Youth Science Journal

Featured Articles

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Second Issue

October 2020

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Letter from the Chairmen

Dear readers,

First and foremost, we'd like to thank you for your support and constructive feedback on our first issue, which, in addition to giving us the necessary motivation to publish the issue between your hands, opened our eyes to some of the issues and flaws present in the first issue. Some of our readers have complained that the articles were too sporadic, as in they would be reading a chemical engineering article only to find themselves 5 minutes later looking at a computer science one.

Accordingly, we have decided to dedicate each issue from now on to a single "theme" or 'problem' in order to better situate the articles around a single topic. For this issue, the theme will be Above & Beyond where we explore topics about black holes, telescopes, and more things beyond our skies!

Furthermore, seeing how the first issue was well-received by our teachers and students, we are delighted to announce that we will be expanding our team as a first step towards building a community of young writers and researchers! The requirements will be nothing extraordinary; just a quality, authentic piece of writing and you are in!

Needless to say, we will be eagerly waiting for our first applicants once we announce the beginning of recruitment on our social media, so make sure to follow us there!
That is it for this letter, and we hope you have an enjoyable read!

Best Regards,
Gasser Mamdouh (Chairman)
Moemen Wael (Vice-Chairman)
Saif Taher (Vice-Chairman)

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Small Satellites: The future of Earth observation and space exploration missions

Ahmed E. Moussa

Abstract

Earth orbiting satellites come in a wide range of shapes and sizes in order to meet a diverse variety of uses and applications. While the larger of these satellites with masses exceeding 1000kg support high resolution remote sensing of the Earth, high bandwidth communications services and world-class scientific studies, they take a long time in development and are overly expensive to build and deploy. Consequently, interest in the smaller-sized satellites has skyrocketed in recent years. Their reduced development time and launch costs, compared to conventional large satellites, have made them an excellent replacement in many areas. This article dives into this technology and how it represents a bright future for space exploration and Earth observation missions.

Background

The exploration and exploitation of space has been a costly endeavor, yet it has undoubtedly yielded a vastly improved understanding of our planet, our solar system and the wonders of the universe. Building satellites required technically advanced and expensive capabilities, launchers were likewise costly and risky, and the ground infrastructure was complex. These factors limited our access to space travel to only the most advanced and wealthy of nations. Small satellites (500 kg or less) have been around for over half a century, but interest in their exploitation is growing now more than ever. Since how big a satellite corresponds directly to expenditures related to materials and parts, labor for development, and launch vehicle fuel, it naturally follows that the principal advantages of small satellites over their counterparts are lower overall costs and shorter times for development. Nevertheless, small satellites have technological and mission-related advantages in their own right. The shorter development cycle allows for the insertion of the newer payload and bus technologies. In addition, compared to a single large satellite, a network of several small satellites is potentially more flexible, as it can be reconfigured according to mission needs. Small satellites and specifically, cubesats (Nano Satellites), are also an opportunity for less advanced countries to begin their path in the Space Technology Ladder. These satellites provide a relatively simple, low-risk and quick method of independently gaining foundational experience in space technologies.

Class	Mass (kg)
Large satellite	>1000
Small satellite	500 to 1000
Mini-satellite	100 to 500
Micro-satellite	10 to 100
Nano-satellite	1 to 10
Pico-satellite	0.1 to 1
Femto-satellite	<0.1

Table 1: general classification of femto-pico-nano-micromini-small-large satellites

Small Satellites Capabilities Development

Since the dawn of the space era, Small satellites skyrocketed in development. New technologies and capabilities were introduced to bolster the applications in different categories: communication, Earth Observation, Space Exploration, weather monitoring, etc. The early small satellites lacked solar cells and completely depended on simple batteries to perform their tasks, it wasn't long before the Solar cells and rechargeable batteries got adopted to accommodate for the short comings of the battery-operated ones in orbit. The passive attitude stabilization techniques were then added to the small satellites. Some of the most significant being spin stabilization and gravity gradient. Those aforementioned techniques depended on the electricity generated from solar panels to control the satellite and keep it tracking its target using reaction wheels that change their rate of spinning creating a torque that shifts the satellite's orientation.

