CS 775: Advanced Computer Graphics

Lecture 1 : Radiometry


PowStudios3, 2010, www.luxrender.net

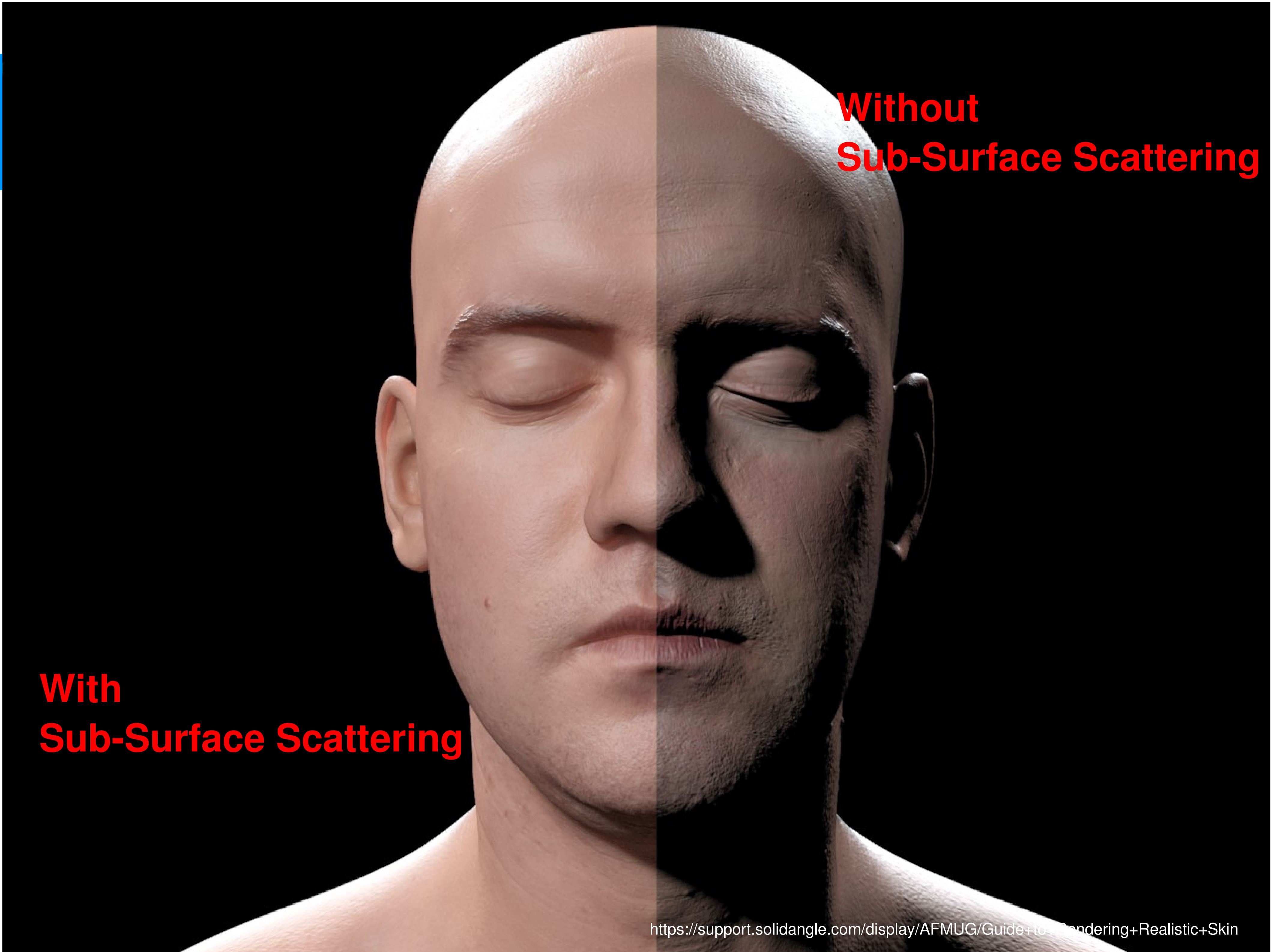

Indirect
Direct
PowStudios3, 2010, www.luxrender.net

Vlad Sattva Miller, 2010, www.luxrender.net


Specular
Diffuse
Glossy
Vlad Sattva Miller, 2010, www.luxrender.net

Aaron Solo - The Rake , 2009
www.luxrender.net

Aaron Solo - The Rake , 2009
www.luxrender.net


Without
Sub-Surface Scattering
With
Sub-Surface Scattering
https://support.solidangle.com/display/AFMUG/Guide+to+Rendering+Realistic+Skin

Sub-Surface Scattering

Henrik Wann Jensen, 2001

Henrik Wann Jensen, 2001

https://en.wikipedia.org/wiki/Subsurface_scattering

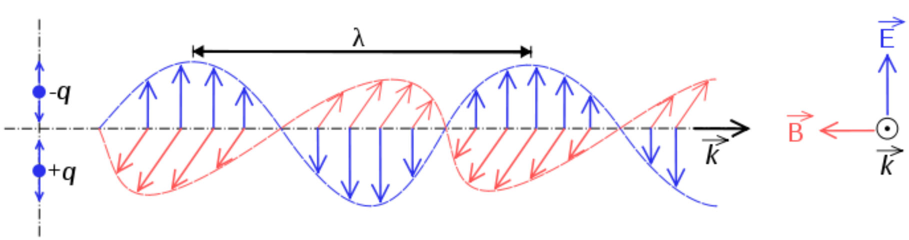
https://support.solidangle.com/display/AFMUG/Guide+to+Rendering+Realistic+Skin

Ground Rules for our study of GI

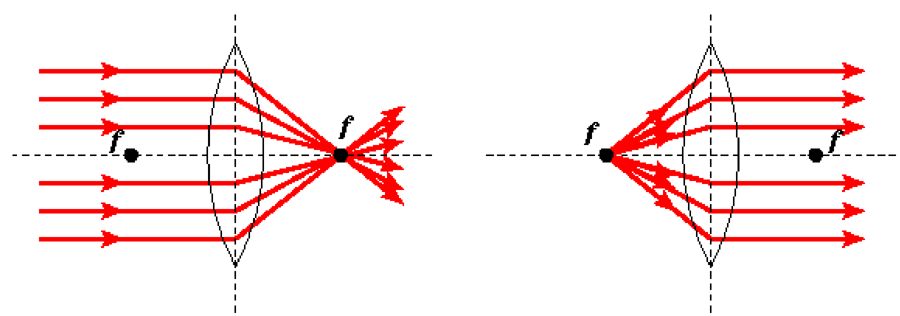
- Geometric Optics – not considering light as oscillating EM fields, not considering quantum properties.

