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POLITECNICO DI MILANO





ESA's Asteroid Impact Mission: Mission Analysis and Payload Operations state of the art

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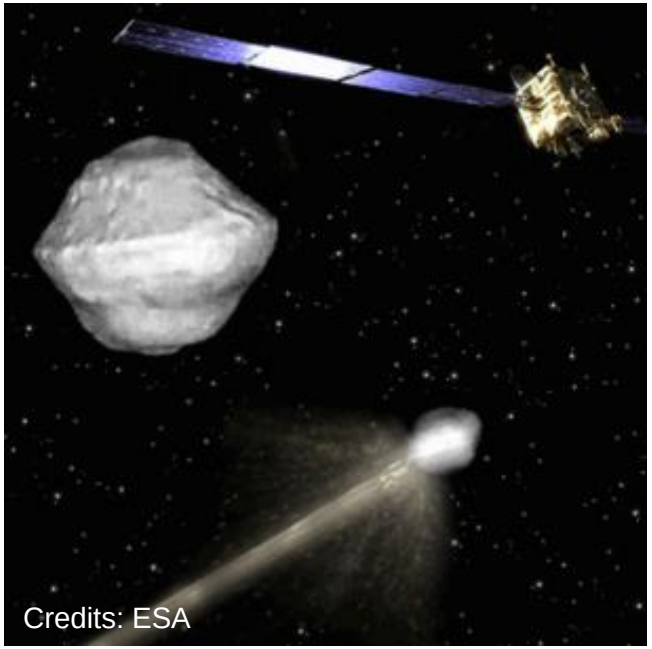
CONTENT

- Introduction: Asteroid Impact Mission (AIM)
  - Mission objectives
  - Payloads on board
- Mission analysis
  - Launch window
  - Rendezvous with asteroid
- Close proximity operations

Asteroid Impact Mission (AIM)



65803 Didymos will transit near Earth (less than 0.1 AU) in late 2022

[Didymos = Didymain + Didymoon]

AIDA - Asteroid Impact & Deflection Assessment

AIM - Asteroid Impact Mission (ESA)

Goals:

- Study of binary system
- Techonogical demonstrations
- Deployment of a lander (MASCOT-2)
- Deployment of cubesats (COPINS)

DART - Double Asteroid Redirection Test (NASA)

Goals:

- High velocity kinetic impact

Mission objectives

AIM

- Scientific goals
  - Characterization of Didymain and Didymoon (shape, mass, dynamics)
  - Geophysical properties of Didymoon (surface, sub-surface, interior structure, mechanical and thermal properties)
- Technological demonstrations
  - Laser-based optical telecommunication (TEX)
  - MASCOT-2 landing
  - Deep-space cubesat network (COPINS)

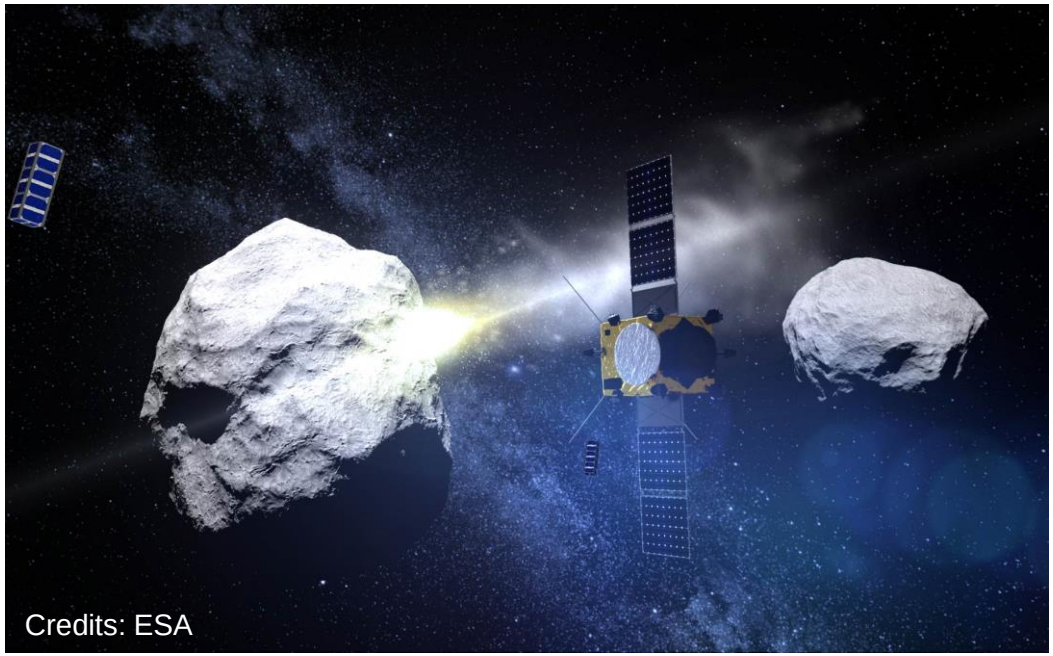
AIDA

- Planetary defense
  - Momentum transfer assessment
- Scientific goals
  - Fragmentation and re-accumulation dynamics

Payloads

- VIS: camera used for GNC and science
- TIRI: thermal infra-red imager
- HFR: high-frequency radar to investigate sub-surface properties
- LFR: bi-static low frequency radar, AIM+MASCOT-2
- OPTEL-D: laser communication terminal
- MASCOT-2: lander
- COPINS: cubesats to establish an inter-satellite link

