National Aerospace Services Company

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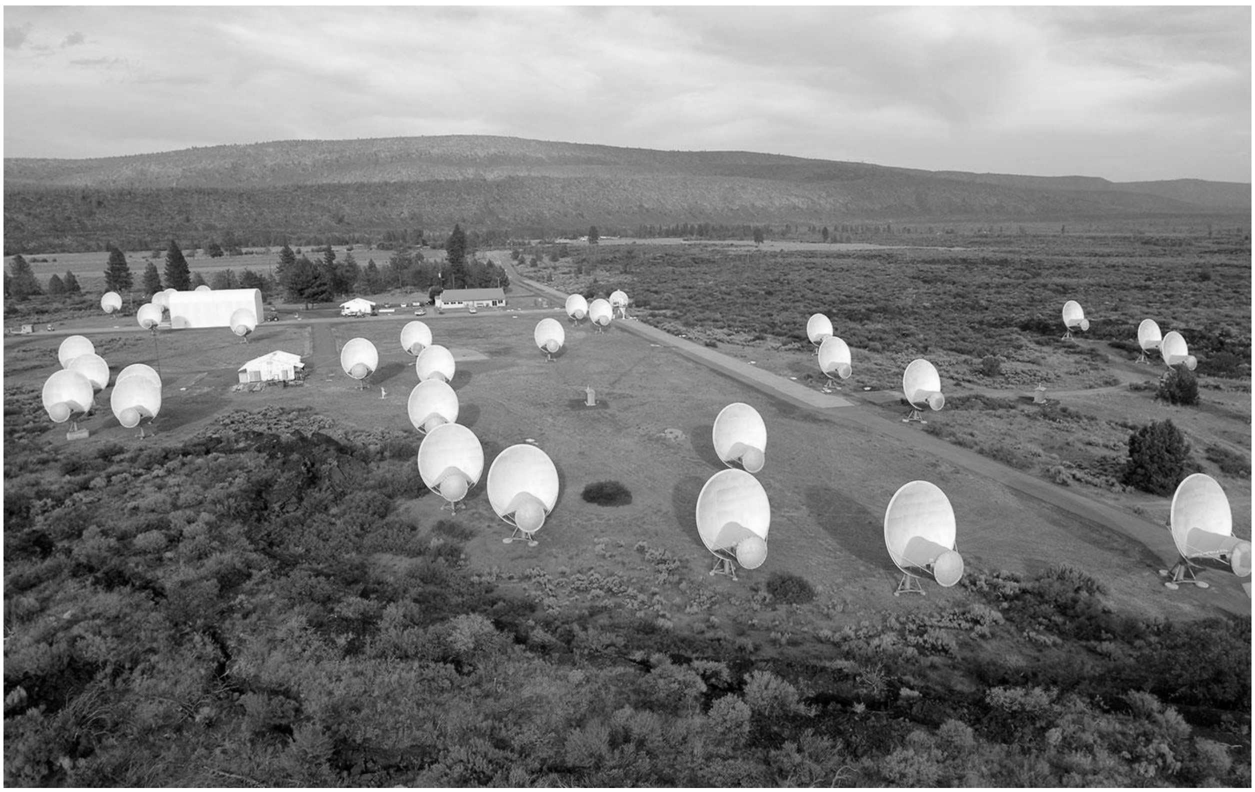
The dynamics of a Radio Detection and Communication Array (RDCA) for Oman



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1 Key Terms

- **Detection:**
  - As a use case, detection is in reference to the radio detection of near earth objects (NEO) for mapping and mineral analysis.
- **Communication:**
  - As a use case, communication is in reference to ground station services for low earth orbit (LEO).
- **Array:**
  - A telescope array is a group of telescopes arranged so that they collectively function as a much larger telescope aided by interferometry.
- **Benefit:**
  - The benefit(s), in the context of the question at hand, will be measured by the intersecting factors of; tourism, research, education, economy, and Oman Vision 2040.
- **Main Technical Feature:**
  - The unique focal point of the project at an international standard which is appealing to tourists, researchers, and institutions who are interested in space science and astronomy.

2 Proposed location

- Location: Jebel Shams, Al Dakhiliyah Governorate
- Altitude: 2,300 meters above sea level

(Figure 1.2) *Elevated view of a potential site within the Jebel shams mountain range*

3. Detection

Asteroid Mining Sub-industry:

Prior to 2013, the notion of asteroid mining was considered to be merely that of fantasy and science fiction by the leading industrial and scientific authorities. However, with the continuous rise of disruptive and frontier technological companies and initiatives such as Planetary Resources Incorporated, and Deep Space Industries, the reality of utilising the vast resources of outer space is beginning to take shape (O'Morain 2017).

