“HyperFluorescence for Real-time Mineral & Material Identification: Update

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“Novel Fluorescence” and “HyperFluorescence”

Initiated as a new means for mineral detection, identification & quantification

1. **Real-time, Non-contact, Species-Specific – requirement for mineral identification and quantification at 5 m/sec cross-belt and applicable for all phases of mining from exploration to tailings management.**

2. **Expanded to SRU, including mineral ores, construction materials, organics & chemicals.**

3. **Discovery of species-specific excitation and emission detection conditions enables design of optimised sensors with widely scalable, application-driven Form Factors.**

“Novel Fluorescence”(NF) is integrated with Hyperspectral imaging to create new sensing capability: “HyperFluorescence” (HF)

NF is Technologically-enabled

- **Enabled by new laser and detection technology**: Facility comprises integrated multiple laser systems, UV-MWIR imaging and spectrometry detectors, cryo-chamber stages

- **Utilises fluorescence regimes previously under-studied or un-studied** ("Novel Fluorescence"), including dual-photon excitation – **Upconversion Fluorescence**

- **NF capable of mineral identification and quantification,** even of low concentrations of grains in mixtures or minor inclusion components in rocks (feldspar, apatite, zircon, spodumene, REE's..). E.g.: NF detects fluorine-bearing fluorapatite grains at fluorine concentration < 0.005 weight %.

Space environment advantage - Thermal conditions and lack of atmospheric absorption are significant advantages intrinsic to Space

Upconversion Fluorescence

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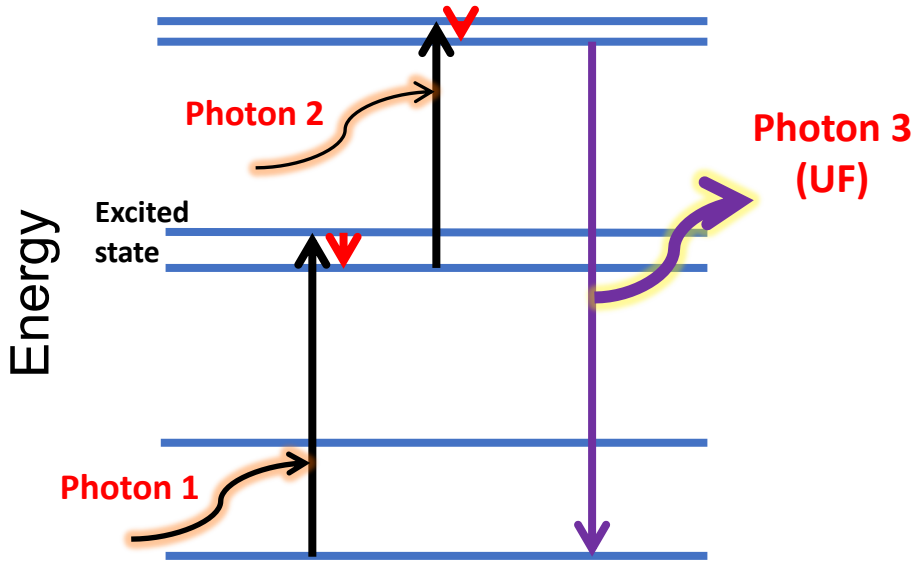
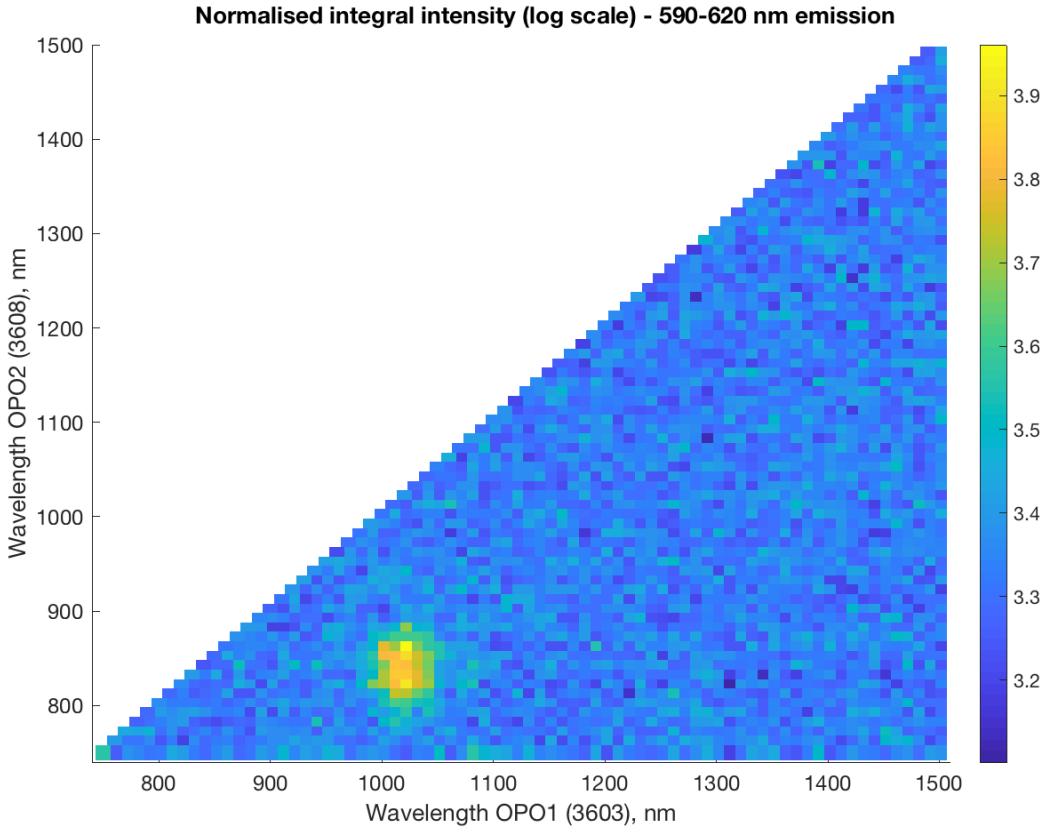
1. **Two photons are consecutively absorbed by a material**
2. **Emission is at shorter wavelength** than either illumination wavelengths: a material-specific 3-photon system with negligible background from scattered excitation photons
3. **UF emission is a material-specific "fingerprint"**





