# Principles of Astrophysics and Cosmology

# Course Instructor

Professor Jodi Cooley

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# Teaching Assistant

Mr. Matthew Stein

Email: mstein@mail.smu.edu

# Availability

Course: MW 6 - 7:20 pm

Office Hours: TBD

Fill out Doodle poll by NOON Friday (Jan 23)

http://doodle.com/7t2aqn3ffqxr6cb5iuq7t5e8/admin#table

NOTE: This course does not use blackboard.

# Course Website

www.physics.smu.edu/cooley/phy3368/

# TextBook

Astrophysics in a Nutshell by Dan Maoz

I also recommend that you consider purchasing a mathematical handbook (i.e. Schaum's Outline Series: Mathematical Handbook of Formulas and Tables by Murray R. Spiegel, 3rd. edition)

# What is Astrophysics?

Which of the following statements best describes astrophysics?

A) Astrophysics is the study of phenomena on large scales (i.e. the Sun, planets, stars, galaxies, etc).

B) Astrophysics is the study of phenomena on small scales (i.e. nuclei, atoms, particles, etc)

C) Astrophysics is the study of the formation of the Earth and effects of astronomical events on the emergence and evolution of life on Earth.

Answer: All of the above.

# Prerequisites

- The prerequisite for this class is PHYS 3305 Modern Physics.
- We will be revisiting practically all of the topics you have studied in physics up to this point including classical mechanics, electromagnetism, thermodynamics, quantum mechanics, statistical mechanics*, relativity and chemistry*.
- Although we will review these concepts as we encounter them, it will be expected that you have mastered this material before.

# Surgeon General's Warning

Too much exposure to Astrophysics & Cosmology may cause severe headaches, ...
ok not true, but:

- We will be using practically all of the physics you have learned up to this point. If you do not have the prerequisites for this course, you will have difficulties.
- Do not expect to be able to do the problems on the very first try. Give it 3-4 legitimate tries before seeking help.
- Collaborating with classmates on solving problems is acceptable (in fact, it is encouraged!), but the solutions you hand in MUST be your own (see SMU Honor Code)
- **No credit for late homework!**
- **Attendance:** Judge for your self, ... how many SMU courses were you able to master by just staying at home and reading the book
- **Corollary:** Don't expect to be able to brush off the course for a whole semester and learn everything by cramming for a whole day prior to the exam, it also doesn't work to eat burgers all semester expect to lose 10 lbs by going to the gym for 24 hrs straight?

# Topics Covered

- Observational Techniques
- Stellar Physics
- Stellar Evolution
- Galaxies
- Dark Matter

- Observations from Cosmology
- Big Bang Cosmology
- Tests and Probes of Big Bang Cosmology

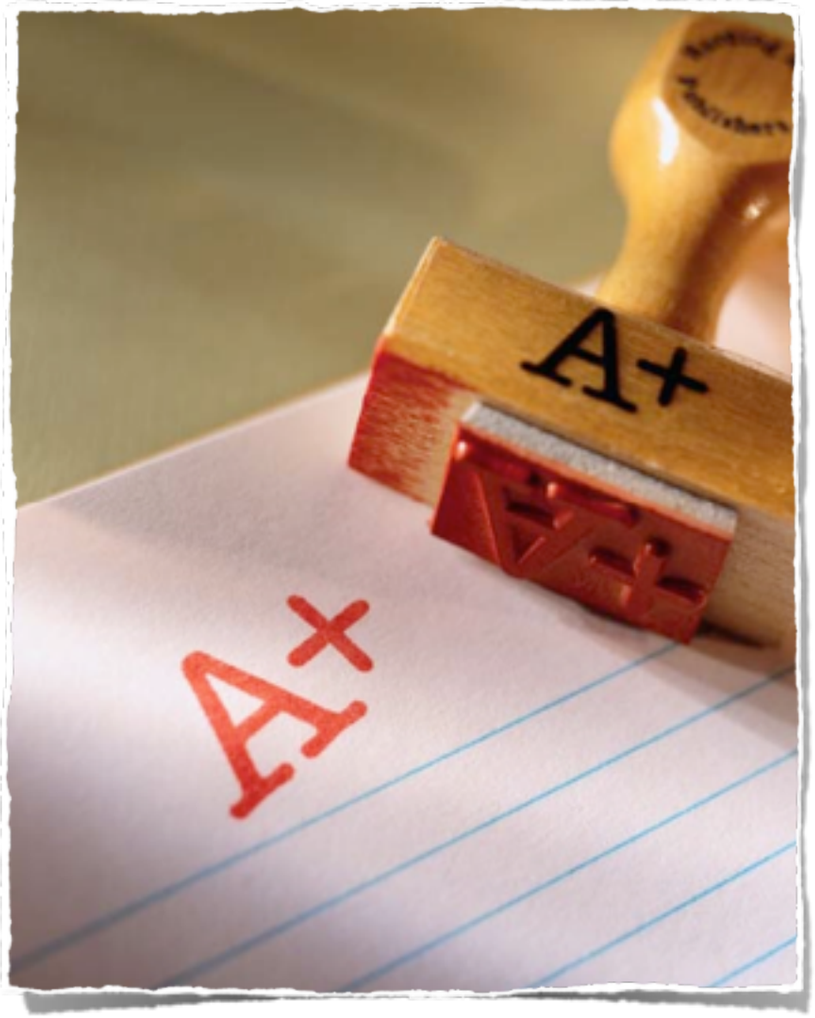
# How to Do Well in the Course

- <u>Do all the homework sets!</u>

- Study in small groups (make sure you're contributing to the group as much as your absorbing from it)

