LECTURE 7

Low Energy Telescope Design and Instrumentation

Optical Astronomy

- Ultraviolet
- Visible
- Infrared

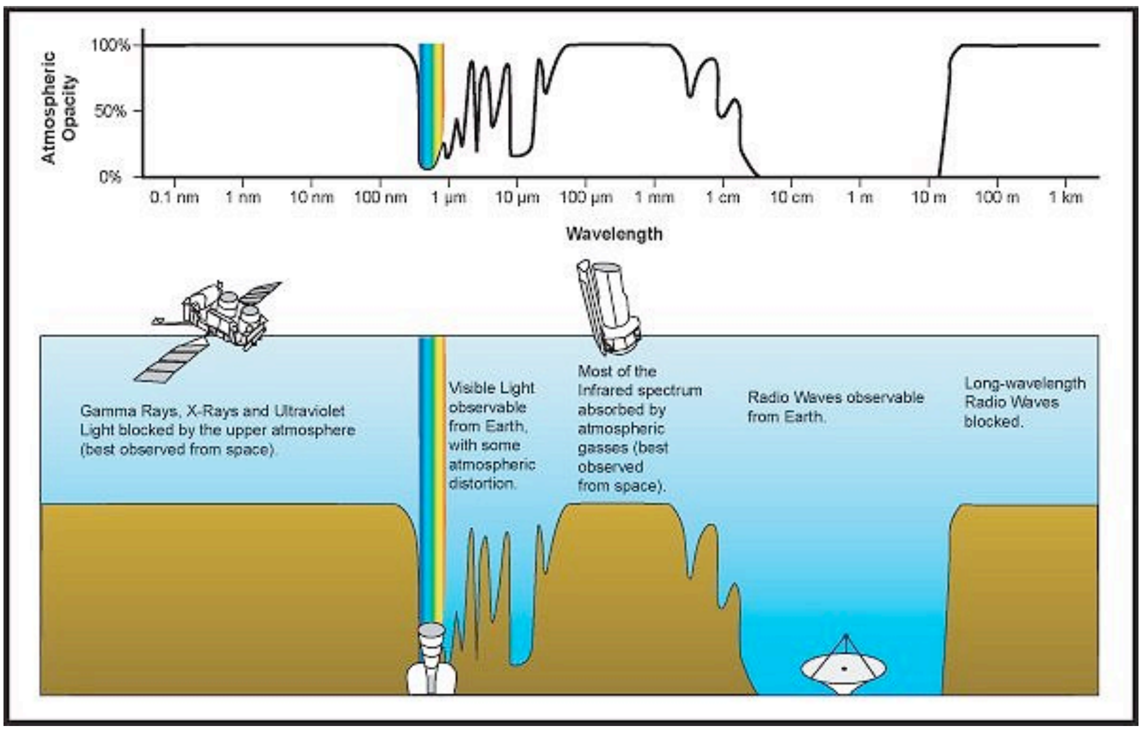
- "Visible" and "optical" are often interchangeable
- Light that humans can see (and a bit more)
- ≈3500 Å – ≈8000 Å

- Oldest branch of astronomy

Main Types of Optical Observations

- Imaging
- Photometry
- Spectra
- Polarimetry

Atmosphere transparent in three bands



- Optical
- Infrared

  with many absorption bands due to H_2O, CO_2, O_2, etc.
- Radio

Most astronomy is optical, although this is changing

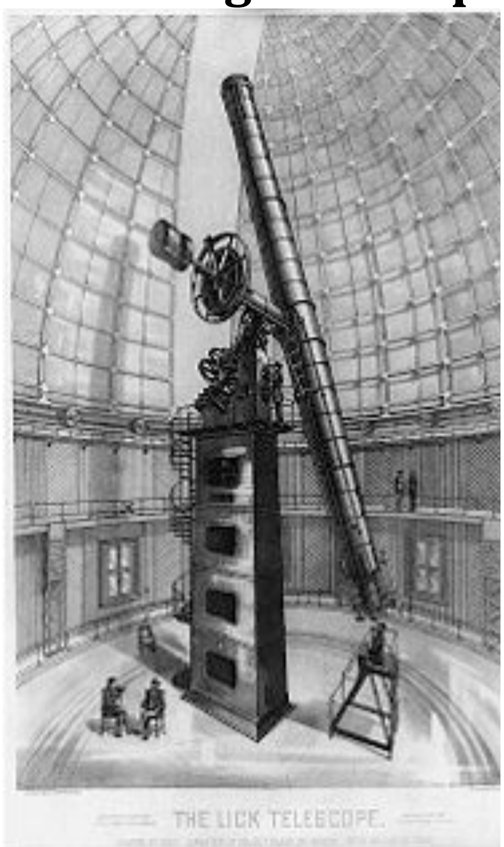
- Atmosphere is transparent
- Many facilities available
- Long history
- Thermal processes (blackbody radiation) tend to peak in or near optical

