Science and Resource Drivers on Infrared Instruments for Outer Planets Missions

5x5 (Beyond 5 AU and beyond 5 microns)

Kevin P. Hand
Jet Propulsion Laboratory,
California Institute of Technology
Brief outline
Case in point, Enceladus

The most striking characteristic of Enceladus’ surface – and this was first observed by the Voyager spacecraft over 25 years ago – is the difference between the northern hemisphere and the southern hemisphere.

Enceladus, South Polar region (area with blue fractures near bottom of the image) has plumes of water erupting from it and there’s decent evidence that the source of the water may be a south polar sea beneath the ice.

e = 0.0047
a = 237,948 km
T = 1.37 d
R = 250 km
rho = 1.6 g cm\(^3\)
Thermal imaging revealing a heat anomaly...

Los Angeles – 7.2 GW
VIMS: C-H along Tiger Stripes

Brown et al., 2006
The optimum fit to the spectrum in the mass range 36–43 Da leaves a significant residual signal at mass 40 (Fig. 2), which we attribute to the presence of radiogenic 40Ar at a volume mixing ratio of 3 $\times$ 10^{-4}. (36Ar and 38Ar—primordial non-radiogenic argon—may also be present, but at a combined abundance of $\leq$10^{-5}.) This amount of 40Ar is greater by three orders of magnitude than would be expected for a chondritic abundance of potassium in Enceladus’ rock fraction, thus requiring both an efficient mechanism for the escape of 40Ar from the rock component and a mechanism for concentrating it. In an undifferentiated rock–ice body, 40Ar could escape through diffusion from small particles over several Gyr; however, solid-state diffusion is inefficient over larger length scales, and this scenario does not provide a means of concentrating 40Ar within the ice. In contrast, water–rock interactions early in Enceladus’ history would naturally facilitate 40Ar escape by leaching both 40Ar and 40K from a rock core. The D/H ratio is close to the cometary value of 3 $\times$ 10^{-4} (ref. 16), nearly twice the terrestrial ocean water value (1.56 $\times$ 10^{-4}) and more than ten times the value of the D/H ratio in the protosolar nebula (2.1 $\pm$ 0.4 $\times$ 10^{-5}) (22). The mixing ratios shown here for CO and H2 (values in square brackets) are included in the mixing ratios for CO2 and H2O given in the first two rows. Analysis of the data from all five encounters shows that the ratios of mass 44 (CO2) to mass 28 and of mass 18 (H2O) to mass 2 (H2) decrease with increasing spacecraft velocity, suggesting that H2 and CO are produced by the dissociation of H2O and CO2 through hypervelocity impact on, and reaction with, the walls of the INMS antechamber (see Supplementary Information). We estimate that 40–80% of the signal in mass channel 28 is due to CO produced in this way. A small contribution of CO from Enceladus is also possible, but cannot be distinguished from the dissociation product. The residual mass 28 signal is attributed to N2, C2H4, or a combination of both, with either HCN or the ethene dissociation product C2H3 contributing to the signal in mass channel 27. The values given for these species are upper limits based on the two alternative scenarios (N2 1 HCN versus C2H4). Neither scenario can be given preference over the other on the basis of the present INMS data set.
On Europa, it is comparable to the energy flux that drives bright aurorae on Earth (IBC II to IBC III) and to the solar energy flux that produces the stratospheric ozone layer.
−280 Fahrenheit

$8 \times 10^{10}$ keV cm$^{-2}$ s

Energy deposited: 80% electrons, 15% protons, 5% ions of sulfur and oxygen.
The energy deposition rate at Europa’s orbital radius is about $10^4$ greater than the cosmic ray flux, 400 the solar wind energy flux (1 AU), and 50 greater than the Europa’s solar ultraviolet irradiance that dissociates and ionizes H$_2$O.
-280 Fahrenheit
Comparison to Europa

Europa: \( \sim 12.5 \, \mu\text{W cm}^{-2} \)

