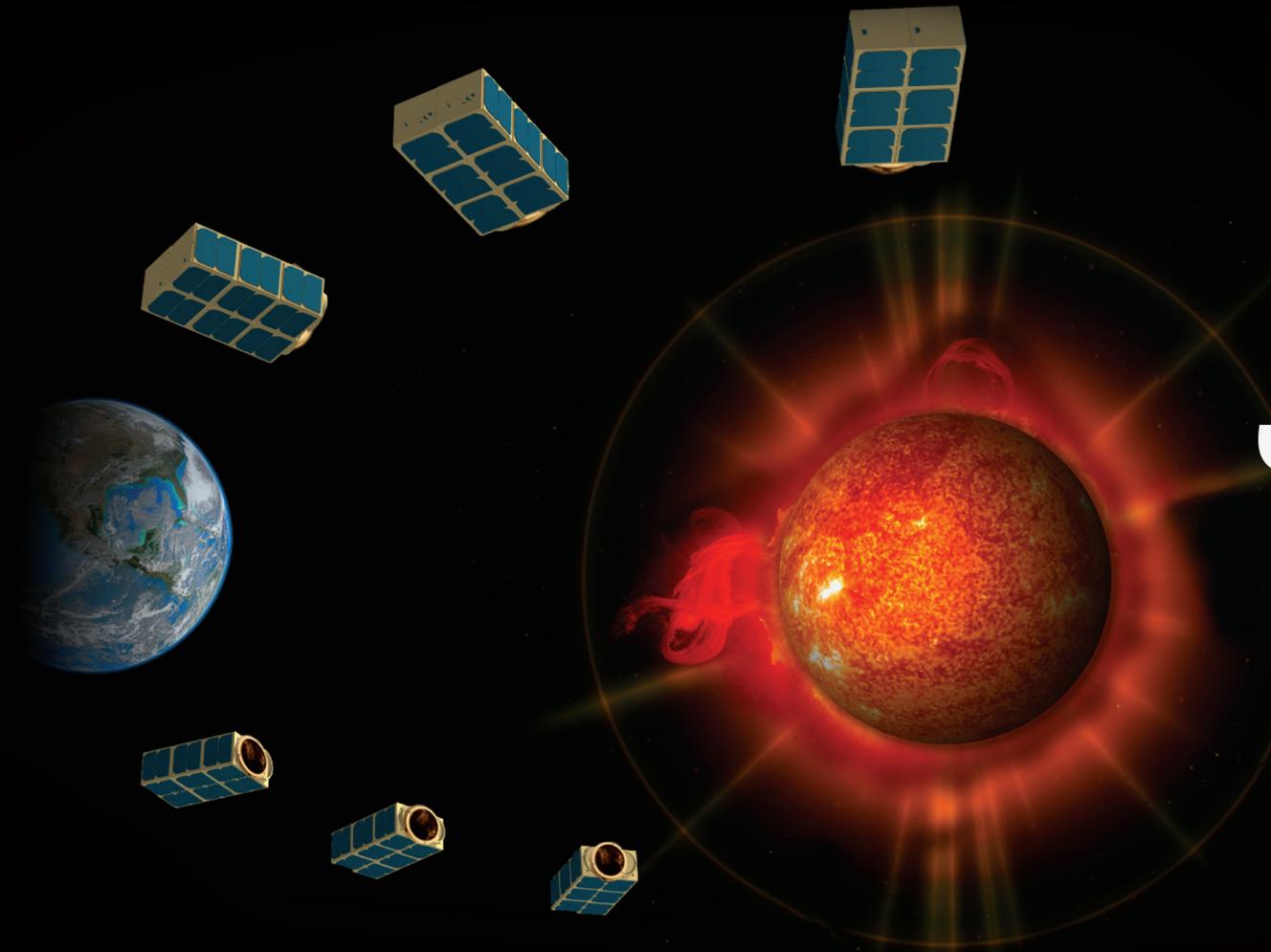


National Aeronautics and Space Administration



GSFC NEWS



CubeSat/SmallSat

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tech transfer

SmallSat/
CubeSat



FROM THE CHIEF

From the Chief

The development of small satellites platforms such as CubeSat is proceeding at a remarkable pace. These spacecraft continue to evolve from academic tools for teaching students the fundamentals of satellite design into a far more robust platform on which serious science experiments can be built.

Enthusiasm for small satellites is building. On May 23, 2016 the National Academies' Space Studies Board released a report calling for greater use of CubeSats. The report refers to these small satellites as a "disruptive innovation" whose capabilities continue to grow while remaining faster to develop and less expensive than more conventional spacecraft. The report goes on to state that "Fueled by the excitement of access to space...the progress of CubeSats toward becoming a science platform has been rapid."

NASA Goddard is playing its part in this effort, with plans to extend the use of small satellites far beyond the classroom. This includes performing a variety of science applications in low Earth orbit and even into deep space. These missions will require enhancing small satellites' reliability and capabilities, both by working with commercial vendors to improve off-the-shelf components, as well as by developing new technologies in house.

In this article we highlight a few aspects of NASA Goddard's SmallSat/CubeSat work. This work includes missions such as IceCube and Dellinger, designed to help validate new CubeSat capabilities. We look at initiatives designed to advance small satellites as a platform, such as DSM (Distributed Spacecraft Missions), which defines and addresses the challenges of flying constellations of small satellites, and Pi-Sat, a very low-cost platform for developing small satellites. We also provide interviews with several NASA Goddard personnel involved in small satellites development.

Beyond the science, NASA Goddard is also helping to develop small satellites as a commercial market. In addition to being an important consumer of CubeSat components and services, we are also developing new technologies that enhance the small satellite platform. Many of these technologies have been made available to commercial companies for product development. We are also working with a number of vendors to help enhance the reliability and versatility of their small satellite products. While enabling commercial CubeSat companies to find new markets for their offerings, NASA Goddard is also helping itself by raising the overall quality of off-the-shelf CubeSat components.

All indications are that small satellites comprise an idea whose time has come. NASA Goddard is proud of the role it has played – and continues to play – in making this happen.

NONA CHEEKS

*Chief, Strategic Partnerships Office
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Interviews

Thomas Johnson
SmallSatellite
Manager,
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Code: 800

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Education:
BS Mechanical
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Thomas Johnson is the Small Satellite Manager at NASA Goddard Space Flight Center/Wallops Flight Facility. In this interview, Mr. Johnson discusses several topics related to SmallSat/CubeSat, including the advantages of using small satellites as a platform, how NASA Goddard has worked with (and helped advance) small satellites, and the current and future commercial opportunities these spacecraft offer.



IceCube under assembly at GSFC.

Q. *What is the difference between SmallSat and CubeSat?*

Thomas Johnson: The term “SmallSat” covers a very wide spectrum of satellite

sizes, with masses ranging from 10 grams up to 180 kilograms. In this context, “small” encompasses several orders of magnitude – nano, pico, and so on.

CubeSat can be considered a “flavor” of SmallSat. The CubeSat platform is defined by standards and specifications. These specifications are evolving. Originally CubeSats came in one size, now referred to as 1U, which is defined as a 10cm x 10cm x 10cm cube. Over the years other larger sizes have been defined, including 2U and 3U, with 3U currently the most common size used for scientific missions. More recently, 6U CubeSats have started to appear, because their enhanced size makes them more suitable for science missions and other demanding applications. NASA Goddard delivered one 6U cubesat for launch to ISS in August, has another 6U in development, and many more 6U CubeSats have been developed within NASA.

In the future, even larger CubeSats will likely be developed. We now have dispensers capable of delivering 12U and 27U CubeSats, with the potential for producing larger sizes.

Q. *What are some of the advantages of CubeSat as a platform??*

Thomas Johnson: One advantage is its specific form factor. This enables CubeSats to be launched from any vehicle equipped with a dispenser.

The dispenser, by the way, is a critical component since it protects the mission payload and vehicle. On more expensive missions, we would be reluctant to load CubeSats on board because they might somehow damage or otherwise jeopardize

the primary payload. The dispenser isolates the CubeSats by literally putting them in a box. This is in keeping with our CubeSat philosophy, which mirrors the medical profession: “Do no harm.”

Another advantage is cost. A typical science CubeSat can be developed and launched for less than \$5 million, which of course is far lower than traditional missions usually cost. This provides a reasonably easy entry point into space, which makes small satellites a very attractive platform. In addition, small satellites can often be a great time-saver. They can be quickly assembled from commercially available components, and in some cases can be purchased as a complete unit. These attributes can greatly accelerate the time between initial design and launch.

Q. *How has SmallSat/CubeSat evolved as a platform?*

Thomas Johnson: Initially, CubeSats and other small satellites started out as a teaching platform. As such, they provided minimal capability, since the primary point was to provide training for students rather than conduct science or test technology applications. Over the years, they’ve grown larger, with enhanced capabilities in areas such as onboard power and communication. As a result, these small satellites are now being applied to science missions.

Q. *What SmallSat/CubeSat missions are in the works?*

Thomas Johnson: There are a number of very ambitious projects in development based on small satellites. One example is IceCube, a 3U CubeSat built entirely from off-the-shelf components. It is in orbit now, performing mission operations. This mission serve as a technology demonstration to help validate a new radiometer. Other missions currently underway include Clouds and the Earth’s Radiant Energy System (CERES), Simulation to Flight-1 (STF-1), and Dellingr, a 6U CubeSat. Dellingr has been delivered to NanoRacks, a commercial payload service provider, for packaging, launch to ISS, and deployment.

Other upcoming missions include HaloSat, which is being developed in collaboration with the University of Iowa. This will employ X-ray detectors to study the “missing baryon” problem. The instrument will fly on a 6U CubeSat spacecraft, which has been pur-

chased from Blue Canyon Technologies, a commercial vendor.

Even more ambitious is Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of SmallSats (TROPICS). This will be a constellation of six 3U CubeSats working in concert to image tropical cyclones.

Q. *How has NASA Goddard’s involvement benefited SmallSat/CubeSat?*



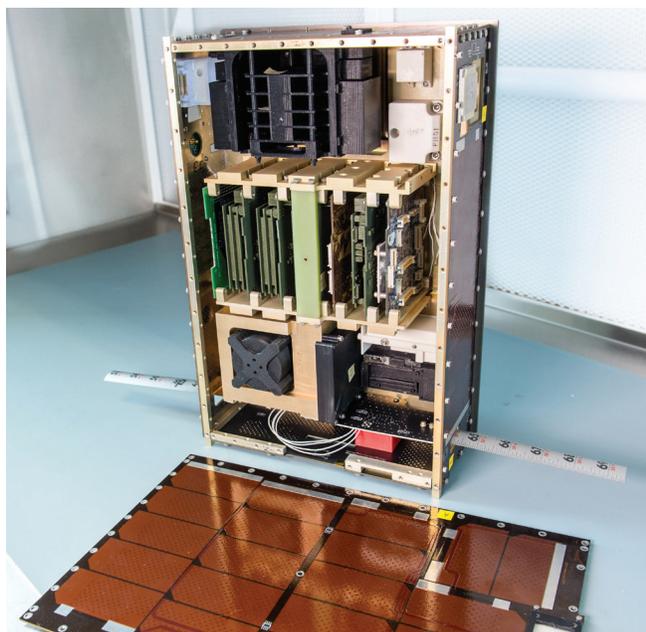
IceCube, the first small satellite project managed by Goddard Space Flight Center’s Wallops Flight Facility.

Thomas Johnson: Our involvement has stimulated the market for these satellites. By purchasing components from outside vendors, we support the development of pointing, attitude control, communications, and other systems. For example, the first CubeSats communicated solely through UHF. Today, we also have communication systems that operate in S-band and X-band.

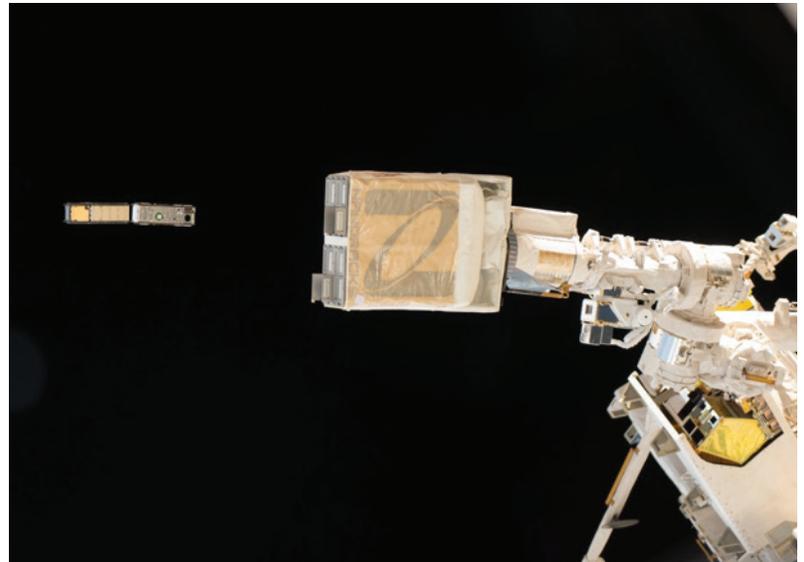
Due in part to our support, the small satellite industry is expanding, with numerous startups entering the market to provide components and in some cases even whole satellites. A few examples are Maryland Aerospace, Blue Canyon Technologies, Tyvak, Parabolis, Microtel, and many others. We now have a wider range of off-the-shelf components from which to choose. This is also good for NASA Goddard, since it keeps costs low and allows us to focus on the science instrument rather than the satellite.

