the Stars

I. Position and Motion
Parallax, Proper Motion, Redshift

II. Size
Dwarfs, Giants, Stefan-Boltzman

III. Brightness
Magnitude, flux, distance

IV. Color & Temperature
B-*V* index, Spectral Type

V. H-R diagrams
Luminosity Classes

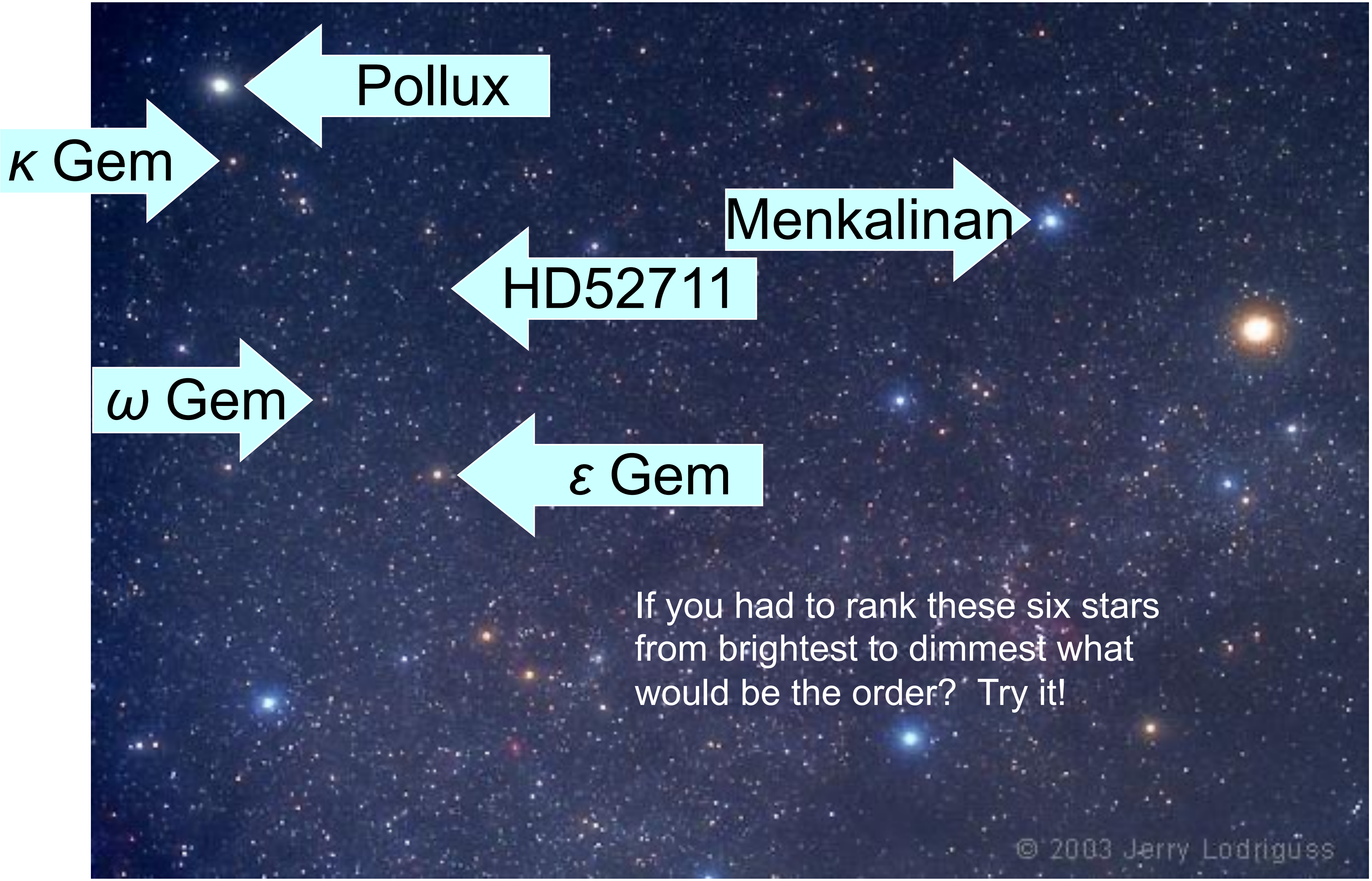
Magnitude

Quantifying Brightness

	The student will be able to:	HW:
1	Define and apply stellar parallax and the unit of the parsec.	1 – 3
2	Relate parallax and the parsec to skinny triangles and other units such as meters and light years.	
3	Define and describe proper motion.	4 – 6
4	Describe and apply methods by which the velocity of a star through space may be determined by including both radial and transverse velocity.	
5	Describe direct and indirect methods used to determine the size of a star and classify stars as giants, supergiants, or dwarfs.	7 – 8
6	State and apply the relation between luminosity, radius, and temperature.	
7	State and apply the relation between luminosity, distance, and energy flux.	9 – 16
8	Define and contrast the concepts: absolute magnitude, intrinsic brightness, luminosity, and apparent magnitude, apparent brightness, energy flux.	
9	Explain and apply the magnitude scale of brightness.	
10	Describe and apply the relation between a stars color and its temperature.	17
11	Define, describe, and apply color index and explain its application in photometry and its relationship to blackbody radiation and Wein's Law.	
12	State in order of temperature the stellar spectral classes and list characteristics and examples of each.	18
13	Describe and define the Hertzsprung-Russell diagram in terms of each axis.	19 – 23
14	Plot a star's coordinates on the H-R diagram.	
15	Explain and illustrate how the H-R diagram is used to help classify and understand different types of stars such as main sequence stars, red giants, blue giants, supergiants, red dwarfs, and white dwarfs.	
16	Define, describe, and give examples of the stellar luminosity classes.	24 – 25
17	Describe and apply the method of spectroscopic parallax and explain the importance of luminosity class to this method.	
18	Describe and explain methods for determining a star's mass and relate to the different types of binary-star systems: visual binary, spectroscopic binary, and eclipsing binary.	26
19	Describe and explain the significance of a star's mass in determining its location on the H-R diagram and in determining the lifetime of the star.	27
20	Describe properties and significance of open clusters and globular clusters.	

Apparent Magnitude

- The **apparent magnitude** of a star (symbol *m*) is a measure of its apparent brightness as seen from Earth.
- The **less** the value of *m*, the **brighter** the star!
- The system was originated by Greek astronomer Hipparchus and was more a ***ranking*** of brightness than a true measure.
- In the original scheme, any star could be ranked from 1 (brightest) to 6 (dimmest).


