SAND2022-12158C

The Dynamic Co-Evolution of Space Policy and Technology: *Historical Overview and Lessons for Assessing Future Trends*

Short Course
Advanced Maui Optical and Space Surveillance Technologies Conference
September 27, 2022

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Sandia National Laboratories

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Course Outline

- **Introductions, course overview and foundations** (30 minutes)
- **Historic dynamics and shifts in space policy and technologies** (30 minutes)

Break (15 minutes)

- **Current policy (governance) frameworks** (30 minutes)
- **Drivers & constraints for space policy and technology development** (45 minutes)
    - Commercial and military interests; policy responses; cislunar and future drivers
- **Introduction of Use Cases: Divergent scenarios for technology and policy evolution** (15 minutes)

Break (15 minutes)

- **Class Exercise in Small Groups** (45 minutes)
- **Large Report outs** (15 minutes)
- **Course Evaluation**

Module Time: 30 Minutes

Introductions
Course Overview and Foundations

Goal at end of module: Build network; understand course goals, framing and terms of reference

Introductions

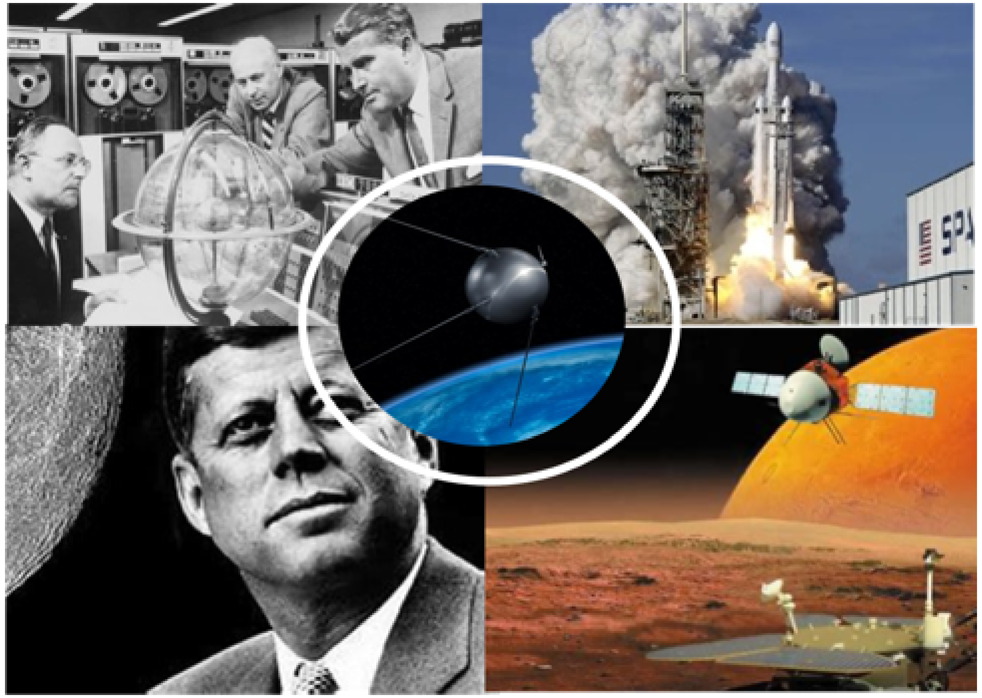
Name, Organization?

What you hope to get out of workshop?

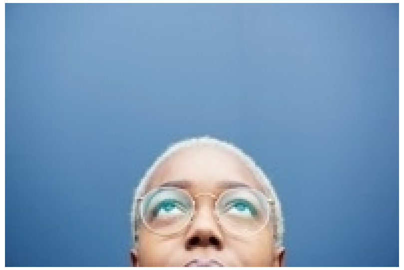
What do you plan to do in Maui besides work?

Course Goals

Provide participants with better understanding of the dynamic evolution between space policy, technology and world events



- ✓Anticipate the potential impacts of evolving space security policy on technical research and development needs for current and future space operations.
- ✓Anticipate how technical research and development advancements might shape future directions and implementation of space security policy.
- ✓**Develop more impactful research and development proposals and effective policy initiatives.**



Course Scope

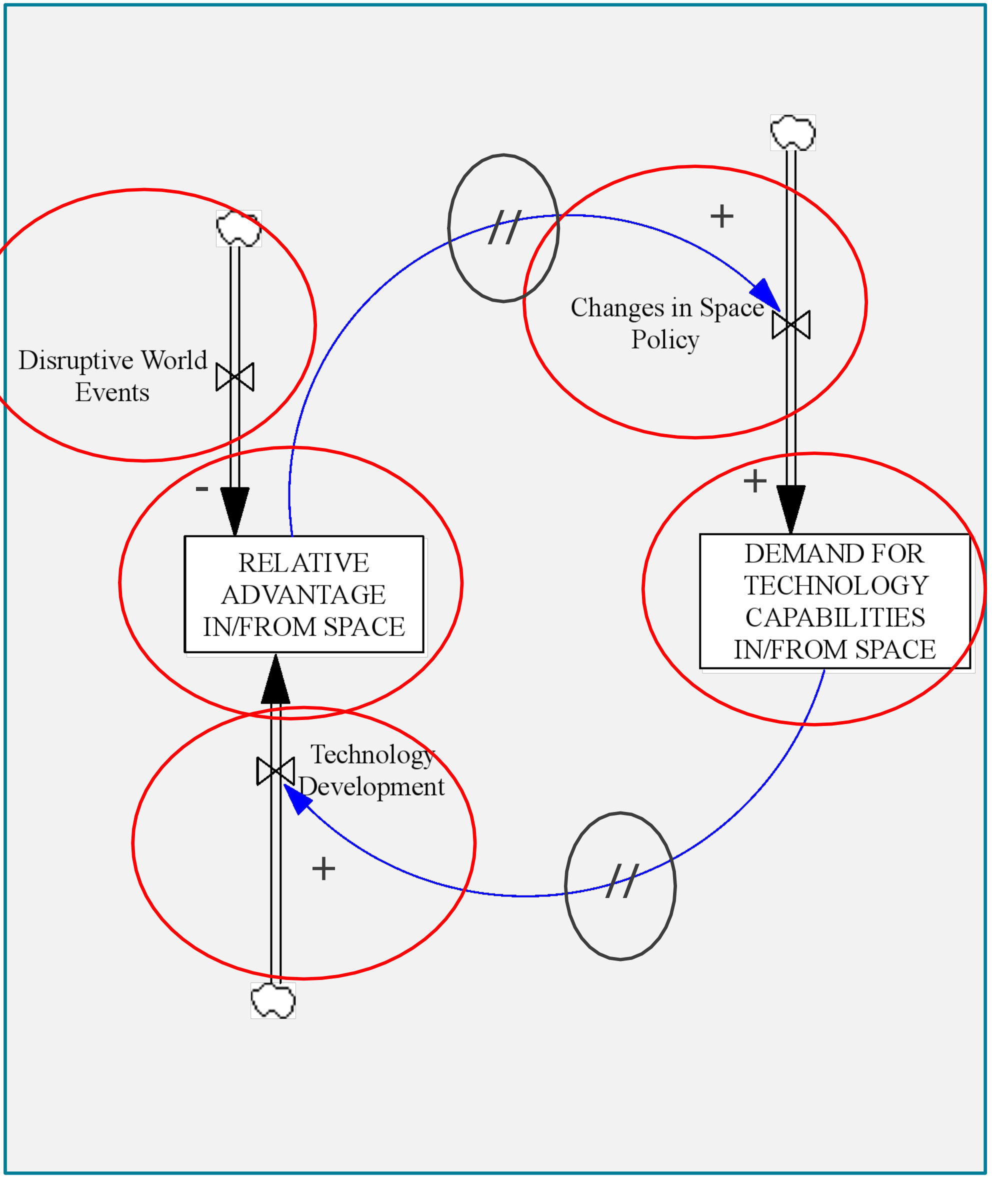
Focus is on understanding key dynamics for stability of space security environment

- Not a comprehensive survey of space policy
- Highlight SHIFTS in policy and DISRUPTIONS in technology development and their impact on relative advantages in and from space

References drawn primarily from US experiences and perspective

- Strategic issues
- Operational implications
- Research and development needs and opportunities
- Near, mid, and long term needs and uncertainties

Extrapolate to global considerations and implications for Space Domain Awareness (SDA) through future use cases

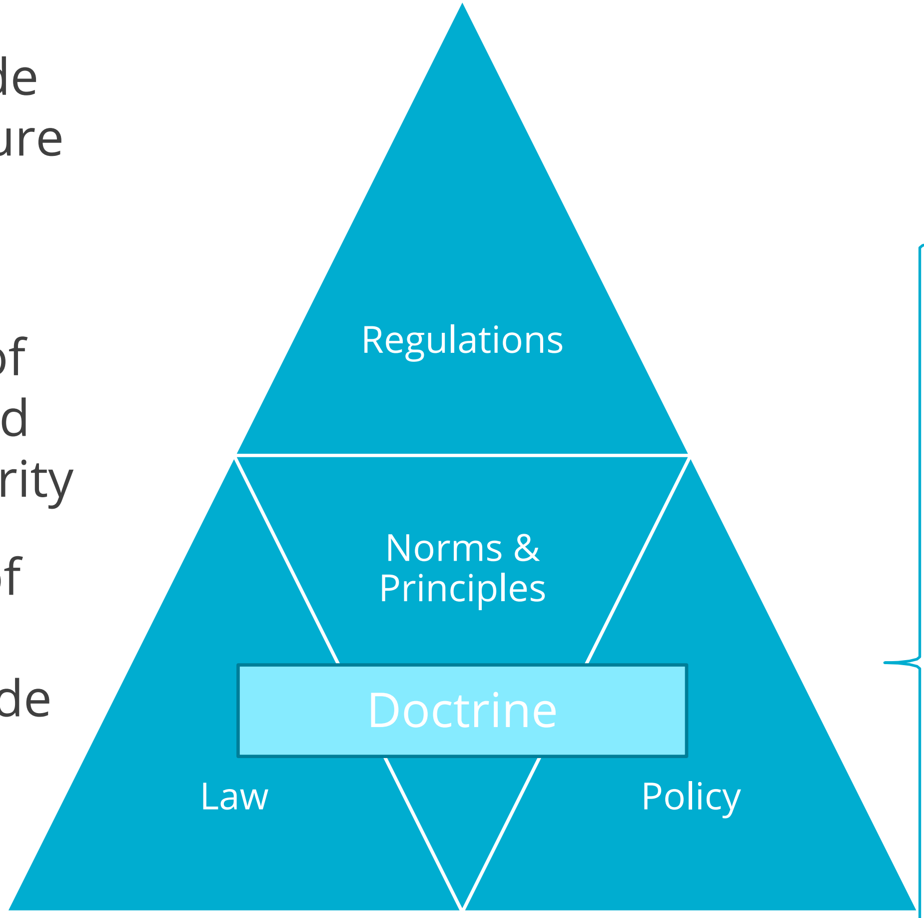


Terms of Reference

Policy: a course of action (selected from among alternatives and in light of given conditions) to guide and determine present and future directions to achieve a desired goal

Law: a binding custom or rule of conduct formally recognized and enforced by a controlling authority

Doctrine: a principle (or body of principles) within a domain of knowledge or operations to guide actions



Governance Framework

- ***Space policy*** *is the political decision-making process for, and application of, public* ***policy*** *of a state (or association of states) regarding spaceflight and uses of outer* ***space****, both for civilian (scientific and commercial) and military purposes.*
- ***Commercial Space Policy*** *is the decision-making process for business decisions such as partnerships, risk posture, technology investments, and exploration to gain advantage in space markets*

KEY SPACE SECURITY TERMINOLOGY

Intelligence, Surveillance, and Reconnaissance (ISR)

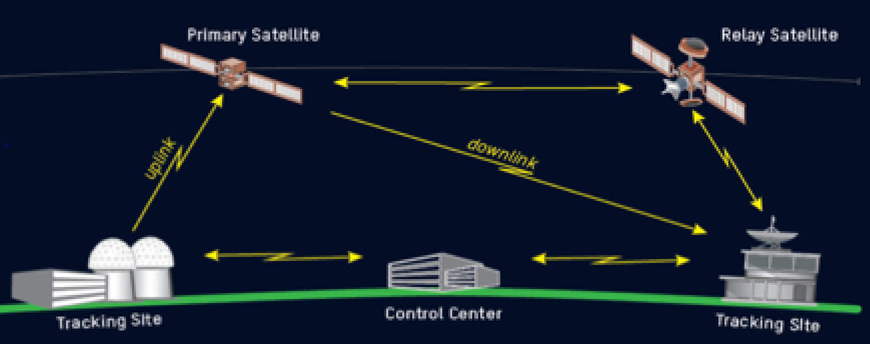
Support civil, commercial, and military interests through remote sensing data, signals intelligence, early warning data, and military assessments.

Positioning, Navigation, and Timing (PNT)

Satellite navigation constellations provide PNT data that enable civilian, commercial, and military users to determine their precise location and local time.

Satellite Command and Control (C2) Architecture

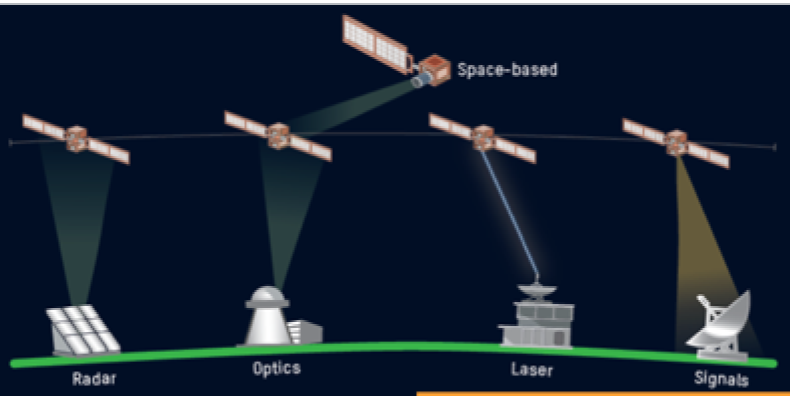
How users control and communicate with satellites. Any component of these systems are vulnerable to a range of attacks



Space Situational Awareness

Possessing current knowledge of a space object's location and the ability to track and predict its future location

SSA also incorporates understanding of an actor's intent for their spacecraft.



Graphics Source: DIA, 2019

Space-based sensors usually provide the first indication of a launch; ground-based radars confirm the attack. Can enable defensive or offensive operations in response.

Missile Warning

Provide a range of communications channels and services for civil, military, and commercial users worldwide.

Communication Satellites

The ability to deliver payloads into space.

Space Launch

Militarization, Counterspace & Weaponization

Militarization of space:

- Militarization of space refers to the placement of assets in space that provide military utility.
- Militarization includes assets such as communication satellites, reconnaissance satellites, PNT satellites, and military capability demonstrators.
- Civilian use may drive to the increased militarization of space.

Counter-space:

- Denying an adversary the use of space-based systems
- Reversible, nonreversible

Weaponization of space:

- Use of space assets to cause kinetic or non-kinetic effects that result in damage to an adversarial asset
- Includes:
  - Space-to Earth kinetic and non-kinetic weapons (e.g., “rods from God”, directed energy)
  - Space-to-Space kinetic and non-kinetic weapons (e.g., co-orbital ASAT, electronic warfare)

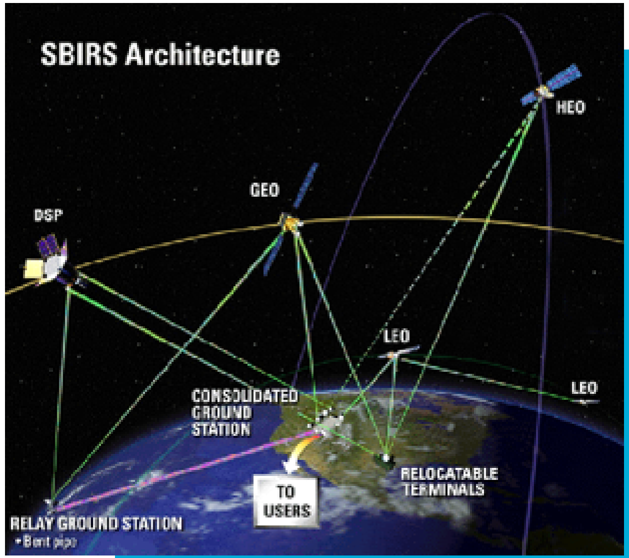


Image Credit: USAF

Image Credit: Lockheed Martin

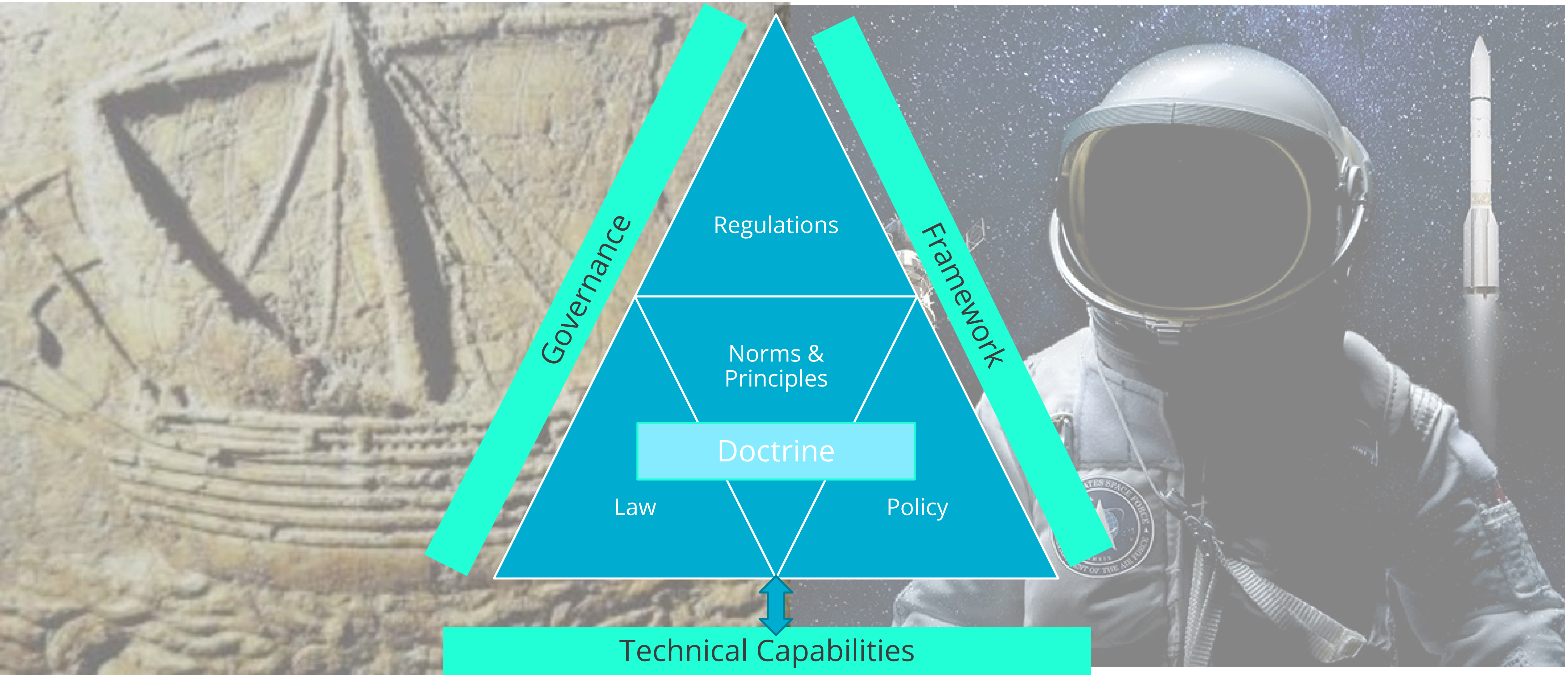
Freedom of Action Has Been Enduring Principle

"The exploration and use of outer space shall be carried out for the benefit and in the interests of all countries and shall be the province of all mankind; outer space shall be free for exploration and use by all States; outer space is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means..." *-Outer Space Treaty, 1967*

"Peace Through Strength: Ensures unfettered access to, and freedom to operate in space, in order to advance America's security, economic prosperity, and scientific knowledge."