Optical Telescope Design

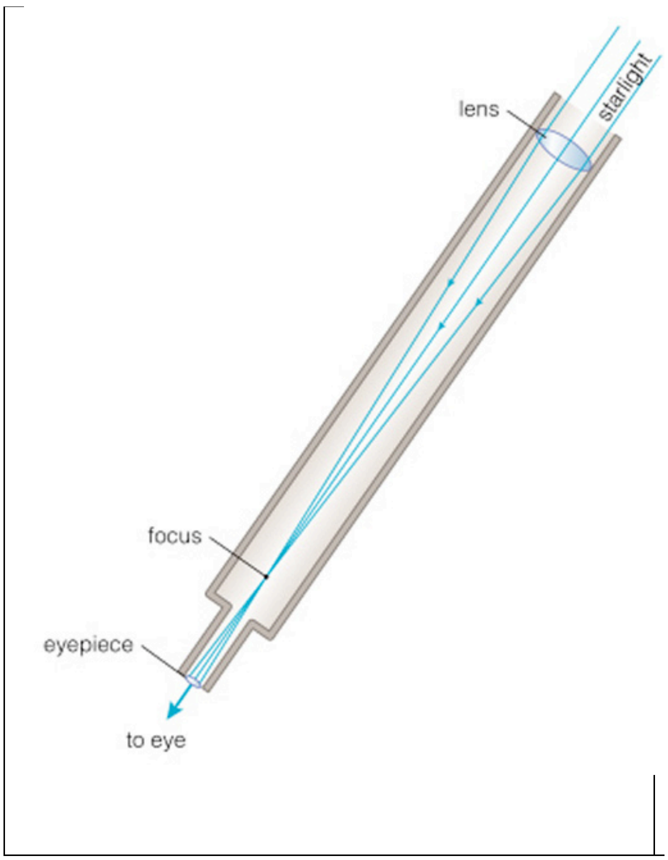
Two basic designs

- Refracting telescope
- Reflecting telescope

Refracting Telescopes



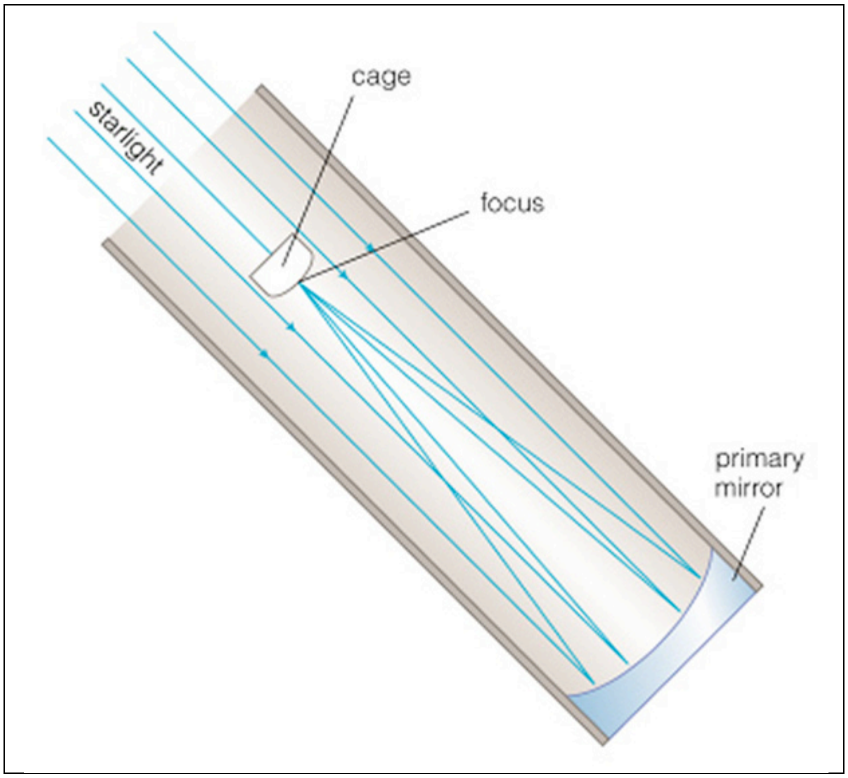
- Invented in 1600s
- Tube with a single lens (the objective) and an eyepiece



