Remote Sensing in Severe Radiation Environments

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•Presented at: 2011 Sensors Tech Forum, Boston, MA

Overview

- Based on a spectrometer for the delayed NASA Jupiter Europa Orbiter mission
- Why go to Jupiter - possibilities and problems
- FTIR Spectral Instrumentation
- Analysis and Removal of Radiation Effects
- Other Applications

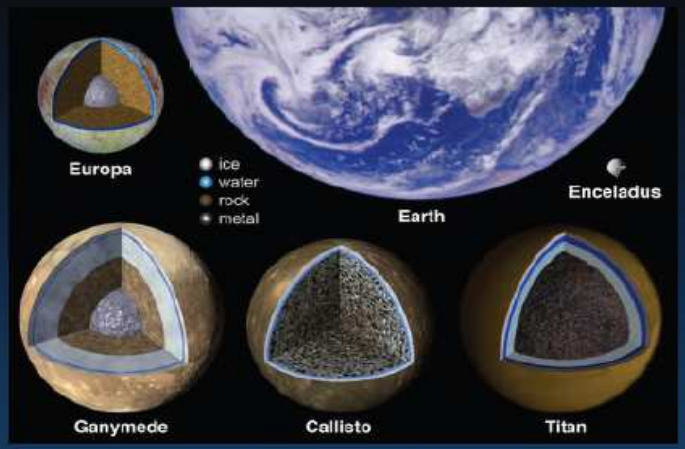
- Work funded by:
  NASA JPL contract #1396649
  Edgewood Chemical and Biological Center DAAD13-03-C-0035
  Quant Engineering internal funding

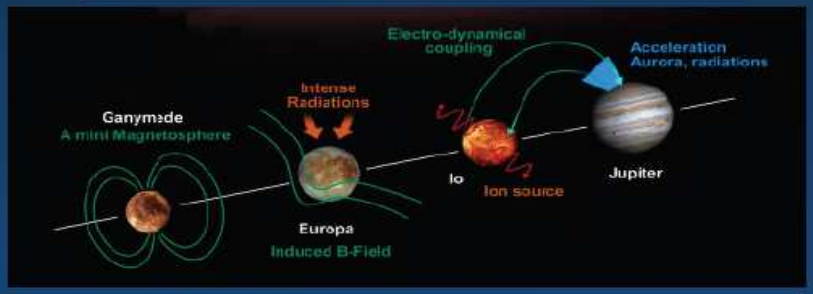
Moons of Jupiter with Liquid Water

esa NASA

EJSM Theme:
The Emergence of Habitable Worlds Around Gas Giants

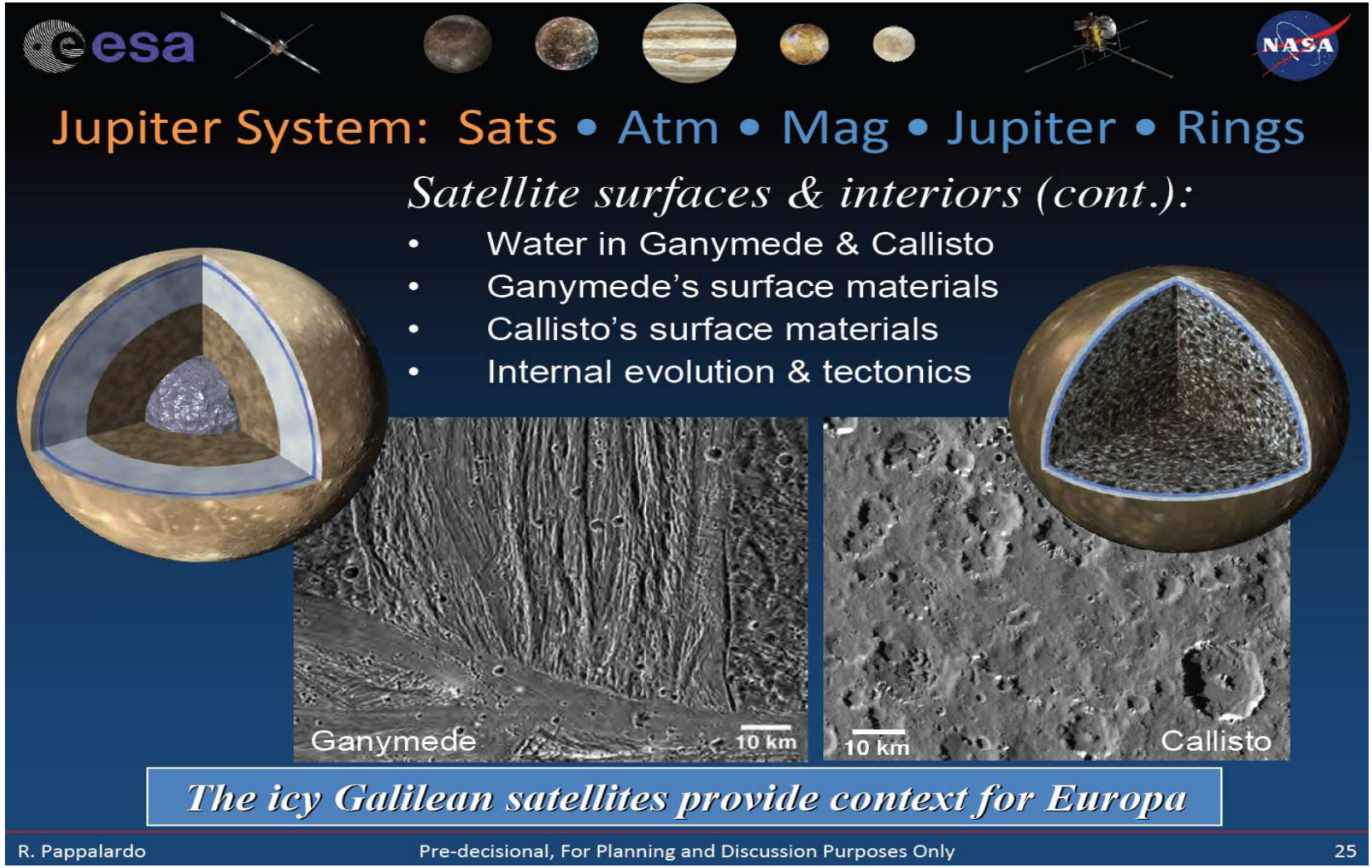
- *Goal 1:* Determine if the Jupiter system harbors habitable worlds
  - Ocean characteristics
  - Ice shells and subsurface water
  - Deep internal structure, and (for Ganymede) intrinsic magnetic field
  - External environments
  - Global surface compositions
  - Surface features and future landing sites
- *Goal 2:* Characterize Jupiter system processes
  - Satellite system
  - Jupiter atmosphere
  - Magnetodisk/magnetosphere
  - Jovian system Interactions
  - Jovian system origin





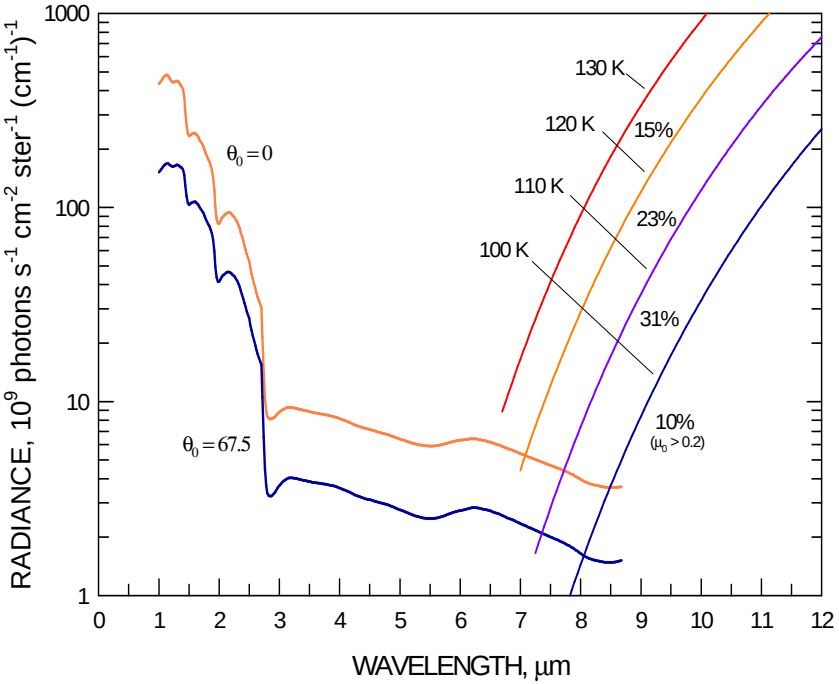
Emphasis on icy moon habitability and Jupiter system processes

