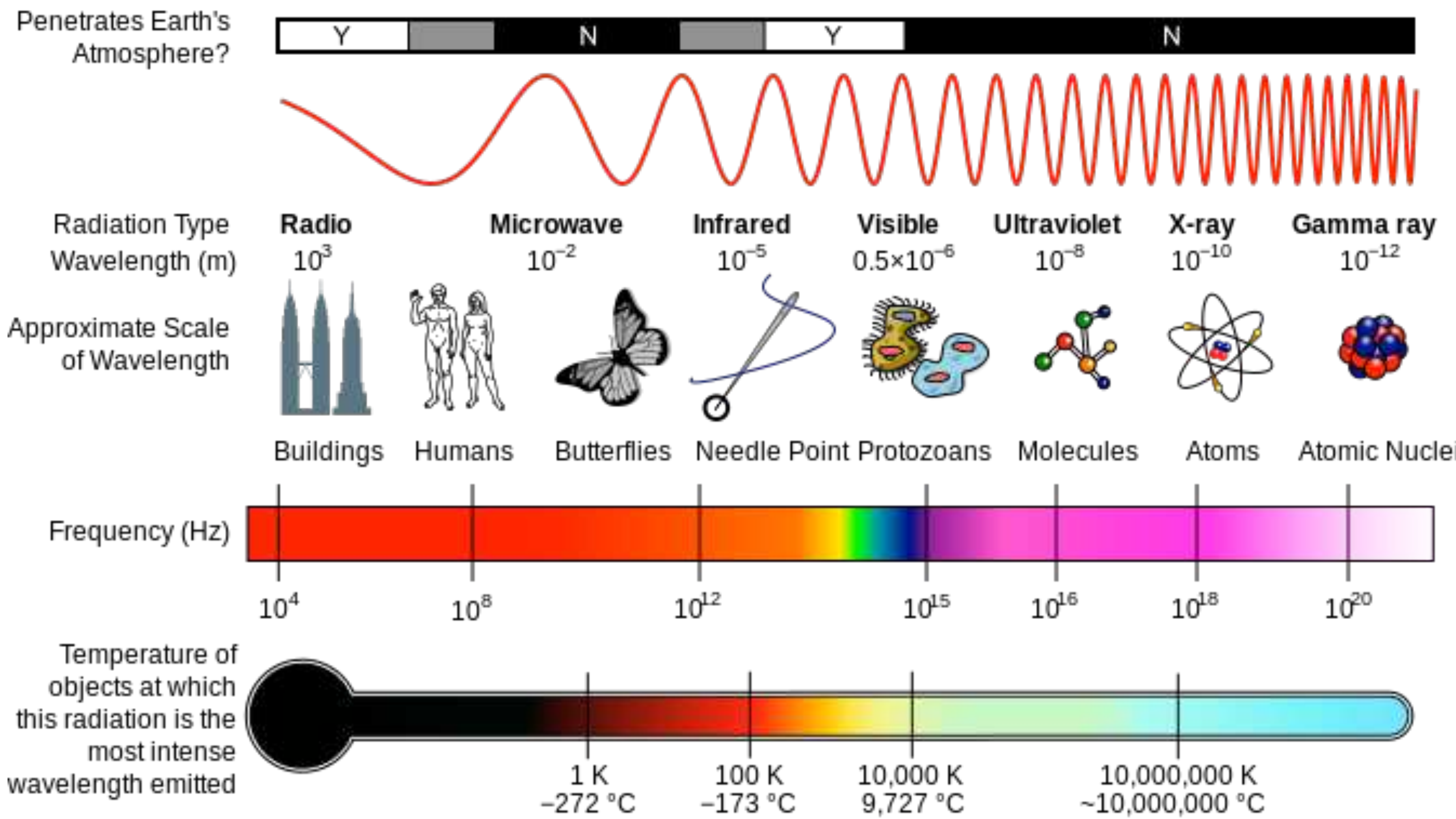
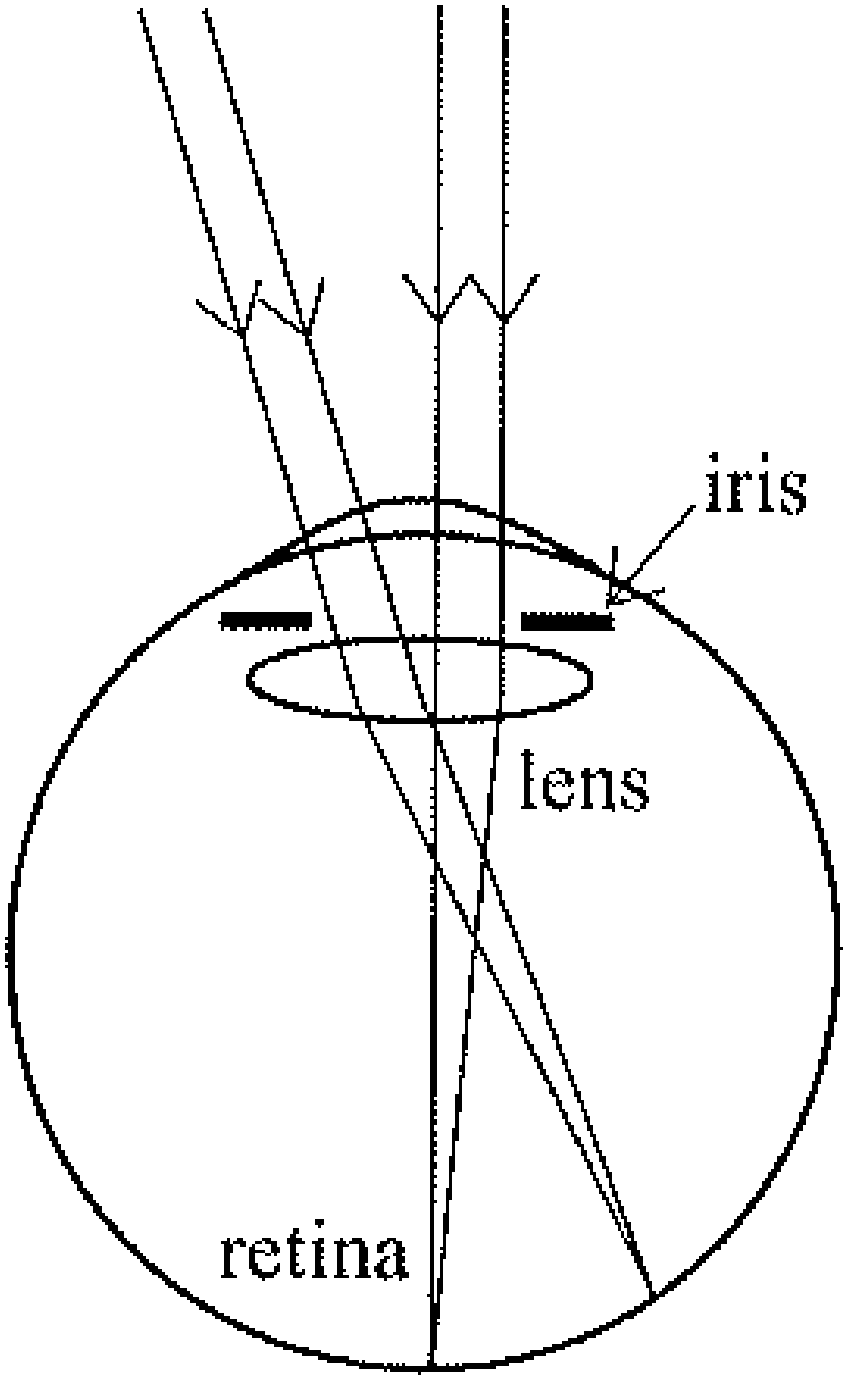
# The Electromagnetic Spectrum

