Talk about

Optical Telescopes and Instrumentation

by
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Overview

- **powers of telescopes**
- **lens refractors, mirror reflectors**
- **interferometry, spectroscopy, optical systems**
- **modern observatories**
- **instrumentation**
- **outlook**

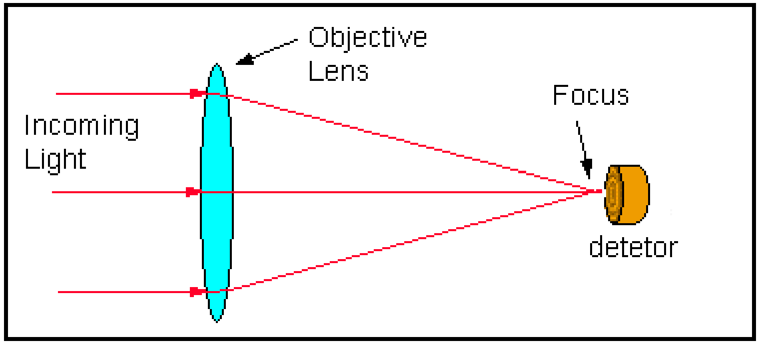
Powers of Telescopes

- light gathering
- resolution
  - ability to see really small objects
  - atmosphere usually smear images which may be avoided by speckle interferometry and adaptive optics
- magnification (less important)
  - ability to make images bigger

Kinds of Telescopes

- refracting telescopes
- reflecting telescopes
  - Newton Reflector
  - Cassegrain Reflector
  - Schmidt Reflector

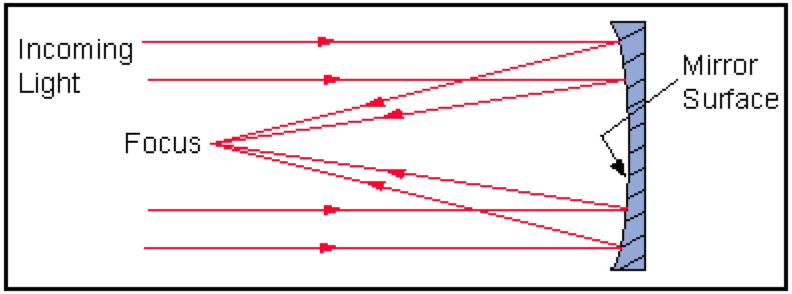
Refracting Telescopes



- lenses are used to bend light
- disadvantages
  - chromatic aberration
    - compensation by using multiple lenses
    - long objective focal length
  - huge mass
    - tends to sag under own weight, so 40 inches is maximum size
  - support for large lenses is not easy

Reflecting Telescopes

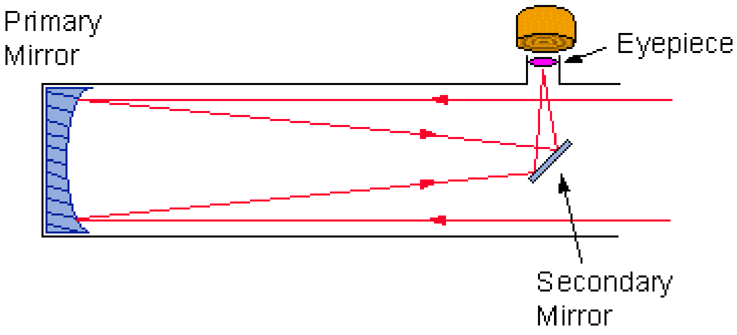
- parabolic-shaped mirrors with metal coated surfaces focus parallel light rays to single point
- advantages



  - no chromatic aberration
  - telescope tubes are shorter
  - mirrors can be better supported
  - glasses with very low thermal expansion may be used
- disadvantages
  - spherical aberration due to badly curved mirrors

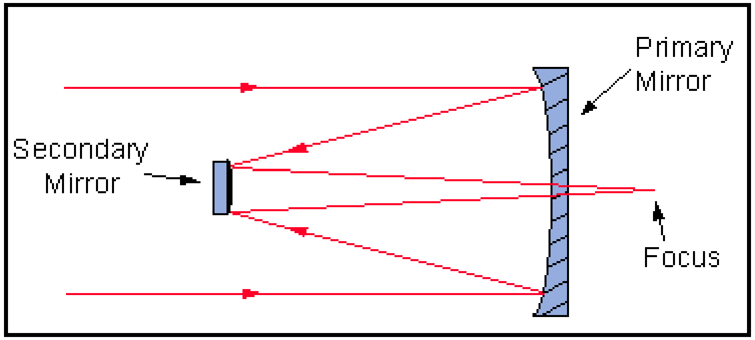
Newton Reflector

- common in small telescopes
- a small mirror reflects the light off to the side of the tube
- the loss of light by secondary mirror is small compared to total light-gathering



