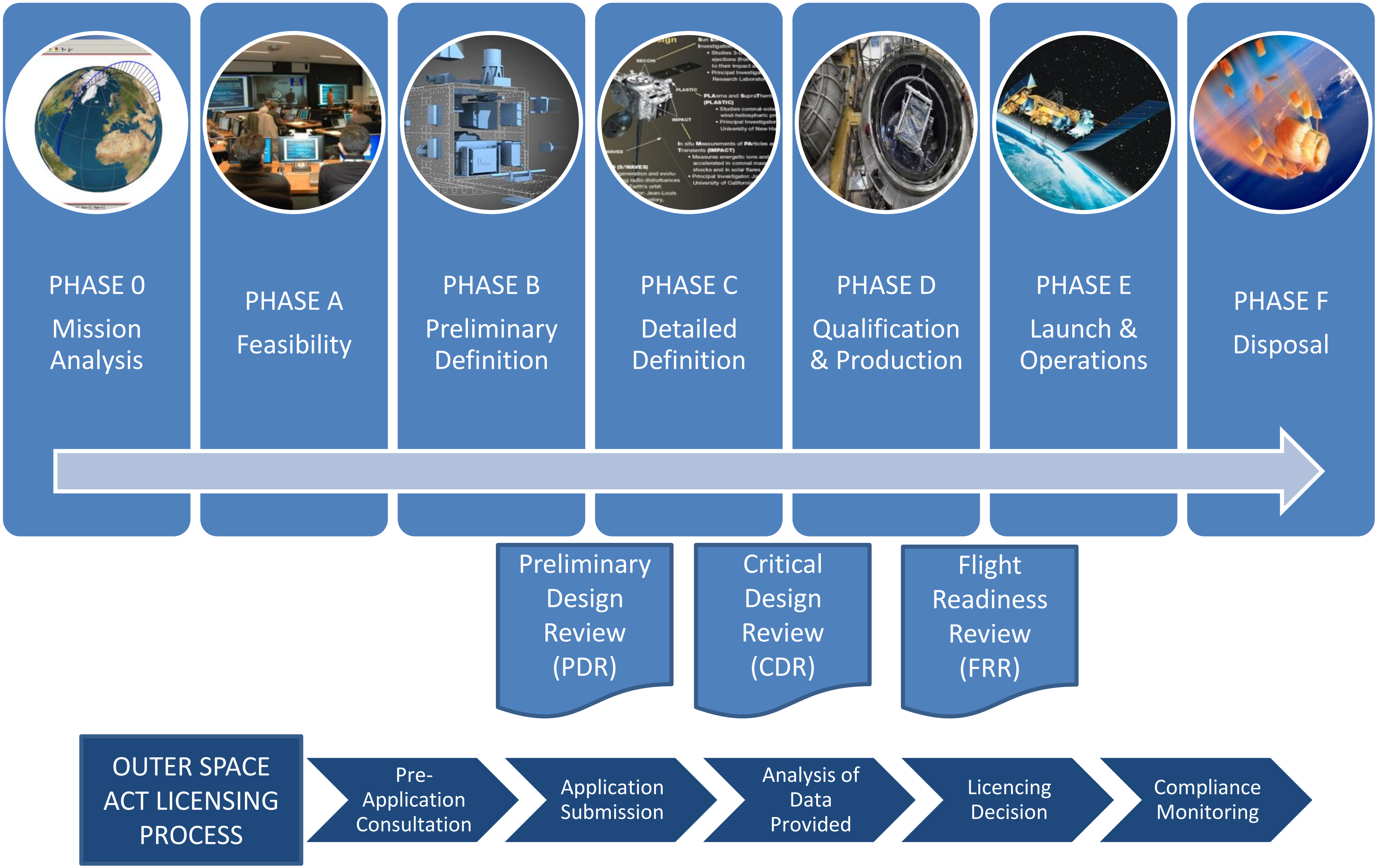
Dealing with Cubesats within the UK's Outer Space Act

Prof Richard Crowther

Chief Engineer, UK Space Agency


PHASE 0
Mission Analysis
PHASE A
Feasibility
PHASE B
Preliminary Definition
PHASE C
Detailed Definition
PHASE D
Qualification & Production
PHASE E
Launch & Operations
PHASE F
Disposal
Preliminary Design Review (PDR)
Critical Design Review (CDR)
Flight Readiness Review (FRR)
OUTER SPACE ACT LICENSING PROCESS
Pre-Application Consultation
Application Submission
Analysis of Data Provided
Licencing Decision
Compliance Monitoring

OSA LICENSING CONSIDERATIONS

WHO?	WHY?	WHEN?
HOW?	WHAT?	WHERE?

PRIMARY ELEMENTS OF OPERATIONAL RISK

HOW?

WHAT?

WHERE?

PRIMARY ELEMENTS OF OPERATIONAL RISK

LAUNCHER

PLATFORM/ PAYLOAD

OPERATING/ DISPOSAL ORBIT

MANAGING OPERATIONAL RISK

MANAGING OPERATIONAL RISK

THIRD PARTY LIABILITY

MANAGING OPERATIONAL RISK

THIRD PARTY LIABILITY

INSURANCE COVER

MANAGING OPERATIONAL RISK

THIRD PARTY LIABILITY

INSURANCE COVER

INFORMED TECHNICAL ASSESSMENT

MANAGING OPERATIONAL RISK

THIRD PARTY LIABILITY

INSURANCE COVER

INFORMED TECHNICAL ASSESSMENT

SYSTEM INFORMATION REQUIREMENTS

MANAGING OPERATIONAL RISK

THIRD PARTY LIABILITY

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SYSTEM INFORMATION REQUIREMENTS

OVERSIGHT AND COMPLIANCE MONITORING

MANAGING OPERATIONAL RISK

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RISKS MOVE FROM OPERATOR TO REGULATOR

MANAGING OPERATIONAL RISK

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RISKS MOVE FROM OPERATOR TO REGULATOR

Recover resource costs through increased licence fee?

MANAGING OPERATIONAL RISK

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OVERSIGHT AND COMPLIANCE MONITORING

RISKS MOVE FROM OPERATOR TO REGULATOR

Recover resource costs through increased licence fee?

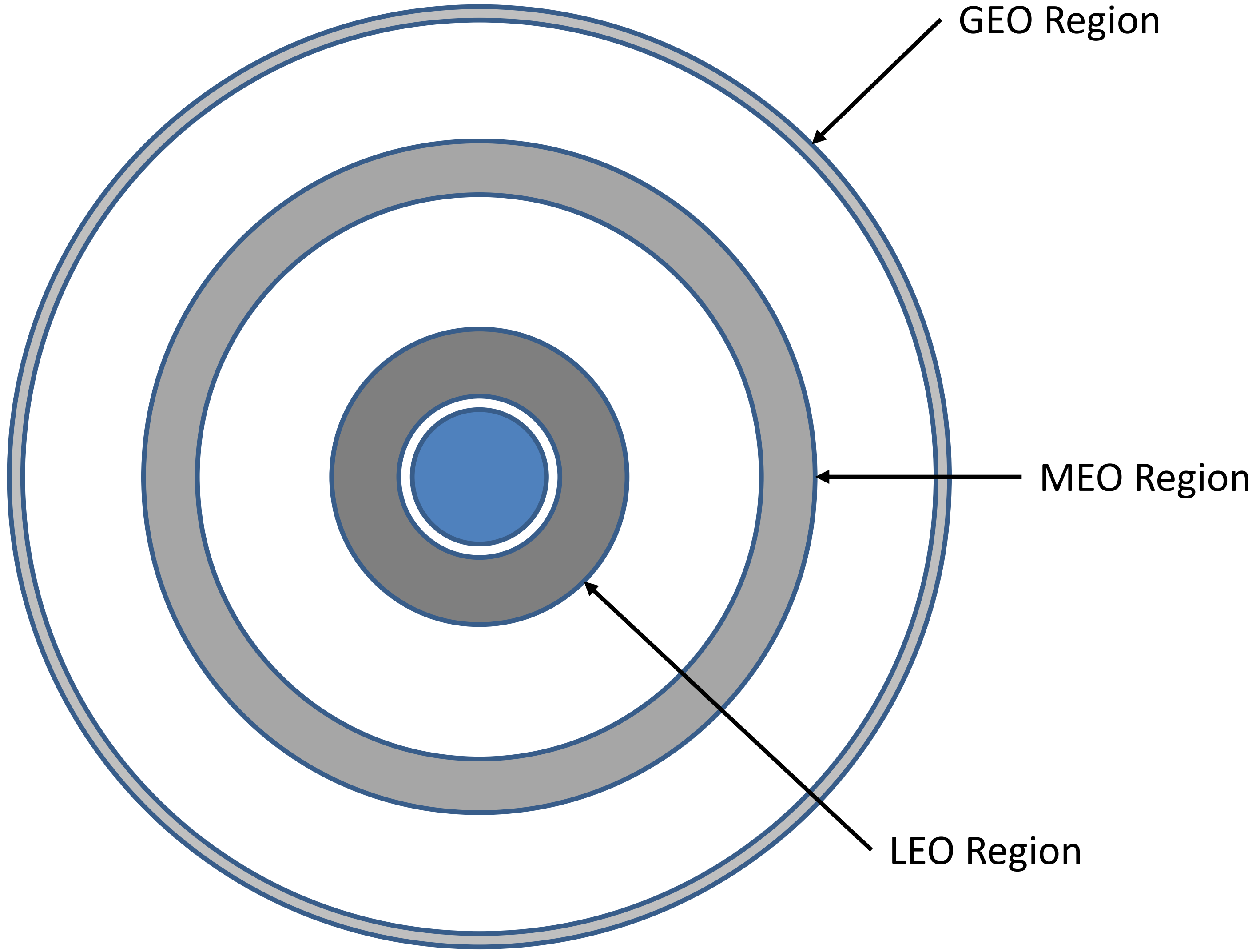
Complex fee structure to reflect equitable burden sharing?

ORBITAL REGIONS

Low Earth Orbit (LEO)
200 km<h<2000 km

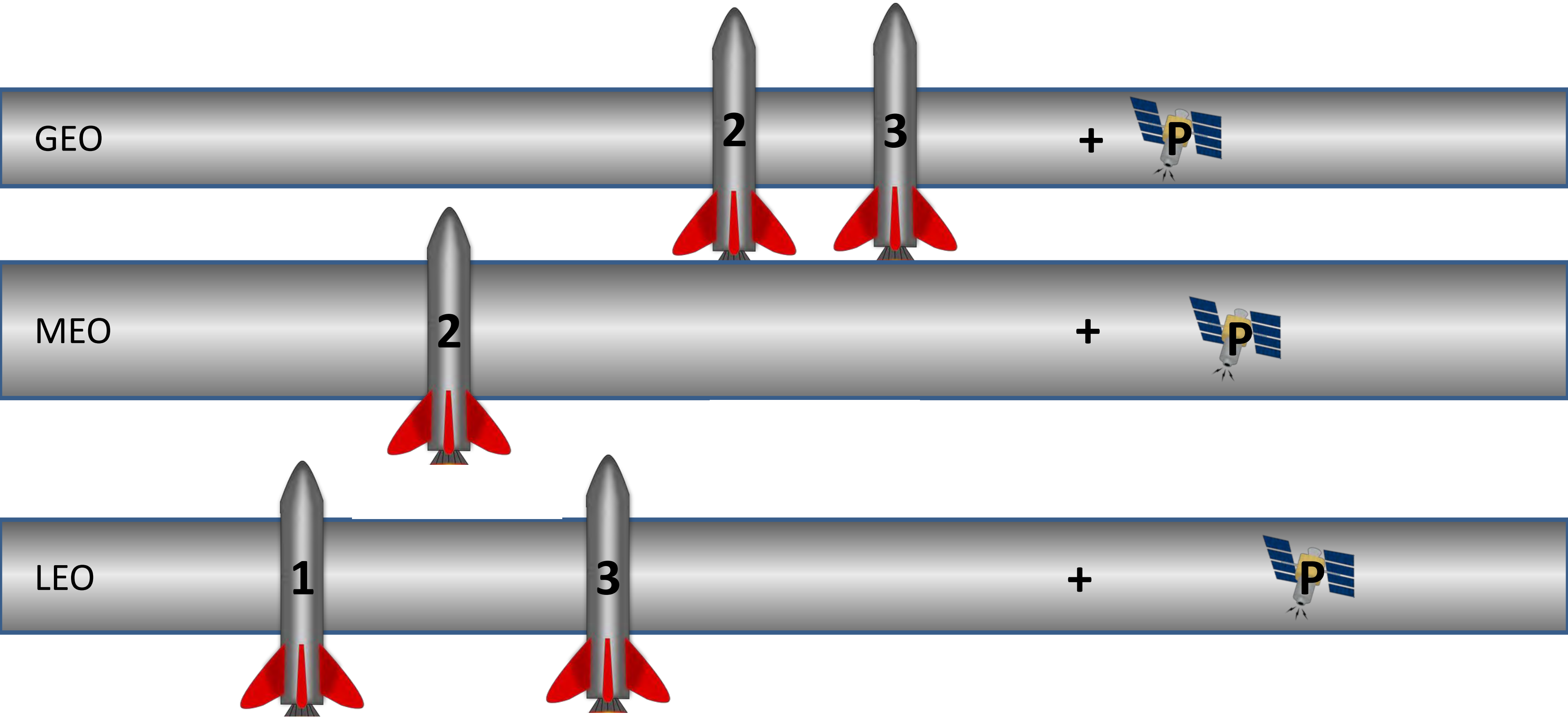
Medium Earth Orbit (MEO)
9000 km<h<25000 km

Geostationary Orbit (GEO)
34000 km<h<38000 km



Not To Scale

TECHNICAL ASSESSMENT STREAMLINING



1: PRIMARY LAUNCH ASSESSMENT (BASELINE)
2: SECONDARY LAUNCH ASSESSMENT (DELTA)
3: TERTIARY LAUNCH ASSESSMENT (EXACT REPEAT)
P: PAYLOAD ASSESSMENT (IN-ORBIT)

INFORMATION REQUIREMENTS OVERVIEW	1	2	3	P
Launch system description (including functionality, performance and operating characteristics)	✓			
Organisational Roles, Responsibilities and Authorities	✓			
Safety Processes and Procedures for Launch Operation	✓			
Flight Vehicle and Flight Safety System General Design and Qualification/Acceptance Testing (including historical and predicted reliability)	✓			
Accident Investigation Outcomes	✓			
General Mission Description	✓	✓		
Trajectory Information and Impact Points (to include launch trajectory and azimuth; ground track and land mass over-flight; sequence of major events; nominal impact locations; parking, operational and disposal orbits; operations; flight termination criteria)	✓	✓		
Risk Assessment to include Failure Analysis, Consequence Estimation, Risk Management approach and Safety Implementation	✓	✓		
Departures from primary baseline information submissions		✓		

