Planet

Planet - Flock Imaging Constellation

Spacecraft Launch Mission Status Sensor Complement Ground Segment References

On Nov. 26, 2013, Planet Labs, a private start-up company of San Francisco, CA, announced that it successfully launched its most recent nanosatellites, Dove 3 and Dove 4, into orbit on a Dnepr vehicle (launch on Nov. 21, 2013 from the Yasny Cosmodrome, Russia), completing a series of four prototype nanosatellites in 2013. Those proved successful, enabling the company to quickly follow up with the production of a 28-member network. The launch of Planet Labs' "Flock 1" fleet of 28 nanosatellites in December/January, which will be the largest constellation of Earth-imaging satellites ever launched. [1), 2)]

The latest additions to the Planet Labs fleet offer improvements in the capability provided by the firm's first nanosatellites launched in April, Dove 1 and Dove 2, which also were 3U CubeSats. Dove 3 and Dove 4 will demonstrate the firm's latest technology, including upgraded communications, attitude control and observation technology.

Background: Planet Labs was founded in 2010 by **Chris Boshuizen, Will Marshall and Robbie Schingler,** three NASA alumni interested in altering the space industry. Their "Dove" nanosatellites are meant to be low-cost and rapidly deployable, and capable of taking pictures of Earth that provide a spatial resolution of 3-5 m. — On March 17, 2014, Planet Labs announced that it has confirmed launches for more than 100 satellites over the next 12 months. This full constellation of nanosatellites will allow Planet Labs to image the entire Earth every day. [3)]

Spacecraft:

The Flock 1 constellation nanosatellites (all 3U CubeSats) were designed and built by Planet Labs Inc. They feature mostly COTS (Commercial-off-the-Shelf) components, including their imagers. Each nanosatellite has a mass of ~5 kg and a size of 10 cm x 10 cm x 34 cm.

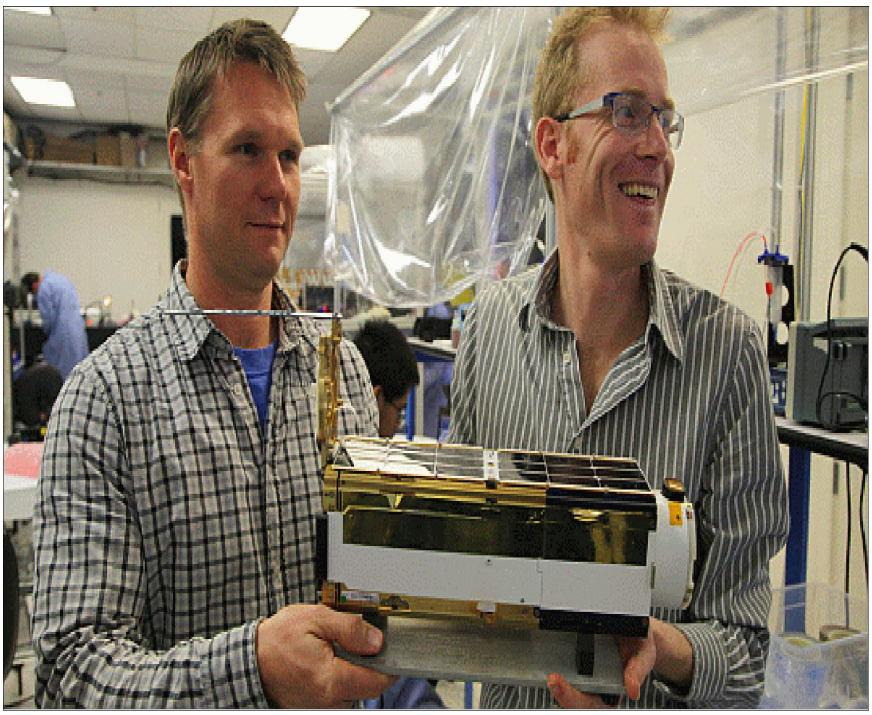

Figure 1: Photo of the proud developers and a close-up view of a Flock 1 nanosatellite (image credit: Planet Labs) [4)]

It can be expected, that the Flock 1 nanosatellite design corresponds closely to the design of the prototype Dove series, which demonstrated that the company's engineers can accurately position the orbiters and capture a continuous stream of imagery with a resolution of 3-5 m.

ADCS (Attitude Determination and Control Subsystem): The attitude is sensed by magnetometers, gyros and photodiodes. The attitude is being controlled by magnetorquers and reaction wheels. The B-dot controller makes use of the B field to reduce the angular rate of the satellite. In this control mode, Dove-1 therefore behaves as a permanent magnet, remaining locked and axis-aligned to the Earth's magnetic field. - Dove-1 will be nadir pointing twice per orbit. The alignment of the magnetic field is known to about 1º at any point.

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Observation of the Earth

EPS (Electrical Power Subsystem): The bus provides central power control through a power supply to the camera, the flight computer and the magnetorquers. The power supply regulates the voltages and ensures a stable power supply to each component. Power storage is provided by 8 Lithium-ion cells, providing 20 Ah of charge at full capacity. The batteries will be recharged by body-mounted TASCs (Triangular Advanced Solar Cells).

C&DH (Command & Data Handling) subsystem: C&DH is controlled by the single board computer. Additionally there will be a discrete watchdog board that will be able to reboot the flight computer in the event of errors.

RF communications: The communication subsystem consists of a VHF radio beacon for transmitting telemetry and an S-band frequency hopping spread spectrum modem for two-way communication and as the primary radio for data downloading. After powering up, the first mission event is to transmit telemetry data over the VHF beacon. The beacon will transmit health packets (including temp/power supply/current/RSSI/solar vector/acceleration) at 1200 baud AFSK approximately every 30 seconds (AX.25 protocol, 145.825 MHz). The beacon can transmit at up to 1 W and will use a quarter wave monopole antenna cut from tape measure.

The S-band radio will operate in the 2.4 GHz half-duplex ISM (Industrial, Scientific and Medical) band at a wireless link rate of 115 kbit/s using a patch antenna.

In Nov. 2013, Planet Labs' Flock 1 nanosatellites were delivered to NASA's Wallops Flight Facility in Virginia for launch on board an Antares rocket in December 2013. These satellites were built in production at the Planet Labs headquarter offices in San Francisco. Planet Labs is on track to launch 32 satellites on four different launches in 2013. [5].

Radio Development History(update to RF communications): [6].

In order to meet Mission 1 data volume objectives, Planet built a custom high-speed **X-band radio** using COTS components that is tightly integrated with the rest of the CubeSat bus. Several radio architecture decisions were made in order to meet the size, weight, and power (SWaP) constraints of the CubeSat platform while also improving the overall system efficiency. For example, the final stage RF power amplifier was integrated adjacent to the antenna to improve the total system power efficiency. This allowed the use of antenna solutions with 10-12 dBi gain, but still achieve data rates comparable to much larger class satellites that typically have very high gain antennas.

The custom development solution also allowed for rapid prototyping and repeated iterations that led to continuous improvements to the radio subsystem. Planet's first satellite launch hosted the sixth iteration (Build 6) of the spacecraft that transmitted 2 W of RF power through a 3 dBi gain patch antenna. A 6.1 m dish at the Chilbolton Observatory in the UK served as the ground station antenna. On April 25, 2013, Planet achieved its first successful X-band downlink at 4 Mbit/s data rate, which set a new data rate record for CubeSat class satellites.

The success of the early launches and tech demos proved that Planet could meet its Mission 1 goals by following the \agile aerospace" philosophy of rapid prototyping, repeated iterations, and continuous improvements. Less than three years after the first launch, the thirteenth iteration (Build 13) of the satellites was launched on the Indian Polar Satellite Launch Vehicle (PSLV) in June 2016. This constellation code named Flock 2P or F2P included twelve \Build 13" satellites (launch in June 2016). Further improvements were made to this build and Flock 3P or F3P consisting of 88 satellites was launched in February 2017. With the F3P launch, Planet set a record for the most number of operational satellites (100 Build 13 satellites and several B10, and B12 satellites). Planet has demonstrated 220 Mbit/s peak data rates with the Flock 3P constellation and average data rates of approximately 160 Mbit/s. Cumulatively, these satellites generate several TB of imagery data daily that is downlinked to eight geographically diverse ground station sites. The active imaging satellites and the ground stations are shown in Figure 55.

Improvements to the spacecraft **HSD** (High-Speed Data) system have followed Planet's iterative design approach. Higher gain antennas have been added and improved, RF circuit impairments have been addressed, amplifier settings have been optimized, and the radio firmware and software has undergone constant development. Table 1 provides a summary of key HSD development milestones.

Date	Milestone	Build#,HSD#	Improvements
Apr. 21, 2013	Dove 1	B6, HSD1	HSD1 with operational X-Band system with patch antenna (3 dBic), achieved 4 Mbit/s using QPSK modulation scheme at 1/2 FEC rate.
Nov. 21, 2013	Dove 3	B8, HSD1	Upgraded system with ACM (Adaptive Coding and Modulation), high gain helical antenna (10 dBic), achieved 25Mbit/s using 8PSK modulation at 8/9 FEC rate.
June 19, 2014	Flock 1c (11 satellites)	B9, HSD1	Increase symbol rate from 10 Mbaud to 20 Mbaud and achieved 34 Mbit/s using QPSK modulation at 8/9 FEC rate
June 1, 2016	Flock 2e (12 satellites)	B12, HSD1	Increased symbol rate to 24 Mbaud, improved helical antenna (12 dBic), optimized and linearized the X-Band transmitter chain and achieved 100 Mbit/s using 32 APSK modulation and 8/9 FEC rate
June 21, 2016 Feb. 14, 2017	Flock 2p (12 satellites), Flock 3p (88 satellites)	B13, HSD2	HSD2 with new hardware, firmware, and software improvements on satellite and ground station, symbol rate increased from 24 Mbaud to 70 Mbaud, achieved 220 Mbit/s using 16 APSK modulation and 3/4 FEC rate (Raw RF link rate achieved 283 Mbit/s)

Table 1: Summary of key HSD development milestones

The HSD radio operates at X-band with a center frequency of 8150 MHz and 70 Mbaud symbol rate. This frequency is within the 8025-8400 MHz (X-band) range where EESS (Earth Exploration Satellite Service) has a primary spectrum allocation.

Figure 2: Photo of the 28 Flock 1 nanosatellites before being sent to the launch site (image credit: Planet Labs) [7].

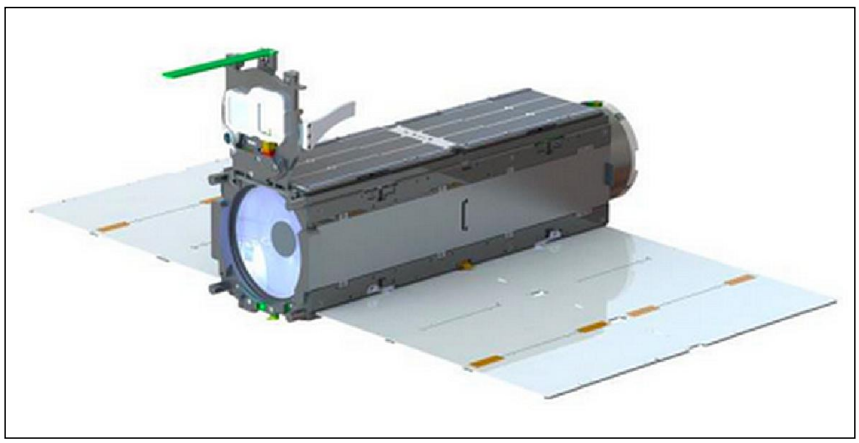

Figure 3: Planet Dove nanosatellite in operational configuration with solar panels deployed and communications antenna flap opened (image credit: Planet)

Launch: The Cygnus CRS-1 logistics flight of Orbital Sciences to the ISS was launched on Jan. 09, 2014 on an Antares-120 Vehicle of OSC from MARS (Mid-Atlantic Regional Spaceport), Wallops Island, VA. [8].

Cygnus CRS-1 (Commercial Resupply Services) Orb-1 logistics flight of Orbital Sciences is the second Cygnus flight to the ISS (International Space Station) and the third launch of the company's Antares launch vehicle from MARS (Mid-Atlantic Regional Spaceport), Wallops Island, VA. The flight is the first of 8 under the CRS (Commercial Resupply Services) contract to NASA. The mission is scheduled to launch on December 18, 2013. Cygnus is expected to deliver 550 kg of cargo to ISS and dispose of about 1,000 kg through destructive reentry.

Orbit: Near-circular orbit of the ISS, altitude between 370-430 km, inclination = 51.6°. — Planet refers to a group of Doves deployed simultaneously into a single orbit as a flock.

Secondary payloads: commercial payloads of Orbital Sciences.

Part of the Cygnus payload consists of 33 CubeSats which will be deployed in early 2014 with the NanoRacks Smallsat Deployment Program using the **J-SSOD** (JEM-Small Satellite Orbital Deployer), located in the airlock of the JEM/Kibo module of JAXA.

The CubeSats are:

• 28 Flock 1 3U CubeSats, the first generation of an Earth observation constellation of Planet Labs. They will be placed into 400 km circular orbits (inclination of ~52°), providing imagery with a resolution of 3-5 m. [9].

• LituanicaSAT-1, a CubeSat which will carry a VGA camera, a GPS receiver and a voice transponder. The satellite has been developed at the Vilnius University (Lithuania) and has been named after the aircraft named Lituanica that flew across the Atlantic Ocean 80 years ago.

• LitSat, a 1U CubeSat developed by the Lithuanian Space Federation. The satellite will carry an onboard VGA camera and a GPS receiver.

• UAPSAT, a 1U CubeSat developed by UAP (Universidad Alas Peruanas), Lima, Peru, as a student educational project. Once in orbit the satellite can be accessed by radio amateurs; UAPSAT will test the behavior of electronic design communication, orientation and stabilization and verify the implementation of the technology and methodology used in the manufacture of the satellite.

• SkyCube, a 1U CubeSat developed by the Southern Stars Group LLC (San Francisco, CA) and funded by thousands of sponsors and mobile app users around the world (crowd funding). Its objective is to facilitate global grassroots public outreach and educational effort whose purpose is to make space exploration accessible as never before by allowing participants to send simple broadcasts - "tweets from space". The satellite is also fitted with a camera for on-demand pictures of Earth. At the end of the 90 days mission, SkyCube will inflate an onboard balloon that will make it visible to the unaided eyes and assist in de-orbiting the satellite cleanly through atmospheric drag. [10].

• Ardusat-2, developed by Nanosatisfi LLC, which is similar to the Ardusats that were sent to ISS earlier this year.

On January 12, 2014, the Cygnus CRS-1 spacecraft arrived at the ISS where Expedition 38 astronauts grappled the spacecraft and berthed it in a flawless operation (Figure 4).

Figure 4: Image of Cygnus grappling with Canadarm2 and berthing to the ISS (image credit: NASA)

Launch: On Oct. 31, 2017 (21.37 UTC), six SkySat minisatellites of Terra Bella (a Planet Labs company) and 4 Dove (Flock-3m) nanosatellites of Planet Labs were launched on a Minotaur-C vehicle of Orbital ATK from VAFB, CA (SLC-576E). The Minotaur-C is an upgraded, renamed version of the Orbital Sciences Taurus rocket. Approximately 12 minutes into flight, the ten commercial Planet spacecraft deployed into their targeted sun synchronous orbit of 500 km altitude. [11], [12].

Orbit: Sun-synchronous orbit, altitude of ~500 km, inclination of ~97°.

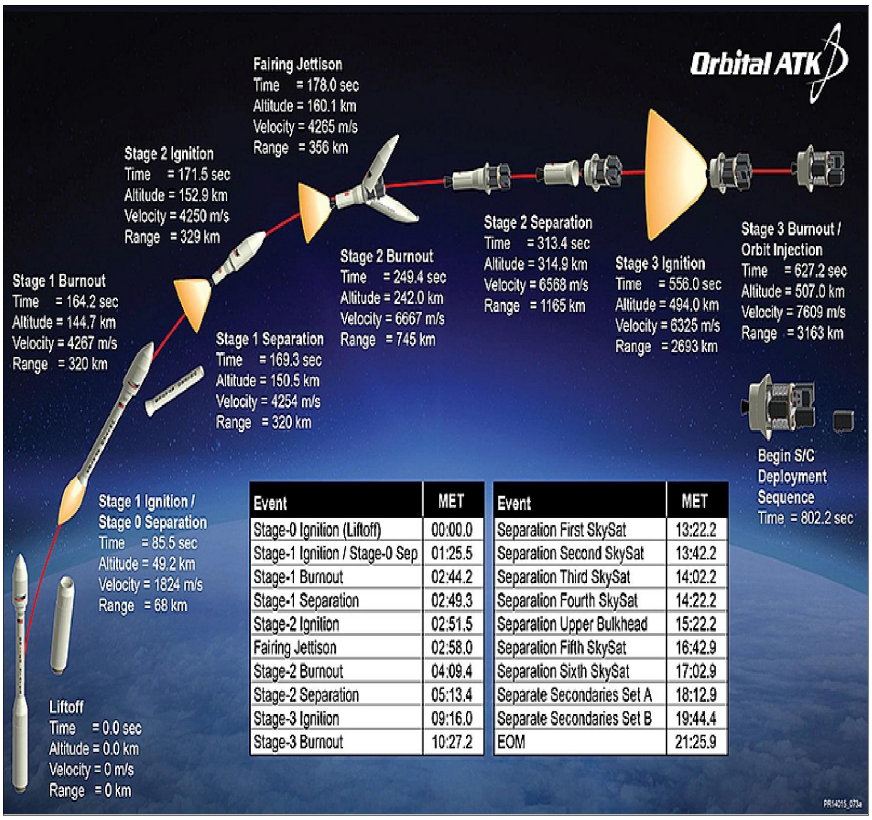

Figure 5: Illustration of the launch sequence (image credit: Orbital ATK) [13].

Figure 6: A closer look at the tech infrastructure that gets an image from a satellite in space down to you your computer (video credit: Planet, Published on Aug 2, 2016)

Status of the Planet Labs Flock Nanosatellite Constellation — and the fleet acquisitions

• On October 28, 2020 Rocket Lab successfully launched Flock 4e', nine latest-generation SuperDoves, on the Electron rocket from their New Zealand launch site. The Flock 4e' SuperDoves were deployed into an approximately 500 km, morning-crossing Sun Synchronous Orbit (SSO), joining the rest of the constellation providing medium-resolution Earth imagery with unprecedented coverage and frequency of update. [14].

- These nine SuperDoves are equipped with 8 spectral bands that provide high image quality and accurate surface reflectance values for advanced algorithms and time-series analysis. Planet's SuperDoves are also interoperable with publicly available imagery, like Copernicus' Sentinel-2, enabling innovative applications and use cases.

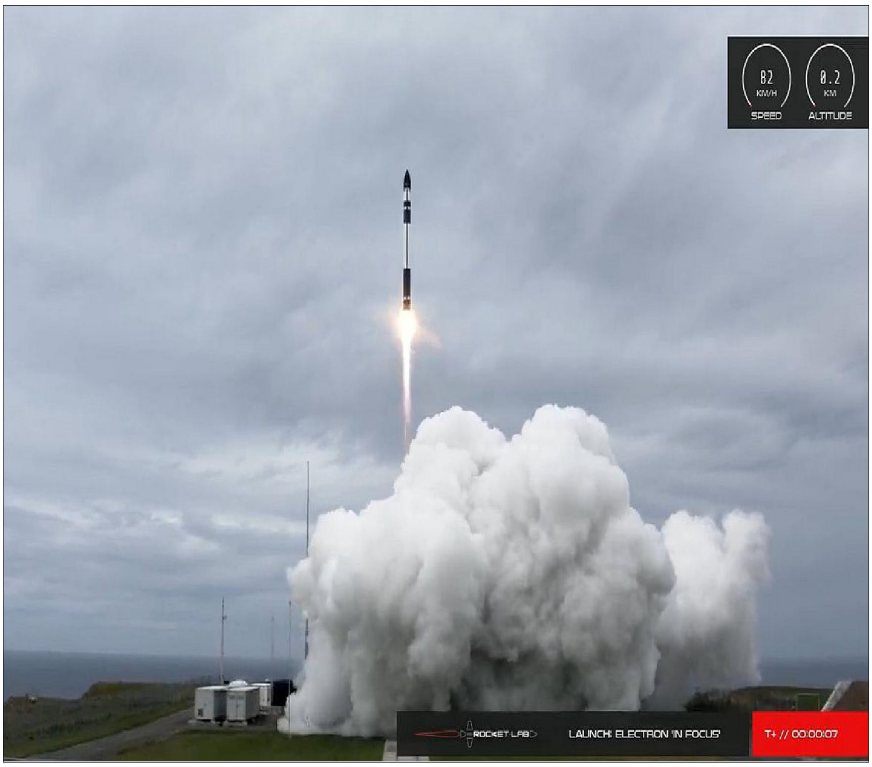

Figure 7: Liftoff of Rocket Lab's Electron rocket carrying Planet's nine SuperDoves (3U CubeSats) and an experimental microsatellite of Canon Electronics (image credit: Rocket Lab)

- Planet's Mission Operations team quickly established contact with all nine SuperDoves and those satellites are currently undergoing commissioning. Rocket Lab's "In Focus" mission was their 15th launch, and the third time carrying Planet satellites.

• September 10, 2020: Last week, 26 SuperDoves (Flock 4v) were launched on Arianespace's VV16 SSMS-POC flight, joining Planet's existing fleet of Doves and SuperDoves. Today, we're thrilled to share the first light images from the new flock, and are happy to report that the satellites are all healthy and on their way to full commercial service soon. This also maintains Planet's 100 percent record of contacting every single satellite successfully deployed in space (357 to be exact). [15].

Figure 8: Planet SuperDove first light image of the Amu Darya River, Turkmenistan (left) Uzbekistan (right), © 2020, (image credit: Planet Labs Inc. All Rights Reserved)

- With the launch of the new SuperDoves, Planet will continue to provide medium resolution multispectral imagery (3-5m) at a global scale, providing critical intelligence at an unparalleled cadence to customers and organizations worldwide.

Figure 9: Planet SuperDove first light image of Nizhny Novgorod, Russia © 2020, (image credit: Planet Labs Inc. All Rights Reserved)

Figure 10: Planet SuperDove first light image of Queensland, Australia © 2020 (image credit: Planet Labs Inc. All Rights Reserved)

• On 3 September 2020, the Vega rocket rideshare mission successfully lofted 26 SuperDoves, Flock 4v, on Arianespace's VV16 SSMS-POC (Proof of Concept) flight, along with several other small satellites. The first 14 SuperDoves were successfully deployed into an approximately 530 km Sun-synchronous orbit, and Planet's mission operations team is already shepherding those satellites through the commissioning process. [16], [17].

- The remaining 12 SuperDove satellites will be deployed into a similar orbit over the next several weeks from D-Orbit's ION platform, at which point they will join the rest of Planet's on-orbit fleet. The Flock constellation of Dove and SuperDove satellites provides high-revisit medium-resolution imagery in a variety of spectral bands at a global scale. D-Orbit's ION will be undergoing its own commissioning process before the remaining SuperDove satellites are to be deployed, and all signs thus far are looking good for a successful completion of the mission.

