Probabilistic Asteroid Impact Risk Assessment:
2023 PDC Hypothetical Impact Exercise Epoch 4

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HYPOTHETICAL EXERCISE

Contents

This presentation summarizes impact risk assessment results for Epoch 4 of the 2023 PDC hypothetical asteroid impact scenario. Epoch 4 represents the assessment phase after ~7 months of data are obtained from an extended rendezvous reconnaissance mission, which obtains direct measurements of the asteroid size and mass. Orbital trajectory is also now known accurately enough to predict the Earth impact location to within several kilometers.

Introductory information on the asteroid threat assessment processes and details on the risk modeling, impact hazards, affected population estimates, and damage risk maps used in this assessment can be found in the Introduction to Impact Risk Assessment presentation on the CNEOS impact scenario website.

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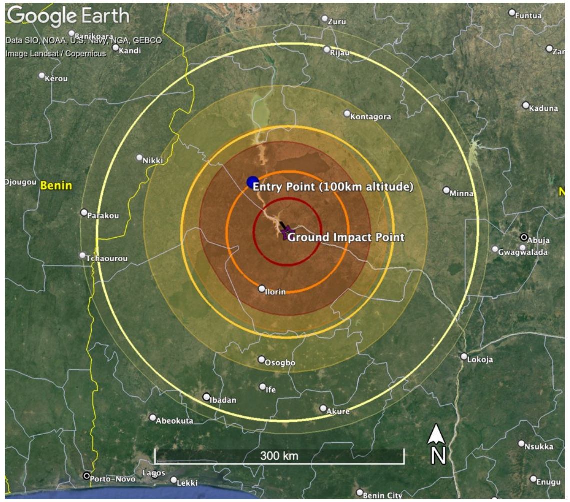
Impact Risk Summary

Assessment 4: Rendezvous Recon Mission Data, 1 June 2027

Asteroid Characterization Summary

- Impact date: 22 Oct. 2036
- Earth impact probability: 100%
- Asteroid size, mass, bulk density, energy, and impact trajectory accurately determined by data from extended rendezvous mission
- Diameter: ~800 m (2625 ft)
- Mass: ~5.36e11 kg, Bulk Density ~2000 kg/m^3
- Asteroid Impact Energy: ~10.3 gigatons (Gt) (10,300 Mt)



Risk Region Swath Map

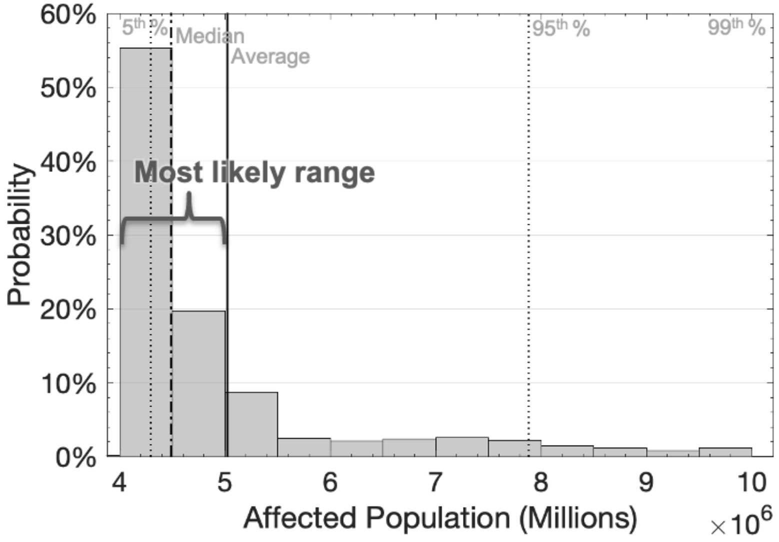
Regions potentially at risk, given range of damage sizes and locations. Median-sized damage areas are shown at sample locations.

- Serious
- Severe
- Critical
- Unsurvivable
- Damage Centers

Hazard Summary

- Primary hazard is a large impact causing devastating blast & thermal damage reaching unsurvivable levels, with very large areas of serious damage
- Unsurvivable regions likely to extend ~40–55 km (~25–35 mi) outward, and possibly out nearly ~110 km (70 mi)
- Serious damage levels (blown in windows, minor structure damage) likely to extend ~230 km (~140 mi) outward (possibly further given current blast modeling uncertainties at these scales)
- Potential for other large regional or cascading environmental effects from such large impacts is unknown but could be significant