Q. *Are small satellites used beyond NASA?*

Thomas Johnson: Yes. There are lots of non-NASA consumers, some of whom have been involved even before NASA Goddard. These include a number of “three letter agencies” such as the Department of Defense (DoD), National Reconnaissance Office (NRO), and other security agencies. All are very actively working with small satellites. The National Science Foundation (NSF) has been part of this effort for a long time, since as a teaching platform CubeSats can support STEM education.



Dellinger 3-D model.



IceCube deploying from the International Space Station on May 16th, 2017.

Quite often, technology first developed in universities finds its way into government, and then goes on to become a commercial product. For example, a spinoff company called Planet was formed by ex-NASA personnel to build a business around the 3U CubeSat platform. The company has launched over 100 satellites, providing rapid Earth imaging services to their clients. Similarly, a company called Spire uses CubeSats for weather monitoring and ship tracking.

And even more ambitious applications are in the works. For example, OneWeb plans to launch up to 700 SmallSats to provide worldwide internet service from anywhere on the planet.

Q. *What does the future hold for SmallSat/ CubeSat?*

Thomas Johnson: As we’ve already discussed, the small satellite market is growing rapidly, with new capabilities constantly being developed. This will likely drive the continued development of SmallSat/ CubeSat into a platform from which to perform real space science, as well as do business.

Further, NASA’s commitment to this platform will likely grow stronger. National Academies recently [May 2016] released a report in which they recommended that NASA and the NSF make greater use of CubeSats for science missions. They based their conclusion on the fact that CubeSat capabilities continue to grow, while the platform itself remains faster to develop and less expensive than traditional satellite missions. So I expect small satellites to play an even greater role in space applications in the future.



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Michael Johnson Interview

Within NASA Goddard, interest in conducting science with CubeSats and other small satellites (SmallSats) has been steadily growing in recent years. These platforms offer numerous advantages in terms of lower cost, quicker development, standardized components, and the ability to implement novel mission architectures. At the same time, there are still a number of challenges to address as CubeSat continues to evolve from its original role as a teaching tool with minimal functionality into a robust platform upon which compelling science missions can be based.

“Our science colleagues are increasingly interested in CubeSats and SmallSats” states Michael Johnson, Chief Technologist in the Engineering Directorate. “One of the roles of my team is to understand the gaps in current capabilities that make my colleagues’ small satellite mission concepts unfeasible-- and once we identify these gaps, eliminate them.”

Dellinger: A Critical Learning Experience

An important milestone in helping close these gaps is the Dellinger (pronounced DELL-in-ger) mission, currently scheduled for an August 2017 deployment to the International Space Station. This mission should help answer several critical questions, including:

- Can NASA Goddard use CubeSats to deliver compelling science?
- What systems and processes do we need to fully realize the advantages offered by small satellites?
- What further lessons do we need to learn?

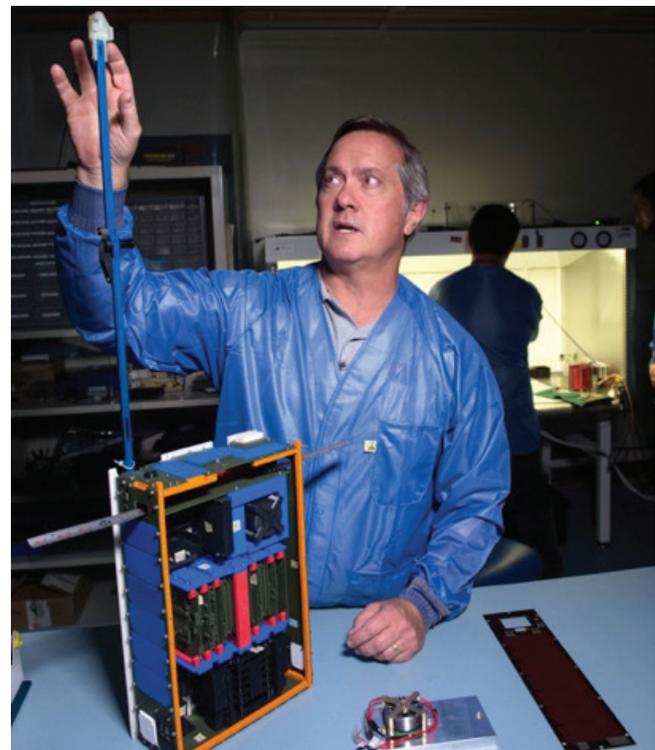
Dellinger has already demonstrated that the answer

to the first question is a definite yes. Answering the second question will likely be critical in determining how effectively NASA Goddard can use SmallSats to achieve Earth and space science objectives.

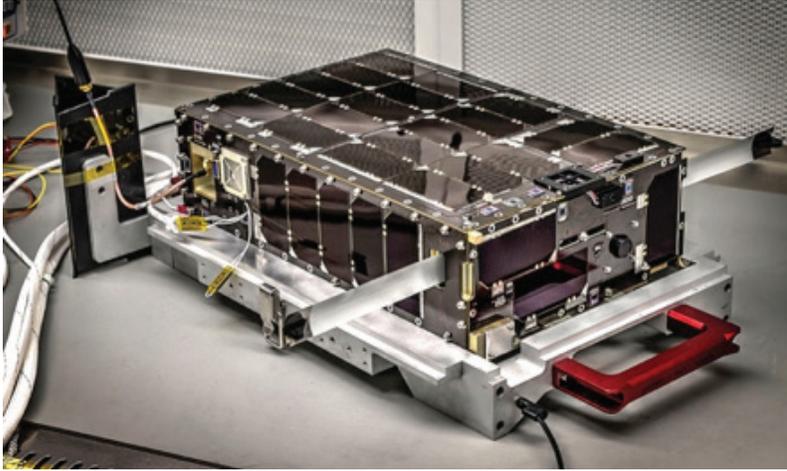
“The systems and processes NASA Goddard employs to develop our spaceflight systems have led to a 50 year record of success”, says Mr. Johnson. “These processes however, may not always be appropriate for smaller, shorter-design-life projects. So one of our goals is to encapsulate our spaceflight acumen into systems, processes, and behaviors that facilitate increased efficiency, yet minimally impact mission success. Or in other words, we intend to improve the ‘cost vs. risk’ metric.”

Dellinger has served as a good hands-on learning experience for furthering this goal. “One important thing we’ve learned from this project,” explains Mr. Johnson, “is that every requirement that’s part of our ‘traditional’ processes is there for a reason – we can’t simply drop it without some impact. So the question becomes, how can we wisely adjust?”

One adjustment involves the composition of the mission team itself. For Dellinger, the intent was to assemble a small multi-disciplinary team comprising members whose experience is broad rather than



Dellinger Project Manager Chuck Claggett points to the boom on a Dellinger CubeSat model, at the end of which is a magnetometer, an instrument that takes measurements of its magnetic surroundings. Dellinger also carries two no-boom magnetometers, a first for such miniature satellites.



Dellinger's exterior is lined with solar panels. Slightly larger than a cereal box, Dellinger is a six-unit, or 6U, CubeSat – indicating its volume is approximately six liters.

deep. This helps enable the team to work quickly and efficiently. The small team also reduces costs.

Improving CubeSat Component Quality

The standardized off-the-shelf nature of the CubeSat platform also presents a significant advantage – as well as an ongoing challenge. According to Mr. Johnson, standard commercial CubeSat components are relatively inexpensive and readily accessible. On the other hand, they do not always provide the levels of functionality and reliability required to achieve our mission objectives. “In terms of quality and reliability, some CubeSat systems are on the same level as the early days of rocketry, when failures were still relatively common and expected. We have purchased a number of subsystems that did not meet our expectations – they were faulty, did not function according to their specifications, or were handled inappropriately. There have been numerous instances where we had to replace these parts. And there are additional challenges, such as the fact that the reliability of many SmallSat systems is not quantifiable, and many systems were designed for benign low-Earth orbits; they will not operate reliably in more stressful environments.

“Here at NASA Goddard, we want to achieve science wherever the science is; and it may be in environments more challenging than those encountered by CubeSats launched to date. This requires far more robust or resilient subsystems than most of the market is now providing.

“One of our small satellite goals at NASA Goddard is to work collaboratively with our government and industry colleagues to address this situation. We’re

eager to engage vendors to collaboratively improve the reliability of the systems they offer. While some reliable products are available, at the same time, there are some systems we still build here at NASA Goddard, including power and command data handling, because it’s imperative that these they work reliably.”

Going Forward

Mr. Johnson believes the best way to raise the quality of commercial SmallSat components is through interagency government and industry collaboration. “NASA Goddard, our colleagues at JPL, and other governmental agencies have begun a conversation with vendors to address this challenge.” This in turn will provide significant benefits not only to NASA Goddard, but also to the larger SmallSat community. “Systems that will operate reliably in our targeted spaceflight environments—wherever they are—will allow us to more readily move mission concepts from imagination to reality.”

The ultimate benefits of such an effort could be very substantial. “I view the current state of CubeSats and small satellites in general as in transition, as we go beyond the 60% to 70% mission success rate to much higher levels. Our goals go well beyond low-Earth orbit; we would like to send these satellites into harsh radiation environments and into deep space. Our interest in small-satellite science is strong and growing, and we’re fully engaged in ensuring that we succeed in meeting our goals.”

Dellinger is a 6U CubeSat in designed to carry Helio-physics-related payloads. The 6U architecture effectively doubles the payload capacity of 3U CubeSats, currently the standard among these small satellites.

Dellinger Instruments Include:

- A miniaturized ion/neutral mass spectrometer to measure the densities of all significant neutral and ionized atom species in the ionosphere
- Magnetometer systems to perform magnetic field measurements

The fully integrated Dellinger is scheduled to fly on a resupply craft headed for the International Space Station (ISS) on August 2017. After deployment from the ISS, its mission is expected to last up to six months.

Once successfully demonstrated, Dellinger’s 6U design — implemented with low-cost, commercial

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Dr. Larry Kepko Interview

Dr. Larry Kepko is a Research Astrophysicist at NASA Goddard Space Flight Center, where his current science interests focus on heliophysics. His work also includes helping to develop CubeSats into a highly reliable and capable platform for performing science, both as standalone spacecraft and as satellite constellations. In this interview, Dr. Kepko discusses NASA Goddard's efforts to enhance the capabilities of CubeSats and other small satellites.

Q. How does NASA Goddard's interest in CubeSats differ from academia's?

Dr. Larry Kepko: CalPoly and Stanford developed the CubeSat standard specifically to enable hands-on training of spaceflight systems for undergraduate and graduate students. Because they are often built by students on tight budgets and schedules, these CubeSats have tended to have low success rates, although that is changing as their experience base grows. NASA Goddard has a different mandate than universities – we “begin and end with science.” We therefore don't want to compete with universities on this level. Instead, our focus is on what can we do to help advance CubeSats as a reliable and capable science platform, while staying true to the low-cost, higher risk culture that have made CubeSats so popular and successful. In addition, we believe our greatest impact is in science and advanced miniaturized instrumentation.

So, in a general sense, NASA Goddard is focused on different objectives than universities. One example is our interest in flying constellations of CubeSats in support of high-priority science objectives. This is a big area for us at the moment, and I

believe one of the areas where NASA Goddard can make a positive impact.

Q. Does NASA Goddard develop its own CubeSat technologies?

Dr. Larry Kepko: Because there is a large university and commercial market for CubeSats, there are a large number of vendors that provide CubeSat components. Whenever possible, we take advantage of this market, but many of our science concepts have specialized needs (radiation tolerance, precision pointing, and so on), and we therefore often need to develop our own custom components.

For instance, NASA Goddard is interested in using CubeSats for science missions beyond low-Earth orbit (LEO), whether it be orbiting L1 to serve as space weather buoy, or dropping onto the surface of Europa, or points in between. Leaving LEO and the protection of Earth's magnetic field exposes these CubeSats to harsh environments, principally radiation; but there are also challenges associated with power production, thermal control, and pointing. There just isn't a commercial market for these types of specialized components - vendors aren't going to mass-produce systems capable of surviving the radiation environment of Jupiter for example, since customer demand for this is non-existent. So we build these components in house. An example is Space-Cube MINI (GSC-16223-1), a radiation-tolerant microprocessor for space applications. Low-impulse thrusters are another key piece, since these are required for precision formation flying in constellations. We worked with George Washington University (GWU) to develop a small, low-power thruster that's about to fly on the CANYVAL-X CubeSat mission.

But our primary focus is on science and science instrumentation. This is the unique value that NASA Goddard brings to CubeSats. In heliophysics we've built miniaturized ion-neutral mass spectrometers, electric-field sensors, magnetometers, and energetic particle sensors. Other science divisions are similarly investing in instrument miniaturization, such as a small, advanced, radiometer developed by my colleague Dong Wu. His cubesat, IceCube, was recently deployed off the ISS and just had 'first light' of the instrument.

Q. What are the challenges involved with flying CubeSat constellations?

Dr. Larry Kepko: There are broadly two types of constellations. One is passive, where basically we launch the satellites without placing them in a tight formation, and let orbital dynamics provide broad spatial coverage. This is problematic when the application calls for the satellites to be separated by certain distances, for example different orbit planes. How do you achieve separation when the satellites are launched from a single vehicle? Traditional ideas center on a dispenser ship, which carries all your spacecraft and moves around to dispense them in different locations. This would necessarily need to launch on a large rocket, costing hundreds of millions, while also requiring a high-reliability spacecraft just for dispensing. This is one reason we're interested in the new Venture-class rockets. A Venture-class launch may cost around \$7 million. If we can place, for example, ten CubeSats on each launch and then conduct three launches (\$21M total), we can place 30 CubeSats into space and ensure they have the precise orbits we need, and it would still cost only a fraction of an Evolved Expendable Launch Vehicle (EELV) launch. We're still a ways off with this, but it demonstrates the types of new applications one can envision with CubeSats.