-*Defense Space Strategy, 2020*

Looking Back to Look Ahead



Module Time: 30 Minutes

Historic dynamics and shifts in space policy and technologies

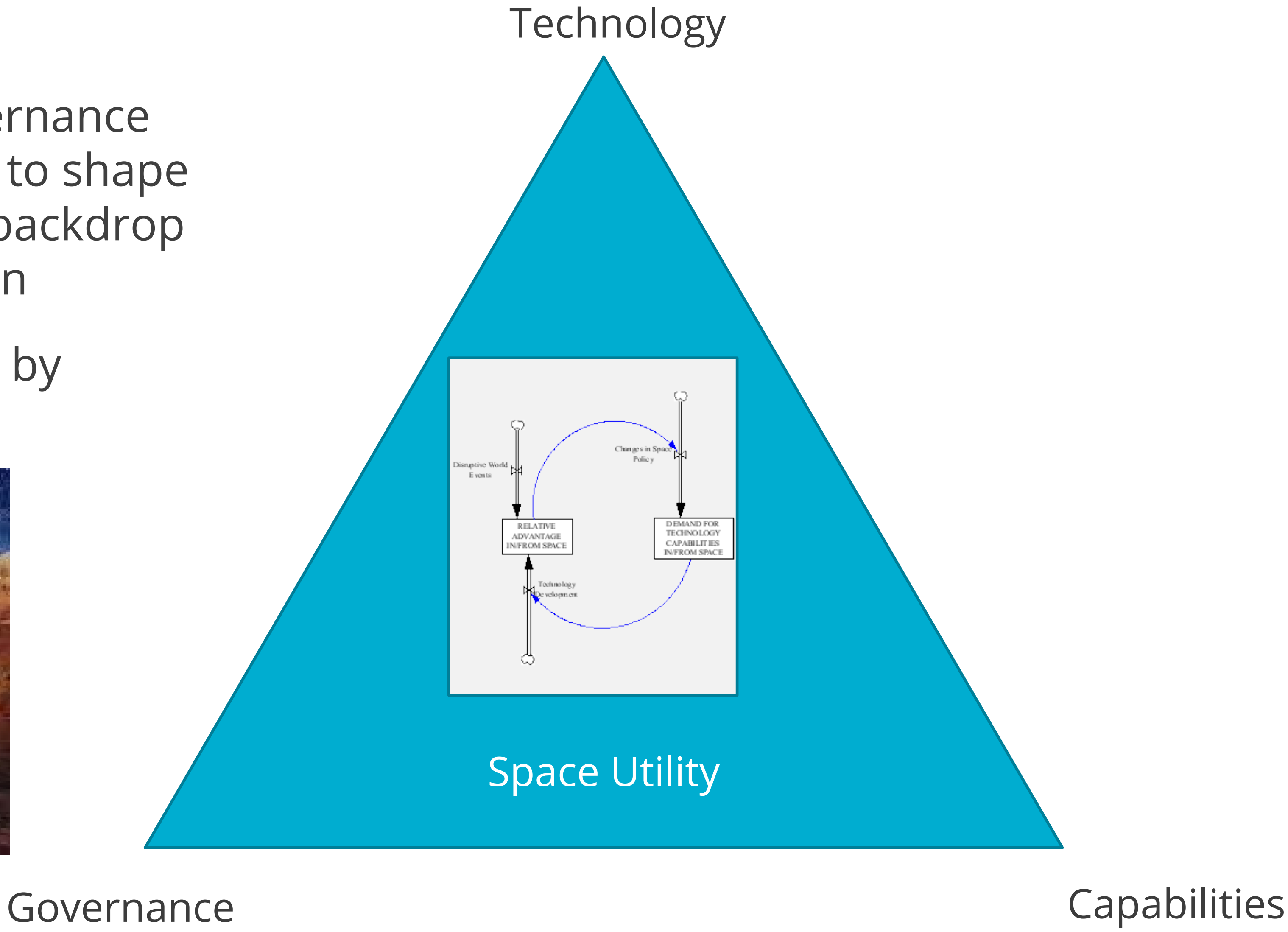
Goal at end of module: Understand how past space security policy and technology development shifts have occurred in response to geopolitical, technical, economic and social events *and the emergent feedback loops that shape the future*

Driving Factors

Historically, Technology, Governance and Capabilities have worked to shape the utility of space, against a backdrop of exploration and imagination

Each factor, in turn, is shaped by additional drivers

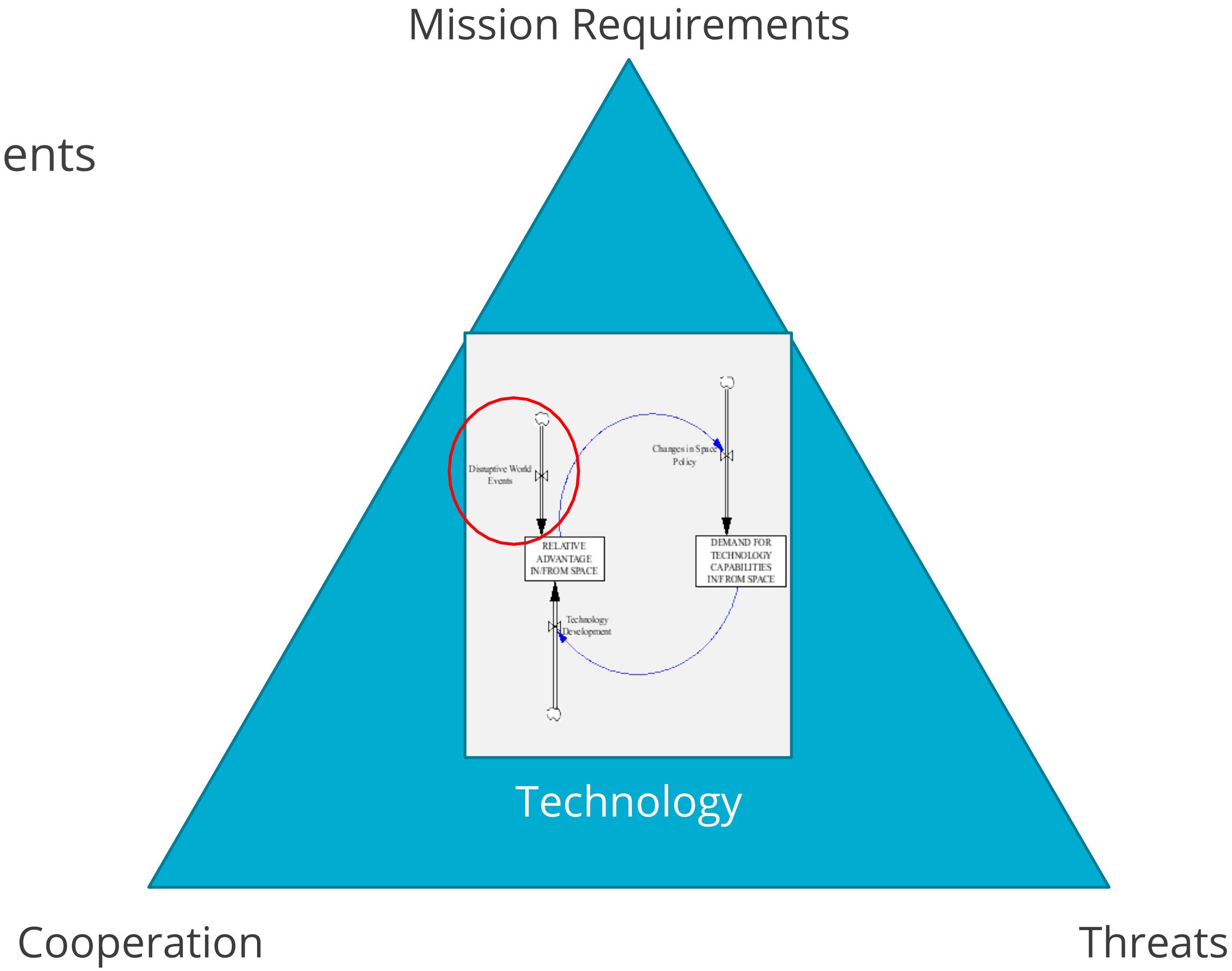
https://www.nasa.gov/webbfirstimages



Driving Factors

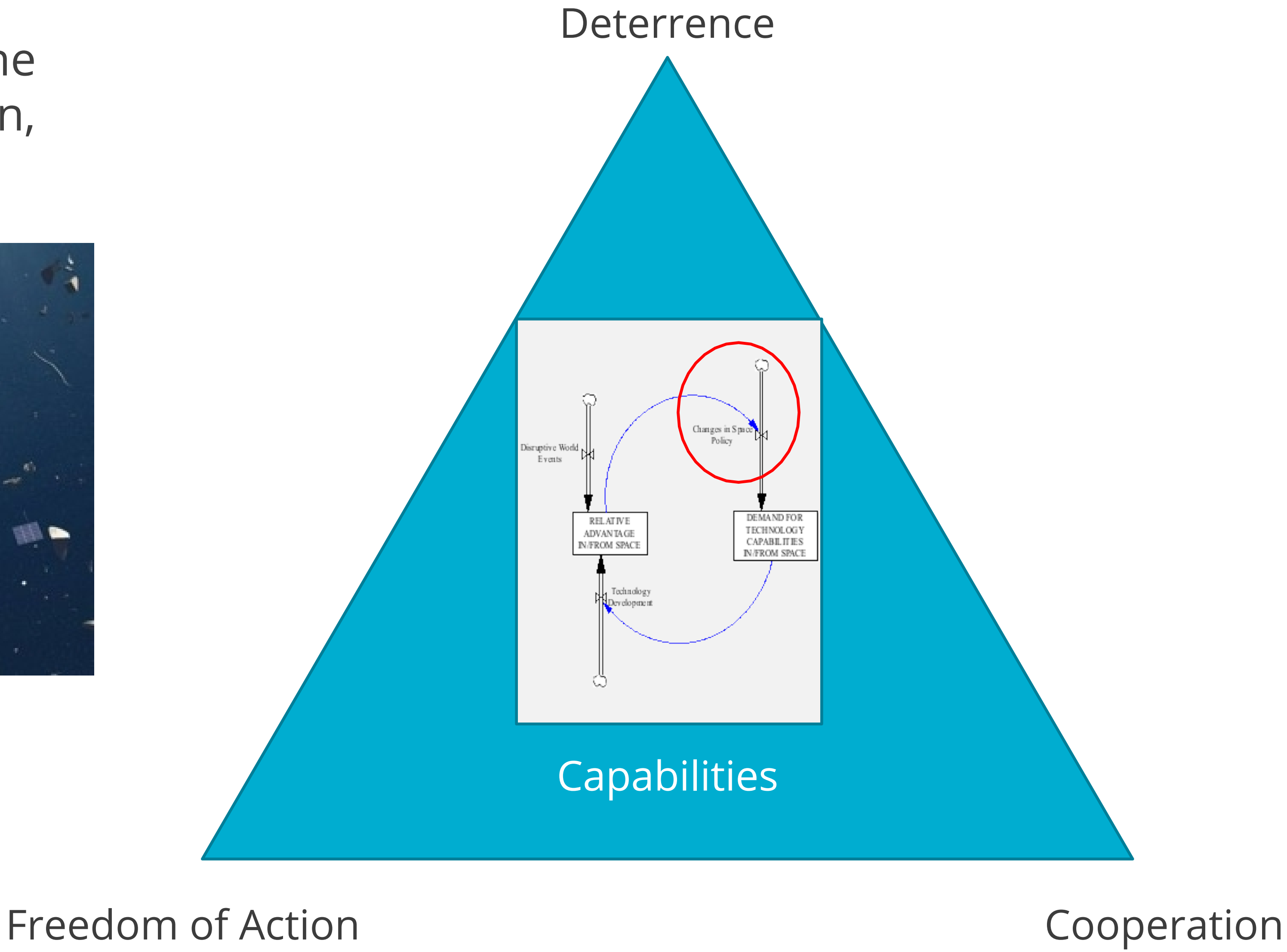
Technology needs are shaped by evolving Mission Requirements, Threats, and Cooperative Agreements

https://www.nps.gov/articles/remotearctic.htm



Driving Factors

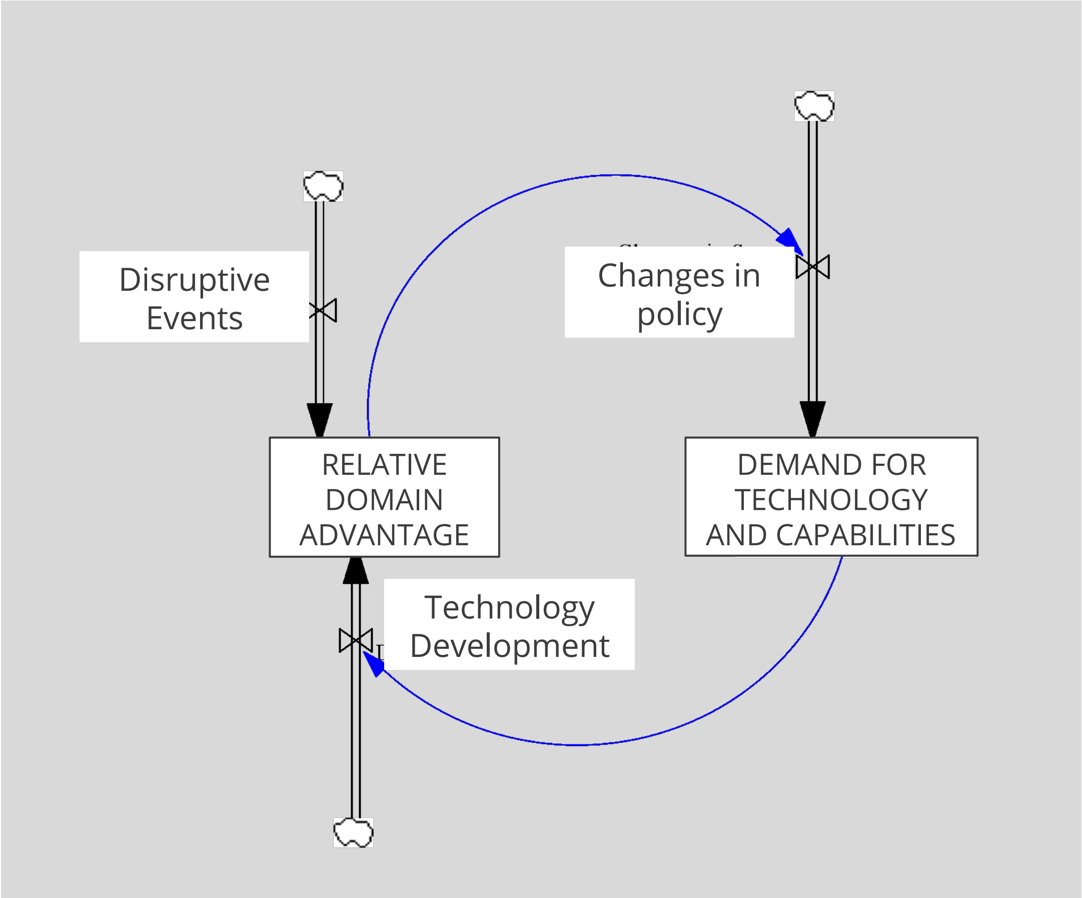
Desired Capabilities are shaped by the perceived need for Freedom of Action, Cooperation, and Deterrence



The Interplay of Policy and Technology Across Domains

To understand the historical development of the interplay of policy and technology in the space domain, it is useful to examine its development of other domains:

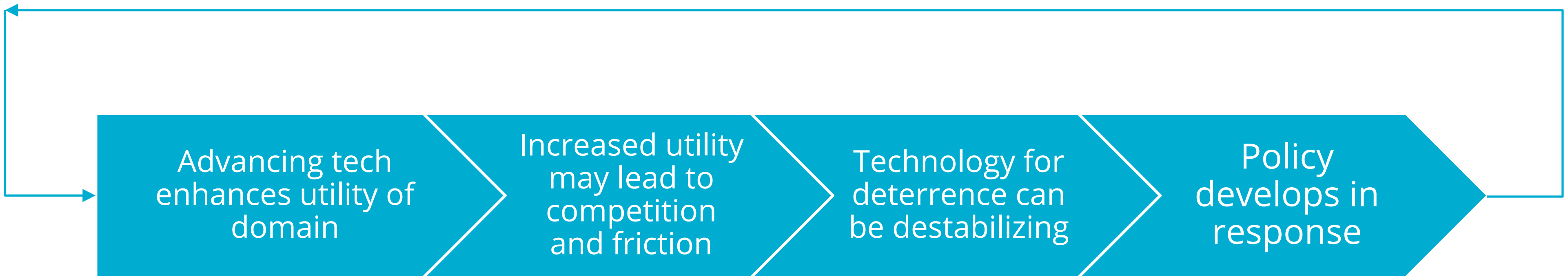
- On Land
- On the Seas
- Beneath the Seas
- In the Air
- In Cyberspace



The Dynamic Interplay of Policy and Technology: Key concepts

Fundamental concepts:

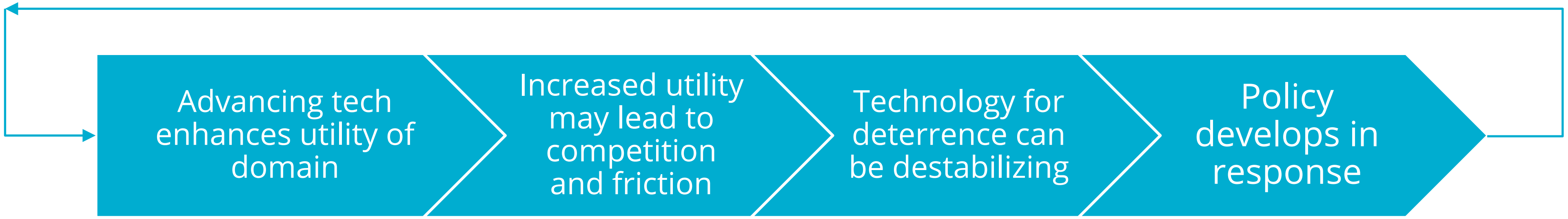
- Policy and technology continually impact one another
  - <u>Technology dual use:</u> Military utility ***and*** commercial utility lead to competition and conflict in advance of policy formulation
  - <u>Technology diffusion</u>: evolution to increase ability to defend territory and project power developed in any one domain likely to be adapted and deployed in other domains



Technology that can be used for good, can be used for bad

Security Dilemma: Anything one party sees as enhancing their utility can be seen by another party as threatening

The Dynamic Interplay of Policy and Technology: Example



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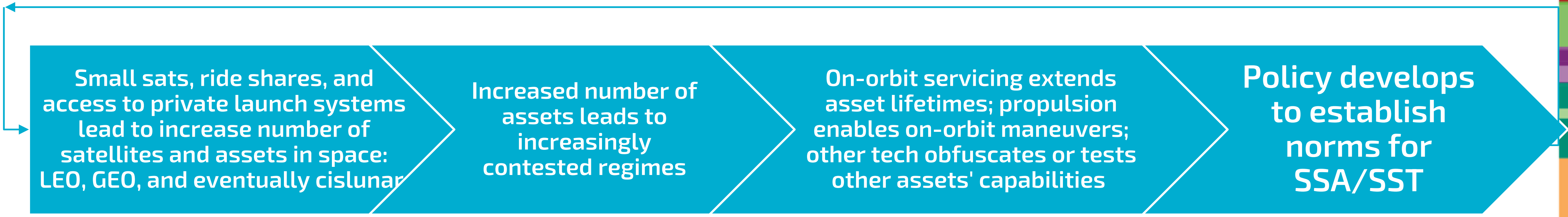
Example



Commerce, Policy, Technology, and Conflict on Land

Key Concept

- If you claim land as yours, you must patrol it and defend it

Photo by
Freysteinn G. Jonsson

Commerce, Policy, Technology and Conflict on Land

Key Concepts:

Exploration and resource potential of new frontiers drove technology developments

Early conflicts arose over **competition for resources** on land and were brutal

New technology led to better weapons that **projected power** (e.g. killing) at longer ranges

New technologies stimulate **new doctrines** for conflict

- Cannons made siege operations more effective
- The decline of castles gave rise to mobile strategies with specialized weapons

Drawing from 1460, note use of:
- **Artillery**
- **Mortars**
- **Crossbows**
- **Armor**

Technology that evolved to increase power projection from a distance (e.g., cannons) developed for one domain (land) was adapted and deployed in other domains (sea)

Commerce, Policy, Technology and Conflict on the Seas

Key Concept extends to sea:

What you claim as yours, you must patrol and defend

Early commerce traveled by both land and water in coastal areas and inland waterways

Naval warfare dates as far back as 3000 years

- Early naval warfare was very primitive – an extension of fighting on land

Piracy dates back 2000 years

- Maritime thieves threatened trade routes

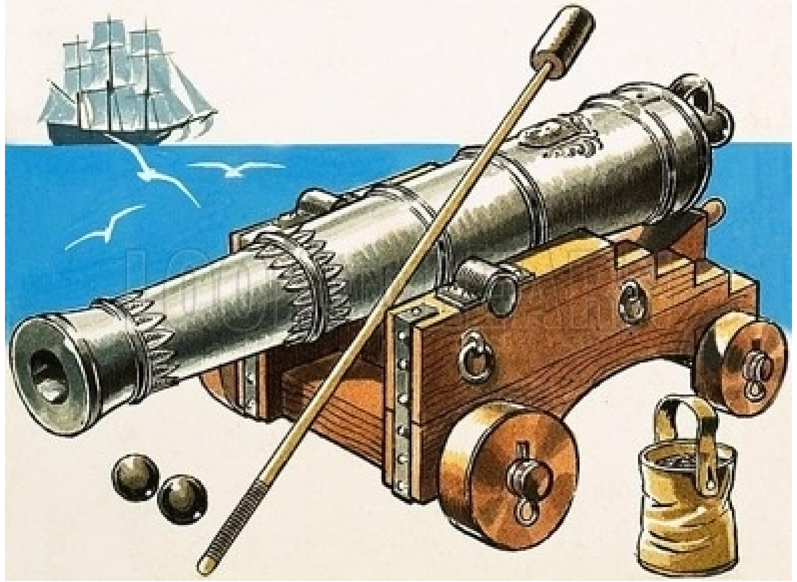
First attempts at governance was by the Byzantines between 600 and 800 AD

- Govern and protect trade routes in Mediterranean

A galley ramming an opponent prior to boarding during the Battle Salamis, 480 BC

Commerce, Policy, Technology and Conflict on the Seas

Key Concept: Convergence of seemingly unrelated technology developments can lead to new capabilities and drive new policies



Technology development and convergence

- Invention of gunpowder – 10th century (development on land)
- Invention of cannon – 13th century (development on land)
- Age of sail – 16th century (enabled long range ocean exploration and trade)

Policy impact: The Cannon Shot Rule

Nations can claim sovereignty over adjacent waters in distance equal to the maximum range of a cannon shot (3 miles in the 18th century)

Commerce, Policy, Technology and Conflict on the Seas: Exemplar

Advancing tech enhances utility of domain → Increased utility may lead to competition and friction → Technology for deterrence can be destabilizing → Policy develops in response

The age of sail (a disruptive technology development) stimulated increased commerce ***and*** conflict

- Nation states developed navies to control lanes of commerce

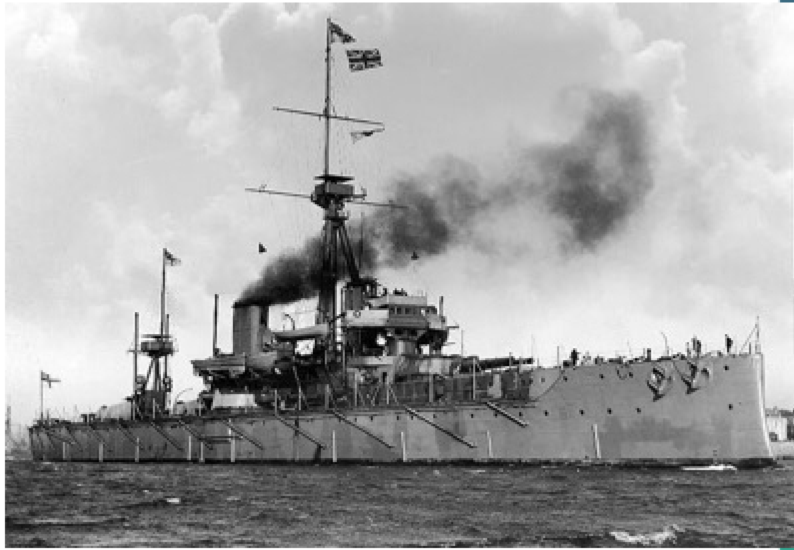
Technology developments beget an arms race

- First iron-clad naval combat (US Civil War) → wooden warships became obsolete
- First true battleships (late 19th century) → existing warships became obsolete
  - Launched naval arms race to build bigger, better, faster battleships (and led to Panama Canal)

Policy attempts to restrict technology (global governance)

- Washington Naval Treaty, 1922 – placed limits on capital ships
- London Naval Treaty, 1930 – further limits on capital and lesser ships

USS Monitor, 1862



HMS Dreadnought – UK, 1906

Commerce, Policy, Technology and Conflict on the Seas:

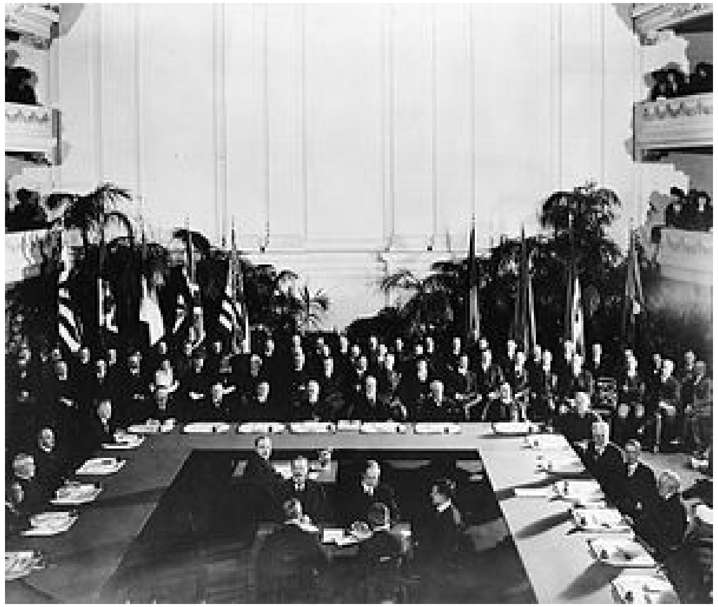
Key Concept: Perceptions of fairness matter

