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An Evaluation of CubeSat Orbital Decay

AGI's Center for Space Stds &Innovation
CEO, 1Earth Research
Dan Oltrogge

SRI International, Inc.

Kyle Leveque

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CubeSat Historical Manifest

Table 1: Compendium of CubeSat Launches to Date

CS #	SCC #	Name	FF(U)	Launch Vehicle	Deploy Date	Decay Date	Actual Lifetime (days)	Adopted_ Mass(g)	g/U	Max CSA (cm^2)	Min CSA (cm^2)	Avg CSA (cm^2)
1	27842	DTU-1	1	Rokot	6/30/2003			1000	1000.0	100	100	150
2	27844	Cute 1	1	Rokot	6/30/2003			1000	1000.0	100	100	150
3	27845	QuakeSat	3	Rokot	6/30/2003			4402	1467.3	300	100	350
4	27846	AAUSAT-1	1	Rokot	6/30/2003			1000	1000.0	100	100	150
5	27847	CanX-1	1	Rokot	6/30/2003			1000	1000.0	100	100	150
6	27848	XI-IV	1	Rokot	6/30/2003			995	995.0	100	100	150
7	28892	UWE-1	1	Kosmos-3M	10/27/2005			1000	1000.0	100	100	150
8	28895	XI-V	1	Kosmos-3M	10/27/2005			1030	1030.0	100	100	150
9	28897	Ncube-2	1	Kosmos-3M	10/27/2005			1000	1000.0	100	100	150
10	28941	Cute 1.7+APD	2	MV-8	2/21/2006	10/25/09	1342	3600	1800.0	200	100	250
11	29655	GeneSat	3	Minotaur I	12/16/2006	08/04/10	1327	5000	1666.7	300	100	350
12	31122	CSTB1	1	Dnepr	4/17/2007			900	900.0	100	100	150
13	31126	MAST	3	Dnepr	4/17/2007			3210	1070.0	300	100	350
14	31128	Libertad-1	1	Dnepr	4/17/2007			995	995.0	100	100	150
15	31129	CP3	1	Dnepr	4/17/2007			836	836.0	100	100	150
16	31130	CAPE-1	1	Dnepr	4/17/2007			851	851.0	100	100	150
17	31132	CP4	1	Dnepr	4/17/2007			1019	1019.0	100	100	150
18	31133	AeroCube-2	1	Dnepr	4/17/2007			959	959.0	100	100	150
19	32787	Compass-1	1	PSLV-C9	4/28/2008			850	850.0	100	100	150
20	32788	AAUSAT-2	1	PSLV-C9	4/28/2008			750	750.0	100	100	150
21	32789	Delfi-C3	3	PSLV-C9	4/28/2008			2239	746.3	300	100	350
22	32790	CanX-2	3	PSLV-C9	4/28/2008			3476	1158.7	300	100	350
23	32791	SEEDS-2	1	PSLV-C9	4/28/2008			1021.5	1021.5	100	100	150
24	35002	PharmaSat	3	Minotaur I	5/19/2009			4500	1500.0	300	100	350
25	35003	CP6	1	Minotaur I	5/19/2009			990	990.0	100	100	150

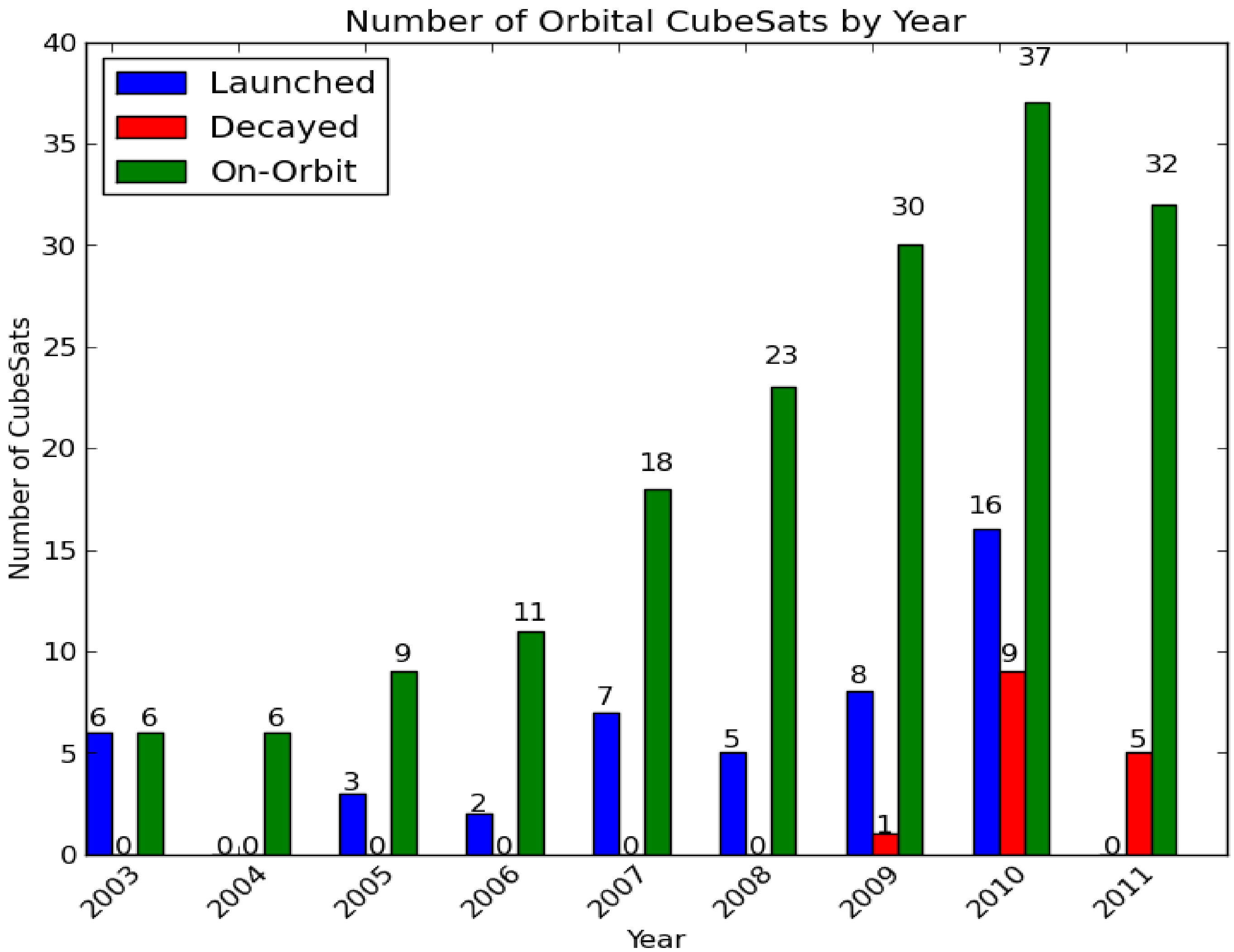
CubeSat Historical Manifest (Continued)

