COSPAR Roadmap on Small Satellites for Space Science (4S)

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Alan Title

Condensed version of presentation made at
COSPAR 42nd Assembly
Pasadena CA, USA, July 18, 2018

What is 4S?

An international study team of scientific and engineering leaders under the auspices of COSPAR has developed an international scientific roadmap on Small Satellites for Space Science (4S), focusing particularly on CubeSats and CubeSat-technology enabled small satellites. (“Space Science” is intended here to include all scientific disciplines covered by COSPAR, including Earth Sciences.)

This roadmap is aimed at the space agencies, and the governments that support them, and that can implement program or programs in support of the subject matter of the roadmap. It may be useful to broaden the audience to also include industry. The roadmap will be published in *Advances in Space Research,* and published versions will be sent to all major space agencies, and the national representatives to COSPAR.

The beauty of the COSPAR roadmap is that no constraints were placed on the recommendations. The committee did not have a charter rather its role was to produce a vision.

4S Committee

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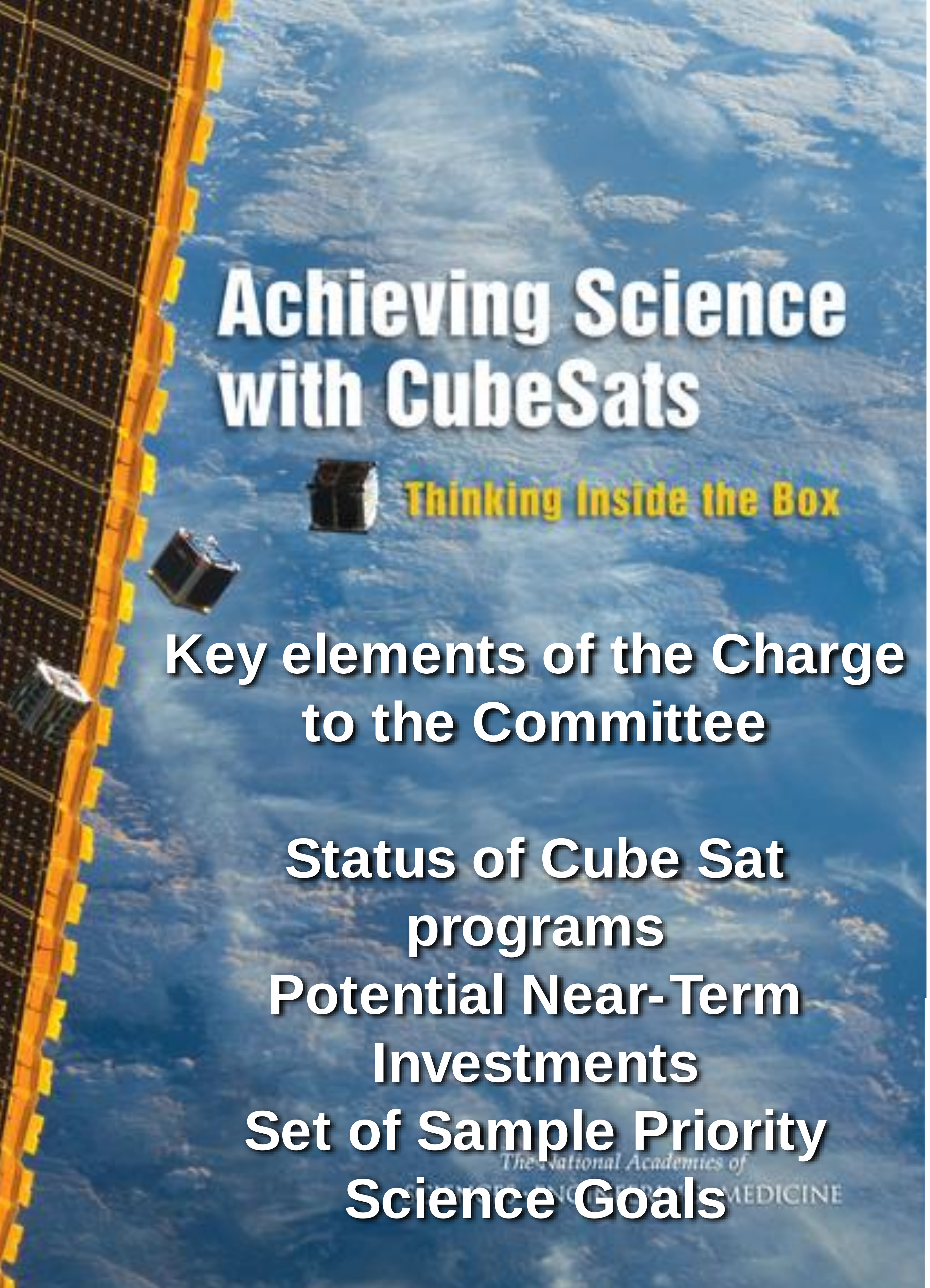
(green: co-chairs)

Foundational Work

The following previous activities laid important and valuable groundwork which could be used and referred to in the COSPAR Roadmap:

- NRC Report *“Achieving Science with CubeSats — Thinking Inside the Box”,* 2016
- NRC Forum *“Performing High-Quality Science on CubeSats”,* January 2016
- IDA Report *“Global Trends in Small Satellites”*, July 2017



Key elements of the Charge to the Committee

Status of Cube Sat programs

Potential Near-Term Investments

Set of Sample Priority Science Goals

IDA

SCIENCE & TECHNOLOGY POLICY INSTITUTE

Global Trends in Small Satellites

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July 2017

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IDA SCIENCE & TECHNOLOGY POLICY INSTITUTE

- *Speed at which enterprise and consumer demand for communication and imagery products/services is materializing.*
- *Rate at which costs of manufacturing and other system costs for constellations are falling*
- *Whether global governmental policies related to spectrum allocation and management and regulations related to SSA and debris are aligned with emerging technologies, and being rolled out at a fast enough rate*
-

4S Contents

For the purpose of this report, the term "small satellite" is somewhat arbitrarily defined to have an upper mass limit in the range of a few hundred kilograms.

Our Motivation

In the first years of the space age decisions were made quickly and programs started and completed just as quickly: The Soviet Union launched the first satellite on 4 October 1957; NASA was formed less than a year later in July 1958; and Project Apollo started in 1961. In the next year, 1962, the NASA Advisory Council asked the Space Studies Board of the National Academy of Sciences (NAS) to produce a set of high-priority objectives for space science. The first Orbiting Solar Observatory (OSO 1) was launched in March 1962.

The unmanned test flight of the huge Saturn V rocket occurred on 9 November 1967; the first manned Saturn V flight occurred on 11 October 1968; the first flight to the Moon started on 21 December 1968; and then the Moon landing quickly followed on 20 July 1969. During the Apollo Project OSO 3, 4, 5, 6, and Skylab were launched.

We can do this now!

The FCC has approved launches by:

SpaceX for 4,425 satellites in ~ 1,200 km orbits

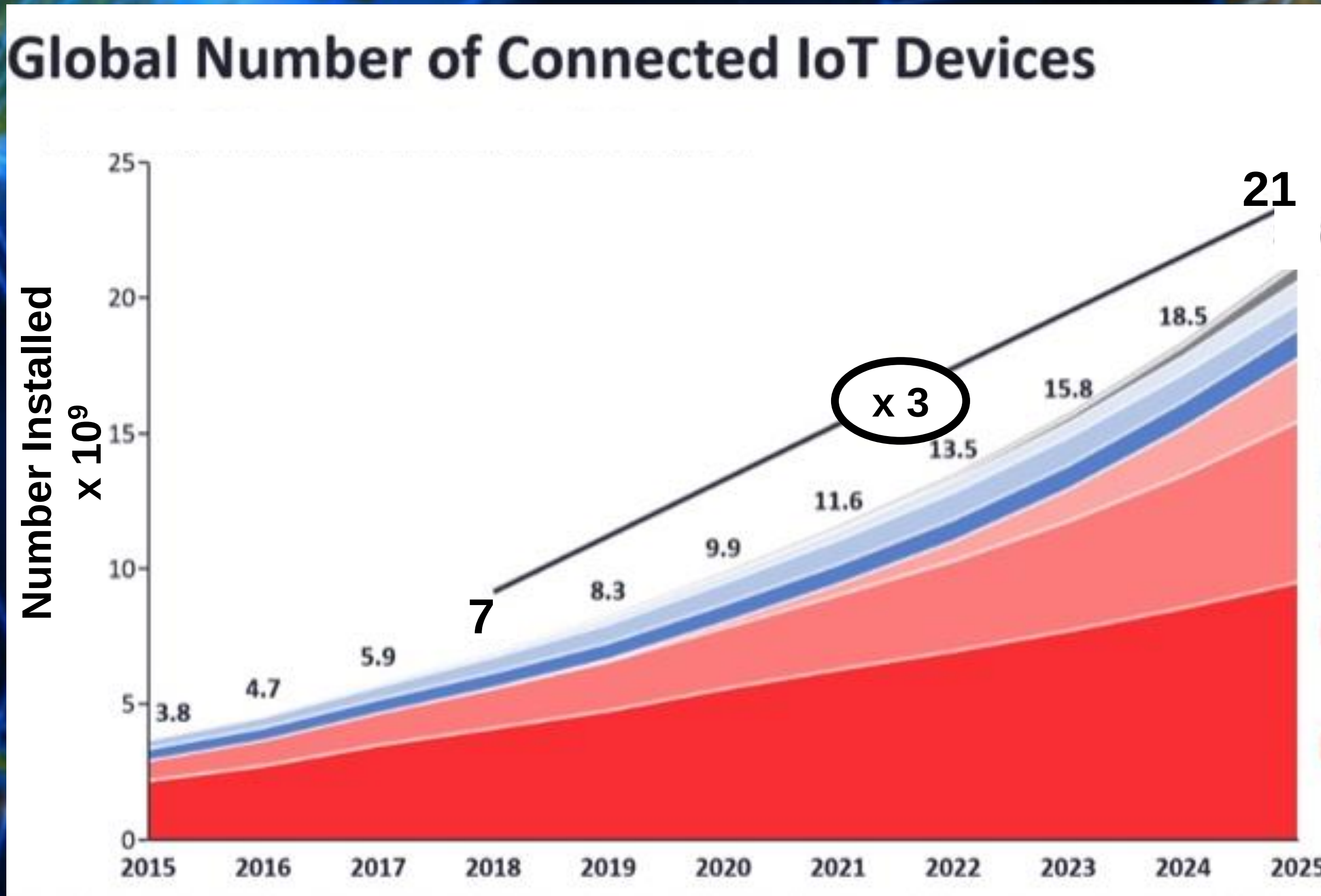
And 7,518 in ~ 340 km orbits

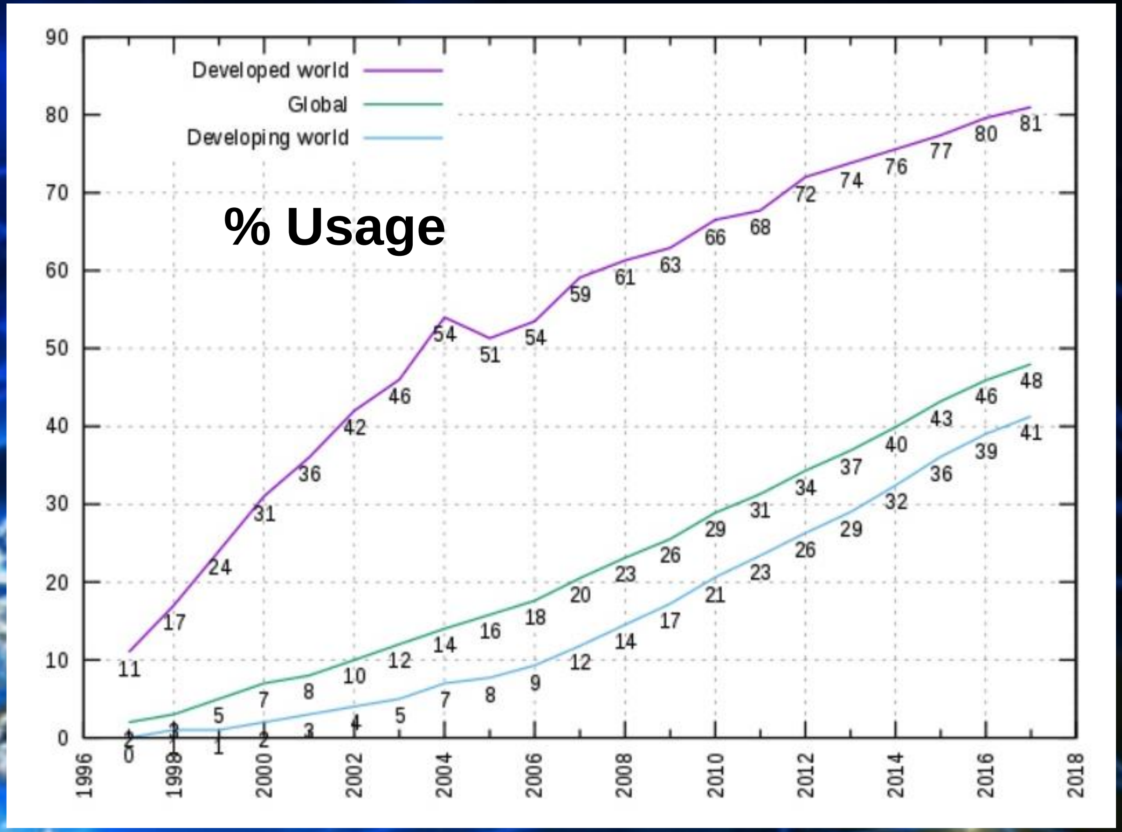
Keppler Communications 140

Telesat 117

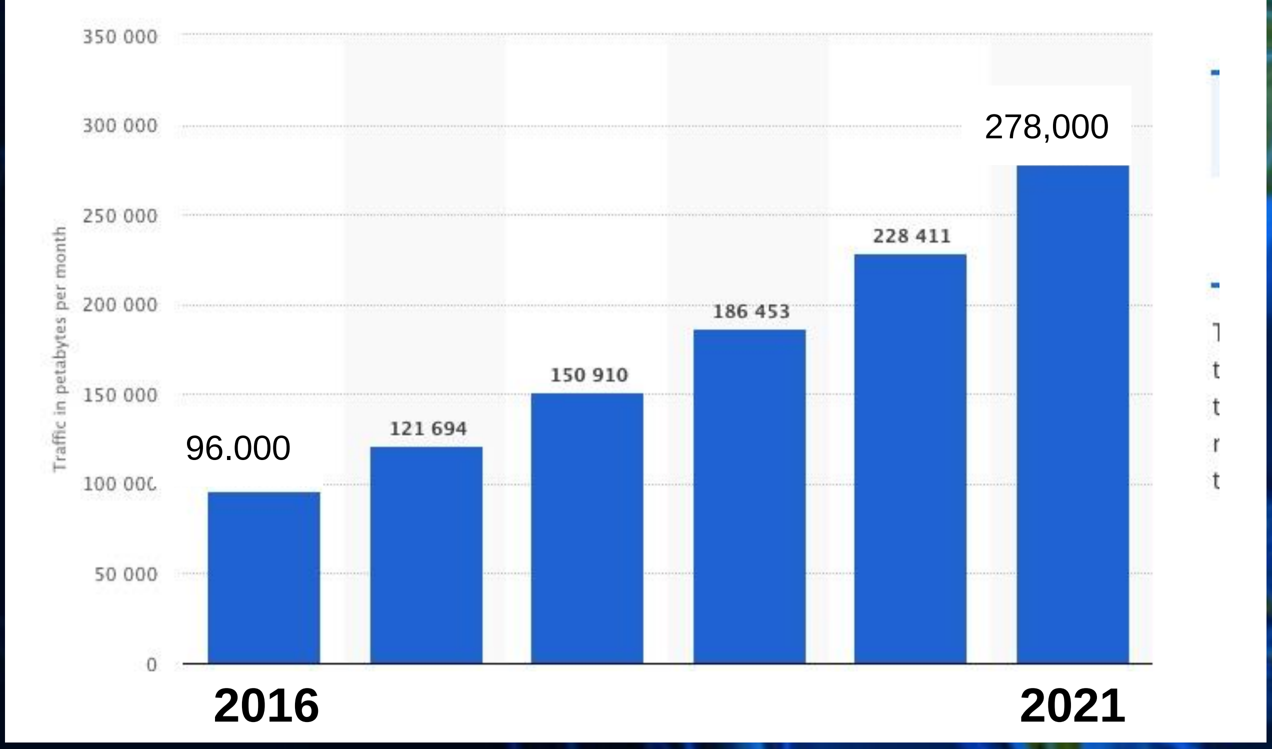
LeoSat 78

Airbus has ~1000 in production





Global IP Traffic -Petabytes/month



Recommendations

Report makes five recommendations to:

- the science community
- space industry
- space agencies
- policy makers
- COSPAR

Recommendations

Recommendation 1 - To the science community:

The science community as a whole should acknowledge the usefulness of small satellites and look for opportunities to leverage developments in the small satellite industry. All branches of ***space science can potentially benefit from the smaller envelope, the associated lower cost, and higher repeat rate.*** Scientific communities from small countries in particular may benefit from investing their budgets in small satellites.

Recommendation 2 - To space industry:

Satellite developers should seek out opportunities to partner with individual scientists and universities as well as larger government agencies. This might include data sharing arrangements, selling space on commercial spacecraft for scientific instruments, etc. Currently, publicly available operational data is very valuable for achieving science objectives. ***Commercial entities should be open to agreements that would continue to make such data available under a free/full/open data policy for scientific use.*** Such partnerships can also contribute to workforce development.

Recommendations

Recommendation 3 - To space agencies:

Large space agencies should adopt procedures and processes that are appropriate to the scale of the project. If this is not possible within existing structures, agencies should find new ways to provide opportunities for science, applications, and technology demonstrations based on small satellites and with ambitious time to launch. Agencies should additionally take advantage of commercial data or commercial infrastructure for doing science in a manner that preserves open data policies***. Finally, space agencies should work together to create long-term roadmaps that outline priorities for future international missions involving small satellites.***

Recommendation 4 - To policy makers:

In order for scientific small satellites to succeed, the scientific community needs support from policy makers to: (1) ensure adequate access to spectrum, orbital debris mitigation and remediation options, and affordable launch and other infrastructure services; (2) ensure that export control guidelines are easier to understand and interpret, and establish a balance between national security and scientific interests; (3) provide education and guidance on national and international regulations related to access to spectrum, maneuverability, trackability, and end-of-life disposal of small satellites.

Recommendations

Recommendation 5 - To COSPAR:

COSPAR should facilitate a process whereby International Teams can come together to define science goals and rules for a QB50-like, modular, international small satellite constellation. Through an activity like e.g. the International Geophysical Year in 1957-1958 (IGY), participants would agree on the ground rules. Agency or national representatives should be involved from the beginning. ***The funding would come from the individual participating member states for their individual contributions, or even from private entities or foundations.*** The ***role of COSPAR is one of an honest broker***, coordinating, not funding. COSPAR should define criteria that must be met by these international teams for proposing.

The results of such an international effort would be valuable for all of the participants, and be more valuable than the individual parts. COSPAR would create a precedent for setting up community science in a very open way. The incentive for participants would be to be part of a worldwide project with access to data of the entire consortium. ***This recommendation is a means to facilitate progress towards really big ideas such as our four Visions for the Future or similar ideas.***

1.1 Current Status of Small Satellites and Cubesats

- 800 CubeSats launched so far (~400 of these by Spire and Planet since 2014). Less than 100 of these are for science.
- Approximately half of *scientific* CubeSats were launched since early 2017, including 36 which are part of the QB50 constellation

Finding 1.1 — ***Small satellites across the full spectrum of sizes,*** from CubeSats to ~300 kg micro-satellites, have enabled ***important scientific advancements*** across the space sciences.

Finding 1.2 — ***Small satellites, particularly CubeSats, have enabled access to space for more nations*****,** and have provided opportunities for countries with new or small space programs to participate in much larger international projects.

Finding 1.3 — The emergence of ***CubeSats has resulted in a significant increase in launch rate.*** However, t**he *launch rate of larger, traditional small satellites has decreased*** in the past few decades, and the development time and cost have ***increased.***

1.1 Current Status of Small Satellites and Cubesats

- An early limitation was lack of launch opportunities.
- Commercialization is changing the way small satellites are built.
- Availability of COTS parts and subsystems has the potential to significantly reduce cost of science missions.

Finding 1.4 — The ***rapid increase in CubeSat launch rate*** can be attributed to standardization which increases ***rideshare opportunities***, cost reduction due to availability of ***COTS parts***, and an explosion of their use in ***the private sector.***

Finding 1.5 —The cost effectiveness of increased rideshare opportunities and larger launchers, in combination with smaller spacecraft and low cost COTS parts h***as already enabled large constellations,*** e.g. QB-50 and Planet, opening up ***new opportunities for science.***

Finding 1.6 —***The science community has not yet fully capitalized on advances in technology or the increased activity in the commercial sector*** in order to reduce the cost or development times of traditional small satellites. A ***lack of frequent flight opportunities persists,*** potentially ***discouraging innovation*** by sponsoring agencies and scientists.