Refractors are not used much in professional astronomy anymore

- Chromatic & spherical aberration
- Hard to make large telescopes
- Lenses suffer from contamination

Reflecting Telescopes



Tube with a mirror at one end
Light is reflected to a focal plane

Invented in 1663 by James Gregory

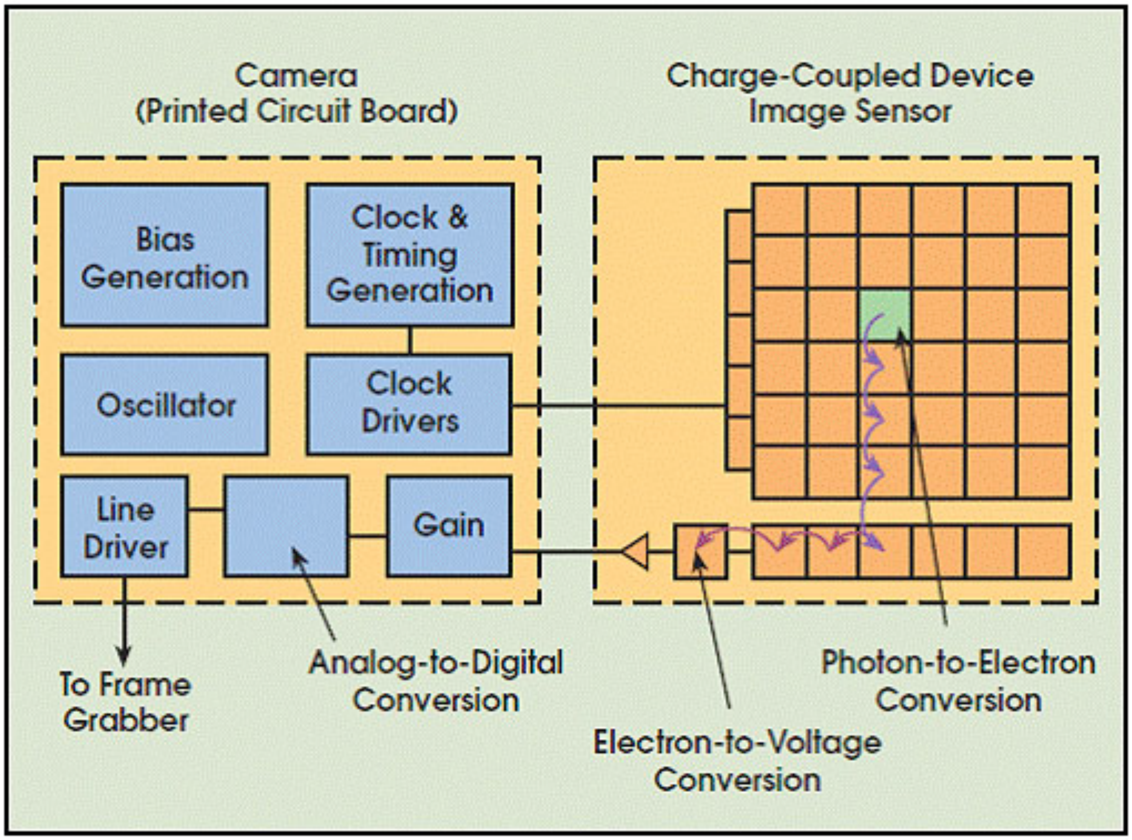
- Large objective mirrors, light gathering power
- Easy to incorporate instrumentation

Instrumentation

Many types of optical instrumentation

- 0-d
  - photometry
  - polarimeter
- 1-d
  - spectrograph
- 2-d
  - photographic plate
  - ccd imager

Most common detector is a **charge-coupled device** (CCD).



