7th IAA Planetary Defense Conference

26-30 April 2021, Online Event

Hosted by UNOOSA in collaboration with ESA

Session 8a: Mission & Campaign Design

Chairs: Marco Tantardini | George Vardaxis | Andy Cheng

Presenters: W. Yirui | A. Herique | G. Di Girolamo |
P. Tortora | A. Falke

Assembled Kinetic Impactor (AKI) for Deflecting Asteroids via Combining Spacecraft with Launch Vehicle Upper Stage

Yirui Wang, Mingtao Li, Zizheng Gong, Jianming Wang, Chuankui Wang, Binghong Zhou

Chinese Academy of Sciences
National Space Science Center

7th IAA Planetary Defense Conference
VIENNA, AUSTRIA
April 2021

Contents

1 Research Backgrounds

2 Concept of AKI

3 Simulation Methods

4 Simulation Results

5 Technical Feasibility

6 Conclusions

1 Research Backgrounds

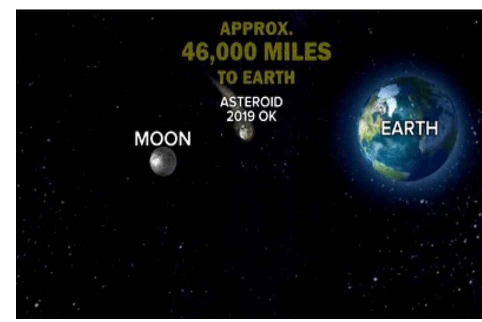
Tunguska Event (1908)
50-m-diameter

2,000 square kilometers of forest were destroyed

Chelyabinsk Event (2013)
20-m-diameter

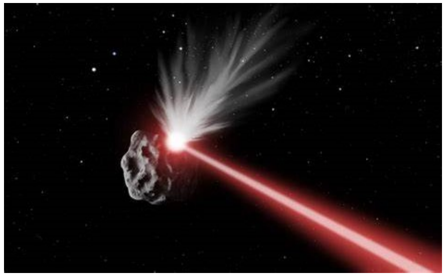
1500 people were injured, 3,000 houses were damaged

2019 OK (2019-7-25)
60-m-diameter

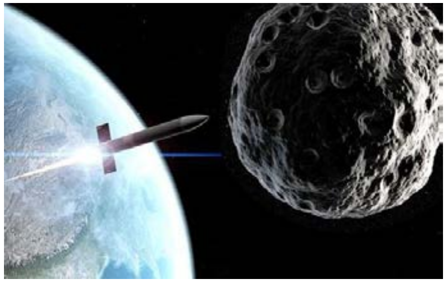


Flyby Earth at a height of 65,000 km

Bunker

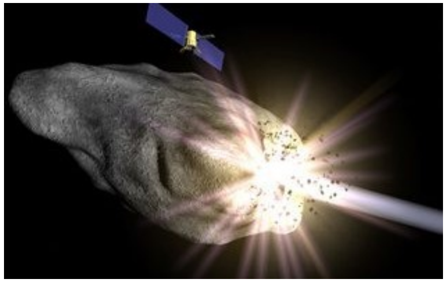


Laser Ablation

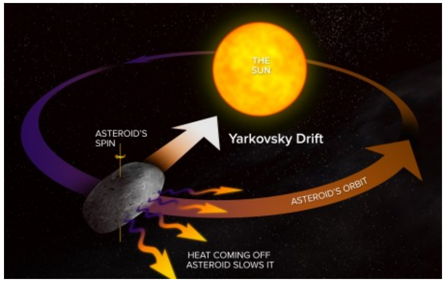


Nuclear Explosion

Gravitational Tractor



Kinetic Impactor

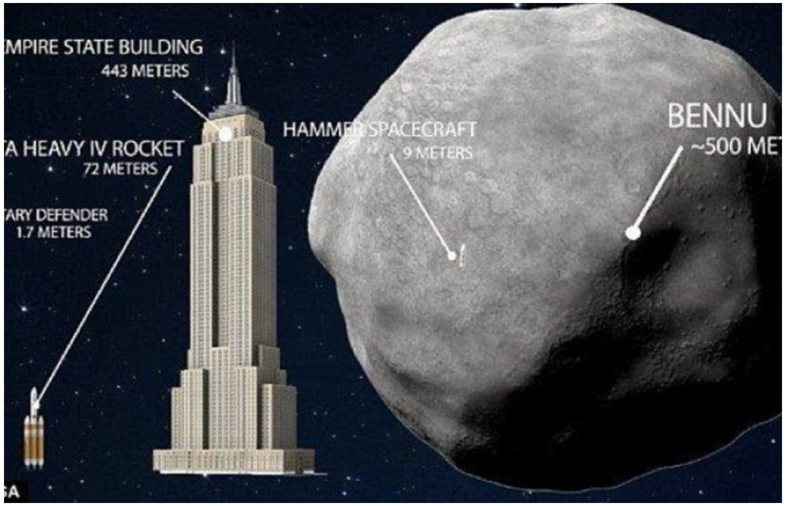


Yarkovsky Effect

- **Nuclear Explosion**: Efficient but controversial
- **Kinetic Impactor**: Feasible but not efficient (for large asteroids)

1 Research Backgrounds

- To deflect a large asteroid, the deflection performance of a kinetic impactor is limited.

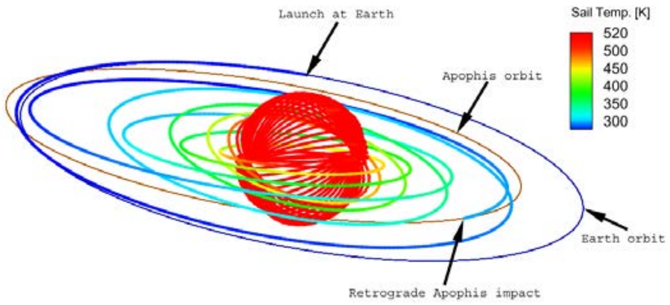


To deflect Bennu for 1.4 Earth radii

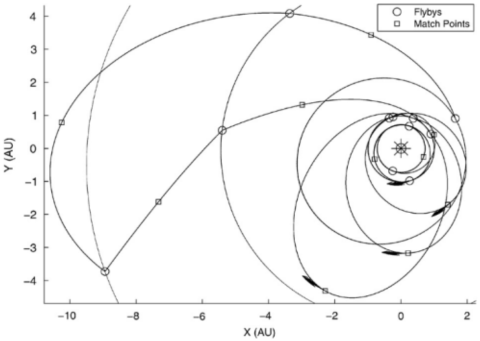
Warning Time	Number of Launches
25 years	17 Delta IV
10 years	75 Delta IV

(Barbee , 2018)

- Reversal orbit, H-reversal orbit concepts are used to improved deflection efficiency.



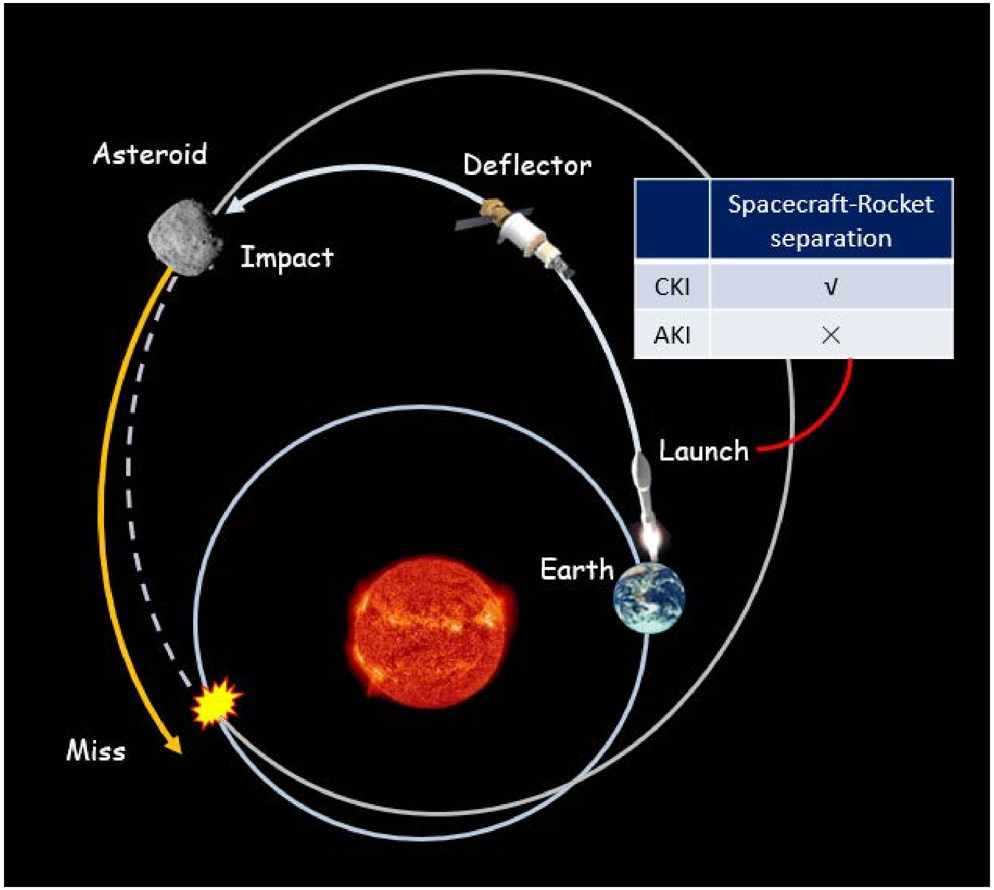
(Dachwald, 2007)



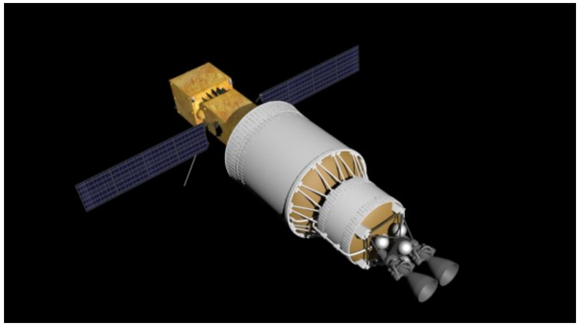
(Petropoulos, 2007)

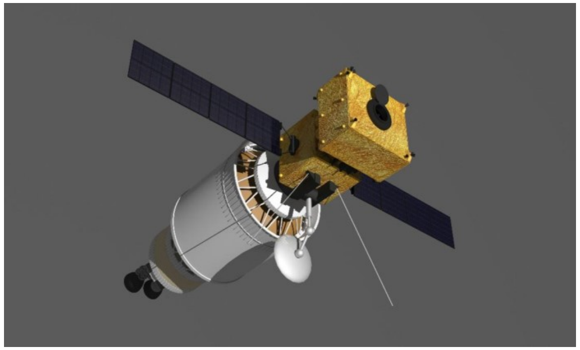
2 Concept of Assembled Kinetic Impactor

- The upper stage can be used as a payload to improve the mass of the impactor
  - The mass of Long March 5 upper stage: 6.5 tons



	Spacecraft-Rocket separation
CKI	√
AKI	×





3 Simulation Methods

- Compare **Assembled Kinetic Impactor (AKI)** with **Classic Kinetic Impactor (CKI)**

Deflection performance in a 10-year launch lead-time:

1. **Maximum deflection distance** of a single impactor
2. **Minimum number of launches** of 1.4 RE deflection distance

– Dynamic model

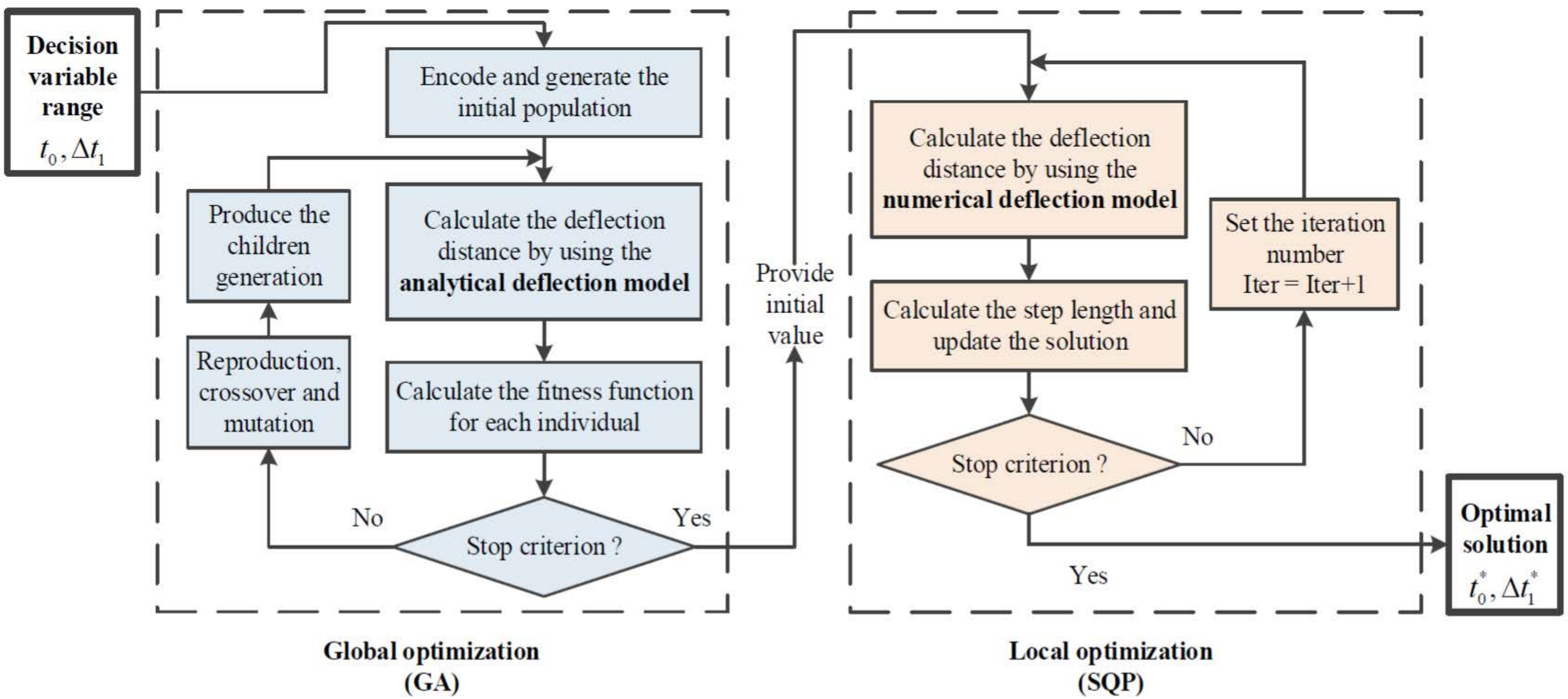
$$\frac{d^2\boldsymbol{r}}{dt^2} = -\frac{\mu_s}{|\boldsymbol{r}|^3}\boldsymbol{r} - \sum_{i=1}^{8}\mu_{pi}\left(\frac{1}{|\boldsymbol{d}_{pi}|^3}\boldsymbol{d}_{pi} + \frac{1}{|\boldsymbol{\rho}_{pi}|^3}\boldsymbol{\rho}_{pi}\right) + \boldsymbol{a}_{moon} + \boldsymbol{a}_{GR} + \boldsymbol{a}_{SRP} + \boldsymbol{a}_{YE}$$

– Impact model

$$\Delta\boldsymbol{v}_{Ast} \approx \beta\frac{m_{AKI}}{m_{AKI} + m_{Ast}}(\boldsymbol{v}_{AKI} - \boldsymbol{v}_{Ast})$$

3 Simulation Methods

– Optimization methods: Genetic Algorithm + Sequential Quadratic Programming



4 Simulation Results

- Deflection Object: Bennu

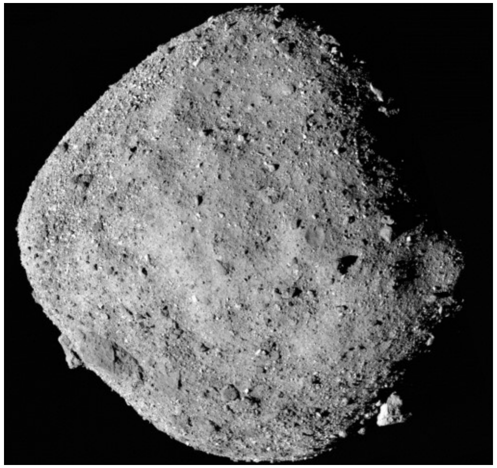
  Diameter: 492 m

  Mass: 7.9×10^{10} kg

  Closest Approach Date: 2135-9-25

  Closest Approach Distance: 0.00199 AU

  Ephemeris: JPL Horizons On-Line Ephemeris System



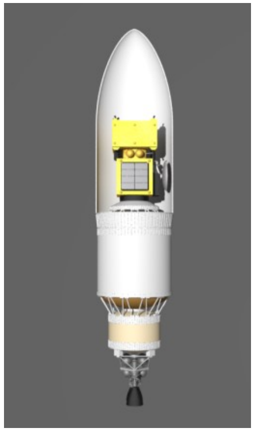
(Image Credit: OSIRIS-REx)

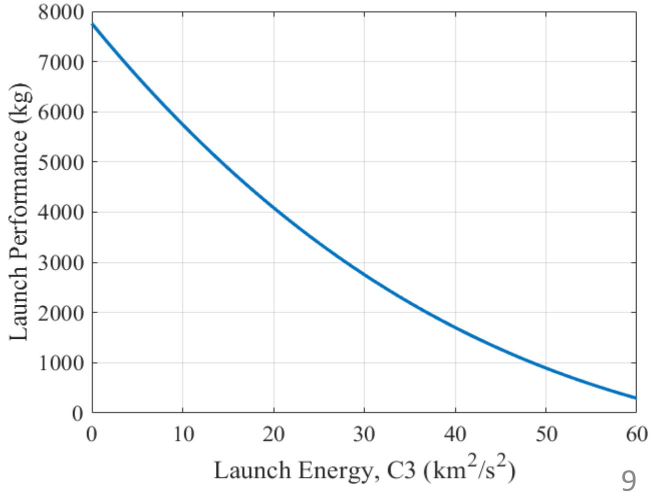
- Launch Vehicle: Long March 5

  Dry mass of upper stage: 6.5 tons

  Fairing diameter: 5.2 m

  Fairing height: 12.7 m





4 Simulation Results

☐ **Maximum deflection distance** of a single impactor

	CKI (Without Upper stage)	AKI (With Upper stage)
Launch Vehicle	CZ-5	CZ-5
Number of Launches	1	1
C3	13.75 km^2/s^2	42.89 km^2/s^2
Impactor Mass	5.09 tons	8.75 tons
Spacecraft Mass	5.09 tons	2.25 tons
Launch Date	2125-1-13 9:7:34	2125-1-27 6:44:25
Flight Time	651.14 days	1057.31 days
Impact Date	2126-10-26 12:24:19	2127-12-20 14:9:41
Impact Velocity	4.15 km/s	7.17 km/s
Bennu Δv	0.27 mm/s	0.79 mm/s
Deflection Time	3256.89 days	2836.82 days
Deflection Distance	**113.57 km**	**399.34 km**

➢ Compared with the CKI, the addition of the upper stage mass can increase the deflection distance **to more than 3 times**.

4 Simulation Results

Minimum number of launches of 1.4 RE deflection distance

	CKI (Without Upper stage)	AKI (With Upper stage)
Launch Vehicle	CZ-5	CZ-5
Number of Launches	**79**	**23**
C3	13.78 km2/s2	43.00 km2/s2
Impactor Mass	401.41 tons	200.96 tons
Launch Date	2125-1-12 1:6:5	2125-1-26 14:27:40
Flight Time	651.65 days	1056.72 days
Impact Date	2126-10-25 16:44:14	2127-12-19 7:45:45
Impact Velocity	4.15 km/s	7.15 km/s
Bennu Δv	21.08 mm/s	18.18 mm/s
Deflection Time	3257.71 days	2838.08 days
Deflection Distance	1.41 Re (8988.86 km)	1.45 Re (9224.73 km)

- Compared with the CKI, the addition of the upper stage mass can reduce the required number of launches **from 79 to 23** for the CZ-5.

