Quick Review of Remote Sensing Basic Theory

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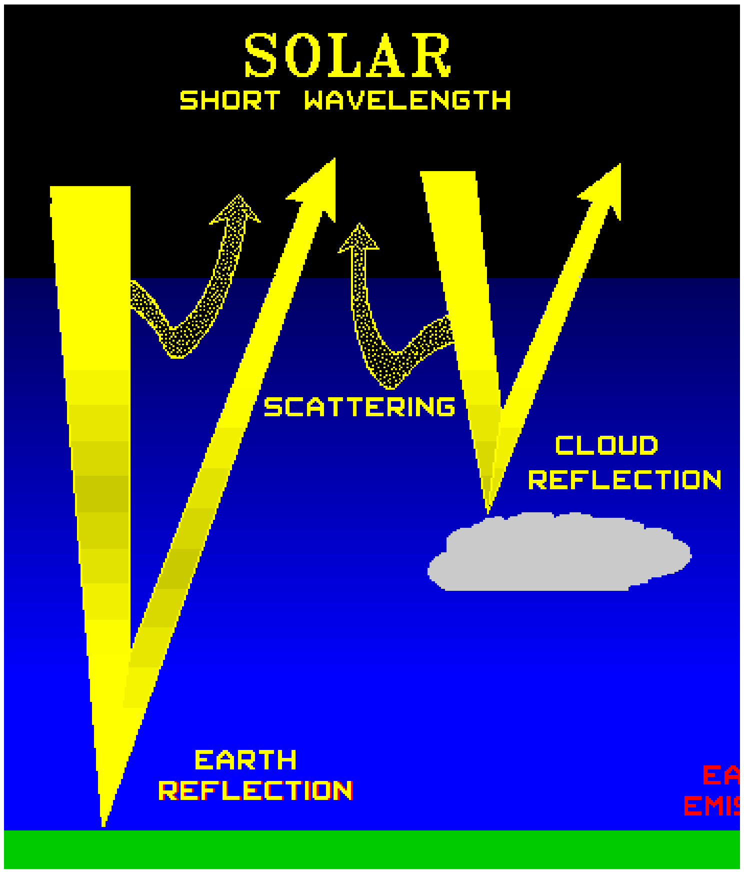
Outline

- Visible and Near Infrared: Vegetation
- Planck Function
- Infrared: Thermal Sensitivity

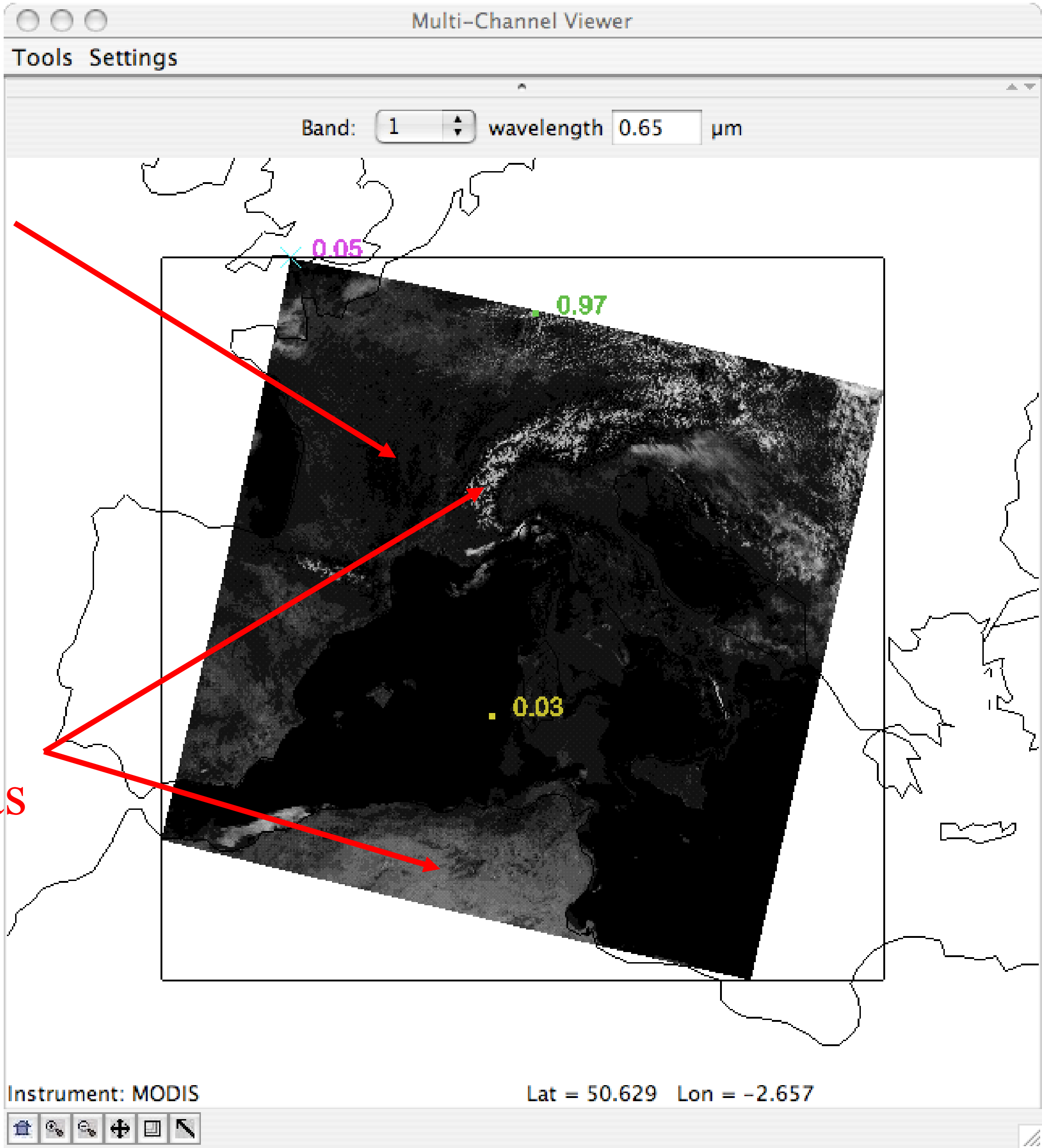
Visible
(Reflective Bands)



MODIS BAND 1 (RED)

Low reflectance in
Vegetated areas

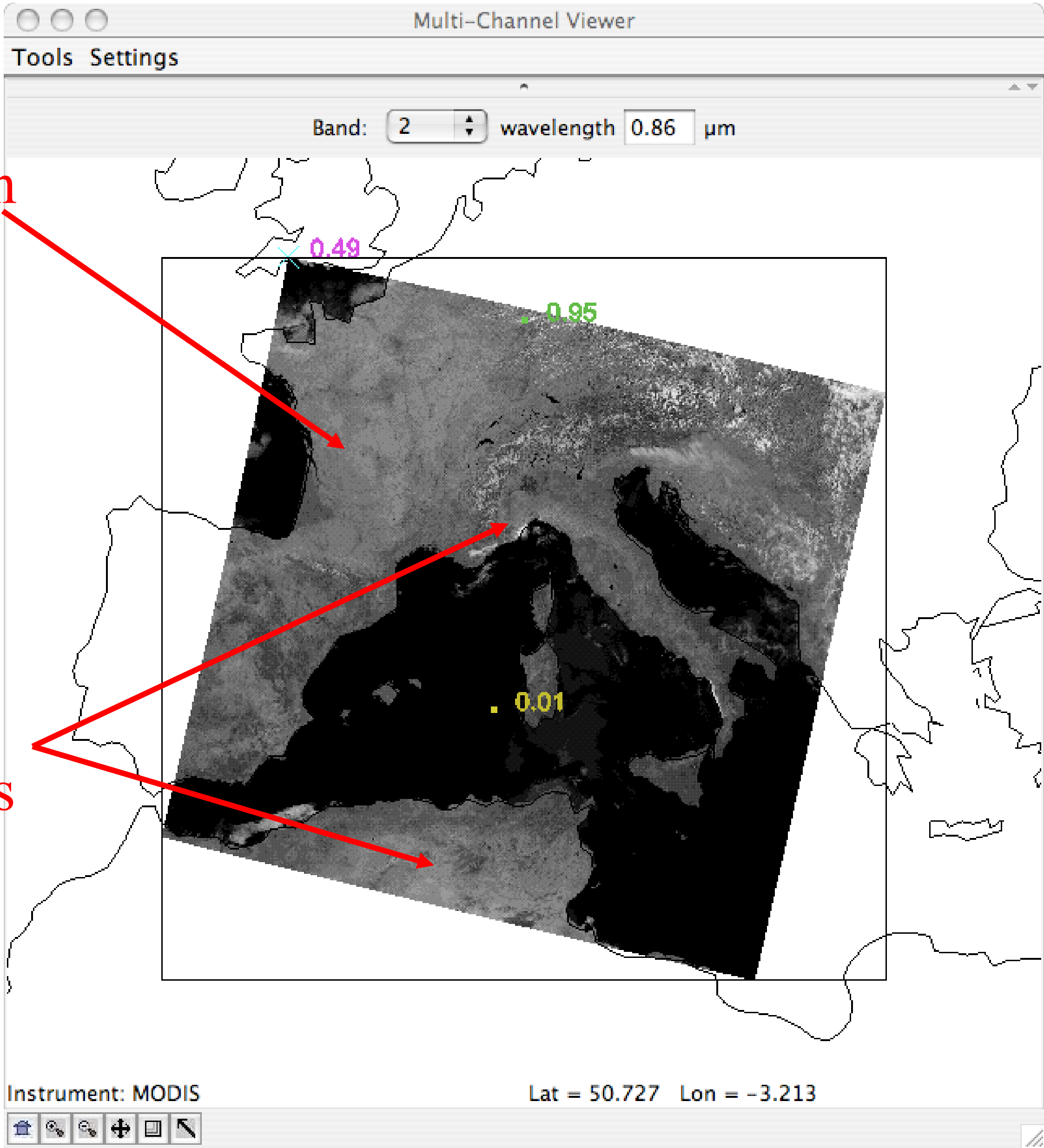
Higher reflectance in
Non-vegetated land areas

