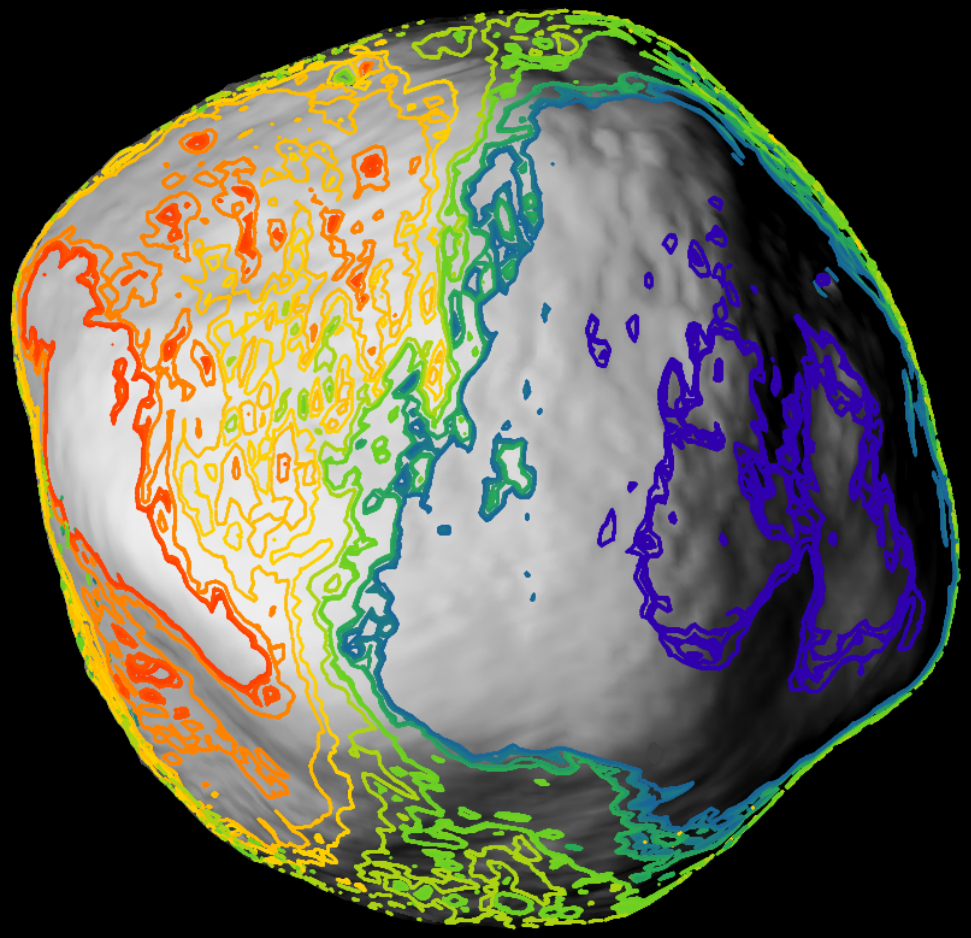


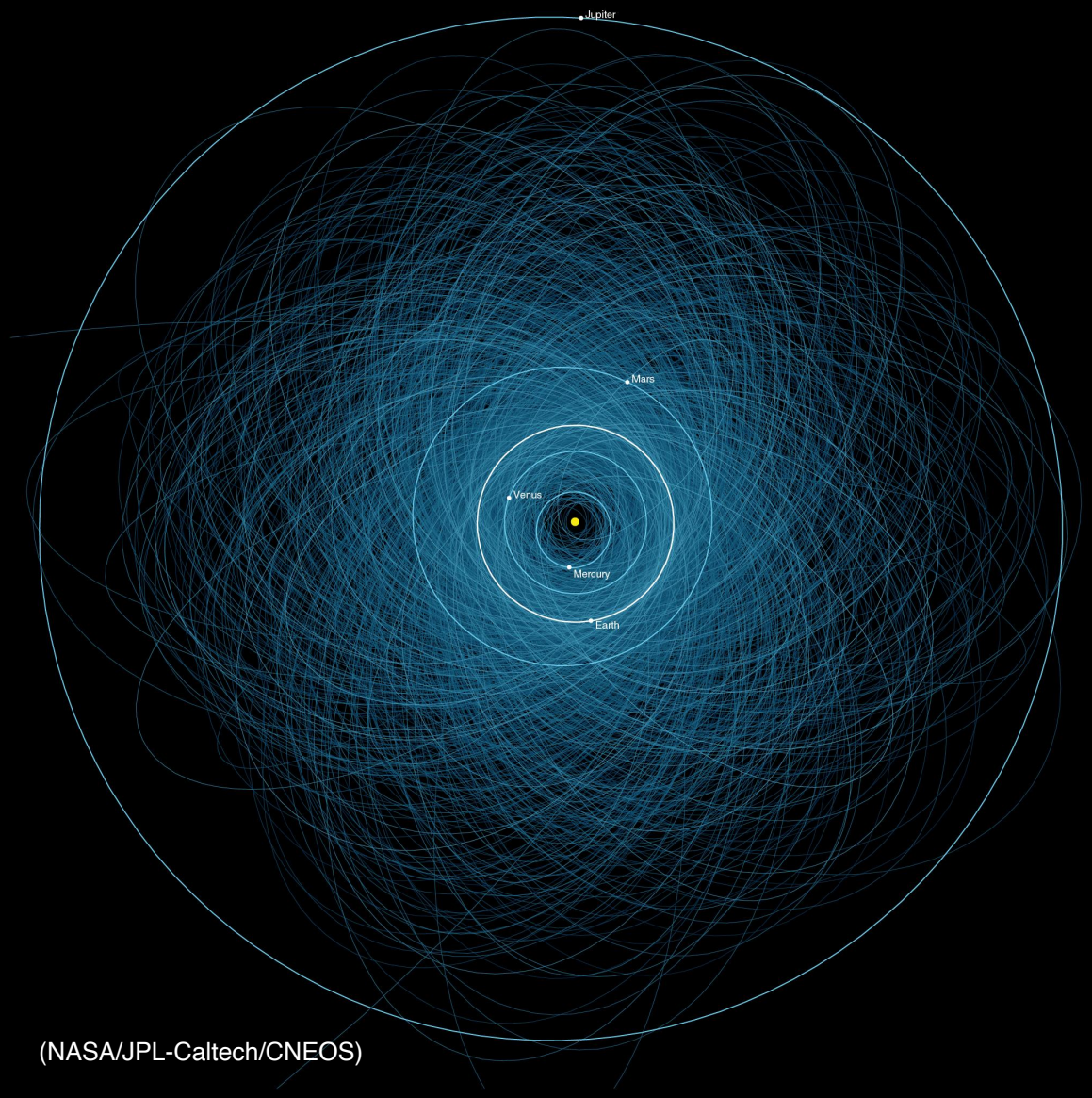
Avoiding Armageddon:

Long Term Asteroid Orbit Deflection Optimization

Siegfried Eggl, Davide Farnocchia,
Steven R. Chesley and Paul Chodas

Jet Propulsion Laboratory
California Institute of Technology

near-Earth asteroids (NEAs)

