Solar Flare Sounding Rocket Campaign

A White Paper on the Scientific Motivation and Feasibility of Introducing Routine Solar Flare Campaigns for Sounding Rockets

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1. Executive Summary

The sounding rocket platform allows instruments and technologies to mature for future satellite missions, provides an opportunity to capture unique scientific measurements not currently available by other means, and trains the next generation of instrumentalists. Historically, solar sounding rocket instruments have been launched from White Sands Missile Range (WSMR), which is a busy range with little flexibility in scheduling or changing a launch time. Additionally, to launch from the NASA launch site on the southern side of the range, a major road and the White Sands National Monument must close starting roughly an hour before the scheduled launch time. Because of this, scientists are provided, at most, a one-hour launch window and encouraged to launch as early in that window as possible. This limited window precludes the ability of an instrument to launch into an event like a solar flare. ***Instruments that are specifically designed for solar flare observations therefore cannot be matured through the sounding rocket program and instruments with significant solar flare capability cannot be fully tested via a standard launch at WSMR.***

We formally request that the Sounding Rocket Program office (SRPO) open an existing launch range for routine solar flare sounding rocket campaigns at least every other year during solar maximum starting in 2023 and ending in 2026. In this document, we briefly discuss the scientific motivation for developing solar flare instruments and present a set of requirements necessary for a successful solar flare campaign. We explore the feasibility of meeting these requirements with existing assets and only a small additional financial commitment. We provide an example schedule and timeline for the first campaign. Finally, we point out potential issues that can be addressed in the years prior to the first solar flare campaign. The success of the ongoing Grand Challenge Initiative, an international, multi-instrument campaign launched from Norway starting in 2018 into geospace events, implies that the capability currently exists to carry out similar campaigns to further instrument development and science in solar physics.

2. Scientific Motivation

Large solar flares and coronal mass ejections (CMEs) are dynamic events that release on the order of 10^{32} ergs of energy. This energy is initially stored in the form of magnetic energy prior to eruption due to stresses in the Sun's magnetic field. During the eruption, this stored energy is converted to thermal energy of the heated plasma, energy that accelerates non-thermal particles, and the bulk kinetic energy of the resulting CME. This energy release results in observable emission from the Sun at all wavelengths during solar eruptions. Earthward CMEs and their charged particles can have detrimental effects on spacecraft, oil and gas pipelines, and electrical grids. Thus it is important to quantify and understand the energetics and dynamics of solar eruptions.

There are several science questions that can be addressed with instrumentation with better temporal, spatial, spectral, and temperature coverage than is currently available. These questions include: understanding the mechanism by which particles are accelerated during solar flares, clarifying the relationship between supra-arcade downflows and the reconnection process, uncovering the dominant heating mechanism during the late phase of flares, and determining the effects of sudden energy input into the chromosphere.

Although flares do occasionally occur during sounding rocket flights, these flares tend to be quite small and faint -- small flares occur much more commonly than large flares -- and thus are inappropriate for a detailed multiwavelength study. Furthermore, even the occurrence of these small flares cannot be expected with high probability during a typical 5-minute interval.

Therefore, at present ***no instrumentation designed specifically for solar flare measurement can be tested via sounding rocket***, unless that instrument can also detect quiescent (non-flaring) solar emission. For example, a solar gamma-ray instrument cannot be tested via sounding rocket for this reason. (Gamma-ray instruments may be able to use high-altitude balloon platforms, but with considerably higher development time and cost.) Instruments in the hard X-ray range usually have as their prime objective the study of particle acceleration in solar flares, which requires observation at high energies and high intensities. However, since flares are considered inaccessible to sounding rocket experiments, these experiments must validate their technology instead with faint, low-energy, quiescent emission, in essence building a fundamentally different instrument. Ironically, if a large flare were to serendipitously occur during a sounding rocket flight, it would likely saturate the instrumentation that is optimized for low intensities.

The addition of a solar flare campaign to NASA's sounding rocket capabilities would open up the possibility for flare-optimized instruments to be validated via rocket experiments and would immediately lead to advances in flare science via multiwavelength observation of a single flare with groundbreaking instruments.

