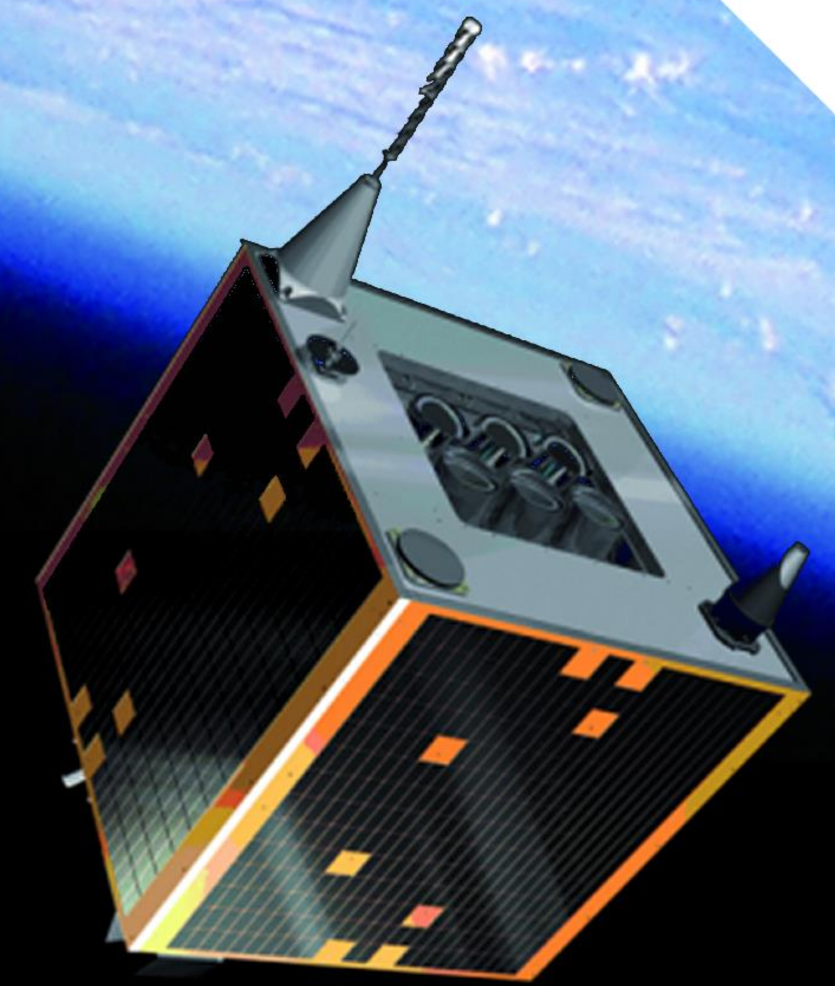
REQUISITOS TÉCNICOS DEL LANZAMIENTO Y OTROS CONTRATOS

Fabrizio Pirondini

Co-fundador Deimos Imaging, Deimos Space, PanGeo Alliance
CEO Deimos Imaging 2011-2018