Negative impact of treaties

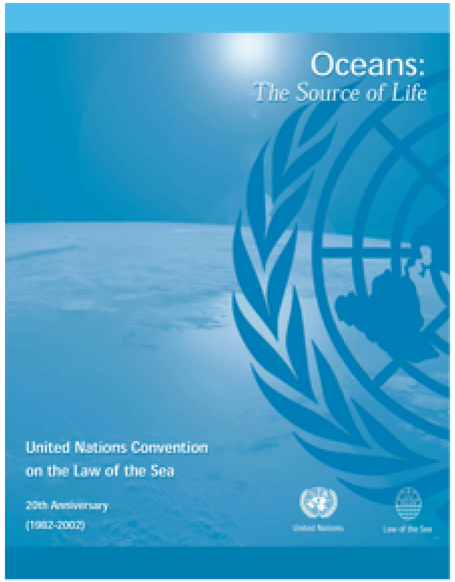
- Washington/London treaties left winners and losers
  - Nations were assigned limit on ship size and numbers
  - Japan felt unfairly treated and withdrew from Second London Naval Treaty, 1936
  - Italy violated the Washington and London Naval Treaties (without penalty)
- A naval arms race restarted in the late 1930s

More recent agreements - UN Convention of the Law of the Sea (1982)

- Discussed in detail in the next section



Washington Treaty meeting, 1922



Commerce, Policy, Technology and Conflict Underwater

Key Concept: Disruptive technologies often developed as strategic offsets to perceived domain advantage of adversary

Submarines are a disruptive technology developed in response to perceived domain disadvantage

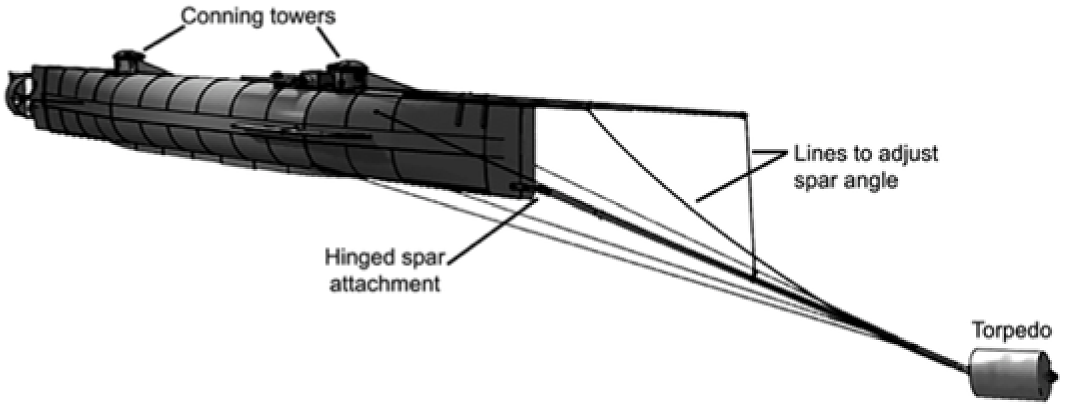
- Primarily used for military purposes

Subject to same law of seas as other vessels

- Allowed innocent passage through another nation's waters
  - Law says they must transit on surface and display their flag
  - But law does not necessarily allow them to be attacked if submerged

The law regarding submarines is ambiguous (also for aircraft)

An example of the asymmetric use of technology in conflict: During the US Civil War in 1864, the CSS *Hunley* sank the USS *Housatonic* in the first successful submarine attack.



Commerce, Policy, Technology and Conflict on Sea

Key Policy Concepts:

- If you claim it you have to defend and protect it (as on land)….BUT…..More of the seas are considered international, not subject to sovereignty by any one country
- International aspects of sea domain drives treaties, conventions and norms with limited success

Commerce, Policy, Technology and Conflict in the Air

Key Concept: Some technologies evolve as dual use in domain (civil, commercial, recreational, military) from onset

Technology – Manned Kites

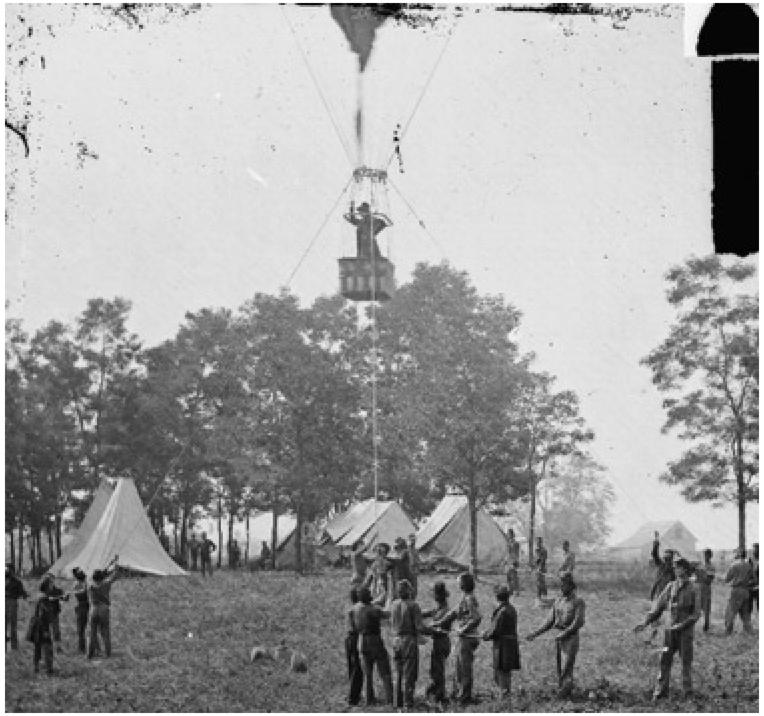
- Used for military observation in China ~7th century AD

Technology - Manned balloons

- Montgolfier brothers – first manned flight – 1783
- First serious military application in US Civil War for observation

Technology – Manned Powered Flight

- Wright Brothers – 1903 – quickly adapted to commerce ***and*** military
- First commerce – 1911 - airmail
- First military use – 1911 – reconnaissance during Italo-Turkish war in Libya



Union balloon *Intrepid*
Virginia, 1862

Commerce, Policy, Technology and Conflict in the Air

Key Concept: Norms may become de facto policy where there are no treaties

Policy: First international principle (norm) pertaining to the air

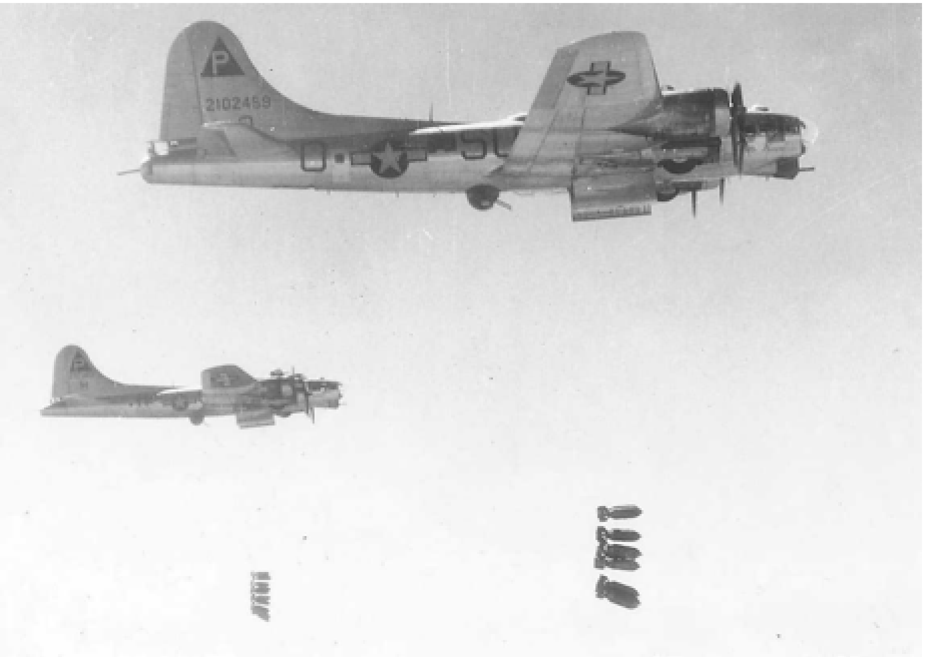
- Hugo Grotius - Mare Liberum (The Freedom of the Seas), published in 1609: **The air is the common property of all**

Absence of Treaty Law regulating aerial warfare

- 1905 – attempts to restrict future aerial bombardment failed as restrictions were perceived to hinder technology development
- 1949 Geneva Convention provide some restrictions on aerial warfare
- 1977 Protocol I provide some additional restrictions

In lieu of specific treaties and/or legal structures for aerial warfare, laws of [land] warfare and law of the sea have been used to define principles and norms

- The principle of proportionality in military actions
- Norms to prohibit deliberately attacking noncombatants
- Similarities between sovereign land and sovereign airspace
- International airspace treated as international oceans with the right of innocent passage



Strategic bombing in WW II

Commerce, Policy, Technology and Conflict in Cyberspace

Key Concept: Critical new domain aspects create unique dynamics, paradigm shifts for domain utility, advantage and deterrence

Cyberspace is the newest domain

- Fundamentally different from other domains – create desired effects from information and the control of information *without use of kinetic, physical power*
- More than just nations - non-state actors have significant power
- Technology changes at a blinding pace
- Infrastructure serves military, civil and commercial interests all at once
- Difficult to attack infrastructure without causing collateral damage
- Attribution is often very difficult
- Attacks in cyberspace still remain under threshold for war

Commerce, Policy, Technology and Conflict in Cyberspace

Key Concept: Effective deterrence paradigm shift is still out of reach

Policy Development:

- Rate of technology development tends to outpace governance
- Existing governance mostly focused on efficient operation, not lawful conduct

A farsighted academic paper: Laws of Cyberspace (1998)

- Described how cyberspace may become the most regulated medium in history
- Stressed four major regulators: **law, norms, market, architecture**

Treaties

- Budapest Convention on Cybercrime entered into force on 1 July 2004
- Important state actors such as Russia, Brazil and India have not signed

Current status

- Cybercrime and State-sponsored cyber espionage are rampant
- Giant information tech companies manipulate information in pursuit of political/economic goals

The Cybersecurity Framework was published by NIST in February 2014 involving industry, academia and government agencies and is periodically updated. The goal is to develop a voluntary Framework to help organizations manage cybersecurity risk in the nation's critical infrastructure.

Key Lessons from Other Domains

Exploration, imagination, and commercial potential drive technology surprise

Technology is a double-edged sword (Security Dilemma)

- New technology makes those who deploy it feel safer or more productive
- New technology makes those watching feel less secure or even threatened

Significant incentives for cheating on agreements and disregarding norms

- Developing new capabilities in secret is an advantage

The advantage of the initiative

- Lessons from battleships - he who shoots first almost always wins

Applying lessons to the Space Domain

" One small step for man, one giant leap for mankind"

Commerce, Policy, Technology and Conflict in Space

Key concept: Space is a uniquely challenging domain

- **Fundamentally different from all other domains**
  - Driven by orbital dynamics and extreme environments
  - Compressed timeline from technology development to disruptive capabilities
- **...But policy-technology dynamics share some aspects with each of the previous domains**
  - Originally pursued for military applications
  - Rapidly developed into a commercial sector as well
    - First demo of communication signals in 1960 (ECHO 1)
    - First successful weather in 1961
    - First commercial communication satellite in 1962
  - Substantial technology development resulted in new capabilities
  - Now space is fundamental to the economies and defense of many states
- **Talk of space control and war in space is now present worldwide**

ECHO 1 - A Passive Communications Satellite

Commerce, Policy, Technology and Conflict in Space: Competing Strategic Interests Have Been Co-Evolving Since Beginning

The *Panama Hypothesis* (1961 – Dandridge Cole) – early policy development

- Stated strategic areas in space may someday be as important as Panama Canal
- Vital areas must be occupied, lest their use be forever denied by prior occupation

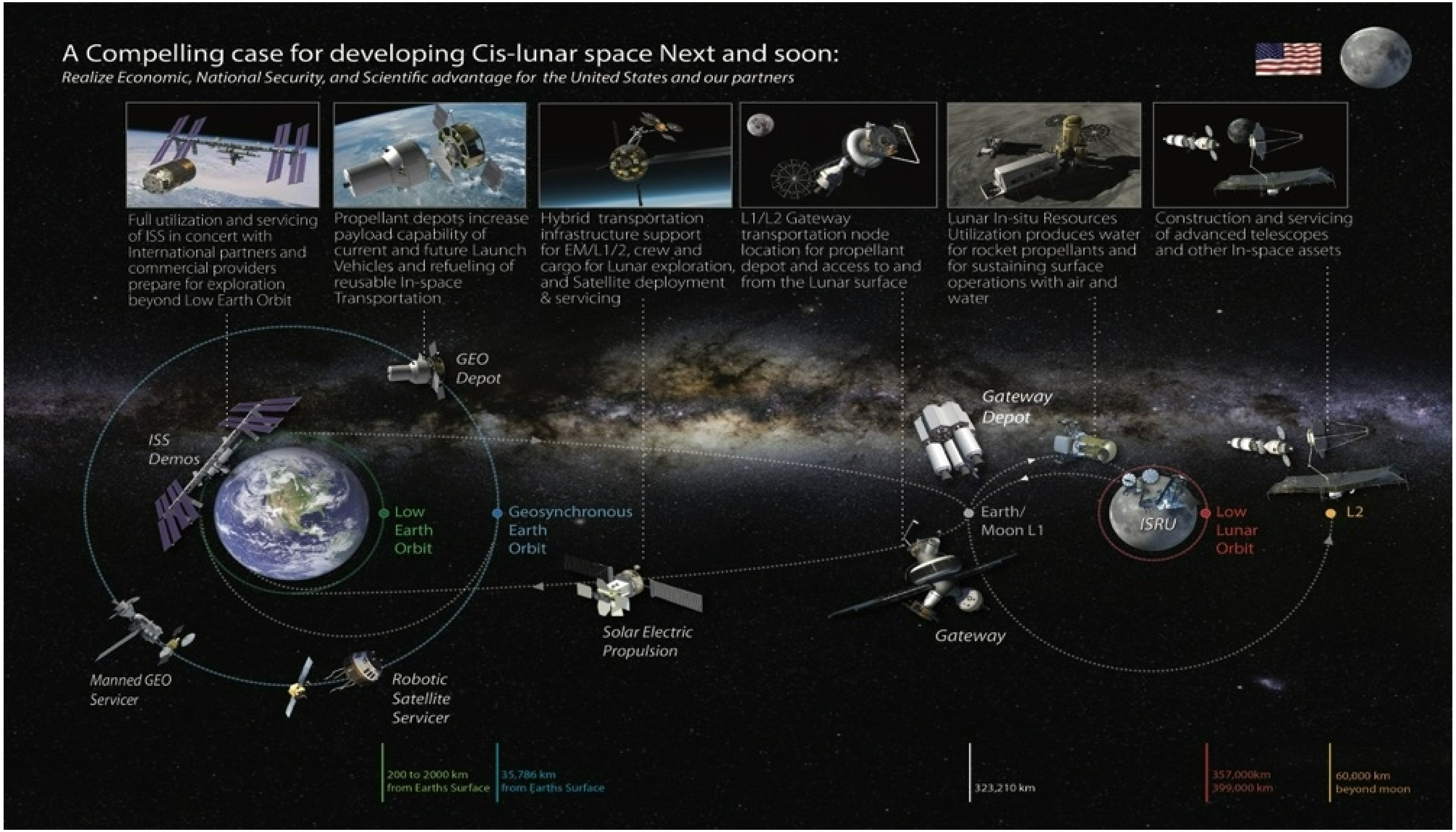
Governance

- Outer Space Treaty establishes organizing principles – described in detail in next section
- Proposed international agreements limit ASAT development and testing
- Proposals not agreeable to all nations as they are seen to favor Russia and China

Complexities of Space Weapons

- Most technologies can be dual use
- Technologies seen as stabilizing by one side seen as threatening by other (as in other domains)
- Significant advantage enjoyed by states who ignore ASAT norms
- Huge incentive to develop weapons technologies

Cislunar: the space between the earth and the moon, and the moons orbit



Source: *Aerospace*

US Policy Interest in Cislunar Space Post-Apollo

Bush 41

Vision for **a** permanent settlement on the **Moon** and **an eventual** crewed mission to **Mars**. **Lacked funding support**.

Space Exploration Initiative

Clinton

ISS construction began. Had high level policy on general robotic and crewed missions and maintaining national security interest in space.

PD/NSC-49/NSTC-8

Bush 43

Return to the moon (robotic) by 2010 and crewed mission by 2020 - started Constellation program; called for retirement of Shuttle Program.

Vision for Space Exploration

Obama

Asteroid Redirect Mission . Cancelled the Constellation Program. "Flexible path" approach with possibility of deep space missions such as Mars (mid-2030s).

Speech at KSC

Trump

Re-formed the NSpC and created Space Force. Redirected focus to the moon with longer-term goal of human mission to Mars. NASA formulated "Gateway" plan.

National Space Strategy

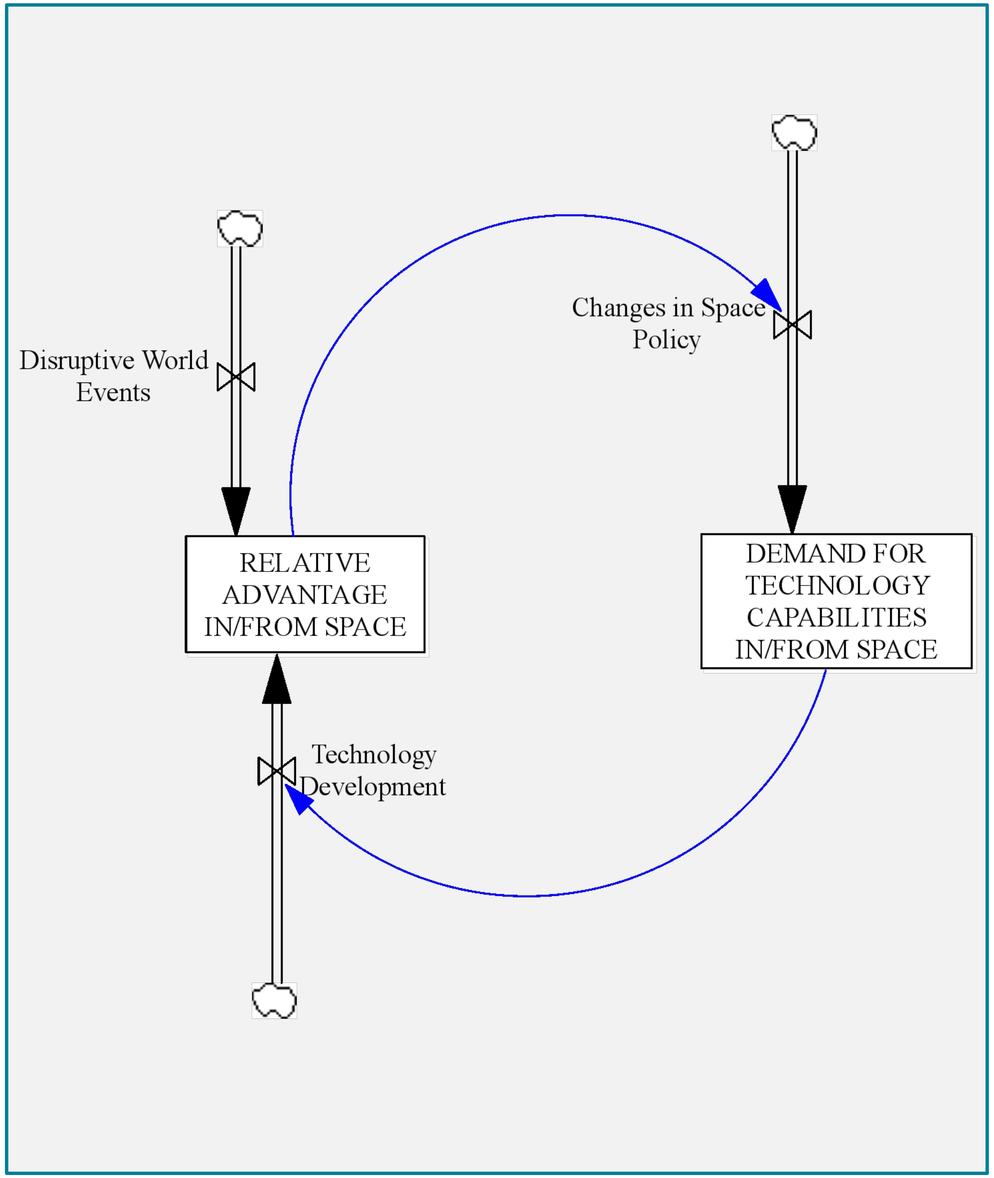
Biden

Strategically stayed the course of previous administrations.