J. E. Moffatt, G. Tsiminis, E. Klantsataya, T. J. de Prinse, D. Ottaway & N. A. Spooner (2019). *A practical review of shorter than excitation wavelength light emission processes.* **Applied Spectroscopy Reviews**, DOI: 10.1080/05704928.2019.1672712

NF and HF Technology Outline – 1

- **Analysis Depth:** NF is a surface optical technique.
- **Spatial resolution:** extends from micro-sized – individual grains, to large-areas: limited only by illumination capability and detection efficiency.
- **Detects mineral species**
- **No sample preparation required**
- **Concentrations can be detected at ppm levels**
- **Detect & quantify target mineral grains even if only a tiny fraction of the sample**
- **Particle size range unlimited, from glasses/clays up to rocks, landscapes**
- **Fluorescence enhanced at low temperatures & no atmosphere = ideal Lunar technique**

NF and HF Technology Outline – 2

- **Highly scalable:** Analysis from micro-scale to km
- **Analysis is near real-time** for each FoV, making NF uniquely suitable for prospecting: simultaneous detection & quantification of target mineral grains in regolith or on rocks
- **No Safety issues**

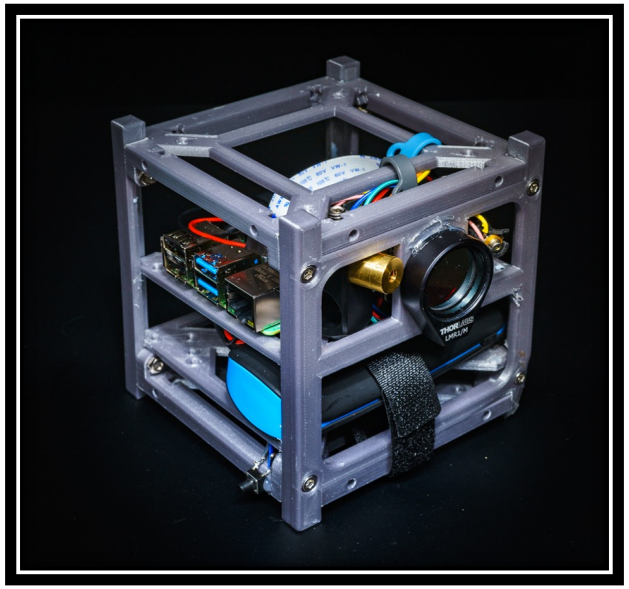
Use cases:

- Rover-borne prospecting
- Real-time mine face analysis as active guide to mineral ore extraction
- Cross-belt analysis - selective mining sensors
- Real-time monitoring for mineral processing control
- Potential for km scale low lunar orbit Moon resource mapping by pulsed-laser analysis (**night side or permanently-shadowed craters for reduced ambient background**)

