Asteroid Impact & Deflection Assessment (AIDA)

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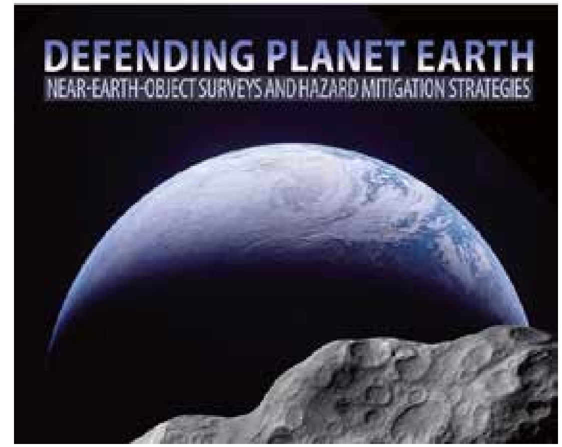
Mitigating the Asteroid Hazard

- *Defending Planet Earth: Near-Earth-Object Surveys and Hazard Mitigation Strategies* (US National Research Council, 2010)
  - Civil defense
  - Slow push or pull
  - Kinetic impactors
  - Nuclear explosions
- *Space Mission Priorities for Near-Earth Object Risk Assessment and Reduction* (ESA NEOMAP, 2004)
  - Don Quijote mission study



ESA Don Quijote study

- Don Quijote asteroid deflection mission studied by ESA in 2005-2007
- Two launches
  - Interceptor
  - Rendezvous
- Not affordable

Asteroid Mitigation

- Target NEO Global Community Workshop in February 2011 (http://www.targetneo.org/)
- International Workshop on Mitigation at the PDC in 2011
- JHU/APL, ESA and other participating NASA Centers started a joint Mitigation Demonstration Mission Study in 2012
  - This has become **AIDA**

ESA web site:
Search web for "AIDA mission"

AIDA Program Overview

- Double Asteroid Redirection Test (DART) study
  - NASA HQ, GSFC, JSC, LaRC, JPL
  - Asteroid impact and deflection, cost under $150 M including launch
- Asteroid Impact Mission (AIM) study
  - ESA HQ, CNRS, DLR
  - Impact test and characterization, cost under €150 M including launch

AIDA = AIM + DART

AIDA Asteroid Deflection Study

- AIDA will send two spacecraft to the binary asteroid 65803 Didymos
- AIDA will demonstrate asteroid deflection and characterize impact effects
- AIDA is an international cooperation with
  - **DART** - asteroid impactor
  - **AIM** - asteroid rendezvous
- Each AIDA component is independent and has unique value