  Radiative transfer – linearity, energy conservation, steady state

- No mention of polarization, phospohoresence



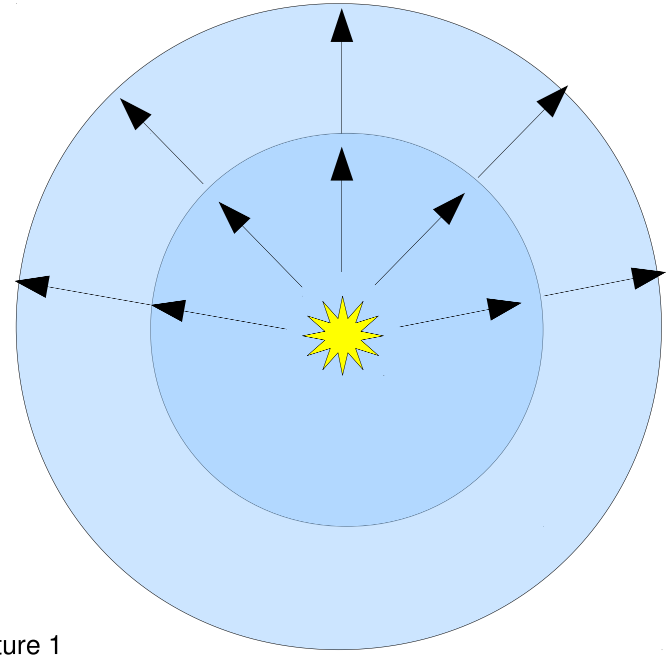
Wikipedia, Electromagnetic Radiation



http://www.physics.upenn.edu/courses/gladney/phys151/lectures/lecture_apr_14_2003.shtml

Basic Radiometry

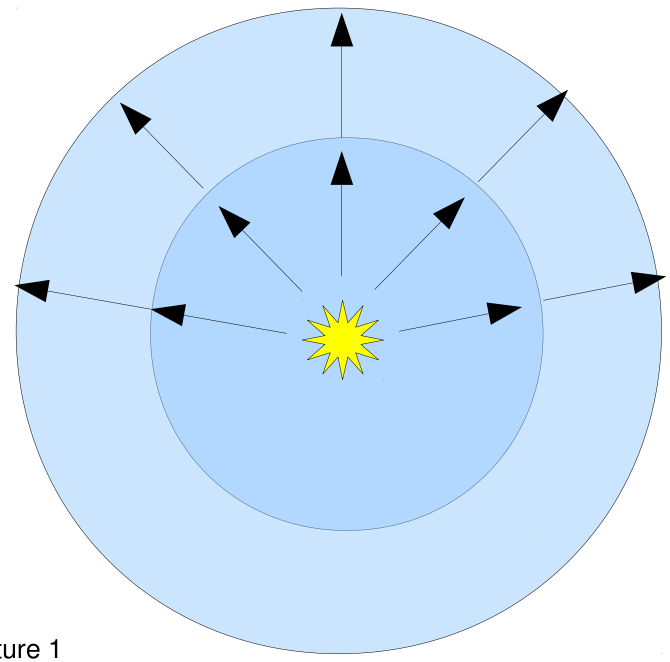
- Radiant Flux Φ
- Total amount of energy passing through a surface/region of space per unit time.
- Has units of Power (Watts (W) or Joules/second (Js^{-1}))



Around a point source, flux measured on imaginary spheres around the source is the same.

Basic Radiometry

- Irradiance E and Radiant Exitance M
- Area density of flux arriving/leaving a surface
- Has units of Wm^{-2}



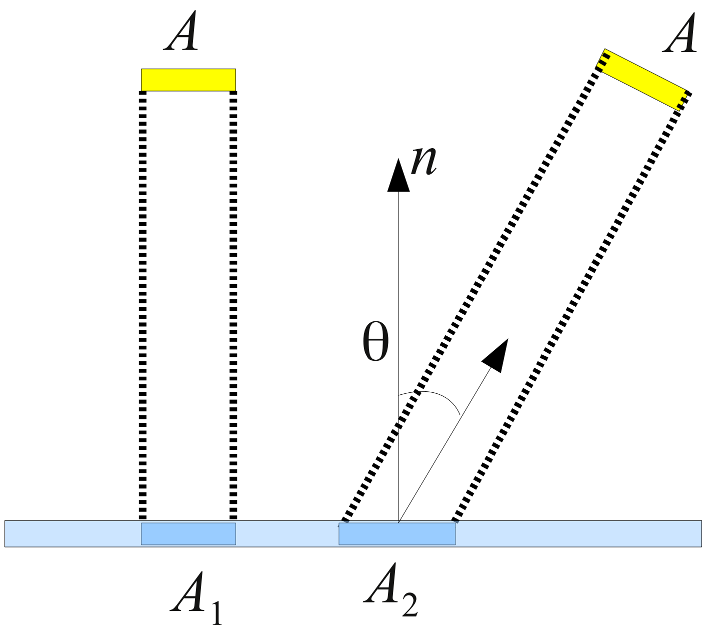
Irradiance at a point on the outer sphere is less than irradiance at a point on the inner one.

Energy received from a light source falls off with squared distance from it.

$$E = \frac{\Phi}{4\pi r^2}$$

Basic Radiometry

- Irradiance E and Radiant Exitance M
- Area density of flux arriving/leaving a surface
- Has units of Wm^{-2}



Origin of Lambert's Law: Light arriving at a surface is proportional to the cosine of the angle between the light direction and surface normal.

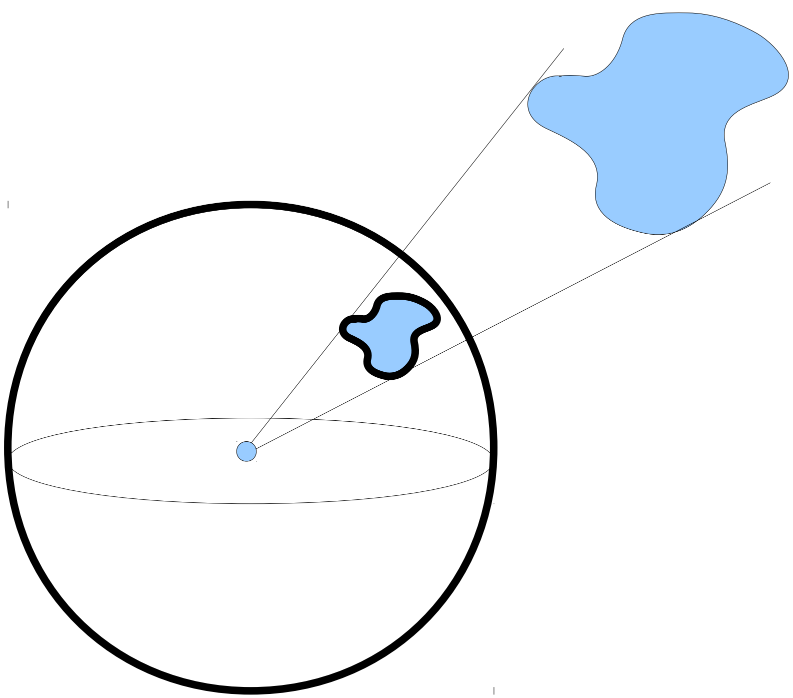
$$E_1 = \frac{\Phi}{A_1} = \frac{\Phi}{A}$$

$$E = \frac{d\Phi}{dA}$$

$$E_2 = \frac{\Phi}{A_2} = \frac{\Phi}{A/\cos\theta}$$

Basic Radiometry

- Intensity I
- Flux density per unit *solid* angle $$I = \frac{d\Phi}{d\omega}$$
- Has units of W sr $^{-1}$

