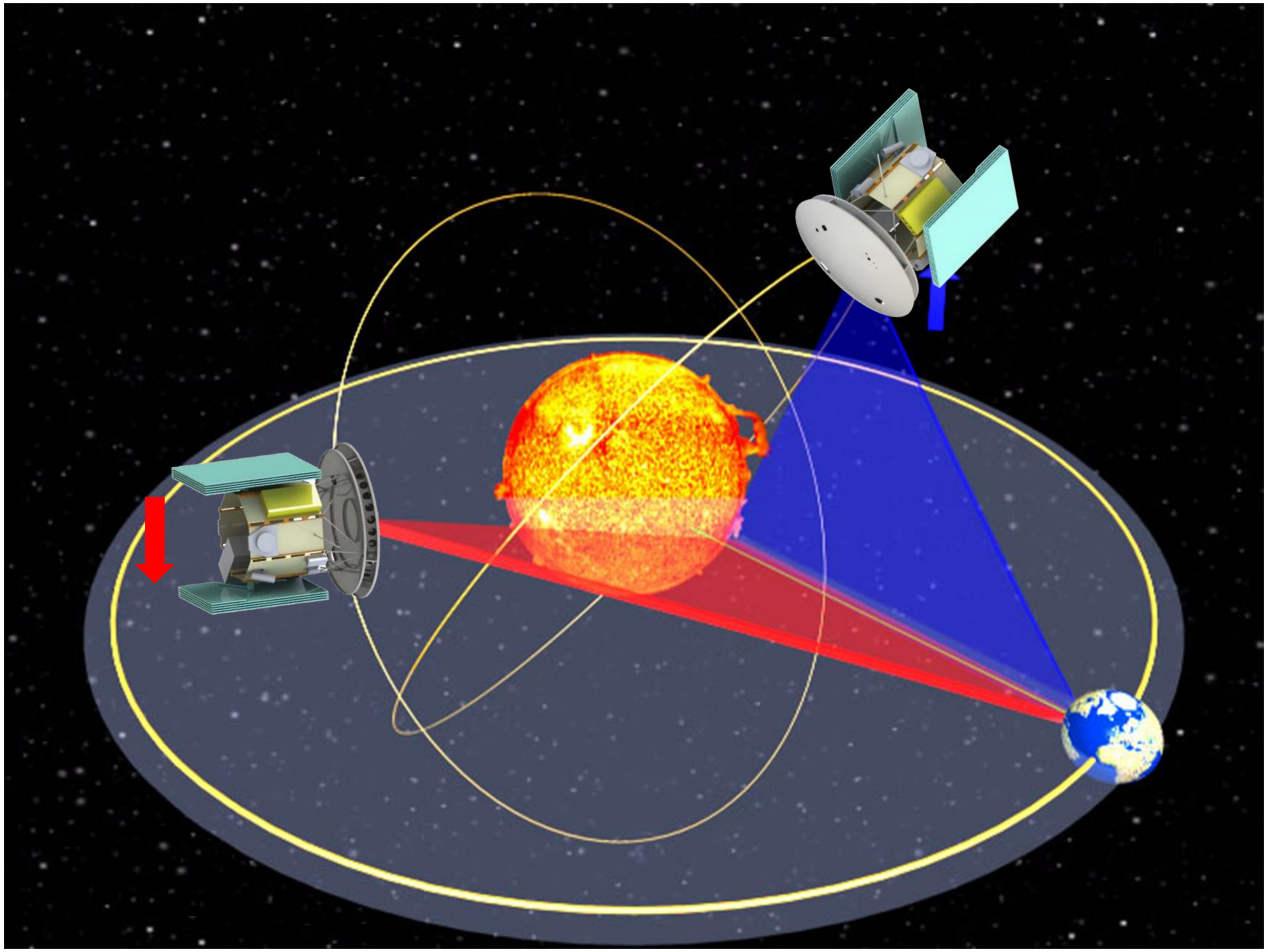
# The Sun & heliosphere explorer – the Interhelioprobe mission

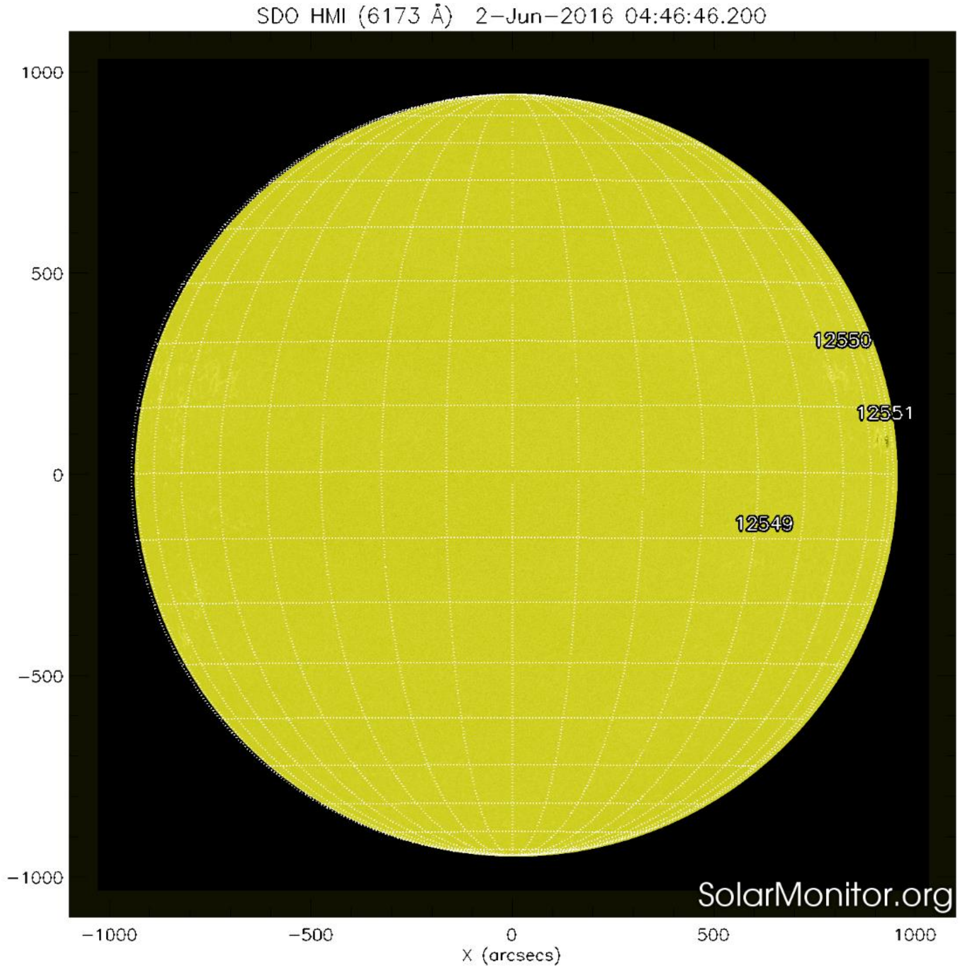


Ivan Zimovets & IHP Team

Russian-Germany Workshop, Berlin, 2 June 2016

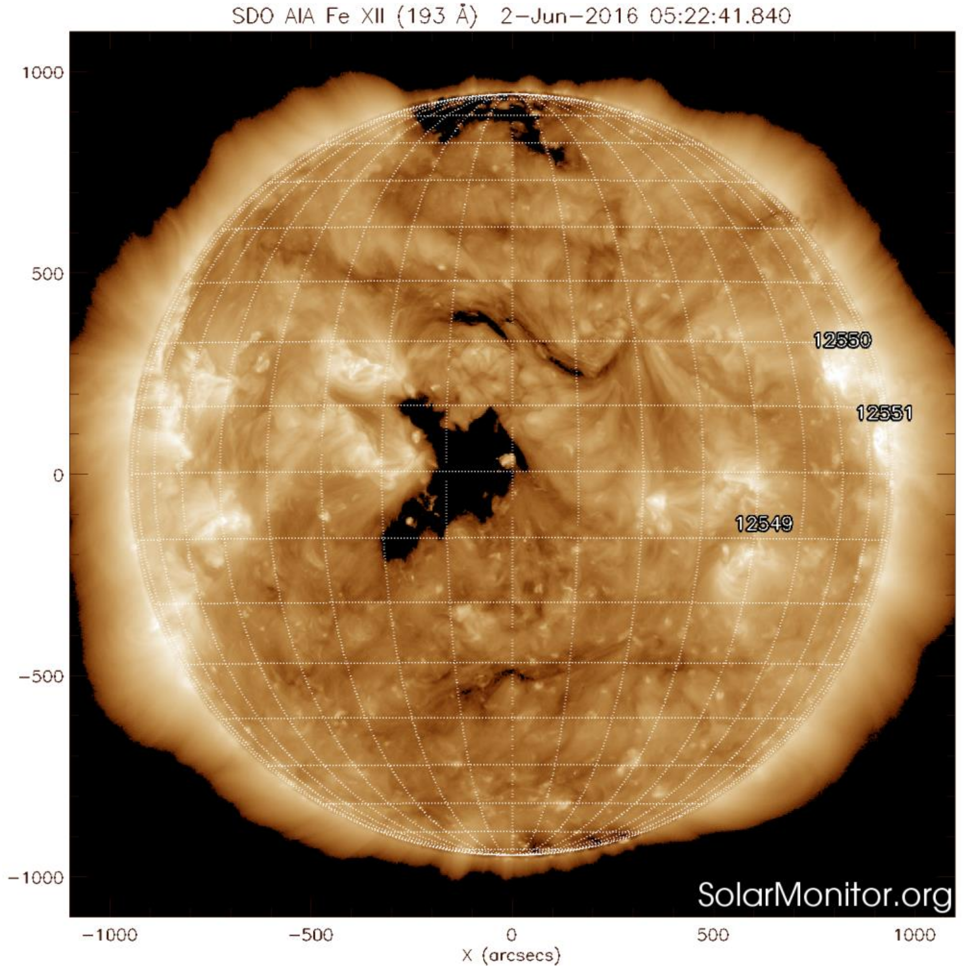
# The Sun today

Optical emission



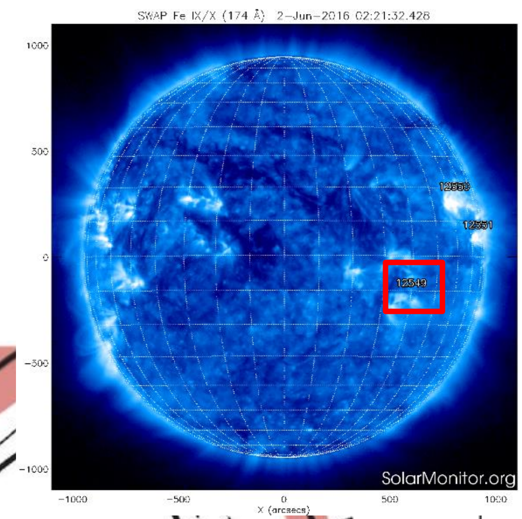

Photosphere (T~6000 K)

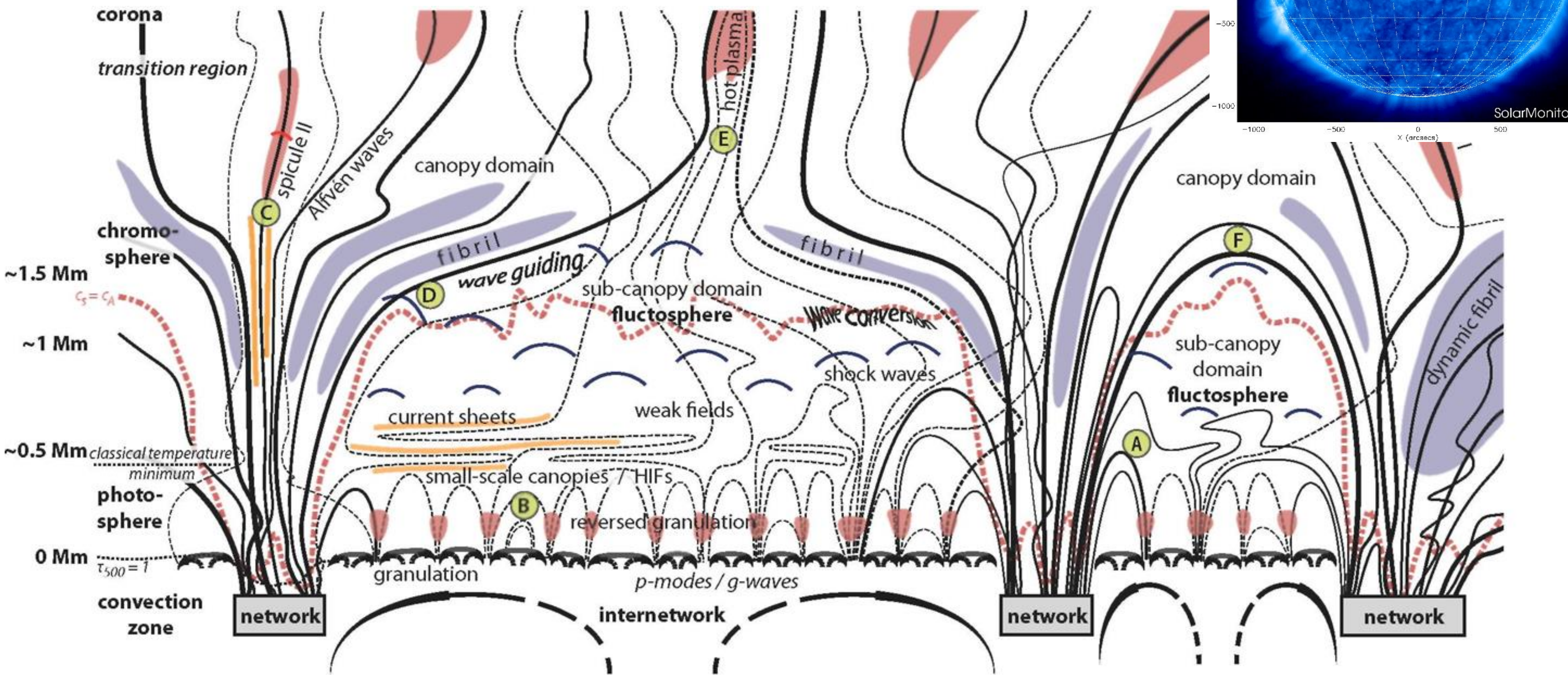
EUV emission

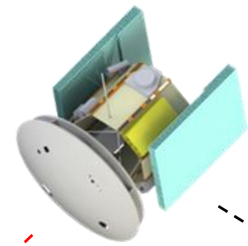



Corona (T~1-2 MK)

