Approaches to Near Term Collision Risk Assessment

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OUTLINE

- Introduction
- Approach to assessing near term consequences of collisions
- Examples
  - Intelsat 702 – Raduga 1-7
  - Iridium 33 – Cosmos 2251
- Issues
- Conclusions

Objectives

To apply a technique for assessing operational risk considering both the likelihood of occurrence and the estimated consequences of a conjunction.

To introduce two concepts for analysis of prompt debris: involvement and ghosting.

Evolution of Collision Debris

- **Equilibrium Environment**

  Long term statistical collision risk

- **Quasi-Steady evolution**

  Growth through interaction of debris fragments and additional launches.

  Depletion through reentry

- **Approach to equilibrium**
- **Prompt Environment**

Debbie Debris Models

- Evolve-like fragment property dependence on characteristic length
  - Distinct Collision and Explosion distributions
- Grady, Kipp, and Gold fragmentation theories
  - Fragment velocities are the result of releasing strain energy
  - Fragment sizes depend on the scales of underlying structural stress and of grain boundaries, inclusions, and other material nonuniformities.

Involved and Uninvolved Mass

- It is unlikely that all of the mass of each colliding object is involved in energy and momentum transfer.
  - Collision model for involved mass
  - Explosion model for uninvolved mass
- Uninvolved portions tear with little initial fragmentation
  - Disturbances are communicated by stress waves which cannot propagate far during the duration of the encounter.

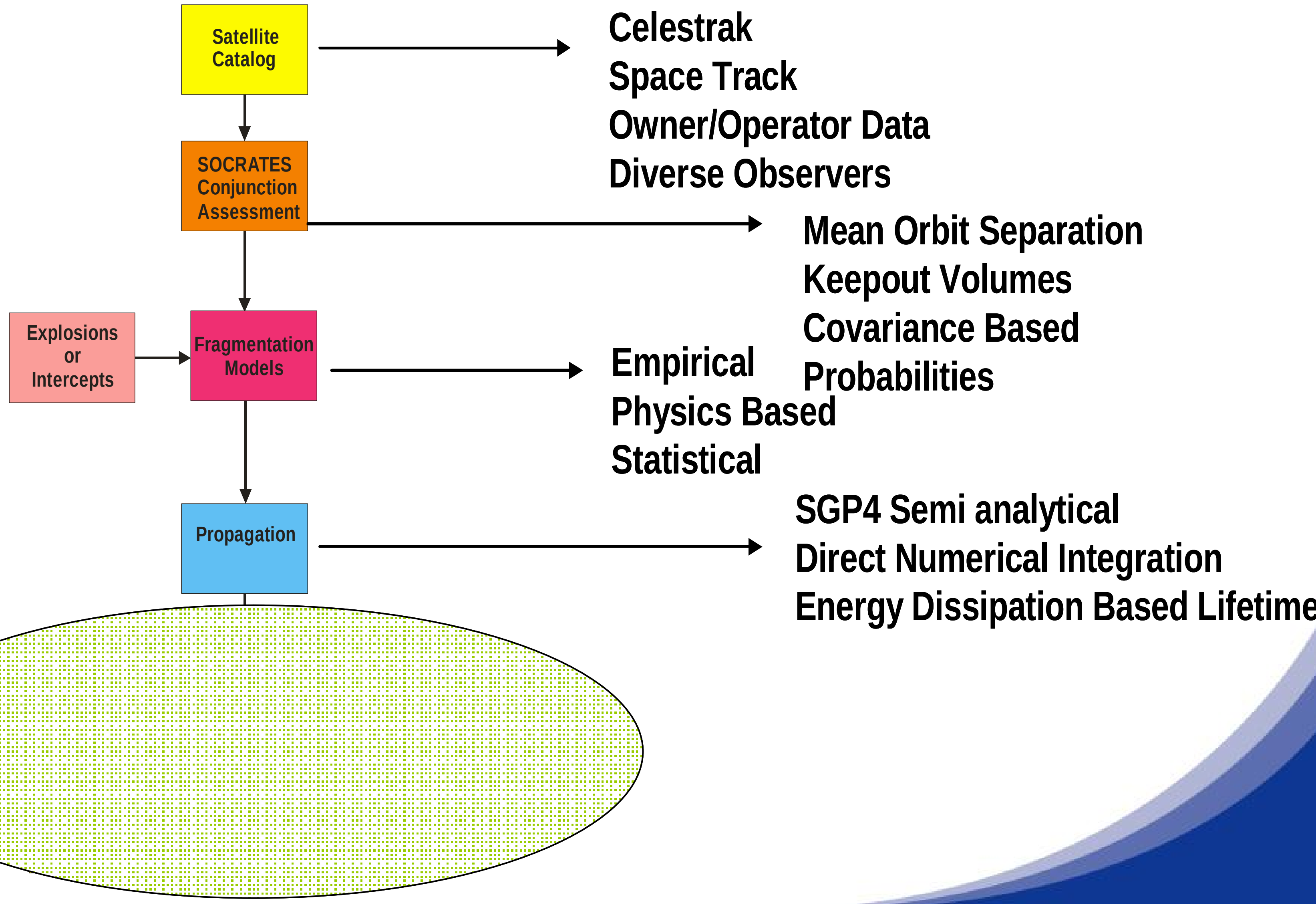
Ghosting

- **Fragmentation is a decidedly nonequilibrium phenomenon**
  - **Post collision momentum and energy distributions are not necessarily Newtonian elastic or inelastic**
  - **A portion of the initial energy is distributed between individual fragment non-directed motion and thermal dissipation.**
- **There is a spectrum of post collision possibilities**
  - **Newtonian with fragment delta V's relative to the barycenter of the pre-collision state.**
  - **Noninvolved portions retain initial momentum, and subsequent fragments evolve relative to those velocity vectors.**

Debris Mitigation Sequence

- Space Surveillance and Situational Awareness
- Conjunction Assessment
- Consequences - Debris Generation
- Course of Action
- Short Term Evolution and Cascading
  - Consequence Management
- Reentry and Hazard Management
- Long Term Environment
  - Operational Guidelines

