Nighttime Observations

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Overview

Terrestrial Issues

Light Sources Beyond Earth

Telescopes

Instruments

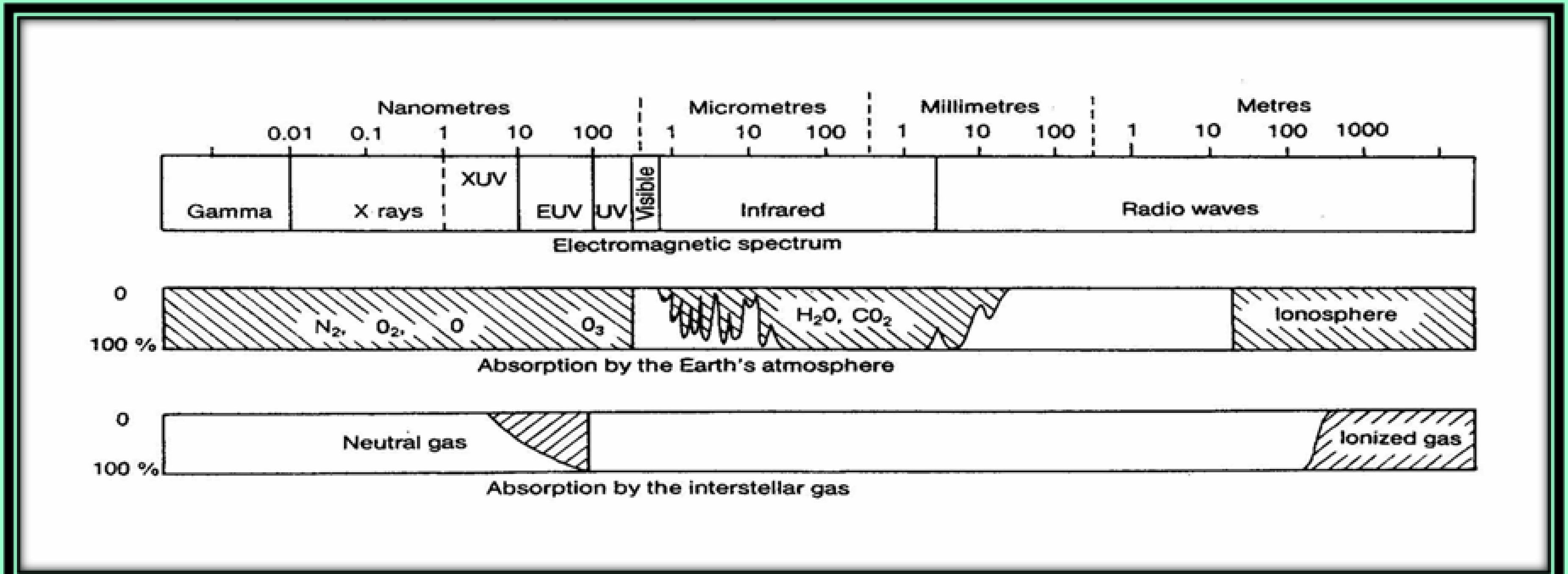
Observing Program from Start to End

The Leisure Part

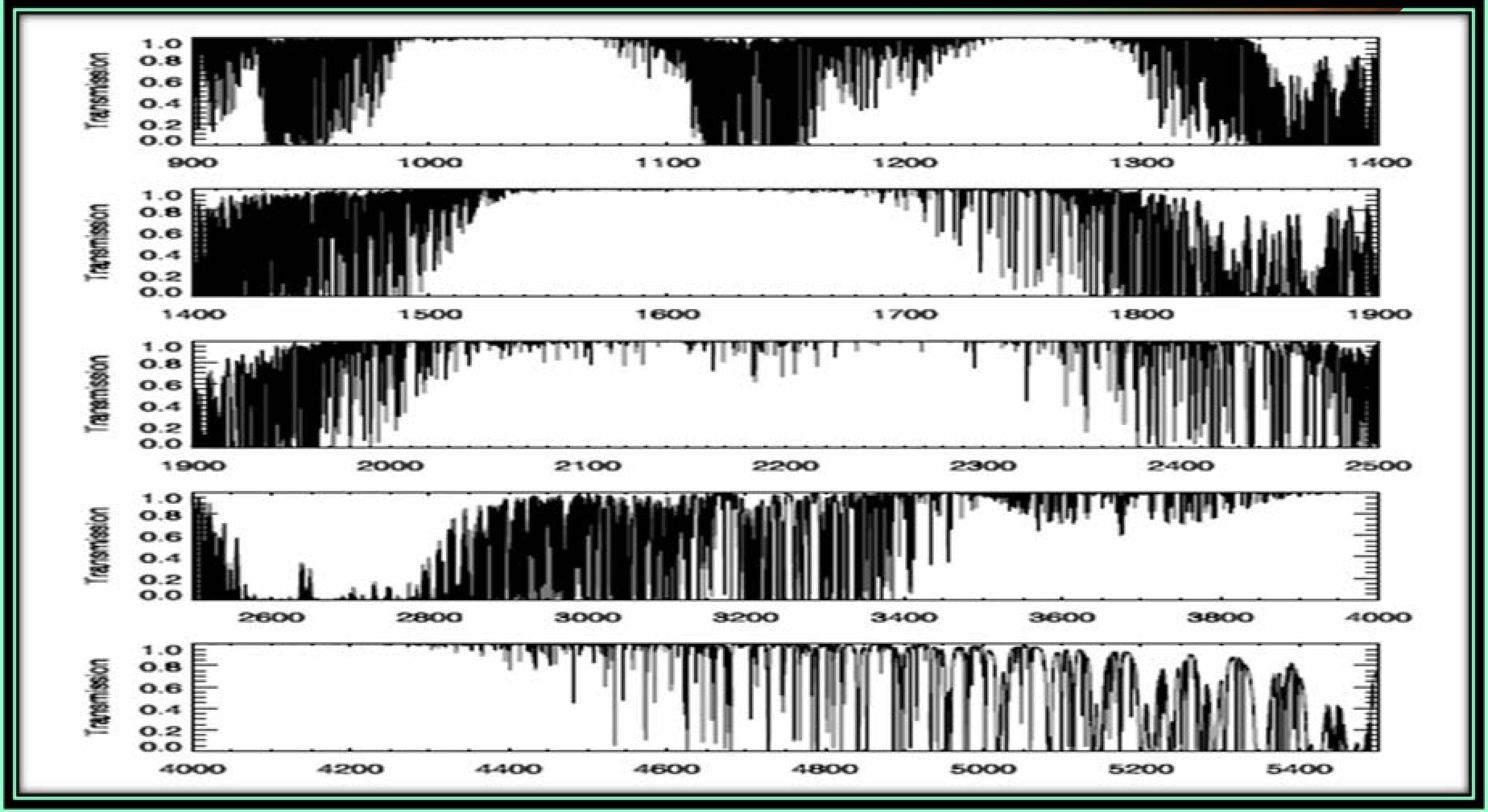
Atmospheric Effects Transmission

Atmospheric Transmission

- The terrestrial atmosphere has different transmission depending on wavelength.
- Absorptions come from electronic transitions of atoms and molecules (UV and short wave) and from rotational-vibrational transitions of molecules and thermal emission (IR and long wave).



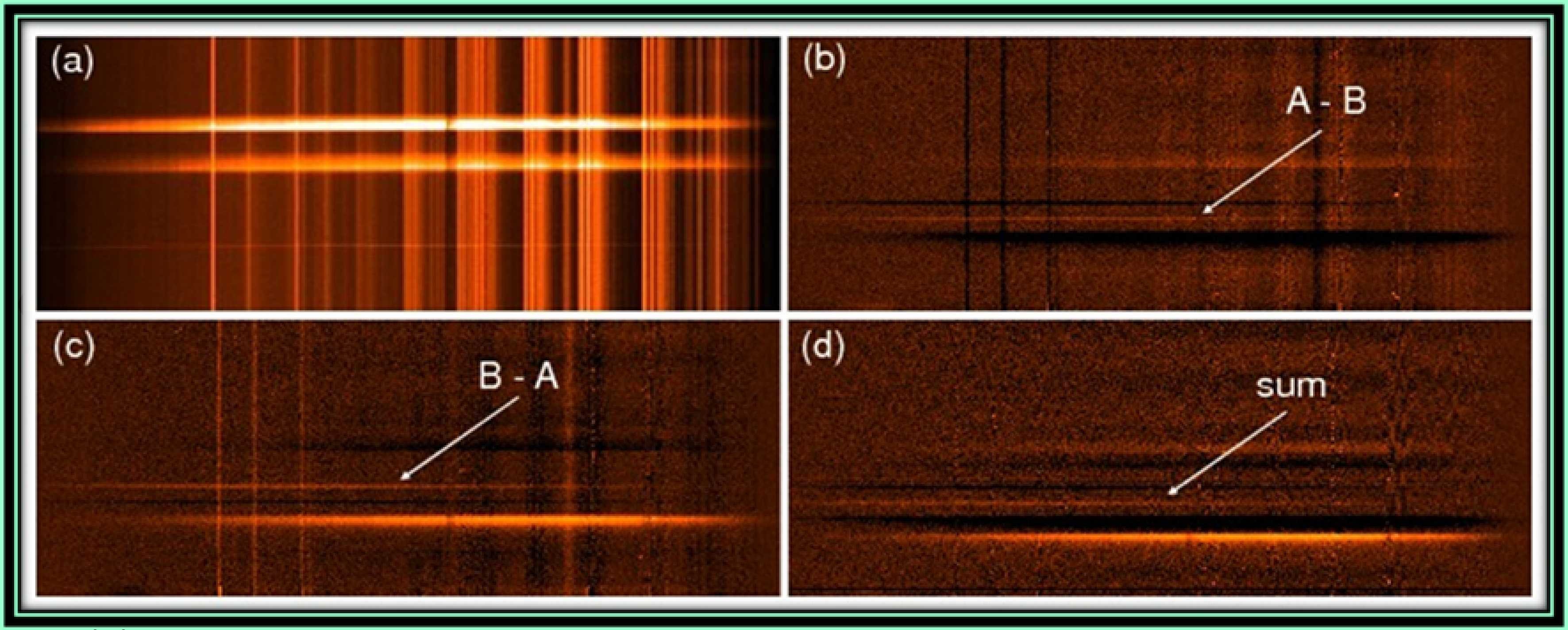
Atmospheric Effects: Sky Brightness and Background



