



THOMAS R. EISENMANN  
JEFFREY J. BUSSGANG  
DAVID LANE

## Analytical Space: The Next Frontier?

Early on July 14, 2018, the founders of Analytical Space, Inc. (ASI), CEO Justin Oliveira and COO Dan Nevius, exchanged high fives in their Cambridge, Massachusetts office as they watched ASI's first satellite, Radix, deploy into Earth orbit from the International Space Station (ISS).<sup>1</sup> The two entrepreneurs were elated to see their satellite in space after years of hard work. Radix's proof-of-concept mission was to show the technical feasibility of relaying data from Earth observation satellites (EOSs). EOSs would transfer data to Radix using their radio frequency (RF) transmitters. Radix would then downlink the data to ground stations on Earth using either a novel, high-speed laser – or, when laser transmission was not feasible – the slower RF technology. The startup aimed to launch a network of small satellites to provide data relay service to EOS operators, thereby boosting the amount of data that operators could collect and sell.

Now that Radix had deployed, successful beta testing of its capabilities would allow Oliveira and Nevius to turn to critical questions regarding their go-to-market and pricing strategies. First, who was their best initial target customer, and – given the emerging nature of the market – how could they best validate demand for their service? Second, what price could ASI command for its service given the novelty of its value proposition? The stakes were high. The company was roughly halfway through their \$3 million seed round and would be out of cash in 12 months. ASI needed to make meaningful progress on these and other questions in order to be well positioned for a new financing round, a critical next step as the founders continued to pursue their dream of building a massive data communications network in space.

### Launching ASI

Justin Oliveira and Dan Nevius met as MBA students at Harvard Business School (HBS), where they founded ASI in 2016. Before HBS, Oliveira earned BS and MS degrees in Aerospace Engineering from Florida Institute of Technology. He then spent eight years at NASA in a range of technical and strategy roles, including principal investigator for a CubeSat mission and program examiner for NASA Human Spaceflight and Aeronautics Research programs in the White House Office of Management & Budget. These experiences educated Oliveira about infrastructure gaps confronting NASA, including space-to-ground data transfer capacity constraints.

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Prior to HBS, Nevius received a BS in Electrical Engineering, Computer Science and Astrophysics from Harvard College, then earned an MPhil in Engineering by Research from University of Cambridge and an MS in Space Science and Engineering from University College London. After working briefly as an associate at the Boston Consulting Group, Nevius decided to pursue his passion for space entrepreneurship and joined Planetary Resources, a startup aiming to mine asteroids for water to be split into hydrogen and oxygen for use as rocket fuel.

The two founders met early in their first year at HBS and immediately began brainstorming concepts for a “space tech” startup. Their first idea was to launch a constellation of CubeSats into low Earth orbit (LEO;<sup>a</sup> <2,000 km in altitude) to provide low-latency data connections between traders and securities exchanges. CubeSats were small, inexpensive satellites built from commercial, off-the-shelf components, and structured as modules that could function independently or be combined to form larger satellites. The proposed venture would cross-link data between CubeSats to connect trading partners who otherwise would rely on fiber optic land lines. High-frequency traders made extraordinary efforts to reduce the elapsed time between order initiation and receipt. When arbitraging miniscule price discrepancies between different exchanges, profits could vanish with delays of far less than one millisecond. Oliveira and Nevius had calculated that a network of LEO satellites could transfer data faster than fiber optic lines, although building and launching the satellites would cost hundreds of millions of dollars – a daunting proposition for an unproven technology.

### *Pivoting to a Data Relay Network*

Nevius and Oliveira searched for an alternative approach that would require a more modest investment. Oliveira’s prior experience with space communications architectures at NASA and Nevius’s prior experience at Planetary Resources pointed to a promising candidate. Nevius had analyzed commercial applications for Earth observation using hyperspectral imaging technology that Planetary Resources had developed to determine, from spectral “fingerprints,” whether there was water on asteroids. Hyperspectral imaging collected electromagnetic spectral information for every pixel in an image plane. Unique spectral signatures could be used for a range of applications, including finding minerals and oil; monitoring crop health; detecting pipeline leaks, oil spills, and illegal waste dumping; tracking emissions from power plants; and spotting troop movements.

From his work at Planetary Resources, Nevius knew that hyperspectral imaging from space would increase rapidly in the coming years – and with it, the need for high-bandwidth, space-to-ground data transfer. From his mission-planning work at NASA, Oliveira in turn knew that: 1) space-to-ground data transfer by EOS operators already confronted significant capacity constraints, which would worsen over time as data volumes increased; 2) data transmission by laser was nearly 10 times faster than the RF technology that EOSs currently used and could help address these constraints; and 3) low-cost CubeSats could be equipped for laser transmission.

The founders devised a new plan for ASI: they would build and launch satellites that would cross-link with EOSs in space using RF technology and downlink the EOSs’ data to the ground using high-speed laser technology. Unlike their original concept, which required launching a full constellation of satellites before earning any revenue, this plan allowed a single ASI satellite to potentially provide a profitable “store and forward” service to an initial set of customers. Over time, ASI could launch more

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<sup>a</sup> Satellites used for purposes other than Earth imaging also operated at medium (2,000-35,756 km altitude), geostationary (35,756 km), and high Earth orbits (>35,756 km). (Source: Umair Hussaini, “Low Earth Orbit, Medium and High Earth Orbits – Types of Orbits (2/3),” Technobyte.org, November 5, 2018, <https://bit.ly/36QuRYF>, accessed November 2018.)

satellites to form a network in space, boosting its downlink capacity and reducing the time required to deliver client data. (Exhibit 1 depicts ASI's phased strategy.)