Debris Assessment Work Flow



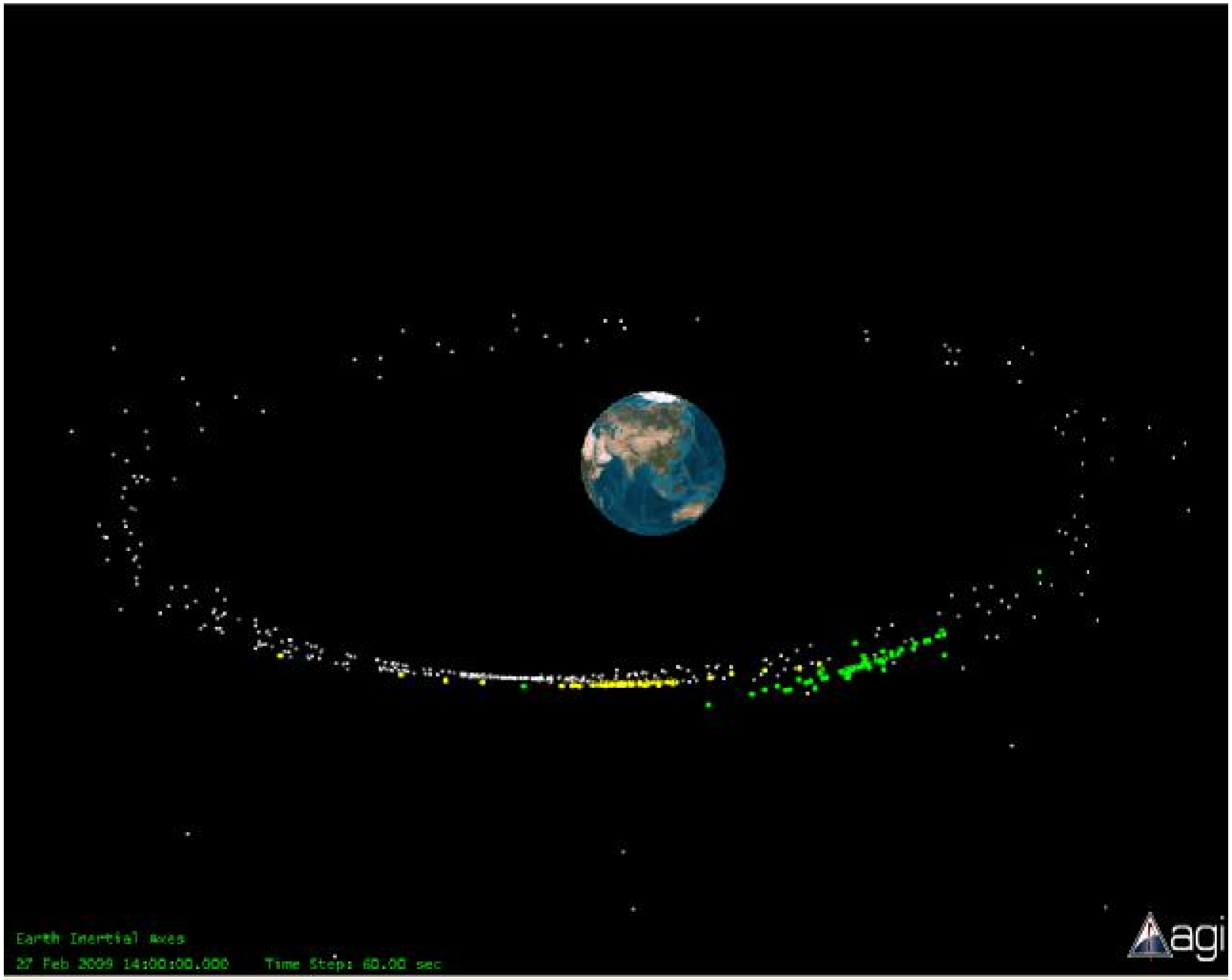
Analysis of Recent Conjunctions

- Intelsat 702 – Raduga 1-7
  - 25 Feb 09 01:48:40.322
  - CPA = 23.6 km
- Iridium 33 – Cosmos 2251
  - 10 Feb 09 16:56
  - CPA = 0
- Several high probability conjunctions 11-14 March 09
- Conjunctions with evolving Iridium 33 – Cosmos 2251 debris