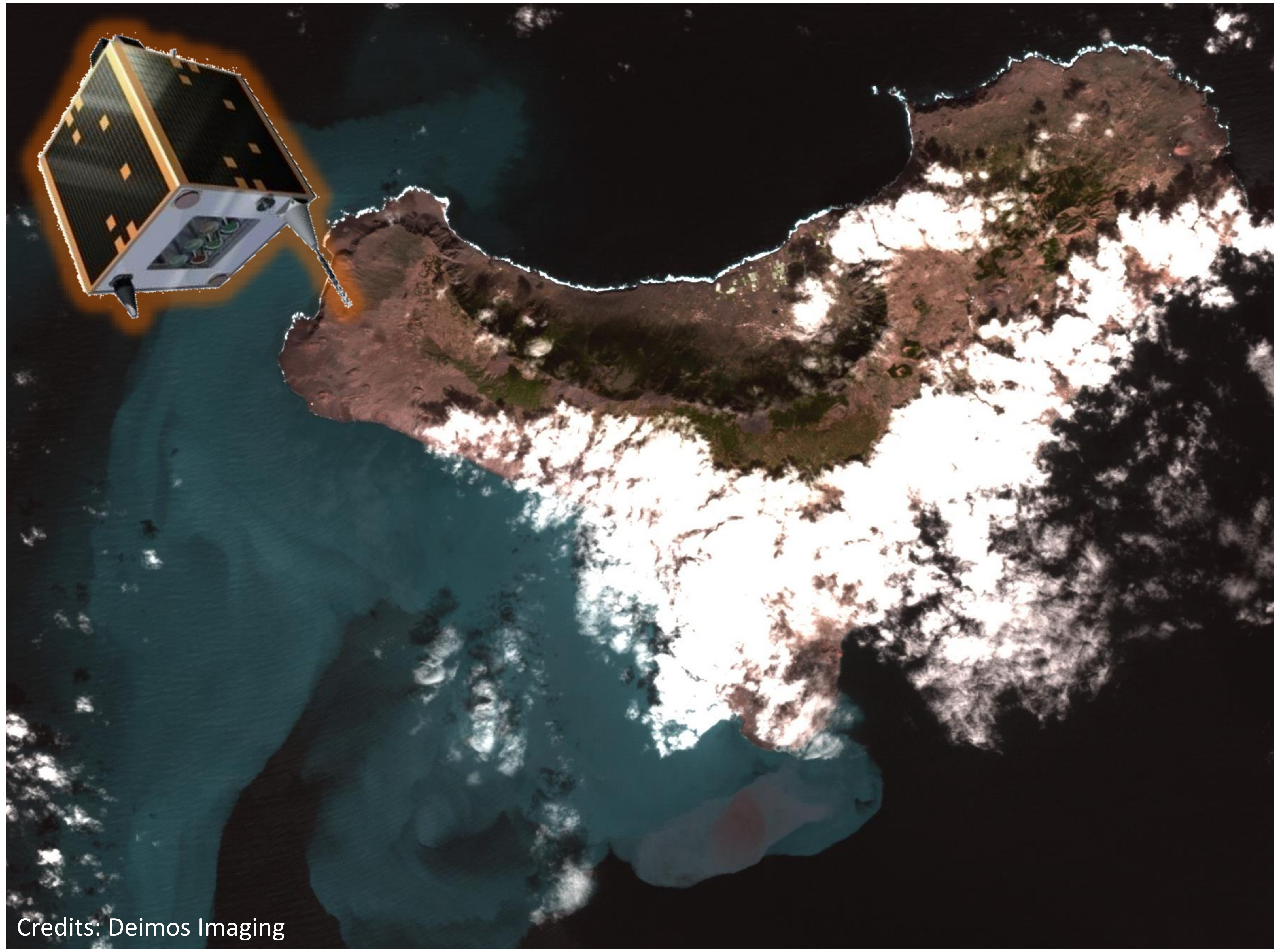
Facultad de Estudios Estadísticos UCM, Madrid - 7 de Febrero de 2019

