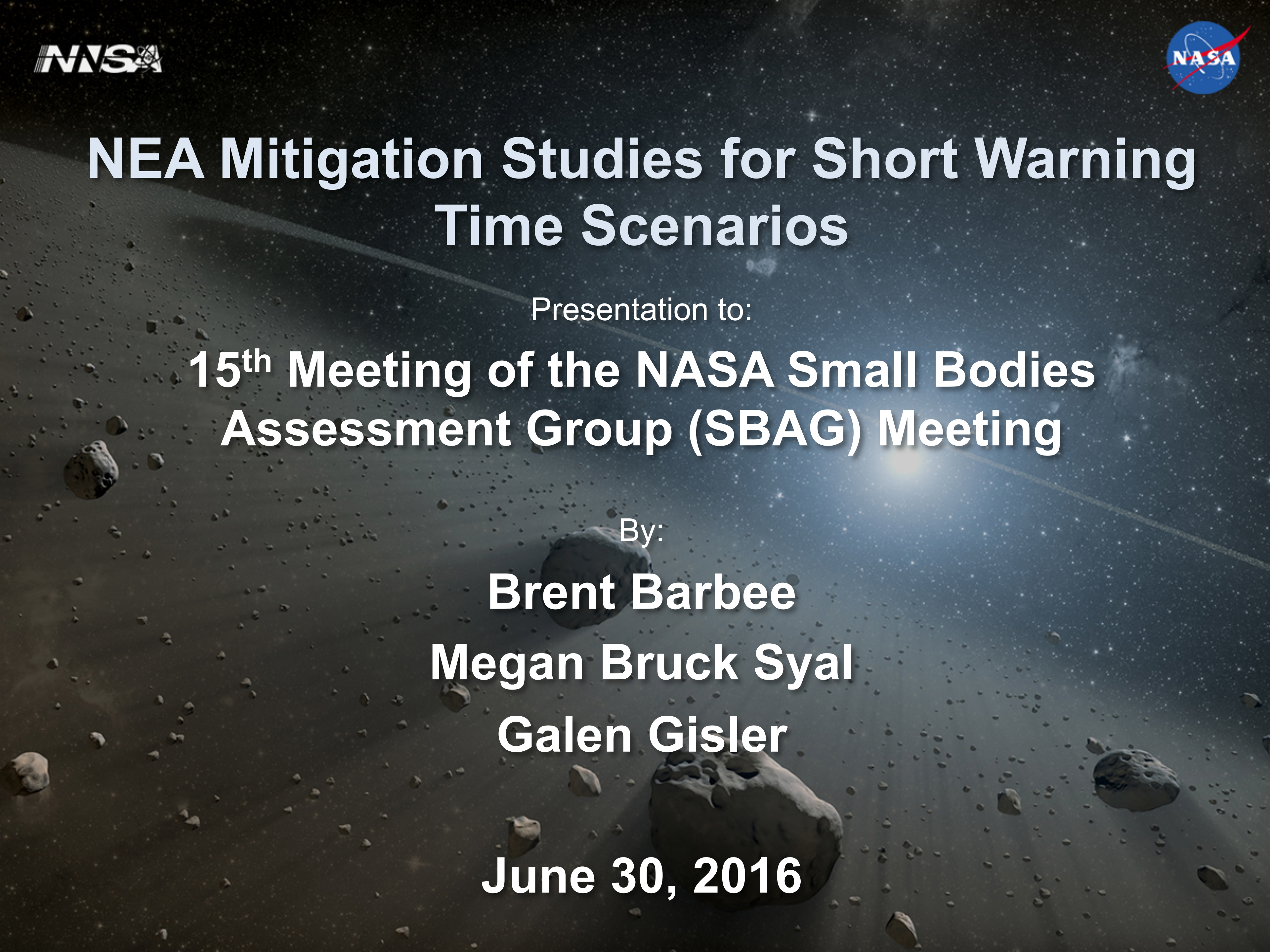


NEA Mitigation Studies for Short Warning Time Scenarios

Presentation to:

15th Meeting of the NASA Small Bodies Assessment Group (SBAG) Meeting

By:

Brent Barbee
Megan Bruck Syal
Galen Gisler

June 30, 2016

DOE

Near Earth Object (NEO) Mitigation Study

Description and Objectives:

- Conduct end-to-end systems analysis of NEO intercept mitigation scenarios for the class of potentially hazardous asteroids (PHA) ranging in size from 100 and 500 meters in diameter
- Study the short warning scenario, where warning times below 10 years are indicated and emergency response solutions are a last resort
- Investigate the range of impulsive solutions for hypervelocity impactor architectures, model the deflection/disruption scenarios using physics based models and advanced mission design concepts
- Conduct detailed timeline analysis for each mitigation scenario

HAMMER **– Hypervelocity Asteroid Mitigation Mission for Emergency Response**

Strategic Partnership:

- Joint research project with LANL, LLNL, SNL DOE/NNSA National Laboratories – IAA
- Parse this multi-dimensional, combinatorially complex problem and solve by parts; recompile using a scenario-based approach
- Set up an off-Lab repository for DRA/DRMs in the short term and design/develop a Framework prototype for the longer run

Key Collaborators:

- NNSA HQs
- LLNL
- LANL
- SNL

3 Year Study Period:

- January 2015– December 2017

Accomplishments and Next Milestones:

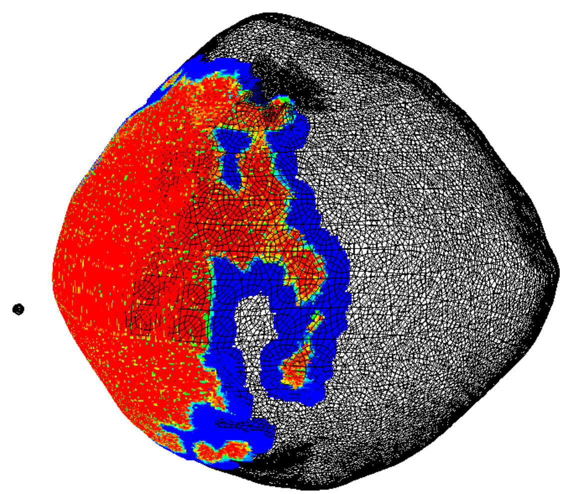
- ✓ Interagency Agreement signed January, 2015
- ✓ Teams awarded funding from DOE and NASA last quarter, 2014
- ✓ Code-to-code comparison completed April, 2016
- DRA 2 – Diddymos Binary – collaborating with APL and ESA on AIDA/DART
- Publication of Case Study 1 complete by Fall 2016

Key Challenges/Innovation:

- High speed approach trajectory
- Uncertainties in asteroid physical properties and overall effectiveness of deflection missions
- Autonomous navigation
- Big Data

Our collaboration is employing a scenario-based approach to the planetary-defense problem

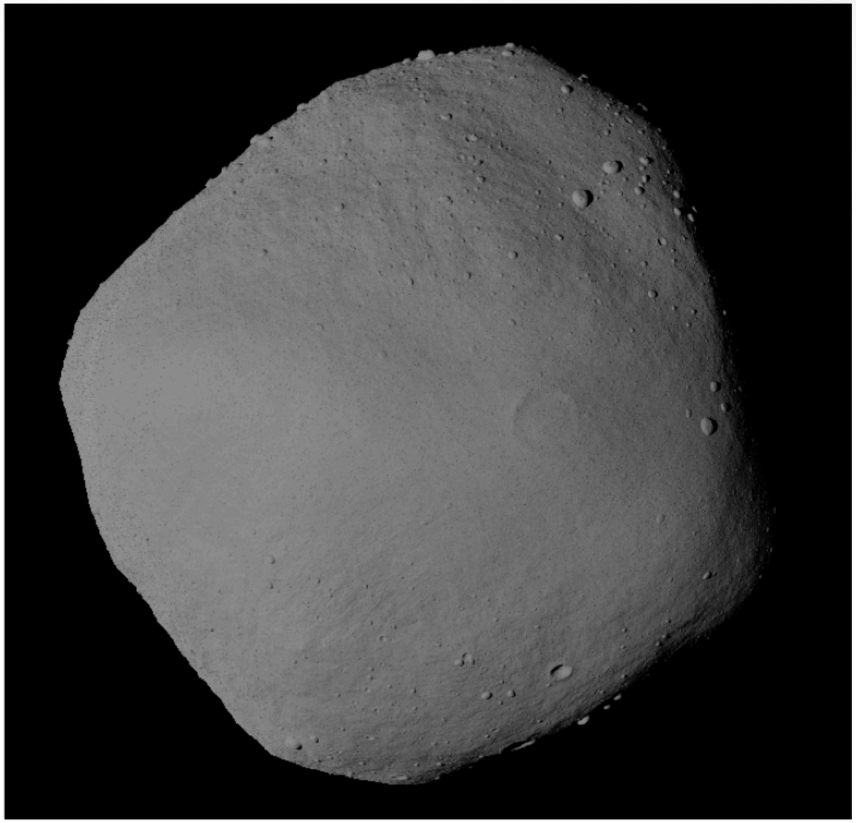
- Case Study 1: Bennu scenario
- The NNSA contributions have included:
  - Contributions to the definition of the scenario
  - Participation in the MDL (2-6 November 2015, at GSFC)
  - Comparisons of simulation methods (code-to-code study)
  - Numerical modeling of deflection events
    - kinetic impactor
    - nuclear deflection
  - Studies of sensitivity of results to parameter variations
  - Debris-field estimates and evolution
  - Estimation of deflection velocities in the context of launch windows and spacecraft trajectories (for comparison with NASA results)
- The GSFC contributions have included:
  - Contributions to the definition of the scenario
  - Leadership of the MDL study
  - Detailed physical and orbital data for Bennu
  - Mission design for Bennu intercept
  - Trajectory optimization for Bennu deflection



Credit: J. Michael Owen

Case 1 Study Target: Bennu

- Carbonaceous asteroid
  - B-type
  - Low albedo (~4%)
- Approximately 500 m in diameter
- Bulk density is approximately 1 g/cm^3
- Rotation period is ~4.3 hours
- OSIRIS-REx Design Reference Asteroid (DRA) document provides full details and is available online
    - http://arxiv.org/abs/1409.4704
    - http://arxiv.org/ftp/arxiv/papers/1409/1409.4704.pdf
- One of the best (remotely) characterized and most hazardous known NEOs
- NASA's OSIRIS-REx mission, scheduled to launch September 2016, will map Bennu in great detail and return samples to Earth

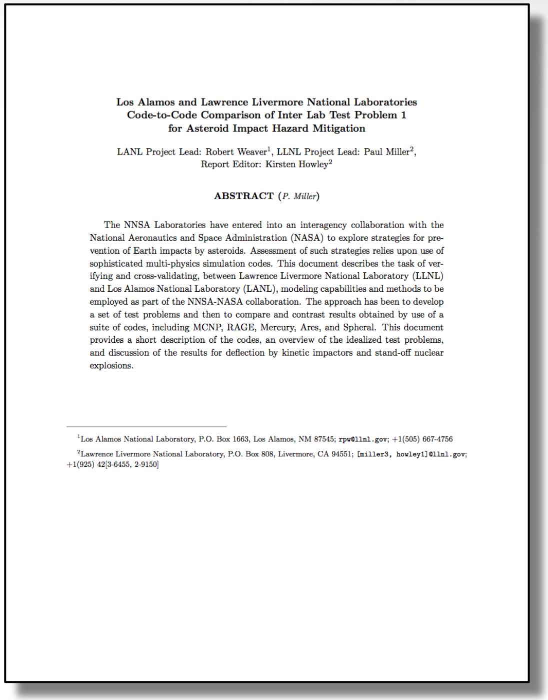


Simulated Image of Bennu

LLNL and LANL have documented a code-to-code comparison of simulation methodologies

- The 36-page report was completed in February

  (LLNL-MI-680901, LA-UR-16-20205)
- Test problems were defined and run
- Kinetic impactors
  - problem defined
  - cases run and compared
- Nuclear deflection
  - problems defined — both neutron and x-ray deposition
  - cases run and compared



Los Alamos and Lawrence Livermore National Laboratories
Code-to-Code Comparison of Inter Lab Test Problem 1
for Asteroid Impact Hazard Mitigation

LANL Project Lead: Robert Weaver[1], LLNL Project Lead: Paul Miller[2],
Report Editor: Kirsten Howley[2]

ABSTRACT (*P. Miller*)

The NNSA Laboratories have entered into an interagency collaboration with the National Aeronautics and Space Administration (NASA) to explore strategies for prevention of Earth impacts by asteroids. Assessment of such strategies relies upon use of sophisticated multi-physics simulation codes. This document describes the task of verifying and cross-validating, between Lawrence Livermore National Laboratory (LLNL) and Los Alamos National Laboratory (LANL), modeling capabilities and methods to be employed as part of the NNSA-NASA collaboration. The approach has been to develop a set of test problems and then to compare and contrast results obtained by use of a suite of codes, including MCNP, RAGE, Mercury, Ares, and Spheral. This document provides a short description of the codes, an overview of the idealized test problems, and discussion of the results for deflection by kinetic impactors and stand-off nuclear explosions.