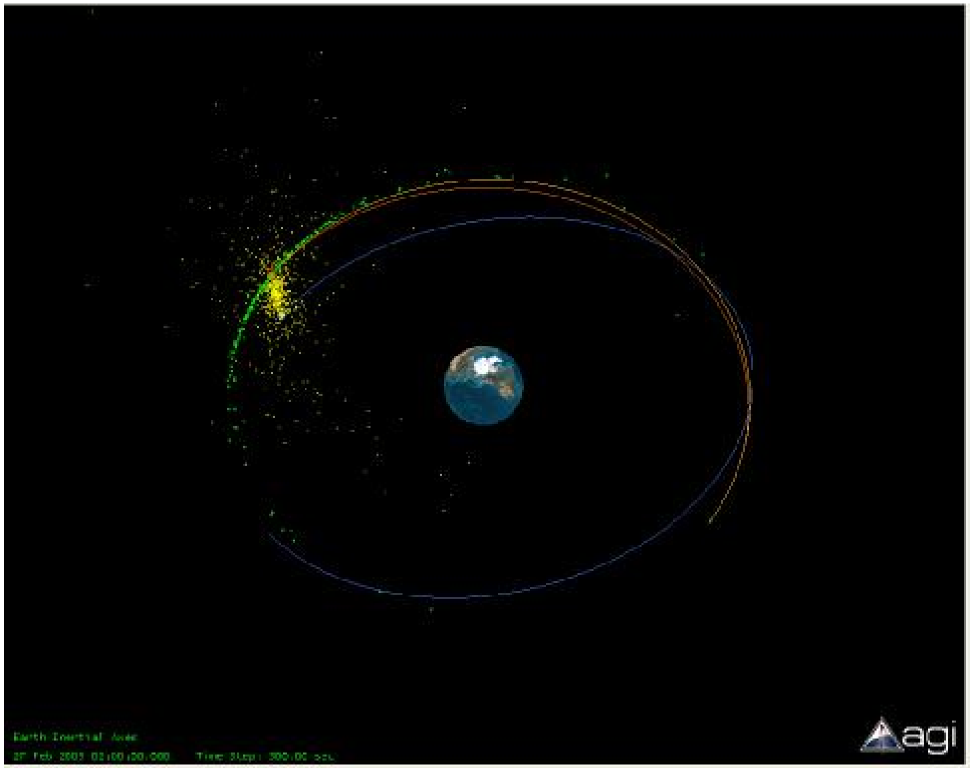
INTELSAT 702 AND RADUGA 1-7

- Intelsat = 3000 kg, Raduga = 2000 kg
  - 40% involvement inferred from satellite geometries
  - 396 fragments with RCS > -20 dbsm
- Two subsequent collisions:
  - 1.48 kg fragment hit INSAT-4B (2500 kg) at 26 Feb 2009 01:18:47 producing 89 fragments
  - 9.08 kg fragment hit ZhongXing-6B (4000 kg)at 26 Feb 09 23:38:35 producing 111 fragments.
  - Fragments fully involved while at most ten percent of the target mass was involved.

