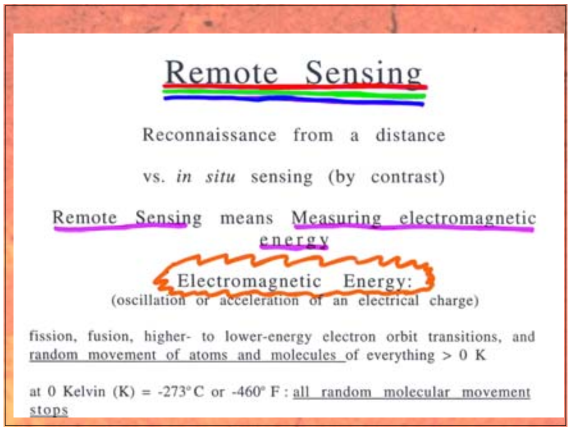
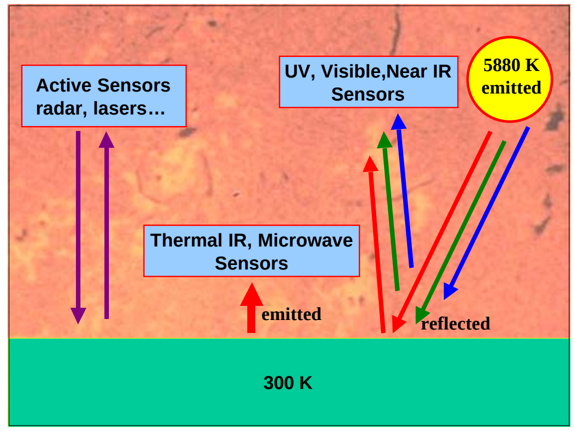
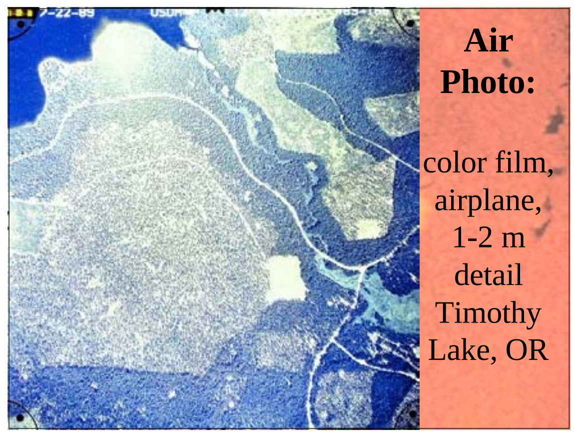
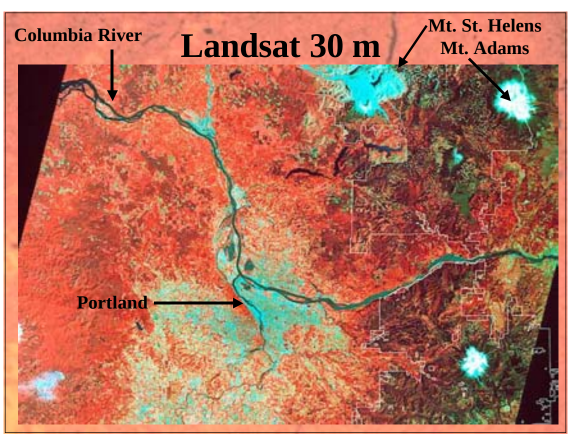
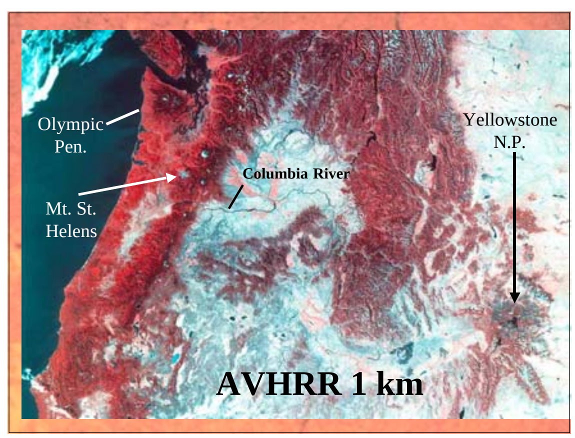

Remote Sensing
Reconnaissance from a distance
vs. in situ sensing (by contrast)
Remote Sensing means Measuring electromagnetic energy
Electromagnetic Energy:
(oscillation or acceleration of an electrical charge)
fission, fusion, higher- to lower-energy electron orbit transitions, and random movement of atoms and molecules of everything > 0 K
at 0 Kelvin (K) = -273°C or -460° F : all random molecular movement stops


Active Sensors radar, lasers…
UV, Visible,Near IR Sensors
5880 K emitted
Thermal IR, Microwave Sensors
emitted
reflected
300 K

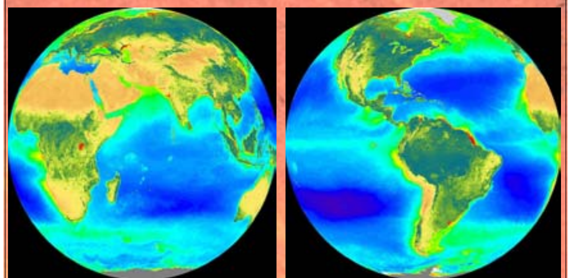

Ground-based remote sensing


Air Photo:
color film, airplane, 1-2 m detail
Timothy Lake, OR


Columbia River
Landsat 30 m
Mt. St. Helens
Mt. Adams
Portland

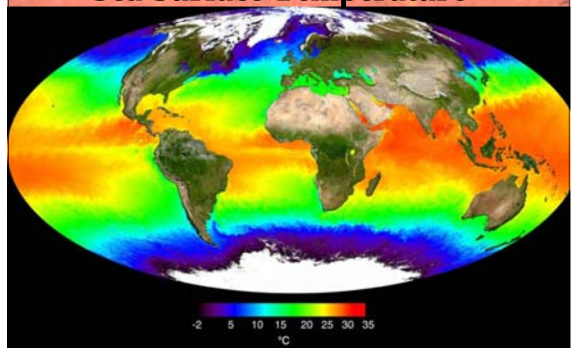

Olympic Pen.
Mt. St. Helens
Columbia River
Yellowstone N.P.
AVHRR 1 km

Satellite remote sensing of earth



SeaWiFS Land-Ocean Chlorophyll
September 1997 to present …

MODIS Land Reflectance and Sea Surface Temperature



Important questions to answer

Remote Sensing Systems

How do we discuss and catagorize remote sensing?

