



The JUICE Lunar-Earth gravity assist from trajectory design, navigation and spacecraft operations perspective

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Abstract. This paper describes the world’s first-ever Lunar–Earth Gravity Assist (LEGA) performed by ESA’s JUICE spacecraft on 19–20 August 2024 from trajectory design, navigation and spacecraft operations point of view.

This double flyby—Moon first, Earth second—enabled a large Delta-V gain while minimizing propellant use, redirecting JUICE toward its next destination: Venus (August 2025) and ultimately Jupiter (2031). The manoeuvre was unprecedented
10 in complexity, requiring extremely accurate navigation, rigorous preparation, and coordinated operations across engineering, flight dynamics, and science teams.

Overall, JUICE demonstrated outstanding platform stability, navigation accuracy, and subsystem robustness during this critical milestone, validating the operational feasibility of LEGA as an enabling technique for complex interplanetary trajectories.

15 This paper is an executive summary of papers published on LEGA trajectory design [Schoenmaekers et al. (2014); Boutonnet et al. (2023)], navigation [Syndercombe et al. (2025)] and spacecraft operations [Heck et al. (2025)].

1 Introduction

1.1 The JUICE mission

The Jupiter Icy Moons Explorer (JUICE) is the European Space Agency’s first dedicated mission to the Jovian system,
20 designed to investigate Jupiter and three of its Galilean moons—Europa, Callisto, and especially Ganymede—through comprehensive geological, geophysical, and habitability-focused studies. Operated from ESA’s European Space Operations Centre (ESOC) in Darmstadt, Germany, the spacecraft was launched on 14 April 2023 aboard an Ariane 5 from Kourou, French Guiana, and is currently navigating its interplanetary cruise through the inner Solar System. As a direct transfer to Jupiter was beyond the performance capabilities of the launcher and incompatible with onboard propellant resources, JUICE
25 follows a complex trajectory incorporating multiple gravity-assist manoeuvres to reach the Jovian system in 2031. Upon arrival, it will perform a Ganymede gravity assist to reduce the Jupiter Orbit Insertion Delta-V, followed by an extensive “Jupiter Tour” comprising 35 flybys of Ganymede, Europa, and Callisto. The mission will culminate in JUICE becoming the first spacecraft to enter orbit around a moon in the outer Solar System, ultimately achieving a 500-km and later a 200-km circular orbit around Ganymede as the final phase of its nominal mission.



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1.1 The JUICE spacecraft

The JUICE spacecraft is a highly redundant deep-space platform engineered to operate across extreme thermal and radiation environments throughout the Solar System. Power is supplied by two steerable cross-shaped solar arrays with a total area of 85 m², enabling efficient energy generation even at Jupiter. The power subsystem also manages a battery capable of sustaining the spacecraft through eclipses of up to five hours.

Attitude control is fully three-axis stabilized, relying on measurements from star trackers and a three-gyro inertial measurement unit, combined with a four-wheel reaction wheel assembly. Propulsion is provided by a 425 N bi-propellant main engine, supplemented by 22 N and 10 N thrusters for attitude and orbit control.

Central data handling is performed by the Control and Data Management Unit (CDMU), which operates over SpaceWire and MIL-Bus networks using the ECSS Packet Utilisation Standard (PUS). Units lacking native PUS capability interface through Remote Interface Units. Extensive cold- and hot-redundancy is implemented across platform units to guarantee long-term reliability.

The telecommunications suite includes a 2.4 m high-gain antenna for high-rate downlink at Jupiter, a steerable medium-gain antenna for inner cruise operations, and two low-gain antennas providing near-omnidirectional coverage for safe mode and contingency scenarios. Housekeeping telemetry and telecommands are transmitted via X-band, while science data can be returned as well in Ka-band. Given the extended communication latency at large heliocentric distances, JUICE implements a high-degree of autonomy.

JUICE carries a comprehensive science payload hosted largely on a +Z-mounted optical bench, with electronics housed inside two radiation-shielded vaults, see also Figure 1. Its instruments can be discriminated as follows:

- Remote sensing package includes imaging (JANUS) and spectral-imaging capabilities from the ultraviolet to the sub-millimetre wavelengths (MAJIS, UVS, SWI).
- Geophysical package consists of a laser altimeter (GALA) and a radar sounder (RIME) for exploring the surface and subsurface of the moons, and a radio science experiment (3GM) to probe the atmospheres of Jupiter and its satellites and to perform measurements of the gravity fields.
- In-situ package comprises a powerful package to study the particle environment (PEP), a magnetometer (J-MAG) and a radio and plasma wave instrument (RPWI), including electric fields sensors and a Langmuir probe. An experiment (PRIDE) using ground-based very-long-baseline interferometry will provide precise determination of the spacecraft position and velocity.

In addition to these science instruments, the spacecraft is equipped with a navigation camera (NavCam) for autonomous guidance and two monitoring cameras (JMCs) originally intended for deployment verification but repurposed for imaging during flybys.

