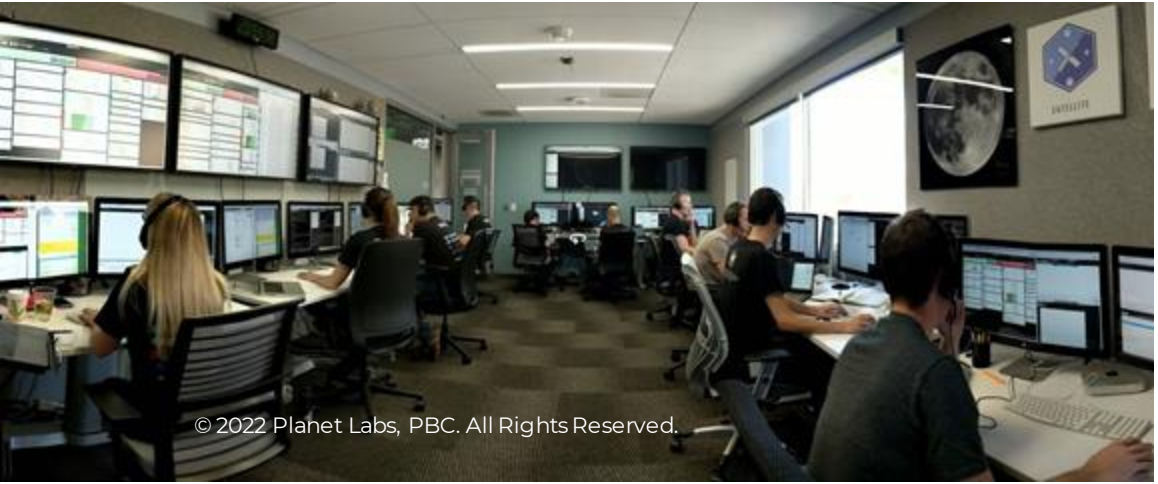
How to Effectively Operate 100's of Satellites

Lessons Learned from Planet Mission Operations

Lisa McGill, June 2022

Bora Bora – March 09, 2018

My background



Planet's Mission

Planet images the whole world every day, making change **visible, accessible, and actionable**.

HISTORY OF PLANET

Founded in 2010 by a team of ex-NASA scientists, Planet is driven by a mission to image the entire Earth every day, and make global change visible, accessible, and actionable.

2010
PLANET FOUNDED

Planet founded by NASA scientists, Robbie Schingler, Will Marshall, and Chris Boshuizen.

2014
MISSION 1 ESTABLISHED

CEO Will Marshall announces Planet's mission to image the entire Earth's surface every day at TED.

2015
LAUNCHES

67 total satellites across four launches Planet acquires Blackbridge, and their RapidEye satellite constellation.

Another 42 satellites are deployed across 5 more launches.

2017
TERRA BELLA ACQUISITION

Planet acquires Terra Bella from Google, adding seven high-resolution SkySat satellites to the fleet.

Launched 146 satellites, including the record-breaking launch of 88 Doves on a PSLV rocket, and six additional SkySat satellites.

2017
MISSION 1 COMPLETE

Planet is now able to image Earth's entire landmass on a daily basis.

2018
VISION FOR QUERYABLE EARTH ANNOUNCED

Planet's vision to use machine learning to deliver a Queryable Earth is announced at TED.

Launch of Planet Analytics.

2019
PLANET FEDERAL ESTABLISHED

Planet acquires Boundless Spatial, Inc., a St. Louis-based geospatial software solutions company. The acquisition expands Planet's commercial business with the U.S. government and commercial agriculture clients.

2021
CARBON MAPPER ANNOUNCED

Carbon Mapper, a new nonprofit organization, and its partners announced a pioneering satellite constellation to help improve understanding of and accelerate reductions in global methane and carbon dioxide (CO_2) emissions.

2021
PLANET BECOMES A PUBLIC BENEFIT CORPORATION

Trading on the New York Stock Exchange as PL.

4 29&47 MEGA-PIXELS

MILLION IMAGES EVERY DAY

AN AVERAGE OF

1800 IMAGES

for every point on the Earth's landmass

AREA COVERED

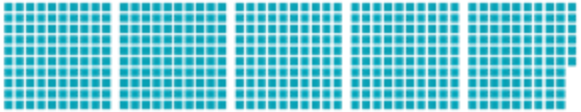
350

million km² per day

10X

ALL OTHER COMMERCIAL SOURCES AND PUBLIC SOURCES E.G. LANDSAT/ SENTINEL COMBINED!

More than 2 times the total landmass of Earth!



496 SATELLITE DEPLOYMENTS

FROM 10 ROCKET TYPES

10 SITES IN 7 COUNTRIES

25TB

DATA PER DAY DOWNLINKED

48 GROUNDSTATION ANTENNAS

100%

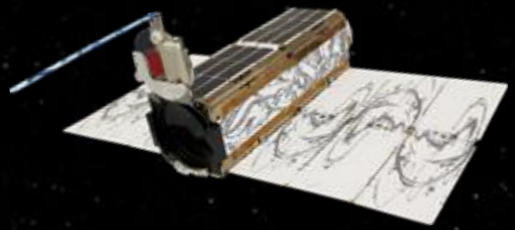
SUCCESSFUL FIRST CONTACT

31

SUCCESSFUL LAUNCHES

planet.

