Remote Sensing, In Situ and Sample Return

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• Purpose of Space Science is to understand our environment using whatever means are available

• Basically two approaches
  – Remote Sensing
  – In Situ (or Sample Return)
    • Solids, surfaces, atmospheres
    • Interplanetary and interstellar - fields and particles

• Will discuss these sequentially
Remote Sensing

- Began with measurement of star positions using astrolabes, etc. in prehistoric times
- Galileo introduced telescope - images of Jupiter’s moons
- Newton discovered properties of prisms - led to spectroscopy
- Bigger telescopes gave more sensitivity and therefore range
- Went into space, starting in 1960 - first US launch (Explorer 1) did “in situ” not remote sensing
Galileo and His Telescope
What Is Measured - Photons

• *Photons* come in different *Energies* (colors/wavelengths), *Quantities* and from *Different places* (spatial distribution)

• Imagers (Cameras), Spectrometers and Radiometers all measure photons or electromagnetic radiation
  
  – *Spatial distribution* is measured by Imagers
  
  – *Energy* (color) is measured by Spectrometers
  
  – *Quantity* (power) is measured by Radiometers
AVIRIS Concept

Each spatial element has a continuous spectrum that is used to analyze the surface and atmosphere.

224 spectral images taken simultaneously.
What Is Measured - *Photons*

Where do the Photons come from...

- There are a variety of sources for the photons we measure:
  - Blackbody radiation - stars, hot gasses, filaments
  - Energy absorption and re-emission; typically this has highly unique characteristics e.g., aurora borealis, lasers, Cherenkov radiation, etc.

- Most local radiation is blackbody - solar
Blackbody Example

- Blackbody radiation is described by Plank’s formula

- Each physical mechanism has its own description; the instrument designer should understand the basic physics for the radiation to be observed
Mechanisms

- Emission (E)
- Reflection (R)
- Scattering (S)
- Transmission (T)
- Absorption (A)
Why Make the Measurement?

- To understand our physical surroundings, both close to us - on Earth, and at intergalactic distances

- The uses vary from weather forecasting, to testing the fundamental theories of physics; from land utilization to checking for life on other planets and elsewhere in the universe

- Scope is virtually unlimited ...
Why Make the Measurement from Space?

- Earth applications
  - High area coverage rates
  - Global data sets
  - “Open Sky” - few international constraints

- Outward looking applications
  - No atmospheric distortion issues
  - $4\pi$ solid angle coverage
Russian Area 51
Gas Disk in Nucleus of Active Galaxy M87

Hubble Space Telescope
Wide Field Planetary Camera 2
How - Remote Sensing

- Acquisition of information about an object without direct physical contact

- Interaction mechanism - *photons*
Idealized Planetary Occultation Experiment

- Phase Change (doppler shift) due to refraction
- Amplitude reduction due to molecular absorption
- Changing transmitter/receiver separation
- Atmospheric diffraction and defocusing
- Local multipathing (reflections)
- Transmitter and receiver gain variations
- Absorption by other constituents
Generalized Instrument Block Diagram

Photons from Object and Elsewhere

Focus Element → Color/Spectral → Detector → Signal Processor Electronics

Display

Data System
Why We Use Active Microwave Sensors

- Sensitivity to physical properties at scale of wavelength which is on same scale as many surface features
  - Topography
  - Morphology
  - Roughness
  - Discrete Scatterers

- Sensitivity to dielectric properties: eg. hydration, soil moisture
  - Hard targets
  - Moisture
  - Salinity

- All-weather, day-night observations
- Selectable geometry
- Long wavelength penetration capability
- Phase coherence allows interferometry at RF wavelengths
TOPEX La Niña

29 NOV 98

11 MAR 00
Shuttle Radar Topography Mission
Type of Interferometers
(Fizeau vs. Michelson) pay per view

• “All imaging is an interferometric process”
  F. Roddier

• Dividing line between telescope and interferometer is not strict, but to first order
  – Fizeau interferometer forms a direct image
  – Michelson interferometer forms a synthetic image
Angular Resolution

- Resolution is a function of
  - Wavelength of light: $\lambda$
  - Largest dimension of instrument: $B$
    - Telescope: diameter
    - Interferometer: separation of apertures
    - Diffraction limits angular resolution to $\sim \lambda / B$

Angular Resolution: $\lambda / B$

Aperture: diameter (length) = $B$
Fizeau Interferometers

Telescope

Sparse Aperture Telescope

Fizeau Interferometer

Detector

Telescope

"Beam Combiner"
PSFs for Sparse Apertures

- **Pupil** (what starlight sees)
- **MTF** (frequency response)
- **PSF** (image of point source)

Filled Aperture

- Autocorrelation
- Fourier transform

Sparse Aperture
Another Way to Look at Fringes

- **Pupil**: (what starlight sees)
- **MTF**: (frequency response)
- **PSF**: (image of point source)

**Filled Aperture**
- Autocorrelation
- Fourier transform

**Sparse Aperture**

**Interferometer**
High Resolution Imaging

HST-WFPC2

Over small fields of view SIM will show details that currently elude large telescopes. A simulated globular cluster core is used to illustrate this.

