

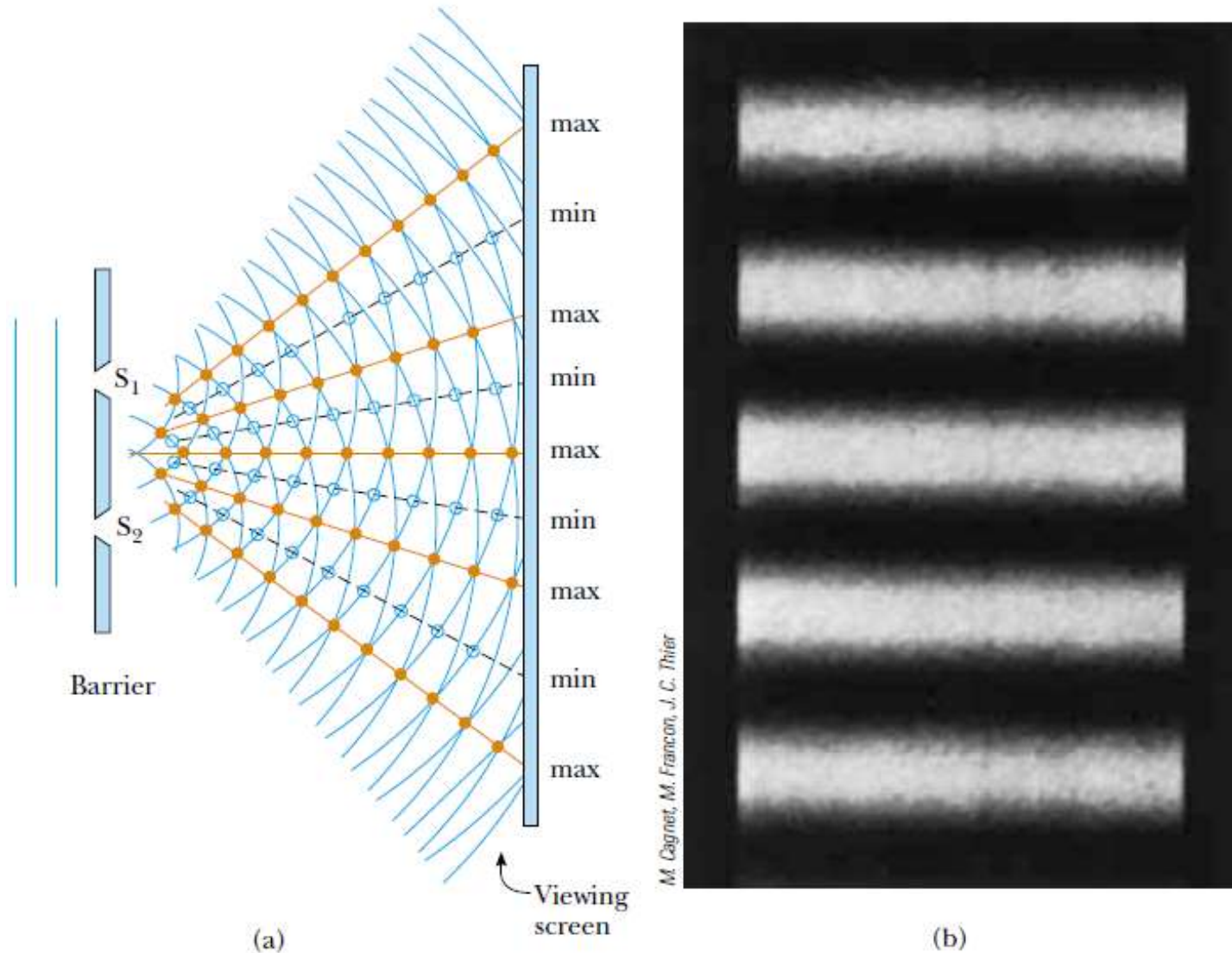
# AGA0414

## Espectroscopia II

- ***Grating (Rede de difração)***
- *Filtros (blocking order filters)*
- Dichroics (espectrógrafos duplos ou múltiplos)
- *Dispersão linear do espectro*
- Disenho básico de espectrógrafos
- *Wavelength calibration lamps*
- *Grisms*

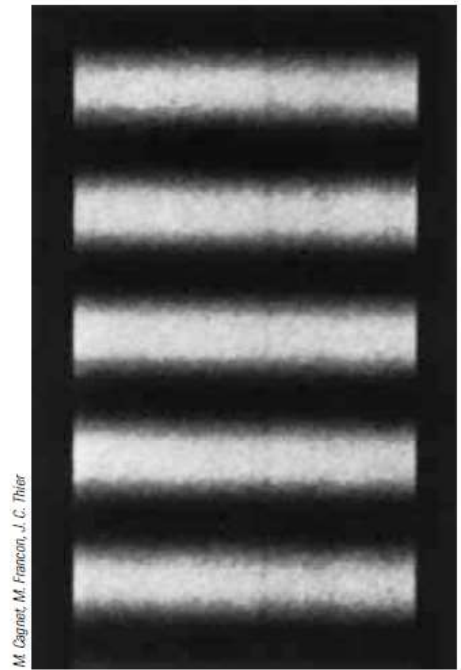
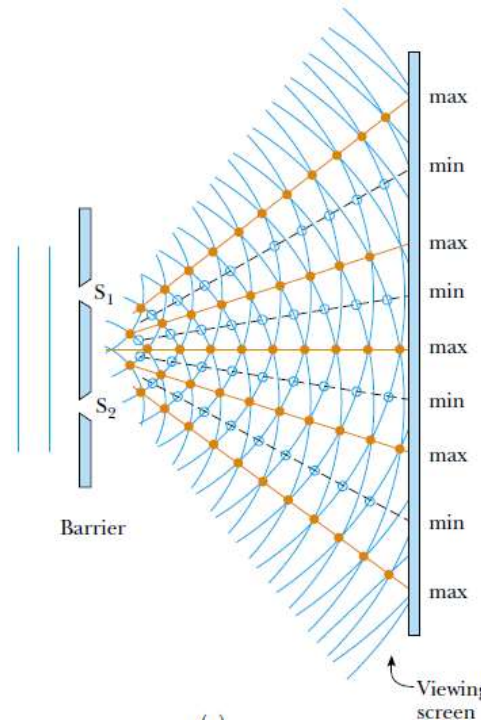
**Prof. Jorge Meléndez**

# Interferência de ondas de luz

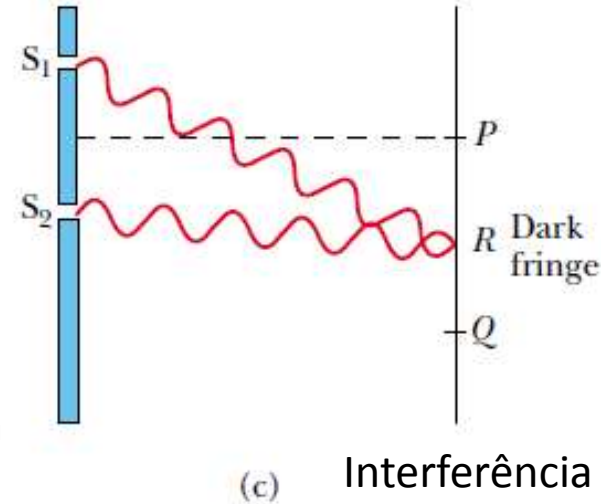
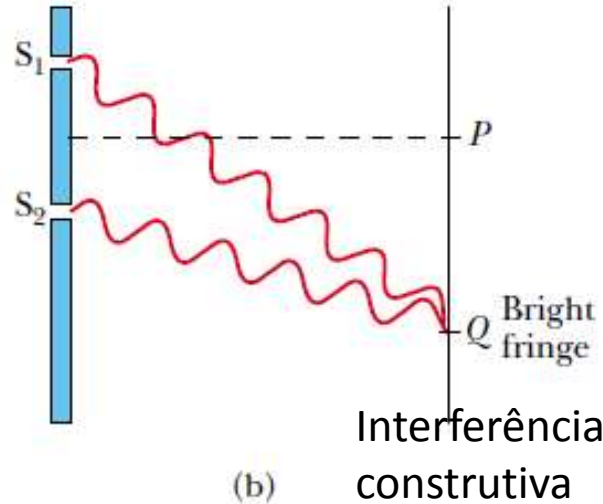
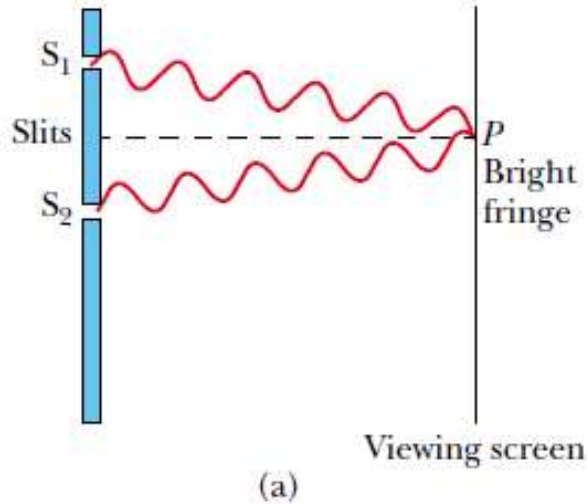


**Active Figure 37.2** (a) Schematic diagram of Young's double-slit experiment. Slits  $S_1$  and  $S_2$  behave as coherent sources of light waves that produce an interference pattern on the viewing screen (drawing not to scale). (b) An enlargement of the center of a fringe pattern formed on the viewing screen.

# Interferência de ondas de luz

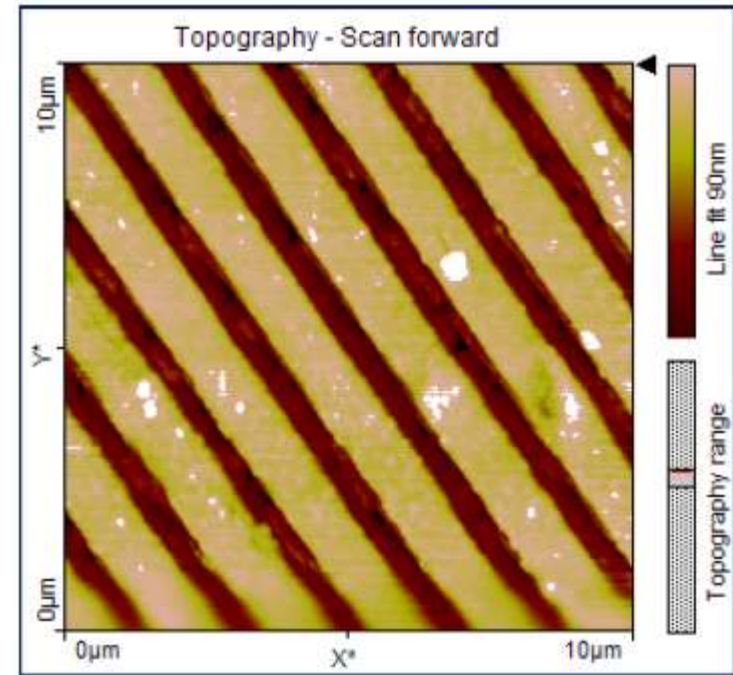


Interferência construtiva



**Figure 37.4** (a) Constructive interference occurs at point  $P$  when the waves combine. (b) Constructive interference also occurs at point  $Q$ . (c) Destructive interference occurs at  $R$  when the two waves combine because the upper wave falls half a wavelength behind the lower wave. (All figures not to scale.)

# Dispersion by a diffraction grating (rede de difração)



**CD-Blank**

**(10  $\mu\text{m}$  scan)**

**Track pitch = 1.57  $\mu\text{m}$**

**Type ----- Capacity --- Track pitch how many per mm (1 mm =  $10^3 \mu\text{m}$ )?**

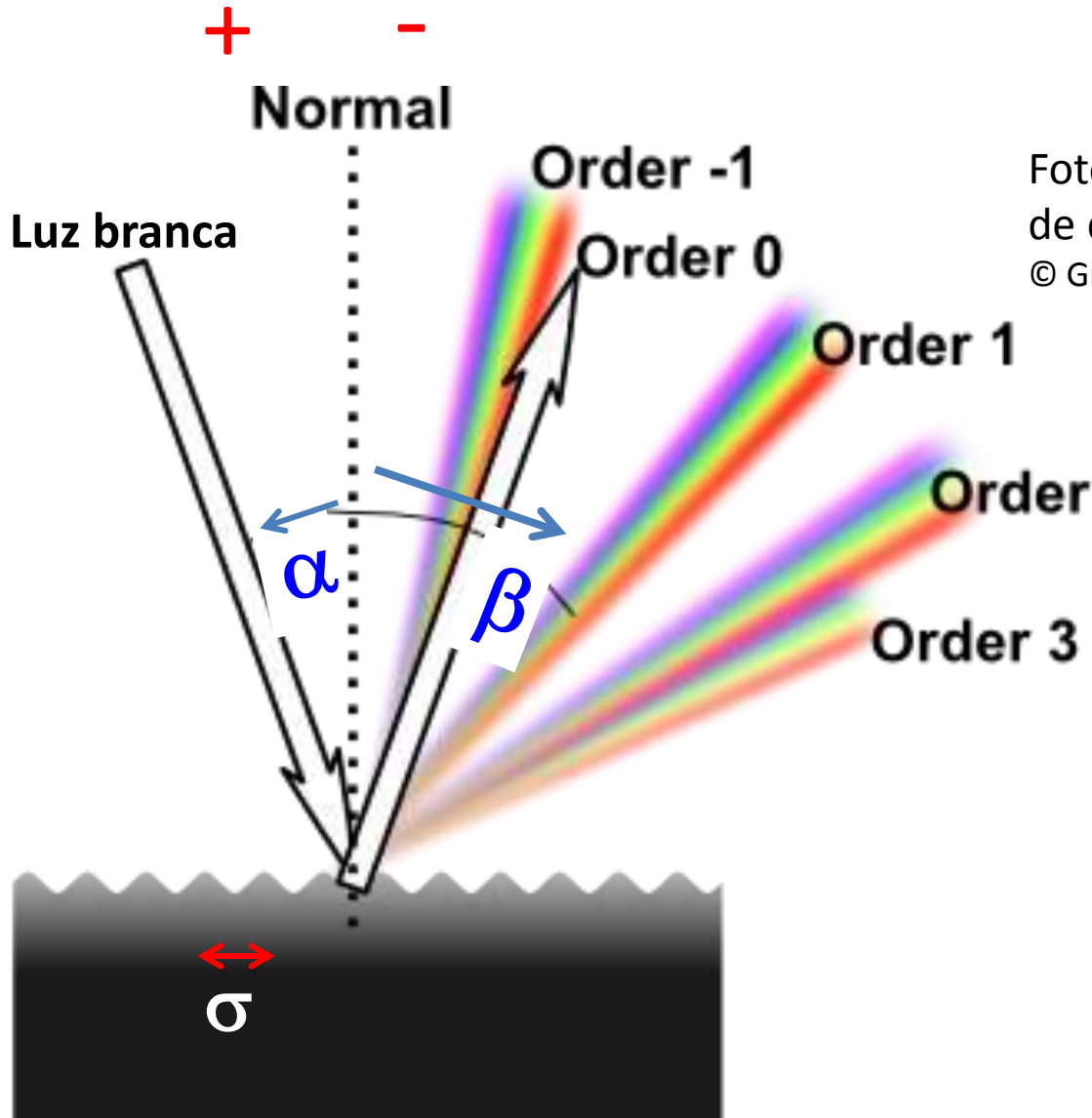
CD ----- 0.7 Gb --- 1.6  $\mu\text{m}$   $\rightarrow 10^3 \mu\text{m}/1,6 \mu\text{m} = 625$  lines/mm

DVD ----- 4.7 GB --- 0.74  $\mu\text{m}$   $\rightarrow 10^3 \mu\text{m}/0,74 \mu\text{m} = 1351$  lines/mm

Blu-ray Disc --- 25 GB ---- 0.32  $\mu\text{m}$   $\rightarrow 10^3 \mu\text{m}/0,32 \mu\text{m} = 3125$  lines/mm