---

[1] Los Alamos National Laboratory, P.O. Box 1663, Los Alamos, NM 87545; `rpw@llnl.gov`; +1(505) 667-4756

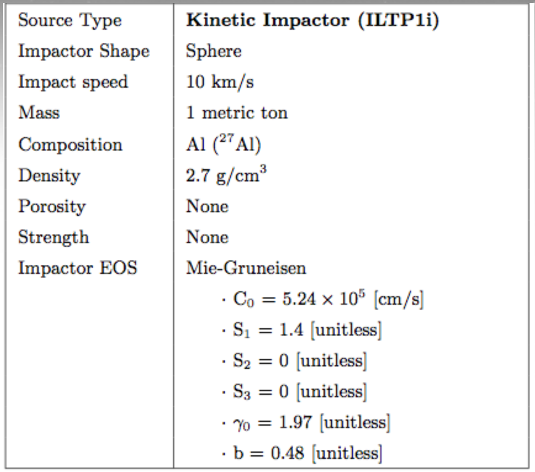
[2] Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, CA 94551; `[miller3, howley1]@llnl.gov`; +1(925) 42[3-6455, 2-9150]

Differences were reconciled and there are currently no significant concerns regarding the comparison

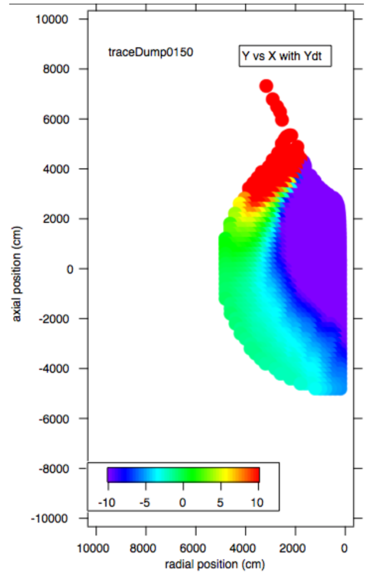
Results by LLNL and LANL for the kinetic-impactor test problem agree well

- There was an initial discrepancy for the porous case, but that was resolved to be a consequence of a particular model
- Once models were run consistently, the results were quite similar

β	LANL result	LLNL result
Full density	31	31.5
40% porosity	3.73	3.69



Source Type	**Kinetic Impactor (ILTP1i)**
Impactor Shape	Sphere
Impact speed	10 km/s
Mass	1 metric ton
Composition	Al (^{27}Al)
Density	2.7 g/cm^3
Porosity	None
Strength	None
Impactor EOS	Mie-Gruneisen
	· $C_0 = 5.24 \times 10^5$ [cm/s]
	· $S_1 = 1.4$ [unitless]
	· $S_2 = 0$ [unitless]
	· $S_3 = 0$ [unitless]
	· $\gamma_0 = 1.97$ [unitless]
	· $b = 0.48$ [unitless]

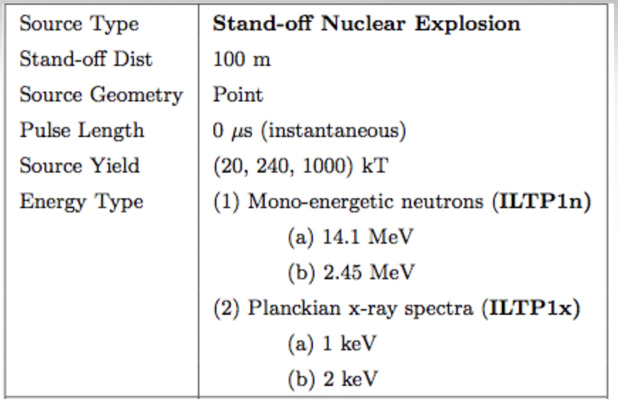


axial velocity example

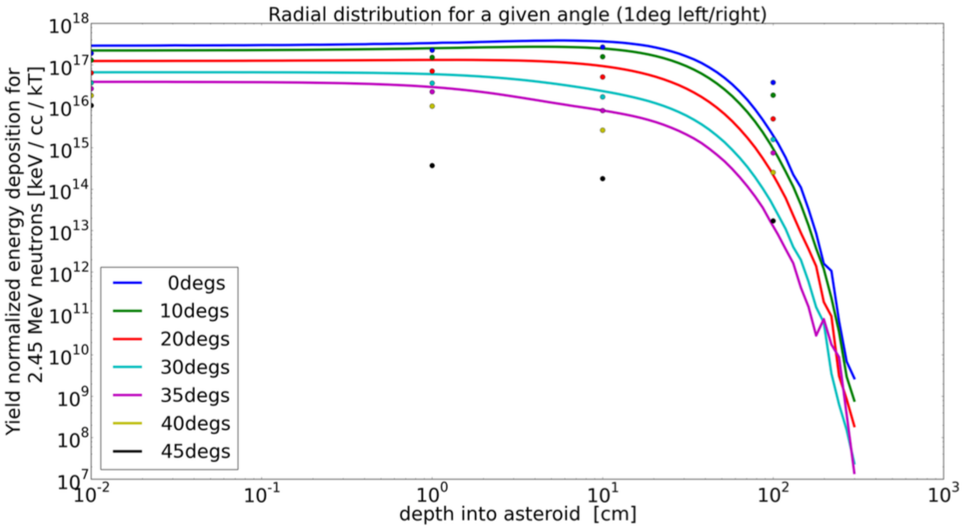
Credits: Megan Bruck Syal, Galen Gisler

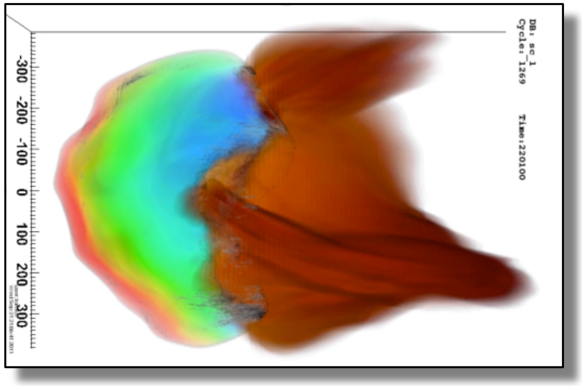
Neutron and X-Ray Depositions Were Compared

- Two problems were examined
  - neutron deposition (ILTP1n)
  - x-ray deposition (ILTP1x)
- The neutron deposition results were in relatively close agreement



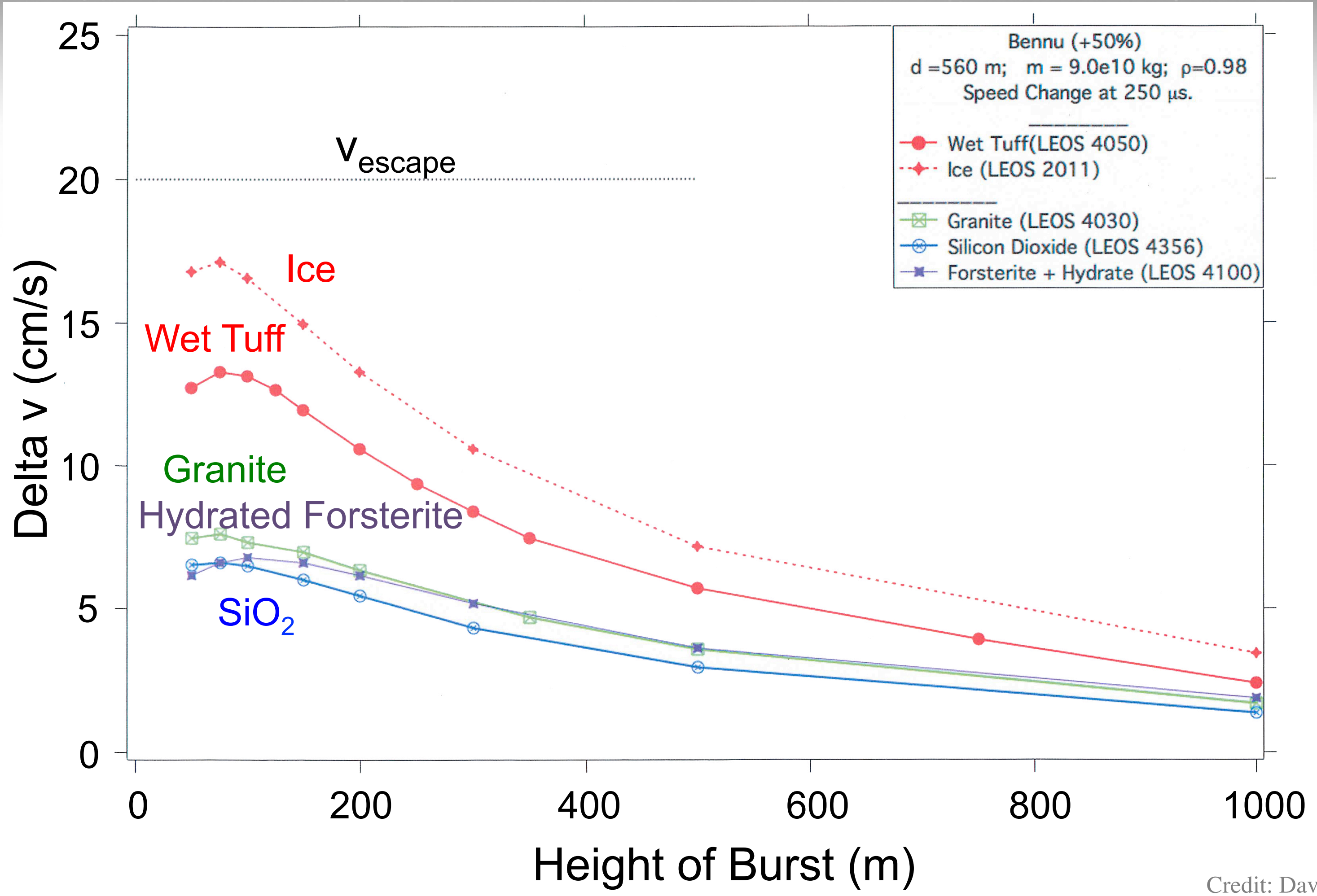
Source Type	**Stand-off Nuclear Explosion**
Stand-off Dist	100 m
Source Geometry	Point
Pulse Length	0 μs (instantaneous)
Source Yield	(20, 240, 1000) kT
Energy Type	(1) Mono-energetic neutrons (**ILTP1n**) (a) 14.1 MeV (b) 2.45 MeV (2) Planckian x-ray spectra (**ILTP1x**) (a) 1 keV (b) 2 keV





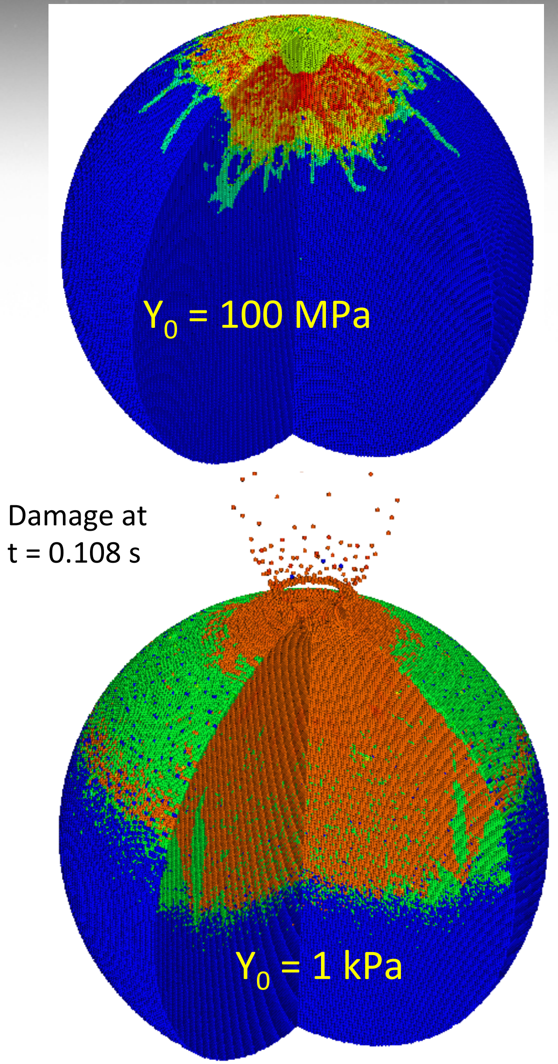
Credits: Kirsten Howley, Jim Ferguson, Rob Managan, Joe Wasem, Ilya Lomov

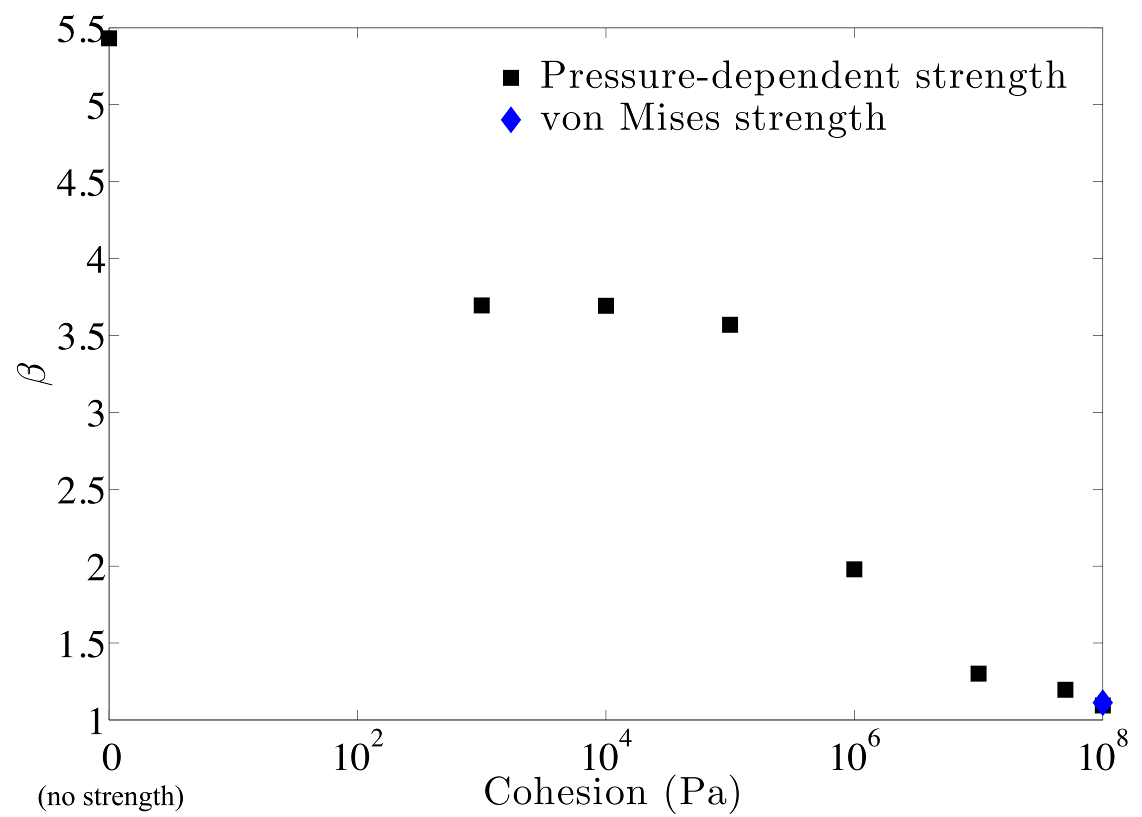
Composition of an asteroid affects deflection results



