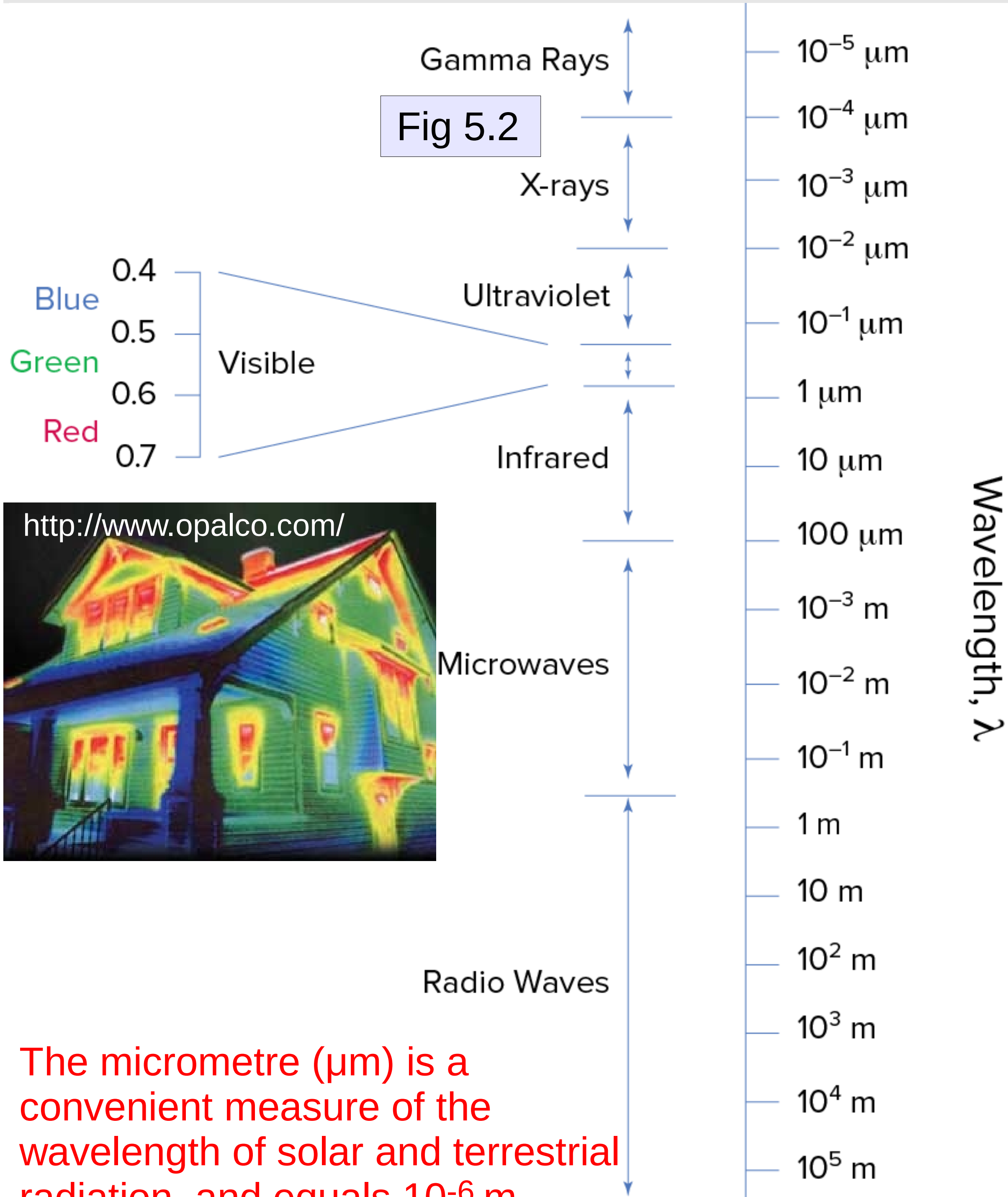
Chapter 5. Radiation (and radiative energy transport). 28 Sept.

EAS270_Ch5_Radiation_A.odp
JDW, EAS U.Alberta, last mod. 27 Sept. 2016

Fig 5.2



The micrometre (μm) is a convenient measure of the wavelength of solar and terrestrial radiation, and equals 10^{-6} m

"Everything emits radiation... hotter substances emit more radiation than do cooler substances" (p82)

Radiation has both wave (freq. f, wavelength λ) and particle properties

Characterized by wavelength λ and speed c . In vacuum,

$$c = 3 \times 10^{8} \text{ m s}^{-1} = f\,\lambda$$

Radiant energy of a single photon

$$E = \frac{h\,c}{\lambda} = h\,f$$

where h is Planck's const.

Ultraviolet (uv) photons are more energetic than those of visible light

- “*Everything* [whose temperature is above absolute zero] emits electromagnetic radiation” (p90)

- cause is the acceleration of vibrating electrons (or other charges)

- this curve is “Planck's (1901) blackbody radiation law”

$$E_\lambda = \frac{c_1}{\lambda^5 \left[\exp\left(\frac{c_2}{\lambda T}\right) - 1\right]}$$

