Goddard Space Flight Center

AN EARLY STUDY OF DISPOSAL OPTIONS FOR THE HUBBLE SPACE TELESCOPE

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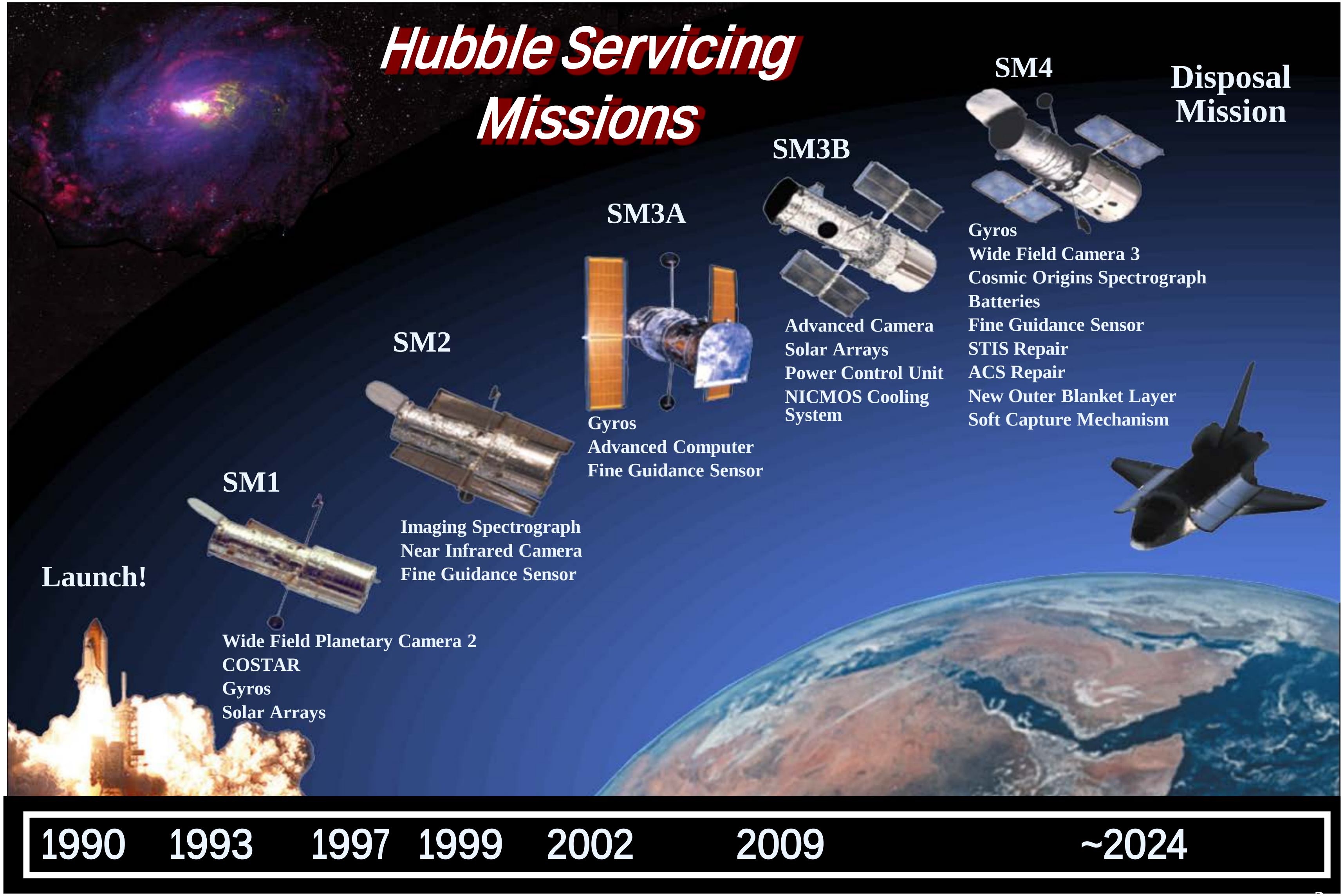
Space Shuttle STS- 31 Deployment of HST on April 25, 1990

