Welcome to Phys 321
Astronomy & Astrophysics II

Course Instructor:

Prof. Bin Chen

Tiernan Hall 101

bin.chen@njit.edu

NJIT Astronomy Courses

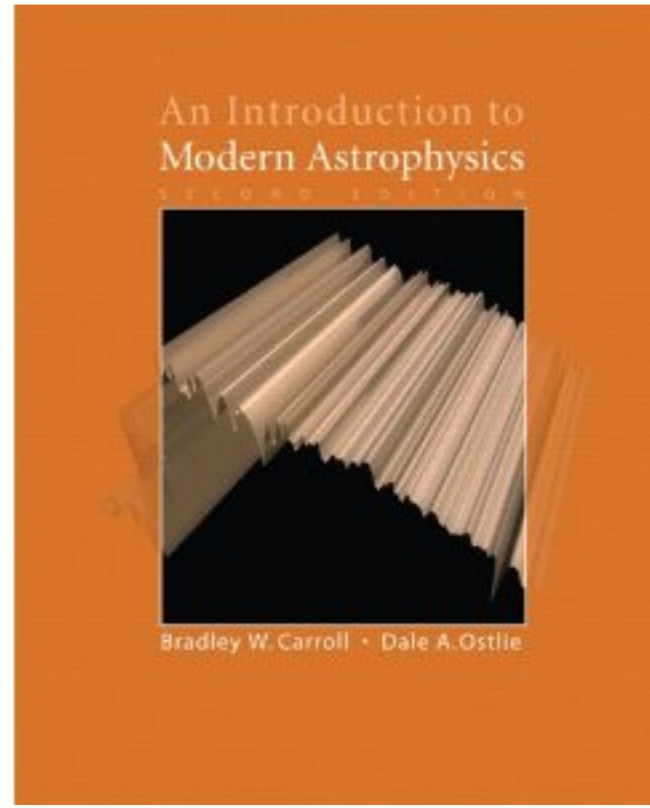
- The Physics Department has an **undergraduate minor and a concentration in Astronomy**, which includes the following courses:
  - Phys 202, 202A − Intro to Astronomy and Cosmology
  - Phys 203, 203A – The Earth in Space
  - Phys 320 – Astronomy & Astrophysics I (last semester)
  - <u>**Phys 321 – Astronomy & Astrophysics II (this course)**</u>
  - Phys 322 – Observational Astronomy
  - Phys 420 – Special Relativity
  - Phys 421 – General Relativity
  - Phys 444 – Fluid and Plasma Dynamics

Course Theme

- Use the physical laws and forces that govern our everyday lives
  - Gravity, electricity & magnetism…
- To understand the cosmos
- Use physics and math to quantitatively determine the physical properties of astrophysical objects
  - Planets, stars, galaxies, clusters of galaxies, and the Universe

Course Information: Material

- MW 11:30 am–12:55 pm. KUPF 208
- Textbook: "**An Introduction to Modern Astrophysics**", 2nd Edition, by Carroll and Ostlie (the same book as Phys320)
- Topics include stars, galaxies, and the Universe
- Discussed in chapters 3, 5, 8, 9, 10, 12, 13, 15, 16, 17, 18, 24, 25, 26, 27, 28, and 29 of the textbook.



Science and Math Disclaimer

- This is astrophysics course using quantitative methods, NOT just general descriptive astronomy
- We use mostly freshman/sophomore physics (physics I, II, III) and calculus
- We will also introduce some very basic quantum physics and relativity
- Be prepared for quite some computation in HWs, quizzes, and exams

Course Information: Homework

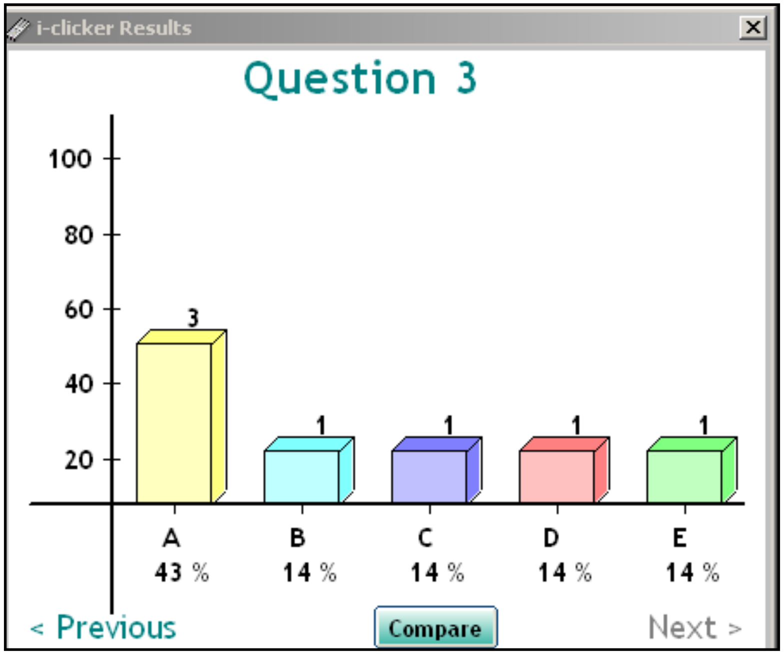
- About one set a week, given Monday/Wednesday after the lecture
- Okay to work in **small** groups (<=2). But must be open and acknowledge who you have worked with. In all cases, you have to write answers clearly in your own words.
- Due in a week (the following Monday/Wednesday) at the **start** of the class
- **Late** submissions will have grades **reduced by 50%**. All assignments **must** be turned in by **4/30** to receive any credit.

Class participation: iClicker quizzes

- iClicker is **required** as part of the course
  - Similar to requiring a textbook for the course
  - Can be purchased/rented at the NJIT bookstore
  - Can't share with your classmate
- iClicker use will be integrated into the course
  - To be used during most or all lectures/discussions
  - iClicker questions will be worked into subject matter
- Watch out for slides with **an iClicker symbol**
- Each lecture will have some iClicker questions
- You will receive both participation and performance credits, which constitute 20% of the final grade
- We will start to use it from the ***second*** week (Wed 1/24)

How will we use the i-Clicker?

- I post questions on the slide during lecture.
- You answer using your i-Clicker remote.
- I can display a graph with the class results on the screen.
- We discuss the questions and answers.
- You can get points (for participating and/or answering correctly)! These will be recorded (e.g., for quizzes and attendance).



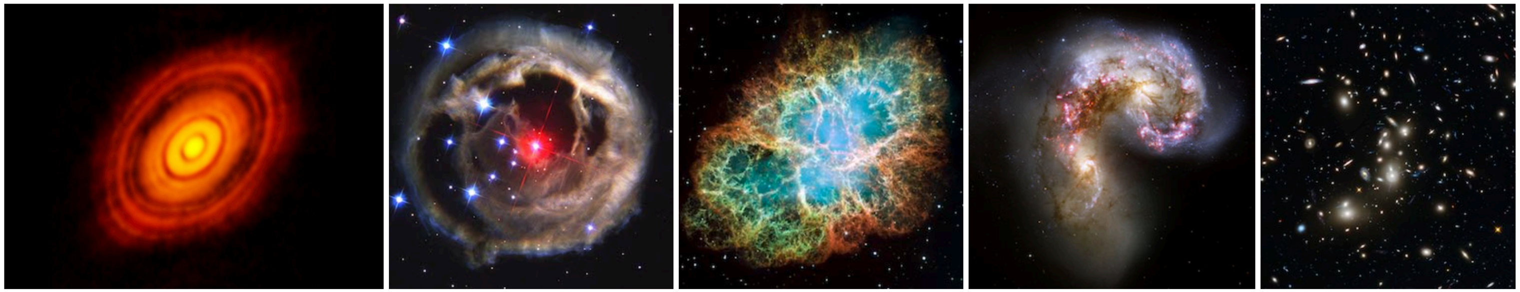
Class Information: Grading

- Homework (20%)
- Class participation and quizzes (20%)
- Two in-class exams (15% each, 30% total)
- Final Exam (30%)
  - Sometime TBD in May 4–10
- Conversion chart to letter grade

