Scientists smash atomic particles to discover secrets of the beginnings of the universe. They fuse the nuclei of atoms in an attempt to re-create the conditions that enflame the sun and furnish it with limitless energy. Researchers build telescopes here on Earth and send satellites out into space in search of a deeper understanding of our planet, our galaxy, and the cosmos beyond. Behind these massive scientific undertakings stand hundreds of companies around the world that strive to meet the needs—and dreams—of the scientific community.

Spanish companies participate in contracts for major scientific installations that are worth more than 420 million euros a year. Manuel Serrano heads the scientific program of Spain’s Center for the Development of Industrial Technology, an agency tasked with financing research projects and assisting Spanish companies to reach international markets. “We’re always working with companies to innovate, so that instruments for scientific teams will be the ultimate, the most advanced products,” says Serrano.

These advances, he adds, can extend beyond the project itself: “The development of technology for scientific installations has a very interesting component, that these technologies can also be adapted for consumer products in the future.”
EXERCISING WITHOUT GRAVITY

Every time astronauts launch into space, their muscles start to deteriorate. “When we’re on Earth, we exercise all day. Just standing up is a form of exercise, because we’re supporting our body with muscle groups,” says Jordi Duatis, Muscular Atrophy Research and Exercise System (MARES) payload engineering manager with NTE-Sener. “But when you’re in microgravity, you’re not doing any exercise. You’re continuously losing muscle mass.”

Astronauts currently exercise about two and a half hours a day while traveling beyond our atmosphere. Scientists wanted more detailed information on exactly what happens to their muscles in microgravity, and whether their exercises are the best to keep them fit. The precursor of MARES, a small system that tests only the ankle and elbow joints, couldn’t fill in the gaps about a whole range of muscle groups.

To delve into these questions, and to help devise a plan to maximize astronaut fitness, the European Space Agency (ESA) began the MARES project together with NASA, using NASA’s Human Research Facility, NTE-Sener, which won the contract for the system, began developing the concept about fifteen years ago.

Working in close coordination with ESA and with the astronauts themselves, NTE engineers created a tool with more than 100 different mechanical elements that can be combined in different configurations to isolate 11 different muscle groups and test them against specific forces and in various modes of muscle contraction.

The astronauts strap themselves into an adjustable chair that includes levers, connectors, pads, and handgrips. “It’s like a contest between you and the machine,” says Duatis. All the information from the tests is fed to a laptop.

Astronauts visited the Barcelona test facility throughout the development of MARES to try it out, from the beginning of the design phase through the final product: it is up to the astronauts to assemble the system in space. MARES was launched in April 2010 inside a logistics module to the International Space Station. After all the tests are done to ensure that the motor, the sensors, the safety devices, and all other mechanical parts are working perfectly, the first scientific experiments are expected to begin by spring 2011.

OUT-OF-THE-WORLD DESIGNS

Machinery that circles the heavens, training its gaze either on Earth or out towards the stars, needs to be first tested and validated on solid ground. Spain’s Telstar group of companies includes Telstar Vacuum Solutions, which capitalizes on its knowledge of vacuum systems to design test chambers for spacecraft.

“A satellite has to be tested in an environment that simulates the space environment,” says Ferran Costas, director of Telstar Vacuum Solutions. “This means you need to re-create a vacuum, with extreme temperature ranges from -190 °C to up to 180 °C.”

The chambers the company designs can reach the necessary ultrahigh vacuum conditions and endure the wide temperature swings, and range from small spaces to test individual pieces of electronic equipment, to large rooms for observation satellite instrumentation.

Sener, an engineering company, began working in the space sector more than 40 years ago, even before the creation of the official European Space Agency (ESA). The company developed the Kiruna launch base in Sweden, and has “the capability to build any moving part in a satellite,” points out Diego Rodriguez, director of Sener’s space division.

The company is currently working on building a sun shield for the telescope for the new ESA satellite Gaia. Gaia’s sensitive telescope is destined to help create a three-dimensional map of our galaxy. “The telescope has to be protected from the sun, with a large 11-meter diameter umbrella,” says Rodriguez, “and that umbrella has to be deployed once the satellite is in space.”