Minos chamber (10 keV, 20 nA): \( \sim 200 \, \mu\text{W cm}^{-2} \)
Hand et al., 2007
JEO Goal: “Explore Europa to Investigate its Habitability”
<table>
<thead>
<tr>
<th>Instrument</th>
<th>Range (μm)</th>
<th>Res'n Δν cm⁻¹ (Nyquist)</th>
<th>Mass (kg)</th>
<th>Optics T (K)(c)</th>
<th>Det'rr T (K)(c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galileo NIMS (a)</td>
<td>0.7-5.2</td>
<td>25(b)</td>
<td>18</td>
<td>128 P</td>
<td>65 P</td>
</tr>
<tr>
<td>Cassini VIMS (d)</td>
<td>0.85-5.1</td>
<td>33 (b)</td>
<td>18</td>
<td>130 P</td>
<td>60 P</td>
</tr>
<tr>
<td>Mars Express OMEGA (e)</td>
<td>0.93-5.1</td>
<td>40 (b)</td>
<td>23.5</td>
<td>190 P</td>
<td>&lt;70 A</td>
</tr>
<tr>
<td>Venus Express VIRTIS-M (f)</td>
<td>1-5.1</td>
<td>20 (b)</td>
<td>NA</td>
<td>NA</td>
<td>~70 A</td>
</tr>
<tr>
<td>SPIRIT (Sounding Rocket) (g)</td>
<td>2.5-22</td>
<td>1</td>
<td>3.6+LHe</td>
<td>10 C</td>
<td>10 C</td>
</tr>
<tr>
<td>Mars Global Surveyor TES (h)</td>
<td>6-60</td>
<td>10</td>
<td>14.4</td>
<td>280 P</td>
<td>280 P</td>
</tr>
<tr>
<td>Mars Exp. Rovers Mini-TES (i)</td>
<td>5-29</td>
<td>20</td>
<td>2.4</td>
<td>280 P</td>
<td>280 P</td>
</tr>
<tr>
<td>Mars Express PFS (j)</td>
<td>1.2-45</td>
<td>1.5</td>
<td>30</td>
<td>290 P</td>
<td>220 A</td>
</tr>
<tr>
<td>Cassini CIRS (k)</td>
<td>7.2-1000</td>
<td>0.5</td>
<td>39</td>
<td>170 P,R</td>
<td>75 P,R</td>
</tr>
<tr>
<td>New Millennium IFTS (l)</td>
<td>4.4-15</td>
<td>0.6</td>
<td>100</td>
<td>140 A</td>
<td>55 A</td>
</tr>
<tr>
<td>Voyager 1, 2 IRIS (m)</td>
<td>4-55</td>
<td>4.3</td>
<td>NA</td>
<td>200 A</td>
<td>200 A</td>
</tr>
<tr>
<td>CIRIS (this proposal)</td>
<td>1.4-15</td>
<td>4</td>
<td>7-8</td>
<td>130</td>
<td>60-85</td>
</tr>
</tbody>
</table>

(a) Carlson et al., 1992. (b) at ~3 μm (c) P = passive, A = active, C = cryogen, R = regulated (d) Brown et al., 2004. (e) Bibring et al. 2004. (f) Coradini et al. 1998, also on Rosetta (g) Dybwad et al., 1987. (h) Christiansen et al., 1992. (i) Formisano et al., 2004. (k) Flasar et al., 2004 (l) EO-3, planned for geosynchronous orbit, but now cancelled. (m) Persky 1995.
Example spectra of organics in Europa analog ices.

Key points:

The most useful and interesting features are between 5.75-7.5 microns.