Visions for the Future

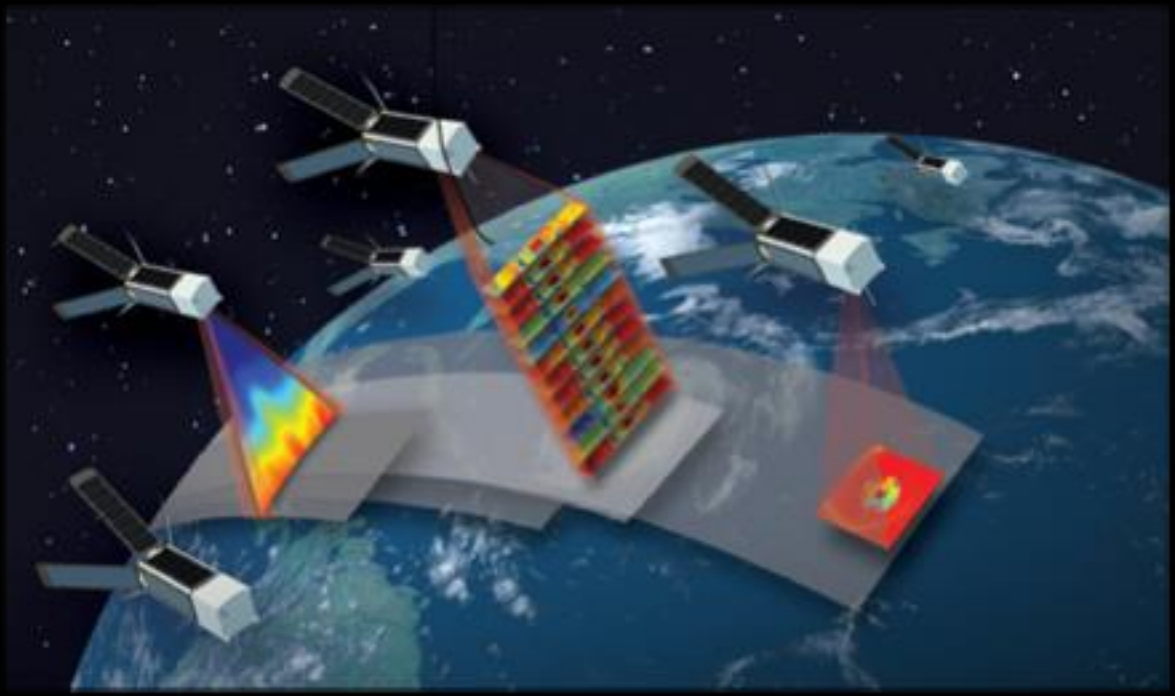
- Four vision missions focus the discussion of the Roadmap.
- These represent missions that are out of reach with current technology, in some cases for several decades.

  - ✦ ***Large Constellations for Earth Observation***
  - ✦ ***Swarm Exploration of a Solar System Body***
  - ✦ ***Small Satellite Synthetic Aperture Telescope***
  - ✦ ***Interstellar Mission***

2.1 Vision: Global Earth Monitoring System

- ***Long term goal: spatial resolution, time resolution, areal coverage well matched to the problems under investigation for monitoring of the Earth and space environment***
- Advantages over current data
  - Many local times (not possible with Sun sync on one orbit)
  - High resolution (hard from Geostationary)
  - Multiple look directions on same point simultaneously
  - Multi-point measurements of space environment, e.g. ionosphere
- Smallsats offer the prospect of large constellation missions
  - Current example: Planet Labs; Future: OneWeb, SpaceX
- A opportunity for scientific/monitoring missions carried on commercial constellations
- Requires development of new approaches to converting measurements to >>>

2.1 Small Satellites for Earth Observation



Cyclone Global Navigation Satellite System (CYGNSS): Eight 28-kg SmallSats to track and study tropical cyclones (NASA, U Michigan)

Launched 15-Dec-16

Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS): Constellation of 3U CubeSats with 12-channel radiometry and a revisit rate of 30 minutes (NASA, MIT)

Launch >= 2020

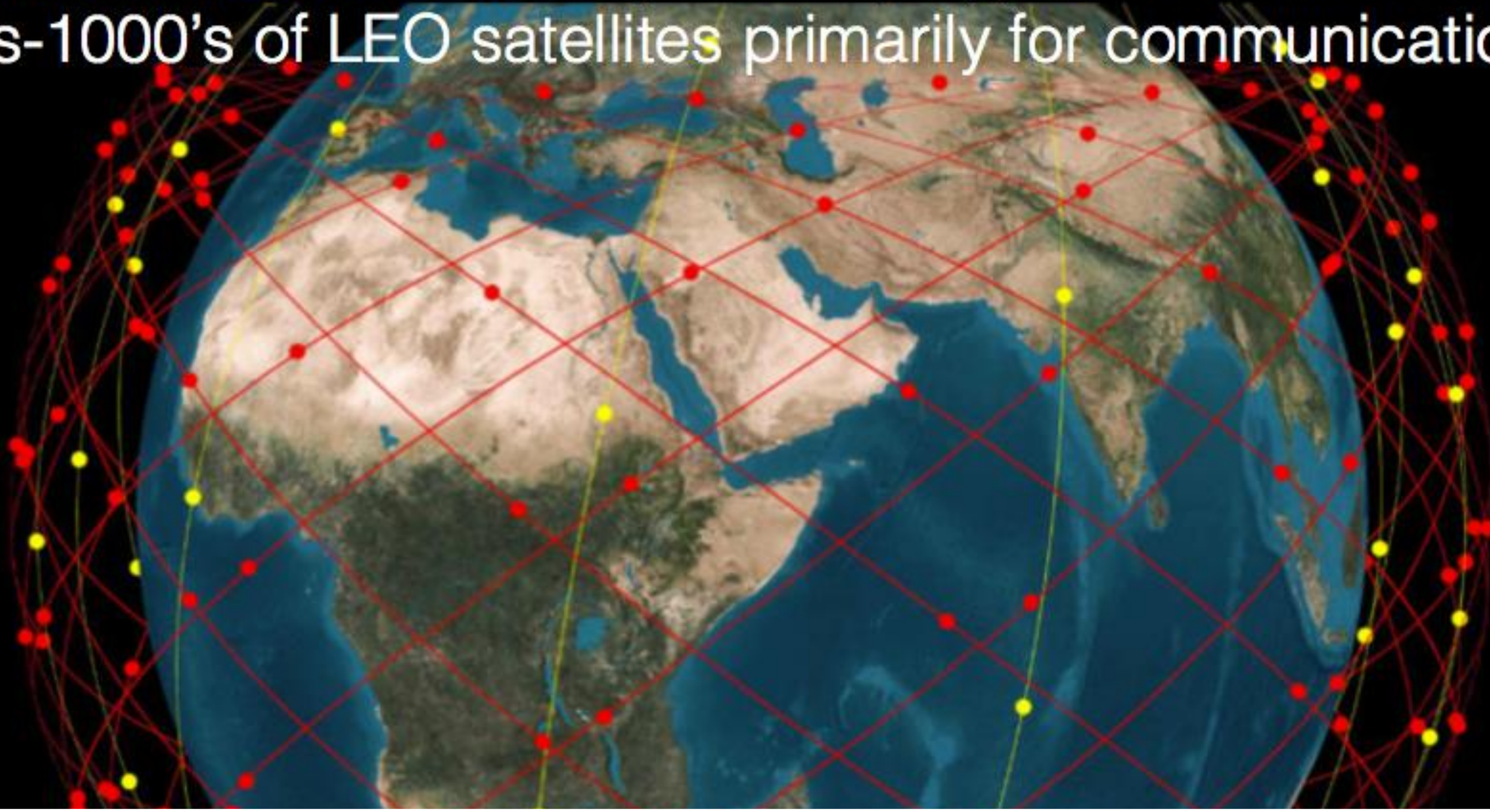
2.1 Small Satellites for Earth Observation

ESA SWARM mission: 3 satellites totalling < 500 kg, launched Nov. 2013

Enabling a unique view inside the Earth core dynamics, the magnetism of the lithosphere and its geological context and study the Sun’s influence on Earth system.

2.1 Vision: Global Earth Monitoring System

Commercial sector: already developing constellations of 100’s-1000’s of LEO satellites primarily for communications



Finding 2.1 - Due to the increasing number of small satellites, higher revisit frequencies are possible, which will increase the number of measurements. In the long run, a fillet of thousands of networked EO satellites will allow uses and applications of enormous scientific and societal impact.

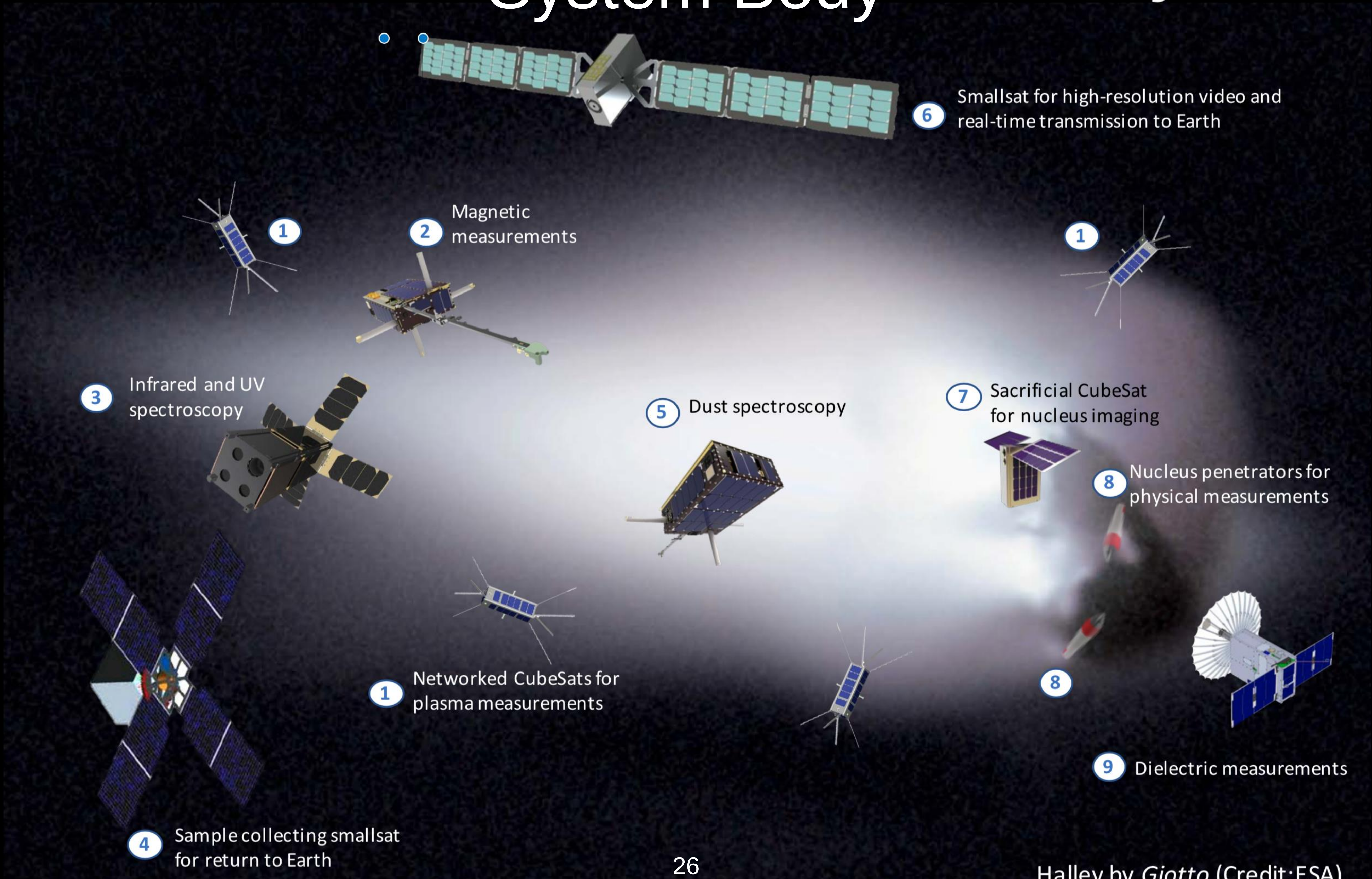
2.2 Swarm Exploration of a Solar System Body

