NS 102 Lecture 9 April 27, 2005

Open: For me this is heaven- Jimmy Eat World

Pieter Bruegel the Elder, ca. 1563

Close: Cold in the Sun-Red Eyed Legends

GnatSigh News

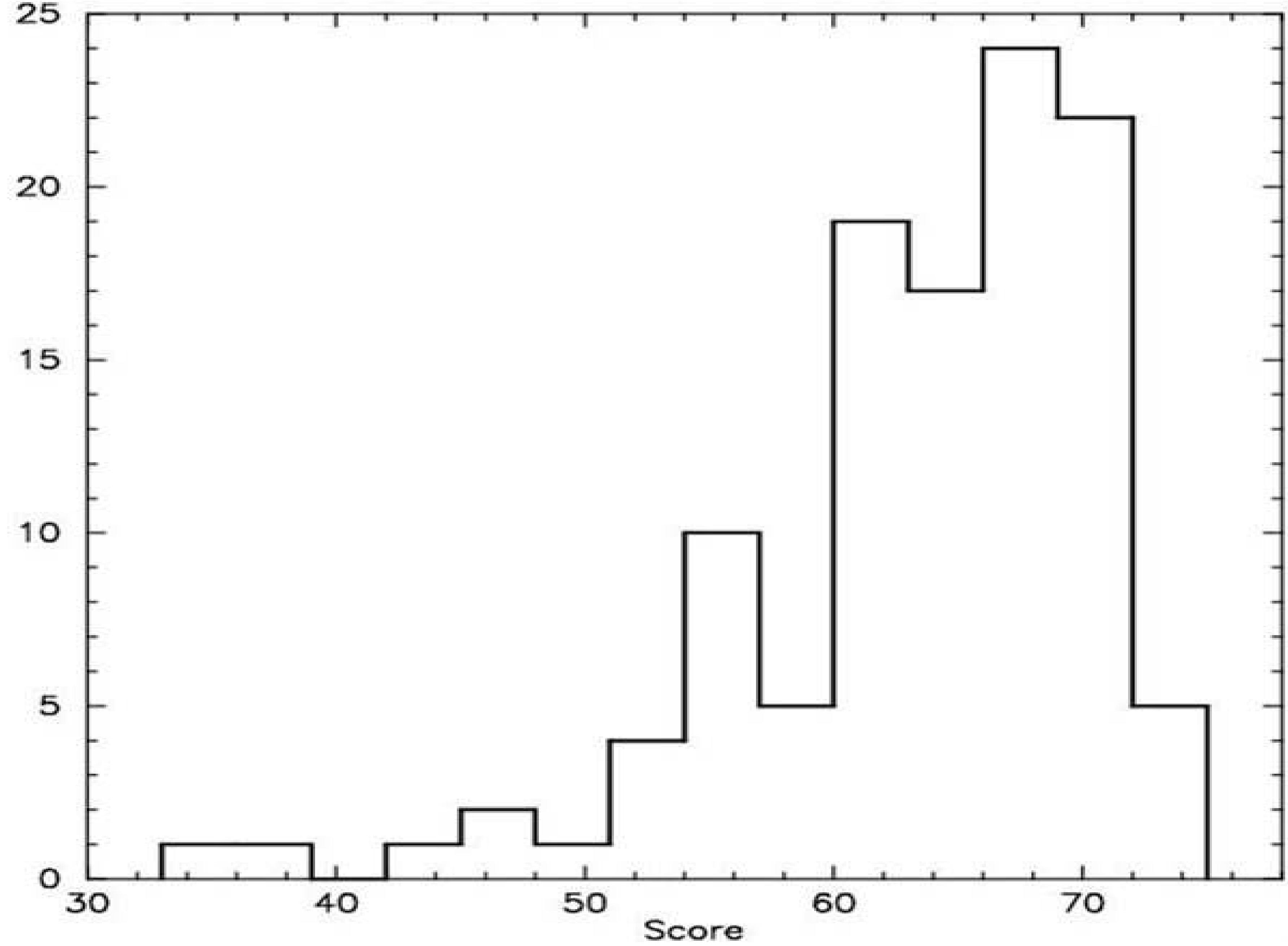
(all the news that fits)

- Website http://home.fnal.gov/~rocky/NS102/
- Need violinist volunteer
- Review logarithms
- Review basic trigonometry (definition of sine, tangent, etc.)
- Exam #1 returned today
- Galileo's Depositions, Defense, and Papal Condemnation on the website

