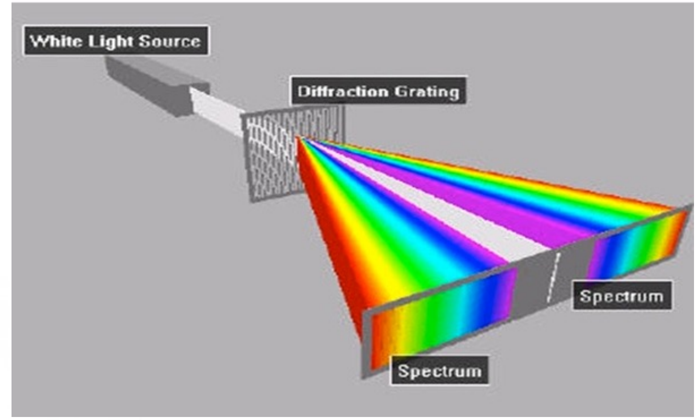
Strumentazione Astronomica: Spettrometri

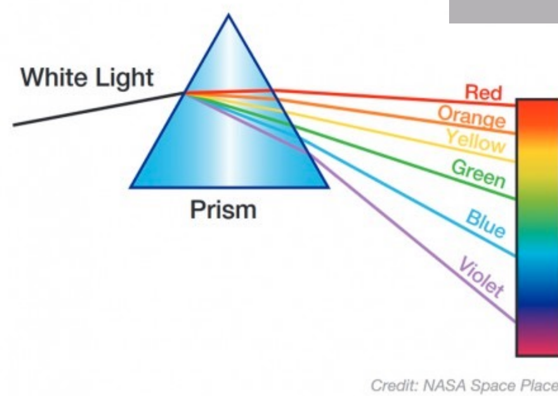
Diffraction Grating



Si basano su due principi fisici:

- interferenza/diffrazione (reticoli, grism, Fabry-Perot, FTS)

- dispersione (prismi)



Di fatto sono spettrometri anche i rivelatori di radiazione ionizzante (UV, X, Y) dotati di una risoluzione energetica intrinseca

$$\Delta E / E = \sqrt{n} / n = 1 / \sqrt{n}$$

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Definizioni generali:

Dispersione Angolare $AD = \frac{d\theta}{d\lambda}$

Dispersione Lineare $LD = \frac{dx}{d\lambda} = \frac{dx}{d\theta}\frac{d\theta}{d\lambda} = f_{cam}\frac{d\vartheta}{d\lambda}$

Potere risolutivo $R = \frac{\lambda}{\Delta\lambda} = \frac{\nu}{\Delta\nu} = \frac{c}{V}$ ← Doppler non relativistico

Table 5.4. Resolution of spectrometers

Spectrometer	Region	Typical resolution
Interference filter	Visible, IR	10^2–10^3
Grating	IR, visible, UV	10^3–10^6
Bragg crystal	X-ray	10^3
Atomic resonance	Visible, UV	10^7
Fabry–Perot	Visible, IR	10^4–10^6
Fourier transform	Visible, IR	10^4–10^6
Heterodyne	Radiofrequencies	$>10^6$
	IR, submillimetre	$>10^5$
Bolometer	X-ray	10^2
Scintillator	γ-ray	10^3

The values given in the table are typical orders of magnitude, and should not be considered as absolute.

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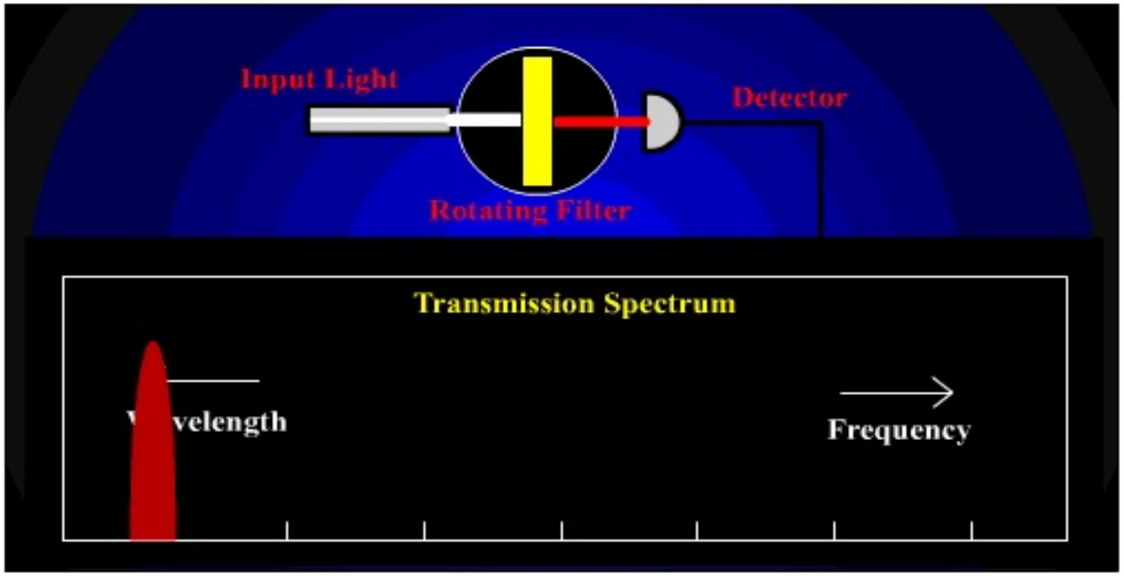
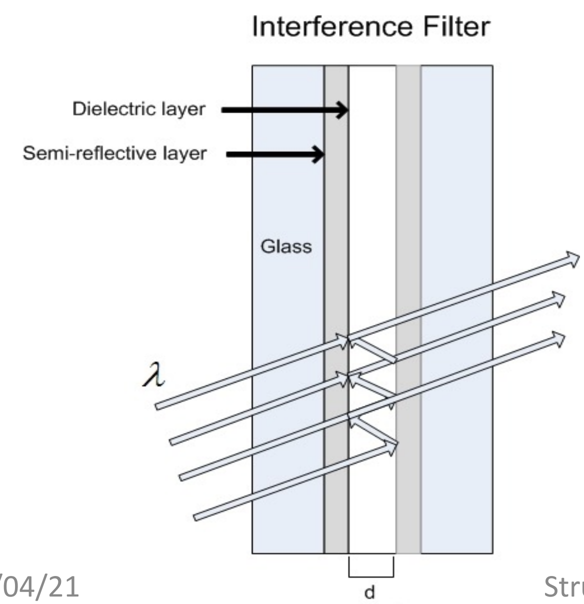


Filtri interferenziali

Se λ_0 è la lunghezza d'onda centrale della banda che incide sul filtro, la lunghezza d'onda che emerge è:

$$\lambda = \lambda_0 \sqrt{1 - \left(\frac{n_0}{n_e}\right)^2 \sin^2\theta}$$



Lunghezza d'onda del massimo di trasparenza in funzione dell'indice di rifrazione del filtro (etalon) e dell'angolo di incidenza.