Exposure starts

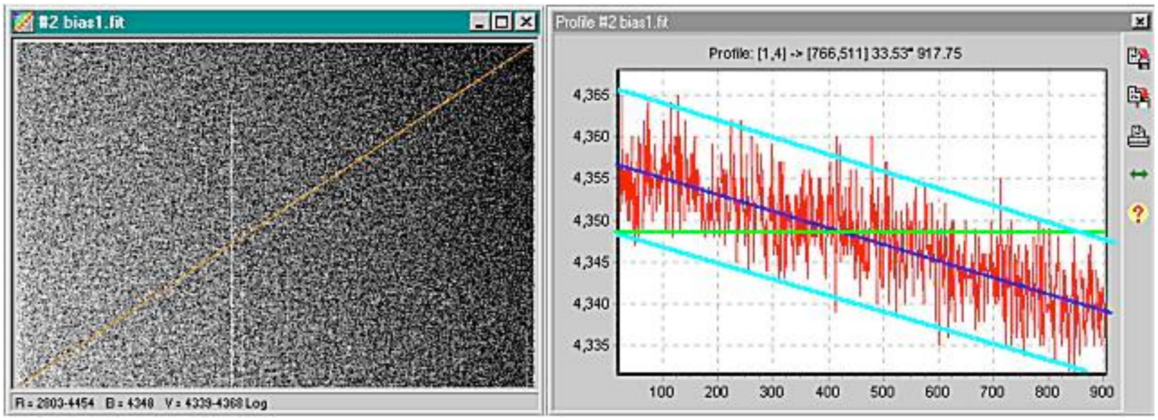
- *N* photons land on a pixel
- Pixel accumulates a charge

Exposure ends

- The charge in a pixel is shifted one pixel down each column to a readout row
- The last row is shifted into a readout row
- The charge is shifted along the readout row to a charge amplifier, then through an analogue-to-digital converter, and then stored
- The processed is timed in order to reconstruct a 2-d image.

Instrumental Effects

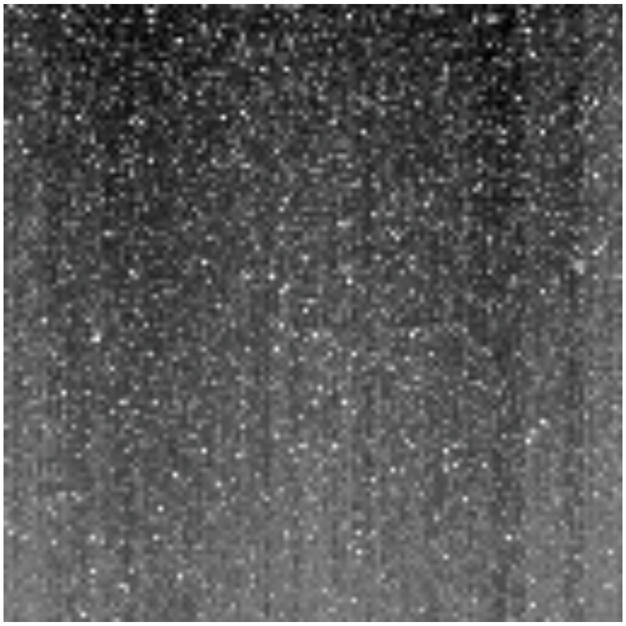
Bias



- CCDs operate with a pedestal voltage
- Slightly different in each pixel
- Need to be subtracted off

- Take several 0-second exposures with closed shutter
- Take the average
- Subtract this from the data

