"HyperFluorescence": A New Technique For Space Resource Assessment And Utilisation

Professor Nigel A. Spooner

School of Physics, Chemistry and Earth Sciences
& Institute for Photonics and Advanced Sensing (IPAS)
University of Adelaide
Australia

Contents

- Andy Thomas Centre for Space Resources - space systems development
- IPAS - Optical Fibres & laser physics
- ISER - mining & mineral processing
- Commercialisation partnership discussions underway

Program Sponsors

THE UNIVERSITY *of* ADELAIDE

- **Cooperative Research Centre for Optimising Resource Extraction (CRC ORE)** (Mining & Mineral Processing).
  Foundation funding & development of cross-belt fluorine mineral sensor

- **Australian Department of Defence** "Next Generation Technology Fund" (Counter IED).
  Sensing of chemical precursors and explosives

- **Cooperative Research Centre for Mineral Exploration (CRC MinEx)**.
  Mineral identification at the drill head

- **Australian Coal Association Research Program (ACARP).**
  Hand-held sensor for fluorine minerals in coal

- **Australian Space Agency (ASA).**
  Materials sensor for deployment on lunar rover

- **Australian Dept Industry, Science and Resources - Business Research and Innovation Initiative (BRII)**
  Hand-held real-time asbestos sensing

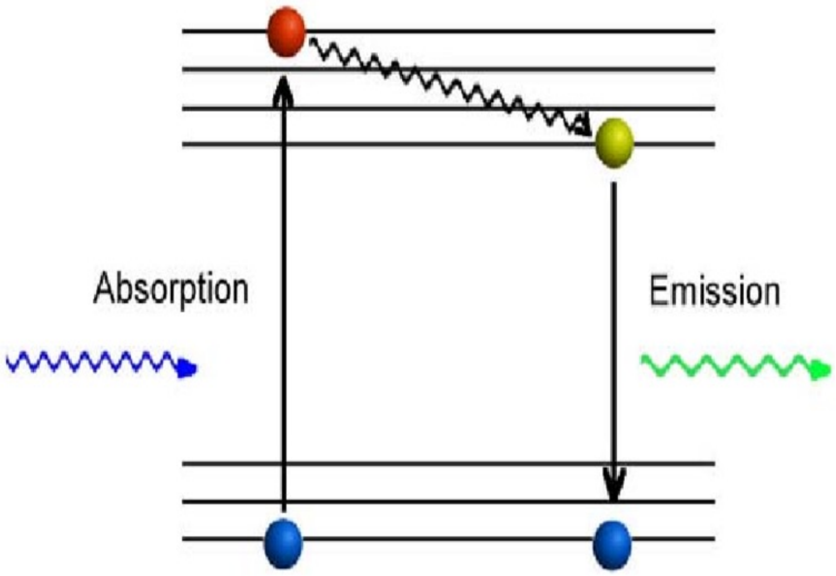
The “Novel Fluorescence” Program

- **Initiated as a new means for material detection, identification and quantification.**
- Response to mining and mineral processing **requirement for mineral identification in real time**, such as at 5 m/s on a conveyor belt.
- Evolution to chemical sensing, and to sensing of materials of importance to space resource utilisation, such as ores, potential construction materials & organic chemicals, in cold vaccuum.
- Utilises new laser systems and detection technology to explore fluorescence regimes not previously investigated for these materials (**“Novel Fluorescence”**).
- Excitation and detection conditions discovered enable optimised specifications for the design of sensor modules for validation and application in space.

"Novel Fluorescence" - Material-specific; Real-time; Non-contact

THE UNIVERSITY of ADELAIDE

Fluorescence basics



- Single-photon absorption, then single-photon emission at longer wavelength than excitation photons
- Conventionally, only UV/blue excitation is used, and emissions are detected only in the UV/Visible/NIR (200 - 1,000 nm)

- UoA is pioneering three new Fluorescence regimes for materials analysis
- Goal: discovery of unique new signatures for materials detection, identification & quantification
- Each regime opens new opportunities for materials sensing
- Technologically-enabled: multi-photon and single-photon excitations; detection from UV-MWIR; thermal conditions and lack of atmospheric absorption are advantages intrinsic to Space

