Science and Resource Drivers on Infrared Instruments for Outer Planets Missions

5x5 (Beyond 5 AU and beyond 5 microns)

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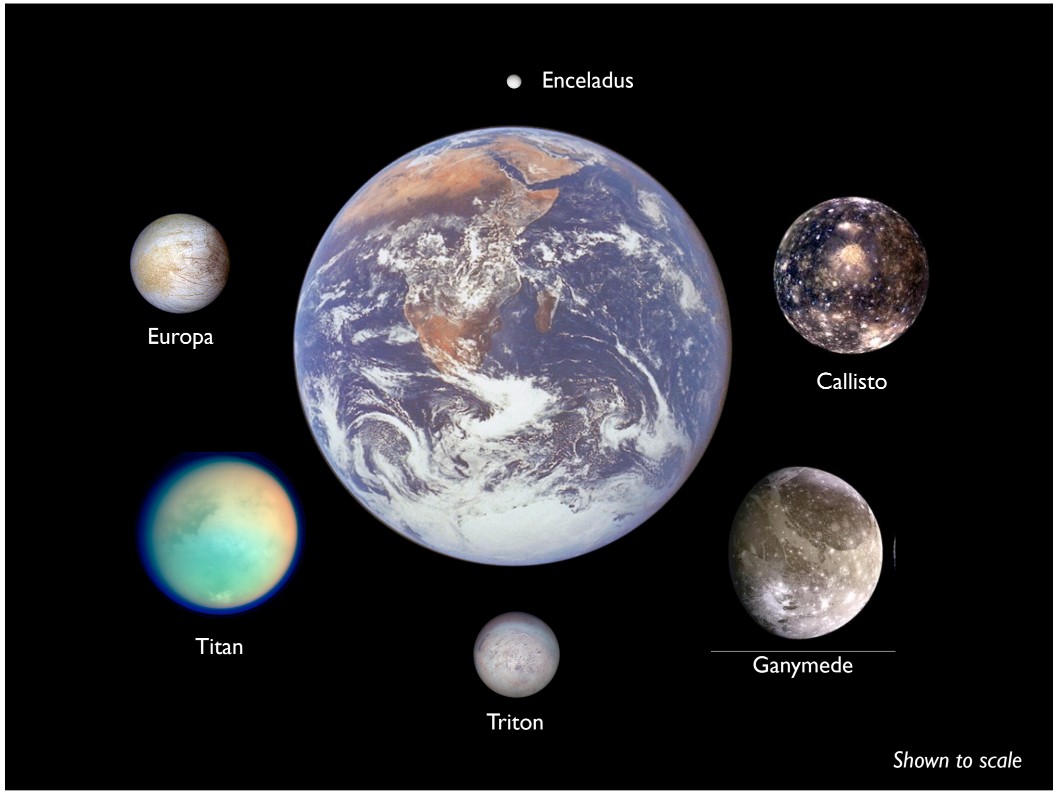
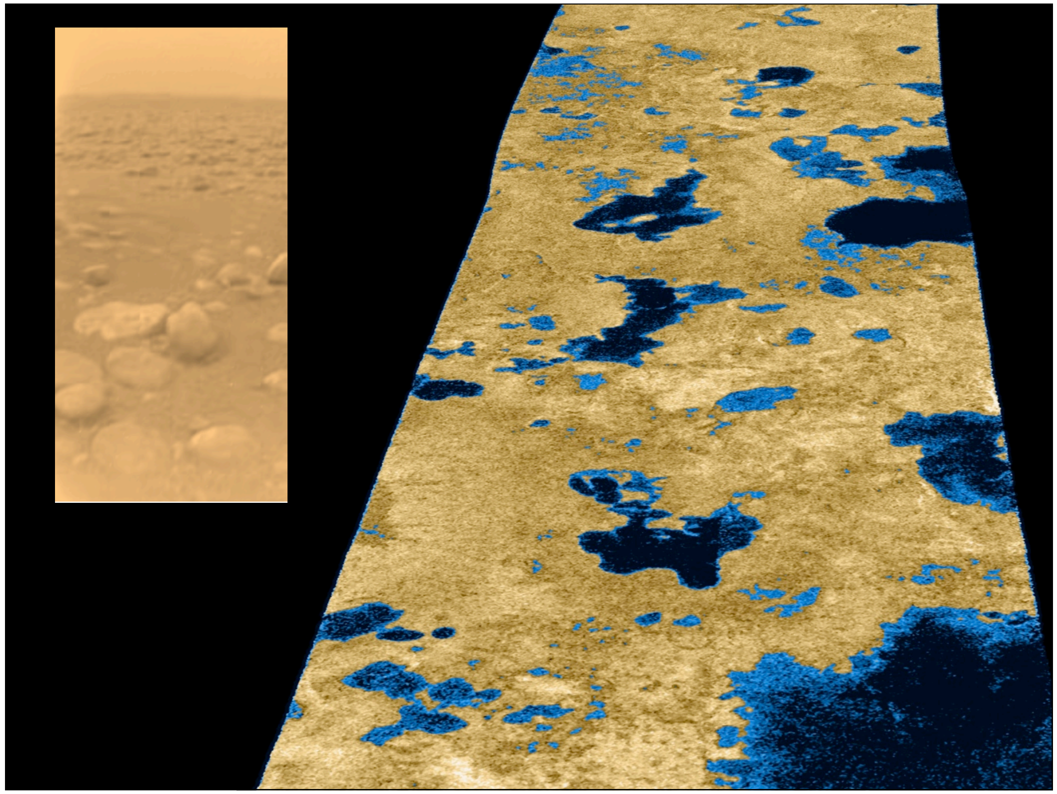
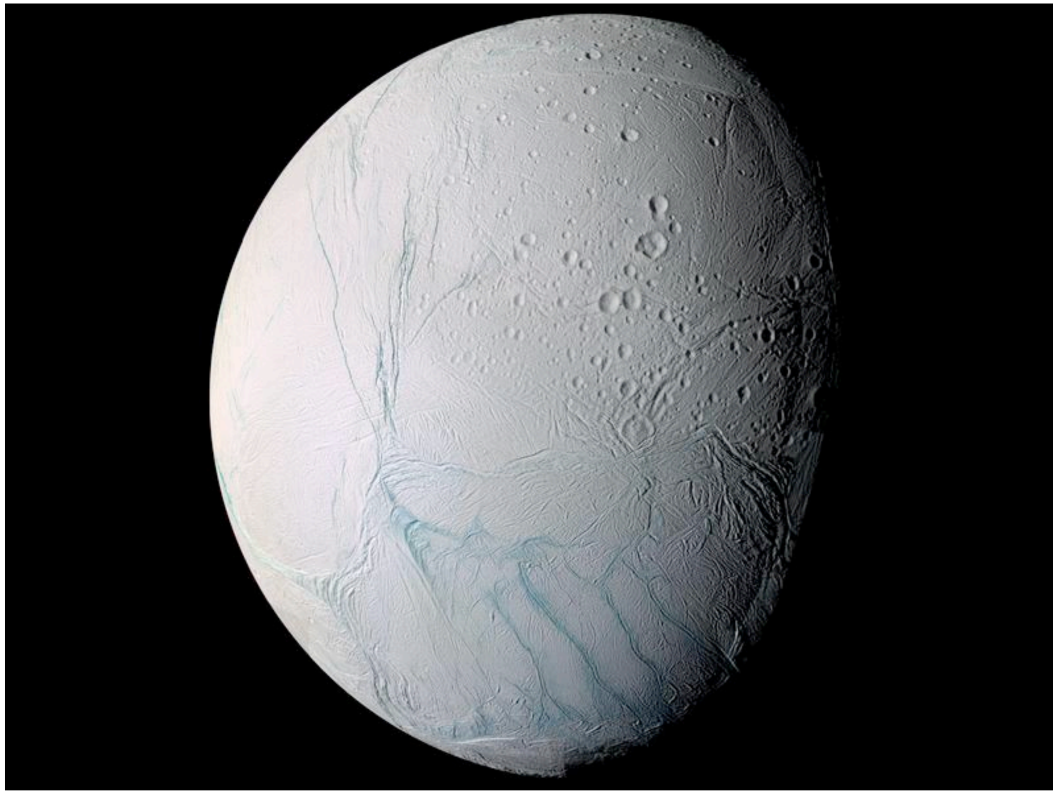