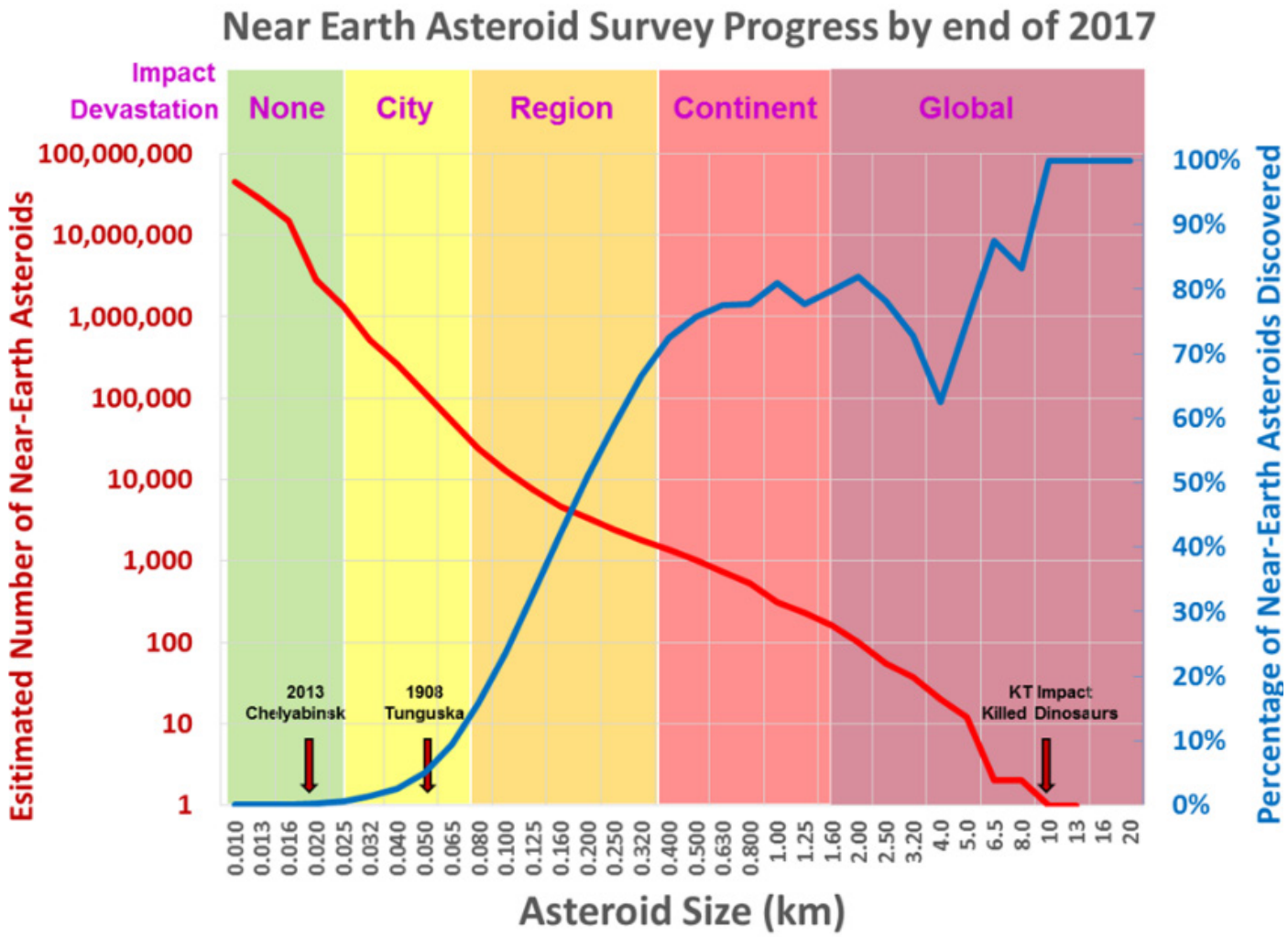


(NASA/JPL-Caltech/CNEOS)

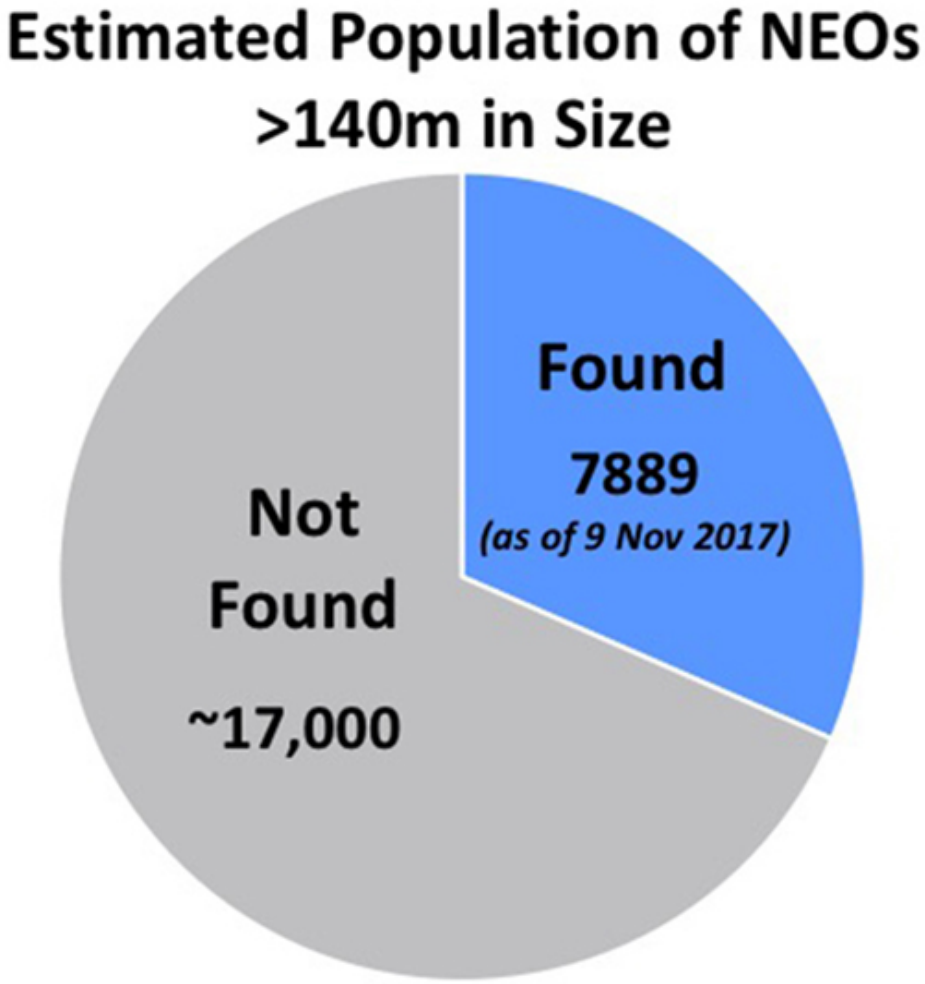
18530	NEAs
8277	> 140m
1923	PHAs

as of 22.08.2018

http://cneos.jpl.nasa.gov

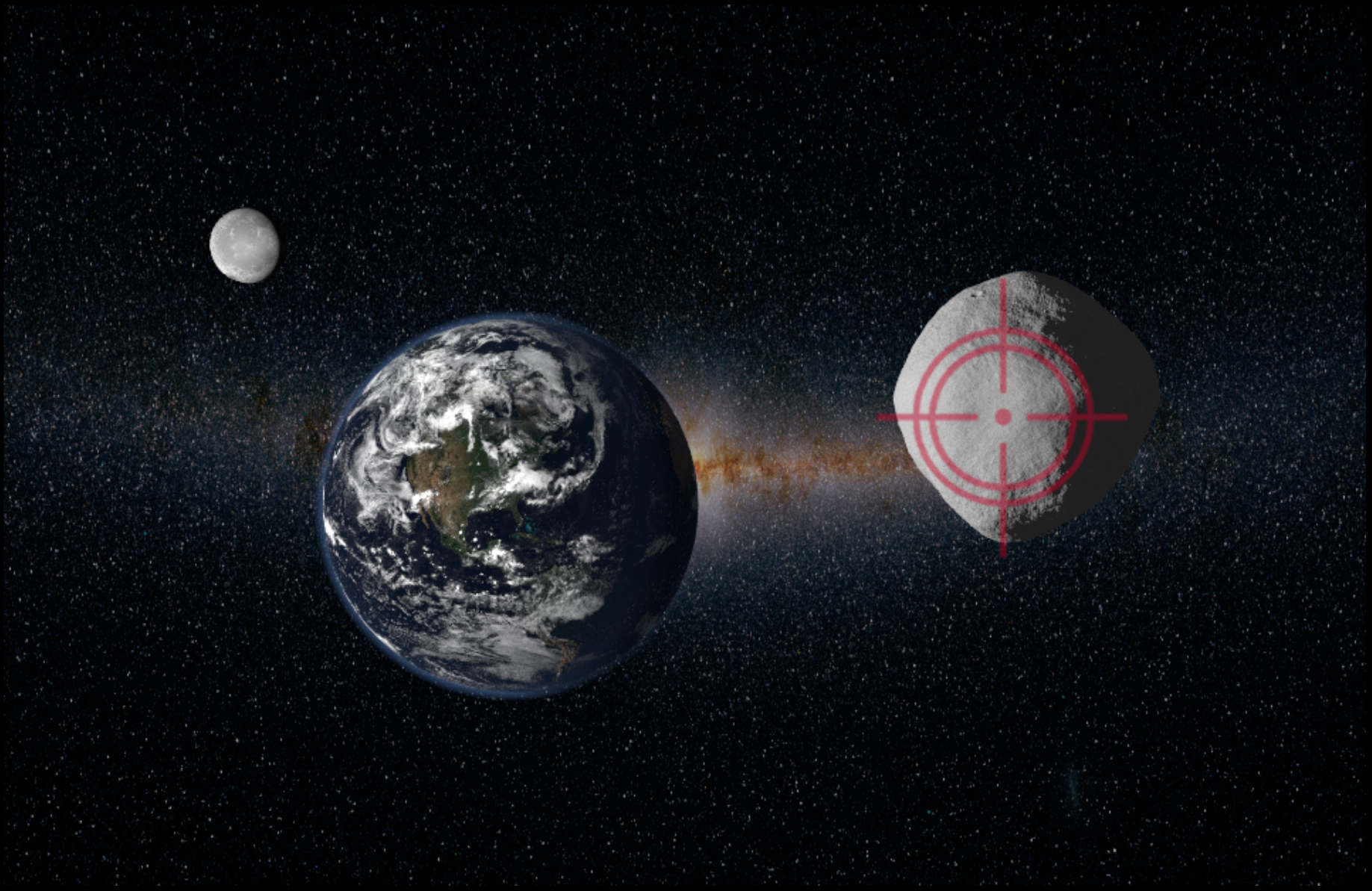


(NATIONAL NEAR-EARTH OBJECT PREPAREDNESS STRATEGY, DAMIEN, 2018)

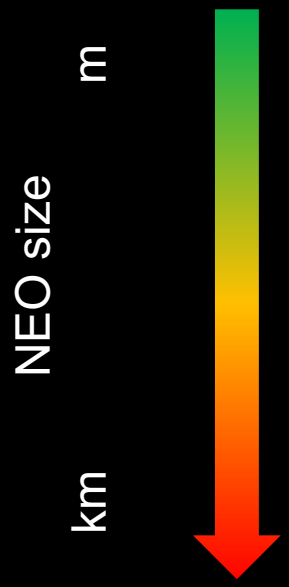


(Planetary Defense Coordination Office, 2018)

What if…?



