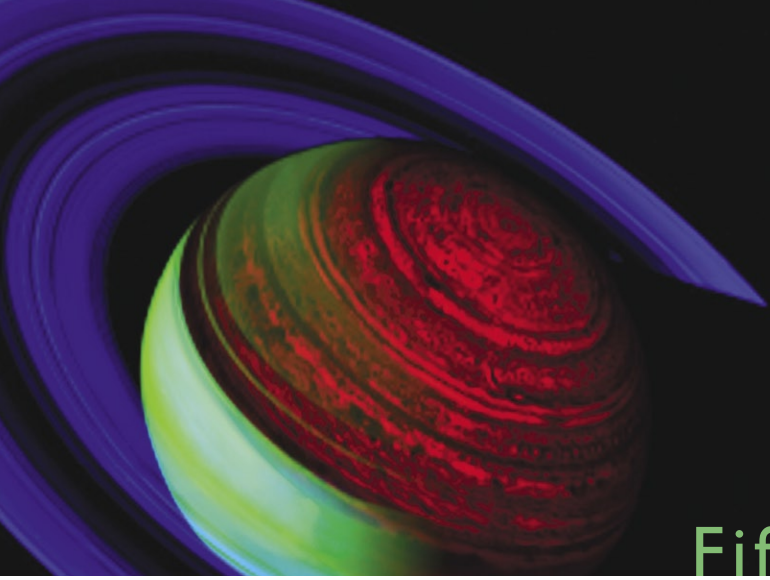


Fifty Years in Space

By Douglas L. Smith

An international Who's Who of aerospace luminaries packed Caltech's Beckman Auditorium last September to celebrate "50 Years in Space." The conference was organized by Ares Rosakis, the von Kármán Professor of Aeronautics and Mechanical Engineering and director of the Graduate Aeronautical Laboratories at the California Institute of Technology (GALCIT), and Dwight Streit, vice president, electronics technology, for Northrop Grumman Space Technology, which cosponsored the event with GALCIT and the Jet Propulsion Laboratory, which Caltech administers for NASA. The heavy hitters from all of Earth's spacefaring nations were invited, says Rosakis, but the representatives from China and Russia were no-shows. According to Rosakis, the conference's three chairs—Caltech president Jean-Lou Chameau, JPL director Charles Elachi (MS '69, PhD '71), and Northrop Grumman Space Technology president Alexis Livanos (BS '70, MS '73, PhD '75)—represented the triumvirate of academia, national laboratories, and industry that has woven the exploration and use of space into the fabric of our society. The speakers, who were drawn from all three branches of the triumvirate, celebrated past accomplishments, reflected on our current situation, and speculated on the future of humanity's endeavors in orbit and beyond. Herewith are some of their thoughts, culled from a day and a half of presentations and panel discussions and reassembled in narrative form. Streaming video of all the presentations, along with event photos and speaker biographies, can be found at http://galcit.caltech.edu/space50.

Where We've Been

The journey into space began humbly enough, as astronaut Ronald Sega, retired undersecretary of the U.S. Air Force, pointed out. The Wright brothers' first flight in 1903 was about 120 feet, roughly the length of the auditorium, and Robert Goddard's first rocket in 1926 reached about 41 feet, or approximately to the ceiling. It took another 30-plus years to reach orbit, with the Soviet Union's October 4, 1957, launch of Sputnik as Earth's first artificial satellite propelling the world into the Space Age and the United States into the Space Race.

Numerous speakers paid homage to the Cold War as a powerful motivator. Opening keynoter Ronald Sugar, chairman and CEO of Northrop Grumman, said that "an international space movement based on cooperation and the quest for knowledge emerged from one originally based on geopolitical struggle and military competition." Joanne Maguire, executive vice president of Lockheed Martin Space Systems, was blunter. "One wonders if the U.S. would have done anything in space in the 1960s if it were not for the Cold War."

DARPA, the Defense Advanced Research Projects Agency, was founded in 1958 along with NASA, both in response to Sputnik. That 84-kilogram sphere, clearly visible every 98 minutes as

Image credit: X-ray–NASA/CXC/SAO; Optical–NASA/STScI; Infrared–NASA/JPL-Caltech

Supernova remnant Cassiopeia A through the eyes of three of NASA's Great Observatories. The outer shell of cold dust seen in the infrared by the Spitzer Space Telescope is colored red, the filaments of warm gas visible to the Hubble Space Telescope are yellow, and the superheated shock wave seen by the Chandra X-ray Observatory is green and blue.

A false-color mosaic of Saturn's far side from the Cassini spacecraft. The rings are backlit, so the most opaque parts appear darkest. Thermal radiation from Saturn's interior lights up the night in red. Thick clouds deep in the atmosphere block some of it, appearing as dark streaks, spots, and globe-encircling bands. Saturn's sunlit side appears greenish-yellow.

it passed overhead, was a great shock to America's presumption of superiority in all things scientific and technical. David Whelan, chief scientist for Boeing Integrated Defense Systems and former director of DARPA's tactical technology office, said DARPA's charter was to "prevent technological surprise," and described how it functions as part think tank and part piggy bank. DARPA foresaw the military usefulness of space for photoreconnaissance, weather forecasting, telecommunications, and GPS. All of these, of course, have now found civilian uses as well, and the synergy between military and civilian space efforts was a constant theme of the conference. The agency started writing checks immediately, said Whelan, with ARPA (the word "Defense" wasn't added to its name until 1972) Order #1 going to Wernher von Braun to develop the first American spacecraft, the Explorer 1. Later ARPA funding orders were for the development of the Mercury and Gemini space capsules that took Americans into orbit, and the Saturn rocket motors that took us to the moon.