As they began their second year at HBS in September 2016, the founders raised a \$500,000 pre-seed round led by Space Angels, an investor group of experienced executives who backed space tech startups. A year later, ASI raised a \$3.5 million seed round from Flybridge Capital Partners, Shasta Ventures, and The Engine. Oliveira recalled that raising capital for ASI was not easy given the new, over-the-horizon nature of the technology (a category commonly known as "Frontier Tech"): "We spoke to about sixty or seventy funds in total. We taught lots of VCs the basic principles of space technology. If, after an hour, we were still explaining orbits, we knew we were in trouble."

After raising venture capital, ASI's team researched the requirements of EOS operators, analyzed network deployment options, and successfully designed and built their first satellite – Radix.

## Earth Observation Satellites

In late 2017, 575 Earth observation satellites were active in low Earth orbit.<sup>2</sup> They were mostly used for imaging (63%), meteorology (13%), earth science (9%), radar imaging (9%), Automatic Identification System applications (e.g., tracking ships at sea, 9%), and electronic intelligence gathering (7%). Fifty percent of EOSs had commercial users; 30% had non-military government users, typically space agencies and meteorological authorities; 17% had military users; and 7% had non-commercial civilian users, principally university researchers.<sup>b</sup> (See Exhibit 2 for information on the distribution of EOSs by purpose, primary use, and weight.) In 2017, the number of EOSs launched into orbit by commercial and civil users (275) for the first time exceeded the number launched for government and military purposes (19).<sup>3</sup>

Globally, the entire satellite industry generated \$261 billion in revenue in 2016. The bulk of the market consisted of ground equipment and satellite services, such as satellite TV broadcasting. Of the satellite services segment, \$2 billion was the amount governments and corporations paid for data from commercial EOS operators, a figure that was growing at a rate of 11% per year. Defense spending drove 61% of commercial EOS revenue; the remainder came from infrastructure (10%), natural resources (9%), energy (7%), location-based services (e.g., mapping images to GPS data, 5%), maritime (4%), and disaster management (2%) uses.<sup>4</sup>

Technological advances were dramatically improving the performance of imaging satellites – and sharply increasing their data downlink requirements. Hyperspectral imaging sliced the electromagnetic spectrum into as many as 50 or more bands, in the process creating a spectral fingerprint that facilitated the detection of objects, materials, and processes. Synthetic-aperture radar (SAR) swept a radar beam over a target to obtain higher resolution 3D images than traditional radar spot beams could obtain, and SAR could locate objects at night and through cloud cover. SAR satellite images were used for military surveillance, forest management, monitoring floods and coastal erosion, measuring glacier growth/shrinkage, and planning new roads, among other purposes. As of mid-2018, only three satellites made SAR data available to commercial customers, but many more were planned.

The number of satellites in orbit was projected to increase significantly as operators pursued better imaging technologies, leveraged reductions in satellite launch costs, and found new uses for inexpensive micro satellites. Early satellite missions focused on scientific research. More recently, entrepreneurs were launching constellations of CubeSats to provide data communications and Earth observation services. Up to 2,600 small satellites would be launched between 2018 and 2022, of which

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<sup>b</sup> Figures for satellite purposes and users do not add to 100% because some satellites had multiple purposes and/or user types.

half would be for Earth observation and therefore part of ASI's addressable market.<sup>5</sup> Many others would be for global broadband internet providers – among a dozen firms with similar plans, OneWeb had raised \$1.7 billion for a constellation of 1,000 satellites; SpaceX had U.S. approval to launch a constellation of 4,425.<sup>6</sup>

### *Commercial EOS Operators*

Commercial EOS operators could be segmented by business model. One segment operated a few large satellites with powerful instruments that could capture very high resolution (VHR) optical and multispectral images, detecting objects as small as 30 cm – the size of a human footprint. These satellites imaged targets specified by large customers who had signed long-term contracts – typically defense and national security agencies. If the satellites had additional data collection capacity after meeting contractual commitments, they would image targets for other customers. In addition to revenue from long-term contracts and spot sales of targeted images, the operators sold archived images, within limits set by the large customers who had originally requested them.

Eight EOS operators who owned a total of 29 satellites fit this profile. The two largest operators were Airbus Defence & Space and DigitalGlobe. The European aerospace giant Airbus was a leading manufacturer of satellites, including EOSs. Through its Defense & Space division, Airbus also operated EOSs, providing imagery to government and commercial customers through a portfolio that included four VHR and two SAR imaging satellites. DigitalGlobe was a U.S. company that earned \$725 million in revenue in 2016 – 64% of which came from U.S. government contracts – and \$102 million in operating income. DigitalGlobe operated five VHR imaging satellites and owned or contracted with eight ground stations. Its newest satellite, WorldView-4, began operations in 2017. WorldView-4, which weighed 2,485 kg and had an expected life of ten years, cost \$835 million to build and launch. In 2017, DigitalGlobe was acquired for \$2.4 billion by MDA, a leading satellite manufacturer and the operator of a SAR imager that was jointly funded by the Canadian Space Agency.

