The 2023 PDC Hypothetical Impact Scenario: Overview of Asteroid Deflection Issues at Epoch 1

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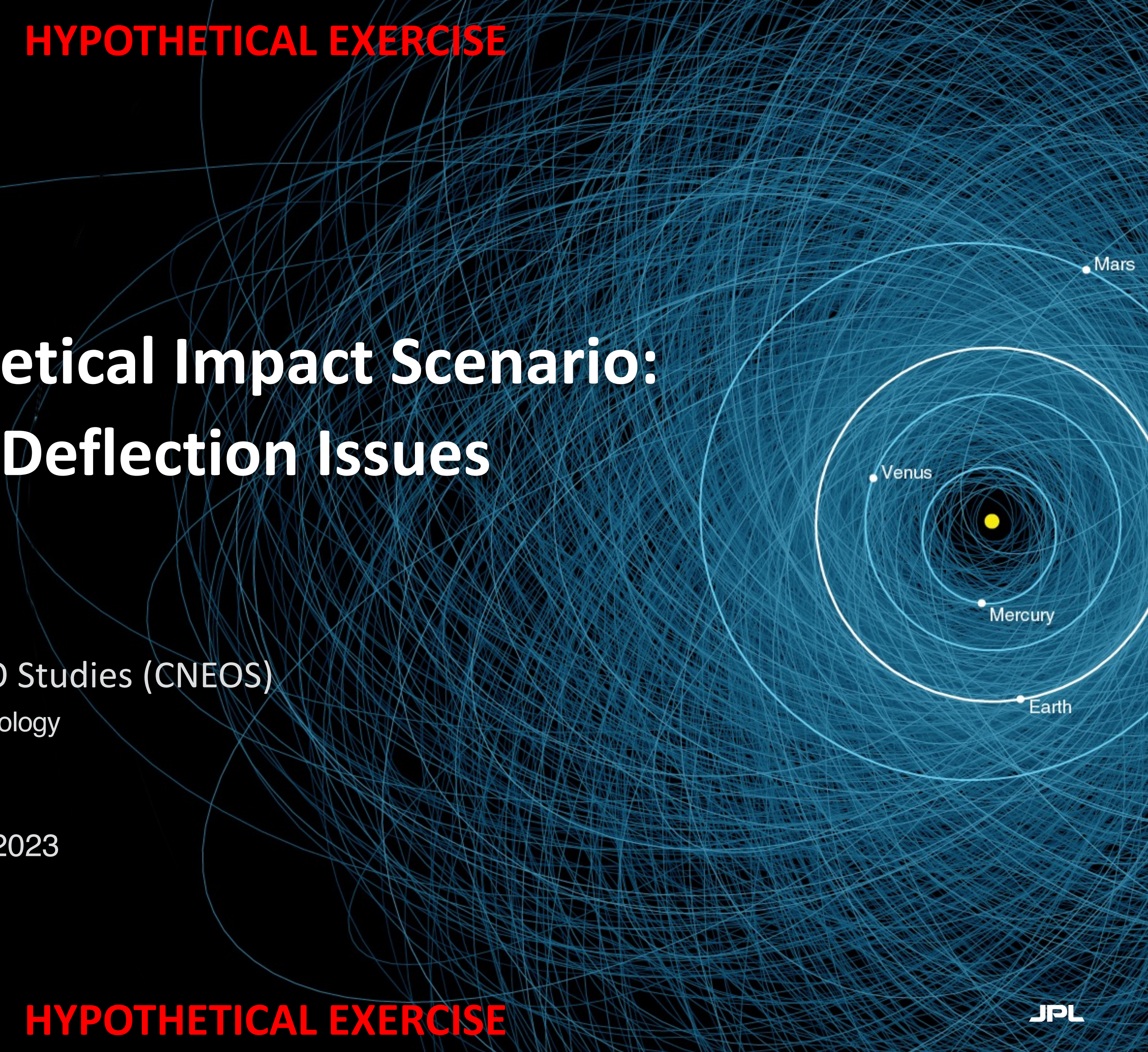
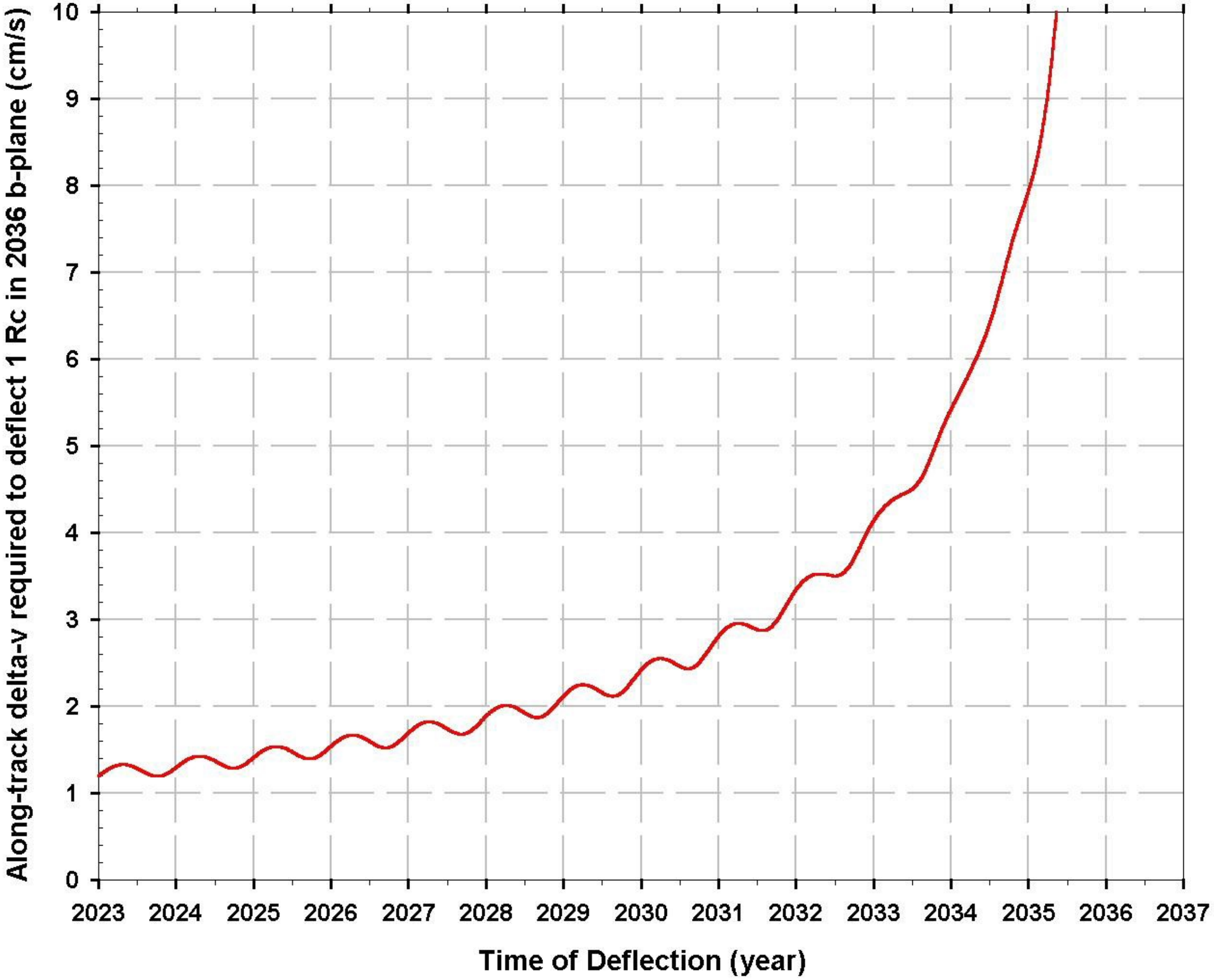


