\square}(t) \equiv$ H-velocity relative to EMB at t

$\Delta t_k \equiv$ duration of the k-th orbital arc for the k-th attitude maneuver during 1-year cycle,

k $= 1 \dots N_m$

Solving an optimization problem appears necessary.

“Minimize the following Objective Function

$$\left|J_{\Delta \mathbf{S}}\right|^2 \equiv \mathbf{J}_{\Delta \mathbf{S}} \cdot \mathbf{J}_{\Delta \mathbf{S}}$$

With respect to the maneuvers angles, the number of maneuvers, and the orbit arc durations with constraints”.

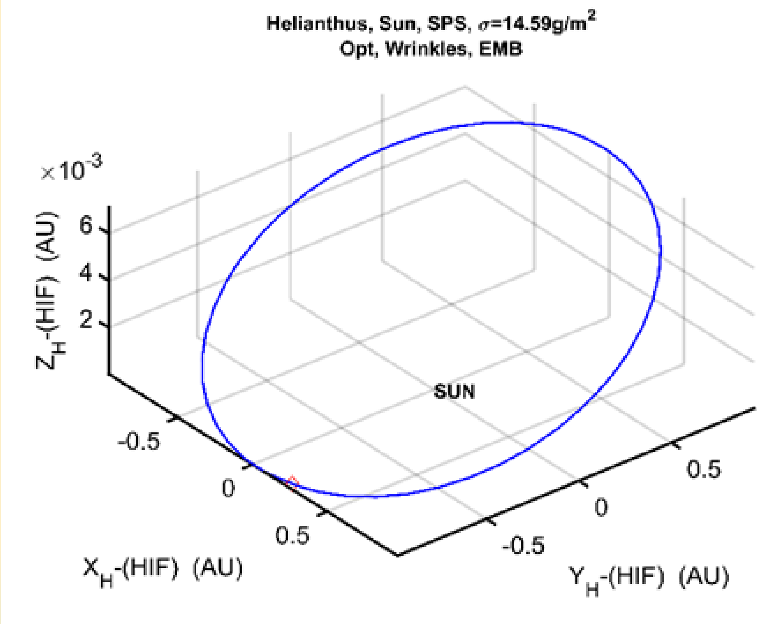
$$m^{\square}(t) = \text{const.}$$

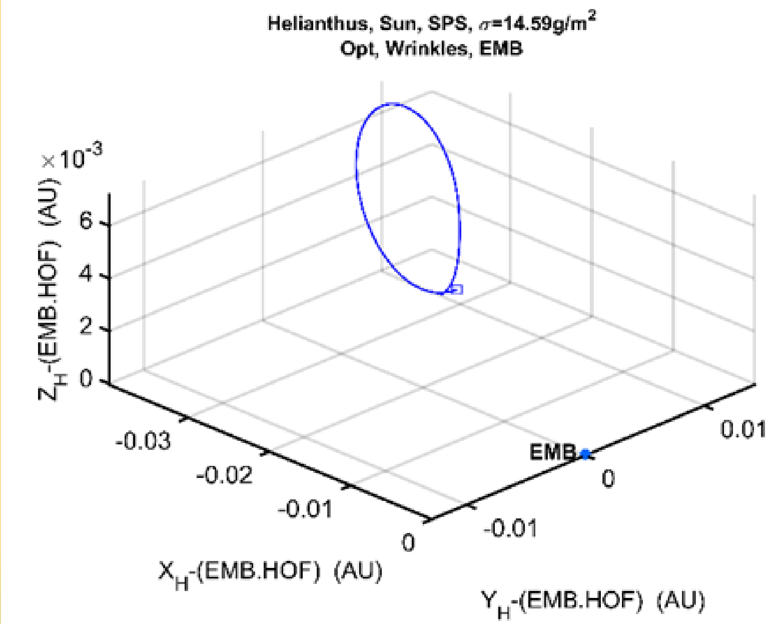
$$\Rightarrow \textbf{no rocket engine for ACS}$$