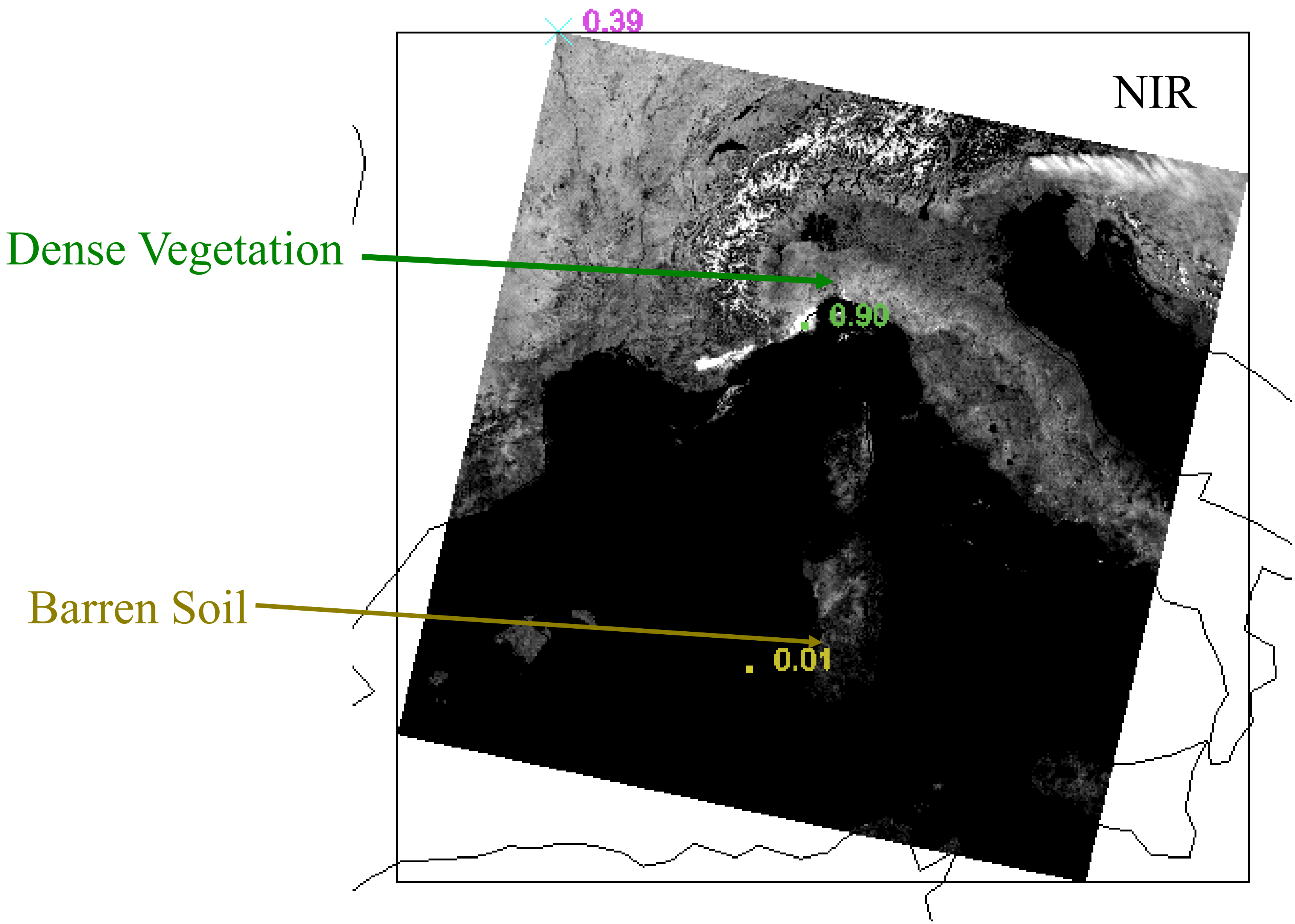


MODIS BAND 2 (NIR)