# Fine structure of the solar atmosphere

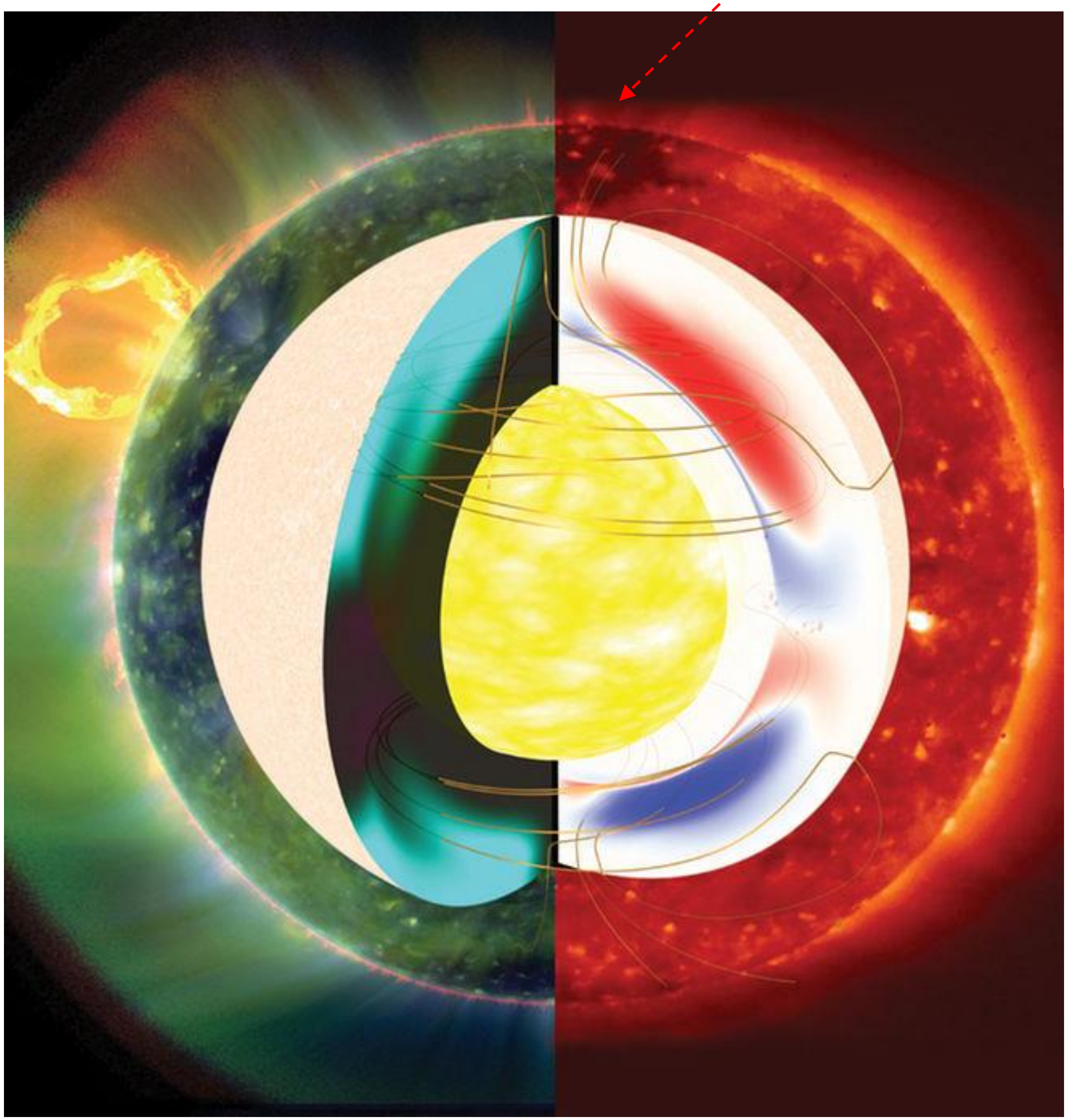


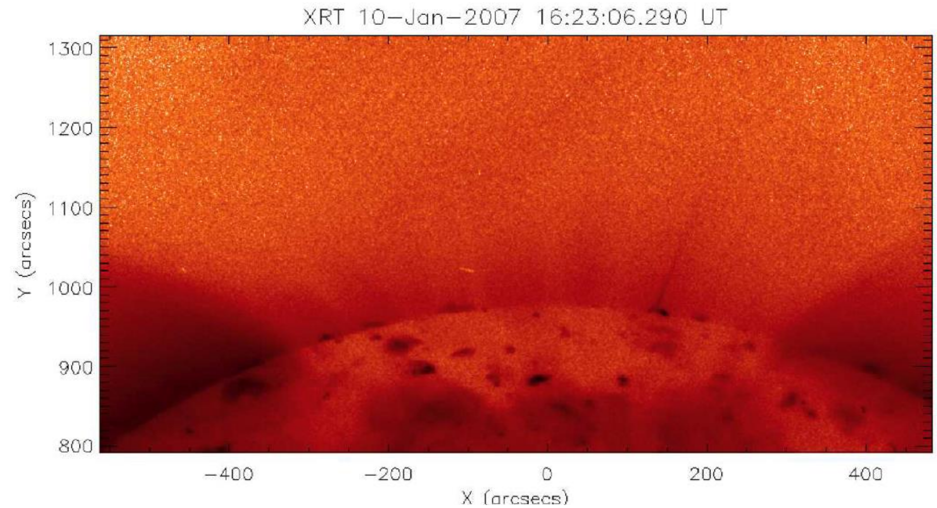


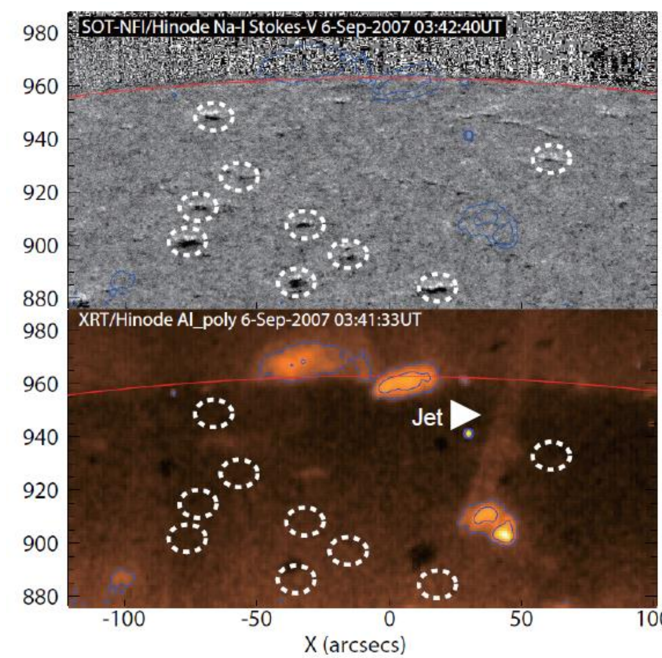
# Solar polar regions

## Differential rotation & meridional flows

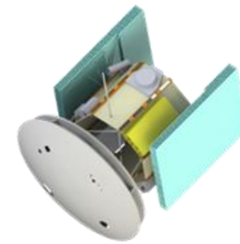


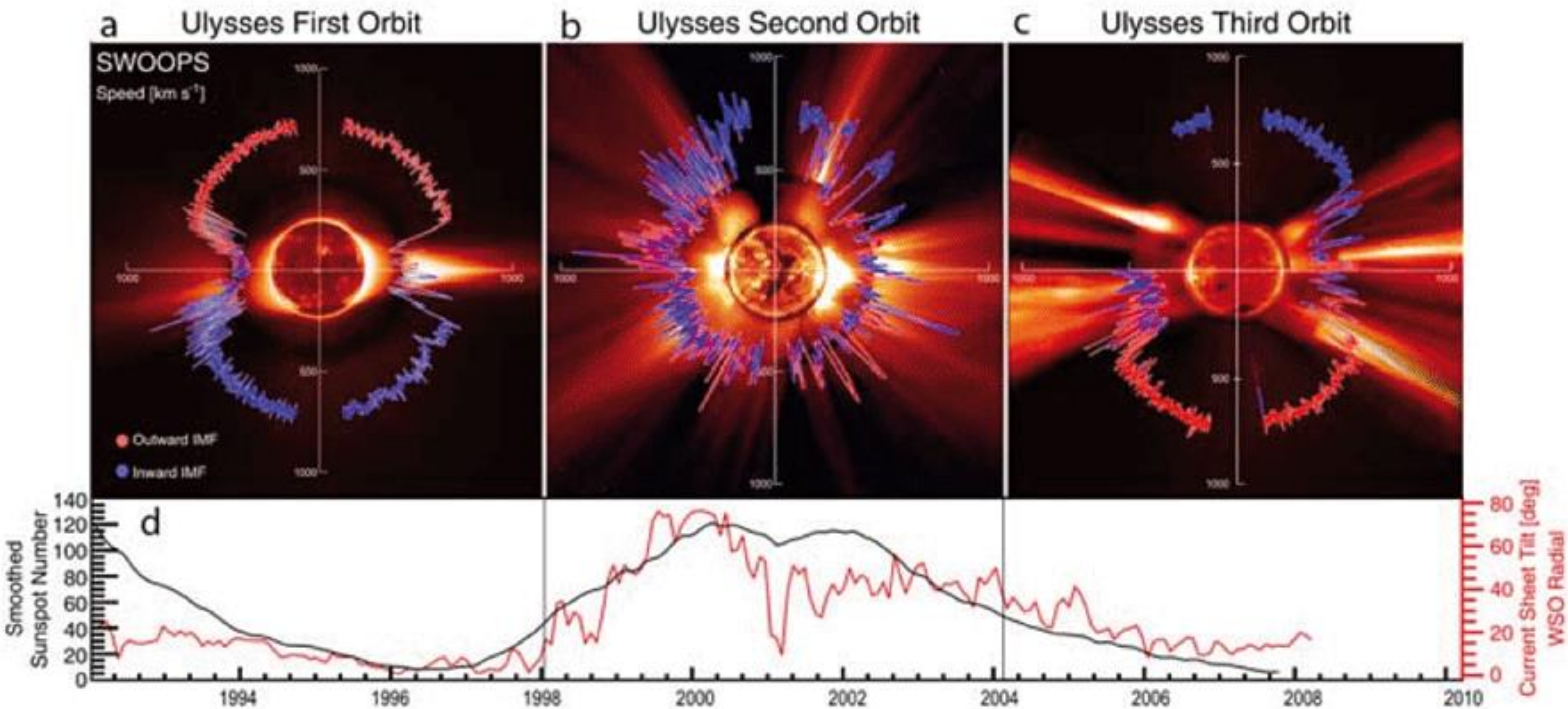
## Jets in polar coronal holes



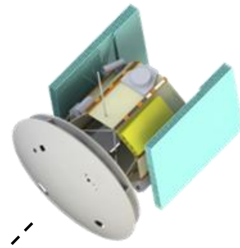



# 3D structure of solar wind

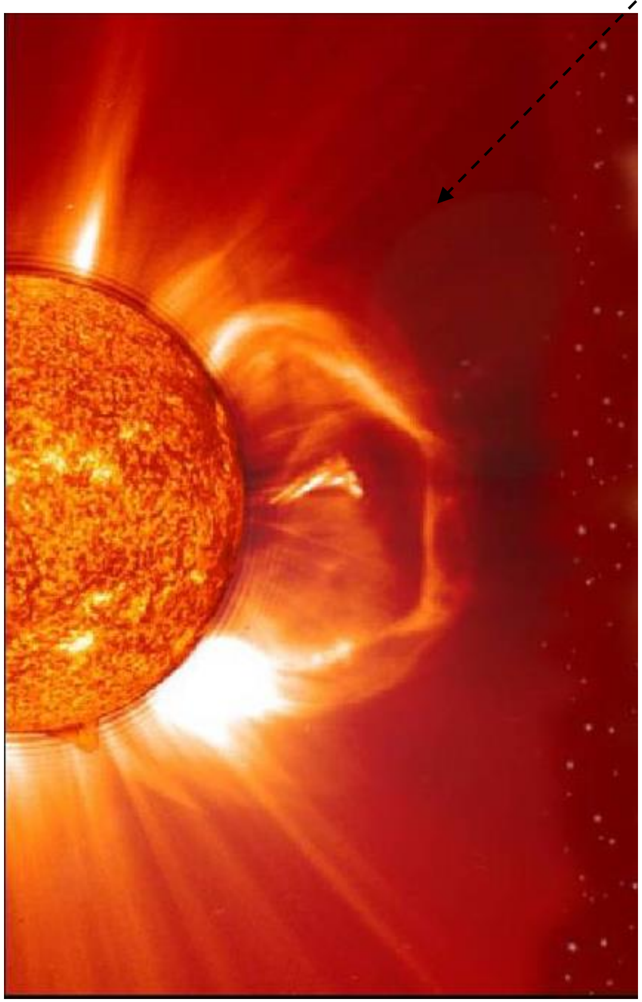




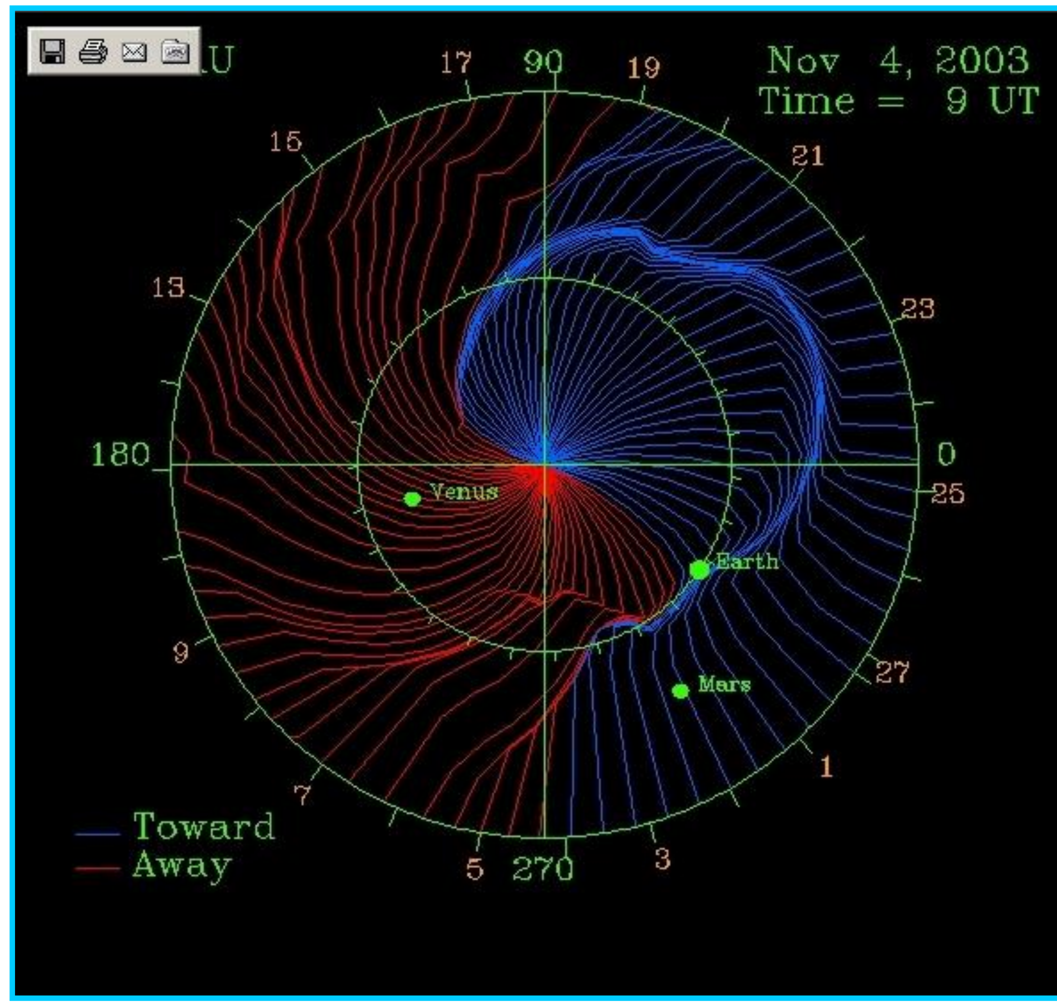
# Direct observations of 3D structure & spread of CMEs



CME side view (from Earth)



CME view (model) from out of ecliptic



# Concept of the Interhelioprobe (IHP) mission

• Multi-wavelength solar observations at short distances from the Sun (up to ~60$R_S$ or ~0.28 AU)

• Out-of-ecliptic solar observations (up to ~30°) and from the opposite (“dark”) side

• In situ measurements in the inner heliosphere (and) out of the ecliptic plane

(Similar to the concept of the Solar Orbiter)

# General information about the Interhelioprobe mission

**Initial idea:** IZMIRAN, IKI (mid-90s)

**Leading scientific organization:** IKI since April 2013 (IZMIRAN before)

**Principal investigators:** Dr L.M. Zelenyi (IKI) & Dr V.D. Kuznetsov (IZMIRAN)

**Launch date:** shifted from 2022 to >2025 (within the RFSP 2026-2035)

**Launch by:** “Soyuz-2/1b” rocket with “Fregat” rocket stage from Baikonur cosmodrome
or *“Angara” rocket from “Vostochnyi” cosmodrome (will be considered)*