Hypothetical Intelsat 702 – Raduga 1-7 Debris Environment



Consequences of a Hypothetical Intelsat 702 Explosion



1 Gigajoule at 25 Feb 09 14:00:00

248 fragments > 100 grams

0.82 kg fragment collides with Ekran-1 26 Feb 09 18:50:00

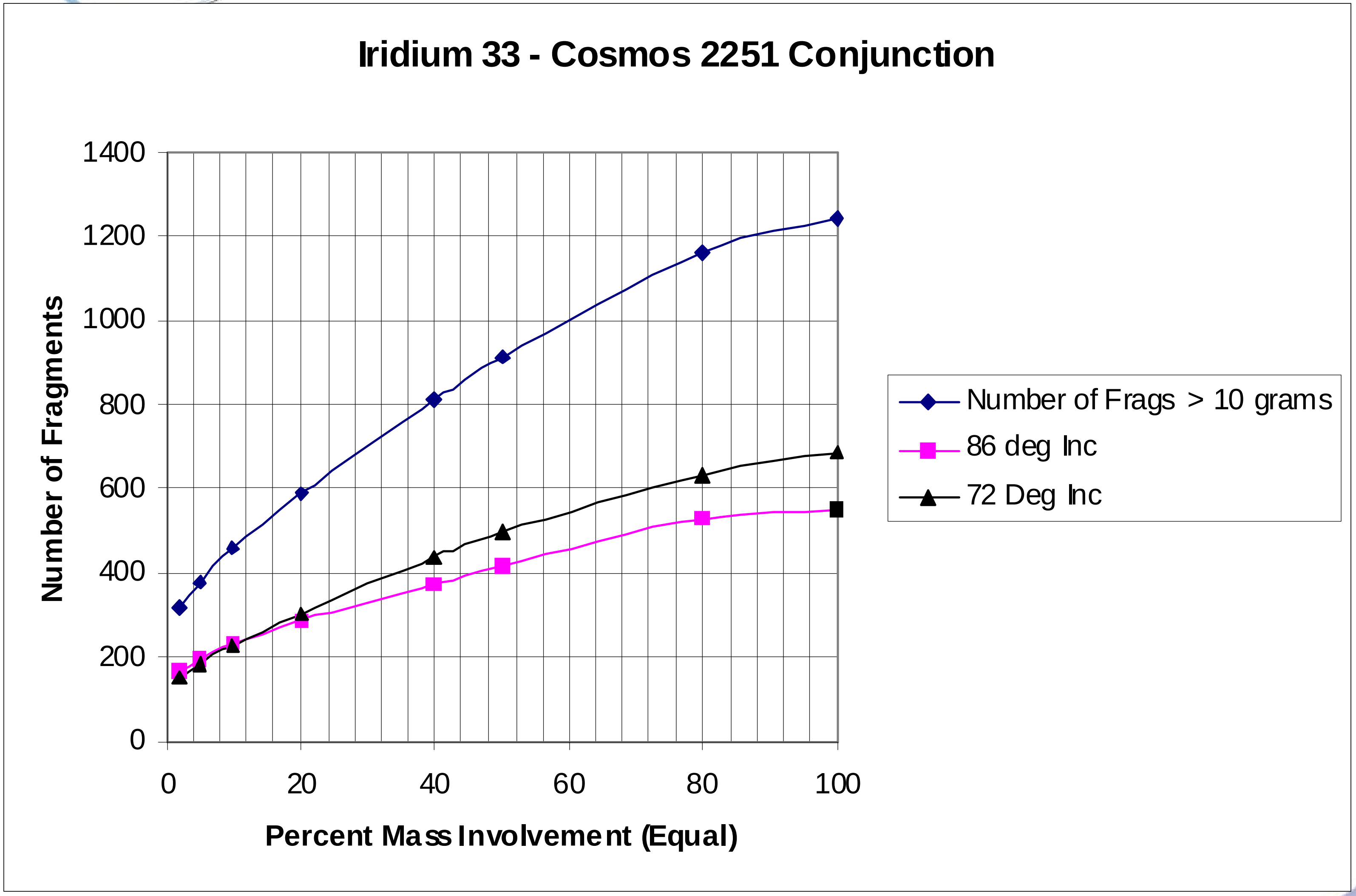
1036 fragments >100 grams

Iridium 33 – Cosmos 2251

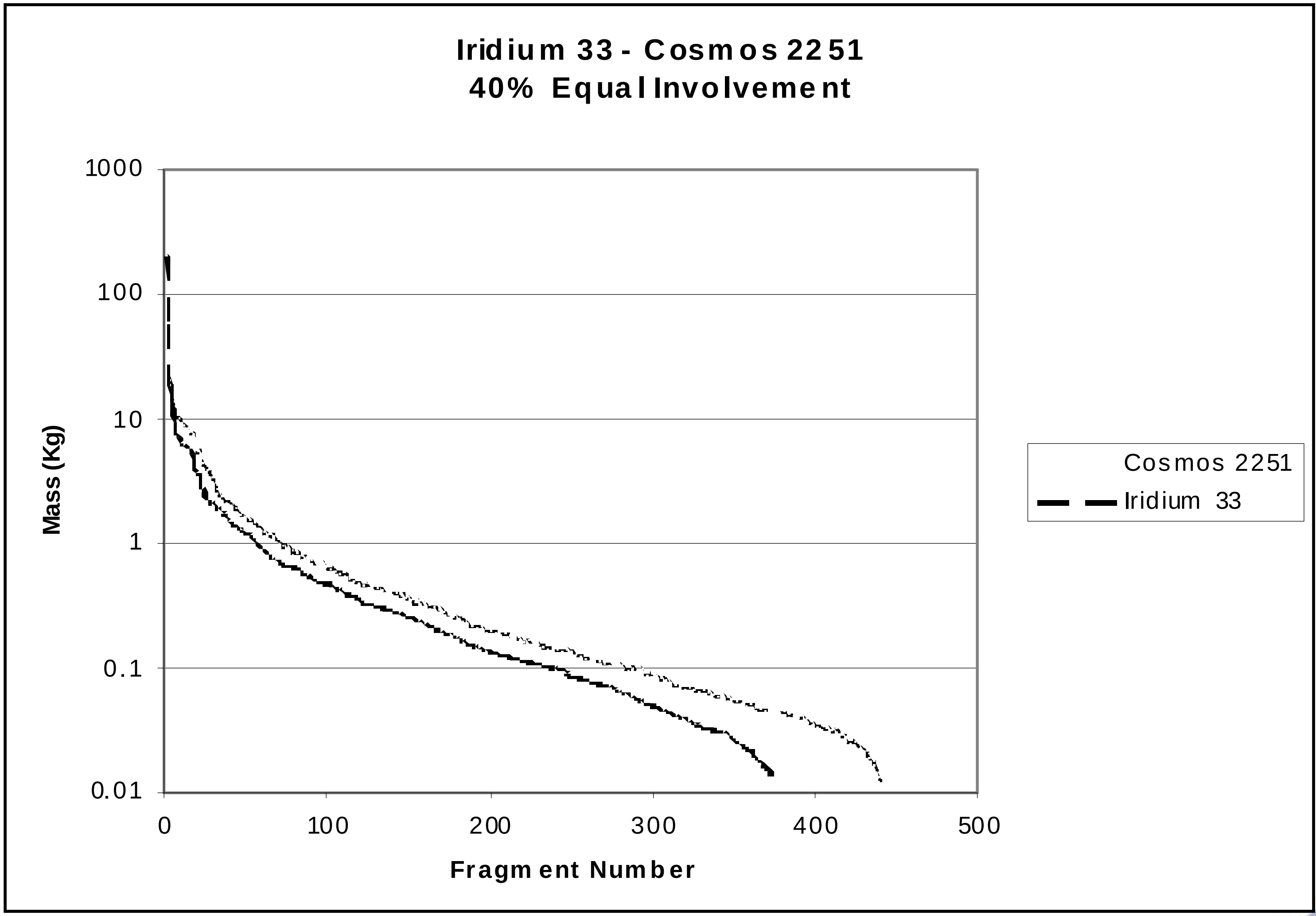
10 Feb 2009

