Projecting Asteroid Impact Corridors onto the Earth

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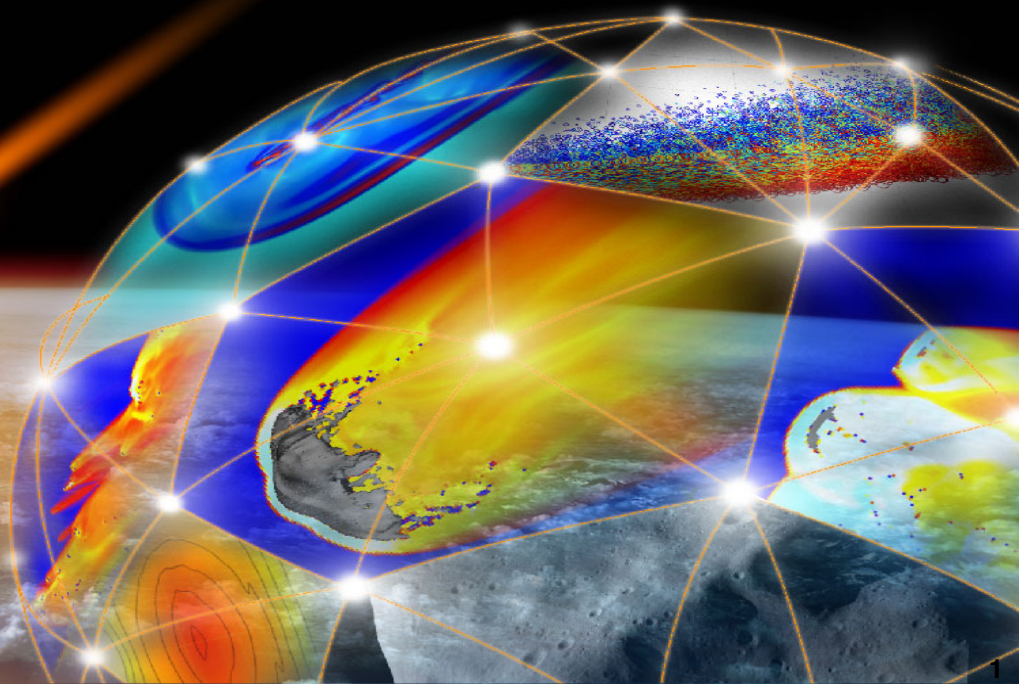


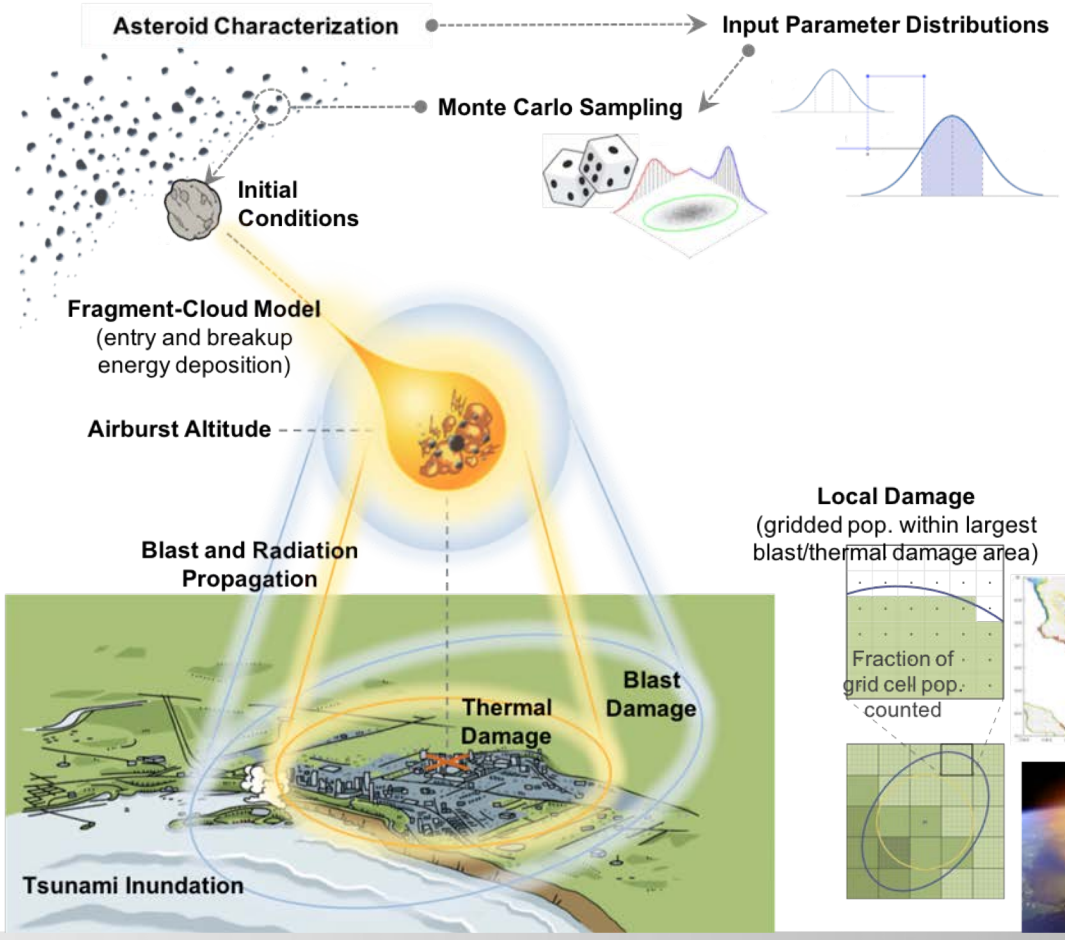
Outline

- Introduction into ATAP and PAIR
- Asteroid impact risk
  - Impact corridors (impact probability representation)
  - Risk representation
- Two methods for calculating spatial impact probability representations
- Examples
- Conclusions

ATAP – Asteroid Threat Assessment Project

- ATAP = Asteroid Threat Assessment Project
- Small team at NASA Ames Research Center
- Various activities in support of asteroid threat assessment
  - Examples:
    - Tsunami modelling
    - Atmospheric flight and airburst modelling
    - Investigating ablation of meteoritic material in arcjet
    - Risk assessment
- PAIR = Probabilistic Asteroid Impact Risk tool
  - In house computational tool to investigate impact risk

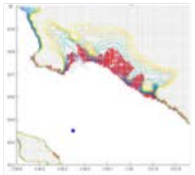
PAIR - Probabilistic Asteroid Impact Risk



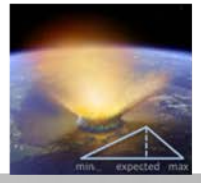
PHA Measurements
- H-magnitude
- Albedo
- Orbital trajectory
- Asteroid class
- Composition

Impact Parameters
- Diameter
- Density
- Strength
- Luminous efficiency
- Velocity
- Entry angle
- Azimuth angle
- Impact coordinates

Local Damage
(gridded pop. within largest blast/thermal damage area)