- Come to class

- Don't waste time on last minute all-nighters



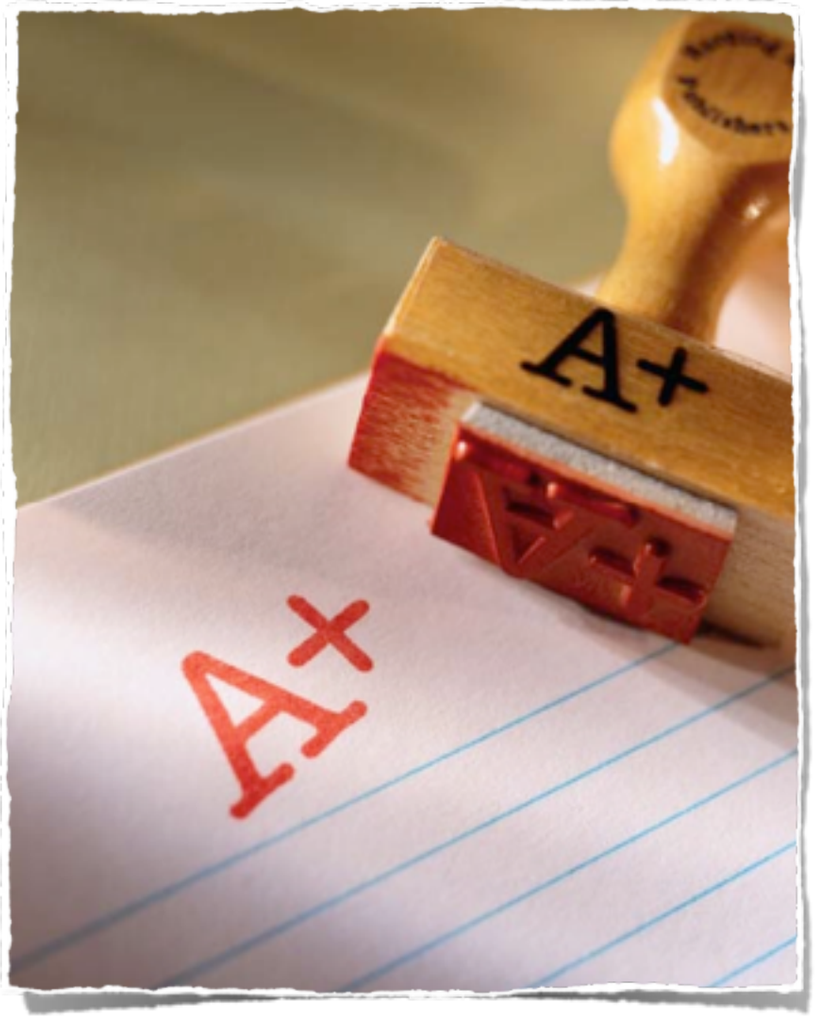

**<u>Your Grade:</u>**

20% Homework
20% Labs
40% Exams (2 midterms)
20% Final Paper

# How to Do Well in the Course

Everyone has a chance to earn an A in this class. There is no 'curve'.

93%: A
85%: A-
80%: B+
75%: B
70%: B-
65%: C+
60%: C
55%: C-




**Your Grade:**

20% Homework
20% Labs
40% Exams (2 midterms)
20% Final Paper

# Labs, Exams & Homework

- There will be 7 in-class laboratory activities lead by Mr. Matt Stein (your TA for the course).

- Labs will be on every other Monday beginning January 26th. (Jan 26; Feb 9, 23; Mar 15, 30; Apr 13, 27). They will meet in FOSC 032.

- Midterm exam 1 will be Wednesday, March 18 (in class) and midterm exam 2 will be Wednesday, May 6th at 6:30 pm.

- Homework will be assigned on a regular basis. Attend class or visit the course website for updates.

- You will be required to write a 3000 word final paper for this course. The paper is due at 6 pm on Wednesday, April 15th.

# Expectations

## What to expect from me

- An interesting and though provoking course
- Consideration and fairness (this does not mean easy!)
- Availability & approachability to talk about any difficulties & questions
- Punctuality

## What I expect from you

- Sincere effort
- Honesty
- Homework should follow the homework guidelines on the course website
- Punctuality

# What is Plagiarism?

PLAGIARISM[5] Intentionally or knowingly representing the words or ideas of another as one's own in any academic exercise.

5 In regards to cases of plagiarism, ignorance of the rules is not an excuse. The University subscribes to the statement on plagiarism which appears on page six of William Watt's An American Rhetoric (1955).S

# Plagiarism

- It is plagiarism to copy your homework from the Instructor Solution Manuel.

- It is plagiarism to copy the homework from another student (current or previous).

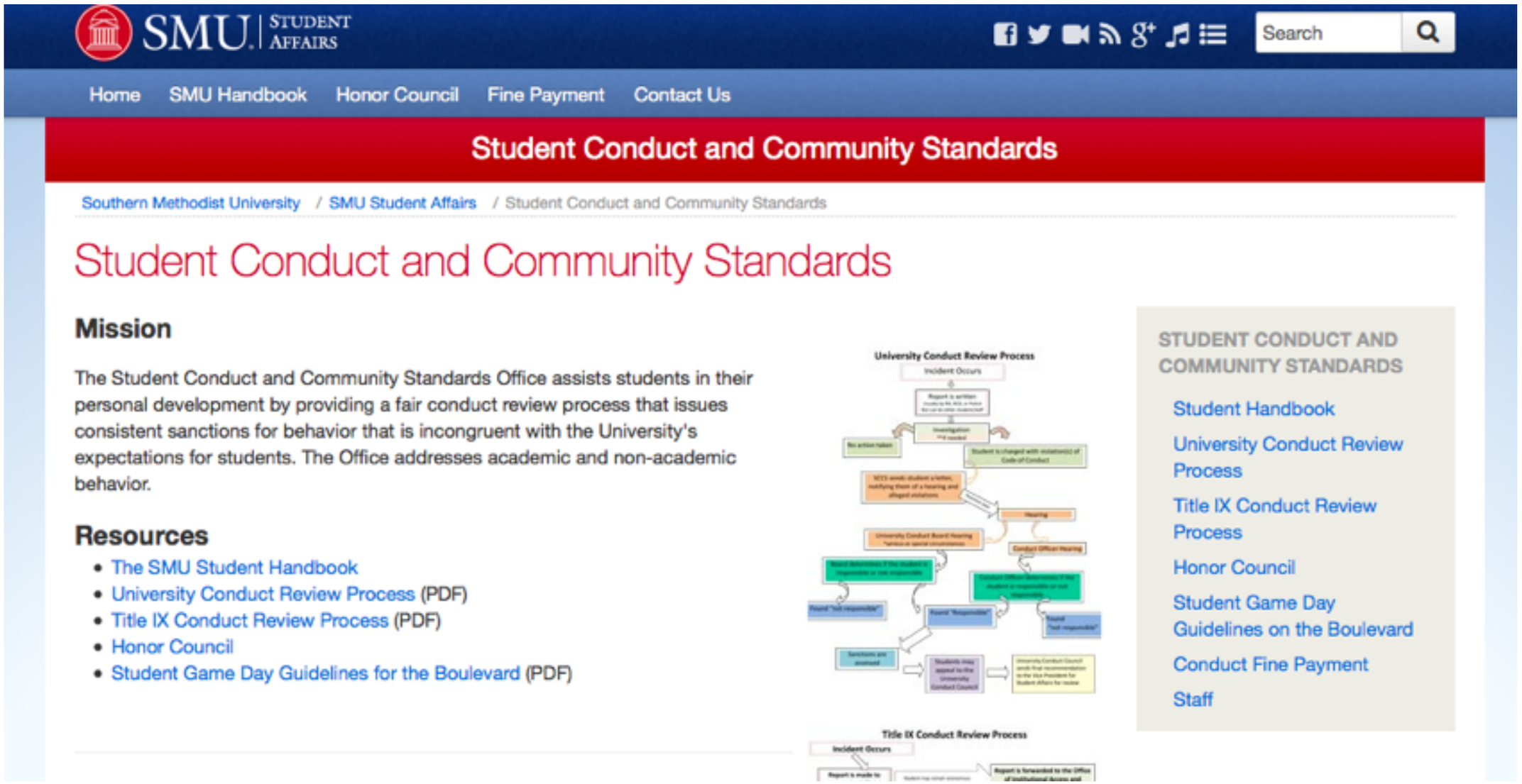
- It is plagiarism to copy the solutions to your homework from google.

- Academic honesty means that you acknowledge your sources! This includes people in your study group.

**I will report incidents of plagiarism to the Honor Council. If you have any questions about academic honesty in this class, please feel free to talk to me during office hours.**

# Student Resources

http://www.smu.edu/StudentAffairs/StudentConduct



# Announcements

- Reading Assignments: Chapter 1 (all) and Chapter 2.1 - 2.2
- Problem Set 1 is due Wednesday, January 28th, 2015.
- Read the Homework Policy!
- Read the Syllabus!
- First lab is this Monday, January 26th. Be sure to report to FOSC 032 that day.