- The return to launch of the Vega was an especially exciting moment for the smallsat industry given that this was the Vega's first flight after an unsuccessful launch of FalconEye1 in July of 2019, which was followed by a thorough accident investigation and several corrective actions put into place by Arianespace and Avio, the prime contractor for Vega's construction. After a handful of subsequent delays due to the COVID-19 pandemic and unfavorable weather conditions, the launcher finally lifted off and proved itself back in flight-shape.

Orbit: Sun-synchronous orbit; target orbit for the 7 microsatellites: altitude of 515 km, inclination of 97.45º; target orbit for the 46 nanosatellites: altitude of 530 km, inclination = 97.51º. The nominal mission duration (from liftoff to separation of the 53 satellites) is: 1 hour, 44 minutes and 56 seconds.

Figure 11: Technicians performing payload integration of the D-Orbit ION CubeSat deployer carrying 12 Flock 4v SuperDoves, with Planet's logo clearly visible. The remaining 14 SuperDove satellites are housed inside the blue and black ISL QuadPack deployers visible on the lower deck (image credit: Arianespace)

Passenger payloads (53) of the Vega rideshare mission

Arianespace has realized the first European "rideshare" mission for small satellites, with 53 satellites onboard the Vega launcher for 21 customers from 13 different countries. With this new SSMS (Small Spacecraft Mission Service) shared launch concept, Arianespace demonstrates its ability to respond – in an innovative and competitive manner – to institutional and commercial requirements of the growing market for small satellites. The total satellite launch mass was 1,327 kg. [18].

With the demonstration of its new SSMS service, Arianespace is strengthening its position in the growing market for small satellites. This service will soon be supplemented by the MLS (Multi Launch Service) – a similar offer available on Ariane 6, allowing Arianespace to increase the number of affordable launch opportunities for small satellites and constellations.

• ESAIL is a maritime microsatellite with a mass of 112 kg for AIS (Automatic Identification System) ship tracking operated by exactEarth. Is was built by a European manufacturing team led by the satellite prime contractor Luxspace. ESAIL features an enhanced multiple antenna-receiver configuration for global detection of AIS messages and high-resolution spectrum capture, which will enable the demonstration of advanced future services such as VDES (VHF Data Exchange System) message reception. [19].

• Lemur-2, eight 3U CubeSats built by Spire Global Inc., San Francisco, CA . These satellites carry two payloads for meteorology and ship traffic tracking. The payloads are: STRATOS GPS radio occultation payload and the SENSE AIS payload.

• TriSat is a 3U CubeSat (5 kg) imaging mission led by the University of Maribor, Slovenia. The mission is focused on remote sensing by incorporating a miniaturized multispectral optical payload as the primary instrument, providing affordable multispectral Earth observation in up to 20 non-overlapping bands in NIR-SWIR (Near to Short Wave Infrared) spectrum.

• The launch integrator company Spaceflight Inc. of Seattle WA is providing its services for four different customers with a total of 28 satellites. These are:

a) **NewSat-6 (**also written as ÑuSat-6**)**, is a low Earth orbit commercial remote sensing microsatellite (43.5 kg) designed and manufactured by Satellogic S.A. with HQs in Argentina, a vertically integrated geospatial analytics company that is building the first Earth observation platform with the ability to remap the entire planet at both high-frequency and high-resolution. This is Satellogic's 11th spacecraft in orbit, equipped with multispectral and hyperspectral imaging capabilities and it will be added to the company's growing satellite constellation. —

The spacecraft is named "Hypatia" after the woman philosopher, astronomer, and mathematician (350-415 A.D.) who lived in Alexandria, Egypt, and was a symbol of learning and science. She was renowned in her own lifetime as a great teacher and a wise counselor and became seen as an icon for women's rights and a precursor to the feminist movement. In line with Satellogic's NewSats already in orbit, Hypatia is equipped with sub-meter multispectral and 30 m hyperspectral cameras. This NewSat Mark IV is also equipped with new technologies in service of Satellogic's research and development of Earth-observation capabilities. Upon successful commissioning, these new capabilities will be available to existing Satellogic customers.

b) **14 Flock-4v**, 3U CubeSats, next-generation SuperDove satellites of Planet Inc., San Francisco, they will join its constellation of 150 Earth-imaging spacecraft.

c) **SpaceBEE, 12 (.25U) picosatellites** of Swarm Technology which provide affordable global connectivity.

d) Tyvak-0171, an undisclosed minisatellite of Tyvak, developed by Maxar with a mass of 138 kg.

• Planet Inc. of San Francisco launches a total of 26 Flock 4v SuperDoves on this mission. They will be split into two batches on the same launch: 14 of them will be housed inside and deployed from ISL's QuadPack deployers and the remaining 12 will be deployed from D-Orbit's InOrbit Now (ION) freeflying deployment platform. [20), 21)].

• Athena, a communications minisatellite mission (138 kg) of PointView Tech LLC, a subsidiary of Facebook. The objective is to provide broadband access (internet connectivity) to unserved and underserved areas throughout the world.

• AMICalSat, a 2U CubeSat, an educational mission, developed by CSUG (University of Grenoble Alpes, France) and MSU-SINP (Lomonosov Moscow State University-Skobeltsyn Institute of Nuclear Physics, Russia). The objective is to take pictures of the Northern light in order to reconstruct the particle precipitation into the polar atmosphere. The payload is a very compact, ultra-sensitive wide filed imager (f=23mm, aperture f/1.4). Firstly, AMICal Sat will observe auroras using nadir pointing, i.e. by determining the center of the Earth to map and link the geographical position of the auroral oval and its internal structures with solar activity. Secondly, the CubeSat will perform image capture 'in limbo' through tangential orientation with the Earth to capture the vertical profile of the auroras and match an altitude to their various emissions.

• PICASSO, a 3U CubeSat mission (mass of 3.8 kg) developed for ESA (European Space Agency) led by BISA (Belgian Institute for Space Aeronomy), in collaboration with VTT Technical Research Center of Finland Ltd, Clyde Space Ltd. (UK) and the CSL (Centre Spatial de Liège), Belgium. The goal is to develop and operate a scientific 3U CubeSat.

• GHGSat-C1 of GHGSat Inc., Montreal, Canada, is the first of two nanosatellites (~16 kg) as the commercial follow-on to the GHGSat-D (CLAIRE) demonstration satellite developed and launched by UTIAS/SFL of Toronto in 2016. GHGSat monitors industries greenhouse gas (GHG) and air quality gas (AQG) emissions, including: oil & gas, power generation, mining, pulp & paper, pipelines (natural gas), landfill, chemicals, metals & aluminum, cement, agriculture, and transportation.

• NEMO-HD of SPACE-SI (Slovenian Center of Excellence for Space Sciences and Technologies) is a microsatellite (65 kg) developed at UTIAS/SFL of Toronto, Canada in cooperation with SPACE-SI. The NEMO-HD (Next-generation Earth Monitoring and Observation-High Definition) satellite is a high precision interactive remote sensing mission for acquiring multispectral images and real time HD video.

• FSSCat (Federated Satellite Systems on Cat) is the winner of the 2017 Copernicus Master "ESA Sentinel Small Satellite Challenge (S^3)". Proposed by the Universitat Politècnica de Catalunya (UPC) and developed by a consortium composed of UPC (ES), Deimos Engenharia (PT), Golbriak Space (EE), COSINE (NL) and Tyvak International (IT).

• Phi-Sat-1 (Φ-Sat-1) is the first on-board ESA initiative (6U CubeSat) on Artificial Intelligence (AI) promoted by the Φ Department of the Earth Observation Directorate and implemented as an enhancement of the FSSCat mission. Among mission objectives, scientific goals are Polar Ice and Snow monitoring, soil moisture monitoring, terrain classification and terrain change detection (i.e. hazard detection and monitoring, water quality), while technological goals are optical Inter-Satellite Link (OISL) demonstration.

• The RTAFSAT-1 (Royal Thai Air Force Satellite-1) mission, also referred to as NAPA-1, is a 6U CubeSat, the first remote sensing CubeSat mission for Thailand. The satellite will carry out an Earth Observation Demonstration mission with SCS Gecko Camera and Simera TriScape-100 payloads; the designed lifetime is 3 years.

• DIDO-3, a commercial 3U CubeSat mission of SpacePharma. The objective is to gather data by researching the effects of a microgravity environment on biological materials. SpacePharma from Israel will be is on board of SSMS POC with DIDO-3 Nanosatellite to perform biological experiment under Microgravity for several customers involved in pharmaceutical business, supported by Italian Space Agency (ASI) and Israeli Space Agency (ISA). Dido-3 will be monitored from the Ground Station developed by SpacePharma in Switzerland.

• SIMBA (Sun-Earth Imbalance), a 3U CubeSat mission led by the Royal Meteorological Institute Belgium, The objective is to measure the TSI (Total Solar Irradiance) and Earth Radiation Budget climate variables with a miniaturized radiometer instrument. This mission will help in the study of the global warming. This science mission will have a design lifetime of 3 years and the satellite performances will be monitored from ground station located in The Netherlands.

• TARS-1, a 6U CubeSat of Kepler Communications, developed at ÅAC Clyde Space for IoT (Internet of Things) applications. TARS-1 features deployable solar arrays, software defined radios (SDR), a narrowband communications payload and high gain antennas.

• OSM-1 Cicero, the first nanosatellite developed in Monaco by OSM (Orbital Solutions Monaco engineers, a 6U CubeSat with a mass of ~10 kg) based on the Tyvak Nano-Satellite Systems design. OSM plans to build nanosatellites to gather environment and climate data.

• TTU100, a 1U CubeSat developed at the Tallin University of Technology, Estonia. The objective is to test earth observation cameras and high-speed X-band communications. It will perform remote sensing in the visible and IR electromagnetic spectrum.

• UPMSat-2 (Universidad Politecnica de Madrid Satellite-2), a demonstration microsatellite (45 kg) of IRD-UPM.

• March 24, 2020: Late last year we launched Planet Orbit, a new partner program that allows Planet partners to gain access to high temporal resolution geospatial data, create powerful solutions and differentiate their business. [22)].

- Today we're excited to announce our new partnership with Seisan, a custom software solutions and systems integration company specializing in leveraging geospatial technologies. By becoming a premiere Planet

partner, Seisan can offer next-level competitive advantages and insights into many industry verticals.

- Planet has redefined every aspect of the Earth imaging pipeline to quickly deliver actionable insights to users. Traditional satellite partners lack the ability to collect meaningful imagery at the speed in which Planet can. Leveraging this unique dataset, Seisan will be able to build machine learning imagery analysis along with traditional systems integration and data transformation techniques. These software solutions will bring an unprecedented level of geospatial awareness that has been previously impossible to achieve.

- Integrating Planet's geospatial data within an enterprise's current technical environment will allow companies to gain greater insights from location data, leading to productivity savings, operational cost reductions and increased situational awareness.

- "Seisan is excited to partner with Planet to help provide previously unattainable levels of imagery detail on a daily basis. We look forward to creating new opportunities to analyze geospatial information and unlock value for customers," said Charles Durham, co-founder and president of Seisan. "Data contained in an image gives far greater detail than what is currently available in traditional geospatial methodologies. With Planet's extensive image archive, we can now go back in time to analyze historical data without the limitations of timed flight aerial photography. Seisan looks forward to utilizing Planet's robust APIs to provide solutions that were never possible before."

- In the age of social media and the speed of technological advances, it is important to gain an edge wherever possible. By adding the elements of historical time lapse with the frequency of geospatial imagery and analysis, Seisan can utilize Planet data to provide enterprise quality and scalable solutions that will disrupt multiple sectors.

- "At Planet, we image the Earth every day and deliver that data as a service with unmatched cadence and speed," said James DeCesare, Planet's head of partnerships for the Americas. "We're excited to combine our unmatched platform with Seisan's excellence in technology and innovation. Together, we'll develop high-quality solutions that deliver the immediate value required by today's enterprise customers."

• February 13, 2020: Planet launches every three to six months to keep its constellation of Earth imaging satellites replenished and flying the latest and greatest technologies. Following on the heels of the successful launch of Flock 4p in November of 2019, Planet's first launch of 2020 will be on Arianespace's European-made Vega rocket, a first for the Doves. The 26 SuperDoves, Flock 4v, are scheduled for lift-off on March 23, 2020 from the Guiana Space Center in French Guiana (Note: The Vega Rideshare mission launch is delayed due to COVID-19). [23].

- These 26 Flock 4v SuperDoves will be split into two batches on the same launch: 14 of them will be housed inside and deployed from ISL's QuadPack deployers and the remaining 12 will be deployed from D-Orbit's InOrbit Now (ION) freeflying deployment platform.

- Over 200 Dove satellites have successfully deployed from ISL's trusty QuadPack system. This will be the first flight of D-Orbit's ION system, and those satellites will be deployed over a handful of weeks. D-Orbit will also be verifying key technologies on their ION platform that will eventually enable future versions to act as a "space tug," with the capability to perform orbit adjustments or accelerate phasing for the satellites it carries.

- Much like the Falcon 9 SSO-A launch in 2018, this Vega launch is going to be a smallsat party. As Arianespace's official mission name "Small Spacecraft Mission Service—Proof of Concept" suggests, this is the first "dedicated rideshare" on a Vega launch vehicle; rather than a primary satellite customer driving the requirements of the mission, this is a dedicated ride for a few dozen small satellites all looking to go to the same orbit.

- We look forward to a successful launch and extend our thanks to our partners at Arianespace, ISISpace, D-Orbit, Spaceflight and SAB Aerospace for all their efforts in making this mission come together.

• November 27, 2019: Today, 12 SuperDove satellites (Flock 4p) were successfully launched and deployed into a 509 km Sun Synchronous Orbit by India's Polar Satellite Launch Vehicle (PSLV) from SDSC SHAR, India. The primary payload on this flight was CartoSat-3 of ISRO. This marks 25 successful launches for Planet and our 407th satellite launch attempt. [24].

- Shortly after the launch, Planet's Mission Operations team successfully made contact with all twelve satellites and initiated the satellite phasing and commissioning process, continuing Planet's long standing record of 100 percent success rate in contacting each Dove satellite after launch. The Flock 4p satellites are now undergoing detumbling maneuvers, various subsystem health checks, solar panel deployments, and calibration of their imagery systems.

Figure 12: Planeteers watch the successful launch of 12 SuperDoves from Planet HQs in San Francisco, CA, (image credit: Planet)

• October 14, 2019: Today we're happy to announce the launch of Planet Orbit—Planet's new partner program—which provides customers with a trusted partner ecosystem and unique data set. The program allows partners to gain access to geospatial data not otherwise available in the commercial market, create powerful solutions and differentiate their business. [25)]

- "Planet is positioned to transform a variety of industries through our unique dataset, providing insights to our customers at a speed never before possible," says John Atkinson, vice president of Channel Sales at Planet. "Unlike traditional satellite imagery service providers who focus strictly on resellers, Planet Orbit works with a range of partners who offer last-mile solutions that leverage our platform's robust APIs, PlanetScope daily imagery, and high resolution SkySat tasking. Planet Orbit partners are disrupting their industries, and moving ahead of their competitors, while setting themselves up for long-term growth in the market."

- Planet Orbit is designed to enable our partners to build market competencies in Planet products and verticals. By introducing Gold and Platinum levels, our customers get access to Planet-certified partners with specific domain expertise. As partners commit to Planet's business, Planet fuels their success through a variety of benefits, including:

a) A new Planet Orbit portal that acts as a one stop shop to learn, manage, and grow our partner's Planet-based business—including a new deal registration process

b) Partner Enablement, which provides the training, tools, and certifications they need to grow their business

c) Access to an exclusive community of innovators and opportunities for strategic collaboration

d) For Gold and Platinum partners, we offer dedicated Partner Business Managers, lead distribution, and joint marketing activities—like webinars, live events, and marketing campaigns.

- "At Kayrros, we have brought together the biggest group of satellite imagery specialists in Europe and have been able to provide clients with an unprecedented level of insight and accuracy, unthinkable even a few years ago," says Antoine Rostand, founder and CEO of Kayrros. "This partnership with Planet and their Stereo SkySat imagery allows us to build on that, particularly in the exciting area of 3D mapping."

- At Planet, we are focused on expanding our world class partner ecosystem to drive the use of Planet data and services. Over the next few months we will be expanding our ecosystem while working with our existing Planet Orbit partners to drive growth. Planet is investing heavily in our partnership program, and it's exciting to see our partners literally changing the world with the solutions they are developing.

• August 2019: Planet is a vertically integrated aerospace and data analytics company that operates the world's largest commercial fleet of remote sensing satellites. Our mission is to image the whole world everyday, and make change visible, accessible, and actionable. We have launched over 350 satellites and built up an automated mission control and ground station infrastructure to monitor and control the satellites, and download the imagery data. Historically, small satellite radios have been downlink limited because of tight size, weight, and power (SWaP) constraints. Rapid prototyping, iteration, and adaptation of the latest COTS technology has allowed for continuous improvements in data throughput on our high speed radio from a very low-cost cubesat platform. Planet's latest X-band radio and antenna solution has achieved a data rate over 1.6 Gbit/s from a 3U CubeSat on-orbit. [26)]

Planet's **HSD2** (High Speed Downlink 2) is the latest generation compact, low-mass, and low-power radio that was built and deployed on 3U form-factor imaging CubeSats in December 2018. This system operates at X-band and is built using COTS parts with a dual polarization antenna. The two physical channels represent the two polarization modes, right hand circular polarization (RHCP) and left hand circular polarization (LHCP) and each physical channel utilizes 300 MHz of total bandwidth. Within each physical channel, there are three logical channels spaced 100 MHz apart center-to-center frequency. The individual channel symbol rate is 76.8 Msps (Msample/s). Each physical channel has 1 W RF output power and 15 dBi antenna gain. The total DC power consumption of the radio including the processor and the FPGA is 50 Wand the total volume occupied by the radio and antenna, including the mechanical deployment structure for the antenna is 0.25U. The commercial digital television broadcasting standard DVB-S2 is used for modulation and coding. An ACM (Adaptive Coding and Modulation) scheme is used to dynamically change the modulation and coding for each channel individually based on the available link margin. Our ground station network includes 15 dishes (29 dB/K gain-to-noise-temperature) across 5 sites located around the world. The HSD2 is capable of providing downlink volume of over 80 GB during a single ground station pass.

- HSD2 overview: The new generation HSD2 is built on the success of the previous generation HSD Dove radio that operates at 220 Mbit/s throughput. [27]. The key features of HSD2 include:

a) X-band operation in the Earth Earth Exploration-Satellite Service (EESS) band (8025-8400 MHz)

b) Dual circular polarization antenna that allows for instantaneous doubling of bandwidth

c) Compact volume of 0.25U including the radio, antenna, and the antenna deployment mechanism

d) DVB-S2 modulation scheme with adaptive modulation (QPSK to 32APSK) and coding rates (1/4 FEC to 9/10 FEC)

e) 50 W total DC power consumption including the processor and FPGA during downlink.

- Satellite Transmitter: The HSD2 satellite transmitter shown in Figure 14 consists of a processor (CPU) and solid state drive (SSD) linked to an FPGA which drives the analog and RF transmitter chains. The FPGA multiplexes the incoming data to six DVB-S2 cores that modulate and provide forward error correction (FEC). Planet's data packets are encapsulated within the DVB-S2 baseband frames. Each DVB-S2 core runs at 76.8 Msps baud rate. The six logical channels are frequency offset and combined into two physical channels and converted to analog baseband using a high-speed DAC (Digital to Analog Converter). Two independent superheterodyne transmitters are used to convert the baseband signals to X-band signals, which are then fed to final stage power amplifiers and right and left hand circular polarized (RHCP/LHCP) antennas for transmission. Table 2 summarizes some of the transmitter parameters. Figure 13 shows the agile and iterative improvements that Planet has made overtime across Dove spacecraft hardware variants.

Parameter	Value
Channel Symbol Rate	76.8 Msps
Channel spacing, Channel bandwidth	100 MHz, 96 MHz
RF output power	1 W per polarization
Antenna polarizations	Ch 0, 1, 2: RHCP, Ch 3, 4, 5: LHCP
Antenna gain	15 dBi per polarization
Radio and antenna volume	0.25U (2.5 cm x 2.5 cm x 10 cm)
DC power consumption	50 W
Modulation	QPSK, 8PSK, 16APSK, 32APSK
Coding	1/4 to 9/10 FEC
Channel data rates	Variable from 37 Mbit/s to 336 Mbit/s
Maximum data rate achieved on orbit	1674 Mbit/s (at the time of publication)

Table 2: HSD2 transmitter parameters

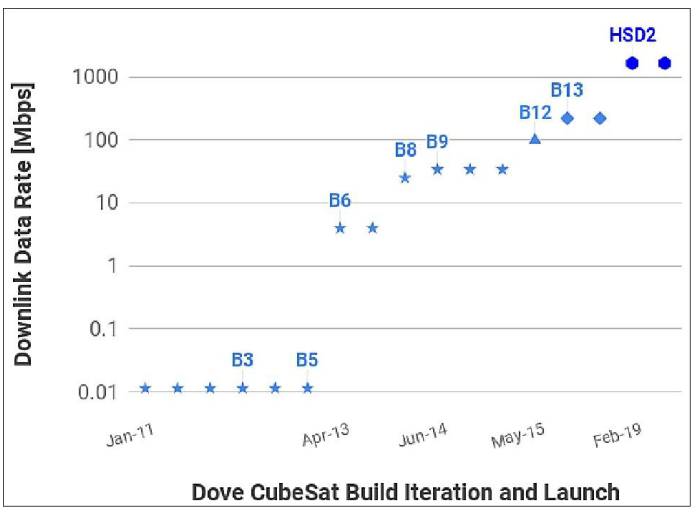

Figure 13: HSD data rate improvements for various Dove build iterations are shown as blue points on the scatter plot. Triangle represents 100 Mbit/s radio launched on B12 in May 2015, diamond

represents the 220 Mbit/s radio launched on B13 in May 2016, and hexagon represents the 1.6 Gbit/s HSD2 radio launched in December 2018 and March 2019 (image credit: Planet)

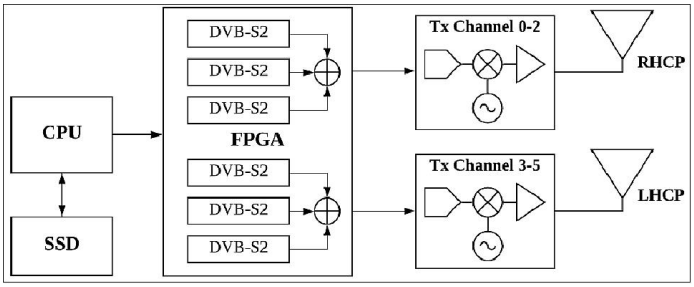

Figure 14: Block diagram of the six channel HSD2 satellite transmitter (image credit: Planet)

- Ground Stations and Receiver: Planet operates its own ground network to efficiently meet the data volume needs of our large constellation and for flexibility and agility in the deployment of new technologies. Rapid flexibility is especially important when a new constellation can be built and launched in the same time needed to obtain a license and construct or lease a new ground station. In total, Planet operates 15 owned S/X-band antennas at 5 sites. Figure 15 shows the Keflavik ground station at Keflavik, Iceland and Figure 16 shows the Canadian ground station at Inuvik, Canada. Planet operates telemetry, tracking, and command (TTC) antennas at UHF band from all the S/X-band sites as well as 5 additional sites. Planet's TTC Low Speed Transceiver is based on OpenLST [28]. and is also used for time-of-flight ranging. [29]. This diversity in assets and locations allows the ground network to scale to meet the demands of both HSD1 and HSD2 radio systems.

