Wednesday, April 22, 2026

Example: Determining distance with a type 1a supernova.

Using the Hubble Space Telescope you observe a type 1a supernova that peaks in apparent brightness at 1000 photons/s (in the visible).

Q: How far away is the supernova?

Step 1: What is the apparent brightness in W/m^2?

Diameter of the Hubble Space Telescope ("HTS") = 2.4 m

↳ Radius $= \frac{\text{Diameter}}{2} = \frac{2.4}{2} = 1.2$ m

↳ Area of HTS $= \pi \, \text{Radius}^2$

$= (3.1415)(1.2)^2$

$= 4.52 \ m^2$

$= 4.5 \ m^2$

$\Rightarrow$ $\boxed{\text{Area of HTS} \simeq 4.5 \ m^2}$

Next, convert 1000 photons/s to "Energy" per second (Joules/s = Watts)

Middle of visible spectrum is $\lambda = 500$ nm ← Green light

$\Rightarrow \lambda f = c \iff f = \frac{c}{\lambda} = \frac{3.0 \times 10^8 \ m/s}{500 \times 10^{-9} \ m}$

$\Rightarrow f = 6.0 \times 10^{14}$ Hz

Energy of 1 photon is $E_\gamma = hf = (6.626\times10^{-34}\,J\cdot s)(6.0\times10^{14}\,s^{-1})$

$= 3.976\times10^{-19}\,J$

$\Rightarrow$ 1000 photons/s $= 1000\times(3.976\times10^{-19}\,J)\,/\,1\,s$

$= 3.976\times10^{-16}\,J/s$ (J/s = Watts)

$\Rightarrow$ **1000 photons/s $= 3.976\times10^{-16}\,W$** = power detected

$\Rightarrow$ Apparent brightness in W/m^2 is Intensity (detected) $= \dfrac{\text{Power}}{\text{Area}}$

$\Rightarrow$ **Intensity (at telescope) $= \dfrac{3.976\times10^{-16}\,W}{4.5\,m^2} = 8.8355\times10^{-17}\,W/m^2$**

Step 2: How far away is the supernova?

From Lecture 32 (slides 4-5): $L_{Max\,1A} = 5\times10^{9}\,L_{sun}$ (visible light power, Watts)

Note: $L_{sun} = 3.8\times10^{26}$ Watts

$\Rightarrow L_{Max\,1A} = (5\times10^{9})\times(3.8\times10^{26}) = 1.9\times10^{36}$ Watts

Apparent brightness = Intensity (detected) $= \dfrac{L_{Max\,1A}}{4\pi d^2}$ ← d = distance to supernova

$$\Leftrightarrow \quad d^2 = \frac{L_{Max,\,1A}}{4\pi \times \text{Intensity}}$$

$$= \frac{1.9 \times 10^{36}}{4(3.1415)(8.8355 \times 10^{-17})}$$

$$= 1.7112 \times 10^{51} \text{ m}^2$$

$$\Rightarrow \quad d = \sqrt{1.7112 \times 10^{51}} = 4.137 \times 10^{25} \text{ m}$$

$$= 4.137 \times 10^{22} \text{ km}$$

$$\div \underbrace{9.4 \times 10^{12} \text{ km}}_{1 \text{ light year}} \qquad = 4.4 \times 10^{9} \text{ light year}$$

The supernova is in a galaxy at a distance of

$$\boxed{d = 4.4 \times 10^{9} \text{ light years} = 4.4 \text{ billion light years}}$$