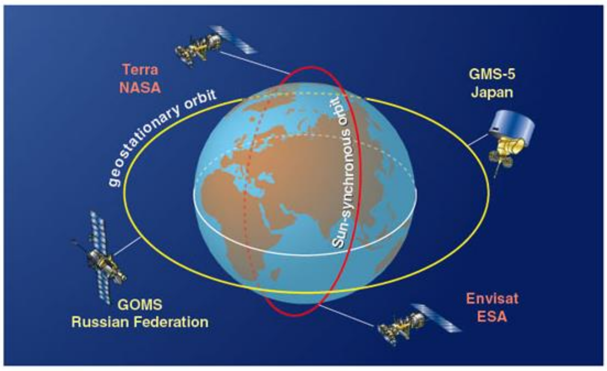

Figure 1: An illustration for the most used orbits in Earth observing satellites, Geostationary and Sun-Synchronous

The advancements in the small satellites' buses did not only provide a greater degree of flexibility but it also enabled more satellites to utilize new payload technologies. The transition to the modern, reprogrammable small satellite first began in 1981 with the launch of a 54kg micro-satellite UoSAT-1 (UoSAT-OSCAR-9) that consisted of two in-orbit reprogrammable microcomputers. Moreover, its on-board RCA1802 and Ferranti F100L microcomputers were launched empty of software, except for a 'boot loader', and a series of programs were subsequently compiled on the ground and were later uploaded to the satellite. The above example illustrates the key impact made on the capability and utility of small satellites through the introduction of early in-orbit reprogrammable microprocessors.

As microsatellite technical capabilities gradually developed throughout the 1990's, interest grew in their use for technology demonstration and verification, new digital services prior to widespread internet infrastructure, rudimentary Earth observation, radio science and military applications and, in particular, training programs for developing space nations. For instance, South Africa developed and deployed SunSat satellite, the first satellite in all developing countries. The satellite included a GPS receiver, laser reflectors, magnetometers, star camera, Amateur Radio communications and a 15 m resolution, 3456 pixel, 3-band push broom imager. Several images were

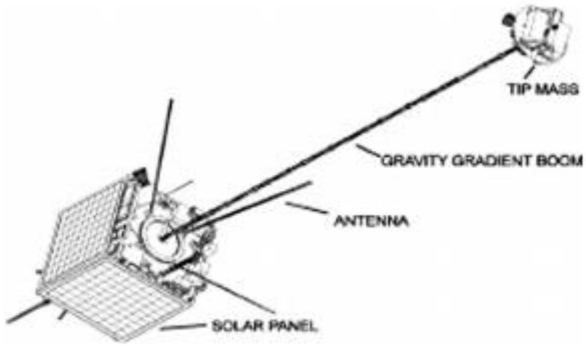

Figure 2: South Africa first small satellite, the SunSat

successfully taken and transmitted to the ground from SUNSAT satellite. Unfortunately. It didn't take long for the satellite to exit orbit, but the country had benefited from the developed technology.

Small Satellites for Earth observation (Earth Remote sensing)

For earth observations sensors are a must, their purpose is to sense reflections of the earth within the range of the electromagnetic spectrum; the majority of Earth-observation satellites carry "passive" sensors, measuring either reflected solar radiation or emitted thermal energy from the Earth's surface or atmosphere. Active sensors (such as radar), however, require antennas for transmission of electromagnetic pulses and for reception of the backscattered reflections from the ground. Of course, due to the lack of complicated components and equipment, passive sensors require less mass and are therefore more preferred in small satellite EO missions. As a result, Earth observation satellites prefer sun synchronous polar orbits at orbital heights between 400 and 1000 km. This choice of orbit ensures perfect illumination conditions. However, passive sensors are challenging some limitations, such as:

- Spatial resolution of the optical system, which is controlled by the diffraction limitation.
- Sensitivity of the detector elements that require at least about 1 millisecond exposure time.
- Image motion, because of the forward motion of the satellite in the order of 7.4 km/sec or 7.4 m/msec.

Fortunately, passive sensors are becoming more advanced leading to an increase in spatial, spectral and temporal resolution. In addition, image motion compensation became possible by time delay integration sensors (TID) or by rotation of the satellite sensor during the exposure time.

Satellite constellations for global coverage

Small satellites provide a unique opportunity for affordable constellations to achieve global coverage on Earth with high time resolution. In this point, small satellites can do things that are impractical with large satellites.

Satellite constellations provide a number of advantages like:

- Increase of time resolution depending on the number of satellites in the constellation.
- The relative low cost of a single satellite makes the replacement of a satellite in a formation or a constellation easier.
- Soft degradation of the performance of the system resulted from the malfunction of one satellite.