Figure 15: The 4.5 m diameter S/X dish in Keflavik,Iceland

Figure 16: Canadian Satellite Ground Station Inuvik (CSGSI), Inuvik, NWT, Canada (image credit: CSA)

- Planet ground stations use COTS components where possible to reduce cost and complexity. All Planet ground systems can support both HSD1 and HSD2 downlinks. Planet's ground station network was originally designed for operating with the single channel HSD1 (Ref. 6). [30]. With the addition of multiple channels and dual polarization, the receiver chain has gone through significant hardware and software upgrades. A left-hand polarized feed and low noise block down-converter (LNB) were added to each dish to support the second polarization. The intermediate frequencies were chosen such that the LHCP is combined onto the same coax cable as the RHCP, with appropriate guard bands. Five demodulators were added to the one existing demodulator in each system to interface with the six-channel HSD2 transmitter.

Parameter	Value
Ground dish size	4.5 m-5 m diameter
Number of dishes	15
Gain at X-band	49 dBi
Beamwidth (half power)	0.55º
G/T (gain over noise temperature)	29 dB/K

Cross polarization	25 dB
Max data downlinked per pass	82.91 GB (at the time of publication)

Table 3: HSD2 ground station parameters

- The demodulators output digital data on a separate 1 Gbit/s Ethernet interface. A COTS network switch bonds these individual channels onto a single 10 Gbit/s fiber optical link that is fed into the ground station server. This approach of maintaining the individual channels on a separate network and multiplexing in the network switch provides the flexibility to change the number of channels or add more channels in the future without significantly altering the existing hardware infrastructure. A block diagram of the HSD2 receiver is shown in Figure 17. If the S/X data throughput exceeds the local network capacity, the ground station will store and then forward the data to Planet's imagery pipeline. Planet's scheduling software takes into account expected data downlinked and limits passes if needed to avoid a backlog of imagery uploads from building up on the local server.

- Channel count and polarization states are stored as configuration variables for both satellites and ground stations, allowing different configurations throughout the network. This makes the network robust as the failure of one or two channel will not impact the remaining channels. Scheduled contacts bring up as many channels that are operational on both the ground station and the satellite. With dynamic per-pass configuration of channels, single-channel contacts (HSD1) become simply a special case of six-channel contacts (HSD2).

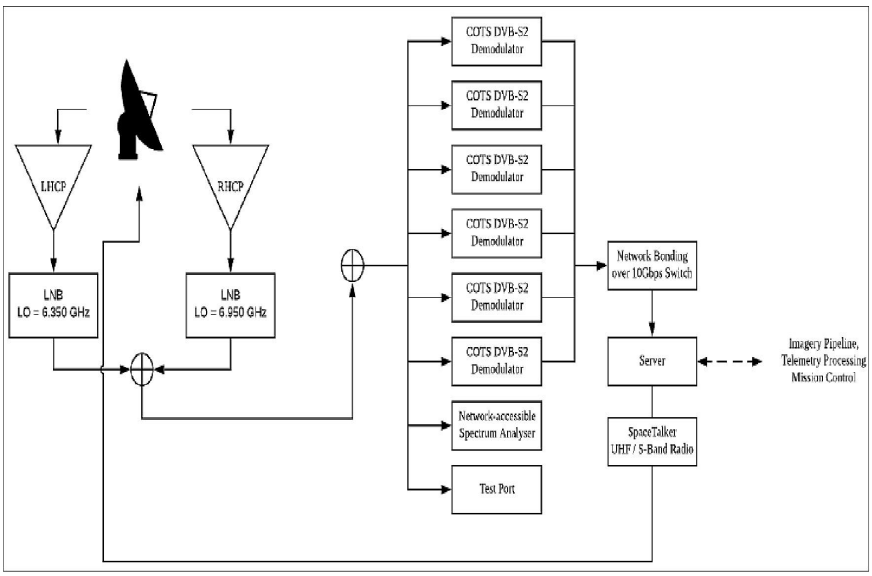

Figure 17: Block diagram of the six channel HSD2-capable ground station (image credit: Planet)

- HSD2 Software: The HSD2 software that runs on the satellite and the ground station ensures that the transmitter and receiver work in tandem to optimize data throughput. The low-level software stack makes the six DVB-S2 channels appear to higher level software as single bonded channel. Because of the low error rate of the communication link, the nature of the data being transmitted (mostly images), and the highly asymmetric uplink (S-band uplink speed of 256 kbit/s), a negative acknowledgement (NAK) based protocol is used to transfer files from the satellite to the ground station.

- The ACM (Adaptive Coding and Modulation) feature of DVB-S2 allows for the selection of the appropriate modulation and forward error correction code (MODCOD) from a set of 28 choices that span QPSK through 32APSK modes and 1/4 FEC to 9/10 FEC. The MODCODs can vary on a per channel and per frame basis. Ground receiver and deframer statistics are closely monitored for link margin. The link margin metric in combination with the currently selected MODCOD and an appropriate safety margin are used to choose the MODCOD for the next epoch. This evaluation is performed on a per channel basis.

- While Planet is still bringing our next generation constellation up to full capacity, HSD2 is already showing great results in the production environment. Typical ground stations passes average 400 seconds in duration, and at peak data rates over 1.6 Gbit/s the ground terminal can collect over 80 GB of data per pass.

• April2, 2019: As announced at the start of the year, the **RapidEye constellation** has retired, capturing its last magnificent images, which we are sharing with you today. [31)]

- While RapidEye satellites will no longer collect imagery for commercial or noncommercial use, their archive of impressive data will remain available to customers, and will be used and appreciated for years to come.

- Customers who use RapidEye imagery will have the option to transition to our Next-Generation PlanetScope products, which will provide higher spatial resolution as well as continuity with the red, green, blue, near infrared and red-edge bands.

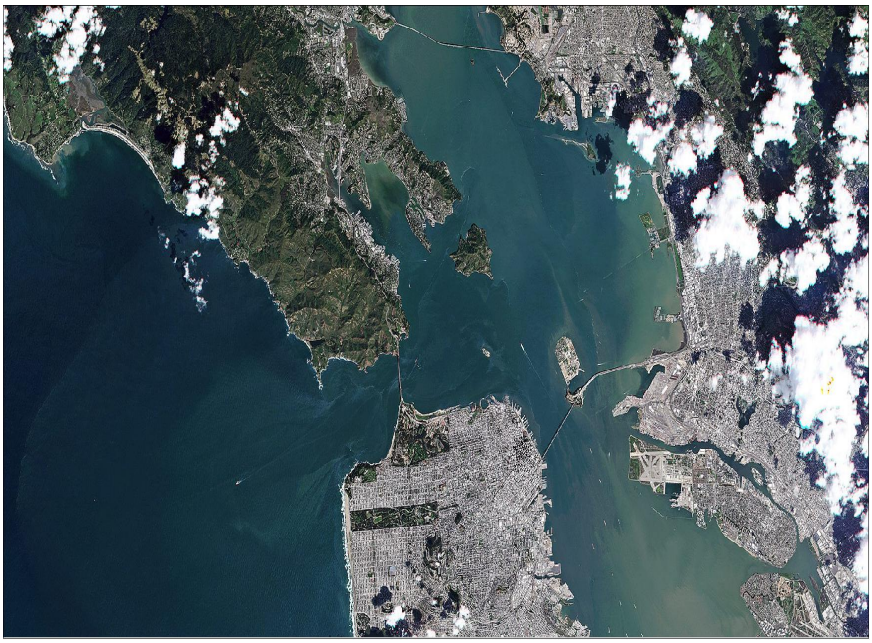

Figure 18: RapidEye last light image of San Francisco, California (image credit: 2020, Planet Labs Inc.)

Figure 19: RapidEye last light image of Berlin, Germany (image credit: 2020, Planet Labs Inc.)

• March 21, 2019: The National Geospatial-Intelligence Agency (NGA) is exercising a six-month option for a $5.9 million contract to Planet, a small satellite, commercial imagery provider, to advance the use of high revisit imagery and automated processing to augment and facilitate NGA analysis processes March 21.[32)]

- NGA exercised the option to continue development and evaluation of the broader National System for Geospatial Intelligence community needs for Planet's commercial imagery data to inform customers' future technical requirements.

- "Over the last three years, Planet data has been used by the combatant commands to support their ongoing missions around the world and to train automated analytic systems to monitor and recognize changes in those operational environments," said Scot Currie, NGA's deputy director of Source Operations Group, that falls under the directorate that delivers geospatial data to internal and external customers.

- The Planet subscription contract provides new daily imagery over the U.S. Southern Command area of responsibility and areas of interest in the U.S. Africa Command and U.S. Indo-Pacific Command areas of responsibility.

- NGA also entered into a cooperative research and development agreement with Planet in April 2018, following the purchase of a $14 million subscription for Planet imagery in July 2017 and an introductory contract NGA signed with Planet in 2016.

• January 3, 2019: There is now some very good optical satellite imagery of the collapsed Anak Krakatau volcano, which generated the devastating tsunami on 22 December 2018. [33), 34).]

- Poor weather conditions over Indonesia's Sunda Strait had frustrated spacecraft that view the Earth in the same type of light as our eyes. But the team at Planet has managed to find windows in the cloud. Pictures from its Dove and SkySat platforms show the extent of the volcanic cone's failure.

- It is easier to appreciate now how the island has been reshaped. What was once a crater at the summit of a 340 m-high edifice has been completely broken open to form a small bay.

- Indonesia's disaster agency says more than two-thirds of Anak Krakatau's volume (150-170 million m^3) is missing. Much of it is assumed to have slipped into the sea in the colossal landslide that produced the tsunami.

- Earth observation company Planet, which is based in San Francisco, operates one of the world's largest satellite constellations. The big network maximizes the chances of seeing the ground when cloud clears above a target.

- Planet's small Dove spacecraft capture details on the ground larger than 3m - what is termed medium resolution; while its SkySat platforms have a high-resolution capability, capturing details larger than 72 cm.

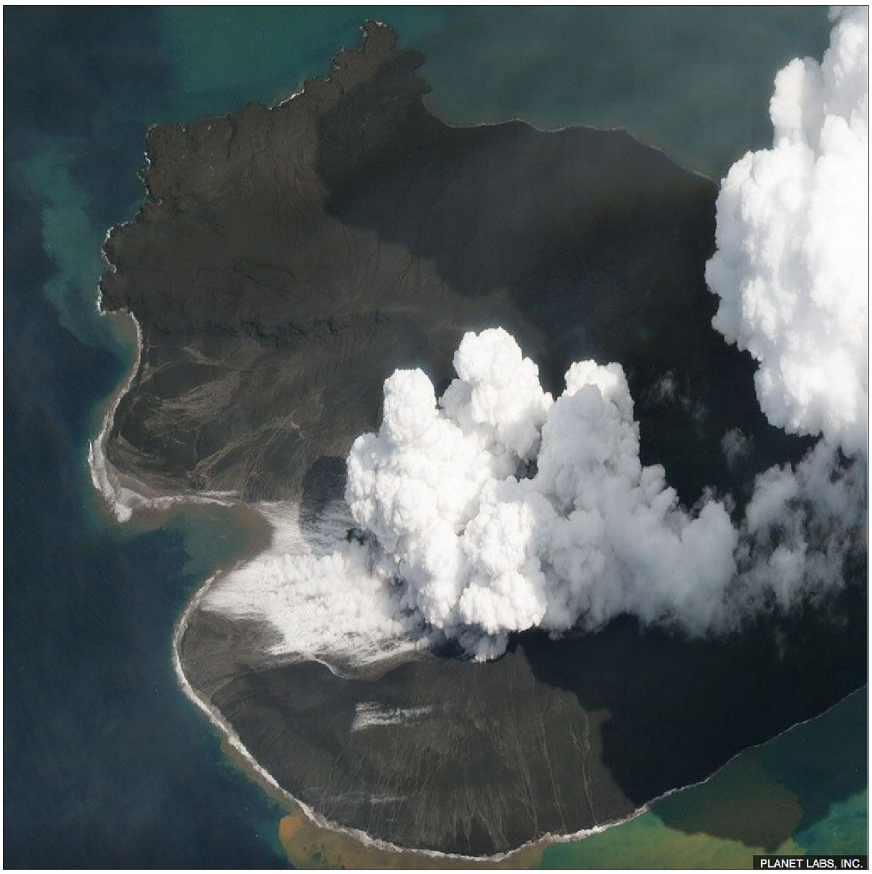

Figure 20: Image of Anak Krakatau as acquired on 2 January 2019 by Planet's SkySat satellite constellation (image credit: Planet Labs Inc.)

- Note: The satellite pictures acquired immediately after the disaster came from radar spacecraft, and gave the first hints that volcano Anak Krakatau had collapsed. - Radar instruments can pierce cloud but they return a very different type of view to optical satellites, and need a particular skill to interpret. — It's now thought some 430 people died along the coastlines of Java and Sumatra when the tsunami hit. Thousands more remain displaced.

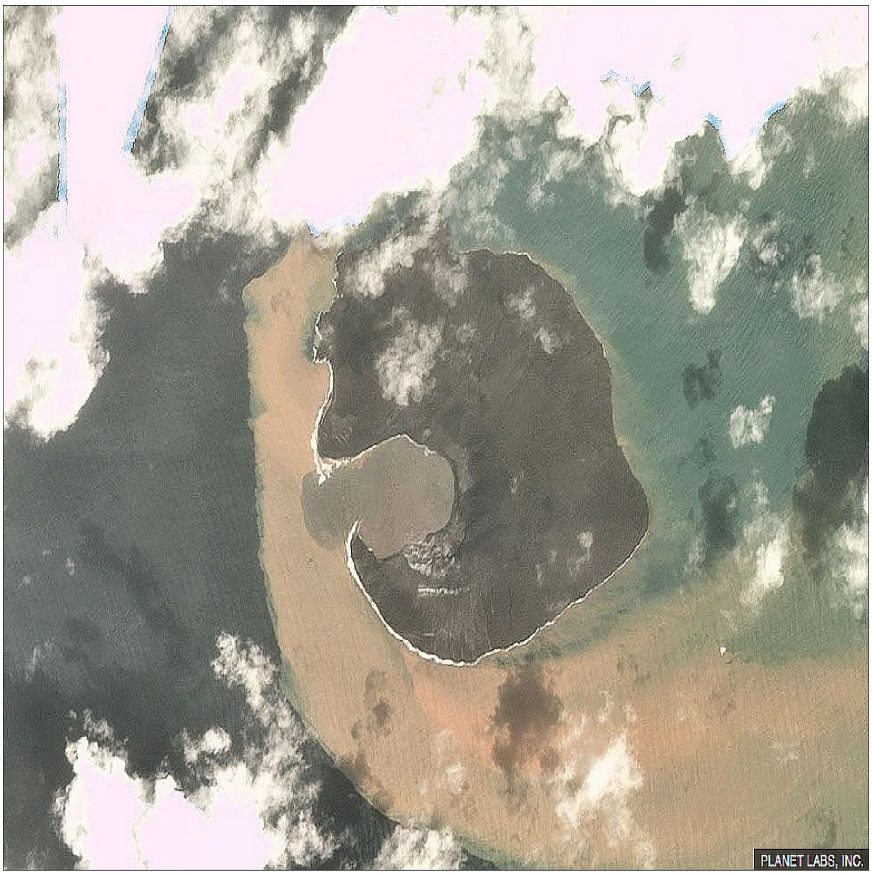

Figure 21: After the event: One of Planet's Doves observes the scene a week after the disaster on 30 December 2018 (image credit: Planet Labs Inc.)

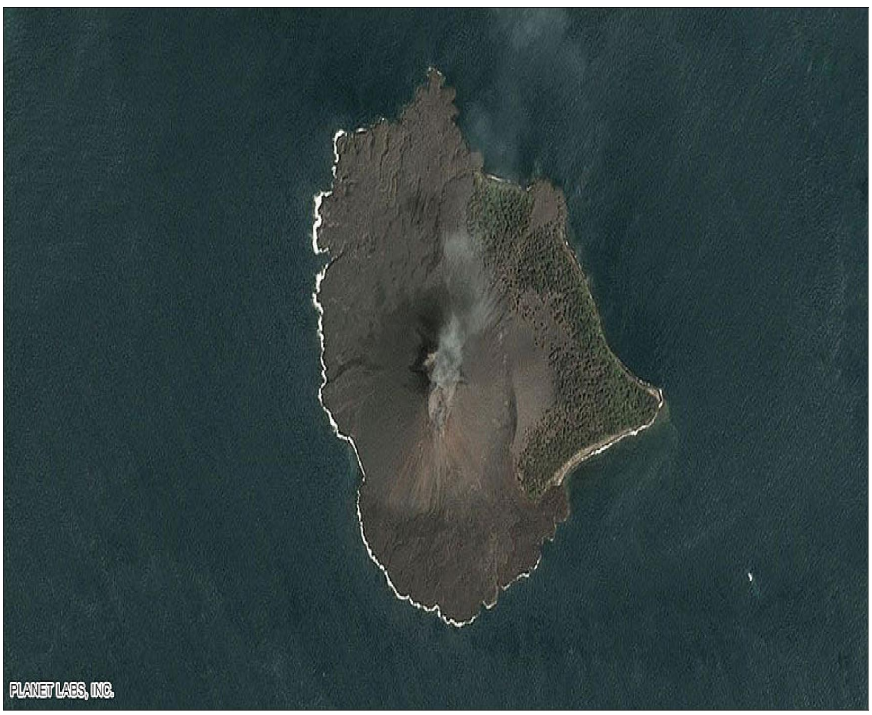

Figure 22: Before the event: A Dove image of Anak Krakatau as acquired on 17 December 2018 (image credit: Planet Labs Inc.)

Figure 23: A close-up Google map of the Indonesian Archipelago with the location of Anak Krakatau (image credit: BBC)

• December 28, 2018: Twelve Flock -3k 3U imaging CubeSats (each ~ 5 kg) of Planet Labs, were part of the secondary payload launched on 27 December 2018 on the Kanopus-V No 5 and No 6 minisatellite flight of Roscosmos on a Soyuz-2.1a / Fregat-M vehicle from the Vostochny Cosmodrome in Russia. [35), 36)]

• December 3, 2018: Three Flock-3s series 3U CubeSats and 2 SkySats were part of the SSO-A rideshare mission of Spaceflight Industries launched on 3 December 2018 (18:34:05 GMT) on a SpaceX Falcon-9 Block 5 vehicle from VAFB (Vandenberg Air Force Base) in California. [37), 38)]

• On 29 November 2018, 16 Flock-3r series 3U CubeSats were part of the payload of ISRO's PSLV-C43 vehicle from SDSC (Satish Dhawan Space Center) SHAR on the east coast of India. [39), 40)]

• October 04, 2018: NASA has launched a pilot program to evaluate how Earth science data from commercial small-satellite constellations could supplement observations from the agency's fleet of orbiting Earth science missions. On 28 September, the agency awarded sole-source contracts to acquire test data sets from three private sector organizations. [41)]

- NASA's Earth Science Division in Washington issued blanket purchase agreements for the "Private Sector Small Constellation Satellite Data Product Pilot" program. Under these agreements, the agency purchases data sets and related products based on observations derived from Earth-orbiting, small-satellite constellations designed and operated by non-governmental entities.

- "This pilot program is an innovative and efficient way for us to acquire, examine, and evaluate a wide range of private sector Earth observation data," said Michael Freilich, director of NASA's Earth Science Division. "As our very capable NASA research satellite fleet ages and more small satellites are launched by private industry, there are opportunities to leverage the strengths of each into even more complete climate data sets."

- NASA will provide the test data products to NASA-funded researchers, who will examine whether the data help advance the agency's science and applications development goals. The pilot program is designed to determine whether these private sector observations and associated products offer a cost-effective means to augment or complement the suite of Earth observations acquired directly by NASA, other U.S. government agencies, and international partners.

- The contracts were awarded to:

1) **DigitalGlobe,** a Maxar Technologies company headquartered in Westminster, Colorado, has five very high-resolution Earth imaging satellites (GeoEye-1, WorldView-1, WorldView-2, WorldView-3, WorldView-4) capable of collecting 30 cm resolution imagery.

2) **Planet,** headquartered in San Francisco, has three satellite constellations (SkySat, Dove, RapidEye) with more than 150 satellites supplying imagery and derived products over the entire Earth at medium and high resolution with high repeat frequencies.

3) **SPIRE Global,** headquartered in San Francisco, operates a constellation of over 60 3U CubeSats collecting radio occultation soundings, aircraft location information and ship reports. GPS radio occultation measurements can be used to sound the atmosphere for temperature, water vapor, and atmospheric pressure.

- These contracts represent the first time that NASA has engaged with commercial small-satellite constellation operators to purchase their data for scientific evaluation. They establish a way for NASA to acquire and

examine the data products during the next 12 months. Each contract includes an option for NASA to extend the agreement for an additional four years, for a total value of up to $7 million for each of the three agreements.

- To be considered for participation in this pilot program, companies had to demonstrate they were currently operating a small satellite constellation of no fewer than three satellites in non-geostationary orbit and producing consistent global coverage. Companies also were asked to supply a comprehensive catalog of their data, describing areal coverage, data latency, pricing, and other factors.

- NASA uses the vantage point of space to understand and explore our home planet, improve lives and safeguard our future. The agency's observations of Earth's complex natural environment are critical to understanding how our planet's natural resources and climate are changing now and could change in the future.

• September 12, 2018: Today, Planet is excited to announce the opening of our new satellite manufacturing and testing factory, located in the heart of San Francisco. As part of the grand opening, held in conjunction with the Global Climate Action Summit, the first batch of Doves manufactured in the new facility will be shipped out to India, via our deployment integration partners in the Netherlands, for launch on the PSLV rocket. [42].

- Planet already was home to the most prolific satellite production facility in the world – enabling us to launch a record 146 satellites in 2017. The new facility takes Planet to a new level. At 27,000+ square-feet (2500 m^2), the state-of-the-art complex is six times the size of our previous lab and brings all aspects of spacecraft design and production – from R&D to manufacturing to testing – under one roof. This enables us to iterate faster and continue to push the envelope of what small satellites are capable of.

- The additional square footage and flexible floor plan also allows for simultaneous production of multiple spacecraft lines, from Doves to future satellite constellations. For example, concurrent with other spacecraft designs, Planet can now build upwards of 40 Doves per week, which is nearly twice the build capacity of our previous manufacturing site.

- A highlight of the new facility is a multi-purpose environmental testing facility capable of simulating space environments and testing the readiness of our hardware for flight. Coupled with Planet's expertise in automation and data aggregation, these physical testing capabilities allow us to qualify and release new designs and missions quickly – without compromising quality or agility.