- Vehicles in "red" did not have publicly-available TLE orbital data

26	35004	HawkSat-1	1	Minotaur I	5/19/2009			880	880.0	100	100	150
27	35005	AeroCube-3	1	Minotaur I	5/19/2009	01/06/11	597	1100	1100.0	100	100	150
28	35932	SwissCube	1	PSLV-C9	9/23/2009			820	820.0	100	100	150
29	35933	BeeSat	1	PSLV-C9	9/23/2009			936	936.0	100	100	150
30	35934	UWE-2	1	PSLV-C9	9/23/2009			1058	1058.0	100	100	150
31	35935	ITU-pSat	1	PSLV-C9	9/23/2009			960	960.0	100	100	150
32	36573	Hayato (K-Sat)	1	H-IIA	5/20/2010	06/28/10	39	1400	1400.0	100	100	150
33	36574	Waseda-Sat2	1	H-IIA	5/20/2010	07/12/10	53	1150	1150.0	100	100	150
34	36575	Negai	1	H-IIA	5/20/2010	06/26/10	37	986.4	986.4	100	100	150
35	36796	StudSat	1	PLSV-CA	7/12/2010			850	850.0	100	100	150
36	36799	Tisat-1	1	PLSV-CA	7/12/2010			995	995.0	100	100	150
37	37224	O/OREOS	3	Minotaur IV	11/20/2010			5500	1833.3	300	100	350
38	37245	QbX2	3	Falcon 9	12/8/2010	01/16/11	39	4516	1505.3	300	100	350
39	37246	SMDC-ONE	3	Falcon 9	12/8/2010	01/12/11	35	4050	1350.0	300	100	350
40	37247	PERSEUS 003	1.5	Falcon 9	12/8/2010	12/31/10	23	1500	1000.0	150	100	200
41	37248	PERSEUS 001	1.5	Falcon 9	12/8/2010	12/31/10	23	1500	1000.0	150	100	200
42	37249	QbX1	3	Falcon 9	12/8/2010	01/06/11	29	4529	1509.7	300	100	350
43	37250	PERSEUS 002	1.5	Falcon 9	12/8/2010	12/30/10	22	1500	1000.0	150	100	200
44	37251	PERSEUS 000	1.5	Falcon 9	12/8/2010	12/30/10	22	1500	1000.0	150	100	200
45	37252	MAYFLOWER	3	Falcon 9	12/8/2010	12/22/10	14	4750	1583.3	300	100	350
46	37361	NanoSail-D2	3	Minotaur IV	11/20/2010			4000	1333.3	300	100	350
47	90021	RAX (37223)	3	Minotaur IV	11/20/2010			2833	944.3	300	100	350

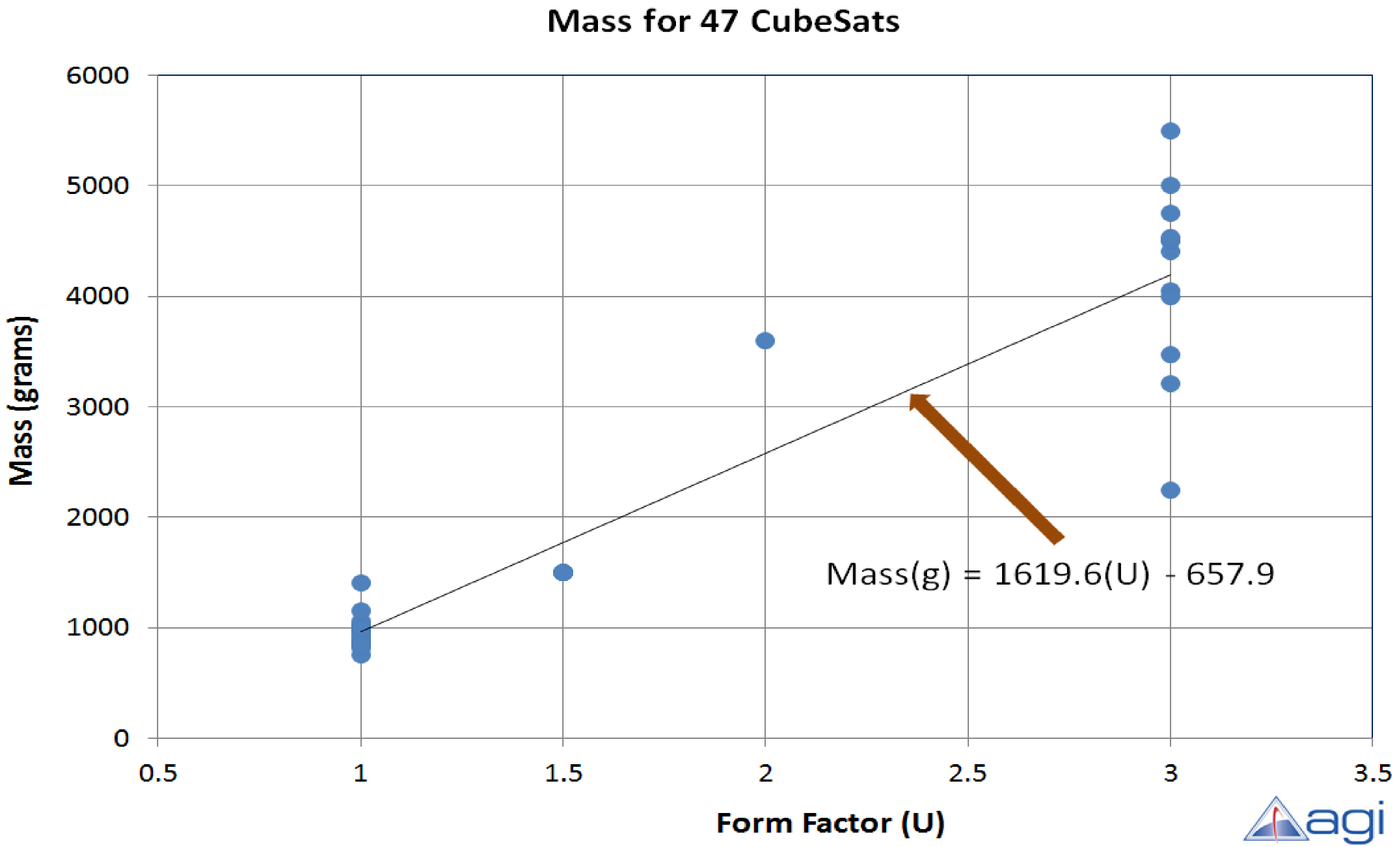
Credit: Kyle Leveque, SRI Intl.