Moons of Jupiter with Liquid Water

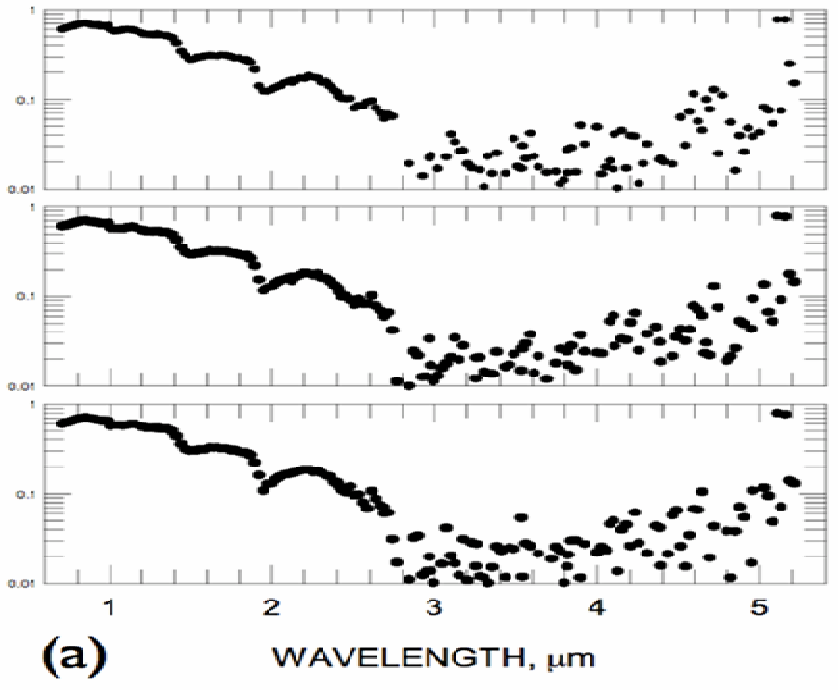


Measurements and Problems

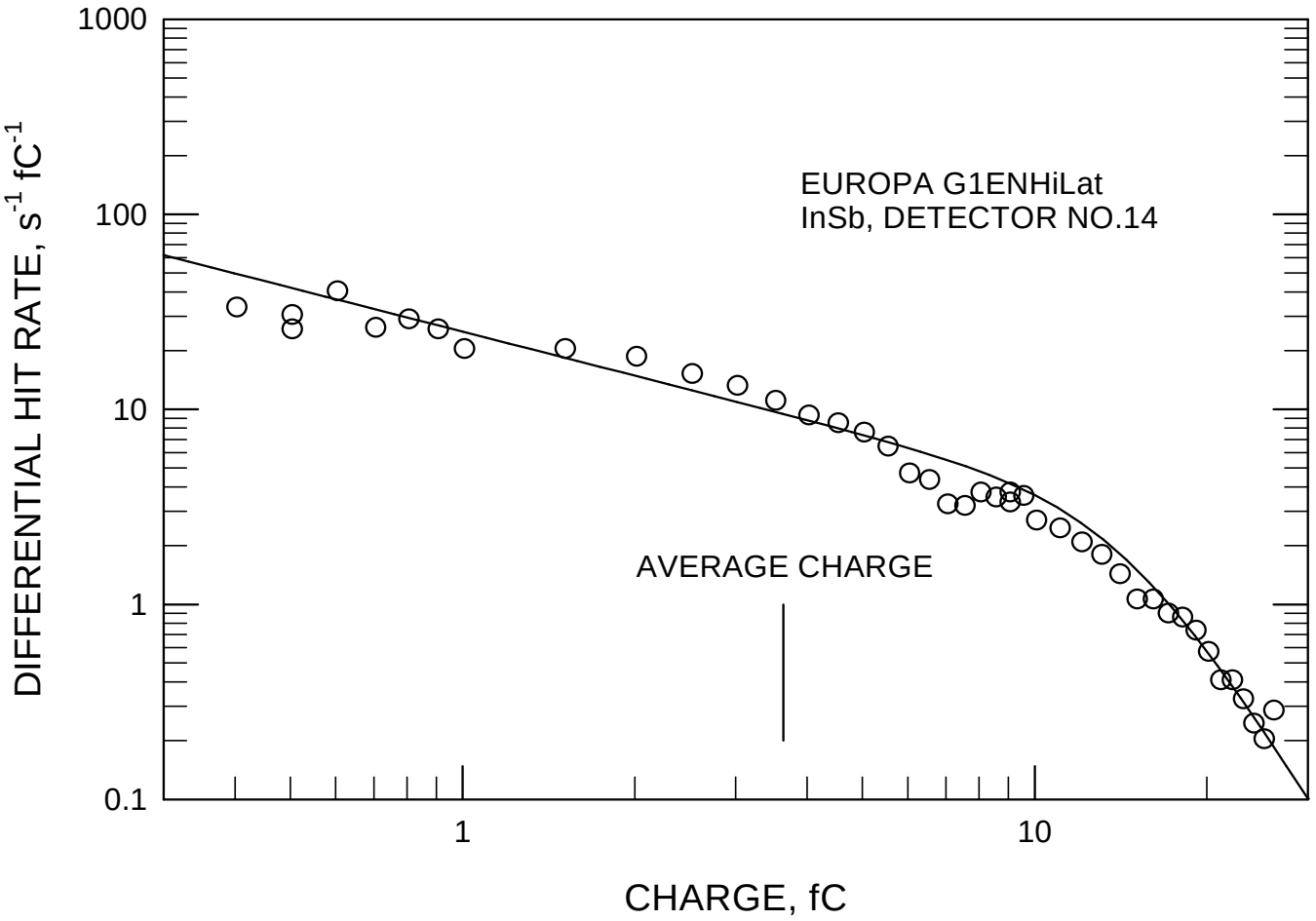
- What we want to measure



What happens when we try

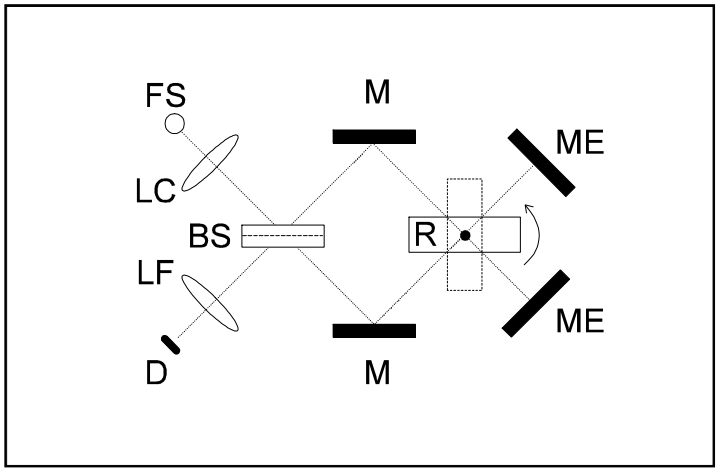


Radiation Environment at Europa



D&P Instruments TurboFT

- Very rugged, only one moving (rotary) part
- Data acquisition triggering
- Spectral resolution is a function of the rotor thickness and rotor material index of refraction
- 4 quadrants for design purposes



FTIR Spectrometer

- Multiplexing (Felgett) advantage, light at all wavelengths is collected simultaneously.
- Higher light-gathering power than dispersive spectrometers (Jacquinot advantage). TurboFT (D&P Instruments) is approximately 50 × more sensitive in light gathering than the Galileo Near Infrared Mapping Spectrometer (NIMS).
- Built-in Radiation tolerance – Noise is spread and apodization
- AC-coupled to data acquisition
- **Signal Processing can greatly increase performance in high radiation environment**

Data Analysis for the TurboFT Spectrometer

- Peculiarities of the TurboFT – 4 quadrants
- Compute spectra by FFT
- Co-Add spectra for each quadrant
- Combine for a single spectrum

Data Rates and Resolution

- Acquire multiple scans
  - Between 10 and 360 scans per second
  - Multi-pixel versions
- Good spectral resolution 8 cm-1 (4096 interferogram data points), tighter if desired.
- At slow rotation speeds (10 scans/sec) the single-pixel data rate is approximately 1 MB/sec.