PRIMARY ELEMENTS OF OPERATIONAL RISK

- LAUNCHER
- PLATFORM/ PAYLOAD
- OPERATING/ DISPOSAL ORBIT

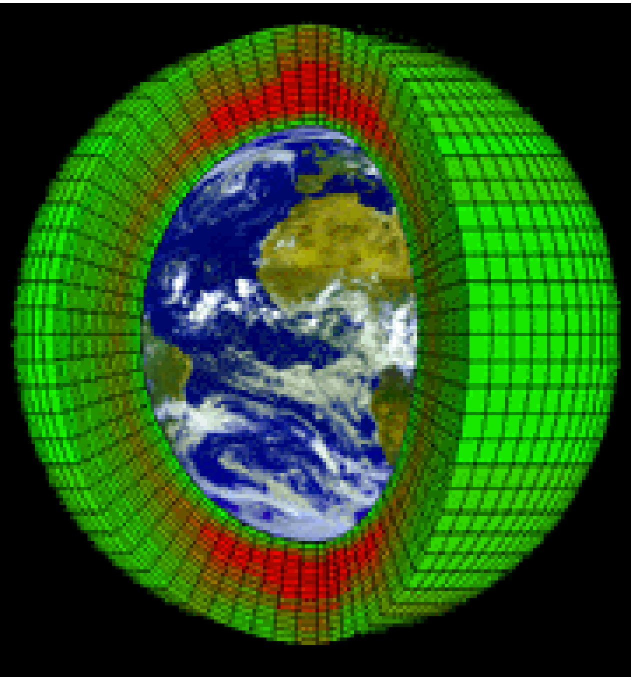
PRIMARY ELEMENTS OF OPERATIONAL RISK

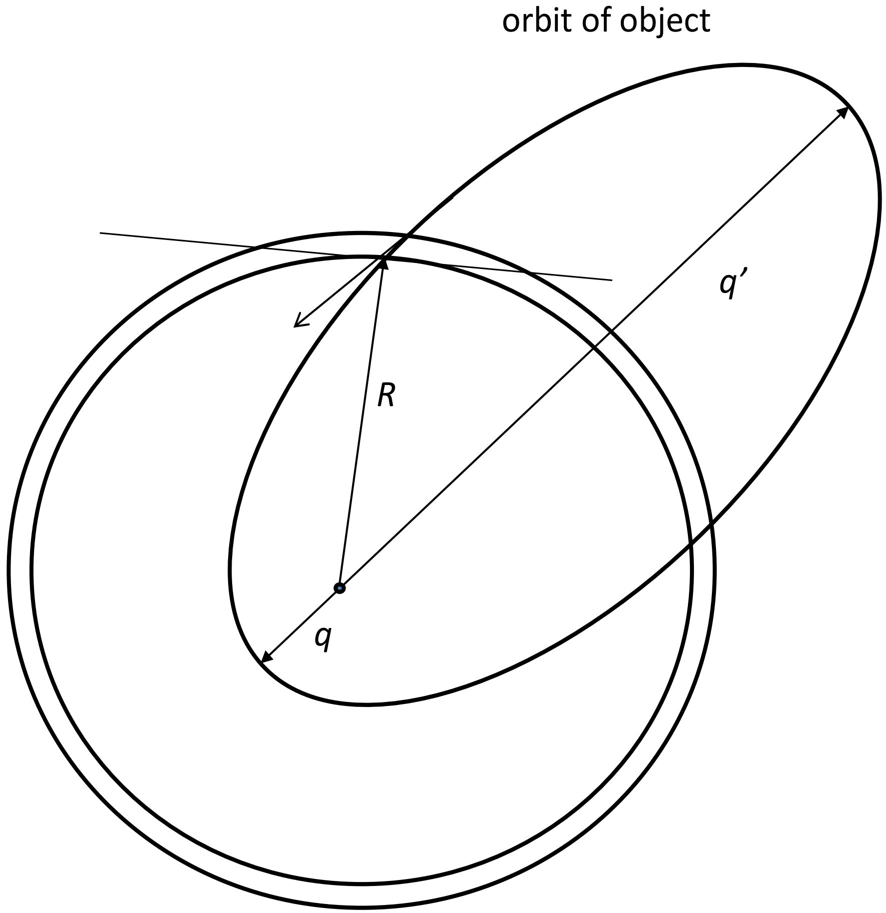
LAUNCHER

PLATFORM/ PAYLOAD

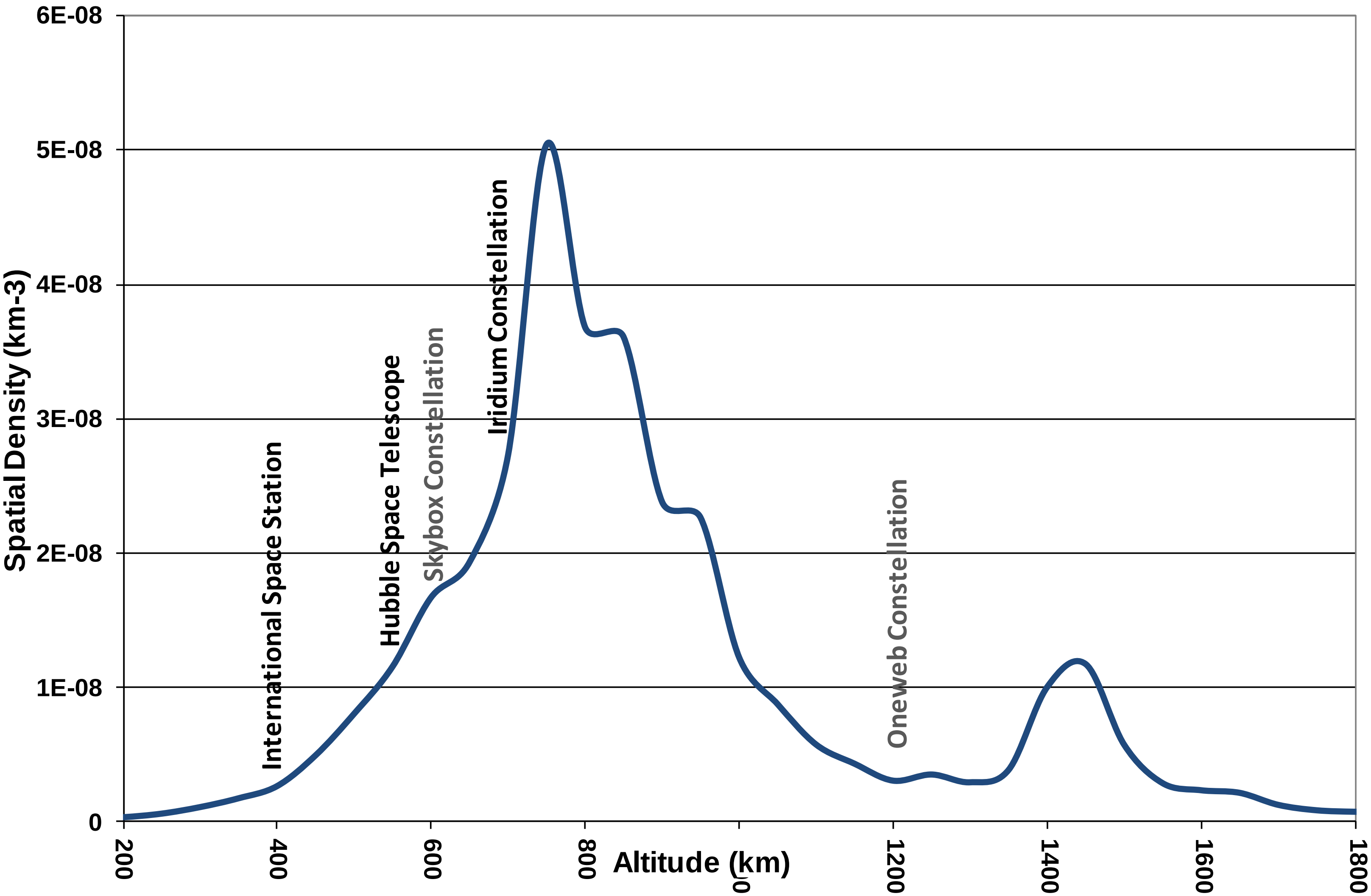
OPERATING/ DISPOSAL ORBIT

Spatial Density

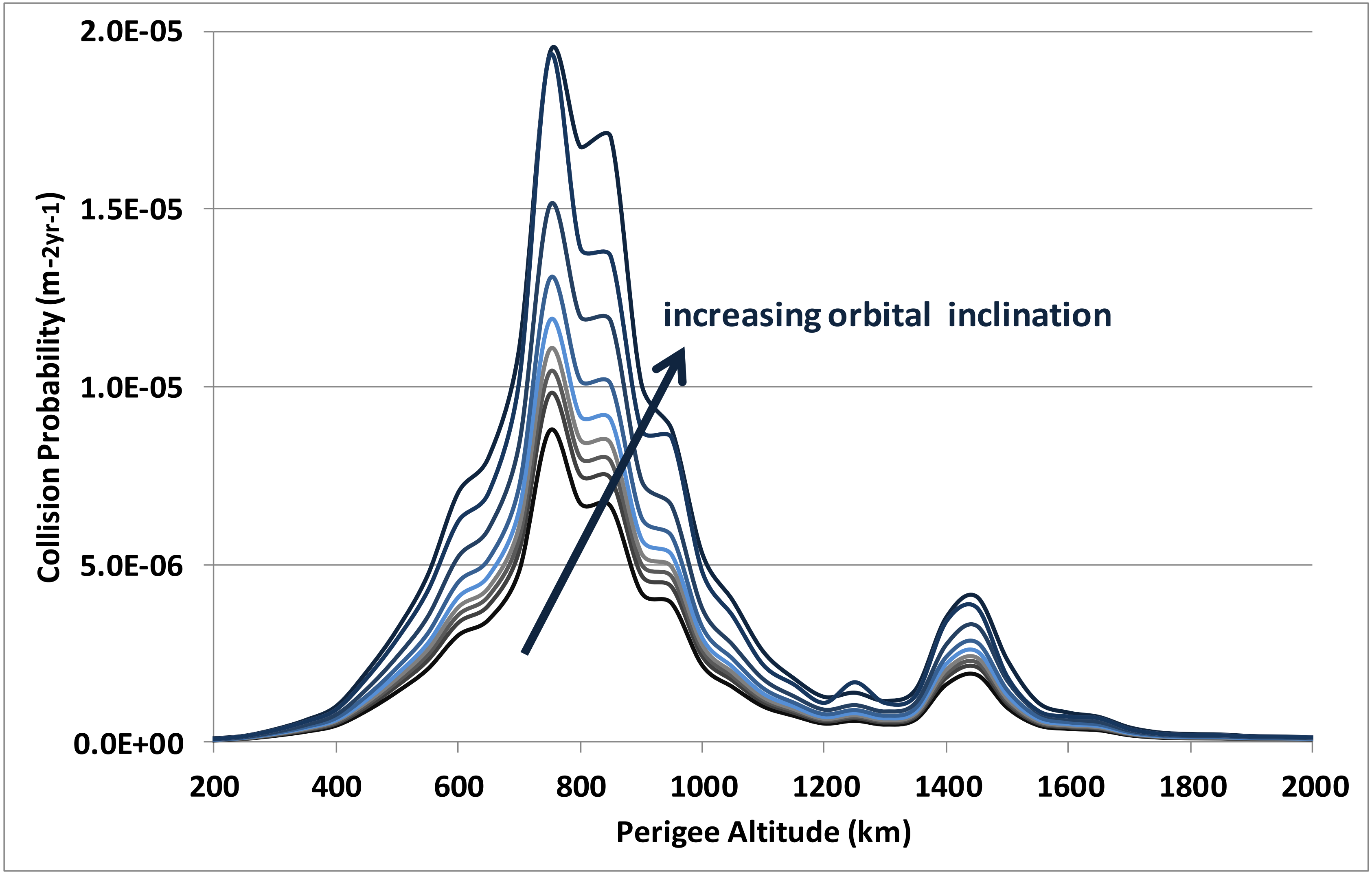




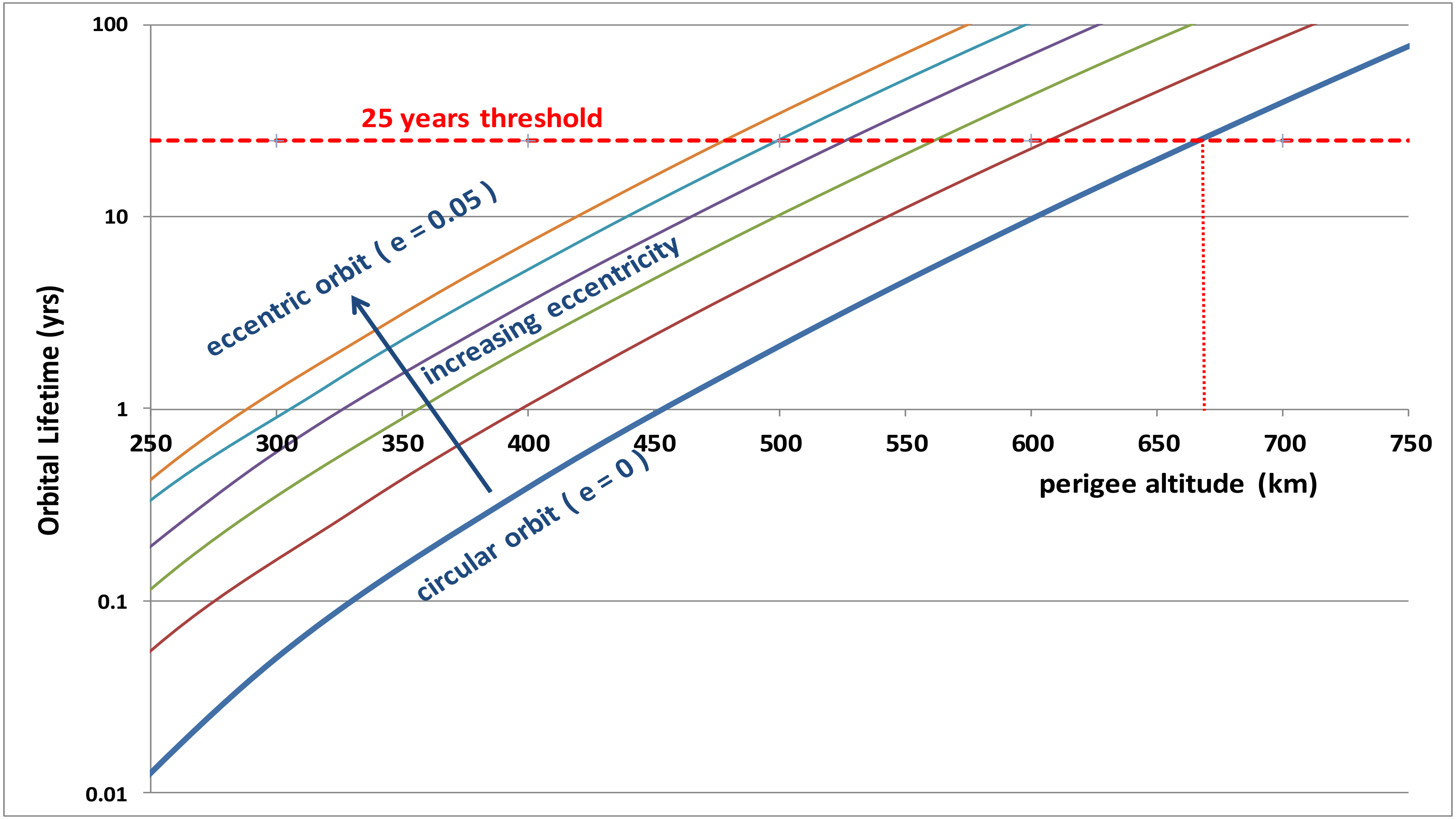
Spatial Density

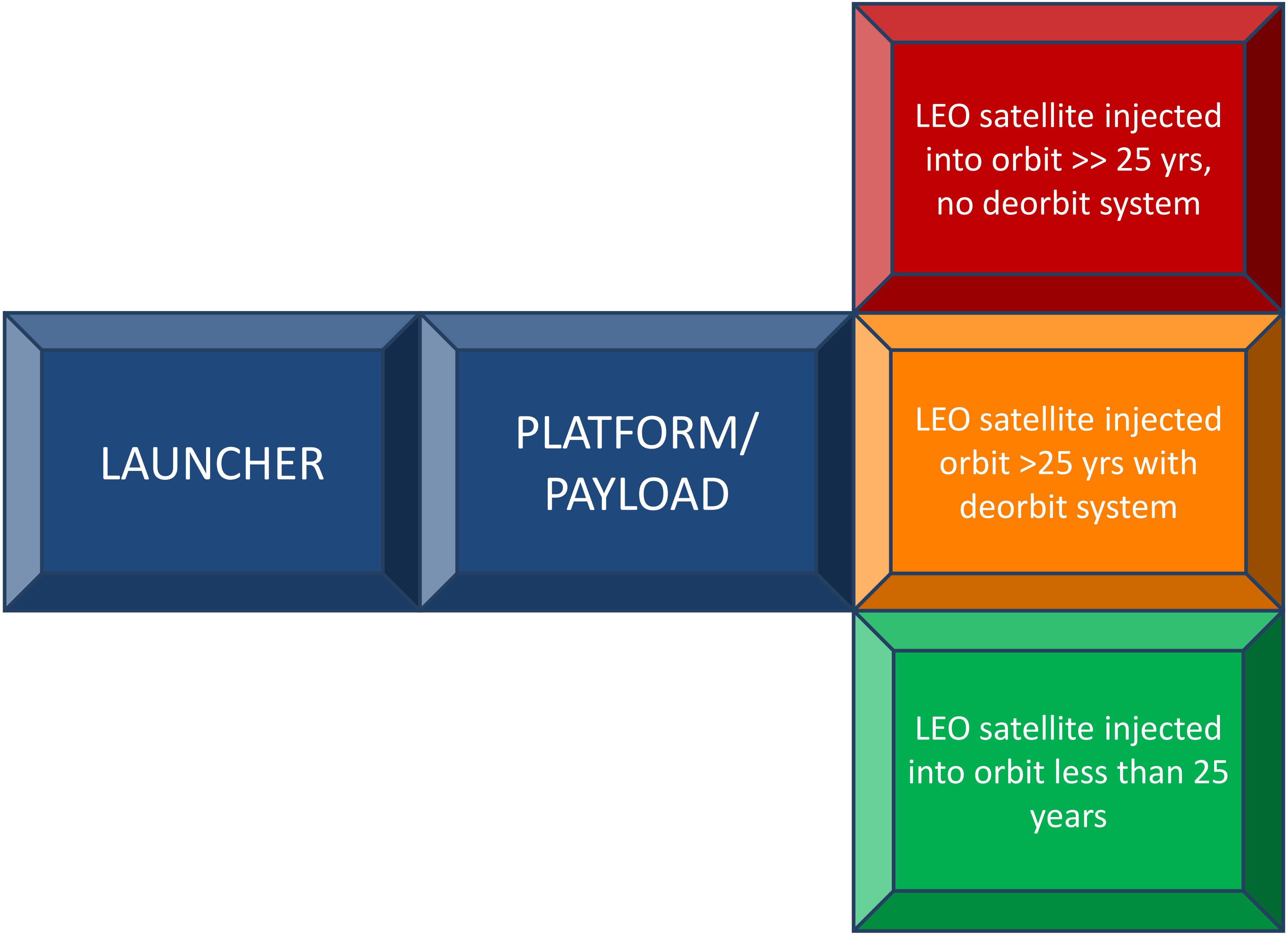


Collision Probability

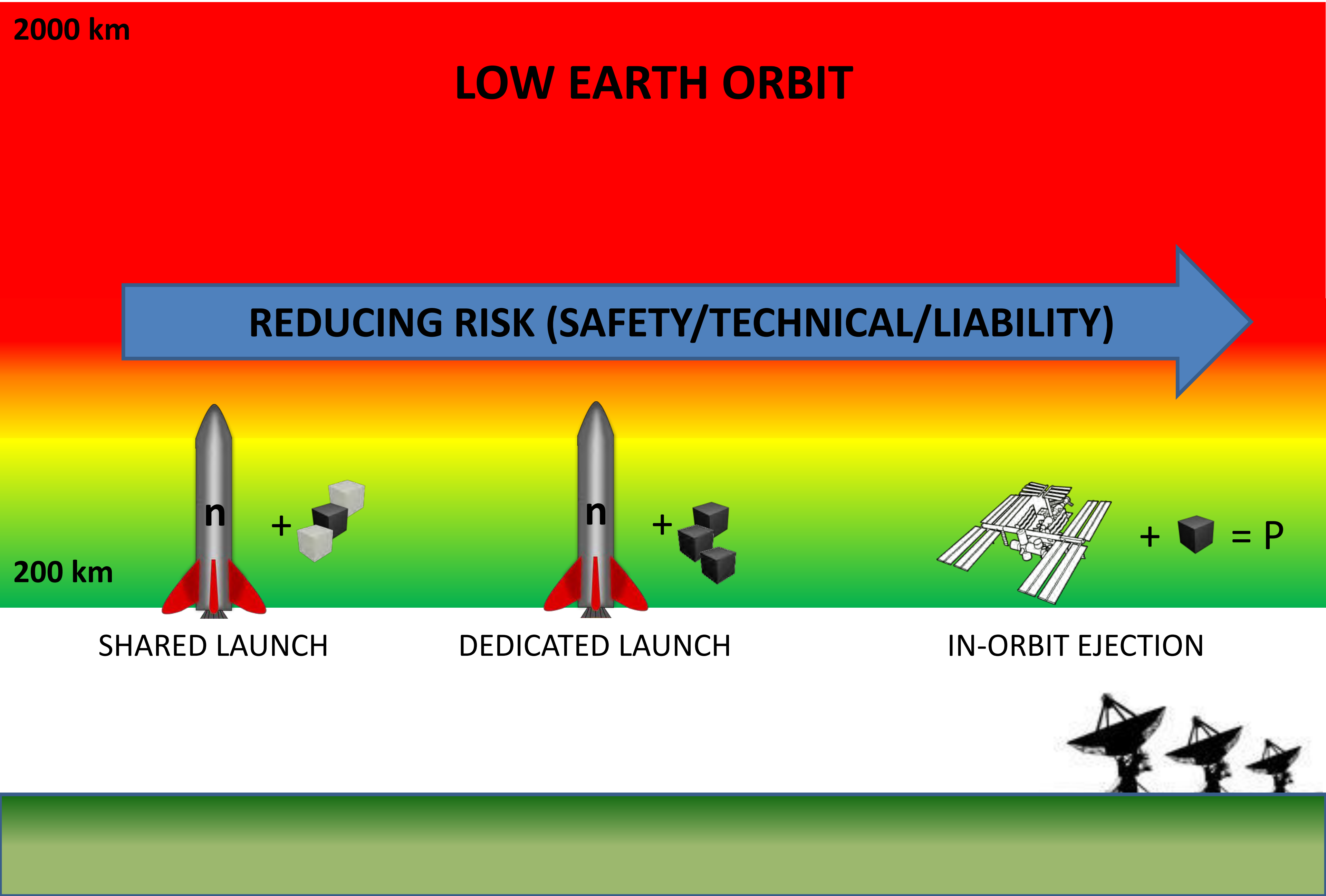


Orbital Lifetime




LAUNCHER
PLATFORM/ PAYLOAD
LEO satellite injected into orbit >> 25 yrs, no deorbit system
LEO satellite injected orbit >25 yrs with deorbit system
LEO satellite injected into orbit less than 25 years

CUBESATS: A SPECIAL CASE?



MANAGING GENERAL RISK

THIRD PARTY LIABILITY

INSURANCE COVER

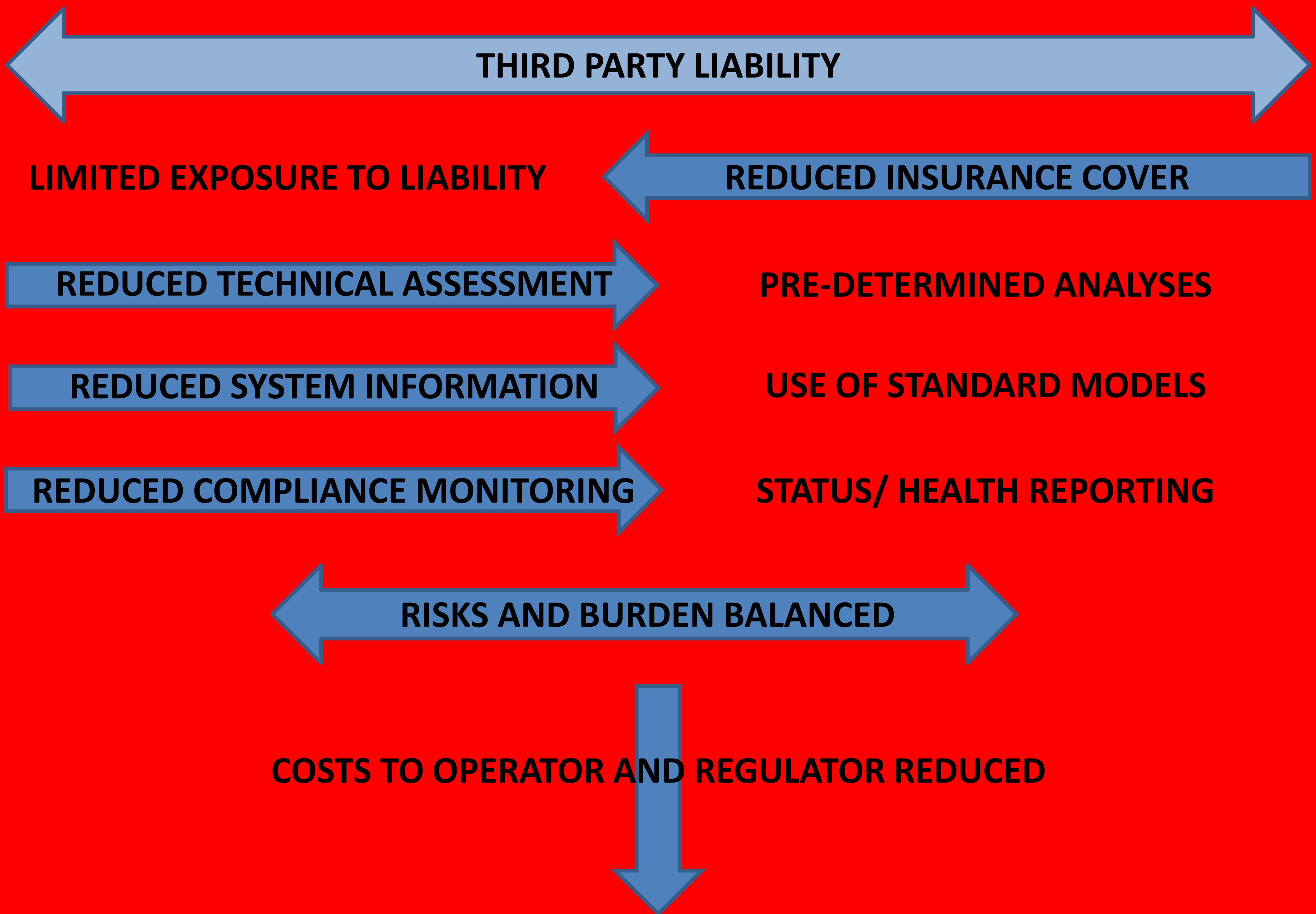
INFORMED TECHNICAL ASSESSMENT

SYSTEM INFORMATION REQUIREMENTS

OVERSIGHT AND COMPLIANCE MONITORING

RISKS MOVE FROM OPERATOR TO REGULATOR

MANAGING CUBESAT RISK




LAUNCHER
PLATFORM/
PAYLOAD
OPERATING/
DISPOSAL
ORBIT

Cubesat ejection from dispenser on ISS

Platform conforms to Cubesat standard

Cubesat injected into orbit < 25 years

BUT ARE CUBESATS REALLY A SPECIAL CASE?

BUT ARE CUBESATS REALLY A SPECIAL CASE?

GIVEN COMMONALITY OF FUTURE LEO/MEO/GEO CONSTELLATIONS, CAN SIMILAR STANDARDISED APPROACH BE APPLIED TO SUCH DISTRIBUTED ARCHITECTURES?

Near Earth Objects

Prof. Richard Crowther, UK

Outline

- Near Earth Objects
  - What are Near Earth Objects?
  - What are the hazards?
  - Is the Earth at risk?
  - What are the issues?

What are Near Earth Objects?

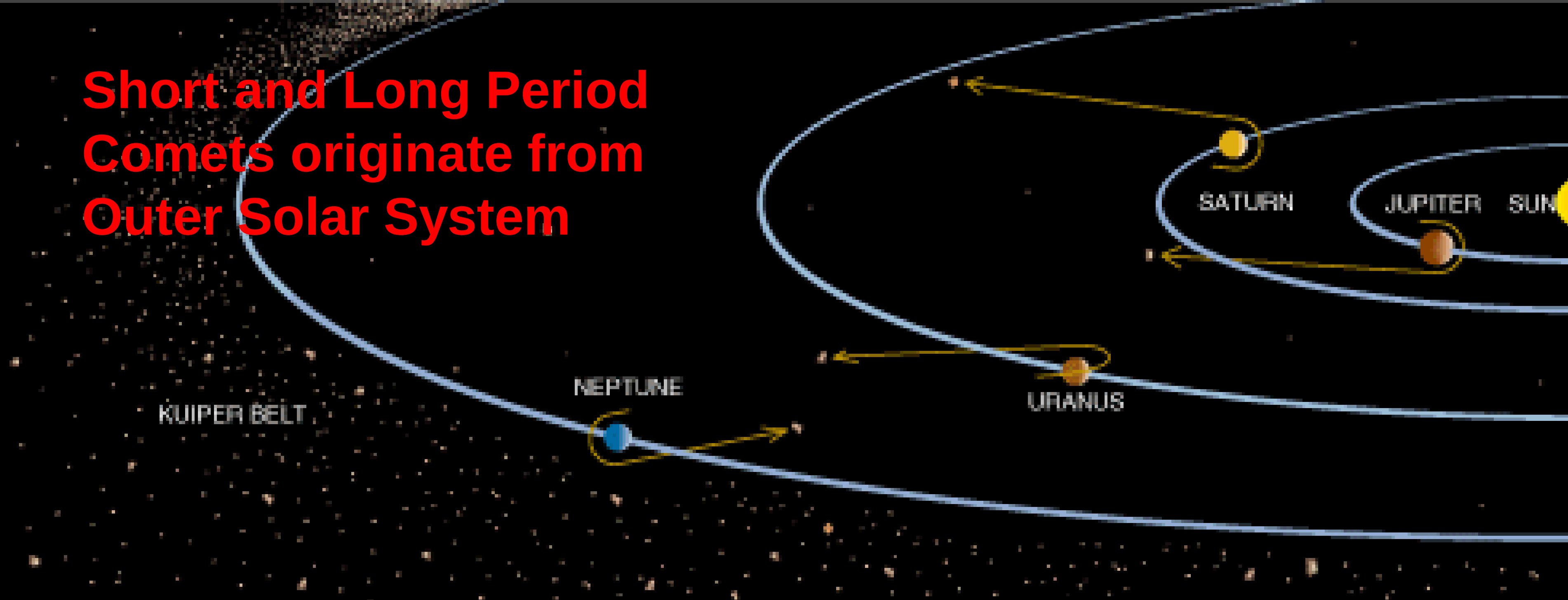
COMET or ASTEROID

with orbit within 0.3 AU of Earth

1 AU = 150,000,000 km

Potentially Hazardous if within 0.05 AU (7,500,000 km) and size > 150m

Short and Long Period Comets originate from Outer Solar System



Near Earth Asteroids are believed to originate from Inner Solar System

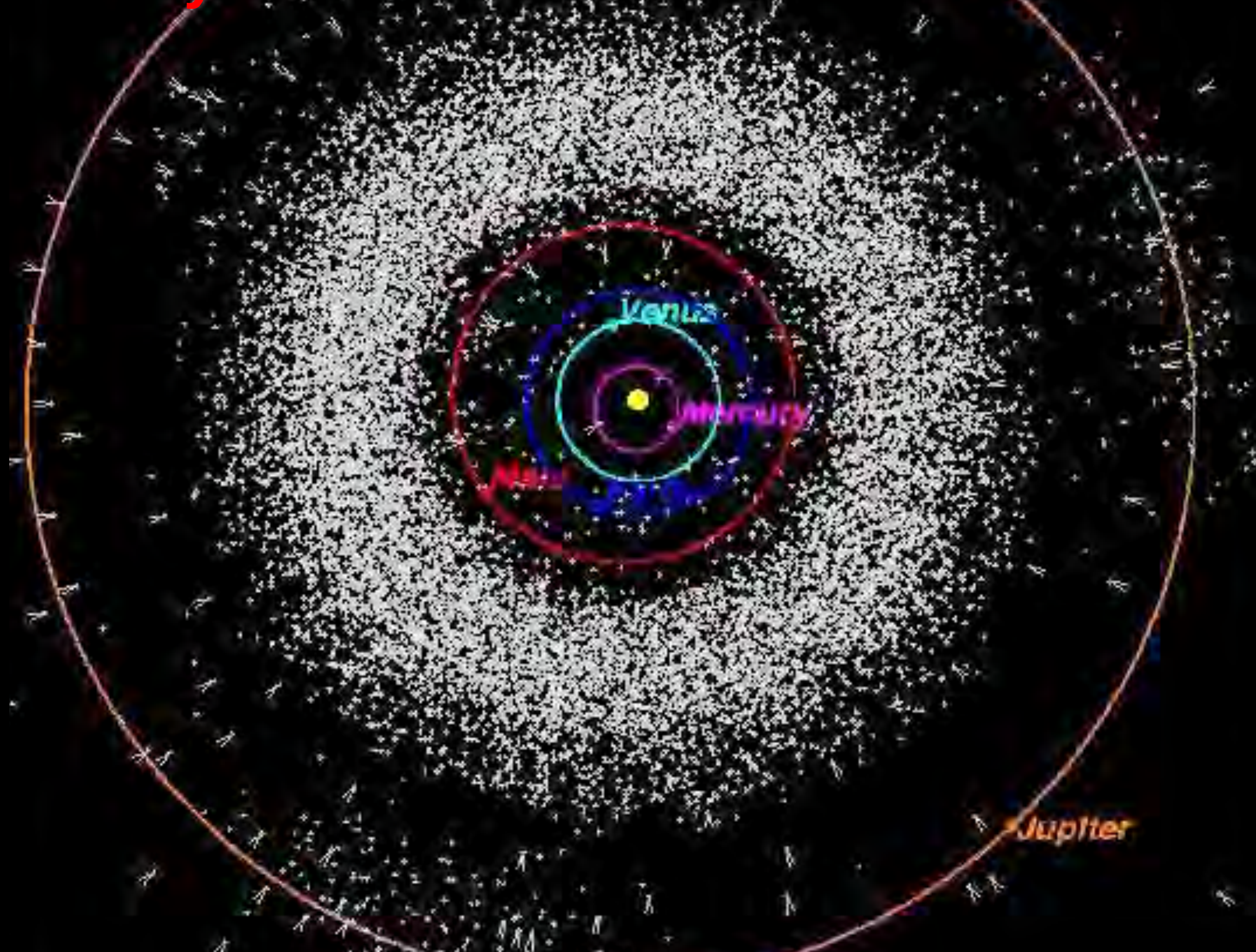
Mercury

Venus

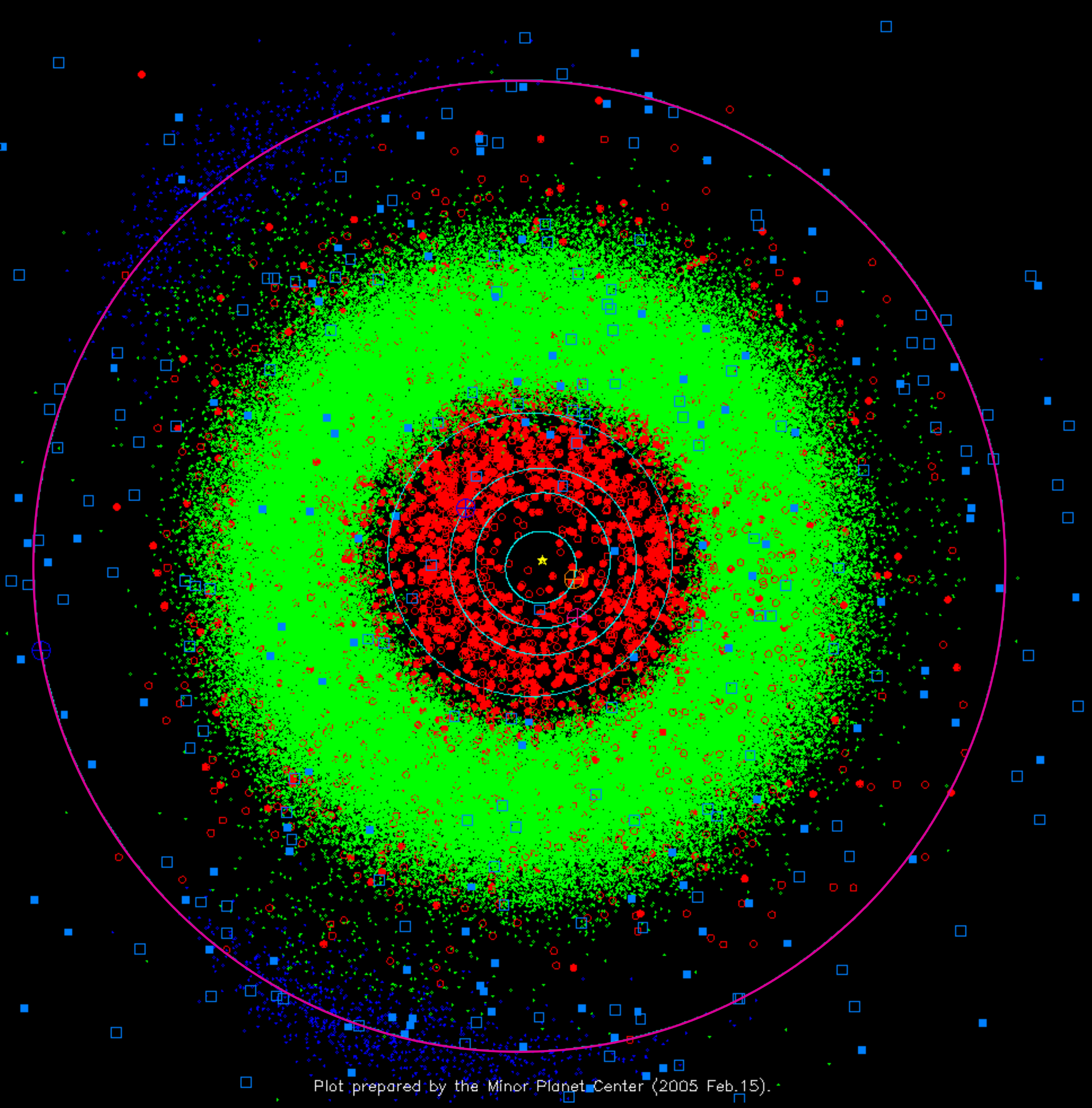
Earth

Mars

Jupiter

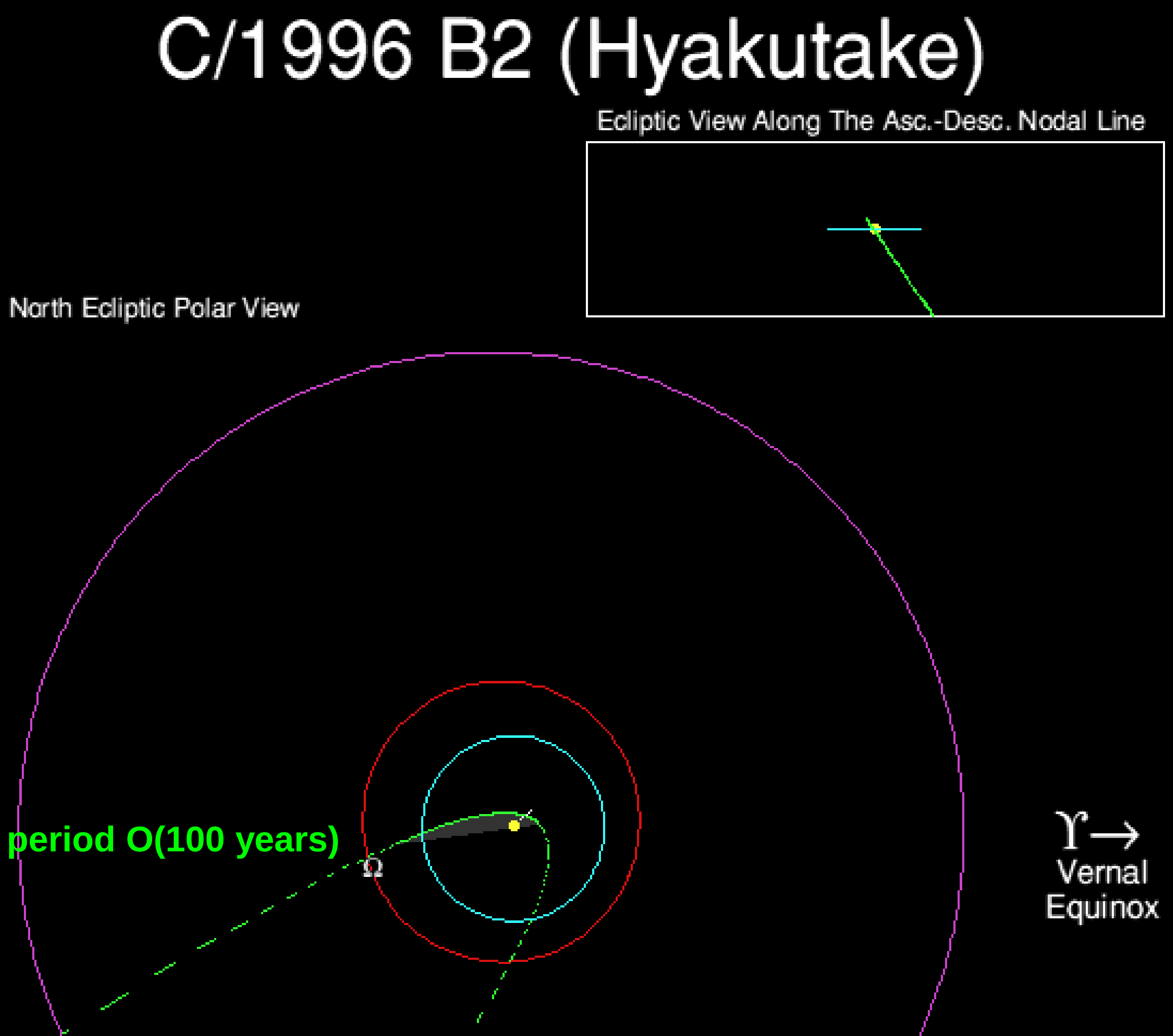


1,000,000 objects in asteroid belt with *d* >1km



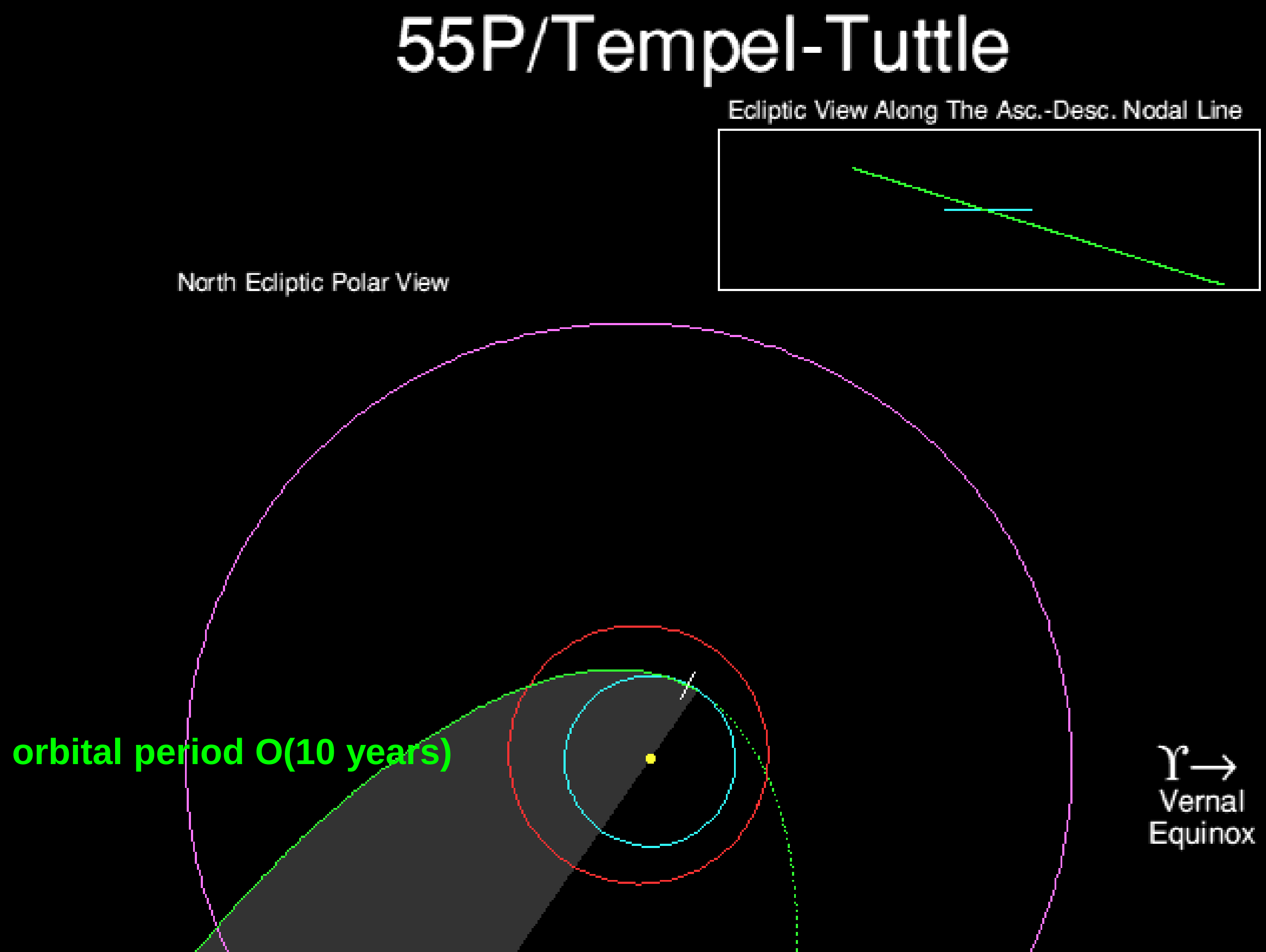
Only a small percentage of comets and asteroids are NEOs