Orbital CubeSats By Year



CubeSat Mass Statistic/Metric

- Can evaluate “Mass-per-U” metric/trend

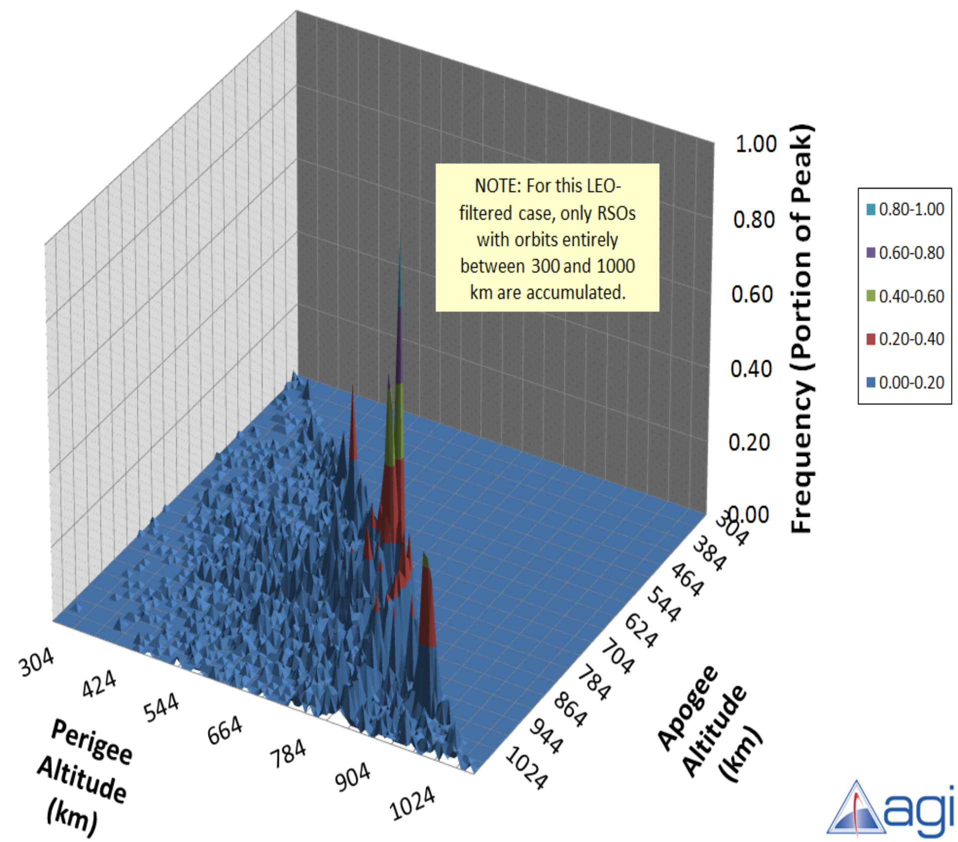


Resident Space Object (RSO) Distribution

- CubeSats coexist with “backdrop” of LEO population

RSO Perigee Altitude Distribution versus Apogee Altitude (LEO)

(8 km bins, 1957-2011, LEO Only, Inc: 0° - 110°, All RCS values)



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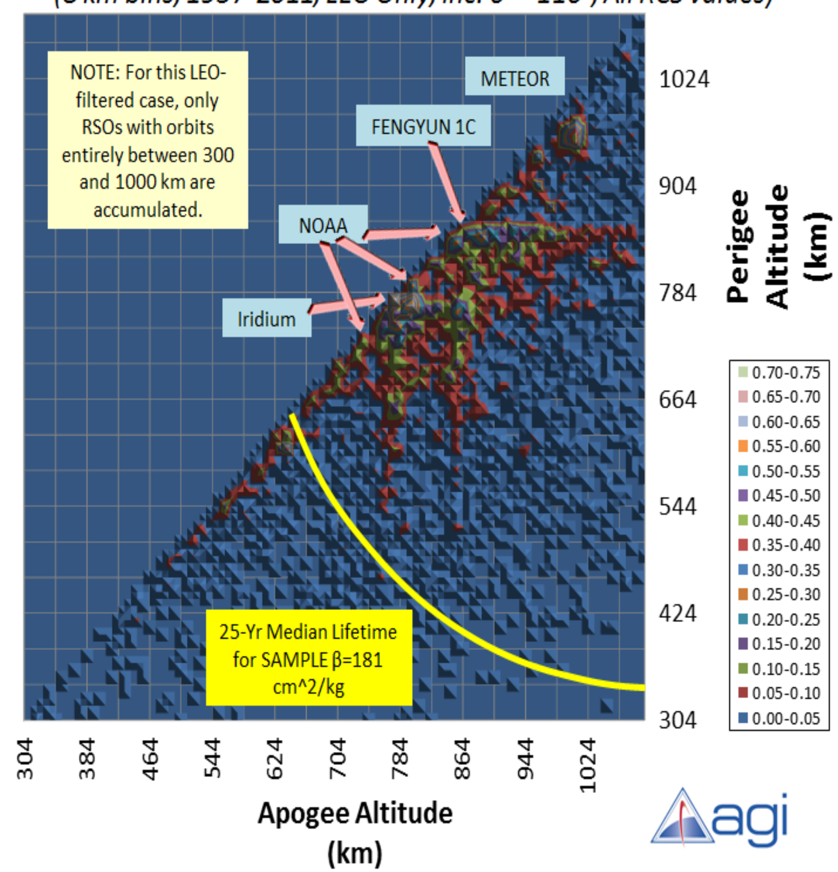
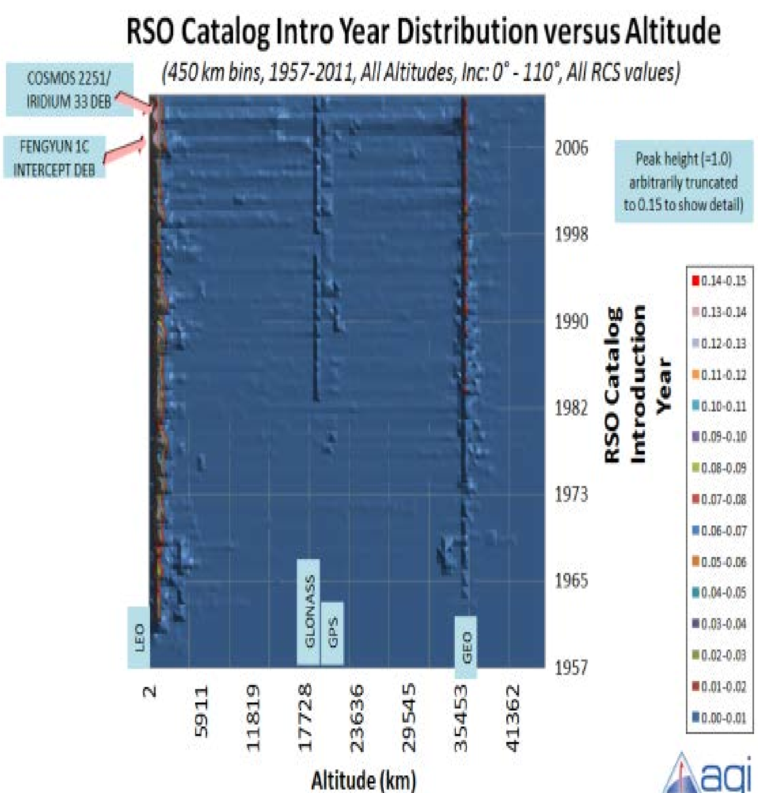