Below 5 microns gets you nothing new and nothing we haven't seen before.
<table>
<thead>
<tr>
<th>Frequency, cm⁻¹ (KBr pellet)</th>
<th>Functional Groups and Molecular Assignments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1900 (1.0-1.5)</td>
<td>Vibration of amide groups</td>
</tr>
<tr>
<td>1620 (1.3-1.5)</td>
<td>O-H stretching in water</td>
</tr>
<tr>
<td>1450 (1.3-1.5)</td>
<td>C=O stretching in amide</td>
</tr>
<tr>
<td>1100 (1.5-1.6)</td>
<td>C-O stretching in ester</td>
</tr>
<tr>
<td>800 (1.6-1.7)</td>
<td>C-H bending in aromatic rings</td>
</tr>
<tr>
<td>600 (1.7-1.8)</td>
<td>C-C stretching in aromatic rings</td>
</tr>
<tr>
<td>400 (1.8-1.9)</td>
<td>C-H stretching in aromatic rings</td>
</tr>
<tr>
<td>3000 (1.9-2.0)</td>
<td>C-H stretching in hydrocarbon rings</td>
</tr>
</tbody>
</table>

**Notes:**
- Vibration: The frequency of vibration is given in units of cm⁻¹ (KBr pellet).
- Functional Groups: Describes the possible functional groups and molecular assignments related to the given frequency ranges.
Here’s the situation we face... 4 types of organic chemistry on the surface,
1) Irrad life forms
2) Irrad endog org material, abiotic
3) Irrad exog org material, abiotic
4) synthesis of org material radiolytically
Abiotic chemistry:
- Radiolysis of $\text{H}_2\text{O} + \text{NH}_3 + \text{C}_3\text{H}_6$
- $\text{H}_2\text{O} + \text{B. pumilis}$ post-irradiation
- $\text{H}_2\text{O} + \text{B. pumilis}$ pre-irradiation

- Amide I, $\alpha$-helical, C=O/C-N: 1655 cm$^{-1}$
- Amide I, $\beta$-helical, C=O/N-H: 1637 cm$^{-1}$
- Amide II, N-H/C-N: 1537 cm$^{-1}$

- Abiotic, NH$_3$: 1592 cm$^{-1}$
- Phosphodiesters (RNA, DNA, ATP): 1240 cm$^{-1}$, 1260 cm$^{-1}$, 1078 cm$^{-1}$
- Tyrosine band: 1514 cm$^{-1}$

- Abiotic, NH$_2$: 1669 cm$^{-1}$
Thermal emission/Blackbody curves

Europa’s cold surface permits reflectance spectroscopy to 7.5 microns

Reflected solar photons

CIRIS does reflectance spectroscopy to 7.5 µm, permitting detailed investigation of organic chemistry and astrobiology

CIRIS does thermal emission spectroscopy to 12 µm, permitting differentiation of species such as hydrated sulfates.

Top: Calculated solar reflectance and thermal emission radiances from Europa. Observing morning (blue) and noon (red) locales enhances the spectral range of reflected and thermal signals, respectively. Depending on time and temperature, reflectance spectra can be obtained to 7 µm and thermal emission to 15 µm. Temperatures based on Spencer et al. (1999). A surface of H$_2$O+H$_2$SO$_4$ hydrate was assumed.

Bottom: Emissivity features may be used for compositional determinations. Brightness variations in the thermal emission signal, showing an H$_2$SO$_4$ peak at 8.4 µm. MgSO$_4$’s peak is shifted to longer wavelengths.
(a) NIMS measurements of Europa’s spectral albedo, illustrating radiation-induced noise spikes. Each point represents an 8–msec integration, during which every integration was found to be altered by radiation. Effects were debilitating beyond 2.5 µm, where the albedo was low and the solar photon flux decreases as $\lambda^{-3}$ (for constant $\Delta\lambda$ sampling). The radiation noise problem is a critical limiting factor for spectroscopy on the JEO mission. (b) Our solution: recognizing and removing radiation noise in interferograms generated by an FTS. A radiation spike is shown at optical path difference = 20 and is easily recognized. Spikes can be automatically removed before transforming to obtain the spectrum. (c) Influence of interferogram noise spikes on the resulting spectrum. A 2048–point TurboFTS interferogram of polystyrene was contaminated with spikes at OPD index = 500 and 1500 with amplitudes $10 \times$ the average signal in these ranges. The spectrum for index = 1500 case (blue line) is within a fraction of a percent of the baseline (circles). The spike at 500 produces ~3% modulation in the spectrum (red, see inset). Spikes of this and smaller magnitudes are recognizable and can be removed using automated algorithms.