Figure 3: The five satellites of RapidEye constellation

The commercial RapidEye constellation may serve here as an example of a constellation's capability. The mission provided a commercial operational GIS (Geographic Information System) service along with high-resolution multispectral imagery. The objectives are to provide a range of EO products and services to a global community. The five observation satellites of RapidEye Earth mission have been launched on a single Russian Dnepr rocket in August of 2008, which proves the point of less costly launch missions (launching five satellites on a single time) and they are deployed in orbits at an altitude of 630 km. The satellites are placed such that the spaces between the satellites are equal in a single sun synchronous orbit to ensure a short revisit time and consistent imaging conditions. The satellites follow each other in their orbital plane at about 19 min interval.

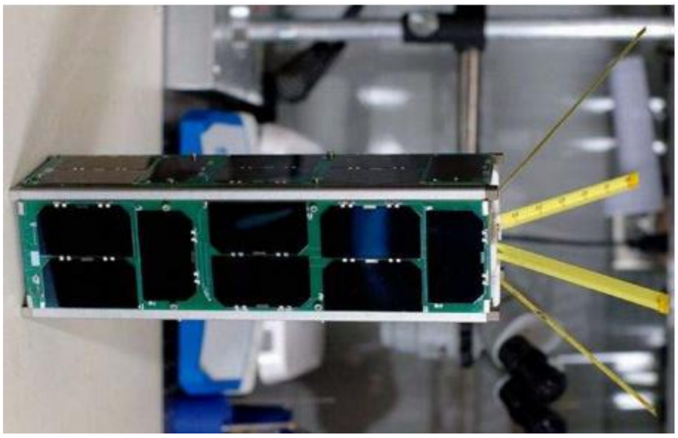

Figure 4: RAX CubeSat

Distributed small satellites can also be used for missions unachievable using a monolithic approach. Such missions have the purpose of studying the variations of a parameter using the intersatellite range change measurements and attitude measurements from each satellite rather than multiplying the payloads for coverage enhancement.

CubeSats for space exploration

CubeSats represent a specific type of nanosatellite measuring 10×10×10 cm3 and weighing slightly more than 1 kg (typically less than 1.33 kg). Their small size and mass make them relatively inexpensive and simpler to build and allow them to be launched as secondary payloads at much lower cost and higher frequency than traditional monolithic satellites. The standard CubeSat size of 1U (10×10×10cm3) has been scaled to other configurations such as the 2U (20×10×10 cm3), 3U (30×10×10 cm3) , 6U and 12 U.

CubeSats can play a supportive role in exploration activities. Several pioneering CubeSat missions have recently demonstrated the ability to conduct scientific experiments in the fields of biology and Earth observation; also, they are currently used in other missions related to space exploration such as planetary science and space weather.

CubeSats are also being used to demonstrate technologies for future space exploration, in particular solar sail propulsion and electric propulsion. Moreover, it is envisaged that CubeSats will piggyback on main orbiters traveling to Mars and the Moon to assist planetary science missions. A worldwide CubeSat program exploration and integration that supports space nations in a significant way will prepare for a future global space exploration program with more participants.

Challenges & Conclusion

Launching to orbit still represents a constraint in small satellite missions. Most of the projects are launched as a secondary payload on launchers for large spacecraft. Small launchers are still under development to become able to survive the aggressive first 20 minutes or so of ascending to orbit. Moreover, in-orbit data processing, communication, and storage need to be improved.

Present day small satellites in many instances now compete and in some aspects surpass traditional large satellites' capabilities but at a fraction of the cost; however, small satellite missions do not replace large satellite missions, as their goals and issues are often different, to be more accurate they complement them. There is a similar relation between small and large satellites as exists between microprocessors and supercomputers: some problems are better addressed via distributed systems, for example, constellations of small satellites (typically used for global coverage), while others may require centralized systems (e.g. a large optical instrument, as in a space telescope or a high-power direct broadcast communications system). To sum it up, small satellites represent a bright future for the space exploration and Earth observation missions in a lot of sides where large satellites are not the appropriate option.

References

[1] M. N. Sweeting, "Modern Small Satellites-Changing the Economics of Space," Proceedings of the IEEE, vol. 106, no. 3, pp. 343–361, 2018.

[2] M. Ansdell, P. Ehrenfreund, and C. Mckay, "Stepping stones toward global space exploration," Acta Astronautica, vol. 68, no. 11-12, pp. 2098–2113, 2011.