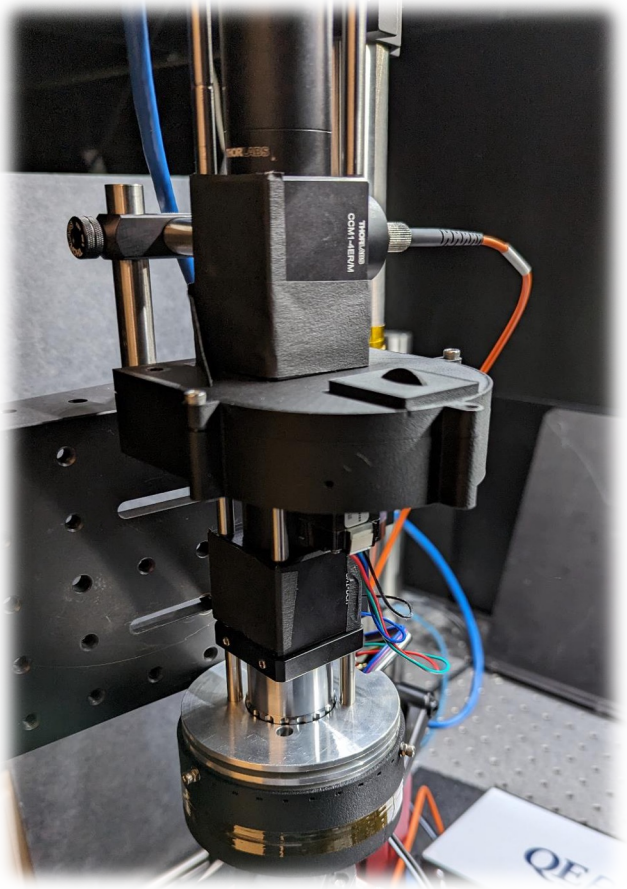
TRL Level: range from **TRL 2** (NF signal discovery) to **TRL 5** (pre-field test hand-held prototype constructed to detect and quantify Fluorine in coal)

Facility to Portability: Scaling Down To Field-Deployable Size

- **“Discovery facility” is complex and large - lab-room scale.**
- **Once unique optical signatures are discovered, the field sensor form factors are versatile, simplified and highly scalable**
- ***HyperFluorescence sensor designed in partnership with Flawless Photonics, Wt < 1.5 kg***