On May 25, 1961, President Kennedy addressed a joint session of Congress after the Russians had beaten the Americans once again by putting cosmonaut Yuri Gagarin in orbit on April 12. Kennedy challenged the nation to put a man on the moon by the end of the decade. NASA hopped to it, and in 1962, Eugene Shoemaker (BS '47, MS '48) of the U.S. Geological Survey helped NASA develop a plan for lunar exploration. In January 1963 he began field-training astronauts, leading the Gemini group—which included future moonwalkers Neil Armstrong, Pete Conrad, and John Young—on a two-day tour of Arizona's Meteor Crater and nearby volcanic features, said Apollo 17 astronaut Harrison "Jack" Schmitt (BS '57). "Shoemaker was one of the best and most infectious of teachers. I know that this trip impressed my future colleagues." By 1967, "science training reached a new level of sophistication," with spacesuited astronaut-geologists using the equipment they would actually be carrying, operating under realistic time constraints, and communicating their observations by radio to scientists at mission control. Shoemaker, USGS colleague Gordon Swann, and William Muehlberger (BS '49, PhD '54)

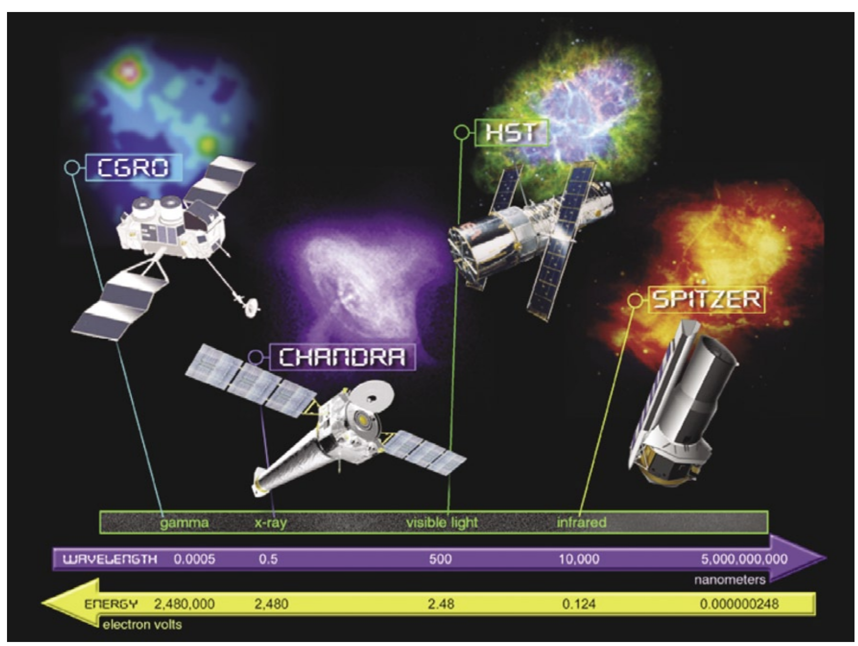
Eugene Shoemaker points with his rock hammer as he describes the geology of Meteor Crater's rim ejecta to astronaut trainees during a field trip in May 1967.

of the University of Texas had become Apollo's field-geology principal investigators. They planned mission-specific training trips, scouted appropriate locations, and, perhaps most importantly, recruited mentors. These included, besides the three PIs, Caltech geology professors Lee Silver (PhD '55) and Robert Sharp (BS '34, MS '35), who "provided infectious emphasis on 'belly geology,'" and Richard Jahns (BS '35, PhD '43), a recent defector to Stanford from the Caltech geology faculty by way of Penn State.

Various speakers described the robotic post-Apollo exploration of the solar system and our growing understanding of the evolution of the cosmos and our place in it through a panoply of astronomical missions, including NASA's Great Observatories. This fleet of four space telescopes has covered the electromagnetic spectrum from ultra-energetic gamma rays down to the coldest of infrared radiation. (The Compton Gamma Ray Observatory was de-orbited in 2000; its successor, the Gamma-

NASA/Eugene Cernan

Harrison Schmitt, Apollo 17's lunar-module pilot and the second-to-last man to set foot on the moon, wields an adjustable sampling scoop. Apollo 17 brought back 109 kilograms of lunar material from the Taurus-Littrow region in December 1972.



Three of NASA's four Great Observatories are still in service.

ray Large Area Space Telescope, is slated for launch this May.) JPL's Michael Werner, the project scientist for the infrared Spitzer Space Telescope, called the ensemble "a programmatic stroke of genius," as they were built in sequence, maintaining a steady stream of funding from year to year and from mission to mission, as opposed to the more usual approach of starting with a clean slate annually and having to rejustify the budget.

"The cost per year of Cassini, all of that three billion dollars amortized over the life of the mission, is about what Americans spend annually on lip balm."

This assortment of intellectual riches led Neil deGrasse Tyson, director of New York City's Hayden Planetarium, to comment that "the highest form of compliment is [that] people see NASA's achievements and they think it's 20 percent of the federal budget. They complain about how much we're spending on NASA to generate what they see, and they have no idea how little it is." For example, "the cost per year of Cassini, all of that three billion dollars amortized over the life of the mission, is about what Americans spend annually on lip balm."

Where We Are Now

In some ways, NASA has been a victim of its own success—space is now such a part of our lives that we don't notice it. William Ballhaus Jr., then president of the Aerospace Corporation, told "two stories about whether people recognize the impact of space. . . . A CNN reporter asked a soldier in Iraq, 'You're in a net-centric environment, space has become an integral part of defense, how is space affecting you?' And he said, 'I don't need space. All I need is my rifle and my GPS.' Another good example is [that] when Dan Goldin was the NASA administrator, a congressman asked him what is a very legitimate question if you don't understand anything about space: 'Why do we need weather satellites when we have the Weather Channel?'" Ballhaus called space a utility. "It's just like power to your house. People don't understand how the power got there, but they sure notice if it doesn't get there. . . . Last week we completely changed the ground system on GPS, and you didn't read about it in the news, because it worked smoothly."