U.S. Space Priorities Framework

Significant Events, Space Technology and Policy: Dynamics

Slides 34 -44 provide a representational, but not comprehensive timeline of interplay between S&T development, increased capability for advantage in space, and **policy/governance responses**



Significant Events, Space Technology and Policy: Dynamics Interplay

"Earth is the cradle of humanity, but one cannot remain in the cradle forever."
- Tsiolkovsky, 1903

1903 - Konstantin Tsiolkovsky

- Published "Exploration of Outer Space by Means of Rocket Devices"
- Included equation for orbital velocity as function of altitude

1920 – Robert Goddard

- Published "A method for reaching extreme altitudes" included mathematical theory for rocket propulsion to send payloads to the Moon

1923 – Hermann Oberth

- Published "Die Rakete zu den Planetriiumen". (Rocket into Planetary Space)
- Proposes first manned space station, space-based telescope for earth observations

1926 – Robert Goddard

- Demonstrated first liquid fueled rocket

1928 - Herman Potočnik

- Published "Das Problem der Befahrung des Weltraums - der Raketen-Motor" (Problem of Space Travel - The Rocket Motor)
- Describes space station, satellite reconnaissance, satellite communication

- S&T development
- Capability demonstrated for domain advantage
- **Governance/Policy Evolution**

Significant Events, Space Technology and Policy: Dynamic Interplay

1942 – German V-2 Rocket enters space

- First manmade object to cross into space – 12-ton rocket capable of carrying one-ton warhead
- This rocket technology served as the driver for future space exploitation
- Basis for an [missile] arms race following WW2

1946 – **RAND Corp. study for US Navy and US Army Air Force**

- Looked at unspecified future weapons in space (possible combination of reconnaissance, communications and kinetic weapons
  - *"Since mastery of the elements is a reliable index of material progress, the nation which first makes significant achievements in space travel will be acknowledged as the world leader in both military and scientific techniques. To visualize the impact on the world, one can imagine the consternation and admiration that would be felt here if the United States were to discover suddenly that some other nation had already put up a successful satellite."*

1948 – **Soviets responded these weapons were instruments of blackmail**

1953 – Initial planning for ASAT capabilities by the USSR

- S&T development
- Capability demonstrated for domain advantage
- **Governance/Policy Evolution**

Significant Events, Space Technology and Policy: Dynamic Interplay

1954 – Multiple nations considering antisatellite defenses

- Lack of governance mitigated by lagging technology

1957 – USAF studies Satellite Interceptors (SAINT program)

- Prevent adversaries from using space for reconnaissance, weather and comm
- An outgrowth of US satellite programs – not a response to Soviet activities

1957 – Soviets launch Sputnik

- US fears realized – an adversary now has capabilities US wanted to deny them
- Event spurred military competition in space

1958 – NASA works with new ARPA on antisatellite technology (response to Sputnik)

- Sought to deny collection capability rather than kinetic destruction
- Policy at this point was to pursue military advantages in space

- S&T development
- Capability demonstrated for domain advantage
- **Governance/Policy Evolution**

Significant Events, Space Technology and Policy: Dynamic Interplay

1958 - Project SCORE (Signal Communications by Orbiting Relay Equipment)

- ARPA project demonstrated first space-based broadcast

1959 - Bold Orion's ASAT test

- ASAT missile test fired from B-47 bomber against Explorer 6 satellite

1959 UN Committee on Peaceful Uses of Outer Space (COPUOS) established

1960 – Francis Gary Powers shot down by Soviets

- End of U-2 spy plan overflights of USSR
- Ushered in need for space-based photographic reconnaissance

1960 - TIROS-1 (Television Infrared Observation Satellite)

- First LEO weather satellite – TV based – insufficient resolution for intelligence

- S&T development
- Capability demonstrated for domain advantage
- **Governance/Policy Evolution**

Significant Events, Space Technology and Policy: Dynamic Interplay

1960 - Echo 1 (actually Echo 1A)

- First satellite communications demonstration
  - 100-foot diameter metalized balloon - passive RF reflector
  - Used for comm experiment between JPL (California), and Bell Labs (New Jersey)

1960 - SOLRAD-1

- Naval Research Laboratory satellite observed solar x-rays
  - Also carried ATHOS receiver to listen to Soviet radars - map air defense network

1960 – Corona – Discoverer 14

- First successful photographic spy satellite

1961 USSR – spy satellites

- Zenit 2 ("Soviet Corona") - carried 4 cameras and an ELINT receiver to detect NATO radar systems

1961 DOD Policy directive on Development of Space Systems

- Assigned Air Force responsibility for development and acquisition of all future U.S. military space systems. Other services permitted to conduct basic research on new ways of using space technology.

1962 - SAMOS F2-1

- First dedicated SIGINT satellites launched by US Air Force

- S&T development
- Capability demonstrated for domain advantage
- **Governance/Policy Evolution**

Significant Events, Space Technology and Policy: Dynamic Interplay

1962 - Starfish Prime

- Radiation from a nuclear test 250 miles over Pacific Ocean damaged some satellites

1962 - TELSTAR-1

- First commercial communications satellite - killed by radiation from Starfish Prime

1962 – US Navy programs Hi-Ho program – demonstrated air launch of space object from F-4 aircraft

1962 – President Kennedy – policy study

- Ordered detailed study of space weapons ban

1963 - Syncom 2 - launched by NASA

- First Geosynchronous satellite - demonstrated GEO satcomm and television relay

- S&T development
- Capability demonstrated for domain advantage
- **Governance/Policy Evolution**

Significant Events, Space Technology and Policy: Dynamic Interplay

1963 - USSR – early space control

- Development began in 1961
- First test of Istrebitel Sputnik (IS) ("fighter satellite")

1963 – Nike Zeus – modified ABM

- Direct ascent ASAT test

1963 – UN General Assembly

- Verbal agreement on banning nuclear weapons in space

1963 – Manned Orbiting Laboratory (MOL) program announced

- Sought to develop manned orbital imaging system to spy on Soviet Union
- Soviet Union had similar program within a few years

1964 - Syncom 3

- First geostationary comm satellite, broadcasted Tokyo Olympics to USA

- S&T development
- Capability demonstrated for domain advantage
- **Governance/Policy Evolution**

Significant Events, Space Technology and Policy: Dynamic Interplay

1964 – Thor direct ascent ASAT test

1964 – USSR space branch

- Established special "anti-space" branch of their PVO Strany air defense organization

1966 – First DOD programs to enhance satellite survivability

1967 – Outer Space Treaty

- First international agreement promoting peaceful uses of space
- Forbids weapons of mass destruction in space

1968 – USSR co-orbital ASAT test

- First test of co-orbital ASAT system in low-earth orbit

1969 – Manned Orbiting Laboratory cancelled

- S&T development
- Capability demonstrated for domain advantage
- **Governance/Policy Evolution**

Significant Events, Space Technology and Policy: Dynamic

1972 - ERTS-1 - LANDSAT-1

- First satellite launched for earth resources monitoring - commercial applications

1975 – USA ASAT

- First test of F-15 launched direct ascent ASAT capability

1978 – ASAT Treaty Negotiations

- Attempt to ban deployment of ASATS – negotiations ended without agreement

1983 – Reagan administration – new space Initiatives

- Announced the Strategic Defense Initiative (SDI - aka "Star Wars")
- Ostensibly an ABM capability, but seen by Soviets as ABM and space control

1985 – US ASAT Test

- Air-launched ASAT used to destroy an aging meteorological satellite

1985 - Congress bans further ASAT testing

- S&T development
- Capability demonstrated for domain advantage
- **Governance/Policy Evolution**

Significant Events, Space Technology and Policy: Dynamic Interplay

1986 - SPOT 1

- First commercial medium-resolution imagery satellite by France

1991 – Gulf War demonstrated military warfare navigation capabilities (GPS) enabled by space

- Dubbed by journalists to be the first space-enabled war
- Military capabilities derived from space shock many nations

2002-2019 UN COPUOS promulgates key principles and guidelines of behavior in space

2003 – Gulf War space-based weather, comms, precision guided capabilities – boost space spending

- Introduction of GPS-guided munitions – mostly launch and leave

2007 – China ASAT Test

- Direct ascent to LEO – irresponsibly created huge debris field

2007 – China's Chang'e Program Begins: Chang'e-1 probe into a polar lunar orbit.

- Scientific missions show China's technological prowess focused on establishing lunar presence.

2008 – USA ASAT activity – direct ascent from Naval ship

- Shoot down of failed satellite – ostensibly over environmental concerns

- S&T development
- Capability demonstrated for domain advantage
- **Governance/Policy Evolution**

Significant Events, Space Technology and Policy: Dynamic Interplay

2009 – Iridium-Cosmos Collision

- Accentuated the debris problem posed by dead satellites

2010/2011 – Updated US National Space Policies and Security Strategies

- Rand Study: Deterrence and First-strike Stability in Space
- US Revised National Space Policy (2010) and National Security Space Strategy(UNC summary)

2012 – China's Chang'e-2 departed lunar orbit and flew to the Earth-sun L2 Lagrange point.

2013 – China's Chang'e-3 successful near-side lunar landing .

2013 – China apparent ASAT test

- Direct ascent to GEO – targeted point in space
- China claims this was not an ASAT test

2015 – Russia ASAT (ballistic intereceptor) launched from transporter-erector-launcher system

- Test of Nudol ASAT system

2018 – Russia ASAT

- Test flight of modified MiG-31 carrying air-launched ASAT

2019 – India ASAT

- Test of LEO direct ascent ASAT capability

2019 – China Chang'e 4 moon lander and rover

- First ever landing on far side of moon

- S&T development
- Capability demonstrated for domain advantage
- **Governance/Policy Evolution**

Significant Events, Space Technology and Policy: Dynamic Interplay

2020

- First commercial crewed fight: Space X launches astronauts in Crew Dragon to ISS May 30 – Aug 2)
- Sample returns: China's Chang'e 5 (lunar); Japan Rugyu asteroid
- US releases 2020 Defense Space Strategy

2021

- Space launches – Most orbital launches ever: 146 success; 111 failures
  - *China (56); US (51): Russia (25); Europe (6); Japan (3): India (2) Iran (2) S Korea (1)*
- Tourist spaceflights – Blue Origin, Space X, Virgin Galatic
- Russian ASAT test and subsequent conjunction "squalls"
- Mars probes, landers, rovers (US, China, UAE)
- NASA launches James Webb Telescope
- China launches Tiahne core module and delivers crew for Tiangong Space Station,
- Space X wins contract to build NASA moon lander
- Space X Starship successful flight tests
- Uncontrolled re-entry China rocket creates more space debris
- US Space policy articulated: DOD memo; White House Space Priorities Framework
- UN COPUOS submits Space 2030 to UN General Assembly

- S&T development
- Capability demonstrated for domain advantage
- **Governance/Policy Evolution**

Significant Events, Space Technology and Policy

Lessons from historical dynamics

- ✓ Most events are technology oriented – demonstrating new capabilities
- ✓ Technology drives new technology
- ✓ Technology is threatening (even if defensive)
- ✓ Events were a mixture of space systems and ASAT systems
- ✓ There is a paucity of effective policy to govern space activities
- ✓ Only a minimal set of informal international norms guide day-to-day use of space

15 minutes

BREAK 1

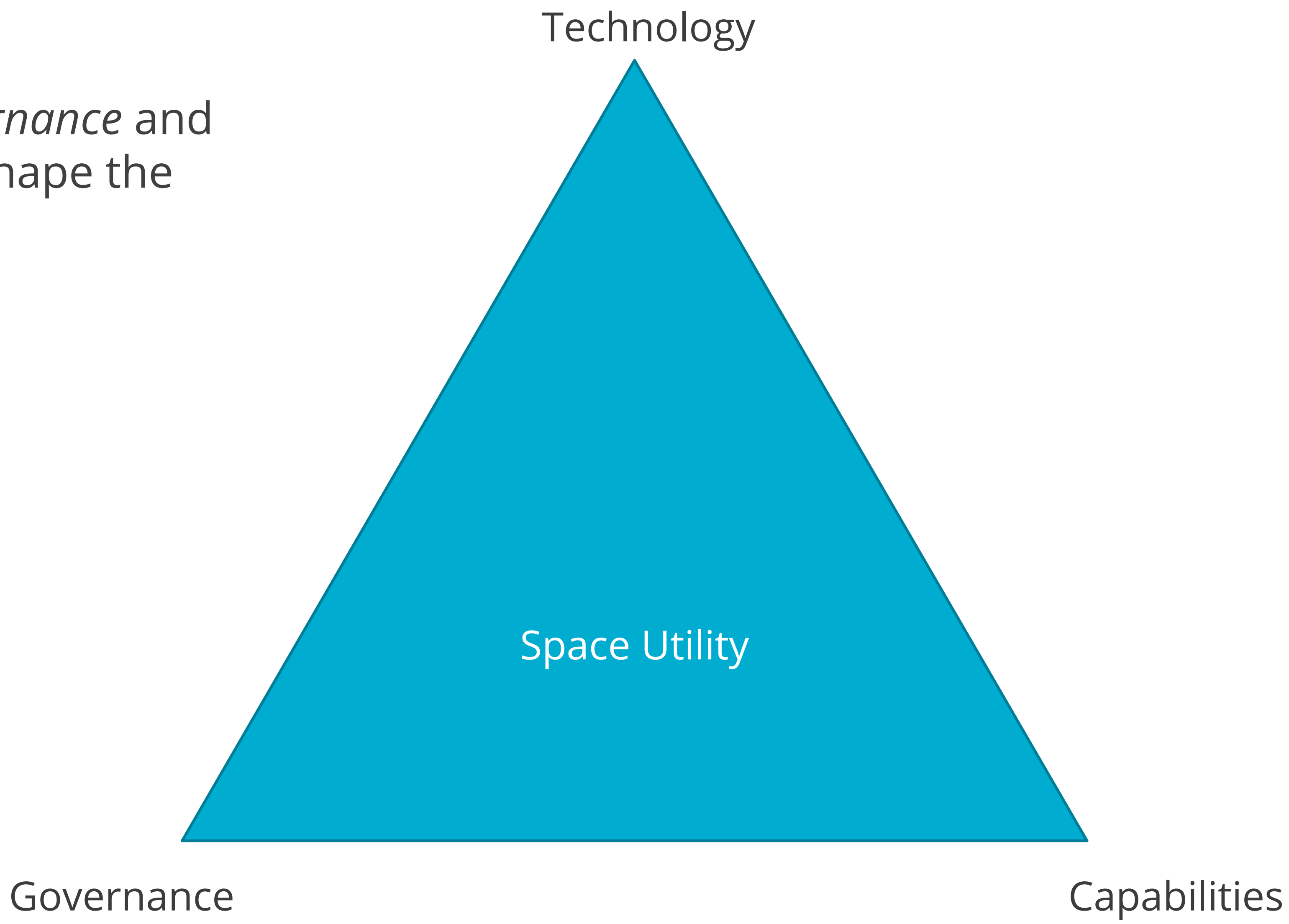
Module Time: 30 Minutes

Current space governance frameworks

<u>Goal at end of module:</u> Understand how governance frameworks evolve to interact with, shape, and constrain policy and technology development with implications for future space governance policy challenges and gaps

Driving Factors for Utility of Space

Historically, *Technology*, *Governance* and *Capabilities* have worked to shape the utility of space



Evolving Space Utility: Examples

Established

- PNT
- Earth observations satellites
- Communications

Implemented

- Space traffic management technologies
- In-space assembly and manufacture

Started

- Privately developed lunar gateway
- Space nuclear power and propulsion

Emerging

- Lunar mining
- Space tourism

A Review of Key Governance Terms

- **Governance**: The set of processes for interaction (laws, norms, organizational power). The British Council definition: "*Governance involves interaction between the formal institutions and those in civil society. Governance refers to a process whereby elements in society wield power, authority and influence and enact policies and decisions concerning public life and social upliftment.*"
- **Treaty/Agreement**: A ***treaty*** (or convention, etc.) is a type of ***agreement*** defining a formal, legally binding written commitment between sovereign states and/or international organizations under international law (the Vienna Convention). Under U.S. law, a treaty requires ratification by the Senate and is equivalent to Federal legislation. ***Executive Agreements*** are not submitted to the Senate. Under national law, a state may withdraw from an agreement with more latitude than with a treaty. However, under international law, both types of agreements are considered binding.
- **Law**: A binding custom or written rule of conduct (a "legal mandatory norm") formally recognized and enforced by a controlling authority.
- **Norm**: A norm is the general rule by which the principles of conduct by people, groups or nations are governed. They guide behaviors and decision making. Although they may be proscriptive or prescriptive, they are not mandatory or legally enforceable (although there may be social or economic sanctions). A norm may evolve into a legal norm.

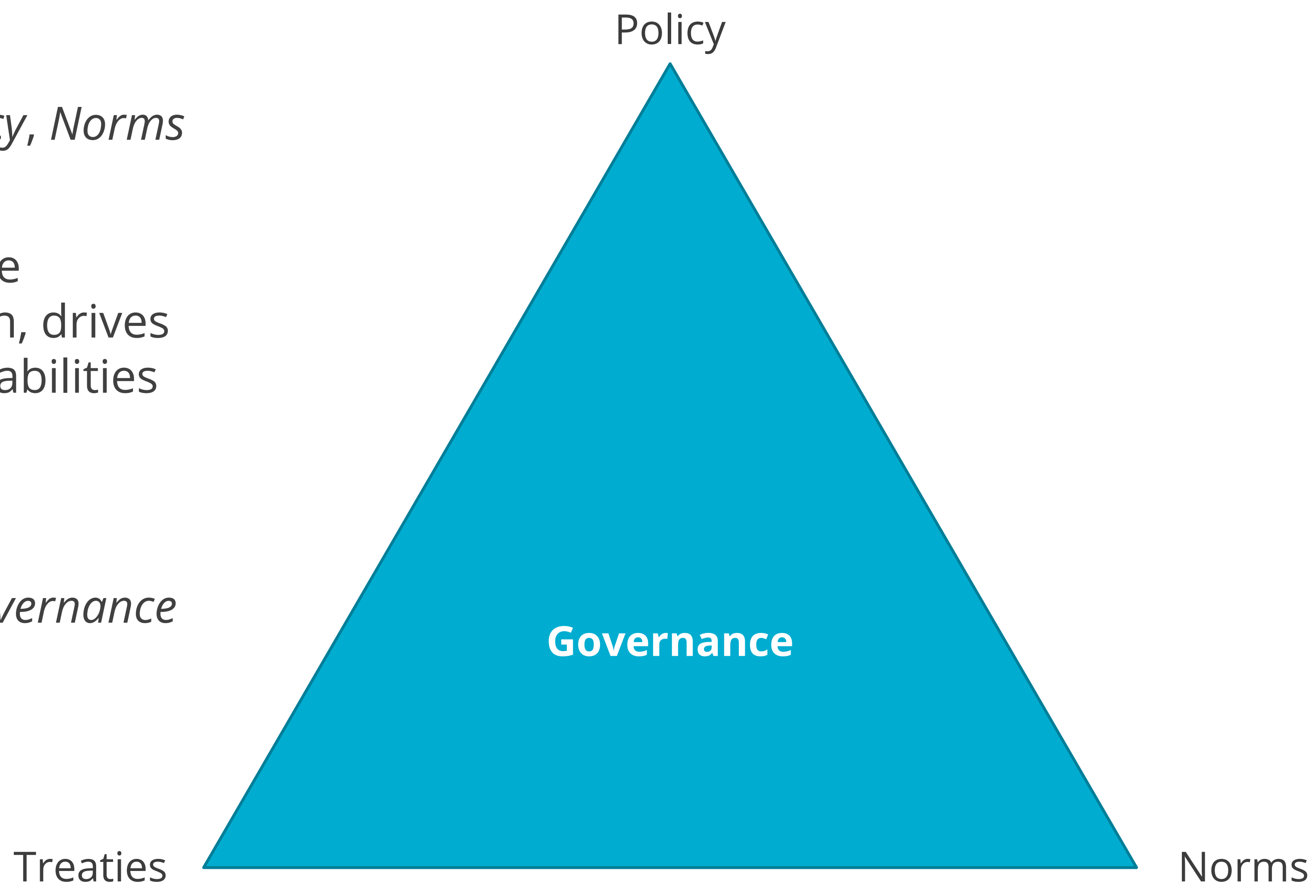
A key difference: Treaties and laws are enforceable; norms are not

Driving Factors for Governance

Governance is shaped by *Policy*, *Norms* and *Treaties/Agreements*

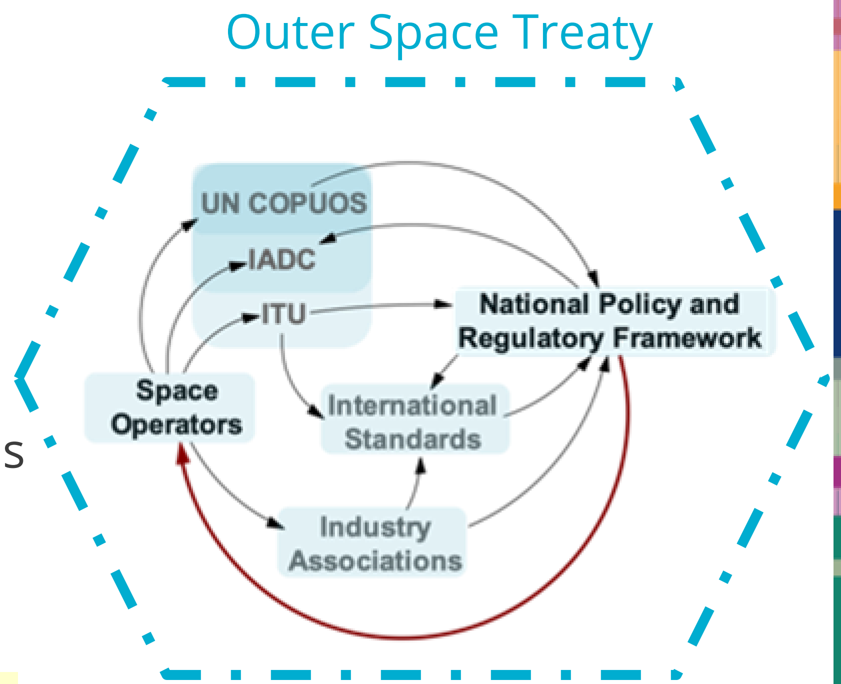
The framework for governance influences policy which, in turn, drives demand for technological capabilities and consequent development

This section will explore how governance affects the Utility of Space



Current Governance Factors in Space

- TREATY
  - The Outer Space Treaty
- MULTILATERAL NORMS:
  - UN Committee on the Peaceful Uses of Outer Space (COPUOS)
  - UN International Telecommunication Union/Space Services Department (ITU/SSD)
  - The Artemis Accords (US NASA initiative became multilateral)
- NATIONAL REGULATION
  - Inter-Agency Space Debris Coordination Committee (IADC)
  - National legislation (e.g., US Space Policy Directives)
- INDUSTRY STANDARDS
  - Space Industry Association (US)
  - International Standards Organization (ISO) Space Subcommittees
    - Space Data and Information Transfer
    - Space Systems and Operations



Freedom of Action has been an enduring principle.

The Outer Space Treaty (OST) (1967)

Key Concept: Freedom of action for peaceful use of space by all established as organizing principle.

- The OST provides the principles and framework for space law:
  - The exploration and **use of outer space shall be carried out for the benefit and in the interests of all countries** and shall be the province of all mankind
  - Outer **space shall be free for exploration** and use by all States
  - Outer **space is not subject to national appropriation** by claim of sovereignty, by means of use or occupation, or by any other means
  - **States shall not place nuclear weapons or other weapons of mass destruction in orbit or on celestial bodies** or station them in outer space in any other manner;
  - The **Moon and other celestial bodies** shall be used exclusively for peaceful purposes;
  - Astronauts shall be regarded as the **envoys of mankind**
  - **States shall be responsible for national space activities** whether carried out by governmental or non-governmental entities
  - **States shall be liable for damage** caused by their space objects
  - States shall **avoid harmful contamination** of space and celestial bodies

Amendments to the Outer Space Treaty

Key Concept: Amendments reinforced principle of Freedom of Action through responsibility and cooperation

- **Rescue of Astronauts Agreement (1968):** Elaborates on articles 5 and 8 of the OST. States shall take all possible steps to rescue and assist astronauts in distress and promptly return them to the Launching State.
- **Liability Convention (1972):** Elaborates on Article 7 of the OST. It defines that a launching State shall be absolutely liable to pay compensation for damage caused by its space objects on the surface of the Earth or to aircraft, and liable for damage due to its faults in space. The Convention provides procedures for the settlement of claims.
- **Registration Convention (1975):** The Convention expands the scope of the UN Register of Objects Launched into Outer Space that was established in December 1961 and addressed issues relating to States Parties' responsibilities concerning their space objects. The Secretary-General maintains the Register and ensures full and open access to the information provided by States and international organizations.
- **Moon Treaty (1979):** The Agreement elaborates on the provisions applied to the Moon and celestial bodies and directs that those bodies should be used exclusively for peaceful purposes, that their environments should not be disrupted, that the UN should be informed of the location and purpose of any station established on those bodies. The Agreement provides that the Moon and its natural resources are the common heritage of mankind and that an international regime should be established to govern the exploitation of resources when such exploitation is about to become feasible.