- Target planetary objects with long period orbits
  - Bodies that visit the inner solar system once in a lifetime
  - Oort Cloud comets such as Halley's comet returning in 2061
  - Interstellar visitors such as the recently discovered 'Oumuamua'
- Constellation enables contributions from many different countries
  - Also allows participation from students and professionals at once
- Mission Concept
  - Fly an armada of CubeSats/SmallSats of various flavors
  - Uses ESPA-ring or other large spacecraft as carrier and telecom relay

Finding 2.2 - Small satellites provide opportunities to significantly enhance infrequent interplanetary mission with, e.g., landers sacrificial satellites

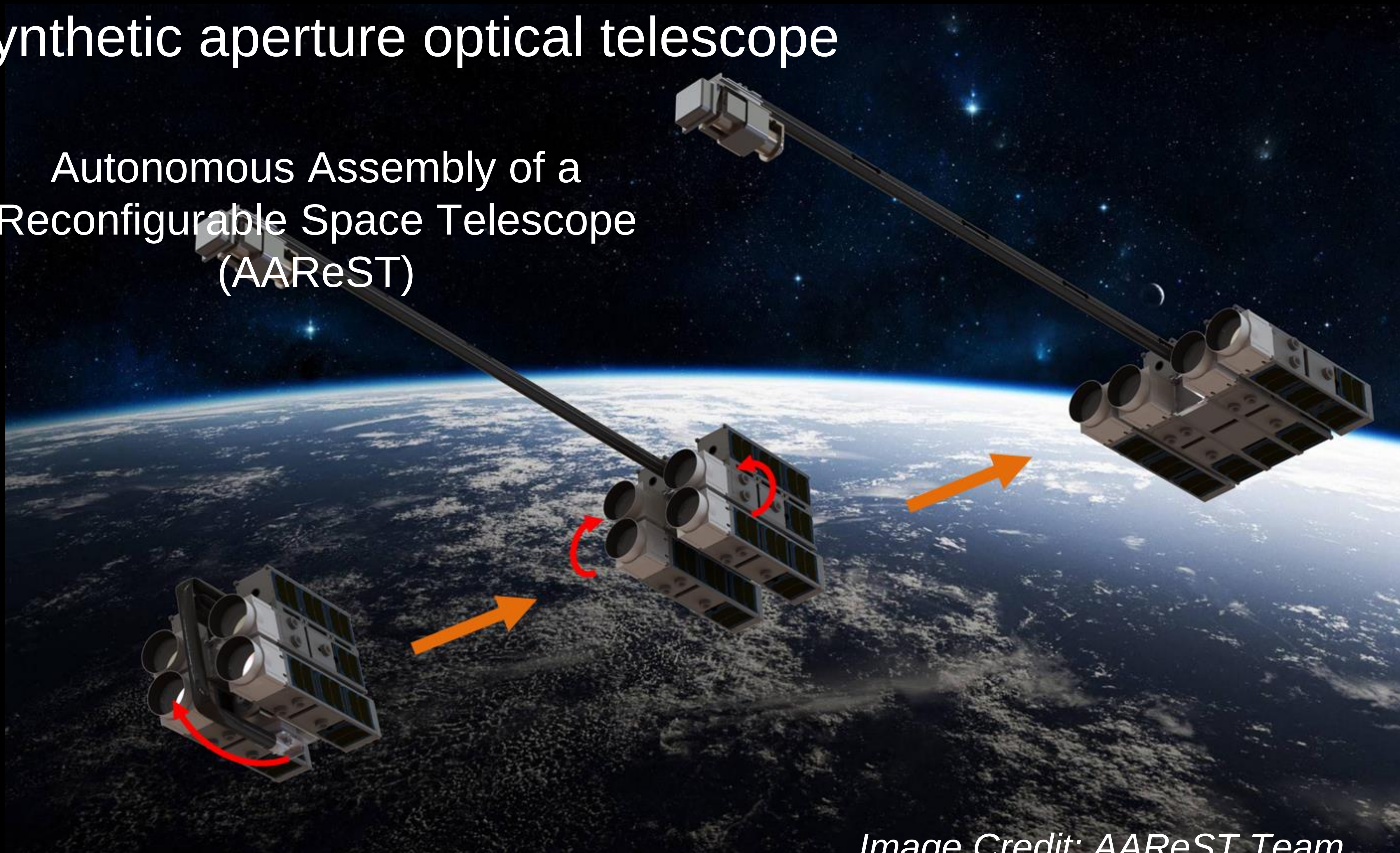
Artist: ESO/M. Kornmesser (original)
Derivative: nagualdesign

2.2 Swarm Exploration of a Solar System Body



Interferometers in Space

Synthetic aperture optical telescope



Finding 2.3 - Monolithic large telescopes in space cannot grow further after JWST. A new approach with distributed aperture on small telescopes in needed to make further progress.

2.3 Synthetic Aperture Optical Telescope

- 2017 NASA study: SunRISE (Sun Radio Interferometer Space Experiment) will consist of a constellation of cubesats operating as a synthetic aperture *radio* telescope to address the critical heliophysics problems (PI Justin Kasper)
- Optical equivalent will need small boards with atomic clocks, laser communication between satellites, orbit control to optical wavelengths.
- At present several 35 cm optical telescopes are operational in 600 km orbits, mass 120 kg, cost ~350 k$, which may drop to 50 k$ in ~5 years.
- 640 of these have the aperture equivalent of a 10 meter telescope, cost 32 M$; launch would cost another ~100 M$.
- Thus a diffraction limited 10 meter telescope might be in space for on the order of 200 M$.

Interferometers in Space

Synthetic aperture optical telescope

Sun Radio Imaging Space Experiment
(SunRISE)

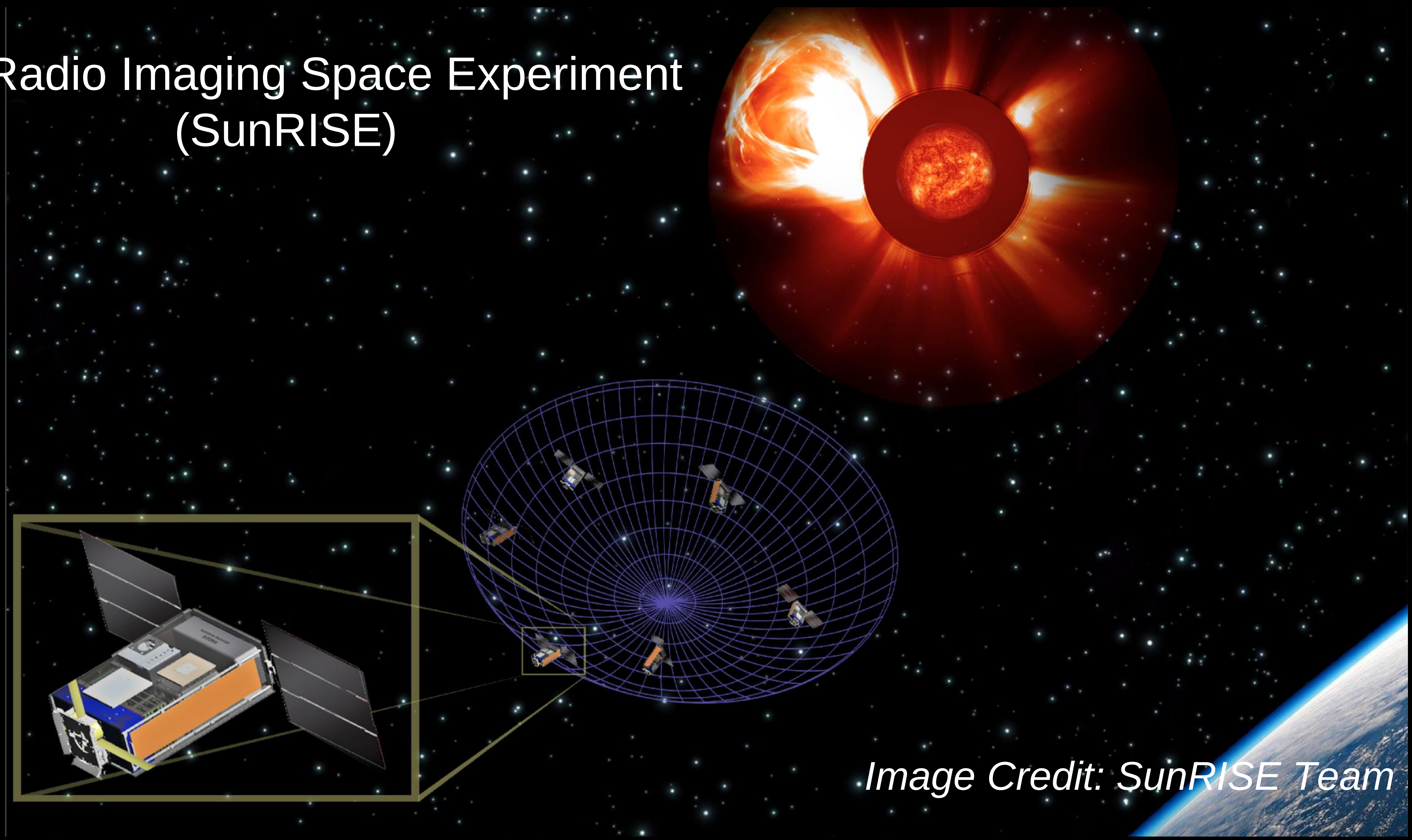


Image Credit: SunRISE Team

A Visit to Alpha Centauri

Image Credit: Kevin Gill, Nashua, NH

Finding 2.4 - Engaging in small satellites enables achievement of exciting visionary goals such as the four vision discussed in the Roadmap.

