Hi-C Flare: Results of the First Sounding Rocket Flare Campaign

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Abstract

Solar flares are among the most powerful events in the solar system and major science questions related to solar flares remain which can be addressed with improved temporal, spatial, spectral, and temperature coverage beyond current technologies. The first ever sounding rocket flare campaign, and the fourth flight of Hi-Resolution Coronal (Hi-C) Imager [1] was launched with the FOXSI-4 mission from Poker Flat Research Range and successfully captured high spatial and temporal resolution extreme ultraviolet (EUV) and soft X-ray (SXR) observations of a class M Flare. The main Hi-C 3 instrument captured >250 full resolution images at a cadence of 1.3 sec (between 22:15:45 - 22:21:25~UT) during the decay phase of an M1.6 flare. Additional EUV and SXR observing instruments were integrated into the payload which were designed to provide unique diagnostics of the hottest flare plasma. Coordinated observations from multiple ground- and space-based telescopes also provide an unprecedented opportunity to observe the mass and energy coupling between the chromosphere and the corona during a flare.

Instruments

- **High-resolution Coronal imager (Hi-C) 3.1** - a high resolution (0.3″), high-cadence (1.3 s)coronal imager with a passband centered at Fe XXI 12.9 nm spectral line formed ~ 11 MK
- **COronal OverLapogram Ancillary Imaging Diagnostics (COOL-AID)** - slitless spectrometers for capturing high speed velocities of hot plasma in the Fe XXI 12.9 nm line with high resolution (< 10 km s−1), high cadence (1.3 s), and moderate spatial resolution (~ 2″)
- **high CAdence low-energy Passband x-Ray detector with Integrated full-SUN (CAPRI-SUN)** - a student-built, full-Sun X-ray detector with energy sensitivity similar to the low-energy passband of the GOES X-ray Sensors (XRS), with 1 kHz cadence.
- **Swift Solar Activity X-ray Imager (SSAXI-Rocket)** - a high time cadence X-ray imager (≥ 10 Hz),capable of spatially resolving soft X-ray emission (~ 5″) forming at temperatures ≳ 10 MK

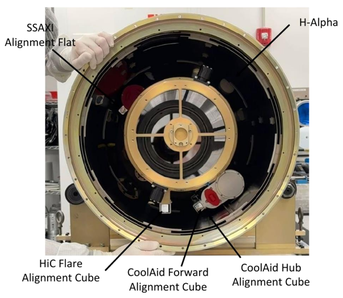


Figure 1. Looking into the Hi-C Flare sounding rocket payload. The main telescope mirror primary mirror is visible, along with the locations of the ride along instruments and alignment features.

Campaign & Launch

The campaign consisted of 2 weeks for 4-hour daily windows to trigger a launch to observe a solar flare. Numerous tools [2-3], produced by campaign collaborators, using the earliest signatures of flare onset, were employed to determine when to trigger launch. Suitable flares were to be class C5+ with duration of >20 mins in order to account for latency in data streams and operational constraints.

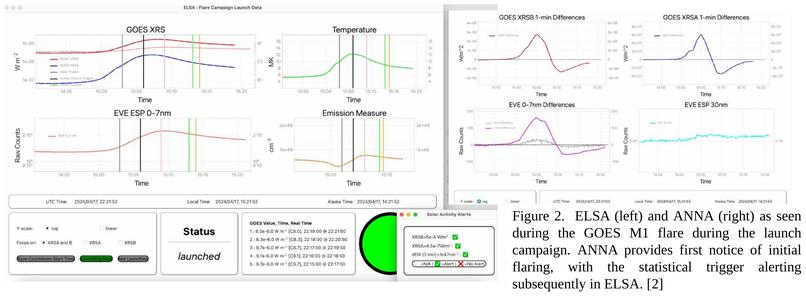


Figure 2. ELSA (left) and ANNA (right) as seen during the GOES M1 flare during the launch campaign. ANNA provides first notice of initial flaring, with the statistical trigger alerting subsequently in ELSA. [2]

Upon flare onset detection and determination that a suitable flare is occurring, launch was triggered on a class M1.6 flare as shown in Figure 3. FOXSI-4 was launched first followed closely by Hi-C Flare. Hi-C Flare observed at an altitude of >200km for >250s capturing high spatial and temporal resolution of the decaying flare (Figure 4). A subset of the data was downlinked during launch and payload was safely recovered a few days after launch along with the full data set. Both payloads had a successful launch and recovery.

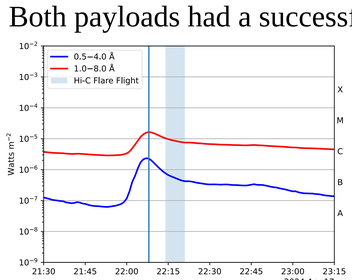


Figure 3. The GOES lightcurve of the observed solar flare. The Hi-C Flare observation window is overlayed onto the flare curve in light blue. The flare was M1.4 and lasted for ~1hr.

