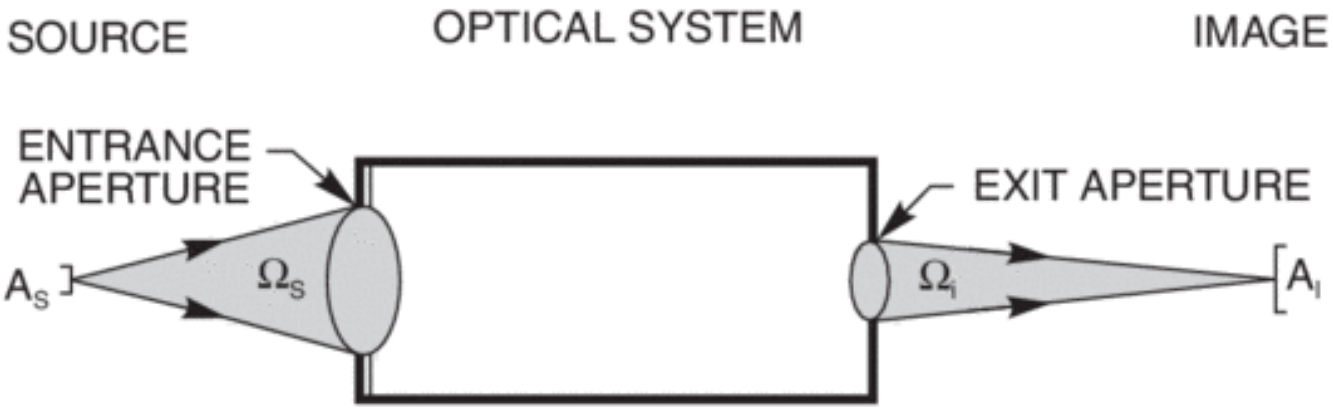
Large gratings for large telescopes

Ernesto Oliva, INAF-Arcetri (Florence)

- Why do astronomers need large gratings?
- Which type of gratings do astronomers need?
- Which (new) gratings-manufacturing technology could be useful to astronomers?

Large gratings for large telescopes

Why do astronomers need large gratings?

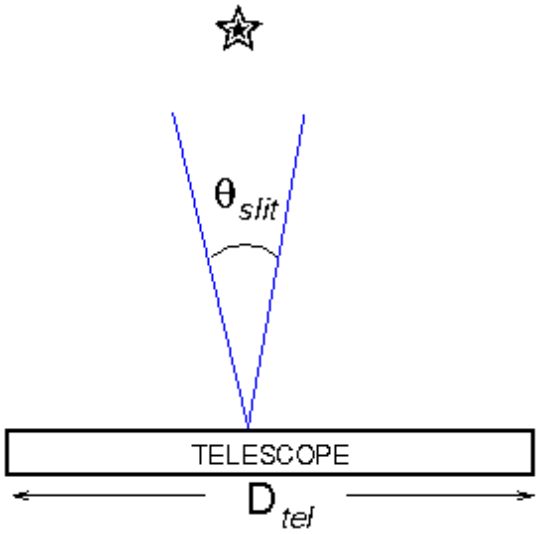


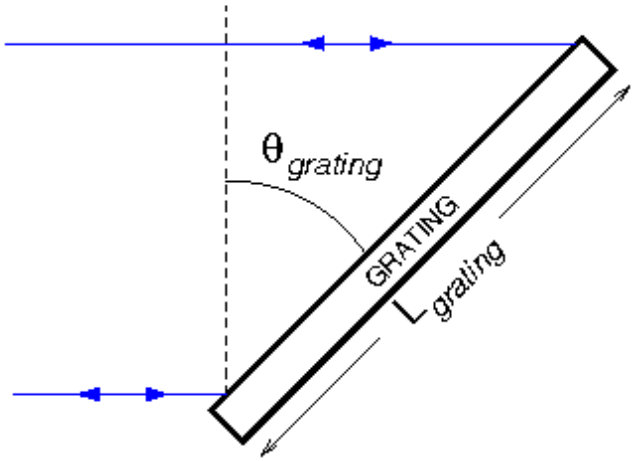
Fundamental physics: energy/throughput/etendue conservation

$$A\Omega = \text{constant}$$

$$(D_x\,\theta_x)\,(D_y\,\theta_y) = \text{constant}$$

Large gratings for large telescopes

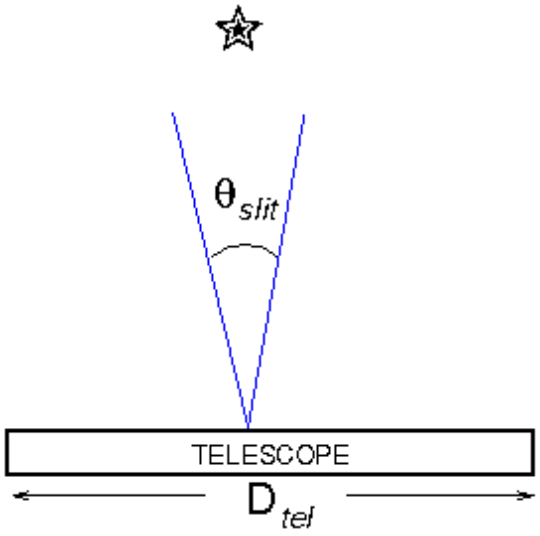


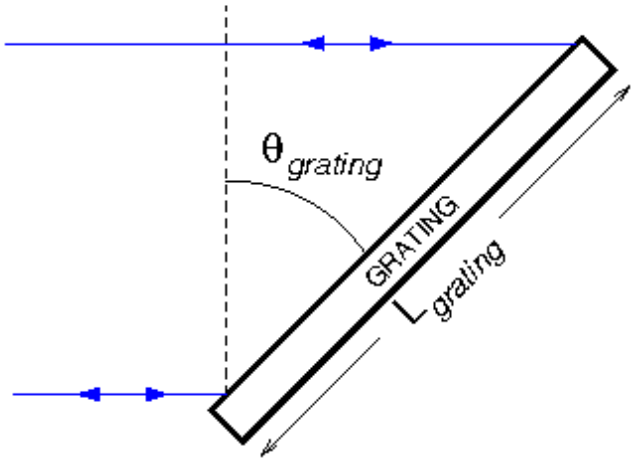


$$R = 10^4 \left(\frac{L_{grating}}{1.0\ \mathrm{m}}\right) (\sin\theta_{grating}) \left(\frac{D_{tel}}{40\ \mathrm{m}}\right)^{-1} \left(\frac{\theta_{slit}}{1''}\right)^{-1}$$

$R=\lambda/\Delta\lambda$ is the resolving power of the spectrometer

Large gratings for large telescopes

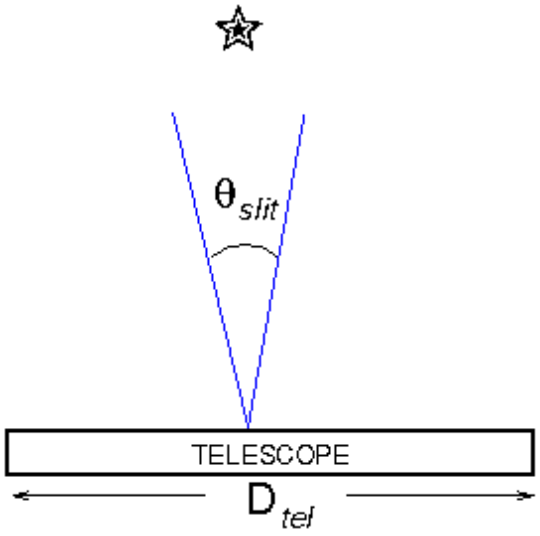


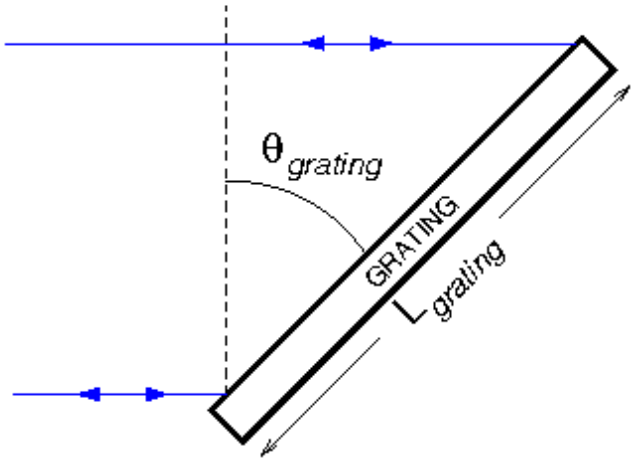


$$R = 10^4 \left(\frac{L_{grating}}{1.0\ \mathrm{m}}\right) (\sin\theta_{grating}) \left(\frac{D_{tel}}{40\ \mathrm{m}}\right)^{-1} \left(\frac{\theta_{slit}}{1''}\right)^{-1}$$

