OTTICA X ASTRONOMY
(Chromey)

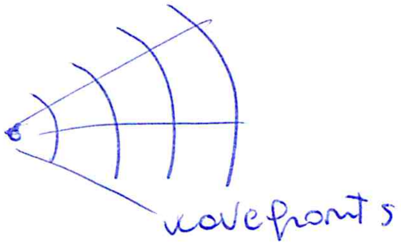
— cenni —
punti + importanti

indice di rifrazione $n(\lambda) = \frac{c}{v(\lambda)}$

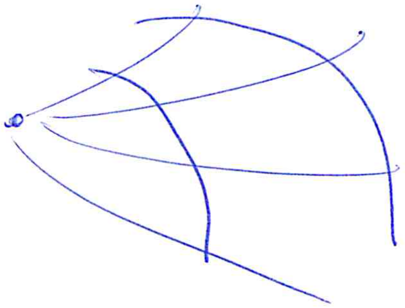
vel. della luce nel mezzo

dispersione cromatica $\frac{dn}{d\lambda}$

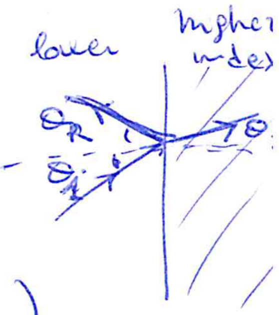
se mezzo omogeneo



se non lo è

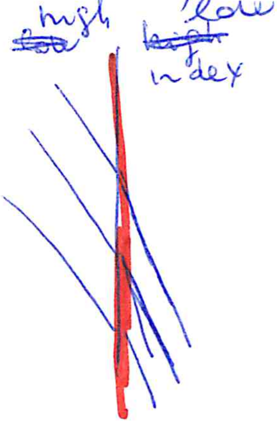


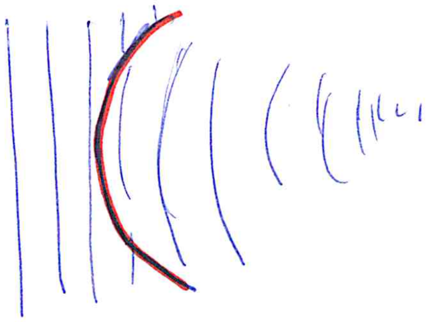
legge riflessione $\theta_1 = -\theta_R$



legge rifrazione (di Snell) $n_1 \, \mathrm{sen}(\theta_1) = n_2 \, \mathrm{sen}(\theta_2)$

fig 5.4

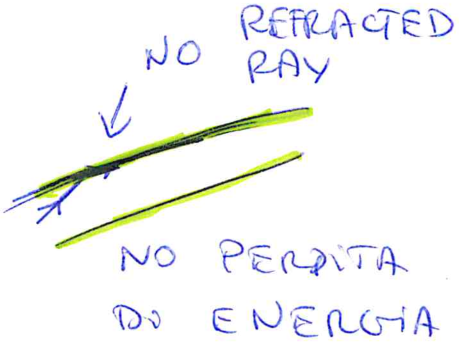




effetto di focalizzazione

certo angolo di incidenza, detto angolo critico, che produce un angolo così lontano da ⊥ che non lascia il mezzo + denso

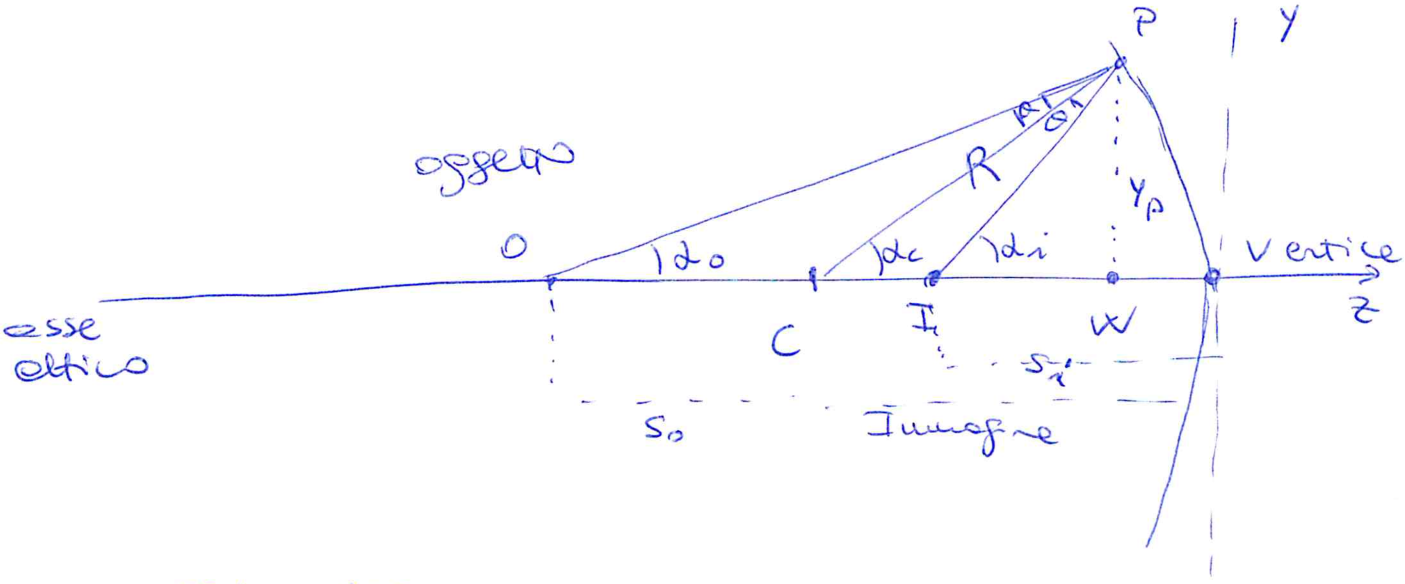
$$\theta_c = \text{sen}^{-1}\left(\frac{n_1}{n_2}\right) \begin{matrix} \rightarrow \text{entrante} \\ \rightarrow \text{uscente} \end{matrix}$$



Total internal reflection

→ FIBRE OTTICHE

RIFLESSIONE DA UNA SUP. SFERICA



approssimazione parassiale

diametro specchio ≪ R
y   raggio di curvatura

$\Rightarrow$ tutti gli α e θ mooolto piccoli!

