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# GLOBAL REPORT ON TECHNOLOGY AND THE ECONOMY™

## SPECIAL LETTER

# NEW SPACE: AN OVERVIEW

## by Michael Sims

# SNS SPECIAL LETTER:
# NEW SPACE: AN OVERVIEW

BY MICHAEL SIMS

In This Issue
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***Publisher's Note***: Today, hardly a media issue goes by without some mention of the promise of the commercial move into space by private firms. SNS member Elon Musk has succeeded in disrupting costs and changing the paradigm of who, what, when, and at what price both cargo and humans can leave the planet, and where they may go next.

But even so, almost all of these media mentions are just that – enthusiastic pieces with little or no real information for those who have more than a passing interest in one of the greatest economic opportunities of our lifetimes. Sure, launch vendors don't like to publish costs, timetables slip, companies and their supply chains suffer, business models are constantly being reinvented, and there is much business data on going into space that remains proprietary, and therefore secret.

For these reasons, it makes great sense that the person we found to share exactly this information is Michael Sims (see bio below), who spent 20 years at NASA, where he worked on Mars rover missions, and has been a pioneer in the private space industry as CEO of Ceres Robotics Inc. For those who want to know the real story behind what it takes to make money in space, this issue will be invaluable. – *mra*.

**SPECIAL LETTER:**

# NEW SPACE: AN OVERVIEW

**by Michael Sims, PhD**

Dual rockets returning to Earth after a day's work:

Dual Falcon boosters land following the initial launch of the Falcon Heavy rocket. (Source: SpaceX)

It's hard to imagine – but nevertheless, a classic sports car with an astronaut figure in a spacesuit is headed on its way to beyond Mars' orbit. It brings back images of the 1960 movie *Visit to a Small Planet*, featuring Jerry Lewis as an alien visitor flying around in a sports car. When the SpaceX Falcon Heavy (FH) rocket was launched in February, the live stream of the event was the second–most-watched in YouTube's history. The feeling of excitement and possibility for the future of space exploration generated by the FH launch evokes the feeling of the beginnings of the human spaceflight era. But is it just about publicity?

 

Actual image of Tesla Roadster and “passenger” flying over Earth. (Source: SpaceX)

Jerry Lewis as “Kreton,” flying over the freeway in *Visit to a Small Planet*.

In this article, I’ll argue the importance of this event for the future of space exploration, beginning with an overview of what’s happening right now that’s new and exciting.

 

## The Import of the Falcon Heavy

Let's consider four domains of space activities in turn: transportation (e.g., launchers), activities in Earth orbit, deep space missions, and missions to the surfaces of planetary bodies such as the Moon, Mars, and asteroids. (This is mostly a US-centric perspective, but many of the points apply internationally.)

SpaceX launched the FH in early February on its maiden test flight, carrying an unusual payload of CEO Elon Musk's first Tesla, a cherry-red Roadster. The Tesla and surrounding spacecraft went into an orbit of the sun that will take it by the orbits of Earth and Mars. We don't yet know what measurements the Tesla and its "Starman" passenger generated, but it's interesting to note that the Tesla is a semi-autonomous, robotlike vehicle designed to generate a lot of data about its environment. Regardless of any measurements, the FH maiden payload was a delightful departure from the usual strategy of flying concrete bricks on initial rocket test flights.

There is much debate about how best to define the term "New Space," but for the purposes of this article I'll use it to mean *any commercial endeavor that is focused on using any new technologies to disrupt space markets by dramatically decreasing the cost relative to traditional approaches of doing those space activities.* The rate at which we explore space has historically been limited by the expense of those endeavors. By disrupting those traditional cost structures, New Space promises to revolutionize humanity's relation to space exploration. We begin by considering those disruptions in space transportation systems.

## Transportation

Let's consider launch systems (i.e., rockets), sorted by size – based on the amount of mass in metric tons (t) they can lift to low Earth orbit (LEO). This allows us to compare all the rockets on a standard scale. Although many of these larger launch rockets are mostly focused on carrying payload to higher Earth orbits and beyond, mass-to-LEO still serves as a useful metric. As is common practice, I'll use the words *launcher*, *launch vehicle*, and *rocket* interchangeably.

### Large launchers (> 25 t to LEO)

In terms of payload to orbit, the FH is the second–most-powerful rocket ever launched, eclipsed only by the Saturn V, which was operational between 1967 and 1973. You may recall that the Saturn V was the rocket that was powerful enough to carry humans to the Moon and bring them home in a single launch.