Diameter of the largest ELT telescope

Large gratings for large telescopes

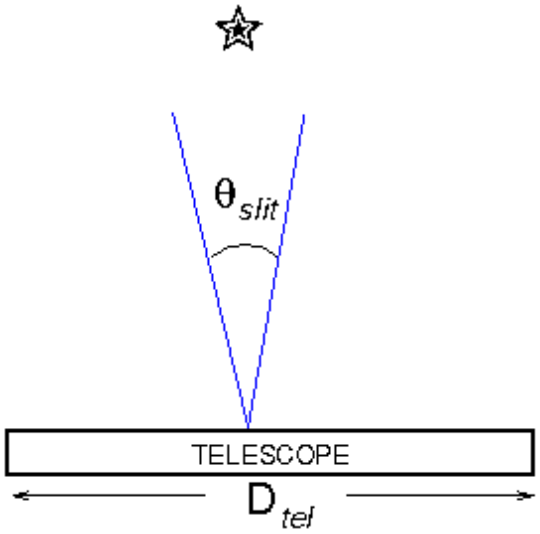


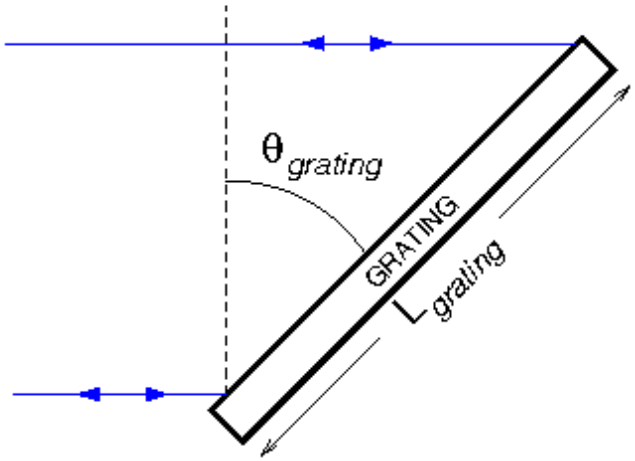


$$R = 10^4 \left(\frac{L_{grating}}{1.0\ \mathrm{m}}\right) (\sin\theta_{grating}) \left(\frac{D_{tel}}{40\ \mathrm{m}}\right)^{-1} \left(\frac{\theta_{slit}}{1''}\right)^{-1}$$

Typical value of resolving power needed

Large gratings for large telescopes

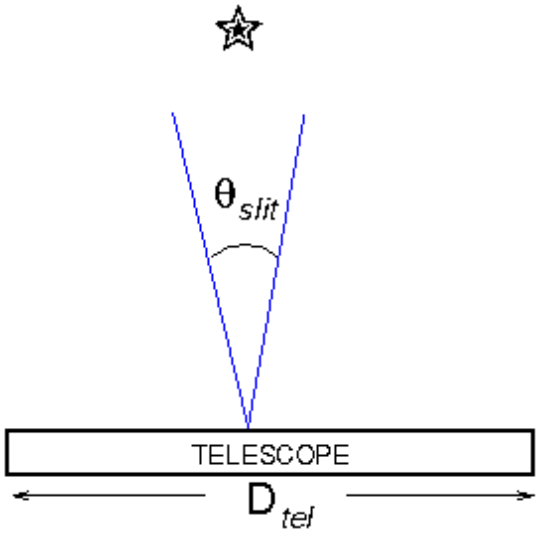


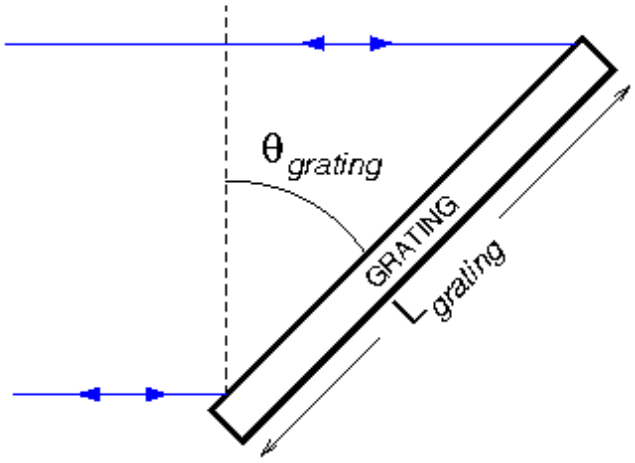


$$R = 10^4 \left(\frac{L_{grating}}{1.0\ \mathrm{m}}\right) (\sin\theta_{grating}) \left(\frac{D_{tel}}{40\ \mathrm{m}}\right)^{-1} \left(\frac{\theta_{slit}}{1''}\right)^{-1}$$

Meter size gratings!!

Large gratings for large telescopes



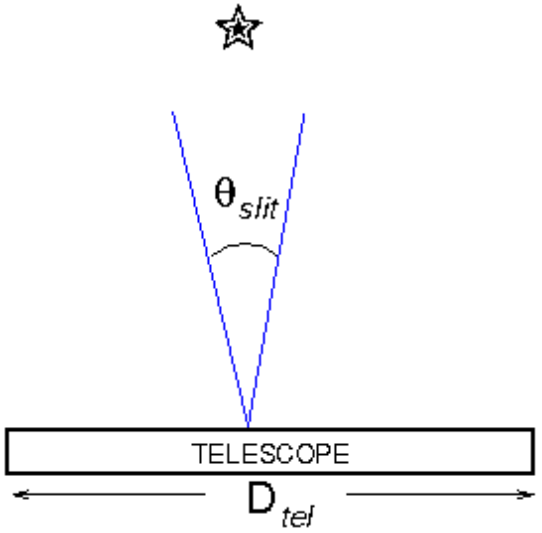


$$R = 10^4 \left(\frac{L_{grating}}{1.0\ \mathrm{m}}\right) (\sin\theta_{grating}) \left(\frac{D_{tel}}{40\ \mathrm{m}}\right)^{-1} \left(\frac{\theta_{slit}}{1''}\right)^{-1}$$

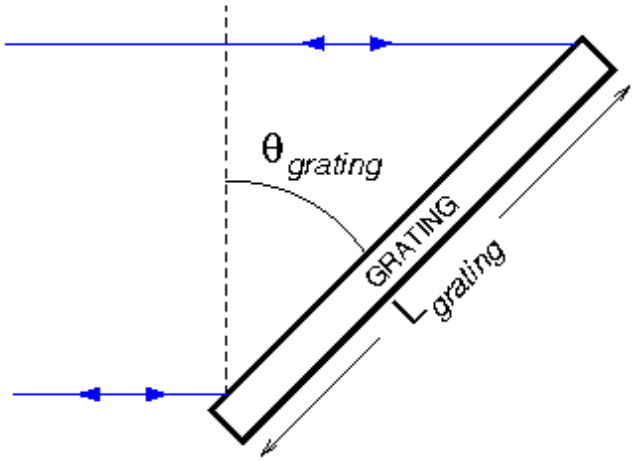
1” is the typical object size without adaptive optics (seeing limited)