Pollux
κ Gem
Menkalinan
HD52711
ω Gem
ε Gem
If you had to rank these six stars from brightest to dimmest what would be the order? Try it!
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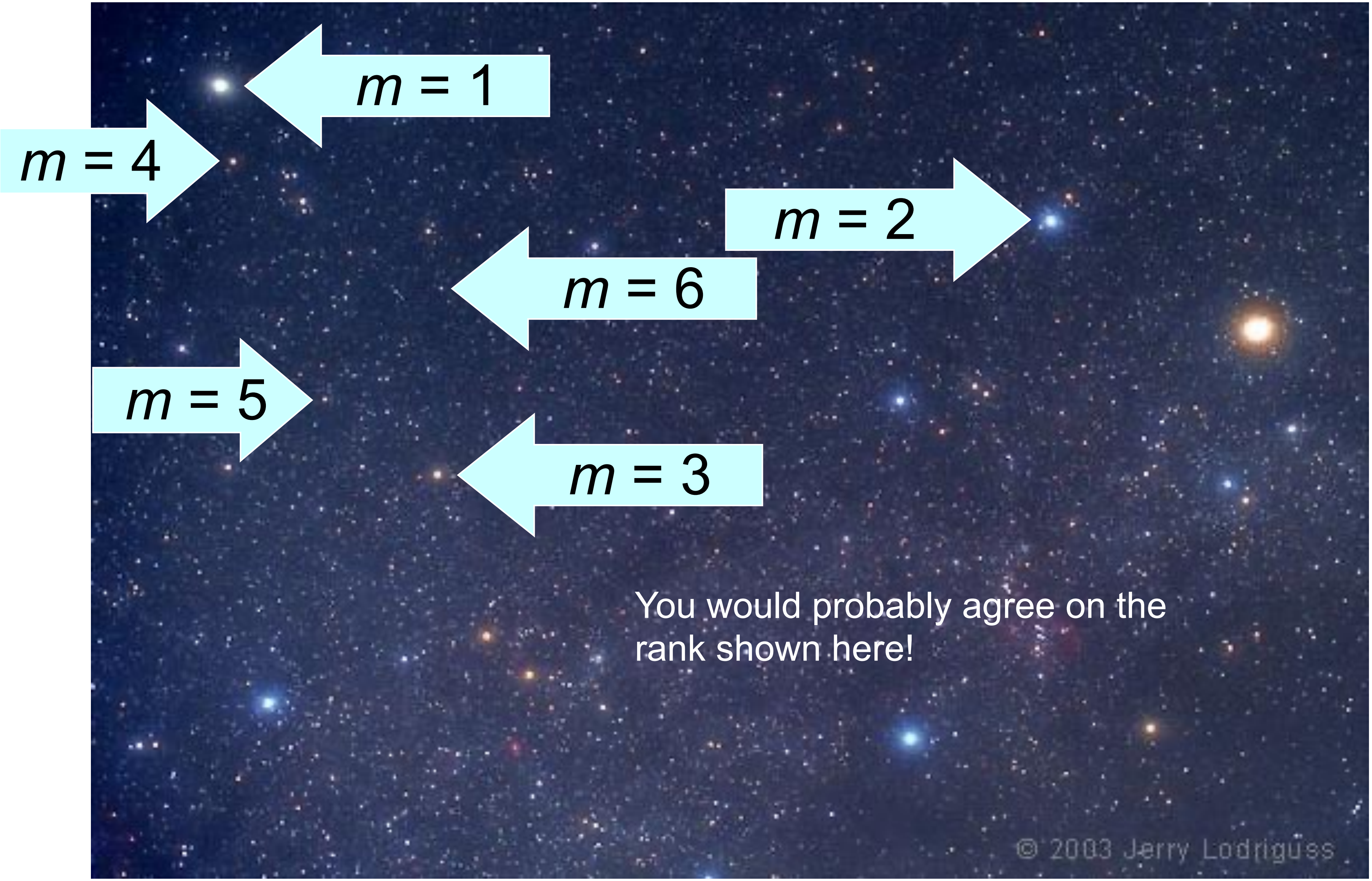
m = 1
m = 4
m = 2
m = 6
m = 5
m = 3
You would probably agree on the rank shown here!
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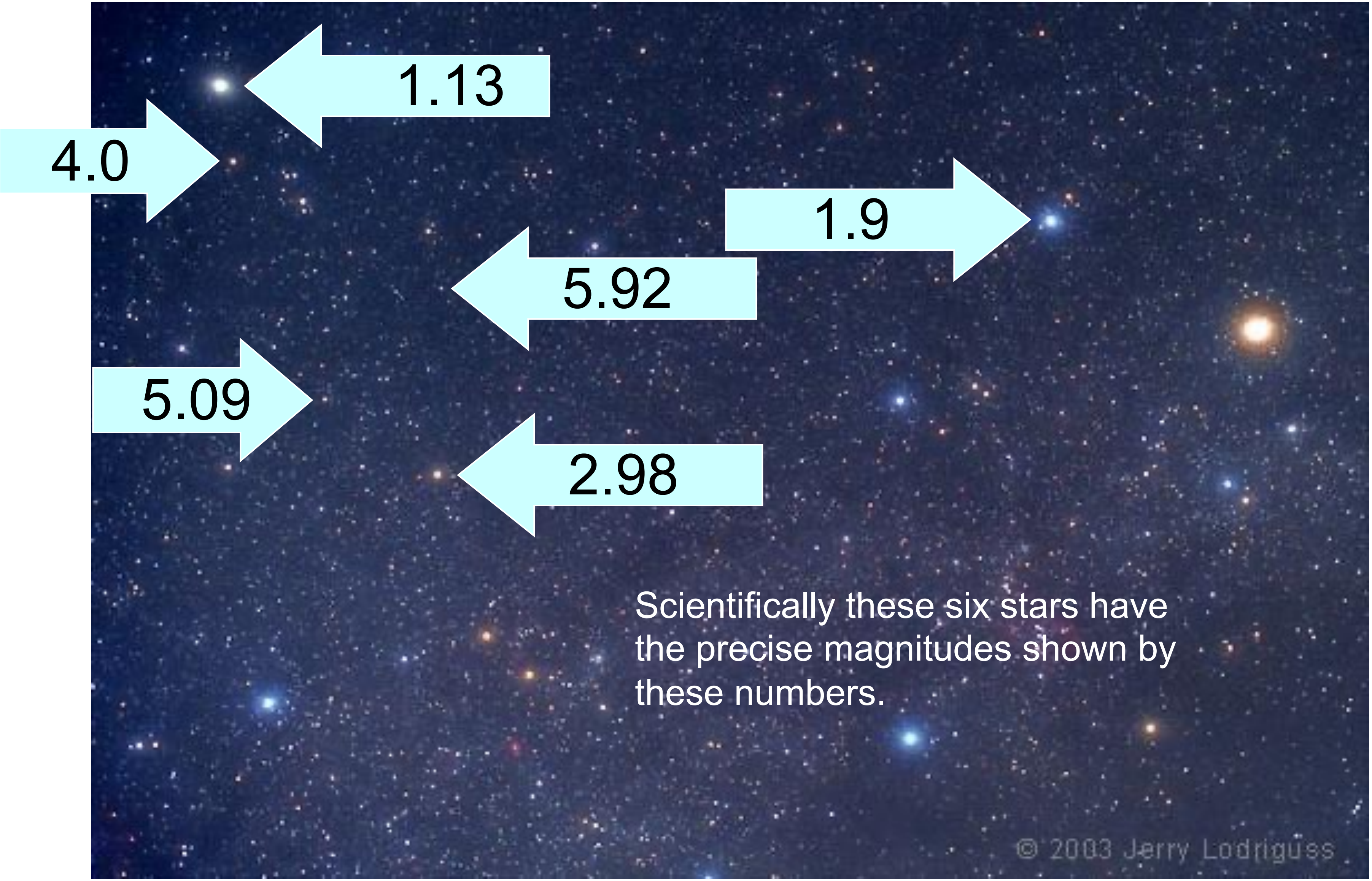
1.13
4.0
1.9
5.92
5.09
2.98
Scientifically these six stars have the precise magnitudes shown by these numbers.
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1
4
6
5
3
2
Use these six stars as references to try and estimate the magnitude of others…
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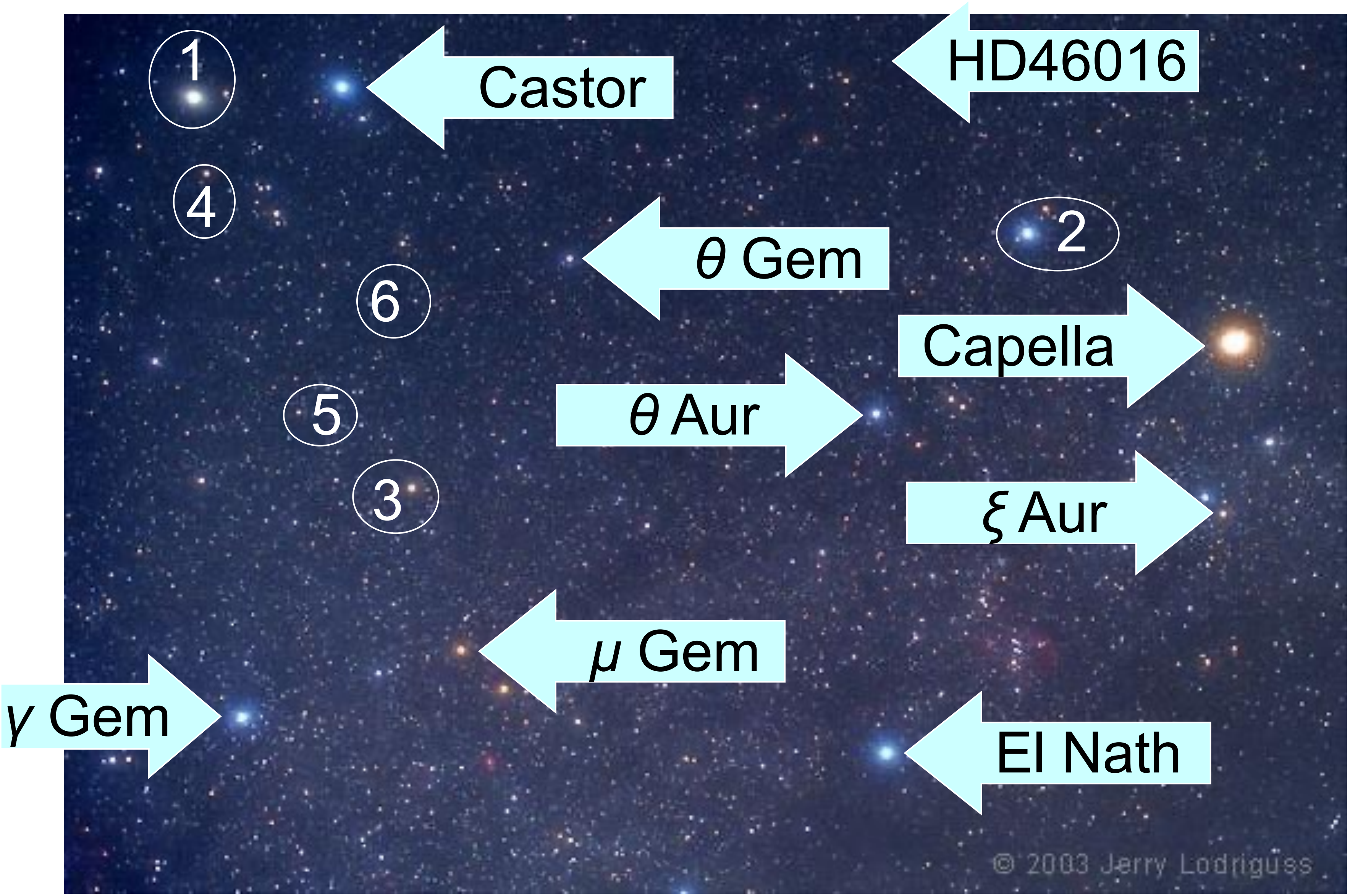