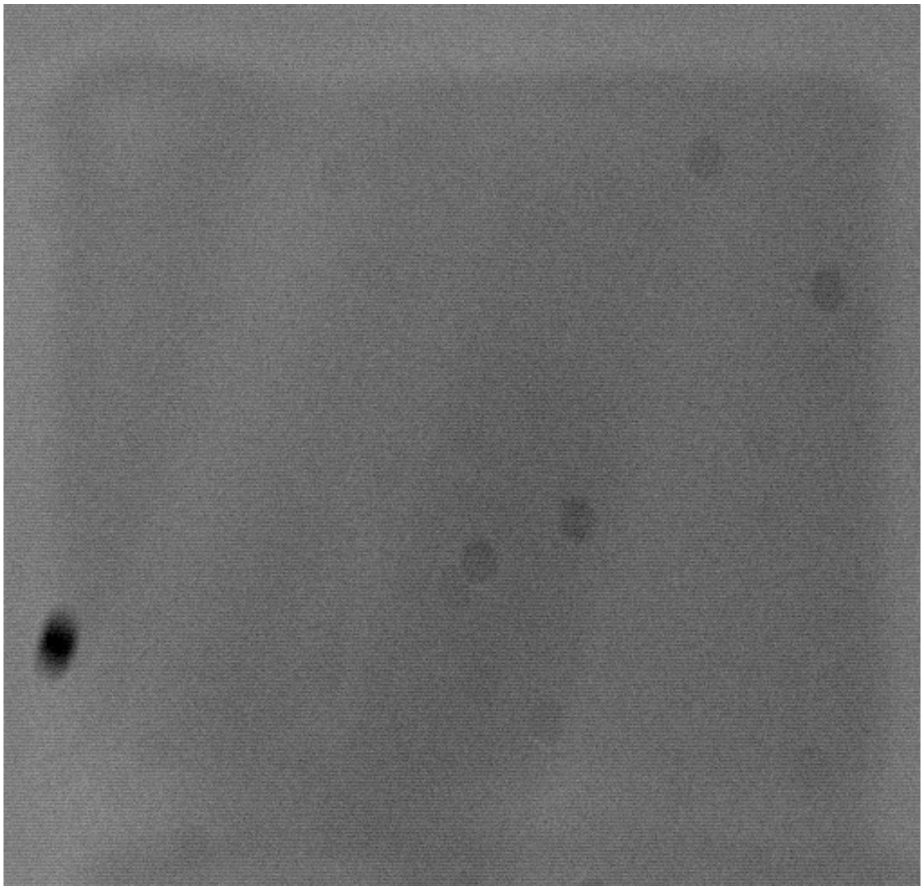
Dark Current



- Caused by random currents in the detector
- Dark current is usually very small
  - A few electrons per hour
- Can be significant for long exposures

- Take an image with the shutter closed with the same exposure as the data image
- Subtract this from the bias-subtracted data image

Flat Field Correction



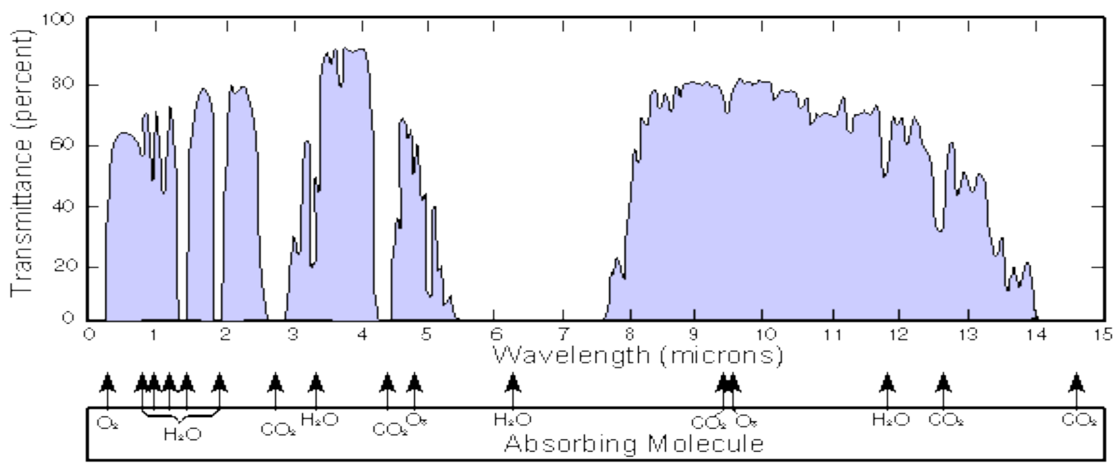
- Corrects for pixel-to-pixel sensitivity variations

- Take an exposure of a uniform field
    - Twilight sky
    - Blank area of the night sky
    - Illuminated screen
- Average many exposures
- Normalize the image
- Divide dark-subtracted data by the normalized flat

Infrared Astronomy

Wavelengths: ≈8000 Å and ≈ 1 mm
Main Infrared Bands

Wavelength (μm)	Band	
0.65–1.0	*R* and *I*	All major optical telescopes
1.25	*J*	Most major optical telescopes and most dedicated infrared telescopes
1.65	*H*	Most major optical telescopes and most dedicated infrared telescopes
2.2	*K*	Most major optical telescopes and most dedicated infrared telescopes
3.45	*L*	Most dedicated infrared telescopes and some optical telescopes
4.7	*M*	Most dedicated infrared telescopes and some optical telescopes
10	*N*	Most dedicated infrared telescopes and some optical telescopes
20	*Q*	Some dedicated infrared telescopes and some optical telescopes
450	Sub-mm	Sub-millimetre telescopes