Didymos system



Properties of asteroids

	Diameter [m]	Mass [kg]	Rotation period [h]
Didymain	750	5.2 e11	2.3
Didymoon	157	4.9 e9	11.9

Heliocentric and binary system orbits

	Semi-major axis	Orbital period
Heliocentric orbit	1.6 AU (1 x 2.2)	2.1 years
Binary system	1.18 km	11.9 hours

INTERPLANETARY TRANSFER
Launch window: ballistic transfer

ASSUMPTIONS

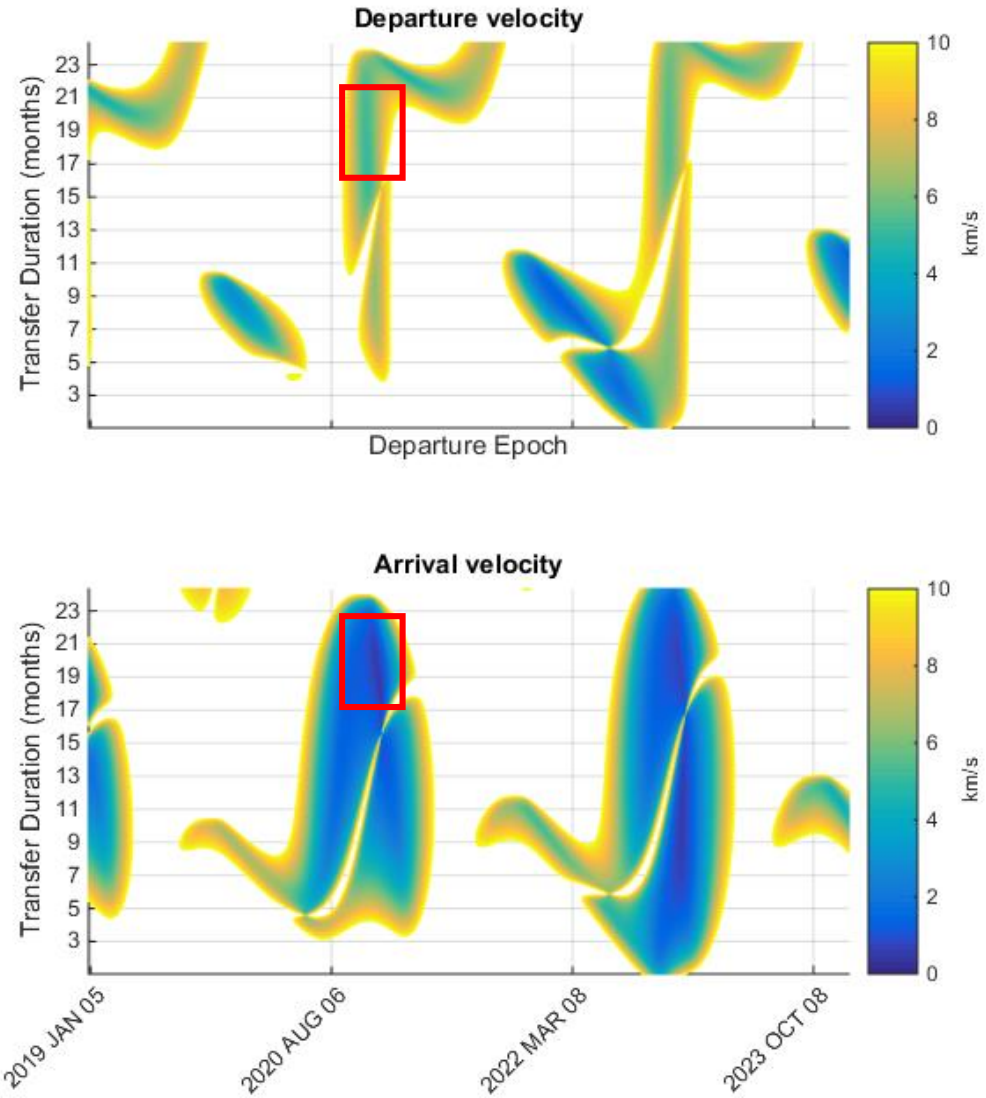
- Keplerian motion between spacecraft and Solar System Barycenter
- Earth and Didymos orbits from Horizons JPL ephemerides

REQUIREMENTS

- Max escape velocity (launcher) = 5.2 km/s
- Max arrival maneuver (AIM) = 1.25 km/s
- Arrival not late than mid 2022
- Departure not before mid 2020

BALLISTIC TRANSFER		Day
Departure day	Earliest	2020 October 23rd
	Latest	2020 November 6th
Asteroid arrival	Earliest	2022 April 5th
	Latest	2022 June 16th