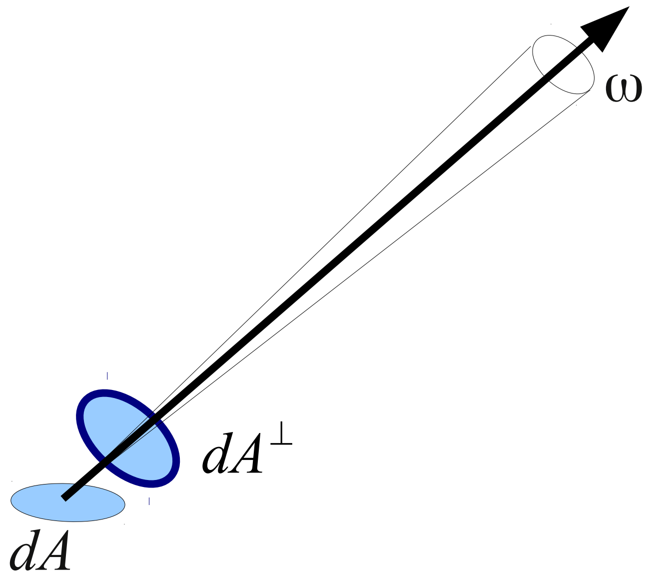


A steradian is defined as the solid angle subtended at the center of a sphere of radius r by a portion of the surface of the sphere whose area, A, equals r^2.

Intensity describes the directional distribution of light.

Basic Radiometry

- Radiance L
- Flux density per unit area per unit *solid* angle $L = \frac{d\Phi}{d\omega \, dA^{\perp}}$
- $dA^{\perp}$ is the projected area on a surface perpendicular to ω

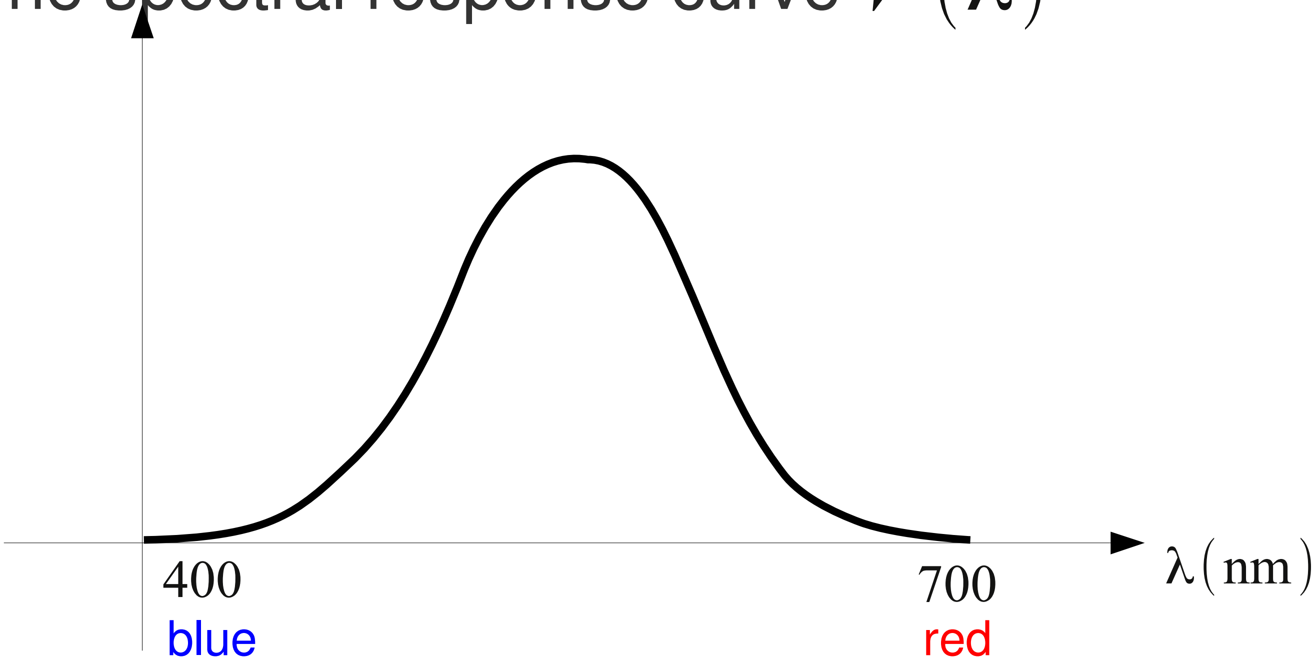


Measured in W m^{-2} sr^{-1}

Radiance remains constant along rays of light through empty space.

Photometry

- The Human Eye is more sensitive to some wavelenghts of the visible light than other.
- The spectral response curve $V(\lambda)$



Photometry

- The **candela** is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540x10[12] Hz and that has a radiant intensity in that direction of 683 W sr^{-1}.

Radiometric Units		Photometric Units	
Radiant Energy Joule (J)		Luminous Energy Talbot (lm s) (non SI)	
Radiant Flux Watt (W = J s^{-1})	Φ	Luminous Flux Lumen (lm = cd sr)	Φ_v
Irradiance W m^{-2}	E	Illuminance Lux (lx = lm m^{-2})	E_v
Radiant Intensity W sr^{-1}	I	Luminous Intensity Candela (cd) (SI base unit)	I_v
Radiance W m^{-2} sr^{-1}	L	Luminance Nit (nt = cd m^{-2}) (non SI)	L_v

Photometry

- Luminance and Radiance

$$L_v = \int_\lambda L(\lambda) V(\lambda) d\lambda$$

$$L_v = 683 \int_\lambda L(\lambda) Y(\lambda) d\lambda$$

where $Y(\lambda)$ is the standard CIE spectral response curve.

- Approximately speaking: Sun at horizon is 600,000 nt, 60W bulb is 120,000 nt, computer display, 1-100 nt.

