Towards a Perturbation Assessment Tool
Developing a Method for Agile Prediction of Expected Impact Perturbations for Comparison to On-Orbit Data

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- Risk assessment process predicted ~24-160 perturbations (Varies per assumed MEF)
  - => **Seven observed**

- Predicted 11.3 MMOD failures
  - => **2 reported**

- This dataset (7 events) fits well with 'sphere with voided mass' assumption and MEF=2
  - Reality: debris various shapes/sizes, MEF varies

- **NESC recommendation: collect additional data on perturbations**
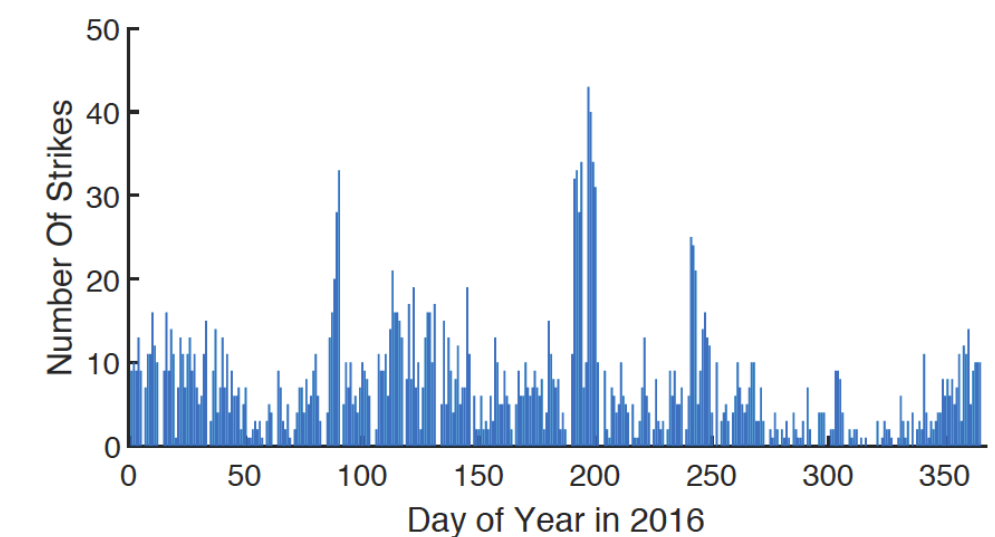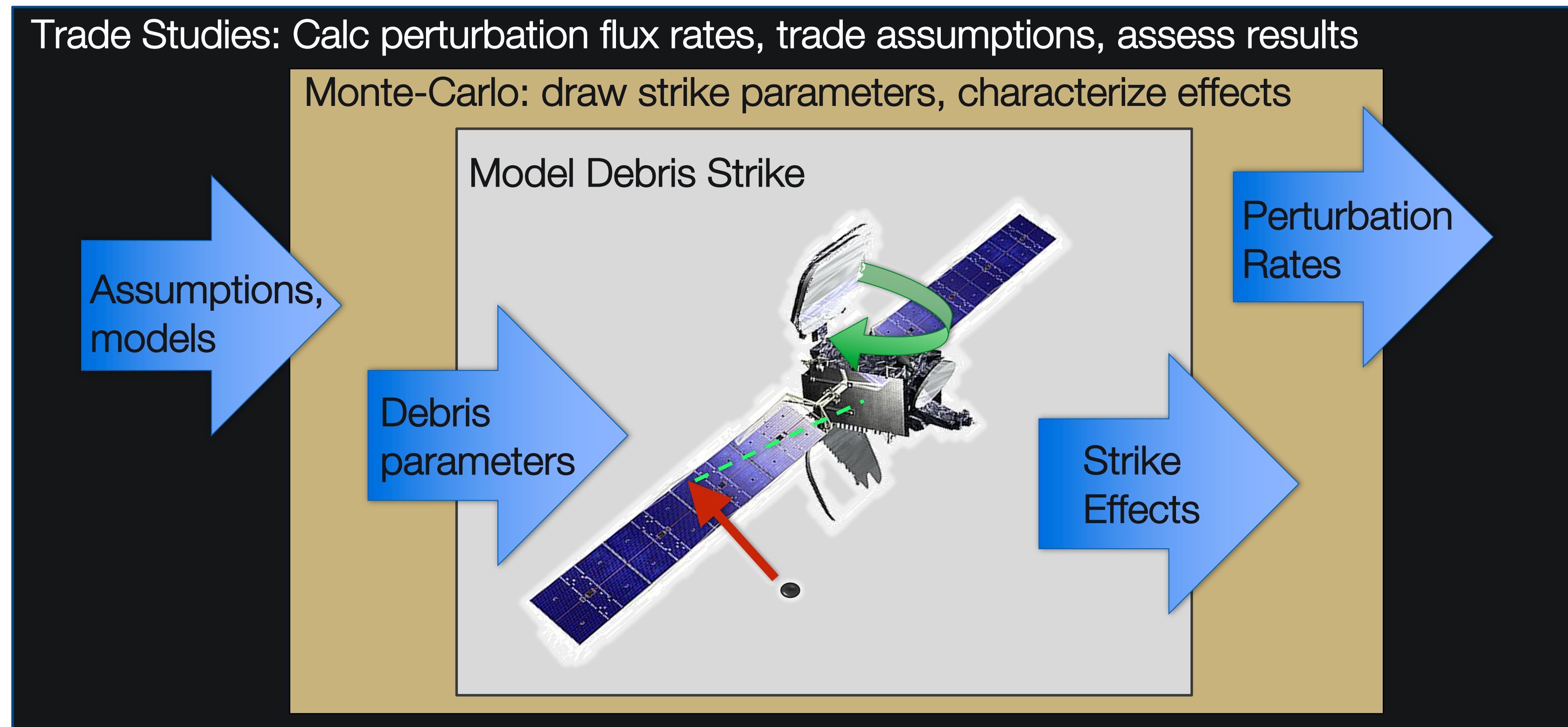 - What to do with data? How to modernize legacy methods?
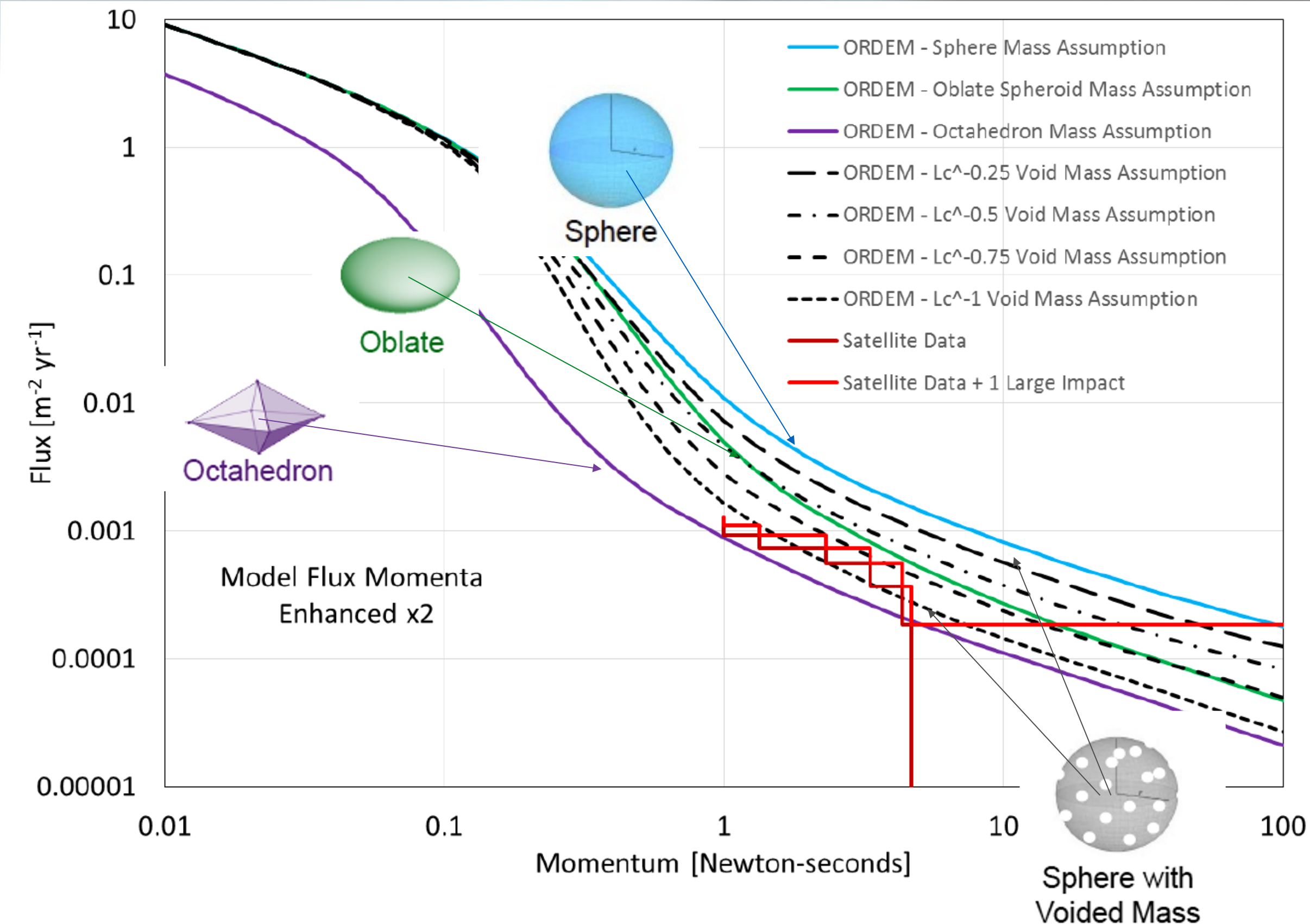
Source: Mike Squire, NASA Langley, "Evaluating Micrometeoroid and Orbital Debris Risk Assessments Using Anomaly Data"
https://ntrs.nasa.gov/api/citations/20170010258/downloads/20170010258.pdf

Need tool to generalize perturbation rate assessment problem:
Trade uncertain variables and assess impact on results

- Goals:

  - Generalize perturbation rate assessment problem for different satellites/orbits

  - Agile to trade assumptions, Monte-Carlo draw from distributions vs. assuming one value for all debris

  - Assess how much perturbation rate varies based on assumptions, trade and test various models