Brief outline



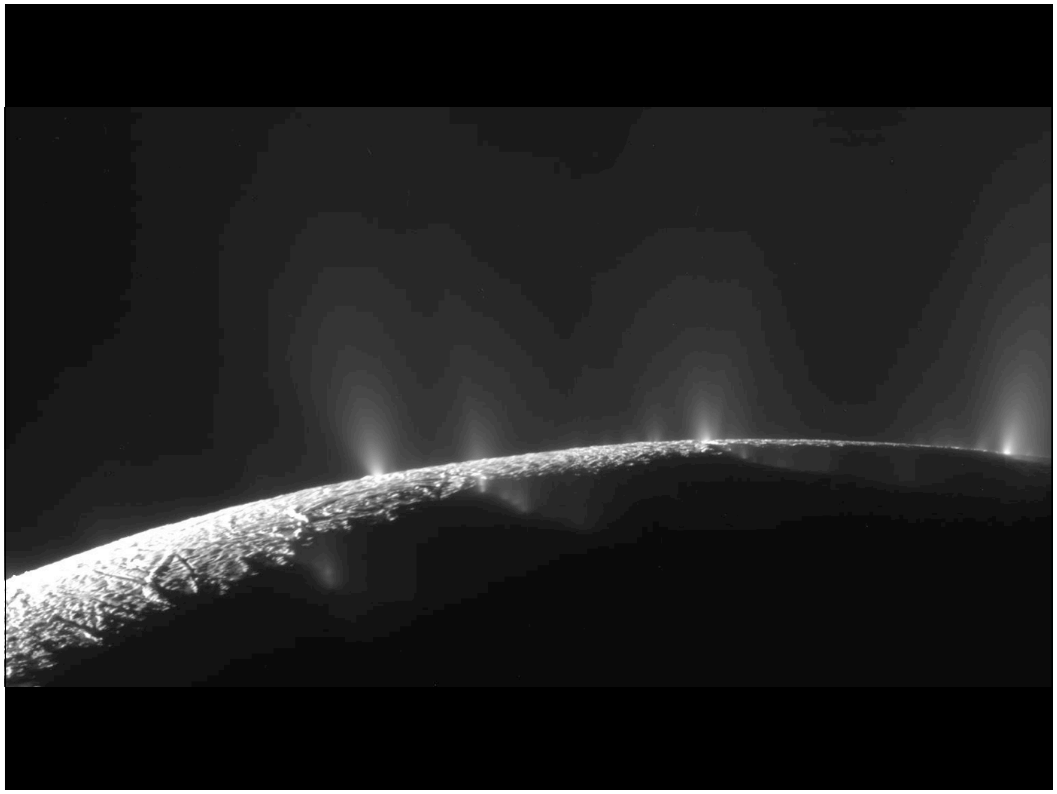


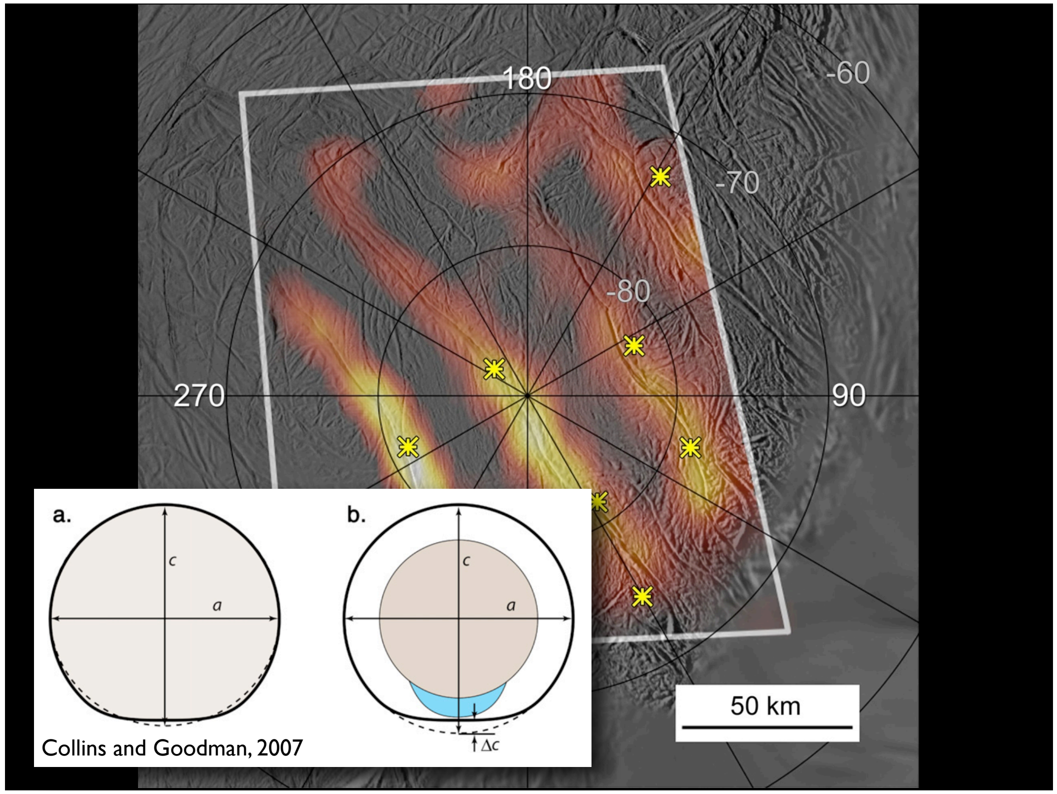
Case in point, Enceladus

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.

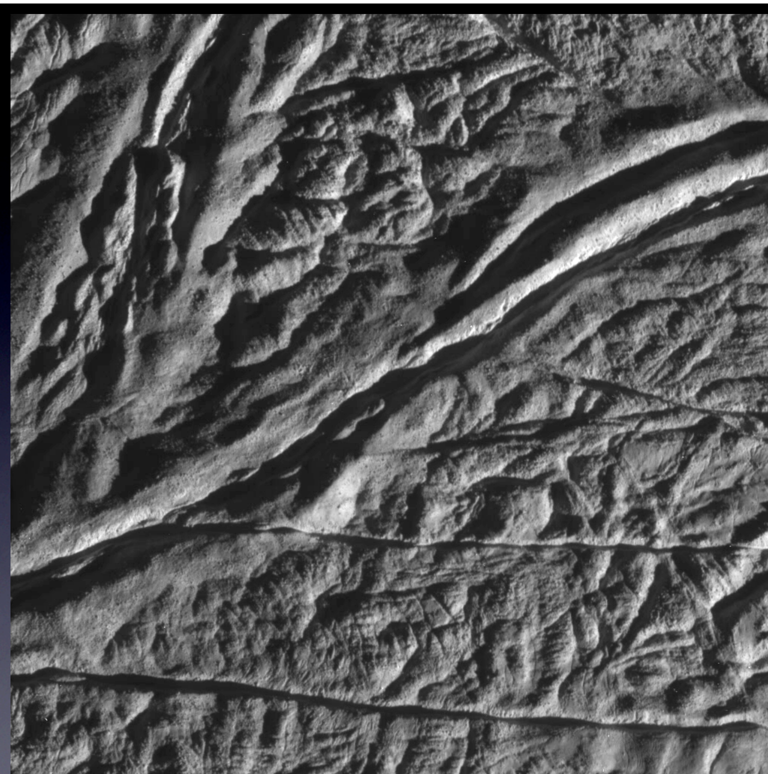
e = 0.0047
a =237,948 km
T = 1.37 d
R = 250km
rho = 1.6 g cm3



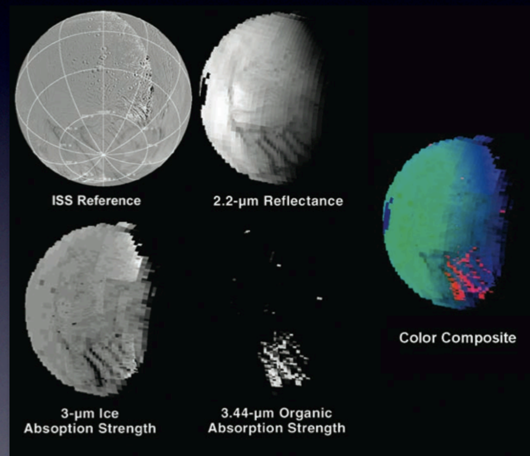


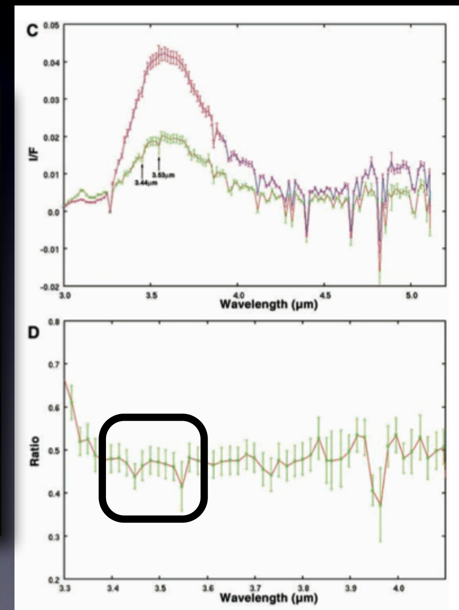
Thermal imaging revealing a heat anomoly...

Los Angeles - 7.2 GW



VIMS: C-H along Tiger Stripes





Brown et al., 2006

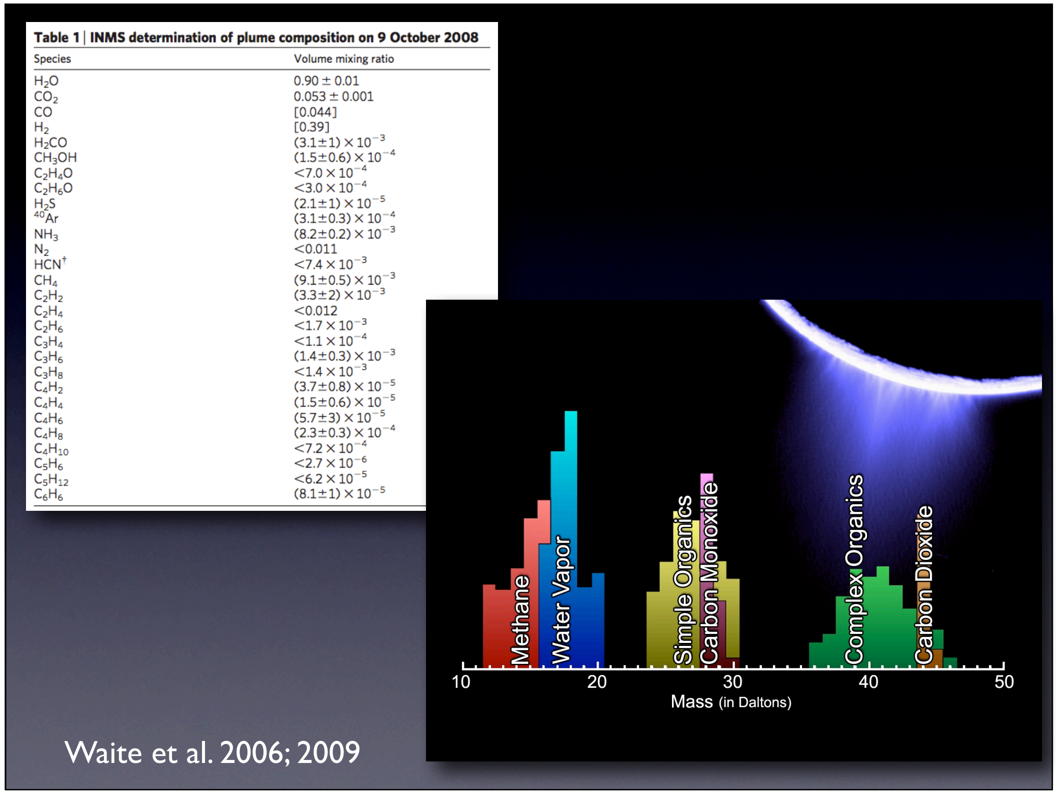
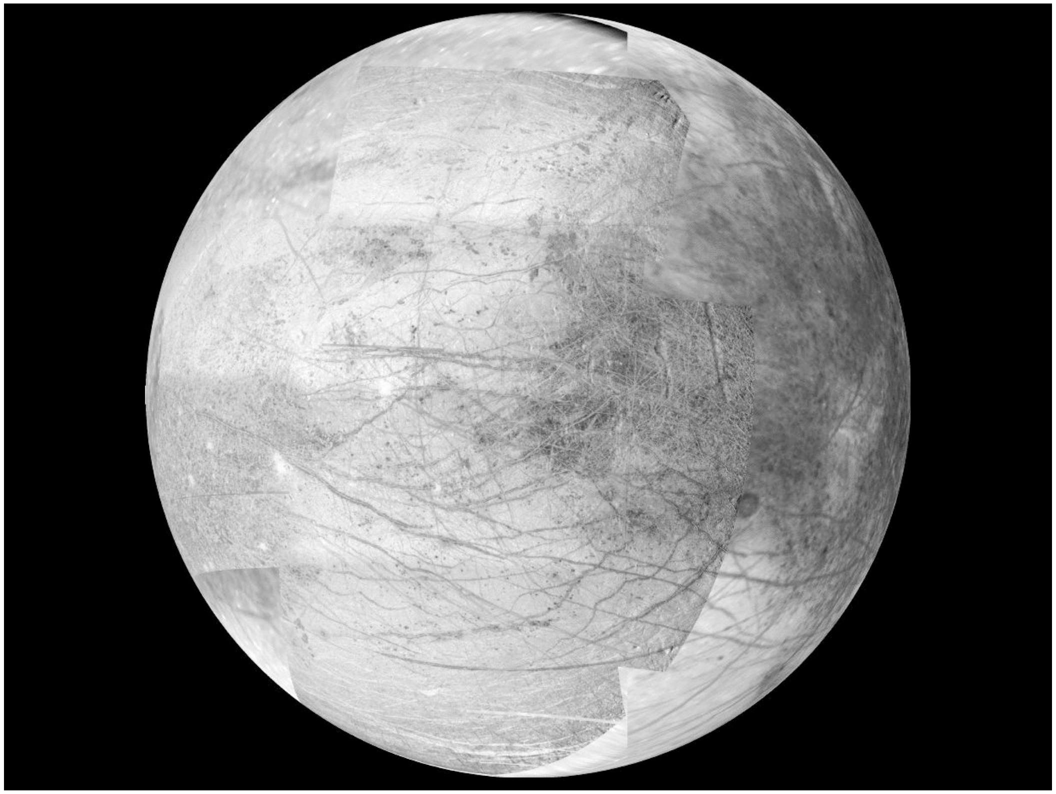