Planet's industry-leading constellations

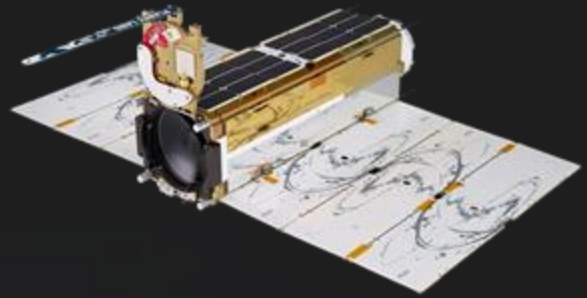


~200

Dove Satellites
PlanetScope

21

SkySat
Satellites



Doves

SATELLITES	GSD	CAPACITY
~200	**3.7 m**	**350 million km²**/day

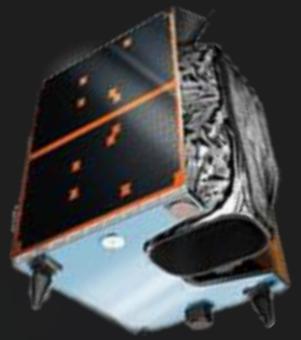
ORBIT ALTITUDE	SPECTRAL BANDS
475 km	**RGB + Green II, Red Edge, Yellow, Coastal Blue,** and **NIR**

SuperDove

Next Gen PlanetScope with 8 bands

Additional bands means more information about the Earth's surface

- **Red, Green, Blue + Near Infrared**
- **Coastal blue** = near-shore bathymetry
- **Red-edge** = vegetation stress & water quality
- **Yellow** = crop and land cover classification
- **530 nm Green** = plant health



RapidEye

SATELLITES	GSD	ARCHIVE
5	**6.5 m**	**Back to 2009**
Retired in March 2020		

SPECTRAL BANDS
RGB, Red Edge
and **NIR**

SkySat

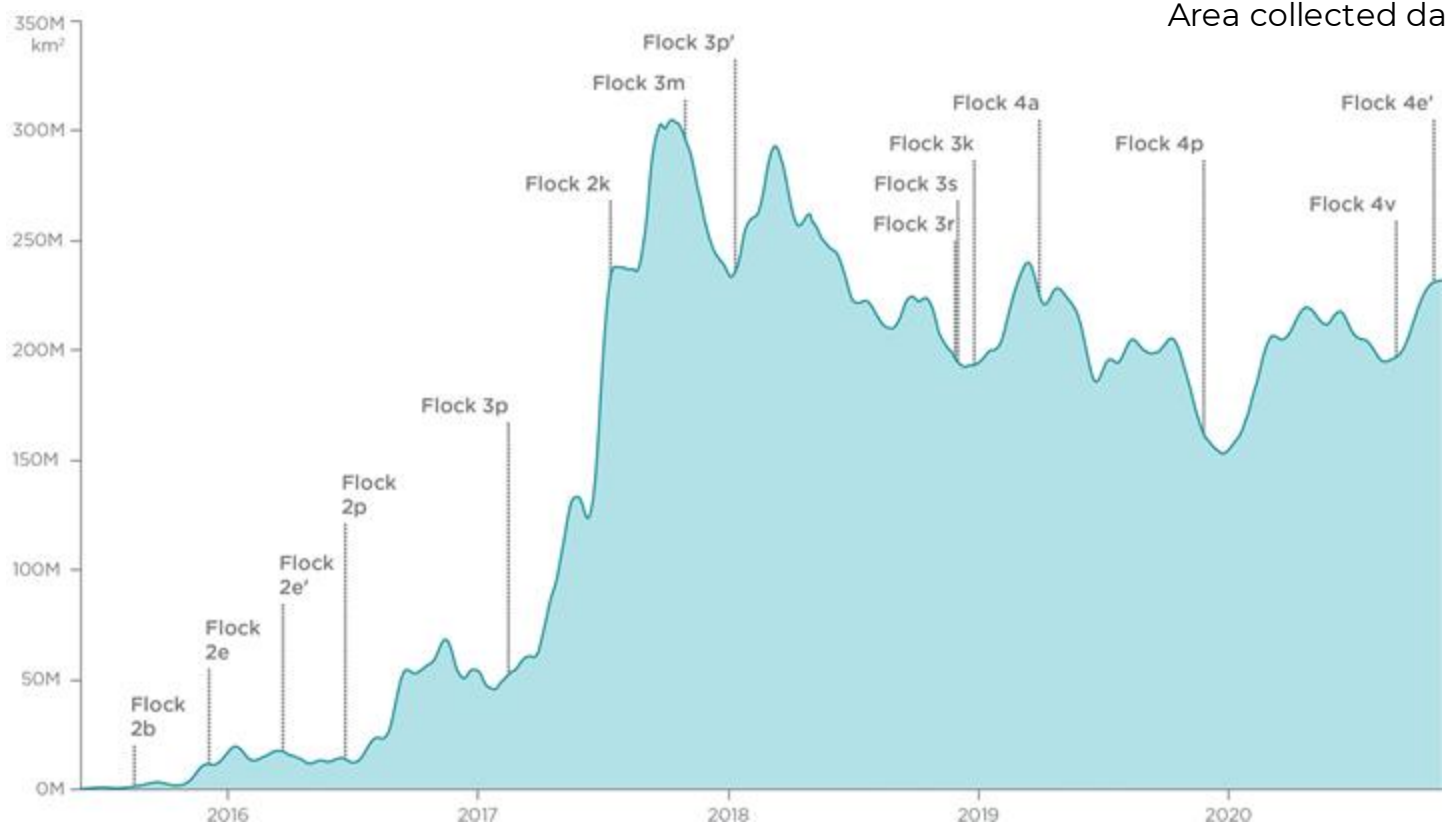
SATELLITES	GSD	CAPACITY
21	**0.65 m**	**600 K km²**/day

ORBIT ALTITUDE	SPECTRAL BANDS
450 km	**RGB, PAN** and **NIR**

OUR CONSTELLATIONS

Constellation	PlanetScope	SkySat
Orbit Altitude	475 km	450 km
Spacecraft #	~200	21
Image capture capacity	350+ million km²/day	600,000 km²/day
GSD (Nadir)	3.7 m	0.65 m
Pixel Resampled	3.125 m	0.50 m
Telescope and Camera	Bayer mask CCD sensor	CMOS Frame Camera with Cassegrain telescope
Spectral Bands	RGB + Green II, Yellow, Red Edge, and NIR	RGB, PAN and NIR

REACHING A DAILY PICTURE OF EARTH

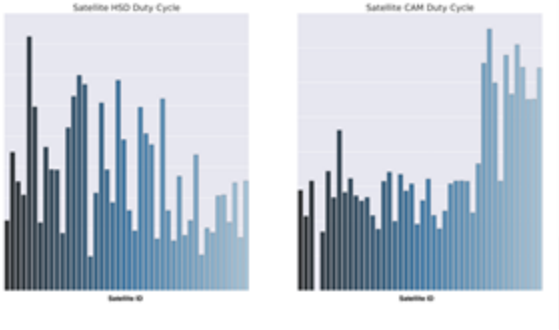


Space Operations Evolution

- Operators (teams of 2) monitored logs and telemetry manually for each SkySat contact 24x7