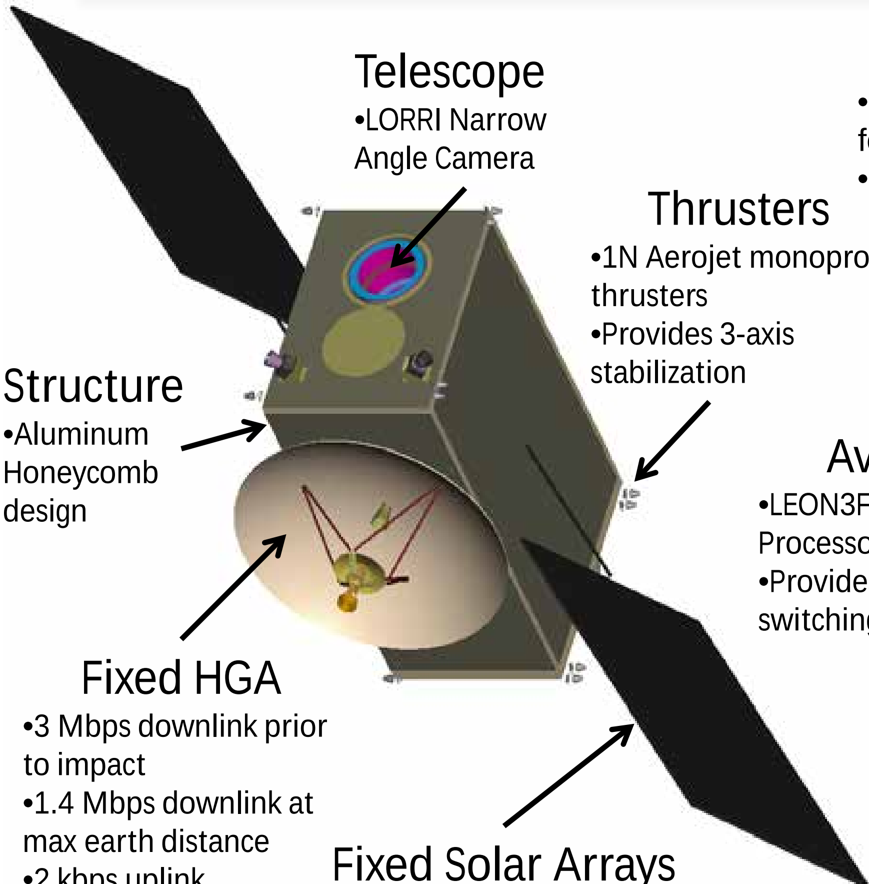
DART as a First Test of Deflection

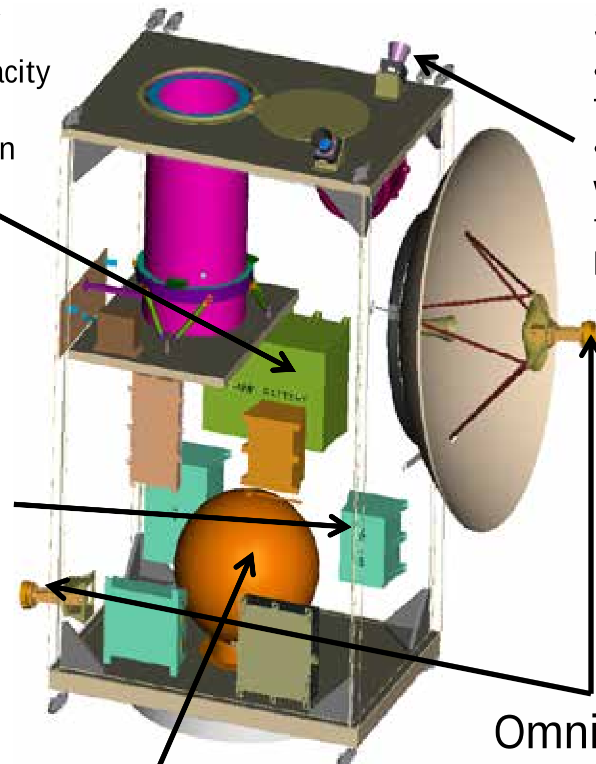
- Asteroid deflection demonstration
  - Must yield measurement of asteroid deflection to within 10%
- Choice of NEA binary [65803] Didymos as prime target
  - Already well-observed radar and optical binary
  - Approaches to 0.071 AU from Earth in Oct 2022, an excellent mission and radar opportunity
  - A relatively low-risk PHA with MOID > 0.04 AU; the target asteroid is gravitationally bound to a massive primary, minimizing change of heliocentric orbit

PHA=potentially hazardous asteroid

MOID=minimum orbit intersection distance

DART Spacecraft Concept





Telescope
- LORRI Narrow Angle Camera

Battery
- 300 W-hr capacity for launch
- 32V lithium-ion

Star Tracker
- Sinclair Star Tracker
- Data combined with LN200 IMU for attitude knowledge.

Thrusters
- 1N Aerojet monoprop thrusters
- Provides 3-axis stabilization

Structure
- Aluminum Honeycomb design

Avionics
- LEON3FT Spacecraft Processor
- Provides power switching

Fixed HGA
- 3 Mbps downlink prior to impact
- 1.4 Mbps downlink at max earth distance
- 2 kbps uplink

Fixed Solar Arrays
- 2.7 m^2 array area 230W End of Life power
- Deployment after launch

Propellant Tank
- 120 m/s Delta-V
- Hydrazine with pressurant

Omni LGA
- 50/125 bps emergency up/downlink
- 15/2 kbps early ops up/downlink

DART Spacecraft Summary

	Mass (kg)	Power (W)
Instrument	9	5
Spacecraft	158	206
Propellant	18	N/A
Total	185	211
Lift Capability	330	N/A
Total Margin	**145**	**63**
Total Margin (%)	**87%**	**30%**

- Simplistic spacecraft design with single instrument enables low mass
- Comprises of low-cost, COTS components
- The Minotaur V selected as launch vehicle due to low cost
- Currently hold large mass margins, and plan to add dummy weight to reach LV capability, in order to increase impact energy

DART Spacecraft Driving Design Requirements
The spacecraft shall impact with enough momentum to change the binary orbital period of Didymos by >0.1%.
Miss distance from the target center of mass (impact parameter) shall be less than 25 m
The impact point location shall be determined to an accuracy of 1m
Final imaging of the target shall be better than 1 m/px, SNR 20; (Goal) <20 cm/px and SNR 100

Rapid Response, Space Intercept

- APL mission experience relevant to asteroid mitigation by spacecraft intercept
  - Operation Burnt Frost in 2008
    - US Navy ship-based missile intercept of a failed satellite, a successful hit-to-kill
  - Vector Sum mission (Delta 180) in 1986
    - First space-based intercept of thrusting vehicle

DELTA 180

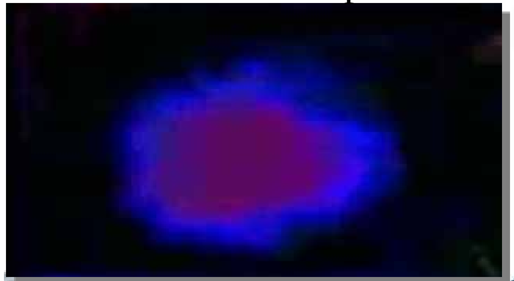
JOHNS HOPKINS UNIVERSITY
Applied Physics Laboratory

Burnt Frost

Critical National Need to Protect Against Potential Loss of Life

- Objective: protect potential populated areas from an unpredictable reentry and possible crash of ~5000lb satellite with hazardous hydrazine propellant
- Integrated government, laboratory, and industry team with ~2 months warning successfully executed a one-time mission for the Navy and Missile Defense Agency using Aegis BMD that
  - Reported satellite as an engageable track
  - Identified satellite as a valid target
  - Computed valid intercept points and revised aimpoint
  - Successfully engaged and eliminated the target

