



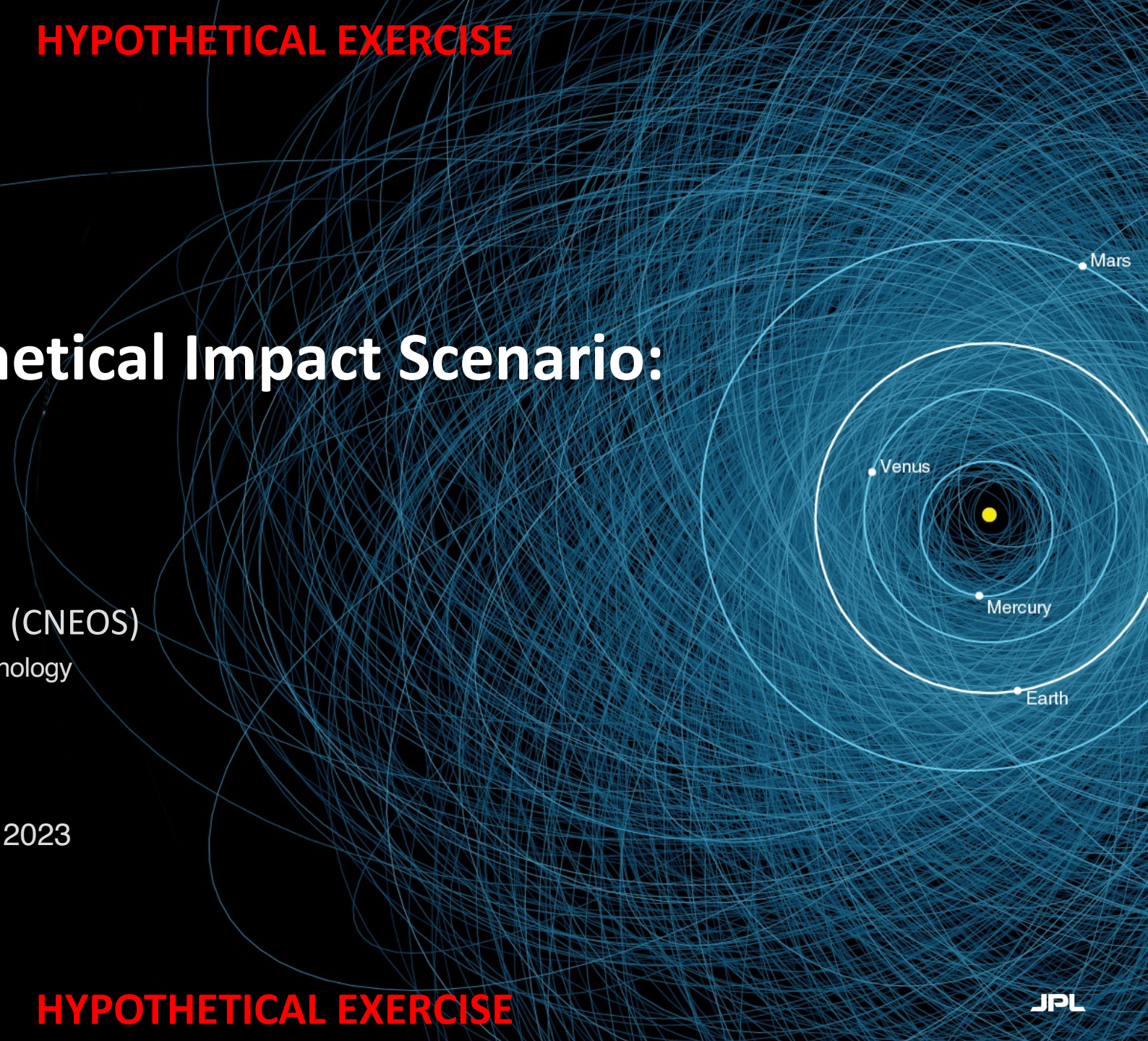
**HYPOTHETICAL EXERCISE**

# The 2023 PDC Hypothetical Impact Scenario: Epoch 1 Summary

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Jet Propulsion Laboratory, California Institute of Technology

8<sup>th</sup> IAA Planetary Defense Conference, April, 2023  
Vienna, Austria

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# Asteroid 2023 PDC: Initial Discovery & Tracking

- New asteroid discovered on **Jan. 10, 2023** in the twilight region of the sky
- Designated "**2023 PDC**" by the Minor Planet Center (MPC)
- Categorized as a "**Potentially Hazardous Asteroid**" (PHA)
- Impact probability initially 1-in-10,000, but steadily increased over 3 months of tracking
- **Impact probability reached 1% today, "Epoch 1", April 3, 2023**
- **The potential impact is on Oct. 22, 2036, 13 years from now**
- Size of 2023 PDC is highly uncertain: based on its brightness, it **could be quite large**
- Allowing for measurement uncertainties and a range of typical asteroid reflectivities, **the most likely size is in the range 220 - 660 meters (720 - 2200 feet)**, but the size could possibly be as large as **2 kilometers (1.3 miles)**
- If 2023 PDC impacts, the **energy released** would likely be in the range **54 Mt - 5.5 Gt**, but the energy **could be as large as 160 Gt**



# Potential 2023 PDC Impact in Context of Expected Events

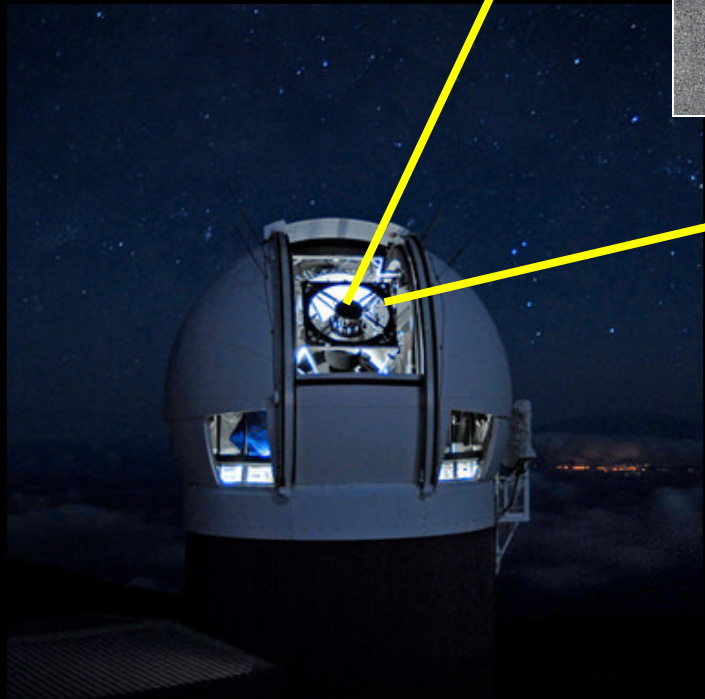
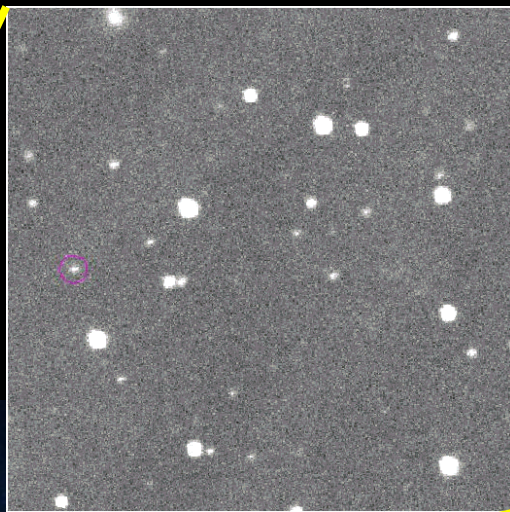
Diameter of Impacting Asteroid	Type of Event	Approximate Impact Energy (MT)	Average Time Between Impacts (Years)
5 m (16 ft)	Bolide	0.01	1
10 m (33 ft)	Superbolide	0.1	10
25 m (80 ft)	Major Airburst	1	100
50 m (160 ft)	Local Scale Devastation	10	1000
140 m (460 ft)	Regional Scale Devastation	300	20,000
300 m (1000 ft)	Continent Scale Devastation	2,000	70,000
600 m (2000 ft)	Below Global Catastrophe Threshold	20,000	200,000
1 km (3300 ft)	Possible Global Catastrophe	100,000	700,000
5 km (3 mi)	Above Global Catastrophe Threshold	10,000,000	30 million
10 km (6 mi)	Mass Extinction	100,000,000	100 million