INTERPLANETARY TRANSFER
Pork chop plot: ballistic transfer



INTERPLANETARY TRANSFER
Launch window: ballistic transfer

BALLISTIC TRANSFER

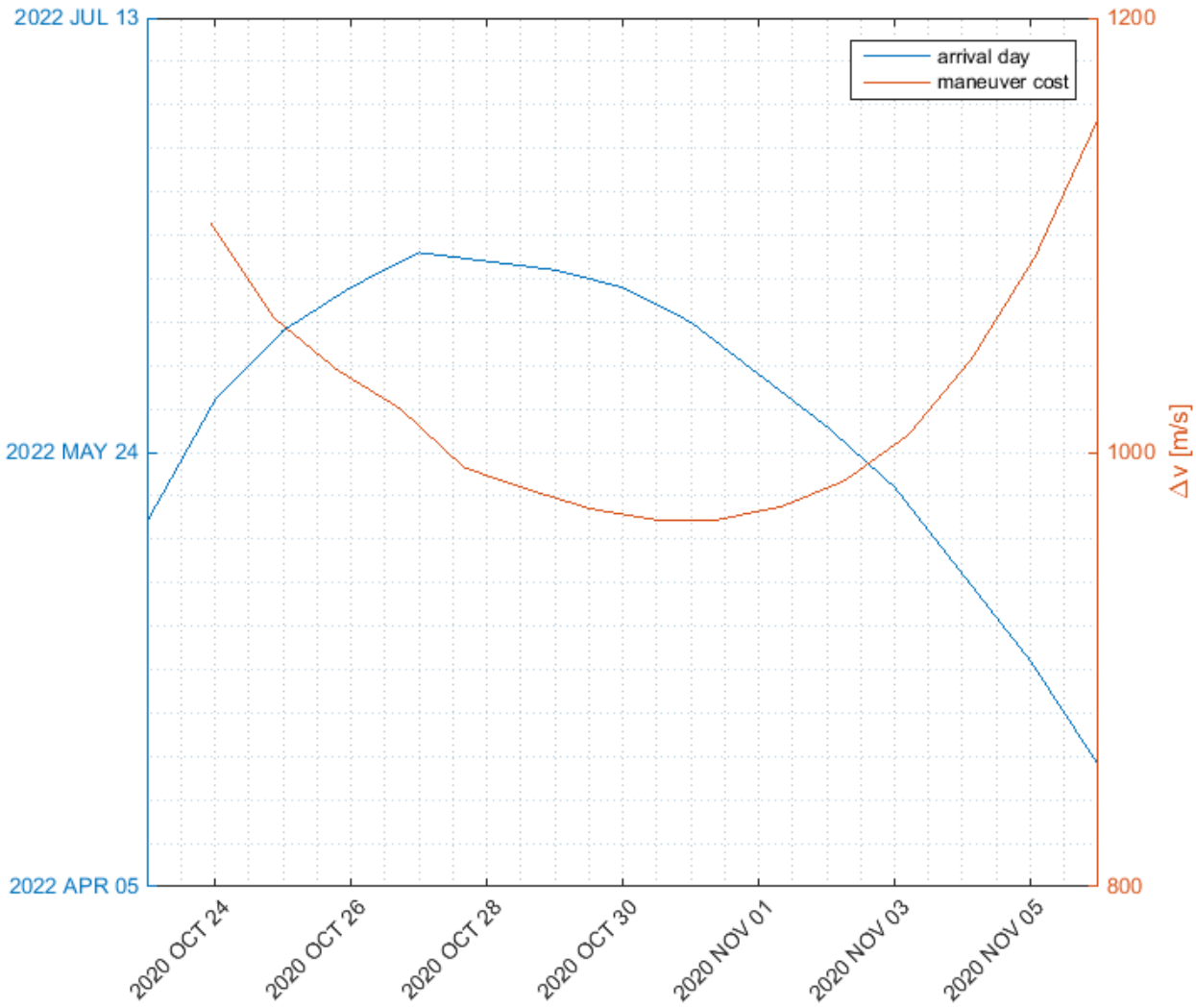
Launch date	2020/10/23	2020/10/24	2020/10/25	2020/10/26	2020/10/27	2020/10/28	2020/10/29	2020/10/30
Escape velocity [km/s]	5.200	5.199	5.199	5.199	5.199	5.199	5.199	5.199
Asteroid arrival	2022/05/16	2022/05/30	2022/06/07	2022/06/12	2022/06/16	2022/06/15	2022/06/14	2022/06/12
Duration [d]	570	583	590	594	596	595	593	589
Arrival manoeuvre [m/s]	1106	1062	1038	1020	993	983	974	969

Launch date	2020/10/31	2020/11/01	2020/11/02	2020/11/03	2020/11/04	2020/11/05	2020/11/06
Escape velocity [km/s]	5.199	5.199	5.199	5.200	5.199	5.199	5.200
Asteroid arrival	2022/06/08	2022/06/02	2022/05/27	2022/05/20	2022/05/10	2022/04/30	2022/04/18
Duration [d]	584	578	571	563	552	541	528
Arrival manoeuvre [m/s]	969	975	987	1008	1043	1090	1154

One solution per day (best during the day)

INTERPLANETARY TRANSFER
Launch window: ballistic transfer

BALLISTIC TRANSFER



INTERPLANETARY TRANSFER
Extended launch window with DSM

OPTIMIZATION

- Arrival on 2022 June 1st
- Departure and arrival time during the day is not fixed
- Optimal solution is found for each day of the extended launch window
- Optimal solution during the ballistic launch window is the ballistic transfer

BALLISTIC TRANSFER	TRANSFER WITH DSM
2020 October 23rd - November 6th	2020 October 17th - November 9th

The launch window with DSM extends of few days before and after the ballistic launch window

INTERPLANETARY TRANSFER
Extended launch window with DSM

TRANSFER WITH DSM: early departure (17-22 October)

Launch date	2020/10/17	2020/10/18	2020/10/19	2020/10/20	2020/10/21	2020/10/22
Escape velocity [km/s]	5.200	5.200	5.200	5.200	5.200	5.200
DSM date	2020/12/18	2020/12/29	2020/12/30	2020/12/18	2020/12/19	2020/12/20
DSM [m/s]	189.6	161.4	135.1	87.2	71.0	32.6
Arrival manoeuvre [m/s]	1054	1053	1052	1060	1056	1062
DSM + arrival [m/s]	**1244**	**1215**	**1187**	**1147**	**1127**	**1094**
Asteroid arrival	2022/06/01	2022/06/01	2022/06/01	2022/06/01	2022/06/01	2022/06/01