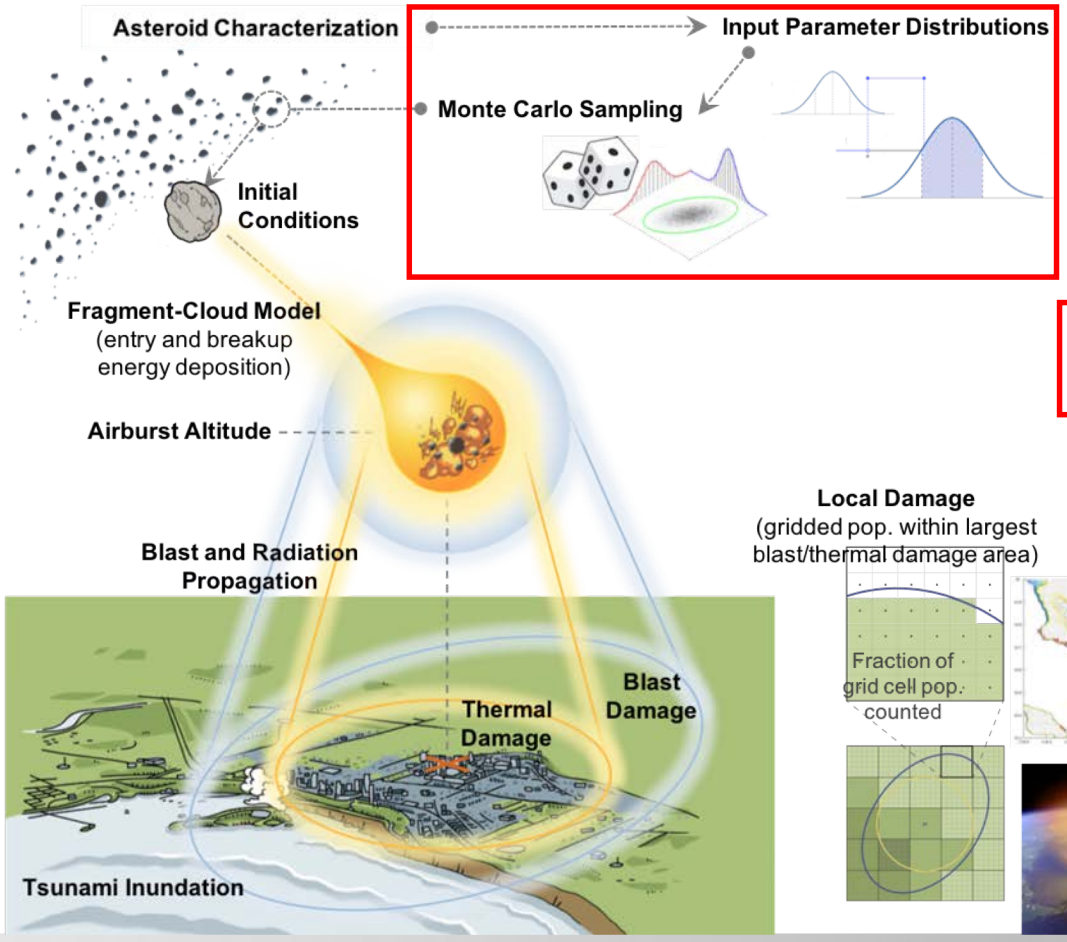


Tsunami
(gridded pop. affected within inundated areas)



Global Effects
(% world pop. affected by climatic effects)

Probabilistic Asteroid Impact Risk



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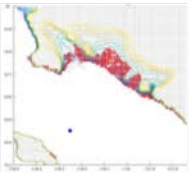

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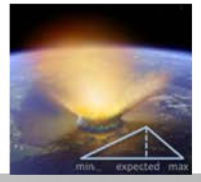
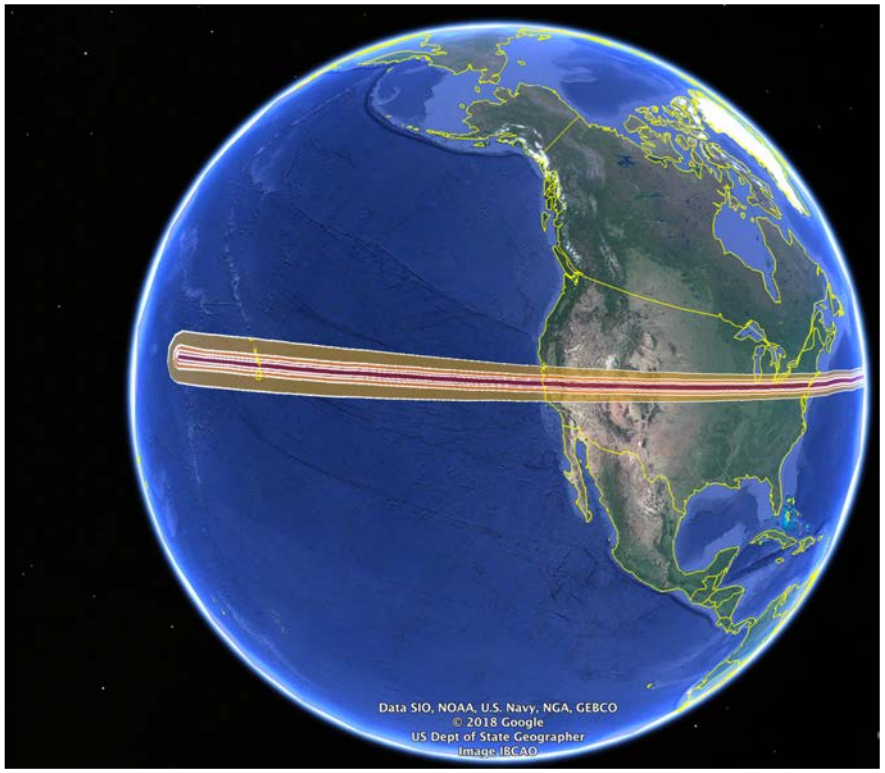


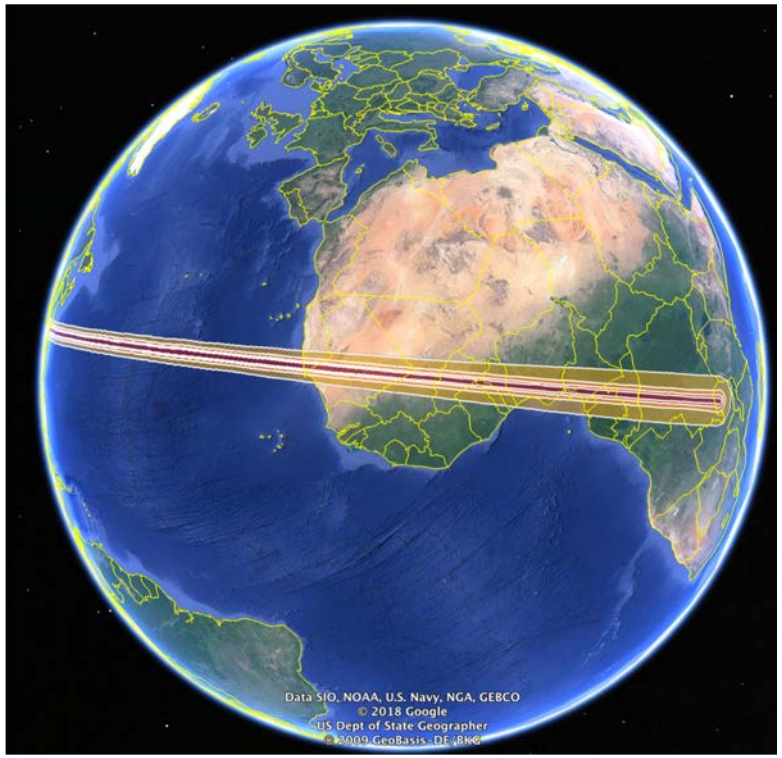
Global Effects
(% world pop. affected by climatic effects)

Problem Description

- Want to provide complete risk representation
- **Asteroid Impact Risk = Impact Probability × Impact Consequences**
- Two schools of thought to obtain asteroid impact risk:
  - Run Monte Carlo simulations that sample statistical distributions
    - Might not cover every binned permutation
    - Result is a statistically representative risk description
    - No requirement to keep track of probability of each binned permutation
  - OR, Run every binned permutation once with knowledge how likely it is
    - Covers every binning
    - Requires keeping track of binned permutation probability
- What is better depends on what needs to be shown

What is an Impact Corridor?