[3] M. B. Argoun, "Recent design and utilization trends of small satellites in developing countries," Acta Astronautica, vol. 71, pp. 119–128, 2012.

[4] R. Sandau, "Status and trends of small satellite missions for Earth observation," Acta Astronautica, vol. 66, no. 1-2, pp. 1–12, 2010.

[5] W. Shiroma, L. Martin, J. Akagi, J. Akagi, B. Wolfe, B. Fewell, and A. Ohta, "CubeSats: A bright future for nanosatellites," Open Engineering, vol. 1, no. 1, 2011.25, 2020, from https://science.jpl.nasa.gov/PlanetaryScience/PlanetaryAtmospheres/projects.cfm

[6] R. Sandau, H.-P. Roeser, and A. Valenzuela, Small Satellite Missions for Earth Observation New Developments and Trends. Berlin: Springer Berlin, 2014.

[7] R. Sandau, "High-resolution imaging with small satellites: what are the possibilities and limitations?," Sensors and Systems for Space Applications, 2007.

The search for a new Earth: Study of Exoplanets and The Current Exploration Projects

Fady Kiroles

Abstract

For thousands of years humanity has been consuming the resources of the Earth at an exponential rate. Scientists have found that the valuable resources humans depend on are nearing depletion. This motivated astronomers to start the search for a new earth outside of the solar system. Space exploration projects are now more focused on finding potentially habitable planets than anything else. While Mars has been a candidate for the first habilitation project for many years, it is not a certain solution to the problem. Therefore, projects aim towards exploring exoplanets and finding a suitable one for humanity.

Background

According to the global footprint network, as indicated in Figure 1, on August 1st of 2018 humans have consumed more than what the Earth could regenerate that year. With this rate of consumption, it would require 1.7-Earths-worth of resources to sustain human needs.

A viable solution for this problem would be to find a new planet with fresh resources. While there are currently projects that aim to habilitate Mars, their chances of success are quite slim. This is due to Mars's consistently poor weather. The red planet suffers from frequent and unpredictable sandstorms that may affect the habilitation process. This started the search for exoplanets, which are planets that lie outside our solar system. However, none of the currently discovered exoplanets satisfy the conditions for human survival.

Exoplanet habitable zone

The habitable zone is the region around a star where planets can have liquid water and a stable temperature. This region varies with the size of the star, as shown in Figure 2, where the habitable region of smaller stars is

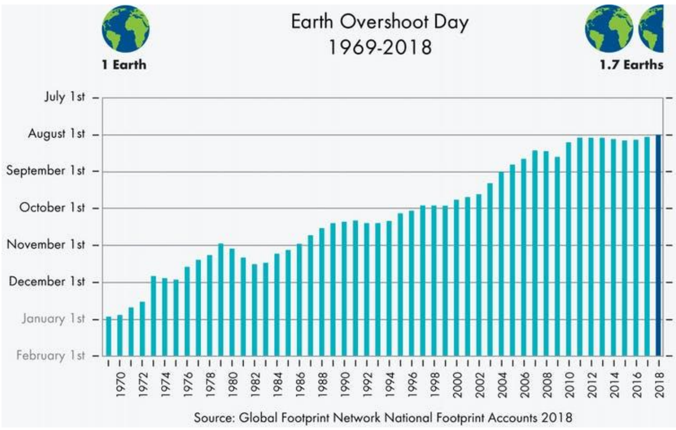

Figure 1: Resource consumption estimation on overshoot day [1]

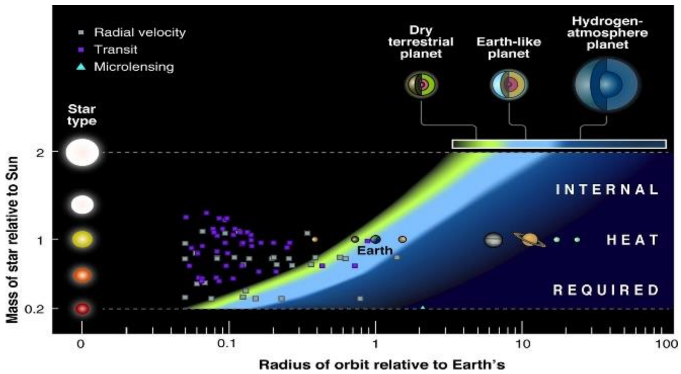

Figure 2: an estimation of the habitable zone [2].