4 Simulation Results

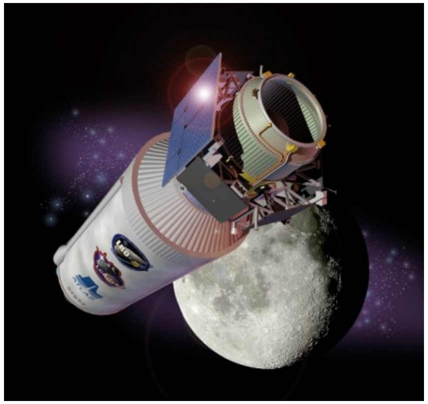
- Deflection performance of a **140 m diameter asteroid** with a 10-year launch lead-time

	CKI (Without Upper stage)	AKI (With Upper stage)
Launch Vehicle	CZ-5	CZ-5
Number of Launches	1	1
C3	13.76 km^2/s^2	42.94 km^2/s^2
Impactor Mass	5.08 tons	8.74 tons
Launch Date	2125-1-13 23:55:12	2125-1-26 18:33:17
Flight Time	651.37 days	1057.26 days
Impact Date	2126-10-27 8:49:55	2127-12-20 0:43:30
Impact Velocity	4.15 km/s	7.16 km/s
Bennu Δv	11.65 mm/s	34.57 mm/s
Deflection Time	3256.04 days	2837.38 days
Deflection Distance	**0.78 Re (4965.44 km)**	**2.75 Re (17538.81 km)**

- A single CKI **can't achieve a deflection distance of 1 Earth radii**, which cannot eliminate the threat of the asteroid impact.
- A single AKI **can achieve a deflection distance of 2.75 Earth radii**.

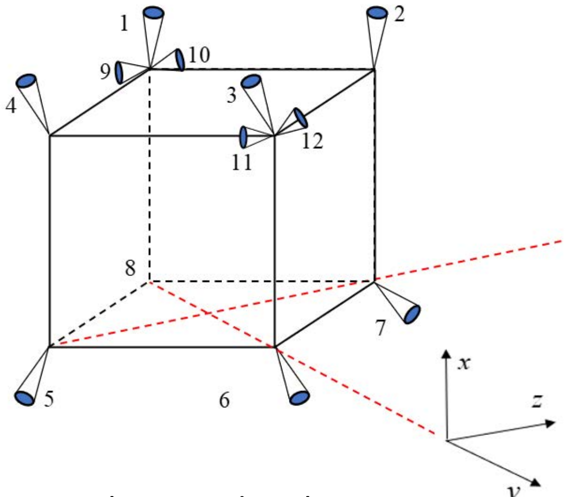
5 Technical Feasibility

- Challenges
  - avoid the coupling of attitude control and orbit control;
  - the center of mass of the AKI is located on the upper stage;
  - prevent the thruster plumes from affecting the solar arrays and upper stage

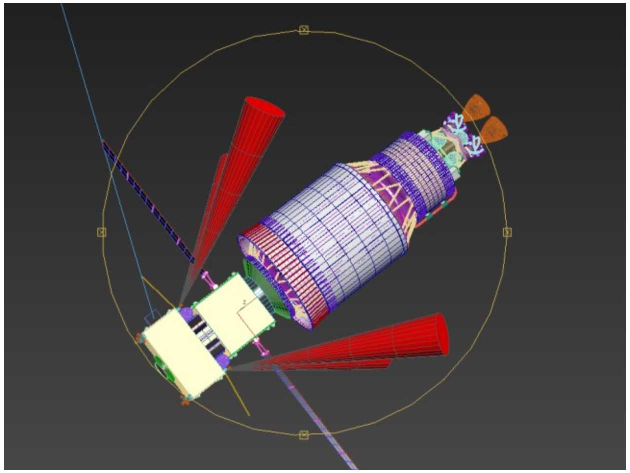


(Image Credit: LCROSS)

- An AKI platform is preliminarily designed



Thruster distribution

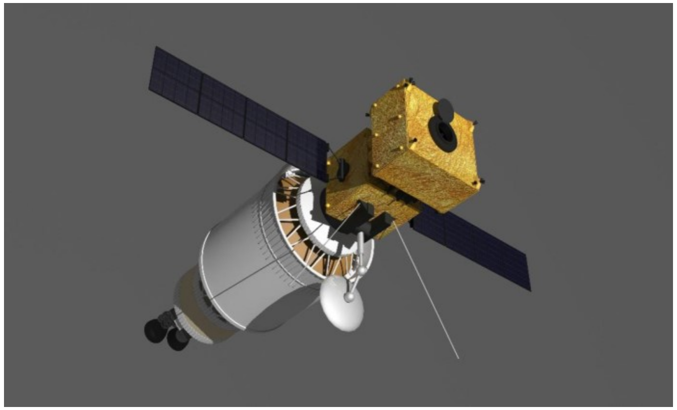


Analysis diagram of the thruster plumes

6 Conclusions

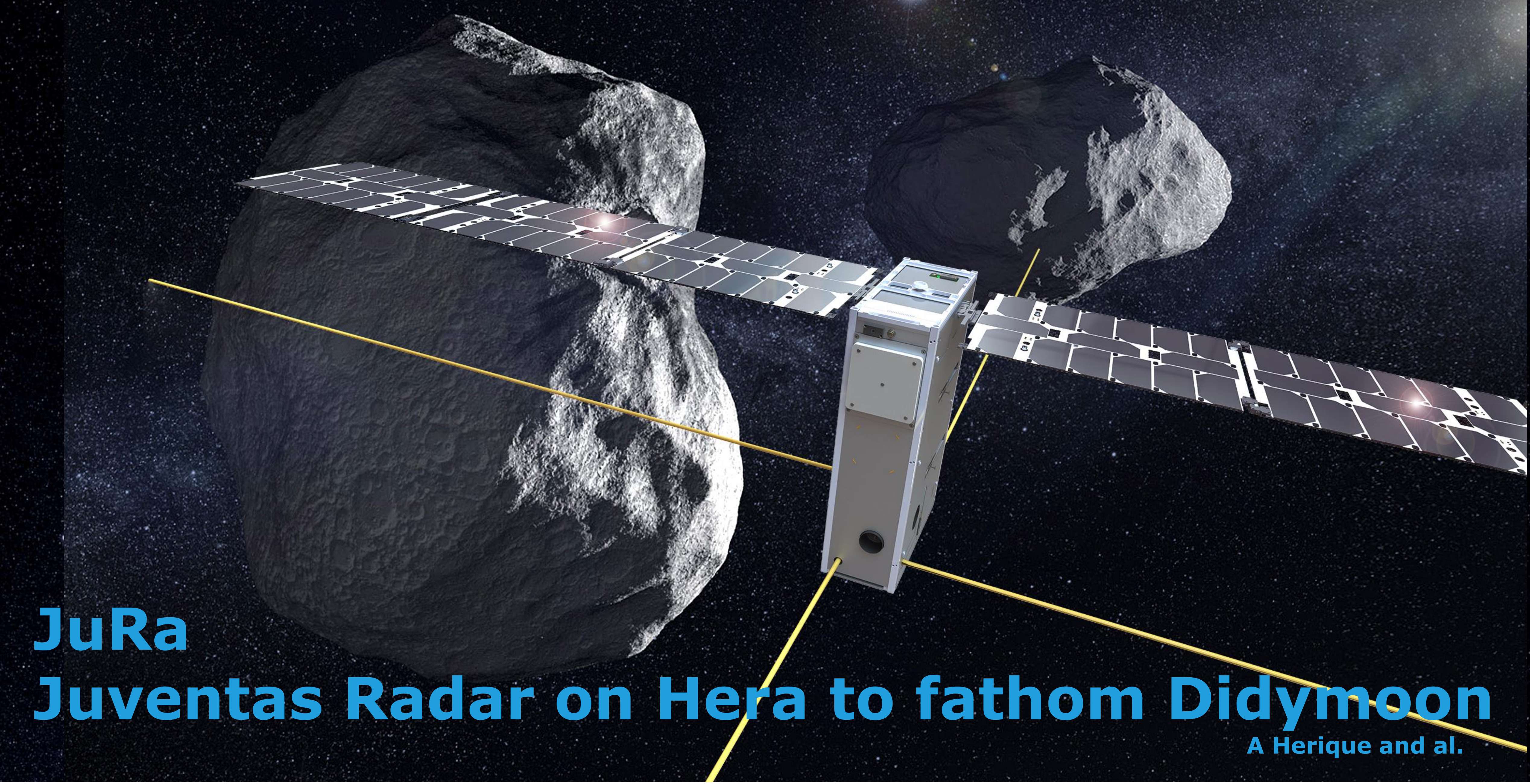
The **Assembled Kinetic Impactor (AKI)** is proposed, the missions of deflecting Bennu are designed to demonstrate the power of the AKI concept. Based on the technical data of the Long March 5 (CZ-5) launch vehicle, compared with the Classic Kinetic Impactor (CKI):

- The AKI concept can greatly **improve the deflection efficiency**, **reduce the launch cost**;
- The deflection distance of a **140 m diameter asteroid within 10 years**, can be increased **from less than 1 Earth radii to more than 1 Earth radii**.



Thanks for Your Attention!

wangyirui17@mails.ucas.ac.cn

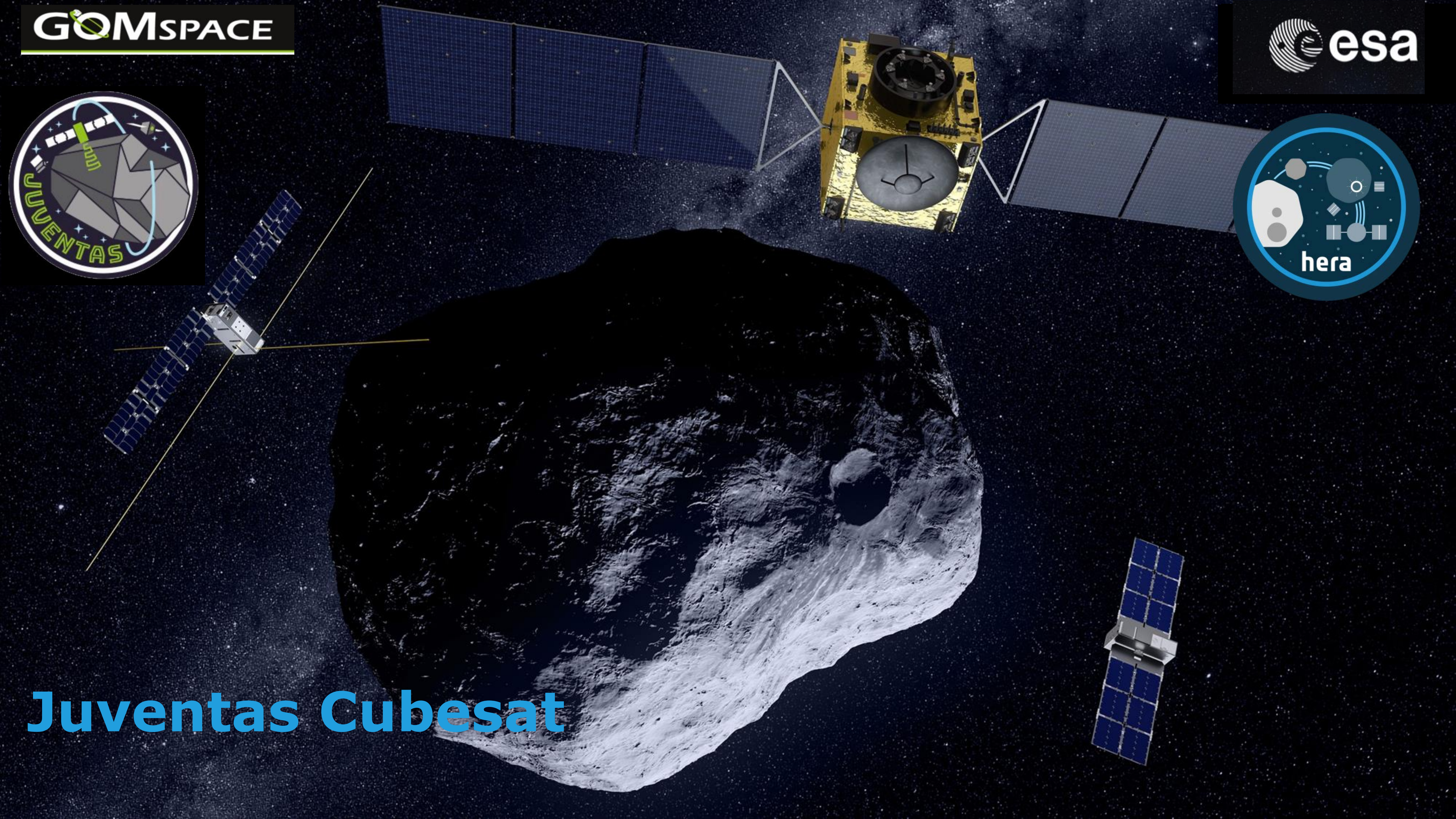


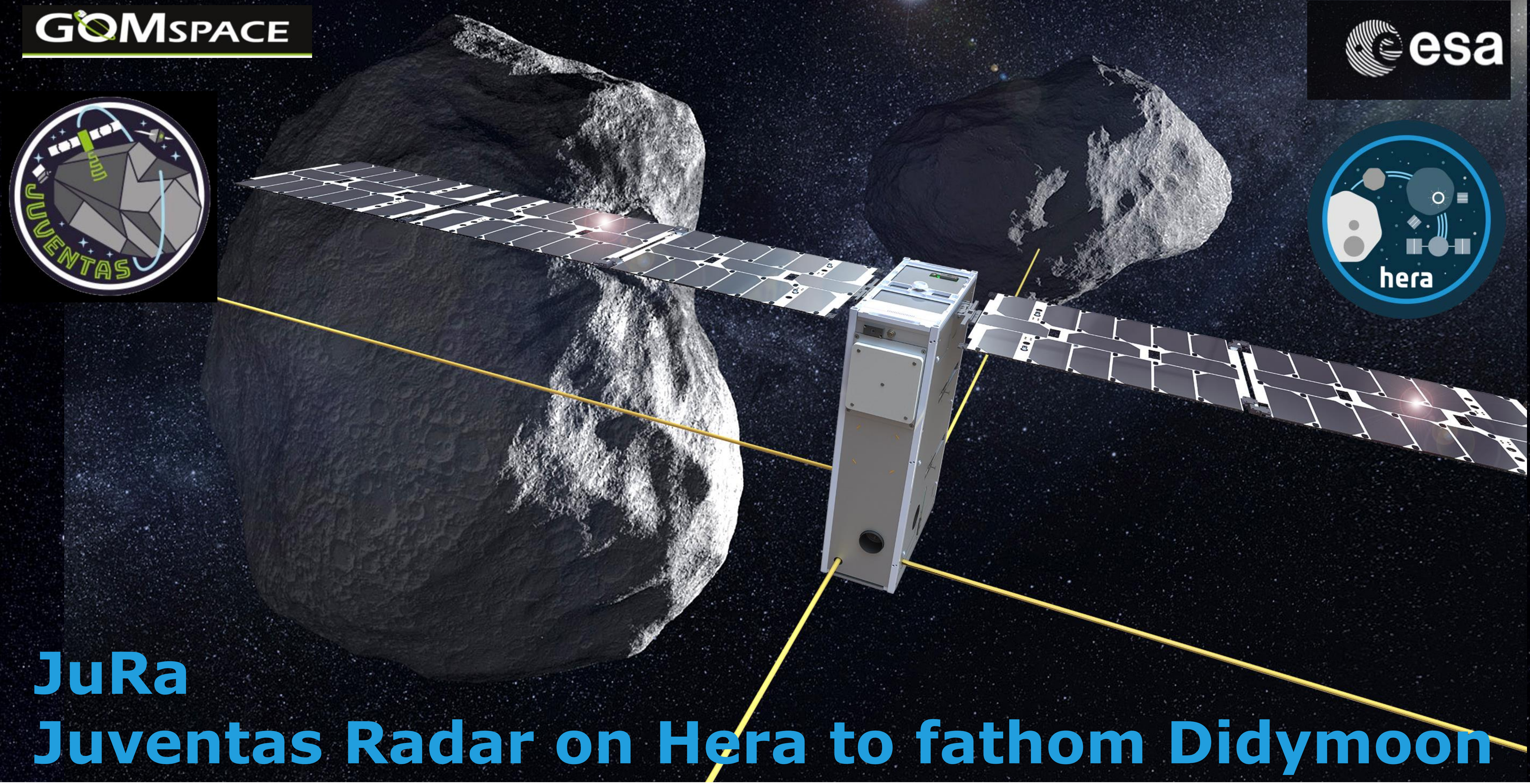
JuRa
Juventas Radar on Hera to fathom Didymoon

A Herique and al.

IPAG Institut de Planétologie et d'Astrophysique de Grenoble
UGA Université Grenoble Alpes
Technische Universität Dresden
EmTroniX electronics and software solutions
Brno University of Technology
Astronika space solutions here & now

Hera mission - Didymos binary system


GOMSPACE
esa
JUVENTAS
hera
Juventas Cubesat



JuRa
Juventas Radar on Hera to fathom Didymoon

Institut de Planétologie et d'Astrophysique de Grenoble
IPAG
UGA Université Grenoble Alpes
TECHNISCHE UNIVERSITÄT DRESDEN
EmTroniX electronics and software solutions
BRNO UNIVERSITY OF TECHNOLOGY
Astronika space solutions here & now

Fathom internal structure of asteroids

Science

- To validate and to improve our understanding of the asteroid's evolution from accretion to now
- to better model low gravity mechanics
  - Aggregate structure, stability conditions and binary formation
  - Regolith origin, mechanical and thermal properties

Spacecraft interactions with asteroids

- Planetary defense, Exploration, Sample return, …
  - Momentum transfer and mass redistribution

Radar to characterize heterogeneities
from metric scale to global scale

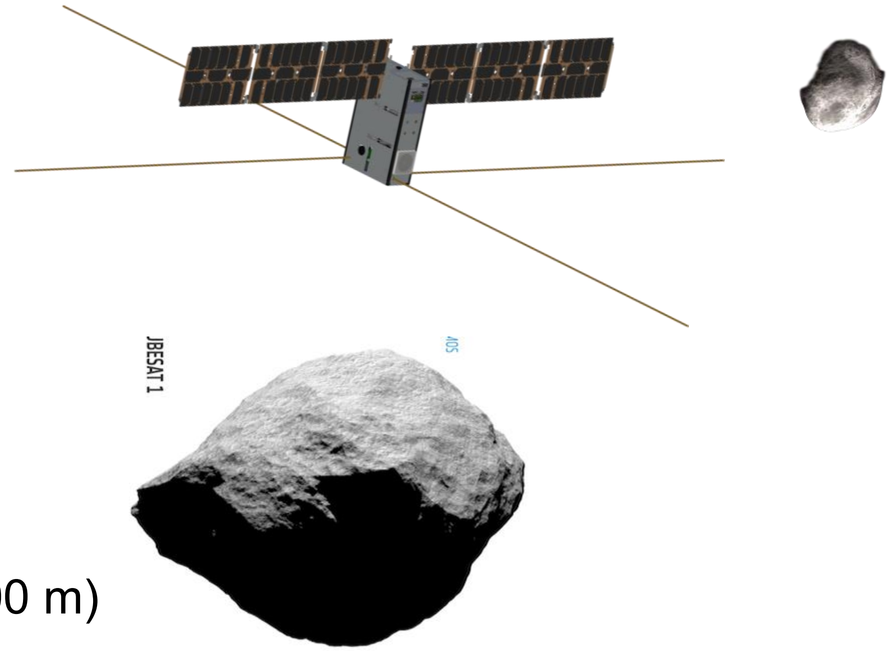
JuRa: the Juventas Radar on Hera to fathom Didymoon

