LEO Earth Observation CubeSat Classification in its second decade

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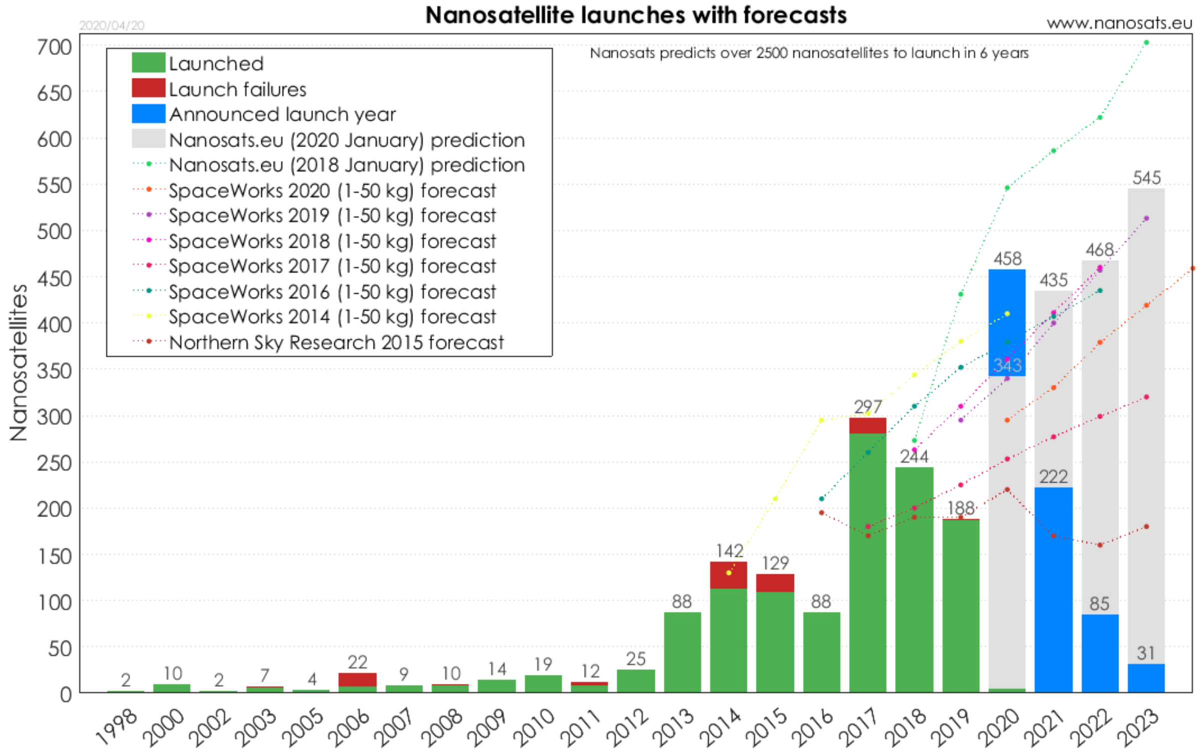
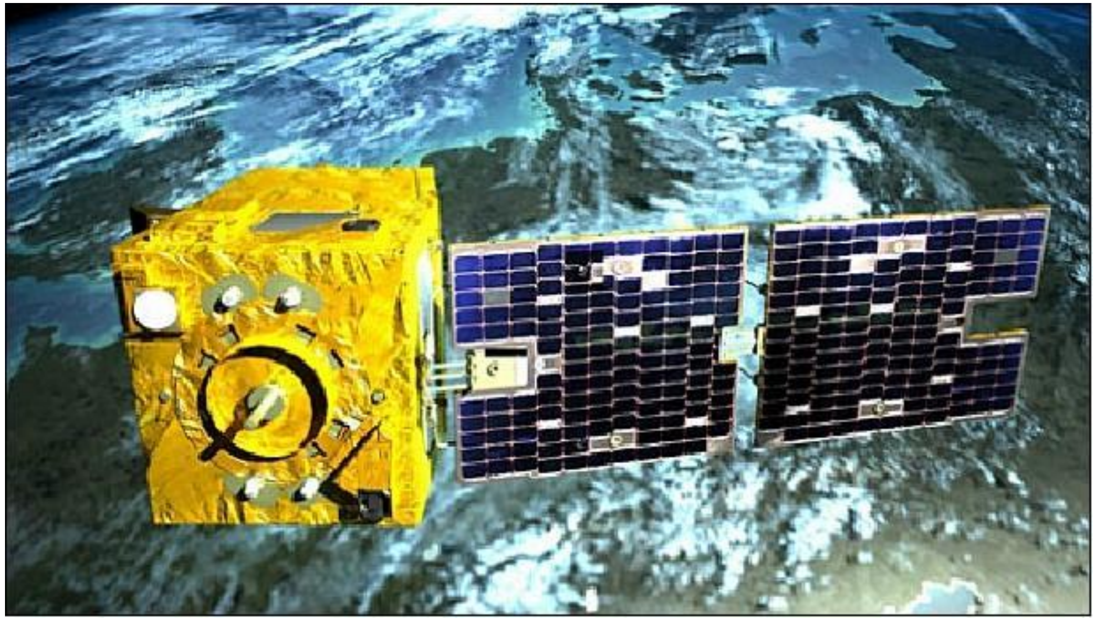
Context: Why CubeSats in LEO? & Why Earth observation?