Credit: David Dearborn

Cohesion of asteroid material affects deflection: significant decrease for cohesion greater than 100 kPa

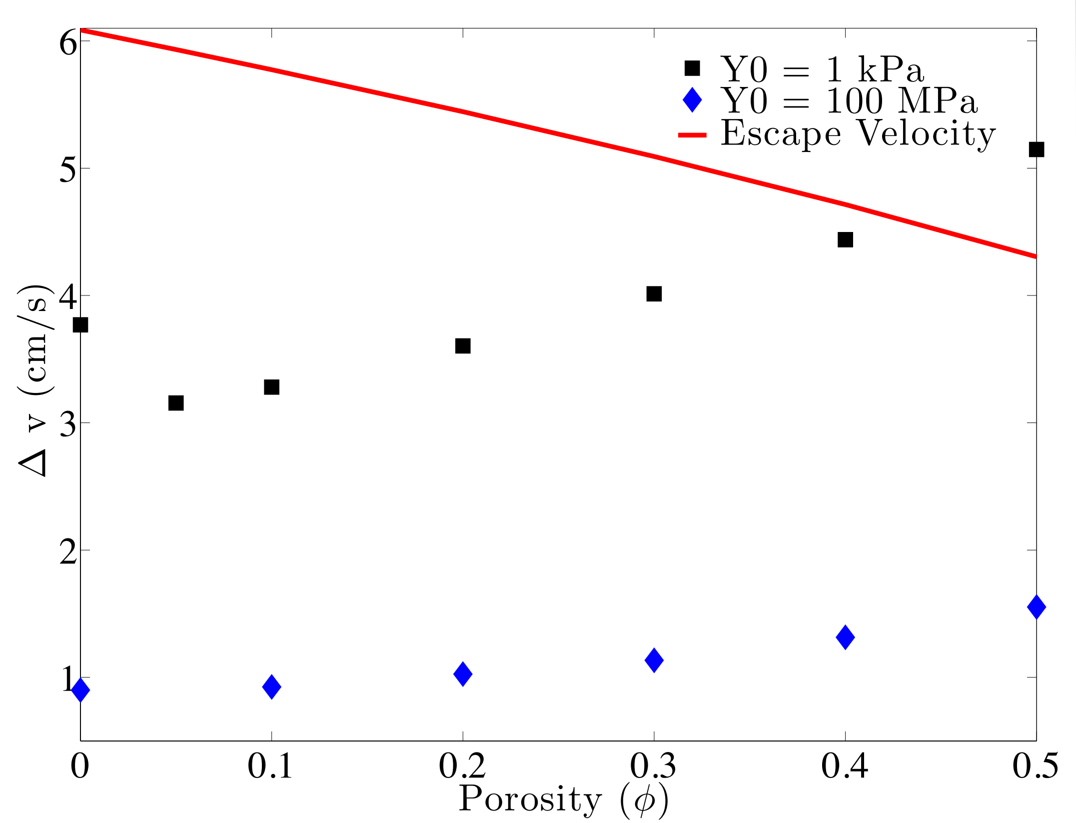




$$Y_i = Y_0 + \frac{\mu_i P}{1 + \mu_i P/(Y_M - Y_0)}$$

Credit: Megan Bruck Syal

Increased asteroid porosity *enhances* deflection (primarily due to lower target mass) while lowering disruption risk



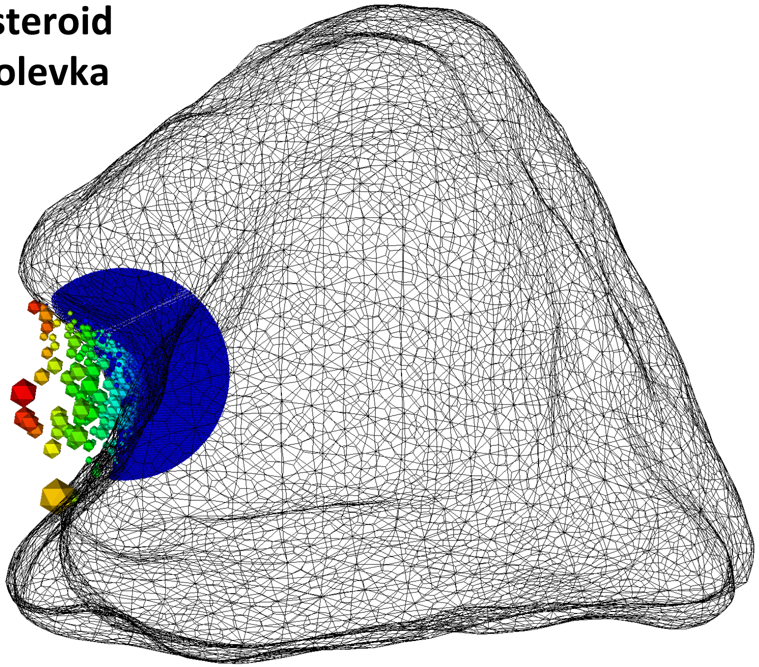
- 10-ton steel impactor at 5 km/s
- Larger Δv at greater porosities, shown for 100-m asteroids
- Even a little porosity protects against unintentional disruption

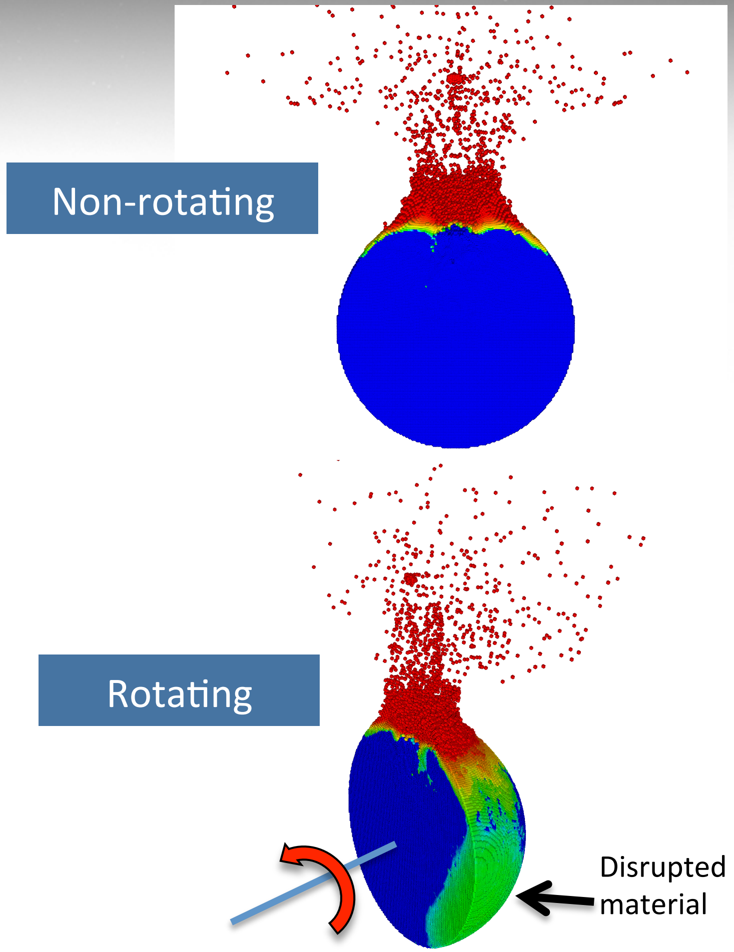
Credit: Megan Bruck Syal

Rotation does not significantly affect deflection but does affect disruption risk

- Rotation enhances ejecta, but not beta
- Slope matters, and may be difficult to control
    - Collaborating with D. Scheeres/UC Boulder

Asteroid Golevka





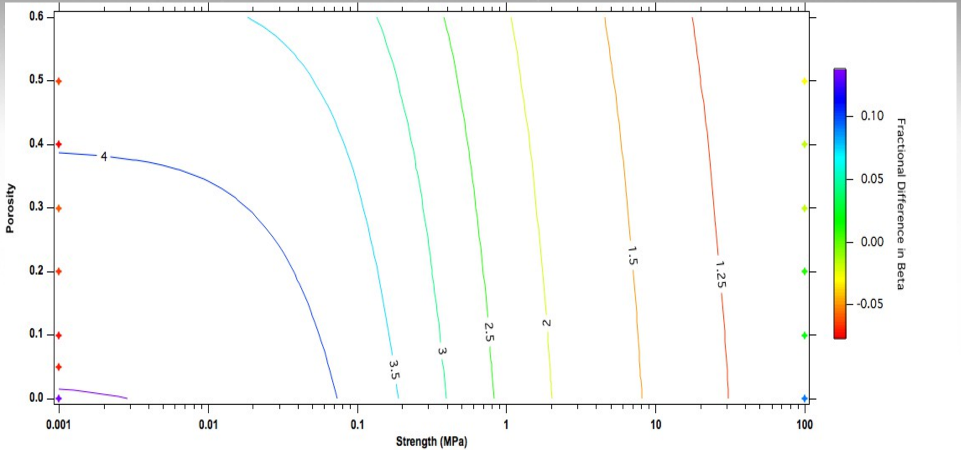
See also: Bruck Syal et al. 2016. Deflection by Kinetic Impact: Sensitivity to Asteroid Properties. *Icarus* **269**, 50-61.

Credit: Megan Bruck Syal

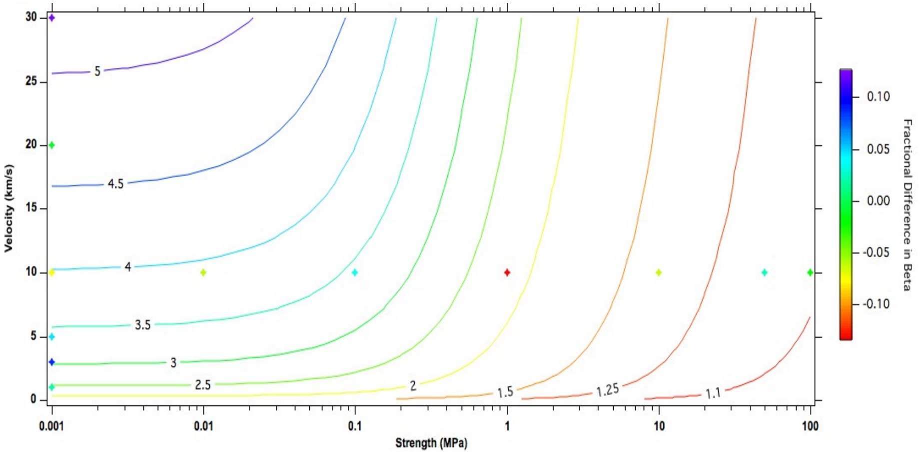
Kinetic impact results can be combined into scaling relations across velocity, strength, and porosity

These relations feed into deflection mission design:

- Selection of launch window
- Kinetic or nuclear choice



Note that modeling resolution matters: Under-resolved simulations over-estimate damage accumulation and momentum transfer for impactors

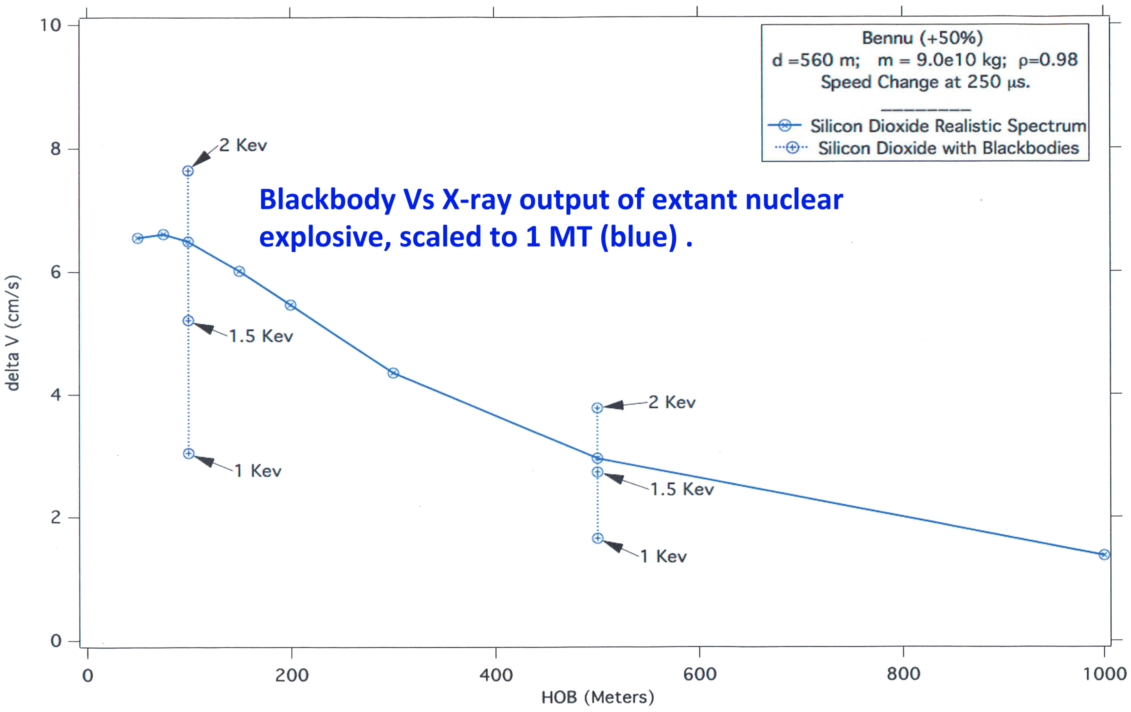


Credit: David Dearborn & Megan Bruck Syal

Deflection velocities from standoff nuclear burst, applied to Case 1 target Bennu, are consistent across codes

LLNL 2D Rad-Hydro Code:	7 cm/s
LLNL 3D Spheral: Extrapolate to	6 cm/s
LANL Parametric study:	6.8 cm/s
LANL 2 or 3D EAP project Code:	TBD est ~ 6.8 cm/s

Again, modeling resolution matters: resolving X-ray deposition is important for correct effect.