Lab this week: Temperature of the Universe

Lab next week: Geometry of the Universe

NS102 Spring 2005 Exam #1



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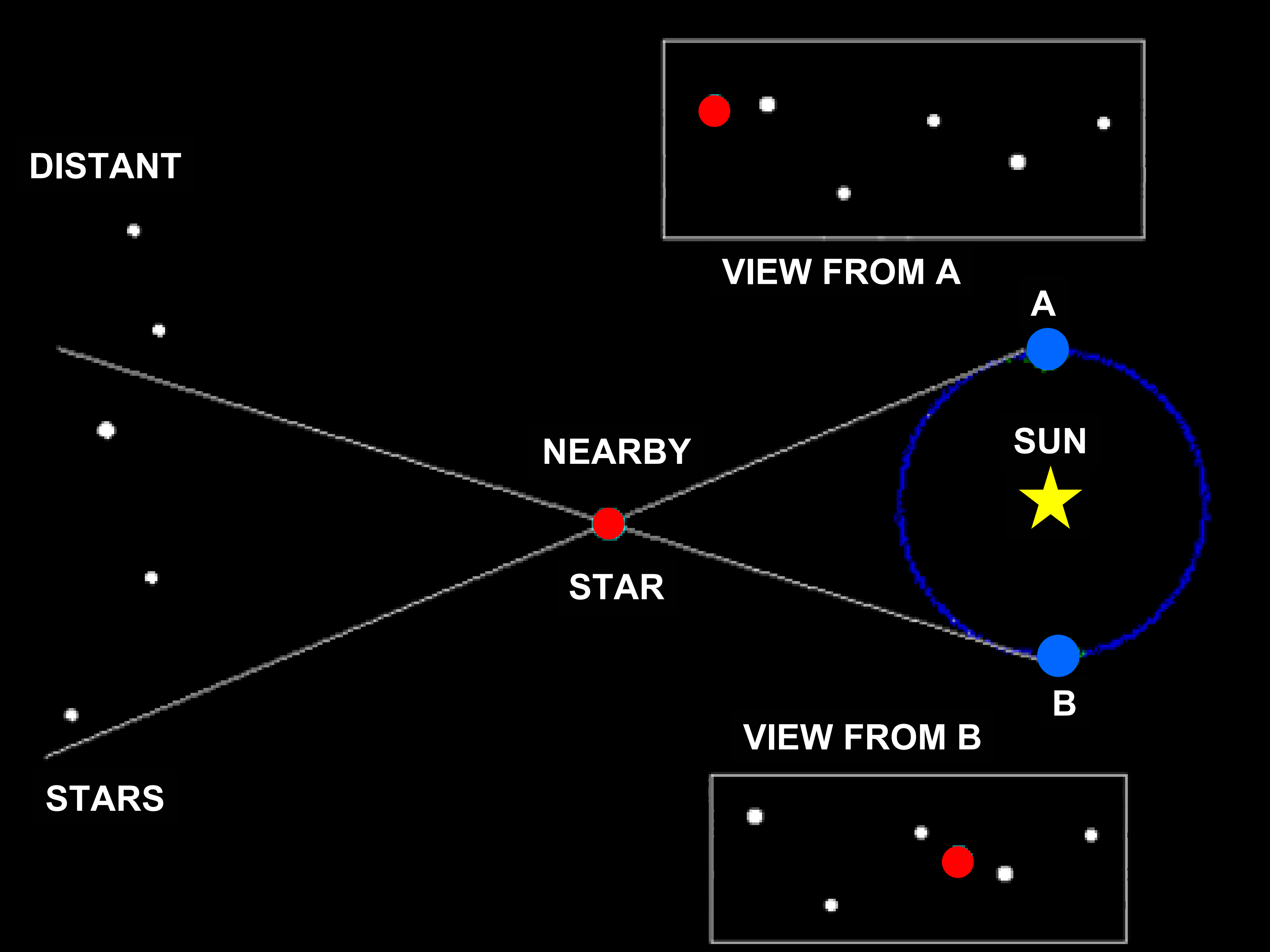
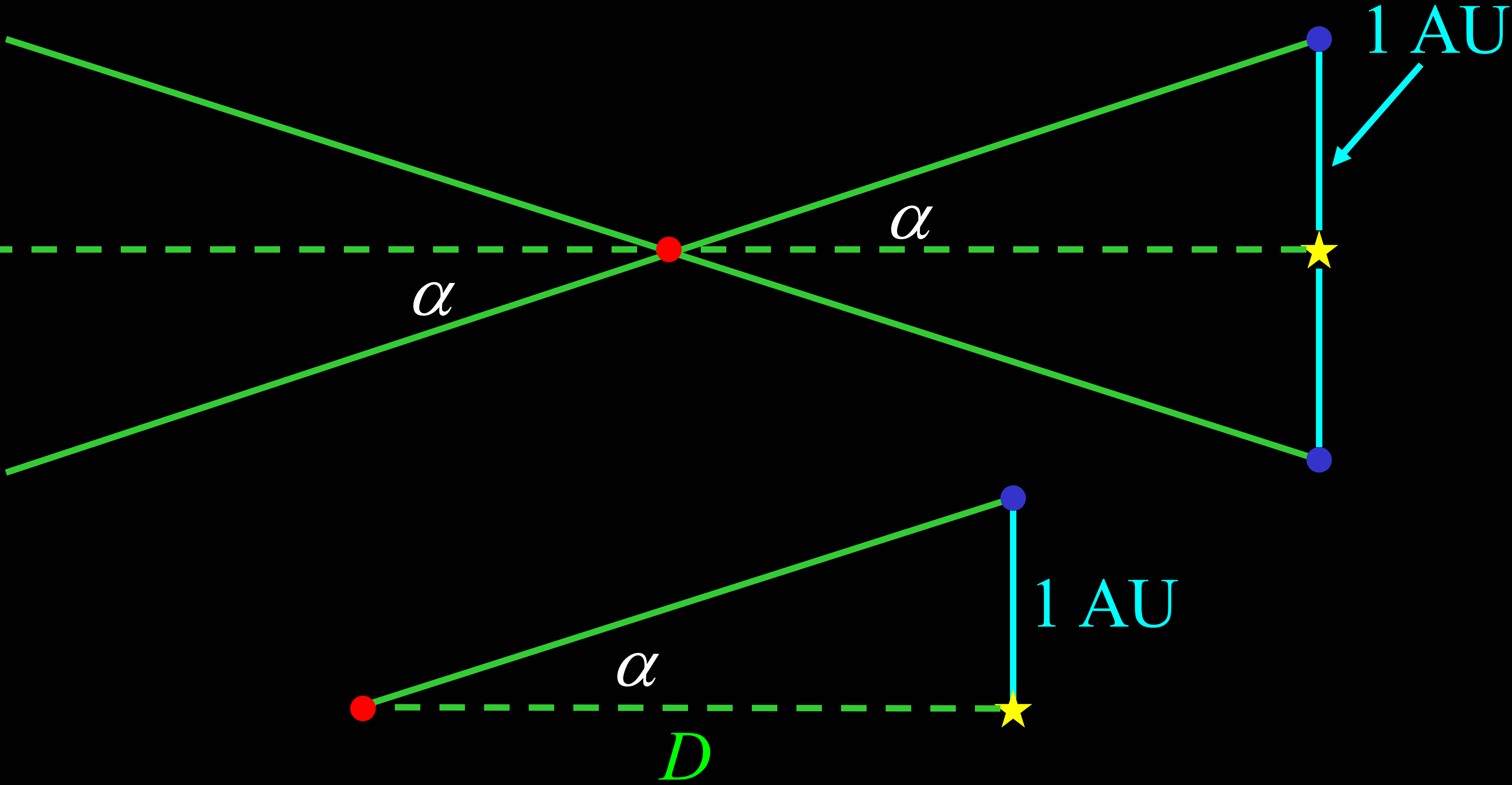
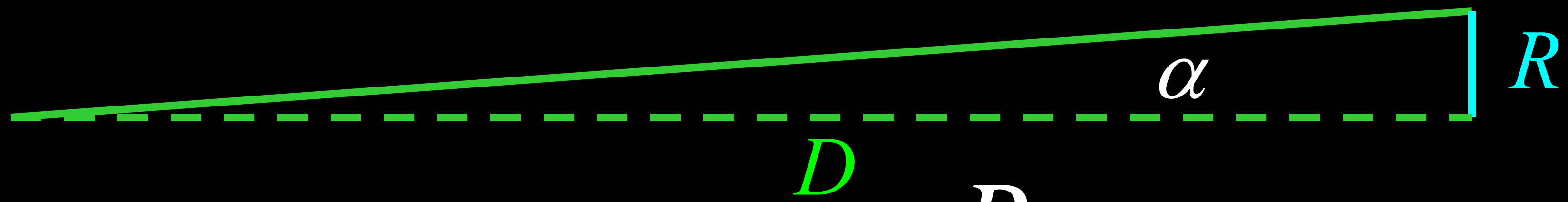
Pieter Bruegel the Elder, ca. 1563

