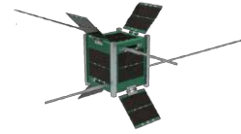




CubeSat Launch Initiative

Big Red Sat-1

Final Mission Report



Final Mission Report Narrative

1. Project Description

Through an interdisciplinary group of middle school, high school, undergraduate, and graduate students, the Big Red Sat-1 project aimed to characterize the performance of experimental perovskite solar cells in a low earth orbit (LEO) environment for the first time. Using a commercial off the shelf 1U CubeSat platform, NearSpace Launch's 1U FastBus system, we developed a custom curve tracing and perovskite pixel multiplexing flight computer to interface with our mission payload. Partial data from the payload was received and analyzed, demonstrating successful operation of perovskites in LEO.

2. Education Accomplishments:

NASA Education goals and objectives

Strategic Goal 1.0: Create unique opportunities for a diverse set of students to contribute to NASA's work in exploration and discovery.

The Big Red Sat (BRS) team engaged students from middle school through graduate school in the development of a CubeSat. The University of Nebraska-Lincoln (UNL) reached out to science and math teachers across the state of Nebraska informing them of the BRS project and asking them to notify students of the opportunity. This recruiting notification was sent at the beginning of the project, and again a year later. Orientation sessions informed students on CubeSats, working in space, projects goals, and participation opportunities.

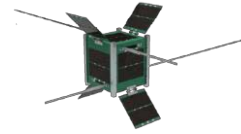
After introducing concepts on the unique aspects of designing for, and working in space, the middle and high school students identified areas of CubeSat payload research interest. They selected and developed projects, tested concepts on high altitude balloons (HABs), and learned design methods and concepts for project applications. Following a preliminary design review from aerospace industry mentors, students selected their CubeSat project to develop. The undergraduate students participated in the drafting of the CubeSat proposal, including technical information, the schedule, and the cost estimate.

Student team members presented their perovskite solar cell payload concepts through ongoing design reviews with mentors, created and tested prototypes, and successfully applied concepts to build, and have deployed, a functional CubeSat with data for analysis.

Students learned and practiced collaboration and exchange of ideas through regular meetings with Rhodes College (also testing perovskite solar cells through CSLI) and receiving perovskite materials and design, performance and analysis with the National Renewable Energy Laboratory (NREL) and Oklahoma University. Collaboration with NREL is ongoing with UNL students testing advances in perovskite solar cells, and now also modules, on high altitude balloon (HAB) test launches, and with a payload scheduled for the 2025 NASA HASP (High Altitude Student Platform). As the payload progressed and roles became limited, BRS students also participated in NASA's Nationwide Eclipse Ballooning



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Project (NEBP). These efforts have provided students multiple opportunities to engage in learning and application over a wide range of NASA, aerospace, and STEM interests.

Over the course of the project, many of the students graduated from high school and college. Students have entered STEM related degree programs in college, and at UNL, some have joined the Aerospace Club to continue engaging in their aerospace interest. Former undergraduate students are attending graduate school or are working in STEM or aerospace careers, including with NASA. A former graduate student still mentors the undergraduate students in testing and developing perovskite solar power with NREL.

Strategic Goal 2.0: Build a diverse future STEM workforce by engaging students in authentic learning experiences with NASA's people, content and facilities.

Students participated in meetings with NASA's LPS personnel throughout the development of the CubeSat project, completing forms required for manifest and communications, providing updates, and discussing issues, advancements, and performance against schedule, and coordinating on plans and requirements.

Increasing interest and excitement in aerospace, STEM, and NASA careers, members of the BRS team travelled to Florida in anticipation of the launch of the rocket carrying their CubeSat payload. As a part of the trip, they visited Kennedy Space Center (KSC) where NASA employees and contractors presented on their work, opportunities at NASA, and the future of NASA. A day was spent touring KSC. They also visited/toured the American Space Museum and Space Walk of Fame and Blue Origin. The trip wrapped up with presentations from members of NASA's Launch Service Providers (LSP) team.

Strategic Goal 3.0: Attract diverse groups of students to STEM through learning opportunities that spark interest and provide connections to NASA's mission and work.

Students gained learning opportunities through their development of the CubeSat, development and participation in the Nationwide Eclipse Ballon Project (NEBP), and HAB launches.

