Observing hydrogen from the stratosphere

The Faint Intergalactic medium Redshifted Emission Balloon (FIREBall-2) is an ultraviolet multi-object spectrograph mission designed to observe the faint gas surrounding $z \approx 0.7$ galaxies from the very top of the Earth's stratosphere, explains Project Scientist Erika Hamden.

FIREBall-2 is unusual as far as telescopes go. It's a 1-m telescope with a sophisticated multi-object spectrograph capable of observing up to 80 targets in a single field, oriented by a sub-arcsecond pointing system (developed by the Centre National d'Etudes Spatiales, CNES). Moreover, it serves as a testbed of emerging detector technology. FIREBall-2 observes for just one night, from 120,000 feet up in the stratosphere, taking advantage of a narrow window in the ultraviolet (UV) accessible only at high altitudes. FIREBall also serves as a pathfinder for a potential space mission (ISTOS) designed to map and observe the circumgalactic medium (CGM) of low-z galaxies at a much wider UV bandpass.

The FIREBall balloon programme (led by Principal Investigator Chris Martin, a joint collaboration between NASA and CNES, with collaborators from Caltech, Columbia, Jet Propulsion Laboratory (JPL), Laboratoire d'Astrophysique de Marseille, CNES, and University of Arizona) is designed to observe and characterize Lyα emission from hydrogen in the CGM of moderate-redshift galaxies. The galaxies observed by FIREBall are in the age of declining star formation, where universal rates of star formation are falling after their peak at $z = 2$. Observations of these galaxies provide an important complement to observations of the CGM at high redshift using ground-based integral field units (KCWI, MUSE), which have found that emission from the CGM at $z > 3$ is nearly ubiquitous around quasars and groups of galaxies. By observing galaxies in emission, FIREBall also provides a link to the absorption-line studies carried out with Hubble's Cosmic Origins Spectrograph in the lower-redshift Universe, which find statistical evidence for gaseous haloes but are not able to image their three-dimensional structure. FIREBall is the only telescope of its kind that is attempting to make these imaging detections.

FIREBall-2 is an upgrade and improvement over FIREBall-1, which used the same gondola structure and telescope optics for two flights in 2006 and 2009. FIREBall-1 used a GALEX spare microchannel plate as a detector, but did not succeed in detecting emission around the three targets it observed. This was caused by a combination of low instrument throughput and low sky transmission due to low altitude during the science flight. Its successor, FIREBall-2, launched under a 40-million-cubic-foot balloon at 10:20 MDT on 22 September 2018, from Fort Sumner, New Mexico.

FIREBall-2 has a UV-optimized electron-multiplying Teledyne e2v CCD, which achieves ~60% efficiency in the 198–213 nm bandpass and, unlike a typical CCD, is able to count photons when operated correctly. The FIREBall-2 detector has been in development for over a decade, led by a team at JPL, and the flight was an important test of this detector technology.

The FIREBall-2 optical design consists of a 1.2-m flat siderostat for pointing, a 1-m primary parabola, two field corrector optics, a set of nine pre-selected slit masks (four science fields, four calibration masks and one open position), a two-optic Schmidt collimator, an anamorphic grating that acts as an additional field corrector, and a two-optic Schmidt camera. The field corrector and spectrograph optics are contained in a vacuum tank held at less than 10^{-6} torr via cryopumping during the flight. The detector is cooled to −105 °C using a Sunpower cryocooler, which also cools a charcoal getter.

The pointing system uses six axes of control and a four-axis closed-loop guidance system. The scientific objectives of FIREBall-2 and the multi-object nature of the spectrograph impose stringent requirements on the instrument pointing. Each science target must be centred in a 50–75 μm slit, corresponding to an accuracy of $\pm 1''$. In addition, FIREBall-2 aims to detect very faint emission, requiring long integration times (~50 s). During each integration, the instrument must maintain stability to within a pixel on the detector (~$1''$) to avoid degrading the image.

After a failed 2017 field campaign with no flight opportunities, FIREBall-2 was successfully launched in September 2018 (Fig. 1). The flight began with promise: all systems nominal. FIREBall-2 reached its expected float altitude of 128,000 feet after a three-hour ascent. It unexpectedly began descending several hours later and continued to drop throughout the afternoon and into the evening. It transpired that the balloon had developed a hole and the flight was cut short, terminating a little after 1:00 MDT on 23 September 2018. The UV transmission of the atmosphere is heavily dependent on altitude and FIREBall-2 was above our minimum altitude for only ~45 minutes of night time. The team is still determining if any usable data was collected during this time.

Fig. 1 | FIREBall-2 prior to launch. The image shows the FIREBall-2 telescope hanging from Big Bill, the launch vehicle, waiting to be rolled out to the flight line in the early hours of 22 September 2018. Credit: P. Balard, Laboratoire d'Astrophysique de Marseille.

FIREBall-2 is currently being refurbished for a 2020 launch attempt. The 2018 landing was harder than those sustained by the gondola in 2006 and 2009, and resulted in some damage to the gondola structure. However, there was minimal damage to the spectrograph, and correctable edge fractures on the large optics. The team remains dedicated to this important mission. ❐

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