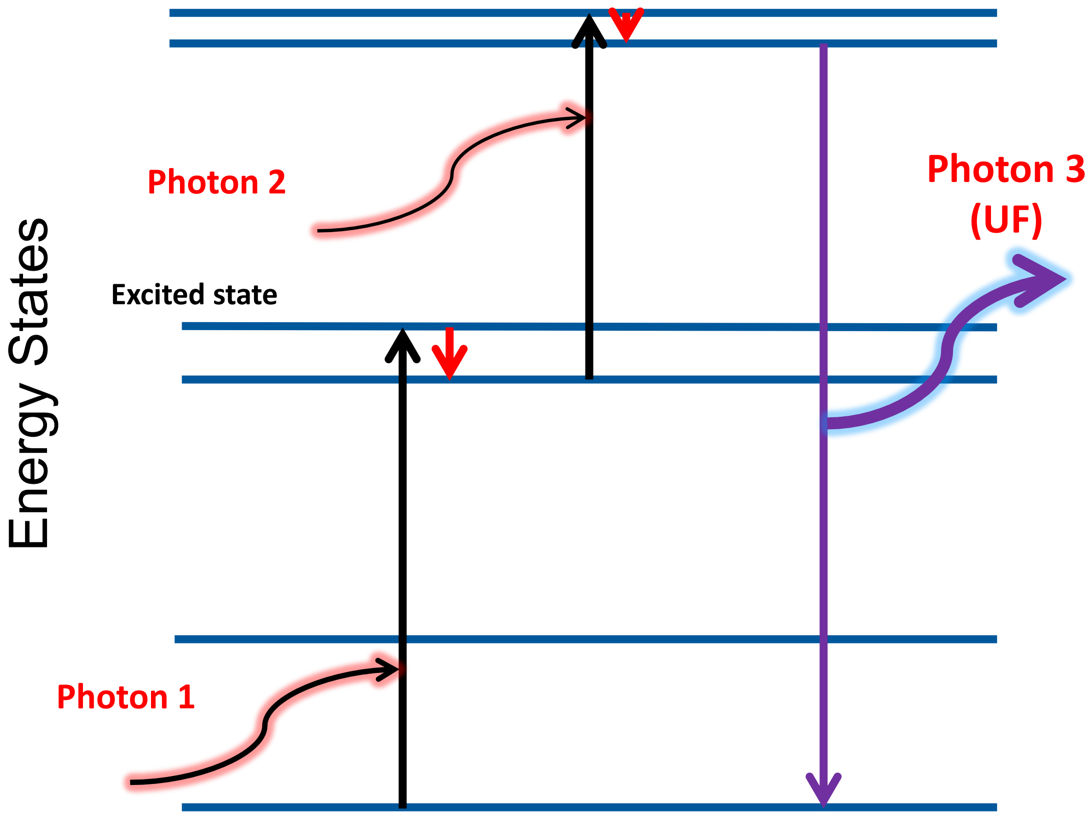
Upconversion Fluorescence

UF is a real-time stand-off technique for material detection and identification

1. UF emission is a material-specific “fingerprint”
2. Emission at shorter wavelengths than the illumination light beams: hence greatly improved S/N with no scattered excitation photon/fluorescence background

- Two photons are consecutively absorbed by a material:
  Photon 1 first excites an electron to a metastable (excited) state
  Photon 2 must be absorbed before the electron drops from the excited state

- One photon (Photon 3) is then emitted that has an energy greater than either of the two excitation photons

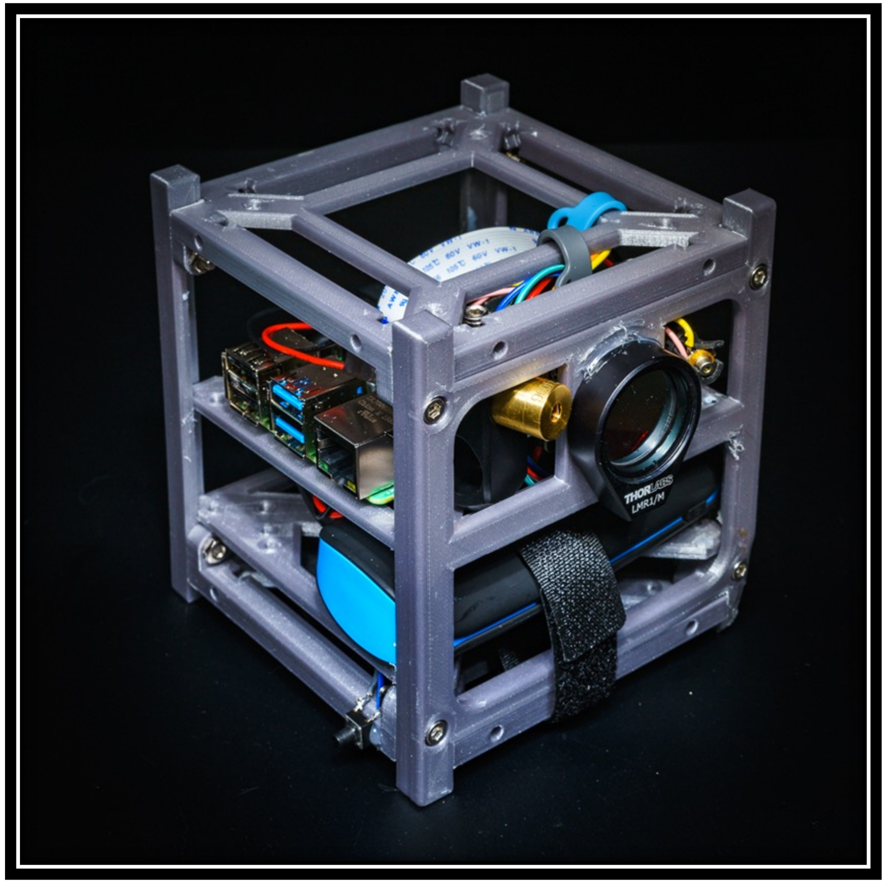


Facility - Globally-unique Fluorescence Analysis Capability

THE UNIVERSITY of ADELAIDE

- World fluorescence databases - almost entirely comprised of data collected using UV-blue excitation, and UV - 1,000 nm emission detection
- UoA Integrated system: built on state-of-the-art tuneable laser systems, enabling either **Single or Dual photon excitation** - **all wavelengths from 210 nm (UV) to 4,000 nm (MWIR)**
- Emission detection system incorporates spectrometers and imagers giving **spectra and images 200 nm to MWIR**
- Sample Chamber: **rampable vacuum cryo-stage, range -190°C to +600°C.** Atmosphere can be air; gas of choice; or vacuum