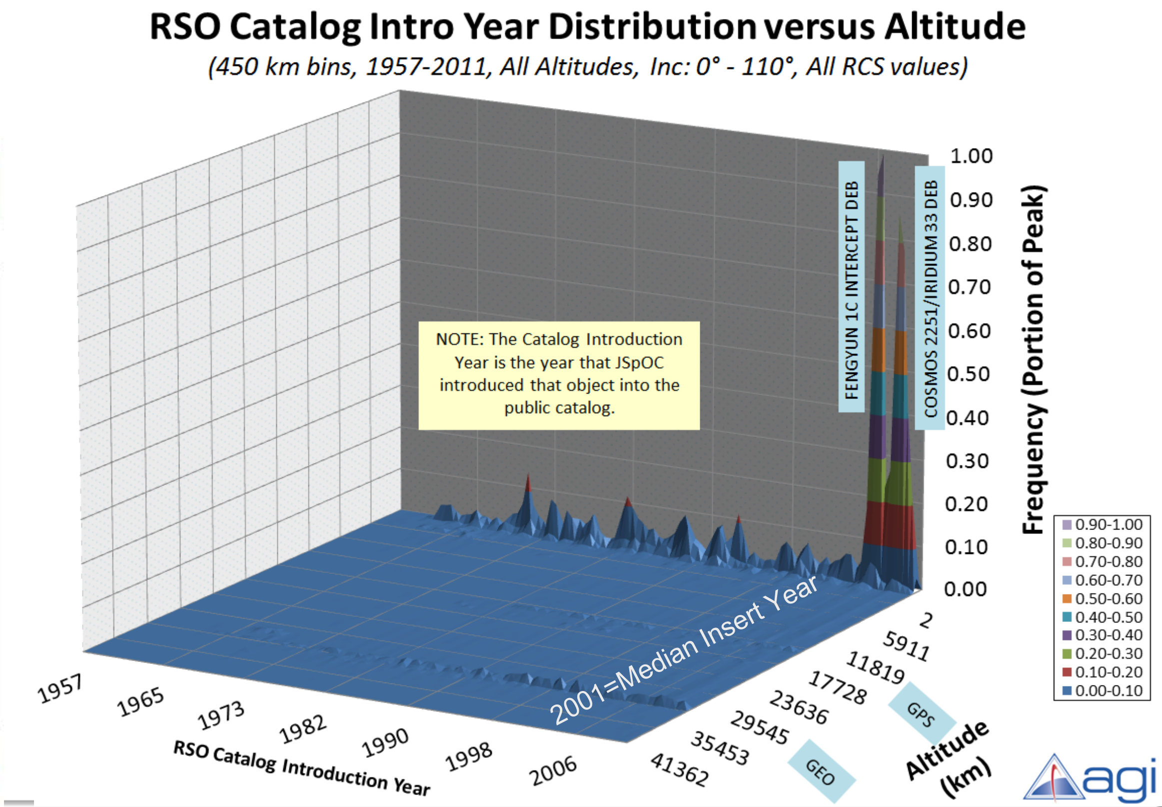
Space Debris Evolution

Credit: T.S. Kelso, 2010

Space Debris Evolution

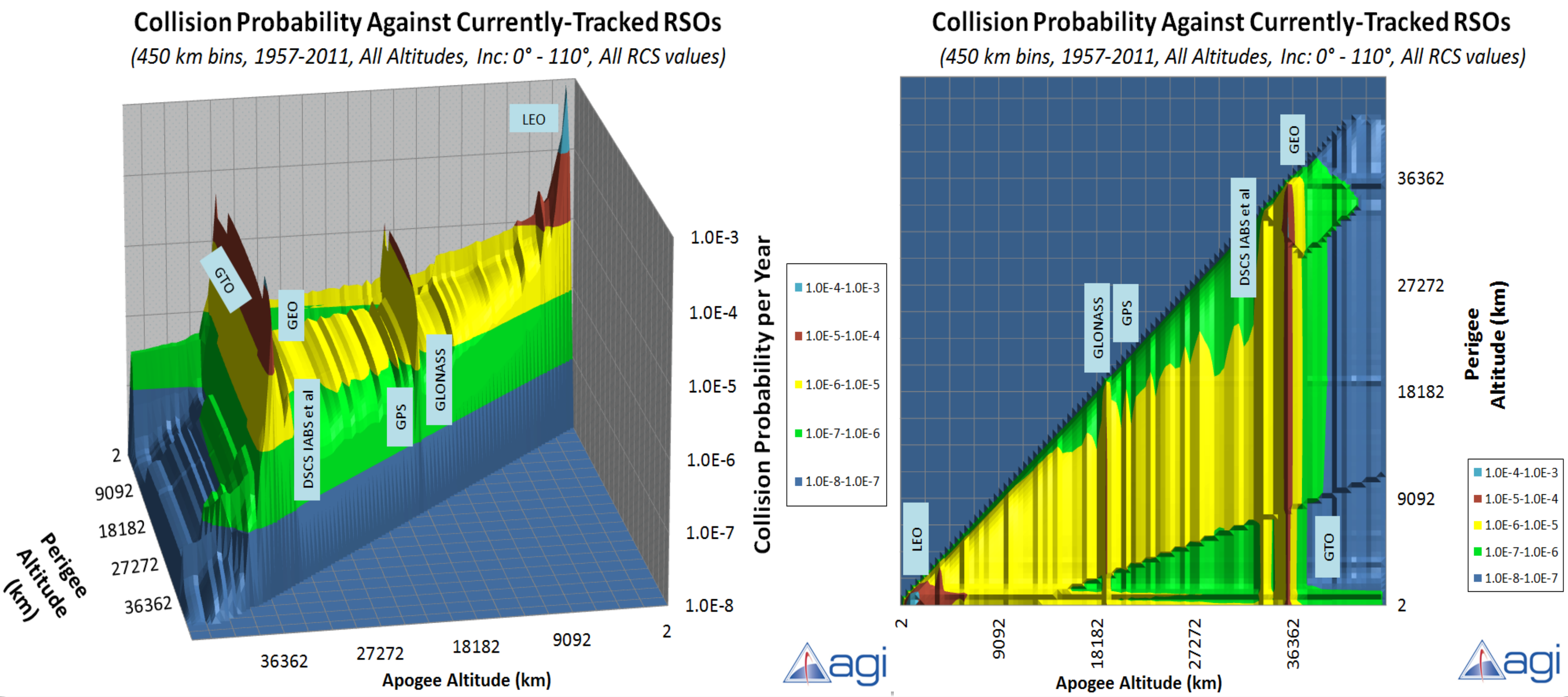
- Must address space debris issue without delay
- Space population increase by tracker introduction year
- Fengyun 1C & Iridium 33/Cosmos 2251 events = BAD!