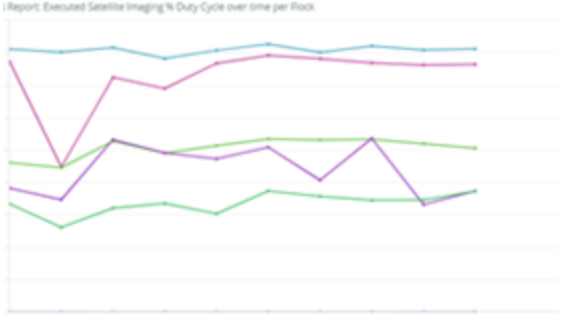
```
ALARMS REPORT:
Reviewing day 1 to day 2

RED: 23 sats; 57 registers;
YELLOW: 10 sats; 17 registers;

RED Telemetry Alarms:
0903:
0904:
     telem.channel.11:     2.00
0905:
090b:
     telem.channel.21:     min:-5.69 max:-5.19
090c:
0b07:
     telem.channel.21:     min:-7.50 max:-5.38
     telem.channel.22:     min:-7.12 max:-5.12

YELLOW Telemetry Alarms:
0905:
     telem.channel.61:     135.00
090b:
     telem.channel.62:     135.00
```

```
WARNINGS:
Reviewing 2016-mm-dd 15:37:12.580 to 2016-mm-dd 15:34:48.657

0711:
 Counts  Message                          File Name      Level Name
--------  -------------------------------  -------------  ----------
     2  Message error                     script1.py     ERROR
     1  Message Task Z failed             script2.py     ERROR
     1  Message Task X failed             script2.py     ERROR
     1  Message Task Y failed             script2.py ERROR
--------

0903:
 Counts  Message                          File Name      Level Name
--------  -------------------------------  -------------  ----------
     3  Sensor[X are pegged               script1.py     WARNING
     2  Y failure flag set                script5.py     ERROR
     1  Message Task X 'task name' failed!  script4.py   ERROR
     1  XY current(s) reading Zero.       script7.py     WARNING
     1  Attempting to fix XYZ sensors by rebooting.  script8.py  WARNING
--------
```

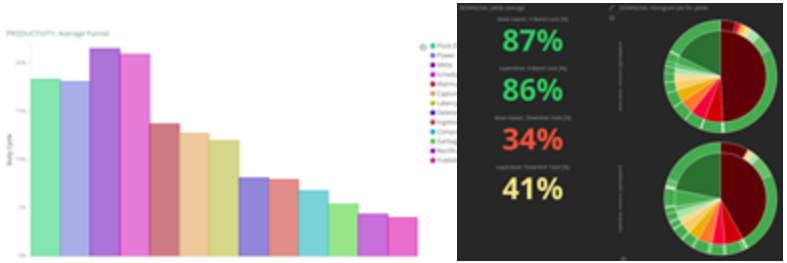


Space Operations Evolution

- Check each satellite
- Time consuming
- Each alert message needs to be evaluated
- New builds, different performance values
- More data to parse through



Dataflow model
Metrics



Mission Control
Orbit data
Telemetry
Logs

Python script
Python script
Python script
Python script
Python script
Python script

aggregated records

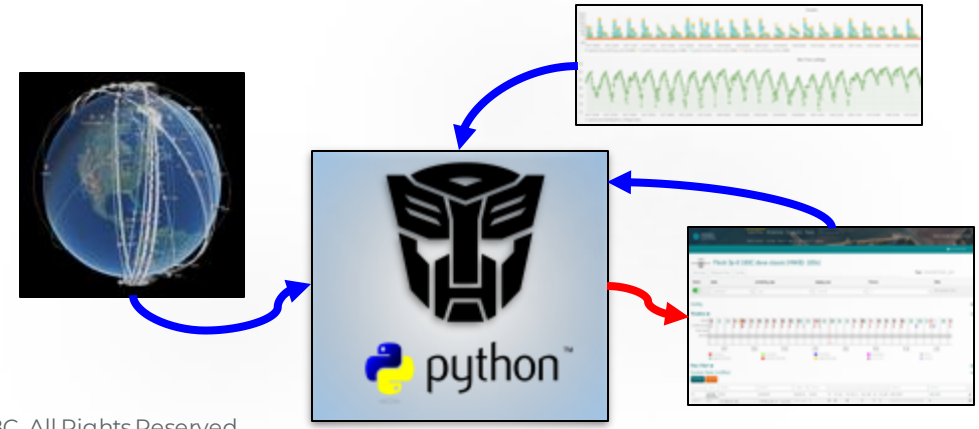
Storage

Metric Reports

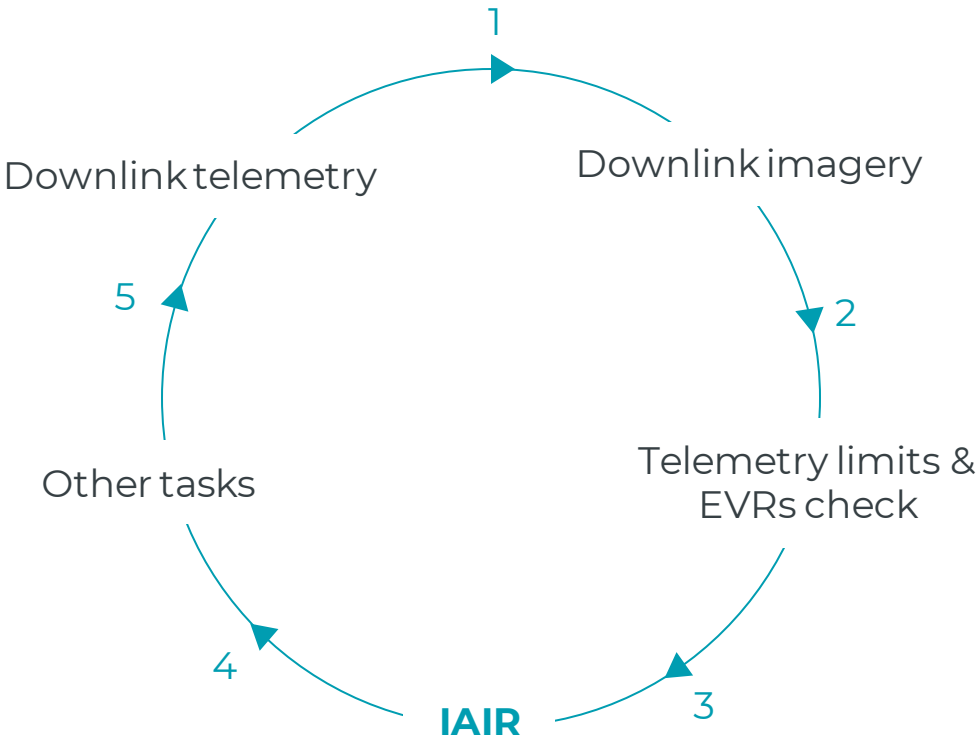
- ***Automated responses scripts***
- ***Notebooks***