The second type of constellation flying is called active, and it's the type that NASA Goddard is most interested in. Active constellations require the spacecraft to maintain orientation both with respect to each other and with respect to inertial space. So picture the Very Large Array (VLA) in space, or a coronagraph where the occulting disk (held by a small spacecraft) is hundreds of meters or a kilometer away. The major requirement for active constellations is active positioning. CANYVAL-X is a demonstration mission about to launch, flying two CubeSats, with one serving as an occulting disk to block out the sun and the other carrying a sensor to conduct observations near the solar disk. This can achieve amazing resolution, but requires extremely precise positioning. Using CubeSats is a great way to bring down the risk and test these new technologies.

Q. What science applications does NASA Goddard have in mind for CubeSat?

Dr. Larry Kepko: One obvious science area is heliophysics. These instruments are generally small to begin with, and have flown in low-Earth orbit: requirements that are very suited to the CubeSat platform. Earth Science may offer the greatest potential for small satellites, because of the ability of CubeSat constellations to offer rapid revisit times. Instead of build-

ing a single large satellite, we could instead distribute components and functions among a constellation of CubeSats. In addition to being far less expensive, this approach would also improve data continuity by enabling quicker refresh and launch times.

Another interesting CubeSat application is planetary exploration – not as standalone missions, but as ride-along satellites accompanying the main spacecraft. For example, it's often difficult to slow down a planetary probe so it can spend extensive time around a solar system object. It would be far easier to do this with a small-mass CubeSat, which could be dropped from the main probe into, say, a planetary atmosphere, similar to what was done (which was basically a SmallSat). Launched in 1997 the Cassini-Huygens spacecraft is a joint endeavor of NASA, the European Space Agency (ESA), and the Italian Space Agency. In 2004 it released the Huygens probe on Saturn's moon Titan to conduct a study of the moon's atmosphere and surface composition. Because CubeSats are relatively low cost, you could use them as disposable probes in regions you couldn't otherwise explore – dropping them into Venus's atmosphere, or onto one of Jupiter's moons, for example. You might only get a few minutes of data, but these would be data not otherwise obtainable.

Finally, there's astrophysics. This may not seem like the best fit for CubeSats, given astronomers' love for large apertures. But just imagine placing each of the James Webb Space Telescope's hexadecimal mirror segments onto its own CubeSat and flying them as a precisely positioned constellation. Or in radio astronomy, using this approach to replicate the Very Large Array in space. These are huge technical challenges of course, but the potential benefits make it worth the effort.



CubeSats under construction

SMALLSAT INITIATIVES

INTERVIEWS

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MS Aerospace Engineering,
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Neerav Shah Interview

Distributed “Virtual” Space Telescopes

In astronomy, bigger often means better. Larger instruments usually provide performance advantages in terms of resolution, image brightness, and other important factors. This is why astronomers strive to build the largest telescopes technology (and budgets) will allow. Of course, this focus on size presents a significant challenge to innovators seeking to perform astronomical observations from the CubeSat platform, which by definition provides a limited volume for packaging instruments.

The CANYVAL-X mission addresses this seemingly intractable obstacle in a very creative way: launch a telescope that consists of two CubeSats working in tandem as a single instrument. CANYVAL-X (CubeSat Astronomy by NASA and Yonsei [Korea] using Virtual Telescope Alignment eXperiment) consists of two CubSats (one 2U and the other 1U) flying in tight formation in a 435-mile sun-synchronous orbit. These two satellites function as two parts

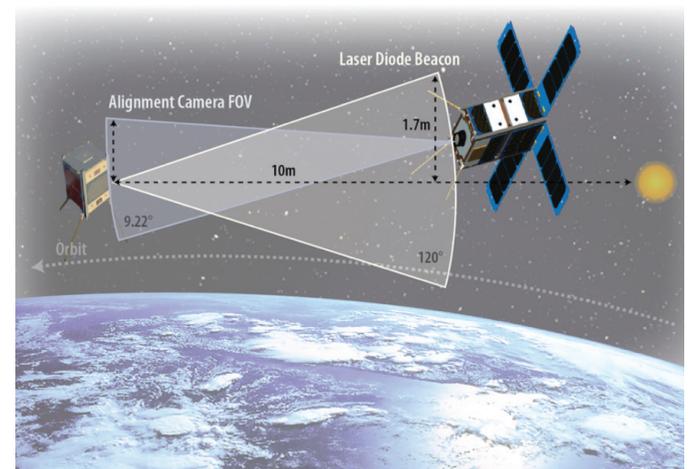
of a single telescope, one carrying the optics and the other a high-energy detector. This mission is scheduled to be placed in orbit by a SpaceX launch later this year.

Testing CubeSat Capabilities

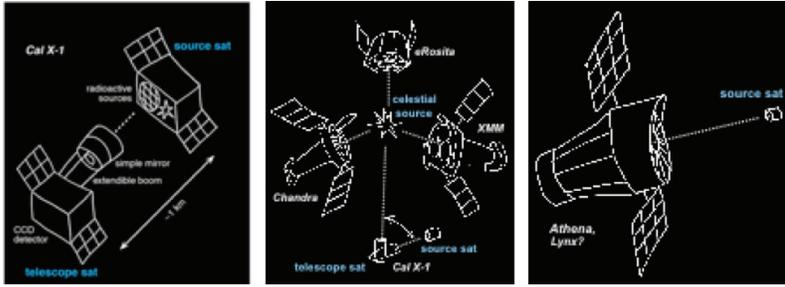
“The purpose of CANYVAL-X is to study techniques for forming and maintaining positional alignment between two space platforms with respect to a distant celestial source,” states Neerav Shah, Aerospace Engineer at NASA Goddard. “We will study different guidance, navigation, and control (GN&C) hardware and software systems to make this alignment in space.”

According to Mr. Shah, CANYVAL-X will test new CubeSat technologies that are on the cutting edge of performance in their respective arenas. These include:

- The micro-cathode arc thruster (mCAT), designed by the George Washington University, will provide 100 micro-Newton thrust in less than a 1U volume. This is a capability that currently does not exist in commercially available CubeSat components.



CANYVAL-X on orbit



Cal X-1 will consist of two CubeSats flying in formation (left). It will perform an in-orbit calibration by observing its radioactive standard and transfer that calibration to other observatories via simultaneous observations of a celestial source (middle). Future observatories may fly their own standard candles (right).

- A fine sun sensor, (GSC-16551-1) developed by the Goddard Space Flight Center Wallops Flight Facility, provides sub-arc-minute data on the direction to the sun, an order of magnitude improvement over current CubeSat-class sun sensors

In addition, CANYVAL-X will provide the first example of multiple CubeSats operating in concert to form a distributed “virtual” science instrument. Flying a pair of CubeSats in formation allows one satellite to block a celestial target from the point of view of the other satellite, thus serving as a coronagraph. This technique will enable astronomers to study objects close to a bright source, such as exoplanets near bright parent stars or the Sun’s elusive corona.

A Proving Ground for Future Missions

The capabilities and concepts demonstrated by CANYVAL-X will be critical for future space science missions. Next-generation NASA science measurements require instruments with long focal lengths, enabling remote sensing of high energy sources, from extreme ultraviolet to gamma-ray. These include targets as diverse as solar flares, accretion disks of black holes, and externally occulted systems used for attenuating visible light to image the solar corona and exoplanets. These instrument concepts will require advances in guidance, navigation, and control (GN&C systems) to enable the formation of distributed “virtual” space telescopes with platform separations ranging from 100m up to 50,000km. In addition, a distributed approach avoids the structural challenges associated with building and placing into orbit a “monolithic” telescope with a focal length of up to 20m or more.

“CubeSats are an enabling platform for testing and demonstrating the innovations of the future for low cost and risk,” says Mr. Shah. “Without CubeSats these innovative new science instruments would not

be matured and demonstrated as rapidly as we can today.”

CANYVAL has been the jumping-off point for several other missions now in development at NASA Goddard. Working under an Established Program to Stimulate Competitive Research (EPSCoR) grant, the Center has been partnering with New Mexico State University on a project called the Virtual Telescope for X-Ray Observations (VTXO). Shah explains, “VTXO is a distributed telescope similar to CANYVAL, but while CANYVAL is an engineering demonstration, VTXO will carry an actual science instrument onboard and will be making observations.” The three-year EPSCoR grant will fund primarily the development of the GN&C component technologies—handling the precise alignment needed for VTXO.

A second project in the works is Cal X-1, which is another x-ray mission, where one CubeSat will carry an x-ray telescope and the other will have a radiation source on board to calibrate the instrument. The two spacecraft will follow each other in LEO. Cal X-1 will take x-ray measurements and cross-match its data w/XMM [the X-Ray Multi-Mirror telescope] and Chandra to help clarify the results scientists are receiving from the big observatories. Shah says, “Chandra and XMM are billion-dollar observatories with high levels of precision. However, the two telescopes were calibrated at levels and are as much as 10-20% off from each other, creating lots of uncertainty for scientists studying x-ray phenomena.” Cal X-1 is designed to match up observations between NASA’s two flagship x-ray telescopes, as seen in the figure below.

A project internal to NASA Goddard, is the currently named Photon Sieve Mission (the official mission name is still pending). This will be a distributed telescope with a photon sieve (diffractive) optic on one CubeSat and a detector on the other. The two spacecraft will be approximately 100 m apart and will provide extreme ultraviolet (EUV) imaging of individual emission lines of the Solar Corona with 20-40 milli-arcsecond (mas) resolution. Shah says, “This is an exciting mission for the team because the mission will fly in a heliocentric drift-away orbit. We’ll be flying in deep space.” The “drift-away” orbit means that the spacecraft will circle the sun like Earth, but will not maintain a constant distance from the planet (drifting away from Earth).

This mission will require a lot of technology development, as it will need more radiation-tolerant hardware, technology for deep-space communi-

cations, and component technology that can withstand a >1year science mission. “All of our missions are pretty cool, but we’re especially really excited about this one. We won’t just be testing GN&C techniques, but also testing instrumentation and advanced CubeSat components, as well as collecting important science data.”

The CubeSat platform offers numerous advantages for these types of technology demonstrations. One obvious benefit is low cost, which is typically 2 to 3 orders of magnitude less expensive than a traditional mission. This allows for a much higher level of acceptable risk, enabling activities that would otherwise be deemed too risky for a billion-dollar mission.

Benefits Outside NASA Goddard

CANYVAL-X and its follow-up missions also offer an opportunity to advance CubeSat as a platform. Currently, CubeSat components do not provide sufficiently high performance to deliver the high level of precision required for CANYVAL-X’s positioning and other critical components. NASA Goddard is therefore developing these capabilities in house, which can then be made available for the general CubeSat community once demonstrated successfully.

In addition, some of this technology may eventually be leveraged into non-NASA terrestrial uses. For example, the GN&C architecture (consisting of both hardware and software components) can be adapted to be used on drones or UAVs for coordinated measurements of distributed systems.

Demonstrating the Value of CubeSat

Beyond its potential contribution to science – for example Cal X1 at several million dollars will cross-calibrate several billion-dollar observatories – the CANYVAL-X mission will serve as an excellent demonstration of how CubeSat has matured into an important platform for testing and proving new capabilities and technologies in space. As Mr. Shah states, “In a tight budget environment we need to find ways to advance science and technology. CubeSats offer a way to do so for low cost and risk and are thereby enablers of innovations in science and technology.”

Dr. Dong Wu Research Scientist

Code: 613

Years at NASA: 5

Education:

Ph.D. Atmospheric Sciences, University of Michigan, Ann Arbor
MS Electrical Engineering, University of Michigan, Ann Arbor
MS Physics, Louisiana State University
BS Space Physics, University of Science & Technology of China



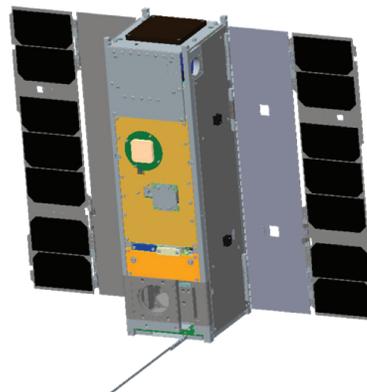
Dr. Dong Wu Interview

IceCube: Earth Science in a Small Satellite

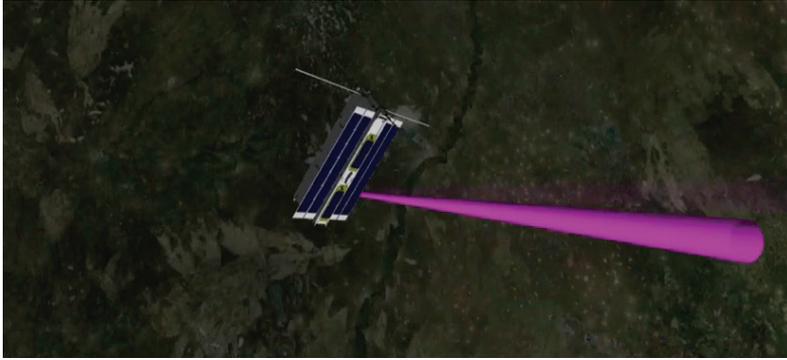
Throughout this issue of the NASA Goddard Tech Transfer News, we’ve focused on the theme of Small-Sats/CubeSats, how these platforms have evolved from a classroom tool towards a robust foundation for performing space science, and NASA Goddard’s role in facilitating this process. One of the more important accomplishments in this regard is IceCube. This 3U CubeSat will serve as the first Earth Science CubeSat from NASA Goddard.

