Understanding Key Parameters in Photobiomodulation (PBM)

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Objectives

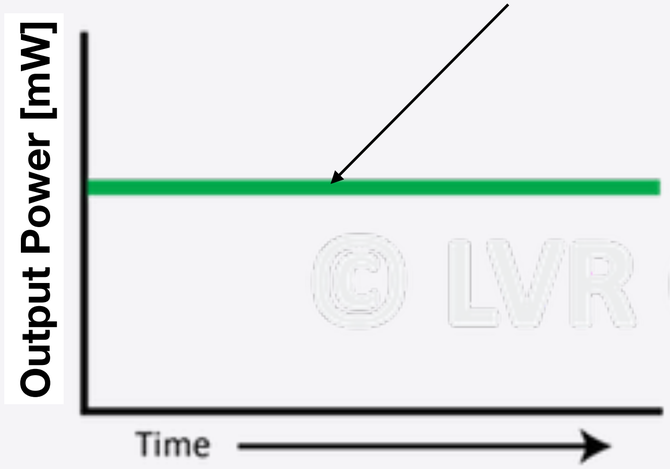
- Explain the concepts of fluence and irradiance
- Explain optical testing methodology
- Importance of optimizing parameters in PBM for clinical effectiveness.

Fluence and Irradiance Defined

- **Energy** (J): The energy delivered from a light source i.e.: the total number of photons emitted times the energy of each photon.
- **Power** (W): Rate of energy from a light source i.e.: Energy delivered per unit time.
- **Fluence** (J/cm^2): Total energy delivered per unit area.
- **Irradiance** (W/cm^2): Rate of energy delivery per unit area
  - Relationship: Irradiance = Fluence / Time.

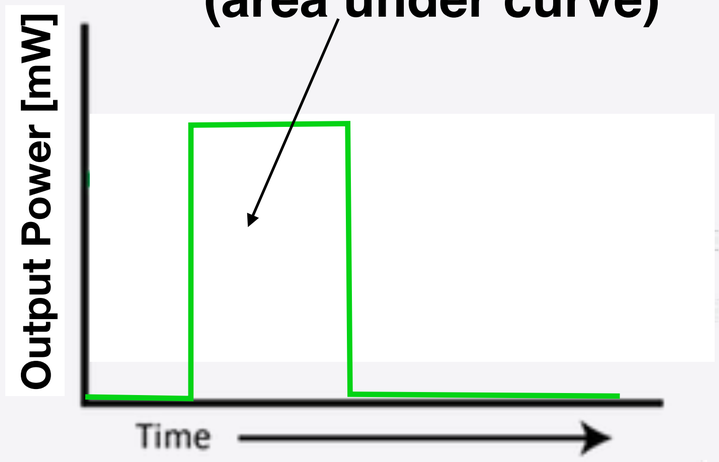
How to measure power

Power = Energy / Time



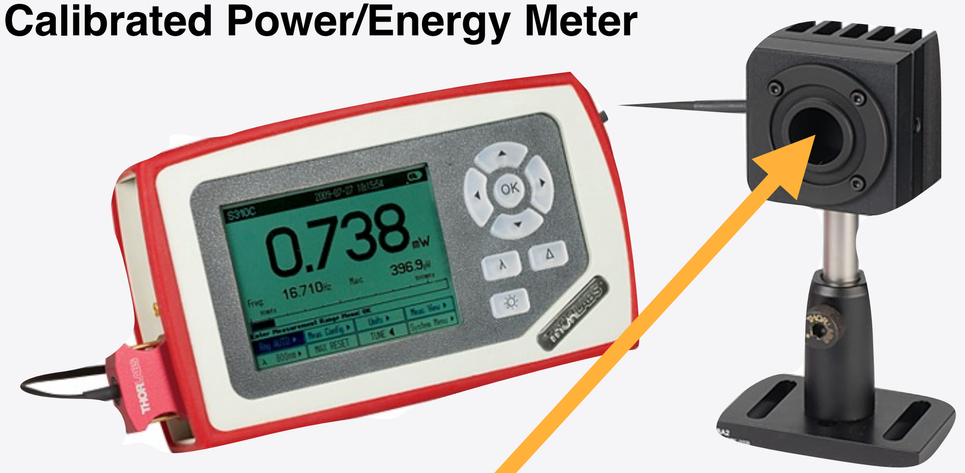
Continuous CW Output

Energy = Power * Time
(area under curve)