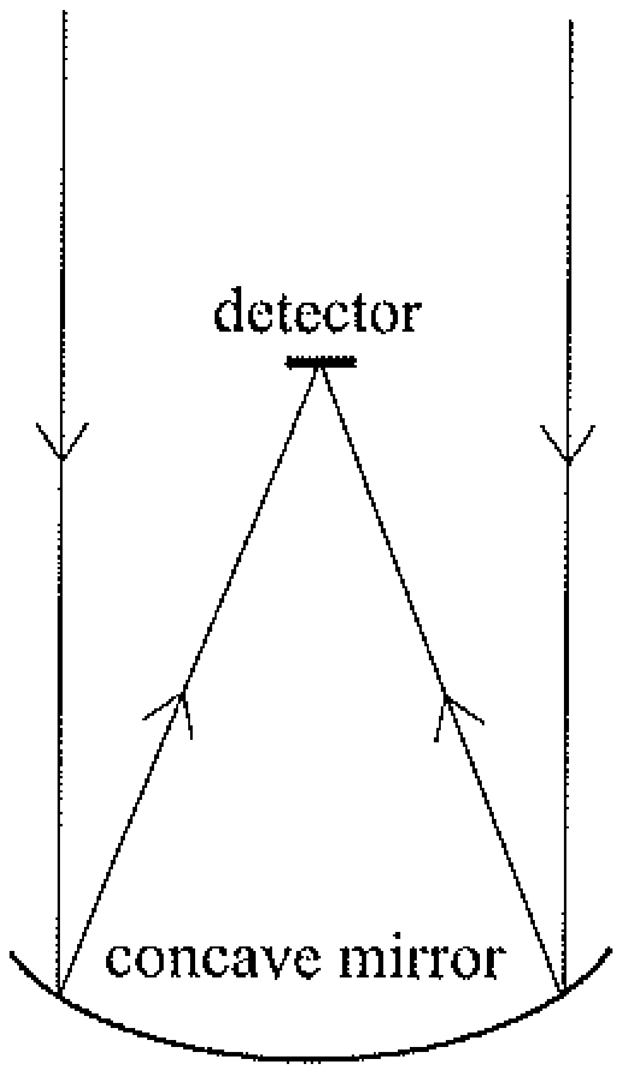


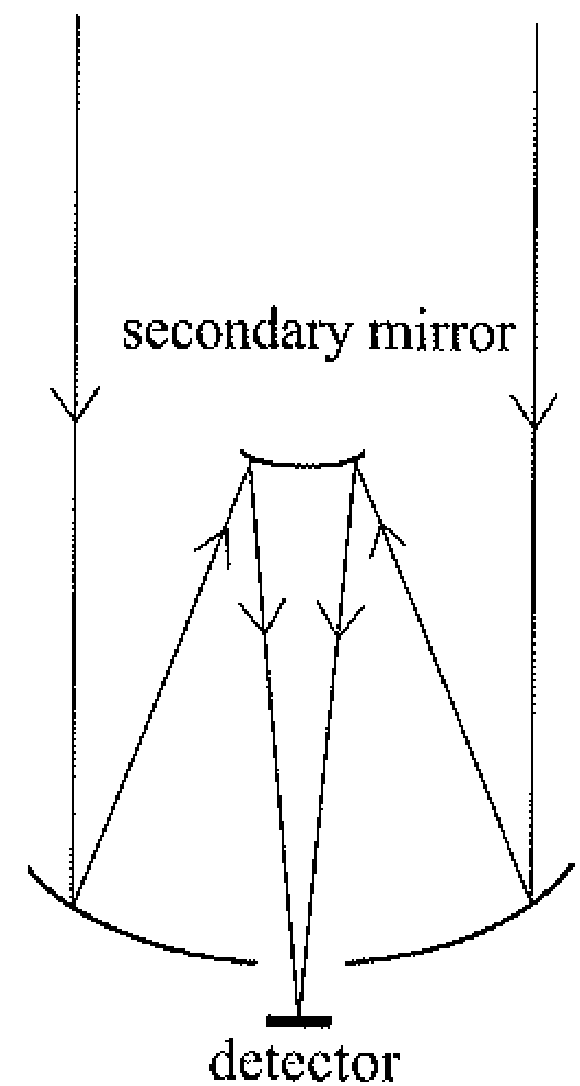
# Camera-Detector: Human Eye




- 