Mon. Feb. 26, 2018

- Midterm exam date:
  - Mon. Mar. 5 or Wed. Mar 7 (decide today in class)
- Reading: Sabins Ch. 5 (Thermal)
- Finish:
  - Theory of mineral absorptions (not in text)
    - Use slides posted for last Monday
- Thermal Remote Sensing

Use previously posted slides for Absorption Theory

Thermal Radiation Intro.

- Thermal Emission – Application (mostly Monday)
  - Direct measurements of temperature (volcanoes, weather, etc.)
  - Mineral composition through "emissivity" (how well it radiates thermal IR)
  - Indirect information from heating & cooling rates (thermal inertia)
- Thermal Emission – Theory
  - Planck Blackbody formula
  - Stefan-Boltzmann law and Wien displacement law
  - Kilauea Aster examples
  - Emissivity
    - Emissivity spectra of silicates and other minerals
    - Emissivity mapping of Mars
  - Thermal Inertia (Monday.)

Temperature and Heat

- Thermal energy is "kinetic energy" of moving atoms and molecules
- Want temperature scale where energy is proportional to T
  - Celsius scale is "arbitrary" (Fahrenheit even more so)
    - 0°C = freezing point of water
    - 100°C = boiling point of water
  - By experiment, available energy = 0 at "Absolute Zero" = –273°C (-459.7°F)
  - Define "Kelvin" scale with same step size as Celsius, but 0K = -273°C = Absolute Zero

- Use Kelvin Scale for most of work in this course
  - Available energy is proportional to T, making equations simple
  - 273K = freezing point of water
  - 373K = boiling point of water
  - 300K approximately room temperature

Thermal Energy Transfer

- Conduction
  - molecule – to – molecule (contact)
- Convection
  - motion of material carrying heat
- Radiation
  - electromagnetic radiation

Planck "Black Body Radiation"

- Hot objects glow (emit light)

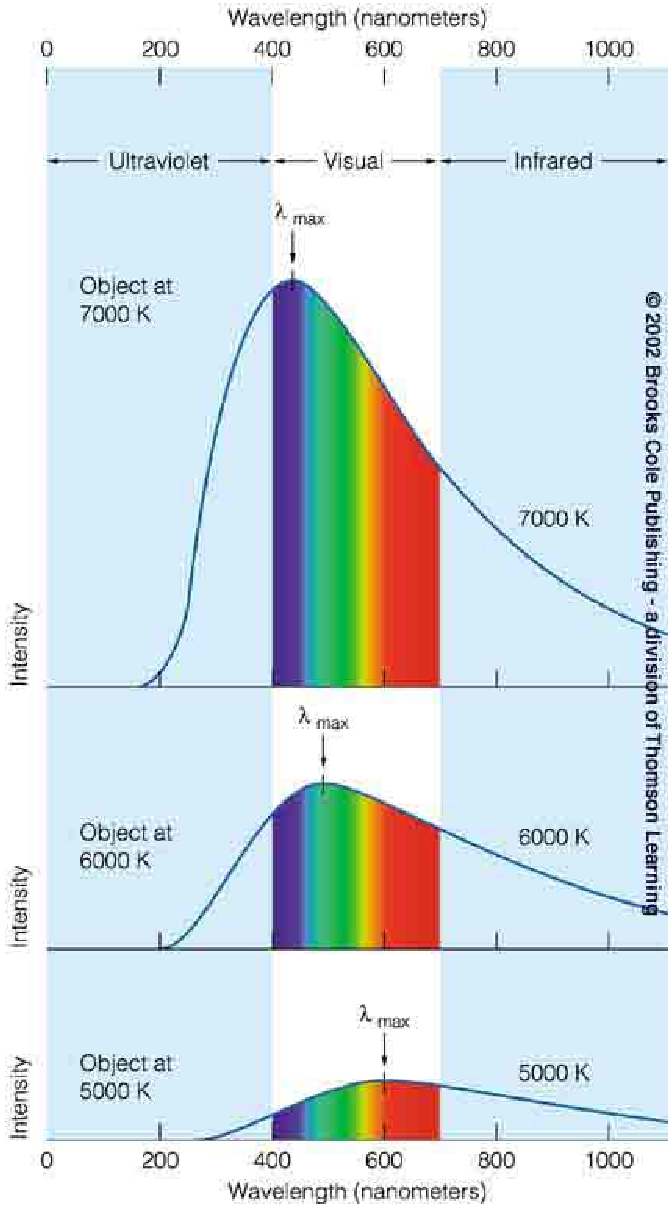
- Reason for name "Black Body Radiation"
  - A material which reflects light also has trouble emitting it:
    - reflectance + absorbance + transmission = 1
    - reflectance + absorbance = 1 if transmission negligible

  - A black material in one which readily absorbed all wavelengths of light. These turn out to be the same materials which also readily emit all wavelengths when hot.
    - reflectance + emissivity + transmission = 1
    - reflectance + emissivity = 1 if transmission negligible
    - $r + \varepsilon = 1$ (at given λ)
    - In thermal infrared, most materials are opaque so this rule holds (and usually $r \ll 1$, $\varepsilon \cong 1$)

- The hotter the material the more energy it emits as light
  - As you heat up a filament or branding iron, it glows brighter and brighter

- The hotter the material the more readily it emits high energy (blue) photons
  - As you heat up a filament or branding iron, it first glows dull red, then bright red, then orange, then if you continue, yellow, and eventually blue

Planck and other Formulae



- Planck formula gives intensity of light at each wavelength

$$B(\lambda, T) = \frac{C_1 \lambda^{-5}}{e^{C_2/(\lambda T)} - 1}$$

  - It is complicated. Often we'll use two simpler formulae which can be derived from it.