- Atmosphere is only only transparent in some infrared bands
- Need space-based observatories

- **Near-Infrared**
  - 7000 Å – 5 μm
- **Mid-Infrared**
  - 5 μm – 40 μm
- **Far-Infrared**
  - 40 μm – 350 μm

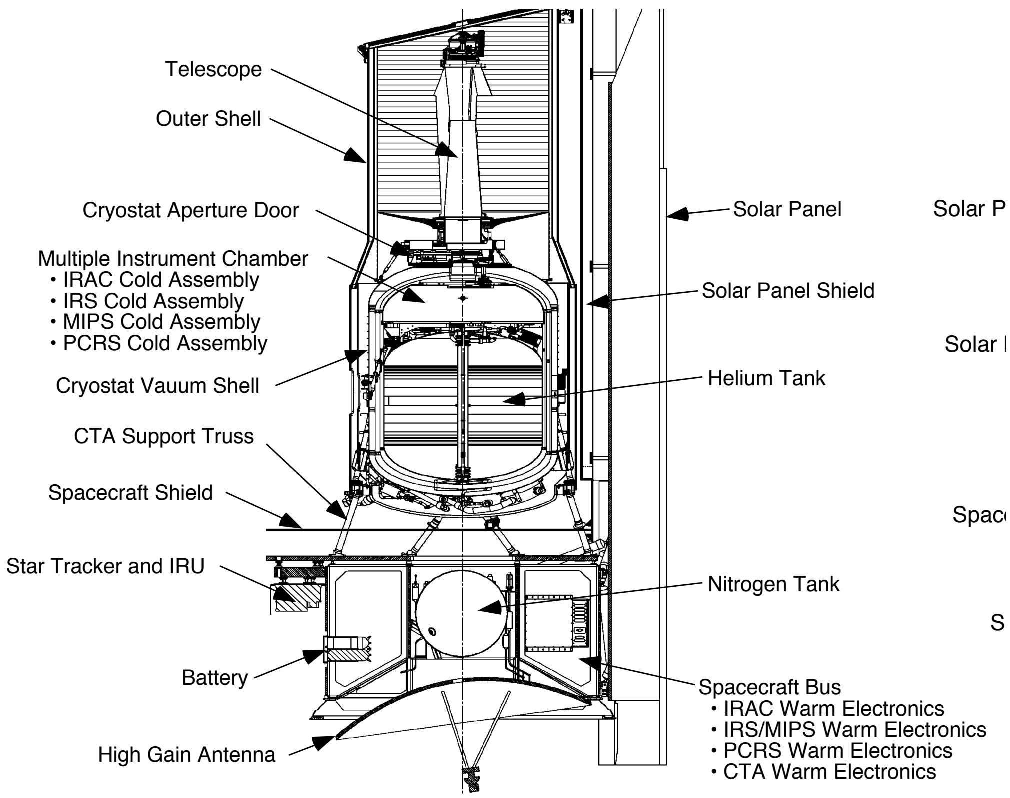
Infrared Science

- protostars
- cool objects
  - brown dwarfs
  - exoplanets
- dust
- AGNs
- high-redshift galaxies

Infrared Telescopes

Near- and mid-infrared telescopes similar to optical telescopes

Spitzer Space Telescope



High thermal background so cooling is needed

- At L2, away from Earth
- Always points away from the Sun
- Active cyrogenic cooling to 4 K
- Coolant ran out in May 2009
- Currently running "warm" mission