• August 2018: When Planet was founded in 2010, "Mission One" was defined as imaging the entire landmass of the Earth every day. From 2013 onward, Planet launched over 280 Dove satellites (representing 13 design iterations) toward achieving this goal. While many of these satellites have decayed naturally from their LEO orbits, as of June 2018, Planet currently operates approximately 190 Doves (constellation size is dependent on orbit lifetime and replenishment launches) and successfully achieved Mission One in November 2017. [43], [44]. Planet is now working toward "Mission Two" – applying machine learning and analytics to imagery to enable users to query what is on the Earth and build customized information feeds – and will continue to launch satellites to replenish the constellation as capabilities improve with future Dove iterations. [45].

- Satellite Operations at Planet: Planet's Mission Operations team is distributed between the US and European offices. This small team is responsible for maintaining the health of the entire Dove constellation, the scope of which includes commissioning, developing tools for anomaly detection/debugging, performing experiments, and upgrading on board software.

- Maintaining an appropriate balance between health and performance metrics is especially important when managing a large constellation. Planet's Mission Operations team works closely with subsystem teams. Aside from launch, Planet is vertically integrated from spacecraft design through delivering analytic products to customers, and this allows for efficient collaboration between teams. In the particular case of the ADCS (Attitude Determination and Control Subsystem), Mission Operations maintains and reports on the health of the sensors and actuators, while the ADCS team is responsible for performance: that is, keeping the satellites well-calibrated and making sure the overall pointing and stability metrics are met.

Summary: The ADCS subsystem is integral to the success of a spacecraft carrying out its mission. Calibrating and monitoring this subsystem across a large constellation is challenging, particularly due to the complexities introduced by distributed launches and multiple hardware revisions. Furthermore, as constellations grow in size, both human and material resources can become constrained and need to be allocated appropriately.

Through its experience building and operating the Mission One constellation, Planet has iterated on an system to allow a small Mission Operations and ADCS design team to ensure that imaging specifications are met. Pre-launch calibrations are moved to post-launch operations, using automated maneuvers and processing. Spacecraft performance is monitored through simple visualizations, firstly of product driven metrics, followed by component level metrics. Both these activities are supported by a general bias toward automation and the availability of data retrieval services. All the services are intended to minimize the need for humans-in-the-loop, but where it is required the systems are designed to enable agile decision making. Planet will continue with this mentality as it continues to iterate on the Dove and replenish the constellation.

• June 25, 2018: Planet is expanding its engagement in Europe in a big way. Today, we're excited to announce a partnership with Airbus, a leader in remote sensing, to enable access to each other's data and joint cooperation on the development of new geospatial solutions. [46].

- As part of the agreement, Planet and Airbus aim to provide customers with a comprehensive suite of global remote sensing data at multiple temporal and spatial resolutions, and to collaborate on new analytic solutions for a range of commercial markets.

Figure 24: François Lombard, Director of the Intelligence Business at Airbus Defence and Space (left); Dirk Hoke, CEO of Airbus Defence and Space (center); and Will Marshall, CEO and co-founder of Planet (right) at the signing of the agreement at Airbus headquarters in Toulouse, France (image credit: Planet)

- Airbus and Planet are truly complementary partners in the sense that Airbus provides reliable, high-resolution remote sensing capabilities, and Planet brings its unique global coverage and temporal cadence, as well as rapid iteration. Together, both partners will be able to deliver new and sophisticated offerings to fit customer needs globally across markets.

- "By combining our strengths, we will provide a key capability to address all market needs, both in terms of data and value-added products, and to best serve our clients, whatever their industry and their requirements" said François Lombard, Director of the Intelligence Business at Airbus Defence and Space.

- Airbus's constellation is comprised of very high-resolution Pleiades-1A and -1B; the high-resolution SPOT-6 and SPOT-7 satellites and the DMC constellation. On the radar side, TerraSAR-X, TanDEM-X, and the PAZ radar satellites ensure customers have access to any location whatever the cloud coverage. Planet operates the largest constellation of satellites in history, offering daily, global 3-5 meter resolution imagery via its over 130 PlanetScope satellites and sub-daily, sub-1 meter resolution imagery of anywhere on Earth with its constellation of 13 SkySats.

- Looking ahead, Airbus and Planet can maximize their global presence in key verticals, while leveraging each other's expertise to bring more comprehensive and advanced geospatial products to market. This partnership spans generations of aerospace innovation and reaches across borders, and Planet is looking forward to a bright future partnering with Airbus.

• January 21, 2018: Today, Rocket Lab's Electron vehicle "Still Testing" successfully reached orbit and deployed a Dove Pioneer Earth-imaging satellite for launch customer Planet, as well as two Lemur-2 satellites for weather and ship tracking company Spire Global. **The Electron vehicle of Rocket Lab lifted off on 21 Jan. 2018 at 01:43 UTC from the Rocket Lab Launch Complex 1 on the Mahia Peninsula in New Zealand.** [47), 48)]

- Following successful first and second stage burns, Electron reached orbit and deployed Humanity Star, a 1m diameter sphere of Rocket Lab, and the customer payloads at 8 minutes and 31 seconds after lift-off.

- "Today marks the beginning of a new era in commercial access to space. We're thrilled to reach this milestone so quickly after our first test launch," says Rocket Lab CEO and founder Peter Beck. "Our incredibly dedicated and talented team have worked tirelessly to develop, build and launch Electron. I'm immensely proud of what they have achieved today."

- "Reaching orbit on a second test flight is significant on its own, but successfully deploying customer payloads so early in a new rocket program is almost unprecedented. Rocket Lab was founded on the principal of opening access to space to better understand our planet and improve life on it. Today we took a significant step towards that," he says.

- Rocket Lab's commercial phase will see Electron fly already-signed customers including NASA, Spire, Planet, Moon Express and Spaceflight. Rocket Lab's offices are in Huntington Beach, California; Washington DC, and Auckland, New Zealand.

• November 30, 2017: **A new partnership with the pioneering satellite-imaging and data company Planet will enable Human Rights Watch to increase substantially the organization's use of satellite imagery to document rights violations around the world.** [49)]

- Satellite imagery plays an increasingly important role in exposing abuses, especially in countries where access for human rights investigators is blocked or heavily restricted, such as Burma or Syria.

- Planet is an integrated aerospace and data analytics company that operates history's largest fleet of Earth-imaging satellites, collecting a massive amount of information about the changing planet with a core mission of "using space to help life on Earth." Decision makers in business, government, and nonprofit organizations use Planet's data and machine learning-powered analytics to develop new technologies, drive revenue, power research, and solve some of the world's toughest challenges. In November, Planet met its goal of imaging the entire Earth's landmass every day.

- In recent months, satellite images have played a key role in documenting widespread burning of ethnic Rohingya villages in Burma, attacks against schools in Syria, and airstrikes in populated neighborhoods of Mosul, Iraq. Beyond its use in areas of armed conflict, Planet's data is uniquely suited for research on abuses related to land rights and the environment.

- Kenneth Roth, executive director of Human Rights Watch, mentioned that Planet's generous arrangement with Human Rights Watch, with access to its vast collection of high-resolution satellite data, will help provide timely evidence of unfolding abuses in some of the world's most dangerous spots. This partnership will boost our ability to monitor complex events as they occur and help identify those responsible for atrocities.

- Andrew Zolli, who leads the global impact initiatives at Planet, furthered Roth's comment by adding that Planet seeks to use their groundbreaking technology to promote human rights, protect the Earth, and diminish suffering. As one of the first satellite companies to originate entirely from the civilian sector, Planet is uniquely suited to support Human Rights Watch's mission of documenting rights abuses wherever and whenever they occur.

• October 31, 2017: Today, 6 SkySats (SkySat 8-13) and 4 Doves (Flock 3m) successfully launched on an Orbital-ATK Minotaur-C rocket destined for a Sun Synchronous, 500 km orbit. Planet is happy to report that all 10 satellites were deployed successfully and that our Mission Control team has made contact with all satellites and begun the commissioning process. [50)]

- This marks the 20th launch for Planet and our first-ever dedicated launch, which gave us the ability to choose our orbital parameters and timing of the launch. We sent these 10 satellites to an afternoon crossing time of approximately 13:30 hour to further diversify our product offerings. Most remote sensing satellites operate in morning-crossing configurations, including our currently on orbit set of 160+ Doves and 7 SkySats, and having the world's largest fleet of medium and high-resolution assets in both morning and afternoon crossing times enables a dataset never before provided in the commercial market at this scale.

- Furthermore, the launch of these 6 SkySats will double the sub-1 meter imaging capacity of our current SkySat fleet, providing a deeper understanding about our changing planet. With this expanded capability, decision makers will gain smarter, more timely insights to solve our world's toughest challenges.

• October 17, 2017: Newly released satellite images reveal that at least 288 villages were partially or totally destroyed by fire in northern Rakhine State in Burma since August 25, 2017, Human Rights Watch said today. The destruction encompassed tens of thousands of structures, primarily homes inhabited by ethnic Rohingya Muslims. [51)]

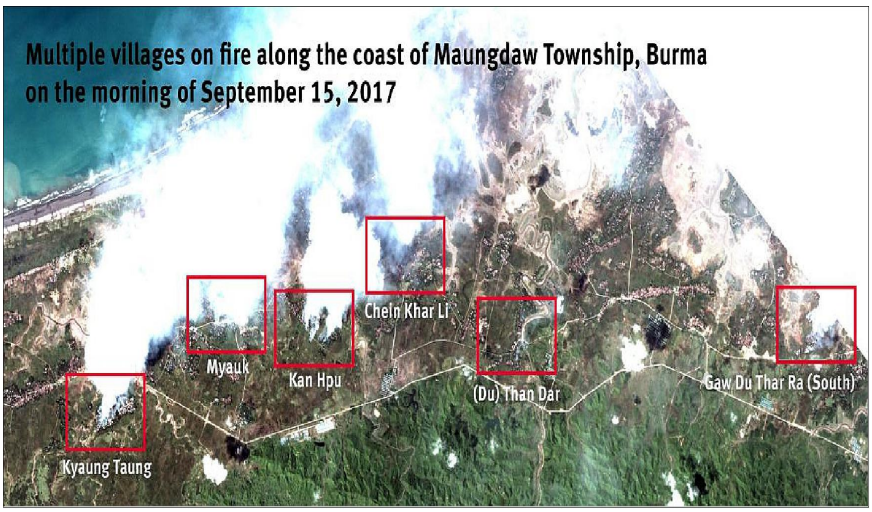

Figure 25: Multiple villages on fire along the coast of Maungdaw Township, Burma on the morning of September 15, 2017. Analysis Human Rights Watch (image credit: Planet Labs)

- Analysis of the satellite imagery indicates both that the burnings focused on Rohingya villages and took place after Burmese officials claimed security force "clearance operations" had ceased, Human Rights Watch said. The imagery pinpoints multiple areas where destroyed Rohingya villages sat adjacent to intact ethnic Rakhine villages. It also shows that at least 66 villages were burned after September 5, when security force operations supposedly ended, according to a September 18 speech by State Counselor Aung San Suu Kyi. The Burmese military responded to attacks on August 25 by the Arakan Rohingya Salvation Army (ARSA) with a campaign of ethnic cleansing, prompting more than 530,000 Rohingya to flee across the border to Bangladesh, according to the United Nations refugee agency.

Figure 26: Complete destruction of Rohingya villages in close proximity to an intact Rakhine village, Maungdaw township, recorded on 21 September 2017. Analysis by Human Rights Watch (image credit: Digital Globe)

• August 2017: Planet's Flock 3p is a constellation of 88 Dove Earth observation nanosatellites launched on a single Indian PSLV (Polar Satellite Launch Vehicle). Commissioning this fleet of satellites is a unique and challenging task that requires significant planning, automation, and operations. At Planet, a small team of operators is charged with shepherding the flock of satellites from initial deployment through full sensor and radiometric calibration. [52].

- Since its founding, Planet has defined and embraced agile aerospace. Planet's culture encourages iterative development based on experimentation. The operations team has grown and refined the commissioning process through experience on eight different launches.

- Spacecraft operations at Planet also demands a focus on automation. By rejecting the idea that satellites require large teams to operate, the team has built one-of-a-kind automated systems for commissioning and operating large fleets of satellites. Operators focus on improvements and anomalies, not day-to-day operations.

- With 88 satellites deployed from a single rocket, Flock 3p is the largest launch in history. Despite requiring an extensive list of calibration and checkout activities, Planet's small spacecraft operations team was able to meet its deadlines and have Flock 3p producing imagery for customers in just over three months.

S/C Name	Launch Vehicle	Launch Date	Orbit	No of satellites launched	Status
RapidEye	Dnepr	Aug. 29, 2008	SSO	5	Operational
Dove 2	Soyuz 2.1b	April 19, 2013	Other	1	Retired
Dove 1	Antares	April 21, 2013	Other	1	Reentered
Dove 3	Dnepr	November 21, 2013	SSO	1	Retired
Dove 4	Dnepr	November 21, 2013	SSO	1	Failed Deployment
SkySat 1	Dnepr	November 21, 2013	SSO	1	Operational
Flock 1	Antares	January 9, 2014	ISS	28	Reentered
Flock 1c	Dnepr	June 19, 2014	SSO	11	Retired
SkySat 2	Soyuz 2.1b	July 8, 2014	SSO	1	Operational
Flock 1b	Antares	July 13, 2014	ISS	28	Reentered
Flock 1d	Antares	October 28, 2014	ISS	26	Failed Launch
Flock 1d'	Falcon 9	January 9, 2015	ISS	2	Reentered
Flock 1e	Falcon 9	April 13, 2015	ISS	14	Reentered
Flock 1f	Falcon 9	June 28, 2015	ISS	8	Failed Launch
Flock 2b	H-IIB	August 19, 2015	ISS	14	Reentered
Flock 2e	Atlas V	December 6, 2015	ISS	12	Operational
Flock 2e'	Atlas V	March 23, 2016	ISS	20	Operational
Flock 2p	PSLV	June 22, 2016	SSO	12	Operational

SkySat 3	PSLV	September 16, 2016	SSO	1	Operational
SkySat 5-7	Vega	September 16, 2016	SSO	4	Operational
Flock 3p	PSLV	February 15, 2017	SSO	88	Operational

Table 4: Historical Planet launch manifest, including RapidEye and SkySat launches (Ref. 52)

- How Planet Launches: Planet's ideal imaging orbit is morning sun-synchronous (like most other remote sensing missions). However, Planet's strategy is to aggressively procure regular launches even if they are not to an ideal orbit. Variability in orbits, such as in power and thermal budgets, is managed through operations and extensive software automation. For this reason, Planet has historically utilized commercial launch services through Nanoracks to provide convenient access to space through the ISS (International Space Station). Flocks are launched as cargo to the ISS and deployed through the J-SSOD (JEM Small Satellite Orbital Deployer) in groups of two. Because the Dove satellites do not have active propulsion, these satellites have an orbit very similar to that of the ISS.

- Planet has also done several direct launches with Doves as a secondary payload to sun-synchronous orbits, which provide the benefit of a consistent sun angle.

Item	ISS Orbit	SSO Orbit
Sun angle	Varies over time	Consistent based on LTAN/LTDN, Can drift over several years
Thermal environment	Solar beta angle maxima require special handling	Minor variation over the year
Orbital altitude	390 km - 450 km at deployment	About 500 km
Inclination	51.6°	~98°
Orbit lifetime	12-18 months (depending on solar activity and drag profile)	4-5 years
Coverage	Missing northern Canada and Russia, Antarctica, southern tip of South America	Full Earth with some seasonal polar gaps

Table 5: ISS versus SSO Orbits

- Planet strives for diversity in its launch manifest for a number of reasons. Vehicle family diversity is important because launch failures will usually delay the manifest of that vehicle family by a year or more while an accident investigation is underway. Geopolitical diversity has also proven to be very important to accommodate unpredictable changes in regulations and the global political environment.

• August 2017: Planet has deployed a constellation of low-cost, state of the art small satellites that will effectively act like a line-scanner of the Earth's surface. Planet's current mission is to provide images of the entire Earth's landmass one time per day, every day. The work with the U.S. Navy seeks to expand this global monitoring capability from the land to the sea, starting with coastal regions and expanding into the oceans. Planet's innovative approach to space is also observed in its image pipeline and rectification processes. Rectification and interpolation approaches are evaluated over water collects to observe how these impact relative geo-accuracies out to 10 km, 60 km, and open water (>=100 km). Analysis revealed relative geo-accuracies of 220 m at 10 km, 221 m at 60 km, and >~1.4 km in open water. 53)

- To date, Planet has launched more than 200 Dove satellites, operates more than 100 Dove spacecraft, and collects and processes more than 150 million km^2 of satellite imagery per day. Toward the end of the second quarter of 2017, Planet's constellation of Doves will revisit every spot on the Earth daily which will include open water areas. Planet complements its imagery collection backbone with an internally developed, web-based, imagery processing platform that enables automated image processing and orthorectification as well as data discovery and delivery.

- In an effort to understand the accuracy of Planet's products over water, Planet was under contract with the Navy's Program Executive Office Space Systems via the Rapid Innovation Fund program. The goal is to measure the relative geo-accuracy of the image data sets over littoral (10 km), coastal (60 km) and open water (>100 km). The purpose is to provide an understanding and drive confidence on Planet's processing pipelines for the addition of maritime imaging to Planet's commercial product line.

- Under contract with the Navy's Program Executive Office Space Systems, Planet determined its data relative accuracy over littoral, coastal and open water regions. Planet demonstrated its technical approach and evaluated the relative geo accuracy for the images produced by the Dove spacecrafts. The goal was to drive confidence in Planet's capabilities to collect over water or in areas where GCPs (Ground Control Points) are not available to provide accurate rectification for the imagery.

- Known relative geo-accuracies over water enables Planet to make collects beyond the Earth's landmass available to users like the Navy that can benefit from these for its day-to-day operations and mission sets by providing them with unprecedented coverage over water, significantly increasing maritime domain awareness. As a result of the work done through the Rapid Innovation Fund, Planet is in the process of releasing an Open Oceans commercial product. The technical preview for the Open Oceans program went live in June 2017 through which Planet has made several open ocean areas available via the platform.

• July 20, 2017: Planet has won a second contract to provide satellite imagery to the U.S. National Geospatial Intelligence Agency (NGA), taking a sole-source award while UrtheCast, Orbital Insight and Sky Hawk Drone Services offered noncompetitive capability statements. 54)

- The one-year, $14 million contract follows a seven-month, $20 million pilot contract that began in September to assess ways San Francisco-based Planet's "persistence and global coverage capabilities could most

effectively support the NGA mission," according to a July 19 agency statement.

- NGA said none of the other companies it considered could offer an imagery subscription service with a high enough revisit rate on a global basis. Though others were assessed, NGA told SpaceNews Aug. 1 that Planet received the contract "without competition."

- NGA said the agency requires the ability to monitor changes across large geographic areas for humanitarian and intelligence missions.

- "Monitoring sources that collect imagery at medium resolution (3-7 meters) at a cadence of weekly or better can satisfy the requirements of making assessments of certain [redacted] intelligence problems, including food security forecasting, [redacted] installation or infrastructure development, military preparedness [redacted] economic forecasting by measuring inventories, and other observations that can be made from analyzing changes over time. In addition, medium resolution monitoring sources improves NGA's ability to maintain current shoreline data and assess whether foundation products require updating," the agency said in an unclassified document released July 20.

- Planet's constellation of remote-sensing cubesats, called Doves, is currently the largest constellation in orbit. The NGA document described the constellation as 160 satellites with 120 active, but Planet spokesperson Trevor Hammond told SpaceNews July 20 that the operator's current fleet numbers 190 satellites, 142 of which are actively imaging; the remaining 48 are still being integrated into the fleet after launching on a Soyuz rocket last week. Dove cubesats have an average resolution of 3.7 meters. The Planet fleet also includes seven larger SkySat satellites from its acquisition of Terra Bella and five RapidEye satellites from BlackBridge.

- Planet has 23 operational ground stations to communicate with its constellation and receive collected imagery. A ground station completed in northern Canada earlier this year is facing protracted licensing delays, prompting the company to look elsewhere for other sites while awaiting an outcome.

- Of the companies who filed capability statements — meant to inform NGA of what services they can or hope to one day provide — only Vancouver-based UrtheCast is a satellite operator, and the company's first UrtheDaily satellites won't be in orbit until early 2019. The company currently leverages cameras on the International Space Station and two free-flyers gained through the acquisition of Elecnor Deimos in 2015.

• May 2017: The Geological Remote Sensing Group (GRSG) has expanded its membership once again with the recent news that **Planet** — the owners and operators of the world's largest commercially-operated fleet of satellites — has joined as the Group's latest corporate member. [55)]

- Founded in 2010 by a team of ex-NASA scientists, Planet has designed, built and launched fleets of smallsats to make images of the Earth from space, affordable and widely available, in pursuit of their Mission 1 — to image the entire Earth, every day. With an agile approach to satellite development and Planet's acquisition of BlackBridge's fleet of five **RapidEye** satellites (in October 2015) and recently, TerraBella's seven high-resolution **SkySat** satellites, the company has grown their presence in the geospatial industry incredibly quickly.

- Blanca Payas, Planet Sales Director for Europe, Russia and Central Asia explained why Planet decided to join the GRSG by stating that, in a very short time, Planet has become a global company with offices in Europe and the US. More and more, we are finding that our capabilities are supporting projects in the domain of geology. The companies hope to develop new initiatives and activities together.

- GRSG Chairman, Charlotte Bishop, added that Planet's data and access model starts to challenge the way we in the industry think about and use satellite data in a way not done before.

• April 19, 2017: As Planet of San Francisco announced, it has completed its acquisition of rival satellite imaging company Terra Bella on April 18, it confirmed that Google is now a shareholder in Planet as part of that deal. [56)]

- Planet announced on February 3 that it had reached an agreement with Google to acquire Terra Bella. Google had purchased Terra Bella, then known as Skybox Imaging, in 2014 for an estimated $500 million. At the time, both Planet and Google declined to disclose the terms of the deal other than that Google signed a multi-year deal to purchase imagery from Planet.

- The deal, though, was rumored to include Google taking a stake in Planet. In an April 18 blog post announcing that the deal had closed, Planet co-founder and chief executive Will Marshall confirmed that. "We're also delighted to welcome Google as a shareholder and customer," he wrote.

- Planet spokesperson Rachel Holm said in an April 18 email that Google took an equity stake in Planet, in addition to the previously announced multi-year imagery contract. Neither company, though, has said how much of Planet that Google now owns.

- The deal closed after receiving regulatory approvals from several federal agencies. "Over the last several weeks, we received all necessary regulatory approvals from NOAA (National Oceanic and Atmospheric Administration), FTC (Federal Trade Commission) and FCC (Federal Communications Commission)," Holm said. The NOAA licenses commercial remote sensing systems in the United States, while the FCC licenses satellite communications.

- The FTC, with the Department of Justice, reviews large acquisitions under the 'Hart-Scott-Rodino Act' for any antitrust issues, setting a waiting period for that review before such deals can close. The FTC issued "early termination" notices March 16 for Planet's acquisition of Terra Bella and Google's acquisition of part of Planet, ending that waiting period early and allowing the deal to proceed.

- Planet will now work to integrate the high-resolution imagery from Terra Bella's fleet of seven SkySat satellites with Planet's own constellation of nearly 150 satellites that provide medium-resolution images. That fleet includes 88 satellites launched in February on an Indian Polar Satellite Launch Vehicle.