The Cosmological Distance Scale


DISTANT
STARS
NEARBY
STAR
SUN
A
B
VIEW FROM A
VIEW FROM B



$$\tan\alpha = \frac{1\ \mathrm{AU}}{D}$$



$$\tan\alpha = \frac{R}{D}$$

law of skinny triangles:

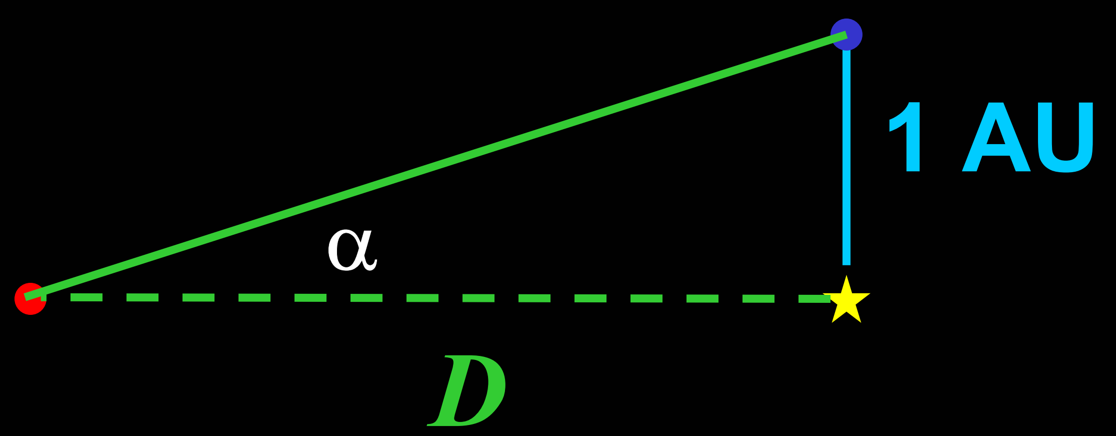
$$\tan\alpha = \sin\alpha = \alpha \quad \text{(in radians)}$$