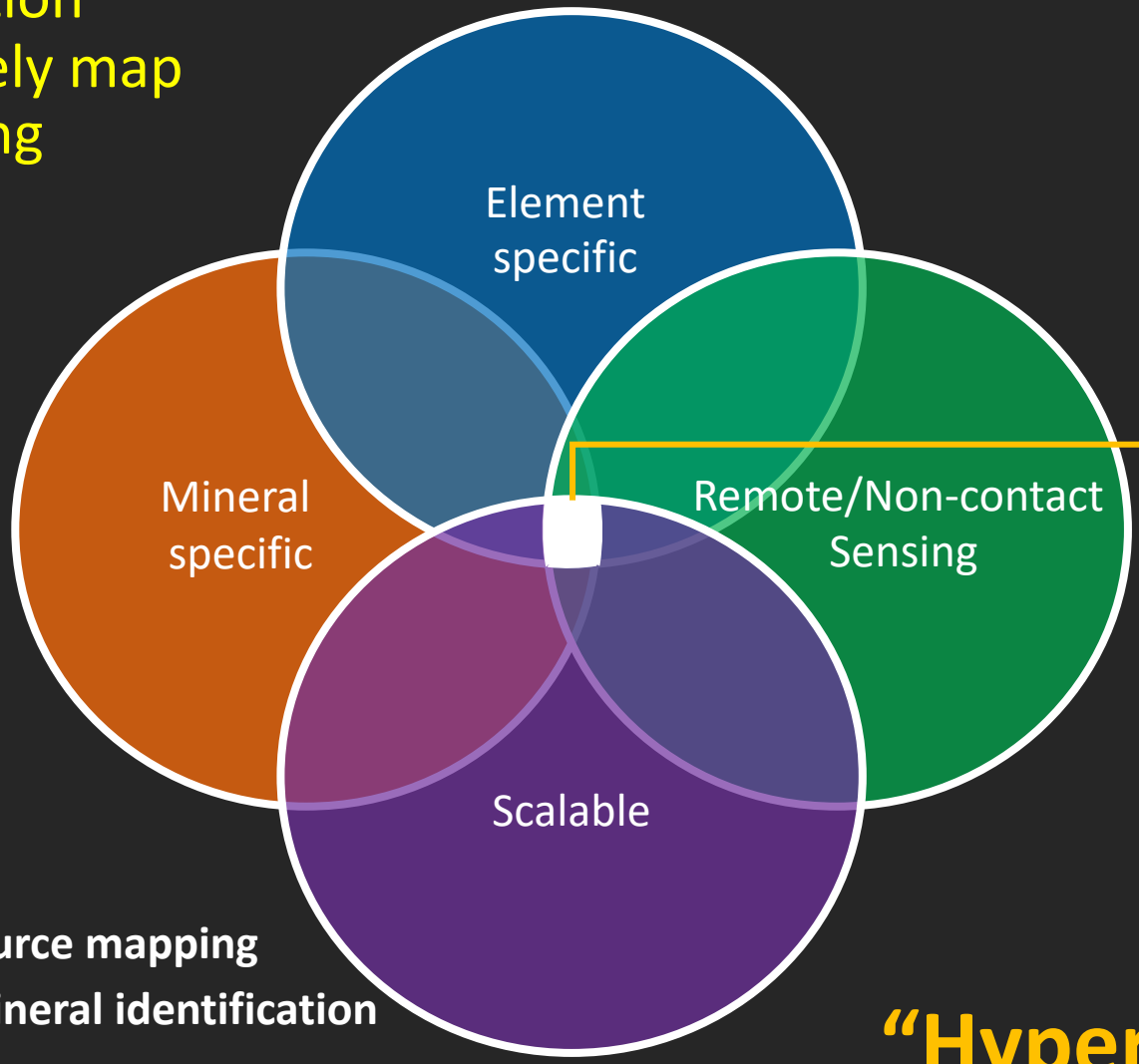


Fluorine mineral sensor in both 1U cubesat and handheld formats



Custom-built portable microscope NF rig to generate data for machine learning analysis. Automatically changes light sources, captures images and spectra and moves samples, including larger, bulk samples.

- Space Resource exploration lacks sensors to accurately map **minerals** for Space mining



Critical Gap - Ideal sensor system for valuable resource identification

1. **Material-specific**
2. **Non-contact (stand-off)**
3. **Real-time**
4. **Scalable :**
   - **Orbit-based large-scale resource mapping**
   - **Ground-level rover-based mineral identification**

✓ **Sample pre-treatment not needed**

✓ **“Active” sensing - low background, high efficiency**

✓ **Can detect tiny samples in complex environments**

“HyperFluorescence” addresses the critical gap

Complementary Sensor Technologies for Space Resources

"Novel" Fluorescence + Hyperspectral Imaging

Sensor	Water	Structural information	Low-value rock	Element specific	Material Specific	Resource viability	Active vs passive	Sensing depth
LIBS							Active	Surface
Hyperspectral Imaging							**Active**	**Surface**
LIDAR							Active	Surface
Gravimetric							Passive	Deep (km)
Magnetics							Passive	Deep (km)
Radar							Active	Deep (100s m)
Neutron Activation							Active	Shallow (m)
Gamma / Xray Fluorescence							Active	Shallow (cm)
Novel Fluorescence							**Active**	**Surface**

Always

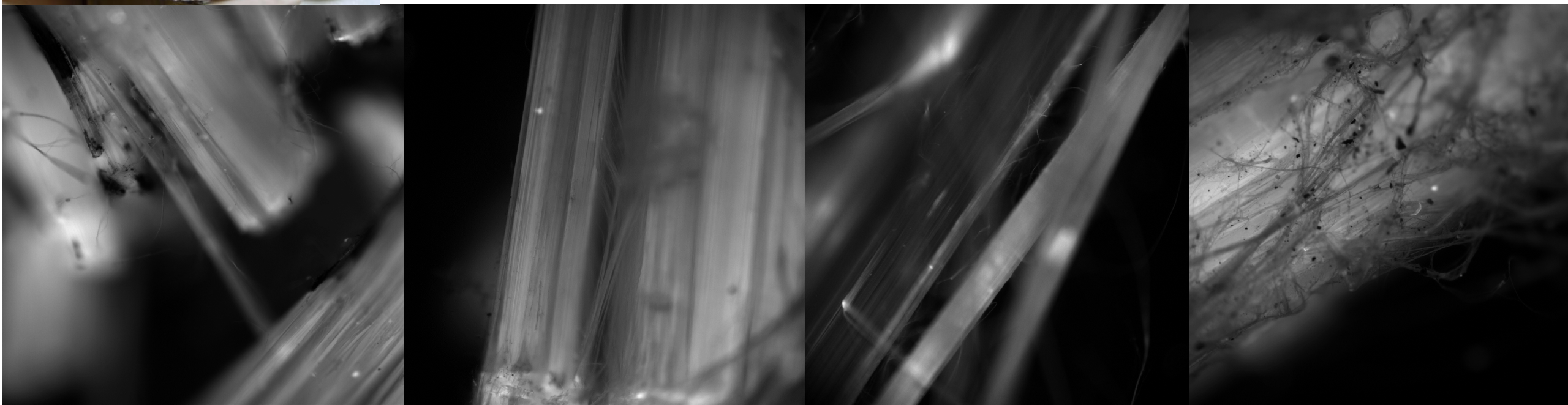
Sometimes

Never

Example 1: Chrysotile Asbestos

Chrysotile asbestos comprises about 95% of the world's asbestos use.