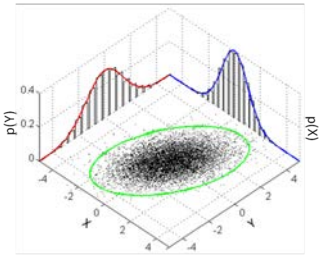


What is an Impact Corridor?

JPL Small Bodies Database / HORIZONS

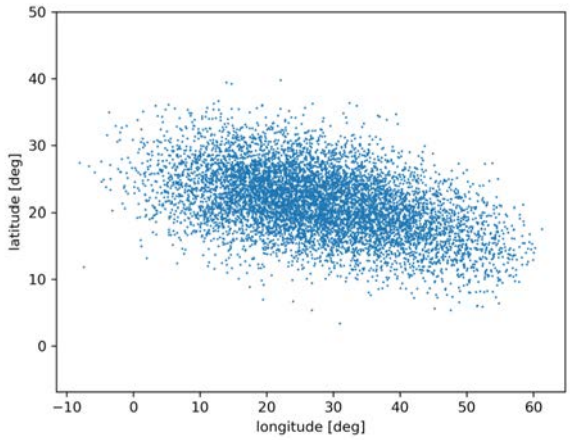
```
EPOCH= 2458705.5
 EC= .5341447408222021  QR= .8940998581953564  TP= 2458645.8671281013136
 OM= 38.42485188856197  W = 226.7149408523268  IN= 17.99750929335642
 SRC=  5.768451674867575E-8 -5.429221585179013E-8  1.665391272106021E-8
      -3.515853343386151E-8  6.096586464133849E-9  1.187423629017885E-6
       1.589963955676750E-8 -1.861211717613133E-9  1.529831485714655E-6
       3.559549562383798E-8  1.086105369009639E-9 -1.778017061376463E-9
       1.037377603221587E-6 -5.181728129728535E-8  6.970915828799288E-8
       3.376633358153743E-7 -6.766740704099438E-8 -2.476395446030395E-6
      -1.032982624889745E-7  1.085387188165522E-7  1.852119950231313E-7
 H= 21.7 G= 0.15
```

Sampling orbital states according to state covariances

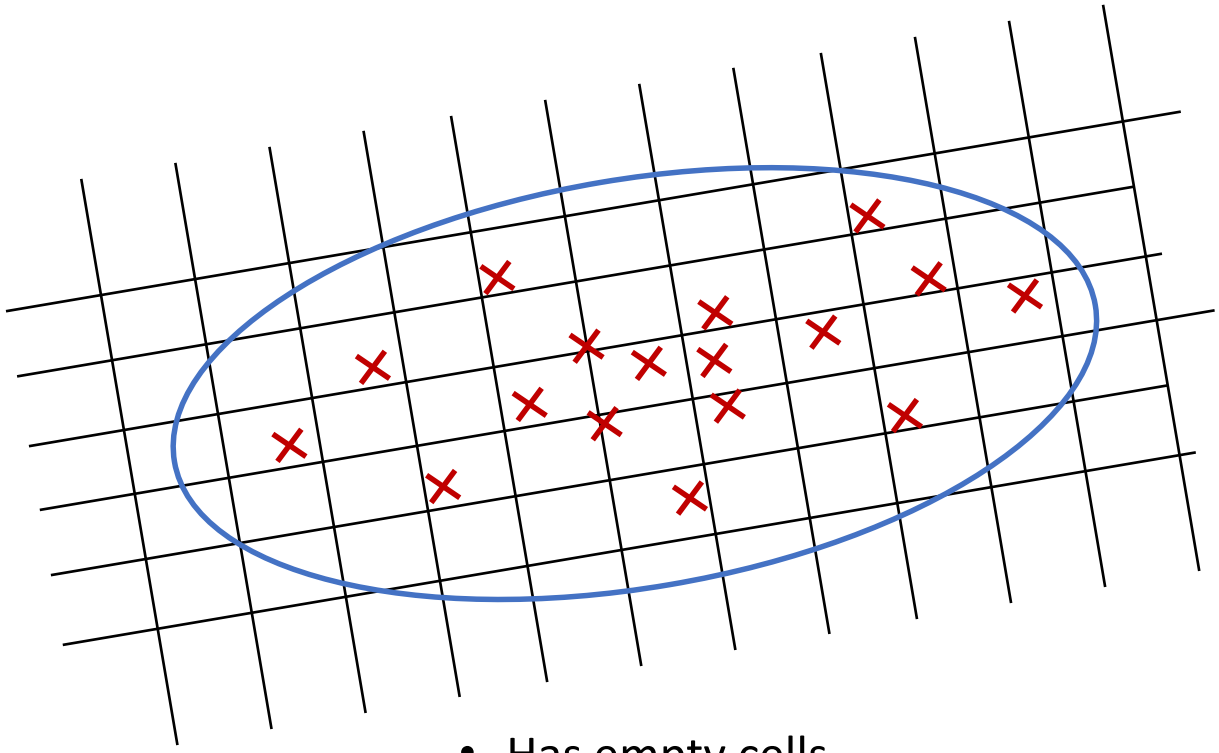


$$\Sigma = \begin{bmatrix} \sigma_e^2 & p_{12}\sigma_e\sigma_{r_p} & p_{13}\sigma_e\sigma_{t_p} & p_{14}\sigma_e\sigma_\Omega & p_{15}\sigma_e\sigma_\omega & p_{16}\sigma_e\sigma_i \\ p_{21}\sigma_{r_p}\sigma_e & \sigma_{r_p}^2 & p_{23}\sigma_{r_p}\sigma_{t_p} & p_{24}\sigma_{r_p}\sigma_\Omega & p_{25}\sigma_{r_p}\sigma_\omega & p_{26}\sigma_{r_p}\sigma_i \\ p_{31}\sigma_{t_p}\sigma_e & p_{32}\sigma_{t_p}\sigma_{r_p} & \sigma_{t_p}^2 & p_{34}\sigma_{t_p}\sigma_\Omega & p_{35}\sigma_{t_p}\sigma_\omega & p_{36}\sigma_{t_p}\sigma_i \\ p_{41}\sigma_\Omega\sigma_e & p_{42}\sigma_\Omega\sigma_{r_p} & p_{43}\sigma_\Omega\sigma_{t_p} & \sigma_\Omega^2 & p_{45}\sigma_\Omega\sigma_\omega & p_{46}\sigma_\Omega\sigma_i \\ p_{51}\sigma_\omega\sigma_e & p_{52}\sigma_\omega\sigma_{r_p} & p_{53}\sigma_\omega\sigma_{t_p} & p_{54}\sigma_\omega\sigma_\Omega & \sigma_\omega^2 & p_{56}\sigma_\omega\sigma_i \\ p_{61}\sigma_i\sigma_e & p_{62}\sigma_i\sigma_{r_p} & p_{63}\sigma_i\sigma_{t_p} & p_{64}\sigma_i\sigma_\Omega & p_{65}\sigma_i\sigma_\omega & \sigma_i^2 \end{bmatrix}$$