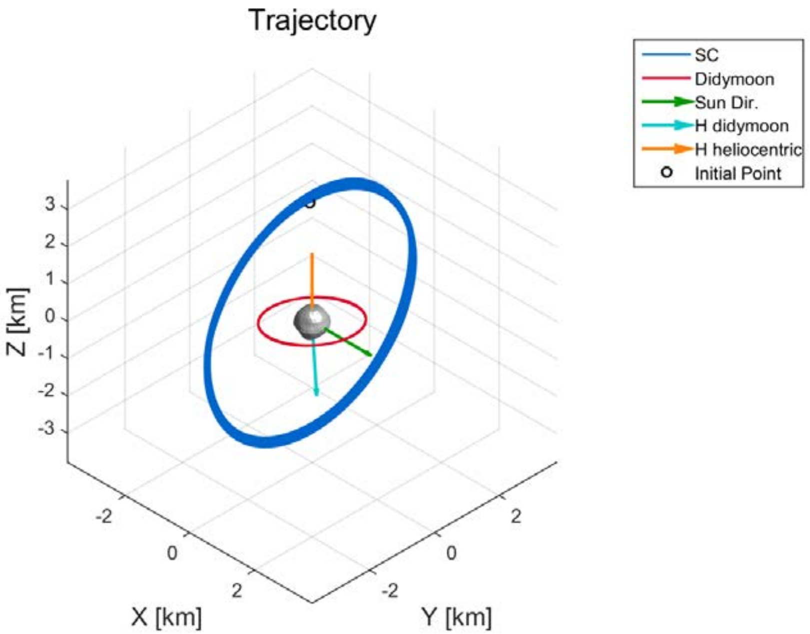
Monostatic radar

- @ 60 MHz
- Full circular polar

Operation

- Launch 2024
- Operation 2027
- Terminator orbit
- 1 month @ 3 km radius
- 1 month @ 2 km radius (300 m)





	JuRa
carrier	60 MHz
signal	BPSK
BW	20 MHz nominal 30 MHz extended
Resolution	10 – 15 m (1D)
Polarization	Full linear
Tx power	6 W
$NE\sigma_0$	-40 dB.m^2/m^2 (Goal)

IPAG Institut de Planétologie et d'Astrophysique de Grenoble
UGA Université Grenoble Alpes
TECHNISCHE UNIVERSITÄT DRESDEN
EmTroniX electronics and software solutions
BRNO UNIVERSITY OF TECHNOLOGY
Astronika space solutions here & now

JuRa : Tomographic SAR

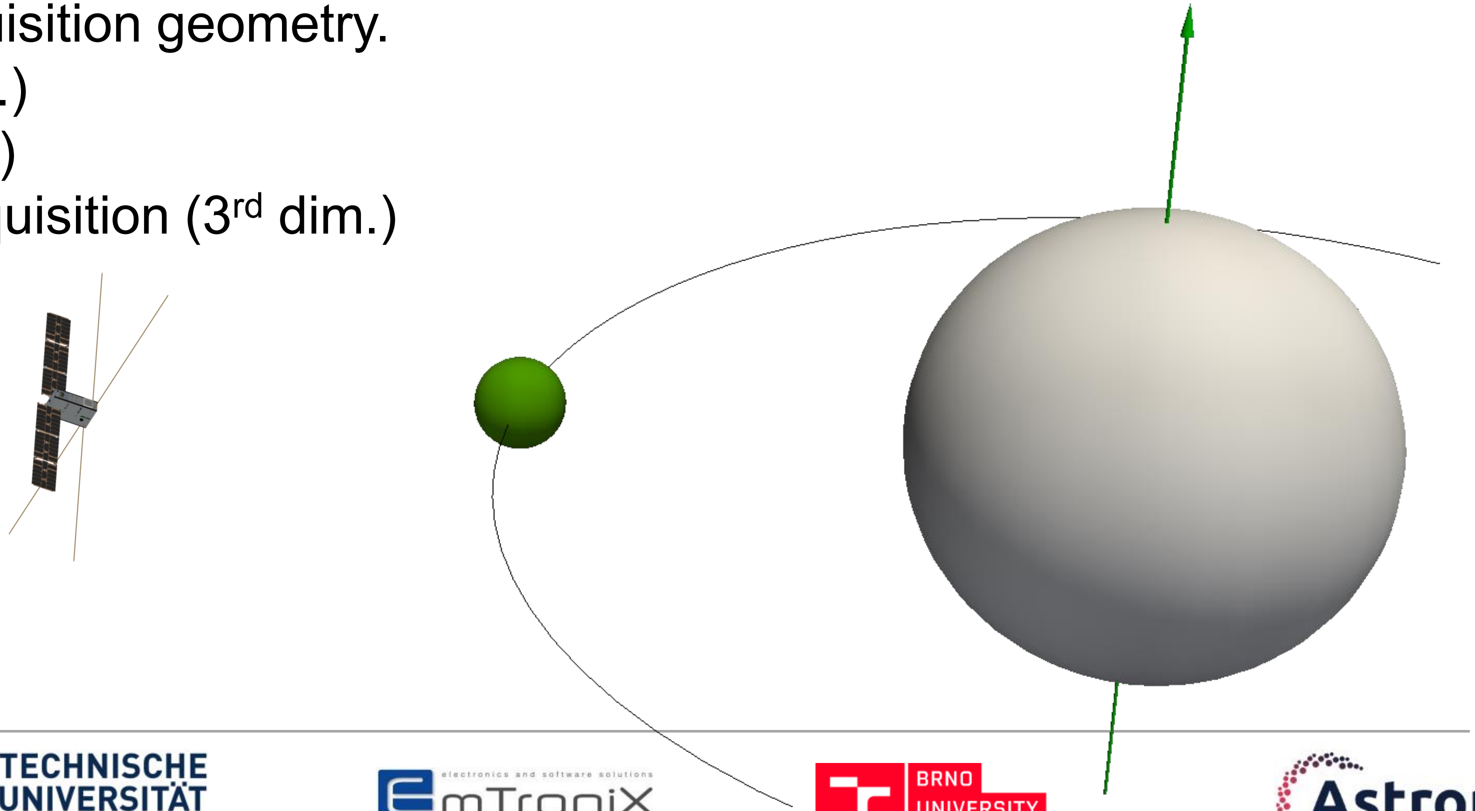
Synthetic Aperture Radar 60 MHz

Backscattering coefficient mapping (power)

Penetration several tens of meters => full?

Performances given by the acquisition geometry.

- range measurement (1st dim.)
- moon / main motion (2nd dim.)
- S/C motion : multipasses acquisition (3rd dim.)



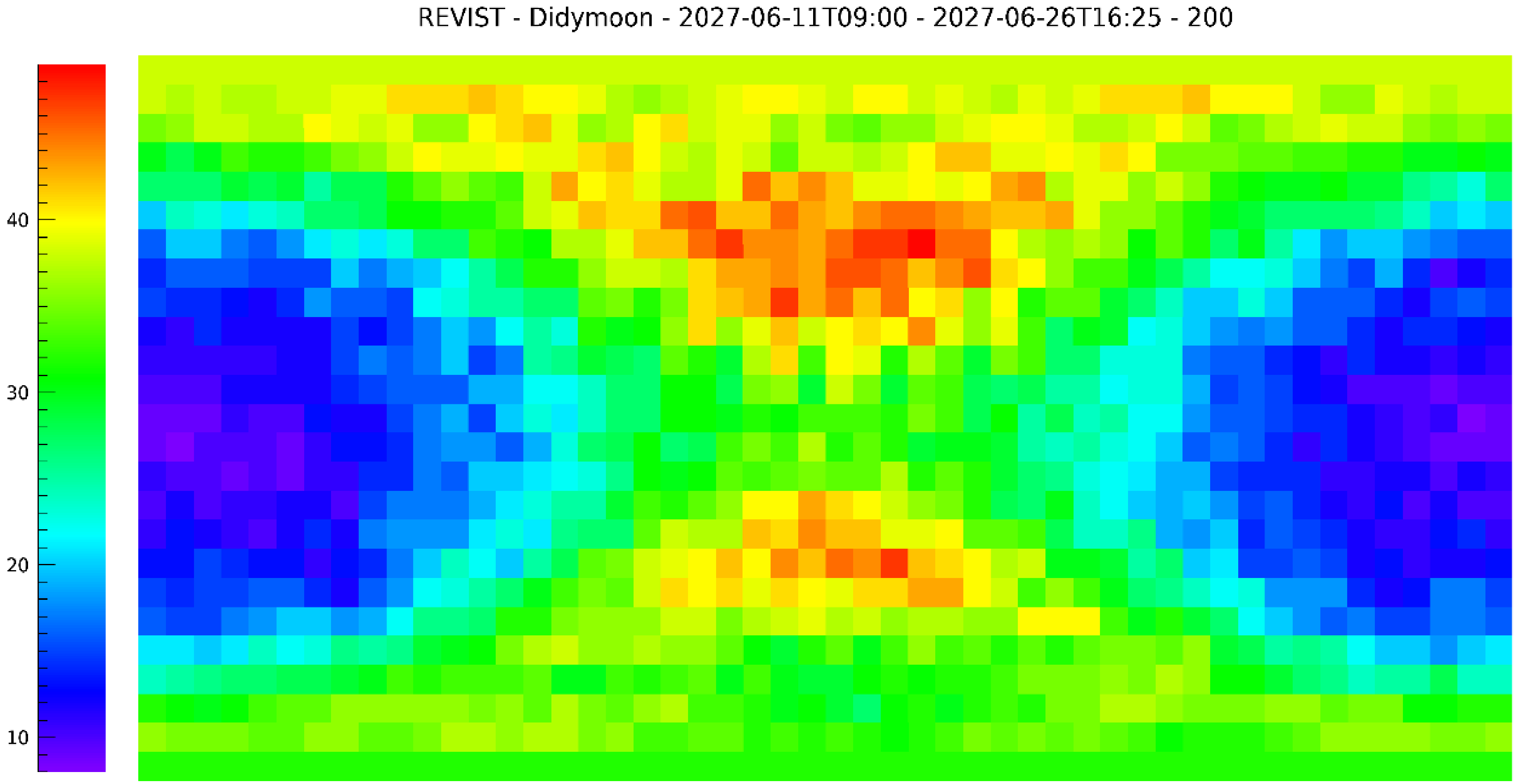
JuRa : Tomographic SAR

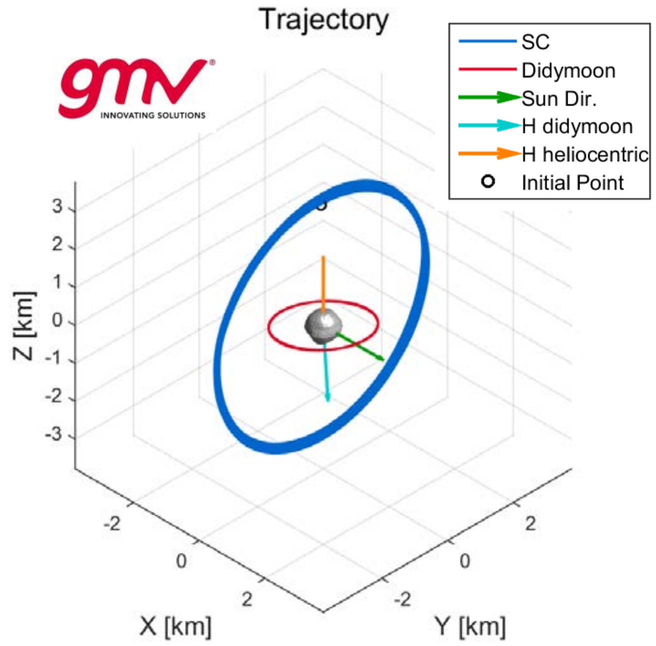
Measurements: With one sequence of operations, SAR processing integrates several thousand measures along acquisition orbit to provide 2D image, mixing in the same resolution cell (pixel) features from surface and subsurface.

If Radar waves penetrate the whole moonlet, signal returned from the opposite side jointly to shape model gives the direct access to the average dielectric permittivity which is related to the composition and to the propagation regime (heterogeneity scales) as done with a bistatic radar;

Multi-pass acquisitions with different geometries allow 3D tomography processing to access vertical distribution of materials. Tomography performances are mainly limited by the number of acquisition sequences and therefore by the overall data volume and by the orbit constraints. With full penetration, the tomography would benefit of the absolute measurement of the propagation delay

JuRa : Tomographic SAR





duty cycle : 45' measurement every 110 minutes

JuRa objectives

JuRa is mapping backscattering coefficient (σ_0) of the surface or subsurface related to the degree of heterogeneity at the scale of the wavelength and to the dielectric contrast of heterogeneities, sub-metric texture of the constitutive material and larger scale structure.

<u>First objective: moonlet interior structures</u>

- to identify internal structure like layers, voids, sub-aggregate,
- to bring out the aggregate structure
- to characterize it constitutive blocks in terms of size distribution, heterogeneity at different scale (from sub metric to global)

$\Rightarrow$ Binary system formation and stability conditions

$\Rightarrow$ Impact crater characterization (with limited resolution)

JuRa objectives

JuRa is mapping backscattering coefficient (σ_0) of the surface or subsurface related to the degree of heterogeneity at the scale of the wavelength and to the dielectric contrast of heterogeneities, sub-metric texture of the constitutive material and larger scale structure.

First objective: moonlet interior structures

<u>***Second objective: average permittivity and its spatial variation***</u>

- to retrieve information on composition and porosity
    - $\Rightarrow$ Full tomography if waves penetrate the whole moonlet
    - $\Rightarrow$ Impact crater characterization (with limited resolution)

JuRa objectives

JuRa is mapping backscattering coefficient (σ_0) of the surface or subsurface related to the degree of heterogeneity at the scale of the wavelength and to the dielectric contrast of heterogeneities, sub-metric texture of the constitutive material and larger scale structure.

First objective: moonlet interior structures

Second objective: average permittivity and its spatial variation

<u>***Secondary objective : The same characterization applied to the main***</u>

- to identify internal structure
- to retrieve information on composition and porosity
- to detect difference in structure, texture and composition

$\Rightarrow$ Mass redistribution, Aggregate structure

$\Rightarrow$ Binary system formation and stability conditions

JuRa Science Lead
Alain Herique (IPAG)
Dirk Plettemeier (TUD)

JuRa Instrument Team
Lucas Cicero (Emtronix)
Laurent Crochet (Emtronix)
Henri Du Faux (Emtronix)
Oriane Gassot (IPAG)
Ronny Hahnel (TUD)
Martin Laabs (TUD)
Yann Le Corre (Emtronix)
Cedric Lorant (Emtronix)
Marco Mütze (TUD)
Hugo Naydenov (IPAG)
Hugo Nowacki (IPAG)
Sylvain Rochat (IPAG)
Yves Rogez (IPAG)
Filip Záplata (BUT)

Instrument Delivery
EM in progress. September 2021
QM February 2022
FM November 2022

Acknowledgments
- Hera is the ESA contribution to the AIDA collaboration.
- Juventas and JuRa are developed under ESA contract supported by national agencies.
- JuRa is built by Emtronix (Lux), UGA/IPAG (Fr), TUD (Gr), Astronika (Pl) and BUT (Cz).
- Juventas is built by Gomspace (Lux).

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 870377 (project NEO-MAPP).

PDC 2021 – ESA's Planetary Defence NEO Coordination Centre DevOps model based Operations

Speaker: **Gianpiero Di Girolamo (ESA Space Safety Ground Segment)**
Co-authors: Johannes Klug, Elmar Brendel. Kamill Panitzek (ESA S2P GS Data Systems)
Alberto Garcia Ruiz, Pablo Hiroshi, Carlo Rafael Barrozzi Pignatari, Sebastian Orozco Pinzon (ESA S2P GS Data Centre) ,
Juan Luis Cano, Detlef Koschny, Angelo Foglietta, Dario Oliviero, Laura Faggioli, Ramona Cennamo, Regina Rudawska, Marco Micheli (PDO),
Ana Maria Teodorescu (ELIA), R. Schneider (ASTOS), Dario Bracali Cioci (SpaceDyS)

7th IAA Planetary Defense Conference - 30/04/2021

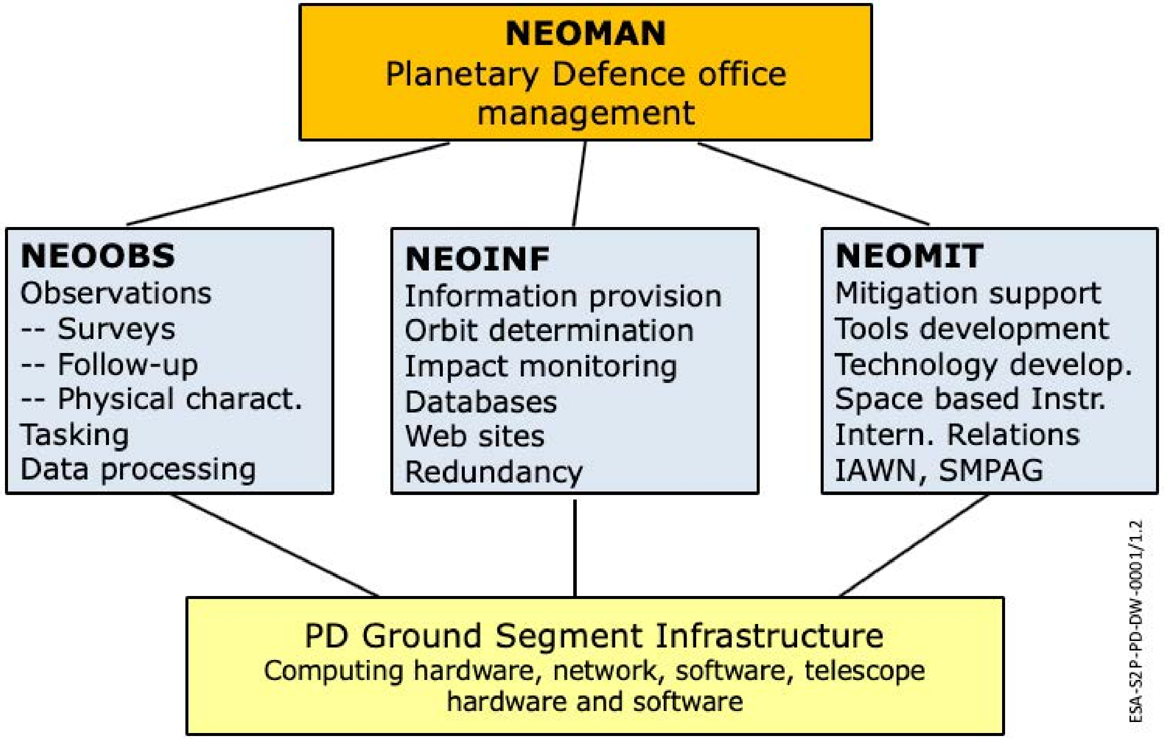
Outline

- Introduction
- Ground Segment
- Operations
- Teams
- DevOps approach
- CI/CD Infrastructure
- NEO Resulting DevOps Quadrant
- Achievements

Planetary Defence OPS Pillars and Foundation

Operations
- Observation
- Information Provision
- Mitigation

Ground Segment Infrastructures
- Asset Engineering
- Development
- Validation
- Deployment
- Monitoring
- Maintenance
- Evolution