Affected Population Risks



Probabilities of how many people could be affected by the potential damage

Total avg. risk ~5M

Median ~4.5M

Most likely 4–5M

Possibly up to ~10M

Asteroid Properties, Entry and Impact Parameters

- Asteroid size, mass, bulk density, and impact entry parameters are now accurately determined by extended rendezvous mission:
  - Size (effective spherical diameter) and mass directly measured by spacecraft
  - Bulk density determined from mass and size
  - Taxonomic type: C (carbonaceous chondrite)
- Other material properties relevant to mitigation and damage modeling are somewhat constrained by known density and type, but remain uncertain:
  - Porosity (bulk macroporosity)
  - Strength (represents bulk aerodynamic breakup strength)
  - Thermal damage modeling parameter (luminous efficiency)
- Entry trajectory is also now accurately known
  - Entry location is determined to within several kilometers
  - Current risk results are based on a single nominal entry point since location uncertainty is small compared to damage areas

Measured Size & Properties

	Measured Value	Modeled Range
Diameter (m)	800 ± 0.25	799–801
Mass (kg)	$5.36 \pm 0.007 \times 10^{11}$	$5.34\text{–}5.38 \times 10^{11}$
Bulk Density (kg/m^3)	2000	1990–2010
Energy (Gt)	10.3	10.25–10.33

Uncertain Material Properties

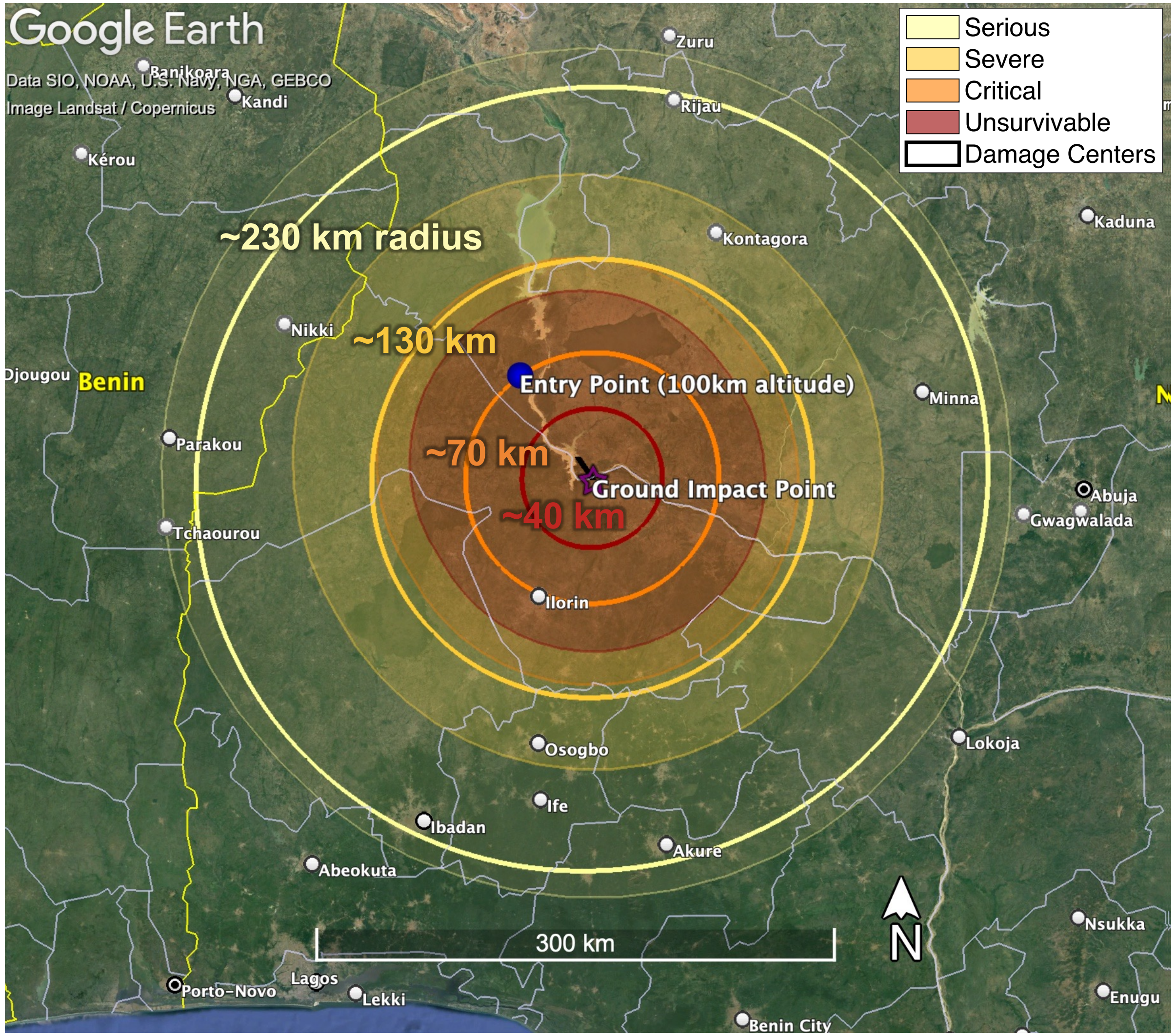
	Mean	Median	Most Likely	Modeled Range
Porosity	30%	31%	22–42%	0–60%
Strength (MPa)	2.1	1.2	0.1–2.2	0.1–10