No large enough gratings? → narrower slit + slice/dice the light

Large gratings for large telescopes



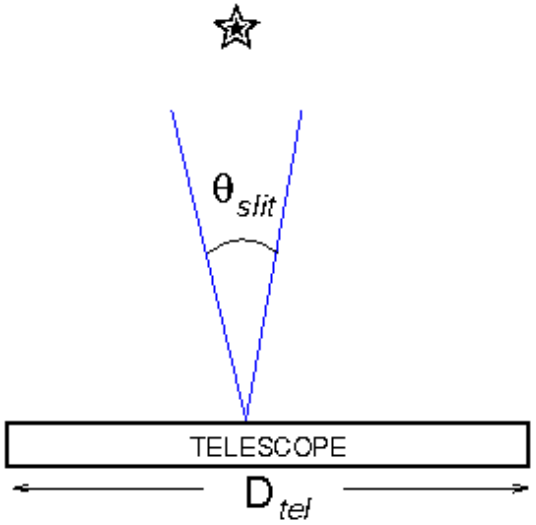
Reflection grating



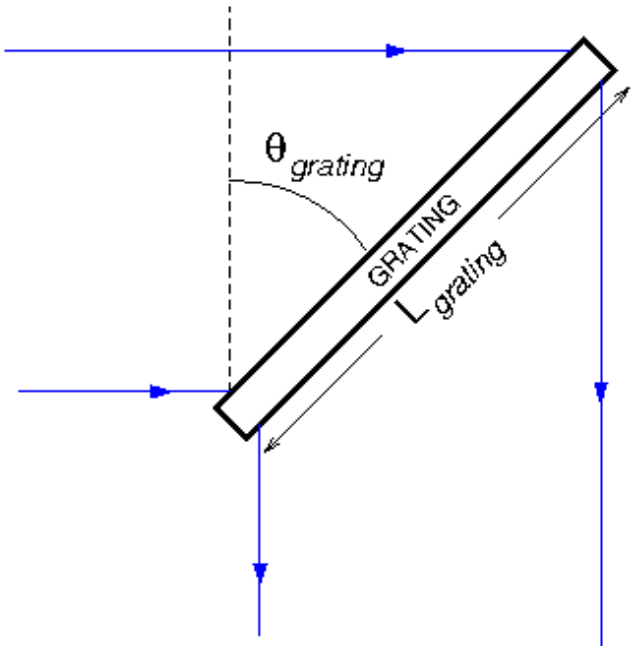
$$R = 10^4 \left(\frac{L_{grating}}{1.0\ \mathrm{m}}\right) (\sin\theta_{grating}) \left(\frac{D_{tel}}{40\ \mathrm{m}}\right)^{-1} \left(\frac{\theta_{slit}}{1''}\right)^{-1}$$

Different grating types, same size

Large gratings for large telescopes



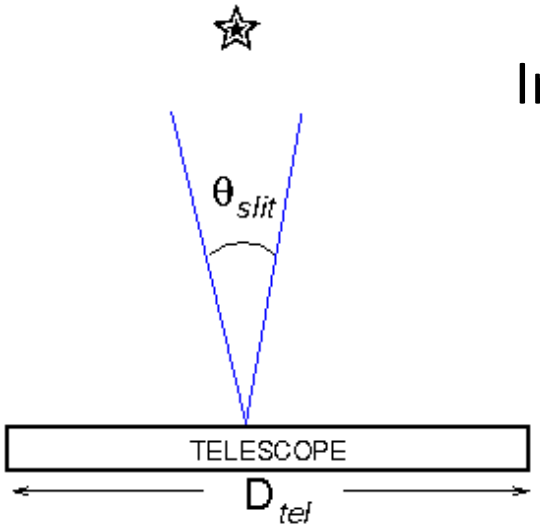
Transmission grating



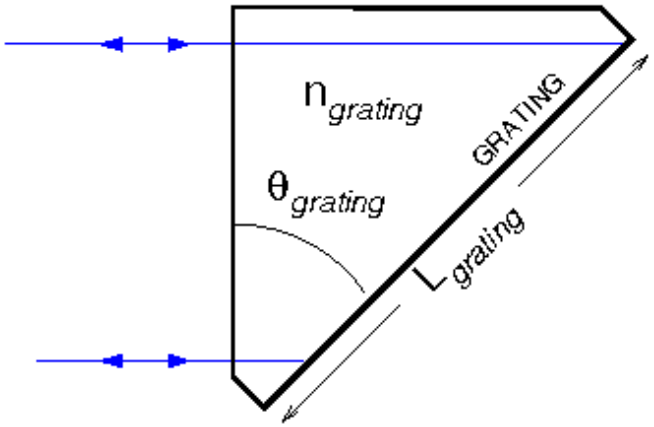
$$R = 10^4 \left(\frac{L_{grating}}{1.0\ \mathrm{m}}\right) (\sin\theta_{grating}) \left(\frac{D_{tel}}{40\ \mathrm{m}}\right)^{-1} \left(\frac{\theta_{slit}}{1''}\right)^{-1}$$

Different grating types, same size

Large gratings for large telescopes



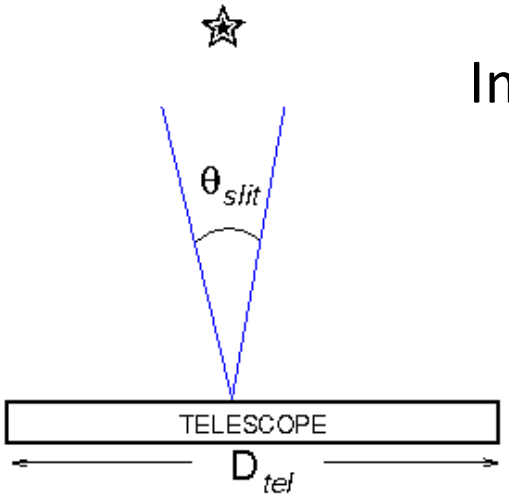
Immersed reflection grating



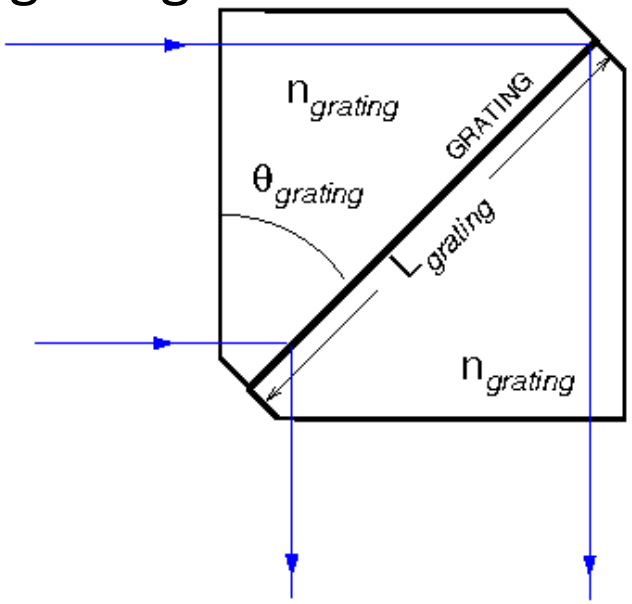
$$R = 10^4 \, (n_{grating}) \left(\frac{L_{grating}}{1.0 \text{ m}} \right) (\sin \theta_{grating}) \left(\frac{D_{tel}}{40 \text{ m}} \right)^{-1} \left(\frac{\theta_{slit}}{1''} \right)^{-1}$$