eq. parassiale × (specchi) riflessione

$$\frac{2}{R} = \frac{1}{S_0} + \frac{1}{S_1}$$

distanze oggetto e immagine

$\frac{R}{2}$ = the focal length = f

$$\frac{1}{f} = \frac{1}{S_0} + \frac{1}{S_1} = -P$$ power of the surface

$S_i \rightarrow f \Rightarrow S_0 \rightarrow \infty$

raggi da ∞ → in f cioè $\frac{R}{2}$

P è il potere di curvare direzione alla luce

P grande ⇒ f piccola (riesco a far convergere luce!)

light gathering power $\propto D^2$

capacità di raccogliere la luce

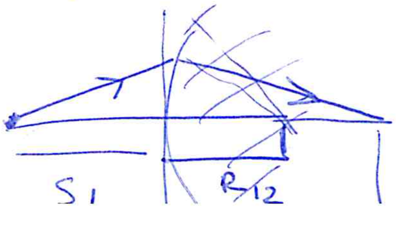
$\propto$ Apertura $\propto D^2$

sorgenti astronomiche deboli ⇒ ~~tel~~ specchi grandi!

Bigger is better!

eq. parassiale × rifrazione

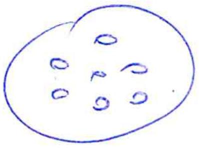
$$\frac{n_2}{\ } - \frac{n_1}{\ } = \frac{n_2 - n_1}{\ }$$



+ (COMBINA ZIONI

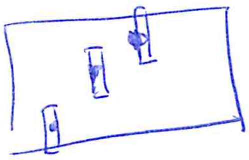
Fibre ottiche

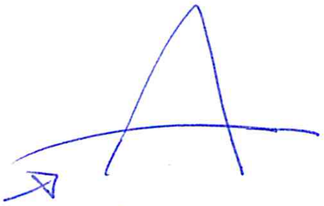
usate molto in
MOS multi-objs-spectroscopy



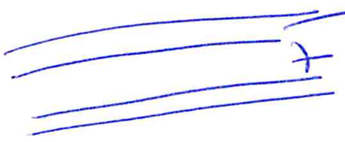
riduzione + facile
+ facile sottrazione del cielo
- si perde un po' di luce

(alternativa è multifenditura)





da togliere x ognuno è diverso



high-index glass

D ~ 50-200 μ

Materiali x str. ottici

Materiali riflettenti

\+ ideale indice = 1.0 x ogni λ

\+ facile dargli forme con accuratezza di frazioni della λ che mi interessa

\+ meccanicamente e chimicamente stabile

\+ leggeri (se vanno in orbita!)

\+ stabili contro variazioni termiche

Specchi di metallo ... ora vetro alluminato
↓ substrato
↖ argento
oro - berillio

~~[illegible] nichelato SiO~~

Materiali x trasmissione

~~Vetri~~

omogeneità

no espansione termica

no bolle e inclusioni

no dipendenza n (temperatura)

Nel visibile glasses vetri

alta dispersione "flints"

bassa " "crowns"

problemi in UV perché vetro è opaco!

allora quarzo SiO_2

PRISMI → PROF. CRISTIANI

~~SCALA DELL'IMMAGINE~~ — ~~IMAGE SCALE~~

TELESCOPI OTTICI (Karttunen + Chromey)

cosa devono fare?