Eq 5.6

Spectral Emission Rate, $E_\lambda(\lambda)$

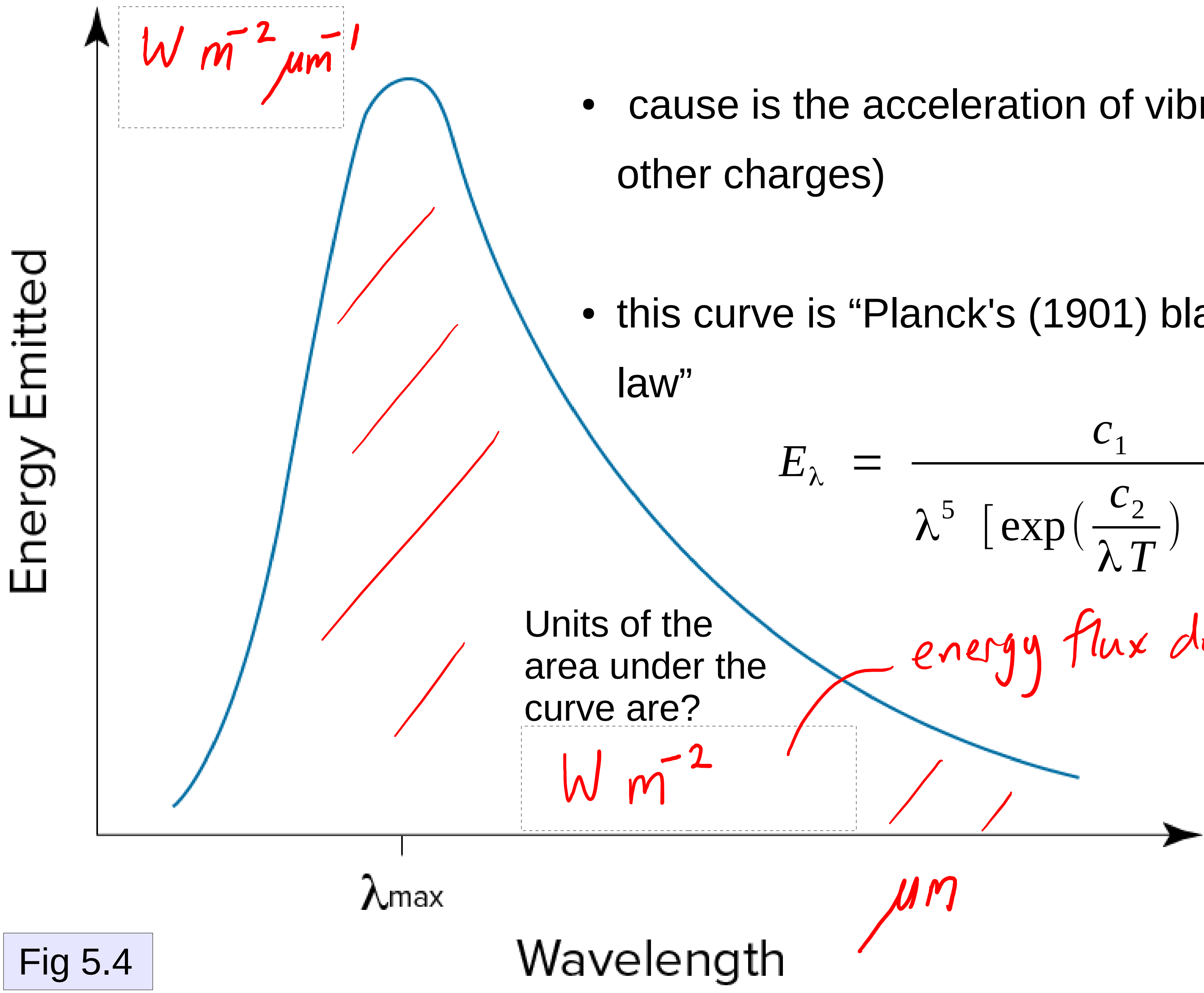
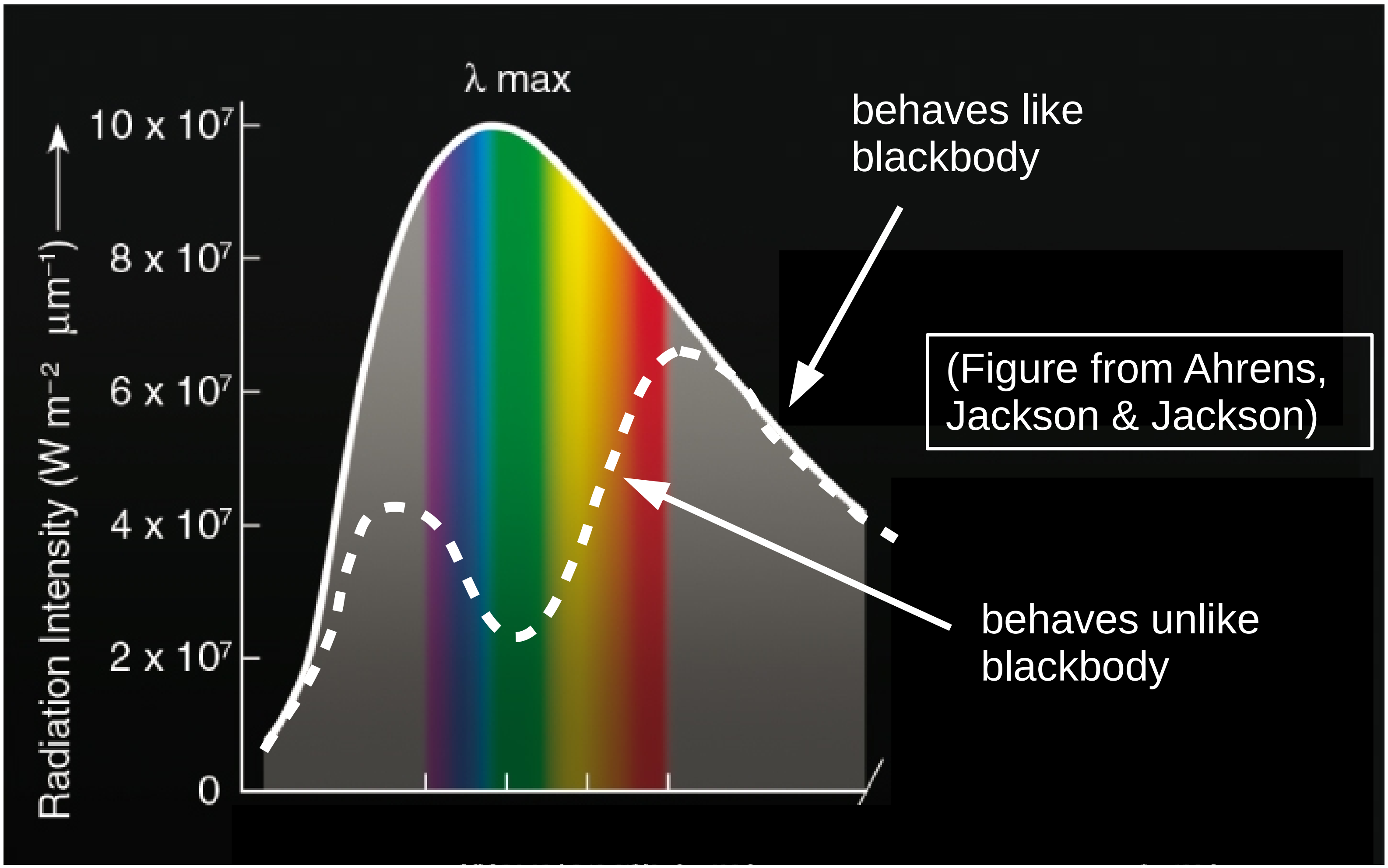


