Introduction to Remote Sensing

Just the Basics

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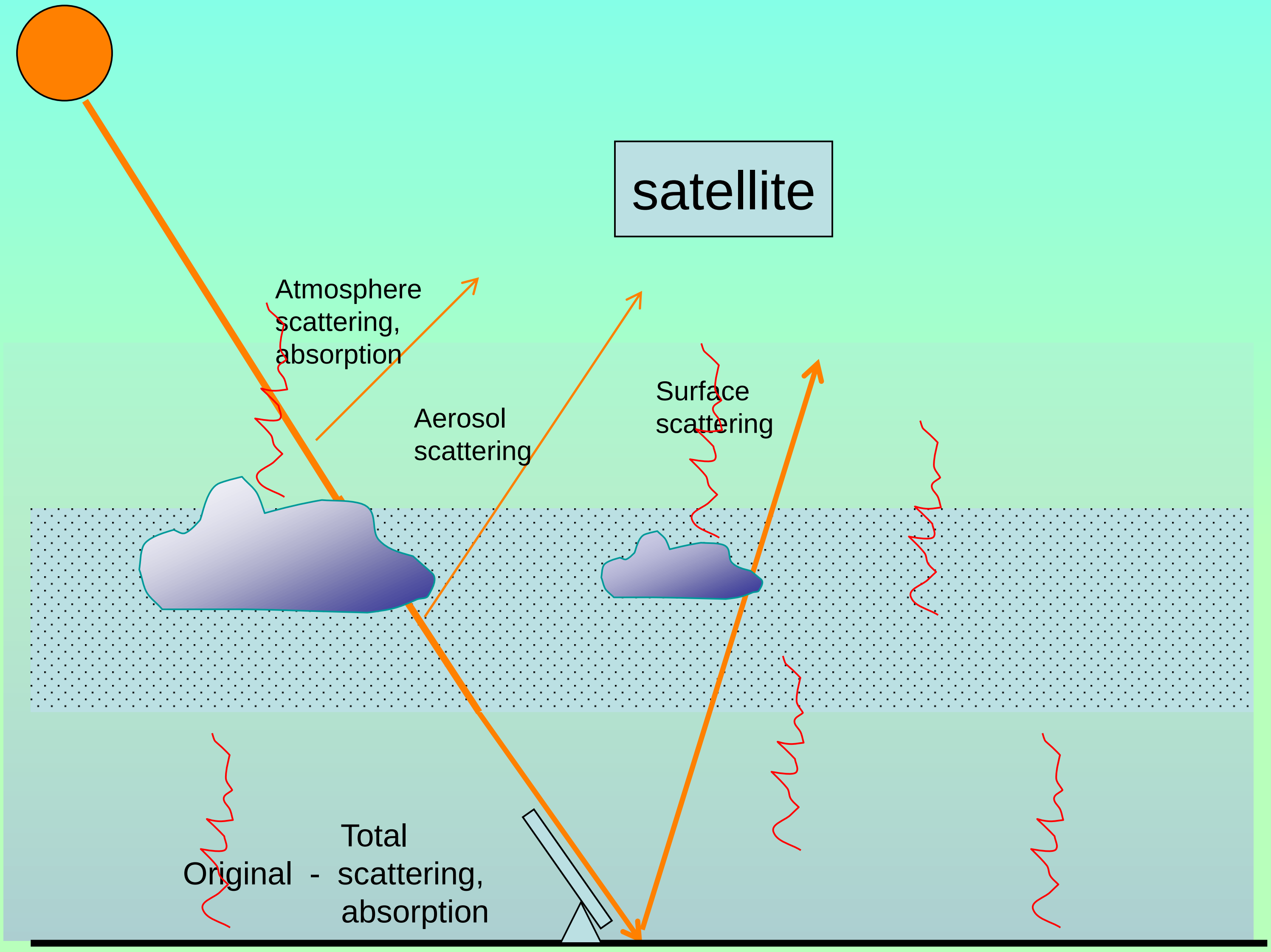
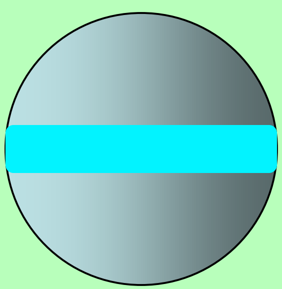
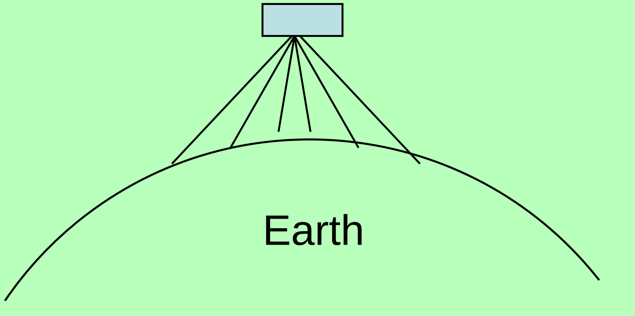
The Big Picture



Satellite Orbits

Low polar orbit

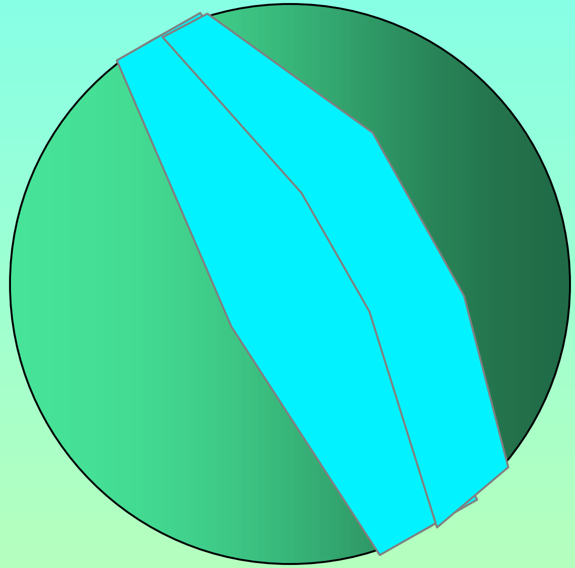




Near Polar Orbits

High Resolution
Episodic

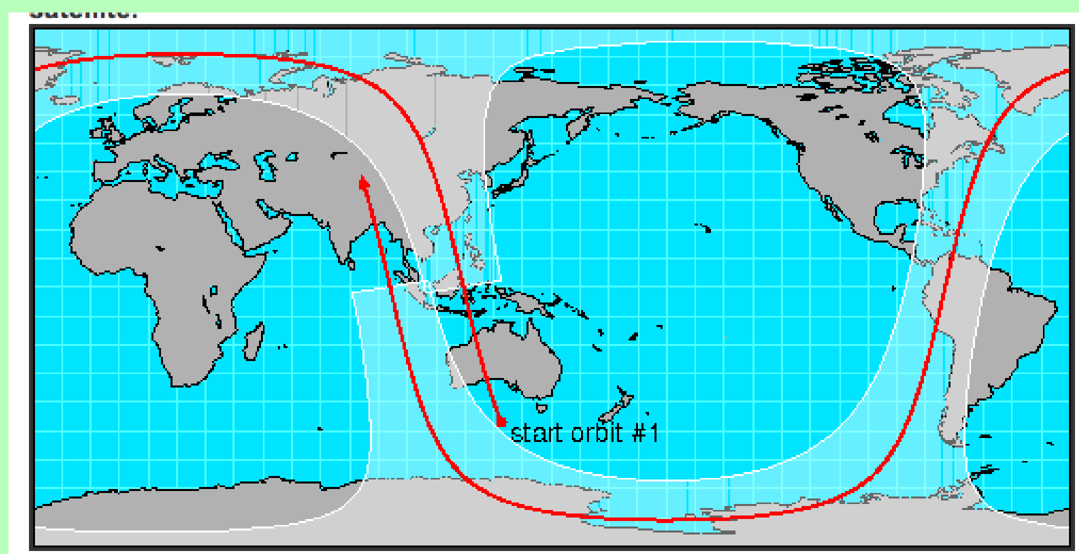
T » 90 minutes



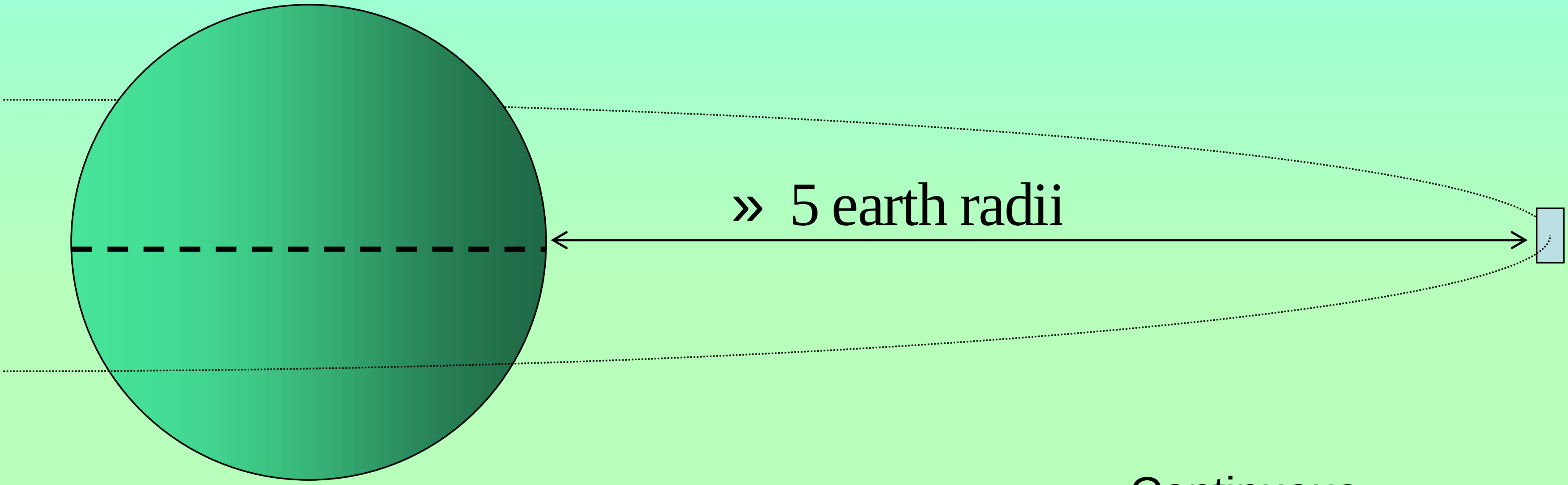
Gravitational acceleration = Centripetal acceleration

