→ AUTOMATED TRANSFER VEHICLE

A story of European success and cooperation

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As ESA's Automated Transfer Vehicle (ATV) reaches orbit for the fifth and last time, a new path beyond low Earth orbit is opening for Europe.

Nearly three decades after the first concept studies, the European ATV spacecraft leaves behind a whole set of flawless missions, a vast industrial knowhow and a team spirit like no other. And it does so with a ticket to ride beyond low Earth orbit by the end of this decade.

When it all started, only about half a dozen people were part of the production team. Nico Dettmann, Head of ESA's ATV Programme, remembers the time when he was trying to recruit experienced engineers. It was not an easy task – being used to do something different every day, those engineers thought that working on recurring missions would be a boring business.

"Today, there isn't a single one of them who would say that ATV production is a tiresome job. None of the different spacecraft production phases has looked like the previous one," says Dettmann.

Building Europe's most reliable and complex spacecraft has been a constant challenge. ESA and European industry

→ The birth of the ATV programme

European industry, under ESA's leadership, had conducted concept and system studies for an automated supply spacecraft from 1987. In the early 1990s, ESA started joint studies with NASA, and then with the Russians, to define supply missions to the International Space Station.

Europe's formal approval for full development of an 'Automated Transfer Vehicle', or ATV, came in 1995. With ATV, ESA gained the right to visit the Space Station with its own space transportation systems. Independent access to the orbital outpost is an important political and operational aspect. This spacecraft is Europe's way of contributing in kind towards its share of the operational costs of the Space Station.

teams have been working together to ensure ATVs were ready for the space endeavour. The programme has built important engineering capabilities for orbital spacecraft, from extremely accurate autonomous docking to free-flight operations.

Since its first voyage in 2008, the Automated Transfer Vehicle has played a vital role in International Space Station logistics: it serves as cargo carrier, 'space tug' and storage facility. The multitasking spacecraft contributes to keeping the Station and its permanent crew of six working at full capacity.

Frequent flyer

The maiden flight of ATV *Jules Verne* in 2008 marked the first rendezvous and docking by a European spacecraft in a resupply mission to the International Space Station. Since then, continuous improvements have been made.

Following that first mission, post-flight analysis came up with 130 technical recommendations and about 30 of them were incorporated into the design of following ATVs. ATV teams repeat this exercise for every mission and agree on corrections and work-around solutions, making every spacecraft slightly different.

The challenge was to upgrade the spacecraft in every mission and yet deal with an ever-changing cargo manifest. Time adds extra pressure, pushing European production and integration chains to work at full capacity.

"None of the ATV missions has been easy. We are launching on a commercial launcher, so we have less flexibility in setting the launch date. That makes it more challenging for us to dock to the Station on time," explains Nico Dettmann.

The second ATV, *Johannes Kepler*, was the first production unit. "The mission was the most difficult of the series. We had to master the transition towards recurrent production, and it was also the first ATV fully loaded with a very challenging manifest," recalls Dettmann.

From a one-of-a-kind spacecraft, the ATV became a frequent flyer with a target launch rate of one per year. There is typically half a year from the end of a mission to the launch of the next ATV, and that leaves very little time to implement upgrades to the spacecraft.

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Liftoff of the Ariane 5 ES-ATV launcher from French Guiana on 9 March 2008, carrying ATV *Jules Verne*, ESA's first Automated Transfer Vehicle (ESA/CNES/Arianespace/Optique Video CSG)

A major advantage of this tight rhythm is that communication and efficiency within ATV teams increased exponentially. Engineers working on the hardware did not have to wait long to see it being launched into space. The nature of the ATV programme allowed them to check results and look for possible solutions as they happened.

From electrical failures and a stuck communication antenna boom, to detached thermal blankets and fans that refused to work, each ATV had its own number of small flaws, but these did not jeopardise the missions.

Made in Europe

It is no coincidence that ATVs are named after great European scientists and visionaries. The vessels carry their names to highlight Europe's deep roots in science, technology and culture.

Each spacecraft is the happy conclusion to a complex industrial cooperation that goes beyond agencies, companies and borders. A highly skilled workforce of ESA employees and European industry made the development of the advanced space systems and technology for ATV possible.