A second segment consisted of commercial EOS operators that were less targeted and instead deployed a large number of small satellites capturing medium resolution images of the entire globe that were refreshed with high frequency. The largest of these players was Planet, a startup that had raised over \$770 million in venture capital. Planet operated a constellation of 190 CubeSats, each weighing just 5 kg and capable of imaging at 3- to 5-meter resolution. To complement their capabilities, in 2017 Planet acquired Google's seven high-resolution SkySat EOSs for an undisclosed amount. Google had paid \$500 million for SkySat in 2014. Planet had multiple emergent rivals who were launching constellations of small satellites for remote sensing. These included BlackSky Global, Satellogic, and UrtheCast; state-backed Chinese firms were also moving into the market, according to one observer.<sup>7</sup>

One recent entrant, ICEYE, had achieved “the impossible” – building a 70-kg SAR satellite that was launched in January 2018 on a three-year budget of roughly \$20 million.<sup>8</sup> In May 2018, ICEYE closed a Series B round that raised \$34 million to fund and deploy a constellation of 18 similar satellites by 2020<sup>9</sup> with the aim of delivering hourly images of any location on earth.<sup>10</sup> ICEYE believed these images would be highly valued for myriad downstream applications, such as the monitoring of crops, icebergs, and natural disasters (fires, floods, oil spills). (**Exhibit 3** lists additional commercial EOS operators. **Exhibit 4** suggests scenarios for the evolution of the EOS imaging market.)

Still other firms differentiated themselves by applying data analytics to EOS content. Based in Santa Fe, New Mexico and spun off from the Los Alamos National Laboratory, Descartes Labs ingested 100 terabytes of satellite data daily to generate datasets that allowed its clients to model geospatial scenarios such as crop yields, the spread of disease, or the impact of fracking. It did so by overlaying

multiple datasets on a base map showing any of 2,600 cities at a resolution of 50 cm.<sup>11</sup> Orbital Insight combed EOS data for evidence of commercial trends, monitoring 260,000 U.S. parking lots to compile data on retail foot traffic, and U.S. cornfields and global oil storage facilities to generate insights on production and stocks well ahead of regularly scheduled government releases.<sup>12</sup> TellusLabs relied on a network of lower-resolution multispectral EOSs to generate daily worldwide metrics on over 20 crops. Its 2017 estimates for U.S. corn and soy production, for example, were available months before the government's and were accurate within 1%.<sup>13</sup>

### *Downlink Capacity*

EOSs downlinked data to ground stations using RF transmitters. EOS operators built their own ground stations or leased long-term access, often from providers in multiple countries. In November 2018, however, Amazon Web Services announced that it would partner with Lockheed Martin to add 12 RF ground stations to its cloud computing services and would charge EOS operators only for transmission minutes used.<sup>14</sup> The move was lauded as a way to further reduce entry costs for satellite companies, eliminating the cost-prohibitive need to create their own ground networks.

Several factors could limit a satellite's downlink capacity. Higher data transmission rates required a larger amplifier and antenna to magnify and concentrate the RF beam but consumed more power, requiring larger and more expensive satellites. A second limiting factor was the amount of time EOSs spent over ground stations. Satellites could only downlink for data transmission when they were within a ground station's line of sight; cloud cover did not block or significantly impede their RF signals. A typical data transfer session lasted 7 to 10 minutes at most.<sup>c</sup> According to ASI's founders, an EOS with access to a network of 20 to 25 ground stations dispersed around the world could achieve a maximum access rate of 30%; that is, it could theoretically spend up to 30% of its time downlinking. In practice, most EOSs spent no more than a handful of hours each day downlinking, due to their inability to capture imagery and downlink data simultaneously.

Peak data downlink rates for RF transmitters ranged between a maximum 25 megabits per second (Mbps) for small satellites and 800 Mbps for the largest commercial imagers, such as WorldView-4. (See **Exhibit 5** for specifications of representative EOSs.)

Adding ground stations boosted access rates, but: 1) satellites spent 70% of their time over water, often out of range of both ground stations and most imaging targets; and 2) ground stations were expensive, costing as much as \$2 million to \$4 million to construct, and more to operate.<sup>15</sup> Finally, the spectrum allocated to satellite transmissions was limited, and multiple simultaneous satellite transmissions to the same ground station at adjacent radio frequencies could create signal interference. These constraints created an opportunity for ASI's network of data relay satellites.

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<sup>c</sup> The distance between a ground station and a satellite orbiting at 600 km just as it rose over the horizon was 2,829 km. If the satellite passed directly over the ground station, this implied a maximum contact time of 12.4 minutes. However, many ground station antennas only tracked satellites through a maximum of 160° rather than a full 180°, which reduced possible contact time to 8.4 minutes at a maximum elevation of 90°—and less if the satellite did not pass directly overhead.

## ASI's Technology

### *ASI's CubeSats*

ASI's first satellite, Radix, could cross-link with most EOSs and with other ASI satellites at distances of up to 2,000 km.<sup>d</sup> The RF system could also be used to downlink data at 100 Mbps, either in parallel with laser transmission or when downlinking to an optical ground station was not feasible.

To receive or transmit data, the satellite itself had to be reoriented via onboard motion control equipment. Radix also incorporated a separate radio for telemetry and control, mass storage and a data handling system, a flight computer, and avionics that facilitated positioning by locating the sun, stars, and horizon. Solar panels provided electric power and batteries held power in reserve. ASI's team purchased most components from vendors but designed and built others before integrating and assembling the system.

ASI's founders projected that their satellites would have a useful life of three years. The eventual cause of mission failure was difficult to predict. If parts malfunctioned in ways that allowed operation but required extra power, then battery cycle fatigue could end mission life. Most CubeSats had no thrusters for propulsion, so they had no way to boost themselves back to their original altitude as atmospheric drag pulled them down. A CubeSat might remain in orbit for over a decade, gradually losing altitude until burning up while re-entering Earth's atmosphere.