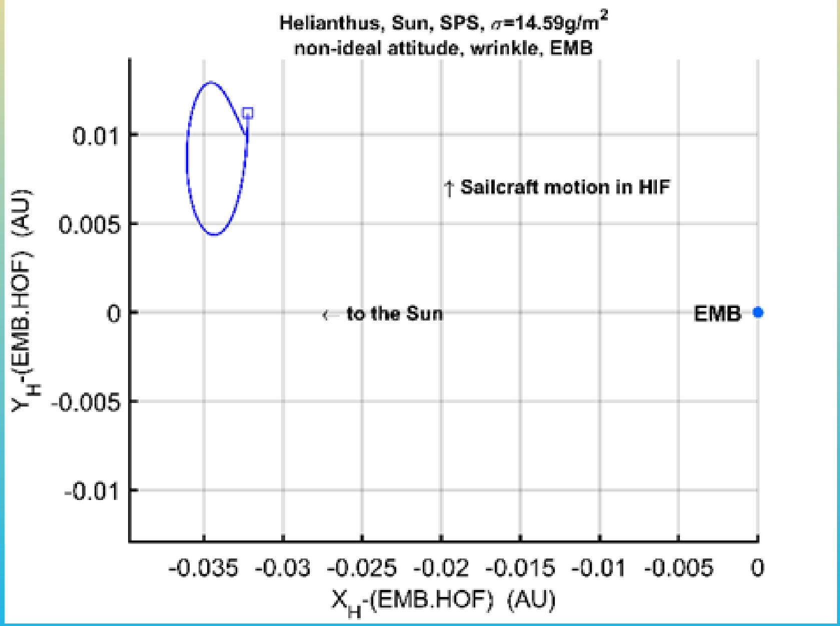
State and Control at t_0

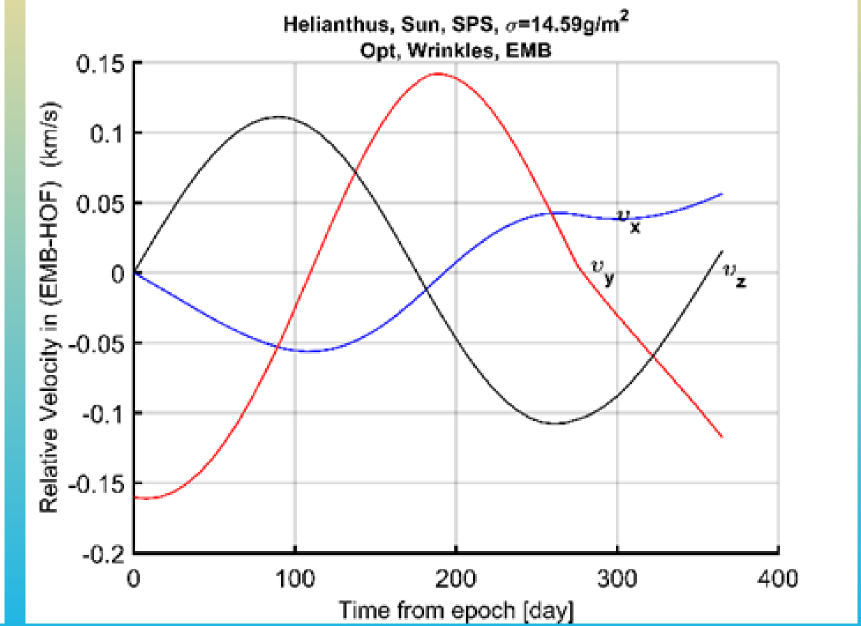
yyyy-mm-dd hh: mm: ss	2030-07-05 12:00:00		State relative to EMB (HOF)	$\mathbf{L}(t_0)$, $\lVert\mathbf{L}(t_0)\rVert$
$\mathrm{EMB}_{t_0}^{(\mathrm{HIF})}$ $\begin{bmatrix}\mathbf{R}_0\\ \mathbf{V}_0\end{bmatrix}$	2.304367E-01 AU -9.902178E-01 6.598967E-05 9.578504E-01 EOS 2.229579E-01 -2.015097E-05	$\mathbf{S}_{t_0}^{\square,(\mathrm{HOF})}$ $\begin{bmatrix}\boldsymbol{\rho}(t_0)\\ \boldsymbol{\upsilon}(t_0)\end{bmatrix}^{\square}$	-4.82 Mkm 1.68 0.0 0.0 m/s -160.0 0.0	9.7843488E-02 -9.0631496E-04 -2.9553411E-03 9.7892306E-02
σ [g/m^2]	14.59	m_0 [kg]	20.34	
$m_{P/L}$ [kg]	5.0	A_0 [m^2]	1394.34	

