Deep Sky Imaging Acquisition Workshop: Optics

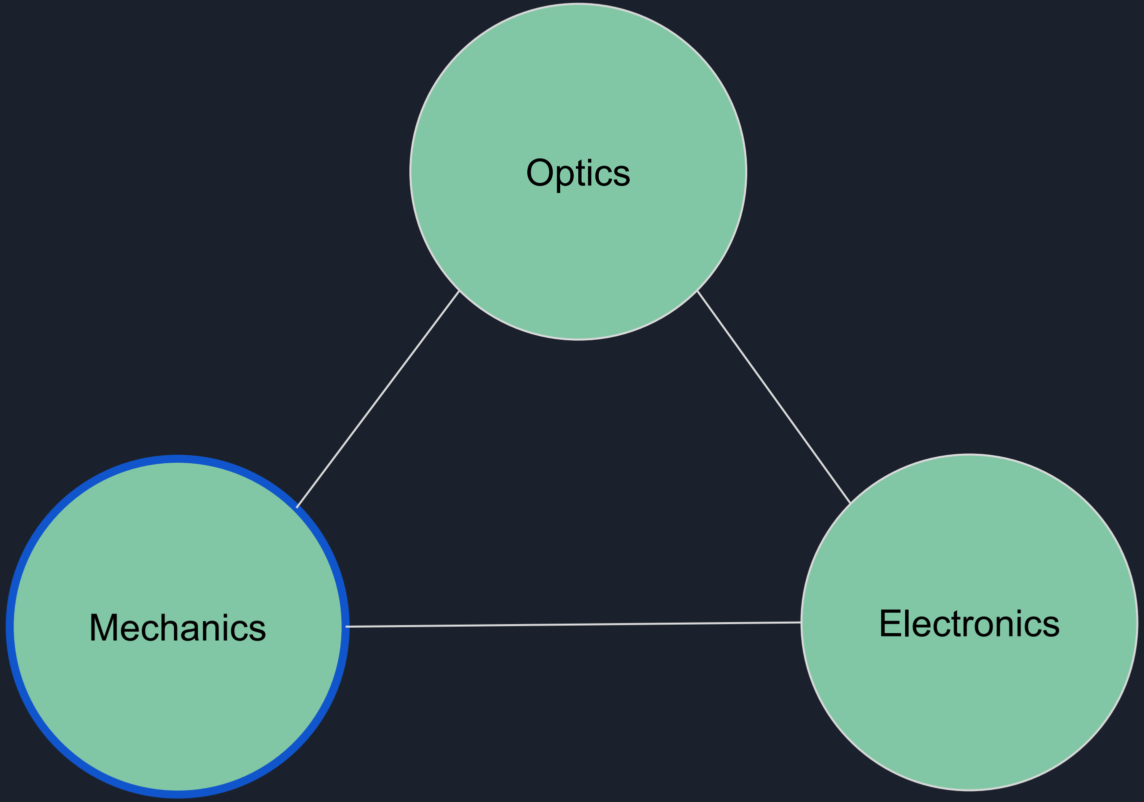
Gabe Shaughnessy

Last time...

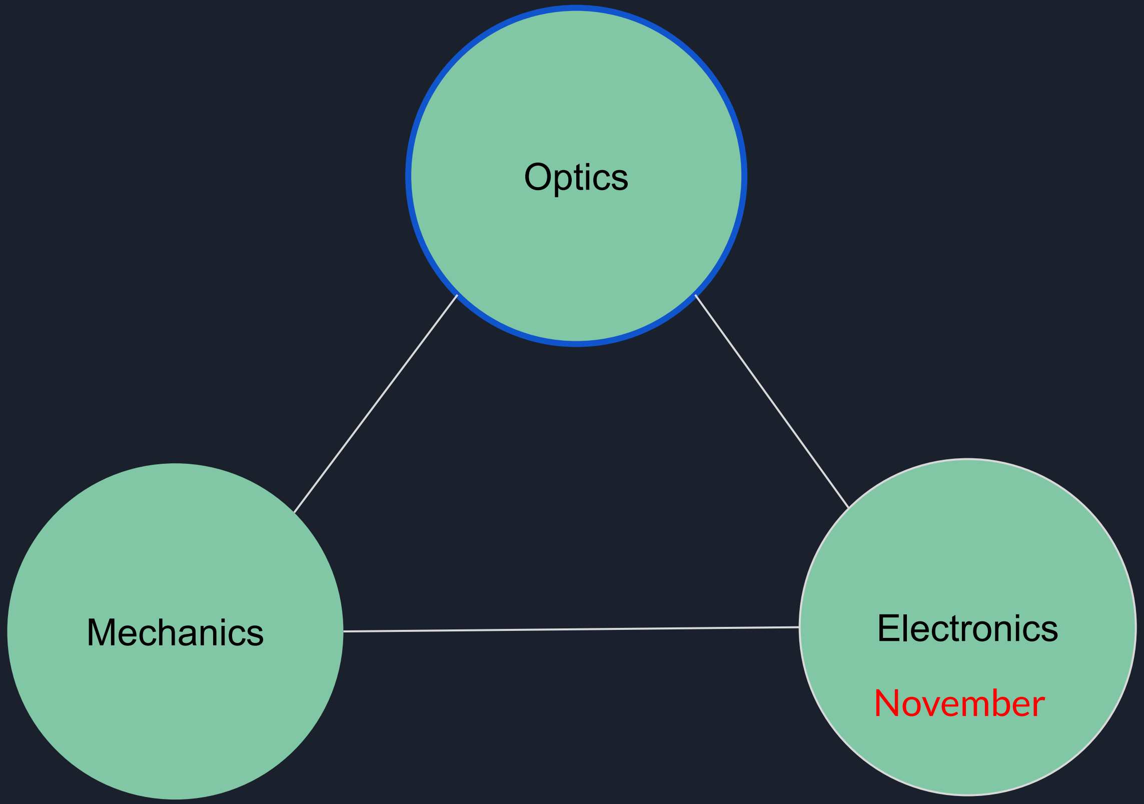
Mechanics of setting up your rig

- Counterweights
- Mount
- Cable Management
- Focus
- Polar alignment
- Environment sensors
- Dew prevention

The Trinity of Imaging



The Trinity of Imaging



Optics

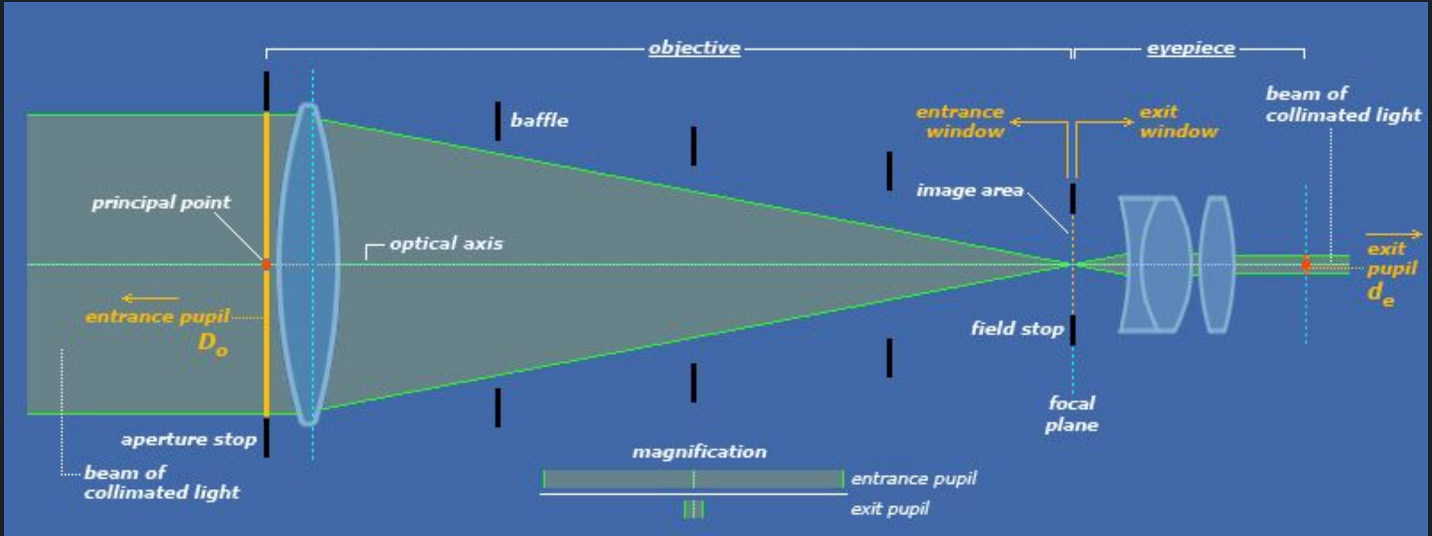
The Telescope

Aperture

- Larger aperture → More detail can be resolved

Focal length

- Longer focal length → more "magnification"



The Airy Disk

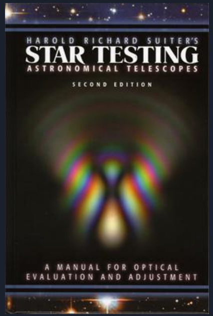
Wave nature of light causes diffraction rings around central spot

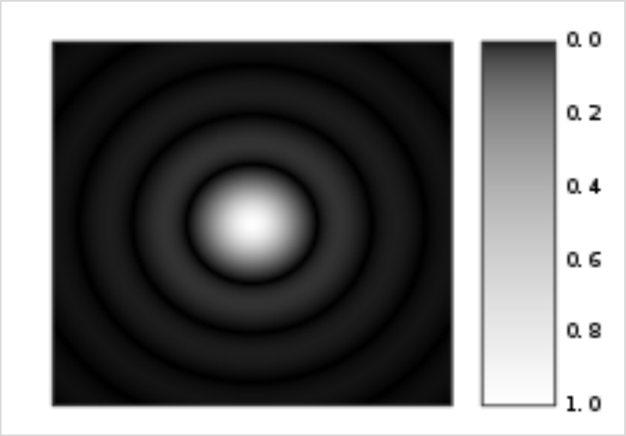
Caused by circular aperture of telescope