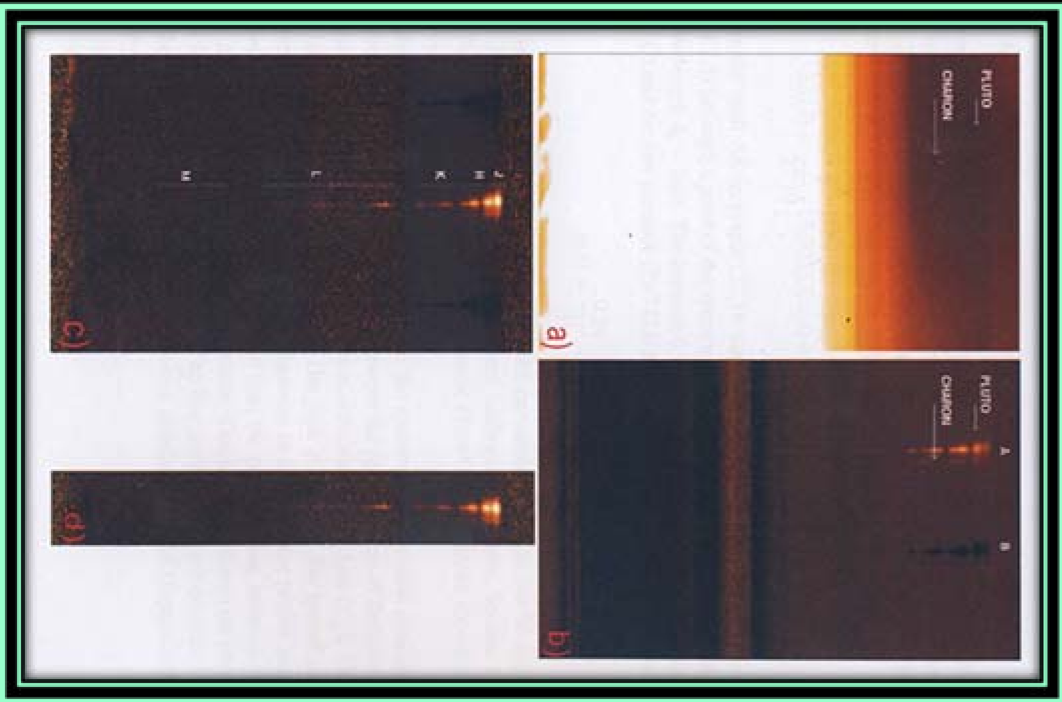
Atmospheric Effects: Sky Brightness and Background

Brightness of the Night Sky

- **Dark is not really dark:** In the visible the sky is not completely dark (airglow) .
- **Reason:** fluorescent emission of atoms (H,O, Na) and molecules (O_2, NO_2) in higher atmosphere , seen easily in spectroscopy in the red
- **Airglow:** Intensity of airglow is variable during the night, intensity higher and variability faster in IR
- **Check it yourself in a dark night:** look to the horizon and you will see that the ground is darker than the sky (i.e. there is still light coming from the sky) and the dark sky appears to be brighter closer to the horizon than in zenith.
- **Work-around:** removal of sky lines during data reduction (visible) or – much better – beam switching technique (AB nodding of the telescope; IR and visible), beam chopping (mid-IR)
- **Background:** in IR thermal radiation of atmosphere and warm equipment in the beam (telescope) produce very high, slowly variable background radiation



Visible wavelength 0.4-1μm



NIR wavelength 1-5 μm

Atmospheric Effects: Refraction

Refraction

- Refraction: change of light path in atmosphere due to refractive index of the air (mostly on the ground), i.e. objects appear at higher elevation than the actually are (most extreme at horizon)

  $z - \zeta \sim (n-1) * \tan(z)$

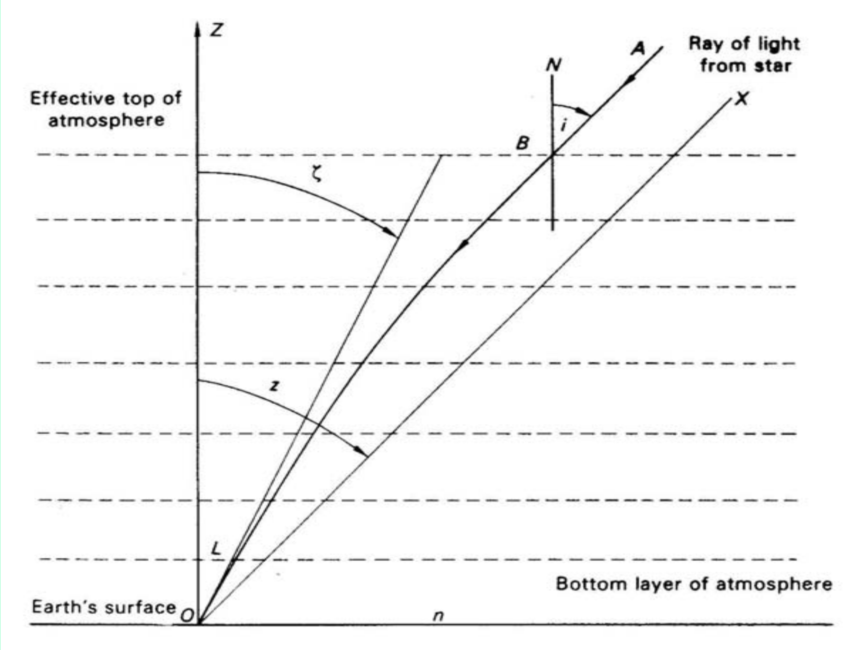
  $z - \zeta$ = refraction angle

  z = zenith distance

  n = refractive index of air

Example:

	z (deg)	10	45	85	90
	R	11”	1’	10’	35’



Atmospheric Effects: Atmospheric Dispersion

Atmospheric Dispersion

- **Refractive index n of air:** n depends on wavelength l

  $(n-1)*10^6 = 64.328 + 29498.1/(146-1/l^2)+255.4/(41-1/l^2)$

  i.e. the refraction is wavelength dependant and light of

  different l from the same object has slightly different

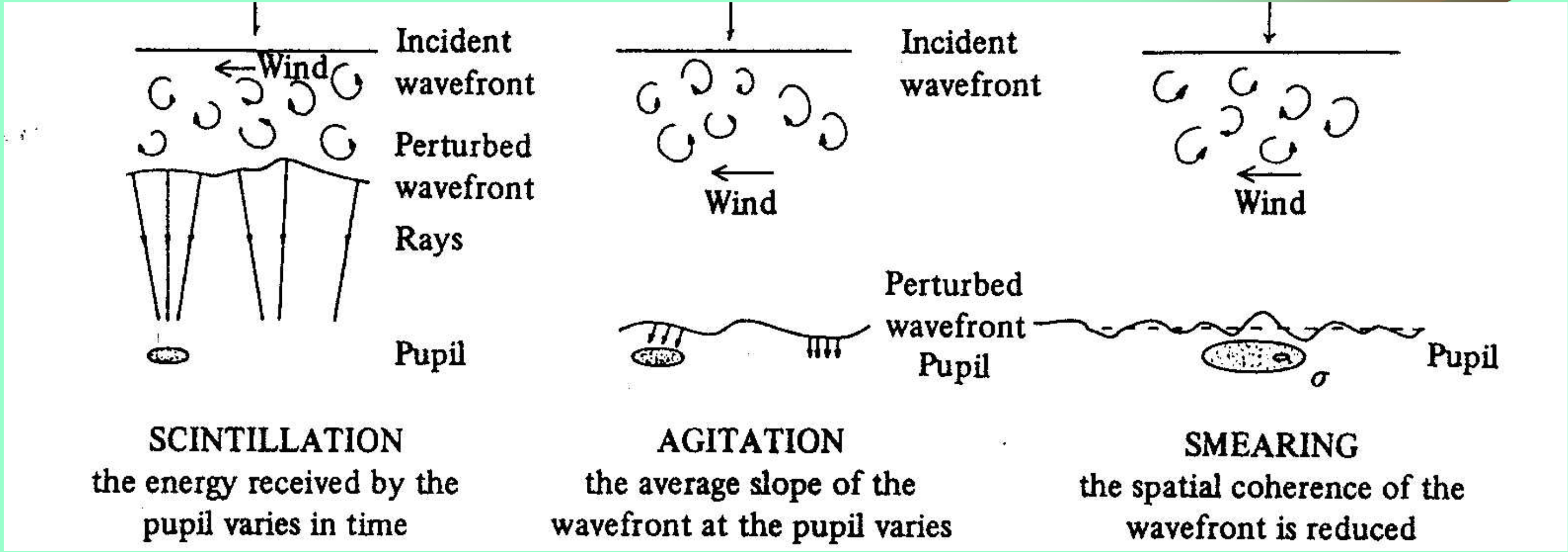
  zenith angle z, it appears dispersed (blue "higher" than red).

  Consequence: ***star appears as spectrum extended in elevation direction. Effect is larger is visible wavelength range than in IR.***

  At z = 45 deg: dispersion is ~2" from l = 300-800nm

- **Work-arounds:** put slit in parallactic angle orientation or use atmospheric dispersion compensator ADC (optical device to correct for atmospheric dispersion of light in the telescope or instrument)