One solution per day (optimum during the day)

INTERPLANETARY TRANSFER
Extended launch window with DSM

TRANSFER WITH DSM: late departure (7-9 November)

Launch date	2020/11/07	2020/11/08	2020/11/09
Escape velocity [km/s]	5.200	5.200	5.200
DSM date	2021/01/03	2021/01/04	2021/01/05
DSM [m/s]	319.5	390.3	540.7
Arrival manoeuvre [m/s]	789	754	684
DSM + arrival [m/s]	**1108**	**1144**	**1225**
Asteroid arrival	2022/06/01	2022/06/01	2022/06/01

→ DSM is much higher for a late departure

One solution per day (optimum during the day)

INTERPLANETARY TRANSFER
Arrival maneuver

BALLISTIC TRANSFER

Launch date	2020/10/23	2020/10/29	2020/10/31	2020/11/02	2020/11/06
Escape velocity [km/s]	5.200	5.199	5.199	5.199	5.200
Asteroid arrival	2022/05/16	2022/06/14	2022/06/08	2022/05/27	2022/04/18
Duration [d]	570	593	584	571	528
Arrival manoeuvre [m/s]	1106	974	969	987	1154

ARRIVAL MANEUVER

Launch date	2020/10/31	2020/11/06
Asteroid arrival	2022 JUN 23 - JUL 3	2022 MAY 7 - 14
Total arrival manoeuvre [m/s]	960 - 1250	1147 - 1250

INTERPLANETARY TRANSFER
Arrival maneuver

NOMINAL SEQUENCE
5 maneuvers, 1 week apart

ARRIVAL MANEUVER		Day
Departure day	Earliest	2020 October 23rd
	Latest	2020 November 6th
Asteroid arrival	Earliest	2022 May 7th
	Latest	2022 July 3rd

DEPARTURE

- Early or late launch opportunities will result in an early arrival
- Departure day constraints the arrival day
- Departure day constraints the maneuver cost

ARRIVAL MANEUVER: design parameters (nominal)

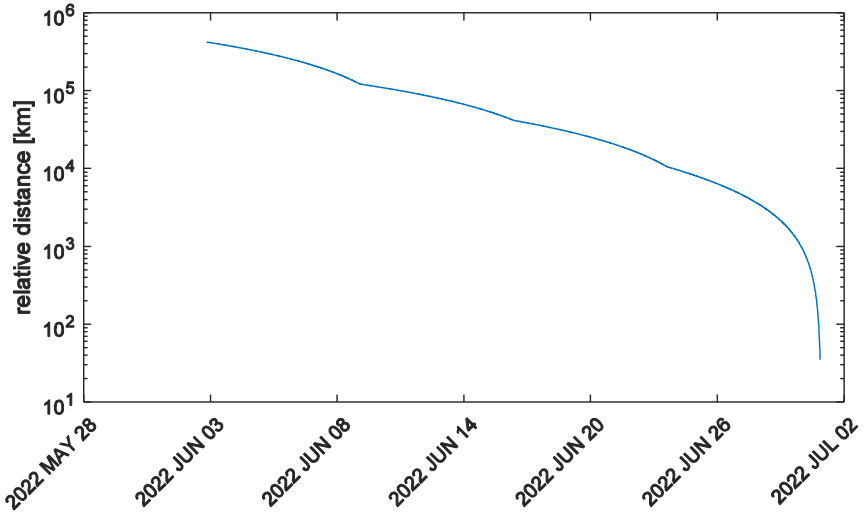
- Number of maneuvers (5)
- Time between two consecutive maneuvers (1 week)

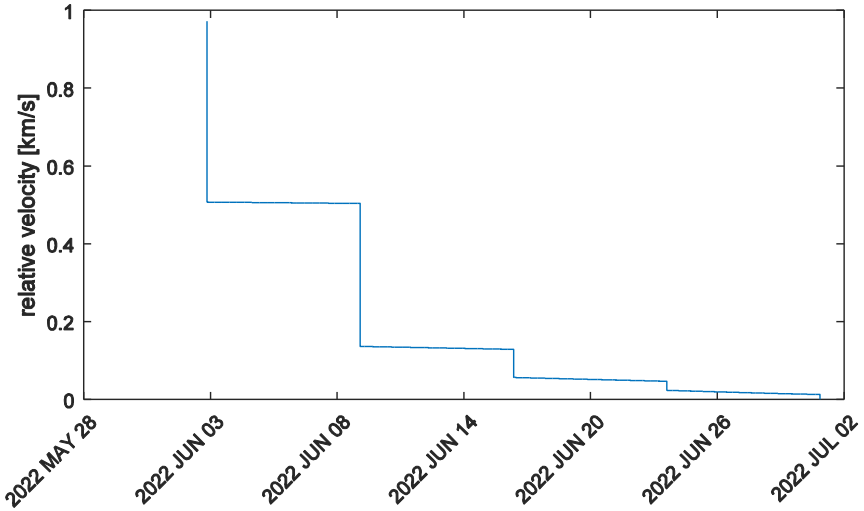
INTERPLANETARY TRANSFER
Nominal arrival sequence

Ballistic transfer with departure on 2020 October 31st

manoeuvre #	date	Δv [m/s]	Distance from asteroid [km]
1	2022 JUN 03	469.6	4.21E+05
2	2022 JUN 10	378.5	1.21E+05
3	2022 JUN 17	75.0	4.16E+04
4	2022 JUN 24	25.0	1.05E+04
5	2022 JUL 01	12.5	35
TOT Δv [m/s]		**960.6**	