A	>85
B+	>75-85
B	>65-75
C+	>55-65
C	50-55
D, F < 50	

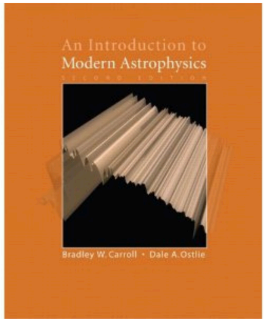
Course Website: https://web.njit.edu/~binchen/phys321

PHYS 321 - Astronomy & Astrophysics II Spring 2018



Course Information

- **Instructor:** Prof. Bin Chen
- **Email:** bin.chen at njit dot edu
- **Class Time:** Mondays and Wednesdays 11:30 am—12:55 pm
- **Classroom:** Kupfrian Hall, Room 208
- **Office Hours:** Wednesdays 01:00-03:00 pm, in Tiernan Hall Room 101
- **Textbook:** Introduction to Modern Astrophysics, 2nd Edition, Carroll & Ostlie (same textbook as Phys 320).
- **Homework:** Assigned approximately every week. Collected at the *beginning* of the lecture in the following week.
- **Exams:** One midterm exam and one final exam.
- **Grades:** Your grade will be based on your homework (30%), attendance and class participation (20%), One mid-term exam (20%), and final exam (30%).
- **Syllabus**: Download PDF

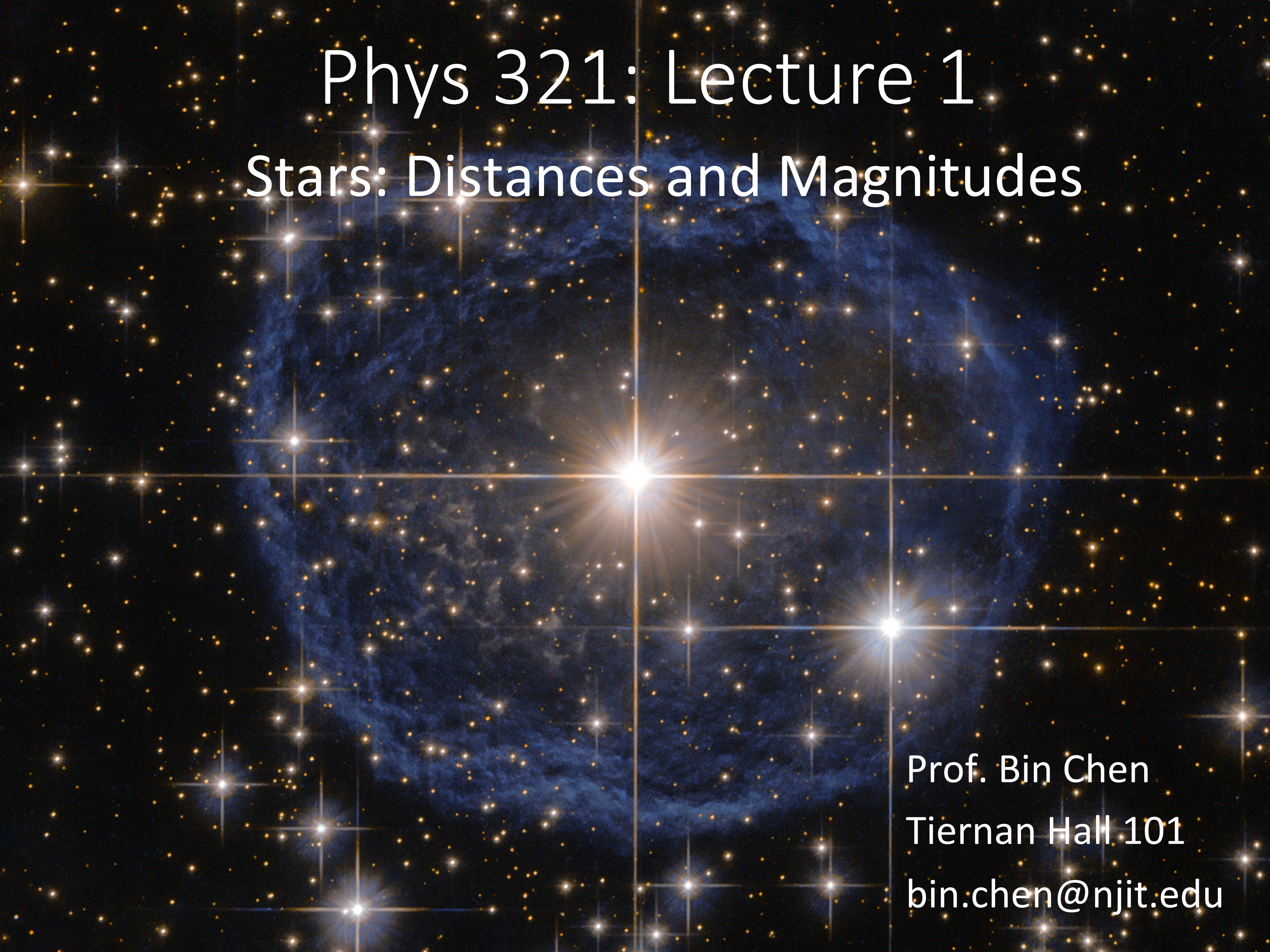


Course Schedule and Lecture Notes

WEEKS		TOPICS	TEXT STUDIES	HOMEWORK ASSIGNMENT
Week 1:	1/17	Stars: Distances and Magnitudes	Chapt 3, Section 1, 2	TBD
Week 2:	1/22	Light, Blackbody Radiation, and Color	Chapt 3, Section 3, 4, 5, 6	TBD
Week 3:	1/29	The Interaction of Light and Matter	Chapt 5	TBD