**Number of spacecraft:** 2 now (in the RFSP 2016-2025)

**Active operation time:** 5 years

# General information about the Interhelioprobe mission

**Funding:** Russian Federal Space Agency (Roscosmos)

**Spacecraft design:** Lavochkin Research and Production Association (NPO Lavochkin)

**Scientific instrumentation design:**

IKI, IZMIRAN, NIRPhI, LPI, SINP/MSU, MEPhI, IPTI +

+ International collaboration (Poland, France, Germany, Czech Republic, Austria, Ukraine, UK)

**Scientific payload:** 10 remote-sensing instruments + 9 in situ instruments

**Mass of the scientific payload:** 160 kg (with cables)

**Telemetry:** 1 Gb/day

# Current Stage

- Phase B (2013-2015)

*(drawings, development of structural, thermal and engineering models of the scientific instrumentation)*

- Contract Break (2016)

- New Contract (to the end of 2016)

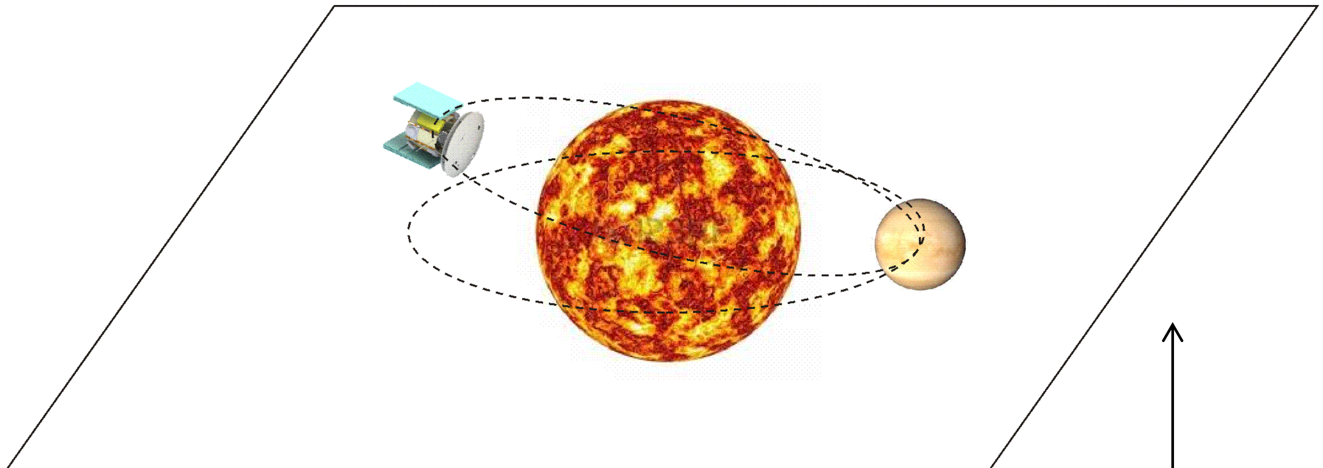
- Extension of Phase B (2017-2018)

*(additional design and drawings)*

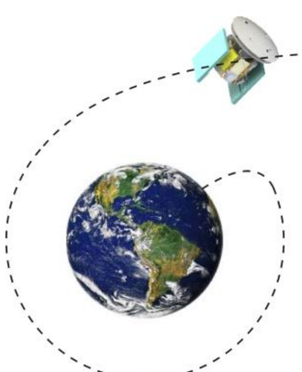
- Phase C start (2019)

# Main stages of the Interhelioprobe flight

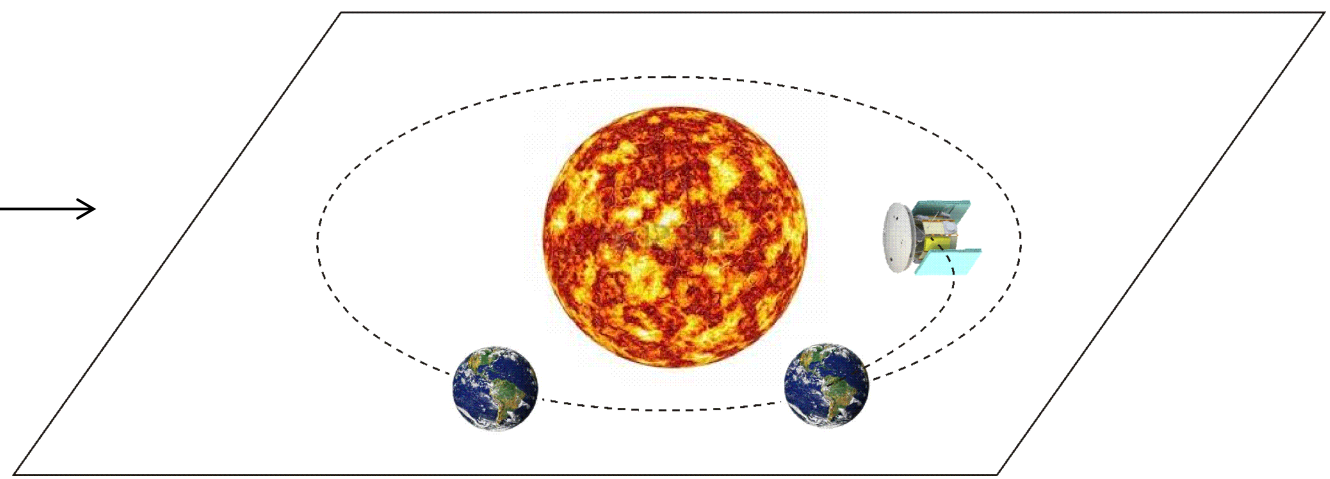
3. Sequence of gravity assists near the Venus