2023 PDC: Worst-Case Required Delta-V vs. Time



This is a plot of the delta-V required to move the worst-case trajectory of 2023 PDC one Earth-disc radius (Rc) in the b-plane

Here, the delta-V is assumed to be applied **along the velocity vector**, usually the optimal direction

Deflecting the asteroid as early as possible is preferred

The wiggles are due to the orbital eccentricity: local minima occur at perihelion, when deflection is more effective

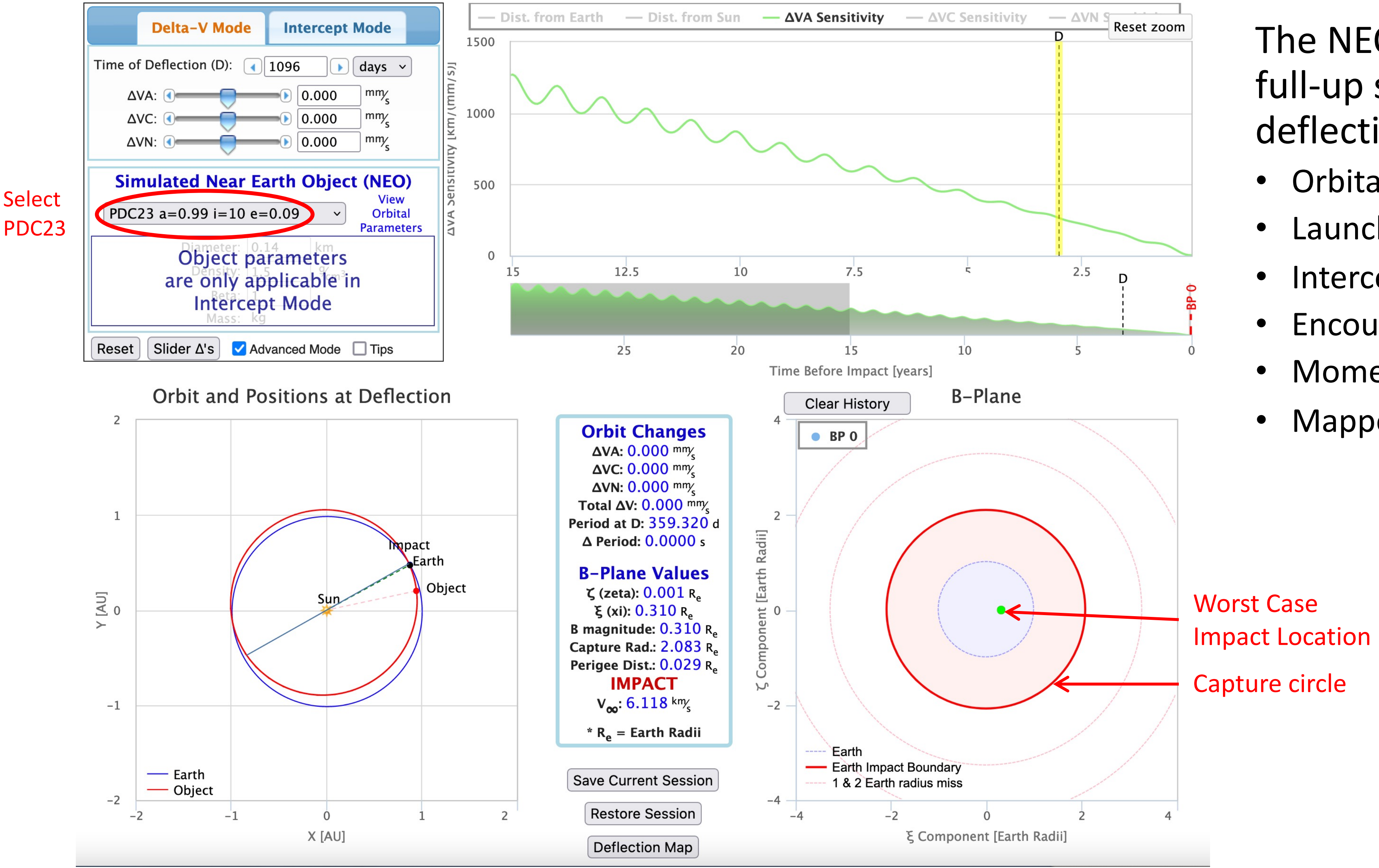
Deflecting Asteroid 2023 PDC

- In the event that 2023 PDC is on a collision trajectory, the impact could be avoided by imparting a small velocity change (delta-V) to the asteroid, thereby deflecting the trajectory away from collision
- The velocity change may not need to be large if is applied many years before the potential impact: a few cm/sec (a few hundredths of a mile-per-hour) may be adequate to move the trajectory enough
- We consider two techniques for deflecting 2023 PDC:
    - **Kinetic Impactor (KI)**: Collide a large spacecraft into the asteroid at high velocity (10-20 km/s); the spacecraft momentum is transferred to the asteroid, along with a momentum enhancement from the ejecta spray (the “beta” factor); last year’s Double Asteroid Redirection Test (DART) was a demonstration of the KI technique, although on a smaller object
    - **Standoff Nuclear**: A Nuclear Explosive Device (NED) is detonated near the surface of the asteroid, some of which then vaporizes (“spalls”) and the asteroid recoils
- If 2023 PDC is on an impact trajectory, the deflection required to move its trajectory off Earth is as yet unknown because the impact location could be anywhere along the risk corridor
- For deflection planning purposes at Epoch 1 we must assume a worst-case trajectory
- Even with 13 years to go, the schedule could be very tight: the delta-v requirement grows with time, and it may take many years to develop one or more deflection spacecraft, launch them and deliver them to the asteroid