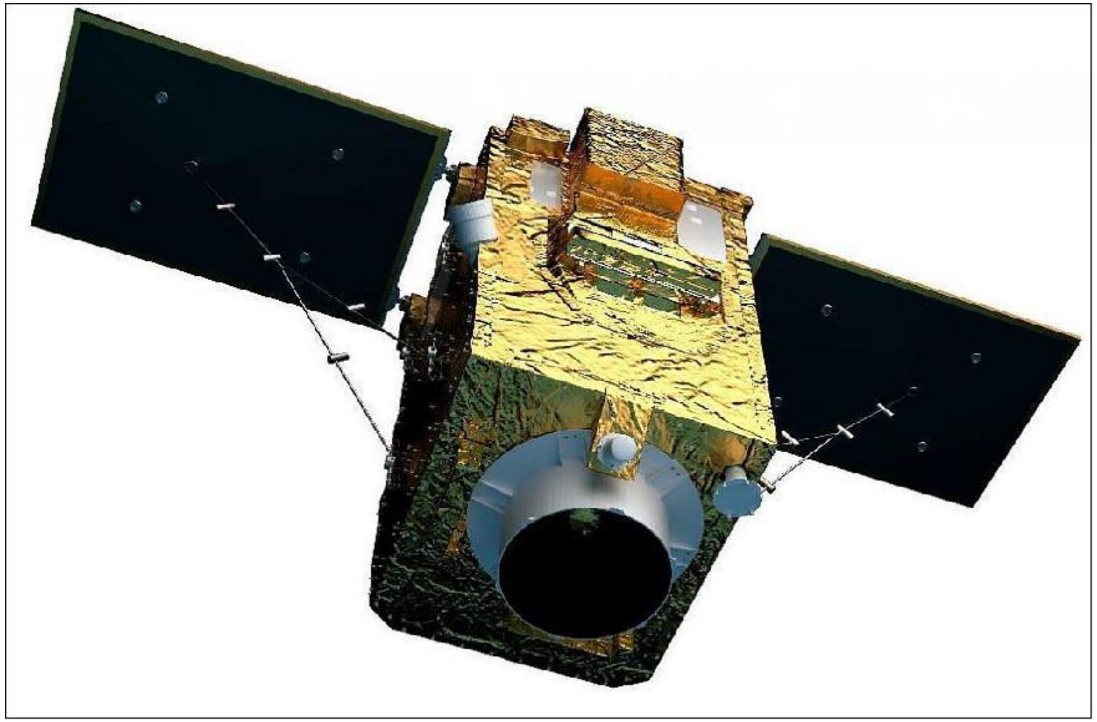


- Planet Labs by the number
  - **2012** Founded (~NASA Ames Spin-off) [Owler]
  - **~60 M** USD Est. revenue [Owler]
  - **480** Est. employees [Owler]
  - **373,9 M USD** in 7 Rounds of Funding [Crunchbase]
  - **387** CubeSats deployed as of April 20th, 2020 [nanosats.eu]
- **Sector: Application Software / Analytics**

Airbus Platforms, best pixel size in the region SSOT 2011 and PeruSat-1 2016

https://directory.eoportal.org/web/eoportal/satellite-missions/s/ssot





https://directory.eoportal.org/web/eoportal/satellite-missions/p/perusat-1

Câmeras Imageadoras CBERS-3 (2005) e 4 (2010)