UN Committee on the Peaceful Uses of Outer Space (COPUOS) (1959)

Key Concept: Space policy dynamics have evolved from cold war competition to include increasing multilateral governance mechanisms

- COPUOS is tasked with reviewing international cooperation for peaceful uses of outer space, studying space-related activities that could be undertaken by the UN, encouraging space research programs, and studying legal problems arising from the exploration of outer space.
  - The topic of militarization of space is under the Conference on Disarmament in Geneva.
- There are currently 95 member states
- COPUOS facilitates the development of international guidelines
  - 1959-80: COPUOS facilitated the negotiation the OST structure
  - 1980 – 2000: Development of international Principles for activities in space
  - 2002: *Inter-agency Space Debris Coordination Committee* guidelines on space debris
  - 2010: *International Telecommunications Union* regarding graveyard orbits
  - 2011: Permanent Court of Arbitration "Operational Rules for Arbitration of Disputes Relating to Outer Space Activities"
  - 2019: *Guidelines for the Long-Term Sustainability of Outer Space Activities*
    - 21 voluntary, non-binding guidelines reached by consensus of the member states
  - 2021: Current focus is on implementation of the guidelines

Guidelines for the Long Term Sustainability of Outer Space Activities

Key Concept: Governance concerned with maintaining viability (utility) of space environment

7 guidelines directly or indirectly address preventing the creation of space debris.

Guidelines directly addressing debris:
- B.3
- D.2

UN COPUOS Guidelines for the Long-term Sustainability of Outer Space Activities

A. Policy and regulatory framework for space activities

Guideline A.1 Adopt, revise and amend, as necessary, national regulatory frameworks for outer space activities
Guideline A.2 Consider a number of elements when developing, revising or amending, as necessary, national regulatory frameworks for outer space activities
Guideline A.3 Supervise national space activities
Guideline A.4 Ensure the equitable, rational and efficient use of the radio frequency spectrum and the various orbital regions used by satellites
Guideline A.5 Enhance the practice of registering space objects

B. Safety of space operations

Guideline B.1 Provide updated contact information and share information on space objects and orbital events
Guideline B.2 Improve accuracy of orbital data on space objects and enhance the practice and utility of sharing orbital information on space objects
Guideline B.3 Promote the collection, sharing and dissemination of space debris monitoring information
Guideline B.4 Perform conjunction assessment during all orbital phases of controlled flight
Guideline B.5 Develop practical approaches for pre-launch conjunction assessment
Guideline B.6 Share operational space weather data and forecasts
Guideline B.7 Develop space weather models and tools and collect established practices on the mitigation of space weather effects
Guideline B.8 Design and operation of space objects regardless of their physical and operational characteristics
Guideline B.9 Take measures to address risks associated with the uncontrolled re-entry of space objects
Guideline B.10 Observe measures of precaution when using sources of laser beams passing through outer space

C. International cooperation, capacity-building and awareness

Guideline C.1 Promote and facilitate international cooperation in support of the long-term sustainability of outer space activities
Guideline C.2 Share experience related to the long-term sustainability of outer space activities and develop new procedures, as appropriate, for information exchange
Guideline C.3 Promote and support capacity-building
Guideline C.4 Raise awareness of space activities

D. Scientific and technical research and development

Guideline D.1 Promote and support research into and the development of ways to support sustainable exploration and use of outer space
Guideline D.2 Investigate and consider new measures to manage the space debris population in the long term

Other Multilateral Organizations

Key Concept: Operational practicalities provide opportunities to advance cooperative governance

- **UN International Telecommunication Union/Space Services Department (ITU/SSD)**
  - The SSD is responsible for coordination and recording procedures for space systems and earth stations. The SSD handles capture, processing and publication of data and conducts the examination of frequency assignment notices submitted by national administrations for inclusion in the Master International Frequency Register. Inclusion is legally binding.
- **The Artemis Accords** (a US NASA initiative that became multilateral)
  - The purpose of the Accords is to establish a common vision via a practical set of principles, guidelines, and best practices that enhance the governance of civil exploration and use of space.
  - Civil space activities may take place on the Moon, Mars, comets, and asteroids, including their surfaces and subsurface, as well as in orbit of the Moon or Mars, in the Lagrangian points for the Earth-Moon system, and in transit between these celestial bodies and locations.
  - The Accord reinforces the commitment to the registration convention, deconfliction of activities, rescue of astronauts, and the public release of scientific data.

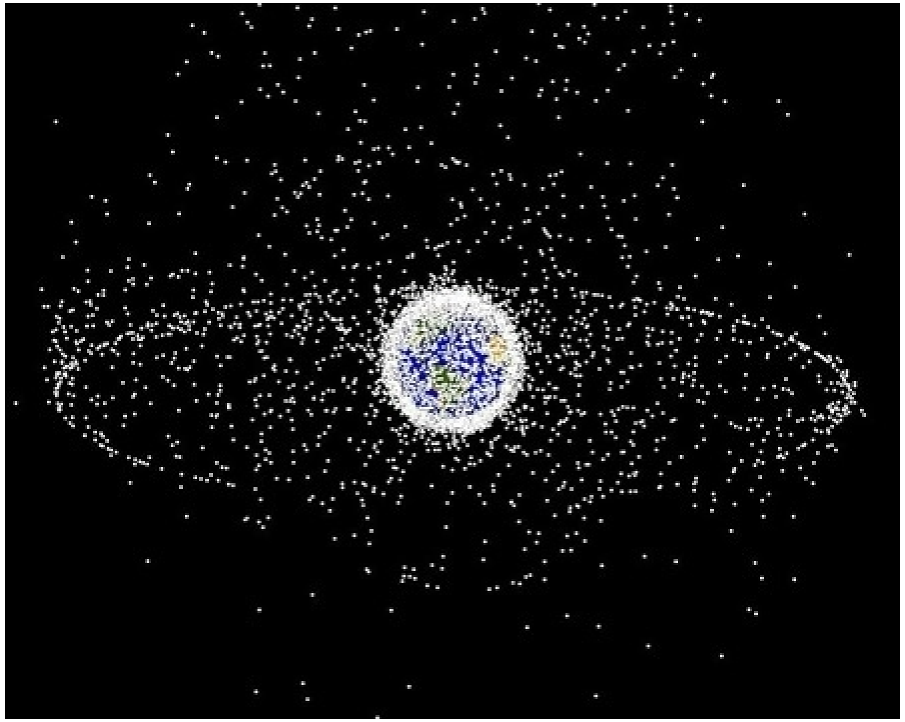
Exemplars of US-Originated Norms and Initiatives

Key Concept: The driver for the US SPDs has been a combination of changes in technology, new space players and policy interests of the USG

- **The *Tenets of Responsible Behavior for DoD Space Operations* (July 2021)**
  - Operate in space with due regard to others and in a professional manner
  - Limit the generation of long-lived debris
  - Avoid the creation of harmful interference
  - Maintain safe separation and trajectory
  - Conduct notifications to enhance the safety and stability of the domain
- **Space Policy Directive-2: Streamlining Regulations on Commercial Use of Space (May 2018)**
  - SPD-2 directs several government agencies and the National Space Council to establish or reevaluate
- **Space Policy Directive-3: National Space Traffic Management Policy (June 2018)**
  - SPD-3 places responsibility for addressing commercial space situational awareness (SSA) and space traffic management (STM) services upon the Department of Commerce.

Space Governance Frameworks: Current and Future Challenges

- Concurrence on norms and principles among divergent interests in emerging space enterprises
- Lack of an institutionalized security architecture
- Ability to regulate the security environment
- Coordination and collective action to resolve problems
- Sovereignty and economic rights
- The tragedy of the commons (debris/junk, safety, traffic)

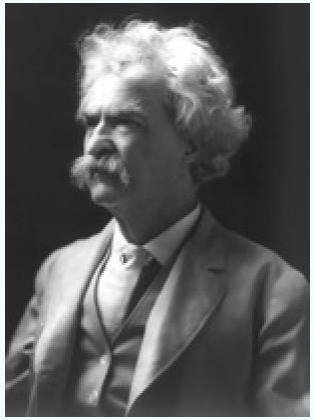


A computer-generated image by NASA of objects in Earth orbit that were being tracked on January 1, 2019. Approximately 95% of the objects are orbital debris - not functional satellites.

Lessons for Space Governance from Maritime Domain

Key Concept 1:
Principles of ***maritime governance*** have analogies in space:

- **Sovereignty**
- **Natural resource extraction**
- **Freedom of transit**
- **Traffic control and safety**
- **Control of waste/junk**
- **Resolution of non-compliant activity**



"History never repeats itself, but it does often rhyme." **- Mark Twain**

Key Concept 2:
Power projection capabilities and **domain utility** changed with technology ➡ policy responses

- First codified law of the seas (*Mare Liberum* - Freedom of the Seas) published in 1609
  The sea is international and free for all nations to use.
- Technology enabled the concept of territorial waters.
  By the late 18th century, the cannon-based 3-mile limit was accepted.
- Serious negotiation of an international maritime governance framework began after WW II.
  Introduced the legal concept of maritime sovereignty
- Changing security dynamics Post 9/11
  USCG ship inspections at 9 nm offshore (RPO limits?)
- Changing economic/environmental dynamics:
  ~8 million tons of plastic waste annually enters the seas (akin to space debris)

The UN Convention of the Law of the Sea (UNCLOS) Provides the Governance Framework

Key Concept: The right to use the sea is analogous to freedom of operations in space

UN Convention of the Law of the Sea (UNCLOS) was negotiated in three phases from 1956 to 1982 (with entry into force in 1994)

- Defined Internal Water, Territorial Waters, Exclusive Economic Zones, the role of islands, and the continental shelf
- Acknowledged the right to freedom of use in international waters and innocent passage elsewhere
- Established specialized UN agencies to implement the principles of UNCLOS
  - The UNCLOS *Division for Ocean Affairs and the Law of the Sea's* mandate includes the repression of piracy (other crimes fall under national jurisdiction).
- The UN agencies partner with analogous national agencies

Maritime Governance Analogies to Space

Analogy to Space	Maritime Objective	Governance Framework	Natl-Intl Org Coop?	Governance Effectiveness (subjective)	Role of Situational Awareness
Sovereignty	Definition of boundaries	UNCLOS	No	High-*	Low after member acceptance
Economic Rights	Definition of property	UNCLOS	No	High	Low after member acceptance
Tragedy of the Commons	Prevention of degradation of the sea	MARPOL, Nat'l regulation of coastal pollution	Yes	Low+	High - needed for timely response (both land and sea pollution origin)
Concurrence with laws & norms	Build acceptance	UNCLOS/ Nat'l Authorities, Regional fishing Mgt (RFMOs)	Yes	Medium+	Medium – ongoing process
Achieve Security and Safety	Create stable environment	COLREG,ISM SOLAS, ISPS, UNCLOS/Legal	Yes	Medium	High - needed for timely response

* Exception – South China Seas

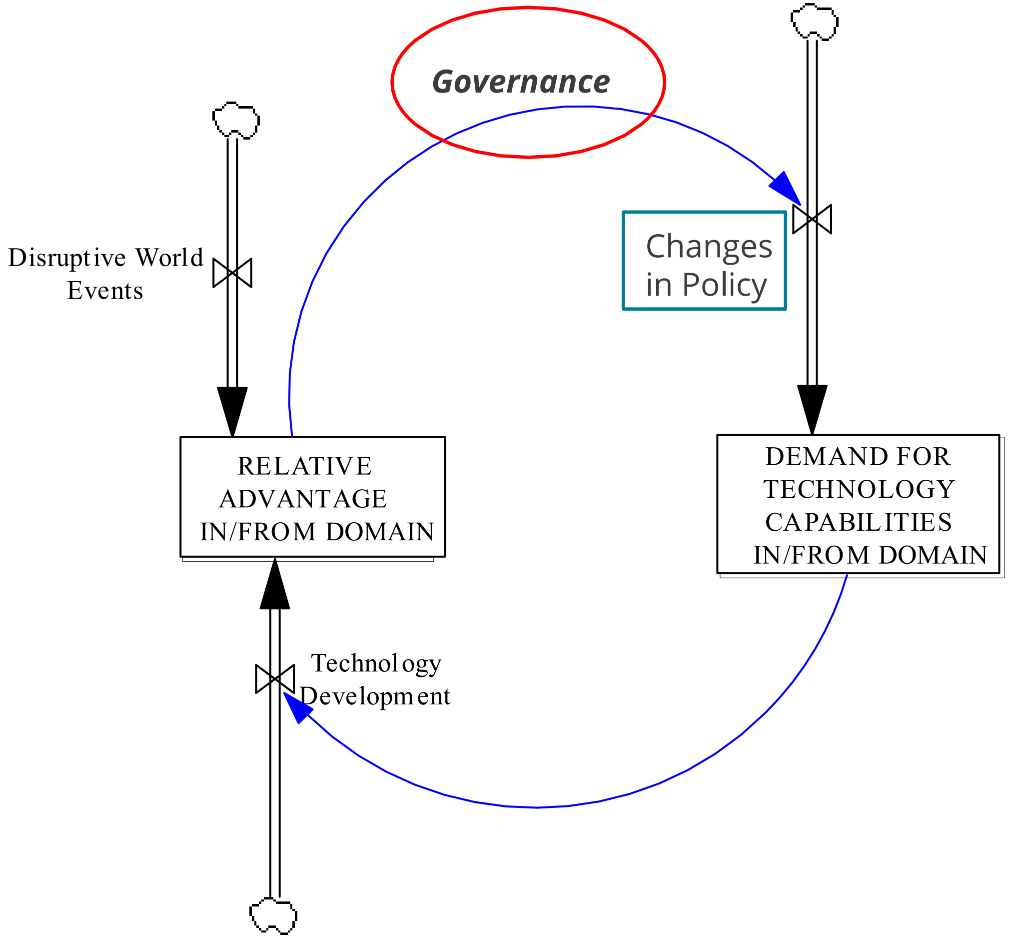
Returning to the space governance and technology development model

Key Concept:

The class introduction identified 3 key variables causing changes in demand for technological capabilities in a domain:

- Disruptive World Events
- Current Level of Technology
- Changes in Policy

But *Governance* regulates how the perception of “relative advantage” is actually expressed in policy



Closing Observations

- Space activity is influenced by various social forces
  - *Economic* (natural resource and terrestrial infrastructure development, specialized manufacturing, tourism)
  - *Military* (threat perception, communications, reconnaissance)
  - *Political* (establish national “presence” in space, extra-terrestrial sovereignty)
- Technology both enables existing and creates new social forces
- Space governance is immature and will continue to evolve
  - Norms will therefore play a large role in the near future
  - There are precedents and analogs in the governance of the land, sea and air domains that may facilitate the development of space governance
- As more participants (national, NGO, commercial) enter space, there will be increased demand for clear rules stimulating the development of governance

Governance plays a role in our subsequent class exercises

SPACE SECURITY FUTURES

2035

Fears Realized

- Weak Strategic Offsets
- Weak Governance
- Overt Weaponization
- Limited commercial partnerships

2035

Global Hopes Realized

- Effective Strategic Offsets
- Strong Governance
- Strong public-private partnerships

2045

Dune (Wild West)

- Weak Governance
- Global ISR
- Competitive and expansive space based industries
  Multiple lunar colonies
- Return from Mars

Module Time: 45 Minutes

Drivers and Constraints of Space Policy and Technology Development

Commercial and military interests; policy responses; cislunar and future drivers

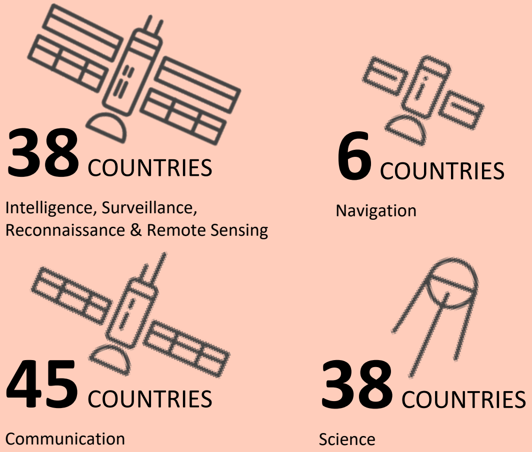
Goal at end of module: Understand how key trends, drivers, and constraints of space policy and technology might interact to create new dynamics, challenges and opportunities – including feedback and second and third order affects

Current Trends (Drivers)

Commercialization

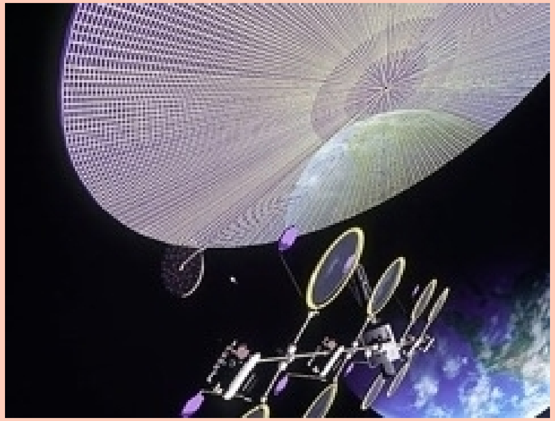
Global space economy estimated to grow from $350bn in 2018 to $1T or more by 2040.

Proliferated LEO



Space launches, satellites, and actors growing exponentially.

Innovation



Extensions of current innovations may enable new operational concepts and human exploration.

Contestation and Weaponization

Counterspace threats are increasing. Militaries reorganizing to emphasize space.

> "Space is an **increasingly complex** …with **significant and rising uncertainty**. Many space systems …are on the bleeding edge of technological development in a field **rife with surprise** from both forward leaps and setbacks. The geopolitics of great power competition in space, rising questions about the civil and commercial regulatory environment…all **pose challenges for future planning**..."
>
> *-Aerospace Corporation, Space Agenda 2021*

Drivers and Constraints

Exhibit 1: Space Age 2.0 in a nutshell

Source: BofAML Global Research based on various sources

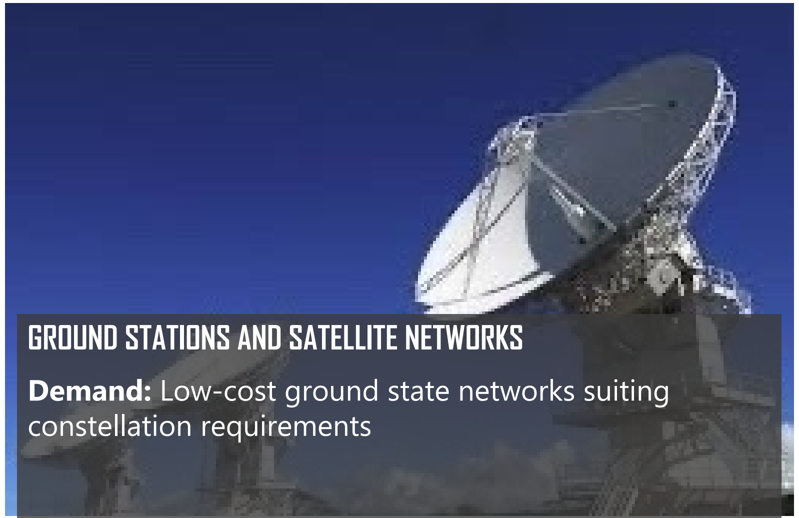
Global Space Industry Sectors

SATELLITE MANUFACTURING

Market Size 2019-2030: $366.06 BN
Demand: high/very high throughput satellites and constellation satellites to meet data demand, 68% of demand from commercial operators, especially North American mega constellation operators, including SpaceX

LAUNCH SERVICES

Market Size 2019-2030: $102.52 BN
Demand: 89% from commercial operators, majority North American operators with a global launch demand of 12,766 satellites for 2019 to 2030, 60% from communication satellites, and 28% from EO



GROUND STATIONS AND SATELLITE NETWORKS

Demand: Low-cost ground state networks suiting constellation requirements

DOWNSTREAM APPLICATIONS

SATELLITE COMMUNICATION

Market Size 2019-2030: $105.35 BN
SATCOM represents 68% of the total satellite manufacturing market revenues; Services to Government customers will be the top growth segment; Increased competition with entry of LEO-based satellite operators

EARTH OBSERVATION (EO)

Industry/market-specific services include:

- Agricultural crop/irrigation monitoring
- Defense action based imagery intelligence
- Energy asset management
- Emergency event management and planning
- Forestry land-use monitoring

NAVIGATION

National agencies, like US, invest heavily in US-based satellite navigation programs (on average $1.0 BN per year)

- Defense technologies, including UAVs and GPS-guided missile systems, rely on high-bandwidth and trusted communications – high spending defense spending projected

Commercial Growth in Space: Challenges and Opportunities

SATELLITE MANUFACTURING

Challenges: Affordable and low-lead time satellites

Opportunities: Smart manufacturing utilizing system standardization, additive manufacturing, collaborative robots, serial production, industrial IoT, and system miniaturization

LAUNCH SERVICES

Challenges: gap between satellite launch demand and the supply services = Lack of launch slots, choice for orbital locations, and end-to-end services

Opportunities: Manufacturing of standardized rockets, vehicle reusability, additive manufacturing of complex systems, new composite structures for lighter/robust vehicles, remote diagnostic technologies, and remote command and control capabilities

GROUND STATIONS AND SATELLITE NETWORKS

Challenges: Latency and multiplexing; EO satellites will require infrastructure at poles and across globe; Ka-band and Ku-band capabilities needed to cater to high-speed connectivity services using small satellites

Opportunities: Partnerships between constellation operators and ground station owners; Development of space-based relay station and low-cost reliable flat panel antenna

DOWNSTREAM APPLICATIONS

SATELLITE COMMUNICATION

Challenges: Convergence of 5G and satellite network, services combining LEO and GEO capacities, satellite launch service supply does not meet demand

Opportunities: Innovation in satellite manufacturing and ground system segments

EARTH OBSERVATION (EO)

Challenges: Ground stations geographically narrow, affordable and faster refresh imagery solutions

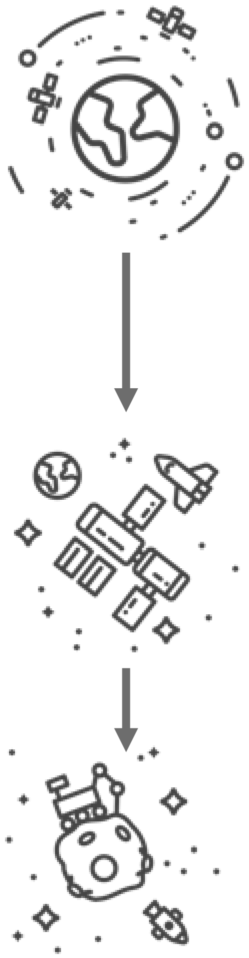
Opportunities: AI, SAR Small Satellites, global ground stations esp. at poles, ground station uberization and space-based relay stations

NAVIGATION

Challenges: High precision and real-time navigation and tracking

Opportunities: Navigation critical for emerging technologies, e.g. autonomous cars, wearable devices

Commercial Evolution Poses Challenges (Constraints) to Space Operating Environment