Atmospheric Effects: Seeing, Scintillation, Defocussing



Scintillation
Stars are twinkling

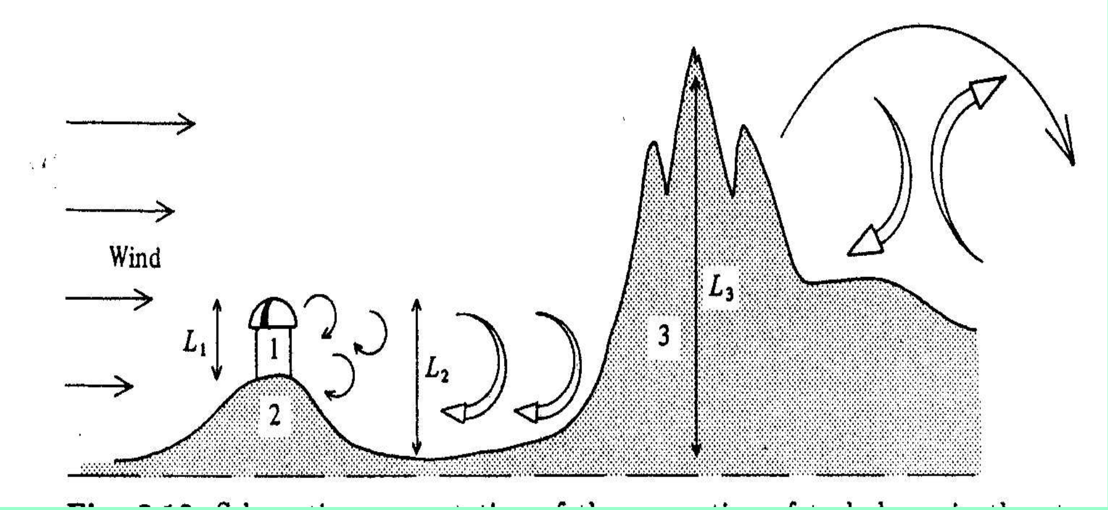
Seeing
Stars are moving

Defocusing and higher order optical distorsions
Stars are blurred

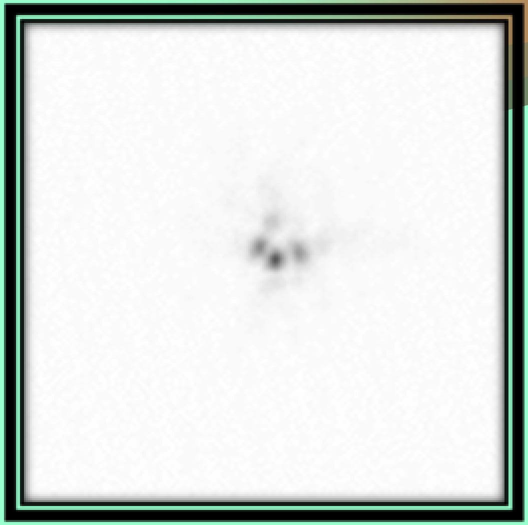
Atmospheric Effects: Seeing

Atmospheric Seeing

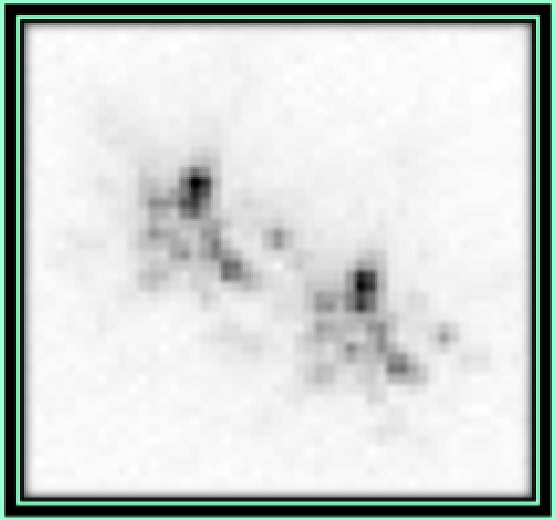
- Turbulence in the atmosphere causes air packages with different refractive indices. Light refraction is changing depending on turbulences. Star is moving around nominal position (a few to several 100 Hz frequency). Integrated over time the star image appears smeared.
- Different seeing contributions:
  - Dome seeing
  - Ground seeing
  - Landscape seeing
  - High atmosphere seeing

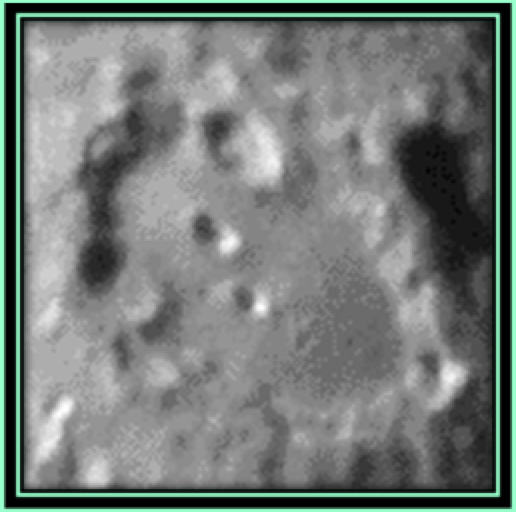


Atmospheric Effects



Atmospheric Speckles





Adaptive Optics

- **Why adaptive optics?**

Goal: trying to overcome image distorsions due to

atmosphere (fast frequency) and/or

optical system (low frequency, gravity, thermal)

in order to achieve diffraction limited image quality

Implementation: removal of distorsions by correcting optics (mirror system) through actuators:

- tip-tilt: mirror displacements
- optical distorsions: mirror deformation

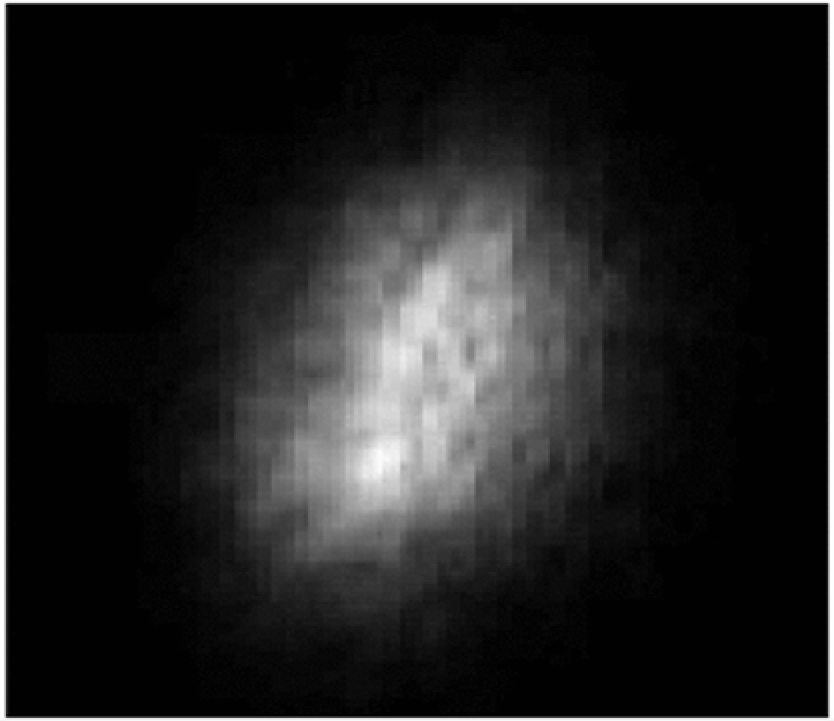
visible: atmosphere > 1KHz

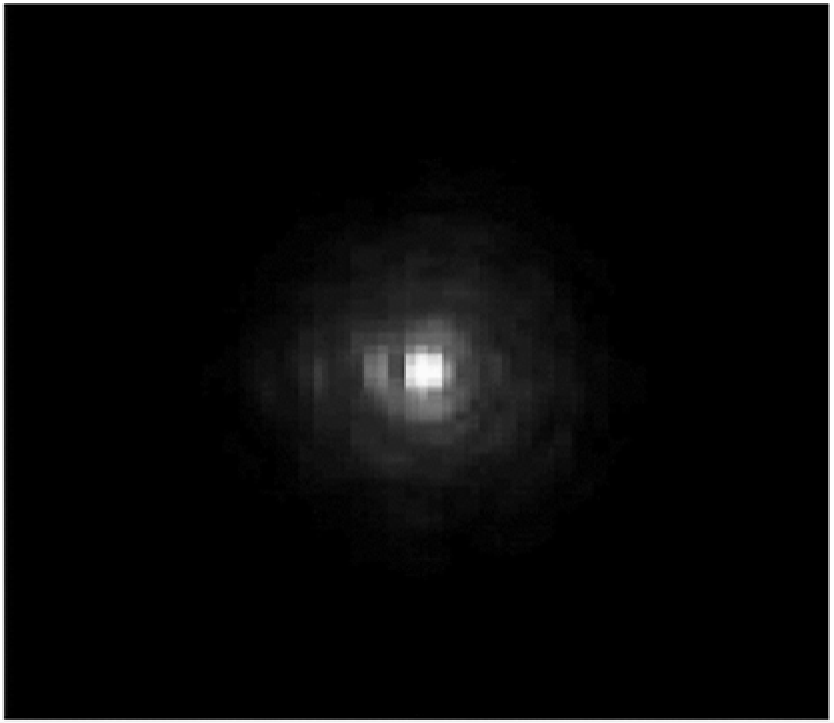
near-IR: atmosphere 0.1-1KHz (AO)

mid-IR: atmosphere 10-100 Hz (AO or secondary)

Result: spatial resolution and image quality & signal-to-noise improvement

Adaptive Optics





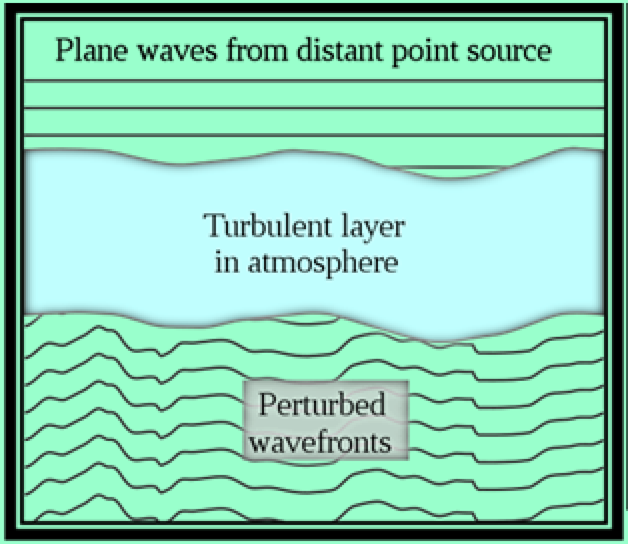
without adaptive optics seeing limited **with adaptive optics diffraction limited**

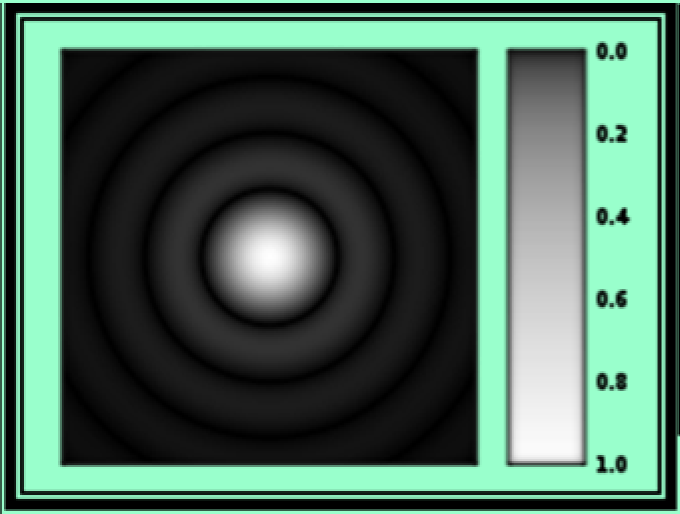
Adaptive Optics Parameters

- **Airy disk:** diffraction pattern of a point source imaged through an optical system
- **Diffraction limit:** angular distance between maximum and first minimum in Airy diffraction disk