HYPOTHETICAL EXERCISE

2023 PDC in the CNEO NEO Deflection App (NDA)

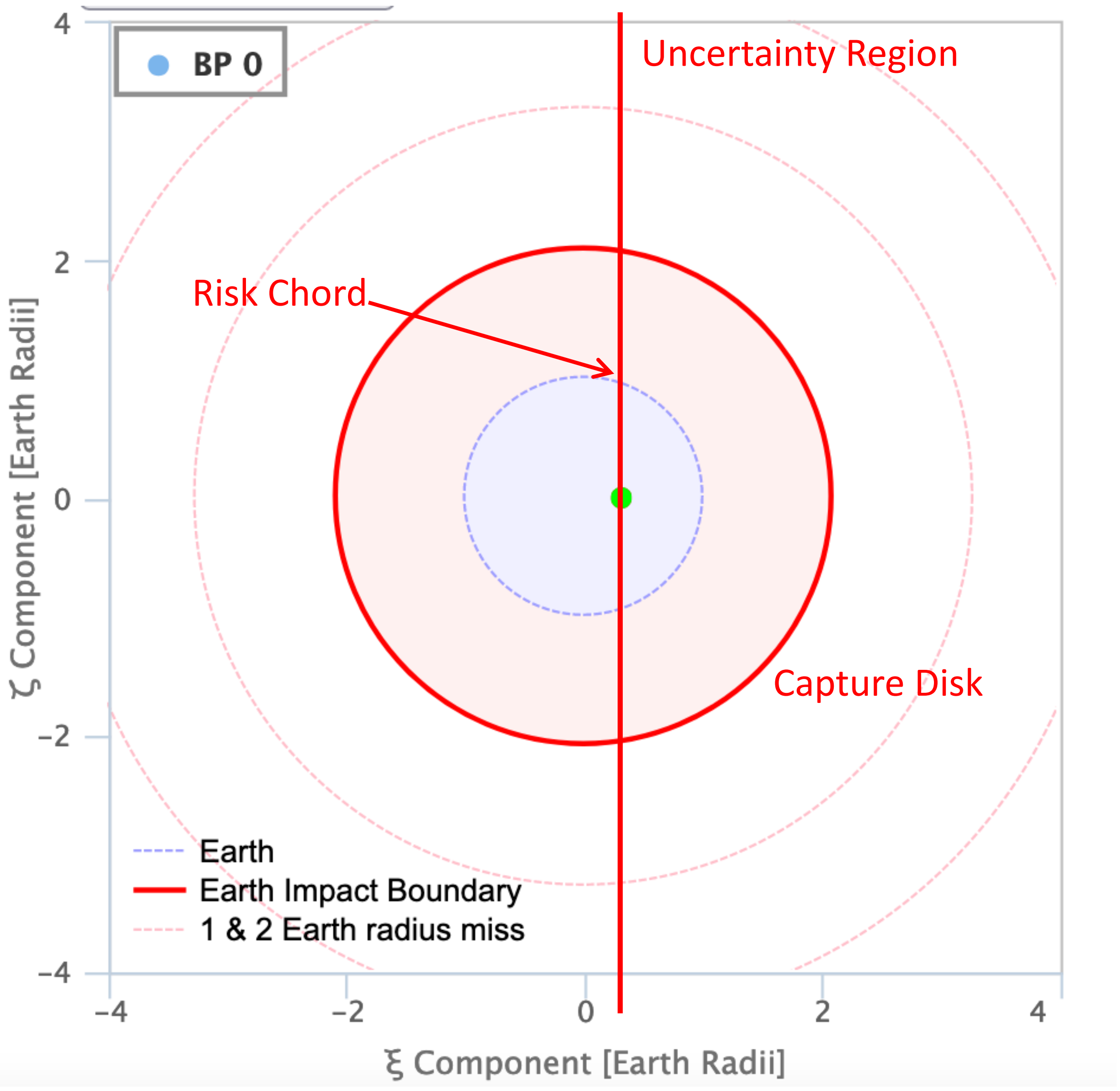
https://cneos.jpl.nasa.gov/nda/nda.html



The NEO Deflection App is a full-up simulation of KI deflection, using realistic:

- Orbital dynamics
- Launch vehicle constraints
- Interceptor mission design