- Wien's law tells us what wavelength has maximum intensity

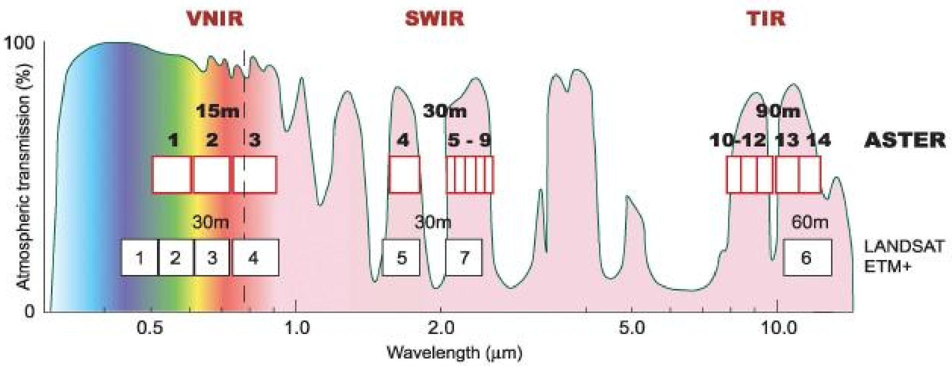
$$\lambda_{Max} = \frac{3{,}000{,}000 \text{ nm K}}{T} = \frac{3{,}000\ \mu\text{m K}}{T}$$

- Stefan-Boltzmann law tells us total radiated energy per unit area

$$F = \sigma\, T^4 \text{ where } \sigma = 5.67 \times 10^{-8} \text{ W}/(m^2\ \text{K}^4)$$

From Horizons, by Seeds

TM and Aster Thermal Channels



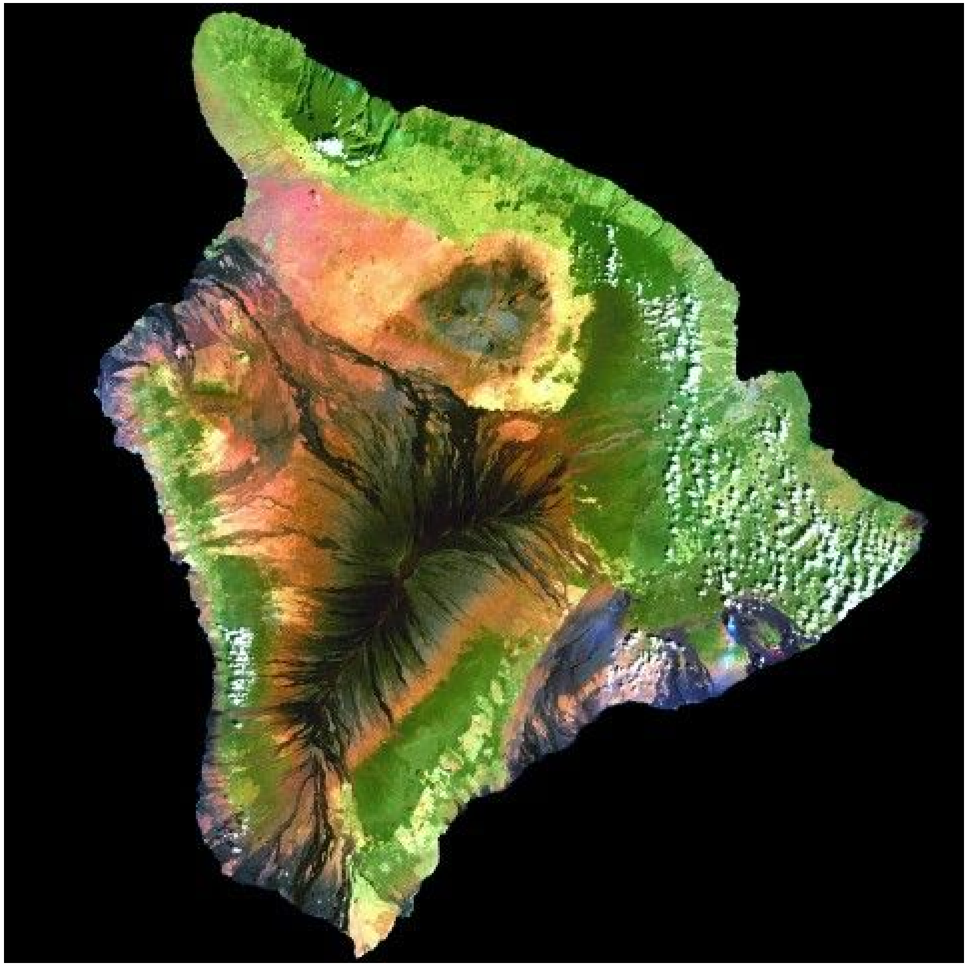
Landsat TM has Band 6 at ~10 µm

120 m resolution on TM

60 m resolution on ETM+ (Landsat 7)