Phys 321: Lecture 1

Stars: Distances and Magnitudes



Prof. Bin Chen
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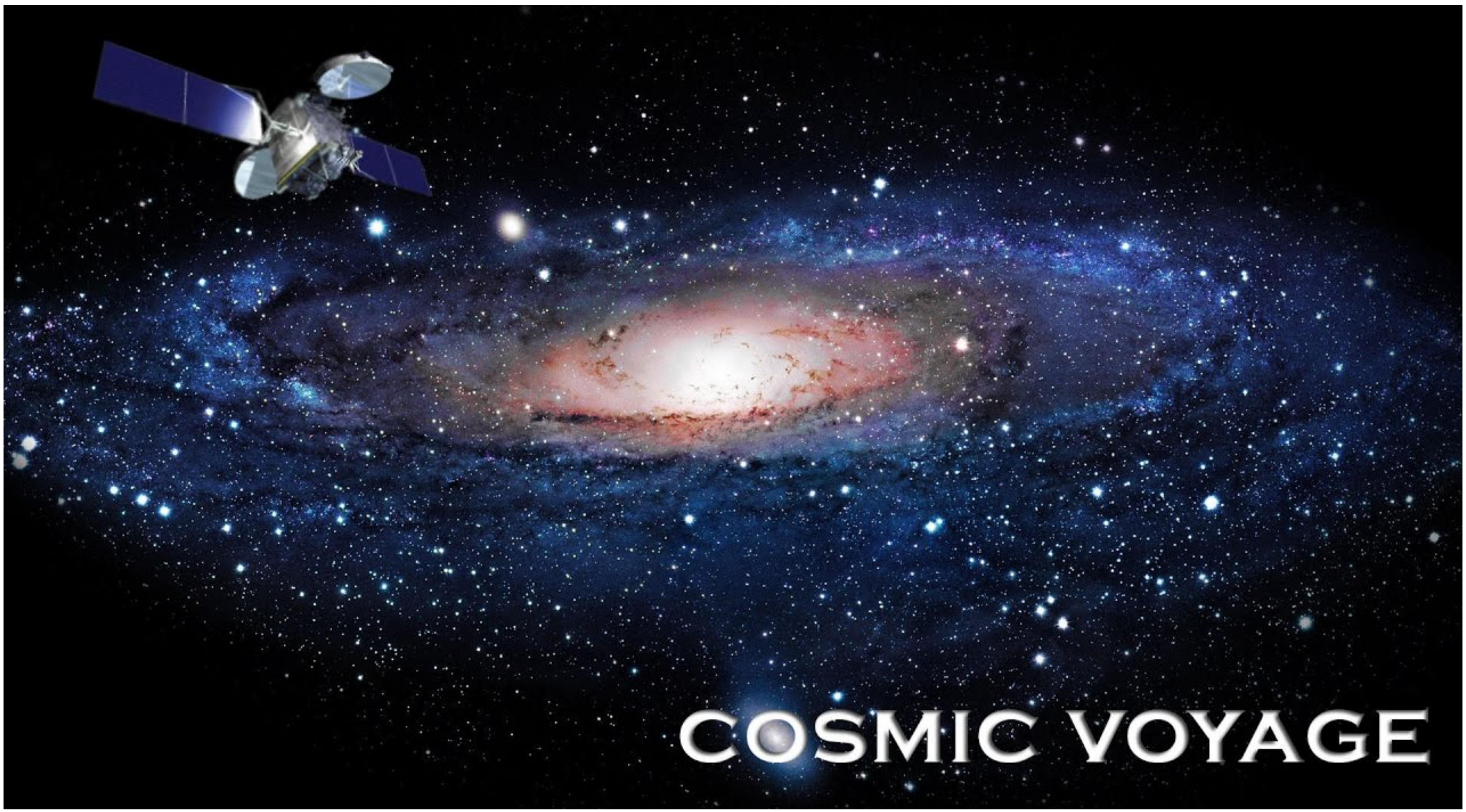
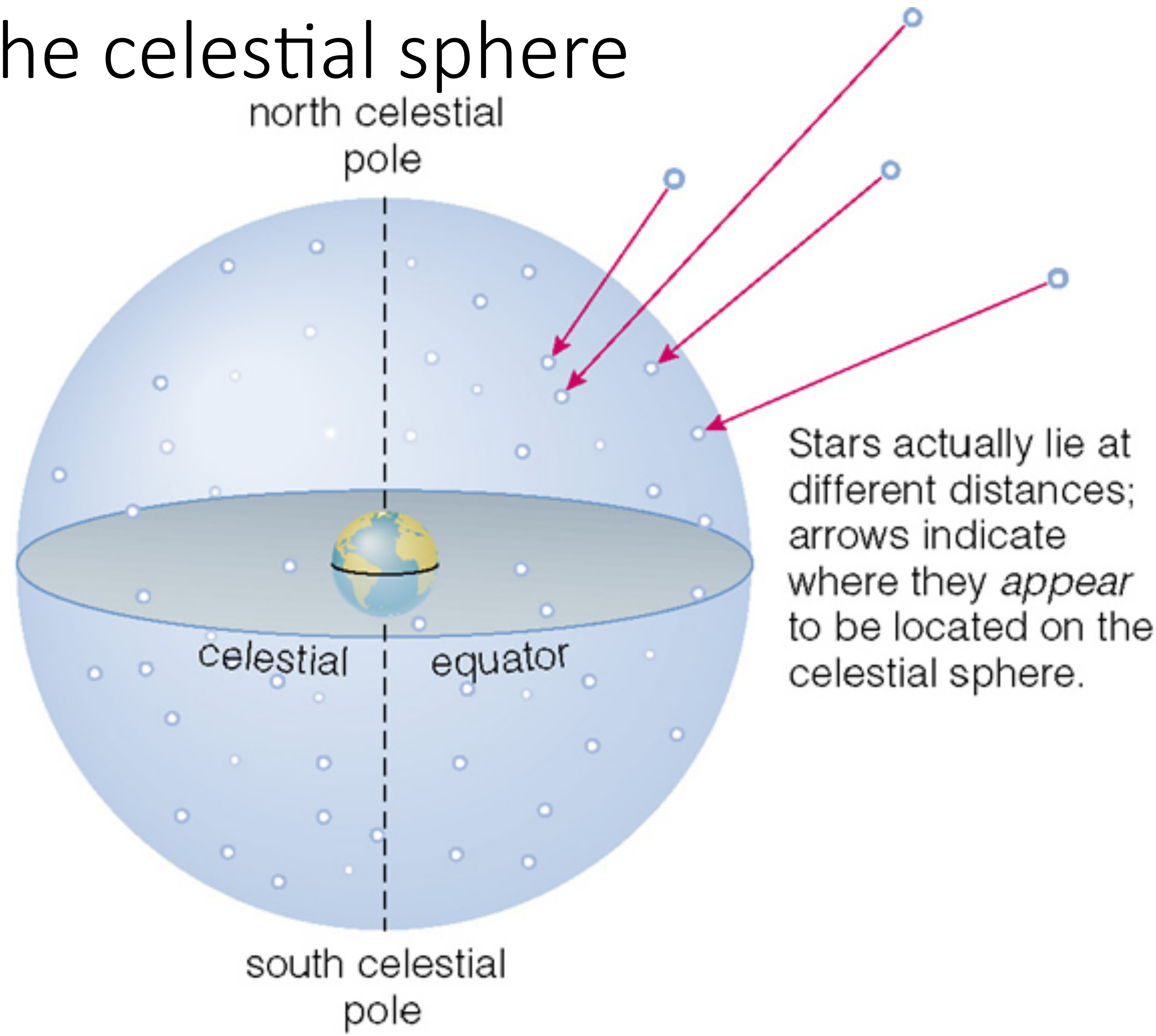
Cosmic Voyage: The Power of Ten



The celestial sphere



How to measure distance

- Direct measurements
  - Using a standard ruler
  - Reflection of laser light/waves
- Indirect measurements
  - Angular size assuming a known physical size
  - Stereoscopic vision

Review on Angle (Phys111)

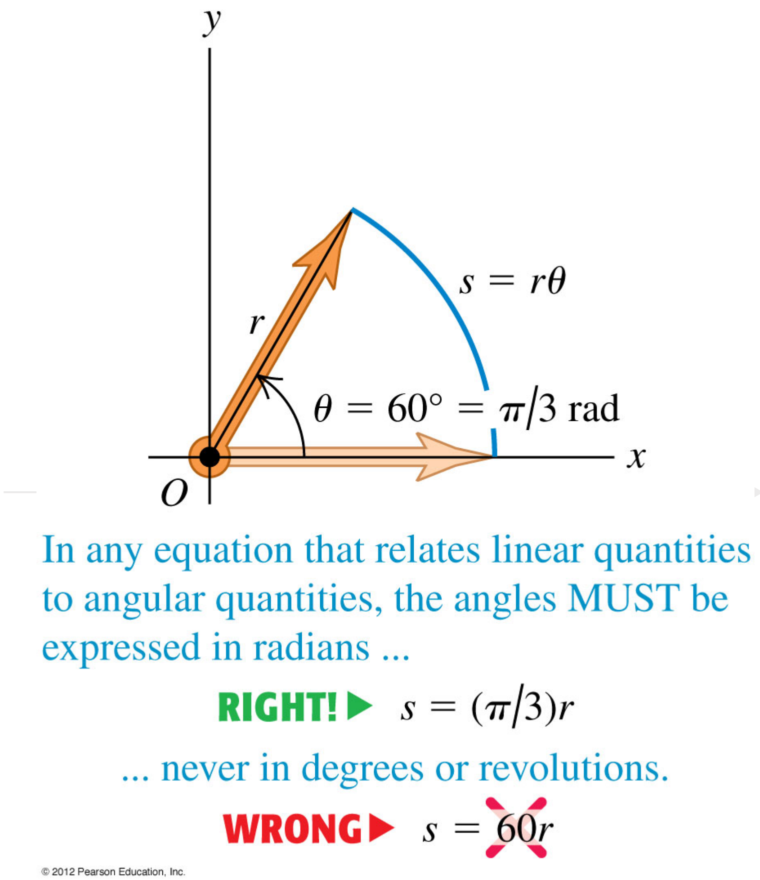
- What is the circumference *S* ?