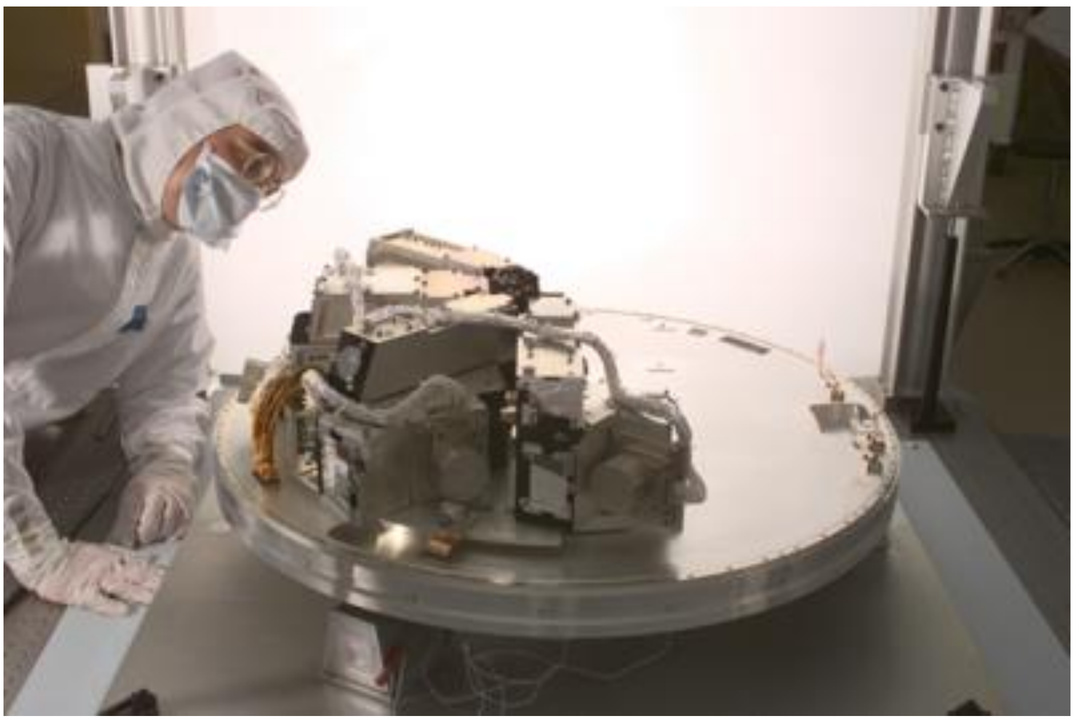
Spitzer Instruments

Infrared Array Camera (IRAC)

- Obtains infrared images
- 4 wavelength simultaneous observations: 3.6 μm, 4.5 μm, 5.8 μm, and 8 μm

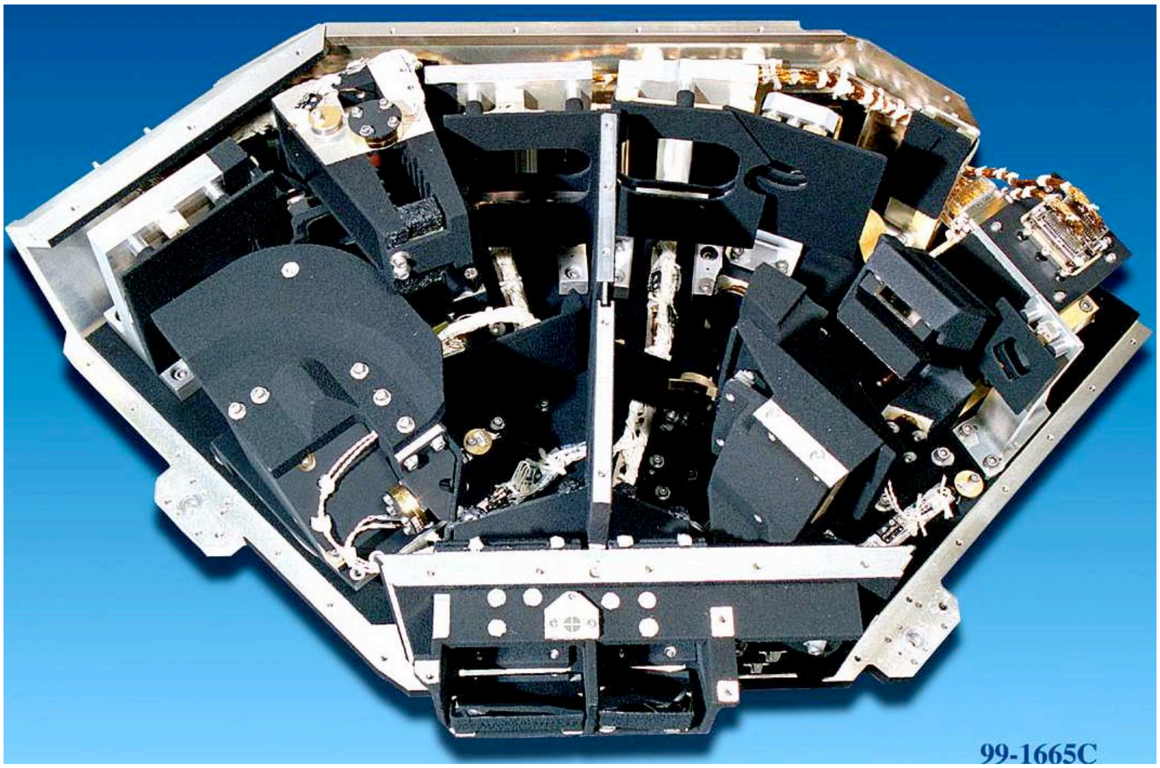
Infrared Spectrograph (IRS)