1
Castor
HD46016
4
θ Gem
2
6
Capella
5
θ Aur
3
ξ Aur
μ Gem
γ Gem
El Nath
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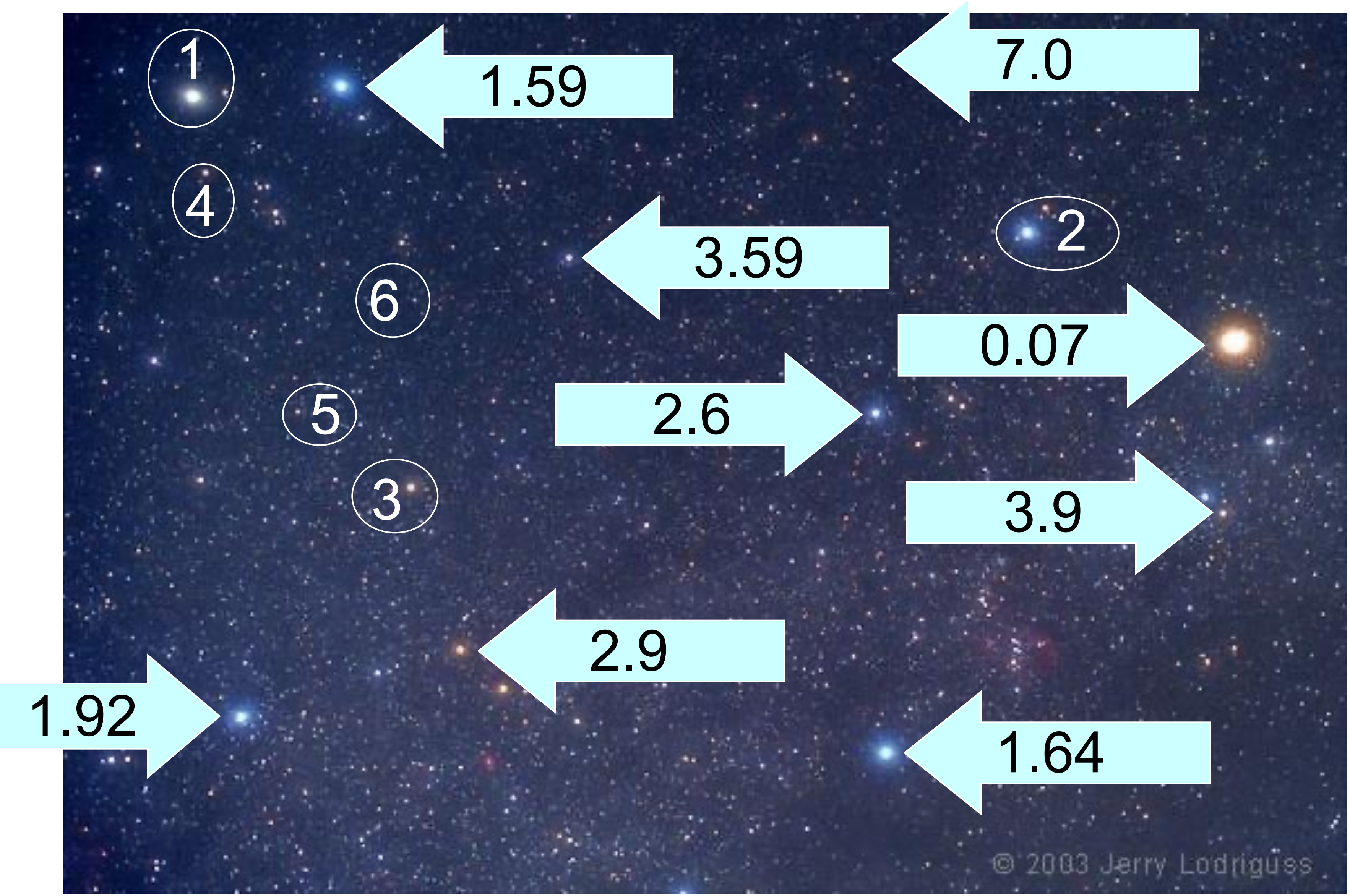
1
1.59
7.0
4
3.59
2
6
0.07
5
2.6
3
3.9
2.9
1.92
1.64
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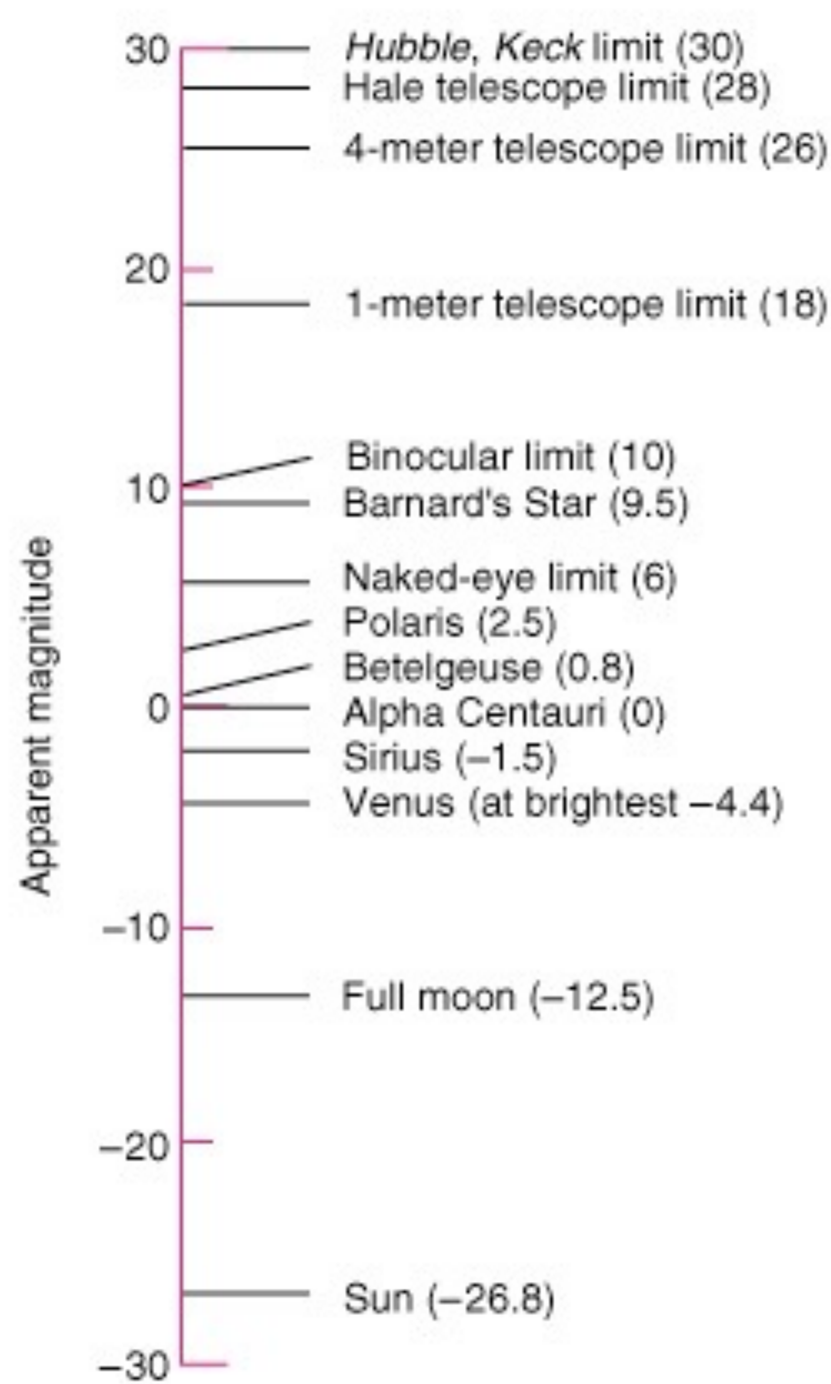
Magnitude Technicalities