Purpose for the Study

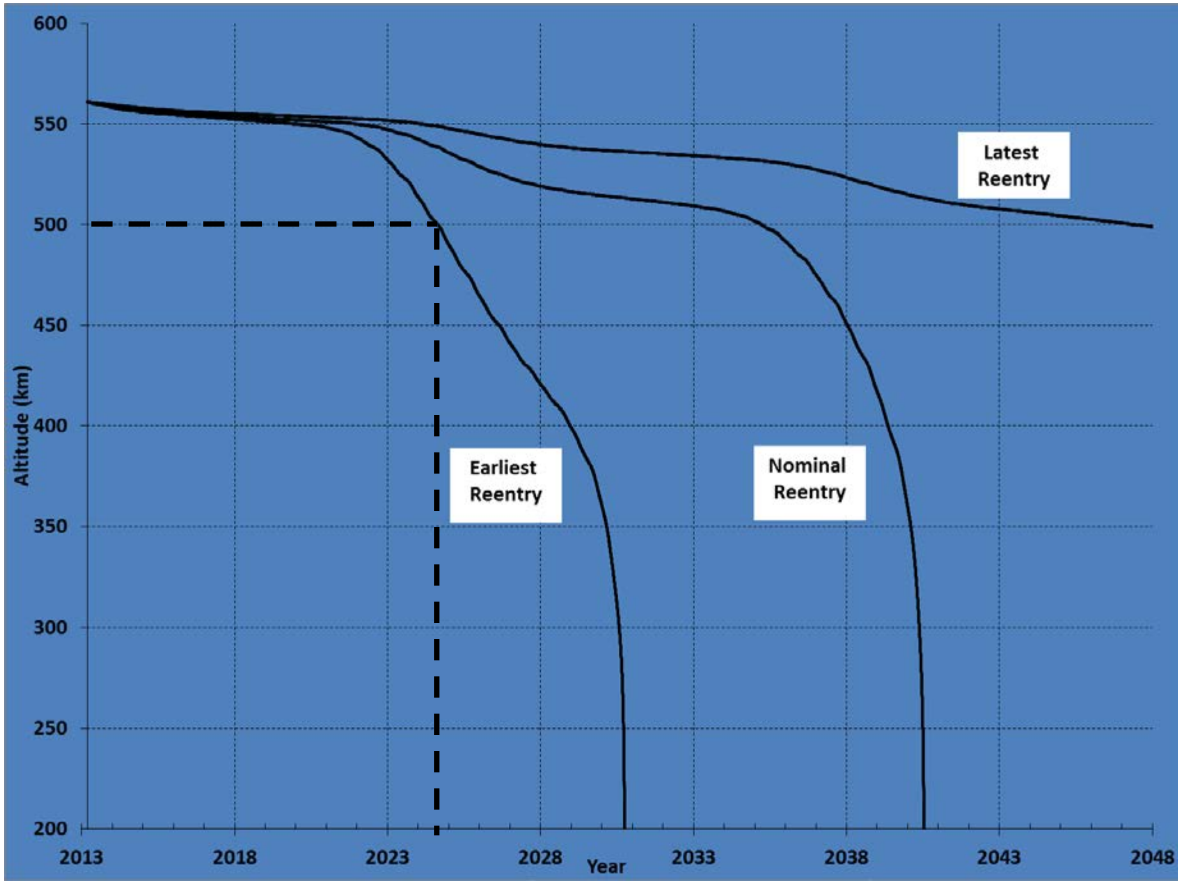
- **Known Reentry Risk**
  - HST has no propulsion system; the orbit is constantly decaying
  - Uncontrolled reentry is expected in 2040 +/- ~10 years
  - Risk to the ground population is ~ 0.004 (about 1:250)
- **Disposal Options**
  - Controlled reentry is one obvious option to study
  - Are there other disposal options available?
- **Study Topics**
  - Are there practical options to controlled reentry for the disposal of HST, and what are the costs and benefits to each in terms of risk to both the public and the shared orbital environment?
  - What is the necessary schedule for successful disposal of HST?


Hubble Servicing Missions
Launch!
SM1
Wide Field Planetary Camera 2
COSTAR
Gyros
Solar Arrays
SM2
Imaging Spectrograph
Near Infrared Camera
Fine Guidance Sensor
SM3A
Gyros
Advanced Computer
Fine Guidance Sensor
SM3B
Advanced Camera
Solar Arrays
Power Control Unit
NICMOS Cooling System
SM4
Gyros
Wide Field Camera 3
Cosmic Origins Spectrograph
Batteries
Fine Guidance Sensor
STIS Repair
ACS Repair
New Outer Blanket Layer
Soft Capture Mechanism
Disposal Mission
1990
1993
1997
1999
2002
2009
~2024