Per una data lunghezza d'onda la TRASPARENZA è MASSIMA quando l'interferenza delle onde riflesse E' DISTRUTTIVA

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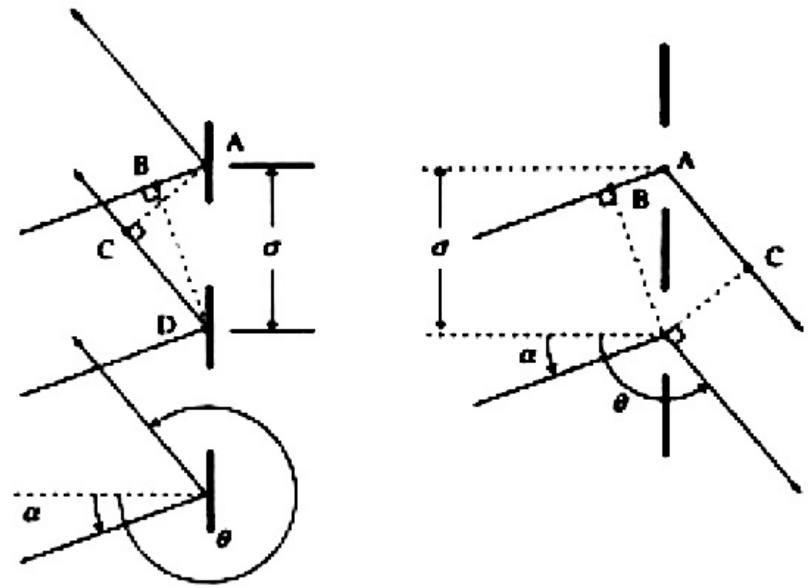
RETICOLI (gratings)



$$\Delta\tau = \mathrm{AB} - \mathrm{CD}$$

$$\mathrm{AB} = \sigma \cdot \sin\alpha$$

$$\mathrm{CD} = \sigma \cdot \sin(2\pi - \theta) = -\sigma \cdot \sin\theta$$

$$\Delta\tau = m\lambda$$

$$\sin\theta \pm \sin\alpha = \frac{m\lambda}{\sigma}$$

+ per rericoli a riflessione,
- a trasmissione

RETICOLI (gratings)

$$\frac{d\theta}{d\lambda} = \frac{m}{\sigma \cdot cos\theta} = \frac{sin\alpha + sin\theta}{\lambda \cdot cos\theta}$$

$$R = \frac{\lambda}{\Delta\lambda} = \frac{v}{c} = mN$$

$m = ordine\ di\ diffrazione$
$N = \#\ fenditure\ per\ unità\ di\ lunghezza$
$\sigma = spaziatura = \frac{1}{N}$
$\alpha = angolo\ di\ incidenza$
$\theta = angolo\ di\ diffrazione$

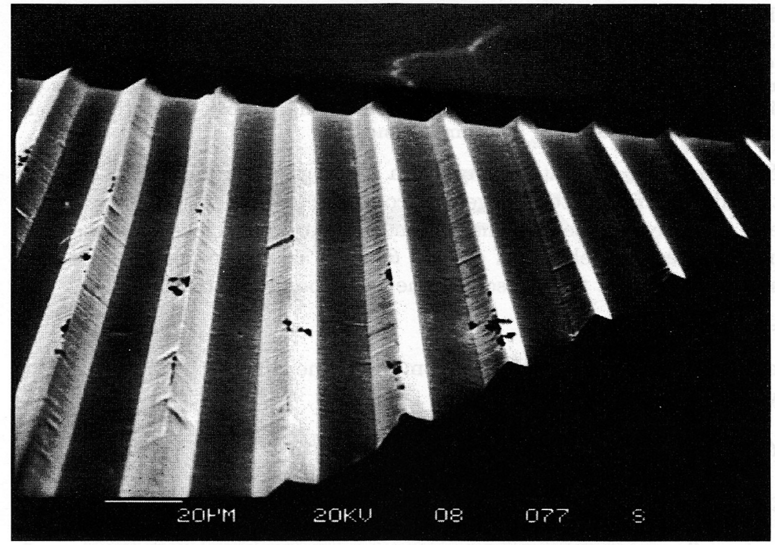


Fig. 5.11. Transmission grating of spacing 35 μm, for a grism, made of germanium by anisotropic ruling. Middle infrared camera project for the European VLT. (Photograph by electron microscope, due to Käufl H.U. and the Fraunhofer Institut, Munich, 1994)

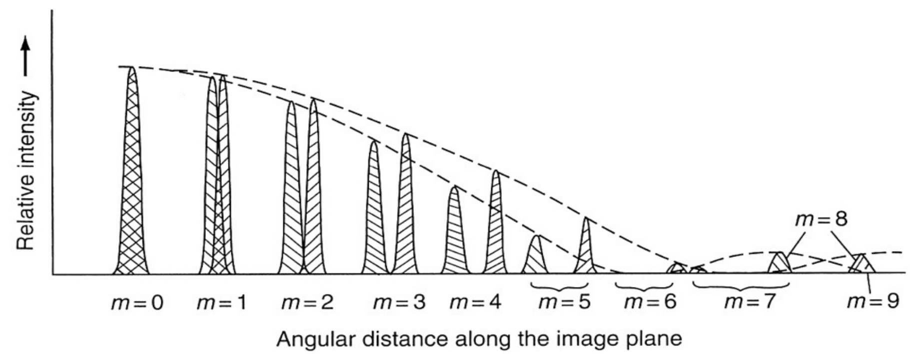


FIGURE 4.3 A portion of the image structure for a single bichromatic point source viewed through several apertures.