$$\frac{GM}{r^2} = \frac{v^2}{r}$$

$$v = \frac{2pr}{T}$$



Geosynchronous Orbits

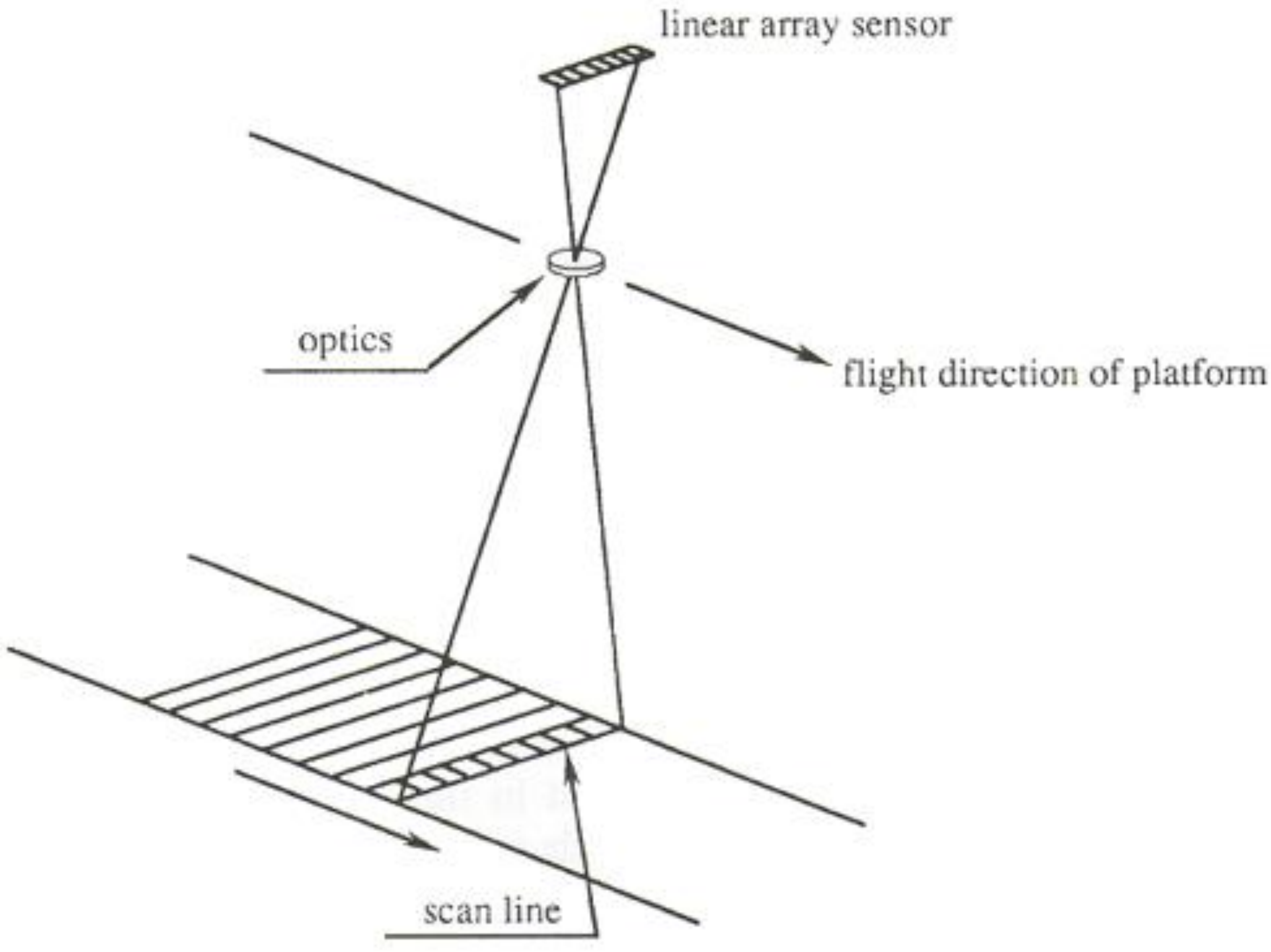


T = 1 day

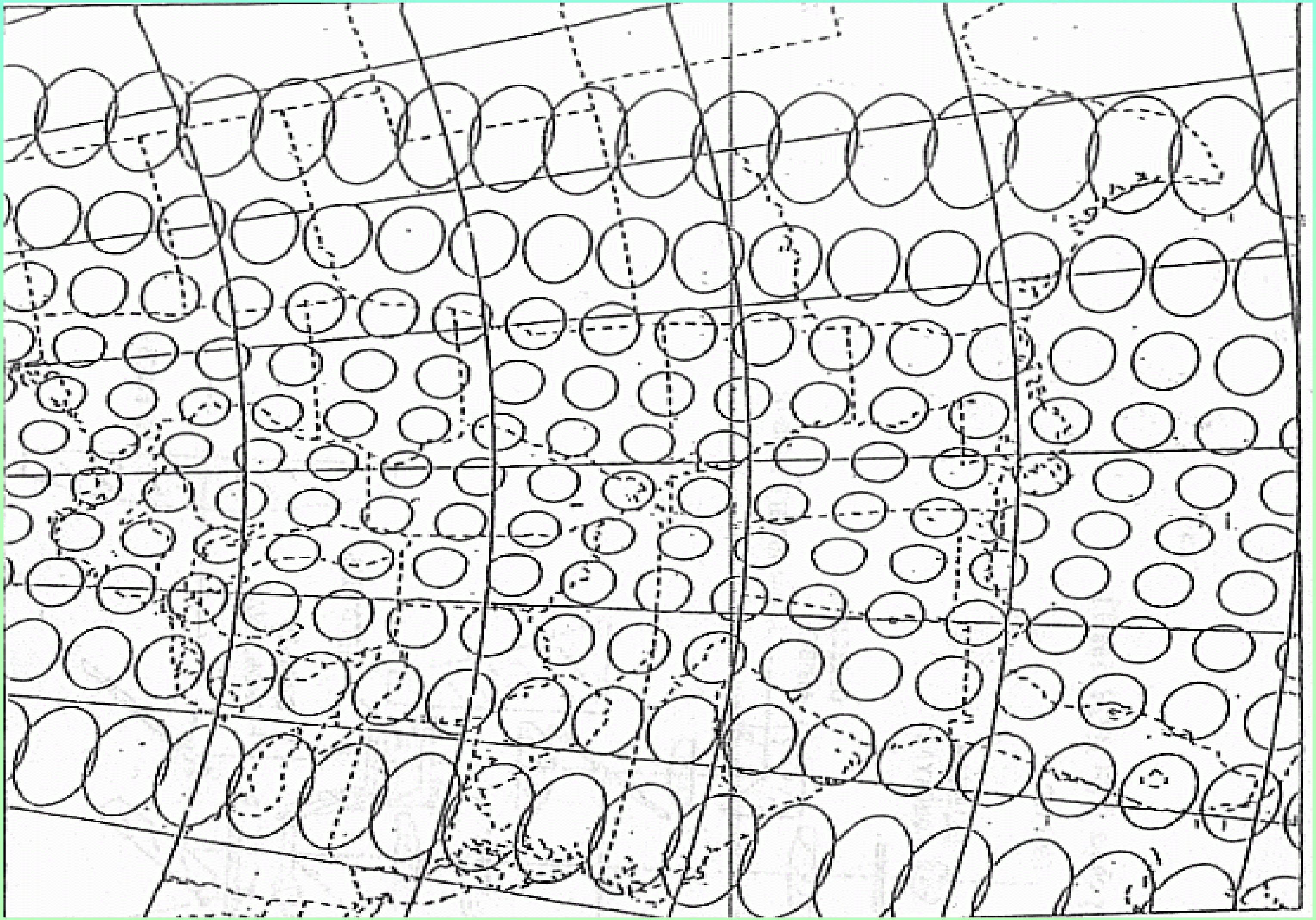
Continuous
Low Resolution

Insert what types of orbits for different tasks?

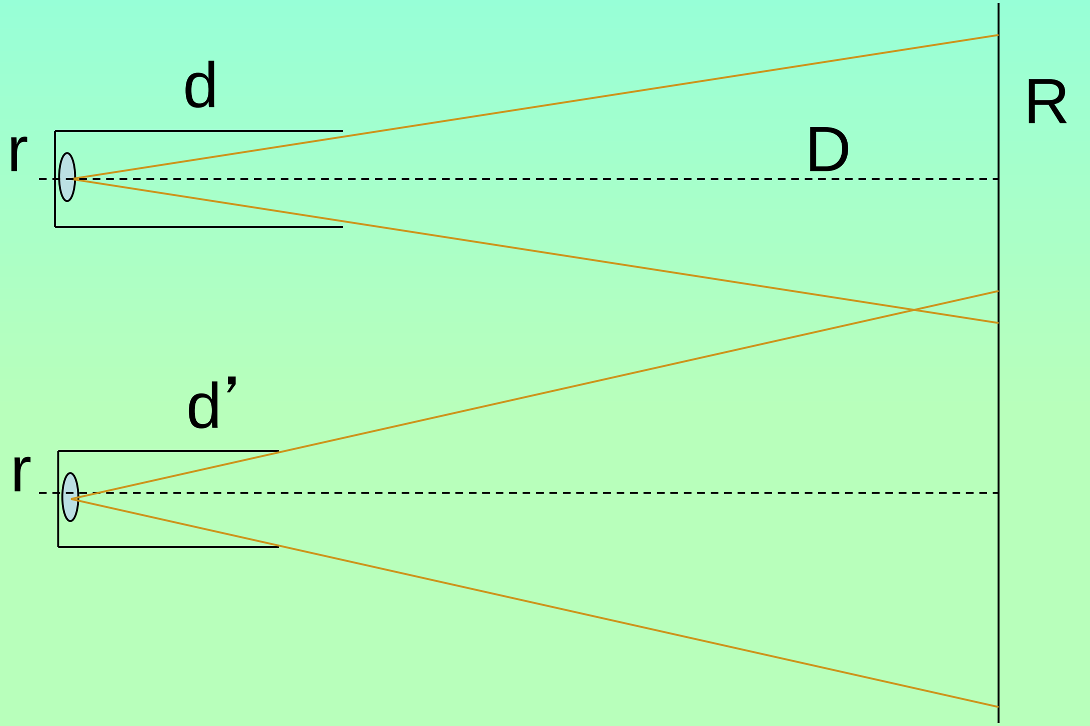
Typical Scan Pattern



Typical Pixel Distortion



Collimation

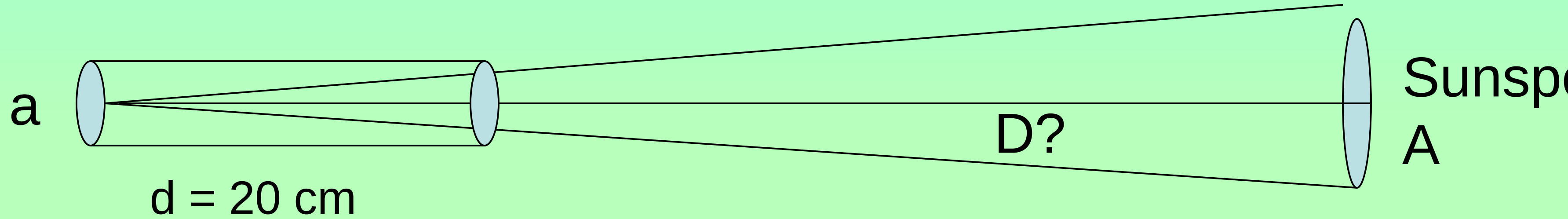


Geometry affects the field of view

by similar triangles: $\frac{r}{d} = \frac{R}{D}$

Insert refresh of metric system and scientific notation

Example: sunspots on the sun are about the size of the earth. If you wanted to resolve sunspots using the pixels on a scanning camera of a satellite orbiting the earth, if the length of the collimator is 20 cm, what would be the area of the base?



r/d = R/D

$a = \pi r^2$ $A = \pi R^2$

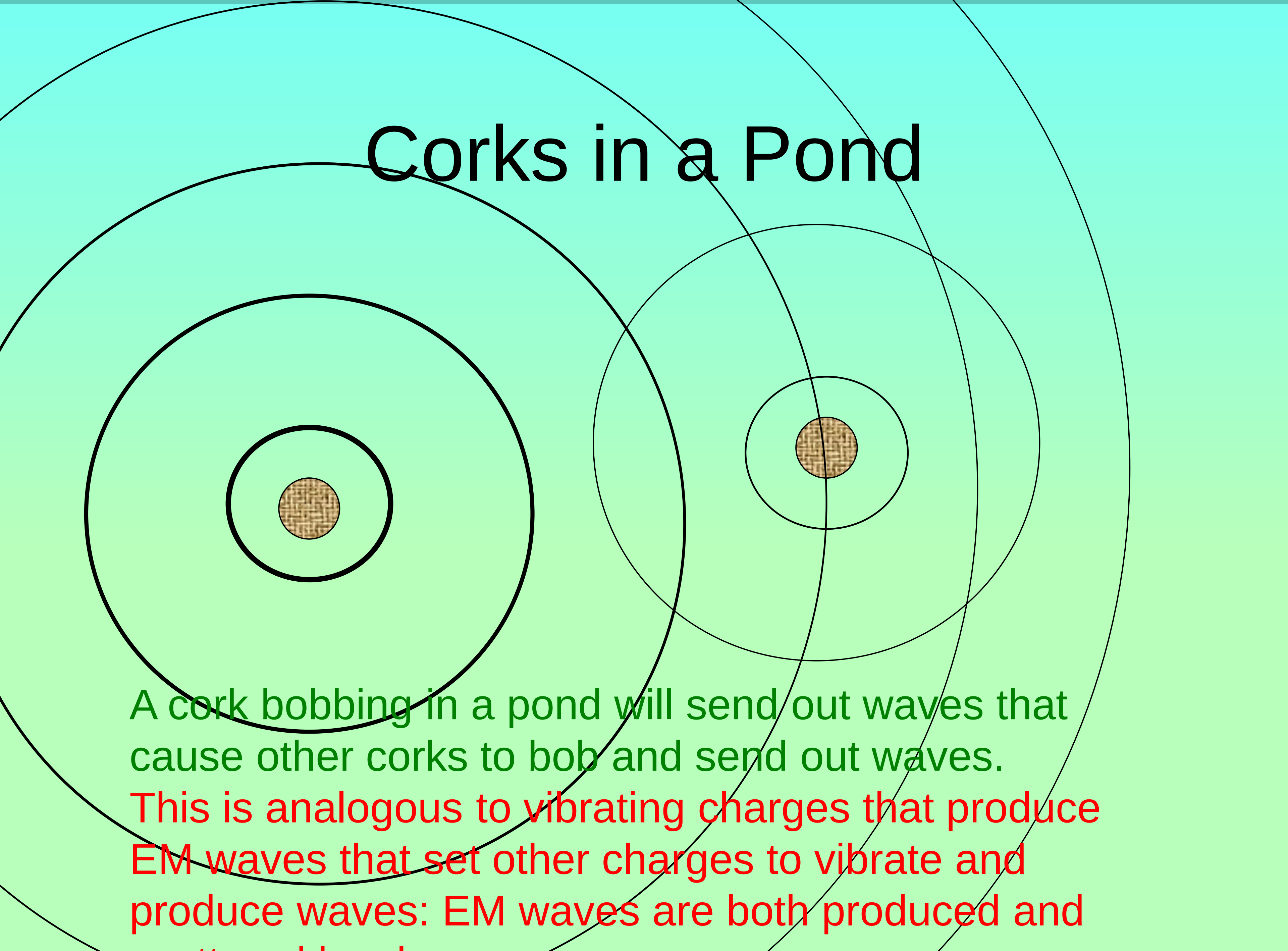
Length of collimator d = 20 cm

Area of collimator a ?