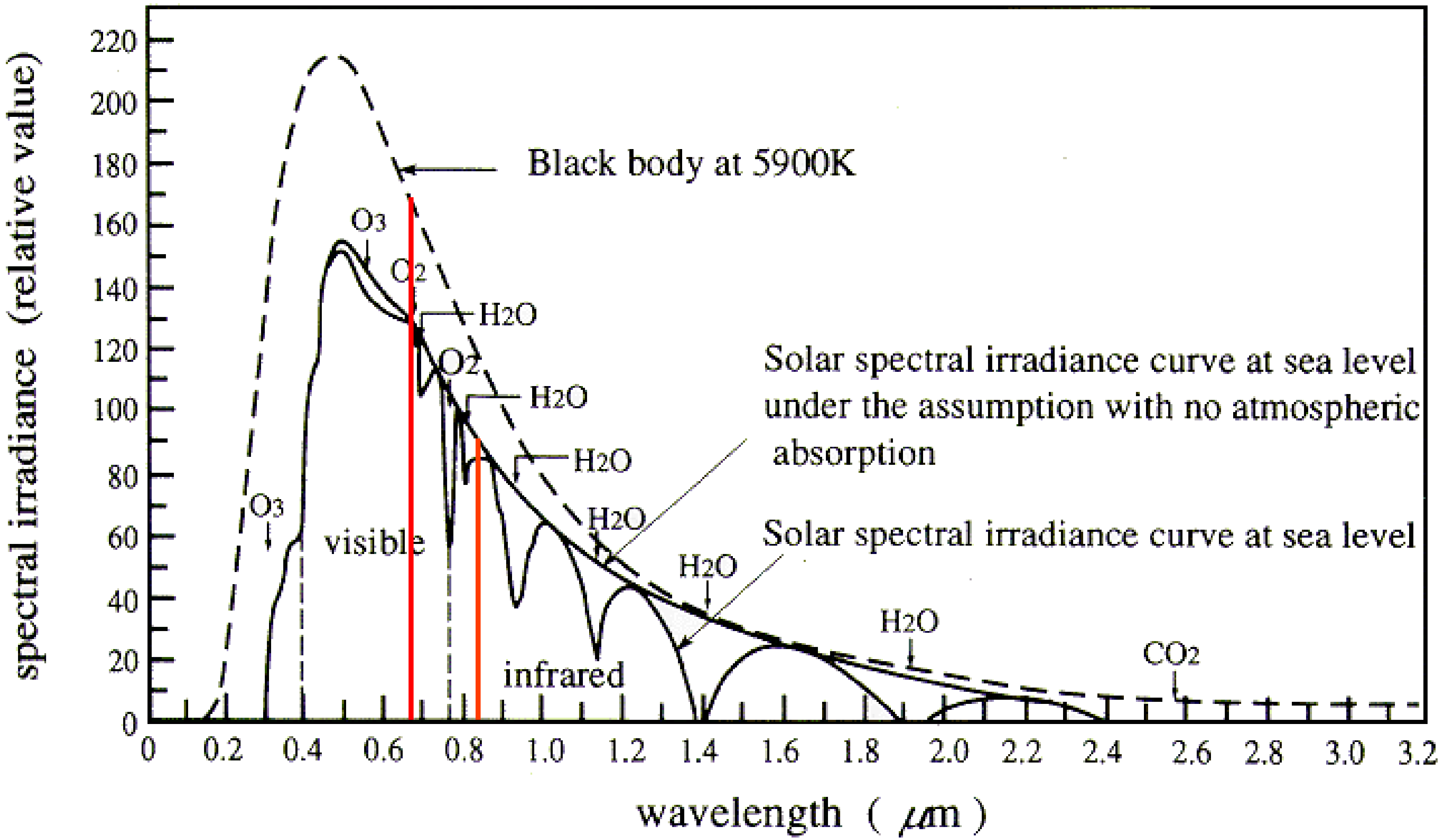
Higher reflectance in Vegetated areas

Lower reflectance in Non-vegetated land areas

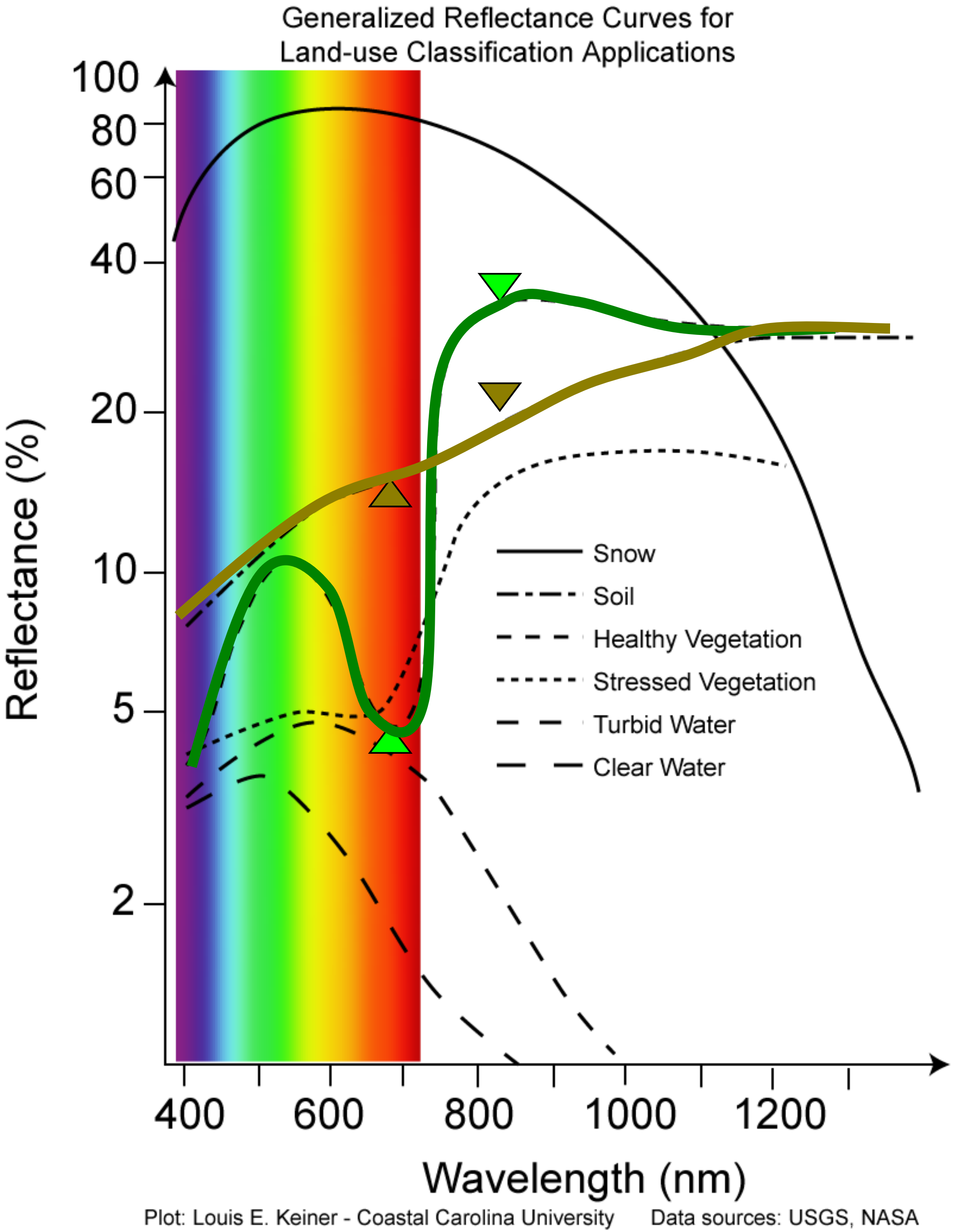




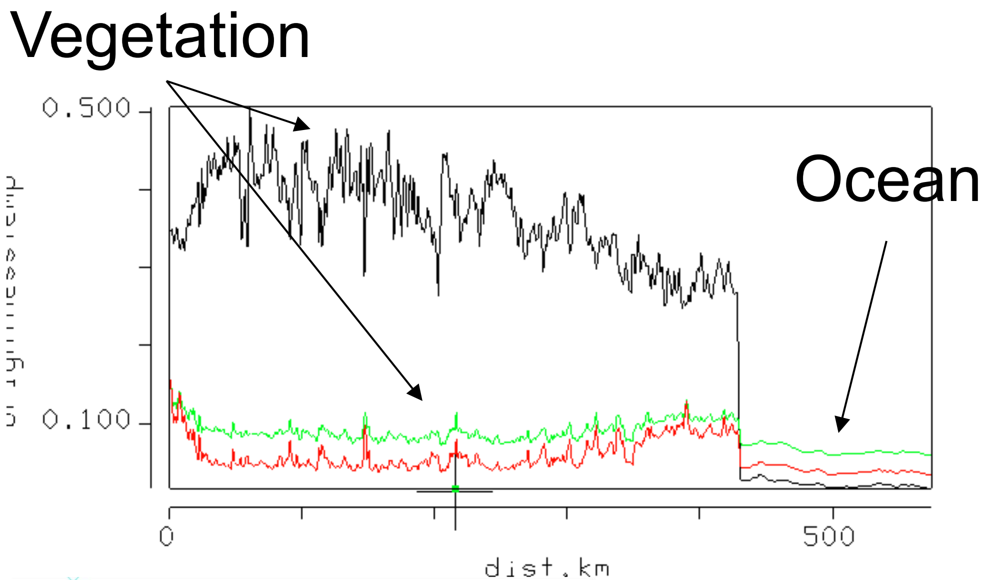
0.39
NIR
Dense Vegetation
0.90
Barren Soil
0.01



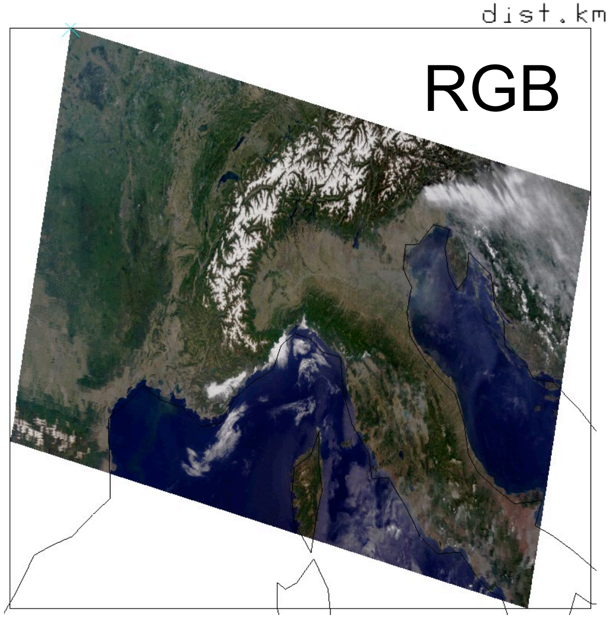
Comparison of spectral irradiance of solar light at sea level with black body radiation

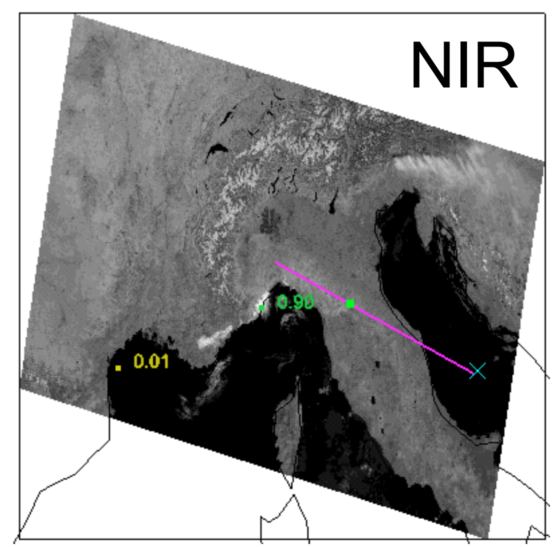

Generalized Reflectance Curves for
Land-use Classification Applications
100
80
60
40
20
10
5
2
Reflectance (%)
400
600
800
1000
1200
Wavelength (nm)
Snow
Soil
Healthy Vegetation
Stressed Vegetation
Turbid Water
Clear Water
Plot: Louis E. Keiner - Coastal Carolina University
Data sources: USGS, NASA

NIR and VIS over Vegetation and Ocean

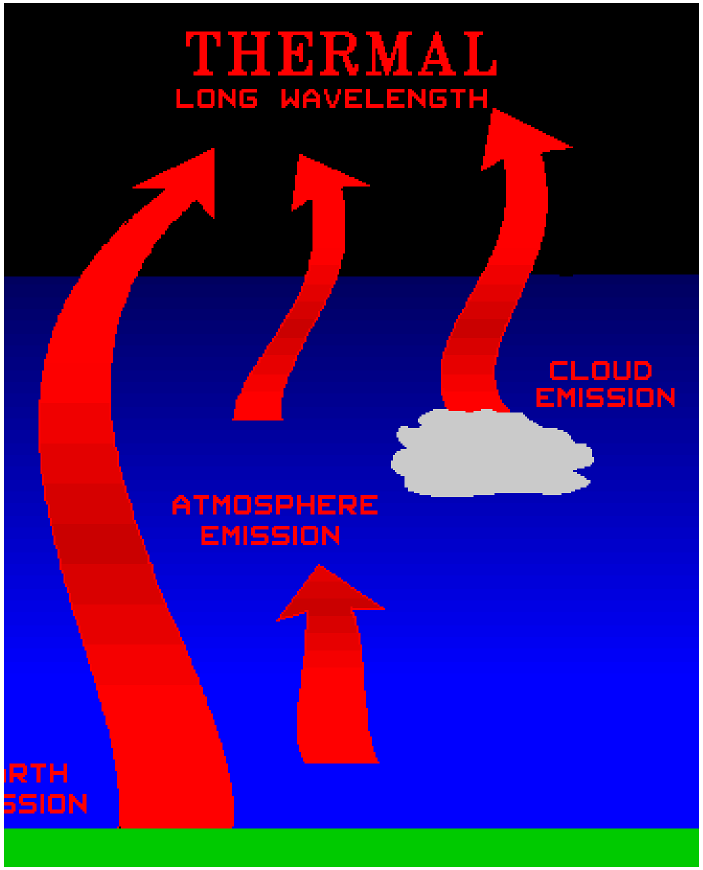


NIR (.86 micron)
Green (.55 micron)
Red (0.67 micron)