Today, the FH is the most powerful rocket in operation, by a factor of two or better. At least as important is that it cost only about one-third of that of its nearest competitor. Putting that together, you get an improvement by a factor of maybe 6+,[1] in terms of the cost of getting large payloads to orbit.

Now operational, the FH immediately becomes a very attractive vehicle for getting payloads to deep space, where missions are always battling the compounding pressures of too little mass and too much expense to get payloads launched. This factor of 6 suddenly opens up whole new possibilities in our exploration of the solar system. For example, we can now launch large and capable surface robots for prospecting, construction, and mining, at reasonable economic prices. So, instead of a large space mission that might cost $1B and was only accessible to the largest national space programs, we can now consider missions that cost less than $200M. That $200M is still a lot of money, but it's money that is possible to afford by single or combinations of smaller nations, by corporations, and even by some individuals.

Critical to the success of the Falcon Heavy is that SpaceX developed it with its own money, and did so for about half a billion dollars in total. In contrast, the Space Launch System (SLS) being developed by NASA and its direct contractors has already cost more than $11B[2] and is still a number of years from being operational. SLS has a powerful political presence, and the role of that in future governmental funding must always be taken seriously. A significant threat to the overall SLS approach is that SpaceX's planned Big Falcon Rocket (BFR) promises (on paper, at least) to be developed earlier, to be more capable, and to be cheaper. Even if, like the Falcon Heavy, the BFR's purported delivery date and price are overly ambitious, if it is delivered the BFR will be a disruptive influence on the large-launcher business.

SpaceX and SLS are not alone in the big-launch vehicle business. The traditional large US rockets – the Delta IV and the Atlas V and variants – are also competing to win launch contracts. Blue Origin (Jeff Bezos's New Space startup), China, and others will compete for large launchers. United Launch Alliance and the two companies that partner in it, Boeing and Lockheed Martin, all have business plans that call for selling large launchers. It's easy to imagine that New Space competition will force these traditional launch suppliers to revamp their current cost drivers and incentives.

Blue Origin is a company not to be ignored – in part because it's so well-funded, with Bezos committing to $1B/year to the company. Unfortunately for our understanding of it, Blue Origin continues to operate largely in stealth mode. We do know, however, that its New Glenn rocket is central to that vision.[3]

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[1] Traditionally, pricing of rockets resembles a rug bazaar model, with the seller asking, "How much can you afford?" One of the advances of New Space is that it's bringing fixed, published prices to the market.
[2] Wherever possible, I've used Wikipedia price/cost numbers. Although not necessarily the most accurate, Wikipedia has the advantage that all players have equal rights to edit the entries. https://en.wikipedia.org/wiki/Space_Launch_System
[3] https://www.geekwire.com/2017/jeff-bezos-blue-origin-makes-pitch-congress-delivering-cargo-moon/

*Note:* It is common traditionally for launcher prices not to be published.[4],[5]

| | | |
|---|---|---|
| Delta IV | $300M | 29 t to LEO |
| Falcon Heavy (FH) | $90M | 63 t to LEO |
| New Glenn/Blue Origin* | Not specified yet | 45 t to LEO |
| SLS* | $1B | 130 t to LEO |
| BFR* | $7M | 250 t to LEO |

* Not yet operational Prices and performance may vary!

Independent of other factors, the cost/affordability of the launcher will drive launch rates, and that frequency of launches is the key to engineering iteration.

**Medium launchers (5-25 t to LEO)**

In the middle size of launch vehicles for commercial payloads, SpaceX, with its Falcon 9, is projected to have more than 50% of the worldwide market in 2018. That's best seen by considering commercial launches by launcher's country between 2010 and 2018, as shown below:

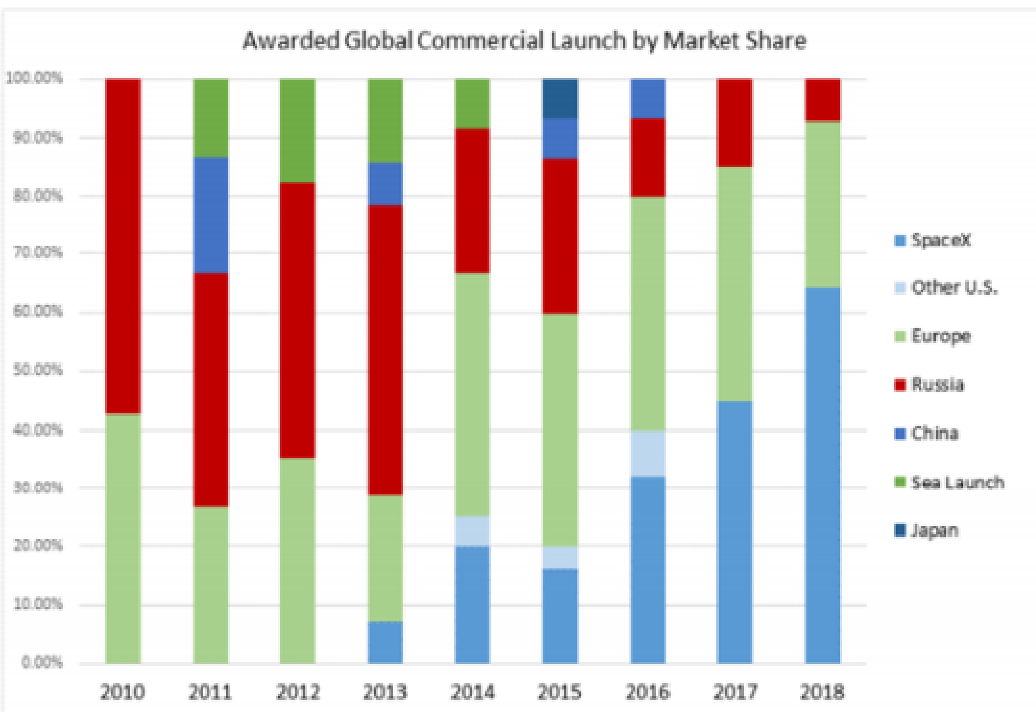



**Figure 1: Global Commercial Market Share**

Market for launch vehicles. (Source: Tweet by Elon Musk)

[4] See previous footnote on cost estimates. Some abbreviations used: FH: Falcon Heavy; t: metric ton (1,000 kg); LEO: low Earth orbit; SLS: Space Launch System; BFR: Big Falcon Rocket.
[5] This is a selected list. You'll find a much more complete list at: https://en.wikipedia.org/wiki/Comparison_of_orbital_launch_systems. Significant vehicles that aren't considered here would include the Indian PSLV and ULV, Japan's HIIB, and China's Long March 7.

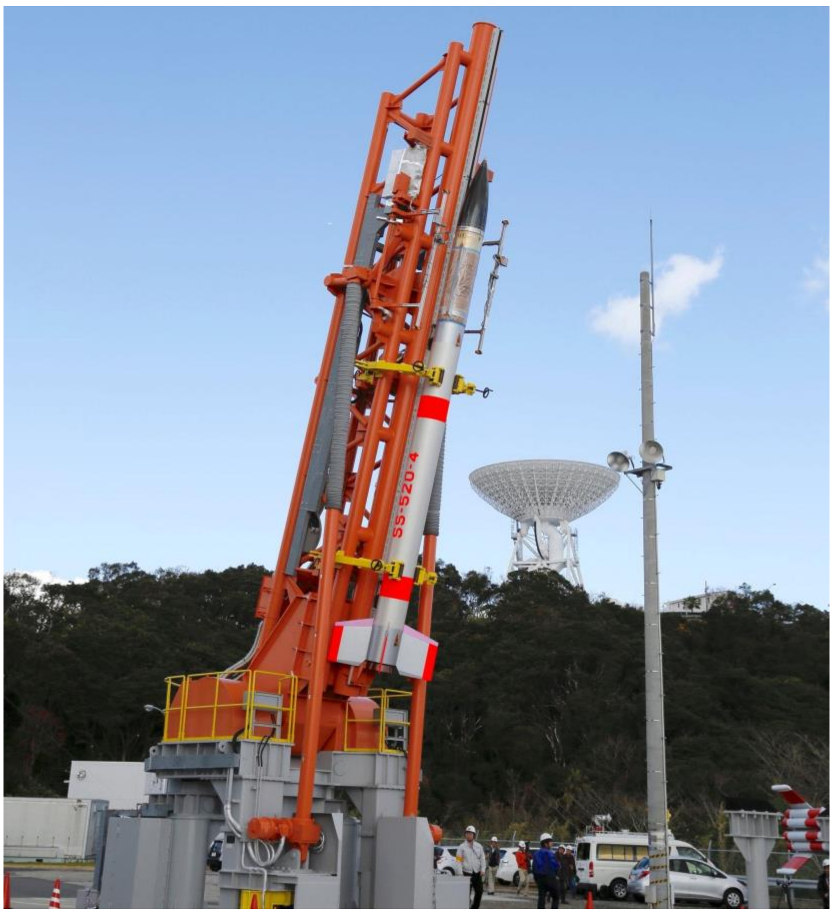
 

Before the Falcon 9, the US percentage of global commercial launches had dropped to zero. This is a field the US once dominated.