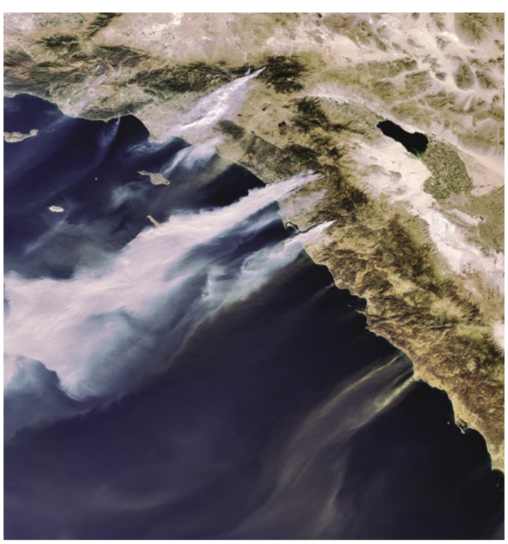
Just like the water and electric companies, space utilities turn a profit. According to Boeing's Whelan, "The U.S. government's cost to pay for and manage GPS for the country is actually offset by the profit to the tax base due to all the revenues from people buying cars with GPS units and so forth. So it's actually revenue-positive to the Treasury." To which Maguire replied, "Try explaining that to Congress."

Several speakers ticked off space's many uses: crop management, traffic management, disaster management, land-use planning, environmental monitoring, antiterrorism. A. P. J. Abdul Kalam, India's 11th president and the aeronautical engineer who founded that country's missile program, boasted that in India, tele-education (2,700 classrooms) and telemedicine (250 hospitals) are practiced routinely, and that the nation plans to link 100,000 villages by satellite in a "knowledge net."

The European Space Agency's director general, Jean-Jacques Dordain, proposed having a "Space Day" once a year on which all satellites are shut off for 24 hours so people can see how much they depend upon them, and suggested, tongue firmly in cheek, that the World Cup finals might be a good day for this.

Unfortunately, we will get an involuntary demonstration of this as America's aging fleet of climate-monitoring satellites starts to go off line. As CNN's chief technology and environment correspondent Miles O'Brien noted, "By the end of the next decade, the U.S. will have 40 percent fewer sensors in orbit because of flat or reduced budgets. Many programs have been canceled; many have been delayed," which will lead to gaps in the data sets required for climate modeling and prediction. Several speakers bemoaned this state of affairs, and hoped that future administrations would do better. Meanwhile, ESA is stepping up to the task, said Dordain, with Earth missions being its fastest-growing area of endeavor. ESA's seven-ton Envisat, launched in 2002, is the biggest Earth-observing spacecraft ever built, returning over 280 gigabytes of data per day. A fleet of much smaller craft of some 500 kilograms each will be launched every six months beginning this spring. But NASA's stumble will be felt—according to Yannick D'Escatha, president of France's Centre National d'Études Spatiales, "the overall European annual space-science budget is equal to the single Mars-exploration budget [line] in the U.S." Said Ballhaus, "The fact that weather mod-

Below right: The European Space Agency's Envisat dwarfs its handlers. Below left: An Envisat view of the smoke plumes from Southern California's wildfires on October 22, 2007.



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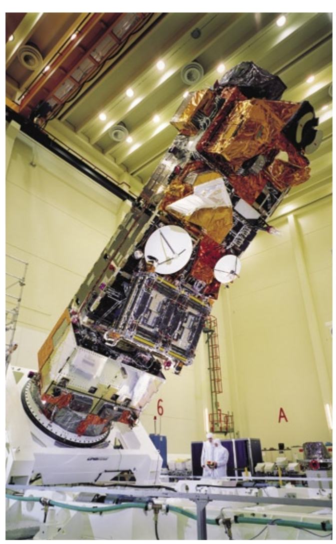

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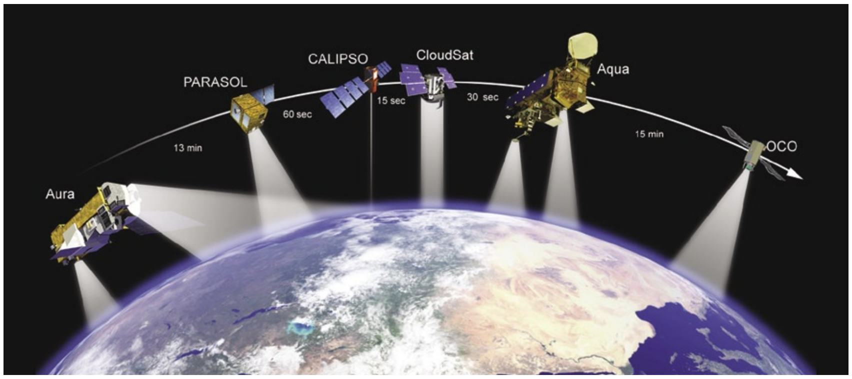


NASA/Alex McClung

Climate modeling requires lots of data about any given place at any given time. Hence the Afternoon Constellation, better known as the "A-Train" in homage to jazz great Duke Ellington. These satellites share a polar orbit, with very short time gaps between them.

There was plenty to see between sessions. Here Jean-Jacques Dordain, ESA's director general (with red folder); Caltech trustee Jon Kutler (with sunglasses), a member of the JPL oversight committee; and Yannick D'Escatha, president of France's Centre National d'Études Spatiales (CNES), check out a replica of one of JPL's current Mars rovers. JPL's first rover, Sojourner, also full-size, can be seen in the background, behind JPL director Charles Elachi (red tie) and Sylvie Callari, head of international affairs at CNES.

eling is a utility and we can't afford to gap it is a national-security issue. It's fundamentally important that we plan the future so we don't have those gaps."

Frank Fernandez, DARPA's director emeritus, said that with the onset of global warming, "We're going to need, in a decade, the global observations to drive the models to make the predictions to tell people when to leave. Because the weather is going to get more *active*. As more energy is trapped in the atmosphere, we're going to have more chaotic weather." He added that "someone needs to make it clear to the policy makers that this is not a 'nice-to-have,' it's a 'gotta-have.' We're doing this amazing experiment. We're putting all of this stuff into the atmosphere, and there's a lot of controversy over what effect it will have, but we do know that it won't go away by itself for a couple of hundred to a thousand years. The only way we're going to be able to get the data to tell us what's going on and to refine the models to do the predictions is going to be global sensing. If we don't start now, in 10 or 20 years when somebody finally decides 'we have to solve this problem,' we won't have the capacity to do it."