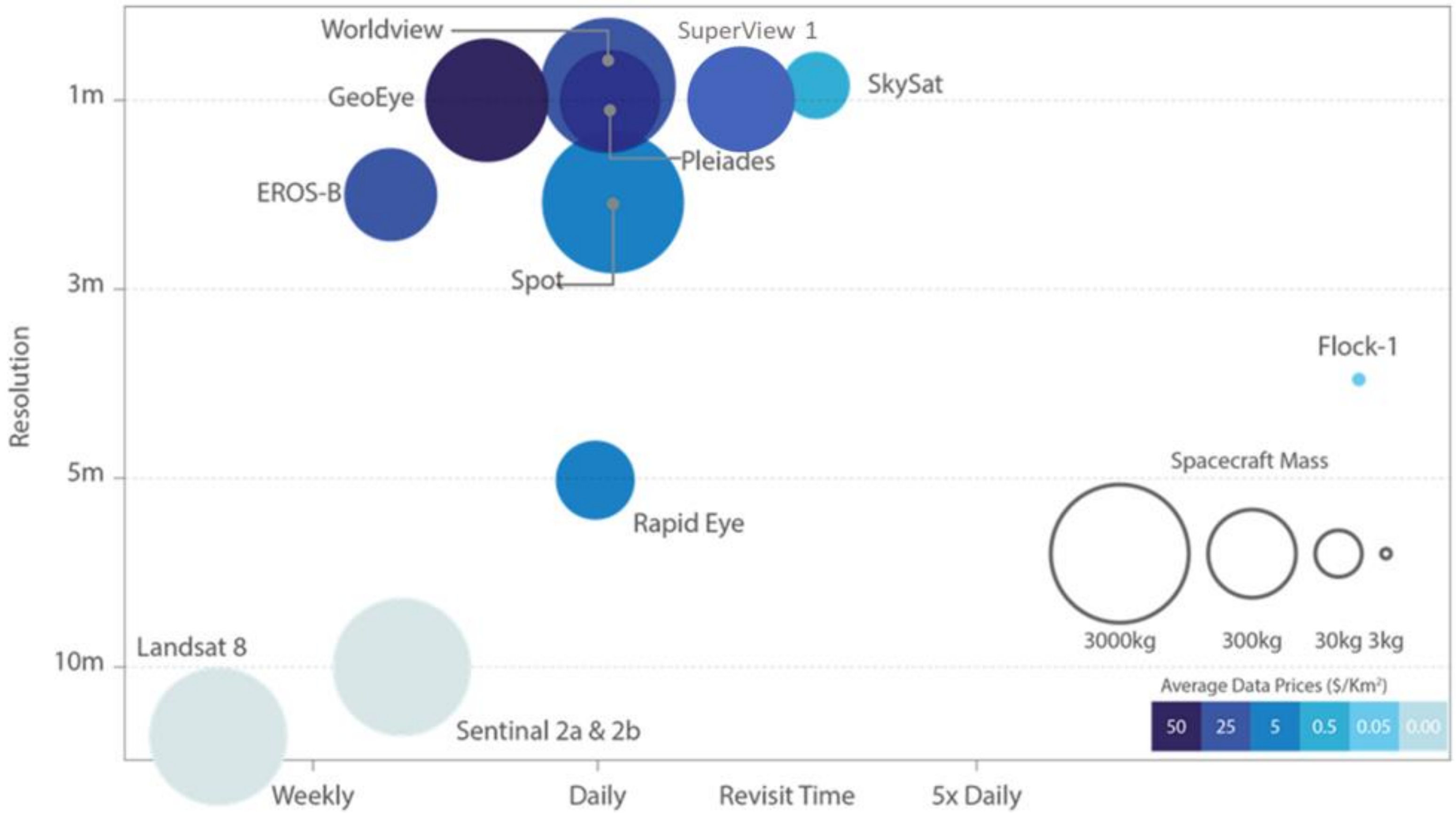
http://www.dgi.inpe.br/CDSR/

- **Câmera Pancromática e Multiespectral (PAN)**
- Bandas Espectrais
  - B01: 0,51 - 0,85 µm
  - B02: 0,52 - 0,59 µm
  - B03: 0,63 - 0,69 µm
  - B04: 0,77 - 0,89 µm
- **Largura da Faixa Imageada 60 km**
- **Resolução Espacial 5 m (B01)/10 m (B02,B03,B04)**
- Visada Lateral de Espelho ± 32º
- **Taxa Bruta de Dados(Mbit/s)**
  - **140 Mbit/s (B01)**
  - **100 Mbit/s (B02,B03,B04)**