Aster has bands 10-14, 90 m resolution

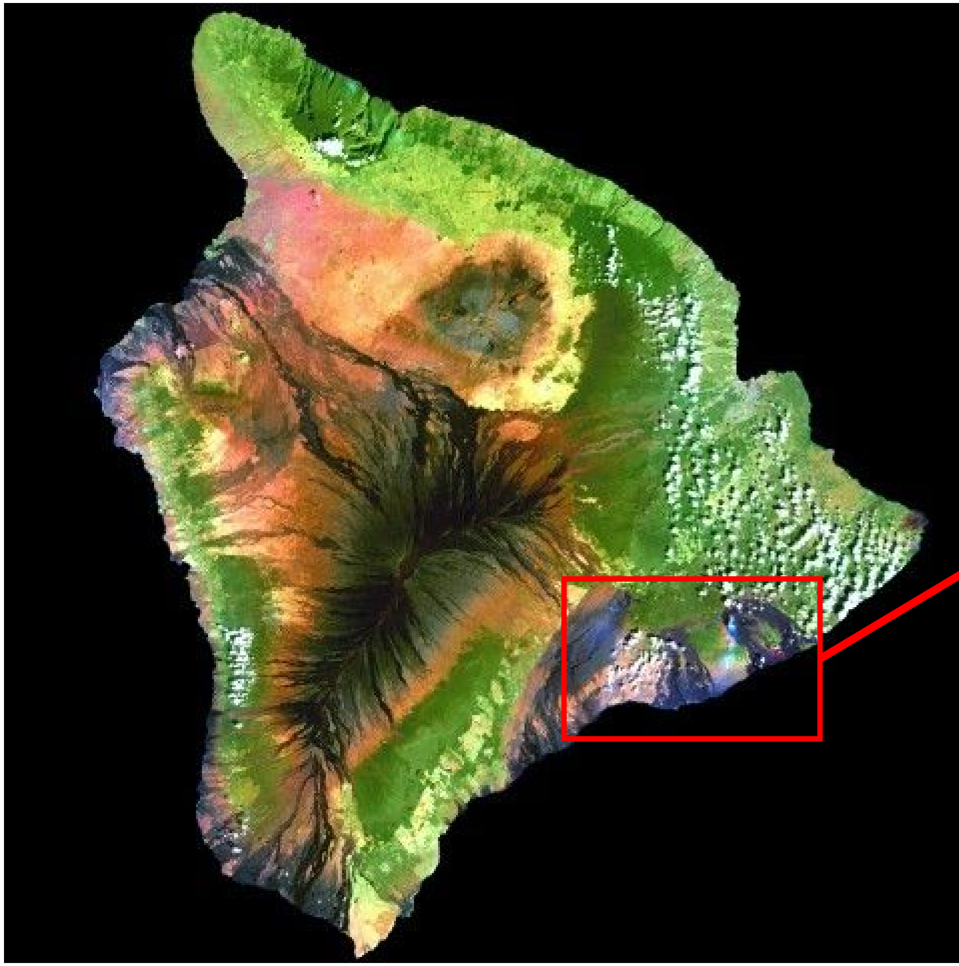
Big Island of Hawaii



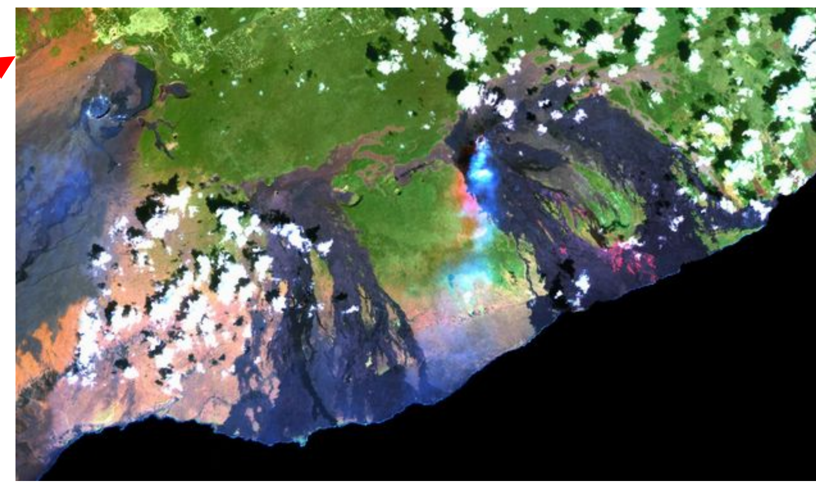
Hot objects glow (emit light)