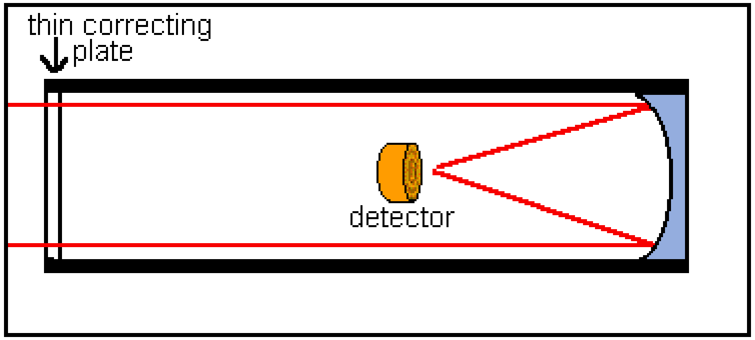
Cassegrain Reflector

- using a small convex mirror to reflect the light back through a small hole in the primary mirror
- detectors can be placed directly behind the telescope



Schmidt Reflector

- both a mirror and a correcting lens are used to avoid distortion
- a Schmidt and a Cassegrain Reflector can also be combined

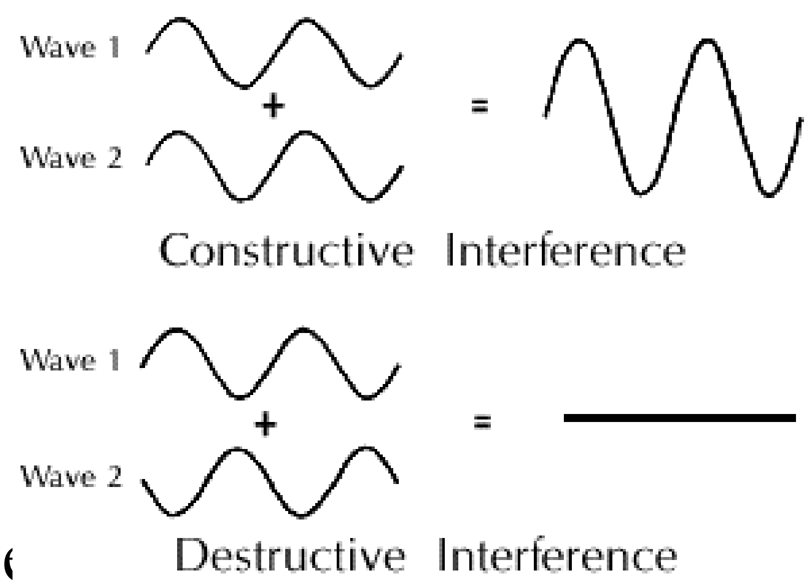


Technical Systems and Experimental Methods

- interferometry
- spectroscopy
- optical systems

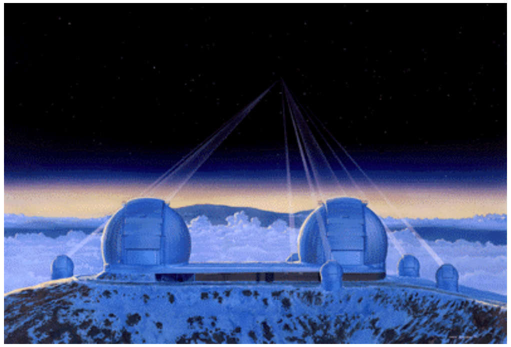
Interference

- adding two light waves causes interference
- either constructive or destructive interference depending on amplitude and phase shift
- constructive interference produces a new wave with twice the amplitude and four times the intensity of a single wave (I α $|A|^2$)



Advantages of Interferometric Telescopes

- specifications of each Keck telescope
  - mirror is 10 m in diameter
  - separation of 85 m from each other
- used as a two-element interferometer
  - light-gathering power of two 10 m telescopes
  - angular resolution of an 85 m telescope



Goals of Interferometry

- direct detection of warm giant planets nearby bright stars in the infrared wavelength range
- astrometric detection of planets using gravitational effects (Uranus-mass planets may be detected in up to 60 light years distance)
- high-resolution imaging of protoplanetary disk (using interferometric technique “nulling”)
- direct detection of brown dwarfs

Technical Systems of Interferometric Telescopes

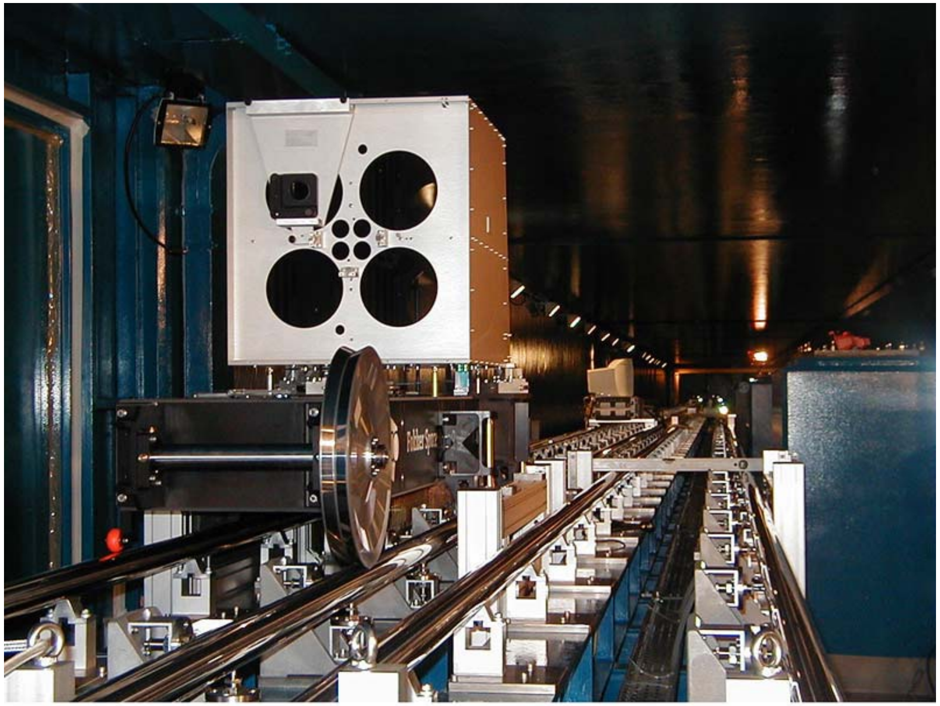
- adaptive optics system
  - removes the distortion of light caused by the atmosphere, so random delays in the light arriving time are avoided
- interferometric tunnel

