Passive Standoff Fourier-Transform Infrared Detectors as Transducers

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Passive Standoff FTIR Detectors as Transducers

- **Background**
- **From radiation to information**
  - Infrared radiation and the atmosphere
  - Hardware
  - Signal transduction
  - Information
- **Conclusions**

Passive Standoff FTIR Detectors as Transducers

- **Transducer:** A device for converting energy from one form to another for the purpose of measurement of a physical quantity or for information transfer
- **Passive Standoff FTIRs** convert infrared energy from the environment into information about chemical hazards such as chemical warfare agents (CWAs)
  - There are other uses, but this use is the focus

Passive Standoff FTIR Detectors

- **Passive - They do not shoot out a beam, rather they receive energy that is in the environment (cameras also do this)**
- **Standoff – They are designed to detect at a distance**
- **FT – Fourier-Transform – Method of acquiring frequency-dependent signal**
- **IR – Infrared – type of radiation that they detect**

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The US Military, Developers, Testers, and Dugway

- **The US Military is interested in detecting chemical warfare agents at a distance to protect soldiers**
- **Developers include**
  - **General Dynamics (JSLSCAD, M21)**
  - **Northrop Grumman (MCAD)**
  - **Bruker (RAPID)**
  - **Block Engineering (Block 100)**
  - **Micro Engineering Software and Hardware (MESH) Inc.**
  - **Aerospace Corporation**
  - **Physical Sciences Inc.**
  - **Mention of manufacturers does not constitute endorsement**
- **Testing – Dugway's role is to test the effectiveness and suitability of the detectors**
  - **We do not make the detectors; we measure their performance**

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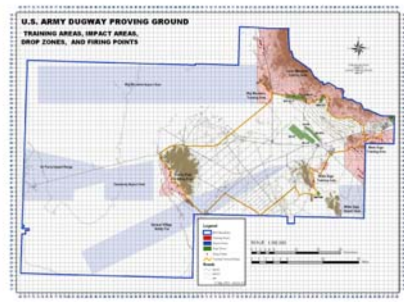
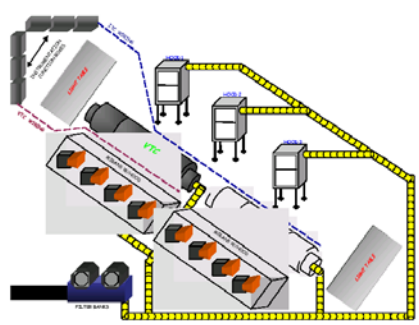
West Desert Test Center – Dugway Proving Ground

- Dugway is the DoD reliance area for CB testing
- Existing Licenses and EAs for CB simulants
- State and federal agency support for mission
- 1300 square miles of area
  - With true no encroachment status
- Expertise with field and chamber CB testing

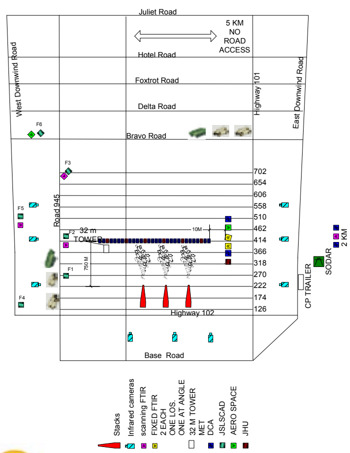


Controlled Chamber Testing

- DPG Chamber facilities allow controlled testing indoors with actual CWAs
- The Multipurpose Chamber has a state-of-the-art fixture for testing passive FTIRs



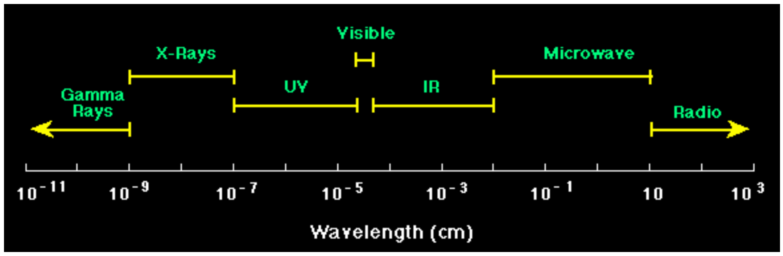
Outdoor Testing with Simulants



- Dugway has a state-of-the art test grid for outdoor testing with simulants
- Simulants released through stacks or explosively
- Ground-truth box is instrumented to verify cloud characteristics
- Wireless ethernet and GPS allow time- and position-dependent results to be acquired.