- Although originally a ranking of brightness "from first to last", magnitude is now a specific comparison of brightnesses.
- It can be thought of as a measure of dimness.
- An object's magnitude is a specific decimal value that usually falls in the range: $-30 < m < 30$.
- A ***difference*** of 5 on this scale equates to a brightness ***factor*** of 100.


Apparent magnitude
30
20
10
0
−10
−20
−30
Hubble, *Keck* limit (30)
Hale telescope limit (28)
4-meter telescope limit (26)
1-meter telescope limit (18)
Binocular limit (10)
Barnard's Star (9.5)
Naked-eye limit (6)
Polaris (2.5)
Betelgeuse (0.8)
Alpha Centauri (0)
Sirius (−1.5)
Venus (at brightest −4.4)
Full moon (−12.5)
Sun (−26.8)

Magnitude Examples

- A magnitude 1 star is ______ times brighter than a magnitude 6 star.
- A magnitude 2 star is ______ times brighter than a magnitude 7 star.
- A magnitude 7 star is 100 times brighter than a magnitude ______ star.
- A magnitude ______ star is 100 times brighter than a magnitude 5 star.

Magnitude Examples

- A magnitude 1 star is __100__ times brighter than a magnitude 6 star.
- A magnitude 2 star is __100__ times brighter than a magnitude 7 star.
- A magnitude 7 star is 100 times brighter than a magnitude __12__ star.
- A magnitude __0__ star is 100 times brighter than a magnitude 5 star.

Magnitude Examples

- A magnitude 0 star is ______ times brighter than a magnitude 10 star.
- A magnitude 0 star is __________ times brighter than a magnitude 15 star.
- A magnitude 0 star is ___________________ times brighter than a magnitude 30 star.
- A magnitude −27 star is ___________________ times brighter than a magnitude 3 star.

Magnitude Examples

- A magnitude 0 star is 10000 times brighter than a magnitude 10 star.
- A magnitude 0 star is 1,000,000 times brighter than a magnitude 15 star.
- A magnitude 0 star is 1,000,000,000,000 times brighter than a magnitude 30 star.
- A magnitude −27 star is 1,000,000,000,000 times brighter than a magnitude 3 star.

What if difference is 1 (not 5)?

- By definition, every 5 steps on the magnitude scale is a factor of 100.
- Therefore every one step on the magnitude scale is a factor of: ***the fifth root of 100 !***