Distance to sunspot D = 150 million km

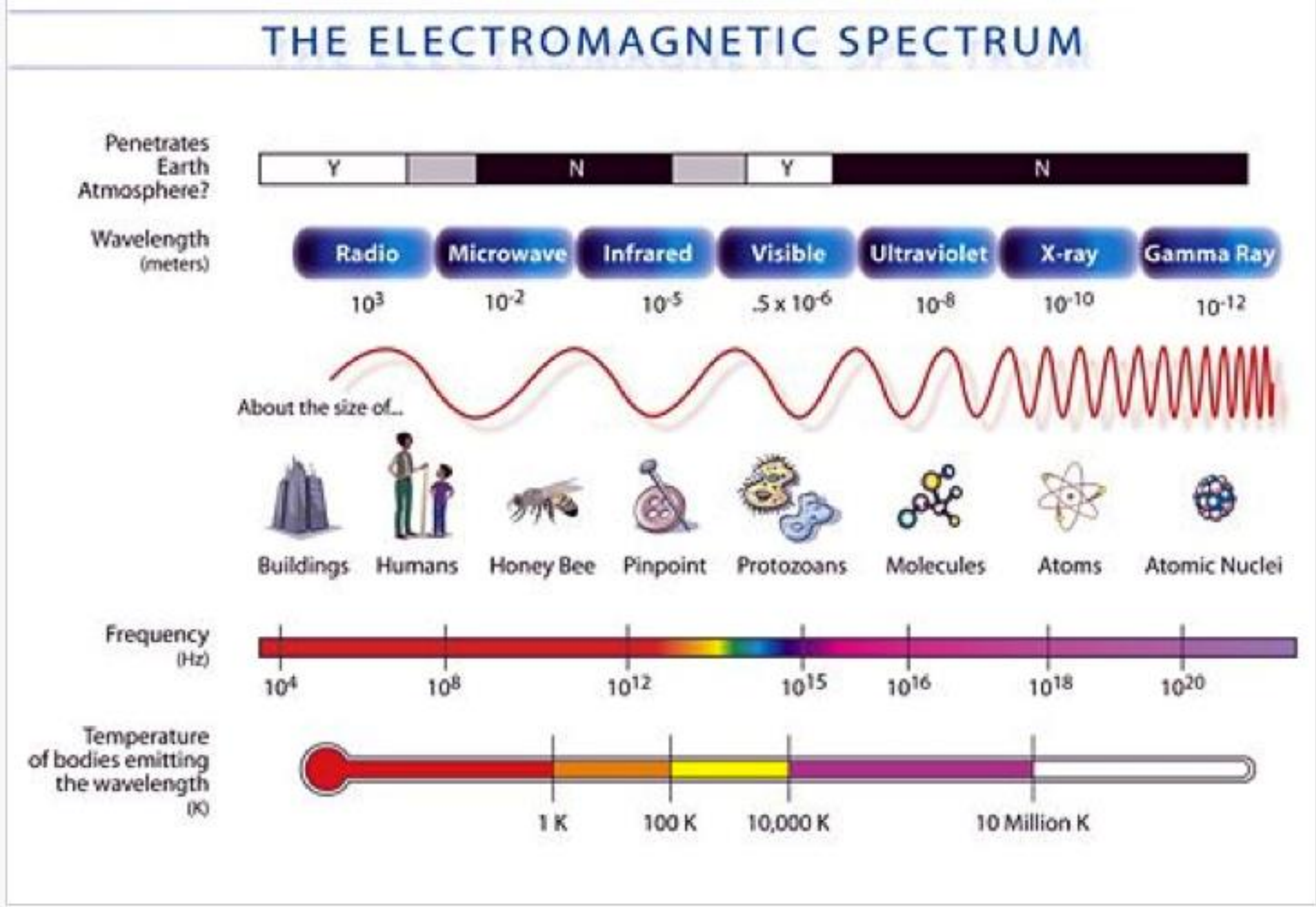
Area of sunspot = $\pi r^2 = \pi(C/2\pi)^2 = C^2/4\pi = (4x10^4 km)/4\pi$

Corks in a Pond

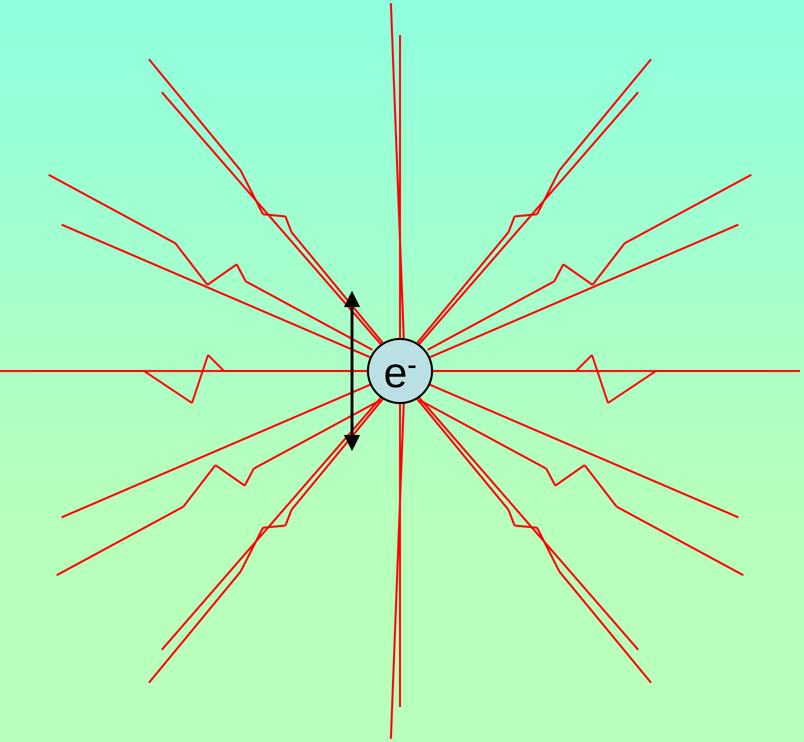


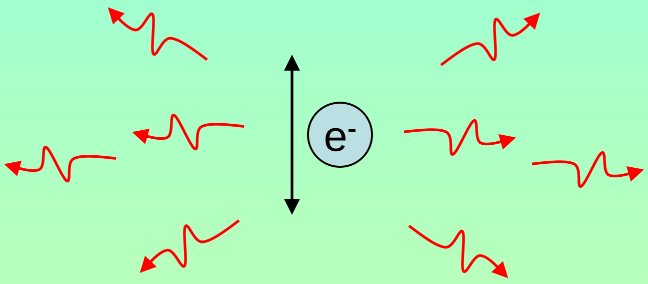
A cork bobbing in a pond will send out waves that cause other corks to bob and send out waves.

This is analogous to vibrating charges that produce EM waves that set other charges to vibrate and produce waves: EM waves are both produced and


THE ELECTROMAGNETIC SPECTRUM
Penetrates Earth Atmosphere?
Y
N
Y
N
Wavelength (meters)
Radio
Microwave
Infrared
Visible
Ultraviolet
X-ray
Gamma Ray
10^{3}
10^{-2}
10^{-5}
$.5 \times 10^{-6}$
10^{-8}
10^{-10}
10^{-12}
About the size of...
Buildings
Humans
Honey Bee
Pinpoint
Protozoans
Molecules
Atoms
Atomic Nuclei
Frequency (Hz)
10^{4}
10^{8}
10^{12}
10^{15}
10^{16}
10^{18}
10^{20}
Temperature of bodies emitting the wavelength (K)
1 K
100 K
10,000 K
10 Million K

Photons and Waves

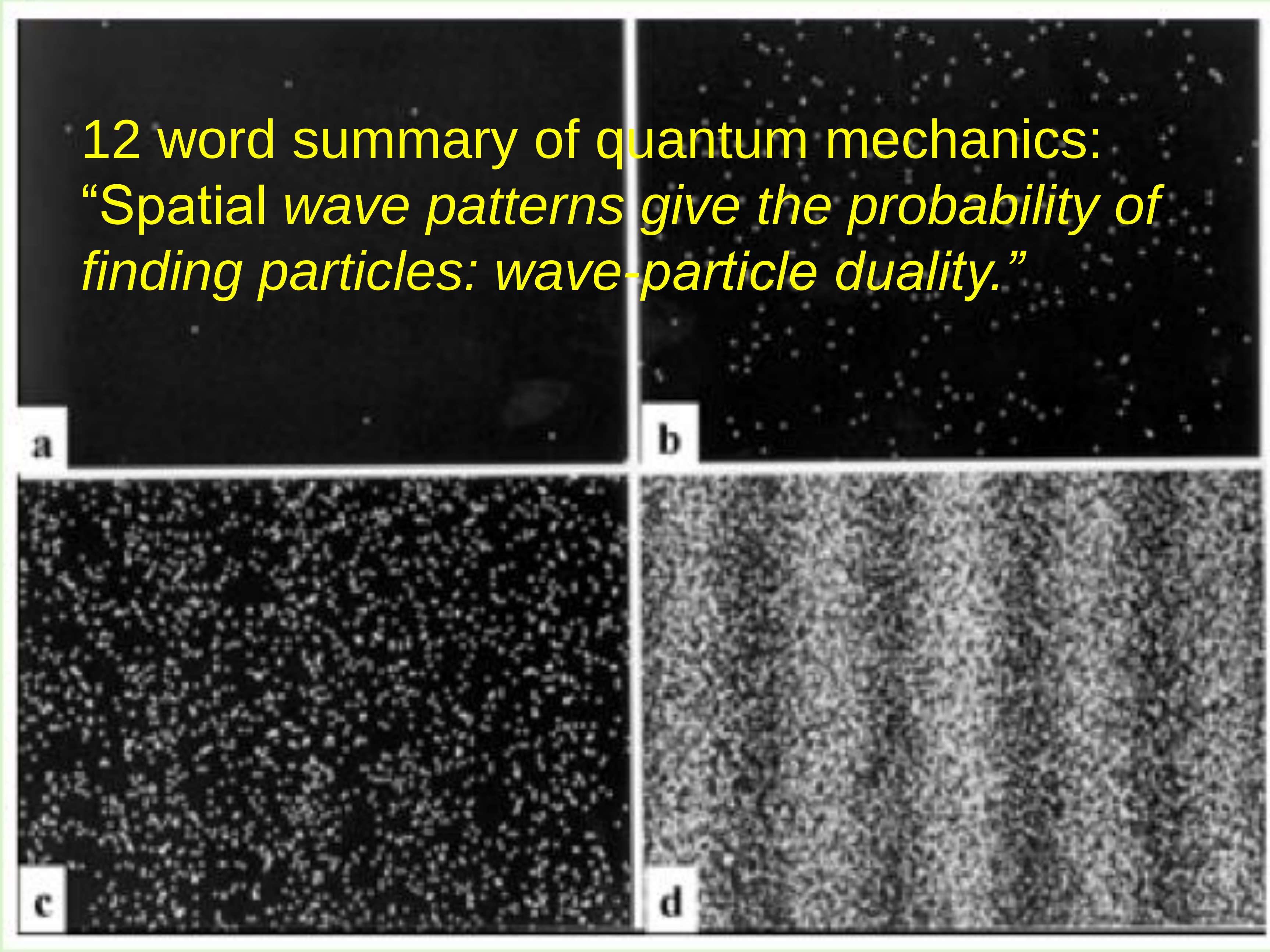




[Double Slit Experiment]

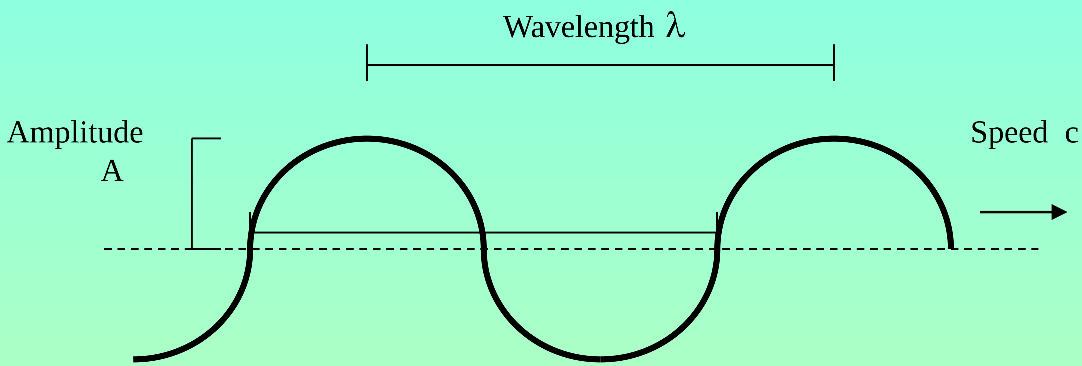
https://www.youtube.com/watch?v=Q1YqgPAtzho

Individual photons, two source interference



12 word summary of quantum mechanics:
"Spatial *wave patterns give the probability of finding particles: wave-particle duality."*