Actual field of view larger than shown

Resolution (FWHM) 53 milliarcsec

Cluster Core Model

"true star positions"

SIM

Resolution (FWHM) 10 milliarcsec

Field of View 0.3 arcsec
Summary

• The common thread is the measurement of photons and their characterization

• The physics of the process to be investigated needs to be understood by the instrument designer

• Quantitative improvements in accuracy tend to lead to qualitative improvements in understanding
In-Situ Instrumentation
Definition and Comments

In situ measurements are those performed in close proximity (near, on, within) the object of interest. In solar system exploration, these measurements are often performed within hostile environments, when compared to those endured for deep-space remote sensing. The environments frequently drive the instrumentation into severe design constraints for adequate capability, longevity and overall performance.
CISSR Roadmap

Key Science Missions

- Mars Exploration
- Comets & Asteroids
- Earth Analogs
- Venus
- Europa
- All Accessible Bodies

Surface Platforms

- Short range rovers
  - In support of sample return mission
- Long-life rovers with
  - Chemical and physical microbots
- Subsurface explorers with exobiology microbots
- Cryobots for subsurface
  - Ocean exploration
- Long-range "field scientist"
  - Rovers working in cooperative networks

Atmospheric Platforms

- Short-life probes for atmospheric
  - Composition and meteorology
- Probes for plasma
  - Particles, and field interactions
- Instrumented lifting body vehicles
- Circumnavigating aerobots for high resolution geochemistry and atmospheric dynamics for Mars & Venus
- Multiprobes and aerobots
  - For outer planets

Sample Return

- Comets coma sample return
- Solar wind sample return
- Mars rock and soil sample return
- Sample return from
  - Low-gravity bodies
- Outer planet rock and ice sample return

Technology Advances

- Sample handling and return technologies
- Microanalytical laboratories
- Highly survivable systems
  - Tolerant of temperature, pressure, radiation and impact extremes
- Fully autonomous fault-tolerant platforms
- Highly distributed and interactive knowledge-based platform with advanced power sources

Vision

- Conduct in situ analysis and acquire samples from all accessible bodies in the solar system
- Capability for surface, subsurface, and atmospheric mobile explorers
- Broad range of knowledge-based autonomous analytic systems
- Sample return from Mars by Humans; Return from all other bodies robotically

For updates, please contact William Hoffman at: william.hoffman@jpl.nasa.gov

DHR
6/6/00
## In-Situ Instrumentation

### Instruments and Applications

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear Magnetic Resonance</td>
<td>Environment of protons in solids and liquids; detection of water, water ice, conversion of water and carbon into simple organics</td>
</tr>
<tr>
<td>Electron Microscopy</td>
<td>Microscopic sample imaging, texture and elemental composition</td>
</tr>
<tr>
<td>Tunable Laser Diode Spectroscopy</td>
<td>Minor constituent detection (vapor phase), isotope ratios, effluent detection</td>
</tr>
<tr>
<td>Chemical Film Systems</td>
<td>Reactivity assessments, trace composition, specific species</td>
</tr>
<tr>
<td>Gas Chromatography</td>
<td>Atmospheric gases, evolved gases, gaseous isotopes, organics, large molecules, horrendous mixtures</td>
</tr>
<tr>
<td>Electrophoresis</td>
<td>Large molecules, peptides, proteins, inorganic salts, soluble minerals</td>
</tr>
<tr>
<td>Mass Spectroscopy</td>
<td>Atmospheric gases, evolved gases, age dating with isotopes, organics, large molecules</td>
</tr>
</tbody>
</table>
# In-Situ Instrumentation