Nominal Entry Trajectory (from 100 km altitude)

Entry velocity	12.672 km/s
Entry angle	53.5° (from horizontal)
Entry direction	145.3° (heading CW from N)
Entry location	9.672°N, 4.489°E
Impact location	9.249°N, 4.785°E – 9.133°N, 4.866°E

[Property inference model: J. Dotson PDC 2023]

Damage Risk Swath

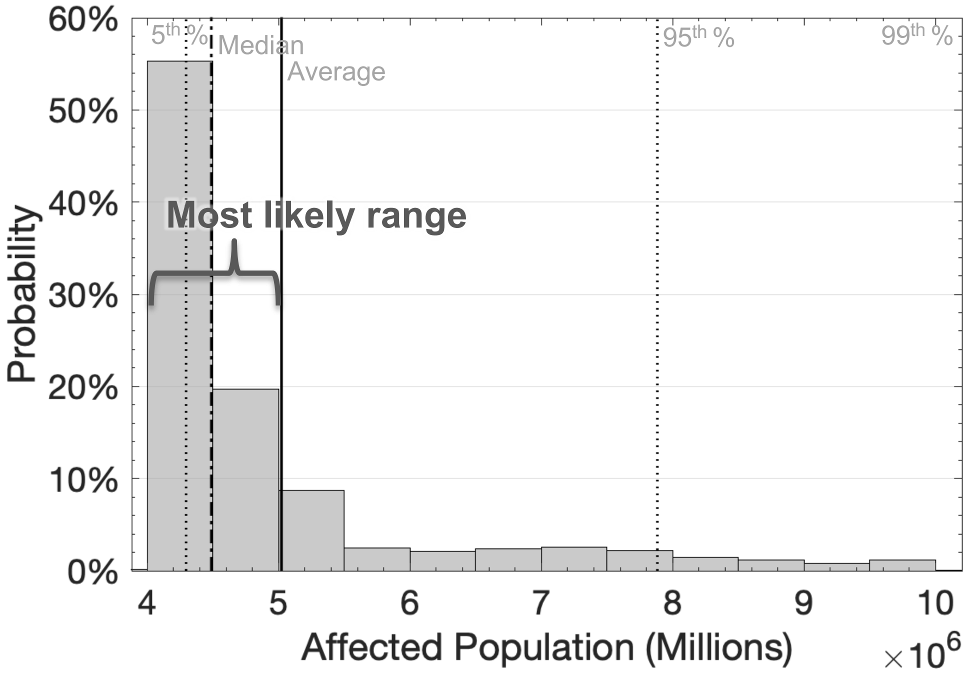


Damage risk swath: Shows extent of regions *potentially* at risk to *local ground damage**, given ranges of potential damage sizes and locations

- Damage risk swath:
  - Black line shows range of impact damage-center locations modeled (very small, with orbital trajectory and ground impact predicted to within several kilometers)
  - Shaded areas show potential extent of *local ground damage**, given range of impact sizes and locations, colored by damage severity level
  - Rings show median-sized damage footprints
- Extent of current risk region:
  - Spans large portion of western Nigeria and into eastern edge of Benin
  - Centered around ground impact region near Jebba, Nigeria, along the Niger River
  - Potential entry and impact location is well known from trajectory
  - Damage risk swath region shown is around ~500 km across

* Swath extent shown covers local blast or thermal ground damage sizes out to the 95th percentile

Affected Population Risks



Population Risk Histogram: Probabilities of affecting the number of people within each range

Affected Population Threshold	Probability of Damage Exceeding Threshold
>4M	99.9%
>5M	25%
>6M	14%
>7M	9%
>8M	5%
9-10M	2%

Population Exceedance Risks: Probabilities of damage affecting ***at least*** the given number of people *or more*

- **Estimated affected population range has narrowed to around 4–10 million people, most likely ~4–5 million**
  - Average population risk: 5M people
  - Median: 4.5M people
  - Most likely range (68%): ~4.3–4.8M people
  - Potential range (99%): ~4M–9.6M
  - Full range modeled: ~3.9M–10.1M
- Estimated range due primarily to uncertain extent of most severe thermal damage levels within the damage region.

