Impact Risk Assessment:

PDC25 Hypothetical Asteroid Impact Exercise

Epoch 1 – Initial Threat Discovery & SMPAG Notification

Lorien Wheeler

Jessie Dotson, Ashley Coates, Michael Aftosmis, Eric Stern, Donovan Mathias

Asteroid Threat Assessment Project (ATAP)

NASA Ames Research Center

9th IAA Planetary Defense Conference

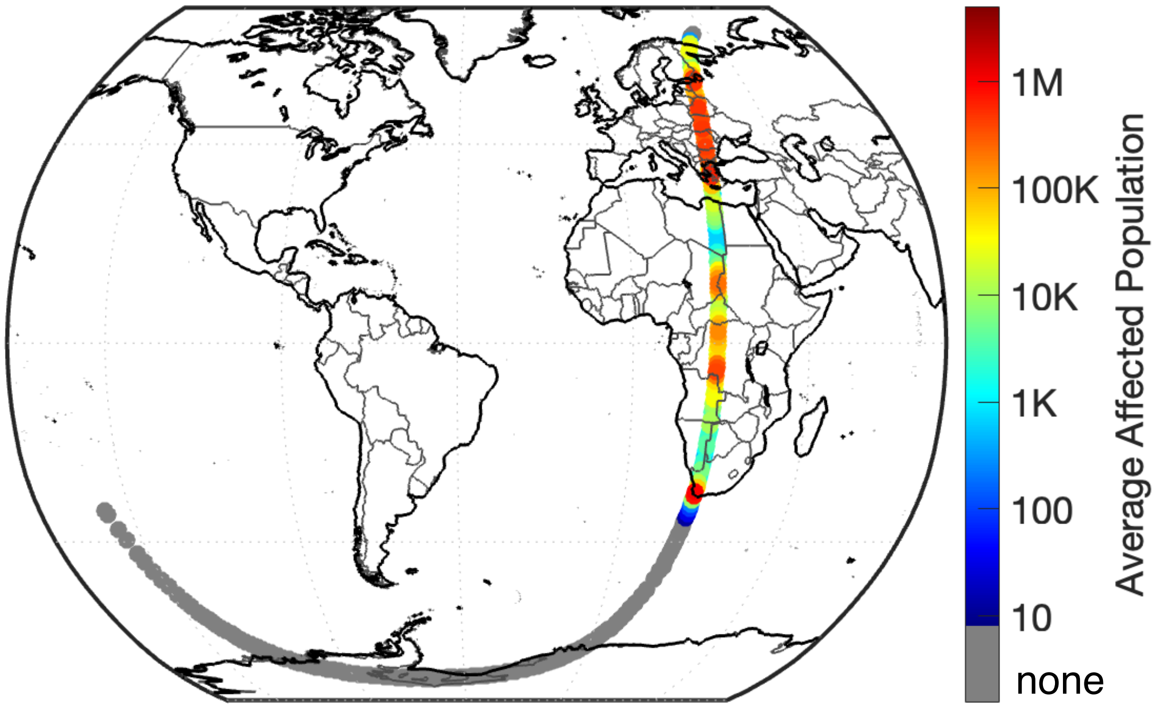
May 2025

Impact Hazard Summary

Epoch 1 assessment date: 1 August 2024

~1.6% chance of Earth impact in 17 years by a **50–280 m** asteroid with **3–720 Mt** of impact energy. Large ranges of potential damage sizes, severities, and locations are possible.

Average affected population along potential impact regions



- ~51% chance of damage to populated regions among possible impact locations
- Primary hazard is a high-energy, low-altitude airburst and fireball causing highly destructive blast waves over large areas
- Blast damage areas would most likely extend ~40–110 km in radius, and possibly out over 200 km in the largest cases
- Airbursts in this size range are unlikely to cause significant tsunami, but largest near-coast cases could cause inundation damage

Potential damage could affect **0–5M people**, with an average of **~52K** among Earth-impact cases. Impact over land would most likely affect between thousands and hundreds-of-thousands of people.

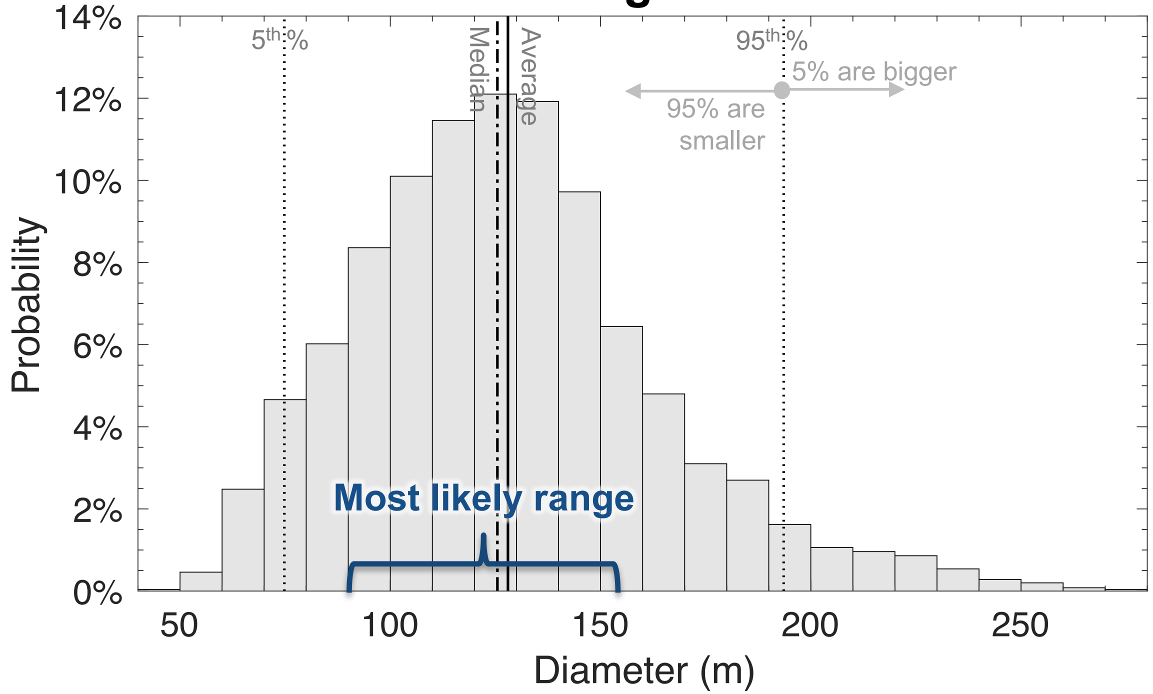
Asteroid Size & Properties

Asteroid size range is hazardous but uncertain. Size and property uncertainties result in large ranges of potential mass, energy, and damage.

- Available observation data to-date:
  - Initial ground-based observations estimated sizes based on brightness (H magnitude)
  - JWST observation refined diameter estimates and identified type S spectral class
- Estimated asteroid size and property ranges:
  - Asteroid diameter is most likely between ~90–160 m but could range from ~50–280 m
  - Stony type composition, but unknown structure, strength, and breakup properties ranging from weak rubble pile to stronger monolithic bodies
  - Bulk densities most likely ~1.6–2.7 g/cm^3, potentially ~1.1–3.8 g/cm^3 with macroporosity between 0–60%

[Property inference model: J. Dotson et al., 2024]

Asteroid Size Ranges & Probabilities



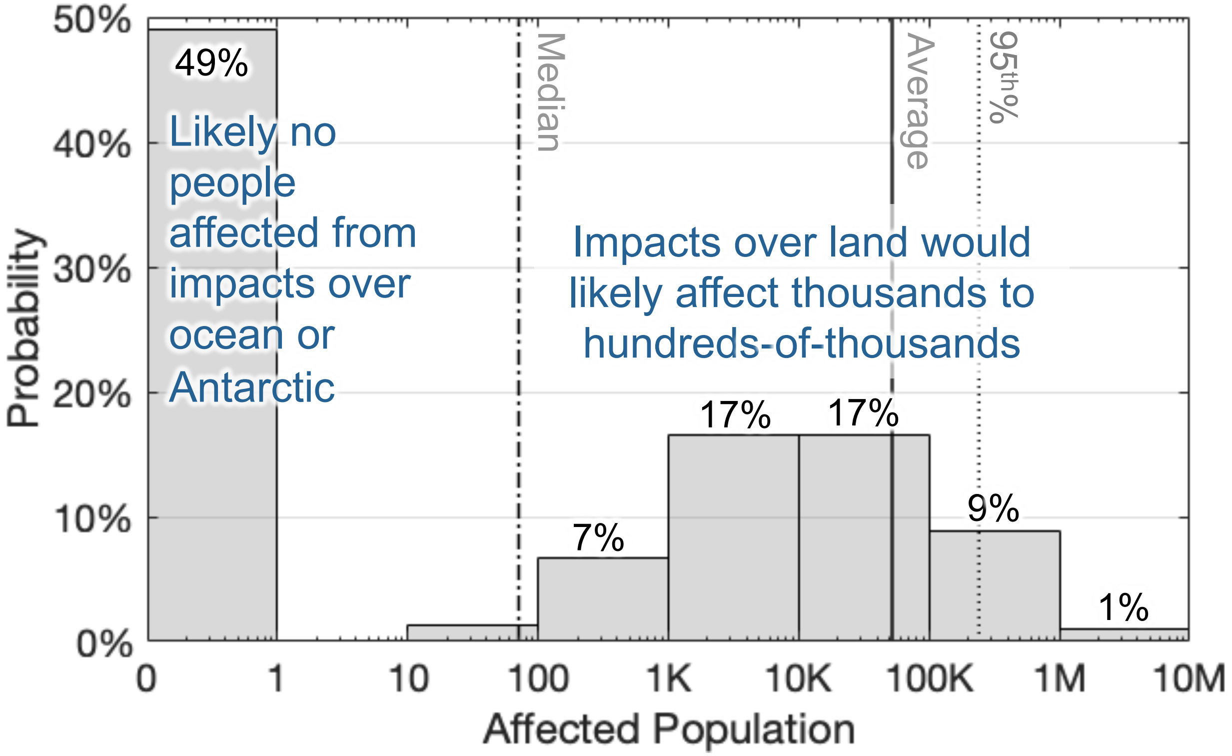
	Diameter	Mass	Energy
Median	125 m (412 ft)	2.2e9 kg	50 Mt
Average	128 m (420 ft)	3.1e9 kg	70 Mt
Most likely	90–160 m (300–520 ft)	2.4e8–3.3e9 kg	5–70 Mt
5th–95th %	70–190 m (230–630 ft)	4.5e8–8.8e9 kg	10–200 Mt
Range Modeled	50–280 m (160–920 ft)	1.2e8–3.1e10 kg	3–720 Mt

* Property stats are computed *independently* and **cannot be combined** to represent a single asteroid.

HYPOTHETICAL EXERCISE

Affected Population Risks

Damage probabilities *among Earth-Impacting cases*



~51% chance of damage to populated regions, with impacts over land likely to affect >1K–100K people, potentially up to 5M people

Affected population threshold	Chance of damage *exceeding* threshold
Any	51%
>1K	43%
>10K	26%
>100K	10%
>1M	1%

Affected population range: **0–5 million** people
~52,000 people affected on average if Earth impact occurs (1.6% impact probability)

[PAIR impact risk modeling: Wheeler et al., 2024]

Ground Damage Risk Swath

Damage risk swath: Extent of regions *potentially* at risk for ground damage, given ranges of potential impact locations and damage sizes (out to 95th percentile). Rings show median damage sizes at sample locations.

If the asteroid hits Earth, areas ***potentially*** at risk to blast damage span from S. Africa to the Barents Sea, across Southern, Central, and Northern Africa, the Mediterranean, and Eastern Europe.