Scaling Operations

- Automation platforms for software play the role of an operator: Take care of the most common anomalies and maximize the performance of the fleet
- Its implementation consists of a set of Python scripts that are periodically triggered
- Metrics and notifications are generated when the automation performs an action

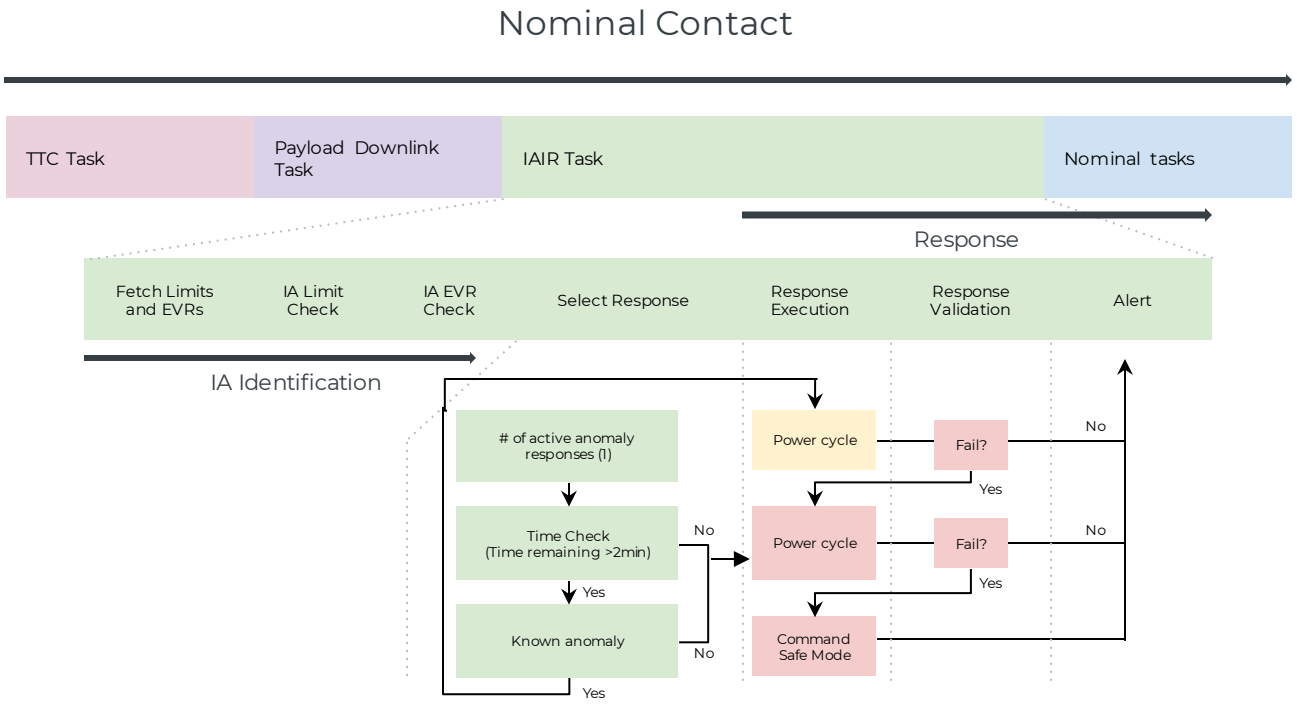


Nominal Contact with IAIR



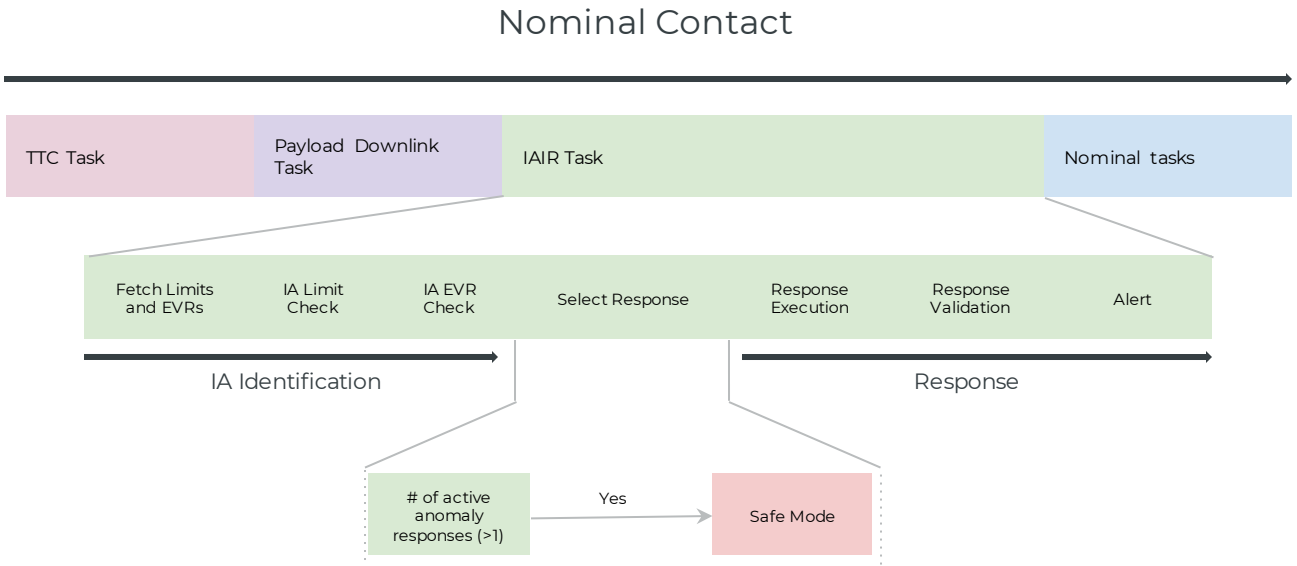