May gain up to a factor of 3 (Si) or 4 (Ge), limits on size/uniformity

Large gratings for large telescopes



Immersed transmission grating

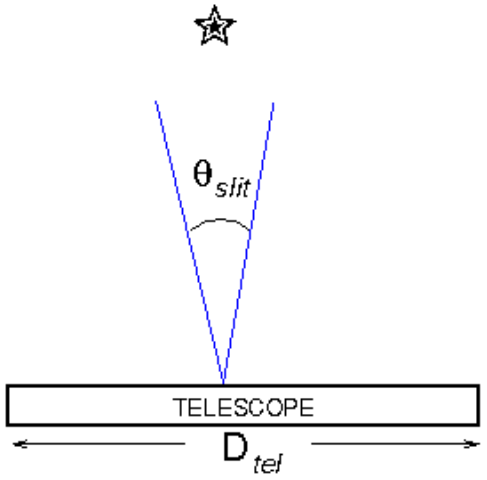


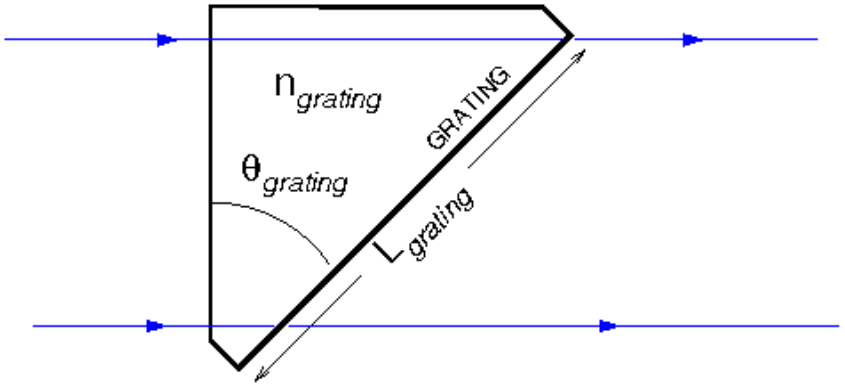
$$R = 10^4 \, (n_{grating}) \left(\frac{L_{grating}}{1.0 \text{ m}} \right) (\sin \theta_{grating}) \left(\frac{D_{tel}}{40 \text{ m}} \right)^{-1} \left(\frac{\theta_{slit}}{1''} \right)^{-1}$$

May gain up to a factor of 3 (Si) or 4 (Ge), limits on size/uniformity

Large gratings for large telescopes

Grism (prism-grating, no deviation at blaze)





$$R = 10^4 \left(\frac{n_{grating} - 1}{2}\right)\left(\frac{L_{grating}}{1.0\ \mathrm{m}}\right)(\sin\theta_{grating})\left(\frac{D_{tel}}{40\ \mathrm{m}}\right)^{-1}\left(\frac{\theta_{slit}}{1''}\right)^{-1}$$

No gain in size even using Ge (n=4)

Large gratings for large telescopes

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- Which type of gratings do astronomers need?
- Which (new) gratings-manufacturing technology could be useful to astronomers?

Large gratings for large telescopes

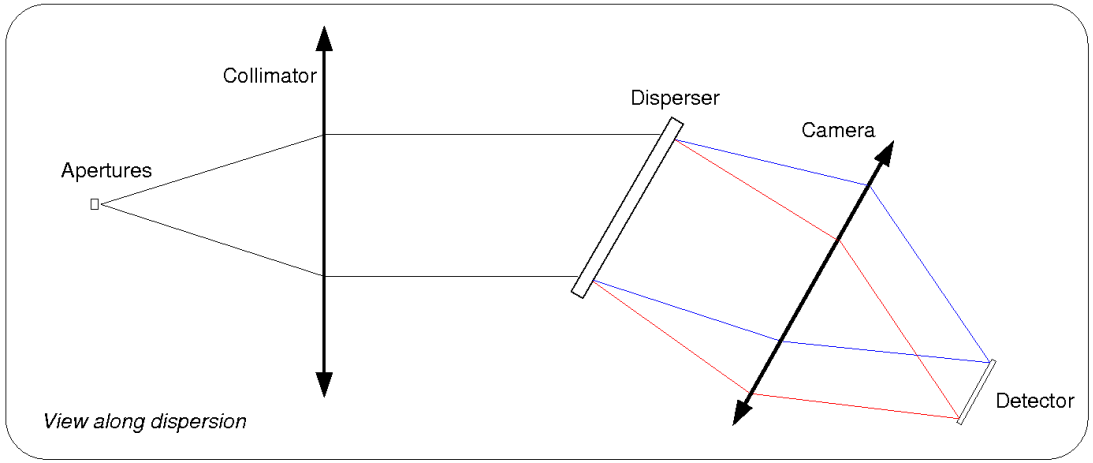
Two main classes of spectrometers for ground based telescopes.

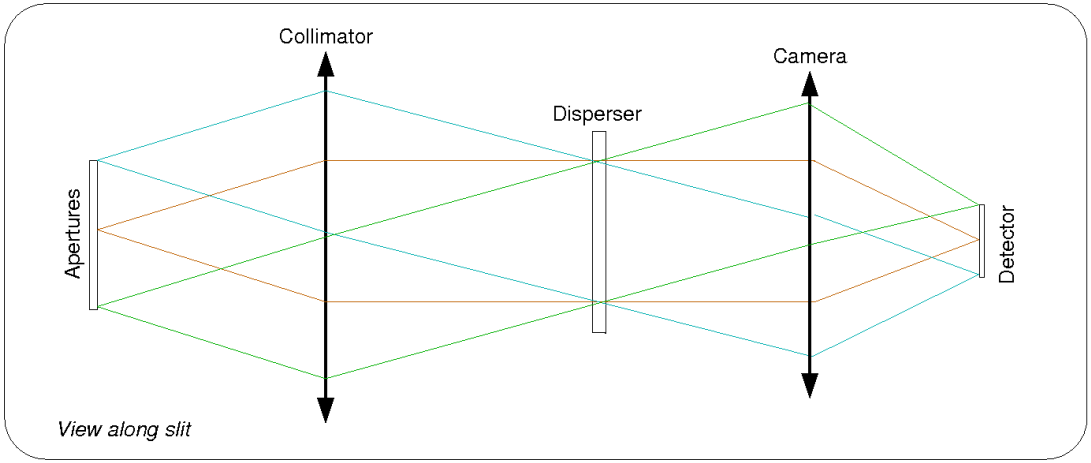
A. many apertures/objects at moderate spectral resolution (R~10^3-10^4), moderate (<1 octave) spectral coverage per disperser
   → gratings working in first order.

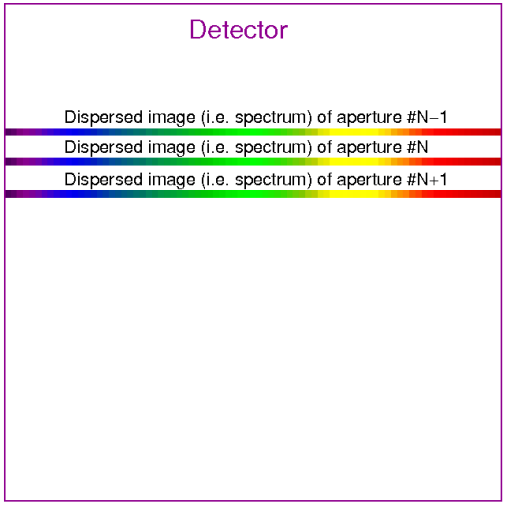
B. few apertures/objects at high spectral resolution (R~10^5), very large (>1 octave) spectral coverage per disperser
   → gratings working at high orders (echelle).

Large gratings for large telescopes

Type A disperser: many apertures → long slit → large input angles on disperser → much easier with transmission gratings