| | | |
|---|---|---|
| Falcon 9 (US) | $60M | 23 t to LEO |
| Proton-M (Russian) | $65M | 23 t to LEO |
| Antares (US) | $80M | 6.5 t to LEO |
| Ariane 6 (European) | $95M | 20 t to LEO |

**Small launchers (< 5 t to LEO )**

There has been somewhat of a race to the bottom (in a good way), with the Japanese recently launching the smallest launch vehicle ever to carry its payload to Earth orbit.




Small Japanese launcher. (Photo: SpaceFlight101)

The need for small-size launchers in part grew out of the need created by the clever use of the ESPA[6] ring structure attached to a launch vehicle as a way to easily carry

[6] https://en.wikipedia.org/wiki/EELV_Secondary_Payload_Adapter

"secondary," smaller payloads on medium launchers. This highlighted the need for the inexpensive launching of a class of small satellites, often called CubeSats, or nanosats (nanosatellites). The CubeSat concept was created initially by Bob Twiggs and his students at Cal Poly and later brought into the mainstream by John Hines of NASA Ames and others. However, being a secondary payload on a medium launcher, as opposed to the primary customer, meant restricted launch opportunities and price uncertainty. It was realized that it would be ideal if one could just launch a number of these small satellites when desired and at low cost.

So, an essential goal of the small launchers is to carry these small payloads to orbit as cheaply as possible. With the relentlessness of Moore's law and other exponential drivers, a small satellite itself can now cost as little as $10,000 or less. But how to launch inexpensively? Currently there are dozens of companies trying to break into this market as small, inexpensive launchers for these payloads. Two of the most prominent new players are Rocket Lab's Electron rocket and Vector – with many others waiting in the wings. These companies tend to use 3D printing, inexpensive manufacturing techniques, and quick turnarounds. A careful evaluation of this market could easily fill its own article; here I'll point out only that this small-launchers business is currently an area of dynamic competition.

| | | |
|---|---|---|
| Electron | $6M | 0.225 t to LEO |
| Vector* | $3M | 0.050 t to LEO |

* Not operational yet. Prices and performance may vary!

## Activities in Earth Orbit

Until quite recently, the business of building satellites, as with the business of selling launch vehicles, was an established, stable business. There was, of course, competition, but that competition was mostly well-understood, and businesses could plan for that competition. Recently a new set of companies selling low-cost small satellites for LEO has emerged. Their satellite products can be orders-of-magnitude less costly than any traditional satellite, and these companies are hungry and willing to find novel ways to compete. (One example of this was the idea of building satellites out of smartphone components, described below.) A characteristic of these new space LEO satellites is that they're largely focused on observing the Earth and in setting up communication relays for worldwide internet connectivity.

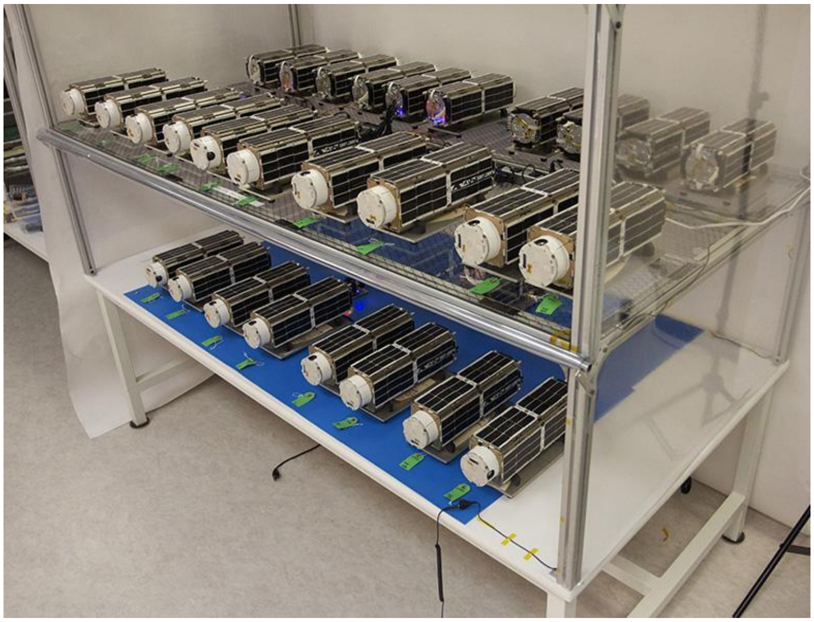
These New Space companies have been able to disrupt the industry of satellites in LEO. Venture capitalist Steve Jurvetsen has pointed out that the individuals doing this disrupting tend to come from outside the business and often with little experience in the industry they are disrupting. Elon Musk, for example, began SpaceX having no previous rocket-building experience.