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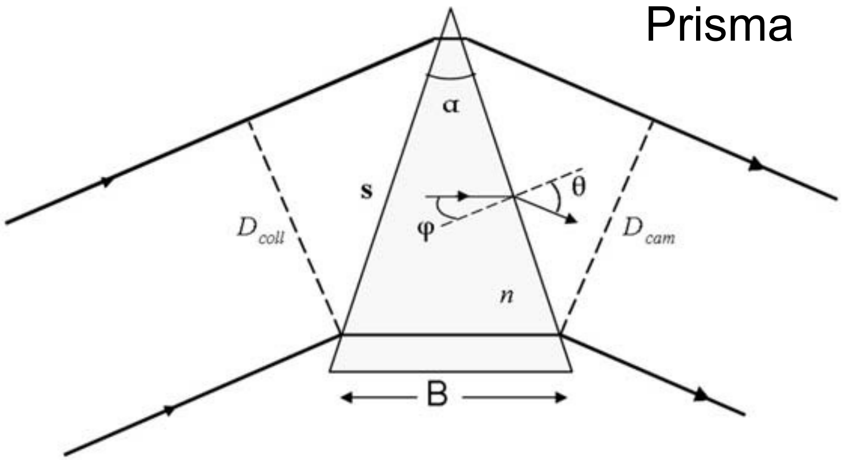
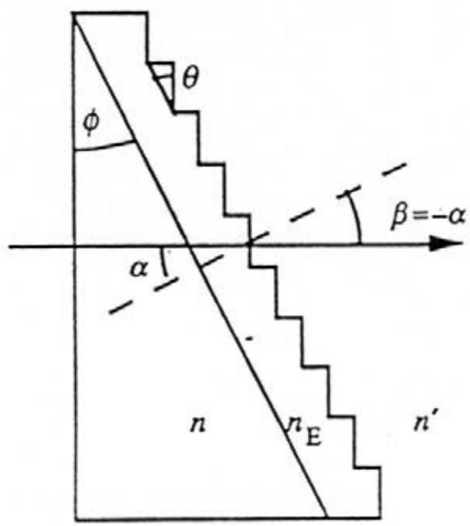
Prisma



$$\frac{d\theta}{d\lambda} = \frac{d\theta}{dn}\frac{dn}{d\lambda} = \frac{B}{D_{cam}}\frac{dn}{d\lambda}$$

$$R = B\frac{dn}{d\lambda}$$

Il grism è il modo più pratico di convertire una camera fotometrica in uno spettrometro depositando un reticolo sull'ipotenusa di un prisma che devii in asse il primo ordine di diffrazione



$$m\lambda_c \frac{1}{d} = (n-1)\sin\phi$$

$$R = \frac{EFL}{2d_{pix}}(n-1)\tan\phi$$

Effective Focal Length

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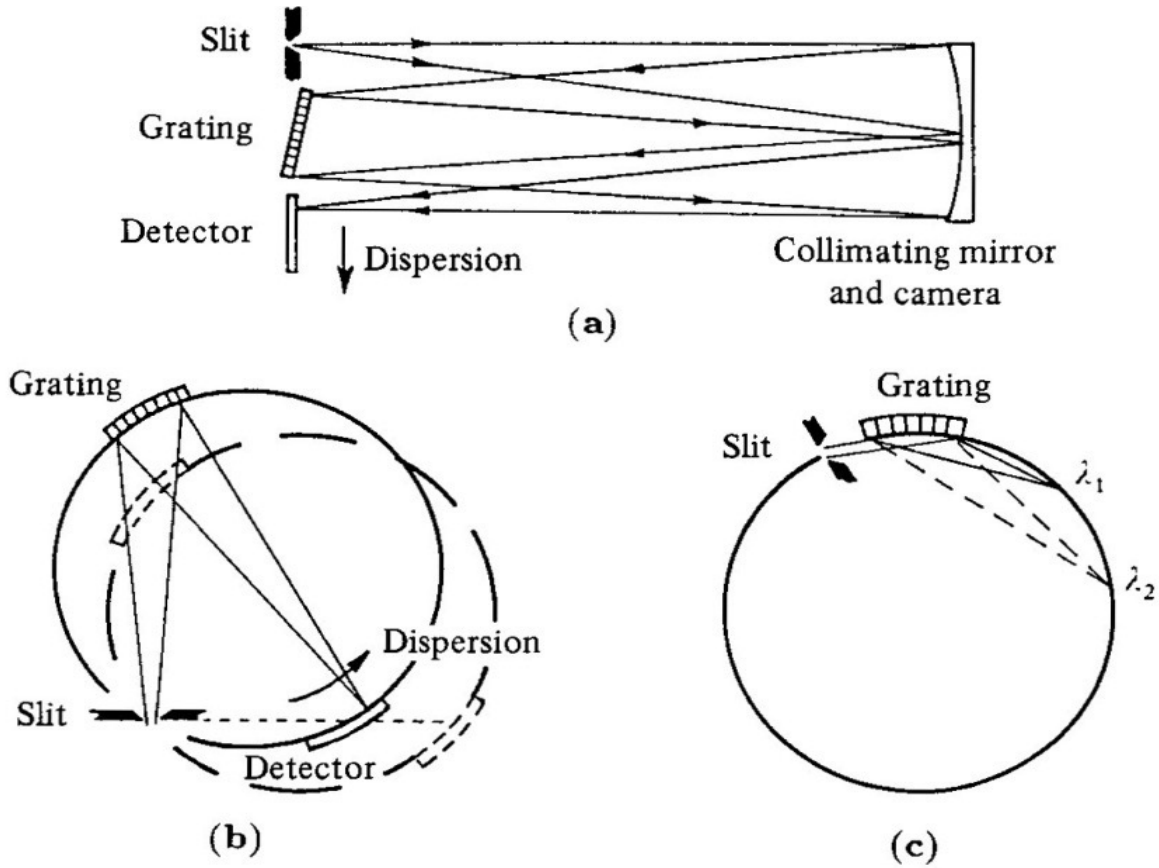