HRSDM Foundations and Lessons

- **In March 2004, a design effort was undertaken to perform the Hubble Robotic Servicing and De-orbit Mission (HRSDM)**
- **Within one year, a full mission was designed through PDR**
  - Rendezvous and capture HST
  - Change out two science instruments and spacecraft bus hardware
  - Detach Servicing Module, leaving the Deorbit Module on HST
  - Controlled reentry some years later
- **Much of the background research and planning is still applicable**
  - Tumble rates
  - Rendezvous and capture techniques
  - Propulsion system sizing
- **This effort spawned the current Satellite Servicing efforts at GSFC**

Orbit Decay Profile for HST



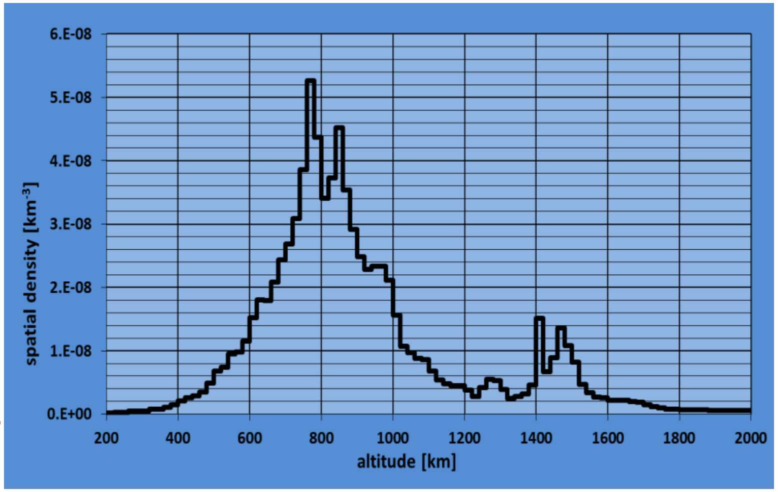
- HST tumble rates are acceptable above 500 km
- Earliest credible date for reaching 500 km is 2024
- Disposal decisions do not need to be made immediately

Orbit Change Options Considered

- **Drag Enhancement**
  - Can accelerate the reentry of HST
  - Insufficient control to positively determine the reentry location
  - Methods included balloon, mist, sail, tether
  - Most still require rendezvous and capture
- **Laser Nudging**
  - Insufficient thrust to make substantial orbit changes
- **Propulsion**
  - Chemical propulsion – monopropellant and bipropellant
  - Electric propulsion
  - Electrodynamic tether
  - All are feasible, and have potential applications for HST disposal
  - All require rendezvous and capture