3. Likelihood of Catching a Flare

To calculate the likelihood a flare would occur within a 14 day campaign with a 4 hour launch window each day (a typical launch window for geospace missions) during the next solar maximum, we examined the GOES X-ray flare list from the previous solar cycle. For each day of the previous year, we determined if there were > C flares in the following two weeks for a given 4 hour window each day. We considered each 4 hour window separately, giving us 2106 sample launch windows (351 start dates for the campaign * 6 launch windows each day). We calculated the number of launch windows that included > C1.0 flare, > C5.0 flare, and > M1.0 flare. The results are given in the table below. Based on these calculations, the years that provide the best chances to capture a flare are predicted to be 2023 - 2026 in the upcoming solar cycle.

Year of Solar Flare Campaign	Representative year from the last solar cycle	Percentage chance of a > C1.0 flare	Percentage chance of a > C5.0 flare	Percentage chance of a > M1.0 flare
2023	2012	98%	64%	44%
2024	2013	97%	54%	33%
2025	2014	99%	81%	61%
2026	2015	97%	64%	43%
2027	2016	61%	20%	7%

We would obviously like to observe the largest flare possible during the flare campaign. The percentages in the above table are calculated assuming the campaign could have started on any date from the representative year in the previous solar cycle. If we restrict the campaign start days to times when there are large, complex, or multiple active regions on the disk, it may increase our chances significantly. Because of this, we request a flexible start to the campaign date. See Section 7 for additional discussion on increasing the chance of catching a large solar flare.

4. Requirements for the Solar Flare Campaigns

- **Launch window of 2 weeks with 4 hours each day** - This is a standard launch window for geospace missions and was used in our calculation of catching a solar flare (Section 3).

- **Flexible Start Date for Launch Campaign -** To increase the chances of catching a large solar flare, we request the launch campaign start only when there is a magnetically active Sun (see Section 3 and 7).
- **Black Brant IX (BBIX) or better** - The weight, length, and required observing time (>5 minutes) and altitude imply most solar payloads require a BBIX.
- **The potential to launch multiple payloads to observe the same event** - Solar flares and accompanying coronal mass ejections cover a wide range of temperatures and wavelengths, and last tens of minutes to hours. To enhance the scientific return of a solar flare campaign, we require the ability to launch multiple payloads into the same event in a sequence to be determined by the science goal of the campaign, including the possibility of launching two rockets nearly simultaneously.
- **Payload recovery** - Solar instruments tend to be expensive telescopes that can be reflown multiple times. To preserve NASA's investment in these instruments, we require payload recovery.

5. Feasibility

Sounding rocket launches occur from three domestic ranges : Wallops Flight Facility (WFF), WSMR, and Poker Flat Research Range (PFRR) in Chatanika, AK. Additionally, they are launched from multiple oversea ranges. It is now somewhat routine to launch from Kwajalein and Norway. Campaigns are also planned from launch ranges in Australia and Peru.

We have presented the draft requirements for this solar flare campaign to SRPO to determine if they can be met with any existing launch range. There are two potential matches, PFRR or launching from a different location at WSMR. Below we briefly discuss each option to demonstrate that a solar flare campaign is feasible with minimal additional investment by the program. The final decision of launch range will of course be made by SRPO with guidance from NASA Headquarters after the options have been fully explored.

Poker Flat Research Range, AK

Currently, PFRR has two launchers that can handle Black Brant IX rockets and three additional launchers that can handle smaller rocket payloads. If desired, new pads can be poured and up to two mobile rocket launchers can be used, implying that as many as four BBIX payloads could be launched. PFRR can also recover payloads launched on a BBIX. PFRR has considerable flexibility in launching. Currently, the range can support daily 6-h launch windows over a two-week period. The 6-hour and two week windows can be extended by hours or number of days based on scientific needs. Additionally, a campaign could be pushed out to future weeks or a follow-on window with coordination from SRPO.

There are no facilities at PFRR to complete the required environmental testing or solar (heliostat) testing prior to launch. Normally geospace instruments complete this environmental testing at Wallops and solar instruments complete environmental and heliostat tests at WSMR. The lone heliostat used for pointing calibrations for all solar missions is located at WSMR. It is expensive and not easily transportable, and no backup option currently exists. We suggest that the solar flare campaign instruments would go to WSMR for environmental and heliostat tests well before the scheduled launch window opens, then be shipped to PFRR with the required GSE (see schedule below).

