The 2023 PDC Hypothetical Impact Scenario: Epoch 1 Summary

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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

<table>
<thead>
<tr>
<th>Diameter of Impacting Asteroid</th>
<th>Type of Event</th>
<th>Approximate Impact Energy (MT)</th>
<th>Average Time Between Impacts (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 m (16 ft)</td>
<td>Bolide</td>
<td>0.01</td>
<td>1</td>
</tr>
<tr>
<td>10 m (33 ft)</td>
<td>Superbolide</td>
<td>0.1</td>
<td>10</td>
</tr>
<tr>
<td>25 m (80 ft)</td>
<td>Major Airburst</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>50 m (160 ft)</td>
<td>Local Scale Devastation</td>
<td>10</td>
<td>1000</td>
</tr>
<tr>
<td>140 m (460 ft)</td>
<td>Regional Scale Devastation</td>
<td>300</td>
<td>20,000</td>
</tr>
<tr>
<td>300 m (1000 ft)</td>
<td>Continent Scale Devastation</td>
<td>2,000</td>
<td>70,000</td>
</tr>
<tr>
<td>600 m (2000 ft)</td>
<td>Below Global Catastrophe Threshold</td>
<td>20,000</td>
<td>200,000</td>
</tr>
<tr>
<td>1 km (3300 ft)</td>
<td>Possible Global Catastrophe</td>
<td>100,000</td>
<td>700,000</td>
</tr>
<tr>
<td>5 km (3 mi)</td>
<td>Above Global Catastrophe Threshold</td>
<td>10,000,000</td>
<td>30 million</td>
</tr>
<tr>
<td>10 km (6 mi)</td>
<td>Mass Extinction</td>
<td>100,000,000</td>
<td>100 million</td>
</tr>
</tbody>
</table>
Asteroid 2023 PDC: Sources of Data

- Optical
- Radar
- Astrometry & Photometry
- Space-Based Infra-Red
- Delay & Doppler
- Size
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HYPOTHETICAL EXERCISE
• 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
2023 PDC Uncertainty Region in 2036
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HYPOTHETICAL EXERCISE
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2023 PDC Uncertainty Region in 2036

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

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

Impact near limb could be “easily” deflected
Impact near limb could be “easily” deflected

Directions Equally Difficult
Directions Equally Difficult

“Worst-Case” Impact Location for KI

Chord length: 26,500 km
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 it 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.