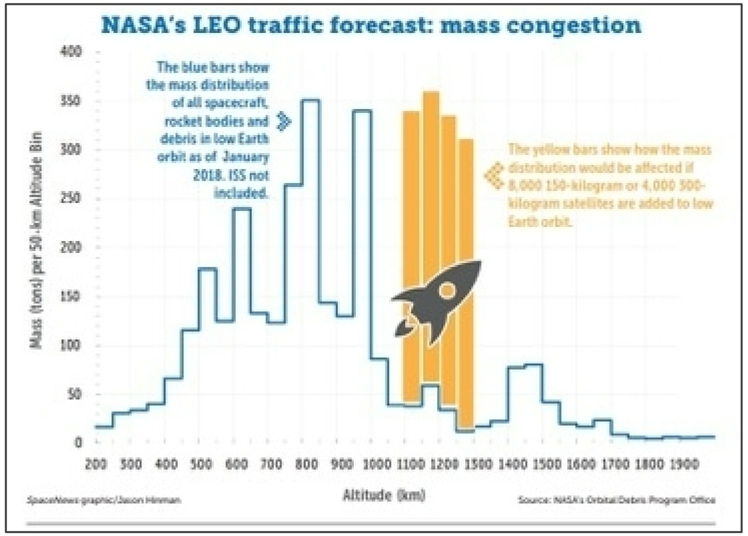
- **Space provides an information pipeline (to Earth)**
  - Proliferation of satellites in LEO
  - Unparalleled, global access to data, imagery, remote sensing

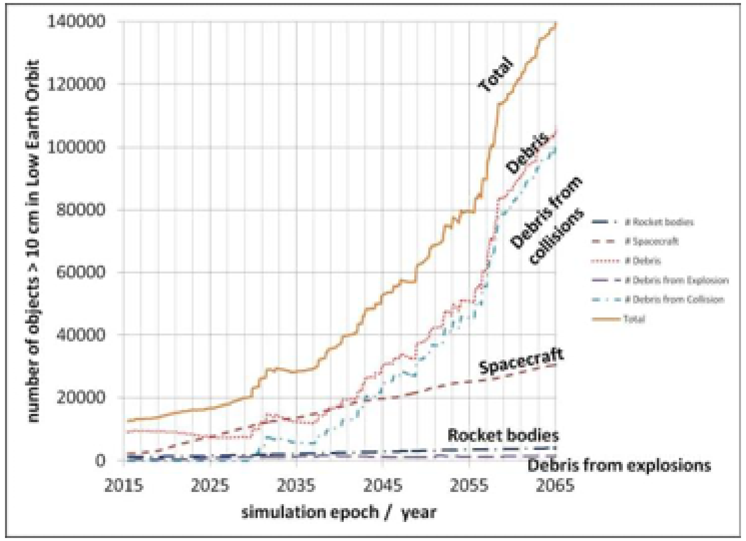
Space activities drive extraterrestrial economy

- On-orbit services, manufacturing
- Tourism

Space becomes a source of commodities

- Resource extraction from orbital bodies
- Power sources





Safety and Security Challenges: Debris, trusted supply chains, cybersecurity, globalization

Security Challenges of Commercial Space-based Infrastructure

Trusted Supply Chain

"Strengthen the security, integrity, and reliability of the supply chains of United States space-related science, technology, and industrial bases by identifying and eliminating dependence on suppliers owned by, controlled by, or subject to the jurisdiction or direction of foreign adversaries"

Globalization

"In this renewed era of great power competition, space policy is moving to address …predatory practices by our competitors and the use of commercial space companies as state capital proxies by foreign adversaries"

Debris Mitigation

"As space debris piles up, the risk of disruption to life on Earth increases. If satellites are destroyed or knocked from orbit, human users face a loss of … a range of other earth observation functions that support our daily lives. There is also the potential for loss of human life if debris were to collide with a space launch vehicle or the International Space Station"

Cybersecurity

"Foster commercial space sector adoption of cyber-secure GPS enabled systems consistent with cybersecurity principles for space systems"

Sustainable Space Operating Environment

Space-power

"The capabilities of all space systems now and into the future are critically dependent on the level of power either periodic or continuous that drive their operations"

Transport/Logistics

"In the commercial domain the ability to transport to and through space reliably and cheaply is the key determinant for the commercial viability of all other space capabilities"

In-orbit servicing

"Re-fueling, hardware replacement/upgrade and debris removal – offers an extended mission life"

Adapting to human presence in space

"Extend human presence and economic activity beyond low Earth orbit"

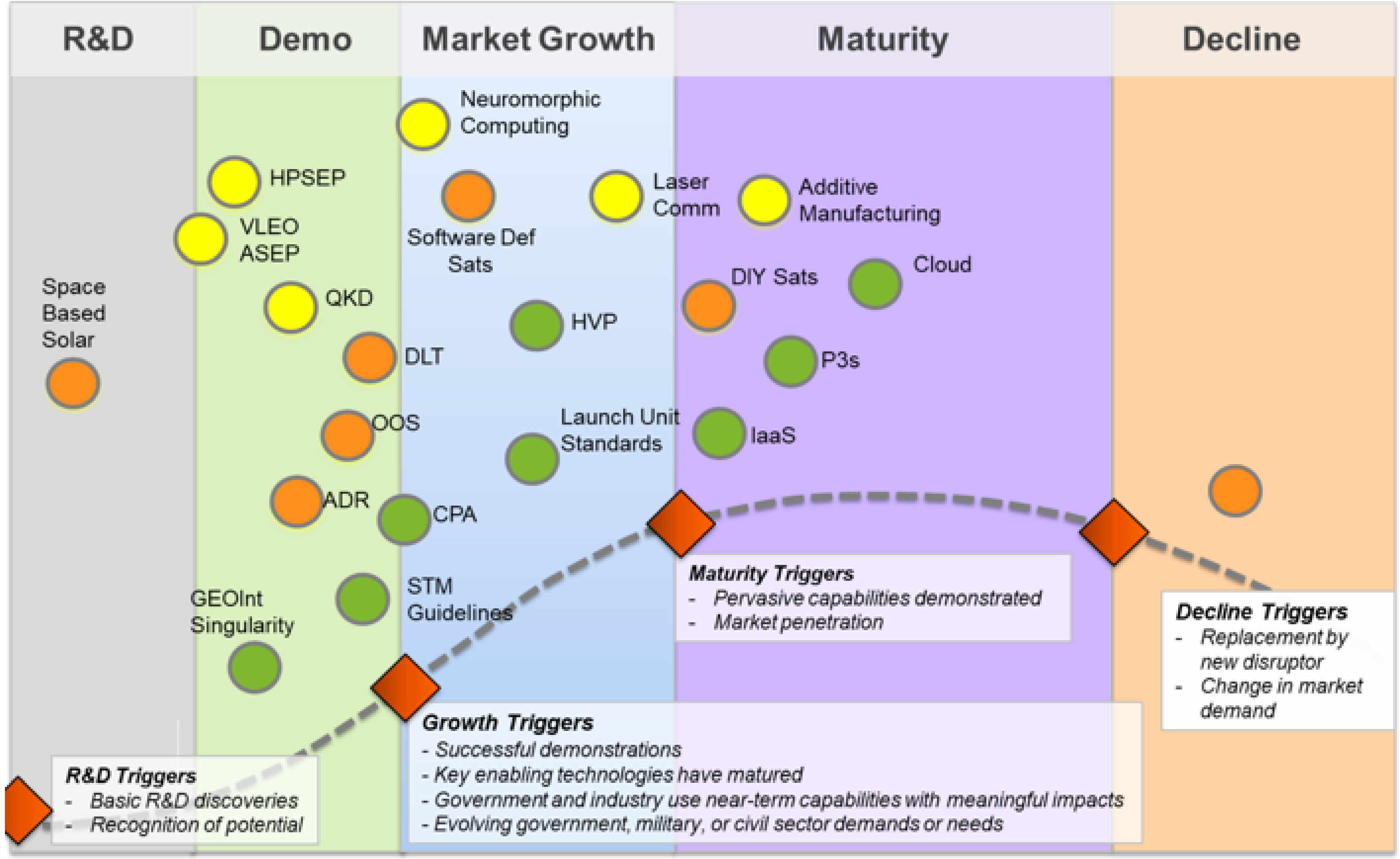
Robotics

"Mining sector to play an increasing role in robotics, resource utilization and advanced manufacturing"

Drivers and Constraints

SpaceTechnology Game Changers

Solar power satellites, The GeoInt singularity, Neuromorphic computing, Very low Earth orbit (VLEO) airbreathing solar electric propulsion (ASEP) satellite



ADR – Active Debris Removal
ASEP – Air Scooping Electric Propulsion
CPA – Continuous Production Agility
DIY – Do-it-Yourself
DLT – Distributed Ledger Technology
HPSEP – High Power Solar Electric Propulsion
HVP – High Volume Production

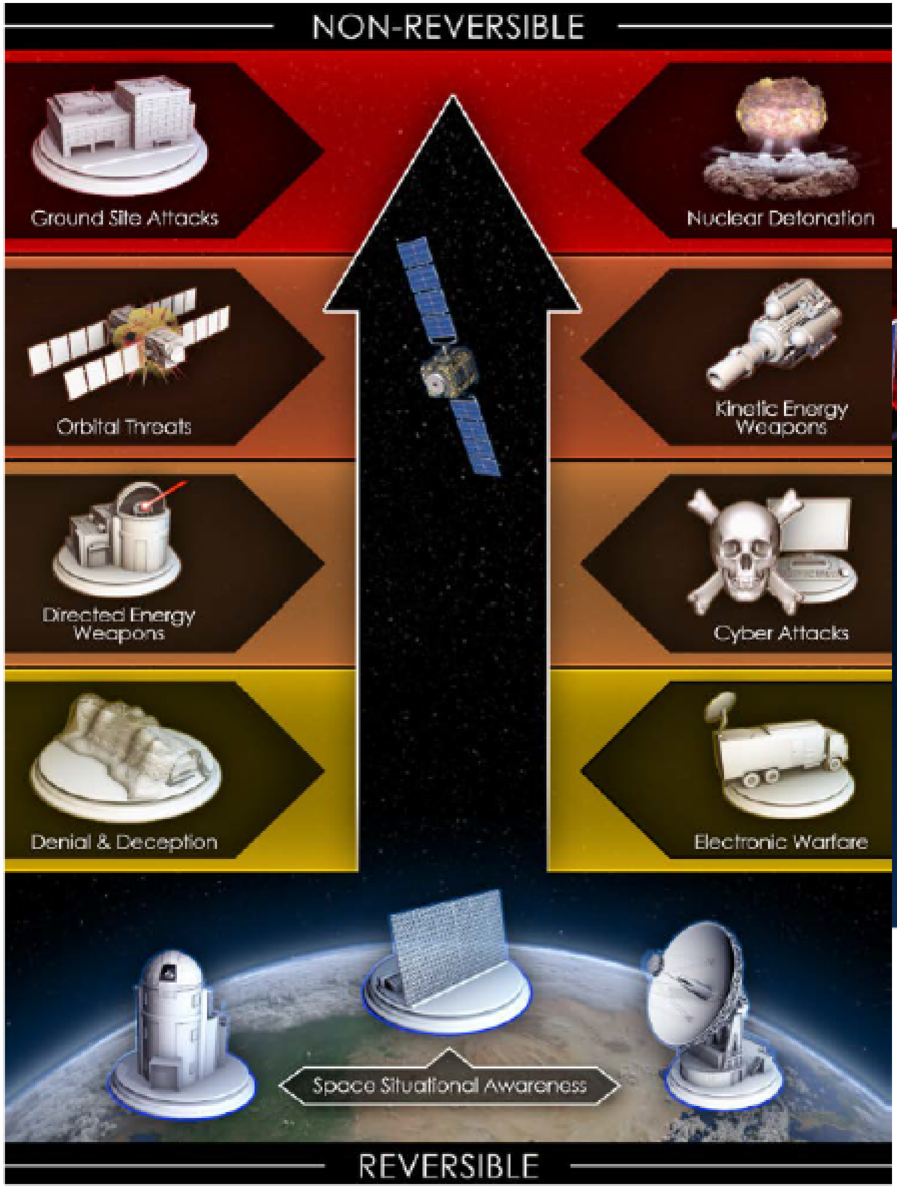
IaaS – Infrastructure as a Service
OOS – On-orbit Servicing
P3 – Public Private Partnerships
QKD – Quantum Key Distribution
STM – Space Traffic Management
VLEO – Very Low Earth Orbit

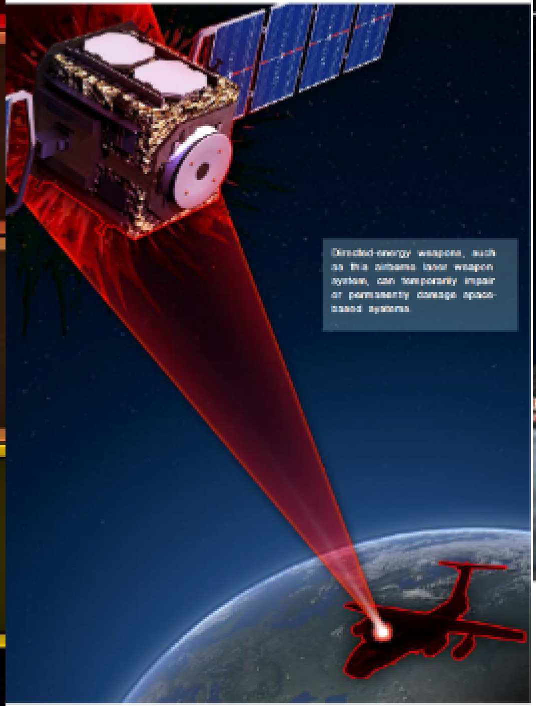
Technologies and materials
Applications
Business models, architectures, and standards

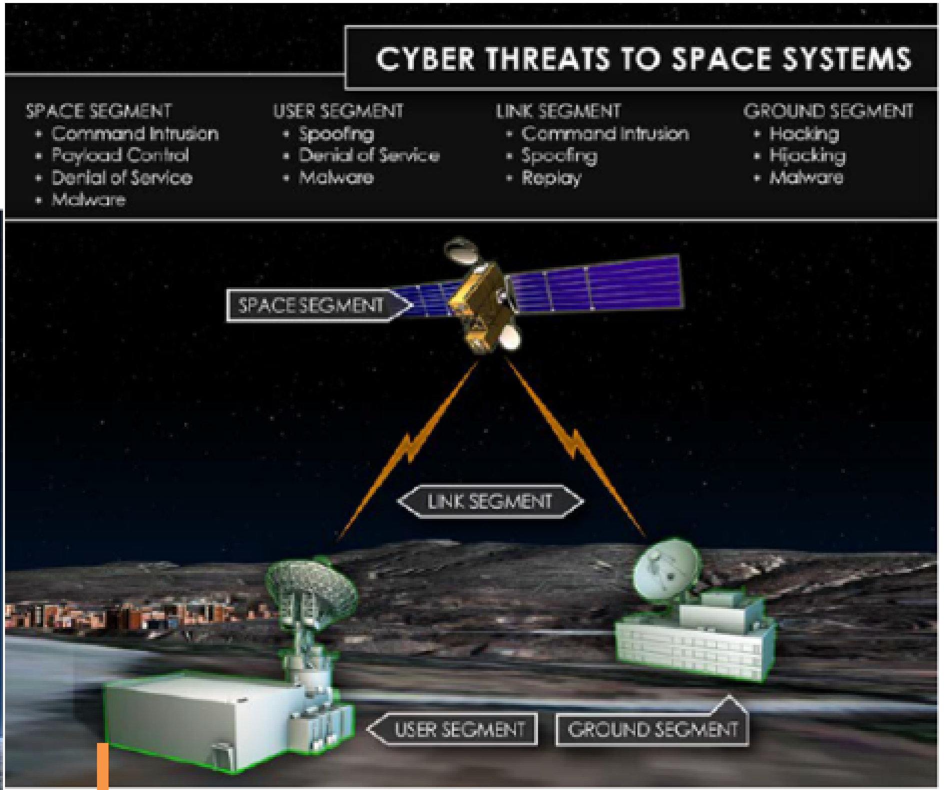
"Influential space elements (technologies, applications, business models, and architectures) in various lifecycle phases. Triggers are inflection points that may cause the space element to advance due to changes in market demand or adoption, performance or efficiency, regulation or policies, or societal expectations and norms."

-Karen Jones, Space Game Changers: Driving Forces and Implications for Innovation Investments, Space Agenda 2021, Aerospace Corporation, 2020.

Contestation and Militarization: Denying Space-Based Systems







> “Potential adversaries are developing and proliferating a number of weapons that could disrupt or deny space services”
>
> *-Wilson, M. S. Z. (2019). Competing in Space. Wright-Patterson Air Force Base, Ohio, NASIC.*

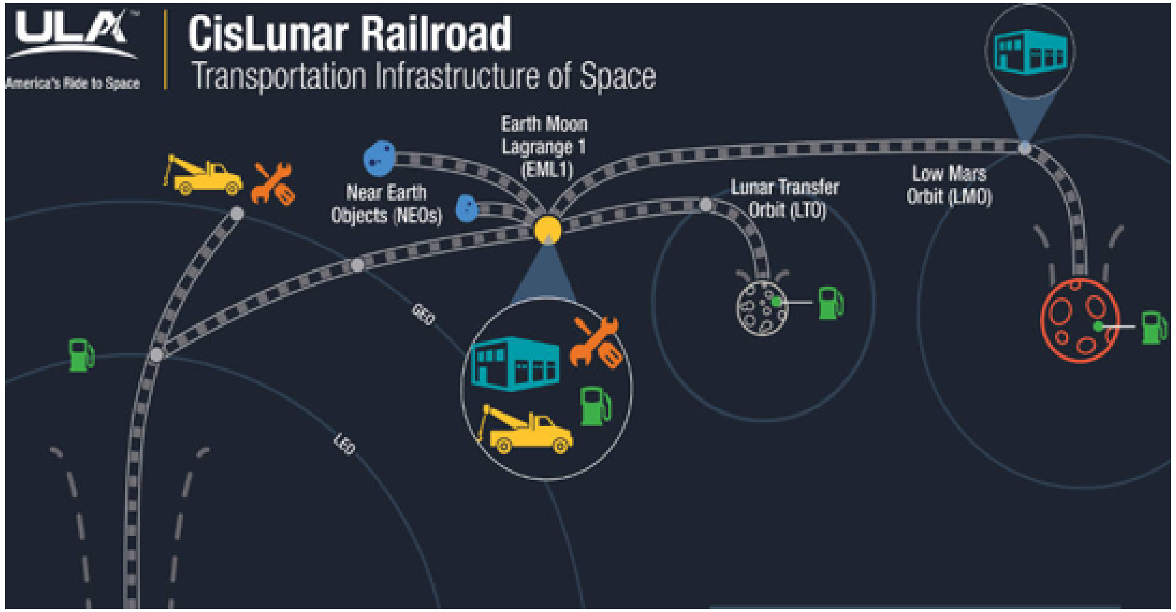
Recent Space Security Policy Responses – US as Exemplar

Institution	Commercialization	Proliferation in LEO	Technology Development	Contestation and Militarization
Executive Branch	Executive Order on Encouraging International Support for the Recovery and Use of Space Resources (2020) EO 13803: Reviving the National Space Council (2017)		NSPM-20 (Space launches with nuclear systems)	National Space Policy (2020): Space as War-Fighting Domain
Legislative Branch	Space Resources Institute Act of 2019		NDAA 2018 - 2021	NDAA 2018 - 2021
National Space Council (Public/private partnerships)	SPD-2 (Streamline Regulations	SPD-3 (Space Traffic Management)	SPD-6 (Nuclear Power Propulsion) SPD-7 (PNT)	SPD-4 (USSF) SPD-5 (Cybersecurity) SPD-7 (PNT)
Military Branches	Shift to leveraging commercial developments	Resilient Space Architecture	Updates to JP3-14 Space operational doctrine	DOD Space Strategy (2020)

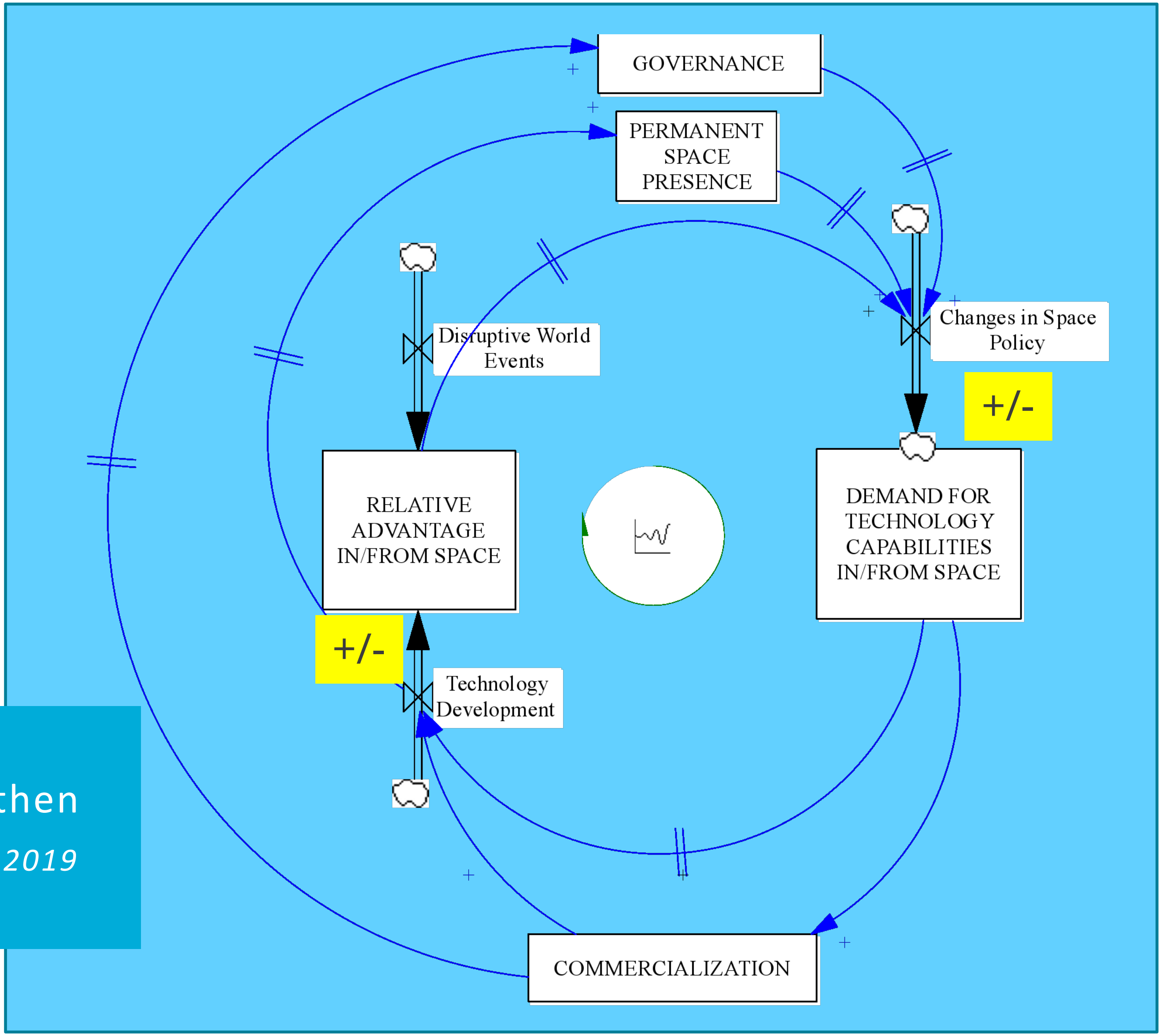
Policy Responses – International Exemplars