Integration Times and Data Redundancy

- Integration times estimated at approximately 60 seconds per physical location at Europa
- With 4 rotational positions, there are 150 (60*10/4) samples of each interferogram data point
- Time interval between successive interferogram points is approximately 8 us

Requirements for Signal-to-Noise are dependent on analysis

- Single wavelength analysis
  - Often what is taught at school
  - Deservedly bad reputation
- Integrated peaks
  - A modest improvement
- Spectral Methods
  - If there is structure in the target spectrum
  - Demonstrated SNR < 1 with high accuracy

- **This talk is not about Spectral Processing Methods but about separable signal and noise in the measurement – a prelude to Spectral Processing**

Statement of the Problem

- Each Interferogram is a sampling of the same signal so there are redundant samples
- Each sample contains signal and ambient noise measured together
- Because the data rate is fast compared to the radiation noise frequency near Jupiter, the “signal” mean can be recovered

Indexed Statistics

- Simple idea – Powerful in practice:
  Throw out what is inconsistent to find what you are looking for

- Start with the median value of the distribution and compute mean value and standard deviation, throw out samples that are outside 2 sigma limits

- Repeat by re-sampling remaining data until convergence (usually <5 passes)

- Replace data outside 2 sigma limits with mean value

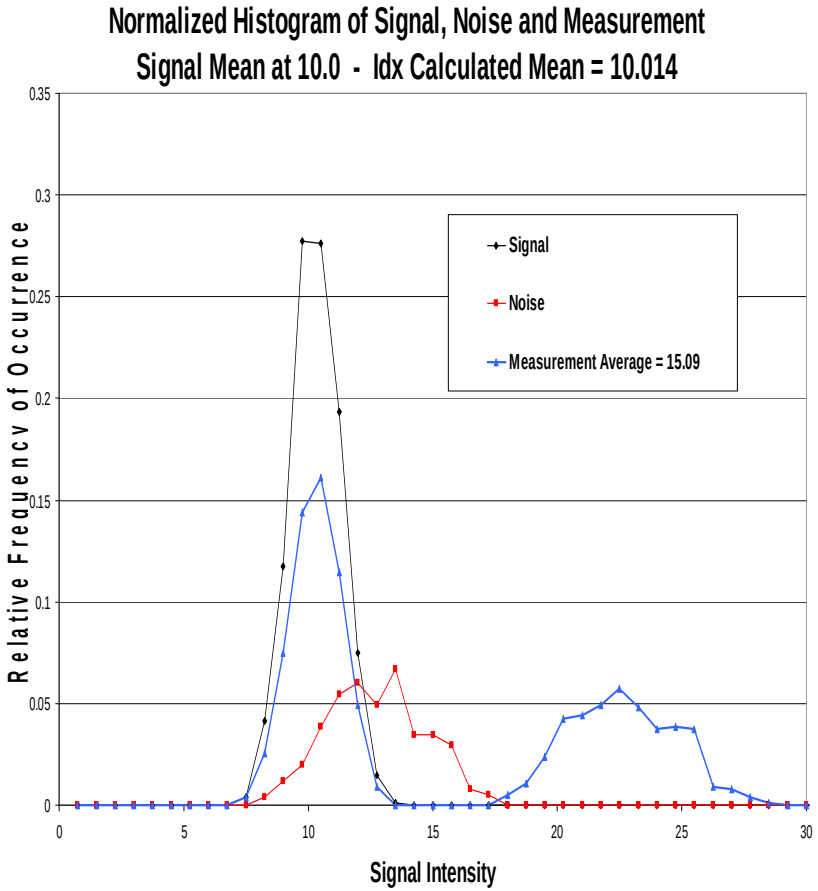
Signals and Noise

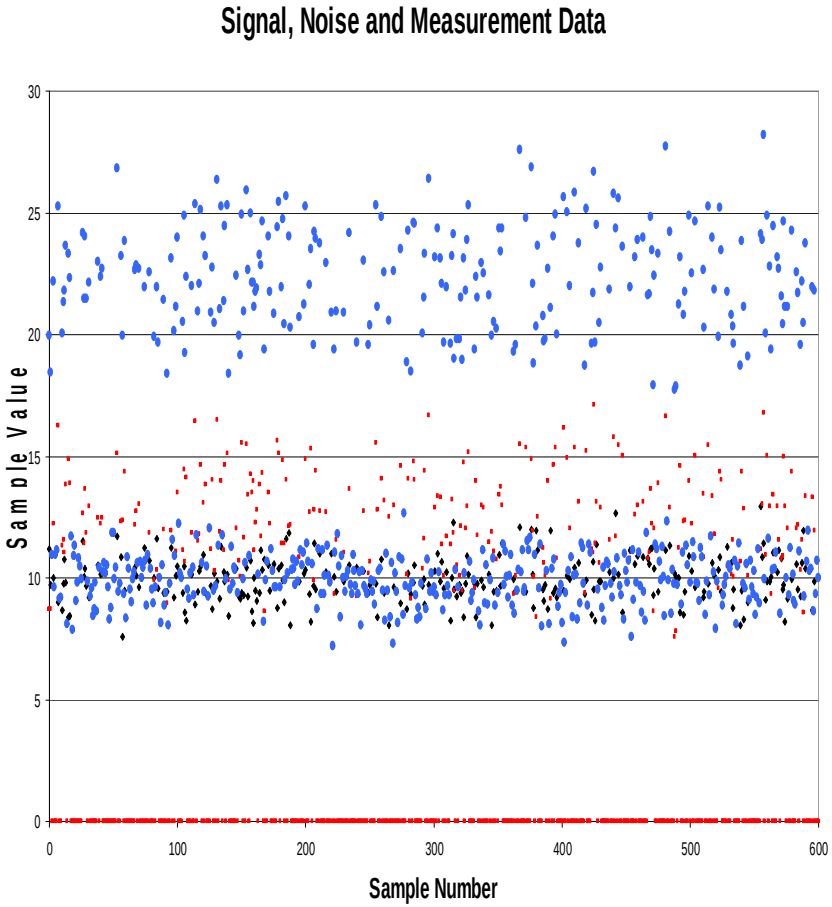
Range of Application and Limitations

- Signals must be separable:
  - Standard deviation of “signal” must be small compared to magnitude of noise
- Examples:
  - Signal with Big noise
  - Signal with White noise
  - Signal with Small noise
  - Signal with Europa noise