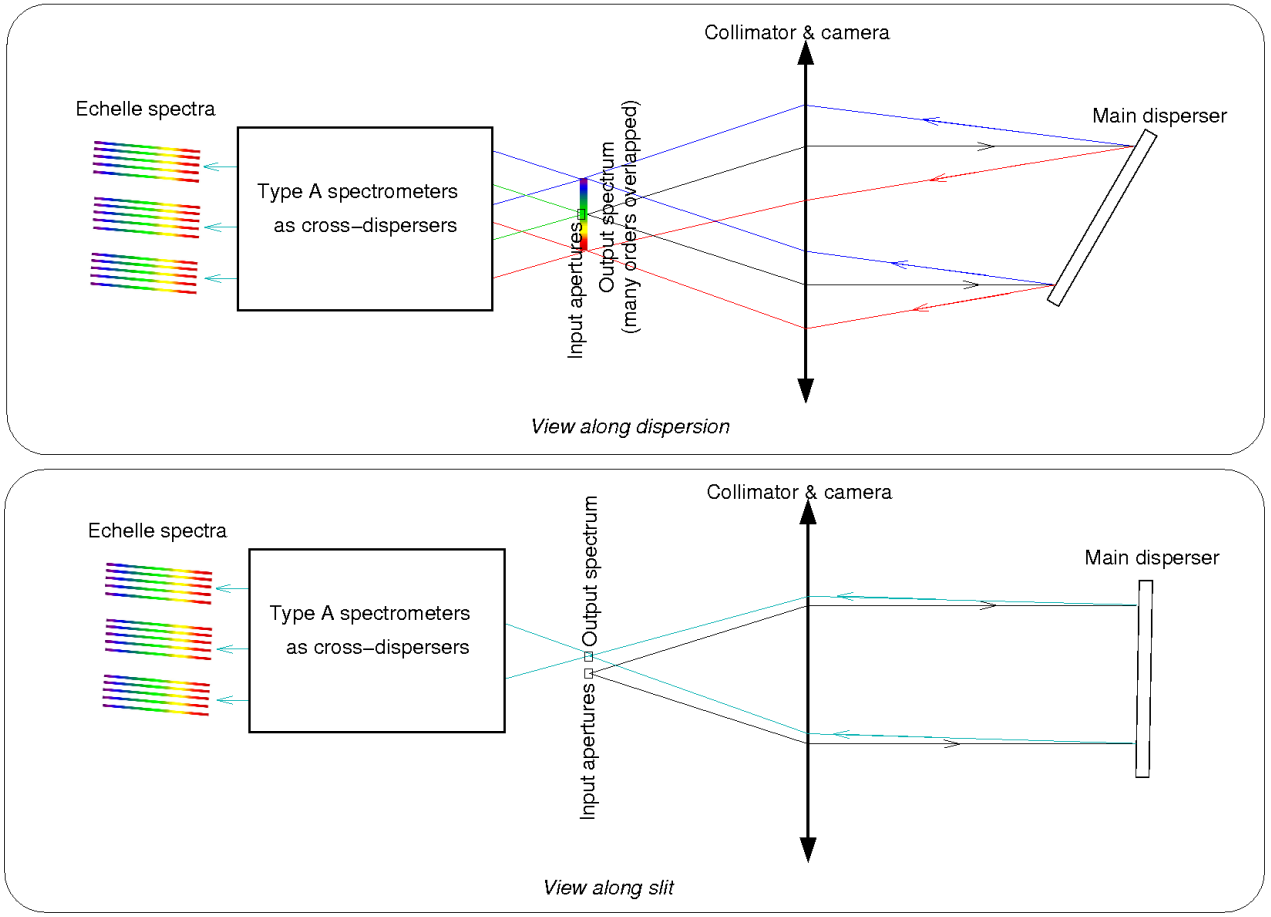
Large gratings for large telescopes

Representative range of parameters for large type-A gratings	
Grating type	Transmission, first order
Wavelength (nm)	350–2000 (300–2500)
Grooves spacing (ll/mm)	200 – 3000
Grating angle (deg)	10-50(60)
Configuration	out-of-Littrow by several deg(*)
Efficiency	as high as possible (non polarized)
Spectral wings(**)	as low as possible

(*) To avoid Littrow ghosts
(**) Within a few arc-min of the peak

Large gratings for large telescopes

Type B disperser: few apertures → short slit → small input angles on disperser → easy with reflection gratings



IMPORTANT: it needs type A gratings for cross-dispersion (!)

Large gratings for large telescopes

Representative range of parameters for large type-B gratings	
Grating type	Reflection, order>60 (echelle)
Wavelength (nm)	350–2000 (300–2500)
Grooves spacing (ll/mm)	10-70
Grating angle (deg)	76 (R4)
Configuration	quasi-Littrow(*)
Efficiency	as high as possible (non polarized)
Spectral/Rowland ghosts	as low as possible

(*) Off-axis ~0.5 deg perpendicular to dispersion

Large gratings for large telescopes

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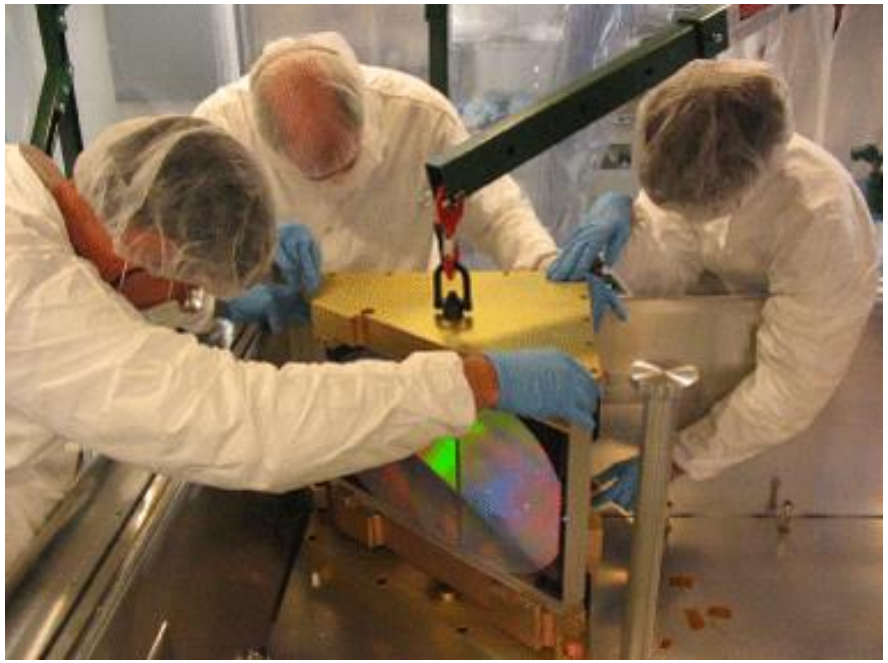
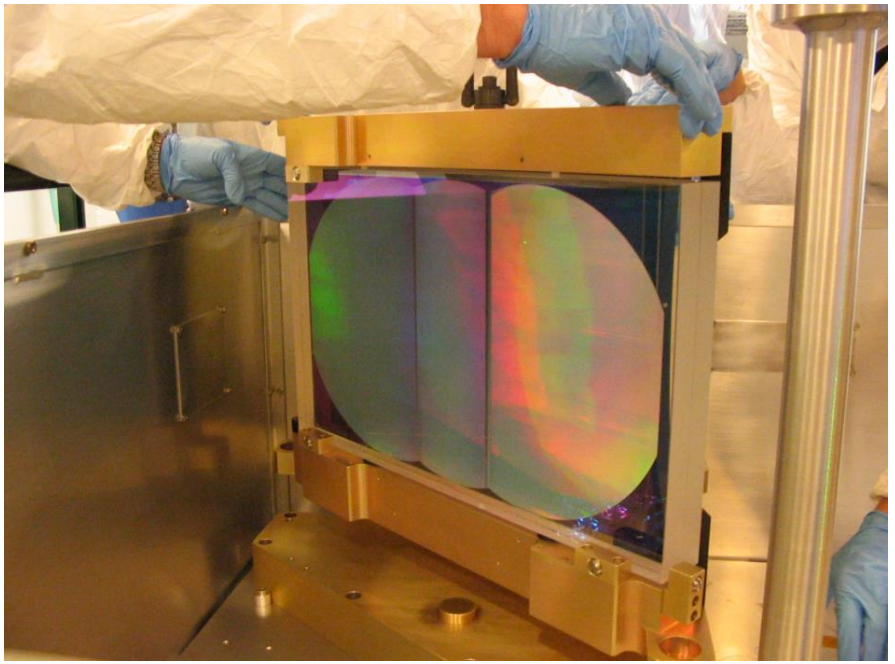
- Which (new) gratings-manufacturing technology could be useful to astronomers?