Facility: Scaling Down To Field-Deployable Size

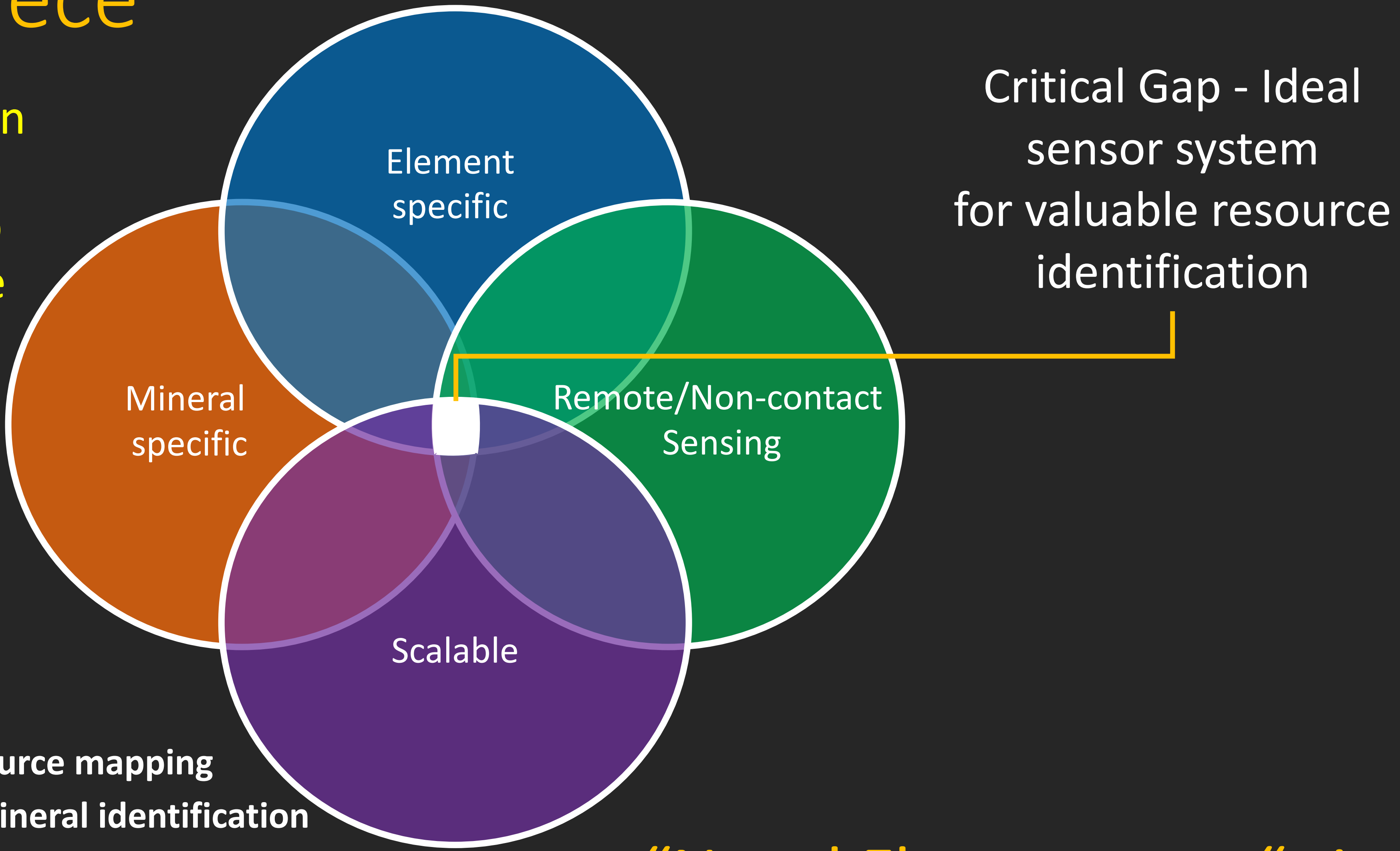


Example: Fluorine mineral sensor built as proof of portable hand held sensing concept (10 x 10 x 10 cm; 450 g)

- **The "Discovery facility" is complex and large - lab-room scale**
- **Once the unique optical signatures of a material have been found, the equipment needed to detect it can be greatly simplified.....**

The missing piece

- Space resource exploration lacks a suitable suite of sensors to accurately map resources for future space mining operations