Signal, Noise and Measurement

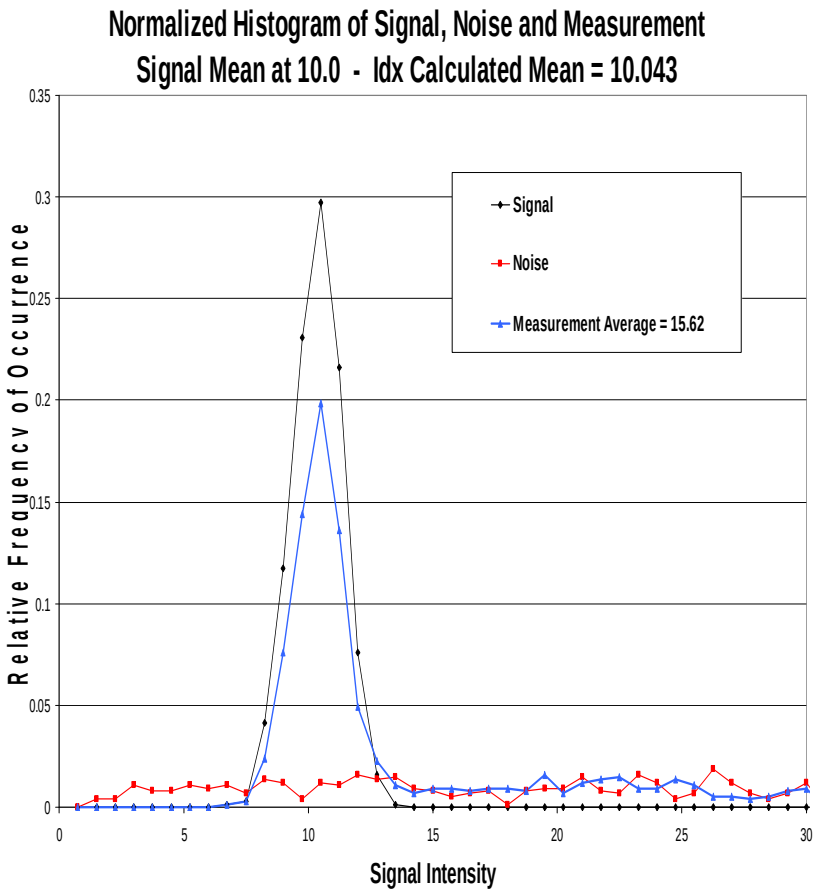
Big Noise

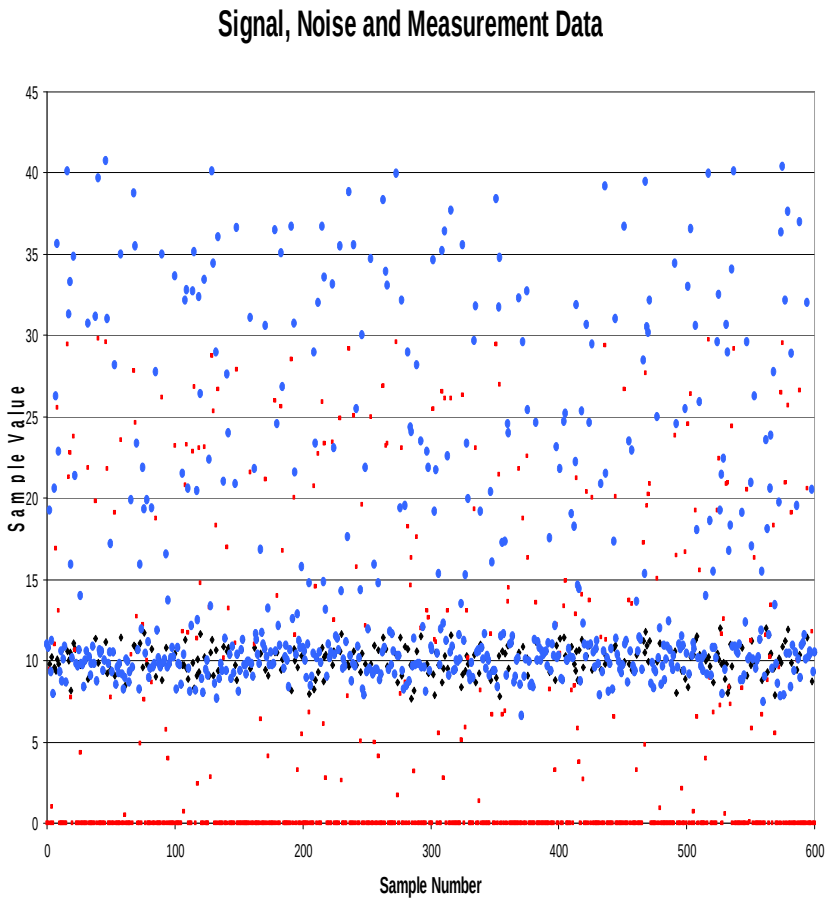




Signal, Noise and Measurement

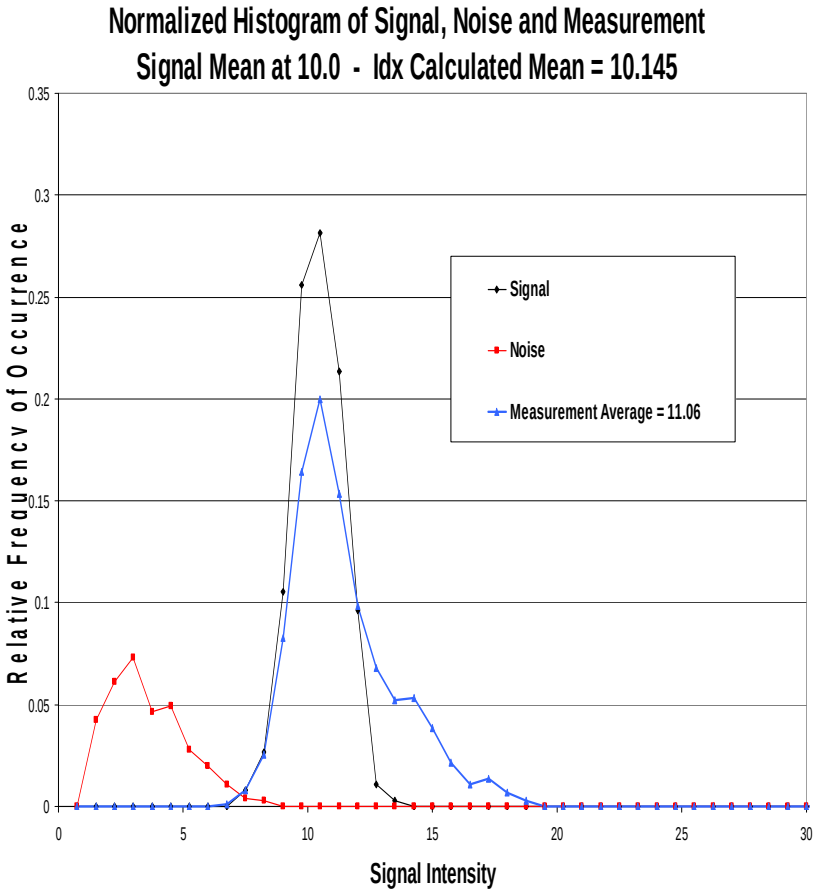
White Noise

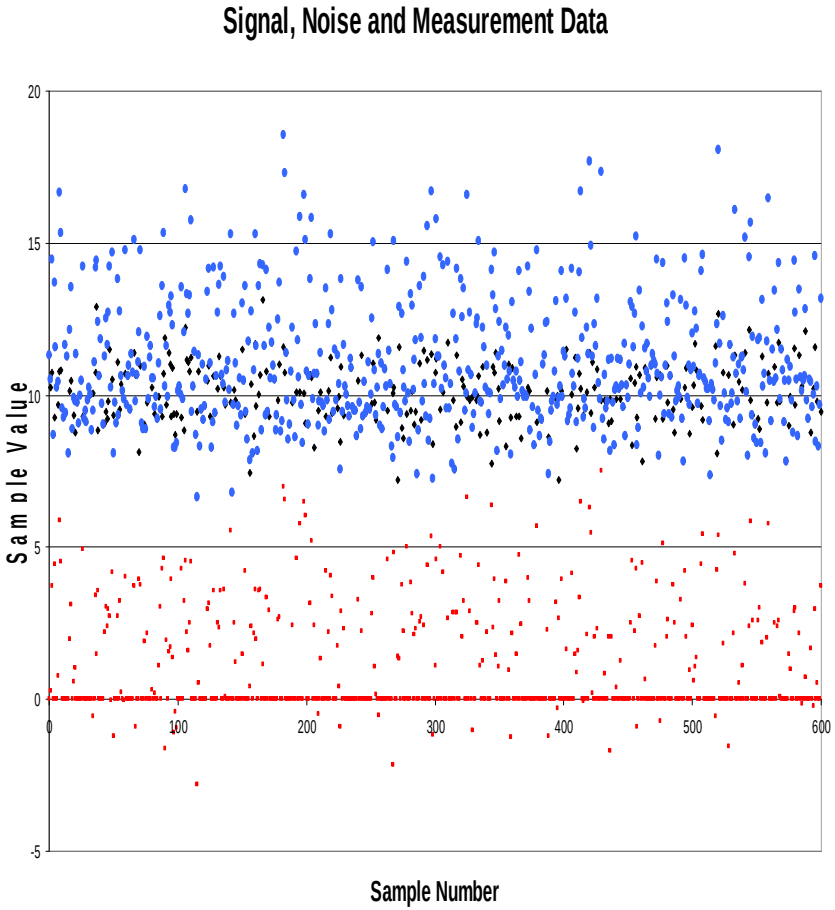