Radiometric Computations

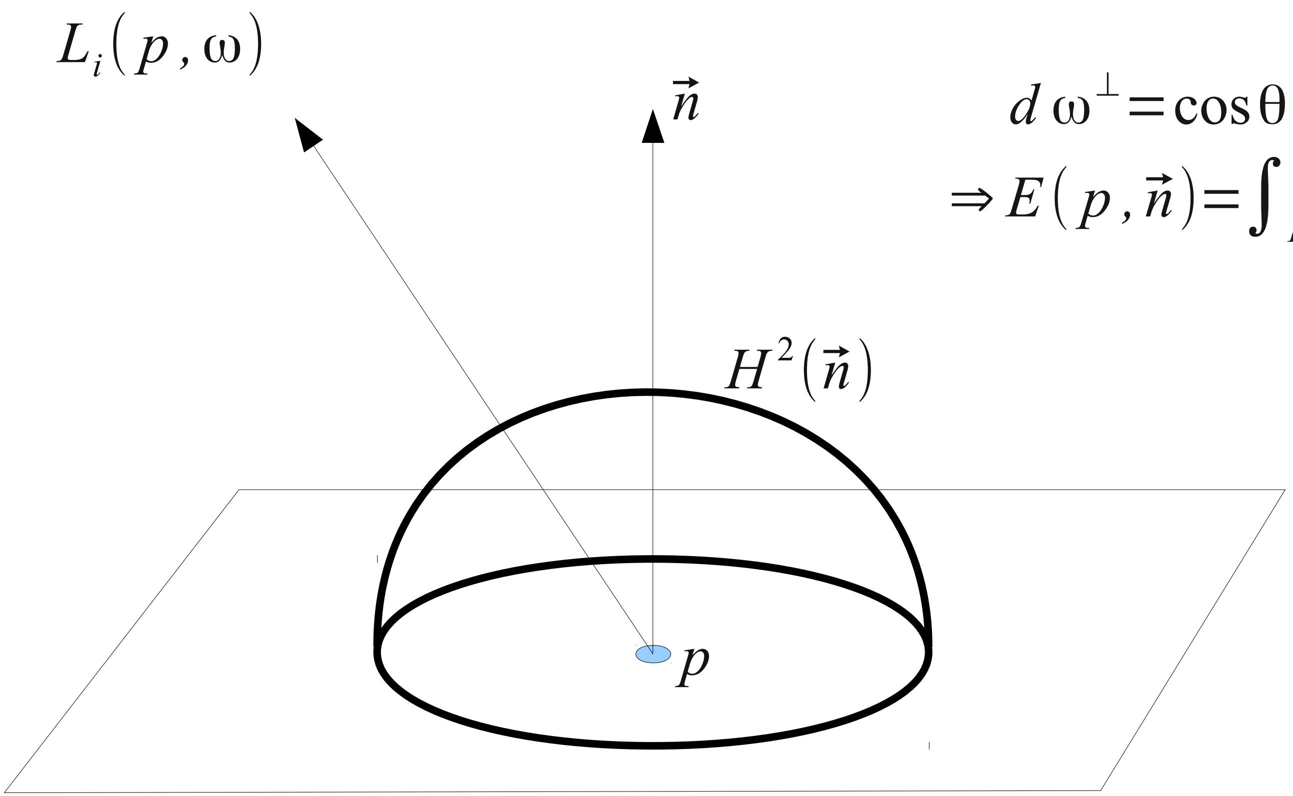
$L_i(p,\omega)$ is *incident* radiance at p coming from a direction ω.

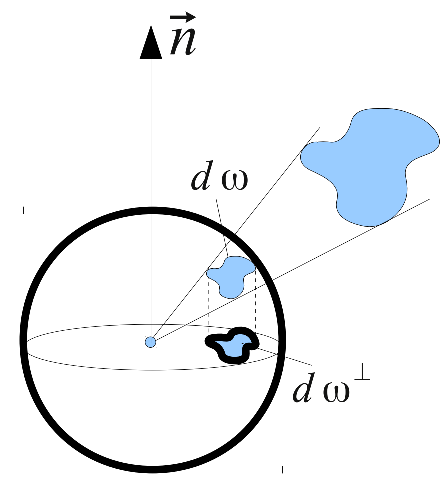
Notice ω always points away from the surface.

$$E(p,\vec{n})=\int_{H^2(\vec{n})} L_i(p,\omega)\cos\theta\, d\omega$$

$$d\omega^{\perp}=\cos\theta\, d\omega$$

$$\Rightarrow E(p,\vec{n})=\int_{H^2(\vec{n})} L_i(p,\omega)\, d\omega^{\perp}$$





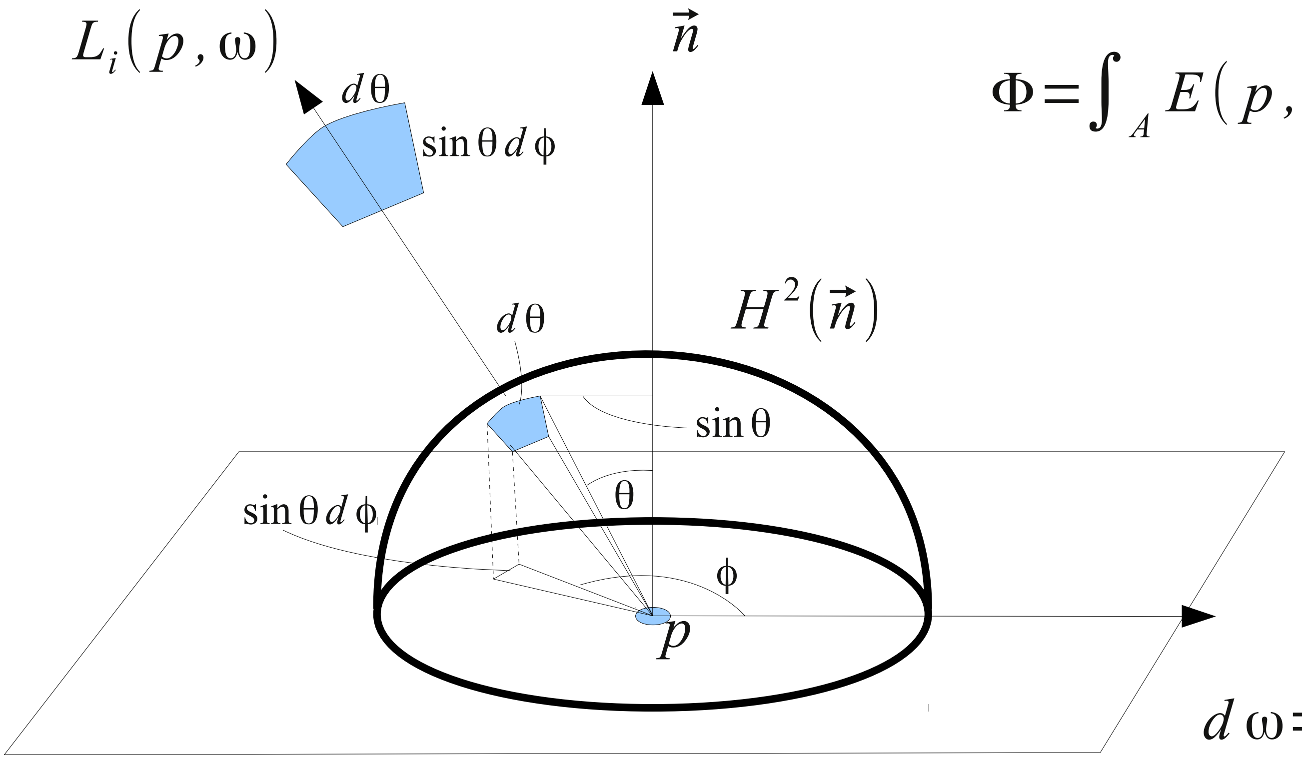
Radiometric Computations

$L_i(p,\omega)$ is incident radiance at p coming from a direction ω.