This capacity is not just in space, but on the ground, in the form of a new generation of scientists and engineers. France Córdova (PhD '79), president of Purdue University and an astrophysicist with an instrument on ESA's XMM-Newton X-ray telescope, noted that Purdue's alumni include Gus Grissom, Neil Armstrong, Gene Cernan, Roger Chaffee, and 18 other astronauts. She recently had the opportunity to talk to the daughters of two of them, now Purdue undergraduates themselves, and "one was in our hospitality management program, and the other was an English major. Both fine majors, but where's the engineering spark?"

Burt Rutan, founder of Scaled Composites and designer of SpaceShipOne, the world's first privately built manned spacecraft, pointed out that "all of the billionaires now who are putting money into space—[Virgin's] Richard Branson, [Microsoft's] Paul Allen, [PayPal's Elon] Musk, [Amazon.com's Jeff] Bezos—were all little kids for Apollo. And that's where their inspiration came from. Right now, kids are inspired by the next iPhone, not by exploration or adventure or taking risks. And that's going to hurt us in future generations."

The average age of Apollo's mission controllers was 26, meaning that they were starting high school when Sputnik was launched, Córdova said. "Now at the dawn of a new century that should push the boundaries of knowledge far beyond 'the surly bonds of Earth,' the United States finds fewer students pursuing degrees in science, technology, engineering, and math." Citing various recent studies, she went on to say that the number of U.S. citizens getting science degrees fell from third in the world three decades ago to 17th in 2004. Forty percent of NASA staff are 50 and older; only 4 percent are younger than 30. Meanwhile, U.S. jobs requiring a science and technology background are growing at 5 percent per year.

America shouldn't look for the last couple of decades' influx of foreign students continuing to make up the difference, said Tyson, who worried that our "jingoistic" policies are making it harder for them to get into the country. American science has been so fertile because we have always welcomed the best from abroad, he said. The atomic bomb and the Apollo program are "American" achievements, but both relied on foreign-born brains, from Hans Bethe to Wernher von Braun.

Speakers proposed various remedies, including more industry-academia-government partnerships, mostly aimed at college students. Former Air Force honcho Sega spoke of the new National Defense Education Program, named by analogy to Eisenhower's National Defense Education Act of 1958, and modeled after it. The Act was designed to bring American students up to speed in science and math—as Northrop Grumman's Sugar observed, "It was not just that beeping metallic sphere that induced so much hysteria in the free world, it was the Russian rocket technology that put it there," and America needed to catch up. Córdova touted Purdue's Discovery Park—a 40-acre complex of labs for biotech, nanotech, and the like—as a model for a steady source of funding for high-risk, high-payoff research, which is what the Apollo program was. Caltech's own Ares Rosakis described the Institute's efforts in this field—see the article on page 34.

Meanwhile, space is getting crowded. There are

240 commercial communications satellites alone in geosynchronous orbit, said India's Kalam. Speakers from various space agencies reeled off head-spinning slates of missions to worlds beyond. The moon is a popular destination—Japan's Kaguya and China's Chang'e-1 are in lunar orbit right now, mapping away. India's Chandrayaan-1 will be launched to the moon later this year. Chinese and Indian rovers will follow, then humans. Lockheed Martin's Maguire quoted Michael Griffin, NASA's administrator, as saying, "I personally believe China will be back on the moon before we are," and added that the Russians plan a manned mission to the moon in 2025, and a permanent base there somewhere around 2030, despite having one-sixteenth NASA's budget.

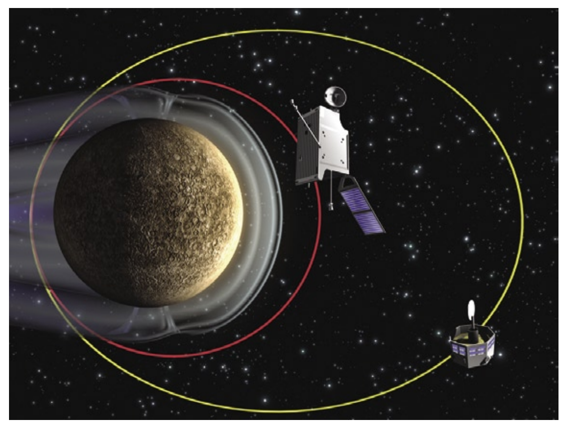
"There's been nothing much new in propulsion technologies in the last 50 years. But there must be some new discovery still around the corner. You young people at Caltech have a reputation for breakthroughs in propulsion technology—let that be your homework assignment for the next week."

Getting any big project off the ground, and especially out of Earth's gravitational well, requires international effort these days. As ESA's Dordain said, "It is always easier not to cooperate, but it is always more difficult to succeed alone." But cooperation won't happen unless every party's national interest is served. Even something as seemingly universally beneficial as free exchange of climate data has pitfalls, said Charles Kennel, former director of NASA's Mission to Planet Earth, the world's largest Earth-science program. "Different nations have different conceptions about the value of their environmental intellectual property." For example, "countries in the Middle East would regard information on the water flows for the next season to be a matter of national security."

The biggest obstacle to the high frontier is the price of liftoff. It costs $20,000 per kilogram to put a payload in orbit, says Kalam; he'd like to see that figure go down to $2,000 and eventually $200. The problem is the oxidizer, which allows fuel to burn once the air gets thin. Liquefied oxygen takes up nearly 70 percent of the launch weight of a liquid-fueled rocket. Kalam said studies in India show that a reusable single-stage-to-orbit vehicle of some 25–30 tons launch weight is feasible. Such a craft would, once up to speed, scoop up air, liquefy it, and extract the oxygen on board, accumulating enough to reach orbit. He foresees scaling these designs up to 270-ton vehicles with a 15 percent payload fraction. "If you had 20 percent payload fraction—10 times current—and reused it 100 times, you'd get about $200 per kilogram launch cost." He said that India is working on such systems, and called for international cooperation to develop the technologies needed.