Basic Wave Stuff



Period T = seconds/wave

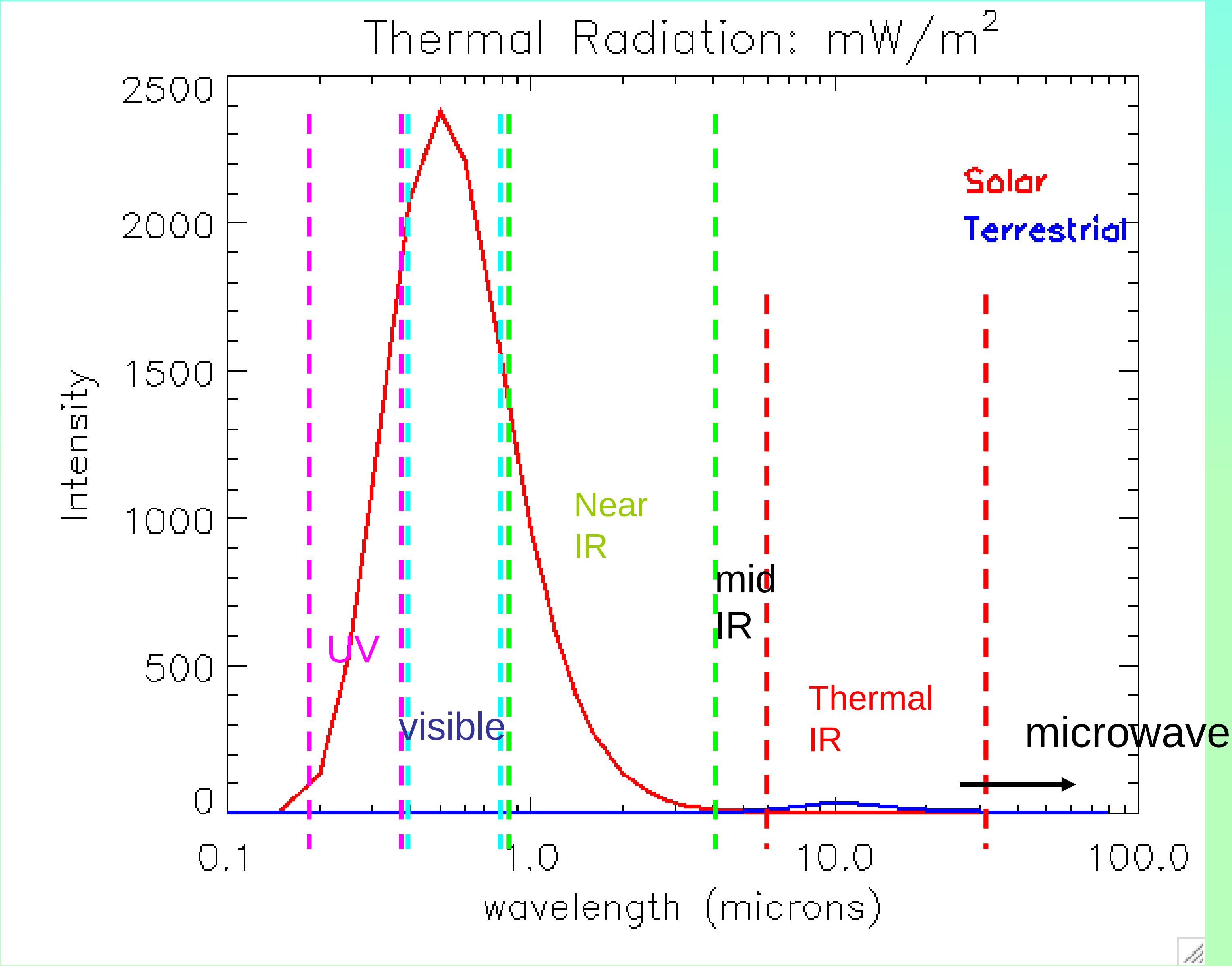
Frequency f = waves/seconds

$f = 1/T$

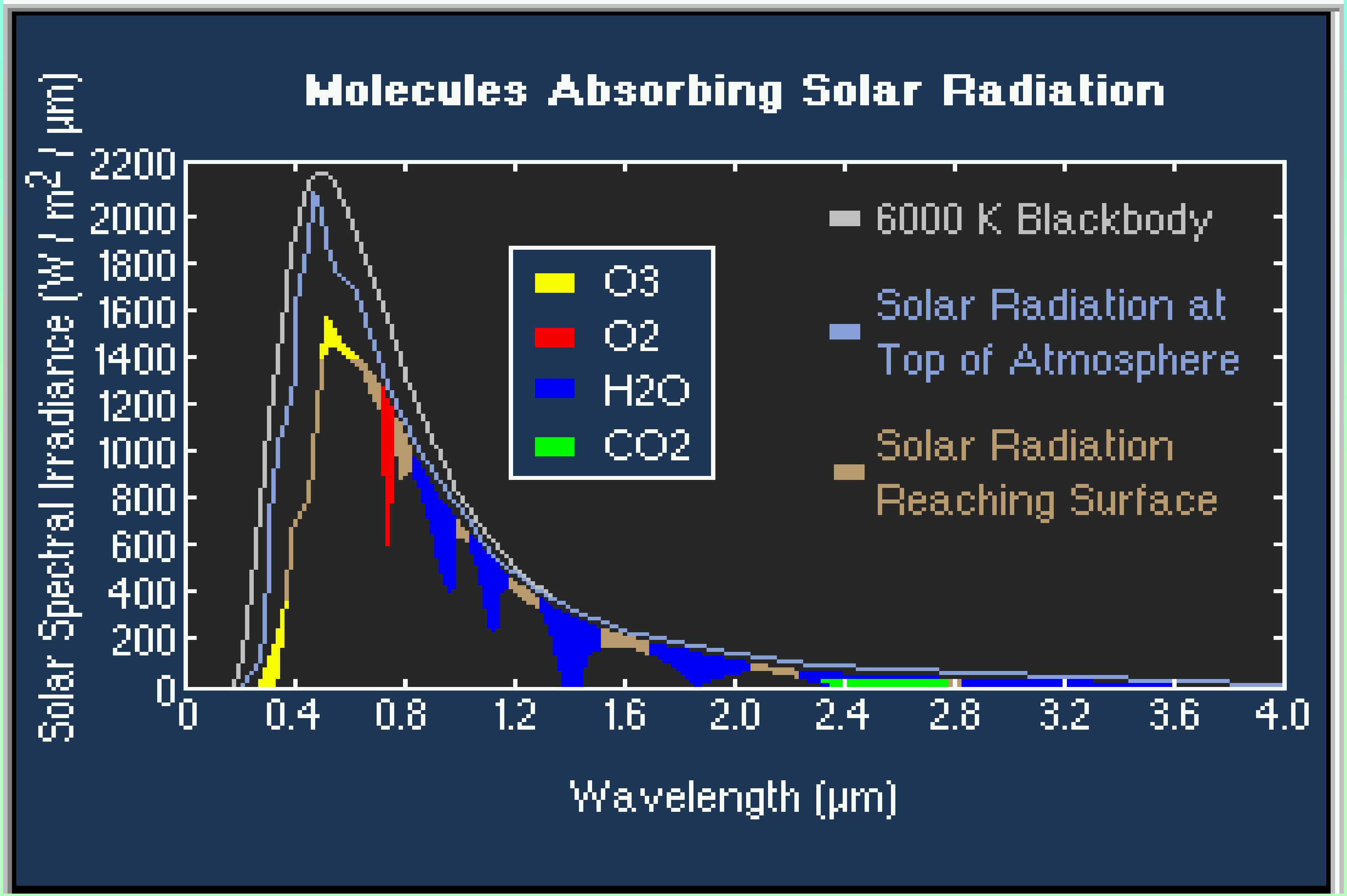
Speed c = distance/time = $\lambda/T = \lambda f$

$c = \lambda f$

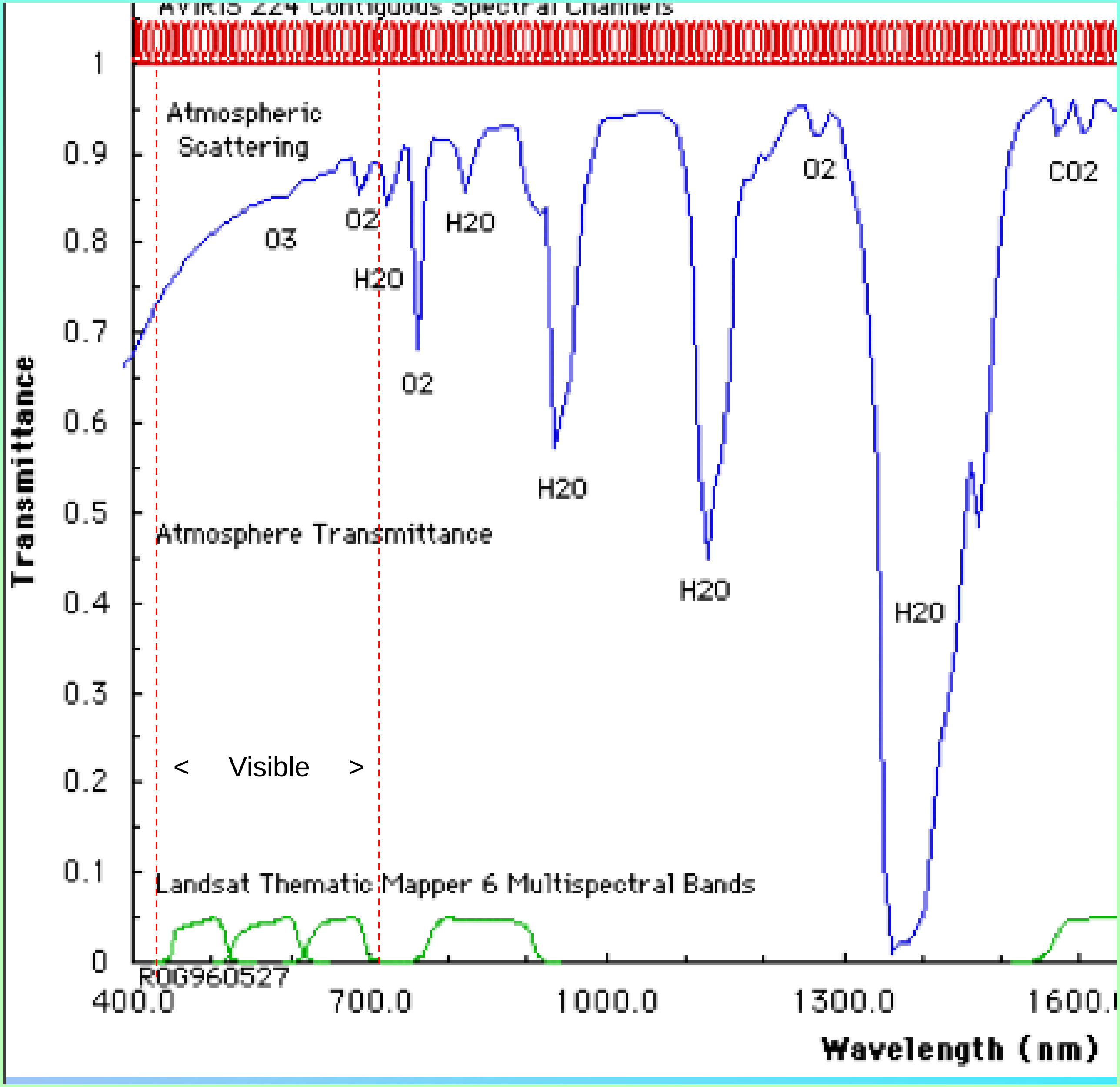
Linear Amplitude, Solar and Terrestrial



Solar Spectrum - absorption



Scattering and Absorption



Scattering depends on geometry and so changes smoothly with wavelength.

Absorption is usually due to electronic transitions and will be sharp.

Some Scales to Know

Angstroms	=	10^{-10} m.	Atoms, molecules, hard X-rays
Microns	=	10^{-6} m.	Cells, pollution(aerosols), cloud drops, solar spectrum
mm	=	10^{-3} m.	Rain drops.

A little Practice

- What is the frequency of visible light?

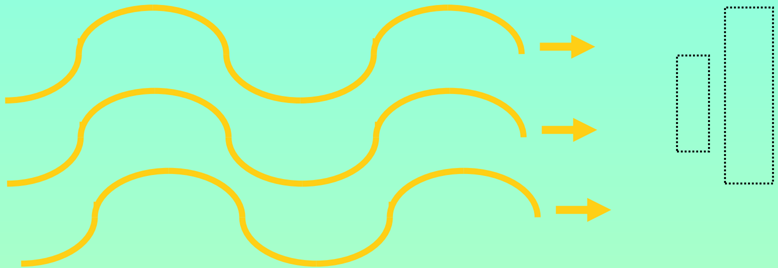
$f = c/\lambda = (3\text{x}10^{8}\text{m/s})/(0.5\text{x}10^{-6}\text{m})$

$= 6\text{x}10^{14}\text{1/s (Hz)}$

- You wave a charged balloon up and down a few times a second, what wavelength of light are you producing? What object has comparable size?

Add: sound waves and instruments

Measuring Light



For the same intensity, the energy that passes increases with area.

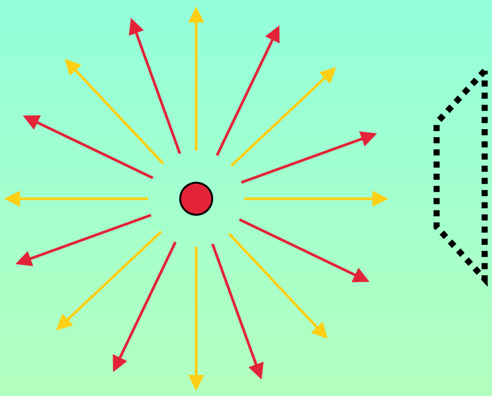
Light waves transport energy at a rate given by its intensity.

For a given intensity, we expect the energy that passes through an area during a given time to be given by

Energy = intensity x area x time   or   Intensity = E/(AT)

But Energy/time = power (watts) so I = P/A => W/m^2

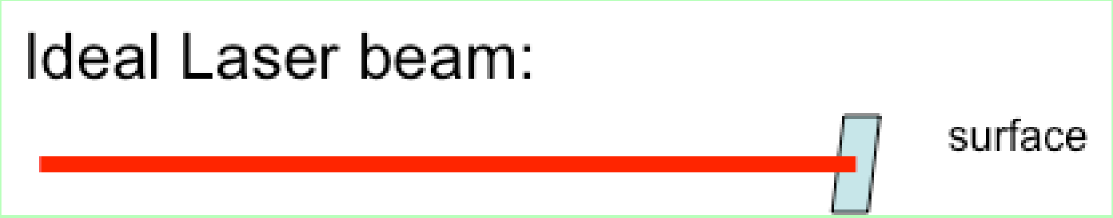
Variations on Intensity



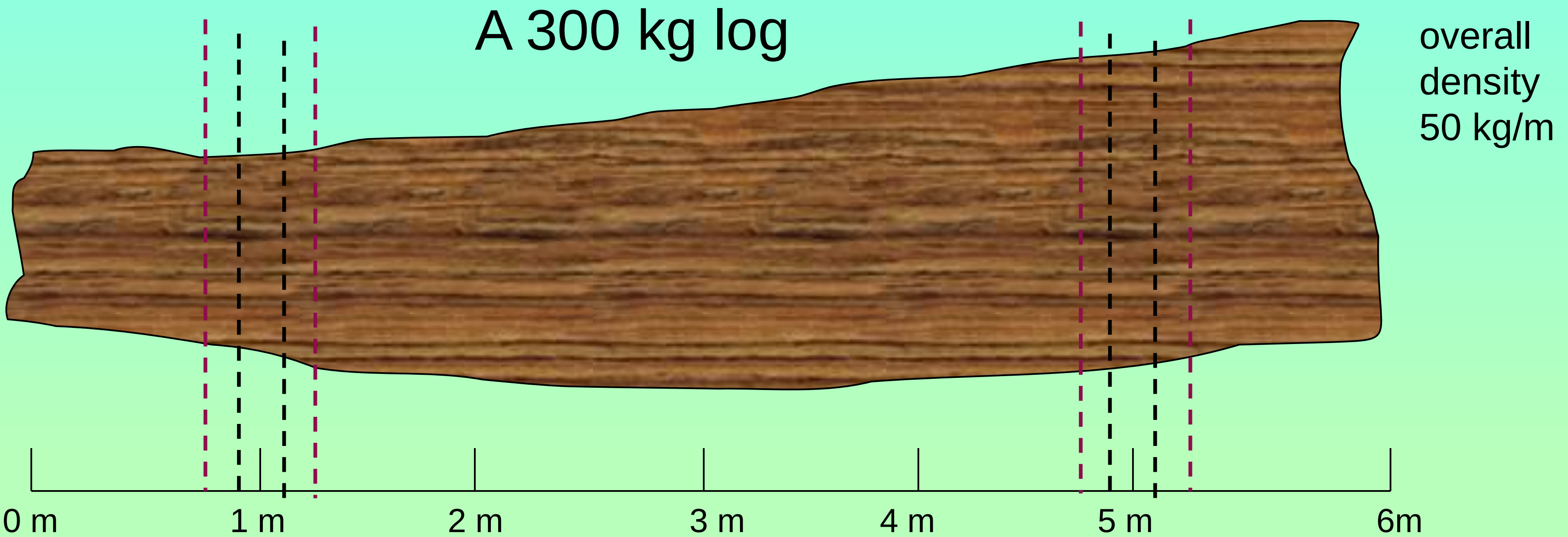
Intensity is measured as power/area that passes through an imaginary surface perpendicular to the light. I = watts/m^2