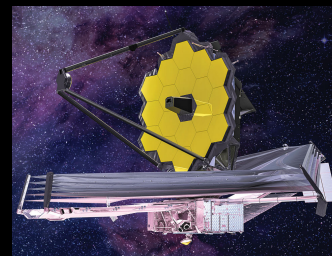
# Asteroid 2023 PDC: Sources of Data

Optical



Astrometry  
&  
Photometry

Space-Based Infra-Red



Size

Radar

Delay &  
Doppler

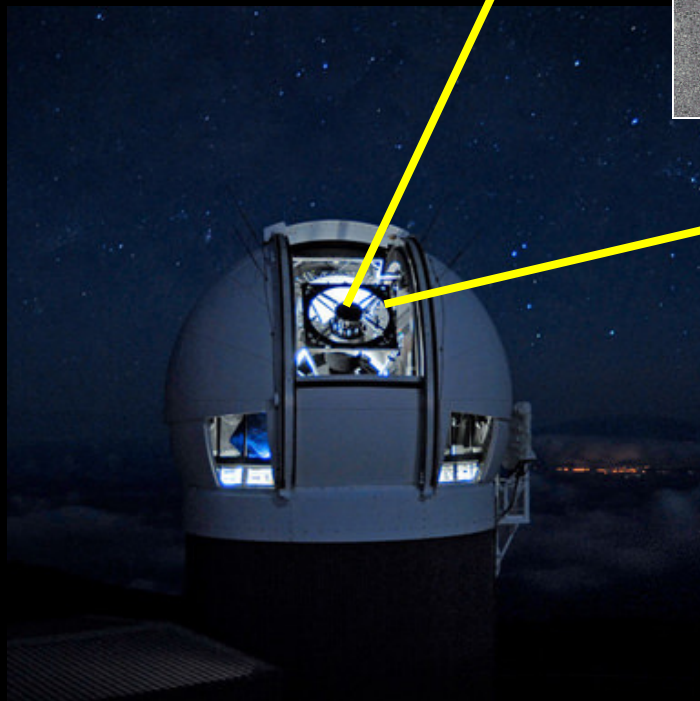
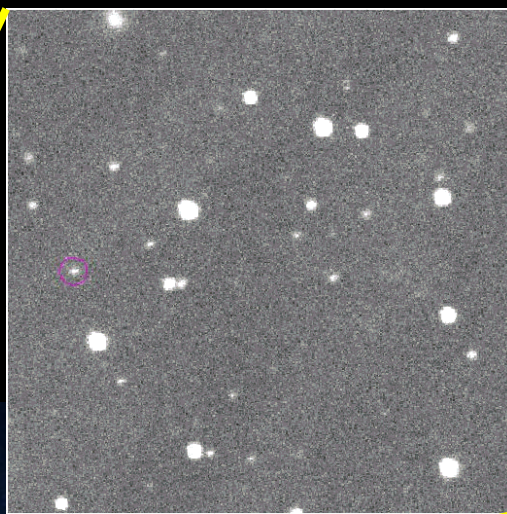