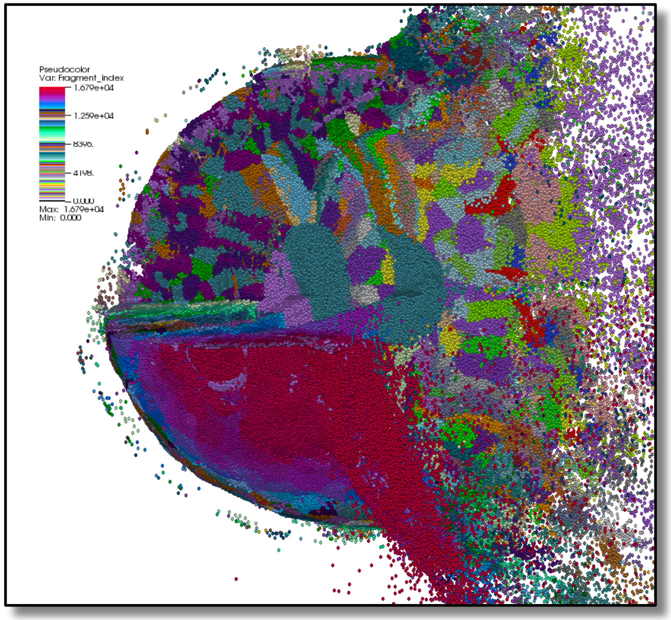


Blackbody Vs X-ray output of extant nuclear explosive, scaled to 1 MT (blue) .

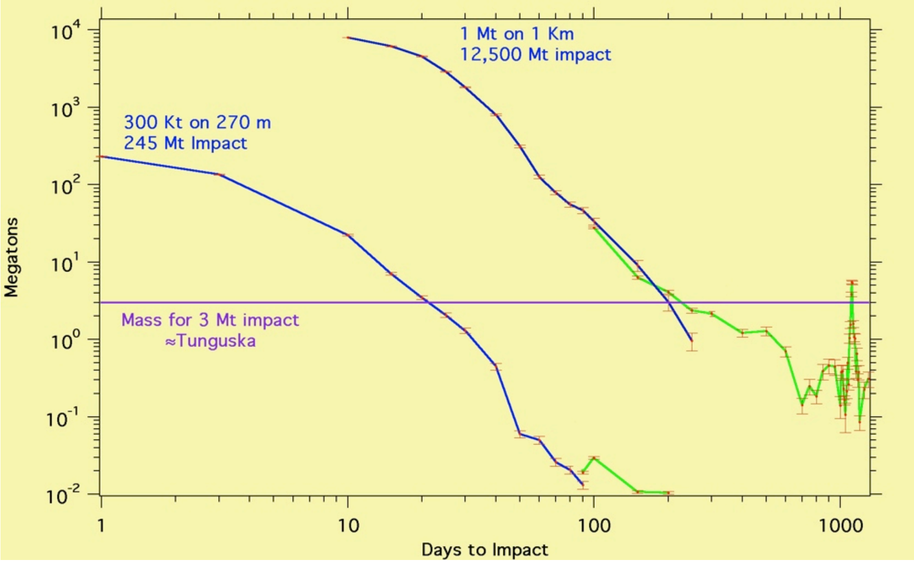
Credit: David Dearborn

Deliberate, robust disruption is an option for smaller objects and/or short warning times

- Example calculation: 270-m body disrupted by 300 Kt Surface burst, 100 days pre-impact
- Satellite damage probability ≈ $6x10^{-6}$ (1 mm dust grain impact on 10 m^2 body)
- For Case 1 (Bennu), disruption not a likely option and is not explored in-depth
  - 500-m diameter is large
  - High porosity makes disruption more difficult

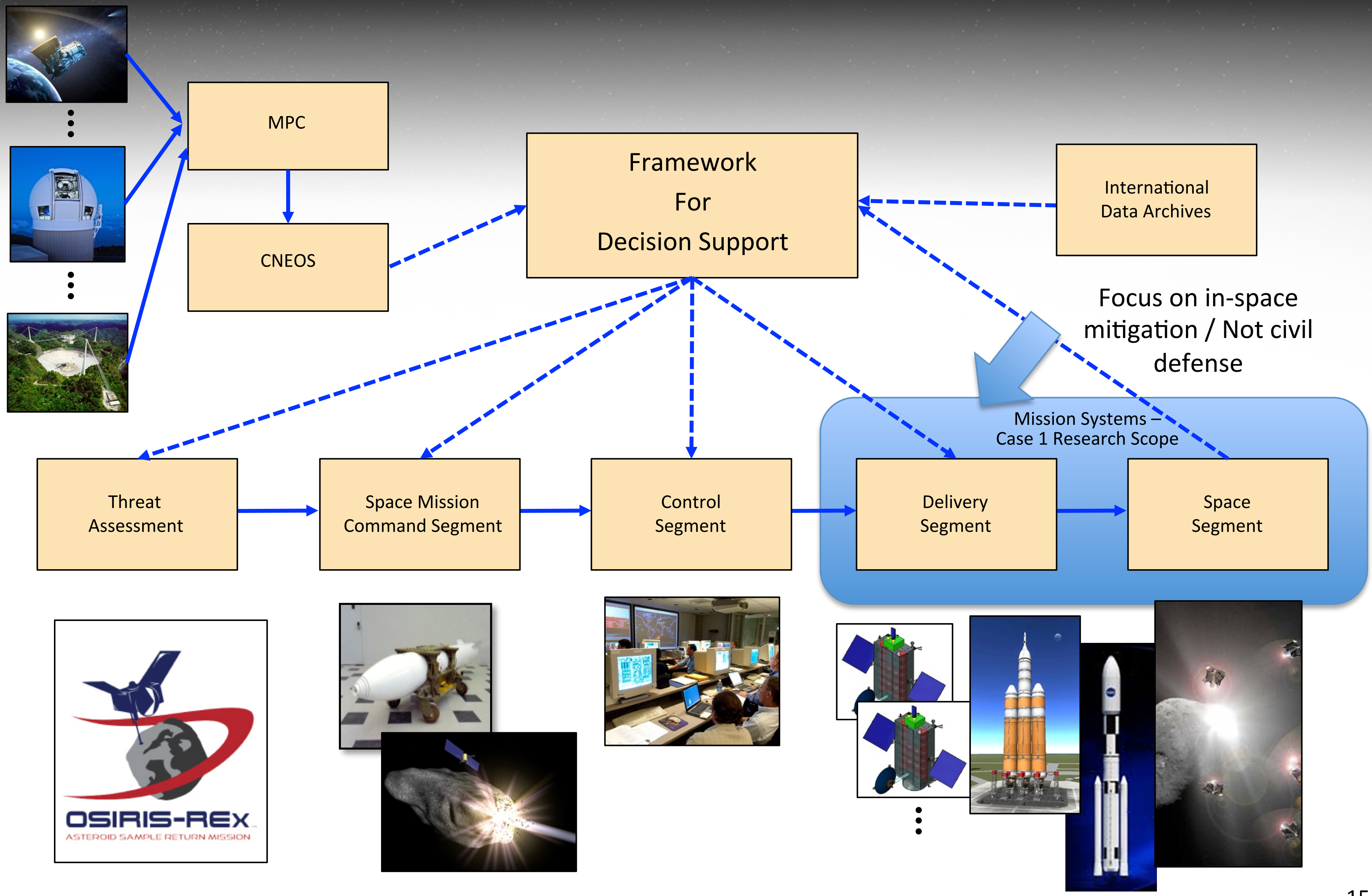


Example: 1 Mt surface burst on 50 m metallic asteroid (similar to Meteor Crater (AZ) impactor); colors represent individual fragments (credit: J. Michael Owen)



Credit: David Dearborn

NEA Mitigation Architecture



MPC

CNEOS

Framework
For
Decision Support

International
Data Archives

Focus on in-space
mitigation / Not civil
defense

Mission Systems –
Case 1 Research Scope

Threat
Assessment

Space Mission
Command Segment

Control
Segment

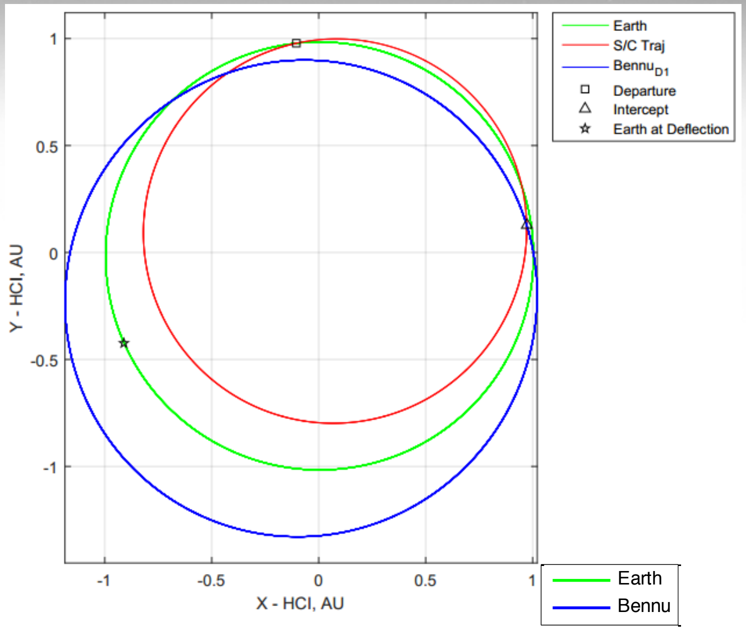
Delivery
Segment

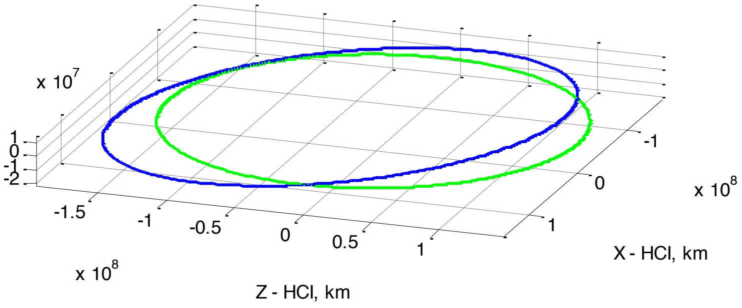
Space
Segment

Bennu Deflection Trajectory Design

Formulation Concept Design Metrics

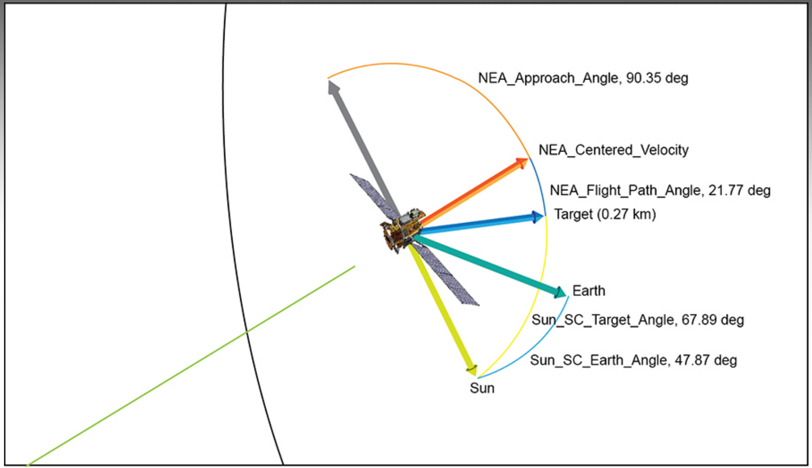
- Hypervelocity intercept of the hazardous asteroid
- An asteroid intercept spacecraft capable of carrying out a deflection attempt
- Spacecraft can function as either nuclear explosive carrier or kinetic impactor
- Spacecraft trajectories optimized to maximize deflection of Bennu away from Earth
- Assumed Delta IV Heavy (currently largest launch vehicle in the U.S. inventory)
- Designed GNC subsystem to be capable of tracking and intercepting an NEA as small as 100 m at 10 km/sec

