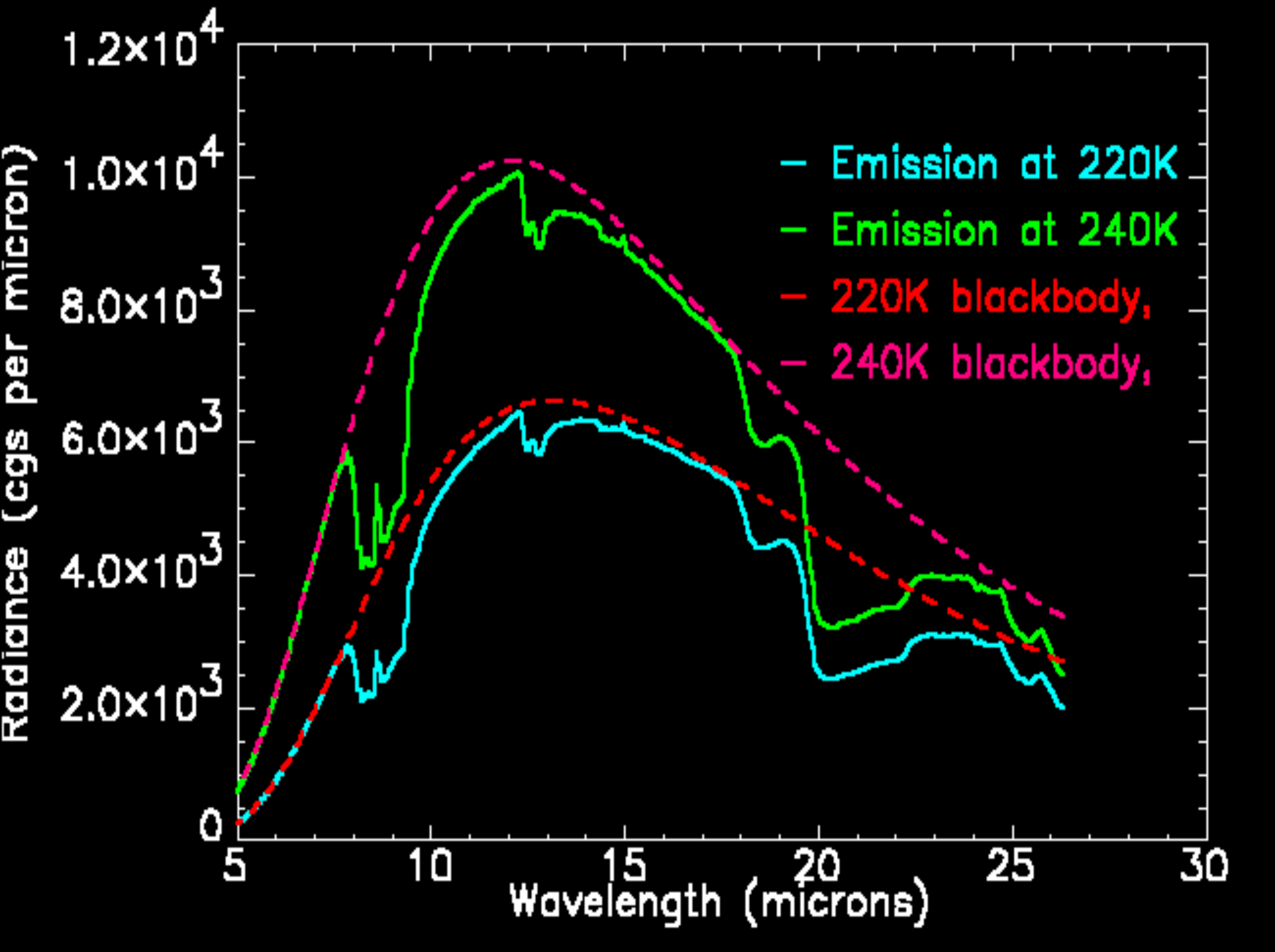
Thermal-Infrared imaging

What is it?

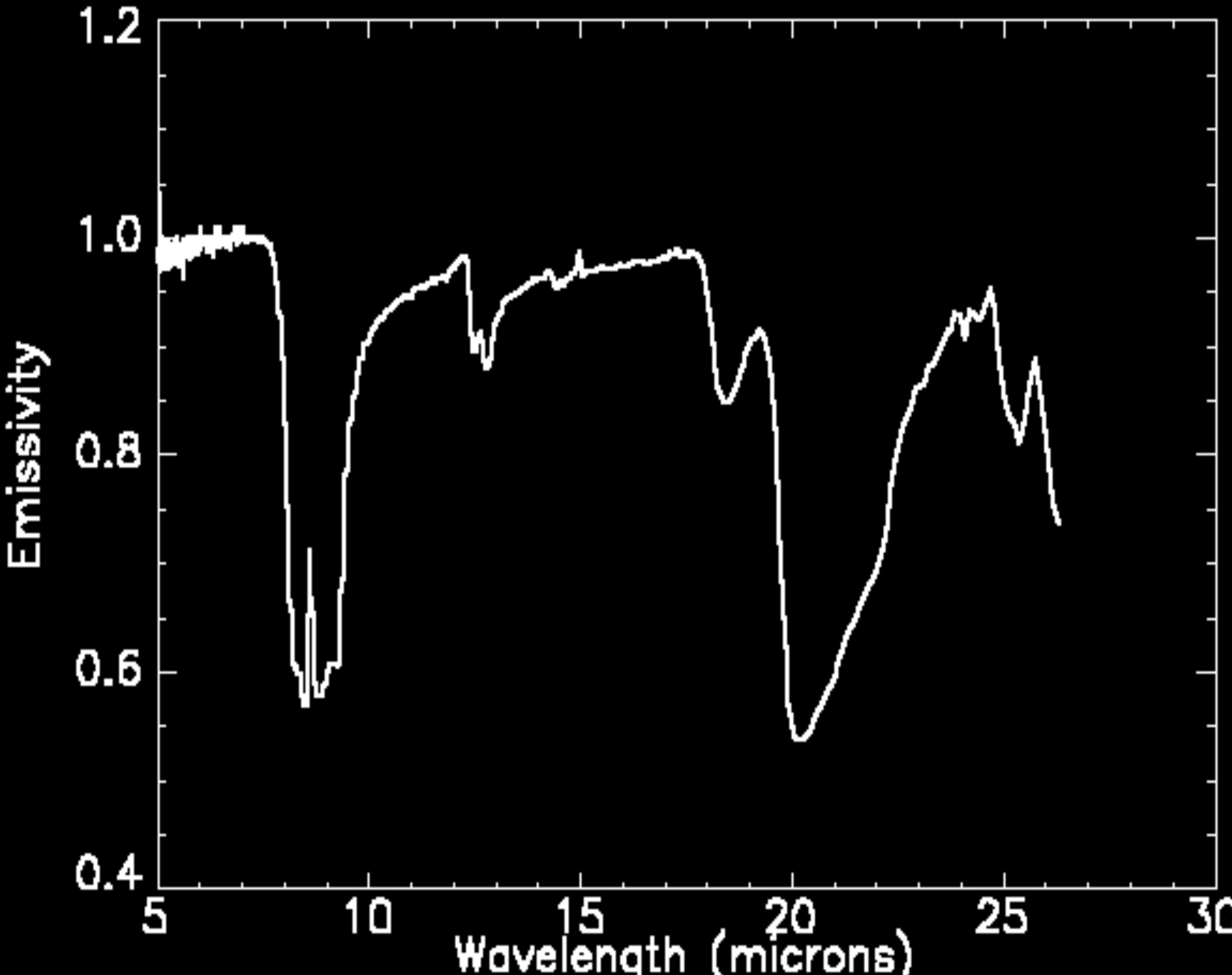
- measurement of emitted radiation (temperature)
- at one or more times (thermal inertia)
- at one or more wavelengths (composition)

Why bother?

- see at night
- temperatures
- energy fluxes
- material properties (resistance to temperature change, i.e. thermal inertia)
- composition (emissivities)