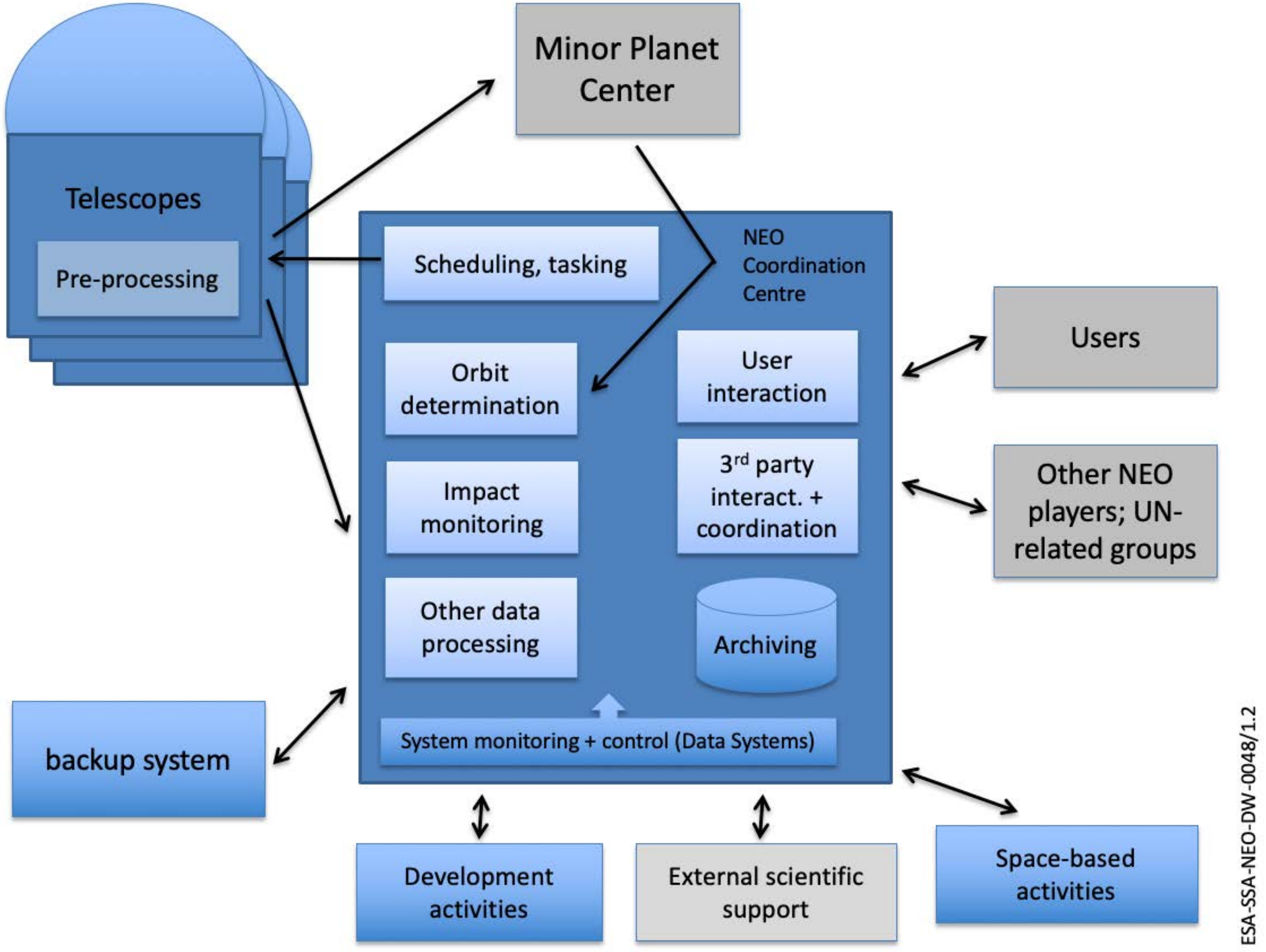


Development and Operation eterogeinity

A overall visual representation

- In grey the external operational interface/relations/cooperation
- In blue the ESA PD NEO operational and asset

- Variety of different activity demanding
  - Software development
  - SLA for data sharing/acquisition
  - Consultancy cooperation with external scientist

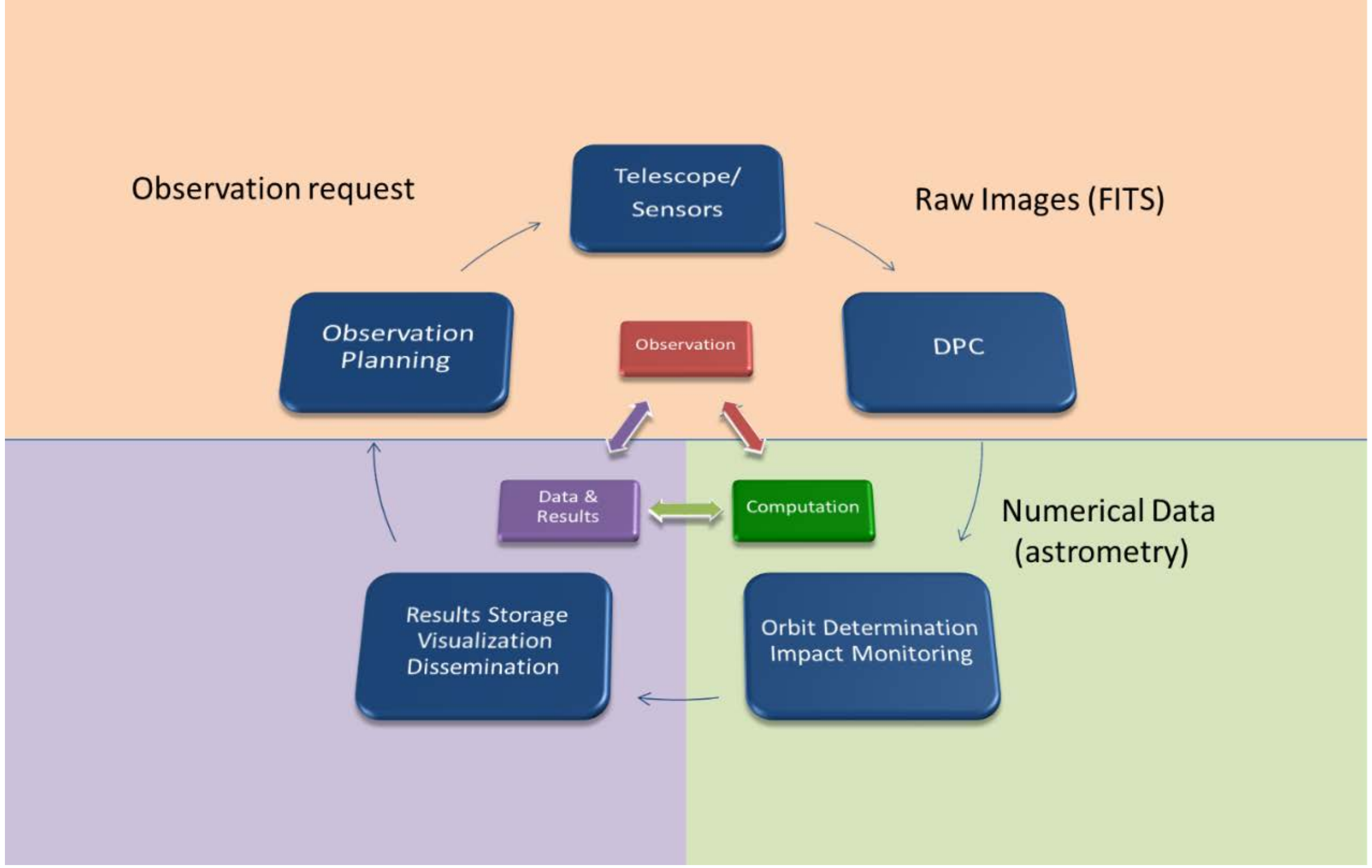


Development and Operation eterogeinity

A overall visual representation

- Survey and follow up observation

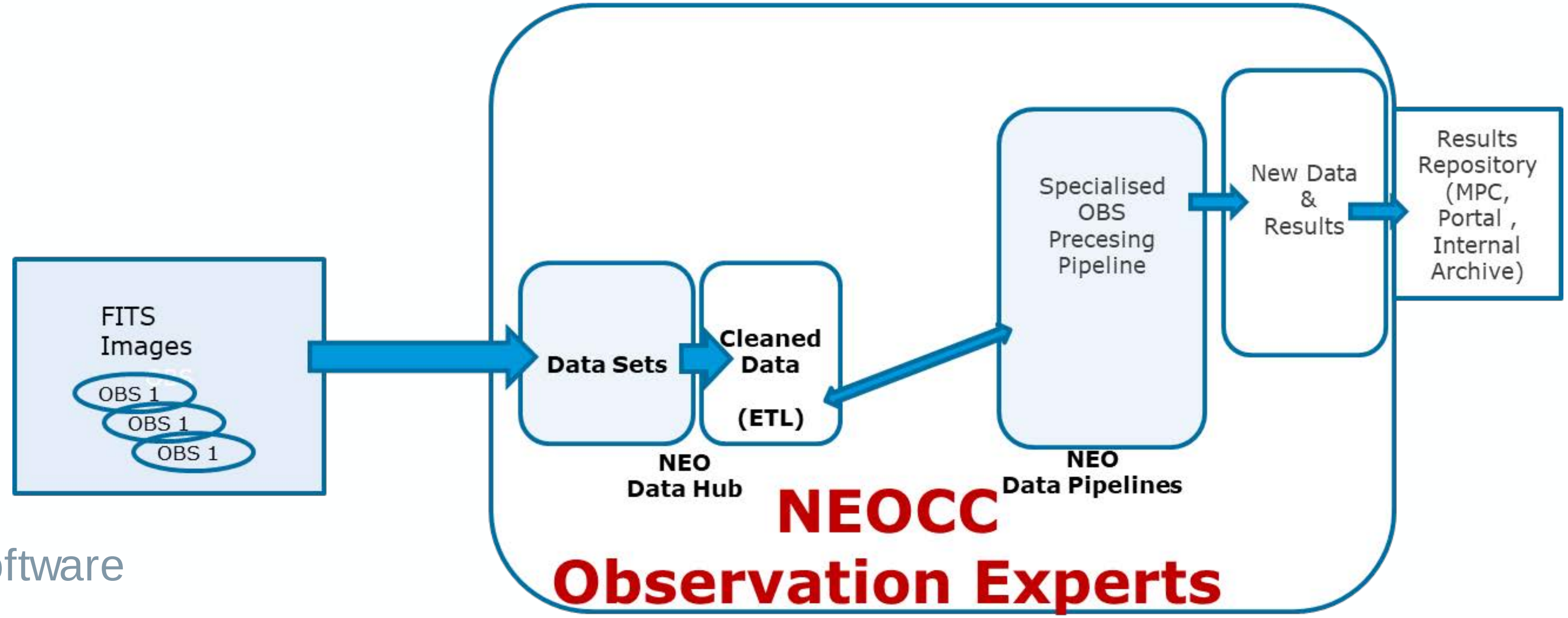
- Big Software development outsourced to Industry



Development and Operation eterogeinity

A overall visual representation

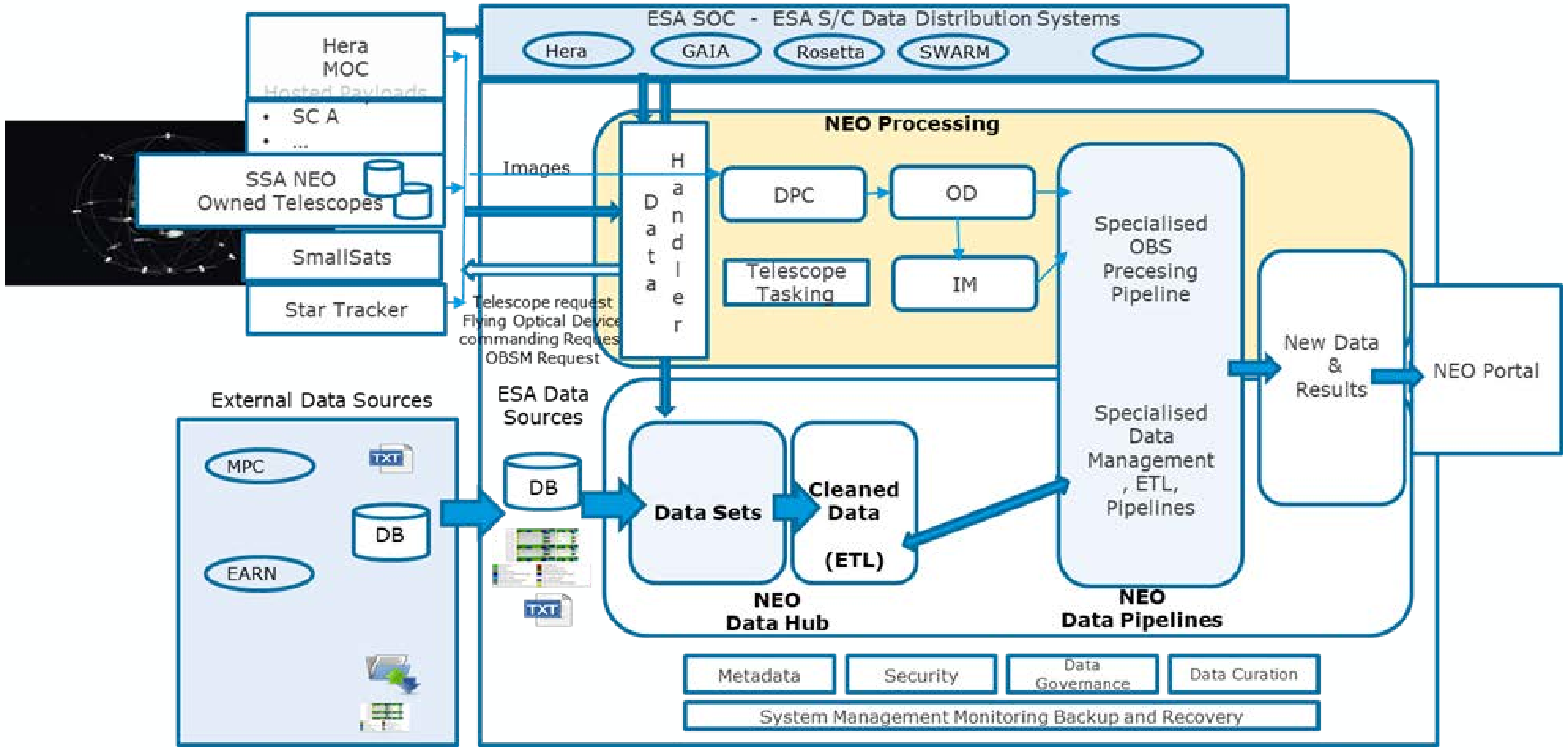
- External data acquisition and refinement
- in IT terms: Data Management



- Micro services, agile in house software development (data pipelines)

Development and Operation eterogeinity

The resulting PD NEO Operational ecosystem



different Teams, Roles and … locations

Industry
- Operational SW Development
- Many industries
- Spread across Europe
- Development

ESA Ground Segment Team
- Data Systems (SW Engineers)
- Data Centre (HW Engineers)
- Located in Darmstadt (Germany)
- Build, Test, Validation

PD Operators
- OD/IM
- Observers
- Data (pipelines) Managers
- Located in Frascati (Italy) Darmstadt (Germany) and Nordwijk (Nederland)
- Operation

different Teams, Roles and … locations

ESA Ground Segment Team
- Data Systems (SW Engineers)
- Data Centre (HW Engineers)
- Located in Darmstadt (Germany)

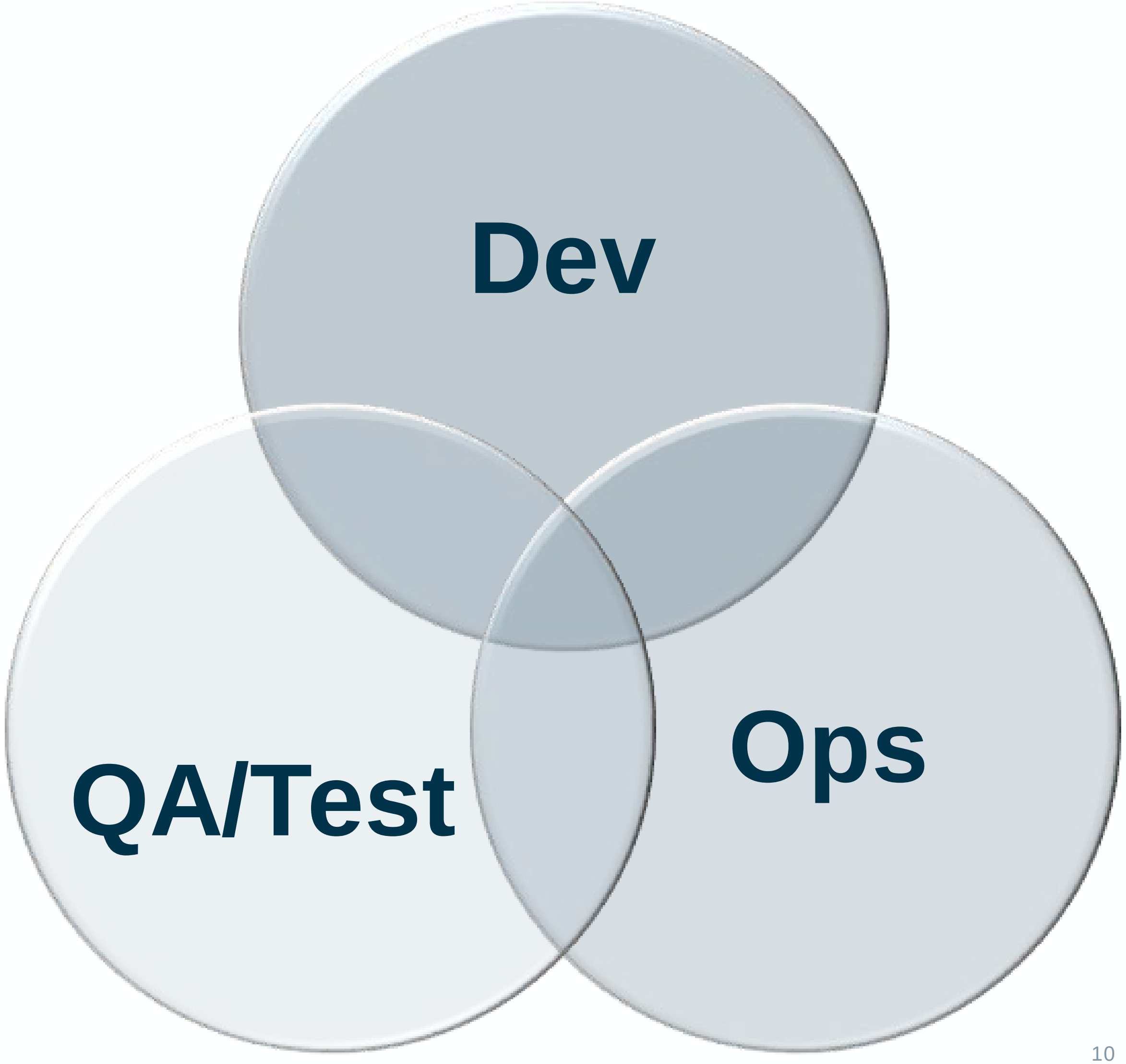
Industry
- Operational SW Development
- Many industries
- Spread across Europe

PD Operators
- OD/IM
- Observers
- Data (pipelines) Managers
- Etc
- Located in Frascati (Italy) Darmstadt (Germany) and Nordwijk (Nederland)

Evolve a Working Model towards DevOps

DevOps model fuses:

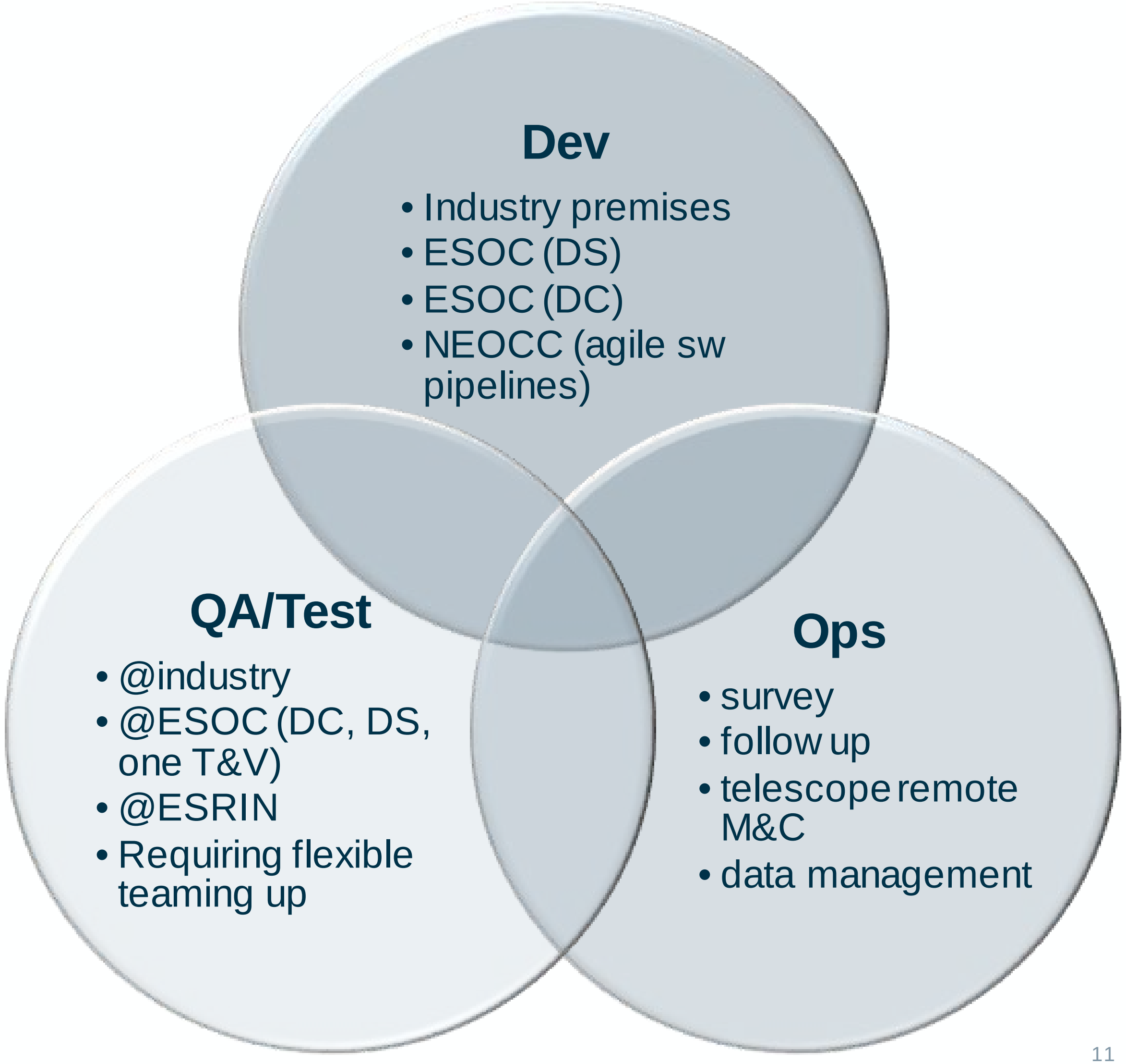
- Development
- QA/Testing/Validation
- Operation



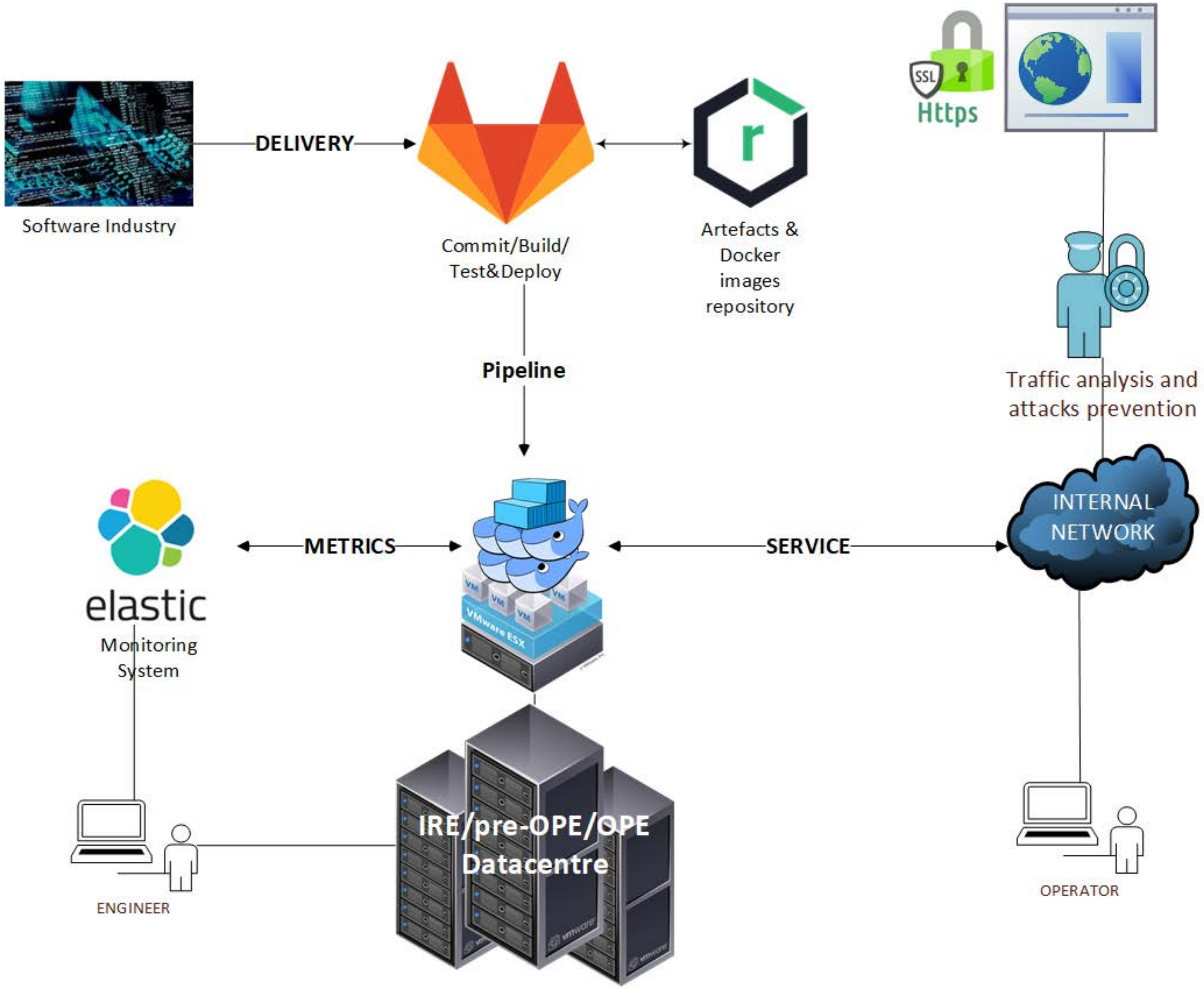
Evolve a Working Model towards DevOps

NEO Peculiarity

- Two Development's cycles
  - Long (WP Procurement)
  - Short (NEOCC Op need agile SW changes)
- Team location
  - Offsite (ESOC, ESA, Industry)
  - Onsite (NEOCC)
- This demands the definition of proper and efficient working model
  - 1 infrastructure capable to support all models to sustainable
  - SW management (dev&maint&op)
  - Data Management (not separated from the SW)



ESA PD CI/CD Infrastructure



ESA PD CI/CD Pipeline Design

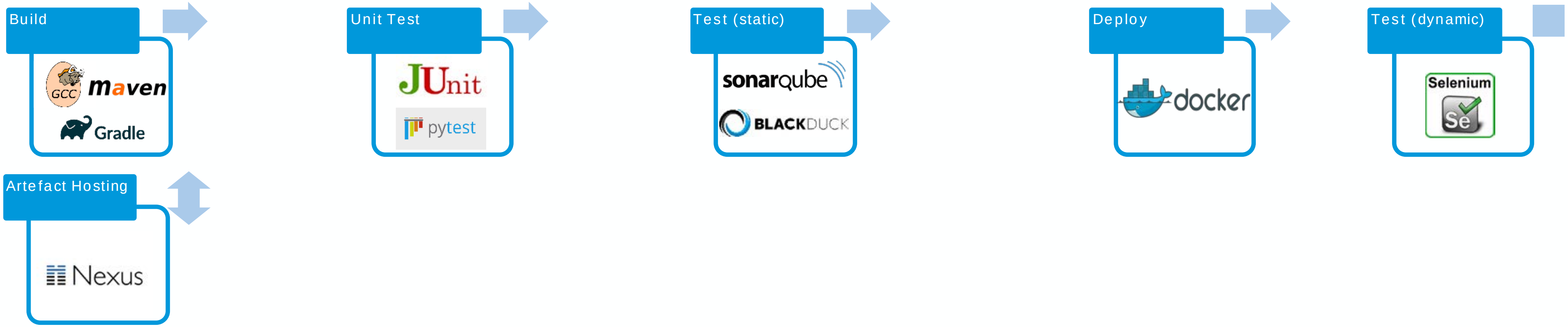
GitLab CI/CD

PD Project Pipeline - Example Run:

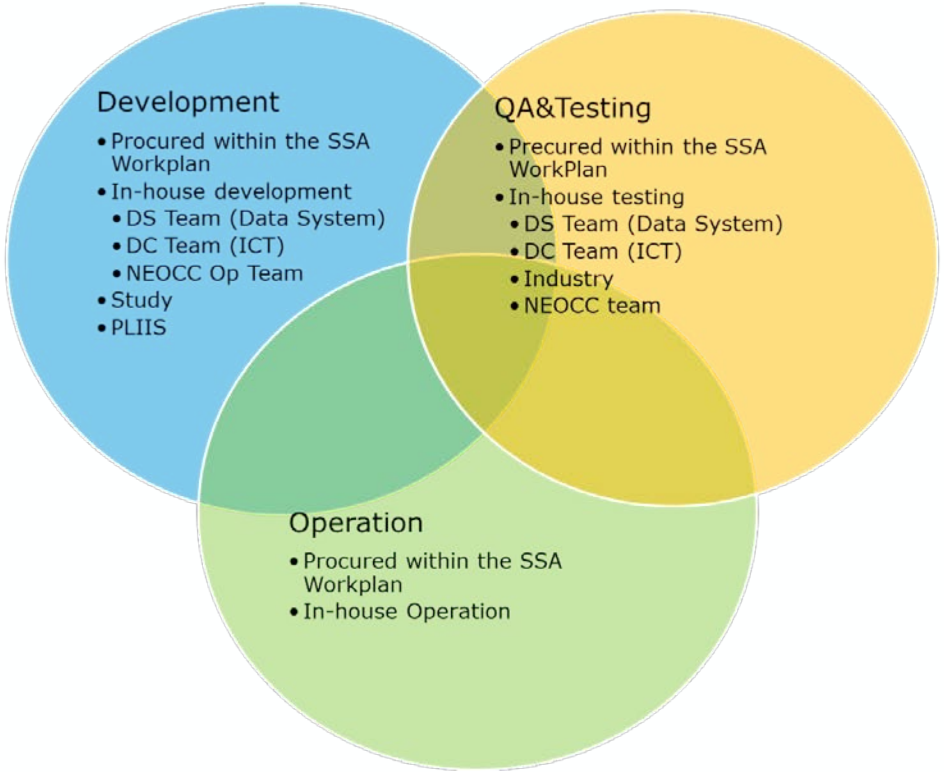
Pipeline Needs Jobs 10 Tests 38

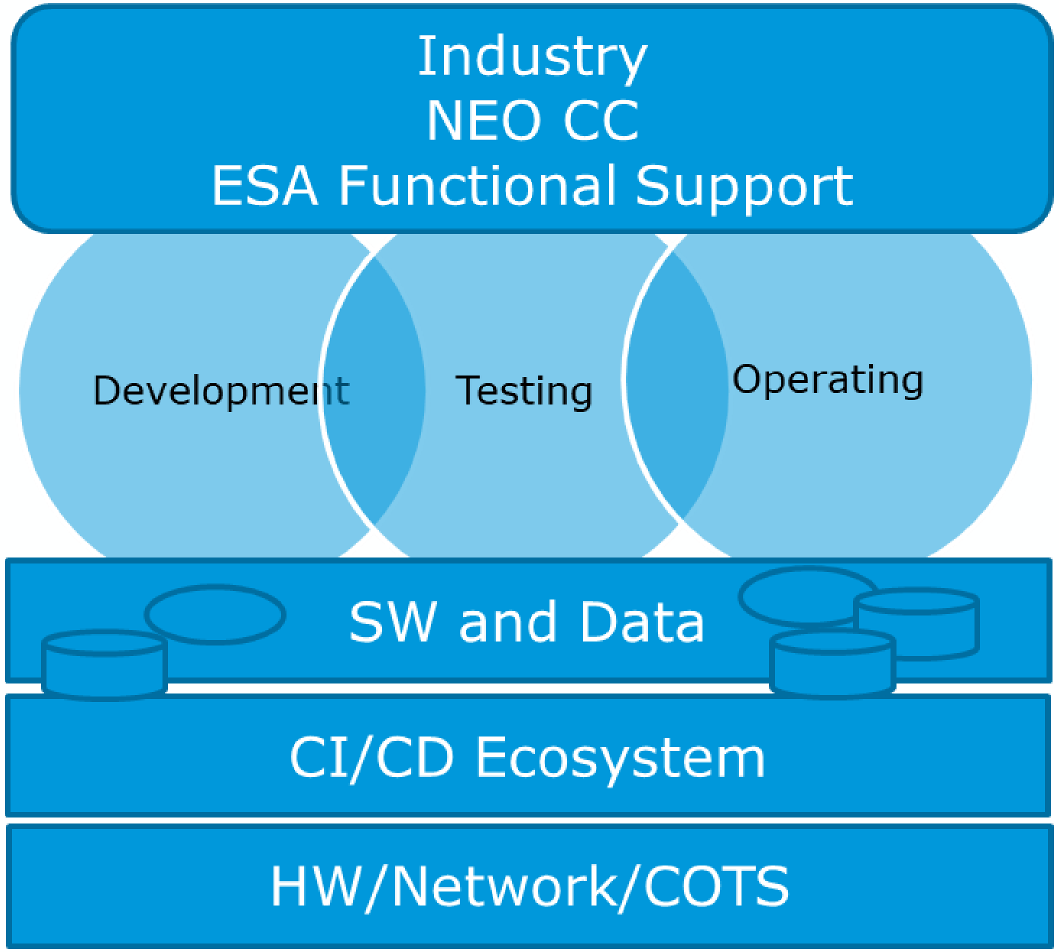
! test_static
<<manually>>

Conceptional CI/CD Pipeline Stages:

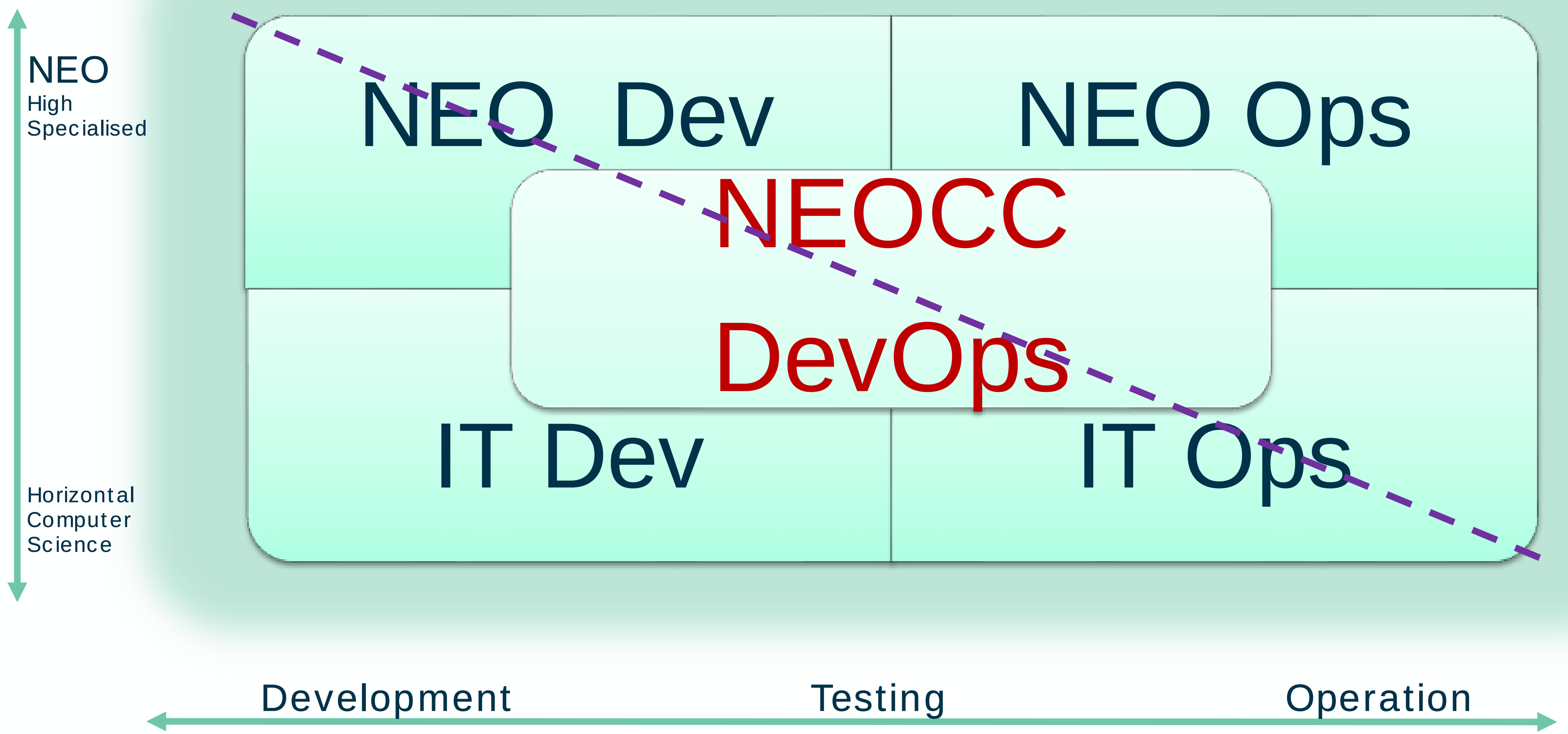


The resulting Work Model view

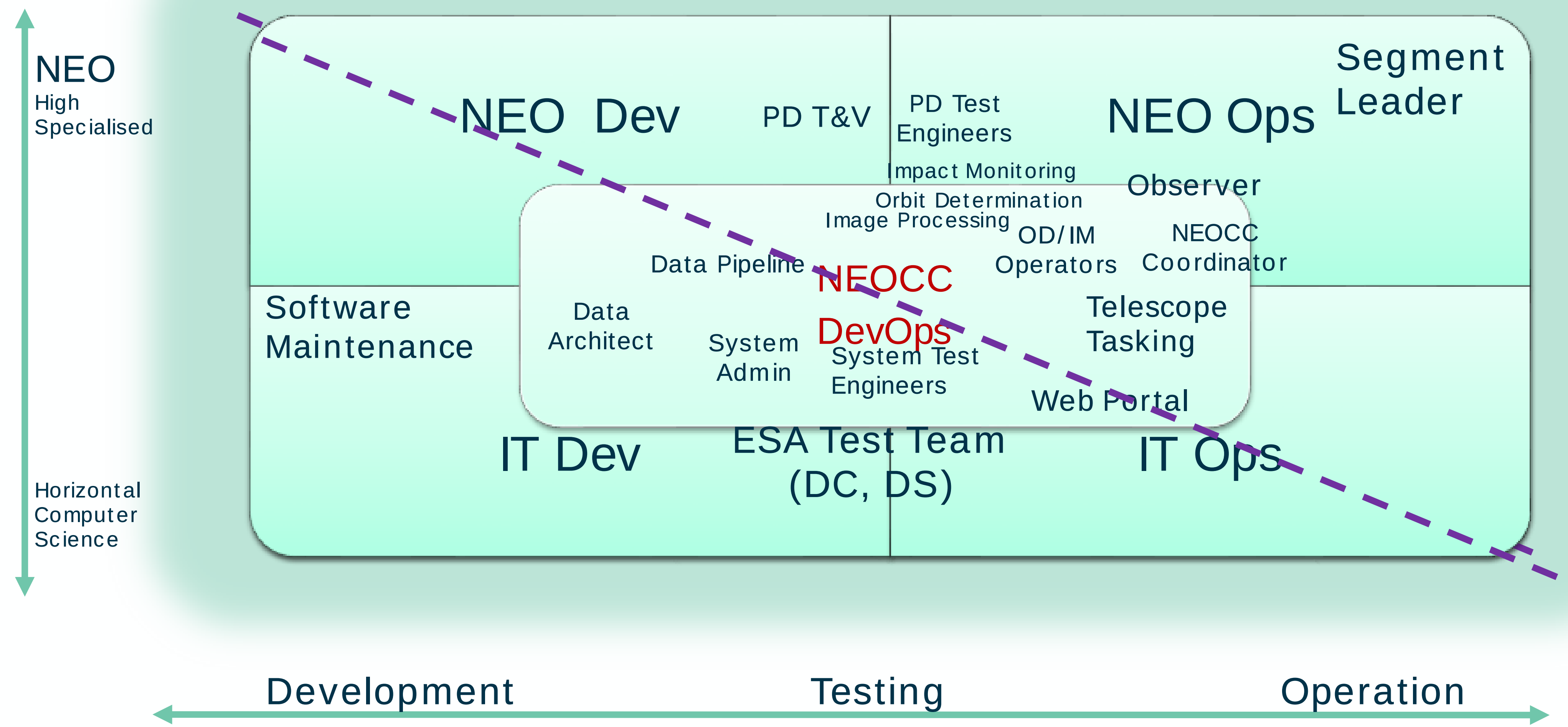




ESA Planetary Defence DevOps Quadrant

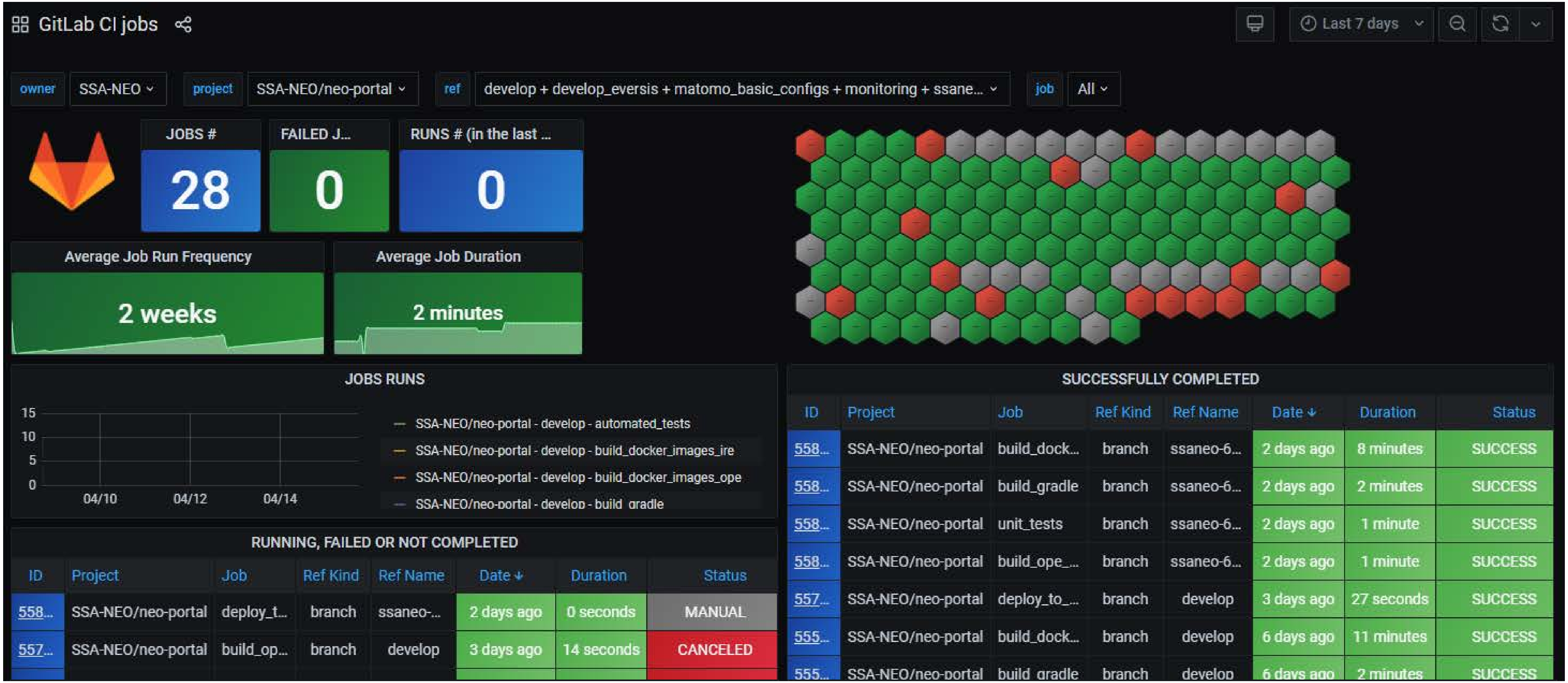


ESA Planetary Defence DevOps Quadrant

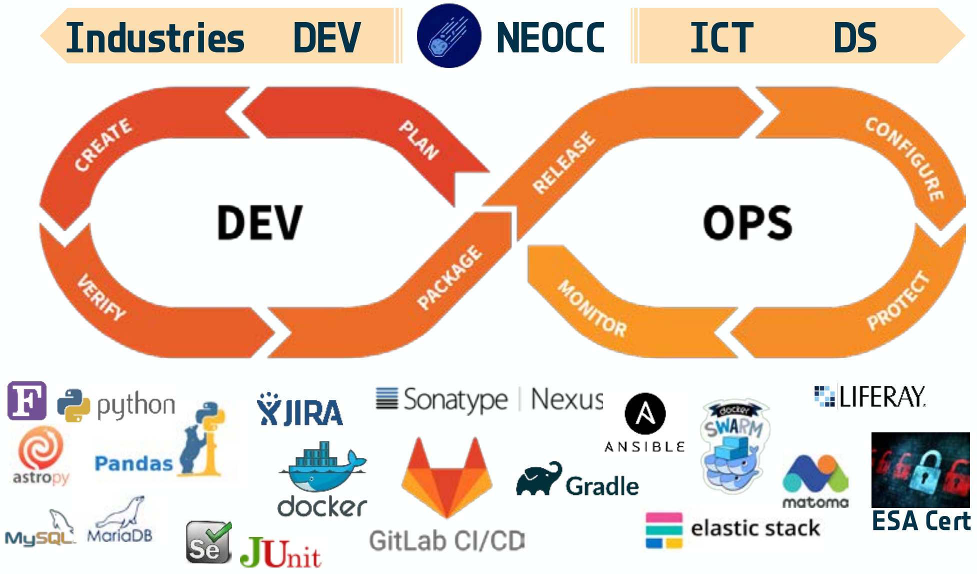


CI/CD & Software Metrics

CI/CD & Software Metrics – NEO Portal

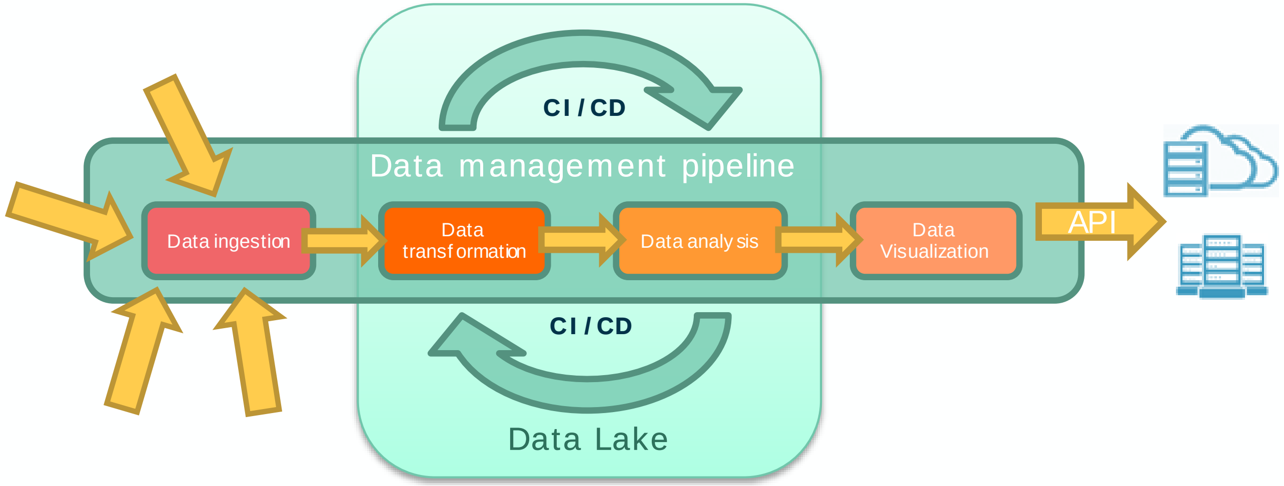


DevOps vision from NEOCC



- Pipelines tend to eliminate skill barriers and facilitate a fair and lean collaboration between groups, respecting roles and responsibilities.
- Automated and controlled CI/CD pipelines speedup and streamline the Software Release Delivery from the development to the deployment,
- Simplifying Development Testing and Operation in a highly heterogeneous and complex ecosystem

- continuous monitoring tools using data pipelines is speeding up troubleshooting and the automatic detection of issues and help to plan new releases.
- NEOCC team is actively taking part to the SW processes (leading in the final deployment phase)



Factual metrics&results

ESA S2P PD

- runs Operations under an evolved, agile, and nonetheless controlled work processes
- Within the overall ESA Space Safety Programme is the segment with the highest number of software applications procured **and** used operationally
  - ---> thus with the highest delivery frequency
- Combines and complements macro functionality procured offsite with microservices (data pipelines) developed in the scope of the specialised Operators activity
- Is the first example in ESA with a fully validated DevOps model used into an Operational context
  - ---> with software providers scattered across industry , ESA, University etc
- The future increase of software components/delivery/ will not require a linear&proportional increase of the IT support

Upcoming (continuous) challenges

- ✓ Agile, efficient. Controlled SW Management via modern CI/CD infrastructure
  - ✓ Removed a cultural barrier of considering IT services on site at the Operational premises and under strict control of the Operation Team → dedicated IT , SW + HW Support on site + Industry on demand on site
  - ✓ NEOCC Operation are supported by a shared Infrastructure and an Infrastructure Team, and by Industry, located elsewhere
- ❑ NEOCC Operation Team will invest more in creating new data management pipelines
  - ❑ by consolidating data collected from different sources into one common destination,
  - ❑ enabling quick data analysis,
  - ❑ ensure consistent data quality, governance and standardization in the data distribution to the internal and external sources
- ❑ Increase Operational Flexibility (still)
  - ❑ The Operation complexity requires hectic and various interaction with software and data
  - ❑ The paradigm still to change/evolve is the improvement/evolution of the MMI vs. current traditional (and old aged) approach of using bash command prompts Agile Software Management

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

RADIO SCIENCE AND
PLANETARY EXPLORATION
- L A B O R A T O R Y -

Hera Radio Science Experiments through Ground-Based and Satellite-to-Satellite Doppler tracking

Paolo Tortora[1], Marco Zannoni[1], Edoardo Gramigna[1], Riccardo Lasagni Manghi[1], Sebastien Le Maistre[2], Ryan S. Park[3], Giacomo Tommei[4], Ozgur Karatekin[2], Etienne Le Bras[5], Paolo Martino[6], Paolo Concari[6], Michael Kueppers[7], Patrick Michel[8], Ian Carnelli[9]

1 University of Bologna, Department of Industrial Engineering, Forlì, Italy (paolo.tortora@unibo.it)
2 Royal Observatory of Belgium, Brussels, Belgium
3 CalTech/ Jet Propulsion Laboratory, Pasadena, CA, USA
4 Università di Pisa, Pisa, Italy
5 GomSpace Luxembourg S.à.r.l., L-4370 Belval, Luxembourg
6 ESA/ESTEC, 2200 AG Noordwijk, The Netherlands
7 ESA/ESAC, Villanueva de la Cañada (Madrid), Spain
8 Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Laboratoire Lagrange, Nice, France
9 ESA/HQ, 75738 Paris Cedex 15, France

The DART and Hera Missions

AIDA (Asteroid Impact and Deflection Assessment):

- International collaboration supported by ESA and NASA to assess the feasibility of the **kinetic impactor technique** to deflect an asteroid.

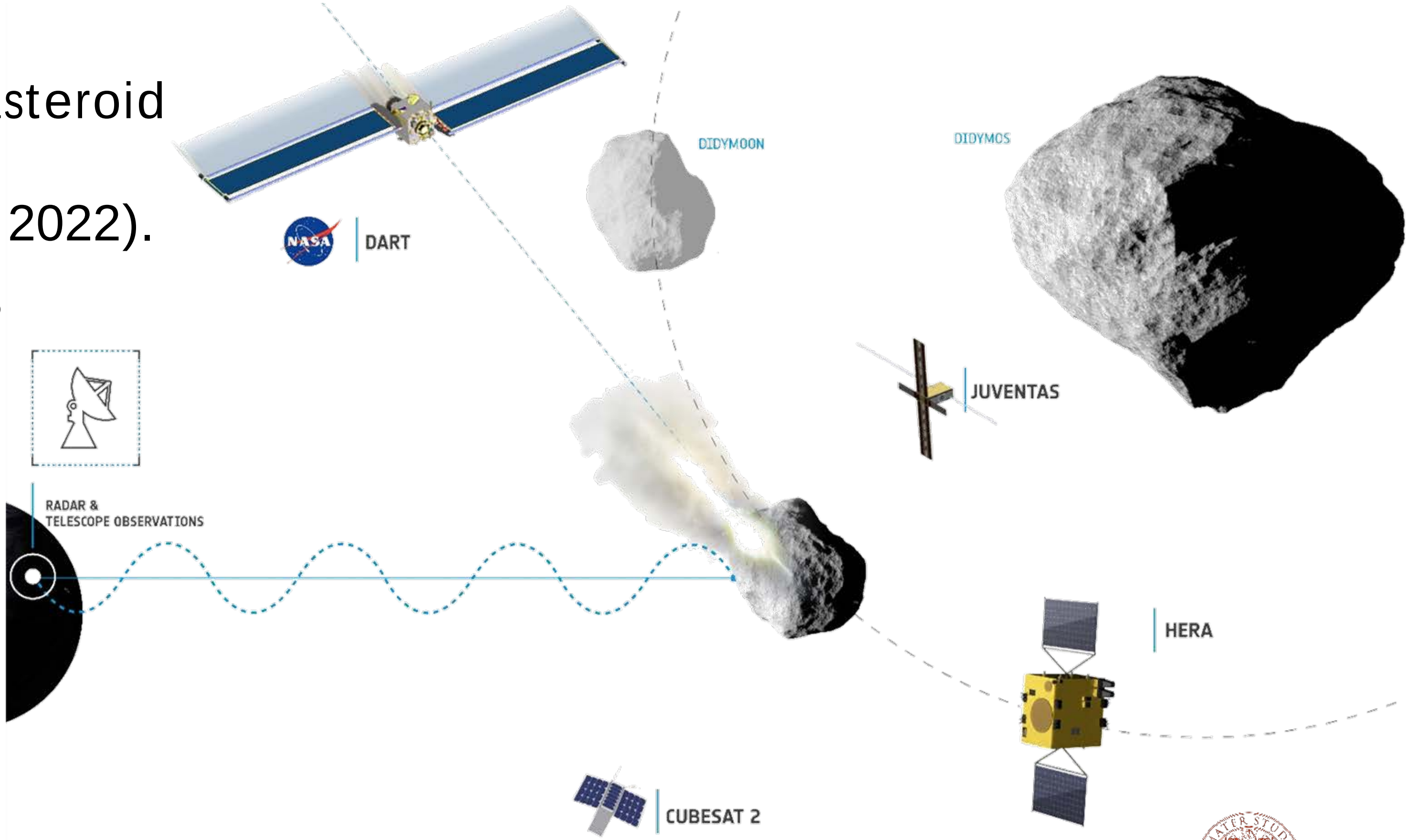
Target: **Didymos+Dimorphos** binary asteroid

NASA/DART: impact Dimorphos (Oct 2022).

- Measure change of mutual orbit's period from ground telescopes.

ESA/Hera: arrive to Didymos in 2024.

- Detailed post-impact survey of the asteroid.
- Release 2 cubesats: Juventas and Cubesat-2 (TBD).



Hera Gravity Science Experiment

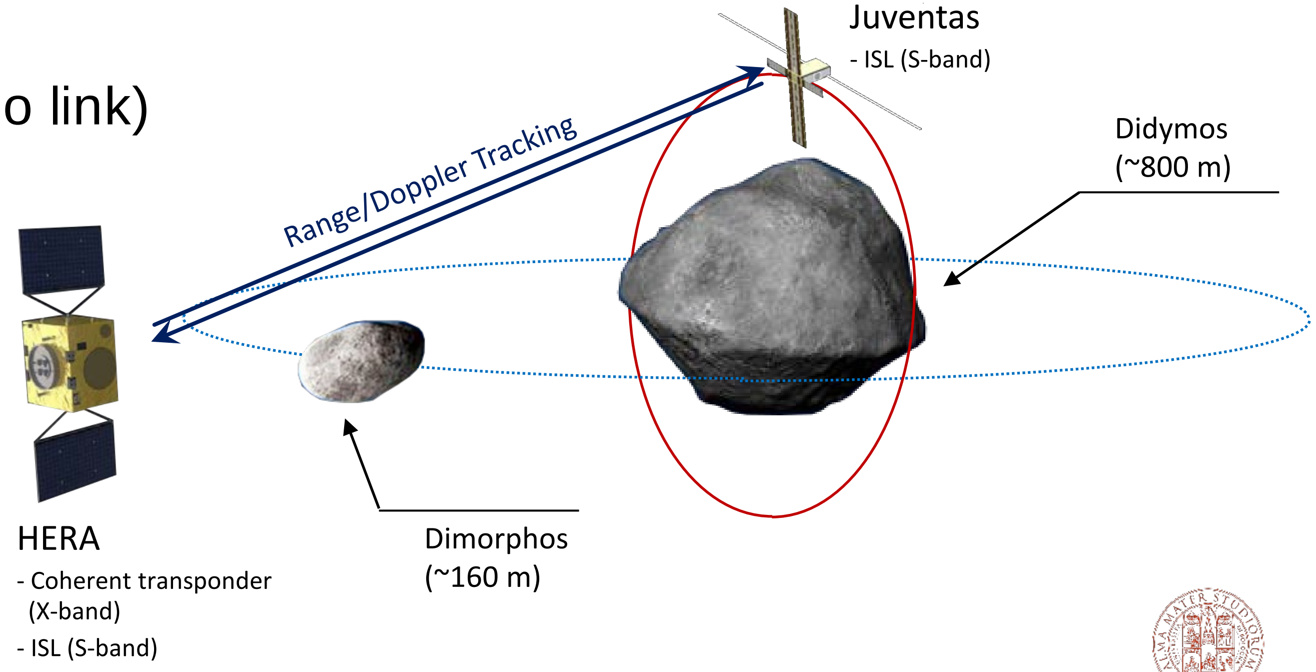
Experiment objectives:

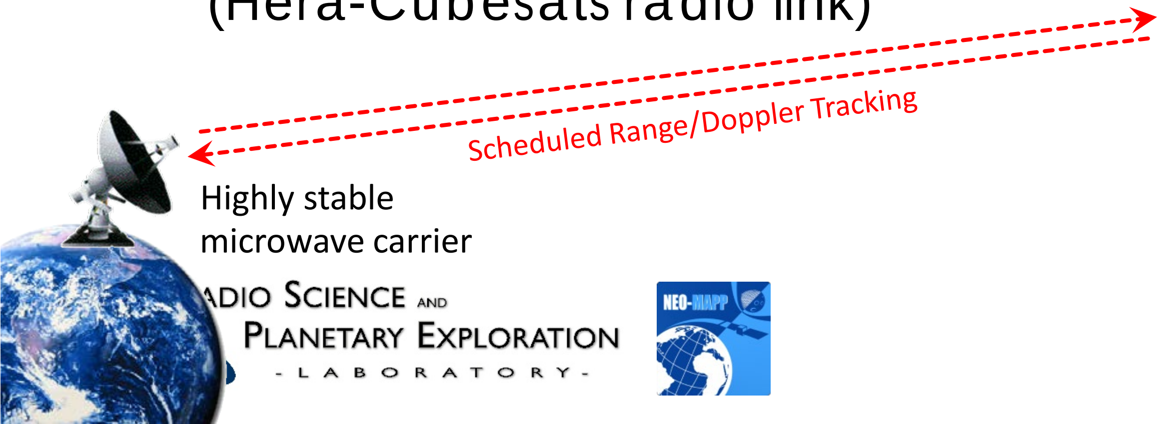
- Measure the asteroids' gravity to constraint their interior structure.
- Characterize the post-impact mutual orbit and rotational states.