The availability of the desired reflected photons, and the intense radiation environment, make spectroscopy in orbit around Europa very difficult. Nevertheless, as shown in the radiance plot at right, the cold surface temperature of Europa (80–130K) means that reflected solar photons dominate over thermal emission photons out to, and a bit beyond, 8 µm. Unfortunately, as shown in the spectra of Fig. (a), noise spikes due to radiation cloud the spectra beyond ~2.5 µm because the radiance is so low. Thus, while the desired photons exist, the radiation noise environment makes it very difficult to achieve reasonable signal-to-noise at longer wavelengths.
(a) NIMS measurements of Europa’s spectral albedo, illustrating radiation-induced noise spikes. Each point represents an 8-msec integration, during which every integration was found to be altered by radiation. Effects were debilitating beyond 2.5 μm, where the albedo was low and the solar photon flux decreases as $\lambda^{-3}$ (for constant $\Delta \lambda$ sampling). The radiation noise problem is a critical limiting factor for spectroscopy on the JEO mission. (b) Our solution: recognizing and removing radiation noise in interferograms generated by an FTS. A radiation spike is shown at optical path difference = 20 and is easily recognized. Spikes can be automatically removed before transforming to obtain the spectrum. (c) Influence of interferogram noise spikes on the resulting spectrum. A 2048-point TurboFTS interferogram of polystyrene was contaminated with spikes at OPD index = 500 and 1500 with amplitudes $10 \times$ the average signal in these ranges. The spectrum for index = 1500 case (blue line) is within a fraction of a percent of the baseline (circles). The spike at 500 produces ~3% modulation in the spectrum (red, see inset). Spikes of this and smaller magnitudes are recognizable and can be removed using automated algorithms.
Heritage: Use on military helicopters, Used in Antarctica by Hand and Carlson, Proposed for MSL

K.P. Hand with FTS in Dry Valleys studying cryptoendoliths
CIRIS Conceptual Design

- Shielded focal plane assembly (FPA)
- Active cooler or passive radiative cooler similar to NIMS (65 K)
- Image motion compensation mirror (30-s stare time)
- Off-axis parabolic telescope ~ 15-cm aperture
- TurboFTS 1.4 – 12 µm 4 cm⁻¹ resolution at 7 µm
- All optics at < 130 K for background noise reduction (passive cooling)
Acknowledgements

R.W. Carlson
NASA PIDD
Jet Propulsion Laboratory,
California Institute of Technology
The noise equivalent radiance for CIRIS at 7 um, assuming a 7.8 um cut off wavelength and 130K background limited sensitivity, and assuming an effective 1-mm square detector accepting radiation in 0.5 sterad, is $3.45 \times 10^7$ photons/s/cm$^2$/sterad/cm$^{-1}$. This is for a 3-sec observation time and 4 cm$^{-1}$ resolution.

Yielding $\lambda I_\lambda \sim 14,000$ nW/m$^2$/st

Much too high...need LHe cooled detectors, front-end electronics, and optics....
CIRIS Performance

What's available?
Europa’s radiance at 7 µm and 67.5 degrees incidence angle is $1.3 \times 10^9$ photons s$^{-1}$ cm$^{-2}$ st$^{-1}$ (cm$^{-1}$)$^{-1}$.

How do we get these photons?
Using: 1) a 200 x 200 µm 7.5-µm cutoff detector with $R/A = 10^4$ Ω-cm$^2$ (junction area $A = 250 \times 250$ µm) and 90% quantum efficiency (AR coated)
  2) a hyperhemispherical immersion lens, collecting 0.5 sterad with detector optical size = 1.17 mm
      and net transmission = 0.75
  3) Beam splitter = 0.5 x 0.9 (half goes back to source, 90% reflectivity + transmission)
  4) Modulation efficiency = 0.5 (per D&P)
  5) FTS mirrors = (0.98)$^7 = 0.87$ (net $T = 0.15$, rule of thumb = 0.1)
  6) 100-MΩ feedback and balancing gate resistor (JFET pair)
  7) 4-cm$^{-1}$ resolution
  8) 130 K optics temperature