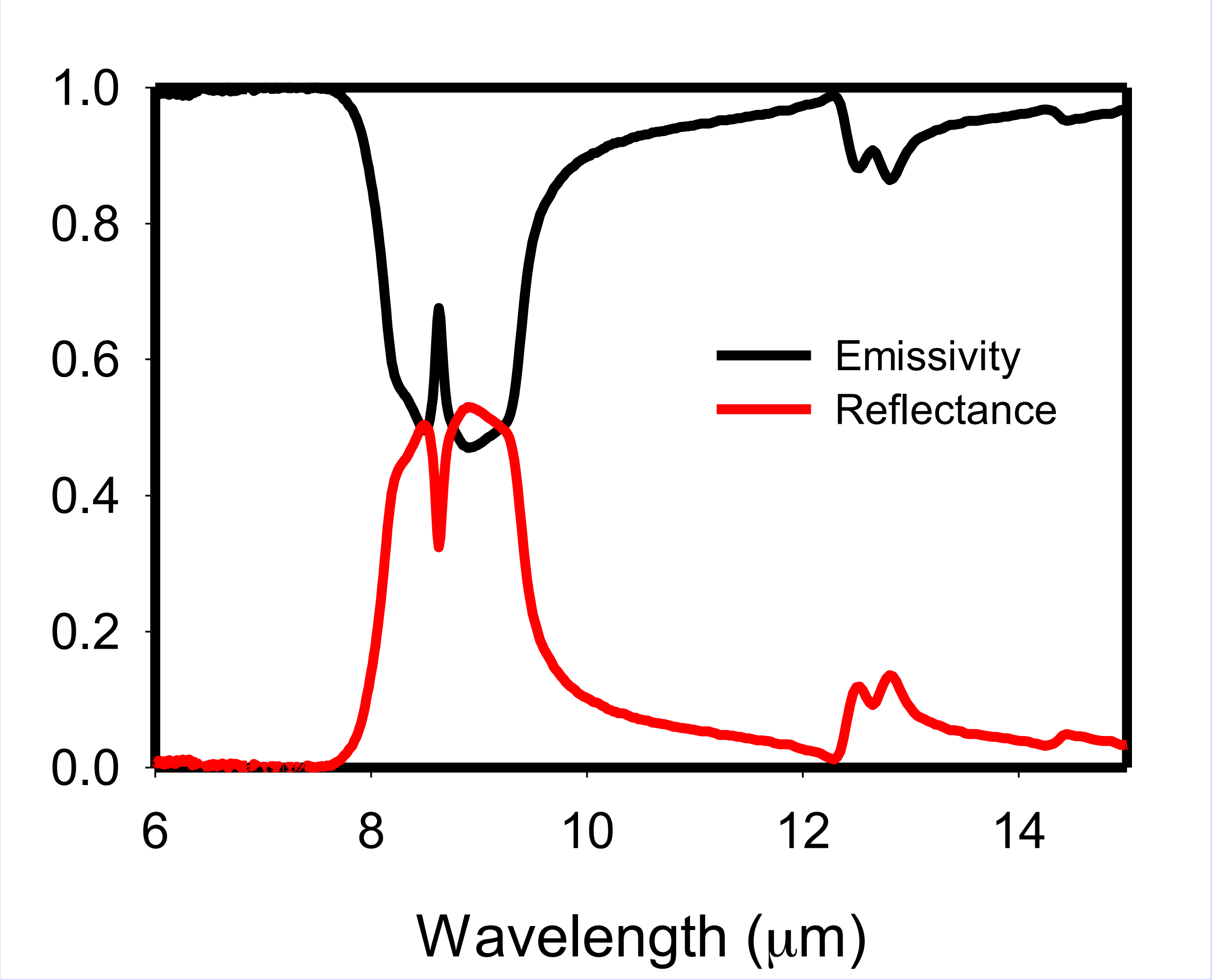
Emission at 220K
Emission at 240K
220K blackbody,
240K blackbody,
Radiance (cgs per micron)
1.2x10^4
1.0x10^4
8.0x10^3
6.0x10^3
4.0x10^3
2.0x10^3
0
5
10
15
20
25
30
Wavelength (microns)



1.2
1.0
0.8
0.6
0.4
Emissivity
5
10
15
20
25
30
Wavelength (microns)

Kirchhoff's Law

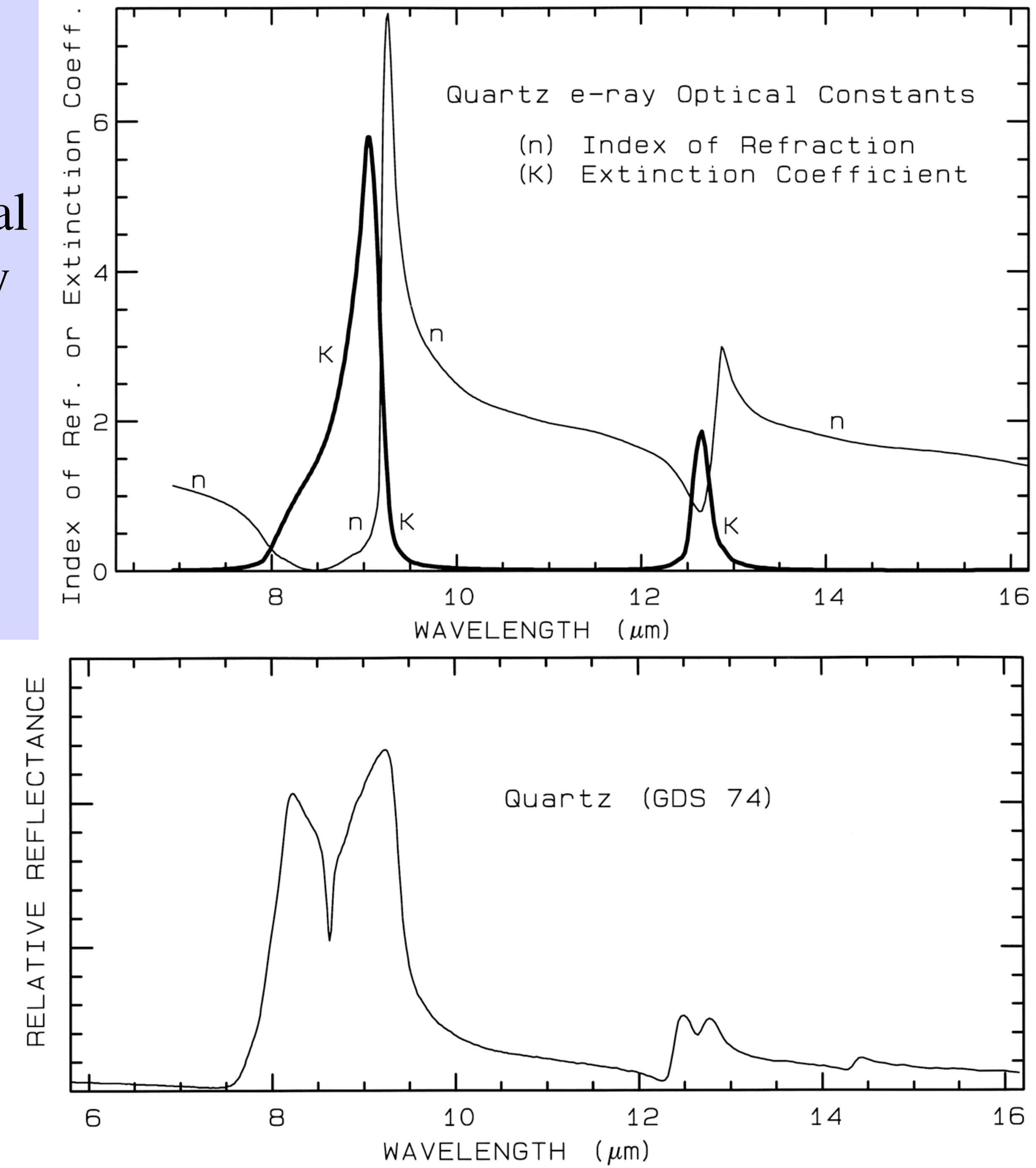
$$\varepsilon = 1 - R$$



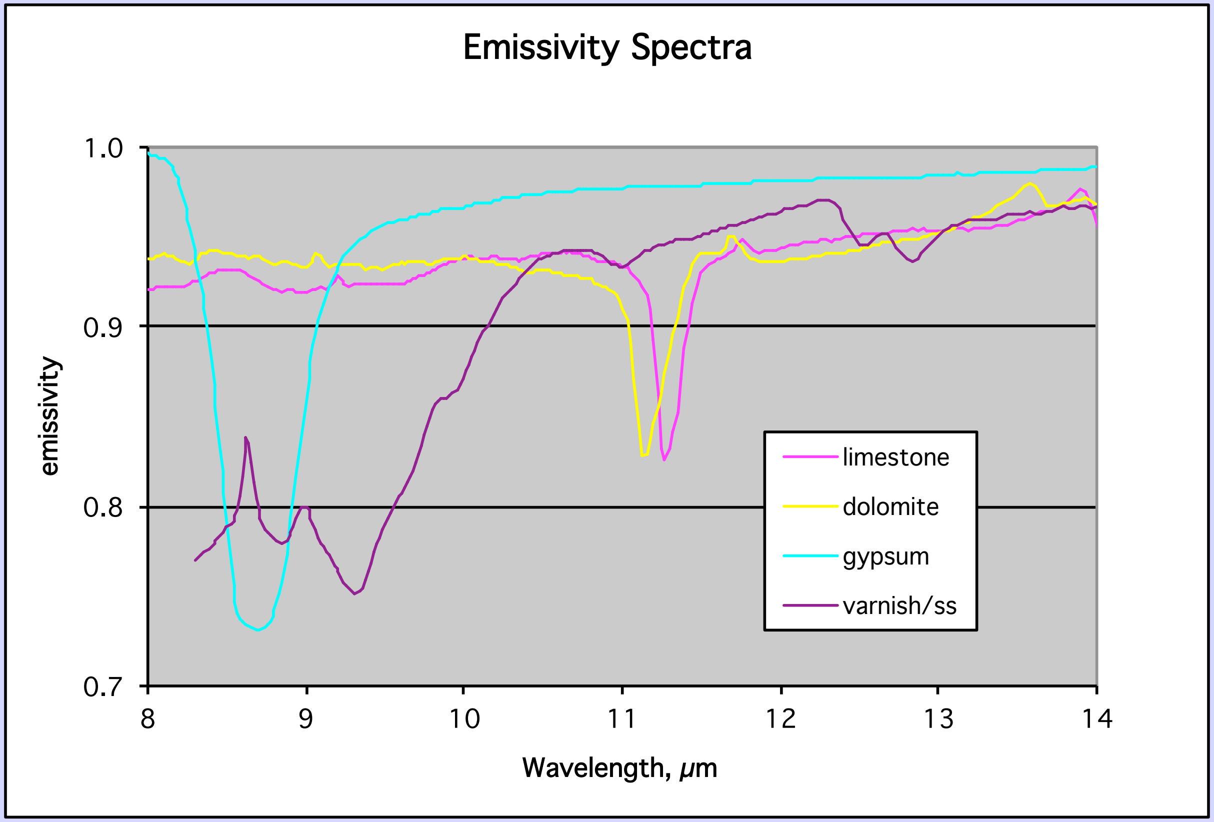
Restrahlen band: k maximized at fundamental vibration mode frequency