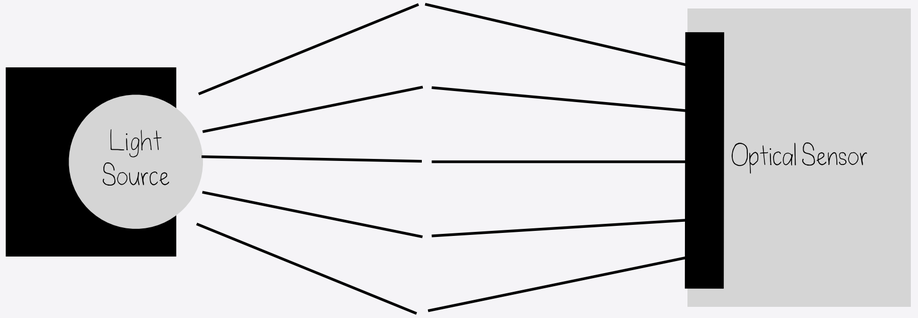
Single Pulse Output

Calibrated Power/Energy Meter



LASER

Optical Sensor

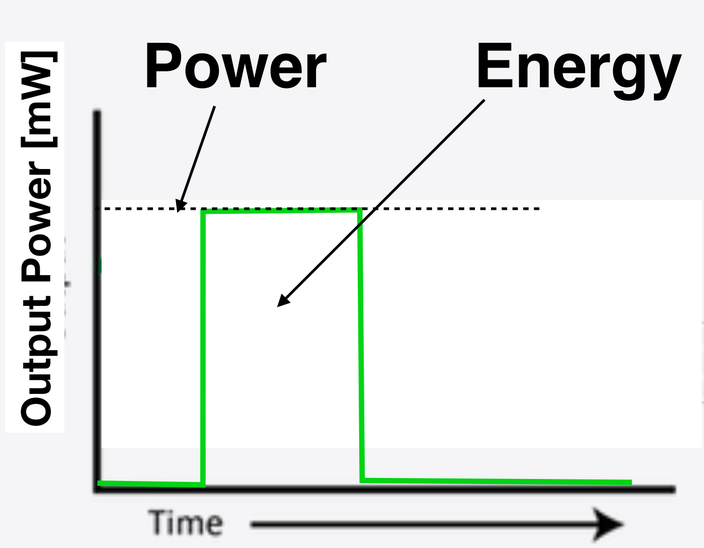


Collect all light into optical sensor

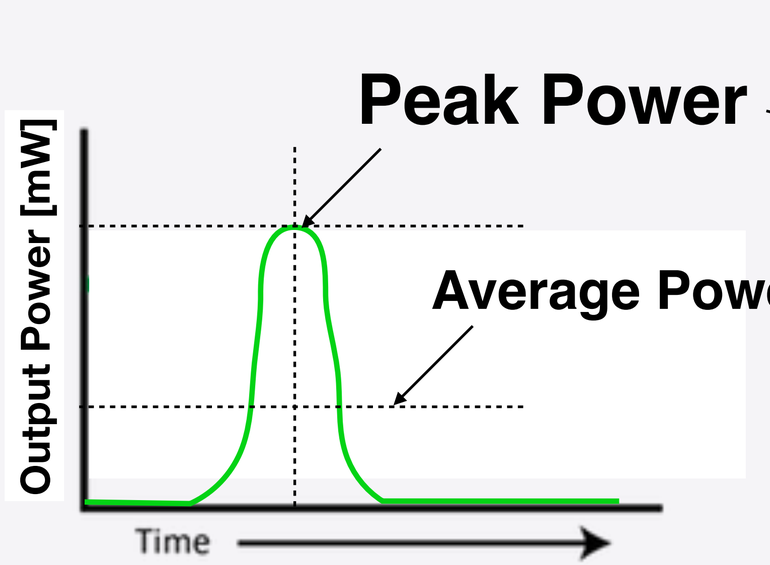
What timescale?

A power meter measures the average power over long timescales.

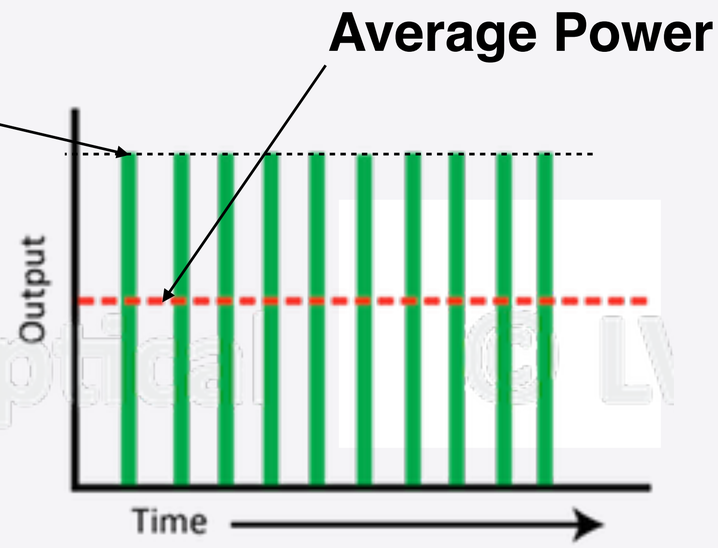
Peak Power is the rate of energy delivery at the point in time where the optical field is at its brightest.



Single Pulse Output



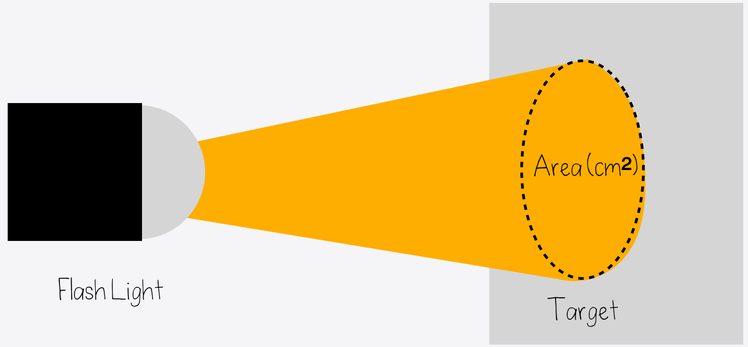
Single Pulse Output



Repetitive Pulse Output

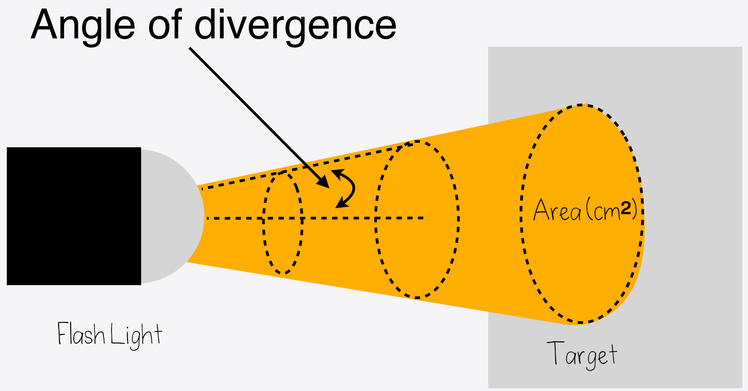
Fluence = Energy Density or Total Energy (dose) delivered per unit area (J/cm²)