 - (Some day): Compare to on-orbit datasets and use to tune model assumptions
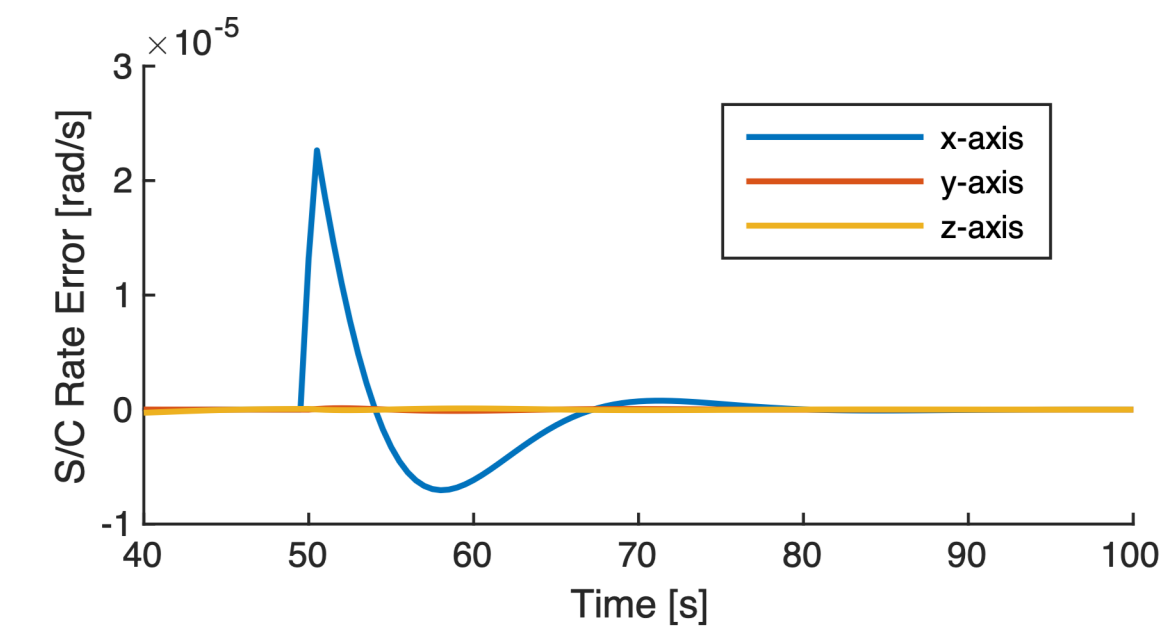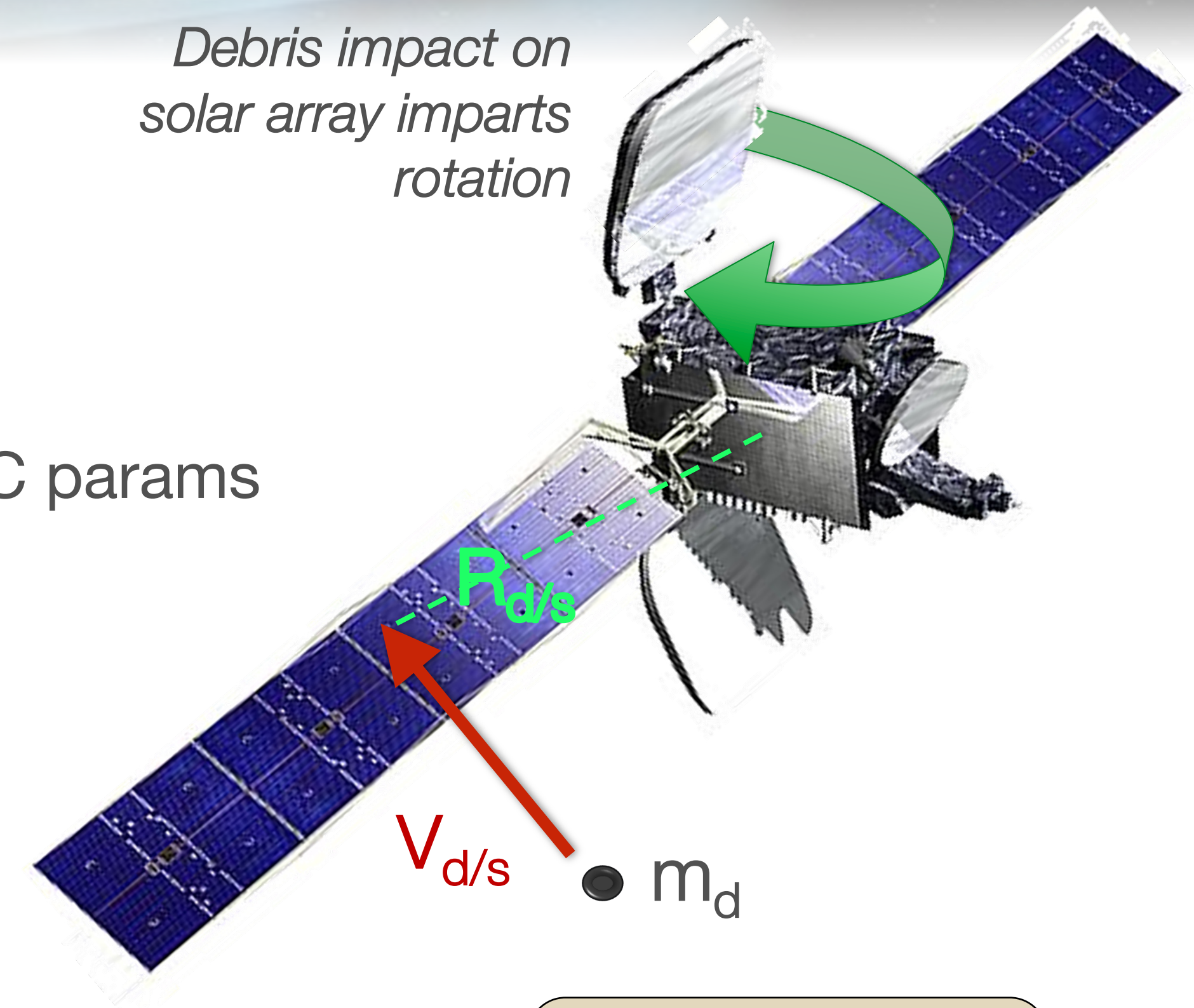
Modeling Debris Strike

- Calculate measurable effects of strike
  - Imparts momentum to satellite
  - Linear momentum measured through orbit changes
  - Angular momentum (DH) measured via ACS telemetry

- Parameters: debris mass, MEF, relative velocity, strike location, S/C params

Debris impact on solar array imparts rotation

$R_{d/s}$

$V_{d/s}$ m_d
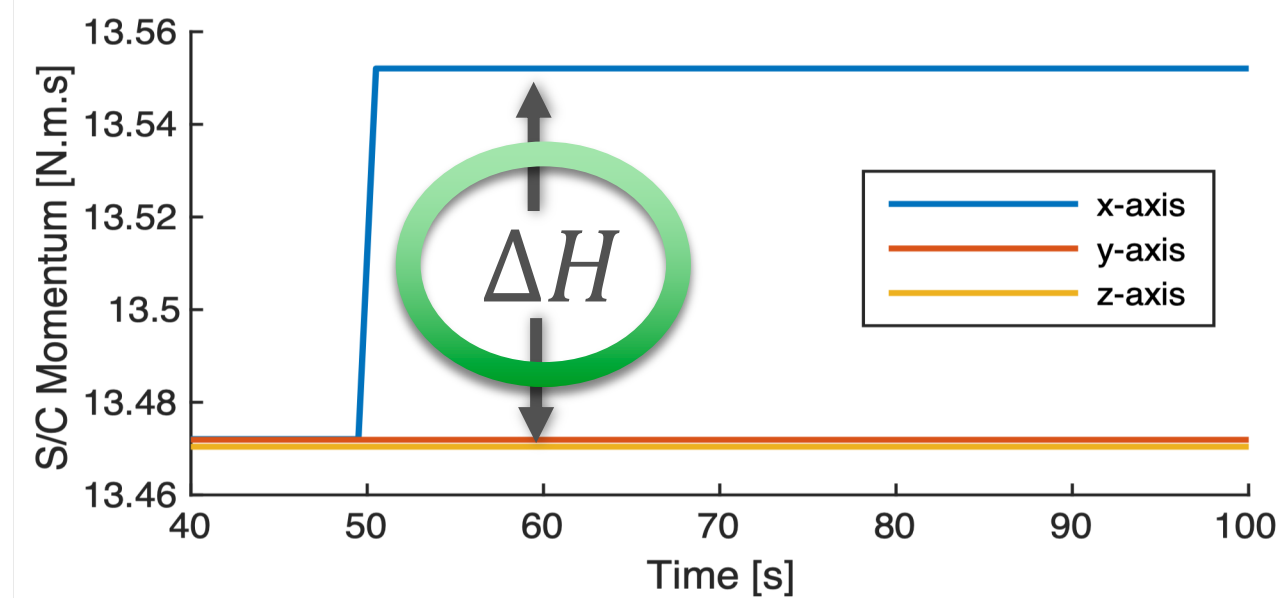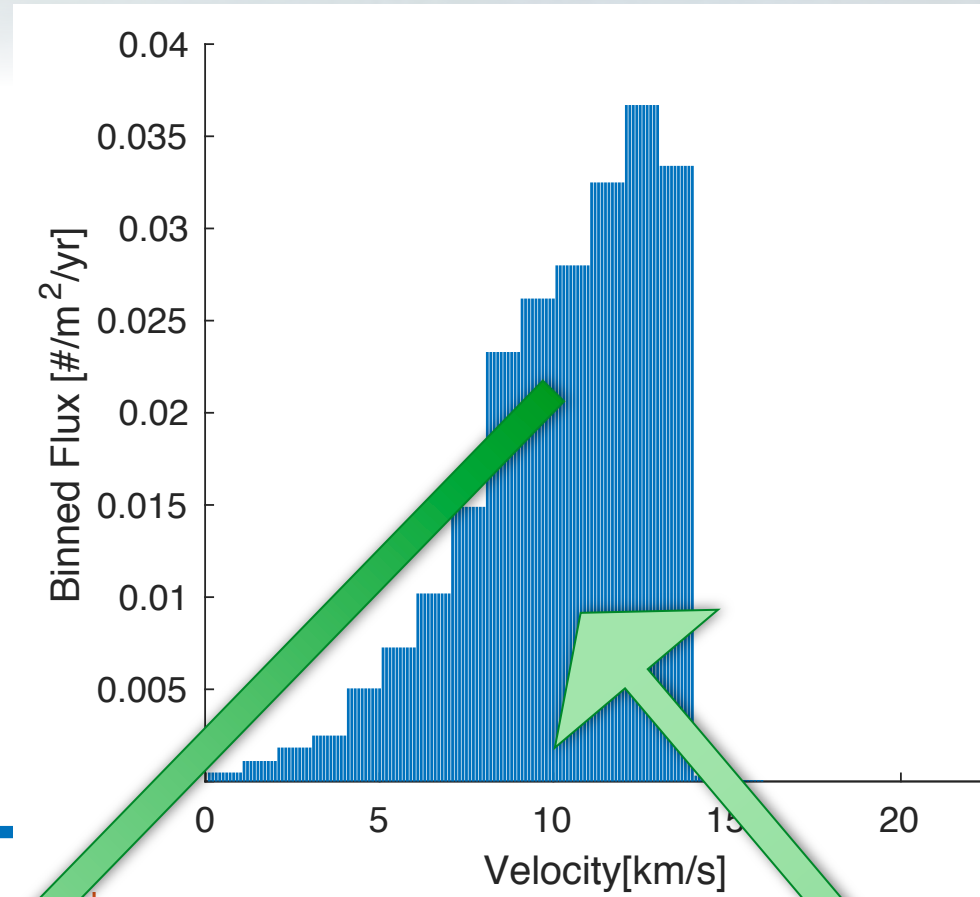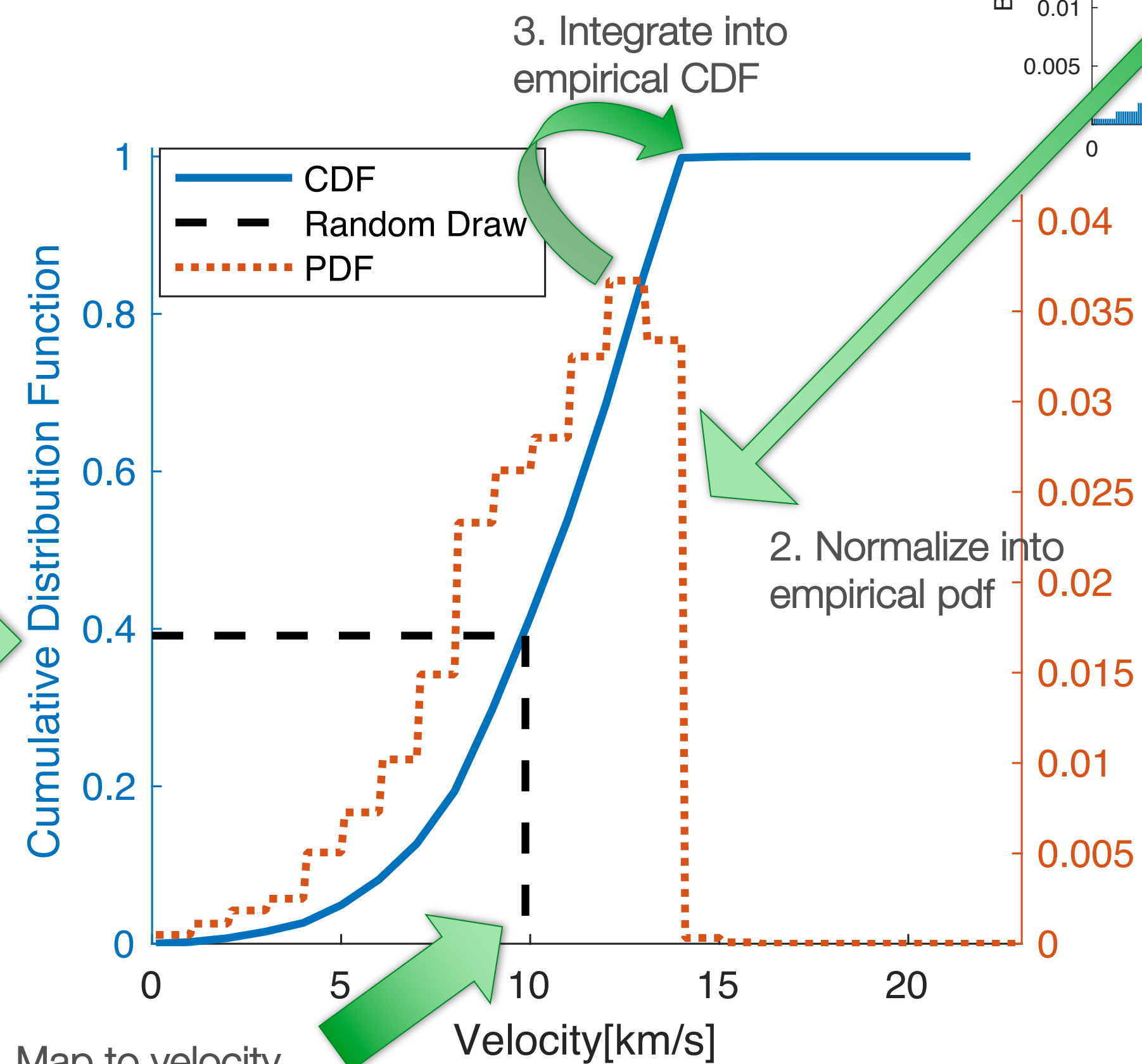
1.2 cm al sphere, 6.8 km/s