$$\sqrt[5]{100} = 2.512$$

$$2.512^5 = 100$$


1
4
2
6
5
2.512 times brighter than 6
3
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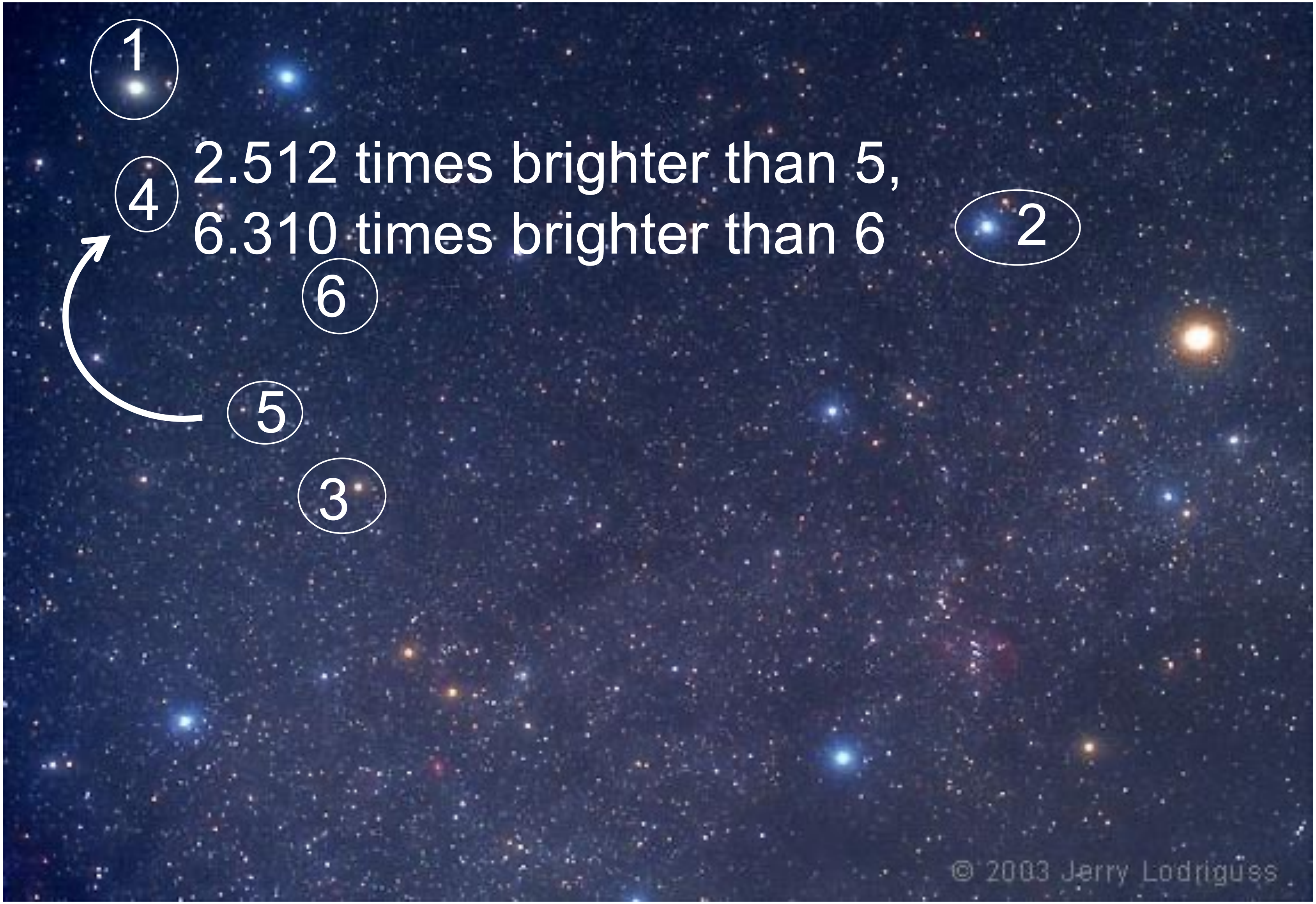
1
2.512 times brighter than 5,
6.310 times brighter than 6
4
2
6
5
3
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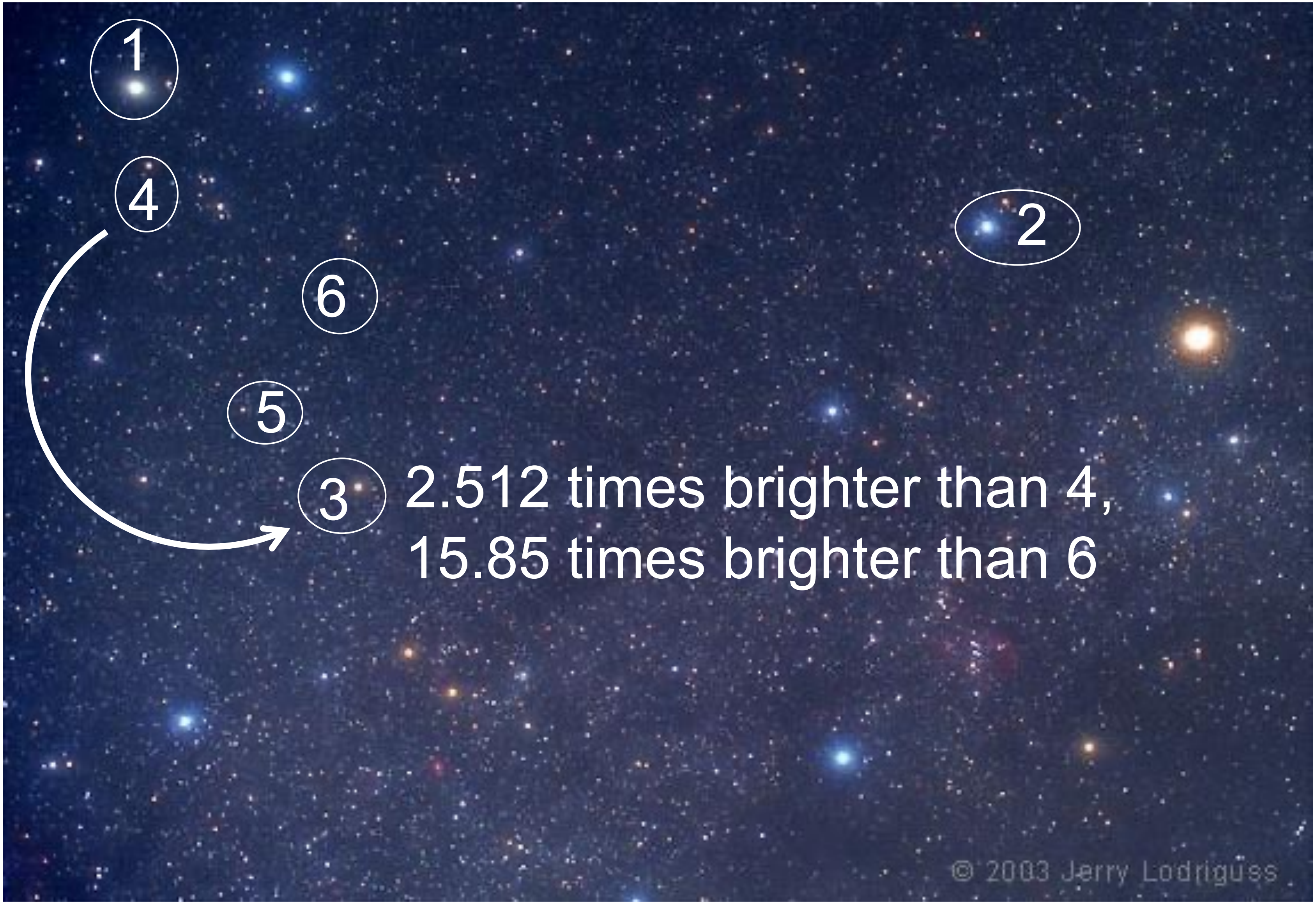
1
4
2
6
5
3
2.512 times brighter than 4,
15.85 times brighter than 6
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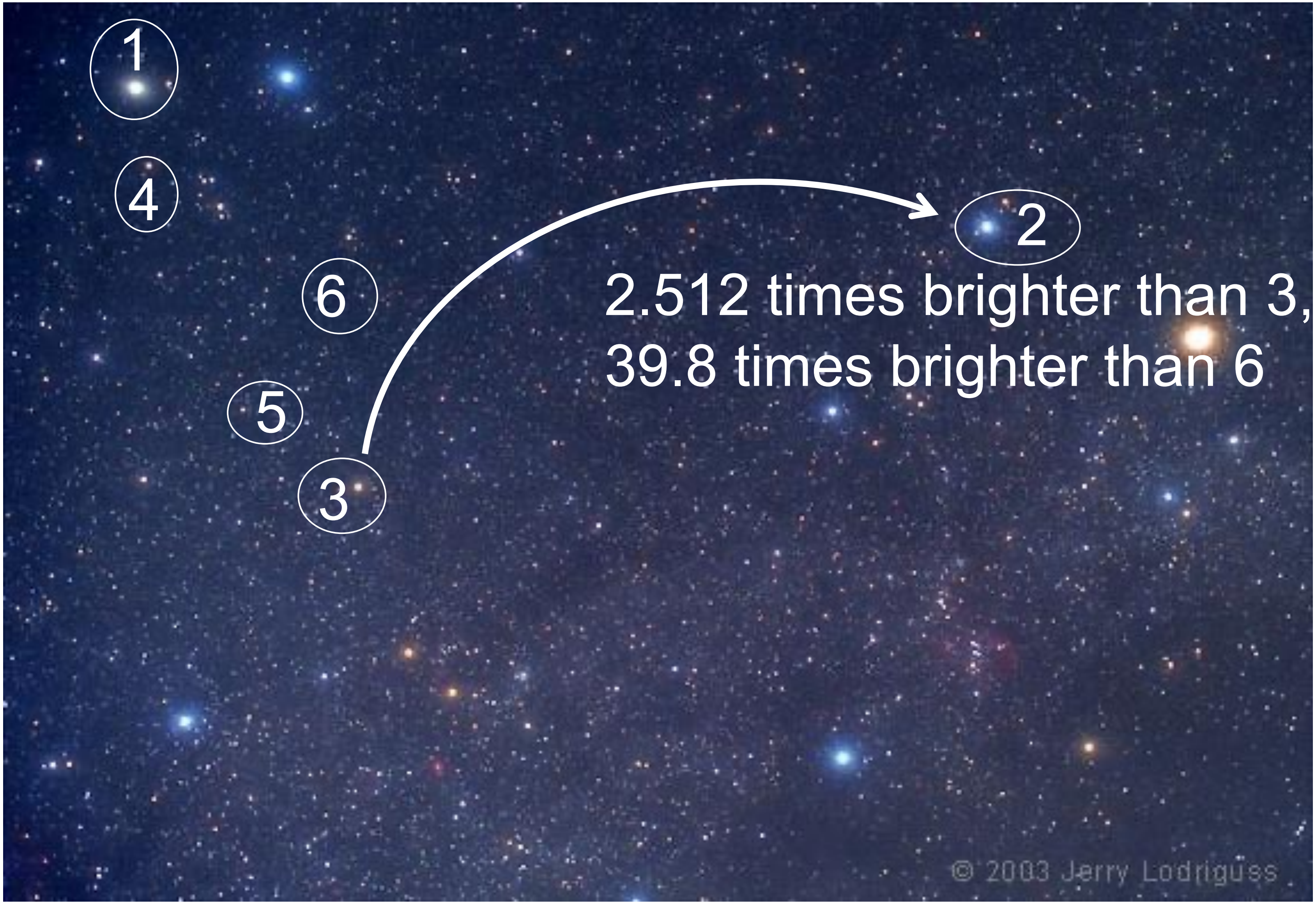