[PAIR affected population details: Stokes et al., 2017]

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Summary

- **Asteroid size and impact location are now well known:** ~800m asteroid will impact in Nigeria with ~10.3 gigatons of impact energy
- **Hazards & Damage Estimates**
  - An impact of this size is expected to cause devastating blast & thermal damage reaching unsurvivable levels, with very large areas of serious damage
  - Serious damage levels (blown in windows, minor structure damage) likely to extend ~230 km (~140 mi) outward or more
  - Unsurvivable regions likely to extend ~40–55 km (~25–35 mi) outward, and possibly out nearly ~110 km (70 mi)
  - Estimated population living within the expected damage region is ~30M people
  - Given estimated range of damage severities across the region, damage is likely to affect at least 4–5M people, possibly up to 10M or more, if region is not evacuated
- **Additional Uncertainties & Recommendations**
  - High-fidelity simulations of large-scale asteroid blast and thermal damage are recommended to more accurately predict damage areas and severities, given current risk model uncertainties for impacts of this size
  - Potential for other large regional or cascading environmental effects from such large impacts sizes is unknown but could be significant

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HAZARD DAMAGE & RISK DETAILS:

Local Damage Region Sizes
Local Affected Populations in Damage Regions
Asteroid Property Details

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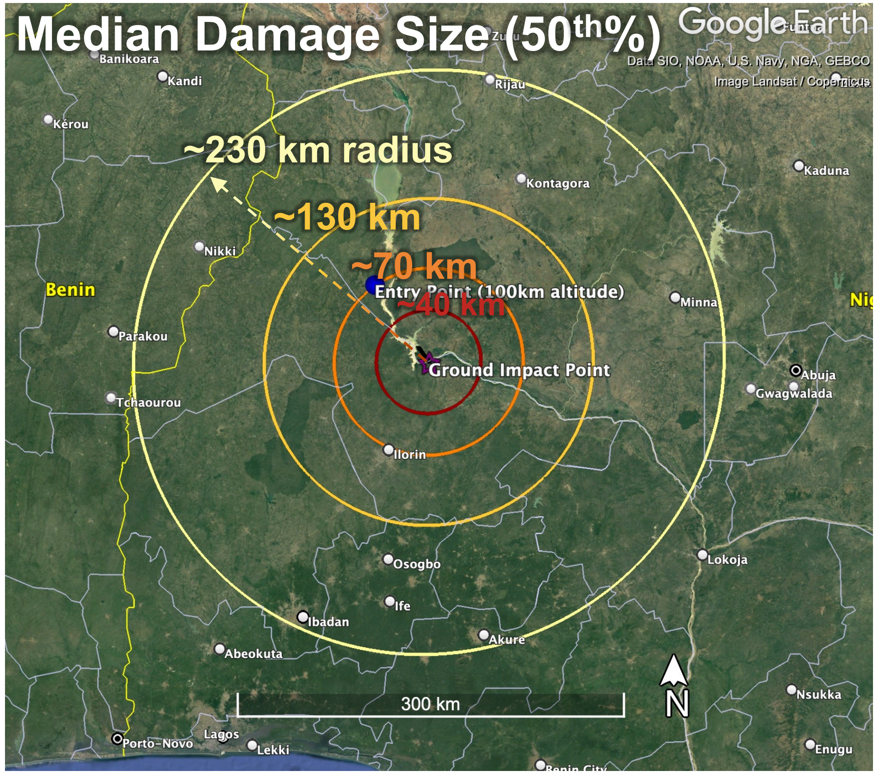
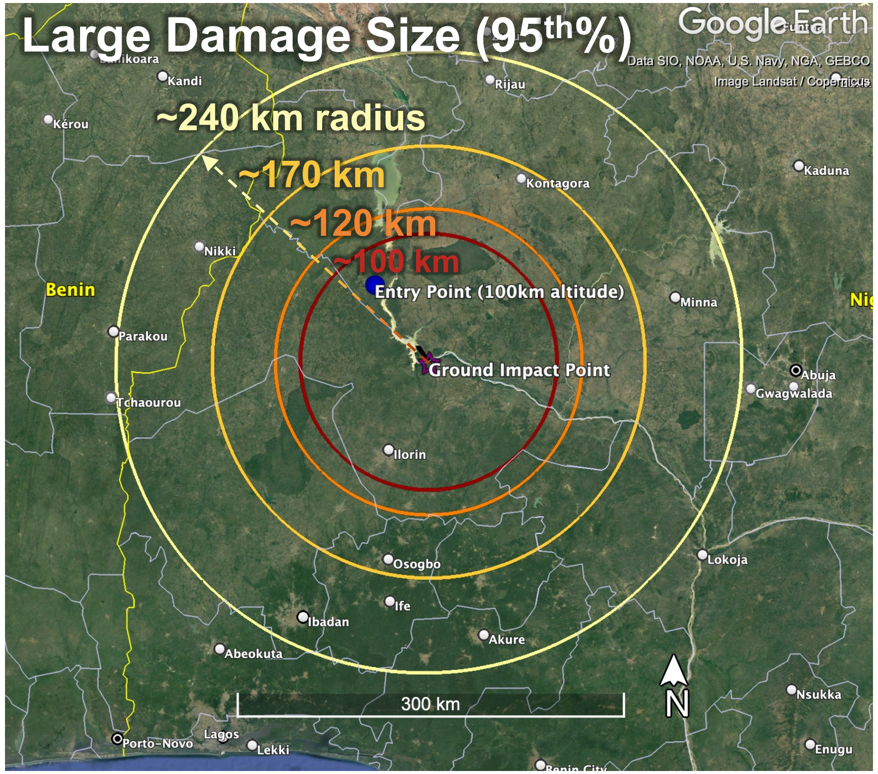
Sample Ground Damage Sizes at Ground Impact Point in Nigeria