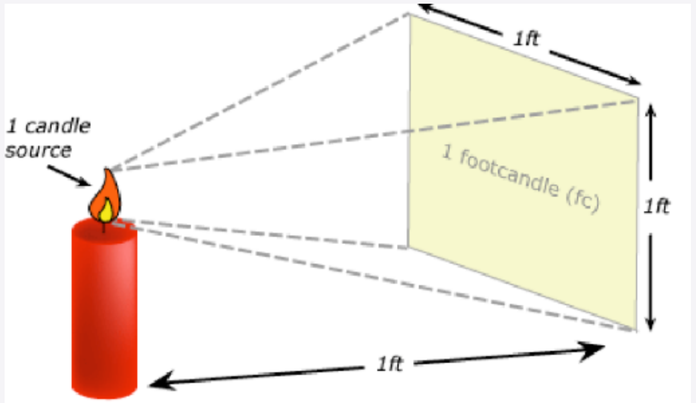
Irradiance = Rate of Dose Delivery per unit Area (W/cm²), i.e. Power/Area



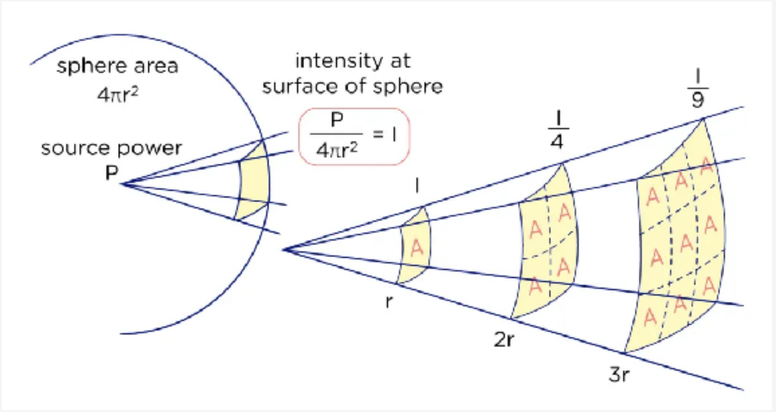
e.g:
Direct sunlight, the irradiance is ~ 1000W/m² = 100 mW/cm²
World record laser intensity ~ 10^{23} W/cm² - fusion ignition
PBM device 5 mW/cm² - 300 mW/cm²

If light source is **divergent** then irradiance/fluence are a function of distance