1) raccogliere (tanta) luce
point sources → grande area

<u>luce</u>

2) aumentare il diametro angolare
degli oggetti → così aumenta risoluzione

3) misurare la posizione

<u>dettagli</u>

<u>separazione</u>
di 2

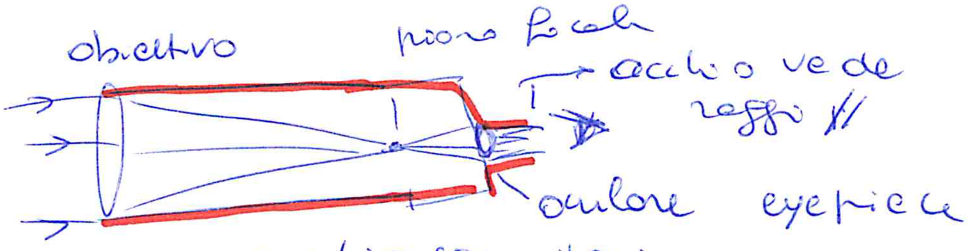
<u>posizione</u>

la superficie di un collettore di luce è

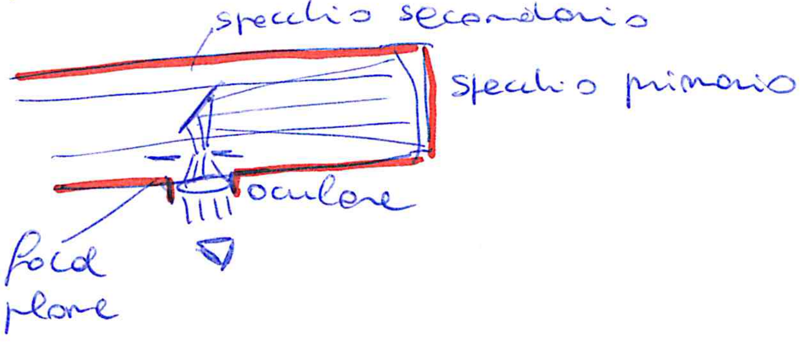
specchio → riflettori

lente → rifrattori

Rifrattori



Riflettori



Quantità importanti

telescopio come RACCOGLITORE

diametro obiettivo (specchio primario) D APERTURE del telescopio

f FOCAL LENGTH

$F = \frac{D}{f}$ APERTURE RATIO

se grande ~ 1 "fast" telescope

× sorgenti brillanti

faccio foto in breve tempo

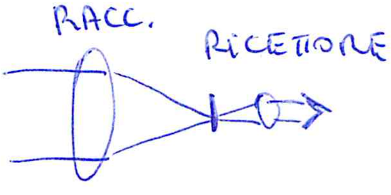
"slow" telescope

$n = \frac{f}{D}$ aperture ratio $\frac{f}{n}$

fast $\frac{f}{1}$ ... $\frac{f}{3}$

SCALE of IMAGE che si forma nel piano focale

se oggetto si vede sotto angolo u



$s = f \operatorname{tg} u \sim f \cdot u$

es/ $f = 343$ cm $1' \rightarrow 1$ mm aumento risoluzione,

va concordato con $\boxed{\text{RICETTORE}}$ ... dettagli che posso

POTERE RISOLUTIVO   RESOLVING POWER

es. minima separazione angolare
x riuscire a separare stelle in sist. binario

LIMITE DI DIFFRAZIONE

Limite Teorico dalla diffrazione

criterio di Rayleigh

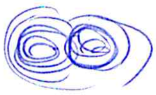
x aperture circolare

$$\sin\theta \sim \theta = 1{,}22\,\frac{\lambda}{D}$$

↓
dimensione angolare dell'immagine

2 stelle sono separabili se

$$\theta \gtrsim \frac{\lambda}{D}$$



D ↑   potere risolut ↑

λ ↑   "   ↓

es. luce giallo $\lambda = 550\ \text{nm}$ ⇒
res. power per $D = 1\ \text{m}$ è $0{,}2''$

MA SEEING È MAGGIORE !

! [per telescopi grossi è il seeing
che fornisce il limite x risoluzione !

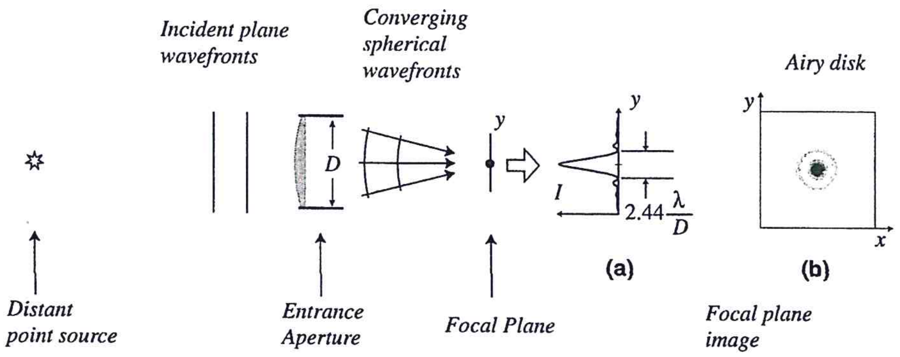


Fig. 5.20 Telescopic images in the absence of an atmosphere. Plane wavefronts diffract upon encountering the circular aperture, and focus as an Airy disk: a bright central spot surrounded by rings of decreasing brightness. (a) The intensity of the resulting image vs. distance on the y-axis. The central peak has a full width of twice the Airy radius: $2\alpha = 2.44\lambda/D$ (b) A negative of the two-dimensional diffraction pattern.

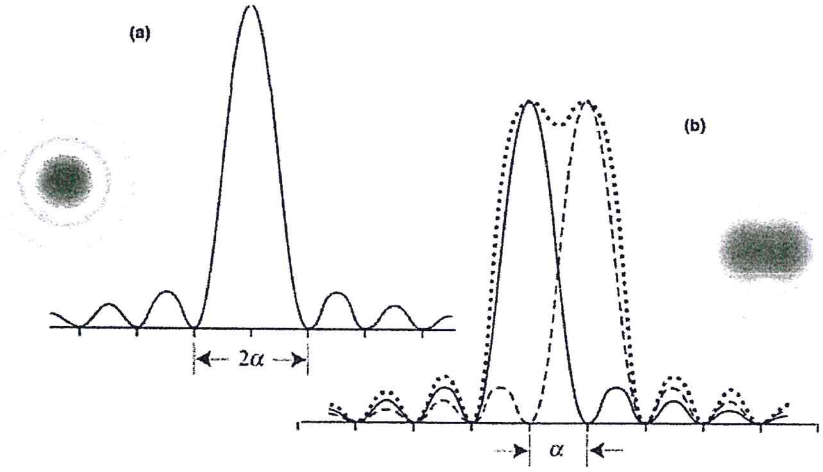


Fig. 5.21 (a) The Airy pattern as a negative image and plotted as intensity vs. radius. (b) The negative image of two identical monochromatic point sources separated by an angle equal to Rayleigh's limit. The plot shows intensity along the line joining the two images. The unblended images are plotted as the solid and dashed curves, their sum as the dotted curve.

resolving power requires that to resolve two sources, the centers of their Airy discs must be no closer than α_A, the angular radius of either central spot (both radii are the same). At this limiting resolution, the maximum intensity of one pattern coincides with the first dark ring of the other; see Figure 5.21. At a wavelength of 510 nm, according to Equation (5.13), a 1-meter telescope should have a resolution of 0.128 arcsec. Details smaller than this size will be lost.

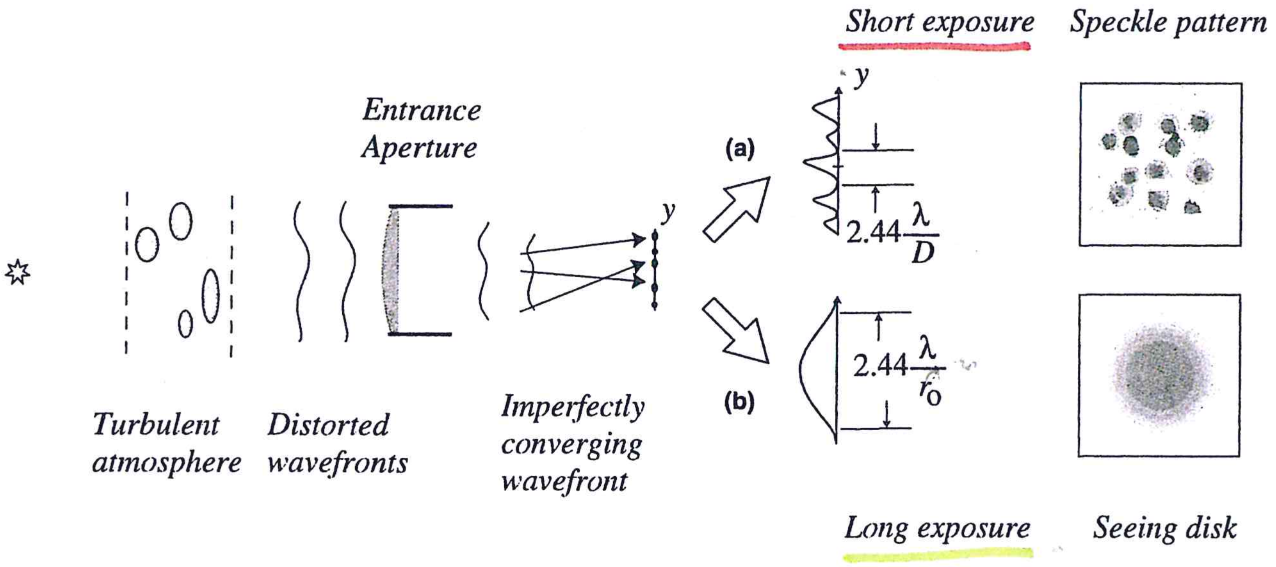
5.4.2 Seeing

Rayleigh's criterion is a good predictor of the performance of space telescopes. On the surface of the Earth, however, turbulence, which causes dynamic density