Students participated in presentations for the Small Satellite Education Conference, the Small Satellite Conference, to a foundation providing funding, and to the UNL Engineering Dean's Advisory Board.

Students participated in the development of a "What if..." segment (available on YouTube), which will hopefully spark interest and inspire others to believe they can contribute and engage in developing ideas and be a part of NASA's mission and work.

BRS team members have demonstrated aerospace concepts and opportunities at UNL through the Aerospace Club and engaged in outreach, including:

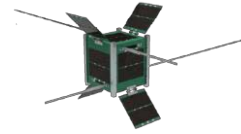
- Hosting a booth at the In-Flight NASA Downlink, spring, 2021 in Grand Island, NE
- Leading an educational session at Discover Engineering Days for middle school youth



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- Presenting on aerospace to elementary school students at a summer day camp
- Participation in the “Introduce a Girl to Engineering Day”

3. Technology Accomplishments:

NASA Strategic Plan Technology Goals, mission progress toward goals:

Strategic Goal 1: Expand Human Knowledge through New Scientific Discoveries

Our project demonstrated the operation of state-of-the-art perovskite solar cells in a novel environment, space. We tested three compositions of perovskite solar cells and found the composition of $(\text{FAPbI}_3)_{0.95}(\text{MAPbBr}_3)_{0.05}$, along with an improved hole transport layer and perovskite interface, outperformed the other two compositions. This provides a necessary first step to determine a viable composition for larger area solar modules, akin to gallium arsenide solar cells commonly used in space environments. This improved composition exceeded T80 performance for the complete mission duration.

Strategic Goal 2: Extend Human Presence to the Moon and on Towards Mars for Sustainable Long-Term Exploration, Development, and Utilization

For the Artemis mission, it is necessary to have the capability to fabricate power generating devices on the lunar surface, and to reduce the power generation to weight ratio. Currently perovskite solar cells appear to be the best candidate to meet this need. Perovskites allow 1 MW of solar power to be generated from 12 kg of material, lowering the cost and weight requirements for transporting materials to the lunar surface. To make these goals a reality, the best fabrication methods, materials, and performance must be realized. Big Red Sat-1 demonstrated that there are better compositions for space conditions and highlights the National Renewable Energy Laboratory’s (NREL’s) improved hole transport layer interface with the perovskite layer.

Strategic Goal 3: Catalyze Economic Growth and Drive Innovation to Address National Challenges

Technology advancements by NASA yield industrial growth and translation to broader industries. Advancement of perovskite solar technologies has the potential to provide lower cost renewable energy on earth and in space to contribute to meeting ever increasing demands for energy.

Strategic Goal 4: Enhance Capabilities and Operations to Catalyze Current and Future Mission Success

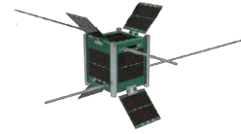
Future missions will continue to deploy perovskite solar cells into low earth orbit. Big Red Sat-1 was the first mission to successfully do so as a characterized, integrated, component on a CubeSat. Due to both the improved composition and monitoring circuitry, future missions can leverage our designs to improve perovskite solar cells into larger modules and potentially achieve a CubeSat powered solely by perovskites, replacing GaAs solar modules for power generation.



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4. Scientific Accomplishments:

NASA Strategic Plan Scientific Research Goals, mission progress toward goals:

Strategic Goal 1: Expand Human Knowledge through New Scientific Discoveries

Critical research is being performed on the composition and performance of perovskite solar cells. BRS-1 has contributed to the understanding of the potential use of perovskites for energy generation in space. By understanding which compositions of perovskite solar cells perform best in space environments, future missions can continue to push on this frontier to achieve future mission power generation needs.

Strategic Goal 2: Extend Human Presence to the Moon and on Towards Mars for Sustainable Long-Term Exploration, Development, and Utilization

The development of a reliable, lower cost, form of energy, such as perovskites, will enhance the potential for humans to maintain a presence on the moon. This mission demonstrated that there are perovskite solar cells that are better suited for space environments and provide potential candidates for power generation on the lunar surface for the Artemis mission.