Optimal Orbit in Time frame 2030.07.05 12:00:00 2031.07.05 12:00:00









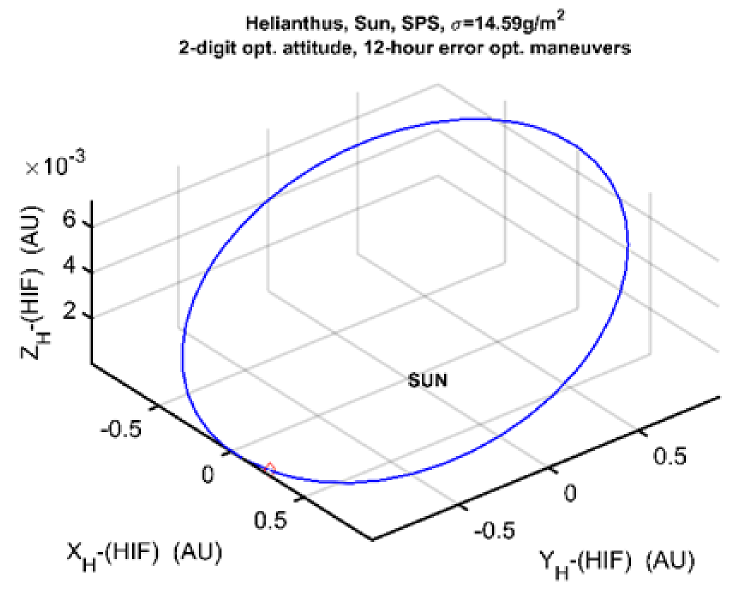
Finally, we must remark that the computed controls are ideal. In principle, they cannot, however, be implemented as such because of the many decimal digits required.

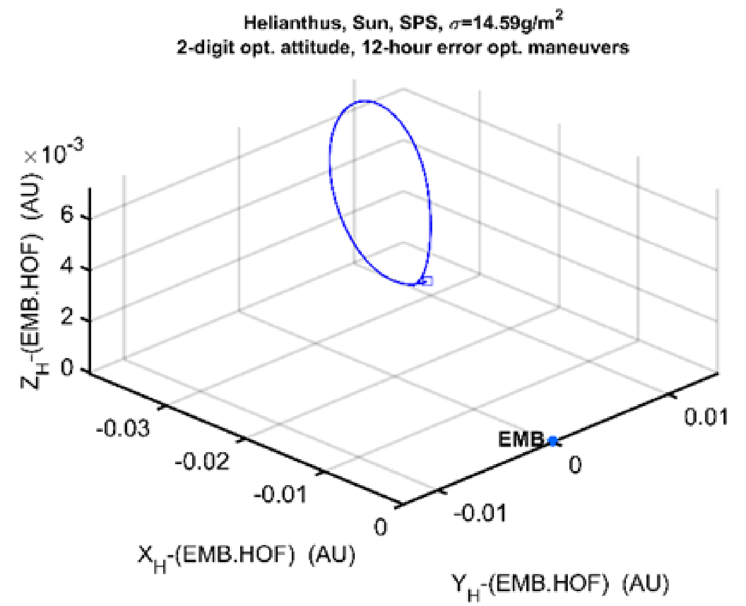
Then, even if a sail's *accurate control* could be improved, there is the need to approximate the ideal sail attitude angles by means of a small number of decimal digits.