"the resolutions"

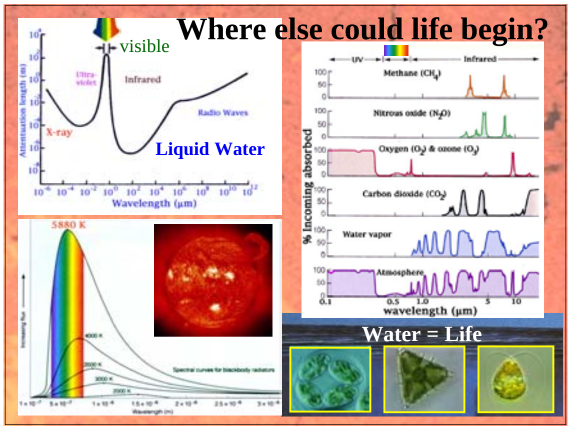
Spatial Resolution -- what **size** we can resolve

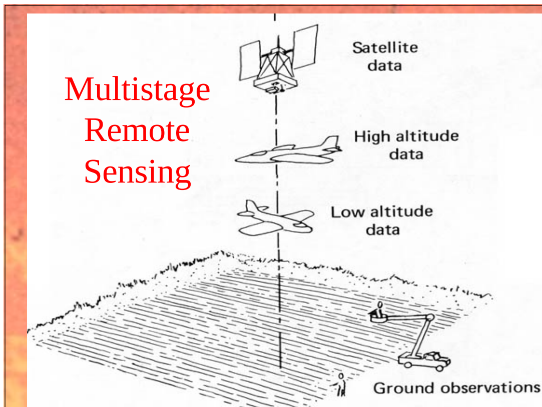
Spectral Resolution -- what **wavelengths** do we use

Radiometric Resolution -- degree of **detail** observed

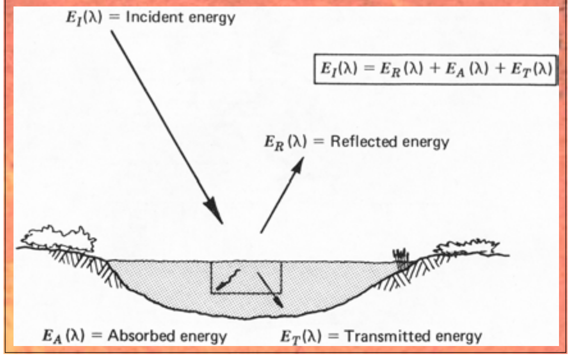
Temporal Resolution -- how **often** do we observe

Where else could life begin?

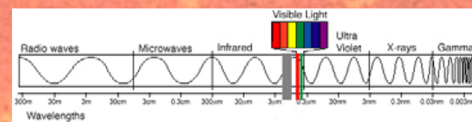




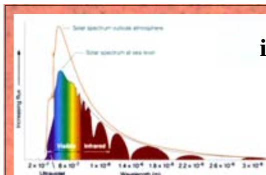
Basic Interactions between Electromagnetic Energy and the Earth's Surface



The Electromagnetic Spectrum

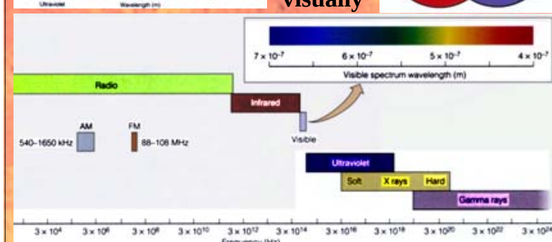


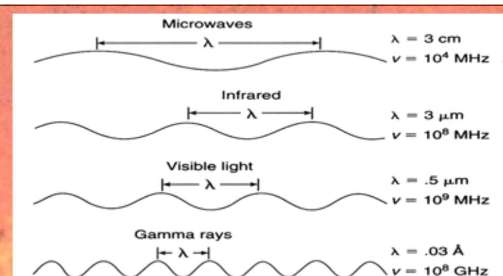
- Remote sensing uses the radiant energy that is reflected and emitted from Earth at various "wavelengths" of the electromagnetic spectrum
- Our eyes are only sensitive to the "visible light" portion of the EM spectrum
- Why do we use nonvisible wavelengths?



Expand information

Express it visually





Visible Spectrum

0.4 0.5 0.6 0.7

Wavelength (µm)

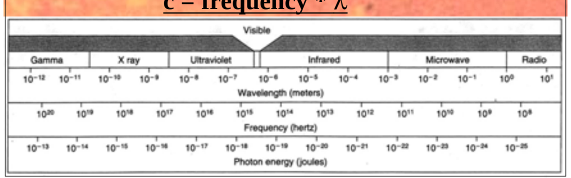
c = frequency * λ

Visible Spectrum

0.4 0.5 0.6 0.7

Wavelength (µm)

c = frequency * λ



Radiation

Speed of light = λ * frequency

The wavelength where the radiance is the greatest is given by

$$\lambda_{max} = \frac{2898\ \mu m\ K}{T},$$

known as *Wien's displacement law*, where
λ_{max} = wavelength of maximum radiance
T = temperature (K)

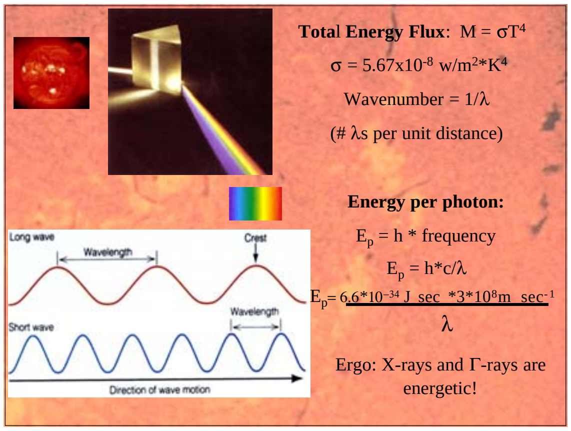
From blackbody radiation, the emitted radiation follows *Planck's law*

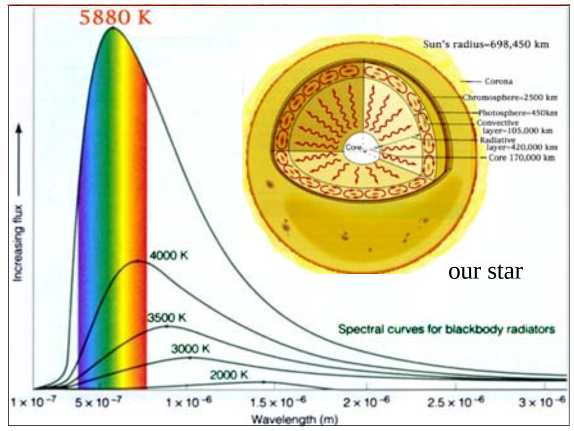
$$I_\lambda = \frac{2hc^2}{\lambda^5 [\exp(hc/\lambda kT) - 1]}$$

