Robust Trajectory Design for the Hera Experimental Phase using Polynomial Expansions

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Background

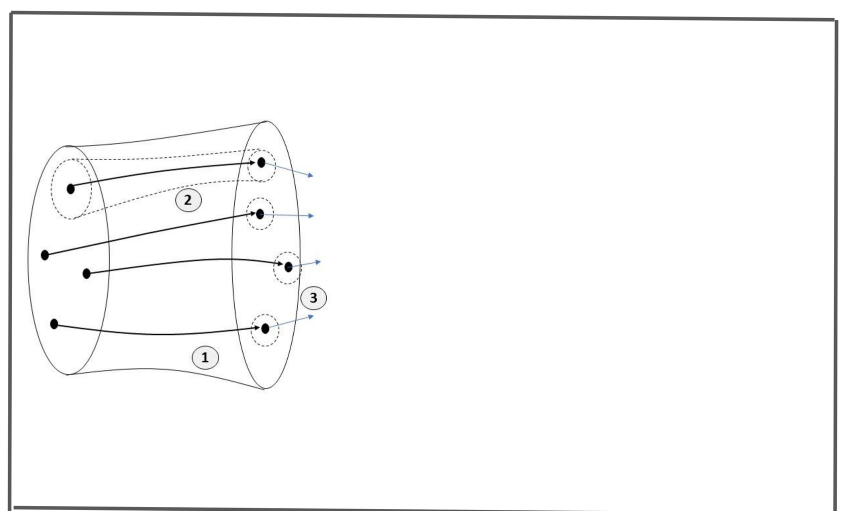
At the end of September 2022, DART successfully impacted the secondary of the binary asteroid system Didymos, called Dimorphos. Hera will launch in 2024 and aims to characterize the physical properties of Didymos and Dimorphos, and investigate the consequence of the impact made by DART in more detail.

It is important to ensure the safety of the spacecraft and minimise the risk of impact. Therefore, the trajectory design of these fly-bys needs to consider the possible execution errors of the maneuvers and the uncertainties in the dynamical system.

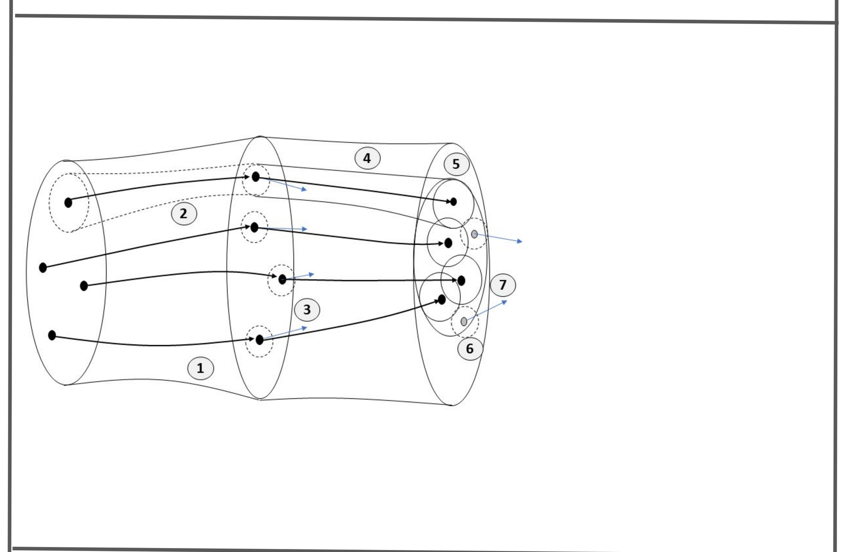
Robust Trajectory Design

To design a trajectory that is robust against uncertainties, a trajectory optimization scheme needs to be used that implements the information on the distribution of these uncertainties. The uncertainty distributions are quantified and propagated using non-intrusive Chebyshev interpolation (NCI), resulting in an efficient polynomial surrogate of the dynamics.

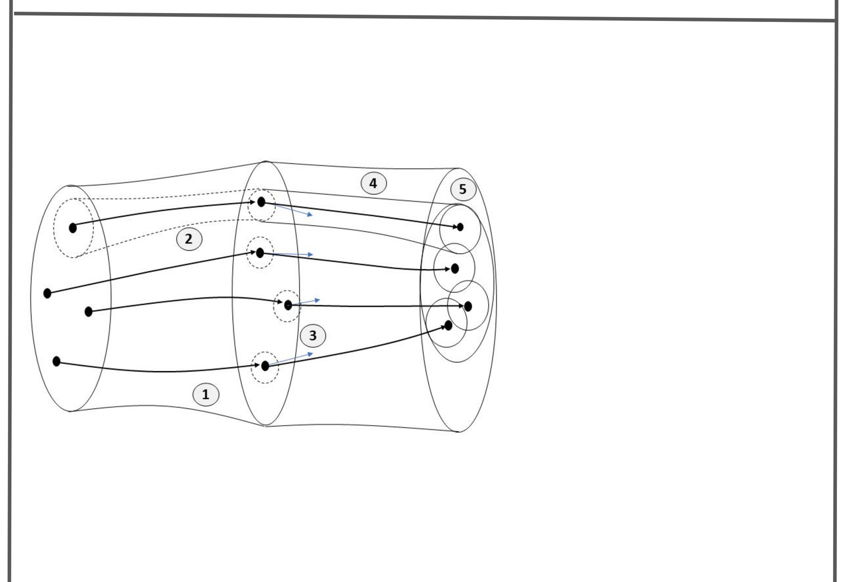
NCI is used to propagate the uncertainties, from which a set of observation are simulated. Then from the knowledge distribution the control at the first autonomous GNC point is calculated.