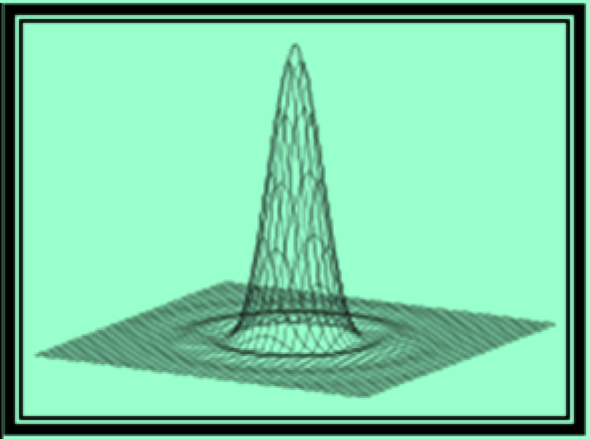
  $\alpha \approx 1.22\ \lambda/D$ [radians] (λ = wavelength, D = aperture diameter of optics)

  ➔ 8m telescope @ 2µm: $\alpha \approx 0.063''$



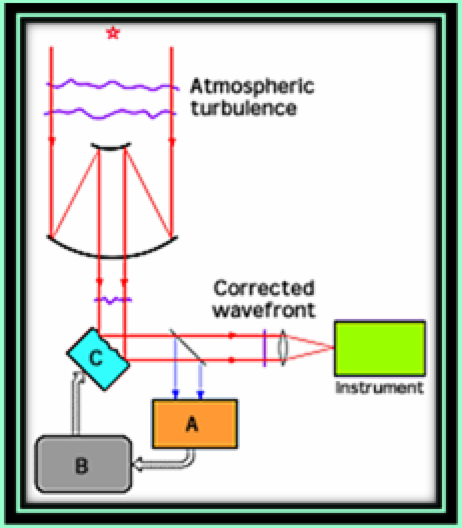


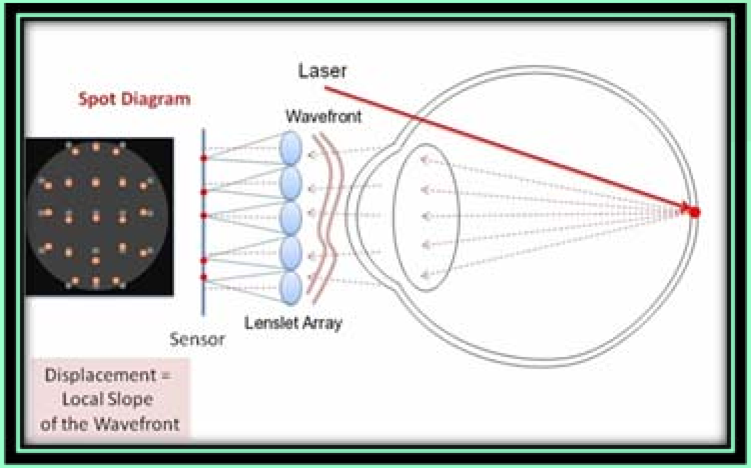
Airy pattern

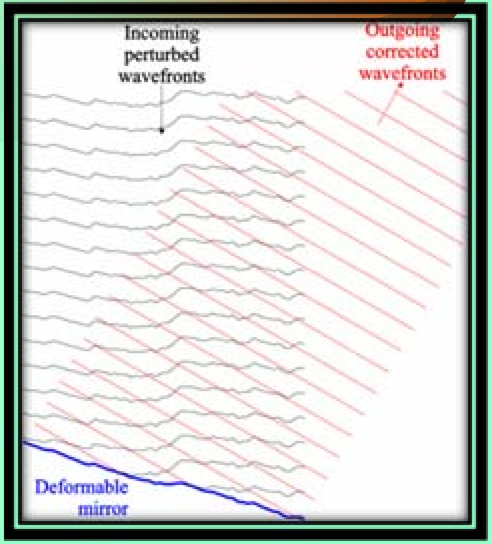


Airy profile

How Adaptive Optics Works?

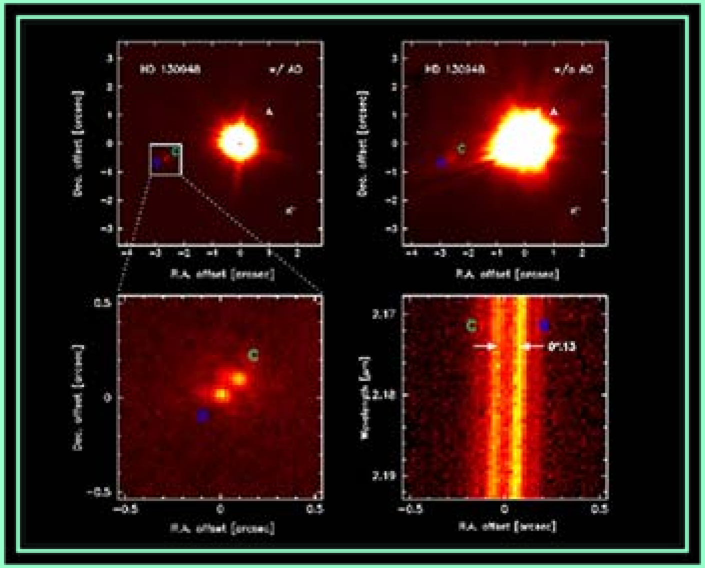






Requirements I

- bright (16-17mag for 8m telescope) reference source close by (isoplanacy)
- Shack-Hartmann or curvature sensor



Requirements II

- sensitive fast detector (KHz)
- very fast computer (several 100 Hz)

Adaptive Optics Parameters

- **Strehl ratio:** ratio between measured peak intensity and theoretical peak intensity of a diffraction limited point source (optimum image quality for Strehl ratio ~ 1)
- **Fried parameter:** scale length over which turbulence becomes significant
  - ***isoplanacy:*** area over which coherent conditions apply (~10-30m for a good site)

    ➔ *multi-conjugated adaptive optics for larger telescopes (like the E-ELT)*
- **Coherence time:** correction time required to correct for the effects of the atmosphere

- **AO star:** natural or artifical star used for AO corrections
- **Sky coverage:** percentage of the sky where one can expect to do adaptive optics
- **Laser guide star:** artificial star in AO field of view, produced by laser excitation of small volume in atmospheric sodium layer (~100km above ground)

Light From Outside The Atmosphere

Moon

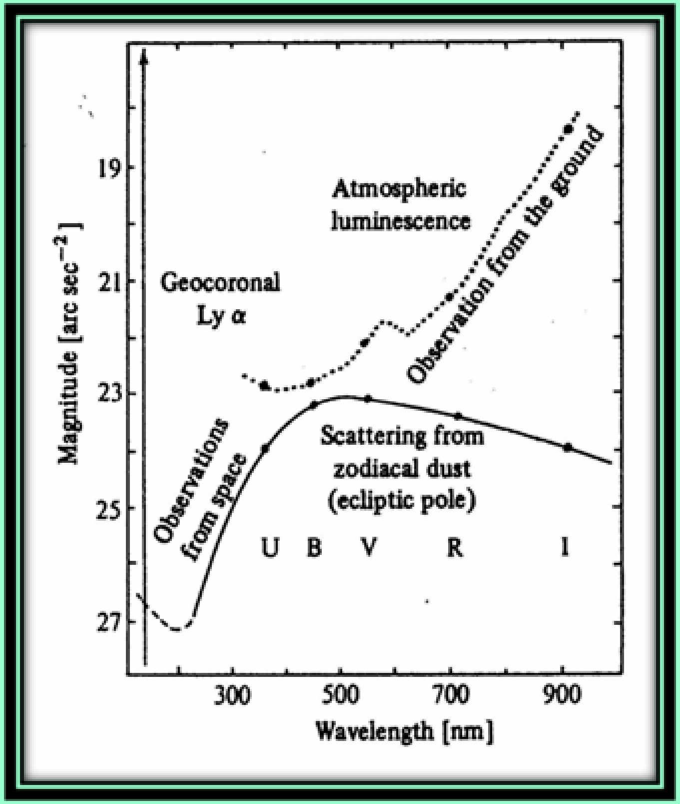
- Reflected light from the moon, scattered in the Earth atmosphere brightens the sky background
- The spectrum (i.e. the solar spectrum) of the moonlight peaks in the visible and drops off short- and long wave. Therefore: it is important in the visible wavelength range, less critical in near-IR, uncritical in mid-IR (when the moon is up)

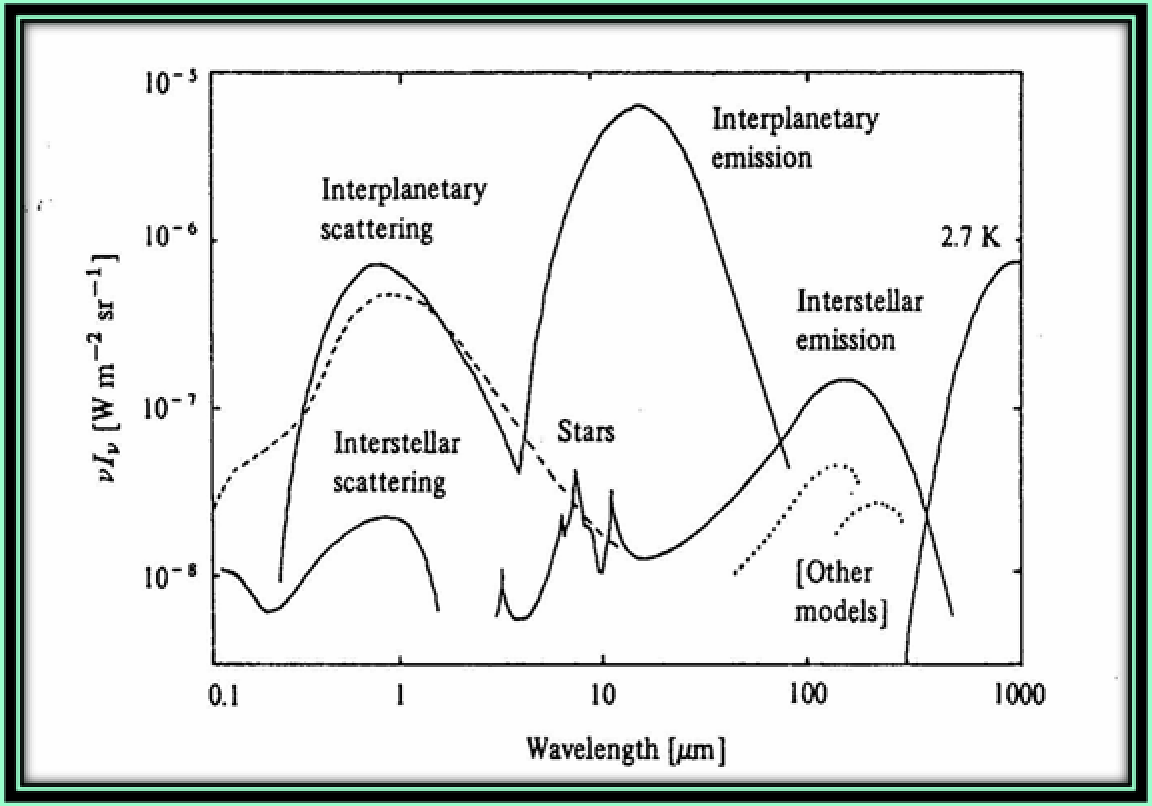
Zodiacal Light

- Solar light reflected by dust in Solar System
- Diffuse narrow triangle in Ecliptic (evening, morning)

Sky Background Brightness

The contributions to the sky background in the visible and IR wavelength range from the various sources: atmosphere, moon, Zodiacal light, stars, dust and cosmic background.