- "This 'close' is also the beginning—the beginning of a new chapter at Planet, and of a lot of work across our organization over the next year to make SkySat imagery available on the Planet platform," Marshall said in his statement. - Holm said that a "significant portion" of Terra Bella's employees will remain with Planet. The company, headquartered in San Francisco, will maintain an office in Mountain View, California, where Terra Bella was based.

Figure 27: An illustration of four of the SkySat high-resolution imagery satellites developed by Terra Bella. Planet announced April 18 it has completed its deal announced in February to acquire Terra Bella from Google (image credit: Space Systems Loral)

• March 5, 2017: Located at the gateway to the Sahara desert, within the confines of the fertile zone of the Sudan and in an exceptionally propitious site near to the river Niger, Timbuktu (also spelled Timbuctoo) is one of the cities of Africa whose name is the most heavily charged with history. It is an UNESCO World Heritage Site. - The town is the capital of the Timbuktu Region, one of the eight administrative regions of Mali with a current population of about 55,000. [57].

- Founded in the 5th century, the economic and cultural apogee of Timbuktu came about during the15th and 16th centuries. It was an important center for the diffusion of Islamic culture with the University of Sankore, with 180 Koranic schools and 25,000 students. It was also a crossroads and an important market place where the trading of manuscripts was negotiated, and salt from Teghaza in the north, gold was sold, and cattle and grain from the south.

- The three big Mosques of Djingareyber, Sankore and Sidi Yahia, sixteen mausoleums and holy public places, still bear witness to this prestigious past. The mosques are exceptional examples of earthen architecture and of traditional maintenance techniques, which continue to the present time.

Figure 28: The Flock constellation acquired this view of the famous city of Timbuktu on March 5, 2017 (image credit: Planet)

• Feb. 23, 2017: The 88 nanosatellites of Planet, launched on Feb. 15, 2017, joined dozens already in orbit, bringing the constellation of "Doves," as these tiny imaging satellites are known, to 144. Six months from now, once the Doves have settled into their prescribed orbits, the company says it will have reached its primary goal: being able to image every point on Earth's landmass at intervals of 24 hours or less, at resolutions as high as 3.7 meters — good enough to single out large trees. It's not the resolution that's so impressive, though. It's getting a whole Earth selfie every day. [58].

- The news has already sparked excitement in the business world, which is willing to pay a premium for daily updates of telltale industrial and agricultural data like shipping in the South China Sea and corn yields in Mexico. But scientists are realizing that they, too, can take advantage of the daily data—timescales that sparser observations from other satellites and aircraft could not provide.

- "This is a game changer," says Douglas McCauley, an ecologist at the University of California, Santa Barbara, who wants to use Planet imagery to map coral bleaching events as they unfold. At present, coral researchers often rely on infrequent, costly reconnaissance airplane flights. "The previous state of the science was, for me, like taking a family photo album and shaking out all the photos on the floor and then being asked to haphazardly pick up three images and tell the story of the family."

- McCauley is participating in Planet's Ambassadors Program, which provides free satellite imagery to researchers as it is collected, with no lag time, under an agreement that prohibits them from reselling the data. Joe Mascaro, a tropical ecologist who runs the program, says it was created in the fall of 2015 in response to queries from scientists yearning for access to the company's growing archive of data. Over the course of 2016, Planet approved the applications of about 160 researchers across a range of fields. "We anticipate there will be many new applications of our data that we didn't anticipate," Mascaro says. The company intends to expand the program in the months ahead, and says it is looking for projects that have social, humanitarian, and environmental impacts—and that have the potential for rapid publication in peer-reviewed journals.

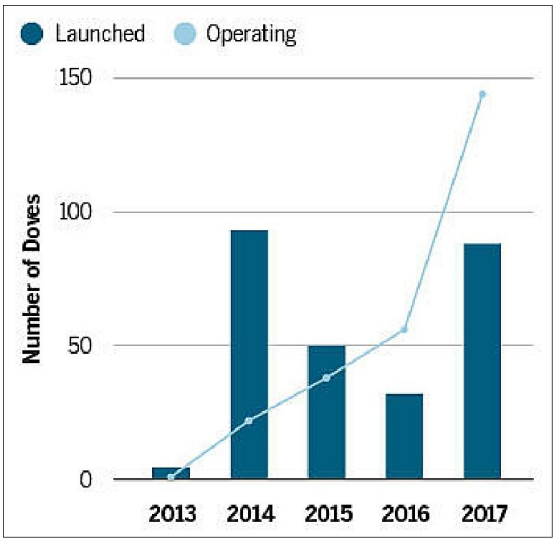

Figure 29: With the launch of 88 tiny Doves on Feb. 15, 2017, the satellite company Planet now has 144 at work, which will permit daily images of the entire Earth (image credit: Jonathan McDowell, Harvard-Smithsonian CfA)

- Andreas Kääb, a geoscientist at the University of Oslo, applied to the program to obtain additional data for his work on glaciers, including an investigation into a massive glacial avalanche in Tibet last July that killed nine herders and hundreds of sheep and yaks. Kääb already had before-and-after imagery from Landsat and Sentinel-2, U.S. government and European Space Agency satellites that have, respectively, 30 m and 10 m resolution and revisit intervals of 16 and 10 days. But higher resolution Planet images provided Kääb with valuable, timely clues. The appearance of large crevasses before the avalanche indicated the glacier was "surging," although surges, typically somewhat slow, don't usually lead to avalanches. But Kääb also saw water pooling on the surface of the glacier—a sign of heavy rainfall or unusually high temperatures. That water might have seeped through the crevasses, soaking the sediments below the glacial bed and creating a lubricant that triggered the sudden slip. When he saw a second nearby glacier with similar patterns, "We warned Chinese authorities, but when our warning arrived the glacier had already collapsed," Kääb says (no people, or yaks, were hurt).

- Kääb also used Planet images to study surface displacements along fault lines in New Zealand following the country's 7.8-magnitude earthquake last November. Though high-resolution GPS ground stations are typically used for this, not all faults have dense GPS networks monitoring them. He used Planet images to determine that two fault lines had slipped between 6 and 9 m — showing that medium-resolution optical satellites can fill the gap.

- Dave Petley, who studies landslides at the University of Sheffield in the United Kingdom, has not joined the Ambassadors Program yet, but says that access to the images would be "transformational" for his research. Orbital imagery has revealed some 80,000 landslides in the wake of the New Zealand earthquake. Aftershocks are likely responsible for many of them. But because available images can be weeks apart, "we just have to assume that everything happened in the main shock," Petley says. Daily images during the sequence of aftershocks would show how the landscape responds to different amounts of shaking, Petley says, and help with disaster response. "You want to know how many of your roads are damaged, how many valleys might be blocked."

- Planet's images are also finding a niche among researchers who deal with human-caused calamities, like deforestation. Matt Finer, a researcher at the Amazon Conservation Association in Washington, D.C., gets weekly deforestation alerts based on Landsat images, but says they are too course to determine whether the damage is natural or human-caused. He now turns to Planet data to decide whether an event is concerning. He recalls one incident when his group spotted 11 hectares of forest loss in Peru, accompanied by extensive dredging—signs of an illegal gold mining operation. "The Peruvian government was on the ground within 24 to 48 hours, kicking the miners out," he says. In previous years, Finer says, hundreds of hectares might be lost before anyone acted.

- Micah Farfour, a special adviser on remote sensing at Amnesty International in New York City, is using Planet images to monitor humanitarian crises as they unfold. Timely images can help her corroborate witness testimony or pinpoint emerging refugee crises. "It's a really, really amazing tool for narrowing down time frames," Farfour says. Still, images acquired from other private satellite companies, like DigitalGlobe, remain crucial to Amnesty's work, because they can offer the 30 cm resolution needed to, say, identify mass graves or count the buildings destroyed in a village that's been burned to the ground.

- Another limitation of Planet's Doves is that they only have four spectral bands—red, green, blue, and near-infrared—compared with Landsat's 11 bands. "Planet's daily observation frequencies are incredibly useful," says David Roy, a remote sensing scientist at South Dakota State University in Brookings and co-leader of the Landsat science team. "But there are lots of things .... that are probably not doable with Planet labs data." A major missing component, he says, are thermal bands in the far infrared, which enable Landsat to monitor the evaporation of water from plants. That's "quite important if you're looking at drought monitoring or water consumption, particularly in agriculture," Roy says. The Doves also lack a shortwave infrared band, which on Landsat can distinguish between different types of vegetation.

- These concerns have not slowed the juggernaut of Planet. In early February, it made two major announcements: It had folded Landsat-8 and Sentinel-2 data into its archive and it had initiated a deal to acquire Google's Terra Bella satellite imaging division and its seven SkySats, which have the capability to image at 0.7 m resolution. However, a spokesperson for Planet declined to say whether scientists will have access to those higher resolution images once the deal is completed.

- In the meantime, as more scientists publish their papers using Planet imagery, word is getting around. Mascaro says he was at a meeting of the American Geophysical Union in December 2016 when Kääb showed how Planet data were enabling the monitoring of glaciers. "Not surprisingly, I got a few Ambassadors applications from people who were in the room."

• February 15, 2017: Today Planet successfully launched 88 Dove satellites to orbit—the largest satellite constellation ever to reach orbit. This is not just a launch (or a world record, for that matter!); for our team this is a major milestone. With these satellites in orbit, **Planet will reach its Mission 1: the ability to image all of Earth's landmass every day.**

Tonight is the culmination of a huge effort over the past 5 years. In 2011 we set ourselves the audacious mission of imaging the entire Earth land area every day. We were convinced that armed with such data, humanity would be able to have a significant positive impact on many of the world's greatest challenges. We calculated that it would take between 100-150 satellites to achieve this, and we started building them. After today's launch, Planet operates 149 satellites in orbit. We have reached our milestone.

It's taken a minor Apollo project to get here! Behind the scenes we've miniaturized satellites; learned how to manufacture them at scale; constructed the world's second largest private network of ground stations; custom built an automated mission control system; created a massive data pipeline able to process the vast amount of imagery we collect; and developed a software platform that lets customers, researchers, governments and NGOs (Non-Government Organizations) access imagery quickly. Each of these has been a significant undertaking in and of itself—and together it represents a major systems engineering project. This is not to mention the non-engineering efforts from raising capital, receiving regulatory licenses, booking launches, and building a base of hundreds of partners that use the data to solve their needs.

Without a doubt, the single largest driver behind this record-breaking success is the **unrelenting dedication of the Planet team.** We've been humbled by them for the last five years and we thank them today.

Next up: getting this data to our customers and to those who need it the most! But for now Planet is having a great start to the year worthy of a little celebration.

Here are some additional facts and figures regarding this launch:

• The 88 Dove satellites (collectively known as "Flock 3p") rode aboard a PSLV rocket from the Satish Dhawan Space Center in Sriharikota, India

• This leads to two world records: a record for the most satellites ever launched on a single rocket; and a record for the largest private satellite constellation in history, totaling 149 satellites in all.

• This is our 15th launch of Dove satellites and second aboard India's PSLV. The launch of Flock 3p comes off the successful launch of Flock 2p on the PSLV in June 2016.

• After deployment, all 88 satellites will be autonomously commissioned in batches. We expect Flock 3p to enter normal imaging operations in about three months.

• Each of the Flock 3p satellites—our 13th build—sports a 200 Mbit/s downlink speed and is capable of collecting over 2 million km^2 per day.

Table 6: Planet Launches Satellite Constellation to Image the Whole Planet Daily [59].

• On February 15, 2017 (UTC), ISRO (Indian Space Research Organization) launched the CartoSat-2D primary mission from SDSC (Satish Dhawan Space Center) on the east cost of India on the PSLV-C37 vehicle, along with a record number of 103 secondary payloads, among them **88 3U CubeSats, (Doves, 4.7 kg each) of Planet**

(formerly Planet Labs), San Francisco. The Dutch nanosatellite company ISIS (Innovative Solutions In Space), Delft, The Netherlands, provided the integration service for 101 nanosatellites on this flight. The total launch mass was 1378 kg into a sun-synchronous orbit of 506 km altitude. [60].

- Less than a minute after reaching orbit, the fourth stage released the CartoSat-2D environmental satellite — the mission's primary payload — about 17.5 minutes into the mission. Ten seconds later, two experimental Indian nanosatellites separated to test new types of sensors to observe Earth's surface, atmosphere and the conditions in the harsh environment of space. [61].

- Then came a carefully-choreographed deployment sequence for the remaining 101 payloads stowed inside 25 Dutch-built "QuadPacks" for the ride into orbit.

- The QuadPacks opened two at a time to eject their CubeSat passengers. Most of the CubeSats separated while the PSLV was flying over a remote stretch of the Indian Ocean between ground stations in Mauritius and Antarctica. Once the PSLV passed in range of the receiving antenna in Troll, Antarctica, launch controllers at the Satish Dhawan Space Center confirmed all 104 satellites separated as planned.

- The launch of 88 Dove satellites came less than two weeks after Planet announced the acquisition of Terra Bella from Google, which has a constellation of seven higher-resolution spacecraft capable of recording high-definition video during passes over ground targets.

Figure 30: A view of the 25 "QuadPacks" holding 101 CubeSats preparing for launch on the PSLV-C37 mission (image credit: Innovative Solutions in Space)

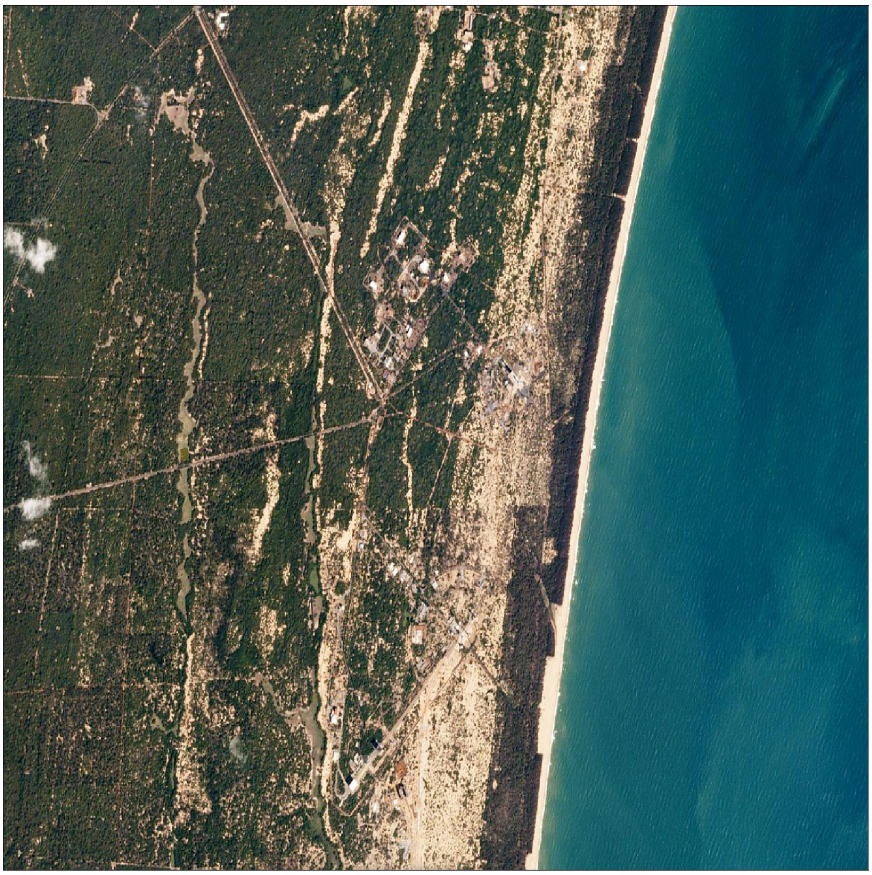

Figure 31: The SDSC (Satish Dhawan Space Center) in Sriharikota, India, imaged by the in-orbit Dove constellation on Feb. 13, 2017, two days prior to the launch of the PSLV-C37 vehicle with 88 Doves onboard (image credit: Planet) [62].

Figure 32: A clear view amid California's rainy winter of Planet's Headquarters, reveals more than just expanse of the Golden Gate Bridge, Park, and Bay Bridge, but the dramatic sediment pulled from the 11900 km^2 of the San Francisco Bay watershed. The image was acquired on Feb. 11, 2017 (image credit: Planet)

• September 29, 2016: The U.S. NGA (National Geospatial-Intelligence Agency) continues to expand its use of commercial satellite imagery, exemplified by the agency's recent contract award to Silicon Valley's startup firm **Planet**, according to Robert Cardillo, the head of NGA. An "introductory" seven-month, $20 million contract to San Francisco-based Planet, formerly Planet Labs, will give defense and intelligence agencies access to the

company's global imagery content. This allows NGA to obtain imagery of at least 85% of the Earth's landmass every 15 days from Planet. The imagery has many operational uses, including environmental monitoring, augmenting higher resolution capabilities, change detection, and answering intelligence questions. [63], [64].

- NGA has partnered with other "NewSpace" providers over the last year, including BlackSky Global and the Google subsidiary Terra Bella. In addition, NGA and the NRO (National Reconnaissance Office) recently created the joint CGA (Commercial GEOINT Activity) to evaluate new commercial GEOINT data and services.

- NGA is also working with the GSA (General Services Administration) to set up the CIBORG (Commercial Initiative to Buy Operationally Responsive GEOINT) program, which will use GSA schedules and other government-wide contracts "to provide efficient, rapid access" to new commercial imagery, data, analysis and services, Cardillo said. CIBORG is slated to begin executing in early 2017.

- The "centerpiece" of NGA's commercial imagery program remains **EnhancedView**, which longtime industry partner DigitalGlobe supports.

• September 2016: The Flock-1 constellation acquired the snow covered Old Crow Flats, deep inside the Arctic Circle, a vast wetland residing within Canada's Vunut National Park (Figure 33). From caribou to grizzly bears, the remote and unspoiled national park plays temporary host to different migratory animals, including waterfowl. [65].

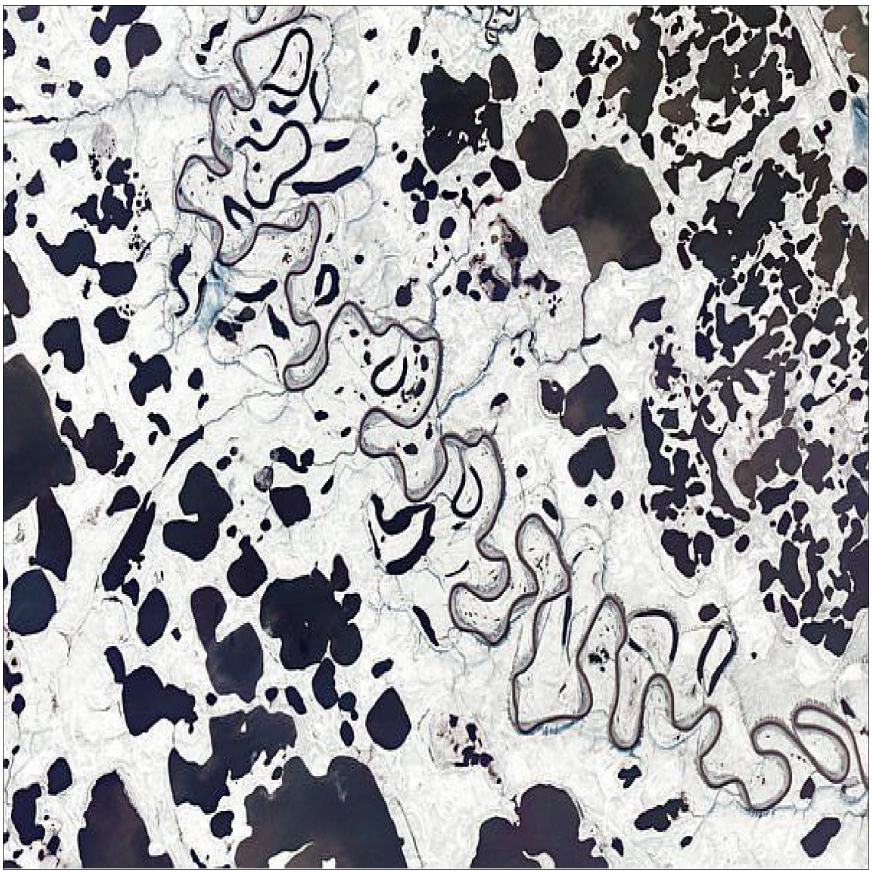

Figure 33: The meandering Yukon River is seen in this Flock-1 image from 19 September 2016. Notice in particular how the September snows cover the landscape, but the various bodies of water are still free of ice (image credit: Planet Labs, eoPortal team)

• July 14, 2016: Off the north-eastern coast of Australia, you'll find one of the seven natural wonders of the world, nearly 1,500 miles long, the Great Barrier Reef (Figure 34). One can see from this image the long veins that look like underwater rivers streaming down, giant avenues for all manner of wildlife (and divers) to explore and navigate – established over thousands of years from the seabed up. [66].

Figure 34: This Flock 1 image, acquired on 8 July 2016, shows the Great Barrier Reef in Australia (image credit: Planet Labs)

• June 17, 2016: The Nazza Lines in Peru are man-made lines and figures in the desert, which are estimated to be between 1500 and 2500 years old. The hundreds of figures vary in form, some of them are simple lines as featured in this image, while others form the shape of animals, people and other life. [67].

- These lines were created by digging shallow trenches in the desert, and removing the red-brown pebbles that coat the Nazca Desert. This made the clear white clay underneath stand out in stark contrast against the ground around the lines. Due to the desert's remote location and arid and windless climate - the Nazca Desert is one of the driest places on Earth - the lines have remarkably been mostly undisturbed in the centuries following their creation.

- The purpose behind the formation of the lines and figures is unknown, leaving scholars with many theories, ranging from astronomical to religious.

Figure 35: This Flock 1 image, acquired on 8 June 2016, shows the enormous Nazca Lines etched into the arid coastal desert in southern Peru (image credit: Planet Labs) [68].

• April 14, 2016: The Saint Lawrence River is one of North America's major shipping channels. The river flows from the Great Lakes Basin into Lake Saint Pierre (Figure 36) — a protected biosphere, home to unique waterfowl — before draining into the Northern Atlantic's Gulf of Saint Lawrence. [69].

- The cities of Trois-Rivières and Sorel-Tracy sit at either end of the lake, where it rejoins the Saint Lawrence River, and part of Trois-Rivières is visible on the mouth of the river here. Lake Saint Pierre is also a Ramsar site, recognized biosphere reserve and wildlife and bird sanctuary, which is an important area for migrating birds.

Figure 36: Lake Saint Pierre in Quebec, Canada, is pictured in this Flock-1 image, acquired on 14 April 2016 (image credit: Planet Labs Inc.)

• Feb. 2016: Figure 37 of the Flock-1 constellation shows a winter scene in the Sumy Oblast region of the Ukraine. This region is known for its rich earth and agriculture. Come summertime, these fields will produce grains, sunflowers, sugar beets, and potatoes. [70].