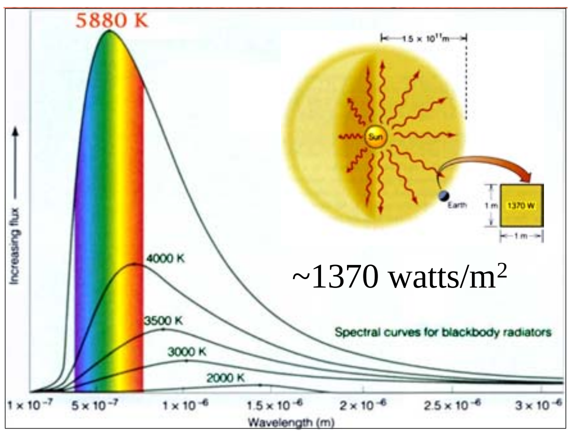
$$E_\lambda = \int_0^\infty I_\lambda(T) d\lambda = \sigma T^4$$

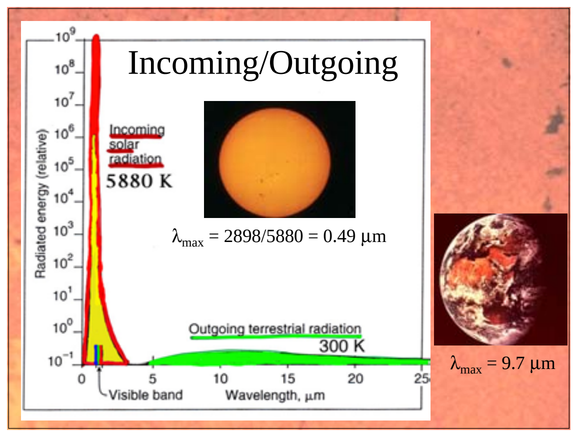
Stefan-Boltzman constant

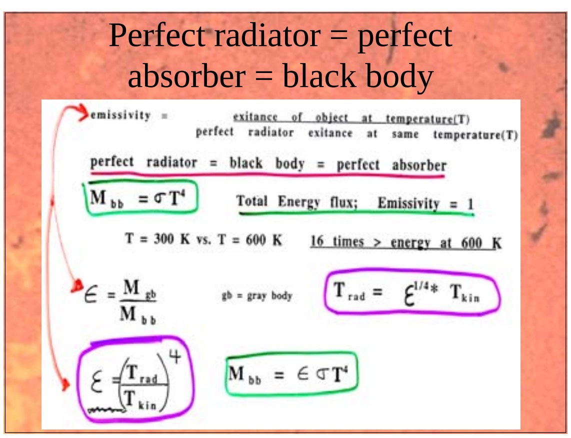
where
c = speed of light (2.998 x 10^{10} cm s^{-1})
h = Planck's constant (6.626 x 10^{-27} erg s)
k = Boltzmann's constant (1.381 x 10^{-16} erg K^{-1})
σ = Stefan-Boltzmann constant (5.6697 x 10^{-8} W m^{-2} K^{-4})

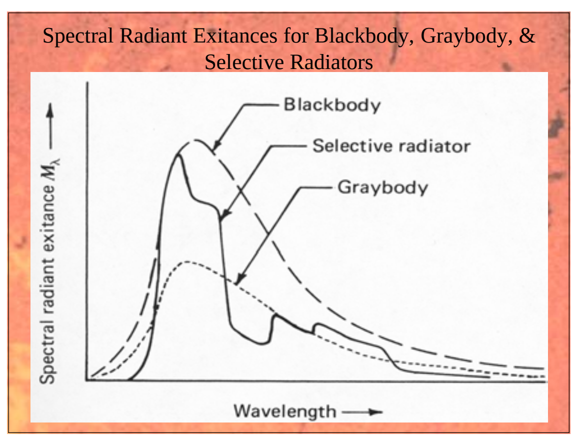

Total Energy Flux: M = σT4
σ = 5.67x10-8 w/m2*K4
Wavenumber = 1/λ
(# λs per unit distance)
Energy per photon:
Ep = h * frequency
Ep = h*c/λ
Ep= 6.6*10-34 J sec *3*108m sec-1
λ
Ergo: X-rays and Γ-rays are energetic!
Long wave
Wavelength
Crest
Short wave
Wavelength
Direction of wave motion

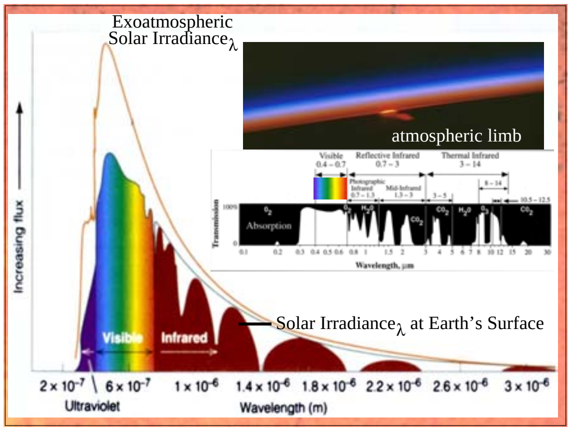

5880 K
Sun's radius–698,450 km
Corona
Chromosphere–2500 km
Photosphere–450km
Convective layer–105,000 km
Radiative layer–420,000 km
Core 170,000 km
Core
our star
4000 K
3500 K
3000 K
2000 K
Spectral curves for blackbody radiators
Increasing flux
1 × 10−7
5 × 10−7
1 × 10−6
1.5 × 10−6
2 × 10−6
2.5 × 10−6
3 × 10−6
Wavelength (m)


5880 K
1.5 × 10¹¹m
Sun
Earth
1 m
1370 W
~1370 watts/m2
4000 K
3500 K
3000 K
2000 K
Spectral curves for blackbody radiators
Increasing flux
1 × 10−7
5 × 10−7
1 × 10−6
1.5 × 10−6
2 × 10−6
2.5 × 10−6
3 × 10−6
Wavelength (m)