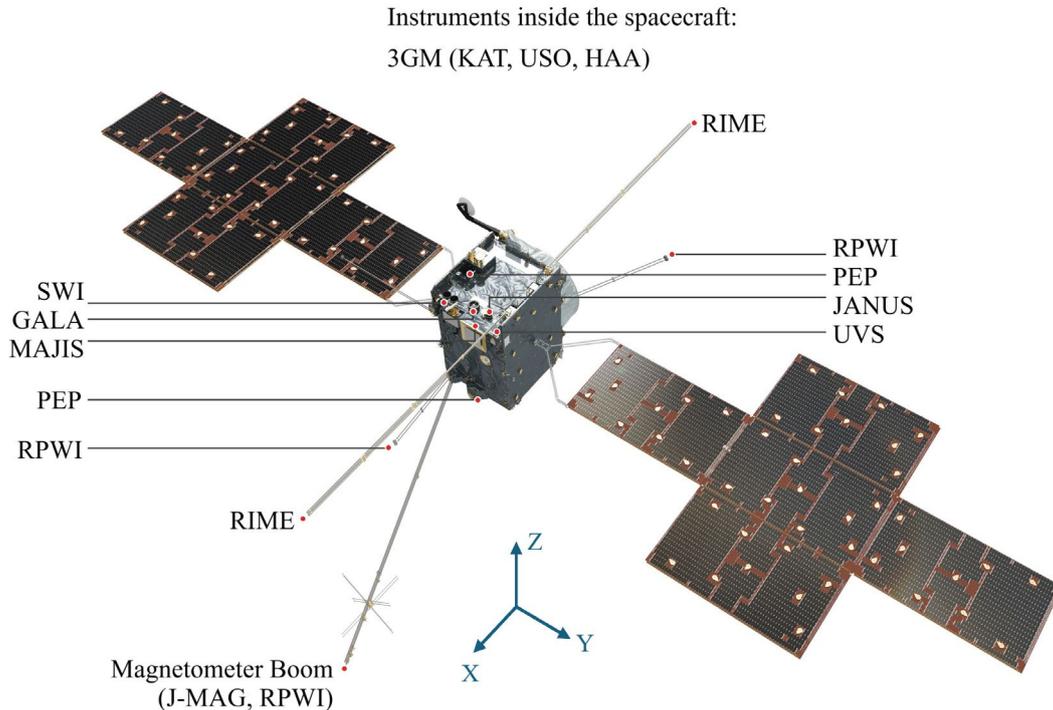


Figure 1: JUICE and its instruments (Credit: ESA/Juice)

65 2 Trajectory Design for the JUICE Lunar-Earth gravity assist

In the multibody environment of interplanetary trajectories or giant planets tours, it can be beneficial – Delta-V-wise – to rely on Gravity Assists (GA) to shape the trajectory. There is a trade-off between Delta-V savings and mission duration; sometimes, the use of gravity assist is mission enabling. The resulting reference trajectory is defined by a given amount of Delta-V needed, called *deterministic* Delta-V, implemented via Deep Space Manoeuvres (DSM).

70 Assuming a patched conic model, the spacecraft trajectory around the planet (for the Sun) or a moon (for a planet) is a hyperbola and is defined by an incoming infinite velocity vector. The mission designer is left free with the selection of the gravity assist parameters, e.g. two parameters in the so-called B-plane, that will fully define the outgoing infinite velocity vector. One standard constraint is that the free parameters are selected such that the hyperbola pericentre altitude is safe vis-
75 a-vis the surface (or the atmosphere if applicable). By definition, the size of the outgoing vector is the same as that of the incoming one, the net effect of a GA is only a rotation of the vector.

As said, the reference trajectory shall be above the surface (or the atmosphere) to be safe. But this requires margins: indeed, when operationally flown, a spacecraft can never be exactly on the reference trajectory. The first reason is the limited

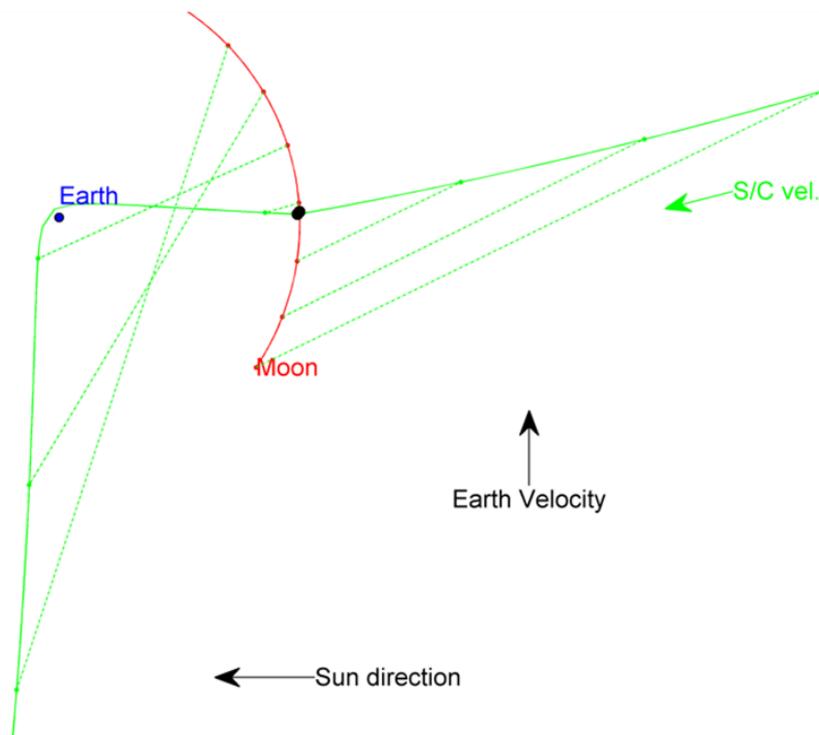


knowledge of the spacecraft state coming from the *navigation* function, measurements uncertainties (e.g. range, Doppler, Delta-DOR), manoeuvres mechanisation errors, or dynamical uncertainties (e.g. solar radiation pressure). The second reason
80 is the application of the *guidance* function along the reference trajectory: at each Trajectory Correction Manoeuvre (TCM), the trajectory is reoptimized, and the spacecraft flies inside a kind of “tube” around the reference trajectory. Therefore, the minimum gravity assist pericentre altitude considers a margin for navigation and guidance. All the TCM used to keep the spacecraft close to its reference trajectory are called *stochastic* Delta-V: the term “stochastic” is linked to the fact that the estimation is based on uncertain parameters. This is why it is considered in the Delta-V budget with a given percentile, e.g.
85 95% or 99%.

A GA acts as an amplifier of the position/velocity errors: a small error before the GA (navigation + guidance) is amplified and requires large correction after the GA, called cleanup. When there is an Earth GA (EGA), a relatively close encounter with the moon is an issue: indeed, the Moon will act as a pre-amplifier, the resulting EGA cleanup will be the result of the amplification of a pre-amplification.

90 From a programmatic point of view, an interplanetary mission requires a launch window. At ESA, the duration of this window is usually three weeks. Assuming a mission with an EGA, if in the window features days with a relatively close encounter with the Moon, it can be decided to simply close these days because the Delta-V penalty (deterministic and/or stochastic) is too large.

What was found by ESOC is that instead of avoiding the Moon, it can be purposely targeted with the objective to save
95 deterministic Delta-V: the Lunar-Earth GA (LEGA) was born. A double GA means the amplification of the amplification of the errors. Two challenges arise from the LEGA: first the potential high stochastic cleanup Delta-V cost; then, the safety of the second gravity assist: indeed, there is only about 24 hours between the two GA, leaving no time for having a nominal correction of the trajectory. The actual JUICE LEGA is shown in Figure 2.