Instrumentation for Exobiology on Planetary Surfaces  
*(Currently Available)*

<table>
<thead>
<tr>
<th>To obtain:</th>
<th>An understanding of planetary environment</th>
<th>Identification of key sample</th>
<th>Key chemical or morphological measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha-proton-x-ray</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>&quot;Aqueous chemistry&quot;</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gamma-ray spectroscopy</td>
<td>X</td>
<td></td>
<td></td>
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<tr>
<td>Gas chromatography</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Imaging</td>
<td>X</td>
<td>X</td>
<td></td>
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<tr>
<td>Infrared spectroscopy</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Mass spectrometry (isotopes)</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Mass spectrometry (organics)</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Mössbauer</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Neutron activity</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neutron spectroscopy</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raman spectroscopy</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Scanning electron microscopy</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Secondary ion mass spectrometry</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Thermal analysis</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>X-ray diffraction/fluorescence</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
**Combination Laser Absorption and Raman IR Spectrometer (CLARIS)**

**Scientific Goals of Instrument**
1. Determination of atmospheric gas composition (e.g., H₂O, CO₂ and isotopes)
2. Determination of mineralogical composition for rocks and soil on Martian surface
3. Determination of atmospheric particle size distributions and number densities

**Measurements Made by Instrument**
1. Concentrations of selected gases using near-IR laser absorption spectroscopy
2. Near-IR laser Raman spectroscopy detection at 1-2 microns
3. Particle size distributions and numbers densities from laser particle spectrometry
4. High resolution (0.0001 cm⁻¹) near IR; < 2% measurement precision required

**Instrument Description**
1. Single room-temperature tunable diode laser at 1.3 microns with detection in 1.3-2.3 microns using AlGaAs arrays
2. Miniature laser spectrometer with capability for simultaneous measurement of gas, mineral and particle abundance's

**Development Status**
1. Gas concentration channel is similar to MVACS TDL spectrometer
2. The laser Raman channel is completely new and untested even in laboratory

**Who/Funding**
1. Chris Webster (PI)
2. JPL, Caltech
3. 1 DRDF, PIDDP

*6/6/00*
Microfabricated Capillary Electrophoresis for the Chiral Analysis of Amino Acids

Scientific Goals of Instrument
1. Search for evidence of past or extant life on Mars
   1. Determination of biotic vs. abiotic origin of amino acids extracted from soil/rock

Measurements Made by Instrument
1. Detects amino acids extracted from Martian rock/soil with femtomolar sensitivity
1. Uses calibration solutions to identify which amino acids are present
1. Resolves D- and L-enantiomers for each detected amino acid

Instrument Description
1. Performs wet-chemistry extraction of organics from soil/rock using emerging microfluidic technologies
1. Isolates and fluorescently tags amino acids
1. Analyzes amino acid abundances using microfabricated capillary electrophoresis (CE) with laser-induced fluorescence (LIF) detection
1. Addition of cyclodextrin inclusion complexes provides for chiral resolution

Development Status
1. Demonstrated enantiomeric resolution of standard amino acid solution using microfabricated CE/LIF (see spectrum)
1. Extraction of amino acids using microfluidics now under
   Possible Options: rover lander mole/penetrator
   Ready for Flight Development: 9 now 9 >'05 9 >'07
   Propulsion/Power Instrument Development?
   Volume: 0.5 liter
1. no

Who/Funding
1. Jeff Bada (PI) 1 NASA Sensor program, PIDD
1. Scripps UCSD, UC Berkeley, JPL
Miniature Proton-Nuclear Magnetic Resonance (NMR) Spectrometer

Scientific Goals of Instrument
1 Detection and quantity of various forms of water (adsorbed, chemically bound) in soil, rock samples

Measurements Made by Instrument
1 Quantitative measurements of water contents in soil, mineral samples
1 Sensitivity 0.1 wt%

Instrument Description
1 Detection of protons through interaction of proton nuclear spins with molecular and magnetic field environment
1 Consists of a permanent magnet, radio frequency coil, pulsed or continuous wave NMR circuit, digital signal processing circuit
1 Sample Size: 1-2 cc

Development Status
1 Will be field tested in Sahara Desert and Antarctica in Nov/Dec, 1998 by Chris McKay

Ready for Flight Development? 9 now (‘03) (‘05) (>‘07)

Profile
Mass: 800 gm  Power: 0.25 W  Volume: 600 cm³

Possible Vehicles
( rover 9 aerobot 9 glider 9 other
( lander

Dependencies on other Instruments Developments?
1 None

Who/Funding
1 Soon Sam Kim (PI) 1 PIDDIP
1 JPL
Europa
Cable System for Interactive Seafloor Observatories