1
4
6
5
3
2
2.512 times brighter than 3,
39.8 times brighter than 6
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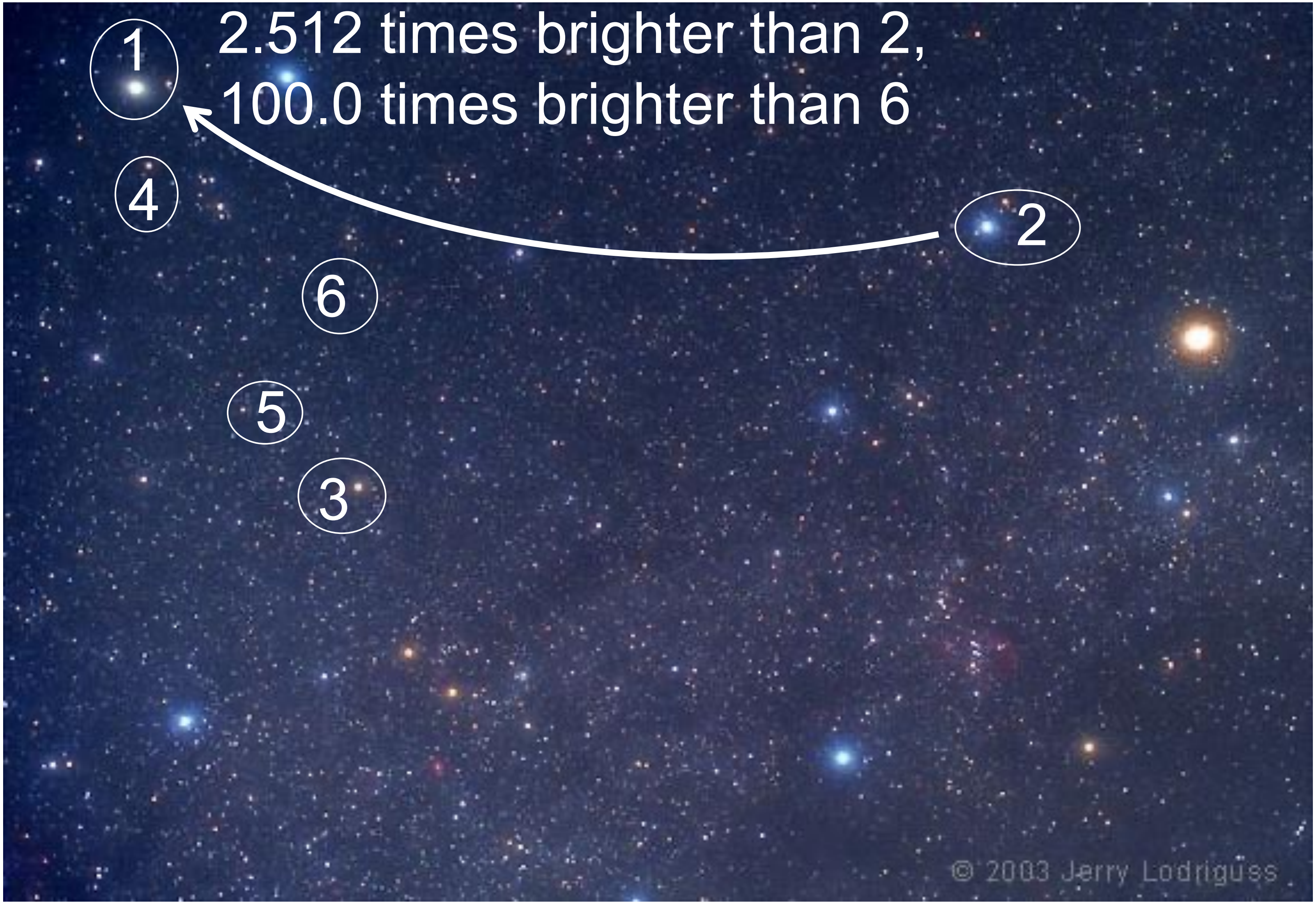


2.512 times brighter than 2,
100.0 times brighter than 6
1
2
3
4
5
6
© 2003 Jerry Lodriguss

Many problems can be solved by using a "brightness factor" given by:

$$2.512^{m_1 - m_2}$$

Tip: always subtract in an order so that $m_1 - m_2$ is positive and then use the factor in a logical way!

Magnitude Examples

- A magnitude 1 star is ______ times brighter than a magnitude 2 star.
- A magnitude 8 star is _____ times _______ than a magnitude 1 star.
- A magnitude –1.5 star is ______ times ________ than a magnitude 1.7 star.
- A magnitude 0.0 star is ______ times ________ than a magnitude –0.5 star.

Magnitude Examples

- A magnitude 1 star is <u>2.512</u> times brighter than a magnitude 2 star.
- A magnitude 8 star is <u>631</u> times <u>dimmer</u> than a magnitude 1 star.
- A magnitude –1.5 star is <u>19.1</u> times <u>brighter</u> than a magnitude 1.7 star.
- A magnitude 0.0 star is <u>1.58</u> times <u>dimmer</u> than a magnitude –0.5 star.

Logarithmic Scales

- One advantage of a logarithmic scale (like stellar magnitude) is that a relatively small range of scale values describes a very large range of absolute numerical quantities.
- Decibels of sound – every difference of 10 is a factor of 10 in intensity (difference of 3 ≈ 2 times louder).
- Seismic magnitude – difference of 1 is factor of $10^{1.5} \approx 32$ times the energy (difference of 2 = 1000 times the energy).
- Musical chromatic scale – difference of 12 is factor of 2 (difference of 1 is 12^{th} root of 2).

actually

Which is a brighter star –
a magnitude 7 star or a magnitude 0 star?

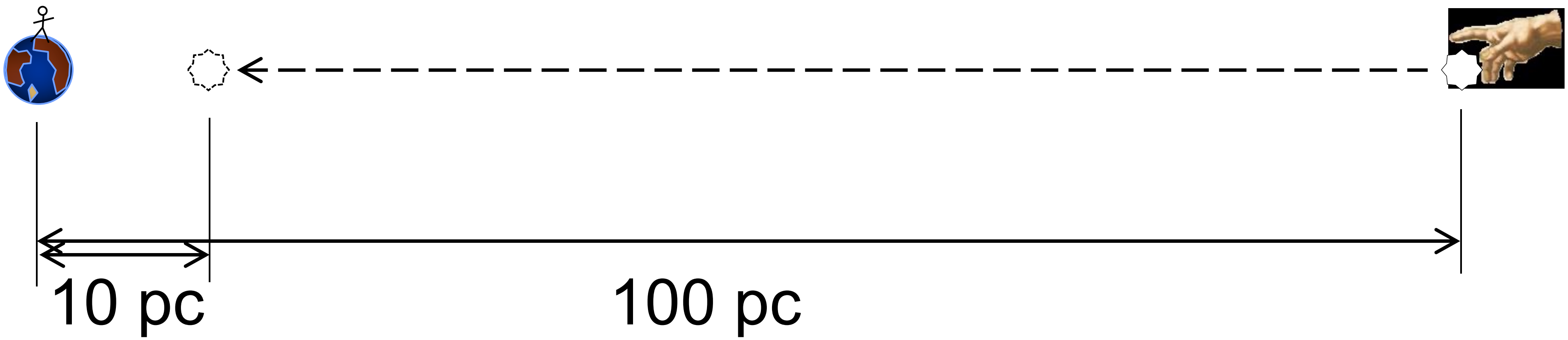
It depends!