Physical parameters estimated reconstructing the trajectory of Hera and Cubesats.

Measurements:

- **Ranging** and **Doppler** (Hera-Earth radio link)
- **OPNAV**: Hera optical images.
- **Inter-Satellite Link (ISL)** (Hera-Cubesats radio link)





Radio Science and Planetary Exploration - Laboratory -

Alma Mater Studiorum Università di Bologna

Numerical Simulations

The experiment expected accuracy were obtained through **numerical simulations** of the orbit determination of Hera and Juventas in the Didymos system.

Simulated scenario:

- o Hera + Juventas (Doppler):
  - Hera-Earth Range+Doppler and Optical
  - Hera-Juventas ISL Range+Doppler
- o Duration:
  - 2.5 months after cubesat deployment
    - 1 month Hera DCP and Juventas SSTO 3.3 km altitude
    - 1 month Hera COP and Juventas SSTO 2.0 km altitude
    - Last 7 arcs Hera COP, without ISL

DCP = Detailed Characterization Phase
COP = Close Observation Phase
SSTO=Sun Synchronous Terminator Orbits

Hera Trajectory and Observables Assumptions

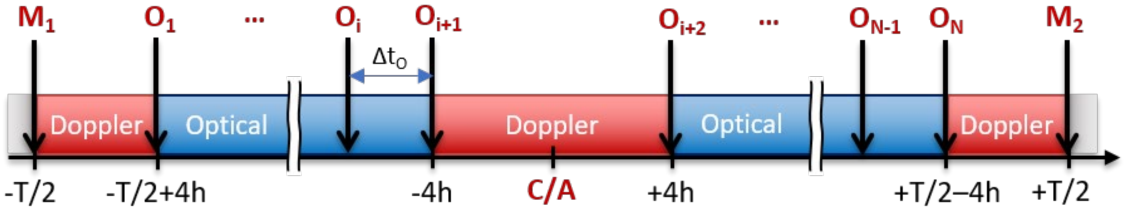
Hera trajectory: series of **hyperbolic arcs** connected by impulsive maneuvers (Rosetta concept)

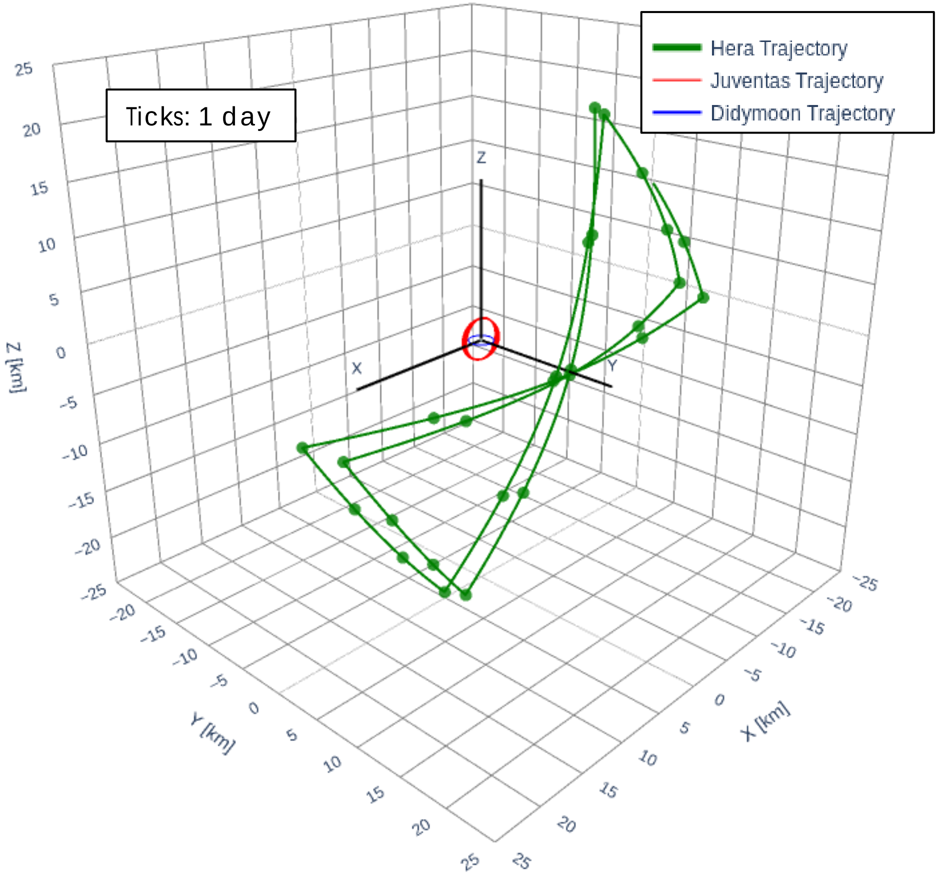
- **All trajectory arcs** are used for radio science.
- **No thruster maneuvers** during arcs (wheel off-loading).

Measurements assumptions:

- Radio tracking around the maneuvers and near C/A.
- Optical measurements acquired outside tracking (maximum Sun phase angle: 60 deg).

Single Arc Timeline





HERA distance from Didymos:
Min. : ~10 km
Max. : ~23 km

Z=Dimorphos Orbit-Normal
Y=Vernal Equinox

RADIO SCIENCE AND PLANETARY EXPLORATION - LABORATORY -

NEO-MAPP

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

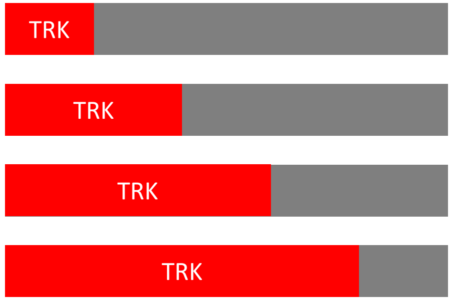
Juventas Trajectory and Observables Assumptions

Juventas trajectory: **SSTO** at 3.3 and 2.0 km altitudes from Didymos

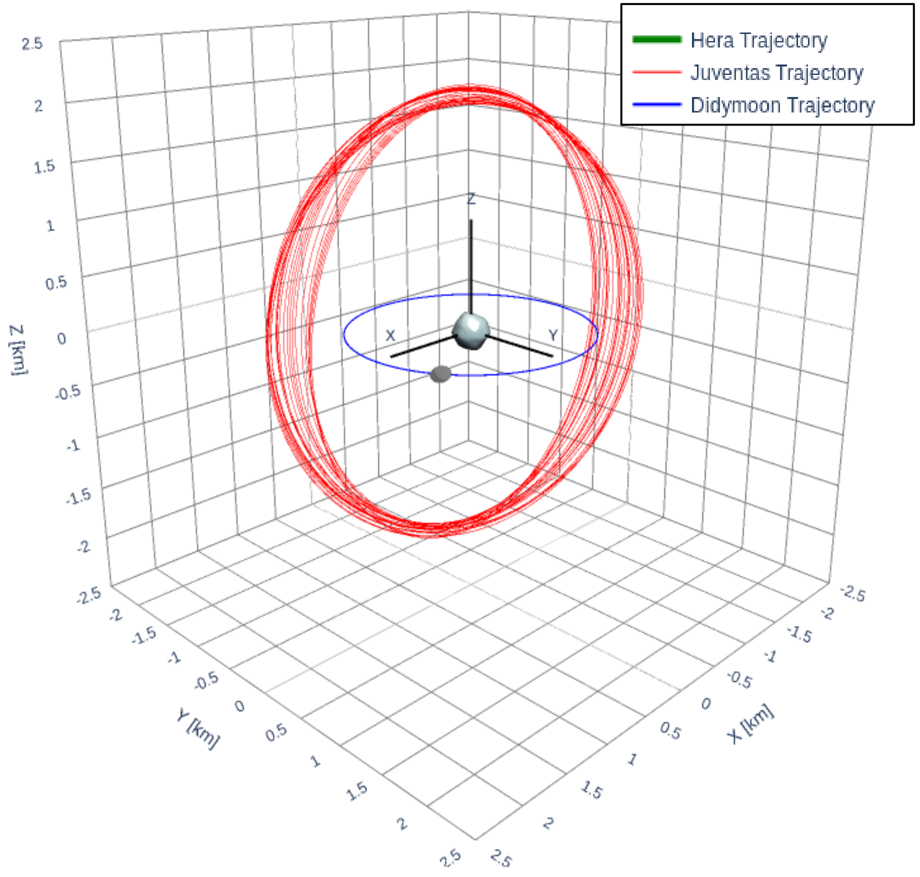
- **No thruster maneuvers** during Hera arcs. (3-4 days)

Measurements assumptions:

- **Continuous ISL** with scheduled Duty Cycle (DC) (quasi-omnidirectional S-band patch antennas):
    - DC 20%: tracking 1 min/5 min
    - DC 40%: tracking 2 min/5 min
    - DC 60%: tracking 3 min/5 min
    - DC 80%: tracking 4 min/5 min



- **ISL Ranging noise**: 50 cm.
- **ISL Doppler noise**: 50 microns/s (60 s integration time).



Z=Dimorphos Orbit-Normal
Y=Vernal Equinox

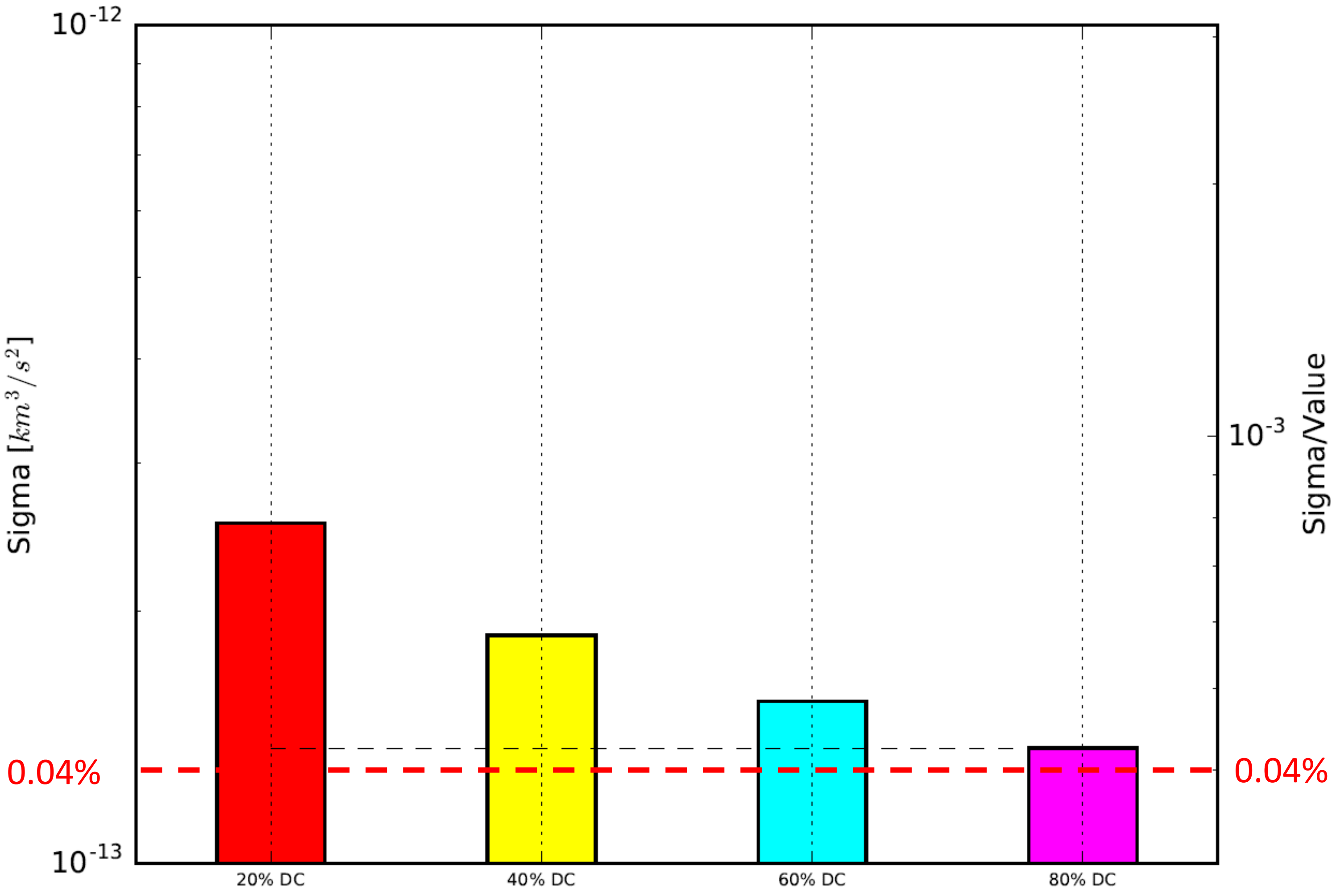
RADIO SCIENCE AND PLANETARY EXPLORATION - LABORATORY -

NEO-MAPP

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

Results: Dimorphos mass

- In this simulation scenario Dimorphos' mass can be estimated with a formal uncertainty between 0.04-0.09%.



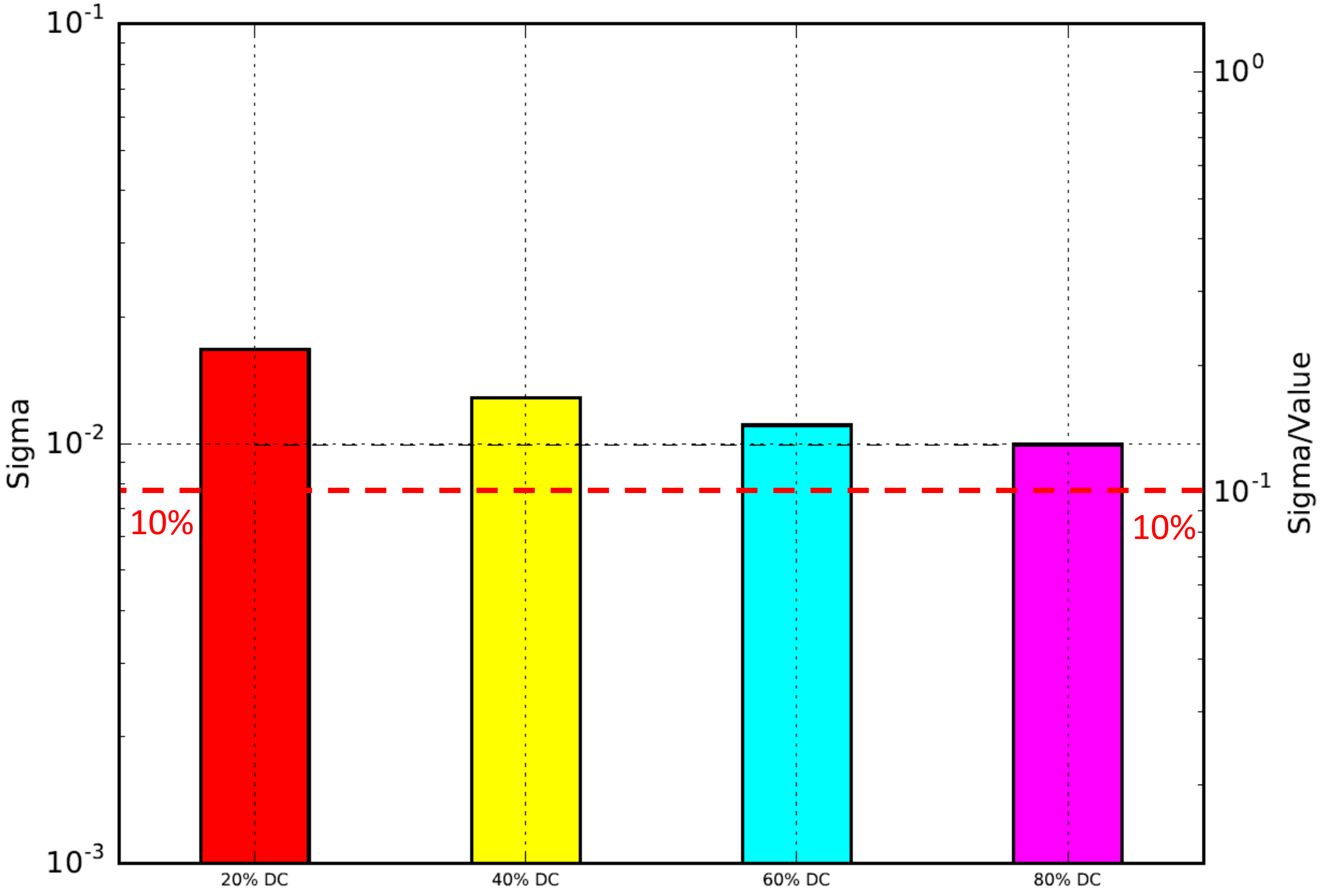
RADIO SCIENCE AND PLANETARY EXPLORATION - LABORATORY -

NEO-MAPP

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

Results: Dimorphos J_2

- Hera-only does not allow to observe J_2.
- The ISL allows to observe J_2 with a formal uncertainty of 10-11%.
- The Duty Cycle is less important



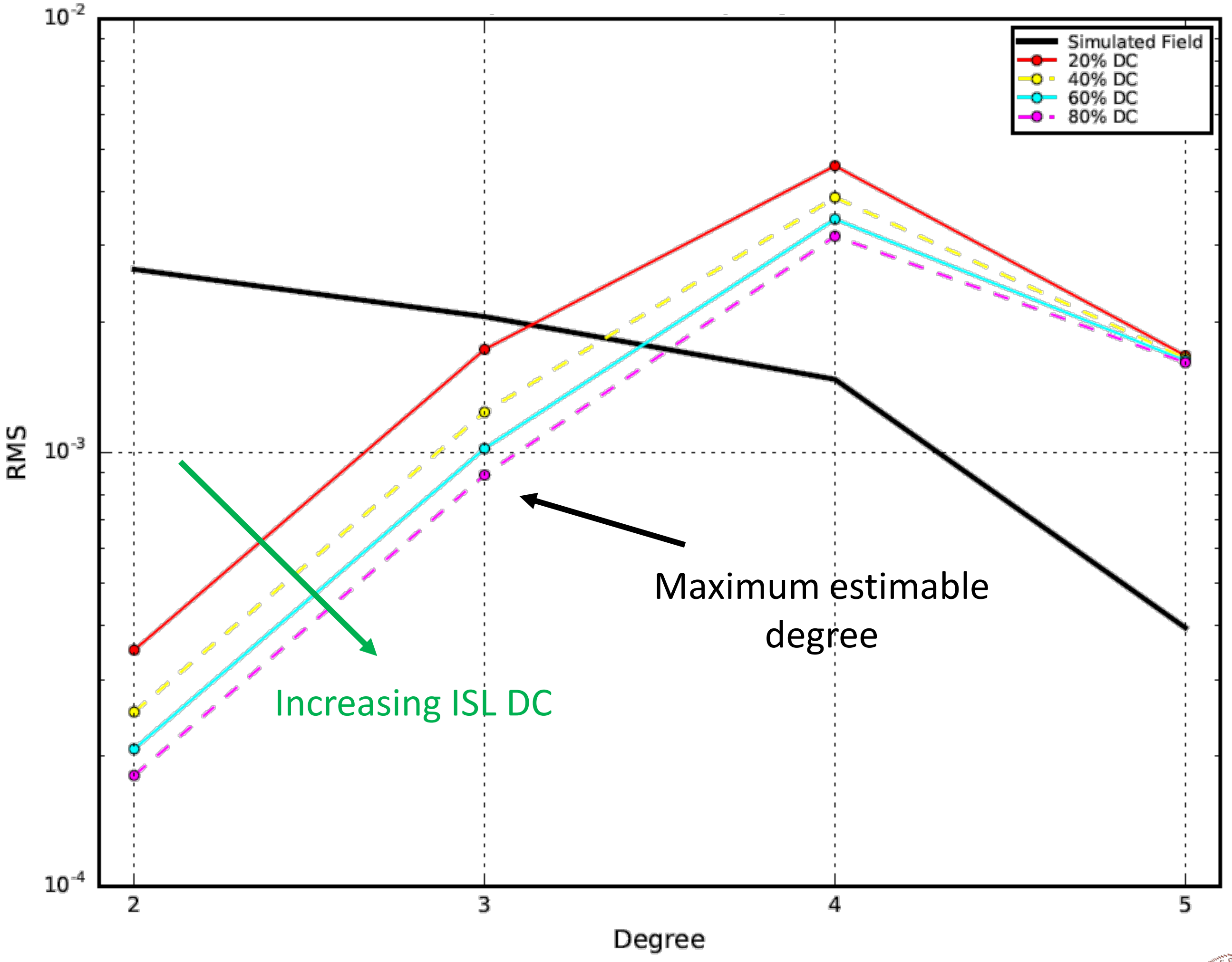
RADIO SCIENCE AND PLANETARY EXPLORATION - LABORATORY -

NEO-MAPP

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

Results: Didymos gravity field

- Hera only does not allow to estimate Didymos' extended gravity field
- ISL Ranging+Doppler allows to estimate degree 2 and 3
- Degree 4 would be observable only by exploiting lower altitudes (SSTO 1.5 km)



RADIO SCIENCE AND PLANETARY EXPLORATION - LABORATORY -

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

Summary and Future Work

- The Hera gravity science experiment at Didymos **proves feasible**, using realistic assumptions on the technological capabilities of the space and ground segment.
- **Optical Navigation** (OPNAV) images are essential to estimate Hera's trajectory.
- **Hera-Juventas ISL Doppler** improves the overall accuracies and enables to estimate the extended gravity field of Didymos and (marginally) Dimorphos:
    - Didymos max observable degree: 3 (20%-80% DC).
    - Dimorphos: J_2 uncertainty 10-11% (20%-80% DC).
- **Future work:**
    - Simulate with detailed operational constraints.
    - Add Milani Cubesat.
    - Better characterization of ISL performance.
    - Improve modeling of the Didymos system (F2RBP, BYORP, tides).