LONG PERIOD COMETS

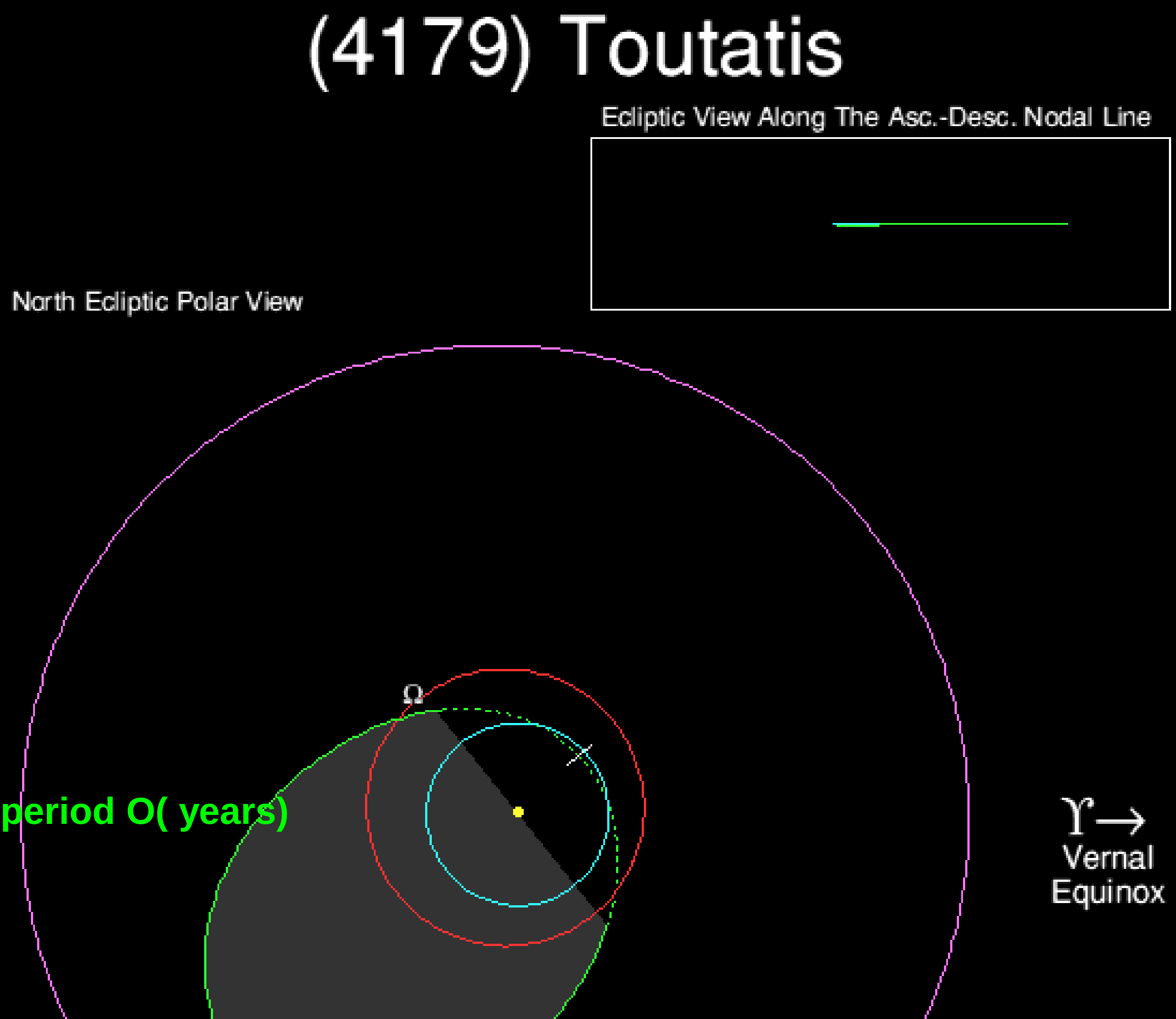


orbital period O(100 years)

SHORT PERIOD COMETS



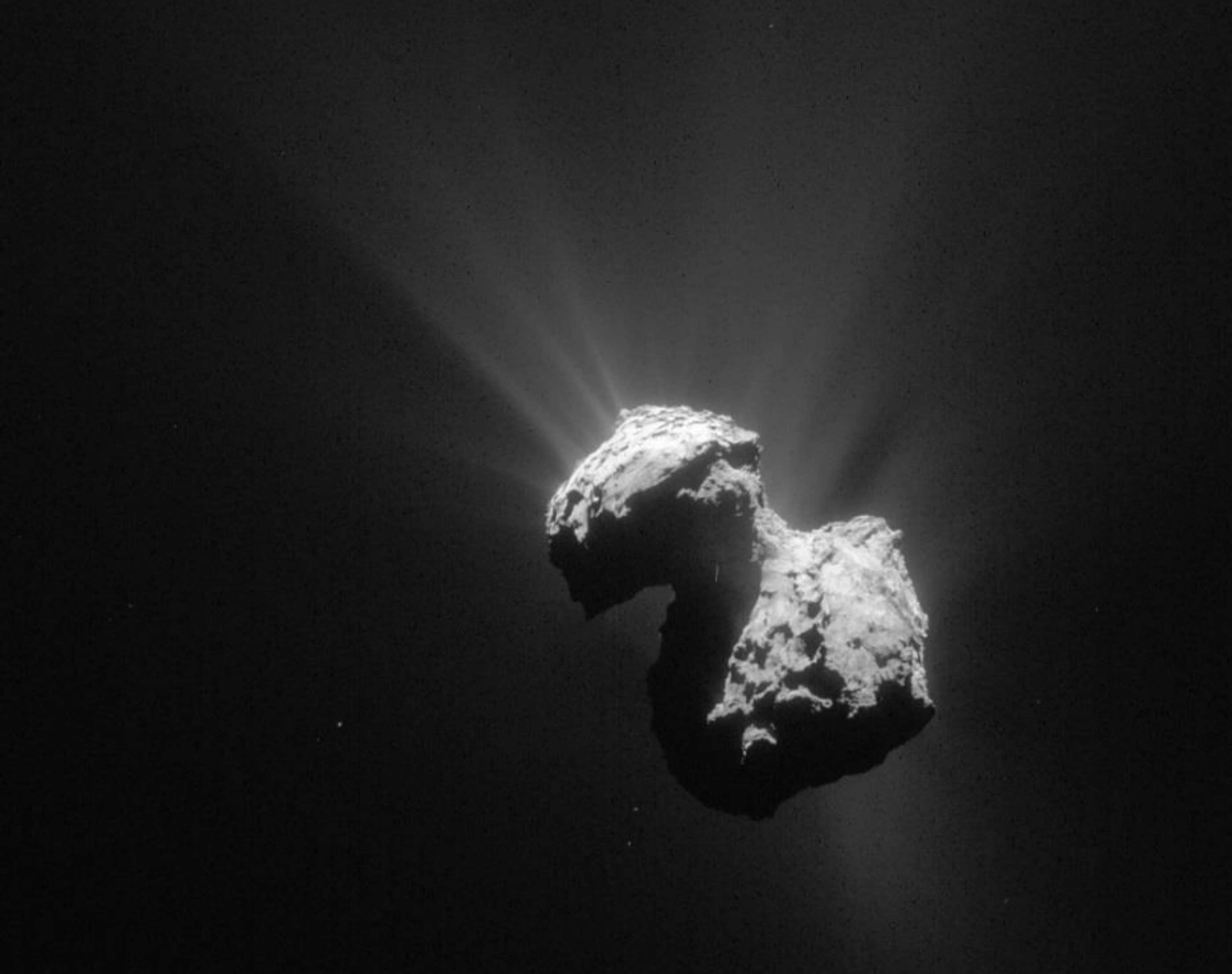
NEAR EARTH ASTEROIDS

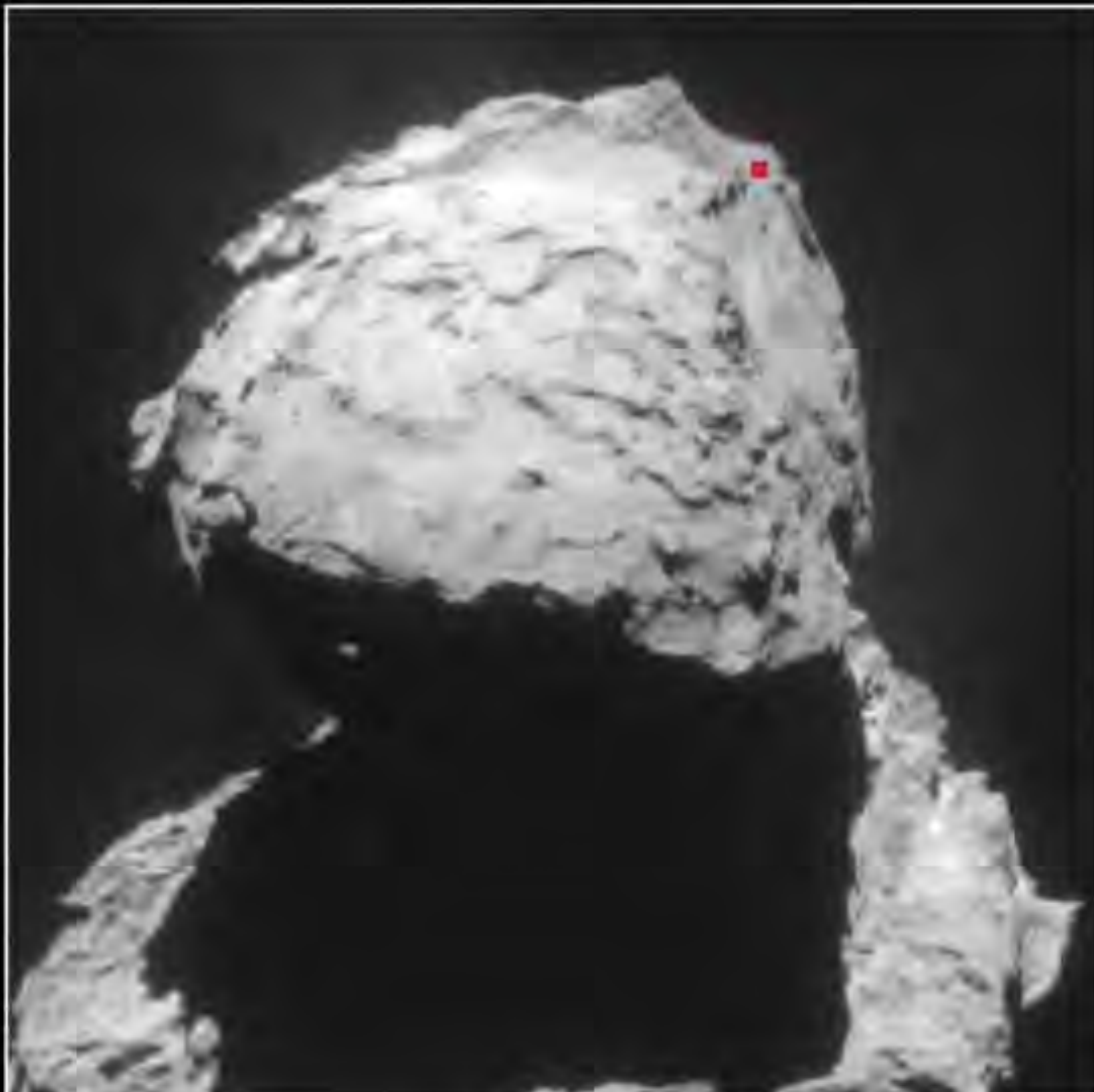


orbital period O(years)

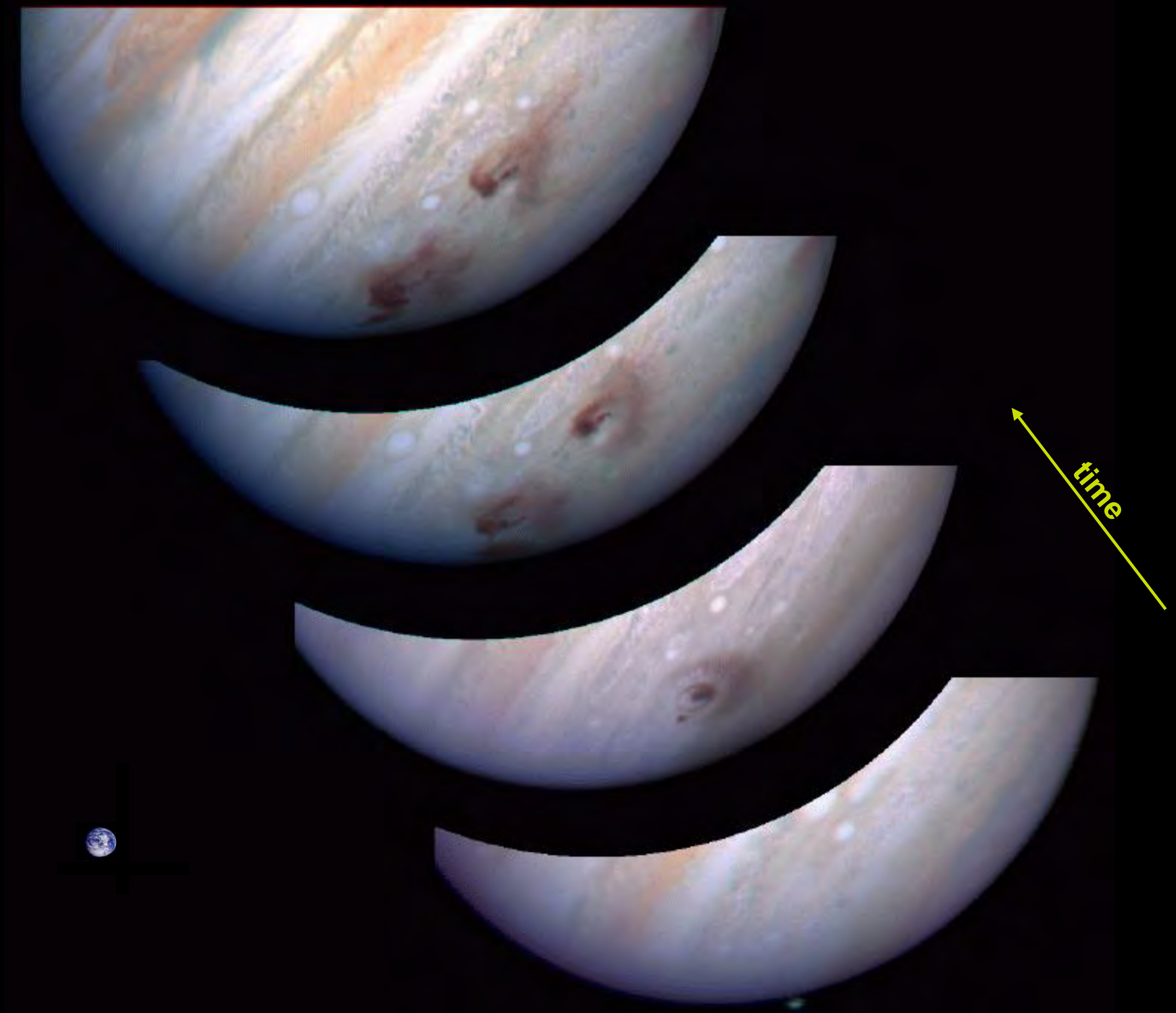
Comets and asteroids are detected from ground by their motion relative to star background

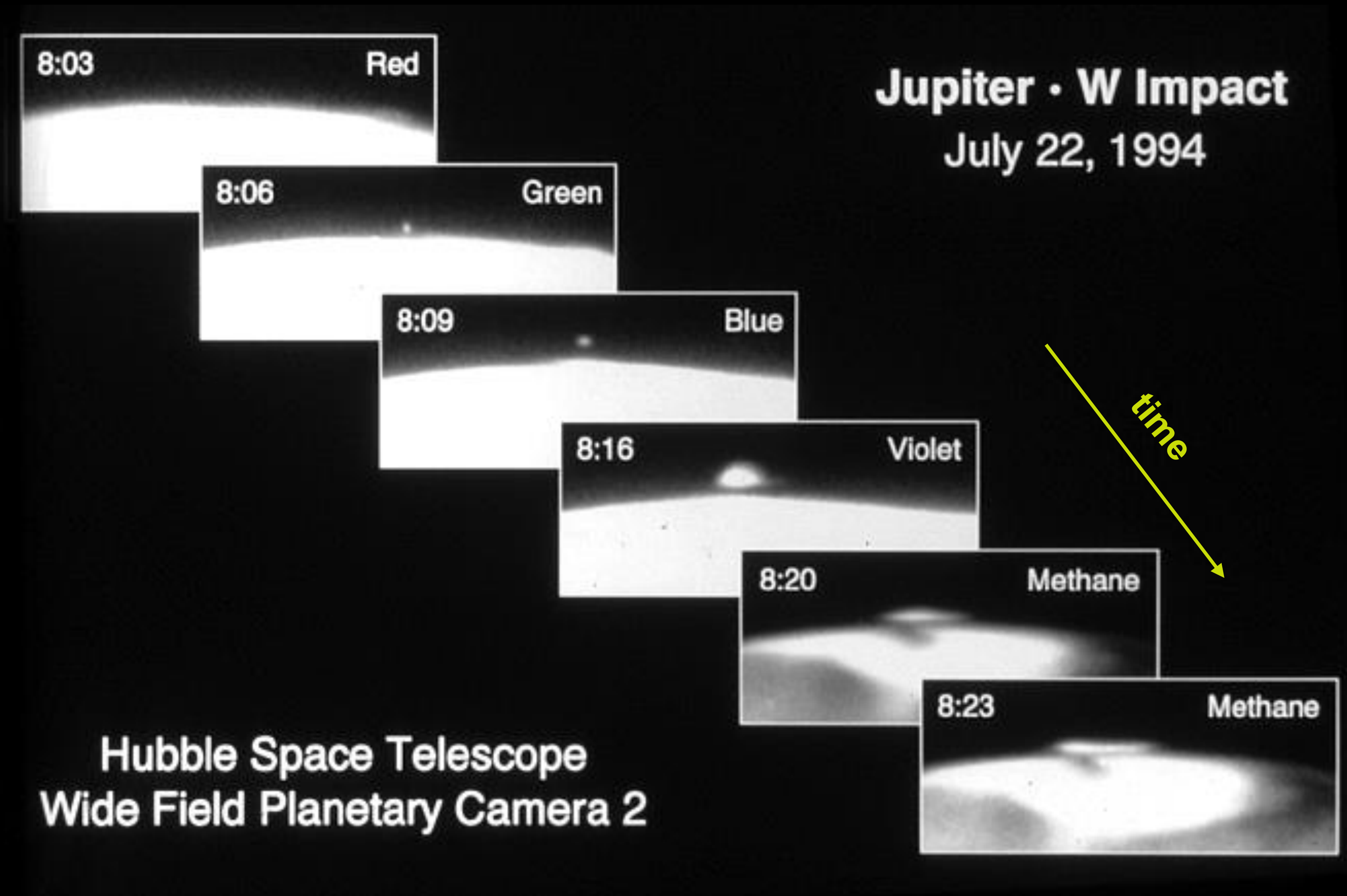

NEAR - 433 Eros
March 07 2000 03:10:00 -27 -158

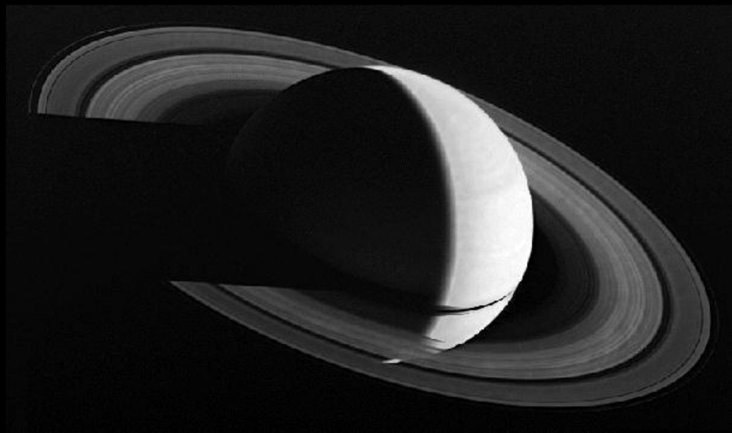


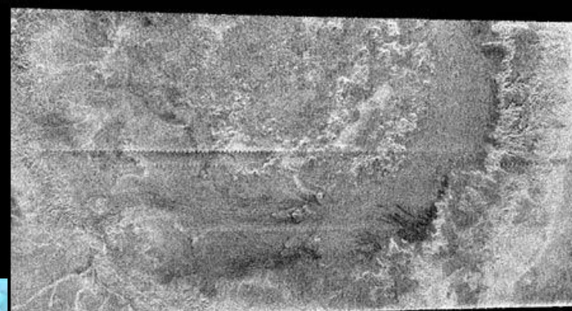


What are the hazards?


time


Jupiter · W Impact
July 22, 1994
8:03
Red
8:06
Green
8:09
Blue
8:16
Violet
8:20
Methane
8:23
Methane
time
Hubble Space Telescope
Wide Field Planetary Camera 2





Is the Earth at risk from NEOs?