Christiansen frequency: $n = 1$, minimizing reflectance

Reflectance or emission spectrum results from combination of n, k variations



Emissivity spectra of rocks



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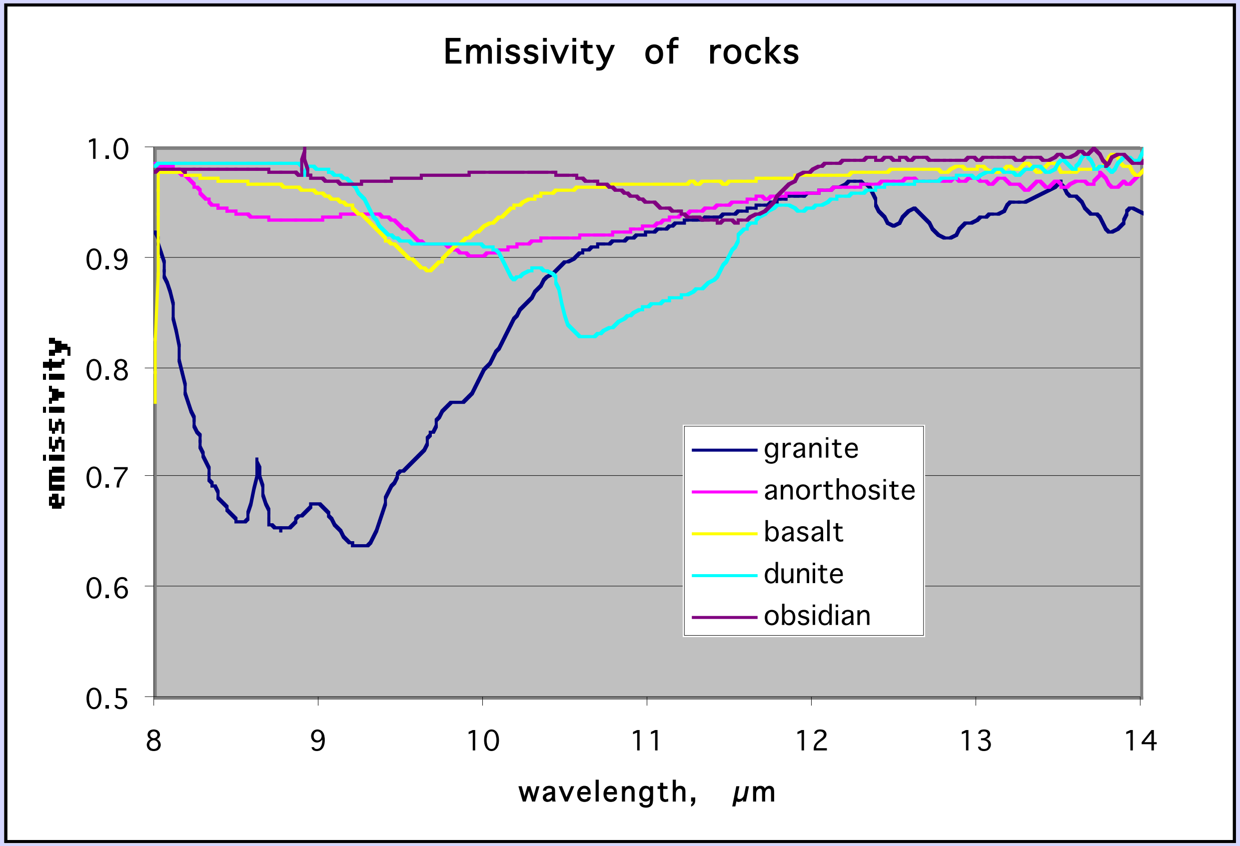
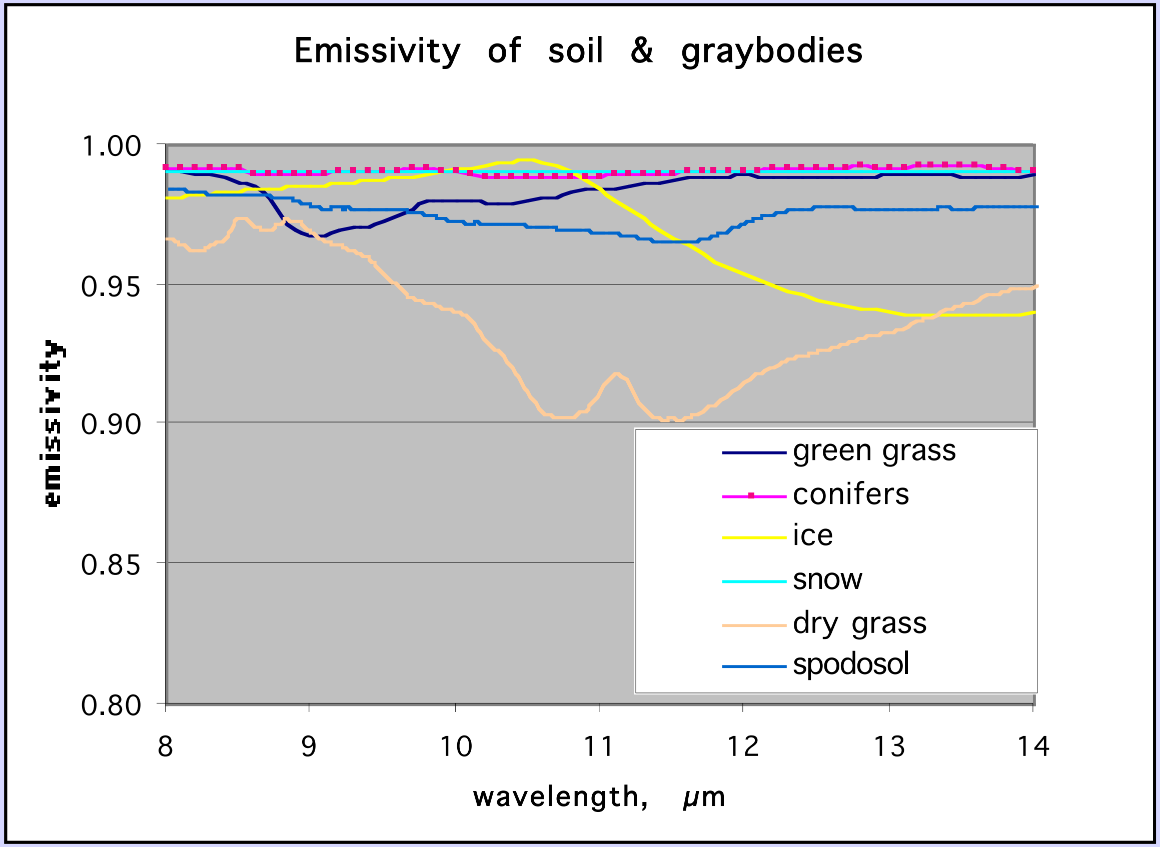


Emissivity spectra of approximate graybodies

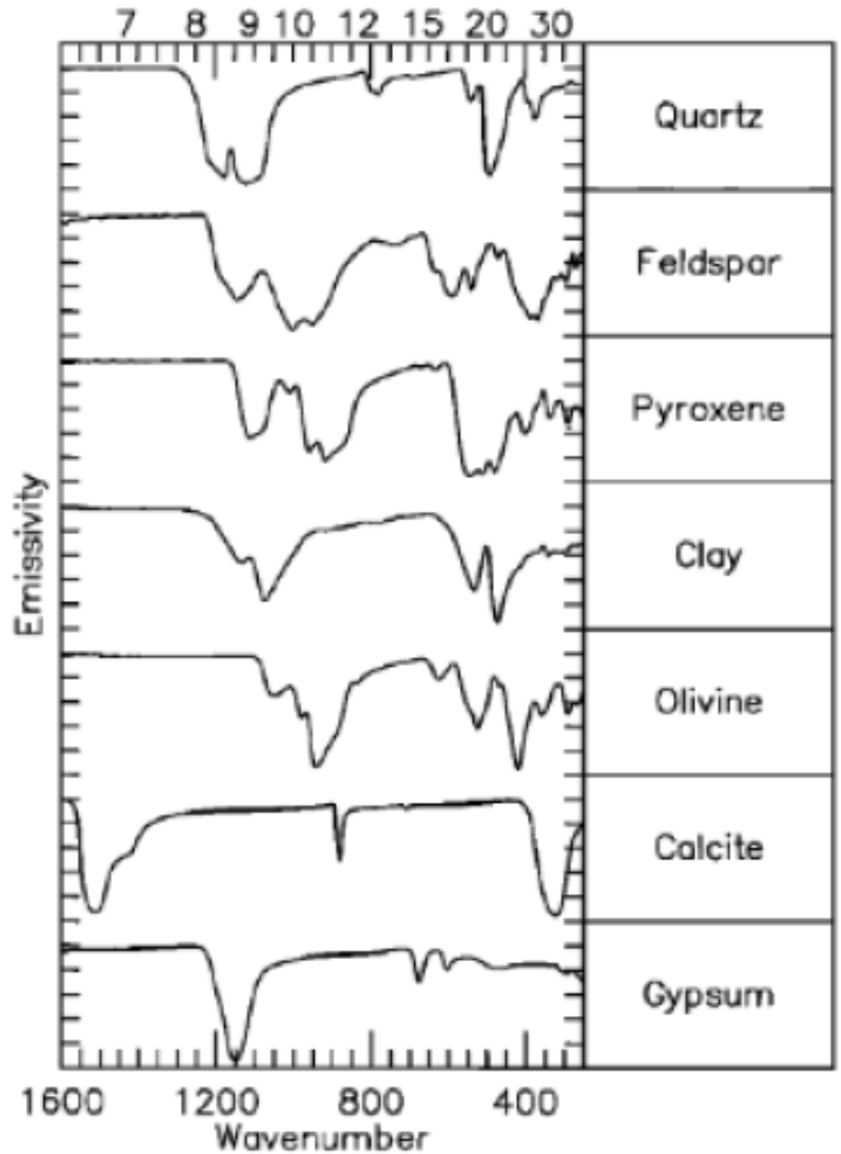


What compositions can be determined in the TIR?