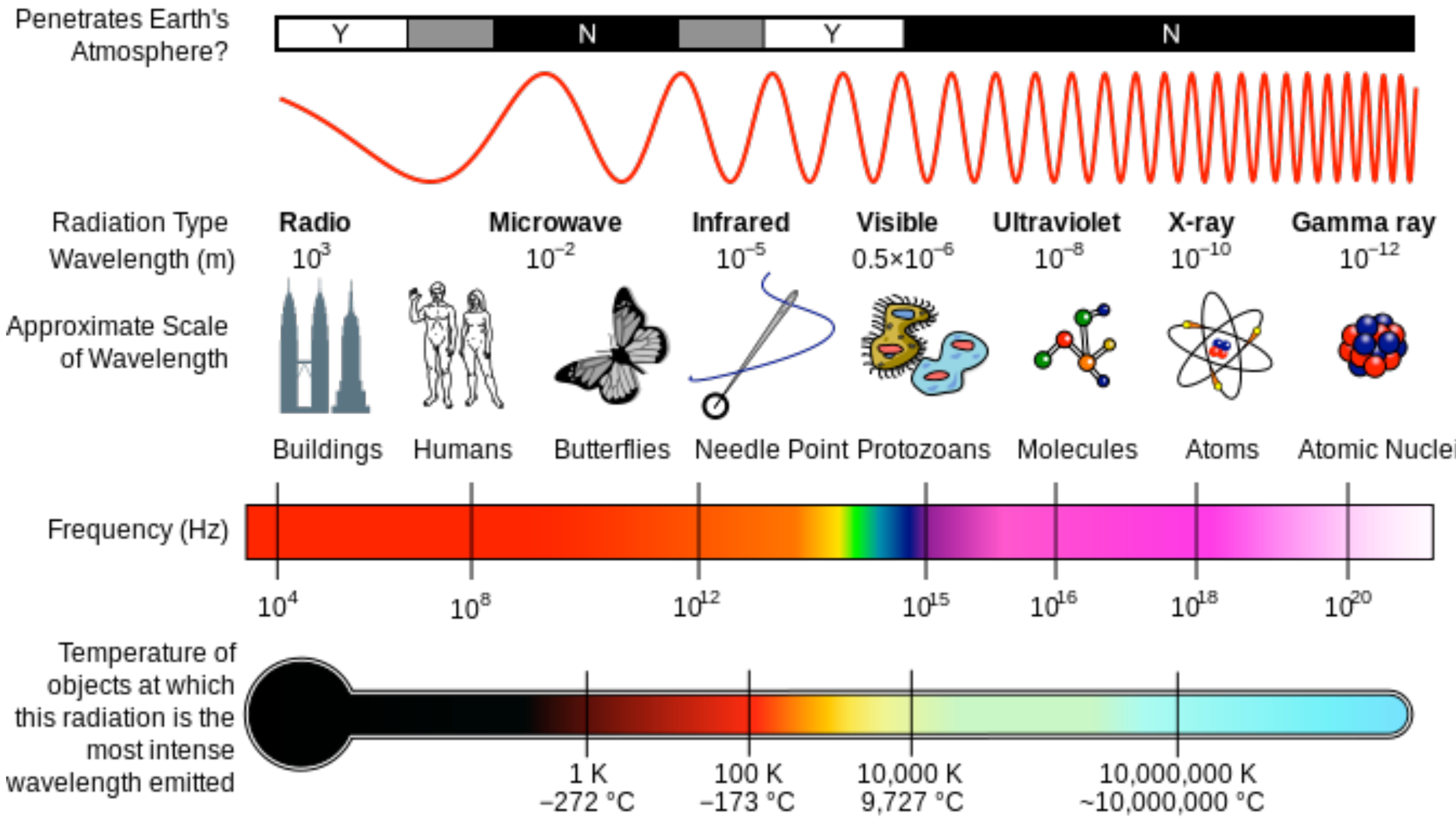
Q: How is experimental astrophysics different from other experimental disciplines?

Astronomers and astrophysicists can not carry out controlled experiments*. They perform observations of phenomena.

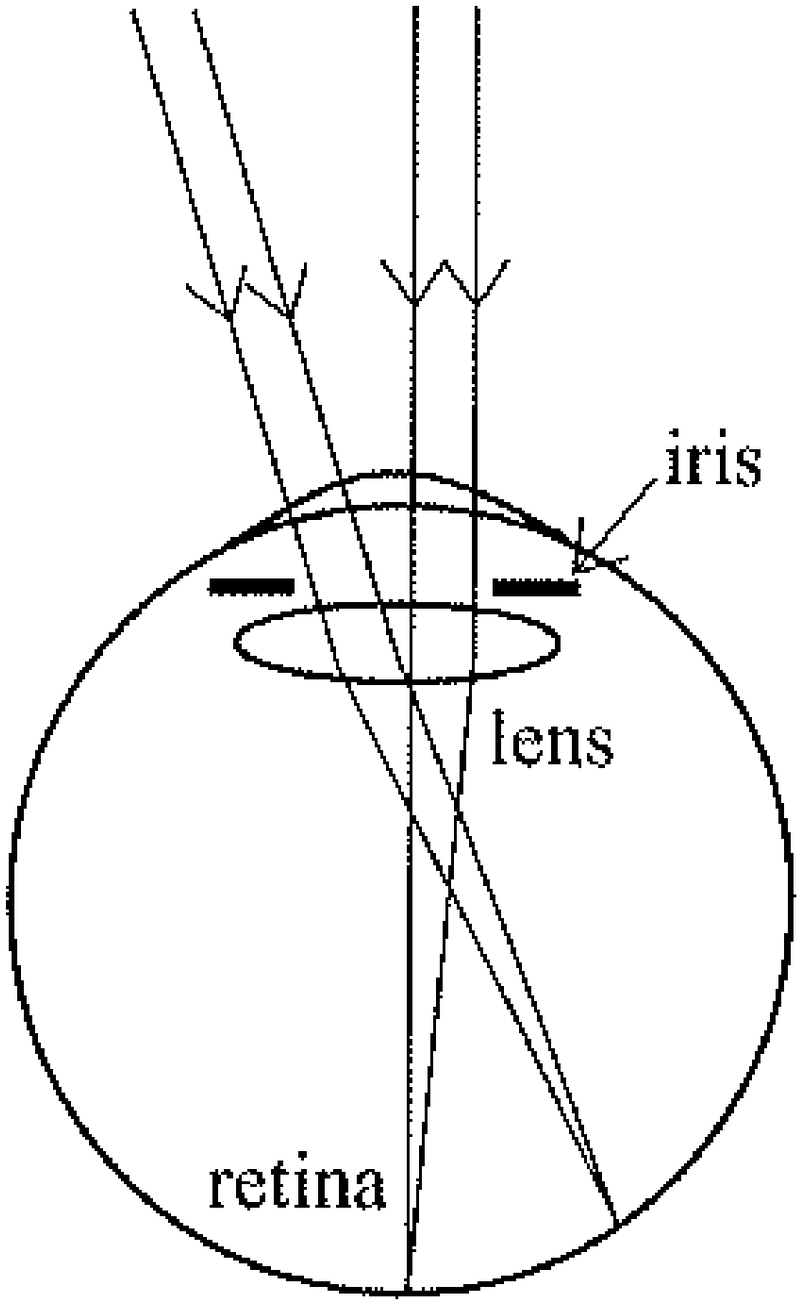
So, let's start with a brief overview of how observations are used to make astrophysical measurements.