Table 1 | INMS determination of plume composition on 9 October 2008

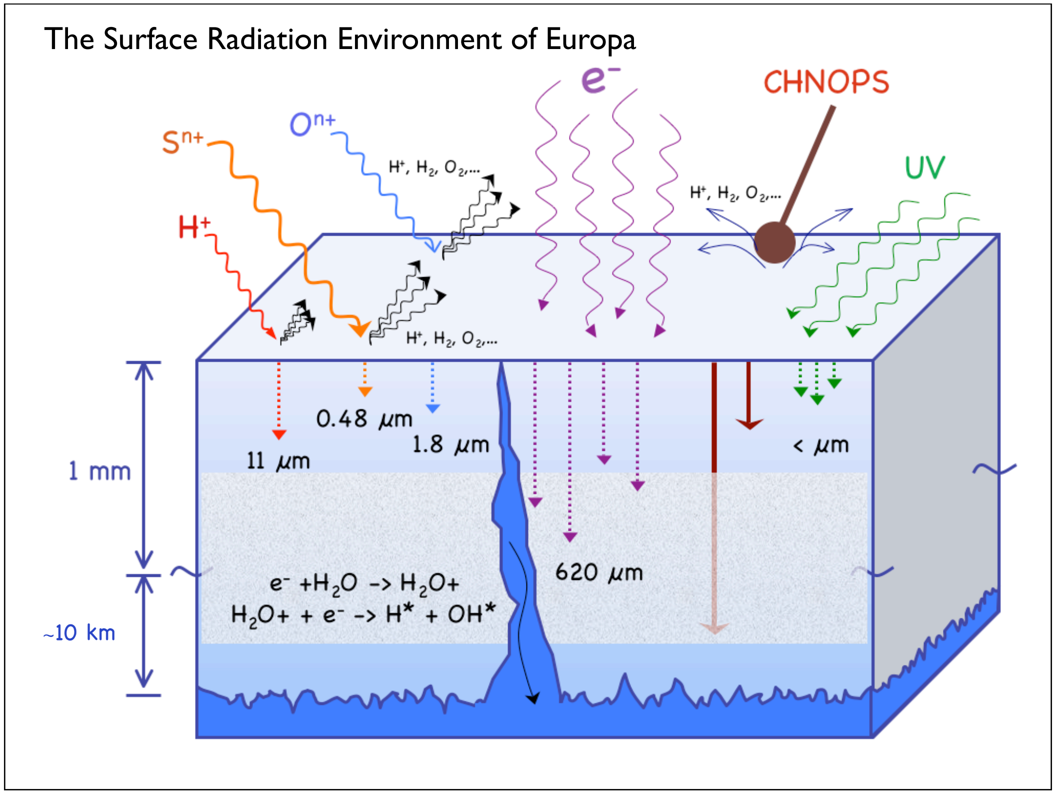
Species	Volume mixing ratio
H_2O	0.90 ± 0.01
CO_2	0.053 ± 0.001
CO	[0.044]
H_2	[0.39]
H_2CO	$(3.1 \pm 1) \times 10^{-3}$
CH_3OH	$(1.5 \pm 0.6) \times 10^{-4}$
C_2H_4O	$<7.0 \times 10^{-4}$
C_2H_6O	$<3.0 \times 10^{-4}$
H_2S	$(2.1 \pm 1) \times 10^{-5}$
^{40}Ar	$(3.1 \pm 0.3) \times 10^{-4}$
NH_3	$(8.2 \pm 0.2) \times 10^{-3}$
N_2	<0.011
HCN†	$<7.4 \times 10^{-3}$
CH_4	$(9.1 \pm 0.5) \times 10^{-3}$
C_2H_2	$(3.3 \pm 2) \times 10^{-3}$
C_2H_4	<0.012
C_2H_6	$<1.7 \times 10^{-3}$
C_3H_4	$<1.1 \times 10^{-4}$
C_3H_6	$(1.4 \pm 0.3) \times 10^{-3}$
C_3H_8	$<1.4 \times 10^{-3}$
C_4H_2	$(3.7 \pm 0.8) \times 10^{-5}$
C_4H_4	$(1.5 \pm 0.6) \times 10^{-5}$
C_4H_6	$(5.7 \pm 3) \times 10^{-5}$
C_4H_8	$(2.3 \pm 0.3) \times 10^{-4}$
C_4H_{10}	$<7.2 \times 10^{-4}$
C_5H_6	$<2.7 \times 10^{-6}$
C_5H_{12}	$<6.2 \times 10^{-5}$
C_6H_6	$(8.1 \pm 1) \times 10^{-5}$

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 3 1024. (36Ar and 38Ar—primordial non-radiogenic argon—
may also be present, but at a combined abundance of ,1025.) This
amount of 40Ar is greater by three orders of magnitude than would be
expected for a chondritic abundance of potassium in Enceladus' rock
fraction19, 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 3 1024 (ref. 16), nearly twice the terrestrial
ocean water value (1.56 3 1024)19, and more than ten times the value
of the D/H ratio in the protosolar nebula (2.1 6 0.4 3 1025)22. The
The mixing ratios shown here for CO and H_2 (values in square brackets) are included in the
mixing ratios for CO_2 and H_2O given in the first two rows. Analysis of the data from all five
encounters shows that the ratios of mass 44 (CO_2) to mass 28 and of mass 18 (H_2O) to mass 2
(H_2) decrease with increasing spacecraft velocity, suggesting that H_2 and CO are produced by
the dissociation of H_2O and CO_2 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 N_2, C_2H_4, or a combination of both, with either HCN or
the ethene dissociation product C_2H_3 contributing to the signal in mass channel 27. The values
given for these species are upper limits based on the two alternative scenarios (N_2 1 HCN
versus C_2H_4). 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.

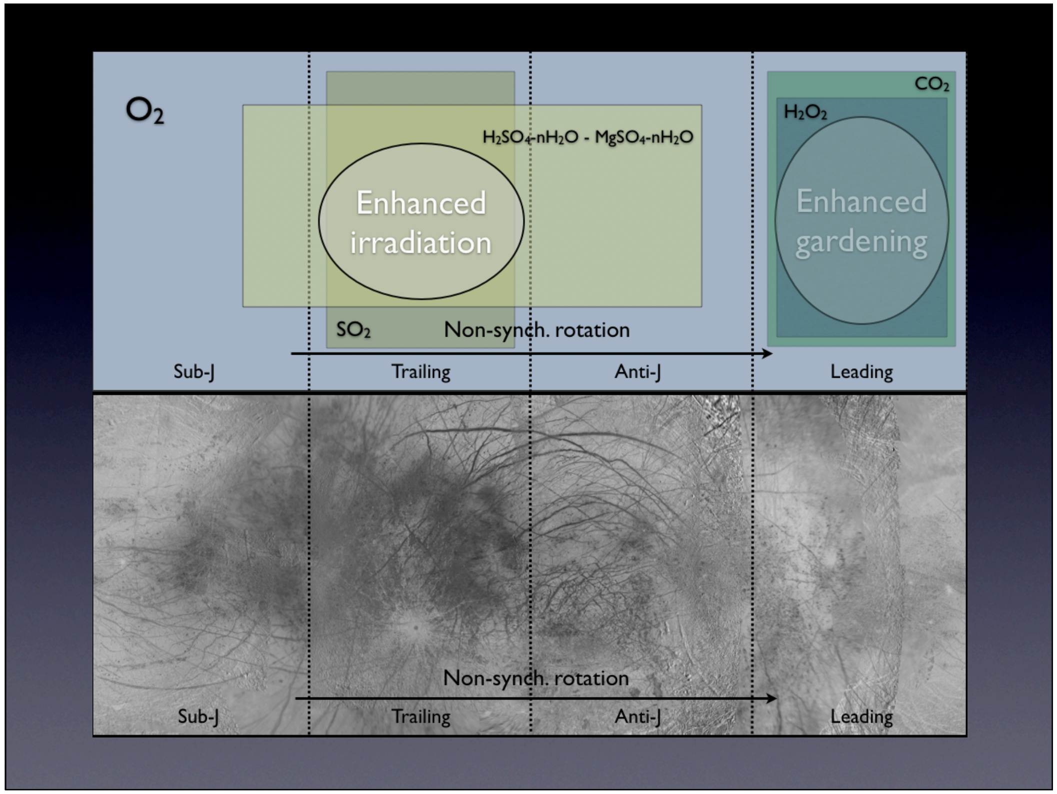


−280 Fahrenheit

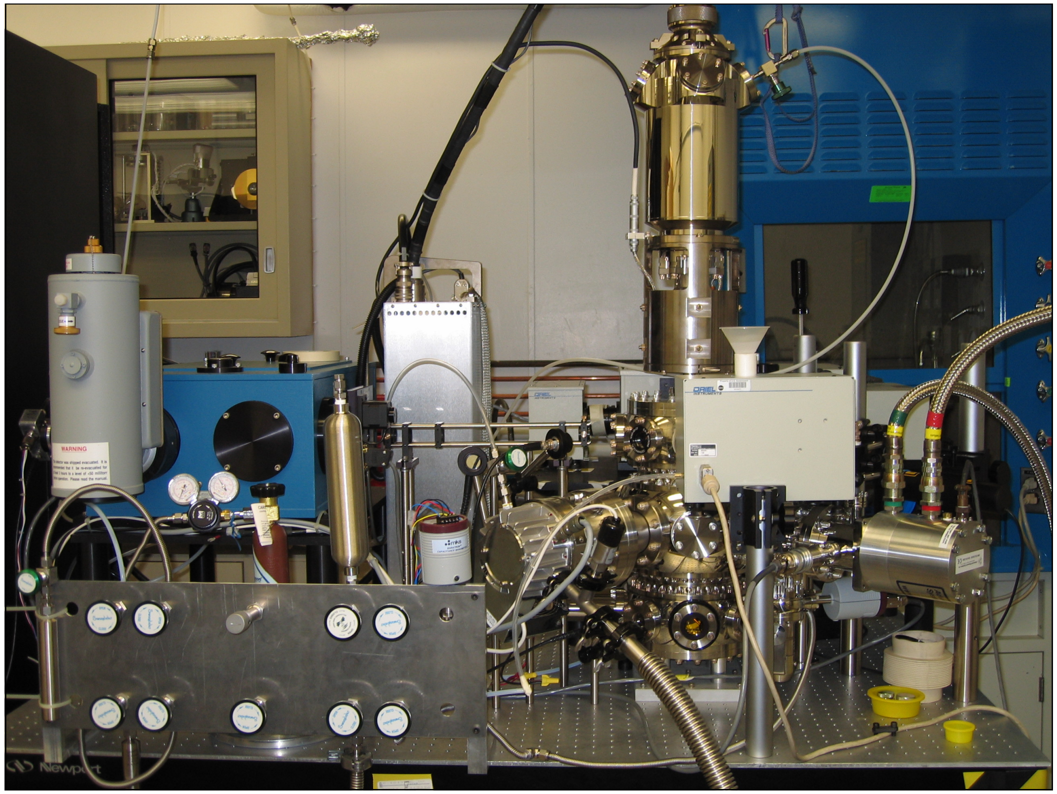
8e10 keV cm_2 s

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_2O.