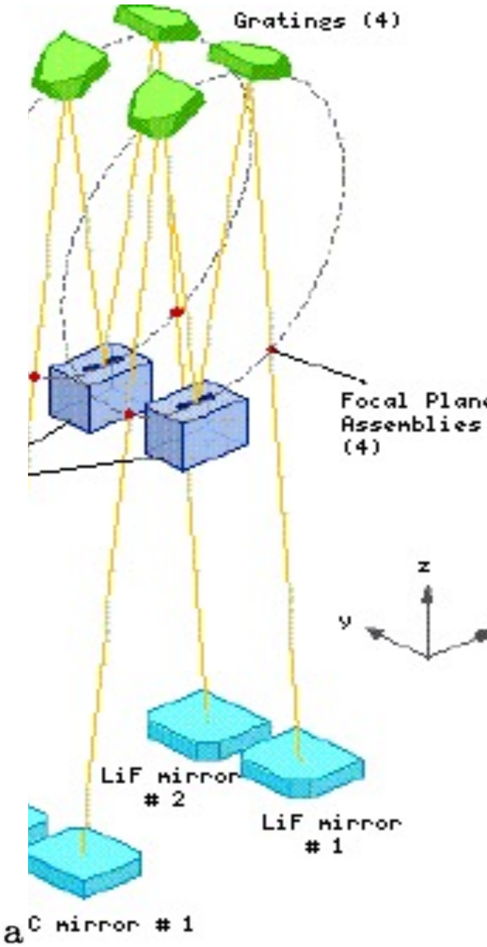

Fig. 5.10. Grating spectrometer arrangements. (**a**) *Ebert- Fastie* mounting with a planar grating. Here, a single mirror plays the role of both *collimator* and *camera*. This could also be achieved using two mirrors. (**b**) *Rowland* mounting with a concave grating. Rotating the assembly around the entry slit varies the wavelength of radiation received by the detector. (**c**) *Rowland* mounting for the far ultraviolet. The grating operates at grazing incidence ($i = 82$ to $89°$)

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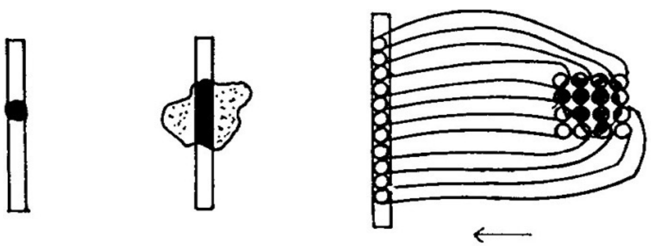

(a) (b) (c)

Fig. 5.12. Image slicer. (**a**) Seeing disk and spectrometer slit of comparable size. (**b**) Seeing disk more smeared, so that part of the energy misses the slit. (**c**) A bundle of optical fibres brings all the energy back to the slit

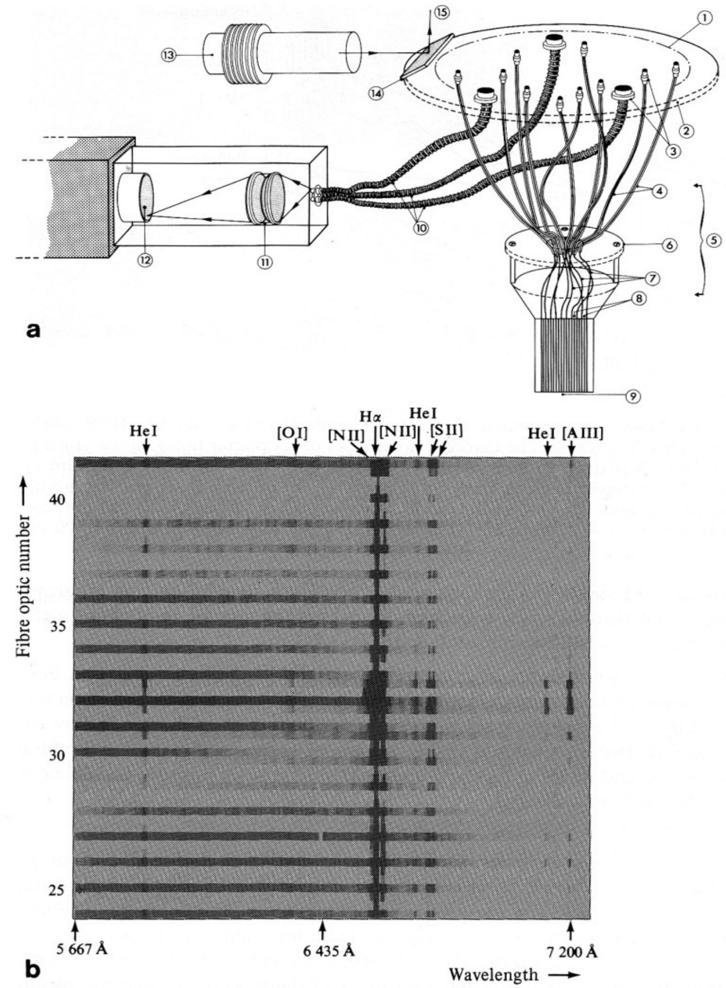

Fig. 5.13. Fibre optic coupling of an extended field to a spectrometer. (**a**) The plate (1), in the focal plane of the telescope, contains one image element per fibre, these being brought together on the entry slit (9). Other fibres (10) correspond to field stars and are used for the TV camera which guides the telescope (12). (**b**) Spectrograms of various regions in the Orion Nebula M42, showing lines characteristic of H II regions. The detector is a CCD. (After Enard D., 3.6 m telescope at the European Southern Observatory)

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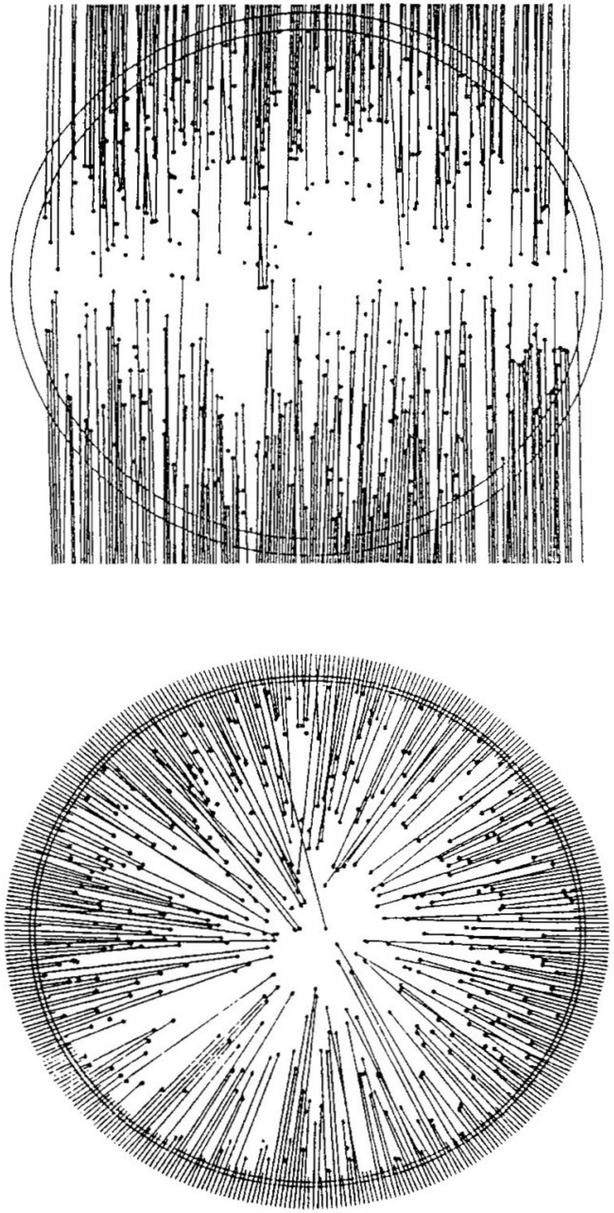