Maturation of New Technology at a Fast Pace

A primary goal of the IceCube mission is to demonstrate and space-qualify an 883-gigahertz submillimeter-wave cloud radiometer. Funded in part by a NASA In-Space Validation of Earth Science Technologies (InVEST) and Advanced Technology Program, this radiometer will eventually be incorporated into an ice-cloud imaging experiment for future NASA’s Aerosol-Cloud-Ecosystems (ACE) mission.



3D-printed IceCube model



IceCube in space. The CubeSat spins around the sun vector at a rate of 3 minutes per revolution to produce maximum power for instrument operation. The beam of the 883 GHz cloud radiometer (illustrated in pink) also spins together with the CubeSat, sampling the atmosphere and the cold space periodically for calibration.

This radiometer will explore global scattering signals from ice clouds at 883 GHz to help scientists better understand the relationship between the hydrologic and energy cycles in the climate system. Ice clouds will ultimately affect precipitation processes and Earth’s radiation budget through reflection and absorption of solar energy.

IceCube launched in April 2017 onboard a supply mission to the International Space Station. The satellite is a 3U CubeSat built at NASA Goddard from commercially available parts.

Atmospheric Ice: The Great Unknown

One of IceCube’s major innovations is the frequency (883 GHz) at which the instrument operates for cloud remote sensing. Sub-millimeter wave remote sensing offers a unique capability for improving cloud ice measurements from space, due to its great depth of cloud penetration and volumetric sensitivity to cloud ice mass. At 883 GHz, ice cloud scattering produces a larger brightness temperature depression than at lower frequencies, which can be used to retrieve vertically integrated cloud ice water path and ice particle size. “This portion of the spectrum represents the highest window frequency we can use for cloud remote sensing” explains Principal Investigator Dong Wu, “and therefore will provide the first global survey of ice clouds at this frequency from a space-based platform.”

Unfortunately, the power consumed by the 883-GHz instrument also presents one of the mission’s biggest challenges. According to Dr. Wu, the instrument will be operated only during the daytime when it acquires solar power through a high-performance solar panel specially customized for this mission.

The IceCube team has also optimized the instrument to reduce its power consumption.

Other Applications

This novel sub-millimeter technology may hold some potential for non-NASA applications. One area of interest may be communications. “This frequency is much higher than what traditional communications use” says Dr. Wu. “But it does offer the advantage of being able to handle very high bandwidth.” As developers of communication systems explore ways to expand data transmission capacity, they will likely need to look at using higher frequencies, without substantially increasing power consumption or raising costs – the same issues currently being addressed by the IceCube team.

And in a more general sense, IceCube will likely advance the CubeSat platform as a whole. “CubeSat is still in its early stage” says Dr. Wu. “In this regard it reminds me of the early personal computer market, with many small vendors trying different things. NASA Goddard can play an important role in helping develop this market.” A more mature CubeSat platform will in turn provide significant scientific value. “CubeSats are an excellent low-impact entry point into space, providing capabilities that traditionally required rockets or high-altitude balloons. And once they’ve been placed in orbit, multiple CubeSats can coordinate and act as a single large instrument, for a fraction of the cost.”

IceCube is managed and co-funded by NASA’s Earth Science Technology Office (ESTO), which has several CubeSat projects under development and in-orbit.

Dr. Jacqueline Le Moigne

Assistant Chief for Technology

Code: 580

Years at NASA: 18

Education: Ph. D. Computer Science, MS Mathematics, BS Mathematics Pierre and Marie Curie University



Dr. Jacqueline Le Moigne Interview DSM & Pi-Sat

Over the years, NASA Goddard has played a vital role in the ongoing evolution of CubeSat from a teaching tool to a robust platform for advancing Earth and space science. Much of this work has taken the form of CubeSat missions such as Dellingr and IceCube. The technologies developed in support of these missions have been made available to the CubeSat community, helping advance the capabilities of these small satellites.

In addition to specific missions, NASA Goddard has undertaken several initiatives to help developers be creative and innovative with their CubeSat projects. For example, NASA Goddard has taken the lead in identifying and addressing the challenges involved in distributed spacecraft missions. NASA Goddard has also developed Pi-Sat, an extremely low cost platform for designing CubeSats and other small satellites.

Distributed Spacecraft Missions (DSM)

According to Dr. Jacqueline Le Moigne, Assistant Chief for Technology for the Software Engineering Division, a ***distributed spacecraft mission*** (DSM for short) is defined as a mission that involves multiple satellites performing a common goal. This may take the form of a general constellation; or the spacecraft may be very accurately controlled to perform formation flying, using either homogeneous or heterogeneous spacecraft. A particular case of a heterogeneous formation flying DSM is a “fractionated” mission; an example of such a DSM could be formed of three small satellites; one flying the computer, the second carrying data storage, and the third flying the communication system.

Distributed spacecraft missions have been considered since 2000 or earlier, and used on multi-spacecraft missions such as Magnetospheric Multiscale (MMS) and GRACE for which the desired science required several spacecraft. Although these missions have been highly successful, the cost of satellites usually precluded wide use of DSMs – it often is not cost-effective to design missions that require several full-sized craft, each of which potentially costing hundreds of millions of dollars or more.

The continued development of SmallSats (including CubeSats, MicroSats, and MiniSats) has sparked renewed interest in DSMs, since each individual spacecraft is less expensive than larger ones. This approach is now being considered for a number of applications. “Four years ago, we conducted a survey, interviewing over 50 Goddard scientists, to

determine what types of science applications could be served by DSM,” says Dr. Le Moigne. “We considered all science domains, including heliophysics, Earth science, astrophysics, and planetary exploration. For example, in the last application, DSM could be in the form of a larger mothership, which could release smaller subordinate satellites when coming close to the planet of interest.”

To help realize the potential of DSMs, Dr. Le Moigne and her colleagues have defined and are investigating several technical challenges, including:

- **Design:** Compared to flying a single satellite, multiple spacecraft missions can be far more complex and difficult to design. To help this effort, NASA Goddard, under funding by the Earth Science Technology Office (ESTO), is developing a “trade-space analysis” tool for designing constellations. A scientist or an engineer can input requirements into this tool, look at various options, and vary the number of spacecraft.
- **Building missions:** “We need to take advantage of economies of scale” states Dr. Le Moigne, “because there can be cost savings in designing ‘in bulk.’ For example, it might be possible to lower testing costs. But to take advantage of such savings, we must define new methodologies for integration and testing.”
- **Launch:** As secondary payloads, there are many ways to launch multiple small satellites. Different craft may require different launches, and multiple options will need to be considered.
- **Communication between craft:** This is a requirement for constellations taking coordinated measurements as well as for maintaining the required configuration for formation flying.
- **Guidance and Navigation for Precision Formation Flying (PFF):** Dual-platform very precise alignment is the main requirement that will enable a new type of science instruments such as distributed “virtual” space telescopes.
- **Onboard Intelligence:** This is one of the main technologies required to coordinate the simultaneous acquisition of multiple heterogeneous or homogeneous observations, e.g., using multiple vantage points or multiple resolutions.
- **Data:** As a general rule of thumb, more spacecraft means more data produced. There needs to be a way to handle this new form of “big” data.

Alan Cudmore
Computer Engineer

Code: 582

Years at NASA: 25

Education: MS
Computer Science,
Johns Hopkins
University, BS Computer
Science, University of Maryland,
Baltimore College



The Pi-Sat is based on the popular Raspberry Pi single-board computer.

Alan Cudmore Interview: Pi-Sat

To help address the preceding list of DSM challenges, NASA Goddard has developed the Pi-Sat. Based on the popular Raspberry Pi single-board computer, Pi-Sat provides a low-cost and easy-to-use test bed to facilitate the research and development of next-generation DSM technologies and concepts. This test bed also serves as a realistic software development platform for small satellite and CubeSat architectures.

The basic Pi-Sat package consists of:

- Credit-card sized Raspberry Pi processor
- 3D printed enclosure and battery
- NASA Goddard's core Flight System (cFS) flight software architecture

According to Alan Cudmore, Computer Engineer in the Flight Software Systems Branch and Pi-SAT project lead, Pi-Sat serves three primary functions:

- Prototyping platform for SmallSat/ CubeSat. Pi-Sat may also be used for larger missions.
- Research and development for distributed platforms. For example, research-

- ers can build several units and have them communicate with each other.
- Testing the core Flight Software. cFS is Open Source, so it is available to anyone to use on a Raspberry Pi based system.

"Pi-Sat is extremely inexpensive" explains Mr. Cudmore. "The Raspberry Pi can be purchased for \$35. This brings it within reach of virtually anyone, even students."

Pi-Sat operates on the Linux operating system and can run the cFS software architecture. Pi-Sat models currently include a 1U Cube, a Wireless Node, and a prototype 1U CubeSat processor card that uses the Raspberry Pi Compute Module.

Originally designed in 2014, Pi-Sat's early purpose was education and training. Students can use Pi-Sat with cFS and interact with sensors. Although initially intended to be a laboratory-only tool with no ability to survive in space, there is now growing interest in adapting Pi-Sat for use in space-based applications.

Conclusion

DSM and Pi-Sat represent only two

examples of how NASA Goddard is advancing the science of SmallSat/CubeSat. As discussed in another article in this issue, missions such as Dellingr demonstrate how multiple small satellites can work in concert to provide space science that historically required a large satellite. These distributed satellites may eventually be able to replicate the capabilities of single “big-ticket” satellite, at a fraction of the cost. Along the way, tools such as Pi-Sat will help developers fully realize the enormous potential of the SmallSat/CubeSat platform as a vital component of NASA’s space strategy.

Scott Schaire
Near Earth Network
Wallops Manager

Code: 453

Years at NASA: 11

Education: MBA
Georgia State University
MSCS Polytechnic
Institute of New York,
BSEE Cornell University



Scott Schaire Interview

Scott Schaire is Near Earth Network Wallops Manager at NASA Goddard Wallops Flight Facility. In this interview, Scott discusses NASA’s Goddard Near Earth Network (NEN) Project small satellite initiatives, an effort to apply existing ground network infrastructure to support small satellite platforms.

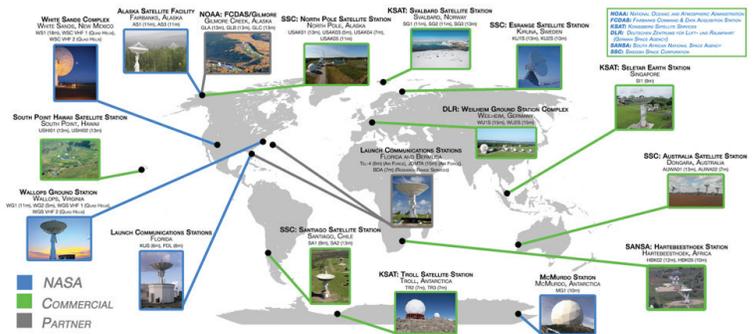
Q. What are the primary goals of the SCaN program?

Scott Schaire: The NEN is one of three NASA networks under the Space Communication and Navigation (SCaN) Program. The NEN ground network is primarily concerned with supports from the Earth out to the moon and L1/L2. The purpose of the NEN is to provide telemetry, tracking and command and launch and early orbit support for NASA missions.

Q. Where are the NEN tracking stations located?

Scott Schaire: The NEN assets include NA-

THE NEAR EARTH NETWORK PROJECT



Near-Earth Network (NEN) Ground Stations

SA-owned and commercial tracking stations, located throughout the world. The NASA-owned facilities are located at Wallops in Virginia; McMurdo Ground Station in Antarctica; White Sands in New Mexico; Kennedy Uplink Station and Ponce De Leon in Florida; and Alaska Satellite Facility in Fairbanks, operated and maintained by the University of Alaska Fairbanks.

Q. What missions does NEN support today?

Scott Schaire: The NEN currently supports about 40 NASA missions across the NASA Science and Human Exploration and Operations Mission Directorates. The NEN is currently well positioned to service emerging small satellite and CubeSat missions. The NEN continues to investigate additional capabilities that will make the NEN even more applicable for these emerging markets.



Scott Schaire presenting at a recent Small Satellite conference.

Q. What benefits can the NEN provide to small satellites?

Scott Schaire: Small satellites such as CubeSats are subject to a number of communication constraints due to their small size, limited power, and other factors. By taking advantage of the NEN, small satellites can greatly enhance their communication capabilities in terms of speed, bandwidth, quality, and reliability. Historically, CubeSats have communicated over UHF, often on secondary frequencies. Among the limitations of this band is susceptibility to interference from sources such as police radios and others. Unfortunately, there's no way to filter out this interference, which can compromise the integrity of the communication.

The NEN operates on multiple bands, including S, X, and Ka. These regions of the electromagnetic (EM) spectrum offer higher data rates than UHF, and communications will be assigned as primary frequencies. Higher data rates provide the potential of higher-resolution science data, which combined with reduced interference means small satellites will be able to deliver much higher-quality data.