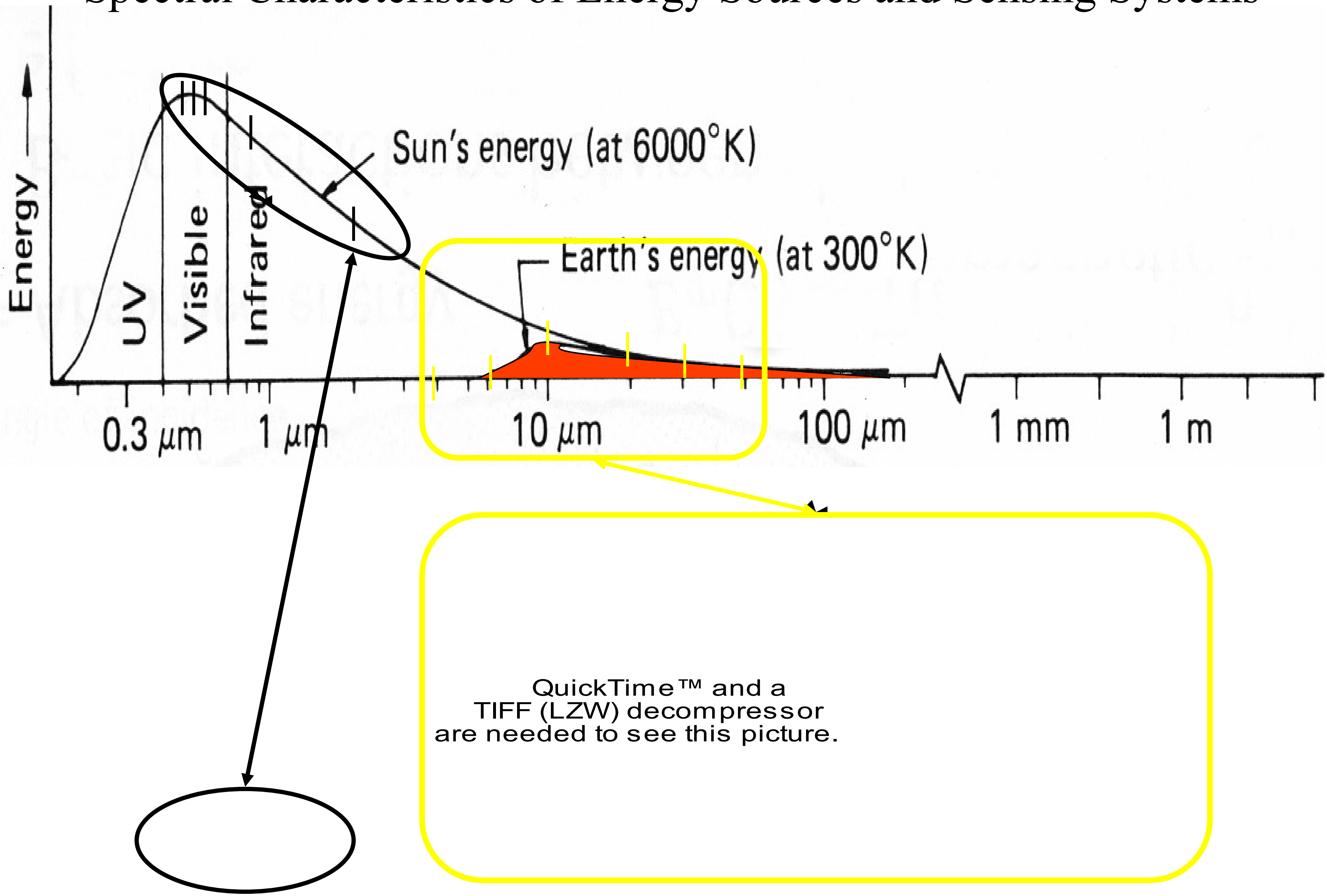




Infrared
(Emissive Bands)

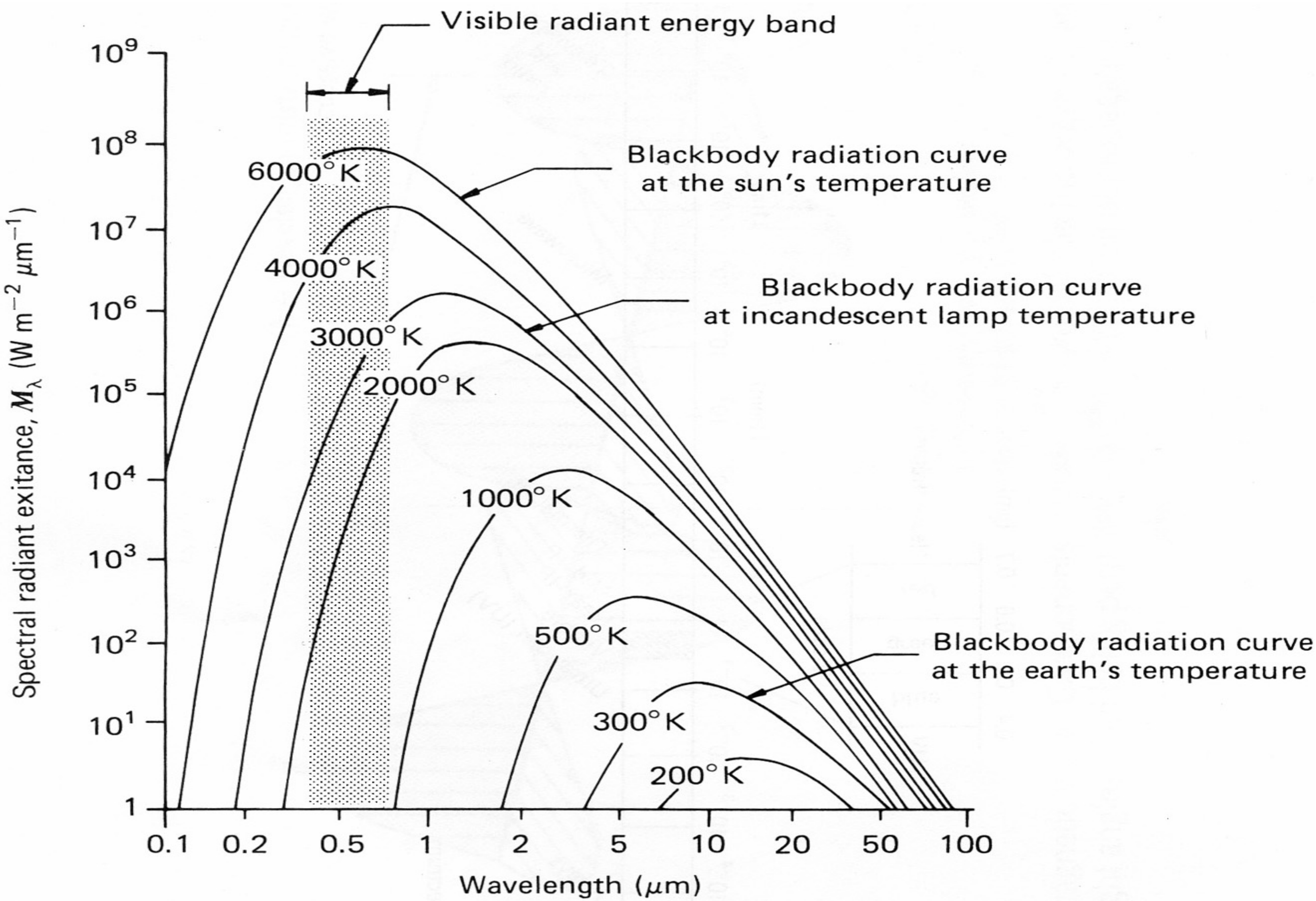


Spectral Characteristics of Energy Sources and Sensing Systems



QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Spectral Distribution of Energy Radiated from Blackbodies at Various Temperatures



Radiation is governed by Planck's Law

In wavelenght:

$$B(\lambda,T) = c_1 / \{ \lambda^5 [e^{c2/\lambda T} - 1] \} \ (mW/m^2/ster/cm)$$

where λ = wavelength (cm)

T = temperature of emitting surface (deg K)

c_1 = 1.191044 x 10-8 ($W/m^2/ster/cm^{-4}$)

c_2 = 1.438769 (cm deg K)

In wavenumber:

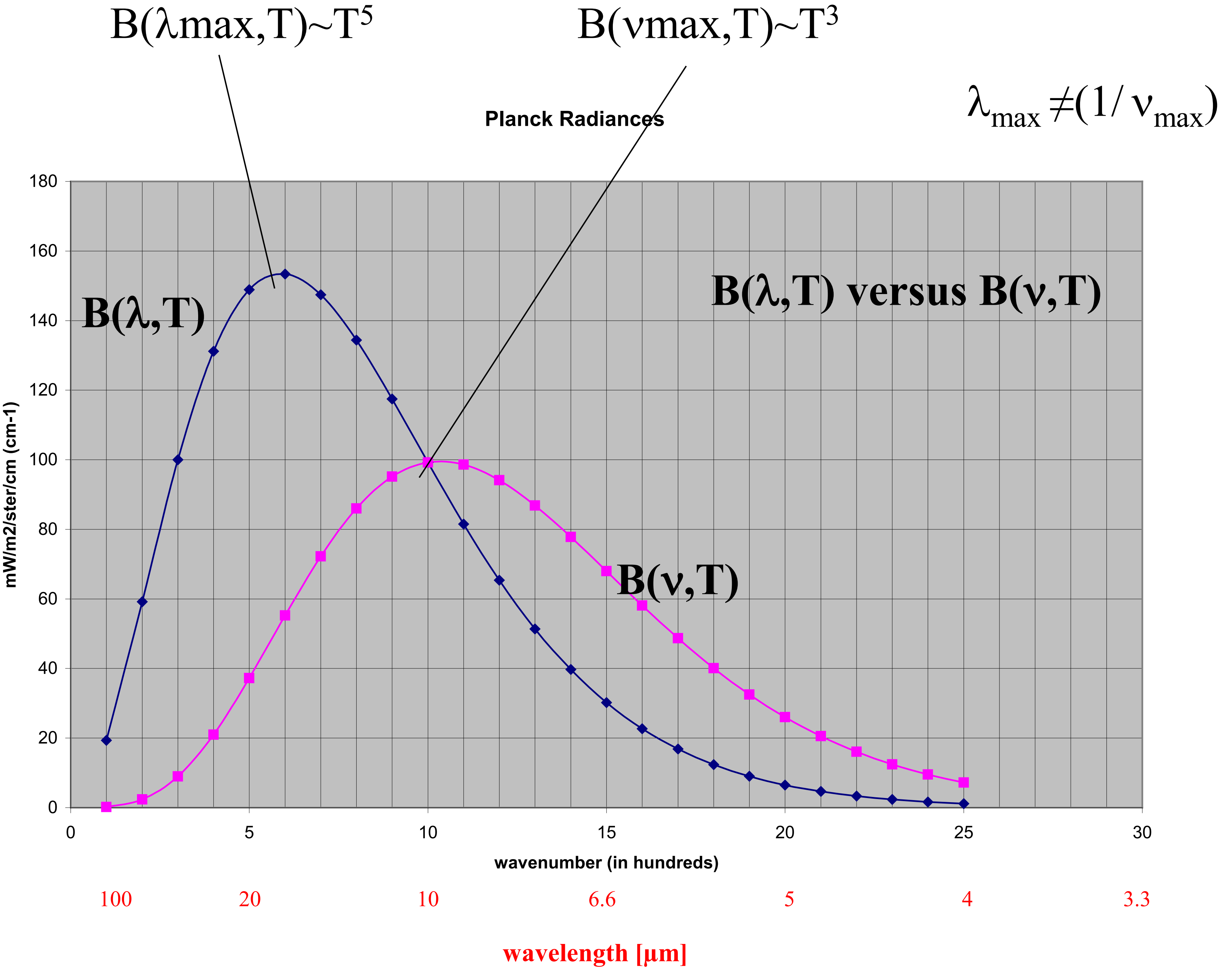
$$B(\nu,T) = c_1 \nu^3 / [e^{c2\nu/T} - 1] \quad (mW/m^2/ster/cm^{-1})$$

where ν = # wavelengths in one centimeter (cm-1)

T = temperature of emitting surface (deg K)

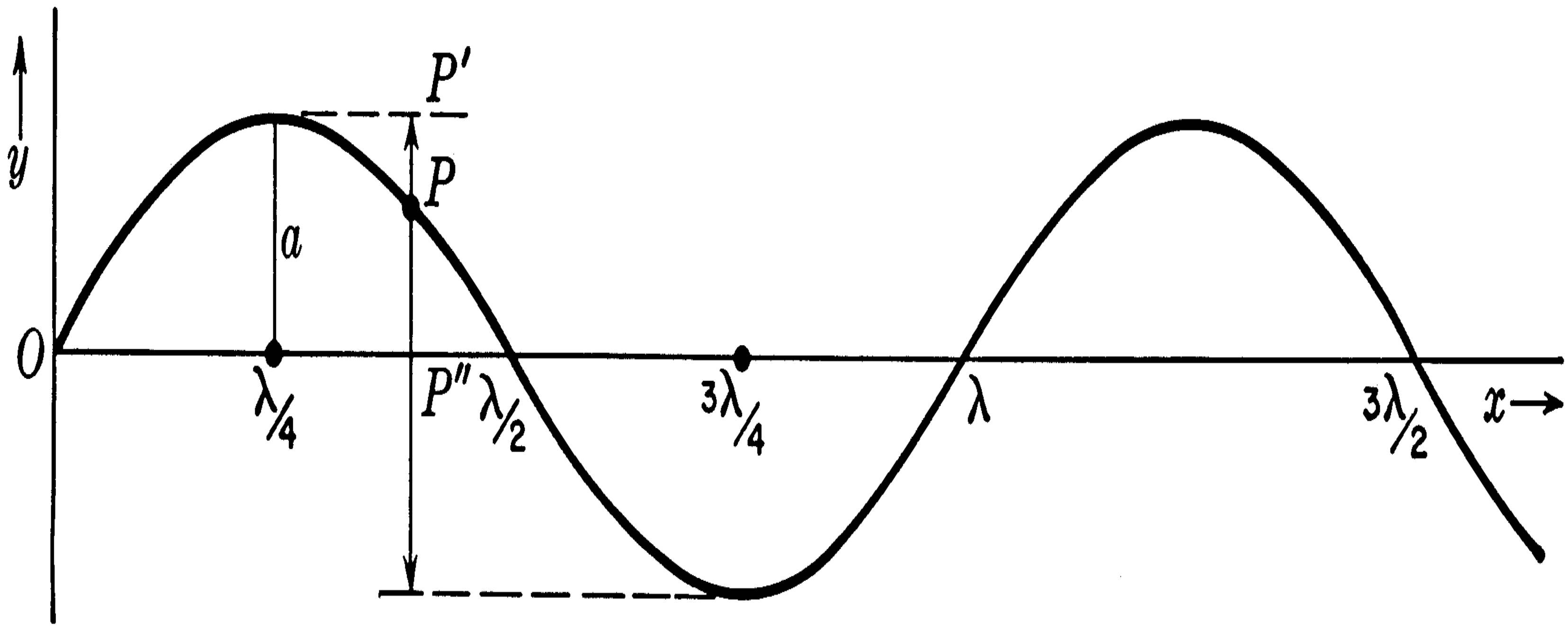
c_1 = 1.191044 x 10-5 ($mW/m^2/ster/cm^{-4}$)

c_2 = 1.438769 (cm deg K)



B(λmax,T)~T5
B(νmax,T)~T3
$\lambda_{max} \neq (1/\nu_{max})$
Planck Radiances
B(λ,T)
B(λ,T) versus B(ν,T)
B(ν,T)
mW/m2/ster/cm (cm-1)
180
160
140
120
100
80
60
40
20
0
0
5
10
15
20
25
30
wavenumber (in hundreds)
100
20
10
6.6
5
4
3.3
wavelength [µm]

wavelength λ : distance between peaks (μm)



wavenumber ν : number of waves per unit distance (cm)

$$\lambda = 1/\nu$$

$$d\lambda = -1/\nu^2 \, d\nu$$

Using wavenumbers

Wien's Law $dB(\nu_{max},T) / dT = 0$ where $\nu(max) = 1.95T$
indicates peak of Planck function curve shifts to shorter wavelengths (greater wavenumbers) with temperature increase. Note $B(\nu_{max},T) \sim T^{**}3$.

Stefan-Boltzmann Law $E = \pi \int_{o}^{\infty} B(\nu,T)\, d\nu = \sigma T^4$, where $\sigma = 5.67 \times 10\text{-}8\ W/m^2/deg^4$.

states that irradiance of a black body (area under Planck curve) is proportional to T^4 .

Brightness Temperature

$$T = c_2\nu/[\ln(\frac{c_1\nu^3}{B_\nu} + 1)]$$ is determined by inverting Planck function

Brightness temperature is uniquely related to radiance for a given wavelength by the Planck function.

Using wavenumbers

$$B(\nu,T) = c_1\nu^3 / [e^{c_2\nu/T} - 1]$$

(mW/m^2/ster/cm^{-1})

ν(max in cm-1) = 1.95T

$B(\nu_{max},T) \sim T^{**}3.$

$$E = \pi \int_o^\infty B(\nu,T)\, d\nu = \sigma T^4,$$

$$T = c_2\nu/[\ln(\frac{c_1\nu^3}{B_\nu} + 1)]$$

Using wavelengths

$$B(\lambda,T) = c_1 / \{ \lambda^5 [e^{c_2/\lambda T} - 1] \}$$

(mW/m^2/ster/cm)