- Perceived in advance but not notable:
  - (1) maximum probability based on spheres of unit aspect ratio,
  - (2) poor quality and latent orbit data, and
  - (3) absence of covariance information.
- Fragment count estimated parametrically
  - Iridium 33 = 600 kg
  - Cosmos 2251 = 800 kg

Parametric Fragment Count



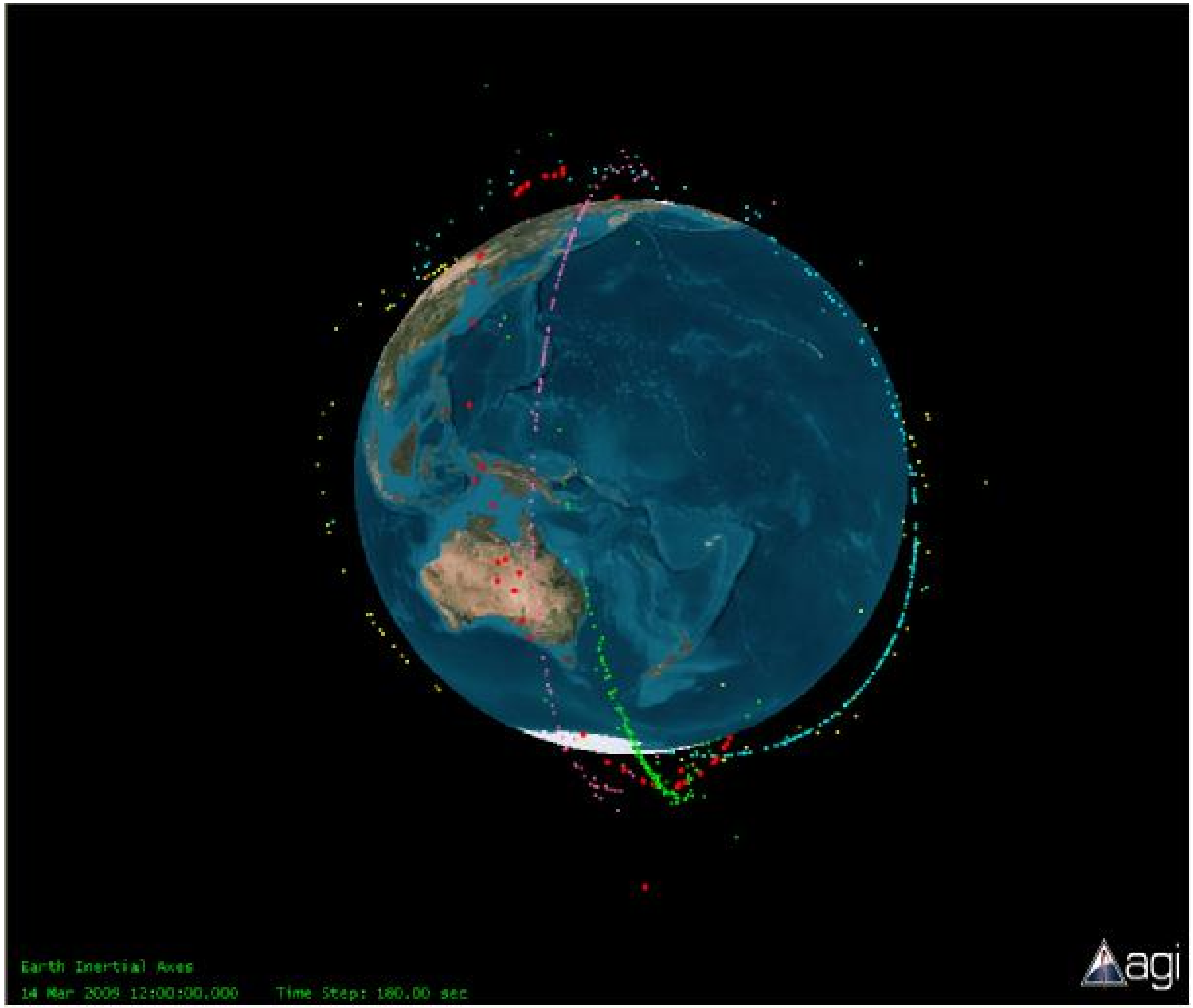
Iridium 33 – Cosmos 2251 Fragment Mass Distributions