### *The Next Innovation: Laser Downlinking*

Laser, or optical, transmission of data through space had other advantages besides its high bandwidth. Laser beams were narrow and consumed less energy per unit of data delivered than RF transmissions, which spread widely as they traveled and required higher power to ensure reception. Further, unlike RF communications, laser transmissions did not cause interference and were not subject to spectrum allocation regulation. Finally, optical transmissions were more secure than RF, a key concern for military users. Intercepting a laser signal required being in its direct path, allowing the receiver to notice any interruption and immediately halt transmission.

However, laser transmission posed challenges. Its narrow beams had to be precisely aimed. Also, lasers could not transmit through cloud cover. Even with clear skies, a high level of atmospheric turbulence (e.g., due to the jet stream) could disrupt transmissions. On average, clouds covered about half of the Earth's surface at any given time. Optical ground stations—those able to receive laser transmissions—could be located in regions with less cloud cover.

European space authorities had already demonstrated satellite-to-satellite laser transmissions at 5.6 gigabits per second (Gbps), and vendors were marketing 10 Gbps laser transmitters for satellites. ASI purchased 1 Gbps laser transmitters for its satellites and contracted for optical ground station services. ASI's founders estimated that with access to a network of 20 to 25 optical ground terminals in dispersed locations, its satellites would spend 25% of their time passing over terminals—slightly lower than the 30% access rate for RF downlinking, because laser transmission required higher minimum elevation angles. Higher elevation angles also shortened downlinking time per pass to an average of 6 minutes.

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<sup>d</sup> The maximum line-of-sight distance between two satellites orbiting at 600 km was 5,658 km, but radios on most EOSs were designed to transmit up to 2,000 km—roughly the distance to a ground station after a satellite rose over the horizon. At greater distances, the attenuation of diffracting RF signals and the modest size of an ASI satellite's RF antenna would impair reception.

On average, weather conditions would allow for successful laser transmission during 25% of passes over optical ground terminals.

The bandwidth gains and other advantages available through laser downlinking raised a question about ASI's strategy: Would the next generation of EOSs adopt lasers for downlinking, obviating the need for ASI's relay network? Nevius commented on this risk:

Laser downlink requires a very focused beam. Adding precise positioning capability for laser downlink would add to the cost, complexity, and weight of an imaging satellite. If you don't point the laser with the satellite body, you need a separate mechanical arm to aim it.

Over time, we could adapt our network to receive laser transmissions from EOSs and quickly send their data through our in-orbit relay network to the nearest cloud-free optical ground terminal. It doesn't make sense for most EOSs to put lasers on their satellites unless they have access to a data relay capability to get around the latency issue. More broadly, if imaging satellite operators could design their future satellites with our network in mind, they might make different choices about how to balance data collection and transfer capabilities, giving them enhanced capabilities and more operational flexibility.

## Creating a Business Model

### *Pricing*

Determining how to price the ASI system was not obvious. RF ground stations typically charged satellite operators \$100 to \$300 per pass. For an EOS downlinking at 300 Mbps for 8.5 minutes per pass, this amounted to \$5 to \$16 per gigabyte (GB), depending on whether the operator required priority for downlinking. Priority downlinks typically cost at least twice as much as "best efforts" downloads that lacked priority.

By reducing latency, ASI was enabling a whole new set of applications and therefore revenue opportunities for satellite operators. For example, by reducing the ground latency to hours and even minutes, operators could create near real-time asset tracking and observation applications that could have an enormous amount of value for national defense, weather forecasting, and other uses. Proving that ASI could deliver the incremental download capacity and low-latency capability would unlock great value, Oliveira explained, because the alternatives were so expensive and impractical:

If satellite operators face downlink capacity constraints, the only way they can collect and sell more data is to launch another satellite. Since big satellites cost dozens or, in some cases, hundreds of millions of dollars to build and launch, that's a dicey proposition. Holding satellite capabilities constant, a new satellite will by definition be less profitable than one they are already operating. They'll sell to the highest-margin customers first, so they'll tend to earn lower margins on the next batch of customers attracted to a new satellite.

There might not be enough new revenue to cover the huge, fixed costs of launching and operating a new satellite. That's where we step in. We dramatically lower the cost of adding new capacity, so an EOS operator can service additional customers and still make a profit. We help them to defer satellite launches until demand matches supply. For those benefits, we think we can command a premium price.

For VHR images, the ASI team estimated that the value of an additional GB to the downstream application providers could be \$1,000 to \$2,000 or even more. Assuming the midpoint of \$1,500, they

calculated that a single ASI relay satellite – not part of an ASI constellation – could relay data from four customers (if used to its maximum capacity by each customer) and would enable each customer to generate up to \$30 million per year in additional revenue.

### *Costs*

To deliver on its vision, ASI needed more than just Radix, their first proof of concept. The startup needed to launch a constellation of satellites to create the relay network in space. The founders estimated that building and launching each new CubeSat would cost them about \$1.75 million. Launching several CubeSats at once would not significantly reduce the cost per satellite.

Based on their initial conversations with ground station vendors, the founders believed that the cost of using a partner's optical ground infrastructure or building would be broadly in line with the roughly \$5 per GB that EOS operators paid to RF ground stations. ASI's relay network faced no other significant variable costs.