- Risk swath maps show the extent of regions ***potentially*** at risk to local ground damage, including range of possible damage sizes (shaded by highest potential severity level) and possible airburst/impact locations (black outline)
- Rings show median-sized damage footprints at sample high-population locations

	Damage Level Description
Serious	Windows shatter, some structure damage
Severe	Widespread structure damage or third-degree burns
Critical	Residential structures collapse or clothing ignites
Unsurvivable	Devastation, structures flattened or burned

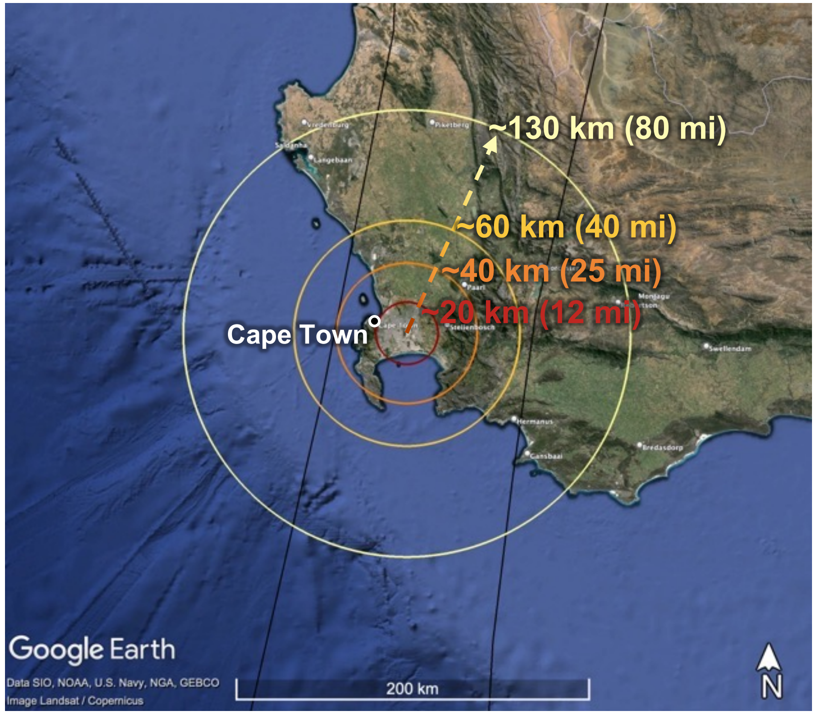
HYPOTHETICAL EXERCISE

Potential Ground Damage Size Ranges

Example over Cape Town, S. Africa – Highest population damage region along swath

Median (50th%) Damage

Large (95th%) Damage



Likely damage sizes could span multiple metropolitan areas or counties

Large damage sizes could span multiple regions or states

- Damage severities could reach **unsurvivable** levels near airburst, extending to larger areas of **structural damage, fires, and shattered windows**
- Outer serious damage areas are most likely between **~40–110 km** (~20–70 miles) in radius (median ~80 km, 50 mi)
- Largest damage areas could extend out over ~**200 km** (~120 miles) or more in radius

* Damage sizes and shapes vary along the potential impact corridor due to different entry angles and airburst altitudes. Additional details and example locations are in backup material.

HYPOTHETICAL EXERCISE

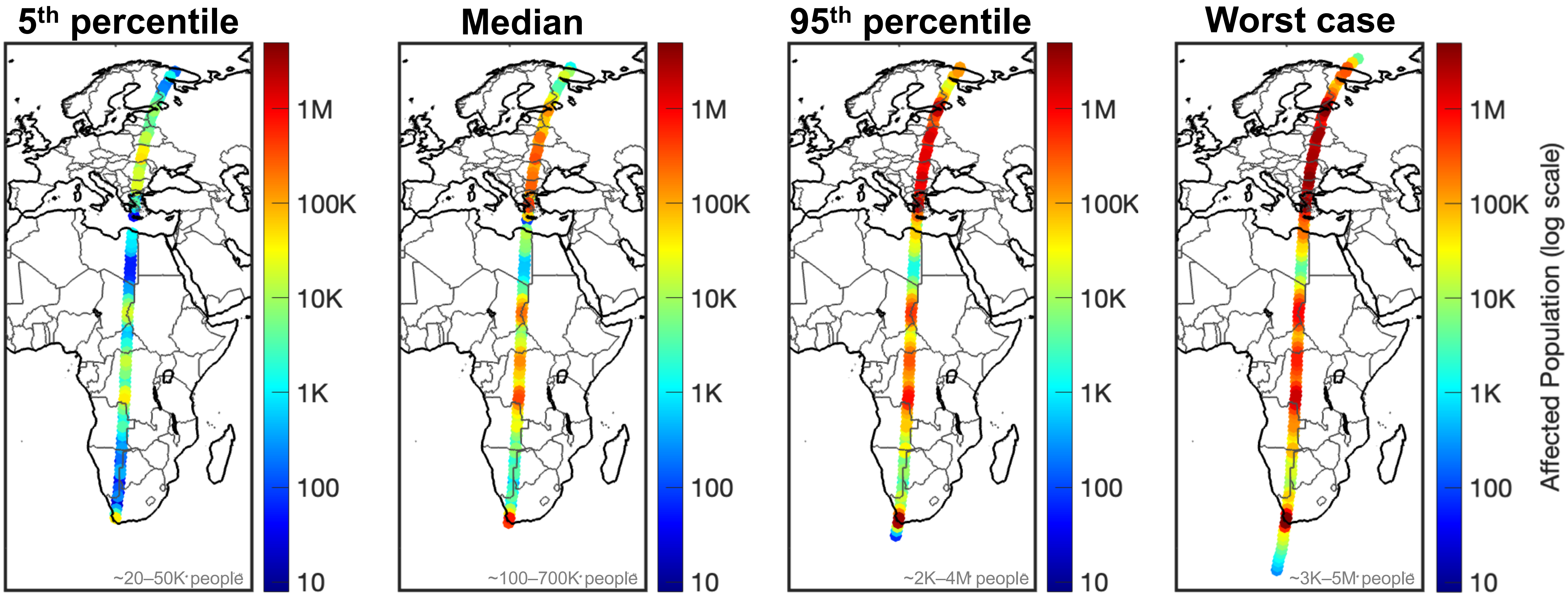
Ames Research Center

Affected Population Ranges by Location

Smaller damage could affect few to ~50K people

Moderate damage could affect hundreds to nearly 1M people

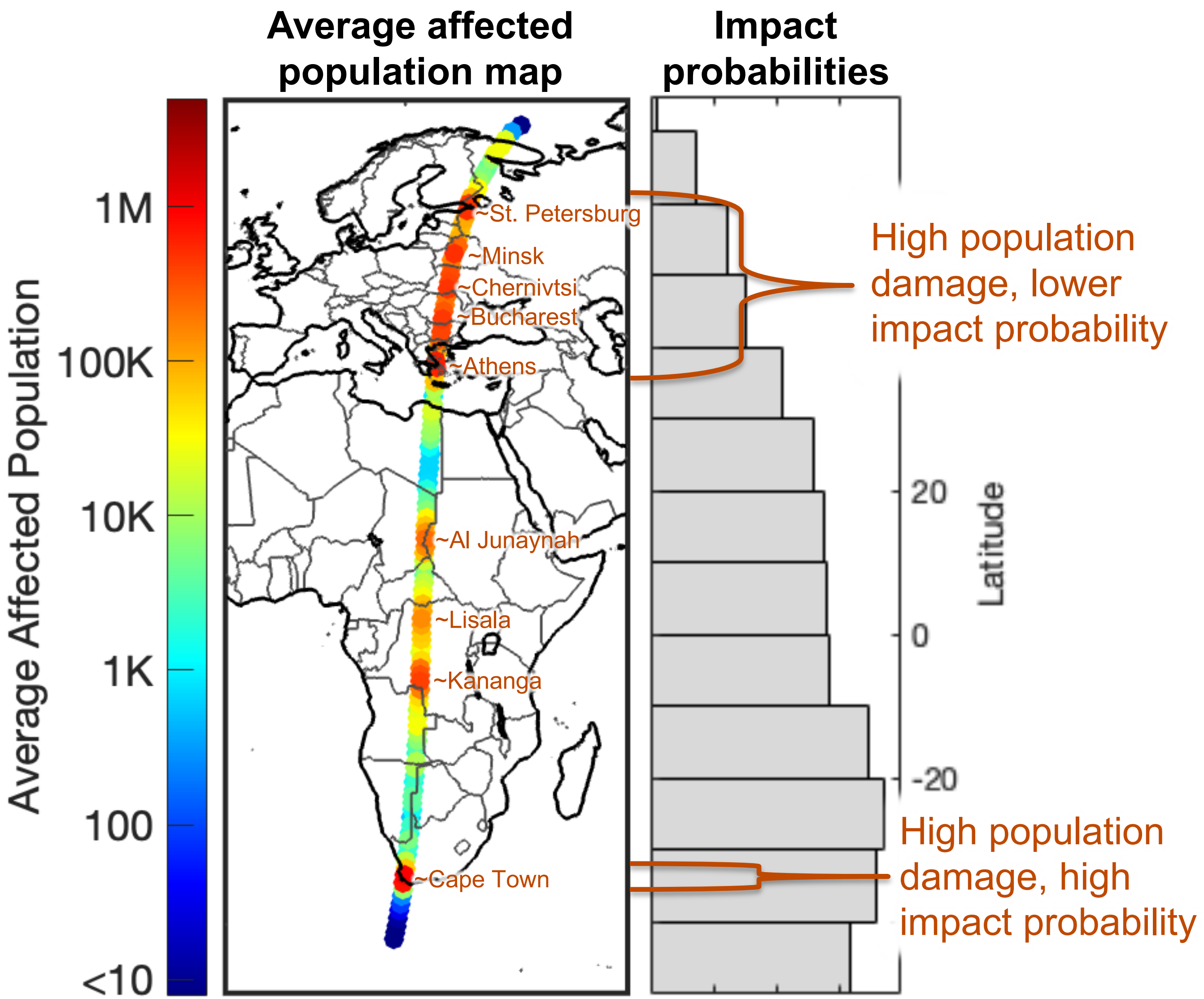
Large damage could affect thousands to several million people



Affected population maps: Map points are colored by affected population statistics (5th percentile, median, 95th percentile, maximums) among the damage cases modeled within each region, given the local population densities and range of potential damage sizes/severities.

HYPOTHETICAL EXERCISE

Relative Impact Risk Probabilities Along Swath



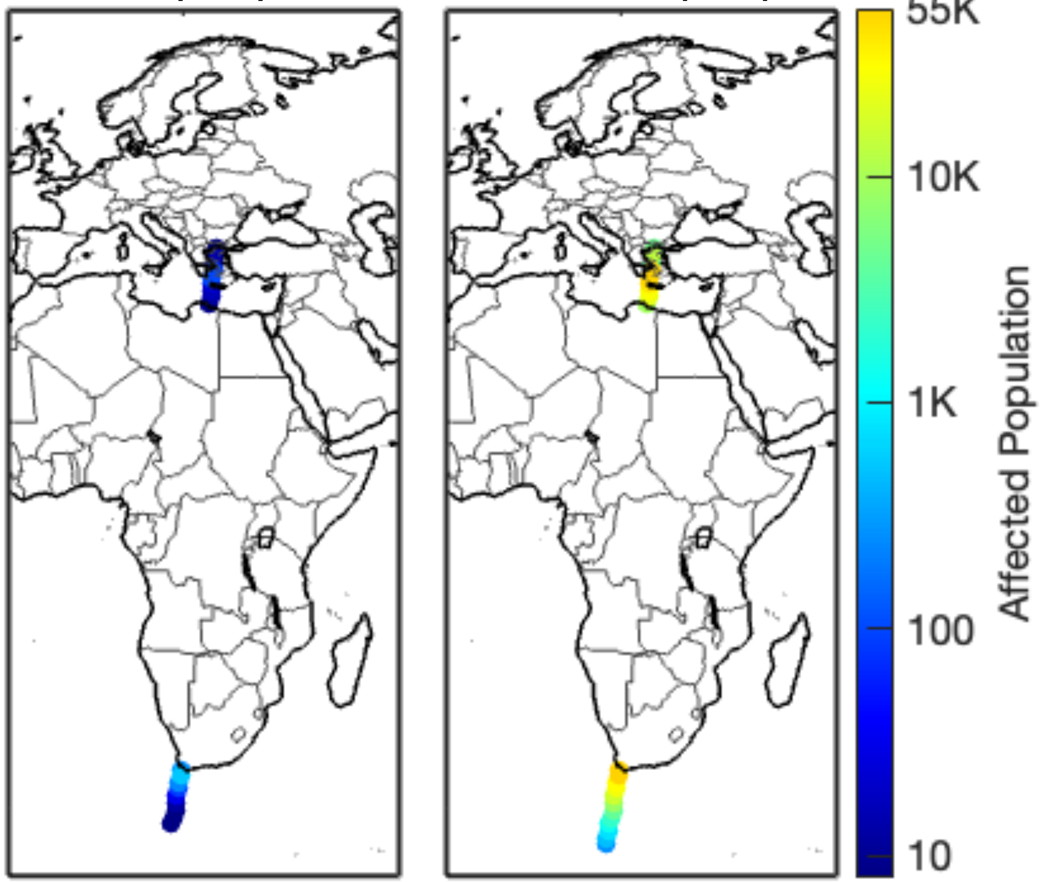
The potential impact location is most likely to occur over Southern Africa and less likely to occur over Eastern European regions

- Cape Town region has both the highest potential population damage along the swath and high relative impact probability
- Impact is less likely to occur over Eastern Europe, but could cause large damage to high-population areas
- Northern and Central Africa regions have moderate relative impact probabilities over some high-population points and low-population regions.