Strategic Goal 3: Catalyze Economic Growth and Drive Innovation to Address National Challenges

Each step towards understanding the capabilities and limitations of perovskite solar cells takes the science a step closer to commercialization. This mission provides a necessary step to ensure that the United States maintains a strategic advantage in the commercialization of this next generation technology that may define the next era of space exploration and human advancement.

Strategic Goal 4: Enhance Capabilities and Operations to Catalyze Current and Future Mission Success

By making Big Red Sat-1 open source for the greater scientific community to access and utilize, future missions can leverage our designs and improve their chances of success. Additionally, our data indicates the ability for perovskite solar cells to operate in a low earth orbit environment.

5. Impact:

Impact Big Red Sat-1 mission had on participants, community, and organization:

Student participants in the BRS project were in middle school through graduate school. Approximately 34 of the students are currently undergraduates (primarily STEM careers), 2 are in grad school, and 4 are in STEM careers.

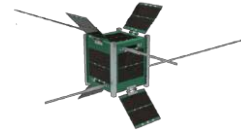
Many former members of BRS are now attending UNL in STEM related fields. Others are at Iowa State University and the University of Chicago Illinois. Graduate students are at UNL (robotics) and the University of Michigan (physics).



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Several of the undergraduates have joined or continue to be members of the UNL Aerospace Club (AC). This club has teams for: Aerospace eXperimental Payloads (AXP) (BRS is a part of AXP), Rocketry (participating in Spaceport America/IREC), Rocket Propulsion Group (RPG is developing high powered rocket motors), DBF (participates in AIAA's Design Build Fly), Lunabotics (participating in NASA Lunabotics), Unmanned Aerial Vehicle (UAV), and WIA (introduces students to aerospace, hosts industry speakers). Former BRS members at UNL participate across many of these teams.

The community has become engaged through presentations (Rotary #14, East Lincoln Business Club), and critically, through Foundations, businesses, schools, and individuals who have helped fund the project and provide in-kind materials. Through Nebraska Public Media's "What If..." feature, people across Nebraska have learned the BRS story.

6. Development Challenges:

When preparing the electrical systems for the perovskite solar cell monitoring and characterization, we encountered an issue where the pixel multiplexer, a circuit responsible for connecting different power generating pixels into the measurement circuit, would bleed power from other cells into the measurement circuit. This is a fundamental hurdle with the construction of perovskite solar cells, where the anode is the common node and the cathodes are broken out to multiple pads. Due to this design constraint, multiplexers suffer from leakage due to the inability to truly disconnect the cathodes from the measurement circuit. Generally, when a cell is not being measured, it should be connected to a "discharge resistor", which bleeds accumulated charge to prevent damage to the cell. This resistor should ideally bias the cell at its maximum power point, where the generated voltage and current are equally maximized, which tends to be around 400 Ohms. This resistor choice leads to the charge bleeding into the measurement circuit when the measurement circuit is below 400 Ohms. This led to multiple development prototypes and the resolution of this issue required the resistor to be set to 0 Ohms, a full short. When looking into the available literature, this was demonstrated to be the second-best operating point to achieve long-term performance.

When preparing the frame that housed the perovskite solar cells, we had been designing for unencapsulated perovskite solar cells. Once we neared integration, we received a batch of encapsulated cells, where the perovskite active layer was sealed from the environment using a 100 micron silicon oxide cover slip which was adhered using a drop of EP30-2 epoxy. This increased the vertical dimension of the cells, leading to an inability to electrically connect the cells to our measurement circuit with our existing design. To resolve this, we redesigned the cell housing to use pogo pins, which increased our clearance between the cell and the electrical connections.

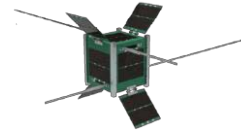
Our initial design specified the perovskite solar cell frame to be a pressurized vessel of inert gas, in anticipation of degradation from environmental exposure while awaiting launch. While this was achieved with the design using ITO glass substrate, this became



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a complication when our final cells, which were fabricated on quartz, arrived. This substrate did not tolerate a torque pattern well and would form fractures from uneven pressure. The encapsulation efforts proved to effectively limit the degradation caused by the environment in standard atmosphere. When the assembly issue occurred, we decided not to use the torque pressurization and instead seal the assembly with EP30-2 epoxy, rendering the pressurized vessel as a redundancy that could be removed.