3.1 Role of Agencies and Industry

- ***Government agencies*** have critical roles to play in:
  - supporting utilization of small satellites
  - enable ***frequent consolidated launch opportunities*** for small satellites
  - promoting ***policies that do not hinder innovation*** in the small satellite realm
  - setting standards (mindful that tight standardization can hinder technological advances)
  - leading and participating in multi-national collaborations
- ***Industry*** has critical roles to play in:
  - develop ***special components and custom software (***e.g. Clyde Space and Blue Canyon)
  - begin to ***manufacture thousands of Small Sats*** to implement a worldwide internet — ***"A Cable in Space"***
  - be open to commercial data buy, ***ride shares***

3.2 Role of Policies

Finding 3.5 - ***Spectrum access*** (for data transmission to Earth as well as accessing frequencies in bands for research) ***is critical*** for an activity in space, and a scarce resource.

Finding 3.6 - The ***undue burden of complying*** with law and regulations related to ***international exchange*** and collaboration are a ***deterrent to scientific collaboration***.

Finding 3.7 ***Low-cost launch***, through easy access to ride share options, has been an ***enabler of smallest driven science.***

Finding 3.8 - As traffic in space (especially in low Earth orbit) increases growing ***restrictions on small satellite operators***, including for science, is likely. Regulations are likely to be related to ***tracking in space, maneuverability , and orbital debris*** mitigation.

3.3 Models of International Collaboration and Exchange

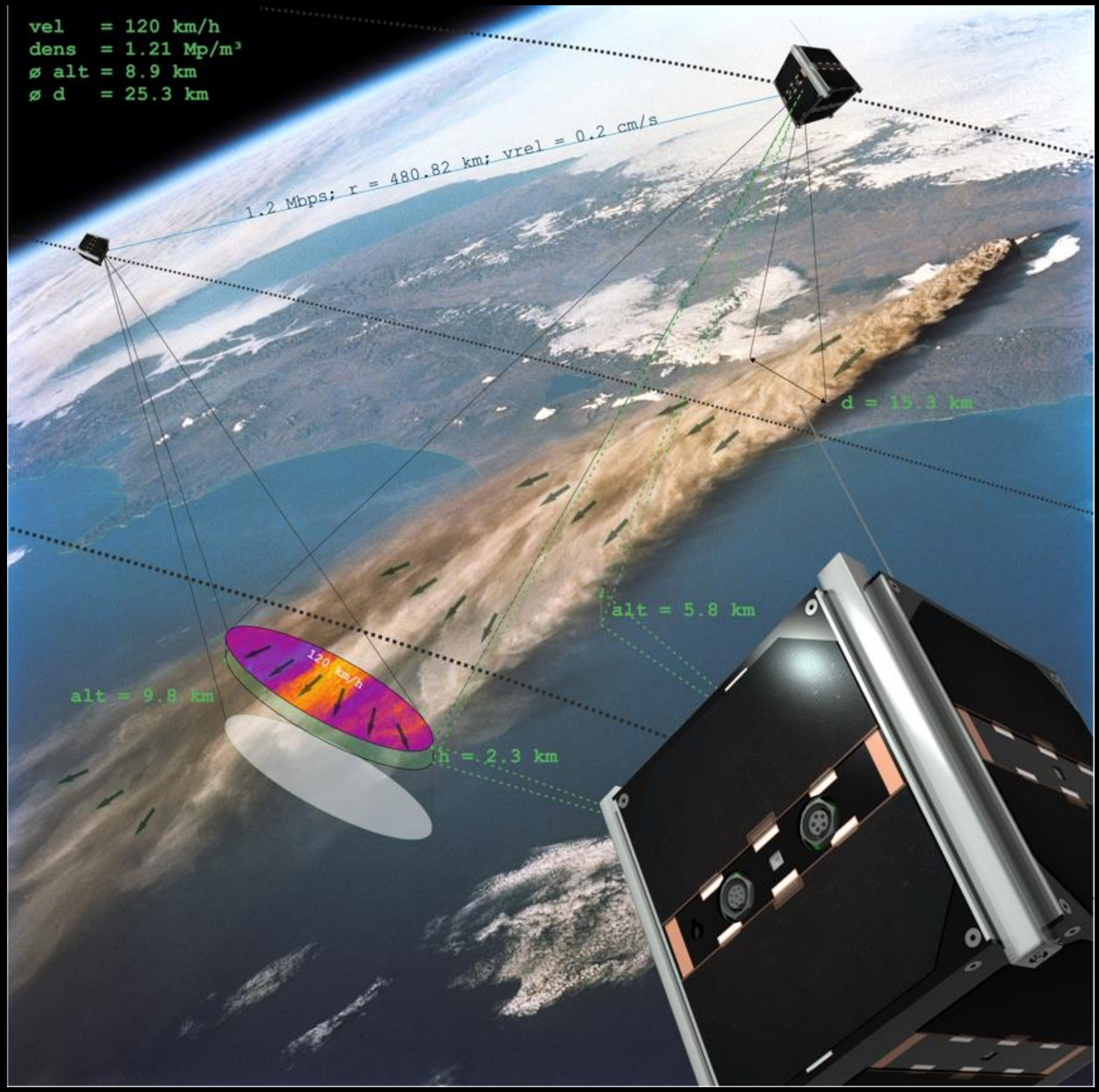
Finding 3.9 - COSPAR as the first and most authoritative international space organization is in a good position to support the international community in the creation and coordination of an infrastructure or tools for a global and even deep-space networks of small satellites to which anyone can contribute in a well-defined format and interface, thus creating a virtual constellations from all contributions of all that will by far exceed what the individual participants could do by themselves.

3.3 Models of International Collaboration and Exchange

- SpaceMaster: a joint international MSc program initiated in 2005 and supported by six European Universities

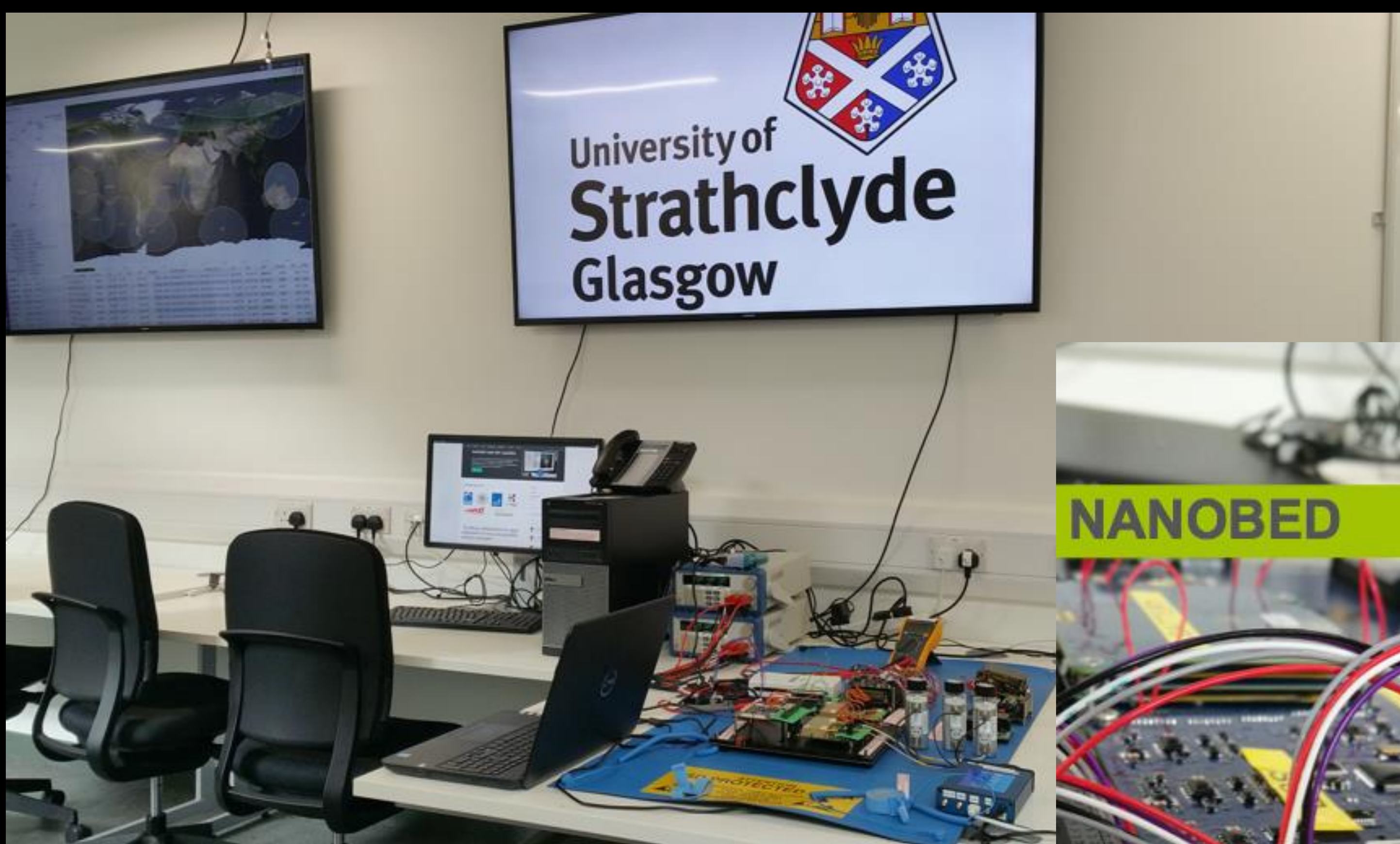
- GENSO (Global Educational Network for Satellite Operation), lead by ESA, an early (2007) attempt to share ground station resources between universities