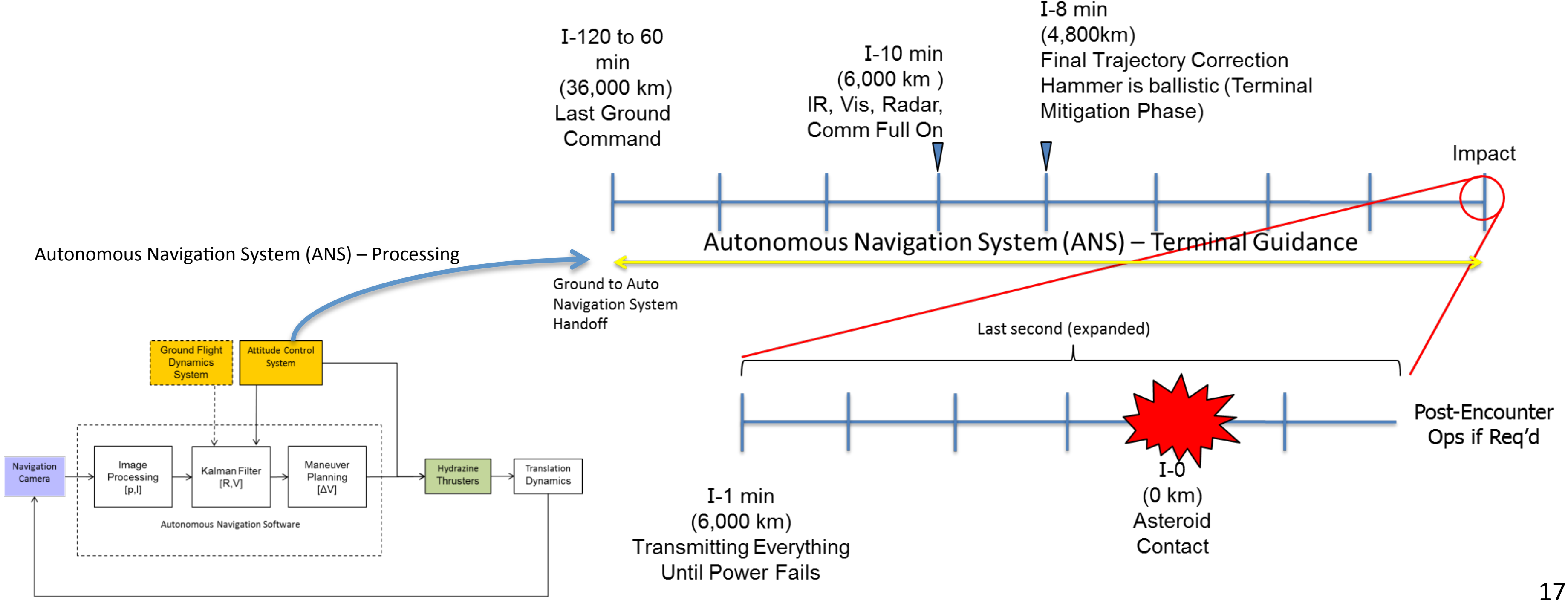




Navigation & Guidance Drivers
Terminal Mitigation Phase

- Case 1 assumptions (drivers):
  - Time of Flight: 740 days
  - Intercept Date: July 11, 2113
  - ➢ Target relative velocity at intercept: 4.48 km/s; concept goal ~10 km/s upper bound, target area goal 100 m dia
  - Approach phase angle at intercept: 90.35°
  - Maximum Distance from Earth: 1.6 AU
  - Maximum Distance from Sun: 1.06 AU
  - Total Mission ΔV: 99.2 m/s




I-120 to 60 min
(36,000 km)
Last Ground Command

I-10 min
(6,000 km)
IR, Vis, Radar, Comm Full On

I-8 min
(4,800km)
Final Trajectory Correction
Hammer is ballistic (Terminal Mitigation Phase)

Impact

Autonomous Navigation System (ANS) – Terminal Guidance

Autonomous Navigation System (ANS) – Processing

Ground to Auto Navigation System Handoff

Last second (expanded)

Post-Encounter Ops if Req'd

I-1 min
(6,000 km)
Transmitting Everything Until Power Fails

I-0
(0 km)
Asteroid Contact

Ground Flight Dynamics System

Attitude Control System

Navigation Camera

Image Processing [p,l]

Kalman Filter [R,V]

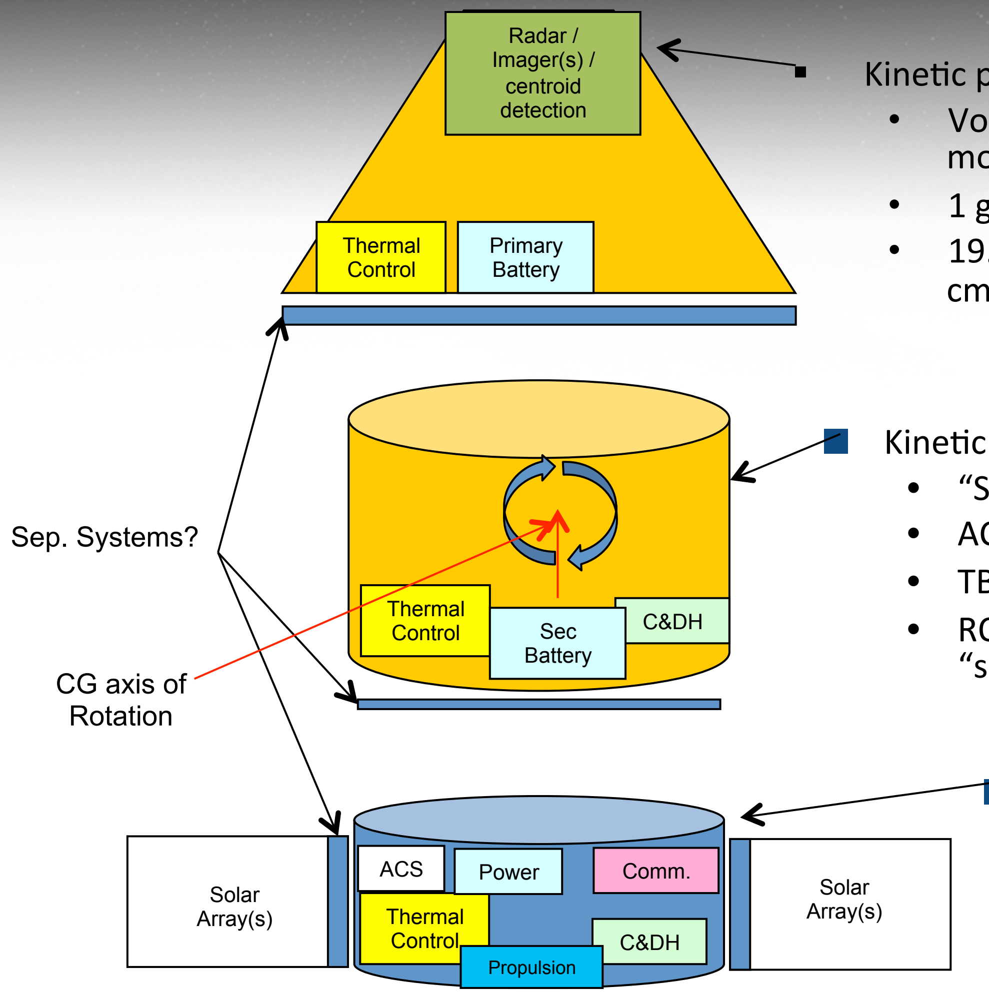
Maneuver Planning [ΔV]

Autonomous Navigation Software

Hydrazine Thrusters

Translation Dynamics

Notional Functional Allocation Concept



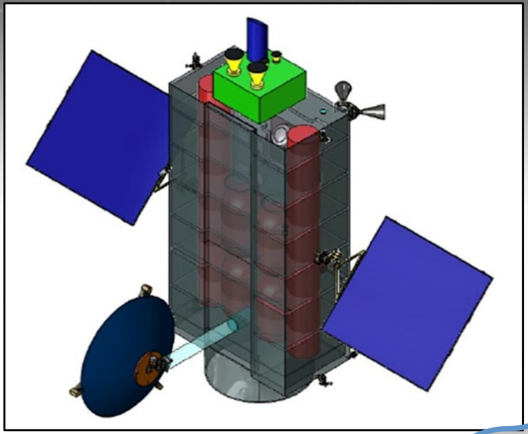
Maximizing Kinetic Payload Mass /
Spacecraft is to transport, guide, and deliver

- Kinetic payload
  - Volumetric “efficient packaging” & “efficient momentum transfer” goals; density ranges
  - 1 g/cm^3
  - 19.1 g/cm^3; ROM dimension for 8,000 kg: 64.5 cm x 157.5 cm dia “slug”
- Kinetic payload part B
  - “Simple” Avionics?
  - ACS ?
  - TBD (Thermal, C&DH, Power, SEP)
  - ROM dimension for 8,000 kg: 21.5 cm x 157.5 cm dia “slug”
- Spacecraft
  - Comm
  - ACS
  - CDH
  - Thermal
  - Propulsion
  - Power (Solar, Battery, RPS, Fuel Cell)

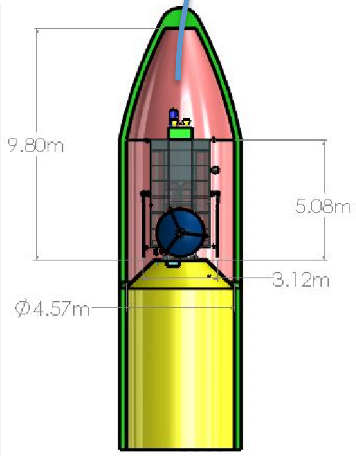
Hypervelocity Asteroid Mitigation Mission for Emergency Response

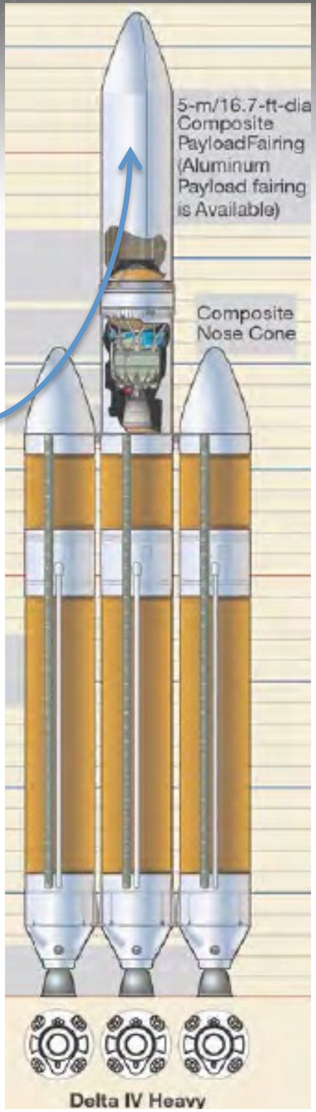
Mission POD Concept Formulation Features

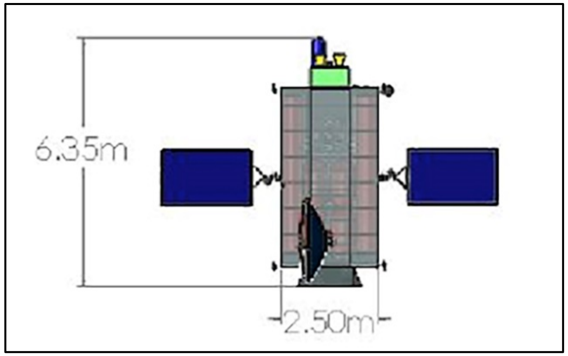
- Class A+ reliability for the deployed system
- Simple, dual string vehicle with triple voting scheme for mission-critical events
- Mass of 8800 kg chosen to max out Delta IV-H for Earth departure C_3 of 10 km^2/sec^2 (from baseline design reference trajectory)
- Fail operational during mission-critical phases
- Bearing and range (?) sensors on-board
- Uplink encryption included for device commanding (arm and execute)
- Autonomous navigation from I – 60 minutes