Notice ω always points away from the surface.

$$E(p,\vec{n})=\int_0^{2\pi}\int_0^{\pi/2} Li(p,\theta,\phi)\cos\theta\sin\theta\, d\theta\, d\phi$$

$$\Phi=\int_A E(p,\vec{n})\, dA$$



$$d\omega=\sin\theta\, d\theta\, d\phi$$

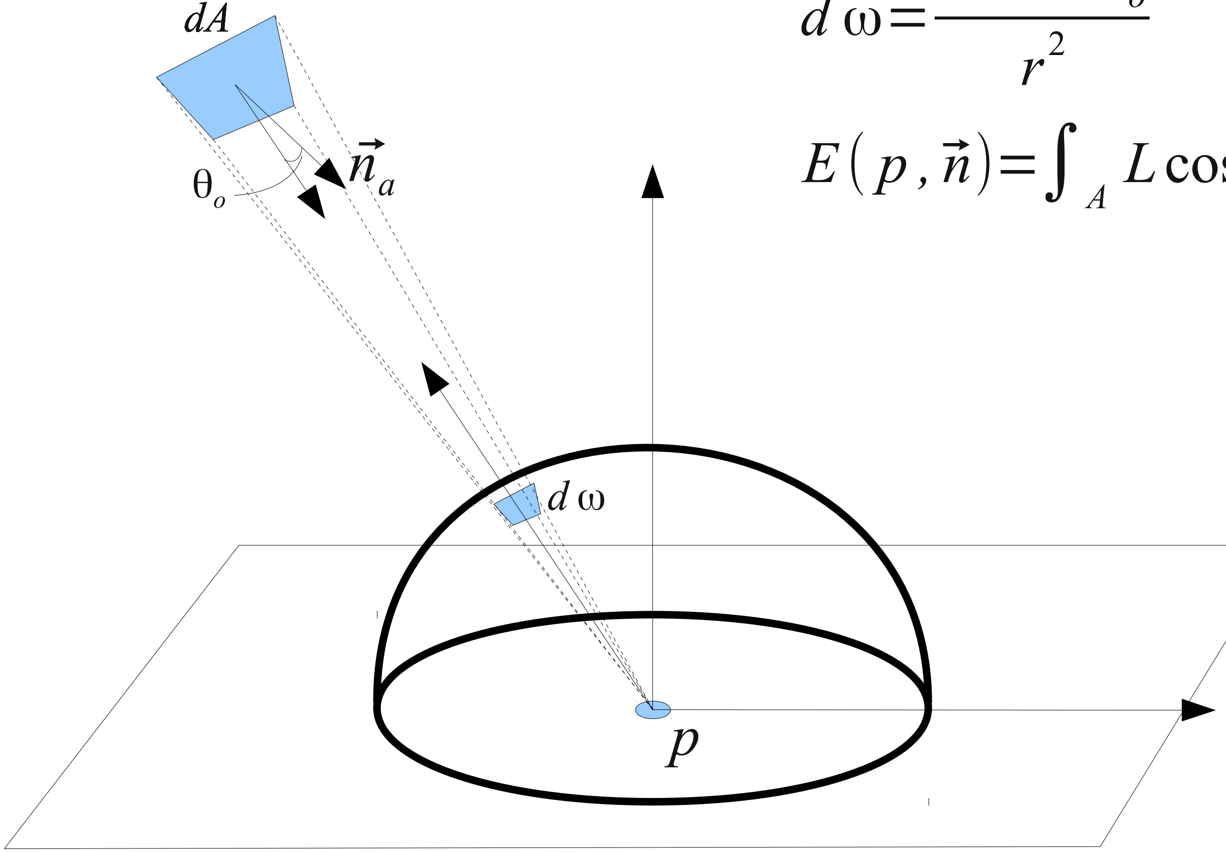
Radiometric Computations

L is emitted radiance from a quadilateral source

Notice ω always points away from the surface.

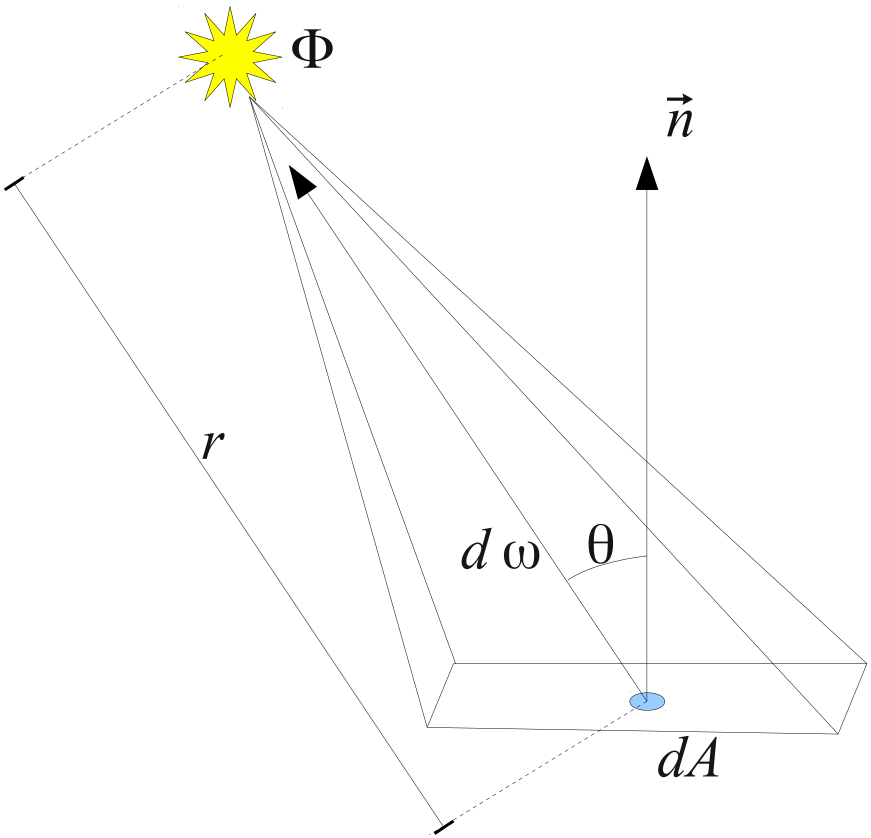
$$d\omega = \frac{dA \cos\theta_o}{r^2}$$

$$E(p, \vec{n}) = \int_A L \cos\theta_i \frac{\cos\theta_o \, dA}{r^2}$$



Radiometric Computations

Φ is radiant flux or power of a source.