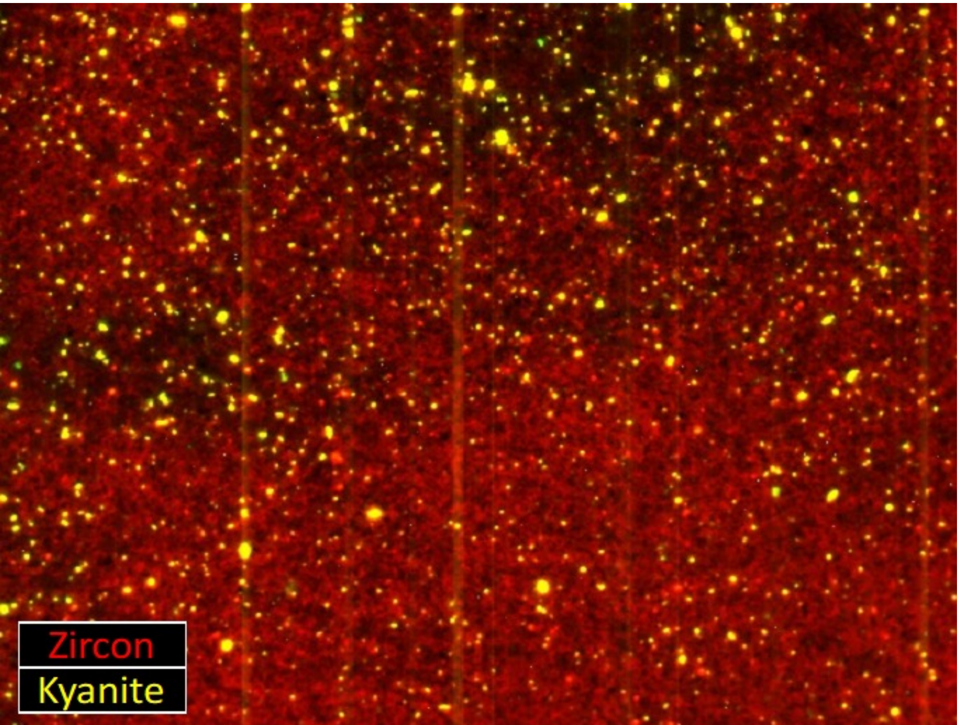
- **Material-specific**
- **Non-contact (stand off)**
- **Real-time**
- **Scalable :**
  - **Orbit-based large-scale resource mapping**
  - **Ground-level rover-based mineral identification**
- **Sample pre-treatment not needed**
- **"Active" sensing - low background, high efficiency**
  Can detect tiny samples in complex environments

"Novel Fluorescence" sits in the critical gap

Example: Mineral Sand Analysis

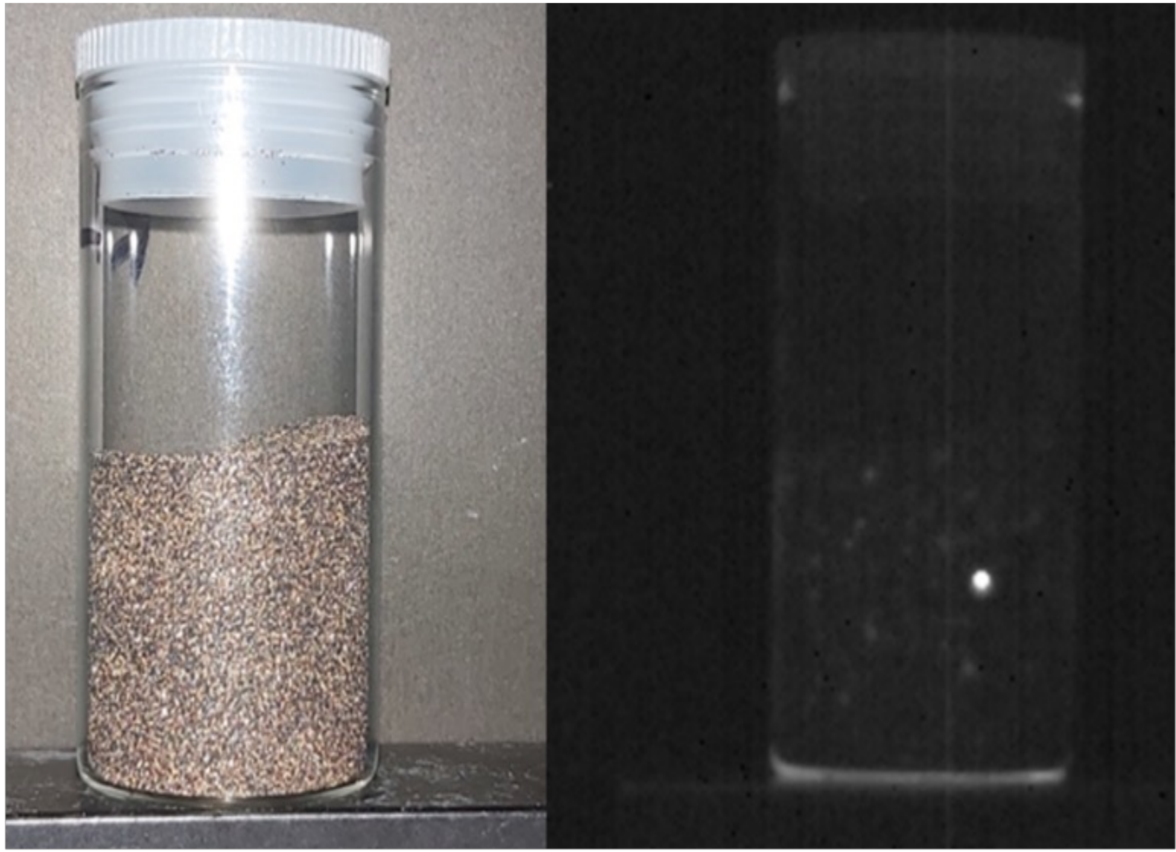
- Visualising grains of economically important target species in complex mineral sand samples
- Mineral differentiation by NF enables spectral-specific visualisation
- real-time inspection; no sample preparation required
- **Enables detection of tiny components in complex mixtures**
- Selective processing to maximize extractable resources
- Enabled by NF field-deployable & on-belt sensor systems

