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| Method | Benefits | Challenges |
| Onboard miniaturised spectrometer | * Optical spectrometers can directly detect elements by observing their unique spectral lines, so real-time data would be provided on materials * Miniaturised versions available for CubeSat missions | * The idea of doing this during satellite demise has never been done before, but measurements have been taken during an ESA mission (QARMAN) for a CubeSat do survive during satellite re-entry * Would need sufficient protection against high temperatures and vibrations * Could be high cost as it’s miniaturised * Challenging due to onboard storage and telemetry difficulties but QARMAN successfully transmitted data to the Iridium satellite network * Required onboard power and storage * Not the greatest resolution- affected by size and power constraints |
| Ground-based spectroscopy | * Easy to store data locally * Setup complexity isn’t massively difficult * High resolution, no limitations on space and power (no onboard constraints) * Issues of in-flight transmission is avoided so analysis can be straightforward | * Requires ground-based infrastructure and timing * Setup does require alignment with re-entry path * Requires access to ground-based spectrometers * Strong reliance on clear skies and appropriate atmospheric conditions- unpredictable * Any deviation in trajectory or timing could result in missed data * The use of high altitude balloons may require permissions |

Onboard miniaturised spectrometer:

We would essentially have a spectrometer inside the CubeSat to measure data on the light emissions produced by atmospheric reactions, so we can understand the composition of gases and particles interacting with or generated by the CubeSat

QARMAN:

The spectrometer was placed behind a cork-based ablative thermal shield so the instrumentation was protected. The spectrometer was installed with an outwards facing window/view port that allowed it to observe the plasma outside while being shielded from direct exposure

Did mention that in the future they would be looking to do the experiment again with a blackbox

<https://www.eoportal.org/satellite-missions/qarman>

<https://www.eoportal.org/satellite-missions/qarman#eop-quick-facts-section>

Mass spectrometers:

Can be specifically designed for nanosatellites and can directly analyse particles and gases, identifying specific ions or molecules released during the degradation of materials

However, these work best in stable conditions so it not a feasible idea for our re-entry experiment. Additionally, they are more expensive and larger than optical emission spectrometers

Ground based spectroscopy:

* Companies include LeoLabs, Planet Labs, and some geospatial analytics firms. These companies often track satellite movements and could potentially help with re-entry plume observations.
* Companies like World View Enterprises or Near Space Corporation provide high-altitude balloons that can carry observational instruments up to the stratosphere. You can equip them with spectrometers or cameras to capture re-entry data at closer proximity than ground-based observations
* Some balloon companies may offer customizable payloads with sensors, cameras, and data collection tools
* Spaceports often monitor objects entering and leaving the atmosphere for launch and debris tracking
  + May only be good for objects and not gas traces like we need

<https://indico.esa.int/event/493/timetable/?view=standard_inline_minutes>

<https://strathprints.strath.ac.uk/78407/1/Graham_etal_IAC_2021_The_design_of_a_fragmentation_experiment_for_a_CubeSat_during_atmospheric_re_entry.pdf>