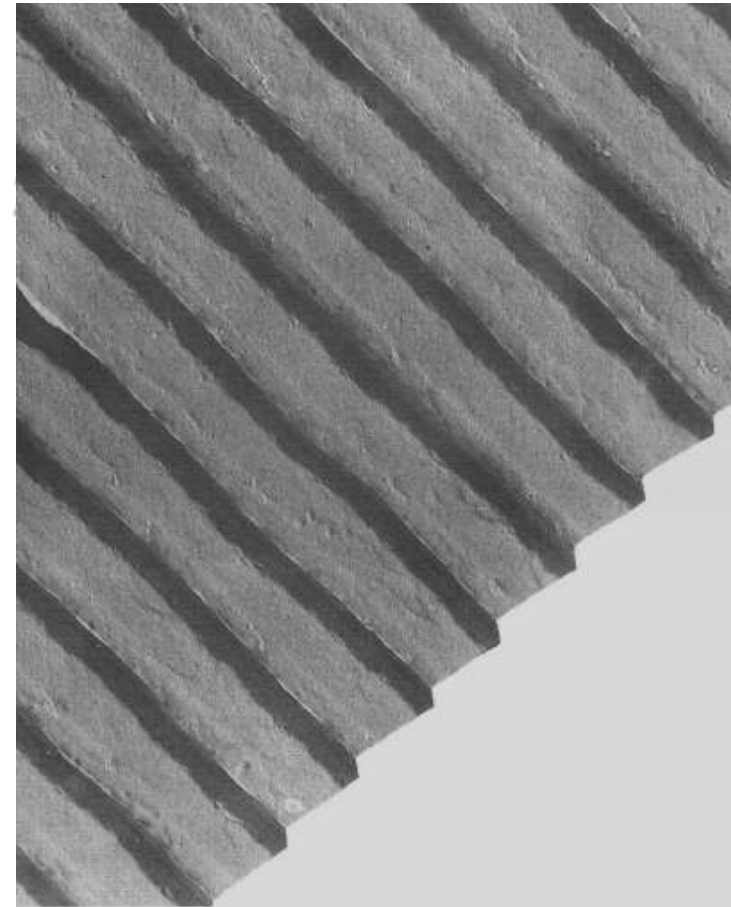
# Rede de difração



$\sigma$ : distância entre os sulcos

Foto microscópica de parte de uma rede de difração de 1180 linhas/mm

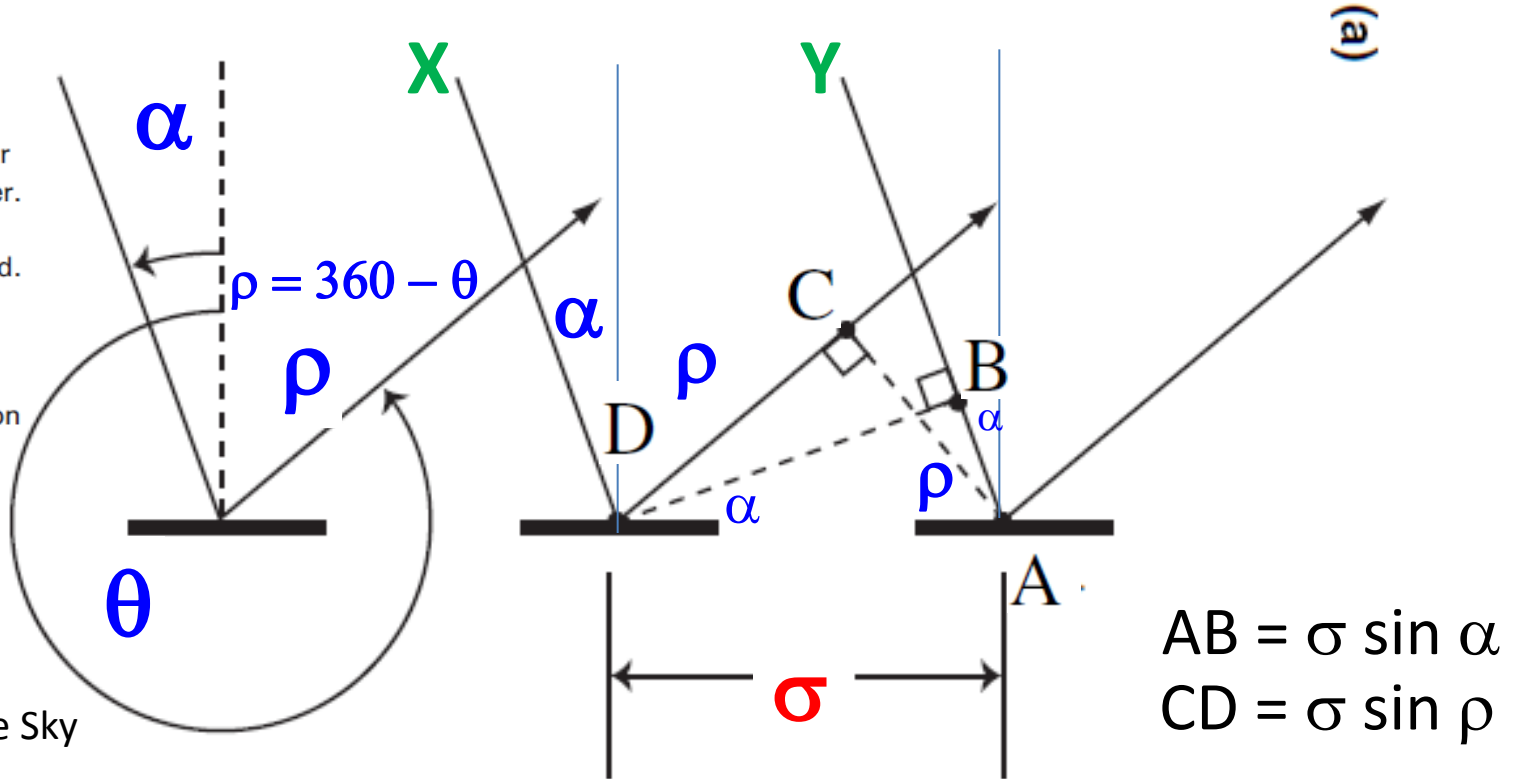
© Gray, Stellar Photospheres, 3<sup>rd</sup> ed., Fig. 3.2 (p. 55)



This microscopic picture shows the rulings on a plane reflection grating having 1180 lines/mm. (Courtesy of Jarrell-Ash.)

# Interferência construtiva em redes de reflexão

Fig. 11.3 (a) A reflection grating. Grating facets are tall, narrow mirrors extending perpendicular to the plane of the paper. Light striking between the facets is not reflected. The figure traces three parallel rays that strike the centers of adjacent facets. (b) A transmission



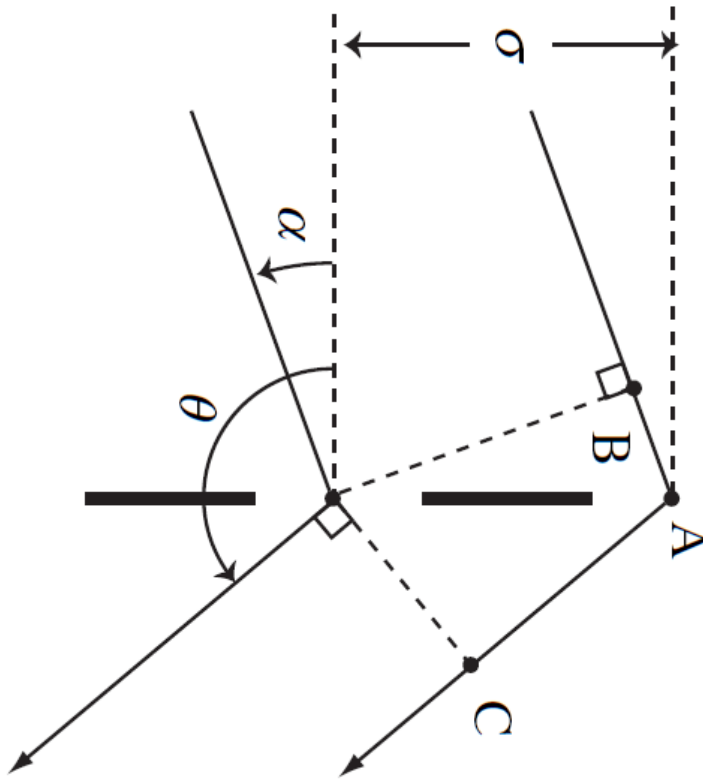
© To Measure the Sky

Ao saírem da rede, o caminho óptico dos raios X e Y diferem por  $\Delta\tau = AB - CD = \sigma \sin \alpha - \sigma \sin \rho \rightarrow \Delta\tau = \sigma \sin \alpha + \sigma \sin \theta$

Interferência construtiva quando  $\Delta\tau = m \lambda$ ,  $m = 0, \pm 1, \pm 2, \dots$

**Equação da rede :  $\sigma \sin \alpha + \sigma \sin \theta = m \lambda$**

# Interferência construtiva em redes de transmissão



(a)

Equação da rede :

$$\sigma \sin \alpha + \sigma \sin \theta = m\lambda$$

order  $m = 0, \pm 1, \pm 2, \dots$



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A light [bulb](#) of a [flashlight](#) seen through a transmission grating, showing three diffracted orders. The order  $m = 0$  corresponds to a direct transmission of light through the grating. In the first positive order ( $m = +1$ ), colors with increasing wavelengths (from blue to red) are diffracted at increasing angles.

# Angular dispersion of a grating

$$\sigma(\sin \alpha + \sin \theta) = m\lambda$$

$$\sin \theta = m\lambda/\sigma - \sin \alpha$$

Differentiating the grating equation :

$$\frac{d\theta}{d\lambda} = \frac{m}{\sigma \cos \theta}$$

- $\cos \theta$  changes only slowly with  $\lambda$ , então a dispersão angular da rede é aproximadamente constante com o comprimento de onda
- Dispersão pode ser aumentada usando ordens maiores



# Poder Resolvente de uma rede de difração

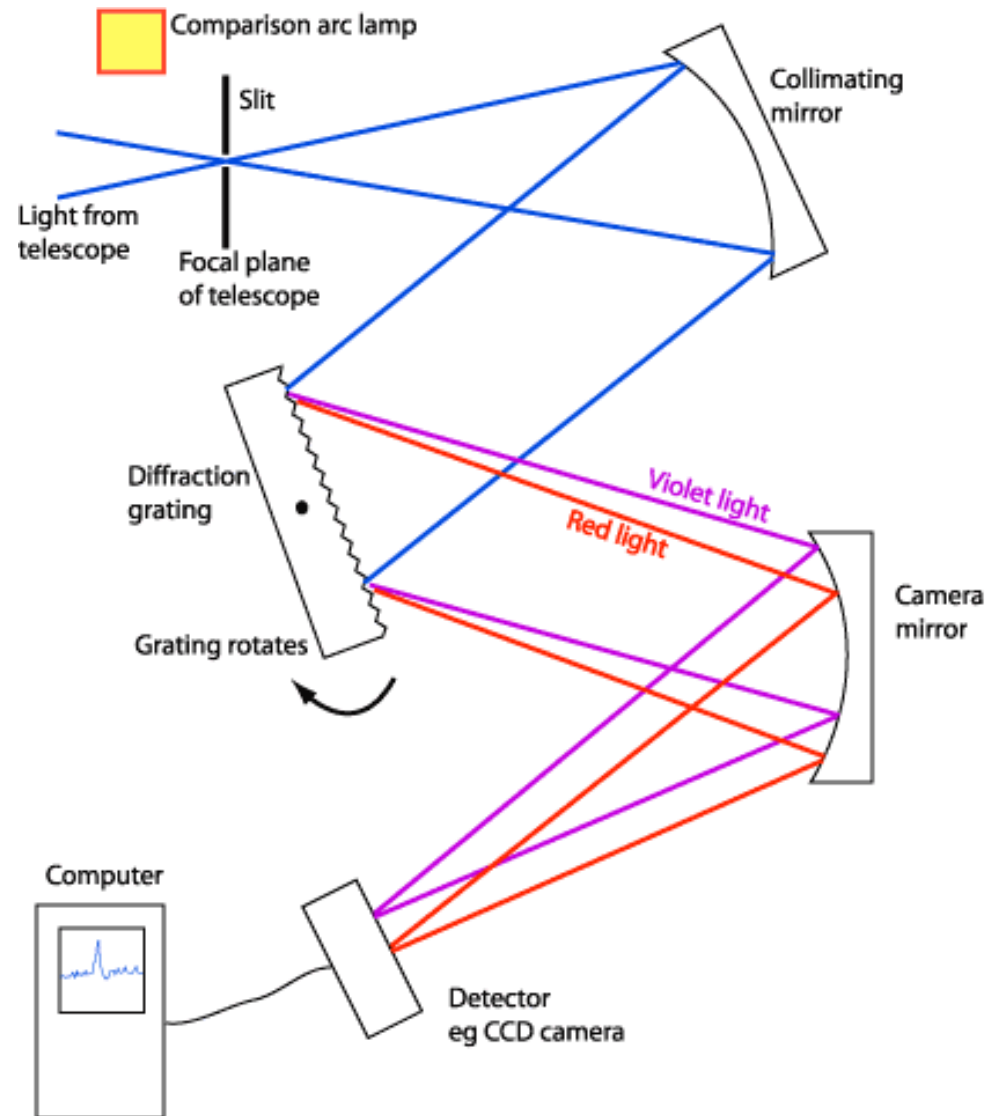
(o poder resolvente do espectrógrafo sempre é menor)

$$R \equiv \frac{\lambda}{\Delta\lambda}$$

$$R = Nm$$

$N$ : numero de linhas  
(iluminadas) da rede

$m$ : ordem



A Schematic Diagram of a Slit Spectrograph

# Poder Resolvente de uma rede de difração

(o poder resolvente do espectrógrafo sempre é menor)

$$R \equiv \frac{\lambda}{\Delta\lambda}$$

$$R = Nm$$

$R$ : poder resolvente

$N$ : numero de linhas  
(iluminadas) da rede

$m$ : ordem

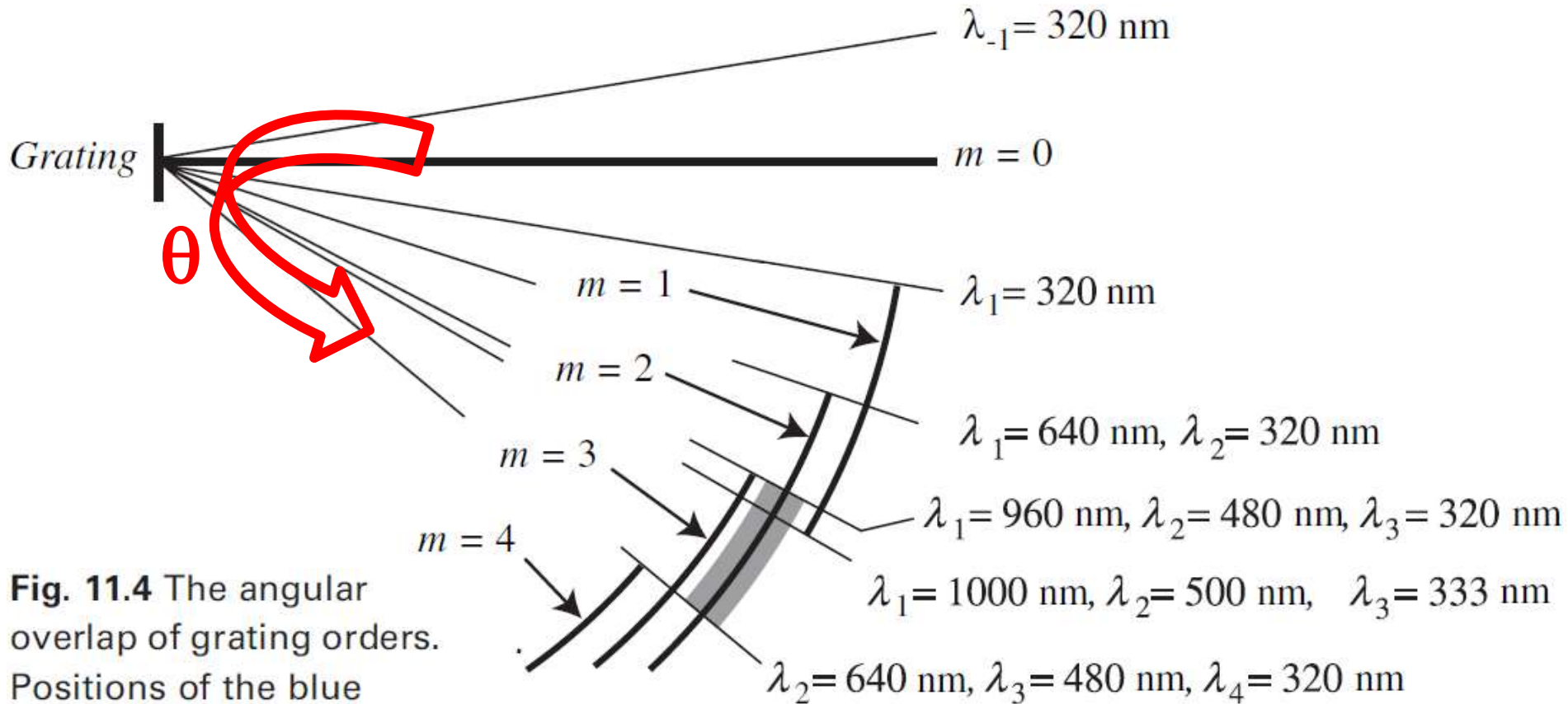
Exemplo: rede 600 linhas/mm e largura de 100mm.