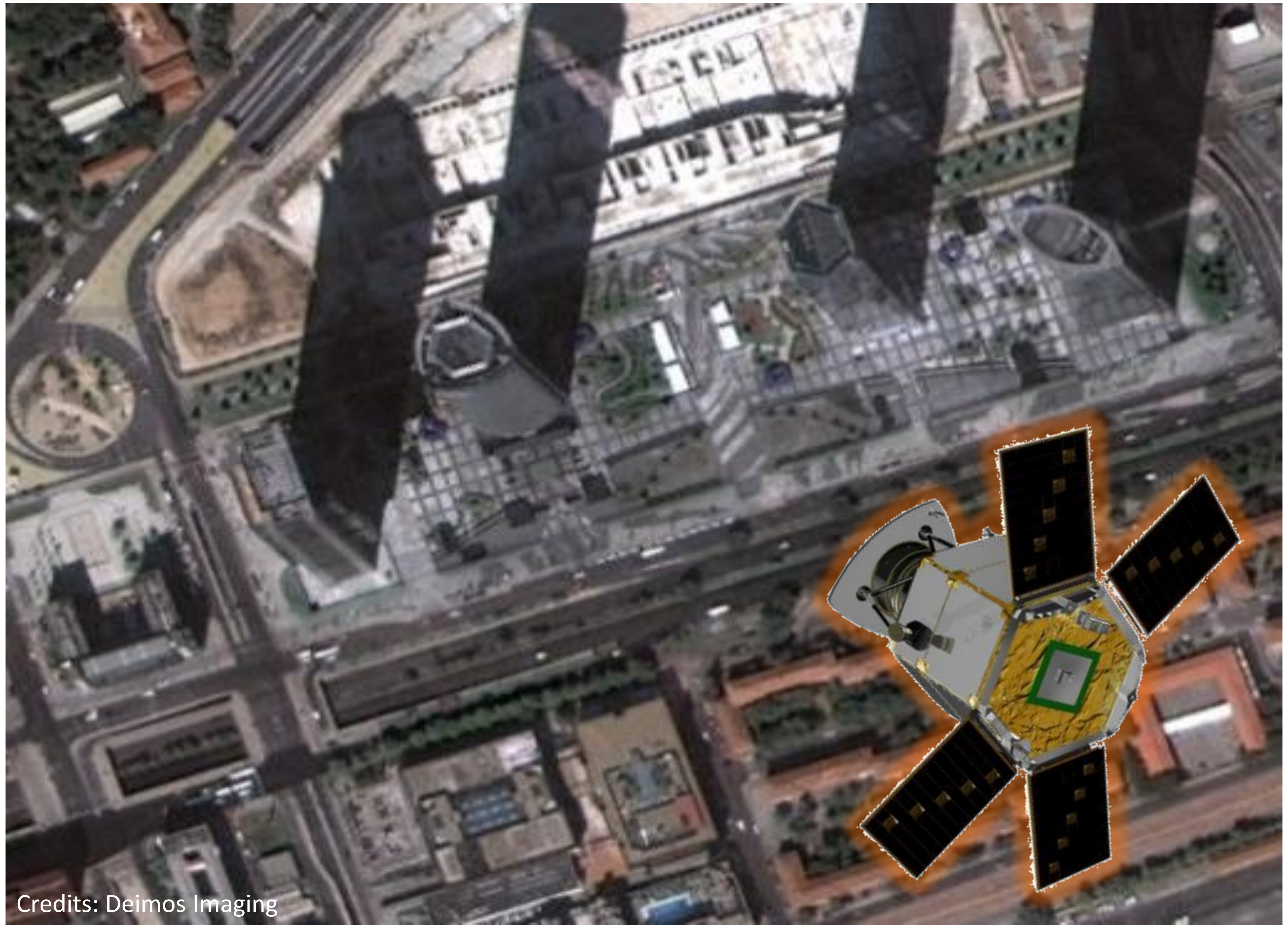
Credits: Deimos Imaging

THE REAL-LIFE EXPERIENCE OF DEIMOS SATELLITES

Credits: Deimos Imaging

DEIMOS-1 & DEIMOS-2: THE FIRST TWO SPANISH SATELLITES FOR EARTH OBSERVATION





DEIMOS-1: THE FIRST SPANISH EO SATELLITE

Owner: Deimos Imaging

Operated: Boecillo (Valladolid)

Launch: July 29, 2009

Rocket: Dnepr (Baikonur, KZ)

Lifetime: 10 years

Mass: 100 kg

Orbit: 650 km (Sun-synch)

Image resolution: 22 m


Credits: Deimos Imaging


Credits: Deimos Imaging

DEIMOS-2: THE BEST PRIVATE EO SATELLITE IN EUROPE

Owner: Deimos Imaging

Operated: Puertollano (Ciudad Real)

Launch: June 19, 2014

Rocket: Dnepr (Yasny, RU)

Lifetime: 10 years

Mass: 300 kg

Orbit: 610 km (Sun-synch)

Image resolution: 75 cm

Credits: Deimos Imaging


Credits: Deimos Imaging

INTERNATIONAL STATE RESPONSIBILITY

Under Article VI of the Outer Space Treaty, states are directly responsible for all their national space activities, whether that activity is conducted by the government itself or by any of its citizens or companies. The direct responsibility of national governments is relatively unique in international law.

Article VI of the Outer Space Treaty reads:

"States Parties to the Treaty shall bear international responsibility for national activities in outer space, including the Moon and other celestial bodies, whether such activities are carried on by governmental agencies or by non-governmental entities, and for assuring that national activities are carried out in conformity with the provisions set forth in the present Treaty."