In the final weeks of preparing for integration of BRS-1 into NRCSD27, the following issues occurred:

1. Our Ossila LED Solar Simulator (a Class AAA Rated System for Small-Area Solar Cells) had a firmware issue causing the system to cease operating, requiring us to coordinate with Ossila, a European company, for the replacement and return of the damaged solar simulator. This device was required to perform our final ground testing before integration. We received a replacement in time to perform the testing and not slip our integration date.
2. The battery pack on NearSpace Launch's FastBus CubeSat platform stopped charging and providing power to the Electrical Power System (also provided by NearSpace Launch). We had to send the battery pack back to Indiana for repair and retesting. The battery was repaired and retested by the NearSpace Launch team and shipped back to us. Our integration date was slipped due to this event.
3. When finalizing BRS-1 for integration, we epoxied all removable joints using space grade EP30-2 epoxy to ensure that no vibrations could unplug our cable harnesses or loosen our screws. The connector for our sun vector sensor was a fine pitch Molex connector, which did not tolerate the epoxy well and separated the electrical contacts, leading to the sun vector sensor not working in-orbit. We did not have enough time to rectify this issue and did not slip integration because of it. We were fortunate that we did not rely on this sensor for our attitude determination to start the characterization of the cells. Instead, we had already incorporated a Gallium Arsenide (GaAs) solar cell onto the perovskite solar cell frame to act as a reference cell and simultaneously used it to trigger the start of the characterization routine.

7. Mission Challenges:

There were no unforeseen challenges during launch, but after deployment we encountered some issues with the mission. The first issue we encountered was that the NearSpace Launch Electrical Power System was resetting our measurement circuit boards by powering it on and off. At reset, the system performs checks on the electrical circuits and resets their configuration to a known starting state. This also includes the resetting of the multiplexer to the first pixel, which means that we only gathered data for first pixel of all three perovskite solar cells. We believe that this resetting was caused by an overload of the radio communication buffer, which tripped a protection mechanism in the Electrical Power System that reset the power bus, causing a reset for our system. This behavior was not confirmed by NearSpace Launch.

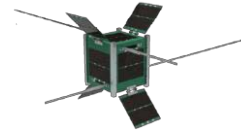
Additionally, we had a failure of our 3-axis accelerometer and magnetometer, where the



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data was unstable. We believe this was due to the power reset, but it could also be due to the sensors not being rated for a low earth orbit environment. These sensors were not essential, as they were added on as a supplement for further data capture.

Additionally, the NearSpace Launch Electrical Power System's altimeter quickly stopped sending data and GPS data was also eventually lost. This would indicate a relation between our intermittent power and the overall performance of this commercial off-the-shelf system. We were able to track BRS-1, both position and altitude, using SatNOGS DB and two-line element data provided by observation stations worldwide.

8. Lessons Learned:

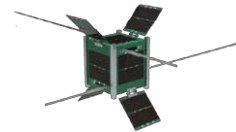
There were several lessons learned as a part of this project:

- Collaborate with other CubeSat teams with similar missions: Rhodes College and UNL both had perovskite projects. UNL and Rhodes held monthly meetings where we discussed progress and issues and were able to help each other out with ideas, contacts, and approaches to design.
- Ensure that teams are using calibrated, laboratory grade equipment: Utilizing an uncalibrated incandescent bulb for measuring the power generation of perovskite solar cells is insufficient and unable to simulate the same conditions used by manufacturers to assess the performance of their devices. While this equipment may have an elevated cost, this is a necessary step to ensure that any instrumentation is working properly and that data generated in orbit is believable to the wider scientific community.
- Look for opportunities to partner: The University of Oklahoma (OU) provided solar cells and insights into their design and performance and idea exchanges. Members of the BRS team visited OU for testing and collaboration. OU introduced the BRS team to National Renewable Energy Laboratory (NREL) representatives working on the development of perovskites. The collaboration with NREL is ongoing, with NREL making design advances and UNL providing high altitude testing.
- Have firm comprehension of state of technology and suppliers when proposing: The student team had overestimated the state of the art of perovskites at the start of the project. This resulted in initially not having a source of perovskites, and once having a source (thanks to Rhodes College, OU, and NREL) not having a plan for moisture sensitivity, jeopardizing the project success.
- Technology may advance over project life: Perovskite technology has significantly advanced from the time this project started. This was helpful but also resulted in design changes. Advances in encapsulation helped address moisture sensitivity issues, however, it changed material configurations, requiring other modifications to the design.
- Design needs to consider all environments and time periods the CubeSat will or may encounter, not just performance in space: Although the primary focus was how the CubeSat would operate after being deployed, some of the key design issues were how the payload would survive the time after integration when subjected to high humidity, high temperatures, vibration from the launch, potential degradation during integration to deployment timeframe, etc.
- Allow time for supplier delays: UNL and Rhodes both experienced delays in receiving