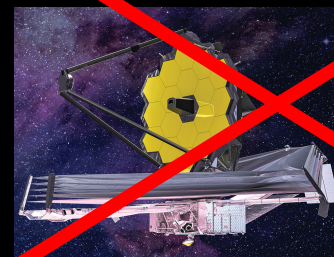
# Asteroid 2023 PDC: Sources of Data

Optical



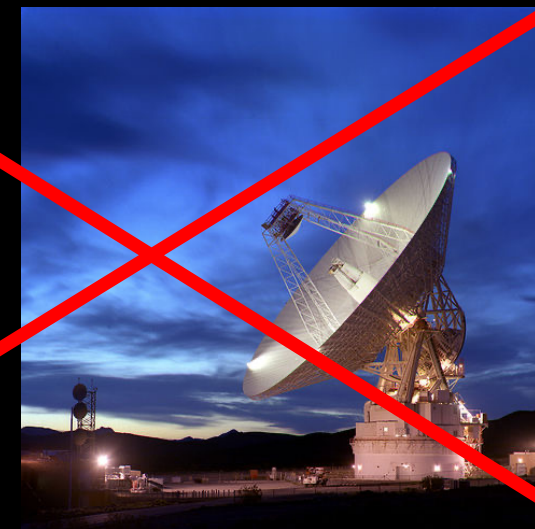
Astrometry  
&  
Photometry

~~Space-Based Infra-Red~~



~~Size~~

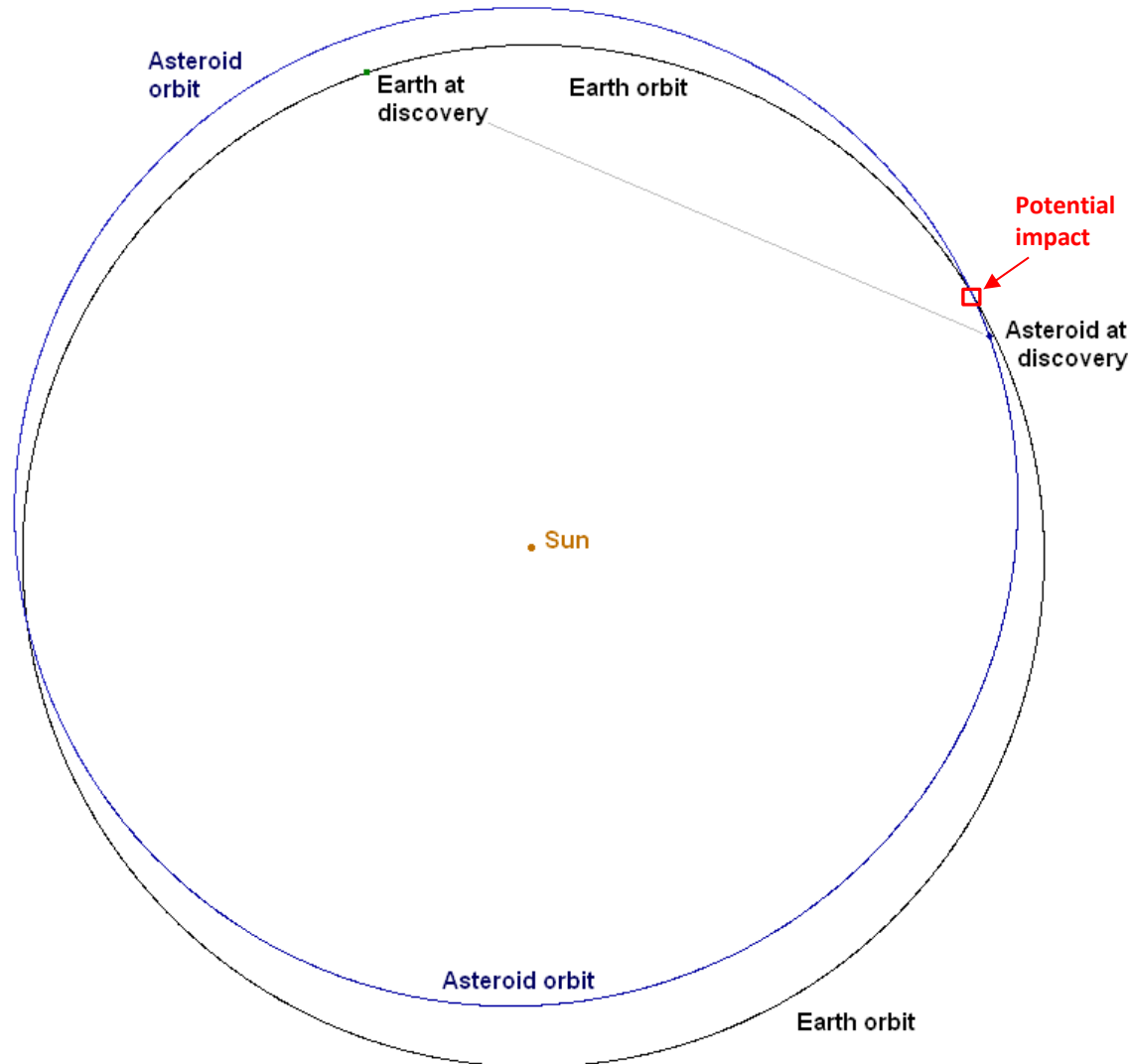
~~Radar~~



~~Delay &  
Doppler~~



# Orbit of Asteroid 2023 PDC About the Sun

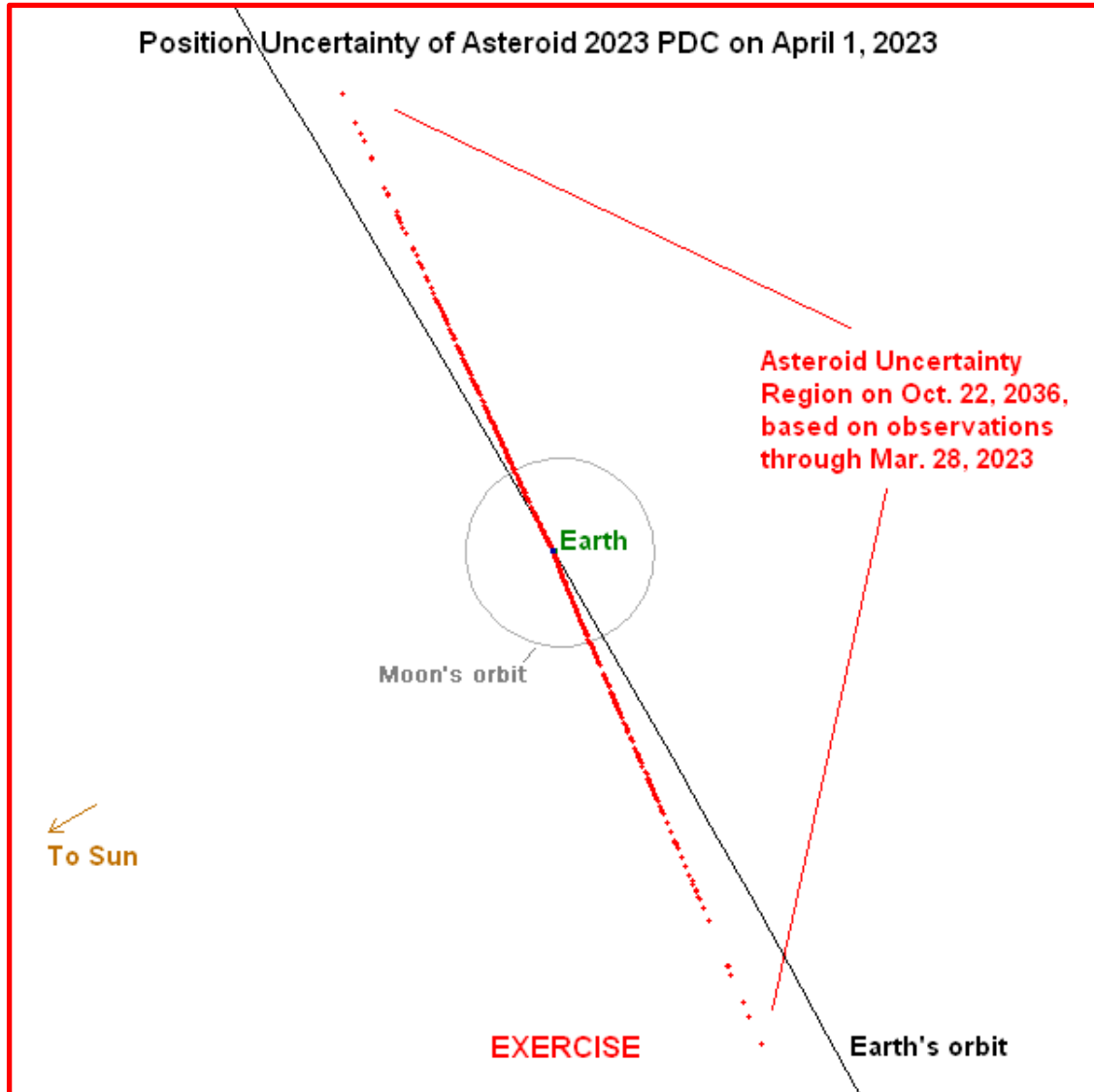


- **Orbit about Sun is similar to Earth's**
- **The orbits intersect (at the red square)**
- **Asteroid is currently very distant:**  
200 million km (125 million mi) from Earth
- **As Earth and asteroid orbit the Sun, the asteroid is slowly catching up**
- **After 13 years, when Earth crosses through the intersection point, the asteroid may be there**
- **Asteroid orbit not known accurately enough yet: more tracking data needed**





# Uncertainty in 2023 PDC Position at Potential Impact Point

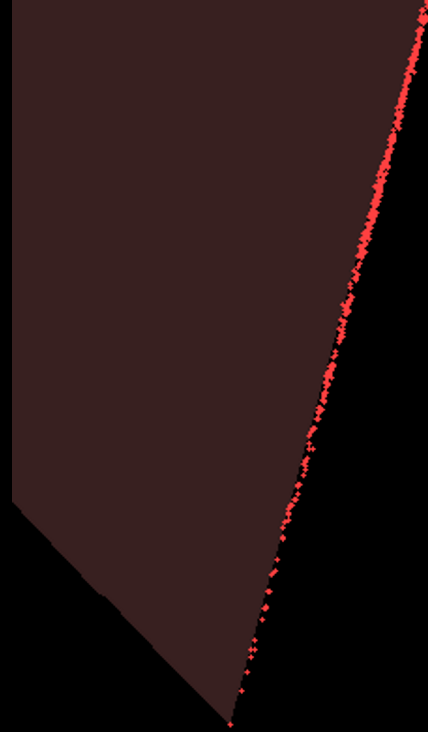


- **The uncertainty in where the asteroid will be in 2036 is currently larger than the Moon's orbit**
- We trace the **uncertainty region** using **red dots**
  - NB: The region is actually continuous
- The region aligns along the asteroid's orbit: the main uncertainty is the asteroid's position **along** its orbit
- Currently, 1% of the region intersects Earth
- **As more observations are made, the uncertainty region will shrink**