*Some properties of astronomical conditions can be simulated in the lab.

# The Electromagnetic Spectrum

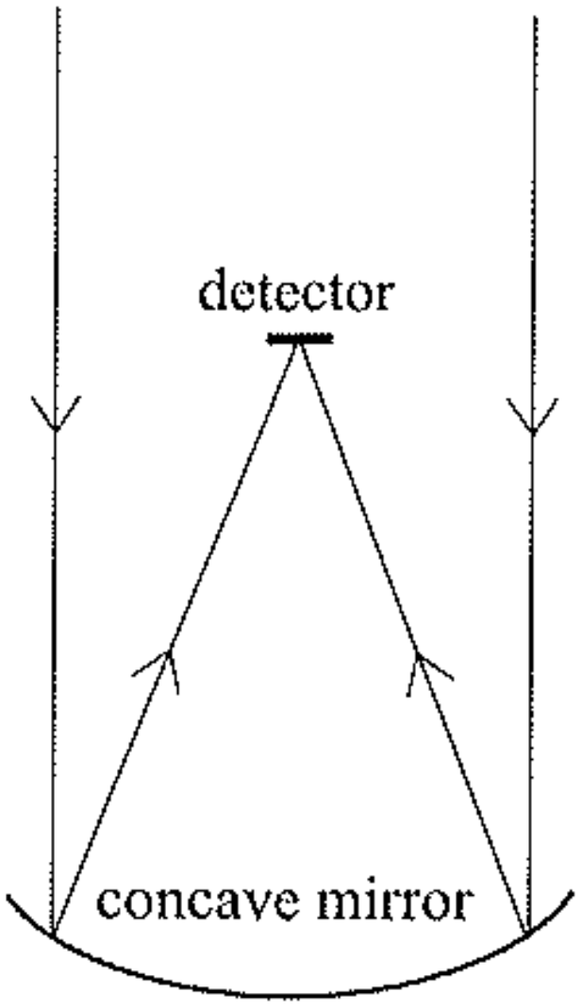


# Camera-Detector: Human Eye

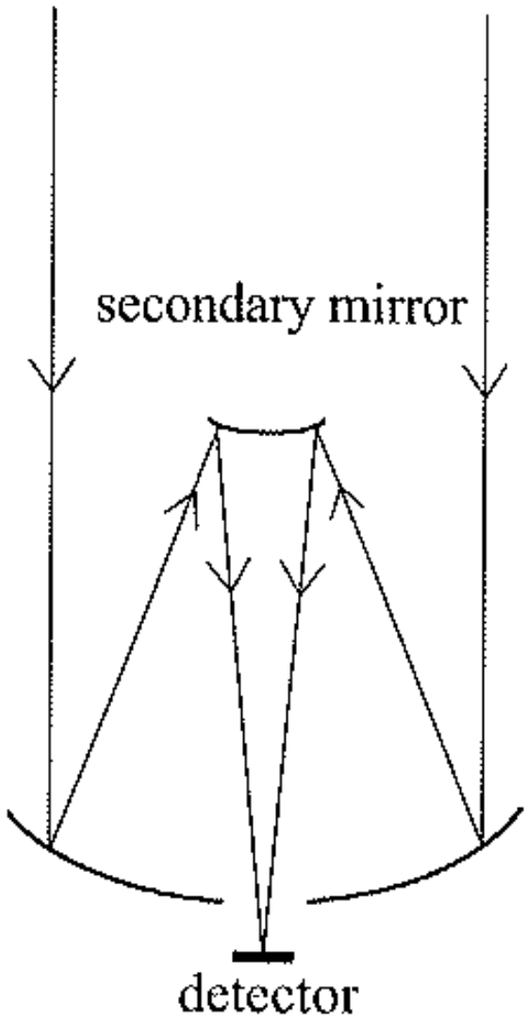



- The lens (camera) focuses light onto the retina (detector).
- Aperture of a dark-adapted pupil is < 1 cm in diameter.
- Limited light gathering and limited angular resolution.