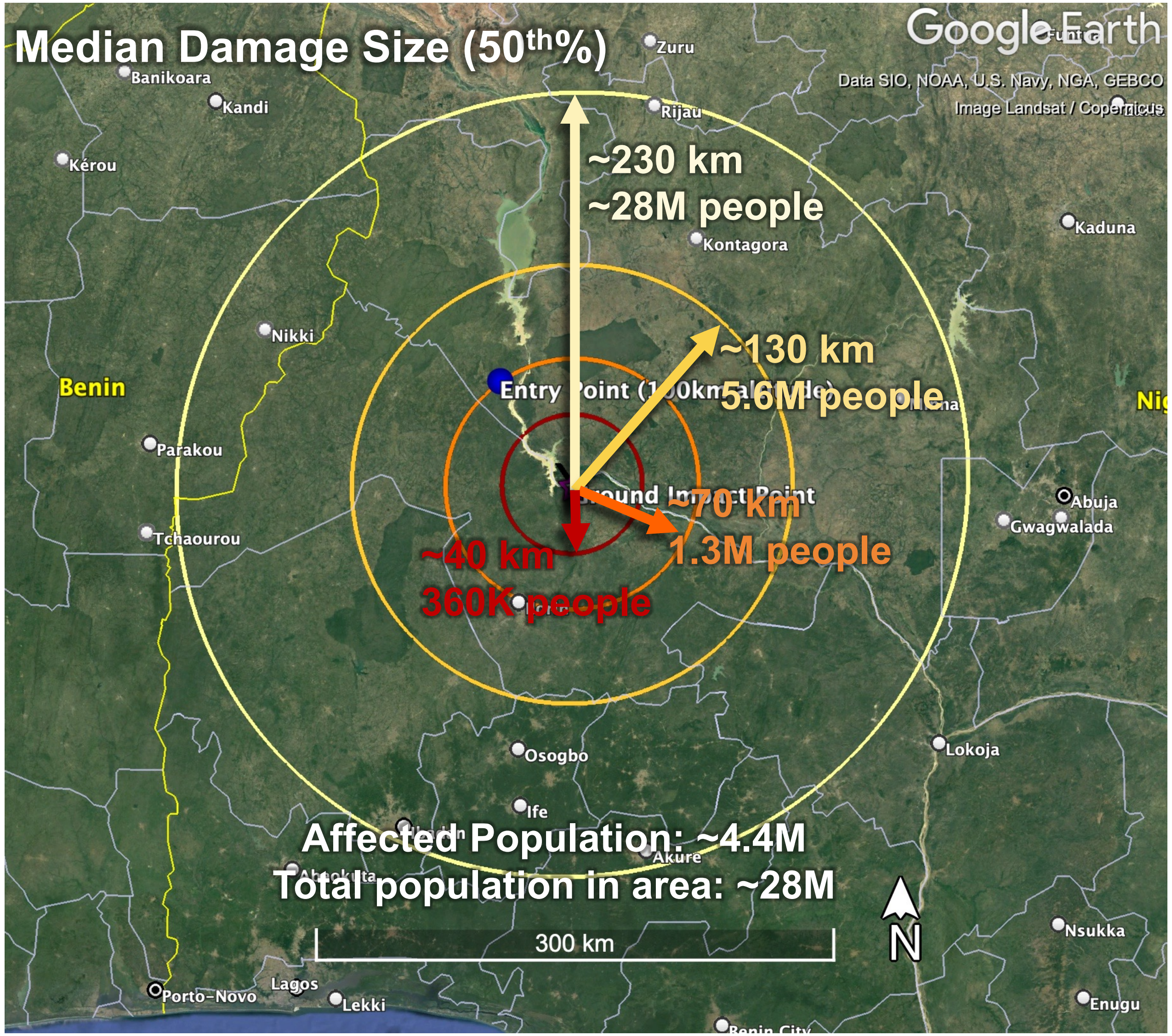
- Rings show sample damage footprint sizes at a single sample location
- Percentiles give the chance that the damage region could be up to the given size or smaller