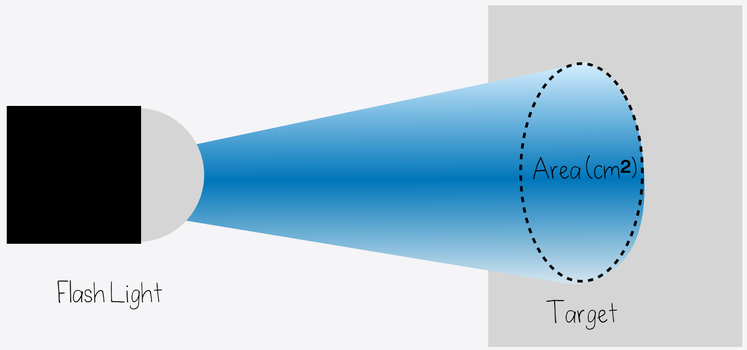




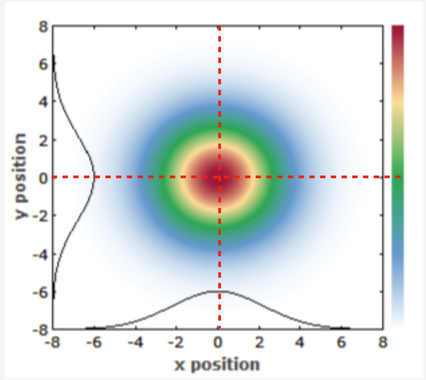
Point Source

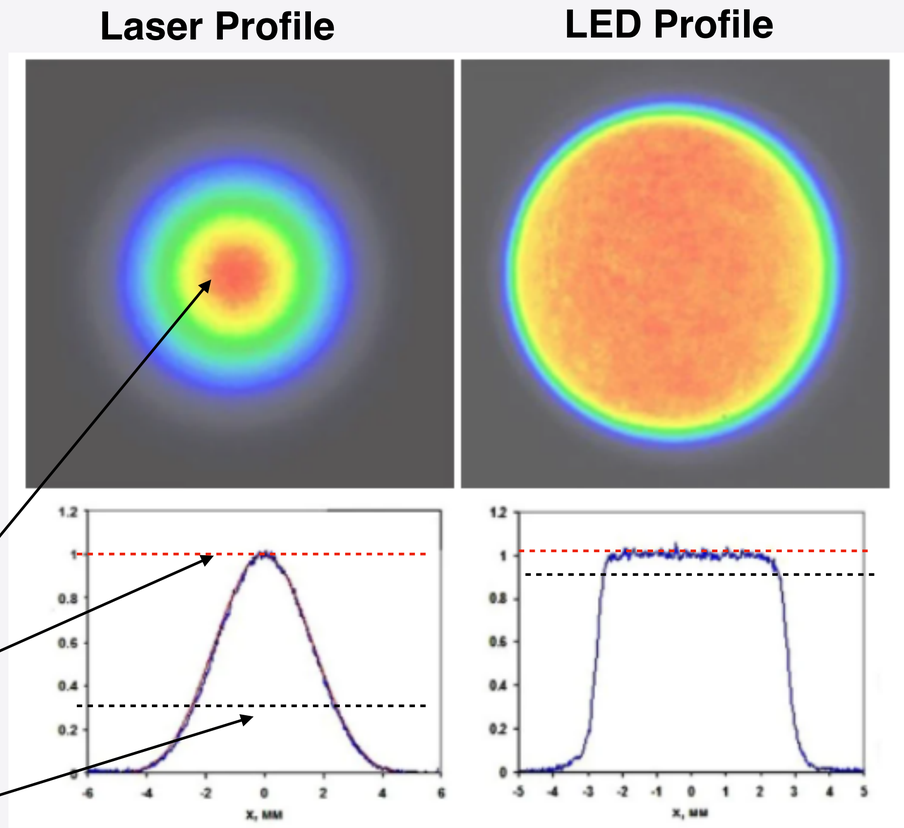


Beam Shape is not always uniform: Consider the difference between the sun (point source at infinite distance), Fluorescent bulb (diffuse source overhead), LED (pseudo point source) , Laser (low divergence)



Beam Profile = Spatial distribution of light





Peak Irradiance

Average Irradiance

Measurement Methodology

- Multiple approaches can be taken to measure irradiance including:
  - Integrating sphere, a device that evenly diffuses the light and measures a portion of the evenly distributed power. Must be carefully calibrated because of many reflections.
  - A calibrated ‘lux’ meter , intended for uniform lighting (e.g. daylight or overhead lights). Difficult to fit close to light source surface.
  - **Calibrated power measurements with an aperture of specific size as in IEC 62471 Section 5.2. Irradiance = Power / Aperture Area.**

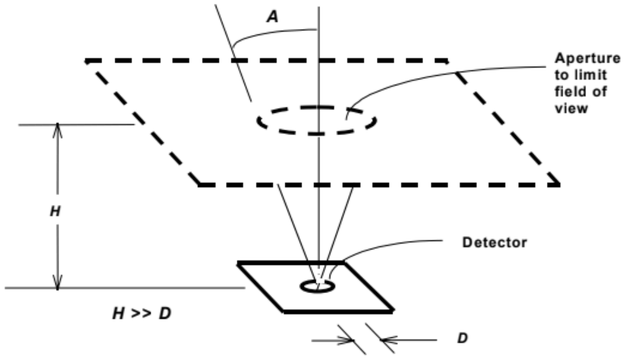
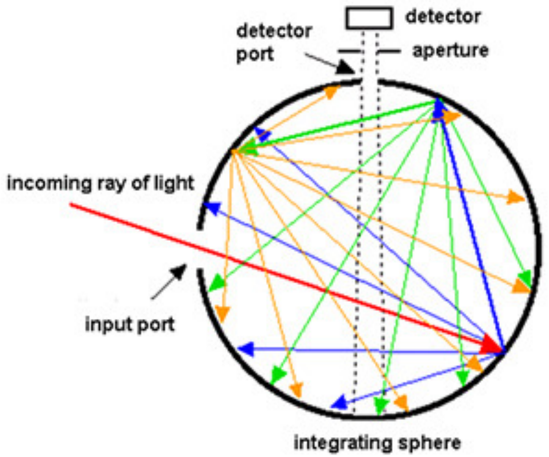
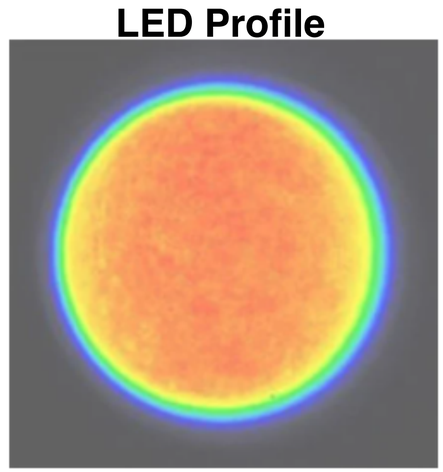


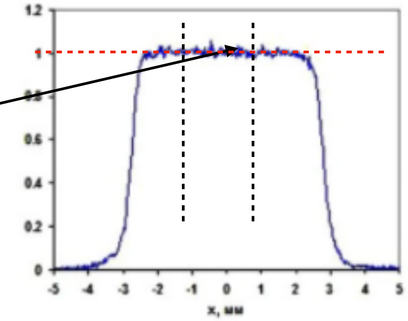
Figure 5.1 Schematic - Irradiance measurements.