- **Câmera Multiespectral Regular (MUX)**
- Bandas Espectrais
  - B05: 0,45 - 0,52 µm
  - B06: 0,52 - 0,59 µm
  - B07: 0,63 - 0,69 µm
  - B08: 0,77 - 0,89 µm
- **Largura da Faixa Imageada 120 km**
- **Resolução Espacial 20 m**
- Visada Lateral de Espelho não
- **Taxa Bruta de Dados 68 Mbit/s**

Context: Why bother with “tiny” spacecraft?

https://business.esa.int/newcomers-earth-observation-guide



https://space.skyrocket.de/doc_sdat/flock-1.htm

Research Objective

Identify and *classify* the last decade earth observation (VIS and NIR) in CubeSats deployed in LEO (200 to 1.000 km altitude),

through

a state-of-the-art review regarding CubeSat Passive Earth Observation (EO) payloads

and *identifying* the mission parameters available in reliable databases,

to *quantify* the evolution in performance over time of payloads concerning “physical” limitations.

Methodology

- Data for missions over the last decade was obtained from different databases
- Data was selected for CubeSats, as a form factor rather than weight ~1.200 CubeSats (as of July 8th, 2020)
- Orbit and main mission declared was used to select the data in the scope of this study (LEO between 200 and 1000 km altitudes, and EO in VIS & NIR
- Characteristics of orbit data were analyzed and the payload is assessed taking the declared performance, and comparing to handbook design relations for passive VIR and NIR payloads
- Results for Planet CubeSat Dove 3U CubeSats are compared to values for “traditional” EO Spacecraft SSOT (2011) & Perusat-1 (2016)