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

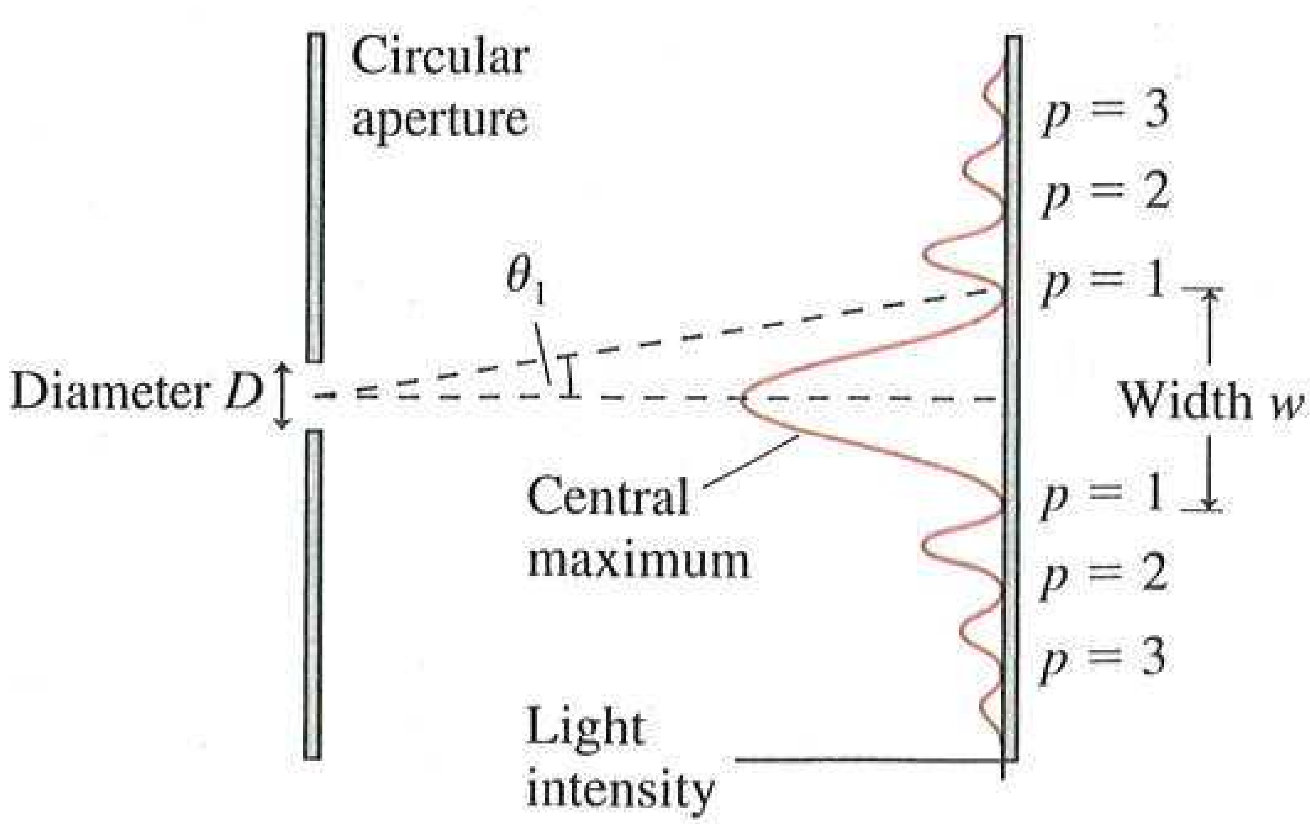



Detector at prime focus
Aperture is primary mirror.