HYPOTHETICAL EXERCISE

Tsunami Risk & Affected Population Ranges

Average <1K people — **Largest Modeled** ~200–55K people



Airbursts in this size range are **unlikely to pose significant tsunami risks**, but largest cases could cause inundation damage if near coasts

- <0.5% chance of tsunami damage to populated regions among all Earth-impact cases modeled (<1% chance among ocean/sea cases modeled)
- About half of tsunami cases also cause blast damage reaching shore, which tends to affect more people than the inundation
- Tsunami damage could occur from largest impacts over the Mediterranean or within ~1000 km (~600 mi) offshore from Cape Town
- Average tsunami damage affects <1K people, but the largest tsunami cases could affect up to ~50K people

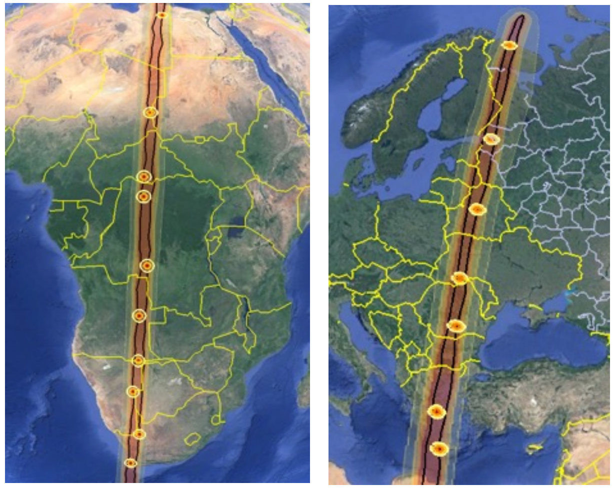
Affected population maps: Map points are colored by the average (left) and largest modeled (right) affected population among the tsunami cases modeled at each location. Map points indicate the location of the impacts/airbursts, while the resulting affected population damage occurs across the nearby coastal regions, depending on the range and severity of the tsunami inundation.

Impact Risk Dashboard

Assessment 1 — Initial Discovery & SMPAG Notification — 1 August 2024

Asteroid Characterization Summary

- ~1.6% chance of Earth impact on 24 April 2041 (~17 years) from a hazardous asteroid with uncertain size and properties
- Available observation data: Ground-based brightness estimates; JWST estimated diameter and determined S taxonomy
- Diameter: 50–280 m (160–920 ft), most likely 90–160 m (300–520 ft), median size 125 m (412 ft)
- Impact Energy: 3–720 Mt, most likely 5–70 Mt, median 50 Mt
- Properties: S type bulk density ranges, unknown structure



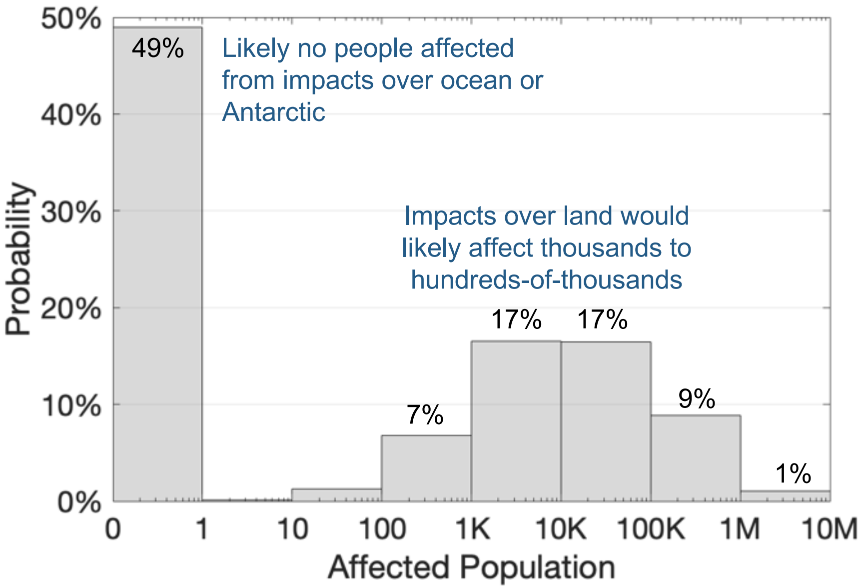
Risk Region Swath Map

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

Hazard Summary

- Large ranges of potential damage sizes, severities, and locations
- Primary hazard is a high-energy, low-altitude airburst and fireball causing destructive blast waves over large areas
- Blast damage could likely reach unsurvivable levels near airburst, with serious damage likely extending ~40–110 km (~20–70 mi) in radius, and possibly out over 200 km (120 mi) or more
- Likely damage sizes could span multiple metropolitan areas or counties, while large damage sizes could span regions or states
- Airbursts in this size range are unlikely to cause significant tsunami, but largest cases could cause inundation damage if near coasts

Affected Population Risks (given Earth-impact)



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

Range: 0–5M ppl

~52K avg. if Earth impact occurs

~830 total avg. risk (with 1.6% Earth-impact probability)

Additional Resources

- Additional scenario information, results, and tools will be available on the CNEOS exercise website: https://cneos.jpl.nasa.gov/pd/cs/pdc25/
  - **Interactive impact risk dashboard:** Additional PAIR impact risk results for this exercise scenario can be explored in an interactive web dashboard tool, which includes additional hazard summaries, detailed plots and data tables on the damage sizes and severities, and zoomable maps of the damage risk swath and sample damage footprint examples.
  - **Google Earth damage risk maps:** A Google Earth KML file of the damage risk swath and sample damage footprint sizes for this exercise scenario will be available for download.
  - **Introduction to Asteroid Impact Risk Assessment presentation**: Introductory background information on the asteroid threat assessment processes and details on the risk modeling, impact hazards, affected population estimates, and damage risk maps
  - **Orbital details:** JPL/CNEOS orbit information, data, and tools.
- ATAP impact risk modeling references:
  - Details on the **Probabilistic Asteroid Impact Risk (PAIR)** model and impact threat assessment process used to produce these results are published in: Wheeler et al., 2024 [doi:10.1016/j.actaastro.2023.12.049]
  - Details on the **Asteroid Property Inference Network (APIN)** model used to generate the asteroid property cases for this assessment are published in: Dotson et al., 2024 [doi:10.1016/j.actaastro.2024.04.020]
  - See reference slide for additional ATAP PAIR, hazard modeling, and entry modeling journal papers.

HYPOTHETICAL EXERCISE

Ames Research Center

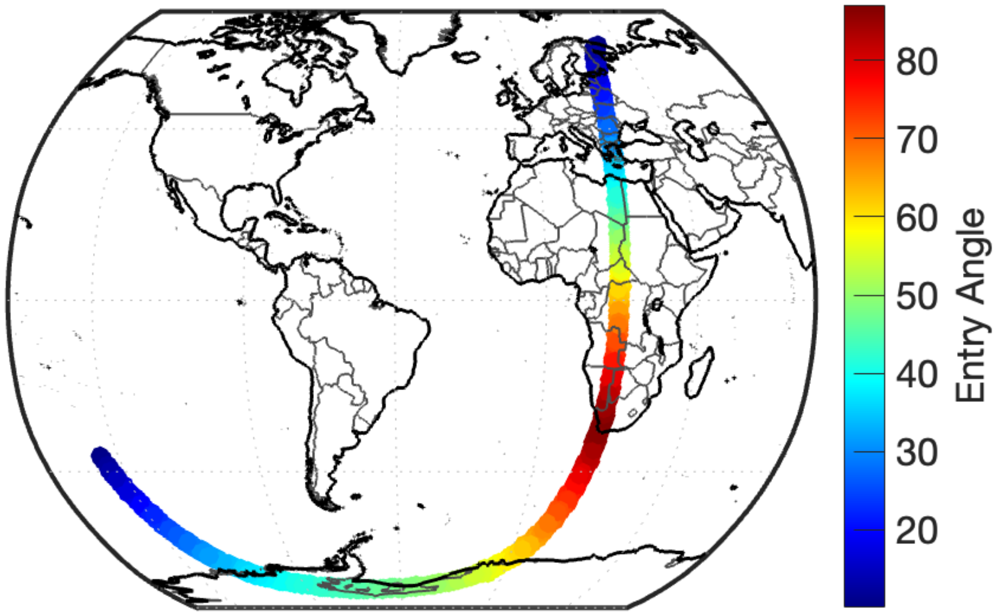
NASA

PDC25 EPOCH 1 BACKUP DETAILS

Entry Parameters & Locations

- **~1.6% chance of Earth impact somewhere along a globe-spanning corridor as of 1 Aug. 2024**
  - Potential impact corridor spans from the Barents Sea on the northern end to the S. Pacific on the southwestern end, crossing Eastern Europe, the Mediterranean, Africa, the S. Atlantic, and Antarctica.
  - Entry parameters vary across the corridor, but are well-known for given impact points
- **Entry Velocity:**
  - ~13.75 km/s (13.68–13.82 km/s)
  - Little variation across swath
- **Entry Angle:**
  - Nearly-vertical entries over S. Africa
  - Shallower entries over Europe
  - Entry angle differences affect ranges of airburst altitudes and resulting blast damage sizes and shapes
- **Entry Direction (Heading):**
  - Entry directions are roughly northward over the primary land-crossing portions of the swath
  - ~NNE (19°) at northmost end of swath to ~WNW (290°) over S. Africa coast

Entry Angle (from horizontal)



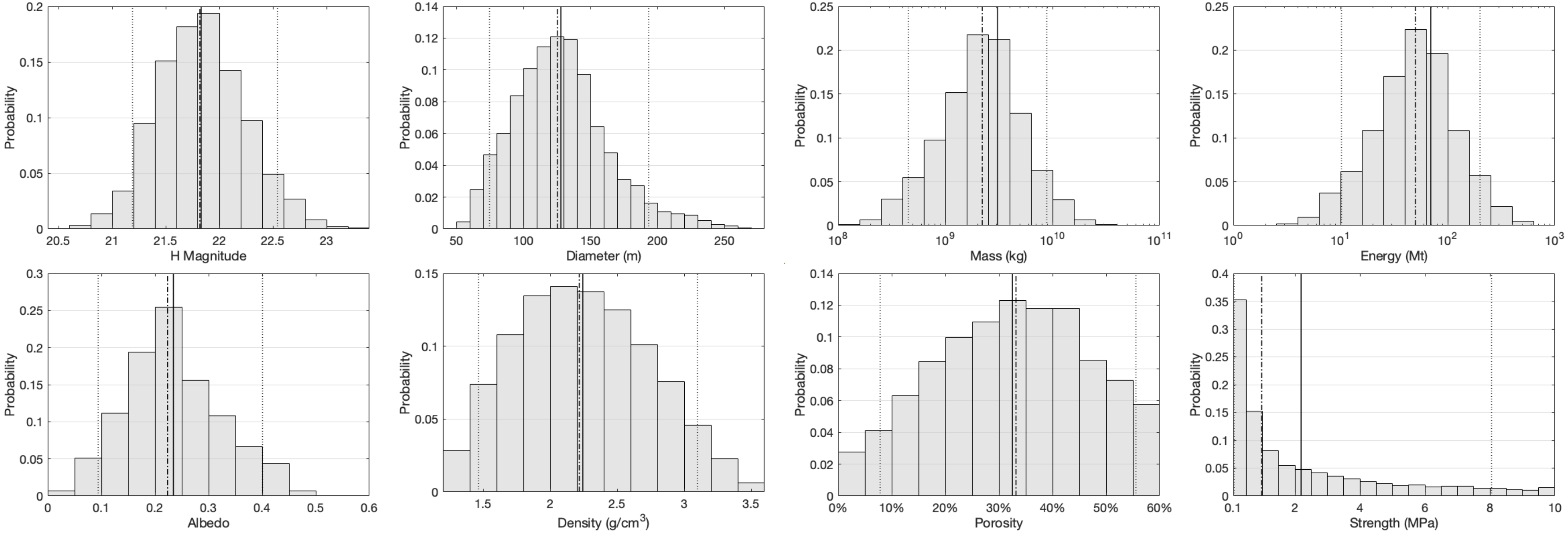
[Impact entry data: D. Farnoccia, CNEOS/JPL, https://cneos.jpl.nasa.gov/pd/cs/pdc25/]