Large gratings for large telescopes

Most popular type-A gratings among astronomers: VPH
Typical limit adopted in the design: grooves length=280 mm (Kosi)
Larger gratings possible with mosaics

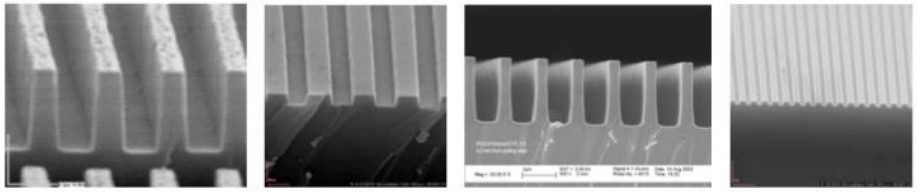




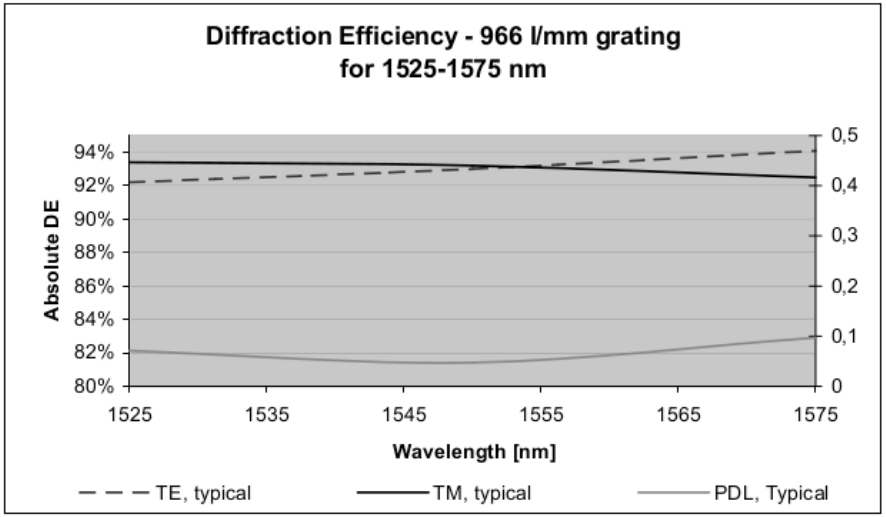
Apogee-SDSS grating *blog.sdss.org*

Large gratings for large telescopes

- New(?) technology: fused-silica transmission gratings.
- Binary profile directly etched on glass.
- Very high efficiencies for angles 30-50 deg
- Extensively used for telecom; relatively small gratings

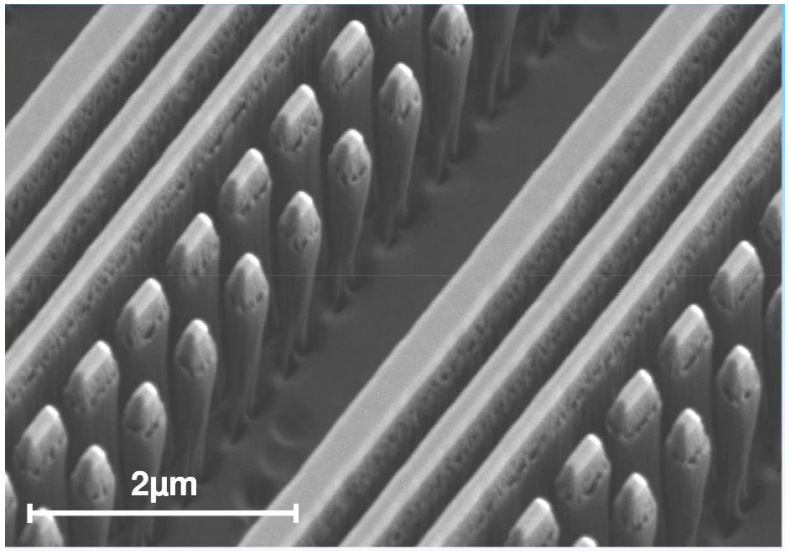


Ibsen.com

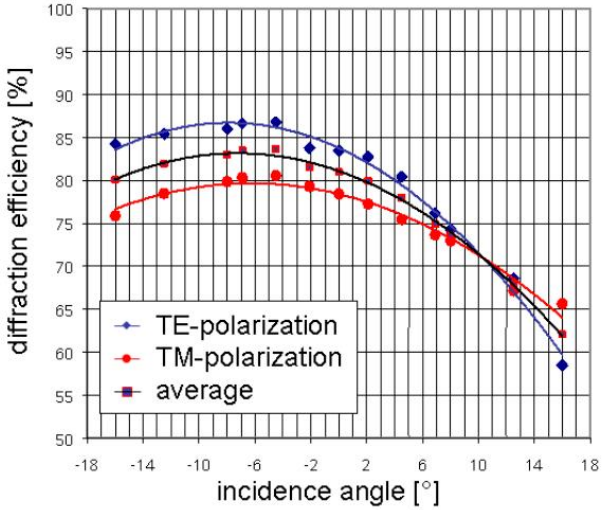


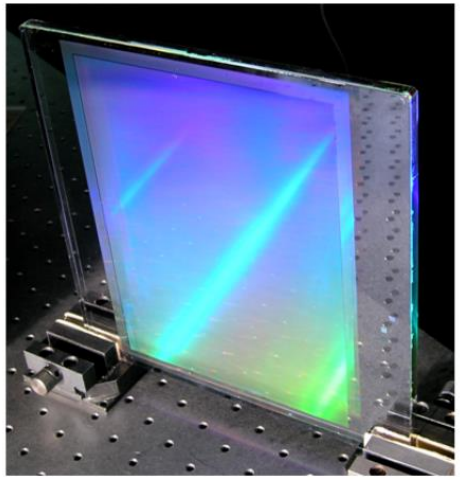
Large gratings for large telescopes

- Improvement on fused-silica transmission gratings technology?
- High efficiencies at angles >50 deg with special coating of grooves
- High efficiencies at angles <30 deg with complex grooves pattern



SEM-picture of etched pattern

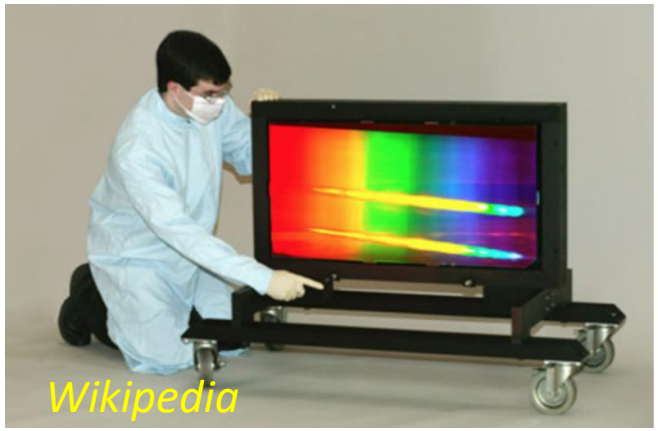


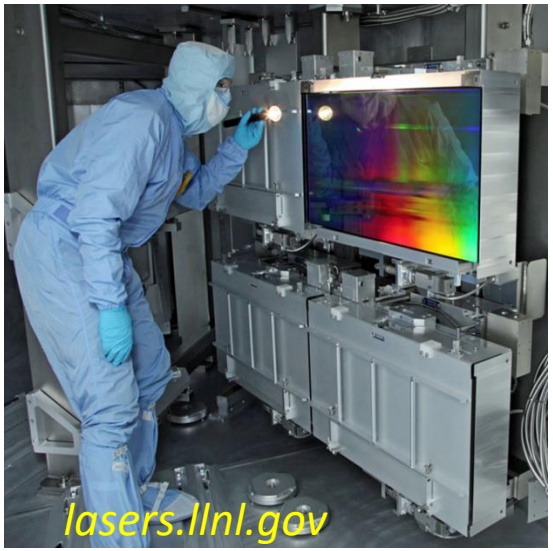


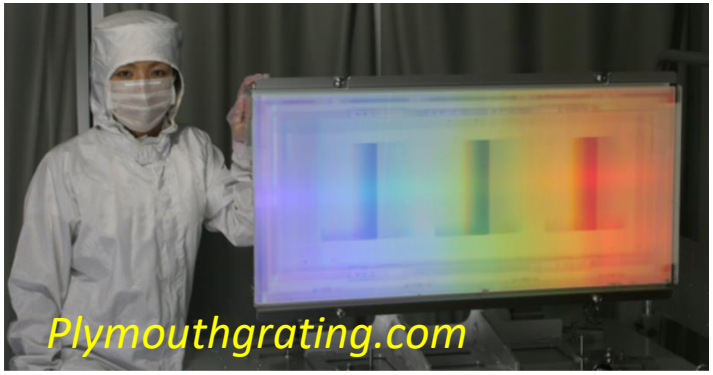
GAIA grating *iof.fraunhofer.de*

Large gratings for large telescopes

Large size fused-silica transmission gratings for high power lasers. Adaptable to astronomers wishes?