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.

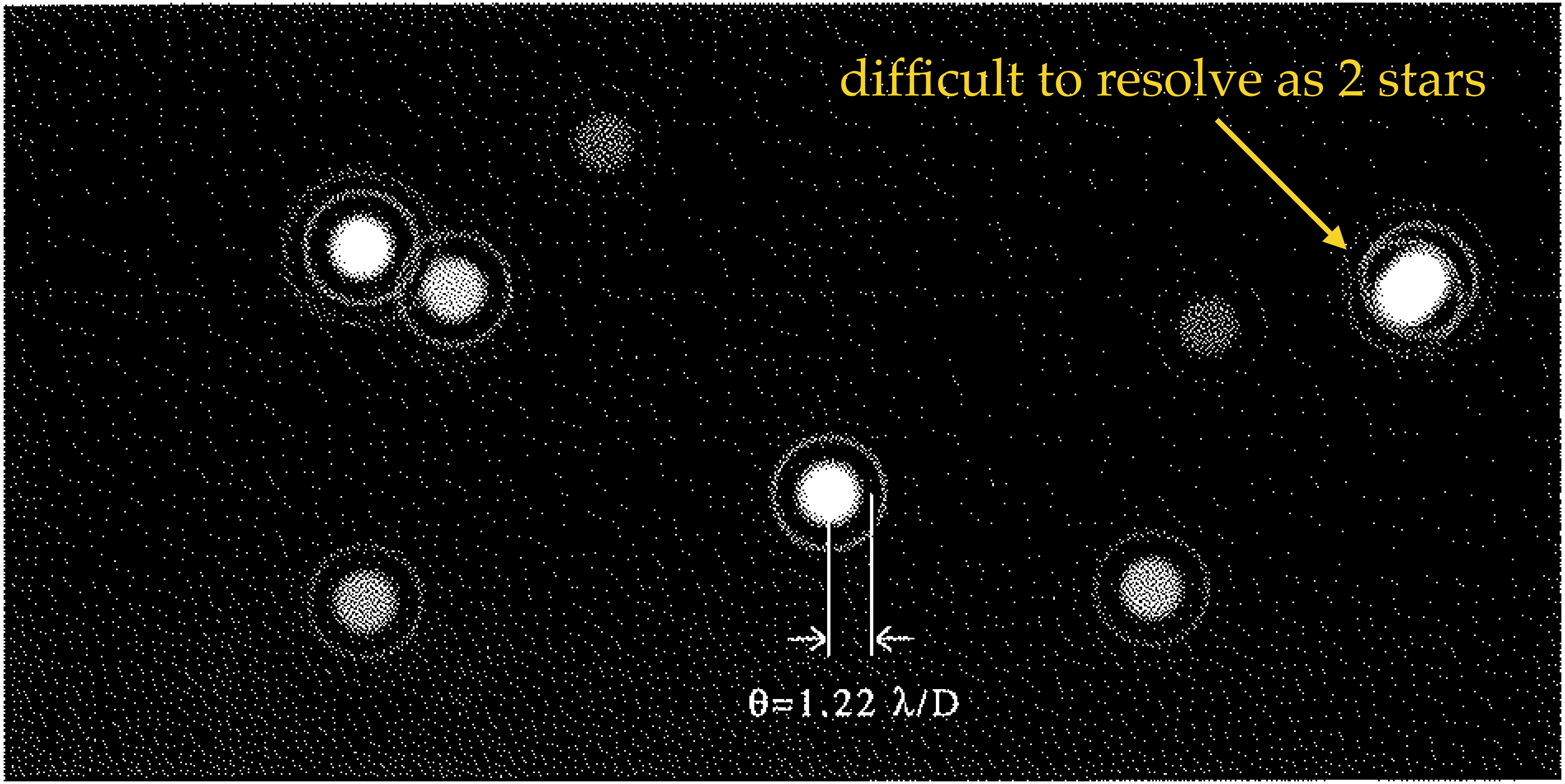
# Angular Resolution:

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.