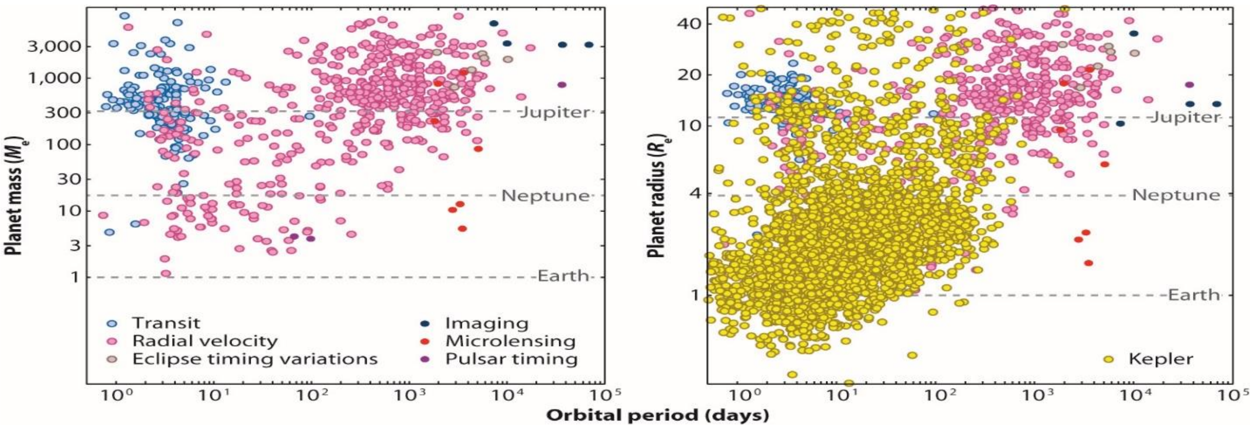

Figure 3: A graph of currently discovered exoplanets and their relative radii and masses.

closer to them than the Earth is to the sun. The reason why the habitable zone has stable temperature is because of the percentage of greenhouse gases in that region. There are currently no means of measuring the percentage of greenhouse gases present in exoplanets and thus, scientists rely on the distance between exoplanets and the star to estimate it.

Exoplanet interior composition

The main reason behind the habilitation projects of exoplanets is to find fresh resources. However, the exact amount and types of resources are quite difficult to estimate relying exclusively on distant pictures of said planets. After studying a variety of planets, scientists spotted a relationship between the interior composition of the planets and the ratio between their mass and radius [3]. This relationship can be utilized to understand the interior composition of exoplanets without sending probes and/or rovers on costly exploration missions.

Exoplanet biosignature gases

Biosignature gases are gases present in the atmosphere at detectable levels produced by living organisms (e.g., acetaldehyde, acetone, benzene, carbon disulfide). Although the presence of said gases could be correlated with that of lifeforms, this method has one major flaw: We only know of biosignature gases that are produced by carbon-based lifeforms here on earth, and those biosignatures wouldn't necessarily be the same ones on exoplanets (if we're to find any). All work of finding biosignature gases to date has been limited to speculating how exoplanetary products would act if they were transplanted onto planets of the same mass and atmosphere of Earth.

Current exoplanet studies

JUNO

Project JUNO launched from Cape Canaveral Air Force Station in Florida on August 5, 2011. It released a spacecraft in polar orbit around Jupiter. This project aims to determine the amount of global water and ammonia present in the atmosphere of ice-rock planets.

SHERLOC

The Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals is going to be used in the next Mars exploration mission. The SHERLOC uses spectrometers, a laser and a camera to search for organics and minerals that have been altered by watery environments and may be signs of past microbial life. This will enable scientists to discover more biosignature gases and consequently give them a better idea of what to look for on exoplanets.

TESS

The Transiting Exoplanet Survey Satellite is one of the largest projects to launch in 2017. It has the capability of surveying 200,000 stars and the planets orbiting them. This will allow for a huge scale scan of exoplanets, easing the search for an Earth-like planet.

Conclusion

Humanity's increasing consumption of Earth's resources will end in their inevitable demise. The only solution is to find a planet that can satisfy humankind's needs, and this would only be possible if space projects concentrated more on exploring exoplanets and ways of habilitating them.