Mostly vibrational resonance, not electronic processes
therefore, relatively large molecules

Silicate minerals (SiO_4^{-4}); quartz (SiO_2)
Sulfates (SO_4^{-2}); sulfur dioxide (SO_2)
Carbonates (CO_3^{-2}); carbon dioxide (CO_2)
Ozone (O_3)
Water (H_2O)
Organic molecules

MIR/TIR



Quartz: SiO_2

Feldspar: $(Ca_x, Na, K)Al_{1+x}Si_3O_8$

Pyroxene: $(Ca, Mg, Fe)_2Si_2O_6$

Clay: e.g. $(Na,Ca)_{0.3}(Al,Mg)_2Si_4O_{10}(OH)_2 \bullet n(H_2O)$

Olivine: $(Mg, Fe)_2SiO_4$

Calcite: $CaCO_3$

Gypsum: $CaSO_4 \bullet n(H_2O)$

Figure 7. Thermal infrared spectra of representative silicate, carbonate, and sulfate minerals. Laboratory data are from the Arizona State University (ASU) spectral library [*Christensen et al.*, 2000a].

MIR/TIR

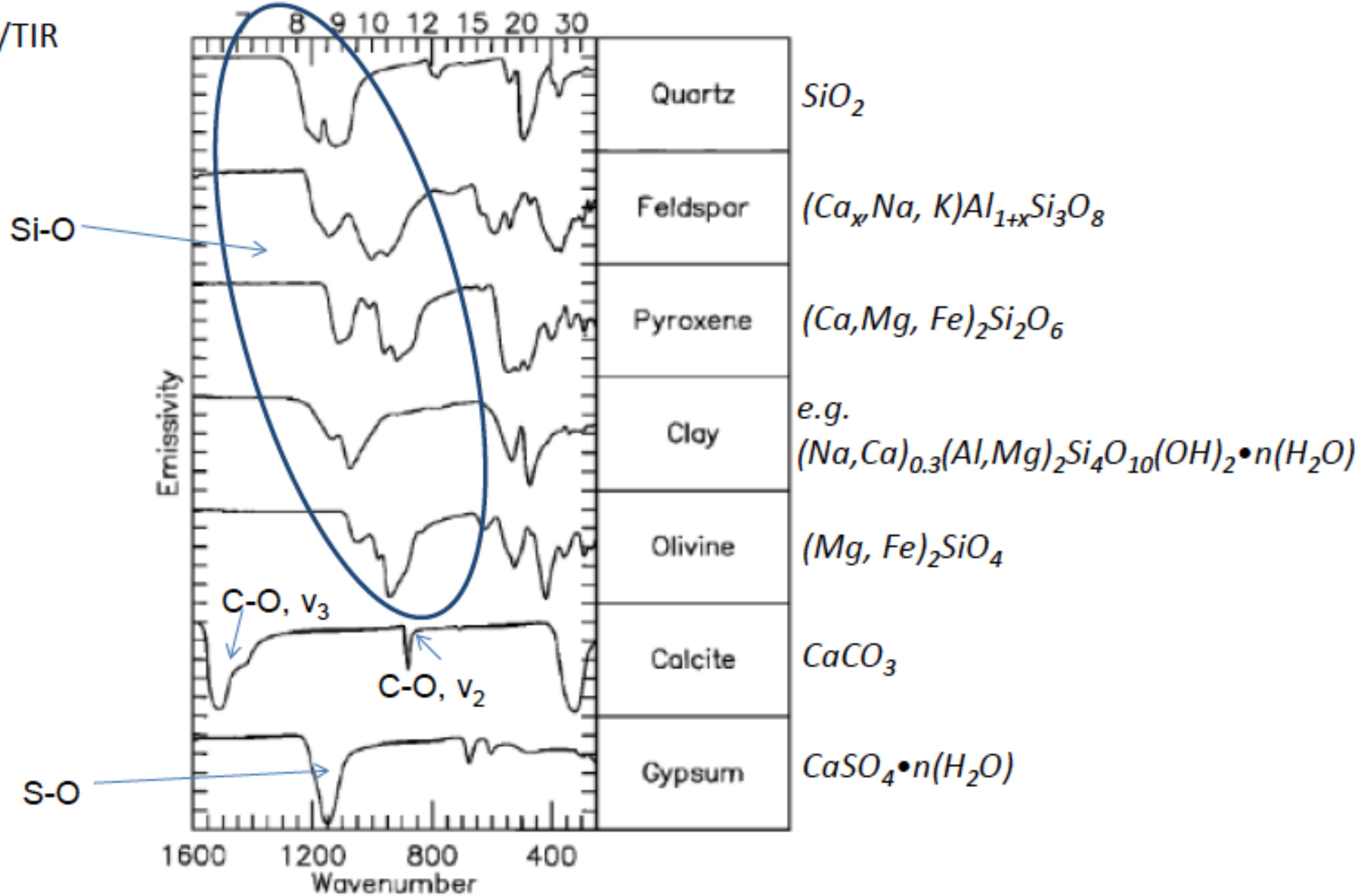
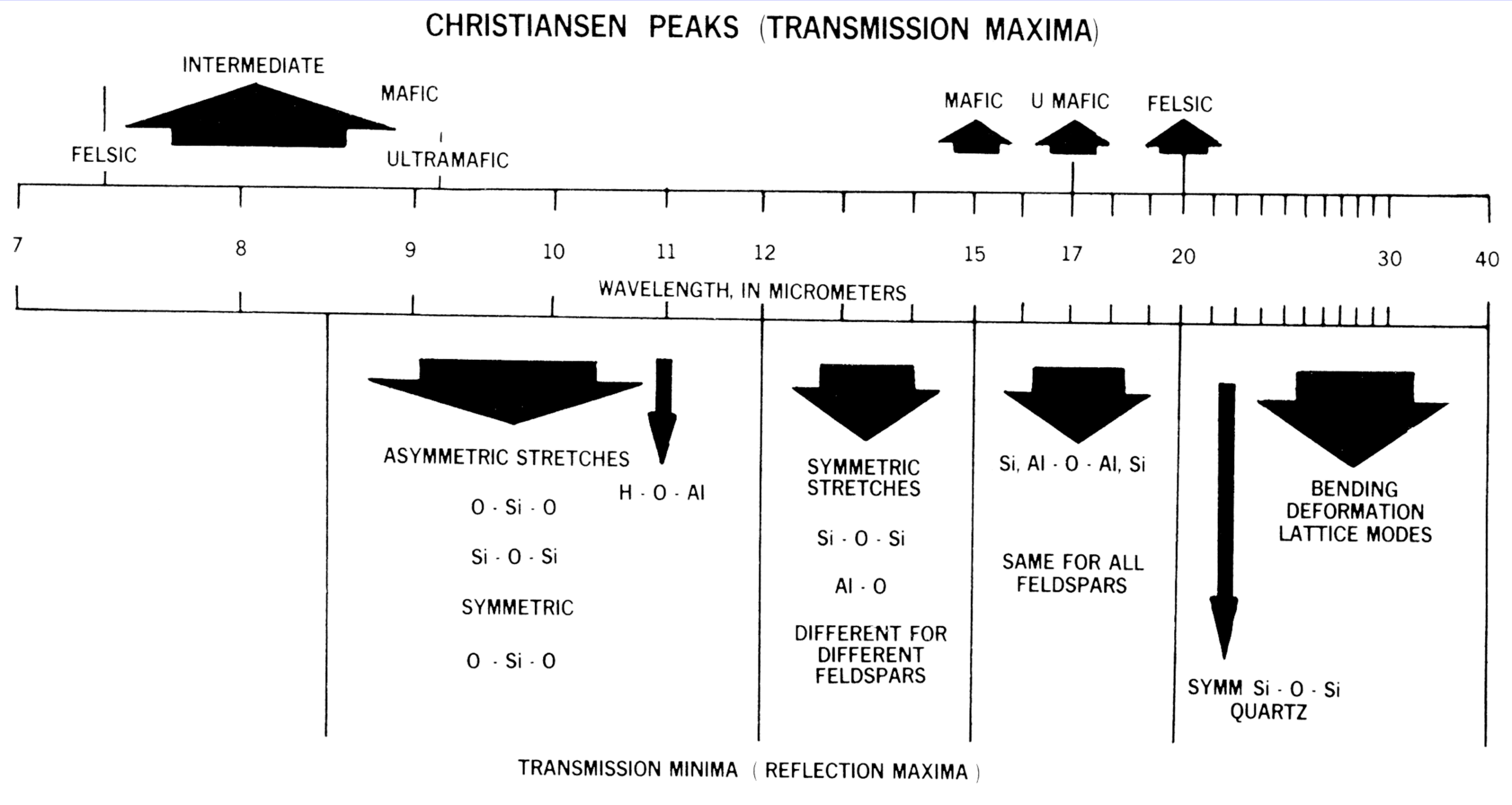
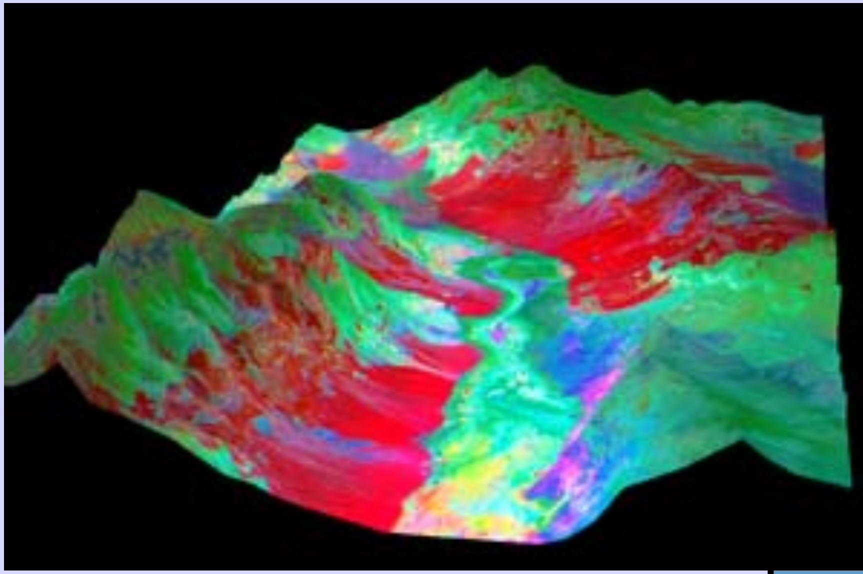