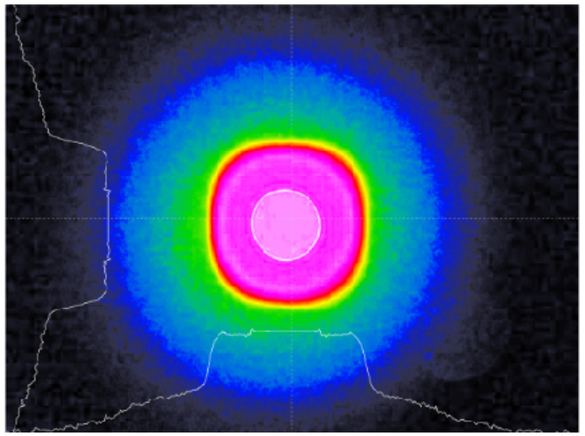


Measurement Methodology - Irradiance

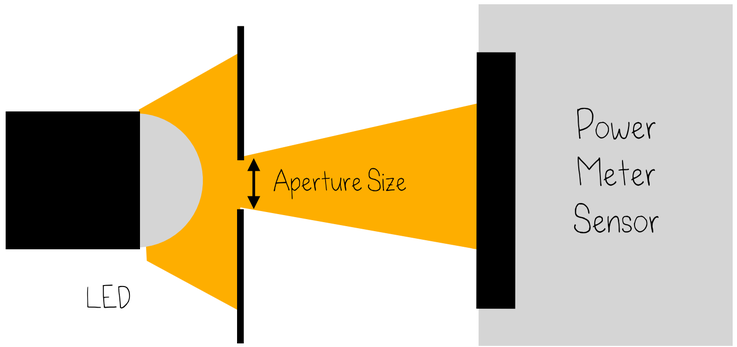
- For measurement of LED source in close contact a small aperture size is chosen to quantify the peak irradiance averaged over the limiting aperture.