$$\boldsymbol{\Delta P = \beta m_d V_{d/s}}$$

$$\boldsymbol{\Delta V_s = \dfrac{\Delta P}{m_{\text{sat}}}}$$

$$\boldsymbol{\Delta H_s = R_{d/s} \times \Delta P}$$

MEF Test, Ernst-Mach-Institut

Credit: ESA

- Determine magnitude and direction
  - Use inverse transform sampling to draw from empirical distribution

3. Integrate into empirical CDF

4. Draw random number U(1,0)

2. Normalize into empirical pdf

1. Pull data from ORDEM files

5. Map to velocity representative of distribution

Source: NASA's ORDEM

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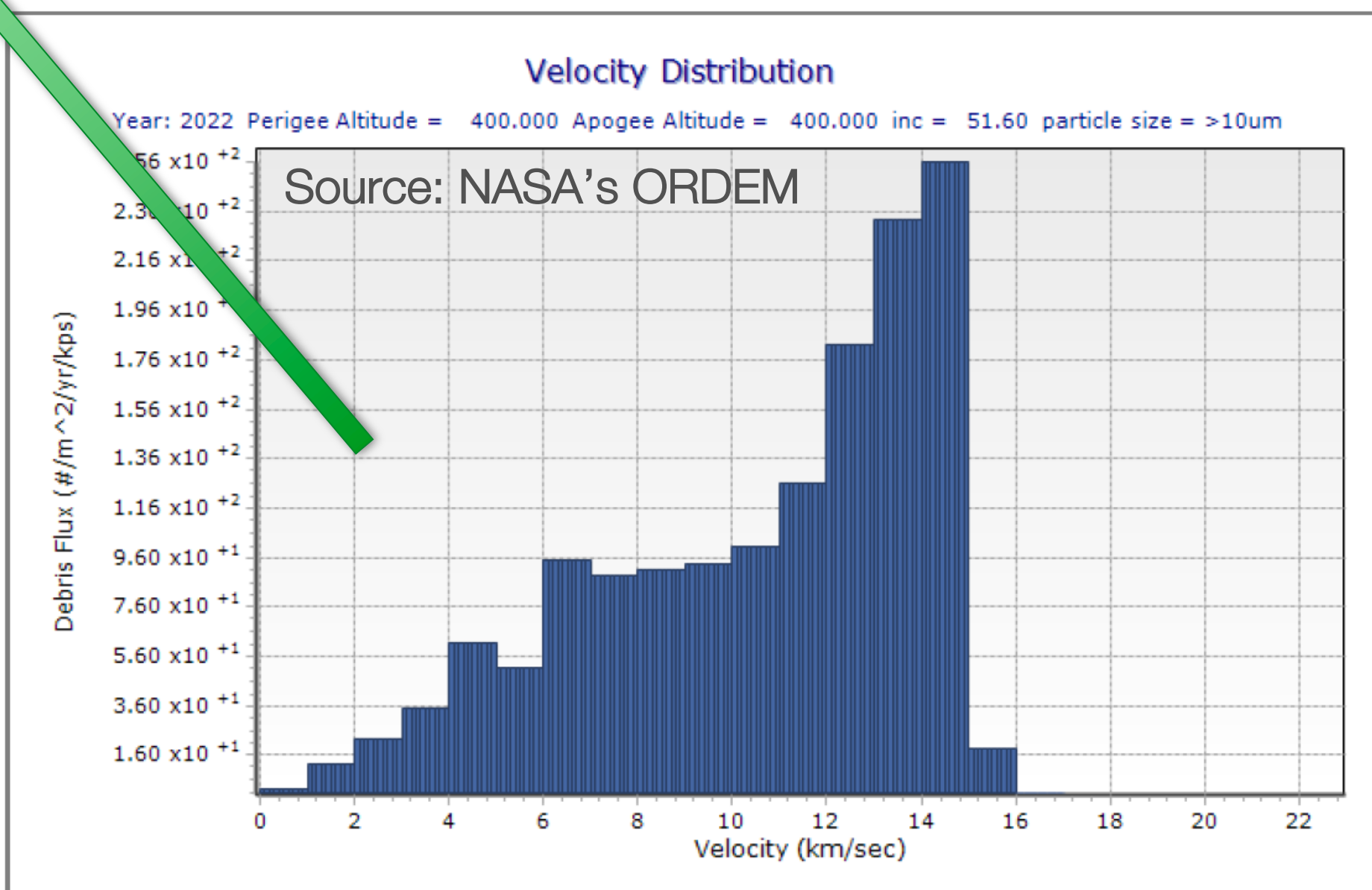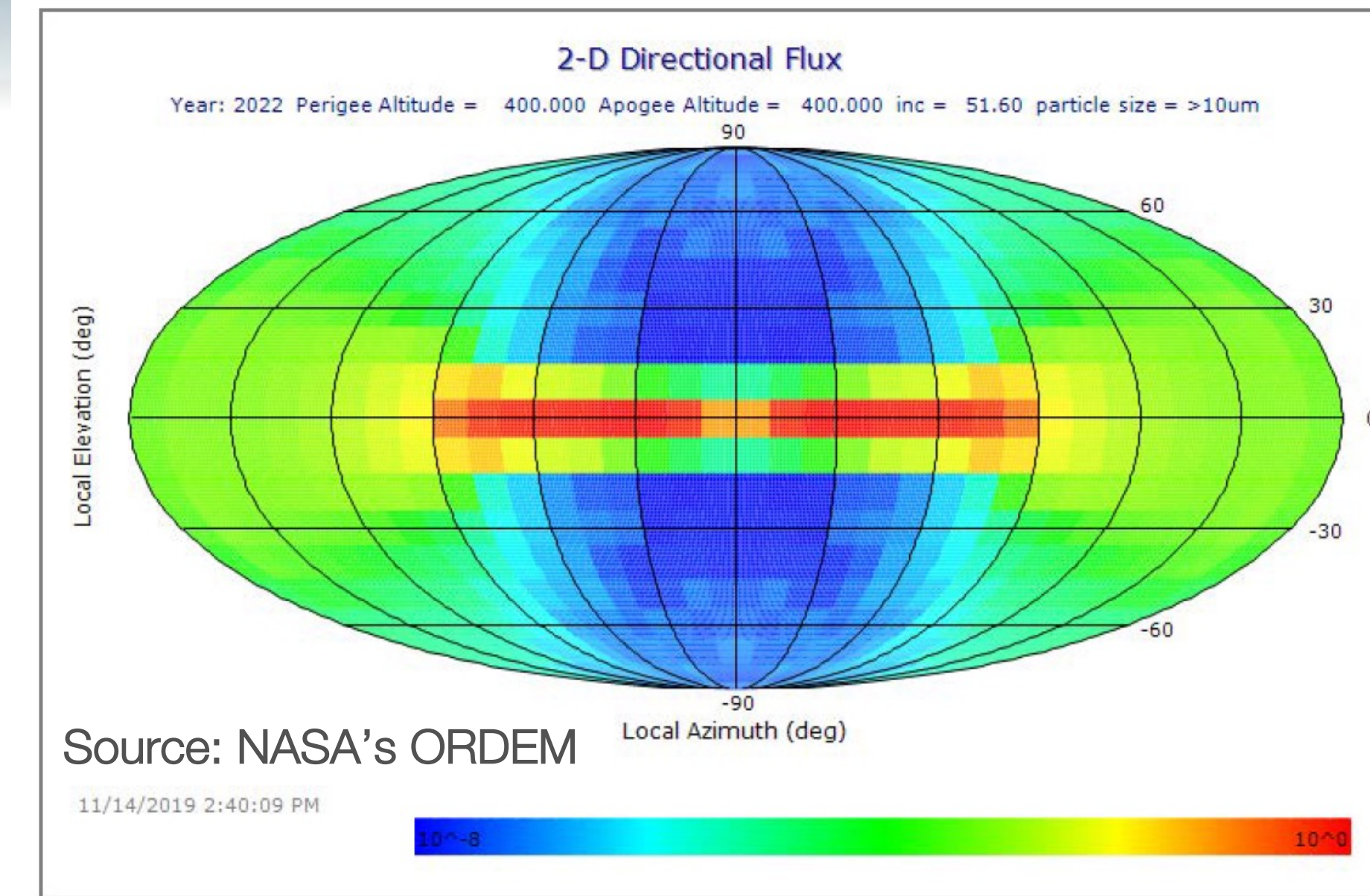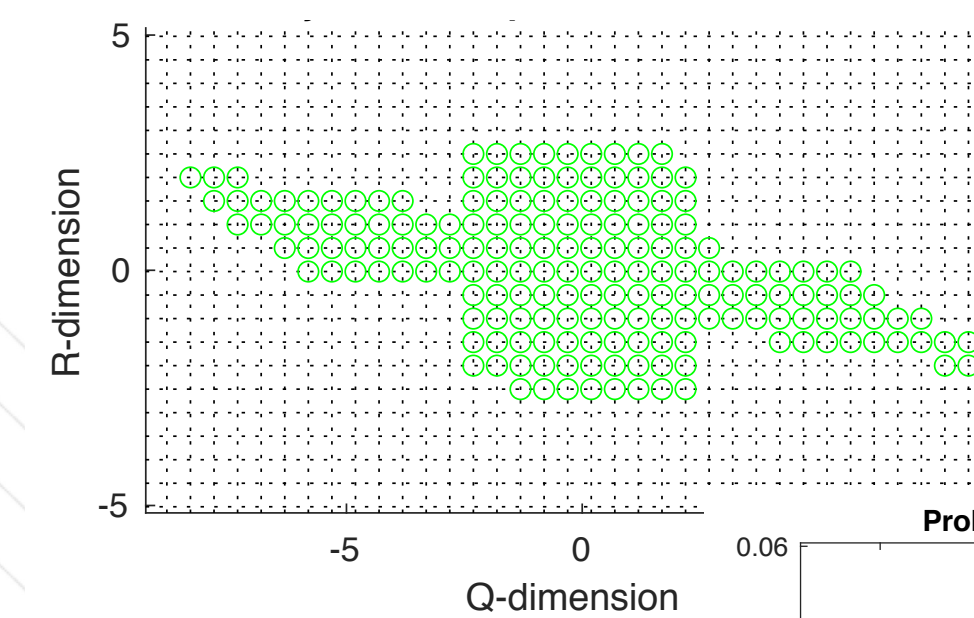
Randomizing Strike Location