Besides satellite depreciation, ASI's engineering and sales staff would represent most of its fixed costs. The founders estimated that annual fixed costs required to manage a constellation of 22 satellites (excluding depreciation) would be in the range of \$3 million to \$4 million, up from the company's current \$1.5 million annual burn rate. As of mid-2018, ASI had 12 full-time employees: 10 engineers (including the founders), a regulatory director, and a CFO. A similar number of interns from area universities contributed to technical and business development. To execute on their business plan, the founders projected that they would double the size of their salaried team in the next year, adding six engineers and five business development staff, including a new head of business development.

### **Decisions**

Based on its burn rate with the ramped up staffing model, the company would be out of cash in mid-2019. Thus, the founders planned to raise a Series A round in early 2019 but were uncertain about the key milestones that would enable them to do so. A standard software-as-a-service company could expect to raise a strong Series A round with annual recurring revenue of \$1 million to \$2 million and year-on-year revenue growth of 50% to 100%. But ASI was not a standard company by any measure. ASI needed more capital to build and launch more satellites, which would allow it, in turn, to validate market demand and pricing. Yet to achieve meaningful revenue commitments and validate market demand and pricing, customers would need to be convinced to work with the startup before its actual capabilities were in place and without a full network of satellites in orbit. The founders felt trapped in this circular loop as they turned their focus to the commercial elements of their business model. "How do we sell something that doesn't quite yet exist?" Oliveira wondered.

### *Business Development and Pricing*

Answering these questions required a more robust go-to-market plan than ASI had time to create in the run-up to the launch and deployment of Radix. No revenue model could justify building a satellite constellation or elicit Series A funding without persuasive evidence of ASI's addressable market and a plausible pricing strategy built upon customers' willingness to pay. In turn, pricing and contract terms, as well as ASI's business development staffing plan, had to reflect insights about customer segmentation, customer demand, and sales cycles.

As Radix's launch approached, Nevius had shifted from supporting Oliveira on product development to leading business development. Over the course of 2018, he had met with over 50

companies and government organizations, collectively representing over 300 EOSs in orbit, to pitch them on the ASI concept and data relay service. The feedback had been very positive; nearly all had indicated, “If you successfully launch it – and can deliver superior data relay capacity – we will buy.”

Converting expressions of interest into actual signed contracts was another story. Nevius and Oliveira designed a five-stage pipeline process: (1) expression of interest; (2) conducting analysis; (3) verbal commitment to purchase; (4) Memorandum of Understanding (MOU) outlining the terms drafted; (5) MOU signed.

Because the ASI team had not settled on pricing, the founders had two possible approaches to the next step in the sales process: to secure multiple signed MOUs without a negotiated price in order to show future investors the breadth of market commitment and the size of the market opportunity, or to negotiate a specific price with a few key operators to show their willingness to pay ASI a rate for superior service that substantially exceeded the standard \$5 to \$16/GB price for downlinked data.

Based on their customer discovery to date, the ASI team believed that their service could generate as much as \$1,500/GB of incremental value in both new revenue opportunities and reduced satellite costs for EOS operators. The founders felt they could argue for as much as one third of that incremental value for themselves, representing a price of \$500/GB. But the last thing they wanted to do in an early market was to scare off their first cohort of pioneering customers. On the other hand, pricing too low might scare off prospective investors. The team estimated its total addressable market as 1,875 satellites – the 575 existing EOSs in orbit and half of the 2,600 EOSs forecasted to launch by 2022. At a downlink price of \$10/GB, the entire market size would represent annual revenue of roughly \$180 million. At \$500/GB, however, ASI’s total addressable market would be \$9 billion in annual revenue – a massive market expansion compared to the \$2 billion governments and corporations paid for commercial data in 2017. Analysts were split with respect to the future of the market, as one report summarized: “[There is no] clear answer to the future industrial, technical and political structure of EO systems [...] The main unknown is the actual role of space data in a big data world.”<sup>16</sup>

The length of the sales cycle was also a concern. Some government clients had high willingness to pay for low-latency data, but public tenders and government procurement processes were lengthy, complex, and favored the low-cost bidder. ASI could be stuck in 12- to 18-month-long procurement processes, or worse. Plus, regardless of whether a client was public or private, ASI would need three to six months of work with operators’ technical teams to integrate with their often proprietary communications protocols, even after having persuaded an operator to purchase its service.

### *Team*

Oliveira and Nevius knew that they were stretched far too thin to handle the business development function by themselves. As the founders thought about adding additional capacity to their team, they wondered what profile for a new hire was best. Over the summer, several MBA interns ASI had hired as business development resources had produced a number of leads and helped support Nevius in preparing for his meetings. Would a full-time junior resource with a similar profile be the right answer, or should the founders seek more of a peer, to whom Nevius could delegate part of the selling and closing process? Would this hire need to have satellite industry experience and an existing network, or just be a skilled seller from another technology-intensive industry?