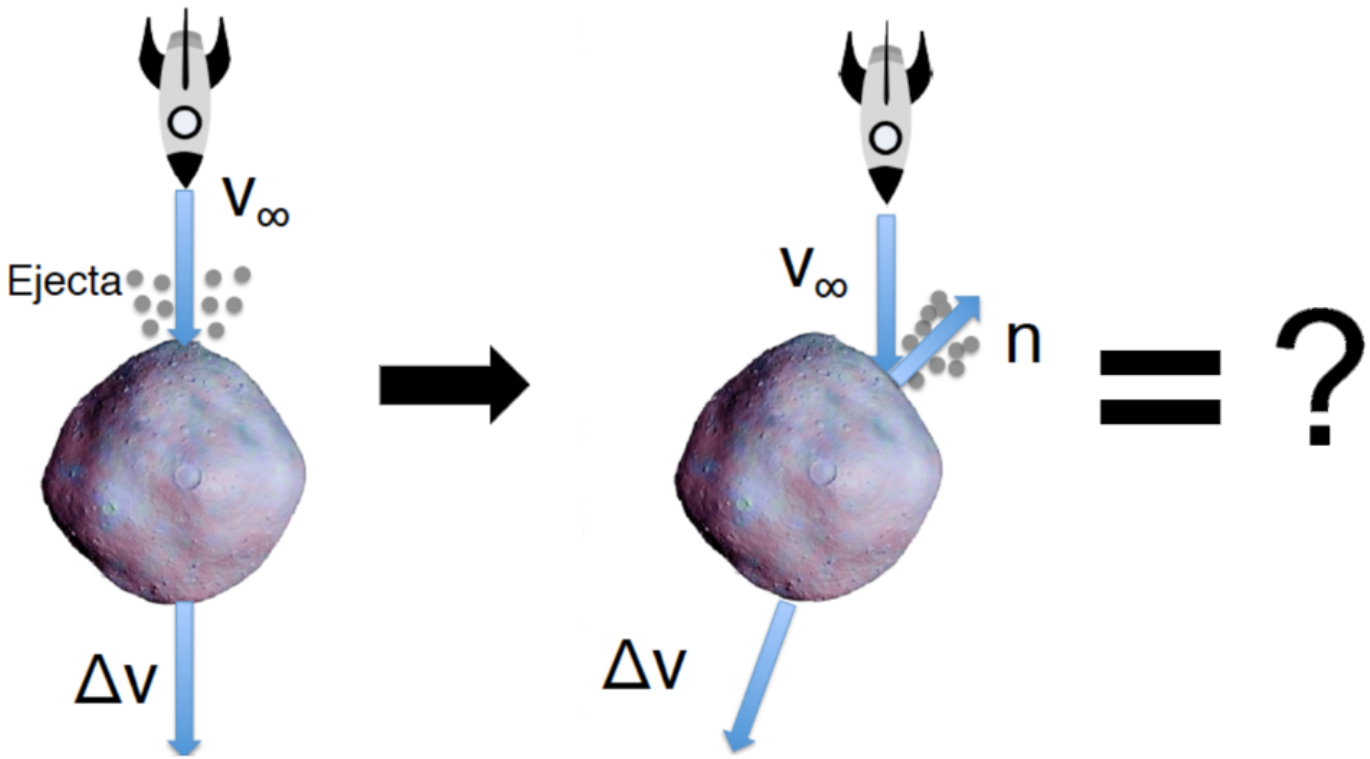
NEO deflection strategies



- Gravity tractor
- Laser ablation
- Ion beam shepherds
- Kinetic Impactors
- Nuclear ablation

(e.g. Thiry & Vasile 2017)

Orbit Deflection, Kinetic Impactor



$$\Delta\vec{V} \approx \frac{m}{M}[\vec{v}_\infty + \vec{\beta}], \qquad \vec{\beta} = (\beta - 1)\,(\vec{n} \cdot \vec{v}_\infty)\,\vec{n},$$

Orbit Deflection Uncertainties

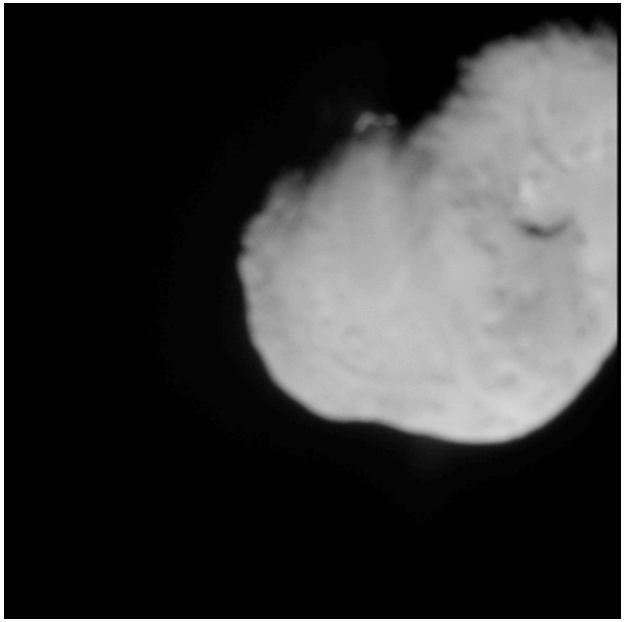
$$\Delta\vec{V} \approx \frac{m}{M}[\mathcal{I} - (\beta - 1)\hat{n}\hat{n}]\Delta\vec{v}$$

10% 100% ?

uncertain parameters

$$\beta = 1 + p_{ej}/(M_p v_p)$$

Momentum enhancement factor



(Image: Deep impact mission, NASA)

$1 < \beta < 3$

Jutzi & Michel (2014), Cheng et al. (2017), Maindl et al. (in prep)

$\beta < 10$

Holsapple & Housen (2012)

A deflected NEA is (most likely) still an NEA

Uncertainties weaken post deflection orbit predictions

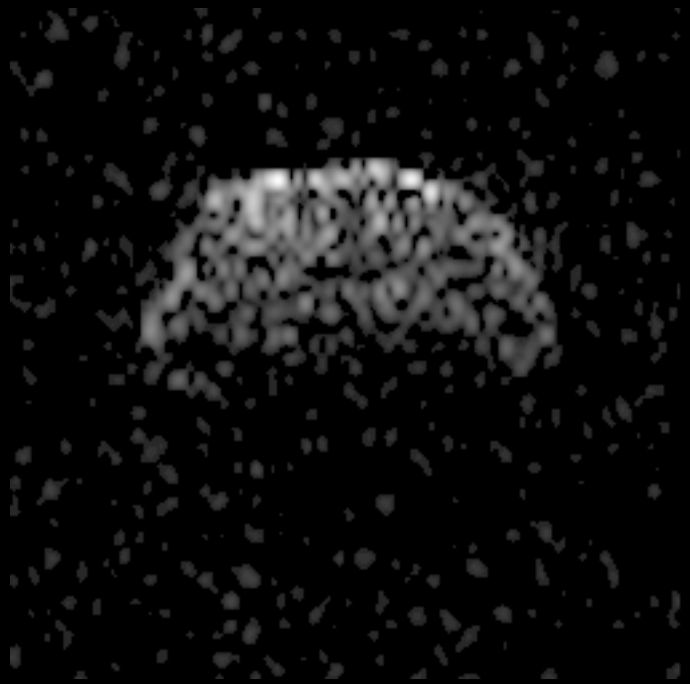
Avoid accidental deflection onto resonant return orbit

Important for deflection and deflection demo missions

Post Deflection Impact Risk Assessment

(e.g. Eggl et al. 2015, Eggl & Chesley 2018)