Ames Research Center

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%)	Full Range Modeled
Diameter (m)	128	75	104	125	147	194	89 – 155	48 – 278
Mass (kg)	3.08E+09	4.52E+08	1.25E+09	2.21E+09	3.79E+09	8.84E+09	2.4E+08 – 3.3E+09	1.2E+08 – 3.1E+10
Energy (Mt)	70	10	28	50	86	200	5 – 74	3 – 716
H Magnitude	21.83	21.19	21.55	21.82	22.10	22.54	21.37 – 22.18	20.48 – 23.34
Albedo	0.234	0.094	0.173	0.223	0.286	0.401	0.14 – 0.32	0.03 – 0.87
Density (kg/m^3)	2244	1466	1861	2217	2601	3099	1678 – 2728	1206 – 3594
Porosity (%)	32.5%	7.9%	21.5%	33.2%	43.5%	55.6%	17% – 48%	0% – 60%
Strength (MPa)	2.2	0.1	0.3	1.0	3.3	8.1	0.1 – 2.4	0.1 – 10



* 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 et al., 2024]

Available Asteroid Characterization Information

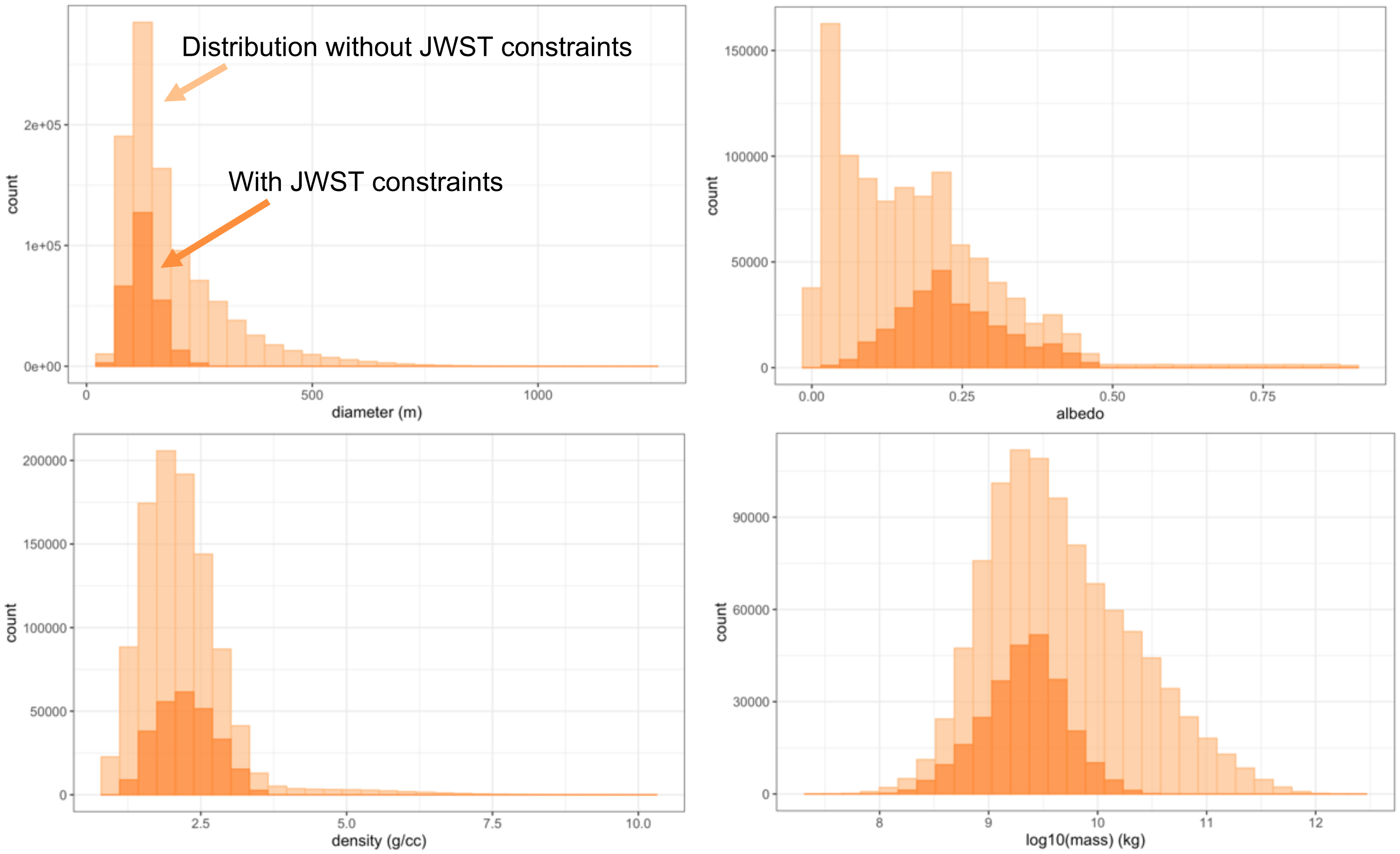
Physical property distributions were determined by combining our knowledge about the properties of the NEO population with constraints derived from the JWST observations. This assessment produced a set of virtual impactors for which cumulative properties reflect the resulting distributions, and individual combinations of parameters are physically plausible.

Observational data as of 1 Aug. 2024:

- Limited ground measurements available
  - H magnitude: H = 21.9 ± 0.4 (1-σ)
  - Visual magnitude since discovery 21.5–22.5
  - Ground-based photometric lightcurves are likely to enable a reduction in uncertainty, but analysis is forward work.
- JWST observed 2024 PDC25 for 6 hours on July 28
  - Determined taxonomic type to be S class
  - Estimated diameter of 132 m ± 30% (1-σ)
  - JWST photometry has higher precision, but JWST did not observe long enough to determine the period or aspect ratio
  - Uncertainty included in this assessment accounts for geometrical uncertainties.

[Property model: J. Dotson et al., 2024]

Asteroid property refinements from JWST

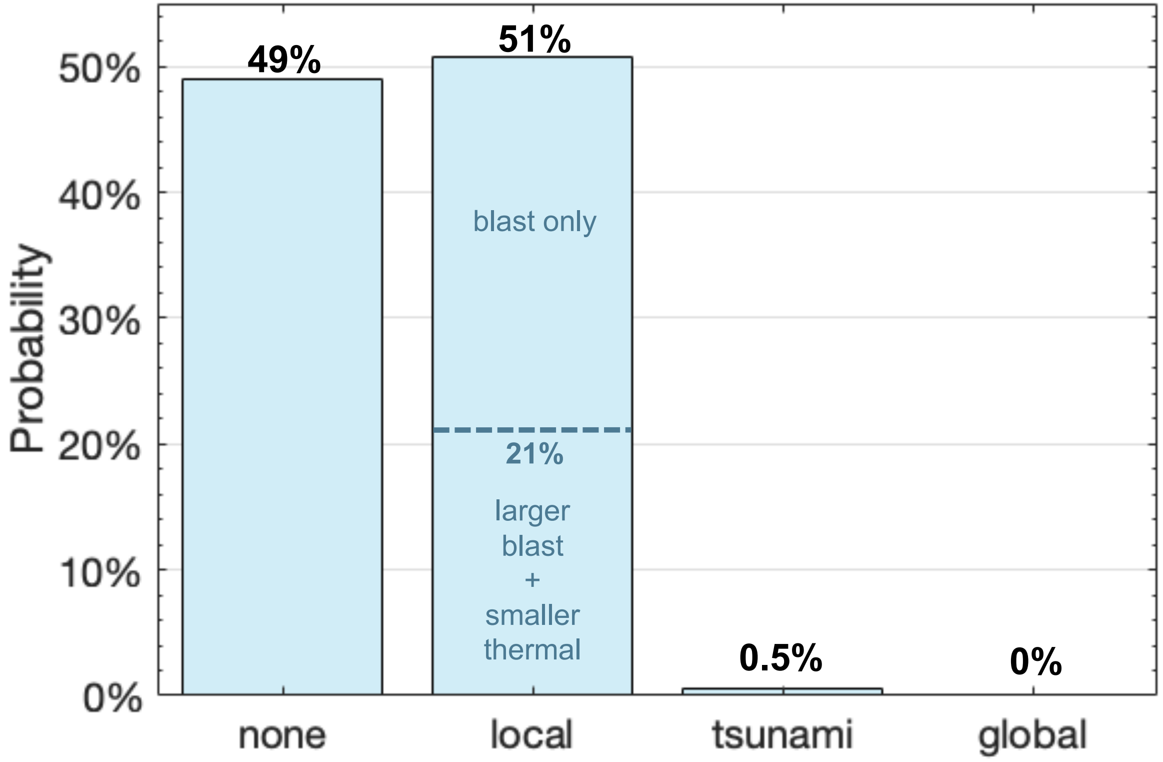


Hazard Sources

Relative hazard probabilities among Earth-impacting cases

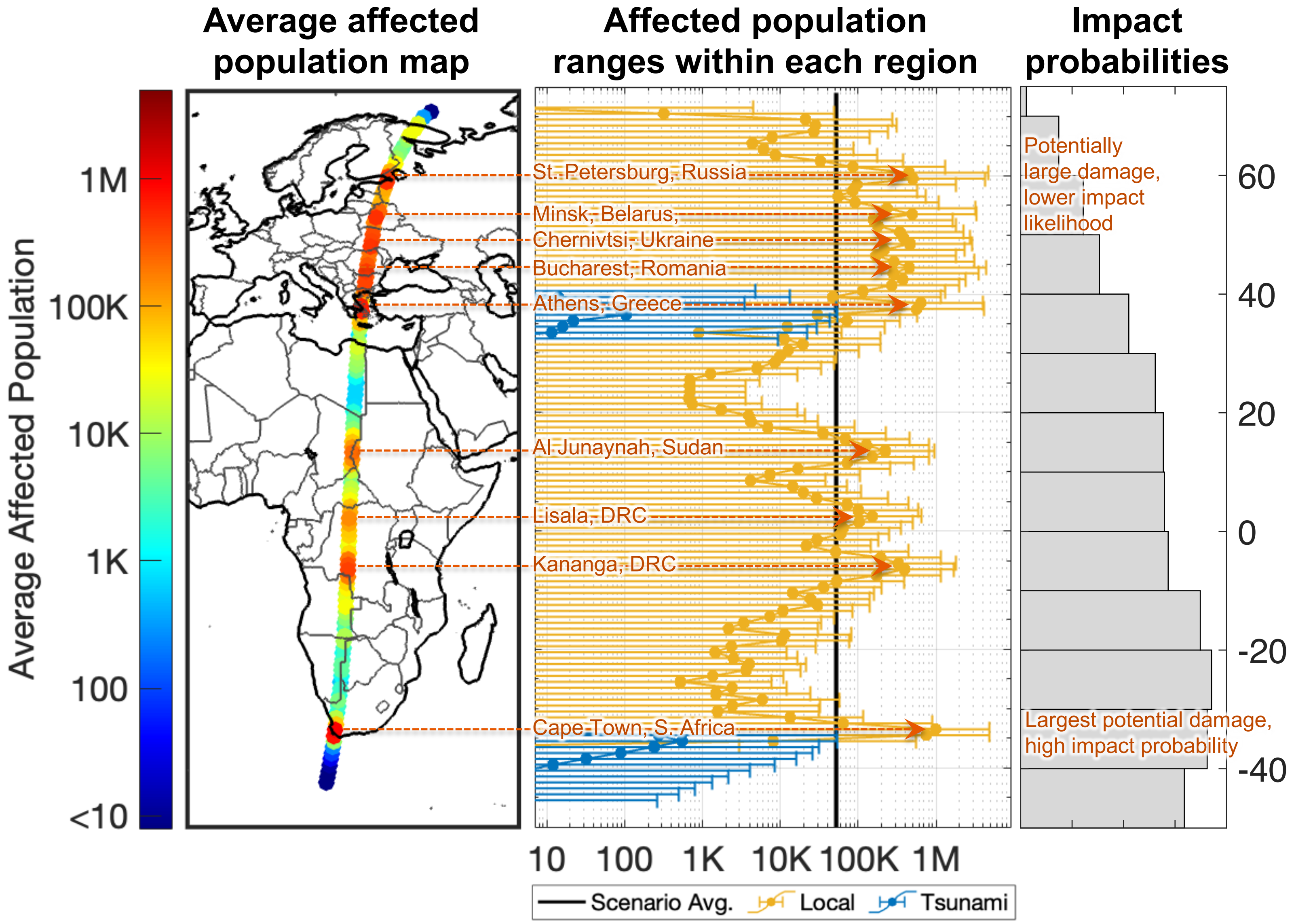
- 47% chance of airbursts over land, 53% over water or Antarctic
- Nearly all airbursts over land cause local ground damage affecting populated areas
  - Blast damage occurs in ~51% of all Earth-impact cases (~100% of cases over land and near shore)
  - Thermal damage also occurs in 21% of Earth-impact cases (~43% of land cases), but is smaller and less severe than blast damage in all cases
- Tsunami damage is unlikely (0.5% chance), but the largest near-shore cases could cause inundation along nearby coasts
- No global-scale climate effects are expected from asteroids in this size range
- No damage occurs in ~49% of Earth-impact cases (ocean and Antarctic locations further than ~1000 km offshore)

