

“HYPERFLUORESCENCE”: A NEW TECHNIQUE FOR SPACE RESOURCE ASSESSMENT AND UTILISATION. Nigel Spooner^{1*}, Jillian Moffatt¹, Thomas Payten¹, Thomas de Prinse¹, Alexandra Chapsky¹, Thomas Slattery¹, Joshua Rusby¹, Georgios Tsiminis^{1,3}, Elizaveta Klantsataya¹, Lewis Teixeira¹, Barnaby Smith¹, David Ottaway^{1,2}

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Introduction: The prohibitive expense of delivering bulk materials into and beyond Earth orbit will necessitate *in situ* resource extraction for future human utilization and settlement of the Solar System. “Living off the Land” by employing Space Resources from off-Earth bodies will require a sequence of essential activities to obtain these resources, broadly characterised as: resource discovery, evaluation and viability assessment, followed by mining and mineral processing, then subsequent utilization via sensor-controlled manufacturing for product creation.

While there are many unanswered questions regarding the technologies required for implementing these activities in Space, many companies recognize the potential and critical future need for R&D for off-Earth resource discovery, assessment, extraction, and utilization.

Target objects for the foreseeable future include small Solar System bodies (SSSB), the Moon, and Mars. Asteroid mining has received considerable coverage in the public domain as they can be rich in iron and nickel, as well as platinum group metals, depending on their type [1]. However, possibly of most value to human settlement are those bodies with accessible water, metals, and organic compounds such as acetone [2,3]. The elemental constituents of organics, namely carbon, hydrogen and oxygen, can be turned into rocket propellant (fuel and oxidizer respectively), as well as providing oxygen, water and food for critical human life support. For example, a class of organic molecules abundant on SSSB & planetary surfaces known as Polycyclic Aromatic Hydrocarbons (PAHs) are a backbone of fossil fuels and are expected to be of great importance for future exploration and settlement of the Solar System.

The first step in any space resource mission will be remotely-managed and mostly autonomous prospecting for suitable targets. More than 750,000 asteroids have been discovered to date, with the vast majority located at the asteroid belt orbiting between Mars and Jupiter. While resource extraction from the asteroid belt is likely further in the future, the closest and most accessible targets for early resource extraction missions will be near-

Earth SSSB’s and asteroids, which narrows down the available objects to just over 20,000 [4].

“HyperFluorescence” Analysis: A variety of optical spectroscopic techniques are currently employed for the extra-terrestrial detection and identification of chemicals and minerals, including absorption spectroscopy (hyperspectral analysis) and fluorescence spectroscopy, laser induced breakdown spectroscopy (LIBS), x-ray fluorescence (XRF), neutron activation, gamma ray fluorescence, and neutron emission [5]. Each technique has its own advantages and disadvantages, and systems have been designed primarily for mineralogical assessments.

However, it is highly challenging if not impractical to detect and identify in near real-time a diversity of mineral species or organic molecules in a complex environment using these current technologies. Although combining the output of multiple techniques can provide a more robust and detailed assessment of environmental content, most current techniques provide elemental data only, not mineral or chemical species. Furthermore, sensor data integration is a difficult process when different techniques are observing different aspects of a complex field of unknown samples.

Space Resource sensing currently lacks a suitable suite of techniques capable of enabling the critical operations beyond discovery, that is, the determination of resource viability and then providing control for autonomous mining, mineral processing and manufacturing - all essential for viable future space resource utilization.

We are developing a “novel fluorescence” method, HyperFluorescence (HF), capable of species-specific discrimination for detection and identification of mineral species and organic compounds such as acetone and PAHs. Fluorescence is an active technique, and as such is capable of detection of tiny target samples in complex environments.

Our HyperFluorescence program is based on the utilization of “novel fluorescence” regimes for real-time material identification in the field. This approach is highly complementary to existing absorption/reflection technologies like hyperspectral analysis, enabling

targeted identification using fluorescence and the collection of context information using absorption/reflection on the same apparatus. This provides data that can be analysed, integrated and interpreted in near real-time.

One sensing modality under the HyperFluorescence program is upconversion fluorescence (UF) spectroscopy. UF occurs under appropriate laser illumination in a process involving the absorption of two photons and subsequent emission of a photon of higher energy [6]. There are two advantages of the technique over conventional fluorescence methods. Firstly, since the emitted photons are of higher energy than either of the excitation photons, emission is spectrally isolated from scattered stimulation light, presenting a signal to noise advantage. Secondly, upconversion fluorescence, being a multi-photon effect that relies on multiple material energy levels, is inherently more material-specific. Conventional fluorescence, especially when exciting with ultraviolet light, has the disadvantage of creating a “noisy” environment full of overlapping peaks that can mask one another; upconversion fluorescence allows emission from a specifically targeted subject material.

For example, acetone and small PAHs typically exhibit a well-known blue photoluminescence emission around 400-500 nm when excited by ultraviolet light. Under dual-wavelength illumination with two photons from the visible waveband, we similarly observed the characteristic blue emissions at both room and cryogenic temperatures [7], indicating applicability of the UF spectroscopy to organic molecules in space conditions.

Conclusions: “HyperFluorescence” is under investigation as a suite of new sensing techniques capable of filling the gap for Space Resource Assessment and subsequent utilization. It promises a unique combination of capability for material species-specific identification, and is non-contact, requires no sample preparation, is scalable, and is capable of detecting very small concentrations of target materials. HyperFluorescence can also be directly integrated with both machine learning algorithms and unsupervised data analysis systems. Good first targets will be the lunar regolith, mineral outcrops and potentially water-bearing materials, and near-Earth asteroids.

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References:

- [1] A.S. Rivkin, et al. (2000) *Icarus*, 145(2), 351.
- [2] K. Kitazato, et al. (2019) *Science*, 364, 6437, 272-275.
- [3] Tom Henshall (2019) *Nature Reviews Materials*, 4, 228.
- [4] NEA Stats (2020) <https://cneos.jpl.nasa.gov/>.
- [5] A.N. Rencz & R.A. Ryerson, (1999). Manual of Remote Sensing, Remote Sensing for the Earth Sciences. V1 & V3, 3rd Ed., John Wiley & Sons.
- [6] J.E. Moffatt et al. (2019) *Applied Spectroscopy Reviews*. <https://doi.org/10.1080/05704928.2019.1672712>
- [7] T. de Prinse, et al. (2022) *J. Fluorescence*, 32, 1051–1057.