Intensity can also be measured per unit wavelength to capture a section of the spectrum.

spectral intensity I = watts/m^2/μm



A Physical Analogy



Density at 1 m:
= 8 kg/(1.1m - 0.9 m)
= 40 kg/m

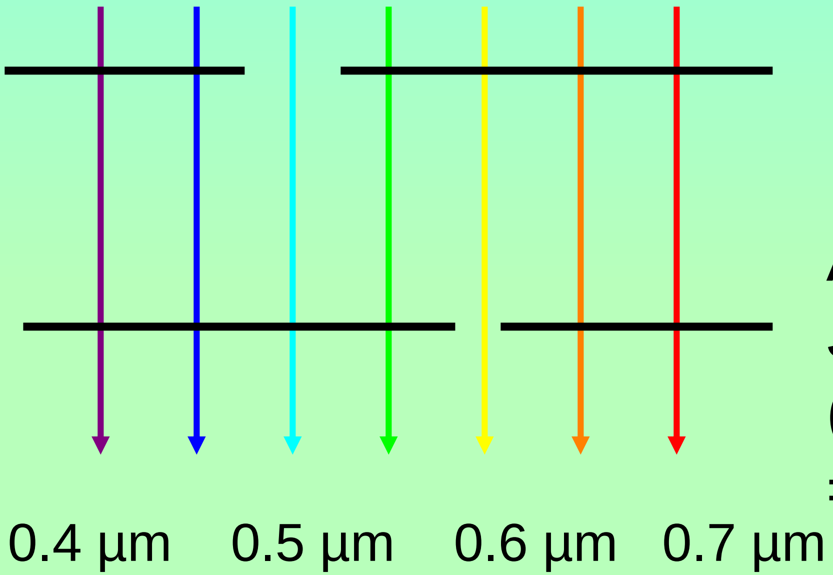
Density at 5 m:
= 12 kg/(5.1m - 4.9 m)
= 60 kg/m

Density at 1 m:
= 16 kg/(1.2m - 0.8 m)
= 40 kg/m

Density at 5 m:
= 24 kg/(5.2m - 4.8 m)
= 60 kg/m

Intensity and Wavelength

Intensity = 1400 W/m^2



At 0.5 µm,
Spectral intensity =
(200 W/m^2)/(0.55µm - 0.45µm)
= 2000 W/m^2/µm

At 0.6 µm,
Spectral intensity =
(60 W/m^2)/(0.62µm - 0.58µm)
= 1500 W/m^2/µm

Spectral Intensity Example

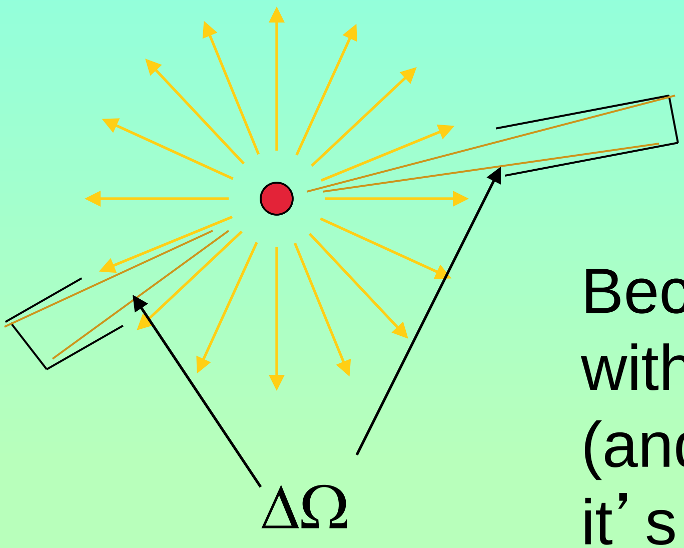
A detector with an area of 2 cm^2 measures power of 0.14 watts. It is sensitive to wavelengths between 0.4 and 0.8 microns. What is the spectral intensity of this light?

I_λ = (power/area)/$\Delta\lambda$ = ((0.14 watts)/(2 cm^2))/(0.8 - 0.4 μm)

= (1.4x10^{-1} W)/(2x(10^{-2} m)^2)/(4x10^{-1} μm)

$$= \frac{(1.4x10^{-1} W)}{(2x10^{-2} m)^2 (4x10^{-1} \mu m)} = 0.175x10^4 \frac{W}{m^2 \mu m} = 1.75x10^3 \text{ W/m}^2/\mu m$$

A Note on Radiance

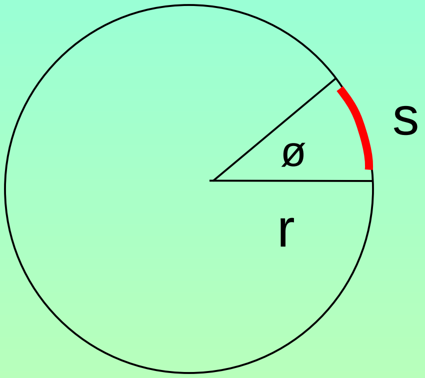


Because detectors collect light within a narrow angular range (and light radiates in all directions) it's common to talk about the light per unit solid angle, or *radiance.*

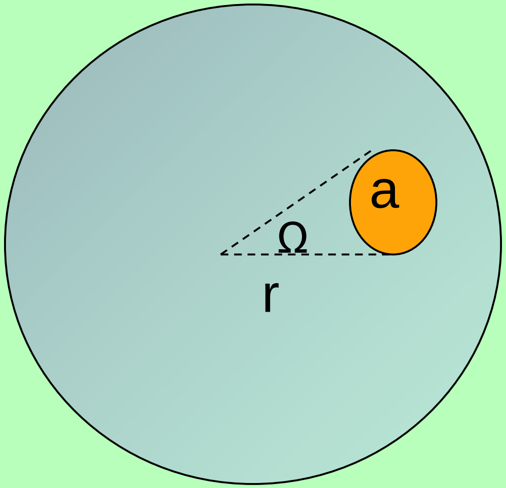
$$I_{rad} = I/\Delta\Omega$$

Solid Angles (steradians)

Radians: $\square ø = s/r$

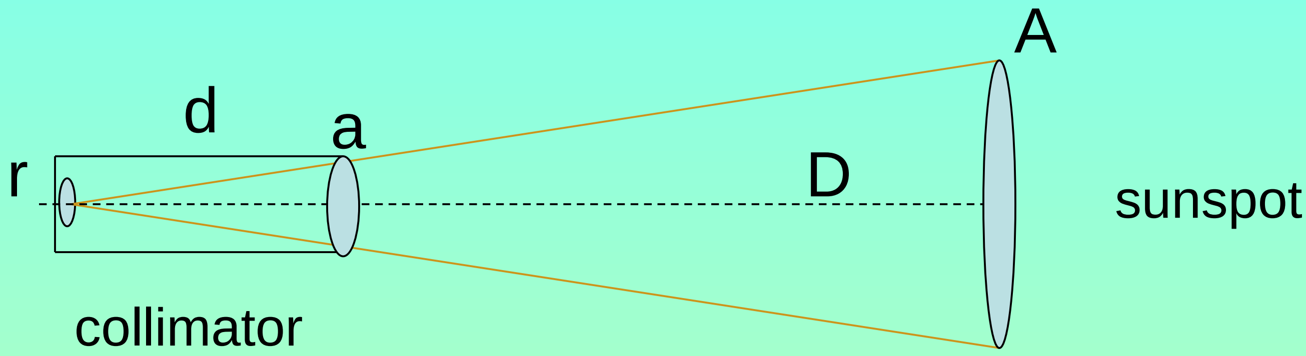


Steradians: $\square \Omega = a/r^2$



Steradians in a sphere:
$4\pi r^2/r^2 = 4\pi$

Note that we could have used steradians to solve our sunspot problem:



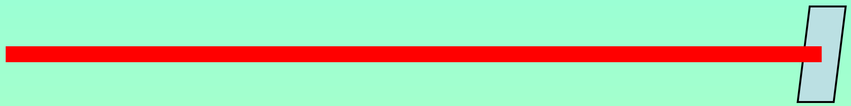
The solid angle for the collimator and sunspot must be the same, so

$$\frac{a}{d^2} = \frac{A}{D^2}$$

There's usually more than one way of solving a problem!

Intensity (Radiance)

Ideal Laser beam:

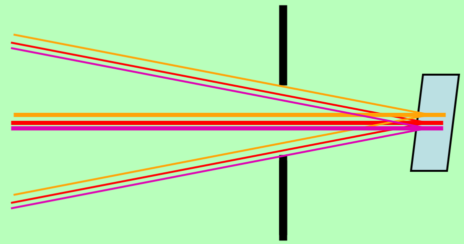


surface

$$I = \frac{energy/\sec}{area} = \frac{Watts}{m^2}$$

At a given wavelength and direction

Reality:



$$R = I/\Omega = \frac{Watts}{m^2 \cdot \mu m \cdot steradian} = W/m^2/\mu m/ster$$

Small range of wavelengths and directions

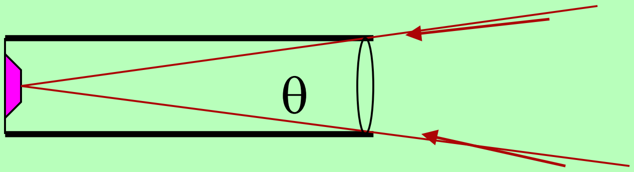
How to think about radiance

"I = 60 W/m^2/μm/ster at a wavelength of 0.6 μm in a given direction"

Means:

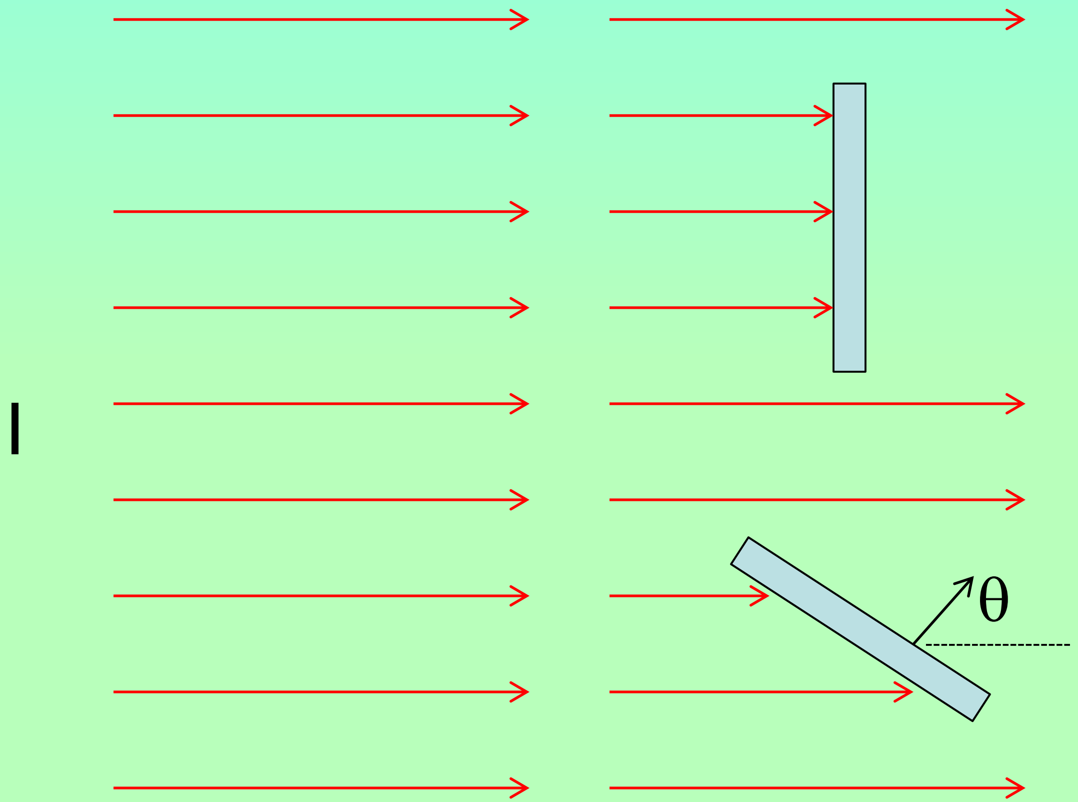
We are measuring light with a certain instrument.
After figuring out how much power was in the light, we divided by the area of the detector.
The detector measures light over a certain range centered on 0.6 μm.
So if the detector measures light between 0.54 and 0.66 μm, we divided by 0.12 μm to get the light per unit wavelength.
Then we divided by the solid angle the detector samples.

detector



Every detector has a sampling angle

Light Intercepted by a Surface

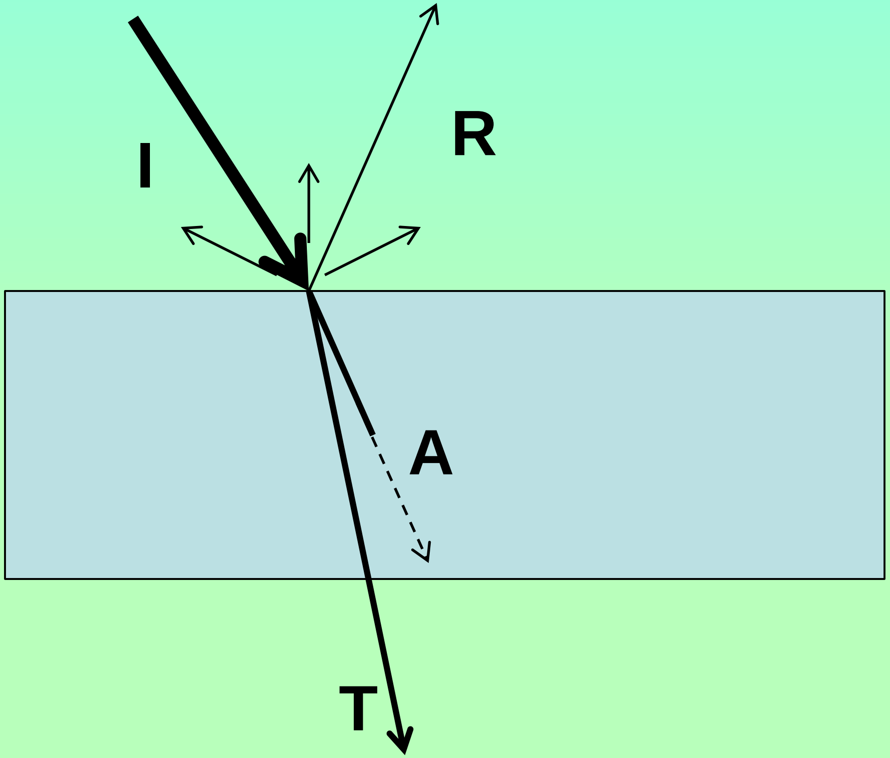


Flux = I•A•cosθ

Energy absorbed per second

Equal areas, which intercepts more light energy?