References

[1] Richardson, R. B. (2018, August 1). Depleting Earth's resources. Retrieved from https://msutoday.msu.edu/news/2018/depleting-earths-resources/

[2] Seager, S. (2013). Exoplanet Habitability. Science, 340, 577-581. doi:10.1126/science.1232226

[3] Seager, S., Kuchner, M., Hier-Majumder, C. A., & Militzer, B. (2007). MASS-RADIUS RELATIONSHIPS FOR SOLID EXOPLANETS. The Astrophysical Journal, 669, 1279-1297.

[4] Science - Planetary And Exoplanetary Atmospheres: Projects. (n.d.). Retrieved September 25, 2020, from https://science.jpl.nasa.gov/PlanetaryScience/PlanetaryAtmospheres/projects.cfm

[5] Madhusudan, N., & Seager, S. (2009). A TEMPERATURE AND ABUNDANCE RETRIEVAL METHOD FOR EXOPLANET ATMOSPHERES. The Astrophysical Journal, 707, 24-39.

[6] Ricker, G., Winn, J., & Vanderspek, R. (2014). Transiting Exoplanet Survey Satellite. Journal of Astronomical Telescopes, Instruments, and Systems, 1(1), 1-10

[7] Seager, S. (n.d.). Exoplanets. Retrieved September 25, 2020, from http://seagerexoplanets.mit.edu/research.htm

The First Sight of Black Holes using the Event Horizon Telescope

Akmal Hashad

Abstract

Black holes were predicted long ago by scientists like Albert Einstein and Karl Schwarzschild. However, they had never been seen until recently: In 2009, the Event Horizon Telescope was launched. It is a telescope array that consists of a global network of 12 radio telescopes. It was built to observe two supermassive black holes which are Sagittarius A and Messier 87 (M87). On April 10, 2019, the Event Horizon Telescope Collaboration announced taking the first direct image of a black hole. The image featured the massive black hole at the center of Messier 87 galaxy*

Background

The idea of the black hole, a celestial body so massive that even light cannot escape its gravity, was first proposed by John Michell in 1784. After that, Albert Einstein predicted the presence of black holes in his theory of general relativity. The black holes are described using three physical quantities: mass, charge, and angular momentum.

A black hole consists of 6 main parts: the singularity, event horizon, photon sphere, relativistic jet, innermost stable orbit, and accretion disc. The singularity is the point at the center of the black hole where the matter has collapsed into infinite density. The event horizon is the radius around the singularity where matter and energy cannot escape the gravity of the black hole, giving it a black appearance. The photon sphere is a bright ring around the event horizon formed by hot plasma which emits photons. The gravity of the black hole is so strong that it bends the light paths making them appear as a bright ring. The relativistic jets are produced when the black hole feeds on stars, gas, or dust. The innermost stable orbit is the area where matter can orbit the black hole safely without being pulled to the point of no return. The accretion disc is a disc of superheated gas and dust that orbits the black hole. This disc plays an important role in revealing the location of the black hole by emitting electromagnetic radiation.

Messier 87 (M87) is a supermassive black hole located at the center of Messier 87 galaxy. Its mass is billions of times that of our sun at 6.5 ±0.7 ×10^9 M⊙ (solar masses). Although we had done a good bit of research on black holes, all of our information was merely theoretical until April 10, 2019.

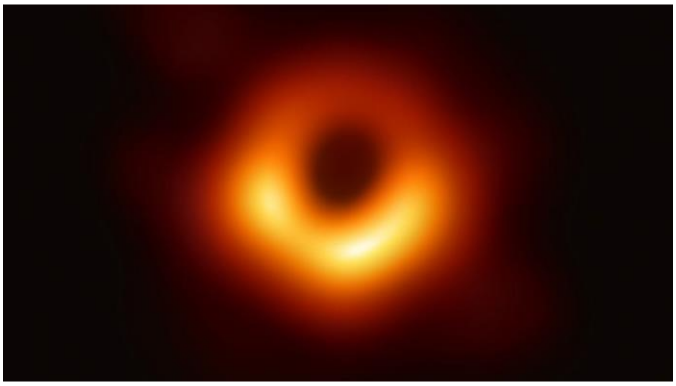

Figure 1: The image of M87 black hole

The Event Horizon Telescope

The Event Horizon Telescope (EHT) was launched in 2009. It is a large telescope array that consists of a global network of radio telescopes around Earth. It combines data collected from several very-long-baseline interferometry stations with high angular resolution that enable it to observe supermassive black holes. The main targets of the Event Horizon Telescope were Sagittarius A*, the black hole at the center of Milky Way galaxy, and M87, the supermassive black hole at the center of the elliptical galaxy Messier 87.