The need for a sun shield introduces a number of complications, such as how to store an element that large in as small a space as possible, adding as little weight as possible, while ensuring that its mechanisms and material won’t be affected by swings in temperature and that it will deploy in space without incident. “This is an important failure point—if we do not deploy properly, we’ll lose the mission,” he explains. Sener is now in the process of evaluating the sun shield deployment in ESA’s test chambers.

For NASA, Sener built the antenna-pointing mechanism used in the new Mars Rover. “On Mars, mechanisms suffer because the dust is so thin, it gets everywhere and gets mixed up with lubrication,” Rodriguez describes. “The best [plan] is to protect junctions with a flexible material that can follow movement but seals the whole junction.”

For a future European Mars rover, Sener is also designing a drill.

Indra, a Madrid-based international technology company with about 30 thousand employees, has a division devoted to space. For the ESA satellite that measures ocean salinity—it’s named Soil Moisture and Ocean Salinity (SMOS)—Indra led a team responsible for building the hardware and software for ground stations and for data processing centers, dedicated to receiving data from the satellite and making it accessible to scientists. The satellite was launched last November.

Mier, which began working in antennas more than a half century...
ago, began to develop applications for telecommunication and research satellites 25 years ago. “The base of our technology is related to high-frequency radio-frequency microwave applications,” says Pedro Mier, president and CEO. Mier’s antenna technology can be used for amplification of extremely low signals.

The scientific team of the SMOS mission needed to identify and measure gradients of signals that are produced by changes in soil moisture or ocean salinity. Mier designed both the microwave sensor that can receive these low signals from thousands of miles away and the signal processor to extract the data. “We worked with ESA for ten years to develop three different versions of the technology, and then finally we worked on the construction of the satellite itself,” says Mier.

The satellite has provided the first-ever global map of ocean salinity; this is relevant for climate change research, as changes in the concentration of salt in oceans drive the currents that help regulate the globe’s climate. The first maps from SMOS were presented at ESA’s Living Planet Symposium in Norway in June 2010.

For Galileo, the European satellite navigation system, Indra built ground stations all over the world, and developed the processing software in those stations. The antennas, monitoring systems, and control software allow Indra engineers to process Galileo’s information in real time. In order to create highly detailed maps that will allow planners on local, regional, and national levels access to comparable information from city to city, Indra is also participating in a project that will use observational satellites (along with planes that fly over cities) to send out signals and, based on the signals sent back, aggregate complete information about land use. The goal is to map the 500 largest urban areas in Europe.

**AN EYE TO THE SKY**

Added Value Solutions, or AVS, develops machines known as mechatronics—large pieces of equipment that combine mechanical features with electronics—to operate both in space and in extreme research conditions, able to withstand vacuums, radiation, cryogenic temperatures, and high magnetic fluxes. AVS technologies supply particle accelerators and fusion research facilities across Europe.

AVS recently developed a novel method of observing the heavens from Earth. Telescopes pointed at the sky have fibers that are controlled to focus on a given point. “You divide [a] one-meter diameter of a focal plane into very small cells in which you have to move a fiber, and this movement follows an object in the sky,” says Miguel Angel Carrera, director of AVS. “So if you divide the plane into a thousand fibers, that means that in a single exposure, you can actually follow a thousand objects in the sky, tracking them and compensating for the movement of the Earth against the sky.”

Above: Indra’s Soil Moisture and Ocean Salinity (SMOS) satellite maps global ocean salinity. Changes in the concentration of salt in the oceans drive the currents that help regulate the climate of our planet.
An Interview with Miguel Angel Carrera,
Director of the Spanish Association for the Industry of Science (INEUSTAR)

INEUSTAR was founded in March, 2010 to promote companies involved in scientific research facilities. “Collaboration, alliances, continuous innovation and a hunger for excellence are the driving forces of the new organization,” states Francisco Javier Cáceres, international technology expert and one of INEUSTAR’s founders, together with the Spanish innovation agency Gipuzkoa Berritzen-Innobasque.

Miguel Angel Carreras, CEO of Added Value Solutions (AVS) and INEUSTAR’s first director, points out that the scientific research sector is a multibillion dollar industry, with projects that span continents and last for many years. It offers Spanish companies the opportunity to work on the frontiers of science and technology and to develop systems that could eventually provide an advantage in the commercial market.

What’s the role of INEUSTAR for companies in the scientific industry?