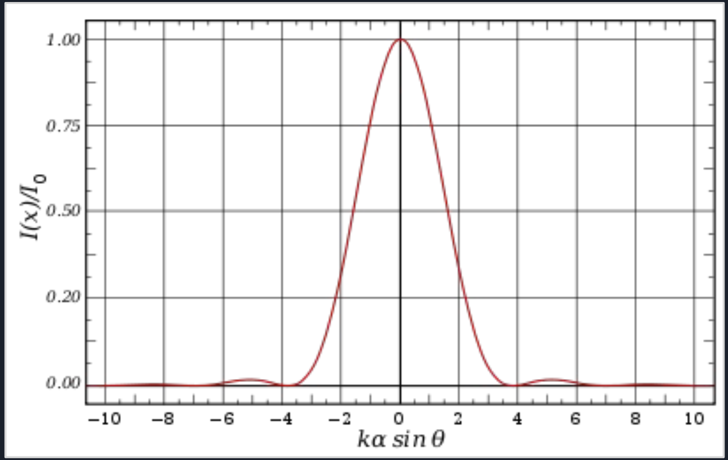
Central obstructions alter the shape of the Airy Disk

Excellent way to test the performance of your telescope

- Suiter's book on star testing



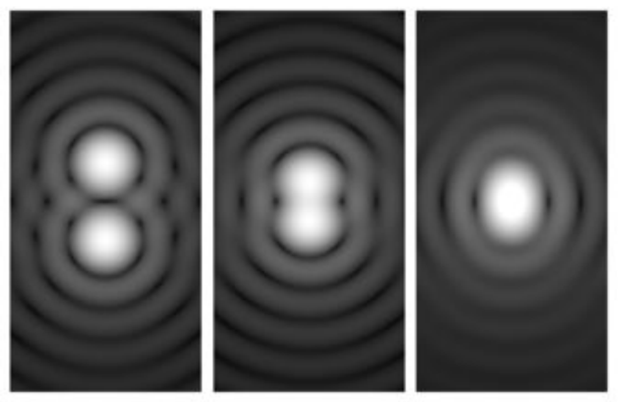


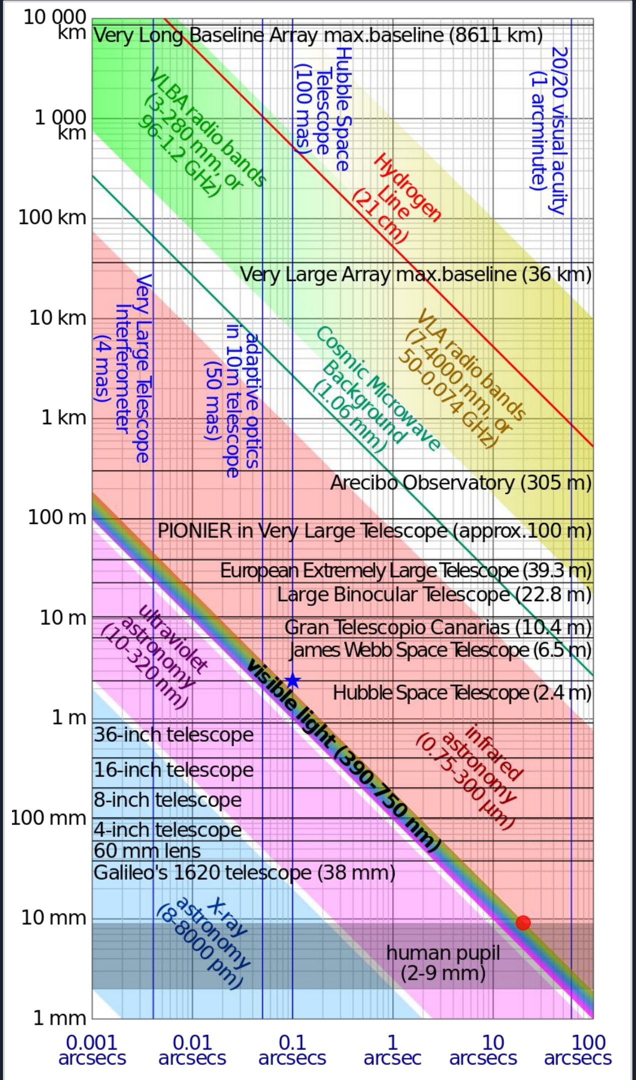


Resolving power

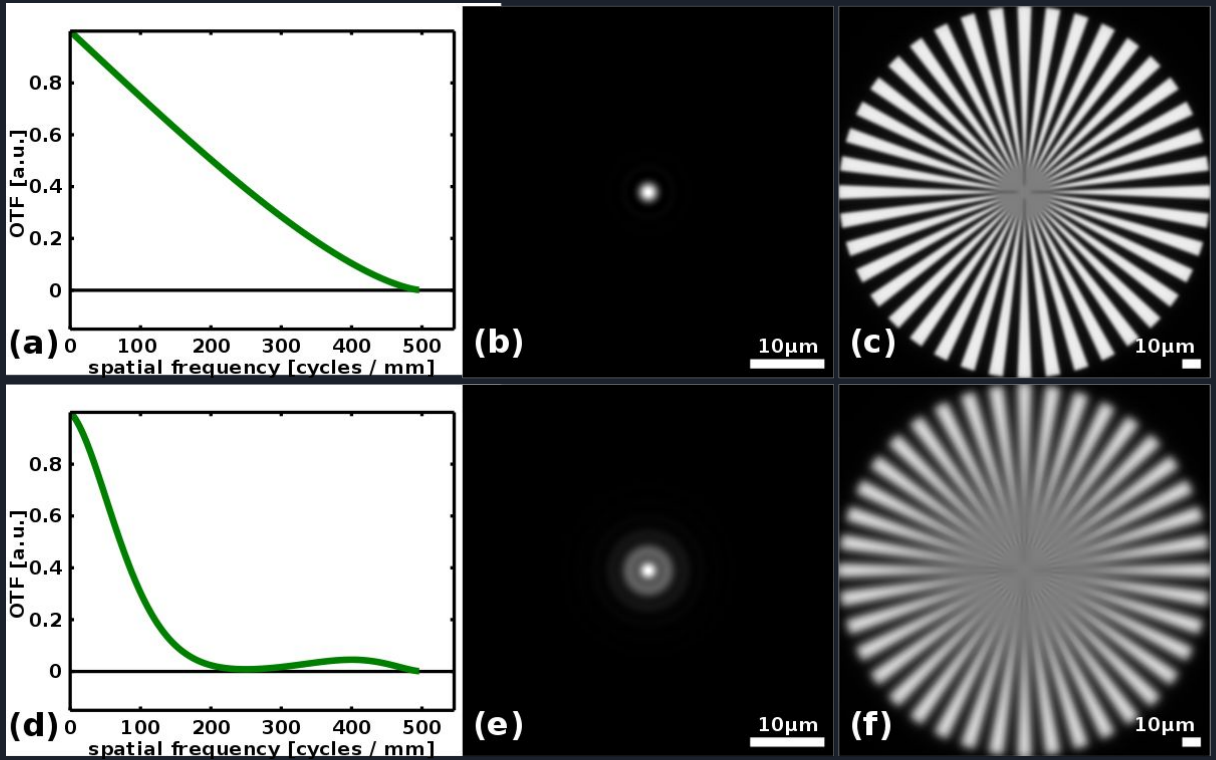
Rayleigh criterion can define resolving power:

- Separation of two Airy disks where maximum of one Airy pattern is located at the first minimum of second Airy pattern