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Figure 2: Ecliptic projection of the actual LEGA flown by JUICE on the 19th and 20th August 2024

To better understand the usefulness of the LEGA, it is important to understand how standard Venus- or Earth- or Mars-GA are used. Upon launch, for an interplanetary mission, the infinite velocity magnitude at Earth is usually around 3 km/s with Ariane 5 ECA. It corresponds to a performance of more than 5 tons. If the mission targets Jupiter, the last leg of the interplanetary cruise must be close to a Hohmann transfer between the Earth and Jupiter. Doing the maths shows that the required infinite velocity at Earth is around 9 to 11 km/s.

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The difference can be partially covered by DSM like for NASA's Juno. But the big chunk necessitates GA. A typical Earth-Venus-Earth sequence leverages the infinite velocity to the required range. But as the vector does not point into the right direction when returning to Earth, two additional EGA are necessary to rotate the velocity before departing to Jupiter.

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One important specificity of Ariane 5 ECA is that its performance is optimal when launching to the East to low escape declinations, while rapidly degrading for higher declinations. As higher declinations are usually needed to fly to e.g. Venus, the solution consists in launching at low declination one or more years earlier into a first Earth to Earth arc. Upon return to Earth, the required high declination is targeted.

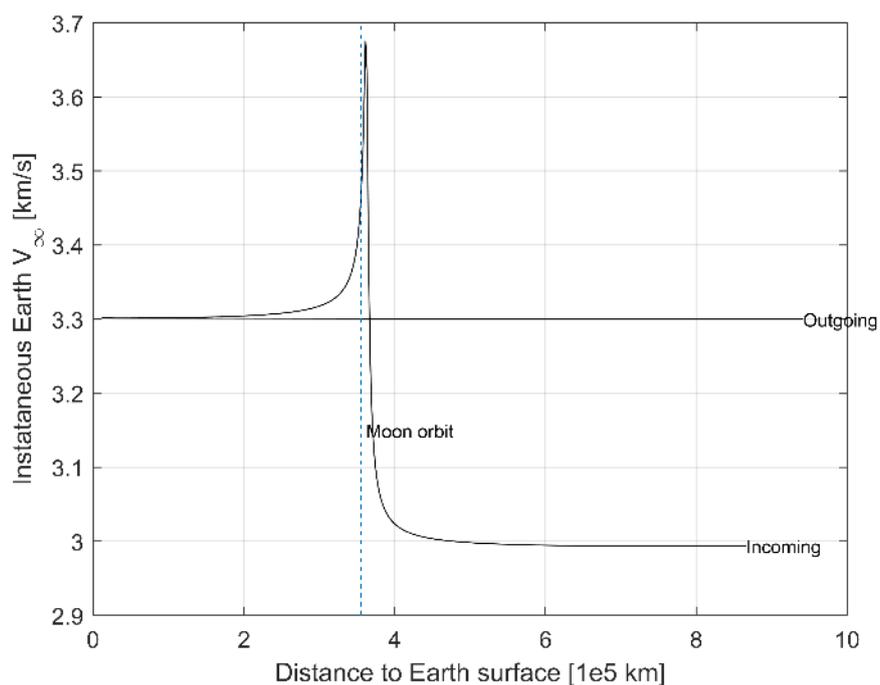
The LEGA concept is an enhancement of this standard strategy: when flying by the Earth, the Moon is purposely targeted.

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Its main effect is not on the direction of the infinite velocity, but on its magnitude instead: as written before, with a normal GA, it remains unchanged. With the LEGA, it is increased. This means that a lower infinite velocity at launch is needed,



which can be converted into e.g. higher payload mass. The increase of the infinite velocity is shown in Figure 3 for the actual JUICE trajectory.



120 **Figure 3: On the incoming leg, the instantaneous Earth infinite velocity is close to 3 km/s. With a standard EGA, it would remain constant until escape. With the LEGA, there is a sharp variation during the Moon GA (around 380000 km altitude). After the Moon GA, the value stabilises around 3.3 km/s and remains constant until escape**

For this case, the infinite velocity is raised by 300 m/s. If this 300 m/s were to be performed by the spacecraft, the optimal DSM, applied far from Earth at aphelion, would be around 150 m/s. This represents more than 100 kg of satellite mass,

125 which can be used for other purposes. More details about the general concept can be found in Schoenmaekers et al. (2014).

As explained before, the first challenge with the LEGA is the stochastic Delta-V cost, while the second is safety. Different cases can happen: Moon first followed by the Earth, or Earth first followed by the Moon. The perigee altitude of the EGA is also variable depending on the overall interplanetary option: it can be as low as 7000 km, but can increase up to 100000 km.

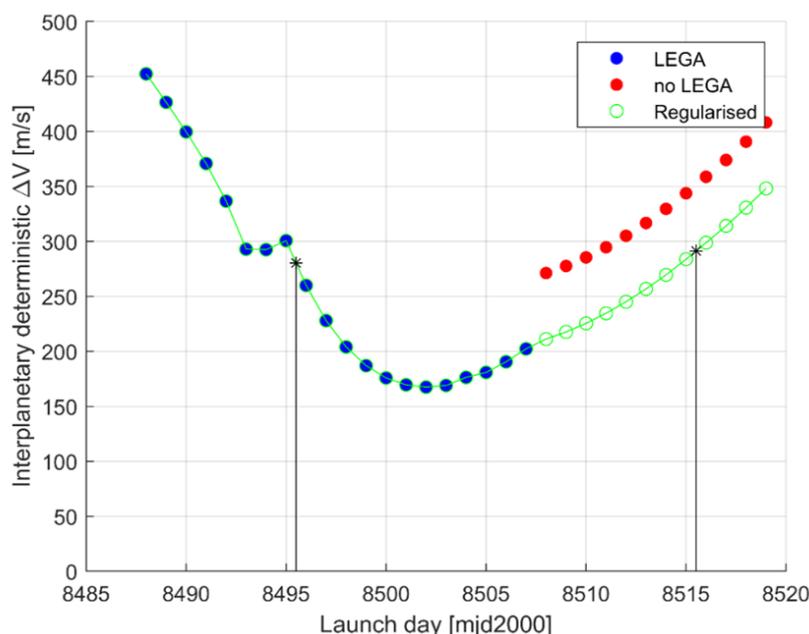
The periselenium altitude is set as low as possible safety-wise (750 km for the actual JUICE LEGA), because it drives the
130 infinite velocity leveraging effect.