"The activities of non-governmental entities in outer space […] shall require authorization and continuing supervision by the appropriate State Party to the Treaty."

When space activities cause physical damage on the ground, to aircraft in flight, or to space objects in space, then international responsibility expands to International Liability.

INTERNATIONAL STATE LIABILITY

In international law, liability is a concept related to but altogether distinct from responsibility. Article VII of the Outer Space Treaty establishes the obligation that states launching space objects shall be internationally liable for damage to another State Party to the Treaty or to its natural or juridical persons by such object or its component parts on the Earth, in air space or in outer space.

This obligation to be held liable for resulting damage is necessarily linked with responsibility, but is distinct enough to require close attention. Whereas responsibility, discussed above, is an obligation to ensure that all national activities are carried out in conformity with the Outer Space Treaty**, the liability provision requires that states undertake action towards the compensation of other states should certain damages occur**.

The definition of damage, as contained in the 1972 Liability Convention, is "loss of life, personal injury or other impairment of health; or loss of or damage to property or of persons, natural or juridical, or property of international intergovernmental organizations," and is usually interpreted to mean actual physical damage rather than pecuniary interests or other forms of non-physical damage.

INTERNATIONAL REGISTRATION OF SPACE OBJECTS

Along with international responsibility for national activities, and potential international liability for damage caused to other states, registration is an obligation placed upon states for their space activities.

On behalf of the Secretary-General, the United Nations Office for Outer Space Affairs (OOSA) is the keeper of this international registry.

UNITED NATIONS
Office for Outer Space Affairs

NATIONAL REGISTRATION OF SPACE OBJECTS

Article VIII of the Outer Space Treaty does not address international registration.

Rather, it discusses national registration, stating that a State Party to the Treaty on whose registry an object launched into outer space is carried shall retain jurisdiction and control over such object, and over any personnel thereof, while in outer space or on a celestial body.

In an area where state sovereignty is absent, the effect of this article is to provide a crucial component of state sovereignty, namely **jurisdiction**.

The right of a state to exercise jurisdiction over space objects depends upon that state listing its launched objects on a national registry.

Currently, over 30 states have national space registries.

REGISTRATION OF SPACE OBJECTS IN SPAIN

National regulatory framework for space activities:

Royal Decree 278/1995, dated 24th February 1995, establishing in the Kingdom of Spain the Registry foreseen in the Convention adopted by the United Nations General Assembly on 2 November 1974.

Space-related norms deal with (quasi-)territorial and personal jurisdiction over launches carried out from Spain or Spanish facilities, and establish a national register of objects launched into outer space, which is maintained by the Ministry of Foreign Affairs, specifically:

Ministerio de Asuntos Exteriores y de Cooperación

Subdirección General de Relaciones Económicas Multilaterales y de Cooperación Aérea, Marítima y Terrestre