Get:  Signal = 47 x 10$^6$ electrons
       Noise = 0.57 x 10$^6$ electrons (detector + amplifier = 0.36 x 10$^6$, background = 0.45 x 10$^6$)
       (background noise ~ detector Johnson noise > amplifier noise)

SNR = 80. Too low!
(a) Background-limited SNR at 7 μm (reflected sunlight) and 8 and 10 μm (thermal emission) for CIRIS with 4 cm⁻¹ resolution and 1-sec integration time. The SNR was derived for 100-m resolution on Europa’s surface from 100-km altitude using a 20-cm diameter telescope. Detectors are 0.1-mm photoconductive HgCdZnTe and HgCdTe illuminated at f/1. The vertical bars show NIMS’ optics temperature range achieved at Jupiter by passive cooling. (b) The noise-equivalent ΔT is the equivalent temperature error due to instrument noise (in this case, 130 K background photon noise, using a 16 μm cut-off detector.) For observations of Europa in the MIR region from 100 km orbit, temperature maps with a resolution of a few tenths, to a few Kelvin are achievable.
Our instrument is a Fourier Transform Spectrometer (FTS) that conducts reflectance spectroscopy in the 1.4-7.5 μm region and thermal emission spectroscopy in the 7.5-12 μm region. Fourier transform spectrometers operate by simultaneously measuring the entire IR flux, modulated by the interference of two split and recombined optical beams with a time-variable optical path difference. By collecting interferograms, radiation noise can be greatly mitigated by removal of noise spikes prior to conducting the transform. In addition to radiation immunity, our FTS has several other advantages for planetary spectroscopy:

1. Multiplexing (Felget) advantage, in which light at all wavelengths is collected simultaneously, greatly enhancing the speed with which a spectrum can be collected. Dispersive spectrometers with array detectors have similar multiplex advantage but integrating arrays preclude radiation noise immunization.

2. Higher light-gathering power than dispersive spectrometers (the Jacquinot advantage). As an example, NIMS’s étendue was $A\Omega = 1.1\times10^{-4}$ cm$^2$-sterad whereas our TurboFTS has a value of $5.2\times10^{-3}$ cm$^2$-sterad, some 50 $\times$ faster.

3. The longer-wavelength sensitivity is much greater for FTs than for grating spectrometers. FTs produce constant wavenumber resolution while the gratings give constant wavelength resolution, so the flux ratio $F_\nu/F_\lambda \propto \lambda^2$. Compared to resolution at 1 μm, there is 25 $\times$ greater flux per resolution element at 5 μm for an FTS than for a dispersive spectrometer. Constant wavenumber (frequency or energy) resolution is appropriate for molecular spectra since energy widths are generally similar throughout the spectrum.
CIRIS Spectral Resolution

For the conceptual FPA with a ZnSe hyperhemispherical immersion lens and 1.5" optics TurboFTS

Get \( \frac{1}{2} \theta^2 = \frac{\Delta \lambda}{\lambda} = \frac{\Delta \nu}{\nu} = 2 \times 10^{-3} \).

A resolution of 4 cm\(^{-1}\) is found for \( \lambda > 5 \) \( \mu m \) providing that the maximum OPD is set for 4 cm\(^{-1}\).

At shorter and longer wavelengths the resolution and resolving powers are:

<table>
<thead>
<tr>
<th>Wavelength ( \lambda )</th>
<th>Wavenumber ( \nu )</th>
<th>( \Delta \lambda )</th>
<th>( \Delta \nu )</th>
<th>( R = \nu / \Delta \nu = \lambda / \Delta \lambda )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 ( \mu m )</td>
<td>6666 cm(^{-1})</td>
<td>3.2 nm</td>
<td>14 cm(^{-1})</td>
<td>472</td>
</tr>
<tr>
<td>2.0</td>
<td>5000</td>
<td>4.2</td>
<td>11</td>
<td>*</td>
</tr>
<tr>
<td>3.0</td>
<td>3333</td>
<td>6.4</td>
<td>7</td>
<td>*</td>
</tr>
<tr>
<td>4.0</td>
<td>2500</td>
<td>8.5</td>
<td>5</td>
<td>*</td>
</tr>
<tr>
<td>5.0</td>
<td>2000</td>
<td>10.6</td>
<td>4</td>
<td>*</td>
</tr>
<tr>
<td>8.0</td>
<td>1250</td>
<td>25.6</td>
<td>4</td>
<td>312</td>
</tr>
<tr>
<td>10.0</td>
<td>1000</td>
<td>40.0</td>
<td>4</td>
<td>250</td>
</tr>
<tr>
<td>12.0</td>
<td>833</td>
<td>57.6</td>
<td>4</td>
<td>208</td>
</tr>
</tbody>
</table>

Hand & Carlson; Not for Distribution
Characterization of the chemical composition of the Europan surface is a critical component of the Europa-Jupiter System Mission (EJSM). Most IR spectrometers sense only to about 5 μm, and radiation noise restricts this range even more. The 5 μm limitation is unfortunate since the strongest and most diagnostic vibration bands of many molecules are found at longer MIR wavelengths, in the spectroscopic “fingerprint region”. Icy worlds of the outer solar system are rich with carbon, nitrogen, and sulfur, yet we currently lack the capability for detailed characterization of these species. We are constructing a Combined near/mid-IR Fourier-Transform Spectrometer (CIRIS) for use at Europa and other icy worlds. CIRIS has the following crucial capabilities: (1) immunity from radiation-induced noise, (2) sensitivity over diagnostic NIR and MIR regions with 4 cm⁻¹ resolution, and (3) low-background detector noise achieved by cooling the optics and housing.
Remote sensing (CIRIS)
Europa perfect for
Requirements
The Painted Bunting, *Passerina ciris*, after Ciris, the mythical bird into which Scylla, daughter of Nisus, King of Madera, was transformed.

Remote sensing application – Europa
CIRIS
Compositional Infrared Interferometric Spectrometer
requirements
CIRIS is ideal for Europa Astrobiological measurements of Europa’s surface composition
Allows full coverage of the near- and mid-infrared (1.4 – 14 μm) using both reflected sunlight (1.4 to ~ 7.5 μm) and thermal emission (~ 7.5 to 14 μm)
The Instrument: A compact refractive scanning FTS
NIMS spectra revealed hydrated sulfate on Europa, but the nature of the cation is still debated; candidates include Mg, Na, and H. NIMS suffered from severe radiation noise issues beyond 2.5 μm.
The Engineering Problem:

The availability of the desired reflected photons, and the intense radiation environment, make spectroscopy in orbit around Europa very difficult. Nevertheless, as shown in the radiance plot at right, the cold surface temperature of Europa (80-130K) means that reflected solar photons dominate over thermal emission photons out to, and a bit beyond, 8 µm. Unfortunately, as shown in the spectra of Fig. (a), noise spikes due to radiation cloud the spectra beyond ~2.5 µm because the radiance is so low. Thus, while the desired photons exist, the radiation noise environment makes it very difficult to achieve reasonable signal-to-noise at longer wavelengths.
The Science:
“Explore Europa To Investigate Its Habitability”

The Jupiter Europa Orbiter has as its primary goal to “explore Europa to investigate its habitability”. Within this broad goal is the objective to “determine global surface compositions and chemistry, especially as related to habitability”. An infrared spectrometer is part of the strawman payload and will be one of the few payload instruments capable of addressing the above objective. As shown in the spectra and table below, the near-infrared (NIR) region contains useful overtone bands that may help identify some surface compounds, but stronger, fundamental vibrations at longer wavelengths provide a wealth of information about organic chemistry and compositional information related to habitability. Given the overarching goal of the mission, the greatest science return will be achieved with a spectrometer that can make reflectance measurements out to ~7µm.
Work currently being done in our lab in prep for 2011 AO

Laboratory breadboard

Laboratory detector testing

Detector cryocooler testing setup

Testing of one our IR detectors
Additional Slides with details on various aspects of CIRIS
FTS is the right solution for high radiation environments.