Landsat Mosaic

Big Island of Hawaii

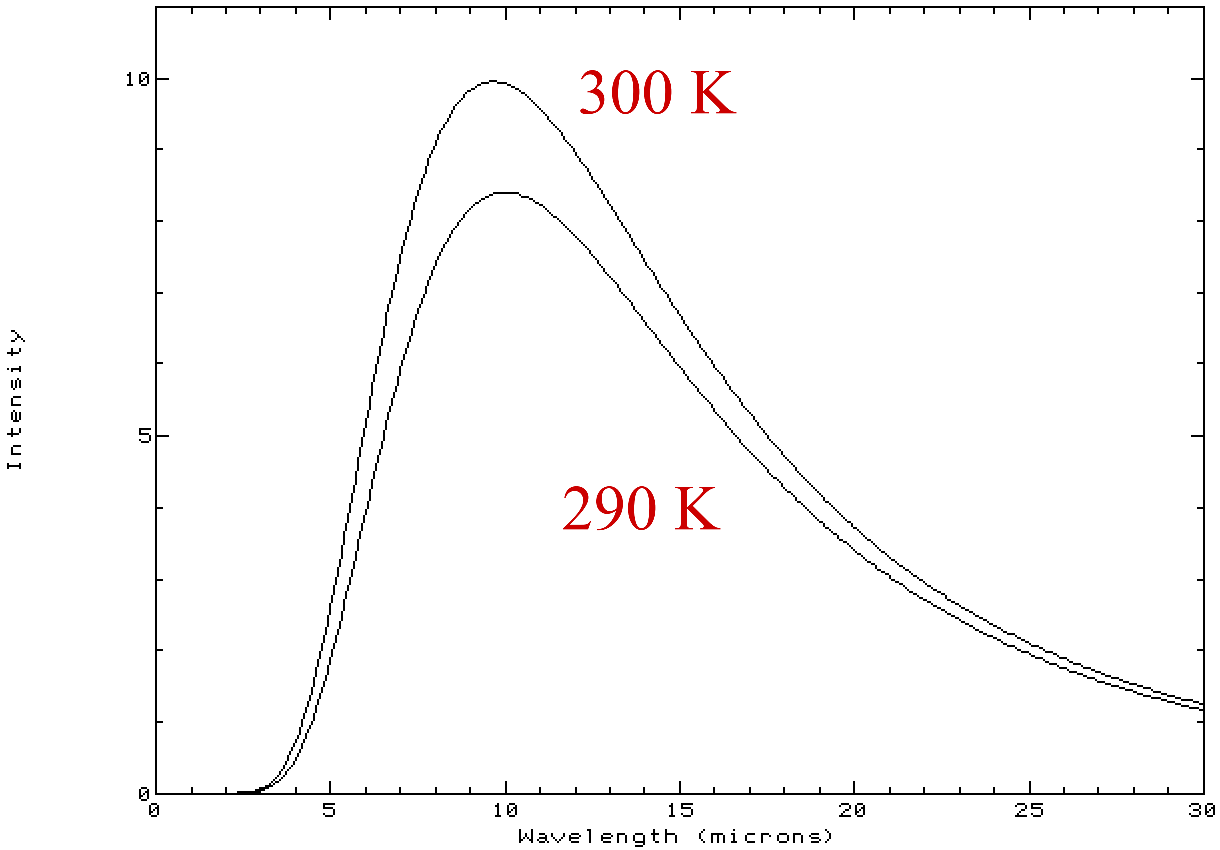


Kilauea



Landsat Mosaic

Planck Blackbody Curves

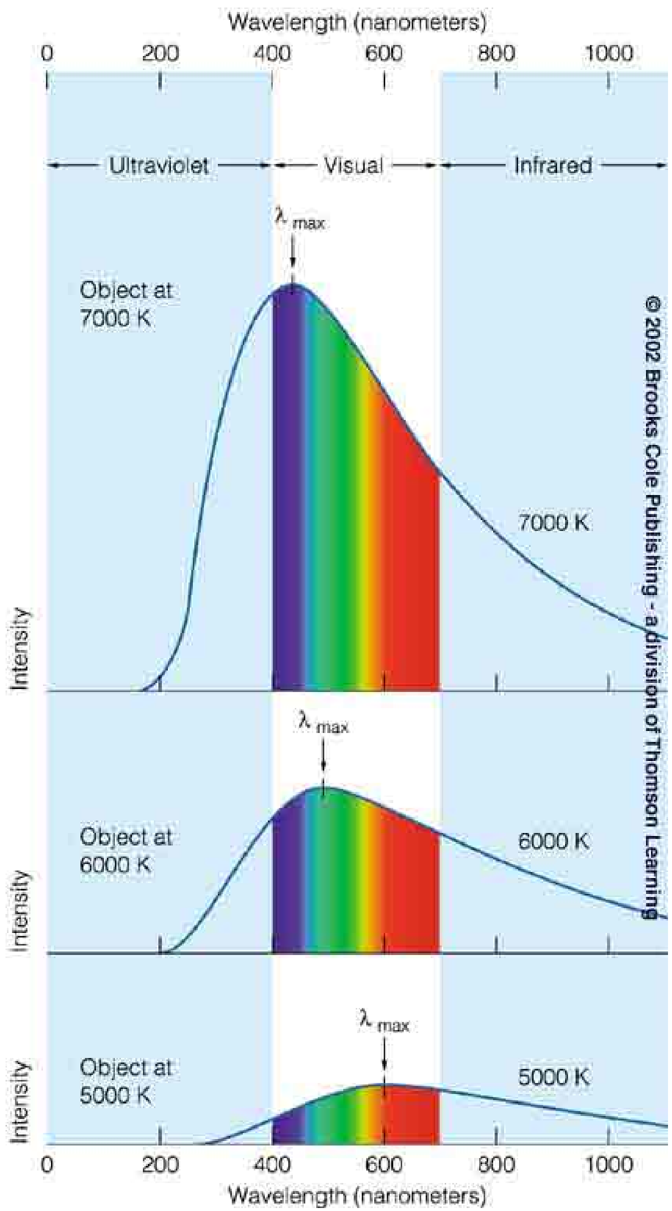


$$B(\lambda, T) = \frac{C_1 \lambda^{-5}}{e^{C_2/(\lambda T)} - 1}$$

Units of I (or B)

Watts m^{-2} μm^{-1} str^{-1}

Color Temperature vs. Brightness Temperature



From Horizons, by Seeds

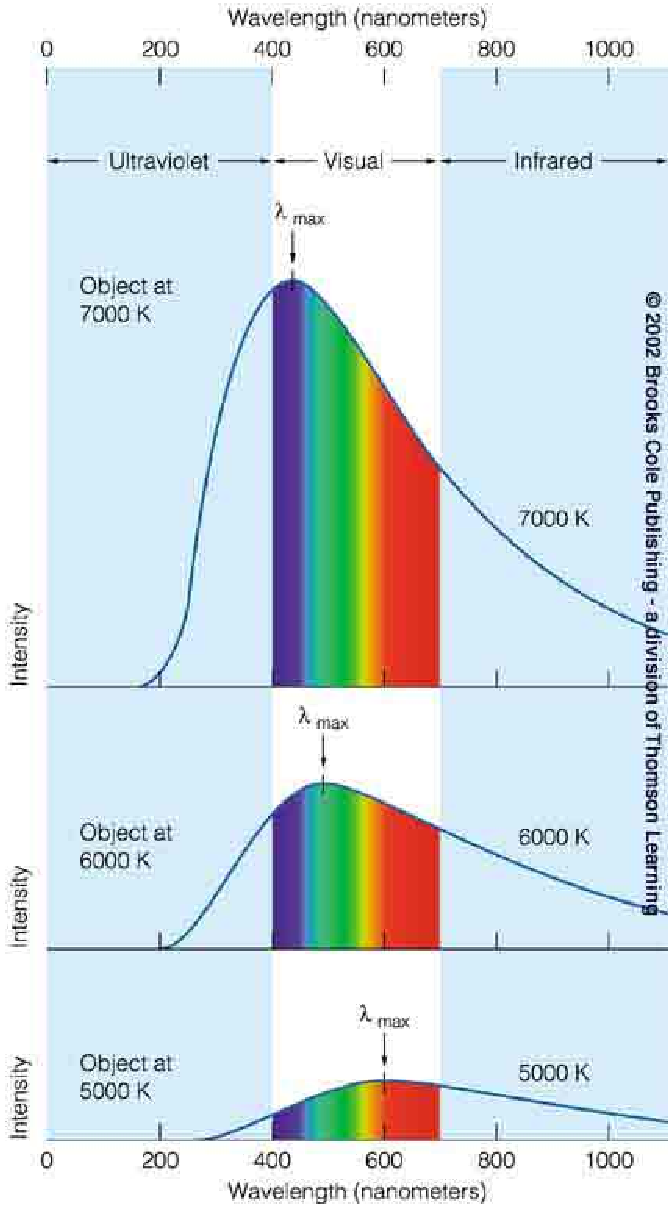
- If you measure intensity at many wavelengths, find λ where I is maximum (i.e. intensity λ_{max}) then use Wien's law to solve for T
- $\lambda_{Max} = \frac{3{,}000\ \mu\text{m K}}{T} \quad \frac{3{,}000\ \mu\text{m K}}{\lambda_{Max}}$
- Examples – Room T, Volcanic T

$$T = \frac{3{,}000\ \mu\text{m K}}{10\ \mu m} = 300\ K \quad T = \frac{3{,}000\ \mu\text{m K}}{3\ \mu m} = 1000\ K$$