Asteroid mining comprises **two fields**; (1) innovations in robotics and propulsion, and **(2) space bodies research and population mapping** (O'Morain 2017). The field which is being proposed is (2) and it is considered to be a primary use case for the RDCA. Population mapping is the process of running long period observations of main belt asteroids (MBAs), potential hazardous asteroids (PHAs), and near earth objects (NEOs), to determine trajectory and speed, reliable mass analysis and determine what metals, minerals, and ices they contain. Such methods surpass the capability of standalone optical telescopes since asteroids are typically very dark and move too fast for detailed observations of imaging cameras. Whereas a radio array can easily track and probe these objects to build a valuable database that would be of substantial importance to future asteroid mining operations (O'Morain 2017).

Comparatively, additional space sub-industries are being initiated at a governmental policy level by Luxembourg who have announced, in partnership with the European Space Agency (ESA) , their plans to inaugurate a **European Space Resources Innovation Centre (ESRIC)**. Such plans are further evidence of the growing interest in space resources from an economic and scientific point of view which in hand is propelling a new industry by adopting an inductive policy and strategy (Mining.com 2018).

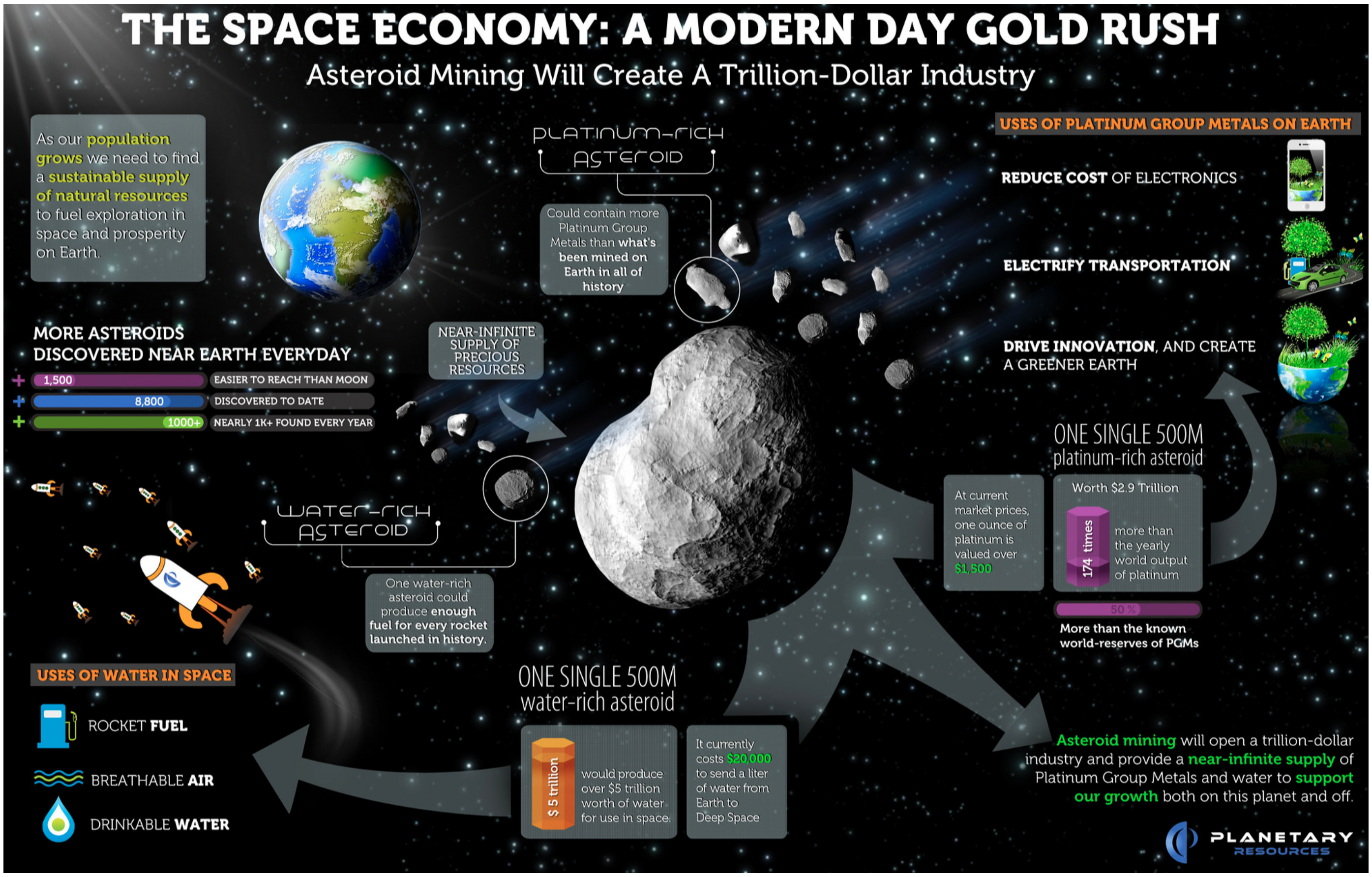
In terms of existing data sets, there are multiple sources in the form of target lists to which the proposed RDCA may begin utilizing and refining:

- **Asterank**. A database of Asteroids composed from scientific data which indicates the approximate value of the body based on mineral composition. The platform calculates the estimated monetary value of each mapped space object based on its mineral composition. (www.asterank.com)
- **International Astronomical Union Minor Planet Center (IAU-MPC)**. The MPC is the main body for asteroid and comet data including observations, ephemeris, astrometry, and monitoring announcements. They maintain an extensive database to work from, as well as provide rapid announcement of newly discovered objects. (www.minorplanetcenter.net)
- **NASA JPL-Small Body Database**. This extensive database, run by NASA's JPL Solar Dynamics Division, contains one of the most comprehensive databases for asteroids and comets available with the data they have accessible. The data they provide includes orbital elements, orbit diagrams, physical parameters, and discovery circumstances. (https://ssd.jpl.nasa.gov/sbdb.cgi)

Currently, in the early stages of the race towards space resources, major countries in the global space community have initiated and completed missions to collect and return mineral samples from asteroids back to Earth. Most notably, **NASA's OSIRIS-Rex** and **JSA's Hayabusa** missions respectively have proven that the technology needed to intercept and rendezvous with an object as comparatively small and fast moving as an asteroid is possible. Moreover, experts have begun to indicate that it is only a matter of scalability when considering the possibility of commercializing such efforts. Such a value proposition is displayed with precious metals in the palladium family that have been discovered in abundance in space, compared to Earth where there is a major environmental impact on the extraction of the said resource. Such discoveries, and their implications have encouraged scientists and theorists to argue that the Earth's first trillionaires will be made from the space mining industry (Tosar 2020).

The overall reasoning as to why space resources are increasing in significance, there are **two main explanations**; (1) Earth Supply, whereby the price of precious metals used in electronics and medical equipment can be reduced and the market price of such metals regulated. (2) For use in space, where the materials can be used for efficient manufacturing in space for space missions and even as fuel, when considering the detection of water.

" Asteroids can be a strategic resource. On the one hand, they contain a large amount of water, which is crucial for the supply of future space missions, both as fuel —water can be broken down into oxygen and hydrogen (which are the most common gasolines for spacecraft)— and to keep the crew alive. On the other hand, asteroids can also be very attractive as a mining resource." (Tosar 2020)



(Figure 2.0) *Planetary Resources infographic on asteroid mining.*

4. Communication

Ground Station as a Service (GSaaS):

Ground station as a service (GSaaS) can be implemented by using telemetry, tracking, command (TT&C) and Tx/Rx (Transmitting & Receiving) which will allow the RDCA to multi-task and monitor satellites and spacecraft, send operational commands, and downlink data directly. The RDCA will operate on the S, X, and Ku bands due to their primary use with research & astronomical satellites and robotic spacecraft. (1) **S Band** is used in space operations and research, including 'deep space' links from beyond Earth orbit. This encompasses the Unified S-band (USB) plan which is used by many spacecraft, and which was also used by the Apollo lunar missions. Many remote sensing satellites downlink in S Band. (2) **X Band** is used heavily for space research, deep space operations, environmental and military communication satellites. Many satellites and spacecraft carry complementary S and X band transmitters. (3) **Ku Band** is used for high speed satellite communication and telemetry control, and is also used for uplink and downlink data services.

Such a service would allow the RDCA to meet the operational, command, and data needs of customers with space based equipment and can be considered as a practical revenue stream. The service, when used with external agencies and customers, can be offered on a contractual basis. Moreover, GSaaS has the potential to reach a global audience by being situated in the **Sultanate as a unique and previously unused location** which can contribute to global monitoring and operations of systems when other locations are not in line of sight (Johnson 2017).