EFFECT OF SEEING

Optics for astronomy

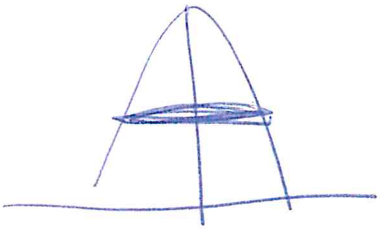
FIG. 5.22



variations in the Earth's atmosphere limits the resolving power of all but the smallest telescopes. This loss of resolution is termed ***seeing***. Seeing (measured as the angular FWHM of the image of a point source) may be as small as several tenths of a second of arc on the very best nights at the very best sites on Earth, but it can reach several seconds of arc at other sites.

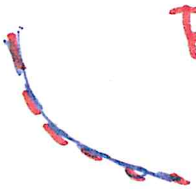
SEEING $\lesssim 1''$ IN BUONI SITI

FWHM
Full width at half maximum



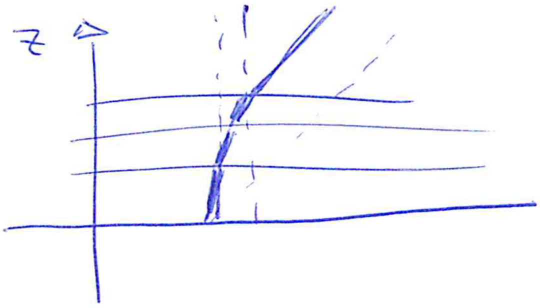
SPECKE INTEFEROMETRY

OTTICA ADATTIVA



parti dello specchio

RIFRAZIONE ATMOSFERICA



raggio arriva + inclinato

→ problema 1 in posizione astro

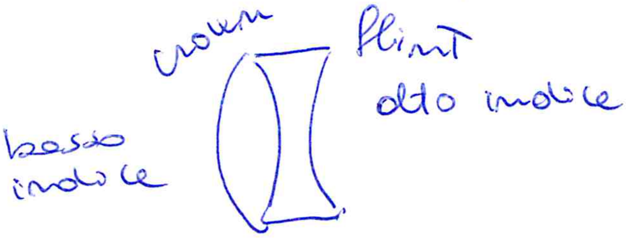
\+ → problema 2
blue image is shifted
more than the red one!

ABERRAZIONE CROMATICA (x RIFRATTORI)

$n(\lambda)$ ~~degli~~ dei vetri ottici decresce con
↗ (nel visibile!)

⇒ $f_{red} > f_{blue}$ ⇒ il fuoco non è perfetto

Soluzione: doppietto acromatico

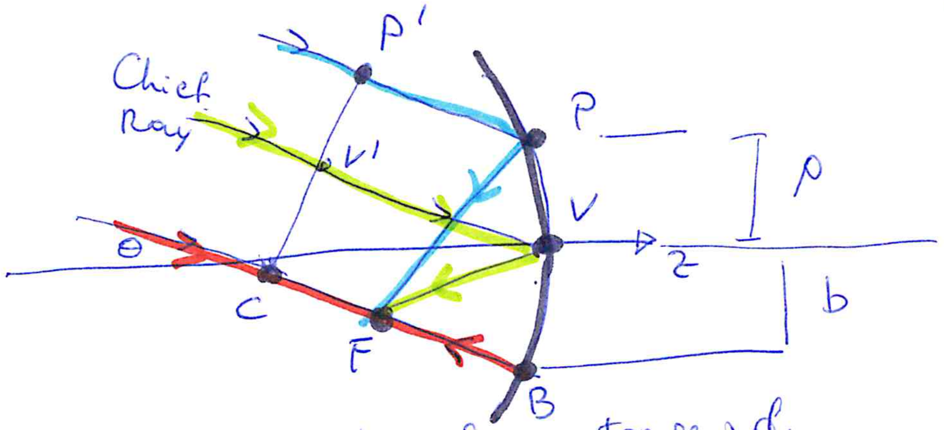


ABERRAZIONI

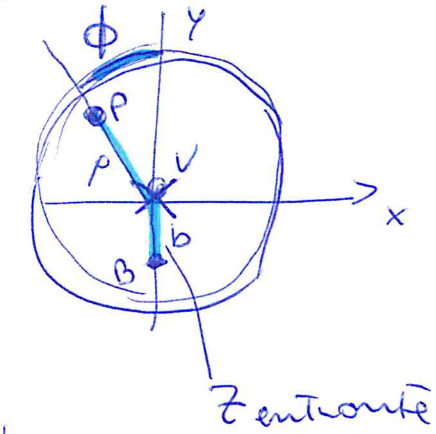
imperfezione che degrada immagine

telescopio perfetto:

onda incidente piana ⟹ fronte sferico convergente al cui centro c'è il fuoco gaussiano (da approssim. parassiale)
(da ∞!)



piano meridionale o tangenziale



piano sagittale

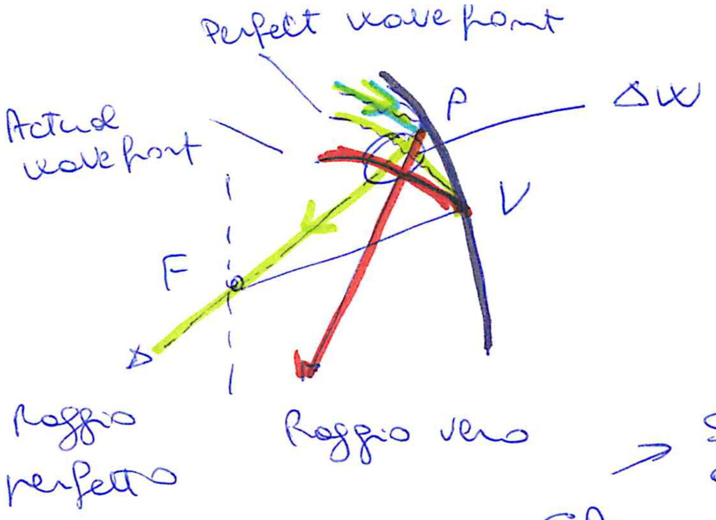
Chief ray V' V F dalla sorgente a vertice dello specchio

CFBFC

P'PF Test rays può star fuori dal piano

sistema ottico perfetto: cammini ottici di V'VF, P'PF e CBF sono uguali!