Airbus DS is the industrial prime contractor for the production of the vehicle. It manages more than 30 subcontractors and about 2000 people, and integrates all the subsystems coming from ten European countries. Arianespace, the world's first commercial space transportation company, specially developed the Ariane 5 ES launcher for ATV with a reignitable upper stage.

But ATV is not only a European endeavour: the project includes the cooperation of Russian companies, which have built the docking mechanism, the refuelling system and the associated electronics. A number of US companies are also involved with the video targets, lights and propulsion components.

Team spirit

There is nothing like a constant challenge to build a strong team culture. People working on this European spacecraft are extremely committed to it, and most of them would not hesitate to declare it as the best part of their careers.

A great sense of cooperation emanates from all the groups involved in the ATV project. Even with short turnarounds, team spirit opened the door to success for ATV missions. "One of the keys to success is that the ATV people are very committed to it, they totally identify themselves with the mission. It is a wonderful team," says Dettmann.

ATV navigates, flies and docks with the Station automatically, but it does require some ground support.

Throughout its mission, the spacecraft is monitored and commanded from the ATV Control Centre in Toulouse, which works day and night in coordination with the other control centres in Russia and the USA. Every command is run in agreement with the Space Station partners.

Three space agencies with three different engineering cultures. The trilateral nature of this cooperation kept the teams open-minded. The ATV project allowed common approaches to be developed to design, build and control this complex space vehicle.

Mission Manager Alberto Novelli is working on the lessons learned from the programme. "To me the most important one is that we managed to work together in good cooperation, sharing the same goals and enthusiasm. That is the strength of the ATV team. Without it, none of this would have been possible."

↓ ATV *Johannes Kepler* ready for launch inside its fairing on the Ariane 5 ES launcher V200 on 14 February 2011

ATV *Georges Lemaître*

The European spacecraft is ready to start its fifth – and last – voyage to supply the International Space Station. Named after the Belgian astronomer and cosmologist Georges Lemaître, the spacecraft is scheduled to lift-off at the end of July from Kourou, French Guiana, on top of the Ariane 5 heavy-lift launcher.

Following the path of its predecessors, ATV *Georges Lemaître* is ready to fulfil its duty of resupplying the crew with food, water, oxygen, air and research equipment. It will also adjust the Space Station's orbit during its six months attached to the orbital outpost.

The last ATV in the series will carry nearly 6.6 tonnes of supplies to the Station. ATV *Georges Lemaître* will hold a record amount of 2622 kg of dry cargo and, for the first time, the space freighter's three water tanks are fully loaded with 855 litres, more water and dry cargo than any other ATV mission to date.

The spacecraft is delivering critical equipment for science research. Included in its cargo are several units for the Electromagnetic Levitator, a facility that allows the melting and solidifying of metals as they float in weightlessness.

Experience with ATV *Georges Lemaître* could also help develop tools for a rendezvous with a non-cooperative object, such as space debris or an asteroid. The spacecraft will serve as a testbed for a suite of optical-sensor prototypes to home in on targets, based on a long-range infrared camera and a short-range 3D imaging sensor.

↑ The ATV *Georges Lemaître* mission logo

ESA astronaut Alexander Gerst will be the prime operator monitoring ATV *Georges Lemaître* as it approaches the Station, a role that should not give him too much work: the 20-tonne vehicle will navigate on its own and dock automatically. Once attached, ATV will be used as an extra living module by the astronauts and will remain available to reboost the Station, or push it out of the way of space debris if needed.

Swan song

At the end of its mission, the vehicle will undock from the Space Station filled with a few tonnes of wastewater, materials and equipment. By then, it should be ESA astronaut Samantha Cristoforetti who monitors the undocking, during her Futura mission later in 2014.