- Encounter geometry
- Momentum transfer with beta
- Mapped b-plane displacement

2023 PDC B-Plane in the NEO Deflection App



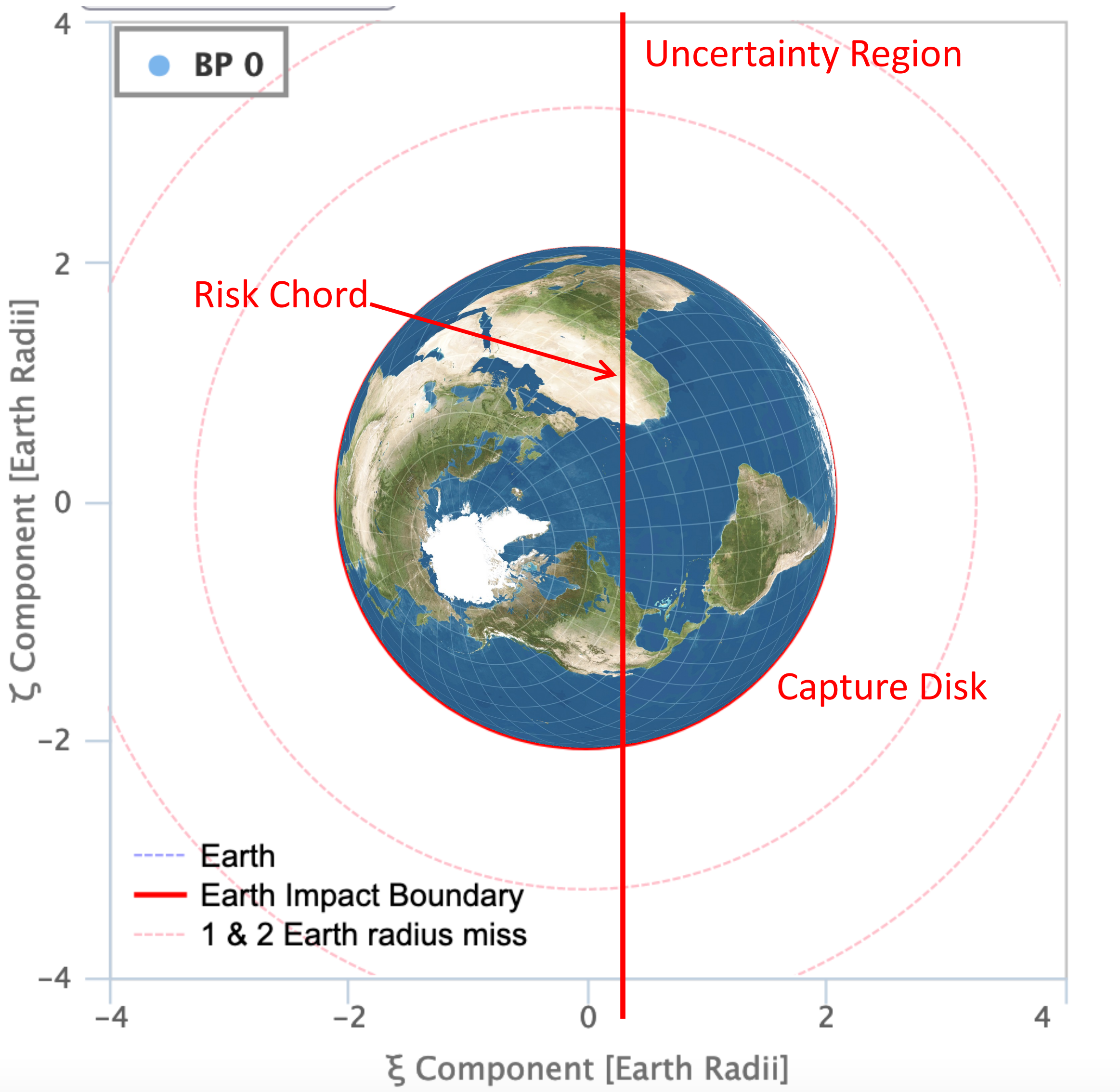
The NDA enables the user to design a realistic KI mission, to see how far the undeflected asteroid trajectory (green dot) can be moved, as a function of:

- launch vehicle lift capability
- launch date, time-of-flight
- asteroid size and mass
- beta enhancement factor, etc.

A successful mission (or suite of missions) moves the green dot outside the capture circle

HYPOTHETICAL EXERCISE

2023 PDC B-Plane in the NEO Deflection App



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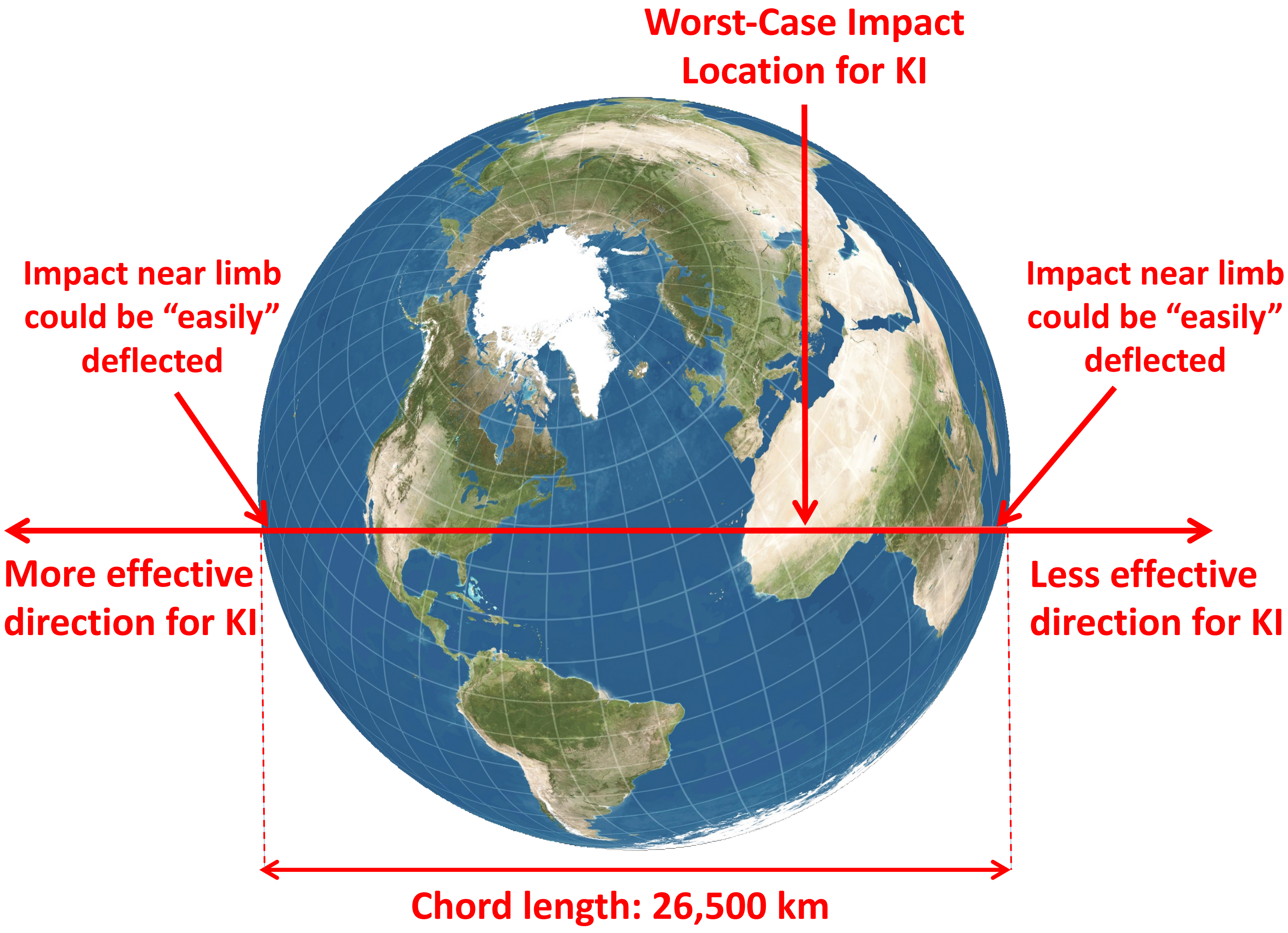
HYPOTHETICAL EXERCISE