NIR image, showing single zircon grain



Discrimination between mineral species using NF. (“Mineralogy at 20 Hz”)

Visible light image of mineral sand concentrate



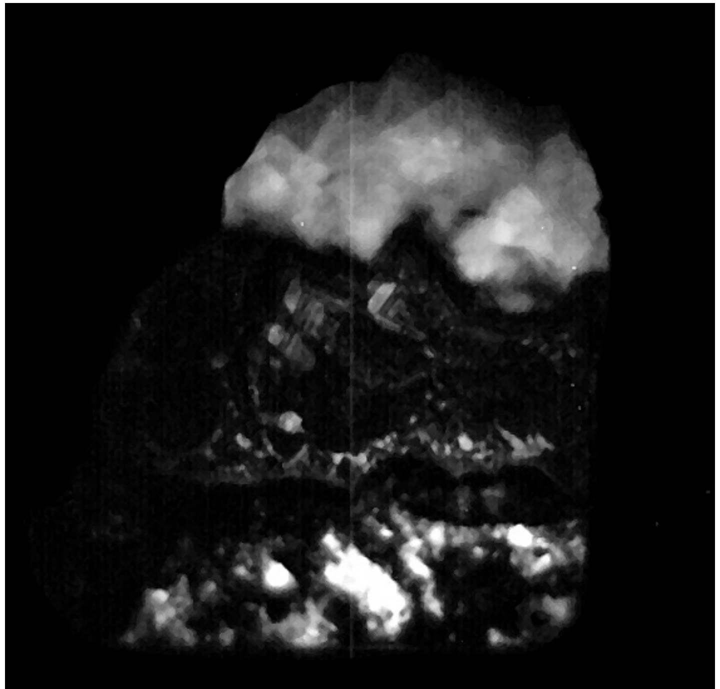
Example: Fluorine-bearing Mineral Signatures

- Fluorine mineral signatures discovered under CRC ORE
- Mineral-specific emission discovered in the NIR.

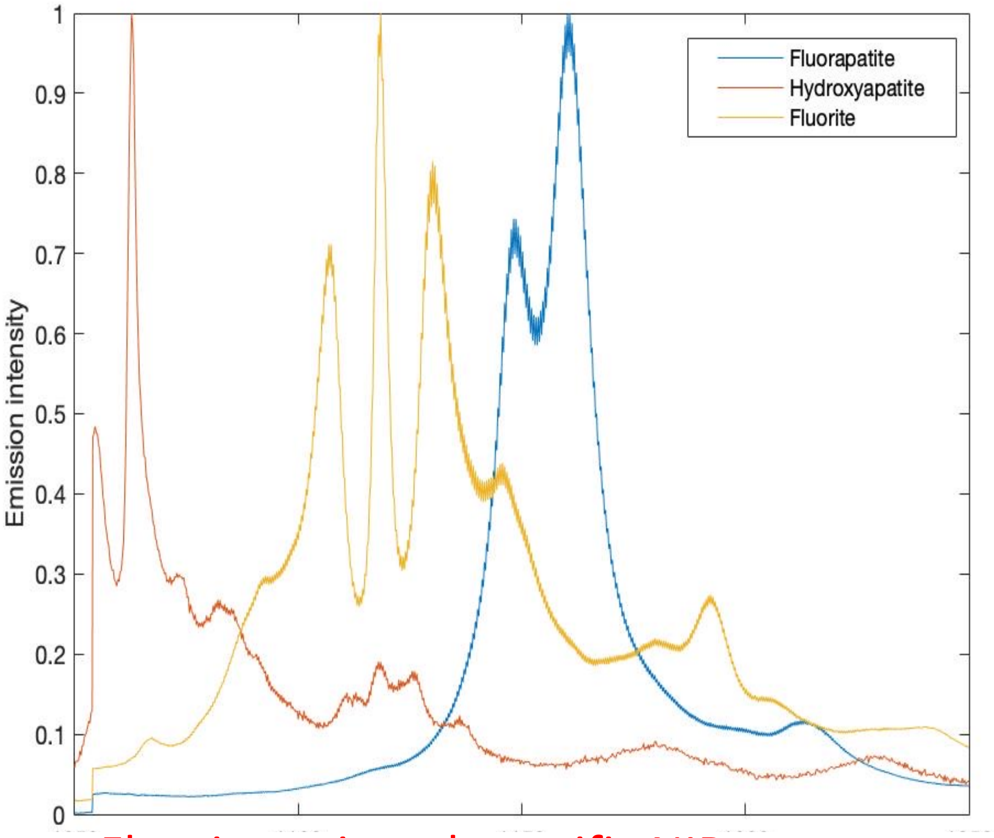
Two modes of identification shown here: **Imaging and Spectral resolution between minerals**