VLTI Delay Lines in the Interferometric Tunnel

ESO PR Photo 26a/00 (11 October 2000)

Technical Systems of Interferometric Telescopes

- delay line retroreflector carriage
  - equalise the retardation of the light collected by each telescope (except for stars directly overhead)



VLTI Delay Line Retroreflector Carriage

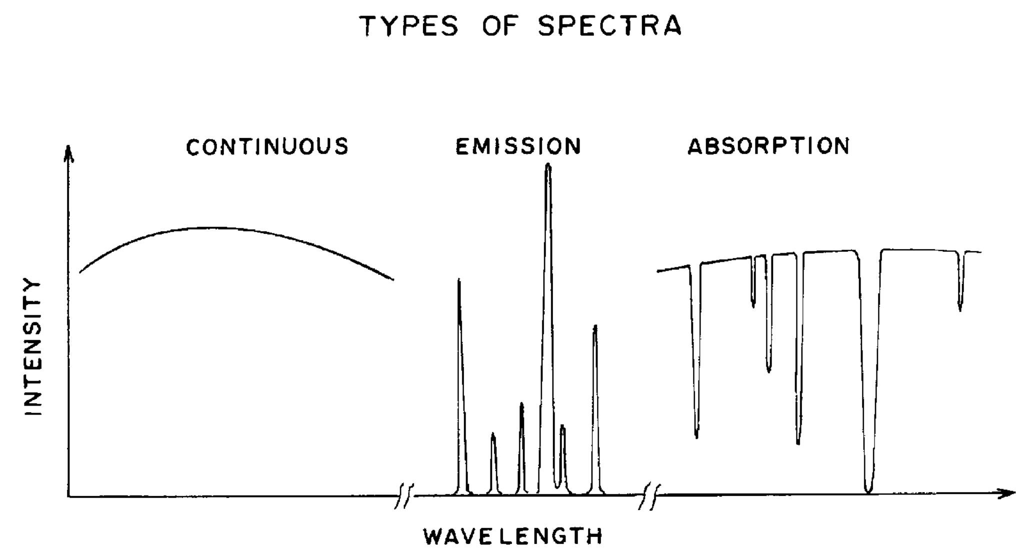
ESO PR Photo 26c/00 (11 October 2000)

Technical Systems of Interferometric Telescopes

- Fringe-tracker
  - measures the optical retardation caused by the spacial arrangement and the rotating earth and sends commands the retroreflector to keep light from each telescope in sync
- Angle-tracker
  - makes sure that both light waves overlap exactly for interference (minimise any tilts)
- Nulling Combiner
  - cancels the light of a star so nearby faint objects may be observed

Spectroscopy

- distribution of the light's intensity is measured over the wavelength so that it can be analysed to determine
  - chemical composition
  - temperature
  - radial velocity
  - rotational velocity
  - magnetic fields



Optical Systems

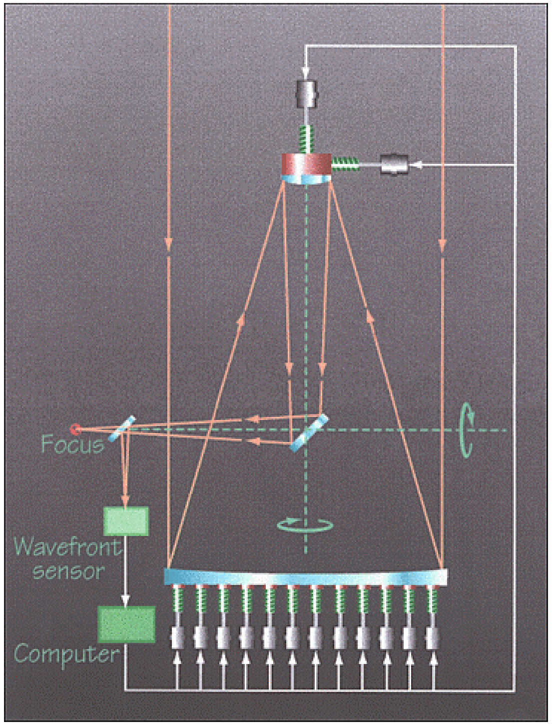
- different kinds of optics
  - passive and active optics
- adaptive optics
  - Why adaptive optics?
  - How does an adaptive optics system work?
  - What is the profit of adaptive optics?
  - What are the limitations to adaptive optics?