Our FTS allows removal of noise spikes in interferogram to mitigate against radiation.

NIMS Data: radiation noise past 2.5 microns
FPA Concept

Need large detector area for signal
Need small detector area to minimize radiation hit rate
Use FPA with immersion lens? (Reduces area by $n^4 \sim 30$)

Hyperhemispherical ZnSe immersion lens
(Acceptance half-angle $\theta = \sin^{-1}(1/n)$, free of spherical aberration, coma, and astigmatism)

Detector layout:

HgCdTe 12 $\mu$m (2)
InSb (10)
HgCdTe 7.5 $\mu$m (2)

FPA Sizes

<table>
<thead>
<tr>
<th>Physical</th>
<th>Optical</th>
<th>Surface Footprint</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 $\mu$m</td>
<td>1.2 mm</td>
<td>600 m</td>
</tr>
<tr>
<td>40 $\mu$m</td>
<td>0.25 mm</td>
<td>120 m</td>
</tr>
</tbody>
</table>

FPA needs on-board input FETs and feedback R (or C)

Same size as NIMS detectors, so the radiation hit rate is predictable

Hand & Carlson; Not for Distribution
Designs & Prototypes Progress
http://www.dpinstruments.com/

1. Adapted TurboFTS for cryogenic operation.
2. Assembled using spare CaF2 refractor, TurboFTS with 1” optics.
3. Conductively and vapor cooled (LN2) <140 K operation (but encoder read out fails at 140 K)
4. No laser stabilization required
5. Robust interferogram synchronization
6. Timing, servo signal, or interferogram itself
7. Using InAs and InSb detectors, signal from <1-5.6 μm (InSb limit).
8. Optical alignment at temperature demonstrated (manual, electronic in future)
Future Activities (D&P )

DP procuring vacuum test hardware
Joint meeting at JPL in mid January?
JPL contract with D&P to be modified
Spring 2010: D&P delivers (loans) breadboard #1 (BB-1) ~ May 30, 2010
   ZnSe refractor and existing optics, 1” optics, manual alignment, no special
   coatings, 1.4 – 12 microns. For demonstration and evaluation in CIRIS thermal
   vacuum chamber.
Participate with JPL in conceptual designs
Design and implement electronic alignment methods
Design AR coatings
Procure 1.5” coated optics
Develop electronics and software for various interferogram synchronization methods
Radiation noise rejection software
December 2010: D&P delivers (loans) breadboard #2 (BB-2) ~ Dec 30, 2010
   ZnSe refractor and coated 1.5” optics, electronic alignment, 1.4 – 12 microns.
   For quantitative SNR evaluation in CIRIS thermal vacuum chamber.

Hand & Carlson; Not for Distribution
Near Term JPL Activities

1) Find vendor for 7.5 micron cutoff PV detector with high $R_0A$. Need a working, low noise detector by Fall, 2010.

2) Evaluate FPA concept.

3) Develop preamp – is resistive feedback OK or is a capacitive integration/differentiation amplifier necessary? (Need response to ~ 40 kHz, low Johnson noise current)

4) Design, procure, and construct thermal vacuum system (some parts already in hand). Need by May 2010
## Opportunity

Fly a low-mass, FTS capable of improving radiation noise immunity and wavelength range for compositional investigation of Europa’s surface.

## Objectives

### 1. Science Objectives
- Develop a spectrometer capable of “mapping organic and inorganic surface composition” of icy worlds and planetary bodies.
- Develop a spectrometer capable of mapping active regions and hot-spots, thereby providing a means for “relating compositions to geological processes.”

### 2. Technical Objectives
- Develop noise-pulse rejection software and demonstrate radiation noise immunity for the spectra.
- Combine NIR and MIR regions in one instrument, covering 1.4-15 µm.
- Reduce thermal background noise effects.