# Camera-Detector: Reflecting Telescopes

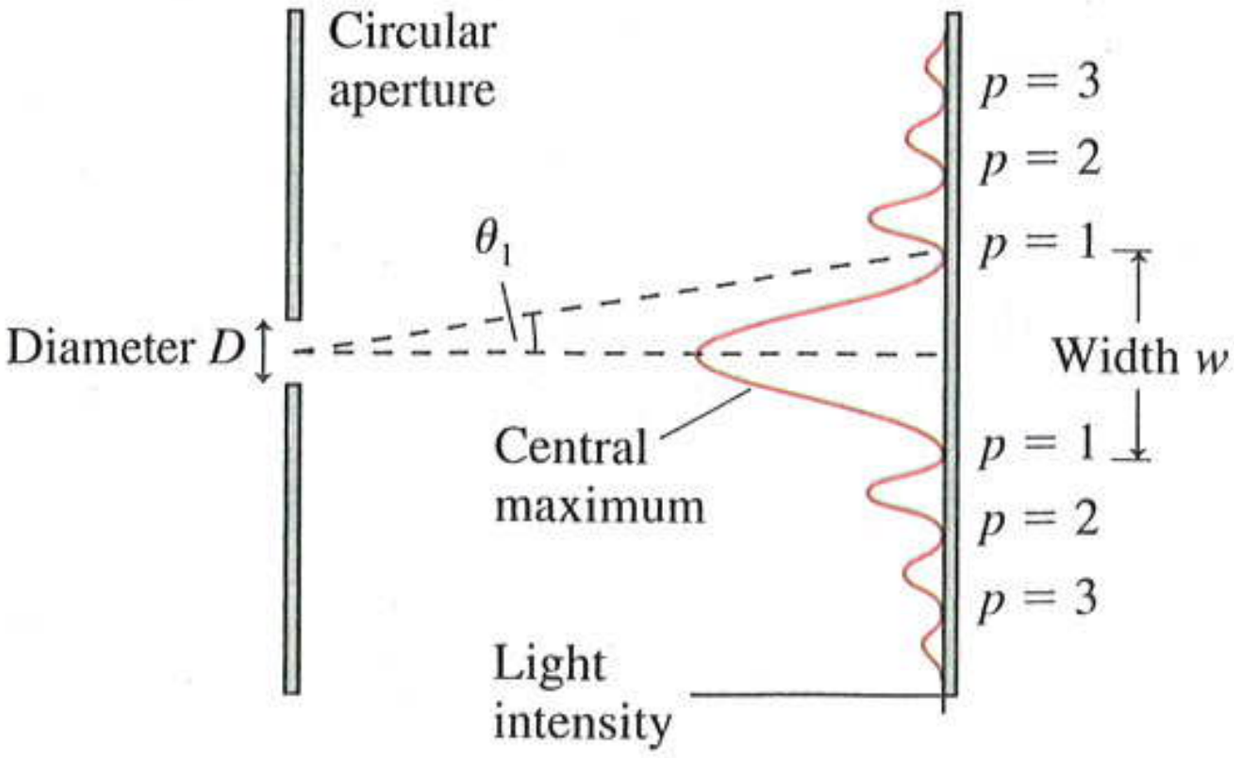


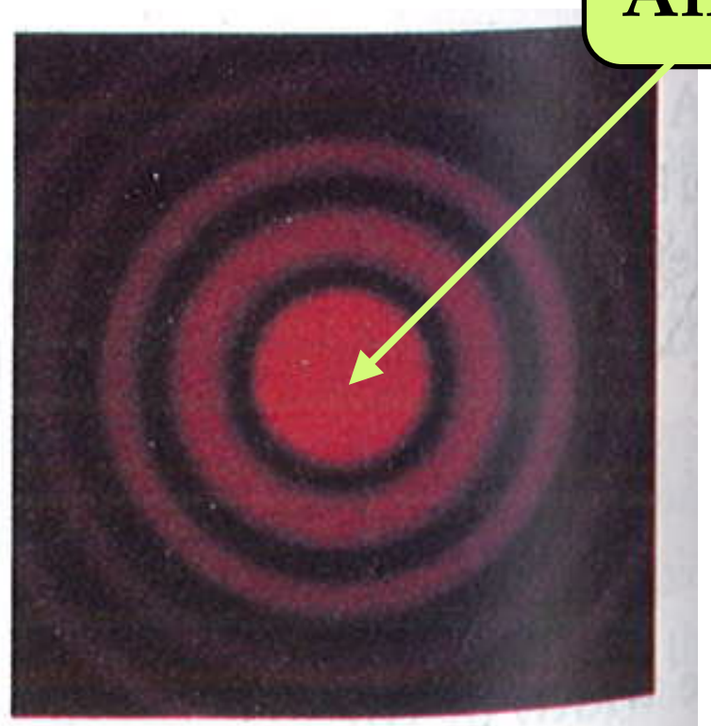

Detector at prime focus
Aperture is primary mirror.




Secondary convex mirror focuses rays through hole in primary mirror onto detector.

# Circular-Aperture Diffraction




Light waves from outside must pass through a circular lens. The performance limit of optical instruments is determined by the diffraction of the circular openings through which the waves must pass.

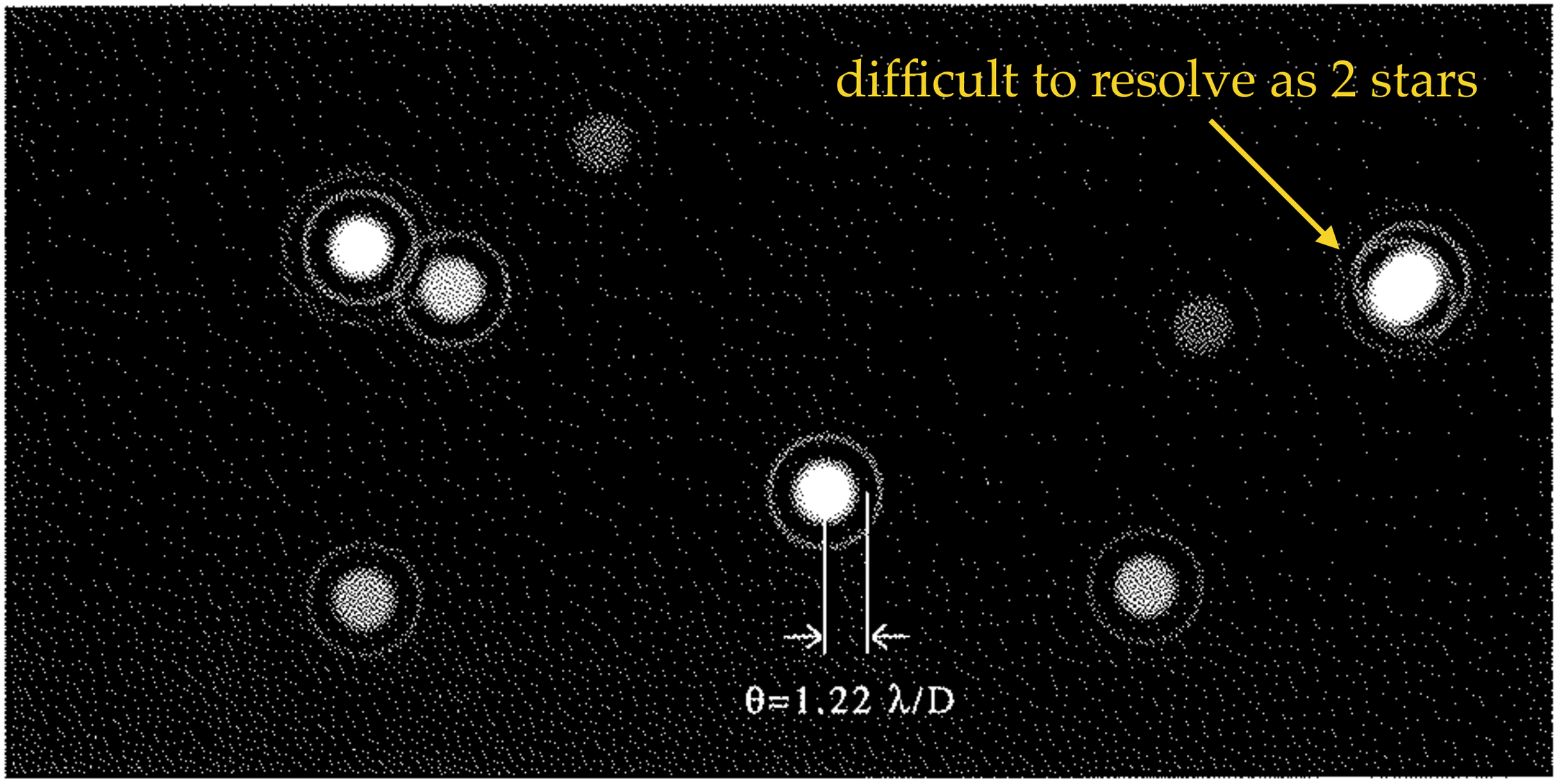
## Angular Resolution:

The smallest angle on the sky between two sources of light that can be discerned as separate sources with that camera.

Two point sources can be resolved as separate objects when the centers of the two light sources are separated by

$$\theta = 1.22\frac{\lambda}{D} \qquad \text{(in radians)}$$

# Example: Diffraction-Limited Image




Simulated image with diffraction pattern due to telescope's finite circular aperture.

## Why can't we see stars during the day?

The high background from the sky.