$$N = 600 * 100 = 60000$$

Para ordem  $m=1$ ,

$$R(\text{máximo}) = 60\ 000$$

# Superposição angular de ordens da rede



**Fig. 11.4** The angular overlap of grating orders. Positions of the blue edges (taken to be at 320 nm) of orders  $-1$  through  $+4$  are shown. The thick gray arc shows the free spectral range of the second order, assuming  $\lambda_{\text{max}} = 640 \text{ nm}$ .

$$\sin \theta = m\lambda/\sigma - \sin \alpha$$

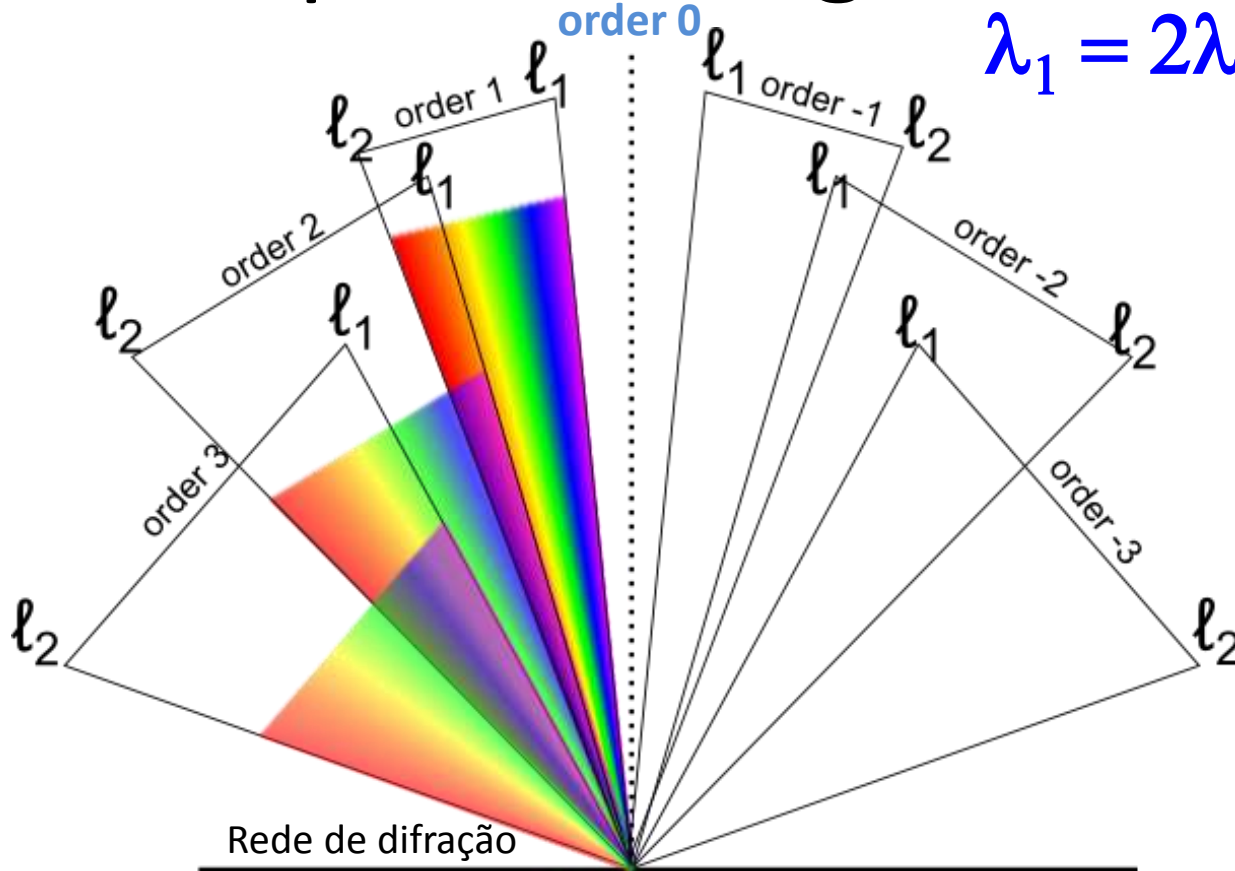
$$\lambda_1 = 2\lambda_2 = 3\lambda_3 = \dots = m\lambda_m$$

$$\lambda_m = \lambda_1 / m$$

# Free spectral range

$$\sin \theta = m\lambda/\sigma - \sin \alpha$$

$$\lambda_1 = 2\lambda_2 = 3\lambda_3 = \dots = m\lambda_m$$



Por exemplo, teríamos o mesmo ângulo  $\theta$  para

$$\lambda_1 = 8000 \text{ \AA}$$

$$\lambda_2 = 4000 \text{ \AA}$$

$$\lambda_3 = 2666 \text{ \AA}$$

...

$$\lambda_m = \lambda_1/m$$

$$\lambda_{m+1} = \lambda_1/(m+1)$$

$$(m+1) \lambda_{m+1} = m \lambda_m$$

$$\lambda_{m+1} = \frac{m}{(m+1)} \lambda_m$$

# Exemplo

$$\lambda_{m+1} = \frac{m}{(m+1)} \lambda_m$$

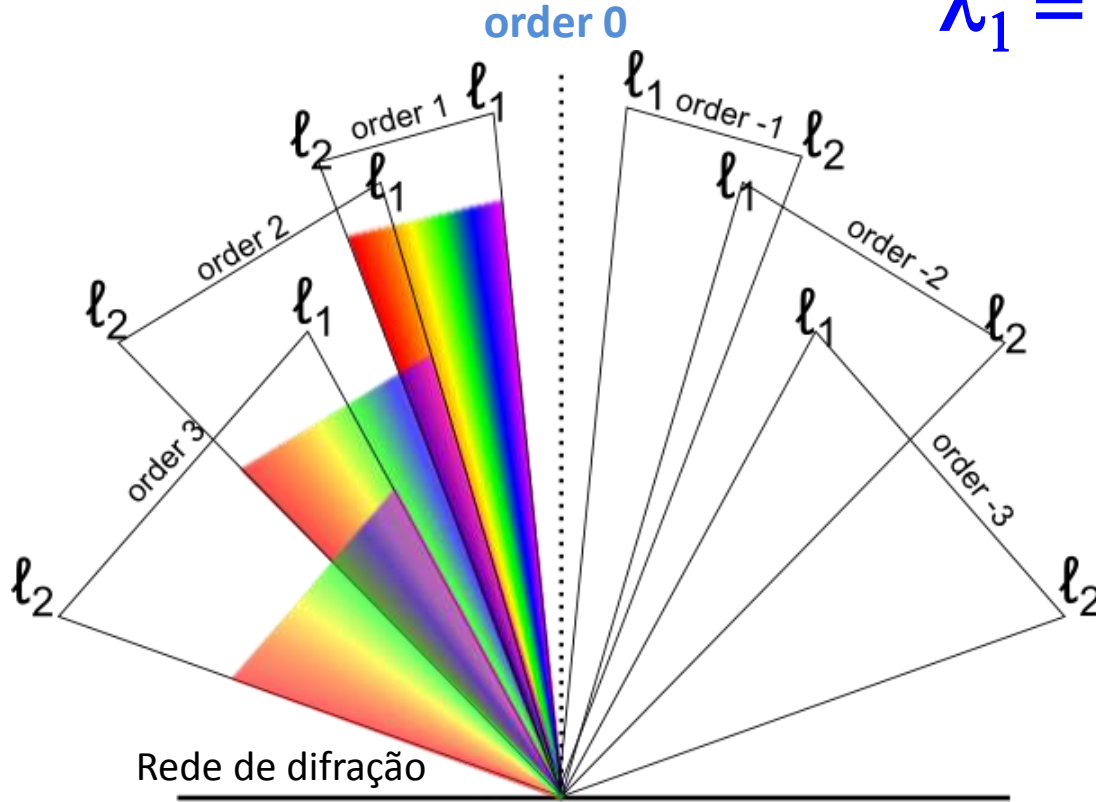
- Para o comprimento de onda 480nm em segunda ordem, qual o comprimento de onda de superposição da terceira ordem?
- *Método 1:*
- $\lambda_2 = 480\text{nm}$
- $\lambda_3 = \lambda_{2+1} = 480\text{nm} * 2/(2+1) = 320\text{nm}$
- *Método 2:*
- $\lambda_2 = 480\text{nm}$ . Como  $\lambda_2 = \lambda_1/2$ , então  $\lambda_1 = 960\text{nm}$
- $\lambda_3 = \lambda_1/3 = 320\text{nm}$



# Cobertura “pratica” de uma ordem

$$\sin \theta = m\lambda/\sigma - \sin \alpha$$

$$\lambda_1 = 2\lambda_2 = 3\lambda_3 = \dots = m\lambda_m$$



Se queremos observar máximo em  $\lambda = \lambda_{\max}$ , qual o  $\lambda$  da seguinte ordem que afetara meus dados ?

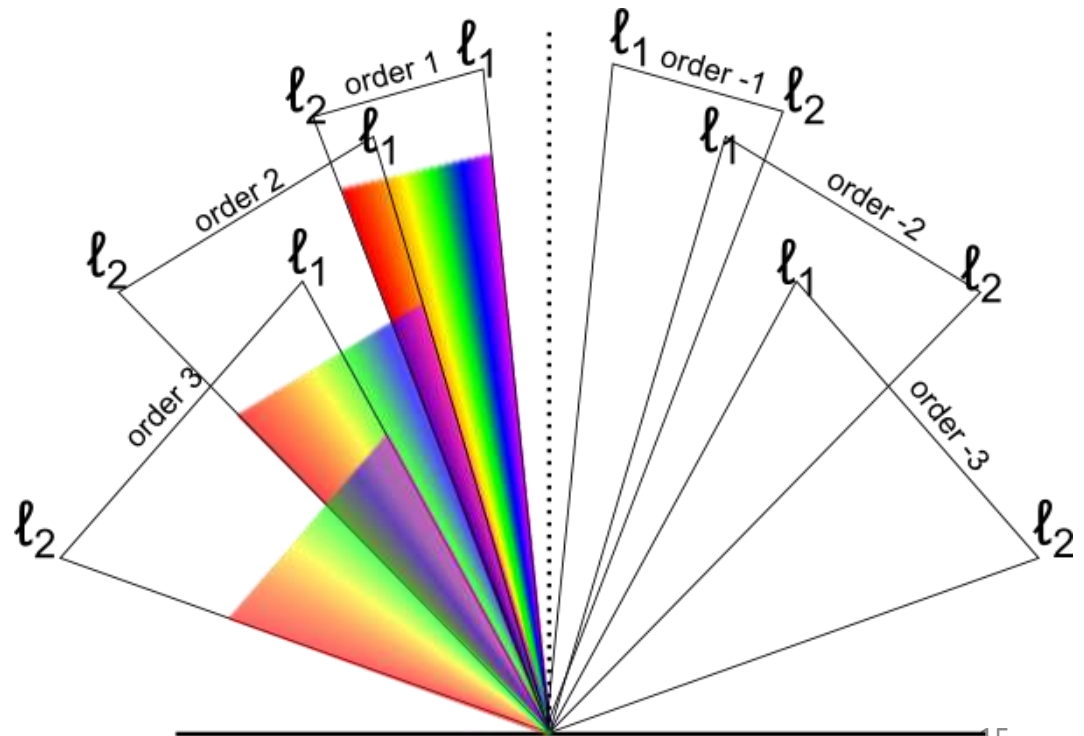
$$\lambda_{m+1} = \frac{m}{(m+1)} \lambda_m$$

$$\lambda_{m+1} = \frac{m}{(m+1)} \lambda_{\max}$$

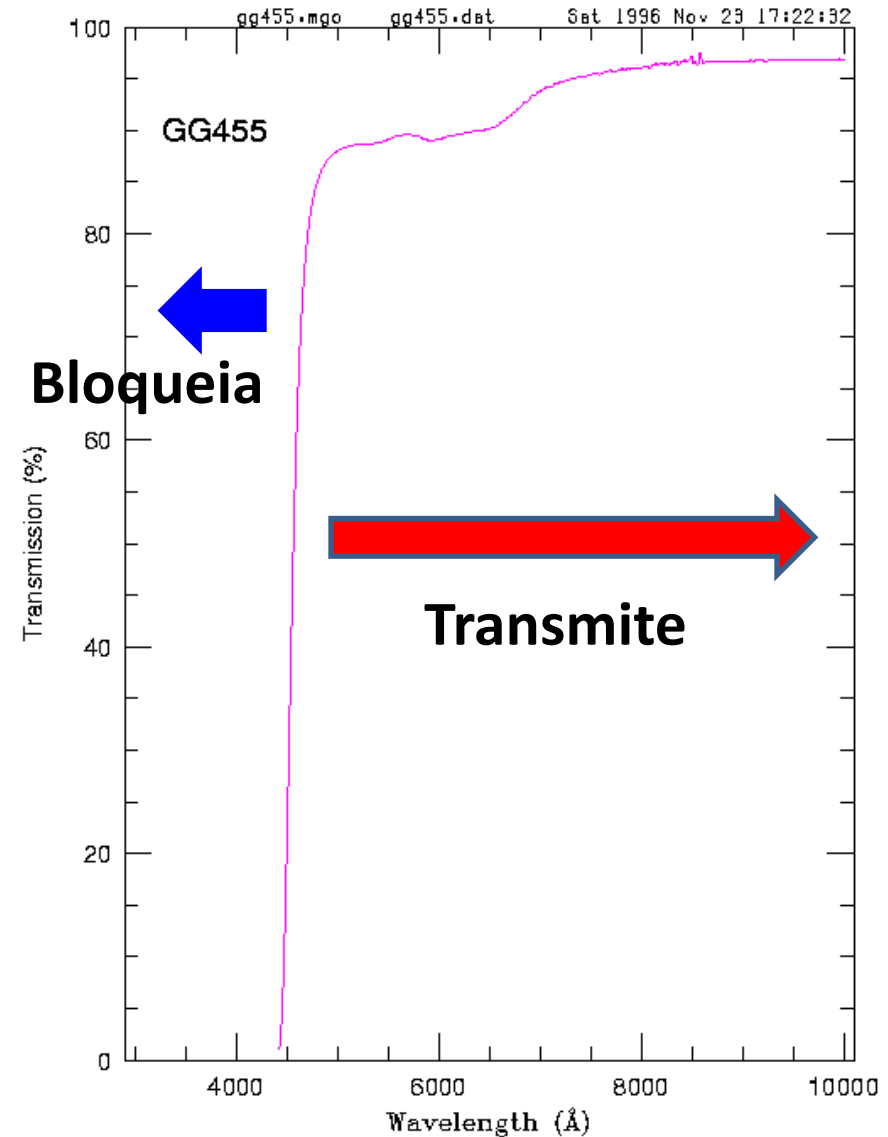
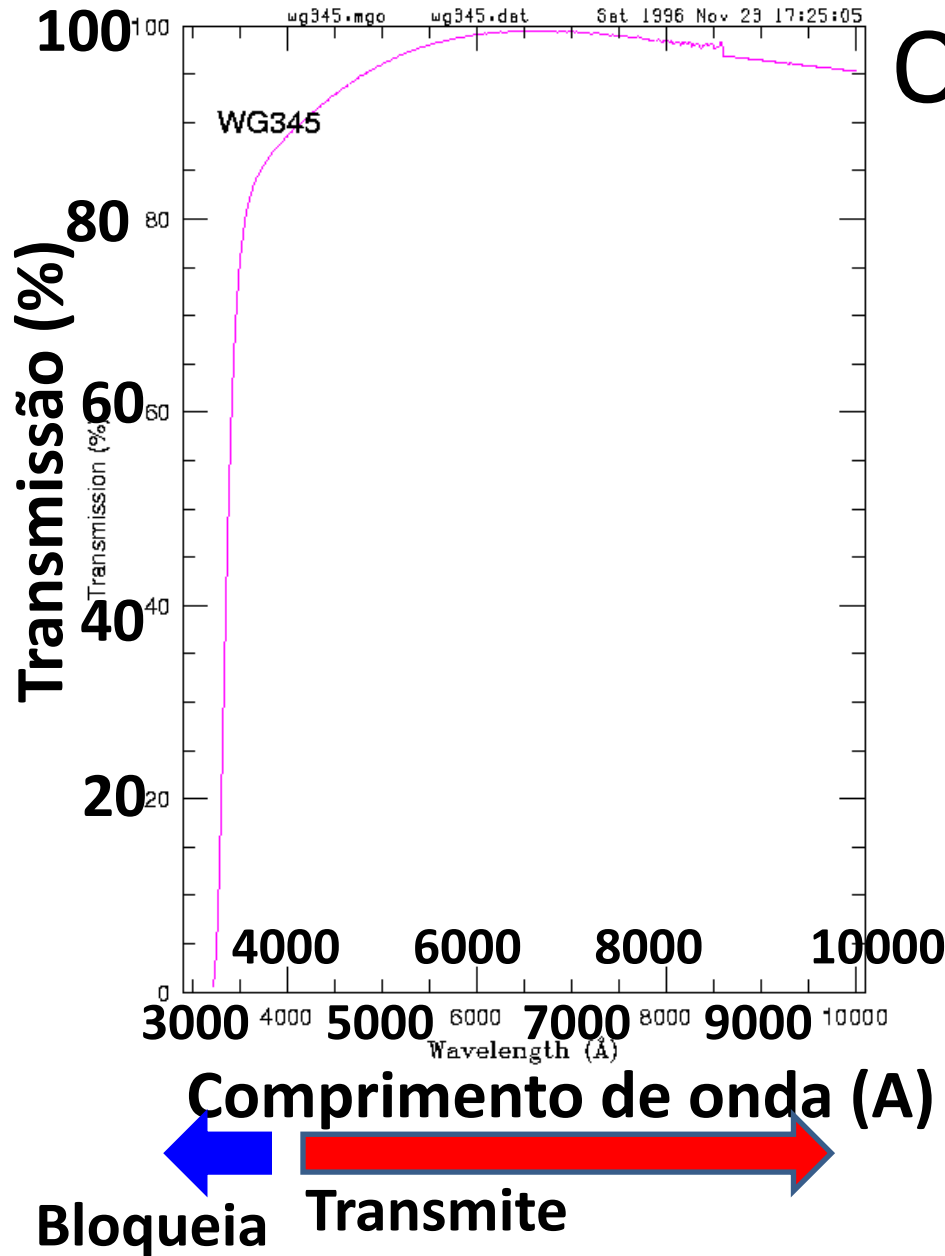
Por exemplo, para  $\lambda_{\max} = 9000 \text{ \AA}$  na 1a ordem teremos contaminação para  $\lambda = 4500 \text{ \AA}$  da 2a ordem. Introduzindo um filtro para bloquear  $\lambda < 4500 \text{ \AA}$ , podemos observar em 4500-9000  $\text{\AA}$ .