Do we mean how bright it *appears*
or how bright it really *is*?

Absolute Magnitude

- The farther away a star is located, the dimmer it will appear. The closer a star is located, the brighter it will appear.
- The apparent magnitude of a star is therefore dependent on its distance.
- In order to make “fair” comparisons astronomers define **absolute magnitude** as the magnitude of a star when viewed from a distance of 10 pc.
- Absolute magnitude allows us to compare the actual intrinsic brightness of the stars.

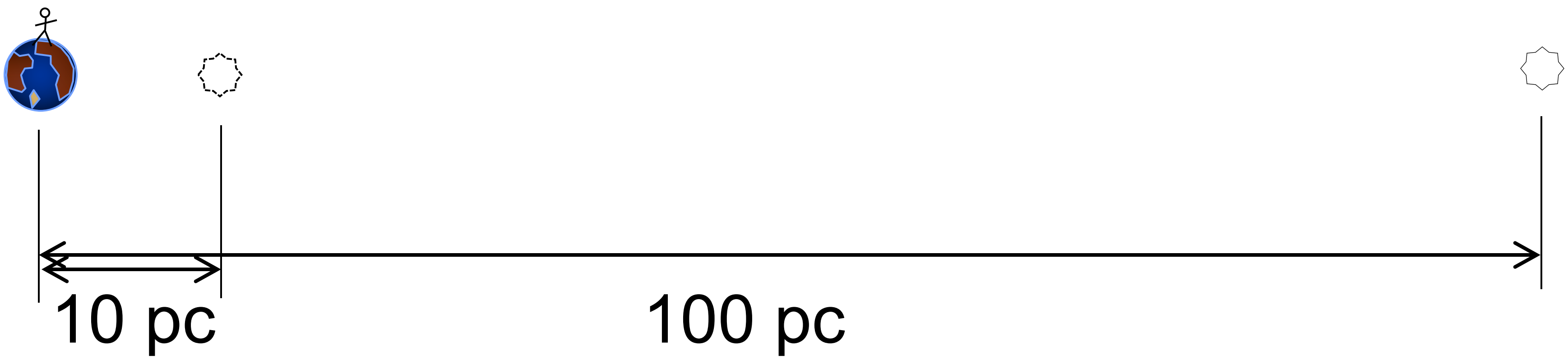
What is the *absolute* magnitude of a star with *apparent* magnitude $m = 7$, $d = 100$ pc?



To answer this question, imagine you could pick it up and move it closer until it is only 10 pc away. It would look a lot brighter at that distance and it would have magnitude 10 **IF** it were that far away. Therefore the absolute magnitude $M = 10$.

Absolute Magnitude

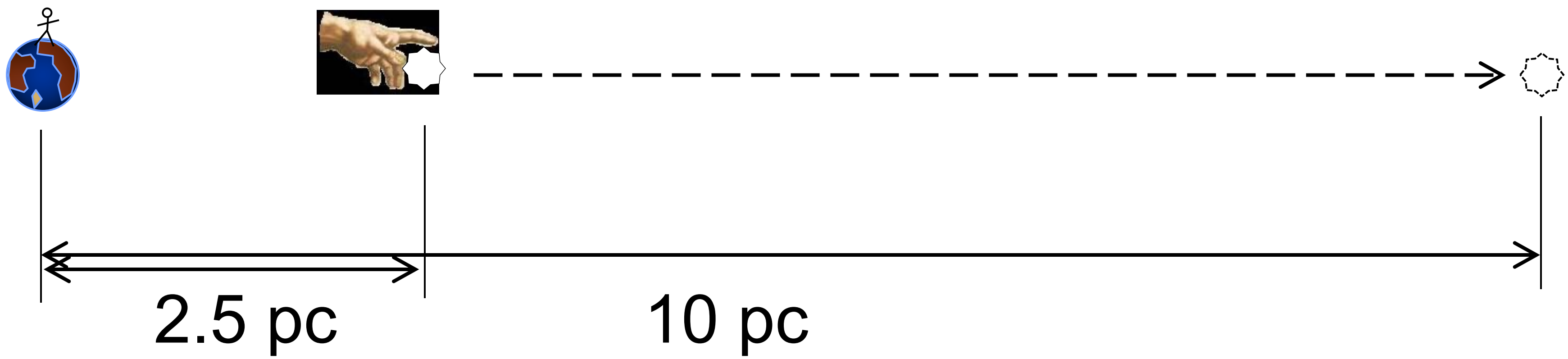
Apparent Magnitude



$M = 2$
(how it *would* appear at 10 pc)

$m = 7$
(how it *actually* appears at its true distance)

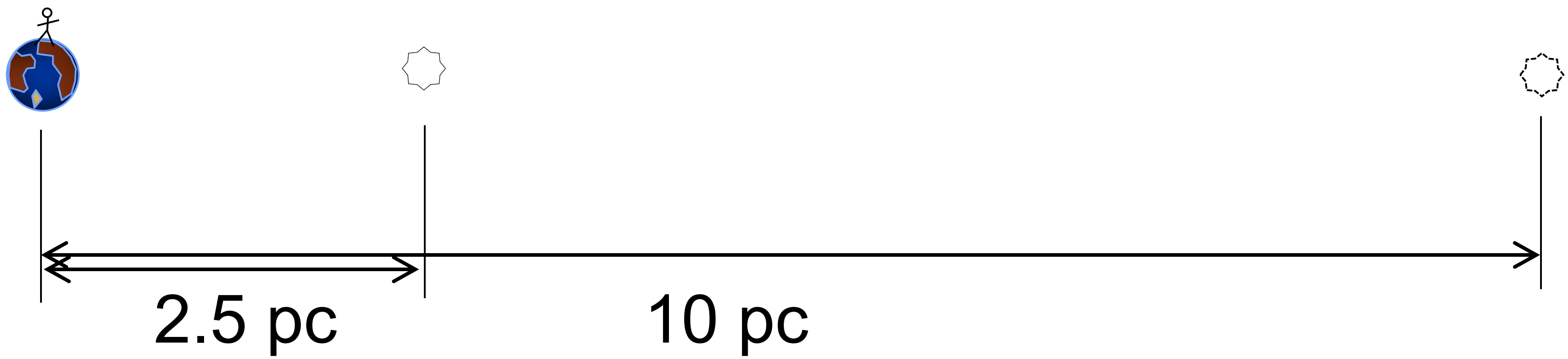
What is the *absolute* magnitude of a star with *apparent* magnitude $m = 0$, $d = 2.5$ pc?



To answer this question, imagine you could pick it up and move it away until it is now 10 pc away. It would look a lot dimmer at that distance and it would have magnitude 3 **IF** it were that far away. Therefore the absolute magnitude $M = 3$.