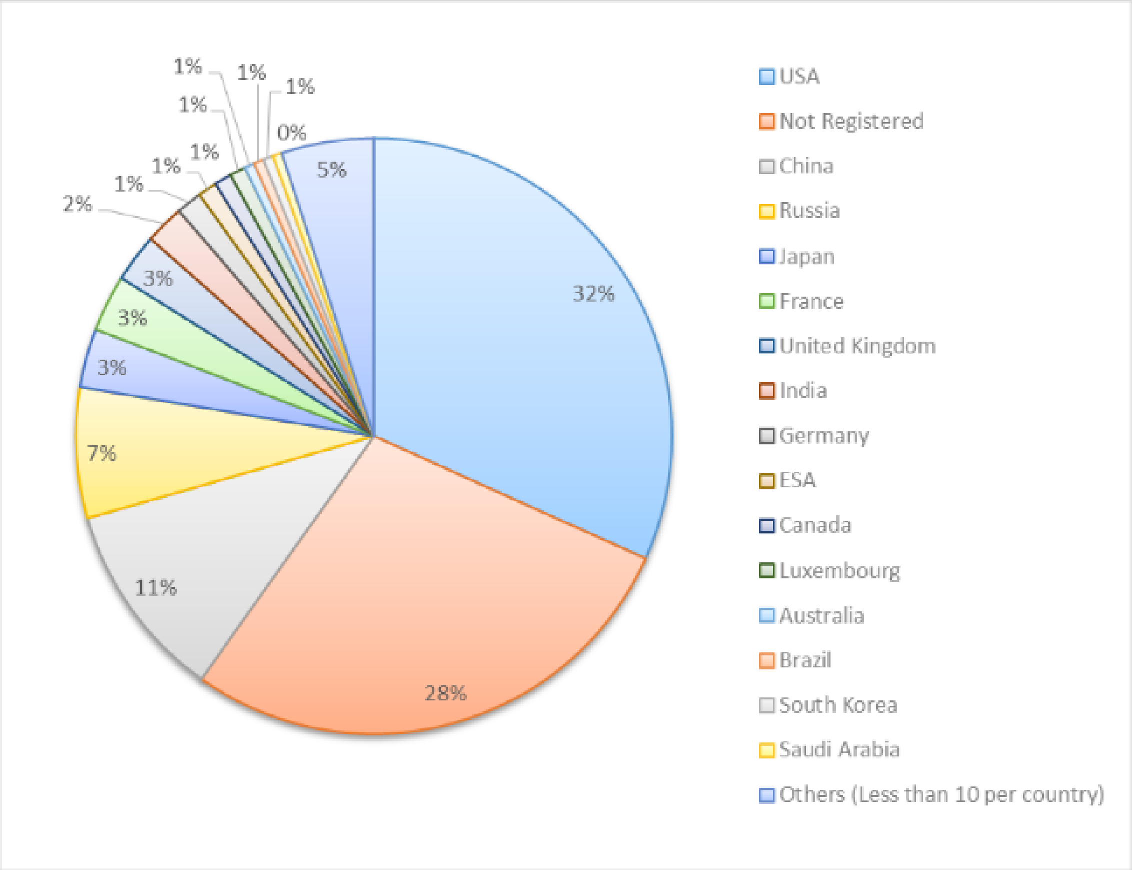
Doha

https://eoportal.org/web/eoportal/images/featured-image/-/article/the-pearl-qatar-in-doha-qatar

Pleiades

SSOT

General spacecraft breakdown by orbit, owner and application



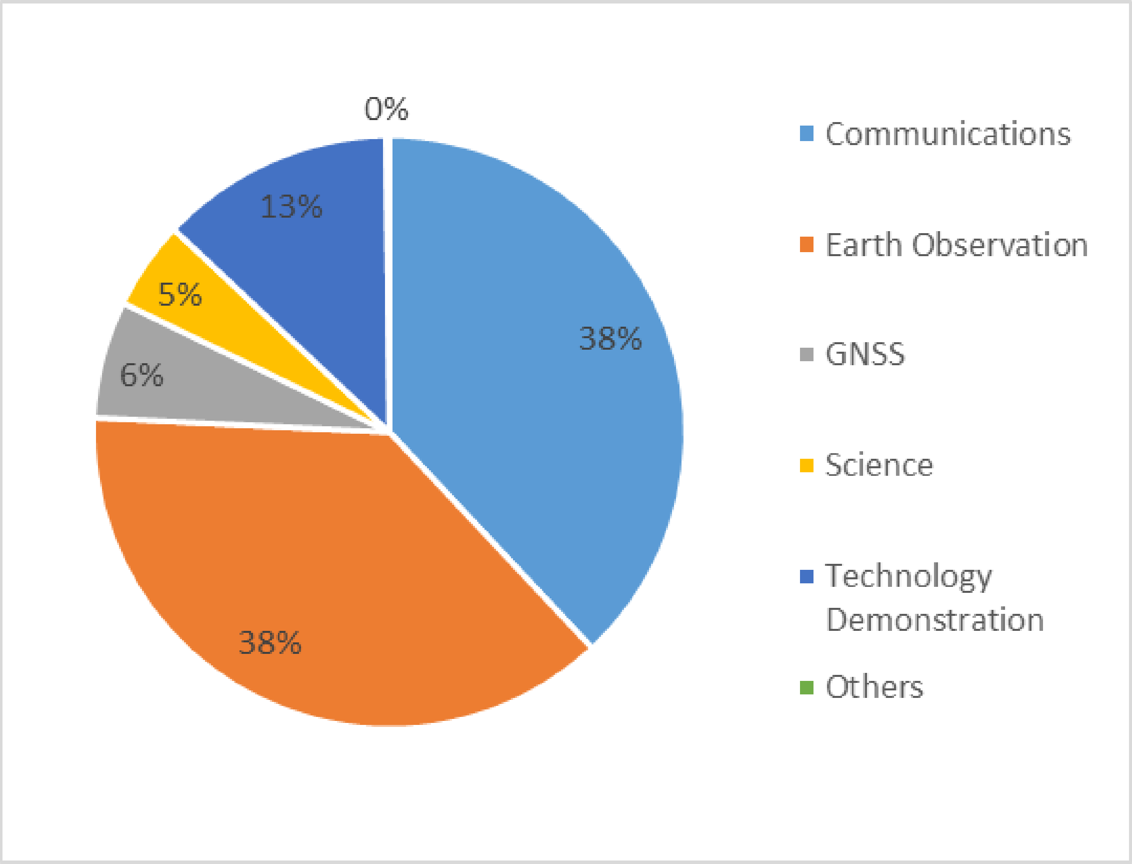


Fig. 2 Spacecraft breakdown as of October 1st, 2019 [Source: Adapted from [7]]