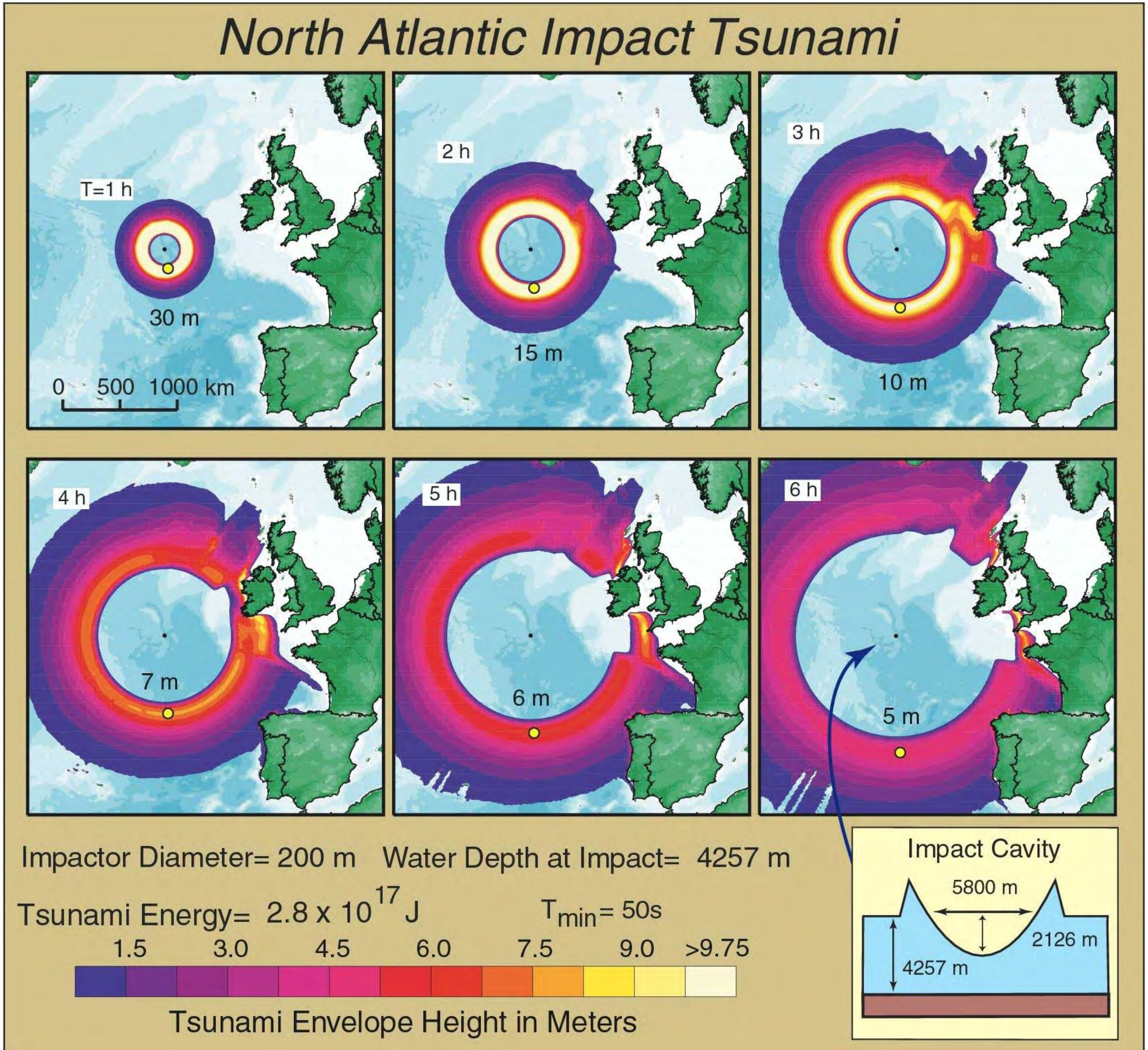


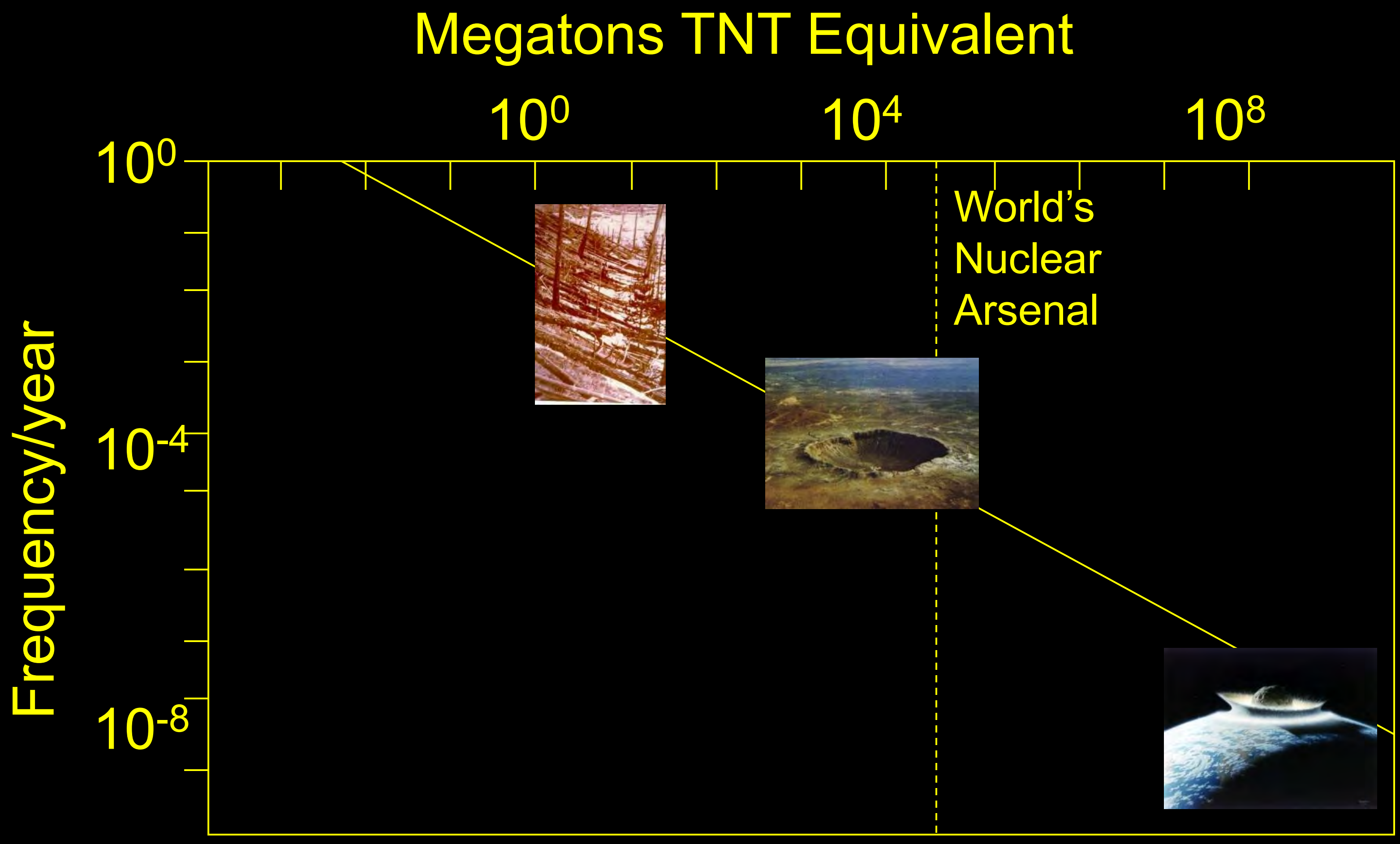
AIR-BURST


Tunguska, Siberia
1908, stone asteroid
2000 sq km of forest flattened


Barringer Crater, Arizona
49,000 years ago
nickel-iron asteroid

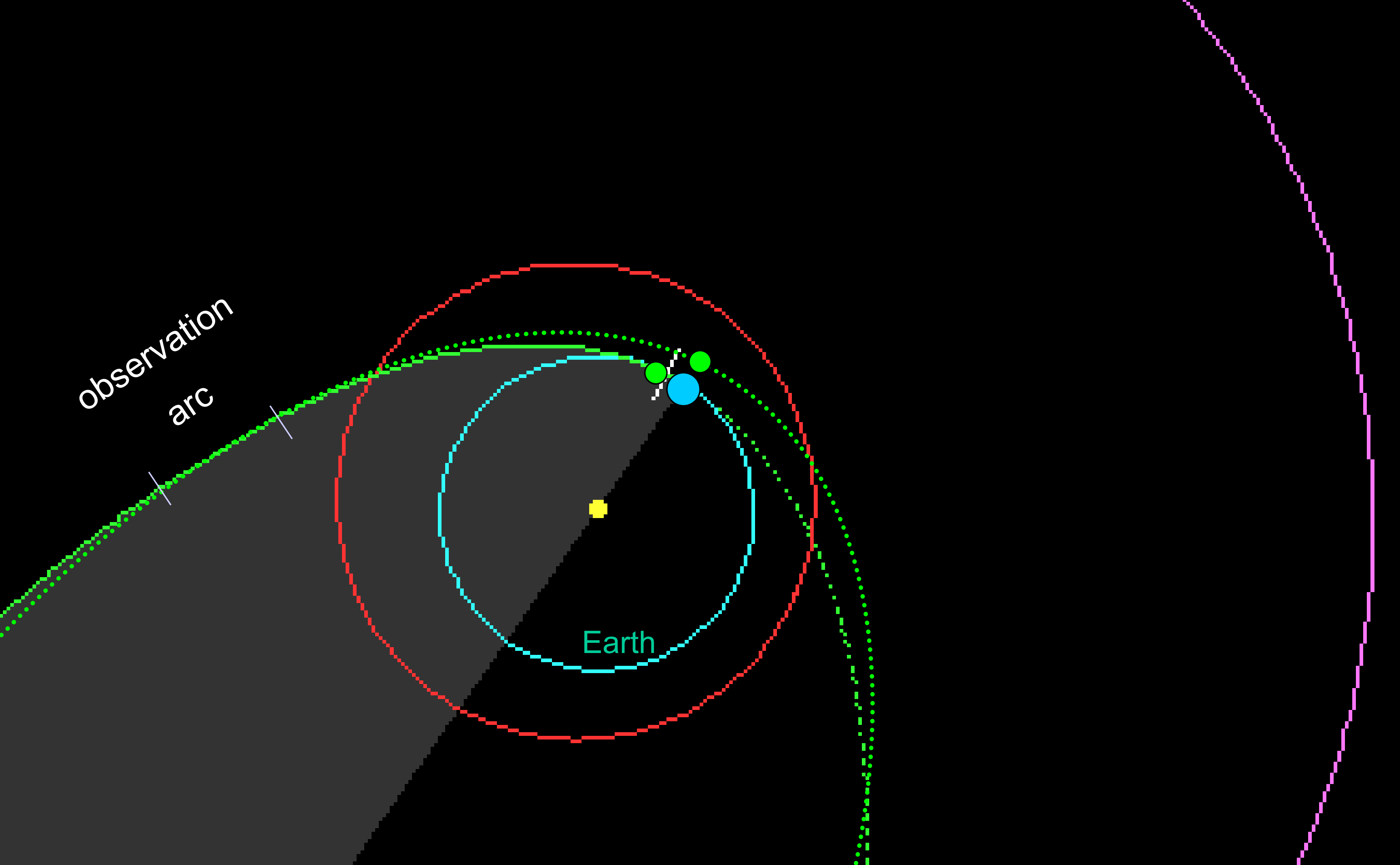
Multiple impacts are common (e.g. Moon and Gannymede)


North Atlantic Impact Tsunami
T=1 h
30 m
0
500
1000 km
2 h
15 m
3 h
10 m
4 h
7 m
5 h
6 m
6 h
5 m
Impactor Diameter= 200 m
Water Depth at Impact= 4257 m
Tsunami Energy= 2.8 x 10^17 J
T_min= 50s
1.5
3.0
4.5
6.0
7.5
9.0
>9.75
Tsunami Envelope Height in Meters
Impact Cavity
5800 m
2126 m
4257 m

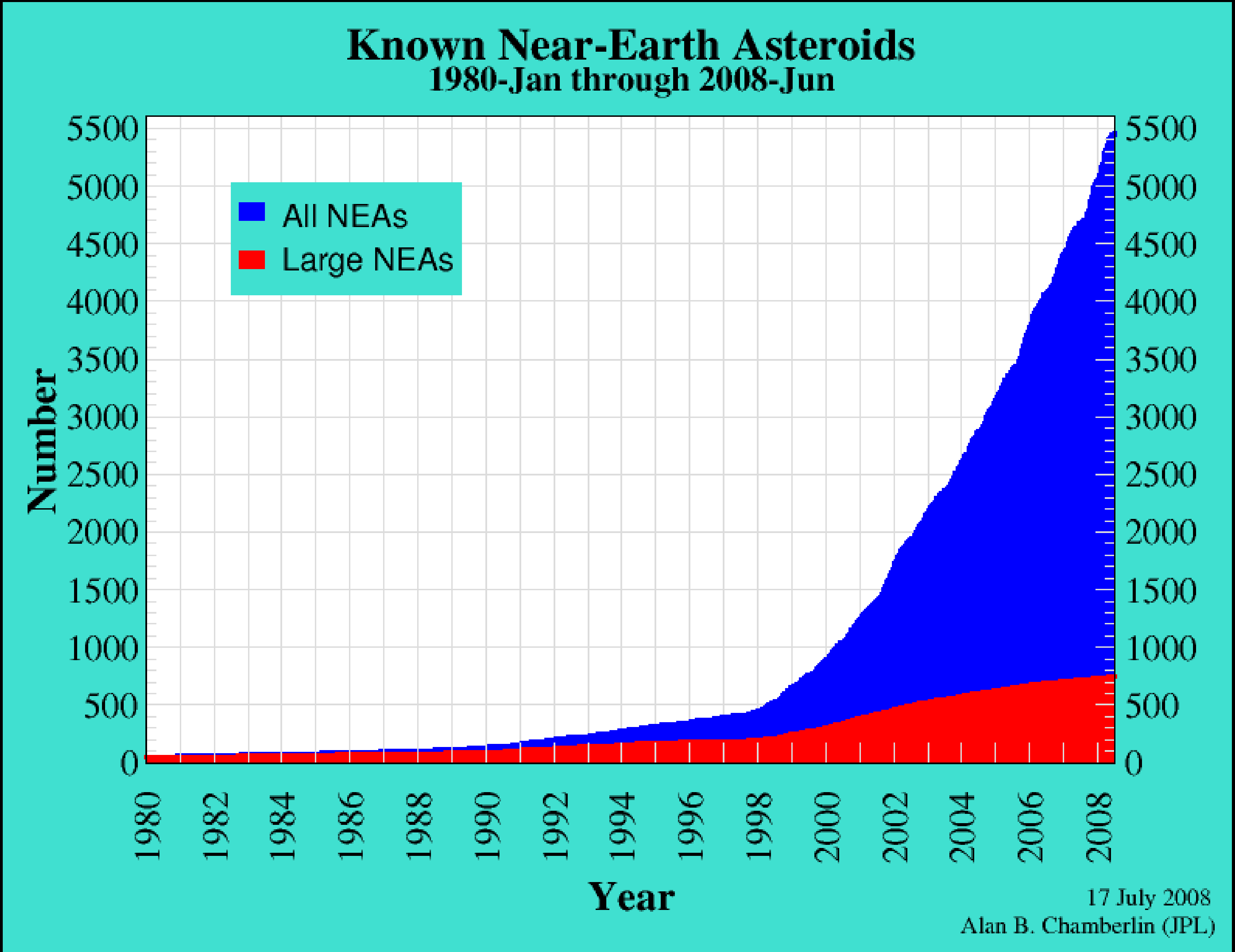


Major uncertainty is frequency, small data set

Accurate impact probability requires extensive observational data




Carancas, Peru
2007 impact crater


Known Near-Earth Asteroids
1980-Jan through 2008-Jun
All NEAs
Large NEAs
Number
Year
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
17 July 2008
Alan B. Chamberlin (JPL)

NEO risk management issues to be addressed

OBJECT IDENTIFICATION	ORBIT DETERMINATION	CONSEQUENCE DETERMINATION	IN-SITU CHARACTERISATION	MITIGATION	EVALUATION
POLICY					
CATEGORISING, CATALOGUING, NOTIFICATION	SENSOR TASKING	NOTIFICATION, RISK CRITERIA	ROLES, RESPONSIBILITIES	TREATY COMPLIANCE, AUTHORITY, RESPONSIBILITY	OUTCOME NOTIFICATION
INFRASTRUCTURE					
SENSOR AVAILABILITY, LOCATION	SENSOR COORDINATION, PRIORITISATION	TOOLS, VULNERABILITY	PAYLOAD DELIVERY, DATA COMMUNICATION	PAYLOAD DELIVERY, COMMAND & CONTROL	SENSOR TASKING
SCIENCE					
SENSOR LOCATION, DETECTION THRESHOLD	FOLLOW -UP STRATEGY	MULTI-DISCIPLINARY STUDIES	SENSOR DEVELOPMENT, DATA EXPLOITATION	NEGATION PHYSICS	SHORT TERM TRAJECTORY PREDICTION


VISITORS LOUNGE



THAILAND

UNITED STATES


International Asteroid Warning Network

International Asteroid Warning Network

Space Mission Planning Advisory Group

Planetary Protection

Prof. Richard Crowther
UK Space Agency

Planetary Protection History

- Questions of life—the fate of life on Earth and the possibility of life elsewhere—have driven space exploration from its beginnings. Thus, planetary protection has been a concern from the start of the Space Age.

  How can we make the observations required to understand the origins, distribution, and destiny of life in the universe:

  - Without destroying or contaminating the evidence required?
  - Without changing the distribution and/or destiny of (Earth or alien) life?

Basic Planetary Protection Policy

- Preserve planetary conditions for future biological and organic constituent exploration
  - avoid **forward contamination**; preserve our investment in scientific exploration
- To protect Earth and its biosphere from potential extraterrestrial sources of contamination
  - avoid **backward contamination**; provide for safe solar-system exploration

The UN Space Treaty of 1967

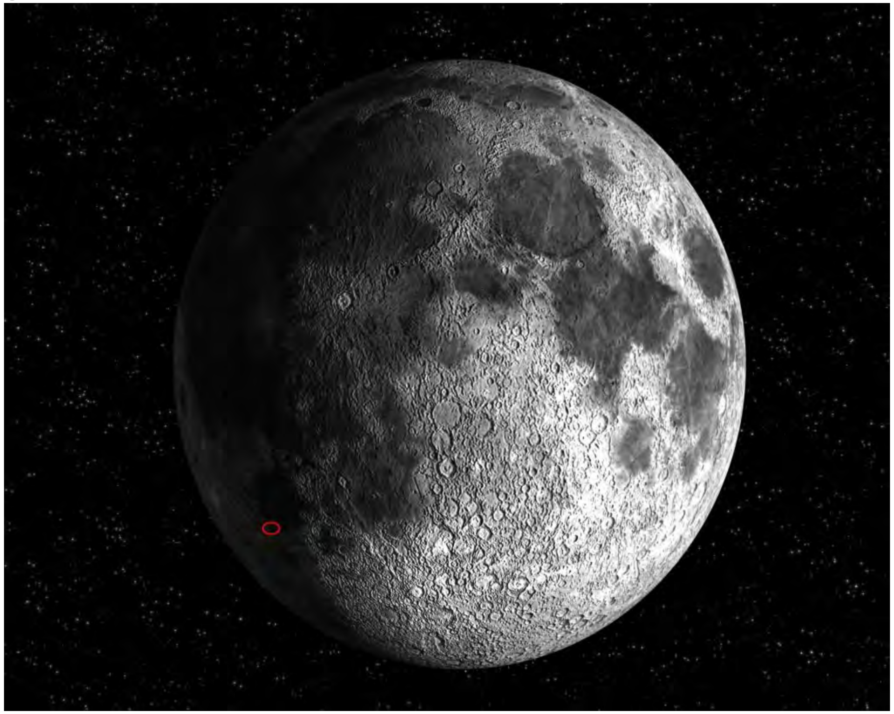
- Article IX (part)
  - "States Parties to the Treaty shall pursue studies of outer space, including the moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose."

COSPAR's Policy Categorization(s)

- Five categories of planetary protection defined by the nature of the mission to be launched and nature and understanding of the target body to be studied or encountered

COSPAR's Policy Categorization(s)

- Category I missions—No planetary protection procedures required for missions to bodies not of interest to the study of chemical evolution and the origin of life

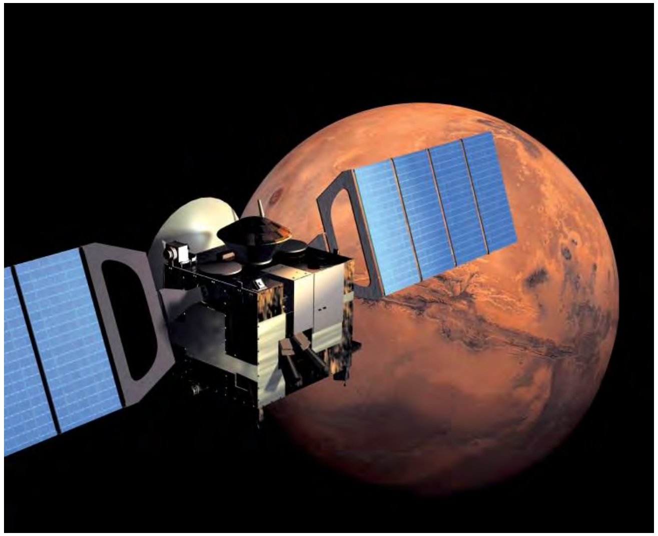


COSPAR's Policy Categorization(s)

- Category II missions are those for which the target body is of interest to researchers studying organic chemical evolution and the origin of life, but where biological contamination is not thought to be possible
    - » Document spacecraft trajectories, inventory onboard organic materials, and possibly provide for the archival storage of certain spacecraft materials

COSPAR's Policy Categorization(s)

- Category III missions that fly-by or orbit planets that could be contaminated by Earth organisms
  - » Category II plus other restrictions, such as cleanroom assembly procedures and orbital lifetime restrictions

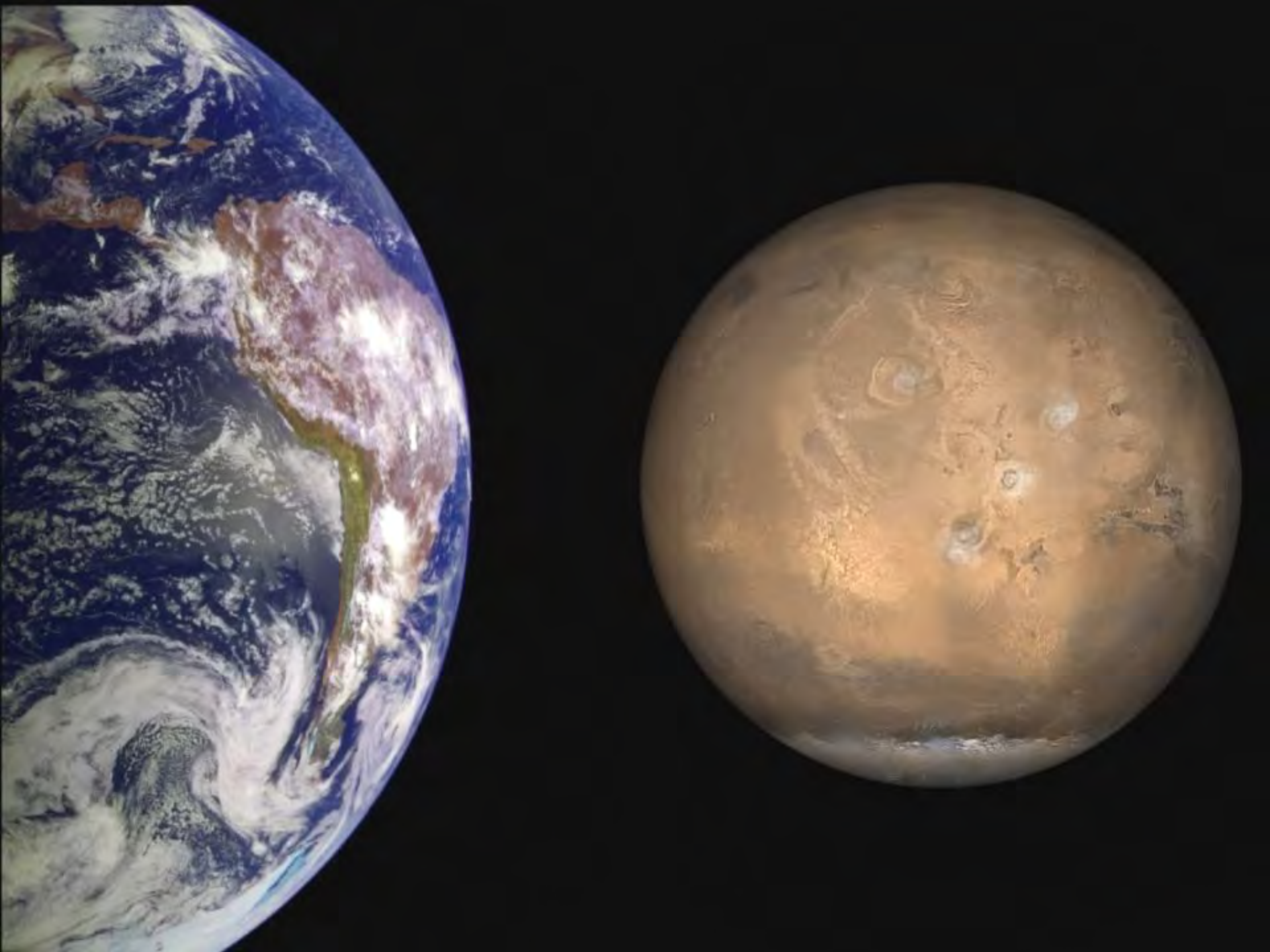


COSPAR's Policy Categorization(s)

- Category IV missions are landers to bodies that may be contaminated
  - Category II and III requirements apply (except for orbital lifetime)
  - Restrictions on biological contamination are generally more severe, and may include comprehensive decontamination and sterilization of the spacecraft
  - A probability of contamination calculation is required for such missions

COSPAR's Policy Categorization(s)

- Earth-return missions are placed in Category V, regardless of the outbound category
  - "Unrestricted Earth return," with no additional planetary protection requirements on the return portion of the mission
  - "Restricted Earth return" missions, with all Category II, III, and IV restrictions plus strict controls on the handling of returned samples until their biological status is determined.



Earth's Deep-Sea Hydrothermal Vents:
Life-as-we-didn't know it...

The discovery of abundant life at deep-sea hydro-thermal vents in 1977 (7 months after the Viking missions landed on Mars) surprised everybody!

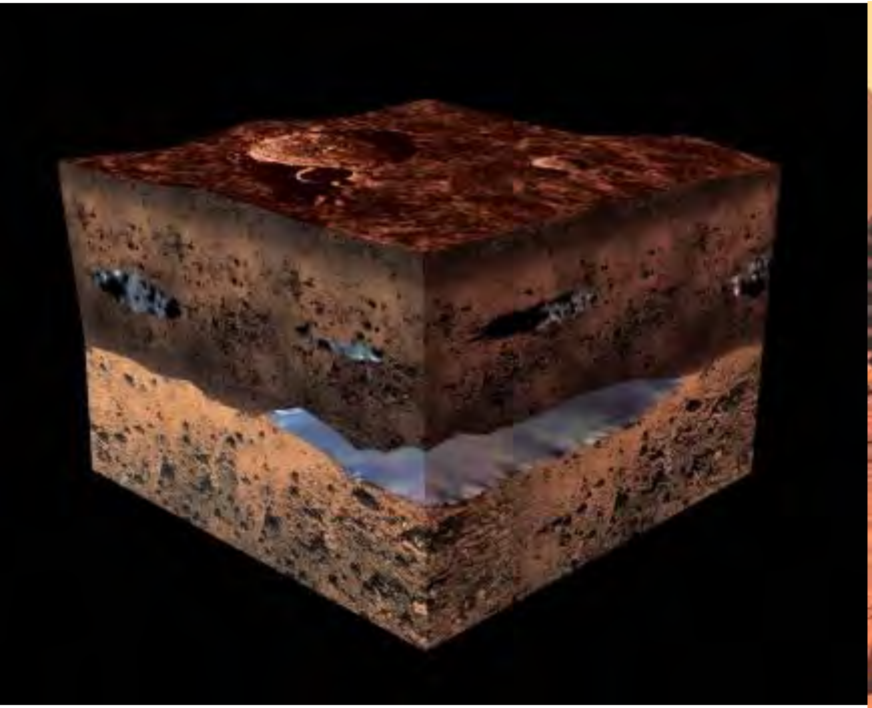
- It isn't that we expect to find these things out there –
- It's that we never expected to find them *here*....

Planetary Protection: Evolving Requirements

Planetary protection evolves as the planetary exploration program progresses and as advances in planetary science—access, knowledge, measurement technologies…

Humans on Mars?

- Human capabilities may be required to explore deep subsurface aquifers, if they exist beneath the Martian deserts
- Requires a preliminary robotic search for life, because of the potential for human-associated contamination: both forward and backward



Current Issues in Forward Contamination Control

- Understand microbial biodiversity of cleanroom environments
- Understand survival of Earth organisms under the range of conditions that may be experienced on Mars, Europa, etc.
- Better understand the location/extent of Mars environments that may be capable of supporting Earth life, and keep track of them using a comprehensive database

- Develop and qualify new methods for the monitoring of microbial contamination on spacecraft
- Develop and qualify new methods for removing biological contamination from Mars spacecraft

SPACE DEBRIS

Prof. Richard Crowther
UK Space Agency

Outline

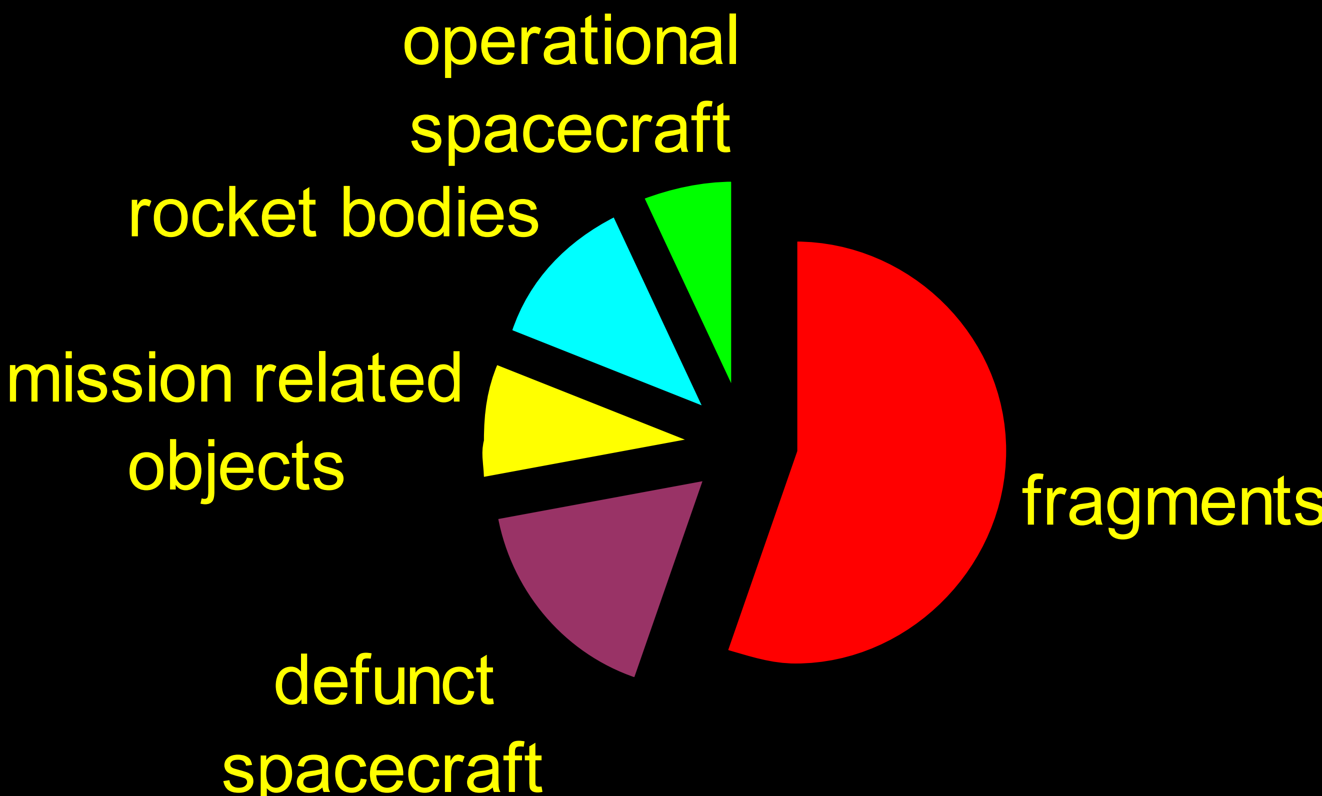
– What is in orbit around the Earth?
– How much space debris is there?
– What is the future for space debris?
– What is the solution to space debris?

WHAT IS IN ORBIT AROUND THE EARTH?