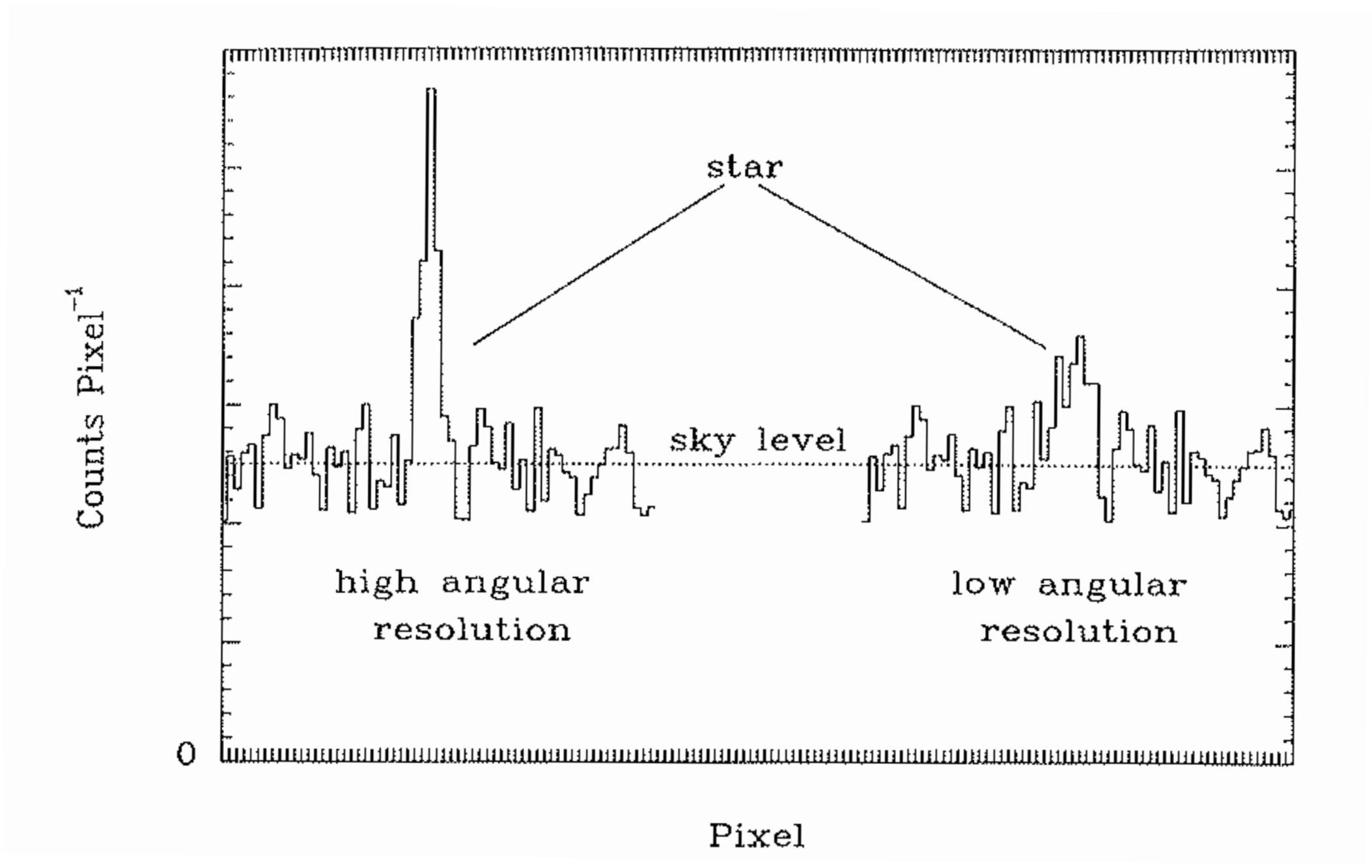
## Why is angular resolution important?

- Discerning fine details of astronomical objects.
- Detecting faint unresolved sources against emission from the Earth's atmosphere.

The night sky shines due to scattered light from stars, the moon, artificial sources and the fluorescent of atoms and molecules in the atmosphere.

Better angular resolution —> smaller solid angle over which star light is spread —>higher contrast of star's image over background.

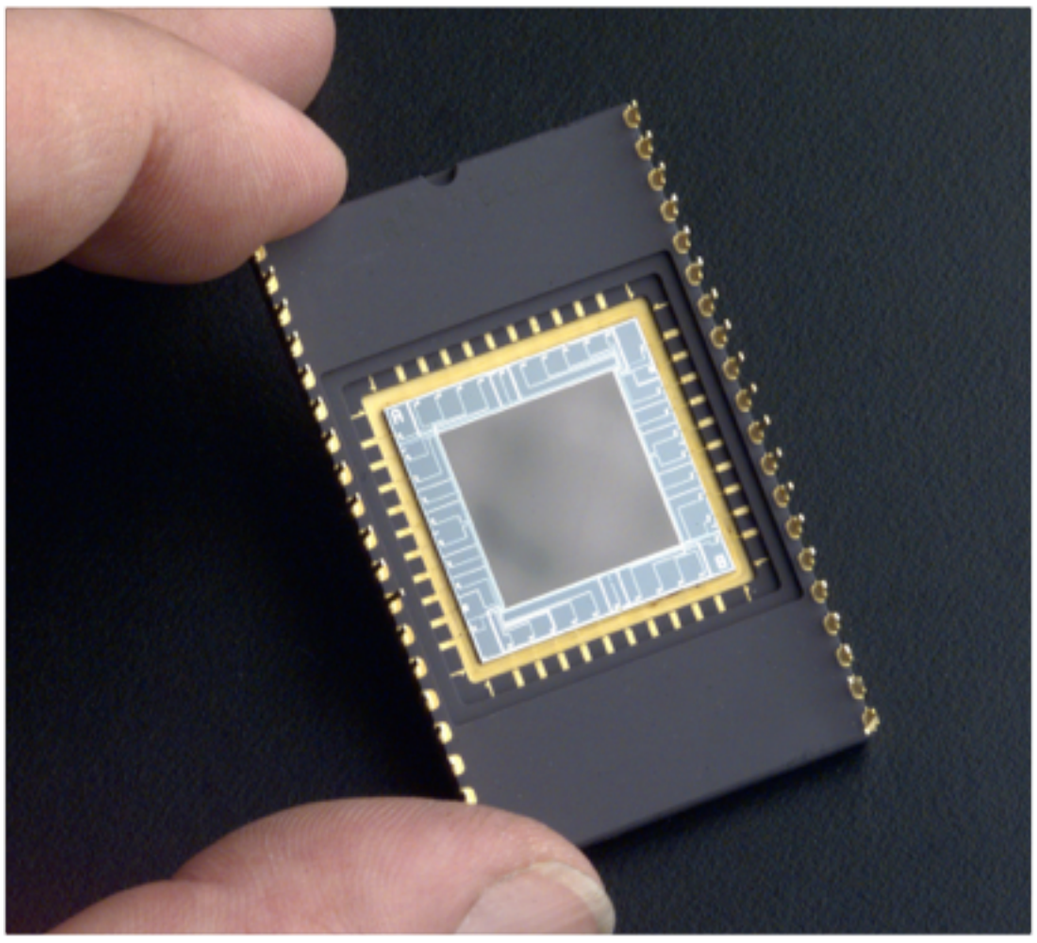
# Example:  Positions of stars with two different instrument resolutions.