$$s = (2\pi)r \qquad 2\pi = \frac{s}{r}$$

- θ can be defined as the **arc length** s along a circle divided by the radius r:

$$\theta = \frac{s}{r}$$

- θ is a pure number, but commonly is given the artificial unit, radian ("rad")



❑ Whenever using rotational equations, you **MUST** use angles expressed in radians

Conversions between radians and degrees

- Comparing degrees and radians

$$2\pi(rad) = 360^\circ \qquad \pi(rad) = 180^\circ$$

- Converting from degrees to radians

$$\alpha\left(rad\right) = \frac{\pi}{180^\circ}\,\alpha\left(degrees\right)$$

- Converting from radians to degrees

$$\alpha(\deg rees) = \frac{180^\circ}{\pi}\alpha(rad) \qquad 1\,rad = \frac{360^\circ}{2\pi} = 57.3^\circ$$

Unit conversion

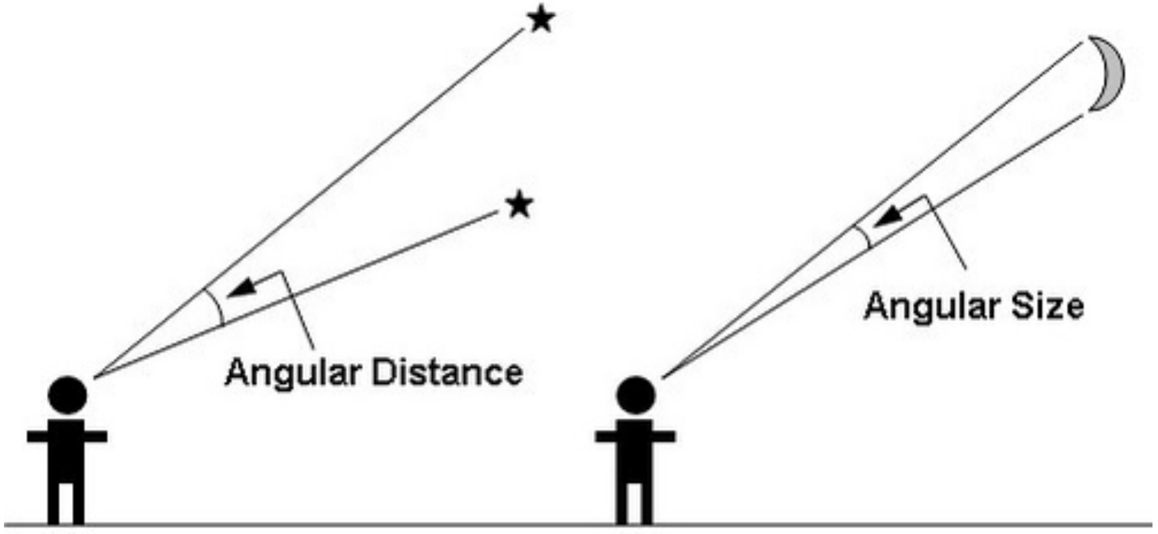
- Degree, arc-minute, and arc-second

$$1^\circ(\deg) = 60'(arc\min)$$
$$1'(arc\min) = 60''(arc\sec)$$
$$1^\circ(\deg) = 3600''(arc\sec)$$

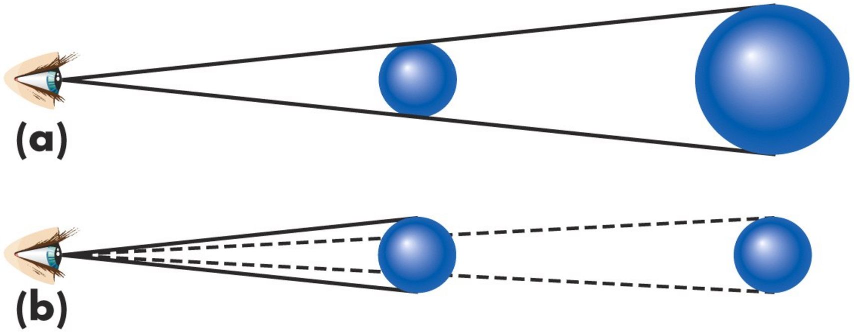
- From radians to arc-second

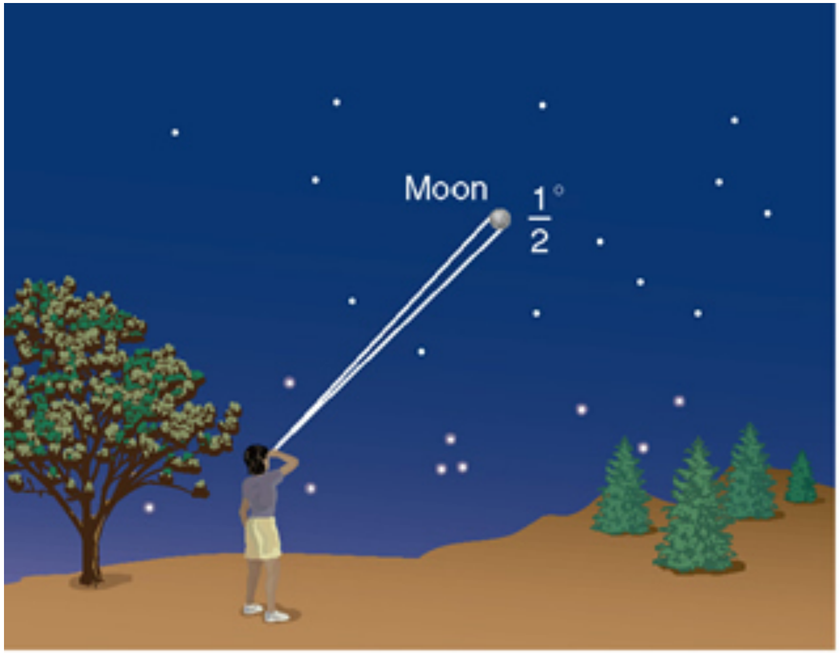
$$1\ rad = \frac{180^\circ}{\pi}(rad) = 57.2958^\circ = 3438' = 206265''$$

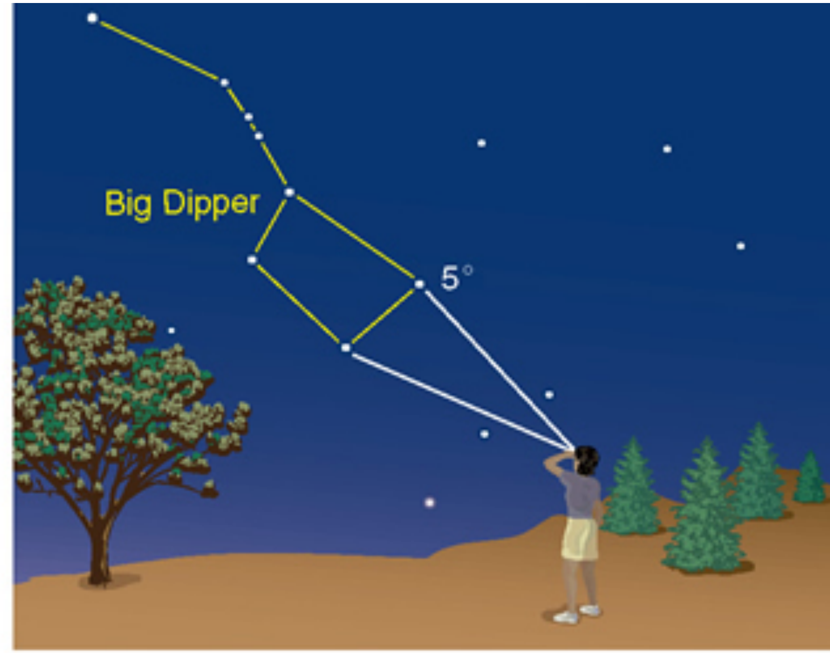
Angular Size and Angular Distance



- Angular size of an object α declines with increasing physical distance d for an object of a fixed physical size s