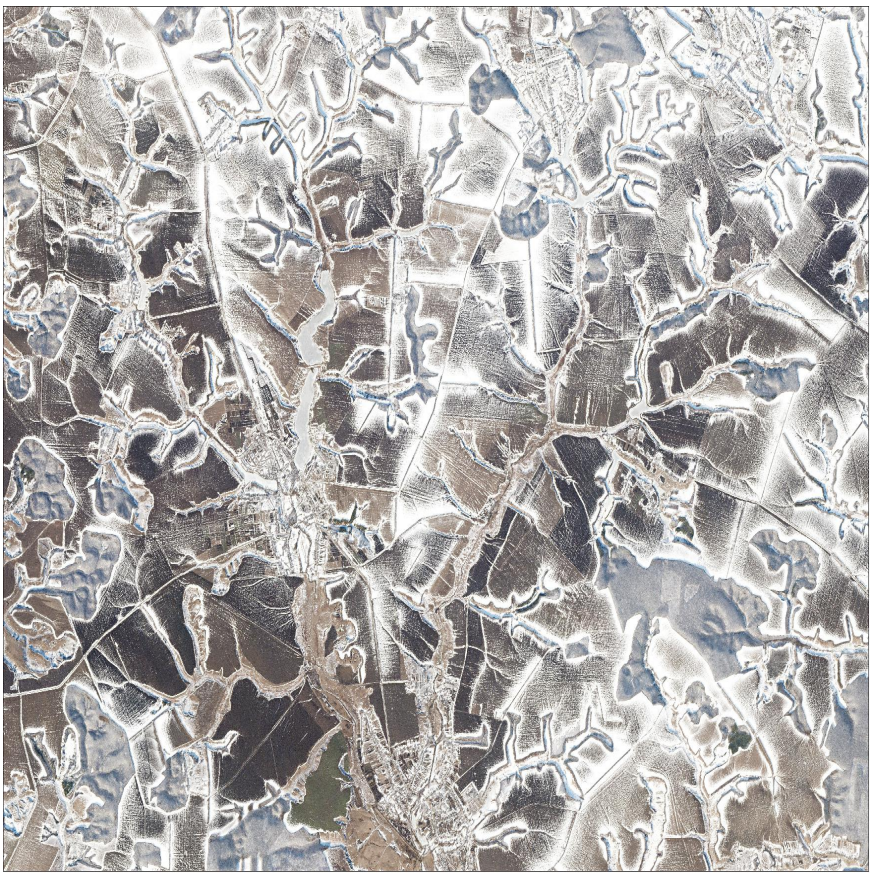

Figure 37: This Flock-1 image, acquired on 17 February 2016, shows icy fields during winter in Sumy Oblast, Ukraine (image credit: Planet Labs)

• October 26, 2015: Niagara Falls is a famous collection of three waterfalls on the border between the United States and Canada and is situated in the Canadian province of Ontario and the American state of New York. The three individual waterfalls are the Horseshoe, American and Bridal Veil Falls. [71].

- The waterfalls pour forth from the Niagara River, which flows North from the United States into Canada. The river splits into three waterfalls as the water flows around Goat Island (in the center of Figure 38) and a series of smaller islands on its north side. Niagara Falls has become a popular tourist destination over the past 150 years. Some visit the location to witness the power of the torrent of water and enjoy its nearby parks, while others take a more active (and risky) interest, notably including daredevils who have gone over the waterfalls in barrels or crossed the gorge on wires.

- Horseshoe Falls is the widest and deepest of the three waterfalls, and water drops 57 m here. Due to the strength of the current at the waterfalls, this natural source of energy has been harnessed over the years. Power plants have been constructed on or near the falls to take advantage of this, though a treaty was signed in 1950 to limit the use of the falls for this purpose out of concern for conservation of the site.

Figure 38: The Flock 1 constellation acquired this image of Niagara Falls on 26 October 2015. — Niagara Falls is a 12,000-year-old relic of the last Ice Age. Since then, the falls have moved more than 6 miles upstream from their original location near Lake Ontario.

• October 15, 2015: **The acquisition of the BlackBridge RapidEye constellation by Planet Labs is now complete.** Our energy is now focused on going to market as one team, under a common brand and executing a single global strategy. Over the coming months we'll role out incremental changes, which will improve our product offerings, service levels and empower our partners and customers to do even more. [72].

• March 1, 2015: The area shown in Figure 39 is in Jeollanam-do, the southernmost province on the Korean Peninsula. This region has some of the most favorable weather for farming, which has resulted in the area producing large amounts of crops. In the small town of Hanja Ri, patchwork grain fields line the shore of an inlet, while intricate rows of seaweed are farmed in the protected waters of the Myeongnyang Strait. [73].

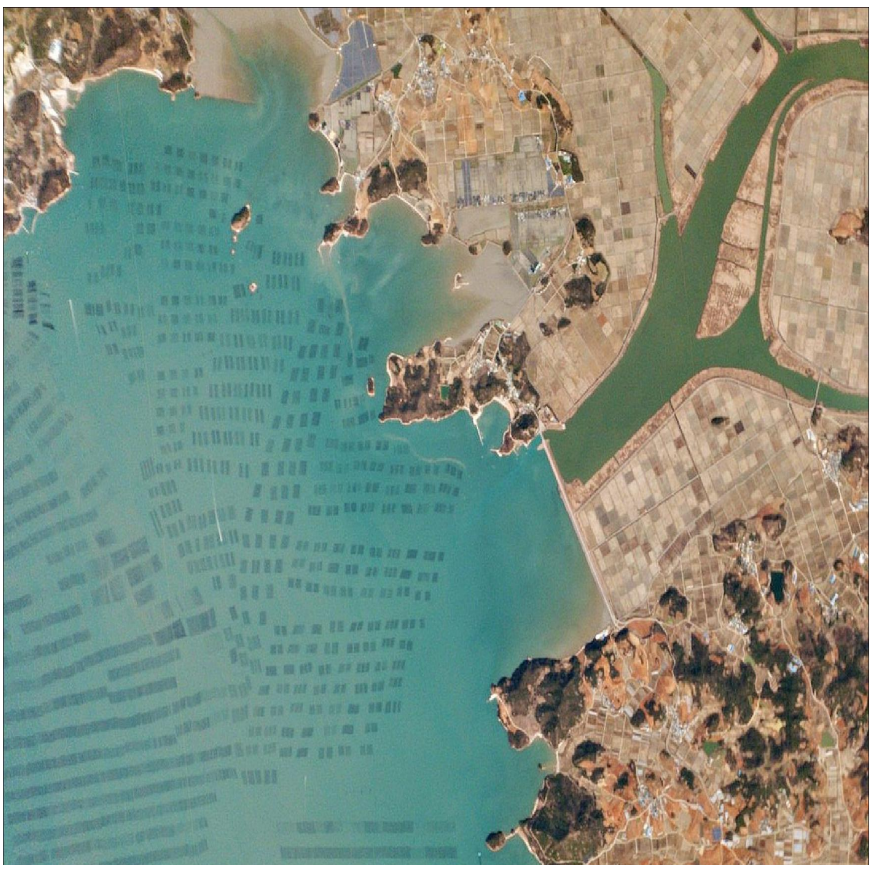

Figure 39: This Flock 1 image, acquired on 01 March 2015, shows aquaculture off the coast of South Korea (image credit: Planet Labs)

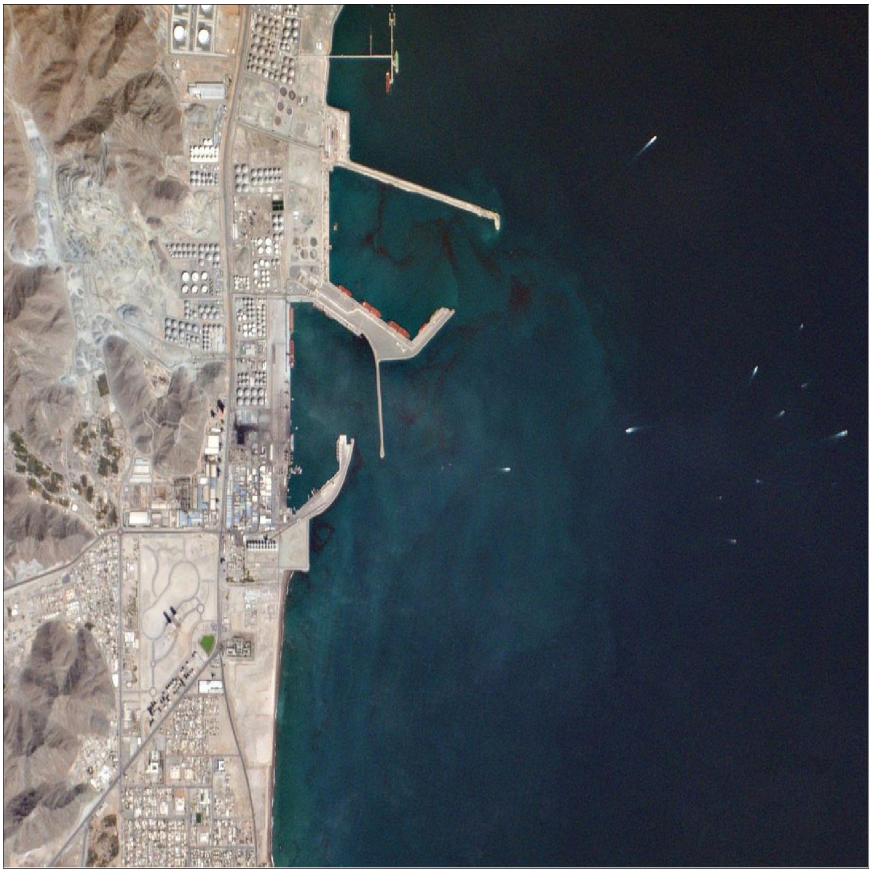

Figure 40: Fujairah oil industry zone, United Arab Emirates, acquired in early March 2015 (image credit: Planet Labs, Ref. 73)

Legend to Figure 40: Massive tankers are berthed in an oil terminal in the port of Fujairah, a major logistical hub for the United Arab Emirates. It sits on the Gulf of Oman, giving cargo ships easy access to major shipping lanes leading to China and India—two of the world's largest petroleum importers.

- As of early March 2015, 12 Doves of Planet Labs were deployed (10 Flock-1B, 2 Flock-1D'). 75)
- As of January 2015, a total of 40 Flock 1 nanosatellites were deployed from the ISS as well as 11 Flock 1c nanosatellites into SSO. All Flock 1 nanosatellites are referred to as "Doves" by Planet Labs (Ref.74).
- 2 Flock 1d': The SpaceX CRS-5 (Commercial Resupply Service-5) flight to the ISS was launched on January 10, 2015 from the Cape Canaveral Air Force Station (Falcon-9 V1.1 vehicle). Two Flock-1d' nanosatellites of Planet Labs were part of the cargo to replace some of the 26 Flock 1d spacecraft lost in a launch failure of Orbital Sciences' Antares rocket on October 28, 2014.
- 11 Flock 1c nanosatellites (each of ~ 5 kg) were launched on a Dnepr vehicle on June 19, 2014 from the Yasny Cosmodrome, Russia. The primary payloads on this flight were KazEOSat-2 and Deimos-2. All spacecraft (a total of 35 secondary payloads) were deployed into a near-circular orbit of 630 km with an inclination of 98º and an LTAN of 10:30 hours.
- 26 Flock 1d nanosatellites were to be launched to the ISS on October 28, 2014 on the Cygnus CRS Orb-3 mission from MARS (Mid-Atlantic Regional Spaceport), NASA's Wallops Flight Facility in Eastern Virginia. **Unfortunately, a launch failure occurred 6 seconds into the flight.**
- 28 Flock 1b nanosatellites of Planet Labs were launched to the ISS on July 13, 2014 with the Cygnus CRS Orb-2 mission. The launch vehicle was Antares-120 of OSC and the launch site was MARS (Mid-Atlantic Regional Spaceport), Wallops Island, VA. The first pair of Flock 1b was deployed on August 19, 2014.
- 28 Flock 1a nanosatellites of Planet Labs were launched to the ISS on January 9, 2014 on an Antares-120 Vehicle of OSC from MARS (Mid-Atlantic Regional Spaceport), Wallops Island, VA. All the Flock 1a nanosatellites were deployed in February 2014 by NanoRacks.

Table 7: Launch record of Planet Labs Flock 1 nanosatellites as of February 2015 74), 75)

Figure 41: Illustration of a fully deployed Flock 1 nanosatellite (image credit: Planet Labs)

• Feb. 2015: The Chinese city of Ordos (Figure 42), located in Inner Mongolia of China (39°36'N 109°47'E), has gained a reputation for being a "ghost town" due to the small population currently living in the city. Built with the capacity to house over a million people when construction began in 2003, this brand new city was expected to reach that total by 2010, but currently only hosts a population of approximately 20,000 instead. [76].

Due to a variety of reasons, the city was never completely finished, leaving a dichotomous mix of new construction and abandoned sections of the city which were left uncompleted. The price of homes in the city was so high when the construction began that few people could afford it. It is estimated that 98% of the city is either still under construction or completely uninhabited. [77], [78].

Figure 42: This Flock 1 image, acquired 24 January 2015, shows the city of Ordos in Inner Mongolia, China (image credit: Planet Labs)

Legend to Figure 42: In this image one can see tall apartment buildings and frozen lakes in the Kangbashi New Area, located close to the Ordos Desert.

Figure 43: Irrigated fields in Pinal County, Arizona captured by Flock 1 nanosatellites in August 2014 (image credit: Planet Labs) [79].

• Once the 28 Flock 1A nanosatellites are operational, Planet Labs will have the largest fleet of orbiting commercial imaging systems on orbit capable of imaging the entire Earth at least once per week.

• Gradually the 28 Flock 1 Earth imaging satellite that were sent to ISS on January 9, 2014 have been deployed from the Kibo module in batches of two over the period Feb. 11-28, 2014 (all were deployed using the NanoRacks deployer system with the JEMRMS (JEM-Remote Manipulator System).

Built and operated by Planet Labs of San Francisco, the Flock 1 small satellites will capture imagery of Earth for use in humanitarian, environmental and commercial applications.

• The Flock1-27 and -28 nanosatellites were deployed on Feb. 28, 2014 (04:20 UTC)

• The Flock1-25 and -26 nanosatellites were deployed on Feb. 27, 2014 (07:40 UTC)

• The Flock1-23 and -24 nanosatellites were deployed on Feb. 27, 2014 (01:50 UTC)

• The Flock1-19 and -20 nanosatellites were deployed on Feb. 26, 2014 (07:35 UTC)

• The Flock1-21 and -22 nanosatellites were deployed on Feb. 26, 2014 (04:20 UTC)

• The Flock1-17 and -18 nanosatellites were deployed on Feb. 25, 2014 (17:00 UTC)

• The Flock1-9 and -10 nanosatellites were deployed on Feb. 15, 2014 (10:55 UTC)

• The Flock1-7 and -8 nanosatellites were deployed on Feb. 15, 2014 (07:00 UTC)

• The Flock1-15 and -16 nanosatellites were deployed on Feb. 14, 2014 (11:45 UTC)

• The Flock1-13 and -14 nanosatellites were deployed on Feb. 14, 2014 (04:15 UTC)

• The Flock1-11 and -12 nanosatellites were deployed on Feb. 13, 2014 (08:20 UTC)

• The Flock1-5 and -6 nanosatellites were deployed on Feb. 12, 2014 (08:30 UTC)

• The Flock1-3 and -4 nanosatellites were deployed on Feb. 11, 2014 (12:41 UTC)

• The first two Flock 1 -1 and -2 nanosatellites were deployed on Feb. 11, 2014 (08:31 UTC) using the new NanoRacks deployer system of JAXA. [80], [81].

The Flock 1 nanosatellites will be released, two at time, over a span of one to two weeks early this year. Flock 1 will orbit beneath the station's ~400 km altitude to prevent any potential collisions. Like the station, the satellites will circle Earth in an orbit inclined by ~51.6° north and south of the equator, flying over most of the planet at some point. From this altitude, the Flock 1 nanosatellites provide imagery with a spatial resolution of 3-5 m. [82].

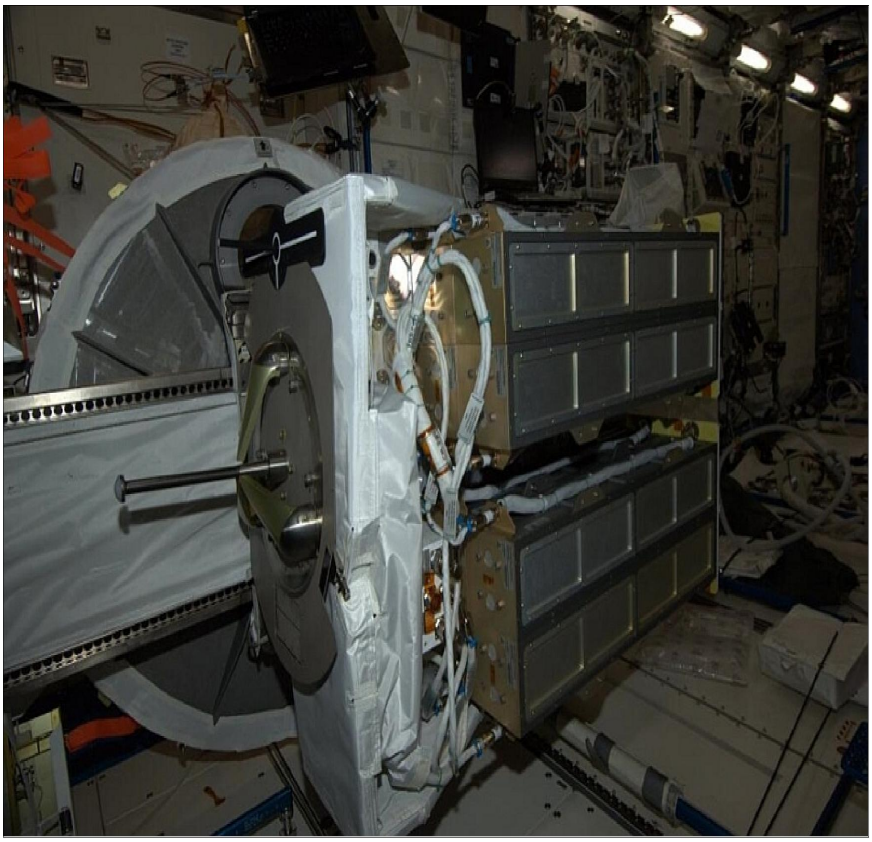

Figure 44: The Flock 1 nanosatellites are prepared for deployment on board the ISS. The photo shows four NRCSDs (NanoRacks CubeSat Deployers), each containing two Doves (image credit: Astronaut Koichi Wakata)

Figure 45: Deployment of the first two Flock 1 nanosatellites from the NanoRacks deployer system attached to the Kibo robotic arm (image credit: NASA)

Figure 46: Deployment of the first two Flock 1 nanosatellites from the NanoRacks deployer system of the ISS (image credit: NASA, Universe Today)

News update: In November 2014, the FCC (Federal Communications Commission) cleared Planet Labs' request to launch and operate non-geostationary orbit (NGSO) Earth Exploration Satellite Service satellites. The company plans to launch up to 500 additional NGSO satellites from the ISS (International Space Station) that are physically and technically identical to those previously authorized. [83)]

Planet Labs has deployed more than 30 such satellites from the ISS, all of which operate under Call Sign S2912, into circular orbits at altitudes between 380 km and 410 km and an inclination of 51.6°.

The additional satellites were authorized to transmit remote sensing and telemetry data to fixed Earth stations in the 8025-8400 MHz frequency band, receive command signals in the 2025-2110 MHz band, and may use the 401-402 MHz and 449.75-450.25 MHz bands for early phase and emergency-backup telemetry, tracking and command operations.

Sensor complement:

Payload design: Planet satellites each carry a telescope and a frame CCD camera equipped with Bayer-mask filter. The CCD sensor converts filtered photons into electrons, which are then amplified in order to produce a digital number corresponding to each pixel in each color band. [84)]

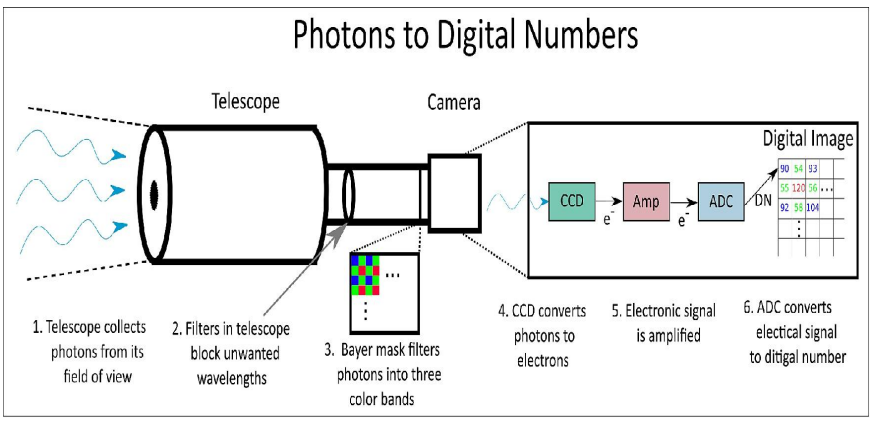

Figure 47: Planet Optical System and Camera (image credit: Planet)

Instruments:

Planet has flown three generations of optical instruments: Planet Scope 0 (PS0), Planet Scope 1 (PS1), and Planet Scope 2 (PS2). Images have different attributes depending on satellite altitude and instrument type.

PS0 features a 2 element Maksutov Cassegrain optical system paired with an 11MP CCD detector. Optical elements are mounted relative to the structure of the spacecraft.

PS2 features a five element optical system that provides a wider field of view and superior image quality. This optical system is paired with a 29MP CCD detector.