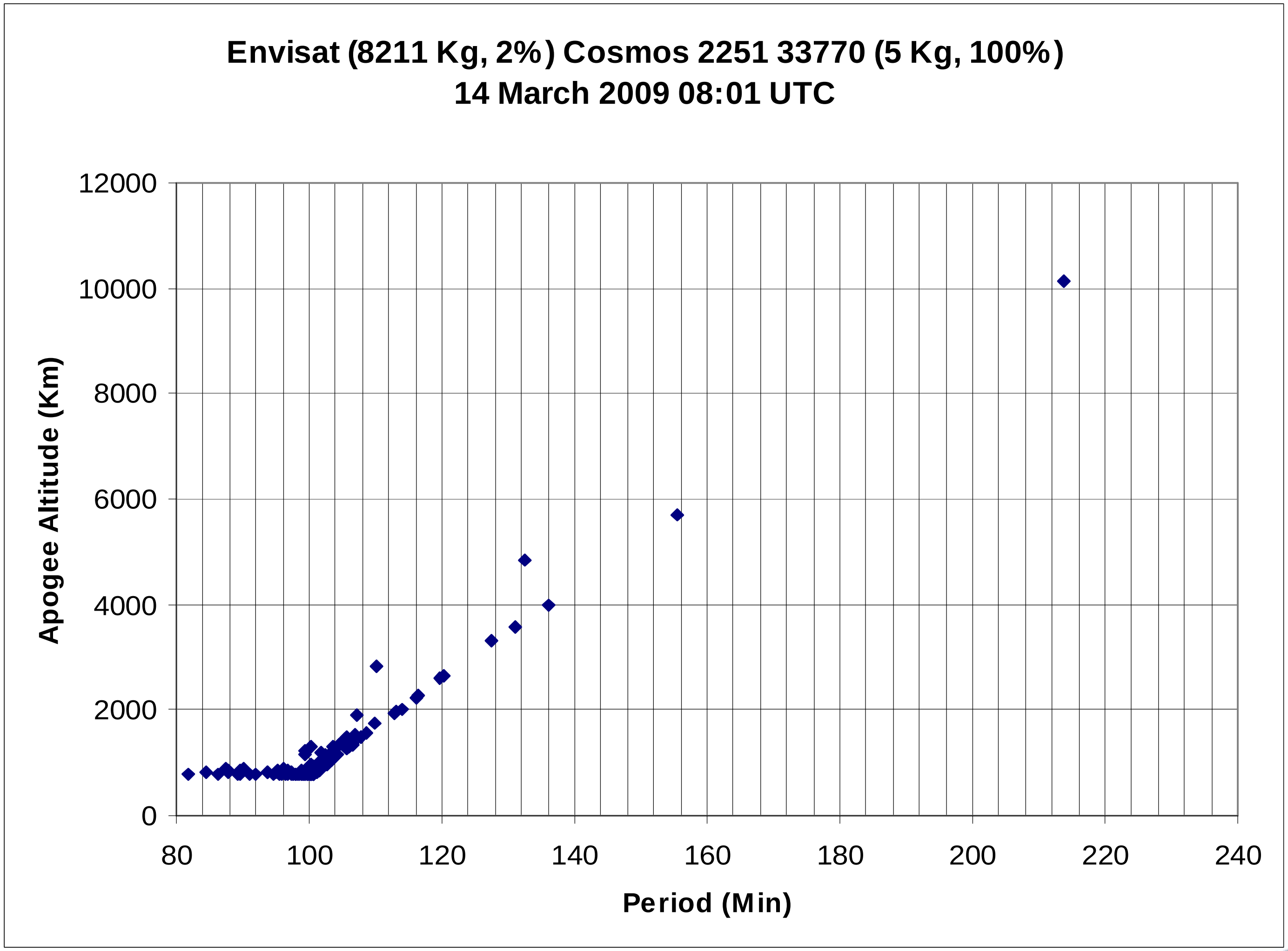
Cascading Conjunctions 11-14 Mar 09

Involved Satellite	Debris Element	Conjunction Epoch	Frags	Color	Type
Iridium 06/10%	Cosmos 34015	11 Mar 09 00 24 UTC	193	Magenta	II
Cosmos 1867/5%	Cosmos 34054	11 Mar 09 10:24 UTC	278	Aqua	II
Fedsat/50%	Iridium 34105	13 Mar 09 03:18 UTC	68	Red	III
Cosmos 1818/5%	Iridium 33950	13 Mar 09 13:20 UTC	278	Yellow	II
Envisat/2%	Cosmos 33770	14 Mar 09 08:01 UTC	626	Green	IV