Passive Optics

- just mechanical improvements minimise errors
  - improved mirror polishing
  - stiffer mirrors reduce gravitational deformations
  - low-expansion glass avoids mirror distortion during day and night variations
  - an air conditioned dome shields the telescope from wind

Active Optics

- applying controlled forces to the primary mirror by actuators
- moving the secondary mirror in order to cancel these errors



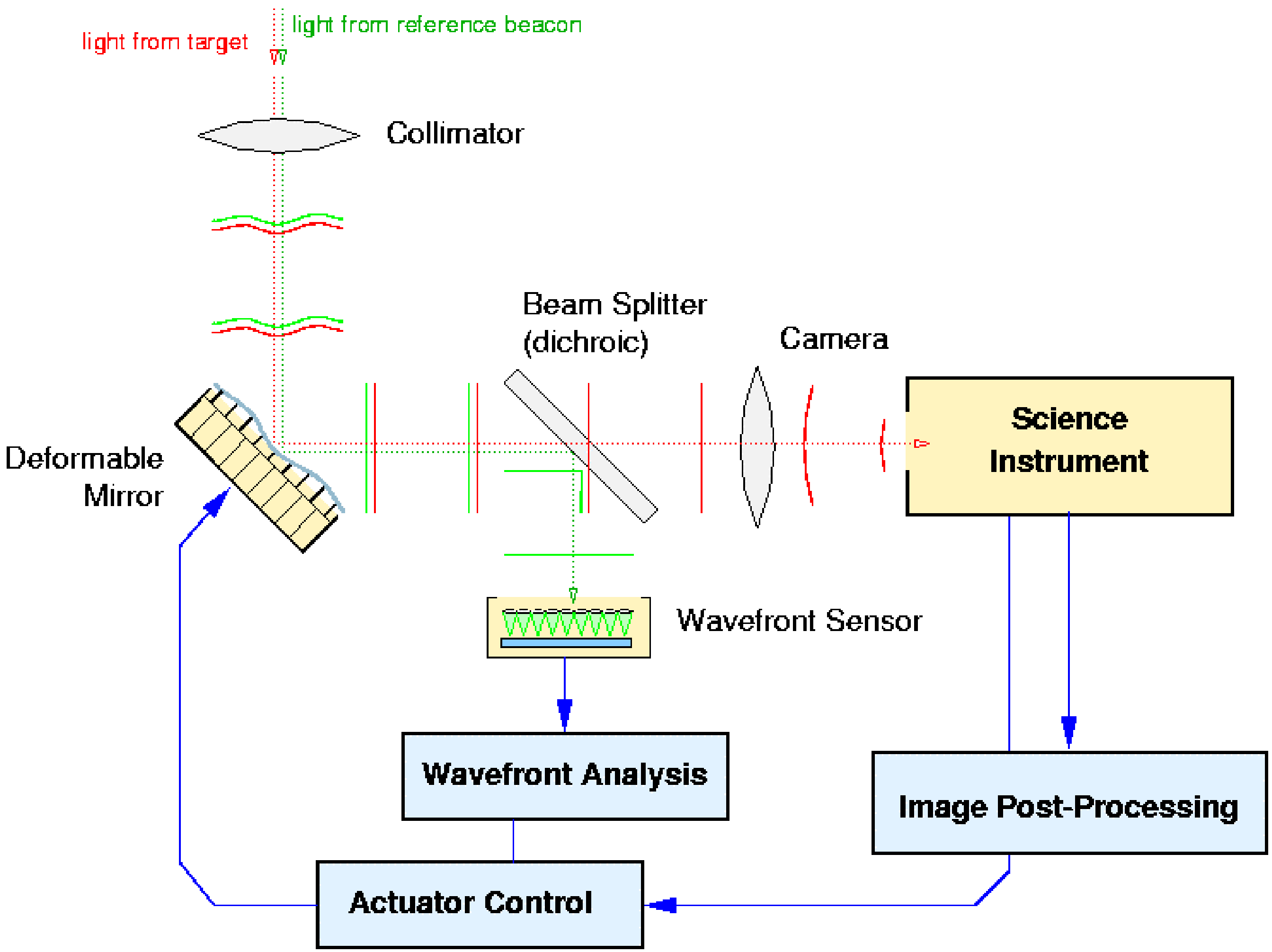
Adaptive Optics
Why adapative optics?

- under ideal circumstances the resolution of an optical system is only limited by the diffraction of light waves ($\alpha = 1.22 \cdot \lambda / D$)
- in practice these limits cannot be reached because light becomes additionally distorted in the earth's atmosphere
- atomspheric blurring can be avoided
  - by going into space (as the HST does)
  - by using adaptive optics

Adaptive Optics
How does an AO system work?