Instrument	Spectral Bands	Field of View (FOV) and Ground Sampled Distance (GSD)		
		620km (Altitude of Planet Flock 1c)	475 km (target altitude for future SSO Flocks)	420 km (ISS Flock altitude)
PS0 and PS1	Red: 630-714 nm Green: 515-610 nm Blue: 424-478 nm	HFOV: 16.1 km VFOV: 10.7 km Area: 173 km sq GSD: 4 m	NA (Instrument not flown at this altitude)	HFOV: 10.9 km VFOV: 7.3 km Area: 79 km sq GSD: 2.7 m
PS2	Red: 630-714 nm Green: 515-610 nm Blue: 424-478 nm	NA (Instrument not flown at this altitude)	HFOV: 24.6 km VFOV: 16.4 km Area: 405 km sq GSD: 3.73 m	HFOV: 21.8 km VFOV: 14.5 km Area: 316 km sq GSD: 3.3 m

Table 8: Spectral band and FOV (Field of View) information for PS0, PS1 and PS2 instruments flown at various altitudes

Spectral Characteristics:

PS0 and PS1 optical systems are designed to collect data in the visible portion (red, blue and green) of the electromagnetic spectrum. The following figures show the expected RGB spectral characteristics of the PS0 and PS1 systems:

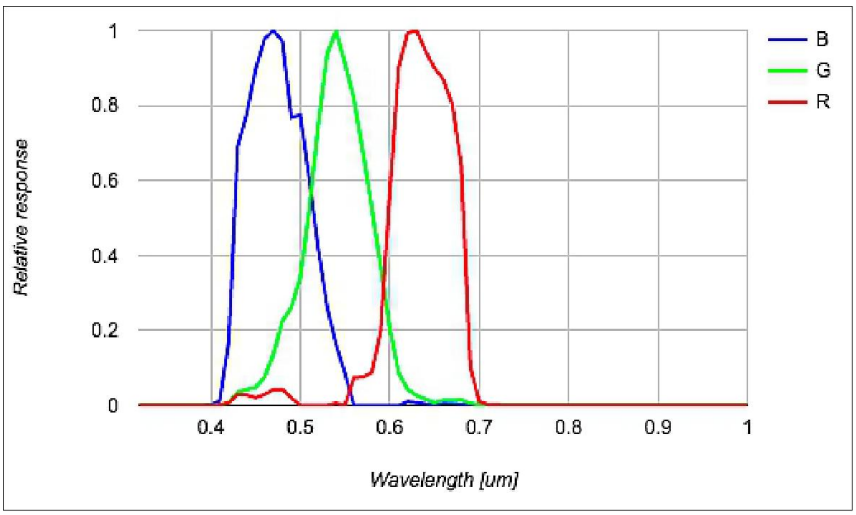

Figure 48: RGB spectral bands for PS0/1 (image credit: Planet)

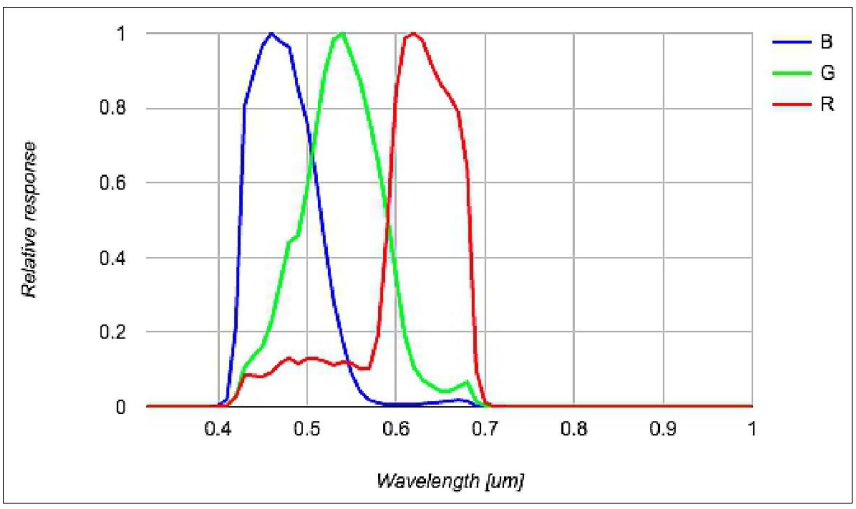

Figure 49: RGB spectral bands for PS2 (image credit: Planet)

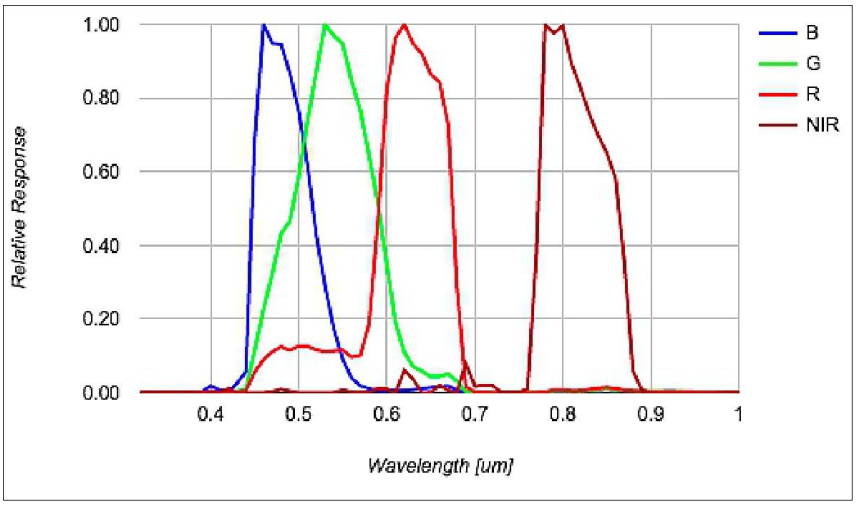

Figure 50: Expected spectral response for PS2 (with NIR capability), image credit: Planet

Description	International Space Station Orbit	Sun Synchronous Orbit
Inclination	51.6º	98º
Expected lifetime	1 year per satellite; constellation is replenished over time	2-3 years per satellite; constellation is replenished over time
Orbital insertion altitude	420 km	475 km (target altitude for future SSO launches)
Equator crossing time	Varies	9:30-11:30am local solar time
Sensor type	Bayer-masked CCD camera	Bayer-masked CCD camera
Spectral bands	Red: 610-700 nm Green: 500-590 nm Blue: 420-530 nm	Red: 610-700 nm Green: 500-590 nm Blue: 420-530 nm
Ground Sampling Distance	2.7-3.2 m (nadir)	3.7-4.9 m (nadir)
Mission continuity	Maintain up to 55 satellite constellation (continually replenishing/upgrading satellites)	Maintain 100-150 satellite constellation (continually replenishing/upgrading satellites)

Table 9: Orbit, constellation and satellite specifications

Coverage:

Throughout 2014 and the first half of 2016, Planet focused collection capacity on North America, Asia, and South America. Focusing on these areas allowed Planet to establish initial imagery archive to develop and refine imagery processing, imagery quality, imagery mosaic, and API capabilities.

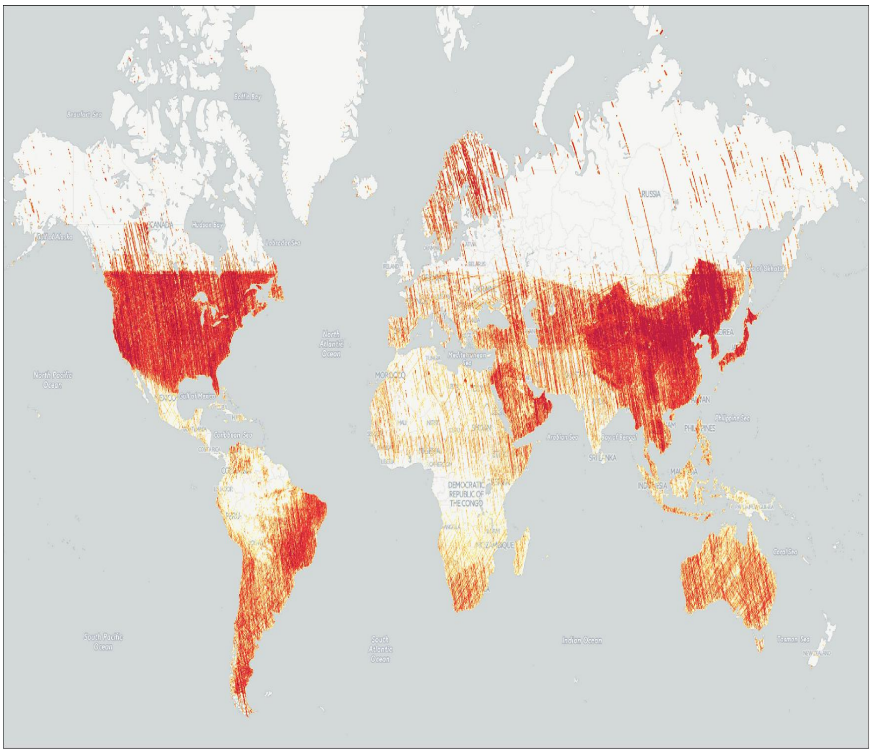

Figure 51: Heat map as of June 2015, showing percent of quad tiles covered by Planet's imagery (image credit: Planet)

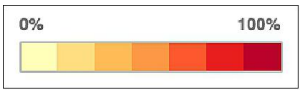

Figure 52: Percent of quad covered (image credit: Planet)

Ground Stations and Network

Planet has developed its own global network of ground stations to support both spacecraft mission operations and image data downlink. Each ground station consists of an antenna and a Radio Frequency (RF) system, coupled with a local computer server, connected via secured VPN (Virtual Private Network) access to centralized services. Downlinked image files are transferred from local ground station servers to Planet's cloud infrastructure for ingestion into Planet's data processing and distribution pipeline.

The ground stations use COTS components where possible to reduce complexity and cost. In total, Planet operates equipment at 15 sites using a combination of rented equipment, co-located antenna systems, and fully independent sites. The diversity in assets allows the ground network to better scale to meet the demands of the on-orbit constellation. Relatively rapid flexibility in downlink capacity is especially important in an industry where a constellation can be built, launched, and deployed in the time needed to obtain licensing for a ground site (Ref. 6).

Nearly all Planet ground station sites include UHF radios for telemetry, tracking, and control (TT&C). These systems are used for scheduling, basic health, and ranging for orbit determination. Eight of the ground station sites also include X-band (HSD) capabilities. These eight geographically diverse sites contain a total of twenty-two dishes of varying diameters, from 4.5 meter to 7.6 meter. All dishes are designed for at least 29 dB/K G/T (Gain to noise Temperature) to optimize both the satellite downlink data rates and ground system cost.

The payload data is downlinked from space at X-band, down-converted to L-band using a low noise block downconverter (LNB), and demodulated using a COTS DVB-S2 receiver. Typical ground stations passes average at 160 Mbit/s and peak at 220 Mbit/s data rates with data volumes of 12-15 GB downloaded per 7-10 minute ground station pass. The receiver deframes DVB-S2 packets, and sends raw IP frames to the ground station server via gigabit Ethernet interface. The ground station server monitors the link status (SNR, link margin, received RF power level, bit error rate), reassembles the picture files, and uploads the pictures and metrics to the cloud. Additionally, many Planet ground antenna systems have a built-in feedback loop for basic open-loop power-tracking using link statistics provided by the DVB-S2 receiver. The power tracking introduces random offsets and tests and checks the feedback look for a positive or negative response. Planet's Dove ground network is nominally autonomous and remotely monitored to enable scalability and improve operational efficiency.[85], [86] Figure 53 shows the internals of Planet's S-band/X-band ground station system, and Figure 54 shows a picture of a 4.5 m diameter dish at Keflavik, Iceland.

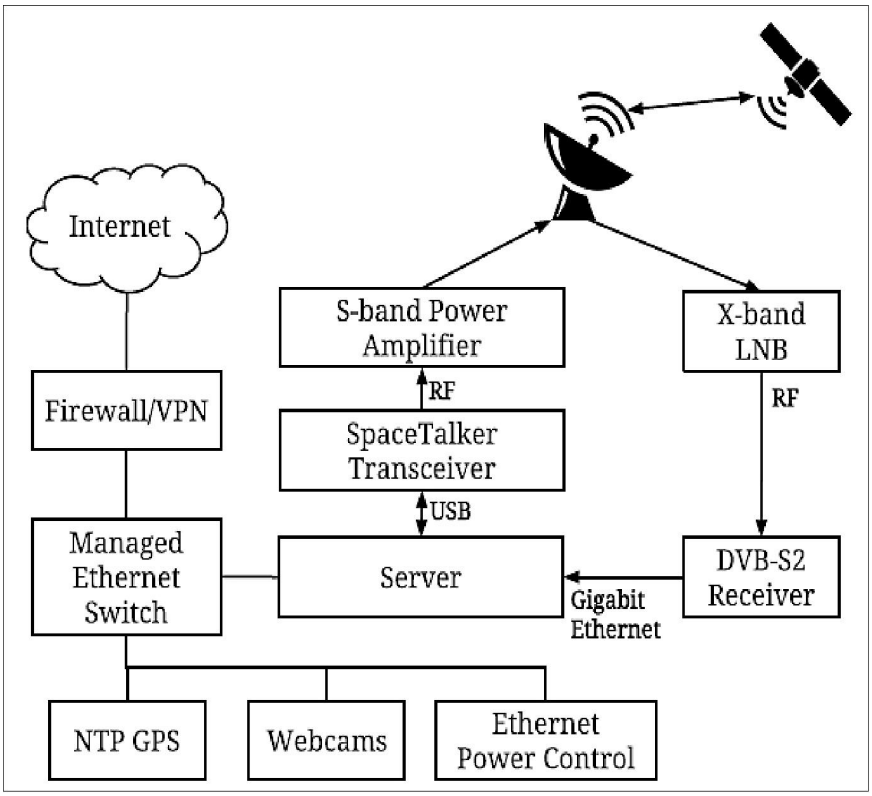

Figure 53: Ground station system functional blocks (image credit: Planet Labs)

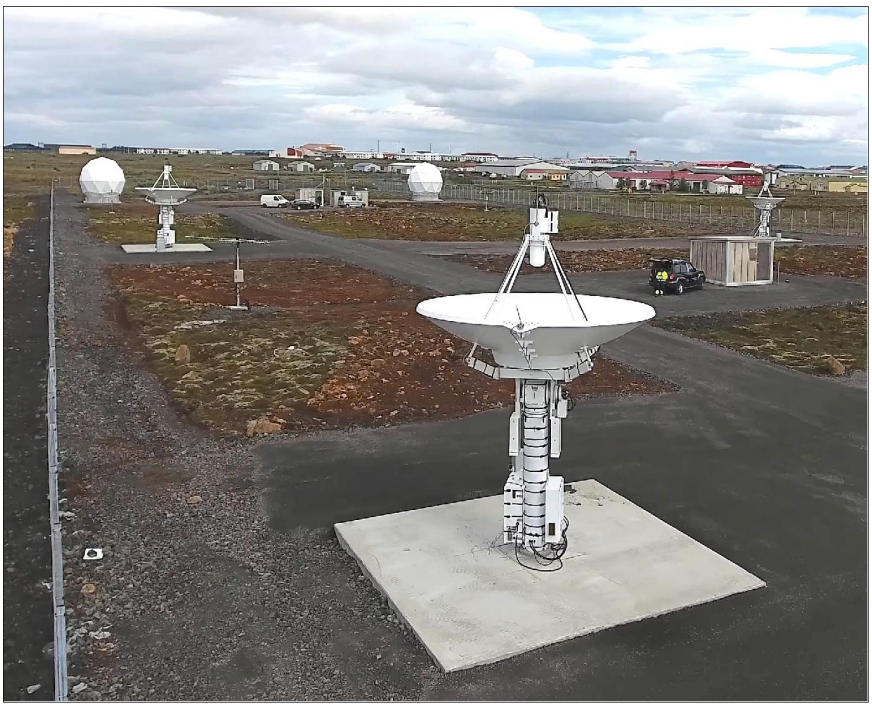

Figure 54: A 4.5 m diameter ground station antenna at Keflavik, Iceland (image credit: Planet Labs)

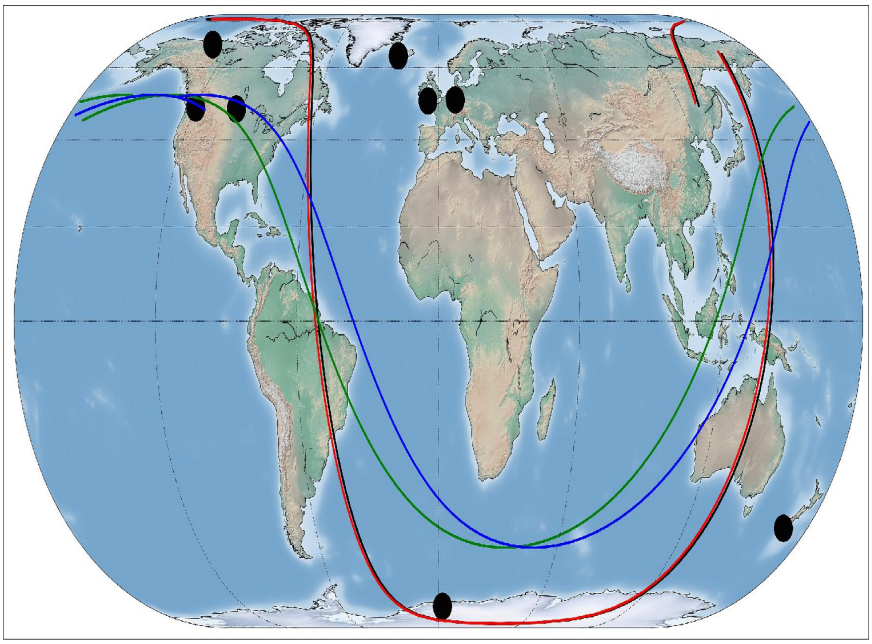

Figure 55: Location of X-band ground station antennas (black circles) and ground tracks of representative Dove satellites per flock (Flock 2P = Black, Flock 3P = Red, Flock 2E = Blue, Green), image credit: Planet Labs (Ref. 6)

Image Pipeline:

During downlink, images are temporarily buffered locally on a server co-located with the receive antenna and added to an Internet upload queue. The imagery gets uploaded to cloud storage over secured Internet connections, which kicks off a per-image processing pipeline. The local storage decouples imagery downlink from network interruptions or congestion and allows sizing the leased line for average bandwidth (as opposed to peak bandwidth or latency). The imagery is also kept stored on the satellite until the next pass so that it can be confirmed as having successfully entered the processing pipeline before being deleted.

Upon ingestion, images are individually de-mosaiced (de-bayered), color-corrected, flat-fielded, and orthorectified. Orthorectification aligns the image to within 10 m (RMSE) horizontally and maps the data to a fine digital elevation model. Further analysis generates a cloud cover mask and ensures that images released to customers satisfy a series of quality metrics. During the month of May 2017, the 90th percentile of the imagery that rectified and passed quality metrics was published within 5.5 hrs of being downlinked by a ground station.

Successfully rectified images are available to customers as soon as processing has completed. To satisfy the multiple use cases of different customers, imagery is available in a variety of forms:

• Orthorectified images (\scenes", which consist of one full-frame capture) are available via REST HTTP API for customers.

• \Tiles" are produced, similar to the OSM \slippy map" architecture, on a grid that is fixed for all Planet products by rectifying and stacking the RGB and NIR bands of scenes from a single strip of imagery.

• All of the rectified imagery that meets minimum quality conditions is made available on a web-based application open to all for browsing and new imagery alerting based on user-defined areas of interest.

Data Analysis and Metrics:

Planet's mission control infrastructure monitors and controls the satellites and the ground network handles over 650 HSD passes per day. Due to the large number of passes and the limited engineer time available, it is impossible to assess each pass manually. Therefore, Planet has created an automated metrics gathering and failure detection system to monitor constellation-wide high speed downlink performance.

The automated metrics system has been built using open source tools, shown in Figure 56 and runs at regular intervals. Pass relevant information, that includes information from the satellite, the ground station, and physical characteristics (orbit-related), is first consolidated. An automated pass classifier assesses the quality of the pass and identifies a possible reason for failure. The combined pass information, along with the failure diagnosis, is written to a database. A dashboard aggregates information from the passes and creates interactive visualizations. The interactive visualizations allow easy access to pass performance information to any engineer without the need to code new tools.

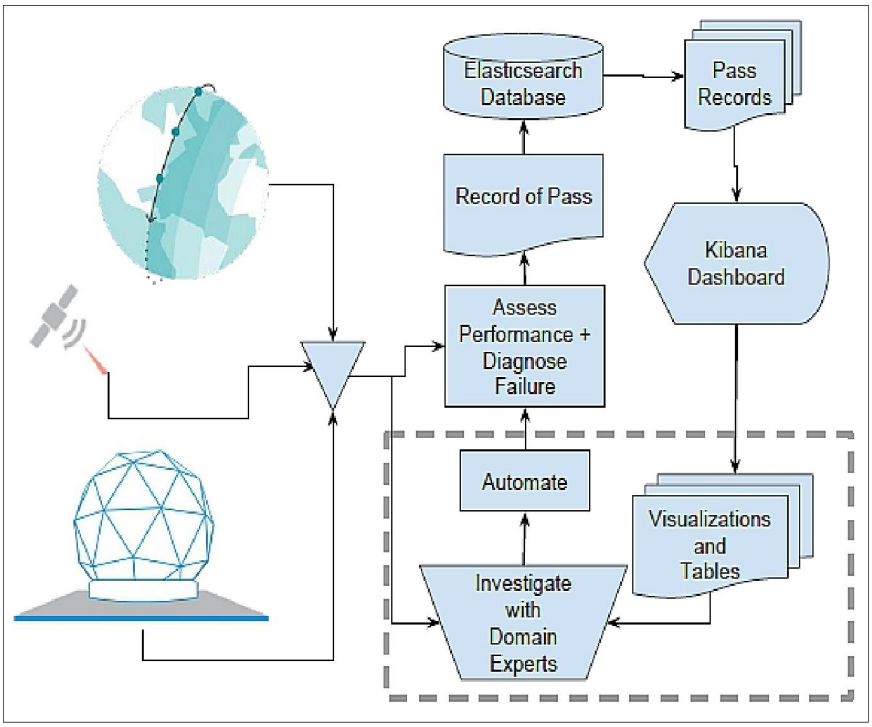

Figure 56: Internals of the metrics generation and reporting system (image credit: Planet Labs)

The pass classifier automates the decision making process of domain experts in order to automatically diagnose possible failure modes for sub-optimal passes. An HSD pass is considered to be a failure if the amount of image data downloaded is less than 80% of the total downlinked data volume predicted using a link budget model. The prediction uses a formula that depends on the transmitter and receiver characteristics, slant range, and orbital geometries during the pass to compute the RF link margin. Once a pass is judged to be a failed pass (which only implies sub-optimality and not an outright failure due to the conservative assumptions in the data rate predictions) the automatic classification begins.

An automated classified has been developed to classify failures. Every week, domain experts from RF and Communication Systems, Orbit Operations, Satellite Operations, System Integrations, and Ground Station Operations teams discuss, classify, and debug failed passes. After manually classifying the passes, the diagnosis is automated by creating a hierarchical tree of failures. The hierarchy of the failure mode is primarily based on the certainty with which that failure mode can be identified.

This automated approach has allowed for the classification of thousands of passes into discrete buckets with well defined problem statements. The total number of failures and the severity of the failure modes provides the direction for problem solving. Using this approach, the HSD performance was improved by ~50% from 110 Mbit/s average to 160 Mbit/s average over a few month period and pass-to-pass variance was reduced.

In summary, using the \agile aerospace" philosophy, Planet has rapidly prototyped and iteratively developed an end-to-end high speed satellite communication solution that not only included the development of the spacecraft and ground station hardware and software, but also the automated monitoring, scheduling, and control systems, and data metrics and analytics solutions. These co-optimized systems are tightly coupled and work together to achieve record downlink speeds of 220 Mbit/s and data volumes of over 4 TB/day. Figure 57 shows monthly aggregated historical downlink data rates and Figure 9 shows constellation wide daily downlink data volume along with the number of active satellites.