INTERPLANETARY TRANSFER
Nominal arrival sequence





INTERPLANETARY TRANSFER
Earlier arrival sequence

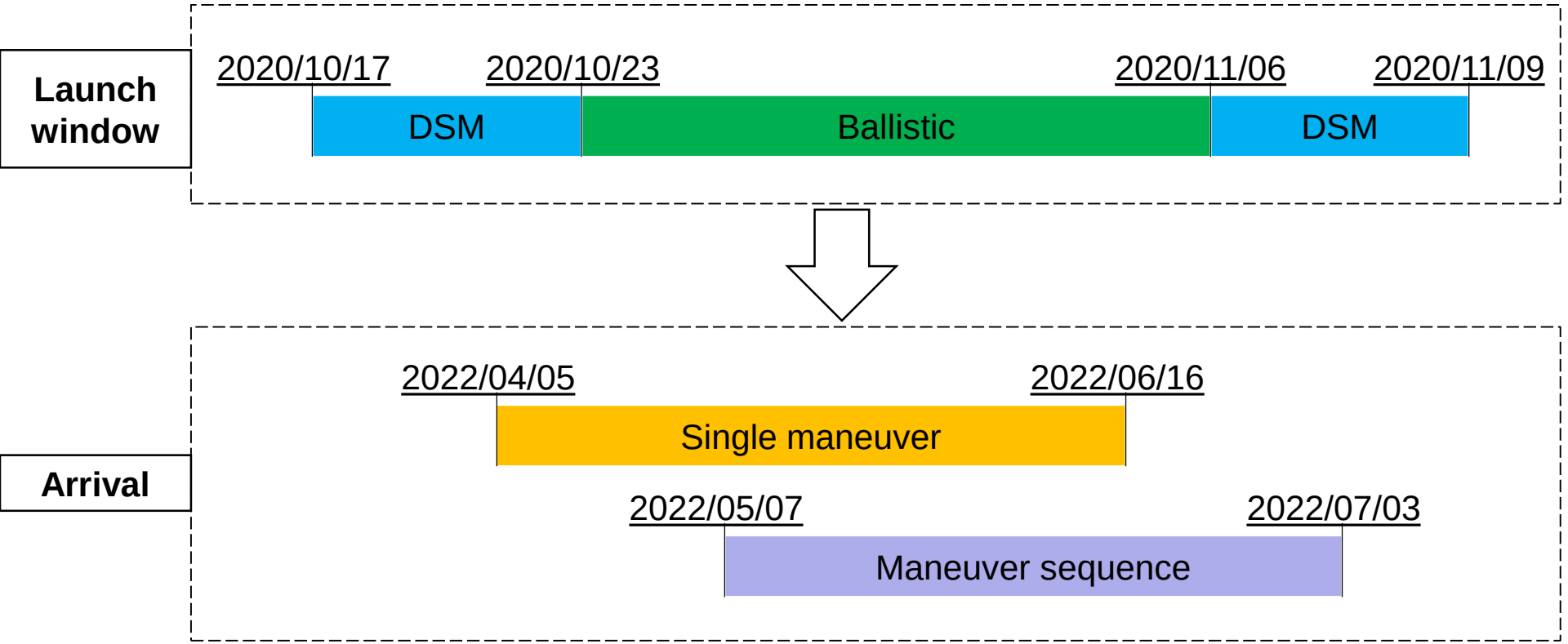
Ballistic transfer with departure on 2020 November 6th

manoeuvre #	date	Δv [m/s]	Distance from asteroid [km]
1	2022 APR 14	584.7	4.52E+05
2	2022 APR 21	449.4	1.08E+05
3	2022 APR 28	75.0	3.51E+04
4	2022 MAY 05	25.0	8.86E+03
5	2022 MAY 12	12.5	35
TOT Δv [m/s]		**1146.6**	

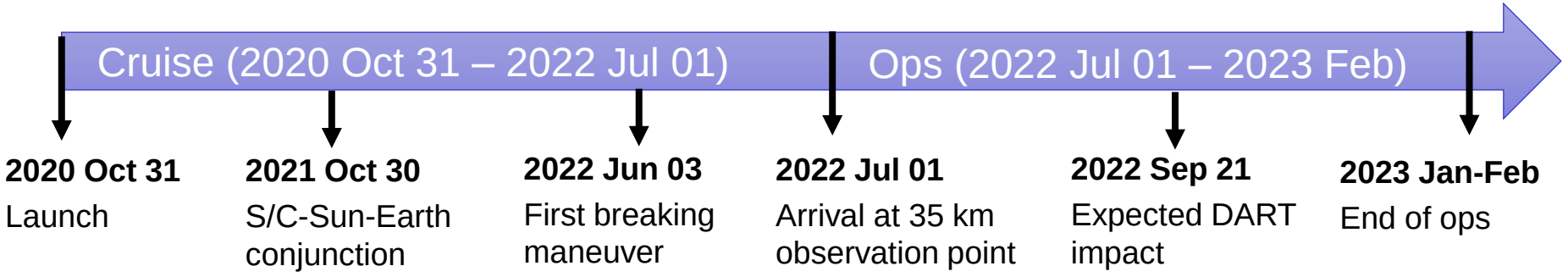
INTERPLANETARY TRANSFER
Summary

ASSUMPTIONS

- Keplerian motion between spacecraft and Solar System Barycenter
- Earth and Didymos orbits from Horizons JPL ephemerides
- Max escape velocity (launcher) = 5.2 km/s
- Max arrival maneuver (AIM) = 1.25 km/s