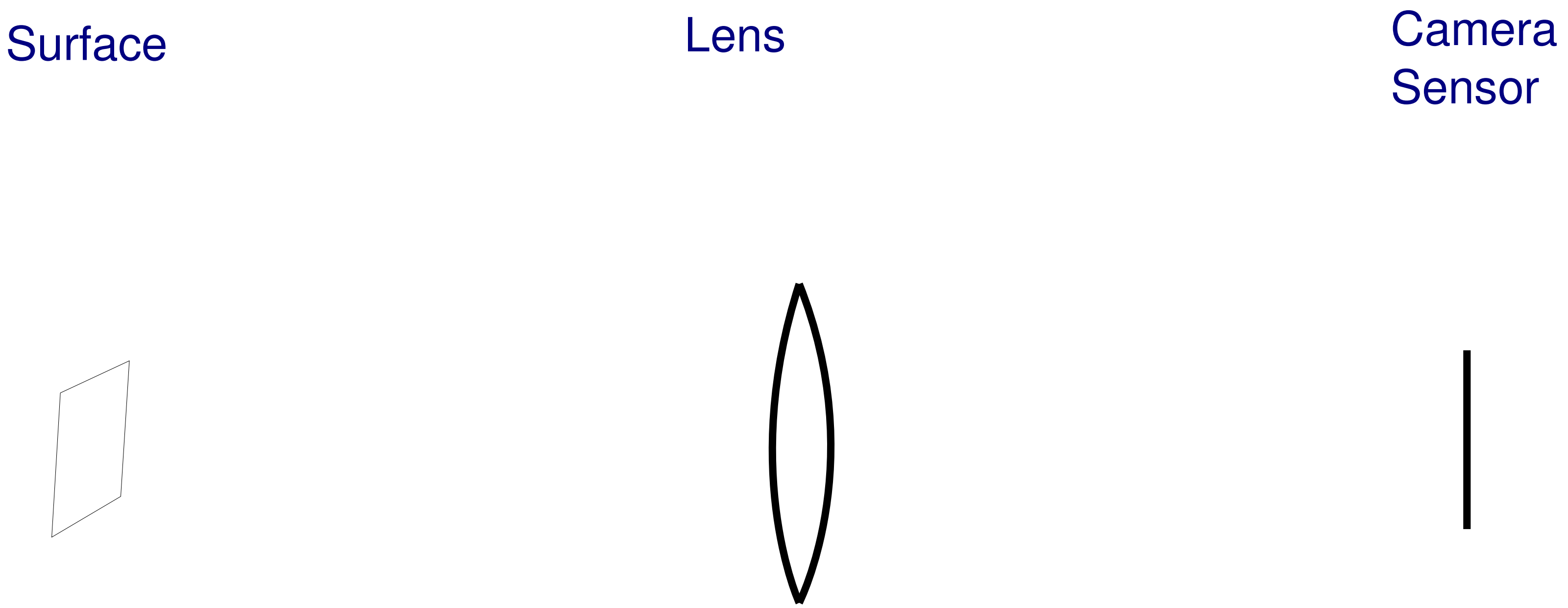


$$d\omega = \frac{dA\cos\theta}{r^2}$$

Intensity, $I = \dfrac{d\Phi}{d\omega} = \dfrac{d\Phi\, r^2}{dA\cos\theta}$

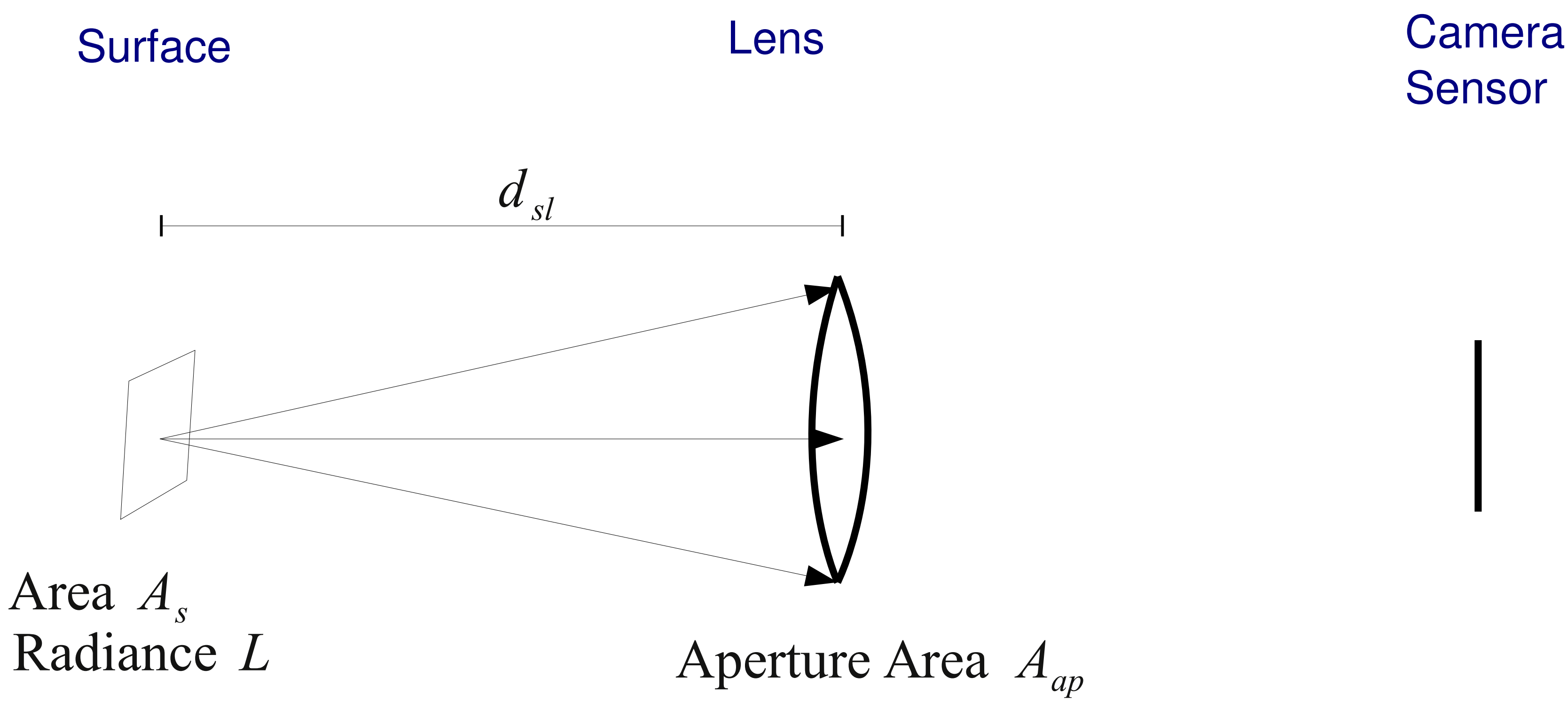
Irradiance, $E = \dfrac{d\Phi}{dA} = \dfrac{I\cos\theta}{r^2}$