Boeing's Whelan proposed a tiered pricing system instead of the current one-cost-fits-all approach. Manned missions need the highest reliability factor—three nines, or 0.999 out of 1.0—and so one might be willing to pay $20,000 per pound. But for satellites, 0.99 reliability would suffice, and the cost should drop to $3,000 to reflect that. And for low-value launches of items like water, fuel, and toilet paper needed for life in low Earth orbit or on the moon, one could opt for 0.9 reliability and pay $200. "It's a commodity—I don't care if you lose it. And in fact, on a strictly economic basis, you only need 0.5 reliability."

Rutan opined that "lift capacity started out being so expensive because there was so little of it. That's true of every new technology—you do it in onesies, twosies. But now, 25, 50 years down the road, it hasn't changed much. I think the problem is the folks . . . don't care that it costs $100 million to buy a booster, because their satellite costs $500 million." The only solution is to drive down manufacturing costs by making it up in volume, he said, and the only way to generate sufficient demand is "if we go through a time period where



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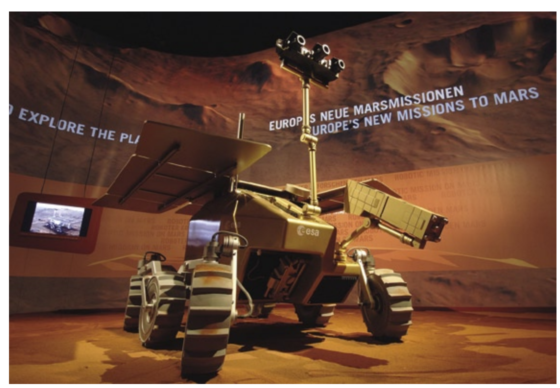
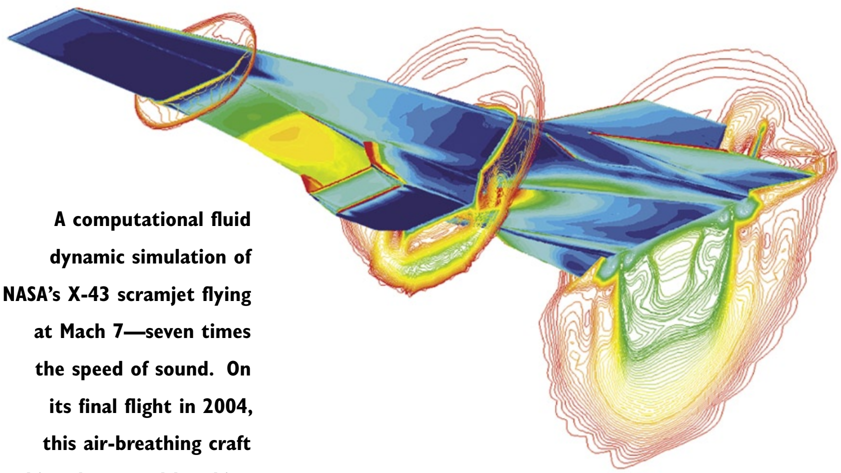


ESA/M. Pedoussaut

In space, international cooperation is the norm. The BepiColombo mission to Mercury (top) consists of two spacecraft, ESA's Mercury Planetary Orbiter and the Japanese space agencies' Mercury Magnetospheric Orbiter. And ESA's ExoMars rover will include Russian and American collaborators. Both missions have 2013 launch dates.



A computational fluid dynamic simulation of NASA's X-43 scramjet flying at Mach 7—seven times the speed of sound. On its final flight in 2004, this air-breathing craft achieved a record-breaking Mach 9.6—nearly one-third the velocity needed to reach orbit.

the focus is on flying the consumer. [Humans] don't cost anything—in fact, they pay to fly. And these payloads can be easily reproduced in huge number with unskilled labor, with tools you already have around the house."

"You can now fly nonstop to London for $500 round trip," Elon Musk, founder of SpaceX, which is developing the Falcon reusable rocket, pointed out. But "the only reason that round-trip flight from L.A. to London is $500 is because that 747 can be reused thousands of times."

Maguire hoped for an outside-the-box solution. "There's been nothing much new in propulsion technologies in the last 50 years. But there must be some new discovery still around the corner. You young people at Caltech have a reputation for breakthroughs in propulsion technology—let that be your homework assignment for the next week."

Where Are We Going?

Developing cheap orbital access will cost quite a lot of money. The feeling among the speakers seemed to be that the cash should come from the private sector as a corollary to the continued commercialization of space. The always-outspoken Rutan led the charge. "NASA should only fund research, not development. When you're spending hundreds of millions of dollars to put people into space using pieces of the shuttle, and pieces of Apollo, you're dumbing down a whole generation of new, young engineers who are told, 'No, you can't take any risks, you've got to do it the way we know will work.' . . . Having the government repeat Apollo 50 years later is just silly." Musk felt that the potential was indeed there. "If we have a base somewhere, on the moon or Mars, hopefully a tiny growing civilization, the transport back and forth will be a multitrillion-dollar industry."

David Thompson (MS '78), chairman and CEO of Orbital Sciences Corporation, which builds and

A Tribute to Si Ramo

A special session of the conference honored Simon Ramo (PhD '36), a founding giant of the aerospace industry. Session chair Alexis Livanos (BS '70, MS '73, PhD '75), the president of Northrop Grumman Space Technology, called him an "entrepreneur, scientist, author, musician, philanthropist." At Caltech, Ramo got dual doctorates in physics and electrical engineering in just three years. "He had more requirements than he had time," which once led him to take a course and its prerequisite concurrently. (He passed both.)

Livanos described how Ramo and classmate Dean Wooldridge (PhD '36) founded the Ramo-Wooldridge Corporation, "the most successful electronics corporation in history." The duo made the cover of *Time* on April 29, 1957; by then Ramo was Chief Scientist of the Air Force's ballistic missile program, and Ramo-Wooldridge was overseeing the production of the Atlas and Titan ICBMs. (The firm's Pioneer 1, launched October 11, 1958, by the newly formed NASA, became the first privately built object in space.) In *Time*'s description, Ramo "'lets his thoughts bounce around like an errant light beam,'" Livanos quoted. "That brilliant light beam has shone brightly at TRW, Northrop Grumman [both Ramo-Wooldridge's successors], and nationally for more than five decades. Si has counseled industry leaders. . . . He was awarded the National Medal of Science by Jimmy Carter, and he was awarded the Presidential Medal of Freedom by Ronald Reagan." Livanos and several other conference participants spoke of how Ramo had mentored them personally—often through one-on-one lunch conversations over simple cheese sandwiches.