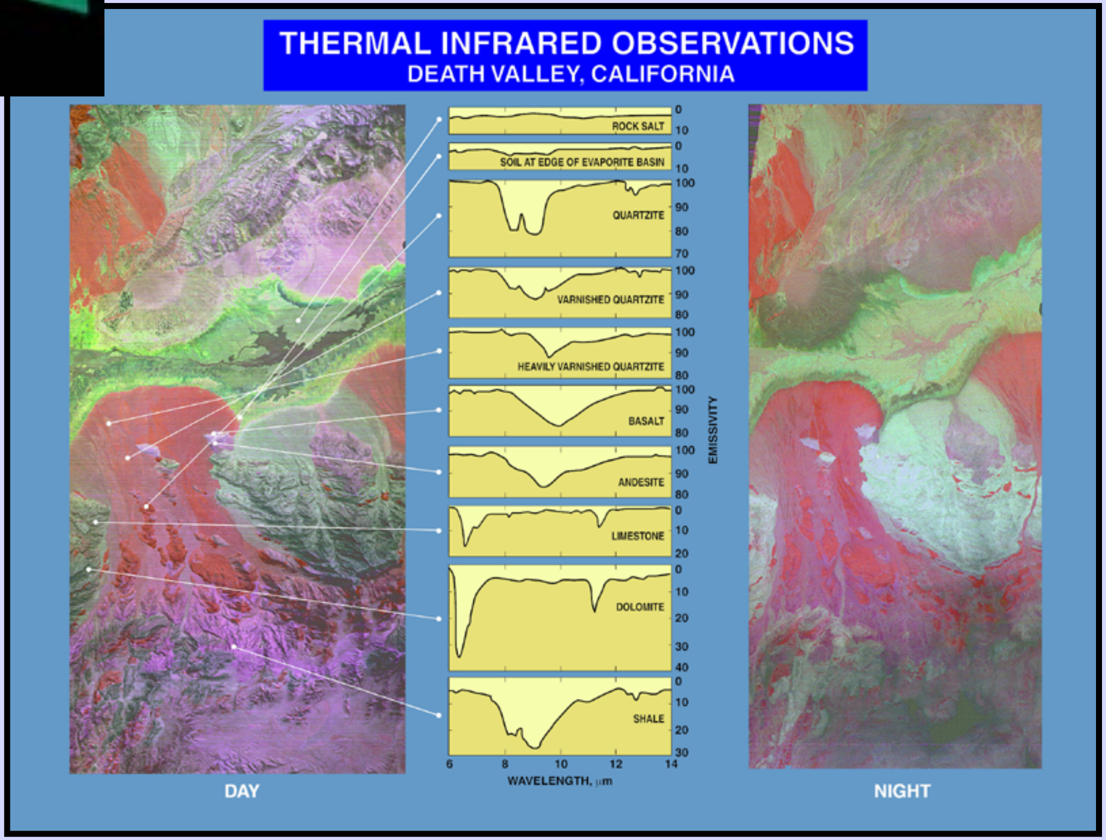
Figure 7. Thermal infrared spectra of representative silicate, carbonate, and sulfate minerals. Laboratory data are from the Arizona State University (ASU) spectral library [*Christensen et al.*, 2000a].

Thermal infrared spectral features of silicates (Clark, 1999)