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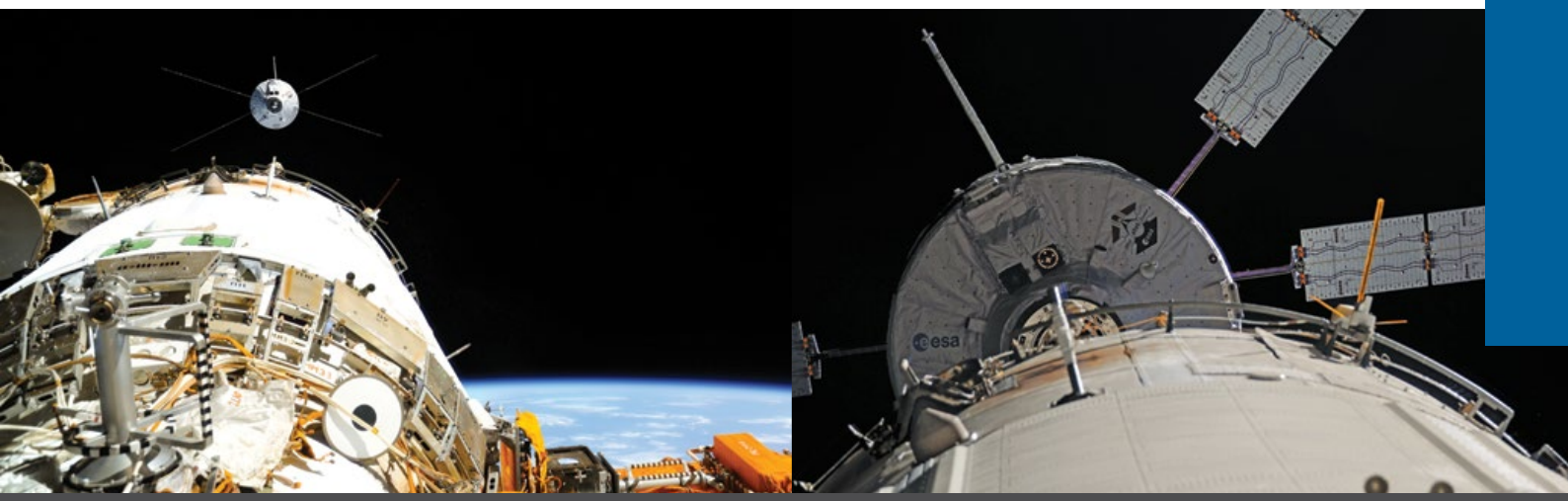
Technicians wearing cleanroom suits pack cargo on ESA's fifth and last Automated Transfer Vehicle, ATV *Georges Lemaître*, in April (ESA/CNES/ Arianespace/Optique Video CSG/P. Baudon)



↑ Views of ATV *Albert Einstein* as it approached the ISS in June 2013 (NASA/ESA)

ATV *Georges Lemaître* will depart with a final gesture before its mission ends. Its 'big dive' will differ from past ATV missions, in that its engines will deorbit the spacecraft on a shallower flight path. This reentry angle will help plan for the Space Station's eventual end of life. While this date is still unknown and some way into the future, engineers are already looking at reentry strategies for the Station.

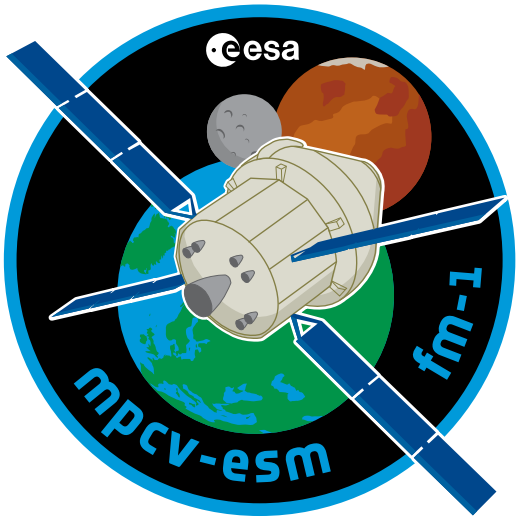
ATV's 'swan song' will be in the spotlight on a moonless night. A camera on the Station will track ATV from above its reentry path. Together with the three onboard experiments and ground-based telescopes also observing ATV's reentry, this will be the most-recorded mission end for a European spacecraft.

The ATV team faces these final moments with mixed feelings. On one hand, there is some sadness to see it coming to an end. "We managed to get each ATV mission done without major hiccups, gaining better precision each year. It feels sad to close the shop now that we are able to manufacture ATVs like the car industry," regrets Daniel Guyomard, Head of ATV Production. On the other hand, there is the pride for the work well done and the memories of 'an exceptional adventure,' as Mission Manager Massimo Cislaghi puts it.