From Radiation to Information

Electromagnetic Radiation

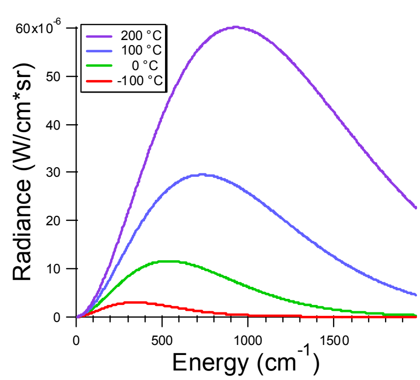


http://csep10.phys.utk.edu/astr162/lect/light/spectrum.html

- **Shorter wavelengths are higher frequencies and higher energies.**
- **Infrared (IR) is electromagnetic radiation between 0.7 and 100 μm in wavelength**

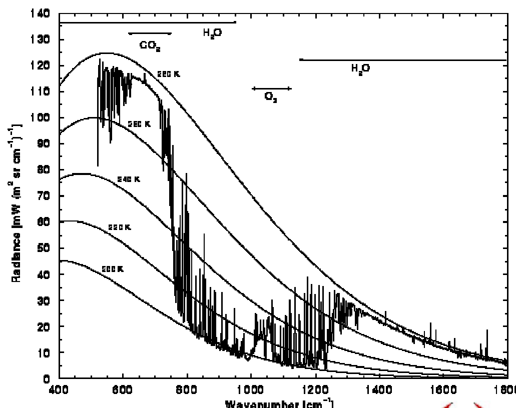
Blackbody Radiation

- **Most materials emit and absorb in the infrared**
- **An ideal body that can emit and absorb all wavelengths is called a blackbody**
- **As the temperature of a blackbody rises:**
  - it emits more radiation
  - at shorter wavelengths (higher energies)



Atmospheric Radiation

- Atmospheric IR is mainly from water, carbon dioxide and ozone
- Atmospheric "Windows" at <u>8-12 μm</u> and 3-4 μm
- Many compounds of interest have "finger prints" in the <u>8-12 μm</u> range



http://lidar.ssec.wisc.edu/papers/dhd_thes/node3.htm

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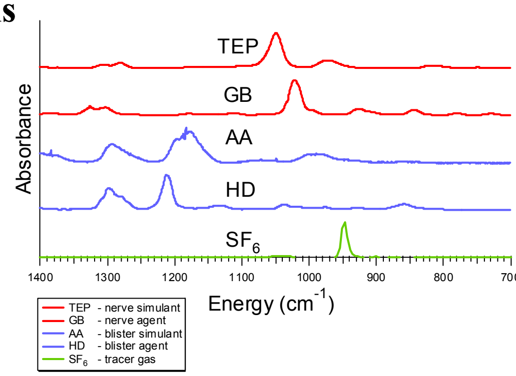
Infrared Spectra

- Different chemicals have different features in the IR
- Structure of the spectrum is like a finger print
- Can quantify the amount of the chemical



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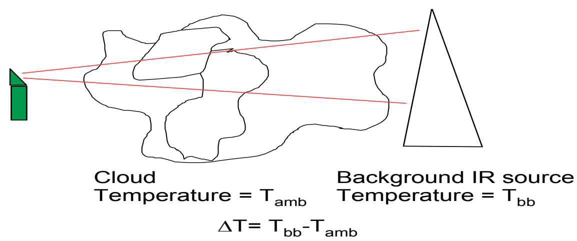
Atmospheric Radiation

- Radiation arriving at a detector depends on:
  - The temperature difference between the cloud and the background
  - The nature of the background (sky, mountains, etc.)
  - The amount and type of chemicals present in the cloud
  - The analytes can absorb or emit radiation