- Advantage of color T: Don't need to know area of source.
- Even if you just know I at two λ you can find color T because ratio $I_1/I_2 = B(\lambda_1,T)/B(\lambda_2,T)$ doesn't depend on area
  Can solve (complicated equation) for T

$$B(\lambda, T) = \frac{C_1 \lambda^{-5}}{e^{C_2/(\lambda T)} - 1}$$

Color Temperature vs. Brightness Temperature



From Horizons, by Seeds

- If you know area of source so you have measured I or F then you can solve for Brightness Temperature using either Stefan-Boltzmann equation or Planck's Equation

$$F = \sigma\ T^4 \text{ where } \sigma = 5.67\times10^{-8}\ \mathrm{W}/(m^2\ \mathrm{K}^4)$$

$$T = (F/\sigma)^{1/4}$$

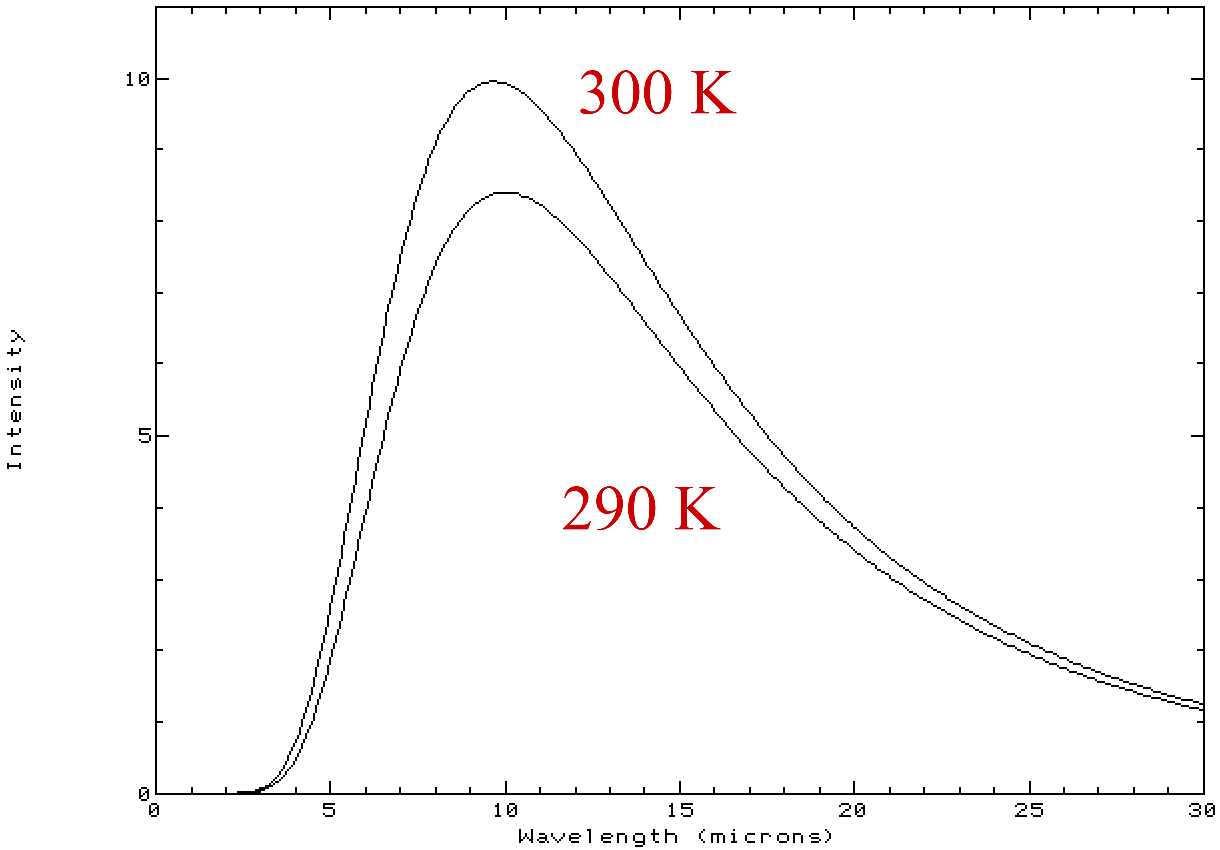
$$T = \left(459\ W\ m^{-2} / \left(5.67\times10^{9} W\ m^{-2}\ K^{-4}\right)\right)^{1/4}$$