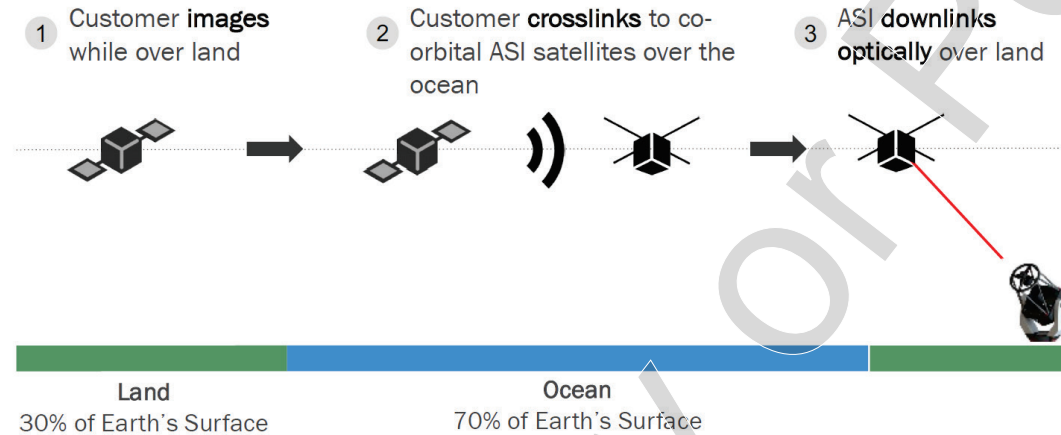
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As the euphoria of the Radix deployment wore off, Oliveira and Nevius decided to sit down for a focused discussion about the range of issues they faced. Oliveira felt the intense pressure of testing

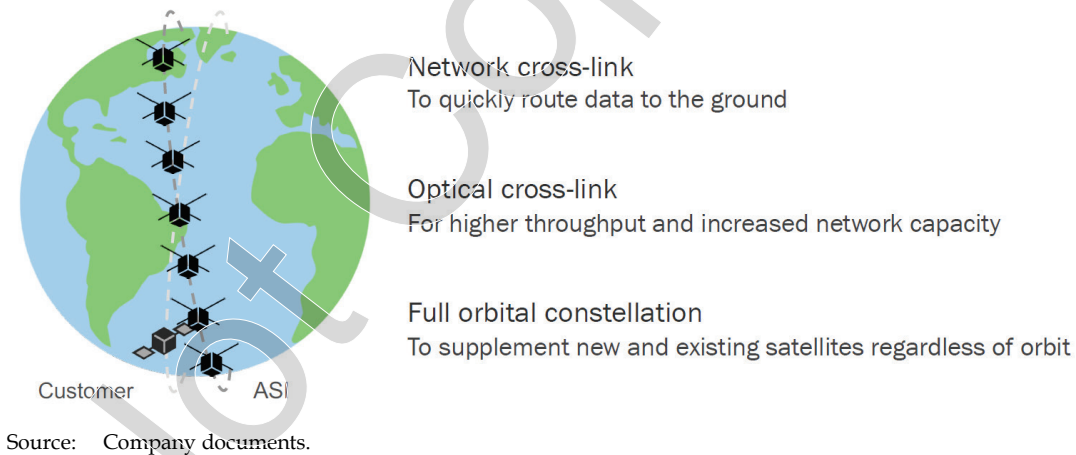
Radix in space while completing a range of adjustments in time to launch a second satellite in early 2019. Both founders knew that their decisions on customers, pricing, business development, and financing could make or break their venture. Lacking extensive startup experience and operating in a completely new market space meant that no good roadmap existed to draw from and guide them. Although they were unsure how to proceed, they knew they had to make the best decisions they could with the information they had at hand.

**Exhibit 1 ASI Phased Network Development Strategy**

**Phase 1: Store and Forward Data Relay**



**Phase 2: ASI Satellite Network at Scale**



**Exhibit 2** Earth Observation Satellites by Purpose, Main Use, and Weight, August 31, 2017

Purpose	Main Use	Weight (kg)				Totals
		>1,000	100 - 999	11 - 99	< 10	
Optical imaging						
	Civil	0	1	3	2	<b>6</b>
	Commercial	5	20	12	191	<b>228</b>
	Government	26	38	7	4	<b>75</b>
	Military	11	8	0	0	<b>19</b>
	<b>Total</b>	<b>42</b>	<b>67</b>	<b>22</b>	<b>197</b>	<b>328</b>
Radar imaging						
	Civil	0	0	0	0	<b>0</b>
	Commercial	1	0	0	0	<b>1</b>
	Government	9	4	8	0	<b>21</b>
	Military	10	7	0	0	<b>17</b>
	<b>Total</b>	<b>20</b>	<b>11</b>	<b>8</b>	<b>0</b>	<b>39</b>
Meteorology						
	Civil	0	0	0	0	<b>0</b>
	Commercial	0	0	0	44	<b>44</b>
	Government	5	3	5	0	<b>13</b>
	Military	0	1	0	0	<b>1</b>
	<b>Total</b>	<b>5</b>	<b>4</b>	<b>5</b>	<b>44</b>	<b>58</b>
Earth science						
	Civil	1	2	2	19	<b>24</b>
	Commercial	0	0	1	0	<b>1</b>
	Government	19	15	2	0	<b>36</b>
	Military	5	1	0	1	<b>7</b>
	<b>Total</b>	<b>25</b>	<b>18</b>	<b>5</b>	<b>20</b>	<b>68</b>
Electronic intelligence						
	Civil	0	0	0	0	<b>0</b>
	Commercial	0	0	0	0	<b>0</b>
	Government	0	0	0	0	<b>0</b>
	Military	16	4	0	0	<b>20</b>
	<b>Total</b>	<b>16</b>	<b>4</b>	<b>0</b>	<b>0</b>	<b>20</b>
<b>Totals</b>						
	Civil	1	3	5	21	<b>30</b>
	Commercial	6	20	13	235	<b>274</b>
	Government	59	60	22	4	<b>145</b>
	Military	42	21	0	1	<b>64</b>
	<b>Total</b>	<b>108</b>	<b>104</b>	<b>40</b>	<b>261</b>	<b>513</b>

Source: Casewriter analysis of Union of Concerned Scientists, UCS Satellite Database, <https://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database#.Wypc-oRKiik>, accessed June 2018.