Preliminary parametric analyses have been conducted by scanning the B-plane of the first body and computing the corresponding LEGA cleanup. By superimposing the expected dispersions at arrival, an estimate of the stochastic Delta-V cost can be obtained. For the actual JUICE trajectory, it is estimated to be 75 m/s. This is much higher than the standard assumption of 15 m/s for a standalone EGA. This difference partially compensates the deterministic Delta-V saving.



135 The preliminary estimate was confirmed by a detailed interplanetary navigation/guidance analysis for the actual trajectory. More details can be found in Boutonnet et al. (2023).

From a mission design point of view, when an interplanetary trajectory option is found, it returns an optimal launch date. The three-week launch window is added on top: the cost is maximum at the edges of the window, while the minimum corresponds to the optimal launch date. When taking the sum of the deterministic and the stochastic Delta-Vs, it turns out
 140 that the actual JUICE trajectory is cheaper with the LEGA than without it (which is its raison d'être). This is true for the optimal launch date (which is slightly different for both the LEGA and the EGA cases), but the slope of the launch window curve is steeper for the LEGA case. At some point, the two curves cross: the overall optimal three-week window is a mixture of the LEGA and the EGA cases. The LEGA is optimal at the beginning of the window, while the EGA is optimal at the end as shown in Figure 4. As the actual launch took place - by chance - two days after the LEGA optimal launch date (14th April
 145 2023 = 8504 mjd2000), the Delta-V saving was maximised.



150 **Figure 4: Comparison of the LEGA and the EGA to derive the optimal launch window. The optimal three weeks launch window is indicated with vertical black lines. The blue (LEGA) and red (EGA) dotted curves correspond to the deterministic Delta-V. The regularised curve (green circles) corresponds to the red (EGA) curve minus the stochastic Delta-V cost difference (75-15 = 60 m/s)**

The second challenge is safety. Again, parametric analyses were conducted varying the B-plane targeting and computing the pericentre altitude deviation at the second body. For the actual trajectory, the Earth nominal perigee altitude is 6800 km. The expected perigee altitude dispersions are 200 km at 99%. For this case, the LEGA is considered safe with the assumed uncertainties. Special contingency cases require emergency procedures; these cases are not handled by mission design, but
 155 by flight dynamics instead, see next section.



The LEGA has been selected in the baseline of the JUICE trajectory for the interplanetary cruise. More details about the entire mission, from launch through the Jupiter tour until the final low altitude Ganymede orbit can be found in Boutonnet et al. (2024).

160 The LEGA inception dates to 2012. From a mission analysis point of view, its feasibility, its optimality and its safety were demonstrated. But there was still a long way towards in-flight implementation...

3 The JUICE Navigation Campaign for the Lunar–Earth Gravity Assist

This section gives a high-level summary of the LEGA navigation campaign. A more comprehensive and detailed description of the navigation process for the LEGA can be found by the interested readers in Syndercombe et al. (2025).

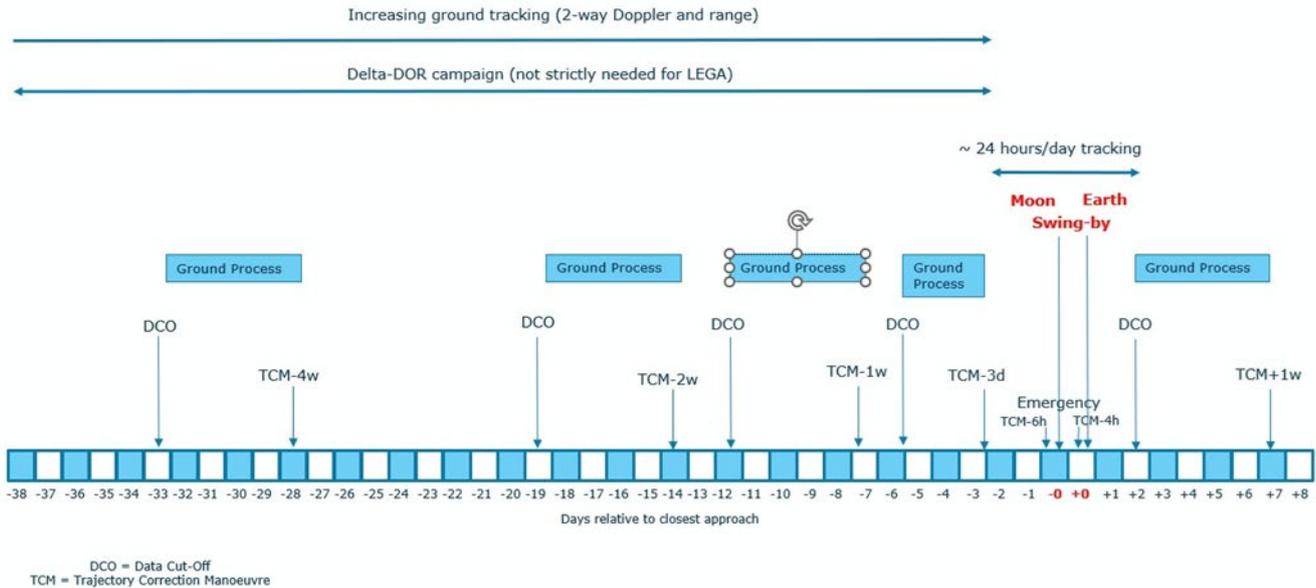
165 In preparation for each navigation campaign, Trajectory Correction Manoeuvre (TCM) slots before and after the flyby are defined. These are stochastic manoeuvre slots, which are a-priori zero and which execution are decided shortly before based on the latest spacecraft orbit determination, judging on the observed orbit dispersion (difference to the reference orbit) and orbit knowledge (uncertainty of the determined orbit). The suitable metric for navigating a planetary swing-by is performed in the so-called Body-Plane, in short B-plane. The B-plane is defined as the plane that is orthogonal to the incoming v_∞ vector of the hyperbolic trajectory relative to the target body and passing through the centre of that body. The two directions in the plane are defined as T and R, whereby the former is usually chosen to be aligned with the projection of the body's equator into the B-plane. In the B-plane the reference orbit is represented by a 2-dimensional target impact point and the orbit knowledge (or uncertainty) is represented by a 2-dimensional error ellipse. For the LEGA, the body that is to be targeted is the Moon, hence, all subsequent shown plots are the Moon B-plane. The subsequent Earth swing-by is performed in open loop, i.e. without any ground intervention after the Moon swing-by. Due to the error amplification described in the previous section, correcting orbit dispersion using a TCM before the LEGA is always far less expensive in terms of Delta-V or propellant usage than correcting it after the swing-by. This is particularly true for the LEGA being a double swing-by.