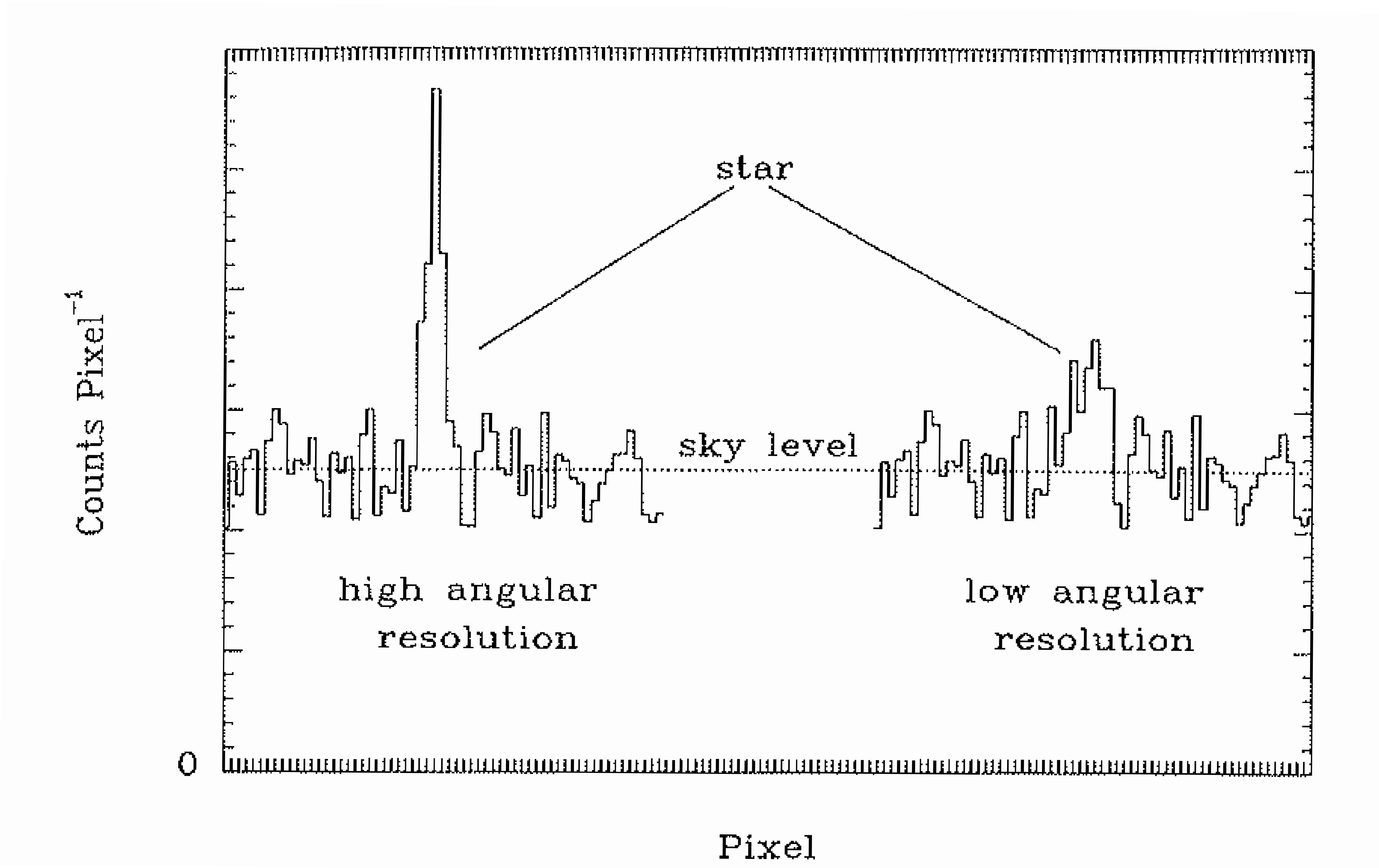
## Why is angular resolution important?

- 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.

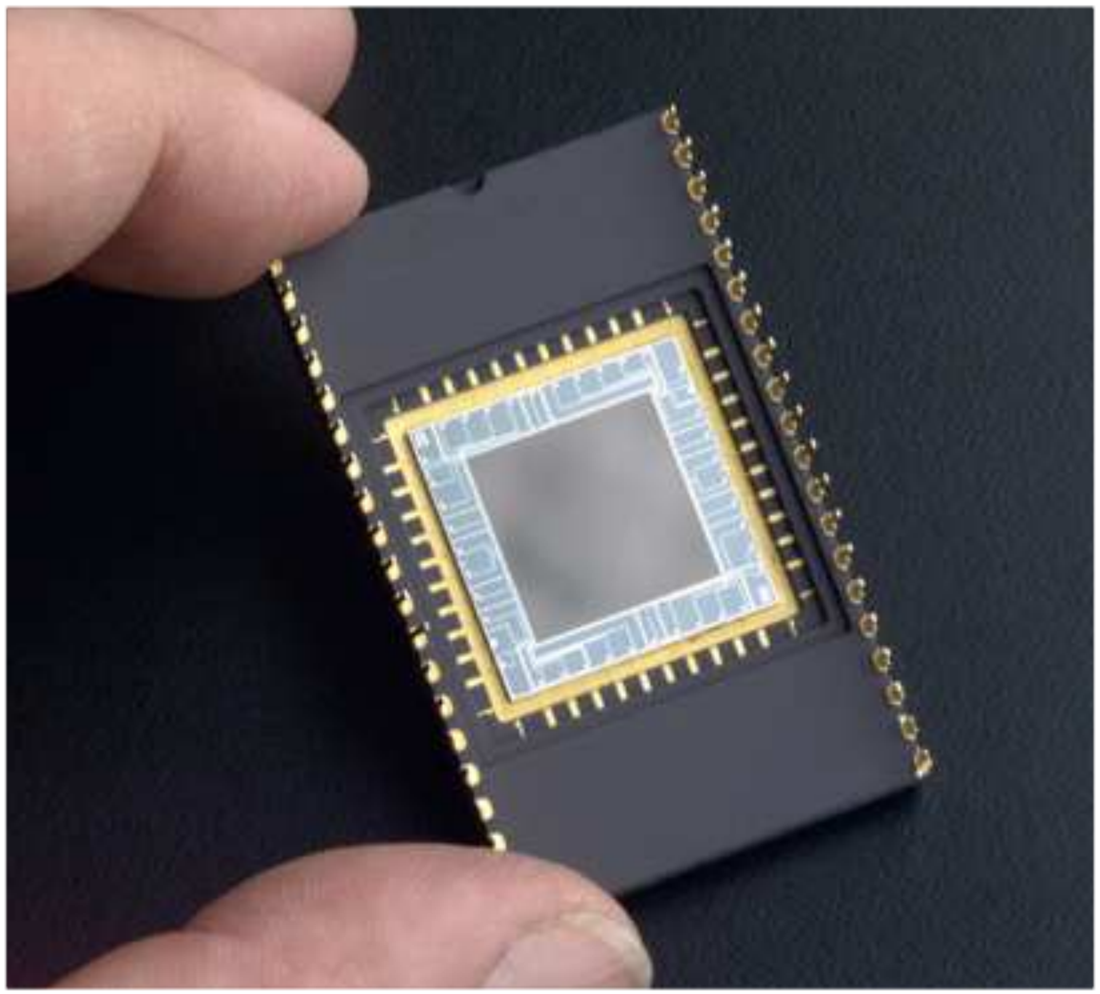
# Example: Positions of stars with two different instrument resolutions.