Relative Hazard Occurrence Probabilities



* A single impact event can cause multiples hazards (e.g., blast + thermal, tsunami + local near-shore, or global + local or tsunami). Sum of all hazard occurrence probabilities may exceed 100%.

Affected Population Ranges Along Swath



Average affected population (left):
Average for each potential entry point, given range of potential asteroid sizes and properties

Affected population ranges (middle):
Averages and min/max ranges within 1° latitude increments along swath

Relative impact probabilities (right):
Likelihood of impact occurring within potential impact regions

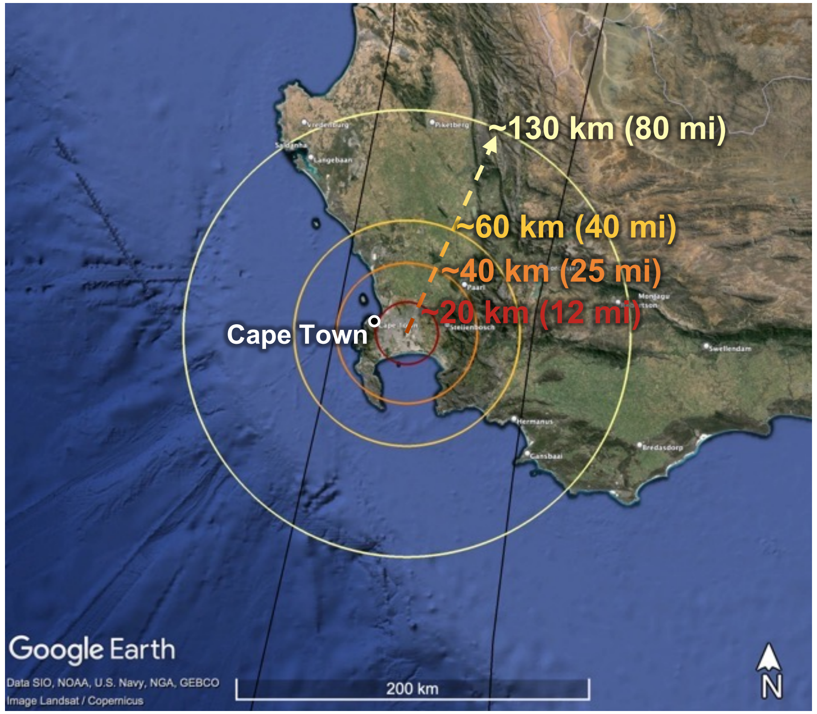
HYPOTHETICAL EXERCISE

Potential Ground Damage Size Ranges

Cape Town, S. Africa – Highest population damage region along swath

Median (50th%) Damage

Large (95th%) Damage



Largest Modeled

Local Ground Damage Radius Size Ranges (km)

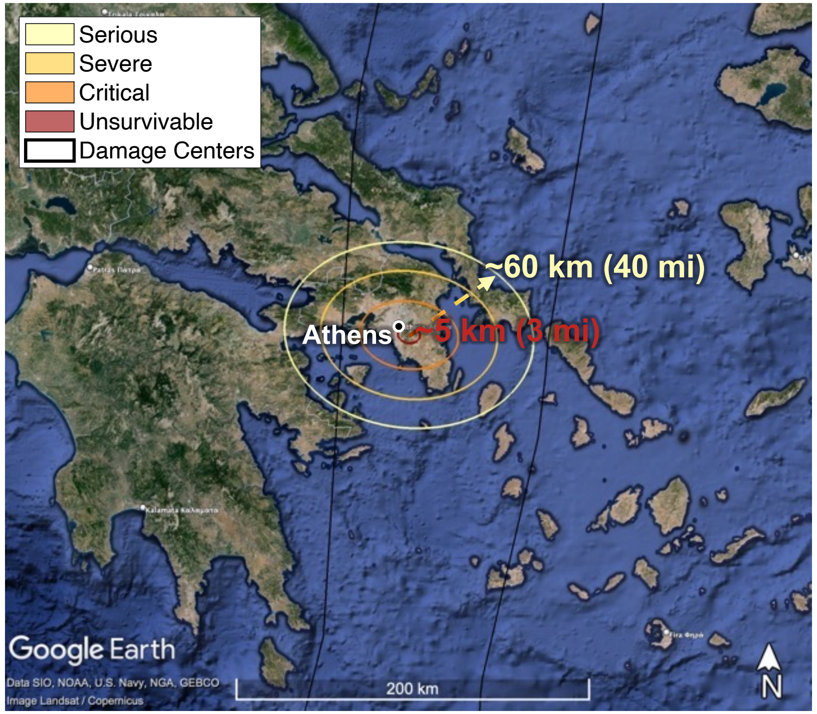
Damage Level	Most Likely	Median	95th percentile	Largest modeled
Serious	40–110	80	140	240
Severe	30–60	45	70	130
Critical	15–40	25	45	90
Unsurvivable	0–13	10	20	35

* Damage sizes and shapes vary along the impact corridor due to different entry angles and airburst altitudes. Table gives approximate values among all damage locations, and images show example values for the given location.

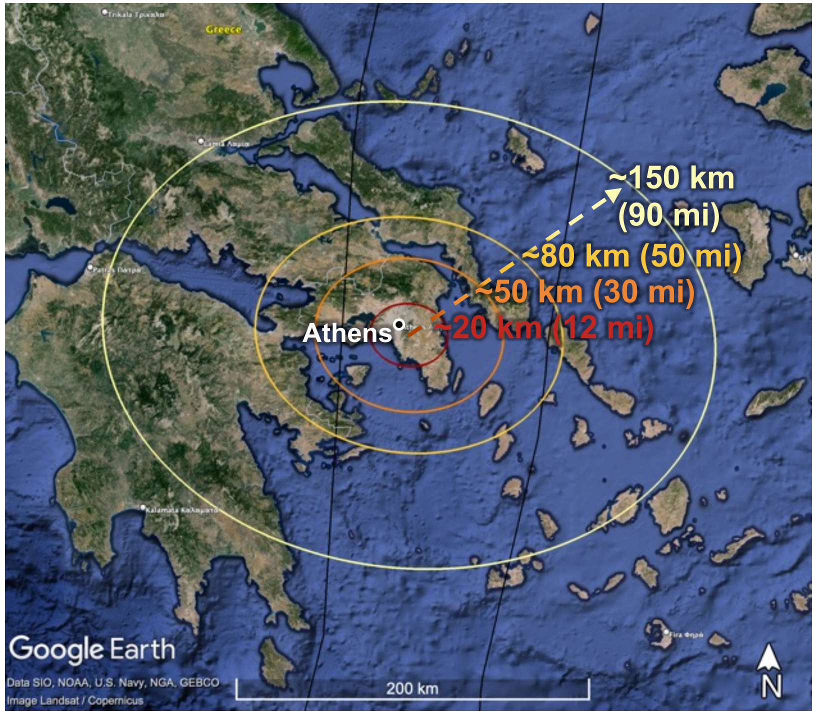
Potential Ground Damage Size Ranges

Athens, Greece – Highest population damage region in Mediterranean

Median (50th%) Damage



Large (95th%) Damage



Largest Modeled

Local Ground Damage Radius Size Ranges (km)

Damage Level	Most Likely	Median	95th percentile	Largest modeled
Serious	40–110	80	140	240
Severe	30–60	45	70	130
Critical	15–40	25	45	90
Unsurvivable	0–13	10	20	35

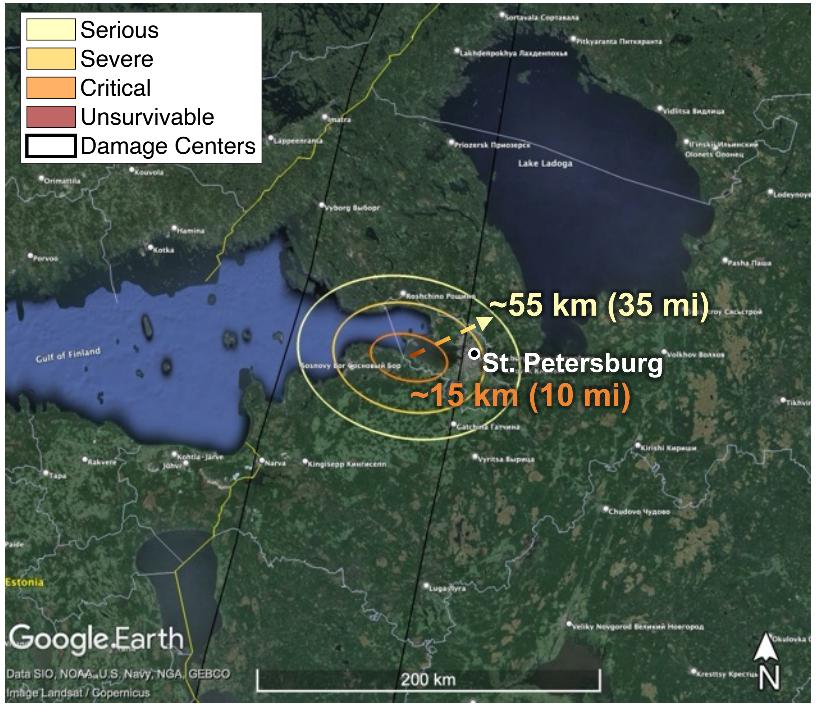
* Damage sizes and shapes vary along the impact corridor due to different entry angles and airburst altitudes. Table gives approximate values among all damage locations, and images show example values for the given location.