Carrera: INEUSTAR is meant to be a tool for companies and scientists to get acquainted with each other. Companies have to understand what will be needed in the scientific industry, and researchers need a map of companies and their capabilities. The organization is intended to help scientists choose the best options in Spanish industry, and to help Spanish companies choose the most promising research projects.

INEUSTAR is also working alongside the Spanish government, which contributes to major scientific facilities. These projects demand collaboration among many countries, and this can take the form of either cash or in-kind donations. But to give in-kind donations, a country has to have an industry that is prepared to meet the needs of top research facilities. So the aim of INEUSTAR is to help the government prepare companies for both the medium and long term to provide services at the top technological levels.

Spain has a significant tradition in industry, and Spanish companies and industries have been quick to change from one technology to another as demands change. For instance, Spain formerly was one of the biggest players in building ships and boats. This industry has since closed, and now companies are providing technology for aeronautics and the aerospace industry. And they’re developing new technologies to meet the needs of the most advanced international scientific centers.

AVS developed a new robot to position those fiber planes and divide the focal plane into eight thousand points of focus. The AVS solution improves on a similar technology developed at the Lawrence Berkeley Laboratories. AVS will be working with Berkeley Lab to present the new system to the U.S. Department of Energy in the fall to apply for funding.

Fractal, which was founded by Marisa Vargas, a former university professor, first consulted for the large telescope on Gran Canaria, the Gran Telescopio de Canarias (GranTeCan), heading a group in charge of some of the project’s instrumentation. Vargas formed the company because, as she explains, “there aren’t big multidisciplinary engineering groups within universities that can make [the] complex instrumentation needed for science.” Fractal builds bridges between scientists and engineers by assisting in converting scientific ideas into useful machines. In one of its latest projects, Fractal is working with a university in Madrid on the management and design of spectrographs (through which light is split into different wavelengths), proposed for the GranTeCan telescope.

One main concern in manufacturing for such large, expensive facilities is the durability of materials. Cryobest has mastered a technique whereby components are treated at cryogenic temperatures—-180 °C—that alter the crystal structure of metals to increase wear resistance, stability, toughness, and conductivity. This technique is unusual in that it involves multiple stages of dipping below -180 °C, instead of a one-time multiday cryogenic freeze. “This process is more efficient; you can achieve the same or better results in 12, 13 hours instead of 20 to 30 hours,” says Luis Angel Alava, president and CEO of the company. Cryobest used this technique to treat large aluminum components known as optical beds for an ESA telescope launched last year.

Cadinox, a family company founded in 1956 that does welding and machining for industrial processes, began working on local Spanish scientific research projects, then expanded into larger scientific installations. “We use advanced processes for cutting raw mate-
Building the structures to house major telescopes requires complicated engineering. Engineers at Idom are currently working on the housing for the European Extremely Large Telescope, the largest optical telescope in the world, to be located on a mountain in Chile's Atacama desert. Asturfeito now has contracts for NASA's space institutions and for manufacturing antennas for a new telescope in Chile called ALMA, one of the largest telescopes in the world. “These require a great deal of know-how and precision,” says Feito. “The antennas can weigh more than 70 tons.”

EXPLORING THE UNIVERSE’S ORIGINS

Hidden 300 feet beneath the Earth’s surface, and looping for seventeen miles, the Large Hadron Collider flings subatomic particles around a race track at nearly the speed of light and smashes them against one another to explore the secrets of the universe’s beginnings. The LHC, built by the European Organization for Nuclear Research (CERN), took 16 years and $10 billion to complete. Its first particles began colliding in the spring of 2010. This machine, the world’s largest collider, demanded extraordinary precision from its suppliers to meet its exacting standards. The tubes through which the particles fly are kept in ultrahigh vacuum conditions to avoid the entrance of any stray particles of gas. The entire system is cooled to -271°C, colder than outer space, while the temperatures generated by colliding particles may become more than 100 thousand times hotter than the temperature of the sun’s core.

Companies from around the world have supplied parts and expertise for the LHC, among them 35 Spanish companies. Scientific research facilities generally work with companies who have already proved themselves through work with other similar facilities. Spain’s DMP, founded in 1999, had developed a core business machining parts for the aerospace market, which demands extremely high precision. “So within the world of the aerospace sector, we have created a small niche [in] manufacturing very difficult segments,” says Philippe Roulet, marketing director. “We saw that the field of scientific installations also needs extreme precision parts,” says Roulet. So he contacted a purchaser for CERN in Geneva. “He said, ‘Sorry, we’re not interested in the aerospace market, because there isn’t the precision we need.’ I insisted, and sent images of difficult parts that we were making,” recounts Roulet.