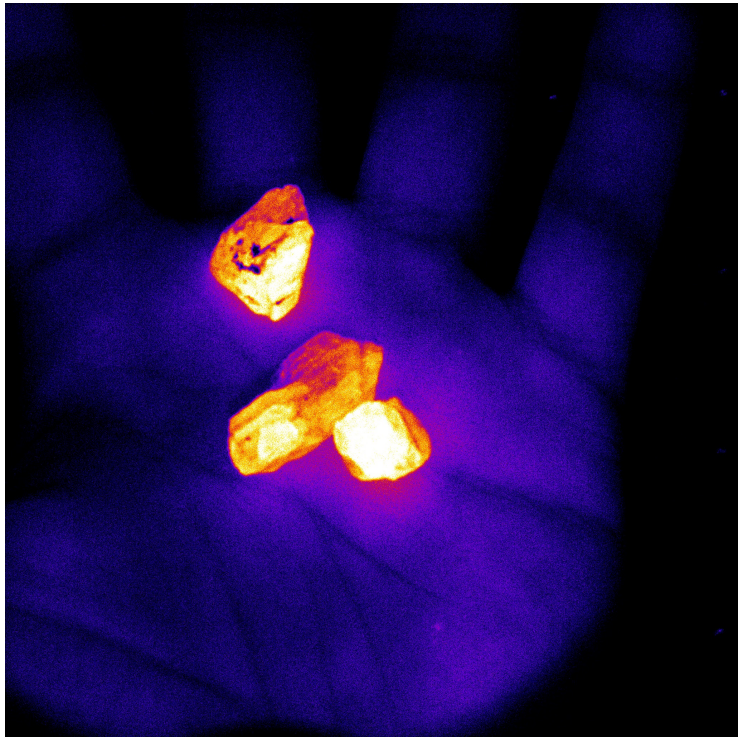
Chrysotile mineral samples –
LHS: visible light photographs
Below: chrysotile fibres imaged in their emitted fluorescence



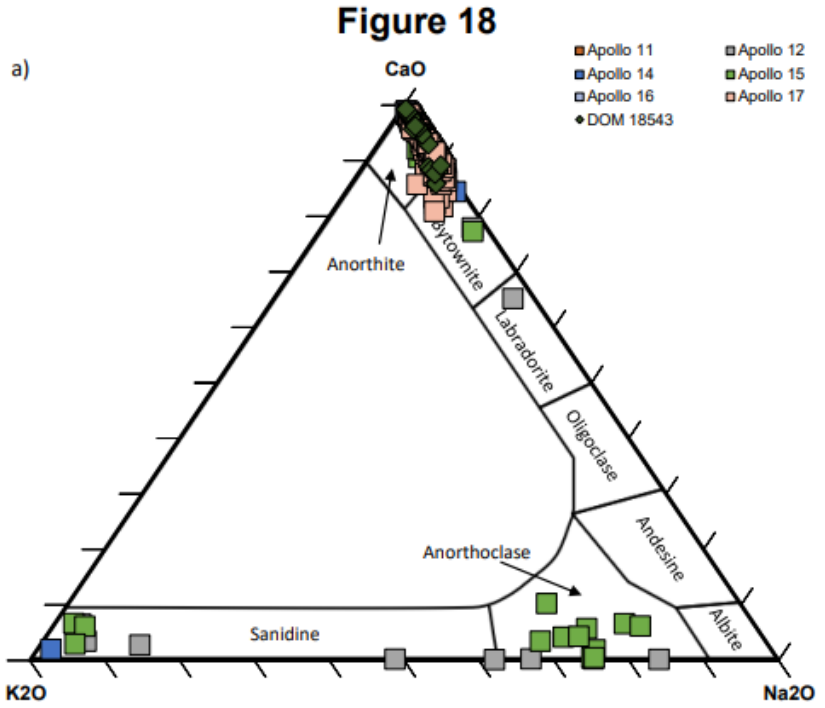
Example 2 - Feldspars

Novel fluorescence from feldspar minerals; sources of Na and Ba, and also Ca, K, Al, Si & O.

Feldspar fluorescence bright and species-dependent, enabling grain detection & identification and non-contact, optical quantification and resource mapping. All tested feldspars fluoresce.



LHS: three sodium-rich feldspar pebbles under white light
RHS: imaged in their NIR fluorescence