The NEN can also be highly valuable in CubeSat mother-daughter constellation flying. For instance, the constellation mothership will be a store-forward relay to downlink the science data to the ground via a NEN direct to ground link. Enhanced power and bandwidth signal techniques will enable higher data rates for these missions.

Q. What enhancements are planned for NEN?

Scott Schaire: Our current plans call for the addition of a new NASA station in Alaska. We are also investigating new capabilities that will increase bandwidth and allow the network to keep up with growing data demands as new missions are launched. At present, there are about 15 NASA CubeSat missions planned by 2020 for NEN; it's likely this number will rise.

Q. How can small satellite operators gain access to NEN?

Scott Schaire: For NASA missions, after mission award, use of NASA NEN stations is free.

Q. How do you justify the costs for enhancements?

Scott Schaire: Small investments in network infrastructure could pay off over dozens or even hundreds of missions.

Q. How does NEN leverage commercial stations?

Scott Schaire: NASA keeps costs low either by owning the ground stations outright or buying bulk time on commercial stations that the NEN then offers at a discount. As commercial service providers upgrade their systems, the NEN will continue to provide discounted access to NASA users, serving as a broker for these commercial networks.

Our mission is to provide satellite operators with the highest communication rates at the lowest costs, enabling them to deliver the highest quality data to their customers. The NEN offers a great deal of advanced NASA-supported communications infrastructure. As a result, it makes sense for more and more providers of small satellites to take advantage of the Near Earth Network.

Luis Santos
Mission Systems
Engineer on
SmallSat Projects



Code: 599

Years at NASA: 12

Education:

MS Systems Engineering Old Dominion University, BS Mechanical Engineering University of Puerto Rico-Mayaguez

Luis Santos Interview: PetitSat

Luis Santos is an aerospace engineer supporting NASA Goddard in Mission Systems Engineering. During his first nine years at NASA, he specialized in structures and mechanism design, analysis, manufacturing, and testing. During the latter part of this period, he worked on CubeSats and CubeSat tech-

nologies from the mechanical standpoint. Since completing a Master's Degree in Systems Engineering in 2013, he has worked as a Mission Systems Engineer on multiple CubeSat missions such as the Dellinger 6U CubeSat and HaloSat 6U CubeSat. Santos is working with Principal Investigator Jeff Klenzing. Klenzing is a research scientist focusing on Ionosphere-Thermosphere science, particularly ion-neutral coupling and plasma irregularities. After completing a Ph.D. in Physics in 2008, he began working with instrument development for several smallsat missions, including the Firefly CubeSat and the FASTSAT SmallSat. The following article discusses the work he and Principal Investigator Jeff Klenzing have been pursuing on the PetitSat mission

Q. What, exactly, is PetitSat? How does it fit within the size scheme of SmallSats, and what is it designed to do?

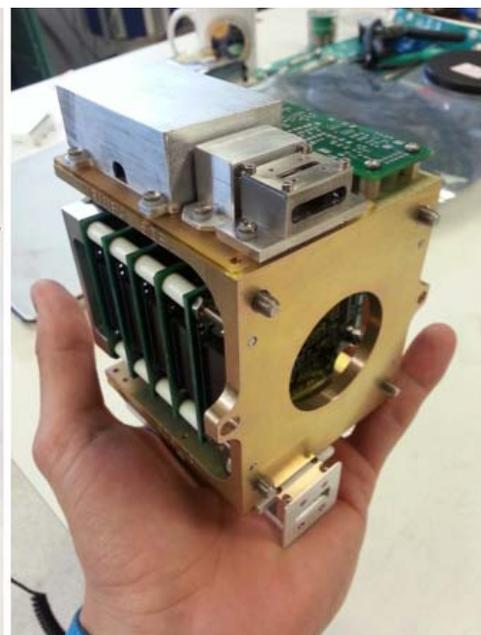
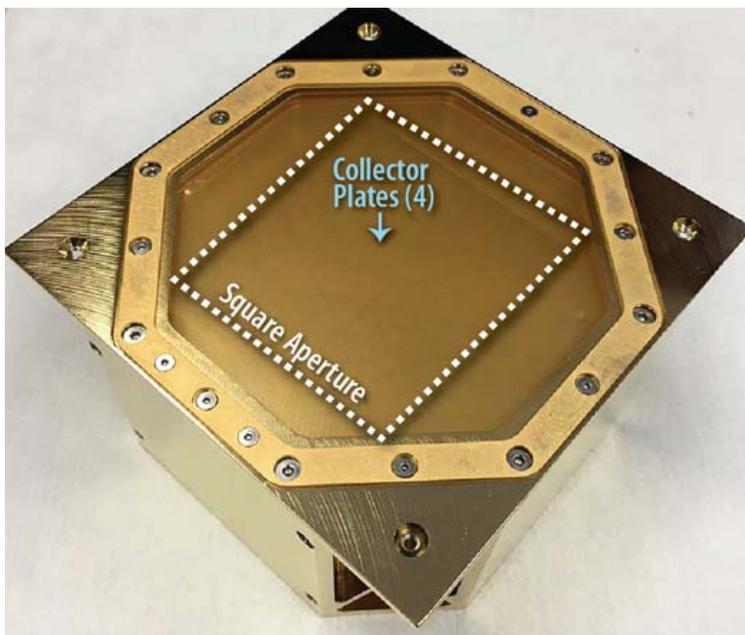
Luis Santos: PetitSat is a 3-axis stabilized 6U CubeSat. It will examine the connection between plasma density enhancements observed in the ionosphere and wave activity in the neutral atmosphere. Klenzing explains: "These density structures have been observed by previous satellites and attributed to multiple physical sources, but we have not yet had comprehensive measurements in the right location in order to determine the dominant mechanism. A CubeSat launch from the ISS will give us measurements near the peak ionospheric density, allowing the physical mechanisms to be identified."

Q. What is NASA Goddard's involvement with this project?

Luis Santos: The NASA Goddard team will manage the mission, science and technical implementation. Klenzing adds, "Goddard is building the Neutral Mass Spectrometer (NMS, PI: Sarah Jones), which is similar to the version that will fly on Dellinger later this year." The NMS will be used to identify local perturbations to the neutral atmosphere. Utah State University is building the Gridded Retarding Ion Drift Sensor (GRIDS, PI: Ryan Davidson), which provides information about the ion distribution, including density, composition, temperature, and 3D drifts. Greg Earle at Virginia Tech will be providing ground calibration of the GRIDS instrument. We will be comparing the in-situ satellite data of both ions and neutrals to conjunctions with the Boston University network of All-Sky Imagers to confirm potential mechanisms acting lower in the atmosphere. Carlos Martinis at BU leads the ground-based efforts.

Q. How will PetitSat advance SmallSat technologies/capabilities?

Luis Santos: Santos explains that PetitSat is a science mission, not a technology development mission. However, it will advance some technology internal to GSFC. Klenzing adds, "The next science step is to expand into a multi-CubeSat constellation to untangle the spatial and temporal variations of meso-scale plasma structures."



PetitSat is flying a version of the Goddard-developed Ion-Neutral Mass Spectrometer and the Gridded Retarding Ion Drift Sensor, or GRIDS, provided by Utah State University and Virginia Tech.

Dr. Ramsey Smith
SBIR/STTR Deputy
Program Manager

Code: 102

Years at NASA: 7

Education: Ph.D.
Physical Chemistry and
Atmospheric Chemistry,
Howard University, BS
Chemistry, Morehouse College



**Dr. Ramsey Smith Interview:
SBIR/STTR**

Dr. Ramsey Smith is one of NASA Goddard Space Flight Center's Leads for the NASA Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs. The goal of the SBIR/STTR program is to "...enable small businesses and small businesses collaborating with universities...to compete for opportunities to solve selected Research and Development (R&D) challenges faced by various government agencies within the United States." In this interview, Dr. Smith shares some insights into how the SBIR/STTR programs help support NASA Goddard's work with CubeSats and other small satellites.

Q. *How do the SBIR/STTR programs help support NASA Goddard goals?*

Dr. Ramsey Smith: The NASA Goddard SBIR/STTR portfolio is a vehicle for filling the technology gaps across many areas. Filling these gaps helps us overcome the

challenges of meeting our science goals and objectives. Among these objectives is our ongoing work with small satellites such as CubeSats.

In regard to CubeSat, NASA Goddard challenges are virtually unique. Our ultimate goal is to enable highly reliable science measurements to be performed on CubeSats and other small satellites. Recent SBIR/STTR solicitations have listed subtopics for technologies that could help our development efforts in this area.

Q. *What are some of the SmallSat/CubeSat technical needs that can be addressed by SBIR/STTR funding?*

Dr. Ramsey Smith: What we're really looking for are disruptive technologies that will enable different types of measurements to be performed from CubeSats and other small satellites. For example, among our needs are miniaturized instruments and sensors for small satellite payloads, as well as the mechanisms and structures needed to support these instruments and sensors. There's also thermal management; small satellites have unique requirements in this regard. Power and data storage are also important areas, as are guidance, navigation, and control.

We need processors to manage the data produced by the sensors, and software for the satellite and ground communications. Our communication requirements fall into two areas. There's short-range, which involves the satellite communicating with the ground. We are also interested in deep space. One communication technology we're considering is optical communication.

One thing to consider is that small satellites may have shorter mission lives, on the order of 3 to 12 months as opposed to 3 to 5 years for large satellites. This may impact the design of technologies intended for use on CubeSats.

Q. *Are technical specifications available for these needs?*

Dr. Ramsey Smith: The technical specifications are listed in the solicitation subtopic descriptions. These subtopics are written by subject matter experts who list out all the elements they need to the particular field of science.

Note that these specifications are only intended to describe the need to be addressed. They are not a detailed blueprint for building a component. Our goal isn't to simply buy a part. Instead, we're trying to meet a technical need. We want the company to feel free to be creative in solving that need, perhaps in ways we haven't considered.

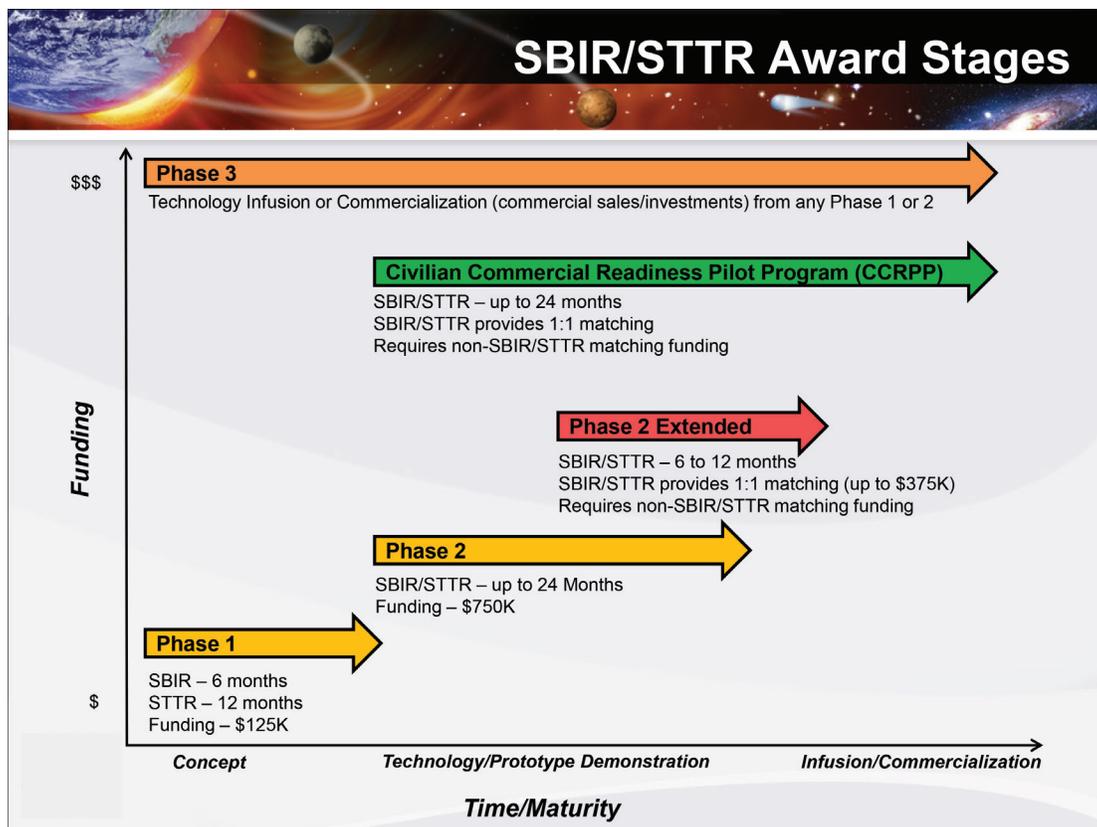
Q. *How can companies develop compliant proposals?*

Dr. Ramsey Smith: The first steps in developing a plan for a compliant SBIR proposal are to determine what technologies NASA is seeking, and then consider how their company can fulfill that requirement. One good way to do this is to engage scientists and engineers to learn what NASA Goddard wants. This helps ensure the company goes down the right development path.

To be compliant, companies should thoroughly read the subtopic, and ensure their proposal is directly addressing the requirements described in the subtopic. Understanding our science needs puts the company in a better position to meet these needs, and enables them to write a comprehensive and compliant proposal.