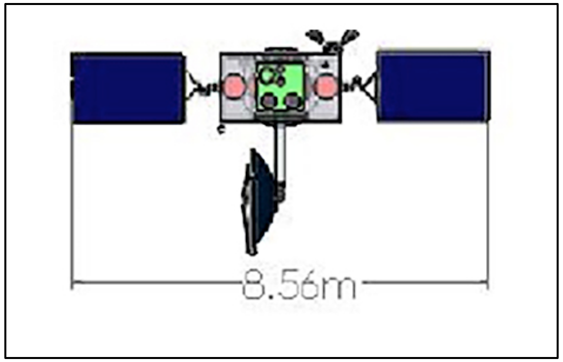


HAMMER

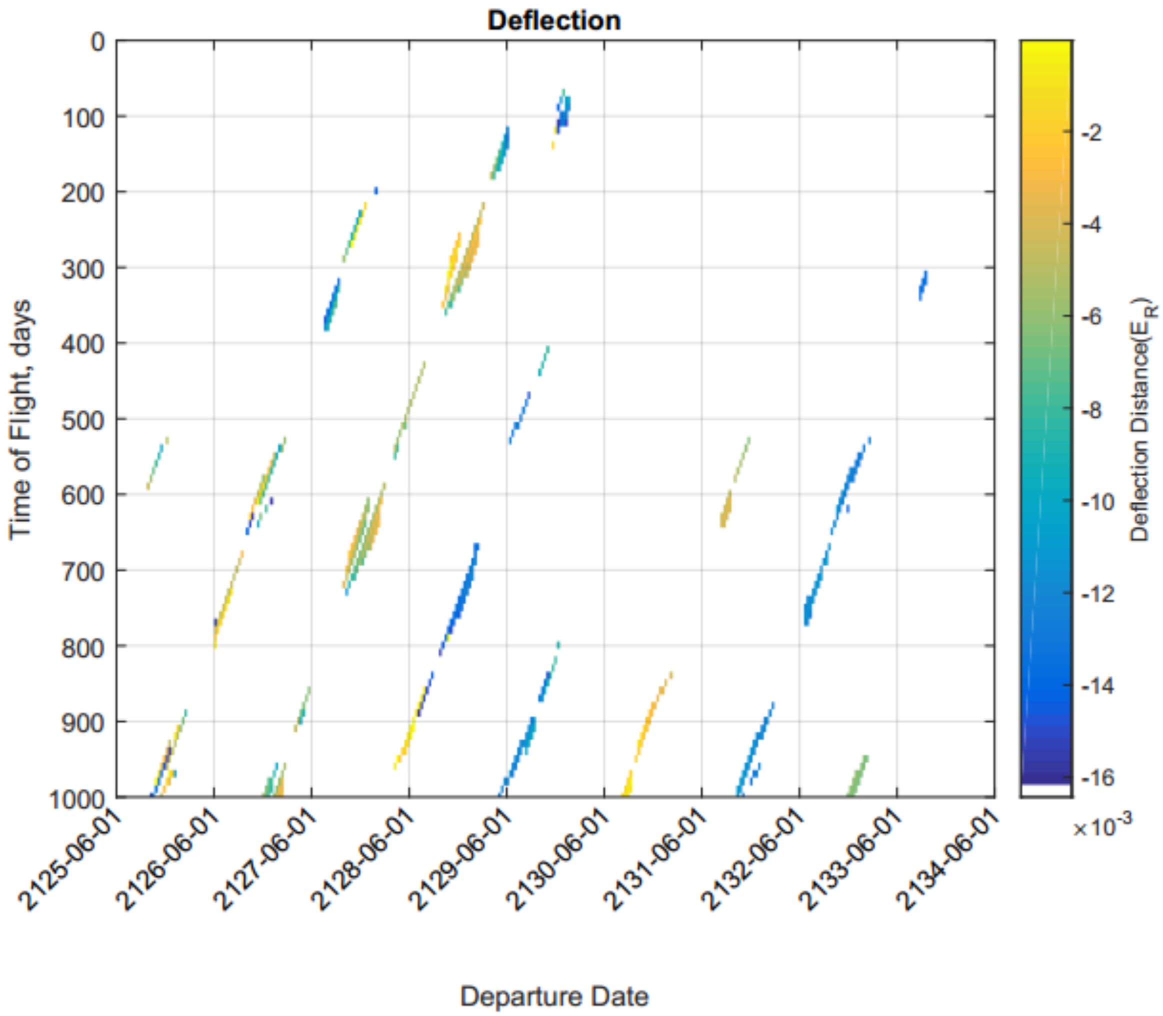




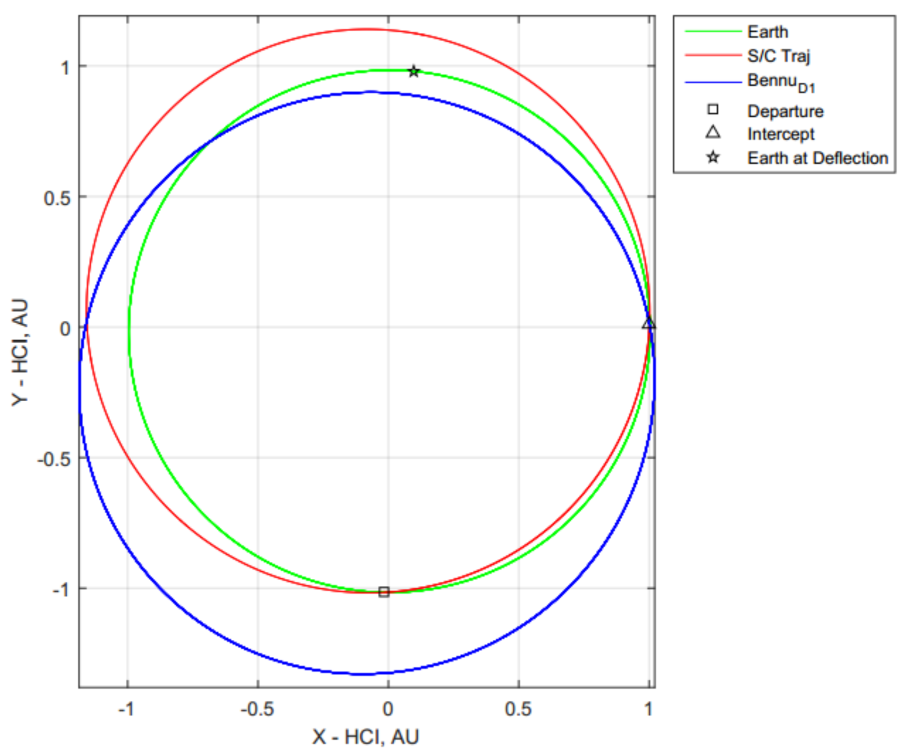




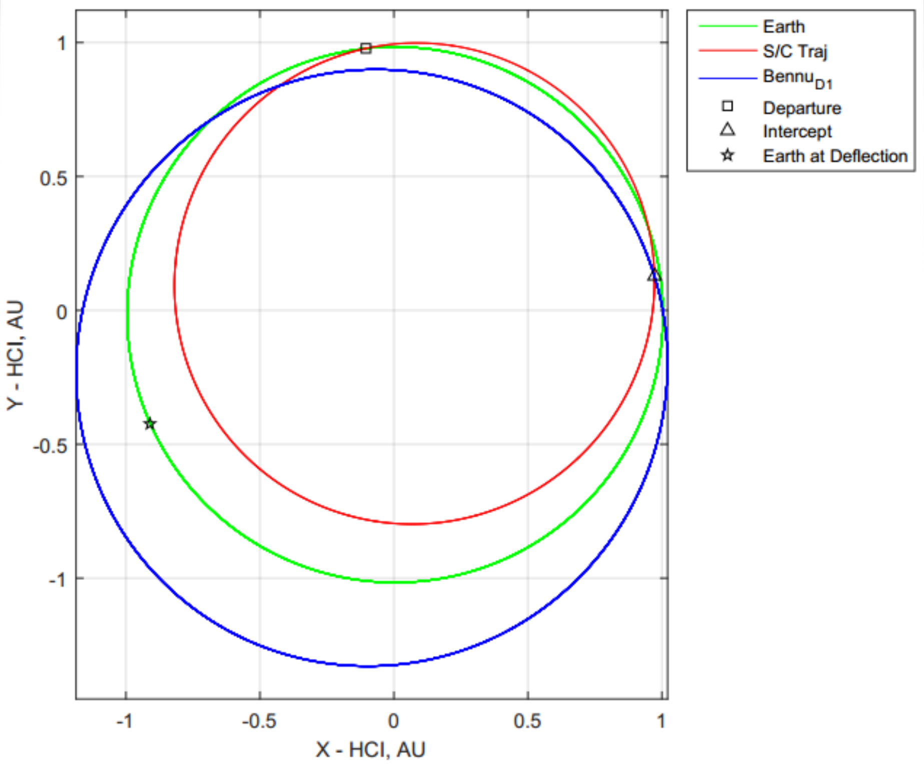
1 HAMMER, Delta IV H, 10 yr Lead



Variance in Optimal Trajectories



25 year lead time



10 year lead time

KI Deflection Analysis Summary (w/ β=1)

Available Launch Lead Time (yrs)	Launch Vehicle	Number of Launches	Used KI Mass (kg)	Specific Energy Imparted to NEO (J/kg)	Time from Deflection to Earth Encounter (yrs)	Δv Imparted to NEO (cm/s)	Defl. (R_E)	Defl. Perigee (R_E)	Defl. Bplane (R_E)
10	Delta IV Heavy	1	6508.07	0.434288	5.40	0.029388	**-0.010**	**0.990**	**0.008**
10	Delta IV Heavy (HAMMER)	1	7300.00	3.542383	4.77	0.088893	**-0.010**	**0.990**	**0.012**
10	Delta IV Heavy (HAMMER) Adjusted Mass (max mass 7300)	1	7300.00	3.542383	4.77	0.088893	**-0.010**	**0.990**	**0.012**
10	SLS Block 1 w/iCPS	1	18223.49	3.330753	5.94	0.136191	**-0.009**	**0.991**	**0.061**
10	Delta IV Heavy	49	380708.89	253.88421	8.33	5.434662	**1.526**	**2.526**	**3.779**
10	Delta IV Heavy (HAMMER)	51	372300.00	248.27655	8.33	5.314624	**1.448**	**2.448**	**3.695**
10	Delta IV Heavy (HAMMER) Adjusted Mass (max mass 7300)	50	362589.96	264.85812	8.33	5.417174	**1.419**	**2.419**	**3.663**
10	SLS Block 1 w/iCPS	19	377773.06	251.92638	8.33	5.392752	**1.499**	**2.499**	**3.750**
25	Delta IV Heavy	1	5355.51	1.288569	14.13	0.045921	**-0.009**	**0.991**	**0.115**
25	Delta IV Heavy (HAMMER)	1	7300.00	1.976445	19.00	0.066399	**-0.010**	**0.990**	**0.016**
25	Delta IV Heavy (HAMMER) Adjusted Mass (max mass 7300)	1	7300.00	1.976445	19.00	0.066399	**-0.010**	**0.990**	**0.016**
25	SLS Block 1 w/iCPS	1	13031.30	12.733071	20.29	0.225175	**-0.007**	**0.993**	**0.287**
25	Delta IV Heavy	21	168708.60	105.5428	21.44	2.332612	**1.417**	**2.417**	**3.662**
25	Delta IV Heavy (HAMMER)	23	167900.00	115.05577	21.44	2.429624	**1.472**	**2.472**	**3.721**
25	Delta IV Heavy (HAMMER) Adjusted Mass (max mass 7300)	23	167900.00	115.05577	21.44	2.429624	**1.472**	**2.472**	**3.721**
25	SLS Block 1 w/iCPS	9	186034.78	116.38192	21.44	2.572168	**1.759**	**2.759**	**4.030**

- A KI may not do the job for large asteroids or really short warning times
- Transportable mass may not be sufficient, given today's launch vehicle inventory
  - surface ablation is more mass efficient
- Risk of unintentional disruption for smaller bodies with really short warning times
  - could create poorly-dispersed debris field
- β >1 scales these results approximately linearly

KI Results For Smaller Deflections (w/ β=1)

Even just barely pushing the NEO from a dead-center Earth impact out to a minimalist Earth flyby perigee of ~1.25 Earth Radii requires a large number of launch vehicles

Available Launch Lead Time (yrs)	Launch Vehicle	Number of Launches	Used KI Mass (kg)	Specific Energy Imparted to NEO (J/kg)	Time from Deflection to Earth Encounter (yrs)	Δv Imparted to NEO (cm/s)	Defl. (R_E)	Defl. Perigee (R_E)	Defl. Bplane (R_E)
10	Delta IV Heavy	31	240856.65	160.62062	8.33	3.438263	**0.285**	**1.285**	**2.389**
10	Delta IV Heavy (HAMMER)	32	233600.00	155.78137	8.33	3.334673	**0.225**	**1.225**	**2.317**
10	Delta IV Heavy (HAMMER) Adjusted Mass (max mass 7300)	32	232057.57	169.50919	8.33	3.466998	**0.247**	**1.247**	**2.343**
10	SLS Block 1 w/iCPS	12	238593.51	159.1114	8.33	3.405956	**0.266**	**1.266**	**2.366**
25	Delta IV Heavy	14	116411.75	55.565216	21.46	1.405917	**0.230**	**1.230**	**2.323**
25	Delta IV Heavy (HAMMER)	15	109500.00	72.254588	21.46	1.554890	**0.253**	**1.253**	**2.350**
25	Delta IV Heavy (HAMMER) Adjusted Mass (max	15	109500.00	72.254588	21.46	1.554890	**0.253**	**1.253**	**2.350**

So, What Can a HAMMER Do?

- The HAMMER in kinetic impactor mode is clearly not an adequate solution for deflecting Bennu (or similar/more challenging NEOs)
- For what size NEO can a single HAMMER in kinetic impactor mode produce an adequate deflection?
  - We want the system to be fully capable of robustly achieving the threshold mission with a single spacecraft.
  - We then deploy a campaign of several spacecraft, for redundancy/robustness.
- **It turns out that with a 10 year launch lead time, a single HAMMER in kinetic impactor mode can minimally deflect an NEO ≤ ~150 m (with bulk density of 1 g/cm^3, Bennu's orbit, and β=1)**
- The largest NEO a single HAMMER in kinetic impactor mode can handle will vary based upon NEO orbit, NEO bulk density, β, and launch lead time (and warning time, which is not the same as launch lead time)

Effects of Density & β On HAMMER

Single HAMMER vs. Bennu’s orbit (a=1.126 AU, e=0.2037, i=6.035°)

These tables show the largest diameter NEA that a single HAMMER in Kinetic Impactor mode can deflect under the associated conditions.

(For Larger (~2.50 ER perigee) Deflections)

Available Launch Lead Time (yrs)	β	Asteroid Density (g/cm^3)	Diameter (m)	Deflection (R_E)
10	1	1	135	1.435
10	1	2.6	98	1.454
10	2.5	1	183	1.448
10	2.5	2.6	133	1.454
25	1	1	176	1.461
25	1	2.6	128	1.461
25	2.5	1	238	1.498
25	2.5	2.6	174	1.445

(For Smaller (~1.25 ER perigee) Deflections)

Available Launch Lead Time (yrs)	β	Asteroid Density (g/cm^3)	Diameter (m)	Deflection (R_E)
10	1	1	157	0.243
10	1	2.6	114	0.252
10	2.5	1	213	0.246
10	2.5	2.6	155	0.242
25	1	1	203	0.245
25	1	2.6	147.5	0.251
25	2.5	1	275.5	0.246
25	2.5	2.6	200.5	0.241

$$D_2(Lead\ Time) = \left(\frac{\rho_1\,\beta_2}{\beta_1\,\rho_2}\right)^{\frac{1}{3}} D_1(Lead\ Time)$$

Lead times must be equal

Effects of Density & β On HAMMER

Single HAMMER vs. 2015 PDC's orbit (a=1.78 AU, e=0.49, i=5°)

These tables show the largest diameter NEA that a single HAMMER in Kinetic Impactor mode can deflect under the associated conditions.