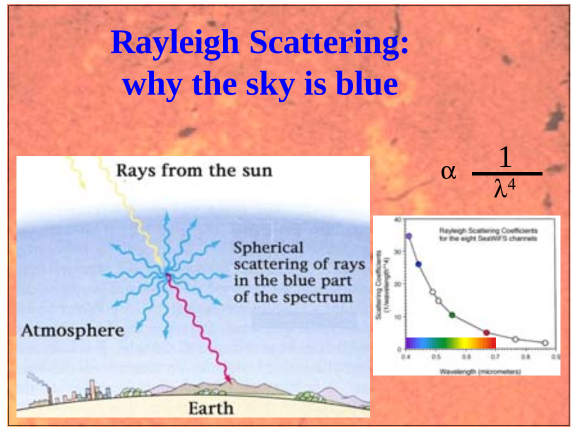

Incoming/Outgoing
Incoming solar radiation
5880 K
λmax = 2898/5880 = 0.49 μm
Outgoing terrestrial radiation
300 K
λmax = 9.7 μm
Radiated energy (relative)
Visible band
Wavelength, μm


Perfect radiator = perfect absorber = black body
emissivity = exitance of object at temperature(T) / perfect radiator exitance at same temperature(T)
perfect radiator = black body = perfect absorber
Mbb = σT4
Total Energy flux; Emissivity = 1
T = 300 K vs. T = 600 K
16 times > energy at 600 K
ε = Mgb / Mbb
gb = gray body
Trad = ε1/4* Tkin
ε = (Trad / Tkin)4
Mbb = εσT4

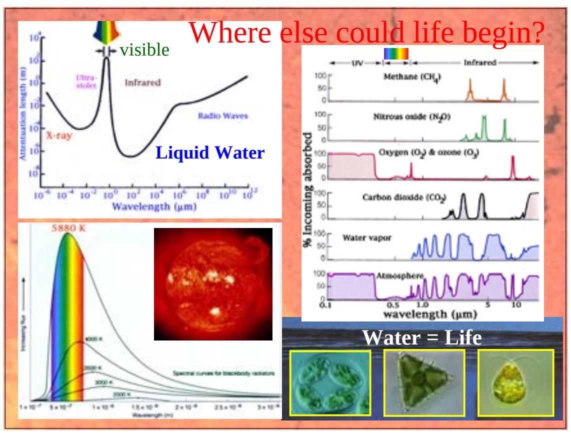

Spectral Radiant Exitances for Blackbody, Graybody, & Selective Radiators
Blackbody
Selective radiator
Graybody
Spectral radiant exitance Mλ
Wavelength



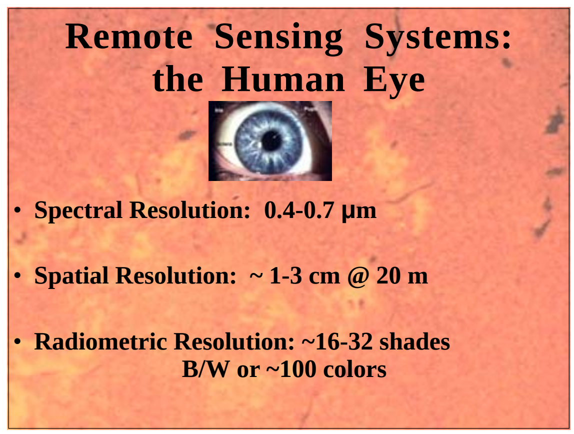
Exoatmospheric Solar Irradiance$_\lambda$
atmospheric limb
Solar Irradiance$_\lambda$ at Earth's Surface
Increasing flux
Visible
Infrared
Ultraviolet
Wavelength (m)
2 x 10^{-7}
6 x 10^{-7}
1 x 10^{-6}
1.4 x 10^{-6}
1.8 x 10^{-6}
2.2 x 10^{-6}
2.6 x 10^{-6}
3 x 10^{-6}



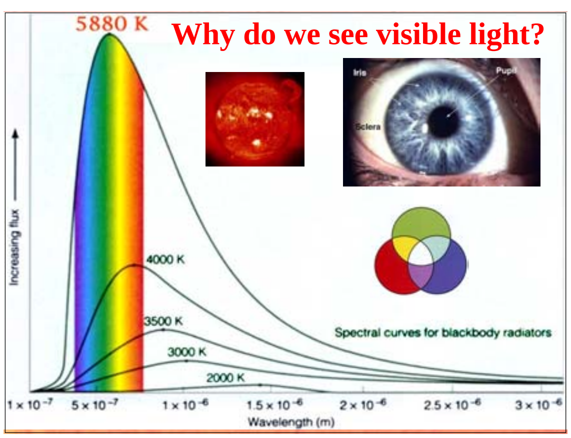
Rayleigh Scattering:
why the sky is blue
$\alpha \frac{1}{\lambda^4}$
Rays from the sun
Spherical scattering of rays in the blue part of the spectrum
Atmosphere
Earth



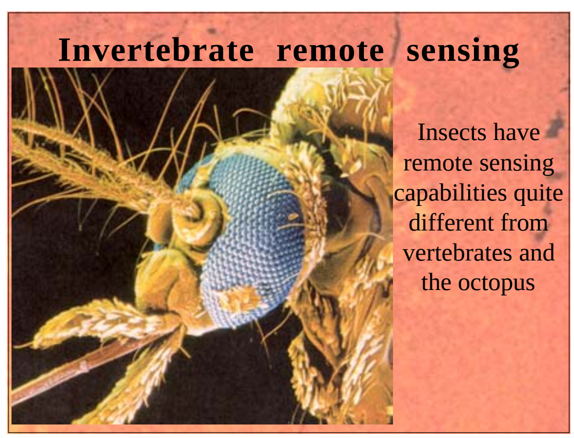
Where else could life begin?
visible
Liquid Water
X-ray
Infrared
Radio Waves
Wavelength (μm)
5880 K
% Incoming absorbed
wavelength (μm)
Water = Life



Remote Sensing Systems:
the Human Eye
• Spectral Resolution: 0.4-0.7 μm
• Spatial Resolution: ~ 1-3 cm @ 20 m
• Radiometric Resolution: ~16-32 shades B/W or ~100 colors



5880 K
Why do we see visible light?
Increasing flux
4000 K
3500 K
3000 K
2000 K
Spectral curves for blackbody radiators
Wavelength (m)
1 x 10^{-7}
5 x 10^{-7}
1 x 10^{-6}
1.5 x 10^{-6}
2 x 10^{-6}
2.5 x 10^{-6}
3 x 10^{-6}