Signal, Noise and Measurement

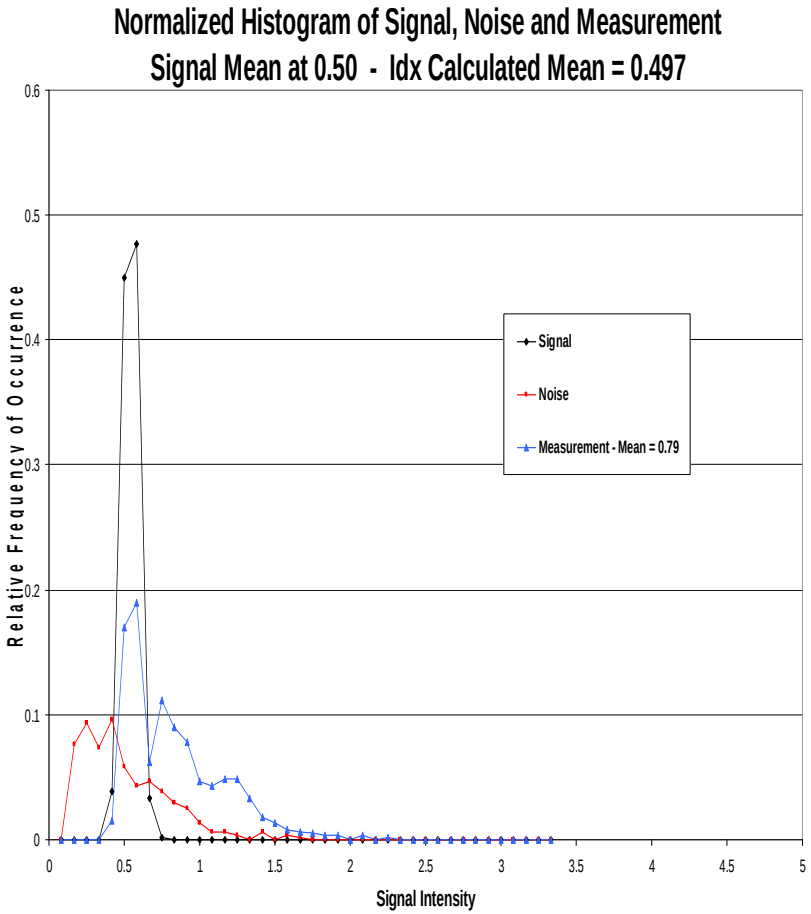
Small Noise

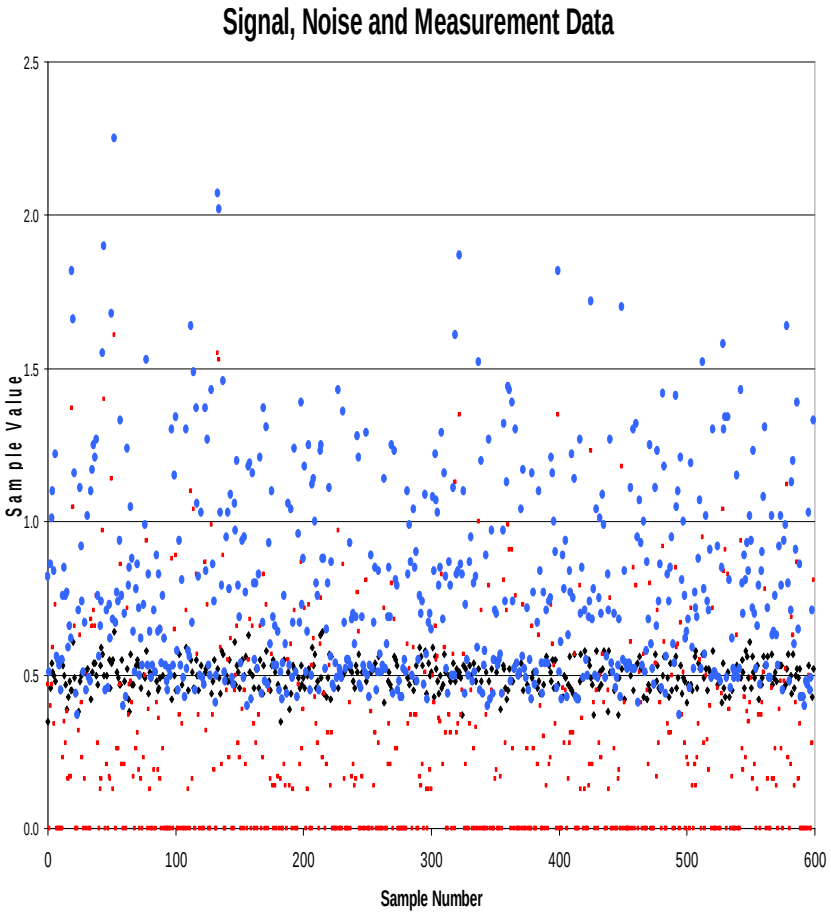




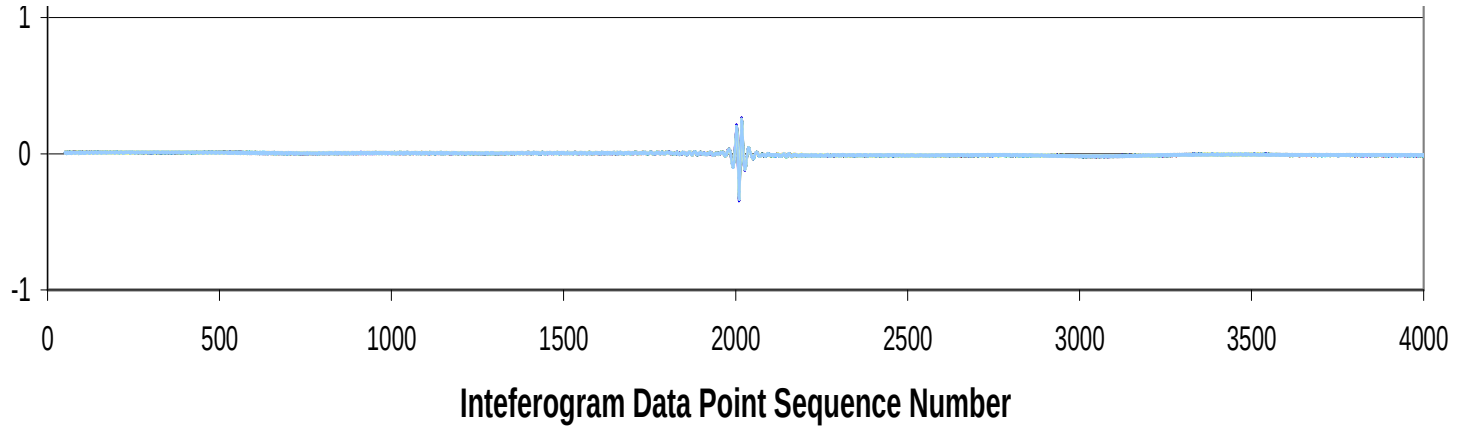
Signal, Noise and Measurement

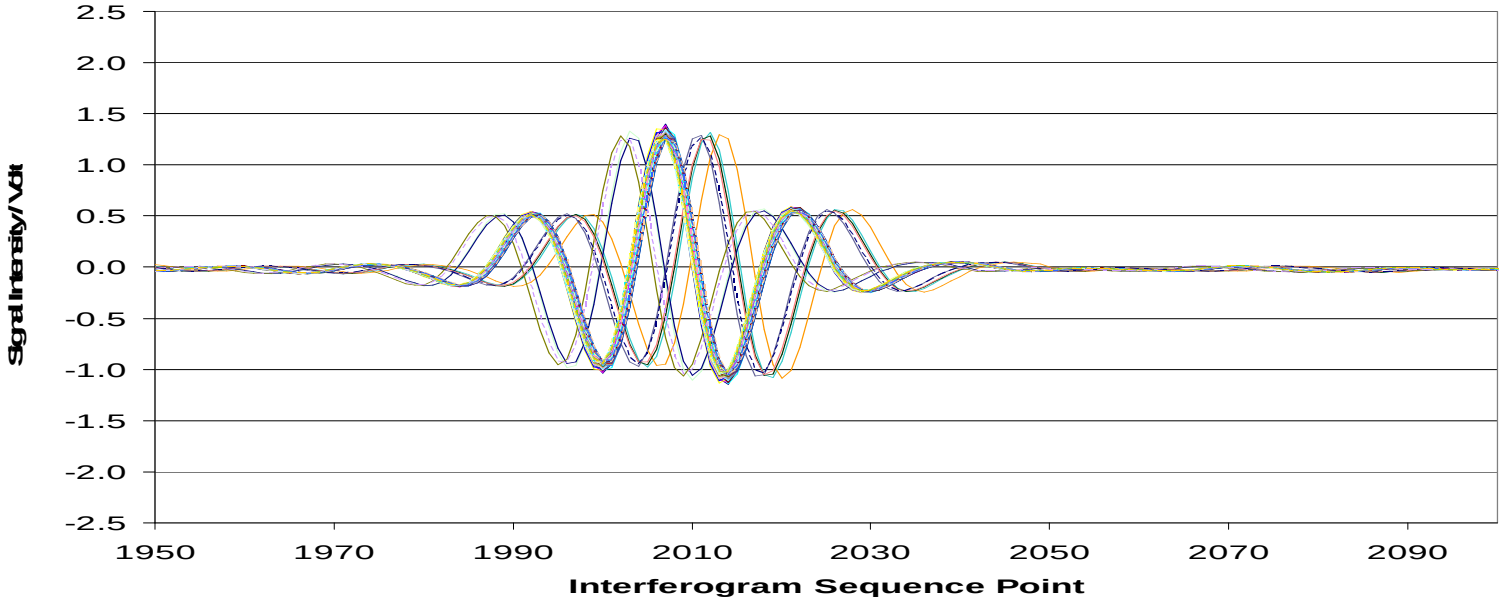
Europa Noise (synthetic)