Orbital Considerations in Asteroid Deflection

- The principal direction an asteroid can be significantly deflected is along its orbital path
- When deflected, the trajectory moves along the risk chord
- If the defection is not enough to move the trajectory off the Earth, the impact point moves to a new location on the risk corridor
- For Kinetic Impactors, deflection is asymmetric: for a given launch vehicle it is generally easier to decrease an asteroid's velocity than it is to increase the velocity
- For an outbound encounter like that of 2023 PDC, decreasing the asteroid velocity moves the impact point westwards, so, westwards is easier for KI deflection in this case
- However, for 2023 PDC, eastwards KI deflections are still possible, just less effective
- For 2023 PDC, the "worst-case" most-difficult-to-deflect impact location for Kinetic Impactors is roughly 1/4 of a chord length from the eastern limb
- Both directions are equally easy for Nuclear Deflection, assuming it's on a rendezvous mission

HYPOTHETICAL EXERCISE

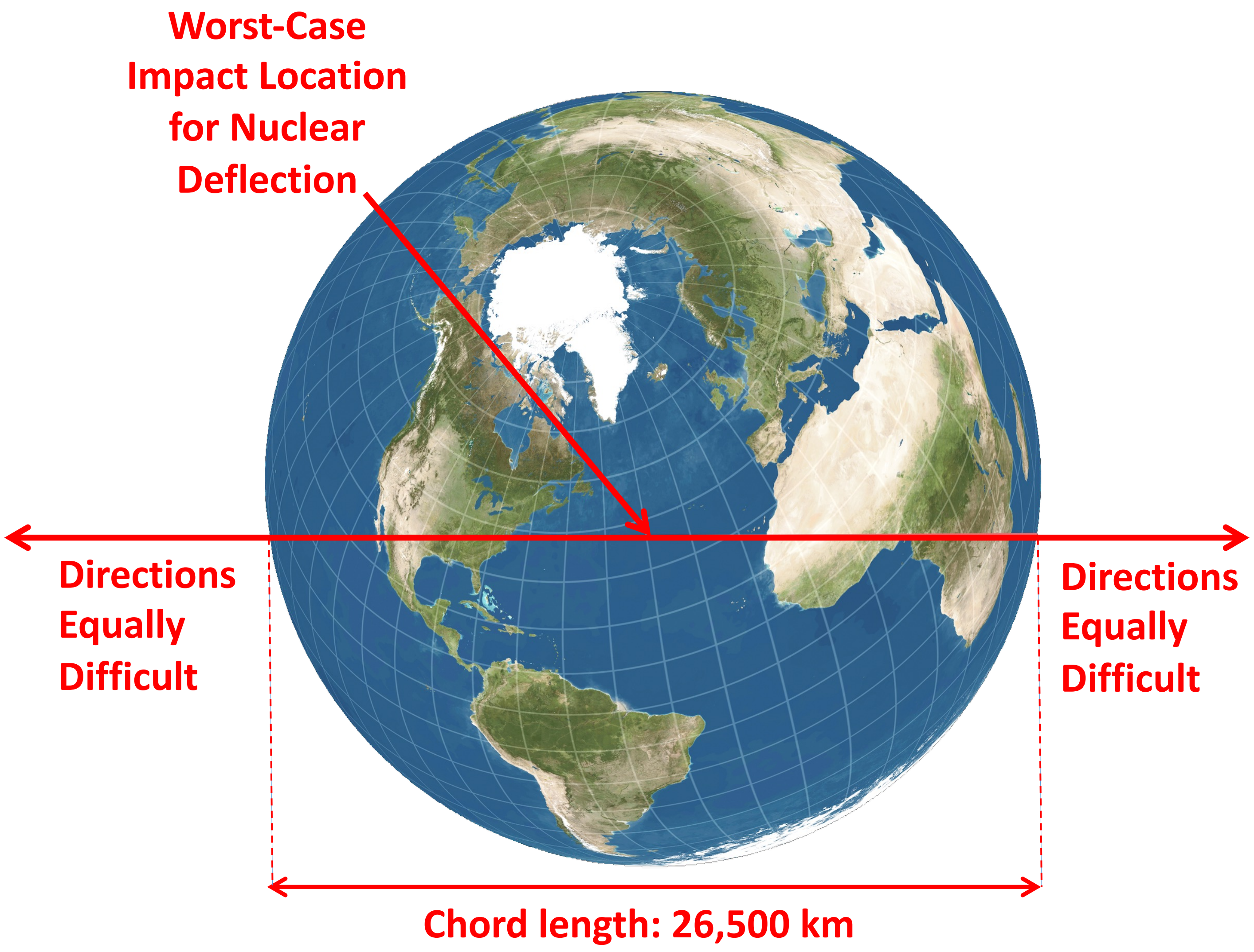
2023 PDC: Considerations for Kinetic Impactor Deflection



- Since we don't yet know the impact location, we cannot yet predict how much deflection will be required
- Since 2023 PDC may be quite large, many KI missions may be required, even if the impact location is favorable
- Since we don't know 2023 PDC's mass to within even an order of magnitude accuracy, we can't predict how much deflection each mission can achieve
- If the asteroid is very small or the impact location near the limb, a small number of KI missions might suffice