$$\alpha \ \text{(in radians)} = \frac{R}{D}$$

$$\alpha \ \text{(in seconds of arc)} = \frac{R}{D} \times 206{,}264.8$$

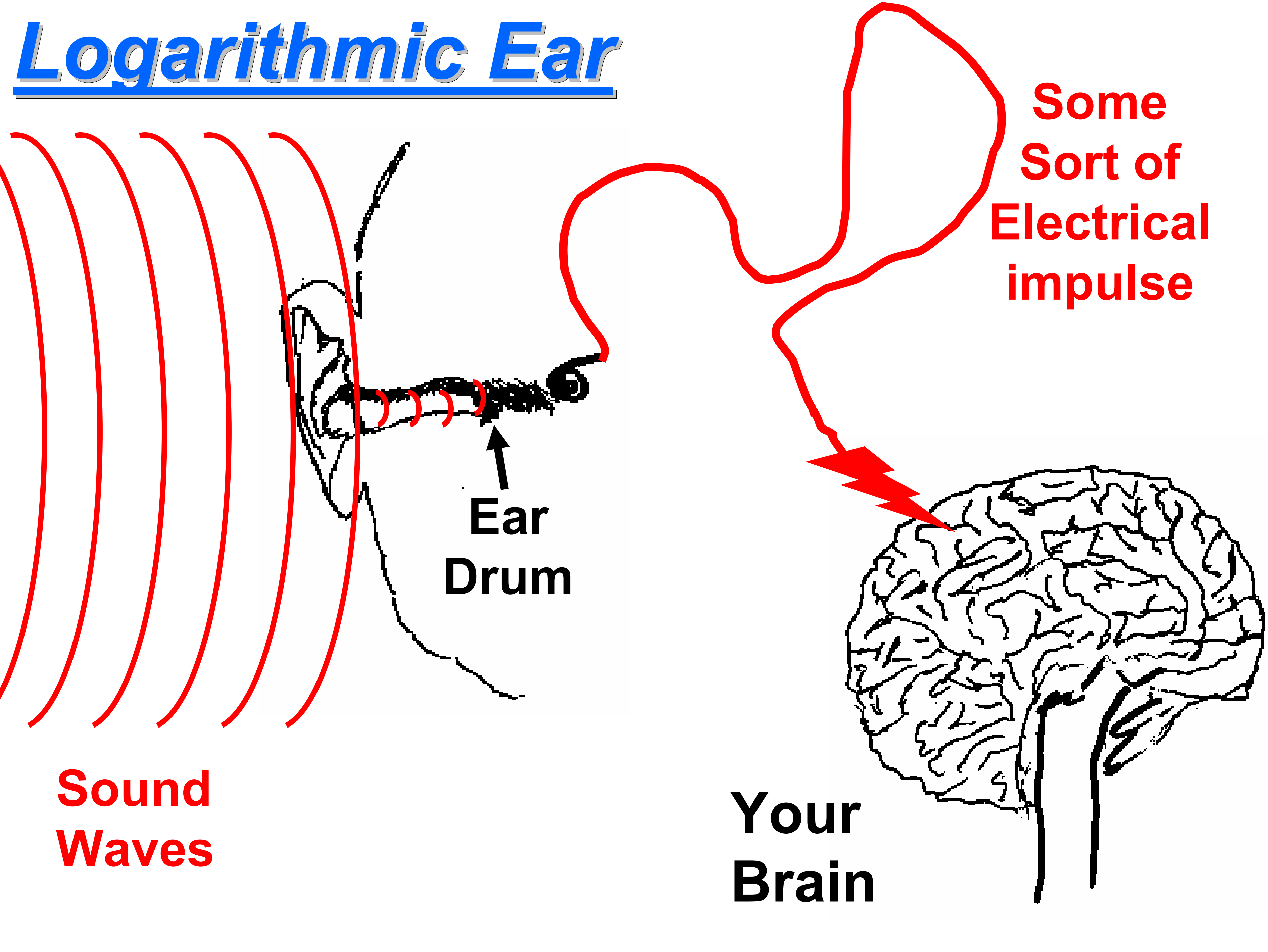
$$\frac{D}{200{,}000\ \text{AU}} = \frac{\text{seconds}}{\alpha}$$

$$\frac{D}{\text{pc}} = \frac{\text{seconds}}{\alpha}$$



They have different apparent brightness
They have different colors
They move
They change in brightness

Logarithmic Ear



Intensity: energy per time per area

$$I = \frac{\text{Energy}}{\text{Time Area}} = \frac{\text{Power}}{\text{Area}}$$

$\frac{\text{Energy}}{\text{Time}}$ (Power) measured in watts

Area measured in cm^2

Intensity in watts per cm^2

Intensity: energy per time per area

$$I = \frac{\text{Energy}}{\text{Time Area}}$$

$$dB = 10 \log (I / I_0)$$

I_0 = threshold of hearing

Hearing threshold

$$dB = 10 \log (I / I_0)$$

$$dB = 0$$

$I_0 = 10^{-16}$ watts per cm^2

Pain threshold

$$dB = 10 \log (I/I_0)$$
$$= 10 \log(10^{12})$$

$dB = 120$

$I = 10^{12} I_0 = 10^{-4}$ watts per cm^2

I_0 is intensity at threshold of hearing

I/I_0	$\log (I/ I_0)$	$dB = 10 \log (I/ I_0)$
10^{-2}	-2	-20
1	0	0
10^{2}	2	20
10^{6}	6	60
10^{12}	12	120
10^{20}	20	200

Difference of about 1 dB is about the smallest change that can be noticed by the human ear

$$\mathrm{dB}_1 = 10\log\left(I_1/I_0\right) \qquad \mathrm{dB}_2 = 10\log\left(I_2/I_0\right)$$

$$\mathrm{dB}_1 - \mathrm{dB}_2 = 10\log\left(I_1/I_0\right) - 10\log\left(I_2/I_0\right)$$