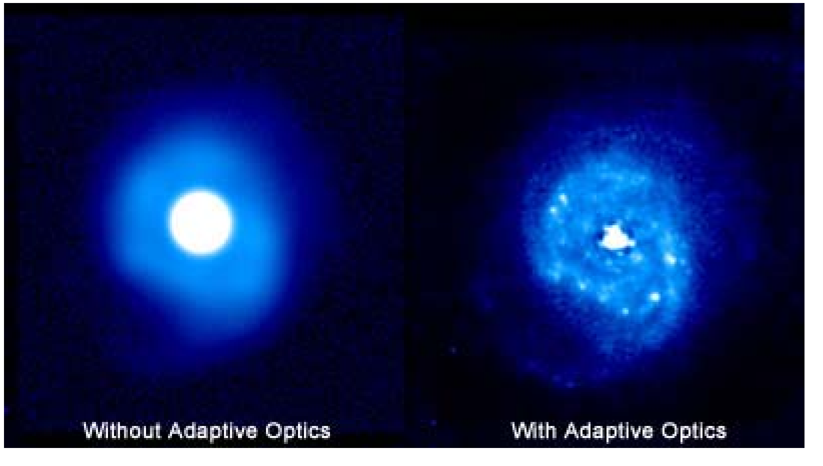
- a reference beacon is used to probe the shape of the lightwave (a bright star or an artificial laser spot)
- light from this reference source is analysed by a wave front sensor
- actuators change the surface of small mirrors in order to the sensor's commands
- the shape of these mirrors is updated several hundred times per second

Schematic of an Adaptive Optics System



Adaptive Optics
What is the profit of AO?

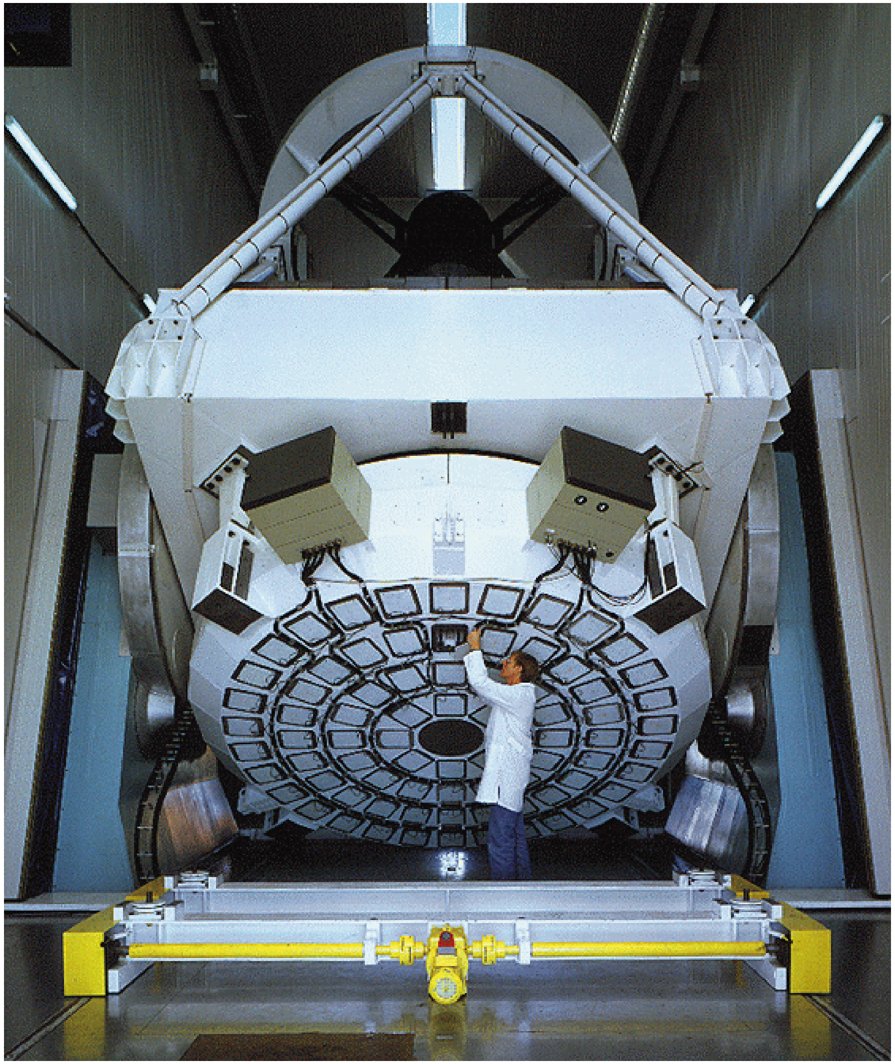
- improved imaging, so very faint objects can be imaged in long exposures
- spectroscopy becomes possible on very small angular scales
- interferometry becomes possible because of no more random delays in the light's arrival time of each telescope



Adaptive Optics
What are the limitations to AO?