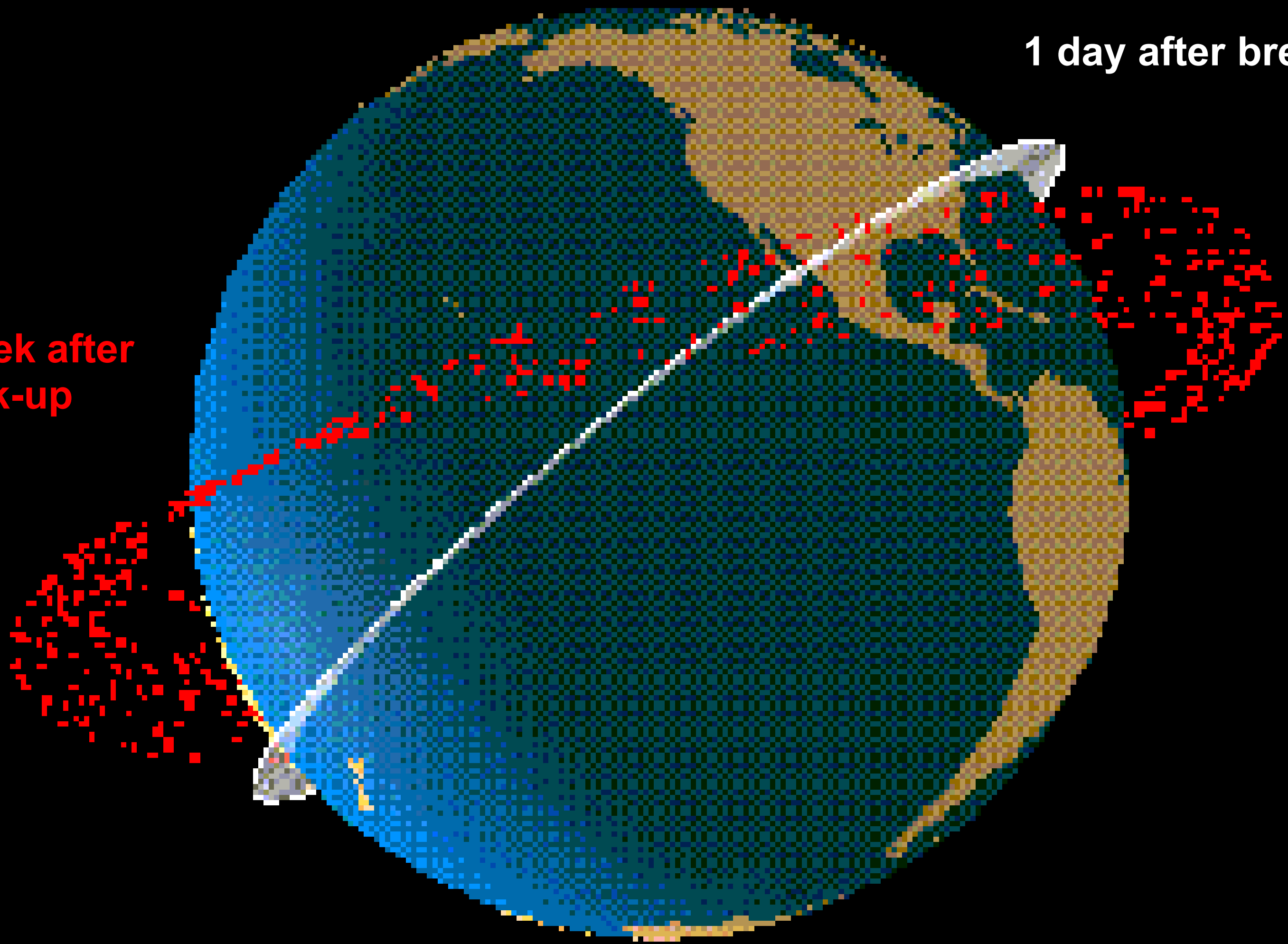
near-Earth satellite population reflects use of space

>16000 catalogued objects concentrated in distinct orbits with unique characteristics

CATEGORIES OF CATALOGUED OBJECTS

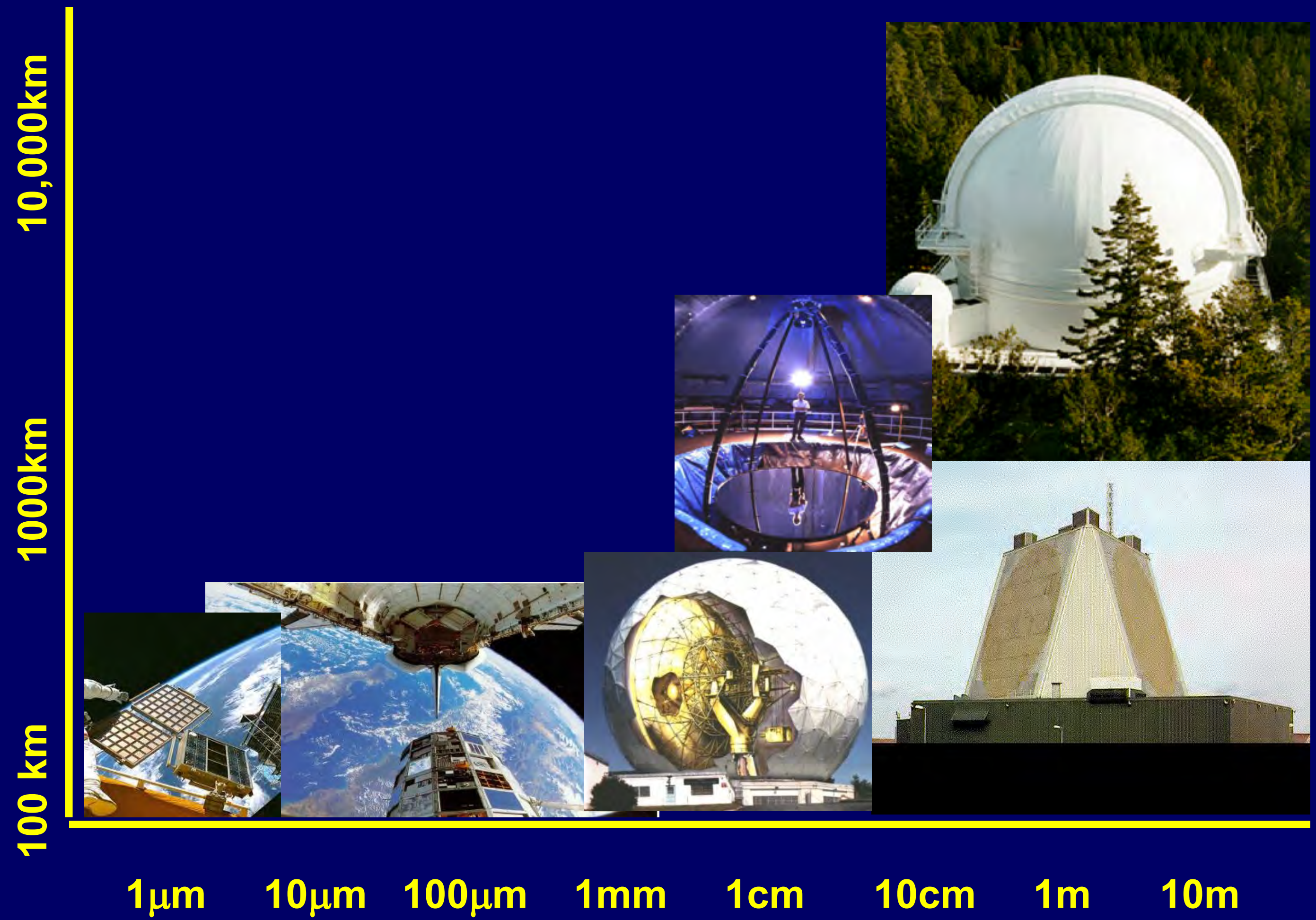


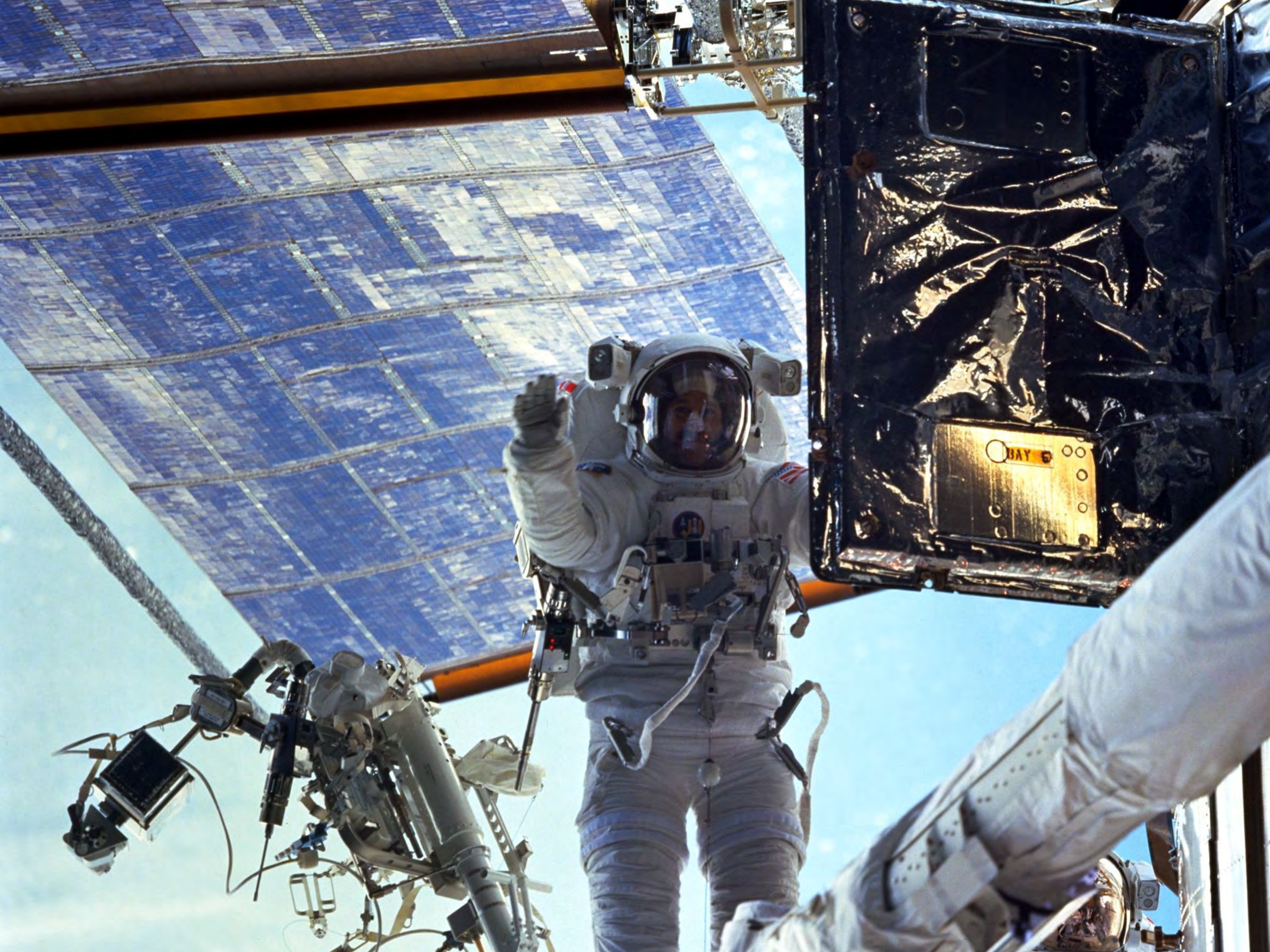
FRAGMENTS FROM BREAK-UP QUICKLY DISPERSE

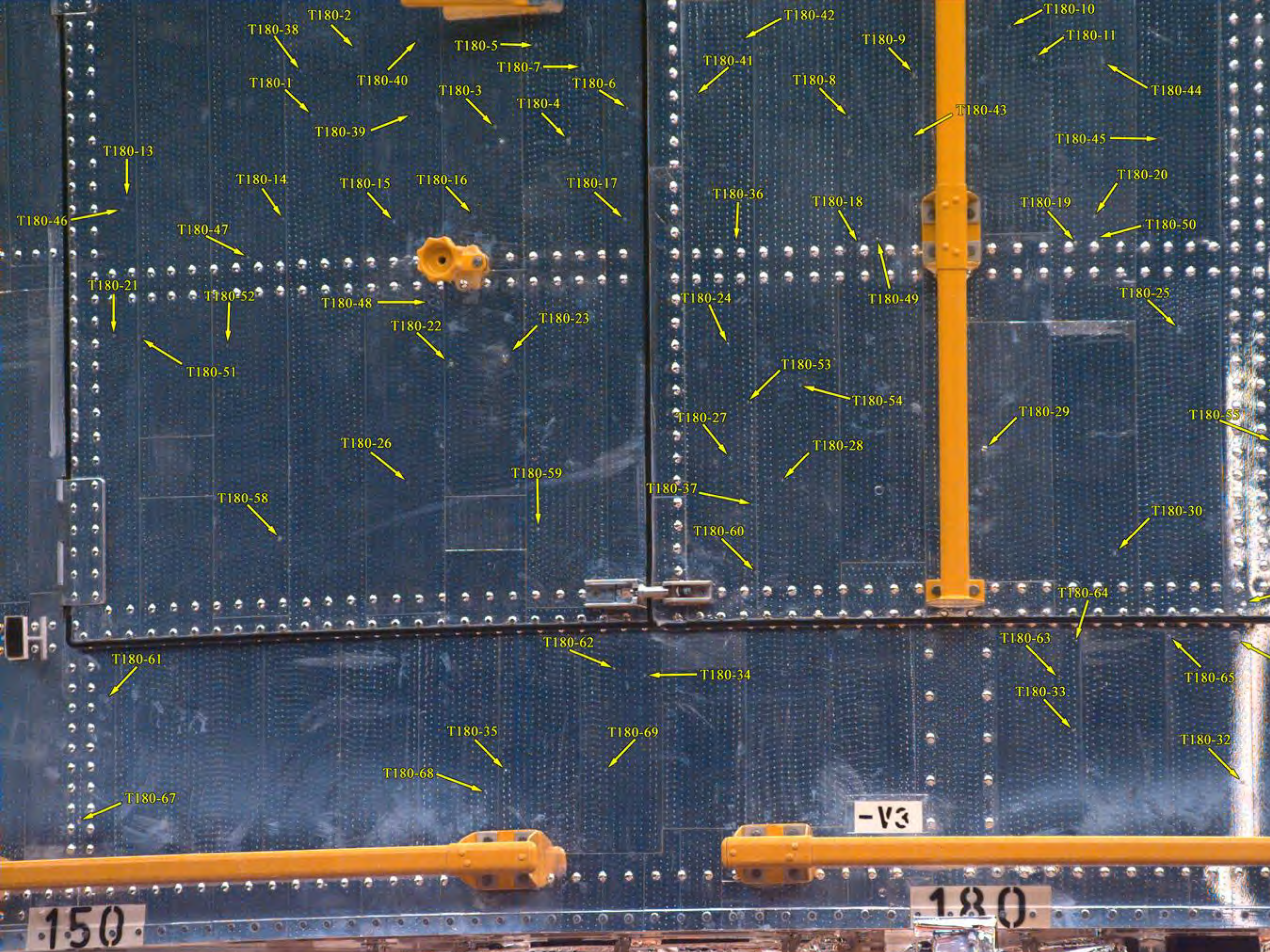


HOW MUCH SPACE DEBRIS IS THERE?

Estimating the debris population




BAY 5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T180-38
T180-5
T180-40
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T180-28
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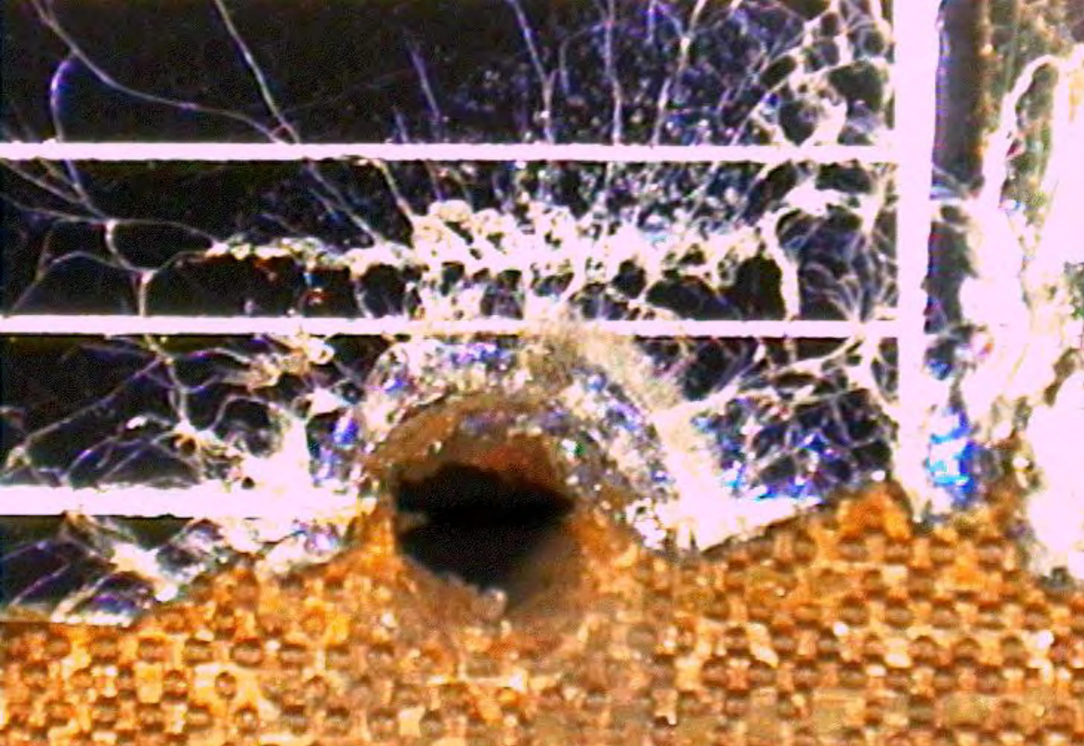
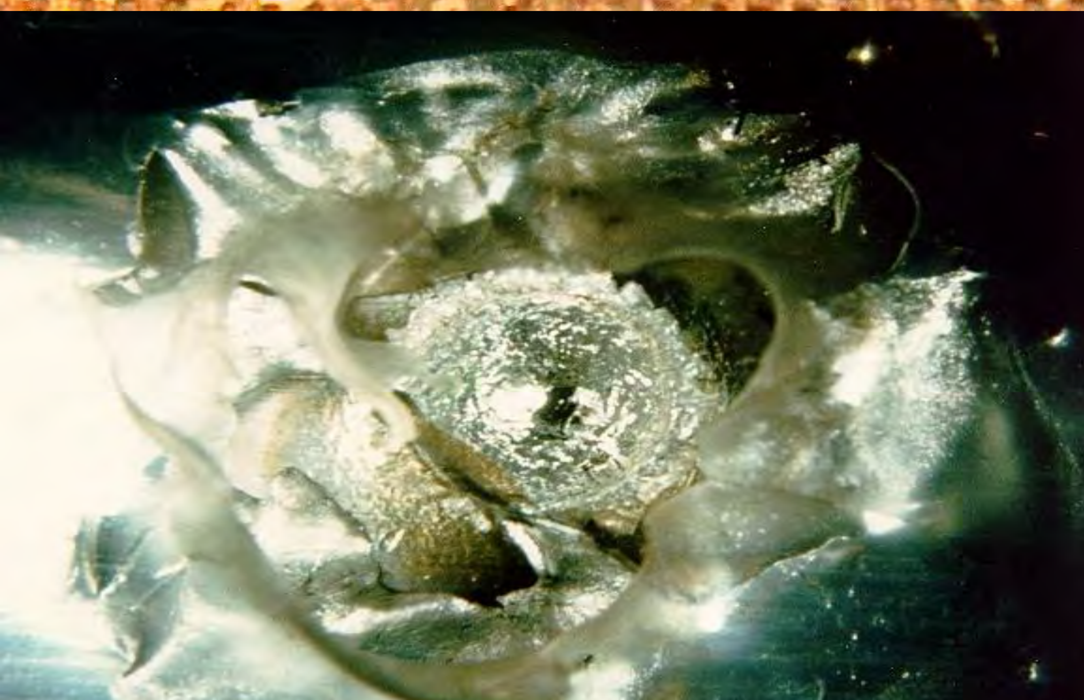
T180-32
-V3
150
180






Estimated Debris Population

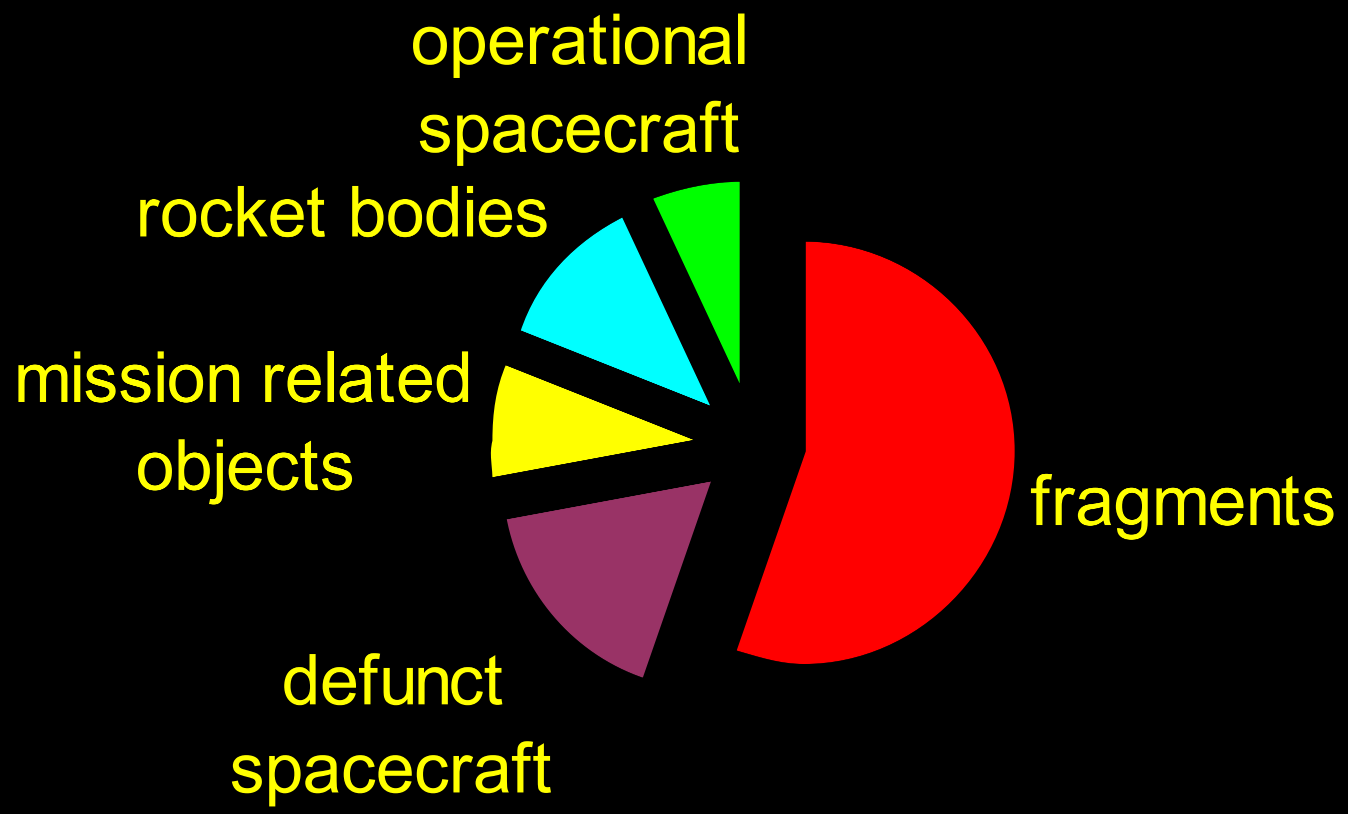
Size	Number	% Mass
>10 cm	>20000	99.93
1-10 cm	>500,000	0.035
<1 cm	>50,000,000	0.035
Total	>50,000,000	>5,000 tonnes

Estimated Debris Population

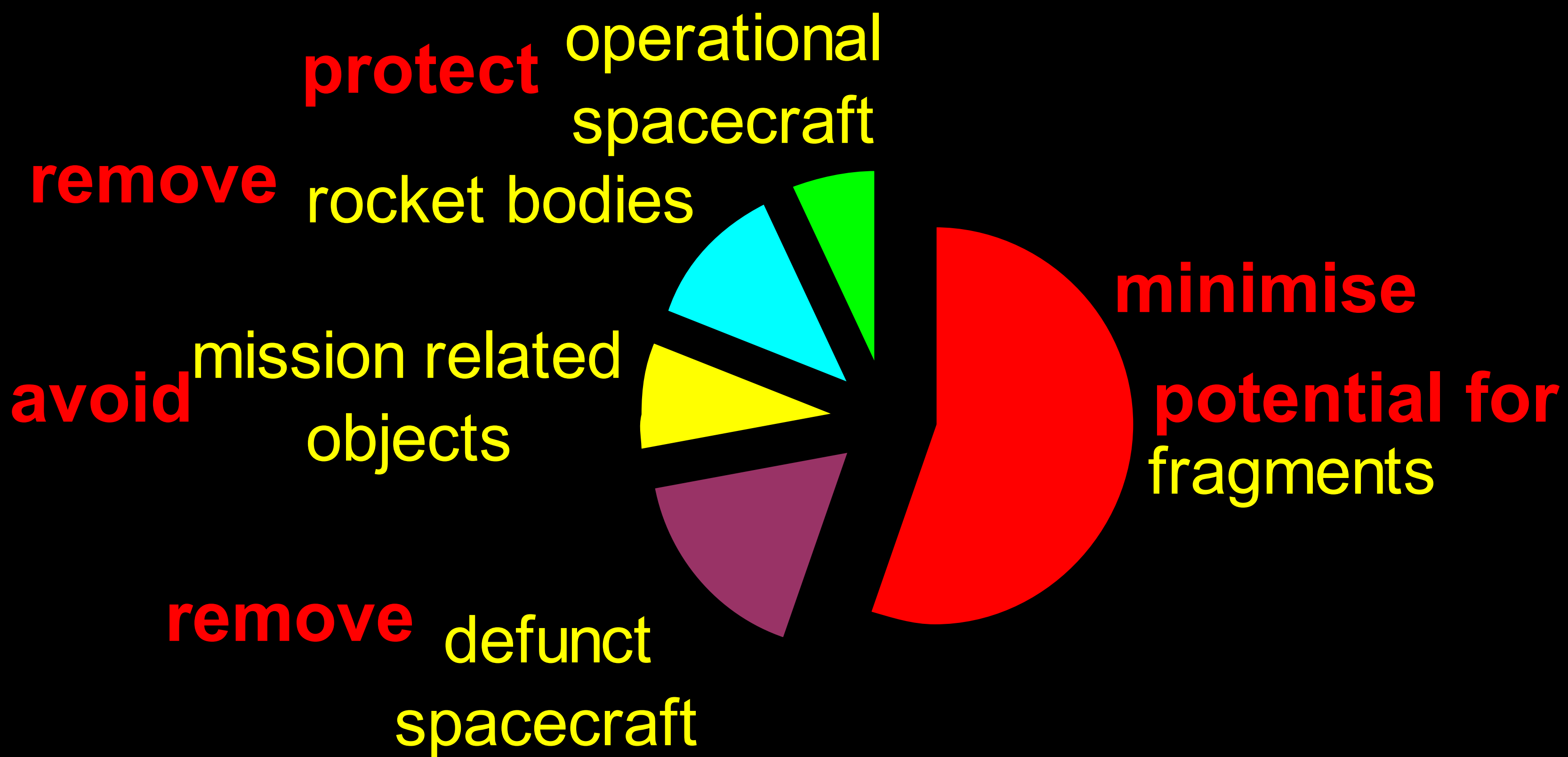
	Size	Number	% Mass
<10% active	>10 cm	>20000	99.93
	1-10 cm	>500,000	0.035
	<1 cm	>50,000,000	0.035
	Total	>50,000,000	>5,000 tonnes

WHAT IS THE SOLUTION TO SPACE DEBRIS?