Propagating sampled states to impact

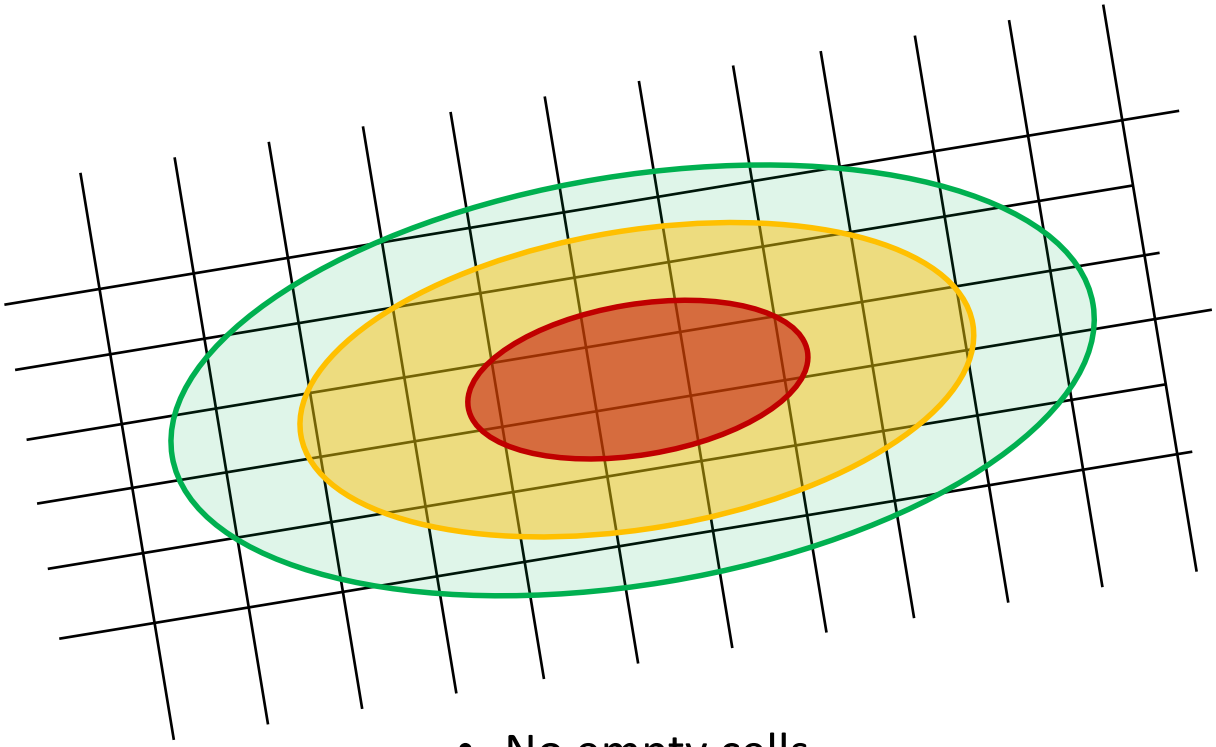


Gridded Corridor Visualization



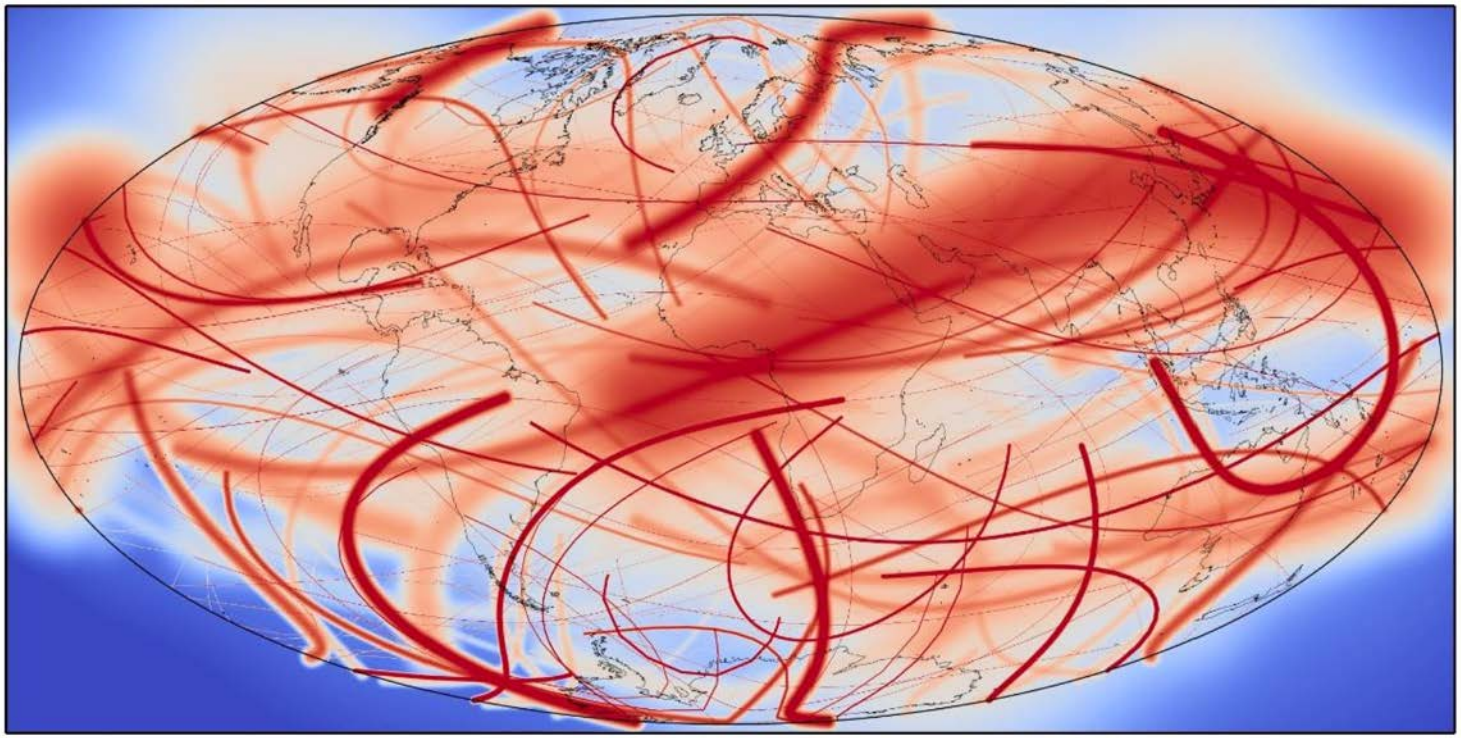
- Has empty cells
- Still provides accurate numerical risk representation