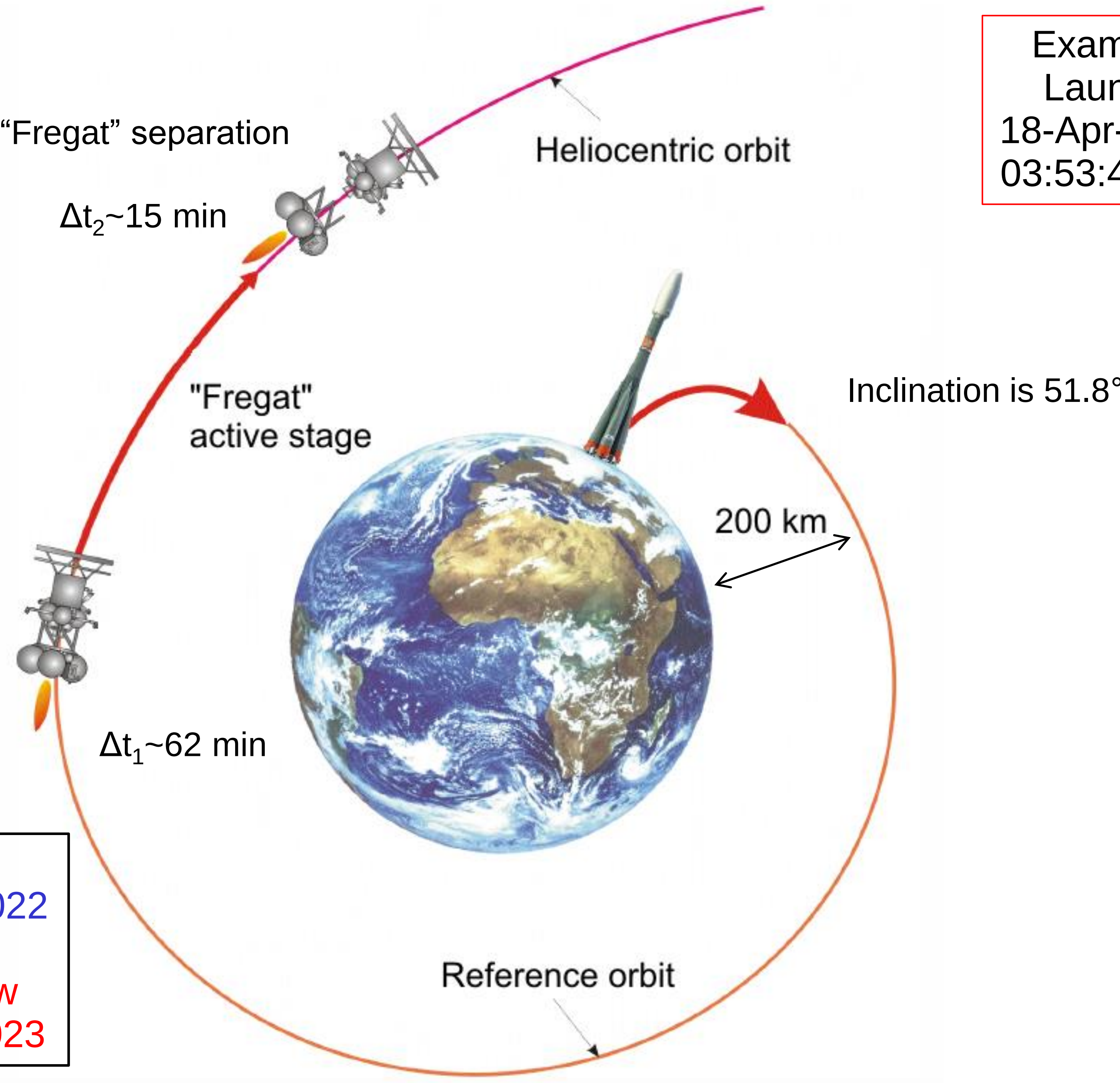
1. Launch and escape to the IP medium



2. Gravity assist near the Earth



# Close-to-the-Earth part of the Interhelioprobe flight



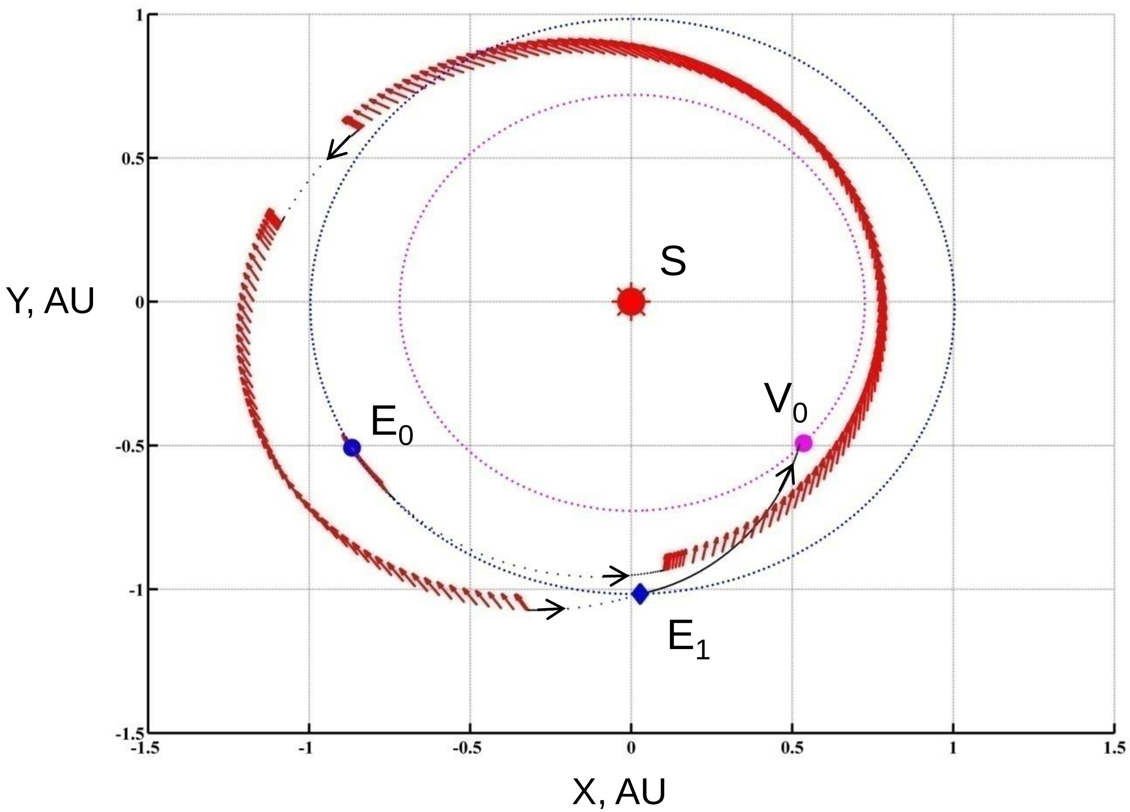

Example
Launch
18-Apr-2022
03:53:43 UT

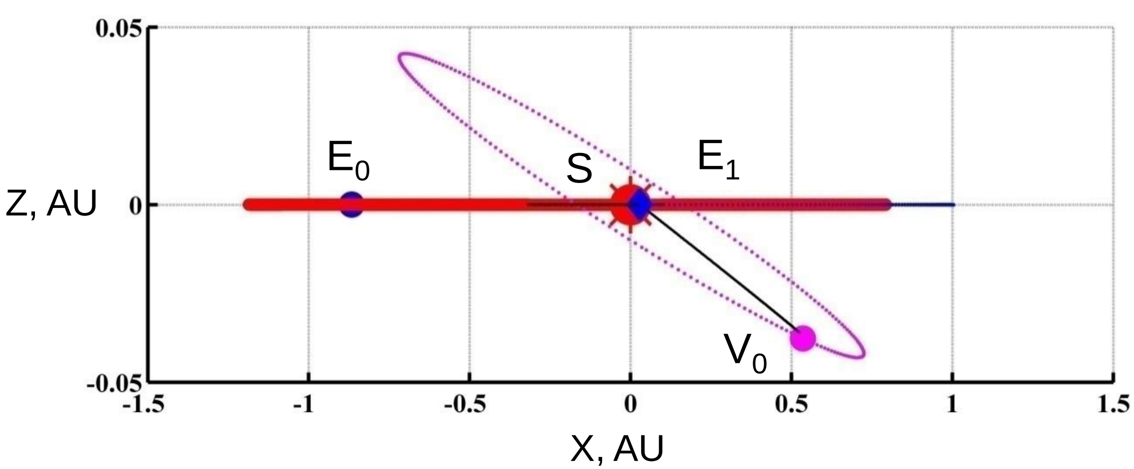
Main start window
08.04.2022-17.05.2022

Reserve start window
19.11.2023-28.12.2023

# Earth-Earth-Venus part of the IHP flight

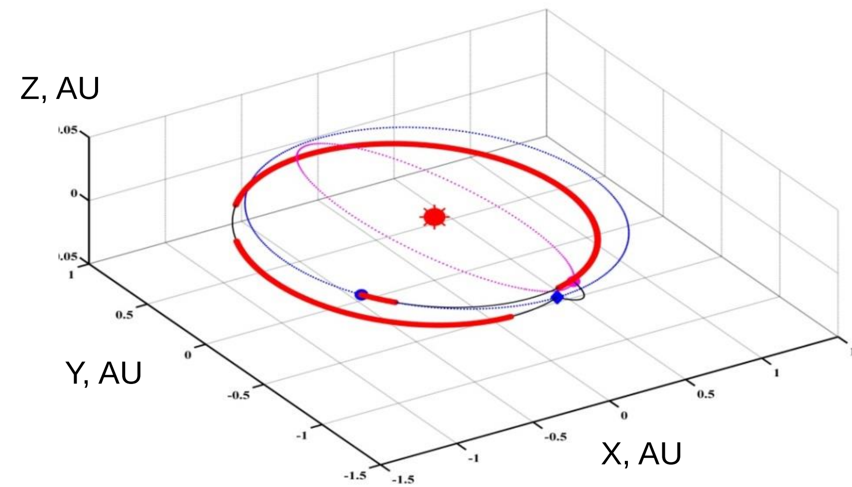
Projection to the ecliptic plane




**March electric propulsion system**
SPD-140D (OKB "Fakel", Russia)
(2 modules, xenon)

↑ Thrust direction during the active phase of the SPD-140D




| Δt | Passive flight time (days) | Active flight time (days) | Total (days) |
|---|---|---|---|
| t1-t0 | | 4 | |
| t2-t1 | 76 | | |
| t3-t2 | | 248 | 407 |
| t4-t3 | 15 | | |
| t5-t4 | | 49 | |
| t6-t5 | 15 | | |
| t7-t6 | 49 | | |

~1.25 year

Without experiments

# Considered variants of the IHP work orbits

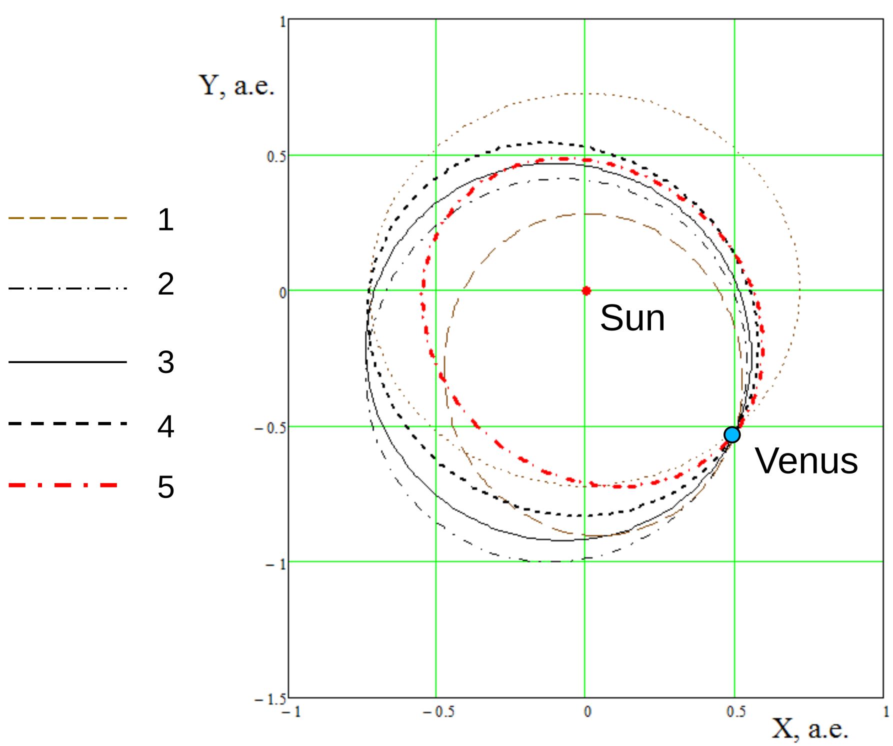
| Variant № | Number of Gravity Assists (GA) at Venus | Resonance after GA-1 k:m | Resonance after GA-2 k:m | Resonance after GA-3 k:m | Resonance after GA-4 k:m | Resonance after GA-5 k:m |
|---|---|---|---|---|---|---|
| 1 | 5 | 1:1 | 4:3 | 1:1 | 1:1 | No resonance |
| 2 | 3 | 1:1 | 6:5 | No resonance | | |
| 3 | 3 | 1:1 | 5:4 | No resonance | | |
| 4 | 4 | 1:1 | 5:4 | 1:1 | No resonance | |
| 5 | 3 | 4:3 | 3:2 | No resonance | | |
| 6 | 4 | 4:3 | 3:2 | 3:2 | No resonance | |
| 7 | 4 | 4:3 | 3:2 | 4:3 | No resonance | |
| 8 | 3 | 4:3 | 4:3 | No resonance | | |
| 9 | 3 | 4:3 | 5:4 | No resonance | | |
| 10 | 3 | 4:3 | 6:5 | No resonance | | |
| 11 | 3 | 5:4 | 3:2 | No resonance | | |
| 12 | 3 | 5:4 | 5:4 | No resonance | | |
| 13 | 3 | 6:5 | 1:1 | No resonance | | |
| 14 | 3 | 6:5 | 3:2 | No resonance | | |
| 15 | 4 | 5:4 | 1:1 | 1:1 | No resonance | |
| 16 | 3 | 5:4 | 4:3 | No resonance | | |
| 17 | 3 | 5:4 | 6:5 | No resonance | | |
| 18 | 5 | 4:3 | 1:1 | 1:1 | 1:1 | No resonance |
| 19 | 4 | 4:3 | 1:1 | 1:1 | No resonance | |