The EHT fielded a global VLBI array of 8 stations spread over 6 geographical locations. These 8 stations are the Atacama Large Millimeter/submillimeter Array and Atacama Pathfinder Experiment telescope in Chile, the Large Millimeter Telescope Alfonso Serrano in Mexico, the IRAM 30 m telescope in Pico Veleta in Spain, the Submillimeter Telescope Observatory in

Arizona, the James Clerk Maxwell Telescope and the Submillimeter Array in Hawaii, and the South Pole Telescope in Antarctica.

Taking the First Picture

Using 1.3mm wavelength, the EHT was able to observe M87 black hole on 2017 April 5, 6, 10, and 11. This was possible due to the good to excellent weather then. The EHT took many scans at night ranging from 7 (April 10) to 25 (April 6). After that, the images were reconstructed using two different classes of algorithms: CLEAN and RML. The CLEAN is an imaging algorithm used to enhance signals from recorded data, thus improving their quality. RML methods improve the fidelity and effective angular resolution of images. After applying CLEAN and RML, the final image, shown in figure 1, was reconstructed and published on April 10, 2019.

Conclusion

Taking the first image of a black hole is an important step towards understanding these celestial objects. Having showed the shadow of M87, the image of the black hole proved that Albert Einstein's assumptions about black holes in his theory of general relativity were correct. After taking said picture, many parameters were determined. Its mass was determined to be 6.5 ×10^9 solar masses. The diameter of its event horizon was calculated to be 40 billion kilometers. Finally, it was found that it rotates clockwise.

Many approaches can be taken to obtain a better image in the future. A better resolution image can be captured by using a shorter wavelength like 0.8 mm. Additionally, using more telescopes could potentially lead to better results. The scientific community hopes that space-based interferometry will provide more precise information in the future

References

[1] The Event Horizon Telescope Collaboration, "First M87 Event Horizon Telescope Results. I. The Shadow of the Supermassive Black Hole," The Astrophysical Journal Letters.

[2] The Event Horizon Telescope Collaboration, "First M87 Event Horizon Telescope Results. II. Array and Instrumentation.

[3] The Event Horizon Telescope Collaboration, "First M87 Event Horizon Telescope Results. III. Data Processing and Calibration.

[4] The Event Horizon Telescope Collaboration, "First M87 Event Horizon Telescope Results. IV. Imaging the Central Supermassive Black Hole.

[5] The Event Horizon Telescope Collaboration, "First M87 Event Horizon Telescope Results. V. Physical Origin of the Asymmetric Ring.

[6] The Event Horizon Telescope Collaboration, "First M87 Event Horizon Telescope Results. VI. The Shadow and Mass of the Central Black Hole.

[7] The Event Horizon Telescope Collaboration, "First M87 Event Horizon Telescope Results.

Robust Materials for Next-Generation Spacecraft

Mostafa Moataz

Abstract

Having reached an advanced level in space technology, humanity has begun to seriously consider large-scale missions, such as mining of space resources, space travel, and even colonization of other celestial bodies such as Mars and the Moon. Nevertheless, it still requires far more dependable technologies to carry out such missions. Knowing that the materials used in manufacturing spacecrafts play a pivotal rule in their efficiency and reliability, researchers aim to foster the materials in three main characteristics: multi-functionality, adaptivity, and self-healing.

Background

If we are to conquer space exploration, we need to rethink how we design spacecraft to provide them with the necessary capacities. Indeed, when the success of an entire 40-year mission rests on proper operation of a single unit, with no ability for service or repair when millions of kilometers away from Earth, reliability becomes paramount. Such a prospect may seem incredibly out of reach, however, recent progress in material synthesis and self-assembly say otherwise.

The nanotech revolution has produced electronics and robotics with an unprecedented level of miniaturization and while retaining a respectable level of functionality. It has also provided material systems and device components that are lighter, stronger, and more robust than ever before, notably reducing the cost of their production and assembly. These achievements will definitely help us navigate vital barriers in the space industry and significantly expand the variety of our space assets.

Needed Characteristics

There are three major features that could be attained by enhancing the materials of our spacecraft; namely: self-restoration, adaptivity, and multi-functionality. The properties of materials required for the realization of the aforementioned features smoothly flow into one another. For instance, adaptivity could be considered as a case of "extreme" self-healing, where the property of a system is changed to another function; multi-functionality may be interpreted in the same way, i.e., as an ability of a system to change to the point of acquiring several functions, as shown in figure 1.