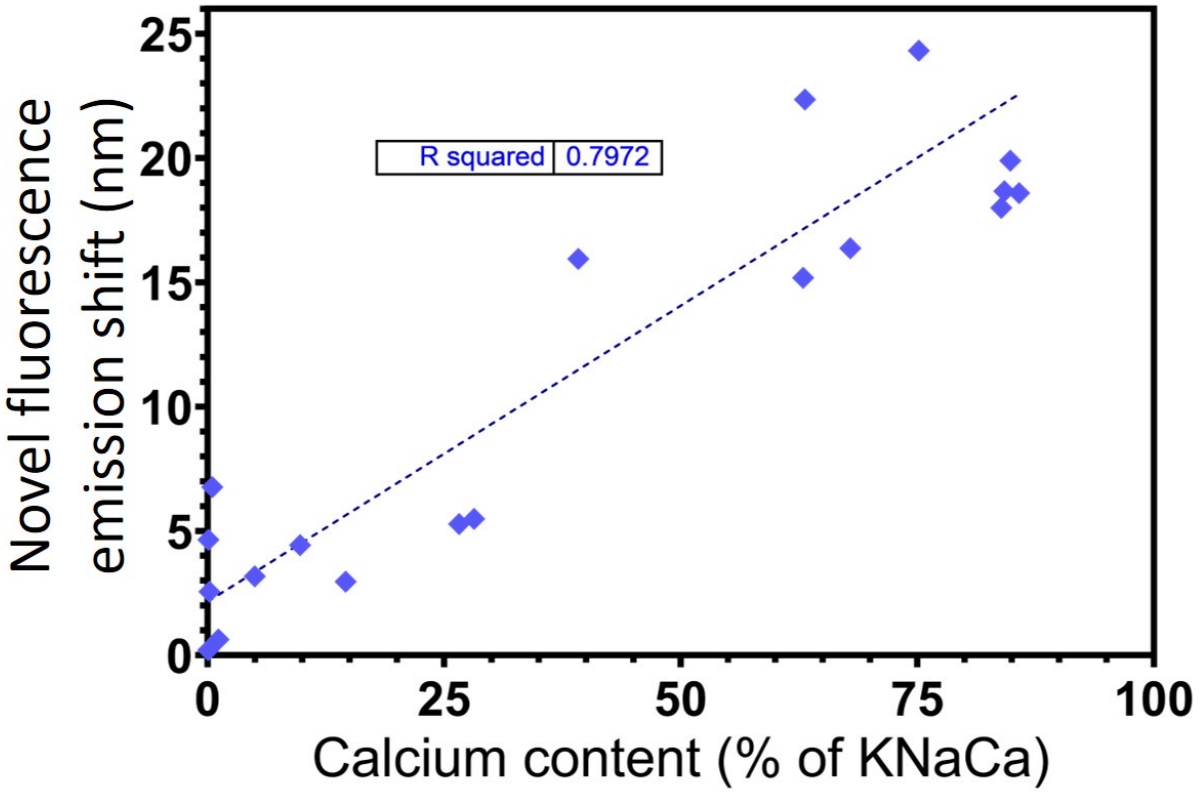


Lunar ternary diagram, from: *"New Insights Into The Petrogenesis Of Lunar Basaltic Breccia Meteorites From The Dominion Range" (DOM)18543*