# Filtros

- Espectrógrafos que usam prismas não precisam de filtros
- Espectrógrafos que usam redes de difração podem precisar filtros para bloquear a luz de outras ordens



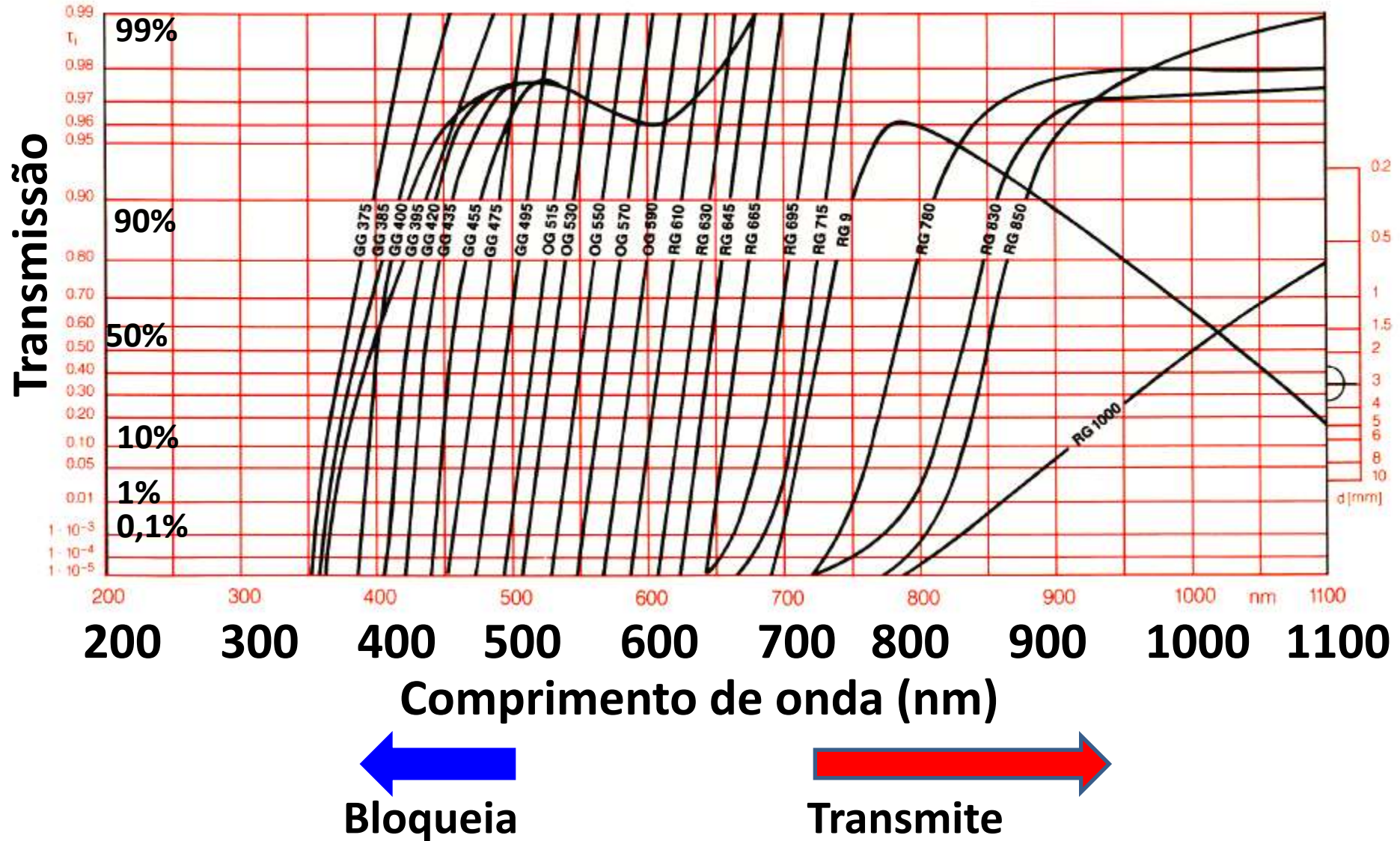
# Order blocking filters



Exemplos do 1.5-m R-C Spectrograph:

<http://www.ctio.noao.edu/spectrographs/60spec/filters.html>

# Order blocking filters

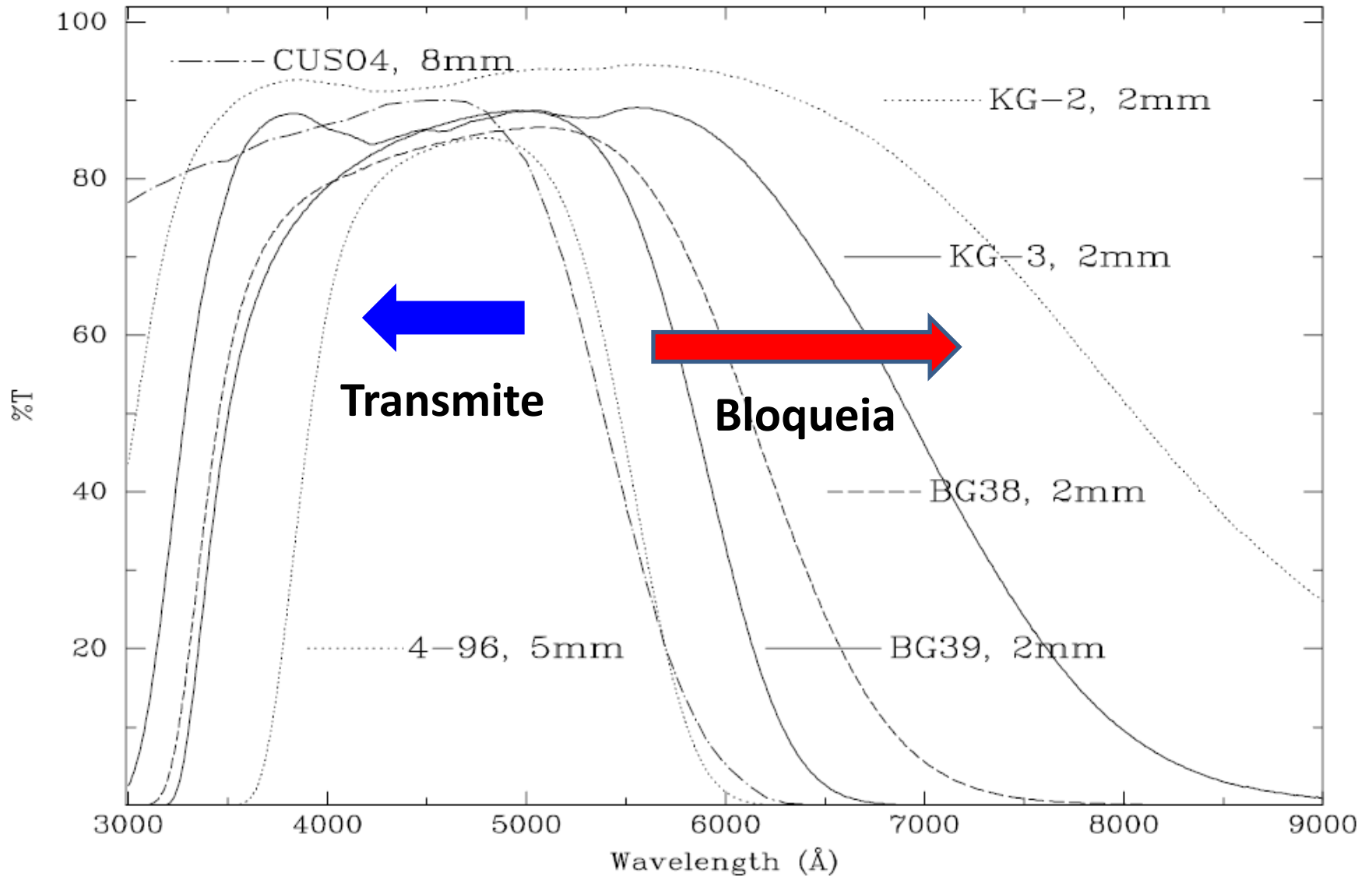


Exemplo:  
Filtros para  
espectrógrafo  
Cassegrain do  
OPD  
(corte no  
azul)

Filtro - Espessura	Corte (1) Verm/Azul	$\lambda_{\text{Corte}} (\sim 1\%)$ (nm)	$\lambda_{\text{Transição}} (\sim 90\%)$ (nm)
RG780-3	Azul	750	815
RG9-3	Azul	705	750
RG715-3	Azul	695	730
RG695-3	Azul	675	715
RG645-3	Azul	630	665
RG610-3	Azul	595	625
OG590-2	Azul	575	600
OG570-3	Azul	555	580
OG550-2	Azul	530	565
OG530-2	Azul	510	545
OG515-3	Azul	500	530
GG495-2	Azul	475	510
GG475	Azul	460	490
GG435-2	Azul	425	450
GG385-1	Azul	355	400



# Red blocking filters



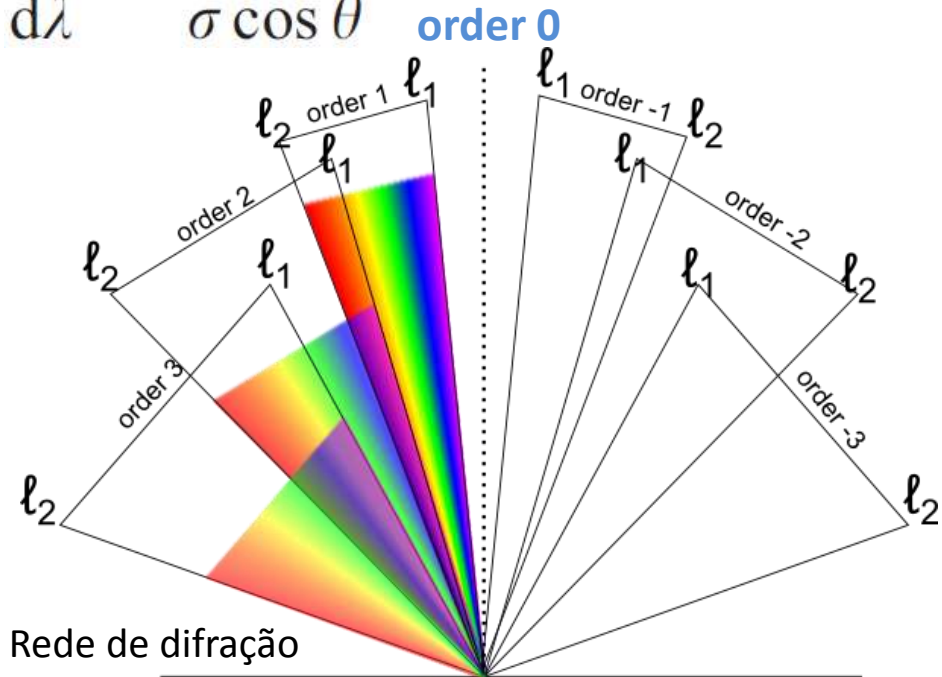
# Exemplo:

Filtros para espectrógrafo Cassegrain do OPD (corte no vermelho)

Filtro - Espessura	Corte (1) Verm/Azul	$\lambda_{\text{Corte}} (\sim 1\%)$ (nm)	$\lambda_{\text{Transição}} (\sim 90\%)$ (nm)
BG38-3 (2)	Vermelho	725	535
BG39-1 (2)	Vermelho	705	555
BG18 (2)	Vermelho	700	525
BG28-1 (2,3)	Vermelho	645	460 (80%)
BG23-3 (2)	Vermelho	625	480 (80%)
BG25-3 (2,3)	Vermelho	500	400 (85%)
BG12-1 (2,3)	Vermelho	540	400
UG11-1 (3)	Vermelho	400	350
UG1-1 (2,3)	Vermelho	415	365 (85%)

# Free spectral range ( $\Delta\lambda_{\text{FSR}}$ )

$$\frac{d\theta}{d\lambda} = \frac{m}{\sigma \cos \theta}$$



A faixa espectral livre (free spectral range : FSR) é a cobertura em  $\lambda$  não bloqueiada pelo filtro

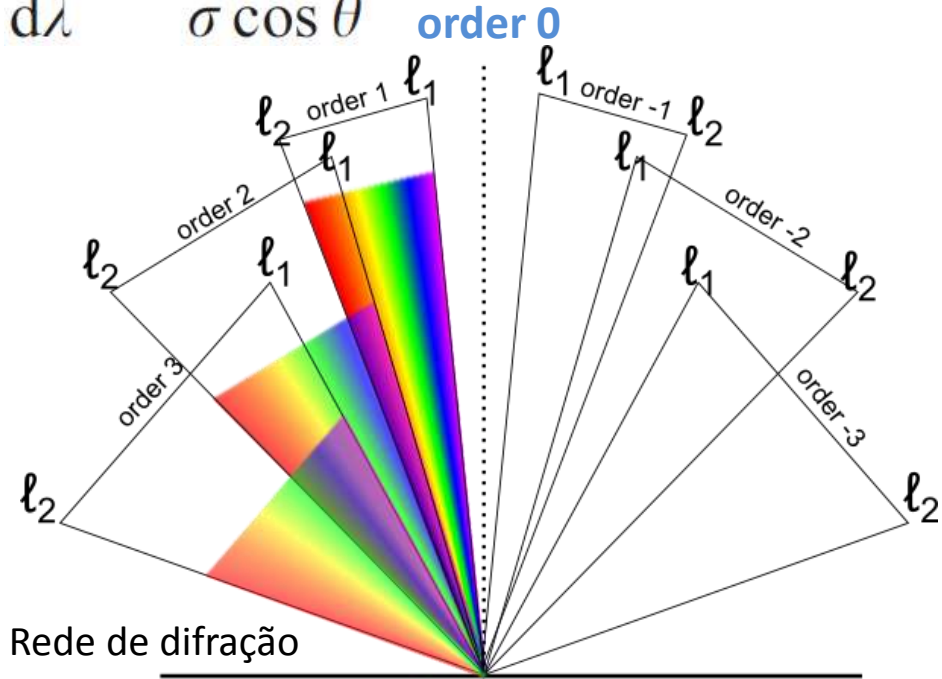
Lambda mínimo:

$$\lambda_{m+1} = \frac{m}{(m+1)} \lambda_{\text{max}}$$

$$\Delta\lambda_{\text{FSR}} = \lambda_{\text{max}} - \frac{m}{(m+1)} \lambda_{\text{max}} = \frac{\lambda_{\text{max}}}{(m+1)}$$

# Faixa espectral livre ( $\Delta\lambda_{\text{FSR}}$ )

$$\frac{d\theta}{d\lambda} = \frac{m}{\sigma \cos \theta}$$



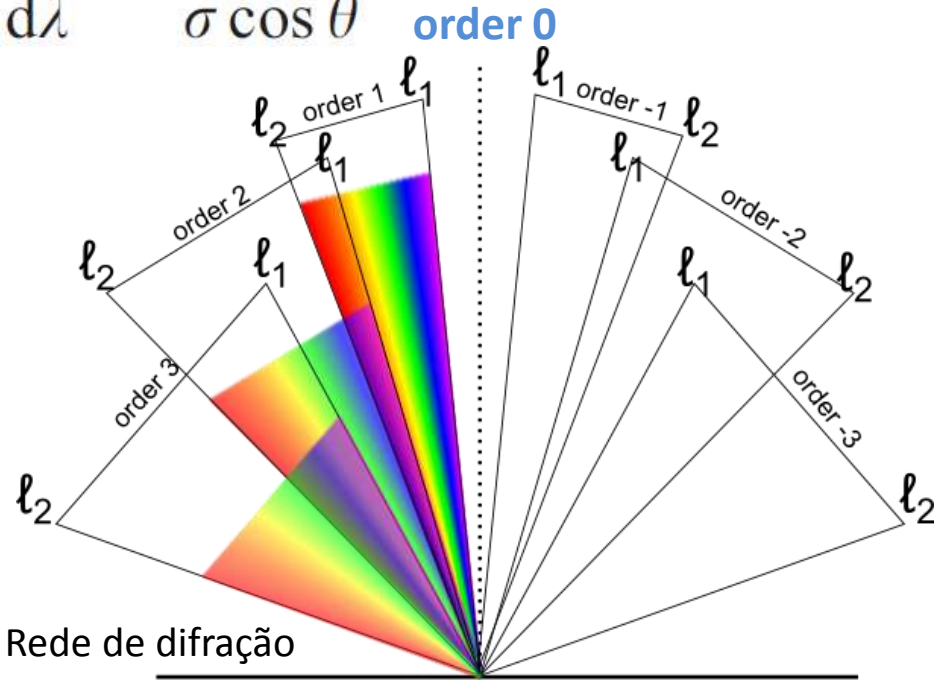
$$\Delta\lambda_{\text{FSR}} = \frac{\lambda_{\text{max}}}{(m + 1)}$$

**Exemplo:** para  $\lambda_{\text{max}} = 900\text{nm}$  na 1a ordem  
teremos  $\Delta\lambda_{\text{FSR}} = 450\text{nm}$ .