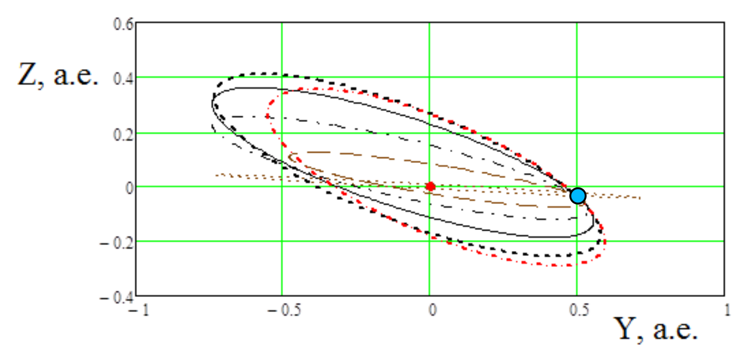
k/m – number of IHP/Venus orbits around the Sun

# Characteristics of one of the probable IHP work orbits

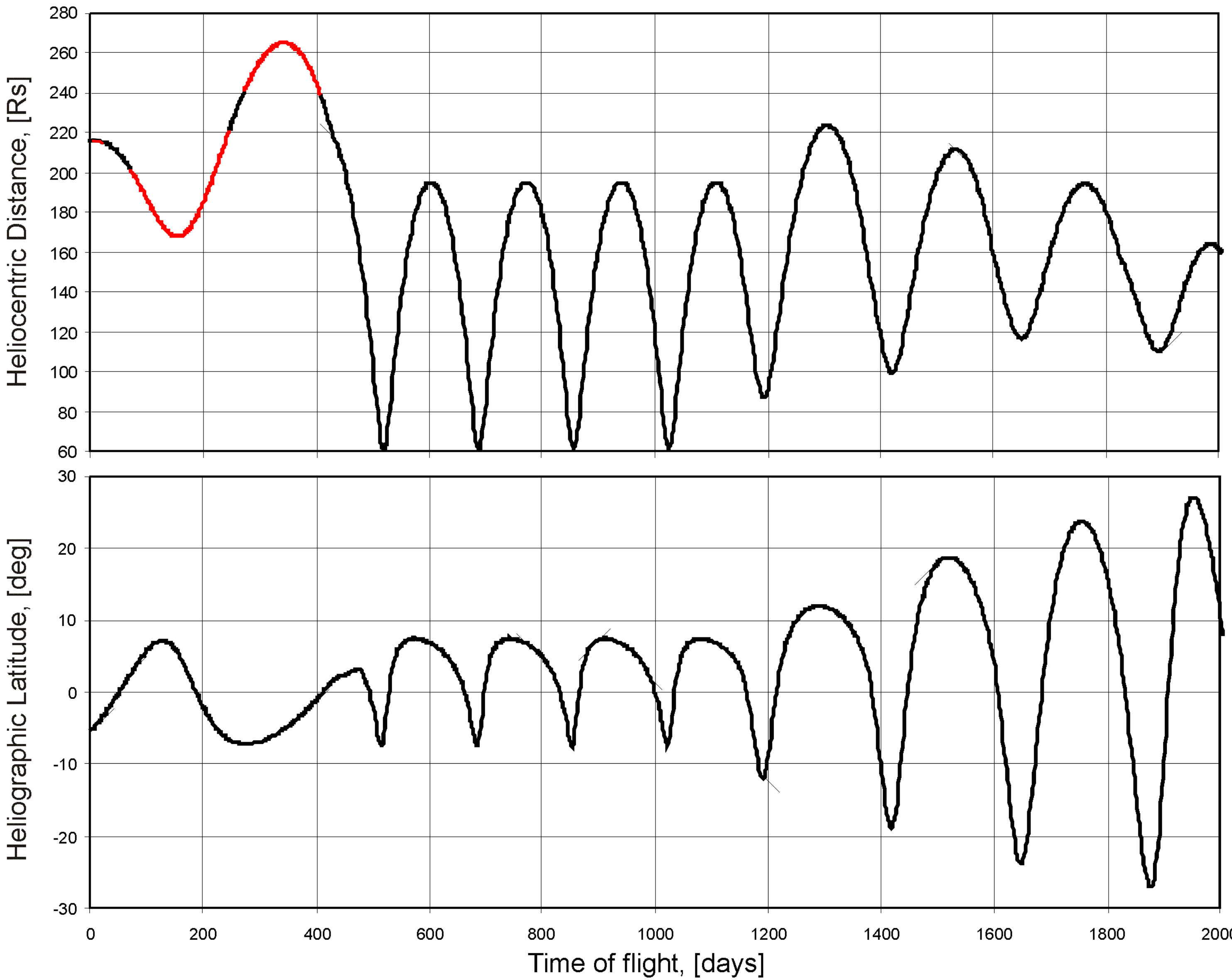
| Gravity assist number | Radius of perihelion [Rs] | Inclination to ecliptic [grad] | Radius of aphelion [AU] | Orbit period [days] | Resonance $N_{IHP}:N_{Venus}$ | Time of flight [days] |
|---|---|---|---|---|---|---|
| 1 | 61.397 | 10.965 | 0.909 | 168.523 | 4:3 | 674.094 |
| 2 | 87.174 | 15.669 | 1.041 | 224.698 | 1:1 | 224.698 |
| 3 | 99.523 | 22.635 | 0.984 | 224.698 | 1:1 | 224.698 |
| 4 | 116.630 | 27.582 | 0.904 | 224.698 | 1:1 | 224.698 |
| 5 | 110.217 | 30.957 | 0.763 | 186.160 | | |