Telescope Types

- **Some basic properties of telescopes**

Three different types of telescopes:

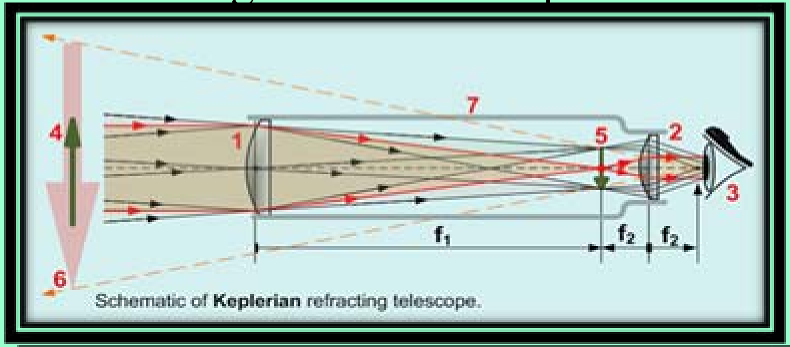
- ***refractor (lens/dioptric telescope)***
- ***reflector (mirror/cataoptric telescope)***
- ***combined optics (lens+mirror/catadioptric telescope)***
  - ➔ most famous lens/mirror telescope type in use: Schmidt telescope

Telescope parameters:

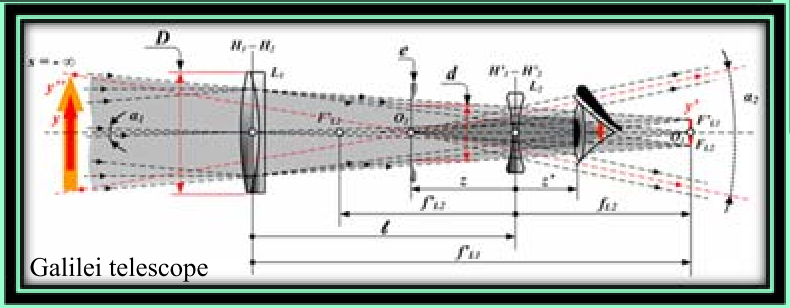
- ***aperture D: diameter of the light collecting surface of the telescope***
- ***focal length L: effective length of the optical path aperture to focus***
- ***focal ratio (f ratio): f = D / L (notation: f/11)***
- ***telescope length T: physical extension of telescope optics***

Telescope Types Refractors

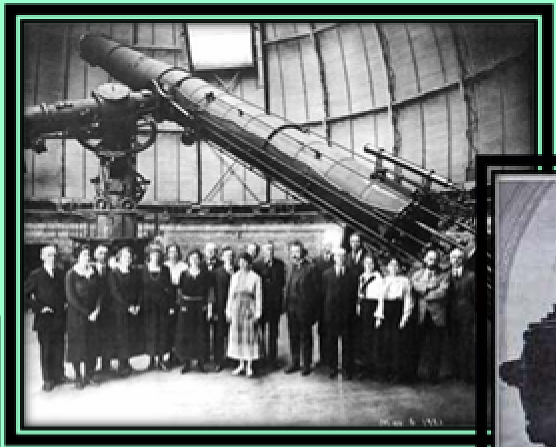
- **Refractor: Dioptric telescope = lens telescope**
  - Galilei & Kepler type with different designs
  - telescope length L = focal length T
  - issues: chromatism , glass transmission, mechanical support& thermal issues for large optics, bulky&heavy telescope and dome structure
  - largest lens telescope = Yerkes 1.02m/19.4m telescope



Schematic of **Keplerian** refracting telescope.

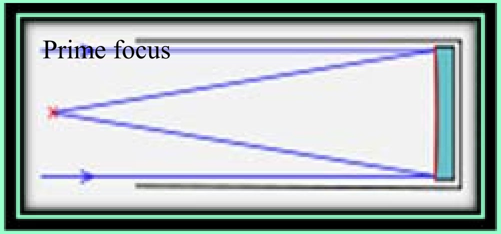


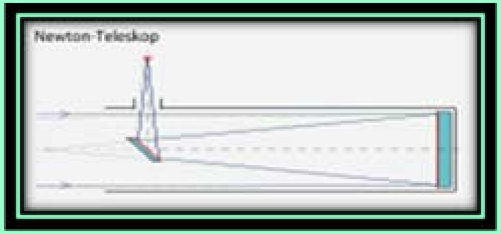
Galilei telescope

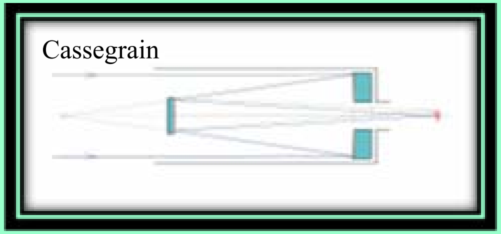


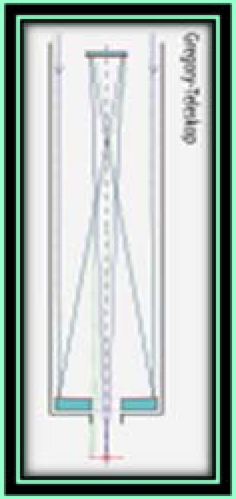
Telescope Types
Reflector

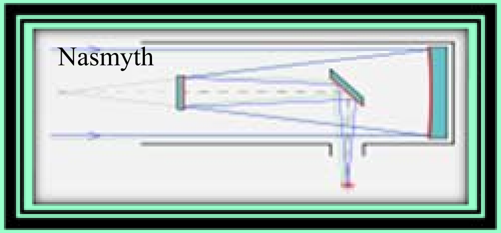
- **Reflector: Cataoptric telescope = mirror telescope**
  - telescope length usually (much) shorter than focal length (optical power of secondary mirror)
  - achromatic & high reflectivity, visible&IR, compact dome, segmenting&monolithic
  - issues: diffraction and straylight issues, telescopic polarization
  - largest mirror telescope = HET, SALT

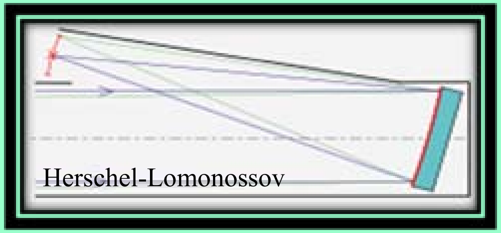


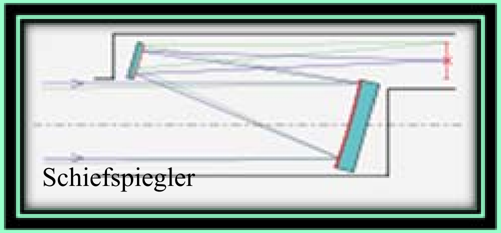




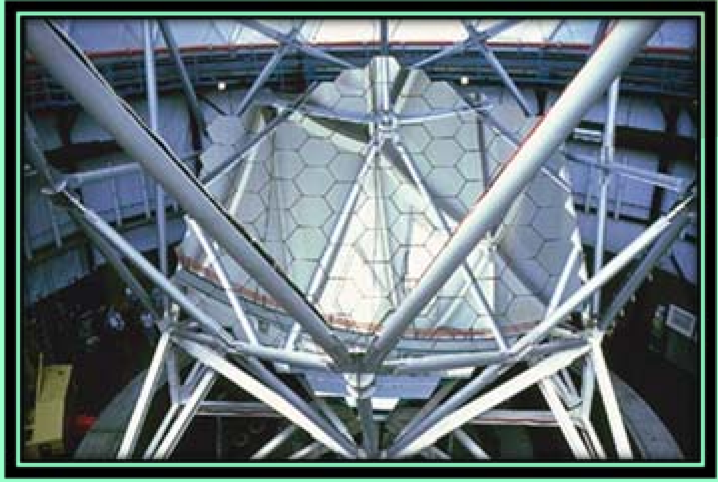








Telescope Types
Reflector

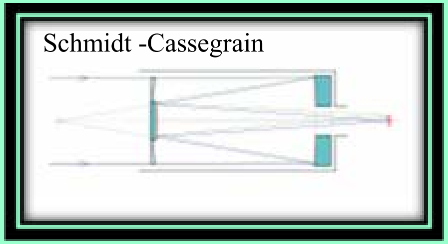


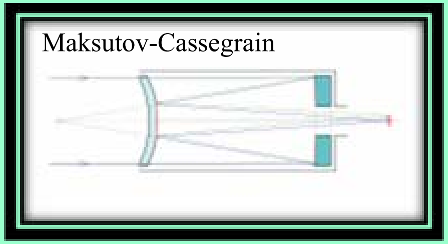
Hobby-Eberle Telescope, Texas

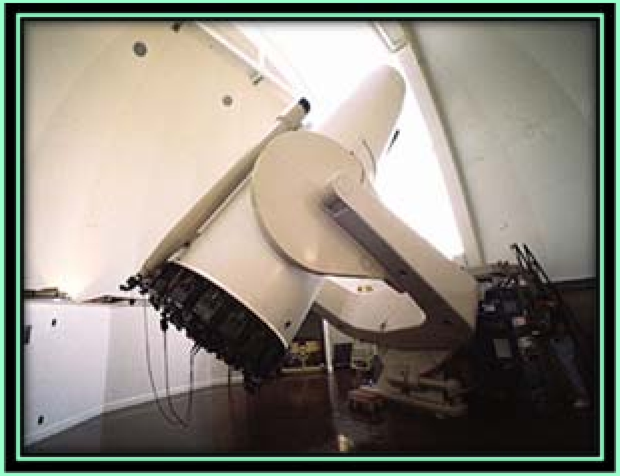
Very Large Telescope Chile

Telescope Types
Combined Optics

- **Combined optics telescope: Catadioptric telescope**
  - telescope length usually shorter than focal length
  - spherical mirror shape, simpler manufacturing
  - corrector optics
  - wide angle cameras
  - Schmidt telescope at Mt. Palomar