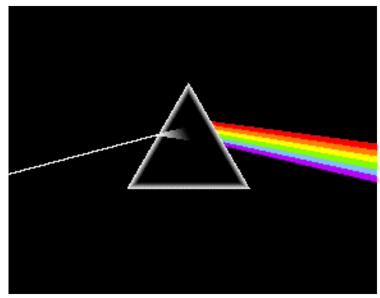


Hardware

- **Collect, Separate and Detect Radiation**
  - **<u>Collect:</u> Optics must either transmit or reflect in the infrared.**
    - » **Zinc Selenide, Germanium, Thorium Fluoride**
  - **<u>Separate:</u> Information is contained in the wavelength dependence.**
    - » **Hardware must separate by wavelength**
  - **<u>Detect:</u> Many existing and emerging detector technologies**
    - » **Thermal Type: e.g. bolometers**
    - » **Quantum Type: photoconductors: e.g. HgCdTe**

Hardware

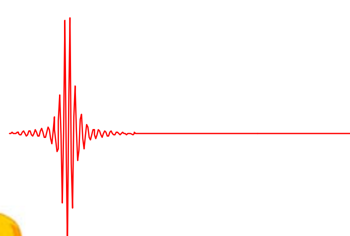
- Basically two ways to separate radiation based upon wavelength
  - Dispersive optics act like a prism
  - Interferometer uses constructive and destructive interference of waves

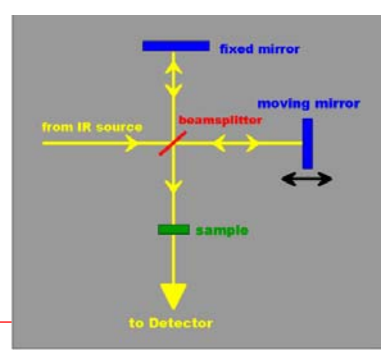


http://www.ece.northwestern.edu/~kumarp/nuosa/images/prism.gif

Interferometers

- Radiation takes two paths which interfere
- Reference laser (monochromatic source) can track mirror spacing
- Resulting signal is an interferogram





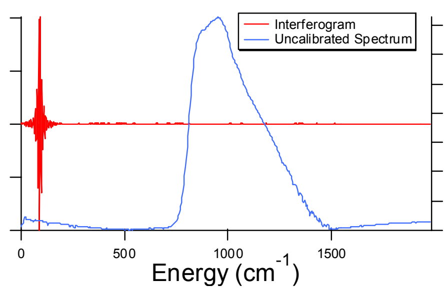
http://www.biophysik.uni-freiburg.de/Spectroscopy/Time-Resolved/michelson%20interferometer.gif

Signal Transduction

- Convert interferogram into a spectrum (Fourier-transform)
- Average multiple spectra
- Remove instrument effects (radiometric calibration)
- Remove atmospheric effects and clutter (background correction or modeling)
- Convert spectrum to information (chemometrics, expert systems, neural networks etc.)

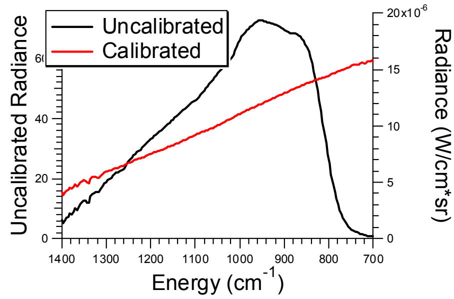
Fourier Transform

- Convert interferogram into a spectrum
  - Based upon sampling rate and reference laser frequency
  - Some additional processing:
    - » apodization and phase correction
  - The resulting spectrum includes instrumental effects



Radiometric Calibration

- **Instrumental Effects**
  - Self-Radiance (the instrument radiates in the IR).
  - Responsivity (the instrument is more sensitive to some wavelengths than others).
- **Calibration based on acquiring black body spectra at different temperatures**
  - A black body spectrum should be a Planck function



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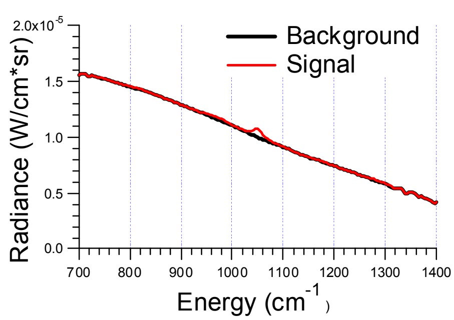
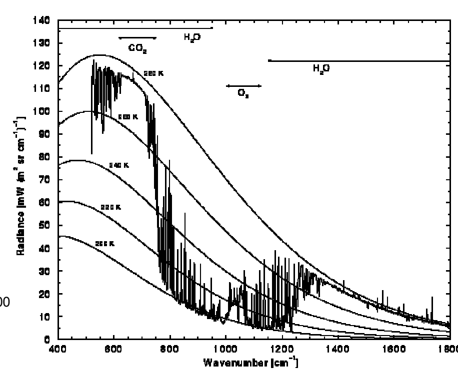
Background Removal