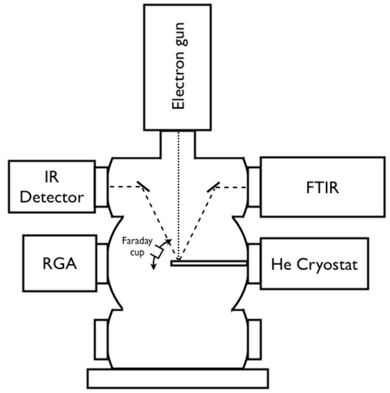
−280 Fahrenheit

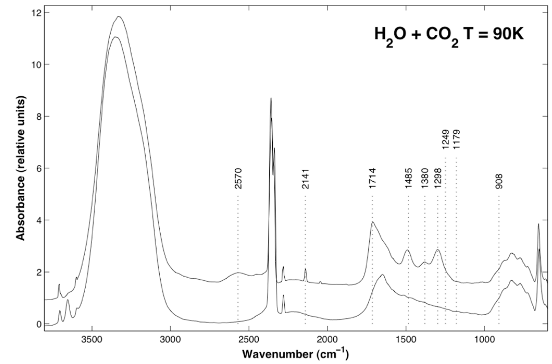


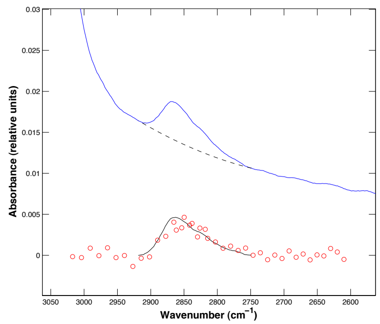
Comparison to Europa

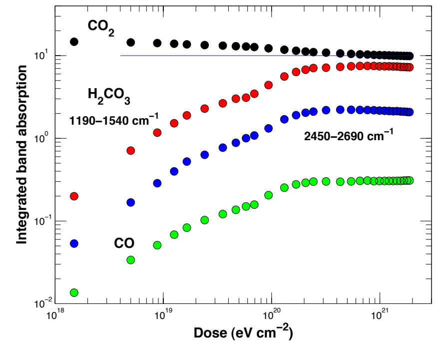
Europa: ~12.5 μW cm^{-2}

Minos chamber (10 keV, 20 nA): ~200 μW cm^{-2}

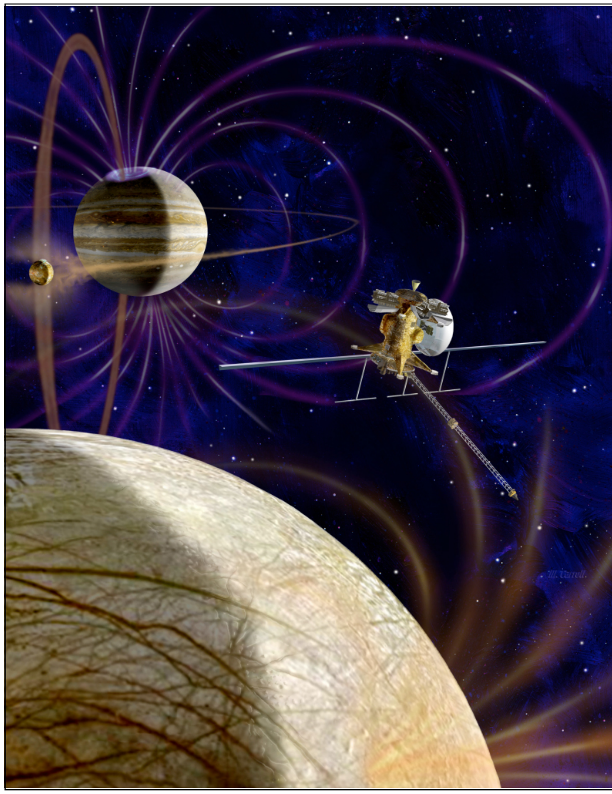








Hand et al., 2007

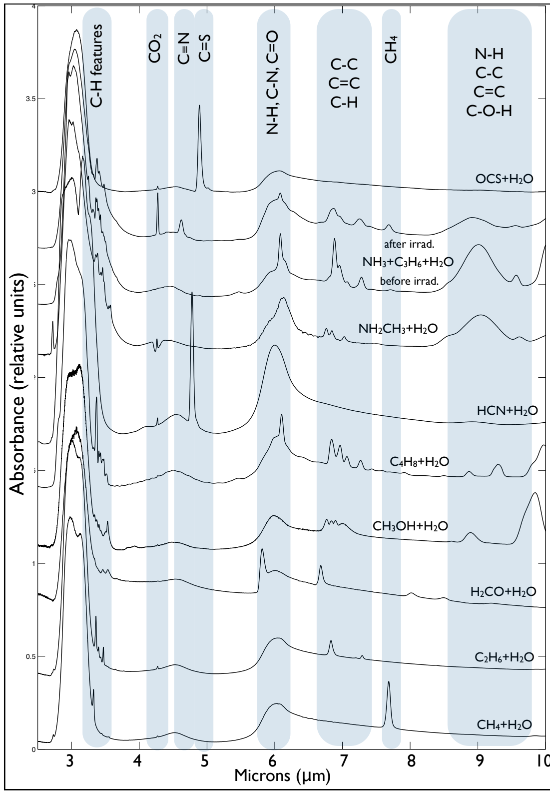


JEO Goal:
"Explore Europa
to Investigate its
Habitability"

Table 1. Properties of some existing flight infrared spectrometers. Blue denotes grating spectrometers, red denotes Michelson FTSs, and green denotes CIRIS.

Instrument	Range (μm)	Res'n Δν cm-1 (Nyquist)	Mass (kg)	Optics T (K)(c)	Det'r T (K)(c)
Galileo NIMS (a)	0.7-5.2	25(b)	18	128 P	65 P
Cassini VIMS (d)	0.85-5.1	33 (b)	18	130 P	60 P
Mars Express OMEGA (e)	0.93-5.1	40 (b)	23.5	190 P	<70 A
Venus Express VIRTIS-M (f)	1-5.1	20 (b)	NA	NA	~70 A
SPIRIT (Sounding Rocket) (g)	2.5-22	1	3.6+LHe	10 C	10 C
Mars Global Surveyor TES (h)	6-50	10	14.4	280 P	280 P
Mars Exp. Rovers Mini-TES (i)	5-29	20	2.4	280 P	280 P
Mars Express PFS (j)	1.2-45	1.5	30	290 P	220 A
Cassini CIRS (k)	7.2-1000	0.5	39	170 P,R	75 P,R
New Millennium IFTS (l)	4.4-15	0.6	100	140 A	55 A
Voyager 1, 2 IRIS (m)	4-55	4.3	NA	200 A	200 A
CIRIS (this proposal)	1.4-15	4	7-8	130	60-65

(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:

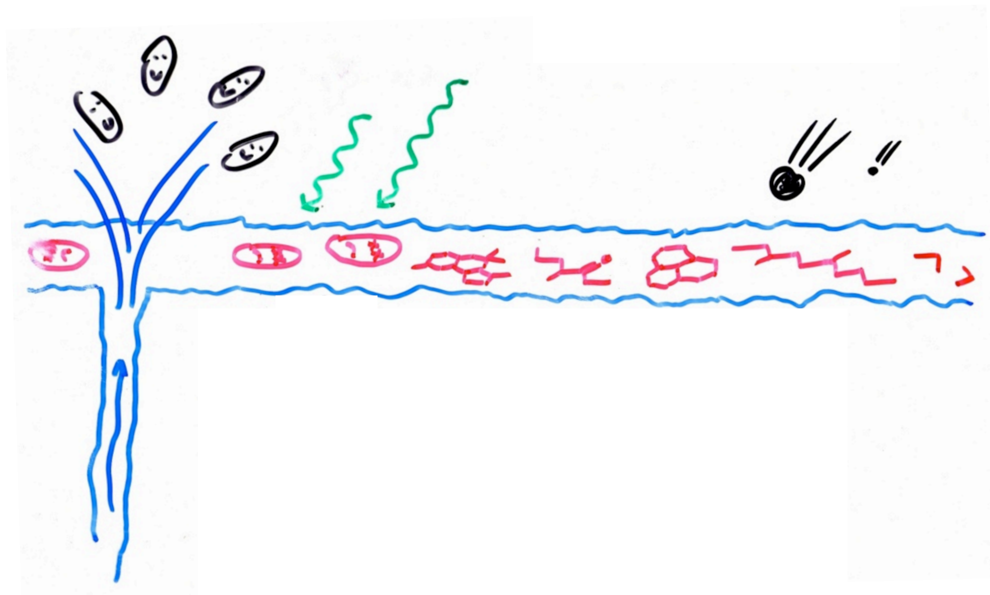
The most useful and interesting features are between 5.75-7.5 microns.

Below 5 microns gets you nothing new and nothing we haven't seen before.