Local Ground Damage Radius Sizes (km / mi)

Damage Level	Mean	50th %	95th %
Serious	228 km (142 mi)	**227** km (141 mi)	**241** km (149 mi)
Severe	131 km (81 mi)	**126** km (78 mi)	**166** km (103 mi)
Critical	79 km (49 mi)	**72** km (45 mi)	**117** km (73 mi)
Unsurvivable	53 km (33 mi)	**40** km (25 mi)	**98** km (61 mi)

	Damage Level Description
	Windows shatter, minor structure damage
	Widespread structure damage, or 3rd degree burns
	Residential structures collapse, or clothing ignites
	Devastation, structures flattened or burned

Population in Median Damage Regions



- Estimated populations within each damage severity region:
  - Total population enclosed in given damage region (including higher damage severity regions)
  - Population in damage level ring (not including people in higher damage severity regions)
- Affected population estimates:
  - Fraction of population considered affected within each damage region ring, depending on relative damage severity (serious 10%, severe 30%, critical 60%, unsurvivable 100%)

Damage Level (% Affected Pop.)	Damage Radius	Total Population Enclosed	Population in Damage Ring	Affected Population
Serious (10%)	227 km	28M	22.4M	2.2M
Severe (30%)	126 km	5.6M	4.3M	1.3M
Critical (60%)	72 km	1.3M	940K	560K
Unsurvivable (100%)	40 km	360K	360K	360K

[PAIR affected population details: Stokes et al., 2017]