- Otherwise, the number of KI missions required would be large (dozens or even hundreds)

HYPOTHETICAL EXERCISE

2023 PDC: Considerations for Nuclear Deflection



- Since we don’t yet know the impact location, we cannot yet predict how much deflection will be required, but the worst-case is half that of KIs
- The directions are equally difficult
- Since we don’t know 2023 PDC’s mass to within even an order of magnitude accuracy, we must design the deflection to succeed with the largest likely asteroid mass and the worst-case impact location

HYPOTHETICAL EXERCISE

Benefits of Reconnaissance Missions

- A Recon mission would provide accurate in-situ orbit information:
  - Enables a much more accurate prediction of the impact location than could be achieved from the ground
- A Recon mission would provide much improved estimates of asteroid size and mass
  - Mass if the key parameter in any deflection attempt: it drives the deflection campaign design
  - A rendezvous recon mission could make a direct measurement of mass
  - A flyby recon mission might obtain a reasonably accurate estimate of mass through measurements of asteroid size and shape, and using assumptions on bulk density
  - A flyby mission might be able to further constrain the mass estimate through deployable gravity probes
- A more accurate mass estimate also enables more accurate predictions of impact energy and damage region size if mitigation is not attempted
- A rendezvous recon mission could remain on station to observe the deflection event, measure the achieved velocity change, and provide data to compute the post-deflection trajectory