Fig 5.4

Max Planck (1858-1947)

- "no true blackbodies exist but... *most (natural) things* are close to being blackbodies" (as we'll see, gases are the exception)

Emission spectrum of a real body falls at or below that of a blackbody at the same temperature



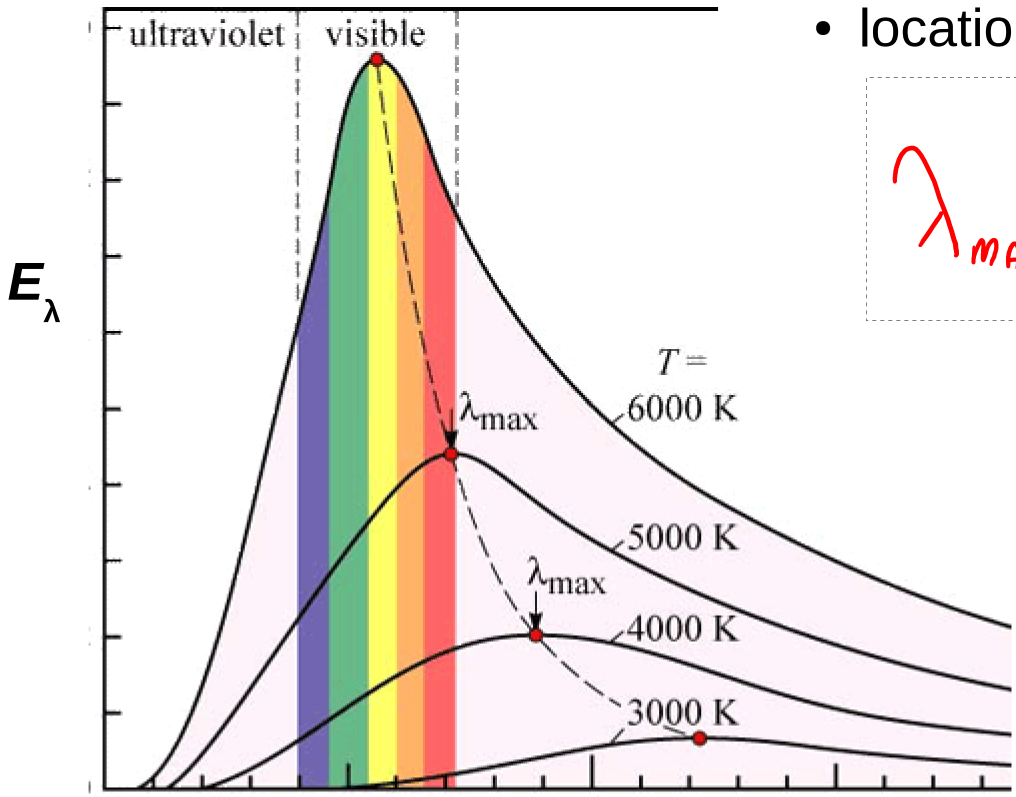
Planck curve describes a *continuous* spectrum, and is appropriate for solids & liquids... but gases have *dis*continuous emission spectra

- area under the curve equals total rate of radiative energy emission (per unit of surface area) summed across all wavelengths (bigger for hotter body). Given by Stefan-Boltzmann law

$$E\,[W\,m^{-2}] = \sigma T^4$$

Eq 5.3

where σ =5.67 x 10^{-8} [W m^{-2} K^{-4}], T in [K]



physics.schooltool.nl/irspectroscopy/images/planck_black-body_radiation.png

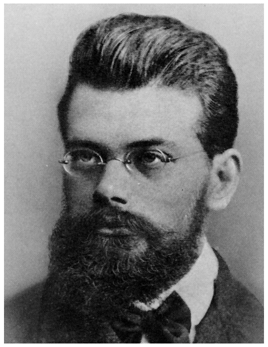
- location of spectral peak given by Wien's Law

$$\lambda_{max}\,[\mu m] = \frac{2897}{T}$$

Eq 5.5

T in K

Wilhelm Wien (1864-1928)



Max Boltzmann (1844-1906)

Joseph Stefan (1835- 1893)

- a black body is the most efficient emitter at given temperature, and perfectly absorbs radiation of any wavelength, i.e. its (spectral) absorptivity $a_\lambda(\lambda)=1$
- to accommodate real bodies, introduce the emissivity $\epsilon \leq 1$

- bulk emissivity

$$E\,[W m^{-2}] = \varepsilon\,\sigma\,T^4$$

Eq 5.4

- spectral emissivity

Planck curve

$$E_\lambda = \epsilon_\lambda(\lambda)\,\frac{c_1}{\lambda^5\left[\exp\dfrac{c_2}{\lambda T} - 1\right]}$$

modifies Eq 5.6

$$\varepsilon_\lambda \leq 1$$

- Kirchoff's law: equality of spectral emissivity and spectral absorptivity

$$\varepsilon_\lambda(\lambda) = a_\lambda(\lambda)$$

Eq 5.7

TABLE 5.1 | Approximate infrared emissivities for various substances.