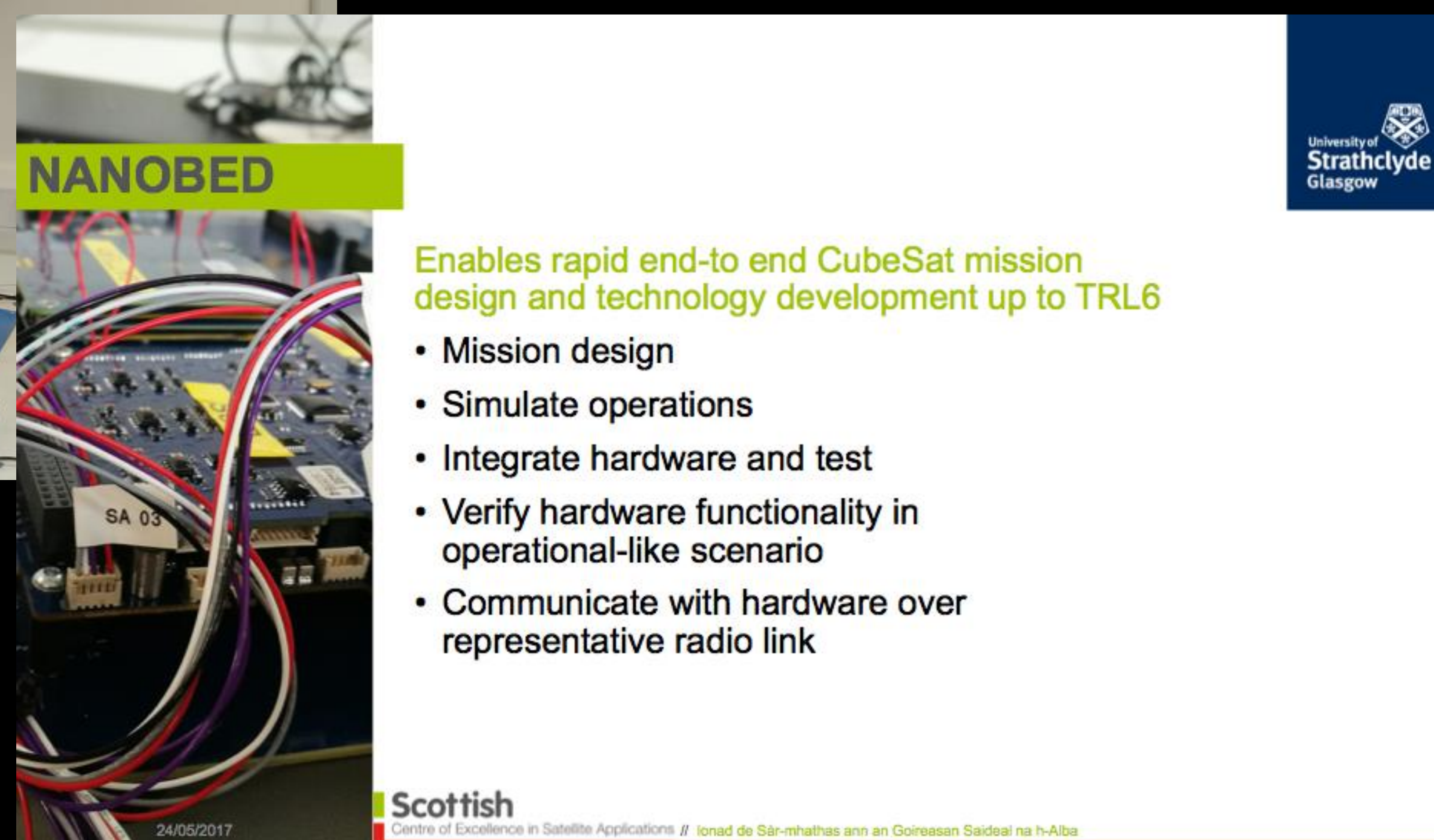
- TIM (Telematics International Mission) is an example for the cooperation of partners contributing satellites to a formation to benefit from a larger database generated.



3.3 Models of International Collaboration and Exchange

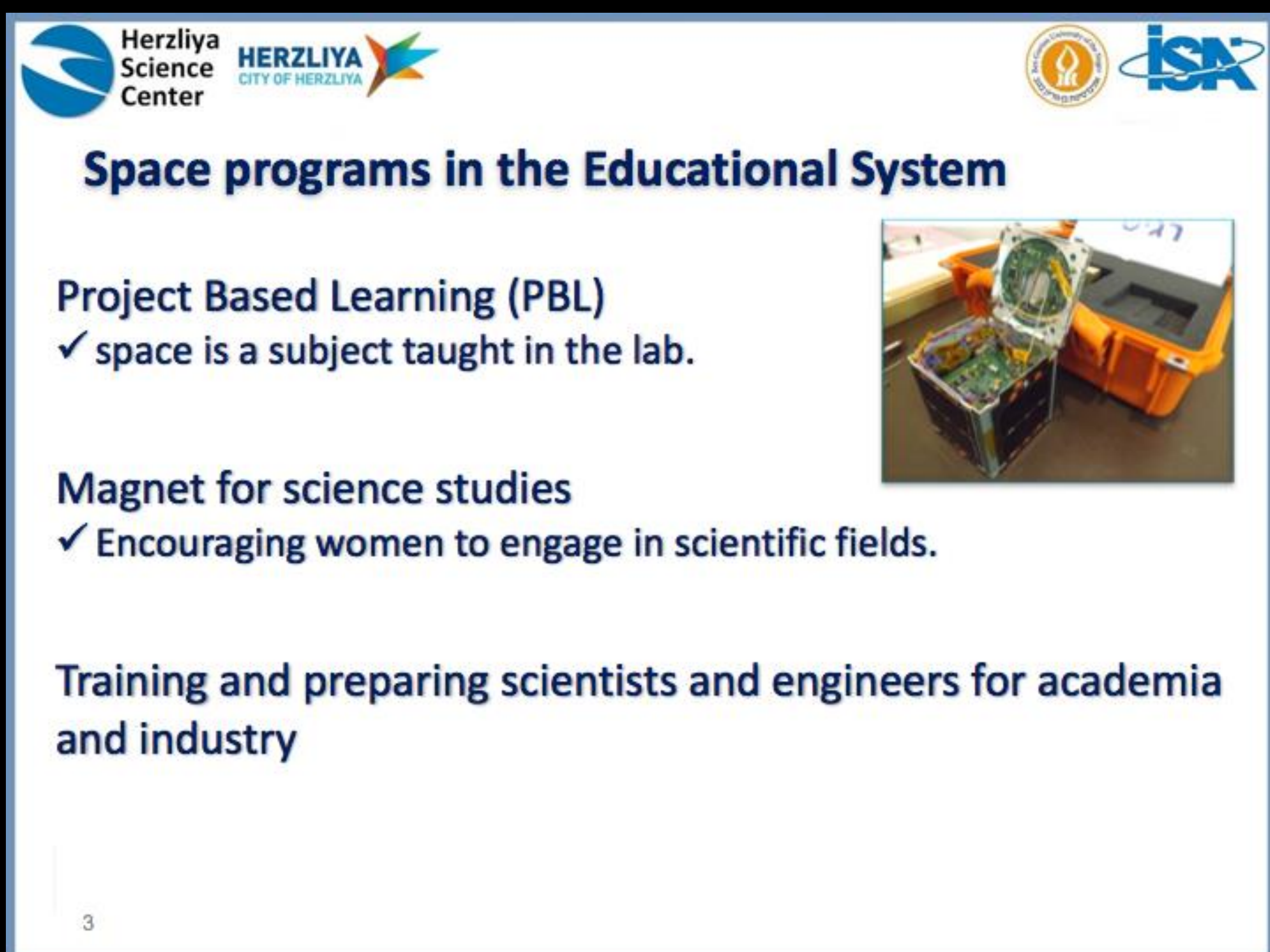
- University of Strathclyde: Nanobed

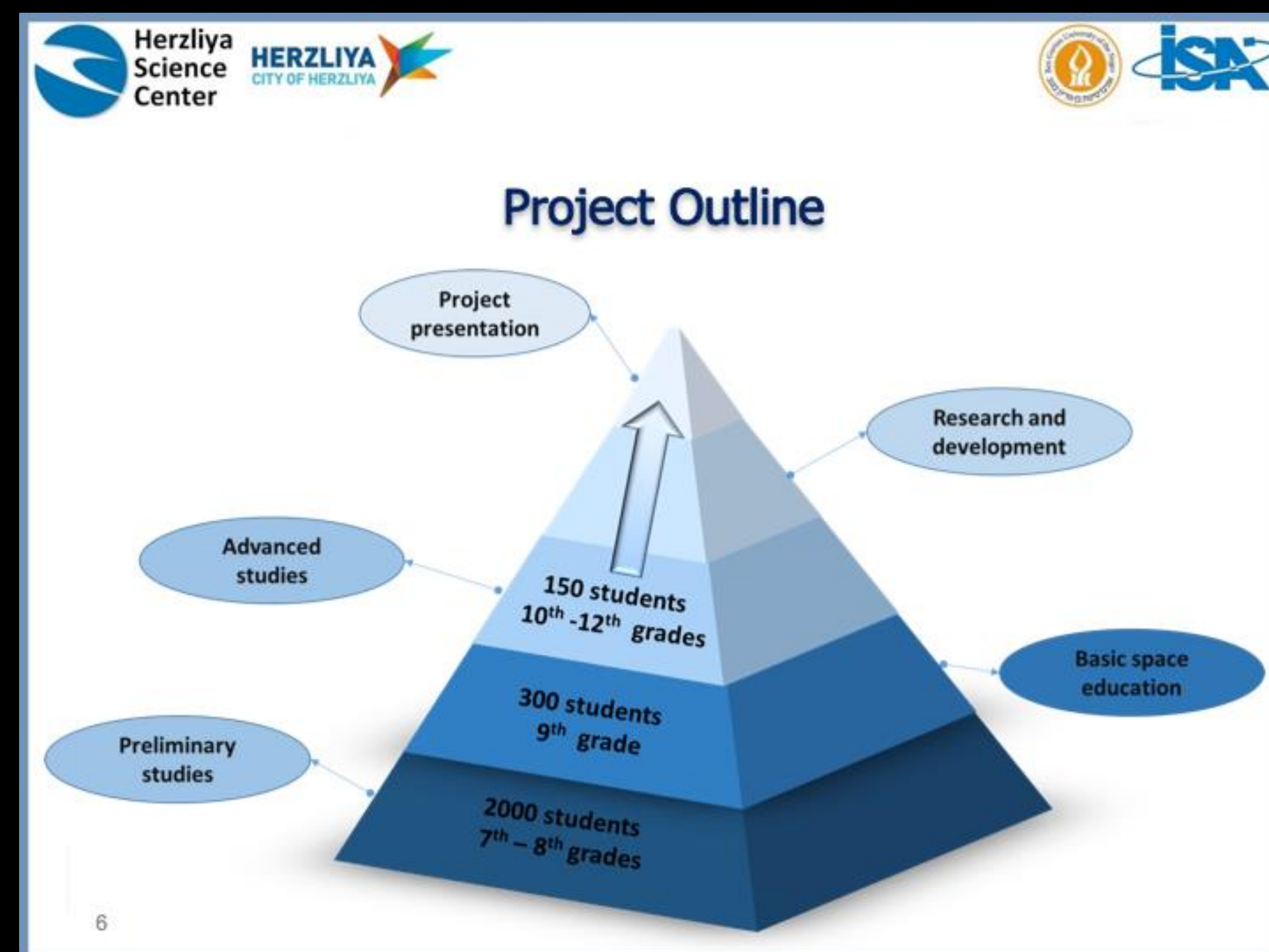




3.3 Models of International Collaboration and Exchange

- Duchifat, a CubeSat-based program in the Israeli secondary education system that involves students aged 12-18 years.





Current Status

- The Roadmap document is completed.
- It has been formally submitted to *Advances in Space Research* in the next couple of weeks.
- After the review and revision cycle it will hopefully be published before the end of the year.
- The Roadmap Committee will actively disseminate and publicize the final paper.