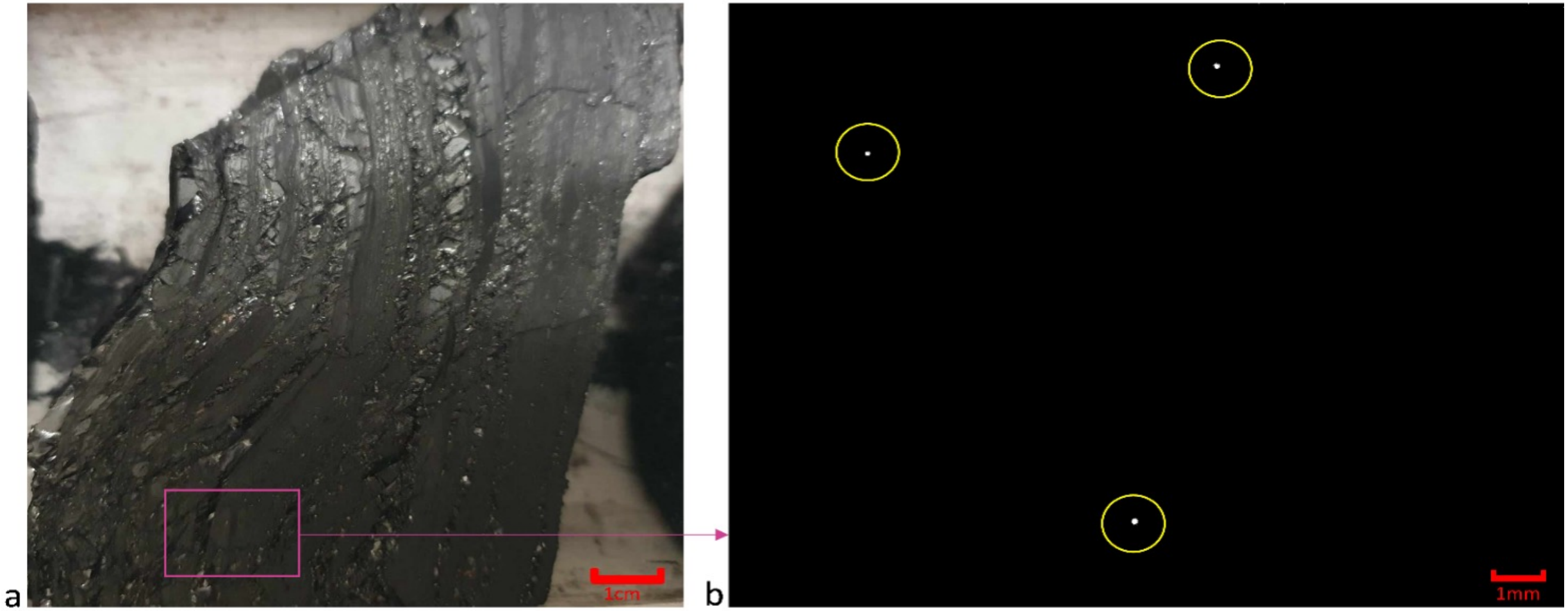
Example 2 - Feldspars

Novel fluorescence enables detection and speciation of the feldspar minerals by three different complementary methods.

Below is shown a graph constructed using a metric derived from fluorescence emission spectral peak shift to determine Ca content – similar approaches define the K-Na alkali axis and refine the plagioclase discrimination.