(101955) Bennu



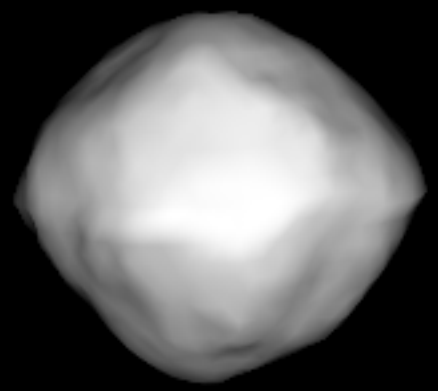
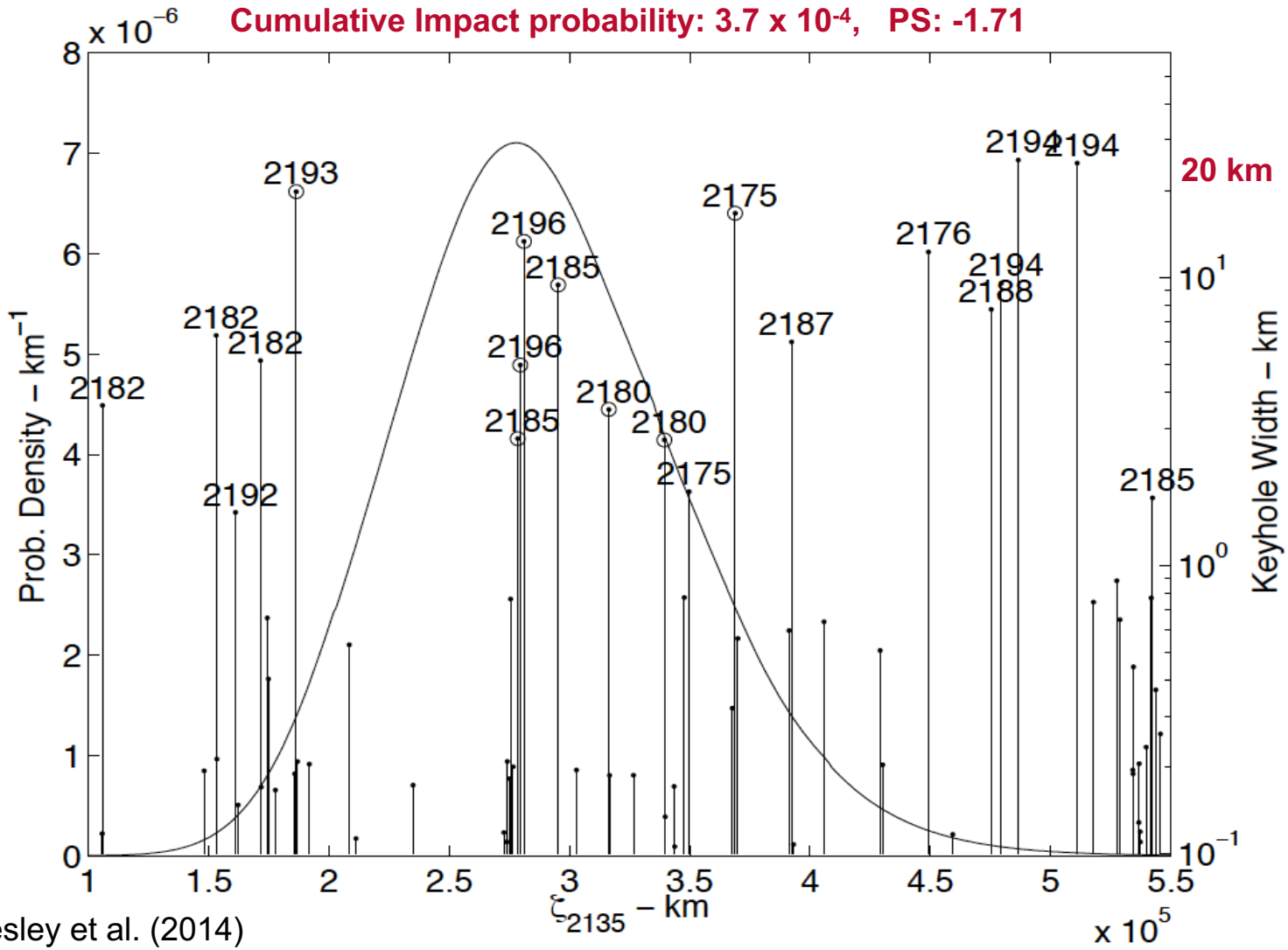


Image: JPL, Nolan et al. (2013)

OSIRIS-REX target

Risk assessment



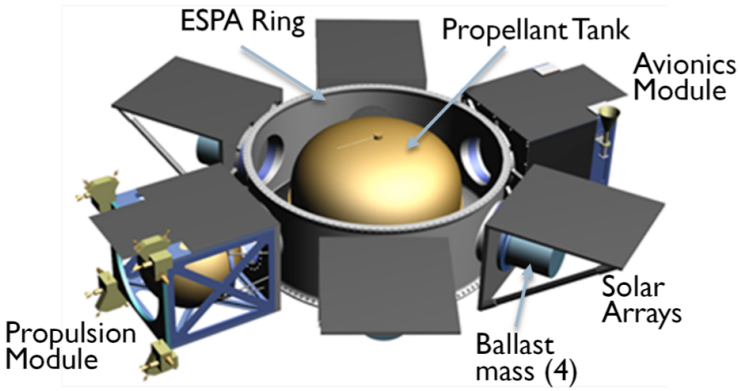
Chesley et al. (2014)

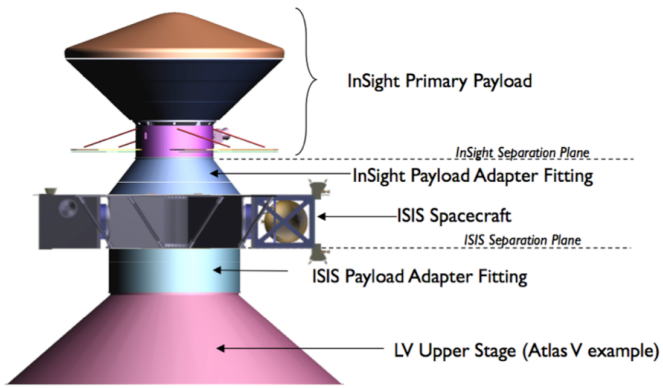
ISIS mission concept

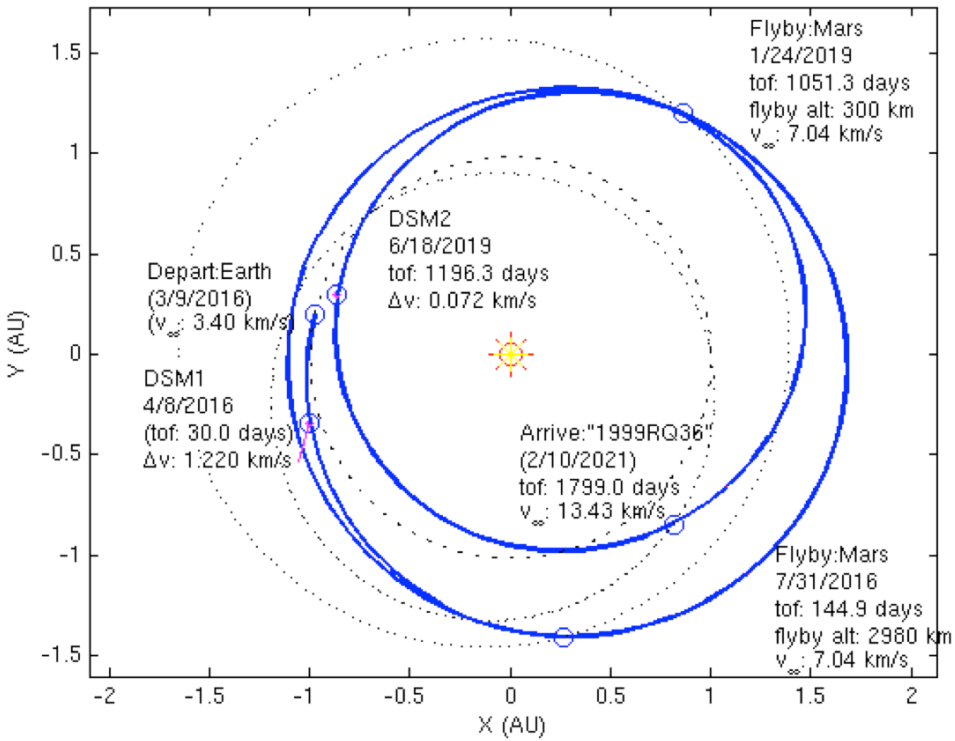
(Chesley et al., 2013)