Cumulative Debris Environment
11-14 March 09



Hypothetical Envisat Debris Orbit Distribution

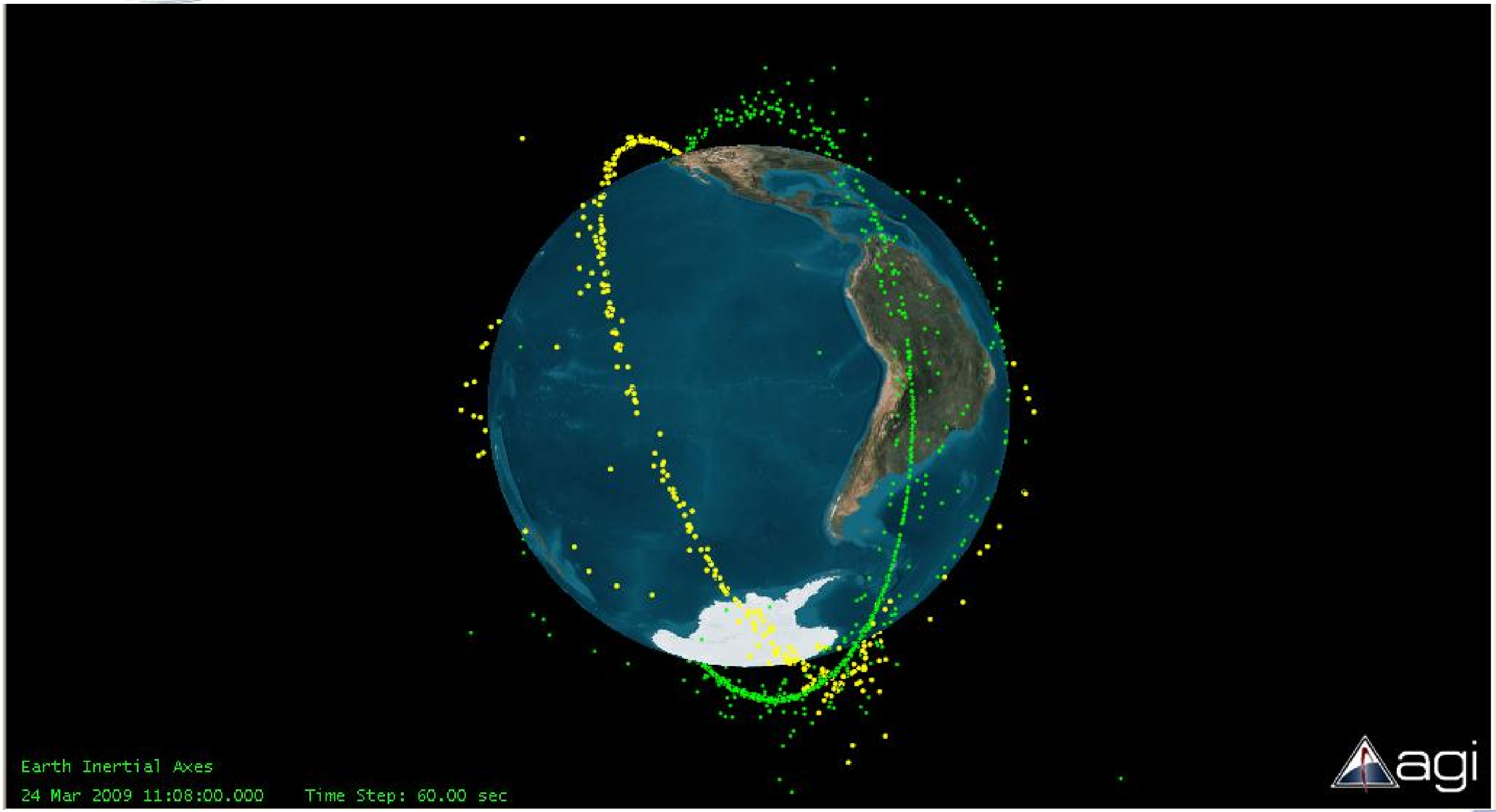


Other Interesting High Probability Conjunctions

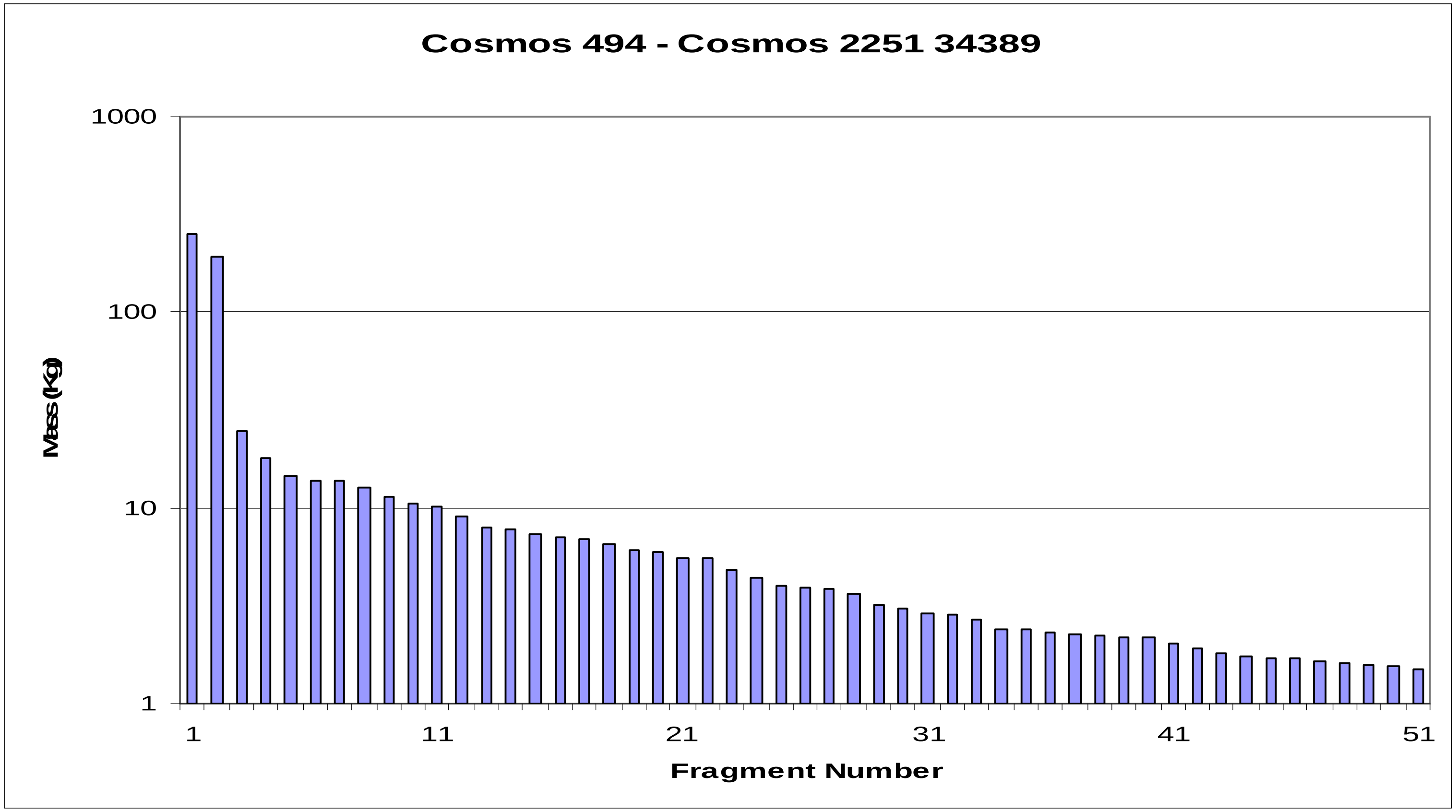
Compact satellites – Any collision will have a high degree of mass involvement

RapidEye 05 (50%) – Cosmos 2251 34034
20 Mar 09 07:41 UTC
707 Frags
(Type IV RapidEye orbit)
Cosmos 494 (20%) – Cosmos 2251 Debris 34389
23 Mar 09 07 :08 UTC
1721 Frags
(Type II: Iridium orbit)

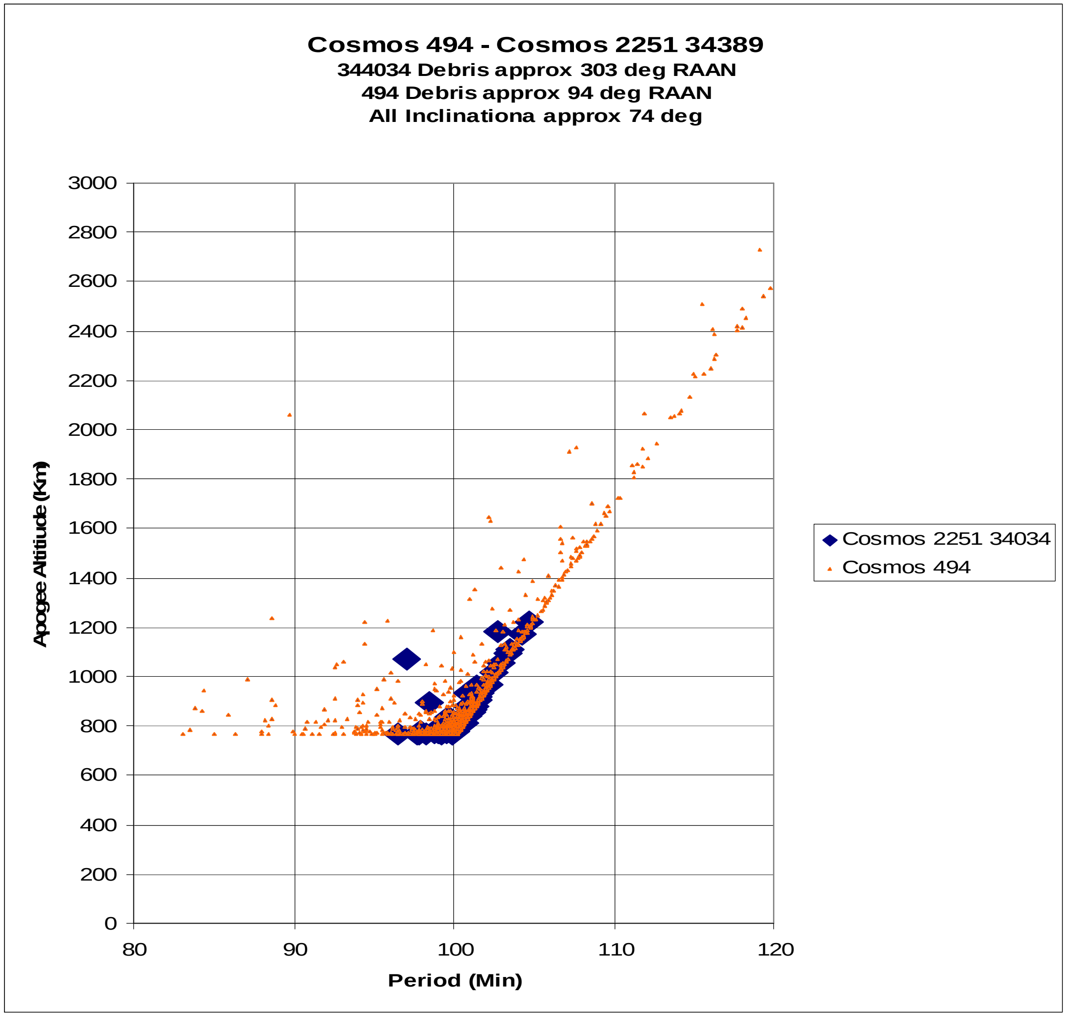
Near Term Debris Environment from Cosmos 494 and RapidEye Conjunctions with Iridium 33 – Cosmos 2251 Debris