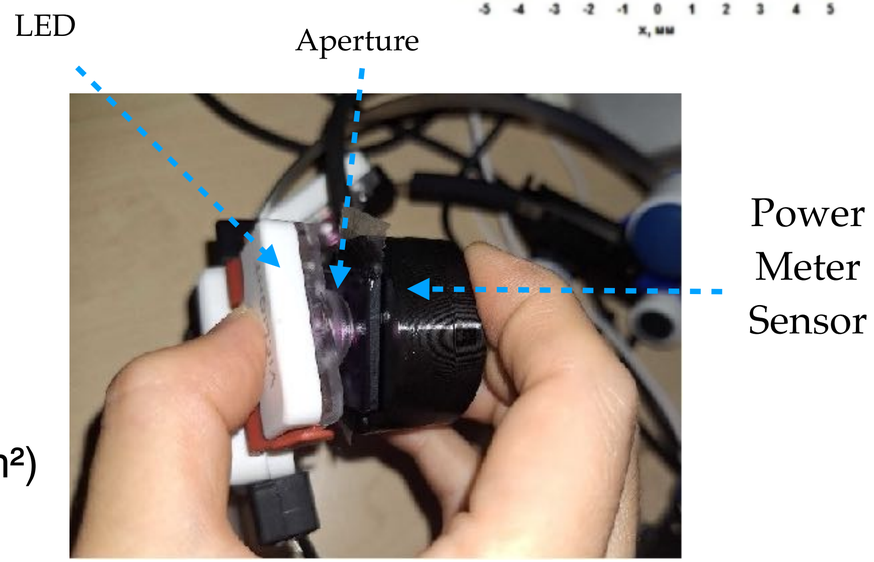




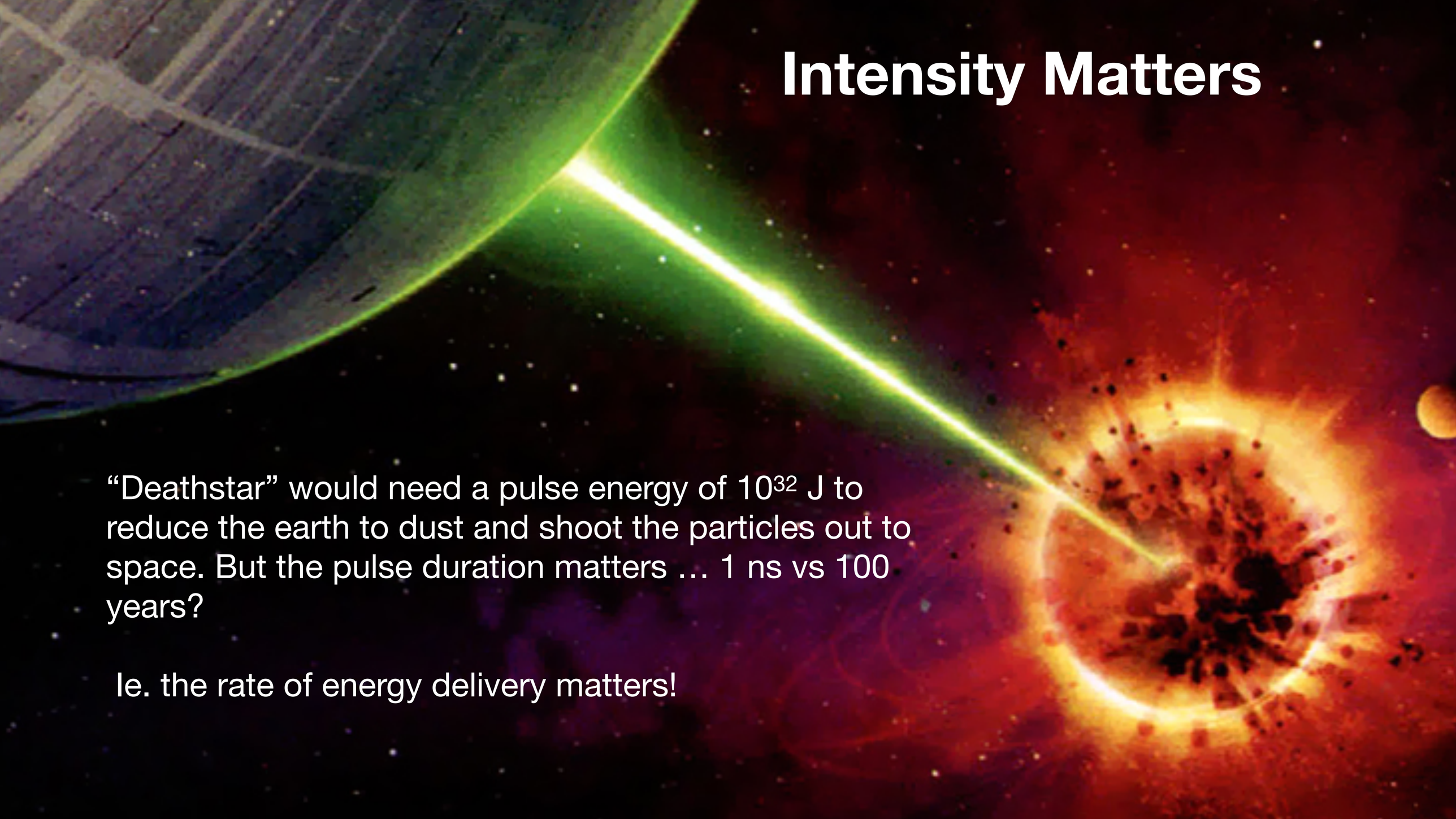
LED Beam Profile at surface



Irradiance = Power/ Aperture Area (W/cm²)



Intensity Matters

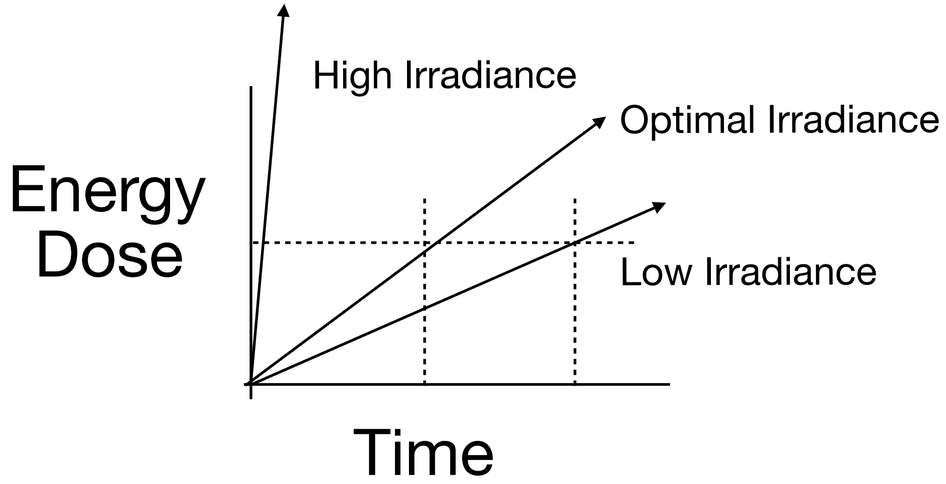


"Deathstar" would need a pulse energy of 10^{32} J to reduce the earth to dust and shoot the particles out to space. But the pulse duration matters … 1 ns vs 100 years?

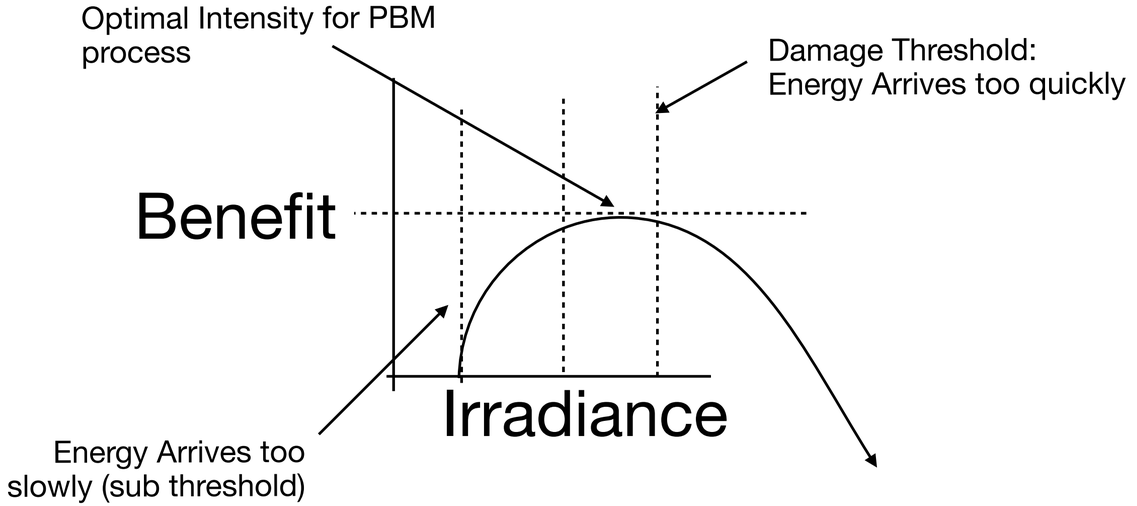
Ie. the rate of energy delivery matters!

The Role of Irradiance in PBM Energy Delivery

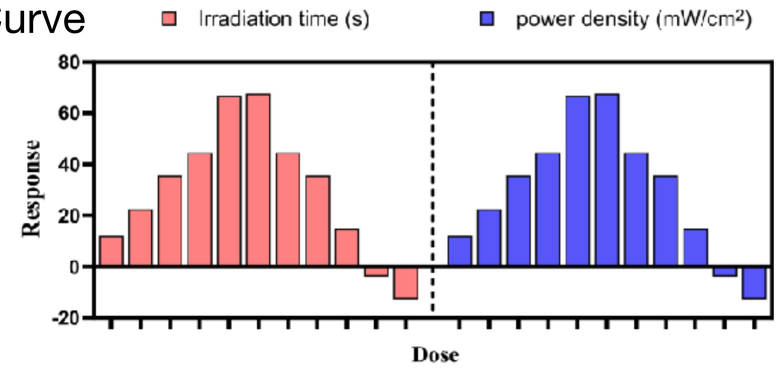
- Fluence depends on how many photons hit the target…i.e. how long the light is left on = Total Dose of photons
- Irradiance is the rate of fluence. Ie. number of photons that hit the target per unit time.
  - High irradiance: Quick energy delivery.
  - Low irradiance: Gradual energy delivery.