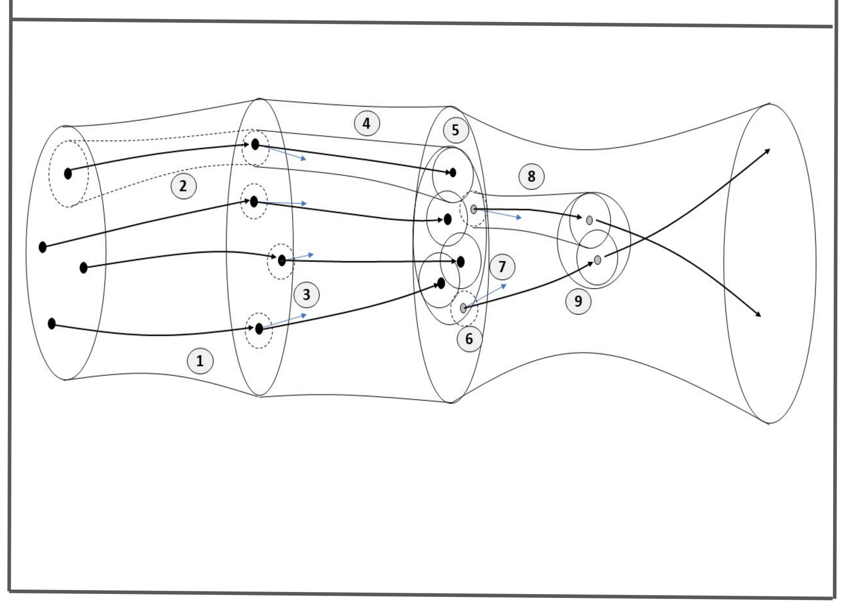
The dispersion due to the knowledge uncertainty is propagated and a new observation simulation is performed to obtain the new state distribution at the second autonomous GNC point.



A single updated distribution is estimated by resampling the different knowledge distributions. The autonomous correction control is calculated for each new point and applied to the full distribution.

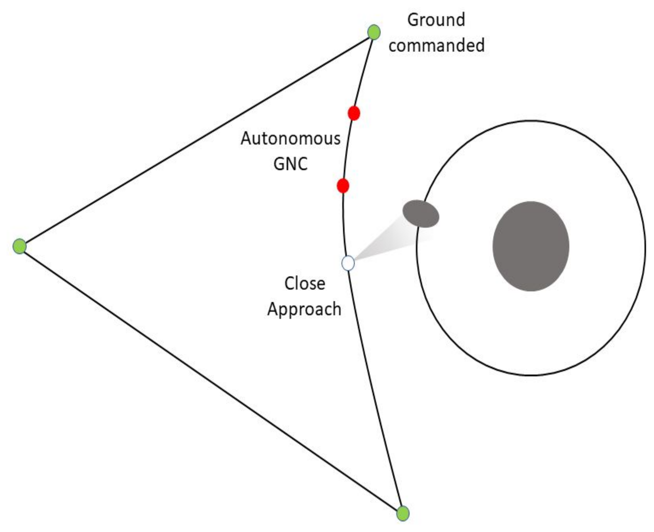


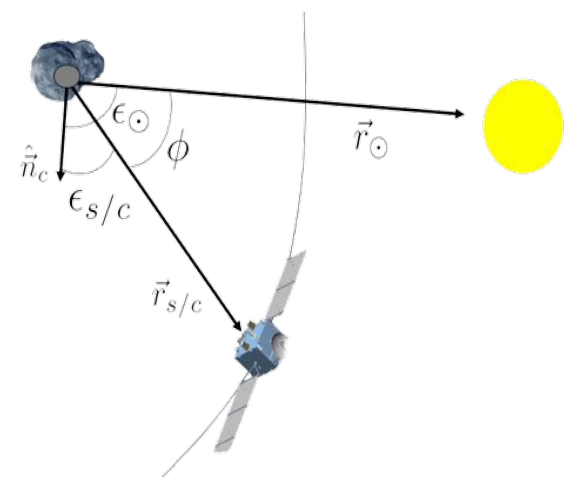
The dispersions are propagated until close approach, at which point all the different objective and constraint distributions/values are calculated. The optimization algorithm selects a new set of decision variables and repeats.