MISSION ANALYSIS TIMELINE



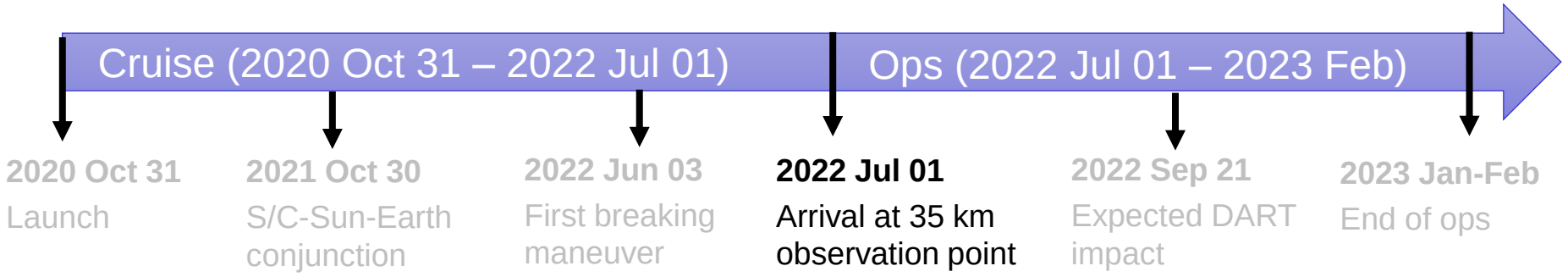
Cruise

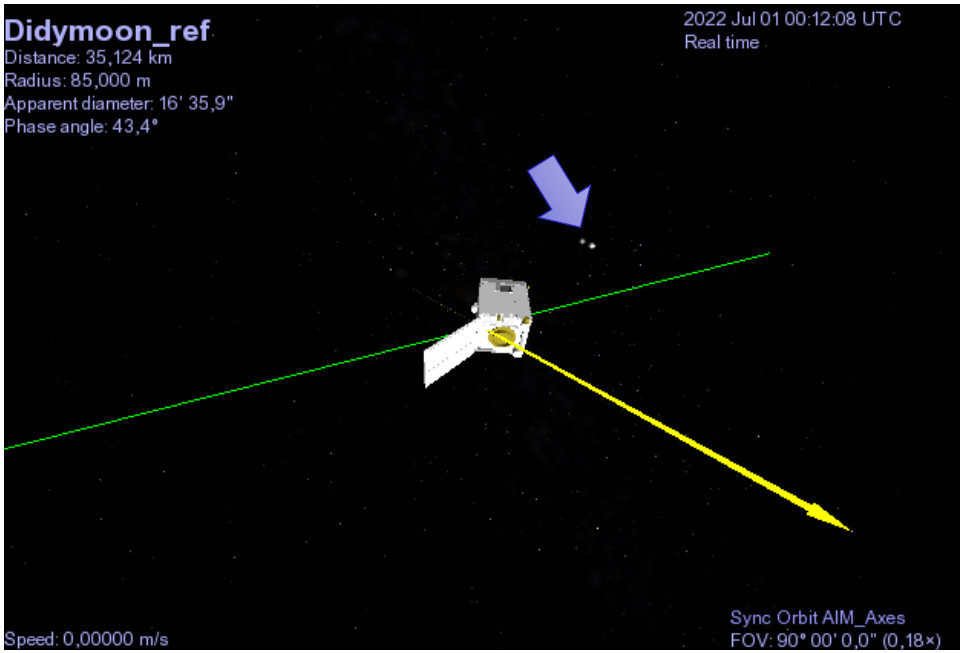
- Launch phase
- Deep space trajectory
- Breaking sequence (5 maneuvers with one week interval between them)

Operations at asteroid

- Early Characterization Phase
- Detailed Characterization Phase 1
- COPINS release
- MASCOT-2 release
- Detailed Characterization Phase 2
- Impact observation
- Detailed Characterization Phase 3
- Disposal