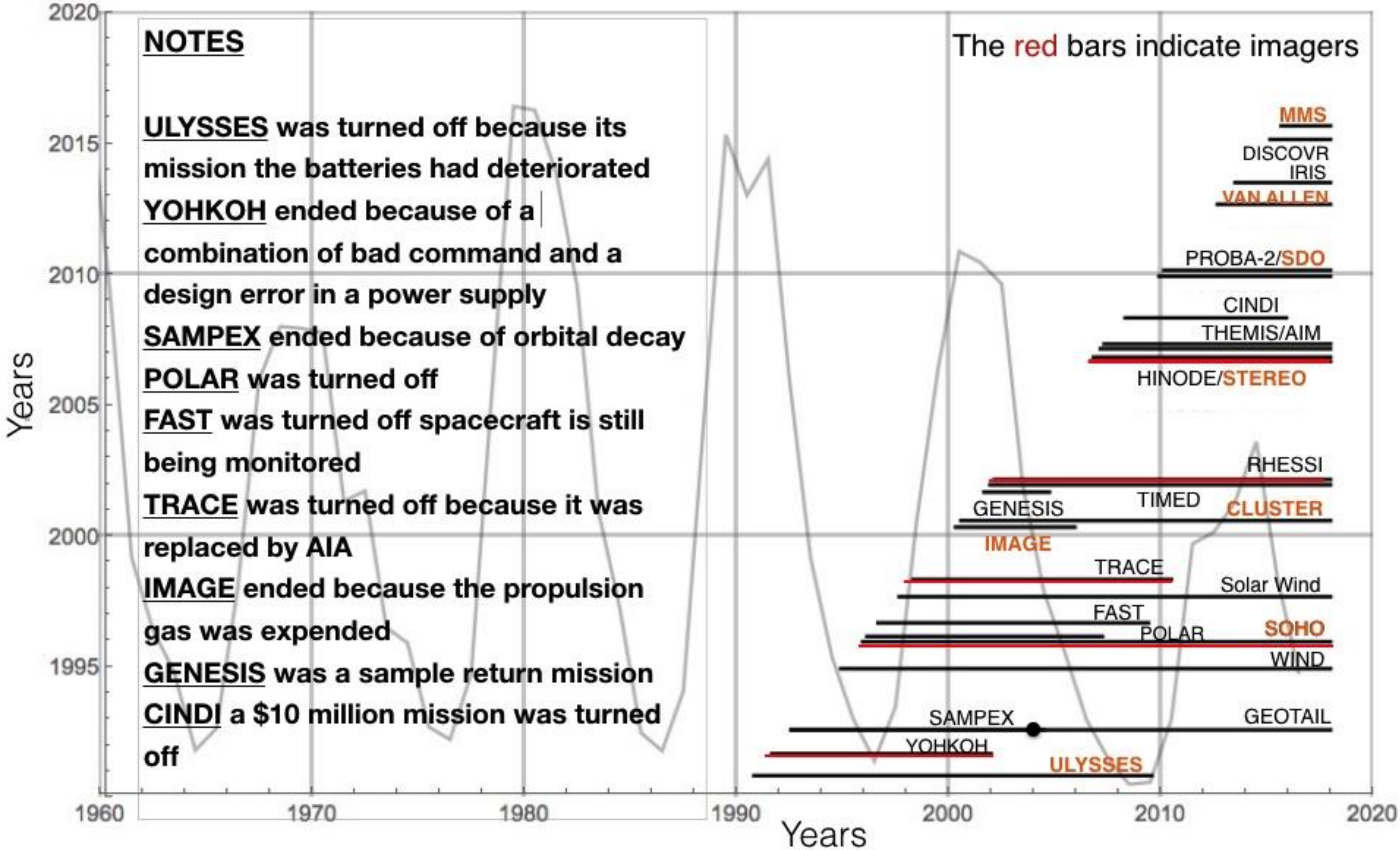
Background Slides

MUSE is One of 5 Missions Selected in the Latest NASA SMEX AO

The schedule below shows will it be 7 years before any scientist sees any data from this mission.

This assumes projected funding and that after the site visit MUSE is selected to be the first mission to fly.

Solar and Heliophysics Missions Launched by NASA, ESA, and ISAS/JAXA from 1990 to Present

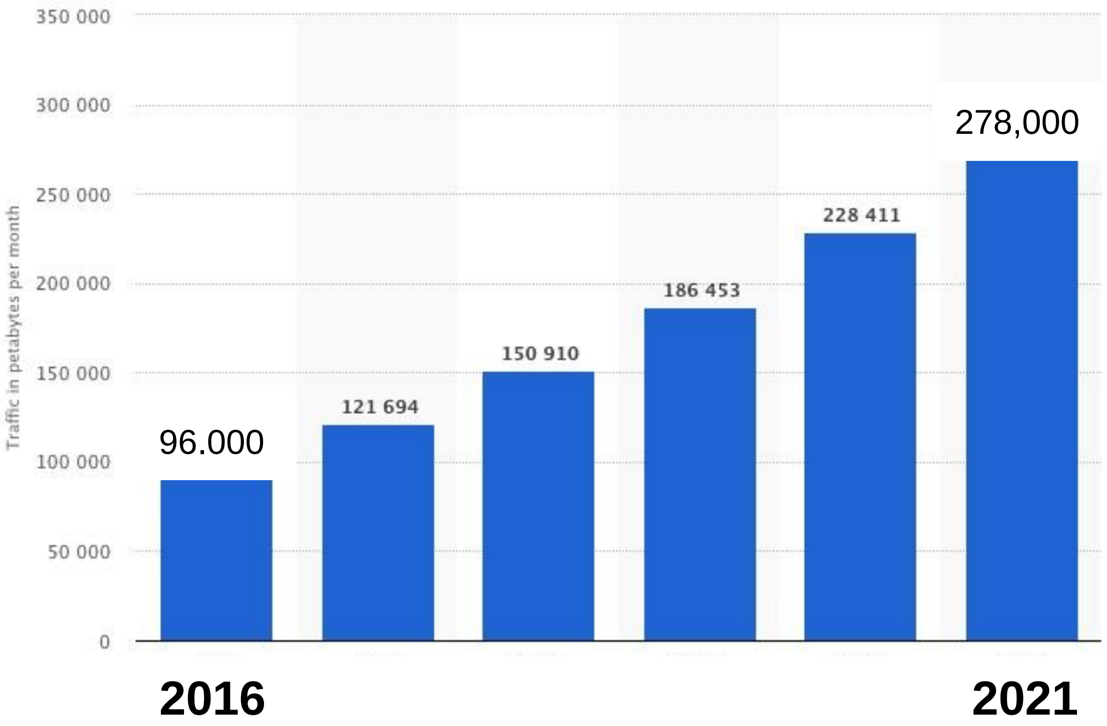


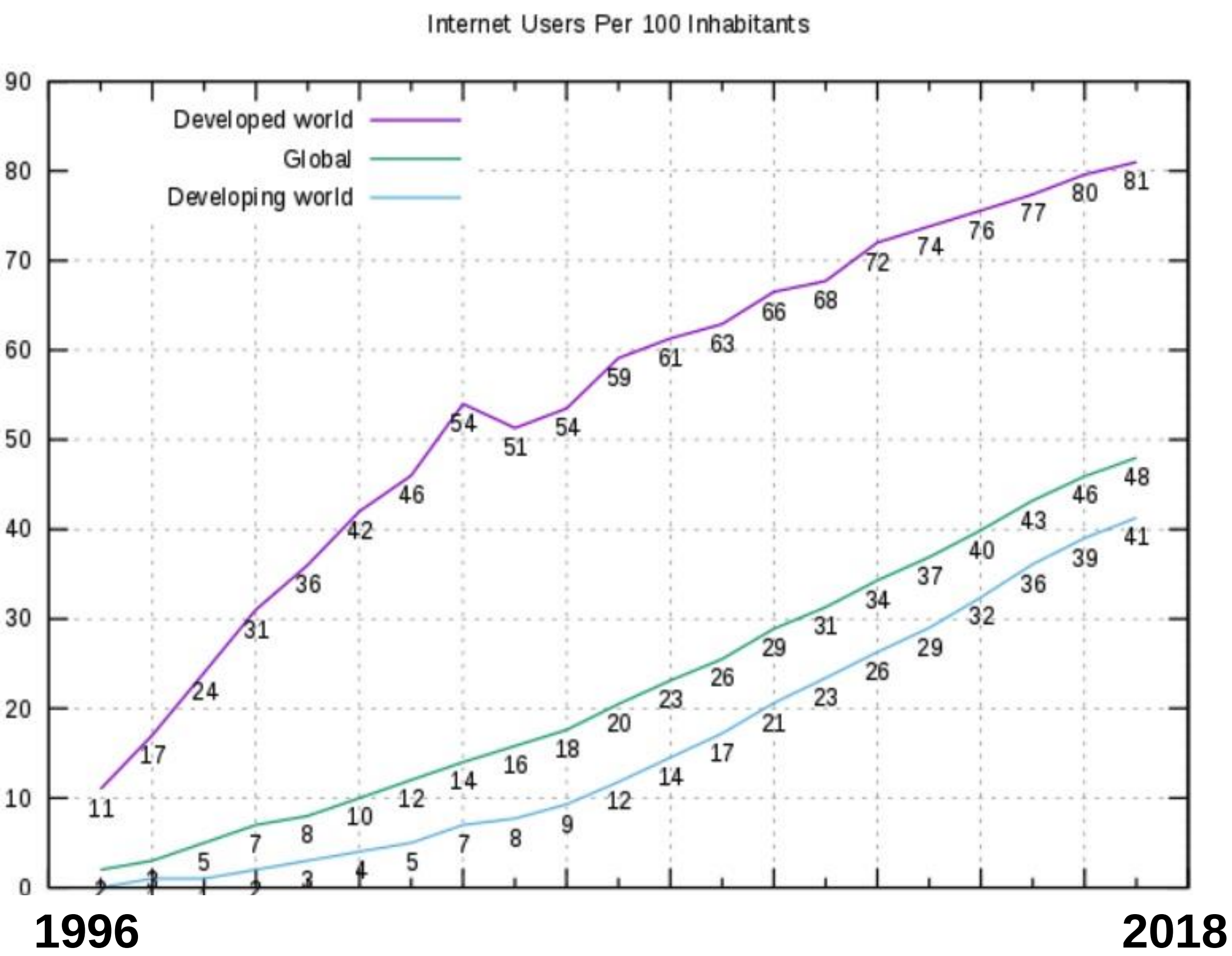
Mission Names in **orange** text are judged to be class A or B, all the others are class D or Lower

Economic Background
Monetization of Internet

- Economic Value - $1.5 Trillion (2017) to $ 4.5 Trillion (2021)