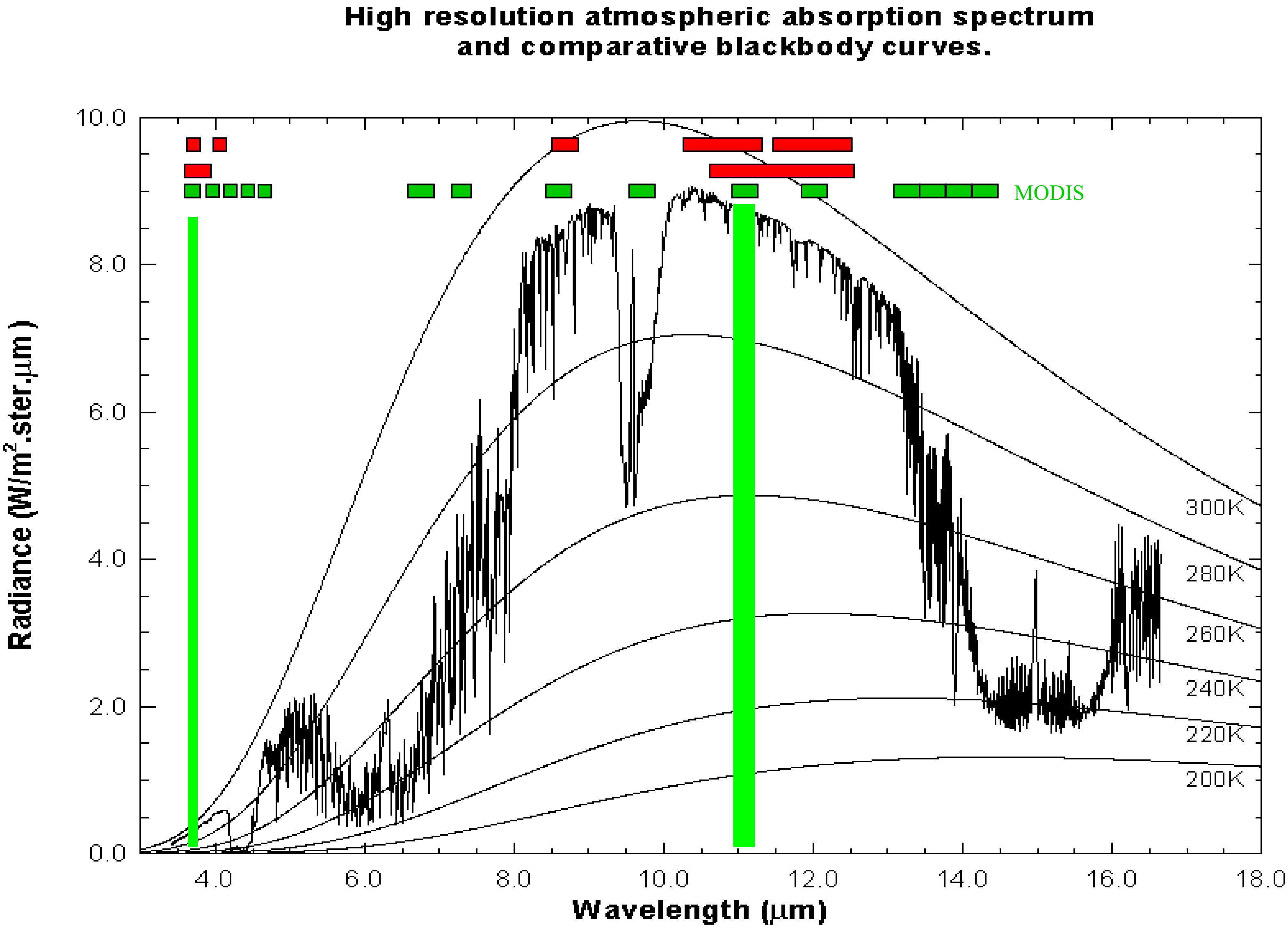
λ(max in cm)T = 0.2897

$B(\lambda_{max},T) \sim T^{**}5.$

$$E = \pi \int_o^\infty B(\lambda,T)\, d\lambda = \sigma T^4,$$

$$T = c_2/[\lambda \ln(\frac{c_1}{\lambda^5 B_\lambda} + 1)]$$

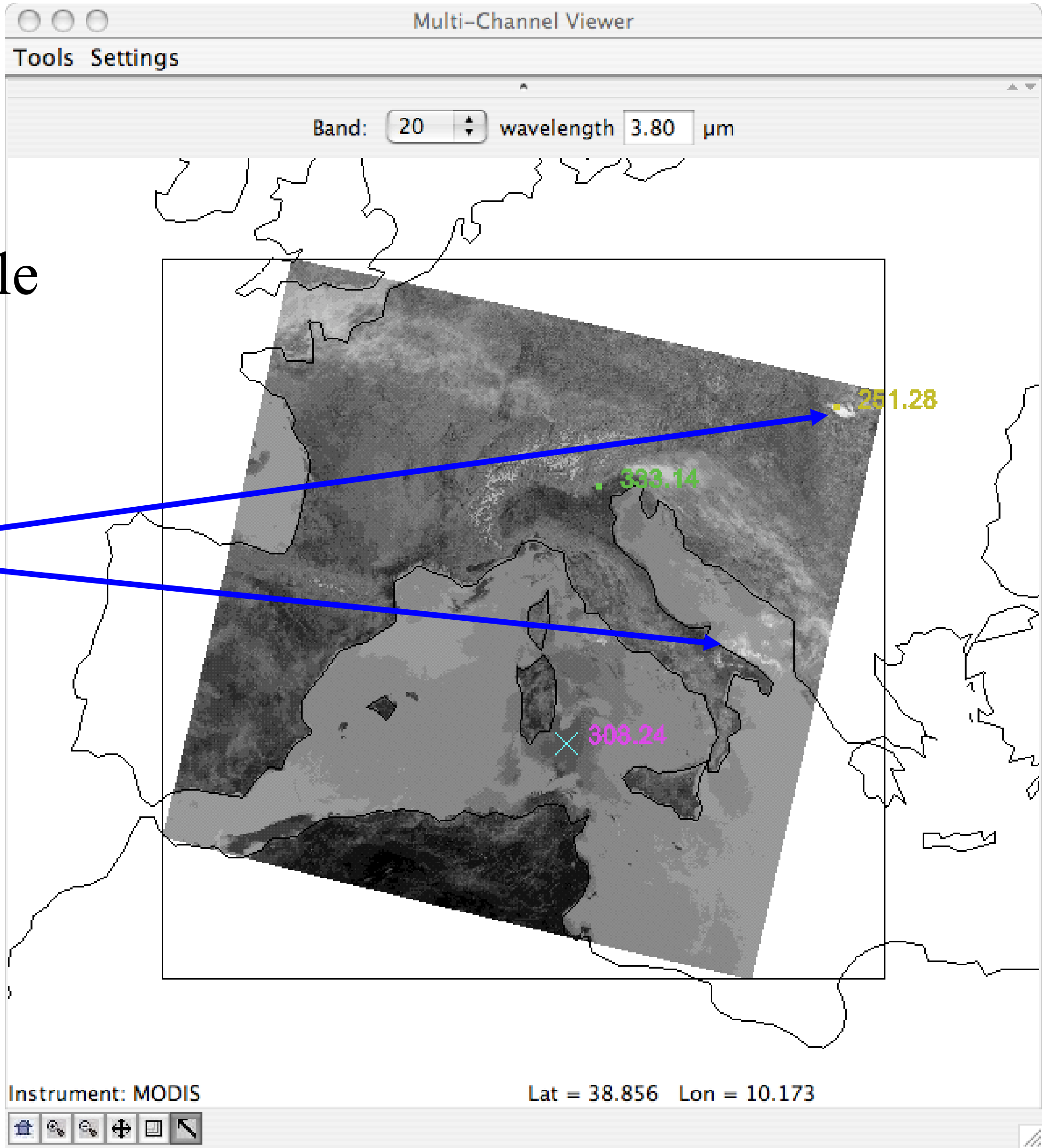
Planck Function and MODIS Bands



MODIS BAND 20

Window Channel:
- little atmospheric absorption
- surface features clearly visible