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Figure 5 shows the adopted TCM slots at 4, 2 and 1 week before the Moon swing-by and a correction 1 week after the Earth swing-by. A second cleanup TCM slot has been planned much later, close to the subsequent perihelion on 1/1/2025, which was found to be more optimum in correcting orbit errors in the B-plane than just using one post swing-by TCM+1w. In addition, two emergency TCMs, eTCM, shortly before each swing-by were defined for being able to react to contingency situations, which are not further elaborated here (and which were not used).

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Figure 5: Schematic schedule for TCM schedule, ground processing and Data-Cutoff (DCO) for orbit determination around the LEGA.

At data cutoff (DCO) before each TCM slot, an orbit determination using ground-based radiometric tracking is performed and the result, estimated orbit state and uncertainty, mapped to the Moon B-plane. The orbit determination for deciding on the execution of TCM-4w was performed on 16/07/2024 and its result is shown in Figure 6. The zoomed in plot shows the orbit dispersion and the error ellipse at 3-sigma level. It is a good approximation to assume that errors from the orbit determination are Gaussian distributed, which gives a 98.89% probability that the true trajectory impact point is within the 3-sigma ellipse. Since the distance to the target impact point – the orbit dispersion - is significantly larger than the 3-sigma uncertainty, the TCM-4w slot was decided to be used to correct the orbit dispersion as early as possible. As indicated in the plot, a Delta-V of 3.8 cm/s was required to move the estimated impact point in the B-plane to the optimum target point. In contrast, correcting the dispersion only after the LEGA would require a total Delta-V of more than 160 m/s (!), as shown by the overlaid contour plot in Figure 6. The TCM was hence commanded on ground, uplinked to the spacecraft and executed flawlessly a few days later.

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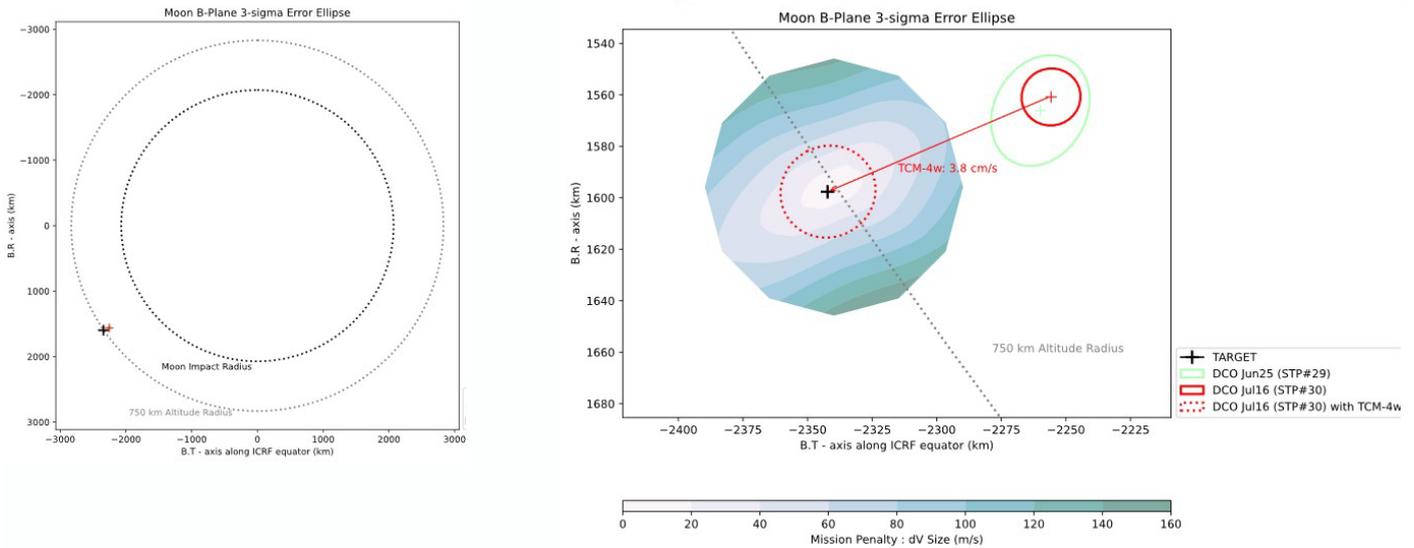
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Status 16 July 2024

Zoomed in

Decision to execute TCM-4w !

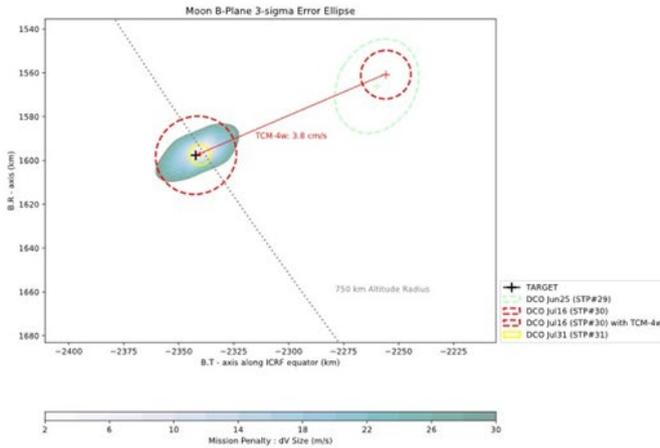


200 **Figure 6: Moon B-plane results before TCM-4w slot. Left: overview showing the target and estimated impact point as well as the Moon impact sphere (below which the spacecraft would impact the Moon); Right: zoomed in version with an overlaid contour plot which shows the Delta-V penalty which would need to be paid post-LEGA for orbit deviations from the optimum target point.**

