PROBA-3: Belgian-made breakthrough in satellite formation flying and understanding the Sun

On December 4 2024, the two PROBA-3 satellites was launched into space from the eastern Indian coast. It marks the end of a very complex development that started 21 years earlier, mainly in Belgium and Spain. During the next two to three years, the two satellites will demonstrate precise formation flying, and at the same time observe unexplored regions of the solar corona with unprecedented precision.

During the nineties of the previous century, a small company near Antwerp started for the first time to work on the development of a Belgian-made satellite in the context of the ESA technology programmes. It was called PROBA (Project for On-Board Autonomy) and contained a highly innovative avionics system controlled by a powerful new type of on-board computer, and a new generation of on-board software. Launched in 2001, it is still functioning and is the longest surviving ESA satellite, thereby convincingly proving its exceptional reliability. The first one having been baptised PROBA-1, PROBA-2 followed in 2009 and PROBA-V followed in 2013, and both are also still operational today.

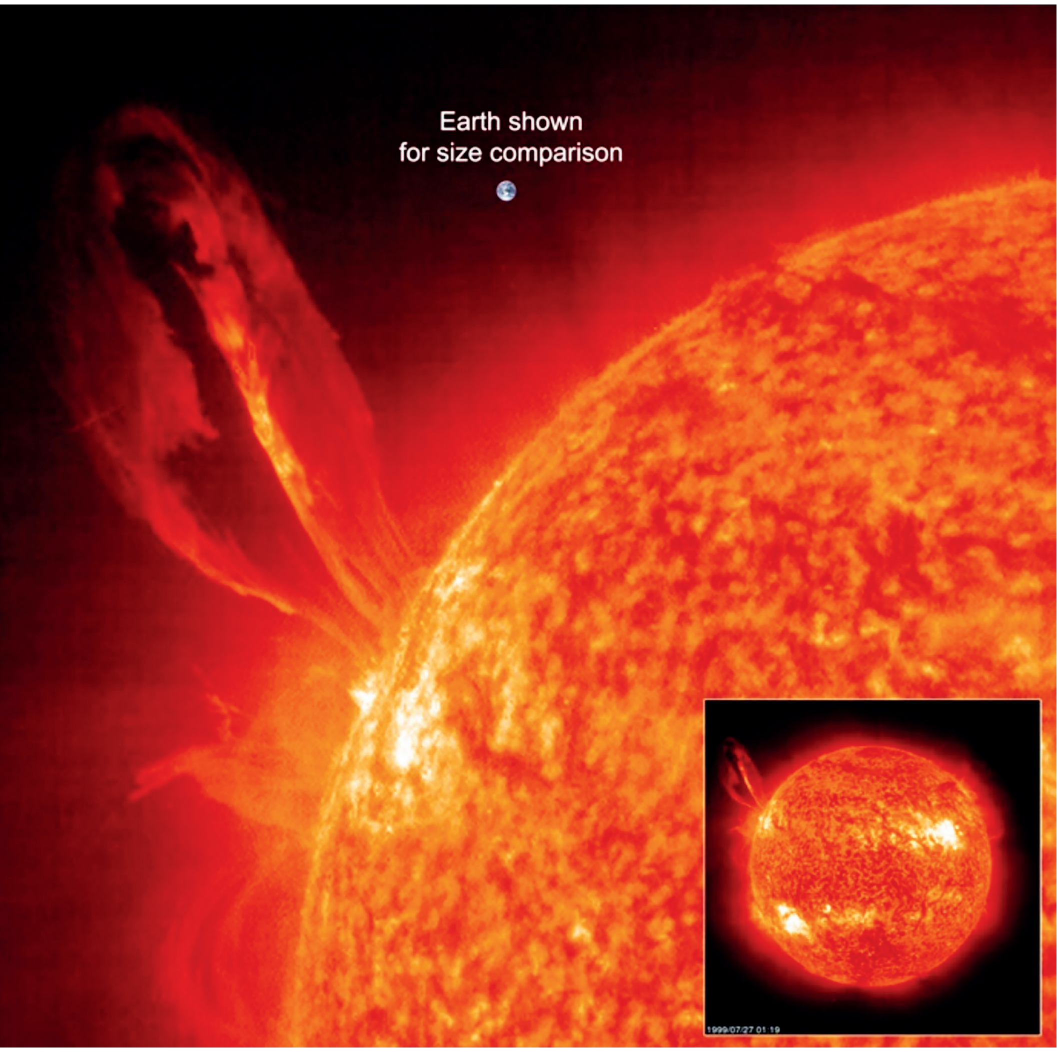
Shortly after the initial success of the first PROBA satellite in orbit, the idea emerged to develop a new double PROBA satellite aimed at demonstrating precise formation flying in space. The potential applications of formation flying are numerous, ranging from satellite in-orbit servicing to precise gravitational measurements and to telescopes with large focal length. But the realisation of another promising application provided a breakthrough in defining the PROBA-3 concept: if one satellite could block the bright light coming from the solar disc, a second one at some large and precisely controlled distance away can observe the solar corona down to much closer distances to the solar disc than can be done with a single and therefore much shorter telescope. The reason is that avoiding straylight caused by diffraction off the occulter's edges is paramount during observations because the corona is so faint. And the further away the occulter is from the coronagraph that measures the light, the less straylight reaches the instrument. A large distance between the occulter and the observer thus minimises straylight, allowing the scientists to obtain more precise measurements and observe closer to the solar disc where all the disturbing light comes from.