Collision Probability

- Can derive collision probability by flight regime
  - Presumes movement thru shells (i.e., GEO least accurate)

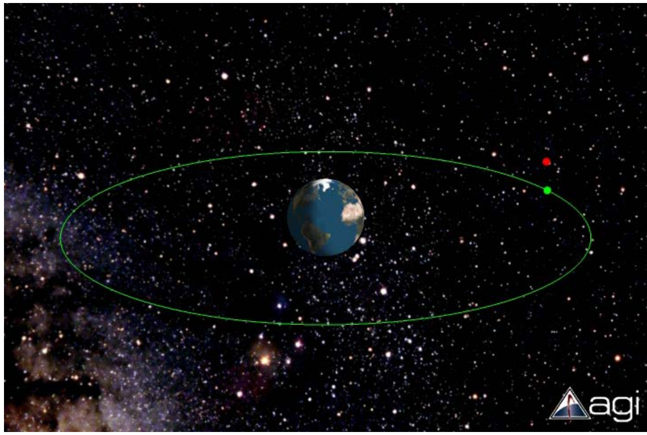


…Resulting in Debris Mitigation & Orbit Lifetime Standards

- Inter-Agency Space Debris Coordination Committee:
  - Analyses indicated ≈25-yr EOL limit helped mitigate debris
  - *Guideline*: Exit LEO-crossing regime (0-2000km) w/in 25 yrs
    - De-orbit or maneuver to suitably reduce orbit lifetime;
    - Dispose in orbit where drag/perturbations will limit lifetime;
- Orbital Debris Coordination Working Group (ODCWG)
  - coordinates conversion of IADC guidelines into ISO standards
- International Standards Organization (ISO)
  - ISO TC20/SC14/WG3 creates Space Operations standards
- 'Orbit Lifetime' deemed standards-worthy by ISO WG3
  - Published June 2011, authored by Oltrogge et al

Unique CubeSat Orbit Lifetime Aspects

- CubeSats relatively easy to scale up production
  - increases collision risk AND impacts other operators
- CubeSats provide unique opportunity for lifetime studies
  - 1U, 2U & 3U standardized form factors and mass properties
  - 47 CubeSats placed in orbit since 2003



- CubeSat orbit lifetime examined to:
  - Demonstrate ISO standards compliance
  - Characterize CubeSat ballistics
  - Evaluate predicted vs actual orbital decay
  - Predict future CubeSat orbit reentries

Let’s Promote Safe Use of Space!

- What appears to be a good use of space must be weighed against its ability to detract from future use of space
- Are “phased arrays” or “swarms” of CubeSats or picosatellites a good idea?
  - YES, if done right!
- Secondary payloads present CubeSat quandary

I was appalled by the article **Big benefits from tiny technologies** in the October 1996 issue (p. 38). Have the writers stopped to think about the implications of “thousands of satellite constellations orbiting, for example, at 700 km altitude”? For a long time I have been worried about such projects as Iridium, which only proposed 77 (though now I see it's 161!). And as for Teledesic...words fail me.

I have already suggested that future space travelers may have to pass through orbiting mine fields. Now what's suggested is even worse—orbiting dust storms!

Although I am understandably biased in favor of geostationary satellites, I feel that the benefits of LEO satellites are exaggerated. They have no power advantage over GEO satellites, if spot beams are employed, and their one undoubted superiority is in the reduced time delay. If space travel develops as we all hope it will, they may have to be banned in the next century, as a hazard to navigation.

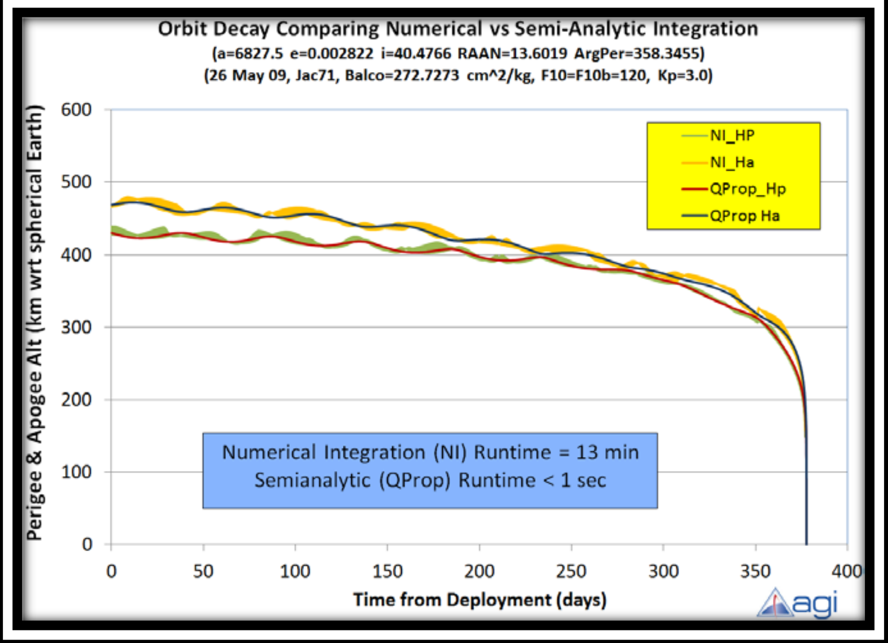
For the ultimate solution, see “3001: The Final Odyssey!”

Arthur C. Clarke
Sri Lanka

agi CSSi Center for Space Standards & Innovation SRI International 1Earth Research, LLC

Many Orbit Lifetime Analysis Tools Exist:

- For this study, we examined:
  - Detailed numerical integration
  - QuickProp (QProp)
    - Supported development of published ISO Standard 27852, "Space systems — Estimation of orbit lifetime"
  - STK
  - NASA Debris Assessment S/W (DAS)



CubeSat Decay Characteristics

- Biggest drag uncertainties: space weather and *satellite ballistic coefficient*

$$\beta = \left[\frac{C_D \cdot Cross - Sectional\ Area\ (cm^2)}{mass(kg)} \right]$$

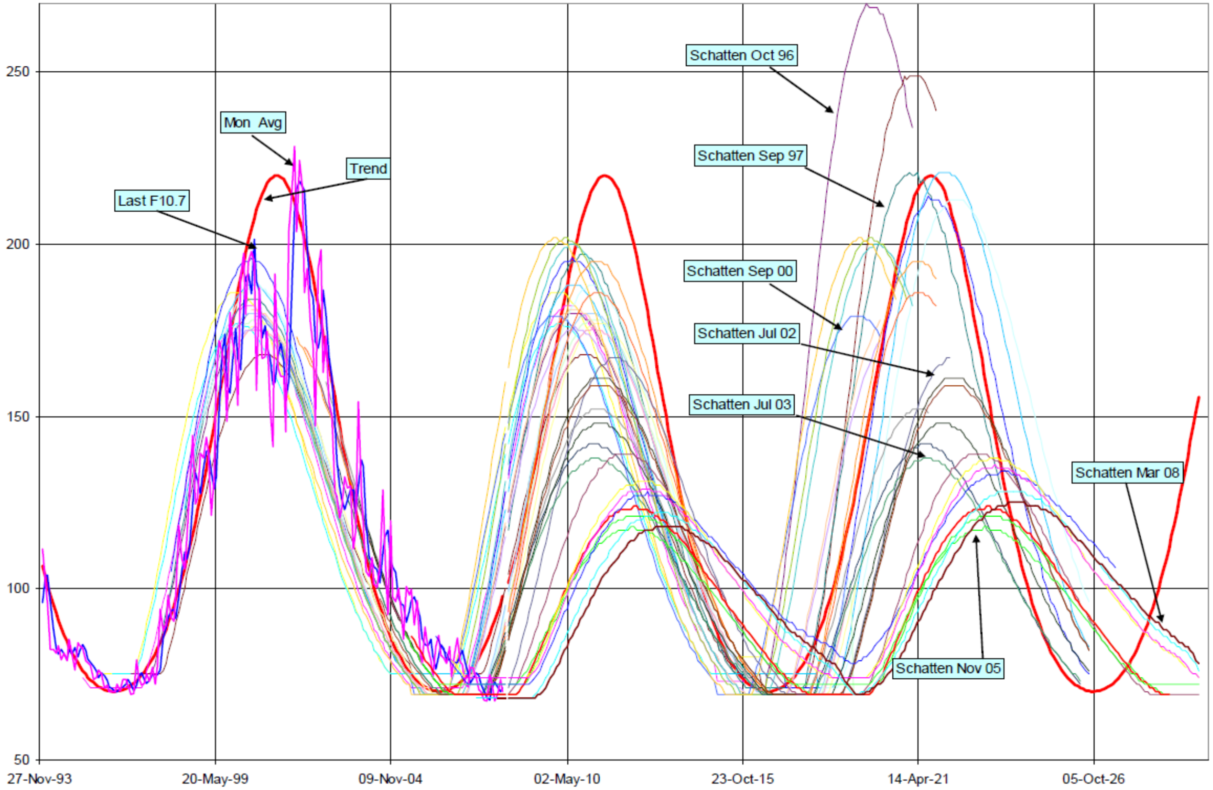
  - Mass is known at launch (exquisitely!)
  - Orbit-Averaged cross-sectional area for tumbling object can be estimated via a composite flat plate model (with plates S_1, S_2, etc.) as:

$$CSA = \frac{1}{2}[S_1 + S_2 + S_3\ (+ S_4 + \cdots)]$$

  - Can then estimate C_D values which match observed CubeSat orbital decay rate

Space Weather Considerations for Orbit Lifetime

- Comparison of solar weather sliding predictions (Vallado/Finkleman) show our inability to predict the future
- ISO standard 27852 provides guidance for space weather modeling



Attempts to "Predict" Space Weather On A 25-Year Scale Are Doomed to Fail!

Figure 5. Recent Solar Flux Predictions. Several Schatten predictions of solar flux are shown along with the polynomial trend. Notice that each Schatten prediction covers about two solar cycles and the latest predictions suggest a lower solar max for cycles 24 and 25.

Drag Coefficient

- C_D has practical limit between 2 and 4.
- By coupling actual (historical) space weather and CubeSat decay, we can determine if our orbit decay modeling yields consistent C_D estimation results.

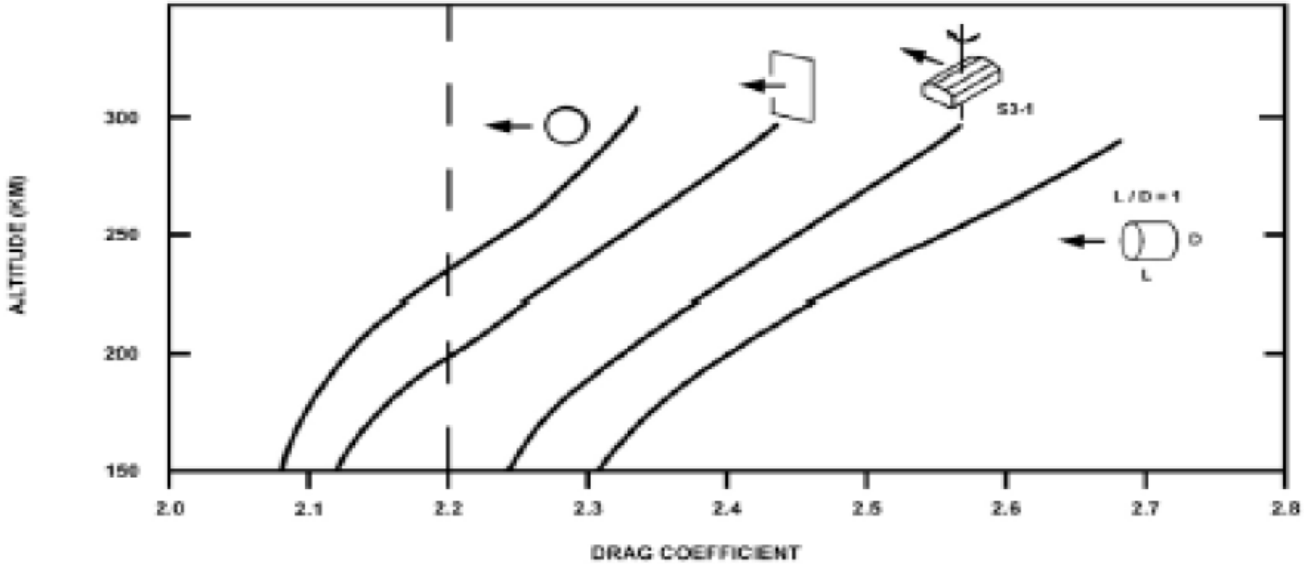
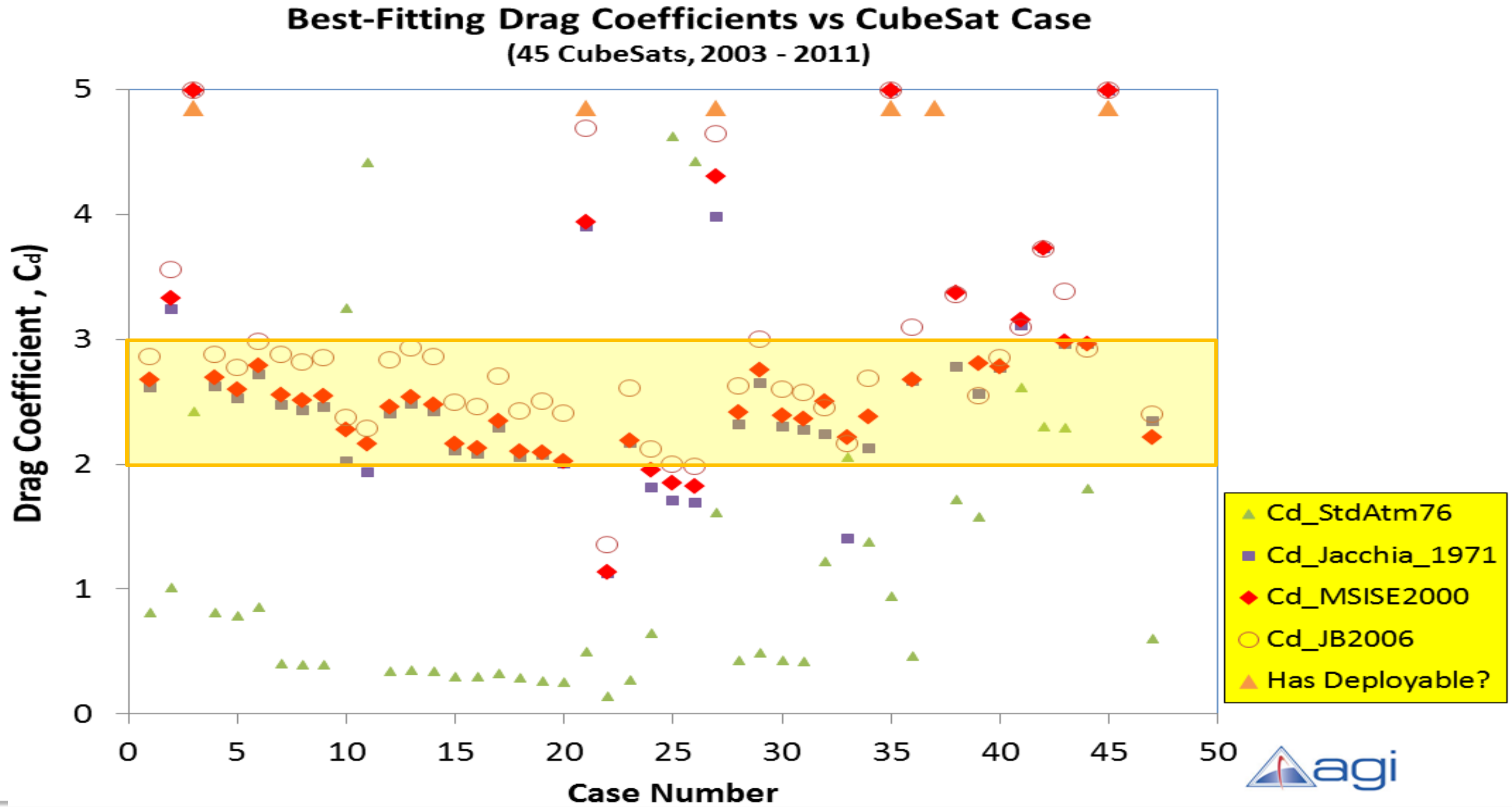