Pre-Intercept



Post Intercept

SM-3 Blk IA

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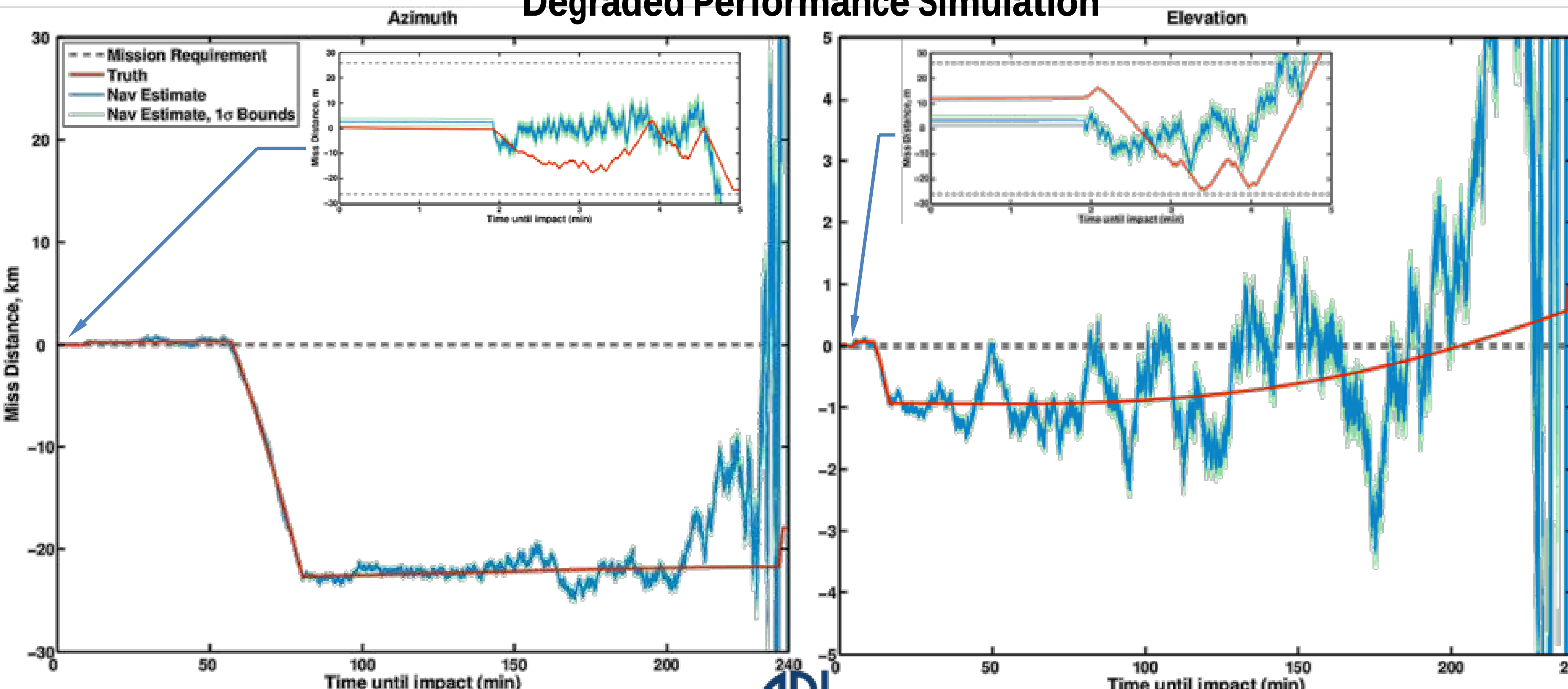
Terminal Guidance Simulation

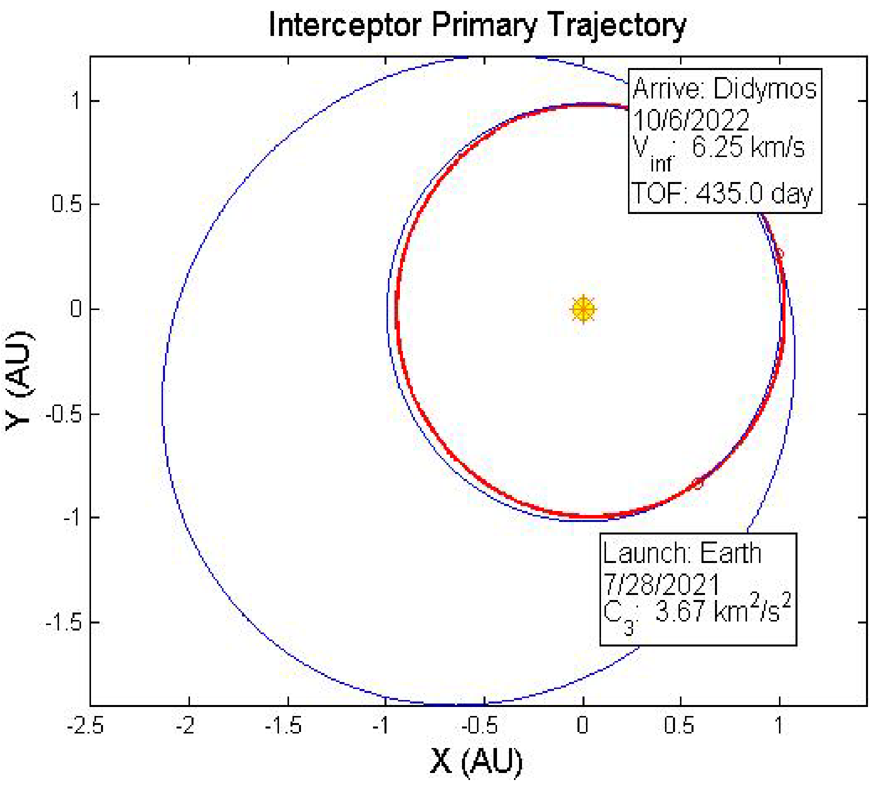
- Ground based navigation aims DART for an intercept with the Didymos primary. At the hand-off, the terminal guidance software initializes and diverts to the target using proportional navigation. The autonomy shuts down in the final 2 minutes to allow for a science imaging campaign.
- In this simulation, DART is initialized with a 20 km error in its targeting, and given highly degraded sensor characteristics. Even in these conditions, the autonomy converges on the target and impacts successfully, using less than 10 m/s ΔV. The nominal case has an accuracy of less than 5m.