HYPOTHETICAL EXERCISE

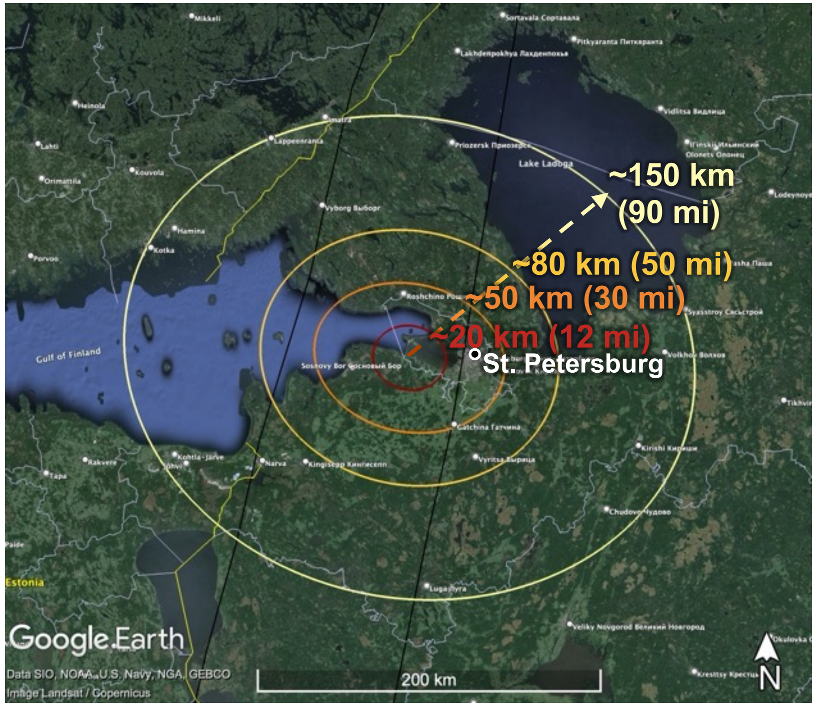
Potential Ground Damage Size Ranges

St. Petersburg, Russia – Highest population damage region in Eastern Europe

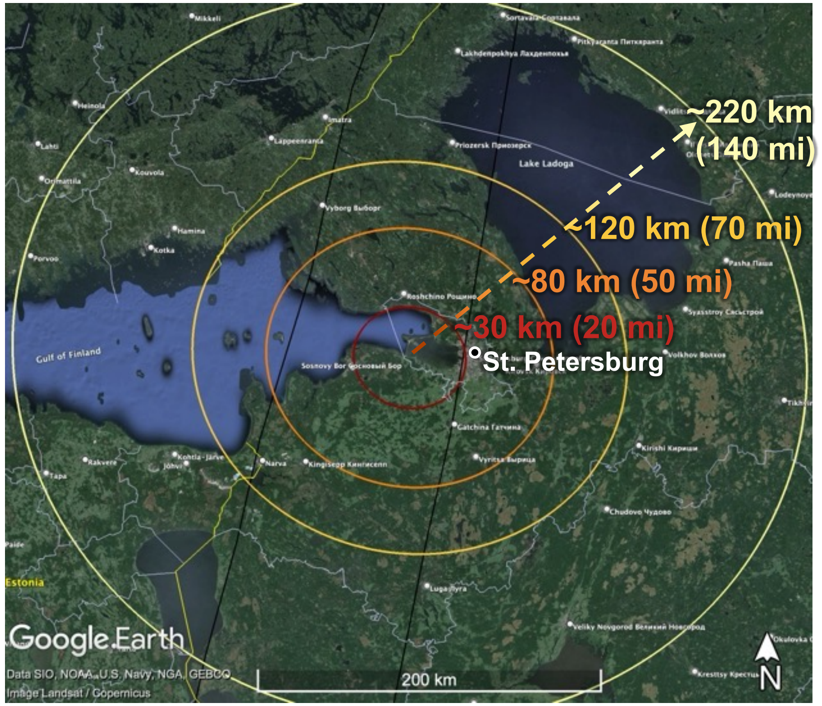
Median (50th%) Damage



Large (95th%) Damage



Largest Modeled



Local Ground Damage Radius Size Ranges (km)

Damage Level	Most Likely	Median	95th percentile	Largest modeled
Serious	40–110	80	140	240
Severe	30–60	45	70	130
Critical	15–40	25	45	90
Unsurvivable	0–13	10	20	35

* Damage sizes and shapes vary along the impact corridor due to different entry angles and airburst altitudes. Table gives approximate values among all damage locations, and images show example values for the given location.

Local Blast & Thermal Damage Area Sizes

- Primary hazard is a high-energy, low-altitude airburst and fireball causing destructive blast waves and potential thermal damage
  - Significant blast damage is almost certain to occur, ranging from unsurvivable levels to shattered windows and structure damage over large areas
  - Thermal damage could also occur along with the blast damage but is almost always much smaller and less severe.
- Uncertain asteroid size, entry/breakup behavior, and airburst altitude result in a large range of possible damage sizes
  - Most likely outer damage radius range is ~40–110 km (20–70 mi)
  - Largest outer damage areas could extend out ~240 km (~150 miles) or more in radius

Potential Blast Damage Severities and Sizes

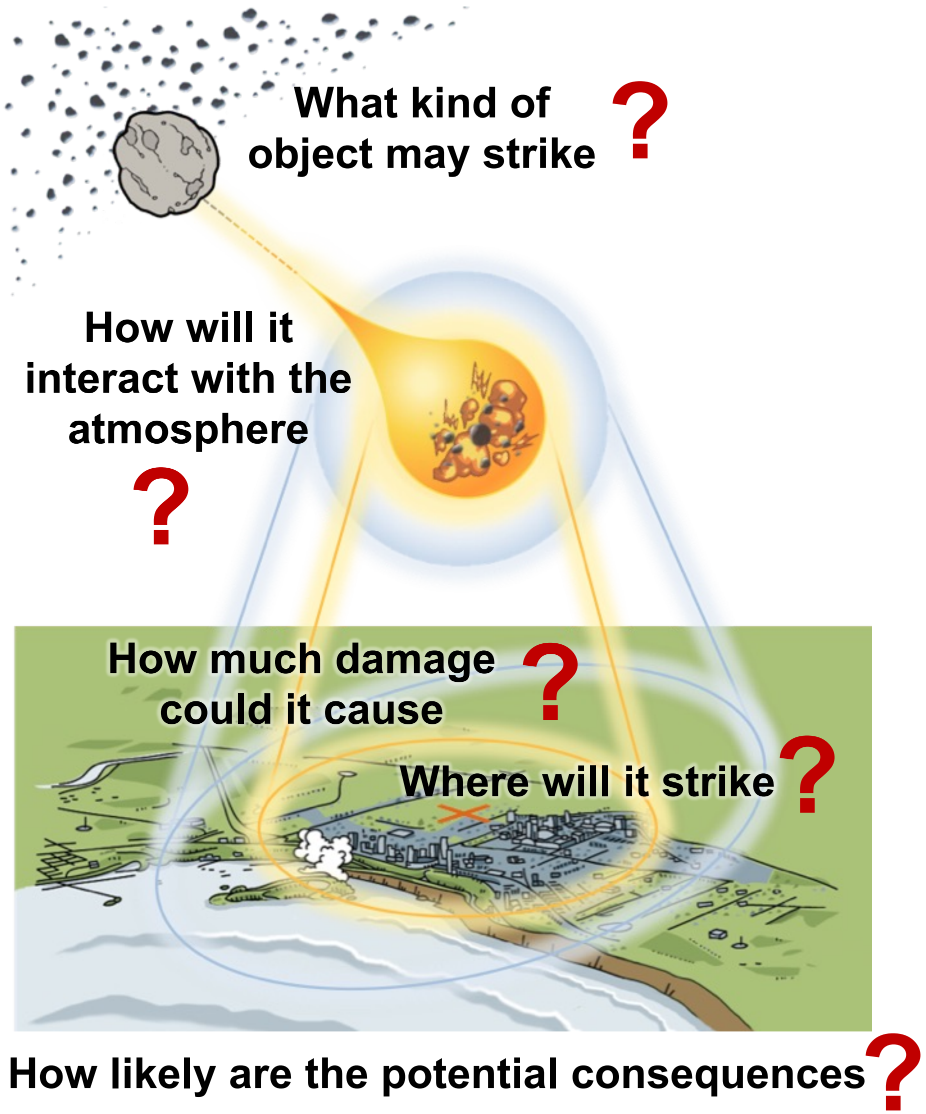
Damage Level	Potential Blast Effects	Chance of Occurring	Damage Radius Ranges (km)		
			Median	Most Likely	Largest
Serious	Shattered windows, some structure damage	~100%	80	40–110	240
Severe	Widespread structure damage	98%	45	30–60	130
Critical	Most residential structures collapse	91%	25	15–40	90
Unsurvivable	Complete devastation	70%	10	0–13	35

Potential Thermal Damage Severities and Sizes

Damage Level	Potential Thermal Effects	Chance of Occurring	Damage Radius Ranges (km)		
			Median	Most Likely	Largest
Serious	2nd degree burns	45%	0	0–13	60
Severe	3rd degree burns	34%	0	0–3	50
Critical	Clothing ignition	24%	0	0–0	35
Unsurvivable	Structure ignition	19%	0	0–0	30

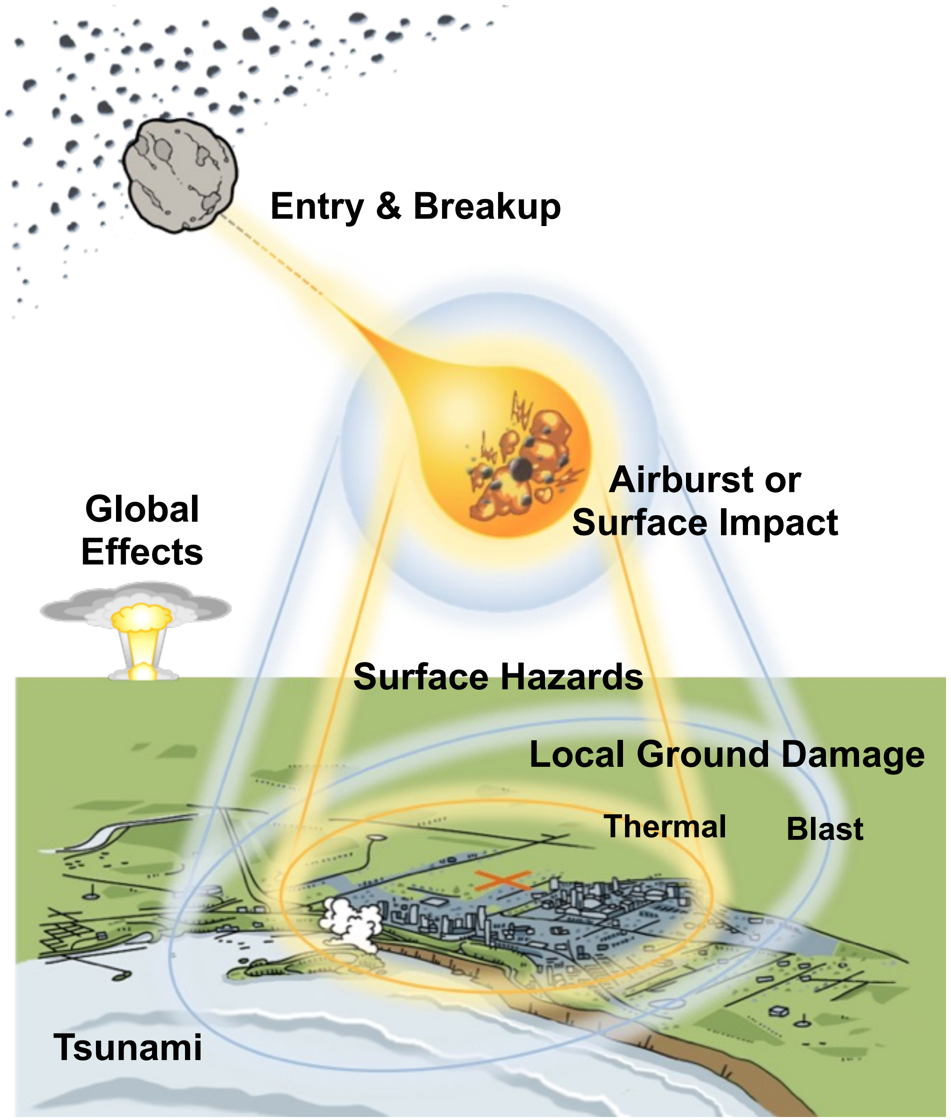
PROBABILISTIC ASTEROID IMPACT RISK MODELING DETAILS & REFERENCES

What is Asteroid Impact Risk Assessment?