$\operatorname{sen}\theta \sim \theta - \frac{\theta^3}{3!}$ third-order aberration theory MEGLIO DI PARASSIA



→ Spherical aberration

$$\Delta w(\rho, \phi, b) = \underset{\text{SA}}{C_1 \rho^4} + \underset{\text{coma}}{C_2 \rho^3 b \cos\phi} +$$

$$+ \underset{\text{astigmatismo}}{C_3 \rho^2 b^2 \cos^2\phi} + \underset{\text{curvature of the field}}{C_4 \rho^2 b^2} +$$

$$+ \underset{\text{distortion}}{C_5 \rho b^3 \cos\phi}$$

ordine di importanza
+imp
↓
-imp

NOTA: SORGENTE SU ASSE $b = 0$

x visual astronomy è importante solo SA

x immagini Tutte!

Se f molto grande → approssimazione parassiale è migliore SA ↓

ma poca brightness

PROBLEMA x RIFRATTORI

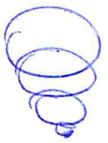
x RIFLETTORI

SA è assente da specchi paraboloidi → telescopi Newtoniani

oppure un plate transparent corrector
vetro
davanti allo specchio
→ telescopi Schmidt

COMA (problema x objs off-axis)
comet-like

sul piano "focale"



fuoco gaussiano

f ↑ SA ↓ coma ↓

se CORREGGO SISTEMA APLANATICO

telescopi rifrattori → sistema di lenti
doppietto acromatico
riduce SA e coma

telescopi riflettori → 2 specchi
oppure specchio + lenti

ASTIGMATISMO $\propto b^2$
aumenta di più x oggetti off axis

fuoco dei raggi sagittali ≠ f. di raggi meridionali

se correggo x SA, coma, astig. SISTEMA ANASTIGMATICO

SCHMIDT - CASSEGRAIN

Since distortion does not change image quality, an observer can remove it from an image if he has the calibrations needed. This is laborious for photographs, but relatively easy with digital images.

5.5.8 Spot diagrams

Figure 5.34 gives a qualitative summary of the distortions in the image of a point source that are introduced by the first four Seidel aberrations. Since more than one aberration may be present in an actual optical system, its image-forming behavior will generally exhibit some combination of the effects illustrated. For a mirror, the magnitude of a particular aberration will depend on the value of b, aperture, focal ratio, and conic constant. The figure shows ***spot diagrams*** for each aberration. Each spot is the focal-plane location of a single ray traced through the system. Rays are chosen to sample the entrance aperture in a uniform fashion, so the density of spots gives an indication of the brightness distribution of the final image.

difetto dipende da

b, $A_p = D$, $\frac{f}{D}$,

conic constant

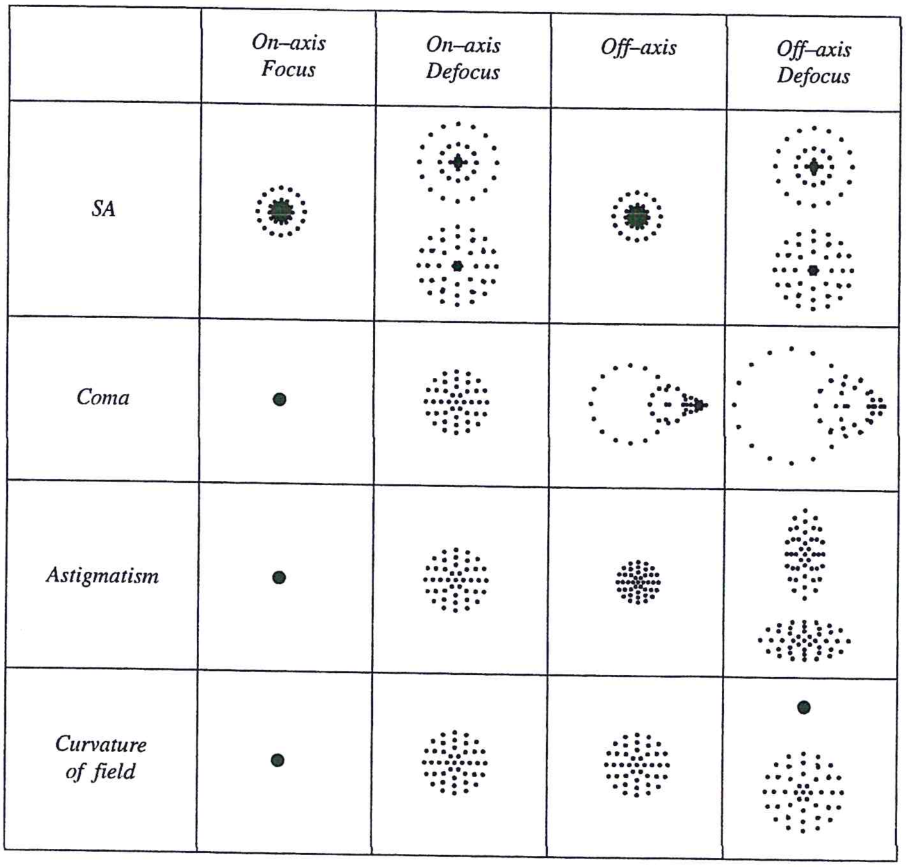


Fig. 5.34 Qualitative appearance of images of a point source in optical systems with a single aberration present. Discrete rays strike the entrance aperture in a pattern spaced around multiple. concentric circles. Actual sizes of the aberrations will depend upon details of the system. In the diagram, "focus" means the best compromise on-axis focus, which may differ from the Gaussian focus.