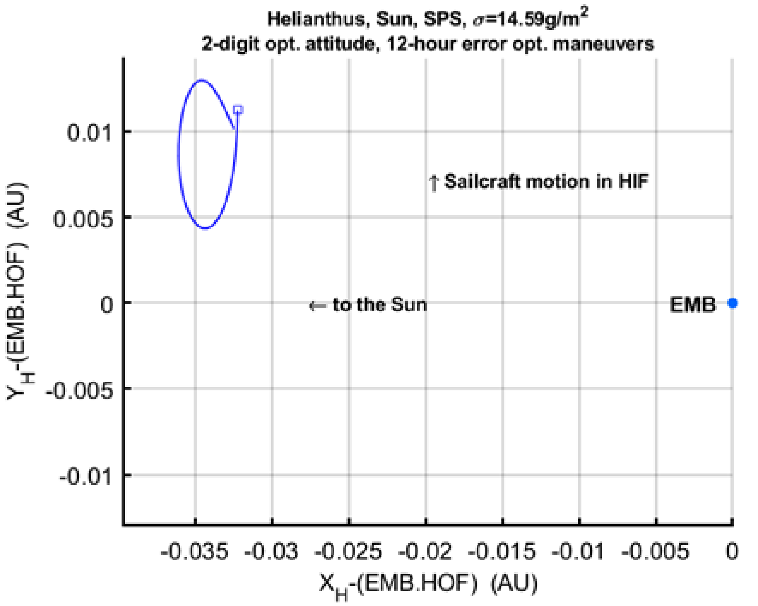
In addition, orbital-arc timing for manoeuvring may be precise only of the order of half a day, or 0.009 in solar units.

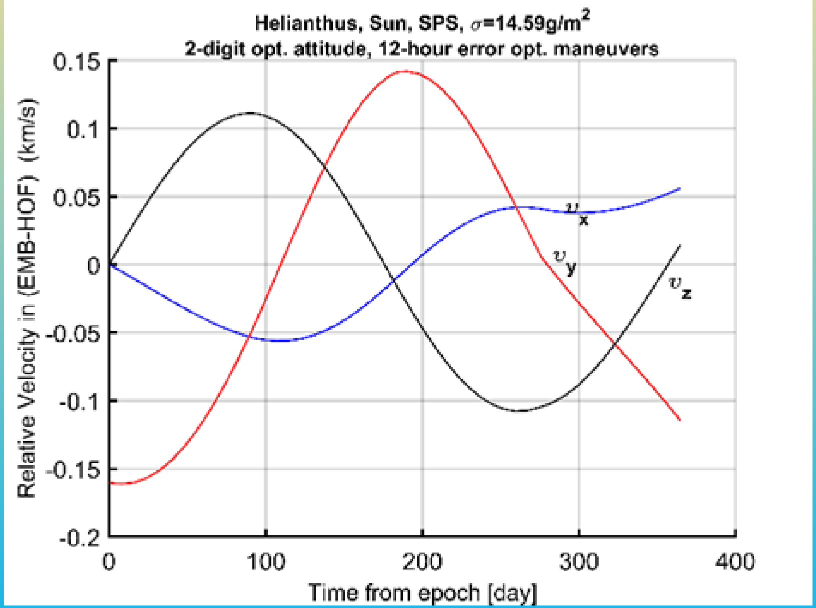
«*Therefore, we analyzed two further cases by approximating the optimal control angles up to either 2 or 1 decimal digits, respectively, and 12 hours in maneuver-time uncertainty*».