Degraded Performance Simulation



2022 Didymos Intercept

- DART trajectory remains near 1 AU from Sun, Earth distance < 0.11 AU.
- DART launch on Minotaur V.
- Impact velocity 6.25 km/s
- Impact event in 2022 occurs under excellent Earth-based viewing conditions including radar

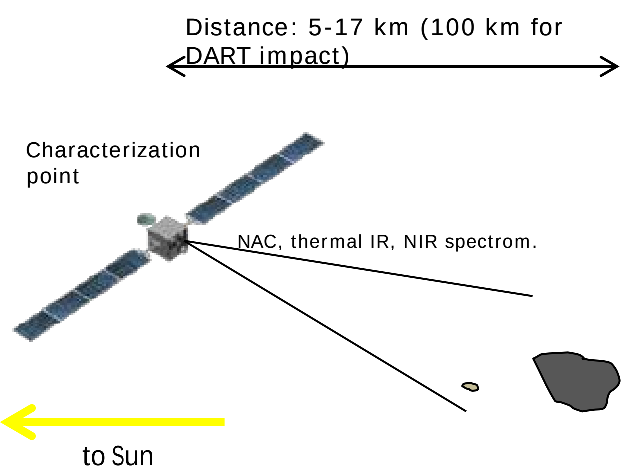


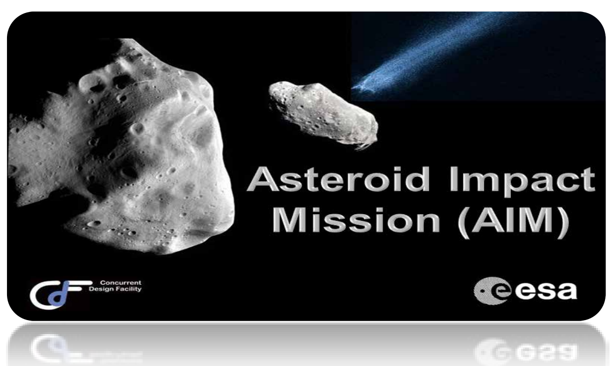
DART Payload Objectives

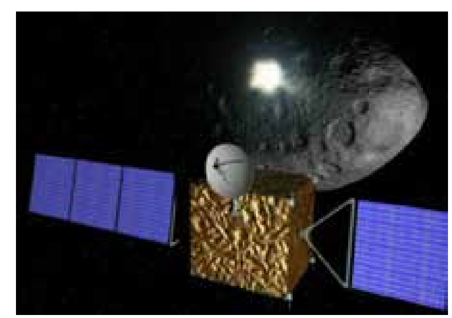
- DART payload is an imager based on New Horizons LORRI
  - 20 cm telescope with CCD camera
- Support autonomous guiding to impact target body through center
- Determine impact point within 1% of target diameter
- Characterize pre-impact surface morphology and geology of target (goal <20 cm/px) and companion body

AIM as a monitoring mission

- target characterization through a rendezvous and observation from a distance
- **characterization also from ground (radar, optical) - *simpler, more robust***
- autonavigation demonstration
- Cost target under 150 M€