~3.69 year



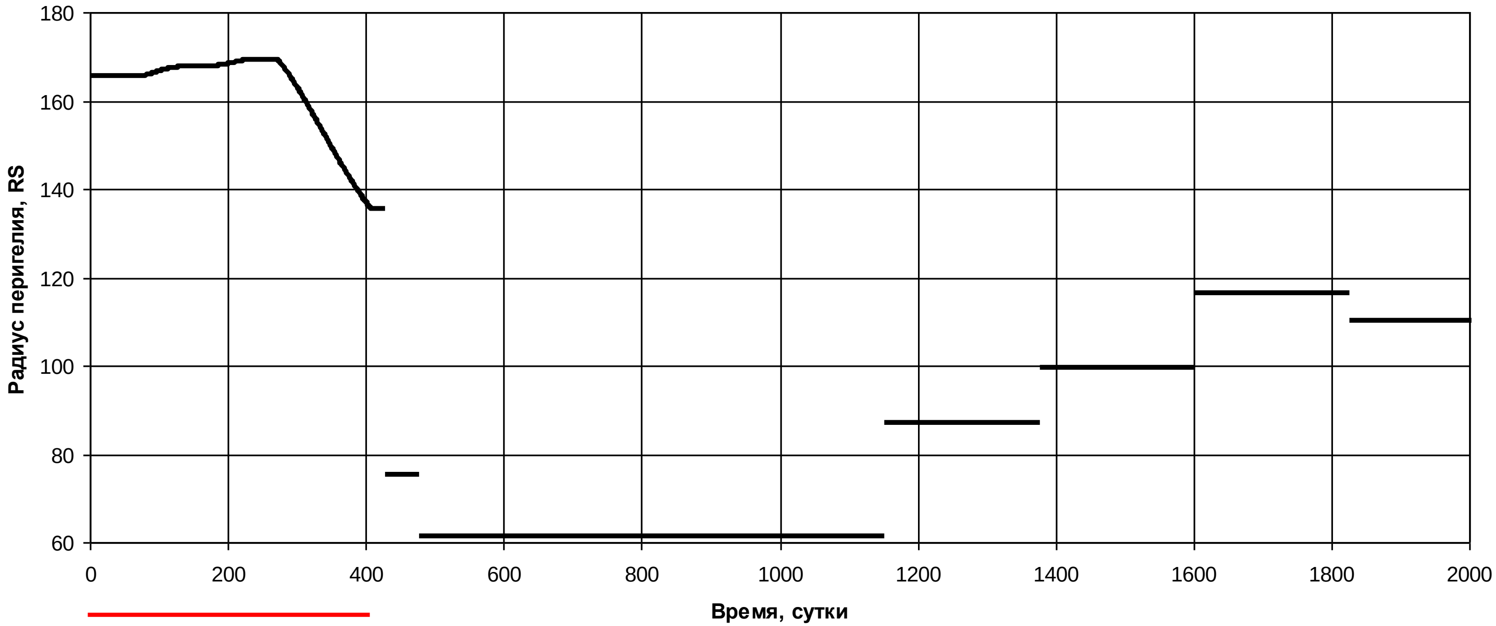



# Characteristics of one of the probable IHP work orbits

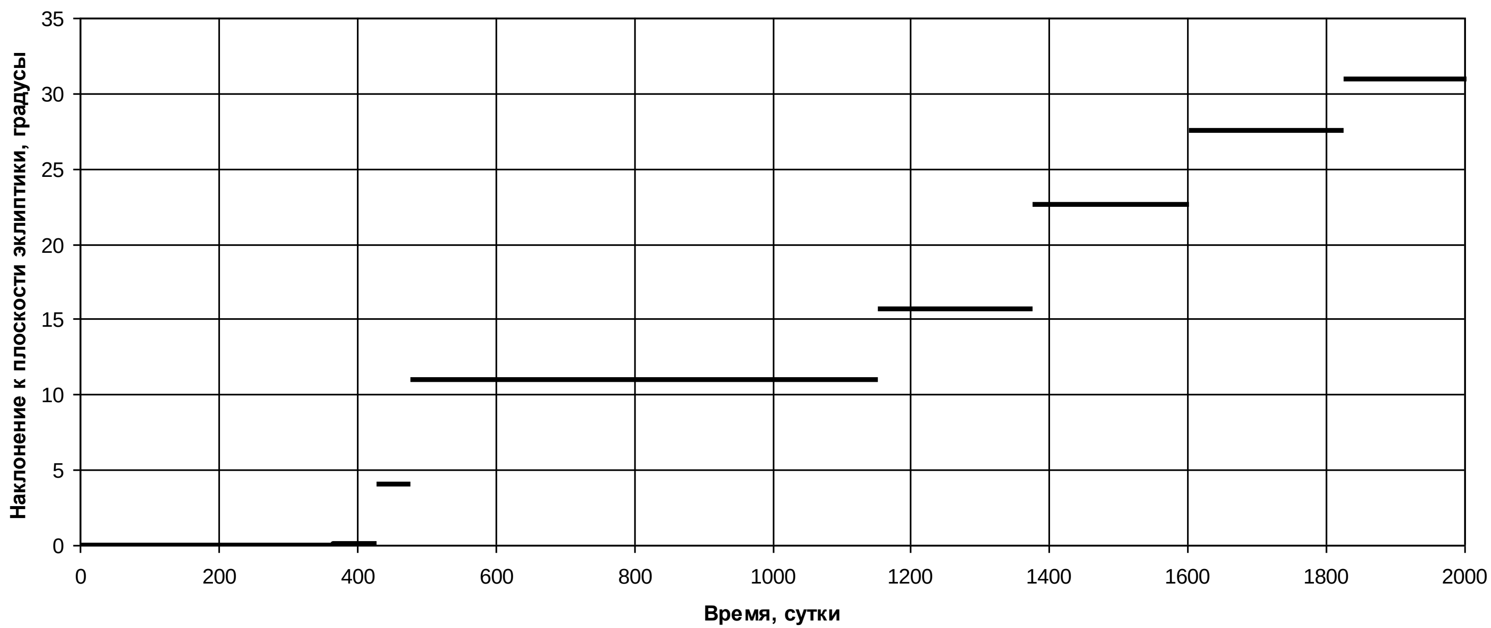


# Characteristics of one of the probable IHP work orbits

Perihelion, Rs




Inclination to the ecliptic, deg

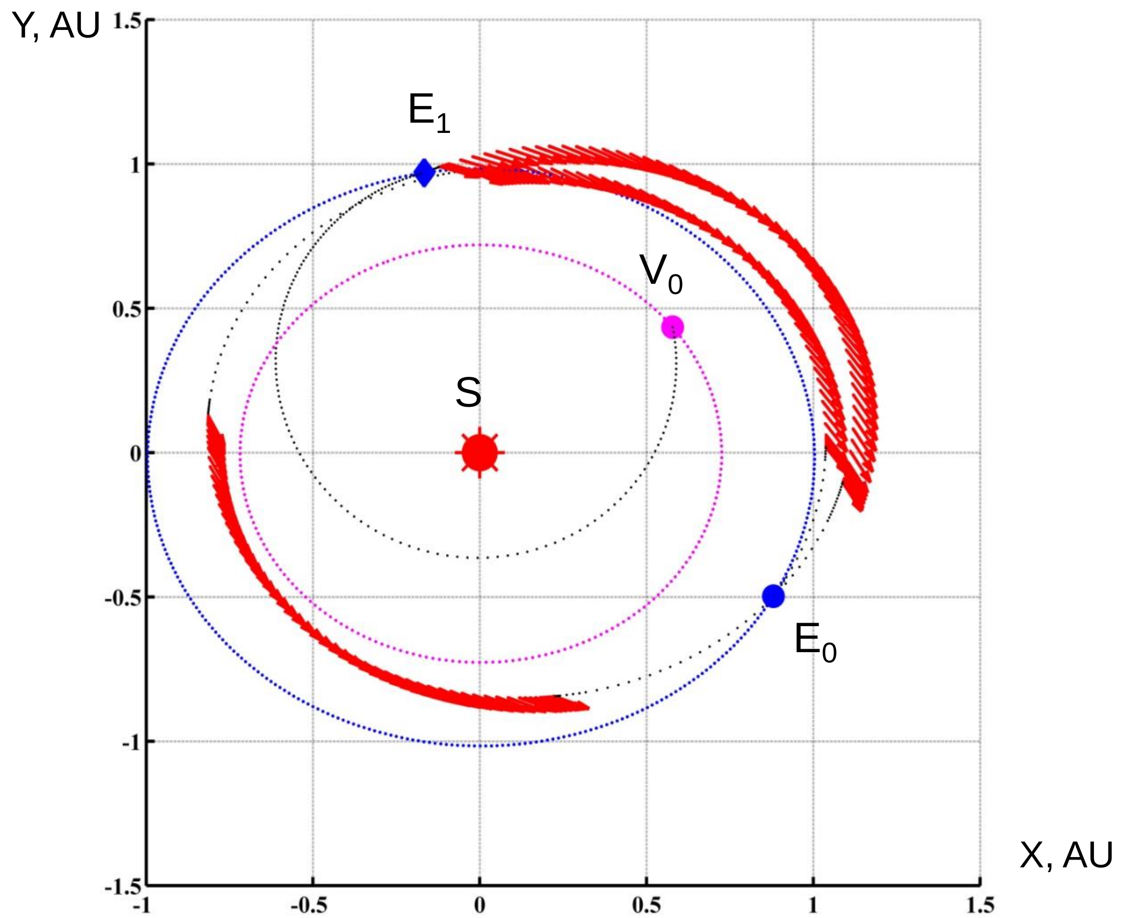



Time of flight, days

# Earth-Earth-Venus part of the IHP-2 flight

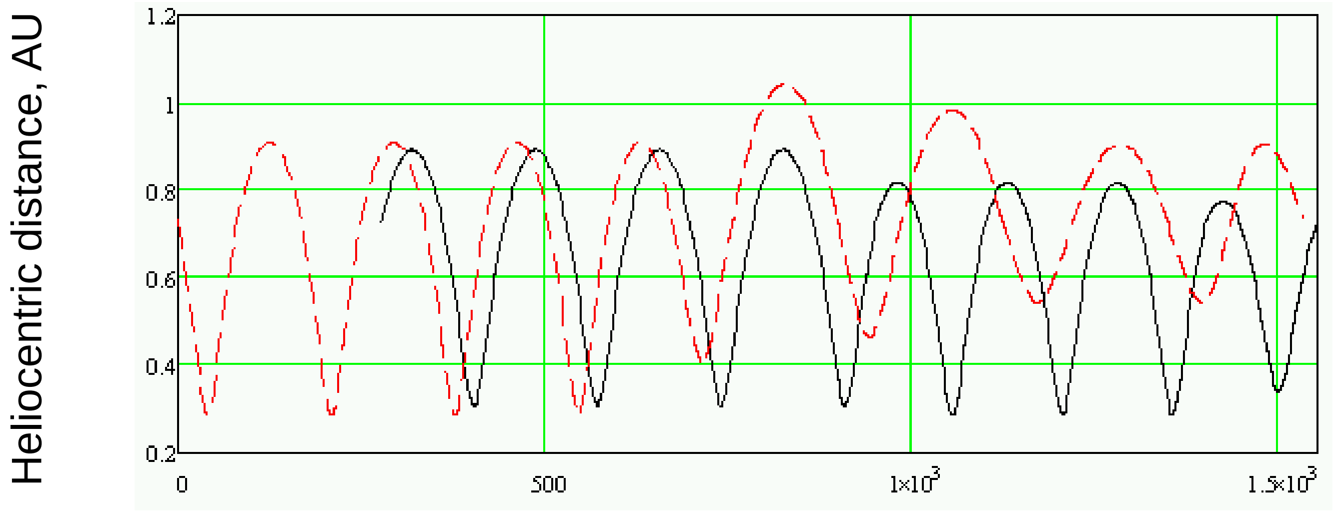
**Main start window**

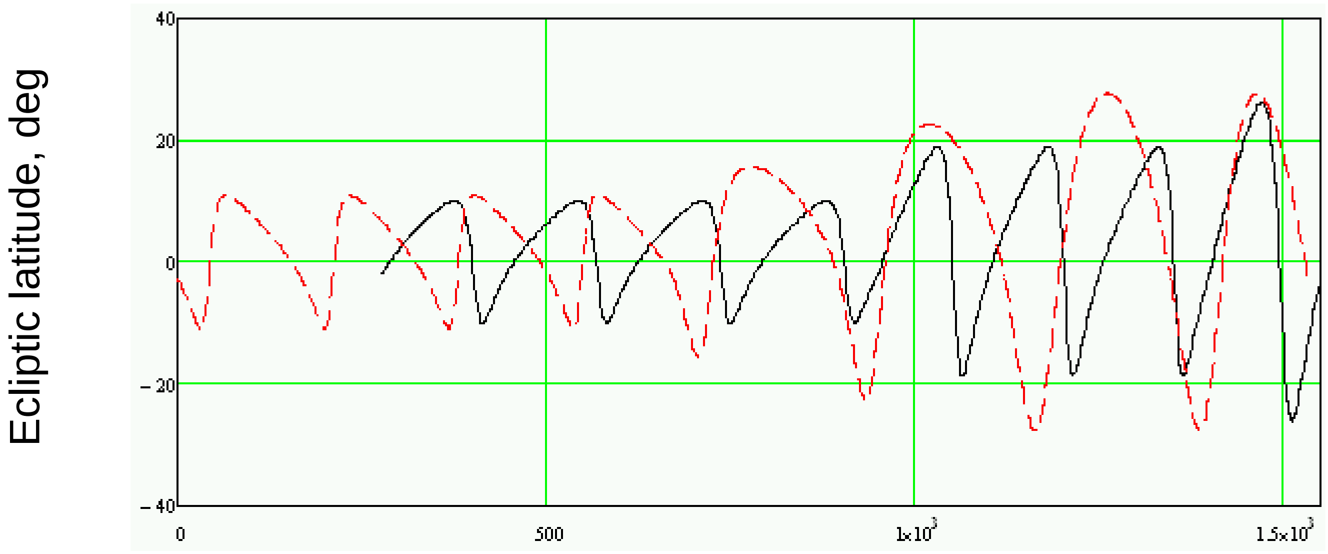
**$t_0$ = 24.08.2022**
**$m_{Xe}$ = 400 kg**
**$m_k$ = 1387 kg**
**$V_{\infty 0}$ = 2190 m/s**
**T = 495 / 132.4 days**




| Gravity assist number | Radius of perihelion [Rs] | Inclination to ecliptic [grad] | Radius of aphelion [AU] | Orbit period [days] | Resonance $N_{IHP}:N_{Venus}$ | Time of flight [days] |
|---|---|---|---|---|---|---|
| 1 | 65.421 | 10.021 | 0.890 | 168.524 | 4:3 | 674.099 |
| 2 | 61.474 | 18.786 | 0.818 | 149.799 | 3:2 | 449.399 |
| 3 | 72.722 | 26.086 | 0.775 | 151.800 | | |

# Characteristics of the probable IHP-1 and IHP-2 work orbits



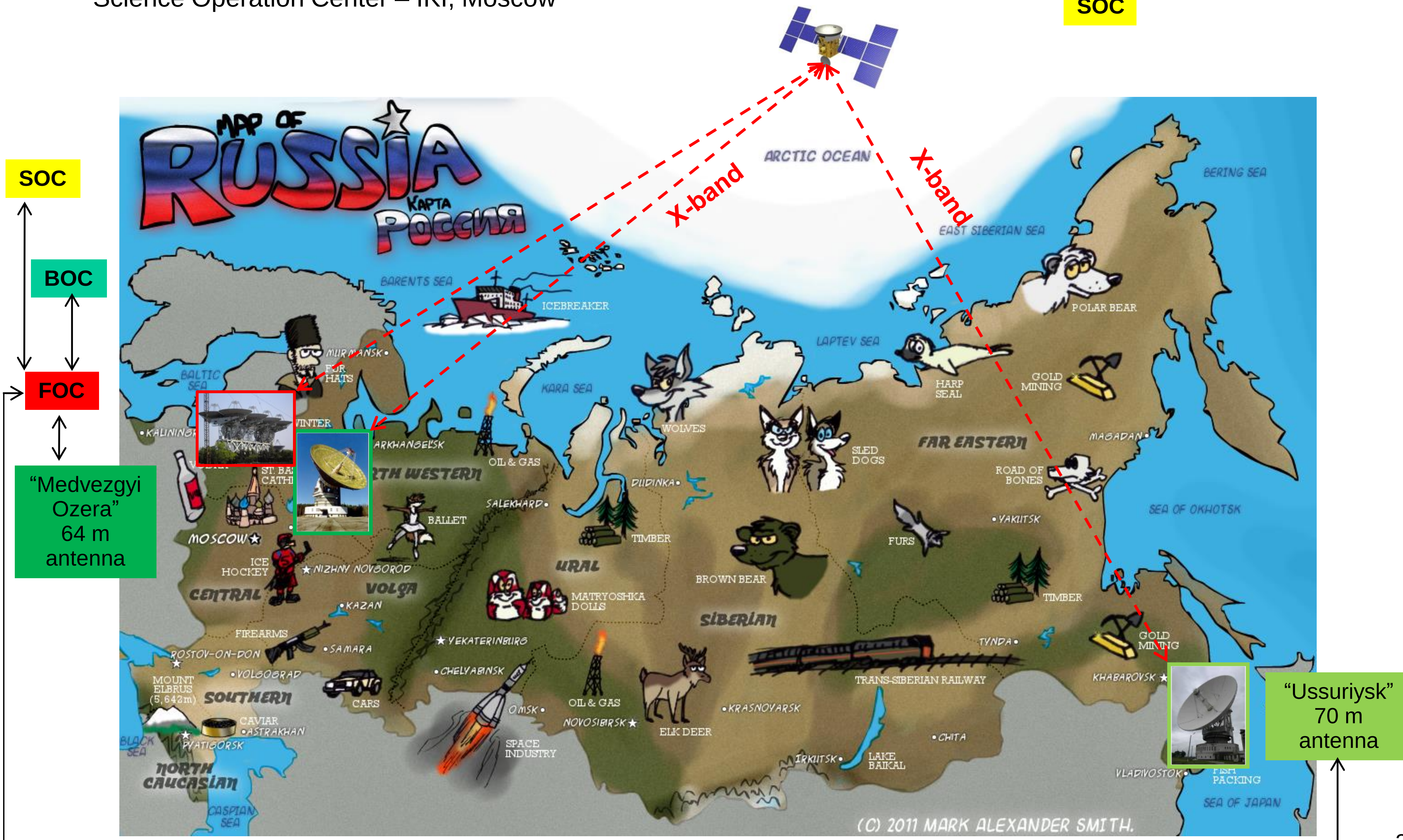

Time of flight, days

# Cartoon of the Interhelioprobe Ground Segment

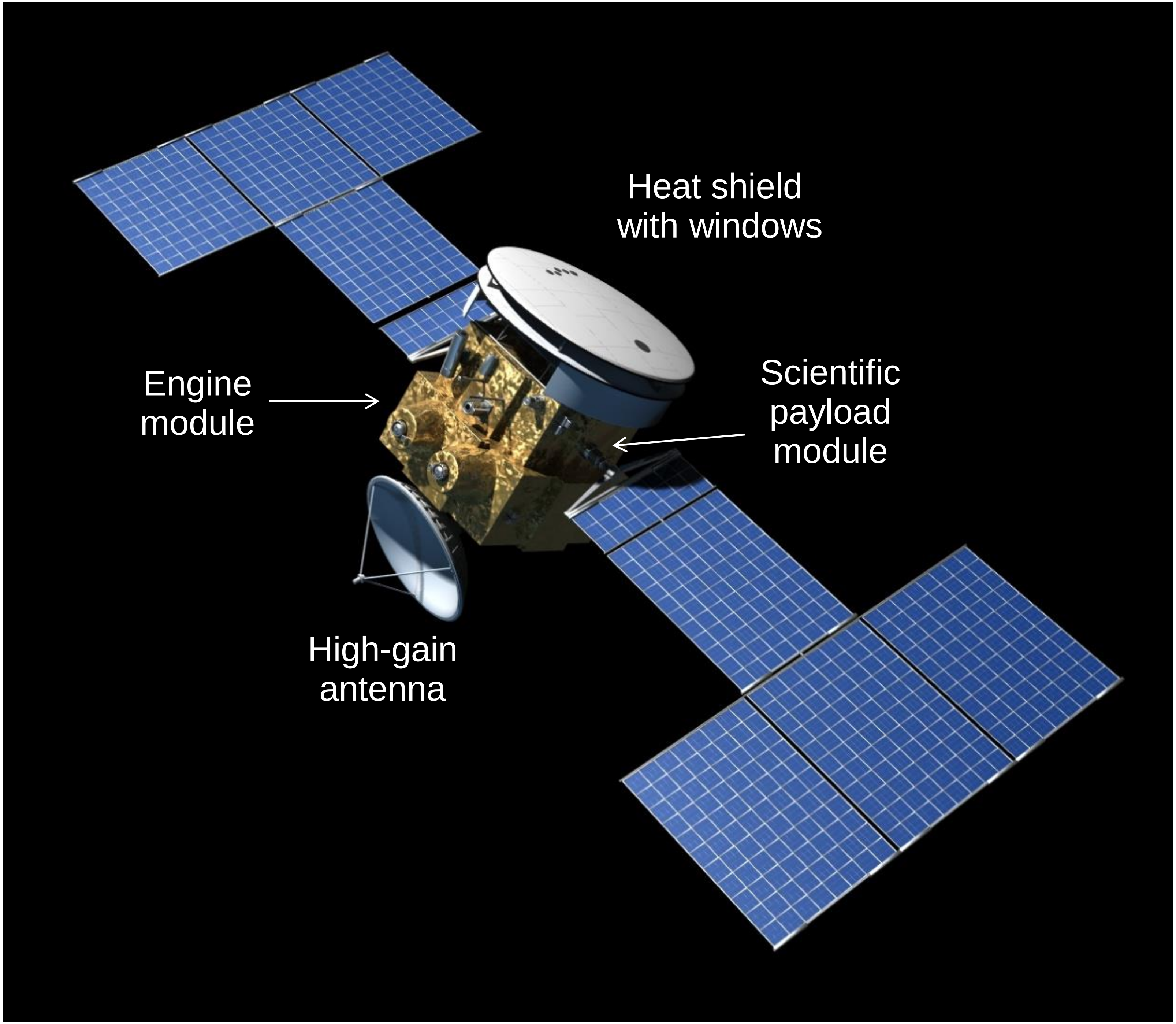
Max Scientific traffic **~1 GB/day** at rates up to 1 Mbit/s (distance dependant)