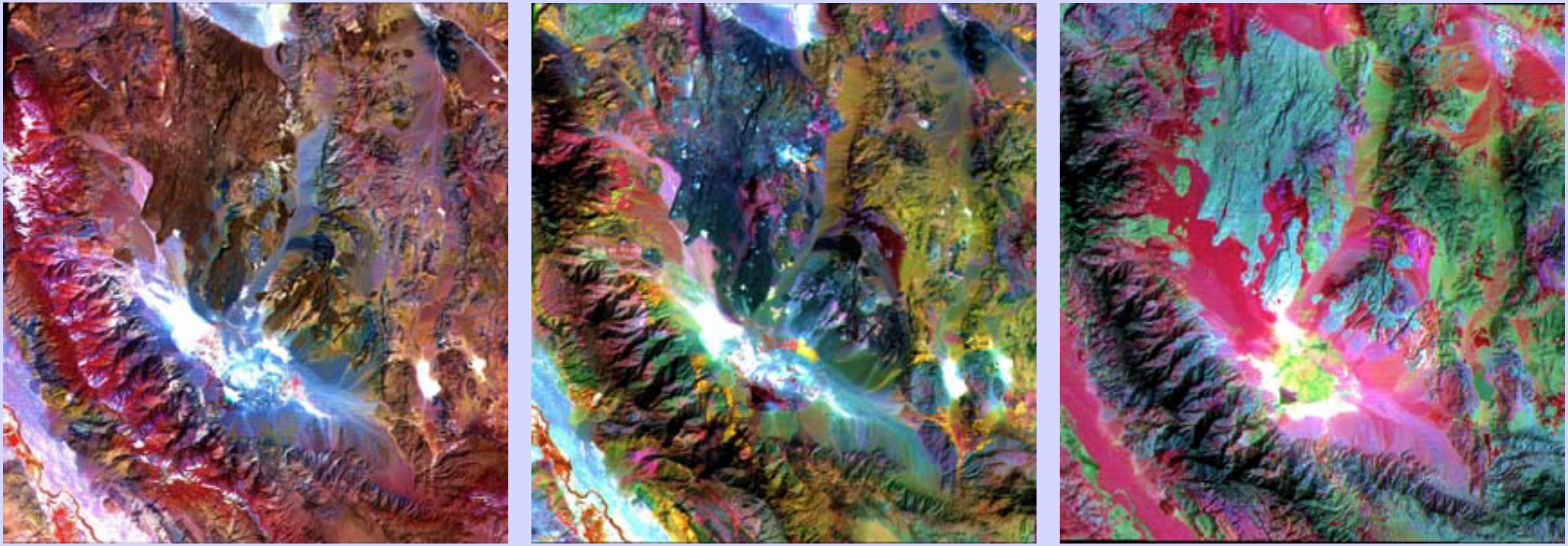


Death Valley, California



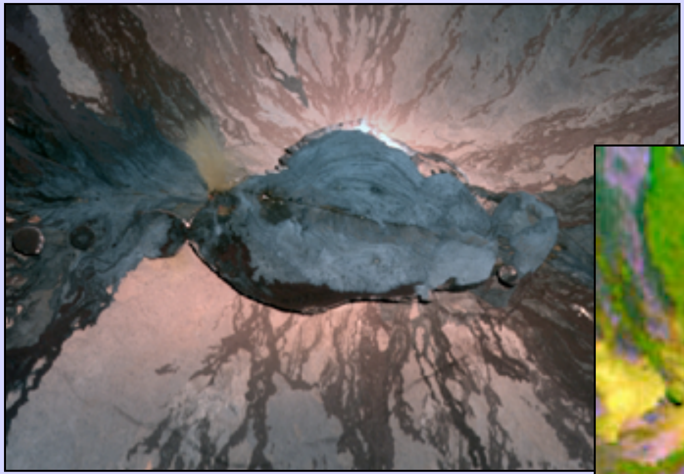


Saline Valley, California

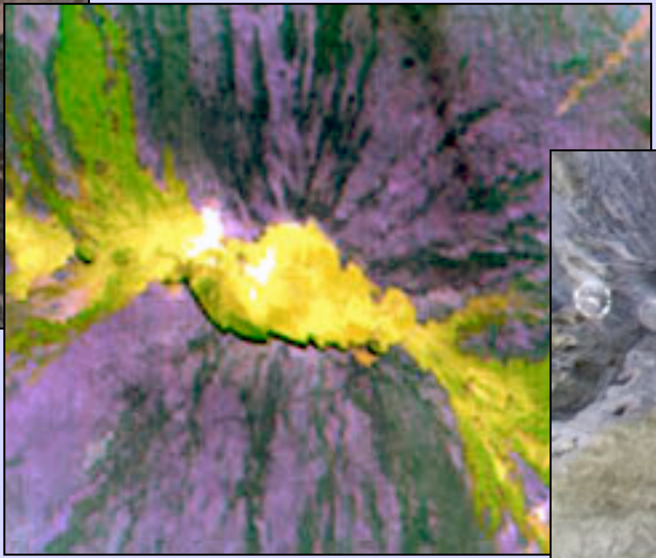


VNIR SWIR TIR

Mauna Loa, Hawaii



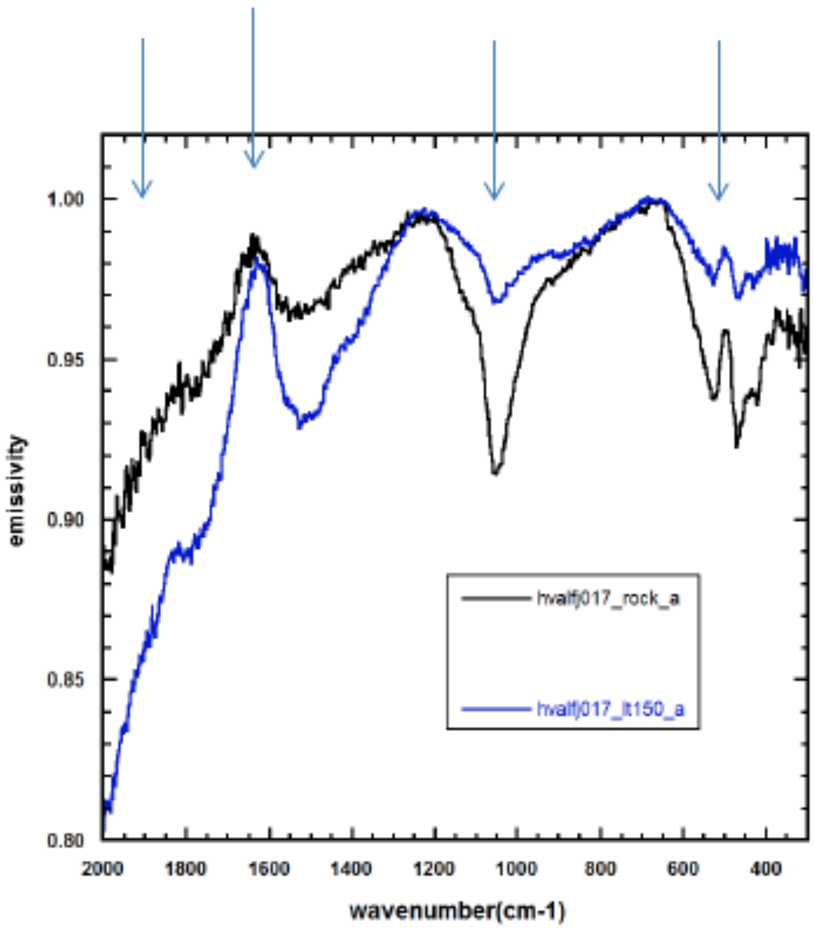
MASTER VNIR
daytime



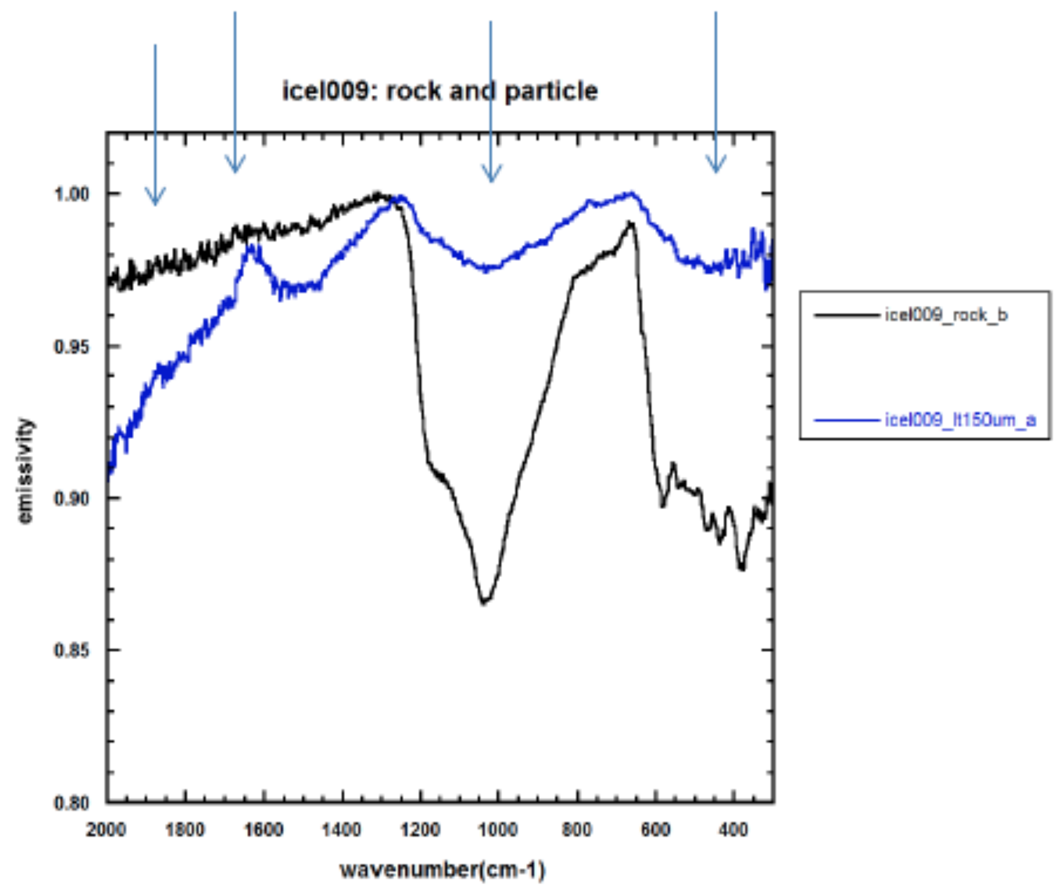
ASTER TIR,
daytime

MTI TIR,
nighttime

Effects of Particle Size, TIR



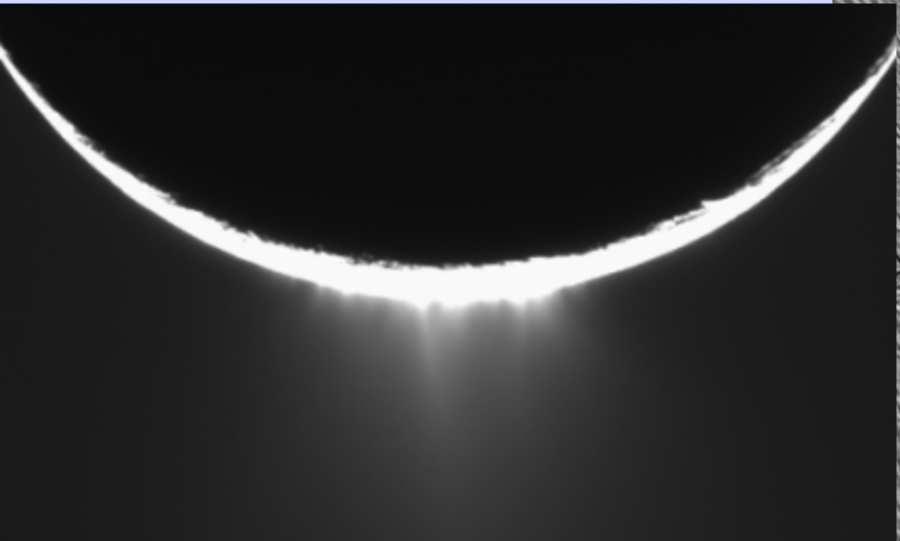
montmorillonite+hematite

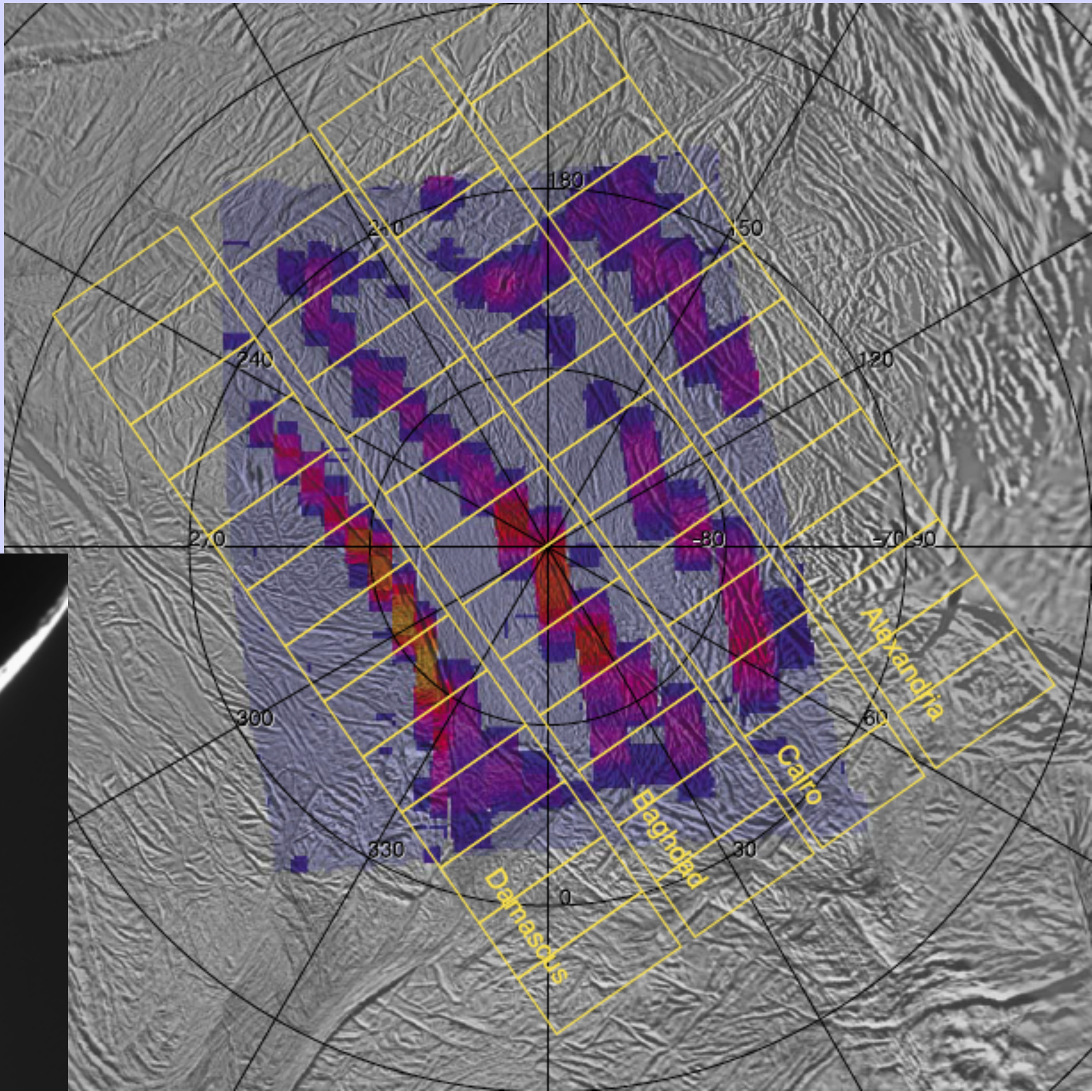


slightly altered basaltic rock

Not all thermal images are dominated by *solar* heating of the surface

Enceladus





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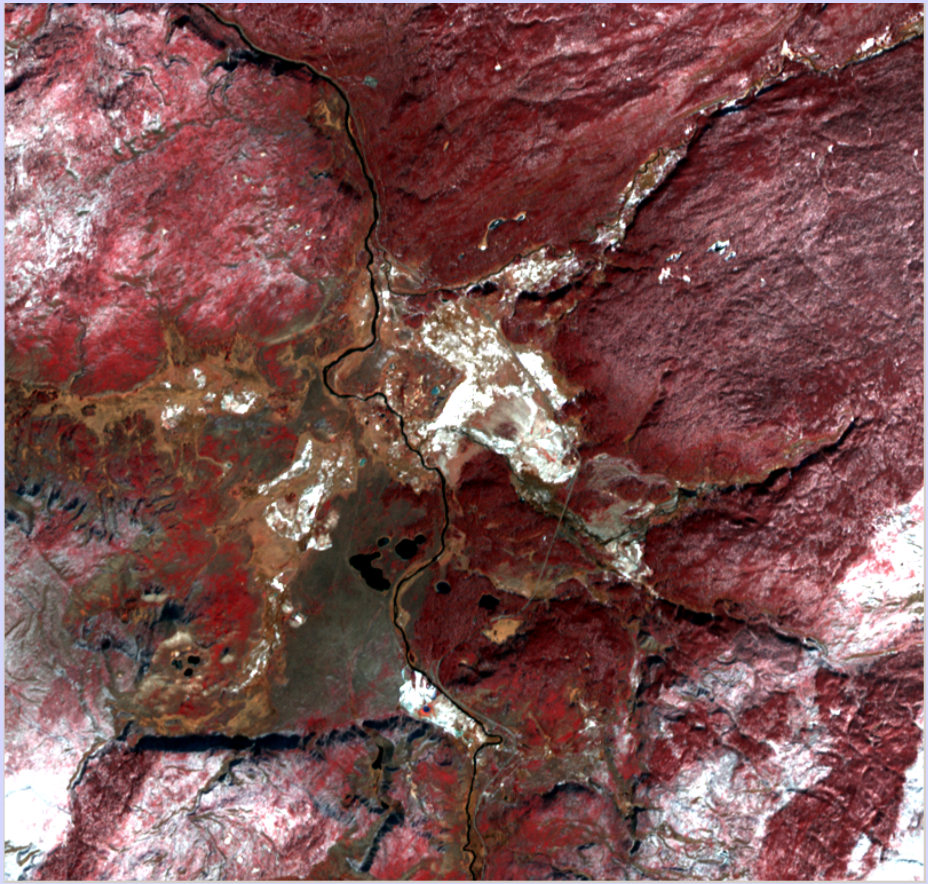