CubeSats by the numbers in context

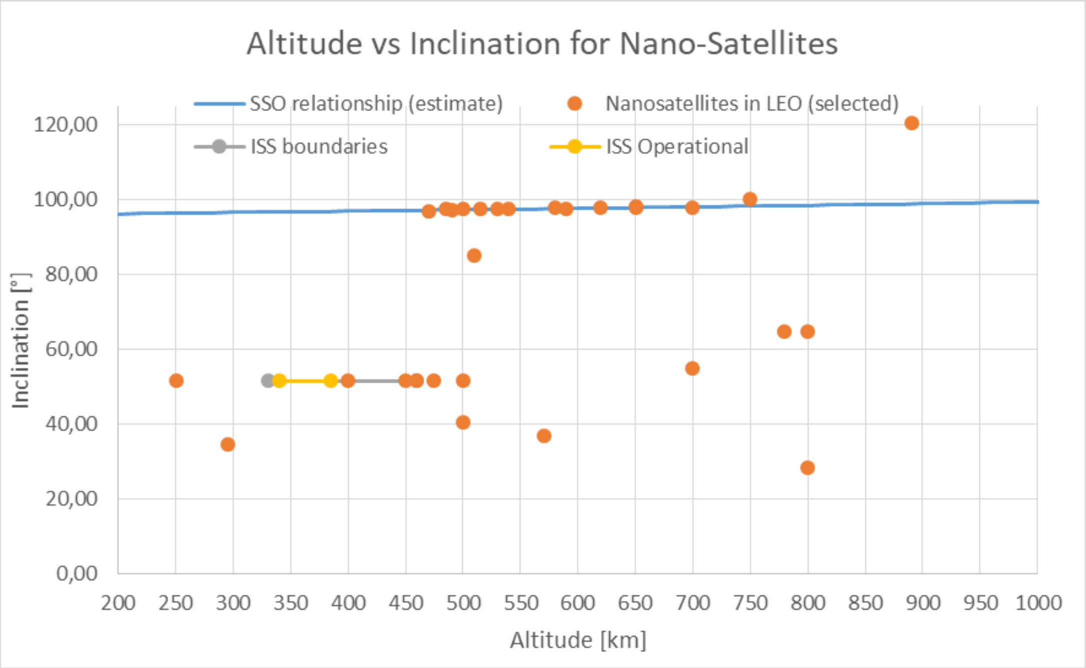
	All Launched	Decayed	Still in orbit	
All CubeSats	1184	407	777	65.6%
Constellations	535	181	354	66.2%
Non-Constellation	649	226	423	65.2%
All US-built	870	332	548	63.0%
Rest of the world	314	85	229	72.9%
Starlink spacecraft	600	3	597	

Orbit breakdown as of **July 8th, 2020** [3]

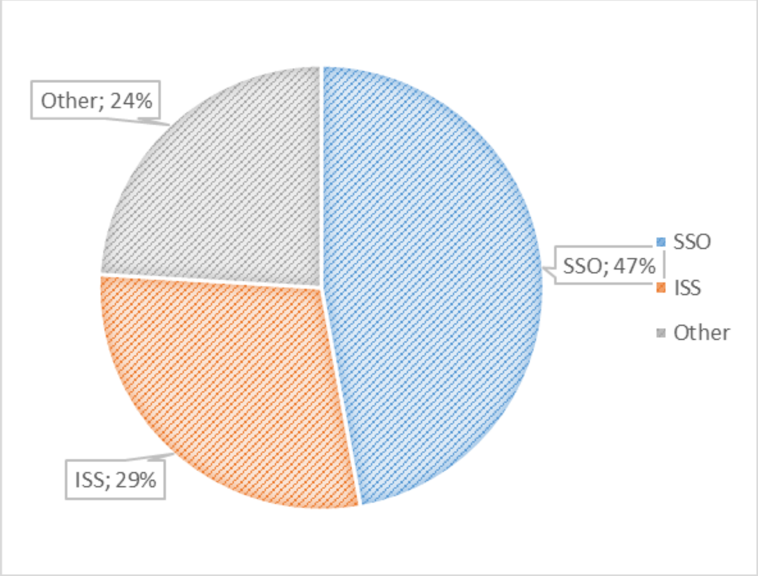
Total number of operating satellites			**2.218**
US: 704	Russia: 157	China: 238	Not Registered: 623
LEO: 1.468	MEO: 132	Elliptical: 56	GEO: 562
Civil: 155	Comm: 1.037	Gov: 565	Military: 461