LHS: Fluorite reflected light - visible waveband
RHS: Fluorite imaged in its own NIR emission

Conventional imaging (Vis.)

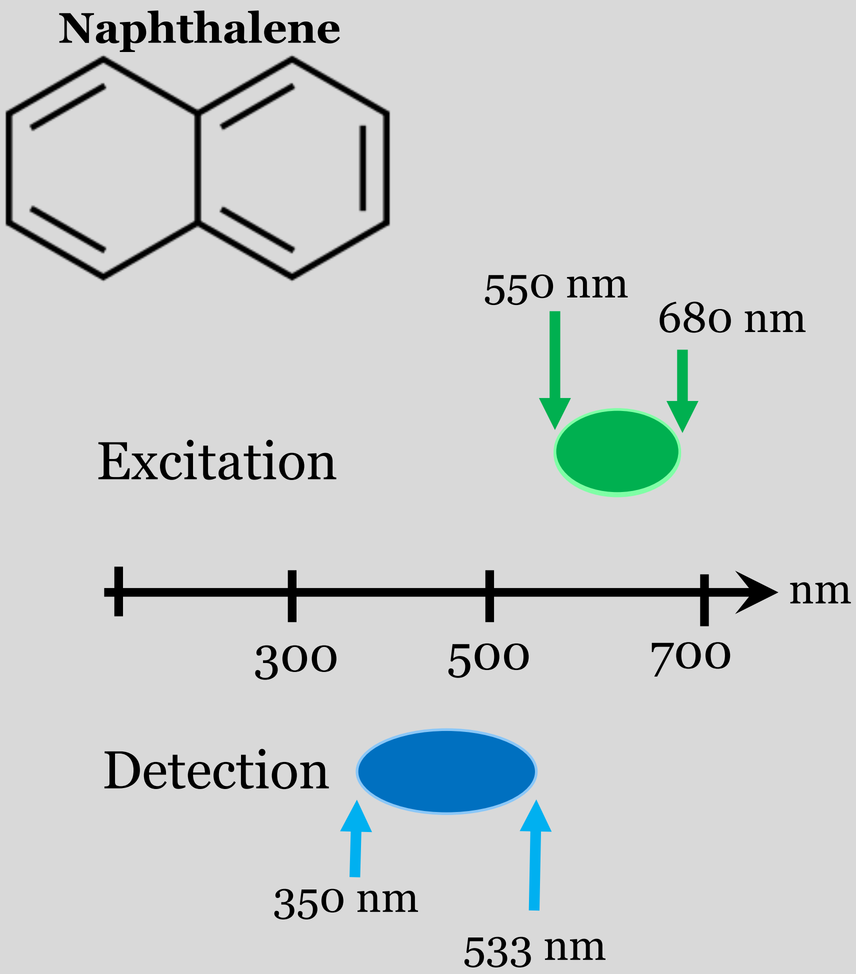


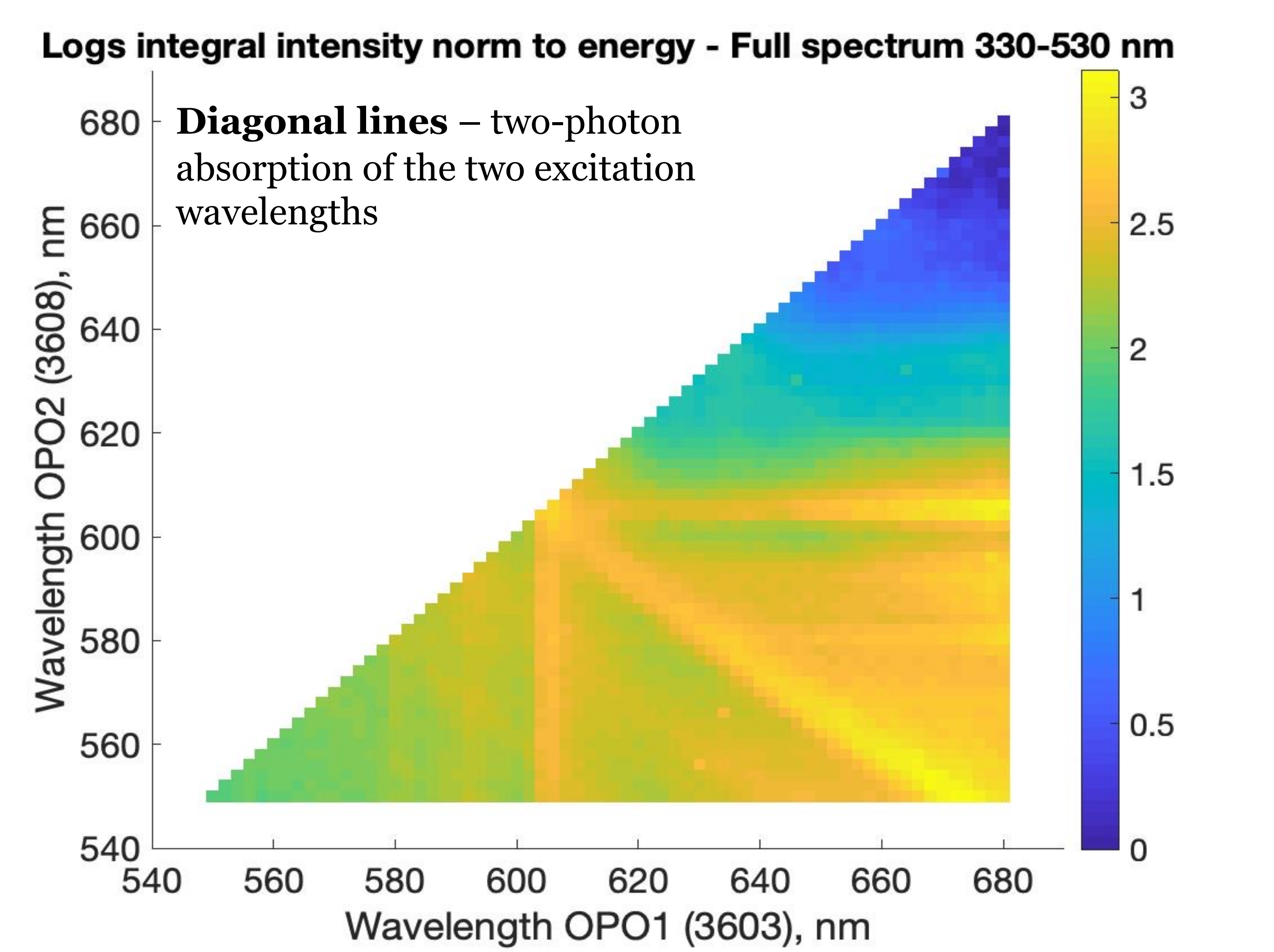
Novel Fluorescence imaging (NIR)



Fluorine-mineral-specific NIR spectra

Example: Chemical Sensing – Multi-Photon Polyaromatic Hydrocarbon (PAH) detection and identification with Dual-Wavelength Excitation