- problem
  - only a tiny fraction of the sky is nearby bright stars that can serve as reference beacons
- solution: laser guide stars (LGS)
  - powerful lasers excite sodium atoms high in the atmosphere (90 km), producing an artificial star that can be placed near any region of interest

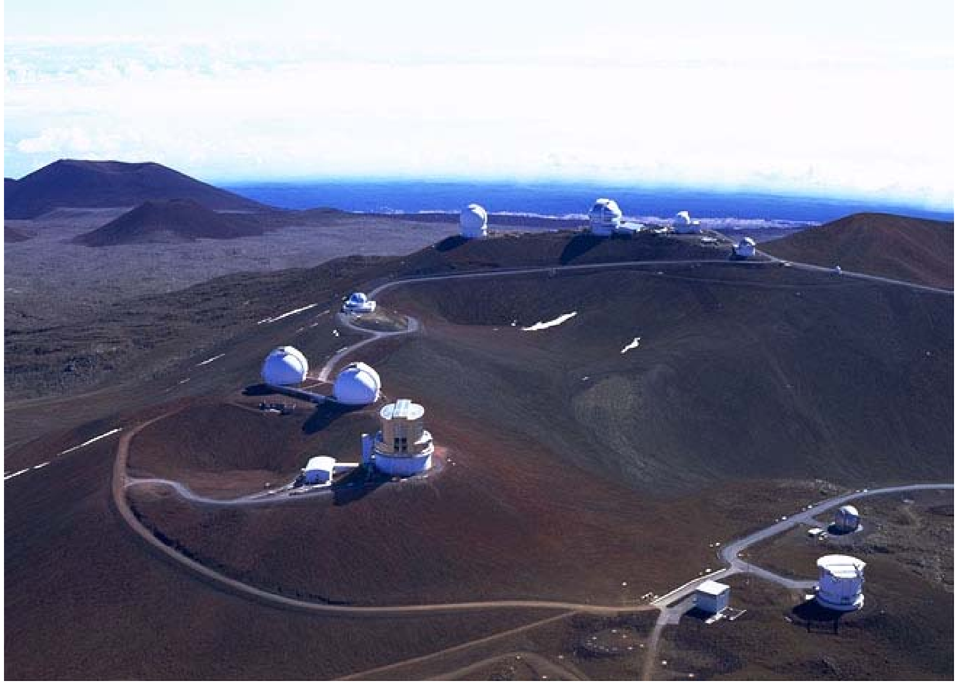
Adaptive Optics System at the New Technology Telescope



Modern Observatories

- W. M. Keck Observatory
  - on top of Hawaii's Mauna Kea volcano
- Very Large Telescope Interferometer
  - on top of mountain Paranal in Chile
- Hubble Space Telescope
  - in space (low-earth orbit, 600 km)

W. M. Keck Observatory



W. M. Keck Observatory

- Keck I started in 1993, Keck II in 1996
- twin telescope for optical and infrared wavelength with a separation of 85 meters
- each mirror has 394 inch (10 meters) in diameter and is composed of 36 hexagonal segments
- optical resolution is about 0.05 arc seconds
- adaptive optics system
- combined mode for interferometry

Very Large Telescope Interferometer

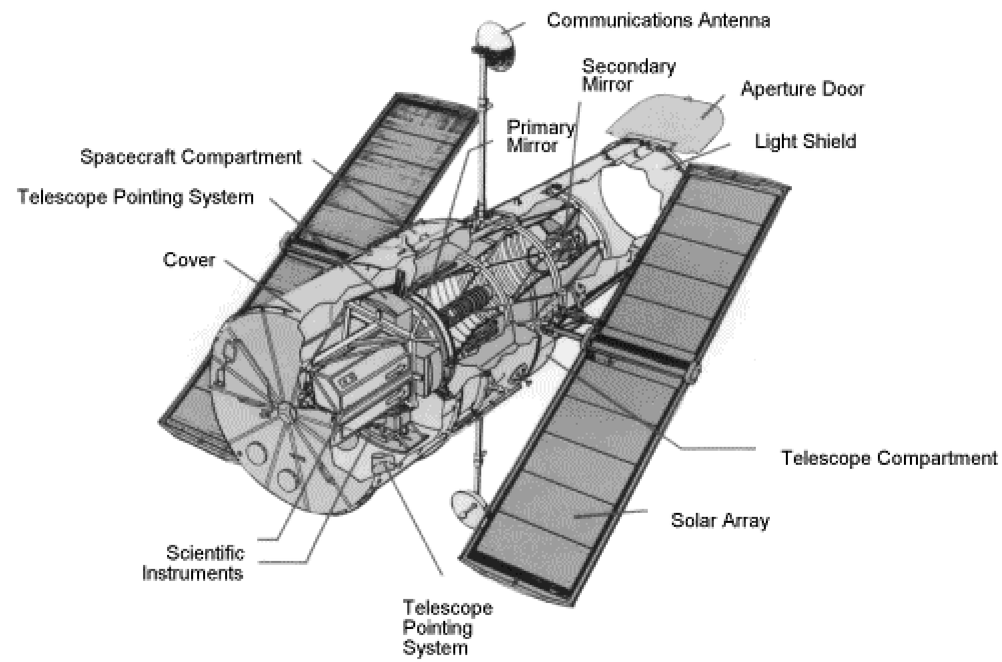
Very Large Telescope Interferometer

- array of four 8.2 meters unit telescopes
- wavelength range extends from near UV up to 25 micrometers in the infrared
- arranged in a quatrilateral configuration
- operated either in independent (mainly for high-resolution spectroscopy) or in combined mode (for high resolution imaging)
- in combined mode: light gathering power of a single 16 meters telescope