Figure 11: Coefficient of Drag Values. Sample cD values from Sentman (1961). There is a practical limit of values between 2.0 and 4.0.

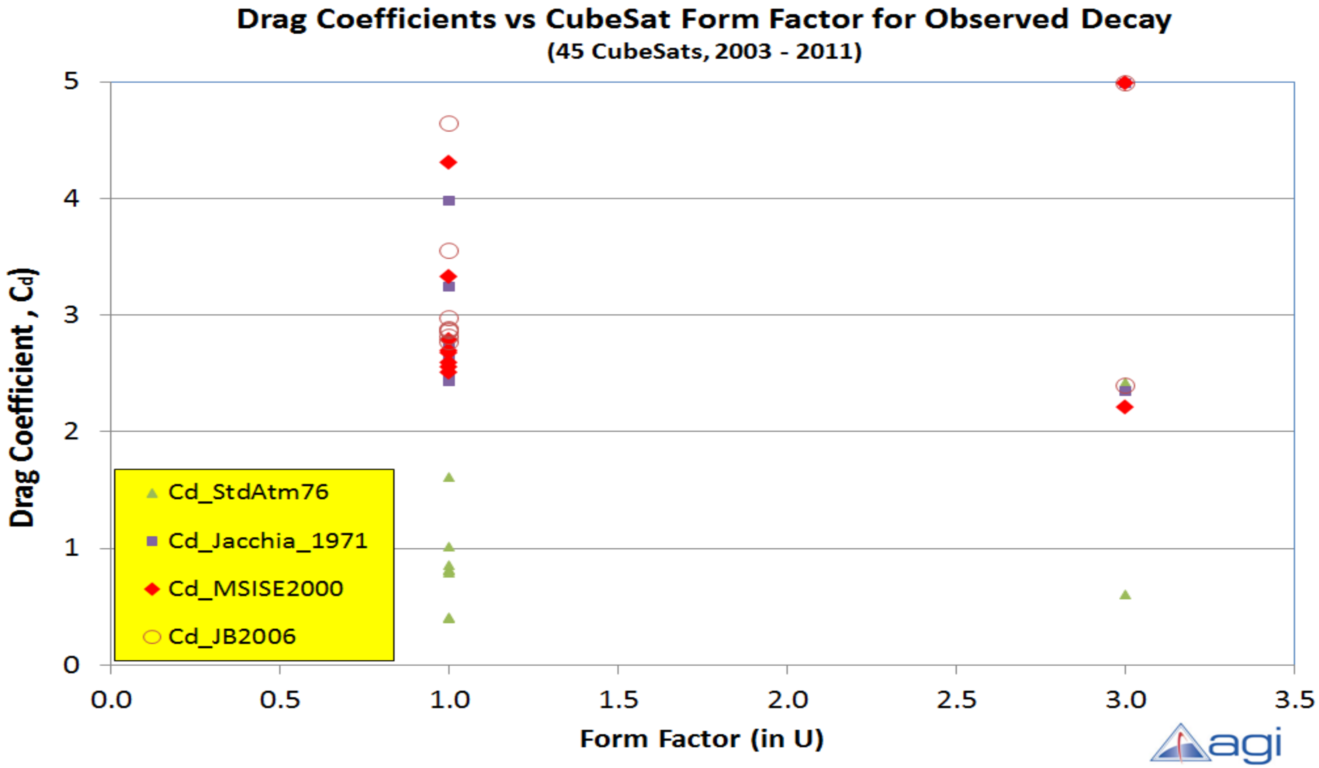
Drag Coefficient Estimation Results

- Typical C_D for good convergence ranged from 2.0 – 3.0
- “Out-of-family” C_D values attributable to deployables



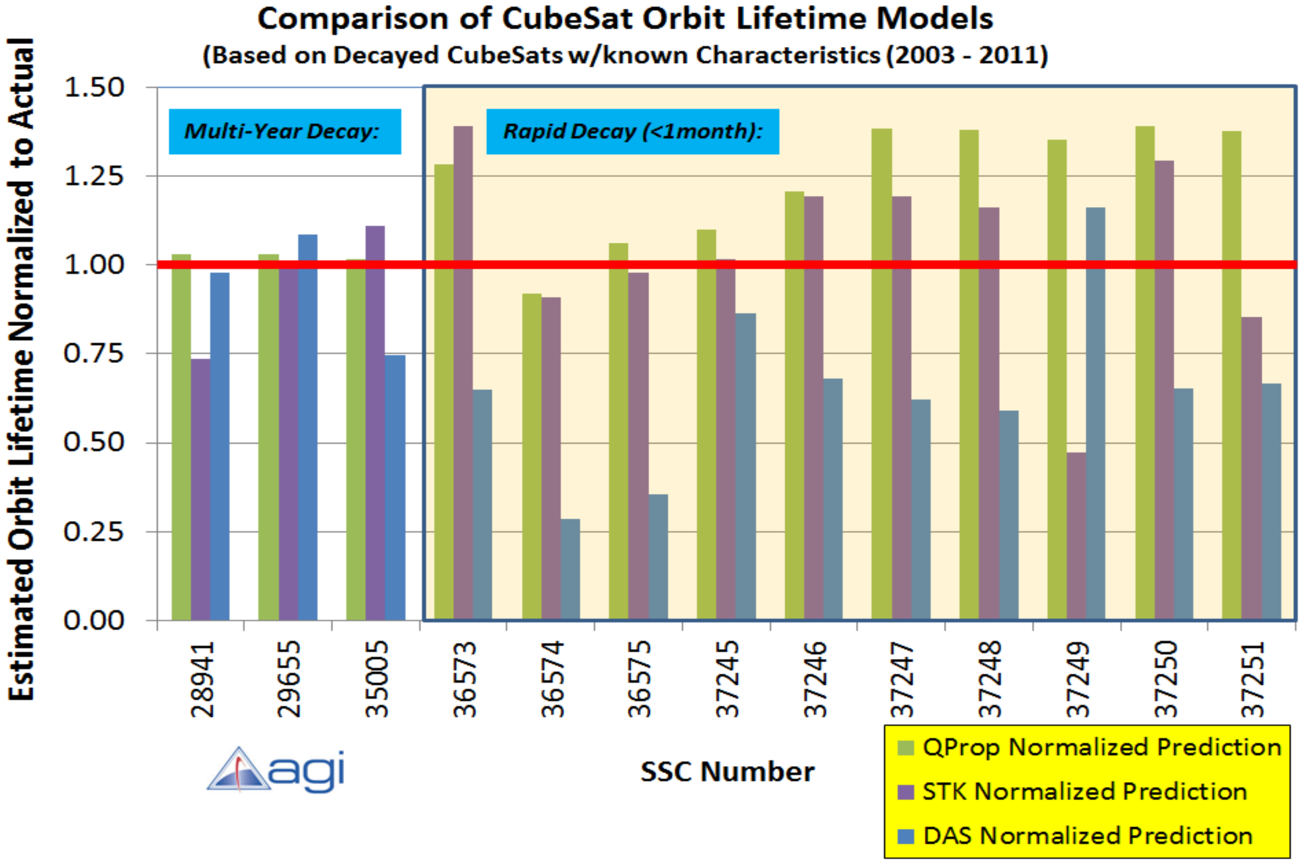
Drag Coefficient Variability vs Form Factor