Gridded Corridor Visualization



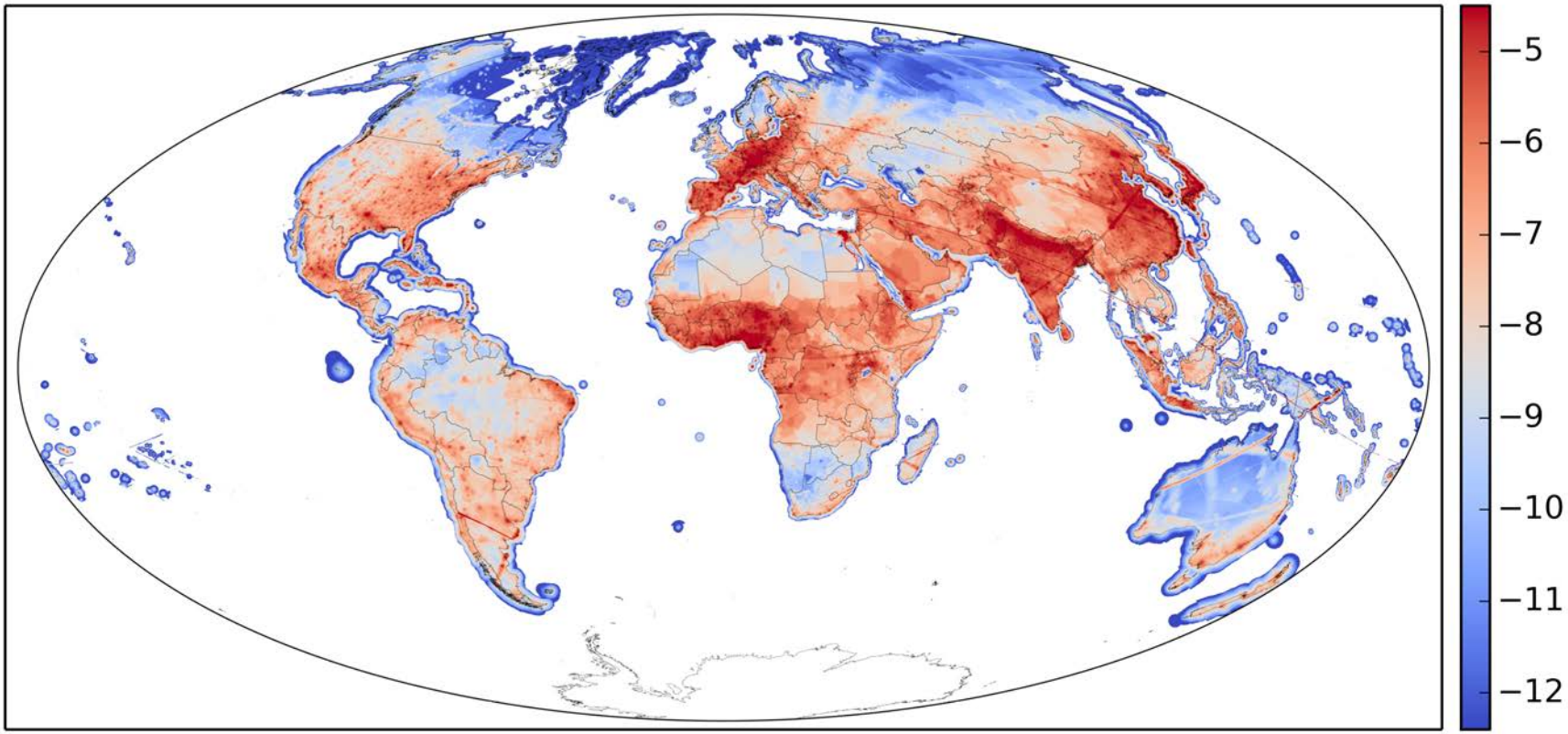
- No empty cells
- Good for risk visualization

Impact Probability Distributions



C. Rumpf, H. Lewis, P. Atkinson, The global impact distribution of Near-Earth objects, Icarus, 2016

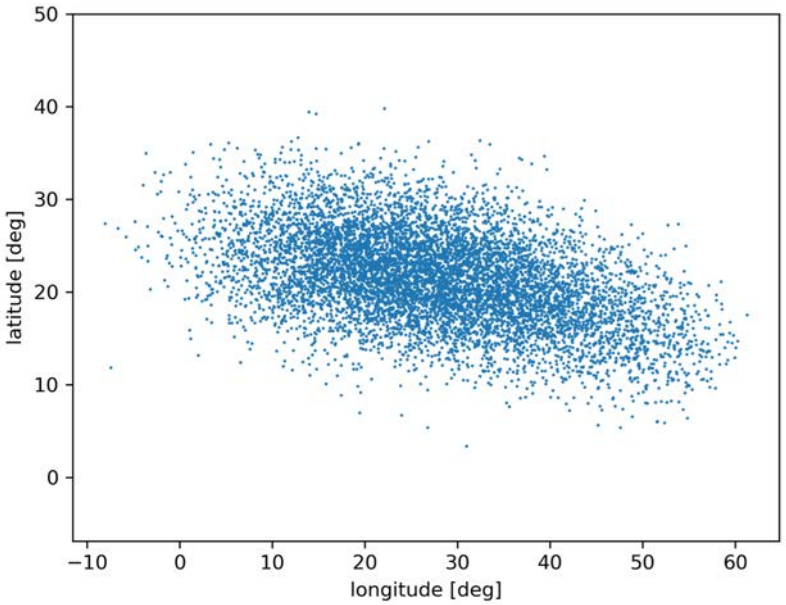
Complete Risk Visualization



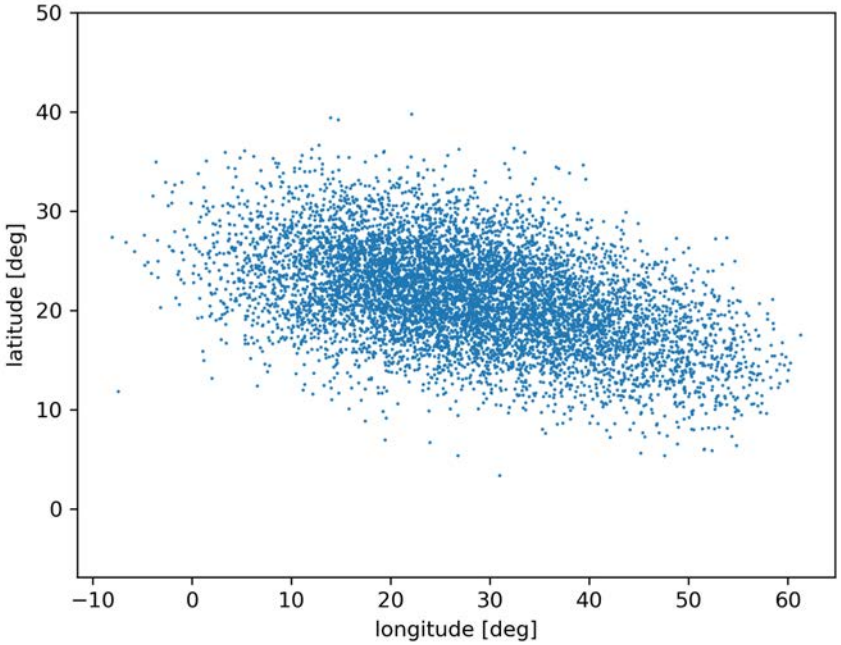
C. Rumpf, H. Lewis, P. Atkinson, Global Impact Risk of Known Asteroids, IEEE Aerospace Conference, 2015