Isto é, podemos observar de 450 - 900 nm  
(será necessário bloqueiar  $\lambda < 450\text{nm}$ )

# Faixa espectral livre ( $\Delta\lambda_{\text{FSR}}$ )

$$\frac{d\theta}{d\lambda} = \frac{m}{\sigma \cos \theta}$$



$$\Delta\lambda_{\text{FSR}} = \frac{\lambda_{\text{max}}}{(m + 1)}$$

**Exemplo:** para  $\lambda_{\text{max}} = 900\text{nm}$  na 2a ordem  
teremos  $\Delta\lambda_{\text{FSR}} = 300\text{nm}$ .

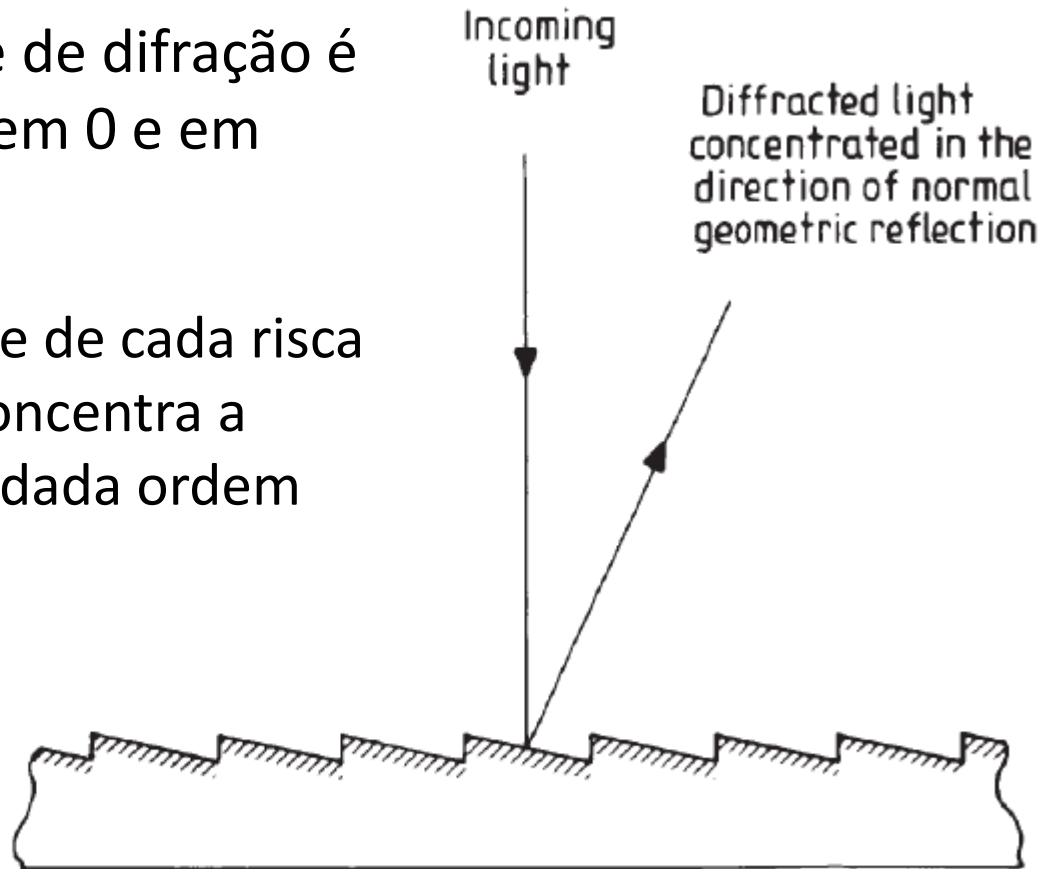
Isto é, podemos observar de 600 - 900 nm  
(será necessário bloqueiar  $\lambda < 600\text{nm}$ )



# Blazed gratings (redes com blazing)

Uma desvantagem da rede de difração é que a luz é perdida na ordem 0 e em outras ordens.

Nas redes com blazing a face de cada risca tem um dado ângulo que concentra a maior parte da luz em uma dada ordem



**Figure 4.1.5.** Enlarged section through a blazed reflection grating.

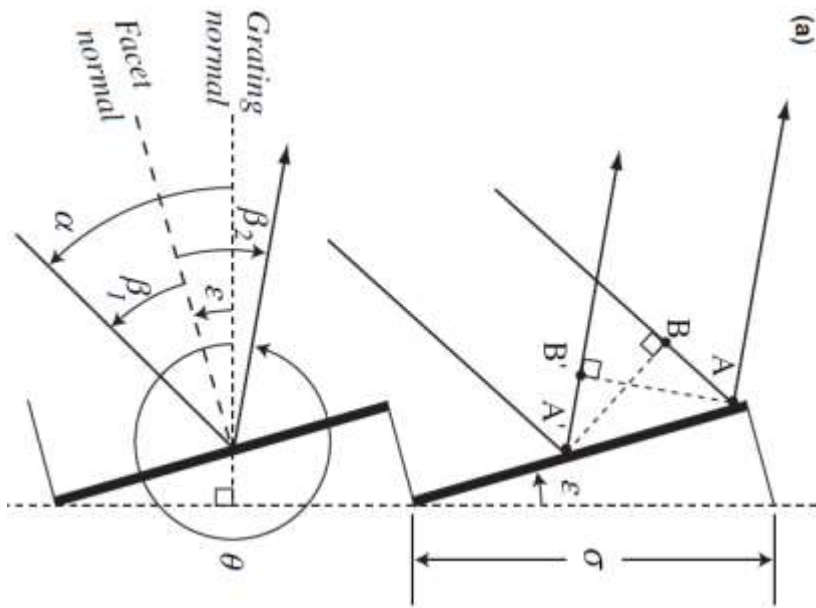
# Blazed gratings

Melhor "tilt" para ter toda a luz em uma ordem:

$$\alpha = \beta + \varepsilon$$

$$\theta = 2\pi + \varepsilon - \beta$$

$$\alpha + \theta = 2\varepsilon$$



grating equation, (11.2), but

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

$$\beta + \varepsilon = \alpha \text{ and } (\varepsilon - \beta) = \theta$$

$$\sin(\varepsilon - \beta) + \sin(\beta + \varepsilon) = m\lambda/\sigma$$

No livro "To Measure the Sky" é  $\alpha$ , mas está errado

$$\sin \varepsilon \cos \beta - \sin \beta \cos \varepsilon + \sin \varepsilon \cos \beta + \sin \beta \cos \varepsilon = m\lambda/\sigma$$

$$2 \sin \varepsilon \cos \beta = m\lambda/\sigma$$

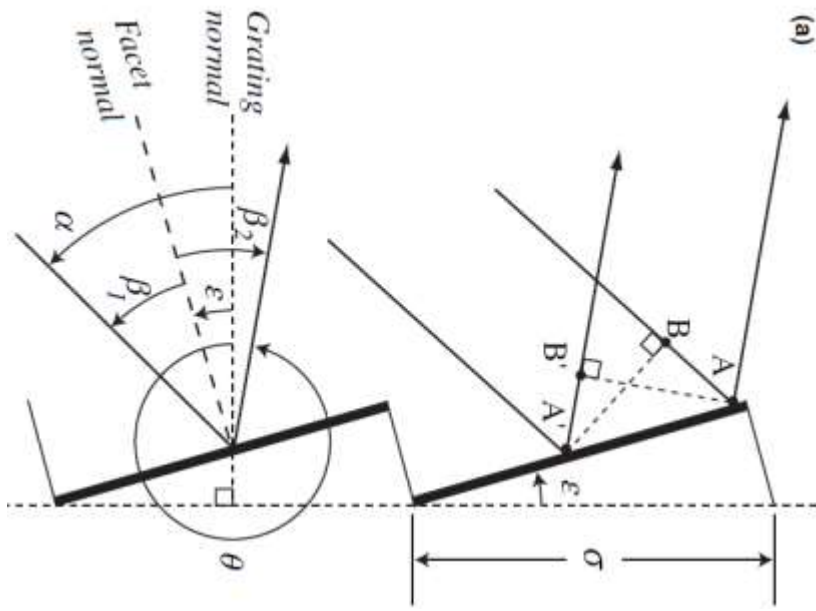
# Blazed gratings

Melhor “tilt” para ter toda a luz em uma ordem:

$$\alpha = \beta + \varepsilon$$

$$\theta = 2\pi + \varepsilon - \beta$$

$$\alpha + \theta = 2\varepsilon$$



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$$2 \sin \varepsilon \cos \beta = m\lambda/\sigma$$

$$\lambda = 2\sigma \sin \varepsilon \cos \beta / m$$

$$\lambda_b = \frac{2\sigma}{m} \sin(\varepsilon) \cos(\alpha - \varepsilon)$$

$\lambda_b$  : comprimento de onda do *blazing*

# Exemplo

Diffraction  
Gratings  
available for LCS

Gratings are blazed for use  
in first order.

grating number	lines/mm	blaze (Å)	effective blaze (Å)	dispersion $\lambda$ / one- pixel $\Delta\lambda$ (TI1 CCD)
40	300	4200	3900	550
41	300	7500	6000	550
42	300	10000	9200	550
43	600	4000	3700	1100
44	600	7500	6900	1100
45	600	10000	9200	1100
46	1200	4000	3700	2200
47	1200	6000	5500	2200
48	1200	7500	6900	2200

# Exemplo: redes do Cassegrain/OPD

Rede <sup>(1)</sup> l/mm – blaze(nm)	Ângulo Blaze (graus,min)	$\lambda^{(2)}$ de Blaze (nm) <i>blaze efetivo</i>	Dispersão <sup>(3)</sup> (nm/mm)	Resolução (FWHM, nm)
Lna 0300-300 <sup>(4)</sup>	02° 30'	275	19,6	0,90
Lna 0300-500	04° 18'	455	19,4	0,90
Lna 0300-640	05° 31'	580	19,2	0,90
Lna 0300-1000	08° 38'	910	18,5	0,45
Lna 0600-500	08° 36'	455	9,25	0,45
Lna 0830-820 <sup>(4)</sup>	19° 42'	740	5,89	0,31
Lna 0900-550	14° 20'	500	5,73	0,26
Lna 1200-400	13° 53'	365	4,24	0,18
Lna 1200-500	17° 21'	455	4,09	0,18
Lna 1200-600	21° 00'	545	3,85	0,18
Lna 1200-750 <sup>(4)</sup>	26° 42'	680	3,48	0,18

# Cobertura útil devido à eficiência do blazing

A eficiência máxima é para  $\lambda_b$ , com a eficiência decrescendo a 50% para aproximadamente:

- $\lambda_{\text{inferior}} = 2/3 \lambda_b$
- $\lambda_{\text{superior}} = 3/2 \lambda_b$

Exemplo,  $\lambda_b = 6000 \text{ \AA}$ , então podemos cobrir com eficiência  $> 50\%$  (da eficiência máxima):  
4000 – 9000  $\text{\AA}$ .



# Important points

1. Due to blazing, the grating is optimized for a particular region of the spectrum (although you can observe different regions using different gratings).
2. Devido à superposição de diferentes ordens a cobertura espectral é limitada ao free spectral range ( $\Delta\lambda_{\text{FSR}}$ ).
3. Diversos elementos (e.g. CCD) podem ser otimizados para uma determinada região espectral



É complicado cobrir todo o espectro “visível” (300-1000nm) com apenas um espectrógrafo



“Double spectrograph” 😊

# Espectrógrafo doble (2 braços)

PUBLICATIONS OF THE ASTRONOMICAL SOCIETY OF THE PACIFIC

94:586-594, June 1982

AN EFFICIENT LOW- AND MODERATE-RESOLUTION SPECTROGRAPH  
FOR THE HALE TELESCOPE

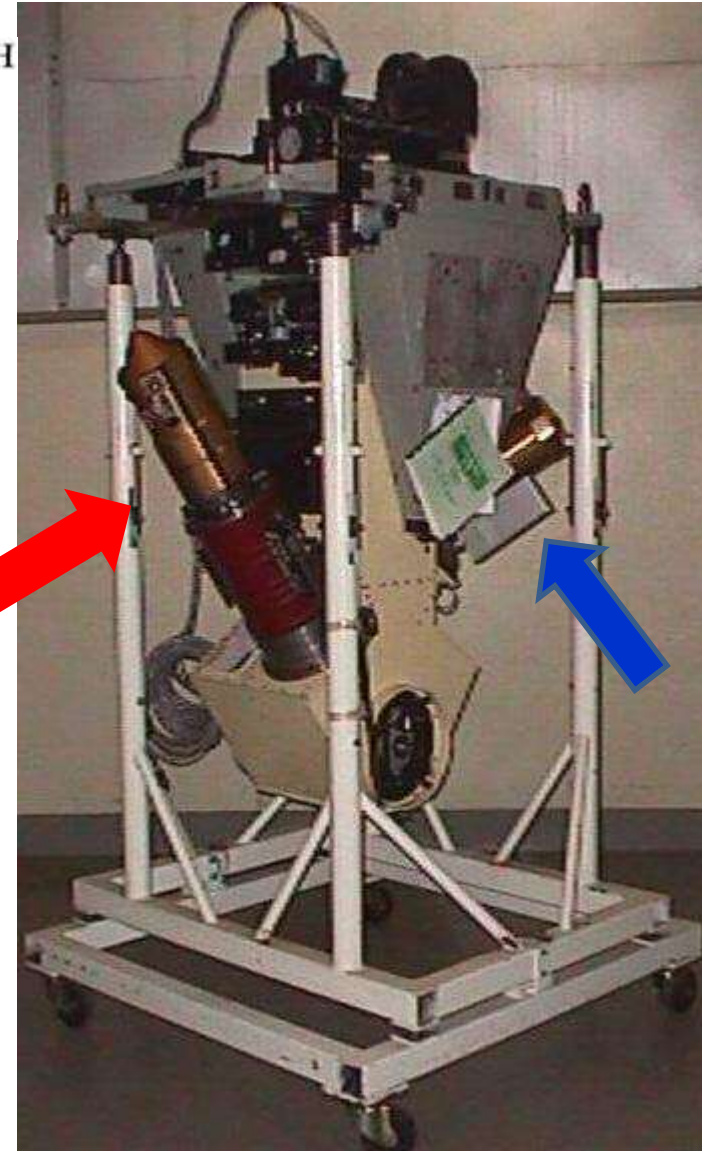
J. B. OKE AND J. E. GUNN\*

Palomar Observatory, California Institute of Technology, Pasadena, California 91125

Double spectrograph para o telescópio  
Palomar (5m).