White Sands Missile Range, NM

Another option would be to launch from a different site at WSMR that would not require the road or national monument closure. It would be considerably easier to complete the required environmental and heliostat testing at the same location as the launch range. Launching from WSMR would save on travel and shipping costs and not require such a large team to travel, as many launch support employees are at WSMR full time. However, though it may be possible to locate a launch location in the northern part of the range, it would still require significant coordination with the Navy and Army to have a long launch window on a busy range. Additionally, the cost of the long launch window may be prohibitive and negate any savings in travel or shipping. SRPO and NSROC are still investigating this option.

Consideration of additional ranges

Launching solar instruments from WFF is also a possibility, but it would require water recovery. Though water recovery is a great innovation, it is not ideal. It increases risk to the payload and solar sensors and adds significant weight (meaning a reduction in observation time and altitude). Also, boats can enter the expected region of impact and delay launches significantly. Keeping the impact region clear during a long daily launch window would be difficult.

There is currently a campaign planned in Australia for astrophysical instruments to observe objects in the southern hemisphere scheduled in May, 2020. The Australian range could be used for solar launches, but there would be several major drawbacks to using the Australian range. It can only launch two rockets into the same event (the range will use the two mobile launchers). Going to Australia would be more expensive and with a longer lead time than using a domestic range, and would require additional paperwork for shipping rockets and instruments to a foreign country. There has been significant difficulty establishing the range in Australia and it is unclear if the same range can be used again after the 2020 campaign.

Sounding rockets are also often launched from Kwajalein Island, one of the Marshall Islands in the Pacific Ocean. Again, these are primarily astrophysical instruments with targets in the southern hemisphere. Kwajalein suffers from strong winds that significantly limit the launch times and only offers water recovery.

6. Request for Routine Solar Flare Campaigns

We request that SRPO provide a range location for solar flare missions at least every other year during solar maximum starting in 2023. Additionally, we request that HQ allow for proposers to submit proposals to launch during a solar flare as a single rocket or part of a multiple rocket campaign during these times without any additional feasibility studies required. Our goal is to open the selected range location and encourage both new instrument development for solar flares and capturing of unique data sets by existing instruments.

We suggest that for the first campaign, we allow two instruments to participate with near-simultaneous rocket launches into the same event. We request that for subsequent campaigns, we allow up to four instruments to participate in the campaign. Neither PFRR or WSMR is capable of launching 4 solar rockets in a short (~1 hour) window at this time so some upgrades to the selected facility must occur before the second campaign and the mobile launchers must be reserved for the campaign.

Unlike other campaigns to remote launch sites, this request is simply to open an existing launch range for flare observations and to allow for multiple solar rockets to be launched in a short time frame for a few months each solar cycle, i.e., every 11 years. The campaigns could be a single rocket instrument or multiple instruments each campaign, depending on proposal pressure and success in selection. The additional cost to the Sounding Rocket Program is expected to be minimal.

Suggestion for formulating a campaign

This proposal is simply to establish routine solar flare campaigns, not to suggest the scientific targets or specific instruments for each campaign. We propose the scientific goals of each individual campaign will be determined from instrument proposal success. The sequence of launching the instruments during the campaign will likewise depend on the instruments selected. Some Principal Investigators may choose to work together in the proposal stage to demonstrate how their instruments should be launched simultaneously or in a specific sequence, while others may be selected without prior coordination. We suggest that after the instruments have been selected, NASA HQ appoint a campaign scientist who will work with the PIs of the individual instruments to maximize the scientific return from each campaign.