Modulation Transfer Function

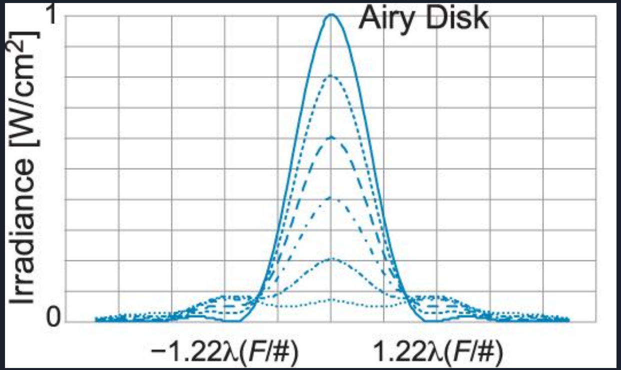


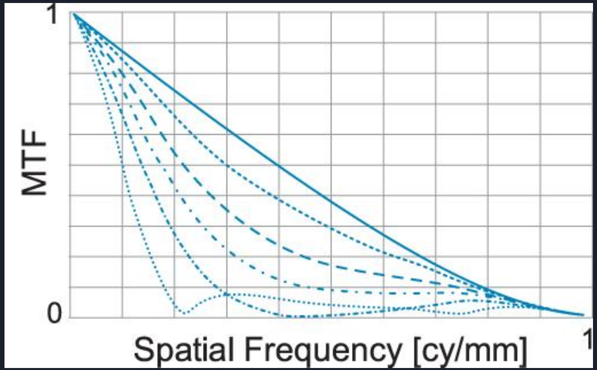
Strehl Ratio

Single number between 0 and 1 for quality of telescope system

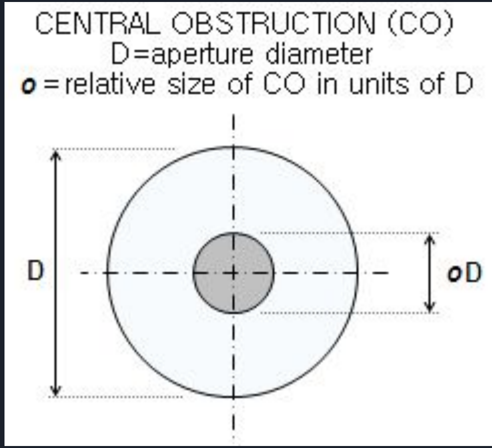
Strehl > 0.8 is diffraction limited

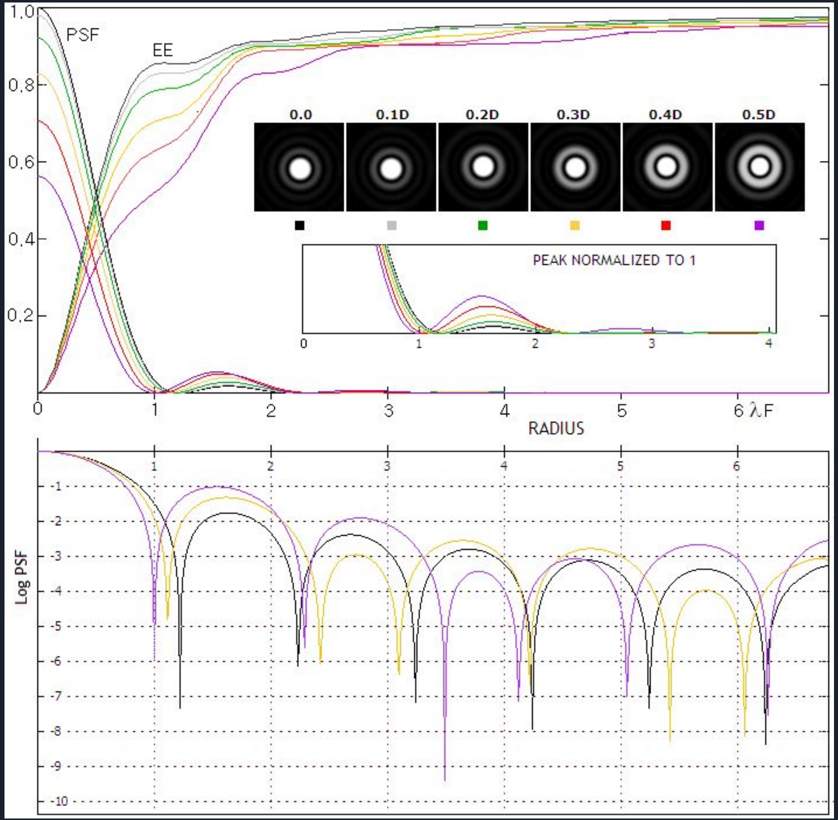
Excellent telescopes have Strehl values > 0.9, 0.95





The effect of a central obstruction





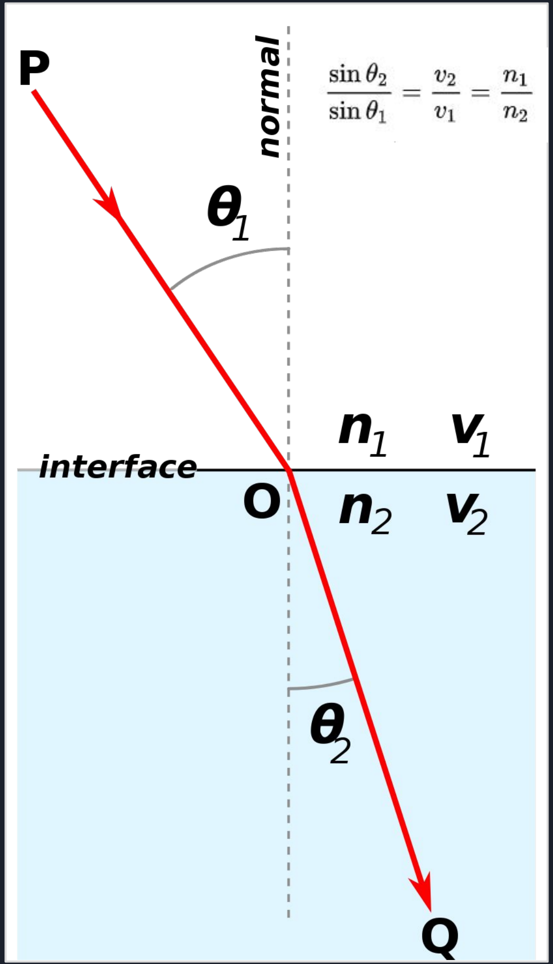
The Refractor

Invented by Galileo Galilei in 1609 as a simple two-lens system

Relies on refraction of light

- Physics behind it is really cool!
- Principle of least action/time

Curved surfaces allow rays to come to focus

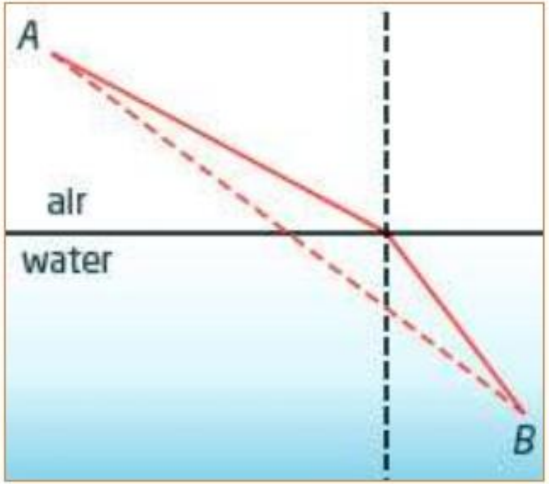


Fermat’s Principle

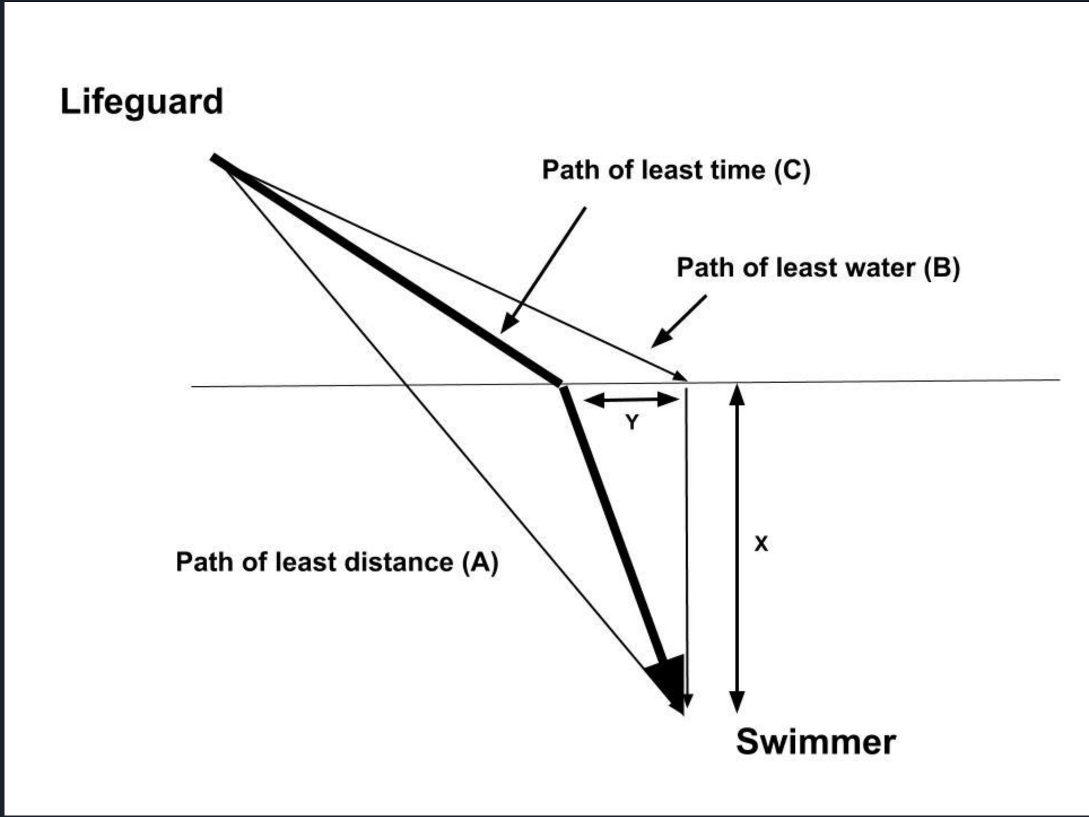
FERMAT’S PRINCIPLE

- Light will follow the path that takes the **least** amount of time
- In a single medium, the pathway is always a straight line
- When travelling from one medium to another the fastest pathway is **not** a straight line

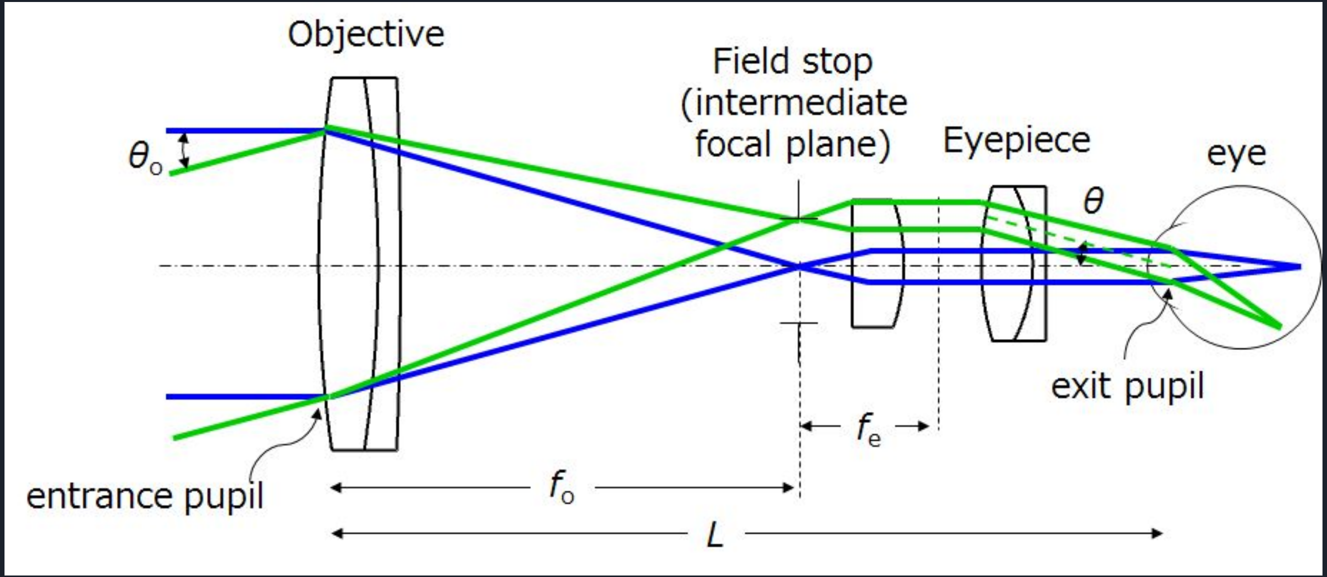
- Which path from A to B is faster?