Middle Valley
Endeavour
Juan de Fuca Plate
Axial

Data source: Smith, W. H. F. and D. J. Sandwell, Global Seafloor Topography from Satellite Altimetry and Ship Depth Soundings combined with GTOP030.
Experiment Development

- Phases of an experiments evolution
- Science/User need ID
- Science ↔ Engineering Interactions
- "The Proposal"
- Winning the Job
- Starting the Job - staffing/facilities/dollars/teaming partners/interfaces/contracts/ ...
Experiment Development

• Implementation
• Delivery
• Integration Support
• “the Launch”
• Data Return
• Data Analysis/Reduction
• Science/User Results/Output
Imaging, Spectrometry & Radiometry
Electromagnetic Spectrum
The Many Energies of Light

X-rays and gamma rays span many decades in energy as “messengers” from different scale sizes and physical processes.

Here are some typical x-rays and gamma-ray energies and the corresponding frequencies, wavelengths and associated scales sizes:

<table>
<thead>
<tr>
<th>Energy</th>
<th>Frequency</th>
<th>Wavelength</th>
<th>Scale Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 KeV</td>
<td>$2.4 \times 10^{17}$ Hz</td>
<td>1.2 nm</td>
<td>Atom</td>
</tr>
<tr>
<td>1 MeV</td>
<td>$2.4 \times 10^{20}$ Hz</td>
<td>$1.2 \times 10^{-12}$ m</td>
<td>Nucleus</td>
</tr>
<tr>
<td>1 GeV</td>
<td>$2.4 \times 10^{23}$ Hz</td>
<td>$1.2 \times 10^{-15}$ m</td>
<td>Nucleon</td>
</tr>
<tr>
<td>1 TeV</td>
<td>$2.4 \times 10^{26}$ Hz</td>
<td>$1.2 \times 10^{-18}$ m</td>
<td>Lepton</td>
</tr>
</tbody>
</table>

When characterizing the energy of x-rays or gamma rays, units of electron volts (eV) are typically used ($1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$)
Blackbody - Planck's Radiation Formula

Planck's idea of quantizing radiation led him successfully to the mathematical description of the spectral distribution of radiation emitted from a perfect radiator or blackbody. Planck's blackbody law can be expressed as

\[ M_\lambda = \frac{2\pi hc^2}{\lambda^5 \left[ \exp(ch/\lambda kT) - 1 \right]} \]

Where the spectral radiant exitance \( M_\lambda \) is in W m\(^{-2}\) \( \mu m \)^{-1} if the quantities in Eq. (3.7) are given in the following units:

- \( h \) = Planck's constant = 6.6256 \times 10^{-34} \text{ W s}^2,
- \( c \) = velocity of light = 2.997925 \times 10^8 \text{ m s}^{-1},
- \( k \) = Boltzmann's constant = 1.38054 \times 10^{-23} \text{ W s K}^{-1},
- \( T \) = absolute temperature in degrees (K),
- \( \lambda \) = wavelength in metres.
Imaging, Spectrometry & Radiometry
Geometric Illustration of Radiometric Terms

\[ \Omega = \frac{a}{r^2} \quad \text{Solid Angle in sterradians} \]

\[ \Omega = 4\pi \sin^2 \left(\frac{1}{2} \theta \right) \]

\[ dA_{\text{proj}} = dA \cos \theta \]

\[ L = \frac{d^2 \Phi}{dA_{\text{proj}} d\Omega} \]
Radar Interferometry
Theory of Spatial Baseline Configurations

Defining geometry and parameters:

- Surface topography $z(x)$
- Aircraft altitude $h$
- Baseline distance $B$
- Slant range $\rho$
- Look angle $\theta$
- Baseline angle $\alpha$
- Path length difference $\delta$

Resulting equations for measured phase $\phi$, wavelength $\lambda$

\[ \delta = \frac{\phi \lambda}{2\pi} \]  \hspace{1cm} (1)
\[ \sin(\alpha - \theta) = (\rho + \delta)^2 - \rho^2 - B^2)/(2\rho B) \] \hspace{1cm} (2)
\[ Z(x) = h - \rho \cos(\alpha) \cos(\alpha - \theta) + \rho \sin(\alpha) \sin(\alpha - \theta) \] \hspace{1cm} (3)
Radar Interferometry
Theory of Combination Baseline Configurations

- Utilize multiple (>2) passes in near repeat orbit
- A1/A2 pass forms one interferogram
- A2/A3 pass forms second interferogram
- Topography fringes are scaled by B1/B2 and differential interferogram formed, canceling out topographic variation
- Residuals is motion of surface over time to subwavelength scale