Coordination with other satellite and ground observations

We anticipate that solar spacecraft and ground-based telescopes (at similar longitudes to our range) will coordinate with this campaign, leading to exceptional multi-observatory coverage of the flare(s). Multiwavelength coverage will even surpass, e.g., the 2014 March 29 flare. We will further attempt to coordinate the campaign to be at a time when Solar Orbiter (SO) or Parker Solar Probe (PSP), two missions observing the Sun with remote and in-situ instruments from close distances, are in prime measurement locations (i.e. viewing the target active region or in position to observe the in-situ emissions from it), enhancing the scientific return from a multitude of NASA instrument investments. For example, March of 2023 and 2024 are excellent times for coordination with PSP and SO, since during this time there are close approaches by both spacecraft on the Earth side of the Sun. September of 2023 and 2024 are also dates of close approach for both PSP and SO, but they are not front-side encounters, affording the opportunity to view flares from different angles with different instruments. We note that this opportunity to coordinate with SO and PSP will be available ***only*** for the upcoming solar cycle.

As mentioned in Sections 3 and 4, to maximize our chances of catching a >C5.0 flare, we would like to require certain characteristics of the Sun (such as significant activity, a large number of active regions, or the magnetic complexity of an active region) before opening the campaign window. Exactly what those parameters are and how to assess them must be determined in the years prior (see Section 7). Therefore, we request to plan the campaigns to coincide with prime coordinated observing times, but the instrument PIs should be allowed to delay the launch window if they judge there is little chance of catching a flare during the scheduled time.

Example schedule for 2023 campaign

Below is an example schedule assuming that we use the PFRR range for a solar flare campaign. We suggest the first campaign target a launch window of March 12 - 26, 2023 to maximize the potential overlap with PSP and SO (based on the current SO launch date in February 2020).

Proposals submitted to LCAS for 2023 solar flare campaign, 1-2 instruments to be selected.	2019 and 2020
Selected instruments complete integration and environmental testing at WSMR, including heliostat, vibration, etc. If multiple instruments are involved in the campaign, their integration and testing can be staggered in time.	November 2022 - January 2023
Instruments shipped to PFRR	February 2023
Campaign begins. Instrument teams arrive at launch site; instruments complete final tests and are loaded on the launch rails	March 1, 2023
Launch window	March 12 - March 26, 2023

Example timeline for 2023 launch

Below we provide an example timeline based on current capabilities and standard practices of a sounding rocket launch, such as halting countdown at T-3 minutes, and using a sustained increase in GOES X-ray flux to determine when to restart of the countdown. See Section 7 for additional discussion on potential improvements to this timeline.

- Daily launch window will open at local solar noon (LSN) - 2 hours and close at LSN + 2 hours.
- Both instruments will go through standard countdown procedures each day of the launch window.
- Countdown will be halted at T-3 minutes, just before the power system switches to internal (battery) power.
- The PIs of the instruments will then monitor the GOES X-ray flux. When the X-ray flux increases and remains above a specified threshold, countdown will be restarted at T-3 minutes.
- Instrument 1 and instrument 2 will be launched simultaneously or in a predetermined sequence with a difference in launch time dictated by the science goals of the campaign.

7. Items to be Addressed Prior to First Campaign

Though the suggested launch campaign is feasible using existing assets or minor upgrades to existing assets, there are several potential issues that will need to be understood and addressed before the first campaign in 2023. In this section we identify potential issues that need to be investigated further. We suggest that the first selected instruments work with SRPO and the NASA Sounding Rocket Operations Contract (NSROC) to assess and resolve these and any other issues.

In the timeline presented above, we have included that the countdown will be halted at T-3 minutes (traditionally when the power is switched to the internal batteries) and that the PIs of the solar instruments will rely on the GOES X-ray flux to determine when to restart the countdown. This implies that there will inherently be a time delay between when the flare starts on the Sun and when the sounding rocket instrument can start making observations. This delay includes both the rise of the flare X-ray flux to cross a predetermined threshold in order to trigger the launch (few minutes), and also the lag between X-ray flux being recorded on the GOES satellite and it being downlinked and available for the PIs to use to judge when to launch. (Using currently available web tools, this delay is ~2 min.) There is an additional delay of 3 minutes after the GOES flux crosses the threshold value to launch the rocket as the countdown has to restart at T-3 minutes, and roughly 2 additional minutes for the rocket to reach altitude, open the door, and acquire the Sun. These delays imply that the earliest we could begin flare observations would be roughly 10 minutes after the flare begins. Though there is still a significant window of scientific discovery with this launch delay, reducing the time from the start of the flare to the beginning of observations would be desirable, especially for instruments that want to target the impulsive stage of the flare. The scientists and NSROC/SRPO should work to determine if there are methods to reduce this time.