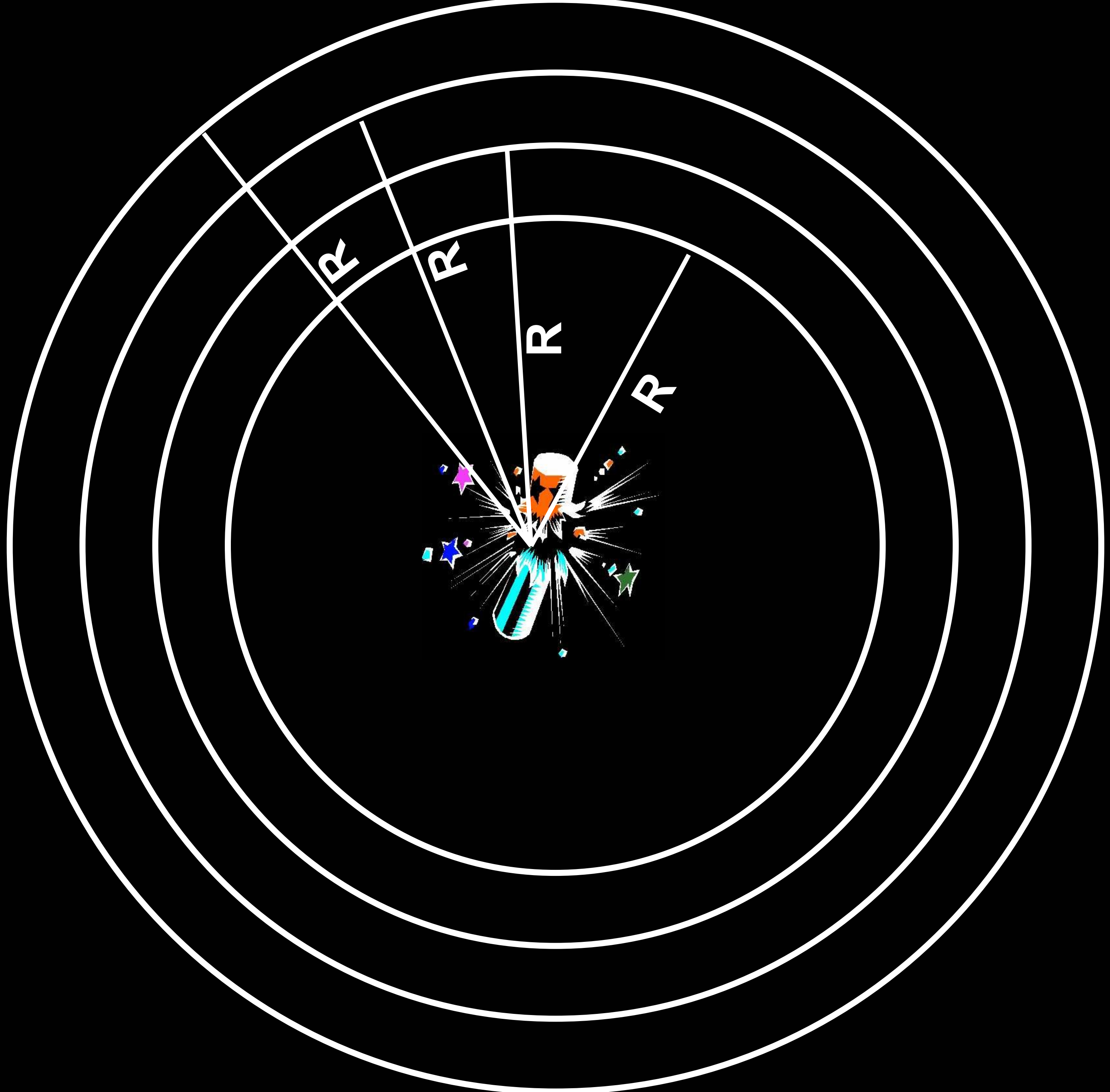
$$= 10\left[\log\left(I_1/I_0\right) - \log\left(I_2/I_0\right)\right]$$

$$= 10\left[\log\left(I_1\right) - \cancel{\log\left(I_0\right)} - \log\left(I_2\right) + \cancel{\log\left(I_0\right)}\right]$$