Spacecraft breakdown by major registry country, orbital region and owner organization (data up to **October 1st, 2019**) [Source: Adapted from [7]]

CubeSats



Altitude vs Inclination for Nano-Satellites
SSO relationship (estimate)
Nanosatellites in LEO (selected)
ISS boundaries
ISS Operational
120,00
100,00
80,00
60,00
40,00
20,00
0,00
Inclination [°]
200 250 300 350 400 450 500 550 600 650 700 750 800 850 900 950 1000
Altitude [km]



Other; 24%
SSO; 47%
ISS; 29%
SSO
ISS
Other

Passive Earth Observation Payloads in VIS and NIR metrics - definitions

- Assuming nadir pointing and estimating different EO performance metrics, as stated by [Valenzuela & Reyes 2019]
- The Ground Sample Distance (GSD) depends only on detector level pitch "*p*", satellite altitude "*H*" and instrument focal length "*f*"

$$GSD_{GSD} = \left(\frac{p}{f}\right) H \; [m]$$

- For the Rayleigh Diffraction Limit (RDL), in the case of an unobstructed circular aperture of diameter "D" and an average wavelength "λ" (that we use as 550[μm] in the middle of the green band)

$$GSD_{RDL} = 1.22 \left(\frac{\lambda}{D}\right) H[m]$$

Passive Earth Observation Payloads in VIS and NIR metrics - definitions (cont.)

- The Ground Spot Size (GSS) of the optics is defined as

$$GRD_{GSS} = GSS = \left(\frac{\lambda}{D}\right) H = \frac{GSD_{RDL}}{1.22} \; [m]$$

- The optical factor "Q", which is a fundamental design parameter of an optical sensor is

$$Q = \frac{GSS}{GSD_{GSD}} = \frac{\lambda}{D}\frac{f}{p} \; [m]$$

Passive Earth Observation Payloads in VIS and NIR metrics - results

Satellite	Pixel pitch	satellite altitude	instrument focal length	Ground Sample Distance	Av. wavelength	Diameter	Rayleigh Diffraction Limit	GSD w.rt.t RDL	Ground Spot Size	Optical factor
	p [m]	H [km]	f [m]	GSD_{GSD} [m]	λ [m]	D [m]	GSG_{RDL} [m]	$GSD_{GSD} > GSD_{RDL}$	GRD_{GSS} [m]	Q [-]
$SSOT_{SSO}$	7,40E-06	620	3,2	1,43	5,5E-07	0,20	2,08	no	1,71	1,19
Dove_{SSO}	5,50E-06	600	0,9	3,67	5,5E-07	0,09	4,47	no	3,67	1,00
Dove_{ISS}	5,50E-06	400	0,9	2,44	5,5E-07	0,09	2,98	no	2,44	1,00
$PeruSat1_{SSO}$	1,20E-05	695	12,2	0,68	5,5E-07	0,64	5,18	no	4,25	6,21
1U $\mathrm{CubeSat}_{ISS}$	5,50E-06	400	0,3	7,33	5,5E-07	0,09	2,98	yes	2,44	0,33

Conclusions

- The increasing number of spacecraft deployed has challenged the UN's registration, and requires a different approach as operational constellations.
- An orbital classification for CubeSats in LEO showed two main orbit classes SSO and ISS-like. The latter is attribute to cost effective access to space opportunities
- The altitude and several design performance parameters where estimated and review against specifications, yielding in agreement. Since SSO yields global coverage as a matter of time, the constellations can theoretically map the entire glove, however, the challenge relies on the size of their swath and the ability to download and process the data on time.
- The progress obtained by Planet and other "new actors" is remarkable, as their 4-5 kg spacecraft can perform at GSD 3 to 5, versus 2011 SSOT 140 kg with 1.45 m GSD. This allows for future analysis and conceptual design trade-offs to be performed in the case of future missions in this performance range.

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