Institution	Commercialization	Proliferation in LEO	Technology Development	Contestation and Militarization
UN COPUOS				Proposed Prevention of Arms Race in Outer Space (PAROS) Treaty
EU		International Code of Conduct for Outer space Activities (2008)		
NASA			Artemis Accords	
UNOOSA/UNCOPUOS		Guidelines on Long-Term Sustainability of Outer Space Activities (2019)		
UNCOPUOS			Principles Relevant to the Use of Nuclear Power Sources in Outer Space (1992)	

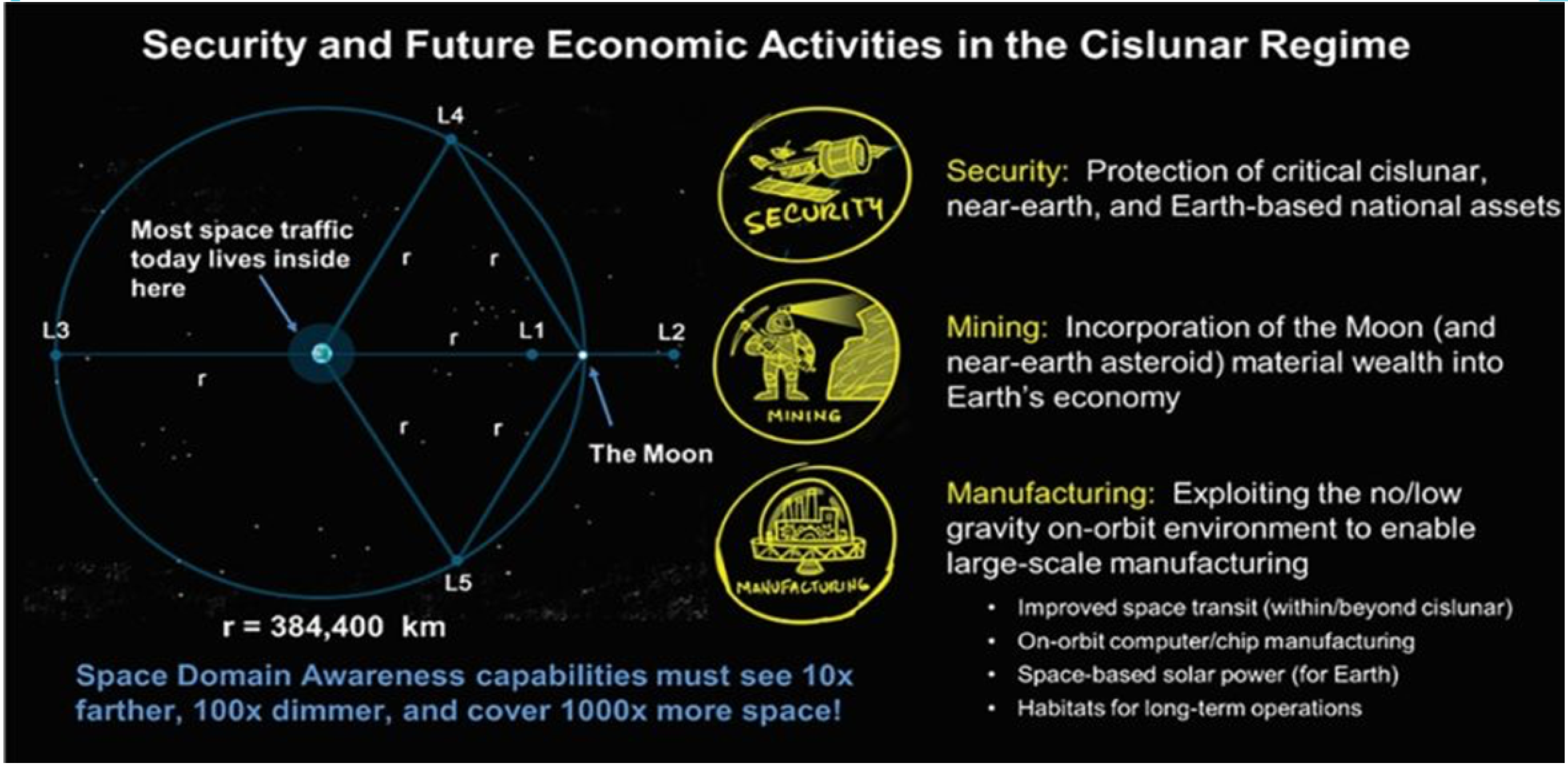
Drivers and Dynamics in cislunar



> "We are going to build a road to space, and then amazing things will happen." *-Jeff Bezos, 2019*



Drivers and Constraints: cislunar



Graphic courtesy of Exoanalytic Solutions

Technology Trends and Players in cislunar space

Trend 1: More cislunar-relevant private companies will emerge in the future. Private sector applied technology will continue to outpace in-government developments leading to a reliance on privately developed launch vehicles, lunar habitats, and other lunar payload services.
Trend 2: The business case for services like lunar mining and space tourism is difficult to close. Therefore, riskier ventures will remain purely private.
Trend 3: Exploration and scientific discovery will continue with support from governments and increasing private funds
Trend 4: Issues of national security in cislunar will remain purely in the wheel house of the Space Force. Because of U.S. advantages in space technologies and intelligence sensitivities, there is little to no incentive for collaboration

Space Security

- Space Force

Launch Vehicles

- SpaceX
- Blue Origin
- Boeing (SLS)

Lunar Mining and In-situ Resource Utilization

- Shackleton

Lunar Habitats

- Lockheed Martin
- Northrop Grumman
- Bigelow Aerospace
- Boeing
- Sierra Nevada Corporation
- NanoRacks

Lunar lander/Commercial Lunar Payload Services

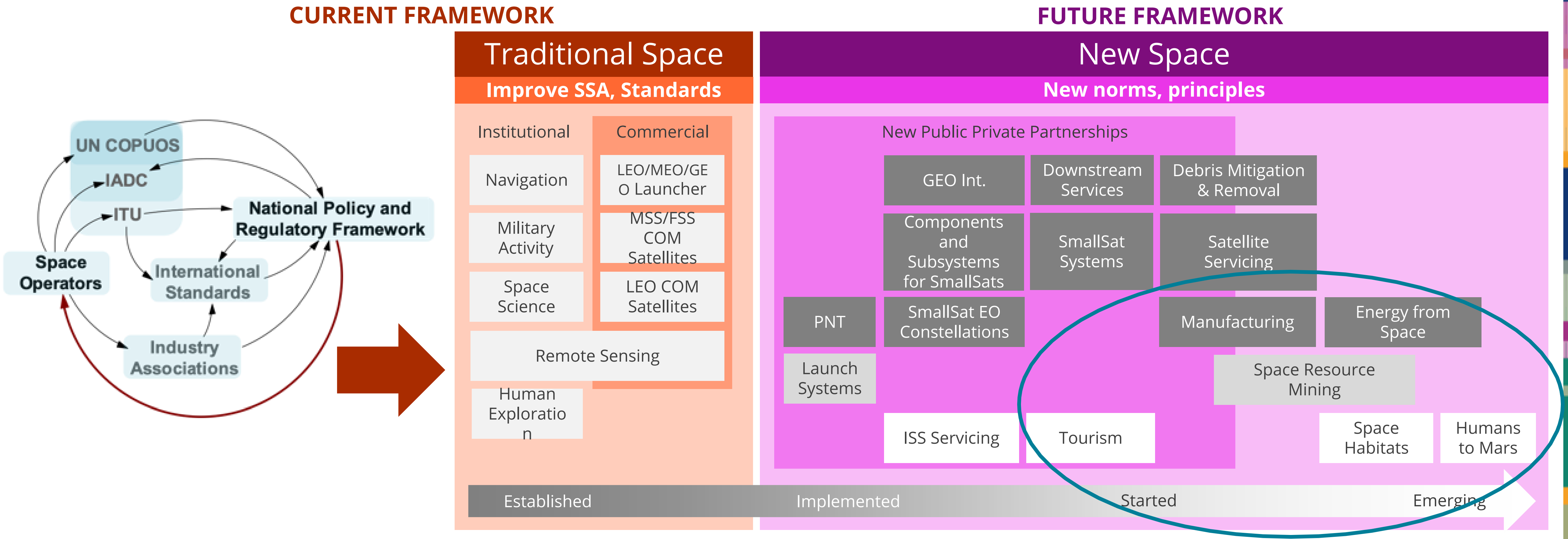
- Astrobotic Technology
- Draper Laboratory
- Firefly Aerospace
- Intuitive Machines
- Lockheed Martin
- Masten Space Systems
- OrbitBeyond
- Blue Origin
- SpaceX

Drivers and Constraints: cislunar

Scope, Strength, Alignment of Governance Frameworks

International Agreements and Treaties: Five treaties negotiated under UN from 1967 – 1984. Key principles and guidelines developed by UN Committee on Peaceful Use of Space from 2002-2019.

Norms and regulations: Promulgated by national governments and industry consortia; focus on capacity, responsibility/obligations, safety, space situational awareness, and contamination.



Where might we be headed?

Freedom of Action and Implications for SSA

1. **Balance of Power:** Freedom of Action in space will depend on *strategic offsets* of nation states *to counterspace capabilities* of their adversaries.

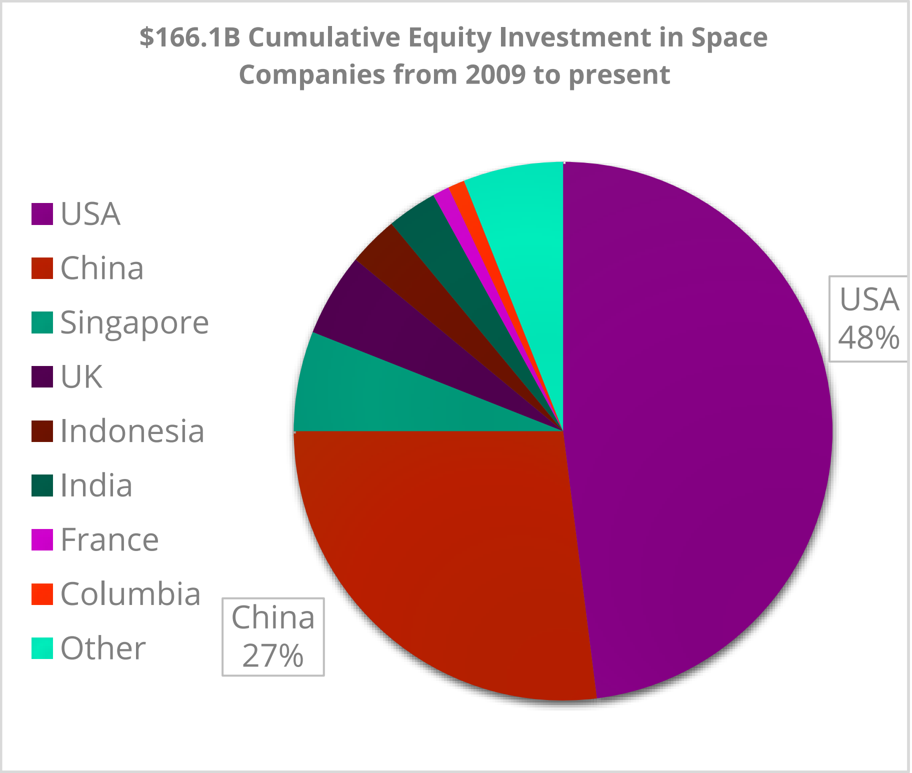
2. **Governance:** Freedom of Action will depend on scope, strength, alignment of future *governance frameworks* in space.

3. **Commercialization:** Freedom of Action in space will be enabled and challenged by *increasing commercialization and its second, third order effects.*

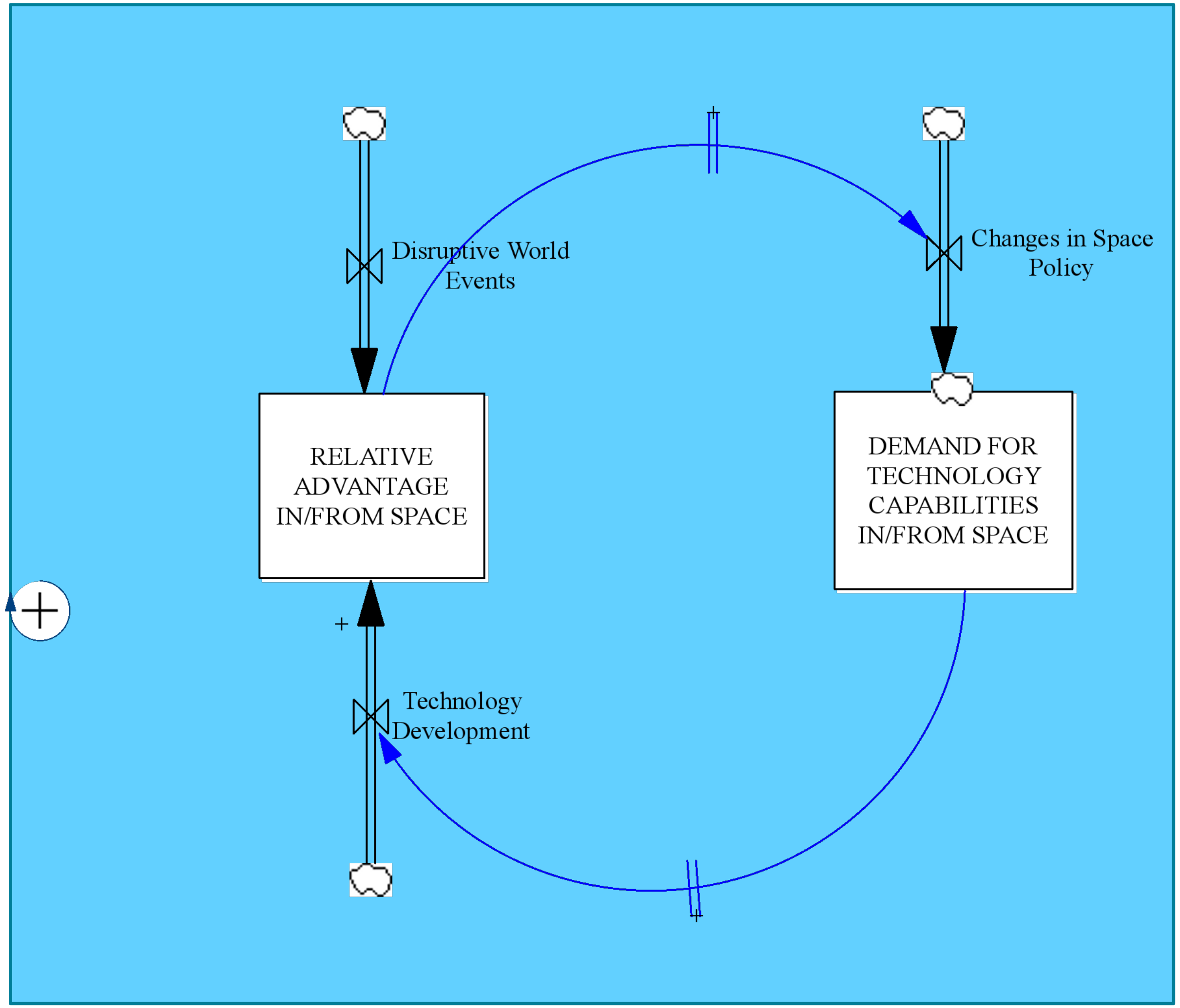
4. **Convergence and Colonization:** Technology innovation, market dynamics, and human exploration may incentivize *Enforcement of Sovereign Claims* over Freedom of Action as guiding principle.

Relative Advantage from Space: Balance of Power Dynamics

"Russia and China are building capabilities to challenge US in space because if they can challenge us in space, …they can challenge us as a nation." -*General Hyten, 2021*



Source: Space Investment Quarterly, Q3 Space Capital 2020



Policy Response: Technology Demand for Strategic Offsets

"That space is now a war-fighting domain is not questioned." *-Vice President Mike Pence, 12/20/2020*

Pivot to Strategic Offsets

- Dedicated military forces for space
- Resilient, hardened systems and architectures
- Space-based information processing, edge computing
  - Quantum technologies (sensing, communication, computing algorithms)
  - Machine learning and Autonomy
  - Data surety

Key Questions for Space Policy- Technology Development Dynamics:

Will nations develop and demonstrate effective strategic offsets to counterspace capabilities, and what might be and what could be second, third order effects on policy responses?

How long will these offsets remain effective?

How do these dynamics affect the challenge space situational awareness (SSA) and space domain awareness (SDA), and what new needs do they drive?

Key Uncertainties

How will industry's approach to safety and security affect future space environments?

To what degree and effect will national space security enterprises leverage commercial innovations and how do these differ?

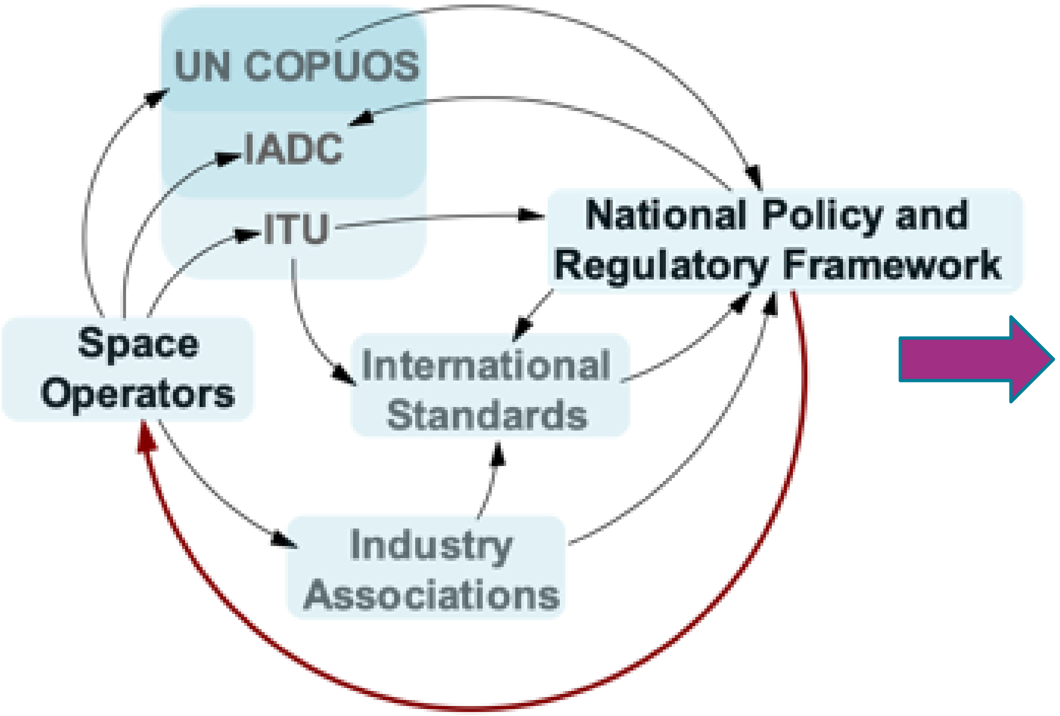
How might global access to commercial data and remote imagery products affect national and global security dynamics?

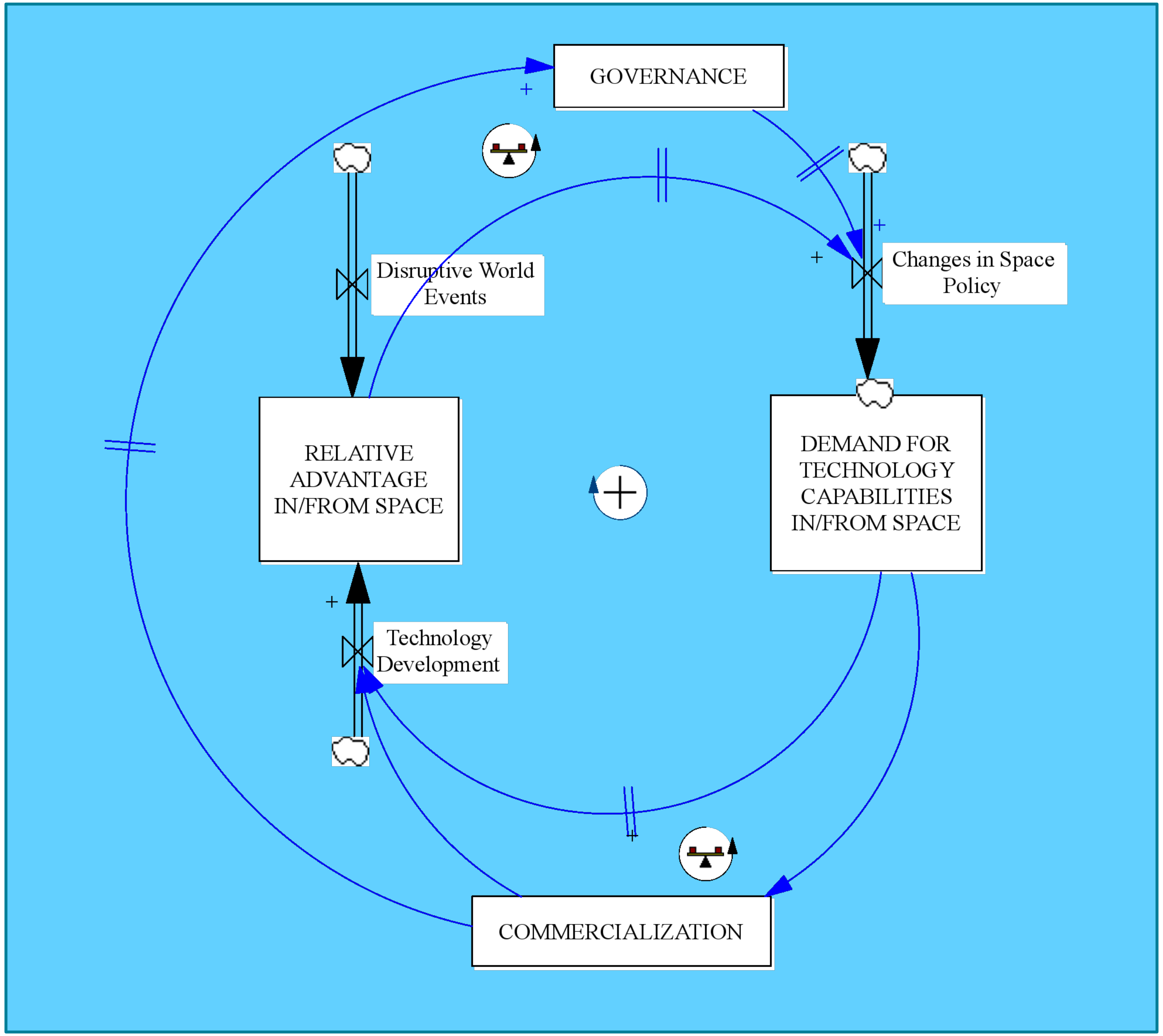
How might evolution of space-based economies affect competition and balance of power?

"There were 429 recorded instances in which dangerous space objects passed close to ISS, breaching the Station's 10-km safety zone, including 112 conjunctions at a minimum distance of less than 4 km."