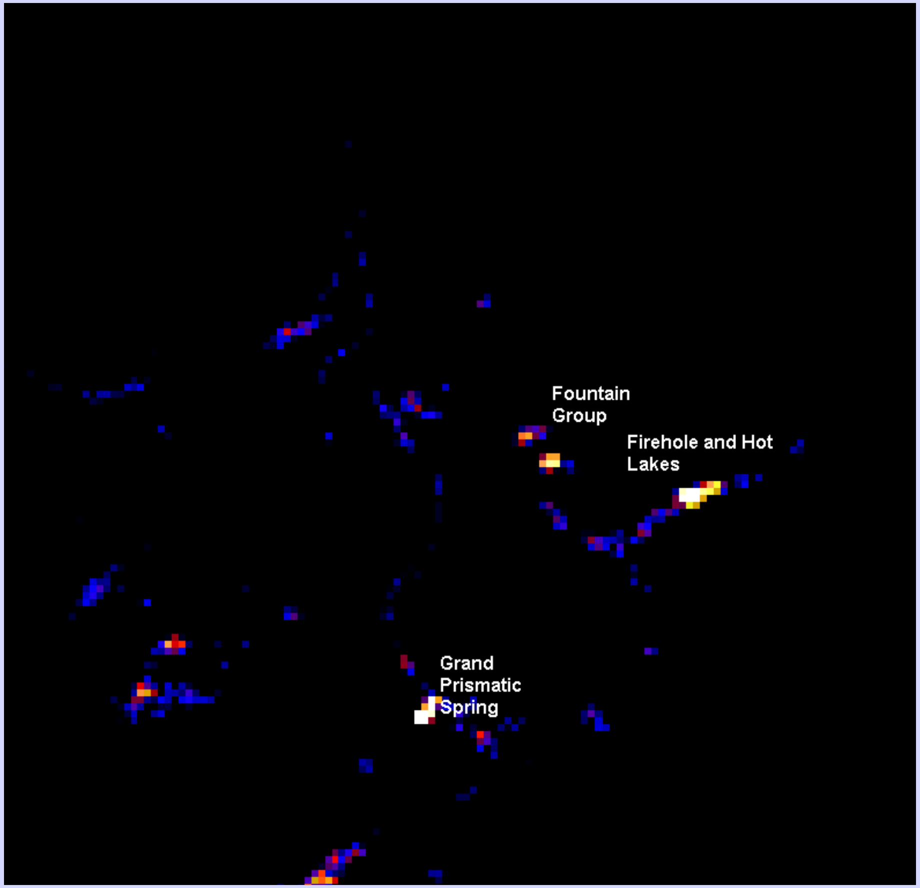




ASTER images of Yellowstone: VNIR (left) and TIR (right)

A little about solving sets of equations

If you measure R there are 2 unknowns: ε and T
If you measure R at a different λ, there is another unknown ε

If you measure a spectrum of n bands, there are n+1 unknowns

You must have the same number of measurements as unknowns to solve a set of equations

How can you do this for TIR data?

Temperature - Emissivity Separation

- Two-time two-channel method
  - *Completely determined*
- Model emissivity method
  - *Assume* $\varepsilon_{10\mu m}=0.96$
- Normalized Emissivity method
  - *Assume* $\varepsilon_{max}=1$