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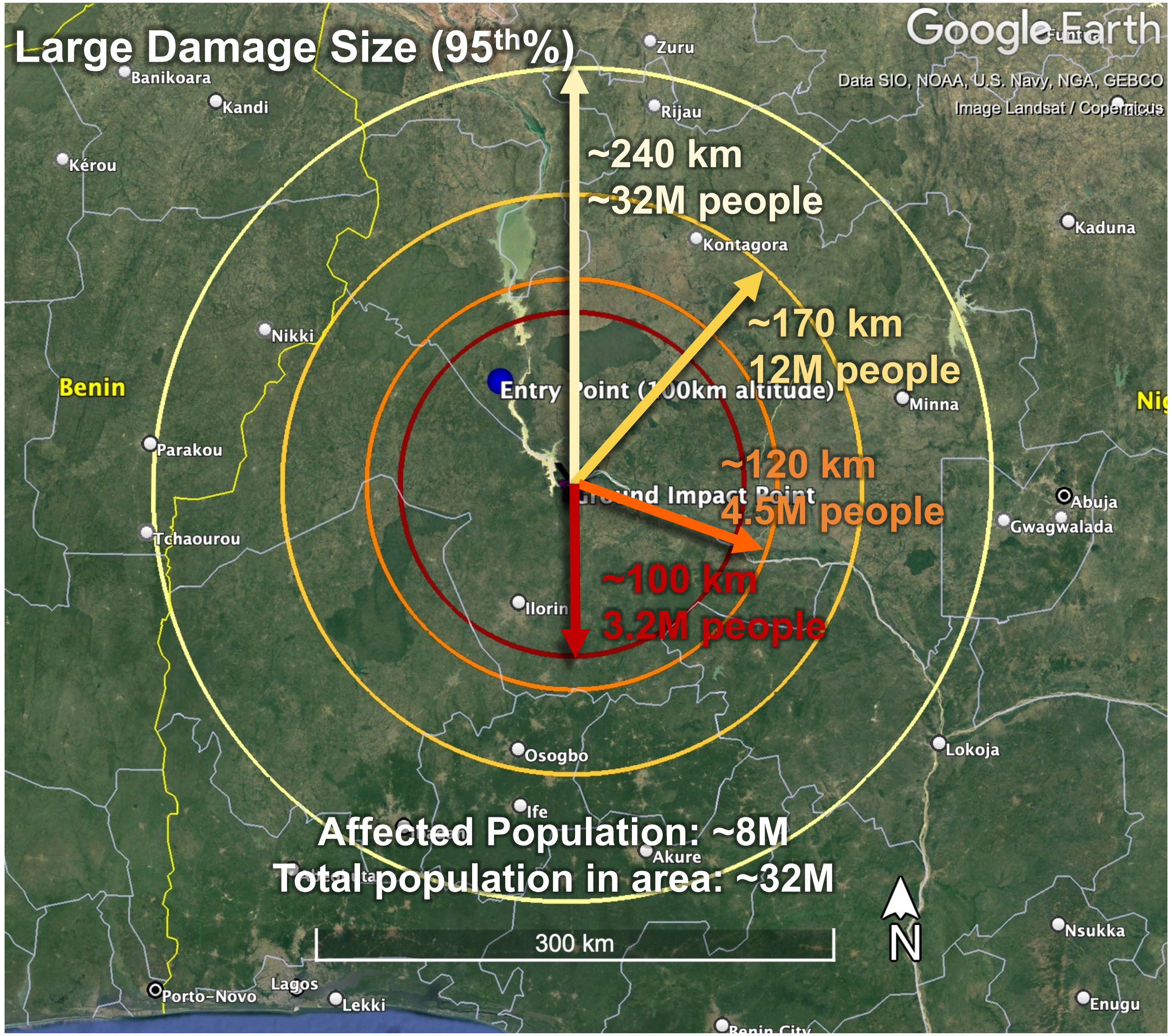
Population in Large (95th%) Damage Regions



- Estimated populations within each damage severity region:
  - Total population enclosed in given damage region (including higher damage severity regions)
  - Population in damage level ring (not including people in higher damage severity regions)
- Affected population estimates:
  - Fraction of population considered affected within each damage region ring, depending on relative damage severity (serious 10%, severe 30%, critical 60%, unsurvivable 100%)

Damage Level (% Affected Pop.)	Damage Radius	Total Population Enclosed	Population in Damage Ring	Affected Population
Serious (10%)	241 km	32M	20M	2M
Severe (30%)	166 km	12M	7.5M	2.25M
Critical (60%)	117 km	4.5M	1.3M	780K
Unsurvivable (100%)	98 km	3.2M	3.2M	3.2M

[PAIR affected population details: Stokes et al., 2017]

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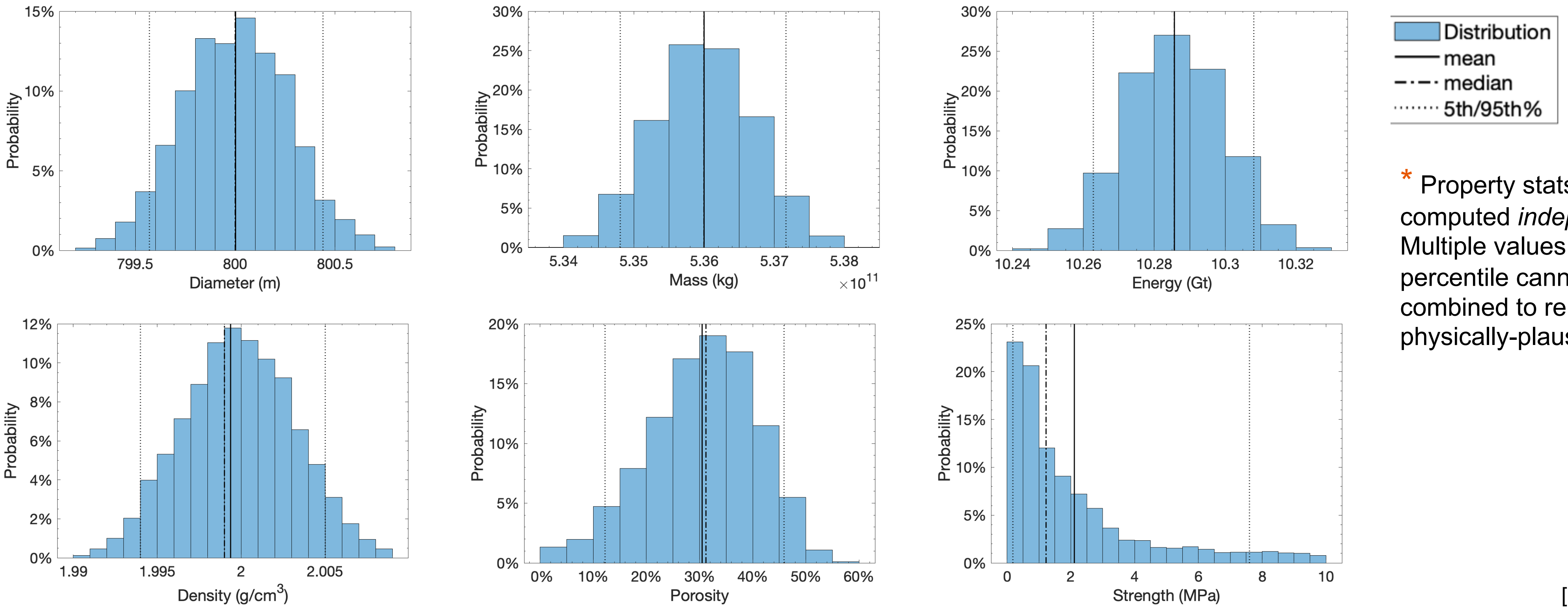
Asteroid Property Details