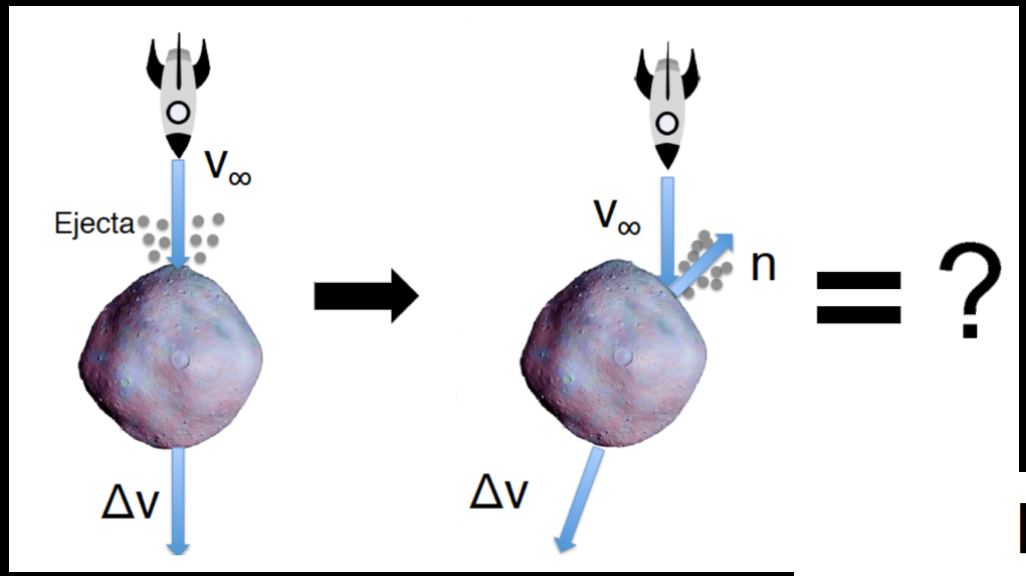
Impact: 2021

v_∞ ~ 13-14 km/s



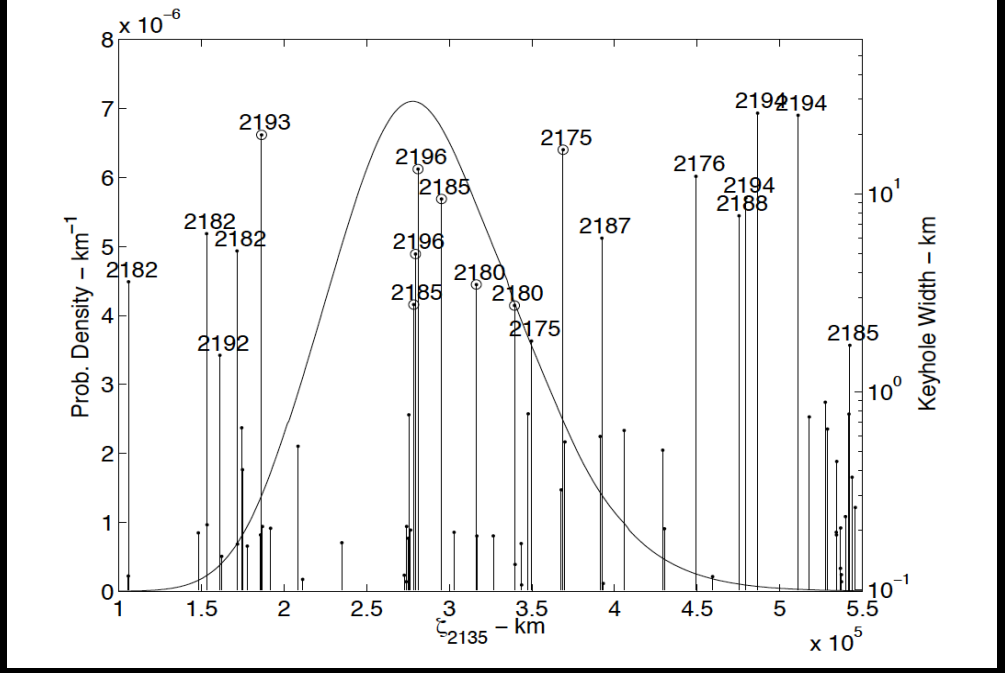






… to avoid Keyholes

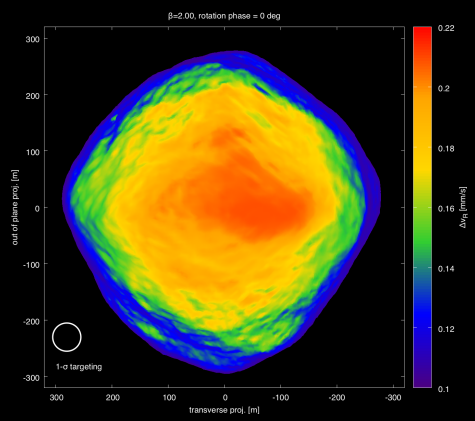
Risk assessment



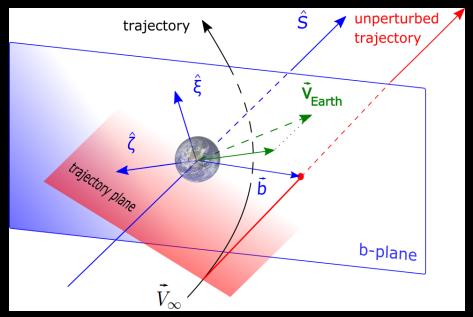
Target the NEA …

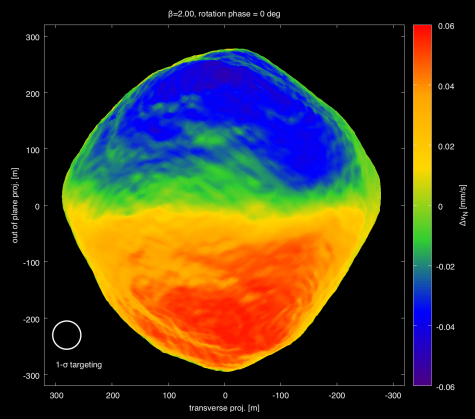
Impact ΔV 2021

B-plane 2135

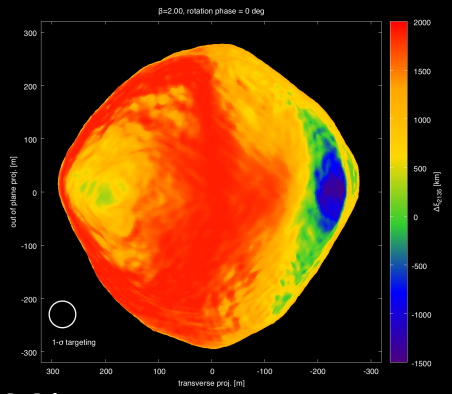


ΔV_R [mm/s]
(0.1, 0.2)

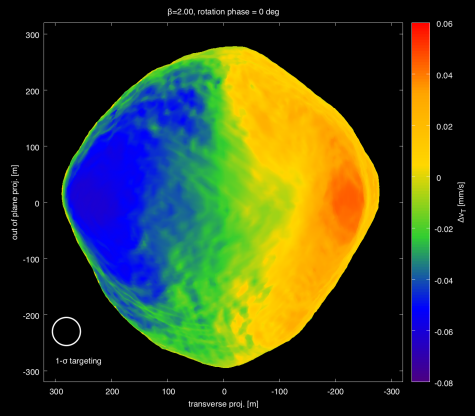




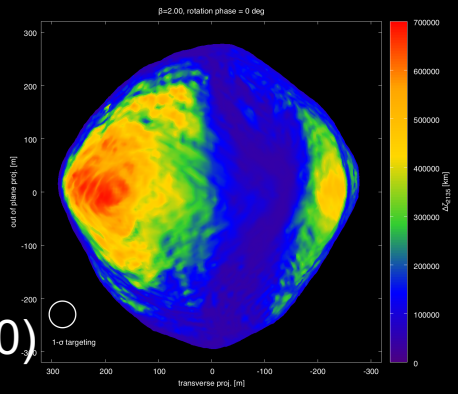
ΔV_N [mm/s]
(-0.06, 0.06)



$\Delta\xi$ [km]
(-1500, 2000)



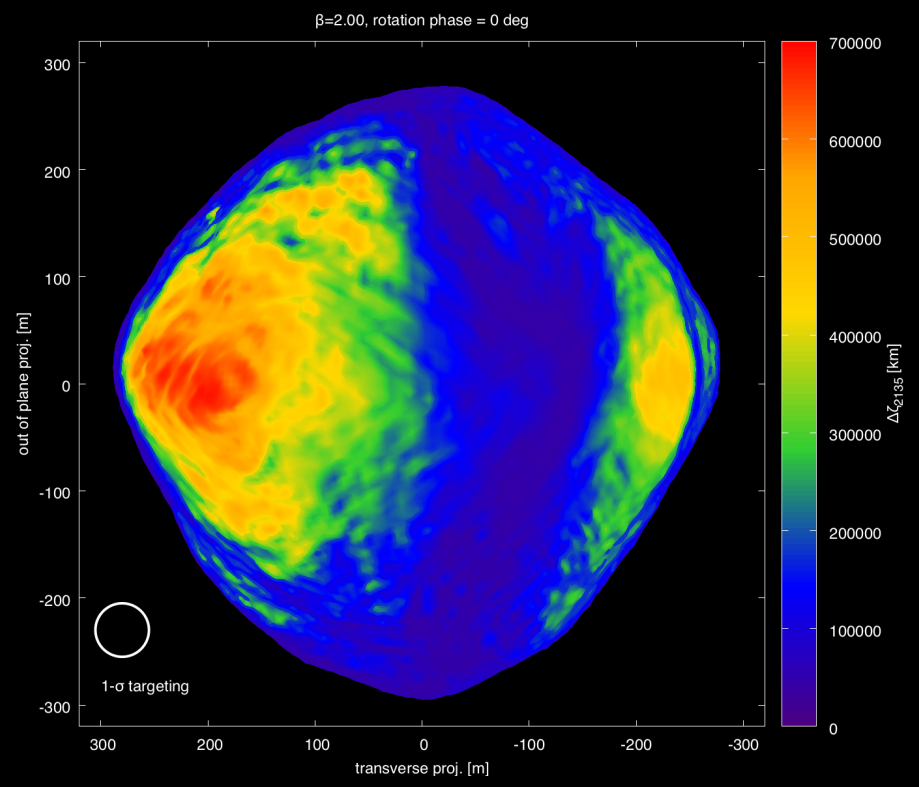
ΔV_T [mm/s]
(-0.06, 0.06)