HYPOTHETICAL EXERCISE

# 2023 PDC Uncertainty Region in 2036



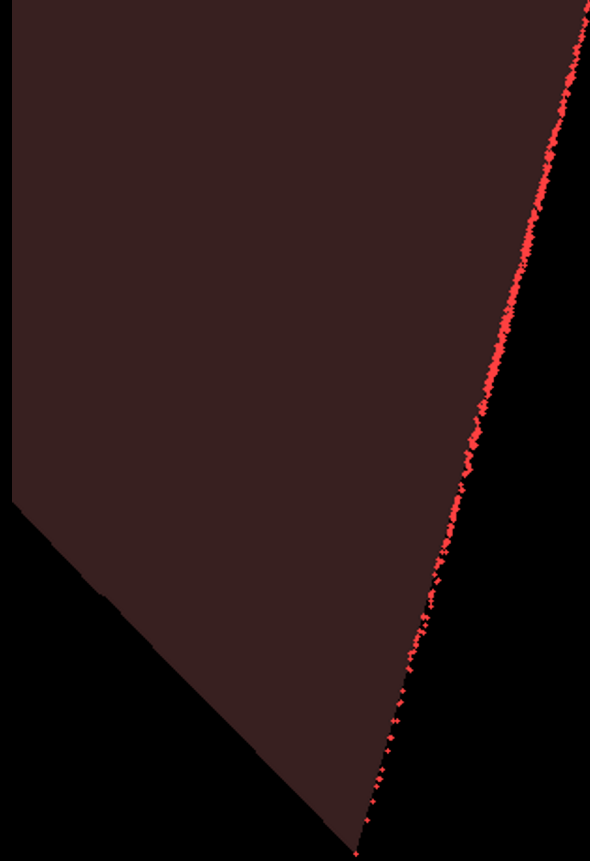
HYPOTHETICAL EXERCISE





HYPOTHETICAL EXERCISE

# 2023 PDC Uncertainty Region in 2036



HYPOTHETICAL EXERCISE



HYPOTHETICAL EXERCISE

# 2023 PDC Uncertainty Region in 2036



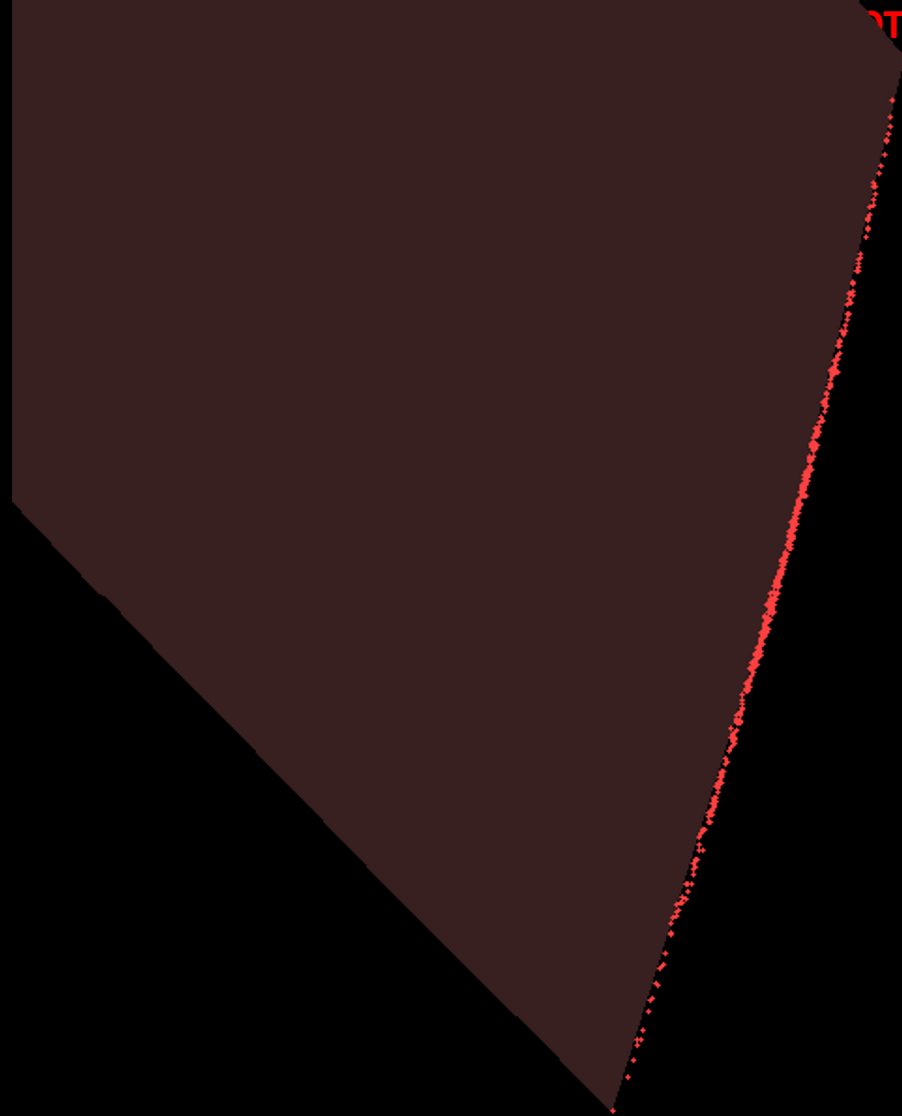
HYPOTHETICAL EXERCISE





HYPOTHETICAL EXERCISE

# 2023 PDC Uncertainty Region in 2036

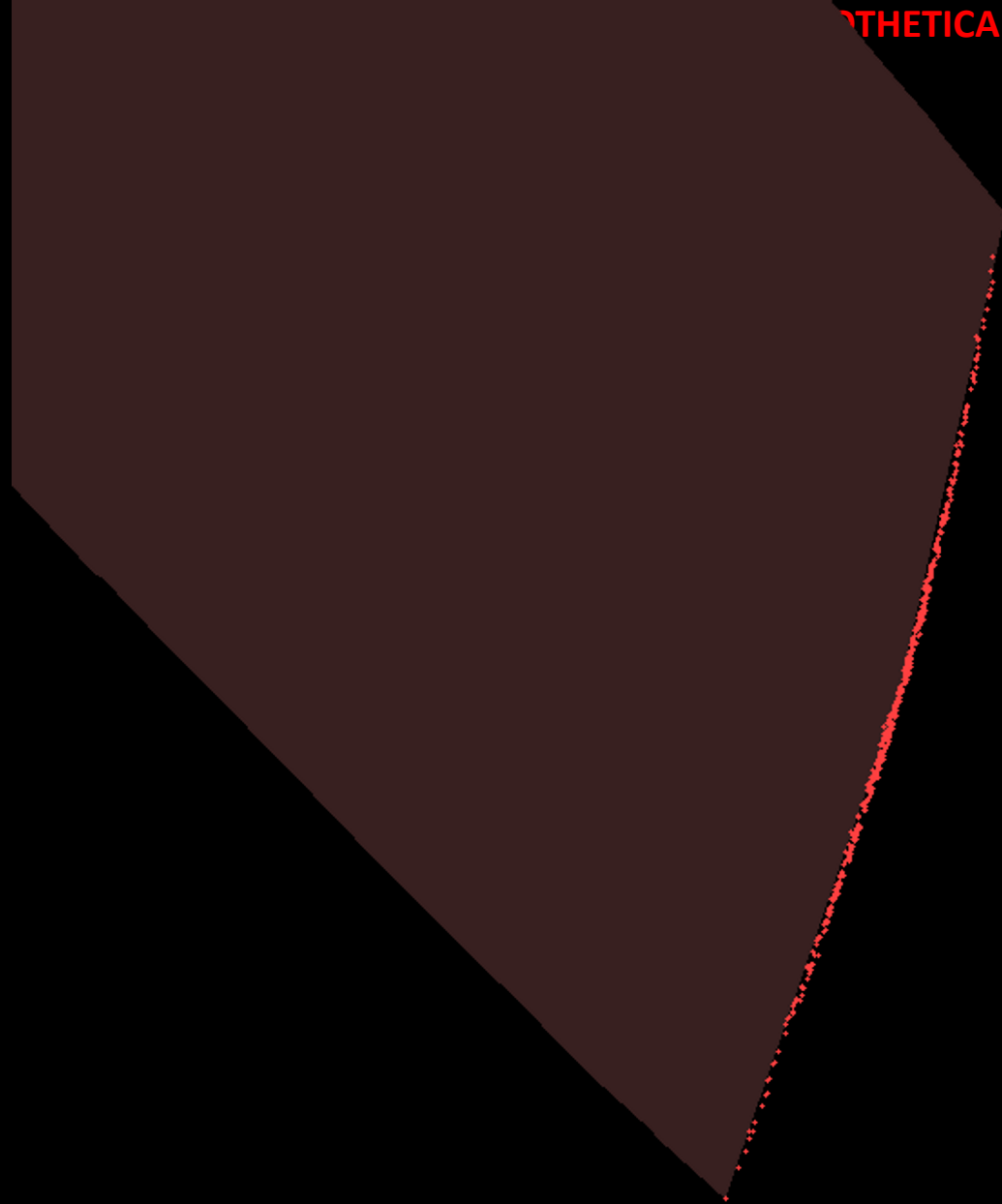


HYPOTHETICAL EXERCISE



HYPOTHETICAL EXERCISE

# 2023 PDC Uncertainty Region in 2036



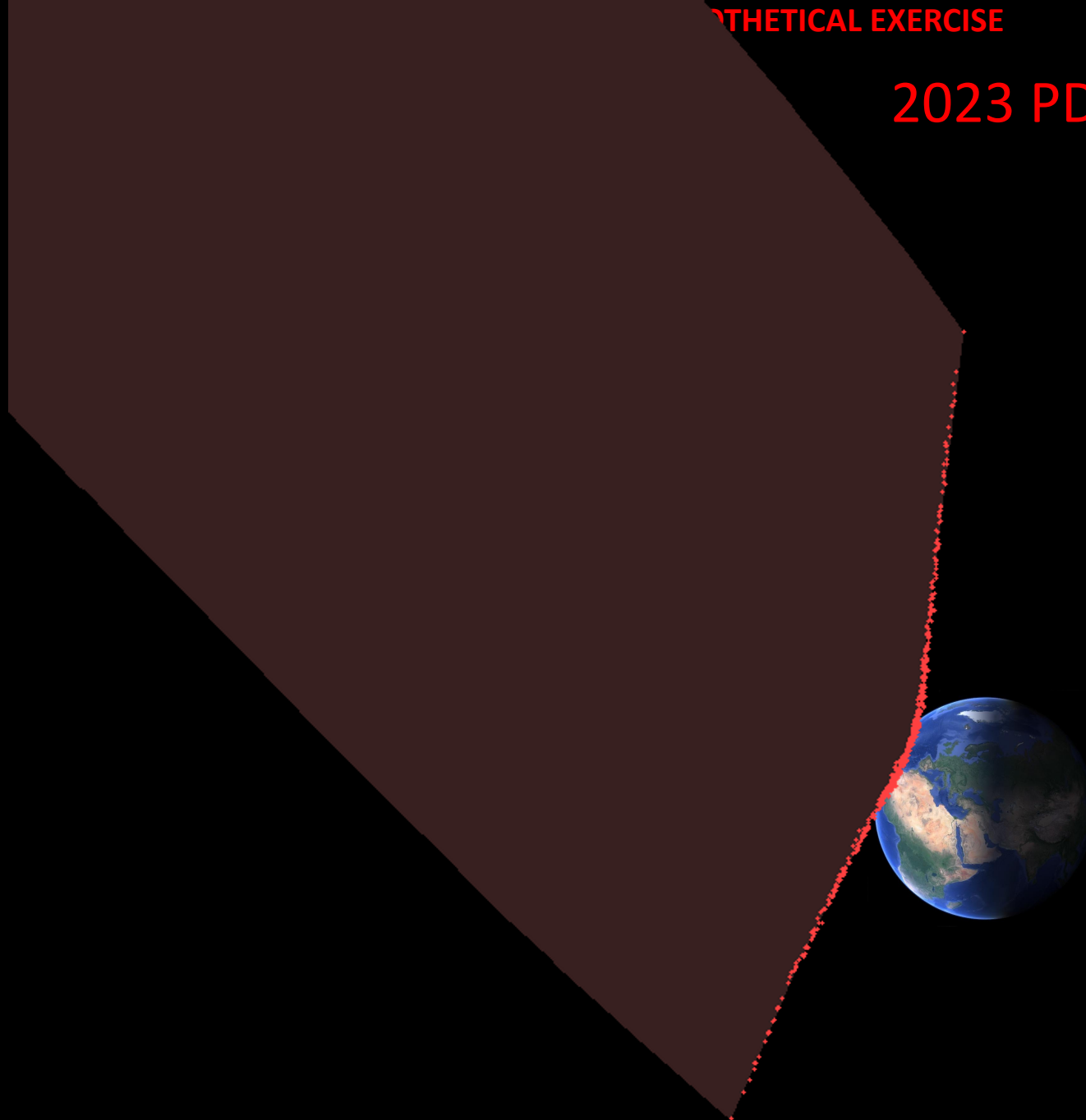
HYPOTHETICAL EXERCISE





HYPOTHETICAL EXERCISE

## 2023 PDC Uncertainty Region in 2036



Note the gravitational focusing effect: Earth's gravity pulls many of the red dots towards impact