Telescope Auxiliary Equipment

- **Image quality devices**
  - **active optics** control of primary/secondary: compensation of gravity & focus variation (bending, rolling, shifting of mirror & mount, temperature; slow frequency ~ 2x per min) & partial correction of atmospheric motion (tip-tilt; up to several 10 Hz)

    active optics probe ➔ telescope is in optimum shape and focus position all the time, but still seeing limited
  - **guiding device**: to follow objects in the sky for optimum image quality

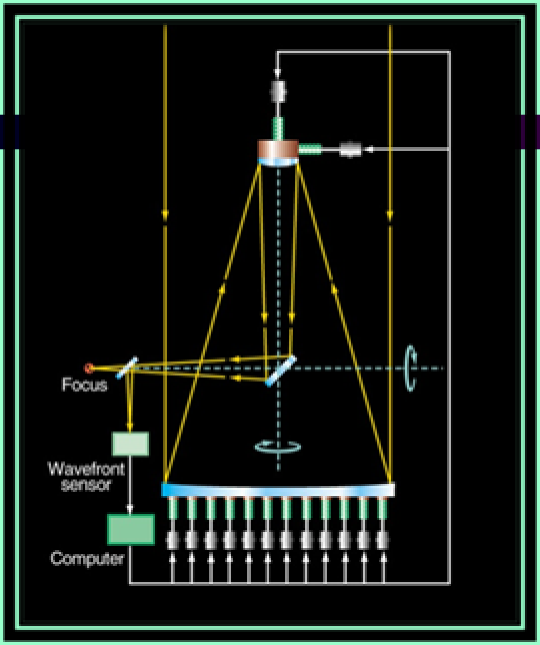
    guide probe ➔ telescope motion corrected by 'star locking': few Hz

    differential guiding at non-stellar velocity possible (not at all telescopes and not always at high quality)
  - **adaptive optics** (close to focal plane of the telescope): atmospheric&optics distorsions (turbulent motion, defocus, image distorsion; up to a few KHz)

    adaptive optics probe ➔ telescope image quality improved to diffraction limit

Telescope Auxiliary Equipment

Active Optics

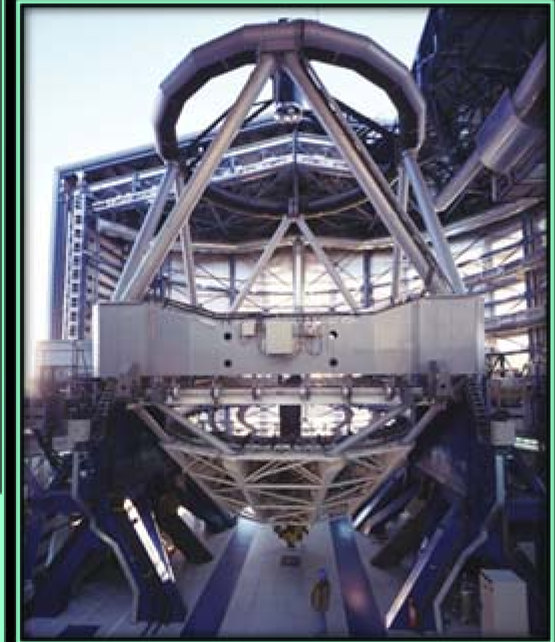


Telescope Auxiliary Equipment

- **Telescope mountings**
  - parallactic (different flavors) = primary axis parallel to celestial pole, secondary axis perpendicular to it ➔ various restriction in telescope pointing
  - ALTAZ (altitude-azimuth) = primary axis pointing to zenith, horizontal secondary axis ➔ blind zenith spot due to restrictions of the field rotation
- **Telescope dome**
  - protection against weather and wind, keep cool nighttime environment during daytime, allow daytime work of engineers, active tool for improvement of seeing quality
- **Life infrastructure**
  - allow survival in a usually harsher (high mountain, dry dessert) environment

➔ *The Observatory (mostly engineers, household staff, administrators and a few astronomers*

Telescope Auxiliary Equipment



A modern observatory is a 365day-24hour facility at a remote site producing astronomical data at ~10-50 KEUR/night/telescope

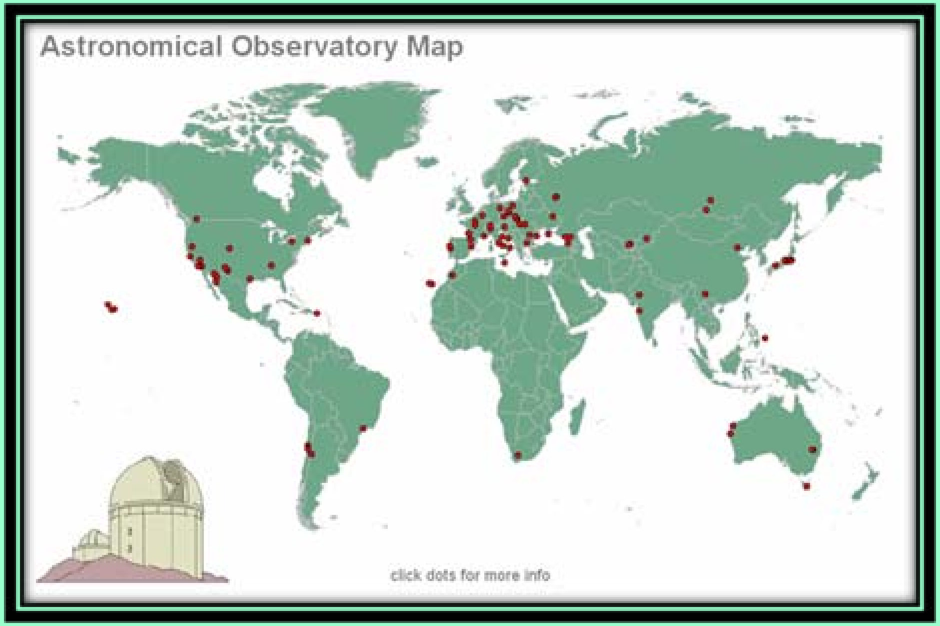
What the Telescope Does *and* Does Not Do *While Observing*

- Time
  - Epoch
  - Sidereal time
- Coordinates
  - RADEC to ALTAZ
  - Equinox
  - Precession
  - Nutation
  - Aberration
  - Guiding
  - Differential tracking
- Atmosphere
  - Refraction
  - Atmospheric dispersion compensation
  - Seeing compensation (partial)

- Coordinates
  - Pole motion
  - Parallaxes
  - Proper motion of stars
- Atmosphere
  - Scintillation
  - Full seeing correction
  - Sky brightness (except sky baffle)