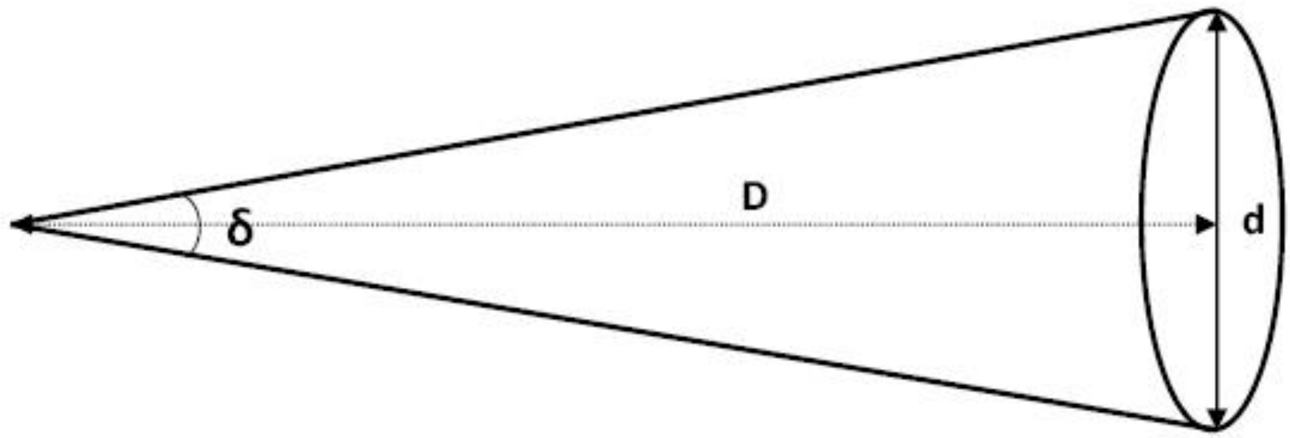






Measuring angular distances in the sky

Calculating angular size in astronomy

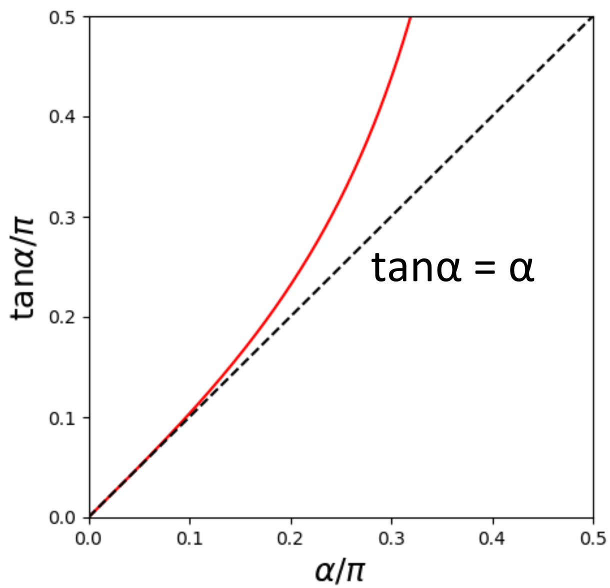


$$\tan(\frac{\delta}{2}) = \frac{d}{2D}$$

For **small angles**, tanα ≈ α, so

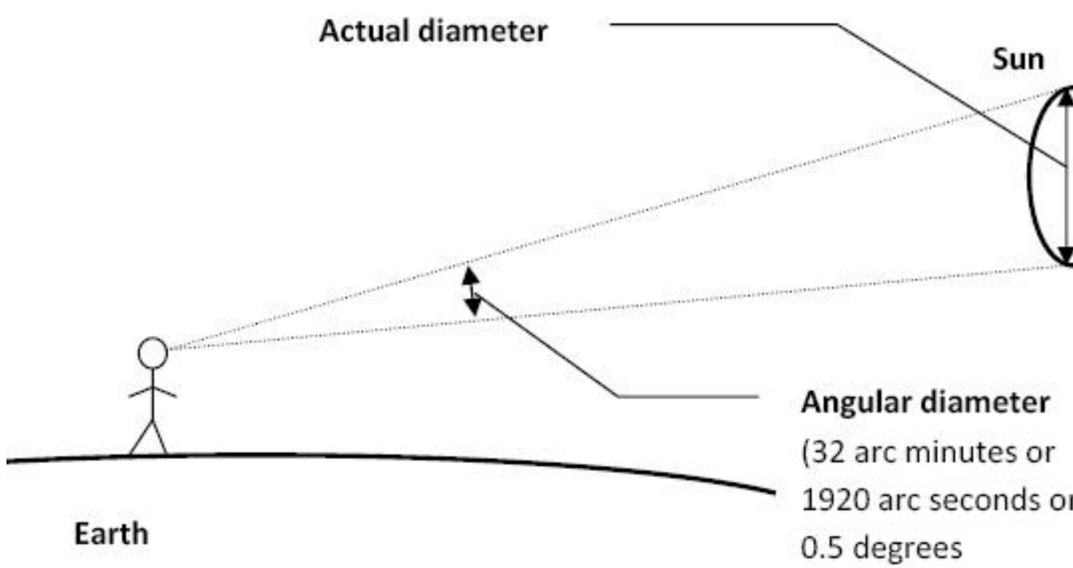
$$\alpha \approx s / D$$

Angular size ≈ physical size / distance



Angular size of the Sun

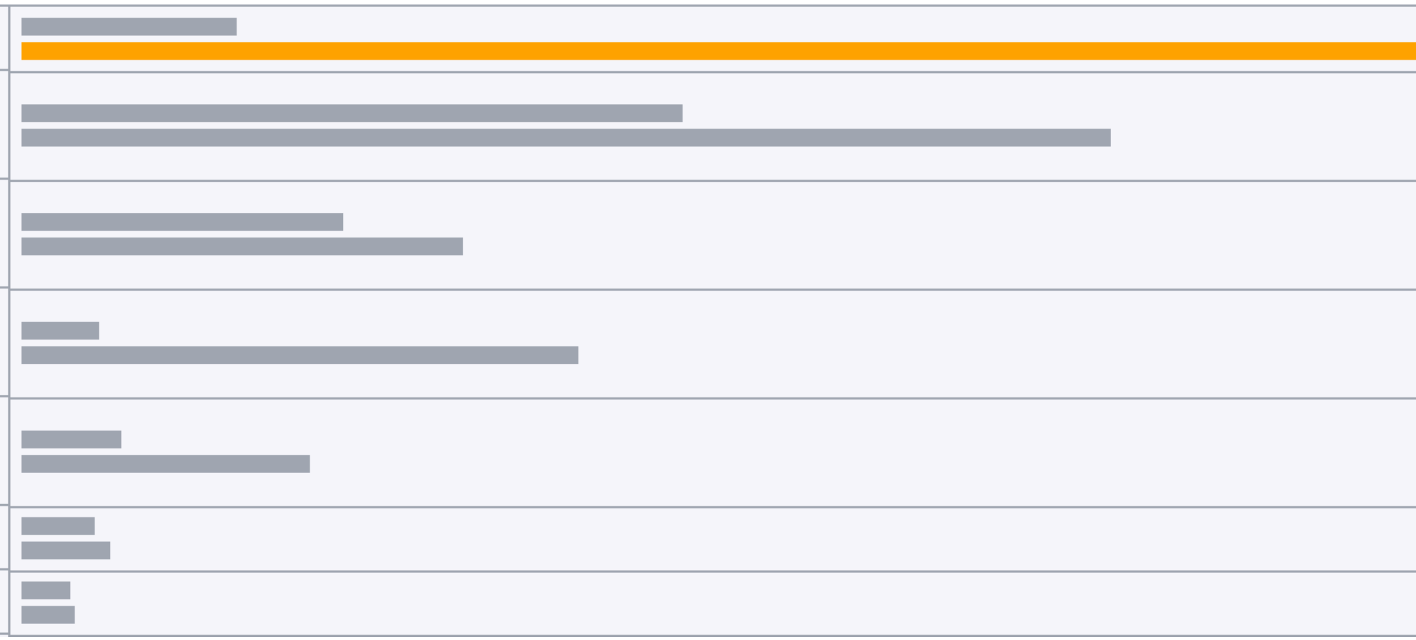
- What is the angular size of the Sun in arcsec?
  - The Sun's radius is 6.96×10^5 km
  - Sun-Earth distance is 1.50×10^8 km