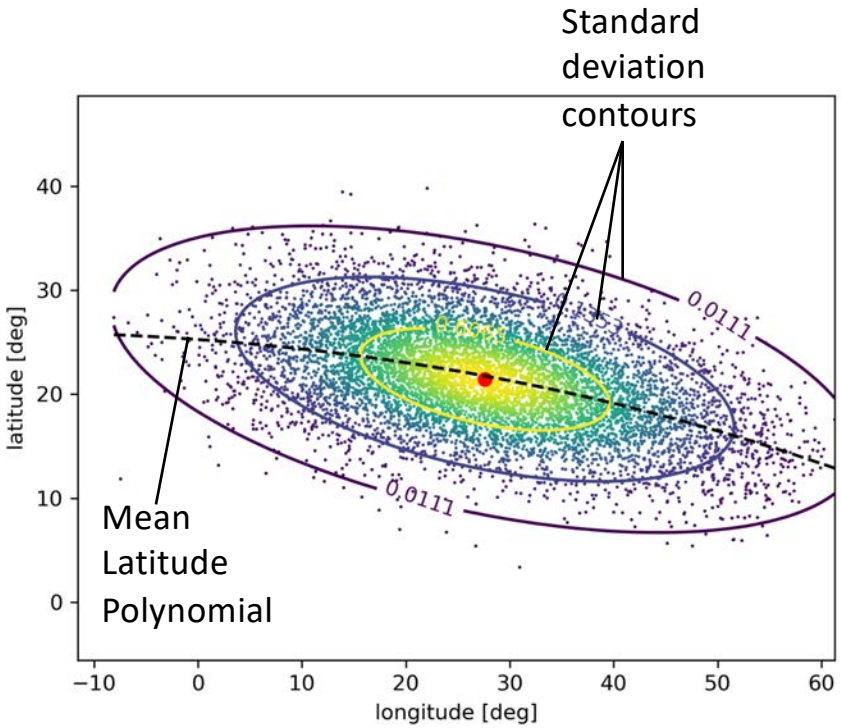
Goal

- For follow on risk analysis we need continuous impact probability
- Obtain continuous impact probability distribution from impactor sample