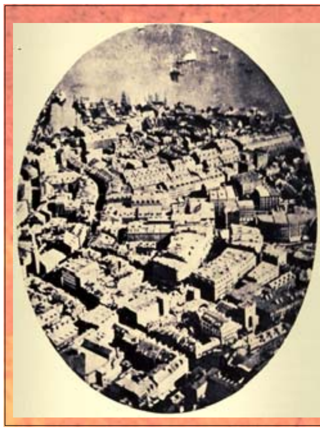


Invertebrate remote sensing
Insects have remote sensing capabilities quite different from vertebrates and the octopus

Key Milestones in Remote Sensing of the Environment

1826 – Joseph Niepce takes first photograph
1858 – Gaspard Tournachon takes first aerial photograph from a balloon
1913 – First aerial photograph collected from an airplane
1935 – Radar invented
1942 – Kodak patents color infrared film
1950s – First airborne thermal scanner
1957 – First high resolution synthetic aperture radar
1962 – Corona satellite series (camera systems) initiated by the Intelligence community
1962 – First airborne multispectral scanner
1972 – ERTS-1 Launched – First Landsat satellite

Balloon Photo of Boston 1836



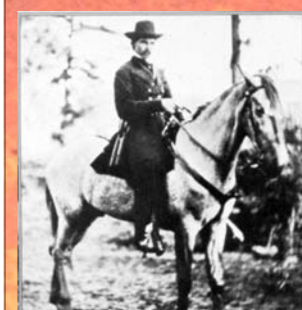
Remote Sensing Systems

- Thaddeus Lowe's Balloon
- Corona System
- Electro-optical systems (Landsat, Terra, AVHRR, SeaWiFS, GOES, VCL, etc.)

- **Balloon, telescope , telegraph**
- **Space craft, camera, film drop**
- **Space craft, scanner or push broom instrument, digital transmission**

Platform, sensing device, data transmission

Thaddeus Lowe's Civil War Balloons
U.S.Army of the Potomac 1861-1865

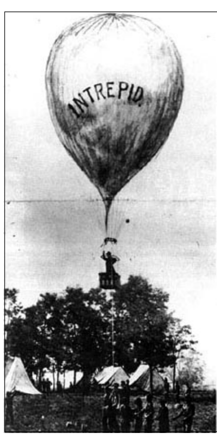


Massachusetts' man, Professor and visionary, Lowe Observatory/Calif.

Platform: **Balloon**

Sensor: **Telescope**

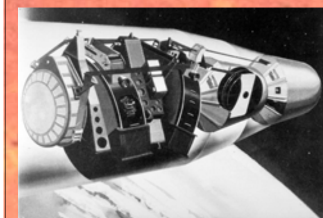
Data System: **Telegraph**



Thaddeus Lowe, circa 1861-1865 remote sensing for military purposes. Then, as now, newest developments are always in the military sphere

Remote sensing in the airplane era 1914 to 1960

CIA's Corona Program
1960-1972 >100 missions



Followed after U-2s…

Platform: **Spacecraft**

Sensor: **Camera**

Data System: **Film Drop**

Started: **August 1960**

Coverage: **7.6 Bil mi^2**

Spatial Resolution: early missions @ 13 m, later missions @ 2 m

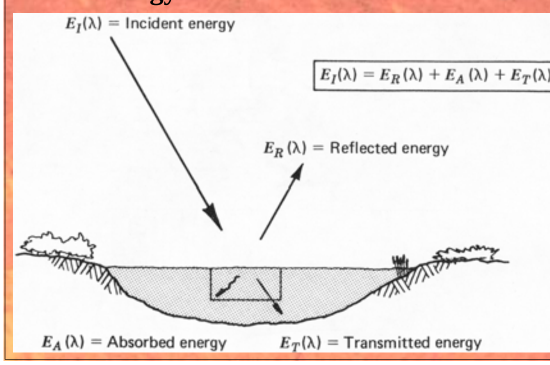
Spectral Resolution: visible and visible-near infrared (both film)

Radiometric Resolution: equivalent 2^4 to 2^6 (4 to 6 bits)

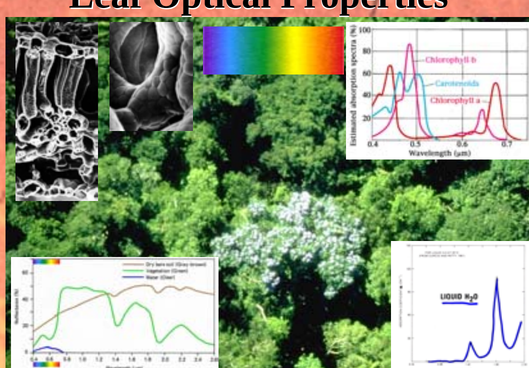
CIA's Corona Program
reentry with air capture

CIA's Corona Program
Washington Monument 1967

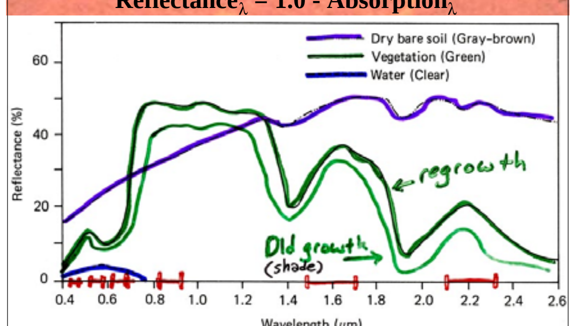
Basic Interactions between Electromagnetic Energy and the Earth's Surface