- Infrared spectrograph with four bands
    - 5.3–14 μm (low resolution)
    - 10–19.5 μm (high resolution)
    - 14–40 μm (low resolution), and
    - 19–37 μm (high resolution).



Multiband Imaging Photometer for Spitzer (MIPS)

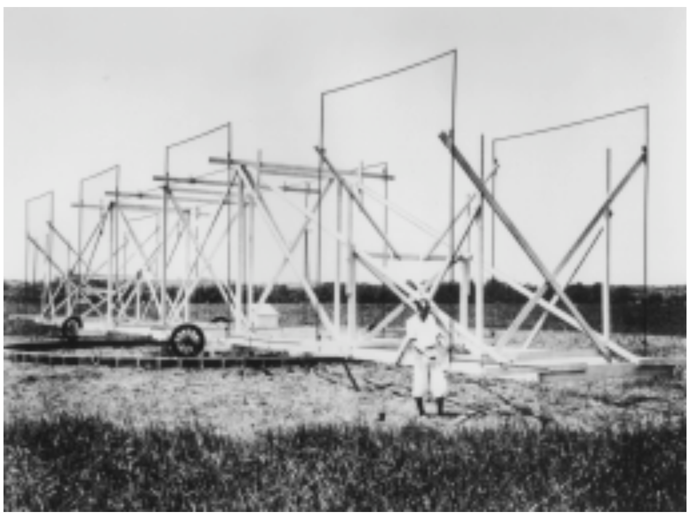
- Far infrared
- 24 μm, 70 μm, and 160 μm



Radio Astronomy

Radio astronomy covers everything longer than ≈1 cm.

Radio astronomy started in 1930 with Karl Jansky's investigation into radio noise.



- Discovered a "noise" signal that came from a fixed direction in the sky.
- Signal matched sidereal day ➔ celestial source.
- Direction corresponded to the centre of the Milky Way.

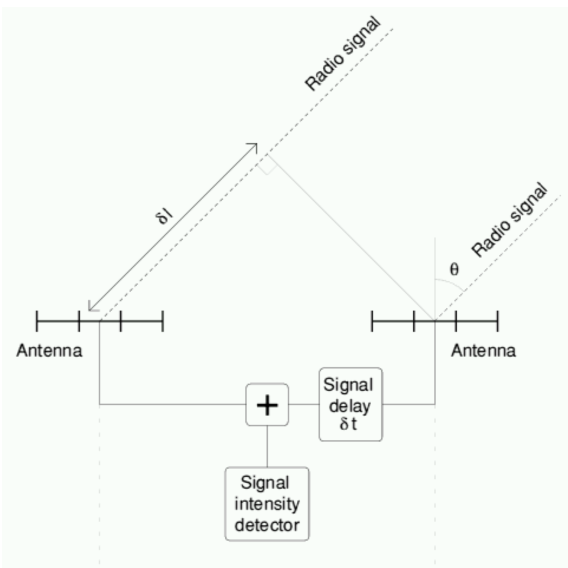
Radio Telescopes

- Dish antenna
- Parabolic dish to focus radio waves
- Directional
- Can produce radio maps

Interferometric Arrays

- Link physically separated antennae to form a virtual telescope
- Increases the collection area
- Aperture synthesis

Aperture Synthesis



- Combine signals from multiple antennae so that they are in phase.
- Coherent addition leads to a telescope with an effective diameter equal to the separation between the antennae.

VLBI Array

- Combine data from several radio telescope sites
  - Hawai`i
  - North America
  - Caribbean
- Longest baseline ≈5000 km
- Effective dish diameter ≈5000 km
- Resolution goes as inverse of diameter
- $\theta \approx$ milliarcseconds