Flight Operation Center – NPO Lavochkin, Khimki, Moscow Region
Ballistic Operation Center – Keldysh Institute of Applied Mathematics, Moscow
Science Operation Center – IKI, Moscow

FOC
BOC
SOC



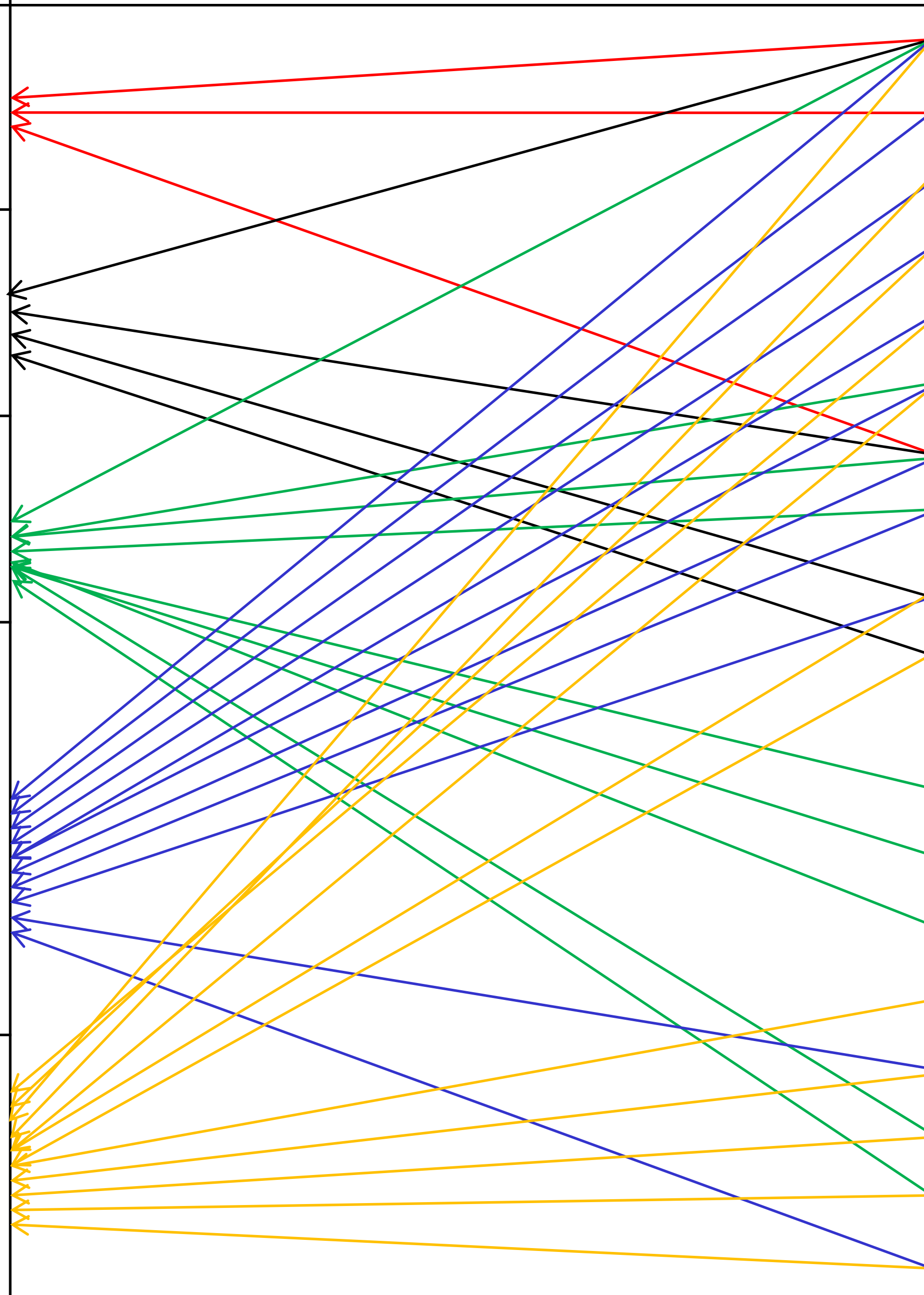
# Interhelioprobe spacecraft raw model



# Scientific goals of the IHP and instruments of their achievement

**Goals**

1. Solar dynamo and solar cycle
2. Thin structure and dynamics of solar atmosphere
3. Corona heating and acceleration of solar wind
4. Flares, coronal mass ejections, solar-terrestrial relations and space weather
5. Generation and transport of energetic particles at the Sun and in the inner heliosphere



**Instruments**

1. TAHOMAG
2. PHOTOSKOP
3. PING-M
4. HELIKON-I
5. SIGNAL
6. SORENTO
7. TREK
8. CHEMIX
9. OKA
10. HELIOSPHERA
11. PIPLS-A
12. PIPLS-B
13. HELIES
14. HELION
15. SKI-5
16. INTERSONG
17. HELIOMAG
18. IMVE
19. RSD

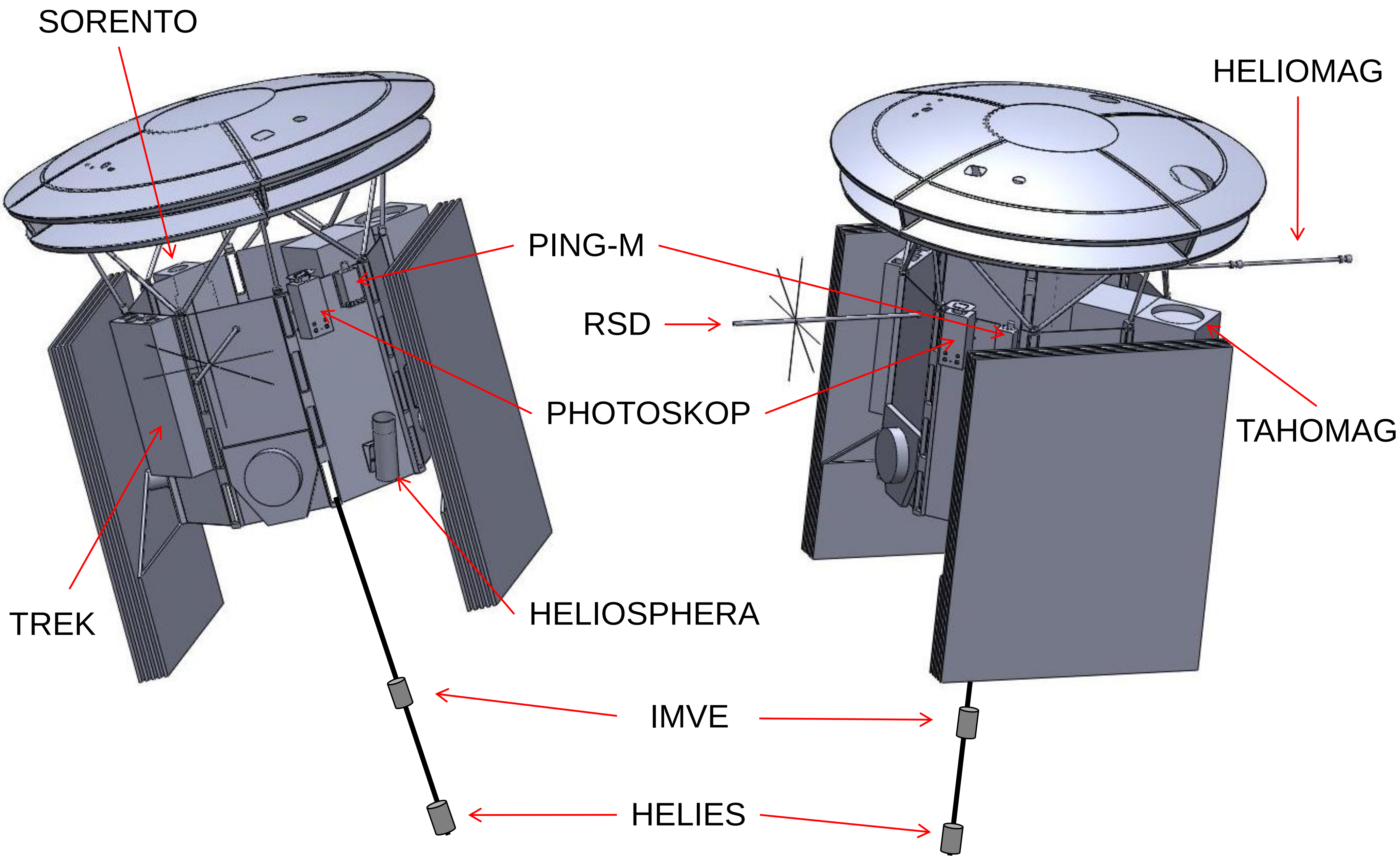
# Instruments for remote observations of the Sun

| № | Instrument | Measurements | Characteristics | Mass [kg] | Power [W] |
|---|---|---|---|---|---|
| 1 | Multi-functional optical telescope **TAHOMAG** | Stokes parameters<br>Vectors of magnetic and velocity fields at the photosphere<br>Intensity of white-light radiation | FOV=600"; dα=0.16"-0.40";<br>λ=3000, 6301, 6302, 6528 Å;<br>dλ=15 mÅ; B=±10 kGs;<br>dB=2-3 Gs (line-of-sight); | 36 | 40 |
| 2 | Multi-channel solar photometer **PHOTOSKOP** | Solar constant<br>Global oscillations of the Sun | FOV=10°; λ=3000-16000 Å;<br>dλ=100 Å; dI=0.3%; dI/dt=0.1%/year | 6.5 | 12 |
| 3 | Imaging EUV and SXR telescope **TREK** | Images of the Sun<br>Localization of active regions | FOV=0.7°-2°; dα=1.2"-3.5";<br>λ=131, 171, 304, 8.42 Å | 15 | 15 |
| 4 | Solar HXR telescope-spectrometer **SORENTO** | Images of solar HXR sources and their spectra | FOV=1.5°; E=5-100 keV;<br>dα=7"; dt=0.1 s | 8 | 6 |
| 5 | Solar coronagraph **OKA** | Images of the solar corona, eruptive events, transients | FOV=8°; dα=30";<br>λ=4000-6500 Å | 5 | 7 |
| 6 | Heliosphereic Imager **HELIOSPHERA** | Images of the outer corona and inner heliosphere | FOV=20°; dα=70";<br>λ=4000-6500 Å | 5 | 7 |
| 7 | X-ray spectrometer **CHEMIX** | Spectra of solar X-ray emission;<br>Chemical composition of solar corona plasma<br>Plasma temperature and velocity diagnostics | FOV=10°; dα=5';<br>λ=1.5-12.0 Å; dλ=0.01 Å<br>dT=1 MK; dv=10 km/s | 6 | 12 |
| 8 | Hard X-ray polarimeter **PING-M** | Fluxes, energy spectra of soft X-ray emission<br>Fluxes, energy spectra, polarization of solar hard X-ray emission | Ex=1.5-25 keV; ΔE=200eV@5.9 keV;<br>Δt≥0.1s<br>Ex,γ=20-600 keV; ΔE/E=0.12@60keV;<br>Δt≥0.1s; Epolar=20-150 keV | 13.5 | 19.5 |
| 9 | Scintillation gamma-spectrometer **HELIKON-I** | Fluxes and spectra of hard X-rays and gamma-rays (of not only solar origin) | E=0.01-15 MeV;<br>dE/E=8% (E=660 keV);<br>dt=0.001-8 s | 13 | 12 |
| 10 | Gas gamma-ray spectrometer **SIGNAL** | Fluxes and spectra of solar (not only) gamma-rays | Eγ=0.05-5 MeV;<br>dE/E=3% (E=660 keV);<br>dt=0.1-60 s | 5 | 20 |
| | | | | **113.0** | **150.5** |