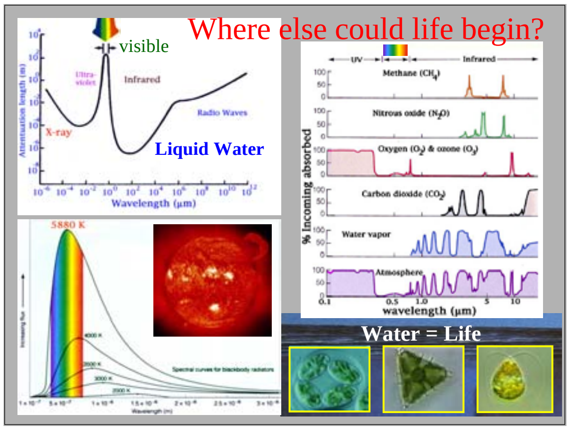


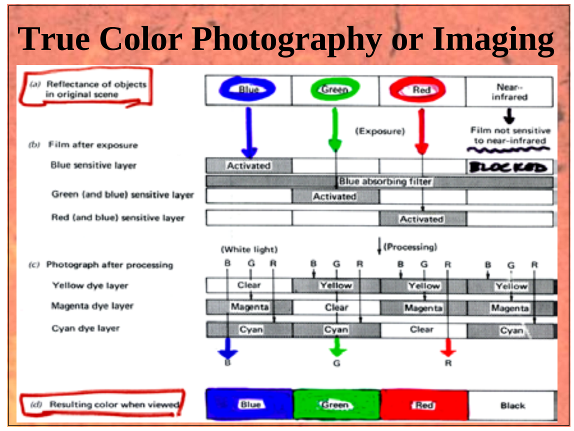
Leaf Optical Properties

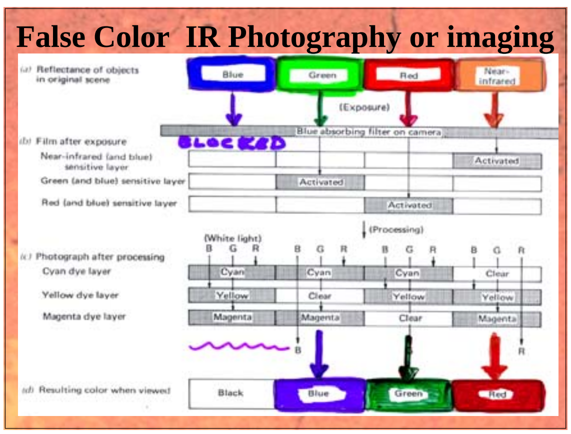


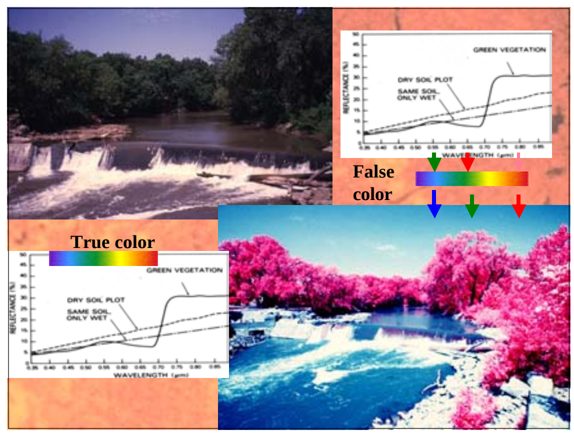
Leaf Spectral Reflectance
Reflectance$_\lambda$ = 1.0 - Absorption$_\lambda$

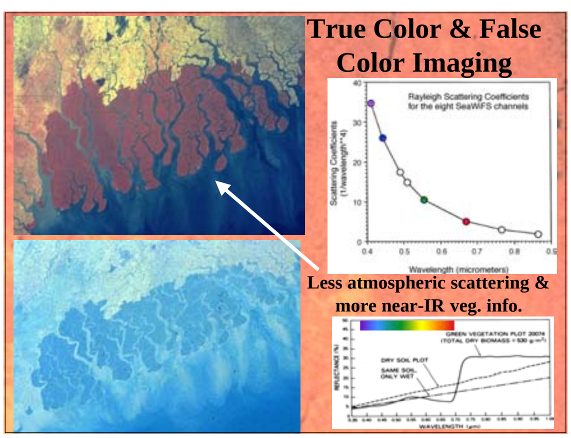


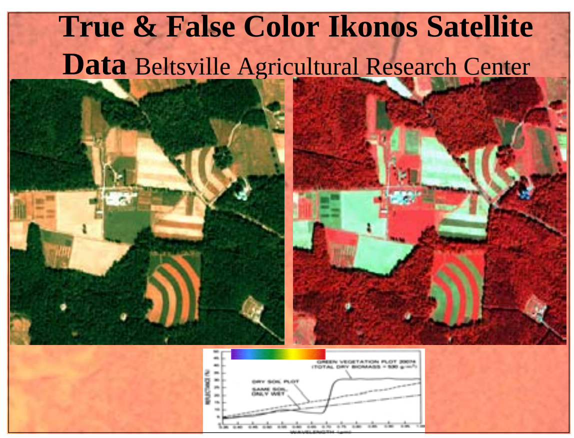

Where else could life begin?
visible
Infrared
Radio Waves
X-ray
Liquid Water
Wavelength (μm)
5880 K
Methane (CH4)
Nitrous oxide (N2O)
Oxygen (O2) & ozone (O3)
Carbon dioxide (CO2)
Water vapor
Atmosphere
% Incoming absorbed
wavelength (μm)
Water = Life

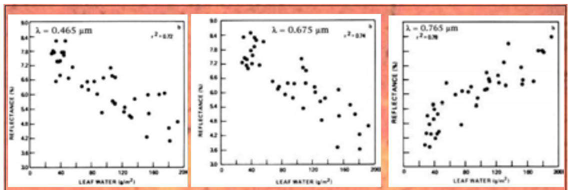

True Color Photography or Imaging
(a) Reflectance of objects in original scene
Blue
Green
Red
Near-infrared
(Exposure)
Film not sensitive to near-infrared
(b) Film after exposure
Blue sensitive layer
Green (and blue) sensitive layer
Red (and blue) sensitive layer
Activated
Blue absorbing filter
BLOCKED
(White light)
(Processing)
(c) Photograph after processing
Yellow dye layer
Magenta dye layer
Cyan dye layer
Clear
Yellow
Magenta
Cyan
(d) Resulting color when viewed
Blue
Green
Red
Black


False Color IR Photography or imaging
(a) Reflectance of objects in original scene
Blue
Green
Red
Near-infrared
(Exposure)
Blue absorbing filter on camera
(b) Film after exposure
BLOCKED
Near-infrared (and blue) sensitive layer
Green (and blue) sensitive layer
Red (and blue) sensitive layer
Activated
(Processing)
(White light)
(c) Photograph after processing
Cyan dye layer
Yellow dye layer
Magenta dye layer
Cyan
Yellow
Magenta
Clear
(d) Resulting color when viewed
Black
Blue
Green
Red

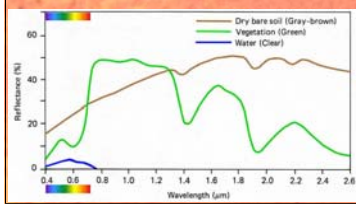

GREEN VEGETATION
DRY SOIL PLOT
SAME SOIL ONLY WET
WAVELENGTH (μm)
False color
True color


True Color & False Color Imaging
Rayleigh Scattering Coefficients for the eight SeaWiFS channels
Scattering Coefficients (1/wavelength^4)
Wavelength (micrometers)
Less atmospheric scattering & more near-IR veg. info.
GREEN VEGETATION
DRY SOIL PLOT
SAME SOIL ONLY WET