-United Nations Office of Outer Space Affairs, 2020

Governance frameworks may balance escalation dynamics





Drivers and Constraints: Future

Key Uncertainties

How might different actors (state, nonstate, industry) shape governance frameworks and for what purpose?

- Will China's advancements in human exploration yield advantages?
- Will market interests or human, security, safety interests prevail?

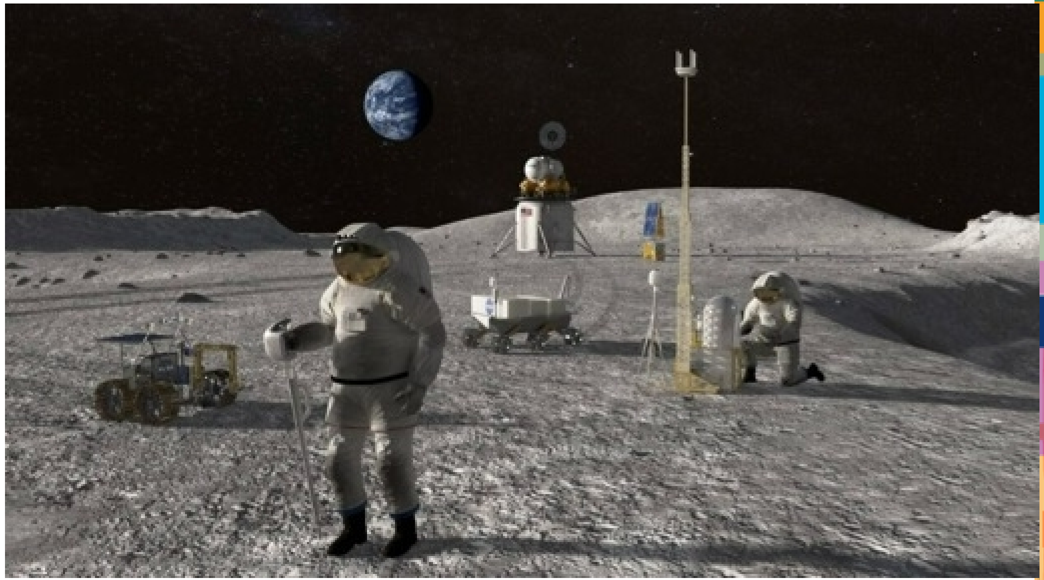
To what extent will governance frameworks influence behavior of different actors in space?

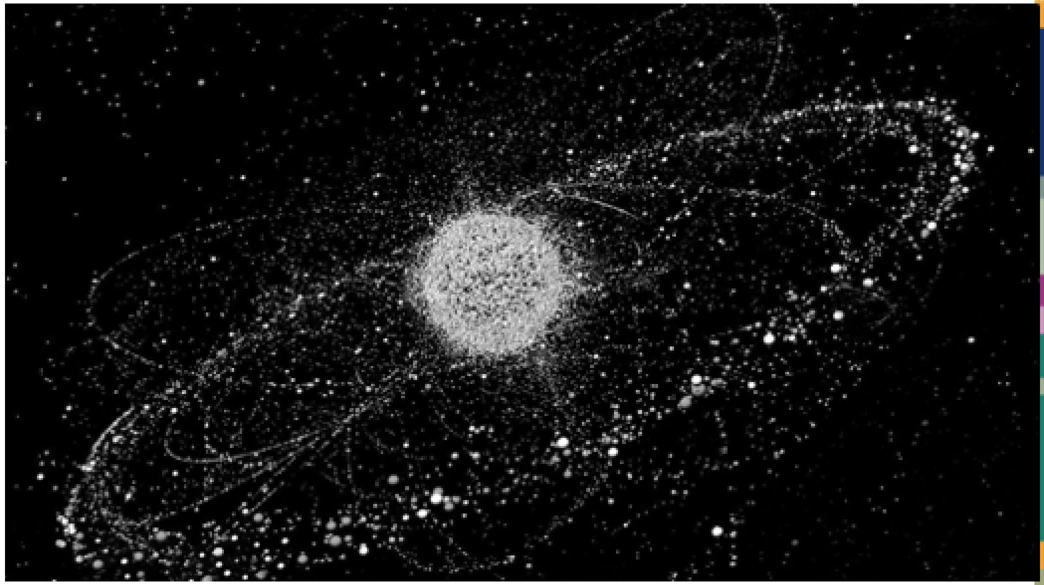
- What will be the scope and how robust?
- Will there be effective monitoring and accountability mechanisms? How might their implementation affect geopolitical dynamics?

"ESA and the UN team up for space debris…"

"Lasers in Space: Debris removal, power supply…"

"Apply magnetic forces to target satellite…"

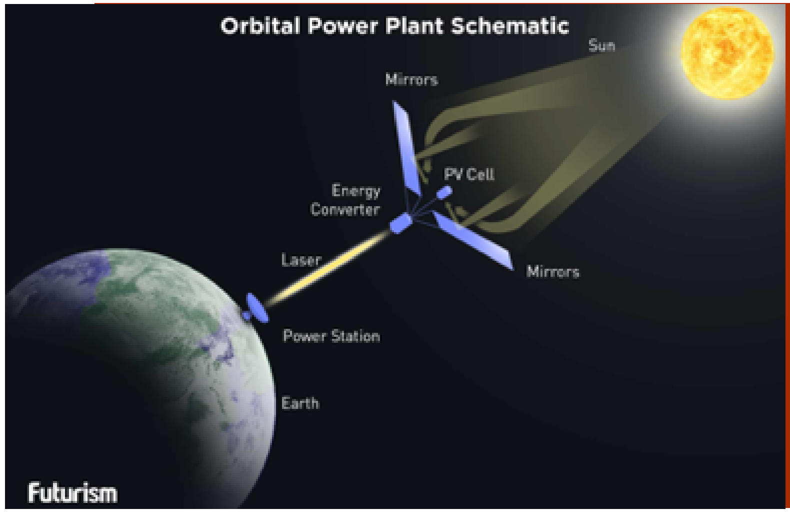




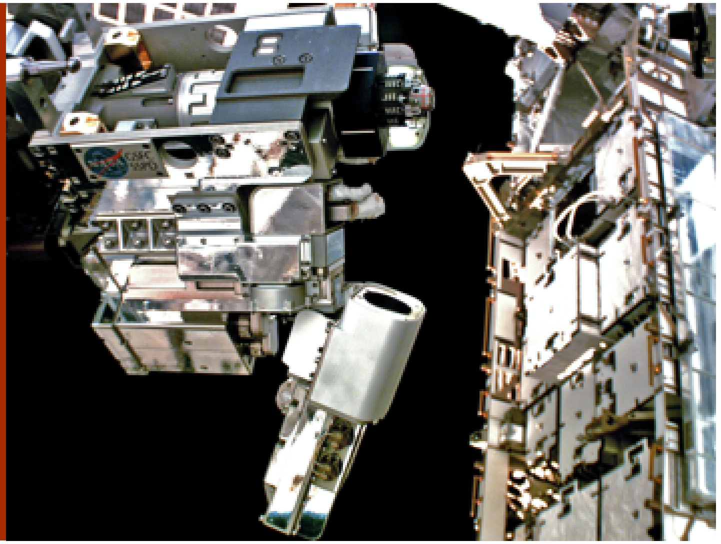
Technology Game-Changers (Exemplars)

Zero Gravity Advanced Manufacturing

Nuclear power and propulsion



Solar Power Space Race



Robotic tools for in-space refueling

Laser Communications in Space

Machine Learning, quantum, neuromorphic computing

Enforcement of Sovereign Claims may compete with Freedom of Action as guiding principle

Plausible Game-Changers

- Ultra Low-Cost Access to Space
- Advanced Manufacturing
- On-orbit servicing infrastructure
- Space-based resource extraction
- Space-based power systems
- Advances in Human exploration

Permanent, Self-Sufficient Stations

- Lunar and Martian bases
- Asteroid Mining
- Massive service-providing Space Stations
- Human habitats

Technology Convergence → Space Habitation and Colonization → Protection of Territory → **Enforcement of Sovereign Claims vs. Freedom of Action?**

Analogy: Evolution from maritime exploration to territorial waters and Law of the Sea

Key Uncertainties

- How might permanent human presence on Moon and Mars evolve, and how will this affect geopolitical, economic and social dynamics on earth?
- Will key actors cooperate or compete in space-based projects to support economic, safety, and security interests?
- How will terrestrial geopolitics influence evolution of, and adherence to, governance principles in human colonies and commerce beyond earth?

Introduction of Use Cases: Divergent scenarios for technology and policy evolution

<u>Goal of module:</u> Develop framework for how key drivers and uncertainties about Freedom of Action in Space may shape future policy and technology evolution and implications

Class Exercise

How might Space Policy and Technology Development co-evolve in these Future Space Security Environments and what are implications for SDA?

SPACE SECURITY FUTURES

2035

Fears Realized

- Weak Strategic Offsets
- Weak Governance
- Overt Weaponization
- Limited commercial partnerships

LEO

2035

Global Hopes Realized

- Effective Strategic Offsets
- Strong governance
- Strong public-private partnerships

LEO

2045

Dune (Wild West)

- Weak Governance
- Global ISR
- Competitive and expansive space based industries
  Multiple lunar colonies
- Return from Mars

Cislunar and Beyond

Class Exercise

US Fears Realized

2035

- Single state dominance of cislunar
- Weak or unverifiable strategic offsets to counter-space capabilities
- Weak Governance
- Overt Weaponization
- Limited commercial partnerships

Select Implications for Space Stability

- USG space policies and funding priorities shift with each new administration, while other space actors stays focused on long term strategy for space dominance
- Countries do not align with traditional partners
  - *Would it be every man for selves, how might geopolitical alliances shift (e.g., in response to new economic partnerships to support aspirations Moon and Mars)?*
- Technology standards development dominated by new space actors. Norms and behaviors are frequently violated.
- Increased space congestion and debris.
- Launch vehicles become a order of magnitude cheaper, but commercial space service providers do not give priority to the U.S.
- Limited ability of any one nation to control space technologies to impede rise of rivals or enforce safety.
  - *Example: Russia, China lead conglomerate to drive where technology goes. How would India respond/fit in?*
- Untraceable, ubiquitous access to space-based data products and services.

Class Exercise

Global Hopes Realized

Select Implications for Space Stability

2035

- Effective (strong and credibly demonstrated) strategic offsets to counter-space capabilities
- Strong governance for earth orbital activities but does not preclude weaponization,
- Strong public-private partnerships supporting the national space security enterprises

- New alliances and asymmetric actions by single countries and companies persistently challenge the status quo in space.
- International cooperation limits space congestion, debris, while strengthening deterrence.

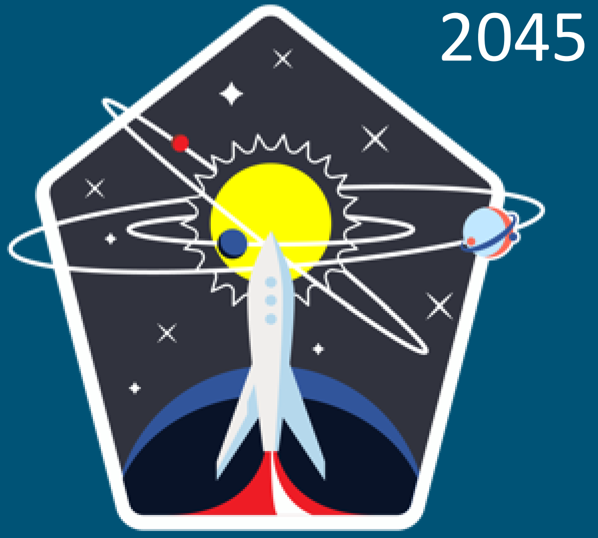
- Challenges to governance structures shifts from geopolitical issues to commercial interests and depend on perceived fairness and effectiveness (cislunar transit, market competition, eminent domain)
  - *Governments share risk with the private sector, increasingly engaging national space forces to protect interests, should governance structures fail.*

- Current space-faring nations and new partners (e.g., Arab states, Latin America) collectively provide global civilian space-based capabilities

- US public –private partnerships advance space nuclear power and propulsion US has a sustained presence in cislunar, deepening and expanding international collaborations.
- Return missions from moon and asteroids accelerate and expand commercial cislunar and Mars races

Class Exercise

DUNE



- Weak governance structures
- Global ISR provided by governments and private entities with limited sharing
- Competitive resource extraction and exploitation
- Multiple lunar colonies
- Sample returns from Mars

Select Implications for National Security

- Freedom of Action erodes in all space domains:
  - *Huge advantage to the first claimants incentivizes aggression*
  - *Multi-national commercial guilds run their own shows:* driving developments and advancements in lunar launch, lander, and habitat technology.
  - *Nation state militaries are strained in space as* no one nation is as advanced as the leading private sector companies.
- Limited government-owned space domain awareness
  - *Competition for resources on earth and in space increases observations needed and challenges SDA resource allocations*
  - *Frequent norms violations and conflicts – especially in cislunar*
  - *Increasing orbital congestion and debris*
  - *Privatized security organizations at remote stations.*
- Autonomous manufacture in space enables huge economies of scale – and provides potential targets.
- Indiscriminate marketing to public and private sectors.
- International tensions between cooperative and competitive goals in cislunar and on Moon, Mars.
- Space operators increasingly rely on machine learning and autonomy for constellation management, creating challenges for safety and security concerns.

Fifteen Minutes

BREAK

Please return on time to break into small groups for class exercise

45 minutes

Class Exercise (Small Groups)

Goal of Module: Apply lessons learned from dynamic co-evolution of space policy and technology to Use Cases and implications for Space Situational Awareness, Space Domain Awareness needs

Instructions for Class Exercise

1. Remind each other who you are and backgrounds (1 minute)
2. Agree on a notetaker and a reporter (2-3 minutes)
3. Read narrative (5 minutes)
4. Discussion questions (15 minutes)
    1. How is utility of space domain affected in this scenario?
    2. What policy and technology developments would be stabilizing to enhance space utility and sustainability and maintain freedom of action?
    3. What is needed from SSA and SDA?
    4. See additional discussion questions in notes
5. Prepare report out (5 minutes)

Class Exercise

Summary of Key Concepts From Historic Analysis

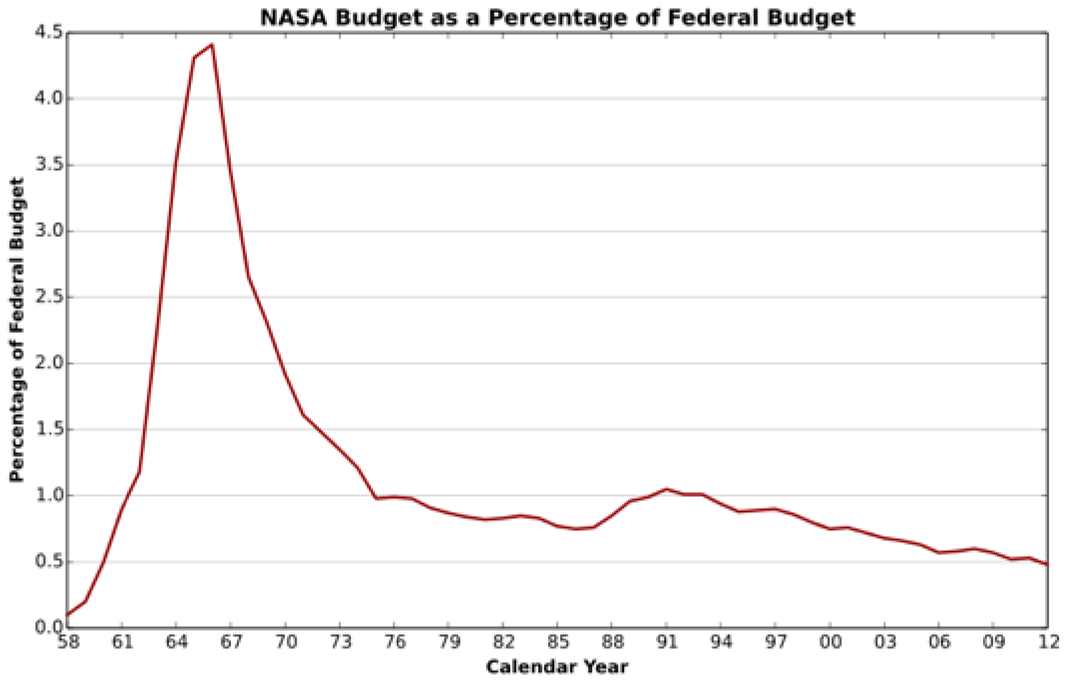
- Territory: If you claim it, you must patrol it and defend it
- Technology developed to increase power projection in one domain can be adapted to other domains
- Convergence of seemingly unrelated technology developments can lead to new capabilities and drive new policies for stability and security
- Perceptions of fairness in governance/policies matter
- Disruptive technologies often developed as strategic offsets to perceived domain advantage of adversary. Some evolve as dual use from onset
- International aspects of sea domain has driven the nature of treaties, conventions and norms with limited success.
- Critical new domain aspects create unique dynamics, paradigm shifts for domain utility, advantage and deterrence…but effective new paradigms take time – more than tech development

Challenges for Balancing Technology and Policy Evolution

Technology development outpaces policy development, changing the strategic environment and stability of the space ecosystem

Democratic governments have difficulty in maintaining long-term public policy and funding priorities (past 4-8 years)

Space is still expensive: difficult to get increases in NASA and other Government budgets



Wikipedia

15 minutes

Large Group Discussion

Goal of Module: Report out from small groups and identify common themes and key take aways

Small Group Report Outs

Common Themes and Key Take Aways

Workshop Feedback

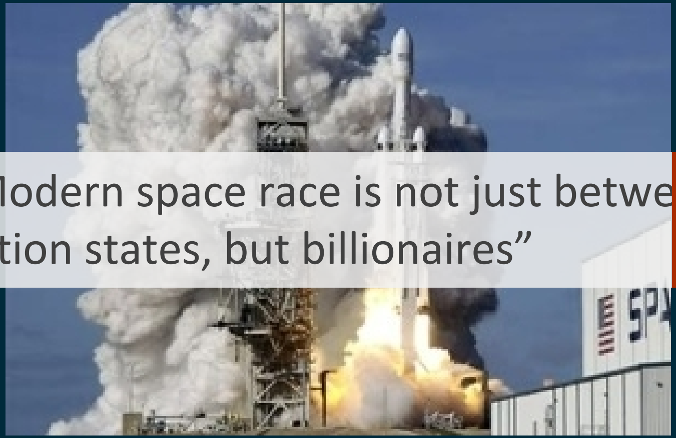
Please fill out course evaluation and submit before you leave!


Thank You!
nkhayde@sandia.gov

BACKUP SLIDES

Space Futures – Overview

"The world looked over the edge of the abyss and chose a different path"



"Modern space race is not just betwe nation states, but billionaires"

Today's Space Race

Sputnik I (1957)

First Space Race

"The space enterprise is engaged in one of the most transformative times in its history"

Future Space Race?

Historical perspective: Dynamics of Commerce, Policy, Technology and Conflict on Land

Earliest humans were hunter/gatherers, then farmers

Lived in clans, tribes, villages and other small units

Early conflicts arose over competition for resources on land

Early conflicts were brutal

- Fought to annihilate
- Kill the men, possibly women and children
- Take their food, animals and other resources, burn what’s left

Rise of city states gave rise to war for women, land and other wealth

- War had no rules
- New technology = better weapons = killing at longer ranges

Historical perspective: Dynamics of Policy, Technology and Conflict on Land

Early limits of war described in Mahabharata and Old Testament, Quran

- Introduced concepts of proportionality, preventing harm to noncombatants, avoiding damage to environment, not to continue attacking the defeated, concept of just war
- Sun Tsu, The Art of War, forbade the killing of prisoners of war

New technologies changed land warfare, and new doctrine evolved

- Cannons make siege operations more effective
- More effective sieges gave rise to maneuver and weapons for mobile fighting

Modern law of land warfare first codified during US civil war

- Protection prisoners, civilians, religious, historical and cultural sites
- War was becoming somewhat more humane

Implementing UN Agencies for Maritime Governance

International maritime governance evolved over time in response to interplay between new players, new technology, new markets and new geopolitics.

- The ***International Maritime Organization*** (IMO) (1948)
  - The IMO sets global standards for the safety, security and environmental performance of international shipping. Its main role is to create a regulatory framework for the shipping industry that universally adopted and implemented.
  - Conventions developed by IMO:
    - **COLREG** (*Convention on the International Regulations for Preventing Collisions at Sea*, 1972)
    - **MARPOL** (*International Convention for the Prevention of Pollution from Ships*, 1973/1978)
      - Integrated environmental issues with the Civil Liability Convention of 1969.
    - **SOLAS** (*International Convention for the Safety of Life at Sea*, 1974)
    - **ISM** (*The International Safety Management Code*, 1993) provides an international standard (including licensing) for the safe management and operation of ships and for pollution prevention.
    - **ISPS** (*The International Ship and Port Facility Security Code*, 2002) includes mandatory requirements to ensure ships and port facilities are secure at all stages during a voyage
  - IMO collaborates with **national authorities** under *Port State Control* agreements that authorize an international inspection system to prevent non-compliance.

The Dynamic Model Applied to the Maritime Domain

Factor	Status Quo	Possible Future	Governance Elements
Int'l & National Policy	• Global supply chains • Increase natural resource supplies • Focus on land/air environment • Reduce CO2 emissions	• Regional supply chains • ISA issues deep sea mining permits • Comprehensive environmental monitoring	• UNCLOS/International Seabed Authority (ISA) • UNCLOS conventions • Regional compacts • National regulation
Disruptive Events	• Chinese claims on S & E China Seas • Chokepoint risk (accidents, conflict) • Increased traffic by large ships • Shift to lower CO2 emissions increases demand for metals	• New Artic shipping routes • New conflict and emergency mgt dynamics • Comprehensive ship status monitoring	• IMO • Regional alliances • Non-Gov't Orgs • UN Tribunal for the Law of the Sea
Technology Capability	• Seabed mining limited < 1600 m in EEZs • Limited ability for deep water environmental monitoring • Current ship designs have significant emissions	• Deep sea mining > EEZs • Environmental monitoring of ocean surface, volume and seabed • Less polluting shipping • Trusted database and reporting systems	• UNCLOS/ISA • MARPOC • National regulation

This example is intended to be illustrative - not comprehensive

Policy, Financial and Economic Trends

COMMERCIAL NEW SPACE LEADERS

SPACEX

BLUE ORIGIN

PLANETARY RESOURCES

Mining Asteroids

Reusable Launch Services

BIGELOW AEROSPACE®

GALACTIC

Habitats in Space

Space Tourism

> "In the same way that every company today is a technology company, the companies of tomorrow will be space companies"

Private Industry

"It used to be a space race between countries, and now it's a space race between billionaires"

Public/Private Financing

"Promote and expand public-private partnerships within space and technology industries to foster transdisciplinary educational achievement in STEM programs, supported by targeted investments in such initiatives"

Commodities

"Striking the right balance between outsourcing and insourcing space commodities needs, and innovating novel procurement strategies that are transparent and accountable, will be key to assuring national security interests terrestrially and in space"

Globalization

"It is important that the U.S. lead in cooperation with our allies. By encouraging joint projects, we can build the common standards and practices that are essential"

Cross-Domain warfare could blur lines between militarization and weaponization

Image Credit: Joint Air Power Competence Centre