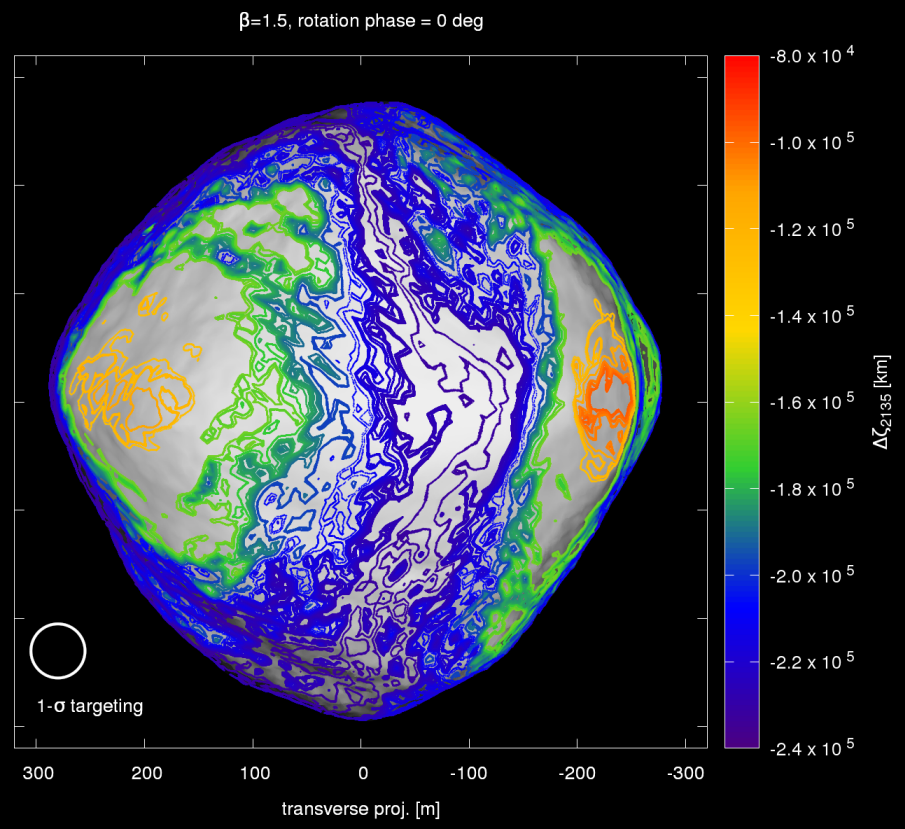


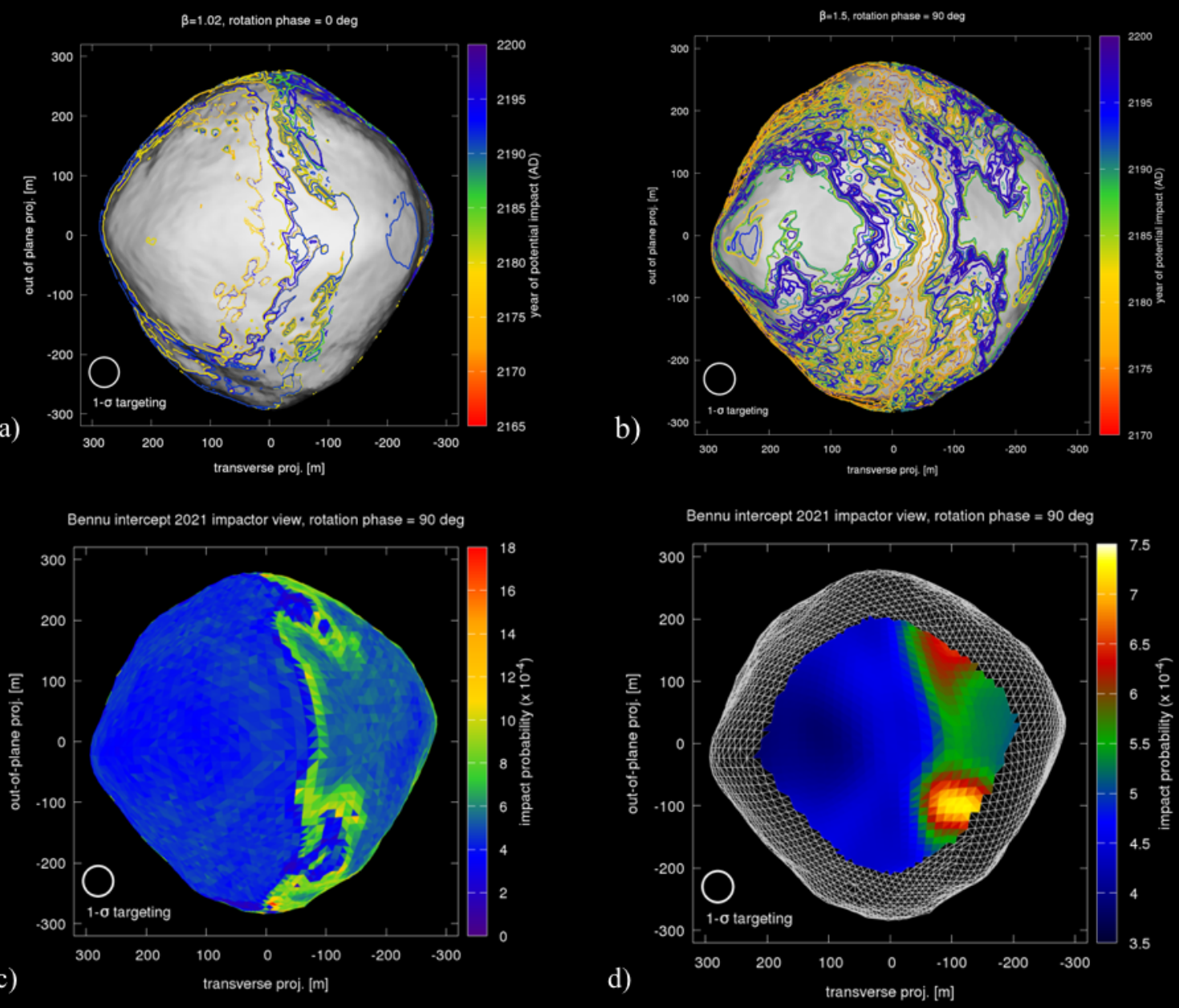
$\Delta\zeta$ [mm/s]
(0, 700 000)