TELESCOPI (Chromey)

Montature (To point / To track) < diurnal motion / proper motion / tel. flexure

altazimutali ed equatoriali

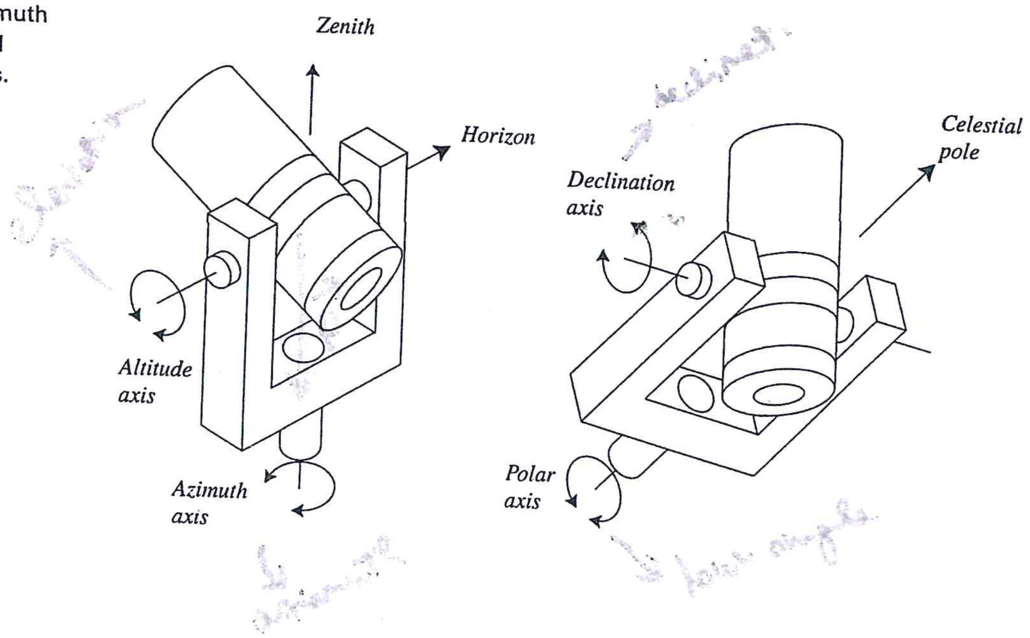


Fig. 6.1 (a) Altazimuth and (b) equatorial telescope mounts.

↓ + stabile ↓ preferito x telescopi grossi

↑ si usano computer per seguire il cielo

R guide star

↓ + facile il tracking ↓ tel. x piccoli

SATELLITES

fixed star

RIFLETTORI

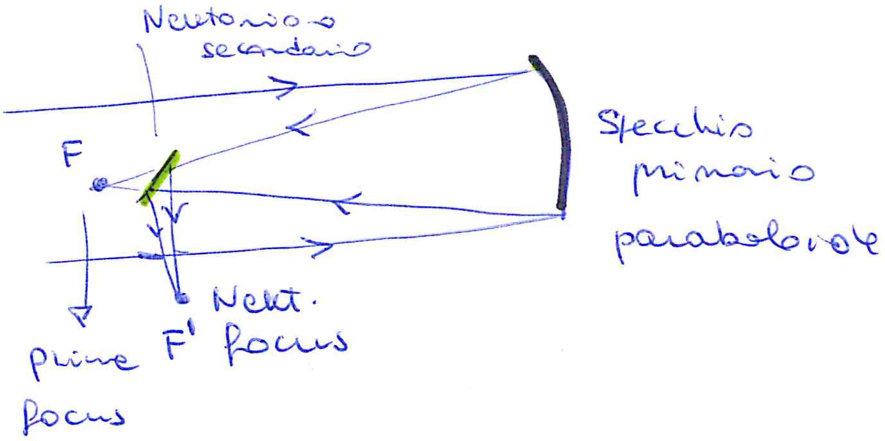
DISEGNI

FUOCO PRIMARIO

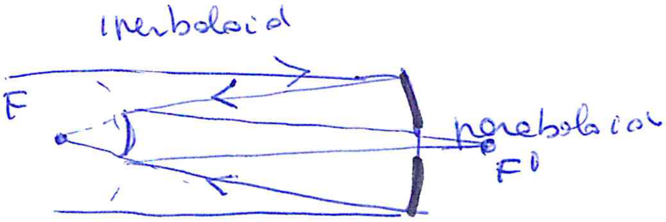
✓ semplicità + no perdite di luce (solo una riflessione!)

✗ ma apparato ostruisce specchio! ← Fuoco Newtoniano

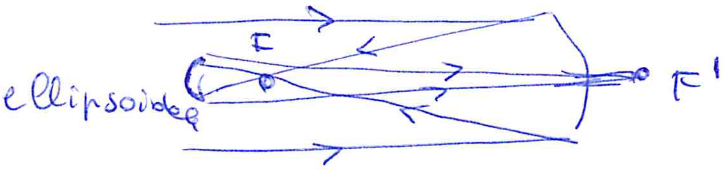
coma e astigmatismo! ← lenti correttrici



CASSEGRAIN E GREGORIANI RIFLETTORI



f grande ma dimensione compatta! + stabili



oltre riflessioni
X METTERE STRUMENTI + PESANTI
rispetto Cassegrain + perdite di luce
onde + aberrazioni