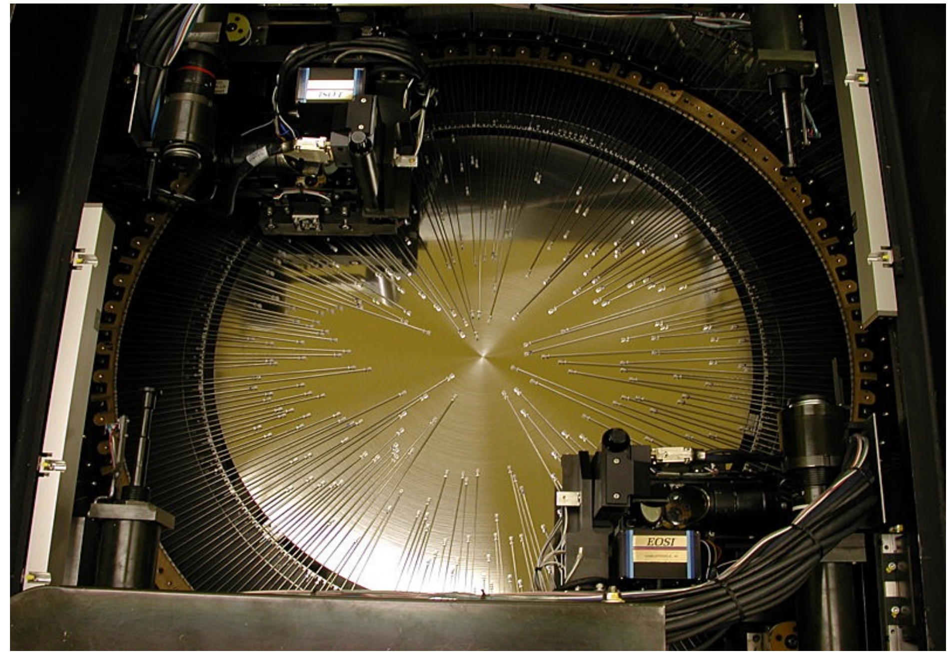

Fig. 5.17. Positioning of optical fibres in a field, using straight robot arms. 400 fibres are fitted to 400 sources, according to two different geometries. (After Lewis et al., in *Fiber Optics in Astronomy II*, ASP Conf. Ser. **37**, 1993)

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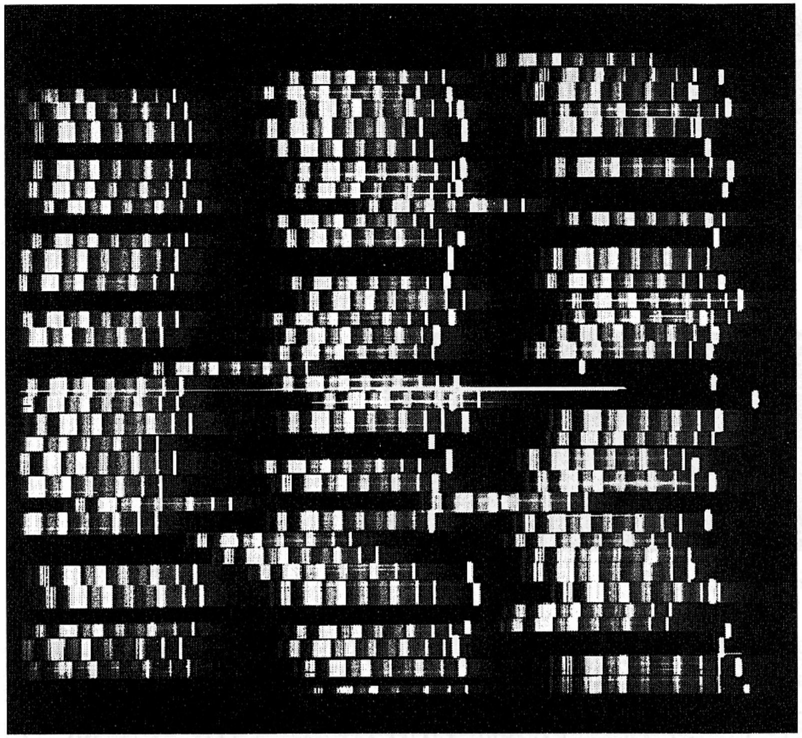
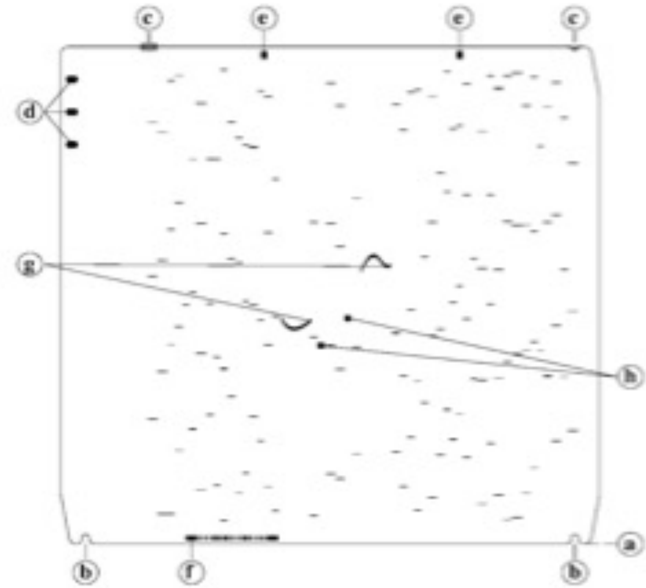