HYPOTHETICAL EXERCISE



# 2023 PDC Risk Corridor - Western Portion



Google Earth

Data SIO, NOAA, U.S. Navy, NGA, GEBCO  
Image IBCAO  
Image U.S. Geological Survey  
Image Landsat / Copernicus

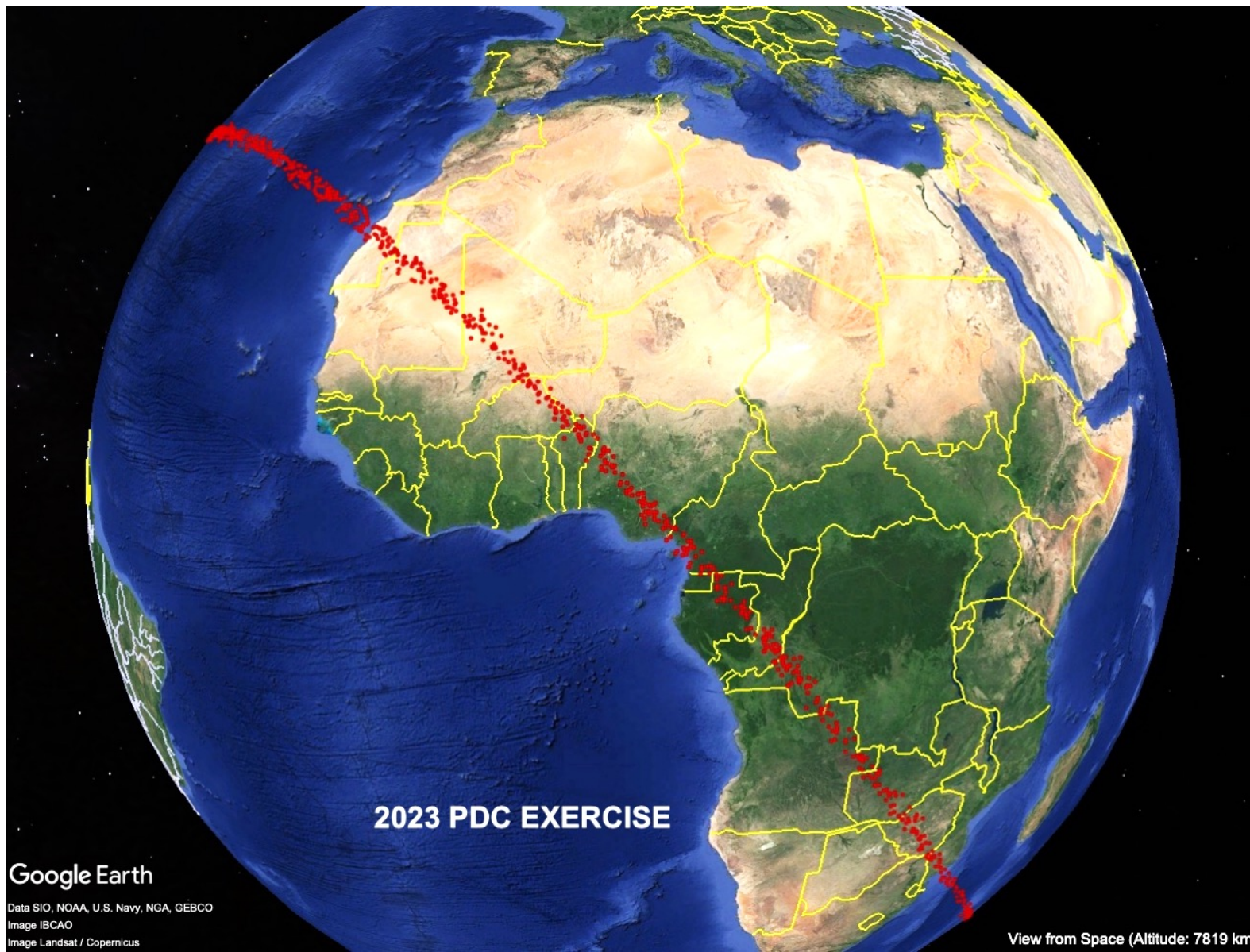
2023 PDC EXERCISE

View from Space (Altitude: 7819 km)





# 2023 PDC Risk Corridor - Eastern Portion



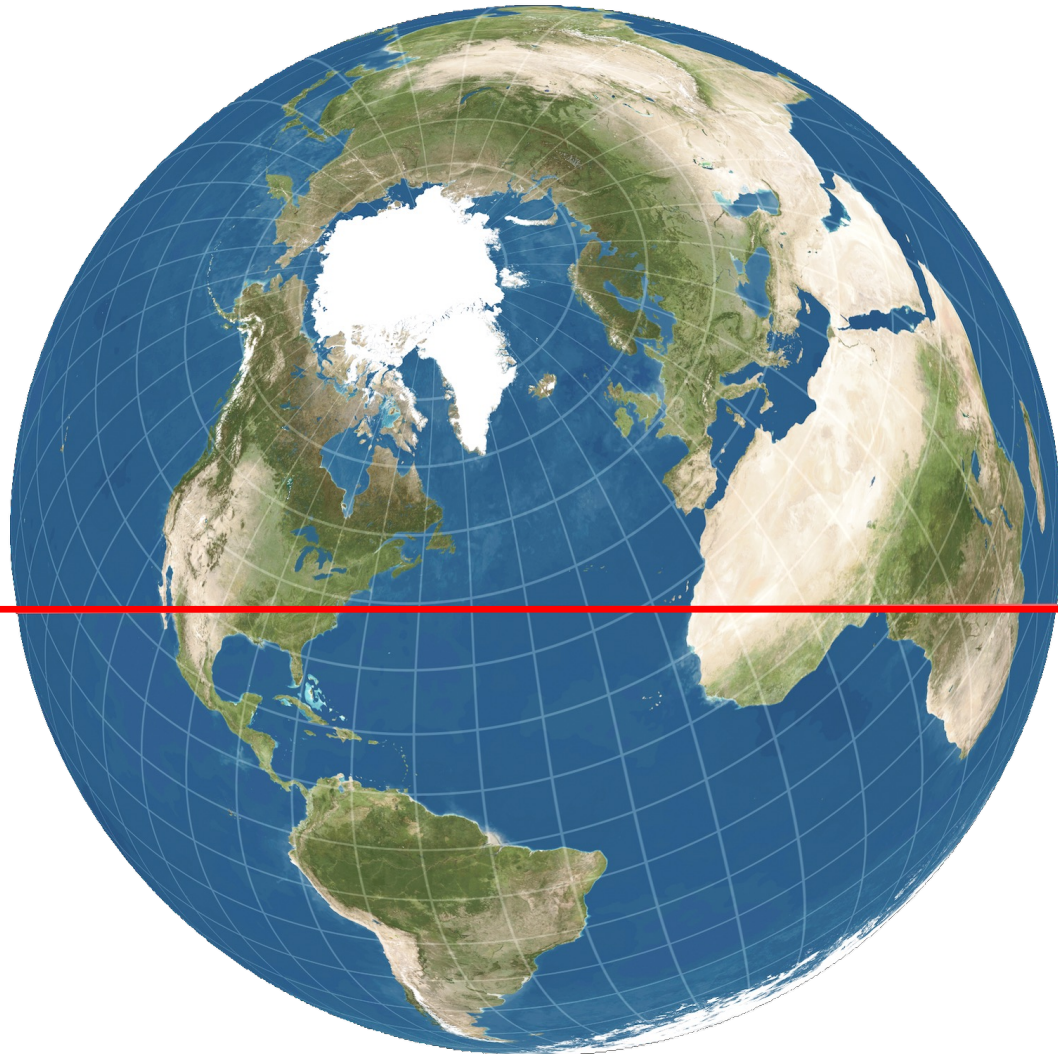
Google Earth

Data SIO, NOAA, U.S. Navy, NGA, GEBCO  
Image IBCAO  
Image Landsat / Copernicus





# 2023 PDC: Uncertainty in the 2036 “Target-Plane”



- The “B-Plane” is a useful projection
- It’s the view of the Earth from the approaching asteroid, with Earth’s gravitational focusing removed
- The asteroid trajectory is perpendicular to the plane: it becomes just a dot
- The image of the Earth is “unrolled”, so it’s larger than the actual size of the Earth