Dirección General de Relaciones Económicas Internacionales

INDEX OF OBJECTS LAUNCHED INTO OUTER SPACE

	International Designator	Name	State/Organization	Date of Launch	UN Registered	Status	Function of Space Object
24	2018-111AJ	LUME-1	(for Spain)	27/12/2018	No	in LEO	------
23	2018-099*	AISTECH SAT 2	(for Spain)	03/12/2018	No	in LEO	------
22	2018-096*	3CAT 1	(for Spain)	29/11/2018	No	in LEO	------
21	2018-023A	HISPASAT 30W-6	(for Spain)	06/03/2018	No	in GSO	------
20	2018-020A	PAZ	(for Spain)	22/02/2018	No	in LEO	------
19	2017-053A	AMAZONAS 5	(for Spain)	11/09/2017	No	in GSO	------
18	2017-006A	HISPASAT 36W-1	Spain	28/01/2017	Yes	in GSO	------
17	2014-033D	DEIMOS 2	Spain	19/06/2014	Yes	in LEO	Earth observation
16	2014-011A	AMAZONAS 4A	(for Spain)	22/03/2014	No	in GSO	------
15	2013-066T	HUMSAT D	(for Spain)	21/11/2013	No	in LEO	------
14	2013-066E	OPTOS	(for Spain)	21/11/2013	No	in LEO	------
13	2012-006F	XATCOBEO	(for Spain)	13/02/2012	No	decayed	------
12	2010-070A	HISPASAT 1E	(for Spain)	29/12/2010	No	in GSO	------
11	2009-041E	NANOSAT 1B	(for Spain)	29/07/2009	No	in LEO	------
10	2009-041A	DEIMOS 1	Spain	29/07/2009	Yes	in LEO	Earth observation
9	2006-007A	SPAINSAT	(for Spain)	11/03/2006	No	in GSO	------
8	2004-049B	NANOSAT 1	Spain	18/12/2004	Yes	in LEO	Scientific research and tech demonstration
7	2002-044A	HISPASAT 1D	Spain	18/09/2002	Yes	in GSO	Telecommunications service
6	2000-007A	HISPASAT 1C	Spain	03/02/2000	Yes	in GSO	Telecommunications service
5	1997-018A	MINISAT 01	Spain	21/04/1997	Yes	decayed	Scientific research and tech demonstration
4	1995-033C	UPMSAT 1	Spain	07/07/1995	Yes	in LEO	Scientific and communication satellite
3	1993-048A	HISPASAT 1B	Spain	22/07/1993	Yes	in graveyard GSO	Telecommunications
2	1992-060A	HISPASAT 1A	Spain	10/09/1992	Yes	in GSO	Telecommunications
1	1974-089C	INTASAT	Spain	15/11/1974	Yes	in LEO	Verification of space technology

UNITED NATIONS
Office for Outer Space Affairs

24 satellites are listed for Spain, even if only 11 are registered in the UN Register.

In the last 15 years, DEIMOS-1 & DEIMOS-2 are the only Spanish satellites in Low-Earth Orbit (LEO) which have been registered in the UN and Spanish National registries.

A KEY PROCESS, BUT TRICKY FOR LEO SATELLITES

Registering into the UN Register is of key importance for private companies, since it is the only way to assure that Spanish jurisdiction applies to its operations.

19/6/2014: Launch of DEIMOS-2.

1/8/2014: Official request to inscribe DEIMOS-2 in the Spanish Register of Objects Launched into Outer Space ("Spanish Register").

21/11/2017: DEIMOS-2 is inscribed in the Spanish Register.

29/12/2017: DEIMOS-2 is inscribed in the UN Register of Objects Launched into Outer Space ("UN Register").

Why a 3-year delay? …and how to avoid it.

MINISTRY REQUIREMENTS

The Spanish Ministry of Foreign Affairs wanted to minimize its liability:

- **Inspect facilities to assure operations comply with Space Debris guidelines**

  Not a problem: Deimos Imaging monitors daily the risk of collision with space debris in cooperation with US Strategic Command, and implements corrective manoeuvres if needed.

- **Cover in-orbit damages (through in-orbit insurance)**

  Not a problem: in-orbit insurance is part of the nominal operations of Deimos Imaging.

- **Cover re-entry damages (through re-entry insurance)** – ONLY FOR LOW-ORBIT (LEO) SATELLITES

  Very tricky. Let’s see why.

END OF LIFE – RE-ENTRY RISK ANALYSIS

Credits: ESA-D. Ducros

END OF LIFE

As satellites reach their end of life and cessation of operations, it is important for satellite operators to dispose of satellites properly.

Highly used and important regions of orbit are already congested, in large part due to satellites or rocket stages that have been left in those active regions.

Increasingly, there are national regulatory obligations, contractual obligations, guarantees, and other responsibilities that need to be met during the end-of-life phase of a space mission.

It is important to properly dispose of satellites and launch vehicles at the end of useable life. Satellites that are not properly disposed of have a chance of interfering with operating satellites and possibly generating additional debris in orbits that are useful and commonly used.

ORBITAL DEBRIS LIMITATION DOCUMENTS

To minimize this risk, the Inter-Agency Space Debris Coordination Committee (IADC), an international governmental forum of experts, has created guidelines for mission developers to use when planning proper disposal of spacecraft.

In addition, 13 nations are participating in an effort organized within the ISO to develop space systems disposal standards.