Fermat's Principle

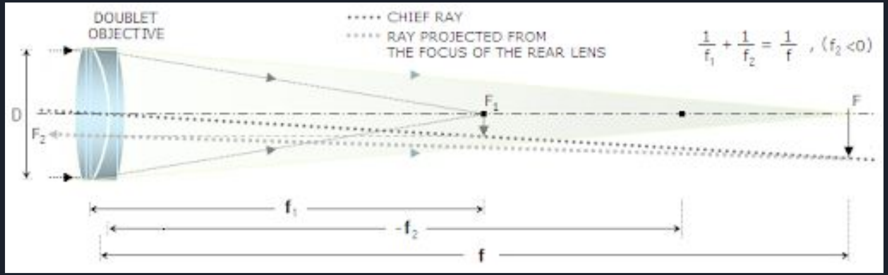


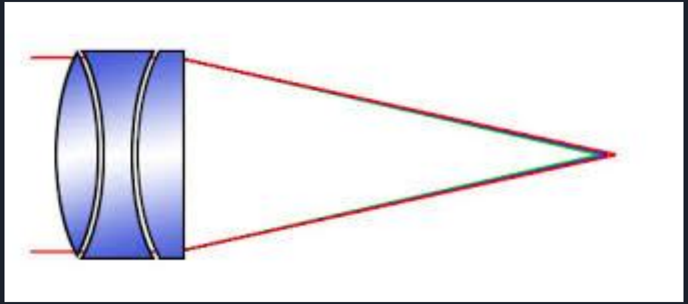
How a refracting telescope works



Refractor types

- Doublet refractor
  - Has detectable chromatic aberration
  - Fast cooldown times
  - Ok for imaging
- Triplet refractor
  - Excellent for imaging
  - Much better control over color correction
  - Takes longer to thermally equilibrate
  - Heavy front end





All of these will have some amount of field curvature

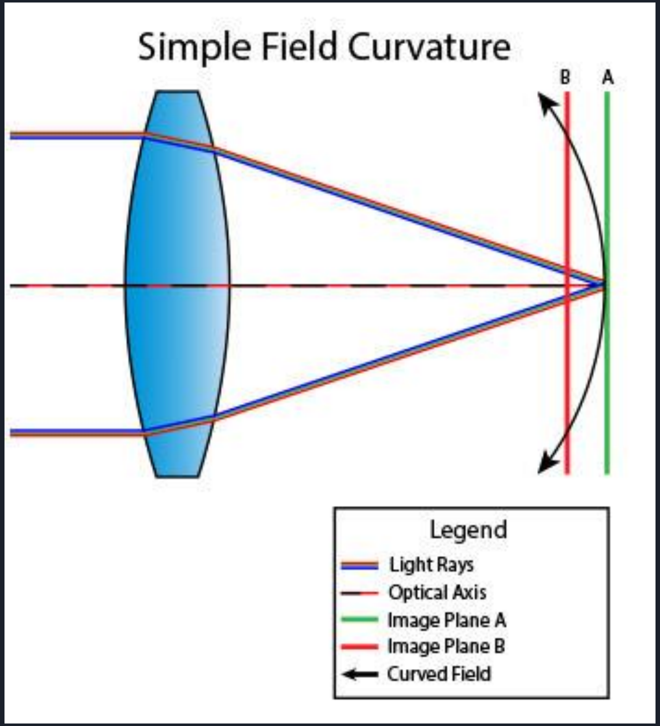
Optical Aberrations

Field Curvature

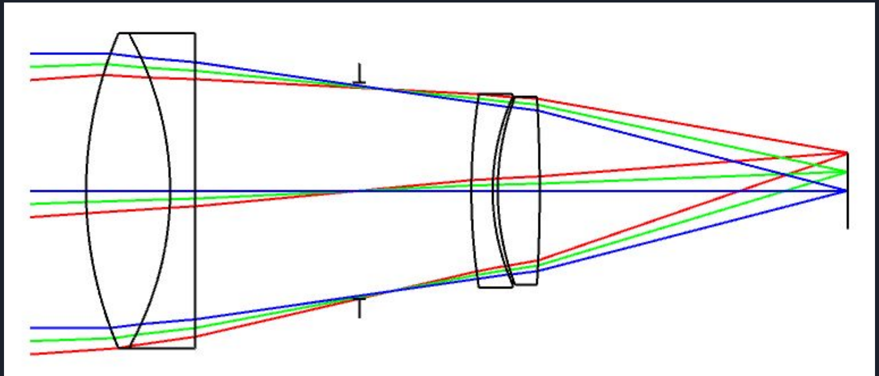
Inherent in any doublet/triplet refractor

Typically solved by using a field flattener element near sensor

Curved field is called the Petzval Surface



Correcting field curvature



Secondary grouping of lenses correct the curved focal surface

Can be achieved with:

- Separate field flattener
  - Backspacing critical
- Petzval design refractor
  - No backspacing issue, just focus
  - Can go out of collimation

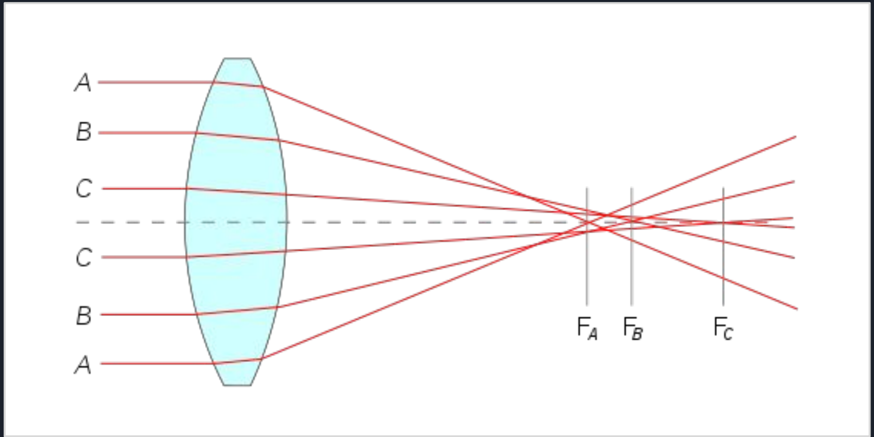
Examples: Takahashi FSQ106, Redcat 51

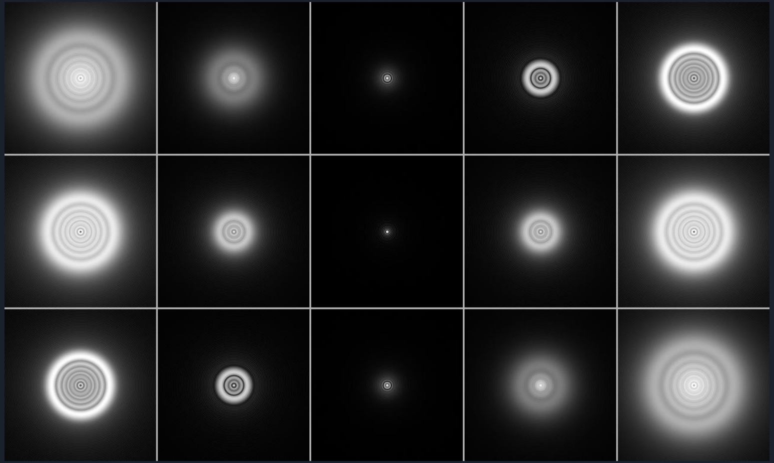
Spherical Aberration

Optical system has different focal lengths depending on how far ray is from optical axis

Visually noticeable in many refractors

Results in softness of stars and detail





Astigmatism

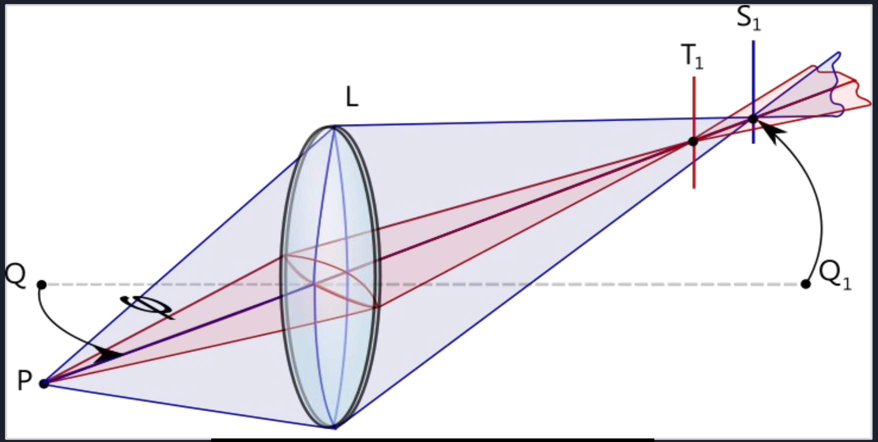
Happens when rays going through optical system have different focal lengths