MITIGATION OBJECTIVES

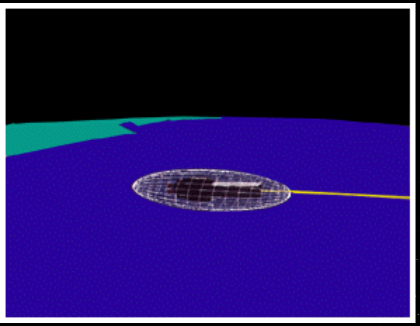


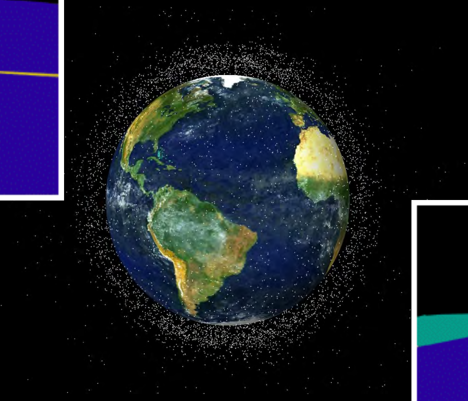
MITIGATION OBJECTIVES

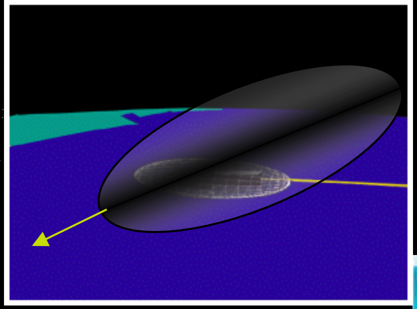


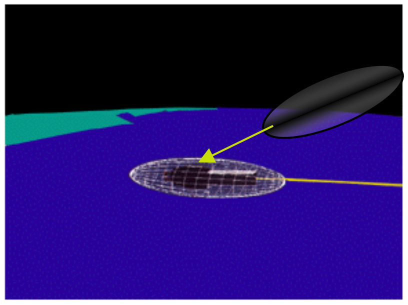

V 503
00:43:14.10
V 503
00:43:14.10

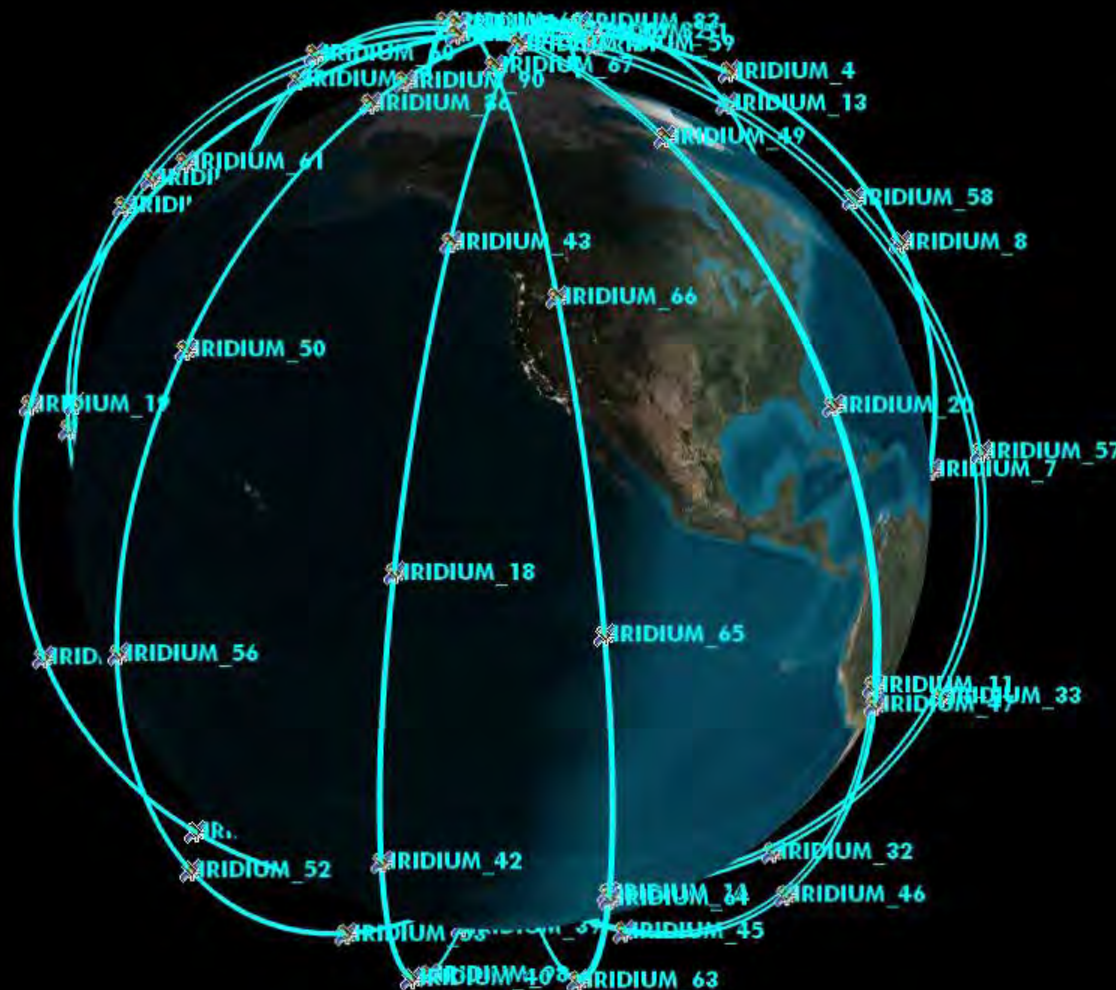
Collision Avoidance











IRIDIUM_4
IRIDIUM_13
IRIDIUM_49
IRIDIUM_61
IRIDIUM_58
IRIDIUM_8
IRIDIUM_43
IRIDIUM_66
IRIDIUM_50
IRIDIUM_57
IRIDIUM_7
IRIDIUM_18
IRIDIUM_65
IRIDIUM_56
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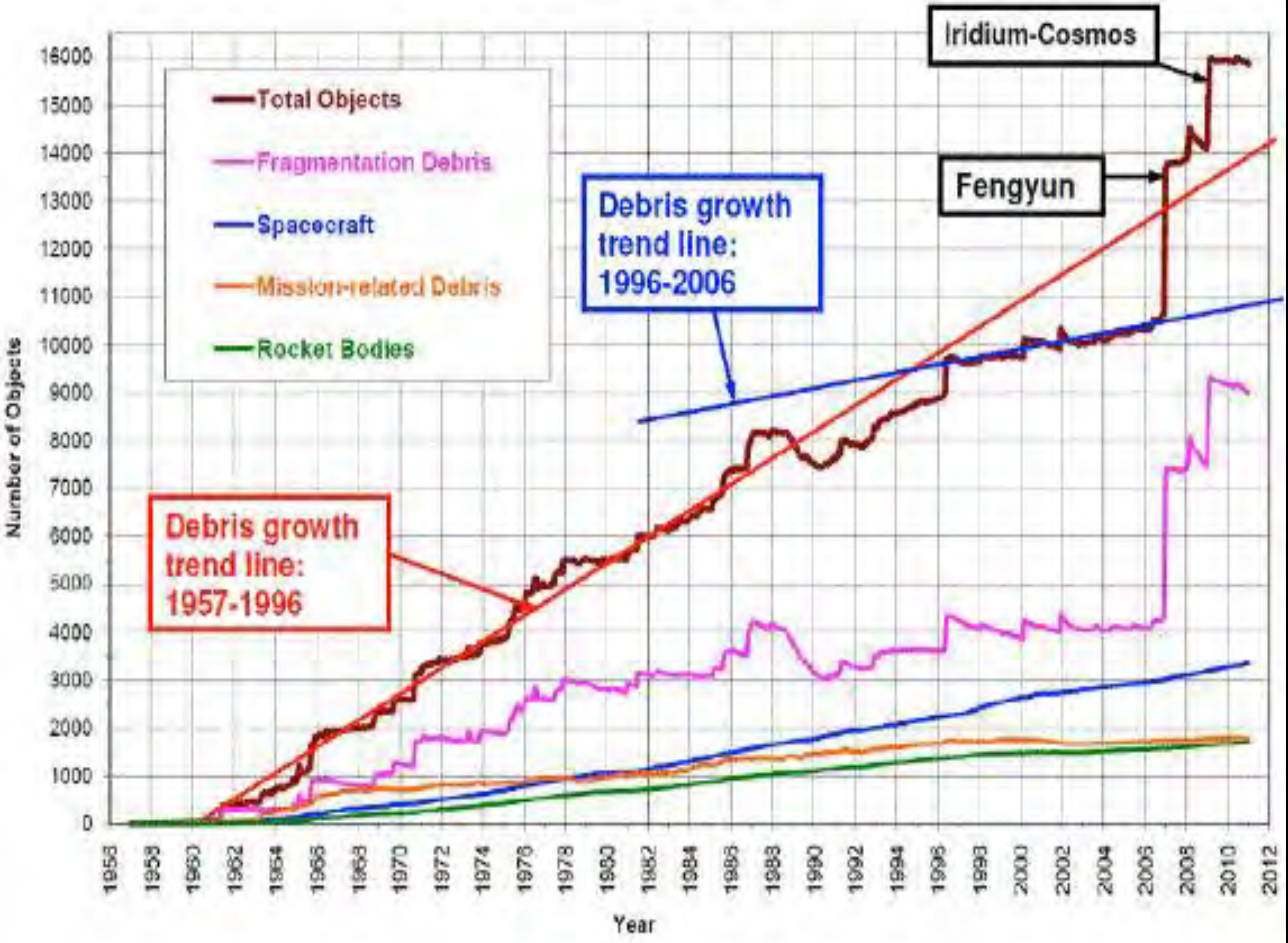
IRIDIUM_32
IRIDIUM_46
IRIDIUM_52
IRIDIUM_42
IRIDIUM_45
IRIDIUM_63



Iridium-Cosmos
Fengyun
Total Objects
Fragmentation Debris
Spacecraft
Mission-related Debris
Rocket Bodies
Debris growth trend line: 1996-2006
Debris growth trend line: 1957-1996
Number of Objects
Year
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
15000
16000
1956
1958
1960
1962
1964
1966
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1972
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1976
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1980
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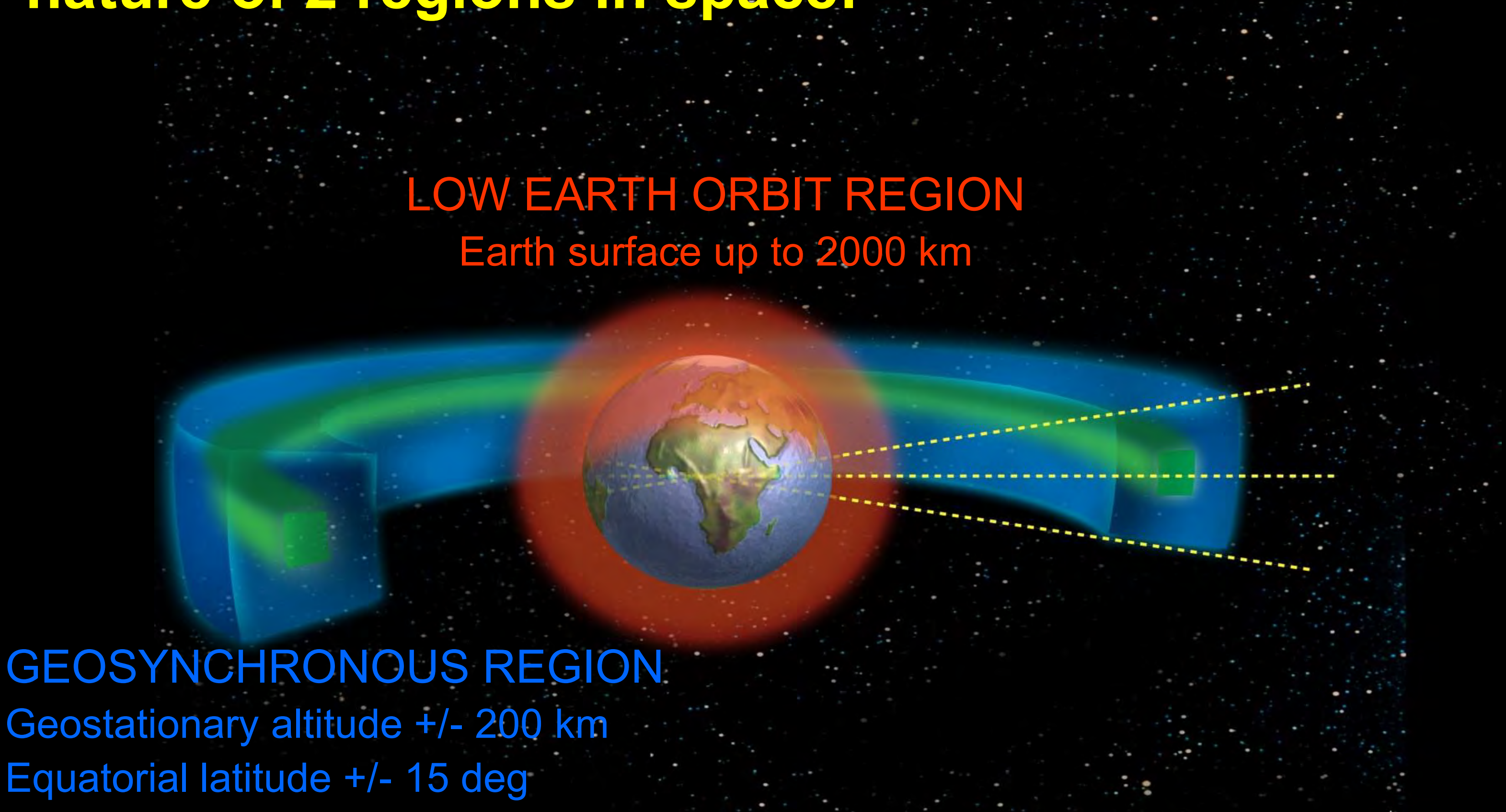
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012

Debris Mitigation

- Managing the debris environment does work
- Requires information of orbital population
- Need to share experience between operators
- Effectiveness of measures can be demonstrated
- Need comprehensive implementation to be effective
- Increasing reflected in national legislation
- Regulators need to assess compliance

Definition of Protected Regions

- **Activities in space should recognise the unique nature of 2 regions in space:**




AP





UK SPACE
FRIBEL

Lessons Learnt

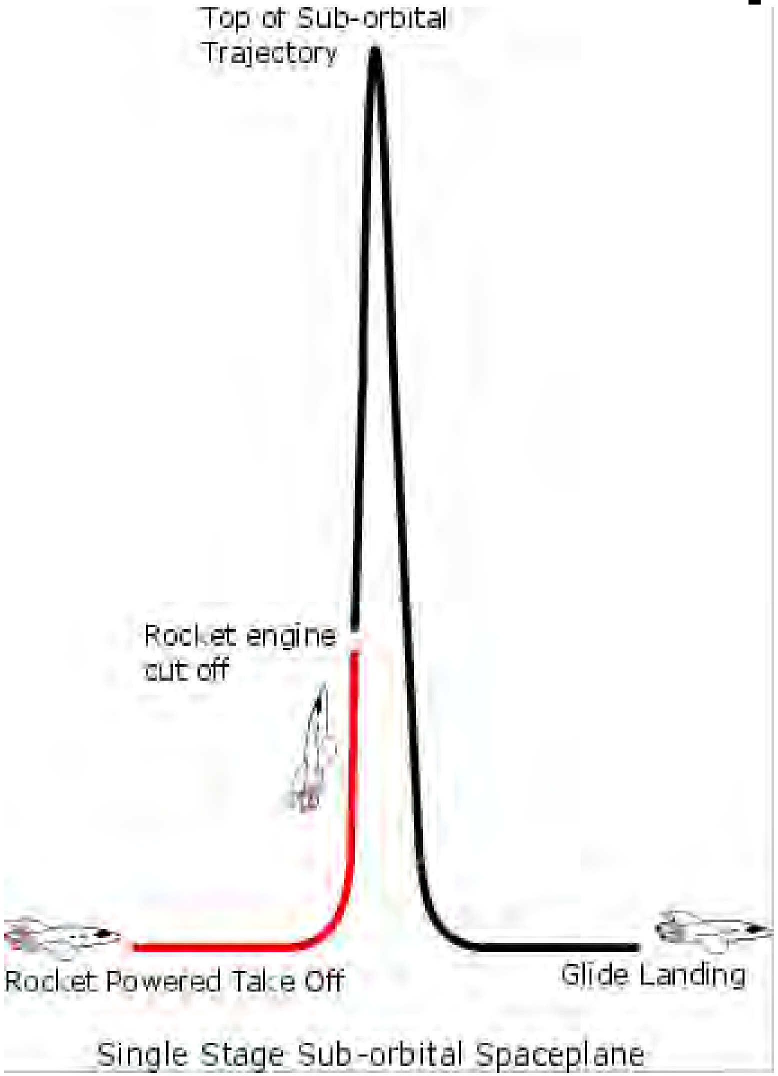
- Need to focus efforts on "cause" rather than just "effect"
- As environment deteriorates, cost impacts will increase significantly for all users of space
  - Loss of systems
  - Loss of fuel budget and lifetime due to increased manoeuvres
  - Increased demands of space surveillance
- Active management will be necessary
- Best practice needs to become <u>common</u> practice

Launch into Space

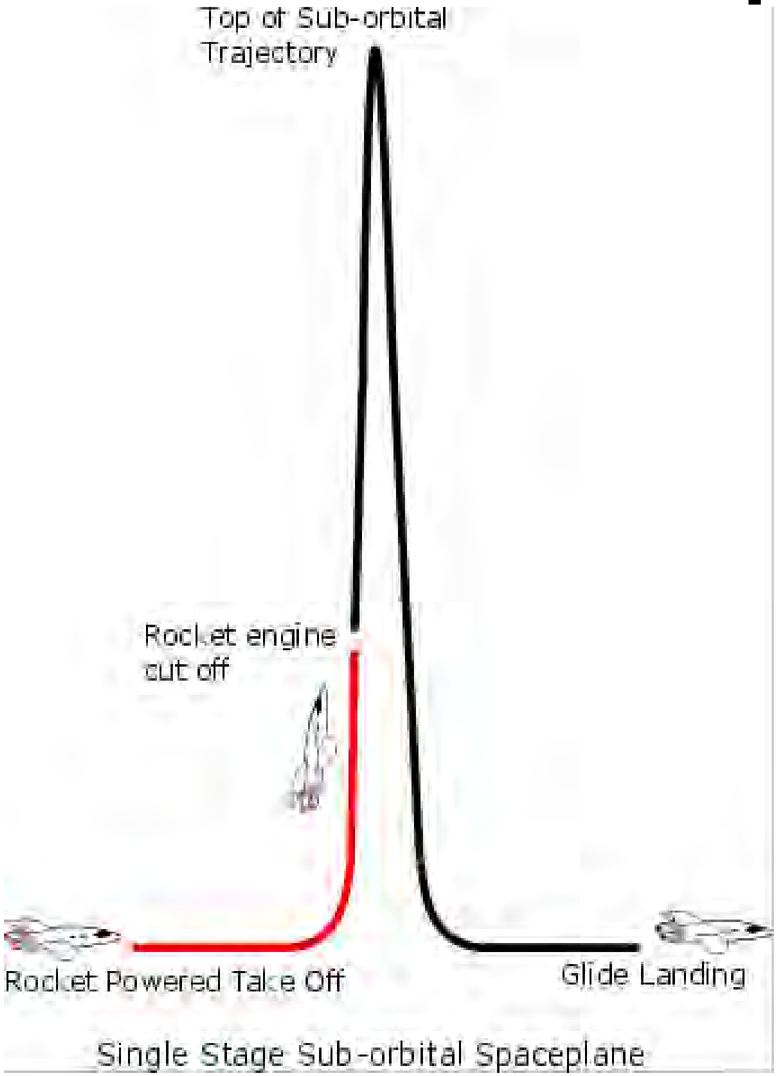
Prof. Richard Crowther
Chief Engineer,
UK Space Agency

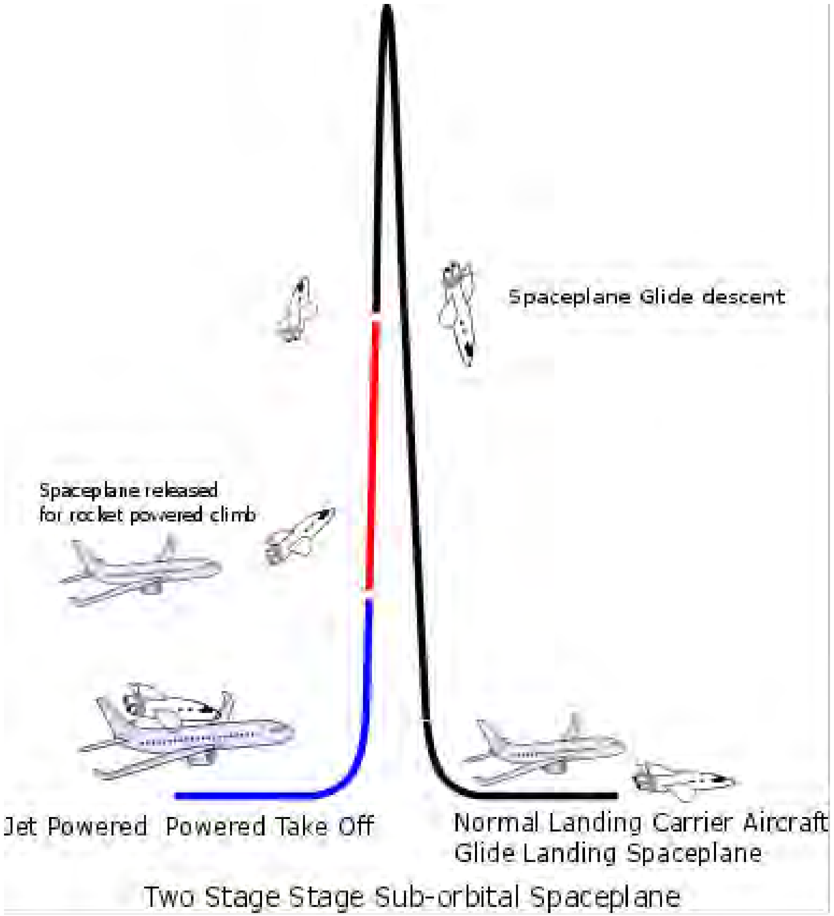
There are many ways to get into space…

There are many ways to get into space…



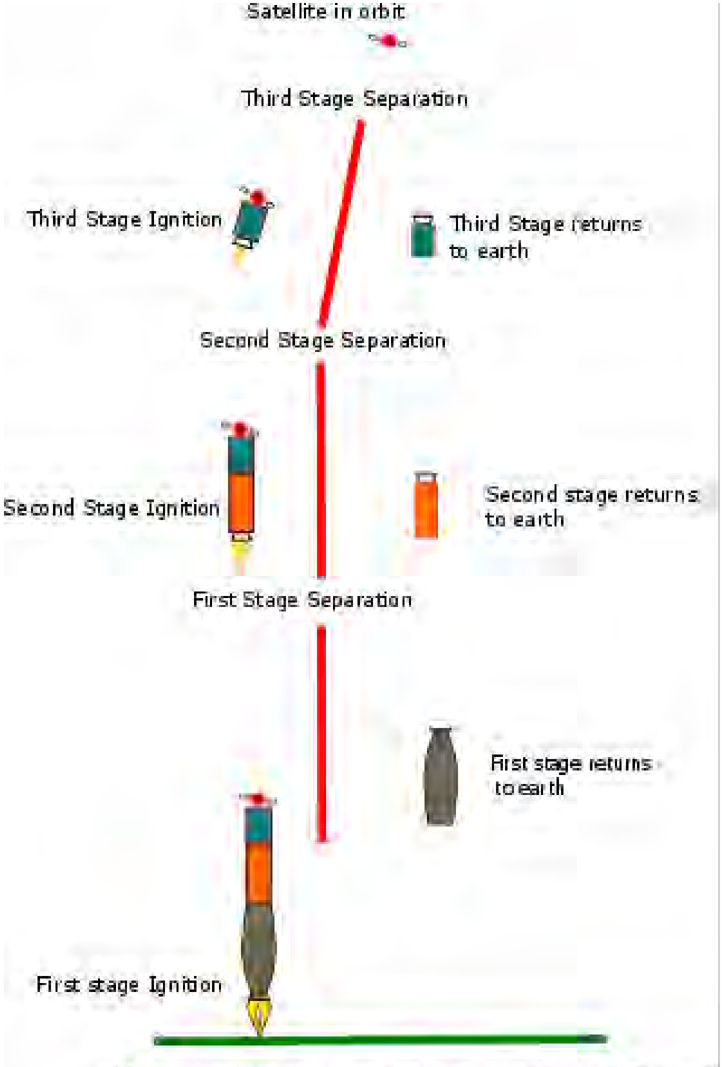
There are many ways to get into space…





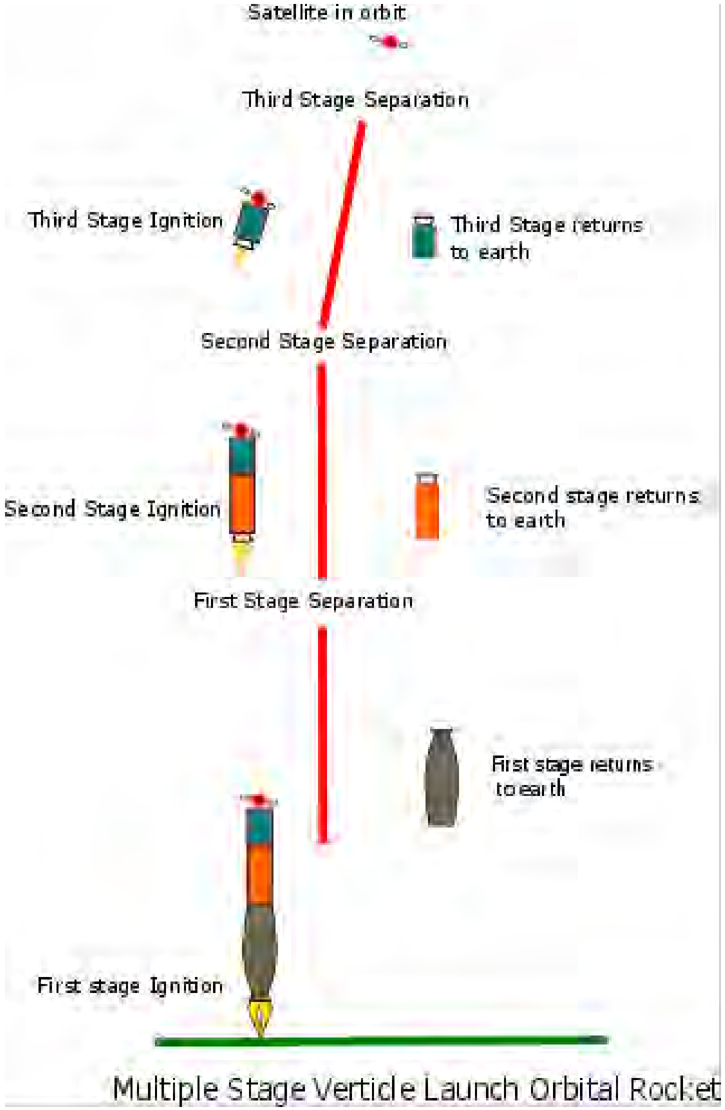
And also stay there …

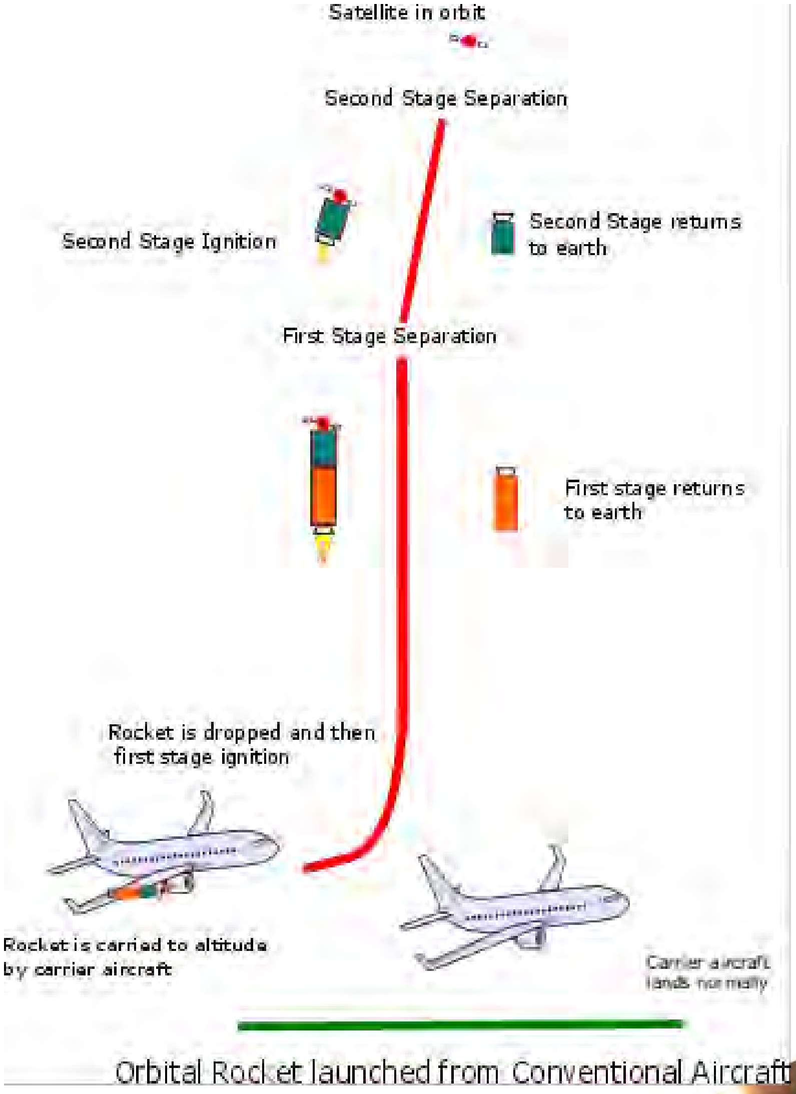
And also stay there …



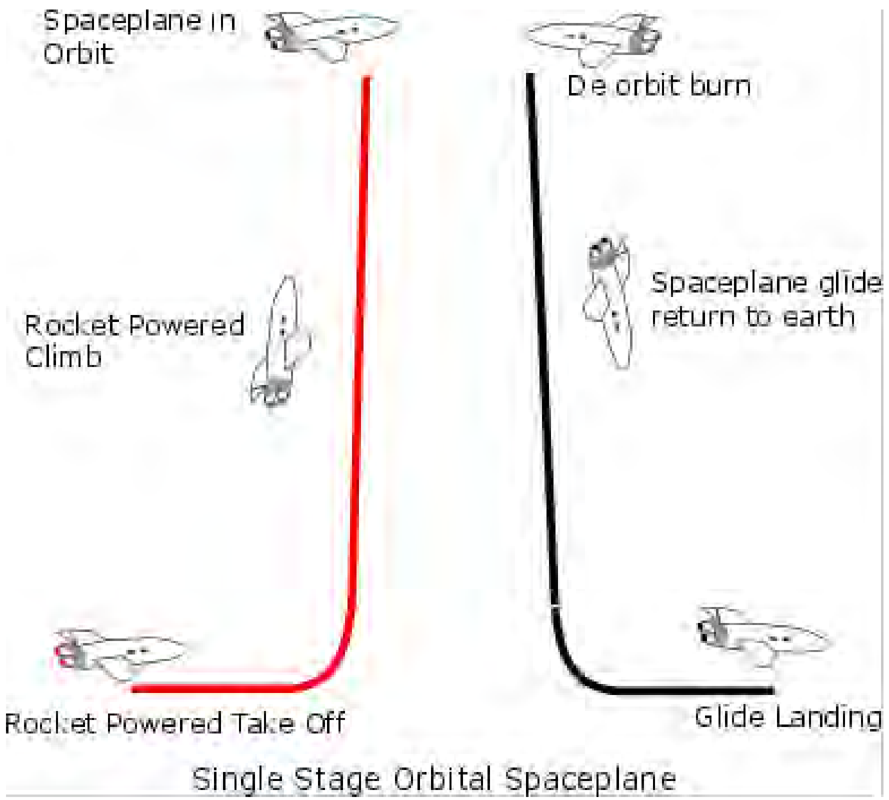
Multiple Stage Verticle Launch Orbital Rocket

And also stay there …





And go back again and again …



Delivering payloads to space

- A launch vehicle must:
  - Use **thrust** and/or lift to overcome the forces of gravity and drag
- A rocket produces **thrust** by expelling propellants
  - High mass at high speed (mass flow rate)
- Propellants can be liquid or solid and tend to comprise a fuel and an oxidiser
  - Solid rockets more reliable, liquid rockets flexible
- Staging used is shed redundant mass
  - Trade-off between altitude, fuel and payload mass

Launch site location can influence achievable orbit

- We can exploit Earth rotation to add 470 m/s at Equator

- Initial orbit inclination of launcher dictated by launch site latitude

- For an expendable launch vehicle, overflight and down-range impact of spent stages may dictate the need for dog-legs to avoid population centres

Launch Site Requirements

- Ground Facilities
  - Vehicle and payload integration and test
- Range with supporting flight infrastructure
  - Telemetry and tracking
  - Meteorological services
  - Flight termination system
- Airspace management to enable access to space
  - Must ensure that launch vehicle does not interfere with aircraft in flight
  - NOTAMs issued for launch and re-entry