I think there are two primary reasons for these outsiders succeeding in being disruptive: first, the new entries don't know what they don't know. As outsiders, they haven't yet learned all of the things a business teaches its employees are going to be impossible. Second, these players passionately care about the domain, and as outsiders, often the easiest way to have the influence they want is to start a new company in competition with the old guard. Musk initially went to Russia with friends looking to buy a rocket to get a payload to Mars. But since the Russians didn't recognize the potential of Elon Musk, they didn't offer to work with him. He then found it easiest to start and direct a New Space company.

### Smartphone meets LEO

A group of bright, young engineers who were encouraged and supported by Pete Worden, then NASA Ames Center director, realized that a modern smartphone has most of the instrumentation needed for a satellite to operate – after all, a smartphone has a camera, a radio communication system, a powerful computer, an accelerometer, a thermometer, etc. So they started developing what they called phone satellites, or phone-sats. This team later formed a New Space startup called Planet Labs, now just Planet.

Planet currently operates the largest constellation of satellites, called Doves, that has ever operated in Earth orbit – 220 as of today. This Dove constellation now covers every spot of land on Earth every day. That impressive accomplishment leads to the next disruption to look forward to: imagining all of Earth's land every hour.[7]



Rows of Planet's Doves awaiting launch. (Source: Planet)

SpaceX, always the competitor, is planning to launch a 12,000-satellite Earth orbit constellation and create a network for broadband communication for every spot on

[7] www.bloomberg.com/news/features/2017-06-29/the-tiny-satellites-ushering-in-the-new-space-revolution

Earth. No longer will there be an internet gap between the first world and developing countries.[8]

### Disruption in Earth orbital data analysis

Earth-orbiting satellites have long generated copious volumes of data, and that has become even more the case with the advent of the latest generation of commercial Earth observation satellites, such as those operated by Planet. Additionally, the last decade has brought forth new, powerful machine-learning technologies for pattern recognition that can be brought to bear on this data. Consequently, there's a new class of software-analysis companies focused on turning the plethora of orbital data into analysis that has commercial and humanitarian uses.

An example of these new companies would be Orbital Insights, which does orbital image analytics of parking lots, etc., to evaluate commercial activities in a timely way (e.g., recording how many shoppers' cars are at a particular Walmart on a Friday night).

### New Space companies – following current patterns into the future

New Space companies now have the dominant market share for small satellites as well as small and medium launch vehicles, and they're threatening to capture a large market share for the heavy-launch business as well. Then what's next?

Before addressing that, it's useful to underscore the driving factor in all of this. As alluded to previously, that driver is drastic reductions in costs. SpaceX is succeeding primarily because it is much, much cheaper. Yes, it has to do good engineering and production, but that's expected of any world-class company these days. As with SpaceX, the reason Planet and other New Space satellite companies are out-competing the old guard is because they're drastically decreasing the cost of goods. Much of this is driven by electronics disruption as codified in Moore's law and things that follow from that.

But why does this Moore's law–driven price reduction stop at low Earth orbit? Won't it continue and dominate the industry in higher orbits, such as geosynchronous Earth orbits (GEO)? Although, so far, we just see inklings of that, it seems almost inevitable that this wave of modern space production and decreasing prices will next lead to technologies that disrupt the business of higher Earth orbits, including all the way to the lucrative market of GEO satellites, where we find communication and media satellites.