Conservation of Energy

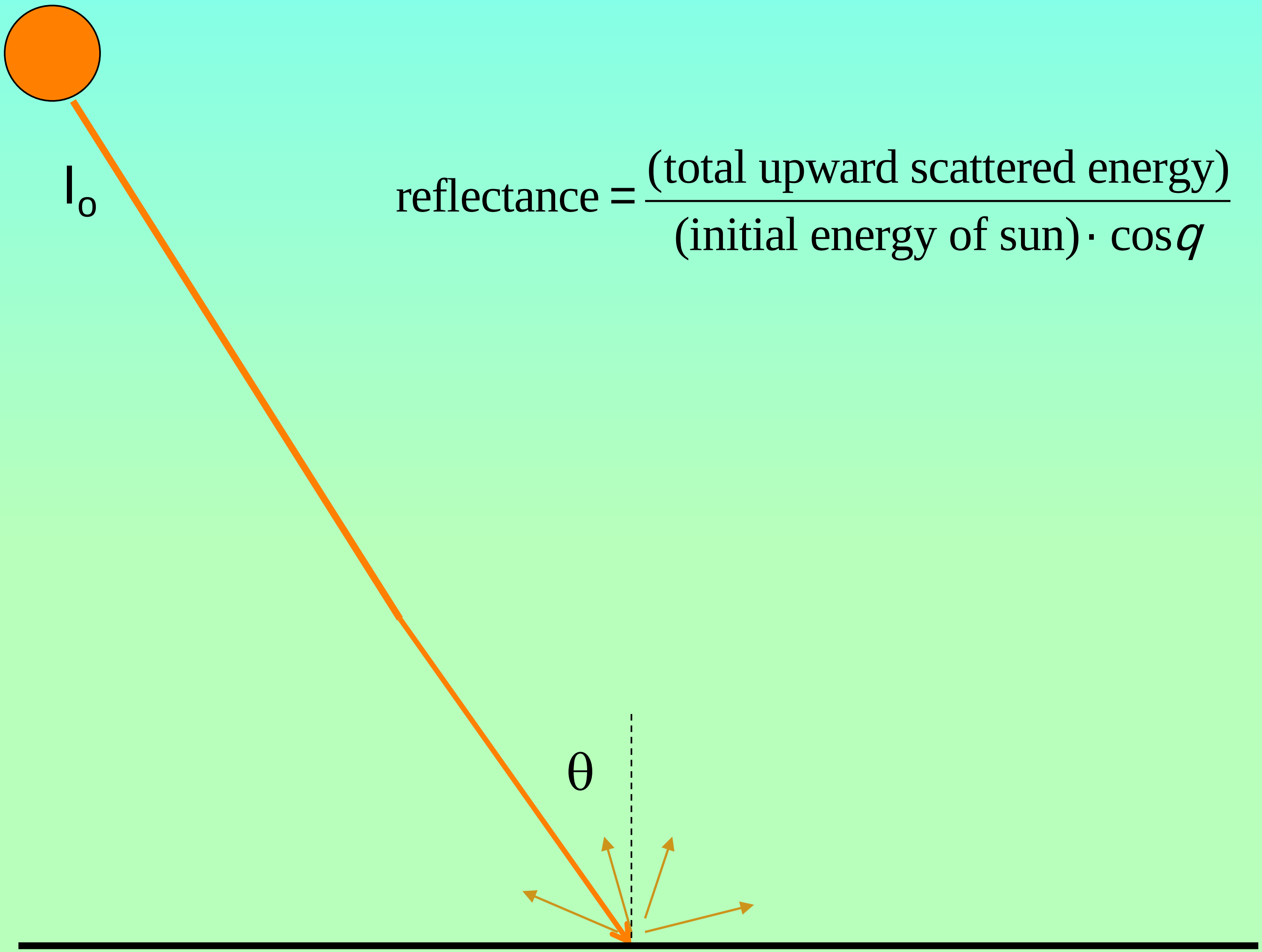


I = R+T+A

Insert some basic practice

Key Concept: Reflectance

$$\text{reflectance} = \frac{\text{(total upward scattered energy)}}{\text{(initial energy of sun)} \cdot \cos q}$$



Notes on Reflectance

- Theoretically adjusts for sun angle over a horizontal surface, so reflectance is intrinsic to the surface, not time of day.
- Is a ratio that should go between 0 and 1, but since the scattering is not always uniform may be calculated to be larger than 1.
- As with all remote sensing, atmospheric correction for scattering and absorption should be done for accurate results.

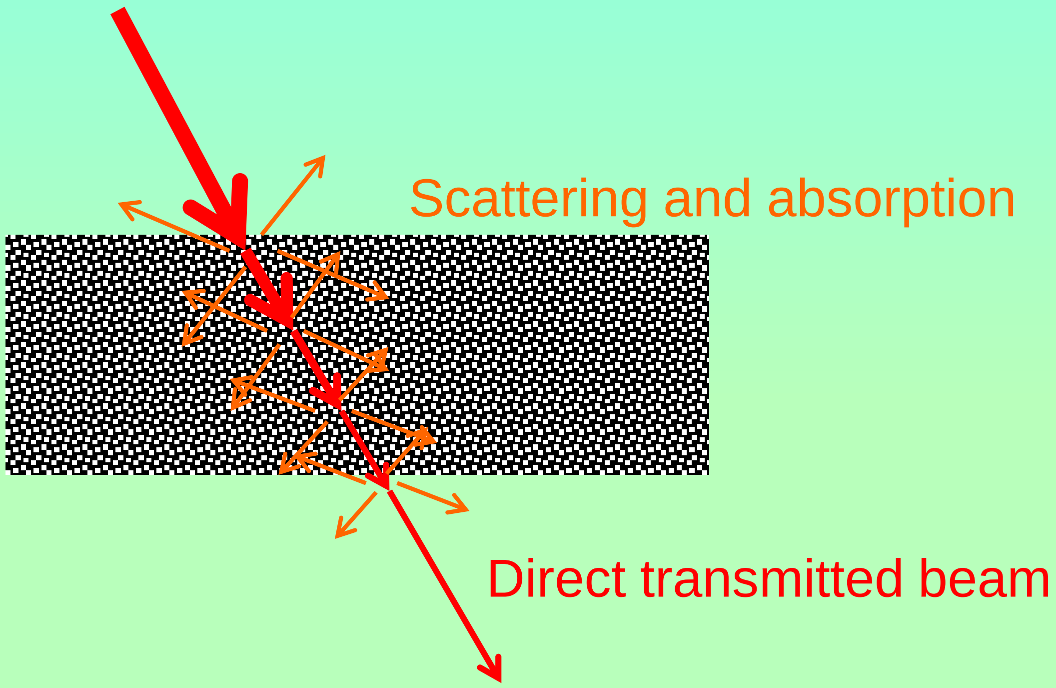
Example: The intensity of sunlight once it passes through the atmosphere is about 1200 W/m^2 . If the sun is at an angle of 60 degrees from directly overhead, and 200 W/m^2 are being reflected, what is the reflectance?

$$r = \frac{I_{ref}}{I_0 \cos q} = \frac{200 W/m^2}{(1200 W/m^2)\cos(60°)} = \frac{200}{600} = 1/3$$

How much light is being absorbed by a square of size 2m x 3 m?

Each square meter reflects 1/3 of the light, so 2/3 is absorbed.
Each square meter reflects 200 W, so 400 W is absorbed.
6 square meters must absorb (6 m^2)x(400 W/m^2) = 2400 W.

A more realistic scenario



- Light is scattered in all directions, not simply reflected
- Scattering, absorption occurs throughout, not just surfaces

Some Classwork

1. A collimator tube has a base with area of 0.8 cm^2 and a length of 20 cm. If mounted on a satellite 300 km above the surface, what would be the area and diameter of the area it views?

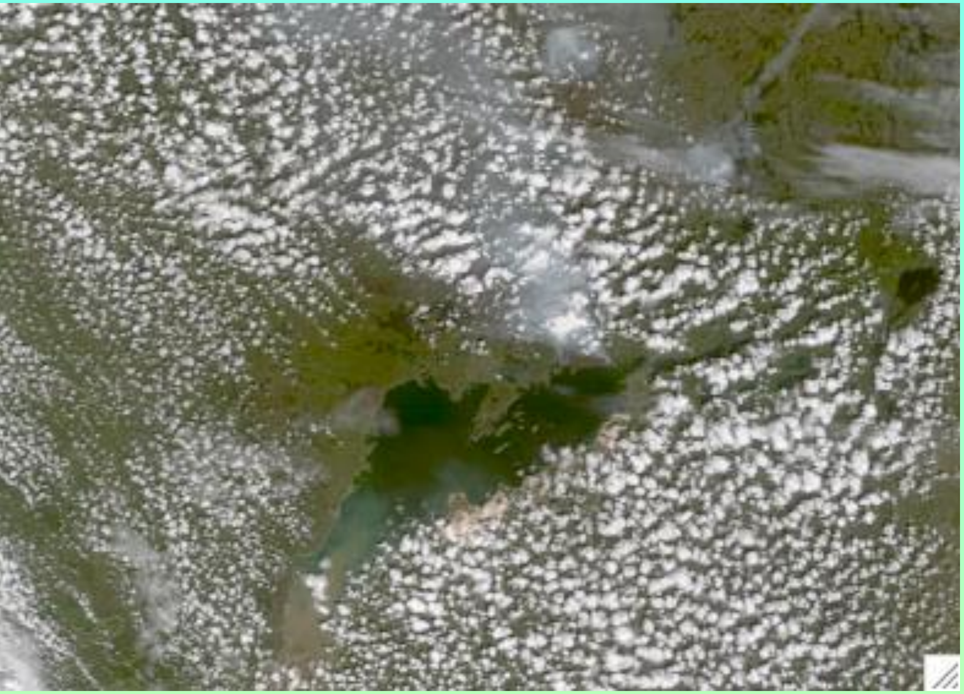
2. Calculate the following:
   - Frequency of visible light
   - Wavelength of a radio station broadcasting at 91.5 Mhz

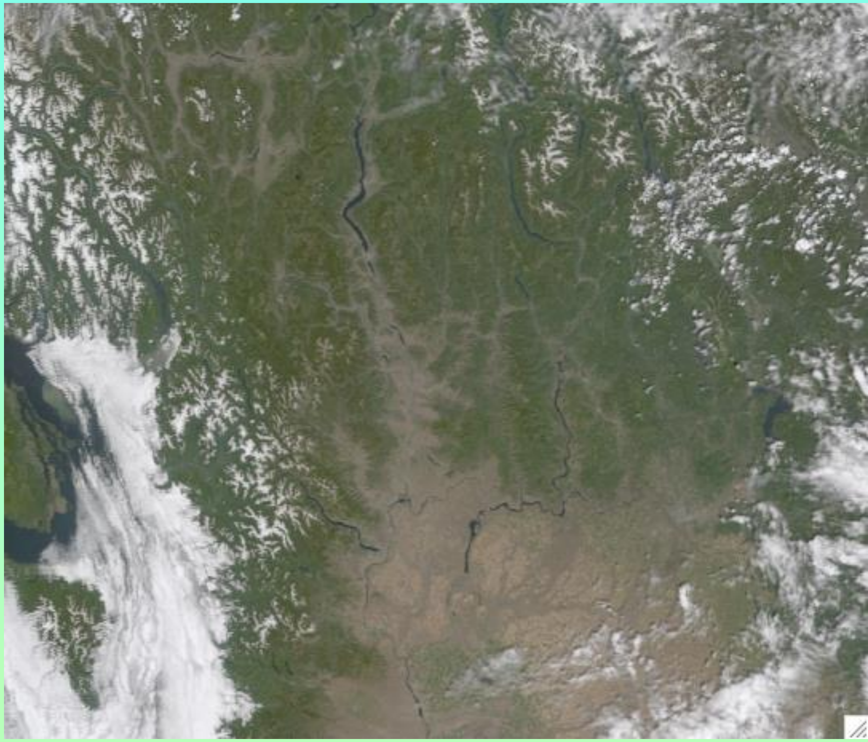
3. Sunlight has an intensity of 1340 W/m^2. If it is 35 degrees above the horizon and the reflectance of grass is 0.2, what would be the intensity of light reflected off a football field? What would be the energy absorbed per square meter? Energy absorbed by the whole field?

Classwork Scoring

- 30 pts for overall presentation style: diagrams, explanation of reasoning, symbolic algebra, keeping track of units and powers of 10
- 10 pts for each correct problem solution, with fractional credit.