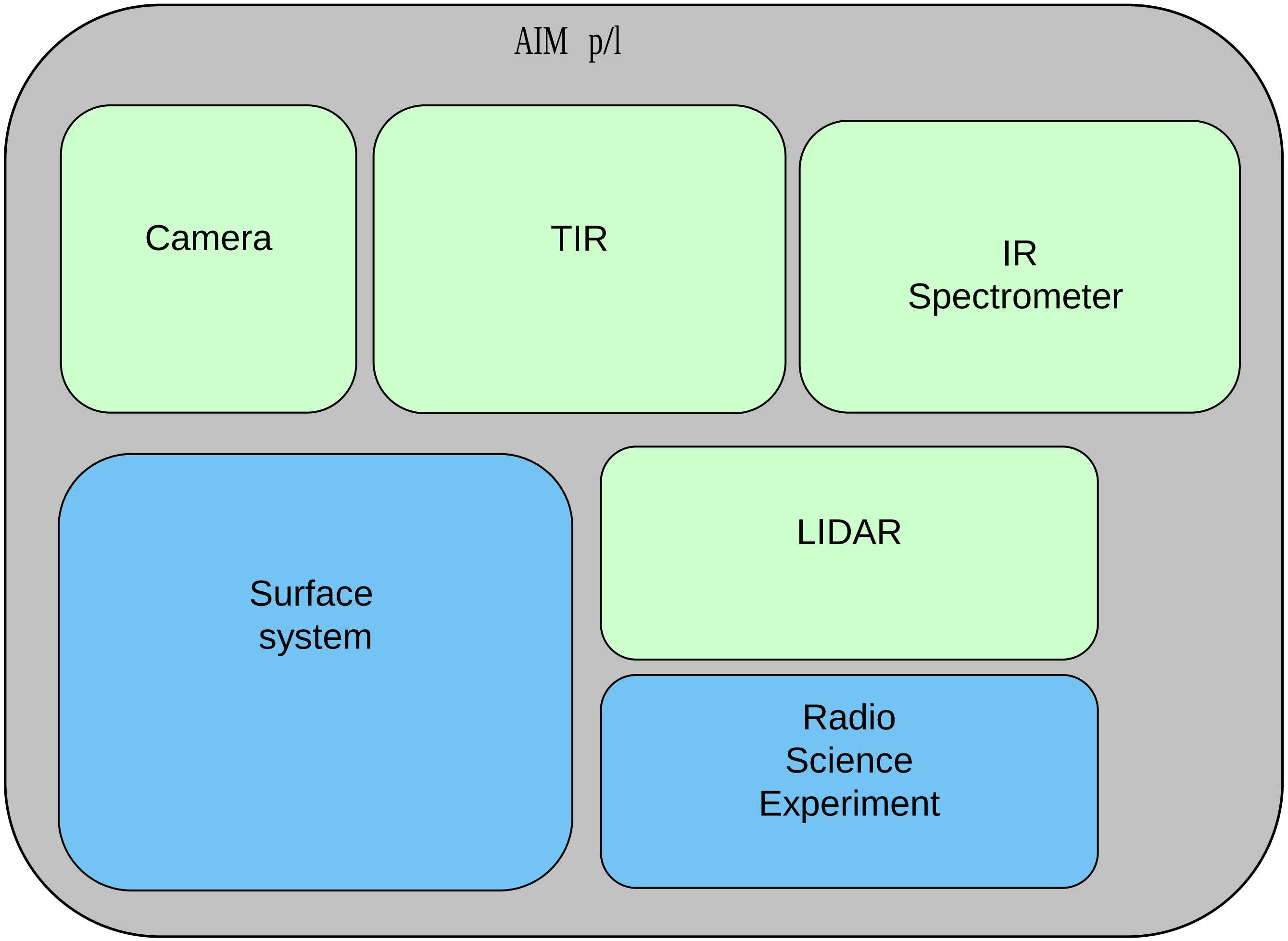




AIM Payload Objectives

P#	Parameter	Relevance to goal	Possible measurement / is it a must have?
1	· Orbital state	· Key to determine momentum	· Ground (photometry, radar), in-space (CAM) – a must
2	· Rotation state	· Key to determine momentum	· Ground (photometry, radar), in-space (CAM) – a must
3	· Size, Mass, Gravity	· Mass key to momentum, size to shape, volume, gravity to internal structure, operations	· Mass from binary orbit, shape model from CAM (or LIDAR), a must, gravity field RSE (not a must?)
4	· Geology, surface properties	· Bulk composition, material mechanical properties, surface thermal inertia	· VIS photometry to derive spectral type (must), IR spectrometer mineralogy (not a must) · TIR for Yarkowski / YORP (not a must if not large source of error)
5	· Density, internal structure	· Affects absorption of impact energy, · "data point" for study of asteroid mitigation.	· Bulk values derived from mass, shape model · Radar Tomography, seismic probing. I largely increases complexity and not a must (conclusion DQ/NEO1). = outside scope AIM