Safety Management System

- Ground and flight safety informed by detailed risk analysis
- All potential hazards identified, evaluated and prevention/mitigation plans assessed
- Accident response plan developed
- Roles and responsibilities confirmed
- Criteria for evaluation and thresholds for action confirmed

UK SPACE AGENCY

Space Security

Prof. Richard Crowther
Chief Engineer, UK Space Agency

Space is changing

Space is becoming more:

Congested, **C**ontested, **C**ompeted

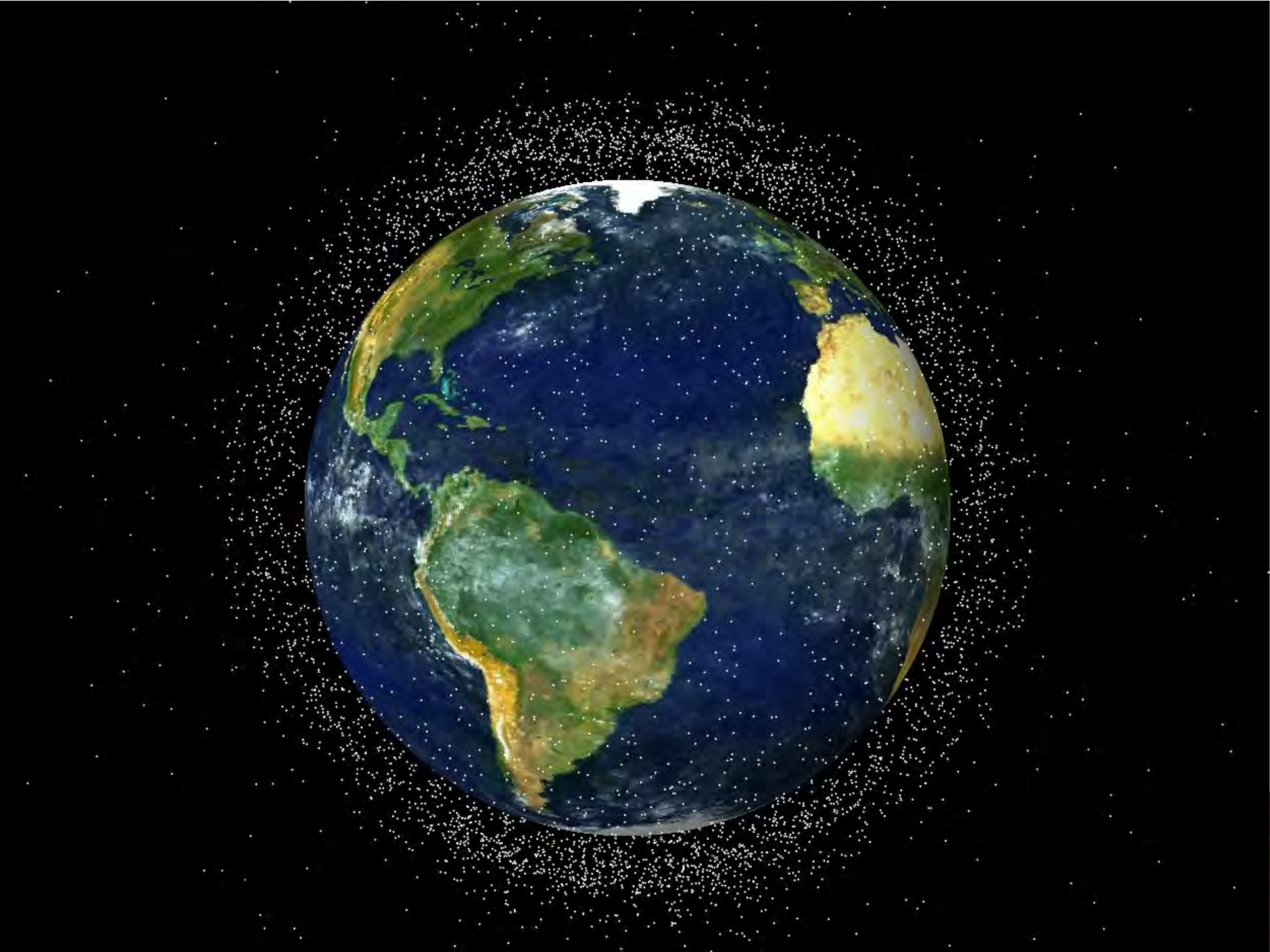
Space is changing

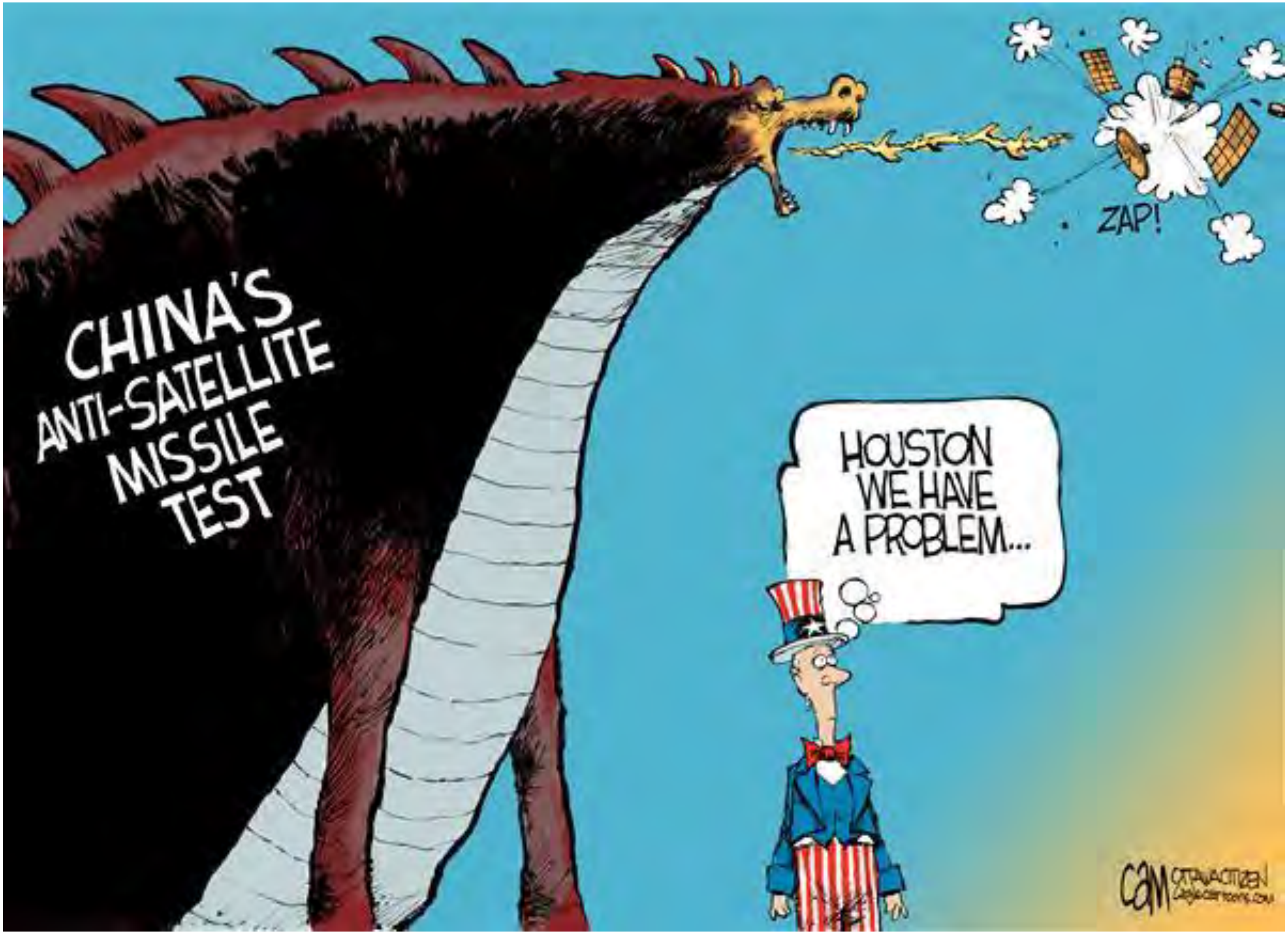
Space is becoming more:

Congested, **C**ontested, **C**ompeted

In response, we need to focus on:

Safety, **S**ecurity, **S**ustainability




CHINA'S
ANTI-SATELLITE
MISSILE
TEST
ZAP!
HOUSTON
WE HAVE
A PROBLEM...
CAM
OTTAWA CITIZEN

Dual Use Systems

- Dual Use systems can be used for either peaceful or military/security aims, or both
- Rapidly evolving technology has already broadened the scope of potential conflict from land, maritime and air environments to encompass cyber and space domains
- Appropriate consideration needs to be given to the potential of dual use space systems

Space services well established across sectors

Launch			
Communications			
Position, Navigation & Timing			
Remote Sensing			

Space services well established across sectors

	Civil	Military	Commercial
Launch			
Communications			
Position, Navigation & Timing			
Remote Sensing			

Space services well established across sectors

	Civil	Military	Commercial
Launch	✓	✓	✓
Communications	✓	✓	✓
Position, Navigation & Timing	✓	✓	✓
Remote Sensing	✓	✓	✓

Governance Structures Controlling Export/Use of Dual Use Products

- Missile Technology Control Regime
- Hague Code of Conduct
- International Trafficking in Arms Regulations
- High Resolution Remote Sensing
  - Imagery dissemination policies

Space services well established across sectors

	Civil	Military	Commercial
Launch	✓	✓	✓
Communications	✓	✓	✓
Position, Navigation & Timing	✓	✓	✓
Remote Sensing	✓	✓	✓

Space services well established across sectors

	Civil	Military	Commercial
Launch	✓	✓	✓
Communications	✓	✓	✓
Position, Navigation & Timing	✓	✓	✓
Remote Sensing	✓	✓	✓
Space Situational Awareness	✓	✓	✓

Space Situational Awareness

- Interdependence of congested, competed, contested space makes SSA critical across all domains
- Cannot afford to work in isolation intra/inter-State
  - Many sensors are military in nature
  - Primary mission not necessarily space surveillance
  - Global coverage requires significant resources
  - Opportunity for civil and commercial systems to supplement military sensors and networks

Space Situational Awareness

- Military requirements driven by air/missile defence/C4ISR and security related
- Commercial requirements driven primarily by mission assurance and reliability/availability/productivity and safety
- Civil requirements driven primarily by safety (in-orbit/re-entry) and treaty/regulatory compliance/monitoring

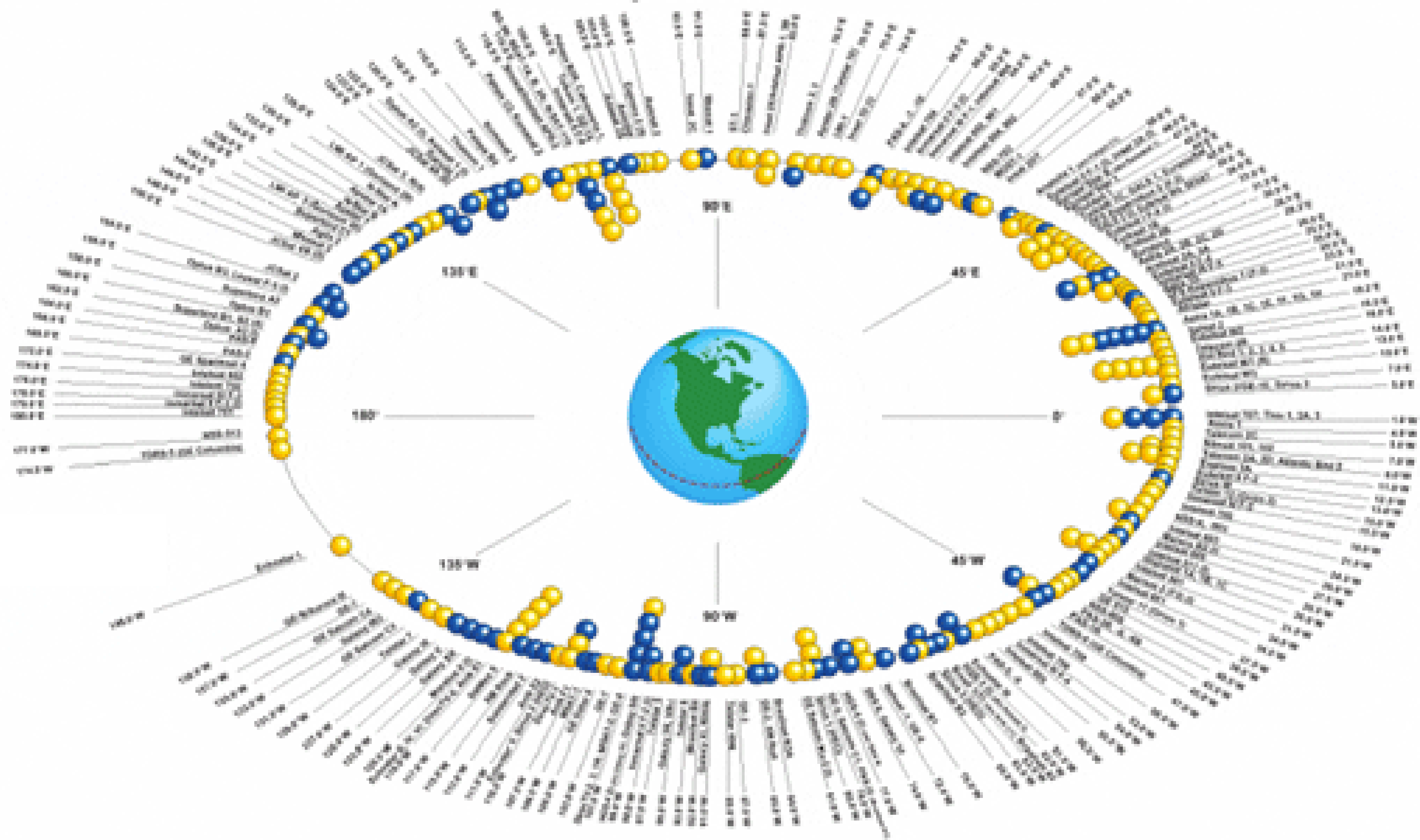
Governance Principles

- Rules and procedures for handling and distribution of:
  - Sensor data
  - Processed data
  - Cataloguing
  - Collision prediction
  - Manoeuvre reporting
- Tasking/availability of sensors/services

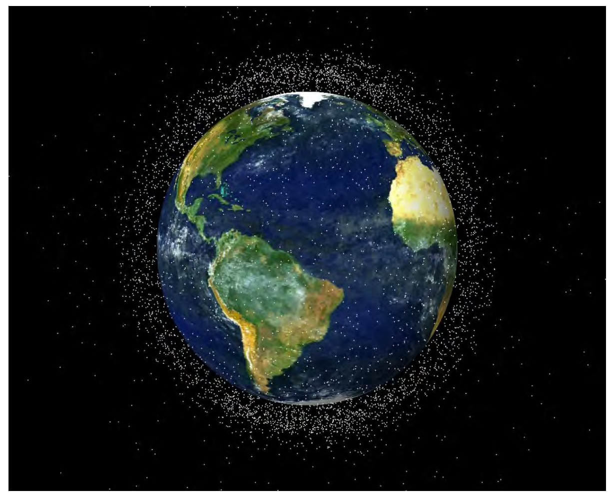
Governance Challenges

- Security/Sensitivity
  - Classified platforms
  - Sensor capability
  - Network coverage (spatio-temporal)
- Reliability
  - Calibration/cross-correlation
  - Verification/Validation
  - Standardisation/integration of data sets
- Availability
  - Tasking/prioritisation of sensors

Commercial Communications Satellites
Geosynchronous Orbit



Governance Forums



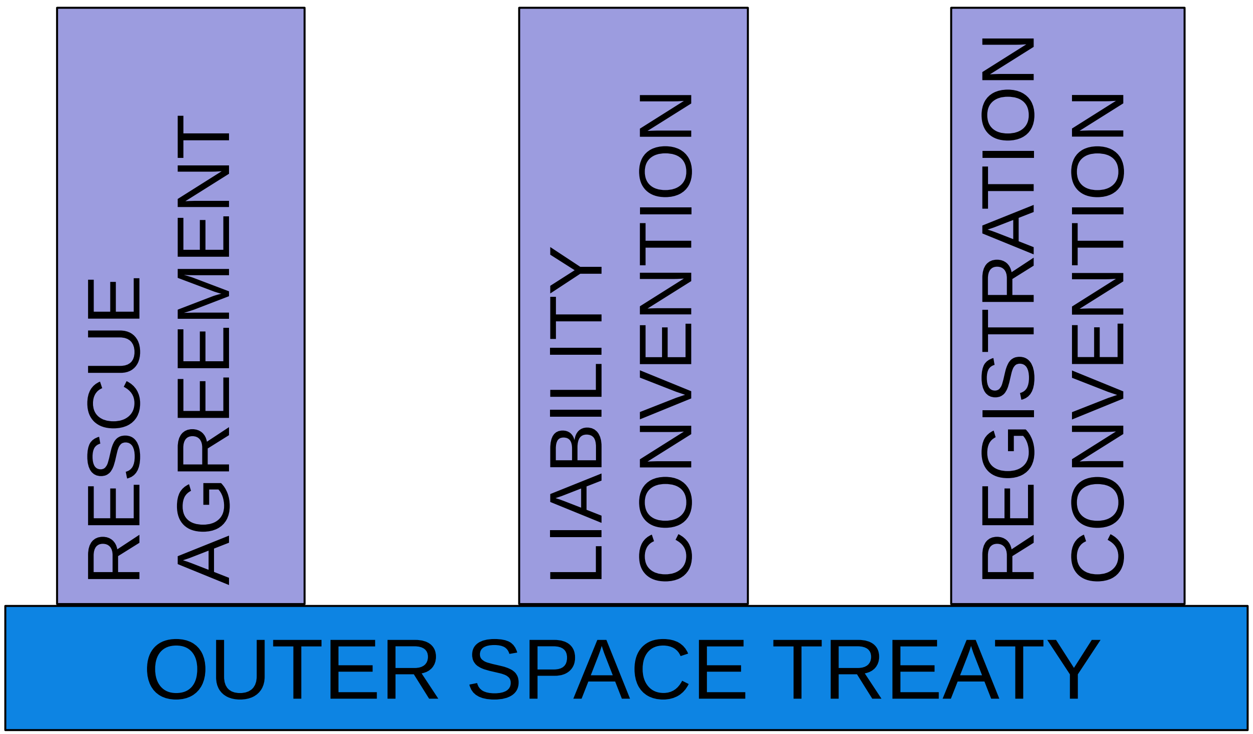
Committee on Peaceful Uses
Of Outer Space (COPUOS)

Conference on Disarmament
(CODUN)

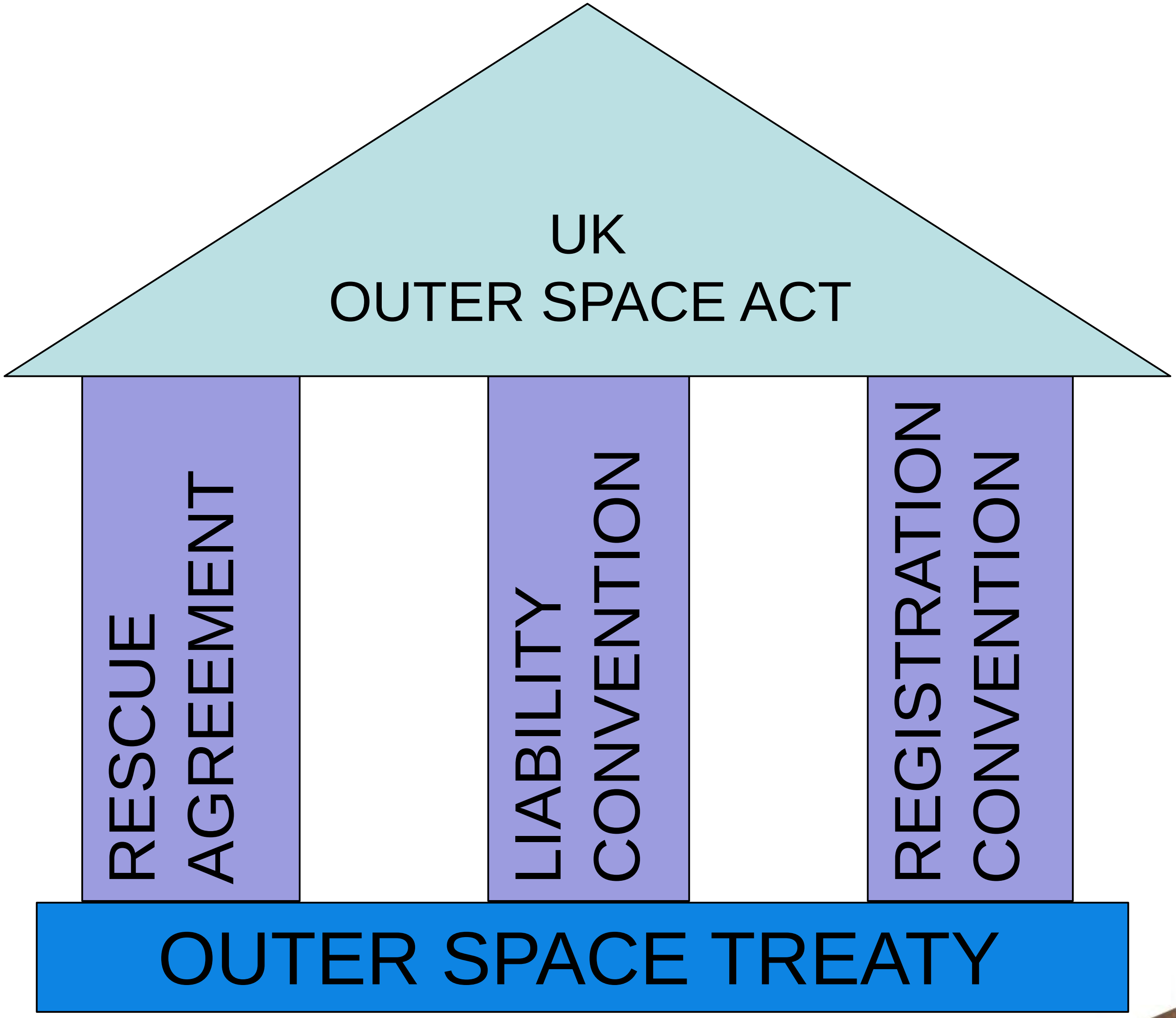
Regulation of Space

OUTER SPACE TREATY

Regulation of Space



Regulation of Space



OSA LICENSING CONSIDERATIONS

WHO?	WHY?	WHEN?
HOW?	WHAT?	WHERE?

Estimated Orbital Population

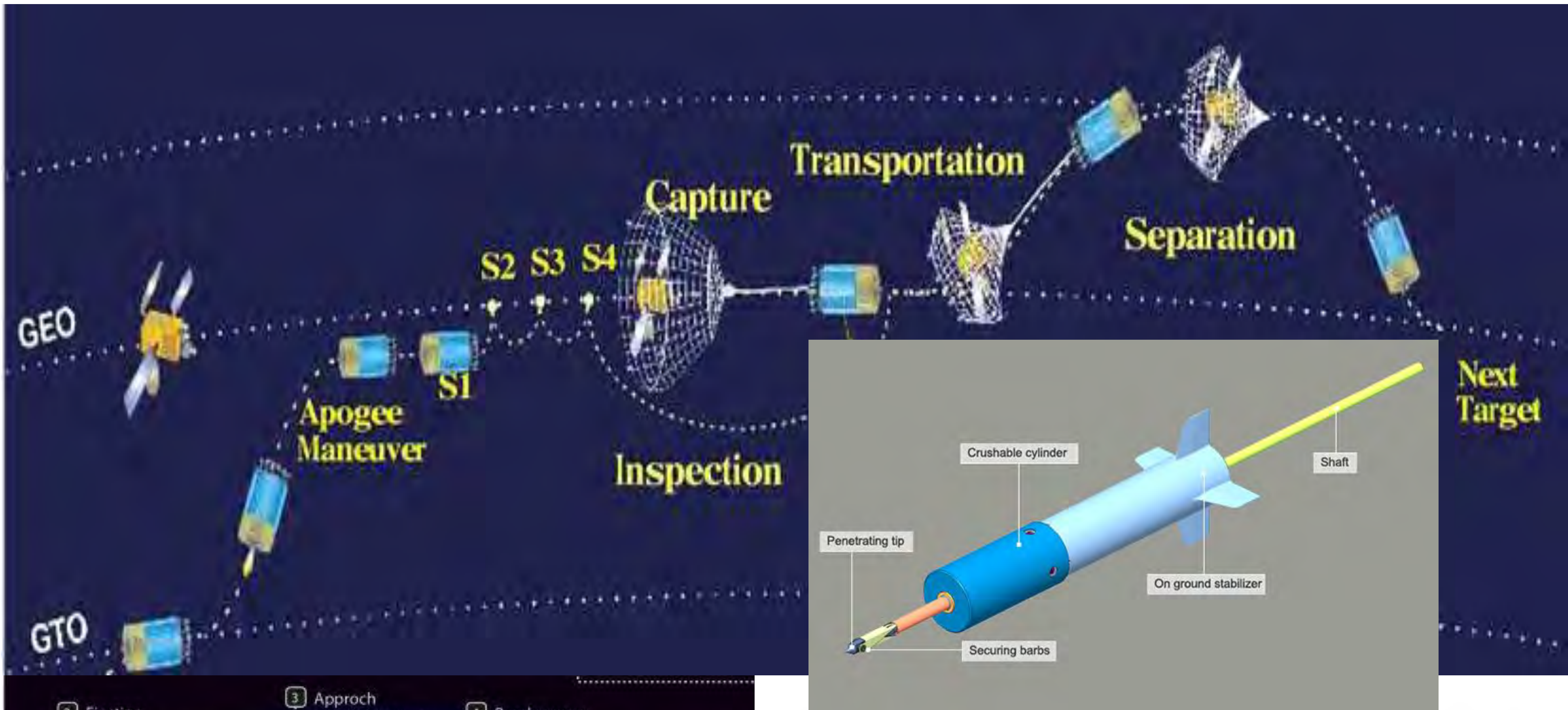
Size	Number	% Mass
>10 cm	>17000	99.93
1-10 cm	>400,000	0.035
<1 cm	>35,000,000	0.035
Total	**>35,000,000**	**>6,000 tonnes**

Estimated Orbital Population

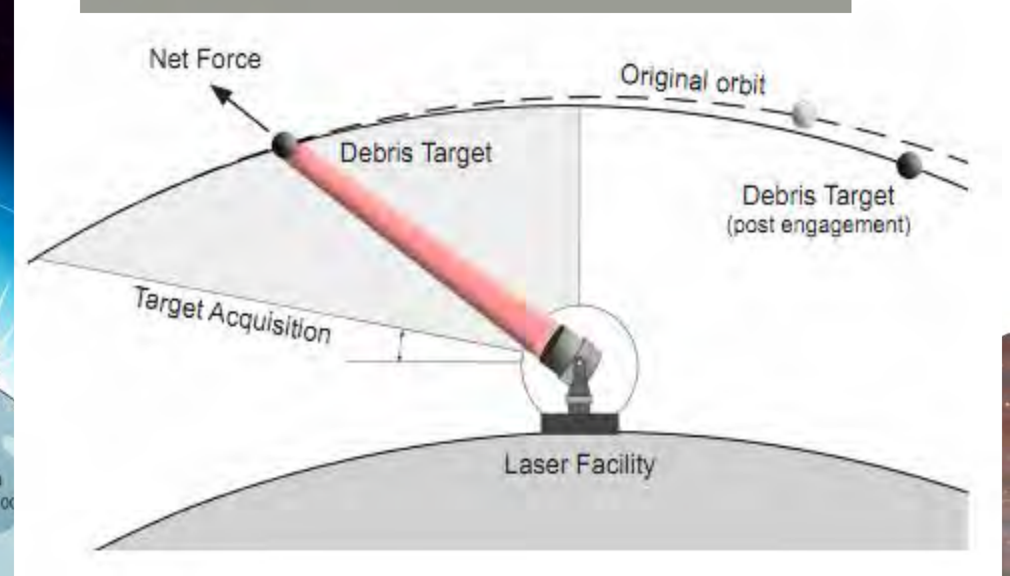
	Size	Number	% Mass	
Tracked objects	>10 cm	>17000	99.93	< 10% operational
	1-10 cm	>400,000	0.035	
	<1 cm	>35,000,000	0.035	
	Total	>35,000,000	>6,000 tonnes	

We can only "manage" a small proportion of objects through "mitigation"

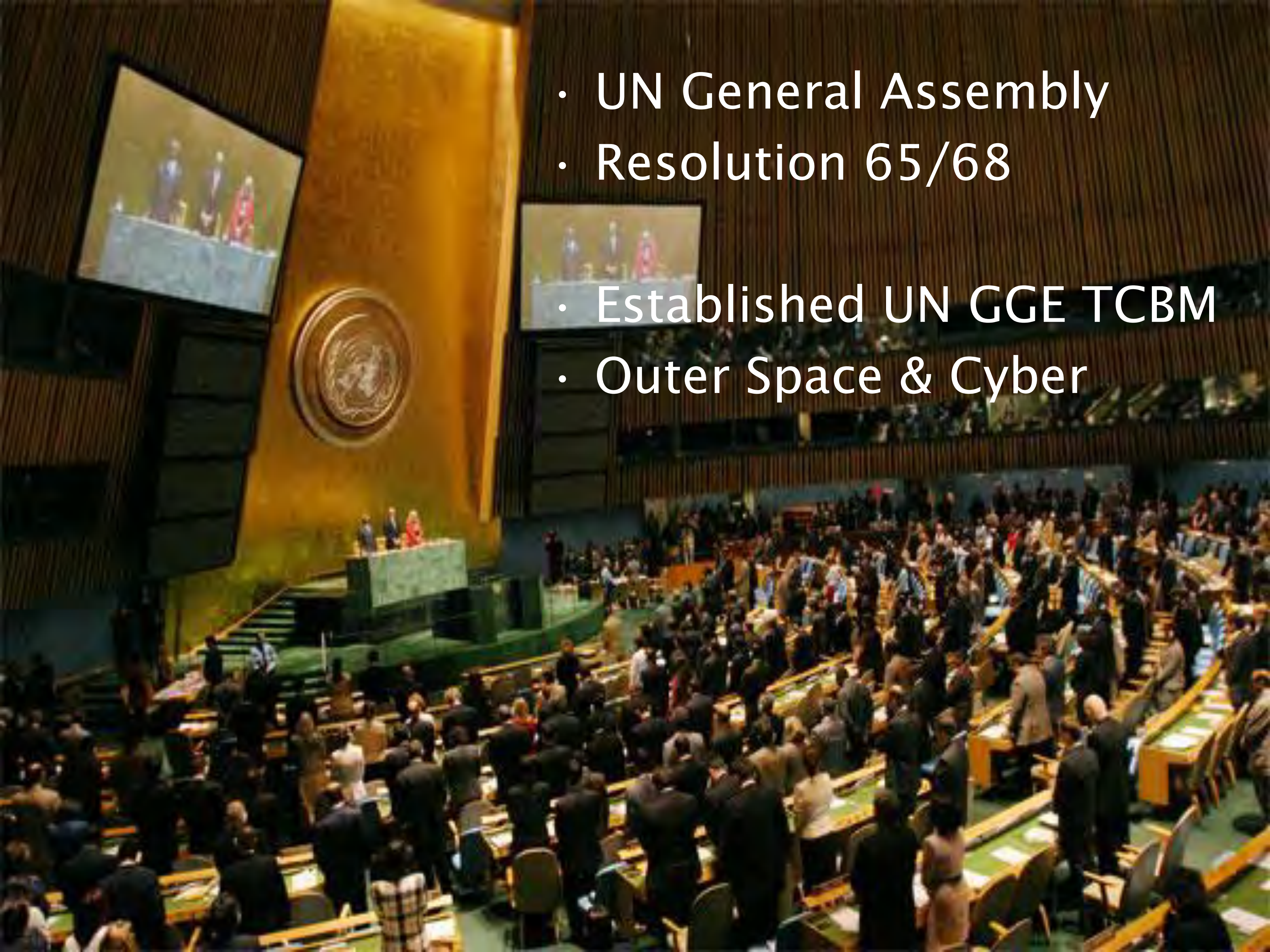
What is the answer?