Radiometric Computations



Parag Chaudhuri

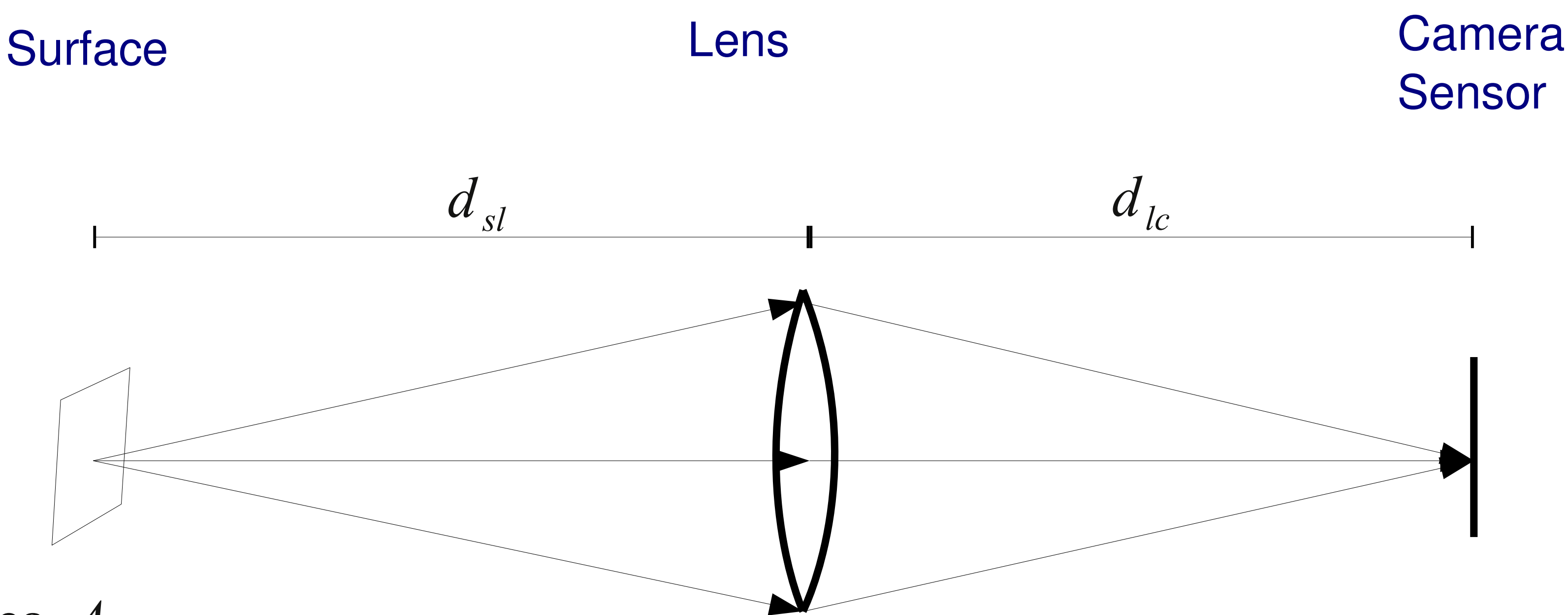
Radiometric Computations



$$I = L\,A_s$$

$$\Phi = L\,A_s \frac{A_{ap}}{d_{sl}^2}$$

Radiometric Computations



Area A_s
Radiance L

Aperture Area A_{ap}

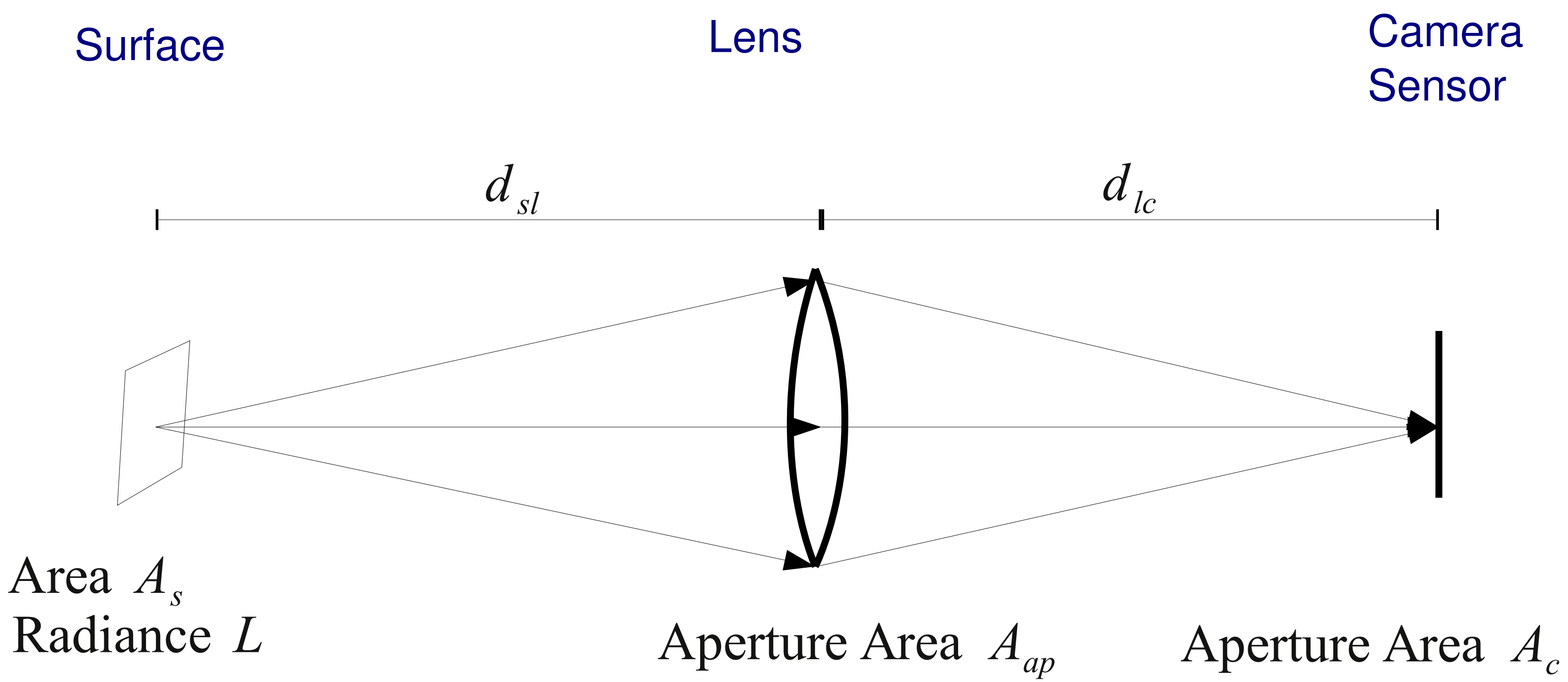
Aperture Area A_c

$$I = L\,A_s$$

$$\Phi = L\,A_s \frac{A_{ap}}{d_{sl}^2}$$

$$E = \frac{\Phi}{A_c}$$

Radiometric Computations

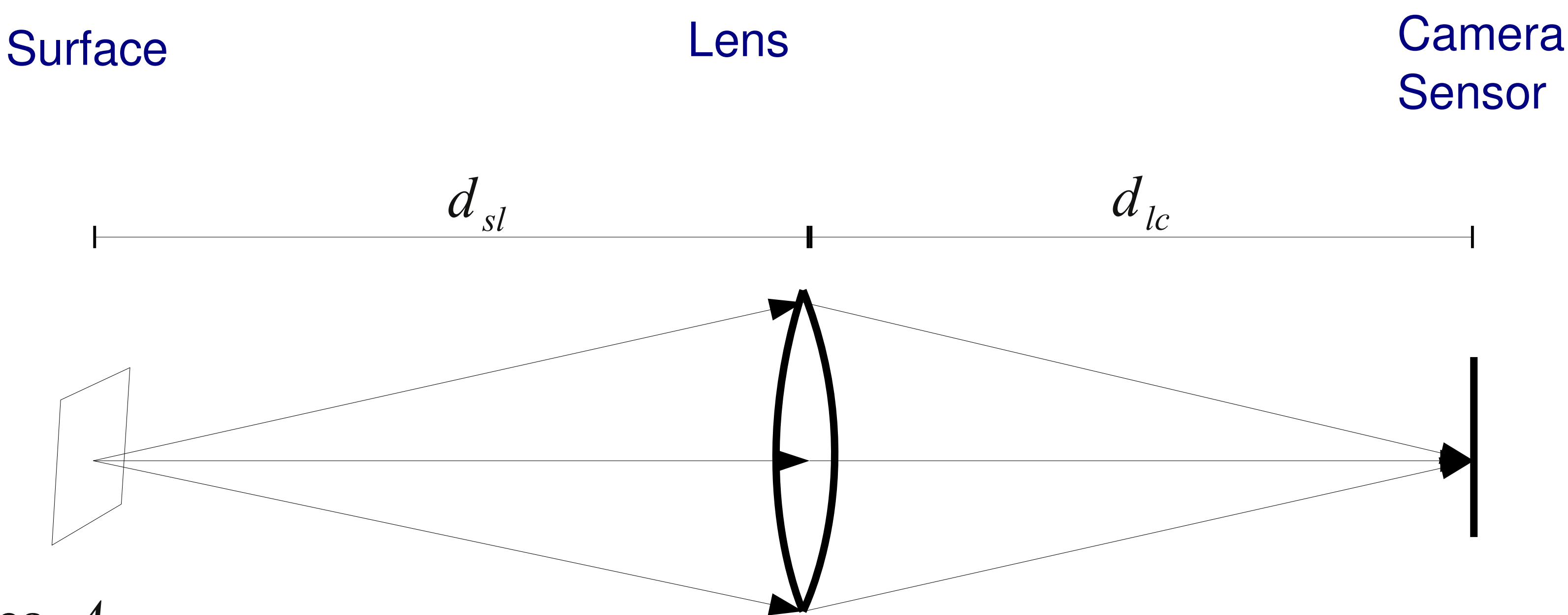