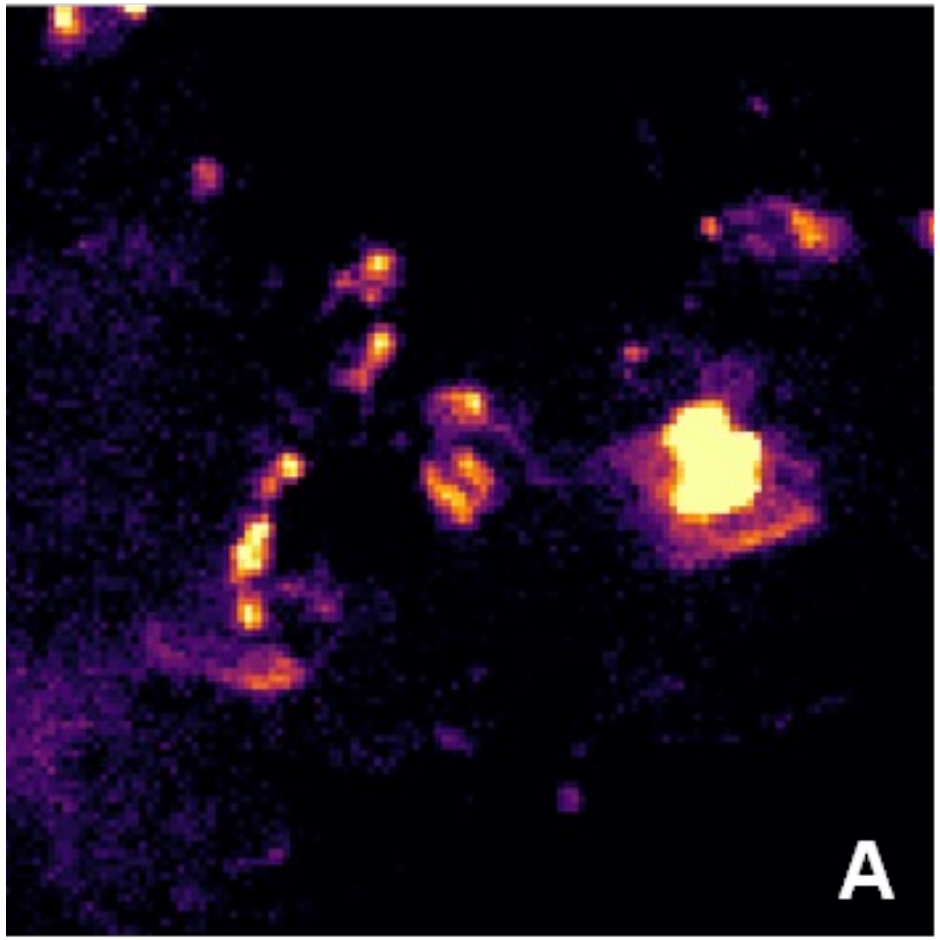


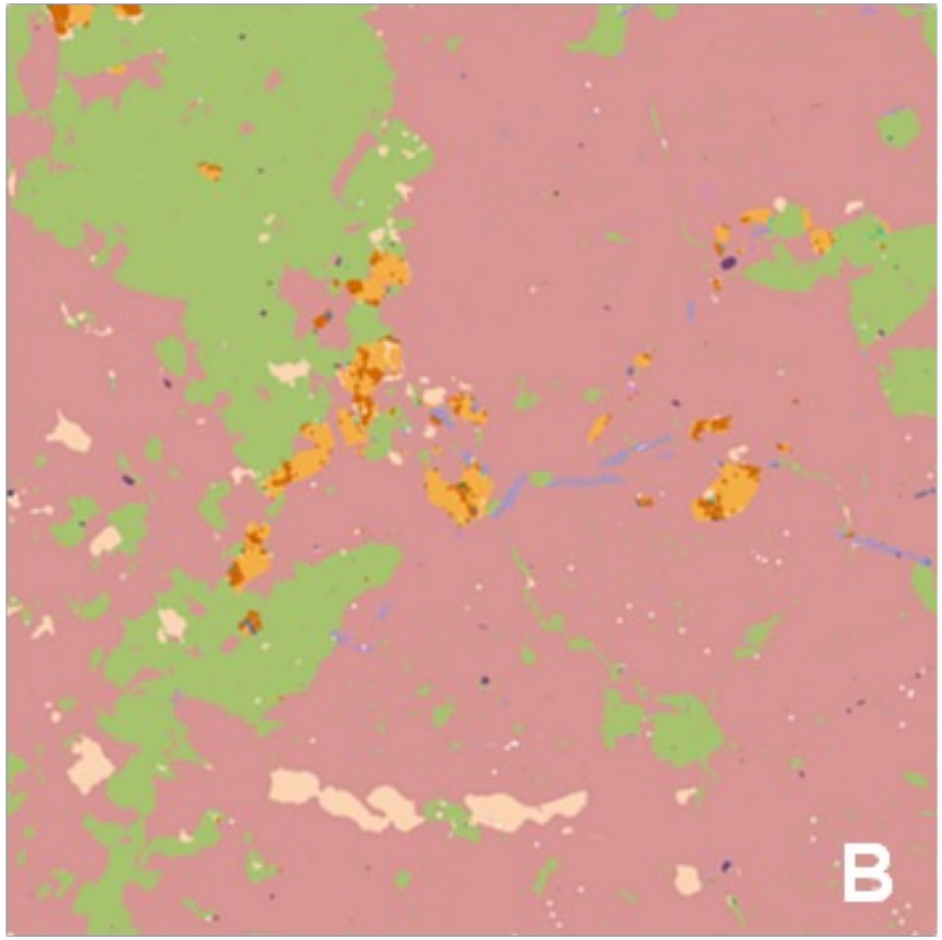
Example 3 - Fluorine-bearing Mineral Contaminants in Coal



A section of coal core: (a) visible light photograph, and (b) image in emitted IR fluorescence using our C43050 prototype sensor.
The three fluorescent inclusions circled yellow are fluorapatite.

Example 4 – Spodumene (lithium ore)





Inclusions of spodumene are clearly observable in polished section. The image obtained using real-time NF processes (A) has exceptional spatial agreement with the mineral map (B). All spodumene inclusions shown in the map are resolvable using NF processes. The NF detection includes slightly sub-surface portions of inclusions.

Additional Novel Fluorescence Emitters

Survey analysis of constituent mineral samples of lunar regolith simulants.

Dust/soil provided by UCF's Exolith Lab & Space Resource Technologies - (https://spaceresourcetech.com/cdn/shop/files/SAMPLEFULLSETLABELED_720x.jpg?v=1707925212;)

Four of the five simulant minerals exhibit NF. The fifth, basalt, has not yet been observed to emit NF but has not yet been extensively investigated:

- **Anorthosite; Ilmenite; Olivine; Bronzite (pyroxene) –** NF emitters under study
- Basalt – non-fluorescent within the limited parameter space so far explored.

A wide range of economically-relevant materials have been analysed and found to have "Novel Florescence" signals, including:

- Various heavy minerals including zircon, monazite, xenotime, rutile, ilmenite,
- REE's including in clay hosts, phosphate minerals
- Feldspars, some other silicates
- Some transition metal ores

HyperFluorescence for Autonomous Real-time Space Resource Assessment

"HyperFluorescence" sensor creates a "Fluorescence Fingerprint" for each sample – comprising a stack of "Hyperspectral cubes"

1. **Each cube is a hyperspectral image of fluorescences excited by a specific wavelength.**

2. **Interpreted via library of fluorescence signatures and Machine learning correlation.**

3. **Detection and Quantification of minerals: grain-scale resolution of regolith minerals.**

4. **New Selective Mining capability: improves resource mapping and evaluation of total economic value, and towards future autonomous mineral processing control.**

Novel Fluorescence/HyperFluorescence Sponsors*

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- **Cooperative Research Centre for Optimising Resource Extraction (CRC ORE)** (Mining & Mineral Processing).
- **Australian Department of Defence** "Next Generation Technology Fund" (Counter IED).
- **Australian Space Agency (ASA).**
- **Cooperative Research Centre for Mineral Exploration (CRC MinEx)**.
- **Australian Coal Association Research Program (ACARP).**
- **Australian Dept Industry, Science and Resources - Business Research and Innovation Initiative (BRII)**

Now establishing a start-up, TeraGlo for commercialisation of Novel Fluorescence; backed by Loughan Technology Group, founder of Flawless Photonics