- Does the rate of energy delivery influence cellular responses for fixed fluence (dose).
  - Nonlinear photochemical reactions.
  - ATP production enhancement at optimal irradiance.
  - Potential thermal/photo-damage at excessive irradiance.

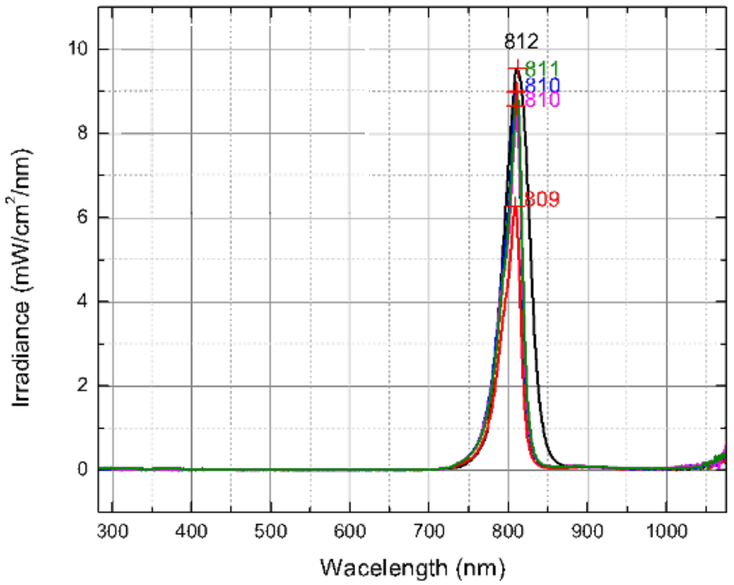


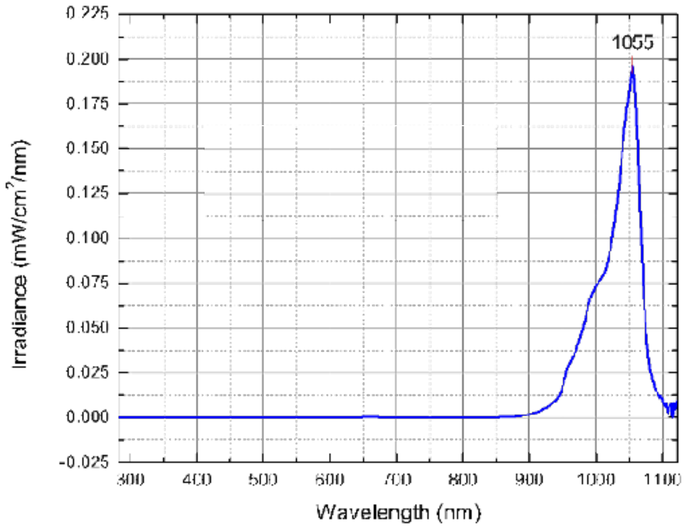
Biphasic Response Curve

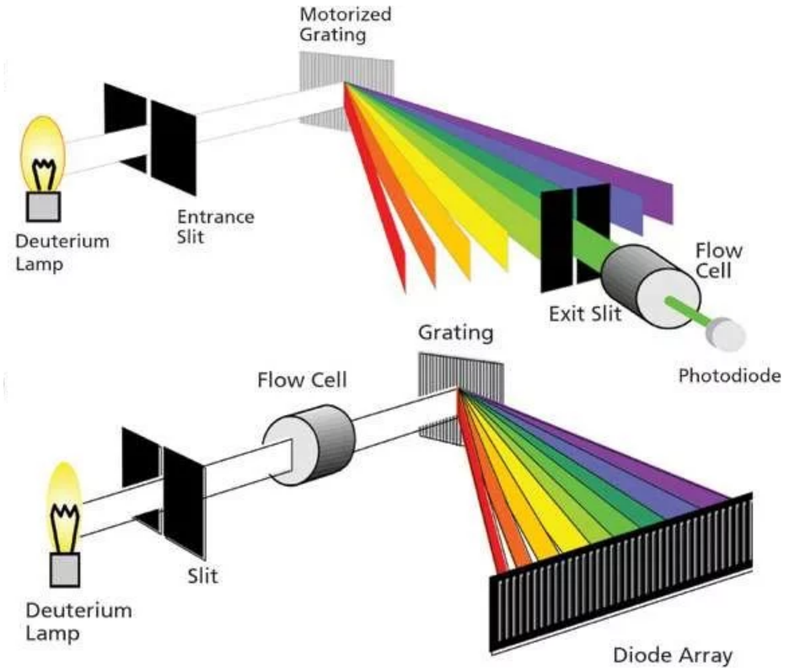


Measurement Methodology - Wavelength

- The distribution of wavelength (colours) in the light source is measured using an optical spectrometer.