Note: Satellites with two purposes or user types are recorded only once, under the first purpose or user type listed in UCS database. The table excludes satellites with unknown weight and other/undetermined use types.

**Exhibit 3** Profiles of Select Commercial EOS Operators, 2018**Agilspace**

- Based in Singapore; operated 400 kg TeLEOS-1, providing 1 m high-resolution images with 12-16 hour repeat cycle

**Changchun Institute of Optics**

- Based in China; six satellites (2 each at 400 kg, 95 kg, and 55 kg) provided 0.72 m high-resolution images; planned to have 16 satellites operational in 2016

**ICEYE**

- Based in Finland; in early 2018 launched the first satellite under 100 kg equipped with synthetic aperture radar; promised imagery of any location on Earth, updated every hour

**Satellogic**

- Based in Argentina; operated three 35 kg optical imaging satellites which were part of a planned 16-satellite constellation

**Siwei Star**

- Based in China; launched two 560 kg Superview optical imagers not initially in stable orbits as part of a planned 16-satellite constellation

**Spire Global**

- Based in the U.S.; operated 40 Lemur-2 3U CubeSats providing weather data and maritime tracking; raised \$140 million in venture capital; planned a 100-satellite network to provide weather updates and other data every five minutes

**Surrey Satellite**

- Based in the U.K.; operated three 447 kg DMC-3 optical imagers that also provided disaster monitoring service

Source: Compiled from Union of Concerned Scientists, UCS Satellite Database, <https://bit.ly/3xW7DMN>; The Optical Society, "Changchun Launches High-Res Optical Imaging Satellite," October 12, 2015, <https://bit.ly/3rpfHDA>; ICEYE, "Every Square Meter, Every Hour," <https://bit.ly/2zdxGmr>; Jeff Foust, "Chinese Satellites Raising Orbits after Launch Anomaly," Space News, December 30, 2016, <https://bit.ly/36SRcoG>; all accessed November 2018.

Note: Three larger EOS operators – Airbus Defence & Space, MDA/DigitalGlobe, and Planet – are profiled in the main text.

Exhibit 4 Scenarios for Evolution of EOS Imaging Market



Source: Gil Denis, Alain Claverie, Xavier Pasco, Jean-Pierre Darnis, Benoit de Maupeou, Murielle Lafaye, Eric Morel, "Toward Disruptions in Earth Observation?" *Acta Astronautica*, vol. 137, August 2017, p. 425, Elsevier/ScienceDirect website, <https://doi.org/10.1016/j.actaastro.2017.04.034>, accessed September 2018.

Note: GSD = Ground Sampling Distance, the size of smallest objects in images. VHR = very high resolution: < 1 m GSD.

**Exhibit 5** RF Data Downlink Rates for Select Non-Military EOSs, by Weight, May 2018

Satellite and Operator	Mission	Weight (kg)	Downlink Rate (Mbps)
Resurs-P1, Russian space agency	1 m optical/multi/hyperspectral imaging	5,900	300
MetOps-A, European space agency	Meteorological monitoring	4,183	70
Radarsat-2, MDA Corp.	SAR imaging	2,924	210
Worldview-3, MDA/DigitalGlobe	0.31 m optical/ imaging	2,800	800
Ziyuan-3A, Chinese space agency	2 m 3D optical/multispectral, for land surveys	2,650	900
Sentinel-3, European space agency	Meteorological monitoring/science	2,300	520
COSMO-5, Italian space agency	SAR imaging	1,700	560
Kompsat-5, Korean space agency	SAR imaging	1,400	310
TanDEM-X, Airbus	SAR Imaging	1,340	300
Gaofen-2, Chinese space agency	0.8 m optical/multispectral imaging	1,000	900
SPOT-7, Airbus Defence & Space	1.5 m optical imaging	714	600
Superview-2, Siwei Star Co.	0.5 m optical/multispectral imaging	560	900
SCATSat-1, Indian space agency	Ocean monitoring	371	105
NigeriaSat-2, Nigerian space agency	2.5 m optical imaging, tech. development	286	150
RapidEye-5, RapidEye AG	6.5 m optical/multispectral imaging	156	80
BIROS, German space agency	Forest fire monitoring	130	25
SkySat-7, Planet	Optical/multispectral imaging	83	470
Hodoyoshi-1, University of Tokyo	7 m optical imaging, technology development	60	20
Uniform-1, Japanese universities	Forest fire monitoring	50	10
Cicero, GeoOptics	Weather forecasting, environmental monitoring	10	2
Dove Flock 3, Planet	5 m optical imaging, high refresh rate	5	160

Source: Compiled from Union of Concerned Scientists, UCS Satellite Database, <https://bit.ly/3xW7DMN>; European Space Agency, eoPortal Directory, "Satellite Missions Database," May 2018, <https://bit.ly/3isKRpc>; both accessed June 2018.

Note: Downlink rates are using X-band radio and reflect peak data transfer rates. EOSs could be grouped into three categories, based on peak data transfer rates, which were not always fully applicable.