Statistical percentiles and highest-probability interval ranges for asteroid property distribution samples modeled*

	Mean	5th%	25th%	Median (50th%)	75th%	95th%	Most Likely Range (68%)	Potential Range (99%)
Diameter (m)	800	800	800	800	800	800	800	799–801
Mass (kg)	5.36E+11	5.35E+11	5.36E+11	5.36E+11	5.36E+11	5.37E+11	5.35–5.37E+11	5.34–5.38E+11
Energy (Mt)	1.03E+04	1.03E+04	1.03E+04	1.03E+04	1.03E+04	1.03E+04	1.03E+04	1.03E+04
Density (g/cm³)	1999	1994	1997	1999	2002	2005	1996–2002	1991–2007
Porosity (%)	30%	12%	24%	31%	38%	46%	22–42%	1–51%
Strength (MPa)	2.1	0.2	0.5	1.2	2.8	7.6	0.1–2.2	0.1–9.5



* Property stats are each computed *independently*. Multiple values from a given percentile cannot necessarily be combined to represent a single physically-plausible asteroid.

[Property model: J. Dotson PDC 2023]

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Related PDC 2023 Presentations

PDC 2023 presentation materials, webcast recordings, and impact exercise details available at:

- https://www.unoosa.org/oosa/en/ourwork/topics/neos/2023/IAAPDC/index.html
- https://atpi.eventsair.com/QuickEventWebsitePortal/23a01---8th-planetary-defense-conference/programme-website/Agenda
- https://cneos.jpl.nasa.gov/pd/cs/pdc23/

PDC 2023 Hypothetical Asteroid Impact Exercise Session (3 April 2023)

- **Wheeler** et al., "Impact Risk Assessment Briefing: 2023 PDC Hypothetical Asteroid Impact Exercise Epoch 1"
- **Chodas** et al., "The 2023 PDC Hypothetical Impact Scenario: Epoch 1 Summary"
- **Barbee** et al., "PDC 2023 Simulated Impact Threat Scenario SMPAG Mission Option Analysis"

Impact Effects (Session 7, 6 April 2023)

- **Wheeler** et al., "Asteroid Impact Risk Across Transitional Hazard Regimes"
- **Dotson** et al., "Consequences of Asteroid Characterization on the State of Knowledge about Inferred Physical Properties and Impact Risk"
- **Coates** et al., "Sensitivity Study of Impact Risk Model Results to Thermal Radiation Damage Model for Large Objects"
- **Chomette** et al., "Machine learning for the prediction of local asteroid damages"
- **Stern** et al., "Advances in Entry Modeling for Impact Risk Assessment"
- **Aftosmis** et al., "High-fidelity Blast Propagation Modeling for Hypothetical Asteroid 2023 PDC"
- **Titus** et al., "Asteroid Impacts and Cascading Hazards"

Disaster Management & Impact Response (Session 8, 6 April 2023)

- **Robertson** et al., "Evacuation and Shelter Plans for Asteroid Impacts"

Space Mission & Campaign Design Session (Session 6, 5 April 2023)

- **Barbee** et al., "Planetary Defense Mission Campaign Design for the 2023 PDC Hypothetical Asteroid Impact Scenario"

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