ATV heritage

The duration, assigned resources and technical complexity of the ATV programme have no equal in the history of European spaceflight. Lessons learned from building

← The fiery reentry of ATV *Albert Einstein* in November 2013 (ESA/NASA)



↑ Logo for the European Service Module Flight Model 1, which will fly on NASA's Exploration Mission-1, the first flight of a complete Orion spacecraft

and operating the spacecraft have delivered enormous knowhow. ESA is pursuing the exploitation of this expertise and technology for future spaceflight applications.

"US companies have already benefited from ATV heritage, bringing extra business to European industry" explains Daniel Guyomard. The Cygnus spacecraft, for example, a commercial spacecraft built by the Orbital Sciences Corporation, have used ATV equipment for its missions to the Space Station.

ATV was designed to be flexible, so that it could be the basis for developing a wide variety of new space vehicles. ATV technologies could be used for other automated missions, such as controlling space debris or servicing other spacecraft in orbit. Concepts for ATV evolution had included an unmanned free-flying laboratory, and even a space tug carrying supplies to lunar and martian orbits.

But with the ATV series coming to an end, ESA had to decide between building a sixth spacecraft and developing something new. The decision was the forward-looking choice: ESA started discussing options with NASA about building a new spacecraft together.

European Service Module

ATV will have a second life after completing its resupply role for the International Space Station – a European module will power NASA's Orion spacecraft for Moon missions and beyond. This will be the first collaboration between ESA and NASA on a crew transportation vehicle that will ultimately carry astronauts farther into space than ever before.

"We have shown reliability and excellence with ATV. Our reputation played a vital role in becoming a big partner for a critical part of Orion," says Philippe Deloo, ESA's Phase-B2 Manager of the European Service Module. The Service Module will be heavily based on ATV technology.

The official name of Orion is 'Multi-Purpose Crew Vehicle', because the spacecraft can be used to complete different missions. If everything goes according to plan, the spacecraft will transport up to four astronauts into space and bring them safely back to Earth. Orion will be able to fly to the Moon, and is aimed at visiting an asteroid in the next decade.

The European Service Module will fly on Exploration Mission-1, the first flight of the completed Orion spacecraft. This mission will be an unmanned lunar flyby, returning to Earth's atmosphere at 11 km/s – the fastest reentry ever. The flight is set to take place by the end of this decade.

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NASA's Orion spacecraft will carry astronauts further into space than ever before using a module based on Europe's ATVs (NASA)

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ATV *Albert Einstein*, silhouetted against Earth, departs from the ISS in November 2013 (NASA/ESA)

←

The ATV-derived Service Module, sitting directly below Orion's crew capsule, providing propulsion, power, thermal control, as well as supplying water and gas to the astronauts in the habitable module (NASA)

ATV 2.0

Orion is a delicate spacecraft with demanding functional requirements. The European Service Module will be located directly under its crew module and will feature ATV-derived technologies to provide propulsion and power to the spacecraft as well as oxygen, nitrogen and water for the astronaut crew.

The Service Module will house Orion's main engine, thrusters and fuel needed for orbital transfers, attitude control and high-altitude ascent aborts. All those basic functions and several other components are the same as used on ATV. Extending from the main body of the spacecraft will be ATV's characteristic X-shaped solar wings.

"This is the first time ESA cooperates in such a critical part of a NASA spacecraft. The entire development will take place in Europe after which US engineers will take care of integrating the European Service Module with Orion," says Philippe Deloo.

The main design and the expertise gained throughout a decade of ATV development will be reused for the Orion spacecraft. ESA is implementing new techniques to redefine and qualify the Service Module, and will give support during the missions in case of anomalies.

Providing the Service Module for Orion will be ESA's remaining in-kind contribution to the Space Station partnership. The plan allows European industry to capitalise on ATV technology while significantly cutting research and production costs for NASA. At the same time, the project will create highly skilled jobs for Europeans in an innovative sector ensuring future space endeavours and could see European astronauts flying beyond Earth orbit. ■

One of the images engraved in my mind of the ATV *Albert Einstein* mission is this one: you can see the spacecraft during free flight against the dark background of space with its thrusters firing, heading towards the International Space Station. It might sound trivial to others, but this picture meant a lot to the team. The last time we saw the spacecraft was during the integration in Kourou, French Guiana. Some ten days later, we saw it there, in space!