I anticipate a drastic price reduction for these higher-orbit satellites over time. There are barriers to new business in these higher-orbit satellites, but those barriers will be bridged. These barriers to new competition come from a few specific requirements for satellites in higher orbits. In higher orbits, there are higher

[8] http://www.businessinsider.com/spacex-starlink-microsat-launch-global-internet-2018-2

radiation levels (hence threatening radiation damage to electronics), stronger requirements for reliability, and much stronger requirements for a satellite not to be a hazard to other space artifacts. The latter two requirements are to limit additional orbital debris being introduced. Orbital satellites in low orbits (say, much below the International Space Station's 255 miles/410 km altitude) quickly decay in their orbits and fall back into the atmosphere, where they burn up, mostly harmlessly.

So, if one of Planet's Dove satellites stops working in its low orbit, it doesn't represent a problem; Planet can just wait a bit and it will be gone, burned up in the atmosphere. On the other hand, as you get to higher orbits, there's very little atmospheric drag; for all practical purposes, your satellite is permanently in orbit, and it can become a danger to other objects in orbit. Even worse, if your satellite has a collision with other debris, that collective debris cloud can create many more dangerous objects flying around space, threatening even more collisions. Hence, it is a requirement for any satellite that we put into these higher orbits that it must change its orbit late in its mission life, to either burn up in Earth's atmosphere or get pushed out far beyond the densely populated orbits. These prospective new satellites to be sent to higher Earth orbits must therefore have high reliability as well as a high probability of successfully managing its end of life.

These requirements are barriers to entry. It seems reasonable, however, that they will only slow down, but not ultimately stop, the progression of the wave of price reductions for Earth satellites moving upward to higher orbits.

Having considered transportation systems and Earth orbital satellites, let's now consider two important destinations beyond Earth orbit: deep space and planetary surfaces.

Before leaving the discussion of Earth orbits, it is useful to mention Bigelow Aerospace. Like Jeff Bezos with Blue Origin, founder Robert Bigelow has been using his sizable personal fortune to fund a number of inflatable habitats that are usable in free space and on planetary surfaces. This should be taken seriously, Bigelow having had inflatable habitat structures for more than five years in orbit and currently having had a module attached to the International Space Station (ISS) for more than one year.[9]

## Deep Space Missions

When I use the term *deep space mission*, I'm referring to any space mission that is not to the Earth, Moon, or Mars. Historically, these missions have only been the domain of the US, the EU, Japan, and Russia. It's reasonable to expect that with the decrease in the cost of transportation currently occurring, with launch vehicles

[9] https://www.space.com/37068-beam-inflatable-habitat-first-year-space.html

costing less than $100M, other nations will become involved in deep space missions in the near term, led by China and India.

Such missions are typically organized by science investigators with the primary outcomes being the gaining of better scientific understanding. There is a concomitant expectation of financial rewards to heavy-launch suppliers and various research institutions. An almost defining characteristic of these deep space missions is that they're doing things never done before. Most of these frontier missions are unique in their instrumentation and mission characteristics, and this arena will likely be dominated by governments for quite a while.

### Missions to the Surfaces of the Moon, Mars, and Asteroids

Human activities on the surfaces of the Moon, Mars, and asteroids are about to change in significant ways. Planetary surfaces missions are usually thought of as having three parts: launching, transferring orbits and landing, and surface activities. Launch was discussed above. Currently, NASA's SLS/Orion vehicle or its variants; SpaceX's BFR project; Blue Origin's Blue Moon project; and projects by the European Space Agency, China, India, and others are all working on different variants of transfer and landers capable of soft landings on the Moon, among other places. These are all in the large-lander category, although the BFR should probably be in a category of its own, promising to land 100 metric tons (t) of cargo on the Moon after an Earth orbital refueling and then to take off from the Moon and fly back to Earth.

Stimulated by the Google Lunar XPRIZE (GLXP), a number of New Space startups are working on vehicles to transfer smaller payloads from Earth orbit to a gentle landing on the Moon. These include Astrobotics (US), Moon Express (US), SpaceIL (Israel), PT Scientists (Germany), TeamIndus (India), Synergy Moon (US), Masten Space Systems (US), and iSpace/Hakuto (Japan), among others.

GLXP rules restricted government contributions to less than 10% of the cost of these efforts. In today's environment, this created a problem to establishing the kind of public-private partnerships that appear to be essential for kicking off the most far-reaching of today's New Space startups. GLXP teams' respective governments were the largest, most credible partners for initial, high-risk missions.