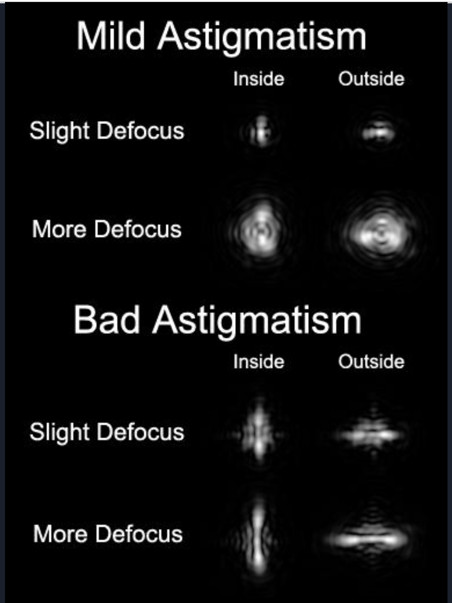
In example:

- Set of blue vs. red rays

Can be caused by pinched optics:

- Cell stress
- Thermal stress





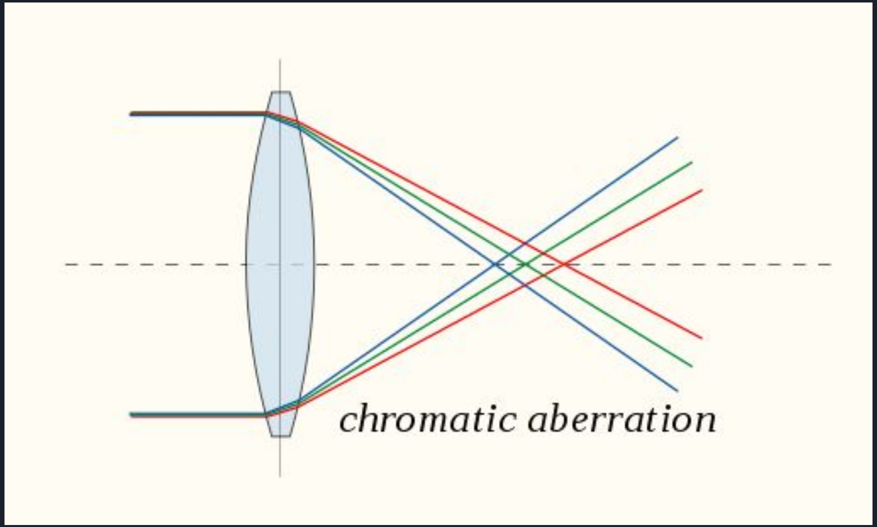
Chromatic Aberration

Colors have different focal lengths

Okay for narrowband

Completely absent in designs with only reflecting surfaces:

- Ritchey Chretien
- Dall Kirkham
- Cassegrain



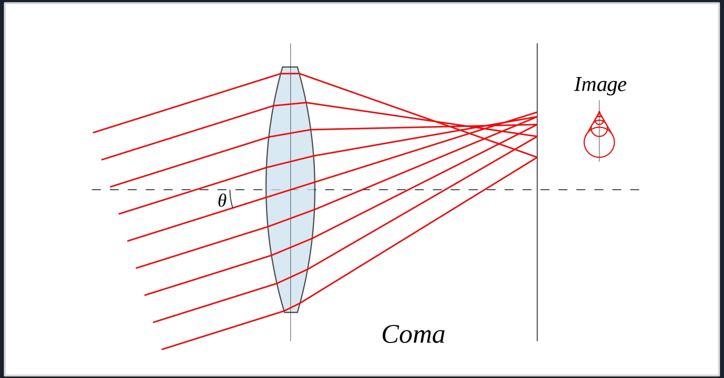
Coma

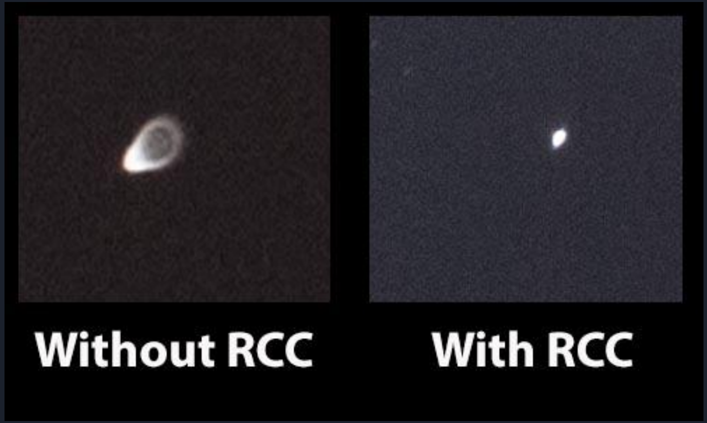
Common in reflector designs

Off-axis analog of spherical aberration

In reflectors, coma increases by the third power of focal ratio

- f/4 has 8x more coma than f/8





The Reflector

Benefits:

- Large aperture
- Typically fast, <f/5

Drawbacks:

- Heavy, need a good mount to support
- Needs collimation
- Cooldown
- Coma - needs coma corrector

Coma corrector

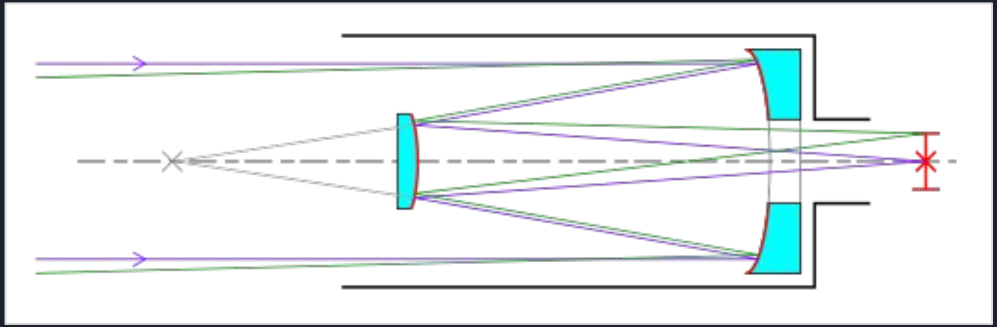
Many coma correctors available:

- Baader, TS, Televue, etc.

Televue Paracorr has slight barlow effect: 1.15x

Excellent performance w/ 56mm backspacing

Cassegrain designs



Ritchey - Chretien

- Hyperbolic mirrors
- Difficult to produce and align
- Mechanicals of OTA/cells crucial to good collimation
- Has some field curvature
- Used in scientific studies

Dall-Kirkham

- Elliptical primary + spherical secondary

In both, add corrector element near focal plane - refractor FFs work reasonably well with RC scopes

The Cats

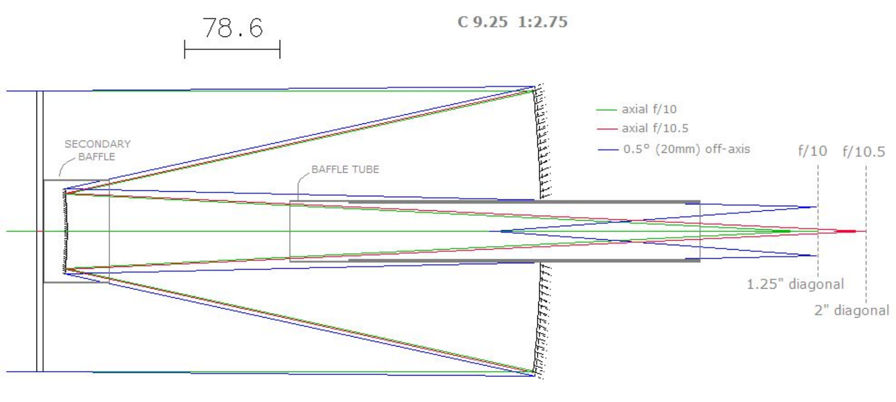
Catadioptric: mixing refracting and reflecting surfaces

Benefits:

- Folded design gives compact long focal length scope
- Fairly easy to collimate

Drawbacks:

- Dew on front corrector plate
    - Dewshield and/or dew heater a necessity
- Closed system, so thermal equilibration can take time



Corrected SCTs

Edge HD f/10 or f/11

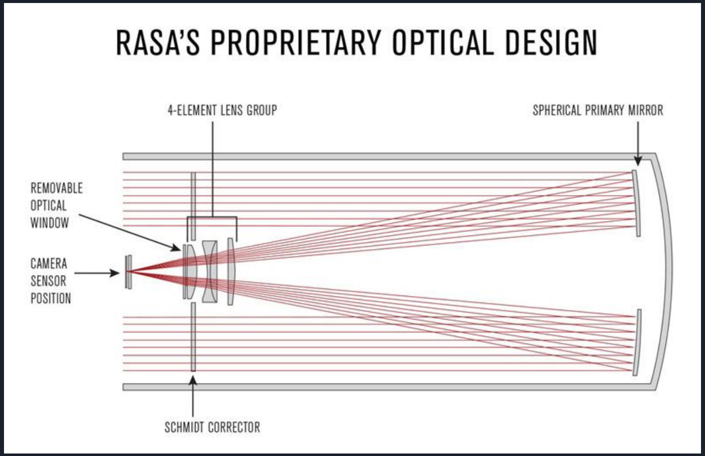
- Has a corrector element in baffle tube
- No field curvature
- Other aberrations very small
- Fans help equilibrate inside
- Focal length can be shortened by 0.7x with optional reducer

Meade ACF f/10

- Coma free
- Still has some field curvature

Other designs

RASA f/2 or f/2.2:



Hyperbolic Newtonian f/2.8:

Filters

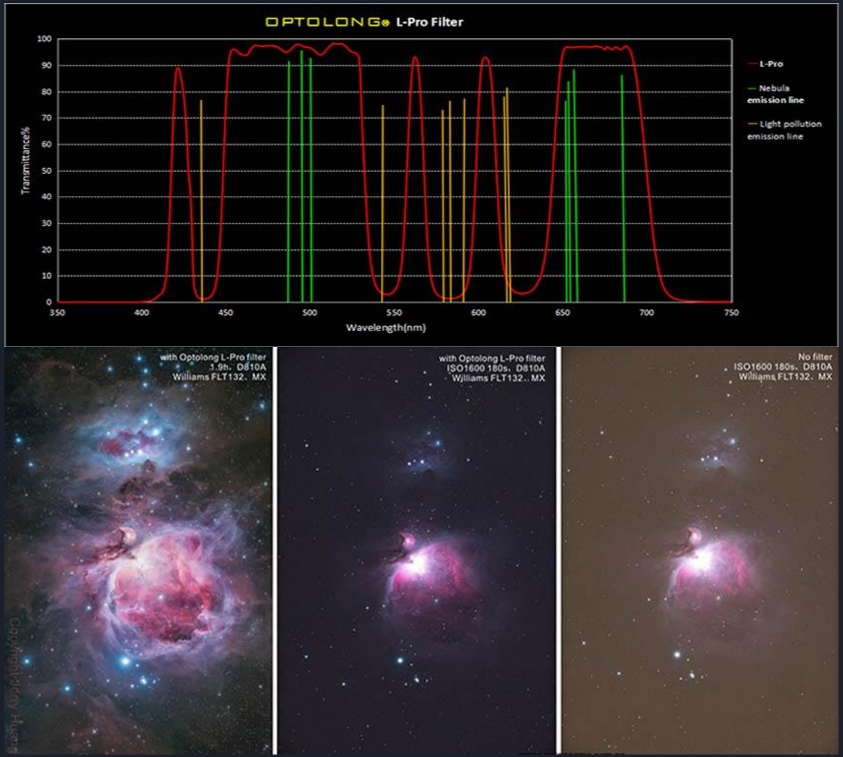
Light pollution filters

Light pollution from cities typically have emission lines.

LP filters remove these source from sky background - better contrast!

Not good for broadband emission:

- Moonlight
- LED lamps

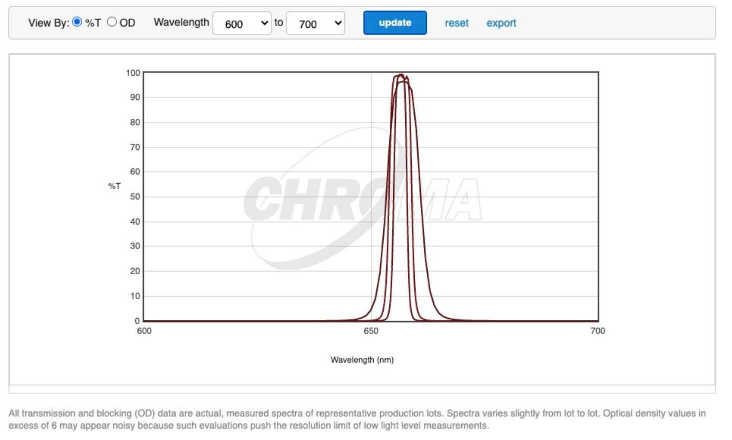


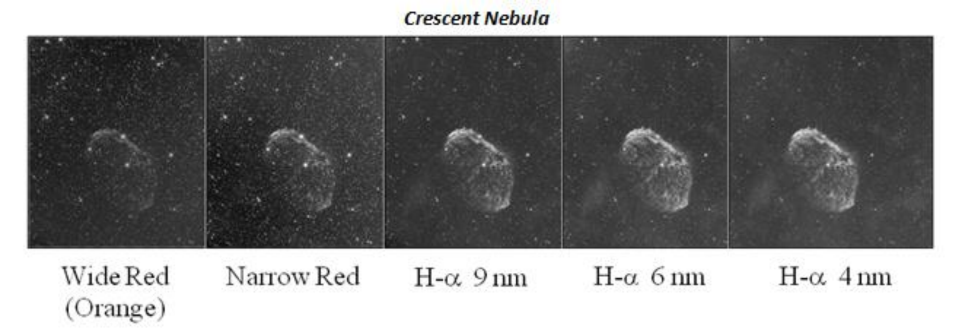
Narrowband

Excellent for Light polluted skies

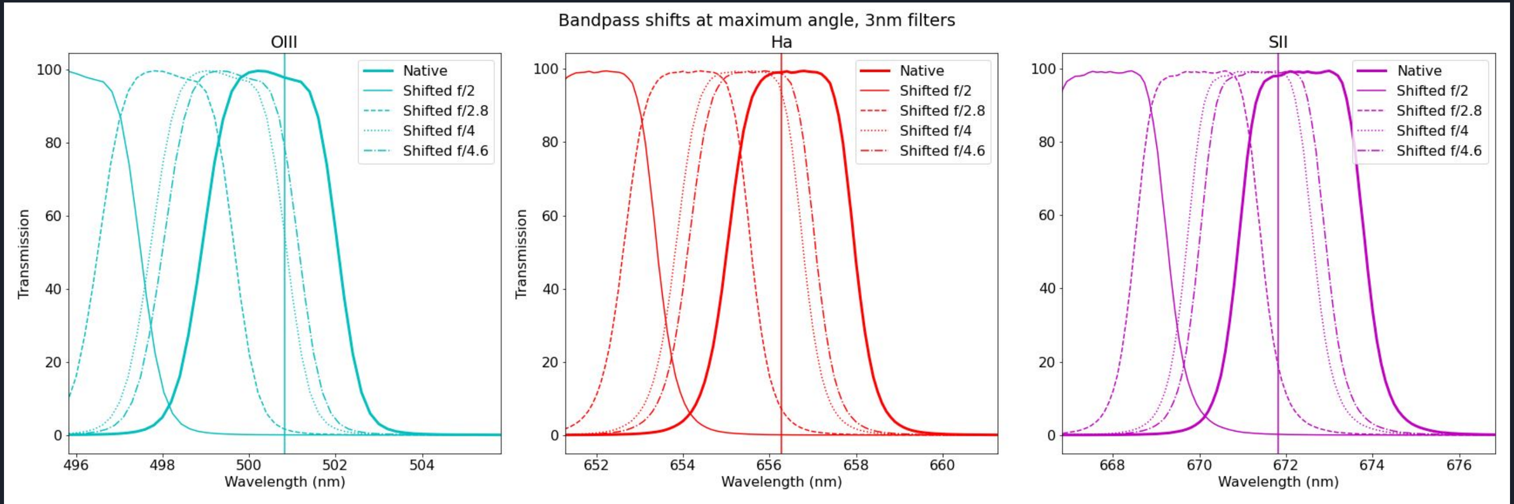
Rejects all light except atomic emission lines of interest: great contrast

Can become less effective with fast systems

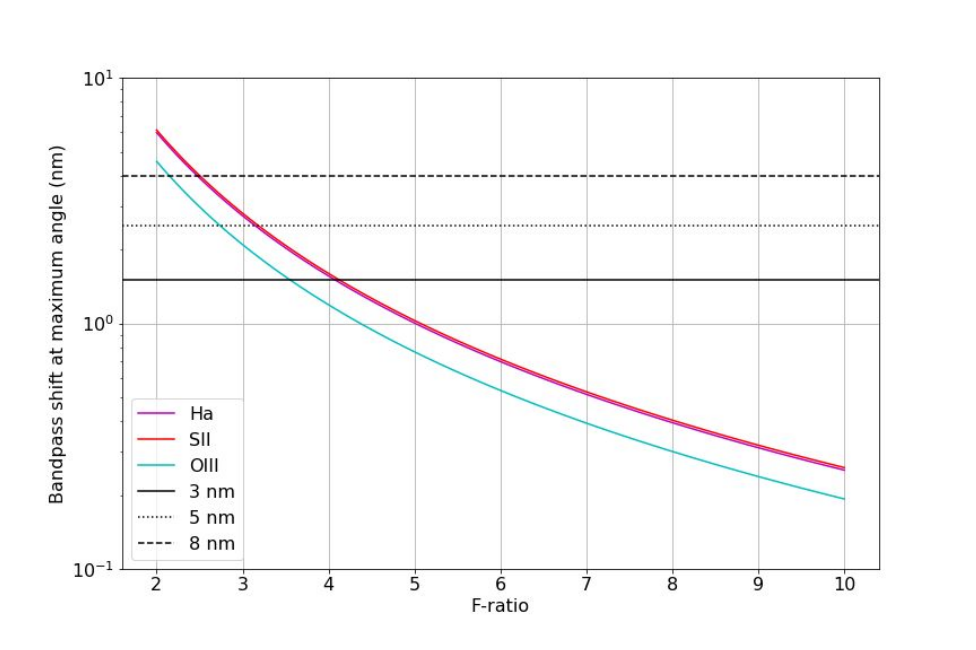




Narrowband imaging in fast systems



Narrowband imaging in fast systems



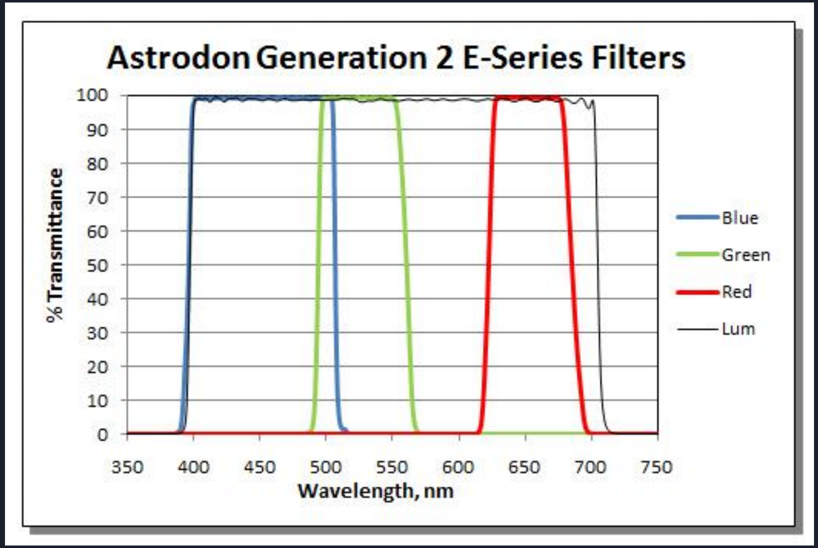
LRGB filters

Luminance:

- Typically clear filter with IR/UV cut.
- Often used to get best detail.