Substance	Infrared Emissivity
Water	0.98
Fresh Snow	0.99
Old Snow	0.82
Ice	0.97
Wet Soil	0.95
Dry Soil	0.92
Sand	0.90
Grass	0.90
Forest	0.98
White Paper	0.93
Highly Polished Silver	0.02
Aluminum	0.03
Glass	0.92
Human Skin	0.98

Thus snow also has very high longwave absorptivity (contrasting with its very high reflectivity in the solar band)

CONTINUING FROM HERE 30 SEPT 2016

Compute the rate of emission [W m^{-2}] and peak wavelength for the sun (5800 K)

$$E = \sigma T^4 = 6.42 \times 10^7 \ W m^{-2}$$

$$\lambda_{MAX} = \frac{2897}{T} = 0.499 \ \mu m$$

Compute the rate of emission [W m^{-2}] and peak wavelength for the earth (288 K)

$$E = 390 \ W m^{-2}$$

$$\lambda_{MAX} = \frac{2897}{288} = 10.1 \ \mu m$$

Solar (shortwave) band: $\lambda \leqslant 3 \mu m$

Longwave (terrestrial) band: $\lambda > 3 \mu m$ (infrared)

Plotted with differing scales for the E_λ axis of sun and earth (otherwise earth's spectrum would be invisible)

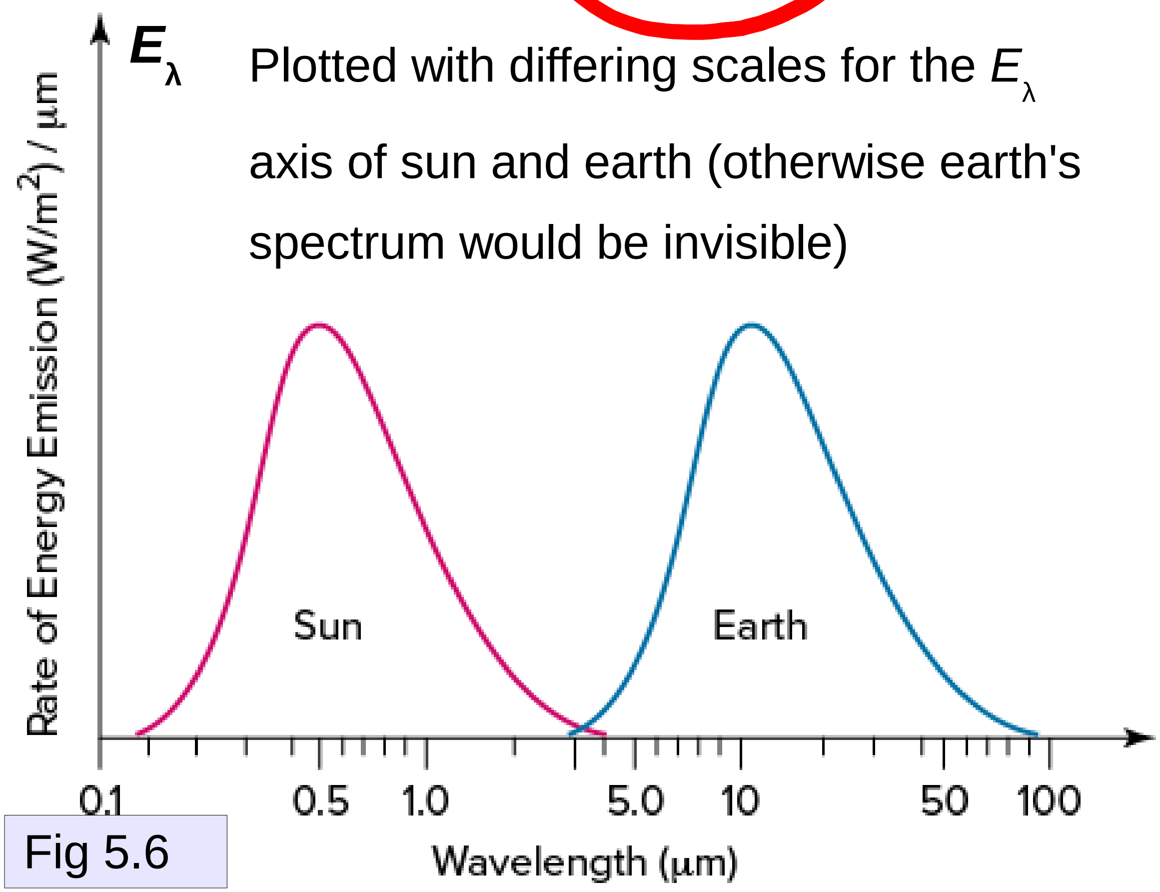
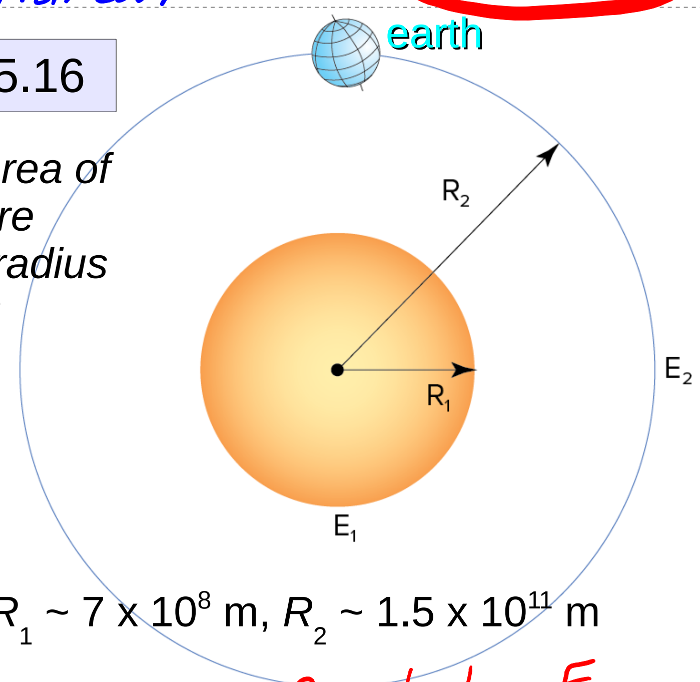


Fig 5.6

Fig 5.16

Sfc area of sphere with radius R is?