(For Larger (~2.50 ER perigee) Deflections)

Available Launch Lead Time (yrs)	β	Asteroid Density (g/cm³)	Diameter (m)	Deflection (R_E)
10	1	1	210	1.413
10	1	2.6	152	1.441
10	2.5	1	285	1.413
10	2.5	2.6	207	1.419
25	1	1	300	1.420
25	1	2.6	218.5	1.408
25	2.5	1	407	1.423
25	2.5	2.6	296	1.422

(For Smaller (~1.25 ER perigee) Deflections)

Available Launch Lead Time (yrs)	β	Asteroid Density (g/cm³)	Diameter (m)	Deflection (R_E)
10	1	1	282.5	0.243
10	1	2.6	205	0.25
10	2.5	1	383	0.246
10	2.5	2.6	279	0.241
25	1	1	406.5	0.245
25	1	2.6	295.6	0.245
25	2.5	1	551.7	0.245
25	2.5	2.6	401	0.240

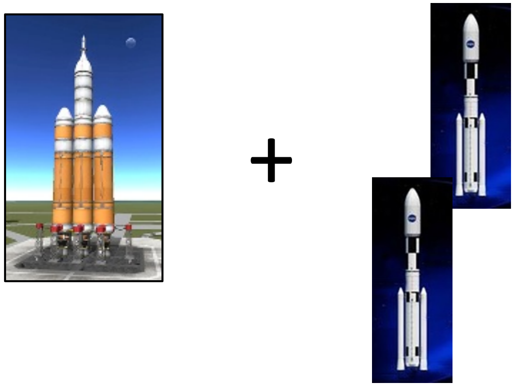
$$D_2(Lead\ Time) = \left(\frac{\rho_1\,\beta_2}{\beta_1\,\rho_2}\right)^{\frac{1}{3}} D_1(Lead\ Time)$$

Lead times must be equal

Formulation Con-OPS Considerations

(“Operational” Impact Trades)

- Reliability–driven campaign mode would require unprecedented launch and operations cadence
- Each of the (notional) redundant “impactor / mitigation” spacecraft in such a campaign would likely be similar in operations to OSIRIS-REx
- All would probably need to be launched within a 20 day window
  - they would additionally need to intercept the target within a 20 day window for deflection operations
- Results from each (serial) deflection would be used to revise models and tune the simulations for higher fidelity and increased confidence in subsequent deflection attempts

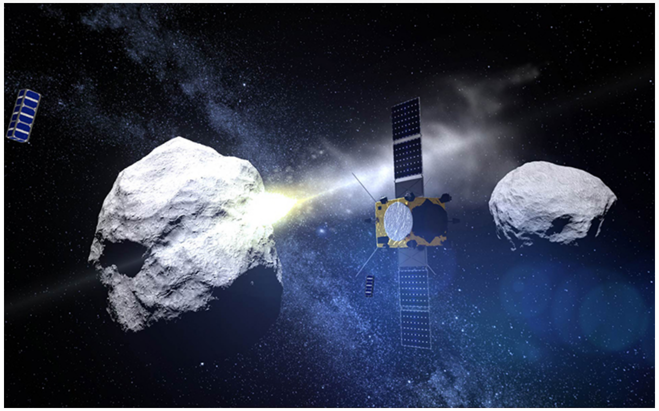


Preliminary Conclusions

- Our research thrust is a scenario-based approach, and it seems effective at addressing the end-to-end integrated problem, from launch readiness to post impact. Still need to complete the impact model runs, AF&F engineering for C.S. 1, and uncertainty analyses
- Successful kinetic and nuclear deflection LLNL/LANL code comparisons
- Deflection using both kinetic and nuclear device momentum delivery systems was examined in the short response regime
- Design reference mission (DRM) 1 involved the formulation and optimization of intercept trajectories, architecture and mission design, high fidelity modeling of both kinetic impact and nuclear detonation, and system uncertainty analyses (TBD)
- A HAMMER spacecraft in KI mode is not adequate for deflecting Bennu-class objects, because of required multiple large launchers and stress on launch site resources
- Nuclear surface ablation is more mass efficient and is the preferred option for this class of NEAs in the limit of short response times
- Our analyses to date have validated the notion that KI is most effective for small, competent asteroids, whereas ablative methods appear best for non-competent bodies, very short warning times, and large (e.g., >150m) NEAs
- Suggest further consideration of using SLS with co-manifesting multiple “HAMMERs” as another formulation architecture segment trade

Next 2 case studies

DRA 2 - Didymoon



- 150 meter diameter object
- Likely spherical or oblate spheroid
- Supports APL/Double Asteroid Redirection Test(DART) with KI model output
- Adds nuclear explosive-based deflection/disruption to our case study compendium

DRA 3 – Comet 67P

- Less frequent, but more dangerous target
- 215x205 m, high speed, short warning
- Both intercept and deflection/ disruption are challenging
- Early shape model based on remote sensing grossly misjudged the "as is" object

QUESTIONS?

Appendices

NEO Mitigation Research Project…*at a glance*

Strategic Partnerships

ARTICLE 19. SPECIAL CONSIDERATIONS

HANDLING OF CLASSIFIED INFORMATION

The Parties recognize that they may need to exchange classified infor
out this Agreement and will comply with all existing statutes, regulati
authorities governing treatment of such information.

ARTICLE 20. SIGNATORY AUTHORITY

Approved and authorized on behalf of each Party by:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION	NATIONAL NUCLEAR SE ADMINISTRATION
BY: James L Green	BY:
Dr. Jim Green Planetary Science Division Director 300 E St SW Washington, DC 20546 Phone: 202.358.1588	Dr. Donald Cook DOE/NNSA Deputy Admini Office of Defense Programs 1000 Independence Avenue, Washington, DC 20585
DATE: 12/11/14	DATE: 1/20/20

Small Body Characterization

(101955) Bennu
Design Reference Asteroid

OSIRIS-REx DOCUMENT

Prepared by Carl Hergenrother
(chergen@lpl.arizona.edu)

OREX-DOCS-04.00-00002_Rev_6
August 5, 2013
Final

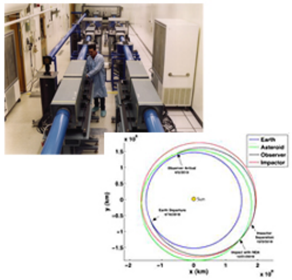
AIMA Te

Observatoire de la CÔTE d'AZUR

ASTEROID IMPACT MISSION:
DIDYMOS REFERENCE MODEL

AIMA TEAM

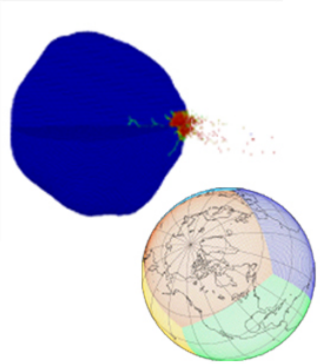
Model Input



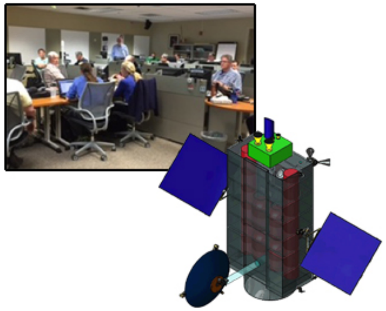
Engagement Approaches

Peta-Scale Computing

2-D and 3-D Simulations

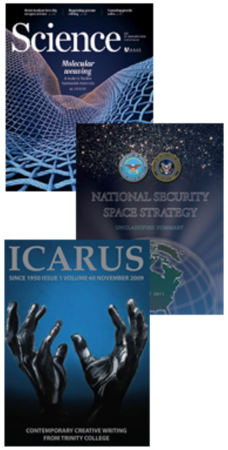


Design Reference Missions



Big Data Framework

Publish



Goddard SPACE FLIGHT CENTER

Lawrence Livermore National Laboratory

Los Alamos NATIONAL LABORATORY

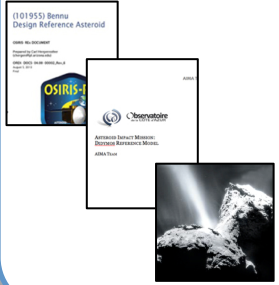
Sandia National Laboratories

GEORGE MASON UNIVERSITY

Framework for NEO Mitigation

Design Reference Asteroids

Physical and Chemical Characterization Data



(101955) Bennu
Design Reference Asteroid

OSIRIS-REx

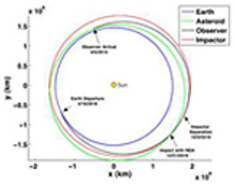
Observatoire de la Côte d'Azur

Asteroid Impact Mission:
Didymos Reference Model

AIDA Team

Optical/Radar Data

Astrodynamics

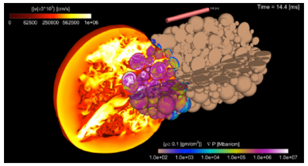


Impact Modeling & Simulation

Model run intercomparisons

Physics-based 2D/3D model output

Data quality

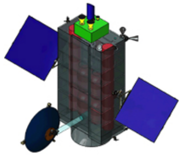


Design Reference Missions

NEO Impact Modeling

Space mission Design including:

Spacecraft launcher
Control Center
Payload I/F
Flight Ops



Decision Support

Deflection/Disruption Uncertainty analyses

Space Mission reliability estimates

Physics-based risk modeling

Deflection/Disruption effectiveness

Big Data Processing

Data Discovery, Access, Simulations & Analytic

Powered by Cloud & High Performance Computing

Hybrid Cloud Computing

Joint agency Government team

LLNL

David Dearborn
- Energy Deposition
- Deflection/Disruption

Souheil Ezzedine
- Entry and Impact Modeling

Eric Herbold
- Physical/Chemical Properties
- Shock Propagation

Kirsten Howley
- Energy Deposition
- Shock Propagation

Rob Managan
- Shock Propagation

Mike Owen
- Shape Rotation Effects

Damian Swift
- Physical/Chemical Properties

Megan Bruck Syal
- Physical/Chemical Properties

Joe Wasem
- Energy Deposition
- Shape Rotation Effects

GSFC

Brent Barbee
- Astrodynamics

Bill Farrell
- Plasma Environment

Keith Noll
- Characterization

Ron Leung
- Systems and Mission Engineering

Joe Nuth
- Physical/Chemical Properties

Luke Oman
- Perturbational Climatology

LANL

Jim Ferguson
- Energy Deposition

Galen Gisler
- Physical/Chemical Properties

Cathy Plesko
- Energy Deposition

Bob Weaver
- Energy Deposition

SNL

Mark Boslough
- Risk Analyses
- Air Bursts

Agency Technical Leads

Paul Miller (LLNL)
miller3@llnl.gov

Bernie Seery (GSFC)
bernie.seery@nasa.gov

Project Managers

Myra Bambacus
(GSFC)

Anthony Lewis
(NNSA)

Agency Leads

Kevin Greenaugh
(NNSA, HQ)

Lindley Johnson
(NASA, HQ)

NNSA Project participants and contributors

Mark Boslough

David Dearborn

Souheil Ezzedine

James Ferguson

Galen Gisler

Eric Herbold

Kirsten Howley

Robert Managan

Paul Miller

J. Michael Owen

Cathy Plesko

Tané Remington

Randy Summer

Megan Syal

Joseph Wasem

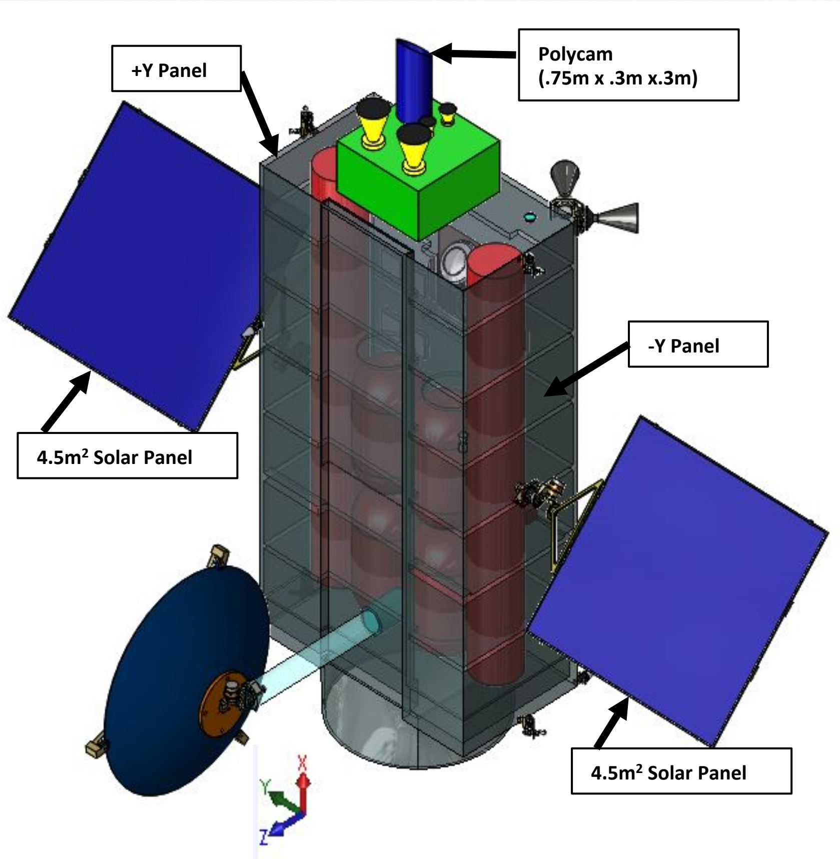
Robert Weaver

Mission Design Lab (MDL) Team

Discipline	Supporting Engineer	Discipline	Supporting Engineer
Attitude Control	Paul Mason	Mechanical Designer	Sara Riall-Waldsachs
Avionics	Porfy Beltran	Mechanical Systems	Acey Herrera
Communications	Blake Lorenz	Mission Ops	Dale Fink
Costing	Larry Phillips	Mission Systems / Launch Vehicle	Frank Kirchman / James Sturm
Debris Analysis/EOM	Ivonne Rodriguez	Propulsion	Dewey Willis
Elect. Power	Bob Beaman / David Kim	Radiation	Alvin Boutte / Shannon Alt
Flight Dynamics	Cinnamon Wright / Frank Vaughn	Reliability	Aron Brall
Flight Software	Kequan Luu	Thermal	Juan Rodriguez-Ruiz
I&T	Pat Kilroy / Lakesha Bates	MDL Team Lead	Mark Steiner
NED – LANL	Catherine Plesko	NED/Import – LLNL	David Dearborn
NNSA Engineer – LLNL	Jason Vanderveen	GSFC Project Manager	Myra Bambacus
GSFC Lead Executive	Bernie Seery	GSFC – Mission Systems Eng	Ronald Leung
GSFC – Study PI	Brent Barbee	NNSA Lead Executive	Kevin Greenough
NNSA Project Lead	Anthony Lewis	GSFC Asteroid Science	Joe Nuth
GSFC Asteroid Science	Keith Noll	LANL – Specialist	Galen Gisler