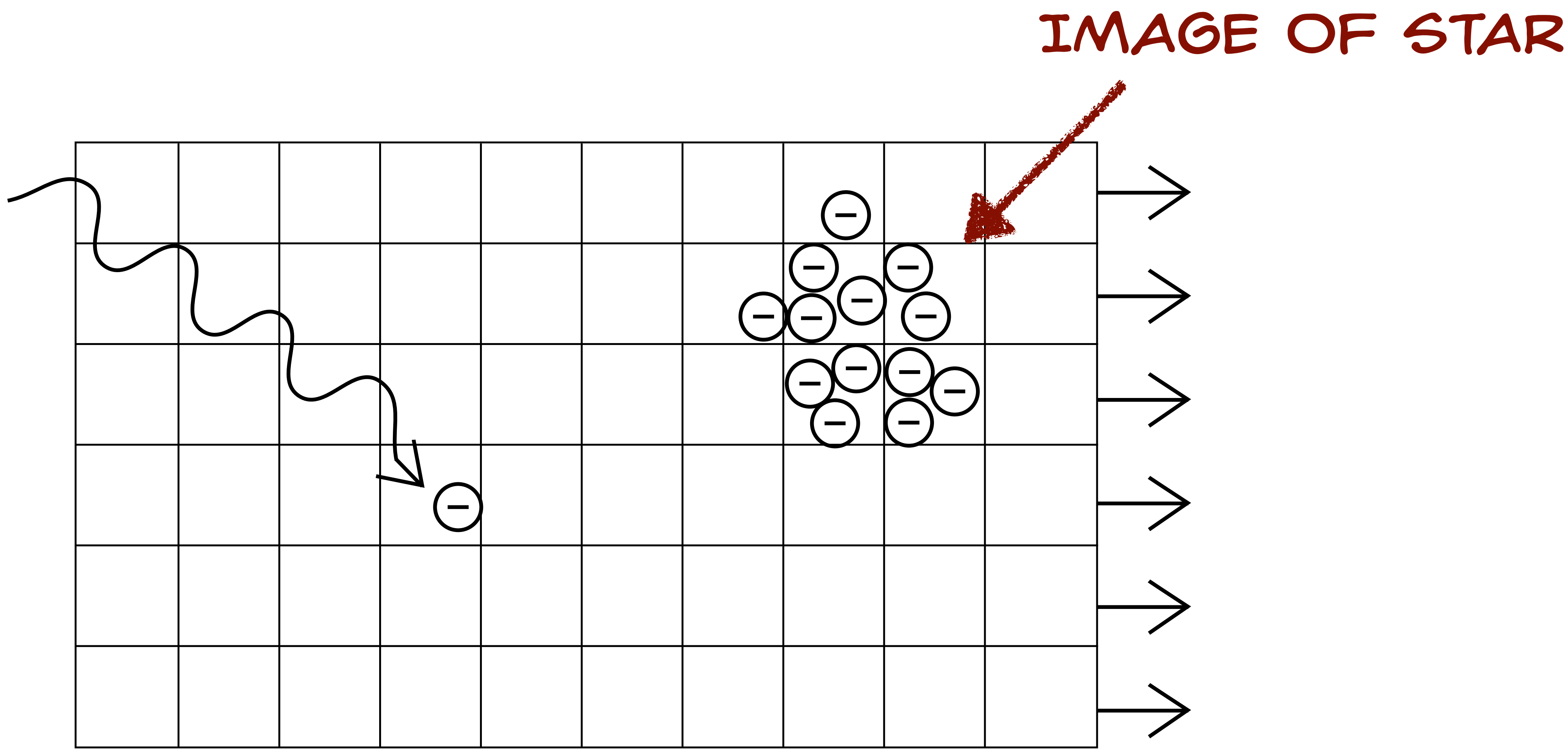
# Short Comings of Human Eye

- 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)