Although there were several outstanding engineering teams, none succeeded with the GLXP requirements within the allocated time. Many of the teams promise to stay the course, although there will likely be a shakeout of the teams with weaker leadership and technical expertise. Regardless, it is reasonable to look forward to seeing great things out of several of these GLXP startups. These teams all planned to use medium or small launchers (such as by Rocket Lab), and all their payloads were to be of relatively small mass. The exception to this is Astrobotics, which hoped to partner with other teams and use a Falcon 9 for its launch.

The GLXP teams that continue all hope to create markets that allow them to thrive in an economically competitive market, primarily with either a "FedEx-like" delivery service to the Moon or by the utilization of some raw resource from space. In addition, many science goals – especially for the Moon – could be economically supported by these GLXP companies which will build smaller landers.

Two of the largest New Space companies, Blue Origin and SpaceX, have their eye on landing on surfaces of the Moon and Mars. SpaceX has its Dragon capsule (needing repurposing from ISS to a Moon/Mars landing) and its future BFR. Blue Origin is actively working on its Blue Moon vehicle designed for shuttling payloads from the Earth to the Moon and back.

**What to do on a planetary surface?**

The Moon has no atmosphere and experiences extremes of temperature. Mars has dust that accumulates and gets into mechanisms and sensors, interfering with their function. Asteroids have low gravity. Among other things, we'll need different modalities of locomotion. In spite of different surface conditions, much of the controlling software, computational components, sensors, and ground control will share a common core.

But once we get a robot to a surface, what does that robot actually do? One can think of three classes of activities: scientific exploration, establishing and supporting human structures, and resource utilization activities.

**Scientific investigations** require both measurements and understanding of the context of those measurements. So, for example, it's usually desirable to know the elemental (e.g., via measurements from an alpha particle X-ray spectrometer instrument) and the mineralogical (e.g., via measurements from a Mössbauer or Raman spectrometer) composition of material from a surface. But a single measurement is fairly useless unless you know the context. Is it bedrock or sand measurement? What is the local topography? What does the detail surface look like with a hand lens? Is it contained in a historical lava flow or aqueous area?

We're also interested in how those measurements have changed over time and by exposure, so we could freshly expose areas, as well as subsurface materials. Ultimately, we want to analyze the most interesting samples in a fully modern laboratory by returning them to Earth laboratories or at a well-equipped surface laboratory. Additionally, there are a multitude of other measurements to be taken for other scientific interests, such as strength of magnetic fields, radiation flux, ground-penetrating radar, and atmospheric/dust environment. In general, these measurements and their contexts can be managed by rovers which are slight variants of the robots that have flown or of the much larger number designed but not yet flown.

The second class of tasks on the surface is **establishing and maintaining human surface structures**. If we land a Blue Moon, Orion, or BFR vehicle on the Moon, we'll need to unload objects onto the surface and appropriately deploy them. It is limiting to do that using humans. First, we often wish to do these tasks when humans aren't around, including before humans arrive. Second, humans aren't very good at this, because space suits required for any deployments to the surface are bulky and not suited for long hours of arduous labor. These are tasks that are readily accomplished by robots, and the economics, workloads, and safety factor favor using robots instead of humans. In addition to these unloading cargo vehicle tasks, some examples of supporting tasks where robots would be utilized include deploying solar arrays, laying cables and other power distribution infrastructure, inspections of vehicle exteriors and habitats, deploying habitats and greenhouses, tending greenhouses, transporting regolith, following humans as assistants, establishing dynamic mobile communication relays, preparing road structures, and so forth.

The third class of surface tasks would be those in support of **in situ resource utilization**. All of the materials mined on Earth are abundant in one space environment or another. Companies such as Deep Space Industries, Planetary Resources, and Moon Express have built business cases targeted at finding resources, accessing those raw materials, and processing those materials. A good model would be an Earth steel business that prospected for accessible rich iron deposits, gathered those deposits, deposited them in a steel mill for creation of steel bars, and finally transported the output products to where they're needed. This kind of processing will be needed for dozens of different materials. Robots will be used in each step, from prospecting, raw-material acquisition, and transport and processing to ultimately transporting end-product to final destination.

Our New Space startup, Ceres Robotics Inc., has a vision of building several kinds of surface robots to assist in the tasks described above to support humans in becoming multiplanetary. We are building the smart shovels and smart wagons for the gold-rush miners of the future. Our first production model, M2, will be adaptable to a broad class of tasks, including surface prospecting, science, deployment, and inspections.