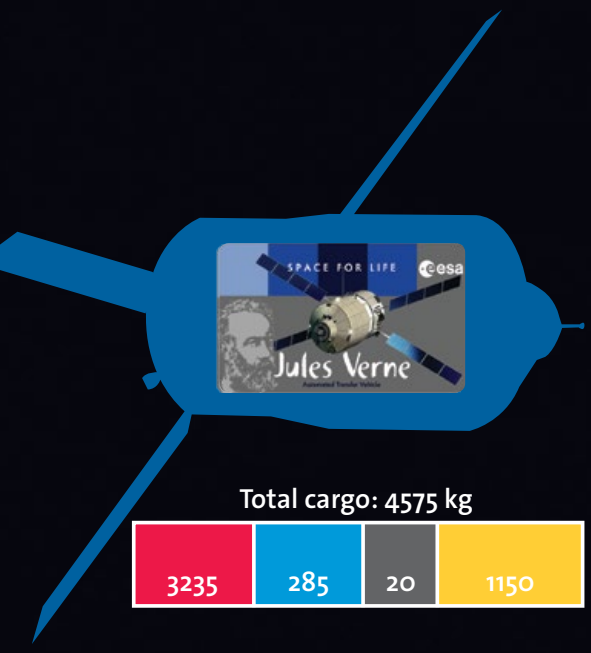
Alberto Novelli

ATV *Albert Einstein* Mission Manager

ATV overview

ATV *Jules Verne*

- 9/03/2008
- 29/09/2008
- 205
- First automated docking of a European vehicle
- 6
- 1

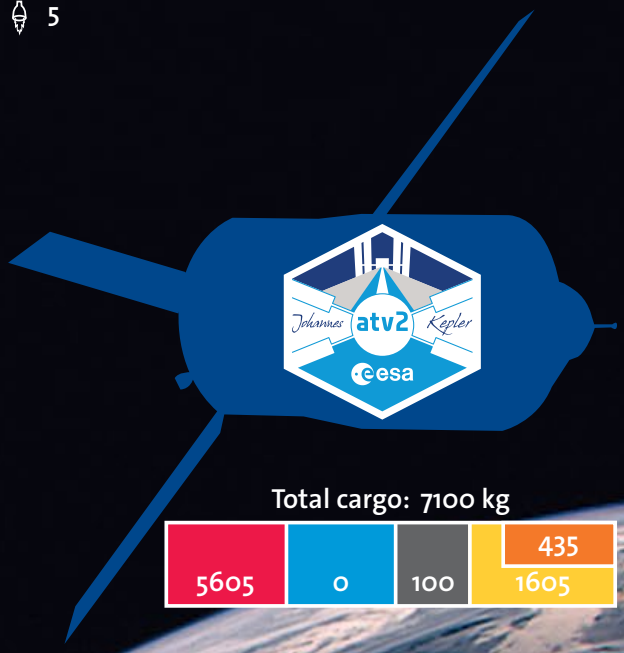


Total cargo: 4575 kg

3235	285	20	1150

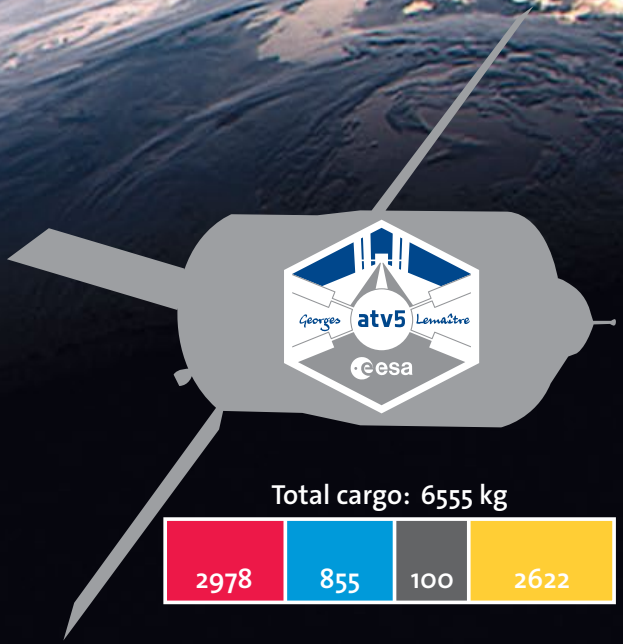
ATV *Johannes Kepler*

- 16/02/2011
- 21/06/2011
- 126
- Largest boost since the Apollo missions to the Moon
  First time a European astronaut welcomed ATV
- Two ESA astronauts in ATV: Paolo Nespoli and Roberto Vittori
- GeoFlow II
- 5