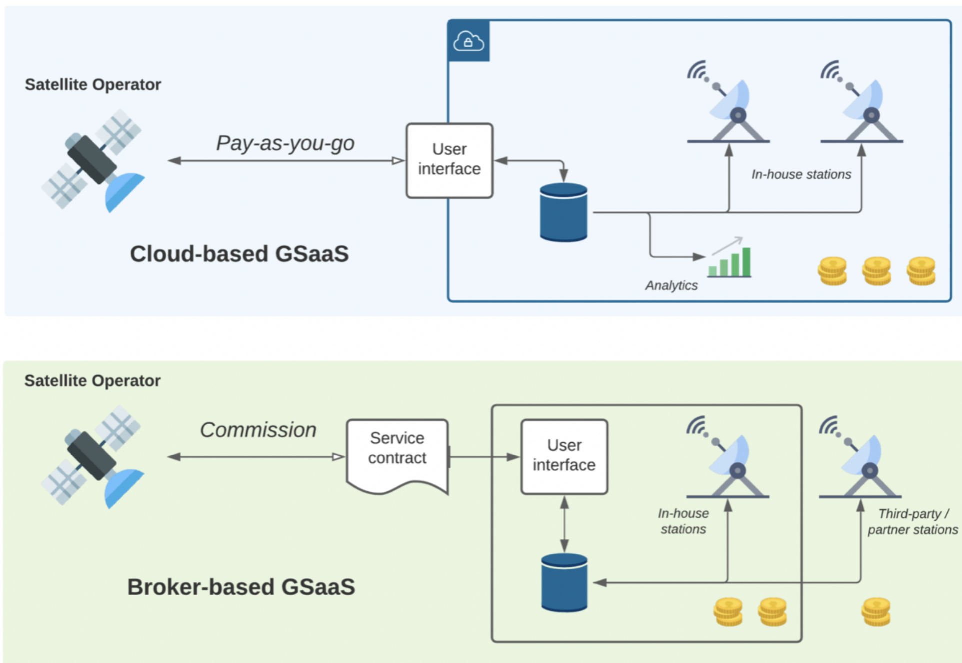
GSaaS is becoming increasingly popular due to the **growing number of communication satellites being launched into orbit**. GSaaS facilities are essential assets to satellite companies because they provide communication, storage, processing, and management of the data being received and transmitted. In most cases the operational requirements of GSaaS facilities require as much accuracy and precision as when building the actual satellite. Such requirements are necessary to ensure that satellites operate efficiently and to their full potential (Hywel 2021).

In terms of the notable providers of GSaaS there are two main subfields available in the industry. A non-exhaustive list of such providers are listed below under their respective categories:

A. Dedicated Ground Network as a Service:
    i. **Leaf Space**: is an Italy-based company pioneering the concept of ground station as a service in the modern market.
    ii. **Kongsberg Satellite Services (KSAT)**: is a Norwegian company that has offered ground station services and solutions since 1968.
    iii. **CONTEC**: is a spin-off of the Korea Aerospace Research Institute (KARI), and provides a suite of services to satellite operators and other space businesses around the world.
B. Ground Station Capacity Aggregators (utilization of spare time on existing infrastructure):
    i. **Infostellar**: is a platform that links satellite operators to antenna owners so that spare capacity and idle systems can be used and monetised.
    ii. **The RBC Signals Global Ground Station Network**: is an aggregation option for satellite owners and operators wishing to take advantage of an existing ground segment infrastructure.
    iii. **The Amazon Web Services Ground Station service:** enables satellite owners to access fully managed ground segment services for applications including weather forecasting, surface imaging, communications, and video broadcasts.

Commonly, major infrastructure for GSaaS exists in the form of teleports which are used to connect ground based systems for telecommunications networks for mobile phones, and internet to their individual satellite networks. Comparatively, smaller GSaaS facilities are used to communicate with objects in low earth orbit. In context, there is a necessity for the location of such a facility to be located remotely and away from any radio interference. Additionally, equatorial locations are of value for such operations as multiple orbital paths are able to be tracked (Hywel 2021).

(Figure 5.0) Example of existing GSaaS operational models



<u>5. Social Impact</u>

5.1 Education:

In parallel to the rapid expansion and growth associated with technology and research based industries, the demand to improve and enhance educational efforts towards Science, Technology, Engineering, and Mathematics (STEM) are gaining recognition and interest as an essential requirement for learning.