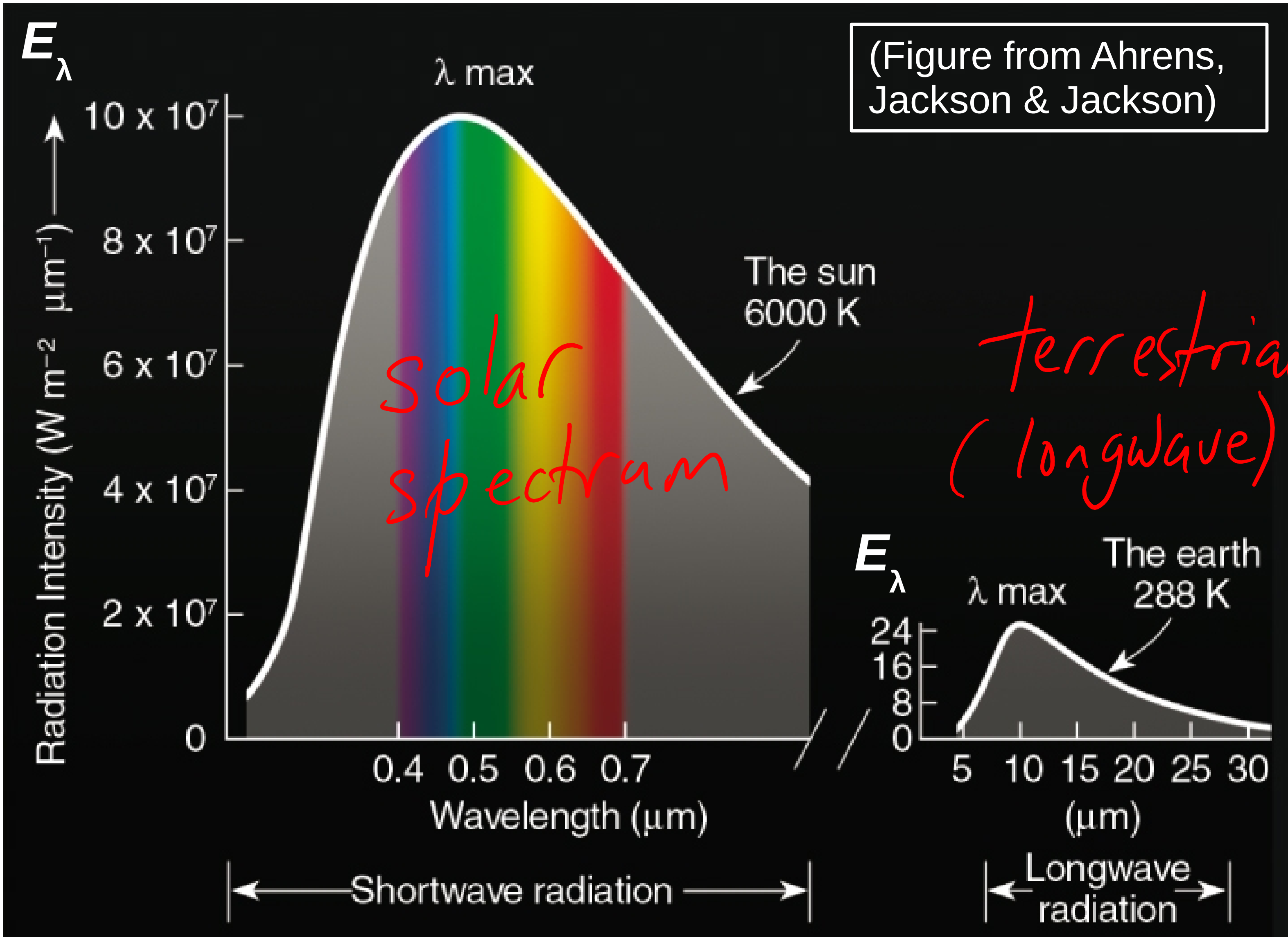


$R_1 \sim 7 \times 10^8$ m, $R_2 \sim 1.5 \times 10^{11}$ m

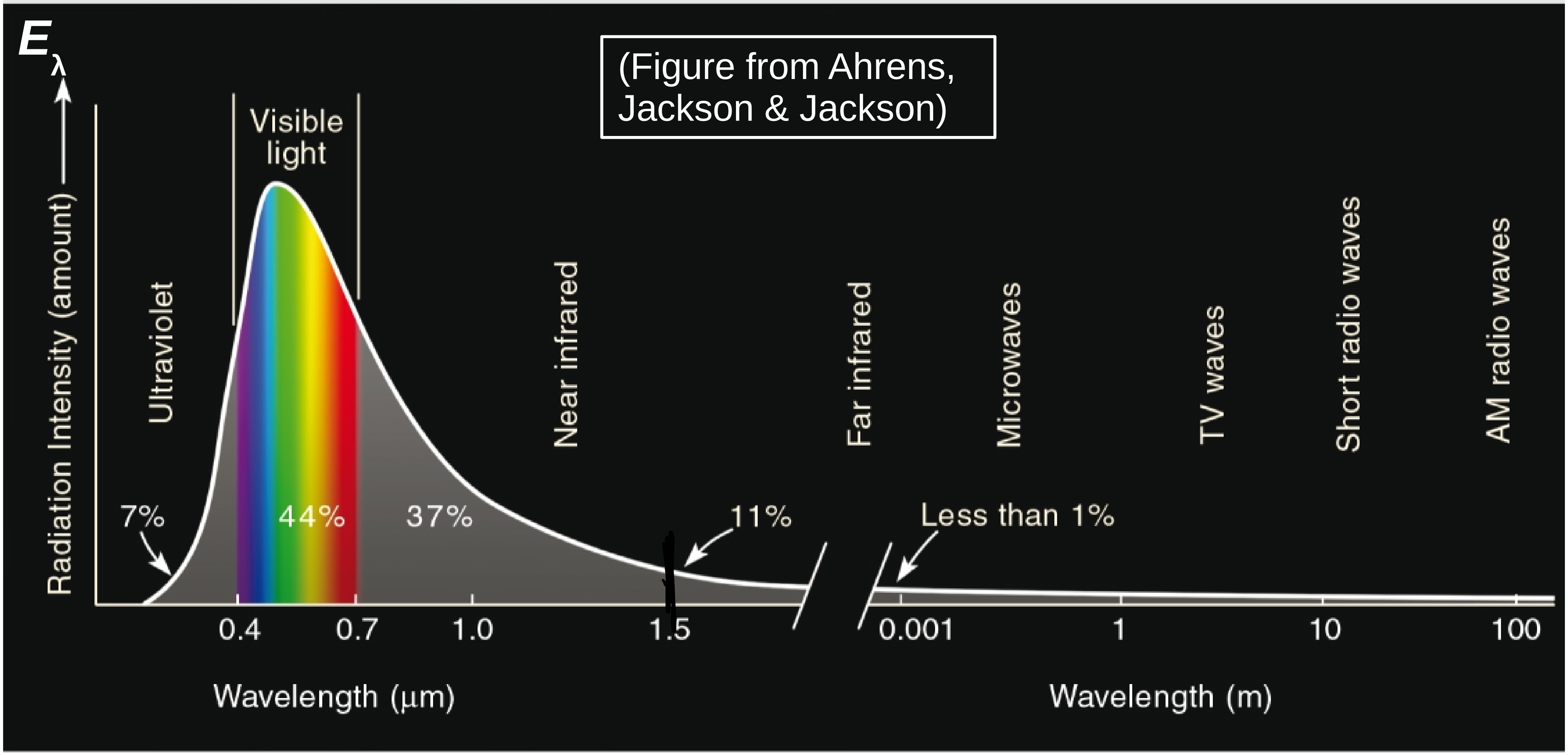
$$\frac{E_2}{E_1} = \left[\frac{R_1}{R_2}\right]^2 = ?$$

Compute E_2 if $E_1 = 6.42 \times 10^7 \ W m^{-2}$

A 10 μm photon seen in the atmos. is unlikely to have originated at the sun – because although sun's (vastly more powerful) spectrum overlaps earth's, the $1/R^2$ distance factor comes into play: sun-earth distance $R \sim 1.5 \times 10^{11}$ m



Note: very different scales of the E_λ -axes of the spectra for the sun and the earth



- percentage emitted in the ultraviolet (0.1 – 0.4 μm)?
- peaks in green-blue near 0.5 μm
- percentage emitted in the visible (0.4 – 0.7 μm)?
- percentage in the near infrared (0.7 ≤ λ ≤ 1.5 μm)?

7%

44%

37% ← strongly absorbed by a humid atmosphere

- solid materials (e.g. soil, water) absorb almost like black bodies (i.e. almost perfectly) at wavelengths in the longwave band, but not necessarily in the shortwave (solar) band (try a white shirt then a black shirt by day in Arizona)
- e.g. fresh snow has a very high albedo (shortwave reflectivity), yet is virtually a perfect emitter/absorber in the longwave. Thus, emissivity is wavelength-dependent
- gases are the ultimate "selective emitters", i.e. have highly irregular absorption-emission "bands"... $a_\lambda(\lambda) = \varepsilon_\lambda(\lambda)$ is very "peaky"

