

## High Temporal Resolution Long Wave Infrared Measurements

The long wave infrared (LWIR, 8-14 microns) is the “fingerprint” region for many compounds, and is one of the most useful spectral regions for identification of larger polyatomic molecules. Most gas-phase detection techniques for polyatomics use LWIR absorption by Fourier Transform Infrared Spectroscopy (FTIR). FTIR is exceptional for this, and can cover large spectral ranges with good spectral resolution. But FTIR is slow, so transient phenomena (e.g. combustion in an engine, electrical discharges, fast chemical reactions, etc.) faster than about .01 sec cannot be analyzed with a single FTIR measurement. One option is to use conventional dispersive spectroscopy with a fast array detector. Microbolometer LWIR arrays are now extremely cheap and fairly efficient, but they’re limited to 30 Hz (.033 seconds per exposure). Coupling a microbolometer with a newly available variable interference filter makes a potentially very efficient LWIR spectrometer at 30 Hz. However, if a line of signal is scanned by a rotating mirror across the array, then a very simple LWIR high speed spectrograph is possible, maybe with up to 1 kHz resolution. This would be a new and exceptional tool for LWIR measurements, and demonstration would likely be a publishable result.

I had a student assemble the components for this approach a year ago, and he was able to test everything to verify it all works. This project would then set these components (camera, spectral filter, optics, source, rotating mirror), test signal levels, and if it looks like it’ll work, do a simple transient experiment to demonstrate the instrument.

Here’s a paper covering a closely related effort without the time resolution part:

<https://ieeexplore.ieee.org/abstract/document/4260984>

## Tunable Diode Laser water vapor temperature scan

Tunable diode lasers are widely used for monitoring all sorts of chemical species. Typically they are current tuned over a narrow range giving high temporal resolution over a limited spectral range (maybe 1 cm<sup>-1</sup>). Usually this gives you only a few lines (2-4), and thus limited temperature range and accuracy. Temperature tuning is slow, but can cover a much larger range of lines, allowing for more accurate measurements and a larger range of potential temperatures that can be measured. For this project, we’ll use a tunable diode laser near 1300 nm to temperature tune over a number of water vapor absorption lines to see if there is a strategy where we can get superior temperature range (like 300-2500 K) and maintain some level of temporal resolution (maybe seconds?), which would be useful for many process monitoring applications.

We have the TDL setup, and the students will basically set up the controller, laser, fibers, optics, detector, and DAQ system on a heated water cell and find the range over which this laser operates. Using HITRAN, they’ll pick a range over which to scan, and test that on Bunsen burner flame system. In the end, they’ll report their strategy and calculations, and results from Bunsen experiments.

Here’s a paper on TDL measurements in general:

<https://www.sciencedirect.com/science/article/pii/S058485471500021X>

## Raman Temperature Measurements in a Supersonic Hydrogen Jet

Hydrogen is the ideal propellant, and Raman is excellent for temperature measurement. In this experiment, we’ll set up a supersonic jet of hydrogen, and we’ll measure upstream pressure and downstream pressure. We’ll set up a simple Raman spectrometer to measure rotational lines of H<sub>2</sub> to get temperature. We’ll calibrate and align the system. If we can get good signal, we’ll look at varying upstream pressure and distance from the nozzle. Final report will include results and a detailed uncertainty analysis.

Here's a paper that did a similar thing at low pressure:

<https://www.cambridge.org/core/journals/journal-of-fluid-mechanics/article/numerical-and-experimental-investigations-of-lowdensity-supersonic-jets-of-hydrogen/388FC9A68DF95EC37060BC7CC7FC40FB>

### **Laser induced fluorescence potassium or calcium**

It's not trivial to do a laser induced fluorescence (LIF) experiment without a complex setup and a lot of caveats. But there are some new diode lasers available that can perhaps be used to make a simple LIF setup that demonstrates the concept very well. To attempt this, we'll make atomic vapor cells of potassium and calcium vapor, then shine 405 nm and (somewhat rare) 422 nm lasers in these cells while varying the diode laser temperatures until we get fluorescence. Then we'll measure the fluorescence spectrum using a spectrometer. I haven't seen this done before with K and Ca, so this will be a unique thing.