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engineering and flight models, in part due to COVID impacts on manufacturing.

- Build in schedule float for the inevitable and unexpected: The BRS team had some challenges meeting internal scheduled milestones due to team member availability and unexpected design issues. NASA LSP and Nanoracks (now Voyager Space) graciously allowed a little extra time for vibration testing to avoid de-manifesting our CubeSat due to issues that would not be expected with equipment provided and testing equipment.
- Engage in succession planning, and making sure access to files and information is maintained. Our team was fortunate to have several good team leads contributing at different times to the project. Recruiting was required, and we were fortunate to have one lead (Joel Murch-Shafer) be with the team through integration (our understanding is most projects take longer, continuity becomes more of an issue). We were challenged as we tried to maintain a website and directories in tracking access, passwords, etc.
- Appreciate what works, what was gained, and the experience with the team: BRS was fortunate to receive communications from their CubeSat, although not the full data that was expected. Although the data was limited, NREL has included some of this information in an article they have submitted to Nature Energy, to supplement other perovskite advancements. In addition, UNL continues to work with NREL on advancing perovskite research. The team can celebrate the efforts, accomplishments, and relationships built from the overall project experience.

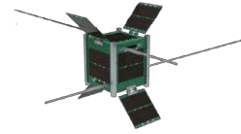
9. Anecdotal Information:

UNL was very fortunate to receive support inside and outside of the University community to make this project a reality. The AXP team had wanted to do a CubeSat for years, but it was not financially feasible. When Lincoln businessmen John McClure and Doc Chaves approached UNL about this project, with the promise to raise the funds, this dream became a potential reality.

- This project was proposed two weeks before the start of the fall 2020 semester. It required the team leads for the undergraduate AXP team (both sophomores) to be willing to take this project on (as well as a succession of other leads over the project). It required the UNL engineering outreach coordinator to contact schools across the state to recruit students. It required middle and high school students (and their parents' support) to decide to engage. It required quick planning and adaptability in the time of COVID. It required rapid identification, vetting, design review (with aerospace mentors) and development of a project and submittal of a CSLI proposal in December of 2020.
- This project might not have happened, but for Kevin Simmons (leader of the Florida Wolfpack CubeSat team). It was a member of his Wolfpack sharing their team's story that inspired John McClure to pursue this opportunity in Nebraska. Kevin was helpful to the team as they started out. Sharing our stories is what helps others see a potential opportunity, and belief in the possibility that they too can launch a CubeSat.
- Without the funding from community foundations and alumni, and the engineering dean's commitment to cover financial shortfalls (which did not occur) this project would not have happened. An Advisory Board of community supporters helped provide insight and raise the profile of the project to state leaders.
- The CubeSat, and perovskites, were more complex than the students anticipated. An



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electrical engineering graduate student interested in CubeSats saw the poster for the project outside the club space and asked about it. Without him (Walker Arce) joining the team and helping the team focus on schedule, get over key technical hurdles, providing critical design, troubleshooting, and mentoring, the project would not have been successful. In addition, this former graduate student created a GitHub site (<https://github.com/Big-Red-Sat>) to share our story and design with others to help future teams building CubeSats and working with solar cell payloads. He continues to be a mentor and benefit the team. We are fortunate he saw the poster and inquired further.

- Without the collaboration with Rhodes College, OU, and NREL, in creating the payload, and Nanoracks and NASA LPS in motivating and accommodating when delays due to equipment failure occurred at a critical time, the project would not have been successful.