Hubble Space Telescope

Hubble Space Telescope
Some Facts

- cooperative program of ESA and NASA
- 2.4 meters reflecting telescope
- resolution is about 0.1 arc-seconds
- each low-earth orbit lasts for 95 minutes



Hubble Space Telescope Instrumentation

- Wide Field/Planetary Camera 2 (WFPC2)
  - pronounced “wiff-pik”
- Space Telescope Imaging Spectrograph (STIS)
  - consists of three detectors each has 1024 x 1024 pixels for two-dimensional spectroscopy
  - cesium iodide photocathode Multi-Anode Microchannel Array (MAMA) for 115 to 170 nm
  - cesium telluride MAMA for 165 to 310 nm
  - charge coupled device (CCD) for 305 to 1000 nm

Hubble Space Telescope Instrumentation

- Near Infrared Camera and Multi-Object Spectrometer (NICMOS)
  - wavelength range from 0.8 to 2.5 micrometers
  - these sensitive HgCdTe arrays are kept cold by a cryogenic dewar
- Advanced Camera for Surveys (ACS)
  - wide-field instrument from the visible to near-IR
- Fine Guidance Sensors (FGS)
  - tracking bright guide stars to keep the telescope pointed

Imaging and Photometry Instruments

- photographic plates
  - large surface, used for sky surveys
  - quantum efficiency about 10%
- photomultiplier tubes (PMTs)
  - high temporal resolution and efficiency, used for measuring magnitudes of faintest objects
  - can be combined by using fiber optics
- charge coupled devices (CCDs)
  - low temporal resolution due to serial readout
  - quantum efficiency about 95%

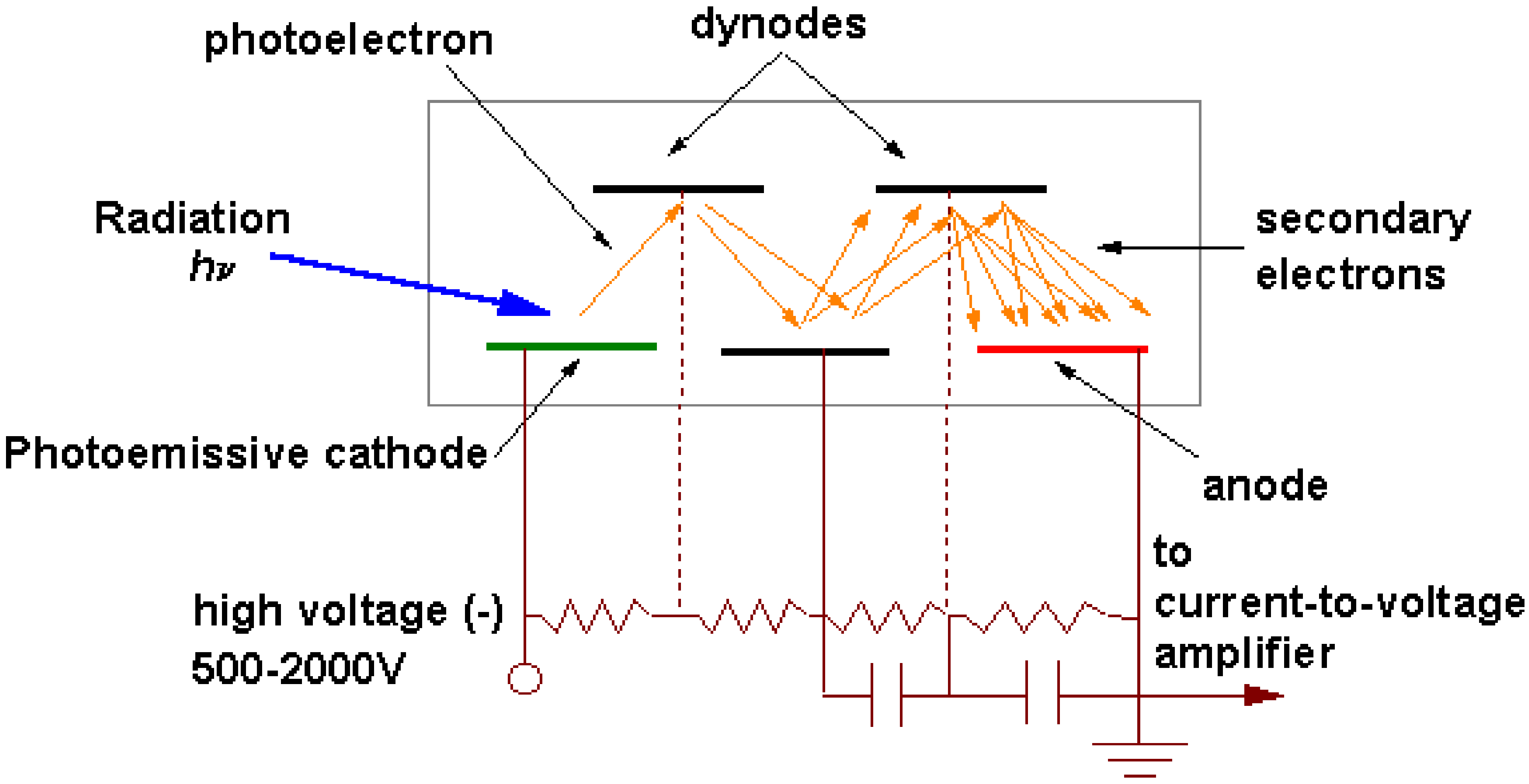
Photographic Plates

- glass plate with silver bromide emulsion
- size of a pixel is equal to grain size
- non-linear sensitivity due to Schwarzschild effect
- still used till 1990