ASTEROID OPERATIONS
Early Characterization Phase





Operations at asteroid

- Early Characterization Phase
- Detailed Characterization Phase 1
- COPINS release
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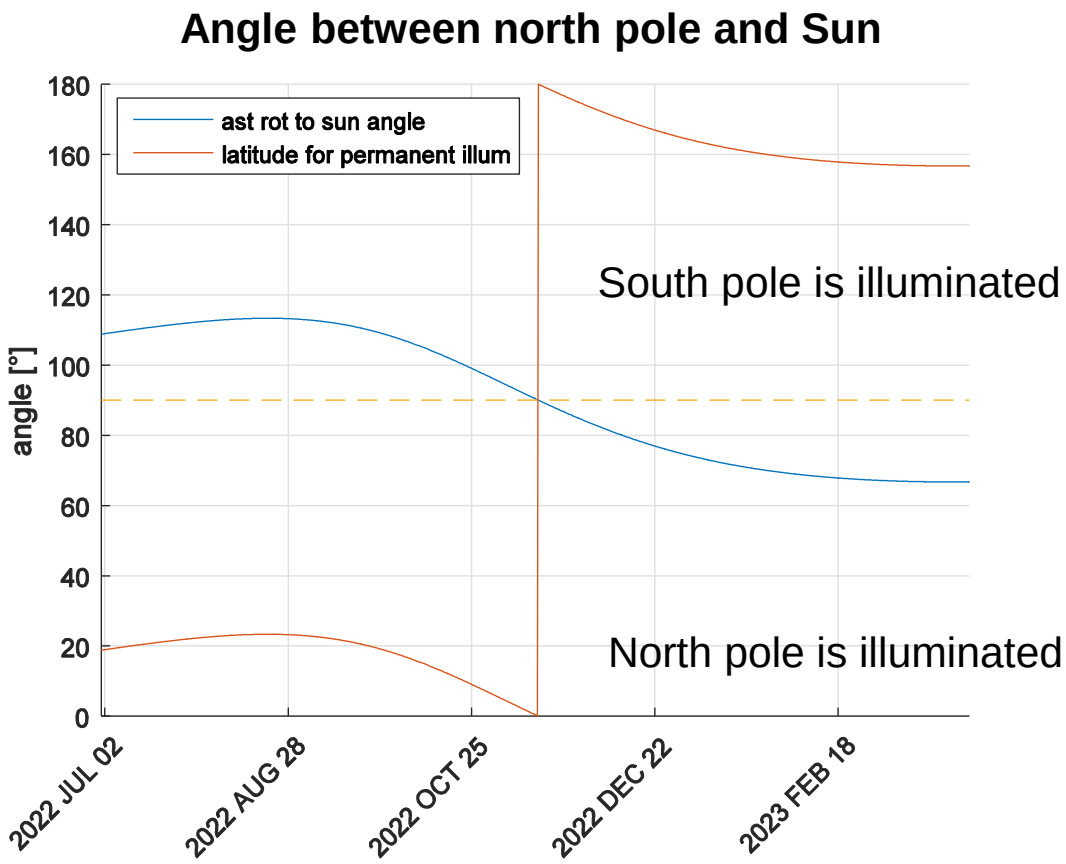
DIDYMOS ILLUMINATION CONSTRAINTS

Pole illumination: it refers to Didymos and Didymoon as well



Didymos north pole

II

Didymoon north pole

II

Didymoon angular momentum about Didymos

MISSION ANALYSIS
DaltaV budget

		Without margin [m/s]	Margin	With Margin [m/s]
Launcher insertion correction		25	50%	37.5
Interplanetary transfer	Arrival (broken manoeuvre)	469.6	5%	493.1
		378.5	5%	397.4
		75.2	5%	79.0
		26.0	5%	27.3
		18.9	5%	19.8
	Navigation corrections (3σ)	19.2	50%	28.8
	TOT arrival (nominal case)	987.4		1045.4
	Max DV in the launch window	1250	5%	1312.5
Station keeping (10 months)		9.4	10 m/s	19.4
Close-proximity operations		100	0%	100
Decommissioning		0.4	10 m/s	10.4
TOT				1479.8

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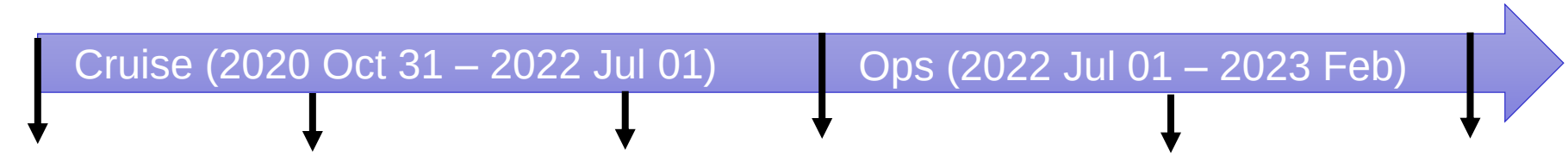
European Space Agency, General Study Program Office, ESA HQ