IAIR scenarios

One anomaly detected

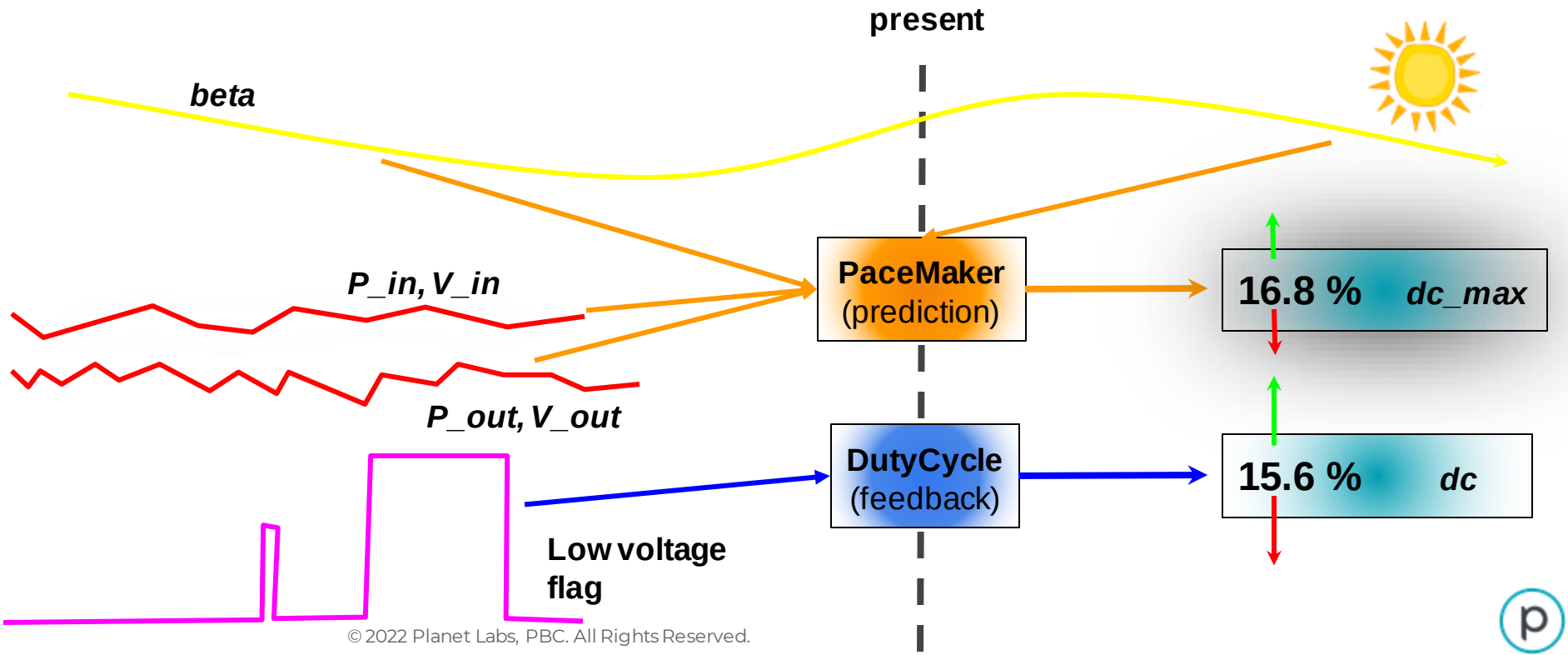


IAIR scenarios

More than one anomaly detected

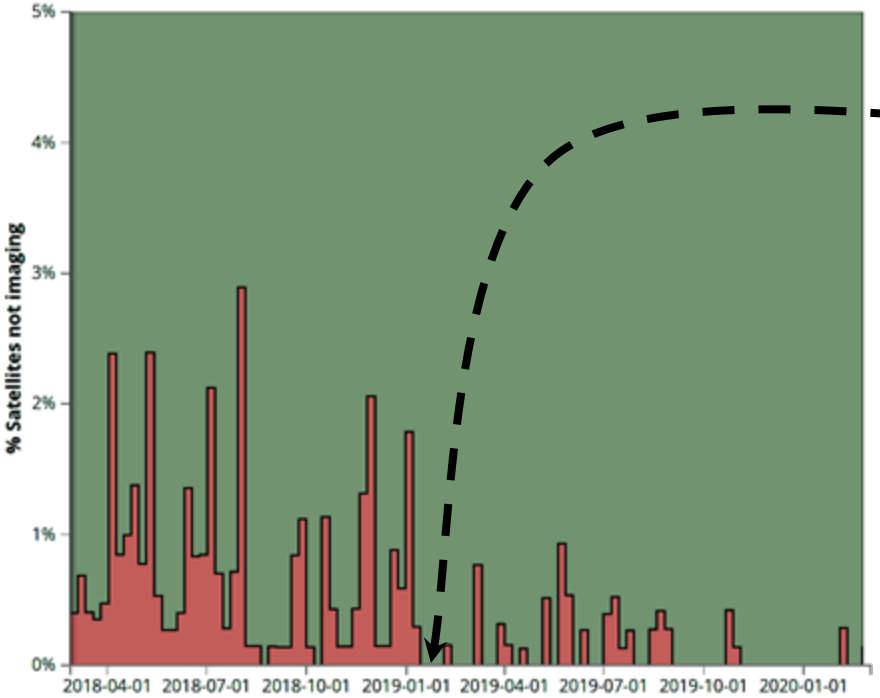


Automated Constellation Management Example
Duty Cycle Control



Results

Satellite downtime (Dove)



Automated Anomaly Response Deploy

Results

Reduction in monitoring effort

Dove Satellites

Reduced time invested in daily monitoring, from ~4 h/day to ~30 min/day.