Roulet’s persistence paid off. CERN’s purchasing team sent DMP plans for a small part, very difficult to machine, which only
two large German companies had been able to manufacture, using specialized equipment. DMP uses conventional machinery to make them, instead employing advanced metrology, or measurement technology, to characterize any precision losses. Explains Roulet, “We have a really strong understanding of what’s happening in the machine, the tools, and the materials, and then we can compensate and correct to guarantee the final results.”

DMP was able to machine the parts with the same precision as the larger German company at a lower cost, and was soon commissioned to make additional parts for the collider. “We’re a smaller company, working in the Basque country in Spain. But now, with important references such as CERN, we can immediately capitalize on this experience.”

Elytt, a machining company that mainly produces tools and parts for the automotive sector, was one of three companies around the world that could develop parts by a process called fine blanking to produce about 8 million parts for CERN (40% of the total volume). Swisslan, a machining company with expertise in high-precision, difficult parts “that other companies don’t want to do,” according to its founder Angel Ibarluzea, is manufacturing a number of parts for CERN experiments, advanced, complex components, made of pure copper. And Antec, also based in the north of Spain, designs and manufactures both normal-conducting and superconducting magnets for international particle accelerators.

On a curved track such as the one at the LHC, superconducting magnets create an electromagnetic field that forces the particles to follow the planned trajectory. “Normal-conducting magnets are not able to create a strong enough electromagnetic field,” says Aitor Echeandia, Elytt’s business manager. Elytt was formed in 2002 by engineers who had worked on superconducting magnets for major scientific research institutions.

Echeandia continues, “We have to use a number of different technologies. We have strong knowledge in superconducting cables, and also in cryogenics, because superconducting magnets are cooled with helium. And we need to know about vacuum technology. And all of this has to be integrated into the calculations.”

The conducting magnets need to be placed with extreme accuracy so that they perform their key function, that of thrusting the particles ahead. Fagor Automation has been engaged in positioning these magnets, using linear encoders, sensors paired with scales that encode and position them with precision measured in nanometers. The encoder’s linear scale includes a tiny code on the micron level—similar to a bar code—that is photographed through special optics. That encoded data is translated into information about where the scale, and thus the magnet, is located. “You need very high resolution to move the magnet even the smallest bit, to be able to detect that movement,” says Pedro Ruiz, Fagor Automation’s general manager. Fagor has been perfecting its linear encoders, which it builds in special isolated chambers that allow nanoscale deposition of materials without disturbances from, for instance, outside vibrations.

**RE-CREATING THE SUN**

Elytt’s experience manufacturing superconducting magnets for the Large Hadron Collider placed it in an ideal position to enter a consortium to manufacture and supply superconducting coils for a new fusion project, the International Thermonuclear Experimental Reactor, or ITER, to be built at Cadarache, in the south of France. The multibillion dollar project will be the world’s largest fusion experiment, with contributions from the European Union, the United States, Russia, and Asian countries. ITER will attempt to re-create the conditions of the process that powers the sun, in order to manufacture a potentially endless supply of renewable, carbon-dioxide-free energy.

Magnetic fields contain the plasma away from the chamber’s walls. To create these fields, the project demands superconducting coils larger than any that have ever been produced. Each coil is about 48 feet long and 18 feet across and weighs approximately 300 tons. The consortium’s leader, the Spanish power company Iberdrola, will oversee design and development and take charge of quality control and construction. Elytt is pairing with the Italian company ASG Superconductor on research, design, and manufacturing. The first phase alone—research and development to produce a mock-up—will take between two and three years, according to Echeandia. Echeandia estimates that the final manufacturing, five to seven years from now, will demand about ten different manufacturing steps.