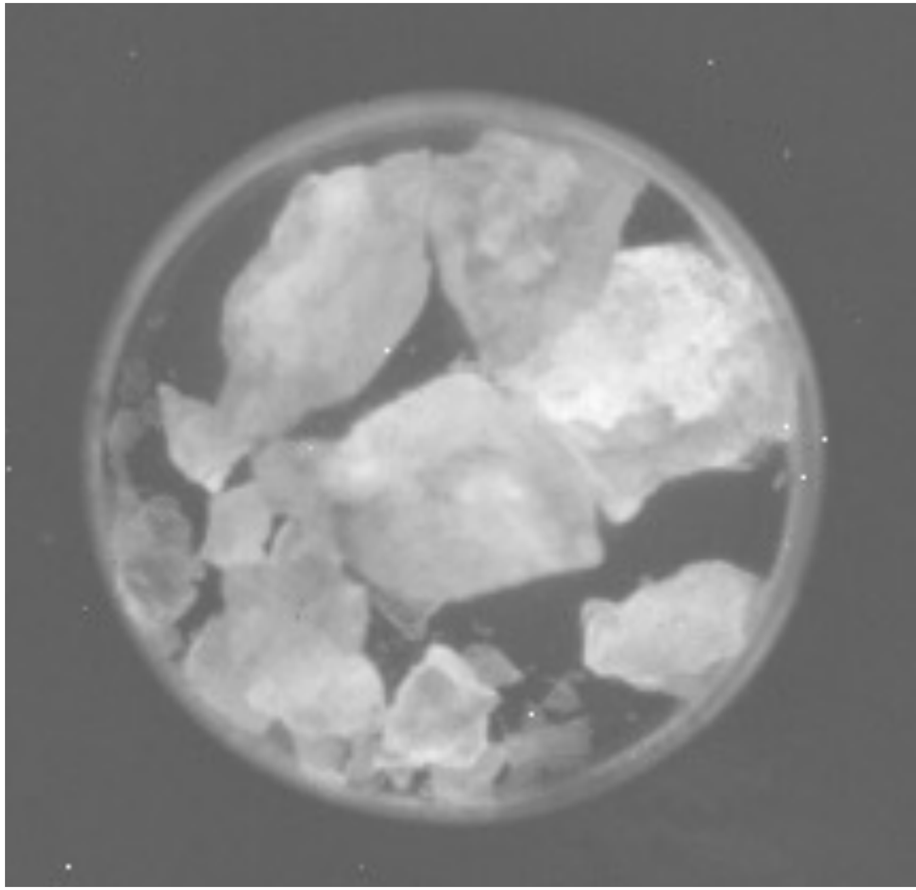


Example: Plagioclase feldspar imaged in its own NIR emission

Plagioclase is a major component of Lunar regolith

1. **Imaging** is critical to confirm the origin of the fluorescence when analysing multi-component targets, and for rejecting spurious sources.
2. **Emission Spectrum** enables identification of the species of plagioclase