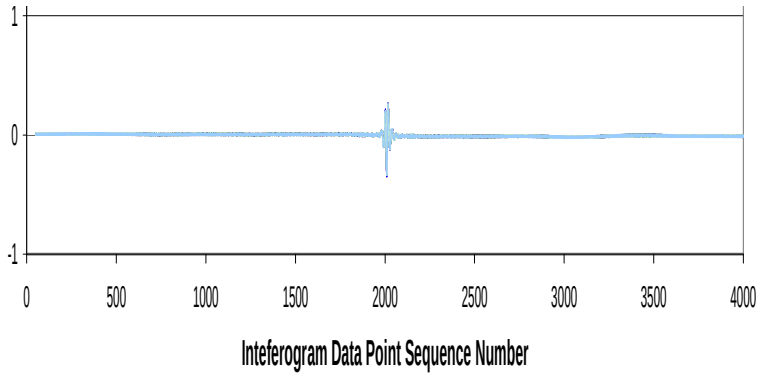


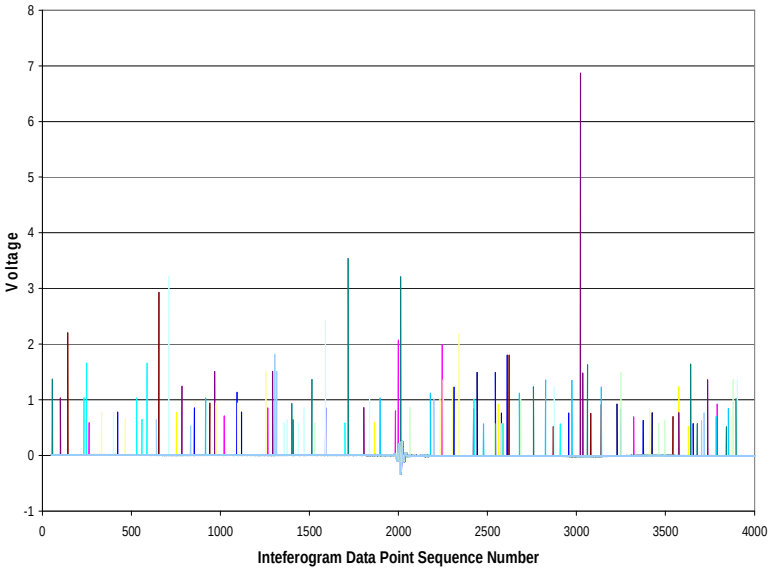
Interferogram Jitter and Registration

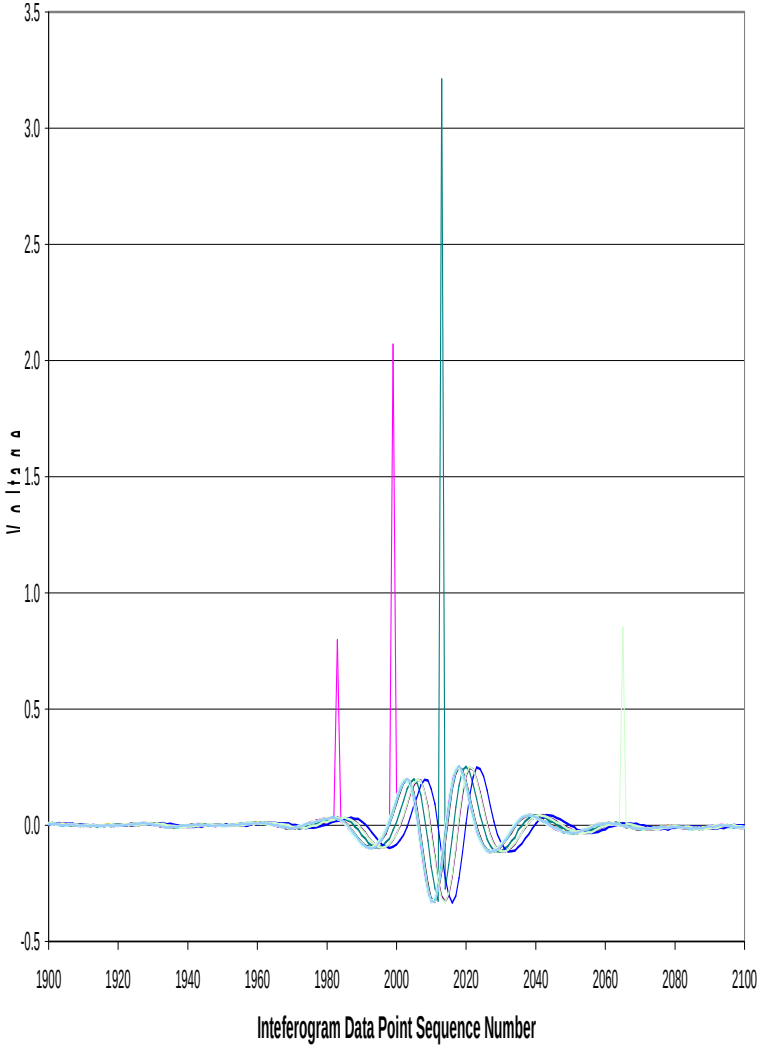




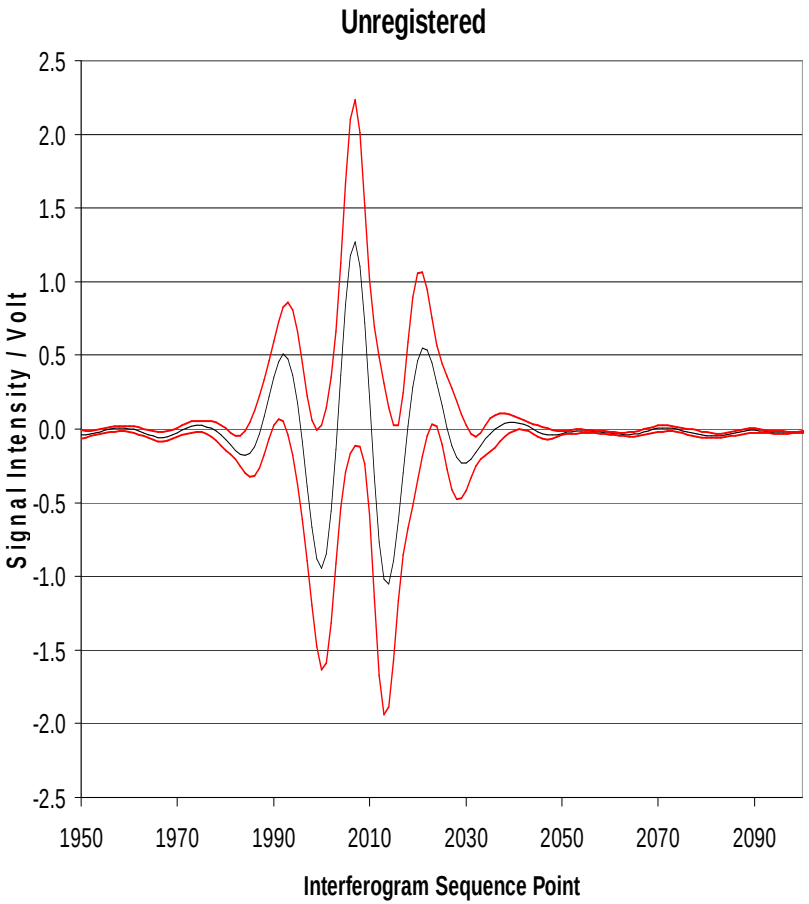
Radiation Effects – 14 Interferograms

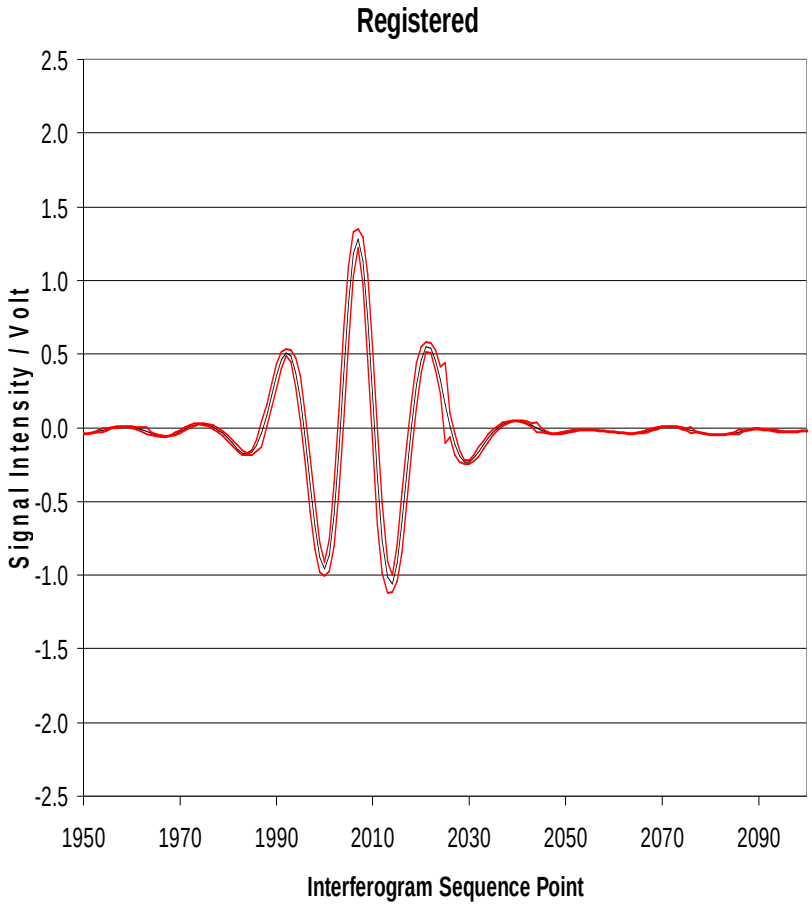




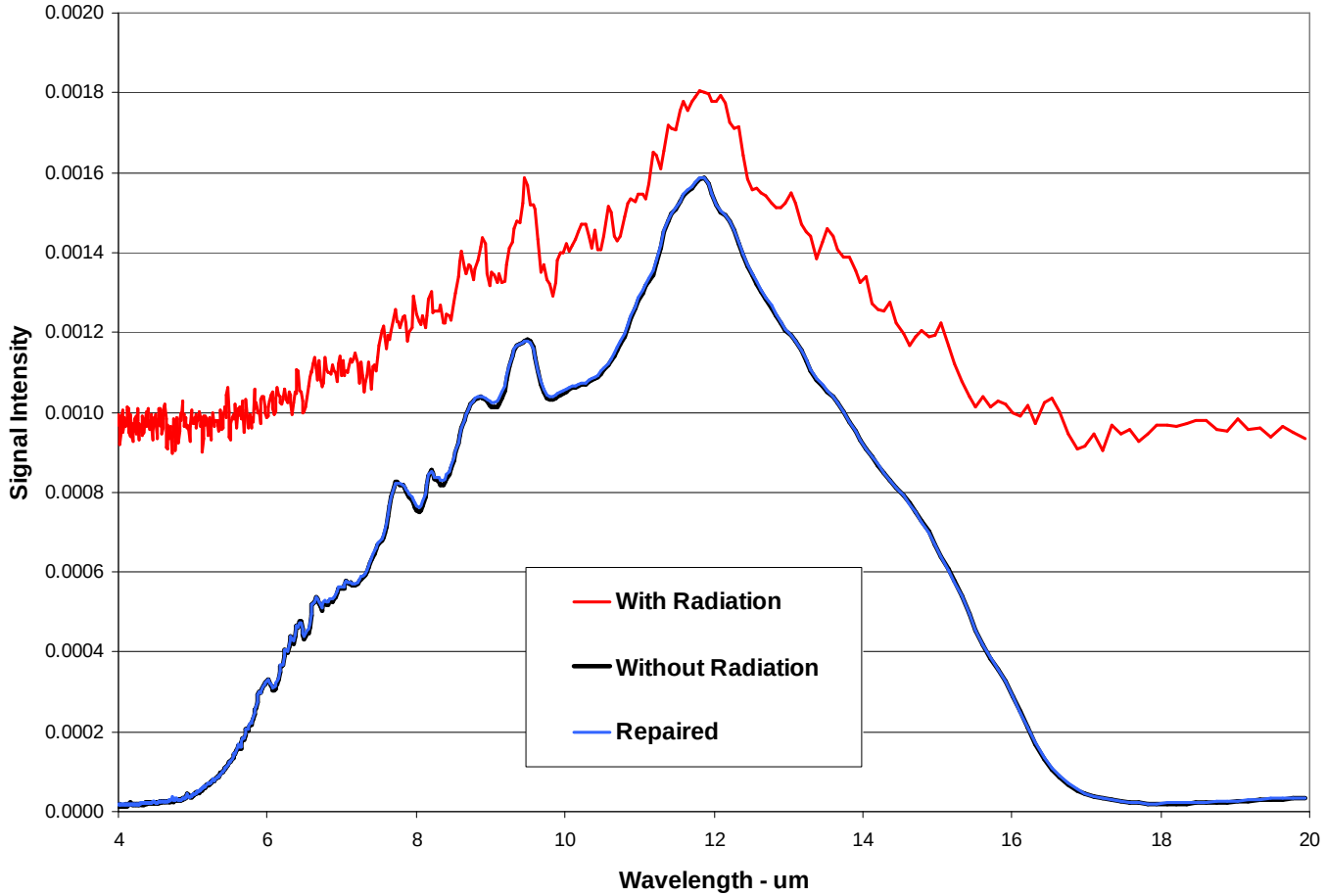


2 Sigma Limits