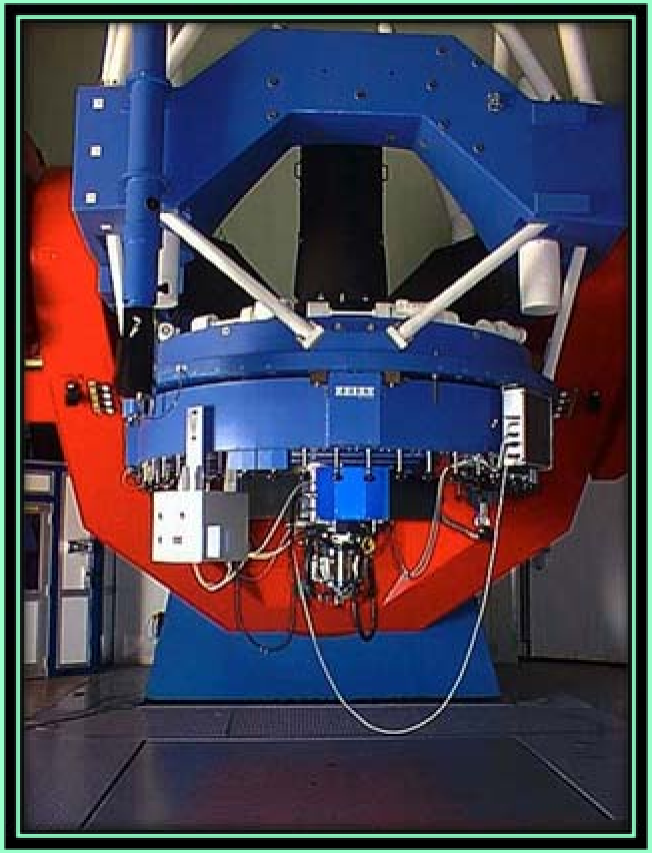
Observatory Sites

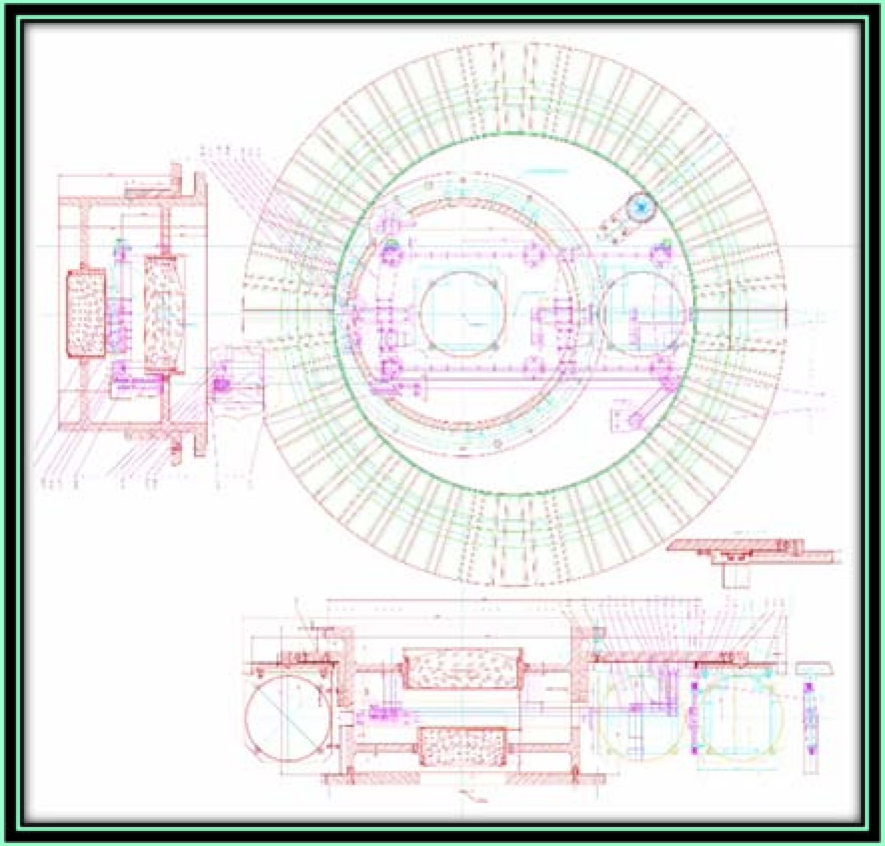
- **Criteria:** large celestial sky coverage (not far from equator), high number of photometric nights, stable atmospheric conditions, high isolated altitude (2000-5000m; seeing and sky brightness), low humidity (dry deserts), accessible for technology, workable for humans
- **Prominent sites:** Mauna Kea, Cerro Paranal/La Silla, Cerro Pachon, Las Campanas, Kitt Peak, Roque de los Muchachos, Sutherland
- **European sites:** La Palma, Calar Alto



Instrument Types: Imager

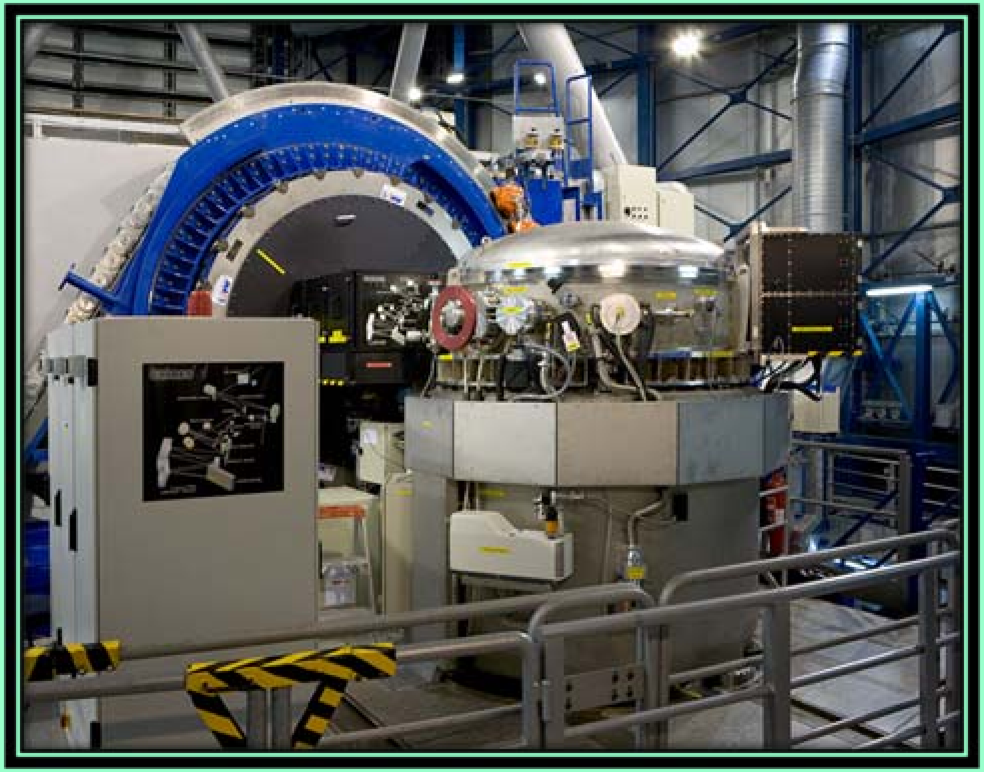
- **Imager**
  - camera optics (with focusing unit), analyzer (filter, polarizer, prism), detector

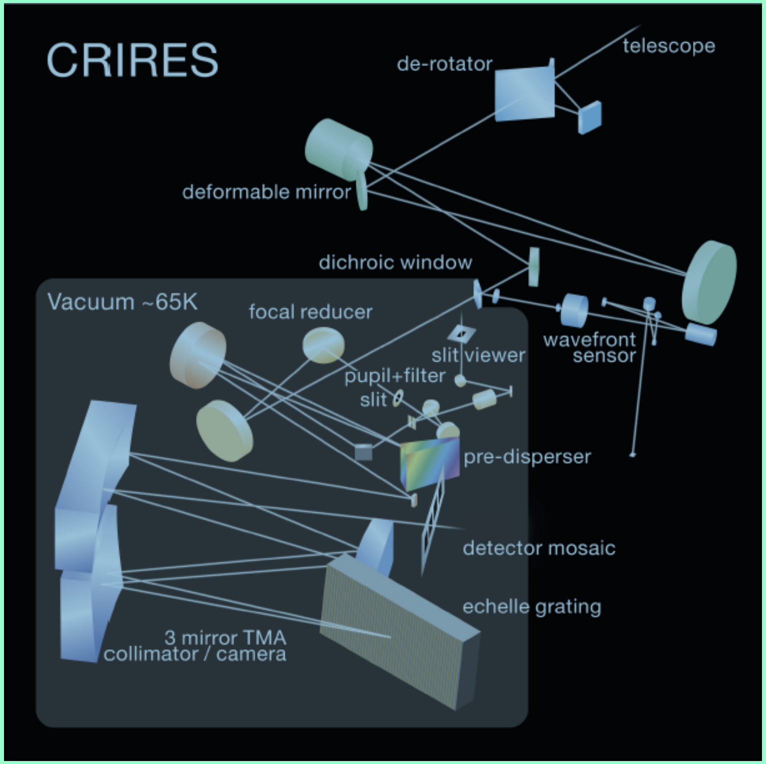




Instrument Types: Spectrograph

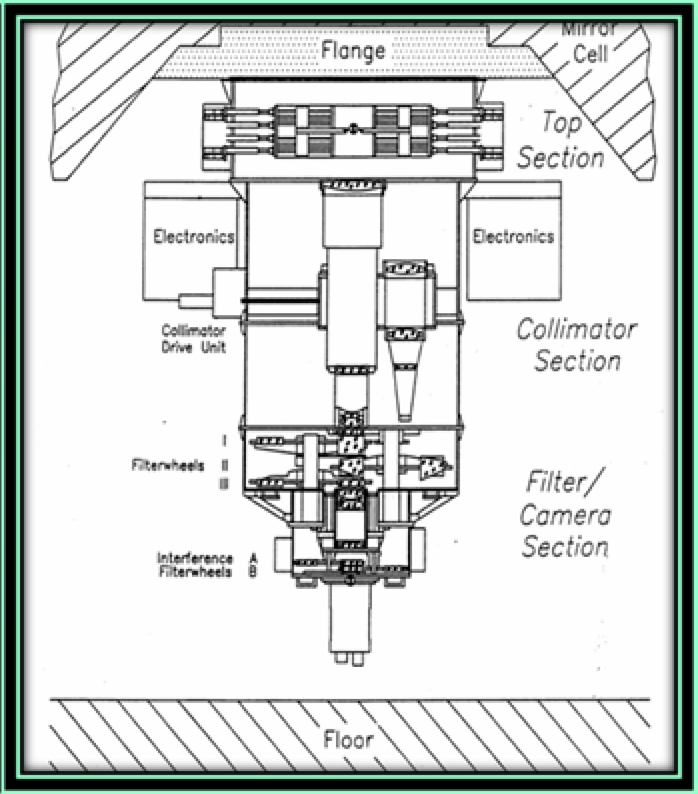
- **Spectrograph**
  - focal plane slit unit, collimator optics (parallel beam), analyzer (dispersers&cross disperser), camera optics (incl. focusing unit), detector

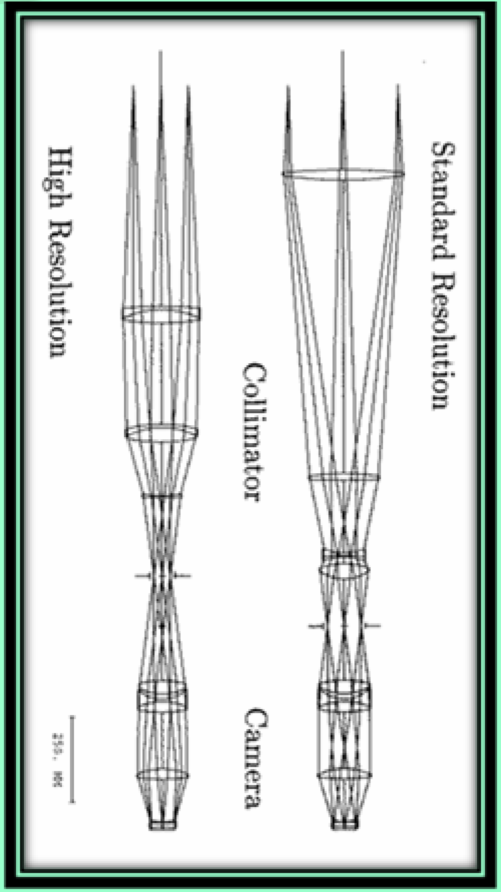




Instrument Types: Focal Reducer

- **Focal reducer**
  - imaging and spectroscopy modes combined in same instrument, instrument design of type spectrograph