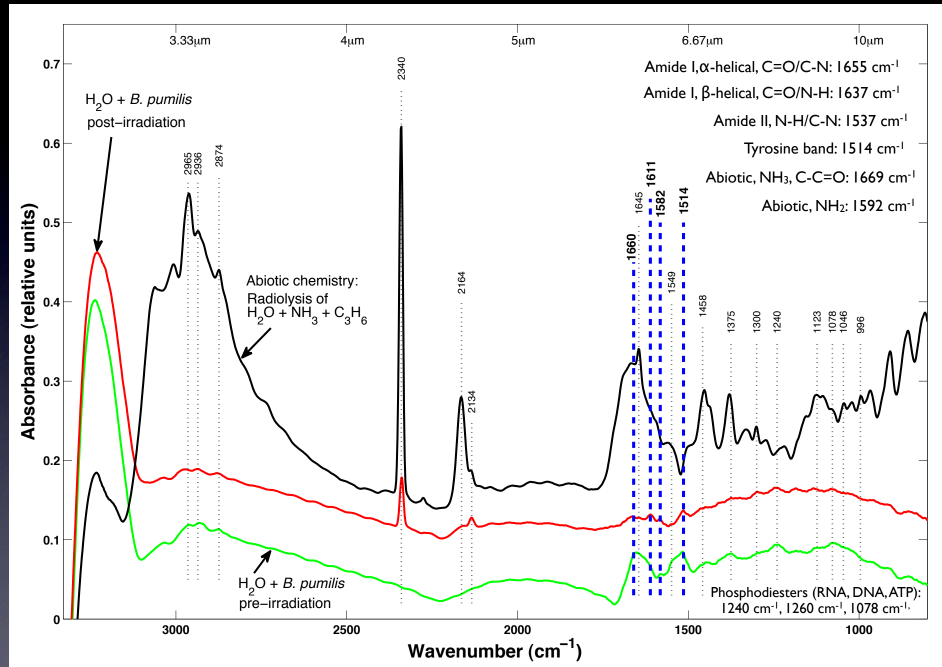
Hand & Carlson; Not for Distribution

Frequency, cm^{-1} (Wavelength, μm)	Functional Groups and Molecular Assignments
25,000 (0.4-0.58)	Carotenoid pigment
16,667 (0.6-0.7)	Chlorophyll-a, -b pigments
10,000 (1.0)	O-H of water of hydration of parent compound ($\bullet H_2O$)
8000 (1.25)	O-H of water of hydration of parent compound ($\bullet H_2O$)
6667 (1.5)	O-H of water of hydration of parent compound ($\bullet H_2O$)
5000 (2.0)	O-H of water of hydration of parent compound ($\bullet H_2O$)
4878 (2.05)	Amide in proteins, N-H vibration with C-N-H bend
4608 (2.17)	Amide in proteins, N-H fundamental with C-N stretch
4348 (2.3)	C-H and methane
~3500 (2.86)	O-H stretch of hydroxyl groups
~3200 (3.1)	N-H stretch (amide A) of proteins
~2955 (3.38)	C-H stretch (a) $–CH_3$ in fatty acids
~2930 (3.4)	C-H stretch (a) $>CH_2$
~2918 (3.43)	C-H stretch (a) of $>CH_2$ in fatty acids
~2898 (3.45)	C-H stretch, CH in methine group
~2870 (3.48)	C-H stretch (s) of $–CH_3$
~2850 (3.51)	C-H stretch (s) of $>CH_2$ in fatty acids
2590-2560 (3.88)	-S-H of thiols
~1740 (5.75)	>C=O stretch of esters
~1715 (5.83)	>C=O stretch of carbonic acid
~1680-1715	>C=O stretch of nucleic acid
~1695 (6.0)	Amide I band components
~1685 (5.93)	Resulting from antiparallel pleated sheets
~1675 (5.97)	Amide I β-turns of proteins
~1655 (6.04)	Amide I of α-helical structures
~1637 (6.11)	Amide I of β-pleated structures
~1550-1520 (6.52)	Amide II
~ 1515 (6.6)	"Tyrosine" specific band
~1468 (6.81)	C–H deformation of $>CH_2$
~1400 (7.14)	C=O stretch (s) of COO^-
~1310–1240 (7.8)	Amide III of proteins
1304 (7.67)	CH_4, methane
~1250–1220 (8.0)	P=O str $>PO_3^-$, phosphodeiesters
1240-1180 (8.26)	O–S=O stretch of sulfites
~1200–900 (8-11)	C-O, C-C, str of carbohydrates
~1200–900 (8-11)	C-O-H, C-O-C def. of carbohydrates
~1100-1000 (9.52)	P-O, PO_4^{-3} stretch
~1090 (9.17)	P=O stretch (s) $>PO_2$
~1085 (9.2)	C–O stretch
~1061 (9.4)	C–N and C–C stretch
1140-1080 (9.0)	S-O- stretch of inorganic sulfates
1070-1030 (9.52)	C–S=O of sulfoxides
~1004 (9.96)	Phenylalanine
~852 (11.7)	Tyrosine
~829 (12)	Tyrosine
~785 (12.7)	Cytosine, uracil (ring stretch)

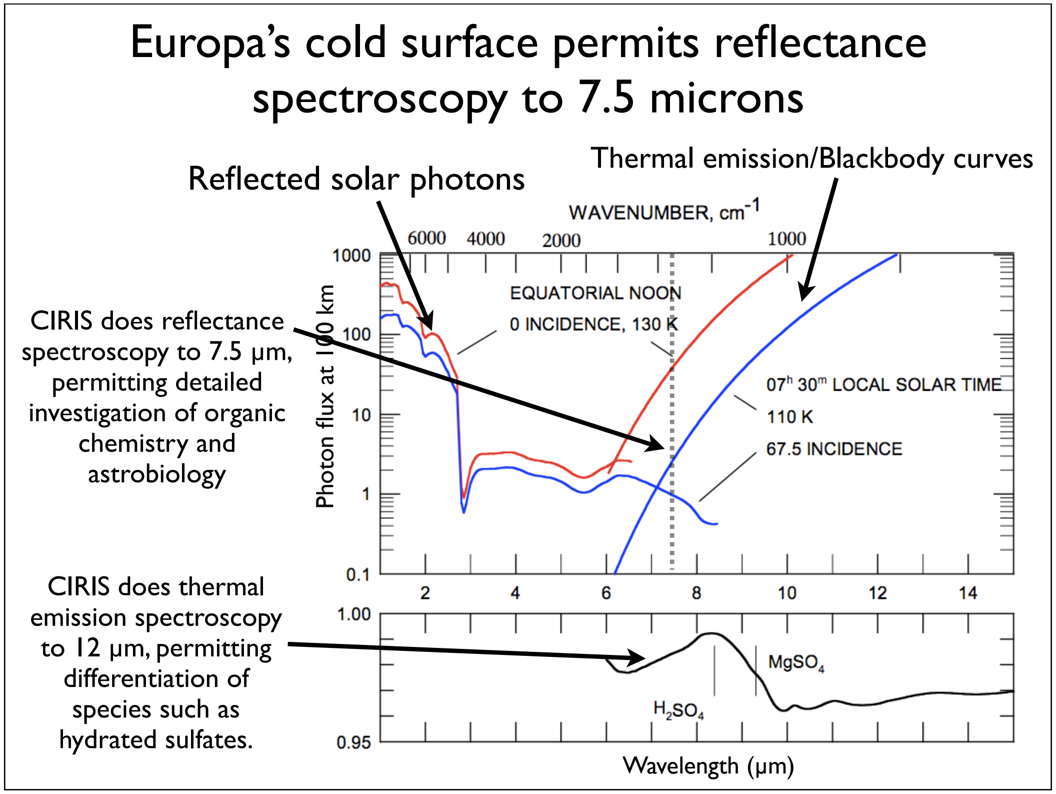
Life Detection on Europa
Biosignatures vs. Abiotic Radiolytic Chemistry



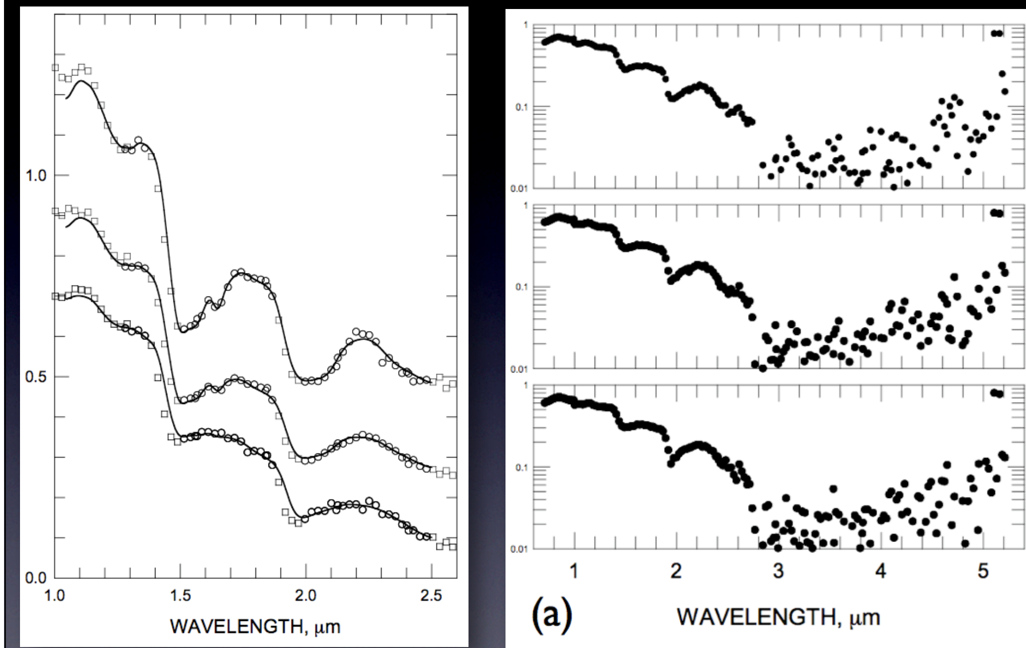
Here's the situation we face...4 types of organic chemistry on the surface,
1) Irrad life forms
2) Irrad endog org material, abiotic
3) Irrad exog org material, abiotic
4) synthesis of org material radiolytically



Absorbance (relative units)
Wavenumber (cm^{-1})
3.33μm
4μm
5μm
6.67μm
10μm
Amide I, α-helical, C=O/C-N: 1655 cm^{-1}
Amide I, β-helical, C=O/N-H: 1637 cm^{-1}
Amide II, N-H/C-N: 1537 cm^{-1}
Tyrosine band: 1514 cm^{-1}
Abiotic, NH_3, C-C=O: 1669 cm^{-1}
Abiotic, NH_2: 1592 cm^{-1}
H_2O + *B. pumilis* post–irradiation
Abiotic chemistry: Radiolysis of $H_2O + NH_3 + C_3H_6$
H_2O + *B. pumilis* pre–irradiation
Phosphodiesters (RNA, DNA, ATP): 1240 cm^{-1}, 1260 cm^{-1}, 1078 cm^{-1}.
2965
2936
2874
2340
2164
2134
1660
1645
1611
1582
1549
1514
1458
1375
1300
1240
1123
1078
1046
996