Fluorescence has been done in rubidium and iodine cells before, and it's quite easy. Here's an example of the Ru case:

<https://opg.optica.org/abstract.cfm?uri=josab-22-1-88>

### **Spectrum of a Comet**

Comets make great spectral sources, and the history of comet spectroscopy is vast. Usually, there's one or two comets bright enough to do spectroscopy on with small telescopes each year. For this term, there are three possible candidates: C/2023 P1 (Nishimura) or 103P/Hartley 2 or 2p/Enke. I've got an 8" telescope and the optics to collect spectra. I've done a few comet spectra in the past, and there's a pretty active group of researchers outside the mainstream astronomy community that do this sort of thing. Few, however, probe the ultraviolet where a lot of the good spectra features are. We could do this with a simple spectrometer camera system we have optimized for weak signals. This one requires a bit of extra effort in calibrating and setting up instruments, and a lot of flexibility in planning around weather conditions, and late night or early morning measurements. But it'd be really neat if it works, and we can classify one of the comets by its spectrum.

A good review of comet spectra is here:

<https://www.sciencedirect.com/science/article/pii/S0019103509000244>

### **Near Infrared Emission Spectrum from Strong Shock Waves**

High speed air shocks and their spectra have been studied for decades, and are fairly well understood. This is obviously important for high speed aerodynamics and re-entry etc. But there's a part in the near infrared that's still very uncertain. There have been lots of low resolution measurements over the years (I'll provide a reading list) but no one has yet identified what these emissions correspond to, though the speculation is that they're due to nitric oxide (NO). But it's not clear because there are no high resolution measurements. This project aims to fill that gap. We've worked on a way to get long duration emission from high speed shock waves by using detonations in a tube. With this method, we can create signals that last maybe 200 microseconds from Mach 20 shocks, allowing sufficient time for a high resolution measurement to accumulate signal for a measurement. We'd set up one of our existing spectrometers with an InGaAs array and collect high resolution spectra on as many regions of the NIR as we can to see if we can shed some light on this conundrum.

Here's one paper on the topic, but there are many:

<https://www.sciencedirect.com/science/article/pii/0022407367900180>

## **Aluminum steam explosions spectroscopy**

No one has yet published an aluminum steam explosion spectrum, though there's a ton of literature on these events which are huge safety concerns for aluminum foundries. Aluminum combustion in air and propellant gases and explosions has been studied ad nauseum, with hundreds of publications including spectra. How do steam explosions compare to other aluminum explosions? No one really knows, but measuring an emission spectrum would go a long way towards explaining things. For this, we have a water tank, and we'll get a steam explosion by dumping a ton of current through an aluminum rod and see what emerges. The student will help set up the tank and calibrate the spectrometer, collect and process the data.

Here's a recent paper on steam explosions:

<https://aiche.onlinelibrary.wiley.com/doi/abs/10.1002/prs.12149>

and here's a classic one:

<https://www.sciencedirect.com/science/article/pii/0029549394008864>

## **Triboluminescence in the absence of nitrogen**

Triboluminescence is a really cool phenomenon that's received lots of attention in the last decade. Adhesive tape gives off surprisingly bright emissions when detached from a surface, and under vacuum, this generates x-rays, which pretty much surprised everyone when discovered. So far, all the studies have been in air or vacuum, and the dominant feature of the spectrum is the emission from diatomic nitrogen. But what if there's no nitrogen around? Are temperatures similar? Do you still see emission? No one has tested this. So we'll test it. I built a fixture a few years back to unwind tape in a configuration that allows the spectrum to be observed. We'll put this in a vacuum chamber and fill with different gases and measure the spectrum that results. No idea what we'll see.