- From velocity direction, know spacecraft orientation

- Create point cloud based on S/C dimensions
  - Previous efforts: assume every S/C 1 m^2, or build full CAD-like model
  - This effort: representative model from basic spacecraft dimensions
    - Quickly assess different spacecraft, could load more sophisticated point cloud

- Randomize strike location, can track solar array vs bus strike
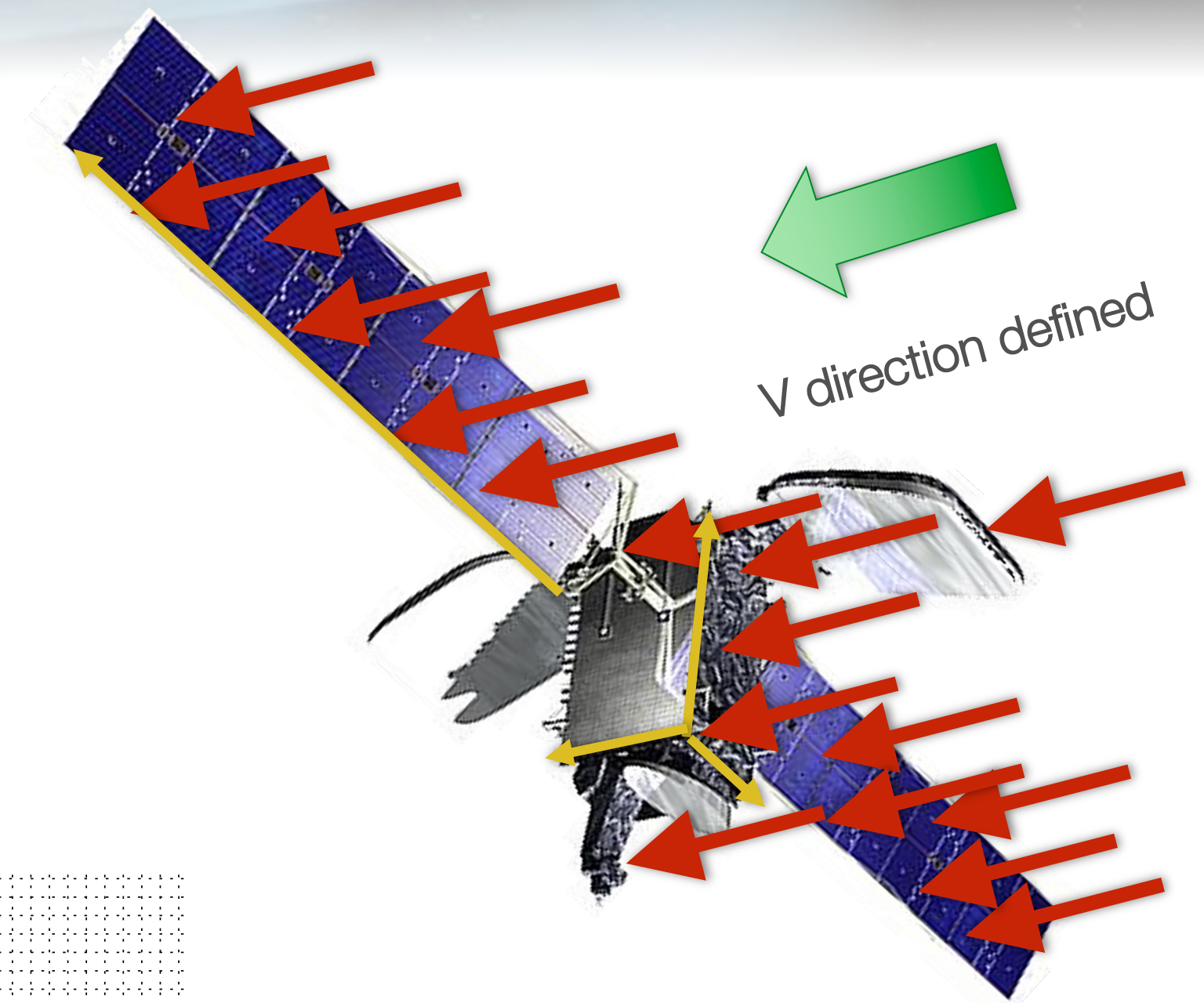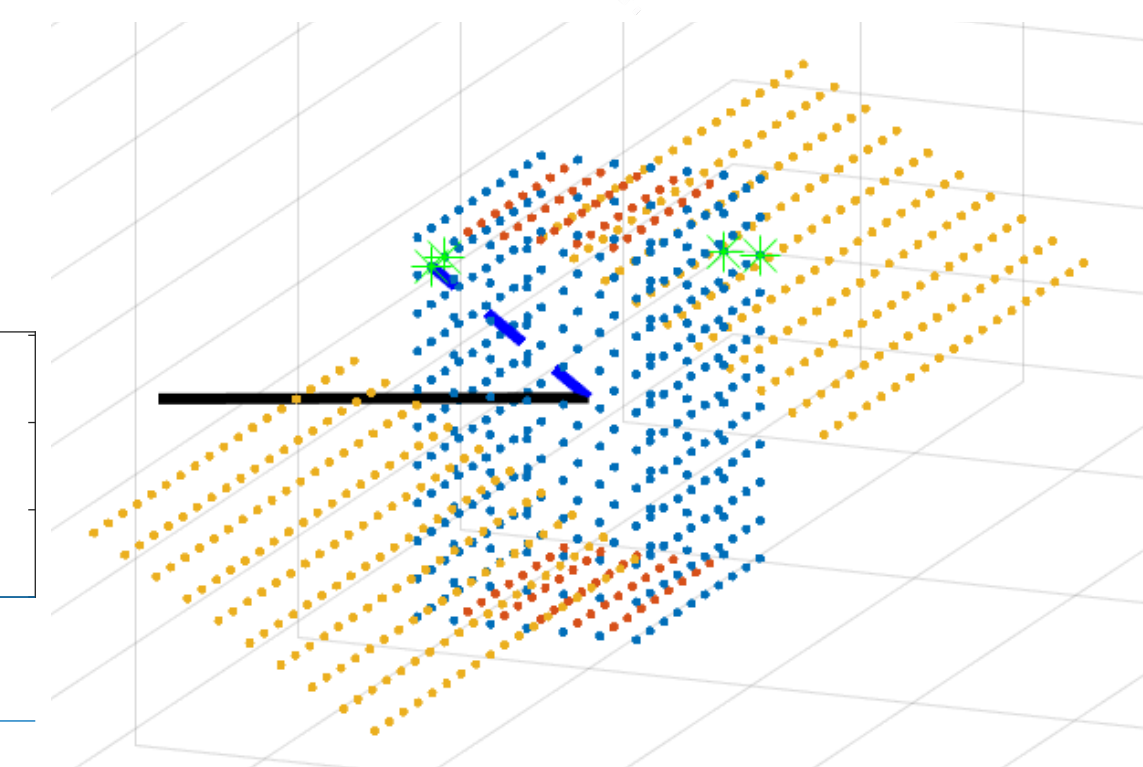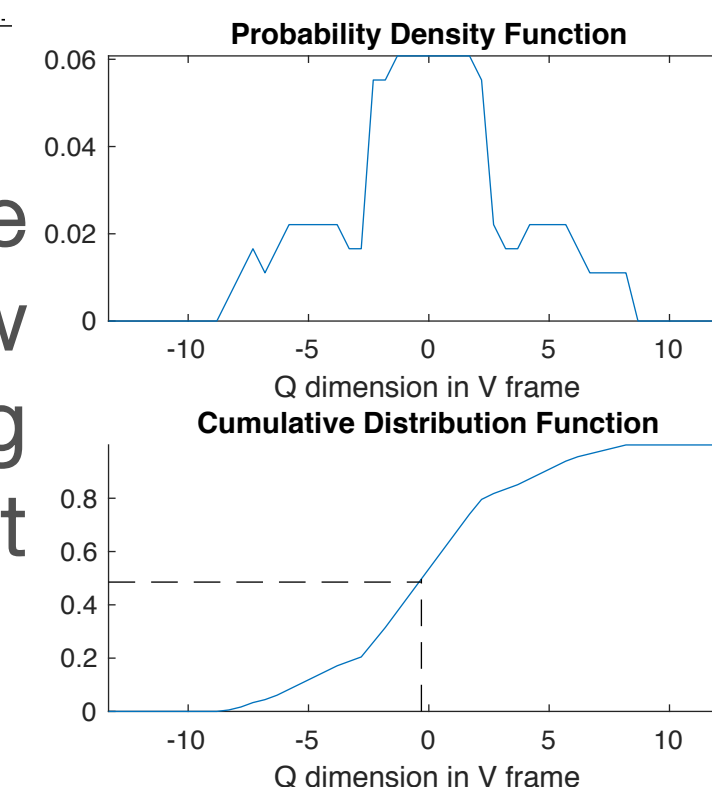
Generate point cloud from bus dimensions
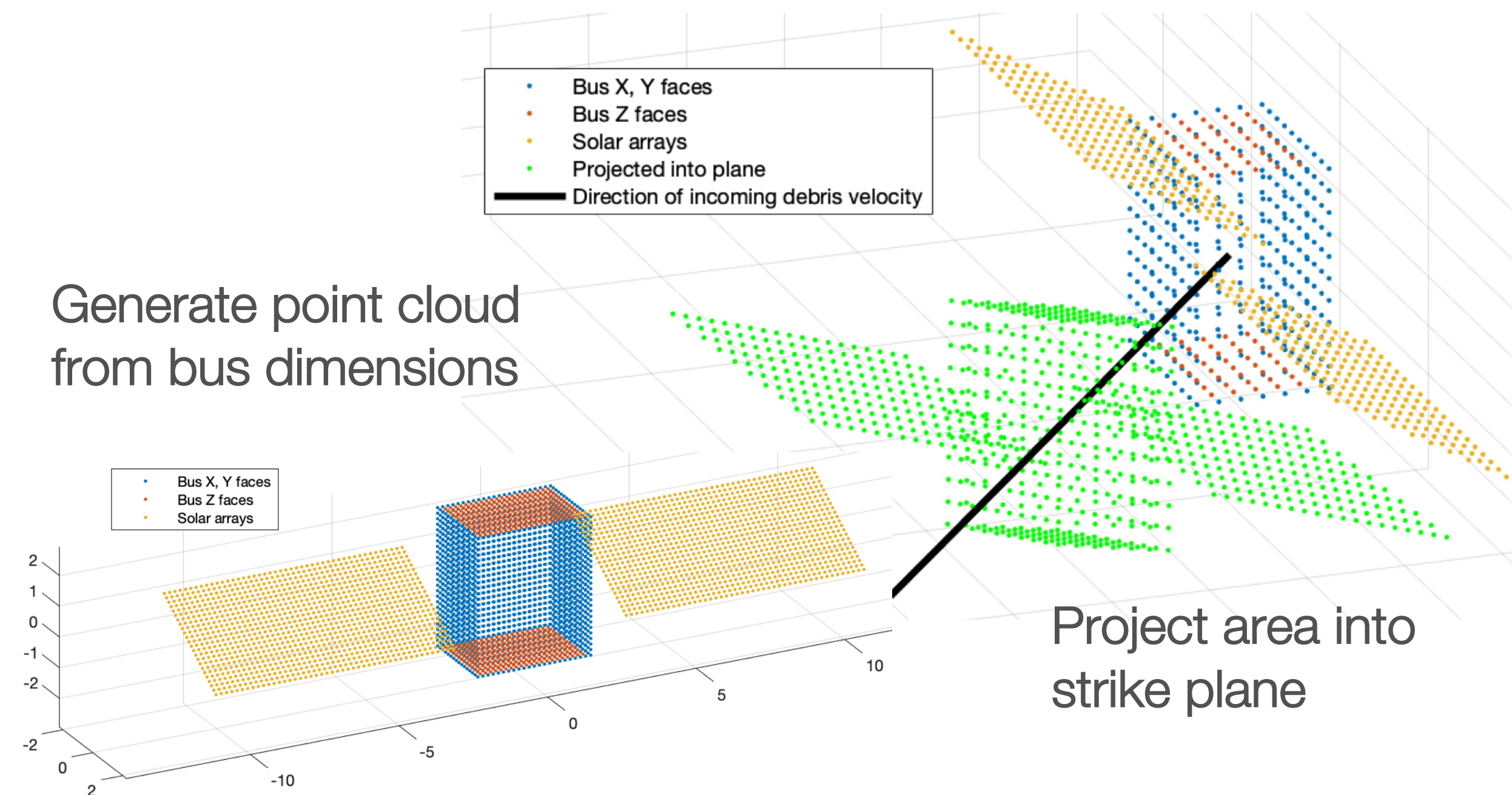
Project area into strike plane