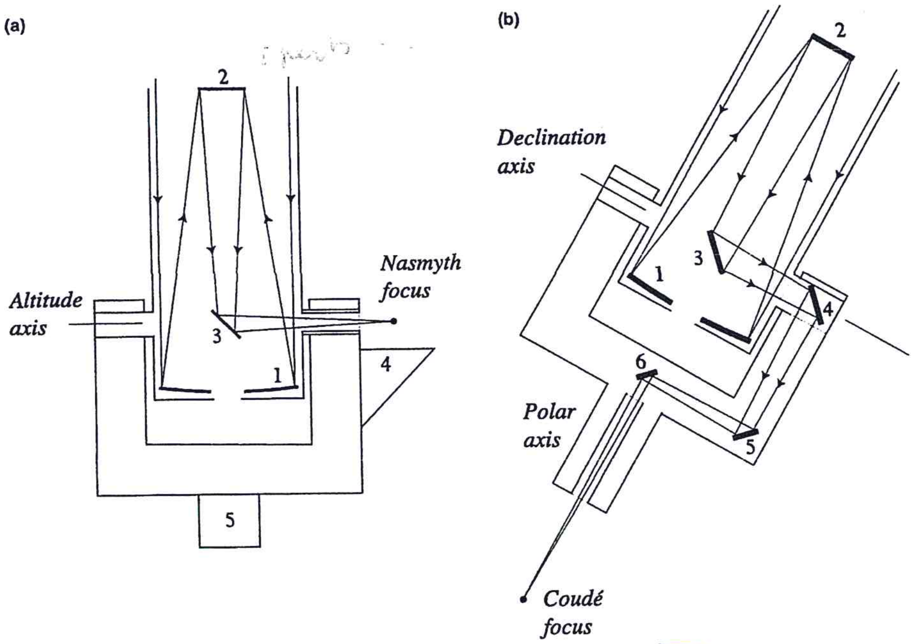


Fig. 6.5 (a) The Nasmyth configuration. Light from the secondary mirror (2) is redirected by a tertiary flat (3) along the hollow altitude axis and reaches a focus above the Nasmyth platform (4). The platform rotates around the azimuth axis (5) as the telescope points and tracks. (b) A coudé configuration. Light from the secondary is redirected by flat 3 to a series of flats (4–5–6) that bring the beam to the polar axis. Similar arrangements can direct the beam along the azimuth axis of an altazimuth.

RIMANE FISSO

mirror intercepts the beam from the secondary and directs it horizontally along the altitude axis. As the telescope tracks, this focus remains fixed relative to the mount. Equipment at the Nasmyth focus thus exerts a gravitational stress on the telescope and mount that will not change over time.

If an instrument is very massive or very delicate, the ***coudé focus*** (French for "bent like an elbow") is superior to the Nasmyth. Figure 6.5b gives an example of this arrangement, implemented in an equatorial mount. A flat mirror redirects light from the secondary along the declination axis, and then a series of flats conducts the beam to emerge along the polar axis, where it reaches focus at a point that does not move with respect to the Earth. Here astronomers can locate elaborate instruments, like very large spectrographs, sometimes housed in stabilized and ultra-clean enclosures. A similar arrangement of flats will establish a coudé focus by directing the beam down the vertical (azimuth) axis of an altazimuth mount.

Both the Nasmyth and coudé have some disadvantages, so are usually implemented as temporary modifications of a general-purpose telescope. Compared with the Cassegrain, both Nasmyth and coudé require additional reflections, so there is some light loss. As the telescope tracks, the image field rotates at both these foci. A third problem concerns aberrations. Suppose you design a telescope to be aplanatic in the R–C configuration with the focus behind the primary, and the conic constants K_1 and K_2 given by Equations (6.7). To switch from the R–C to the Nasmyth or coudé, swap in a new secondary to get a longer focal length, and therefore get different values for m and β. However, the x large FIELD OF WIEW

SCHIMDT

corrector lens x evitare SA

+ [illegible] x evitare aberrazioni fuori asse

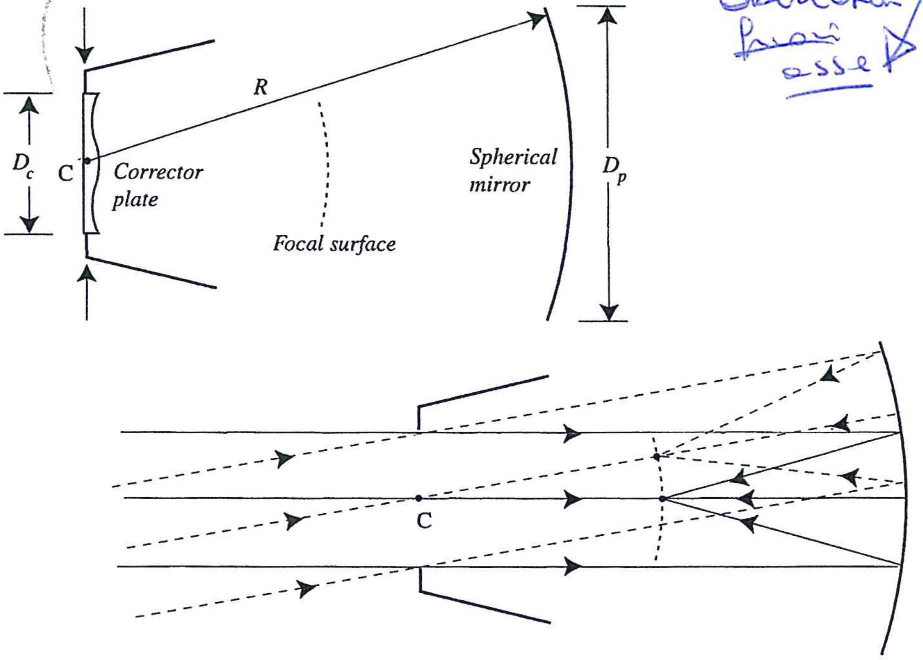


Fig. 6.6 The Schmidt telescope: (a) shows the arrangement of aperture stop, corrector plate, primary mirror, and focal surface; (b) shows how the aperture stop located at the center of curvature results in identical optics for beams from different directions.

es. UK SCHIMDT

The corrector plate, located in the plane of the aperture stop, is designed to remove SA. If you review Figure 5.28, and Equation (5.16) you can see that SA in a spherical mirror means the marginal rays (the ones near the edge of the aperture, ρ large) converge more strongly than the axial rays (the ones near the center). A Schmidt corrector, then, should be a refracting element whose power is larger (more positive) for the axial rays and smaller for the marginal. An entire family of shapes can do the job. Two possible shapes are sketched in Figure 6.7. The shape labeled (b), which is thickest at center and thinnest at 86.6 % radius, is the one usually chosen, since it minimizes the chromatic aberration introduced by the corrector plate. It is possible to further minimize chromatic aberration by using a two-element achromatic corrector. Unlike the spherical mirror, the corrector plate *does* have an optical axis, and introduces some off-axis aberrations, which are of concern in systems with very fast focal ratios ($< f/2$). The refracting corrector plate limits apertures to modest values, and the focal surface is inaccessible to a human observer, so the instrument is often called a Schmidt camera.