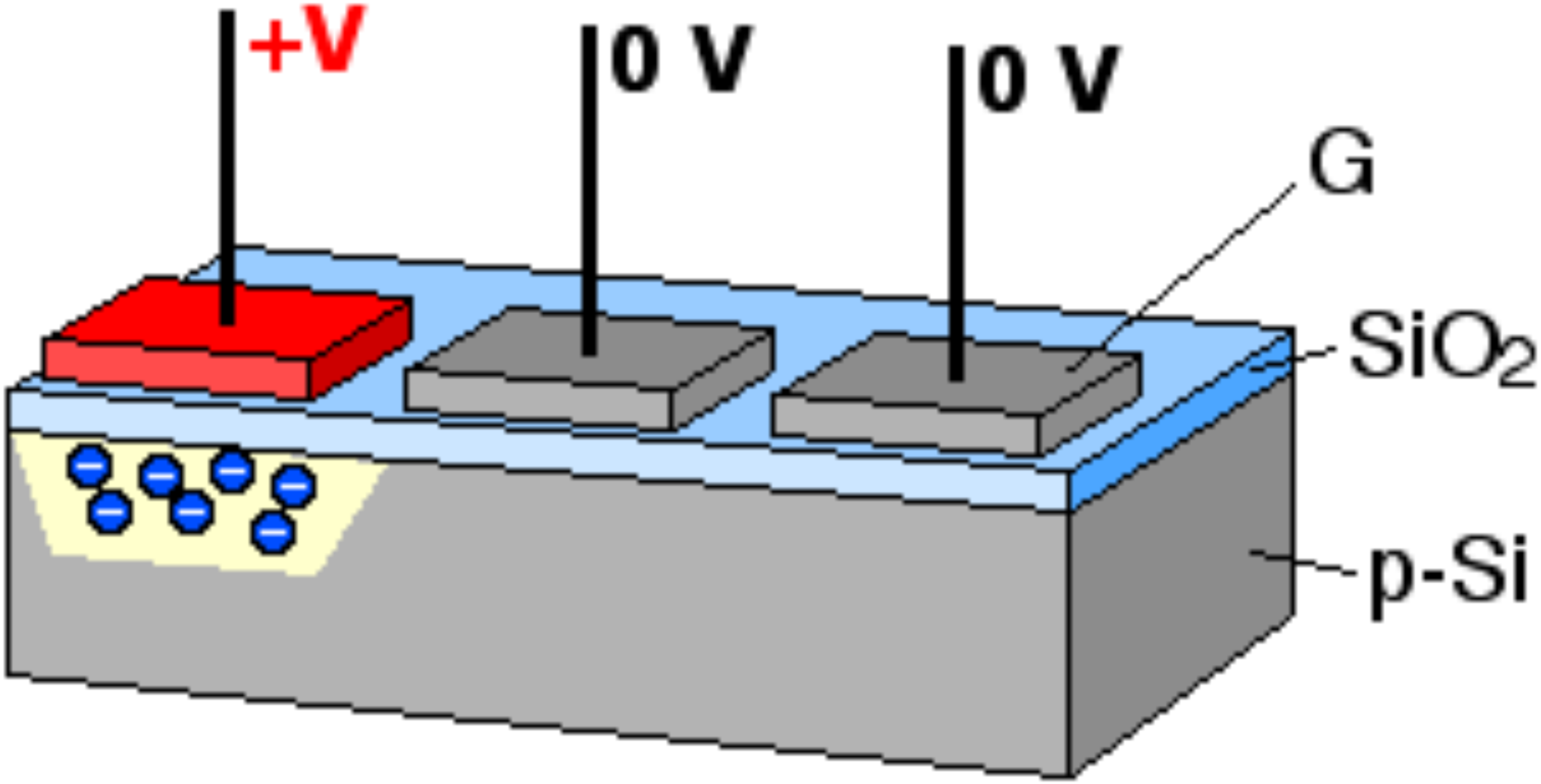
- First invented at AT&T Bell Labs by Willard Boyle and George Smith (1969).
- They were working on semiconductor bubble memory at the time.