RGB:

- Can be taken w/ lower resolution (2x2 binning)
- Can have gaps in coverage to remove LP emission lines



Cleaning/Installing Filters

Steps:

- Blower to remove large debris
  - No compressed air!
- Microfiber wipe
- Solvent:
  - Make sure no contaminants, etc.
- Microfiber wipe

Removing filters:

- Toothpick to raise unmounted filters out of cell
- Never touch surface, only edges

Before closing:

- Always use blower as final step

Star Shapes for the Pixel Peeper

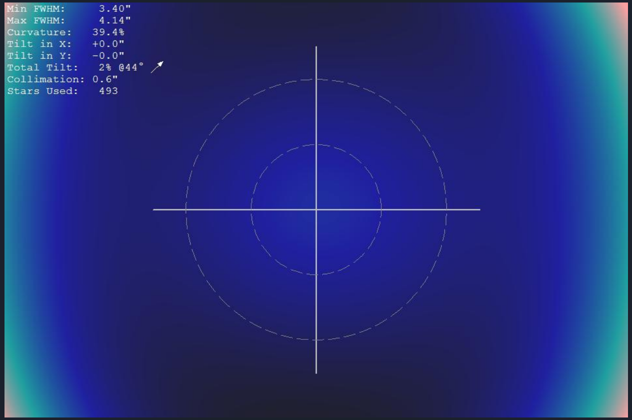
Tools to help diagnose star shapes

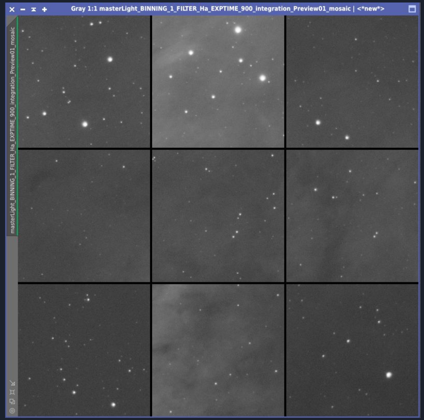
CCD Inspector

- Dial in spacing and collimation
- Can be done on acquisition computer

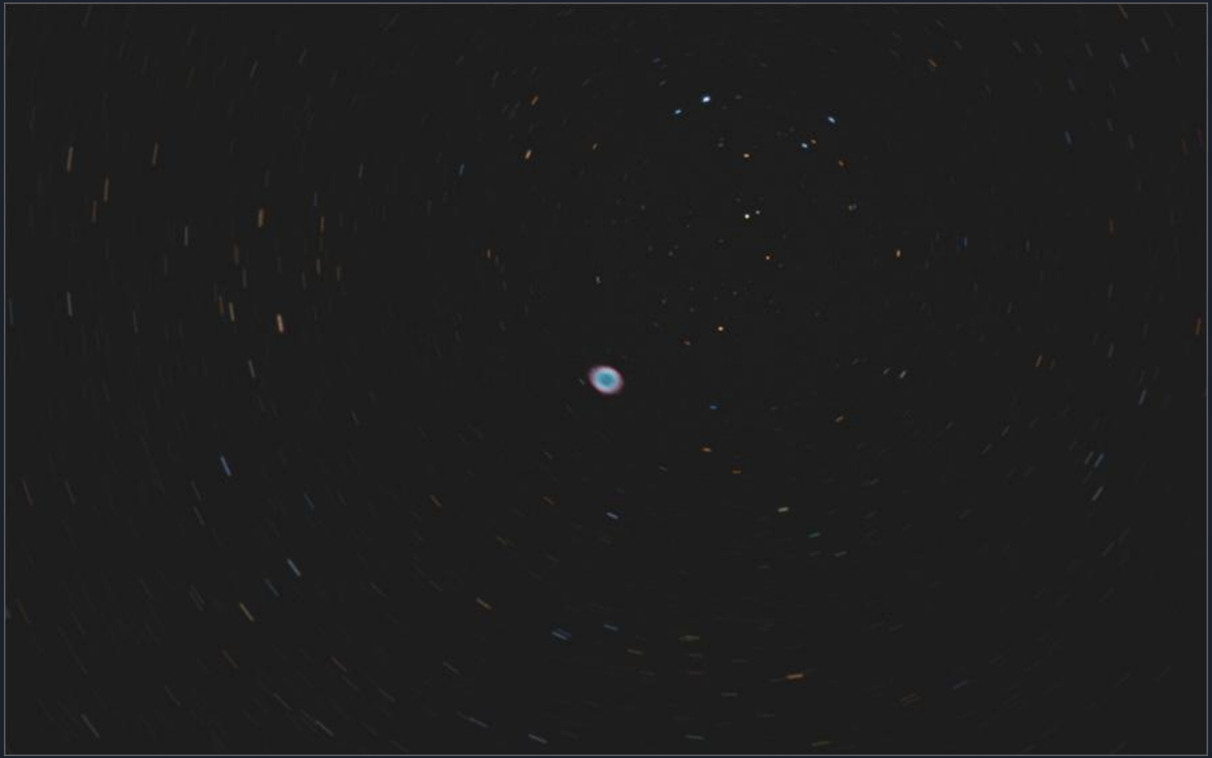
Pixinsight:

- AberrationInspector
- FWHMEccentricity
    - Typically an offline process





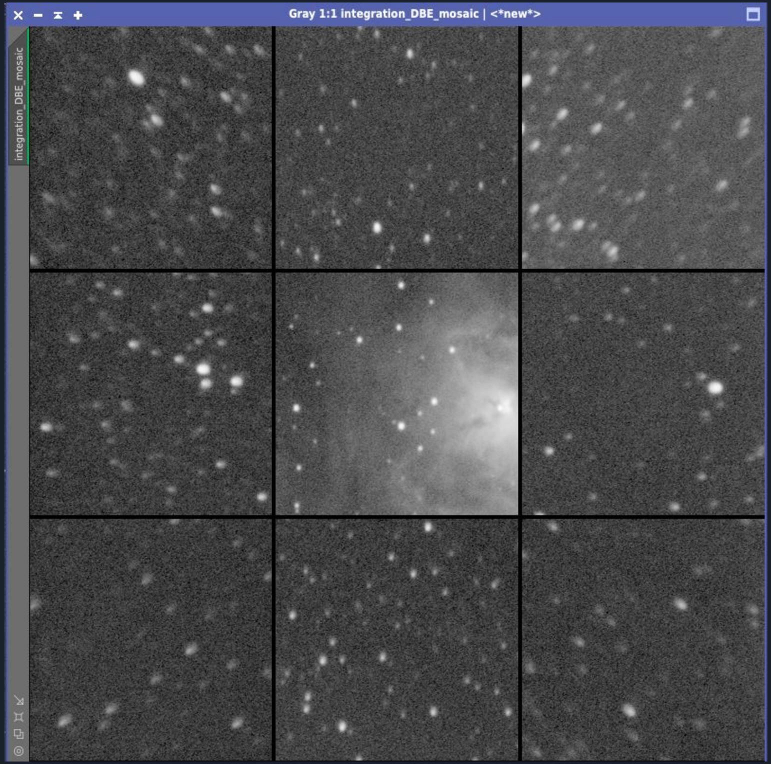
Diagnosing Star Shapes



Bad polar alignment

Diagnosing Star Shapes

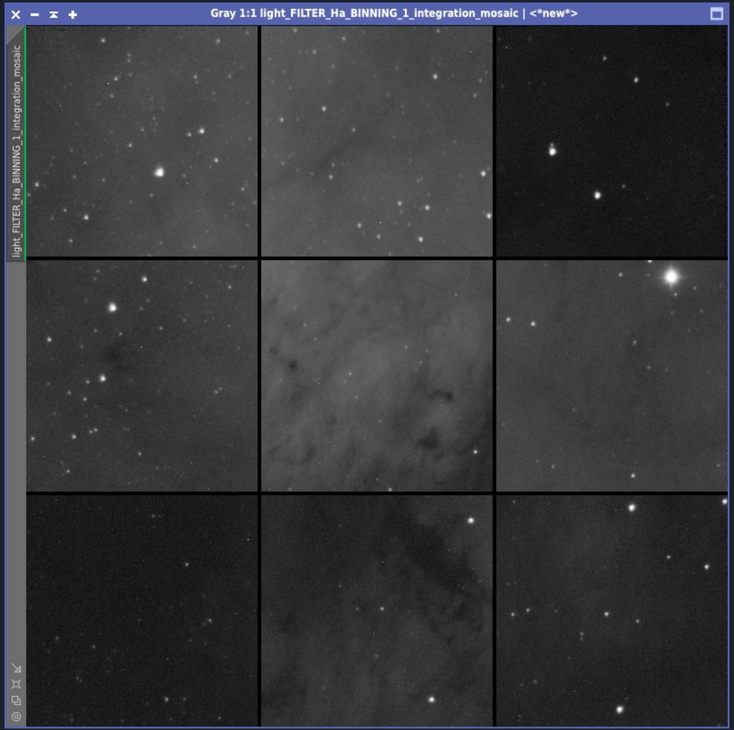
Diagnosing Star Shapes



Field curvature - needs field flattener

Diagnosing Star Shapes

Diagnosing Star Shapes



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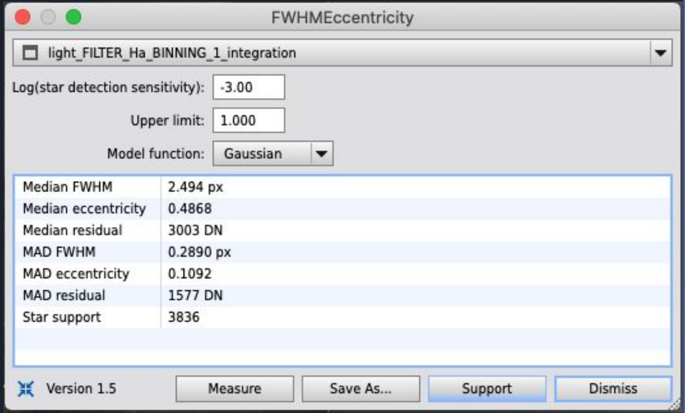
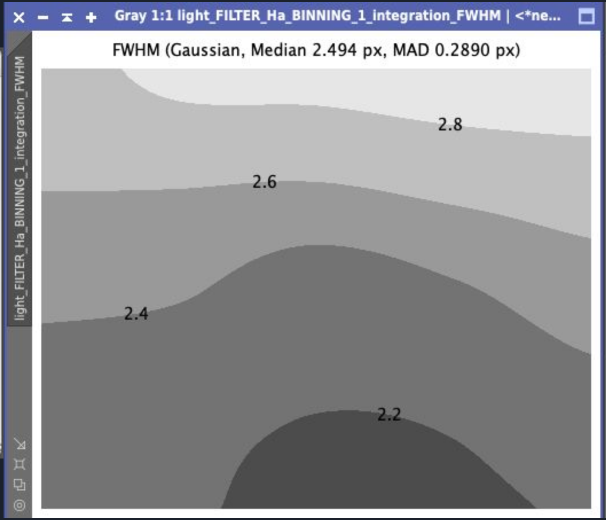
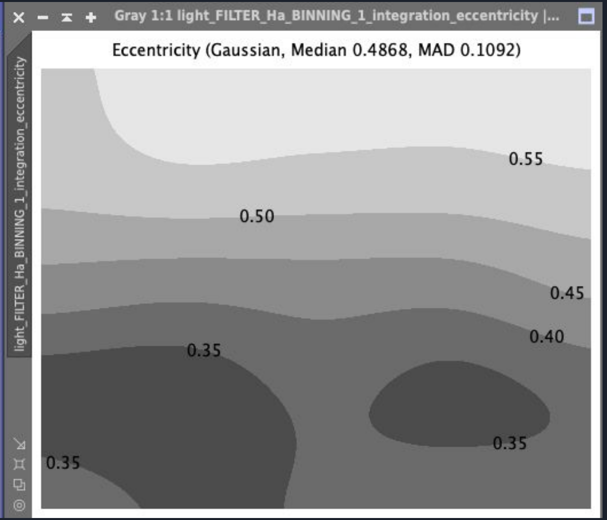
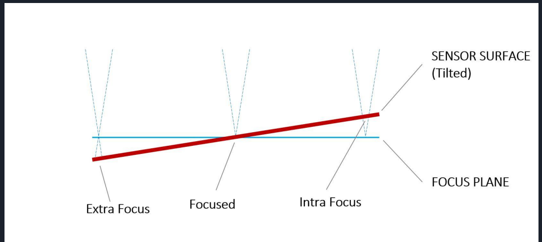


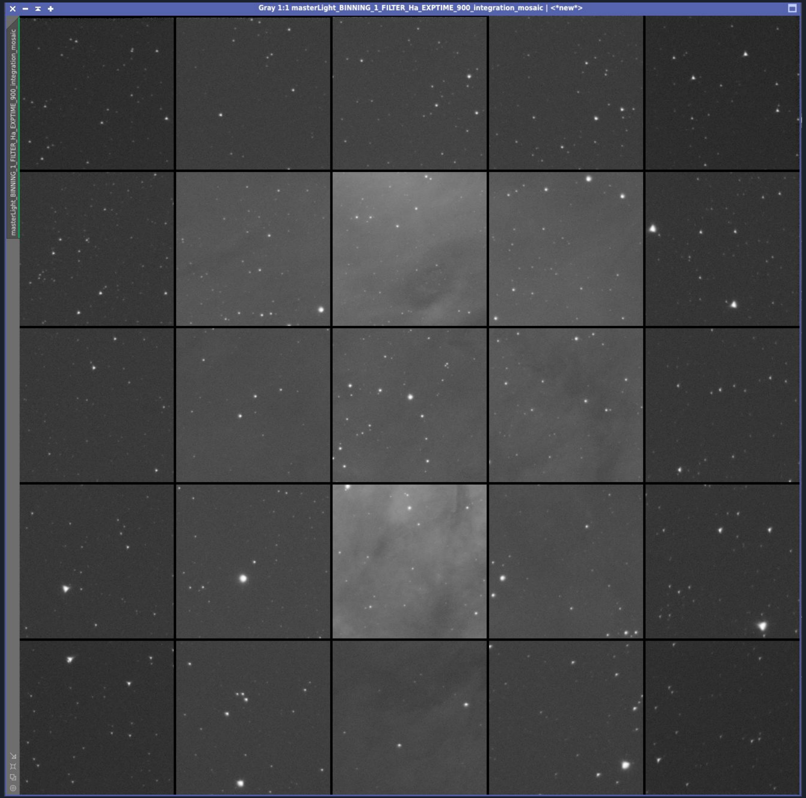






Tilt

Diagnosing Star Shapes

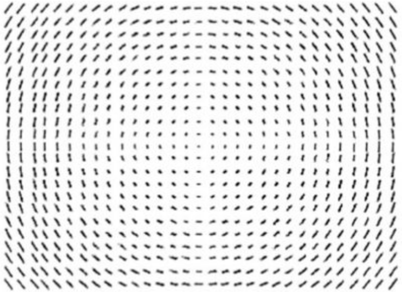


Frame too large for field flattener

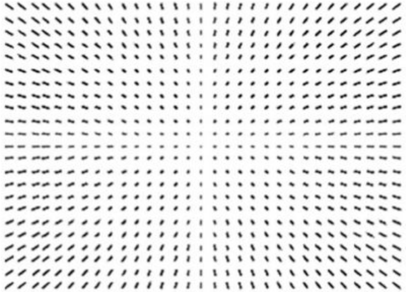
Zeroing in on Backfocus

Flattener/Reducer Star Patterns

For REFRACTORS:

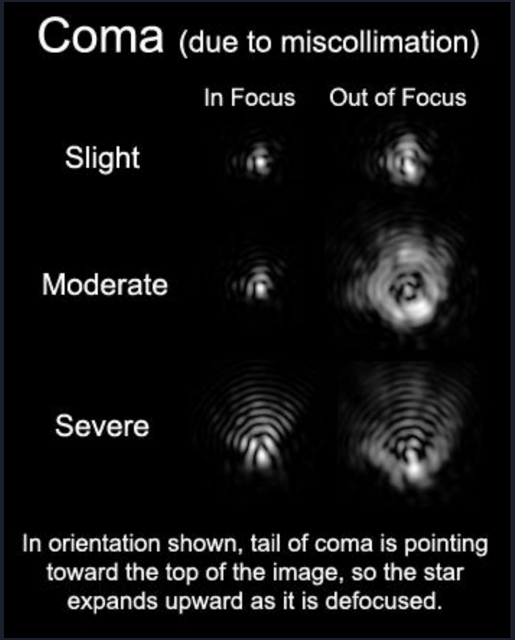


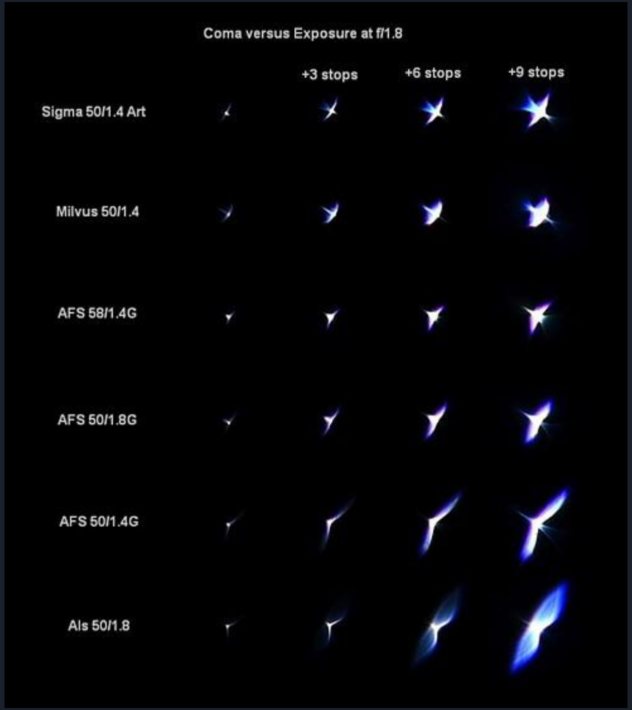
If stars appear to form arcs or concentric circles around the center, the distance between the flattener and CCD must be REDUCED.



If stars appear to radiate out from the center, the distance between the flattener and CCD must be INCREASED.

Diagnosing Star Shapes - Other Examples





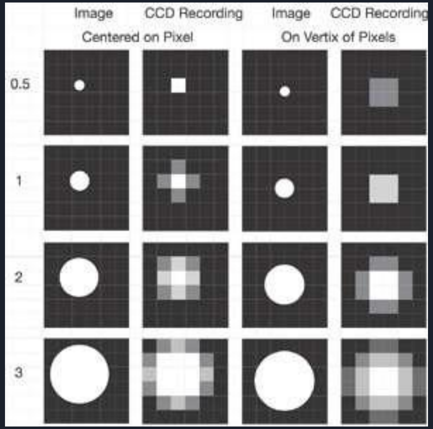
Next time:

Jeff (October 14):

- All about guiding

Me (November 11):

- Electronics



Down the road

- Cameras and settings
- Calibration frames
- Acquisition software (SGP, etc.)
- Target planning/sequencing
- Data management
- Weather resources
- Observatory topics
- More processing topics
    - PS/PI

Looking for volunteers for some of these topics