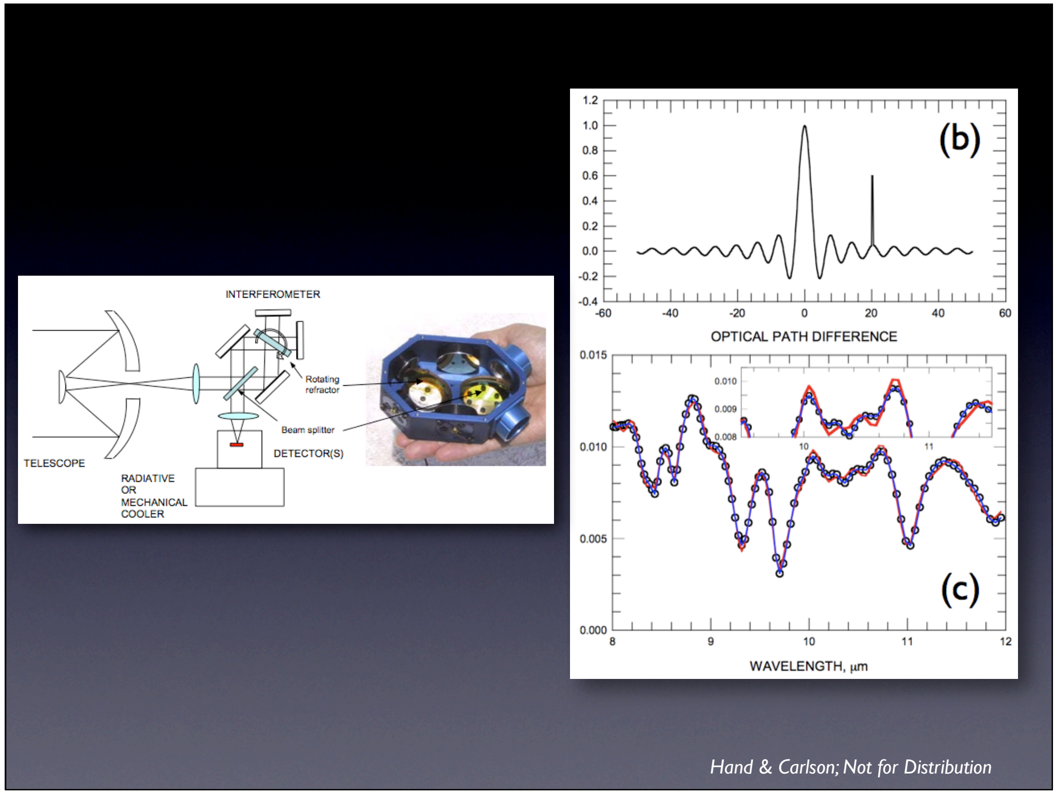
Top: Calculated solar reflectance and thermal emission radiances from Europa. Observing morning (blue) and noon (red) locales enhances the spectral range of reflected and thermal signals, respectively. Depending on time and temperature, reflectance spectra can be obtained to 7 µm and thermal emission to 15 µm. Temperatures based on Spencer et al. (1999). A surface of $H_2O+H_2SO_4$ hydrate was assumed. Bottom: Emissivity features may be used for compositional determinations. Brightness variations in the thermal emission signal, showing an H_2SO_4 peak at 8.4 µm. $MgSO_4$'s peak is shifted to longer wavelengths.



Radiation noise - Galileo NIMS example.

(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× 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.

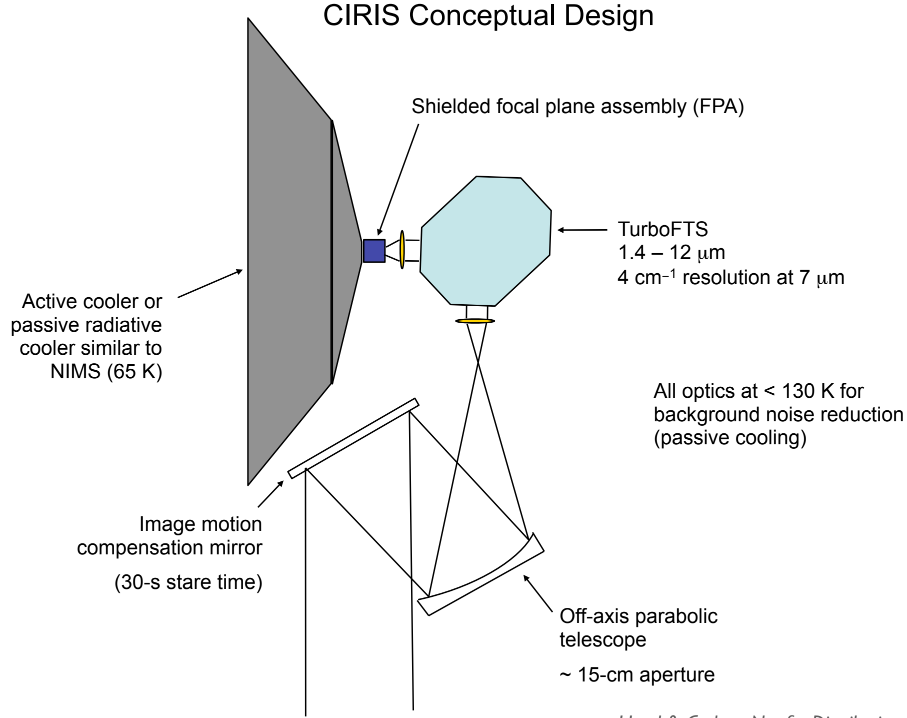


(a) NIMS measurements of Europa's spectral albedo, illustrating radiation-induced noise spikes. Each point represents an 8-msec integration, during which every integration was found to be altered by radiation. Effects were debilitating beyond 2.5 μm, where the albedo was low and the solar photon flux decreases as λ−3 (for constant Δλ 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× 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



Hand & Carlson; Not for Distribution

Acknowledgements

R.W. Carlson
NASA PIDDP
Jet Propulsion Laboratory,
California Institute of Technology

(Very) Rough Calc.

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 x 10^7 photons/s/cm^2/sterad/cm^{-1}. This is for a 3-sec observation time and 4 cm^{-1} resolution.

Yielding λI_λ ~ 14,000 nW/m^2/st

Much too high...need LHe cooled detectors, front-end eletronics, and optics....

CIRIS Performance

What's available?

Europa's radiance at 7 μm and 67.5 degrees incidence angle is 1.3×10^9 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 $R_0A = 10^4$ Ω-cm^2 (junction area A = 250 x 250 μm) and 90% quantum efficiency (AR coated)

2) a hyperhemispherical immersion lens, collecting 0.5 sterad with detector optical size = 1.17mm
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)

5) 10-sec total integration time (30-sec observation, FTS duty cycle = 30%)

6) 100-MΩ feedback and balancing gate resistor (JFET pair)

7) 4-cm^{-1} resolution

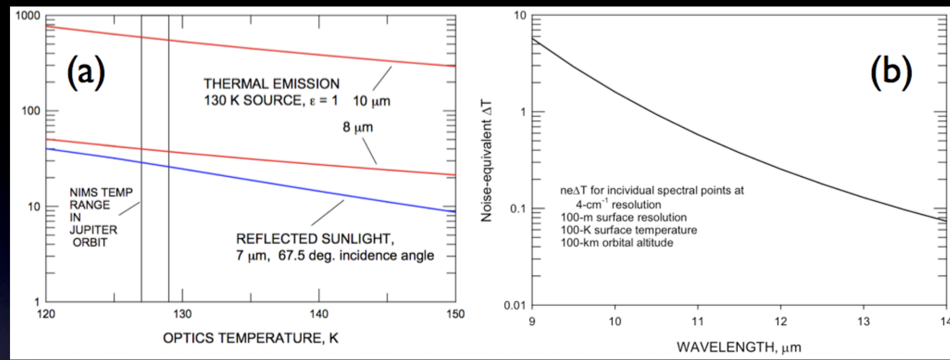
8) 130 K optics temperature

Get: Signal = 47×10^6 electrons

Noise = 0.57×10^6 electrons (detector + amplifier = 0.36×10^6, background = 0.45×10^6)

(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 (Felgett) 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 5.2×10^{-3} cm^2-sterad, some 50 × faster.
3. The longer-wavelength sensitivity is much greater for FTSs than for grating spectrometers. FTSs 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× 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 $\frac{1}{2}\theta^2 = \Delta\lambda/\lambda = \Delta\nu/\nu = 2 \times 10^{-3}$.

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

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

Wavelength λ	Wavenumber ν	Δλ	Δν	$R = \nu/\Delta\nu = \lambda/\Delta\lambda$
1.5 μm	6666 cm^{-1}	3.2 nm	14 cm^{-1}	472
2.0	5000	4.2	11	“
3.0	3333	6.4	7	“
4.0	2500	8.5	5	“
5.0	2000	10.6	4	“
8.0	1250	25.6	4	312
10,0	1000	40.0	4	250
12.0	833	57.6	4	208

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.

The Science: Collecting the Desired Photons

Remote-sensing astrobiology for the Europa Orbiter (JEO)

CIRIS†, Compositional InfraRed Interferometric Spectrometer

A comprehensive compositional investigation requires *full* spectral coverage, from the NIR to the MIR.
(We must do better than Galileo's NIMS, which went to only 5.2 μm.)

The 5- to 8-μm region is especially important for astrobiology, since it allows searches for N-H, N=O, C=O, C-C, C=C, and C-H functional groups..

Shorter and longer wavelengths (1.4 to 2.5 μm and 7 to 12 μm) provide identification of hydrates (salts and acids) and other species.

The wide wavelength coverage of CIRIS's TurboFTS enables reflectance and thermal emission spectroscopy over this full range .

†The Painted Bunting, *Passerina ciris,* after Ciris, the mythical bird into which Scylla, daughter of Nisus, was transformed.

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

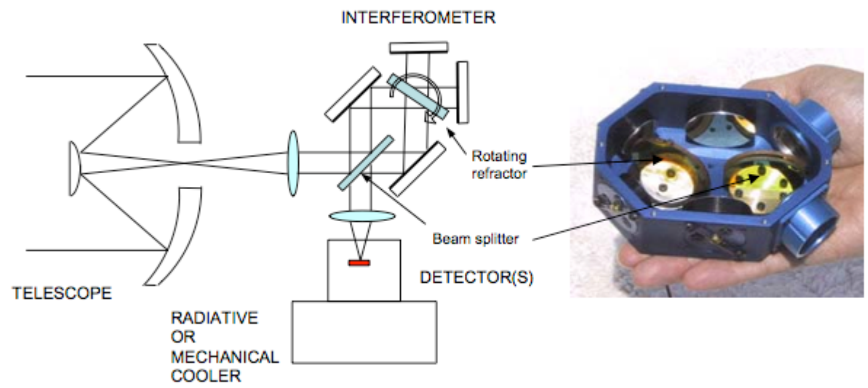
Compositional Infrared Interferometic Spectrometer

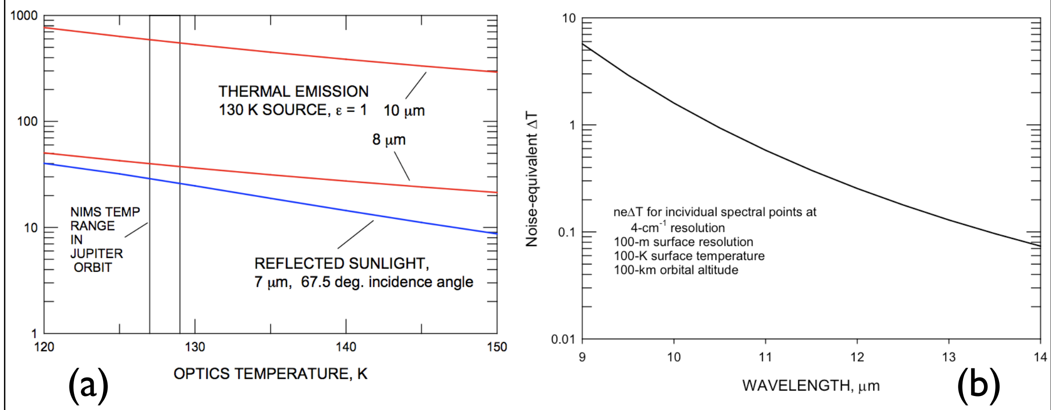
requirements

CIRIS is ideal for Europa Astrobiological measurements of Europa;s syrface composition