Angular size of planets

	Angular size in arcsec
Venus	9.67″ – 1′3″
Jupiter	29.80″ – 50.59″
Saturn	14.50″ – 21.37″
Mars	3.49″ – 25.13″
Mercury	4.54″ – 13.02″
Uranus	3.31″ – 4.08″
Neptune	2.17″ – 2.37″

Relative Size (orange bar is the maximum value for Venus)



Small angle approximation works pretty well for all celestial bodies!

How to measure astronomical distance?

- Angular size assuming a known physical size

Angular size ≈ physical size / distance

$$\alpha \approx s / D$$

↓

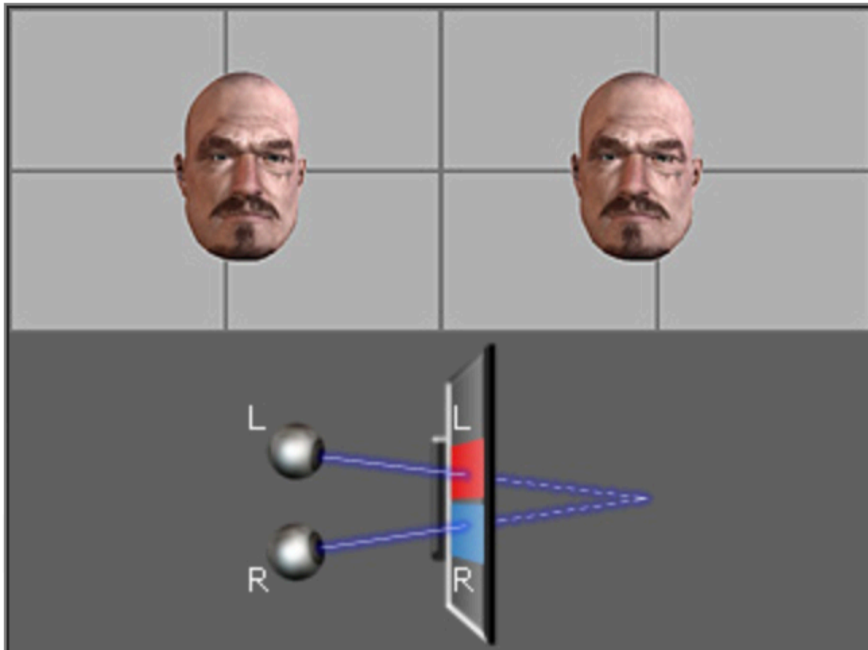
Distance ≈ angular size * physical size

$$D \approx \alpha s$$

- Stereoscopic vision

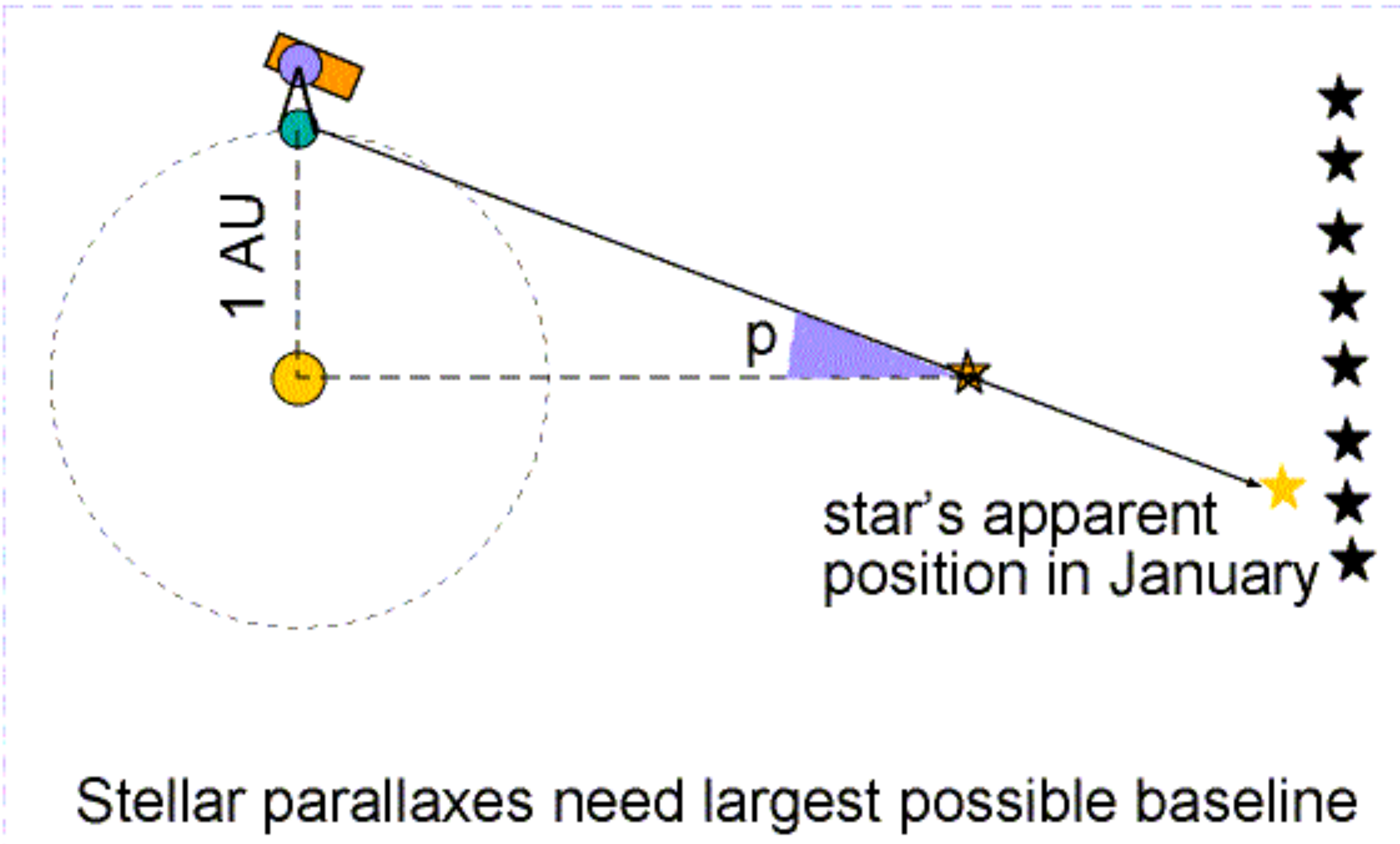
Stereoscopic Vision: 3D movie

Stereoscopic Vision: 3D movie

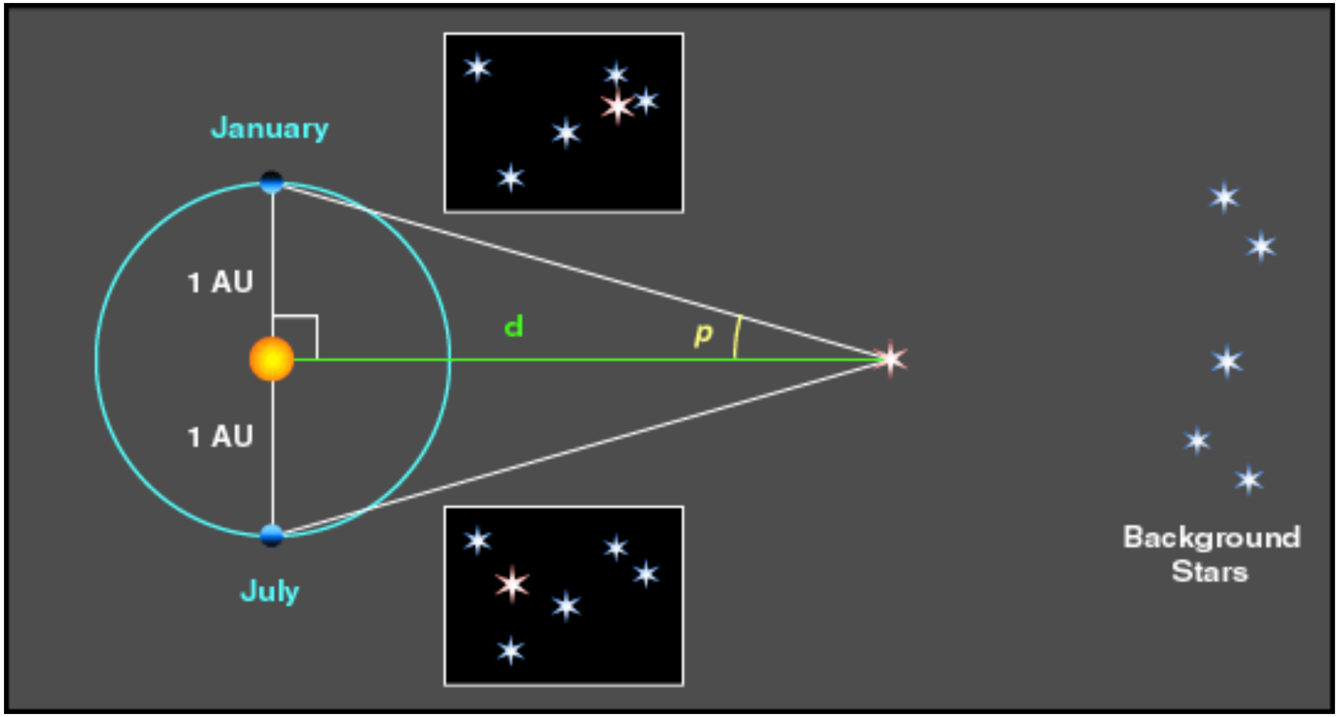
	
Your convergence point is lead to fall behind the display.	Positive Parallax

From reallusion.com

Parallax: Stereoscopic in astronomy



Measuring distances using parallax



$$d = \frac{1AU}{\tan p} \approx \frac{1}{p} AU$$

p is the parallax angle in *radians*

AU is the ***Astronomical Unit***, which is the mean distance from the Sun to Earth: 1.496 x 10^8 km

Parallax continued

$$d = \frac{1AU}{\tan p} \approx \frac{1}{p} AU$$

p is the parallax angle in *radians*

Converting to arcseconds, knowing 1 radian ≈ 206,265”

$$d \simeq \frac{206,265}{p''} \text{ AU}$$