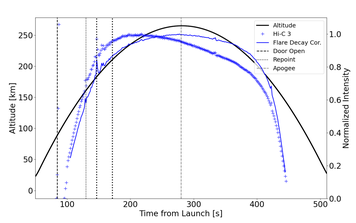


Figure 4. Altitude curve (black) and mean observed intensity of Hi-C images (blue). Raw light cruve (+) and flare decay corrected curve (-) are shown. Key times in observation are called out including door open (--) and re-pointings (:).

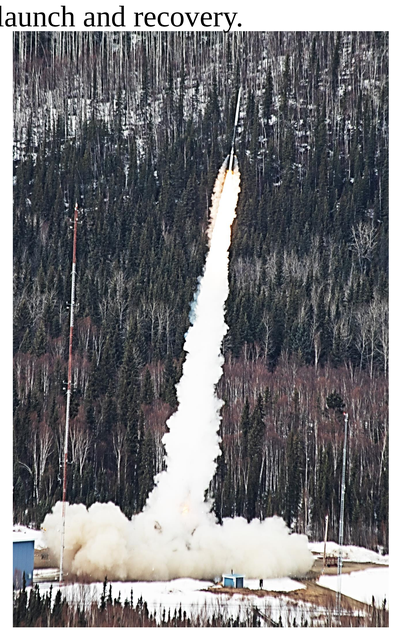


Figure 5. Hi-C Flare as it was launched from Poker Flat Research Ranger near Fairbanks Alaska on April 17th, 2024.

Results

Hi-C 3 observed the decaying flare at 129 Å with a spatial resolution close to 0.3 arcsec. Compare to AIA 131 at ~1.5 arcsec (Figure 6.B). The temporal resolution of Hi-C 3, 1.3 s vs. AIA at 12s, allows us to observed rapidly changing structure of the flare (Figure 6.E). SAXXI-rocket was misaligned and observed only indirect SXRs (Figure 6.D). COOL-AID observed EUV spatially resolved spectra, but at a much lower flux than anticipated due to errors in grating fabrication and assembly (Figure 6.C). CAPRI-SUN made high cadence x-ray observations but unfortunately no data was recovered due to an error in storing data.

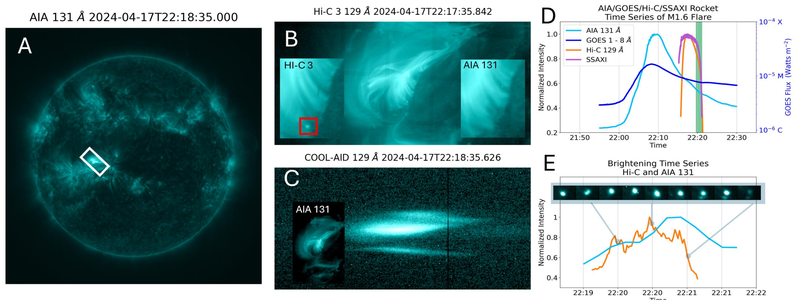


Figure 6. Hi-C Flare results. Full disk AIA 131 (A) shown with Hi-C 3 FOV. Hi-C 3 (B). Zoomed in regions of Hi-C and AIA 131 are shown in insets for comparison of fine structure. COOL-AID data is shown in (C) compared with the AIA FOV (inset). GOES and AIA light curves of the observed flare with Hi-C and SSAXI flight light curves (D). Rapid variation (E) of a small brightening observed by Hi-C (orange) compared to AIA 131 (cyan) in the same region (red box on inset of B) along with a view of the brightening at different time points.

Conclusions & Future Work

Hi-C Flare 2 is currently in planning. We hope to correct the errors of the ride along instruments and augment them with an additional COOL-AID arm to enable better data reconstruction. Hi-C Flare is currently undergoing post-flight calibration tests and we hope to refly Hi-C Flare 2 in Spring of 2027

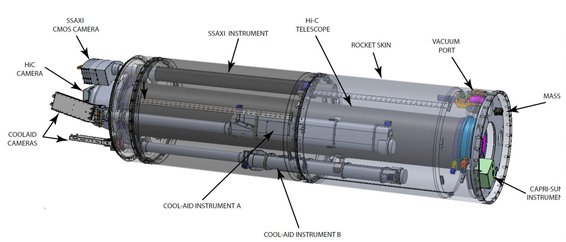


Figure 7. Instrument layout for the proposed Hi-C Flare 2. The payload will include an additional branch of COOL-AID and improvements to the original instrument suite. The locations of SSAXI and CAPRI-SUN are shown in addition to the main Hi-C Telescope and COOL-AID instrumetns and the context H-alpha camera

References

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2. Peterson, M., Vievering, J., et al *How Do We Know When to Launch? Statistical Basis for Sounding Rocket Flare Triggers*.
3. Reep, J. W., & Barnes, W. T. (2021). Forecasting the Remaining Duration of an Ongoing Solar Flare. *Space Weather*, *19*(10). https://doi.org/10.1029/2021SW002754