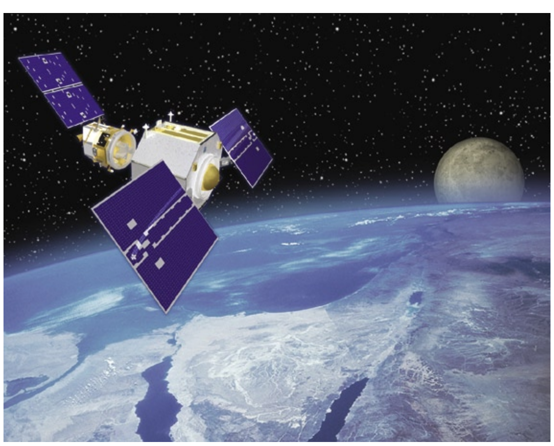
Ramo, who was in the front row with his wife, Virginia, did not take the mike, but reflected on his career in a recorded interview with former JPL director Ed Stone. After talking about Sputnik, systems engineering, the proper role of humans in space, and the future of society, the conversation turned personal. When asked what career advice he would give the next generation, Ramo replied, "If something will interest you and be right for you, my advice is do what comes naturally. . . . When I got to Caltech, I found it was a science school. It didn't really teach engineering, it taught the science underlying engineering . . . at a period of time where engineering was about to be changed greatly, because of the scientific breakthroughs taking place." He got a job at General Electric upon graduation, and "the older engineers . . . did not know the new physics. So I had opportunities right off the bat to do some things. . . . It was an acccident. I was just lucky." □—*DS* launches satellites, charted the vital signs of a large and thriving space industry—$82 billion in commercial satellites and ancillary services worldwide in 2007, versus $42 billion in defense and $27 billion in all other areas, including manned spaceflight. Satellite TV revenues are now double the total U.S. national security space budget—$52 billion versus about $25 billion—"not bad for a business that didn't even exist 15 years ago." GPS equipment revenue, "the success story of the next decade," is bigger than our missile-defense budget ($10 billion versus $9 billion). And commercial remote sensing (think Google Earth, through which, as Rutan remarked, "in the last few years, with free downloadable software, you've been able to do what only a few analysts at the CIA used to do.") is approaching a billion dollars a year.

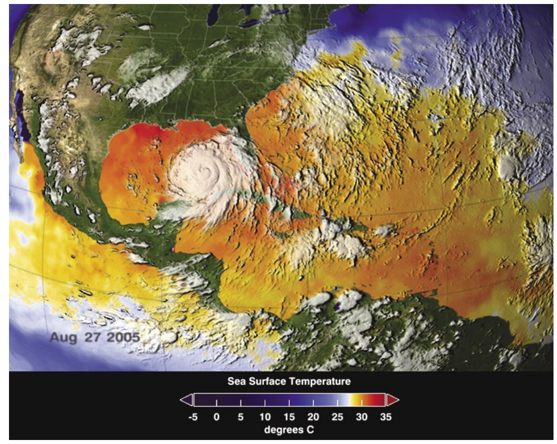
"While Apollo and its predecessors drove the technology development that launched the first generation of space businesses, now technology development often flows in the other direction," Thompson concluded. "It is time for the private space sector to repay the debt to NASA that got it started in the 1960s."

Several speakers speculated about the Next Big Thing. Would it be tourist hotels in low Earth orbit? Mining helium-3 on the moon and exporting it to Earth to produce clean energy by nuclear fusion? Orbiting arrays of solar panels that would beam their harvested power down? But all agreed that an airtight business plan would be required to start such a venture, and none were in the offing.

Boeing's Whelan sketched out an infrastructure for space, using DARPA's Orbital Express as the exemplar. A collaboration with NASA, the Air Force, Boeing, and other firms, Orbital Express consisted of two vehicles, Boeing's Autonomous Space Transport Robotic Operations, or ASTRO (the servicer, named in homage to the family dog in the 1960s prime-time animated TV series, *The Jetsons*) and Ball Aerospace's NextSat (the client). For four months in 2007, the two spacecraft demonstrated that they could perform such feats as rendezvousing with each other, docking themselves, and executing service missions such as refueling and component swap-outs—all using only their onboard computers and navigation systems, with no human intervention. Whelan proposed that fleets of unmanned transports carrying fuel and spare parts would one day rendezvous with automated service vehicles. These sophisticated robots would do whatever maintenance was needed on clients near their orbits, and even assemble large structures like space stations, or spacecraft destined for Mars and beyond. NASA is already planning to use a similar approach for moon base construction, launching the lunar lander with just crew and cargo and then fueling it aloft, allowing it to ferry a lot more weight per trip. Said Whelan, "I may not be able to reduce gravity, but I can improve the productivity of every pound I send into space."

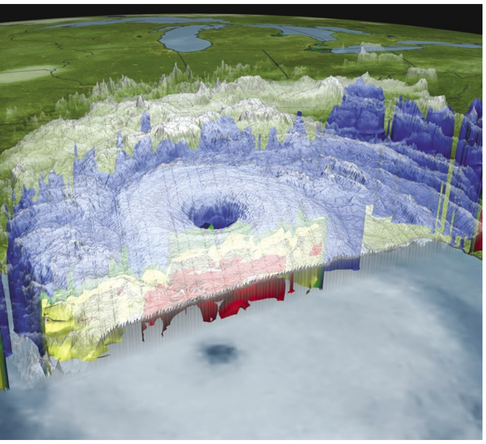
Had there been a third spacecraft watching, Orbital Express's ASTRO (two solar panels) and NextSat (one solar panel) might have looked like this while docked.