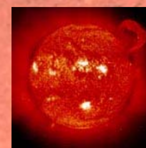

True & False Color Ikonos Satellite Data Beltsville Agricultural Research Center
GREEN VEGETATION
DRY SOIL PLOT
SAME SOIL ONLY WET

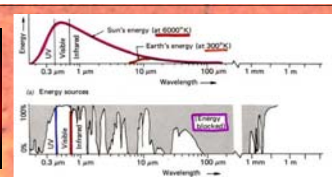


Blue region | **red region** | **Near-IR region**



More green leaves affect visible & near-ir reflectances

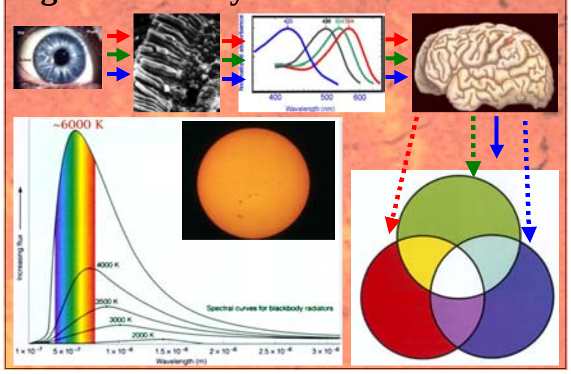




Sun's radiant energy (~6000 K)

Spectral Region	Wavelength (μm)		Percent of Total Energy
Gamma and X rays	<0.01		0.02
Far UV	0.01–0.2		
Middle UV	0.2–0.3		1.95
Near UV	0.3–0.4	92%	5.32
Visible	0.4–0.7		43.50
Near IR	0.7–1.5		36.80
Middle IR	1.5–5.6		12.00
Far IR	5.6–1,000		0.41
Microwave and radio waves	>1,000		
Total			100.00

Signals from Eye Processed in Brain

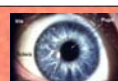


Remote Sensing Systems: the Human Eye

- **Spectral Resolution: 0.4-0.7 μm**
- **Spatial Resolution: ~ 1-3 cm @ 20 m**
- **Radiometric Resolution: ~16-32 shades B/W or ~100 colors**

---

120 M rods, 5 M cones, & 1 M optic axons



Human Eye

Cones--color sensitive, form sharp images, require many photons

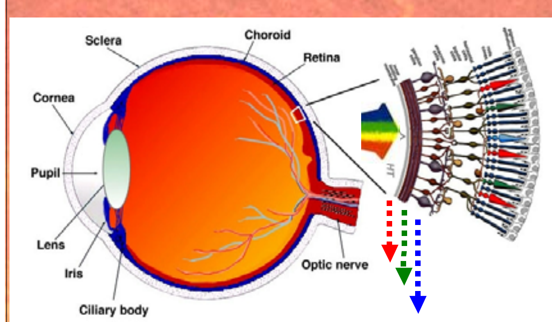
Rods are intensity, but not color, sensitive & form blurred images

Birds--big eyes, more cones, "faster" eye muscles, more support, and **best** vision (**8x**)

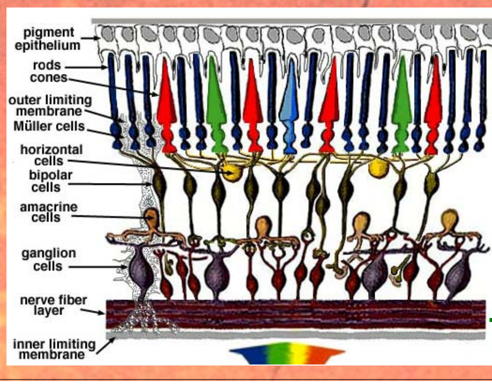
Nocturnal animals have big eyes & more rods/fewer cones

Retina Rods & Cones: our visible detectors

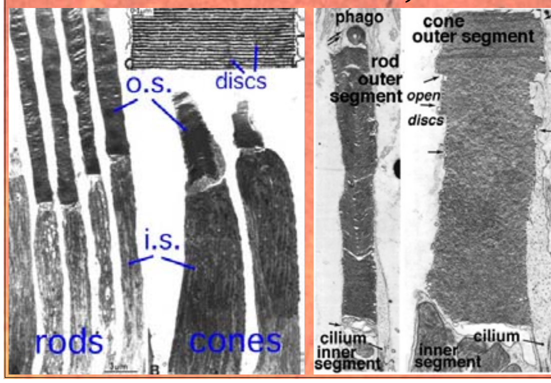
Human Eye and Retina

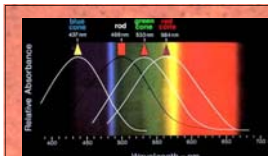


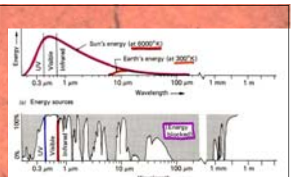
Retinal structure

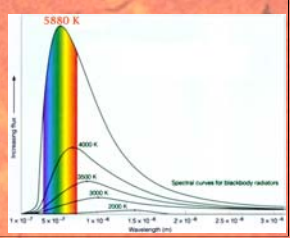


Rods and Cones at 10,000x



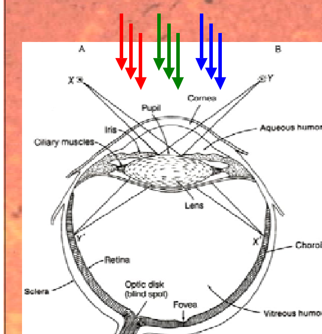




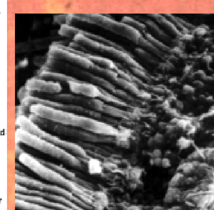


Our vision is optimized for receiving spectral radiance from our star. evolution?