But if $\varepsilon_{max} < 1$ …

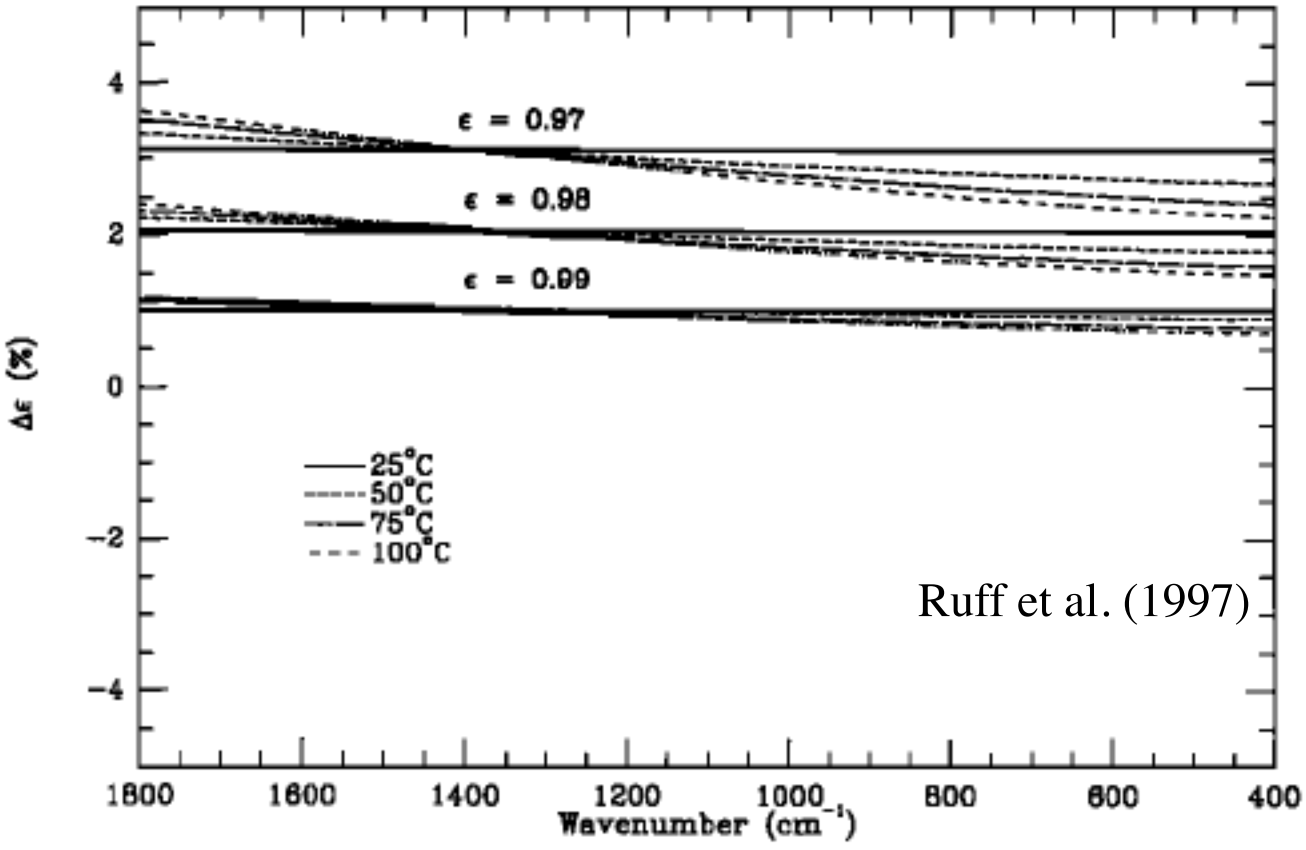
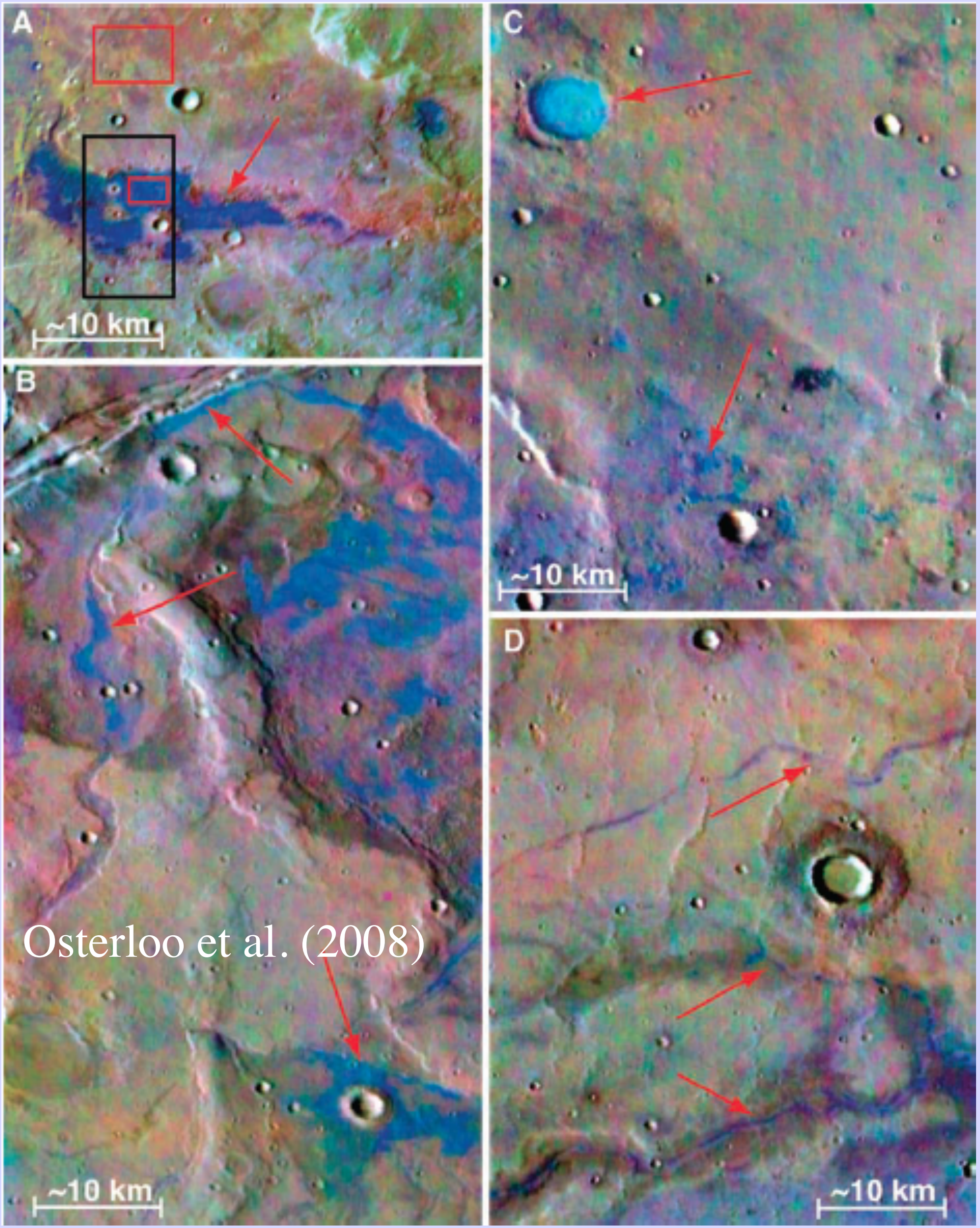
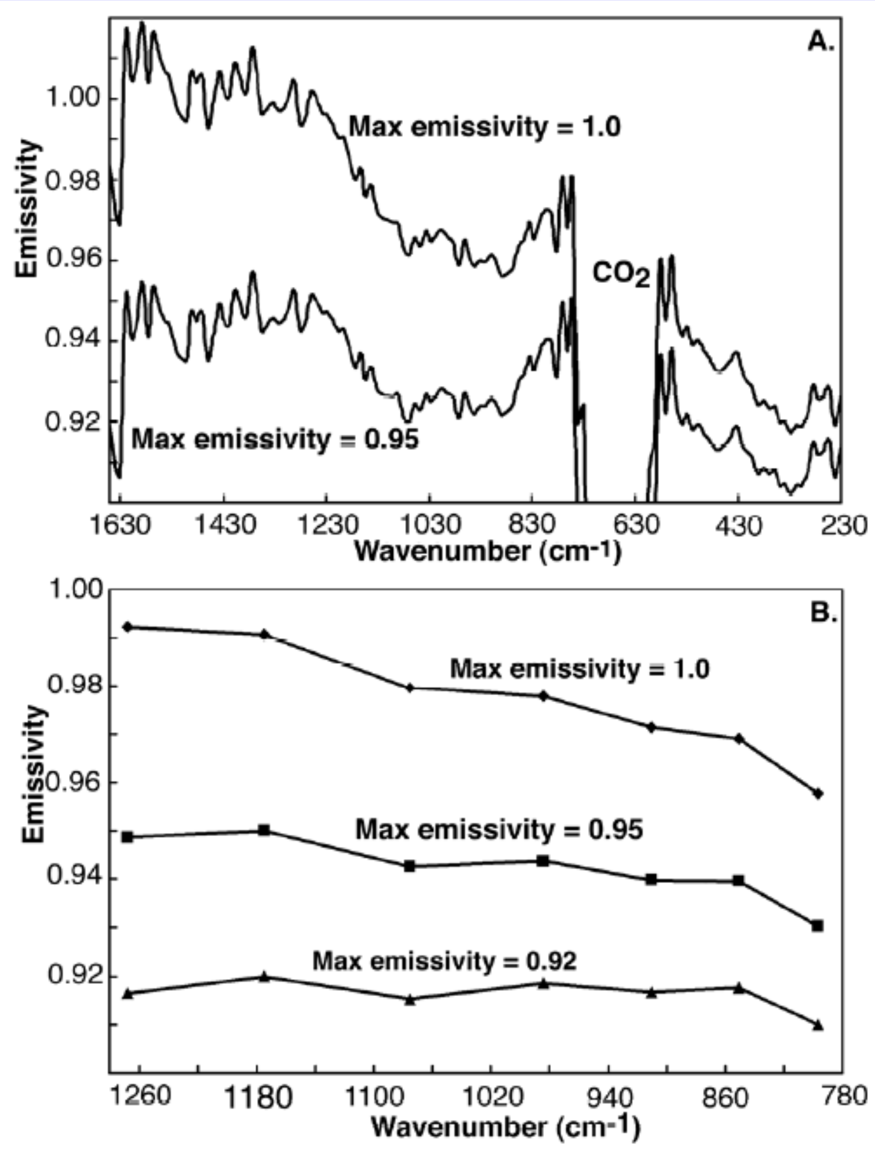


Figure 11. The emissivity error that arises from deriving sample temperature from a nonunit emissivity Christiansen feature (1359 cm^{-1} is used here). Three different ε_{CF} cases are plotted for four different sample temperatures.

Example of $\varepsilon_{max} < 1$: chlorides

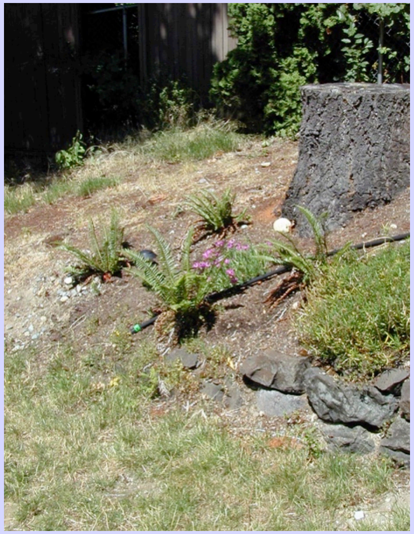


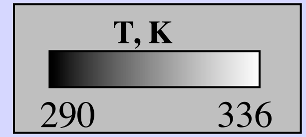


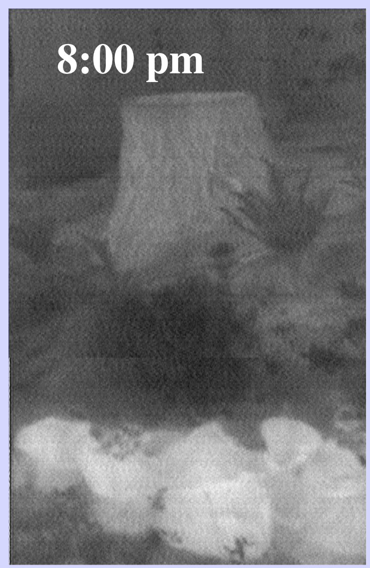
Day/night

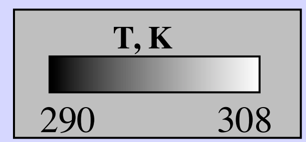
Vis

10.8 μm









Thermal inertia:
dQ/dT
Resistance of matter
to changing temperature
as heat is applied