- Risk assessment evaluates both the severity and likelihood of potential outcomes, given the uncertainties about the contributing factors
- Evaluating asteroid impact risks involves large uncertainties across all aspects of the problem:
  - Impact probability, potential impact locations, entry trajectories (speed, entry angle)
  - Initial asteroid sizes and properties (density, strength, structure, composition, shape, etc.)
  - Atmospheric entry, breakup, airburst or impact behavior
  - Severity and range of resulting hazards
  - Population and infrastructure within damage regions
- Some uncertainties shrink as we gain knowledge over time (impact locations, asteroid size), while some remain unknown (specific asteroid properties, entry/breakup behavior, damage uncertainties)

Asteroid Impact Hazards

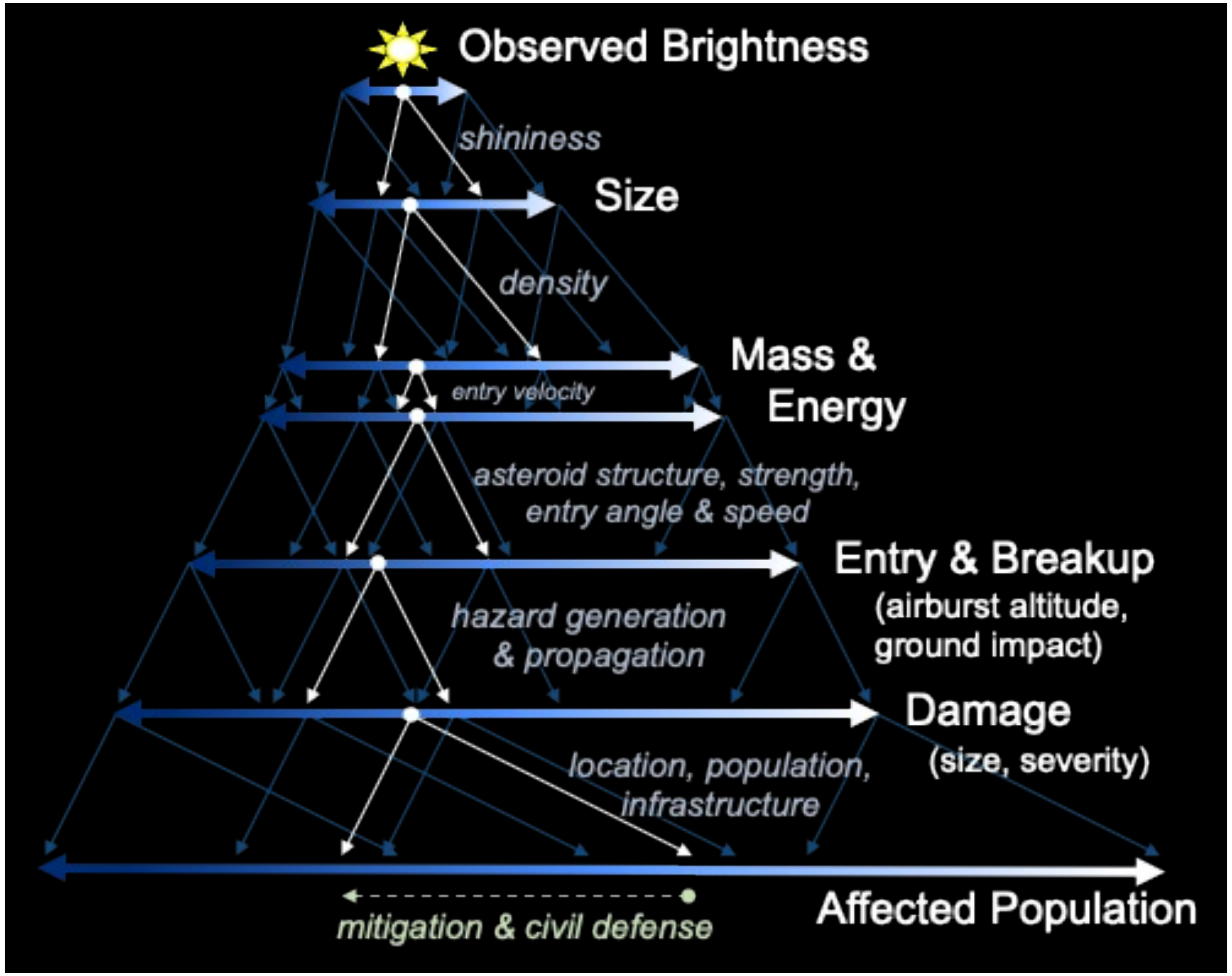


- **Asteroids can cause damage by breaking up and bursting in the atmosphere or impacting the surface**
- **Primary impact hazards are:**
  - **Local ground damage:** Airbursts and surface impacts can produce explosive blast waves and thermal fireballs
  - **Tsunami:** Ocean impacts could cause significant tsunami inundation if impact is very large or near to a populated coast
  - **Global effects:** Large-scale impacts could produce enough atmospheric ejecta to cause global climatic effects
- **The asteroid sizes in this scenario are most likely to cause blast damage from a high-energy, low-altitude airburst.**

Asteroid Property & Damage Uncertainties

- Evaluating the potential damage & risk from an asteroid threat involves many large uncertainties
  - Asteroid size and property uncertainties from limited observational data
  - Potential impact location, velocity, and entry angle from orbital uncertainties
  - Uncertainties in entry and damage modeling for large impact events
- Each factor contributes additional uncertainty, leading to very large ranges of potential impact energy and resulting damage estimates
- Some uncertainties will shrink as we gain data (impact locations, asteroid size), while some factors may remain unknown (damage modeling uncertainties)

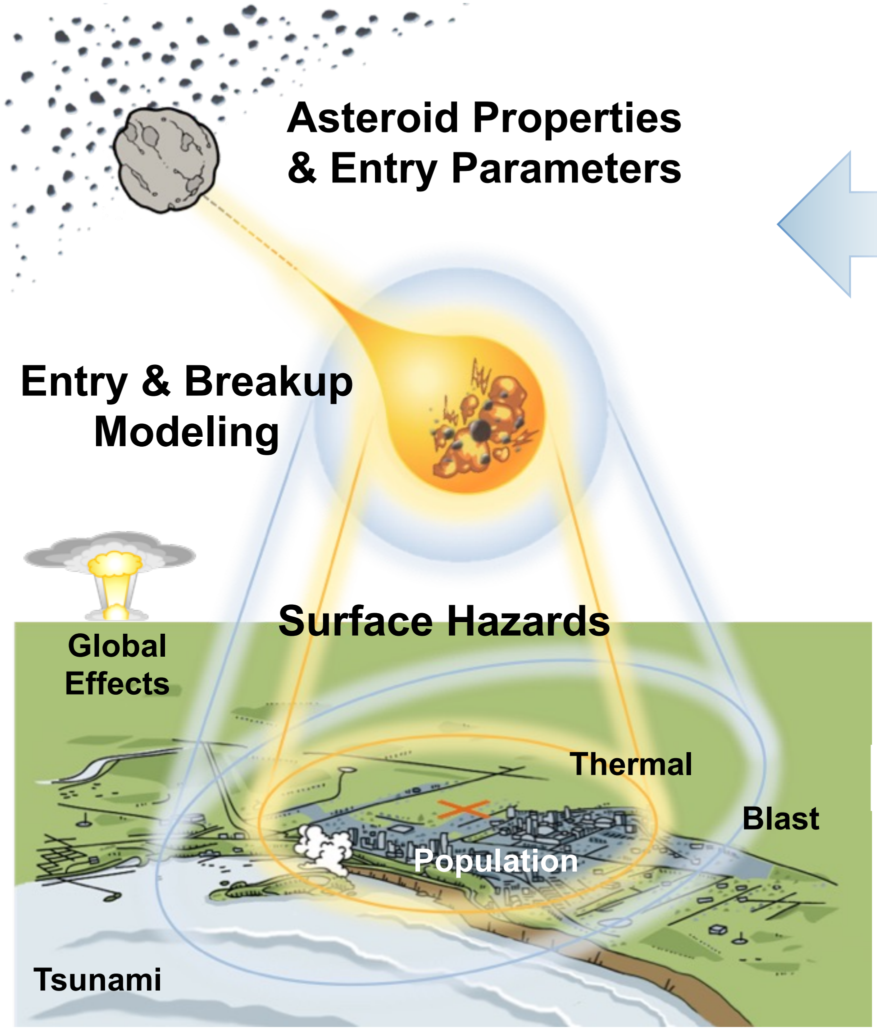
Cascade of uncertainty ranges from asteroid observation to damage potential



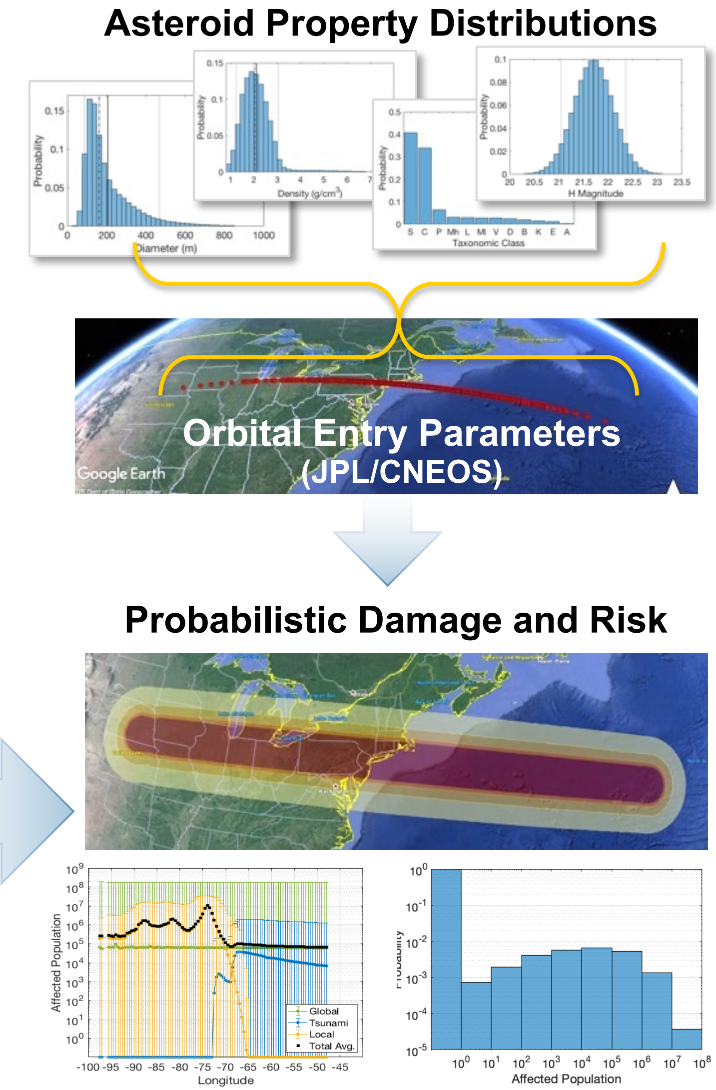
HYPOTHETICAL EXERCISE

Asteroid Impact Threat Assessment

Probabilistic Asteroid Impact Risk (PAIR) Model



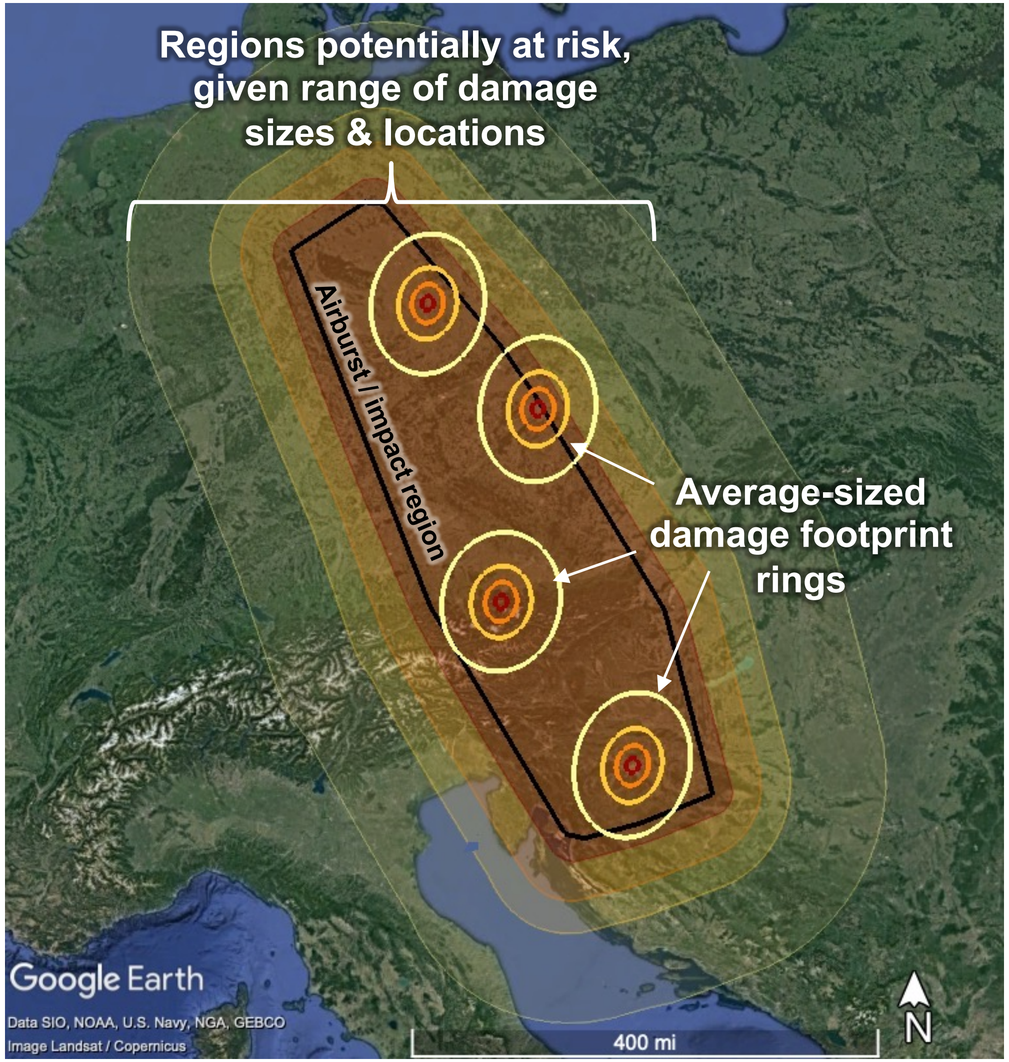
Impact Threat Scenario



- Risk model uses fast-running physics-based models to assess millions of impact cases representing the range of possible asteroid properties and impact locations.
- Atmospheric entry, breakup, and resulting hazards (blast, thermal, tsunami, global effects) are modeled for each case.
- Probabilities of the resulting damage sizes, severities, and affected populations are computed.
- Regions at-risk to local damage are mapped.