O lado **VERMELHO** cobre 550-1000 nm

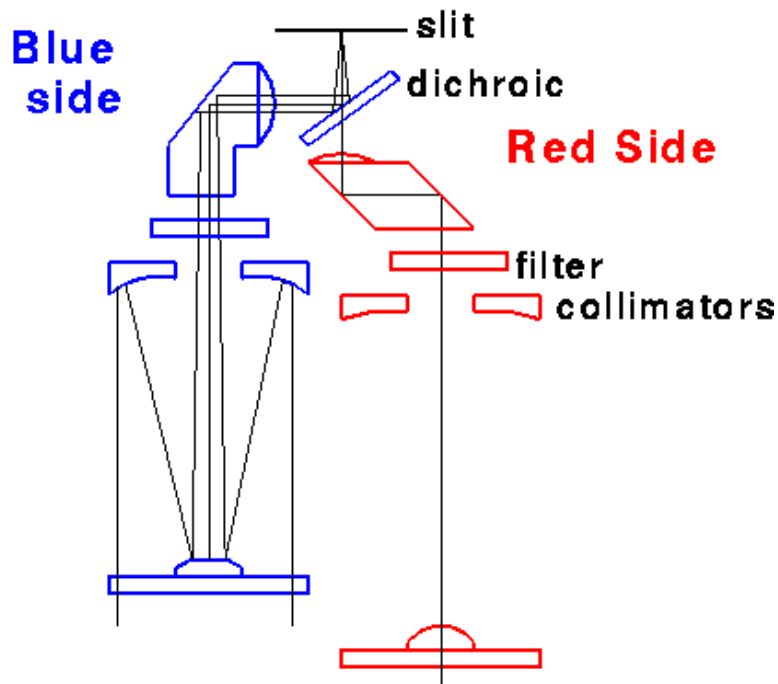
O lado **AZUL** é otimizado para 300-550 nm



# Dichroics : dividem a luz para os braços do espectrógrafo múltiplo

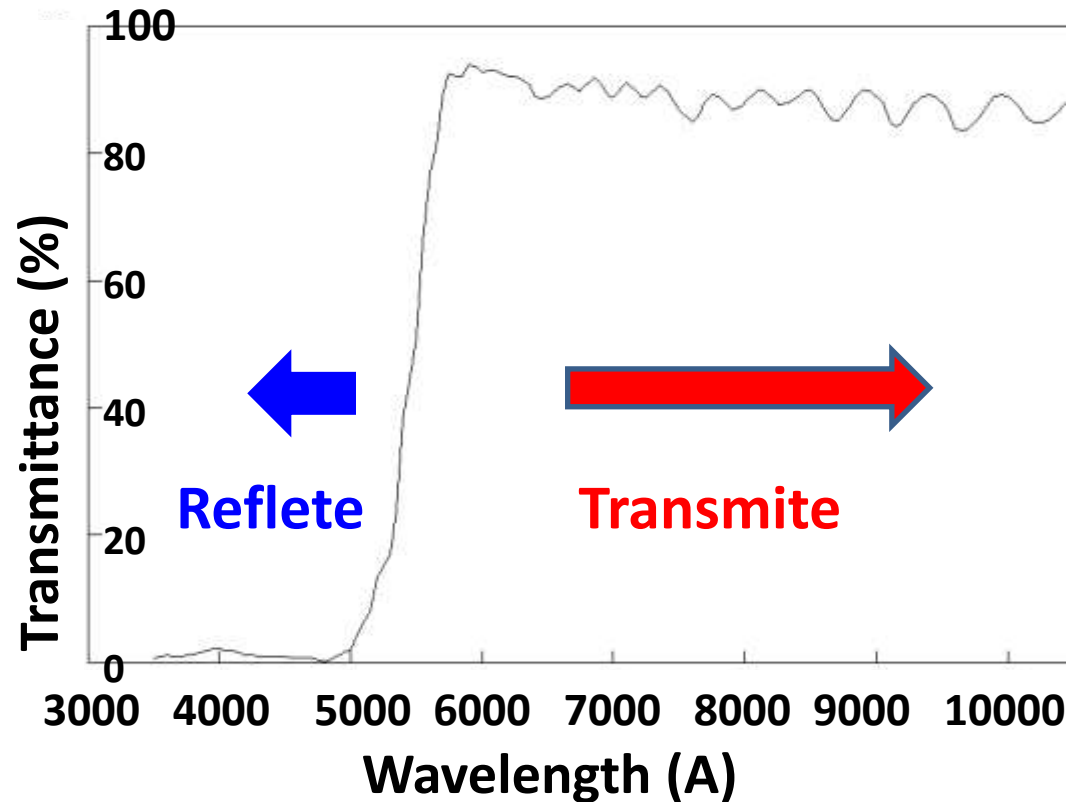
espelhos refletem um intervalo espectral e transmitem em outro

Exemplo : Palomar Double Spectrograph



Upper portion of Double Spectrograph (after Oke and Gunn, 1982)

Dichroic D55



# Gratings for the Palomar double spectrograph

(F) GRATING SPECS (lines/mm, blaze, dispersion) **R ~ 1,000 to 10,000**

---

lines/mm	1st Order Blaze (Å)	Useful Range (Å) (to blaze 1/2- intensity)	Red Camera Dispersion (Å/mm)	Blue Camera Dispersion (Å/mm)
158 [a]	7560	5000-11300	201 1st [c]	135 2nd [d]
300 [b]	3990	2700-6000	-	140 1st
316 [a]	7150	4800-10700	102 1st	-
600 [b]	3780	2500-5700	-	71 1st
600 [a]	9500	6300-14300	54 1st	-
1200 [b]	4700	3100-7100	-	36 1st
1200	7100	4700-10700	27 1st	36 1st
1200	9400	6300-14100	26 1st	35 1st

## NOTE:

"Useful Range" gives the wavelength limits at which diffracted intensity drops to 1/2 of its peak value (2/3 and 3/2 of the blaze wavelength, by a common rule of thumb).

[a] silver coating...can be used only longward of 3500 Å.

[b] can be used only in blue spectrograph.

[c] first order.

[d] second order.

# X-shooter no VLT/ESO

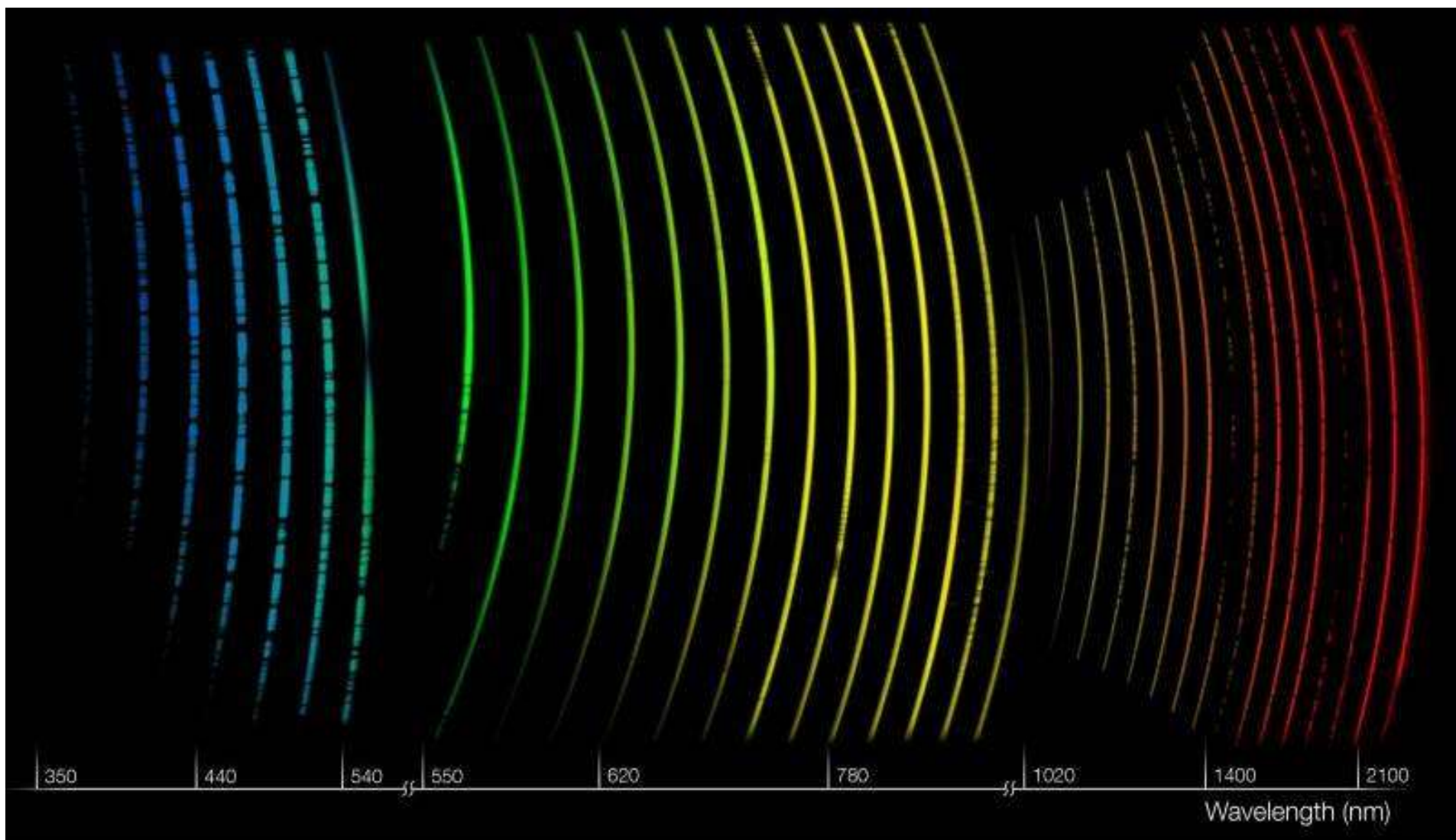
3 braços: 300 – 2500nm

*oferecido desde 2009*

UVB, covering 300-559.5 nm

VIS, covering 559.5-1024 nm

NIR, covering 1024-2480 nm



# Dispersão **linear** do espectro (válido para prismas e redes de difração)

Dispersão angular do prisma

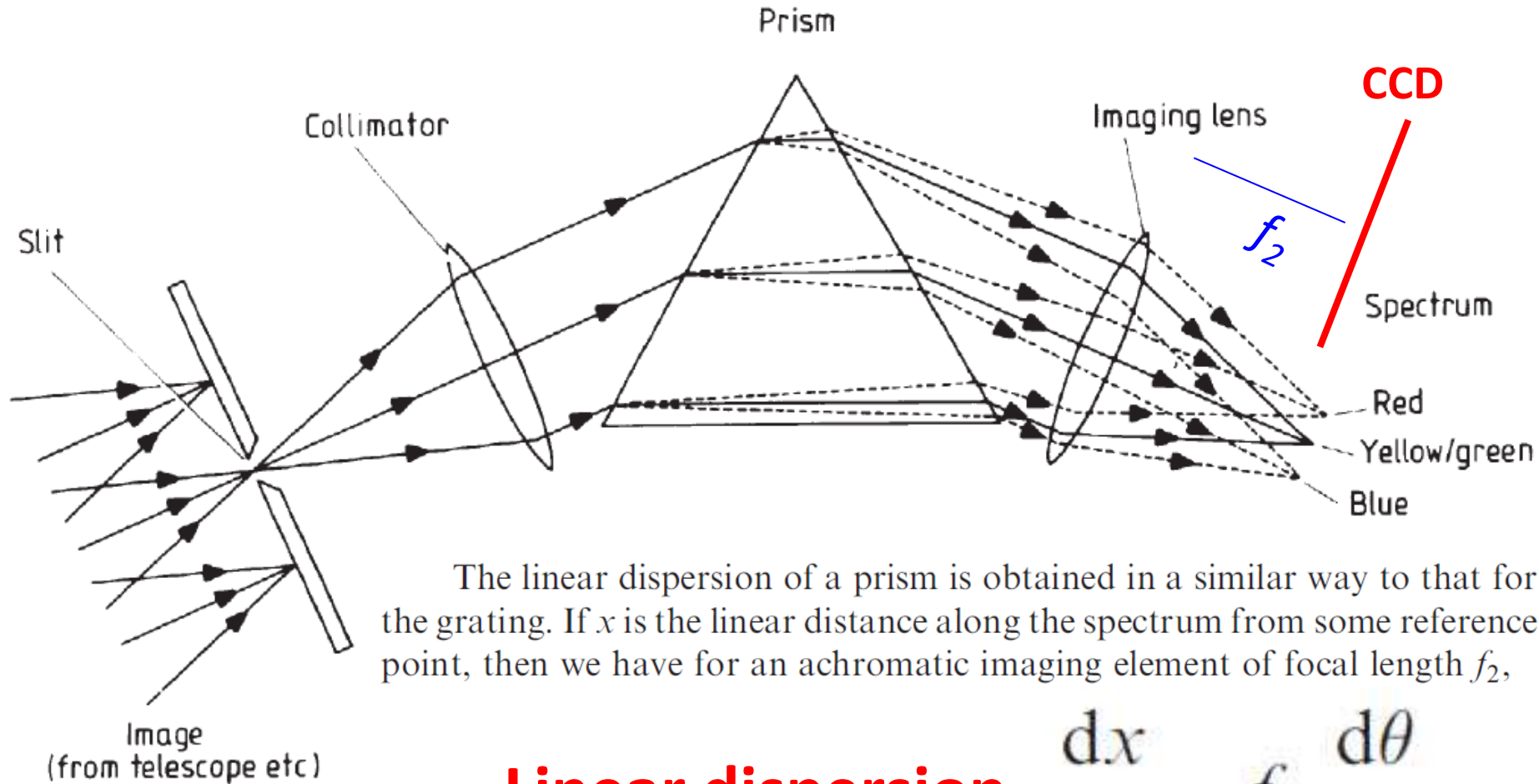
$$\frac{d\theta}{d\lambda} \approx \frac{-180AB}{\pi(\lambda - C)^2} \quad \circ \text{ m}^{-1}$$

Dispersão angular da rede

$$\frac{d\theta}{d\lambda} = \frac{m}{\sigma \cos \theta}$$



# Dispersão linear $dx/d\lambda$



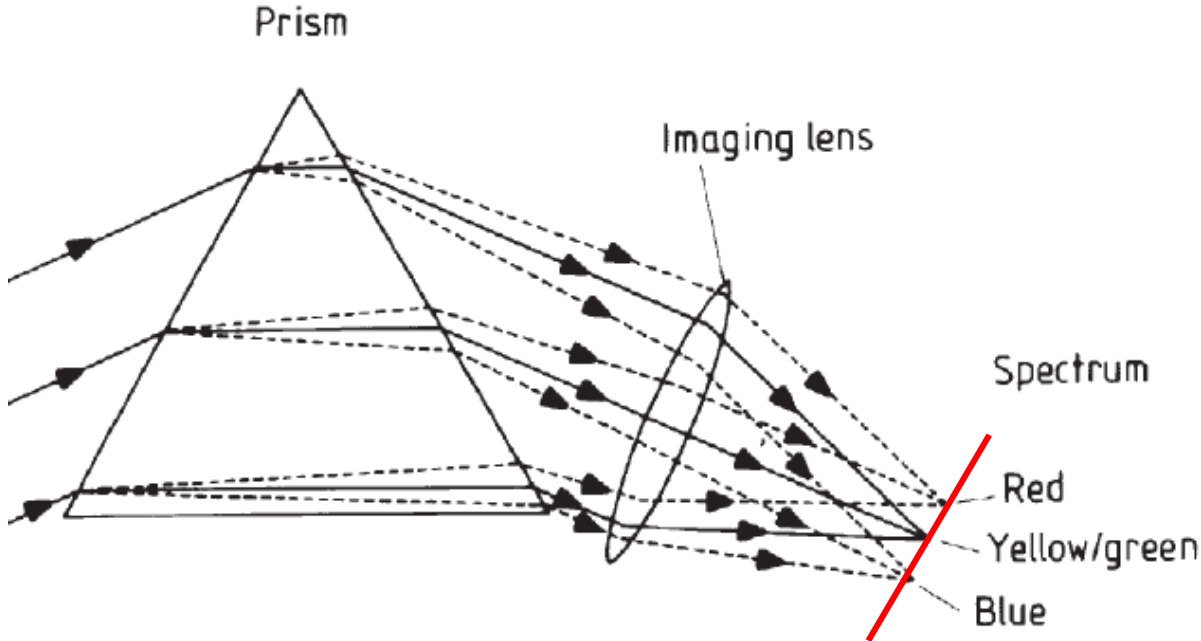
The linear dispersion of a prism is obtained in a similar way to that for the grating. If  $x$  is the linear distance along the spectrum from some reference point, then we have for an achromatic imaging element of focal length  $f_2$ ,