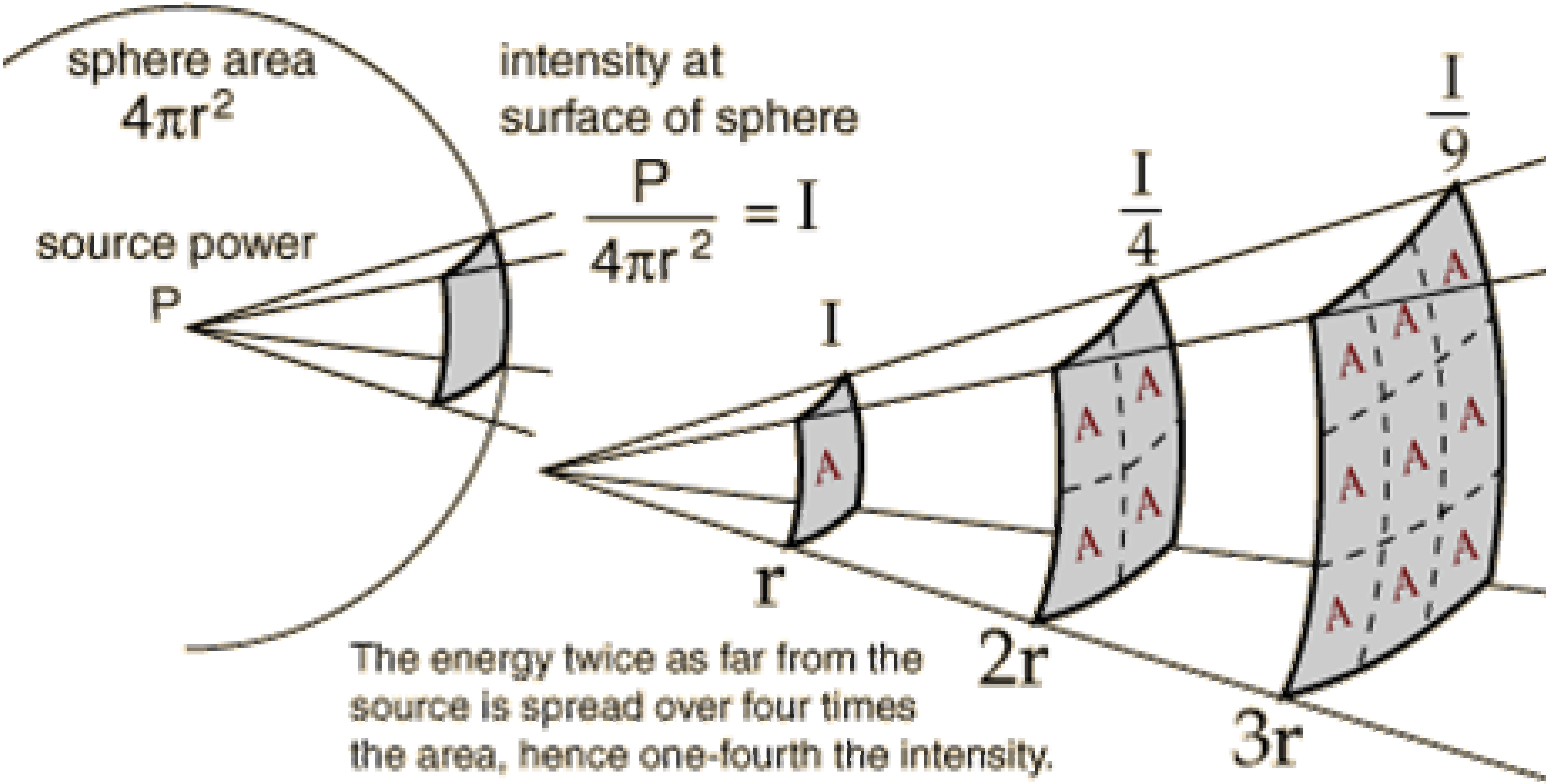
$$= 10\left[\log\left(I_1\right) - \log\left(I_2\right)\right] = 10\log\left(I_1/I_2\right)$$

$$1 = 10\log\left(I_1/I_2\right)$$

$$0.1 = \log\left(I_1/I_2\right) \rightarrow 10^{0.1} = I_1/I_2 \rightarrow 1.25 = I_1/I_2$$


R
R
R
R

Inverse-square law



Intensity: energy per time per area

$$I = \frac{\text{Energy}}{\text{Time Area}} = \frac{\text{Power}}{\text{Area}}$$

Power property of source

Intensity depends on power and distance between source and detector

$$\text{Intensity} = \frac{\text{power}}{4\pi R^2}$$

Let there be light

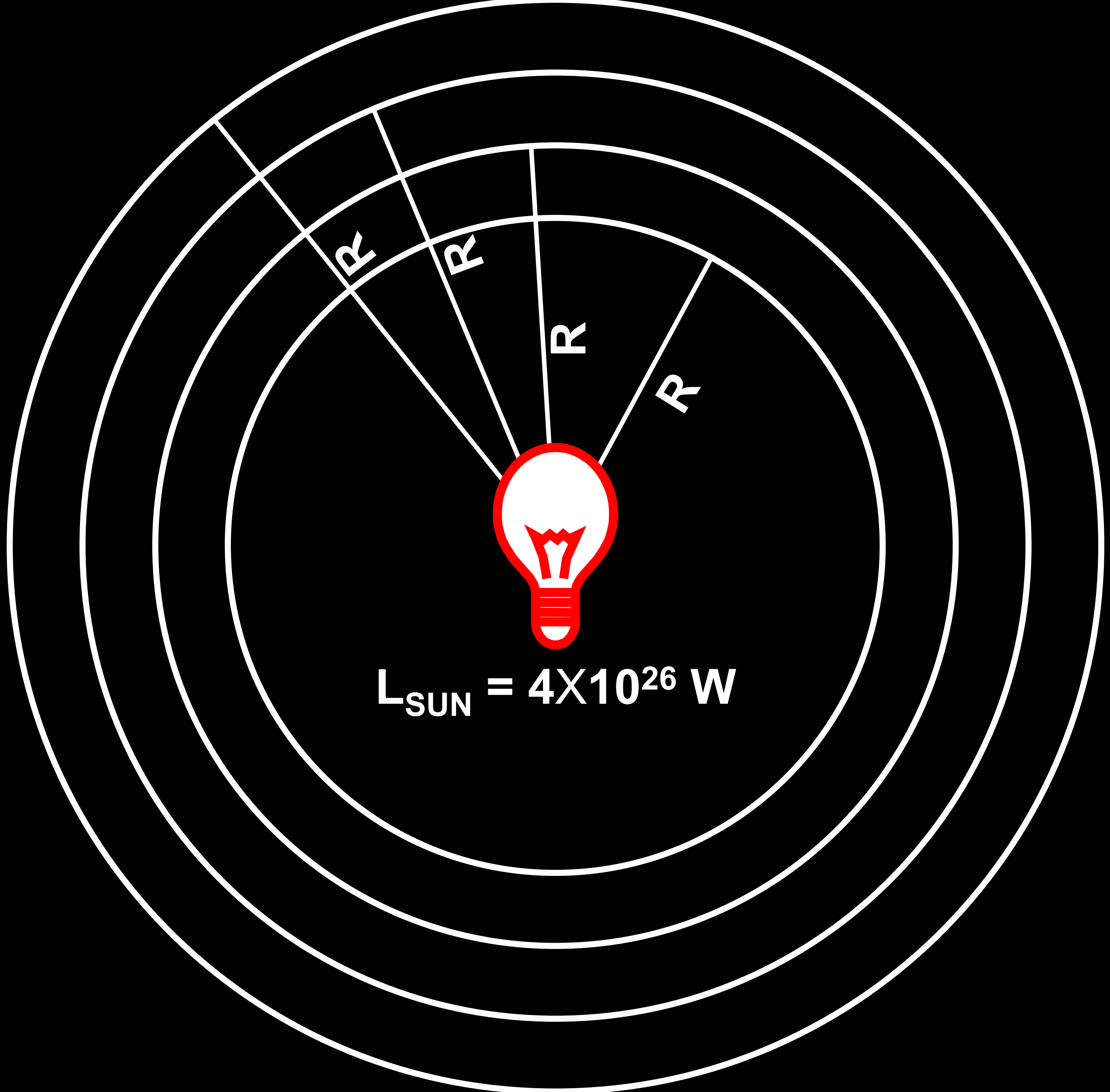
For light!!!