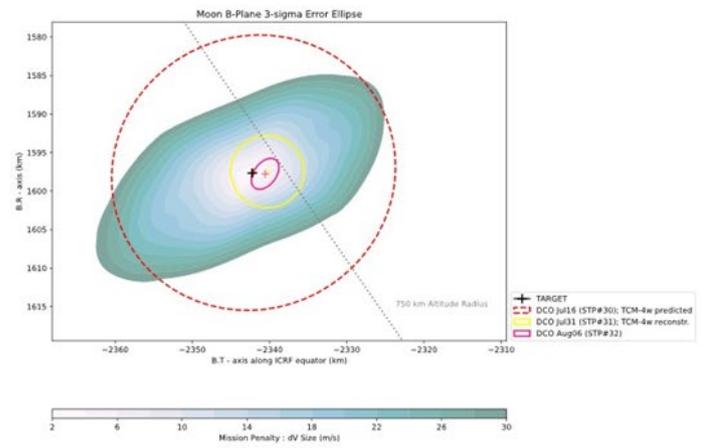
205 The process was repeated shortly before TCM-2w and TCM-1w slots on 31/07 and 06/08/2024 respectively, which results are both shown in Figure 6. The 3-sigma error ellipses were in both occasions larger or close to the orbit dispersion. Moreover, the resulting Delta-V penalty if corrected after the LEGA would be less than 10 m/s which is at an acceptable level compared with the stochastic Delta-V budget of 75 m/s that was allocated to the LEGA before launch. It was hence decided to not execute any of these TCMs.



Status 31 July 2024



Status 06 August 2024



➡ **Decision to not execute TCM-2w.**

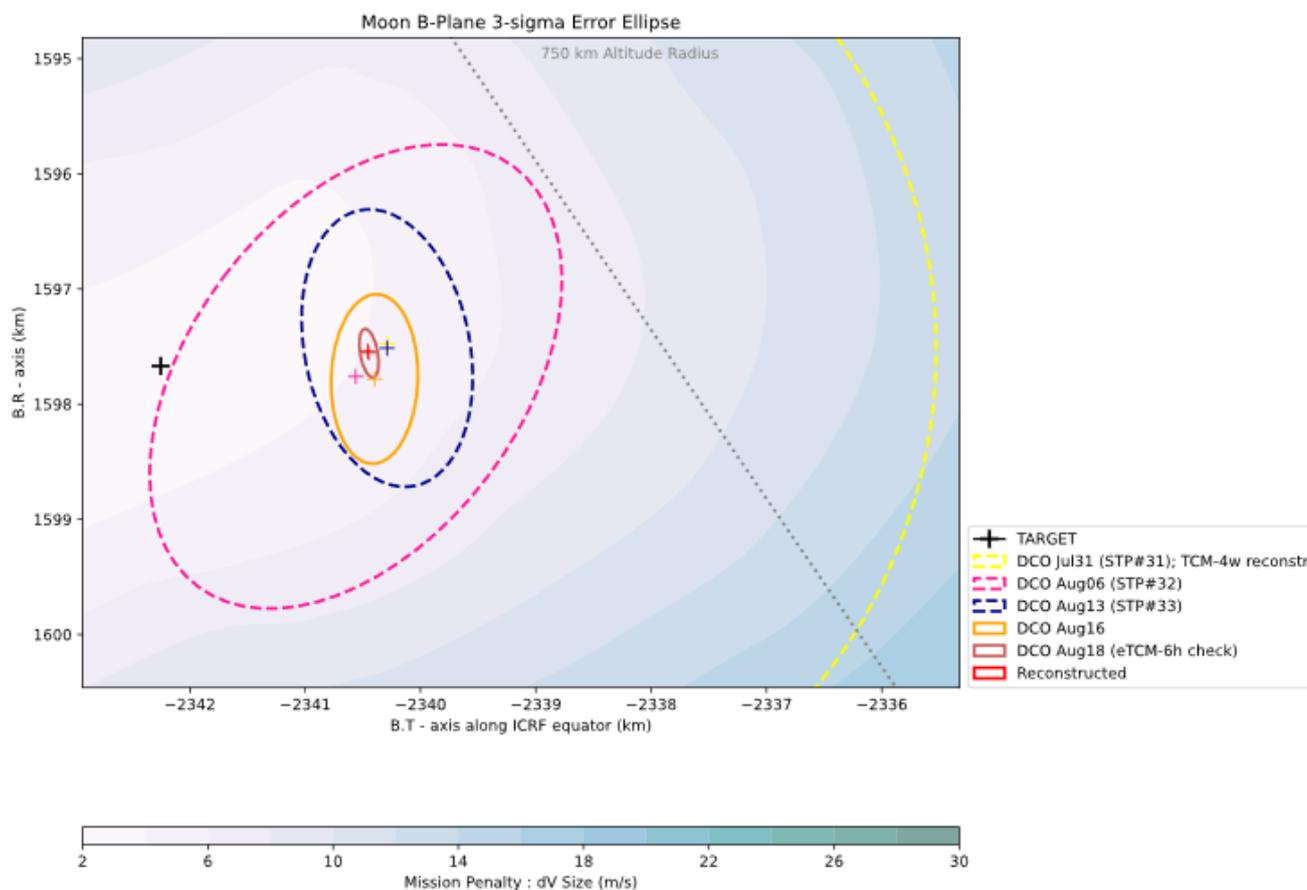
➡ **Decision to not execute TCM-1w and accepting the orbit dispersion.**

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Figure 7: Moon B-plane results before TCM-2w on 31/07/2024 (left) and before TCM-1w on 06 August/2024 (right).

The further evolution of the impact point and error ellipse in the B-plane was continued to be closely monitored after TCM-1w slot while the spacecraft was approaching the Moon with spacecraft tracking continuously increased, which results are shown in Figure 8. The successive estimates of the impact point remained stable, and the error ellipses were continuously shrinking, each of them being nested in the previous, which gives confidence in the correctness of the orbit determination and prediction results, and which is what spacecraft navigators love to see.

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220 **Figure 8: Moon B-plane results evolution before and after the swing-by. The reconstructed impact point that has been estimated after the swing-by is given in red.**

Figure 8 also shows the reconstructed impact point with the associated 3-sigma error ellipse which has only a distance of 2 km from the optimum target. Due to the bending of the trajectory around the swing-by, the radiometric tracking data give very strong information on the reconstructed trajectory relative to the Moon, yielding a very small error ellipse in the B-plane, which is shown but is not discernible on the scale of Figure 8, and very small formal uncertainties in the finally reconstructed parameters of the swing-by. These were

- Moon time of closest approach: 19/08/2024 at 21:14:54.681 UTC with a 3-sigma uncertainty of 0.001 sec.
- Moon closest approach distance: 2 489.519 km with a 3-sigma uncertainty of 0.001 km = 752 km distance from the Moon surface
- Earth time of closest approach: 20/08/2024 at 21:56:13.637 UTC with a 3-sigma uncertainty of 0.001 sec.