Human Vision



Fovea >rods & cones

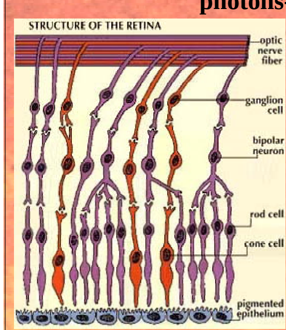


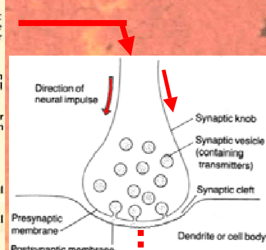
Retinal rods & cones

our visible detectors

Eye Function

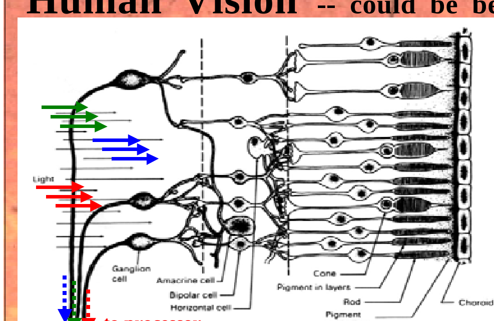
photons->electrical signal->brain





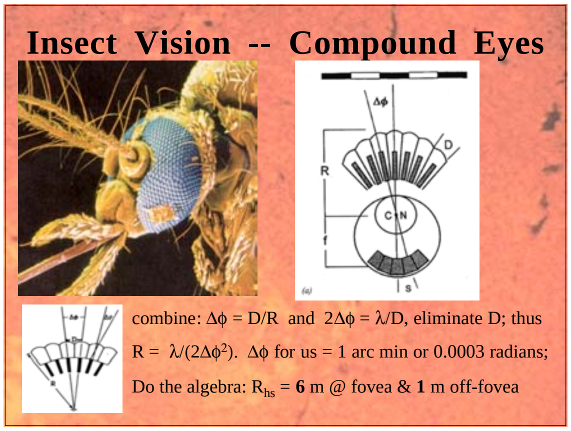
To brain

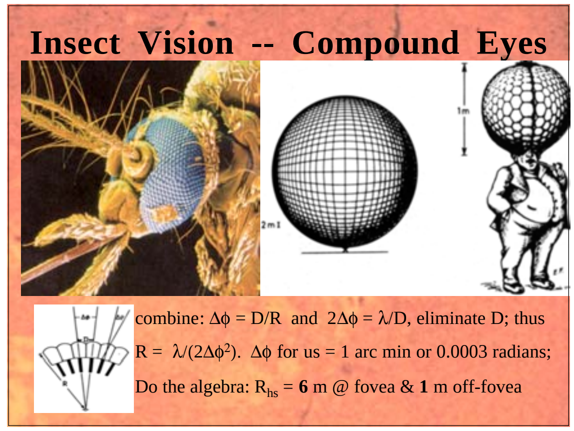
Human Vision -- could be better

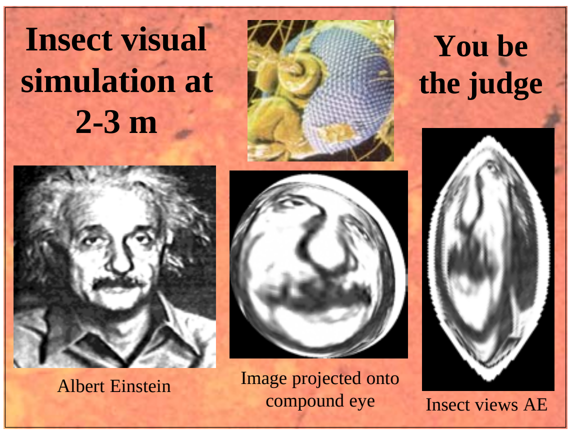


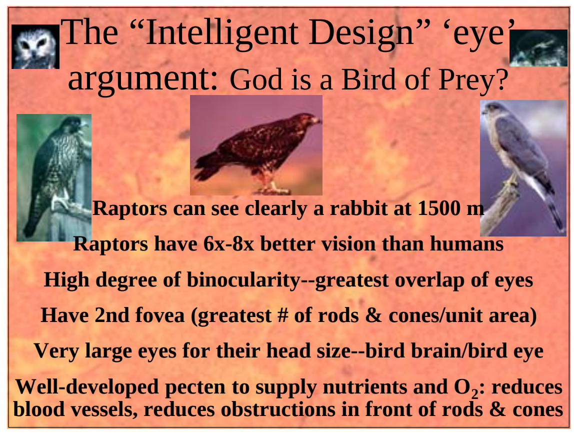
Not optimum design--lots of nerve cells in optical pathway

(give us a few more million years without a major extinction event…)

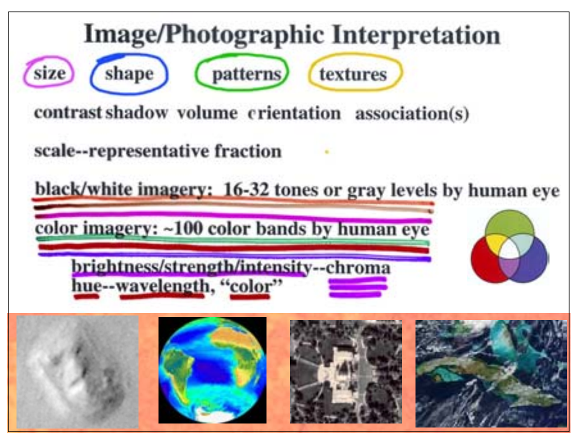

Insect Vision -- Compound Eyes
combine: $\Delta\phi = D/R$ and $2\Delta\phi = \lambda/D$, eliminate D; thus
$R = \lambda/(2\Delta\phi^2)$. $\Delta\phi$ for us = 1 arc min or 0.0003 radians;
Do the algebra: R_{hs} = **6** m @ fovea & **1** m off-fovea


Insect Vision -- Compound Eyes
combine: $\Delta\phi = D/R$ and $2\Delta\phi = \lambda/D$, eliminate D; thus
$R = \lambda/(2\Delta\phi^2)$. $\Delta\phi$ for us = 1 arc min or 0.0003 radians;
Do the algebra: R_{hs} = **6** m @ fovea & **1** m off-fovea


Insect visual simulation at 2-3 m
You be the judge
Albert Einstein
Image projected onto compound eye
Insect views AE


The "Intelligent Design" 'eye' argument: God is a Bird of Prey?
Raptors can see clearly a rabbit at 1500 m
Raptors have 6x-8x better vision than humans
High degree of binocularity--greatest overlap of eyes
Have 2nd fovea (greatest # of rods & cones/unit area)
Very large eyes for their head size--bird brain/bird eye
Well-developed pecten to supply nutrients and O_2: reduces blood vessels, reduces obstructions in front of rods & cones


All alone in our neighborhood of space
Apollo 12's Classic Earth Rise from Moon


Image/Photographic Interpretation
size
shape
patterns
textures
contrast shadow volume orientation association(s)
scale--representative fraction
black/white imagery: 16-32 tones or gray levels by human eye
color imagery: ~100 color bands by human eye
brightness/strength/intensity--chroma
hue--wavelength, "color"