For even fine components in a complex mixture, spatial resolution capability enables assigning fluorescence emission to the actual source rocks or grains, thereby enabling concentration calculation and mineral identification.



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	Never	Never	Sometimes	Always	Sometimes	Sometimes	Active	Surface
Hyperspectral Imaging	Always	Sometimes	Always	Never	Always	Never	**Passive**	**Surface**
LIDAR	Never	Always	Never	Never	Never	Never	Passive	Surface
Gravimetric	Never	Always	Sometimes	Never	Never	Never	Passive	Deep (km)
Magnetics	Never	Always	Sometimes	Never	Never	Never	Passive	Deep (km)
Radar	Always	Always	Never	Never	Never	Never	Passive	Deep (100s m)
Neutron Activation	Sometimes	Never	Never	Always	Never	Sometimes	Active	Shallow (m)
Gamma / Xray Fluorescence	Never	Never	Never	Always	Never	Sometimes	Active	Shallow (cm)
Novel Fluorescence	Sometimes	Never	Sometimes	Sometimes	Always	Always	**Active**	**Surface**

Always

Sometimes

Never

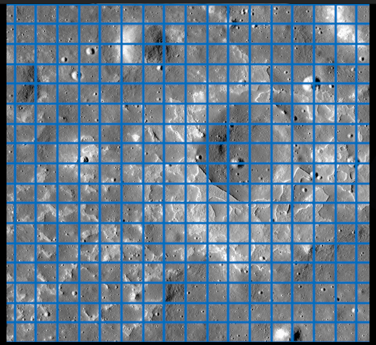
“HyperFluorescence” - Addressing the Critical Sensing Gap

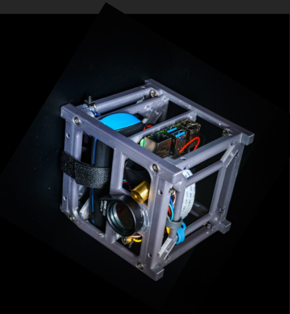
Australian Space Agency: Moon-to-Mars Program Bid

We propose to develop a Lunar Rover-mounted integrated sensor module for “Novel Fluorescence + Hyperspectral Imaging”

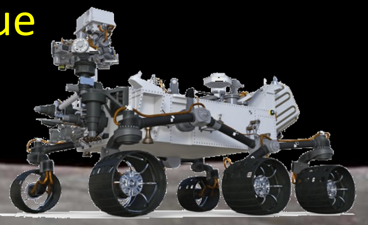
- Existing sensor systems can identify the presence of valuable elements only if present at large scale →
- Campaigns to sample these locations lack sensor systems of capability to direct their sampling or future utilisation →
- Without suitable sensors, landers are sampling blind & mining feasibility is varied

Satellites/remote sensing – excellent information on the big picture, and identifies areas of potential interest





Autonomous exploratory rovers/landers – **NF+HI** sensors to identify the potential value of regions and target sampling locations



Usage Case: Concept for deployment on the "Trailblazer" Lunar Rover (LR)

Mission context: the LR (Aust Artemis contribution) deploys from the Lander, & collects and returns regolith to the Lander for developmental oxygen extraction apparatus test processing.

Proposal: instrument the LR with a "Hyperfluorescence" module which will optically analyse and **create an "Optical Fingerprint"** for each aliquot of regolith returned to the Lander.

"Optical Fingerprint": a stack of "Hyperspectral cubes" - Active sensing - multiple-wavelength induced fluorescence images acquired by the hyperspectral camera; including conventional hyperspectral reflectance image

Enables grain-scale mineralogical resolution of the regolith

The Optical Fingerprints will enable the LR to utilise machine learning to develop a **"search, assess and select"** capability within the Mission duration.

HyperFluorescence for Autonomous near-real-time resource assessment

Build library of optical signatures correlatable to oxygen extraction from regolith samples

LR enabled to near real-time assess mineralogy; then choose to select or reject new regolith feedstock based on learned performance

Selective Mining capability to preferentially choose high-quality regolith for oxygen yield analysis in-mission, or to reject low-quality, or to identify regolith mixtures not yet sampled.

Future outcomes: higher quality of resource mapping and evaluation of total economic value than is currently possible, enabling selective mining and intelligent mineral processing.

HyperFluorescence sensing will enable mineral discrimination and the visualizing of economically significant grains in complex samples, including organic compounds.