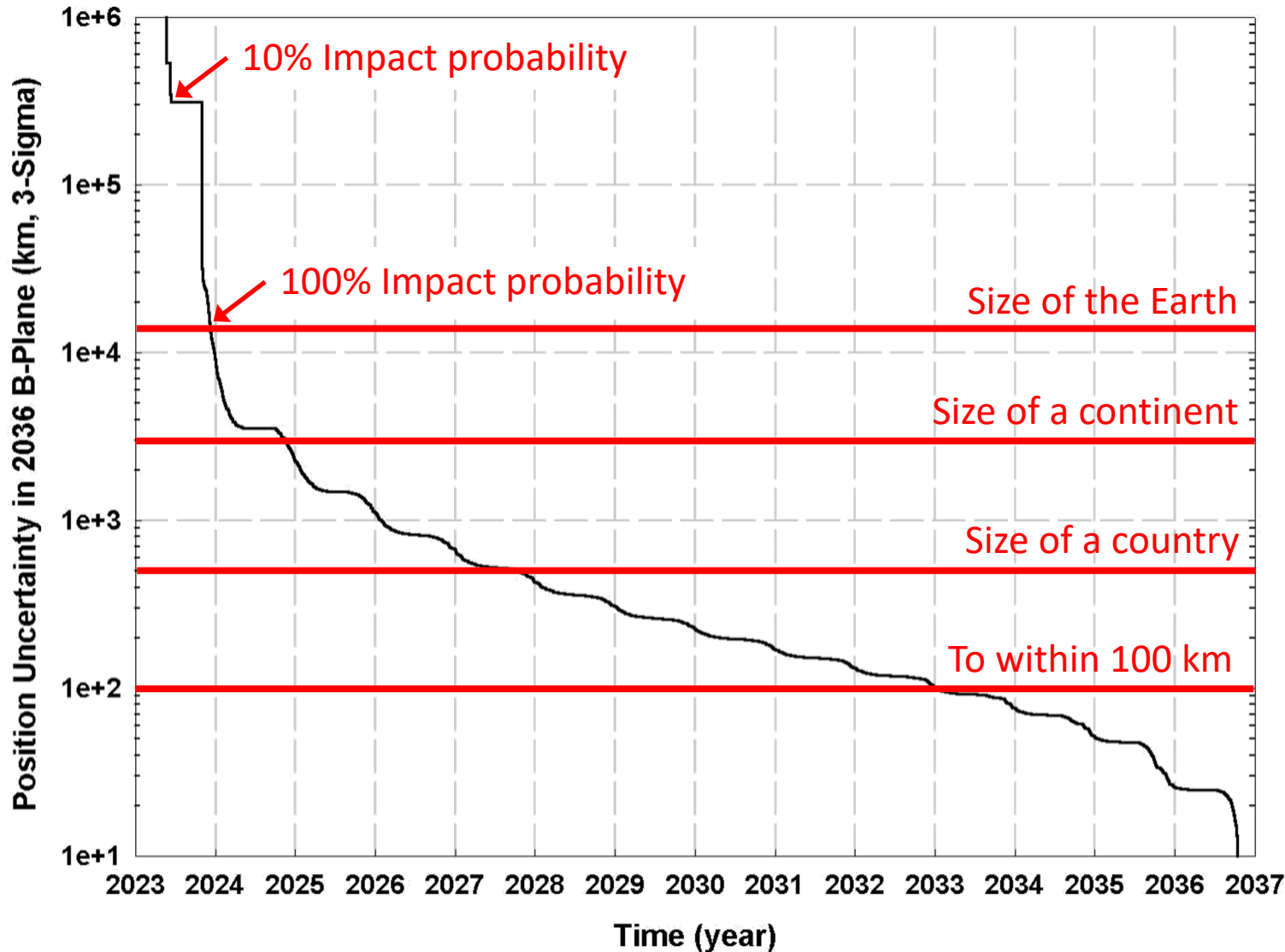
←  
**Uncertainty  
Region**

Advantage of using this projection:  
**Orbit uncertainties and deflection  
sizes are independent of the  
impact location**





# 2023 PDC: Position Uncertainty at 2036 Encounter vs. Time



2023 PDC will be almost continuously observable from Earth

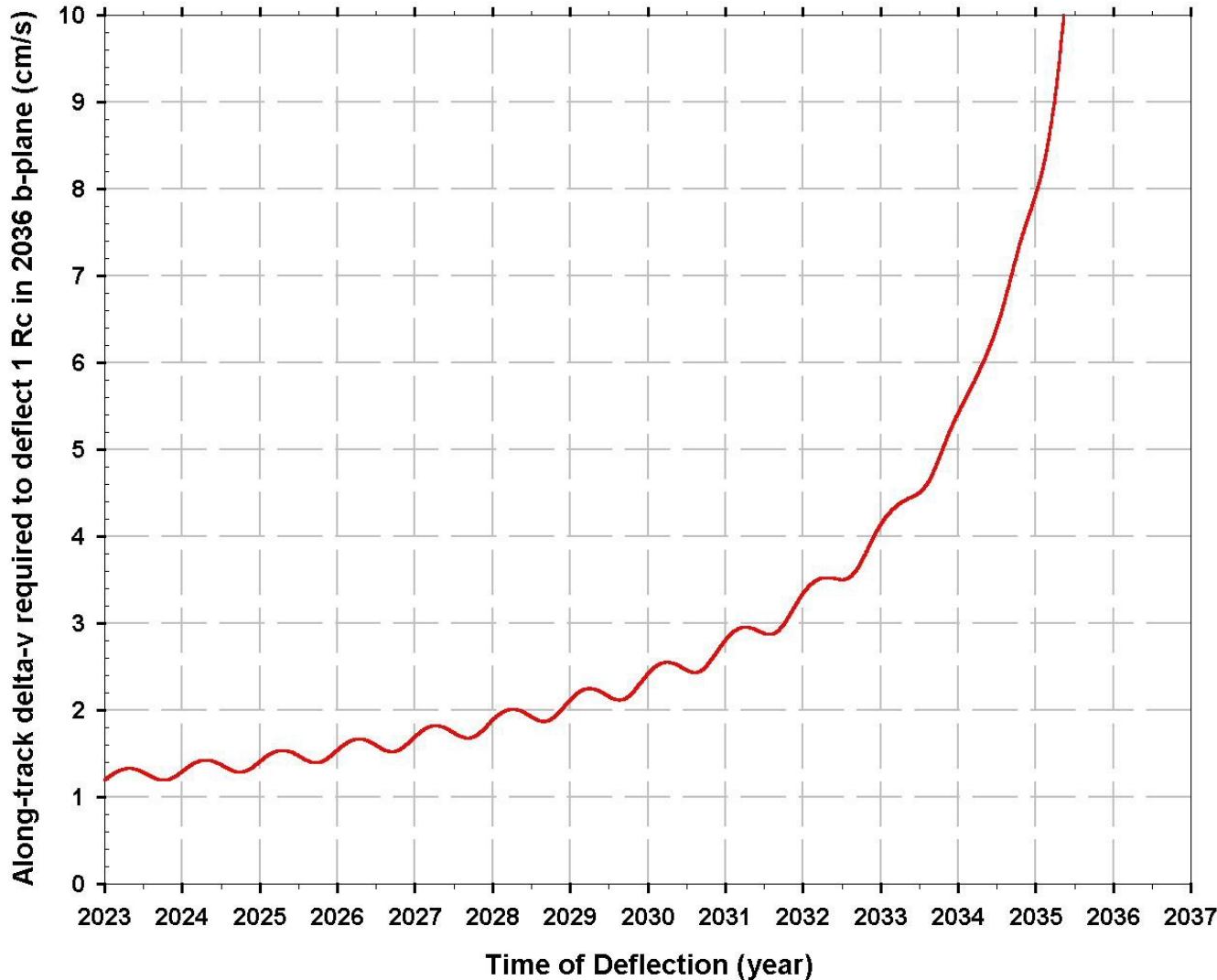
We can predict the accuracy of the impact predictions

With only Earth-based data, we won't know the impact location accurately until the 2030s

**A reconnaissance mission could pinpoint the impact location as early as late 2025**



# What's Required to Deflect 2023 PDC Off Earth?



**A few cm/sec velocity change may be enough, but the sooner the better**

How many Kinetic Impactor missions?