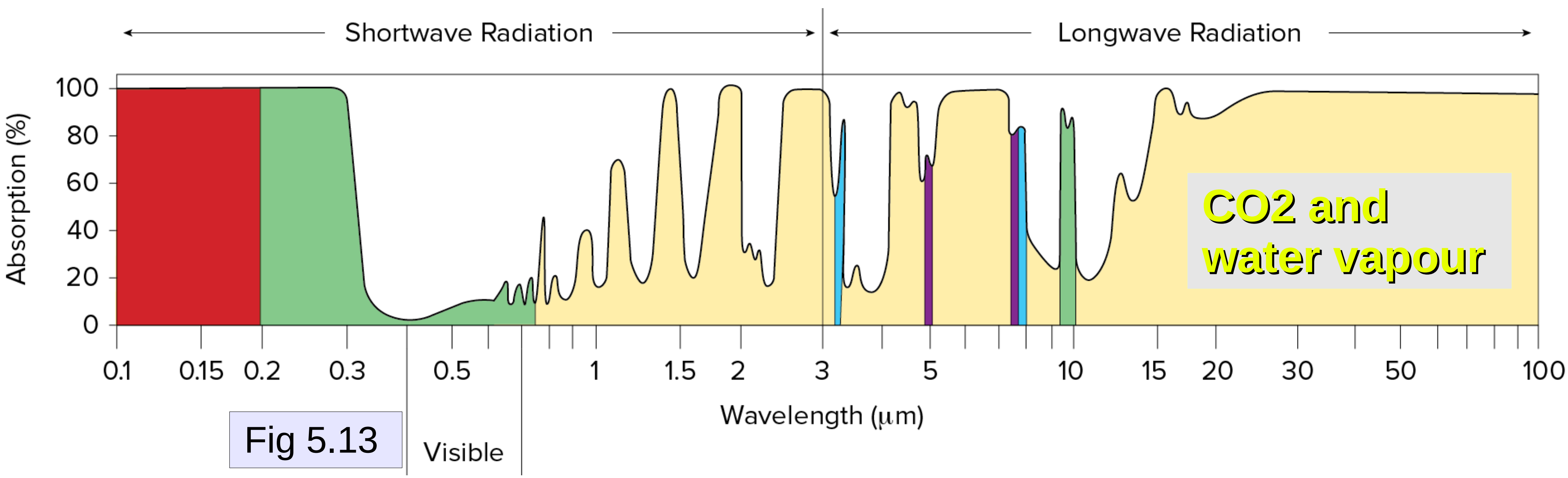


Fig 5.13

Kirchoff's law applies: at any wavelength where a given gas is a good absorber, it is also a good emitter $a_\lambda(\lambda) = \varepsilon_\lambda(\lambda)$

This is spectral absorption for a beam traversing the whole atmospheric column at perpendicular incidence. Effect of (say) ozone alone would be equivalent to having an ozone-only atmosphere with the same column-integrated $[O_3]$ in kg m^{-2}

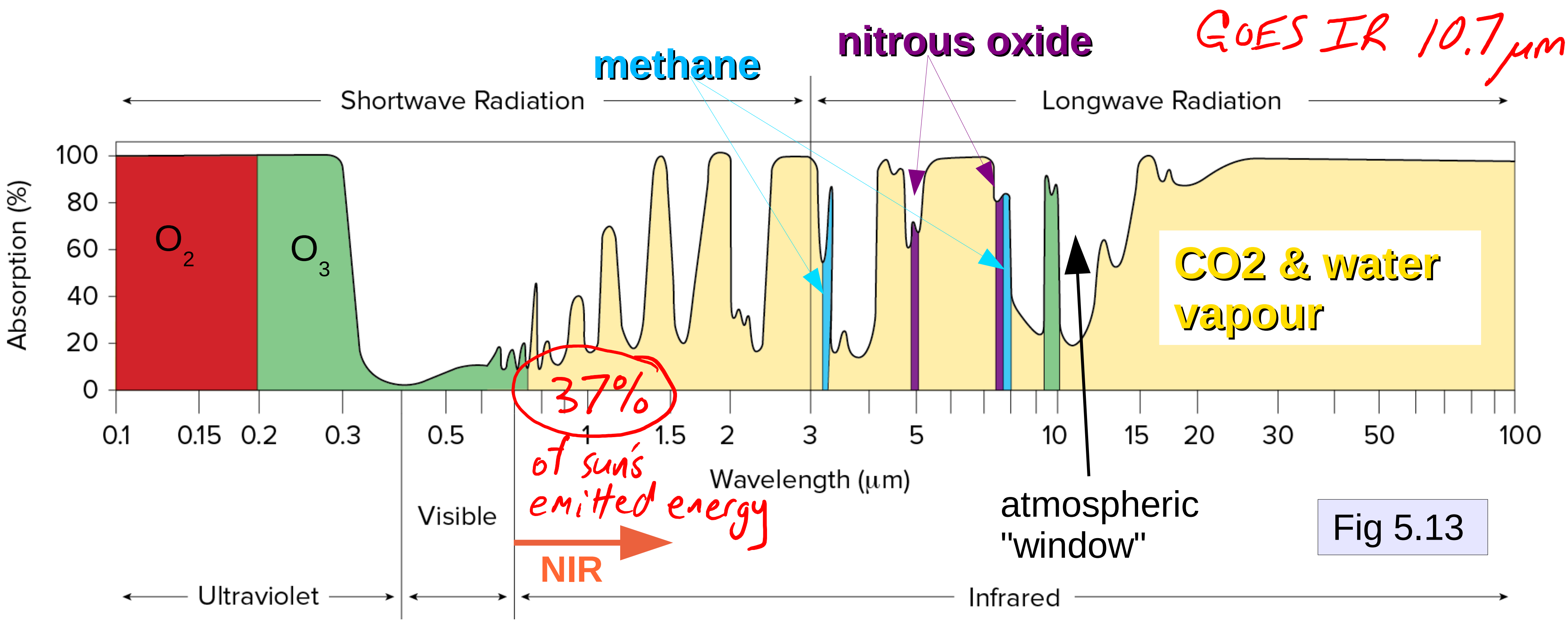


Fig 5.13

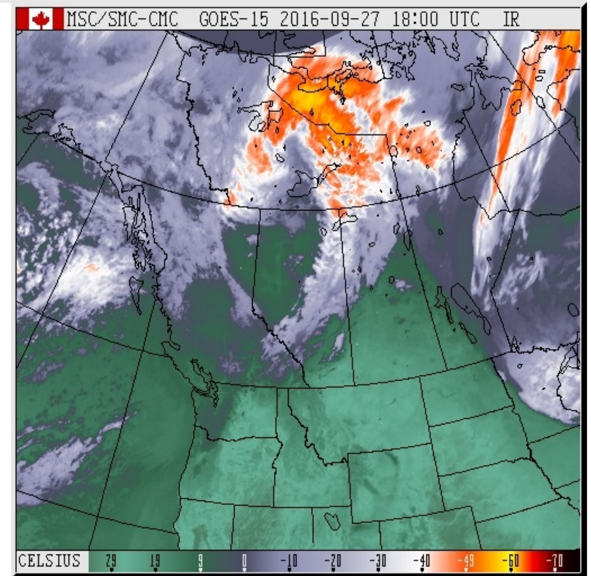
Monday's high 25°C: explaining Tuesday's cool, cloudy, windy conditions...

EC 7:00 AM CDT TUES. SEPT. 27 2016.