B-plane displacement

Keyholes

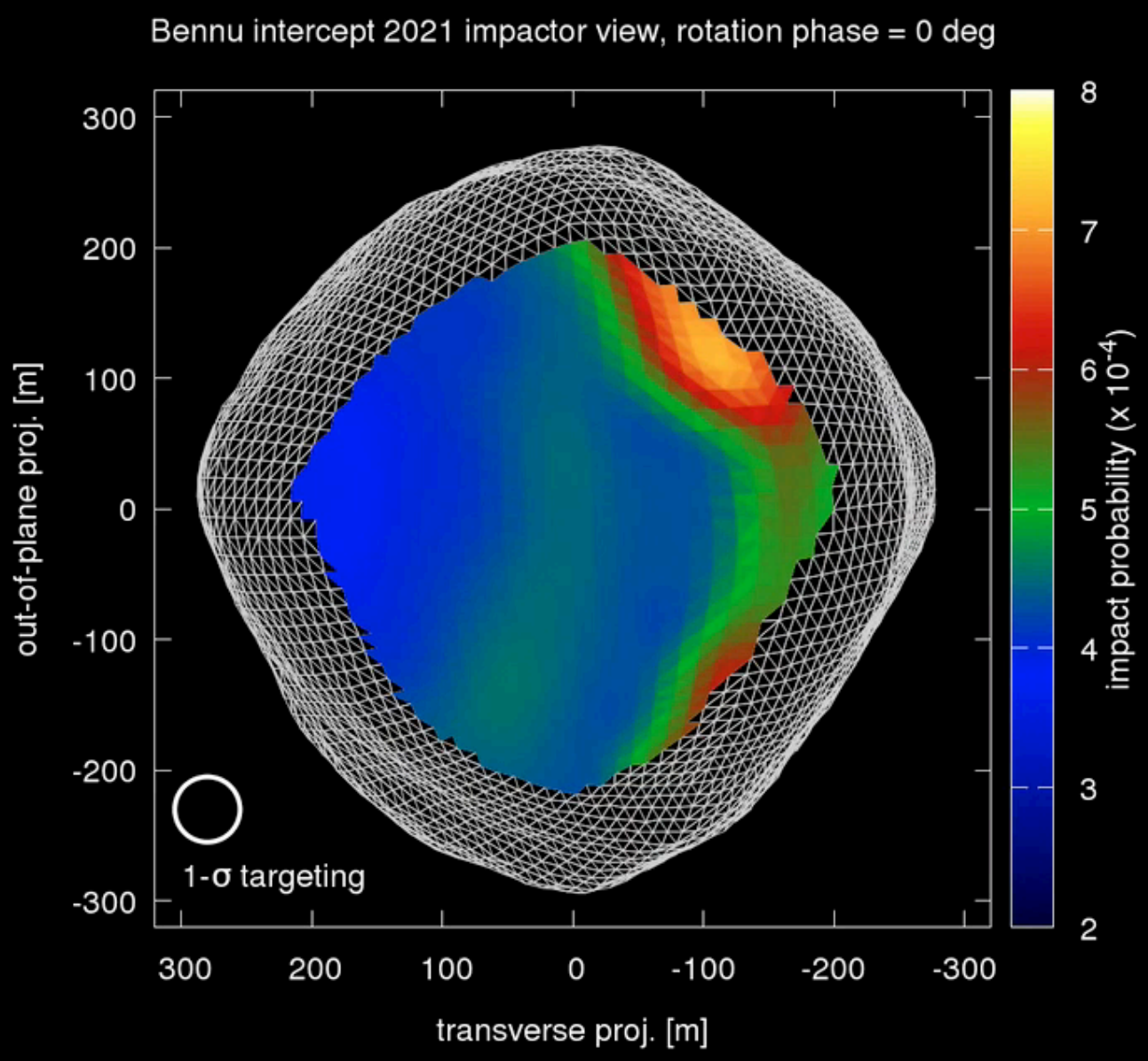






Keyhole location depends on β!

IP via MC over β, mass and targeting uncertainties.

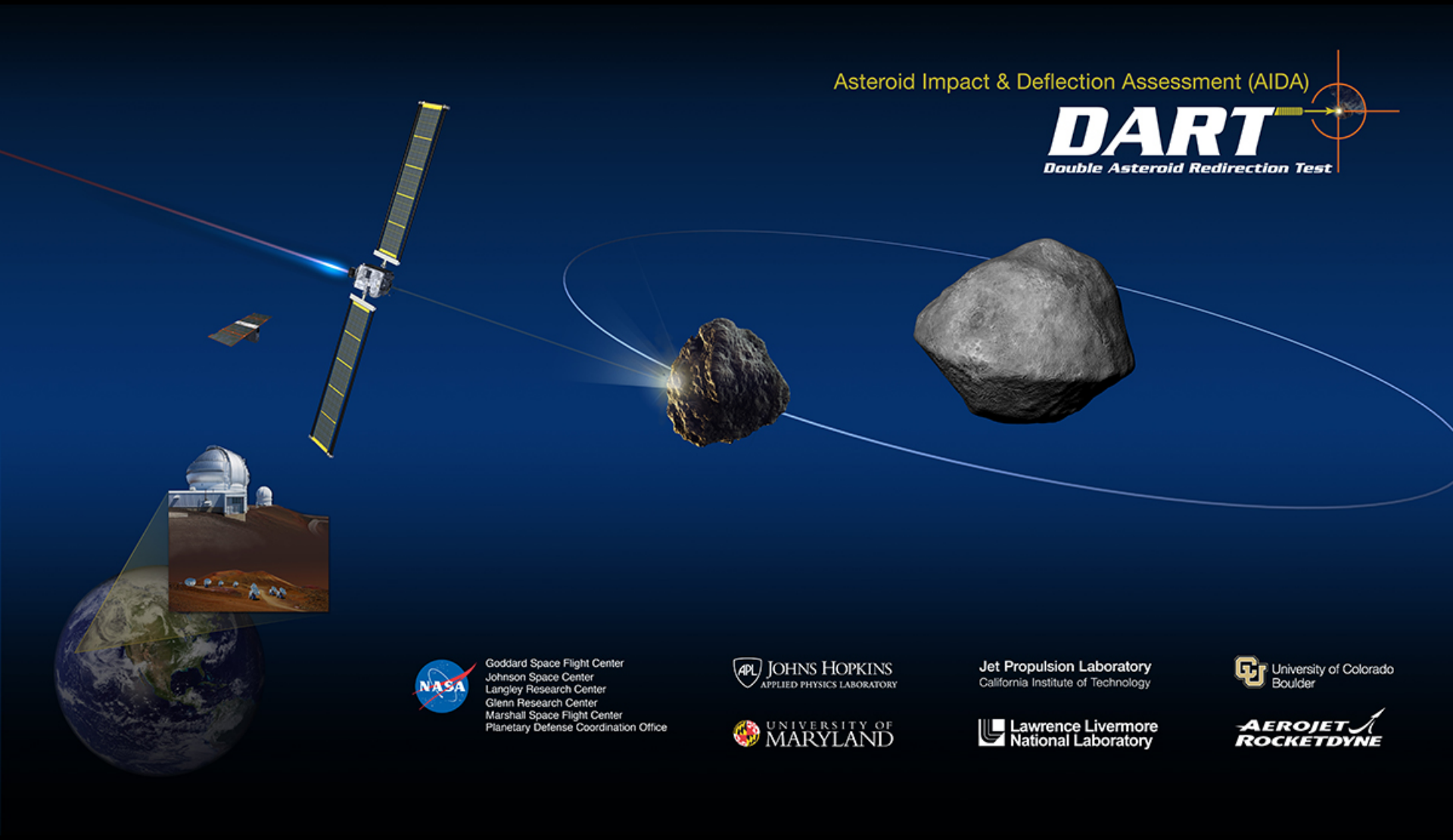

Bennu intercept 2021 impactor view, rotation phase = 0 deg
out-of-plane proj. [m]
300
200
100
0
-100
-200
-300
transverse proj. [m]
300
200
100
0
-100
-200
-300
1-σ targeting
impact probability (x 10^-4)
8
7
6
5
4
3
2