- Earth closest approach distance: 13 210.572 km with a 3-sigma uncertainty of 0.002 km = 6839 km distance from the Earth surface

235 The orbit dispersion of 2 km in the B-plane was corrected with two post-LEGA TCMs:

- TCM+ 1 week on 27/08/2024 with a Delta-V of 1.60 m/s
- TCM close to subsequent perihelion on 1/1/2025 of 1.78m/s.

Both manoeuvres were executed successfully at the time of writing. The total stochastic manoeuvre Delta-V used for the LEGA navigation was hence 3.42 m/s which is much smaller than the 75 m/s stochastic Delta-V budget allocation made

240 before launch. The JUICE LEGA navigation was hence a large success giving the mission a significant propellant margin back that will be used for the future exploration of the Jupiter system.

4 LEGA from the Operations Perspective

This section describes the high-level operational aspects of the LEGA. More details can be found in Heck et al. (2025).

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The spacecraft overall performance was excellent during the double flyby. The Earth Distance reached a minimum of 6839 Km above Southeast Asia and the Pacific Ocean during the Earth closest approach on 20/08/2024 with a Sun distance of 150 million km, or 1 AU. The spacecraft approached the flyby during a full Moon, arriving from the dark side. This resulted in near-simultaneous eclipse and ground contact occultation shortly before the Moon closest approach. The spacecraft was

250 aligned with the Moon, Earth and Sun, thus in opposition with a very low Sun-spacecraft-Earth angle.

4.1 Moon eclipse

The batteries were fully charged four weeks before the Lunar Closest Approach, to cope with manoeuvre slots and the Moon eclipse of 32 minutes. During the eclipse shortly before the closest approach (between 20:36 to 21:08 on 19/08/2024), the

255 batteries discharged by around 6%. During a single telemetry frame four solar array power regulators (APR) have been observed in maximum power point tracking (MPPT) while in the eclipse penumbra. This is the first time that this APR mode is observed in flight.

4.2 Platform observations

260 The spacecraft was able to deliver exceptionally accurate manoeuvre performances. Additionally, the parasitic forces induced by pure torque wheel-offloading are barely noticeable in the orbit determination. These two factors combined allowed to execute only two of the overall eight allocated manoeuvre slots, as described in depth in the previous section.



Flight Dynamics noticed a small torque and Delta-V shortly starting at the Moon closest approach +5 minutes and lasting around 20 minutes. At this time the Sun-Moon-spacecraft angle decreased from 80 to 40 degrees, thus the sunlight reflection on the Moon was illuminating the +X face of the spacecraft, which is usually always kept in the dark. This small impact on the trajectory is suspected to be due to spacecraft outgassing and confirmed by several instrument measurements.

Multiple star tracker optical head blindings and straylight happened during both flybys that were monitored by the flight control team. All star tracker optical heads were blinded by the Earth for around 2 hours, however, never all three at the same time. The AOCS continued nominally; at no time the Gyro Stellar Estimator had to propagate the attitude using only internal measurement unit (IMU).

The communications subsystem was switched from medium gain antenna (MGA) to low gain antenna (LGA) 3 days around the Earth flyby, i.e. when the spacecraft was below 1 million kilometres from the Earth. This helped to increase the ground coverage during the fast trajectory induced changes of spacecraft attitude close to Earth.

For 6 days around the flybys, JUICE had almost permanent ground station visibility, however, the Earth flyby occurred outside visibility with ground. Around the Earth closest approach, the transmitter was switched off due to ITU regulations to transmit at full power below 45,000 km. Afterwards, the low gain antenna visibility was not very favourable, therefore no communication was attempted. Overall, this resulted in a communication blackout of more than 8 hours.

During the LEGA, a special on-board mission timeline (MTL) strategy was used. MTL breakpoints were defined that marked the times, where emergency TCM products (if needed) from Flight Dynamics would become valid. The mission timeline was therefore split into 3 parts and the MTL parts 2 and 3 were loaded automatically via execution of a TC file on-board that was re-filling the Mission Timeline.

4.2 Instrument operations

All instruments operated during the Earth-Moon flyby. Two slots of payload observations had been selected:

- at the Moon between closest approach – 1 hour to closest approach + 1 hour
- at the Earth between closest approach – 4 hours to closest approach + 3 days

There was a period of a few minutes around the closest approach of the Moon flyby, where only RIME was operated with the other instruments in quiet mode. Generally, the payload operations performed very smoothly, thanks to the previously performed LEGA dry-run operations in early July 2024. The laser altimeter GALA was the only payload affected by an anomaly due to a still unexplained instrument reset. This prevented GALA to measure at the Moon closest approach.

Concerning attitude, the spacecraft was kept with –X Sun pointing throughout the entire phase. The phase angle around the Sun direction was the only degree of freedom that was optimised for payload operations as follows:

- Earth Closest Approach – 3d: roll around –X to point +Z (instrument optical bench) towards the Moon
- Earth Closest Approach – 12h: 180 degrees roll around –X to ensure circa 30 min of Earth visibility on +Z before closest approach



- Earth Closest Approach + 2h: 180 degrees roll around $-X$ to keep $+Z$ at an angular distance of around 5 degrees from the Earth direction
- Earth Closest Approach + 2d + 6h: a full 360 degrees roll around $-X$ is carried out

300 The NavCam was operated during the LEGA and 15 images were obtained – 6 of the Moon and 9 of the Earth, see two examples in figure 9. In addition, the two JUICE Monitoring Cameras (JMC) obtained 140 images with JMC1 and 144 images with JMC2, see two examples in figure 10.