Total cargo: 7100 kg

5605	0	100	1605	435



Total cargo: 6555 kg

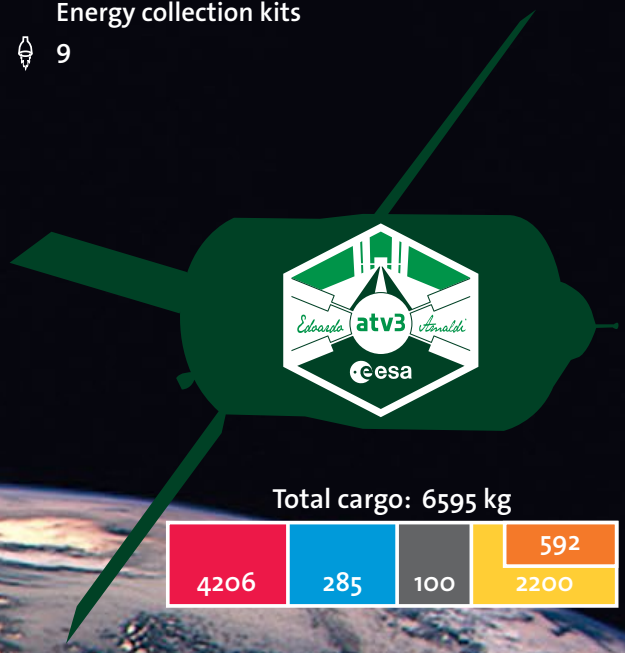
2978	855	100	2622

LEGEND

- Launch
- Deorbit
- Days in Space
- Records
- Cargo anecdote
- Science payload
- Reboosts
- Debris avoidance manoeuvre
- Propellant
- Water
- Gas
- Dry cargo
- Late load cargo

ATV *Edoardo Amaldi*

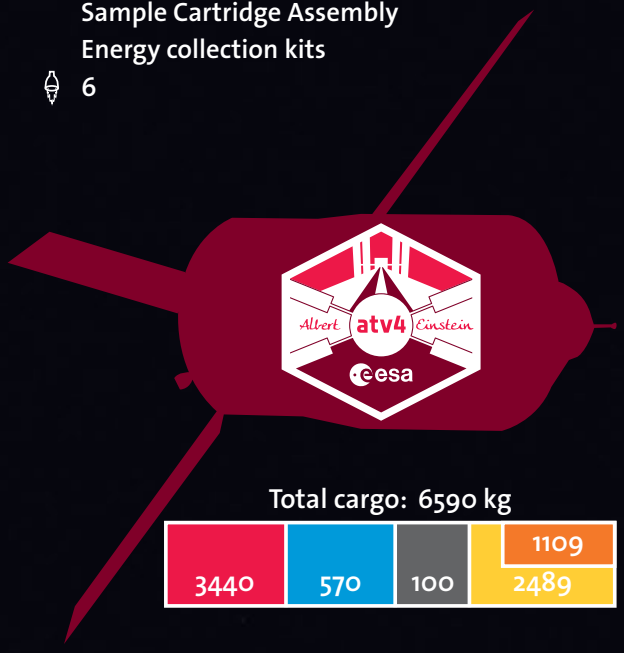
- 23/03/2012
- 04/10/2012
- 196
- Longest attached phase to Space Station: 184 days
- Launched just one year after its predecessor
- Pump to recycle urine into drinkable water
- Tiles for Altea-Shield
- Biolab Life Support Module 3
- Energy collection kits
- 9



Total cargo: 6595 kg

ATV *Albert Einstein*

- 05/06/2013
- 02/11/2013
- 151
- Docked to the Space Station with maximum accuracy
- Reentry seen from space
- 3D-printed toolbox
- FASES sample container
- New microscope for Biolab
- Sample Cartridge Assembly
- Energy collection kits
- 6



Total cargo: 6590 kg

ATV *Georges Lemaître*

- 25/07/2014
- Heaviest spacecraft ever launched by Ariane 5: 20 275 kg
- Includes piece of meteorite 'Field of the Sky'
- Pump to recycle urine into drinkable water
- Shallow reentry experiments (REBR-W , I-Ball, BUC)
- Electromagnetic levitator
- Rendezvous demonstrator