Possibly just a few

Most likely, dozens or even hundreds

Kinetic Impactor deflection depends on:

Launch vehicle capability

Momentum enhancement from ejecta

Impact location

Asteroid mass (uncertain by a factor of 100)

**A reconnaissance mission is needed to scope out deflection requirements as soon as possible**



# The Importance of Reconnaissance Missions

- **Would provide accurate in-situ orbit information**
  - Much more accurate orbit measurements than could be obtained from Earth
- **Would provide much improved estimates of asteroid size and mass**
  - Mass is the key parameter that drives the deflection campaign design
  - A flyby recon mission might allow a reasonably accurate estimate of mass to be inferred through measurements of asteroid size and shape, and using assumptions on density
  - A rendezvous recon mission could make a direct measurement of mass
- **Enables more accurate predictions of impact energy and damage region size if mitigation is not attempted**
- **Could remain on station to confirm the deflection event**

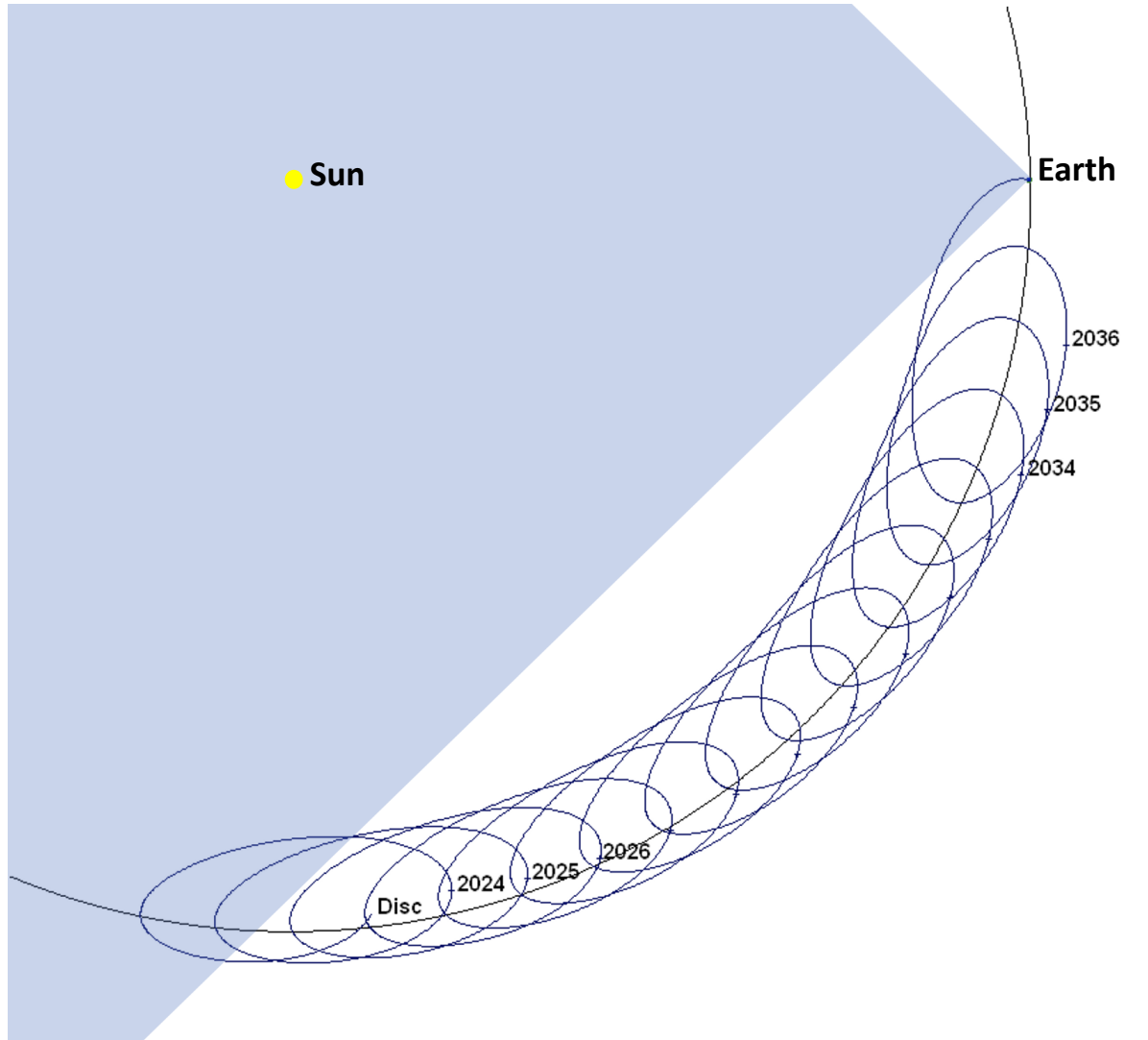




# BACKUP



# Position of 2023 PDC Relative to Earth , 2023-2036



This shows where 2023 PDC will be **relative to Earth with the Earth-Sun direction fixed**

The asteroid seems to make yearly loops as it slowly approaches Earth

When the asteroid is within the shaded region it's **too close to the direction of the Sun** to be observed

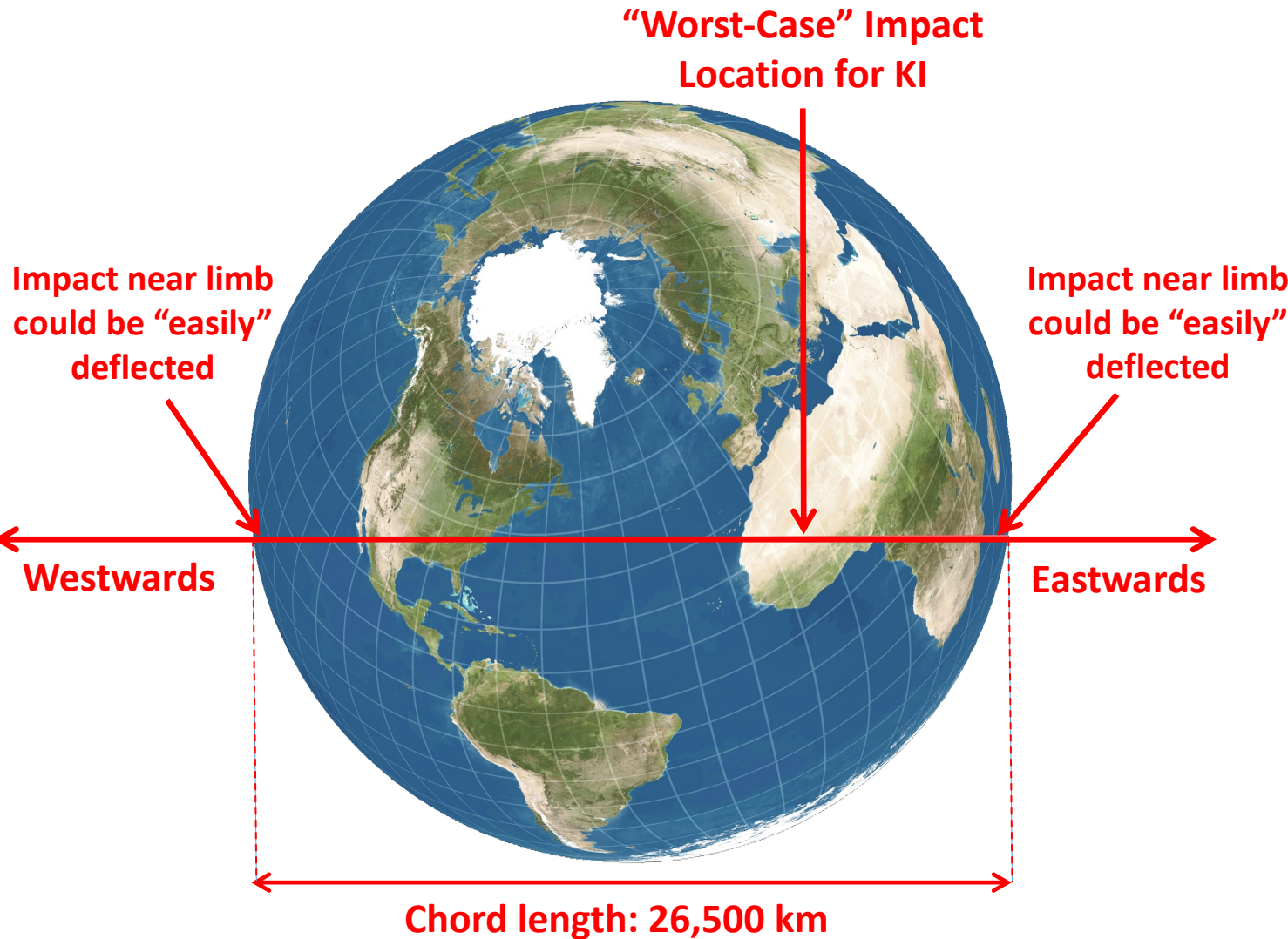
The asteroid will be **almost continuously observable, after 2024, although it will be distant and quite faint for a several years**

As the asteroid is observed, and as it gets nearer Earth, the orbit accuracy improves and predictions for the 2036 encounter become more accurate