Payload Options

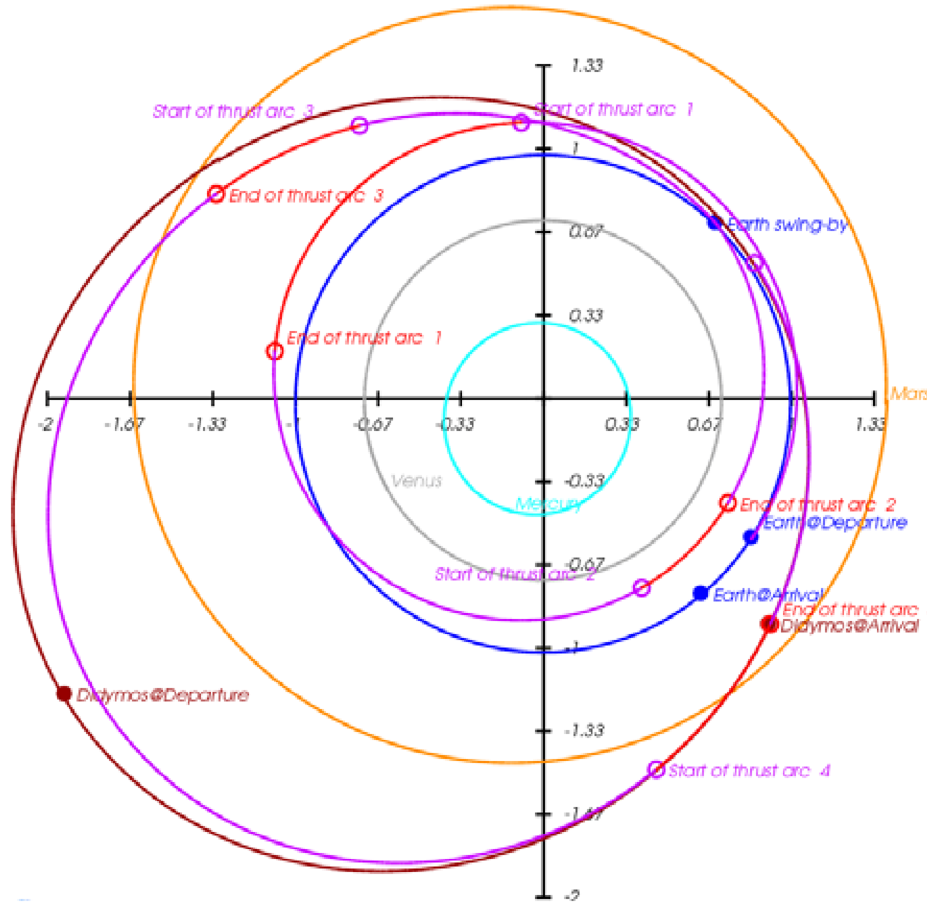


Green = nominal payload

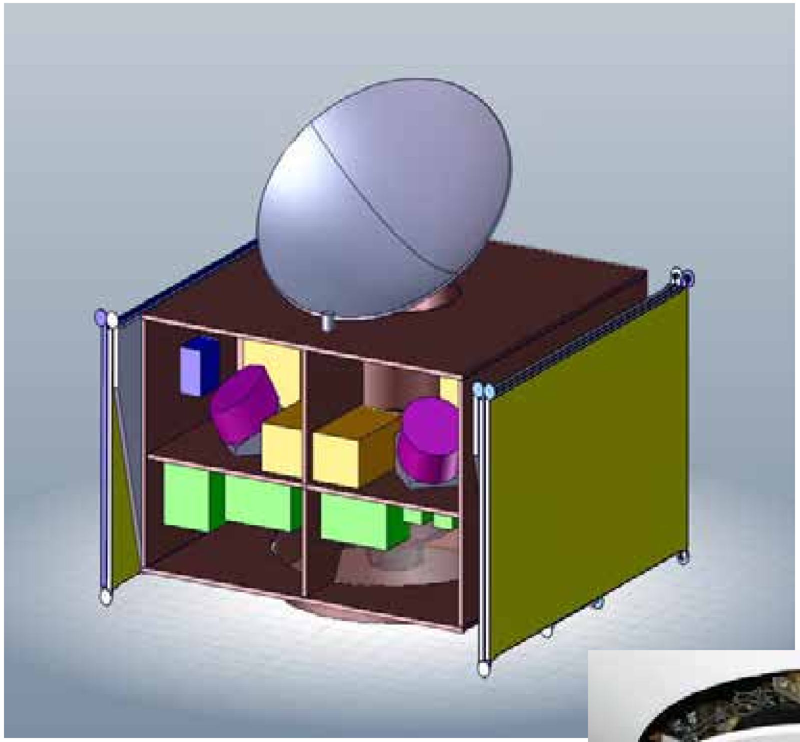
Blue = optional payload

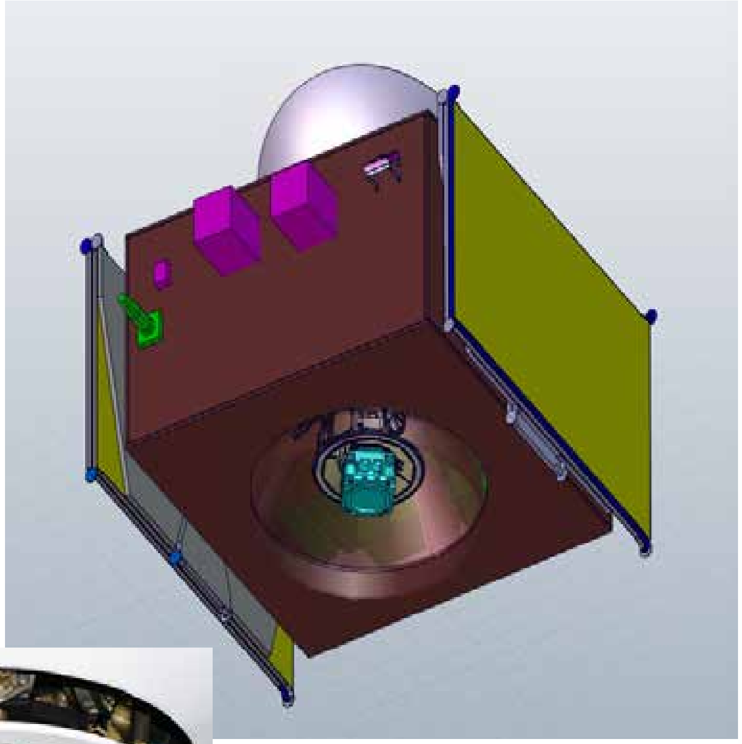
Interplanetary transfer (EP option)