Figure 1: A "life ring" of novel materials for future space technology

Dynamic material properties are agility, strength/rigidity, healing, adapting, and the ability to transform, in contrast to "inanimate" structural materials that could decay by fatigue, cracks, degradation of an internal structure and composition, and de-shaping. The major physical, chemical, and structural properties that impart a "dynamic character" to materials are:

- Presence of reversible bonds and dynamic covalent bonds, capable of forming networks and supramolecular assemblies.
- Intense diffusion of specific elements and bonds.
- Reversible formation of crosslinkers. Capacity of the free radicals generated as a result of mechanical damage to re-establish covalent bonds.

Many of these features could be found in metallic materials, metal alloys, and compositions, including metal-frame systems and more complex architectures and metamaterials.

The materials for electronic devices can also possess the dynamic character and can self-heal and adapt. Nanostructured electronic compositions and graphene-based smart materials for micro and nanoelectronics also feature self-healing ability, thus laying a cornerstone for long-lasting, self-healing electronics.

Satellite Parts and Used Materials in Manufacturing Them

The materials used in manufacturing satellites are crucial when it comes to navigating the severe environment of space. Firstly, the external protection of the satellite is made of nanocrystalline diamonds. It has printable electronics for cheap, fast mission adaptation. Besides, it has solar cells which are highly efficient and nanostructure-based power system composed of metamaterial-based supercapacitors and power cells, and a thruster made of novel material for service life, efficiency, and adaptivity. The satellite body is custom-designed, mission-adaptable satellite chassis equipped with multi-metal and advanced polymer 3D-printed parts with high rigidity and high heat, ultraviolet, and radiation resistance. A satellite also contains strong, light design parts made of carbon nanotube fibers and advanced self-healing materials for chassis, antennas and other critical parts. Carbon nanowires and graphene are highly efficient, light-weight electronics. The propellant tank is made of composite propellant tanks made of thin metal layers and carbon nanotube-based fibers.

Challenges & Conclusion

Most of the mechanisms rely on integration of several distinct materials within a single system, which brings challenges of maintaining desirable material properties and structural integrity. Indeed, introduction of nonstructural components, e.g., encapsulated healing agents or catalysts, may undermine mechanical strength and chemical stability of the composite system. Furthermore, certain areas of the material may be subject to more extensive load and as a consequence experience damage more frequently or to a greater degree.

More dedicated research efforts will be required to deeply understand the numerous chemical and physical mechanisms and effects that contribute to the behavior of self-healing and other adaptive materials, to make them robust, reliable, and safe for human health. This is apparently one more significant issue critically important for long-lasting space travel and living in the interiors of Moon or Mars bases and stations, as well as in long-term orbital systems.

References

[1] Levchenko, I., Bazaka, K., Belmonte, T., Keidar, M., & Xu, S. (2018). Advanced Materials for Next-Generation Spacecraft. Advanced Materials, 30(50), 1802201. doi:10.1002/adma.201802201

[2] a) Boeing introduces all-electric propulsion commsats, http://www.boeing.com/space/boeing-satellite-family (accessed: April 2018); b) The International Afternoon Constellation, https://atrain.nasa. gov/ (accessed: March 2018); c) NASA’s Cyclone Global Navigation Satellite System started the Public Data Release, https://www. nasa.gov/cygnss (accessed: June 2018).

[3] a) V. Amendola, M. Meneghetti, Nanoscale 2009, 1, 74; b) J. Chen, T. Shi, T. Cai, T. Xu, L. Sun, X. Wu, D. Yu, Appl. Phys. Lett. 2013, 102, 103107; c) X. Yu, H. Cheng, M. Zhang, Y. Zhao, L. Qu, G. Shi, Nat. Rev. Mater. 2017, 2, 17046

[4] a) 3D Printed Satellites: Build in ULTEM 9085, a high strength engineering-grade thermoplastic qualified for spaceflight, http:// diy3dprinting.blogspot.com/2012/12/3d-printed-satellites.html (accessed: March 2018; b) A. Behroozfar, S. Daryadel, S. R. Morsali, S. Moreno, M. Baniasadi, R. A. Bernal, M. Minary-Jolandan, Adv. Mater. 2017, 30, 1705107.