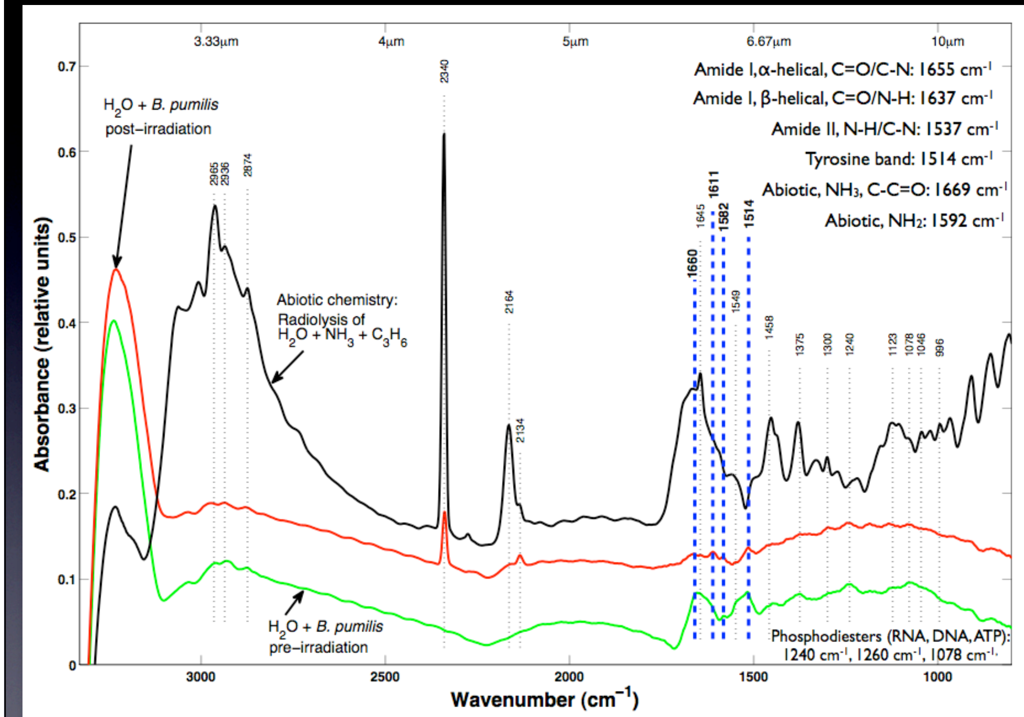
Allows full coverage of the near- and mid-infrared (1.4 – 14 μm) using both reflected sunlight (1.4 to ~ 7.5 μm) and thermal emission (~ 7.5 to 14 μm)

The Instrument: A compact refractive scanning FTS

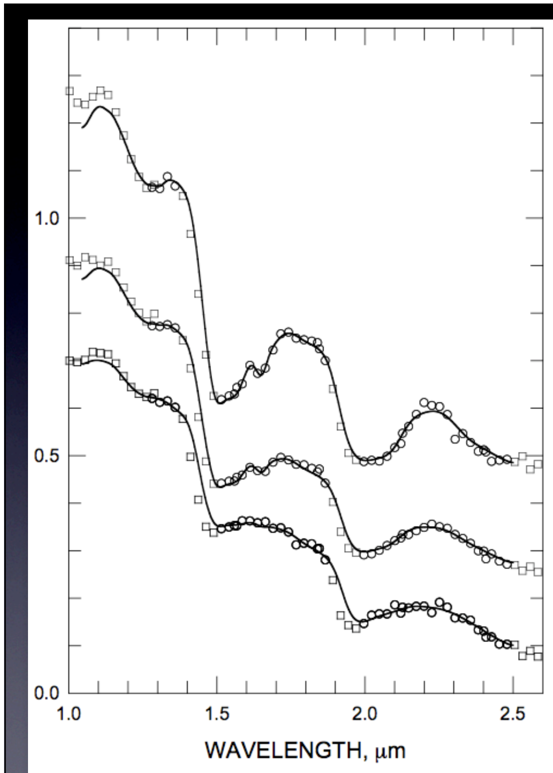




1000
100
10
1
120
130
140
150
THERMAL EMISSION
130 K SOURCE, ε = 1
10 μm
8 μm
NIMS TEMP RANGE IN JUPITER ORBIT
REFLECTED SUNLIGHT,
7 μm, 67.5 deg. incidence angle
OPTICS TEMPERATURE, K
(a)
10
1
0.1
0.01
9
10
11
12
13
14
Noise-equivalent ΔT
neΔT for incividual spectral points at
4-cm-1 resolution
100-m surface resolution
100-K surface temperature
100-km orbital altitude
WAVELENGTH, μm
(b)



3.33μm
4μm
5μm
6.67μm
10μm
Amide I, α-helical, C=O/C-N: 1655 cm⁻¹
Amide I, β-helical, C=O/N-H: 1637 cm⁻¹
Amide II, N-H/C-N: 1537 cm⁻¹
Tyrosine band: 1514 cm⁻¹
Abiotic, NH₃, C-C=O: 1669 cm⁻¹
Abiotic, NH₂: 1592 cm⁻¹
H₂O + B. pumilis post–irradiation
Abiotic chemistry: Radiolysis of H₂O + NH₃ + C₃H₆
H₂O + B. pumilis pre–irradiation
Phosphodiesters (RNA, DNA, ATP): 1240 cm⁻¹, 1260 cm⁻¹, 1078 cm⁻¹
Absorbance (relative units)
Wavenumber (cm⁻¹)



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:

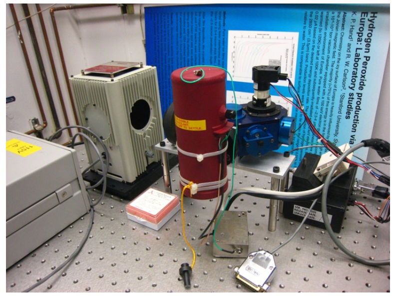
The availability of the desired reflected photons, and the intense radiation environment, make spectroscopy in orbit around Europa very difficult. Nevertheless, as shown in the radiance plot at right, the cold surface temperature of Europa (80-130K) means that reflected solar photons dominate over thermal 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”

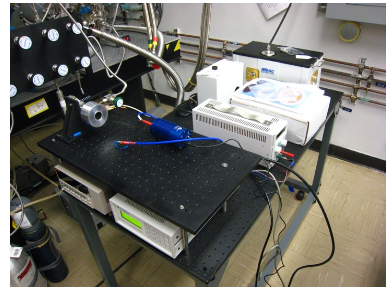
The Jupiter Europa Orbiter has as its primary goal to “explore Europa to investigate its habitability”. Within this broad goal is the objective to “determine global surface compositions and chemistry, especially as related to habitability”. An infrared spectrometer is part of the strawman payload and 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.

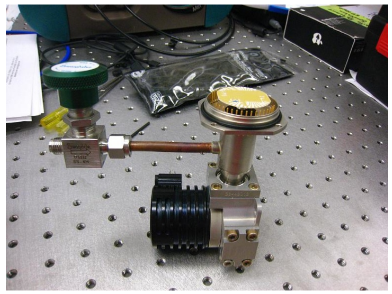
Work currently being done in our lab in prep for 2011 AO

Laboratory breadboard



Laboratory detector testing





Detector cryocooler testing setup

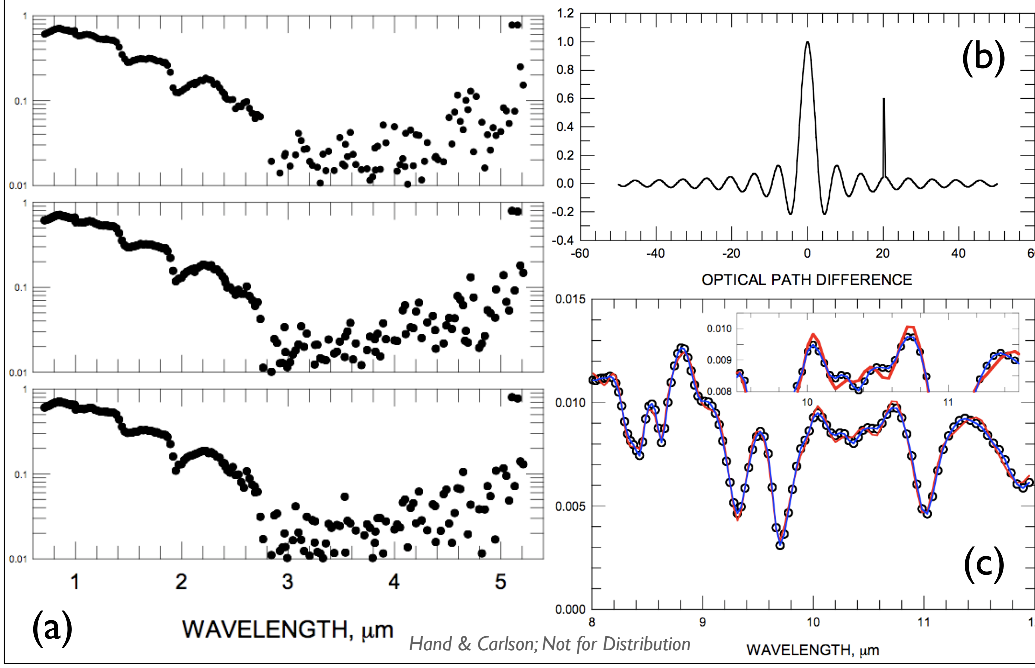
Testing of one our IR detectors

Additional Slides with details on various aspects of CIRIS

FTS is the right solution for high radiation environments

NIMS Data: radiation noise past 2.5 microns

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



Hand & Carlson; Not for Distribution

FPA Concept

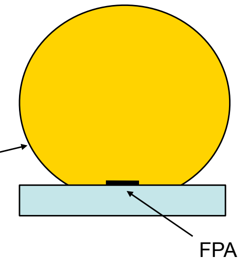
Need large detector area for signal

Need small detector area to minimize radiation hit rate

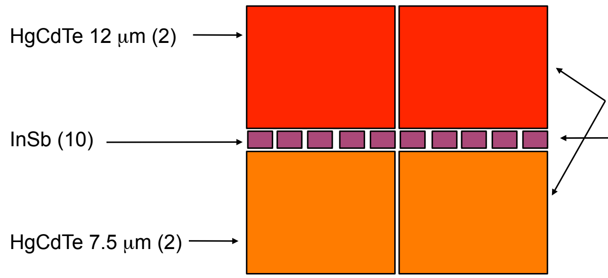
Use FPA with immersion lens? (Reduces area by $n^4 \sim 30$)

Hyperhemispherical ZnSe immersion lens

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



Detector layout:



Sizes

Physical	Optical	Surface Footprint
200 μm	1.2 mm	600 m
40 μm	0.25 mm	120 m

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

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

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 demontration 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.