$$I = \frac{\text{Energy}}{\text{Time Area}}$$

$\frac{\text{Energy}}{\text{Time}}$ (Luminosity) measured in watts

Area measured in cm^2

Intensity in watts per cm^2


R
R
R
R
$L_{SUN} = 4 \times 10^{26}$ W

For light!!!

$$I = \frac{\text{luminosity}}{\text{cm}^2}$$

Luminosity property of source

Intensity depends on power and distance between source and detector

$$\text{Intensity} = \frac{\text{luminosity}}{4\pi R^2}$$

Logarithmic Eye

Eyes, like ears, are logarithmetic detectors.

LET THERE BE LIGHT!

Greeks classified stars into 6 classes, or magnitudes

Brightest stars were 1st magnitude
Dimmest stars were 6th magnitude

Intensity of brightest stars = 100 X dimmest.

For sound: $$\mathrm{dB}_1 - \mathrm{dB}_2 = \alpha \log\left(I_1 / I_2\right)$$

To define scale:

1. **Define α for convenience,**
   - $\Delta\mathrm{dB} \equiv$ **120 between threshold and pain**
   - **Measure <u>ratio</u> of intensities**

$$120 = \alpha \log\left(I_{\mathrm{pain}} / I_0\right)$$

$$= \alpha \log(10^{12}) = \alpha \times 12 \rightarrow \alpha = 10$$

$$\mathrm{dB}_1 - \mathrm{dB}_2 = 10 \log\left(I_1 / I_2\right)$$

2. **One measurement & one definition**

$$I_0 = 10^{-16}\,\text{watts cm}^{-2} \qquad \mathrm{dB}_0 \equiv 0$$

$$\mathrm{dB} = 10 \log\left(I / 10^{-16}\,\text{watts cm}^{-2}\right)$$

For light: $$m_1 - m_2 = \alpha \log\left(I_1 / I_2\right)$$

To define scale:

1. **Define α for convenience,**
   - $\Delta m \equiv 1\text{–}6 = -$**5 between brightest & dimmest**
   - **Measure ratio of intensities**