Here's the classic paper on the topic:

<https://www.nature.com/articles/nature07378>

## **Mechanoluminescence spectrum of crystals under fracture**

Mechanoluminescence is where a material is subject to large stress, and emits light. Some people have seen lights right before earthquakes and suggest that this may be mechanoluminescence. It's a field in its infancy. Mechanoluminescence is (in my opinion) ripe for an influx of information from the spectroscopy community. Lots of measurements of mechanoluminescence have been made, but few spectrally resolved. Most papers on mechanoluminescence measure intensity versus some parameter, but there is little spectral data. Let's change that with this project. We'll generate simple drop systems that impinges a heavy drop weight onto a crystal sample, and we'll take spectra of mechanoluminescence spectra for different materials. Is it just air emissions, or does the crystal matter? Let's find out.

Review paper on mechanoluminescence:

<https://analyticalsciencejournals.onlinelibrary.wiley.com/doi/abs/10.1002/bio.2647>

## Vaporization in fracture

During fracture, the physics are fairly extreme locally with conditions that can lead to vaporization. The appearance of vapor has been discussed extensively, but there has been no measurement, to my knowledge of actual vapor absorption signal using spectroscopy, though such a measurement is probably not that difficult. In this project, we'll see if we can measure vapor content from fracture under different conditions – maybe ballistic impact, maybe explosive fragmentation. We'll do it in vacuum to maximize signal, and we'll pick a readily vaporizable metal like magnesium. Easily publishable if we get some data. At the very least will provide a lower limit on potential vaporization amounts, which is useful by itself.

Here's a paper on local conditions at fracture:

[https://www.sciencedirect.com/science/article/pii/S0734743X11001035?casa\\_token=2c\\_gM1X8KS0AAAAA:0TDRkNNjHzVDIfEz3C0zdToMKRVMVOZ6v541ey3I4sgmXqIB-Q8ShTC822SRQZGS14Vwy5W6fMk](https://www.sciencedirect.com/science/article/pii/S0734743X11001035?casa_token=2c_gM1X8KS0AAAAA:0TDRkNNjHzVDIfEz3C0zdToMKRVMVOZ6v541ey3I4sgmXqIB-Q8ShTC822SRQZGS14Vwy5W6fMk)

## Solar induced fluorescence

This is a hot new area in agriculture. Solar induced fluorescence is a new way to probe plant conditions, and there are a ton of papers on it, with more and more each year. Still in its infancy w.r.t. spectroscopy, though, so there are lots of cool, simple things that can be done with a basic spectrograph and light sources to add to the state of knowledge. Fluorescence spectra of different plants under different excitation conditions have not nearly fully been catalogued. We could look at exotic colored plants. We might starve a plant of moisture or nutrients to test its fluorescence spectrum against a healthy plant. Temporal response – fluorescence spectrum versus time – has limited characterization. Little has been done on deep UV sources. For this, we'll review the current literature, then figure out what a useful experiment would be, then get the plants, and set up the sources and spectrometers to make the measurement. Lots of different ways this project could go, so it's probably the most open ended of all the projects. But almost anything we do will be novel.

Here's a review paper on SIF:

[https://www.sciencedirect.com/science/article/pii/S0034425719301816?casa\\_token=l8RTgZpE16MAAAAA:LYuqja4c2L2tqwqqvK7zNQdeBCKwAbs95Xoall02cYv1hzTqetS4wGu59xOgtXtKtKt-CS0vQak#f0025](https://www.sciencedirect.com/science/article/pii/S0034425719301816?casa_token=l8RTgZpE16MAAAAA:LYuqja4c2L2tqwqqvK7zNQdeBCKwAbs95Xoall02cYv1hzTqetS4wGu59xOgtXtKtKt-CS0vQak#f0025)

## Thulium combustion spectrum

I do a lot of work in metals combustion, and I've looked at many different metal systems, but there are a few that are potentially interesting, but haven't received much attention. The element thulium (Tm) is one of those metals that has potential applications in flares and pyrotechnics, should burn very energetically, and is commercially available. It's very rare, but not ridiculously so. There are very few spectra in the literature of Tm combustion (I know of only one reference: *Flame Spectroscopy* by Radu Mavrodineanu Henry Boiteux). No detailed characterization. We can fill this gap with some very simple experiments using flash powders of Tm and oxidizer, and dust cloud experiments. We have the setup and spectrometers. We can get and mix the powders – we may need to pulverize the Tm, as it seems to come in fairly coarse powders, but that's not hard. Then we do some low resolution survey spectra, followed by some higher resolution spectra on the key features. If we can see the spectral features, it'll definitely be new information for the literature.