HAMMER Concept

- Coordinate system / System overview



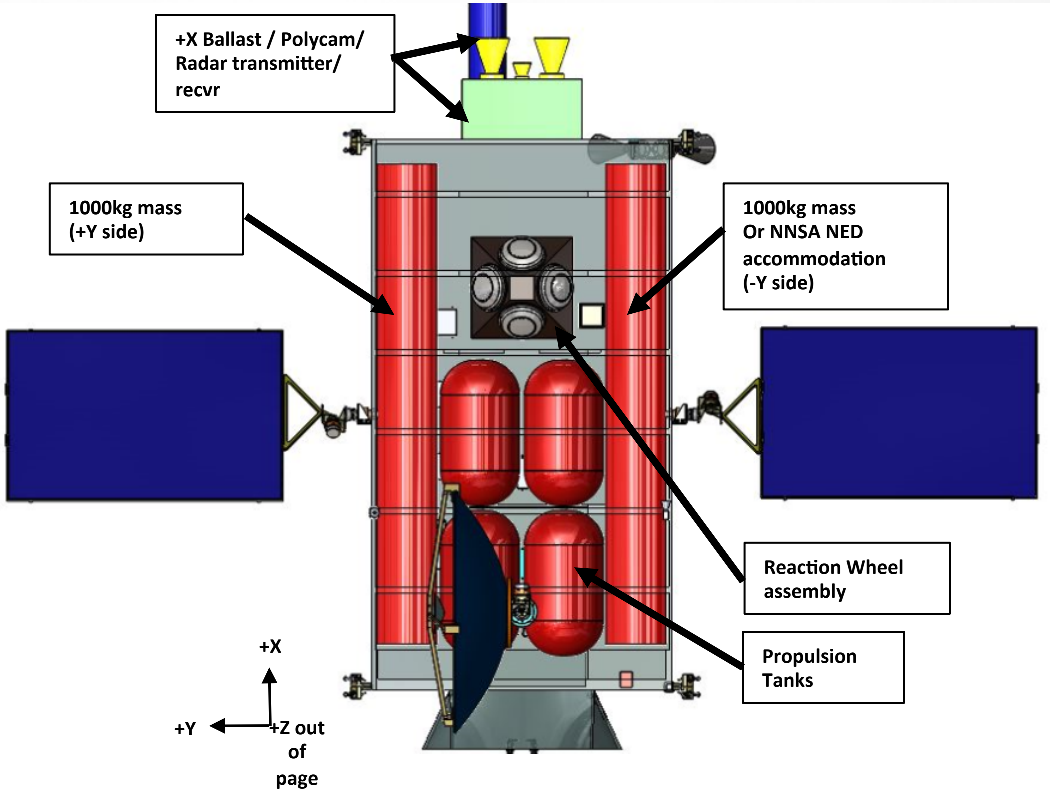
+Y Panel

Polycam
(.75m x .3m x.3m)

-Y Panel

4.5m^2 Solar Panel

4.5m^2 Solar Panel



+X Ballast / Polycam/
Radar transmitter/
recvr

1000kg mass
(+Y side)

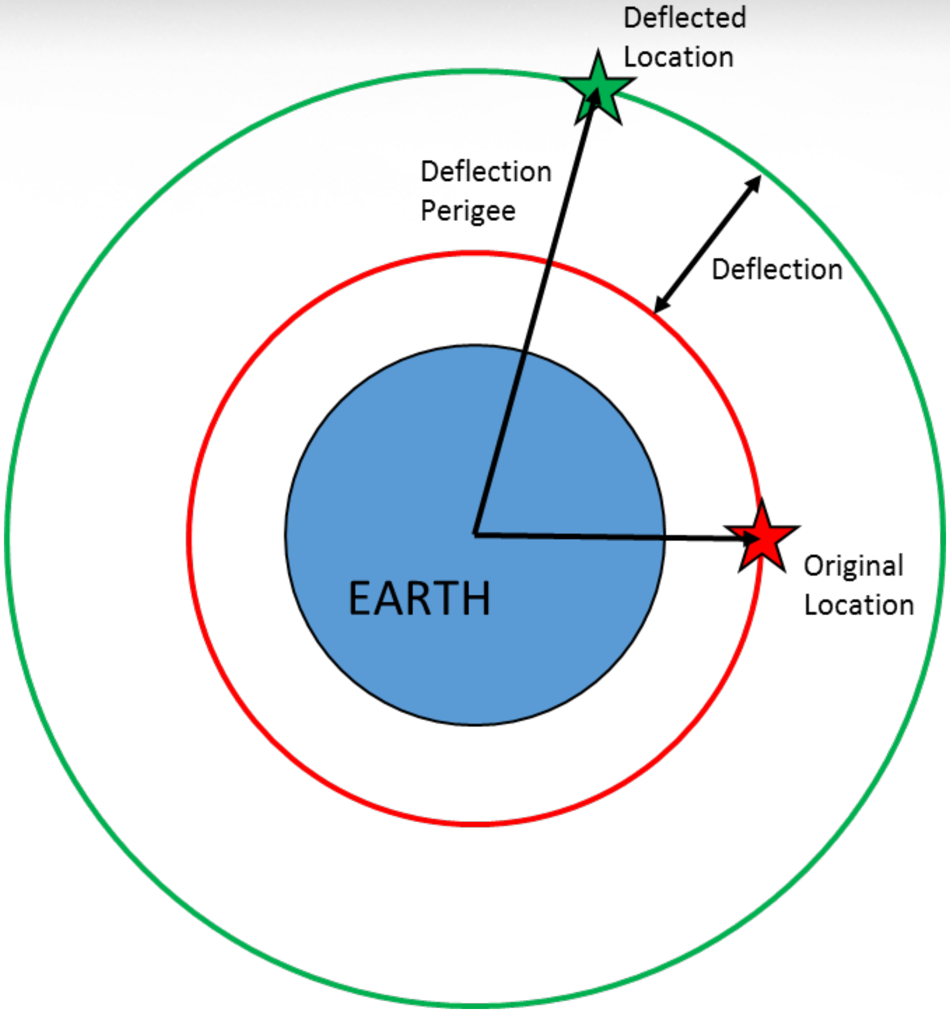
1000kg mass
Or NNSA NED
accommodation
(-Y side)

Reaction Wheel
assembly

Propulsion
Tanks

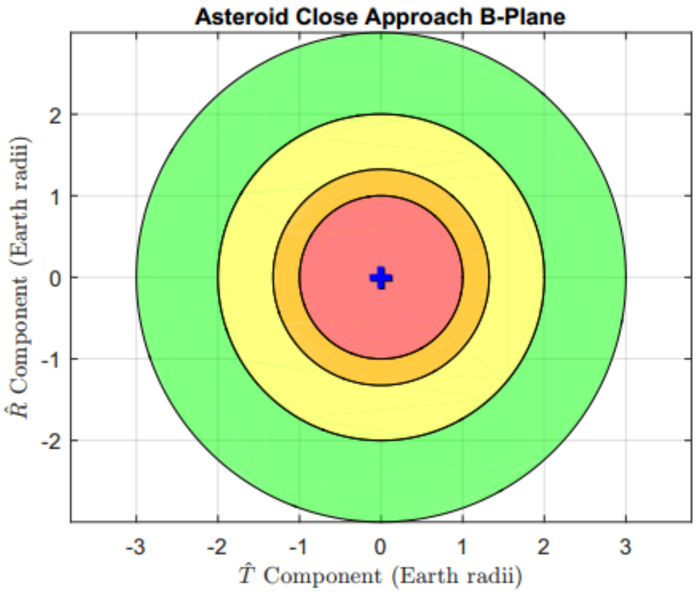
+X
+Y
+Z out
of
page

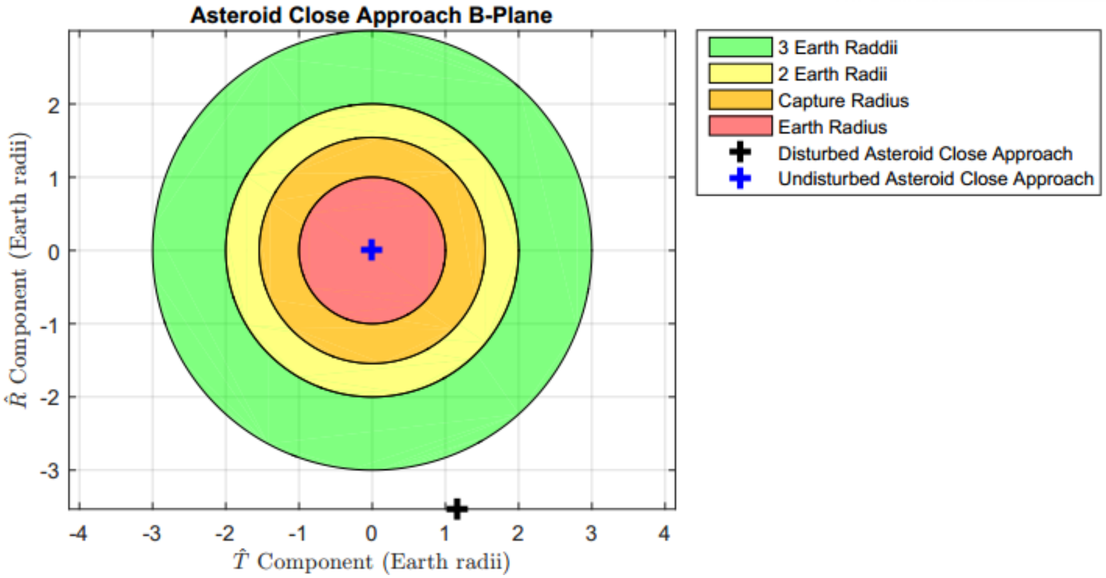
Deflection Definition



1 HAMMER, Delta IV H, 10 yr Lead

23 HAMMERs, Delta IV H, 25 yr Lead





Deflection Results w/ β=2.5

Available Launch Lead Time (yrs)	Launch Vehicle	Number of Launches	Used KI Mass (kg)	Specific Energy Imparted to NEO (J/kg)	Time from Deflection to Earth Encounter (yrs)	Δv Imparted to NEO (cm/s)	Defl. (R_E)	Defl. Perigee (R_E)	Defl. Bplane (R_E)
10	Delta IV Heavy	1	4961.20	3.922845	4.71	0.19279	-0.010	0.990	0.047
10	Delta IV Heavy (HAMMER)	1	7300.00	1.646286	2.41	0.15150	-0.010	0.990	0.048
10	Delta IV Heavy (HAMMER) Adjusted Mass (max mass 7300)	1	7300.00	1.646286	2.41	0.15150	-0.010	0.990	0.048
10	SLS Block 1 w/iCPS	1	21722.50	3.444975	5.97	0.37805	-0.008	0.992	0.165
10	Delta IV Heavy	19	147621.82	98.444898	8.33	5.26831	**1.423**	**2.423**	**3.667**
10	Delta IV Heavy (HAMMER)	21	153300.00	102.23152	8.33	5.47096	**1.549**	**2.549**	**3.804**
10	Delta IV Heavy (HAMMER) Adjusted Mass (max mass 7300)	20	145035.98	105.94325	8.33	5.41719	**1.419**	**2.419**	**3.663**
10	SLS Block 1 w/iCPS	8	159062.34	106.07427	8.33	5.67660	**1.683**	**2.683**	**3.948**
25	Delta IV Heavy	1	7075.84	0.377054	17.82	0.07138	-0.009	0.991	0.116
25	Delta IV Heavy (HAMMER)	1	7300.00	2.800896	21.46	0.19761	-0.007	0.993	0.267
25	Delta IV Heavy (HAMMER) Adjusted Mass (max mass 7300)	1	7075.84	0.377054	17.82	0.07138	-0.009	0.991	0.116
25	SLS Block 1 w/iCPS	1	22311.59	3.401781	17.85	0.38073	-0.007	0.993	0.218
25	Delta IV Heavy	9	72303.69	45.232628	21.44	2.49923	**1.654**	**2.654**	**3.918**
25	Delta IV Heavy (HAMMER)	9	65700.00	42.797199	21.41	2.31735	**1.244**	**2.244**	**3.473**
25	Delta IV Heavy (HAMMER) Adjusted Mass (max mass 7300)	9	65700.00	42.797199	21.41	2.31735	**1.244**	**2.244**	**3.473**
25	SLS Block 1 w/iCPS	4	77013.41	52.774495	21.44	2.78609	**1.969**	**2.969**	**4.254**