## Team Members

**PI:** K.P. Hand, JPL  
**Co-PIs:**  
Robert W. Carlson, JPL  
Roger Clark, USGS  
Wendy Calvin, UNR  
Mike Brown, Caltech  
Ralph Milliken, JPL  
Rachel Mastrapa, NASA Ames  
Tom Painter, Univ of Utah  
Will Grundy, Lowell Observatory  
Ralph Lorenz, APL  
Christophe Sotin, JPL  
Christopher Chyba, Princeton
For any given instrument there is both engineering risk and science risk. Though other spectrometers may have lower engineering risk, I argue that they harbor unacceptable science risk - they will not be able to do science worthy of a $3.1+ billion dollar mission.

CIRIS has its challenges, but these are engineering risks that can be greatly mitigated by immediate support from JPL.

NASA Headquarters believes in this technology and has invested by awarding us a ROSES PIDDP (Spring 2009)
## Planetary spectrometers

<table>
<thead>
<tr>
<th>INSTRUMENT</th>
<th>RANGE $\mu$m</th>
<th>RES’N $\Delta v$ cm$^{-1}$ (Nyquist)</th>
<th>MASS kg</th>
<th>OPTICS TEMP, K (c)</th>
<th>DET’R TEMP, K (c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galileo NIMS (a)</td>
<td>0.7-5.2</td>
<td>25 (b)</td>
<td>18</td>
<td>128 P</td>
<td>65 P</td>
</tr>
<tr>
<td>Cassini VIMS (d)</td>
<td>0.85-5.1</td>
<td>33 (b)</td>
<td>18</td>
<td>130 P</td>
<td>60 P</td>
</tr>
<tr>
<td>Mars Express OMEGA (e)</td>
<td>0.93-5.1</td>
<td>40 (b)</td>
<td>23.5</td>
<td>190 P</td>
<td>&lt;70 A</td>
</tr>
<tr>
<td>Venus Express VIRTIS-M (f)</td>
<td>1-5.1</td>
<td>20 (b)</td>
<td>Not Given</td>
<td>Not Given</td>
<td>~70 A</td>
</tr>
<tr>
<td>SPIRIT (Sounding Rocket) (g)</td>
<td>2.5-22</td>
<td>1</td>
<td>3.6 + LHe</td>
<td>10 C</td>
<td>10 C</td>
</tr>
<tr>
<td>Mars Global Surveyor TES (h)</td>
<td>6-50</td>
<td>10</td>
<td>14.4</td>
<td>280 P</td>
<td>280 P</td>
</tr>
<tr>
<td>Mars Exp. Rovers Mini-TES (i)</td>
<td>5-29</td>
<td>20</td>
<td>2.4</td>
<td>280 P</td>
<td>280 P</td>
</tr>
<tr>
<td>Mars Express PFS (j)</td>
<td>1.2-45</td>
<td>1.5</td>
<td>30</td>
<td>290 P</td>
<td>220 A</td>
</tr>
<tr>
<td>Cassini CIRS (k)</td>
<td>7.2-1000</td>
<td>0.5</td>
<td>39</td>
<td>170 P, R</td>
<td>75 P, R</td>
</tr>
<tr>
<td>New Millennium IFTS (l)</td>
<td>4.4-15</td>
<td>0.6</td>
<td>100</td>
<td>140 A</td>
<td>55 A</td>
</tr>
<tr>
<td>CIRIS</td>
<td>1.4-15</td>
<td>4</td>
<td>7-8</td>
<td>130</td>
<td>60-65</td>
</tr>
</tbody>
</table>
Top: Calculated solar reflectance and thermal emission radiances from Europa. Observing morning (blue) and noon (red) locales enhances the spectral range of reflected and thermal signals, respectively. Depending on time and temperature, reflectance spectra can be obtained to 7 μm and thermal emission to 15 μm. Temperatures based on Spencer et al. (1999). A surface of H₂O+H₂SO₄ hydrate was assumed. Bottom: Emissivity features may be used for compositional determinations. Brightness variations in the thermal emission signal, showing an H₂SO₄ peak at 8.4 μm. MgSO₄'s peak is shifted to longer wavelengths.
Follow the water...SECOND ORIGIN

Europa as a Case Study