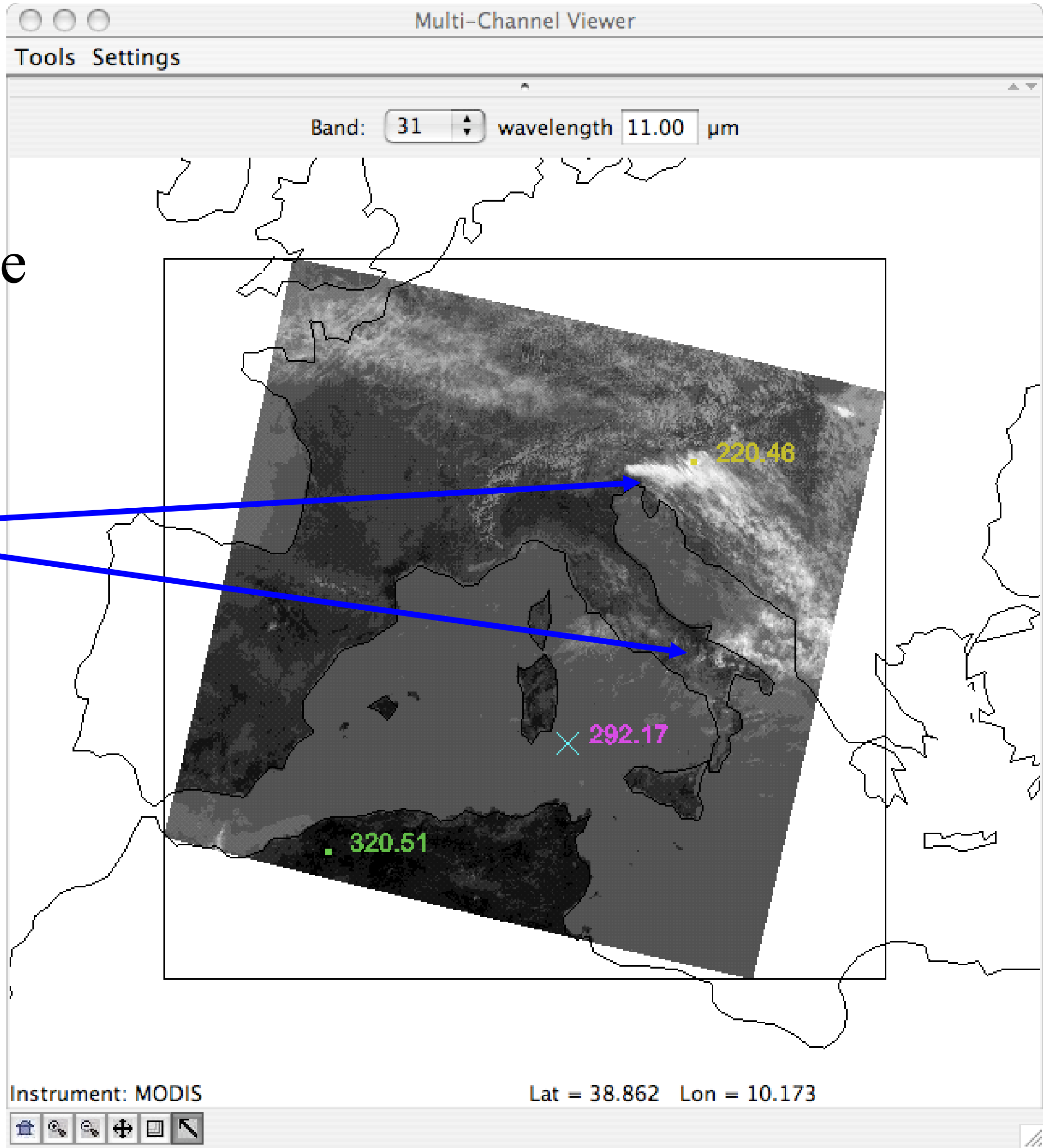
Clouds are cold



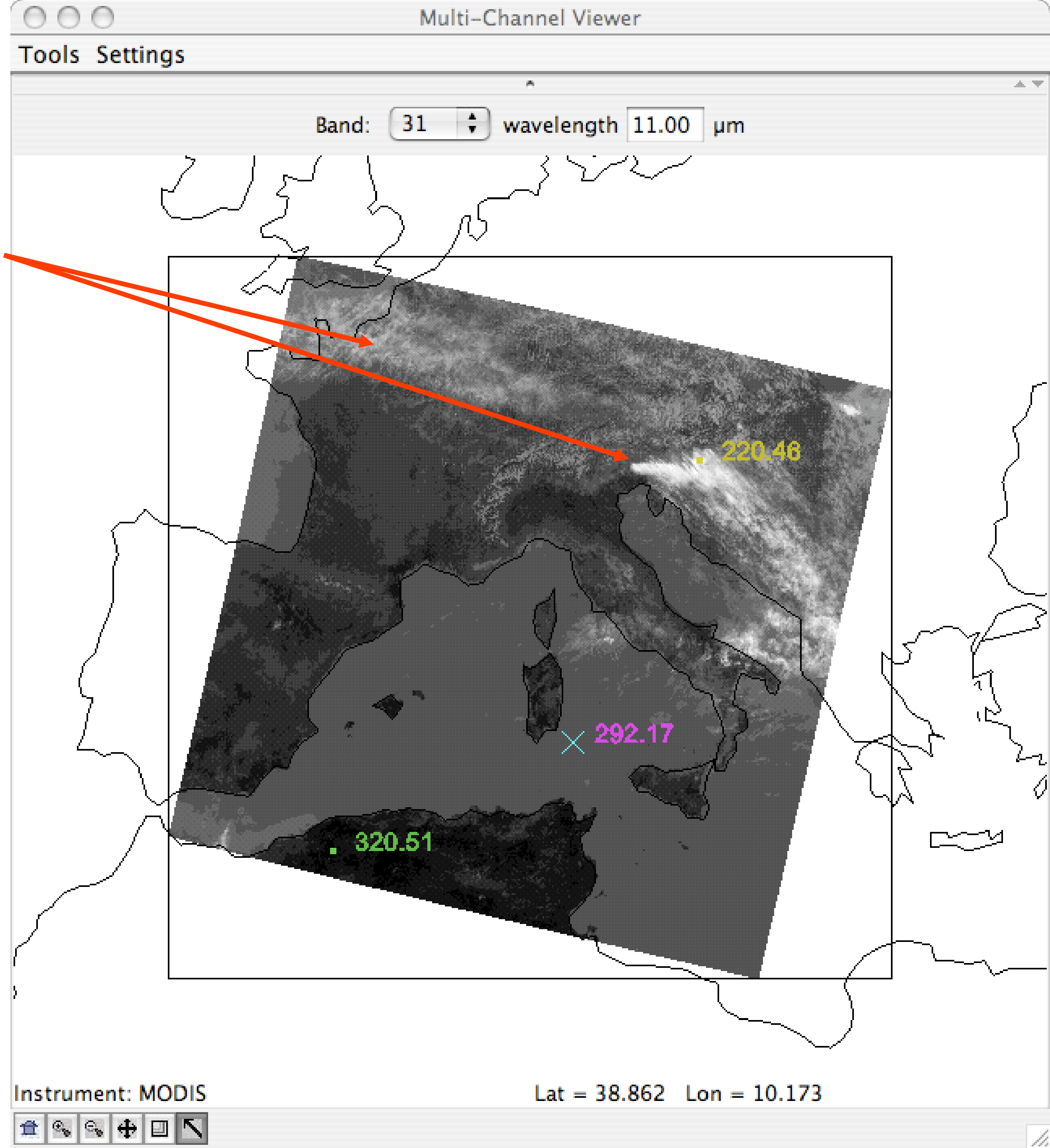
MODIS BAND 31

Window Channel:
- little atmospheric absorption
- surface features clearly visible

Clouds are cold



Clouds at 11 µm look bigger than at 4 µm



Temperature sensitivity

$$dB/B = \alpha \, dT/T$$

The Temperature Sensitivity α is the percentage change in radiance corresponding to a percentage change in temperature

Substituting the Planck Expression, the equation can be solved in α:

$$\alpha = c_2 \nu / T$$

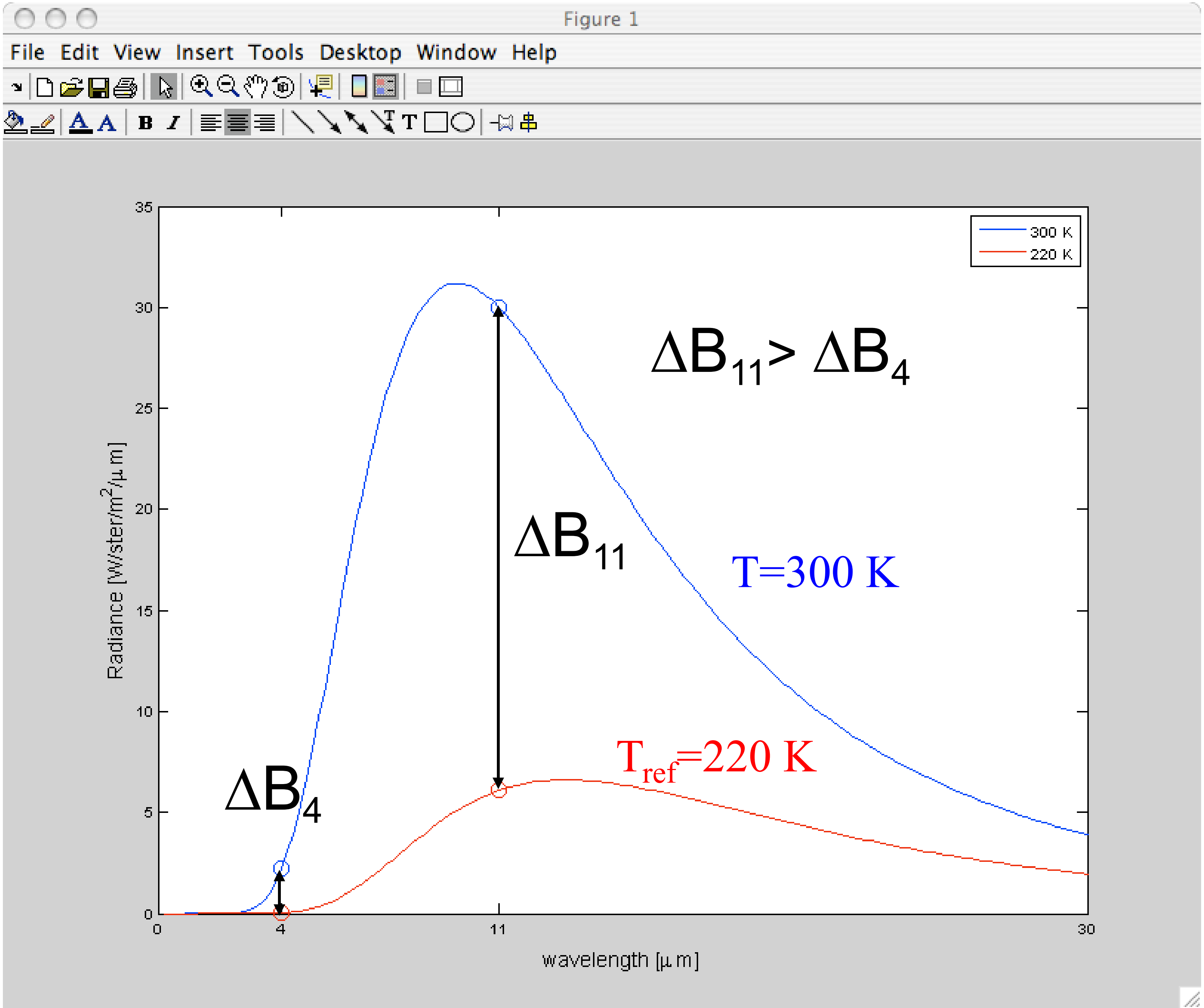
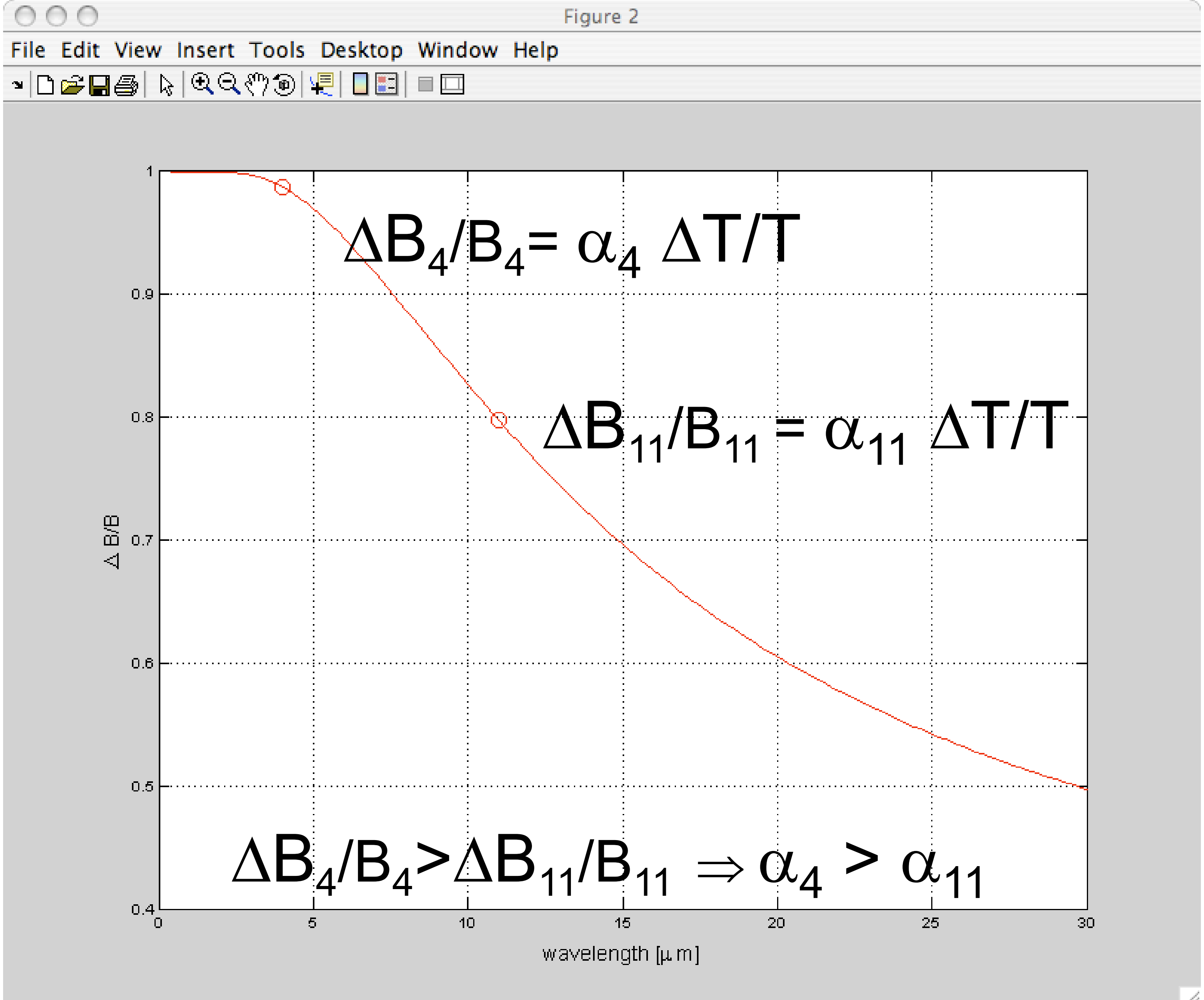


Figure 1
File Edit View Insert Tools Desktop Window Help
300 K
220 K
ΔB11> ΔB4
ΔB11
T=300 K
Tref=220 K
ΔB4
Radiance [W/ster/m2/μ m]
wavelength [μ m]
0
4
11
30
0
5
10
15
20
25
30
35



(values in plot are referred to wavelength)

(Approximation of) B as function of α and T

$\Delta B/B=\alpha\ \Delta T/T$

Integrating the Temperature Sensitivity Equation Between T_{ref} and T (B_{ref} and B):

$B=B_{ref}(T/T_{ref})^{\alpha}$

Where $\alpha=c_2\nu/T$ (in wavenumber space)

$$B = B_{ref}(T/T_{ref})^{\alpha}$$

$$\Downarrow$$

$$B = (B_{ref} / T_{ref}^{\alpha})\ T^{\alpha}$$

$$\Downarrow$$

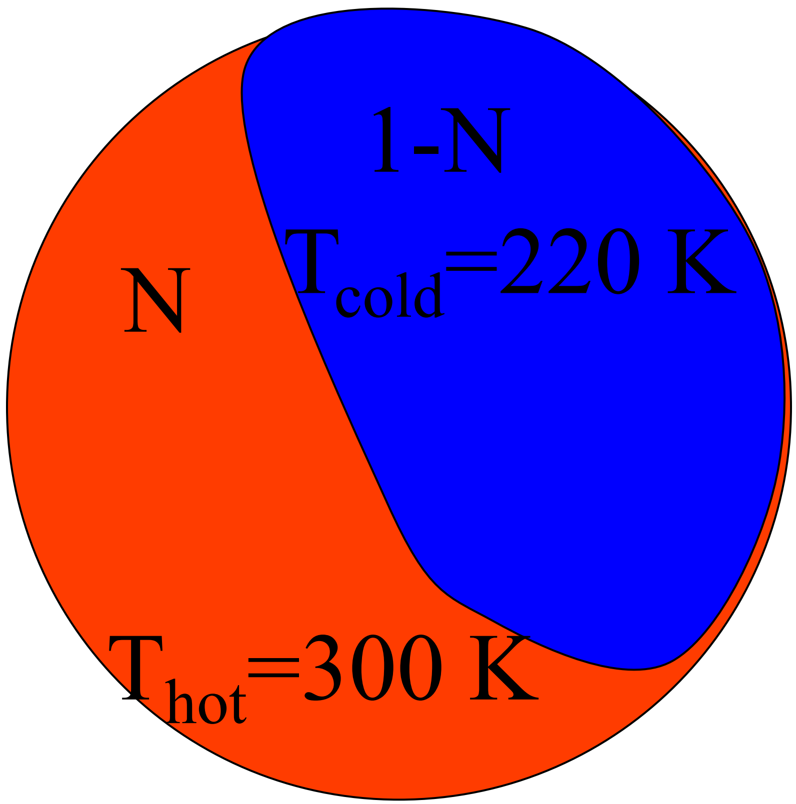
$$B \propto T^{\alpha}$$

The temperature sensitivity indicates the power to which the Planck radiance depends on temperature, since B proportional to T^{α} satisfies the equation. For infrared wavelengths,

$\alpha = c_2\nu/T = c_2/\lambda T.$

Wavenumber	Typical Scene Temperature	Temperature Sensitivity
900	300	4.32
2500	300	11.99

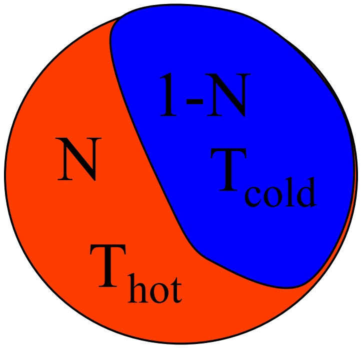
Non-Homogeneous FOV



$$B = N B(T_{hot}) + (1-N) B(T_{cold})$$

$$BT = N BT_{hot} + (1-N) BT_{cold}$$

For NON-UNIFORM FOVs:



$B_{obs}=(1-N)B_{cold}+NB_{hot}$

$B_{obs}=(1-N)\ B_{ref}(T_{cold}/T_{ref})^{\alpha}+N\ B_{ref}(T_{hot}/T_{ref})^{\alpha}$

$B_{obs}=B_{ref}(1/T_{ref})^{\alpha}\ ((1-N)\ T_{cold}{}^{\alpha}+NT_{hot}{}^{\alpha})$

For N=.5

$B_{obs}=.5B_{ref}(1/T_{ref})^{\alpha}\ (\ T_{cold}{}^{\alpha}+T_{hot}{}^{\alpha})$

$B_{obs}=.5B_{ref}(1/T_{ref}T_{cold})^{\alpha}\ (1+(T_{hot}/\ T_{cold})^{\ \alpha})$

The greater α the more predominant the hot term

At 4 µm (α=12) the hot term more dominating than at 11 µm (α=4)

Consequences

- At 4 μm (α=12) clouds look smaller than at 11 μm (α=4)
- In presence of fires the difference BT_4-BT_{11} is larger than the solar contribution
- The different response in these 2 windows allow for cloud detection and for fire detection

Conclusions

- Vegetation: highly reflective in the Near Infrared and highly absorptive in the visible red. The contrast between these channels is a useful indicator of the status of the vegetation;
- Planck Function: at any wavenumber/wavelength relates the temperature of the observed target to its radiance (for Blackbodies)
- Thermal Sensitivity: different emissive channels respond differently to target temperature variations. Thermal Sensitivity helps in explaining why, and allows for cloud and fire detection.