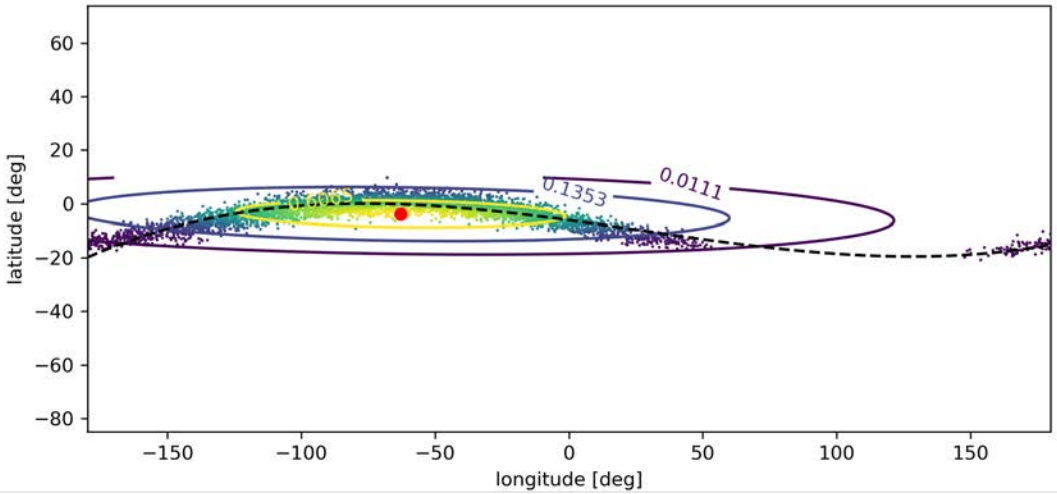
Method 1: Fit a Bivariate-Gaussian

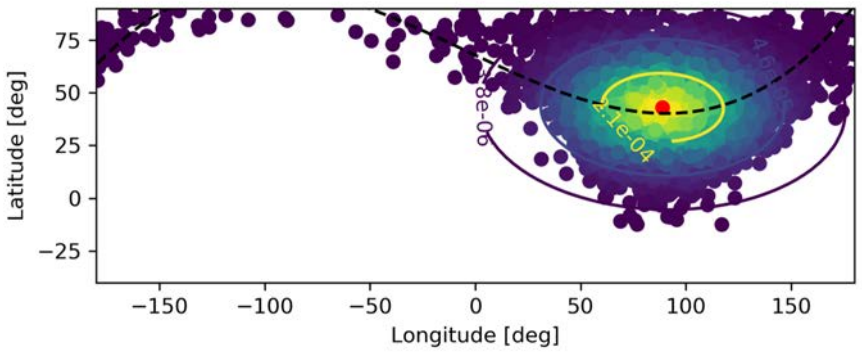




Very good representation of simple elliptical impact corridor shapes

Complex Shape Examples

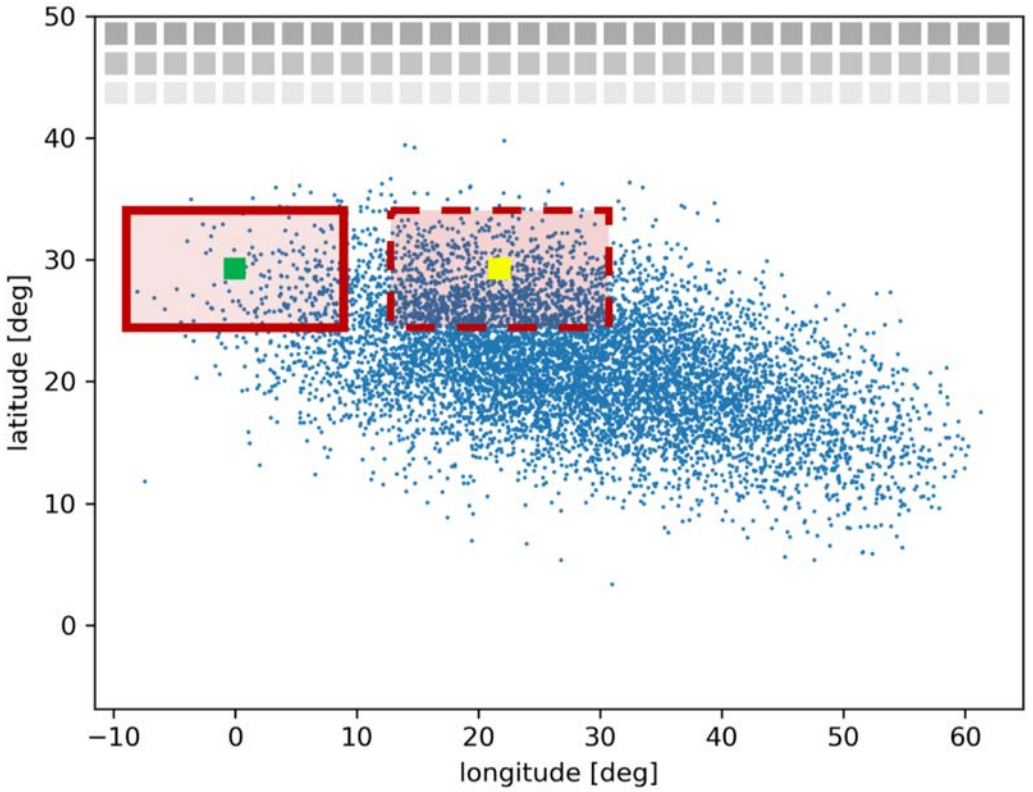




Method 2: Numerical Density Estimation

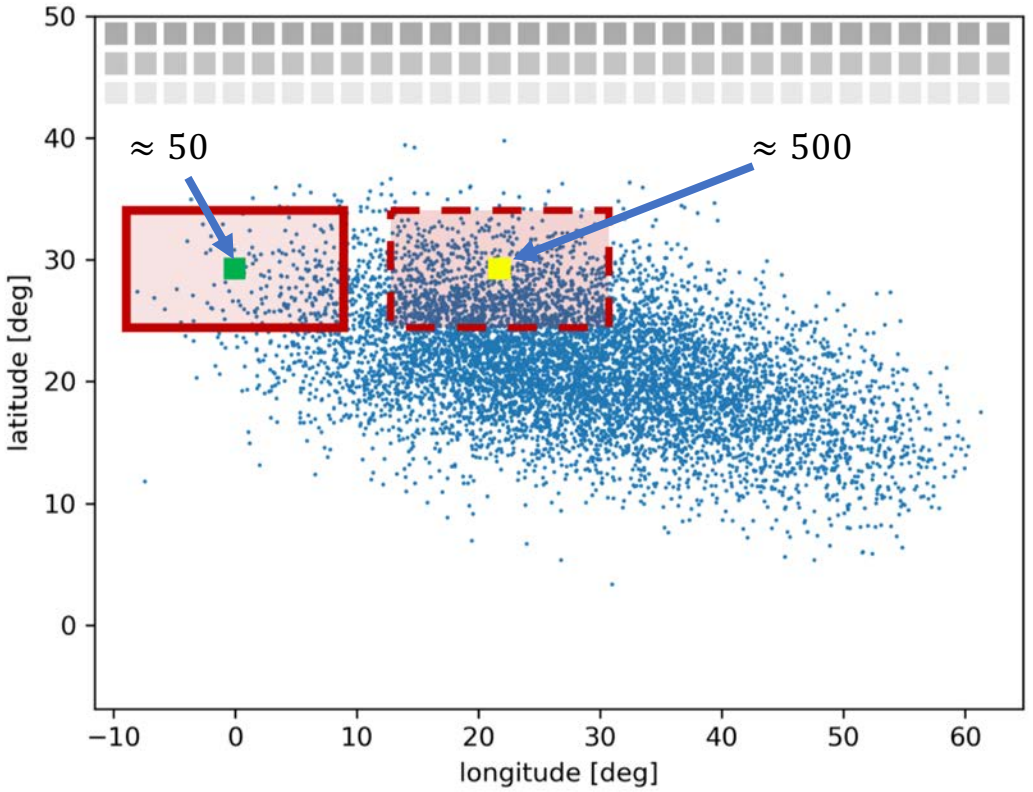
- A scanning window moves over grid
- Number of impactors in window is assigned to grid cell

- Issues: Sensitive to window size
  - Small → sparse sampling
  - Large → corridor "fattening"

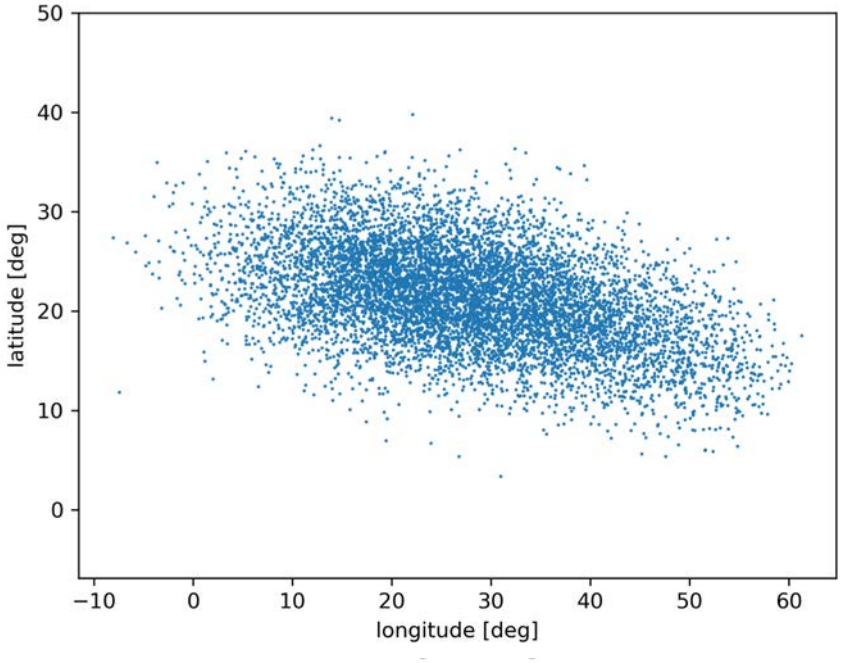


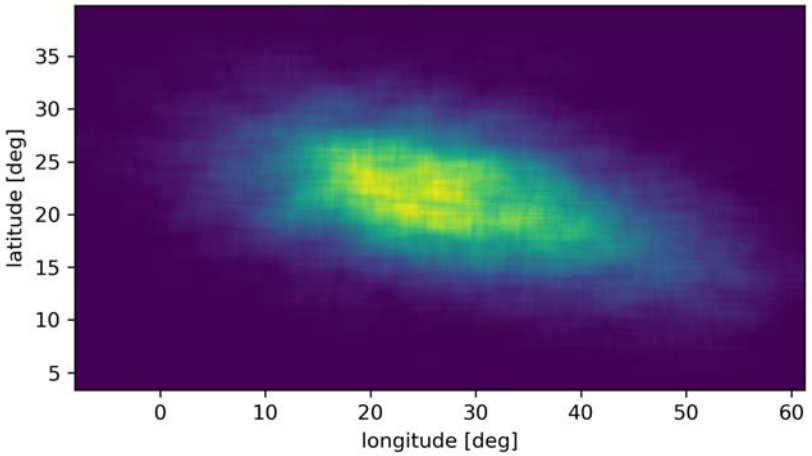
Method 2: Numerical Density Estimation

- A scanning window moves over grid
- Number of impactors in window is assigned to grid cell
- Robust against any corridor shape
- Issues: Sensitive to window size
  - Small → sparse sampling
  - Large → corridor “fattening”