International Orbital Debris Limitation Documents

Entity	Document
IADC	IADC-02-01, Rev 1
ISO	ISO 26872, ISO 16699, ISO 16164
USA	US Government Orbital Debris Mitigation Standard Practices
NASA	NPR 8715.6A, NASA-STD-8719.14
Department of Defense (DoD)	DoD Space Policy Directive, 3100.10, AFI 91-217
FAA	Title 14, Code of Federal Regulations (CFR) Part 415.39
JAXA	JAXA JMR-003
CNES	MPM-50-00-12
European Space Agency (ESA)	European Code of Conduct for Space Debris Mitigation
Roscosmos	Space Technology Items General Requirements on Mitigation of Space Debris Population

ORBITAL DEBRIS LIMITATION GUIDELINES

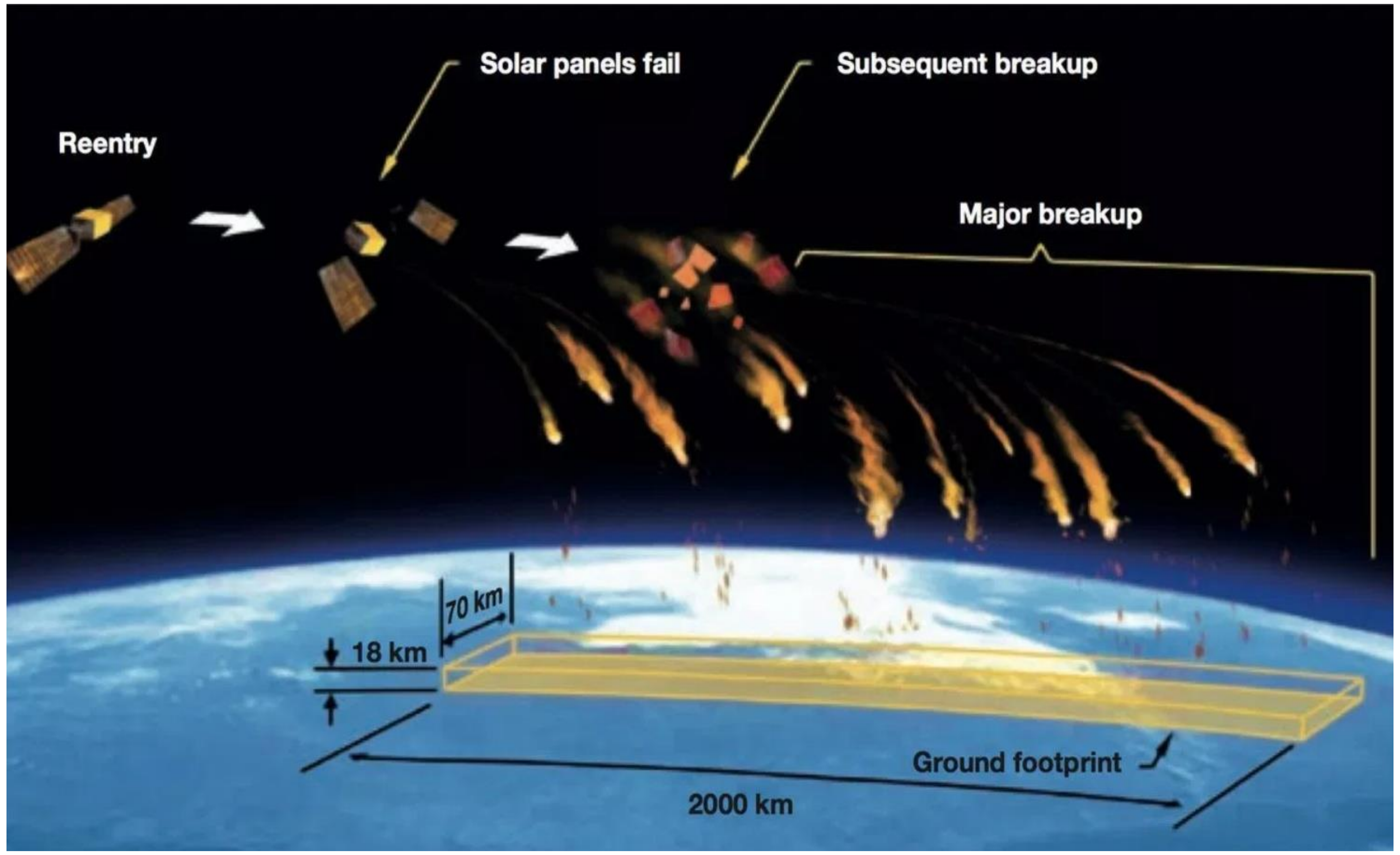
ATV-1 re-entry. Credits: ESA

End-of-Life Disposal Actions

Disposal Action	Subsynchronous GTO	Supersynchronous GTO	MEO Navigation Satellite Orbits	Molniya
25-Year Decay	Lower perigee to ~ 200 km	Initial perigee ~ 200 km	Not recommended due to large Delta-V (DV) or change in velocity required	Not studied, but lowering perigee would require least DV
Disposal Orbit	Between 2500 km and GEO-500 km. Launch Vehicle Upper Stages should reach GEO-500 km in less than 25 years.	Not recommended	TBC: 1. Minimum long-term perigee of 2000 km, apogee below MEO. 2. Perigee 500 km above MEO or nearby operational region and e < 0.003; RAAN and argument of perigee selected for stability	Set initial perigee of disposal orbit at 3000 km
Direct Reentry	Broad ocean area impact or other safe zone	Not studied, but similar to Sub-synchronous GTO case	Not recommended due to large DV required	Broad ocean area impact or other safe zone

ATMOSPHERIC RE-ENTRY

During re-entry, friction and compression generate immense heat as a satellite traveling at 30,000 kilometers per hour enters the atmosphere. That tremendous heat can melt and vaporize the entire spacecraft. However, if a satellite component's melting temperature is not reached during re-entry then that object can survive re-entry and impact the ground. In addition to heat and pressure, a spacecraft experiences immense loads as it decelerates. These loads, which can exceed 10 Gs, or ten times the acceleration of gravity at the Earth's surface, coupled with the immense heat, cause a spacecraft's structure to break apart.



The broken-up components will continue to decelerate and, depending on the density of the atmosphere in the region of re-entry, may reach a low ground speed, virtually falling straight down from the sky. The broken-up spacecraft should impact the ground at relatively low speeds, but it still presents a hazard to people and property on the ground and **the satellite operator will be liable for damages caused by the debris.**