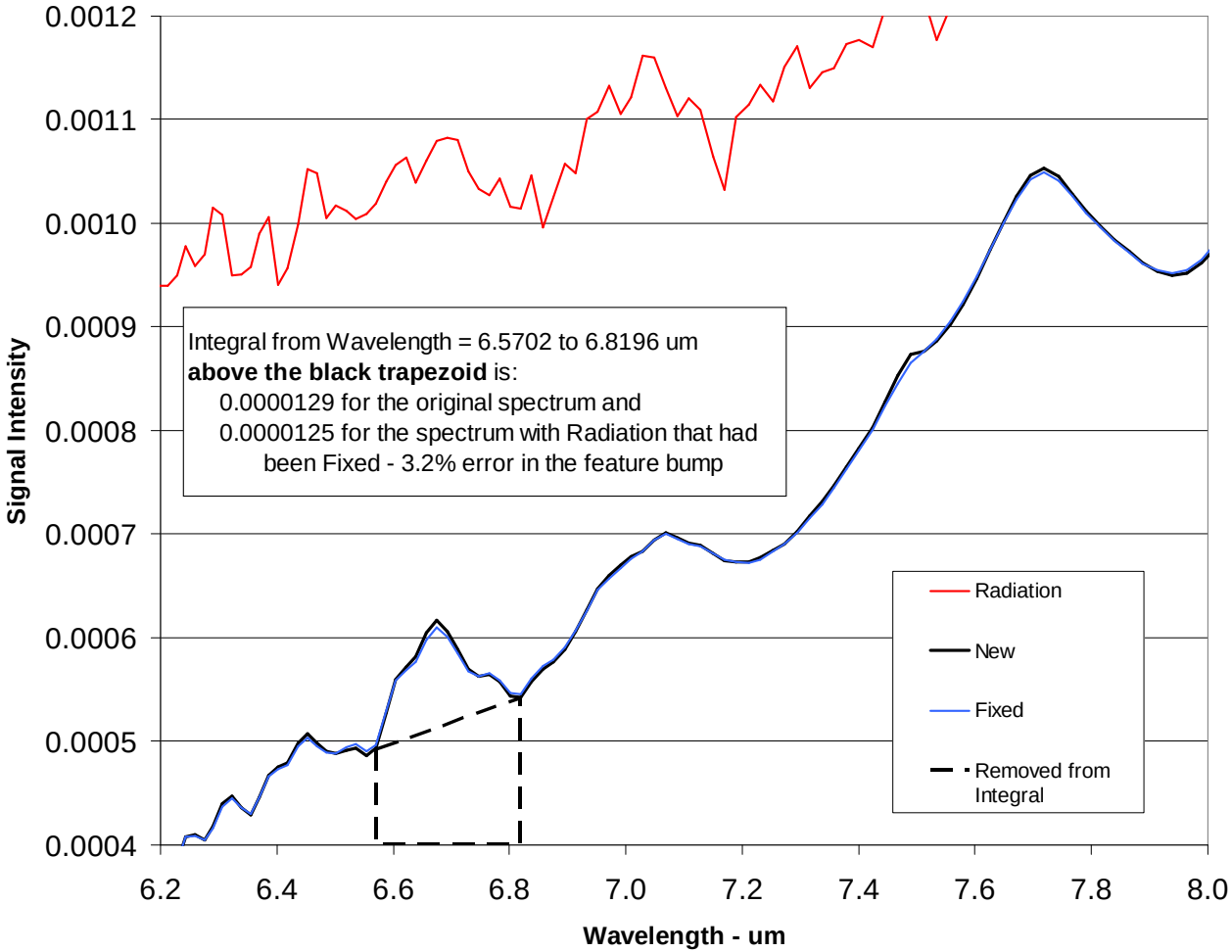




Application to Radiation in FTIR Data

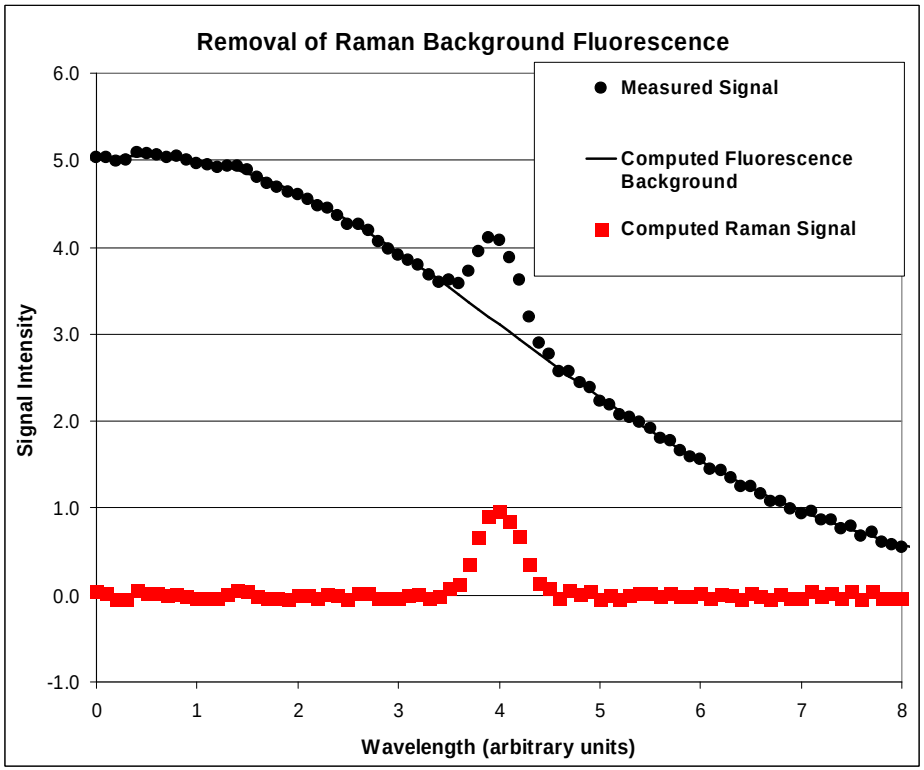


Another Example



An Inverse Application to Curve Fitting of Noisy Data

- Fluorescence Background Removal in **Raman Spectroscopy** – where this numerical technique was originally developed
  - Compute fluorescence signal, e.g., as Gaussian (3 variables)
  - Compute Error and throw out big points with large error (Raman signal)
  - Optimize fit of Gaussian to reduced data set



Take-Aways

- FTIR has inherent tolerance for Radiation
- Instrument design can influence operation
- Data analysis can pull much information out of some types of noise

JPL Jovian References

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