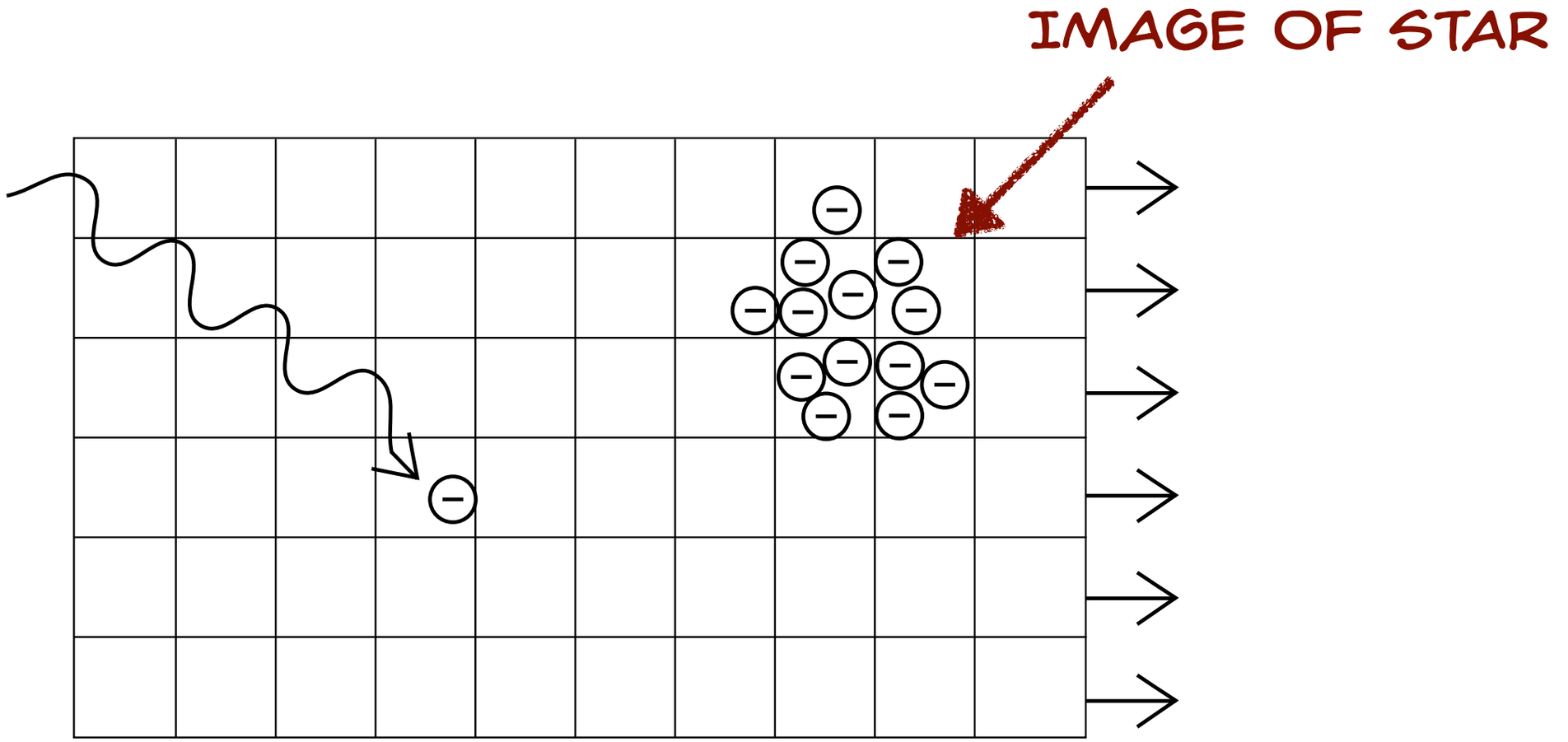
# Short Comings of Human Eye

- Exposure time is limited to 1/30 of a second.
    - If a source can be collected over long periods of time, you have a better chance of observing faint sources.
- Sensitive only to the visible spectrum.
    - Information for many objects exists in all regions of the EM spectrum (radio to gamma)
- Does not record information.
    - Recorded objective information can be examined, analyzed, re-examined and disseminated to others.

# Charge-Coupled Devices (CCDs)



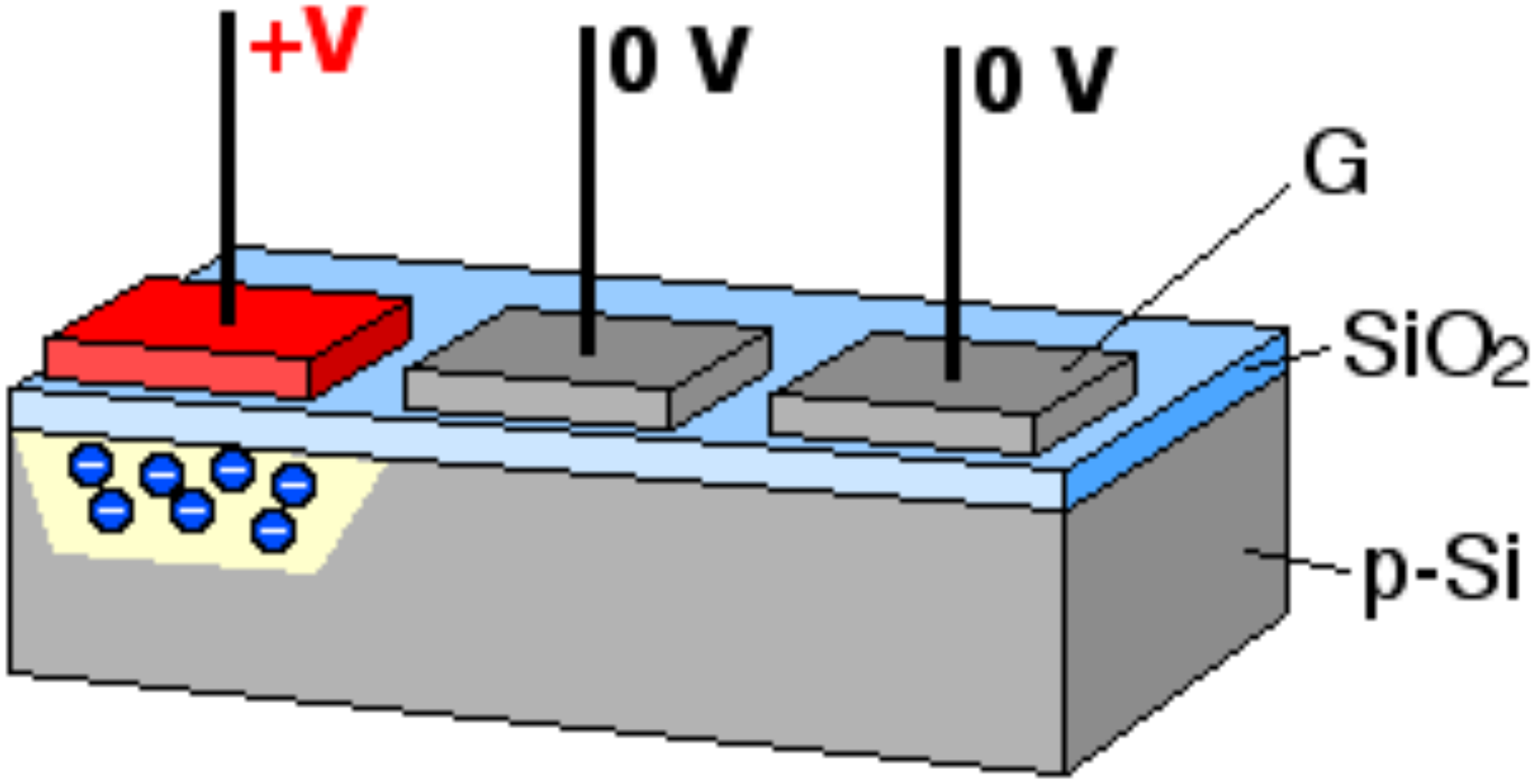
- First invented at AT&T Bell Labs by Willard Boyle and George Smith (1969).
- They were working on semiconductor bubble memory at the time.




- Slab of silicon divided into pixels.
- Photons reaching the CCD liberate “photoelectrons” via the photoelectric effect.
- Photons accumulate in every pixel during exposure period.
- At end of exposure, the accumulated charge is transfered horizontally and readout.