**Linear dispersion**

$$\frac{dx}{d\lambda} = f_2 \frac{d\theta}{d\lambda}$$

Figure 4.1.12. Basic optical

# Example for $\alpha = 60^\circ$



apex angle of  $60^\circ$   
 $1.39 \times 10^7 \text{ }^\circ \text{ m}^{-1}$

$$\frac{d\theta}{d\lambda} \approx \frac{-180AB}{\pi(\lambda - C)^2} \text{ }^\circ \text{ m}^{-1}$$

Valor típico para  
 $d\theta/d\lambda = 1,39 \times 10^7 \text{ }^\circ \text{ m}^{-1}$

**Qual o  $d\theta$  para  $d\lambda = 1 \text{ \AA}$  ?**

$$d\theta = 1,39 \times 10^7 \times 1 \times 10^{-10} \text{ }^\circ$$

$$d\theta = 1,39 \times 10^{-3} \text{ }^\circ$$

$$d\theta = 5 \text{ arcsec}$$

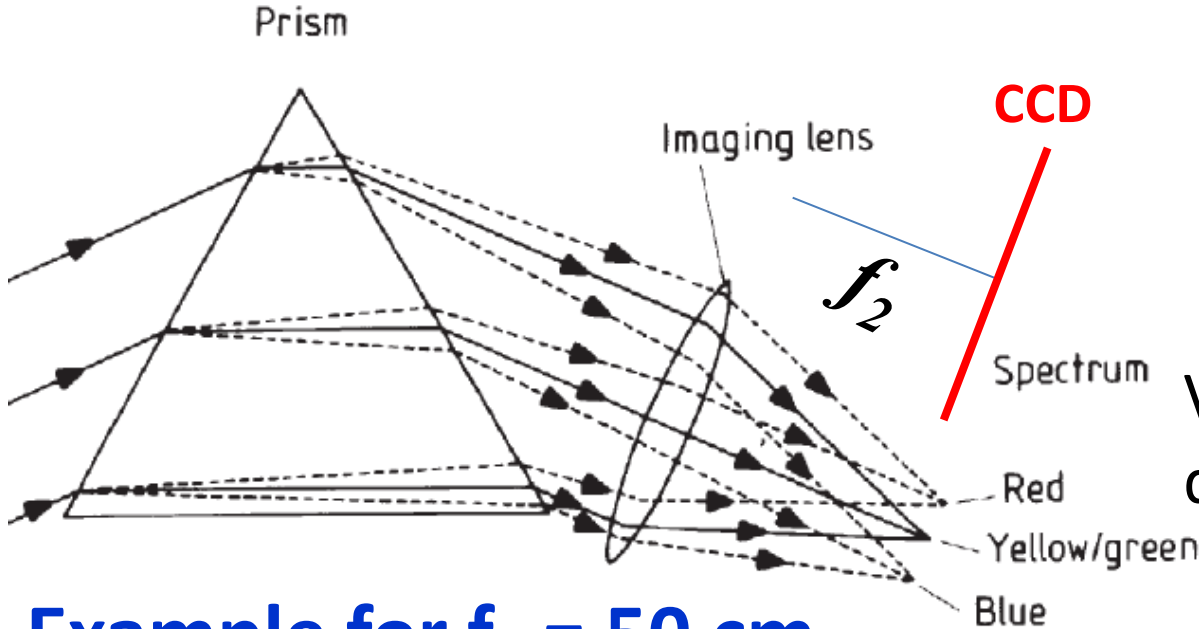
**Linear dispersion no CCD ?**

# Linear dispersion $dx/d\lambda$

Linear dispersion:

$$\frac{dx}{d\lambda} = f_2 \frac{d\theta}{d\lambda}$$

Valor típico para  
 $d\theta/d\lambda = 1,39 \times 10^7 \text{ } ^\circ\text{m}^{-1}$



Example for  $f_2 = 50 \text{ cm}$

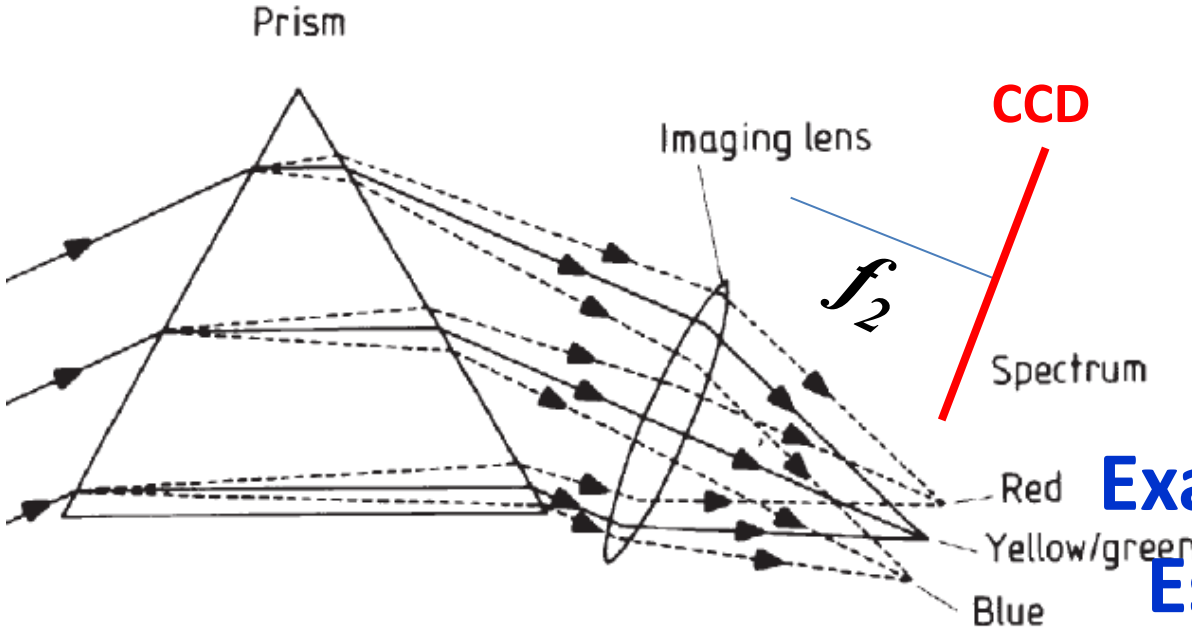
Estimate  $dx$  in  $d\lambda = 2\text{\AA}$ .

$$d\theta/d\lambda = 1,39 \times 10^7 \text{ } ^\circ\text{m}^{-1}$$

1 degree = 0,0174 radians

$$\rightarrow d\theta/d\lambda = 2,426 \times 10^5 \text{ radians m}^{-1}$$

# Linear dispersion $dx/d\lambda$



Linear dispersion:

$$\frac{dx}{d\lambda} = f_2 \frac{d\theta}{d\lambda}$$

Example for  $f_2 = 50 \text{ cm}$   
Estimate  $dx$  in  $d\lambda = 2\text{\AA}$

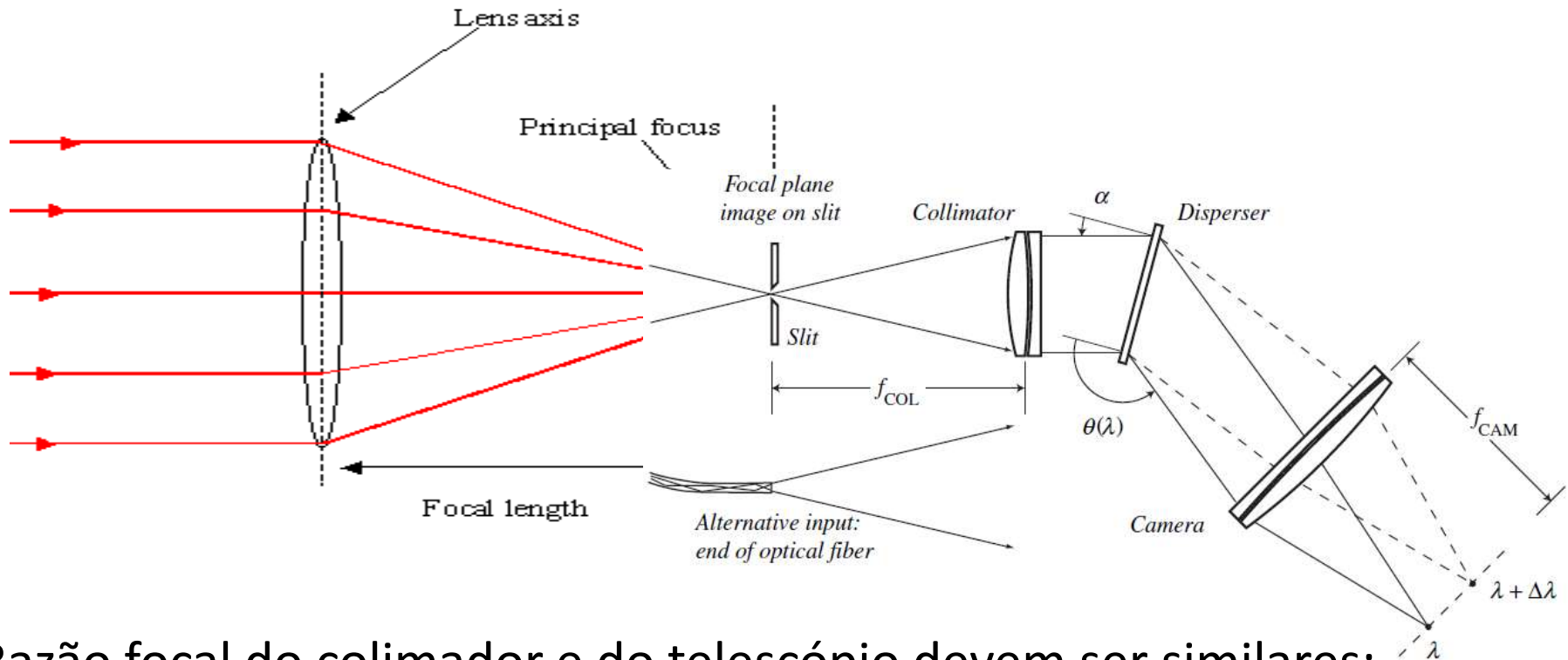
$$d\theta/d\lambda = 2,426 \times 10^5 \text{ radians m}^{-1}$$

$$dx/d\lambda = f_2 d\theta/d\lambda = 0,5\text{m} \times 2,426 \times 10^5 \text{ radians m}^{-1} \\ = 1,21 \times 10^5$$

$$dx = d\lambda \times 1,21 \times 10^5 = 2\text{\AA} \times 1,21 \times 10^5 \\ = 2,42 \times 10^5 \times 10^{-4} \mu\text{m}$$

$dx = 24 \mu\text{m}$ . Se o pixel for de  $12 \mu\text{m}$ , cabem 2 pixels

# Disenho básico de espectrógrafos



Razão focal do colimador e do telescópio devem ser similares:

$$\frac{f_{COL}}{D_{COL}} \approx \frac{f_{TEL}}{D_{TEL}}$$

# Properties of the basic spectrograph

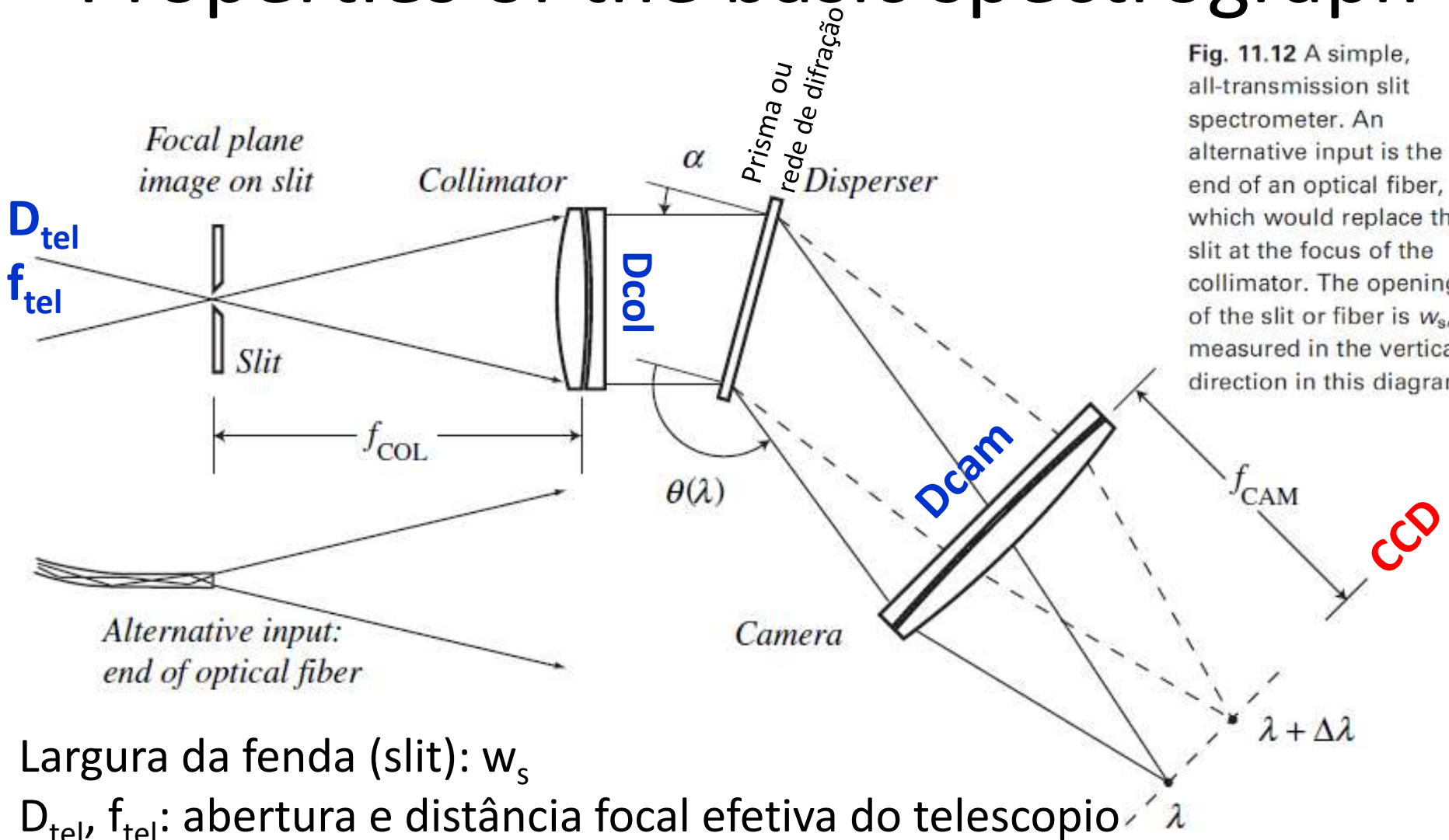


Fig. 11.12 A simple, all-transmission slit spectrometer. An alternative input is the end of an optical fiber, which would replace the slit at the focus of the collimator. The opening of the slit or fiber is  $w_s$ , measured in the vertical direction in this diagram.