$$= \left(8.1\times10^{9}\ K^4\right)^{1/4} = 300\ K$$

$$B(\lambda, T) = \frac{C_1 \lambda^{-5}}{e^{C_2/(\lambda\ T)} - 1}$$

$$T = \frac{C_2}{\lambda\ \ln\left[\left|C_1/(I\ \lambda^5) + 1\right|\right]}$$

Planck Blackbody Curves

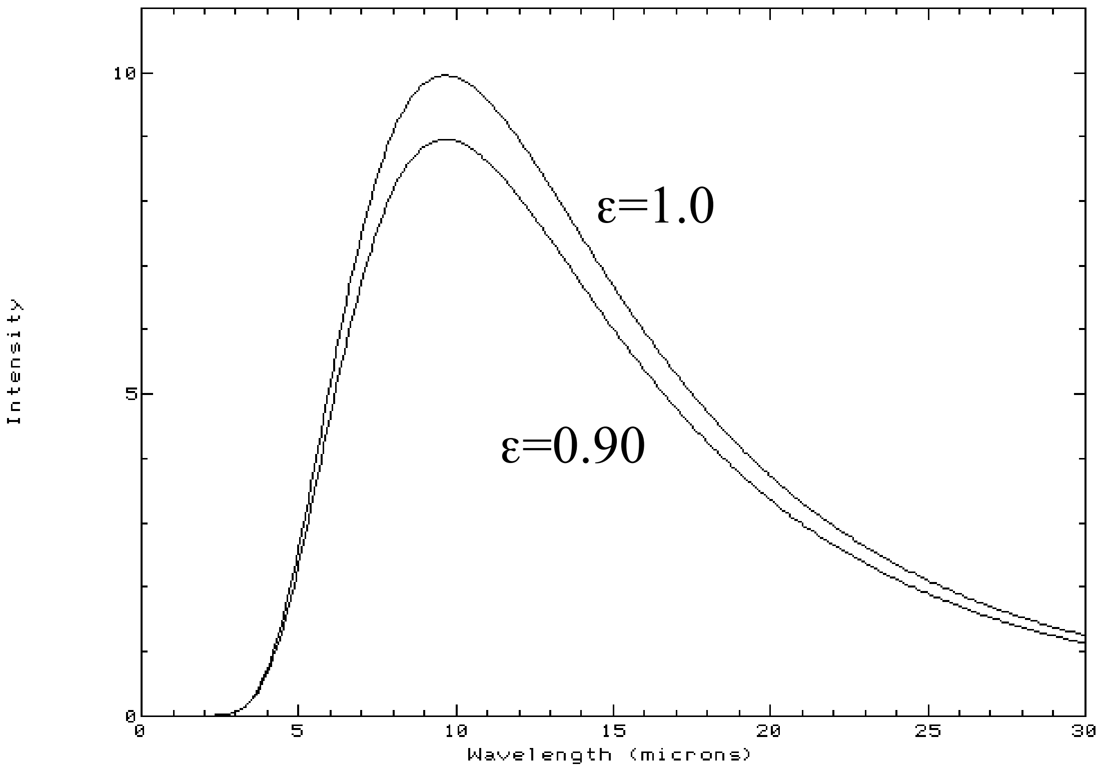


$$B(\lambda, T) = \frac{C_1 \lambda^{-5}}{e^{C_2/(\lambda T)} - 1}$$

Units of I (or B)

Watts m^{-2} μm^{-1} str^{-1}

Actual Thermal Emission Curves



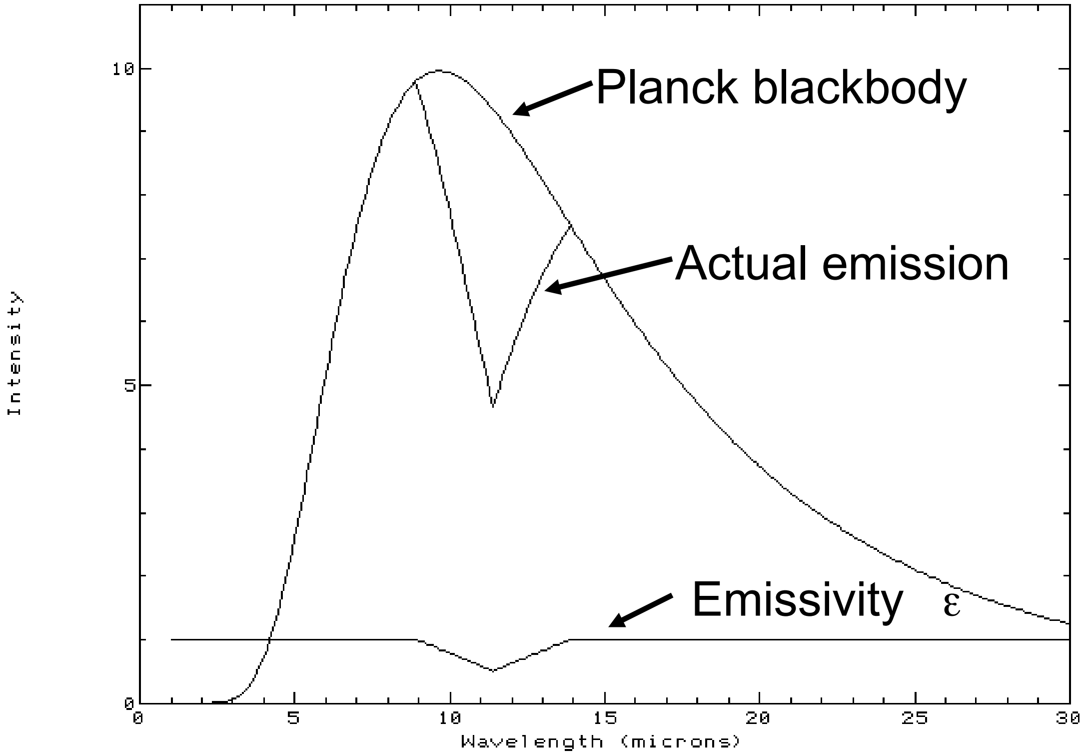
$$B(\lambda, T) = \frac{C_1 \lambda^{-5}}{e^{C_2/(\lambda T)} - 1}$$