# 2023 PDC, Epoch 1: Considerations for KI Deflection

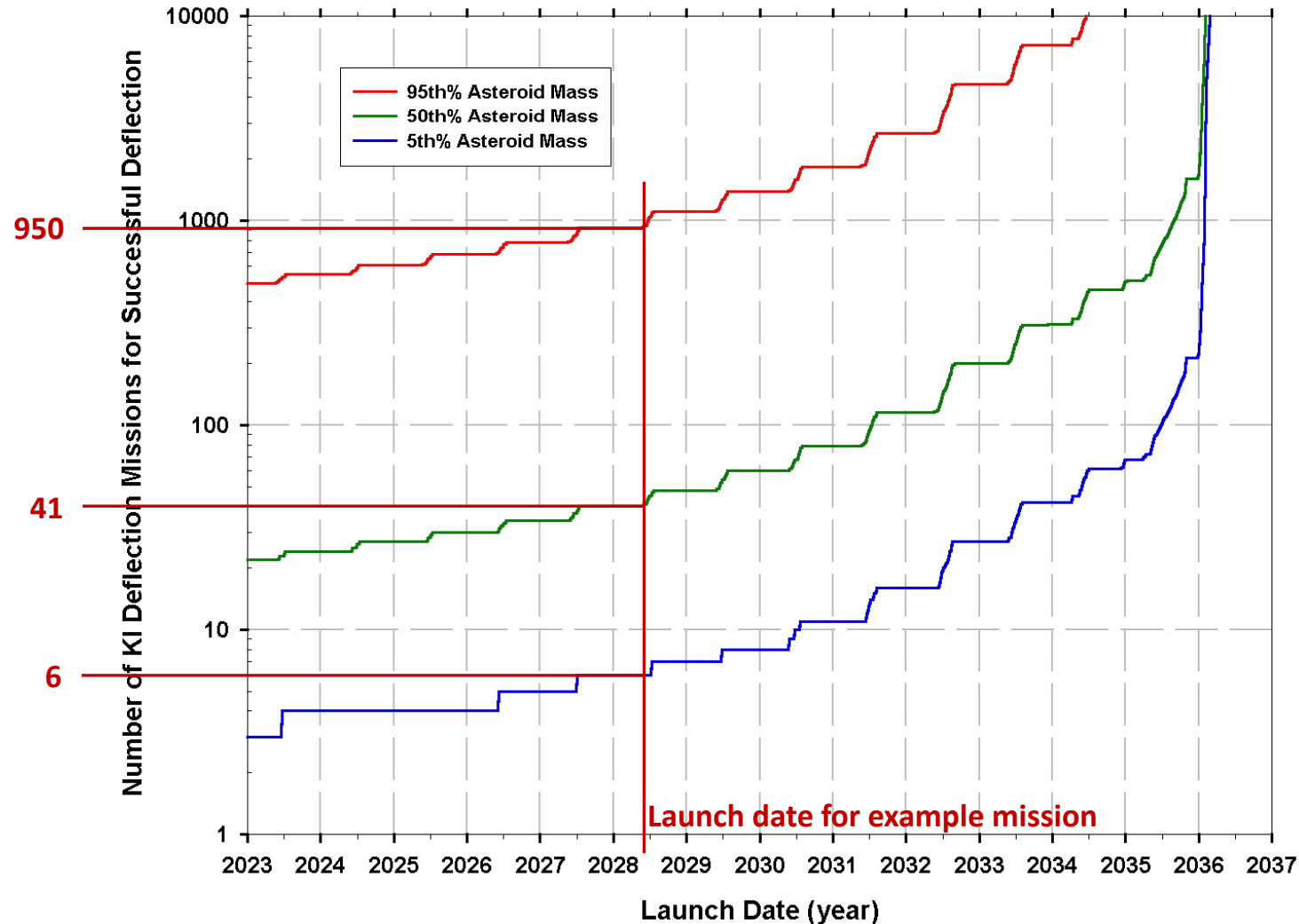


- Deflections move the impact point along the risk corridor
- Required amount of deflection is unknown, but multiple KI missions will likely be needed
- Westwards is easier than eastwards
- For a given launch vehicle, **the amount of deflection a KI mission can impart depends on the mass of the asteroid, which is uncertain by 2 orders of magnitude**
- If the asteroid is very small, or the impact location is near the limb, **KI deflection may be possible with a small number of missions**
- If the asteroid is **not** small or the impact is **not** near the limb, **the number of required KI missions could be large (dozens or hundreds)**





# 2023 PDC: Number of KI Missions for Worst-Case Deflection



How many Kinetic Impactor missions for the worst-case impact location?

- Depends on the asteroid mass, which spans 2 orders of magnitude

The required number of KI missions spans 2 orders of magnitude

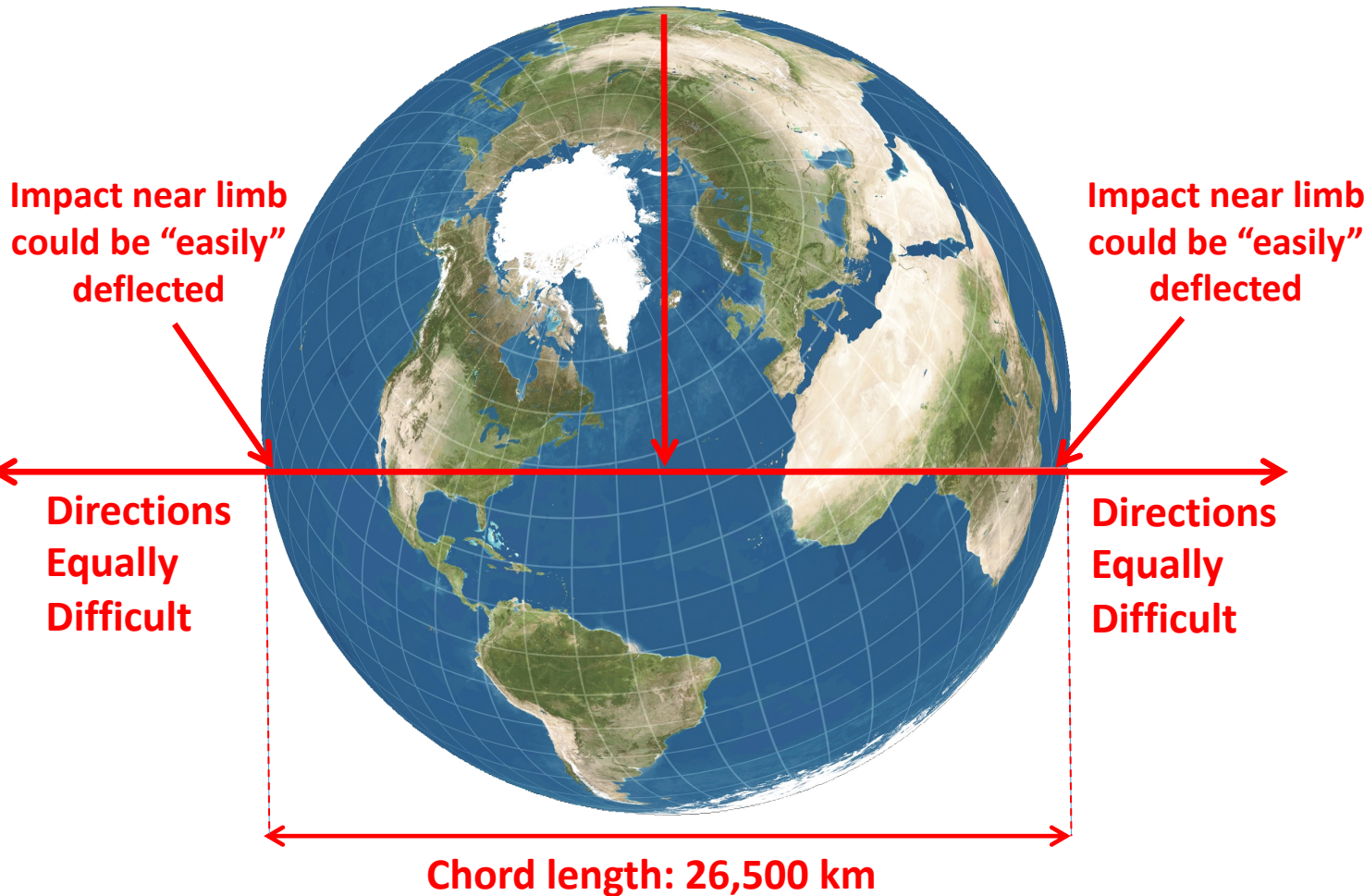
Assumptions:

- Worst-case impact location
- Falcon Heavy launcher
- Optimal intercept trajectory
- Ejecta enhancement factor 3.0



# 2023 PDC: Considerations for Nuclear Deflection

**“Worst-Case” Impact Location for KI**



- We don't yet know the impact location
- We can't yet predict how much deflection will be required
- For Nuclear deflection, the worst-case impact location is at the chord midpoint
- We don't know the mass of the asteroid to within an order of magnitude
- We must design the deflection to succeed with the largest likely asteroid mass and the worst-case impact location
- Even in this worst case, Nuclear deflection could probably be accomplished with 1 or 2 Falcon Heavy launches





# When Will We Know If 2023 PDC is on a Collision Course?

As the prediction uncertainty shrinks, the impact probability could increase or decrease:

- If Earth remains within the uncertainty as it shrinks, the impact probability will increase
- If the falls outside the uncertainty as it shrinks, the impact probability will decrease

By forcing the Earth to remain at the center of the ellipses, **we can predict how quickly the impact might increase in the worst case:**

- 10% in June 2023, and
- **100% in November 2023**