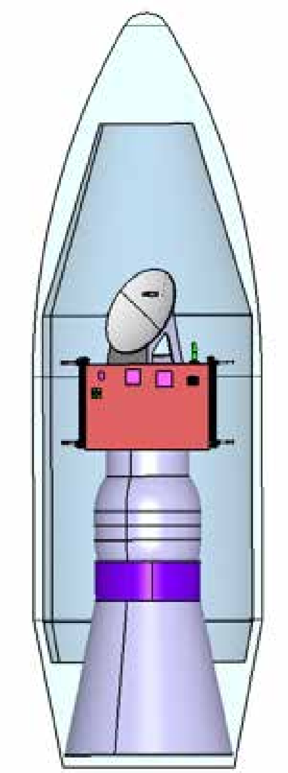
Launch	**19/08/2019**
Escape velocity [km/s]	1.0
Declination [deg]	-14.46
Escape mass [kg]	400
Earth swing-by	**07/11/2020**
Infinite velocity at SB [km/s]	5.44
Vel. at pericentre [km/s]	10.8
Pericentre altitude [km]	2854
Arrival	**01/08/2022**
Final mass [kg]	324
SEP delta-v [km/s]	2.9
Xenon consumption [kg]:	73
Hydrazine consumption [kg]:	5
Thruster on time [d]:	213
Total Impulse[10^6kg m/s]:	1.05



AIM Spacecraft Concept







AIM Mass Budget

Propulsion Stage Mass (kg)	
Structure	**23.21**
Clampbands S/C I/F	6.60
S/C adaptor	16.61
Mechanisms	**35.20**
Clamp Band spin table	14.30
Spring set spin table	3.30
Clamp Band prop module	14.30
Spring set prop module	3.30
Propulsion	**137.55**
SRM Star 48	137.55
Dry Mass Propulsion Stage	**195.96**
Propellant STAR 48	**1222.00**

Rendezvous S/C Mass (kg)	
Dry Mass w.o. margin	269.60
Dry Mass + 20% margin	323.52
Propellant Hydrazine	9.00
Propellant Xenon	73.00
Wet Mass	**405.52**

A Simpler Mission than Don Quijote

DQ	AIM/DART	Comment
2 s/c launched separately	2 s/c launched separately	AIM and DART C/D phase independence
Impactor launched after Orbiter rdv	AIM launched to rdv (in principle) before DART hits	AIM and DART still fully meaningful in absence of the other spacecraft
NEA CoG Δa ≥ 100 m	Binary ΔP/P>0.1, no requirement on Δa	Measure in-space (CAM) and ground (photometry),
Orbiter and RSE required	Co-flying, orbiting or RSE not strictly required	Simple telecom subsystem and operations possible
In-situ experiment only at end of mission	In-situ as an option, likely after impact	Secondary p/l depends of mass, operations cost, PI contribution
Autonomous optical navigation 2 days before impact	Autonomous optical Autonav as an option for AIM, not mandatory	Technology experiment for rendezvous spacecraft

AIDA: affordable, low risk cooperation

- Science
  - Visit a binary near-Earth asteroid
  - Estimate internal structure and composition
  - Measure crater formation and redistribution of material
- Planetary Defense
  - Understand kinetic impact effects for future deflection technologies
  - Estimate momentum transfer by impact and by enhancement of ejecta
- ESA Call for AIDA Payload Ideas
  - NEO Mitigation International Workshop on Friday

BACKUP

Overlapping Goals of NEO Missions

Planetary Defense

Deflection demonstration and characterization
Orbital state
Rotation state
Size, shape, gravity
Geology, surface properties
Density, internal structure
Sub-surface properties
Composition (mineral, chemical)

Science

Orbital state
Rotation state
Size, shape, gravity
Geology, surface properties
Density, internal structure
Sub-surface properties
Composition (including isotopic)

AIDA

Deflection demonstration and characterization
Orbital state
Rotation state
Size, shape, gravity
Geology, surface properties
Density, internal structure
Sub-surface properties

Human Exploration

Orbital state
Rotation state
Size, shape, gravity
Geology, surface properties
Density, internal structure
Composition (mineral, chemical)
Radiation environment
Dust environment

Resource Utilization

Geology, surface properties
Density, internal structure
Sub-surface properties
Composition (mineral, chemical)

Science Objectives

- First measurements of spacecraft hypervelocity impact experiment
  - Beta factor highly uncertain
- First cratering experiment on a NEO using a known impactor at known incident velocity
  - Pin down cratering histories and surface ages of inner solar system bodies, relating them to impactor populations
  - Opportunity for seismic measurements

Science Objectives

- Measure or infer surface properties of NEO
  - Strength, density, porosity
  - Inferences on internal structure of a binary asteroid companion
  - Implications for binary formation scenarios
- Spacecraft impact may expose subsurface material to depths of many meters

Planned NASA Involvement and Contributions

- **NASA contributions to AIDA mission**
  - Follow-up ground-based characterization
    - Photometry/Lightcurve
    - Radar
    - Spectroscopy
    - Orbital Dynamics
  - Mission concept analysis and development
  - Team members on observing and characterization spacecraft (ESA’s AIM)
  - Secondary impact spacecraft (APL’s DART)
  - DSN coverage for critical events

AIDA Connections to NASA Interests

- **Science**
  - Conduct a visit to a binary near-Earth asteroid
  - Detect possible mass transfer between primary & secondary bodies
  - Measure crater formation and redistribution of material
  - Estimate internal structure and composition