Randomize strike location i.a.w likelihood of hitting each point
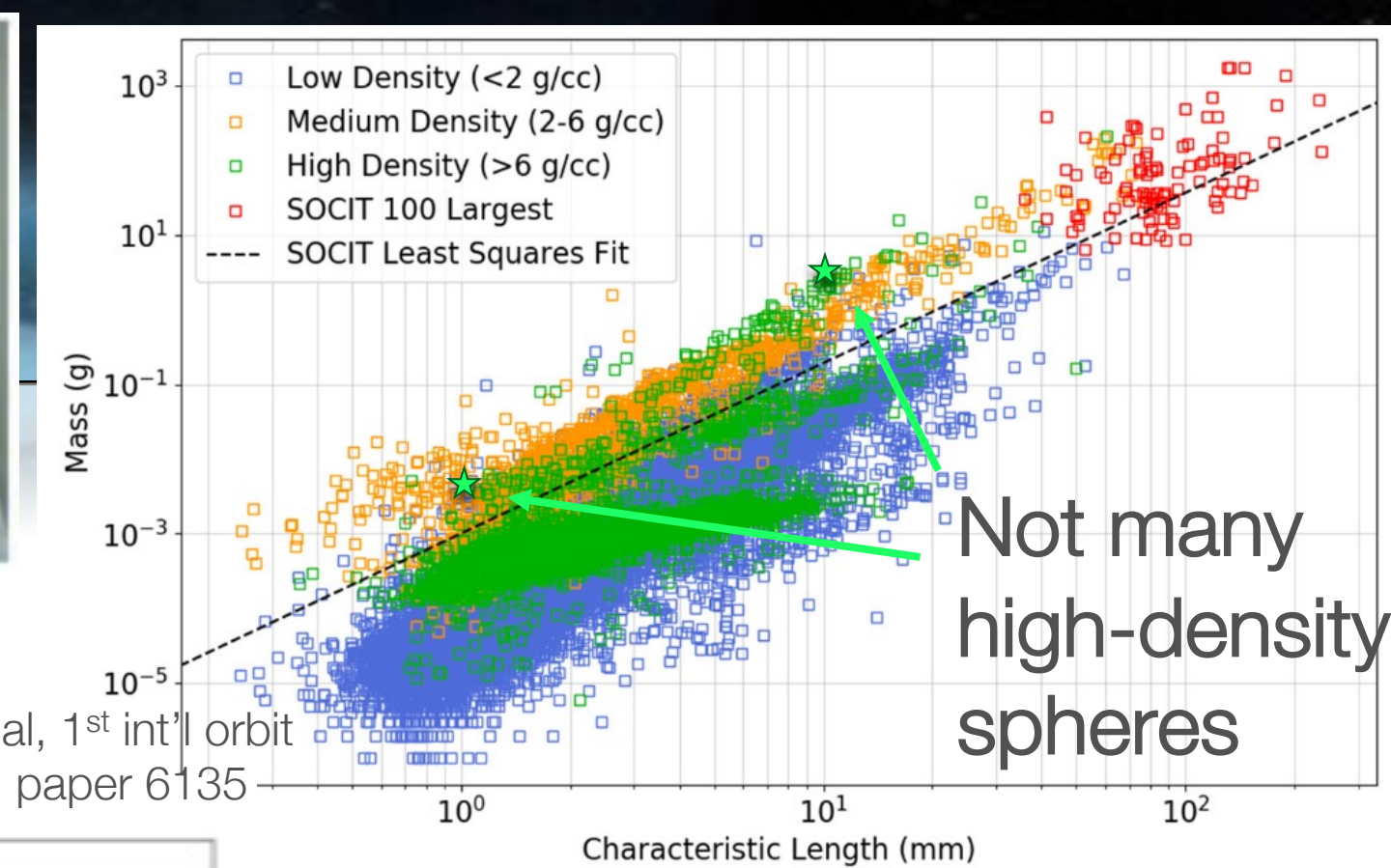
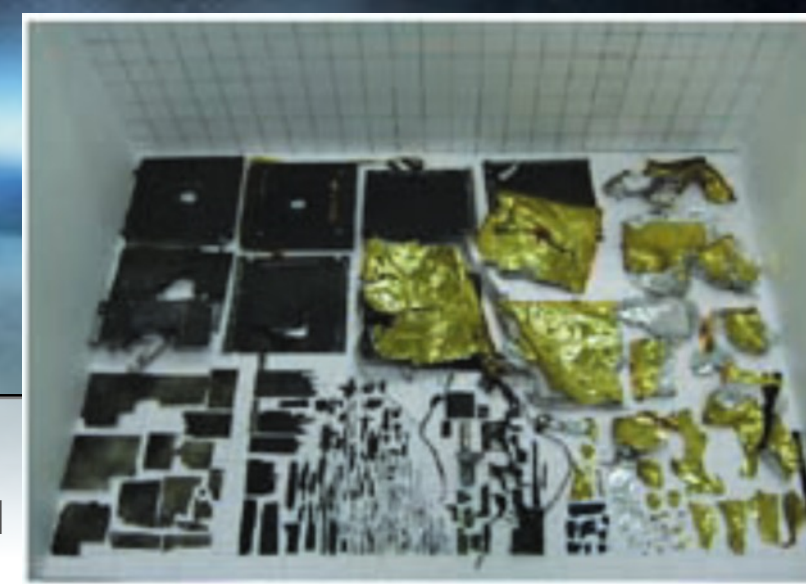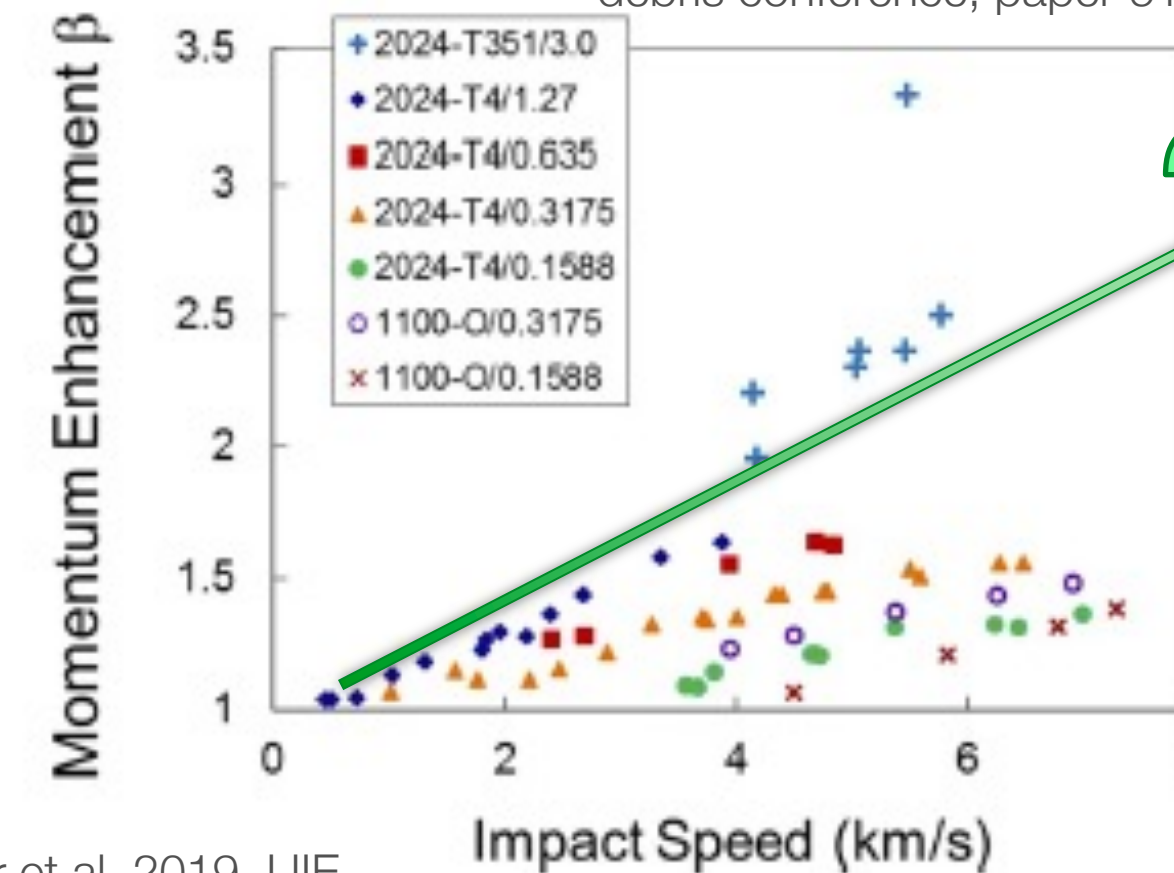=> Defined strike location, save bus or SA

V direction defined

Bus X, Y faces
Bus Z faces
Solar arrays
Projected into plane
Direction of incoming debris velocity

Probability Density Function

Cumulative Distribution Function

Mass, MEF, and Ballistic Limit

Source: NASA ODQN, v 13 iss. 1

Not many high-density spheres

- Typical practice: assume each piece is a sphere

  - ORDEM returns characteristic length (from radar/optical measurements) and density classes (LD, MD, HD, NaK)

  - assuming sphere maximizes mass, very conservative

  - Tool: Trade sphere vs. SOCIT fit vs. debris sat distribution vs. ?

- NESC used static MEF (bound with MEF=1, MEF=3)

  - Can only test MEF to ~8 km/s usually, 10 km/s for EMI

- BLEs deterministic, truth probabilistic

  - Promising efforts on machine learning approaches, for now just randomize

Source: Murray et al, 1st int'l orbit debris conference, paper 6135

Source, Walker et al, 2019, IJIE, https://doi.org/10.1016/j.ijimpeng.2019.103388

EMI
Most tests
?