ATMOSPHERIC RE-ENTRY AND RISK ASSESSMENT

Spacecraft designers must consider what will happen to a spacecraft at the end of its lifespan.

For satellites operating in LEO, it is likely that atmospheric drag will eventually cause a spacecraft to re-enter Earth's atmosphere. As satellites re-enter, they disintegrate, but some debris may survive the heat of reentry and could impact the ground and cause casualties. Unfortunately, it is very difficult to predict specifically where debris will impact as the density of the Earth's atmosphere is constantly changing.

It is recommended that satellite operators design spacecraft that will completely burn up during re-entry.

If debris is expected to survive re-entry and cause an <u>unacceptable</u> risk of casualties, it is necessary for operators to conduct a controlled re-entry that will spread debris over uninhabited areas of Earth's surface.

RE-ENTRY THREAT STATISTICS

While the impact threat to human life and property from re-entry debris is serious, it is interesting to note that only one person has ever claimed to have been struck by falling space debris, and that person was hit by a lightweight object and was not injured. Over the last 50 years, more than 5,000 metric tons of material are believed to have survived re-entry, but no casualties from the debris have been reported. It has even been calculated that the risk that an individual will be struck by re-entered debris is less than 1 in 1 trillion.

Stainless steel tank (250kg)

Titanium pressure tank (30kg)

Motor thrust chamber

DEFINING RE-ENTRY RISK (1)

There is no legal international definition of "unacceptable safety risk" for reentry.

The United Nations space debris mitigation guidelines leave the definition of acceptable risk to national authorities, but the IADC identifies two guidelines (which are accepted by the Spanish Ministry):

First, to minimize the accumulation of orbital debris, it recommends satellite missions leave a satellite in an orbit that will result in **re-entry within 25 years**.

About 80 percent of rocket upper-stages currently comply with the rule, while only 60 percent of satellites are designed to lower their orbits to re-enter within 25 years. While compliance is not perfect, most major spacefaring nations support the 25-year rule and are taking steps to improve compliance.