To quantify the period between 2008 and 2018, there is a significant increase in the number of papers published by academics relating to the benefits of STEM subjects as a buzzword more than any previous period. Unlike most education subjects, STEM subjects have become increasingly interdisciplinary and transdisciplinary since the popularization of the buzzword whereby those involved in STEM may have more adaptability towards innovative research methods (Li et al. 2020). Thus, as the aforementioned trend continues to gain momentum, the demand for STEM related space science activities is expected to increase.

5.2 Independent Research:

Time allocations for independent research can be made available for access via a time purchase model, which can be significantly attractive to the international academic and amateur astronomy communities. Such communities are known to divest substantial capital for observations and scientific research with equipment purchase, instead of a time purchase on facilities such as RDCA due to lack of availability (O’Morain 2017).

Enabling independent and amateur astronomers to practice at a higher level of accuracy and informational depth can significantly increase the chances of discovering new objects and refining our understanding of existing bodies. Some of the most notable astronomical discoveries of the last century have been made by amateurs, with the famous example of Clyde Tombaugh's discovery of Pluto in 1930 as a novice researcher at the Lowell Observatory in the United States of America. Another worthy example is the Australian amateur astronomer Robert Evans, who began searching for supernovae in 1955 and as of 2021 he holds the record for the most visual discoveries of supernovae.

6. Operations summary

6.1 Hardware:

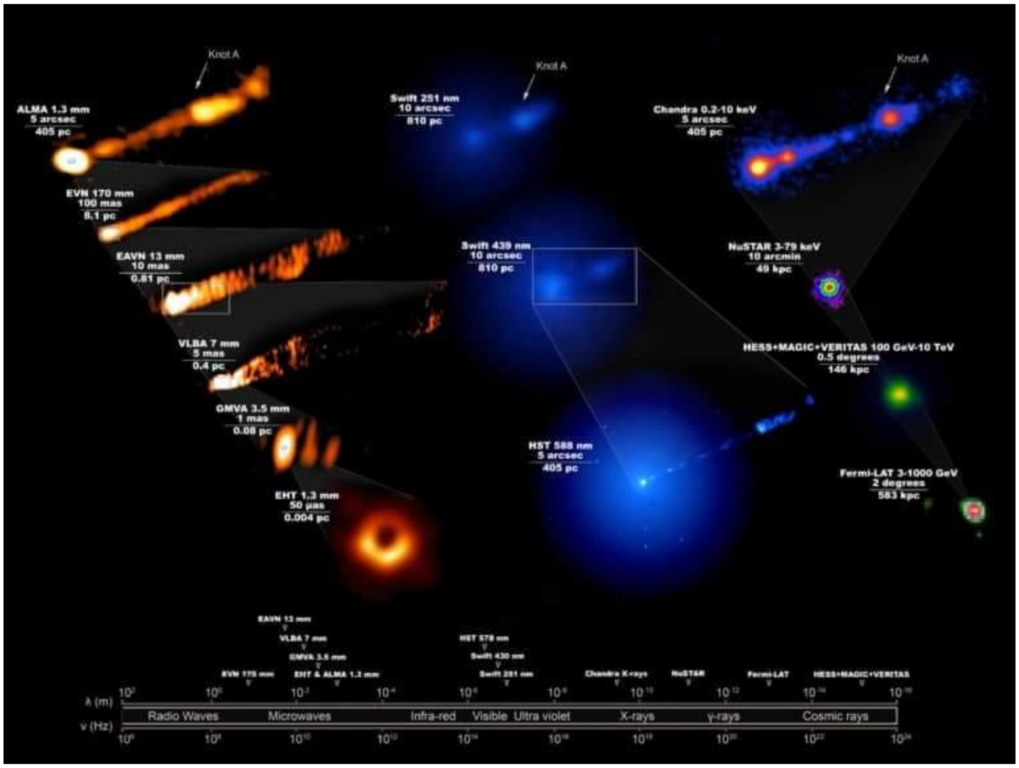
In order to achieve accurate and meaningful readings which can be applied in the aforementioned use cases, a hybrid approach must be implemented to enhance the imaging quality and capability of RDCA via a telescope array. When considering the basic apparatus required for a hybrid array as such, the requirements include:

- Radio:
  - High-Gain Radio Telescopes
  - L, C, Ka-band Front End Radio Receivers
  - 1500 MHz Variable Band Radio Receivers
  - TT&C and Tx/Rx Units (S-band, X-band, Ku-band)
  - Multi-waveband Radio Telescopes
  - VBR receivers
  - Telescope control
- Optical:
  - Vis NIR/IR
  - Adaptive optics
  - Spectrographs
  - CCD Cameras
  - Scientific Filters

The exact hardware requirements will ultimately depend on a **comprehensive design** and **the budget** of the project. Taking such factors into consideration, the choice of an array of telescopes instead of a large singular telescope can reduce the cost and time constraints associated with mobilizing such infrastructure.