Jeff Bezos and Elon Musk have suggested that as humans become multiplanetary we will see 1 million people off Earth. It's reasonable to expect a timeline of, say, 40 to 100 years for that. Robots have advantages over humans in their tolerance to harsh environments and in the economics of transportation and operations. It's also reasonable to project that we will need at least as many robots in space as humans off Earth. At Ceres Robotics Inc., we see this both as a business opportunity and as a chance to make a difference in the path we take in space exploration.

## The Shocks to the Space Exploration Paradigm

Musk's goal is to bring down the cost of transporting a person to Mars, and supporting that person, to a cost comparable to the price of a California house – a few hundred thousand dollars. The reason this is critical is that it implies that there can be a profitable business that sells only to individuals, with no direct need for government funding of that endeavor – no need for the next US humans-to-Mars big Apollo-like commitment at a high cost for a government program.

Launch competitors planning to be competitive with the Falcon 9 must look back at the BFR goal price/mass to LEO in the table above. The goal of a cost of $7M per mission for a BFR wasn't a misprint. The design for BFR calls for it to be more than an order of magnitude cheaper than Falcon 9, and it's designed to carry 4*x* the mass. So, in this one new vehicle, SpaceX is designing a 14*x* improvement in cost of mass-to-LEO, and hence to planetary surfaces – over the company's own current product! Just to be concrete by analogy: this kind of change in an airline would mean that your usual $140 airline seat would now cost $10. Maybe the BFR will fall somewhat short of its goals, but we're definitely talking about an improvement of more than a few percentage points here.

A BFR is designed to do those things while going from the Earth's surface to the surface of the Moon or Mars, and to reuse all the rocket parts. It's unlikely that this is the last step in SpaceX's ambition for inexpensive spaceflight.

With most businesses, you can understand their actions by understanding their short-term expected profits. It helps in understanding SpaceX to appreciate that virtually everything it does is focused on how best to get from today to a world where a million people can individually afford to travel to Mars, and in doing so, establish humanity as multiplanetary.

This is change designed to be occurring at an exponential rate. Think of the exponential change in the power and cost of computers as an analog. SpaceX is focused on driving the costs of transportation to make that possible, because that's what leads to costs that affluent individuals can afford.

On the other hand, Ceres Robotics is focused on the other part of the equation. Ceres' focus is on driving the technologies and costs of planetary surface activities – specifically, the robotic tools we need – until we can afford to do everything we need to do on planetary surfaces to become multiplanetary. Affordable robot technologies coupled with affordable transportation systems together will allow us to become multiplanetary in the near future.

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*Author's Note:* A number of related other significant and interesting topics not covered here include: the lunar gateway, the ISS space station, orbital transfer tugs, nuclear power for transportation systems and surfaces, infrastructures for humans such as surface and orbital habitats/stations, orbital debris cleanup, satellite servicing, communication systems (interplanetary internet, surface-space, wireless LAN, mesh networks), and sample return missions.

## About Michael Sims

Michael Sims, PhD, is the CEO and founder of a new space startup, Ceres Robotics Inc., that is in the business of building robots for the construction of facilities and habitats on the Moon, Mars, asteroids, and beyond.

Michael's career has been devoted to using AI and robotics to enable exploration and to support humans becoming a multi-planetary species. He was previously vice president at Moon Express, and for more than 20 years worked at NASA, where he worked on Mars rover missions.

Michael was a founding member of the NASA Ames Artificial Intelligence group and its field robotics program, the Intelligent Robotics Group. He was previously the chief agent for Automation, Robotics, and Human Factors for NASA's Office of Exploration, which had responsibility for planning all human missions below low-Earth orbit.

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I would like to thank Michael for taking the time to provide this detailed roadmap into commercial space, so that we can share it with SNS members.

And, last and never least, our gratitude to Editor-in-Chief Sally Anderson, for putting all of these thoughts into perfect shape.

Your comments are always welcome.

Sincerely,

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## ADDITIONAL SUPPORTING ORGANIZATIONS

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## Where's Mark?

• On March 13, Mark will be giving a Google Talk at Google HQ on his discovery regarding the universal drivers of Flow and Interaction. • On May 7, he'll host a dinner discussion at the annual Info-Tech Research LIVE Conference (www.infotech.com/events/live) in Toronto, and on May 8 he'll be the conference keynote speaker on the subject of “Pattern Discovery: Digital Transformation's Missing Ingredient.”

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