Photomultiplier Tubes

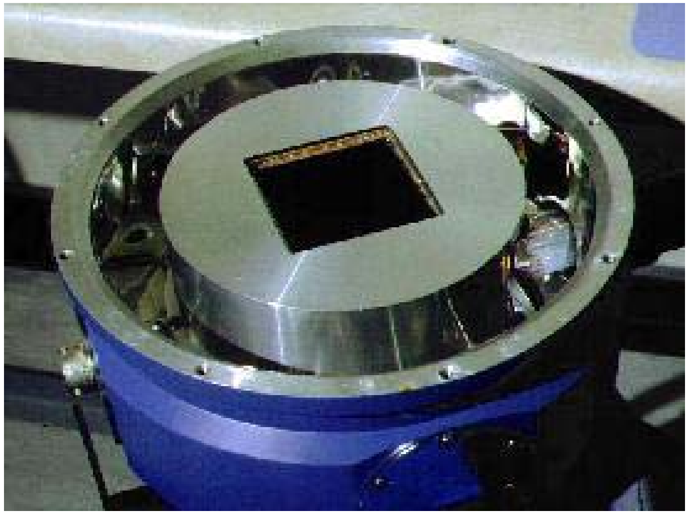
- consisting of a photocathode and a series of dynodes in an evacuated glass tube
- photons striking with sufficient energy eject photoelectrons due to photo effect
- the photocathode is usually a mixture of alkali metals and is on high negative voltage
- photo electrons are accelerated towards a series of dynodes generating secondary electrons
- 10^5 to 10^7 electrons are produced for each photoelectron

Schematic of Photomultiplier Tubes



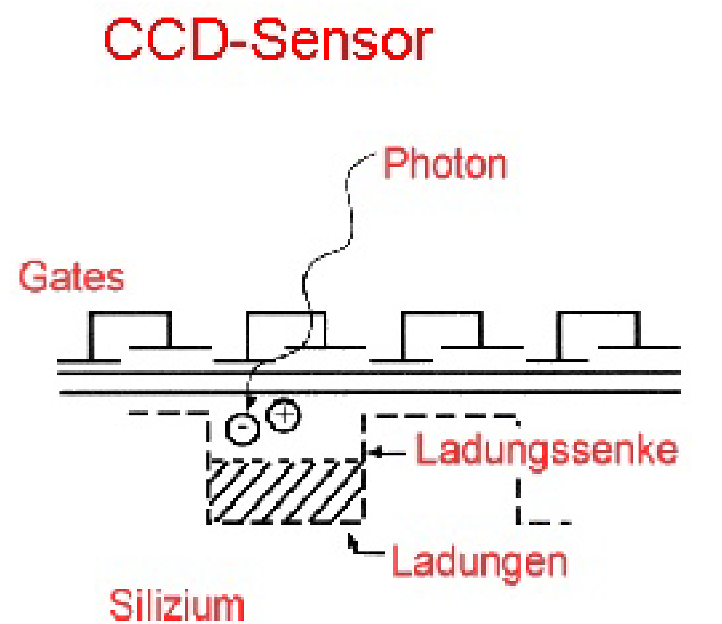
Charge Coupled Devices

- based on silicon semiconductors
- need to be kept cold
- high quantum efficiency and linear sensitivity
- first used at Kitt Peak National Observatory in 1979

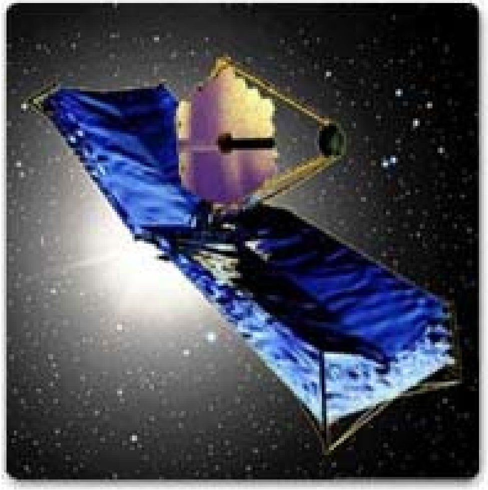


Charge Coupled Devices

- photons striking the chip get absorbed and produce an electron cloud due to photo effect
- small source-drain spacings keep those electrons at their position (pixel)
- periodic voltage alterations are used to move those spacings to get a serial readout



Outlook
Next Generation Space Telescope



- current status
  - still very much in development
- key elements
  - 6m mirror, lightweight, deployable
  - telescope passively cooled by large sunshade
  - Secondary Lagrange point (L2) orbit
  - imaging and spectroscopy instruments over a range from 0.6 to 26 micron
  - 5 years required lifetime, 10 years goal

Optical Telescopes and Instrumentation

Thank you for listening!