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Thank you!

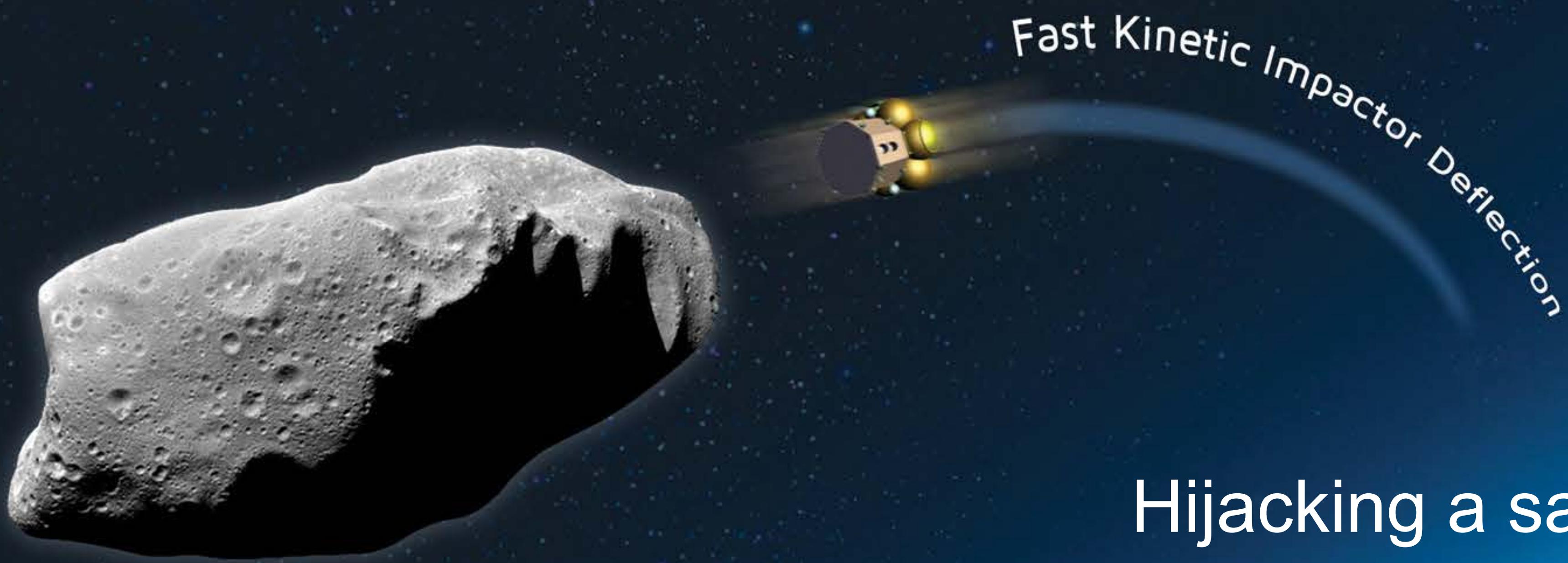
paolo.tortora@unibo.it

RADIO SCIENCE AND PLANETARY EXPLORATION
- LABORATORY -

Near Earth Object Modelling And Payloads for Protection

NEO-MAPP

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870377



Hijacking a satellite for Short-Warning Asteroid Deflection – FastKD Mission, Design and Implementation

IAA-PDC-21-08-12
7th IAA Planetary Defense Conference – PDC 2021
26-30 April 2021, Vienna, Austria

DEFENCE AND SPACE

Albert Falke, Karl Atkinson, Marc Chapuy
28 April 2021

esa

AIRBUS

This activity has been performed under a program of, and funded by, the European Space Agency. The view expressed by the authors in this publication does in no way reflect the official opinion of the European Space Agency.

Study objectives

Imagine an asteroid threat scenario, which is just discovered to impact Earth within 1-3 years from now!

What do we need to prepare to enable our Deflection Capabilities for short warning asteroid threats?

Study objective → **Assess the feasibility of modifying a commercial spacecraft platform in order to perform asteroid kinetic deflection in the shortest possible time**

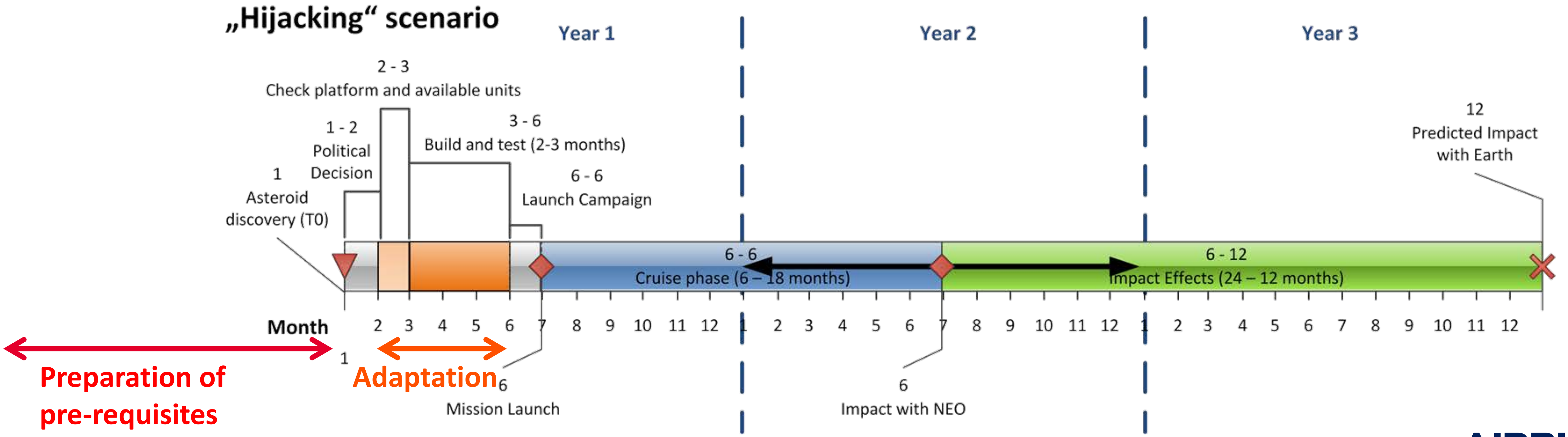
Driving requirement → Launch readiness within 6 months from threat discovery

Tasked to identify the

- needed pre-requisites,
- the platform capabilities,
- system requirements (with emphasis on GNC sub-system),
- minimal modifications & required activities to re-purpose a commercial platform,
- critical technology developments and long-lead items, and
- limitations of such an emergency kinetic deflection mission in terms of warning time and a priori knowledge.

Timeline of FastKD “Hijacking” Scenario

- Incoming asteroid is detected, analysis of the orbit propagation reveals a high probability of Earth impact in ~3 years
- Political decision makers push for rapid deflection attempt using KI technology
- Extremely constrained preparation time scenario with a **“to Launch” requirement of 6 months** or less
  → build/adaptation time of only 2-3 months
- Approach foreseen is to “hijack” an existing commercial platform already in build in integration facility and with minimal adaptations and additions convert to a kinetic deflection mission to achieve “best possible” deflection performance

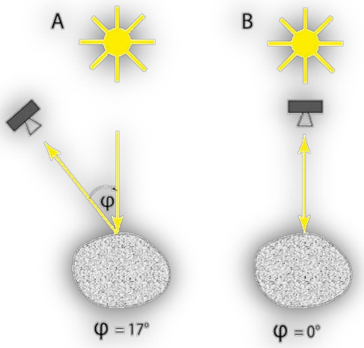


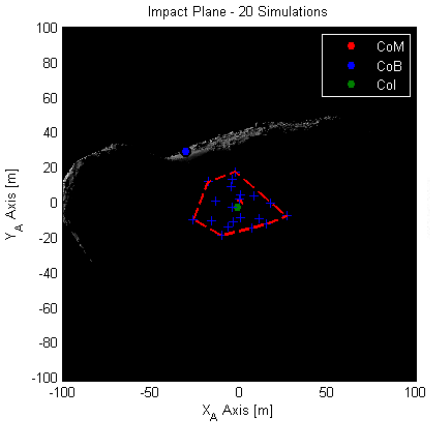
AIRBUS

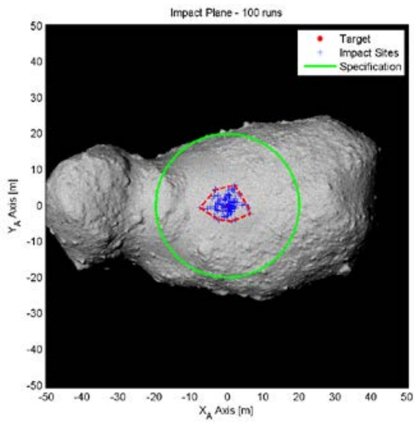
Mission Analysis

- …revealed the **deflection needs**, meaning the KD mission & system requirements to be met for successful asteroid deflection
- From all known NEOs: creation of a dedicated asteroid catalogue with NEOs in size range and close Earth encounters within next decade (252 objects D~20-80m, 45 PHAs included) → realistic asteroid threat scenarios
- Most relevant findings from trajectory analysis:
  – Deflection performance primarily depends on **early deflection** (short transfer time), impact impulse (mass*velocity), **relative Earth-asteroid geometry** and not so much on Impactor arrival mass.

  – For short warning scenarios: **higher allowed Solar Phase Angle** (SPA) at impact is required to achieve high deflection performance.
  And: SPA largely affects the launch opportunities: higher SPA results in many more feasible missions and thus increases the mission flexibility & deflection capabilities.
  → TIR NAC needed for greatest mission flexibility/applicability!
- 5 representative scenarios and deflection trajectories selected for more detailed Mission Analysis and requirements derivation.
  → Generic / Enveloping system design approach!







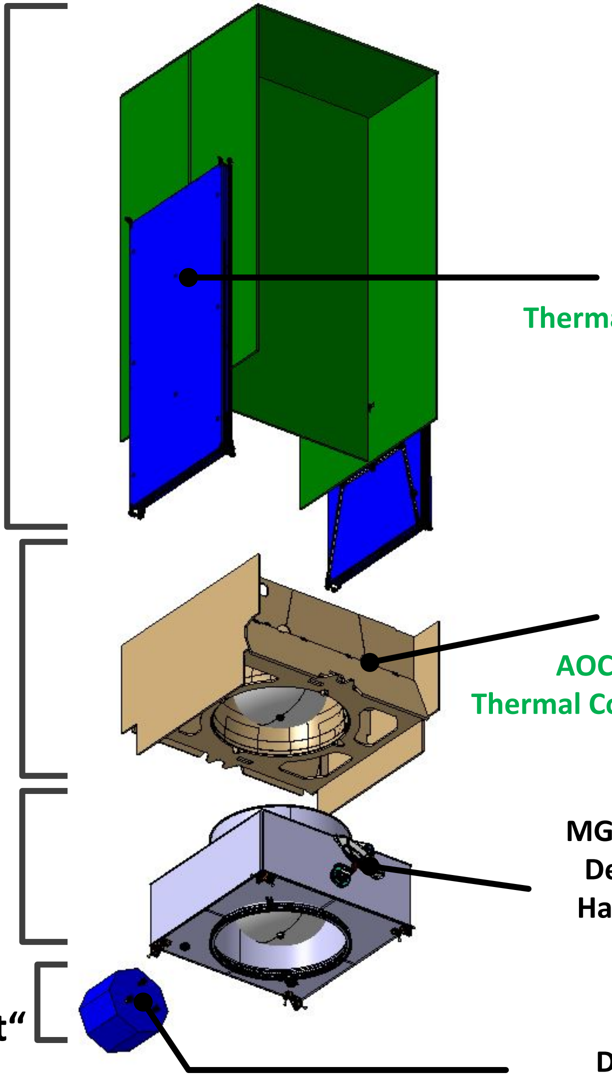
Impactor Design, Architecture

Survey of European platforms:

- identified availability & applicability for KD mission
- revealed need for “KD module” adding mission specific elements

Design Philosophy:

- Effort to minimise changes/adaptations and re-use platform „as is“
- “KD module” predeveloped as pre-requisite:
  – Contains all parts unique in nature (KI specific elements, lower TRL, pose higher risk of failure if not well developed and tested in advance (e.g. GNC, Software …)



AIRBUS

GNC

- Study performed extensive GNC analysis & design activities, supported by existing & reuse of tools developed in earlier projects
  - NEOShield-2: Tools and **Kinetic Impactor GNC design validated at TRL5-6**
    - Real-time compatible with space target
    - Tests done with COTS HW in the loop

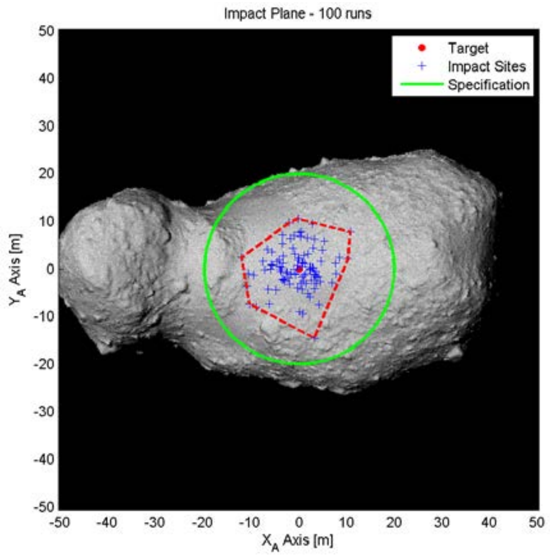
- Assessment of reusability of repurposed telecom platform equipment
  - Thruster type & configuration (thrust, mass & configuration; thruster errors relevance for changed NAC performances)
  - Sensors, OBC

- Assessment & proposal of GNC designs for 2 FastKD reference scenarios
  - **Targeting performance shown for Worst Case scenario**

- Sizing of Narrow Angle Camera suite, in particular TIR detector and its specification
  - Required because of potentially high phase angles & generally unknown asteroid shape
  - NAC is critical key technology & long lead item
    → feasibility study & development to be initiated ASAP

Worst Case scenario: 2015 JJ (100 cases)

Parameter	Value
NAC FoV	0.5 degree
Thrust error	3 % (1σ)

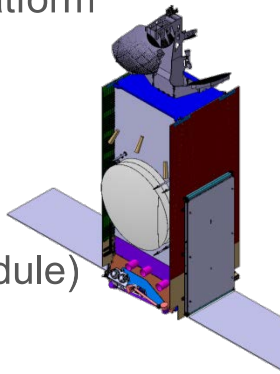


Statistical Parameter	Results
Mean Accuracy (m)	5.4
Min Impact Error (m)	0.5
Max Impact Error (m)	14.8
Standard deviation (m)	3.2
Mean +3 sigma (m)	15.0
Control ΔV range (m/s)	5.3 - 8.9

AIRBUS

Conclusions

- **A Fast Kinetic Deflection mission (with 6 months launch readiness) for short warning time asteroid threats is feasible!**
  - The FastKD activity identified:
    - the pre-requisites needed therefore and modification activities to **“hijack”** and re-purpose a commercial telecoms platform
    - critical key technologies and long lead items
  - Platform capabilities and limitations of such an emergency kinetic deflection mission are identified.



- A viable preliminary design solution is proposed and targeting GNC performance is successfully demonstrated
  - Largely driven by 6 months launch readiness → requires high efforts for pre-developments & pre-requisites (= KD module)
  - KD module to encompass all unique mission specific components not available/suitable on hijacked platform, primarily: GNC, Propulsion and Communication subsystems.

- Alternatives: Dedicated S/C or “Cherry Picking” scenario(*)

- To build up and establish European “Asteroid Deflection Capabilities” it is recommended to initiate as soon as possible
  - Corresponding FastKD Phase A design study and
  - NAC suite feasibility and subsequent development studies

	Stored dedicated spacecraft	"Hijacking" scenario	"Cherry Picking" scenario
Targeted launch readiness	Fastest (≤1 month)	Fast (6 months)	Medium (1-1.5 years)
Preparation efforts (even if no threat materializes)	**Highest preparation efforts:** Full dedicated S/C	**High preparation efforts** for needed pre-requisites: KD module	**Low preparation efforts:** Phase A/B1 design study + key technology development
Total implementation efforts	Medium S/C production costs + storage	Highest S/C production costs (KD module + Hijacked Platform + emergency adaptations) + storage	Medium S/C production costs, no storage

(*) “Cherry picking” scenario: Emergency reallocation of any suitable platform/hardware units from any European integration facility followed by fast-track AIT to build the KI spacecraft. S/C design and fast-track AIT to be extensively prepared in advance.

AIRBUS


Fast Kinetic Impactor Deflection
Many thanks for your attention.
AIRBUS

7th IAA Planetary Defense Conference

26-30 April 2021, Online Event

Hosted by UNOOSA in collaboration with ESA

Q&A

Session 8a: Mission & Campaign Design

7th IAA Planetary Defense Conference

26-30 April 2021, Online Event

Hosted by UNOOSA in collaboration with ESA

Break

Up next: EXERCISE SESSION: UPDATED THREAT CORRIDOR & DETAILED OVERVIEW OF CONSEQUENCES