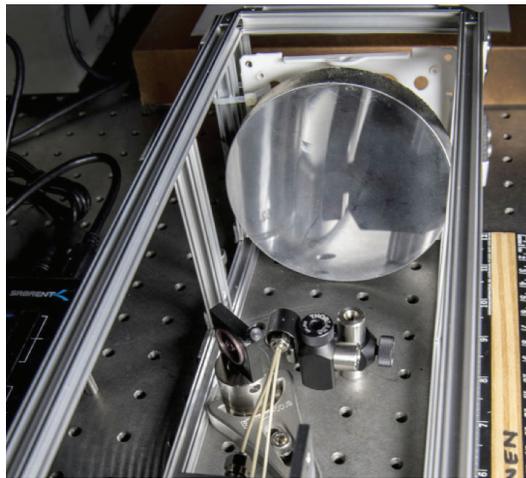
Q. *In what other ways can an SBIR award benefit a company?*

Dr. Ramsey Smith: An SBIR award puts the company in a better position to work in the commercial and government arenas through special procurement vehicles such as Phase III contract. Our funding should place companies on the pathway towards commercialization.



SBIR/STTR Awards Stages.

The following is a brief review of recent news stories prominently featuring NASA Goddard's ongoing work with the CubeSat platform.



A Carbon Nanotube Telescope Mirror for CubeSats

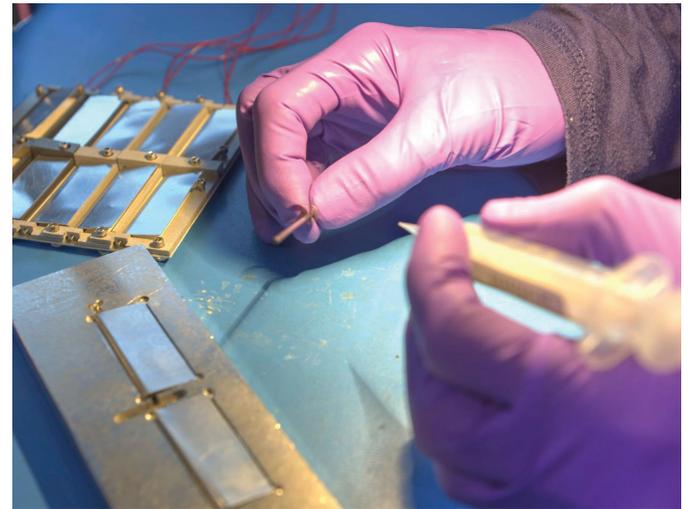
NASA Goddard is developing a highly innovative telescope mirror for eventual use on CubeSats. This mirror is the first ever fabricated from carbon nanotubes embedded in an epoxy resin, a material that provides a variety of advantages. In addition to offering exceptional strength-to-weight ratio, carbon nanotubes are damage-resistant and form an efficient thermal conductor. The optics will be sensitive to the ultraviolet, visible, and infrared wavelength bands. It will be designed to use off-the-shelf components such as spectrometers and imagers. One application for these instruments would be as a quick exploratory tool in preparation for potential larger missions.

For more information, see: <https://www.sciencedaily.com/releases/2016/07/160712173322.htm>.

Thermal Control Technology for CubeSats

By repurposing a large panel of louvers initially designed for 1960's era spacecraft, NASA Goddard innovators have developed a passive thermal-control technology designed to integrate with CubeSats. Current plans call for the small thermal-control system on the Dellingr mission, a 6U CubeSat. (See the separate article on this mission in this issue of the NASA Goddard Tech Transfer News.)

For more information, see: <http://www.executivegov.com/2016/05/nasa-goddard-scientists-develop-cubesat-thermal-control-tech/>



Technologist Cindy Goode holds the tiny spring essential to operating the new thermal-control device that will be tested during Goddard's 6U Dellingr mission.

Disclosures

PERL6 LIBCURL

Curt Tilmes

NIOBIUM TITANIUM NITRIDE THIN FILM COATINGS FOR FAR-INFRARED ABSORPTION AND FILTERING

Ari Brown, Edward Wollack, Kevin Miller

SATA HOST CONTROLLER IMPLEMENTATION ON XILINX 7-SERIES FPGAS FOR USE IN HIGH SPEED CAPTURE OF ARBITRARY DIGITAL DATA

Roman Novoselov, David Watt

HYBRID ANALOG/DIGITAL COMPLEX DOWNCONVERSION SCHEME

David Watt

DATA TO SURETRAK

Nathan Riolo

COMPACT RF DATA CAPTURE AND PROCESSING MODULE

David Watt, Roman Novoselov, Steven Chen

COLLISION AVOIDANCE SOFTWARE

Marissa Herron

ROBUST CALIBRATION TARGET WITH MINIMAL POLARIZATION SIGNATURE

Edward Wollack, David Chuss, Karwan Rostem

COMPACT CUBESAT-COMPATIBLE 600W S-BAND PULSED POWER AMPLIFIER

Mark Schutzer, John Buonocore

INTEGRATED COMPACT RADAR TRANSCEIVER

David Watt, Roman Novoselov, Steven Chen, John Buonocore

TRANSFER OF WIND WEIGHTING SOFTWARE TO WHITE SANDS MISSILE RANGE

Michael Disbrow

COMPUTER MODELING FOR GENERATION OF SYNTHETIC RADIO REFLECTION-TRANSMISSION TOMOGRAPHY (RRTT) DATA FOR EXPLORING SUBSURFACE GEOLOGY OF ASTEROIDS AND COMETS

Manohar Deshpande

NOVEL ANTENNA CONCEPT FOR CUBESAT PLATFORMS

Manohar Deshpande

RFI MITIGATION AND TESTING EMPLOYED AT GGAO FOR NASAS SPACE GEODESY PROJECT (SGP)

Lawrence Hillard, Ganesh Rajagopalan, Charles Turner, Thomas Stevenson, Berhanu Bulcha

MANUFACTURE OF MONOLITHIC TELESCOPES WITH FREEFORM SURFACES

Joseph Lawson, Todd Blalock, Matt Brunelle

DATA MANAGEMENT SYSTEM (DMS) 4

Timothy Singletary, Mark Neuberger, Michael Deschu

PERL6 LVFS: DISHAS CLIENT

Curt Tilmes

PERL6 SLURM CLIENT

Curt Tilmes

OPEN-JAW MONOLITH

Joseph Lawson, Todd Blalock, Matt Brunelle

FREEFORM CORRECTION OF MONOLITHIC PRISMS

Joseph Lawson, Todd Blalock, Matt Brunelle

SPACECUBE V2.0 FLIGHT CARD MECHANICAL SYSTEM

Milton Davis, David Petrick

PASSIVATED BATIO3 - PBT50 BASED CONDUCTIVE TCMS FOR SPACE APPLICATIONS

Hetal Patel, Vivek Kamat, Mukund Deshpande

A COMMUNITY-DRIVEN WORKFLOW RECOMMENDATION AND REUSE INFRASTRUCTURE

Jia Zhang, Ian Foster

LI INTERCALATED BORON NITRIDE, NANO TUBE AND NANO MESH FOR TAILORED CONDUCTIVITY TCMS SPACE APPLICATIONS

Mukund Deshpande, Dr. Narayan Hosmane, Vivek Kamat

DOPED AND MISCIBLE SOLID SOLUTIONS OF -LI(AL/GA)O2 FOR CONDUCTIVE TCMS SPACE APPLICATIONS

Mukund Deshpande, Hetal Patel, Vivek Kamat

LI4TI5O12 BASED CONDUCTIVE TCMS FOR SPACE APPLICATIONS

Mukund Deshpande, Hetal Patel, Vivek Kamat

LI INTERCALATED BORON NITRIDE NANO MESH FOR CONDUCTIVE TCMS FOR SPACE APPLICATIONS

Mukund Deshpande, Amartya Chakrabarti

NASA CLAUSE FINDER

Geoffrey Sage

EVOLUTIONARY MISSION TRAJECTORY GENERATOR V8.1

Jacob Englander, Jeremy Knittel, Donald Ellison

NASA EXHAUSTIVE LAMBERT LATTICE SEARCH (NELLS)

Donald Ellison, Jeremy Knittel

GENERAL MISSION ANALYSIS TOOL (GMAT) VERSION R2017A

Steven Hughes, Rizwan Qureshi, Mark Nicholson, Steven Slojkowski, Linda Jun, Wendy Shoan, Darrel Conway, Tuan Nguyen, Thomas Grubb, Joel Parker, D.S. Cooley, Tetyana Royzman, John Downing, John McGreevy, Donald Ginn, Michael Stark

ULTRA-COMPACT STAR SCANNER

Sean Semper, Andrew Salamon

**DELPHICORE TOTAL
VERIFICATION
SYSTEM FPGA DESIGN**

Omar Haddad, Shahana Pagen

**LIDAR AND CAMERA IMAGE
REGISTRATION AND SLAM**

Alonzo Kelly

**TUNING IN TO COSMIC RAYS
AND NEUTRINOS USING NOVEL
RADIO DETECTION TECHNIQUES**

*Tonia Venters, Theresa Brandt,
Victor Marrero-Fontanez*

**RECONFIGURABLE
OPERATIONAL SPACECRAFT
FOR SCIENCE AND
EXPLORATION (ROSE)
CONNECTOR
INTERFACE MECHANISM**

*Richard Michael, Beth Keer,
Thomas Hanyok*

**DUAL WAVELENGTH LASER
TRANSMITTER DEVELOPMENT
FOR TIME OF FLIGHT MASS
SPECTROMETRYPROJECT**

Anthony Yu, Steven Li, Molly Fahey

**GODDARD'S RECONFIGURABLE
LASER RANGER (GRLR)**

*James Leathan, Matthew Jenkins,
Tim Johnson*

**OFFLOAD ADJUSTMENT
FOR SATELLITE
IMAGE DIVERSITY**

*James Leathan, Matthew Jenkins,
Tim Johnson*

**IMPROVED LED AS AN
ILLUMINATION SOURCE USING
BUTT-COUPLED FIBER
OPTICS FOR SIDESCATTER
IMAGING OF CLOUD DROPLETS**

Andrei Vakhtin

**PROCESS TO PROVIDE
UNIFORMITY IN
SUB-MM LENSLETS**

Charles Dupuy

AETD OPEN JOBS

Gregory Wood

C & I CABLE TESTER

John Murad

**CONDUIT (OPEN SOURCE
SOFTWARE RELEASE REQUEST)**

*Nathan Clark, John
Cromartie, Maitreyee Pasad,
Nevin Apondo*

SOLAR DATA TOOL

Daniel Pachura

**SMALLSAT COMMON
ELECTRONICS BOARD (SCEB)
COMPLEMENT BOARD
DESIGN: MEMORY CARD**

James Fraction, Andrzej Jackowski

**IMPLEMENTATION OF
PRACTICAL FIBER OPTIC
GYROSCOPES (FOGS) FOR HIGH
ACCURACY SPACE
APPLICATIONS BASED
ON PHOTONIC CRYSTAL
FIBER (PCF)**

*Behzad Moslehi, Ram Yahalom,
Levy Oblea, Richard Black*

**SINGLE COVARIANCE
MAXIMUM PC**

Daniel Pachura

**CALCULATE INFRARED
PUMPING RATES BY SOLAR
RADIATION IN COMETARY COMA**

Miguel De Val Borro

LTAS MDDF GRAPHICS

Nathan Riolo

**DISTRIBUTED HASH ARCHIVE
SERVER (DISHAS)**

*Navid Golpayegani, Curt Tilmes,
Damon Earp, Jihad Ashkar*

**WAFER-SCALE MEMBRANE
RELEASE PROCESS**

*Ari Brown, Joseph Oxborrow,
Vilem Mikula, Kevin Denis,
Timothy Miller*

**PHOTONIC IC SPECTROMETER
FOR SPACECRAFT**

*Mark Lucente, Kyle Hoover, George
Nehmetallah, Nicolas Gorius*

**DENOISING IMAGE SEQUENCES
VIA 3-D FOURIER ANALYSIS**

Craig DeForest

**IMPROVING FLATNESS OF THZ
MICROMACHINED SPLITBLOCK
WAVEGUIDE CIRCUITS**

*Matthew Underhill,
Christopher Groppi*

**SLR DATA OPERATIONS CENTER
(DOC) SERVER OPERATING
SYSTEM UPGRADE**

*Oscar Brogdon, Ralph Harman,
Davis Johnson, John Kim*

HERMES

Navid Golpayegani

**METHODS INVOLVING OXYGEN
PLASMA EXPOSURE TO
IMPROVE ADHESION OF
SILICATE THERMAL COATINGS**

Mark Hasegawa, Kenneth O'Connor

**METHODS FOR INCREASING IR
EMITTANCE OF THIN FILM
SECOND SURFACE MIRRORED
THERMAL CONTROL COATINGS**

*Mark Hasegawa, Grace Miller,
Alfred Wong, Kenneth O'Connor*

**DATA ACQUISITION
(DAQ) SERVER**

James Bible

**PLANETARY CRATER
DETECTION AND REGISTRATION
USING MARKED POINT
PROCESSES, GRAPH CUT
ALGORITHMS, AND WAVELET
TRANSFORMS**

*Jacqueline Le Moigne-Stewart,
Sebastiano Serpico, Alberto Gotelli,
Gabriele Moser*

**PLANETARY CRATER
DETECTION AND REGISTRATION
USING MARKED POINT
PROCESSES, MULTIPLE BIRTH
AND DEATH ALGORITHMS, AND
REGION BASED ANALYSIS**

*Jacqueline Le Moigne-Stewart,
Sebastiano Serpico, David Solarna,
Gabriele Moser*