Apparent Magnitude

Absolute Magnitude

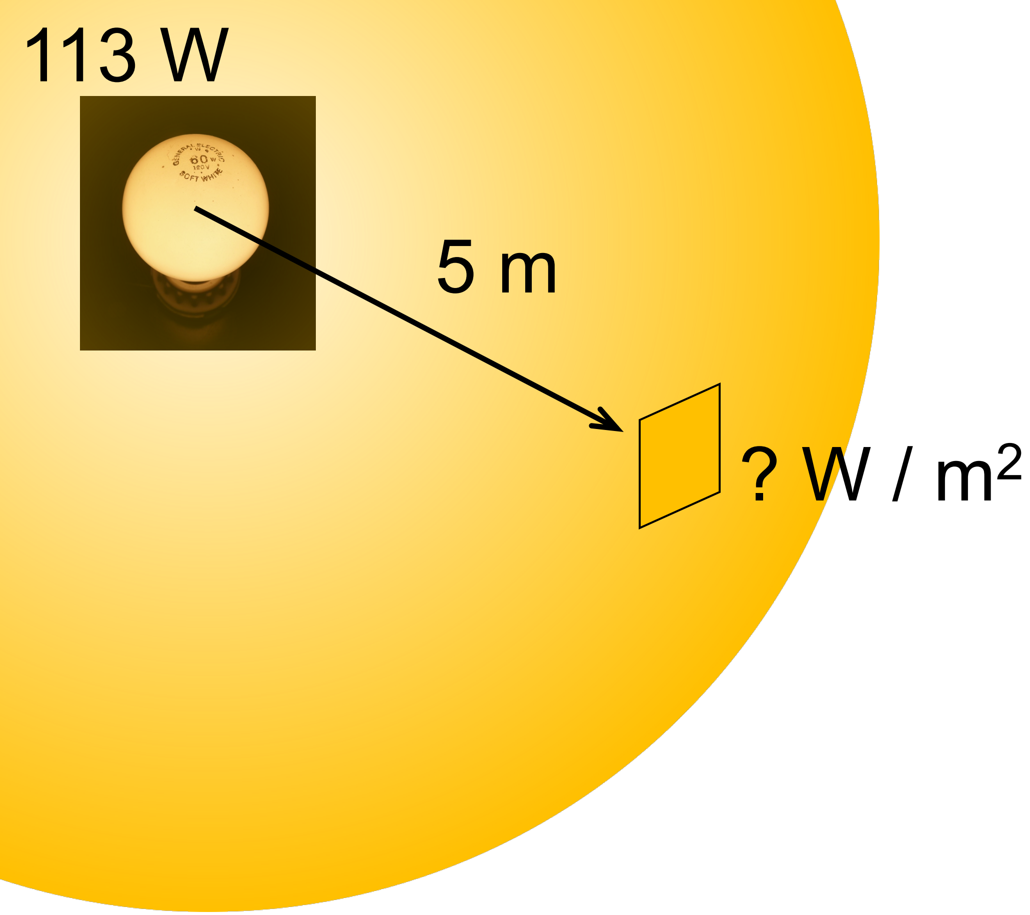


$m = 0$
(how it *actually* appears at its true distance)

$M = 3$
(how it *would* appear at 10 pc)

Distance Related to *m* and *M*

- The total power output of a star influences how bright it looks to us; the more luminous it is the brighter it appears.
- But, the distance is also a factor; the farther it is the dimmer it will appear.
- If a star's apparent and absolute magnitudes are known its distance can be determined from these two numbers…

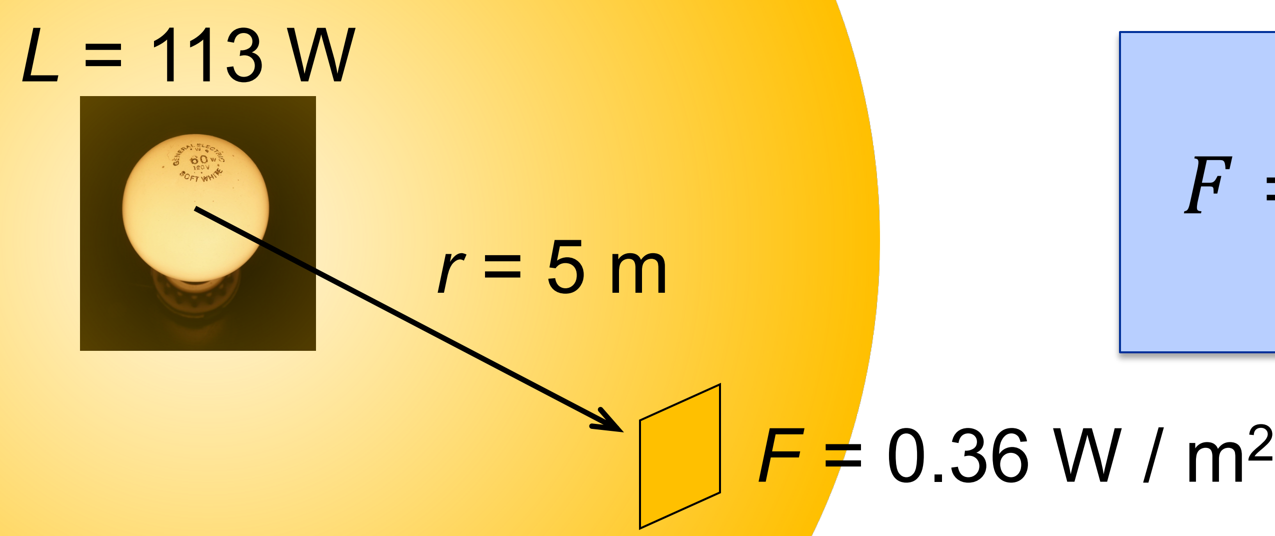


$$F = \frac{L}{4\pi r^2}$$

F = flux
L = luminosity
r = distance

Apparent Brightness vs. Distance

Apparent Brightness vs. Distance

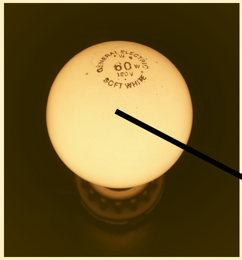


$$F = \frac{L}{4\pi r^2}$$

r (m)	F (W/m^2)
5	0.36
10	0.09

Apparent Brightness vs. Distance

L = 113 W



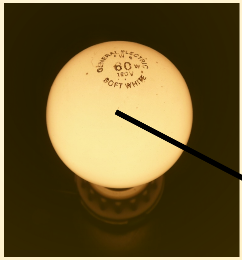
r = 10 m

$$F = \frac{L}{4\pi r^2}$$

F = 0.09 W / m^2

r (m)	F (W/m^2)
5	0.36
10	0.09

L = 113 W



$$F = \frac{L}{4\pi r^2}$$

r = 15 m

r (m)	F (W/m^2)
5	0.36
10	0.09
15	0.04

F = 0.04 W / m^2

Apparent Brightness vs. Distance

Inverse Square Law

- As distance to a source of light increases the intensity of its light decreases in proportion to the distance squared.
- A star's apparent brightness is directly proportional to its luminosity and inversely proportional to its distance squared.
- The greater the difference in apparent and absolute magnitudes the greater the distance to the star…

Practice With Inverse Square

1. Star A is the same luminosity as Star B but it is twice as far away. Which star appears brighter and by what factor?
2. Sunlight at Earth has intensity 1380 W/m^2. What is the approximate intensity of sunlight at Saturn, which is about 10 A.U. from the Sun?
3. Two stars appear to be the same brightness, but Star C is 3 times farther away than Star D. Which star is more luminous and by what factor?

Practice With Inverse Square

4. Stars E and F have the same luminosity. Star E is 25 pc away and Star F is 300 pc away. Which star appears brighter and by what factor?
5. Sunlight at Earth has intensity 1380 W/m^2. What is the approximate intensity of sunlight at Venus, which is 0.72 A.U. from the Sun?
6. Star G is 5 pc away and appears 100 times brighter than Star H. If the two stars have the same intrinsic brightness, how far away is Star H?

$$\left(\frac{d}{10}\right)^2 = 2.512^{m-M}$$

where: m = apparent magnitude

M = absolute magnitude

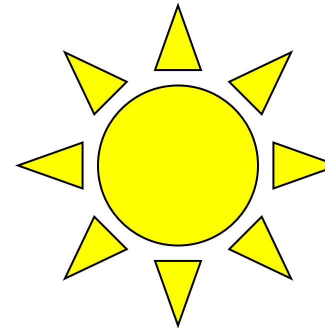
d = distance in parsecs

How to Get Rid of Magnitude

- If astronomers wanted to ditch the magnitude system it would be possible to simply <u>measure</u> brightness.
- Instead of "apparent magnitude" there would be "luminous flux" in watts per square meter.
- Instead of "absolute magnitude" there would be "luminosity" in watts.

Flux:
1380 W/m²

$$F = \frac{L}{4\pi r^2}$$



Luminosity:
3.9×10^{26} W

apparent magnitude:
$m = -26.8$

$$\left(\frac{d}{10}\right)^2 = 2.512^{m-M}$$

absolute magnitude:
$M = 4.85$