10. Publications:

Publications:

Kong, C., Schutt, K., Sharma, M., Arce, W.S., Parashar, M., Kerner, R.A., You, S., Kuciauskas, D., Tirawat, R., DeCrescent, R., Buh Kum, T., VanSant, K.T., Wieliczka, B.M., Afshari, H., Sellers, I.R., McGehee, M.D., Stelling, K., Rout, B., Zhu, K., Luther, J.M., Kirmani, A.R, "Phosphonic acid reinforced PTAA for deployable p-i-n perovskite photovoltaics" submitted to Nature Energy April 2025 (2025-04-10987)

Publications & Presentations:

Arce, W.S., Afshari, H., Orsi, V., Wayman, N., et al. "Big Red Sat-1: Mission Overview and Future Opportunities for Perovskites in Low Earth Orbit" Proceedings of the Small Satellite Conference, Weekend Session III: Science/Mission Payloads Research & Academia 1, SSC24-WIII-02. Aug 2024. <https://digitalcommons.usu.edu/smallsat/2024/all2024/10/>

Arce, W.S., Stelling, K. "Big Red Sat-1: Nebraska's First CubeSat Experience and Lessons Learned for our Middle School to Graduate School Team." Virtual oral co-presentation at: NASA's Small Spacecraft Community of Practice; Oct 2024; <https://www.nasa.gov/smallsat-institute/community-of-practice/big-red-sat-1-nebraskas-first-cubesat-experience-and-lessons-learned-for-our-middle-school-to-graduate-school-team/>

Orsi, V., Anderson, H., "Uno-Nasa Space Grant: Aerospace Experimental Payloads," Nebraska Academy of Science (Aeronautics and Space Science), Apr 2023, <https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1018&context=nasproc>

Murch-Shafer, J, Helzer, J., "Low Earth Orbit Missions For Education And Research," Nebraska Academy of Science (Aeronautics and Space Science), Apr 2022, <https://neacadsci.org/docs/ProandPro2022.pdf>

Presentations:

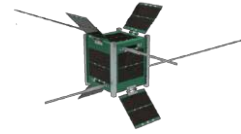
Wayman, N., Arce, W.S., Stelling, K., "Big Red Sat-1 (BRS-1) Bringing Aerospace to Nebraska," SmallSat Education Conference, Oct 2024



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Stelling, K., Orsi, V., Much-Shafer, J., Helzer, J., Meyer, E., et.al, “The Big Red Satellite Team,” SmallSat Education Conference, Oct 2022

Interest Group presentations:

Stelling, K., Arce, W., Wayman, N., “Big Red Sat-1 (BRS-1): Overview and Future Satellite and Aerospace Opportunities at UNL,” UNL Engineering Dean’s Advisory Board, Oct 2024

Stelling, K., “UNL Aerospace Club and the Big Red Satellite Project,” East Lincoln Business Association Mar 2023

Stelling, K., Chaves, D., “Adventures in Aerospace and Beyond,” Lincoln Rotary Club #14, Jun 2022

News/Media:

Tobias, M., BigRedSat coverage in the Nebraska Public Media series “What If…” on website and YouTube: <https://nebraskapublicmedia.org/en/series-media/what-if-video/standalone-video-16501/student-satellite-50026670/>;
<https://youtu.be/lf0781LjPGU?si=YQwxcLcnTA7SSb4R>

Big Red Sat-1 Spacecraft, Nanosats Database, December 16, 2024,
<https://www.nanosats.eu/sat/big-red-sat-1>

Tobias, M., Young Nebraska scientists built a satellite, it’s now headed to space, March 15, 2024, Nebraska Public Media, <https://nebraskapublicmedia.org/en/news/news-articles/young-nebraska-scientists-built-a-satellite-its-now-headed-to-space/>

Vogel, K., Big Red Sat Team readies for ISS Launch, March 6, 2024,
<https://news.unl.edu/article/big-red-sat-team-readies-for-iss-launch>

NASA selects Nebraska students’ satellite to orbit in space, April 21, 2021,
<https://news.unl.edu/article/nasa-selects-nebraska-students-satellite-to-orbit-in-space>

Website and Repository:

Big Red Sat, <https://github.com/Big-Red-Sat>

Scientific or Technical Data:

See files provided