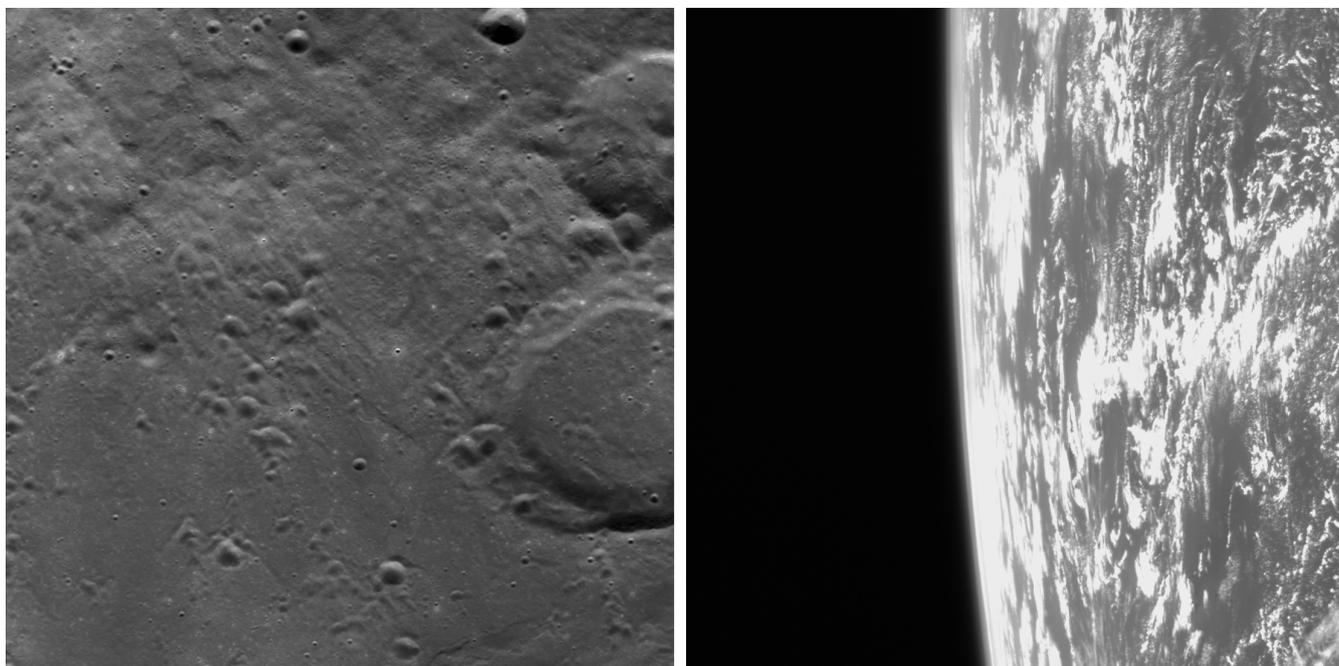
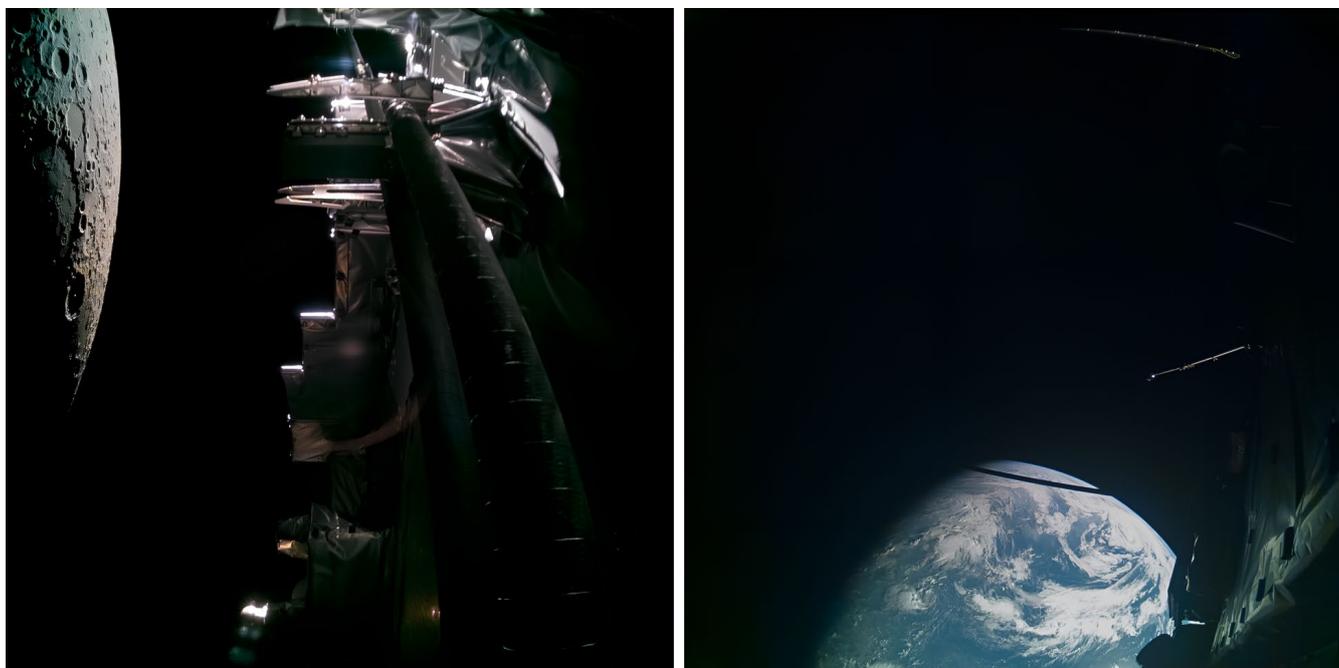


Figure 9: Moon image from NavCam on 19/08/2024 (left) and Earth image on 20/08/2024 (right). (Credit: ESA/Juice/NavCam)



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Figure 10: Processed Moon image from JMC2 on 19/08/2024 (left) and Earth image from JMC1 on 20/08/2024 (right). (Credit: ESA/Juice/JMC)

5 Conclusions

The JUICE Lunar-Earth gravity assist was an outstanding operational and technical success. It demonstrated ESA's capability to execute complex multi-body gravity assists with exceptional precision. Through careful campaign planning, execution and excellent spacecraft performance, the teams involved achieved near-perfect targeting of both swingbys and preserved almost the entire stochastic Delta-V budget. This efficiency directly enhances the mission's scientific potential at Jupiter by freeing additional propellant margin for the Jupiter Tour. JUICE was precisely on track for its following Venus flyby in August 2025 and its later Earth swingbys en route to Jupiter.

315 Acknowledgements

The authors would like to acknowledge all the colleagues contributing in the teams of ESOC Mission Analysis, Flight Dynamics and JUICE Flight Control team, as well as all other ESA support teams, whose contribution was key to the success of JUICE's Lunar Earth Gravity Assist.



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