Atmospheric Correction





If you want to look at anything other than the atmosphere, you must subtract out the effect of the atmosphere. We must account for extinction and ‘path radiance’ (light scattered into the beam).

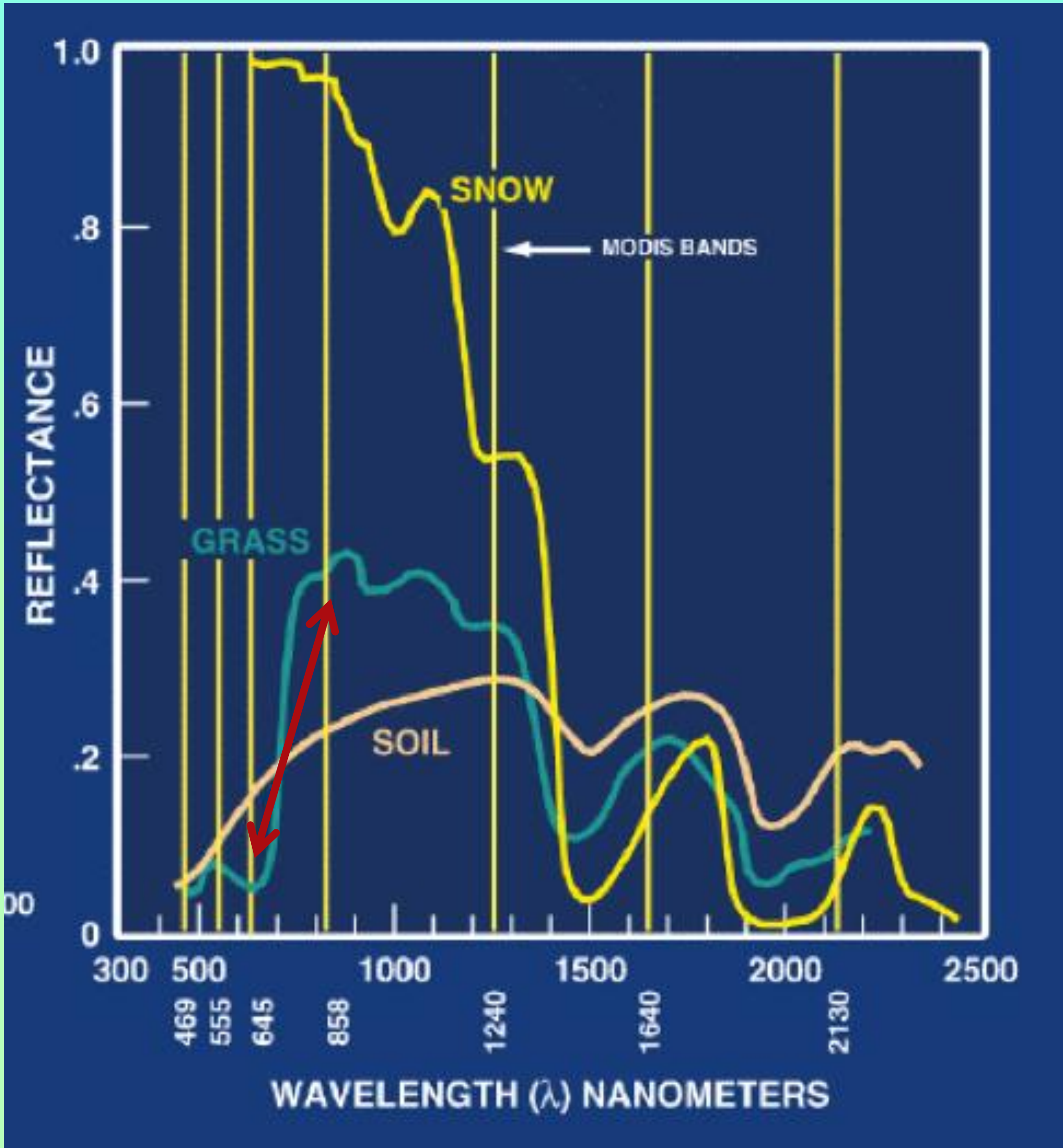
Normalized Difference Vegetation Index

High absorption in the red with high reflectance in the near infrared (NIR) is characteristic of chlorophyll.

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

$-1 < NDVI < 1$

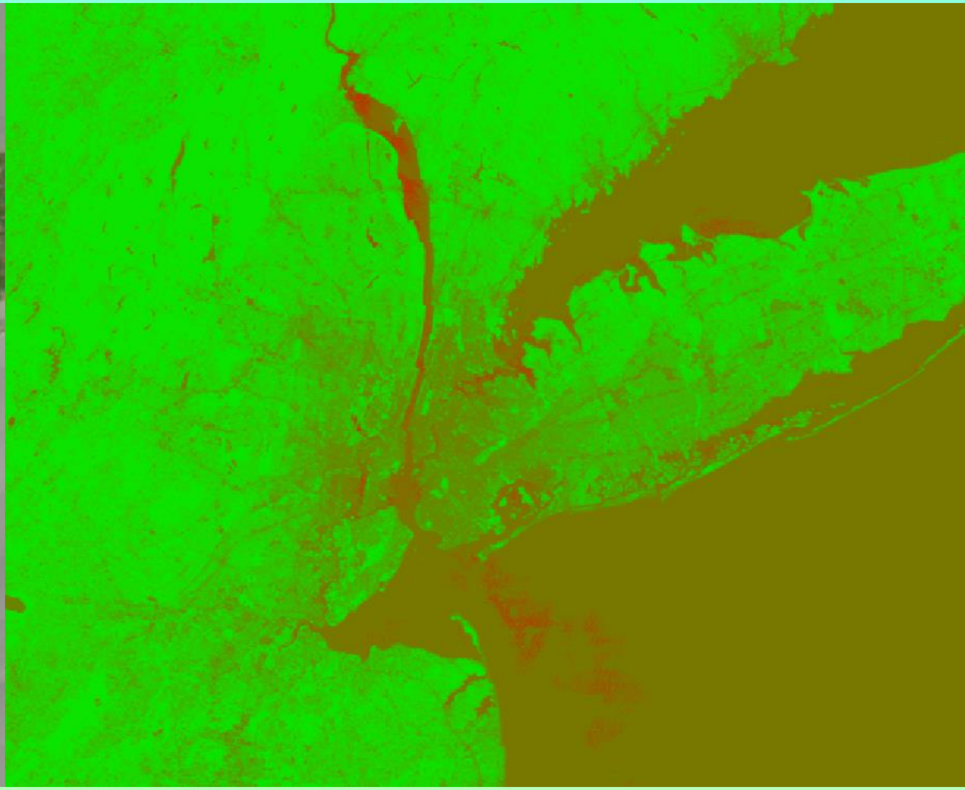
High NDVI indicates vegetation density



Vegetation by Satellite

Visible RGB

500 m resolution



NDVI: red is negative

250 m resolution

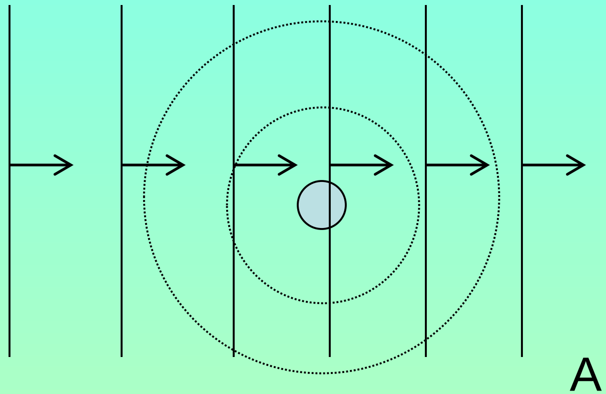
Everything from here on out is to help you understand the science behind some projects, but we don’t have enough time to expect it to sink in; so just enjoy the discussion as a sort of science entertainment.

Black Demo Screen for Ripple Tank

Double slit: 2:30 4;45

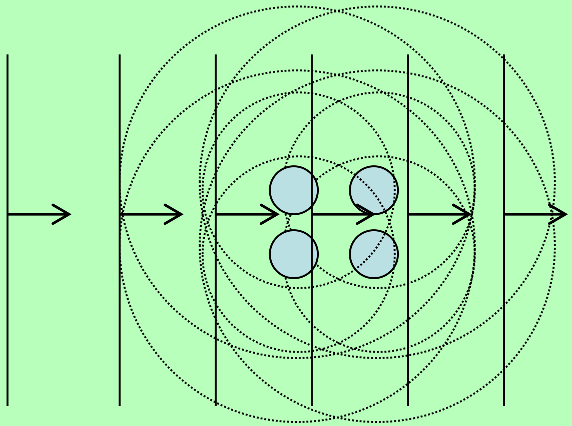
Waves, Charged Scatterers, and Interference Patterns

Driving wave



A single charge responds with a circular wave.

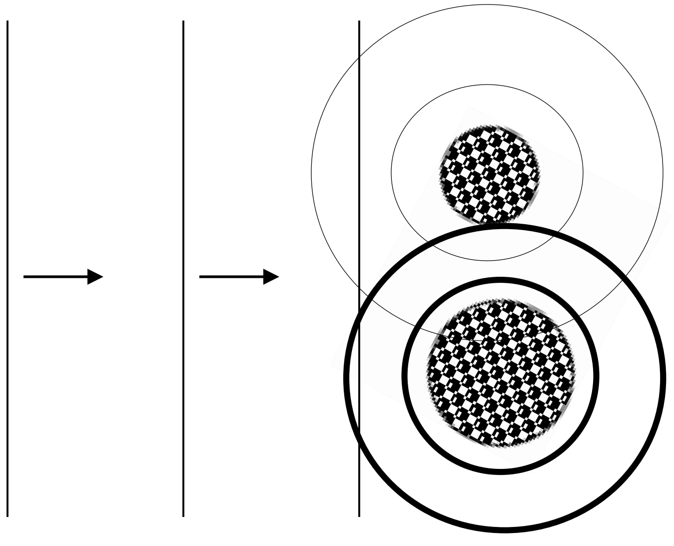
Driving wave



A collection of charges will produce a more complex pattern.

Rayleigh Scattering

Wavelength >> radius
(all charges in same part of wave)



The amount of scattered energy increases with the amount of charge, which increases with volume. So scattered energy increases faster than the cross sectional area.

Milk Scattering Demo

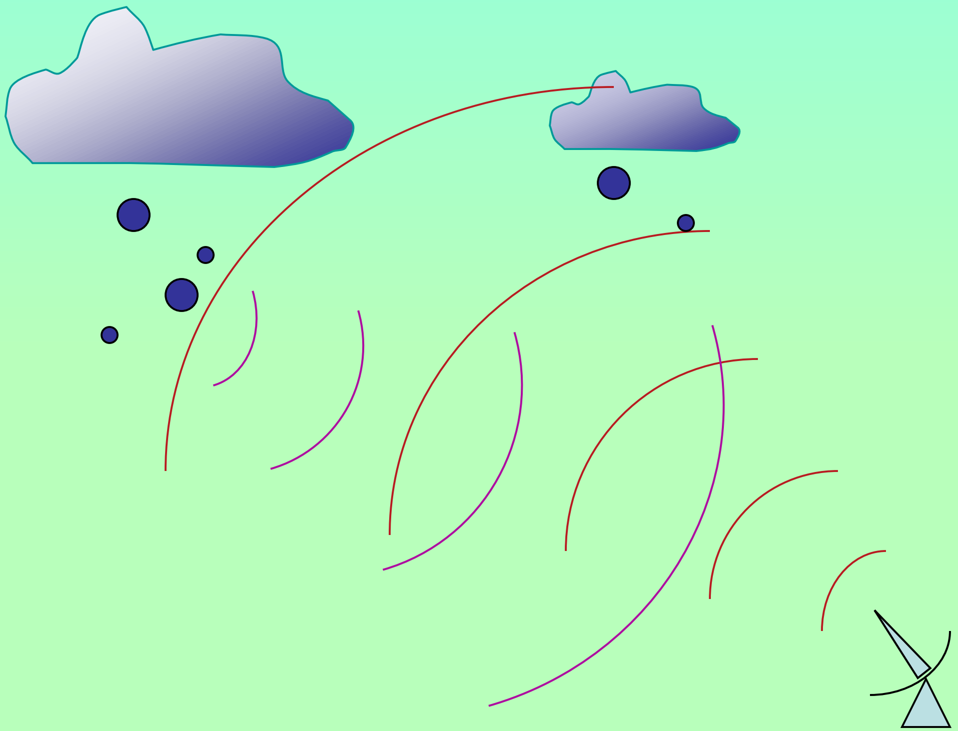
Online demo

Weather Radar

cm waves with mm raindrops equals Rayleigh Scattering!

(cloud drops too small to matter)

The Basic Idea



The *time* it takes a signal to return is used to calculate the distance.