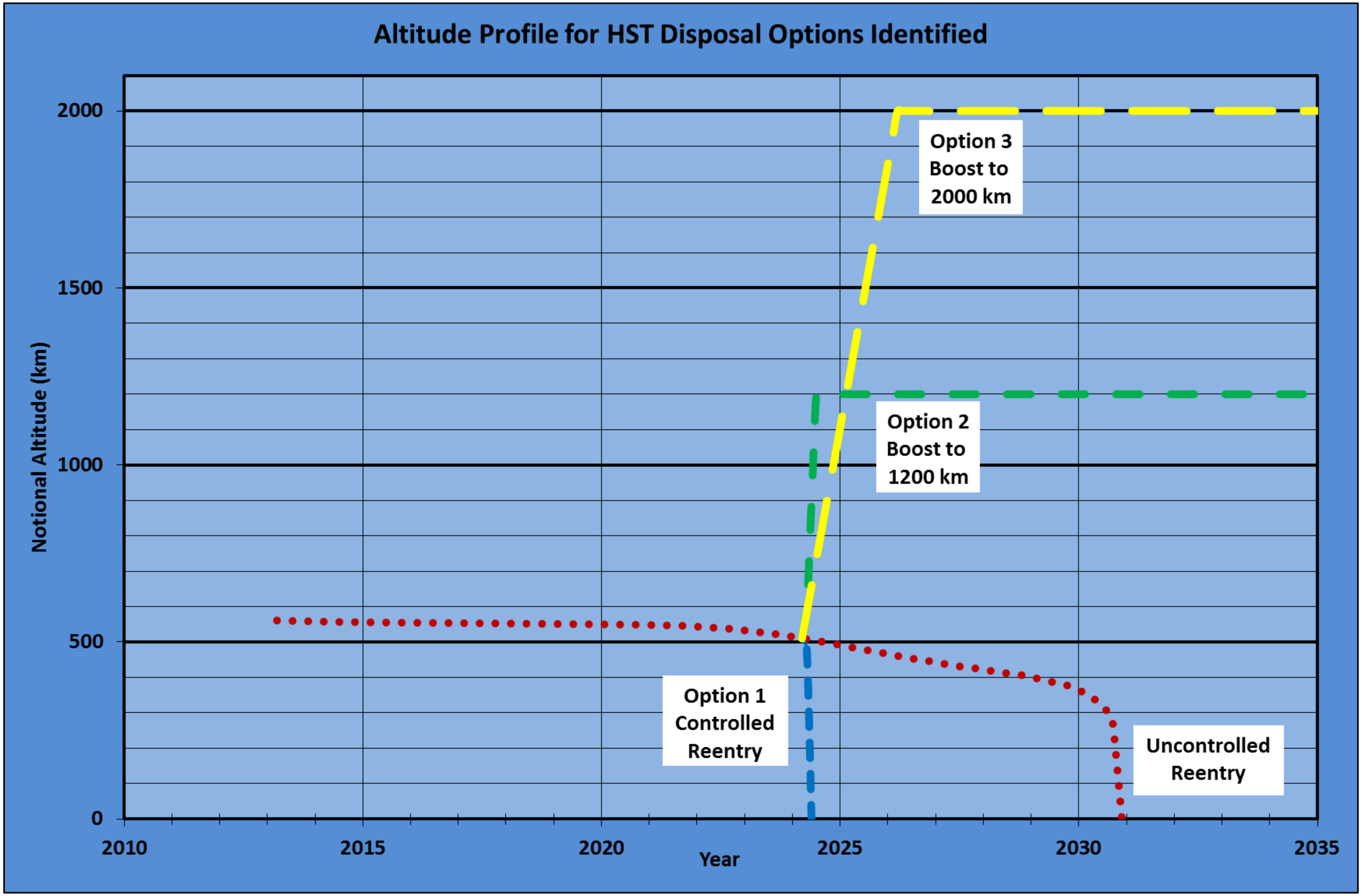
Disposal Location Options Considered

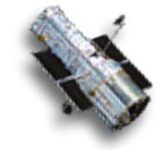
- **Option 1: Controlled Reentry**
  - Bipropellant propulsion to 50 km perigee and ocean reentry
  - Removal from orbit at least 6-10 years before natural decay
  - High profile event, with great consequences for anomalies
- **Option 2: Boost to 1200 km**
  - Highest practical altitude for chemical propulsion
  - Very low existing debris density
  - Long-term stable orbit
  - **Incompatible with existing guidelines**



- **Option 3: Boost to 2000 km**
  - Electric propulsion or electrodynamic tether
  - Longer time to reach the final orbit
  - Naturally circular resulting orbit, meets existing guidelines