Solar missions use the Solar Pointing Attitude Rocket Control System (SPARCS) for guidance, pointing and tracking during flight. SPARCS requires two sensors (a coarse and fine sensor mounted inside each payload), uplink and downlink ground stations, and adequate personnel to drive the systems. There are currently a limited number of the sensors, ground stations, and personnel available, as multiple solar launches in a short time window have not been the norm. If this proposal is accepted, NSROC and SRPO must work to understand and mitigate the limited ability of the current SPARCS system to accommodate a multi-instrument solar flare campaign.

During a standard solar launch, the required solar pointing is given to the SPARCS personnel several hours before launch. They calculate the location of the the solar target on the sky over the launch window and are prepared to upload the correct coordinates depending on the launch time. A flare campaign would demand a much longer launch window to consider and there may be multiple active regions on the disk that could be responsible for the flare. The SPARCS personnel would be required to track multiple active regions and the PIs would need to determine which active region to point to during the flare. This is a departure from standard procedure of a solar launch and would need to be carefully considered before the solar flare campaign.

One additional consideration in using the range in Alaska is the increase in the column depth of the Earth's atmosphere during observations, which may reduce the throughput into the instrument depending on the wavelength range. This should be noted by the observers with appropriate atmospheric absorption models to verify the throughput is sufficient. Given that solar flares can be orders of magnitude brighter in various wavelengths than the quiescent Sun, this is not expected to be a major issue.

Even during solar maximum, the Sun may undergo multiple-week quiet intervals. While the occurrence of such an interval during the flare campaign would negate the likelihood of a major flare occurring, these intervals can be assessed ahead of time. For example, if there is no productive active region present on the visible solar disk, and no productive active region about to rotate onto the disk, the campaign could be paused or postponed to a later set of weeks. In fact, if such postponement flexibility is built into the campaign planning, then the likelihood of triggering on a major flare becomes even higher. In the intervening years, the Principal Investigators of the instruments should work with SRPO and NSROC to determine parameters that define optimal time for the campaign window to open with existing assets.

8. Endorsements

We have shared this white paper with a subset of the solar physics community, primarily current and former solar sounding rocket Principal Investigators, leads of current satellite instruments, and other interested scientists for comments. The following scientists responded that they endorse this request for routine solar flare campaigns.

S. Antiochos (NASA Goddard Space Flight Center)
S. Bradshaw (Rice University)
A. Caspi (Southwest Research Institute)
M. Cheung (Lockheed Martin Solar and Astrophysics Laboratory)
S. R. Cranmer (University of Colorado Boulder)
S. Christe (NASA Goddard Space Flight Center)
A. Daw (NASA Goddard Space Flight Center)
B. De Pontieu (Lockheed Martin Solar and Astrophysics Laboratory)
B. Dennis (NASA Goddard Space Flight Center)
T. Forbes (University of New Hampshire)
L. Golub (Smithsonian Astrophysical Observatory)
L. Harra (University College London Mullard Space Science Laboratory)
C. Kankelborg (Montana State University)
C. Korendyke (Naval Research Laboratory)
K. Korreck (Smithsonian Astrophysical Observatory)
S. Krucker (Space Sciences Laboratory, UC Berkeley)
J. C. Martínez Oliveros (Space Sciences Laboratory, UC Berkeley)
J. McAteer (New Mexico State University)
S. Mcintosh (High Altitude Observatory)
D. Mckenzie (NASA Marshall Space Flight Center)
C. Moore (Smithsonian Astrophysical Observatory)
R. Moore (NASA Marshall Space Flight Center / University of Alabama - Huntsville)
J. Newmark (NASA Goddard Space Flight Center)
V. M Pillet (National Solar Observatory)
S. Savage (NASA Marshall Space Flight Center)
D. B. Seaton (University of Colorado/NOAA National Centers for Environmental Information)
A. Shih (NASA Goddard Space Flight Center)
S. Tun (Naval Research Laboratory)
P. Young (NASA Goddard Space Flight Center)