Source, Schonberg,2016 http://dx.doi.org/10.1016/j.reach.2016.06.001
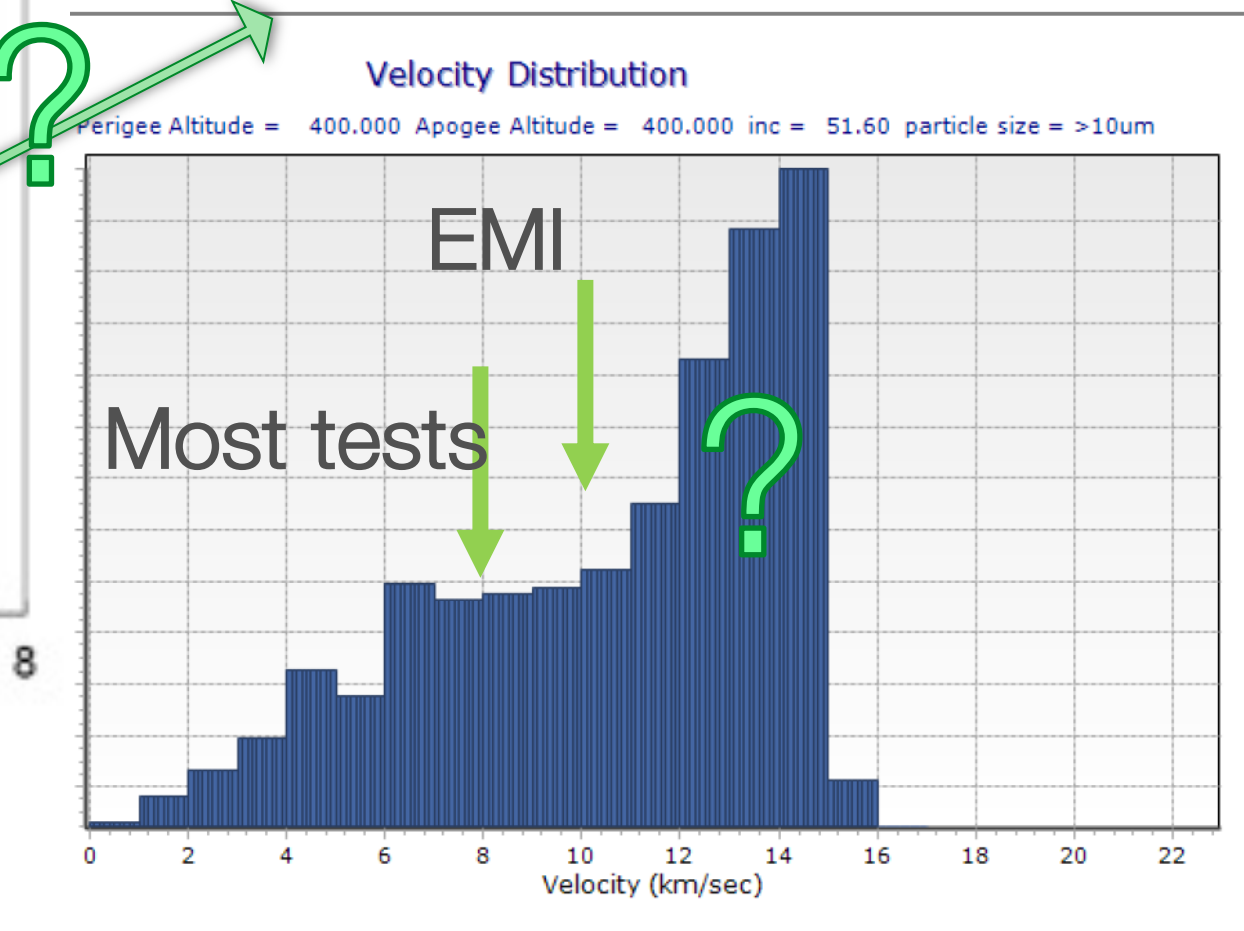
BLEs for various shapes
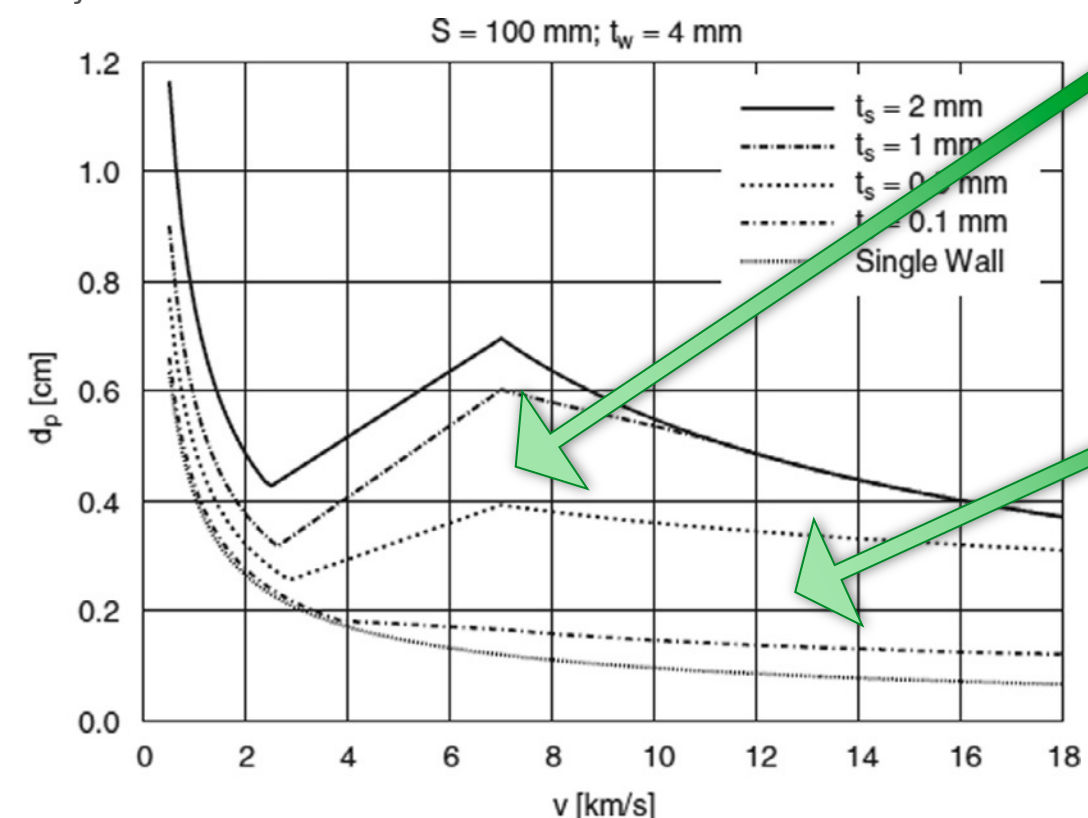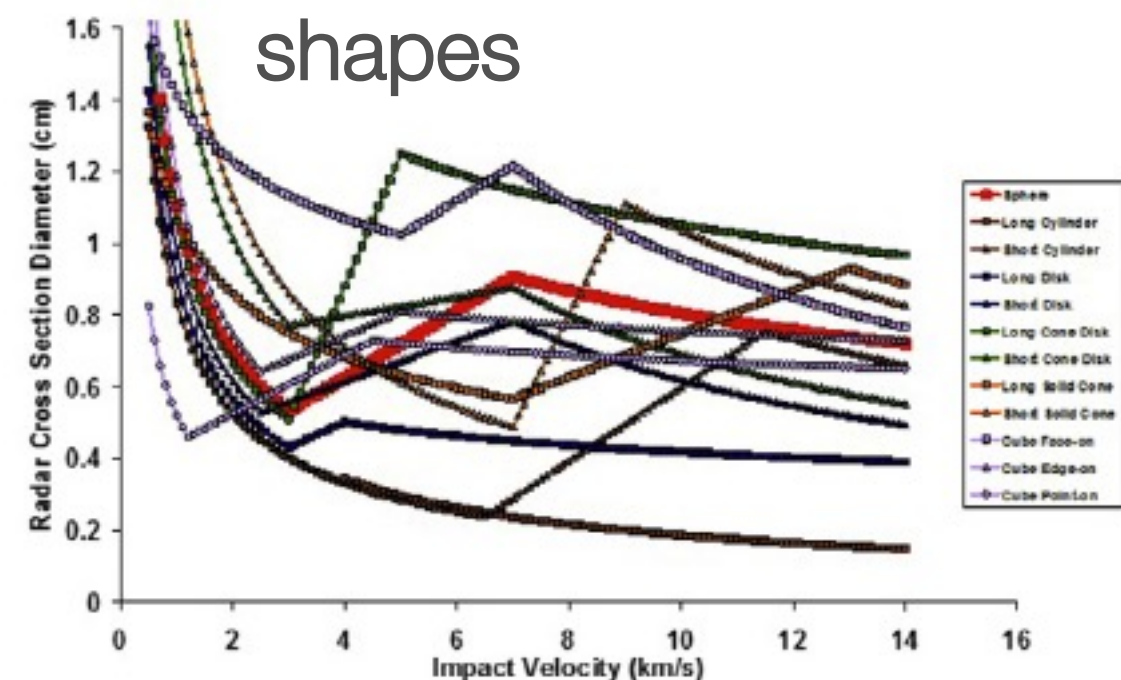
Physics change ~3-8 km/s, do they not change 10-14 km/s?

Test results inaccurate vs BLE ~+/- 30%?

Source, Schonberg,2016 http://dx.doi.org/10.1016/j.reach.2016.06.001

- Making some <u>rough</u> approximations:

  - MEF is a function of velocity, solar array MEF is 0.5

  - The density is a probabilistic function of characteristic length

    - Very coarse approximation of debris sat data

    - Later: include density classes, tune distributions

  - For comparison: SOCIT fit

  - Small, medium, and large S/C

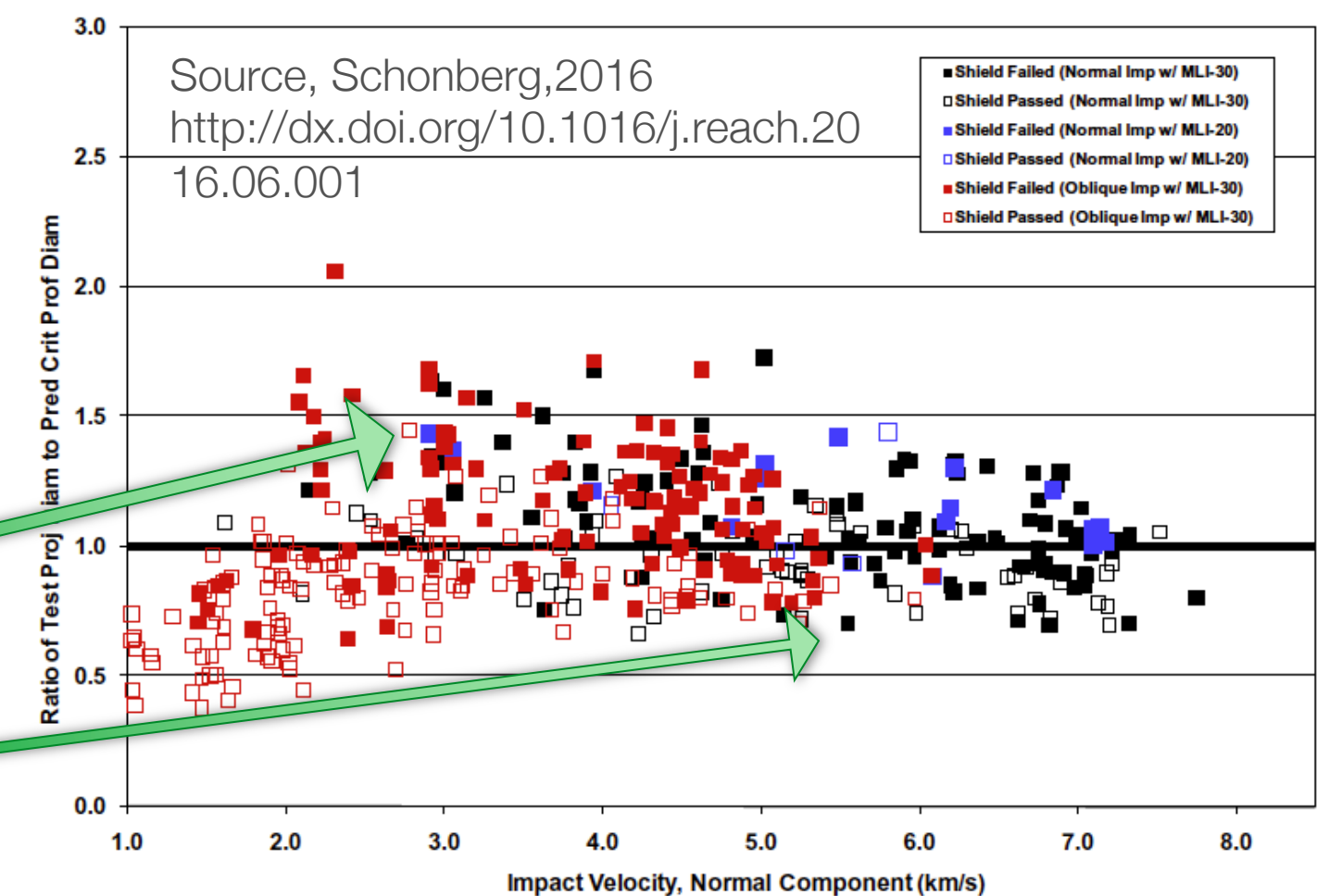- Tool architecture is agile to update with more sophisticated models easily, and trade results between models