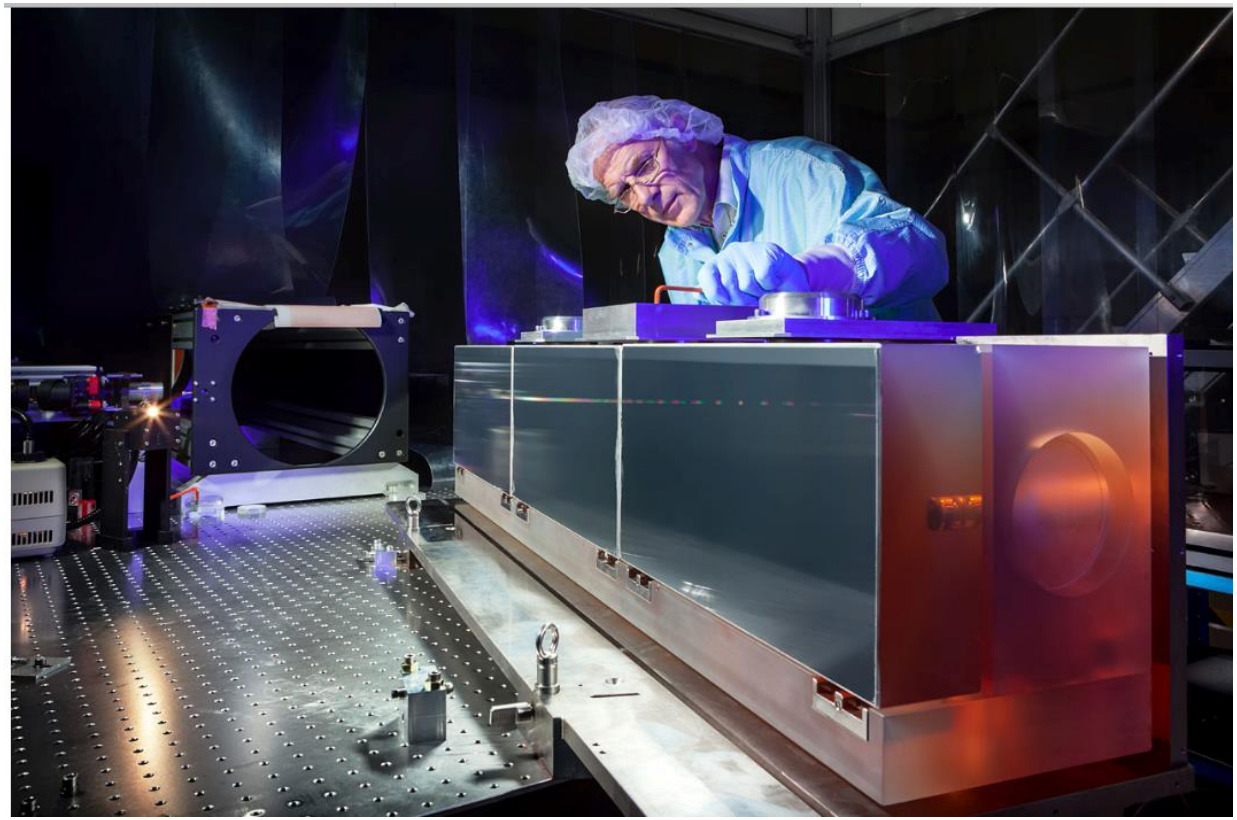






Large gratings for large telescopes

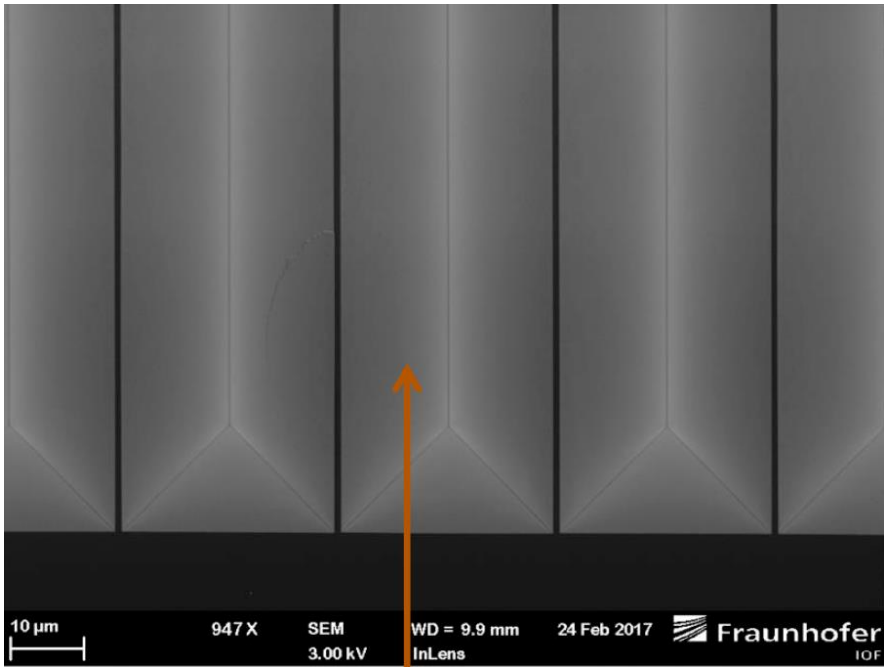
Type-B gratings (echelle) are old friends of astronomers.
Classic replica of ruled gratings with maximum length of 400 mm
Larger gratings possible with mosaics



ESPRESSO grating mosaic L=1.2 m *eso.org*

Large gratings for large telescopes

- Type-B gratings (echelle) coarser than ~30 gr/mm are missing, practical problems with direct ruling of such deep grooves.
- Coarse gratings with superb profiles easy with anamorphic etching on Silicon, max size of Si grating ~ max size of Si wafer ~ 0.4 m (?)
- A master grating of Si replicated using standard technologies? (??)