Feasible Options that were Identified

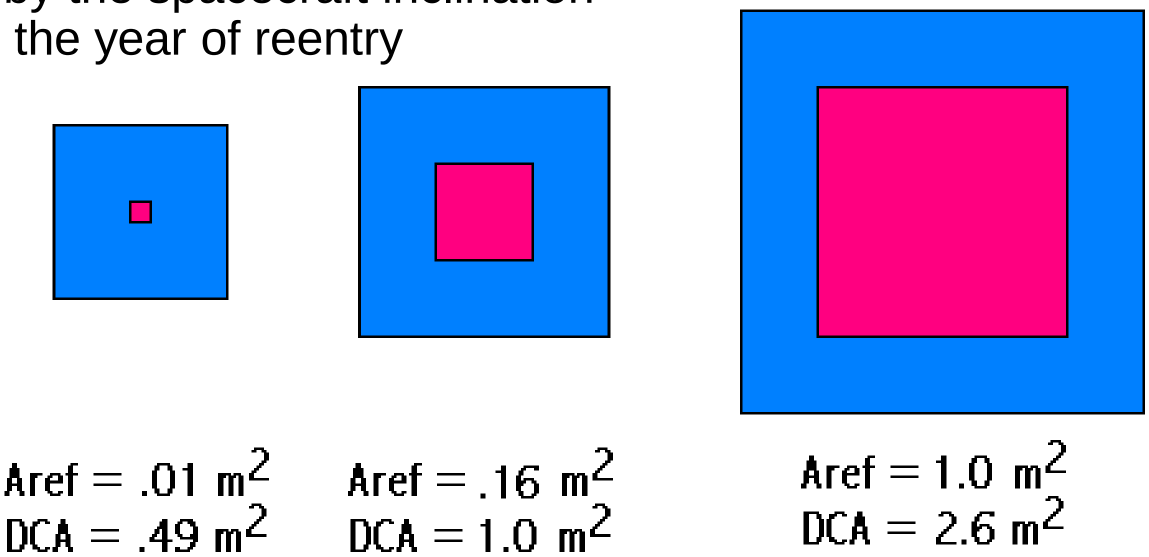




Reentry Risk Assessment

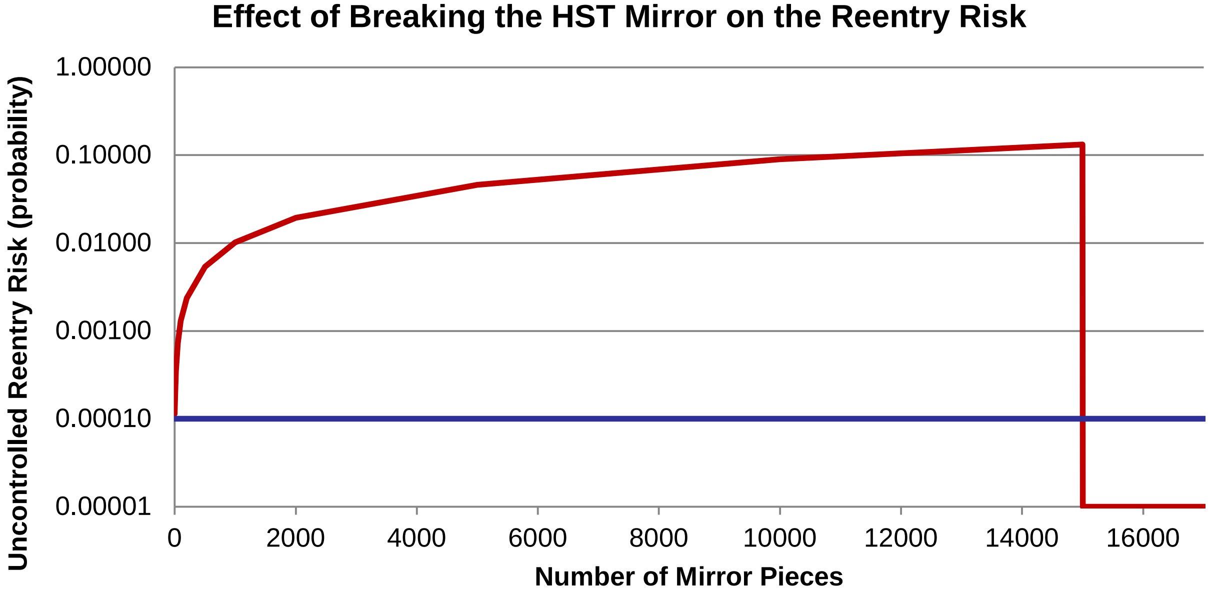
- **Reentering spacecraft is modeled, and assessed for survivors**
- **A 0.3 m “man-border” is essentially added to the circumference of each surviving object, to arrive at a Debris Casualty Area (DCA)**
- **The DCA for all surviving objects is summed**
- **DCA is the portion of the Earth surface at risk due to the reentry**
- **Reentry Risk R = DCA x ρ_{pop}**
  - ρ_{pop} is the average population density in the latitude band bounded by the spacecraft inclination extrapolated to the year of reentry

The largest red block is 100x the area of the smallest, but its DCA is only 5.3x that of the smallest block: 100 smaller pieces would be ~19x worse than the same size large piece.



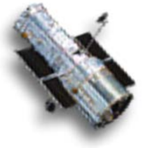
Disposal by Intentional Breakup

- **Why not just 'blow it up'?**
- **Examining just the Main Mirror – ULE Glass, survives reentry**
  - Even whole, it exceeds the reentry risk requirement by itself
  - Each additional piece creates a higher probability of hitting a person
  - Until pieces are smaller than ~60 grams, they are dangerous
- **Makes the reentry risk worse unless all resulting particles are very small**
  - 60 grams ≈ 15,000 pieces
  - How do you ensure that no pieces bigger than 60 grams survive?
  - Also need to consider the rest of the telescope



Total Reentry Risk for HST Disposal

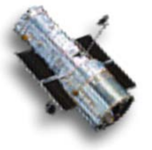
- **HST is a special case, because of the external actions necessary for disposal**
- **Σ $DCA_{outcome} \times \rho_{pop} \times P_{outcome}$**
- **Sum of all of the possible outcomes**
  - Launch vehicle fails
  - Capture successful, but disposal fails
  - Disposal is successful
- **Same basic idea for all 3 scenarios**
  - Probability varies
  - DCA varies, but always 0 if disposal is successful
  - Reentry year varies → population density varies



Reentry Risk Assumptions

In case of failure after capture, any of the options would represent an increased amount of hardware, and an increased reentry risk How much?