$$I = L\,A_s$$

$$\Phi = L\,A_s \frac{A_{ap}}{d_{sl}^2}$$

$$E = L\,A_s \frac{A_{ap}}{d_{sl}^2\,A_c}$$

Radiometric Computations



Area A_s
Radiance L

Aperture Area A_{ap}

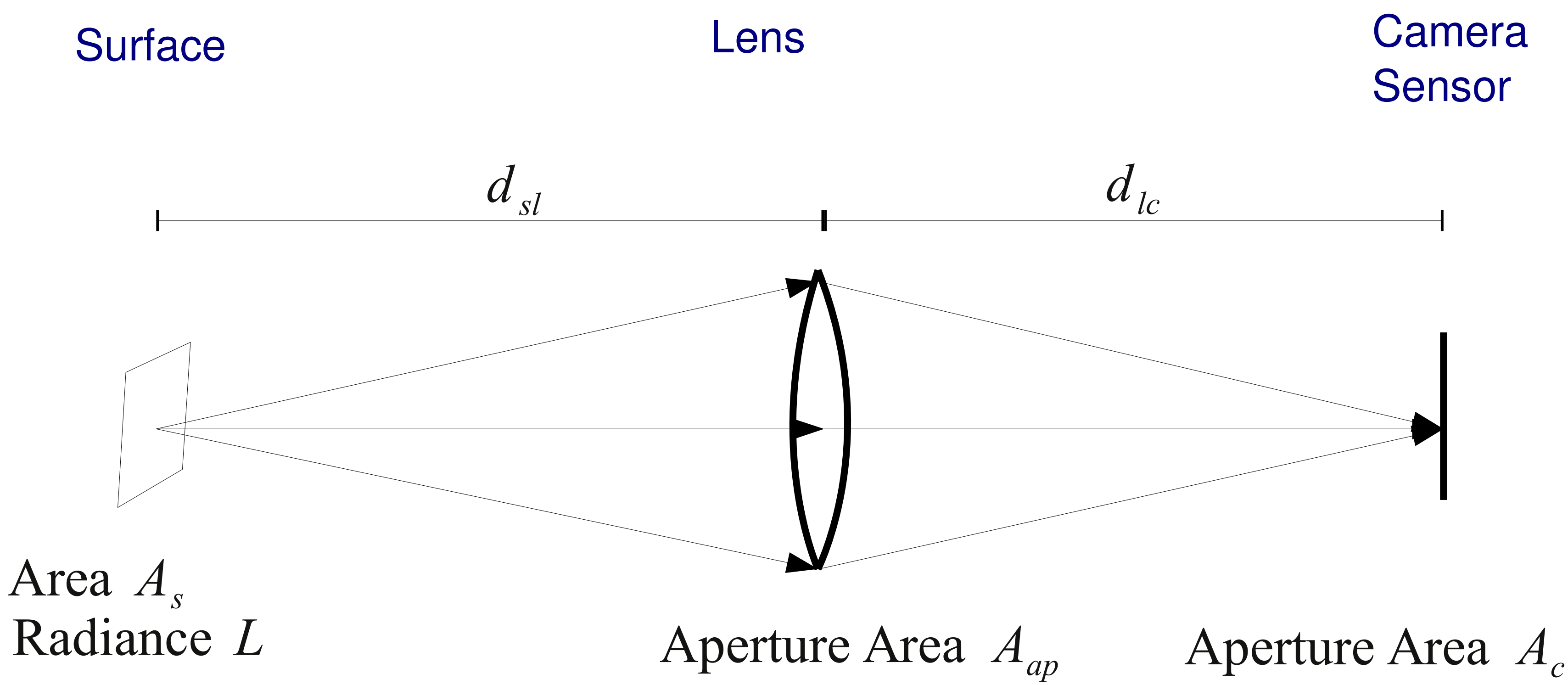
Aperture Area A_c

$$I = L\,A_s$$

$$\Phi = L\,A_s \frac{A_{ap}}{d_{sl}^2}$$

$$E = L \frac{A_{ap}}{d_{lc}^2}$$

Radiometric Computations



$$I = L\,A_s$$

$$\Phi = L\,A_s \frac{A_{ap}}{d_{sl}^2}$$

$$\boxed{E = L \frac{A_{ap}}{d_{lc}^2}}$$