**STRAY LIGHT BAFFLE DESIGN
AND OPTICAL DESIGN OF
NESTED X-RAY TELESCOPES**

Timo Saha

TRADE-SPACE ANALYSIS TOOL FOR DESIGNING CONSTELLATIONS: TAT-C

Jacqueline Le Moigne-Stewart, Philip Dabney, Matthew Holland, Steven Hughes, Olivier de Weck, Veronica Foreman, Afreen Siddiqi, Sreeja Nag, Paul Grogan

RANGE SPACE (rSPACE)

Andrew Parkinson

PC UNCERTAINTY

Matt Hejduk, Lauren Johnson

(ITAR) ROBOT ELECTRONICS UNIT (REU) MOTOR CONTROLLER BOARD (MCB) - SSPD RESTORE-L PROJECT

Ike Orłowski, Pietro Sparacino, Seshagiri Nadenlda, Roger Chiei, David Petrick

ROBOTIC INFLATABLE TOOLS FOR ON ORBIT REPAIR OF SATELLITES (RESOLVE SOLAR ARRAY AND ANTENNA DEPLOYMENT ANOMALIES)

Joseph Pellegrino, Neil Barrett, Nicholas Behnke, Devin Padron

US Patents Issued

NORMALLY-CLOSED ZERO-LEAK VALVE WITH MAGNETOSTRICTIVE ACTUATOR

9,657,858

CSAZI-AMP: CHOPPER STABILIZED AUTO-ZERO INSTRUMENTATION AMPLIFIER FOR A THERMOPILE READOUT

9,685,913

Patent Applications Filed

NEW LENSLET ARRAY BASED INTEGRAL FIELD SPECTROGRAPH DESIGN FOR HIGH DETECTOR PIXEL EFFICIENCY

STEERING MIRROR ASSISTED LASER FINE POINTING

MICROCONTROLLER ALTIMETER (UCA)

SYNTHETIC SLOT CLOCK GENERATION FOR HIGH CARDINALITY PULSE POSITION MODULATION (PPM)

CUSTOM APPLICATION SPECIFIC INTEGRATED CIRCUIT FOR DETECTOR CONTROL AND DATA ACQUISITION

Provisional Patents Filed

FAST COUPLED LOADS ANALYSIS METHOD USING NORTON THEVENIN AND RECEPTANCE COUPLING (NTRC)

NASA GODDARD RELATED TECHNOLOGIES

RELATED TECHNOLOGIES

Case No.	Technology	Technology Description
GSC-17902-1	SmallSat Common Electronics Board (SCEB) Complement Board Design: Memory Card	Future small satellite (SmallSat) missions that will require more than 16 GB of memory storage will require a separate Memory Card design to meet this requirement. This board can be integrated with the existing Smallsat Common Electronics Board (SCEB) [e-NTR #: 1432651073] and its Adapter Board. This board will have up to 96 GB of NAND Flash memory along with either a radiation tolerant FPGA or a set of three commercial FPGAs to implement additional mission requirements. The Memory Card will have interfaces to the C&DH subsystem (i.e. the SCEB and its Adapter Board), the spacecraft high speed transmitter, and multiple spacecraft instruments.
GSC-17888-1	Reconfigurable Operational spacecraft for Science and Exploration (ROSE) Connector Interface Mechanism	A mechanism that engages connectors of various types and sizes between two (2) independent units, ie. S/C and ORU. This mechanism would be actuated via a robot during servicing of a Spacecraft while in orbit.
GSC-17887-1	Ultra-compact Star Scanner	An innovative approach to fuse the rapid advancements in miniaturized high-speed electronics with the ultra-compact freeform optical design from our efforts to create the next generation of stellar scanner instruments. The next major step to reduce this instruments volume, power consumption and cost will rely on simplified optical alignment and packaging methods. In addition, a credit card-like footprint sensor board prototype will be created with optimally packed electronics to push the limits for volume and resource reduction.
GSC-17868-1	SpaceCube v2.0 Flight Card Mechanical System	The SpaceCube v2.0 flight mechanical system leverages seven years of heritage spaceflight designs while advancing the technology several more steps. This version of the architecture is better suited to handle higher environmental and reliability requirements than its predecessor. It is also being built for a longer life cycle. In addition, it is intentionally designed to accommodate multiple use cases and missions. It is targeted for, but not limited to, space missions operating in and beyond low earth orbit (LEO) that require thermal and structural not available in other space processor and power systems. The system ensures the mechanical and thermal integrity of the high power dissipation and extremely complex processor and power daughter board (or electronics card) assemblies even mounted in a back-to-back, mirror-image configuration. The design is implemented specifically for the extended 3U SpaceCube system and its variations. The mechanical frame is intentionally designed to be scaled up or down for various power dissipative, structural vibration, electromagnetic, and radiation use cases of the SpaceCube system.
GSC-17864-1	Novel Antenna Concept for CubeSat Platforms	RF antennas are essential component of any communication and remote sensing radar/radiometer systems. Types of antennas that are currently used on CubeSat/ SmallSat platforms are : (1) monopole/dipole antennas (2) Printed antennas, (3) printed antennas integrated with solar cell, (4) printed antennas printed on the backside of solar cell. These types of antennas need packaging and deployment mechanism. Hence their use poses a deployment failure risk to a mission. Furthermore, these types of antennas add extra volume and weight to its payload. This innovation describes a novel embedded antenna concept that is free from the disadvantages described above. Basic structure of any CubeSat structure consist of four solid railing rods at its four corners. These railing rods are made of solid square rods. In the present novel antenna concept these railing are replaced by rectangular waveguides to carry RF signals. These rectangular waveguides at the four corners of a Cubesat with radiating slots on either its broad or narrow walls will act as antennas for a desired operating frequency . Thus the railing will provides an RF antenna functionality in addition to supporting the CubeSat structure.

NASA GODDARD RELATED TECHNOLOGIES

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Case No.	Technology	Technology Description
GSC-17854-1	Compact CubeSat-Compatible 600W S-Band Pulsed Power Amplifier	SRI has developed a compact power amplifier for CubeSats and UAV platforms that can generate radar pulses at S-band frequencies with a peak power of 600W RF at a 10% duty cycle.
GSC-17845-1	SpaceCubeX : A Framework for Co-Design and Evaluation of Heterogeneous Computing Platforms	SpaceCubeX is a co-design environment for heterogeneous systems that are integrated at the chip or board level, currently supporting processors, FPGAs, and DSPs. Our environment allows hardware design to iterate with software creation, and generates simulation and emulation test harnesses for application developers. SpaceCubeX automates the system-level tasks required to integrate and manage IP hardware cores, interconnects, memory interfaces, and other devices, providing a unified mechanism to direct communications between devices that can be managed from typical embedded programming languages such as C as well as modern scripting languages such as Python. We have evaluated SpaceCubeX-developed systems using a suite of high performance embedded computing benchmarks and Earth science scenarios in both simulation and emulation, across four simulation testbed models, a baseline SpaceCube 2.0 system, a dual ARM A9 processor system, a hybrid quad ARM A53 and FPGA system, and a hybrid quad ARM A53 and DSP system.
GSC-17782-1	Steering Mirror assisted laser fine pointing	An apparatus for improving a pointing capability of an optical pointing system includes a star tracker attitude control system for maintaining an alignment between the optical pointing system and a target, a beam steering mirror controlled by the star tracker attitude control system to direct an optical signal to impinge on the target, a fixed optical assembly configured to direct a portion of the optical signal from the beam steering mirror into a field of view of a star tracker telescope of the star tracker attitude control system, and a detector array for detecting the portion of the optical signal superimposed over a location in a current star scene in the star tracker telescope field of view, where the star tracker attitude control system is configured to operate the beam steering mirror to maintain the optical signal on the target by maintaining the superimposed signal on the location in the star scene.
GSC-17762-1	Multispectral Imager using Quantum Dot Spectrometer	We are developing an ultra-compact, low mass, and low-cost multispectral imager based on an innovative concept of quantum dot array that acts as an absorptive filter array and replaces prisms, gratings, interference filters or other optical components currently used in spectrometers. The advantages of such a Quantum Dot Spectrometer (QDS) make it a suitable instrument for small satellite missions in Earth Science, Heliophysics and Planetary Science
GSC-17723-1	A Housekeeping Slave Node (RH-HKSN) chip implemented in a Radiation Hardened Mixed-Signal Structured ASIC	The Radiation Hardened Housekeeping Slave Node (RH-HKSN) Application Specific Integrated Circuit (ASIC) will serve as a low-power data acquisition system-on-a-chip suitable for miniaturized instruments, CubeSats and spacecraft housekeeping data collection. The device will be used as a remote terminal unit (RTU) where it operates as a standalone housekeeping/telemetry collection node reducing wiring, complexity and power. The implementation for this devices varies from the standard custom ASIC implementation by implementing it in a new radiation hardened Mixed-Signal structured ASIC platform.
GSC-17670-1	Implementation of GPS L2C Signal Tracking Capability on SpaceCube2.0 flight platform and on NavDev platform	The innovation described here is the development of GPS L2C tracking capability on both the SpaceCube 2.0 flight platform and the Navigator Development (NavDev) platform. In Two previous NTRs, implementation of GPS L1 C/A tracking capability on both the SpaceCube 2.0 and NavDev platforms have been reported. The addition of the L2C tracking capability will enable dual frequency GPS tracking on these platforms. This technology development was funded by the Office of the Chief Technologist at NASA Goddard Space Flight Center, Internal Research and Development (IRAD) program.

NASA GODDARD RELATED TECHNOLOGIES

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Case No.	Technology	Technology Description
GSC-17669-1	Dual-Frequency, Two RF Chain, Discrete Component GPS RF Card for the SpaceCube 2.0 platform	The innovation described here is the development of a dual frequency, two RF chain, discrete component GPS RF card for the SpaceCube 2.0 Navigator flight platform. This RF card has two RF chains that can be configured to receive GPS L1/L1 signals, GPS L1/L2 signals, or GPS L1/L5 signals. This technology development was funded by the Office of the Chief Technologist at NASA Goddard Space Flight Center, Internal Research and Development (IRAD) program.
GSC-17633-1	Radiation Hardened Compute Module - Small form factor PCB stack to fit in cube-satellite form factor	A compute module based on a HARDSIL enabled MCU and associated board stack was developed with unique characteristics. This will allow rapid product development, a high degree of configurability, a small form factor and a highly robust system for both space and terrestrial missions. Silicon Space Technology already has proven radiation hardened ARM Cortex MO-based Microcontroller Units (MCUs). The connector design provides unique channels for 12C, SPL, and UART for four separate compute modules in the board stack. A prototype was designed that showed how a mother board could bridge the compute module stack to a Pumpkin Inc. development system.
GSC-17629-1	Deployment System for CubeSat Electric Field Instrument	Our present understanding of magnetosphere-ionosphere coupling is limited, partly due to the lack of broad statistical observations of the 3-dimensional (3D) electric field in the altitude region between 300 and 1000km. This understanding is of national importance because it is a necessary step toward developing the ability to measure and forecast the "space weather" that affects modern technology. The high cost of space access and short satellite lifetimes below 500 km make traditional satellites uneconomical for performing these measurements. Therefore, it is desirable to develop smaller and lower-cost sensor/satellite systems, such as CubeSats, so that the largest possible number of distributed measurements can be economically made in this region. CTD has developed a deployment system for a 3D vector electric field instrument that can be accommodated in less than half of a 6U (10x20x30 cm) CubeSat. This instrument is enabled by CTD's game changing deployable composite boom technology that provides lightweight, stiff, straight, and thermally stable booms capable of being stowed within a Cube Sat form factor. The proposed development will also provide the CubeSat community with the capability to include one or more deployable booms with lengths greater than 5 meters for future CubeSat missions.
GSC-17593-1	NASA Operational Small Sat Simulator (NOS^3)	NASA Operational Small Sat simulator (NOS^3) is a general purpose software-only simulator developed to support small satellite software development and verification, test procedure dry runs, and training. NOS^3 is equipped with Global Positioning System (GPS) receiver simulators, magnetometer simulator, electrical power system (EPS) simulator, antenna simulator, and camera simulator. NOS^3 includes a simulator terminal to support common message bus and nodes that are used to support connecting the flight software under development and test to the simulations. NOS^3 is packaged in a ready-to-run virtual machine which provides a consistent, easy-to-use development environment for small satellite software by including all the software needed to develop and run the complete system in a software only mode with no hardware.
GSC-17579-1	Deployable Boom for CubeSats	The deployable boom for CubeSats is a rigid boom over 50cm in length when deployed that houses a 3-axis magnetometer. It is stowed on one side of the CubeSat with a double hinge system. Harness runs on the side of the boom. Constant torque springs are used to help keep a healthy torque margin during the entire articulation of the deployment and provide a strong positive torque at the end for stiffness without needing a positive latch.