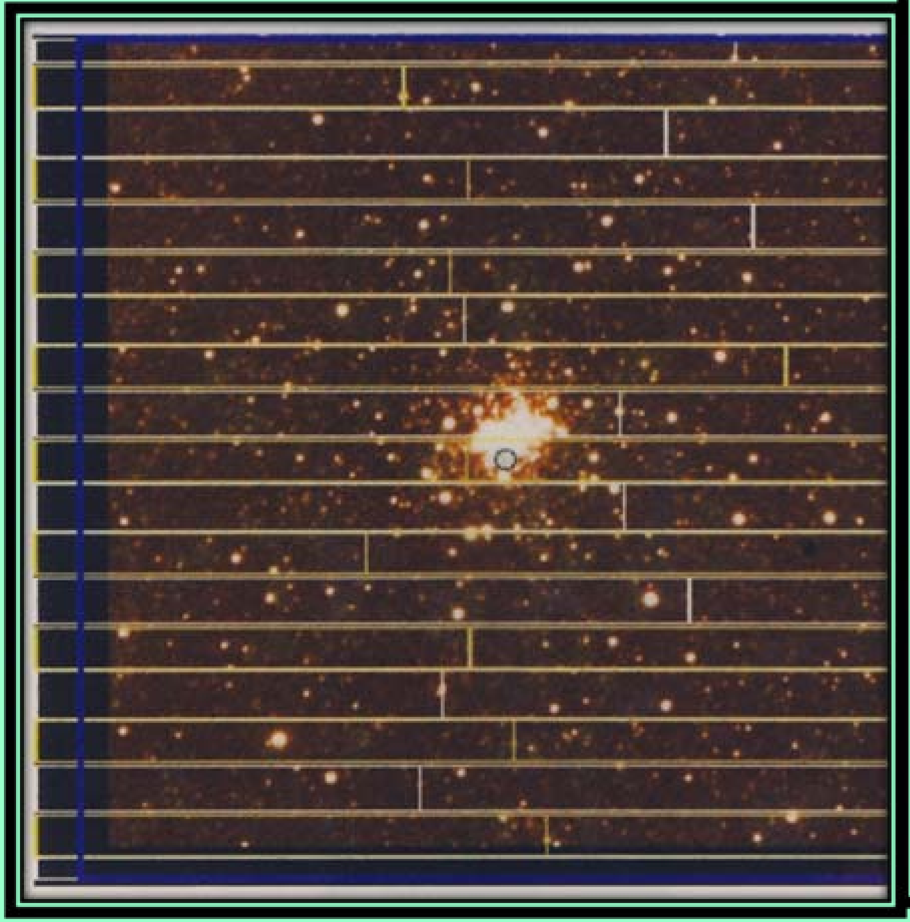


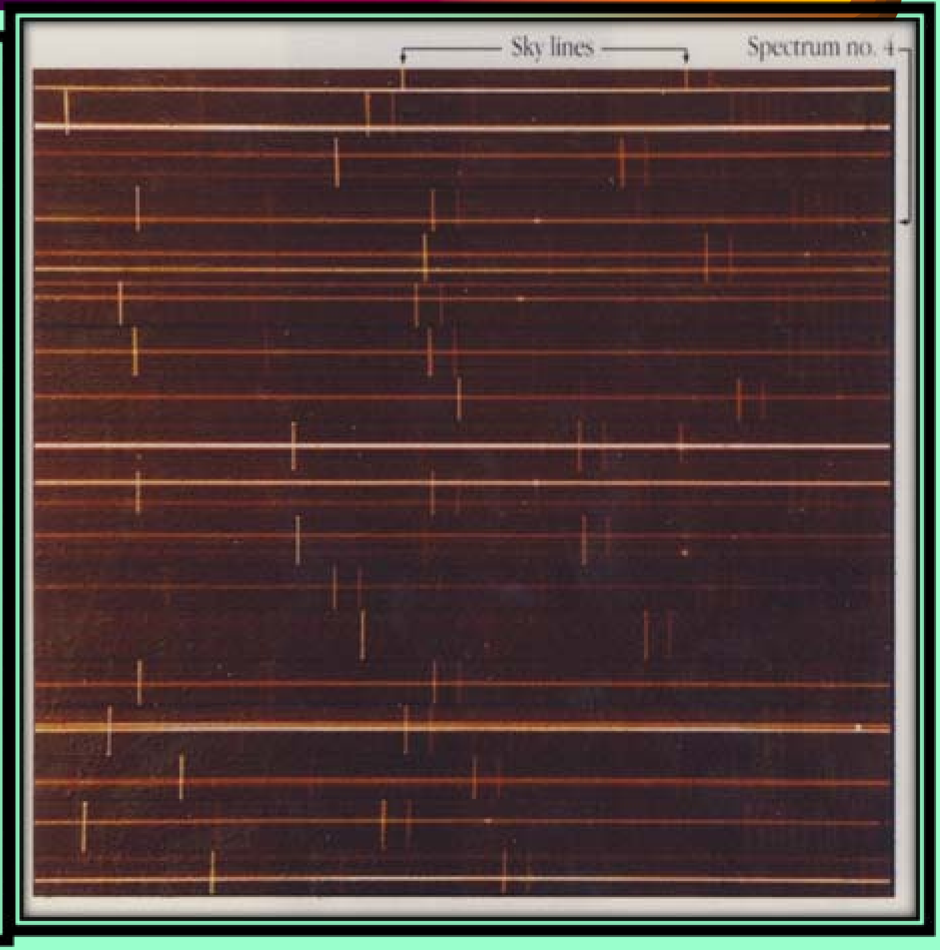


Instrument Equipment

- **Specifics**
  - detectors are at LN2 temperature in vacuum
  - for IR whole instruments in cold environment & vacuum
- **Focal plane unit**
  - longslits, pinhole, multi-object slit unit, fibre assembly
- **Analyzer optics**
  - filters: broadband, medium & narrowband, tunable filters (etalon, circular variable filters)
  - disperser: grating (low-medium-high), prism (low), grism (low-medium)
  - polarizer: Wollaston prism, half/quarterwave retarder plate (linear&circular polarization), polarization foil
- **Detectors**
  - visible: CCD
  - IR: CMOS

Instrument Equipment Multi-Object Slit Unit





Instrument Observing Modes

Observing Mode	Visible (0.3-1.0µm)	Near-IR (0.9-5.0µm)	Mid-IR (7.5-28µm)
Imaging	X	X	X
Low/medium-dispersion spectroscopy	X	X	X
High-dispersion spectroscopy	X	X	
Multi-object spectroscopy	X	X	
Imaging polarimetry	X	X	X
Spectro-polarimetry	X	(X)	

Observing at a Night Observatory

- **Observing proposal:** 4-6-12 months before start of period (6-10 pages), pressure factor 2-7, modes: visitor, remote, service
- **Time allocation:** happens 2-3 months after proposal submission and is given in nights/hours for visitor/service/remote observing modes

  visitor/remote obs. modes: ½ - 7 – 20 nights (2-3 nights)

  service mode: ½n – 100nights (2-3 nights)
- **Service mode:** full preparation and submission to the observatory of the observation for execution at the telescope within ~2 months after time allocation, verification and acceptance by the observatory

  execution of observations during obs. period by observatory staff according to requirements and with quality check, no participation of proposers

  data are shipped to proposers after program completion or upon request
- **Visitor/remote observing:** preparation of the observations just before observing run

  proposers do participate in observations at the telescope or remotely

  data immediately accessible to proposers

Observing at a Night Observatory

- **Input preparation:** travel preparation, science case review, selection of and request for observing modes and instrument set-ups, exposure time estimations, calibration measurements: standard stars, flatfields, bias/darks, wavecals, on-line analysis tools, preparation of observing schedule, back-up programs (for adverse atmospheric conditions, (un-)expected online results
- **Daytime activities:** check of telescope&instrument set-ups, installation at telescope console, daytime calibrations: bias/darks/flats/wavecals, observing protocol, preparation of on-line analysis, data storage
- **Nighttime activities:** start shortly before sunset, twilight sky calibrations (stress): flats/standards, observing of science program according to obs.schedule, on-line analysis, revision of science/calibration schedule, observing protocol, data archiving, observations report, set-up changes
- **Rest of the day:** sleeping, eating, other work, some leisure

Catalogues And Star Maps: The Meaning Of Positions

Positions with Adjectives

Astronomical positions can be given as:

Apparent position: observed position, effects from instrument (for instance distorsions), refraction and daily aberration removed

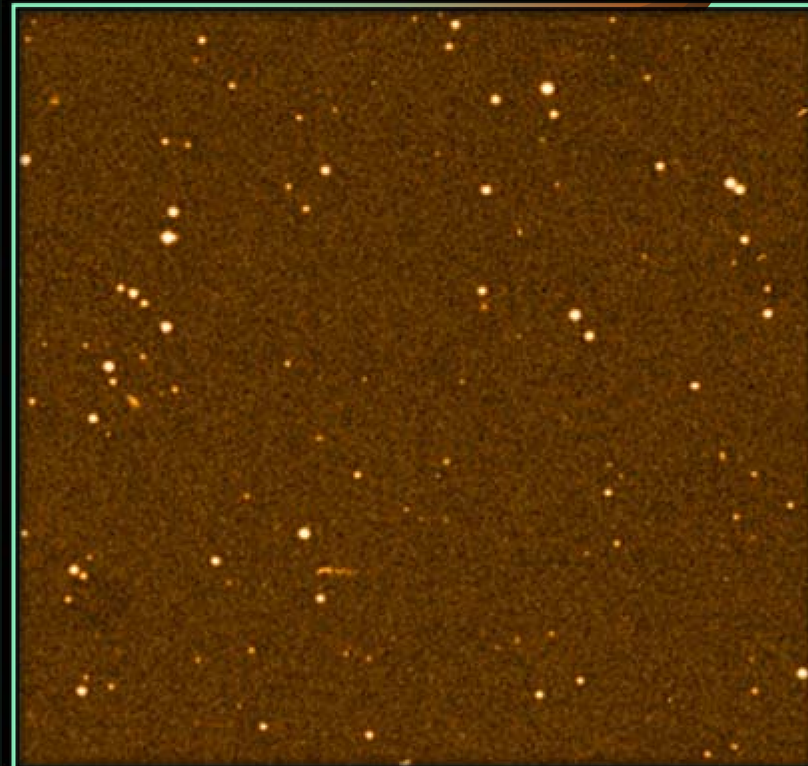
True position: apparent position, effects of annual aberration and parallax removed

Mean position: true position with precession and nutation effects until specified date (equinox!!!!!) included

Catalogues And Star Maps

Catalogue	Number of stars	Mean epoch	Accuracy of 1990 positions	Accuracy of proper motions
FK4	1 500	1949	0.1″	
FK5	1 500	1949	0.05″	0.0008″/year
FK5 extended	3 000		0.08″	0.002″/year
Hipparcos	120 000	1991	0.001″	0.001″/year
Tycho	1 000 000	1991	0.03″	0.003″/year
PPM	380 000		0.3″	0.006″/year
SAO	250 000		1.5″	
GSC	20 000 000		1.5″	

List of star catalogues



Digital Sky Survey image of N pole (20-21 mag)