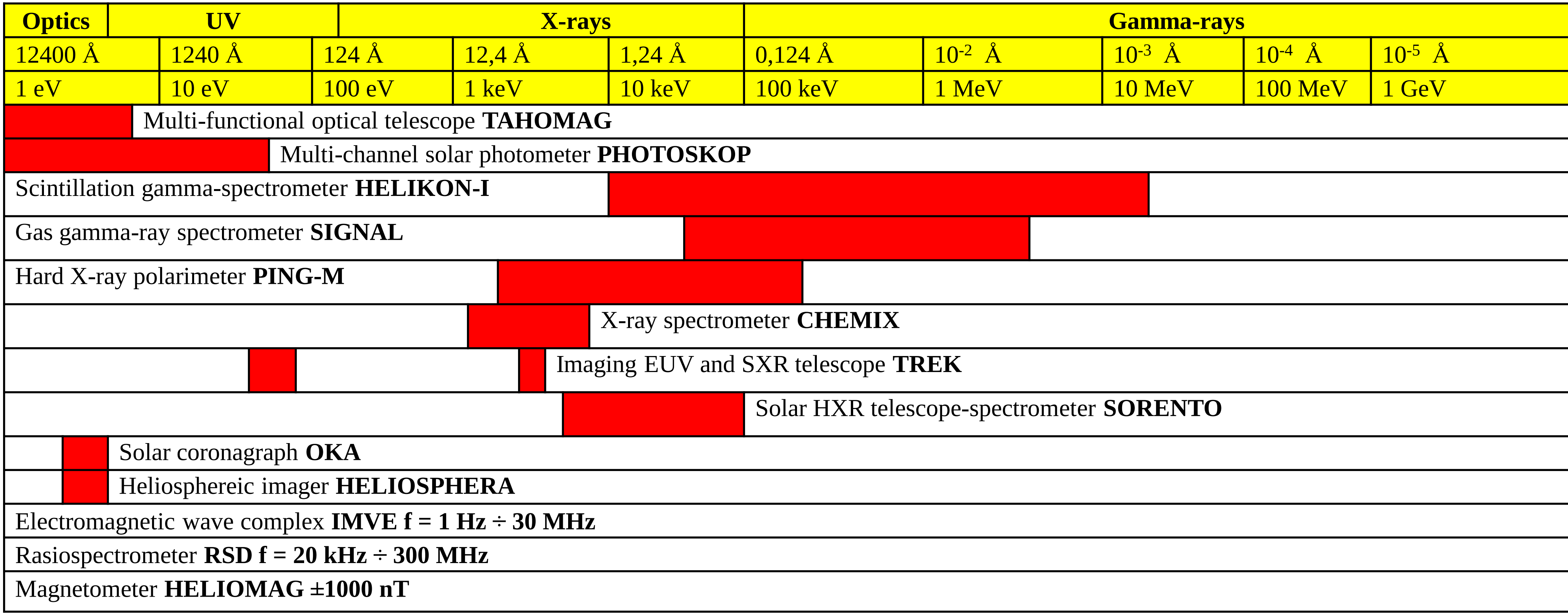
# Instruments for local (in situ) measurements

| № | Instrument | Measurements | Characteristics | Mass [kg] | Power [W] |
|---|---|---|---|---|---|
| 1 | Analyzer of solar wind electrons **HELIES** | Distribution functions of solar wind electrons | FOV=65°x360°; E=2 eV-5 keV; dE/E=18%; dt=2 s | 2.5 | 3 |
| 2 | Analyzer of solar wind ions **HELION** | Energy and angular spectra of solar wind ions | Ions: FOV=120°x100°; E=40 eV-12 keV; dE/E=7% Electrons: FOV=15°x60°; E=0.35eV-6.30 keV; dE/E=16% | 1.8 | 0.8 |
| 3 | Energy-mass-analyzer of solar wind plasma **PIPLS-B** | Energetic and mass composition of solar wind ions; distribution functions of solar wind ions | FOV=45°x45°; E=1-20 keV; m/q=2-9; m/dm=10-40; dα=2°-9°; dE/E=5%; dt>1 min | 2.5 | 4 |
| 4 | Dust particle analyzer **PIPLS-A** | Interplanetary and interstellar dust particles | M = $10^{-16}…10^{-6}$ g; M/dM=100; v=5-100 km/s; | 2.5 | 9.8 |
| 5 | Magnetometer **HELIOMAG** | Heliospheric magnetic field and its disturbances | B=±1000 nT dB=2 pT | 1.5 | 5 |
| 6 | Electromagnetic wave complex **IMVE** | Magnetic and electric fields, plasma waves | f =1 Hz - 30 MHz | 6 | 12 |
| 7 | Rasiospectrometer **RSD** | Radioemission of solar corona and solar wind plasmas | f=20 kHz – 300 MHz | 2.2 | 8 |
| 8 | Charged particle telescope **SKI-5** | Energetic charged particles in the interplanetary space | Electrons: E=6-20 keV & E~0.15- 10 MeV Protons: E~1-100 MeV Ions:E~1-100 MeV/nucleon | 4.5 | 14 |
| 9 | Neutron detector **INTERSONG** | Solar neutrons | En~0.1-100 MeV | 6.5 | 15 |
| | | | | **30.0** | **71.6** |

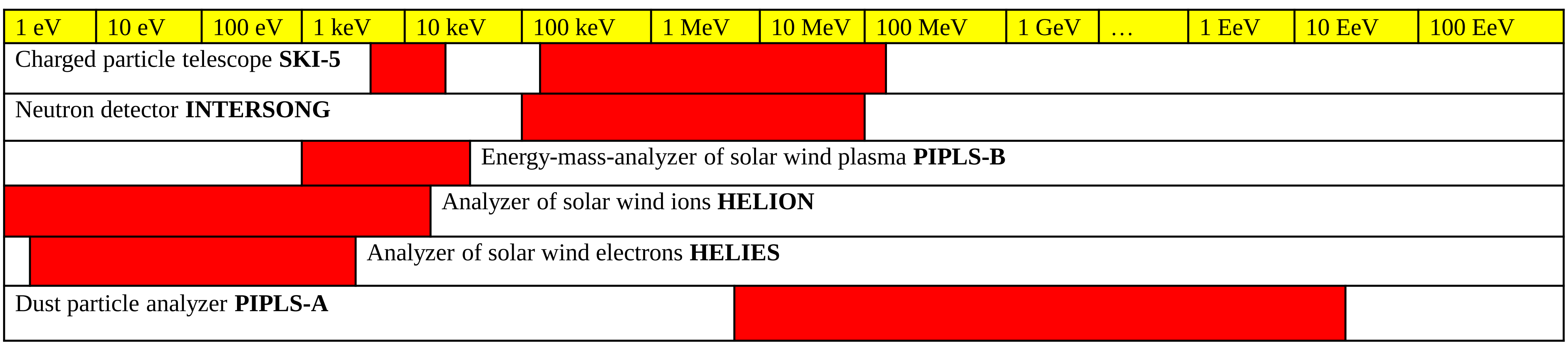
# Preliminary location of scientific instruments on the spacecraft



# Interhelioprobe coverage of electromagnetic emission




# Interhelioprobe coverage of corpuscular emission



## Solar Orbiter payload


## Interhelioprobe payload

| Remote-Sensing Instruments | |
|---|---|
| Polarimetric and Helioseismic Imager | PHI |
| | |
| EUV full-Sun and high-resolution Imager | EUI |
| X-ray spectrometer/telescope | STIX |
| Coronagraph | METIS |
| Heliosphereic Imager | SoloHI |
| EUV spectral Imager | SPICE |
| | |
| | |
| | |

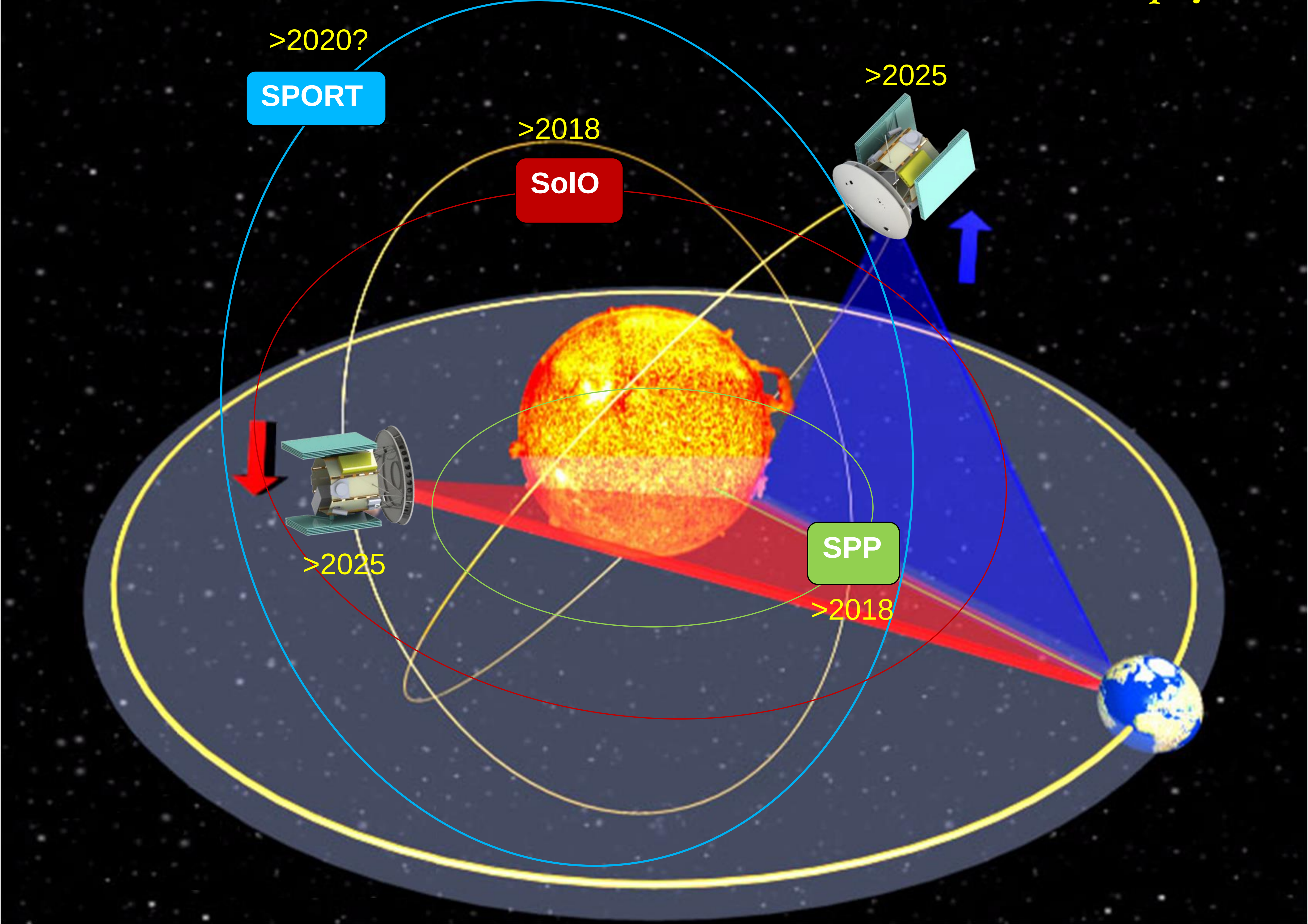
| Remote-Sensing Instruments | |
|---|---|
| TAHOMAG | Multi-functional optical telescope |
| PHOTOSKOP | Multi-channel solar photometer |
| TREK | Imaging EUV and SXR telescope |
| SORENTO | Solar HXR telescope-spectrometer |
| OKA | Solar coronagraph |
| HELIOSPHERA | Heliosphereic Imager |
| CHEMIX | X-ray spectrometer |
| PING-M | Hard X-ray polarimeter |
| HELIKON-I | Scintillation gamma-spectrometer |
| SIGNAL | Gas gamma-ray spectrometer |

| In-situ Instruments | |
|---|---|
| Solar Wind Analyser | SWA |
| | |
| | |
| | |
| Magnetometer | MAG |
| Radio and Plasma Wave analyser | RPW |
| | |
| Energetic Particle Detector | EPD |
| | |

| In-situ Instruments | |
|---|---|
| HELIES | Analyzer of solar wind electrons |
| HELION | Analyzer of solar wind ions |
| PIPLS-B | Energy-mass-analyzer of solar wind plasma |
| PIPLS-A | Dust particle analyzer |
| HELIOMAG | Magnetometer |
| IMVE | Electromagnetic wave complex |
| RSD | Rasiospectrometer |
| SKI-5 | Charged particle telescope |
| INTERSONG | Neutron detector |

From Muller et al. (Sol. Phys., 2012)

# Great situation for solar physics



# Thank you!