SkySat Satellites

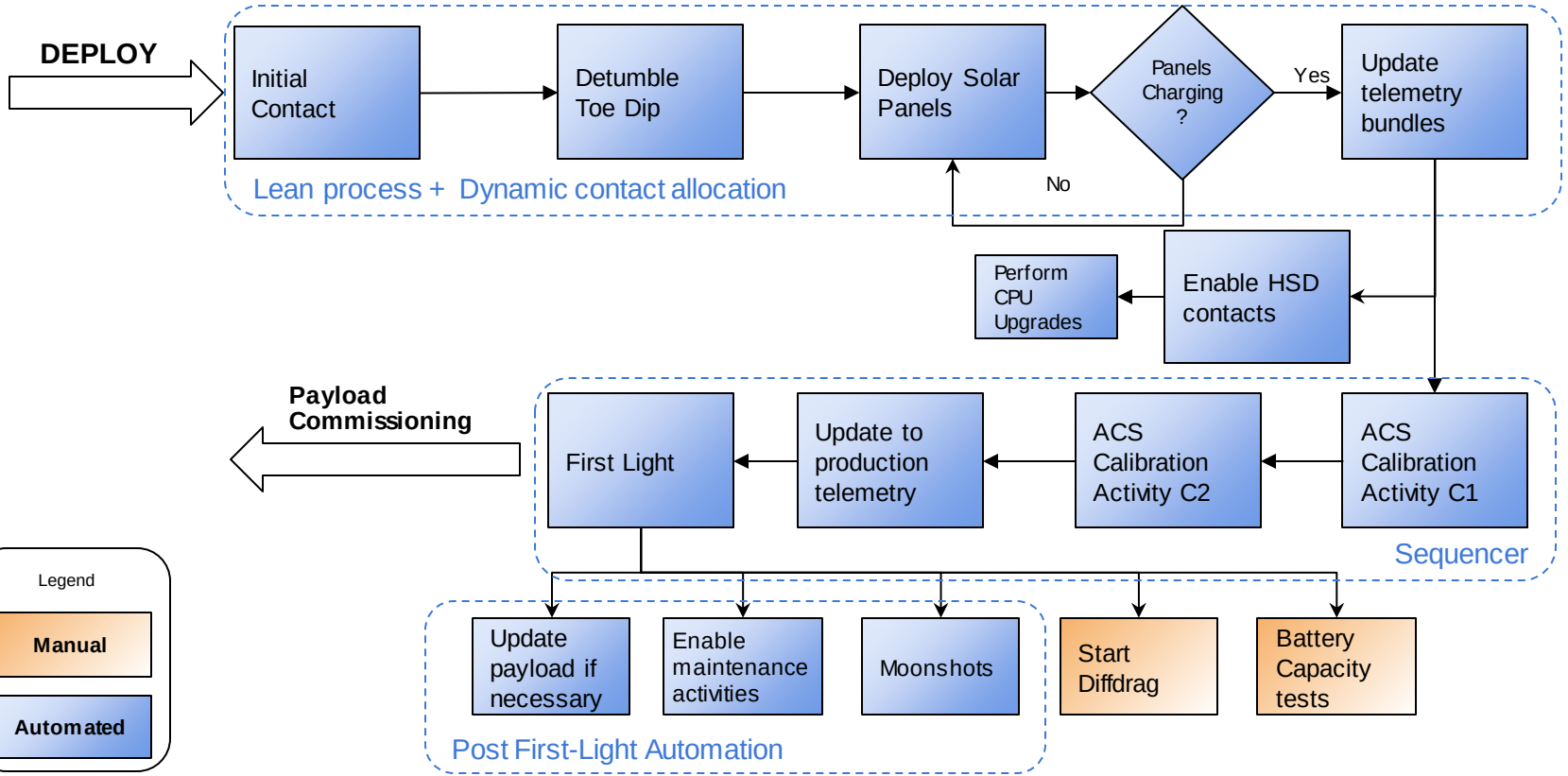
Eliminated night-shifts and 24/7 support. Substituted by regular workday.

Scaling Operations
Paradigm Shift

- Focus primarily on the **value of the constellation** rather than on each satellite.
- Identify **fleet wide problems**: Alerting systems based on aggregated metrics
- **Identify anomalous sats**:
  - Derived metrics and customized alerts
  - Automated detections of anomalies and reactions
- **Optimize system availability and capacity**

Dove Commissioning

Automation



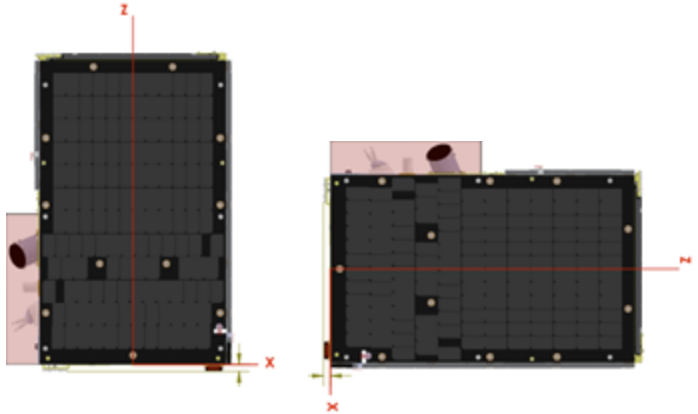
SkySat Commissioning

Ground Station Network

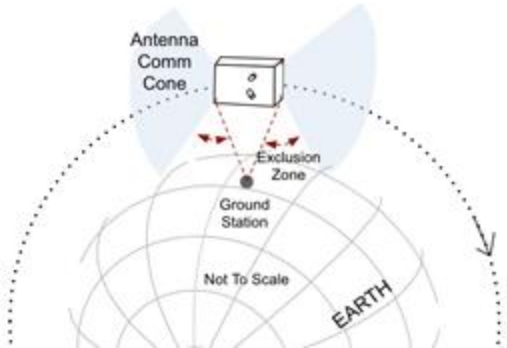
- Awarua, New Zealand
- Goonhilly, United Kingdom
- Maddock, North Dakota, USA
- Punta Arenas, Chile
- Jeju Island, South Korea