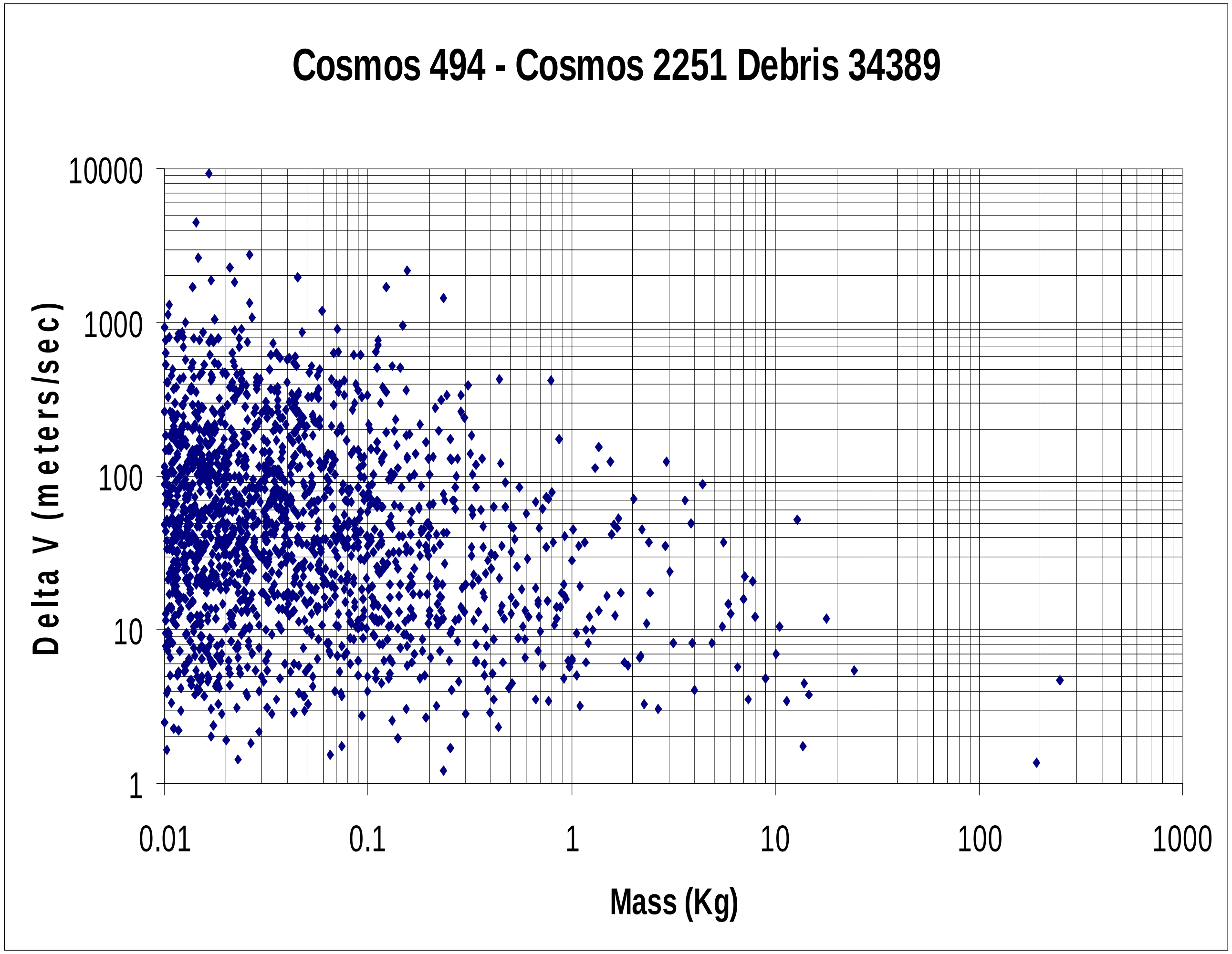
50 Most Massive Cosmos 494 Fragments



Orbit Distributions for Estimated Cosmos 494 Conjunction with Cosmos 2251 Debris



Fragment Particular Velocities for Estimated Cosmos 494 Conjunction with Cosmos 2251 Debris



Observations

- **Nothing will ever collide with a hypothetical, statistical fragment**
  - **Predictions are indicative, not specific**
  - **A more comprehensive near term statistical treatment is required.**
  - **Bridging between prompt and equilibrium debris states is required.**
- **Conjunction probability estimates depend on objects sizes and shapes as well as osculating orbit close approach distances.**
  - **Close approach and high collision probability do not necessarily occur simultaneously**
  - **We need better satellite shape and orientation information in addition to covariances**

Observations (Continued)

- **What were once occasional close approaches between high inclination satellites and elements of the Iridium constellation are now frequent conjunctions with debris distributed around the Iridium 33 plane**
  - **This introduces the concept of constellation and orbit design for safety as well as for mission goals. The considerations are not antithetical.**
- **Cumulative probabilities of conjunctions between important or dangerous satellites and Iridium 33 or Cosmos 2251 debris are noteworthy.**
  - **Envisat**
  - **Cosmos 1818 and 1867**

Conclusions

- The community needs a well understood and trustworthy process.
  - Is this one?   If not, improve it.
- The operational sequence employs reasonable but still deficient models and data.
  - Make them better.
- The outcomes are very likely not to be as determined.
  - Virtually no estimated conjunctions occur.
- But .. The process and tools employed provide some guidance for actions to mitigate and manage the prompt space debris environment of estimated conjunctions.