Optimal Orbit in Time frame 2030.07.05 12:00:00 2031.07.05 12:00:00
2-digit (0.01°) approximation of the attitude angles

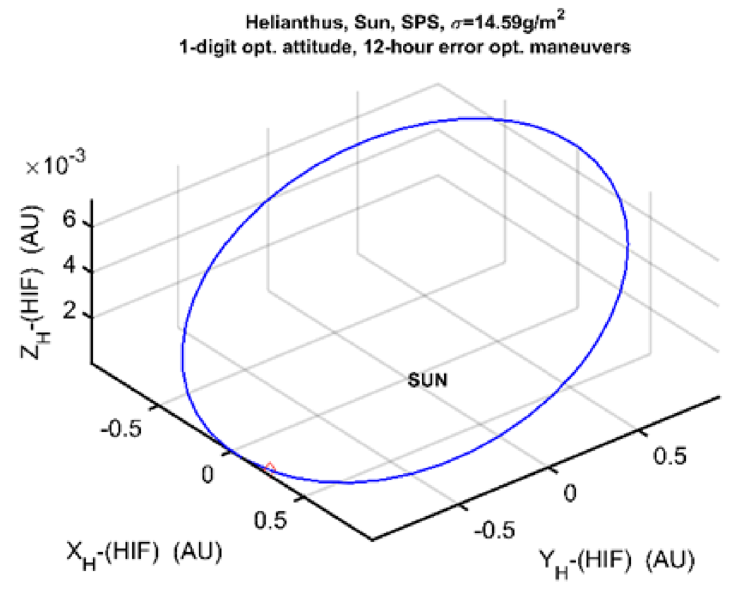

Helianthus, Sun, SPS, σ=14.59g/m^2
2-digit opt. attitude, 12-hour error opt. maneuvers

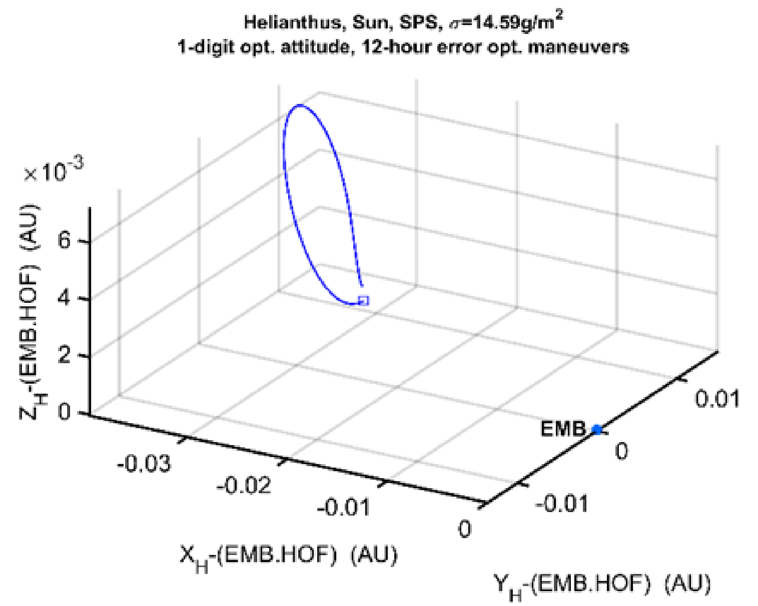

Helianthus, Sun, SPS, σ=14.59g/m^2
2-digit opt. attitude, 12-hour error opt. maneuvers

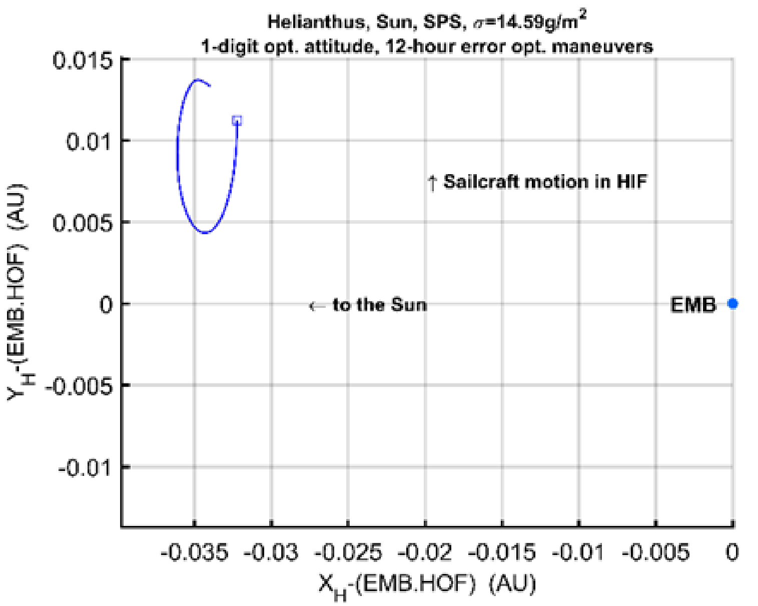

Helianthus, Sun, SPS, σ=14.59g/m^2
2-digit opt. attitude, 12-hour error opt. maneuvers