$$\varepsilon(\lambda) = 1 - r(\lambda)$$

$$\varepsilon(\lambda) + r(\lambda) = 1$$

Example where emissivity = 0.9 over all wavelengths

Actual Thermal Emission Curves



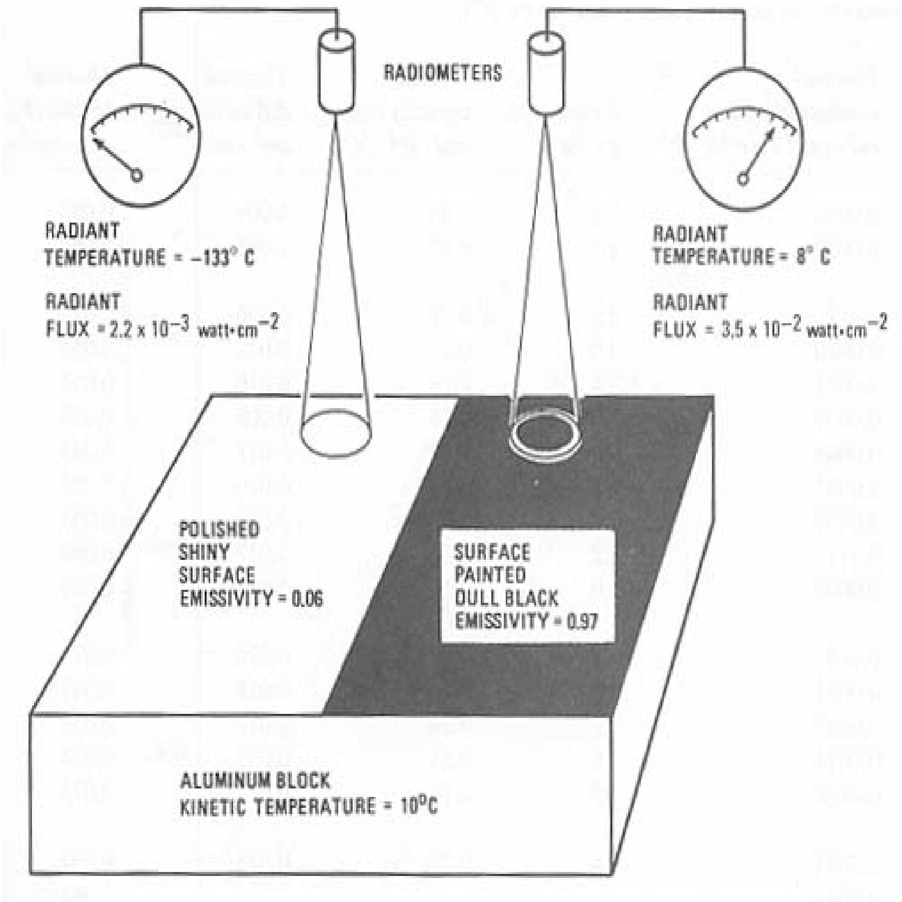
$$B(\lambda, T) = \frac{C_1 \lambda^{-5}}{e^{C_2/(\lambda T)} - 1}$$

$$\varepsilon(\lambda) = 1 - r(\lambda)$$

$$\varepsilon(\lambda) + r(\lambda) = 1$$

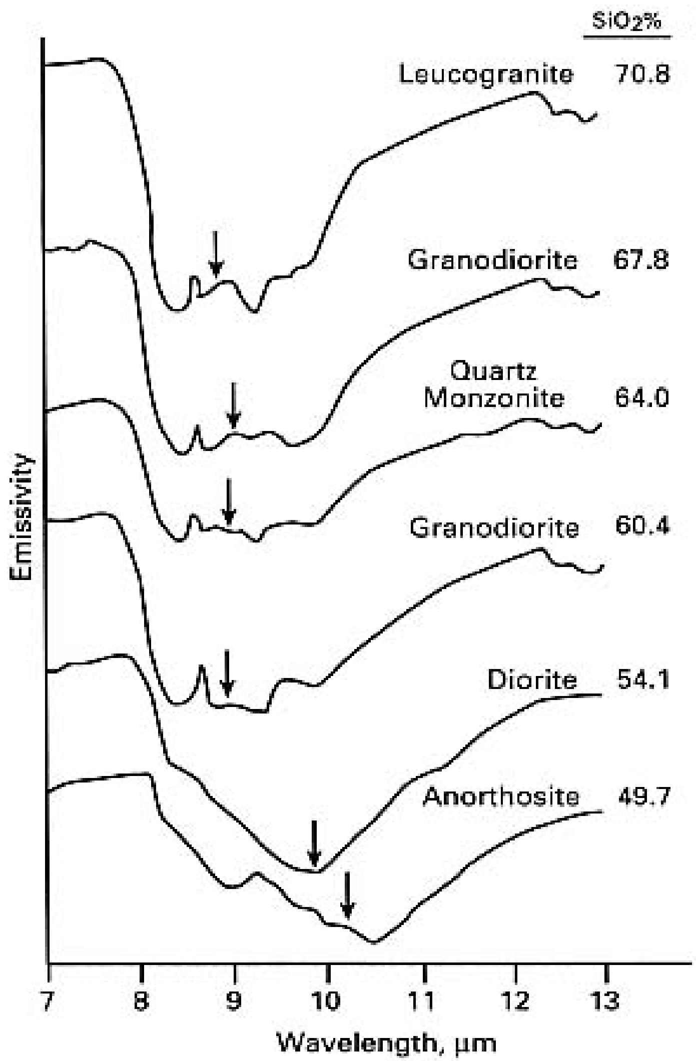
Example where emissivity drops below 1 from 9 to 14 μm