DH from strike vs. DV from strike

Small spacecraft detects mostly via DV

Large spacecraft detects mostly via DH

Legend:
- 4000 kg, rough debriSat
- 4000 kg, SOCIT fit
- 200 kg, rough debriSat
- 200 kg, SOCIT fit
- 12 kg, rough debriSat
- 12 kg, SOCIT fit

DV [mm/s] vs. DH [mNms]

mass vs. Lc

mass [g] vs. Lc [mm]

Legend:
- 4000 kg, rough debriSat
- 4000 kg, SOCIT fit
- 200 kg, rough debriSat
- 200 kg, SOCIT fit
- 12 kg, rough debriSat
- 12 kg, SOCIT fit

Rates of Debris Strikes

- Small, medium, large S/C in two LEO orbits: 550 km and 800 km

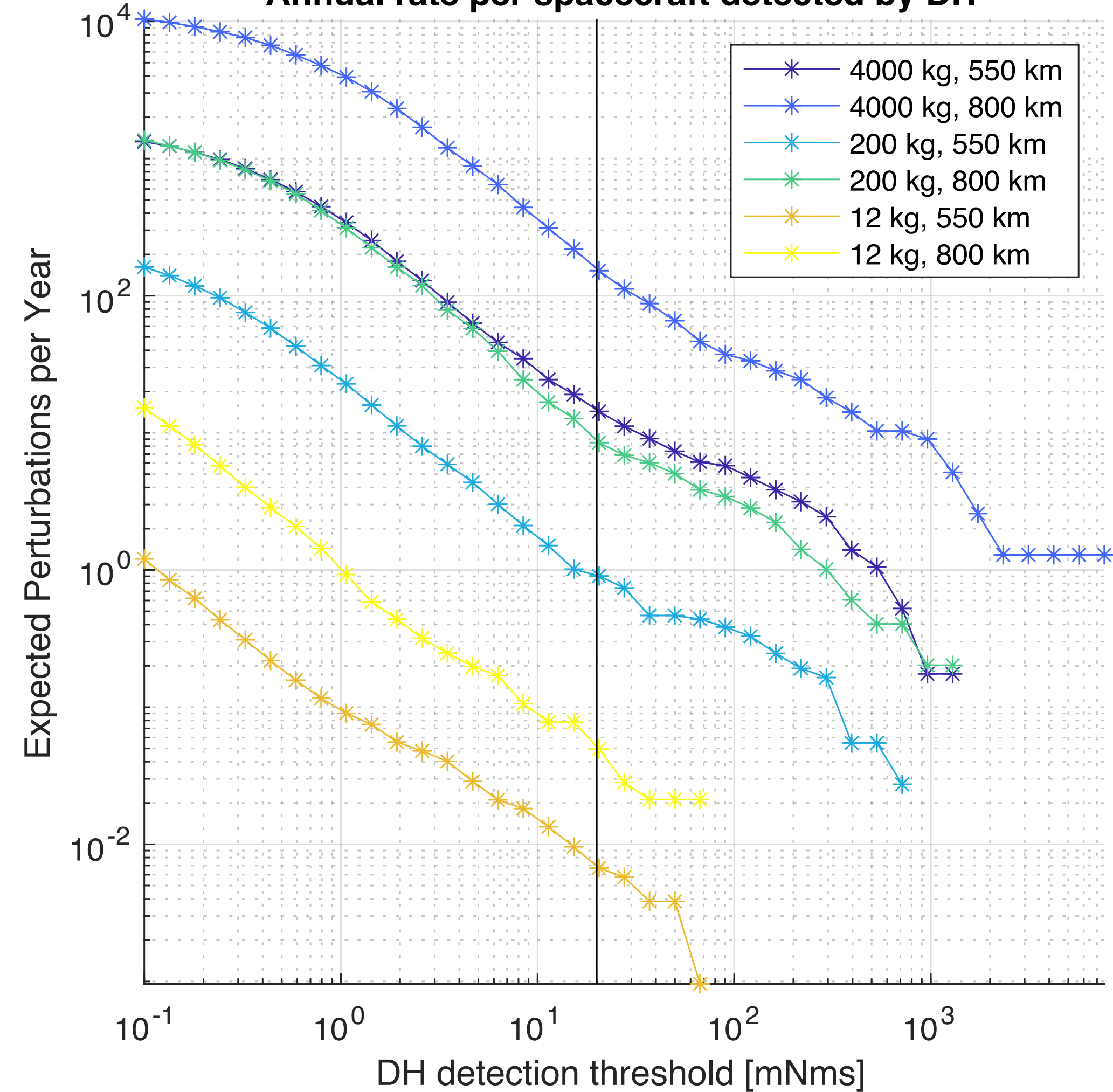Annual rate per spacecraft detected by DV