Fig. 5.16. Multi-object spectroscopy using slits. One hour exposure with the Canada-France-Hawaii Telescope (CFHT) in a field of 10′. 80 masks were used. Each vertical rectangle corresponds to the sky (slit = 12″) plus source spectrum, covering 450 to 850 nm. Sky emission lines and bands (*horizontal lines*) predominate. The fainter objects ($m_{\mathrm{I}} = 22$, $m_{\mathrm{B}} = 24$) are only visible after processing and recombining 8 exposures of 1 hour each. (Document due to LeFèvre O., Canada-France Redshift Survey, 1995)



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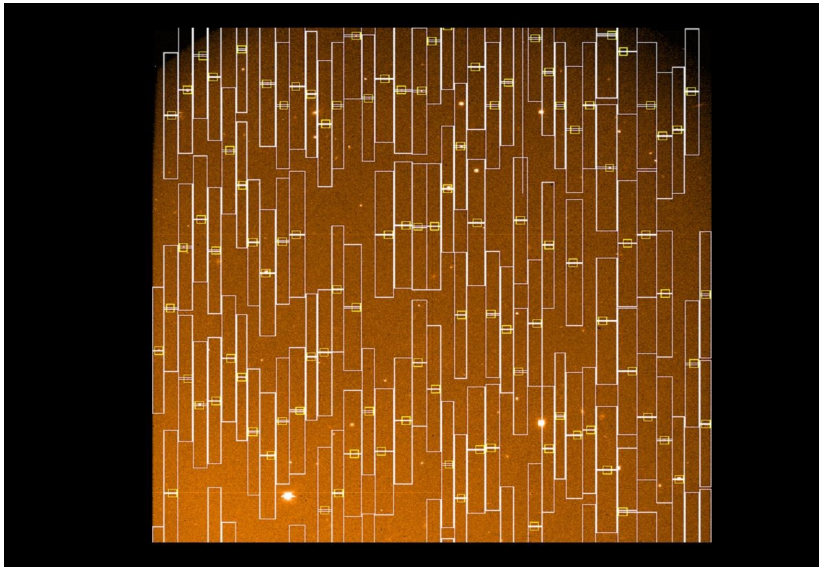