The location and curvature of the focal surface is the main inconvenience of the design. Until recently, the usual observing method was photographic. A special frame mechanically flexed a large[3] glass photographic plate to match

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[3] The UK Schmidt, for example, uses square glass plates that measure 356 mm (14 inches) on a side and are 1.0 mm thick. Each of these plates will photograph an area 6.4° × 6.4° on the sky. A large detector, of course, also vignettes (blocks) the beam.

CATADIOTTRICI rifrazione + riflessione
popolare x amatori

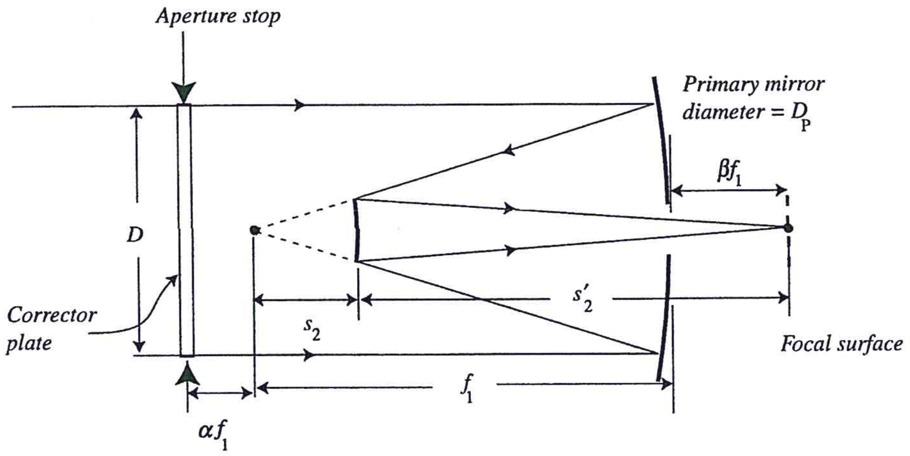

Fig. 6.8 The Schmidt–Cassegrain.

> carrying out a secret study of a possible large artificial satellite, to circle the Earth a few hundred miles up. "Would you be interested," he asked me, "in writing a chapter on how such a satellite might be useful in astronomy?"
>
> – Lyman Spitzer (1914–1997), "Dreams, Stars, and Electrons", *Annual Reviews of Astronomy and Astrophysics*, vol. 27 (1989)

In 1946, Lyman Spitzer quickly recognized the usefulness of a space telescope, and became a leader in the effort that culminated on April 25, 1990, when the crew of the Space Shuttle *Discovery* placed the Hubble Space Telescope (HST) into Earth orbit.

We judge the excellence of a telescope by three criteria: its ability to resolve detail, its ability to detect faint objects, and the angular size of the field over which it can perform these functions. In all these categories, telescopes in space offer obvious advantages over ground-based instruments. The 44-year delay between the conception and actualization of the HST suggests that there might also be some impediments to realizing these advantages.

eccellenza di un telescopio
resolution
mag. limit
field of view
a [illegible]
[illegible]

The HST has the largest aperture of any astronomical instrument in space to date (2.4 meters), and has generated results of unprecedented volume: roughly five scientific papers each week since launch have been based on HST data. The HST was designed to operate for a total of 20 years, and its replacement is of intense concern. NASA plans to place the 6.5-meter James Webb Space Telescope (JWST) at the Sun–Earth Lagrange point, L_2, sometime around 2011.

6.3.1 Advantages of space telescopes

Resolution

In space, the complete absence of the wavefront distortions caused by Earth's atmosphere means a space telescope (if its optics are perfect!) should have diffraction-limited resolution. Specifically, in the absence of atmospheric seeing

TELESCOPI SPAZIO

risoluzione (no seeing!)

limite di detezione

misure = Signal + Background

↓ legato molto al seeing

Area collettore

converte da energia a num. fotoni

tempo oss.

~~F~~

$$S = \text{Signal} = \frac{\pi D^2}{4}\,\frac{\lambda}{hc}\, f_\lambda\, t\, Q \to \text{eff. detector}$$

f_λ ↓ flusso stelle

surface brightness del cielo

$$B = \frac{\pi D^2}{4}\,\frac{\lambda}{hc}\,\frac{\pi \theta^2}{4}\, b_\lambda\, t\, Q$$

θ → diametro angolare stelle

Se stella è point

$$N = \sqrt{S+B} \sim \sqrt{B} = \frac{\pi D \theta}{4}\left(\frac{\lambda b_\lambda t Q}{hc}\right)^{1/2}$$

$$\frac{S}{N} = \left(\frac{\lambda Q t}{hc\, b_\lambda}\right)^{1/2} \frac{D}{\theta} f_\lambda \boxed{\sim 1}$$

↓ se stella è al limite di detezione

$$f_{\lambda,det} = \left(\frac{hc}{\lambda Q}\right)^{1/2}\left(\frac{b_\lambda}{t}\right)^{1/2}\frac{\theta}{d}$$

A TERRA θ è dato da seeing, indip. da D

$f_{\lambda,det} \sim \frac{1}{D}$ SPAZIO $\theta \sim \frac{1}{D}$ $f_{\lambda,det} \sim \frac{1}{D^2}$

Background

no luce zodiacale (dovuta ad atm.)
luce scatterata da polveri

HST $b_V \sim 23{,}3 \frac{\text{mag}}{\text{arcsec}^2}$
Hubble space telescope

TERRA $b_V \sim 22 \frac{\text{mag}}{\text{arcsec}^2}$

JWST $b_V \sim 12 \frac{\text{mag}}{\text{arc}^2}$?
James Webb

NO TRASMISS. ATMOSFERICA
↳ non è trasparente !

ACCESSO A TUTTO IL CIELO

NO GRAVITATIONAL STRESSES
O AMBIENTALI

SVANTAGGI

costo → poco peso

trauma del lancio

particelle energetiche

riparazioni

TELESCOPI DA TERRA

correzioni x immagini

ottica adattiva x evitare seeing → PROF. CRISTIANI

~~luogo~~ sito è importante

BASOVIZZA   Celestron C14

SCHIMDT - CASSEGRAIN   D = 356 mm
f = 3910 mm

$$\frac{f}{11}$$

2 specchi sferici (+ lastra correttrice)
montatura equatoriale

\+ HELIOS 1
D = 70 mm   x sole