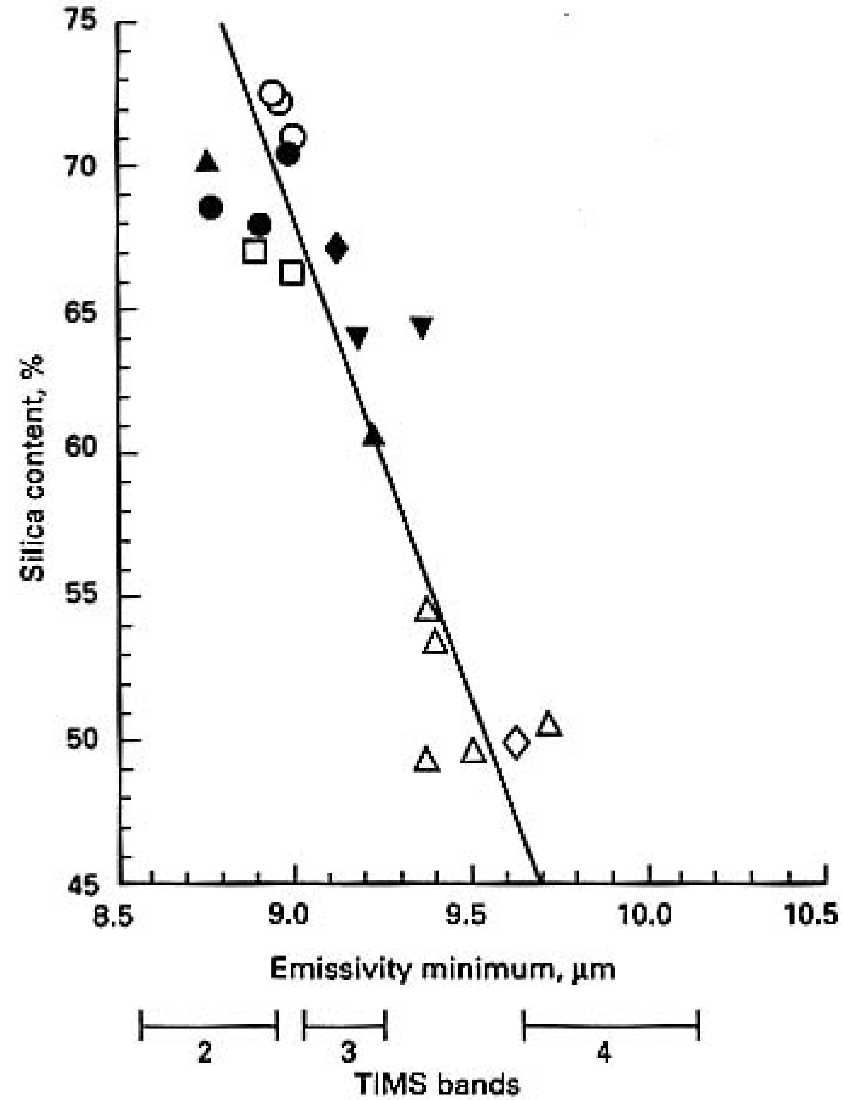
Emissivity of Materials



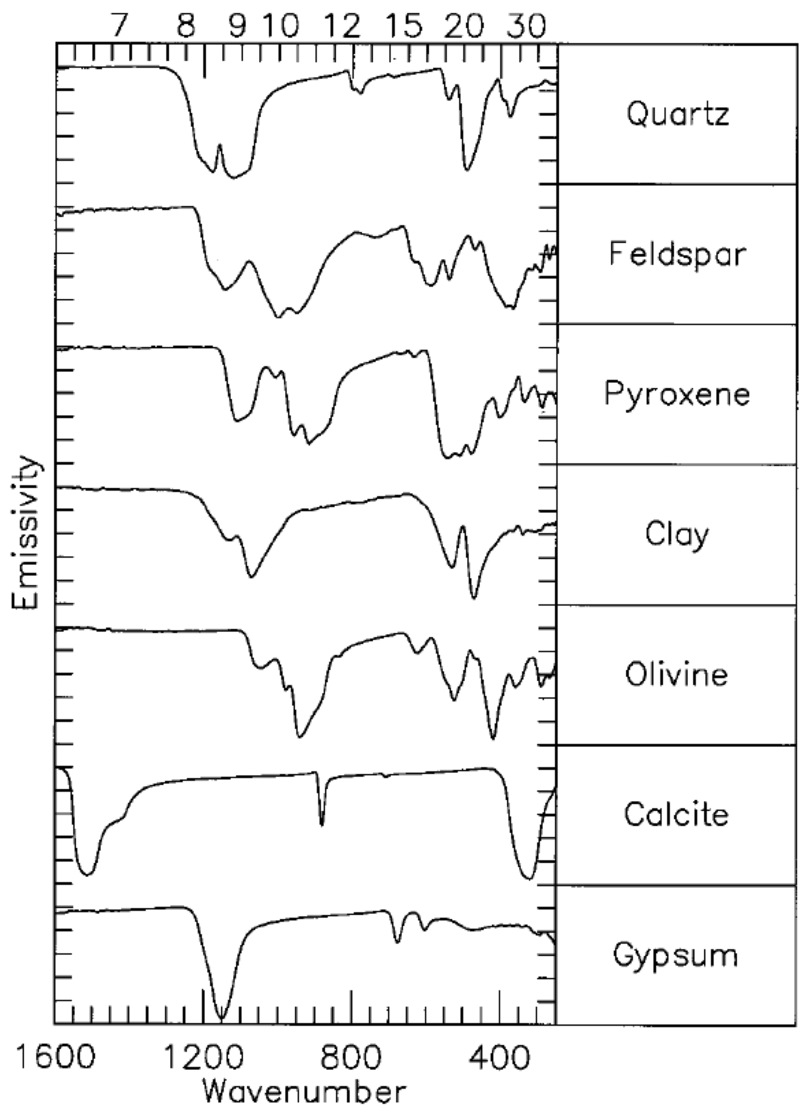
Material	Emissivity, ε
water, distilled	0.99
water	0.92 – 0.98
water with petroleum film	0.972
concrete	0.71 – 0.90
asphalt	0.95
tar/stone	0.97
loamy soil, dry	0.92
loamy soil, wet	0.95
soil, sandy	0.90
brick, red and rough	0.93
vegetation, closed canopy	0.98
vegetation, open canopy	0.96
grass	0.97
wood, planed oak	0.90
deciduous forest	0.97 – 0.98
coniferous forest	0.97 – 0.99
stainless steel	0.16
aluminum, foil	0.05
aluminum, polished	0.08
aluminum, paint	0.55
polished metals	0.16 – 0.21
oxidized steel	0.70
granite	0.86
dunite	0.78
basalt, rough	0.95
snow	0.83 – 0.85
paint	0.90 – 0.96
human skin	0.98

Emissivity minimum and silica %





Emissivity for other minerals



Mars "TES" Results