GEO
GTO
Apogee Maneuver
S1
S2
S3
S4
Capture
Inspection
Transportation
Separation
Next Target
Crushable cylinder
Shaft
Penetrating tip
On ground stabilizer
Securing barbs


2 Ejection
Altitude: 630-750 km
3 Approch
Speed: 28,000 km/h
4 Rendez-vous phase
5 Grappling
target orbit
1 Launch
CleanSpace One
Size: 30 x 10 x 10 cm
Predicted launch: 2015-2016
Mission: De-orbit an obsolete satellite
6 and disintegration
Temperature: more than 10


Net Force
Original orbit
Debris Target
Debris Target
(post engagement)
Target Acquisition
Laser Facility


ED



• UN General Assembly
• Resolution 65/68
• Established UN GGE TCBM
• Outer Space & Cyber

UN GGE on TCBMs

UN: United Nations

GGE: Group of Governmental Experts

TCBMs: Transparency and Confidence Building Measures

Aim is to remove potential for suspicion over motives and escalation of hostilities

TCBMs

TCBMs include:

- Treaties (Anti-ABM)
- Forums (IADC)
- Codes of Conduct (Hague/EU?)
- Removal of capability (SORT)
- Inspections
- Workshops
- Exchanges

The Group of Governmental Experts on Transparency and Confidence-Building Measures in Outer Space Activities, United Nations, New York, 27 July 2012

From left to right: João Marcelo Galvão de Queiroz - Brazil, Chulmin Park - Republic of Korea, Richard Crowther - United Kingdom, Musthafa M. Jaffeer - Sri Lanka, Peter Martinez - South Africa, Andrii Kasianov - Ukraine, Frank Rose - USA, Victor L. Vasiliev - Russian Federation - Chairman, Augustine U. Nwosa - Nigeria, Gérard Brachet - France, Dumitru-Dorin Prunariu - Romania, Sergio Marchisio - Italy, Huaicheng Dai - People's Republic of China, Hellmut Lagos - Chile, Ruslan Amirgereyev - Republic of Kazakhstan

Tiered approach to security of space

- Aim is to deter potentially damaging activities in outer space through:
  - Establishment of norms of behaviour to identify irresponsible actions
  - Building of international partnerships to forge alliances and encourage inter-dependency
  - Development of resilient systems to mitigate consequences of impacts on systems
  - Enabling self-defence to respond to hostile actions/actors

Summary

Our goal is a stable space environment.

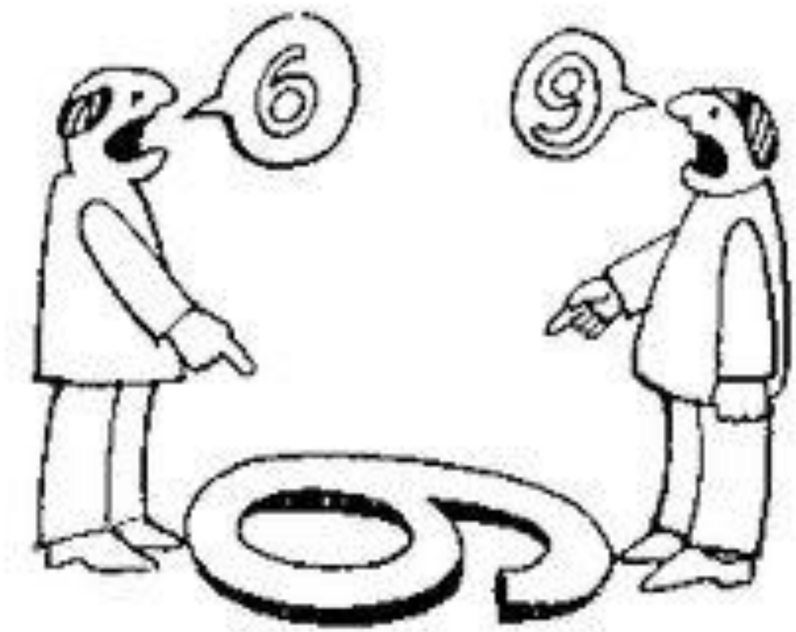
However, space is becoming more:

Congested, **C**ontested, **C**ompeted

In response, we need to focus on:

Safety, **S**ecurity, **S**ustainability

Summary



Safety=**S**ecurity=**S**ustainability

UK SPACE AGENCY

Space Weather Effects

Prof Richard Crowther

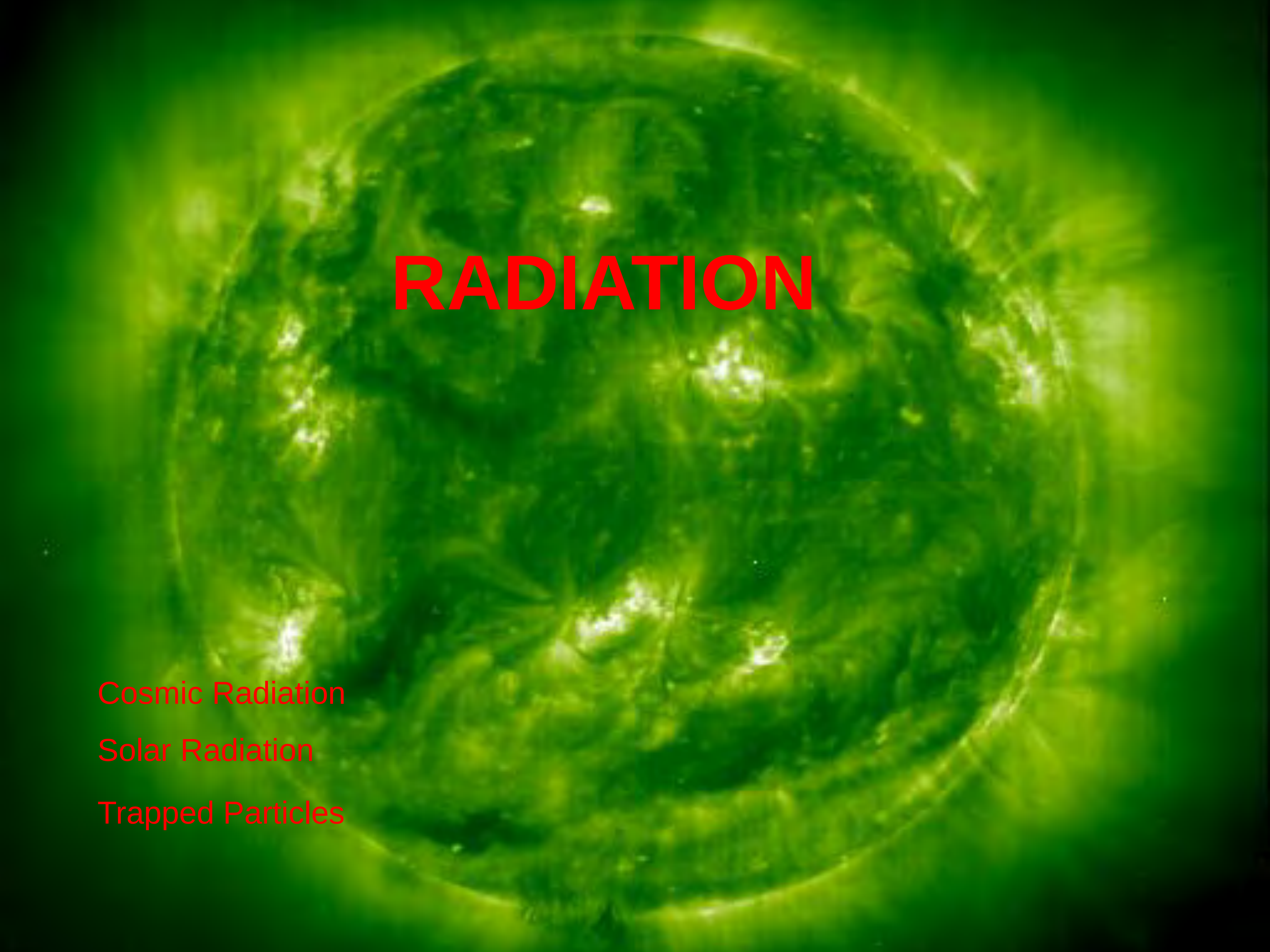
ISPL Space Policy and Law Workshop 2016

Outline

- Background
- Aviation
- Power
- Ground Transport
- Communications
- Pipelines
- Oil and Mineral Industries
- Finance

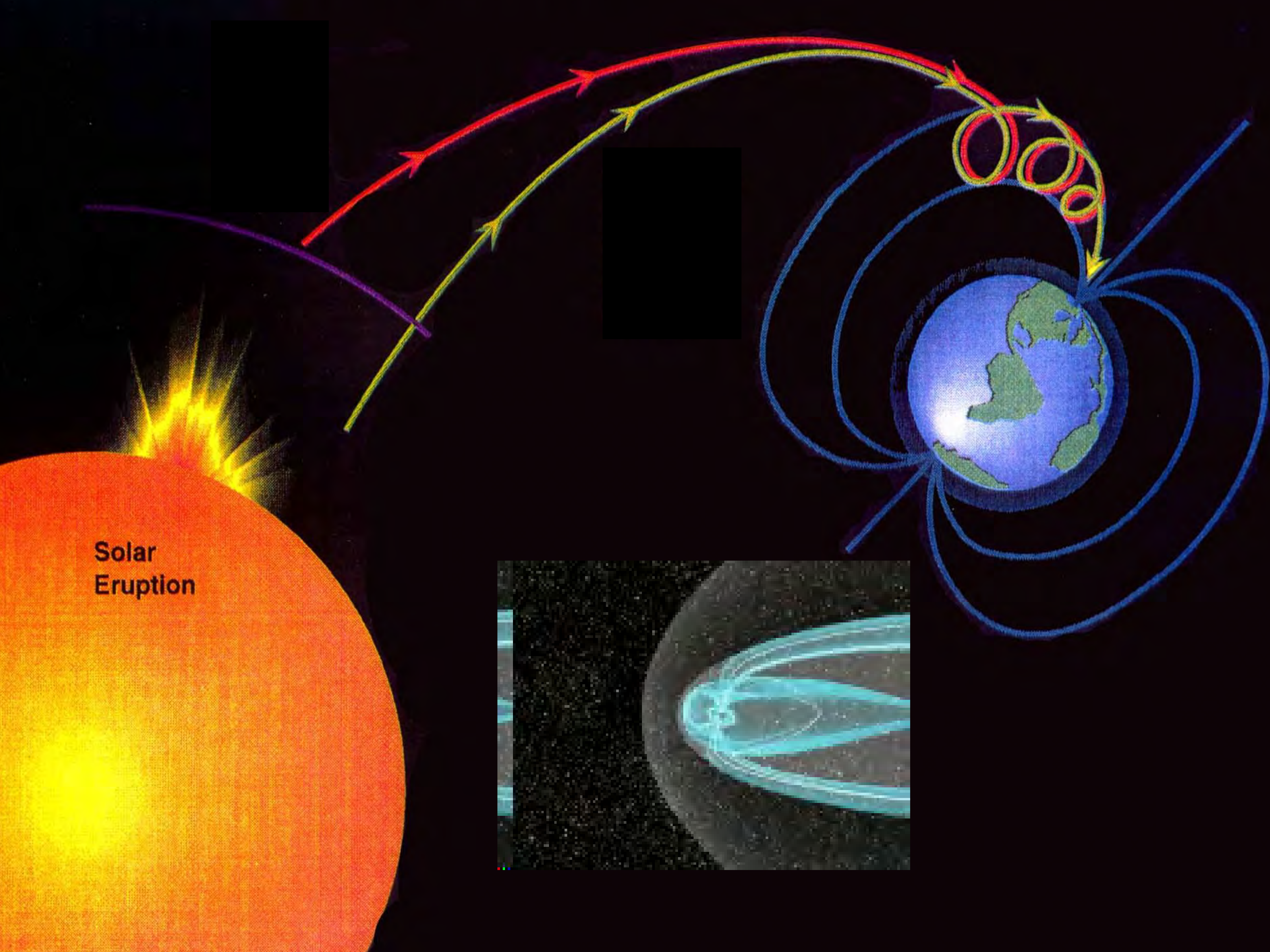
Background (Environment)

- Magnetic Storms
- Solar Radiation Storms
- Solar Radio Bursts
- Galactic Cosmic Rays
- High Speed Solar Wind
- Solar Flares



RADIATION

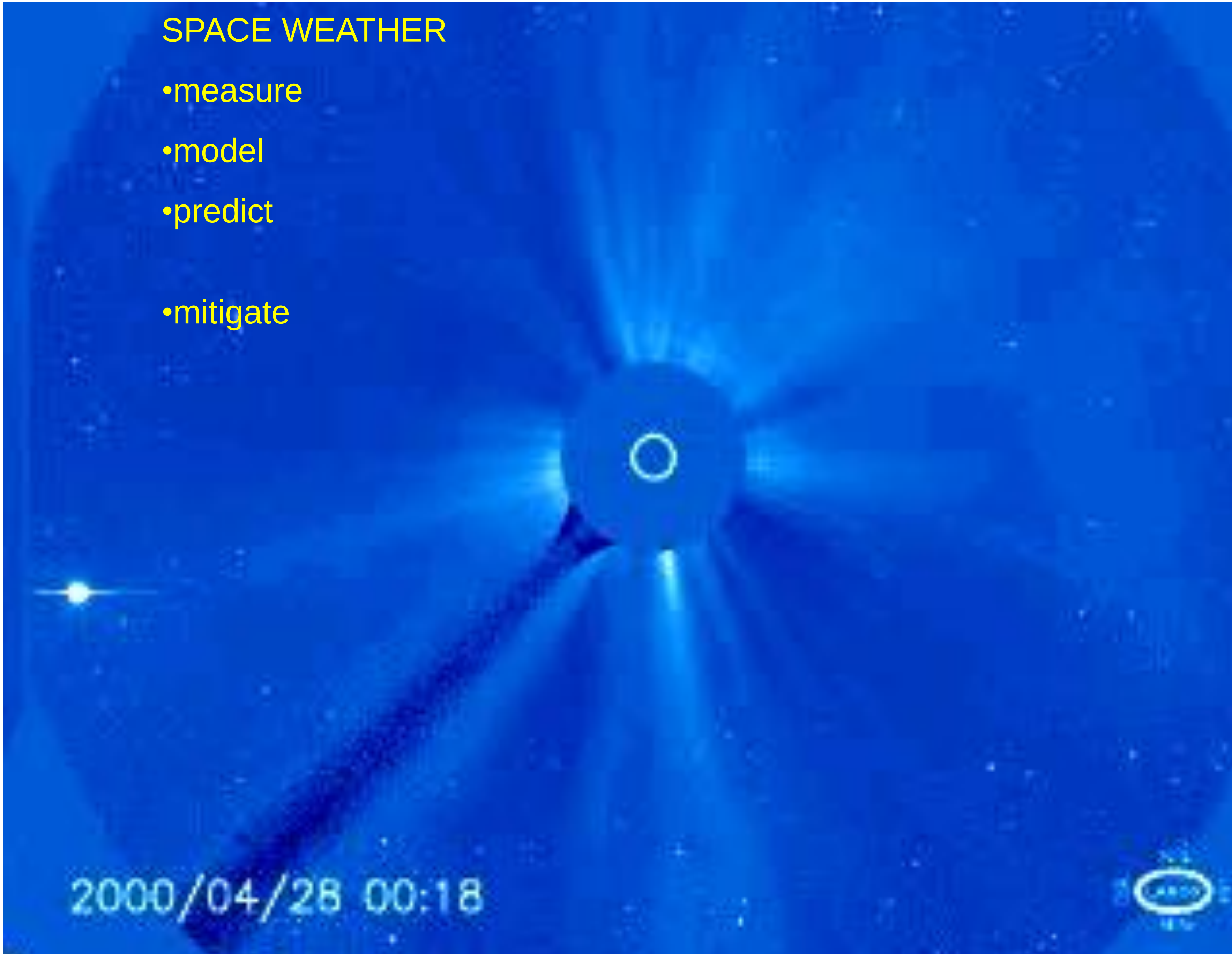
- Cosmic Radiation
- Solar Radiation
- Trapped Particles

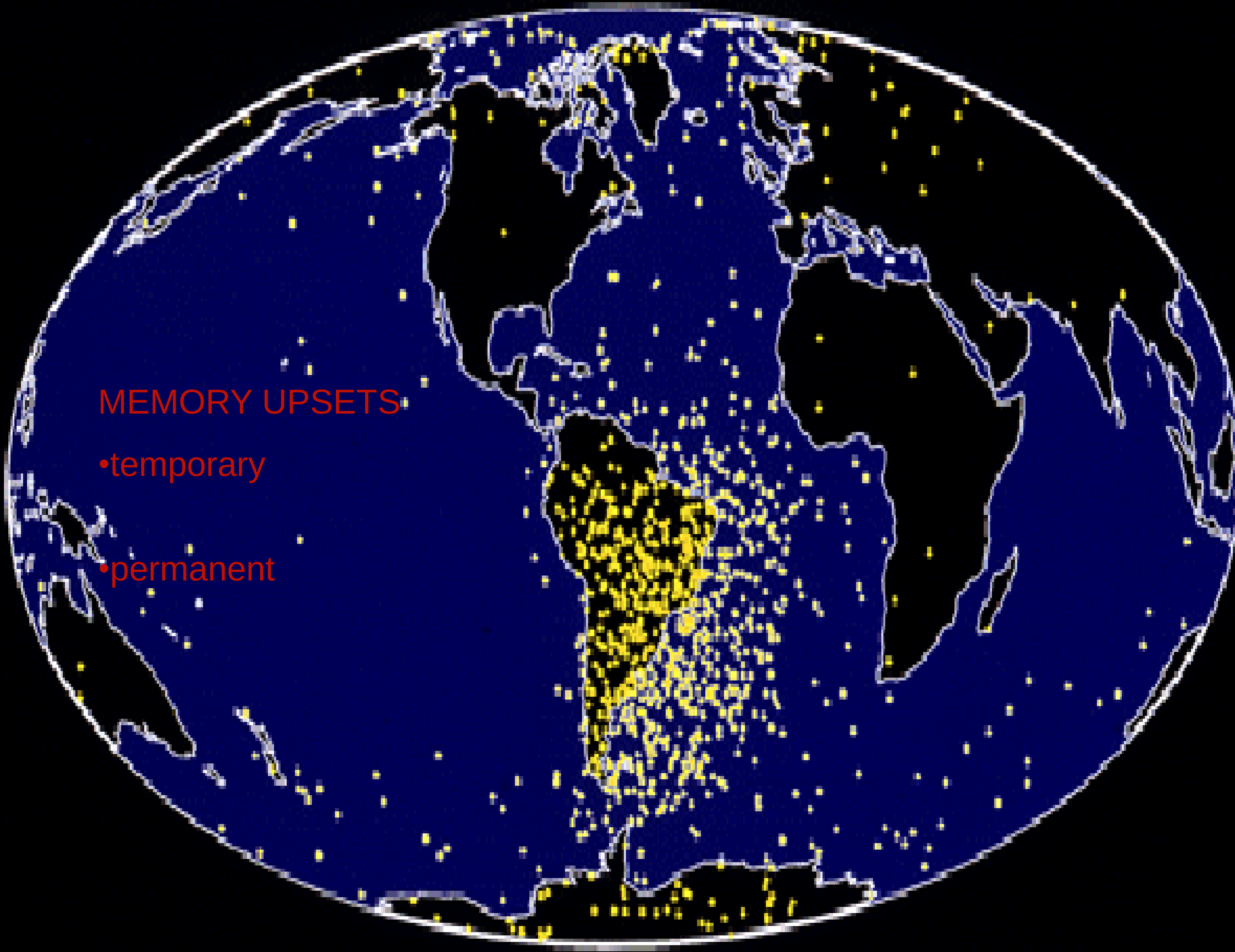

Solar
Eruption

SPACE WEATHER

- measure
- model
- predict

- mitigate




MEMORY UPSETS
•temporary
•permanent

RADIATION DAMAGE

- astronauts
  - tissue damage
- spacecraft systems
  - degradation in performance
  - malfunction

Aviation

- Space weather has significant impact on Aviation, esp. trans-polar routes
- Communications
  - HF radio links can be degraded (2003, blackout)
  - GEO satcom not accessible above 82 degrees)
- Navigation
  - Accuracy can be degraded & signal lost
- Radiation Hazards
  - Compromise operation (Single Event Effects)
  - Health of aircrew and passengers

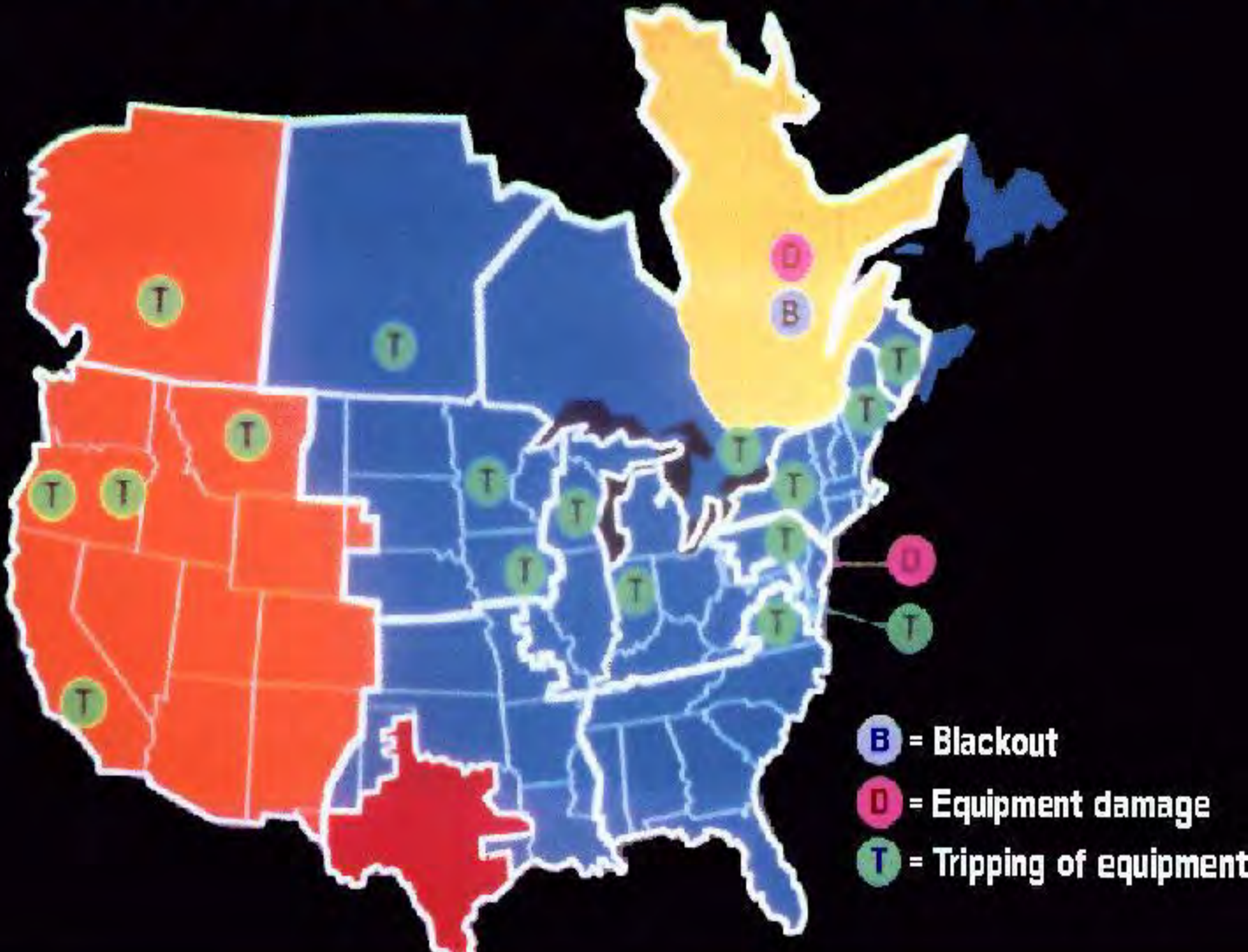
CHARGING

- Surface
- Internal

Power

- During magnetic storms, changes in Earth’s magnetic field can generate sub-surface electric fields
  - Damaging currents in power grids (1989, Quebec C$2bn, New Jersey, UK)
  - Permanent damage requiring replacement
  - Cascade failure & need to restore
- Implications for “renewables” which have long transmission lines?
- Indirect consequences for fuel, food, sanitation, finance, …

POWER SYSTEM EVENTS DUE TO SMD MARCH 13, 1989



Transport

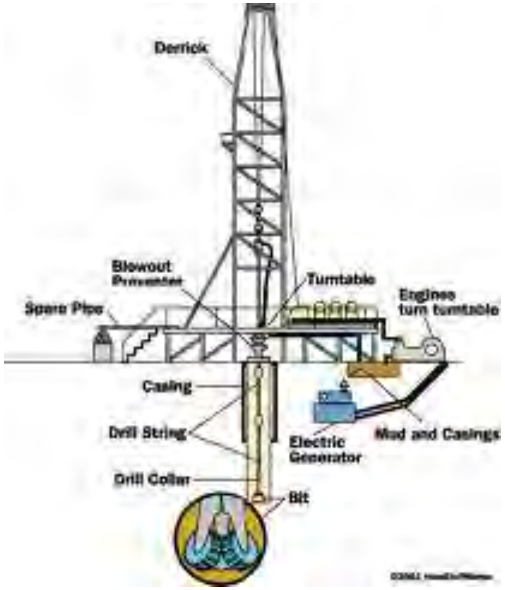
- Road and Maritime transport which use GPS less susceptible to space weather effects
  - – New electronic controls may be vulnerable to SEE
- Rail traffic
  - – Electric power networks (direct/indirect)
  - – Currents in signalling systems
  - – Control/communication technologies susceptible

Communications

- Telephones:
  - Historic risk for:
  - Long distance systems & calls routed via comsat
  - Mobile phone links vulnerable to solar radio bursts
  - Mobile phone networks use GPS timing
- Internet is relatively robust as most traffic carried by optical fibre
- Low power wireless vulnerable to interference from solar radio bursts

Oil and Mineral Industries

- Magnetic measurements used to search for natural resources and guide drilling
- Surveys are scheduled during quiet magnetic storm conditions
- Drilling suspended during severe events to avoid misdirection ($O(10^0)$)
- Miniature magnetic sensors are reaching the consumer market



Finance

- Time stamping of financial transactions is critical to operation of markets
  - Time stamps tend to be derived from satellite navigation or internet
  - Automated trading could also be affected
  - Power and communications outages could have indirect impact

Pipelines

- Space weather can induce electrical currents (up to 1000 amps) in long metal pipelines
  - Effect is accentuated in auroral zones
  - Australian study indicates effects at moderate latitudes
- This can lead to increased corrosion rate and associated ageing & decreased lifetime

Summary

- Growth of technologies has left society more at risk from space weather
- Space weather could create major disturbances in the transport, aviation and power sectors
- GPS signals are vulnerable to space weather
- Severe space weather event could create risk to society