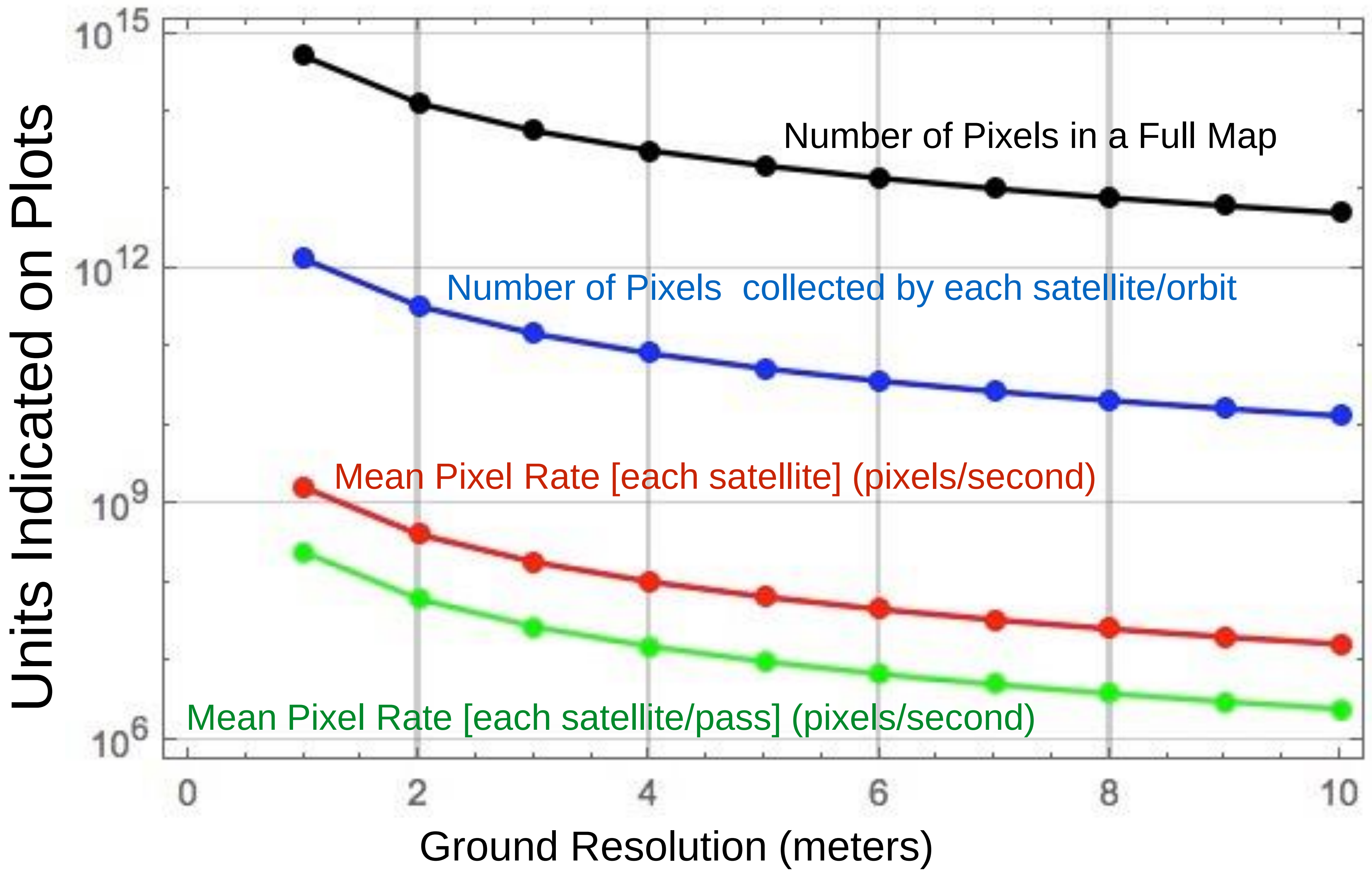
Global IP Traffic -Petabytes/month





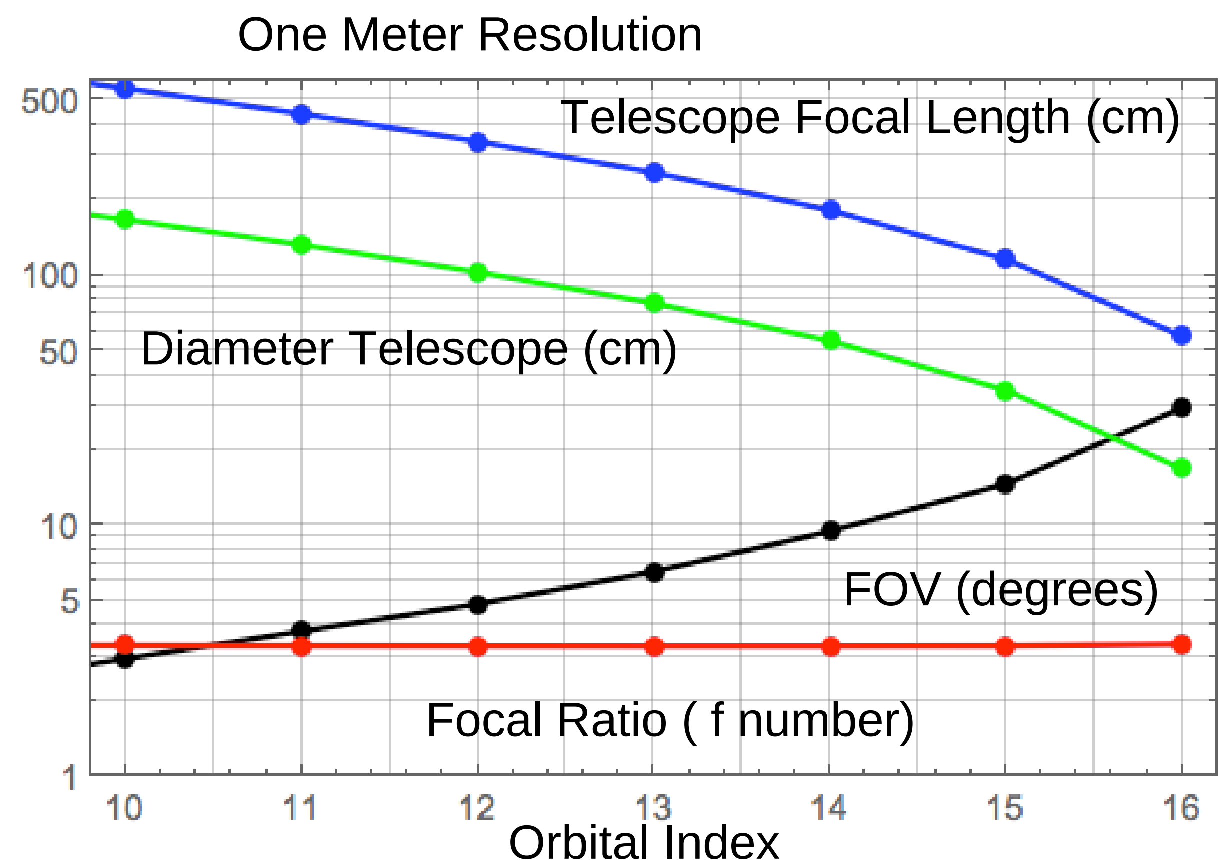
There is growth opportunity because of increasing usage in the developing world and a multiplier for the developing world

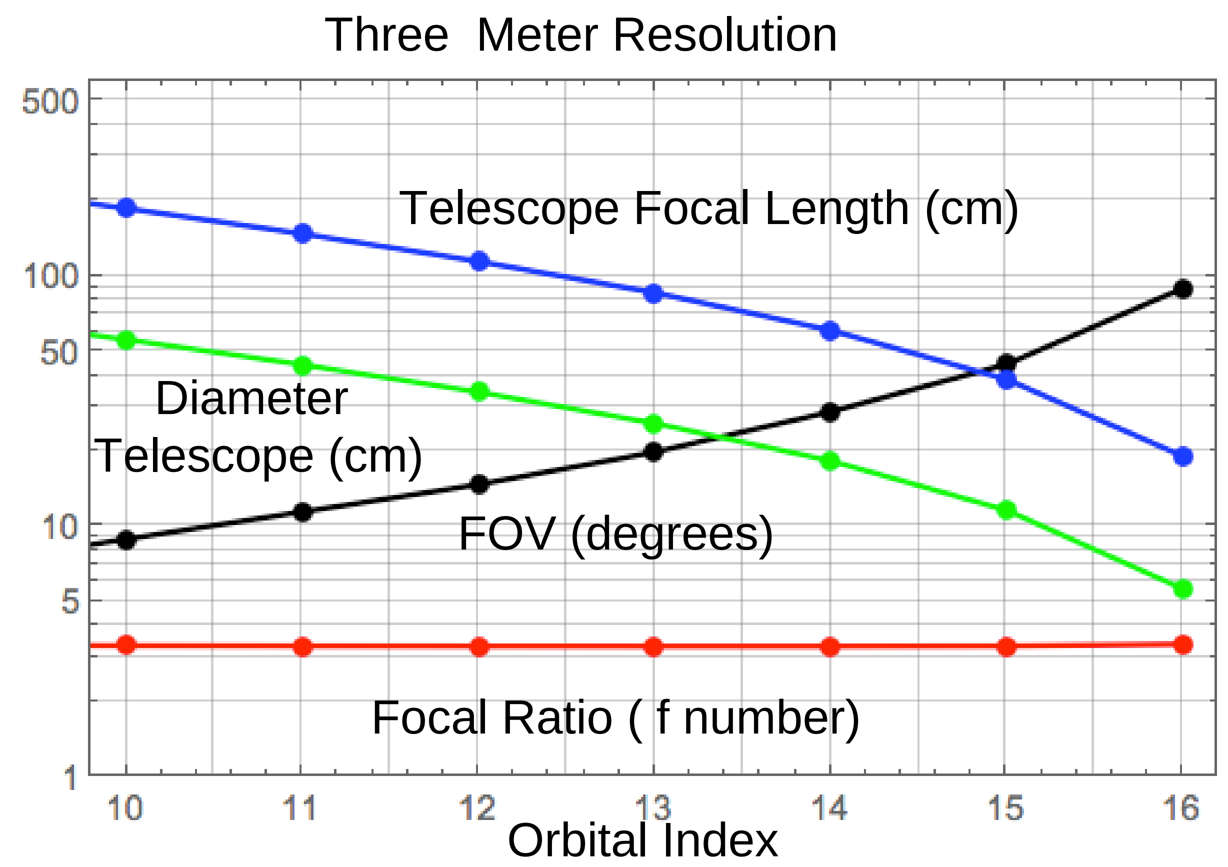
Example of Communication Characteristics when a full Map is made every Hour



ation with 90 minute satellite orbits, orbital height of 274 km, and one 9 m

Optical Properties of Telescopes





One Meter Resolution Case

Orbital Index	Satellite Height (km)	Number Satellites	Width Satellite Path (km)	Diameter Telescope (degrees)	FOV Telescope (Degrees)
10	2725.5	280	143.122	166.255	2.95839
11	2165.05	275	145.724	132.068	3.80209
12	1683.59	276	145.196	102.699	4.88089
13	1264.69	273	146.792	77.1459	6.57633
14	896.274	266	150.655	54.6727	9.5235
15	569.27	270	148.423	34.7254	14.7365
16	276.698	272	147.331	16.8786	29.59