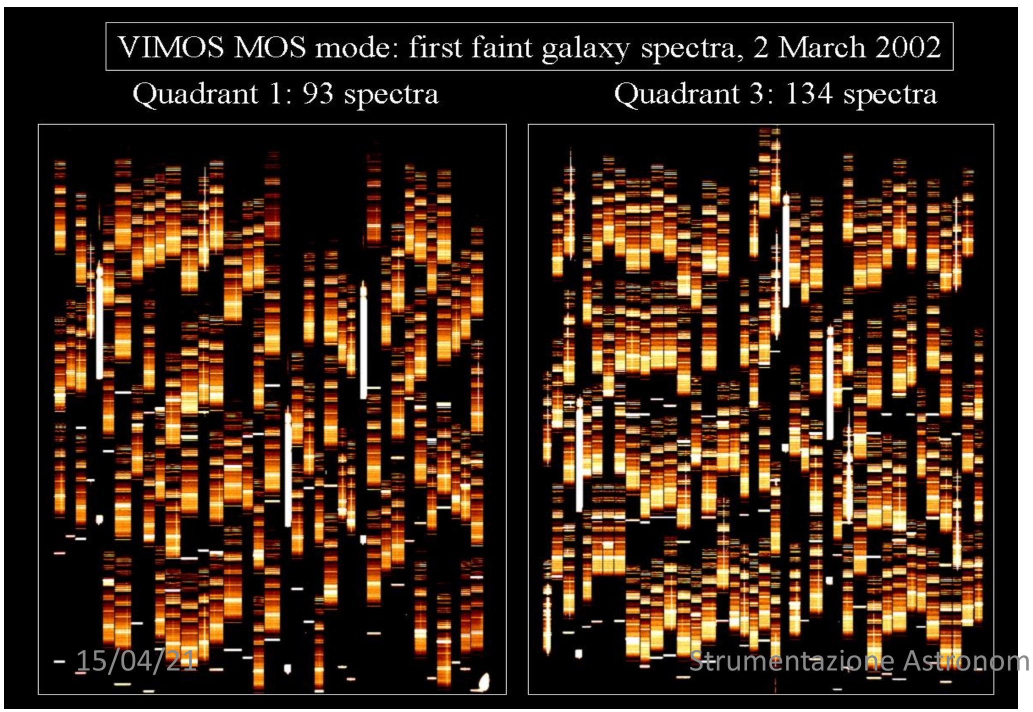

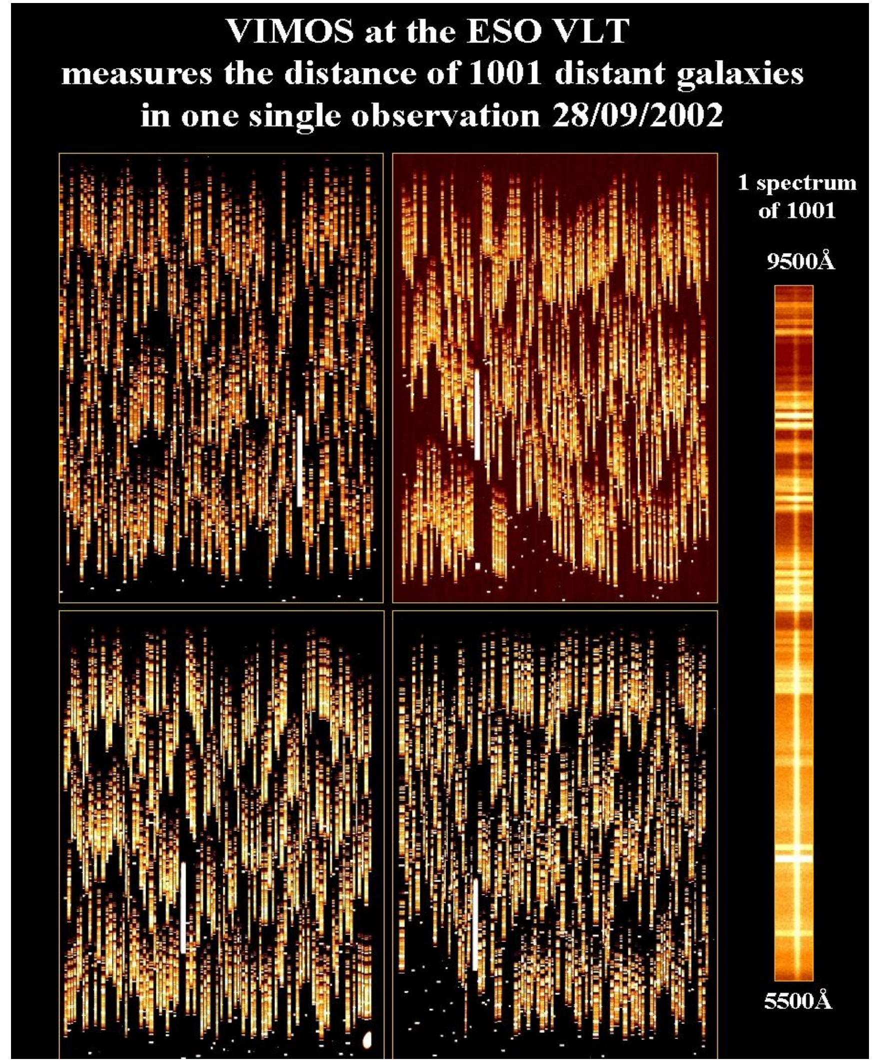

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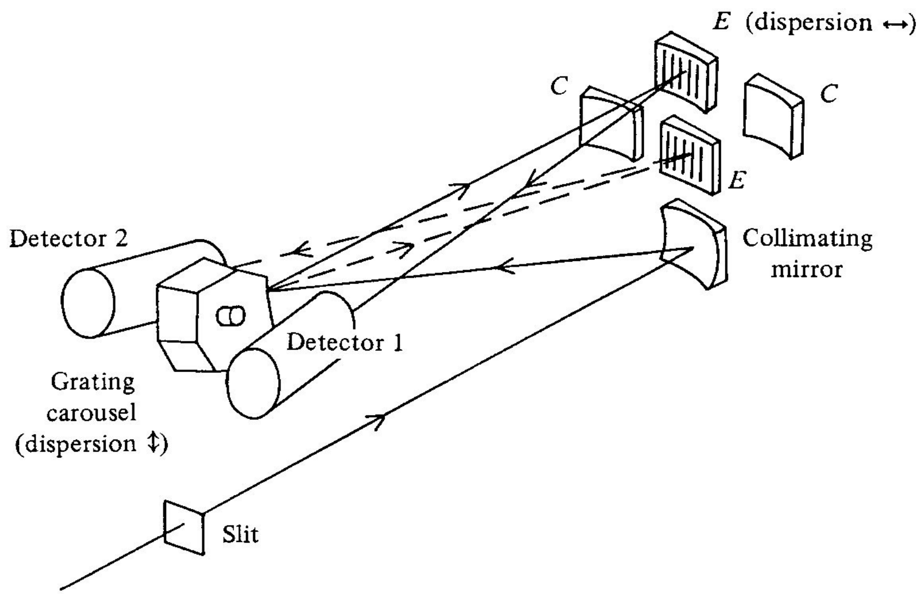
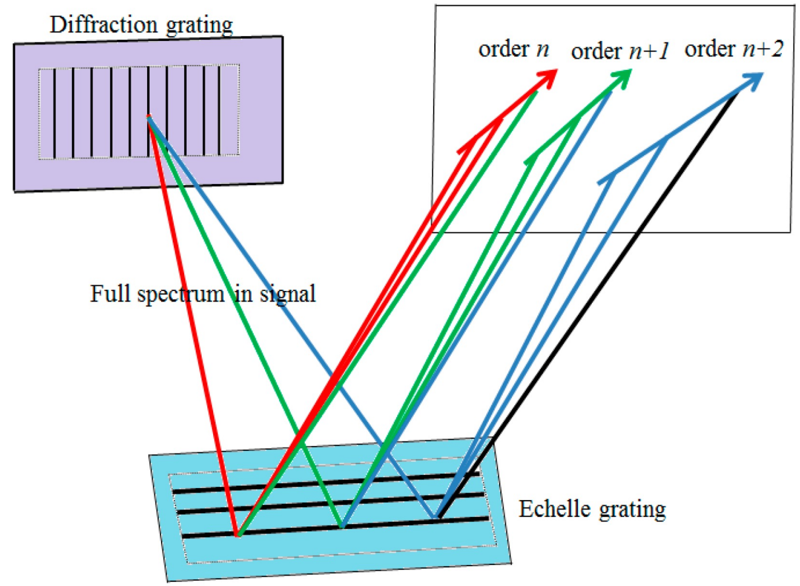
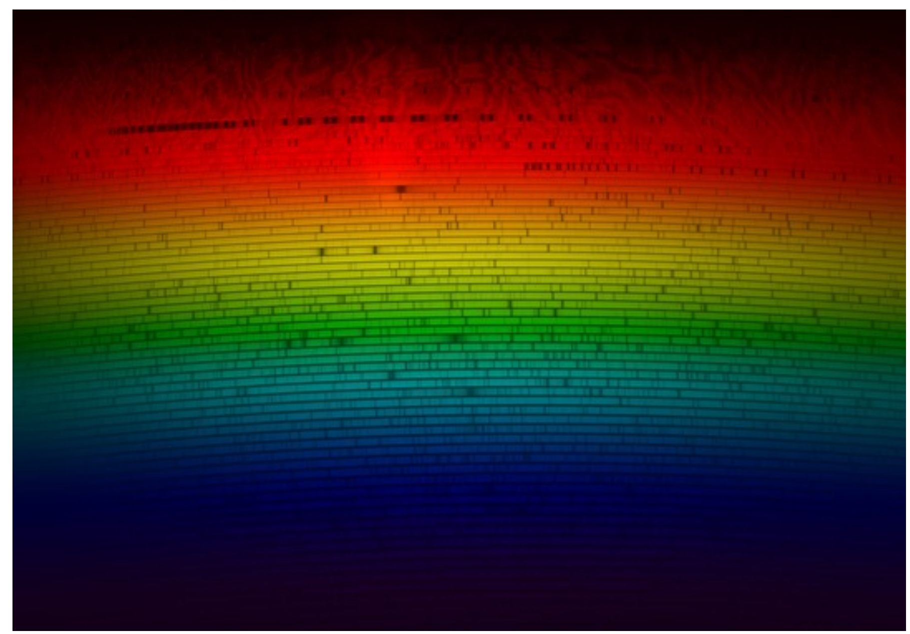


Fig. 5.14. Optical arrangement of the High-Resolution Spectrograph (HRS) of the Hubble Space Telescope. The carousel holds a set of six planar holographic gratings ($a = 0.16$ to $3.16\,\mu$m). In normal operation, the mirrors C form the spectrum on detector 1 or 2 (linear Digicon arrays of 512 pixels), the mirrors E are gratings giving the cross-dispersion for the echelle mode. Wavelengths are from 105 to 320 nm, and resolution from $R = 2\,000$ to 10^5. The useful spectral interval is from 2.5 to 29 nm