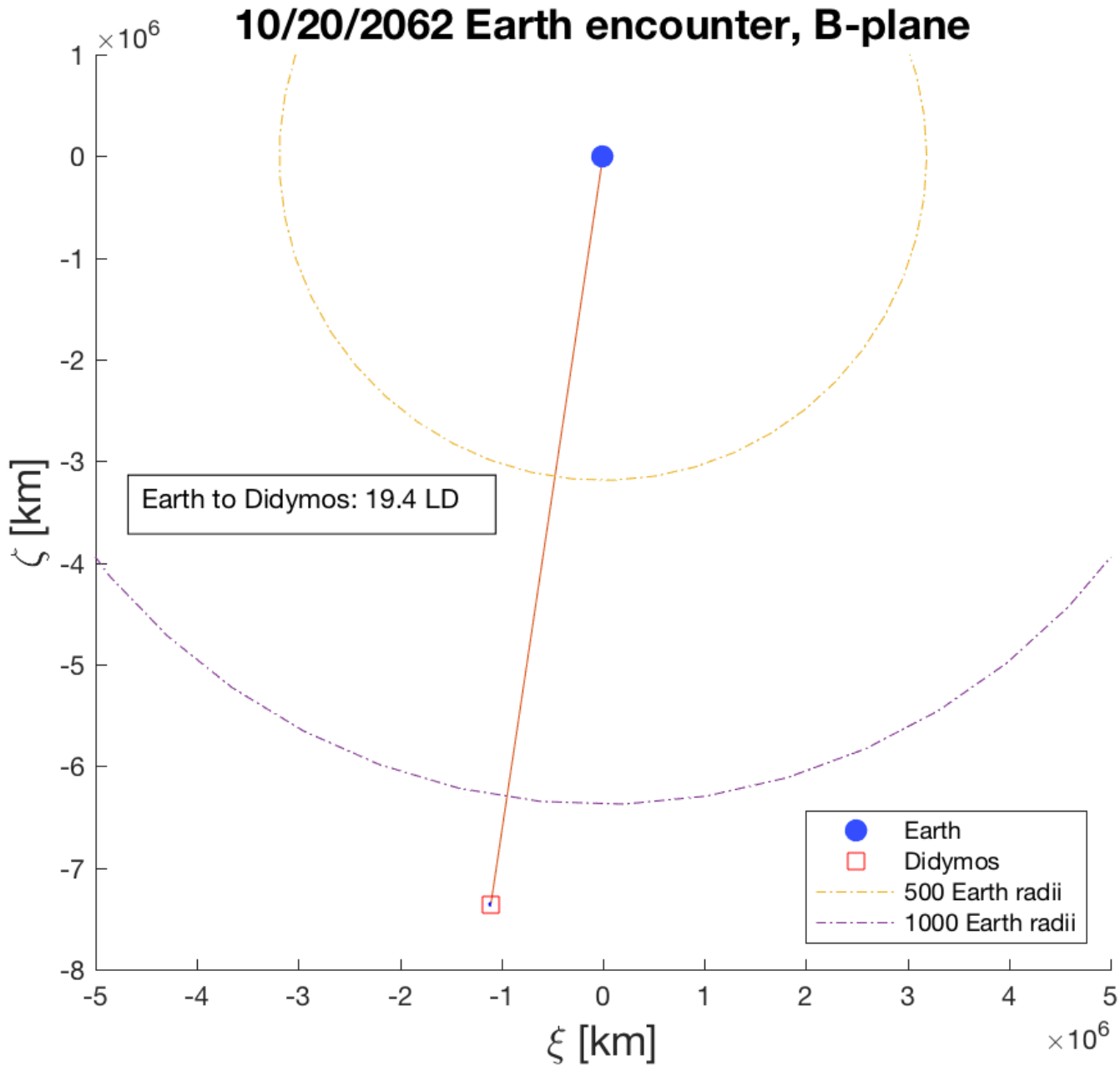
Key concepts

- post deflection impact risk assessment
- keyhole-to-surface targeting maps

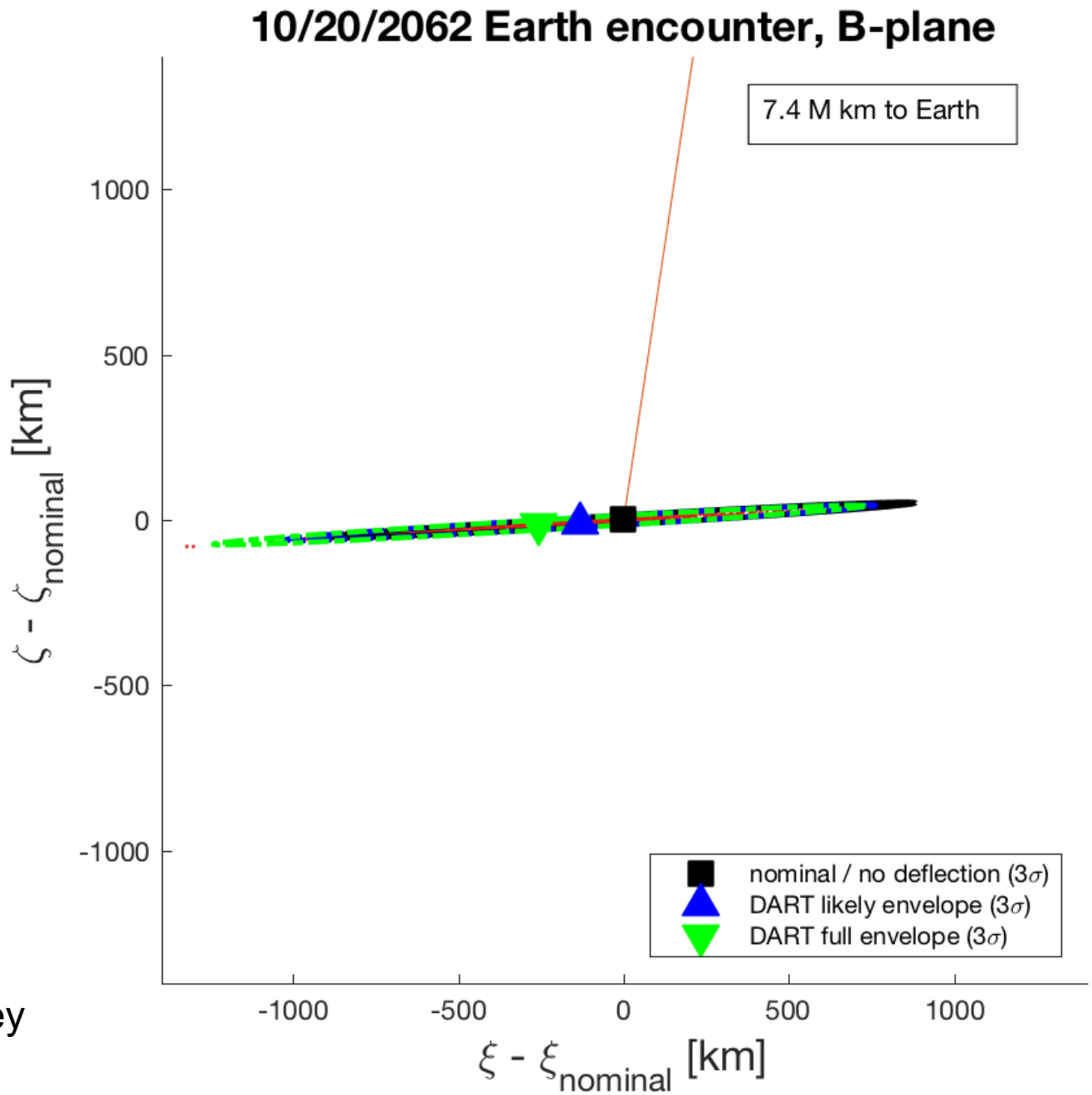
Conclusions

- Knowledge of physical and spin properties is vital for a controlled KI based deflection of potentially hazardous near-Earth asteroids.
- Large uncertainties in β in combination with realistic shapes necessitate a careful evaluation of the safest impact location!
- Impulsive deflection missions can take advantage of a target's shape to avoid keyhole passages and optimize impactor trajectories.


Asteroid Impact & Deflection Assessment (AIDA)
DART
Double Asteroid Redirection Test
Goddard Space Flight Center
Johnson Space Center
Langley Research Center
Glenn Research Center
Marshall Space Flight Center
Planetary Defense Coordination Office
JOHNS HOPKINS
APPLIED PHYSICS LABORATORY
Jet Propulsion Laboratory
California Institute of Technology
University of Colorado
Boulder
UNIVERSITY OF
MARYLAND
Lawrence Livermore
National Laboratory
AEROJET
ROCKETDYNE



Eggl & Chesley (2018)



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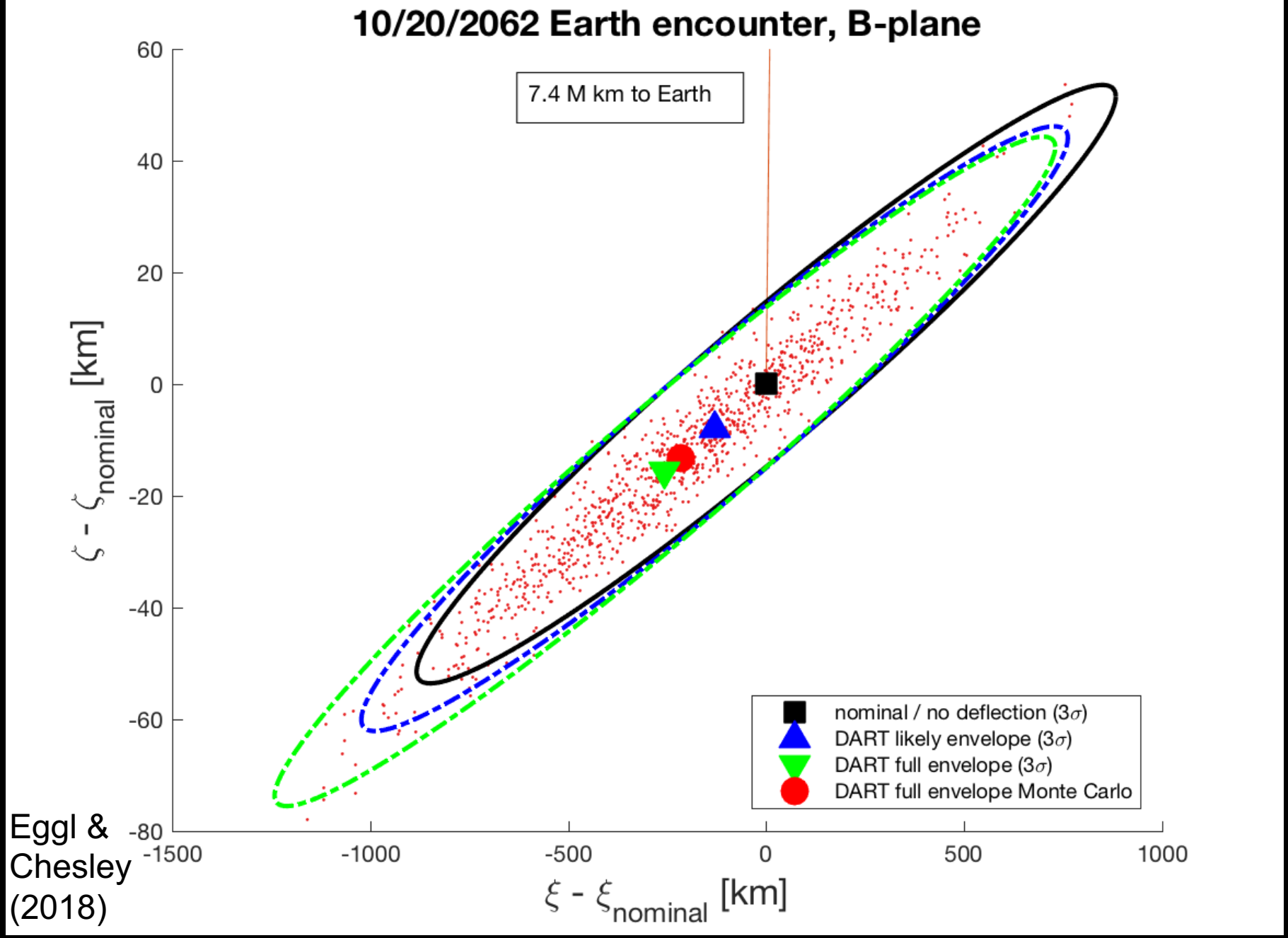

Eggl & Chesley (2018)