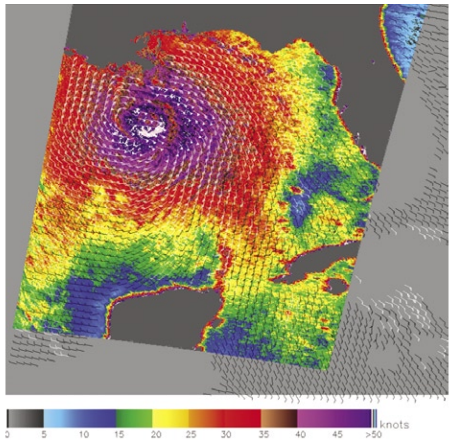


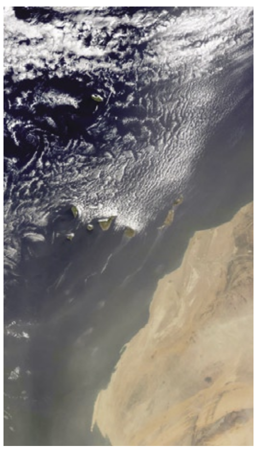


These three views of Hurricane Katrina give an inkling of the wealth of data that needs to be integrated into climate-prediction models. From left: NASA's Aqua satellite recorded sea surface temperatures on a three-day average. The Tropical Rainfall Measuring Mission, a joint project of NASA and the Japan Aerospace Exploration Agency, tracked rain-cell intensity in three dimensions. And NASA's QuikSCAT satellite depicted wind speeds in color and wind directions with small barbs.

Not surprisingly, the future of space science was a hot topic. Our own planet will continue to get close scrutiny, although Berrien Moore III, then director of the University of New Hampshire's Institute for the Study of Earth, Oceans, and Space, remarked that global warming in and of itself is "not what the body politic is interested in. After all, if we double the amount of CO_2 in the atmosphere, it will lead to a three-degree, on average, temperature rise. Many people move from New Hampshire to Arizona for that three-degree global warming. What people are interested in are changes in severe events or extreme events." With advances in computing, "we are learning to put the pieces together—we can link wind fields with rainfall fields and sea-surface temperatures to understand the mechanisms of hurricanes." He pointed out that even though atmospheric CO_2 levels do not cause Earth's glacial cycle—that's an orbital thing—they have closely tracked the temperature records for the last 400,000 years. Earth is now in an interglacial period, which means that CO_2 levels should be about 350 parts per million by volume. Instead, "we're now at 450, 100 over





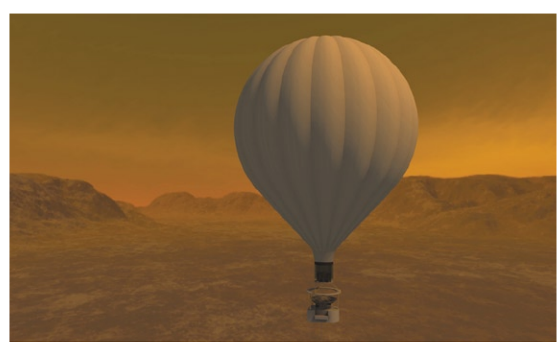


Saharan dust storms like this one have been revealed to deliver trace nutrients, including iron, to vast areas of the ocean that would otherwise be much less fertile. Through global satellite monitoring, "we're beginning to understand couplings that we didn't expect," said Moore. This shot of northwest Africa and the Canary Islands was caught on July 24, 2003, by NASA's Terra satellite.

the recorded high, and if we convert to a clean energy system the IPCC [Intergovernmental Panel on Climate Change] thinks we can stabilize it at 550. Business as usual puts us over 1,000. Even if CO_2 were not a greenhouse gas, this would be a major disruption in the carbon cycle, and it would be worth studying very carefully." Several missions, including JPL's Orbiting Carbon Observatory and Japan's GOSAT (Greenhouse Gases Observing Satellite) will track carbon's sources and sinks, and the decadal plan is to "orchestrate that with other missions that look at changes in vegetation, changes in radiation balance, changes in aerosols, changes in ozone to begin to get a handle on changes in climate." The radiation balance—how much heat we get from the sun versus how much we lose back to space—is critical, Moore said, because climate change is altering the rate at which the planet soaks up heat. Bright, reflective ice and snow is becoming dark, absorbent open water and exposed soil, for example. "We see that in the Arctic sea ice. Envisat in 2007 showed us that the long-searched-for Northwest Passage has finally appeared."

As for other worlds, Jonathan Lunine (MS '83, PhD '85), professor of planetary science and physics at the University of Arizona and an interdisciplinary scientist on NASA/ESA's Cassini/Huygens mission, talked about its exploration of Saturn's moon Titan as a paradigm, both as a model of international cooperation and an intrinsically interesting destination. He called Titan a "Once and Future Earth" because its atmospheric chemistry—hydrocarbons and nitrogen, but no oxygen—resembles prebiotic Earth's, and at the same time Titan may presage Earth's eventual fate long after humans have died off or moved on. "As the sun's luminosity grows [Earth's] temperatures will rise, the oceans will evaporate into the stratosphere, and the water will be photolyzed, just as methane is on Titan." He described a JPL proposal to explore Titan "in a leisurely way, with imaging that covers hundreds of thousands of square kilometers, rather

Moore quoted what poet Archibald MacLeish wrote in *The New York Times* on Christmas Day, 1968, upon seeing the first photo of our home planet ever taken from deep space: "To see the earth as it truly is, small and blue and beautiful in that eternal silence where it floats, is to see ourselves as riders on the earth together, brothers on that bright loveliness in the eternal cold." The picture had been taken on December 22 by Apollo 8 astronauts Frank Borman, James Lovell, and William Anders as they rounded the far side of the moon.



A balloon-borne survey of Titan could send back data for months instead of hours.

Backdropped by Earth's horizon and the blackness of space, the International Space Station is seen from space shuttle *Atlantis* as the latter departed on February 18, 2008.

than just 150," riding the gentle winds in a hot-air balloon lifted by the waste heat from the radioisotope power source that would provide the electricity for the instruments in the gondola.