- Jacchia '71 and MSIS C_D tends to be more representative
- Insufficient data to draw conclusions on 1U vs 3U



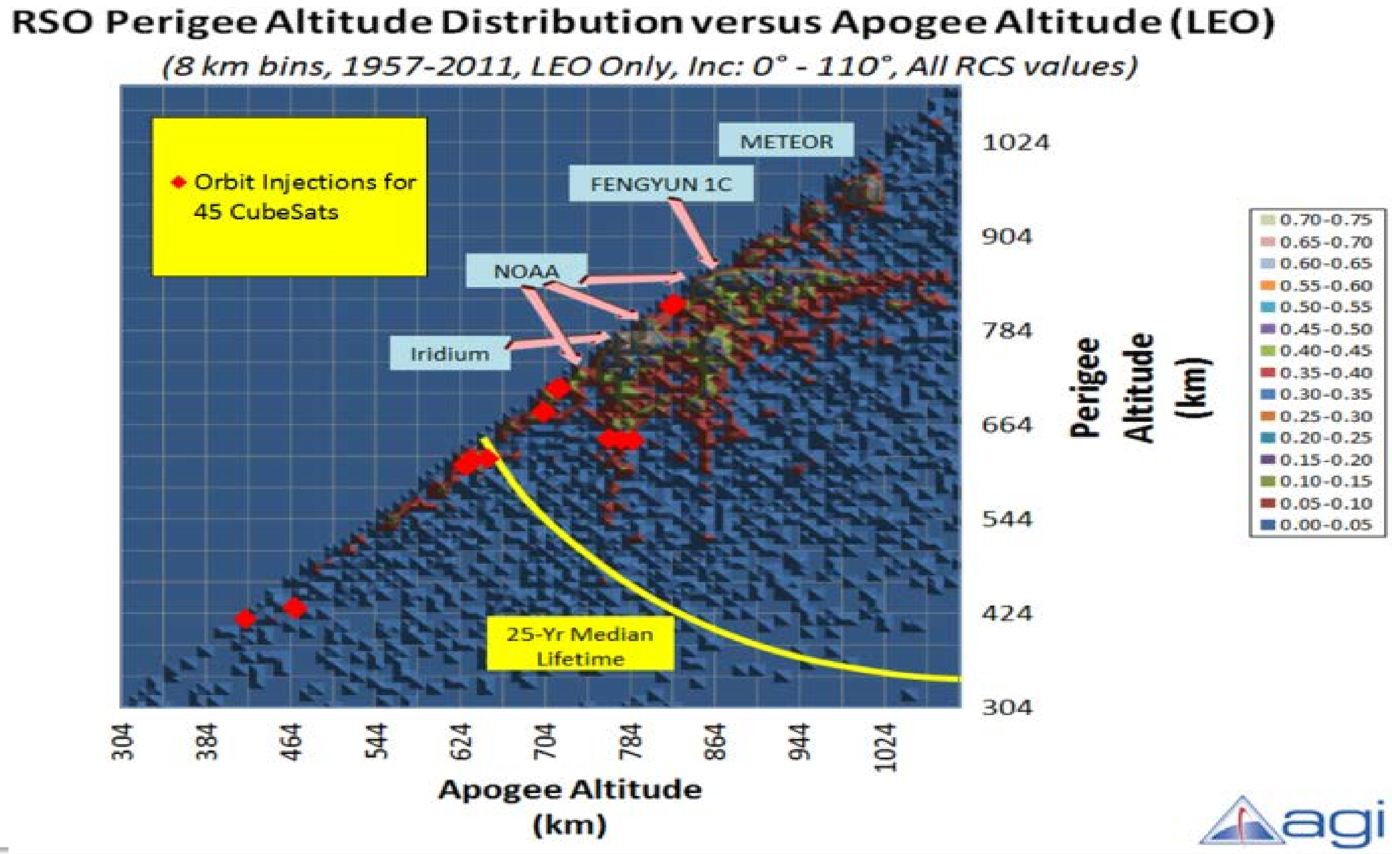
Orbit Lifetime Comparison

- Can compare various models vs actuals
  - STK and QProp worked well, especially on long-term decays
  - NASA DAS didn't do as well (lacks C_D input)



So How is CubeSat Community Doing?

- Only 38% of all CubeSats launched to-date have orbit lifetimes that protect our fragile space environment



Orbital Debris Mitigation is Our Responsibility!

- Long-term vitality and viability of CubeSat community may depend upon ability to actively address:
  - ***Real and perceived orbital debris threat posed by CubeSats to government and commercial space operations***
- Can address by:
  - Taking leadership roles in orbital debris assessment
  - Invoking effective mitigation strategies:
    - Avoid mission orbits that prevent near-term natural decay
    - Limit post-mission orbit lifetime to prevent debris population growth
  - Ensuring all current and future orbital debris mitigation standards, guidelines and directives are met
    - Help develop Stds: "Operational Guidance for Small Satellites"

Conclusions

- CubeSat community: must adhere to <25-yr post-EOL
  - Flying as secondary payloads makes this difficult
  - Explore drag enhance, solar sail & ConOps for <25 yrs
- Final analysis: Not many CubeSat decays to examine!
  - Long decays: C_D of 2.4 (Jacchia '71 & MSIS '00) & 2.8 (JB2006)
  - Do not use exponential/static drag models!
  - STK, QProp most accurate; lack of DAS C_D input problematic
- Future work:
  - Test GOST, GRAM, JB2008 (w/native coeffs) on new decay data
- Thanks to CubeSat community for providing vehicle data

Is the CubeSat Community Considering Reentry?