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Case No.	Technology	Technology Description
GSC-17562-1	A Study for Optimum Space-to-Ground Communication Concept for CubeSat and SmallSat Platforms	National Aeronautics and Space Administration (NASA) CubeSats missions are expected to grow rapidly in the next decade. Higher data rate CubeSats are transitioning away from Amateur Radio bands to higher frequency bands. A high-level communication architecture for future space-to-ground CubeSat communication was proposed within NASA Goddard Space Flight Center. This architecture addresses CubeSat direct-to-ground communication, CubeSat to Tracking Data Relay Satellite System (TDRSS) communication, CubeSat constellation with Mothership direct-to-ground communication, and CubeSat Constellation with Mothership communication through K-Band Single Access (KSA).
GSC-17561-1	Pi-Sat 2.0: A Low Cost Distributed Mission and Cubesat Test Bed	The Pi-Sat project provides a preconfigured flight software development system for Distributed Spacecraft Mission and Smallsat/Cubesat research and development. The project includes three low cost software development platforms including a 1U Cubesat Prototype, a Wireless Node for Distributed Spacecraft Mission flight software research, and a Cubesat form factor processor card. All Pi-Sat platforms use the inexpensive, widely available Raspberry Pi ARM computer. All of the Pi-Sat platforms include NASAs Core Flight System flight software, and provide a low cost convenient way to develop and test new flight software applications. The low cost and ease of use also make the Pi-Sat an ideal platform for flight software education.
GSC-17554-1	Instrument Design for the CubeSat Ultraviolet Transient/Imaging Experiment (CUTIE) Project	We are developing a mission concept for a CubeSat-based synoptic imaging survey to explore the ultraviolet sky for several key discoveries in time-domain astrophysics. The IRAD investigation will mature a sensitive, wide-field instrument design optimized to produce new and unique observations of transient astrophysical events.
GSC-17550-1	Lithium-Ion Batteries Development for CubeSat and SmallSat Use	Lithium Ion (Li-ion) cells are being developed for high-power applications in space because they offer superior performance in terms of power and energy density over current cell chemistry. It is very important to understand the safety of these cells and control over testing to design a high quality, user-configurable, affordable, and risk reduction battery.
GSC-17549-1	Power System Electronics (PSE) Development for SmallSat Technology Project	We will develop a modular Power System Electronics (PSE) that is reliable, efficient, and flexible to meet the Goddard Modular Smallsat Architecture (GMSA) challenge. With GSFC careful in-house design, we will have control over testing and manufacturing to produce a high quality, user-configurable, and affordable flight PSE compatible with the Common Electronics Board (CEB) to support NASAs small satellite missions.
GSC-17522-1	Freeform Optics Telescope for small satellite applications	This effort results from a funded FY15 IRAD entitled "Freeform Optics Enabling CubeSat Missions". The opportunities for CubeSat, SmallSat, and NanoSat missions are growing as they are seen as a low-cost alternative to meet NASAs science objectives. These small-sized instrument payloads are very challenging for traditional optical design forms due to the severe packaging constraints, especially when science requirements demand large fields of view and fast F/#s. Optical surfaces with freeform shapes, however, enable additional degrees of freedom to help reduce volume and even eliminate surfaces from the more traditional design options.
GSC-17491-1	SmallSat Common Electronics Board (SCEB)	The Smallsat Common Electronics Board (SCEB) will be an evolution to a previous design concept that involves the development of a C&DH design within less than a 1U Cubesat form factor using a combination of robust rad tolerant components and COTS components.

NASA GODDARD RELATED TECHNOLOGIES

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Case No.	Technology	Technology Description
GSC-17462-1	Using Mini Paraffin Phase Change Material Packs to Maintain Thermal Stability of Payloads on CubeSat Type of Micro-Satellites	A concept of using mini paraffin phase change material packs with a melting point of -10C to 30C to meet thermal stability requirement of payloads on CubeSat type of micro-satellites is presented. It stores heat when the thermal environment is hot or when power is available, and releases heat when the thermal environment is cold or when power is unavailable. It overcomes the problem of micro-satellite payload thermal instability for orbits that have significant variations in thermal environment or power cycling.
GSC-17318-1	Cubesat Application for Planetary Entry (CAPE) Missions: Micro-Reentry Capsule (MIRCA)	The Cubesat Application for Planetary Entry Missions (CAPE) concept describes a high-performing Cubesat system which includes a propulsion module and miniaturized technologies capable of surviving atmospheric entry heating, while reliably transmitting scientific and engineering data. The Micro Return Capsule (MIRCA) is CAPEs first planetary entry probe flight prototype. Within this context describes CAPEs configuration and typical operational scenario, and summarizes ongoing work on the design and basic aerodynamic characteristics of the prototype MIRCA vehicle. CAPE not only opens the door to new planetary mission capabilities, it also offers relatively low-cost opportunities especially suitable to university participation. In order to reduce CAPEs implementation risks, a PEP re-entry demonstrator is currently being designed and prototyped at the NASA Goddard Space Flight Center (GSFC). MIRCA is expected to validate key system technologies, including advanced miniaturized sensors and supporting technologies. The prototype also serves to establish geometric and mass properties required to analyze its aerodynamic performance under varying flight regimes. Preliminary results are presented.
GSC-17313-1	Cubesat Ultraviolet Transient/Imaging Experiment (CUTIE)	The Cubesat Ultraviolet Transient/Imaging Experiment (CUTIE) was designed to monitor the sky in the ultraviolet to discover and characterize rare transient astrophysical events.
GSC-17312-1	Cubesat Chlorophyll/Zodiacal-Light Absolute Radiometer (CCZAR)	The objective of CCZAR is to measure the absolute intensity of the zodiacal dust cloud around the Earth and monitor the health of the terrestrial biomass. A breadboard version of instrument (capable to do field runs) has been designed and built; filter wheel now accommodates 9 narrow band filters.
GSC-17308-1	HaloSat: A CubeSat to Study the Hot Galactic Halo	Evidence for an extended Galactic halo has been obtained from high-resolution absorption line spectra. However, absorption measurements depend on the fortuitous presence of a bright extragalactic continuum source and are possible only along a limited number of lines of sight. Emission lines can be measured in any direction. HaloSat will conduct a near all-sky survey of oxygen line emission with the goal of constraining the mass and spatial distribution of hot gas associated with the Milky Way. Constraints on the hot Galactic halo will help address the cosmological missing baryon problem (Wang & Yao 2007; Nicastro et al. 2012; Gupta et al. 2012; Henley & Shelton 2014).
GSC-17279-1	Graphene Field Effect Transistors for Radiation Detection	The present invention relates to a graphene field effect transistor-based radiation sensor for use in a variety of radiation detection applications, including manned spaceflight missions. The sensing mechanism of the radiation sensor is based on the high sensitivity of graphene in the local change of electric field that can result from the interaction of ionizing radiation with a gated undoped silicon absorber serving as the supporting substrate in the graphene field effect transistor. The radiation sensor has low power and high sensitivity, a flexible structure, and a wide temperature range, and can be used in a variety of applications, particularly in space missions for human exploration.

NASA GODDARD RELATED TECHNOLOGIES

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Case No.	Technology	Technology Description
GSC-17252-1	Smallsat attitude control and energy storage	To fully-enable cutting edge science through small satellites (smallsat), this technology will reduce the overall size and net power consumption of conventional three-axis attitude control systems by replacing reaction wheel ensembles with reaction spheres.
GSC-17246-1	Spherical Occulter Coronagraph CubeSat (SpOC Cube)	Develop a complete coronagraph that fits into a 6U cubesat.
GSC-17220-1	Micro scale Electro Hydrodynamic (EHD) Modular Cartridge Pump	This innovation is a micro-scale EHD pumping system that incorporates a simplistic design that reduces the number of components required to make an assembly by up to 90% over previous iterations, insures a solid reliable electrical connection to the electrodes that form the pumping sections and is modular in overall design to allow for flexibility in incorporating the pump cartridge into various assemblies and applications.
GSC-17197-1	Tool for CubeSat/SmallSat Design Semiconductor Part Selection With Regard to Radiation Effects	Small spacecraft built with commercial of the shelf (COTS) components carry a high risk in terms of radiation and reliability. A tool that provides tailorable guidelines for part selection based on mission architecture and existing data would help to increase the life of the spacecraft.
GSC-17152-1	Dellingr 6U CubeSat AETD/ Heliophysics Skunkworks	This NTR describes Dellingr, the first 6U CubeSat project at NASA Goddard Space Flight Center (GSFC). The Dellingr project involves designing, building, and flight qualifying a 6U scientific mission within a one-year time period based upon a 6-U CubeSat platform. The objective is to define and develop a mission to conduct heliophysics science investigation utilizing science payloads already in development at GSFC. If successful, the program will demonstrate a revolutionary approach to cost-effectively conducting small yet meaningful scientific missions. More specifically, Dellingr will provide measurements of high latitude Field-Aligned Currents (FAC), which are a manifestation of magnetospheric dynamic responses to solar wind disturbances and to energy input in the upper atmosphere. Simultaneous observations of densities and velocities of the ion and neutral constituents will provide the response of the upper atmosphere, while measurements of energetic proton and ion particle fluxes are included to determine the response of the radiation belts.
GSC-17113-1	Cubesat Compatible High Resolution Thermal Infrared Imager	We have designed a small, adaptable, and stable thermal imaging system that can be flown on an aircraft, deployed on the International Space Station as an attached payload, launched on a ride-share as an entirely self-contained 3U CubeSat, flown on a small satellite, or be a co-manifested satellite instrument. When the instrument design is proven, multiple copies of our instrument could be assembled and aligned into an instrument array to enable large-swath thermal imaging from space, all to provide more detailed spatial and temporal data for biomass burning and land surface temperature studies than has heretofore been available from orbit. The instrument we propose has an Earth observing expected NEDT <0.20 C and a spatial resolution of 60 m from orbit. The same instrument can also be flown on an aircraft to provide much higher spatial resolution thermal data for our science objectives, while evaluating our instrument design and its operation.
GSC-17034-1	CubeSat Form Factor Thermal Control Louvers	This is a thermal control louver assembly based on the CubeSat form factor with a passive thermal control and improvement in internal thermal stability for small spacecraft. This will be achieved through miniaturization of the existing thermal louver design normally used for large spacecraft. Key differences from previous technology include a miniaturized spring design which entails the use of different attachment to the back plate and flaps, and miniaturized flaps which will be manufactured using selective laser melting instead of machining. The louver assembly conforms to CubeSat standards.

NASA GODDARD RELATED TECHNOLOGIES

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Case No.	Technology	Technology Description
GSC-16902-1	Radiation Hardened 10BASE-T Ethernet PHY	NASA Goddard Space Flight Center has developed a radiation hardened 10BASE-T Ethernet solution that combines a custom circuit and a front-end field programmable gate array (FPGA) design to implement an Ethernet Physical Interface (PHY) in compliance with IEEE 802.3. The custom circuit uses available radiation-hardened parts, and handles the electrical interface between standard differential Ethernet signals and the digital signal levels in the FPGA.
GSC-16900-1	Diminutive Assembly for Nanosatellite deployables (DANY)	CubeSat appendices such as solar panels and antennas are constrained and deployed using an unpredictable/unreliable release mechanism is used, which occupies a considerable amount of the CubeSat precious internal space. The DANY mechanism provides a secure method to constrain these deployables without using any internal space due to its minimized thickness. DANY is fastened to the chassis and it provides a preloaded threaded interface to attach the deployable. After actuation, the threaded block is released, allowing the deployment to happen.
GSC-16805-1	SpaceCube v2.0 SpaceCube v2.0 Micro Micro	A single board computer system radiation hardened for space flight includes a printed circuit board having a top side and bottom side; a reconfigurable field programmable gate array (FPGA) processor device disposed on the top side; a connector disposed on the top side; a plurality of peripheral components mounted on the bottom side; and wherein a size of the single board computer system is not greater than approximately 7 cm x 7 cm.
GSC-16795-1	Wallops Flight Facility 6U Advanced CubeSat Ejector (ACE)	The ACE ejector system interfaces to the launch vehicle and functions to protect the primary payload from the nanosatellite, constrain the nanosatellite during launch, and perform a guided ejection afterwards. The standard 1-3U CubeSat ejector's (P-POD) method for the constraint and guided ejection functions were found to be inadequate. This ejector system was designed to provide the nanosatellite with a more secure constraint interface during launch and an efficient guided ejection, while permitting a less restrictive inner volume.
GSC-16720-1	42: A Comprehensive General-Purpose Simulation of Attitude and Trajectory Dynamics and Control of Multiple Spacecraft Composed of Multiple Rigid or Flexible Bodies	42 is a simulation of spacecraft attitude and orbit dynamics. It supports spacecraft models composed of multiple bodies, each of which may be rigid or having flexible structural modes. 42 simulates multiple spacecraft simultaneously, supporting rendezvous, proximity ops, and precision formation flying studies. 42's environment models include ephemerides for all planets and major moons in the solar system, as well as selected asteroids and comets, supporting design studies for deep space as well as geocentric missions. The environment also contains standard models for gravity, atmospheric density, and magnetic fields. Disturbance force and torque models include aerodynamic, gravity-gradient, solar radiation pressure, and "third-body" gravitation. In addition to the dynamic and environmental models, 42 supports geometrical visualization through an OpenGL interface. 42 is open-source and portable across computing platforms, making it customizable and extensible. It is written to support the entire GNC design cycle, from rapid prototyping and design analysis, to high-fidelity flight code verification.
GSC-16551-1	CRUQS A Miniature Fine Sun Sensor for Nanosatellites	A new miniature fine sun sensor has been developed. The sun sensor uses a quadrant photodiode and housing to determine the sun vector. Its size, mass and power make it especially suited to small satellite applications, especially nanosatellites. Its accuracy is on the order of 1 arcminute and will enable new science in the area of nanosatellites.
GSC-16494-1	Standard Bus for Picosatellites	This is a reusable computing platform for Picosatellites devices. It consists of a processor, programmable logic, watchdog circuit, and non-volatile memory on one board. Analog circuitry and communication drivers could be added.

NASA Goddard Tech Transfer News

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