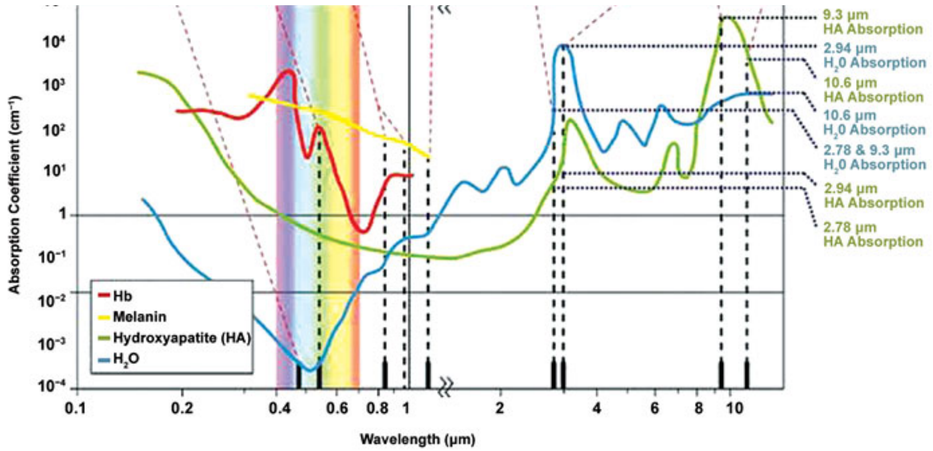




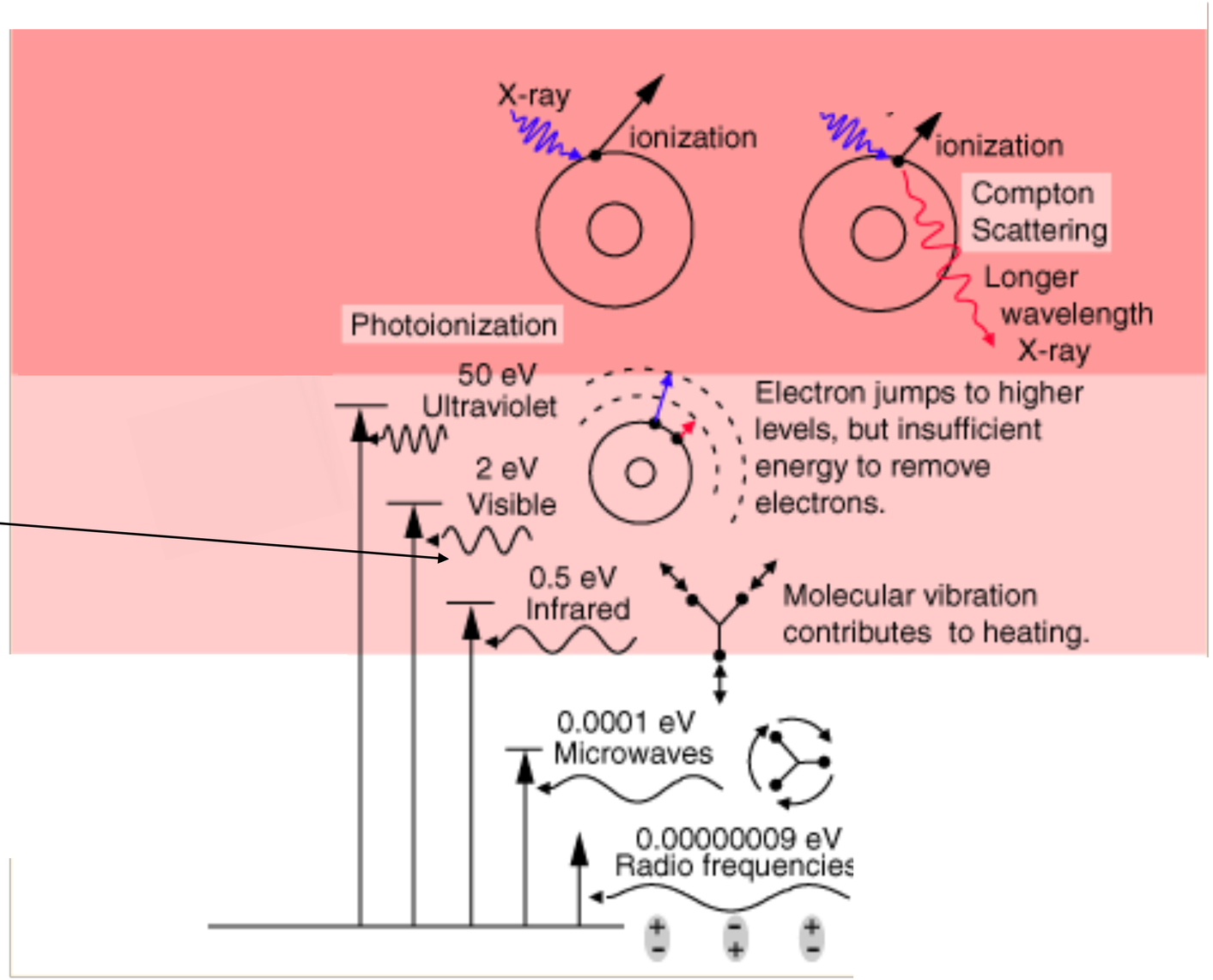
Wavelength

- Determines not just the absorption of the light, but also its type of interaction with tissue.
- PBM uses avelength range of 600 to 1100 nm, with specific wavelengths of interest, such as 630 nm, 810 nm, and 980 nm
- Wavelengths target chromophores in cellular processes to try and promote tissue repair, reduce inflammation, and modulate pain.

PBM



Absorption Spectrum of Tissue



Key Takeaways

- Both fluence and irradiance are critical to optimizing PBM therapy.
- Quantitative and accurate measurement of PBM device parameters is essential for standardized treatment