Why is it important to observe the solar corona? Because the corona of the Sun is a very intriguing place which interests us from two perspectives. First, while the temperature of the solar disc is 'only' 5800°C, the corona is heated up to a few million degrees. We know it extends a few million kilometres in outer space and that it is composed of a thin plasma of material ejected from the Sun. However, we don't know which mechanism causes the coronal heating, except that magnetic fields must play a role and that the heating happens in the inner corona, close to the solar disc. We also know that the acceleration of the solar wind, which fills the entire Solar System, originates in the corona, but the exact physics behind this process remains unclear. In summary, studying the inner corona is crucial for understanding how our Sun works.

The second reason why the corona is so important is related to our own safety on Earth. The inner corona is where solar eruptions occur, ejecting radiation and energetic particles that regularly reach the Earth's atmosphere. Scientists call this phenomenon 'Space Weather' and it poses a threat to sensitive technologies in space, astronauts' safety, navigation and telecommunication accuracy, power grid operations, etc. To protect ourselves from these dangers, we need to be able to predict these eruptions as early as possible and since they originate in the inner corona, it is there that we must point our telescopes.

The PROBA-3 concept is therefore an ideal tool to learn more about how our Sun works and to predict Space Weather phenomena more timely. Additionally, it allows ESA to demonstrate its expertise in precise formation flying technologies. And the latter is not an easy job. The two satellites will be at a distance of 150 metres from each other, and their relative position needs to be maintained in longitudinal and lateral directions with an accuracy of a few millimetres. To achieve this, PROBA-3 is equipped with a laser and a shadow metrology system with mm accuracy, as well as a high precision propulsion system capable of rapidly and precisely correcting the unavoidable drift of both spacecrafts as they orbit Earth. All this must be controlled in real time by a powerful on-board computer and associated efficient software. If all goes well, the launcher rocket will place PROBA-3 in a highly elliptical orbit, ranging from 600 to 60000 kilometres distance from Earth, and with a period of almost 20 hours. Formation flying will only take place during the furthest distances from Earth where the disturbing gravity gradient is smallest. Both spacecrafts will autonomously acquire their formation flying positions every 20 hours and maintain it during 6 hours.

The PROBA-3 satellites are of the 'minisat' type, with a rectangular shape measuring about 2 metres in diameter and each satellite weights about 250 kilograms. The development of PROBA-3 was in the hands of a consortium of companies, led by the Spanish company SENER. Key contributions to the platforms came from the Belgian companies Redwire Space and SPACEBEL and from the Spanish companies Airbus and GMV. The coronagraph instrument (called ASPIICS) is a purely Belgian endeavour, built by an industrial consortium led by the Centre Spatial de Liège (CSL) and scientifically led by the Royal Observatory of Belgium (ROB). The latter will also be responsible for the science operations during the two years nominal lifetime of the mission. The Mission Operations Centre is located in the ESA site of ESEC (European Space Security and Education Centre) in Redu in Belgium, specialised in the operations of small satellites.



In addition to the main coronagraph, PROBA-3 also embarks two additional scientific instruments. The first is 3DEES (3-Dimensional Energetic Electron Spectrometer) which will measure the amount of energetic particles and their incoming direction as they are ejected by the Sun and arriving in our neighbourhood. It was designed by researchers of the University of Louvain-la-Neuve and built by Redwire Space together with the Belgian Institute for Space Aeronomy in Uccle. The second instrument is DARA (Davos Absolute Radiometer). It will continuously measure the total amount of energy from the Sun reaching the Earth, also known as the 'total solar irradiance'. This quantity, and especially its variation in time, is an essential ingredient in climate studies. The instrument was designed and built in Switzerland but Belgian researchers from the Royal Meteorological Institute will also have access to the data.

This is in a nutshell the exciting PROBA-3 story, but nothing comes for free. The total cost of PROBA-3 amounts to 166 million euro, of which Belgium paid 63.4 million. This budget, as well as the PROBA-3 administrative management at Belgian level, was provided by the Federal Science Policy Office (BELSPO), and was implemented through two ESA Programmes: GSTP (General Support Technology Programme) and PRODEX (Programme for the Development of Scientific Experiments). Going to space is not cheap, but once you are there, the laboratory you have access to is unique and allows breakthroughs in science and technology that can never be achieved from the Earth's surface. Go PROBA-3!