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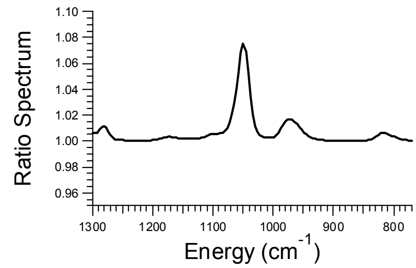
Feature Extraction

- **Need to know the background**
  - **Measure or model**
- **Many methods to correct for known background**
  - **Division**
  - **Subtraction**
  - **Other methods**
- **Extracted features can be used to identify and quantify**



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From Data to Information

- **Identify the spectrum: compare with spectral library**
- **Quantify the spectrum**
  - **Peak height can be used to extract the concentration*pathlength product (CL)**

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Taking the Human out of the Loop

- CWA detector needs to make a decision on whether a threat is present
- Needs to balance low false alarm rate with high probability of detection
- Decision is not based merely on intensity of a band at a given wavelength
- Band shape and secondary features matter

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Possible Approaches

- Chemometrics: linear algebra with known target, interferent sets
- Rules-based systems
- Neural networks etc.

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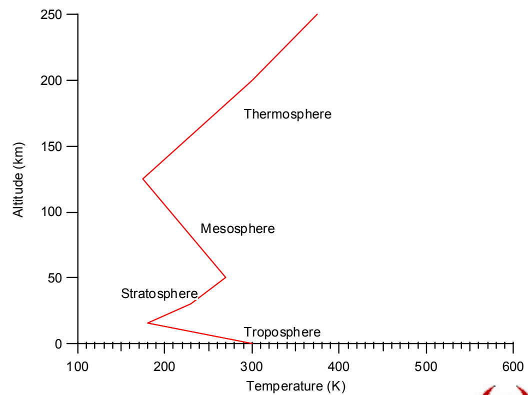
Conclusions

- Traced story from radiation to information
- Real-life problems are difficult to solve
- Additional complications are possible

Backup Slides

Structure of the Atmosphere

- Troposphere: H_2O, CO_2, O_3
- Stratosphere: O_3
- Stratospheric Ozone emits against a cold sky background
- Tropospheric interferences may emit or absorb



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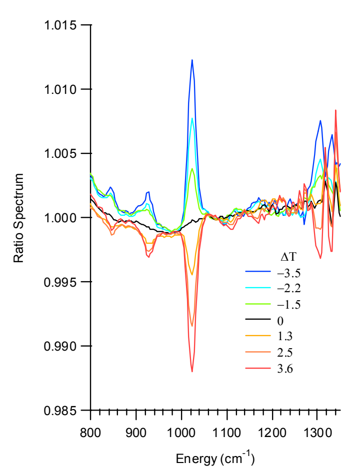
Temperature Effects on Passive Spectra

- As ΔT changes, so do passive spectra
- A given signal level can be reached by increasing CL or ΔT
- Need to measure detector response as a function of CL and ΔT



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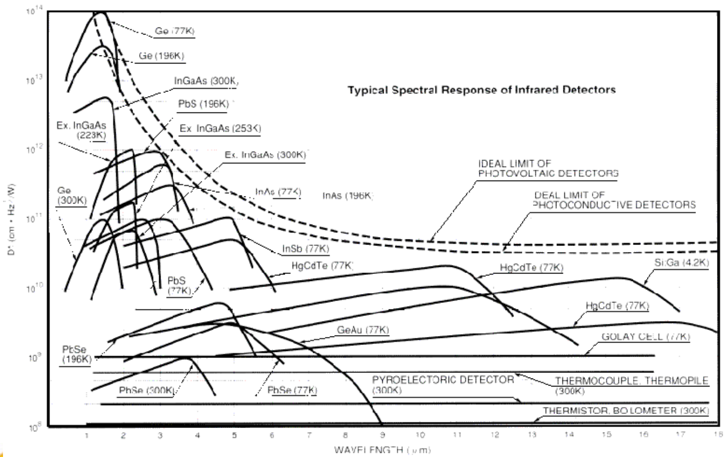
Detectors



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