Here's a paper that mentions the utility of Tm combustion and looks at related materials.

[https://www.researchgate.net/profile/Ernst-Christian-Koch/publication/268521693\\_CONSIDERATION\\_OF\\_SOME\\_4f-METALS\\_AS\\_NEW\\_FLARE\\_FUELS\\_-\\_EUROPIUM\\_SAMARIUM\\_THULIUM\\_AND\\_YTTERBIUM/links/5506ffc60cf2d7a281229d2c/CONSIDERATION\\_OF\\_SOME\\_4f-METALS\\_AS\\_NEW\\_FLARE\\_FUELS-EUROPIUM-SAMARIUM-THULIUM-AND-YTTERBIUM.pdf](https://www.researchgate.net/profile/Ernst-Christian-Koch/publication/268521693_CONSIDERATION_OF_SOME_4f-METALS_AS_NEW_FLARE_FUELS_-_EUROPIUM_SAMARIUM_THULIUM_AND_YTTERBIUM/links/5506ffc60cf2d7a281229d2c/CONSIDERATION_OF_SOME_4f-METALS_AS_NEW_FLARE_FUELS-EUROPIUM-SAMARIUM-THULIUM-AND-YTTERBIUM.pdf)

## **High explosive detonations into vacuum: visible and vacuum ultraviolet emissions**

Emission spectra from explosions are widely studied for both scientific purposes and for battlefield monitoring. A high explosive detonation generates rich spectra from the deep UV to the far infrared and further, with many spectral lines and bands and strong temporal dependence. One thing that has almost zero effort has been the study of emissions from high explosive detonations in vacuum. This is becoming important with the weaponization of space. What does a high explosion in vacuum look like spectrally? Can we distinguish a high explosive detonation from an electrical explosion or explosion from impact? At this point, there's little data on this. We have vacuum chambers and spectrometers and explosives – so let's find out? Of particular interest is the 4<sup>th</sup> Positive CO system in the vacuum ultraviolet, which is an extremely strong transition but is not seen in air since air absorbs it so quickly. In vacuum, this might be the dominant emission band. We have a vacuum ultraviolet spectrometer, and we could see whether or not this emission is present. We did some very low resolution experiments the last time I ran the class, and it looked promising, but we need to follow up with higher resolution measurements. Zero information on this is in the literature, so anything we do is new.

Here's a paper on explosions in vacuum, showing the unique conditions that prevail:

<https://pubs.aip.org/aip/jap/article-abstract/42/2/815/5315>

## **Headlight spectrum forensics**

Automotive and aircraft headlights seem pretty simple, but there's a very interesting complexity that makes the headlights on each vehicle unique and detectable. In principle, this idea could allow for monitoring and detection of headlights for purposes of detecting stolen cars, assisting police investigations, friend-or-foe identification on the battlefield, etc. The basic idea is that (nowadays) there are many different types of headlight sources now: various types of LED, HIDs, xenon, and incandescent. Those are broad classes that can segregate to some degree different cars. But even more useful is the fact that the headlight glass or plastic housing and reflector have spectral transmittance and reflectance that vary from manufacturer to manufacturer and due to wear over time (e.g. clouding of the plastic). This effect is most pronounced at the ends of the spectrum – near-infrared and UV. For this experiment, students will set up a couple spectrometers and gather lots of data on passing headlights, cataloging the different spectra to assess how well individual vehicles could be identified using headlight spectra. This is easily publishable if we get enough data, and it's not out of the question that it could lead to research funding from the federal agencies who want to monitor and subjugate the general population.

Here's a link that discusses automobile headlight spectra for the application of distinguishing unidentified lights from automobile headlights:

<https://pubs.aip.org/aapt/ajp/article/77/8/697/310879>

and a more recent article more directly related:

<https://www.mdpi.com/1424-8220/16/7/1058>