- **Planetary Defense**
  - Understand kinetic impact effects for future deflection technologies
  - Estimate momentum transfer by impact and by enhancement of ejecta

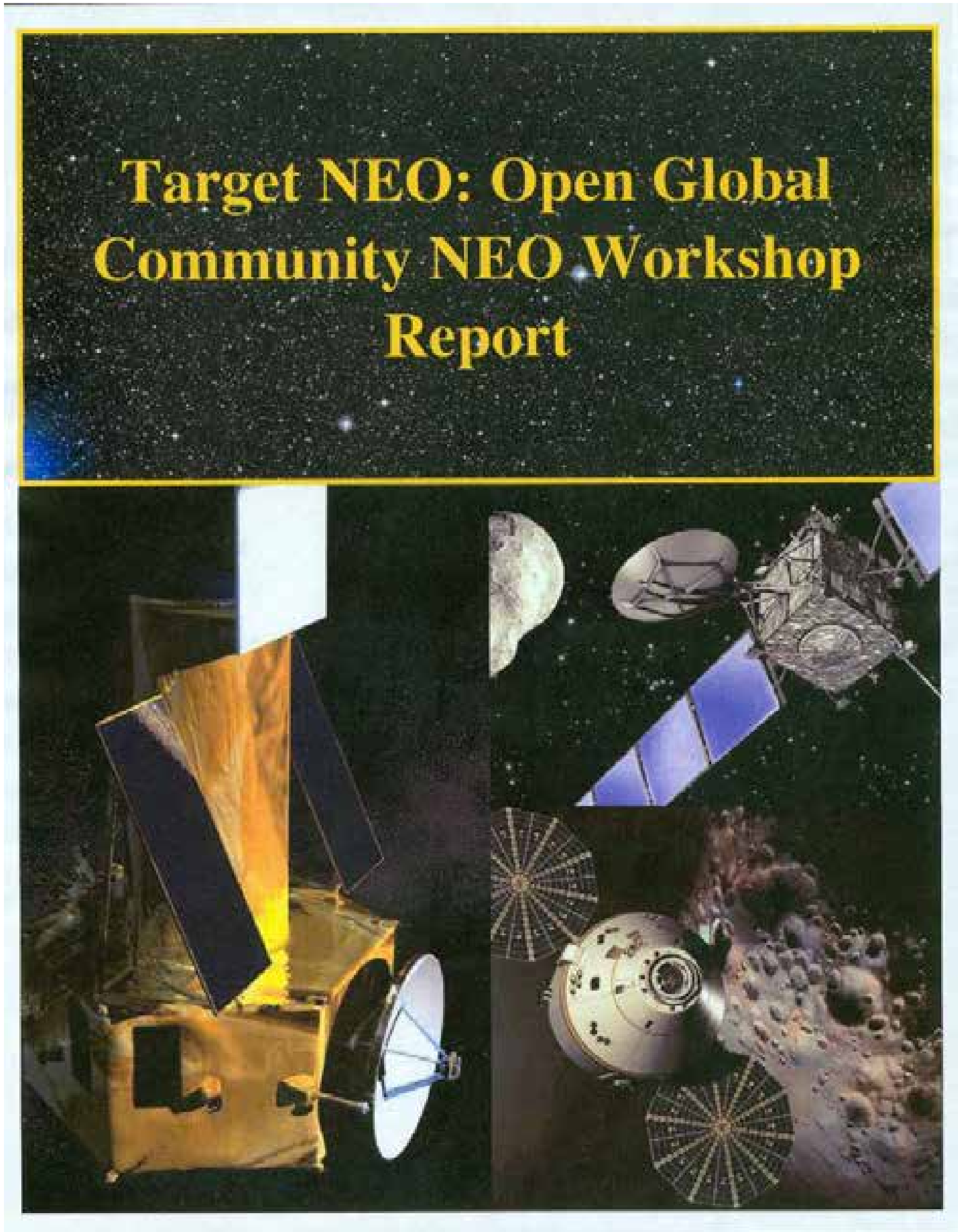
- **Exploration**
  - Coordinate international deep space mission operations
  - Develop flight techniques and experience for small body missions
    - Optical navigation and acquisition
    - Rendezvous
    - Proximity Operations
  - Plan and perform detailed characterization

• Target NEO Global Community Workshop (February 2011) confirmed the critical necessity for a Space-based Survey Mission for both NEO mitigation and exploration (http://www.targetneo.org/)

•A companion international workshop was held in conjunction with the PDC on 13 May 2011. NEO Survey priority was confirmed, and second priority defined for a NEO Mitigation Demonstration Mission

• Next step: Introduce a mitigation demonstration mission both for US stakeholders and for ESA stakeholders in preparation for an element within the SSA Programme

•Our global response to this next step....



Didymos for AIDA

- **Discovered in April 1996 by Spacewatch**
  - 2 years before NASA accepted Congressional mandate
- **It is a NEO (Apollo group)**
  - Also a Potentially Hazardous Asteroid (PHA)
  - Relatively low delta-V target for rendezvous missions
- **Follow-up characterization**
  - Lightcurve observations in Nov. 2003 showed that Didymos was binary (Pravec, P. *et al*., 2006).
  - Additional observations from Arecibo confirmed it was binary (Benner, L. *et al*., 2010).