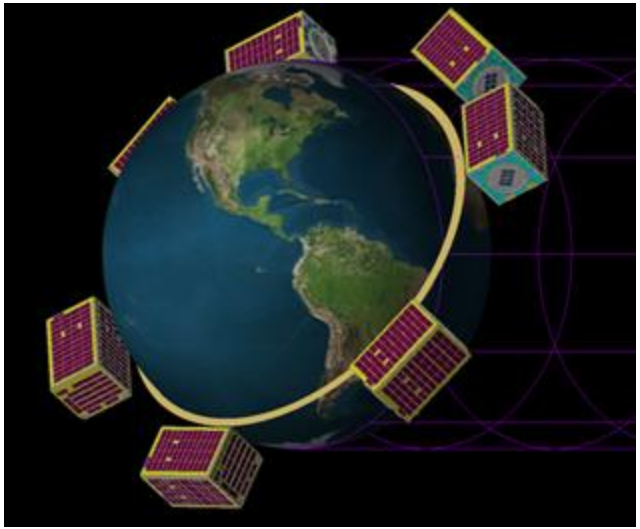
Low Drag

- Pitch 90 degrees to expose its smallest cross-section to be parallel to velocity direction
- Payload door remained closed
- Reduce atmospheric drag
- Updates to ops scripts to support telemetry and commanding



High Drag **Low Drag**



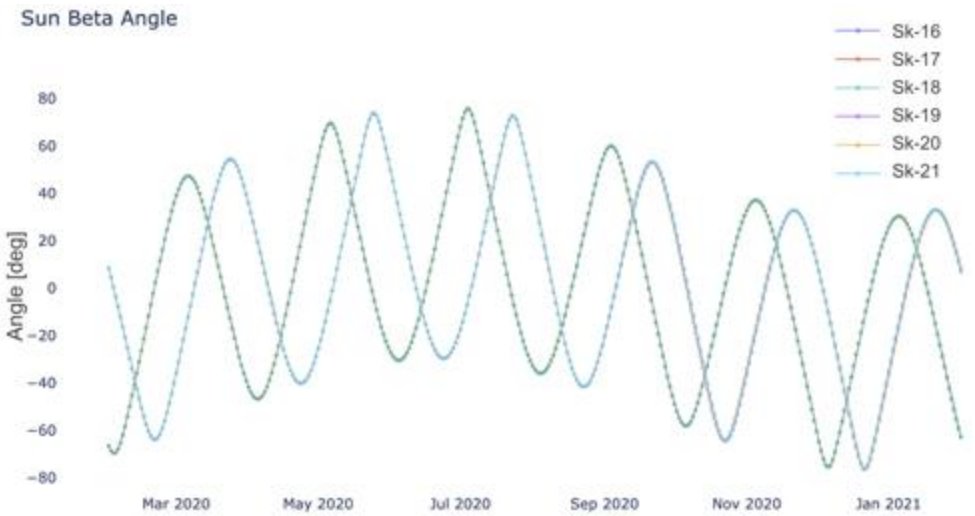


Attitude Management

What is a beta angle?

- A measurement that describes the angle between a satellite's orbital plane and a vector from the center of the Earth pointing toward the sun

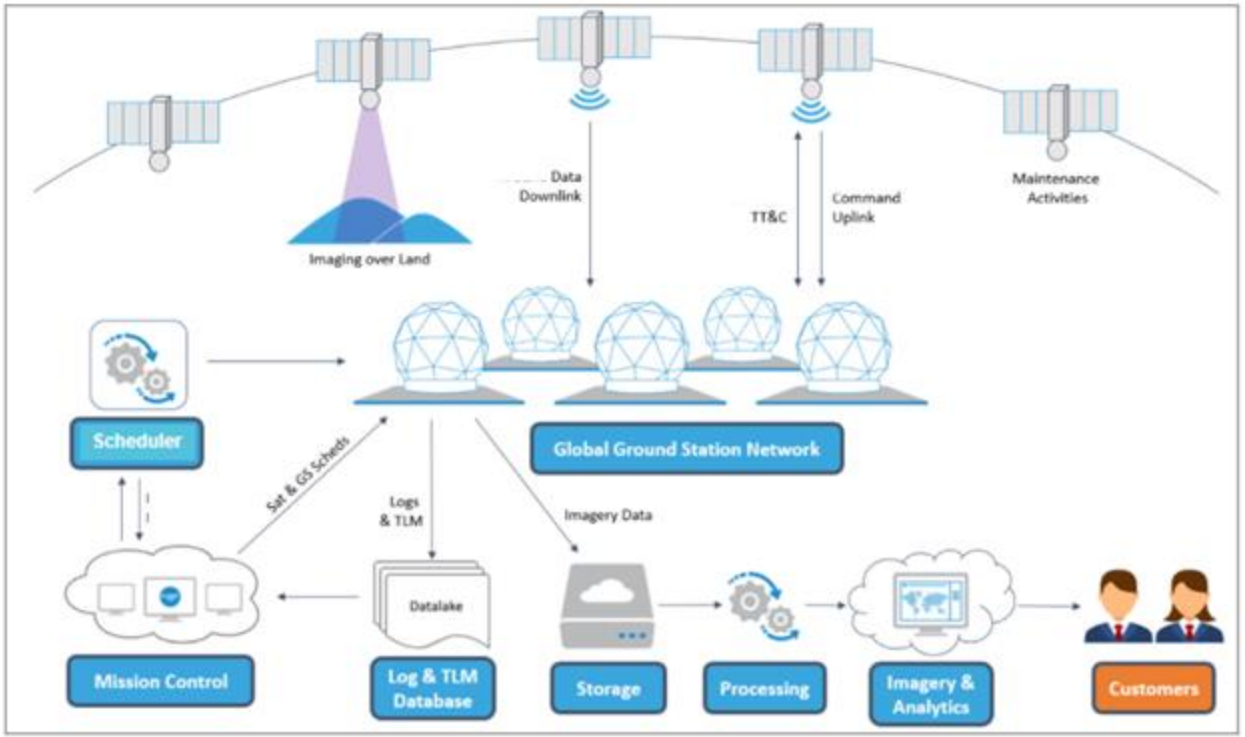
Develop a new attitude management scheduling system!