# Simple Illustration of CCD Readout

http://astro.unl.edu/classaction/loader.html?filename=animations/telescopes/buckets.swf&movieid=buckets&width=550&height=460&version=6.0.0




"CCD charge transfer animation" by Michael Schmid - animated drawing created myself. Licensed under CC BY 2.5 via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:CCD_charge_transfer_animation.gif#mediaviewer/File:CCD_charge_transfer_animation.gif

# Other Imaging Methods

Consider an EM wave that is plane-parallel and monochromatic.

$$\mathbf{E} = \hat{\mathbf{e}} E(t) \cos(2\pi\nu t - \mathbf{k}\cdot\mathbf{r} + \phi)$$

$\hat{\mathbf{e}}$ = direction of polarization of the e-field

$E(t)$ = time-dependent amplitude of field

$\nu$ = frequency

$\mathbf{k}$ = wave vector (direction of wave propagation)

$\phi$ = phase shift

Recall Relations:

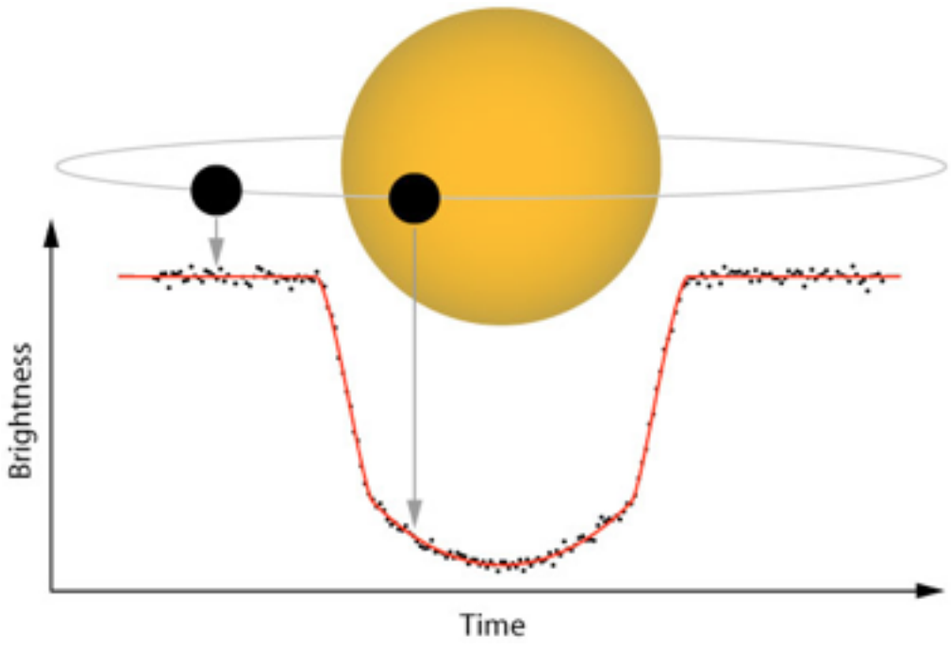
$$|\vec{k}| = \frac{2\pi}{\lambda} \qquad \text{and} \qquad \nu = \frac{\lambda}{c}$$

Thus, an image gives —

- A measurement of **k** (direction).
- Strength of signal produced.
- Intensity (related to photon flux) —> $\langle E^2(t) \rangle$

**Photometry** = measuring the photon flux from a source.

Time-Resolved Photometry = repeated photometric measurements as a function of time. This gives long-term time dependence of $\langle E^2 \rangle$

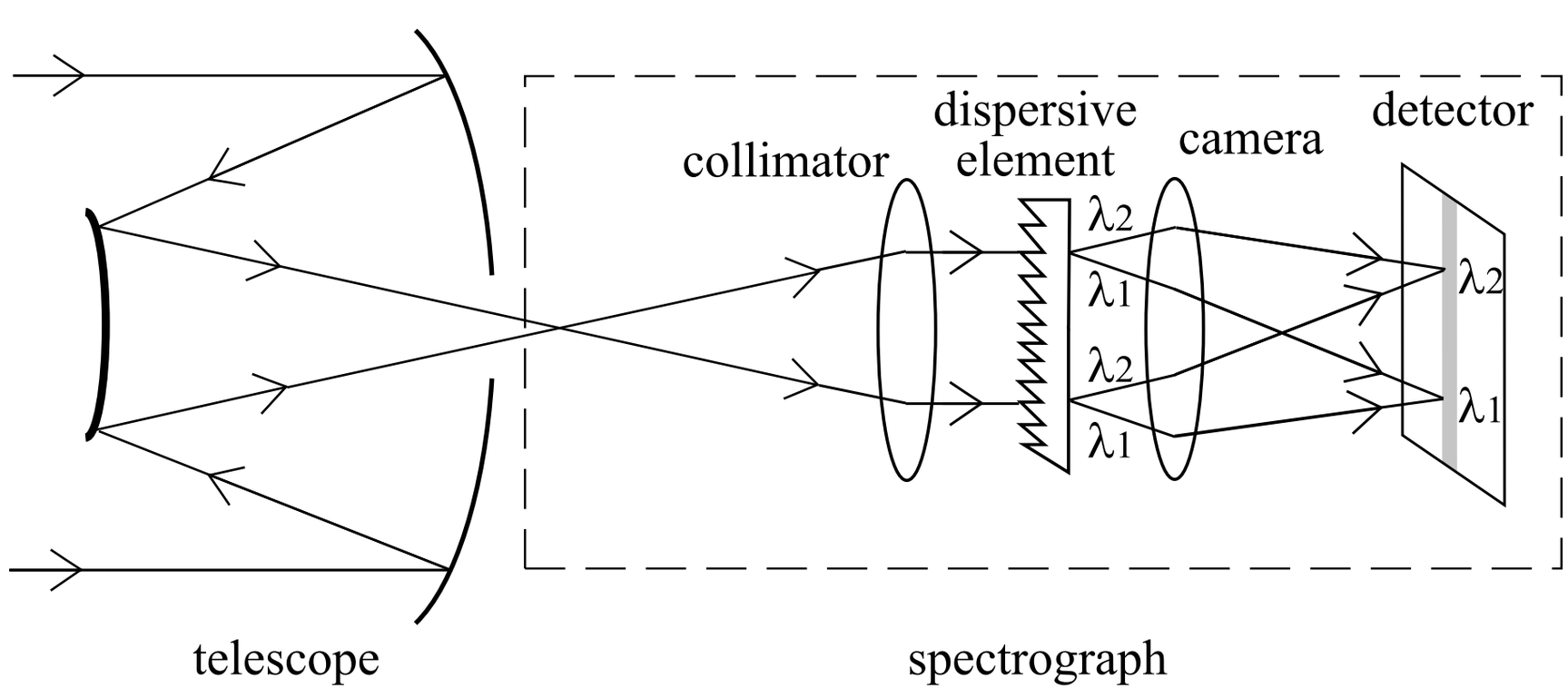



combined with inverse square law, determine luminosity if distance known (or vis versa)
study of light variation in variable stars, minor planets, AGN, supernova and transient exoplanets.

**<u>Wavelength and Frequency</u>** —

- Use a band-pass filter before detector allows radiation of only a certain frequency to pass.
- Reflection off or transmission through a dispersing element (think diffraction grating or prism)

Spectroscopy -



# Summary

- We discussed several observational techniques.
- Short-comings of the human eye.
- Discussed the multiple ways that we can get information from an image.

**NEXT TIME:**

Review of blackbody radiation and measurements of stellar parameters.