INTERPLANETARY TRANSFER: APHELION
Earth-sun-s/c-didymos geometry



2020 Oct 31
Launch

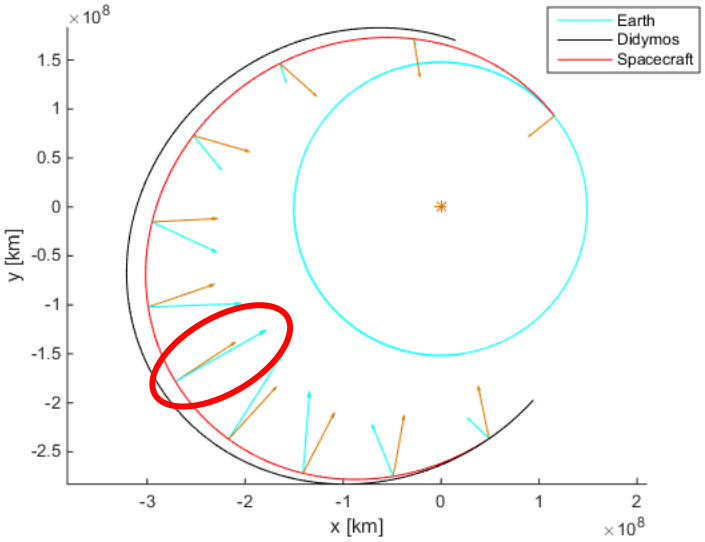
2021 Oct 30
S/C-Sun-Earth conjunction

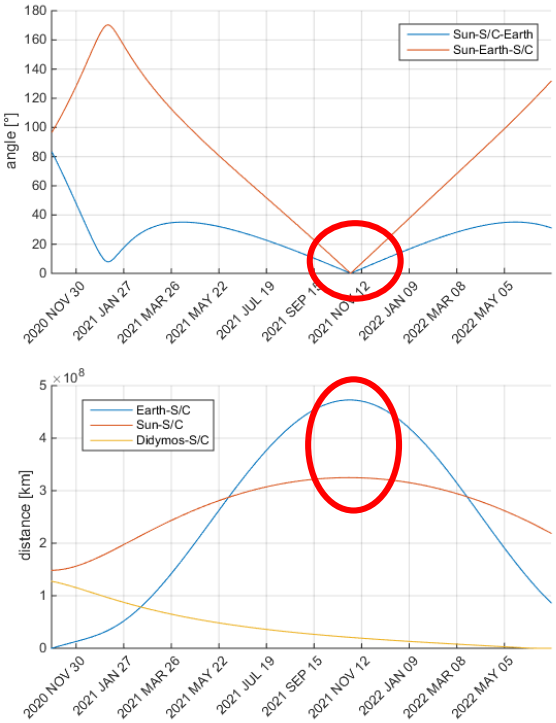
2022 Jun 03
First breaking maneuver

2022 Jul 01
Arrival at 35 km observation point

2022 Oct
Expected DART impact

2023 Jan-Feb
End of ops



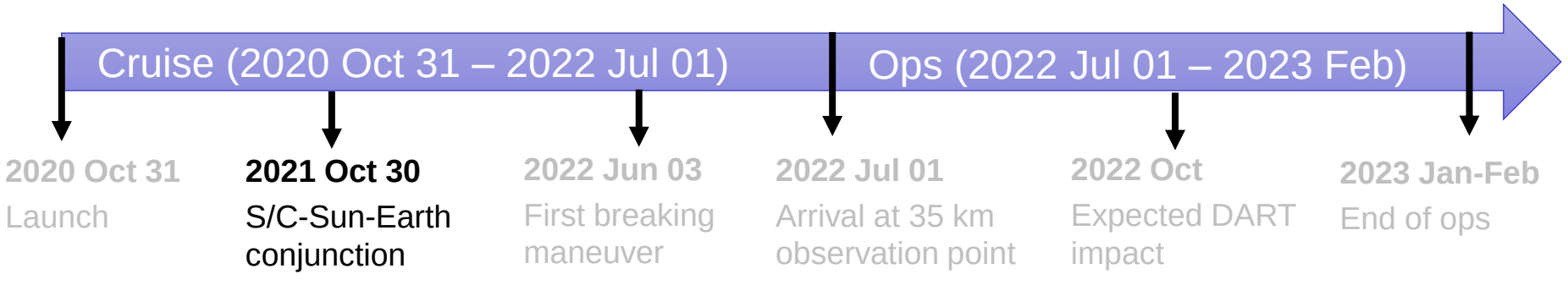


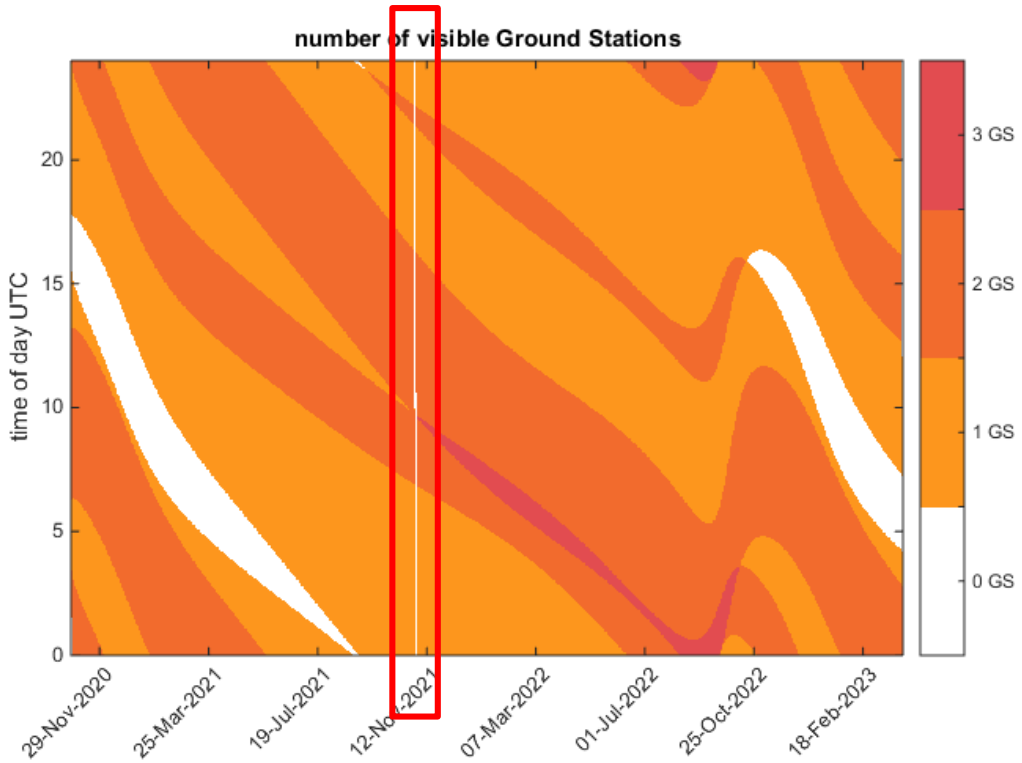
Earth-Solar elongation: 0°

Distances

- Earth-S/C: 3.2 AU
- Sun-S/C: 2.2 AU

INTERPLANETARY TRANSFER: APHELION
Communication window





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- Earth-S/C: 3.2 AU
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