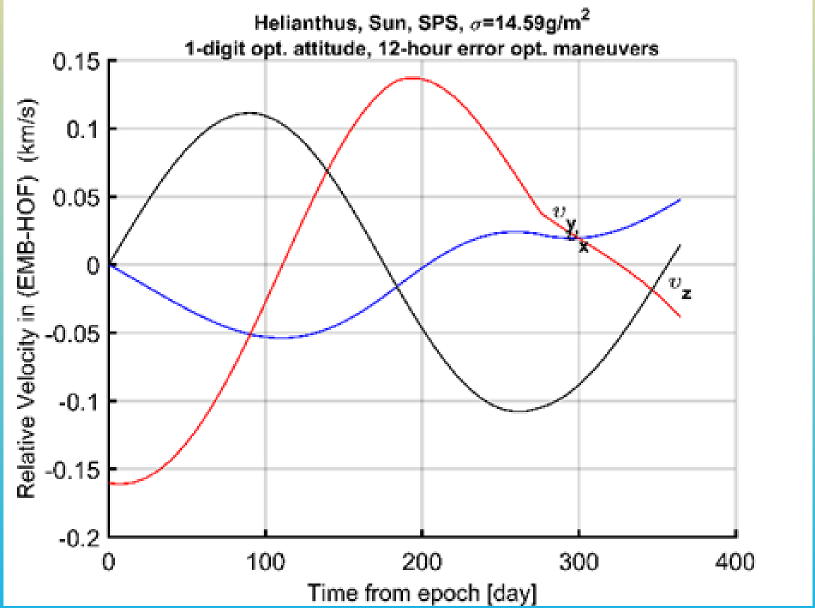

Helianthus, Sun, SPS, σ=14.59g/m^2
2-digit opt. attitude, 12-hour error opt. maneuvers

Optimal Orbit in Time frame 2030.07.05 12:00:00 2031.07.05 12:00:00
1-digit (0.1°) approximation of the attitude angles


Helianthus, Sun, SPS, σ=14.59g/m^2
1-digit opt. attitude, 12-hour error opt. maneuvers


Helianthus, Sun, SPS, σ=14.59g/m^2
1-digit opt. attitude, 12-hour error opt. maneuvers


Helianthus, Sun, SPS, σ=14.59g/m^2
1-digit opt. attitude, 12-hour error opt. maneuvers


Helianthus, Sun, SPS, σ=14.59g/m^2
1-digit opt. attitude, 12-hour error opt. maneuvers

Summary

i. *The optimal number of sail attitude maneuvers was found to be* ***4/year****. The optimal sail attitude maneuver angles range from* 0.2° *to* 0.9° *accomplished by electrochromic (our reference here) or liquid-crystal actuators.*

ii. *Both the optimal control and the approximated solutions entail a sailcraft loop that guarantees the continuous measuring and recording of the payload instruments data. Data can be sent to the mission control center - via ground stations - for processing.*

iii. *Processed data are sent to the designated national space-weather center.*

iv. *Each year, a set of commands related to new optimized maneuvers can be computed at the control center and sent to Helianthus' onboard computer.*

The intent of Italian Space Agency is to achieve a challenging national development of all items related to *in-space* solar-photon propulsion, including facilities and spinoffs.

Incidentally, the sail's specific-area current goal, i.e. ~68.5 m^2 /kg, is close to 83 m^2 /kg, namely, the minimum specific area for an unmanned Earth-Mars sail-shuttle, as computed in our related paper we published in 2017.