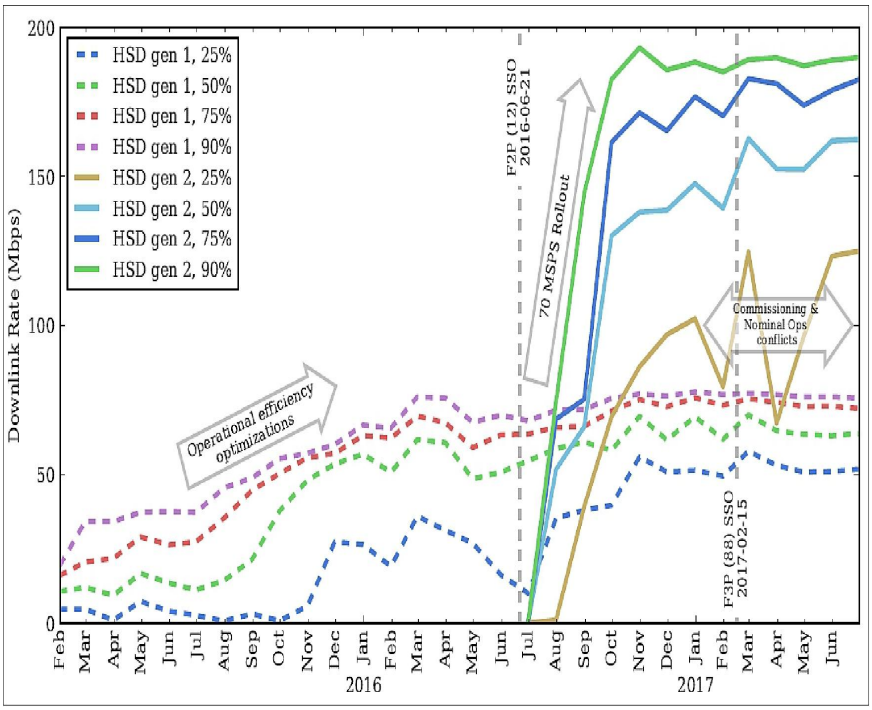

Figure 57: Data rate quantiles for HSD1 and HSD2 annotated with key milestones, aggregated monthly. (image credit: Planet Labs)

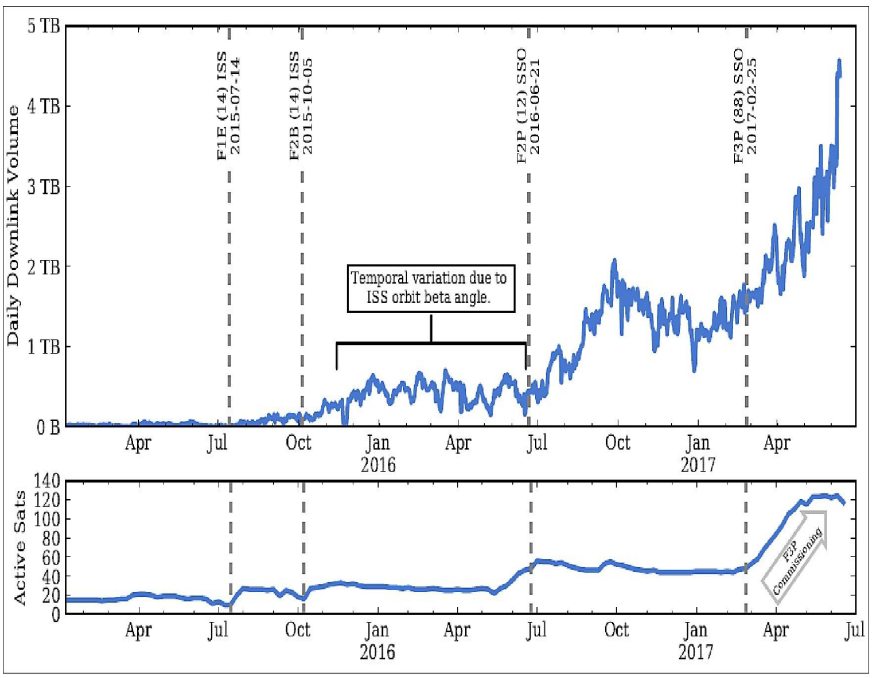

Figure 58: Top: Constellation-wide daily downlink data volume with key launch dates. Bottom: Number of active satellites (image credit: Planet Labs)

References

1) "Planet Labs Launches Two More Satellites - Delivers Largest Imaging Fleet to Launch Pad;Company's Latest Remote-Sensing Satellites Launch from Russia," Planet Labs Blog, Dec. 11, 2013, URL: http://blog.planet-labs.com/2013/12/11/planet-labs-launches-two-more-satellites-delivers-largest-imaging-fleet-ever-to-launch-pad-companys-latest-remote-sensing-satellites-launch-from-russia/

2) Christopher R. Boshuizen, James Mason, Pete Klupar, Shannon Spanhake, "Results from the Planet Labs Flock Constellation," Proceedings of the AIAA/USU Conference on Small Satellites, Logan, Utah, USA, August 2-7, 2014, paper: SSC14-I-1, URL: http://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=3016&context=smallsat

3) "Planet Labs set to launch largest satellite fleet in history," Planet Labs, Match 17, 2014, URL: http://www.planet.com/assets/themes/planet/press-releases/2014-03-17-pr.pdf

4) Quentin Hardy, Nick Bilton, “Start-Ups Aim to Conquer Space Market,” The New York Times, March 16, 2014, URL: http://www.nytimes.com/2014/03/17/technology/start-ups-aim-to-conquer-space-market.html?_r=0

5) “Planet Labs Launches Two More Satellites - Delivers Largest Imaging Fleet to Launch Pad,” SpaceRef, Nov. 26, 2013, URL: http://spaceref.biz/2013/11/planet-labs-launches-two-more-satellites---delivers-largest-imaging-fleet-to-launch-pad.html

6) Kiruthika Devarajy, Ryan Kingsbury, Matt Ligon, Joseph Breu, Vivek Vittaldev, Bryan Klofas, Patrick Yeon, Kyle Colton, ”Dove High Speed Downlink System,” Proceedings of the 31st Annual AIAA/USU Conference on Small Satellites, Logan UT, USA, Aug. 5-10, 2017, paper: SSC17-VII-02, URL: http://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=3797&context=smallsat

7) “Planet Labs Launches Two More Satellites; Delivers Largest Imaging Fleet Ever To Launch Pad; Company’s Latest Remote-Sensing Satellites Launch from Russia,” Planet Labs, Dec. 11, 2013, URL: http://blog.planet-labs.com/2013/12/11/planet-labs-launches-two-more-satellites-delivers-largest-imaging-fleet-ever-to-launch-pad-companys-latest-remote-sensing-satellites-launch-from-russia/

8) Trent J. Perrotto, Josh Byerly, “New Science, NASA Cargo Launches to Space Station Aboard Orbital-1 Mission,” NASA, Release 14-009, URL: http://www.nasa.gov/press/2014/january/new-science-nasa-cargo-launches-to-space-station-aboard-orbital-1-mission/#.Us98i_uFf_o

9) Laura Niles, “Largest Flock of Earth-Imaging Satellites Launch into Orbit From Space Station,” Feb. 11, 2014, URL: http://www.nasa.gov/mission_pages/station/research/news/flock_1/#.UxHvwc7ihqM

10) “SkyCube: The First Satellite Launched by You!,” Southern Stars, URL: http://www.southernstars.com/skycube/

11) ”Update: Includes Orbital ATK's Statement and Planet's Doves and SkySats Successfully Launched by Orbital ATK's Minotaur C Rocket,” Satnews Daily, 31 Oct. 2017, URL: http://www.satnews.com/story.php?number=734611390

12) Mike Safyan, ”Planet Doubles Sub-1 Meter Imaging Capacity With Successful Launch Of 6 SkySats,” Planet, Oct. 31, 2017, URL: https://www.planet.com/pulse/tag/skysat/

13) ”Mission Update: Minotaur C SkySat Launch,” Orbital ATK, Oct. 2017, URL: https://www.orbitalatk.com/news-room/feature-stories/MinotaurC_SkySat_Mission-Page/default.aspx?prid=283

14) Mike Safyan, ”Successful Launch of Flock 4e’ on Rocket Lab’s Electron,” Planet News, 28 October 2020, URL: https://www.planet.com/pulse/successful-launch-of-flock-4e-on-rocket-labs-electron/

15) Mike Safyan, ”Flock 4v’s Captivating First Light Imagery,” Planet News, 10 September 2020, URL: https://www.planet.com/pulse/flock-4v-captivating-first-light-imagery/

16) Mike Safyan, ” Planet, 3 September 2020, URL: https://www.planet.com/pulse/arianespace-26-superdoves-vega/

17) ”Vega return to flight proves new rideshare service,” ESA Enabling & Support, 3 September 2020, URL: https://www.esa.int/Enabling_Support/Space_Transportation/Vega/Vega_return_to_flight_proves_new_rideshare_service

18) ”With Vega, Arianespace successfully performs the first European mission to launch multiple small satellites,” Arianespace Press Release, 3 September 2020, URL: https://www.arianespace.com/press-release/with-vega-arianespace-successfully-performs-the-first-european-mission-to-launch-multiple-small-satellites/

19) ”Vega flight VV16,” Wikipedia, URL: https://en.wikipedia.org/wiki/Vega_flight_VV16

20) Mike Safyan, ”,” Planet, 3 September 2020, URL: https://www.planet.com/pulse/arianespace-26-superdoves-vega/

21) Mike Safyan, ”Planet’s First Launch of 2020: 26 SuperDoves on a Vega,” Planet, 13 February 2020, URL: https://www.planet.com/pulse/planets-first-launch-of-2020-26-superdoves-on-a-vega/

22) Deepthi Shankar, ”Seisan Partners with Planet to Solve Complex Business Problems Using Daily Satellite Imagery,” Planet, 24 March 2020, URL: https://www.planet.com/pulse/seisan-partners-with-planet-to-solve-complex-business-problems-using-daily-satellite-imagery/

23) Mike Safyan, ”Planet’s First Launch of 2020: 26 SuperDoves on a Vega,” Planet, 13 February 2020, URL: https://www.planet.com/pulse/planets-first-launch-of-2020-26-superdoves-on-a-vega/

24) Mike Safyan, ”A Successful Launch for Flock 4p on the PSLV,” Planet News, 27 November 2019, URL: https://www.planet.com/pulse/a-successful-launch-for-flock-4p-on-the-pslv/

25) Deepthi Shankar, ”Introducing Planet Orbit: Planet’s New Partner Program,” Planet, 14 October 2019, URL: https://www.planet.com/pulse/introducing-planet-orbit-planets-new-partner-program/

26) Kiruthika Devarajy, Matt Ligon, Eric Blossom, Joseph Breu, Bryan Klofas, Kyle Colton, Ryan Kingsbury, ”Planet High Speed Radio: Crossing Gbps from a 3U Cubesat,” Proceedings of the 33rd Annual AIAA/USU Conference on Small Satellites, August 3-8, 2019, Logan, UT, USA, paper: SSC19{VI{01, URL: https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=4405&context=smallsat

27) Kiruthika Devaraj, Ryan Kingsbury, Matt Ligon, Joseph Breu, Vivek Vittaldev, Bryan Klofas,Patrick Yeon, Kyle Colton, ”Dove High Speed Downlink System,” Proceedings of the 31st Annual AIAA/USU Conference on Small Satellites, Logan UT, USA, Aug. 5-10, 2017, paper: SSC17–VII–02, URL: https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=3797&context=smallsat

28) Bryan Klofas, "Planet Releases OpenLST, an Open Radio Solution," Planet, 6 August 2018, URL: https://www.planet.com/pulse/planet-openlst-radio-solution-for-cubesats/

29) Cyrus Foster, Henry Hallam, James Mason, "Orbit Determination and Differential-drag Control of Planet Labs Cubesat Constellations," 10 September 2015, paper: AAS 15-524, URL: https://arxiv.org/pdf/1509.03270.pdf

30) Kyle Colton, Bryan Klofas, "Supporting the Flock: Building a Ground Station Network for Autonomy and Reliability." Proceedings of the 30th Annual AIAA/USU SmallSat Conference, Logan UT, USA, August 6-11, 2016, paper: SSC16–IX–05, URL: https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=3368&context=smallsat

31) "Historic RapidEye Constellation Captures Last Light," Planet News, 2 April 2019, URL: https://www.planet.com/pulse/historic-rapideye-constellation-captures-last-light/

32) "NGA to leverage high-revisit Planet imagery, automated processing," NGA Press Release, 21 March 2019, URL: https://www.nga.mil/Careers/Documents/20190320_Planet_Contract.pdf

33) "Planet Provides Dramatic Photos of Before and After Krakatau Volcano Eruption," Satnews Daily, 3 January 2019, URL: http://www.satnews.com/story.php?number=725847427

34) Jonathan Amos, "Anak Krakatau volcano: Satellites get clear view of collapse," BBC, 3 January 2019, URL: https://www.bbc.com/news/science-environment-46743362

35) Stephen Clark, "Soyuz launches cluster of 28 satellites," Spaceflight Now, 27 December 2018, URL: https://spaceflightnow.com/2018/12/27/soyuz-28-satellite-cluster-launch/

36) Mike Safyan, "12 Dove Satellites Successfully Launched on Soyuz Rocket," Planet News, 27 December 2018, URL: https://www.planet.com/pulse/category/news/

37) Stephen Clark, "Spaceflight's 64-satellite rideshare mission set to last five hours," Spaceflight Now, 3 December 2018, URL: https://spaceflightnow.com/2018/12/03/spaceflights-64-satellite-rideshare-mission-set-to-last-five-hours/

38) Mike Safyan, "Flock 3s and 2 SkySats successfully Launch on Falcon 9 SSO-A," Planet, 3 December 2018, URL: https://www.planet.com/pulse/five-satellites-launch-on-falcon-9-sso-a/

39) Mike Safyan, "16 More Doves Successfully Launch on ISRO's PSLV C-43 Rocket," Planet News, 29 November 2018, URL: https://www.planet.com/pulse/category/news/

40) "ISRO launches HysIS satellite, 30 others with PSLV-C43 rocket today: Everything to know ," Indian Express, 29 November 2018, URL: https://indianexpress.com/article/technology/science/isro-launch-hysis-satellite-30-others-pslv-c43-rocket-5469076/

41) Steve Cole, "NASA Evaluates Commercial Small-Sat Earth Data for Science," NASA Release 18-086, 04 October 2018, URL: https://www.nasa.gov/press-release/nasa-evaluates-commercial-small-sat-earth-data-for-science

42) Will Marshall, "Planet Opens New State-of-the-Art Satellite Manufacturing Factory in San Francisco," Planet, 12 September 2018, URL: https://www.planet.com/pulse/planet-opens-satellite-manufacturing-factory/

43) Will Marshall, "Mission 1 Complete!," Planet, 9 November 2017, URL: https://www.planet.com/pulse/mission-1/

44) V. Beukelaers, B. Howard, J. Mason, M. Safyan, D. Doan, J. Perera,"Completing Mission 1: Imaging Everywhere, Every Day," Proceedings of the 4S Symposium Small Satellites Systems and Services, 28 May - 1 June 2018, Sorrento, Italy

45) Lawrence Leung, Vincent Beukelaers, Simone Chesi, Hyosang Yoon, Daniel S. Walker, Joshua Egbert, "ADCS at Scale: Calibrating and Monitoring the Dove Constellation," Proceedings of the 32nd Annual AIAA/USU Conference on Small Satellites, Logan UT, USA, Aug. 4-9, 2018, paper: SSC18-WKII-03, URL: https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=4239&context=smallsat

46) Will Marshall, "Planet and Airbus Partner to Deliver New Geospatial Solutions," Planet, 25 June 2018, URL: https://www.planet.com/pulse/airbus-partnership-geospatial-solutions/

47) "Rocket Lab successfully reaches orbit and deploys payloads," Rocket Lab, 21 Jan. 2018, URL: https://www.rocketlabusa.com/news/updates/rocket-lab-successfully-reaches-orbit-and-deploys-payloads-january-21-2018/

48) "Rocket Lab Celebrates Kiwi's Second Successful Launch with a Smile and Still Testing," Satnews Daily, 21 Jan. 2018, URL: http://www.satnews.com/story.php?number=1575755313#

49) "Planet to Assist Human Rights Watch with Satellite Imagery and Data," Satnews Daily, 30 Nov. 2017, URL: http://www.satnews.com/story.php?number=1093131236

50) Mike Safyan,"Planet doubles sub-1 m imaging capacity with successful launch of 6 SkySats," Planet, 31 Oct. 2017, URL: https://www.planet.com/pulse/planet-doubles-sub-1-meter-imaging-capacity-with-successful-launch-of-6-skysats/

51) "Burma: New Satellite Images Confirm Mass Destruction," Human Rights Watch, 17 Oct. 2017, URL: https://www.hrw.org/news/2017/10/17/burma-new-satellite-images-confirm-mass-destruction

52) Rob Zimmerman, Deanna Doan, Lawrence Leung, James Mason, Nate Parsons, Kam Shahid, "Commissioning the World's Largest Satellite Constellation," Proceedings of the 31st Annual AIAA/USU Conference on Small Satellites, Logan UT, USA, Aug. 5-10, 2017, paper: SSC17-X-03, URL: http://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=3669&context=smallsat

53) Ricardo Rios-Olmo, Martin Miller, "Planet's Open Water Imaging - Geo-Accuracy Assessment," Proceedings of the 31st Annual AIAA/USU Conference on Small Satellites, Logan UT, USA, Aug. 5-10,

2017, paper: SSC17-I-07, URL: http://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=3598&context=smallsat

54) Caleb Henry, "Planet wins second NGA satellite-imagery contract," 20 July 2017, URL: http://spacenews.com/planet-wins-second-nga-satellite-imagery-contract/

55) "Planet Joins With Geological Remote Sensing Group," Satnews Daily, May 3, 2017, URL: http://www.satnews.com/story.php?number=761128932

56) Jeff Foust, "Planet confirms Google stake as Terra Bella deal closes," Space News, April 19, 2017, URL: http://spacenews.com/planet-confirms-google-stake-as-terra-bella-deal-closes/

57) "Timbuktu," Planet, March 5, 2017, URL: https://www.planet.com/gallery/timbuktu-20170305/

58) Markus Strauss, "Flotilla of tiny satellites will photograph the entire Earth every day," Science Magazine, Feb. 23, 2017, URL: http://www.sciencemag.org/news/2017/02/flotilla-tiny-satellites-will-photograph-entire-earth-every-day

59) Robbie Schingler, Will Marchall, "Planet Launches Satellite Constellation to Image the Whole Planet Daily," Planet News, February 14, 2017, URL: https://www.planet.com/pulse/planet-launches-satellite-constellation-to-image-the-whole-planet-daily/

60) "PSLV-C37 / CartoSat -2 Series Satellite," ISRO, Feb. 15, 2017, URL: http://www.isro.gov.in/launcher/pslv-c37-cartosat-2-series-satellite

61) Stephen Clark, "India lofts a record 104 spacecraft on a single rocket," Spaceflight Now, Feb. 15, 2017, URL: http://spaceflightnow.com/2017/02/15/india-lofts-a-record-104-spacecraft-on-a-single-rocket/

62) Gallery of Planet, accessed on March 1, 2017, URL: https://www.planet.com/gallery/san-francisco-20170211/

63) Marc Selinger, "Satellite Today, Sept. 28, 2016, URL: http://www.satellitetoday.com/nextspace/2016/09/28/nga-growing-acceptance-satellite-imagery-startups/

64) "SmallSats In The White House — Harnessing the Small Satellite Revolution to Promote Innovation and Entrepreneurship in Space ," Satnews Daily, Oct. 24, 2016, URL: http://www.satnews.com/story.php?number=1949829205

65) "Yukon River Canada," Planet Labs, Sept. 19, 2016, URL: https://www.planet.com/gallery/yukon-20160919/

66) "Great Barrier Reef, Australia," eoPortal team, July 14, 2016, URL: https://eoportal.org/web/eoportal/images/featured-image/-/article/great-barrier-reef-australia

67) eoPortal team, "Naaza Lines," June 17, 2016, URL: https://eoportal.org/web/eoportal/images/featured-image/-/article/nazca-lines

68) "Nazca Lines, Peru 2016-06-08," Planet Labs, June 2016, URL: https://www.planet.com/gallery/nazca-lines/

69) "Our Planet - A collection of our favorite images and insights from around the planet," Planet Labs, April 14, 2016, URL: https://www.planet.com/gallery/lake-saint-pierre/

70) "Icy Sumy Oblast, Ukraine," eoPortal Newsletter, Feb. 24, 2016, URL: https://eoportal.org/web/eoportal/images/featured-image/-/article/icy-sumy-oblast-ukraine

71) "Our Planet: A collection of our favorite images and insights from around the planet," Planet Labs, Oct. 26, 2015, URL: https://www.planet.com/gallery/niagara-falls/

72) "BlackBridge is Now Part of The Planet Labs Family," BlackBridge, Oct. 15, 2015, URL: http://blackbridge.com/planet/

73) Our Planet - A collection of our favorite images and insights from around the planet," Planet Labs, March 1, 2015, URL: https://www.planet.com/gallery/korea-aquaculture/

74) Rachel Holms, "A Look Back: Planet's Progress in 2014," January 11, 2015, URL: https://www.planet.com/pulse/a-look-back-planets-progress-in-2014/

75) "NanoRacks Completes Historic Third Round of ISS CubeSat Deployments," Space Daily, March 11, 2015, URL: http://www.spacedaily.com/reports/NanoRacks_Completes_Historic_Third_Round_of_ISS_CubeSat_Deployments_999.html

76) https://www.planet.com/gallery/kangbashi-new-area/

77) http://www.thebohemianblog.com/2014/02/welcome-to-ordos-world-largest-ghost-city-china.html

78) Chris Boshuizen, "Results from Flock 1," URL: http://digitalcommons.usu.edu/cgi/viewcontent.cgi?filename=0&article=3016&context=smallsat&type=additional

79) "Planet Labs Strikes Agreement with Wilbur-Ellis to Enhance AgVerdict® Data Tool," Feb. 2, 2015, URL: https://www.planet.com/pulse/

80) Elizabeth Howell, "When Doves Fly: Swarm Of Tiny Satellites Shot From Space Station," Universe Today, Feb. 13, 2014, URL: http://www.universetoday.com/109317/when-doves-fly-swarm-of-tiny-satellites-shot-from-space-station/

81) Patrick Blau, "Flock-1 CubeSat Constellation begins Deployment from Space Station," Spaceflight 101, Feb. 11, 2014, URL: http://www.spaceflight101.com/flock-1-cubesat-constellation-begins-deployment-from-iss.html

82) “Saving the Planet One Tiny Satellite at a Time,” Discovery Channel, Jan. 16, 2014, URL: http://news.discovery.com/space/private-spaceflight/saving-the-planet-one-tiny-satellite-at-a-time-140116.htm

83) “FCC Clears Planet Labs to Proliferate,” EIJ (Earth Imaing Journal), Nov. 2014, URL: http://eijournal.com/industry-insights-trends/planet-labs-has-been-cleared-to-proliferate

84) ”Planet Spacecraft Operations and Ground Control,” Version 1.2 , Last updated September 2015, Planet, URL: https://www.planet.com/docs/spec-sheets/spacecraft-ops/

85) Bryan Klofas, ”Planet Labs Ground Station Network,” 13th Annual CubeSat Developers Workshop Cal Poly SLO, April 21, 2016, URL: http://mstl.atl.calpoly.edu/~bklofas/Presentations/DevelopersWorkshop2016/1_BryanKlofas.pdf

86) Kyle Colton, Bryan Klofas,”Supporting the Flock: Building a Ground Station Network for Autonomy and Reliability." Proceedings of the 30th Annual AIAA/USU SmallSat Conference, Logan UT, USA, August 6-11, 2016, paper: SSC16-IX-05, URL: http://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=3368&context=smallsat

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