P” is the parallax angle in *arcsecs*

Defining a new unit of distance, the **parsec** (**par**allax-**sec**ond, or pc), as 1 pc ≈ 206,265 AU ≈ 3.086×10^{16} m, which leads to

$$\boxed{d = \frac{1}{p''} \text{ pc.}}$$

- 1 pc ≈ 3.262 light year
- Measured parallax angle of 1” gives a distance of 1 pc
- Smaller parallax angle -> larger distance

Proxima Centauri: the nearest star

- The measured parallax angle of Proxima Centauri is 0.77", what is its distance in pc? And light years?

$$\boxed{d = \frac{1}{p''} \text{ pc.}}$$

d ≈ 1.3 pc ≈ 4.23 ly

- Proxima Centauri has a planet (called Proxima b) located in the habitable zone of the star. Stephen Hawking has a plan to build a solar sail (called "Breakthrough Starshot") to travel to the stellar system. In theory, the nanocraft can reach 20% of the speed of light. If so, how long does it take to reach the star?

Image of Proxima Centauri by the Hubble Space Telescope

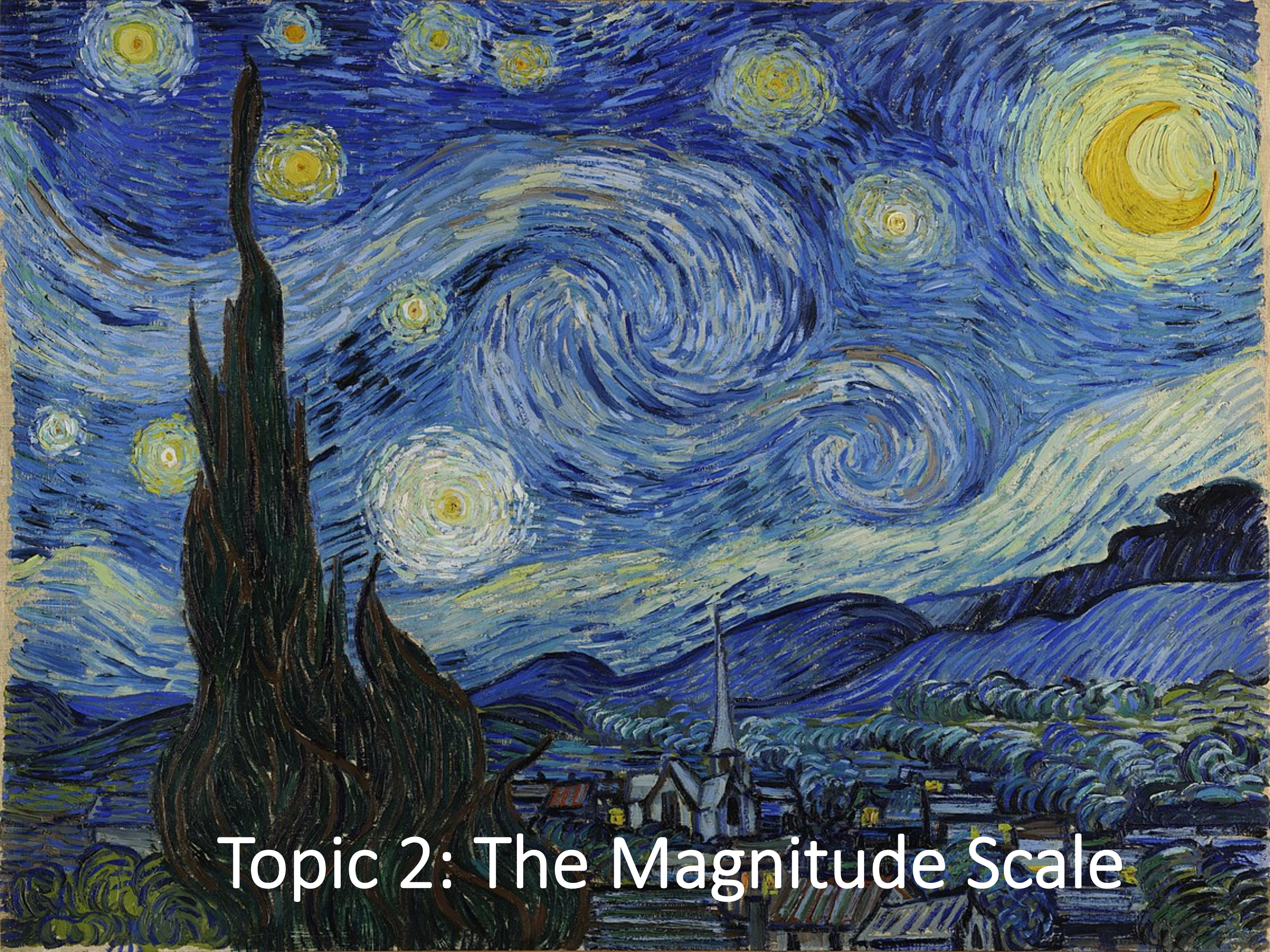
Parallax Example

Example 1.1. In 1838, after 4 years of observing 61 Cygni, Bessel announced his measurement of a parallax angle of $0.316''$ for that star. This corresponds to a distance of

$$d = \frac{1}{p''}\ \mathrm{pc} = \frac{1}{0.316}\ \mathrm{pc} = 3.16\ \mathrm{pc} = 10.3\ \mathrm{ly},$$

within 10% of the modern value 3.48 pc. 61 Cygni is one of the Sun's nearest neighbors.