[PAIR model details: Mathias et al., 2017; Stokes et al., 2017]

Risk Region Swath Maps



Example from 2021 Planetary Defense Conference Exercise

Risk swaths show range of regions ***potentially*** at risk to local ground damage, including range of possible damage sizes* and locations

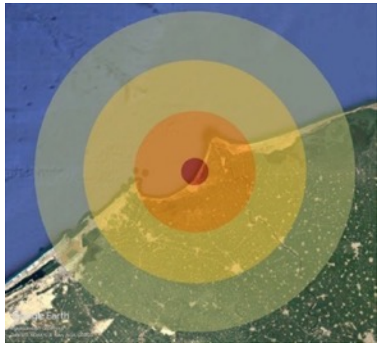
- Black outline shows range of potential impact points (damage-center locations)
- Shaded areas show potential at-risk regions given range of damage sizes and locations
- Rings show median-sized damage footprints at sample locations

Damage Level	Description
Serious	Window breakage, some minor structure damage
Severe	Widespread structure damage, doors/windows blown out
Critical	Most residential structures collapse
Unsurvivable	Complete devastation

* Swath extents shown for the 2024 PDC25 results cover local ground damage sizes out to the 95th percentile. Local damage maps do not include regions potentially at at risk to tsunami or global effects.

Local Blast & Thermal Damage Effects

- Large impacts and airburst can generate destructive blast waves and thermal heat radiation that can cause various levels of injury, fatalities, structural damage, and/or fires extending far around the impact location.
- Blast and thermal ground damage are assessed *independently* at four equivalent severity levels
  - The damage region for each severity level is determined from the *larger* of the equivalent blast *or* thermal damage area
  - Local ground damage regions indicate *either* blast or thermal effects could exceed the given severity threshold (*not* necessarily the occurrence of both effects within the entire region)
  - Local affected population estimates within each region are scaled by the relative severity of each damage level
- Blast is the predominant hazard for most airbursting and sub-global-scale asteroid sizes
  - Blast tends to be larger and more severe than the potential thermal damage in most cases, and usually defines the larger outer damage risk regions for emergency response planning
  - Depending on blast energy, airbursts can cause larger blast damage than ground impacts, while thermal damage decreases with airburst altitude



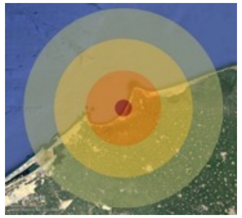
Damage Level	Relative Severity	Blast Damage Effects	Thermal Damage Effects
Serious	10%	Shattered windows, some structural damage	2nd degree burns
Severe	30%	Widespread structural damage	3rd degree burns
Critical	60%	Most residential structures collapse	Clothing ignites
Unsurvivable	100%	Complete devastation	Structures ignites, incineration

HYPOTHETICAL EXERCISE

Affected Population Risks

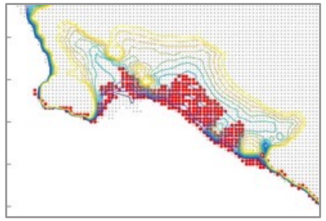
- For each impact case modeled, PAIR computes the estimated number of people affected by each hazard type, based on the modeled damage location, area, severity, and local population
  - **Local blast & thermal ground damage:** affects 10–100% of local population depending on severity (additional details in following slides)
  - **Tsunami:** affects up to 10% of the local population depending on flood depth in each coastal area (based on tsunami wave height and ground elevation)
  - **Global effects:** affects estimated fractions of total world population, based on total impact energy and a randomly sampled severity factor
  - **Total affected population** estimates for each impact case are taken as the number of people affected by the largest hazard produced (not sums of multiple hazards)
- **Affected population risks:** population results for each impact case are aggregated to compute total population ***risks,*** reflecting the likelihoods of the possible effects for the overall impact scenario (i.e., probabilities of the impact affecting given ranges or thresholds of people)
- **Population data source:** SEDAC Gridded Population of the World (GPW) v4.11 gridded population counts, year 2020 UN-adjusted values

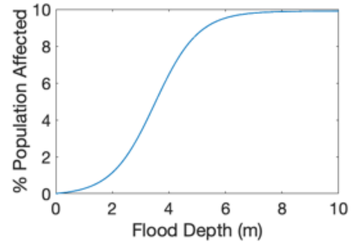
Local Blast & Thermal Affected Population



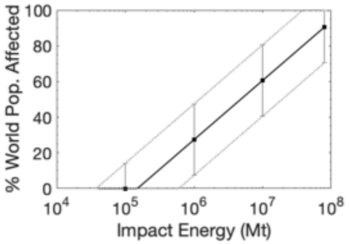
Severity	% Pop. Affected
Serious	10%
Severe	30%
Critical	60%
Unsurvivable	100%

Tsunami Affected Population





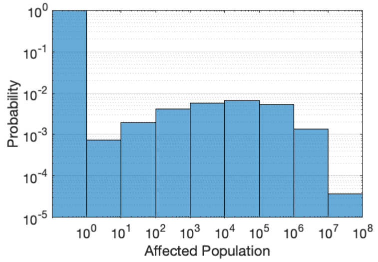
Global Effects Affected Populations



Impact Energy (MT)	% Population Affected		
	Min	Nominal	Max
4.E+04	0	0	0
8.E+04	0	0	10
2.E+05	0	0	20
3.E+05	0	10	30
6.E+05	0	20	40
1.E+06	10	30	50
2.E+06	20	40	60
5.E+06	30	50	70
1.E+07	40	60	80
2.E+07	50	70	90
4.E+07	60	80	100
8.E+07	70	90	100

SEDAC Gridded Population Data

Population Risks



[PAIR model details: Mathias et al., 2017; Stokes et al., 2017]

HYPOTHETICAL EXERCISE

REFERENCES

ATAP Impact Risk & Hazard Modeling Papers

Probabilistic Asteroid Impact Risk (PAIR) & Asteroid Characterization:

- **Wheeler et al., 2024.** Risk assessment for asteroid impact threat scenarios. Acta Astronautica. doi:10.1016/j.actaastro.2023.12.049
- **Dotson et al., 2024.** Consequences of asteroid characterization on the state of knowledge about inferred physical parameters and impact risk. Acta Astronautica. doi:10.1016/j.actaastro.2024.04.020
- **Coates et al., 2024.** Sensitivity study of impact risk model results to thermal radiation damage model for large objects. Acta Astronautica. doi:10.1016/j.actaastro.2024.02.022
- **Chomette et al., 2024.** Machine learning for the prediction of local asteroid damages. Acta Astronautica. doi:10.1016/j.actaastro.2024.01.049
- **Robertson et al., 2024.** Evacuation and shelter plans for asteroid impacts informed by hurricanes and nuclear explosions. Acta Astronautica. doi:10.1016/j.actaastro.2023.11.020
- **Mathias et al., 2017.** A probabilistic asteroid impact risk model: assessment of sub-300m impacts. Icarus. doi:10.1016/j.icarus.2017.02.009
- **Stokes et al., 2017.** Update to determine the feasibility of enhancing the search and characterization of NEOs. NASA. 2017_neo_sdt_final_e-version.pdf
- **Wheeler & Mathias, 2018.** Probabilistic assessment of Tunguska-scale asteroid impacts. Icarus. doi:10.1016/j.icarus.2018.12.017
- **Rumpf et al., 2020.** Deflection driven evolution of asteroid impact risk under large uncertainties. Acta Astronautica. doi:10.1016/j.actaastro.2020.05.026
- **Reddy et al., 2024.** 2023 DZ2 Planetary Defense Campaign. Planet. Sci. J. doi:10.3847/PSJ/ad4a6d
- **Reddy et al., 2022.** Apophis planetary defense campaign. Planet. Sci. J. doi:10.3847/PSJ/ac66eb
- **Reddy et al., 2022.** Near-Earth Asteroid (66391) Moshup (1999 KW4) Observing Campaign: Results from a Global Planetary Defense Characterization Exercise. Icarus. doi:10.1016/j.icarus.2021.114790
- **Reddy et al., 2019.** Near-Earth Asteroid 2012 TC4 Campaign: results from a global planetary defense exercise. Icarus. doi:10.1016/j.icarus.2019.02.018
- **Geographic population data:** SEDAC GPW v4.11 gridded population counts, year 2020 (UN-adjusted values). CIESIN, Columbia University, 2016. doi:10.7927/H4SF2T42

Entry & Breakup Energy Deposition Modeling:

- **Wheeler et al., 2018.** Atmospheric energy deposition modeling and inference for varied meteoroid structures. doi:10.1016/j.icarus.2018.06.014
- **Wheeler et al., 2017.** A fragment-cloud model for asteroid breakup and atmospheric energy deposition. Icarus. doi:10.1016/j.icarus.2017.02.011
- **Register et al., 2020.** Interactions between asteroid fragments during atmospheric entry. Icarus. doi:10.1016/j.icarus.2019.113468

Blast Modeling and Simulation:

- **Aftosmis, et al., 2019.** Simulation-based height of burst map for asteroid airburst damage prediction. Acta Astronautica. doi:10.1016/j.actaastro.2017.12.021
- **Robertson & Mathias, 2019.** Hydrocode simulations of asteroid airbursts and constraints for Tunguska. Icarus. doi:10.1016/j.icarus.2018.10.017
- **Aftosmis, et al., 2016.** Numerical simulation of bolide entry with ground footprint prediction. 54th AIAA Aerospace Sciences Meeting. doi:10.2514/6.2016-0998

Thermal Radiation Modeling and Simulation:

- **Johnston et al., 2021.** Simulating the Benešov bolide flowfield and spectrum at altitudes of 47 and 57 km. Icarus. doi:10.1016/j.icarus.2020.114037
- **Johnston & Stern, 2018.** A model for thermal radiation from the Tunguska airburst. Icarus. doi:10.1016/j.icarus.2019.01.028
- **Johnston et al., 2018.** Radiative heating of large meteoroids during atmospheric entry. Icarus. doi:10.1016/j.icarus.2018.02.026

Tsunami Simulations:

- **Berger & LeVeque, 2022.** Towards adaptive simulations of dispersive tsunami propagation from an asteroid impact. Proc. ICM, 2022. doi:10.4171/icm2022/73
- **Robertson & Gisler, 2019.** Near and far-field hazards of asteroid impacts in oceans. Acta Astronautica. doi:10.1016/j.actaastro.2018.09.018
- **Berger & Goodman, 2018.** Airburst-generated tsunamis. Pure Appl. Geophys. doi:10.1007/s00024-017-1745-1

HYPOTHETICAL EXERCISE