DEFINING RE-ENTRY RISK (2)

In addition to the 25-year rule, the IADC recommends that **if a satellite has a 1 in 10,000 chance (10^{-4}) of surviving re-entry and causing a casualty, its re-entry must be controlled**.

For a piece of debris that survives atmospheric re-entry, the debris casualty area is the average debris cross-sectional area plus a factor for the cross-section of a standing individual. The total debris casualty area for a re-entry event is the sum of the debris casualty areas for all debris pieces that survive atmospheric re-entry. The total human casualty expectation is equal to the total casualty debris area times the average population density for the particular orbit.

A variety of models exist to calculate the likelihood that specific pieces of a satellite will survive re-entry, including NASA's Debris Assessment Software or its higher-fidelity Object Re-entry Survival Analysis Tool, and various ESA tools.

CONCLUSIONS: THE CASE OF DEIMOS-2

Credits: University of Surrey

THE CASE OF DEIMOS-2

A re-entry insurance would be extremely difficult to contract in the case of Deimos-2.

- **Re-entry is predicted in 2060, but surely will not happen before 2050.**
  How to insure now for something that will surely not happen in the next 30 years?

- **Impossible to perform a controlled re-entry.**
  Not enough fuel on-board (controlled re-entry is a very costly manoeuvre with huge implications on system design, launch mass and therefore overall mission costs).

- **Impossible to re-design the satellite.**
  Satellite is already flying.

AGREEMENT WITH THE FOREIGN MINISTRY

Solution proposed by the CDTI (Aerospace Programmes Department) and accepted by the Ministry:

“if an independent risk report prepared by the European Space Agency (ESA) confirms that there is no “unacceptable safety risk” for DEIMOS-2 re-entry (i.e. if the satellite has less than a 1 in 10,000 chance of surviving re-entry and causing a casualty) the Ministry will proceed with the register without a dedicated re-entry insurance policy.”

INDEPENDENT ASSESSMENT BY ESA

Independent assessment performed by ESA of the DEIMOS-2 satellite re-entry casualty risk

Location: ESA-ESTEC

Technical coordinator: Product Assurance & Safety Department ("TEC-Q")

Cost: ~20 k€

Duration: Less than 1 month

Output: Re-entry casualty risk report

The analysis predicts that 5 elements (made of the most resistant materials like titanium, glass ceramics and tungsten) will not be completely destroyed in the re-entry. The combined mass to ground is around 2 kg.

Conclusions of the ESA report:

"The analysis results in an estimated casualty risk of 8.4x10^{-5} at the time of expected re-entry in 2060. The DEIMOS-2 spacecraft is therefore compliant with the ESA requirement for casualty risk not to exceed the 10^{-4} value."

APPROACH FOR FUTURE MISSIONS: DESIGN FOR DEMISE

Design for Demise is a method of satellite design with the goal of ensuring each component of a satellite will be completely destroyed during the heat of reentry. By designing for demise, satellite operators can avoid having to conduct a controlled re-entry, which can lengthen the mission lifespan, lower the cost of development, and reduce the mission ground-support costs.

"Design for Demise" is a great approach for ensuring compliance with the 1 in 10,000 risk threshold.

The International Organization for Standardization (ISO) is developing standards (ISO 27875:2010) that can be applied at the planning, design, and review stages of satellite development to assess, reduce, and control the potential risk that spacecraft and launch-vehicle orbital stage pose during re-entry.

LESSONS LEARNED

For a private satellite which wants to be under Spanish jurisdiction:

- **Apply Design for Demise techniques.**

  From the very beginning of the design cycle.

  Pay special attention to Export Licenses and ITAR issues while defining satellite components.

- **Obtain a re-entry casualty risk report from ESA as soon as possible.**

  Clearly before launch: if the risk is too high and there is not enough fuel for a controlled re-entry (which is almost always the case), then the Ministry will not proceed with the Register, unless a dedicated re-entry insurance is obtained (which may turn out to be very complex).

  That could impact, e.g., the applicable Remote Sensing Licensing, which depends on jurisdiction.

THANKS !!

Fabrizio Pirondini

fabrizio.pirondini@gmail.com

Main References:

Secure World Foundation, "Handbook for New Actors in Space", 2017

European Space Agency, "ESA Space Debris Mitigation Compliant Verification Guidelines", 2015