$$-5 = \alpha \log\left(I_{\text{brightest}} / I_{\text{dimmest}}\right)$$

$$= \alpha \log(10^2) = \alpha \times 2 \rightarrow \alpha = -5/2 = -2.5$$

$$m_1 - m_2 = -2.5 \log\left(I_1 / I_2\right)$$

2. **One measurement & one definition**

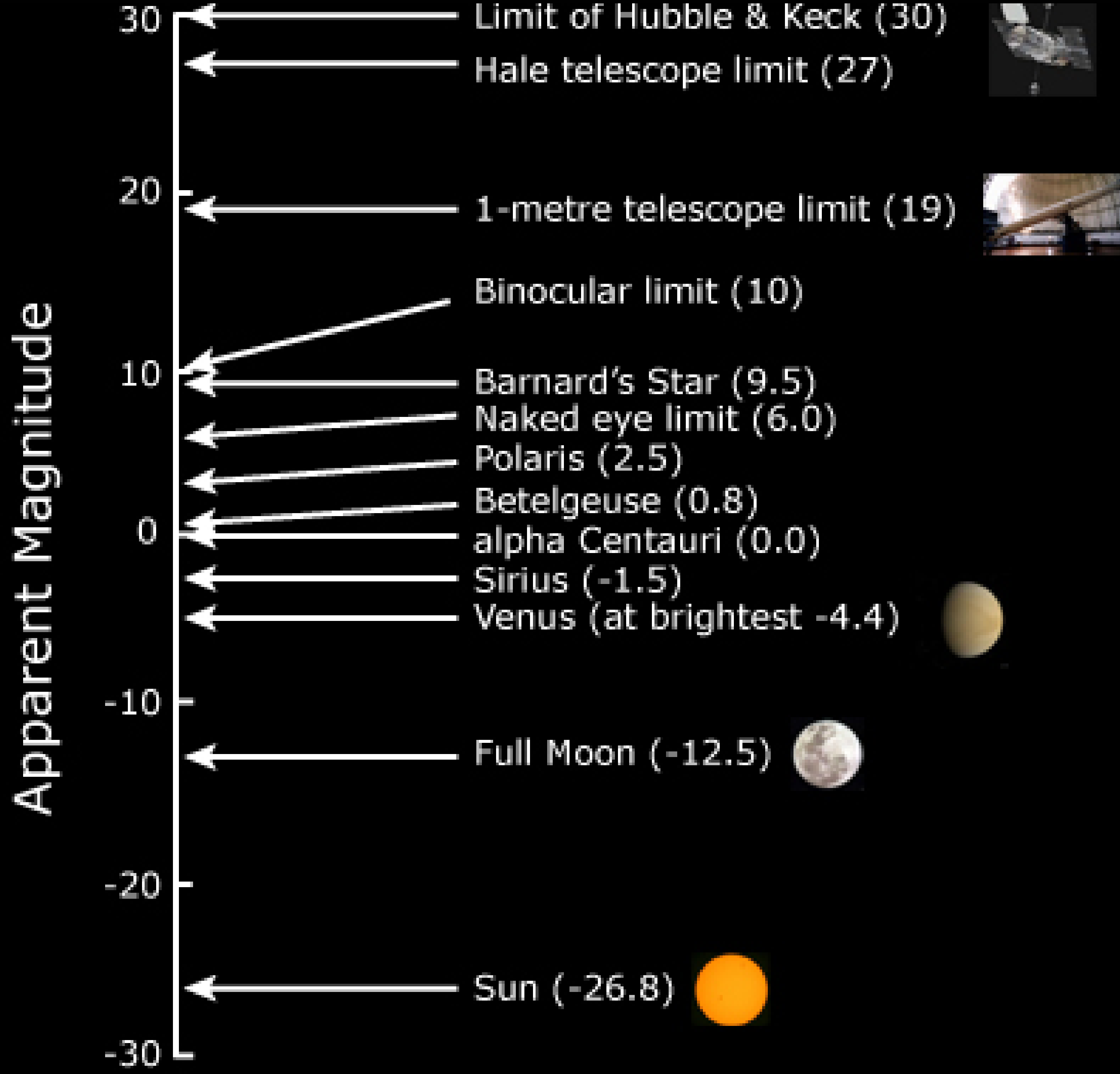
$$I_\odot = 0.137 \text{ watts cm}^{-2} \qquad m_\odot = -26.8$$

$$m_1 - (-26.8) = -2.5 \log\left(I_1 / 0.137 \text{ watts cm}^{-2}\right)$$

For sound: $\mathrm{dB}_1 - \mathrm{dB}_2 = 10\log\left(I_1/I_2\right)$

For light: $m_1 - m_2 = -2.5\log\left(I_1/I_2\right)$

"–" means smaller *m* is brighter!



Apparent Magnitude
30
20
10
0
-10
-20
-30
Limit of Hubble & Keck (30)
Hale telescope limit (27)
1-metre telescope limit (19)
Binocular limit (10)
Barnard's Star (9.5)
Naked eye limit (6.0)
Polaris (2.5)
Betelgeuse (0.8)
alpha Centauri (0.0)
Sirius (-1.5)
Venus (at brightest -4.4)
Full Moon (-12.5)
Sun (-26.8)

Intensity of sun vs. naked eye limit

Sun $m_S = -26.8$

Naked eye limit $m_N = 6$

$$m_S - m_N = -2.5 \log(I_S/I_N)$$

$$-27 - 6 = -2.5 \log(I_S/I_N)$$

$$\cancel{-}33 = \cancel{-}\frac{5}{2} \log(I_S/I_N)$$

$$33 \times \frac{2}{5} = 13 = \log(I_S/I_N)$$

$$10^{13} = I_S/I_N$$

Intensity of Venus vs. Pluto

Venus $m_{♀} = -4$

Pluto $m_p = 15$

$$m_{♀} - m_P = -2.5 \log(I_{♀}/I_P)$$

$$-4 - 15 = -2.5 \log(I_{♀}/I_P)$$

$$\cancel{-}19 = \cancel{-}\frac{5}{2} \log(I_{♀}/I_P)$$

$$19 \times \frac{2}{5} = 8 = \log(I_{♀}/I_P)$$

$$10^8 = I_{♀}/I_P$$

Intensity of Venus vs. Sirius

Venus $m_{♀} = -4$

Sirius $m_S = -1.5$

$$m_{♀} - m_S = -2.5 \log(I_{♀}/I_S)$$

$$-4 - (-1.5) = -2.5 \log(I_{♀}/I_S)$$

$$\cancel{-}2.5 = \cancel{-}2.5 \log(I_{♀}/I_S)$$

$$1 = \log(I_{♀}/I_S)$$

$$10^1 = 10 = I_{♀}/I_S$$

The luminosity of nearby stars?

Measure: intensity of light, I

parallax → distance

$$I = \frac{L}{4\pi R^2}$$

$$\frac{D}{\text{pc}} = \frac{\text{seconds}}{\text{parallax}}$$

$$I = \frac{L}{4\pi R^2}$$

$$-26.8 - m = -2.5 \log\left(0.137 \text{ watts cm}^{-2} / I\right)$$

star	parallax (″)	distance (pc)	apparent magnitude	luminosity (solar)
α Centauri	0.75	1.3	0	1.5
Barnard’s star	0.5	2.0	9.5	0.0005
Sirius	0.4	2.5	-1.5	25
Altair	0.2	5.0	0.8	10
Canopus	0.003	330	- 0.7	200,000
Arcturus	0.1	10	0	90
Betelgeuse	0.01	100	0.5	14,000