- **Uncontrolled Reentry baseline DCA (from ORSAT) = 195 m^2**
- **Controlled Reentry**
  - Four Ti propellant tanks, COPV pressurant tanks: ~12 m^2
  - Additional surviving components: ~13 m^2
  - Total DCA = 195 m^2 +25 m^2 = 220 m^2
- **Raise to 1200 km: same equipment as Controlled Reentry**
- **Raise to 2000 km**
  - One Ti propellant tank: ~3 m^2
  - Additional surviving components: ~7 m^2
  - Total DCA = 195 m^2 +10 m^2 = 205 m^2



Total Mission Risk Summary

Outcome - LV Failure	Option 0	Option 1	Option 2	Option 3
DCA (m^2)	195	195	195	195
Probability	1	0.02	0.02	0.02
Reentry Year	2030	2030	2030	2030
Population Density (people/km^2)	22.17	22.17	22.17	22.17
Risk	0.004323	0.000086	0.000086	0.000086
Outcome - Unsuccessful Disposal				
DCA (m^2)		220	220	205
Probability		0.0051	0.0051	0.0638
Reentry Year		2030	2030	2030
Population Density (people/km^2)		22.17	22.17	22.17
Risk		0.000025	0.000025	0.000290
Outcome - Successful Disposal				
DCA (m^2)		220	0	0
Probability		0.975	0.975	0.7087
Reentry Year		2024	N/A	N/A
Population Density (people/km^2)		0.00	0	0
Risk		0.000000	0.000000	0.000000
Total Risk	**0.004323**	**0.000111**	**0.000111**	**0.000376**
Odds of an injury	**1:231**	**1:8995**	**1:8995**	**1:2658**

Option 0
Do Nothing,
Uncontrolled Reentry

Option 1
Controlled Reentry

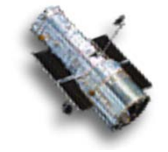
Option 2
Raise the orbit
to 1200 km

Option 3
Raise the orbit
to 2000 km

Reentry Risks

- **Do Nothing: Uncontrolled Reentry**
  - Reentry risk is estimated as 0.004323 for reentry in 2031 (1:230)
- **Option 1: Controlled Reentry**
  - If successful, reentry risk is zero
  - End-to-end risk is 0.000111 (1:9000), 39X reduction in overall risk
- **Option 2: Boost to 1200 km**
  - If successful, reentry risk is zero
  - End-to-end risk is 0.000111 (1:9000), 39X reduction in overall risk
- **Option 3: Boost to 2000 km**
  - If successful, reentry risk is zero
  - End-to-end risk is 0.000376 (1:2650), 11.5X reduction in overall risk

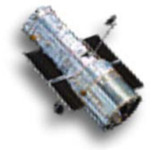
End-to-end risks include the reliability of the launch, rendezvous, and orbit change



Conclusions

Disposal Option	Advantages	Disadvantages
Uncontrolled Reentry	Zero cost	**Unacceptable public risk**
1) Controlled Reentry	**Lowest cost, Short time** Meets all disposal requirements Mature technology Accepted approach	Sensitive to errors **High visibility**
2) Boost to 1200 km	Short time Low cost **Insensitive to errors**	**Violates NASA requirements and International agreements** Higher collision risk
3) Boost to 2000 km	**Meets all disposal requirements** Insensitive to errors	Longest time **Highest cost** Technology maturity

- **There are feasible disposal options for HST, in addition to controlled reentry**
- **Each of the disposal options carries a different set of advantages, disadvantages, and challenges**
- **Drag enhancement, intentional breakup, and laser nudging were all found to be impractical approaches for the disposal of HST**
- **A decision on the ultimate HST disposal method and design can be delayed at least five years without reducing its success**



Questions

Please feel free to email questions to

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any time