PRAIRIES...COLD FRONT SWWD FROM GREAT SLAVE LAKE LOW WILL SWEEP SEWD ACROSS AB/NRN SK TODAY... MODERATE WINDS GUSTING 50 TO 70 KM/H AND A FEW SHOWERS ARE EXPECTED WITH THE FRONT.

Noon MDT Edmonton

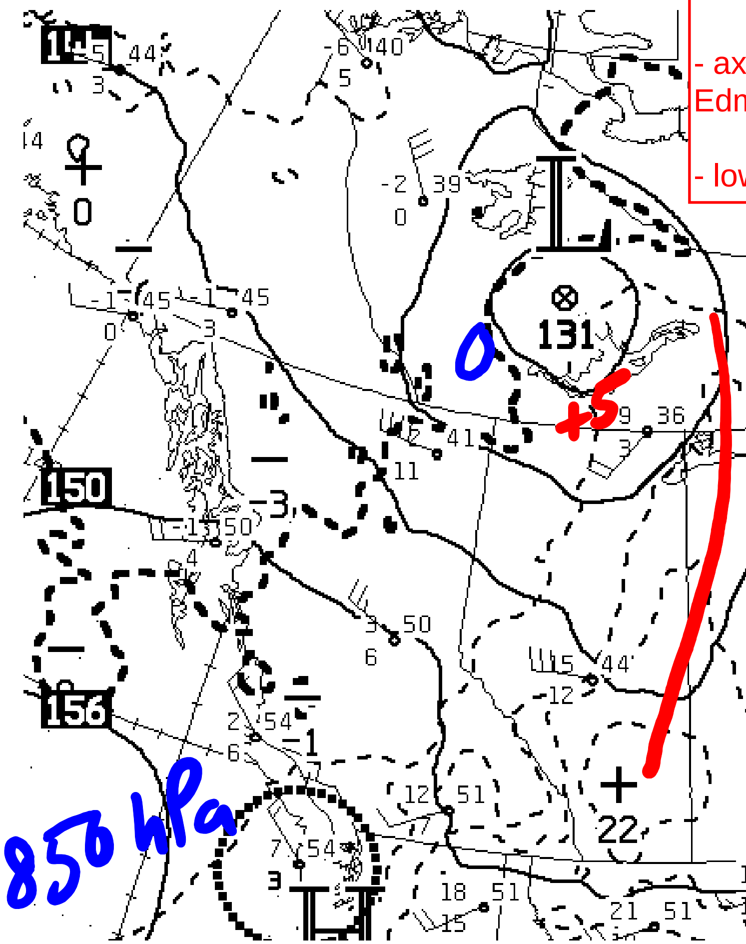
Temperature: **12.9°C**
Dewpoint: **2.3°C**
Humidity: **48%**
Wind: **WNW 22 gust 35 km/h**



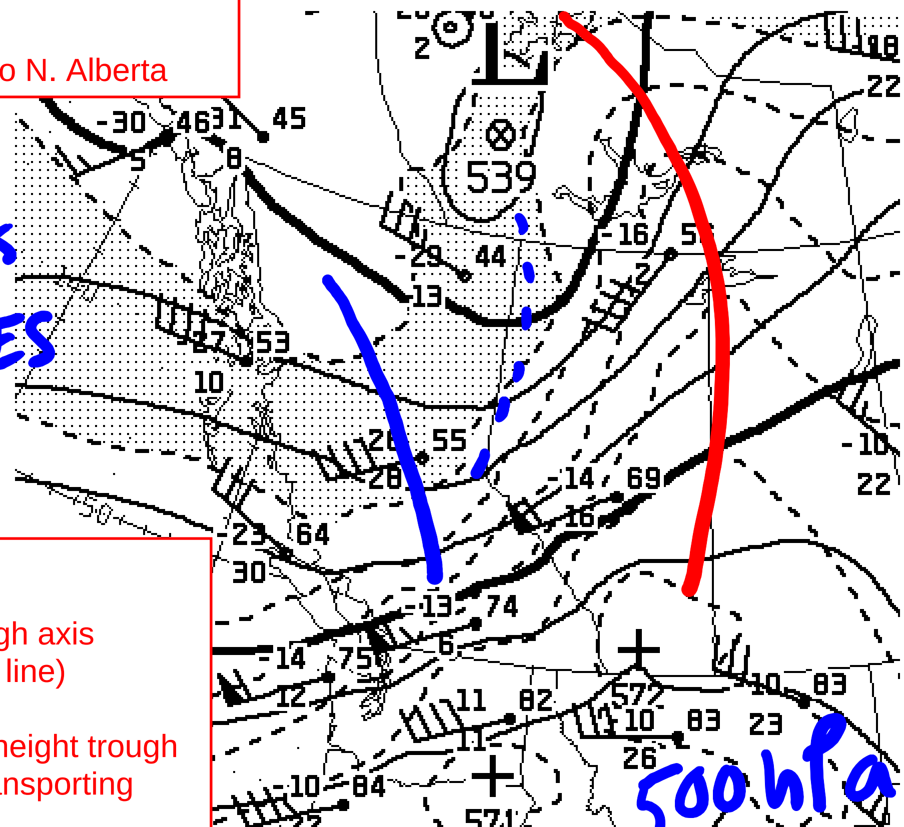
850 hPa level:

- axis of the thermal ridge has moved east of Edmonton

- low is wrapping colder air into N. Alberta



CMC analyses 12Z TUES



500 hPa level:

- thermal (thickness) trough axis through B.C. (added blue line)

- strong SW flow around height trough (added blue dash line) transporting cooler air into Alberta

Topics/concepts covered

- Planck radiation curve (shape; units on axes; temperature dependence)
- Wien's law for the location of the spectral peak
- Stefan-Boltzmann law (area under Planck curve)
- rationale for distinguishing “shortwave” (solar) from “longwave” (terrestrial) radiation
- distinction between continuous emitters and discontinuous emitters (gases)