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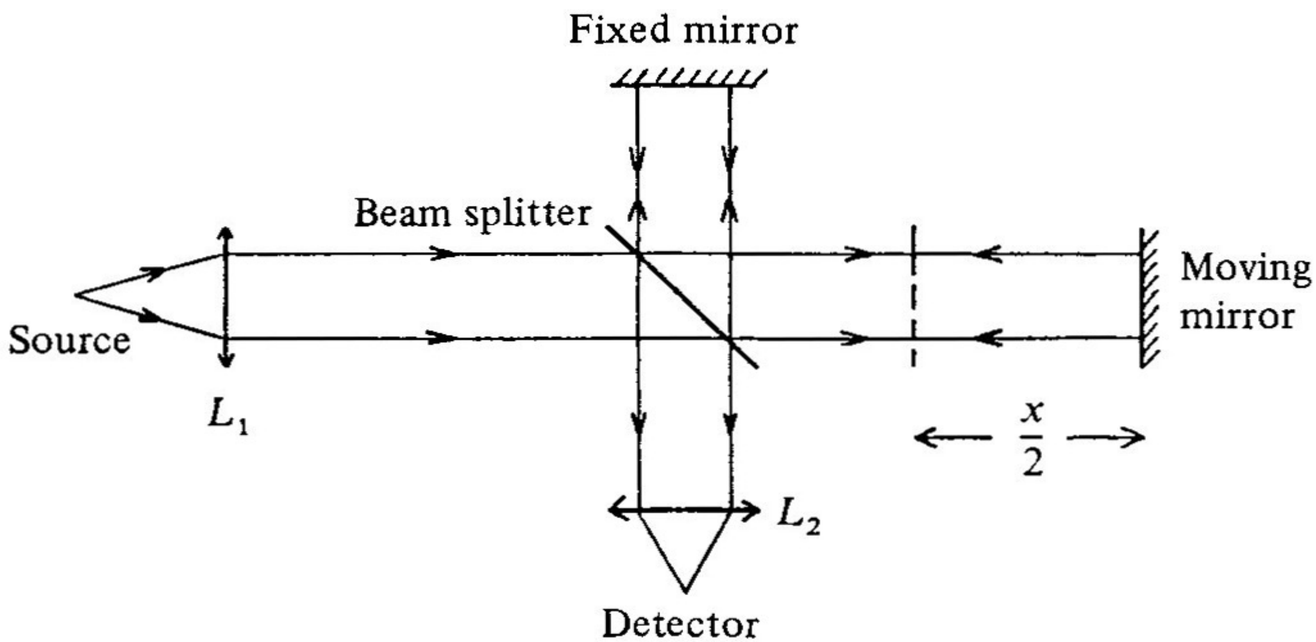

Fig. 5.21. Optics of a Fourier transform spectrometer

$$R = x_{max} / \lambda$$

Autocorrelatore = Spettrometro

Risoluzione è data dal massimo percorso che può fare lo specchio mobile

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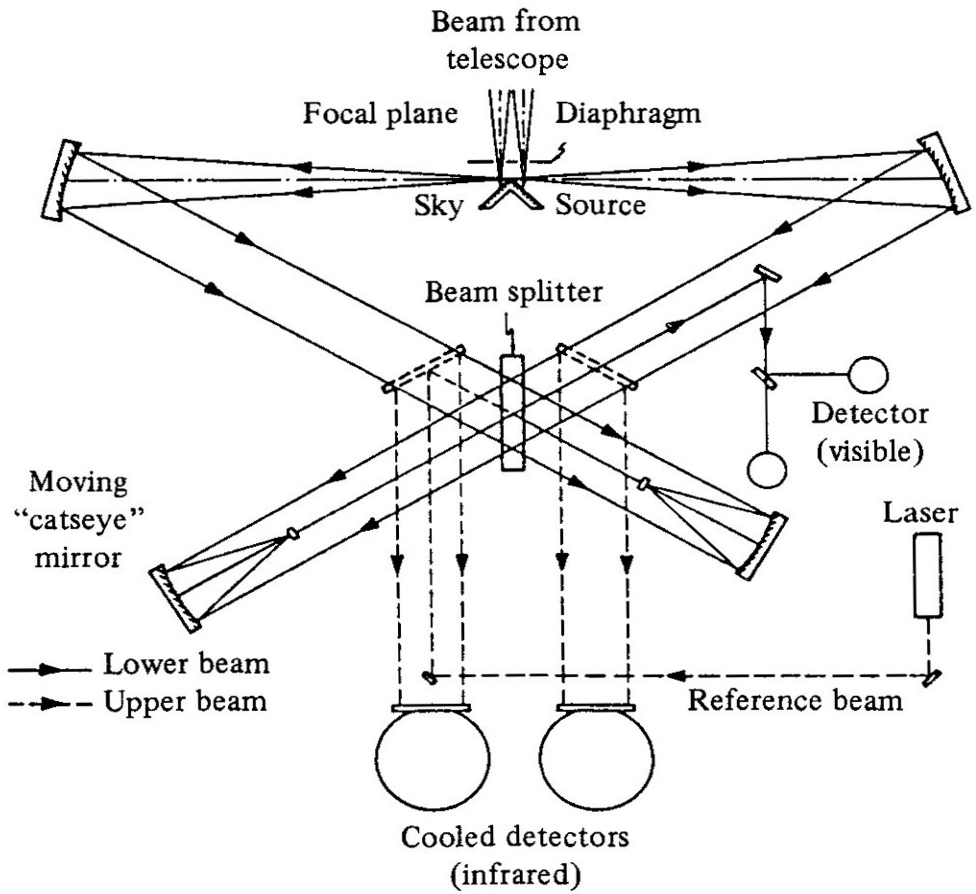

Fig. 5.25. Fourier transform spectrometer, Canada-France-Hawaii Telescope. The instrument is symmetrical, with signals, $I_1(x)$ and $I_2(x)$, received at the two infrared detectors. The quantity $(I_1 - I_2)/(I_1 + I_2)$ is independent of atmospheric fluctuations. The beam from the visible He-Ne laser provides reference fringes which control the sampling of the infrared signal. Upper and lower beams are spatially separated. The whole setup is mounted at the Cassegrain focus of the telescope. (After Maillard J.P., Michel G., *I.A.U. Colloquium*, **67**, Reidel, Dordrecht, 1982. With the kind permission of D. Reidel Publishing Company)