Experimental Phase (EXP)

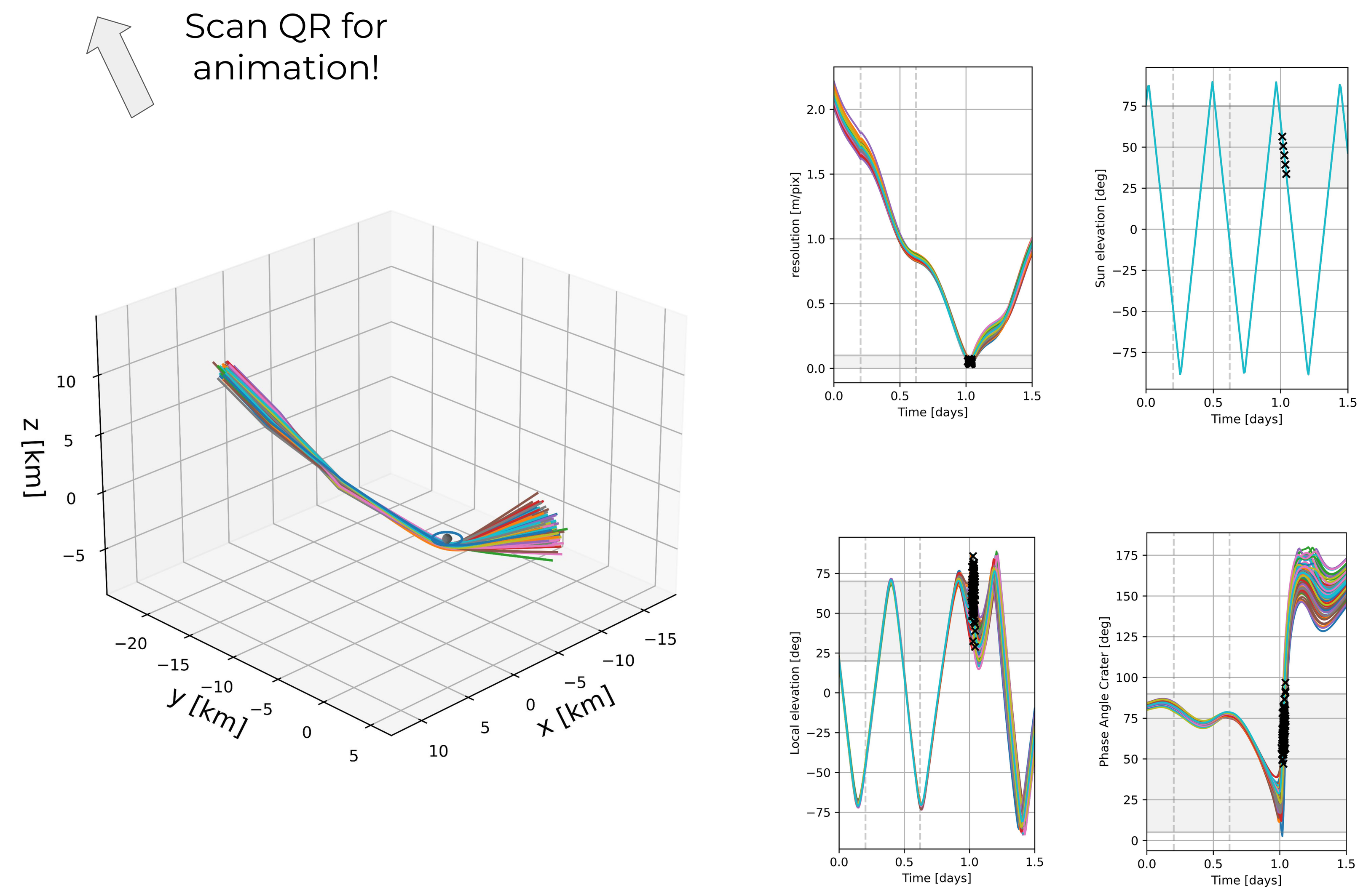
The main goal of the EXP is the detailed characterization of the crater made by the DART impact. It consists of three hyperbolic arcs: one incoming arc, one fly-by arc, and one outgoing arc.





During the very-close fly-by, the spacecraft will try to image the crater at low resolutions under proper lighting conditions. Three maneuvers are used: one ground based and two autonomous.

Results



Conclusion

A novel method is used that combines nominal trajectory design with a navigation assessment using the NCI method for the Hera very-close fly-by. This method is shown to be sufficiently efficient to be able to be used inside an optimization problem and is thus able to solve for objective functions and constraints that are a dependent on a probability distribution. The resulting fly-by trajectory is less sensitive to the uncertainties and fulfills all safety constraints, without needing to perform additional navigation analyses or adding extra safety margins.

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