- 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


+V
0 V
0 V
G
SiO2
p-Si

# 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:

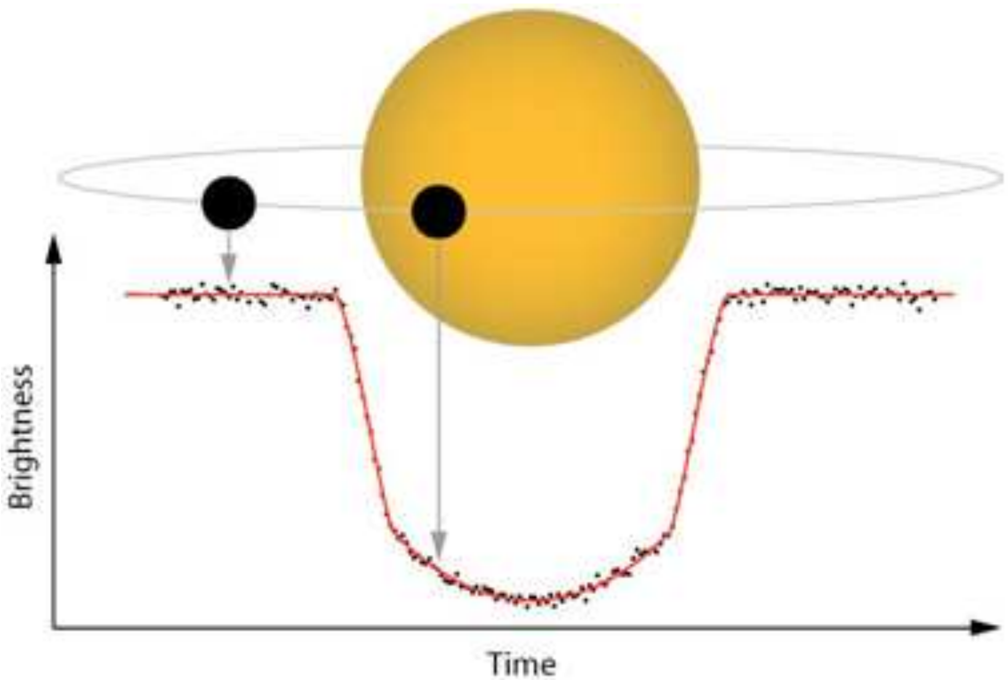
$$|\vec{k}| = \frac{2\pi}{\lambda} \qquad \text{and} \qquad \nu = \frac{\lambda}{c}$$

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 $\langle E^2 \rangle$

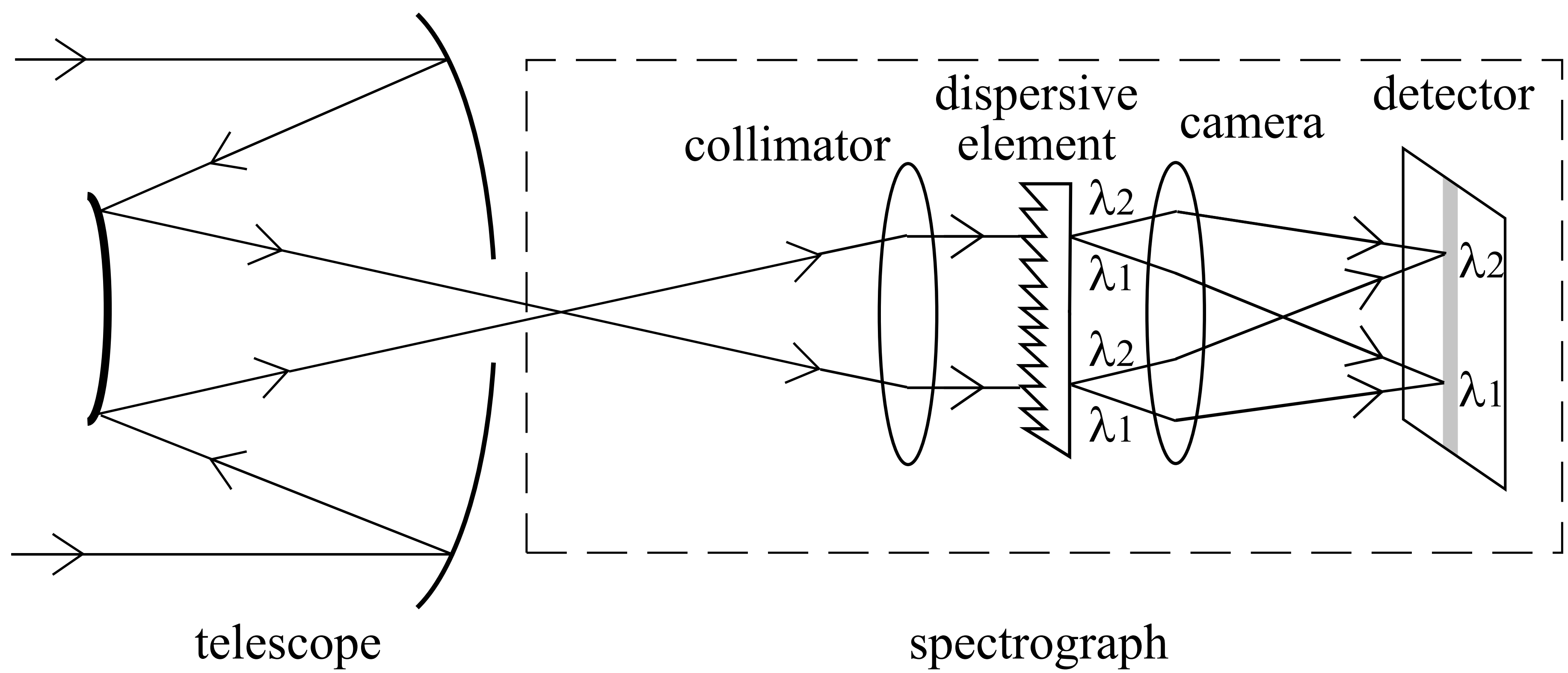



combined with inverse square law, determine luminosity if distance known (or vis versa)
study of light variation in variable stars, minor planets, AGN, supernova and transient exoplanets.

## Wavelength and Frequency —

- 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.