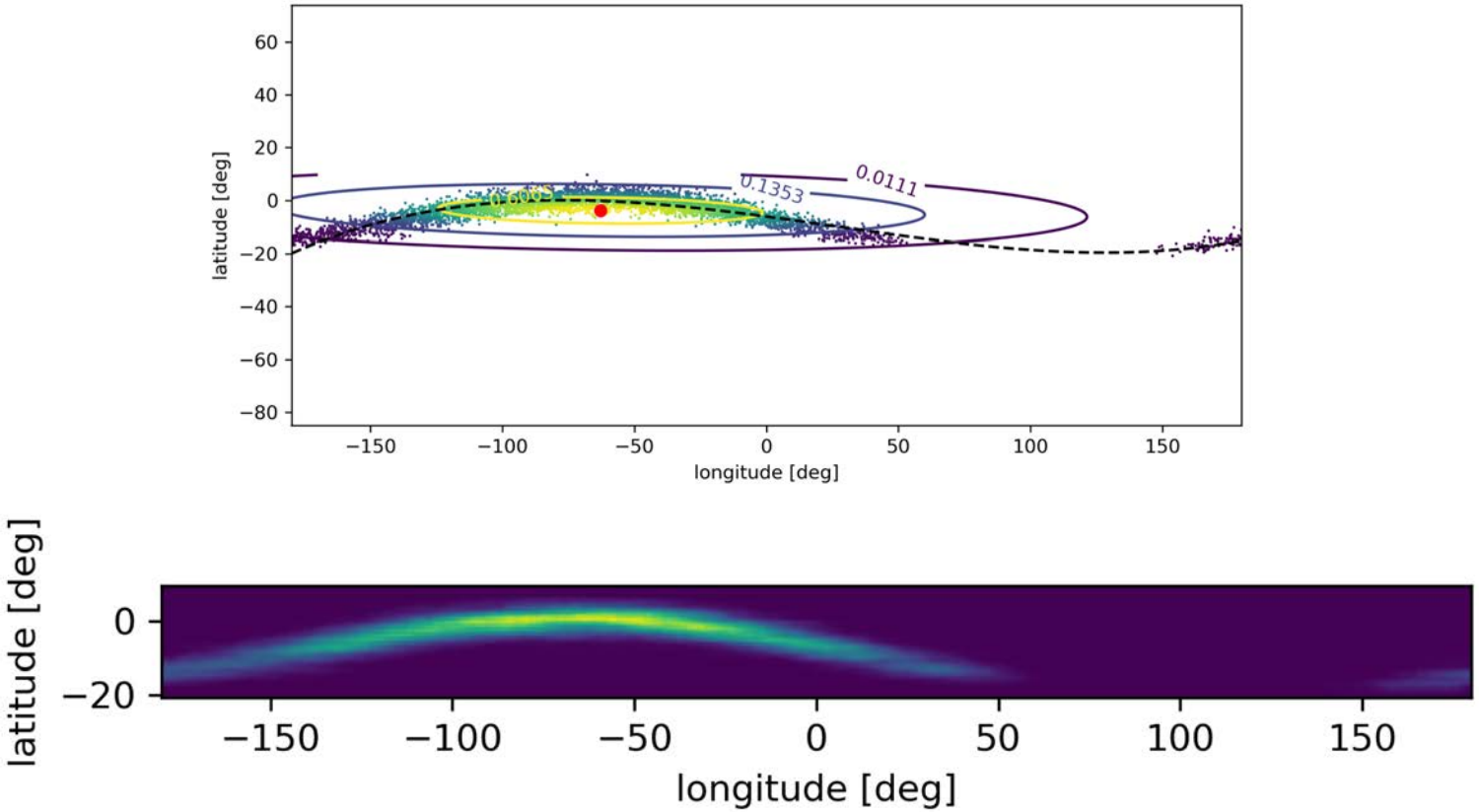


Numerical Density Estimation Example 1

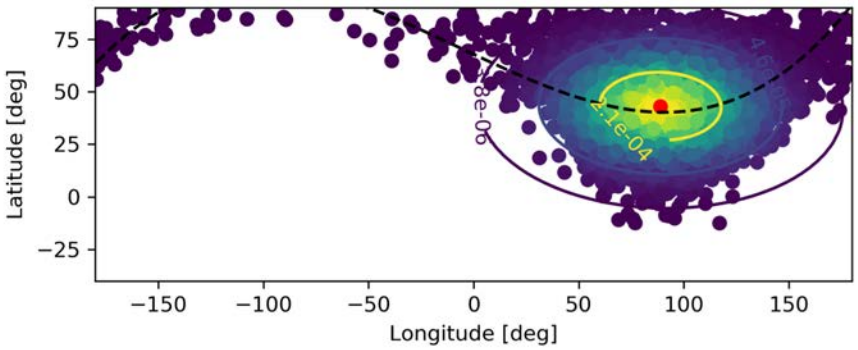


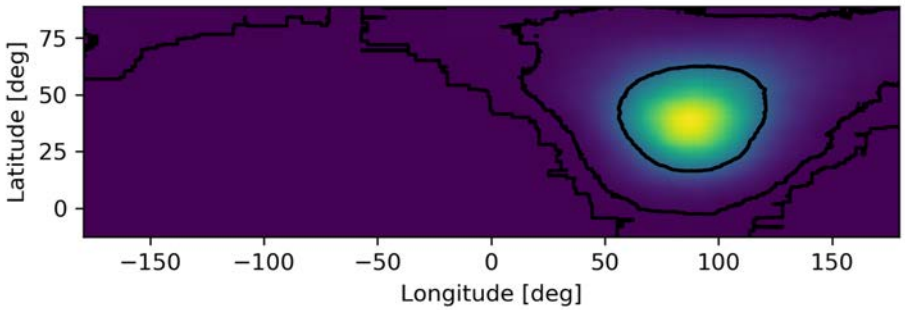


Numerical Density Estimation Example 2



Numerical Density Estimation Example 3



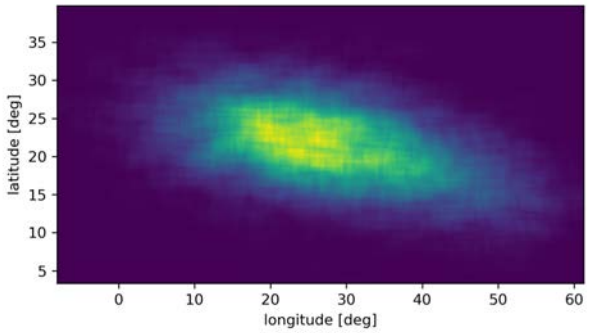


Discussion

Numerical Approach

+ Robust to any geometry
+ Good for risk assessment with poor orbit accuracy → large impact corridors

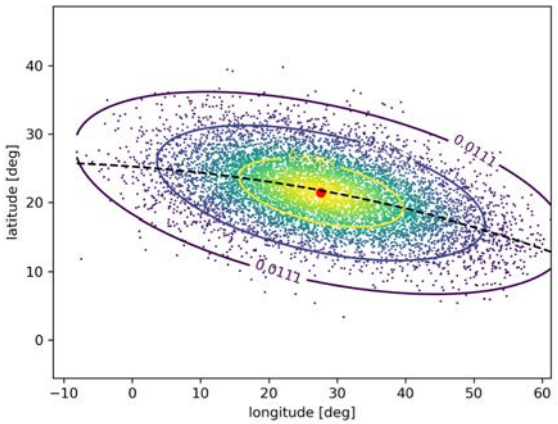
- Higher computational cost
- No analytical description
- Sensitive to window size



Analytical Approach

+ Analytical description
+ Fast execution
+ Good for risk assessment with good orbit accuracy → small impact corridor

- Not applicable to complex shapes



Conclusions

- Problem description
  - **Numerical risk** versus **risk visualization**
  - Continuous impact probability distribution is beneficial for risk visualization
- Two methods of calculating spatial impact probability distributions
  - Analytical is fast and more suited for elliptical geometries
  - Numerical is expensive but robust to complex geometries
- Adequate representation helps to communicate risk

Thank You For Your Attention

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