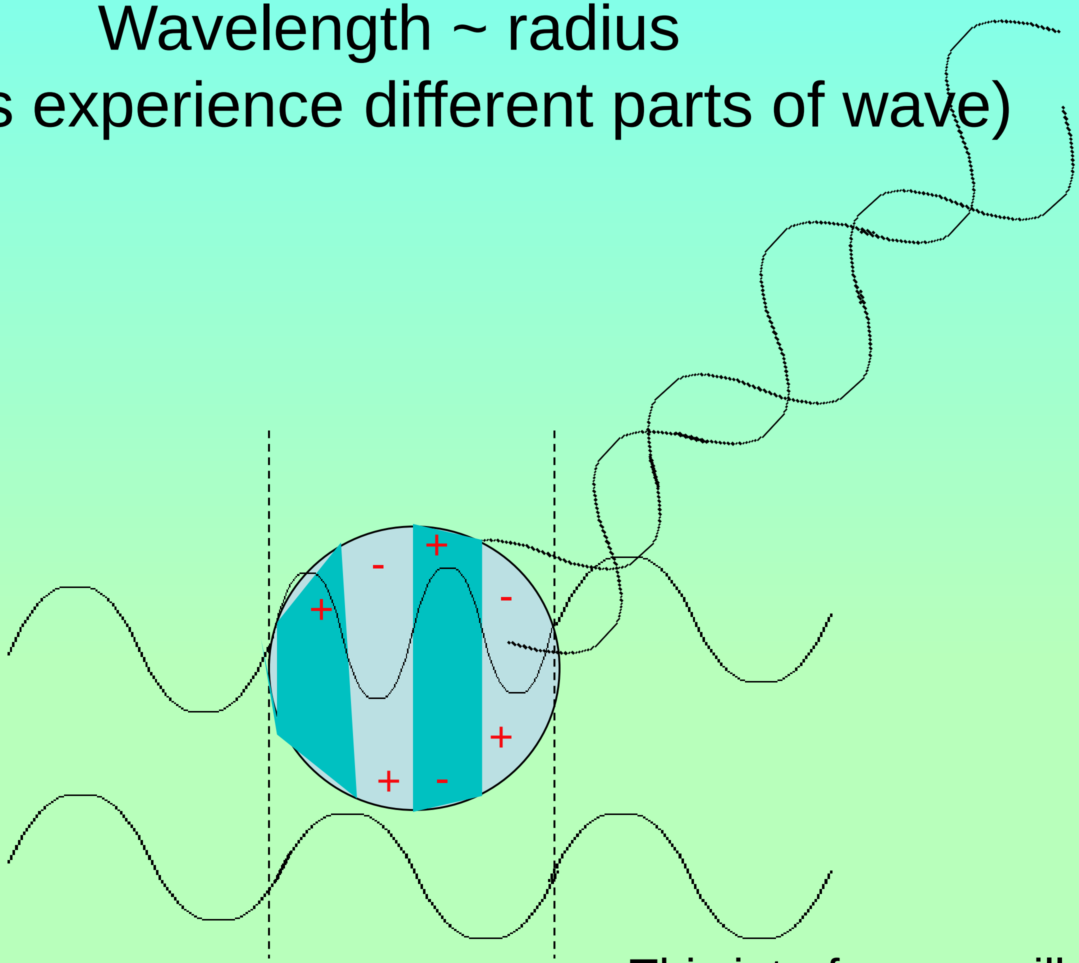
The *intensity* of the returned signal is used to calculate the amount of rainfall.

Ratio of Radius/Wavelength Matters

Wavelength ~ radius

(charges experience different parts of wave)

Waves going through and around the sphere may interfere constructively or destructively, depending on the geometries and index of refraction.



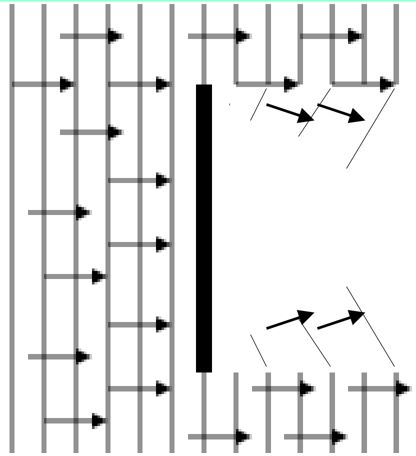
This interference will change with scattering angles.

Geometrical Scattering

wavelength << radius

(wave effects average out)

We'd like to think the light rays act like little bullets instead of waves; only those intercepted by the object are affected.



In this case the optical cross section would just equal the cross sectional area.

Geometrical Scattering is independent of wavelength.

In reality some waves will always bend around the edges of an object, so there's no such thing as pure geometrical scattering.

Things to Know: Scattering

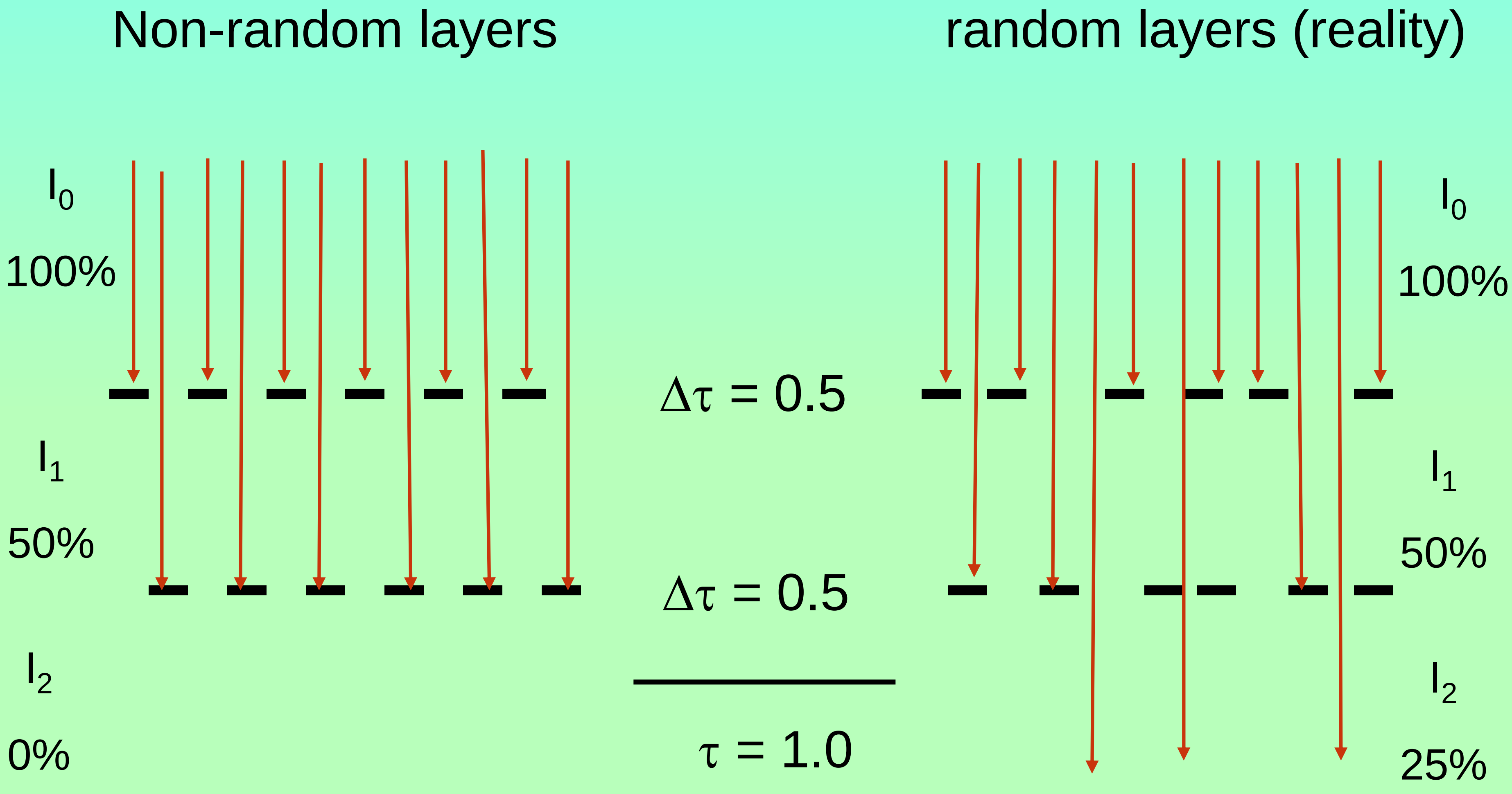
- If the particle is very, very much smaller than the wavelength, you can ignore the scattering. Weather radar uses this to see raindrops, not cloud drops.
- If particles are several times smaller than the wavelength, scattering increases rapidly with size (more charges to oscillate!). Scatters in all directions. This makes our sky blue: molecules scatter shorter waves.
- If the particle is close to the size of the wavelength, the scattering can be strong but complicated.
- If the particle is more than several times larger than the wavelength, scattering is proportional to cross sectional area (geometrical scattering). Mainly scatters forwards (transmission). This is our everyday world.

Key Concept: Optical Depth

- Tells you what fraction of light will be affected. When small, the fraction IS the optical depth. Approaches 1 as optical depth increases.
- Can be thought of as the average number of times a photon will strike the material it passes through.
- The optical depth of a material changes with wavelength because absorption and scattering changes with wavelength - even though the material stays the same.

Optical Depth and Probability

Optical depth is the amount of stuff in light beam, and how strongly it interacts

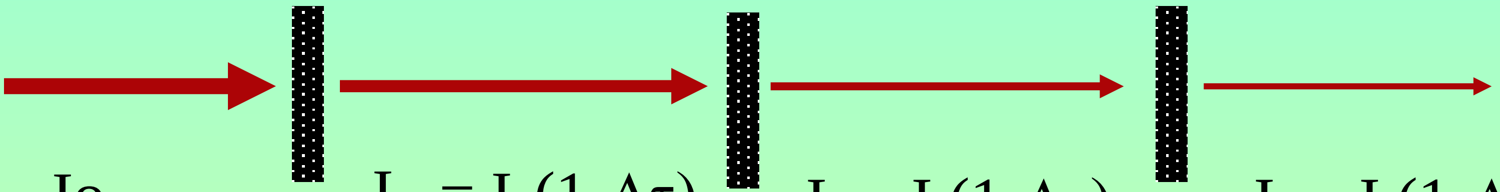


Purely Absorbing Material: Exponential Decay

The symbol for optical depth is τ*;* Δ *means "change in"*

$\Delta I = I_1 - I_o \quad = - I_o \Delta\tau \qquad \Rightarrow \quad I_1 = I_o(1-\Delta\tau)$

$\Delta\tau$ $\qquad$ $\Delta\tau$ $\qquad$ $\Delta\tau$



Io $\qquad$ $I_1 = I_o(1-\Delta\tau)$ $\qquad$ $I_2 = I_1(1-\Delta\tau)$ $\qquad$ $I_3 = I_2(1-\Delta\tau)$

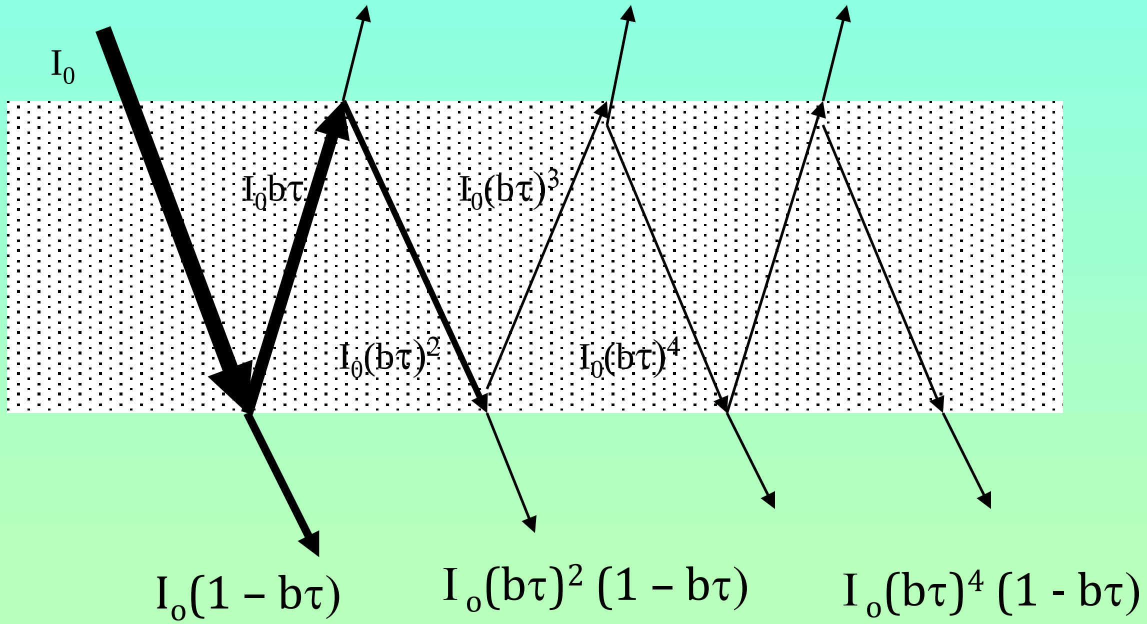
$\qquad = I_o(1-\Delta\tau)^2 \qquad = I_o(1-\Delta\tau)^3$

But $\tau = n\Delta\tau$ so $I_n = I(\tau) = I_o(1-\Delta\tau)^n = I_o(1-\tau/n)^n$

$I(\tau) = I_o(1-\tau/n)^n$ □ □ $= I_o e^{-\tau}$ □

Purely Scattering Transmission

b = backscatter fraction



$$\text{total I} = I_o(1 - bt + (bt)^2 - (bt)^3 + (bt)^4 \ldots) = \frac{I_o}{1+bt}$$

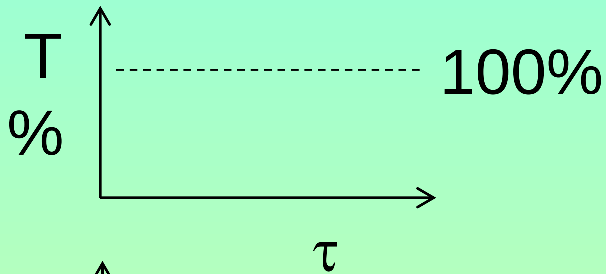
or $$\frac{I_T}{I_0} = \frac{1}{1+bt}$$

What about the reflected light?

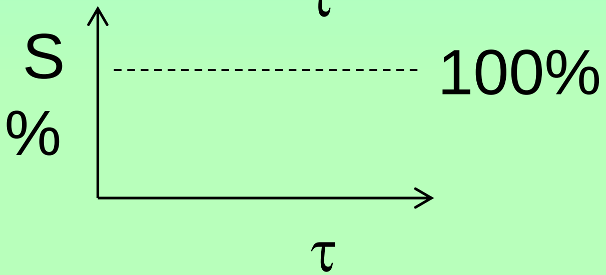
So as Optical Depth Increases…

Optical depth is the amount of stuff in the way of a light beam, multiplied by how strongly it interacts with light at a given wavelength.

Transmission: decreases



Scattering: increases



Absorption: increases

All asymptotically towards their ultimate value