Creating the magnetic field also requires an electrical current to be driven through the plasma. The extreme power needs of this process match the experience of Northern Spain’s Jema group, which since 1953 has been providing electronic power equipment, such as secure power systems for power plants, and advanced systems for laboratory applications, including fusion reactors and particle accelerators. In the late 1980s, the company delivered the first solid-state high-voltage power supply for the Spanish government’s fusion research laboratory, feeding plasma heating for the experimental fusion reactor. They were then able to continue on to other fusion laboratories in Europe. Says Francisco García, Jema’s engineering manager, “For these highly skilled technical projects, the markets are limited to only a few potential suppliers. The number of references is key for accessing new clients.”

Jema most recently completed four high-voltage 17-megawatt supplies for plasma heating for the Joint European Torus (JET) experiment in the United Kingdom, the largest nuclear fusion experiment to date. “The chamber where the hydrogen is confined, you have to get it to a very high magnetic confinement at very high temperatures to produce the fusion reaction,” García explains. “You need strong magnets that have to be fed by very strong power supplies.” At the same time, he continues, “If you’re injecting a huge amount of power, like 20 MW, you need to be able to stop in microseconds, which is a very demanding requirement.”

To do so, they take power from the grid, store it and then pass it through different stages to get to the power and current that the
Revolutionary Reactor

This is a graphical representation of the International Thermonuclear Experimental Reactor, or ITER, which will be the world’s largest fusion experiment. ITER will attempt to re-create the conditions of the process that powers the sun, in order to manufacture a potentially endless supply of renewable, carbon-dioxide-free energy.
customer requires, so that it can be delivered and stopped at quick command.

Jema’s experience in fusion reactors throughout Europe positions it to apply for the contracts to provide power to the ITER’s new facility. “This will be the second-biggest scientific cooperative project in the world, behind the International Space Station. As we have many references in fusion, we’re focusing our next target on ITER itself,” says García.

ITER’s ultrahigh vacuum prevents any stray particles from interfering with the reaction. Within the reactor, special containers will be positioned to capture byproducts of the fusion reaction. The research team needed a company to build robots to enable the remote handling of these containers; Telstar, with its experience in vacuum containers to test space technology, won the contract to design, manufacture and supply these robots.

“The unit has to manage a load of nearly 10 tons, and has to operate in a vacuum without breaking the vacuum of the ITER vessel,” says Telstar’s Costas. “They also have to withstand heavy radiation from the thermonuclear fusion; there’s a radioactive environment inside the vessel even when the fusion reaction is stopped.” One example of this problem and its solution: most oils used in hydraulic equipment can’t withstand this radiation, so for ITER, Telstar is using water-based lubricants.

One potential goal of ITER is to replace nuclear power generation, and large companies that work with nuclear power have been able to supply a great deal of the necessary experience to design ITER’s buildings and systems and to help determine the safety procedures. Empresarios Agrupados, founded in 1971, was created as an engineering company to serve the nuclear industry. “Apart from building the Spanish nuclear power plants, we’ve now been involved in all the new nuclear reactors in Europe,” says Teresa Dominguez, advanced projects manager of Empresarios Agrupados. The company’s background in filling the engineering needs of such large and complex structures gave it the experience to take on designing buildings for the ITER facility and calculating the electrical distribution system for the experimental fusion power plant.

Many Spanish companies working in fusion first delved into that sector via Spain’s National Fusion Lab, which began research in the early 1980s in partnership with the U.S. Oak Ridge National Laboratory. Spain’s reactor was built by the mid 1990s, with about 60 percent of the contracts awarded to Spanish companies. “At the time, those contracts were not the ones requiring the highest level of technology,” says Joaquin Sanchez, director of the Fusion Lab. “They were for more accessible requirements, such as the electrical equipment and the buildings.”

But after acquiring experience in Spain, many of those companies moved on to compete for projects at the European level, with increasingly higher levels of technological complexity. “They became more confident in working in this market; it’s no longer new to them,” says Sanchez.

The budget for ITER, explains Sanchez, is made up of contributions from member countries, about 15 percent of which is in cash. The remaining 85 percent can be an in-kind contribution—but only if companies have the technological experience and knowledge to meet the requirements. So CIEMAT, the Spanish research organization that directs the country’s fusion research, has begun a program of grants to develop new technologies for fusion. “It’s not easy to start from scratch and get a contract,” points out Sanchez. “It’s much better if you’re already in the system, and know exactly what the needs are.” This has already paid off: in 2010, Sanchez says, the contracts awarded to Spanish companies totaled about 90 million euros.