## Endnotes

- <sup>1</sup> A video clip of the deployment can be seen at Analytical Space, @lasercomm, "Our first #CubeSat, Radix, has successfully been deployed from the @Space\_Station and is now in low-Earth Orbit. Big thanks to @NanoRacks for the deployment!" Twitter, July 13, 2018, 9:49a.m., [https://twitter.com/laser\\_comm/status/1017813266825768967](https://twitter.com/laser_comm/status/1017813266825768967), accessed October 2018.
- <sup>2</sup> Union of Concerned Scientists, USC Satellite Database, <https://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database#.Wypc-oRKiik>, accessed June 2018.
- <sup>3</sup> Union of Concerned Scientists database data, reported in Research and Markets, "Global Satellite Based Earth Observation Market Analysis, Growth, Trends & Forecast, 2018-2023," BusinessWire press release, July 27 2018, <https://www.businesswire.com/news/home/20180727005397/en/Global-Satellite-Based-Earth-Observation-Market-Analysis>, accessed November 2018.
- <sup>4</sup> Euroconsult data, cited in Gil Denis, Alain Claverie, Xavier Pasco, Jean-Pierre Darnis, Benoît de Maupeou, Murielle Lafaye, and Eric Morel, "Toward Disruptions in Earth Observation?" *Acta Astronautica*, vol. 137 (August 2017), p. 425, <https://doi.org/10.1016/j.actaastro.2017.04.034>, accessed September 2018.
- <sup>5</sup> Small satellites weighed up to 100 kilograms. SpaceWorks Enterprises, "2018 Nano/MicroSatellite Market Forecast, 2018-2022," eighth edition, pp. 8, 12, <http://www.spaceworkscommercial.com/wp-content/uploads/2018/04/Nano-Microsatellite-Market-Forecast-8th-Edition-2018.pdf>, accessed November 2018.
- <sup>6</sup> Nathan Hurst, "Why Satellite Internet Is the New Space Race," *PC Magazine*, September 2018, via Business Source Complete, EBSCO; Andy Pasztor and Mayumi Negishi, "SoftBank to Invest \$500 Million More in OneWeb Satellite-Internet Venture," *The Wall Street Journal*, December 11, 2017, [www.wsj.com/articles/softbank-to-invest-around-500-million-more-in-oneweb-satellite-internet-venture-1512990003](http://www.wsj.com/articles/softbank-to-invest-around-500-million-more-in-oneweb-satellite-internet-venture-1512990003), both accessed November 2018.
- <sup>7</sup> Forecast International's Bill Ostrove, quoted in Alex Knapp, "Satellite Startup ICEYE Raised \$34 Million to See through the Clouds," *Forbes.com*, May 24, 2018, <https://www.forbes.com/sites/alexknapp/2018/05/24/satellite-startup-iceye-raised-34-million-to-see-through-the-clouds/#6591469e7499>, accessed November 2018.
- <sup>8</sup> Until raising a Series A round of \$14 million August 2017, ICEYE had relied since its 2014 founding on grants and loans, some revenues, plus \$5.6 million in seed funding raised in November 2015. Debra Werner, "Q&A | ICEYE Achieves the 'Impossible' with Miniature Radar Satellite," *SpaceNews*, May 14, 2018, republished as <https://spacenews.com/qa-iceye-achieves-the-impossible-with-miniature-radar-satellite/>; ICEYE, "Iceye History," 2018, <https://www.iceye.com/resources/company/history>; both accessed November 2018.
- <sup>9</sup> Werner, "Q&A | ICEYE Achieves the 'Impossible' with Miniature Radar Satellite;" Knapp, "Satellite Startup ICEYE Raised \$34 Million to See through the Clouds;" both accessed November 2018.
- <sup>10</sup> The company's tagline was "every square meter, every hour." ICEYE, <https://www.iceye.com/>, accessed November 2018.
- <sup>11</sup> Frederic Lardinois, "Descartes Labs Launches Its Geospatial Analysis Platform," *TechCrunch.com*, August 15, 2018, <https://techcrunch.com/2018/08/15/descartes-labs-launches-its-geospatial-analysis-platform/>, accessed November 2018.
- <sup>12</sup> Orbital Insight, "Products," 2018, <https://orbitalinsight.com/products/#slider-4>, accessed November 2018.
- <sup>13</sup> John Mannes, "TellusLabs Wants to Help Us Better Understand Our Planet," *TechCrunch.com*, January 17, 2017, <https://techcrunch.com/2017/01/17/telluslabs-wants-to-help-us-better-understand-out-planet/>, accessed November 2018.
- <sup>14</sup> Michael Sheetz, "Amazon Cloud Business Reaches into Space with Satellite Connection Service," *CNBC*, November 27, 2018, <https://www.cnbcm.com/2018/11/27/amazon-launches-aws-ground-station-satellite-data-collection-service.html>; Amazon Web Services, "AWS Ground Station Features," 2018, <https://aws.amazon.com/ground-station/features/>; Jeff Foust, "Amazon-Lockheed Venture Casts Shadow on Ground Station Startups," *SpaceNews*, November 29, 2018, <https://spacenews.com/amazon-lockheed-venture-casts-shadow-on-ground-station-startups/>; all accessed November 2018.
- <sup>15</sup> Mary Ann Ingram et al., "LEO Download Analysis for a Network of Adaptive Array Ground Stations," *Software Engineering Research and Practice 2005*, conference paper, January 1, 2005, <https://ntrs.nasa.gov/search.jsp?R=20050210122>, accessed June 2018.
- <sup>16</sup> Denis et al., "Toward Disruptions in Earth Observation?"