Beta Angle Magnitude	Classification	Issues
$0 \leq \beta \leq 15$ deg	Low Beta	Poor star tracker performance
$15 < \beta < 45$ deg	Mid Beta	No issues
$45 \leq \beta < 68$ deg	High Beta	High temps; thermal buildup
$\beta \geq 68+$ deg	Extreme Beta	No eclipses; severe thermal buildup

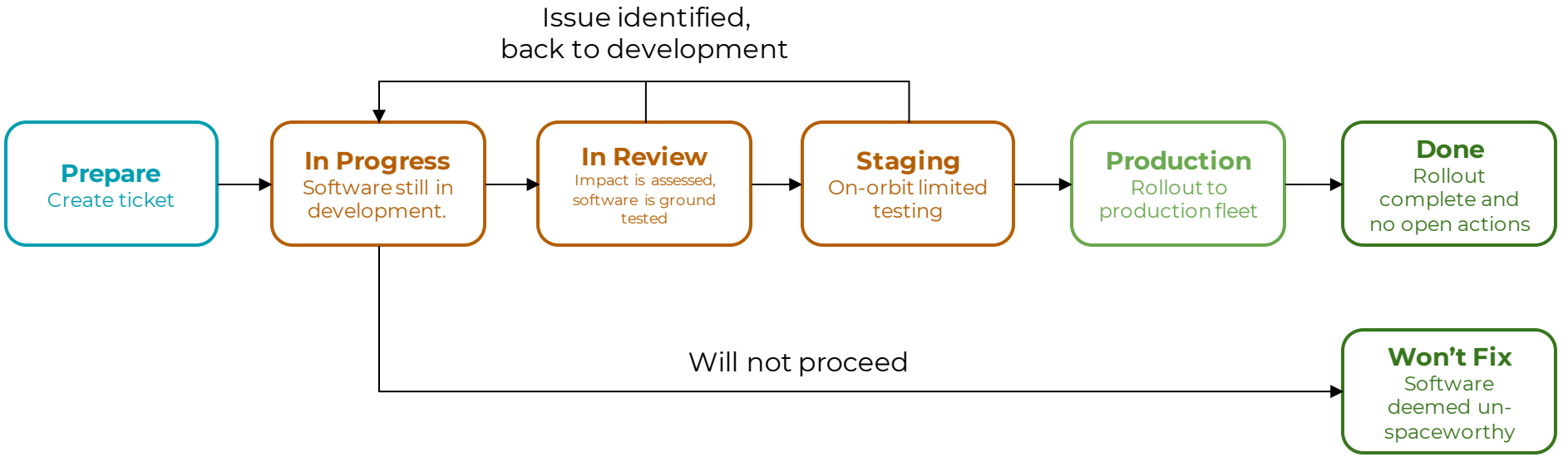
Automation is Key

- Nominal operations is 100% automated
  - Automated pass commanding for uplink and downlink of data
  - Automated scheduling for ground contact plans
  - Automated fleet reporting
  - Automated delivery to image pipeline



On-Orbit Software Deploys

Agile Operations



Approaches to Fleet Management

On-call and Sprint planning

Dove Fleet

- One-week on-call rotations with one daily check-in (~1 hr)- > Plan for low/medium priority development work
- Review aggregated metrics to identify out-of-family signatures, no real-time monitoring
- All known responses are automated

Skysat Fleet

- Weekly rotations with 3 full dedicated days -> Plan for a 7 day sprint
- Real-time monitoring is only needed for off-nominal situations or unique maintenance activities
- Most known responses are automated

Being "agile" requires that we accept that sprints may not go according to plan, and that is ok.

Lake Okeechobee, Florida, USA

Managing On-Orbit Anomalies

Agile Operations

Inability to predict satellite anomalies forces software development work to take a backseat.

Measures taken to mitigate impact of interrupts:

- Develop automation for anomaly recovery
- Plan for interrupts by building in margins into sprints
- Incorporating on-call schedule into sprint planning

Lake Okeechobee, Florida, USA

Managing priorities across multiple missions

Case study: SSO-A Express Launch containing Skysats, Doves, and SuperDoves

Define Prioritization Tiers

- **P0** - Any Health and Safety anomaly which imminently jeopardizes the spacecraft's mission.
- **P1** - Any anomaly which prevents the spacecraft's commissioning goals from being completed on schedule.

This tiered approach clarified priorities for commissioning but it did not address the likelihood that there would be competing priorities related to concurrent activities in Manufacturing as well as on-orbit anomalies with the existing production fleet.

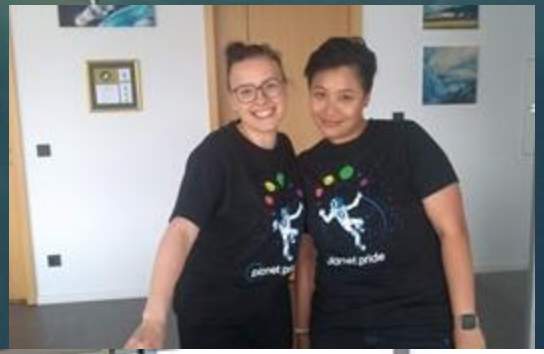
Daily morning tag-ups with the engineering teams enabled efficient communication of blockers and competing priorities.

Agile Aerospace

- **5 launches in 2020**
- 26 SuperDoves on a Vega rocket, released from 2 different deployers
- 6 SkySats deployed in inclined orbits and record-setting low altitudes (280km)
- At one point, 3 active commissioning campaigns in parallel all supported fully remotely
- Our global ground station network received over **5 petabytes of data** from both constellations managing thousands of contacts every day.

Impact

Thank You! Questions?



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