Topic 2: The Magnitude Scale



Apparent magnitude

- Some stars appear brighter and some stars appear fainter. How to characterize this “brightness”?
- Apparent magnitude, introduced originally by Greek astronomer Hipparchus (190-120 BC)
  - Magnitudes 1 through 6 for the brightest to the dimmest stars visible to the naked eye
  - The ***brighter*** the object, the ***smaller*** the magnitude
- The magnitude scheme follows a logarithmic scale
  - A m=1 star is 100 x brighter than a m=6 star
  - A m=1 star is $100^{1/5}$ brighter than a m=2 star
  - A m=1 star is $100^{2/5}$ brighter than a m=3 star
  - A m=1 star is $100^{3/5}$ brighter than a m=4 star
  - …

Redefine "brightness"

- The apparent "brightness" of an object is actually measured in terms of the **radiant flux** F received from the object
- That is, brightness is really the radiant energy *passing through a given area in a given time.* For our eye, it is the area of the pupil.
- Unit: $J/s/m^2$, or W/m^2

Inverse Square Law

- The "brightness", or flux decreases at greater distance following the *inverse square law:*

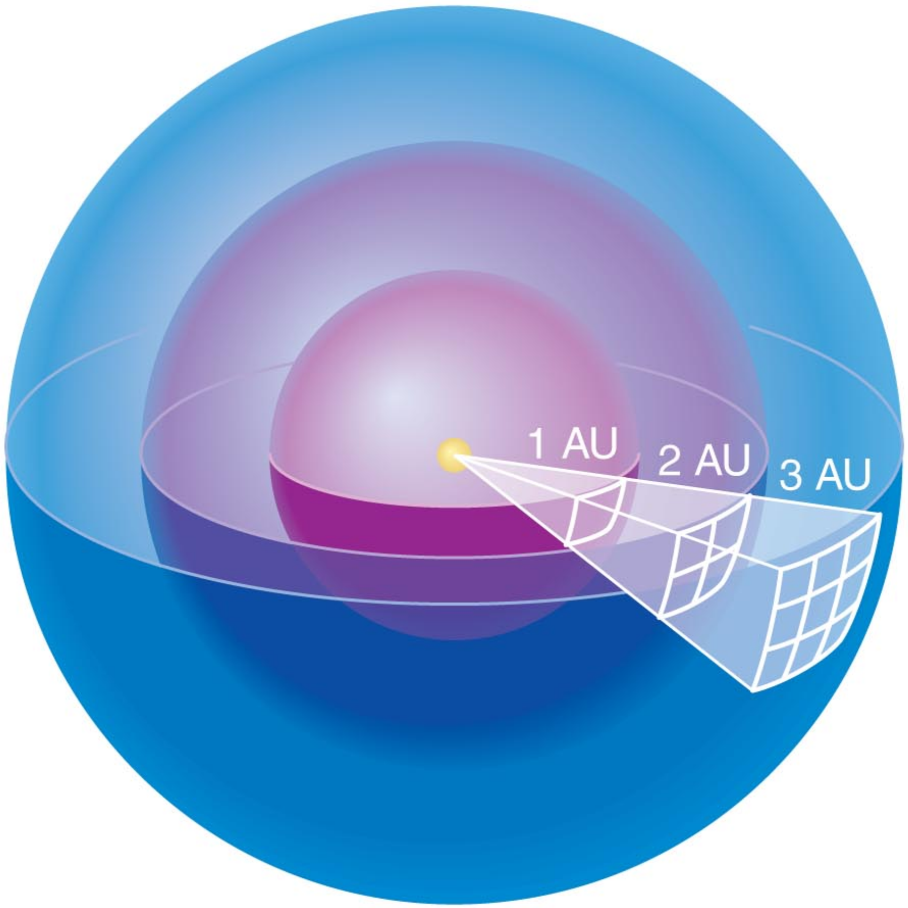
$$F \propto \frac{1}{d^2}$$

Why?

Energy is conserved!

The total amount of power passing through each sphere is the same

Area of sphere: $4\pi(\text{distance})^2$



Luminosity and Flux

- The intrinsic "power" of the star is defined as the ***luminosity L,*** which is the total energy given off by the star per unit time (unit: J/s, or W)

For our Sun: $L_\odot = 3.839 \times 10^{26}\ \mathrm{W}$

- So, the flux is $\text{Flux} = \dfrac{\text{Luminosity}}{4\pi(\text{distance})^2}$

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

Brightness and Apparent Magnitude m

- Recall: A difference of 5 magnitudes, or m_1-m_2 = 5, corresponds to the smaller-magnitude star (with m_2) 100 times brighter in its apparent brightness than the larger-magnitude star (with m_1), or F_2/F_1=100
- It means:

$$\boxed{\frac{F_2}{F_1} = 100^{(m_1 - m_2)/5}.}$$

- Taking the logarithm of both sides

$$m_1 - m_2 = -2.5 \log_{10} \left(\frac{F_1}{F_2} \right)$$

Absolute Magnitude M

- Apparent magnitude m depends strongly on distance – inconvenient to compare the intrinsic brightness among stars

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

$$\frac{F_2}{F_1} = 100^{(m_1 - m_2)/5}.$$

- We define ***Absolute Magnitude*** (M) of a star as the apparent magnitude the star would have if it were placed at a distance of 10 pc.

$$100^{(m-M)/5} = \frac{F_{10}}{F} = \left(\frac{d}{10\ \mathrm{pc}}\right)^2$$

Distance Modulus

- From the expression of Absolute Magnitude

$$100^{(m-M)/5} = \frac{F_{10}}{F} = \left(\frac{d}{10\text{ pc}}\right)^2$$

- Take logarithm on both sides

$$m - M = 5\log_{10}\left(\frac{d}{10\,pc}\right)$$

- The difference $m - M$ is a measure of the distance, called the ***distance modulus***
- Very useful in measuring distance if m is measured and M can be inferred (standard candles) –> this principle is the key in the discovery of ***the accelerating expansion of the Universe – 2011 Nobel Prize***

Summary

- Distance in astronomy
- Parallax
- Apparent magnitude
- Flux, Luminosity, and inverse square law
- Absolute magnitude and distance

Register your iClickers

- Step 1: Switch your frequency to "AB"

✓Press and hold power button until the indicator starts to flash

✓Enter AB using the buttons (ABCD) on the clicker

- Step 2: We will start a Roll Call session to register your iClickers. You will see your name on the screen. Enter the *2-letter codes* associated with your name.

Clicker Questions

Two stars in a binary system are observed to orbit each other with a fixed angular separation 1”. If the system has a measured parallax angle of p=0.1”, the physical separation between the two stars is:

A. 0.1 AU
B. 1 Au
C. 0.01 AU
D. 10 AU
E. 100 AU

Two stars A and B have a luminosity ratio of $L_A/L_B = 64$. However an observer claim that they appear to have the same brightness. From parallax measurements, people find that star A is located at 80 pc. How far is star B in pc?

A. 8
B. 10
C. 1.25
D. 5120
E. 640