6.2 Data processing

The two main analysis packages used for the processing of data are the Astronomical Image Processing System (AIPS) and the *Common Astronomy Software Applications* (CASA) package. The CASA software can process data from both single-dish and aperture-synthesis telescopes, one of its core functionalities is to support the data reduction and imaging pipelines. Data acquisition and recombination processing are carried out onsite to prepare the data to be transferred to a local off-site data storage center. Researchers typically submit requests for telescope time, then download the data to analyze. Traditional models of data extraction can be replaced with the ability to upload code to the data and perform analysis remotely via cloud computing technologies.



(*Figure 7.0*) Variety of imaging possible with radio/optical/nir

7. Existing Space Attractions

International space attractions are able to draw the attention of thousands of space and science fans per year to learn about and visit their unique facilities as tourists. All such facilities have one thing in common, which is the focus and commitment that they dedicate towards their main attraction. Among the numerous existing space attractions are active rocket launch facilities which allow visitors such as the Baikonur Cosmodrome in Kazakhstan, and an astronaut training base which features a museum for visitors such as the Star City in Russia. Below is a non-exhaustive selection of space attractions that have been compiled as examples which are technically comparable to RDCA's features:

- **Palomar Observatory**
  - Location: San Diego, California, USA
  - Completed: 1930
  - Features:
    - Situated 1.8 kilometers above sea level
    - 5.1 meter “Hale” optical telescope
    - 1.2 meter “Samuel Ochin” optical telescope
    - 1.5 meter “Palomar” optical telescope
    - Interferometry
  - Use: NEOs
  - Annual visitors: 70,000
  - Virtual access: Yes

- **Karl G. Jansky VLA** (Very Large Array)
  - Location: Socorro County, New Mexico, USA
  - Completed: 1980
  - Features:
    - Array of 28 x 25 meter radio telescopes
    - Interferometry
  - Use: Space mission communications and deep space detection
  - Annual visitors: 20,000
  - Virtual access: Yes

- **Arecibo Observatory** (closed as of 12/2020 due to cable failure)
  - Location: Arecibo, Puerto Rico
  - Completed: 1963

- Features:
  - 265 meter radio telescope
  - 16 meter radio telescope
  - Interferometry
  - Lidar
- Use: Deep space detection and SETI (search for extraterrestrial intelligence)
- Annual visitors: 80,000
- Virtual access: yes

(Figure 8.0) Karl Jansky Very Large Array.

8. Stakeholders

8.1 “New Space”

Over the last two decades the increase in commercialized space activities has prompted industry leaders to define such a movement as “New Space”. The said increase has been a result of the rapid decrease in cost of manufacturing and development of space materials and components due to emerging technologies such as 3D printing and compounding of performance polymers (Airbus 2021).

Furthermore, “New Space” signifies an era whereby space related activities are more accessible than they have ever been, which in turn has driven private companies to push the boundaries of innovation within the operative and policy framework of their national governments (Reuters 2019). Thus, the landscape of space stakeholders can be considered to have become a **trinity of governmental, civil, and commercial entities** where each entity has complementary roles and objectives to the other.

8.2 Global Stakeholders

There are groups of academic and research institutions that operate outside national or governmental structures which are increasingly active in space. With the advent of cubesats, many more academic institutions are playing a direct role in the space environment by launching their own spacecraft and conducting experiments. Some universities spin off these activities into private commercial entities that are still partly owned by the university and serve as a source of revenue.

International organizations are engaged in space activities and represent another group of space stakeholders outside of the traditional public and private sectors. The United Nations (UN) has several offices actively involved in space activities such as the UN Institute for Training and Research (UNITAR) Operational Satellite Applications Programme (UNOSAT) and the UN Platform for Space-based Information for Disaster Management and Emergency Response (UNSPIDER). Outside of the UN, a number of other international organizations such as the European Space Agency (ESA), the Commonwealth Scientific and Industrial Research Organisation (CSIRO). Ultimately there is a significant abundance of end users for space capabilities at a subcontractor level including commercial entities such as SpaceX and Starlink.

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