Looking beyond our solar system, JPL's Michael Werner of the infrared Spitzer Space Telescope noted that the visible-light follow-on to NASA's Great Observatories program, the James Webb Space Telescope, is slated for launch in 2013 and will have 50 times the light-collecting area of the Hubble. With this and other missions, we will one day answer the Big Questions: Where do we come from? Are we alone? Some of the answers are already coming in, he said. "How prevalent are planetary systems around other stars? We can say with confidence that they are either prevalent or very, very prevalent."

The running controversy in the academic community over the merit of manned versus unmanned missions was explored. NASA administrator Michael Griffin debunked the widely held notion that NASA's budget peaked during the Apollo years, and has been in steady decline ever since. Although it is true that NASA spent more money in the few years when it was buying large pieces of expensive hardware like Saturn Vs, he said, if the budget is averaged over the length of time it takes to see a big project like Apollo or Cassini through to its end—say a 10-year running average—the flow of money has been remarkably steady.

Over 1,000 people in more than 17 countries are developing the James Webb Space Telescope. Some team members pose with a full-scale model at NASA's Goddard Space Flight Center in Greenbelt, Maryland.

Griffin sees NASA's funding as remaining constant at about 0.6 percent of the federal budget, or "about 15 cents per American per day" for the foreseeable future. "In Washington, it's very difficult to get programs started, but it's even more difficult to get them stopped." Given that, he said, "the president's goal, return to the moon by 2020, is a rational goal in constant dollars." The Hayden's Tyson agreed that more could be done with the manned program's share of the money than what we have to show for it recently. "We designed Mercury, Gemini, Apollo, and Skylab on that budget. We got out of low Earth orbit on that budget. And ever since, we've been driving around the block on the Shuttle, boldly going where hundreds have gone before."

Griffin said that even Mars is reachable on that budget. Assuming that the manned portion ($9 billion of NASA's $14 billion per year) continues to go to the International Space Station until around 2020, and then gets rolled over into developing a lunar base—which would cost a few billion dollars a year to sustain—there would be five or six billion a year left over to begin working on Mars. At that rate, we could get to Mars in about 15 years, because most of the heavy lifting—literally, the development of the Ares V booster—will have been borne by the moon program. "We could be launching in 2035 and landing in 2037. And so by the time we are celebrating the 100th anniversary of Sputnik, we can be celebrating the 20th anniversary of landing on Mars."

In a rousing closing keynote speech, Tyson stated that manned space flight was NASA's top priority. "We in the academic community have this delusion that NASA is our own private science funding agency. But it has never been that." In fact, he said, NASA's science budget began at around 10 percent in the '60s and has grown to about 30 percent today. "But most of the money was *never* directed at science." He pointed out that the manned program is spread out across the country, where the representatives who vote NASA's budget live, and that the citizens who elect those representatives are interested in people. "I don't think anybody is ever going to name a high school after a robot. Yes, people love the rovers. I'm told the number of hits to the JPL website monitoring the rovers in the two weeks after they landed exceeded the total world traffic in Internet pornography." But, he said, "I would bet you that if humans were on their way to Mars at the same time, the rover site would go unremarked-upon." In the early days of manned flights, "every mission was an advancement on the previous one, which gave the media something to talk about. . . . That is a truth that's never recognized by the naysayers of the manned program—science is piggybacking on the manned program, and always has been. And I have not been given reason to presume that that will ever change. So if you have a healthy manned program, science will be riding on its back. Maybe not as much as we academics would like, but *it's there*."

While agreeing that sending mankind to Mars *could* be done, Tyson wondered if it *would* be done. He summed up our species' other great cultural investments of human and financial capital, and stated that there were only three drivers powerful enough to motivate them. "War. That is the biggest driver there ever was. There is always money for war." In this category he put the Great Wall of China, the Manhattan project, and the interstate highway system. (It, like Apollo, was a product of the Cold War—highway construction began in earnest in 1956 to move troops and tanks around the nation in the event of a Soviet invasion.) "The Promise of Economic Return." Here he listed the voyages of Columbus and Magellan, and the Tennessee Valley Authority. "Praise of Power." This could be civil or religious, he said: pyramids, cathedrals, or castles. "If you're a wealthy nation, you can do a billion-dollar mission. But can you do a 10-billion-dollar mission? I don't know. There's a threshold. Did we build the Superconducting Supercollider? No. Because there wasn't a weapon at the end of the supercollider. There weren't diamond mines at the end of the supercollider. We didn't see the face of Jesus at the end of the supercollider." To sustain a project with a Mars-sized price tag, he argued, only one of the Big Three will do. "All it would take would be one message from Beijing: 'We're going to put military bases on Mars.' Badda-bing; we'd be on Mars in nine months."

Tyson ended the conference with slides of various technologies at infancy and maturity: Karl Benz's first motorcar and a high-end Mercedes, a Wright Flyer and an Airbus A380, and so on. "The first one looks quaint and should go in a museum. . . . But the Saturn V, 36 stories tall, does not look quaint. You have the urge to genuflect when you walk by it and ask, 'How the hell did we achieve this thing?' . . . The challenge today is to work at something that will make the Saturn V look quaint. That's what's going to have to happen to enable the next generation of space exploration." Whether the means to get us into orbit will undergo the same rapid technological evolution as the telephone, the mouse, the PC, and other workaday devices, ushering in a bright new era in space, only the next 50 years will tell. □

Spacecraft old and new: Up front is a mockup of the Phoenix Lander, slated to touch down in the north polar region of Mars on May 25. In the background is Explorer I atop its second-stage Jupiter-C rocket.

Clockwise from the top: 1. Conference co-organizer Dwight Streit, vice president, Northrop Grumman Space Technology. 2. Conference cochair Alexis Livanos, president, Northrop Grumman Space Technology. 3. (from right to left) Conference co-organizer Ares Rosakis, director of the Graduate Aeronautical Laboratories at the California Institute of Technology; A. P. J. Abdul Kalam, the 11th president of India; and Kent Kresa, chairman emeritus of Northrop Grumman and chairman of Caltech's board of trustees. 4. Ronald Sugar, chairman of Northrop Grumman.

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