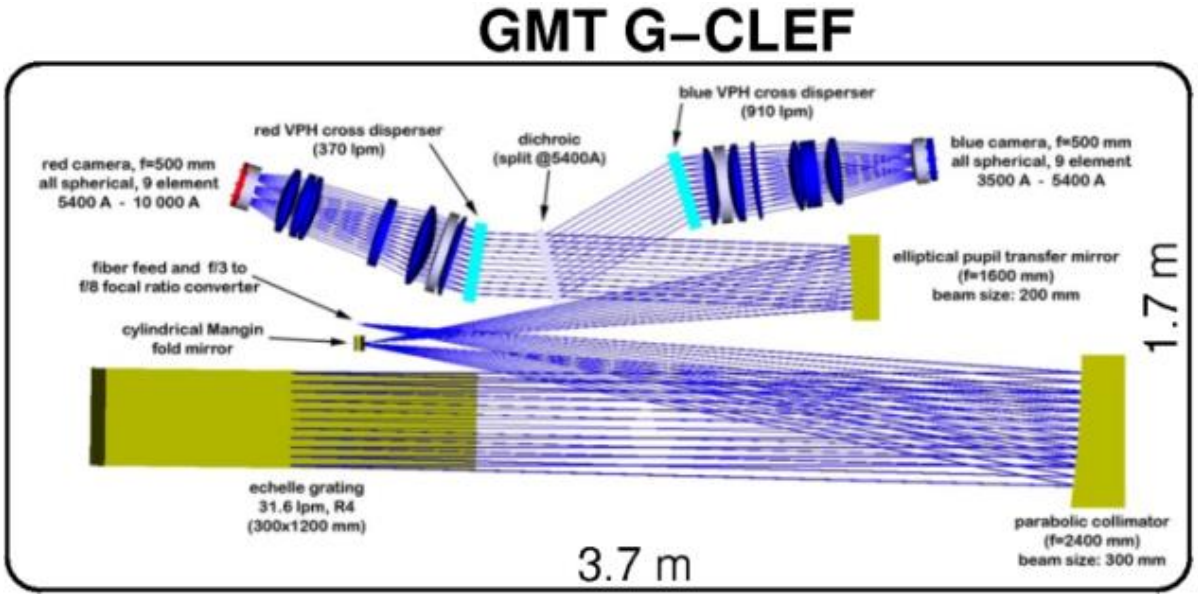


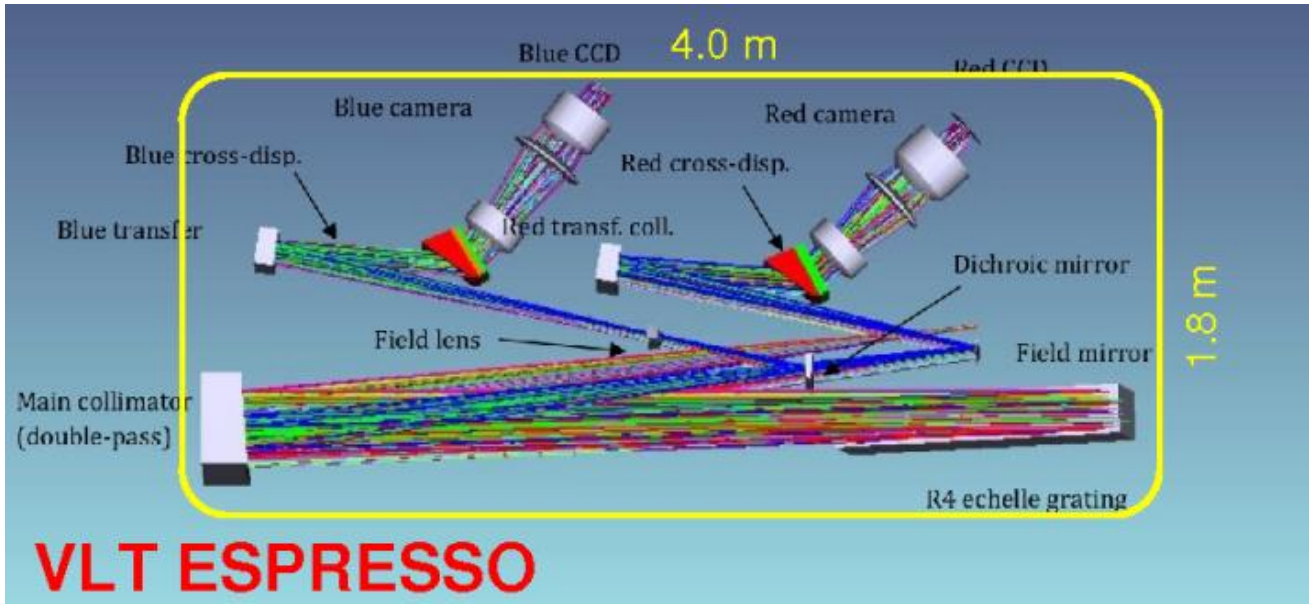
Anamorphic etched grating on Silicon, courtesy of IOF

Examples of seeing-limited HR spectrometers designs

Very similar, mostly imposed by market.

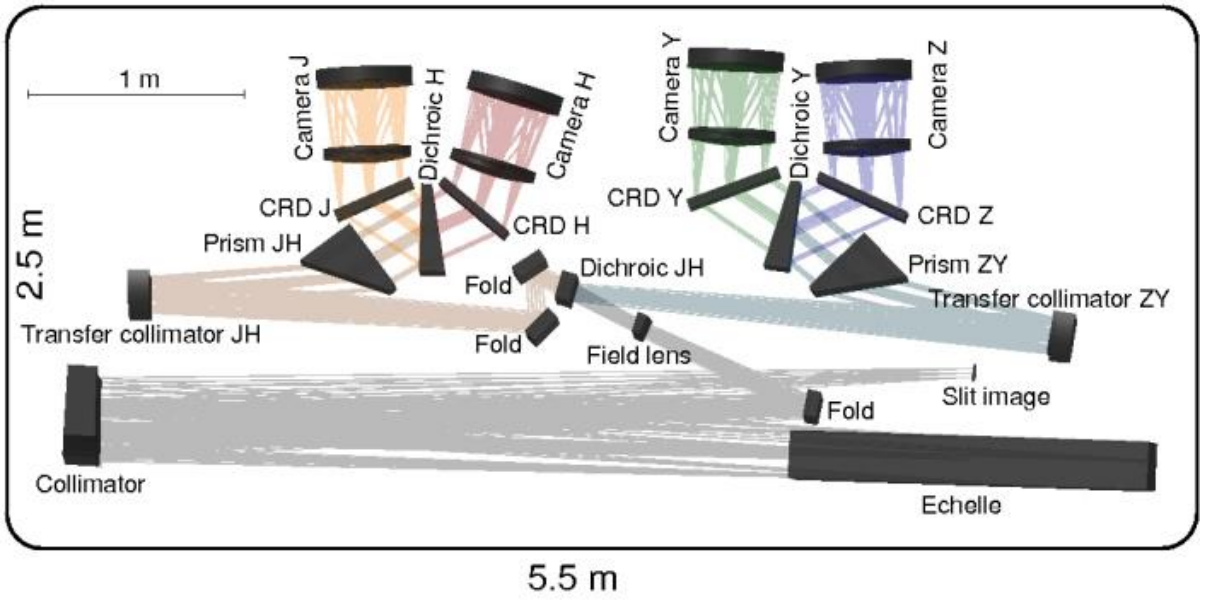
L=1.2 m echelle

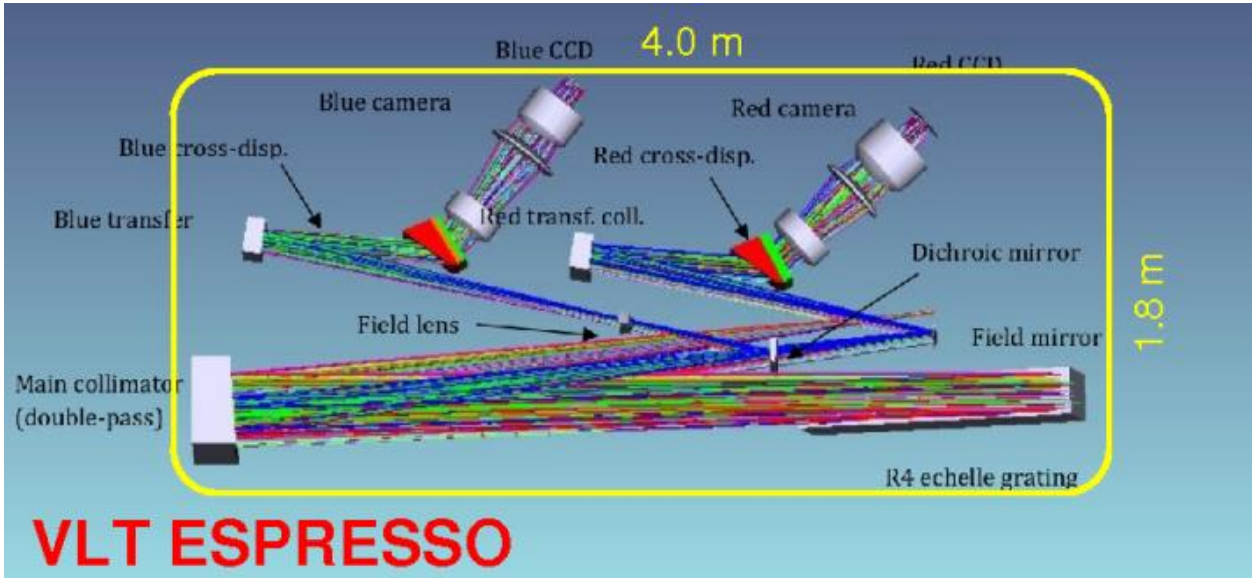




Examples of seeing-limited HR spectrometers designs

ELT HR spectrometer:
a double-espresso
L=1.6m echelle





Examples of seeing-limited HR spectrometers designs

Instructive example of classical design scaled up to ELT sizes