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

Jupiter Europa Orbiter Payload Instrumentation

CIRIS: A Combined Infrared Interferometric Spectrometer

Opportunity

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

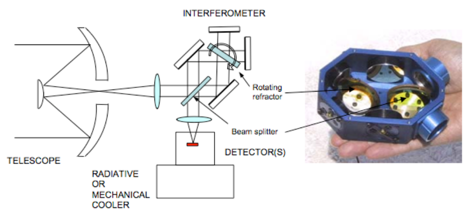
Objectives

1. Science Objectives

- Develop a spectrometer capable of "mapping organic and inorganic surface composition" of icy worlds and plantary 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-I's:

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

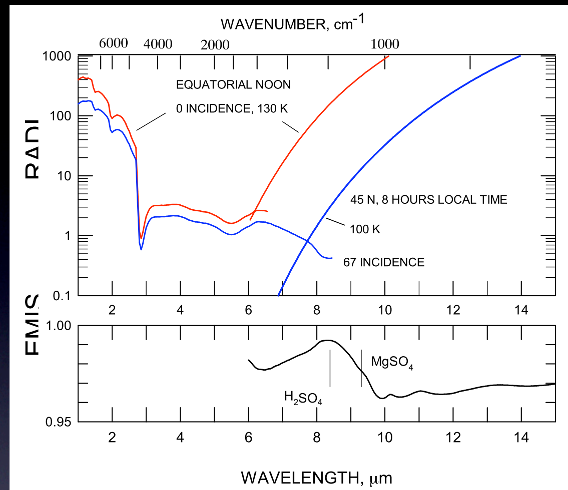
For any given instrument there is both engineering risk and science risk. Though other spectrometers may have lower engineering risk, I argue that they harbor unacceptable science risk - they will not be able to do science worthy of a $3.1+ billion dollar mission.

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

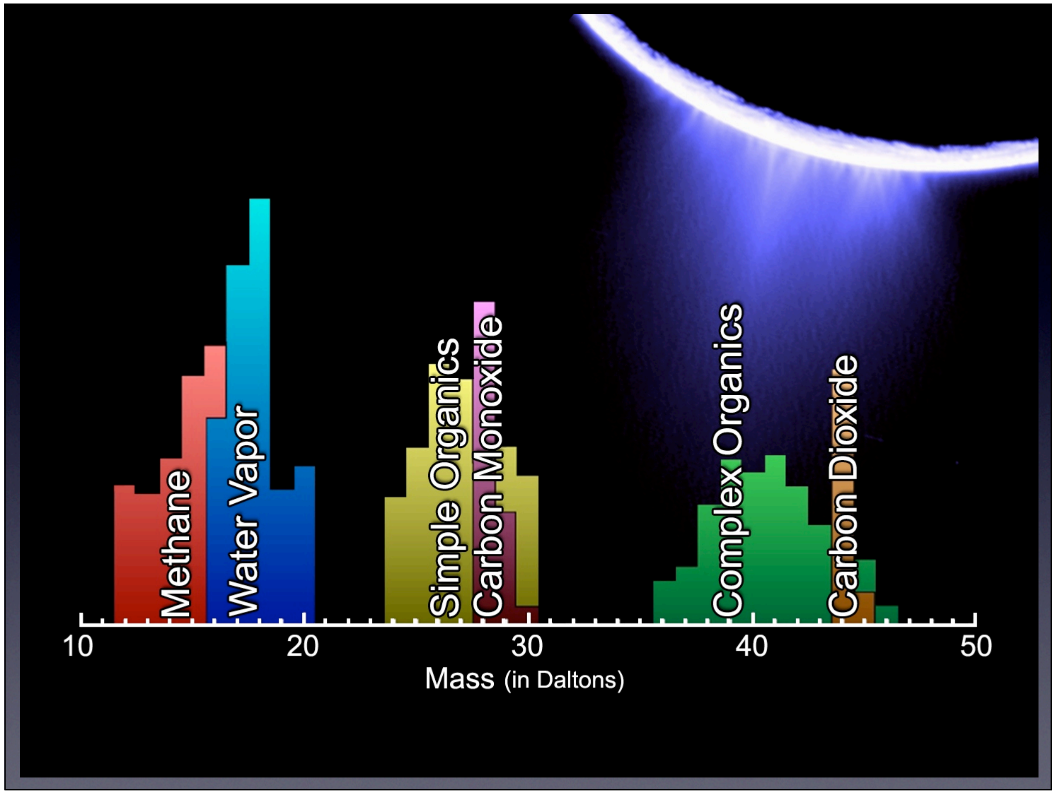
NASA Headquarters believes in this technology and has invested by awarding us a ROSES PIDDP (Spring 2009)

Planetary spectrometers

INSTRUMENT	RANGE µm	RES'N Δν cm⁻¹ (Nyquist)	MASS kg	OPTICS TEMP, K (c)	DET'R TEMP, K (c)
Galileo NIMS (a)	0.7-5.2	25 (b)	18	128 P	65 P
Cassini VIMS (d)	0.85-5.1	33 (b)	18	130 P	60 P
Mars Express OMEGA (e)	0.93-5.1	40 (b)	23.5	190 P	<70 A
Venus Express VIRTIS-M (f)	1-5.1	20 (b)	Not Given	Not Given	~70 A
SPIRIT (Sounding Rocket) (g)	2.5-22	1	3.6 + LHe	10 C	10 C
Mars Global Surveyor TES (h)	6-50	10	14.4	280 P	280 P
Mars Exp. Rovers Mini-TES (i)	5-29	20	2.4	280 P	280 P
Mars Express PFS (j)	1.2-45	1.5	30	290 P	220 A
Cassini CIRS (k)	7.2-1000	0.5	39	170 P, R	75 P, R
New Millennium IFTS (l)	4.4-15	0.6	100	140 A	55 A
CIRIS	1.4-15	4	7-8	130	60-65

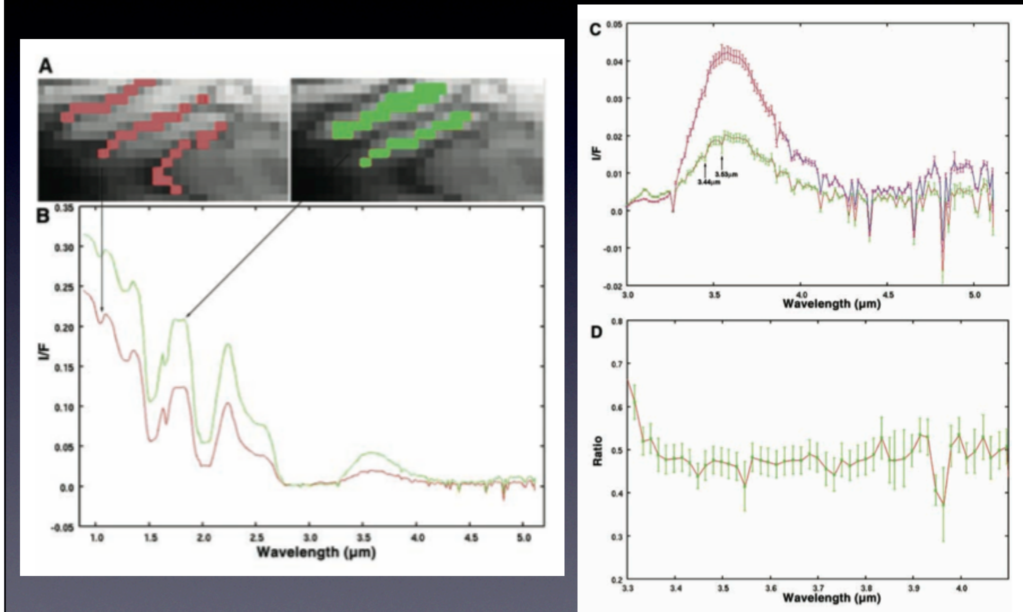


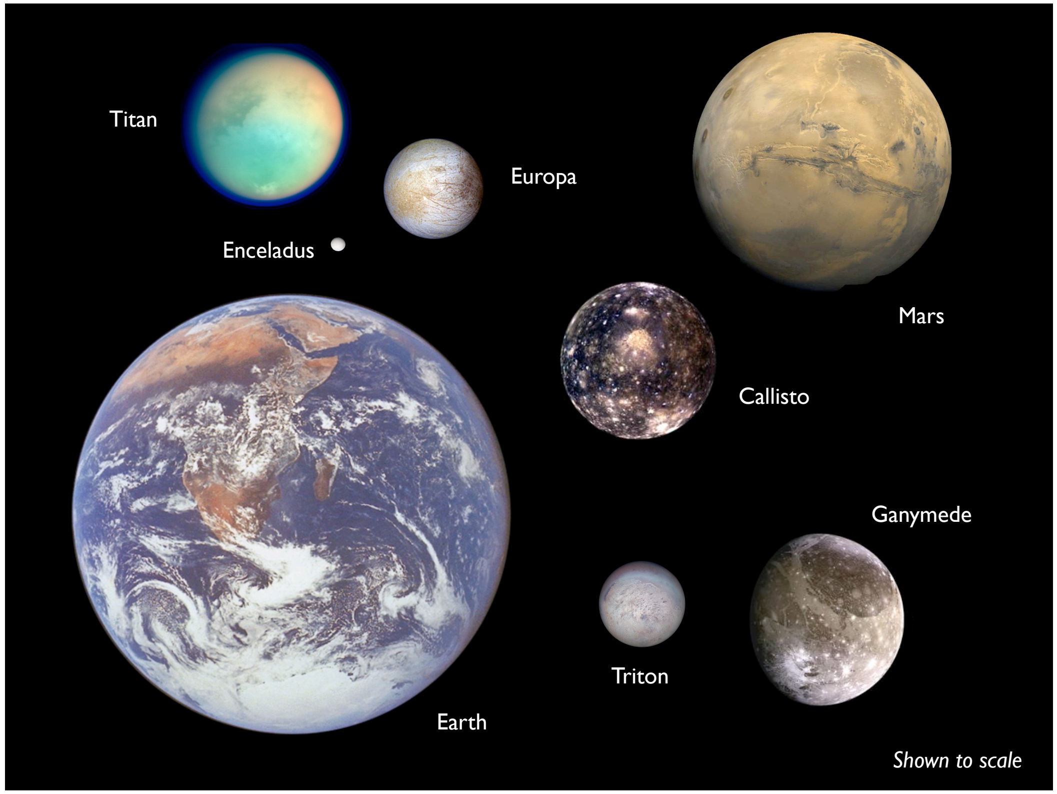
Top: Calculated solar reflectance and thermal emission radiances from Europa. Observing morning (blue) and noon (red) locales enhances the spectral range of reflected and thermal signals, respectively. Depending on time and temperature, reflectance spectra can be obtained to 7 µm and thermal emission to 15 µm. Temperatures based on Spencer et al. (1999). A surface of $H_2O+H_2SO_4$ hydrate was assumed. Bottom: Emissivity features may be used for compositional determinations. Brightness variations in the thermal emission signal, showing an H_2SO_4 peak at 8.4 µm. $MgSO_4$'s peak is shifted to longer wavelengths.



Methane
Water Vapor
Simple Organics
Carbon Monoxide
Complex Organics
Carbon Dioxide
10
20
30
40
50
Mass (in Daltons)

Cassini VIMS: Enceladus surface





Follow the water...SECOND ORIGIN

Europa as a Case Study