Annual rate per spacecraft detected by DH

- State of health monitoring, anomaly attribution/response

  - Quicker response/resolution to immediate strike-induced anomalies

  - Monitor for anomalies that may not manifest immediately

    - Example: startracker baffle strike leads to straylight issues later

- Improve operator knowledge of local debris environment

  - Especially constellations

Source: DARPA website

- Concrete method for implementing 'Satellite as a Sensor' concepts

- Great fit for constellations and product line satellites

  - i.e., commercial GEO bus product lines

  - More satellites, more autonomy

Potential Applications: Wider Adoption, Broader Impact
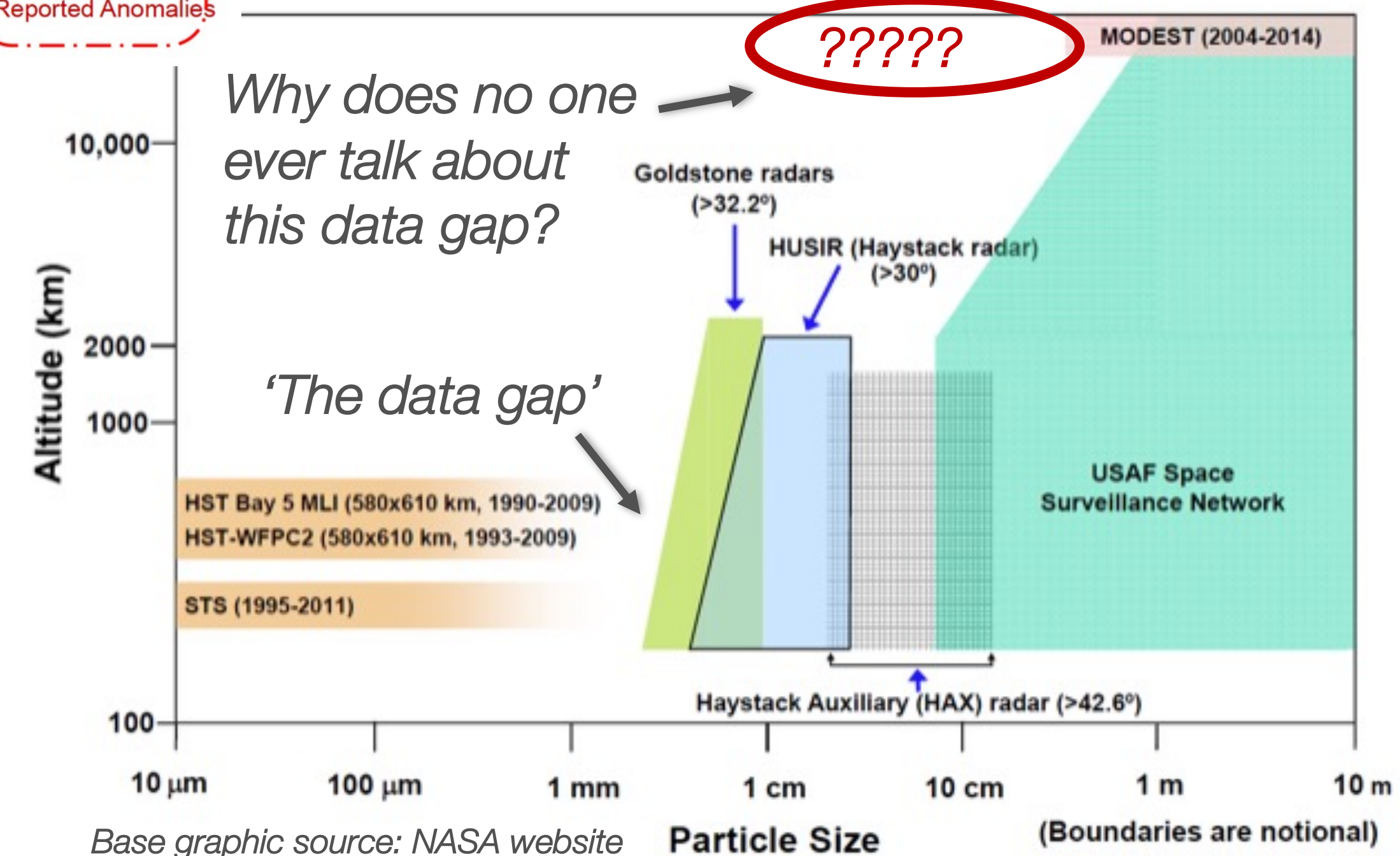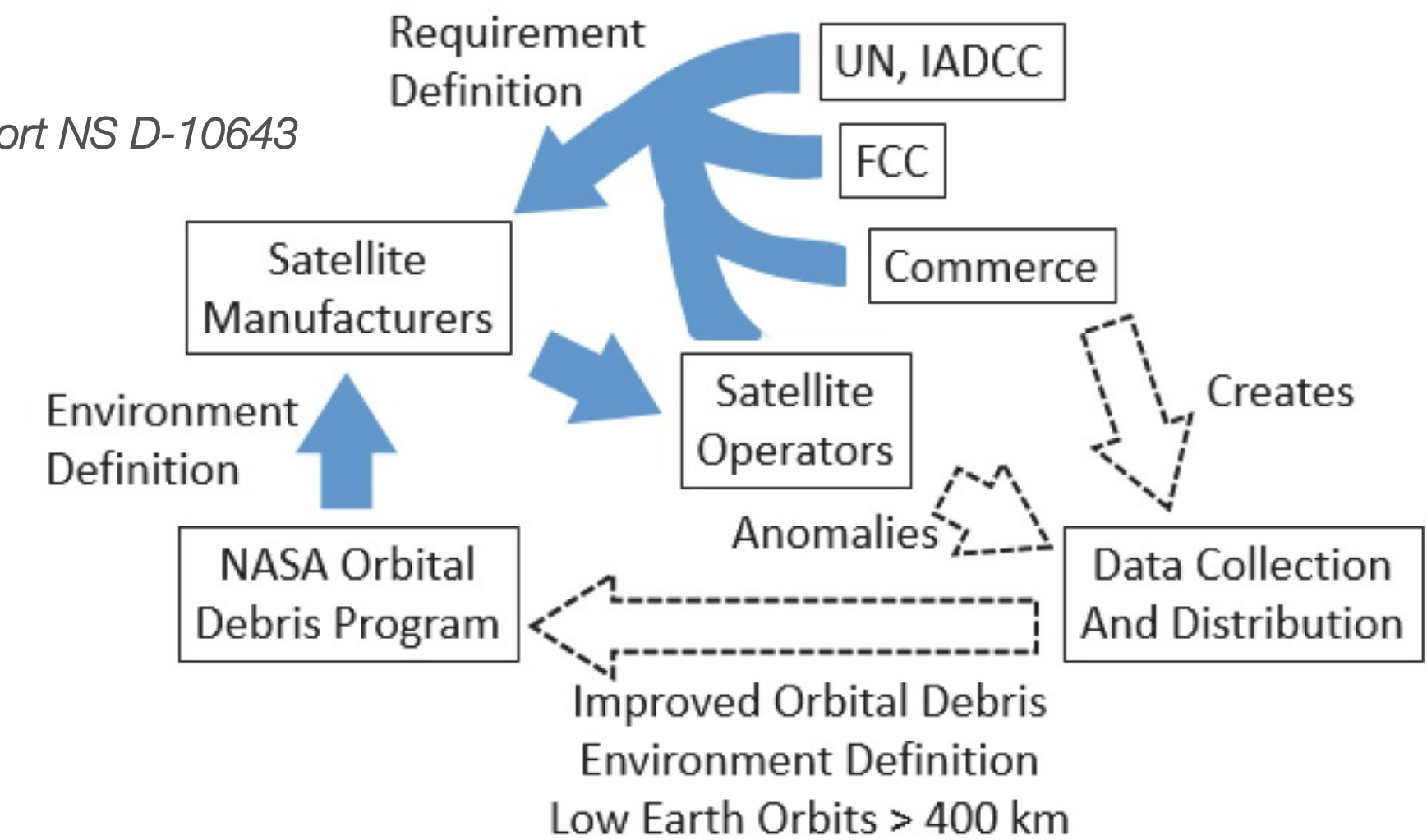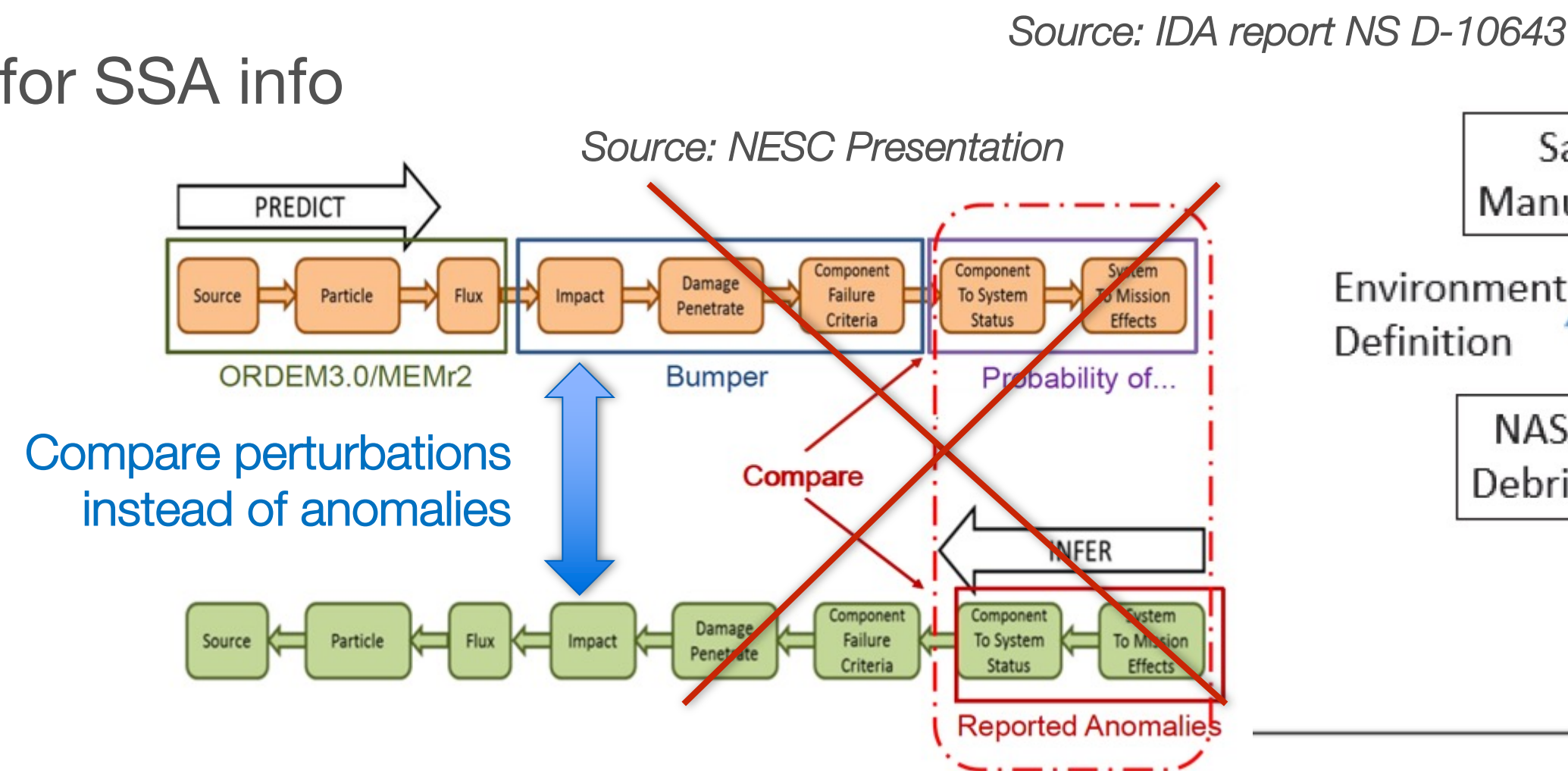
- Department of Commerce STM

  - Open architecture data repository for SSA info

  - Recent paper by IDA on orbit perturbations

  - Perturbations provide more data than anomalies, fewer barriers?

- Additional model validation

  - Data correlated to debris mass

  - Data collection in GEO (little to no data on small debris)

- Validated and/or improved debris risk assessments

  - Motivate appropriate behavior from New Space actors

  - Space insurers can assess risks more accurately

    - Insurers can provide <u>significant</u> incentives to commercial

  - Build consensus, guide policymakers

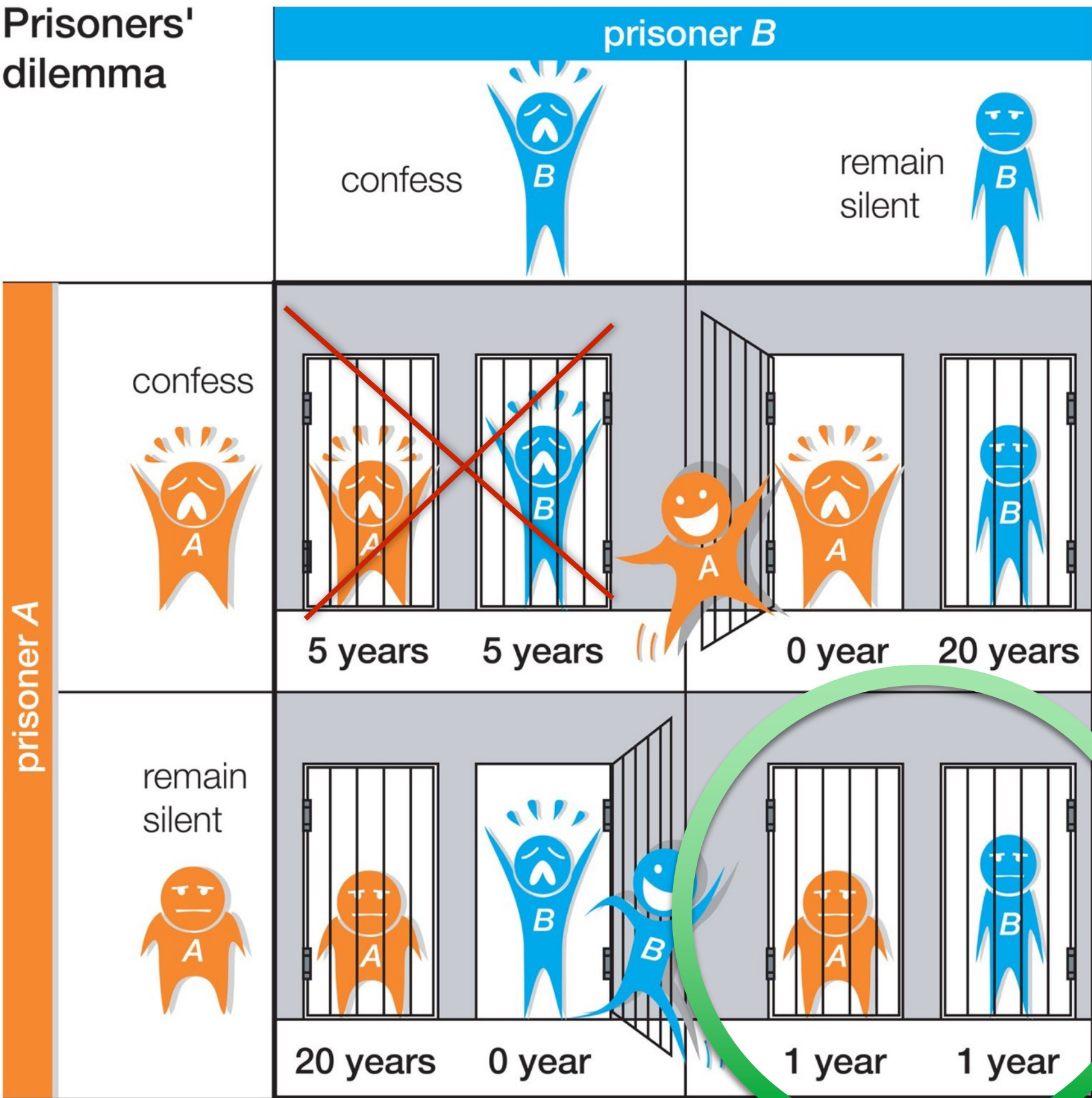   - Justify appropriate legislation and remediation

Source: IDA report NS D-10643

Source: NESC Presentation

Compare perturbations instead of anomalies

Why does no one ever talk about this data gap?

'The data gap'

Base graphic source: NASA website

"Of course any data would help"

"3,236 commercial sensors" *[on orbit soon to improve models] – Amazon Project Kuiper engineer*

Source: Encyclopedia Britannica

"If data is available it will benefit you as operators" *[with better models, better risk assessments]*

"Who's gonna be brave enough to step out first?"
[on data sharing]

Prisoner's dilemma: mutually beneficial solution requires bravery & trust

Prisoners' dilemma

prisoner B

confess | remain silent

prisoner A

confess

5 years | 5 years | 0 year | 20 years

remain silent

20 years | 0 year | 1 year | 1 year

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Questions?