Largura da fenda (slit):  $w_s$

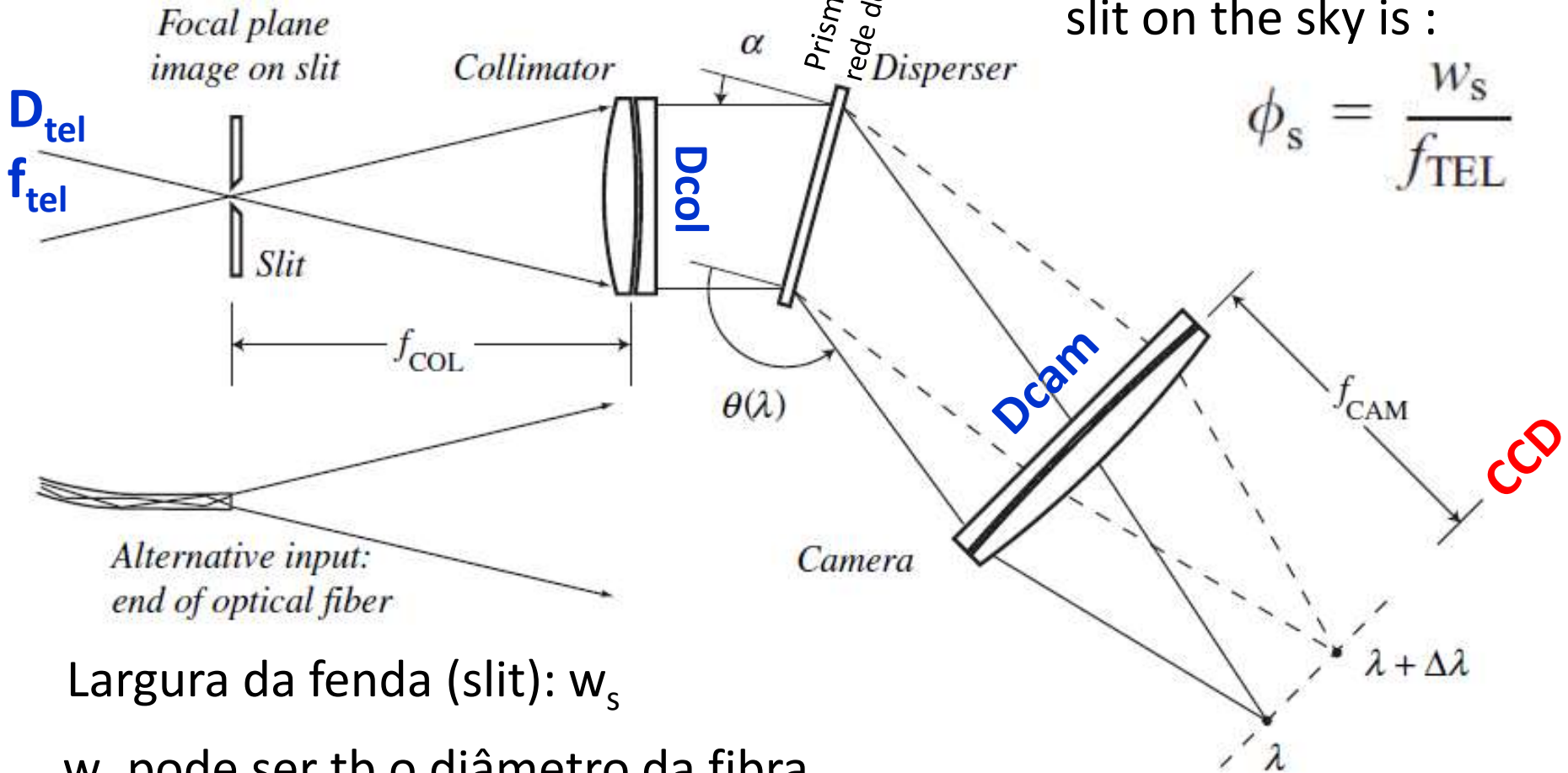
$D_{tel}$ ,  $f_{tel}$ : abertura e distância focal efetiva do telescópio



# Qual a distância angular da fenda no céu ?

The angular size of the slit on the sky is :

$$\phi_s = \frac{w_s}{f_{TEL}}$$

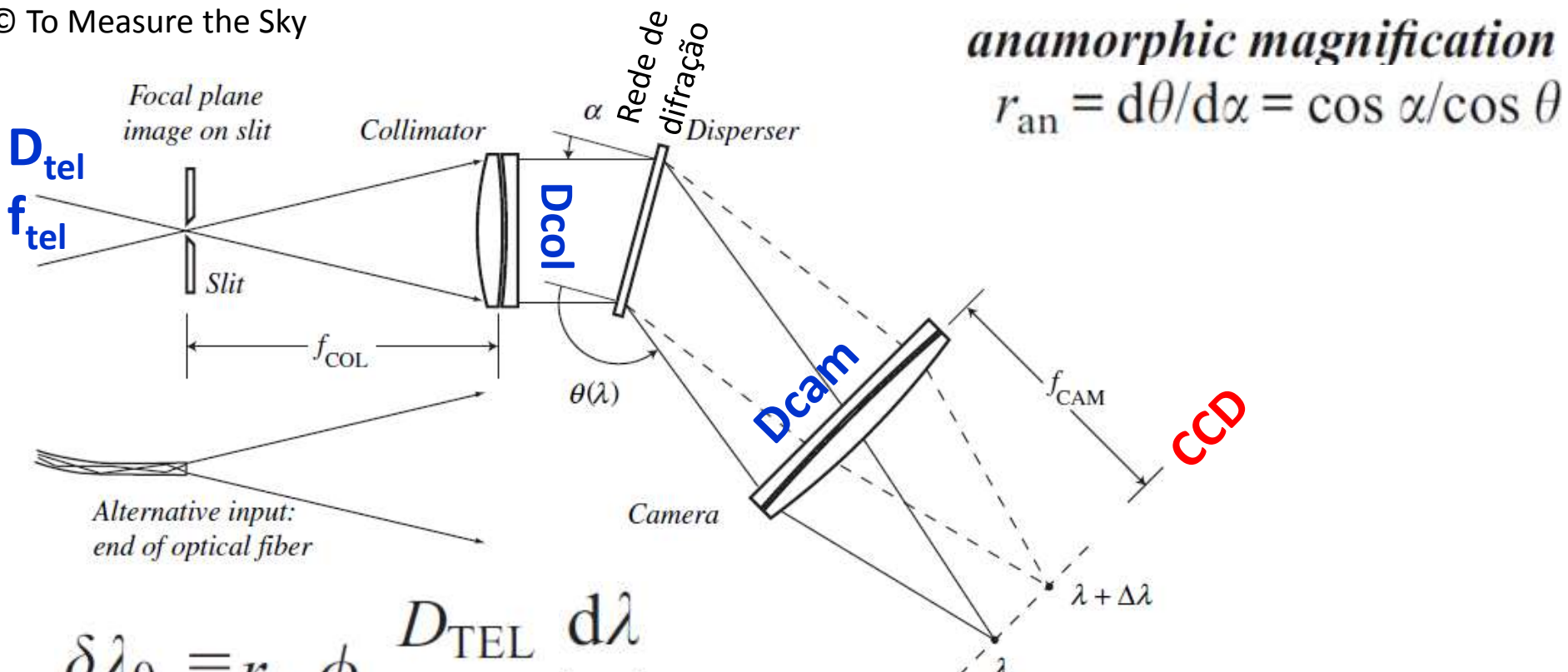


Largura da fenda (slit):  $w_s$

$w_s$  pode ser tb o diâmetro da fibra

# Resolução $\delta\lambda_0$ do espectrógrafo

© To Measure the Sky



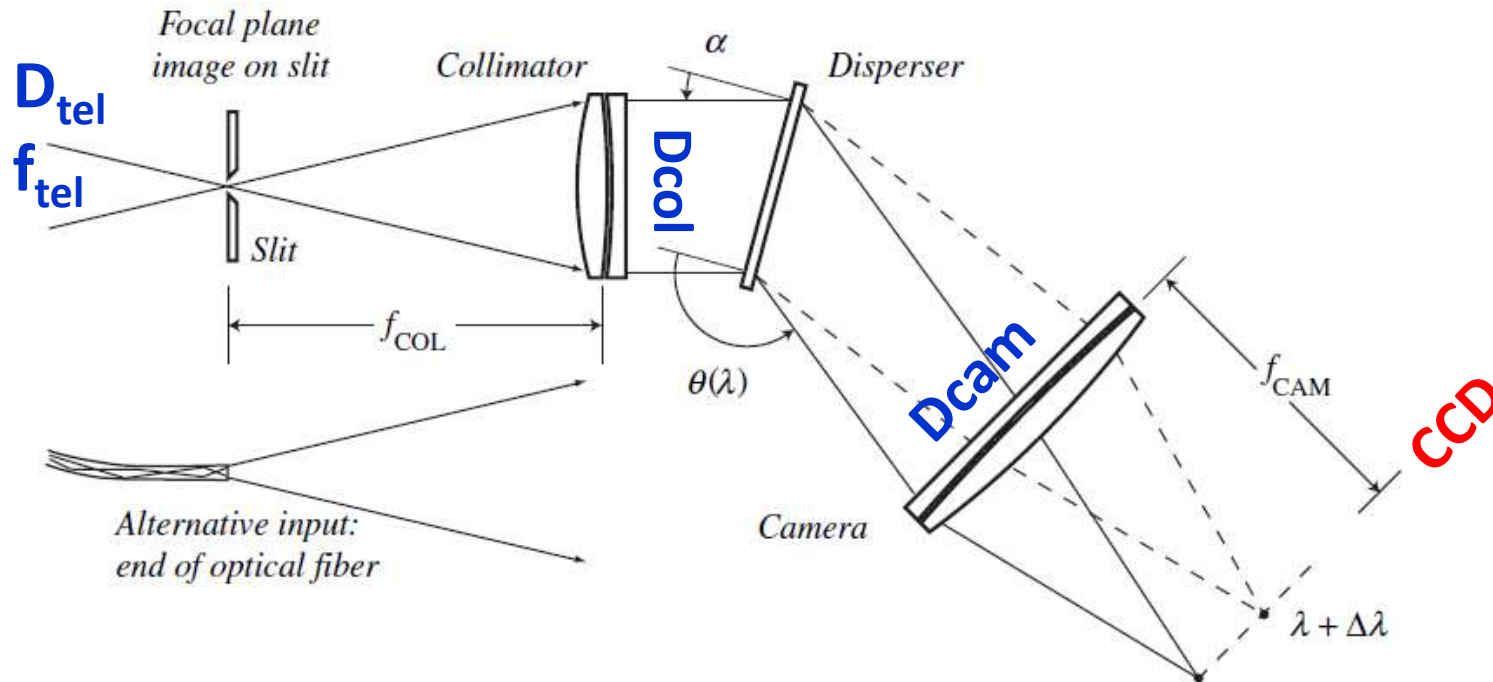
$$\delta\lambda_0 = r_{an} \phi_s \frac{D_{TEL}}{D_{COL}} \frac{d\lambda}{d\theta}$$



$$\delta\lambda_0 = r_{an} \phi_s \frac{D_{TEL}}{D_{COL}} \frac{\sigma \cos \theta}{m}$$

Rede de difração:  $\frac{d\theta}{d\lambda} = \frac{m}{\sigma \cos \theta}$

# Poder resolvente $R (= \lambda/\delta\lambda_0)$ do espectrógrafo



$$R = \frac{\lambda}{\delta\lambda_0} = \frac{\lambda}{r_{an} \phi_s} \frac{D_{COL}}{D_{TEL}} \frac{m}{\sigma \cos \theta}$$

Para fontes pontuais (p.ex. estrelas) o ângulo da fenda no céu  $\phi_s < \phi_{seeing}$

Se o seeing (FWHM) for menor que  $\phi_s$  usar  $\phi_{seeing}$  para o  $R$

Na verdade podem existir vários tamanhos de fendas

# Poder resolvente do espectrógrafo em função de $m$ , $\sigma$ , $f_{col}$ , $w_s$

$$R = \frac{\lambda}{\delta\lambda_0} = \frac{\lambda}{r_{an} \phi_s} \frac{D_{COL}}{D_{TEL}} \frac{m}{\sigma \cos \theta}$$

$$\phi_s = \frac{w_s}{f_{TEL}}$$



$$R = \frac{\lambda}{\delta\lambda_0} = \frac{\lambda}{r_{an} w_s} \frac{D_{COL} f_{TEL}}{D_{TEL}} \frac{m}{\sigma \cos \theta}$$

$$\frac{f_{COL}}{D_{COL}} = \frac{f_{TEL}}{D_{TEL}}$$



$$R = \frac{\lambda}{\delta\lambda_0} = \frac{\lambda}{r_{an}} \frac{m}{\sigma \cos \theta} \frac{f_{COL}}{w_s}$$

$m$ : ordem,  $\sigma$ : distância entre riscas da rede

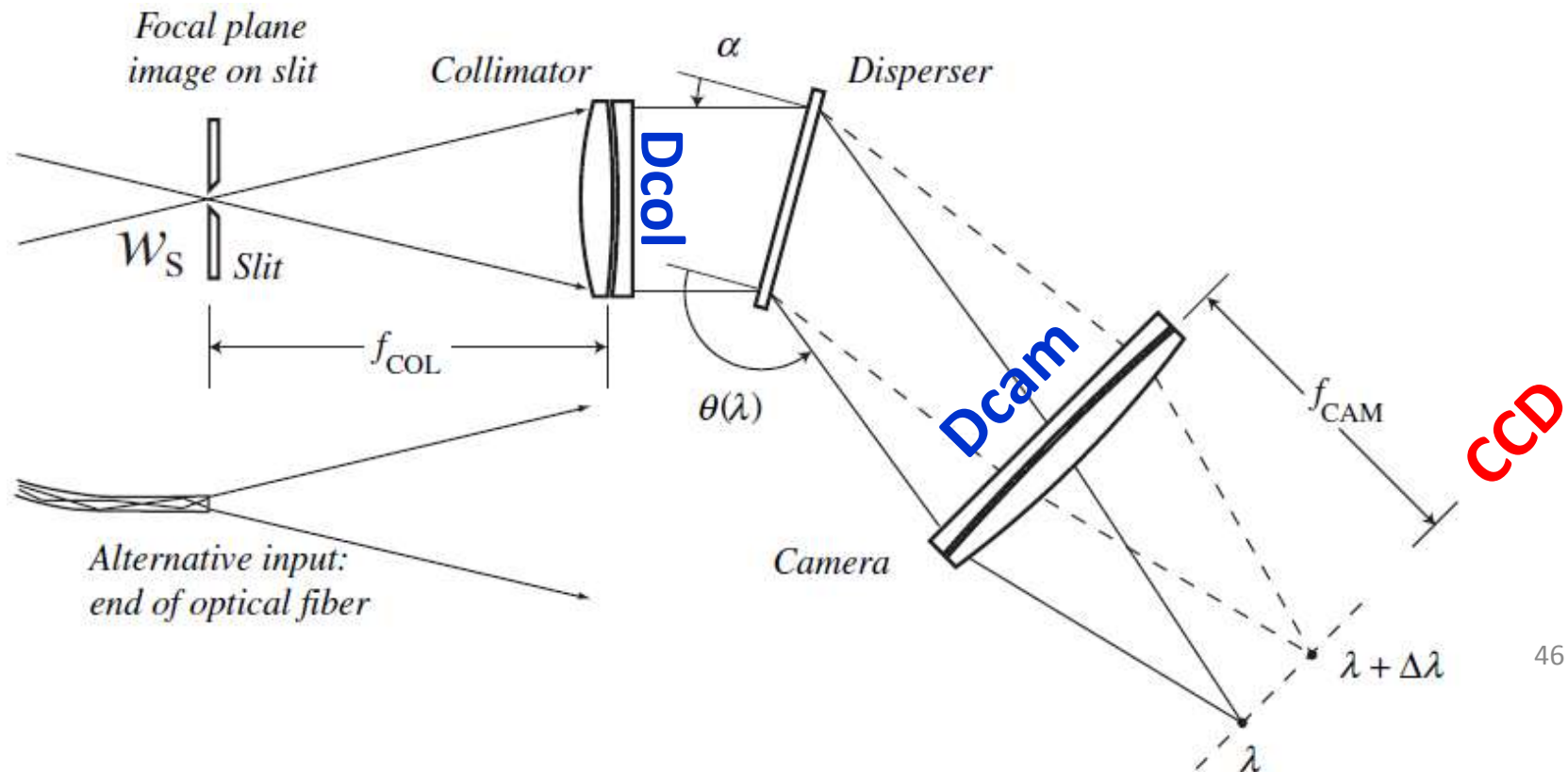
$f_{col}$ : distância focal do colimador,  $w_s$ : largura da fenda

# Poder resolvente do espectrógrafo

$$R = \frac{\lambda}{\delta\lambda_0} = \frac{\lambda}{r_{\text{an}}} \frac{m}{\sigma \cos \theta} \frac{f_{\text{COL}}}{w_s}$$

$m$ : ordem,  $\sigma$ : distância entre riscas da rede

$f_{\text{col}}$ : distância focal do colimador,  $w_s$ : largura da fenda



# Resolution vs. slit width $w_s$

Phoenix spectrograph  
at Kitt Peak (2m & 4m)

$$R = \frac{\lambda}{\delta\lambda_0} = \frac{\lambda}{r_{\text{an}}} \frac{m}{\sigma \cos \theta} \frac{f_{\text{COL}}}{w_s}$$

- EXAMPLE with PHOENIX spectrograph, slits available:  
2 pixel (54  $\mu\text{m}$ ), 3 pixel (81  $\mu\text{m}$ ), and 4 pixel (107  $\mu\text{m}$ )
- $w_s = 4$  pixels on detector  $\rightarrow R = 50\,000$
- $w_s = 2$  pixels on detector  $\rightarrow$  devia ser  $R = 100\,000$
- $w_s = 3$  pixels on detector  $\rightarrow$  devia ser  $R = 75\,000$



# Resolution vs. slit width $w_s$

$$R = \frac{\lambda}{\delta\lambda_0} = \frac{\lambda}{r_{\text{an}}} \frac{m}{\sigma \cos \theta} \frac{f_{\text{COL}}}{w_s}$$

HIRES spectrograph on  
10m Keck telescope

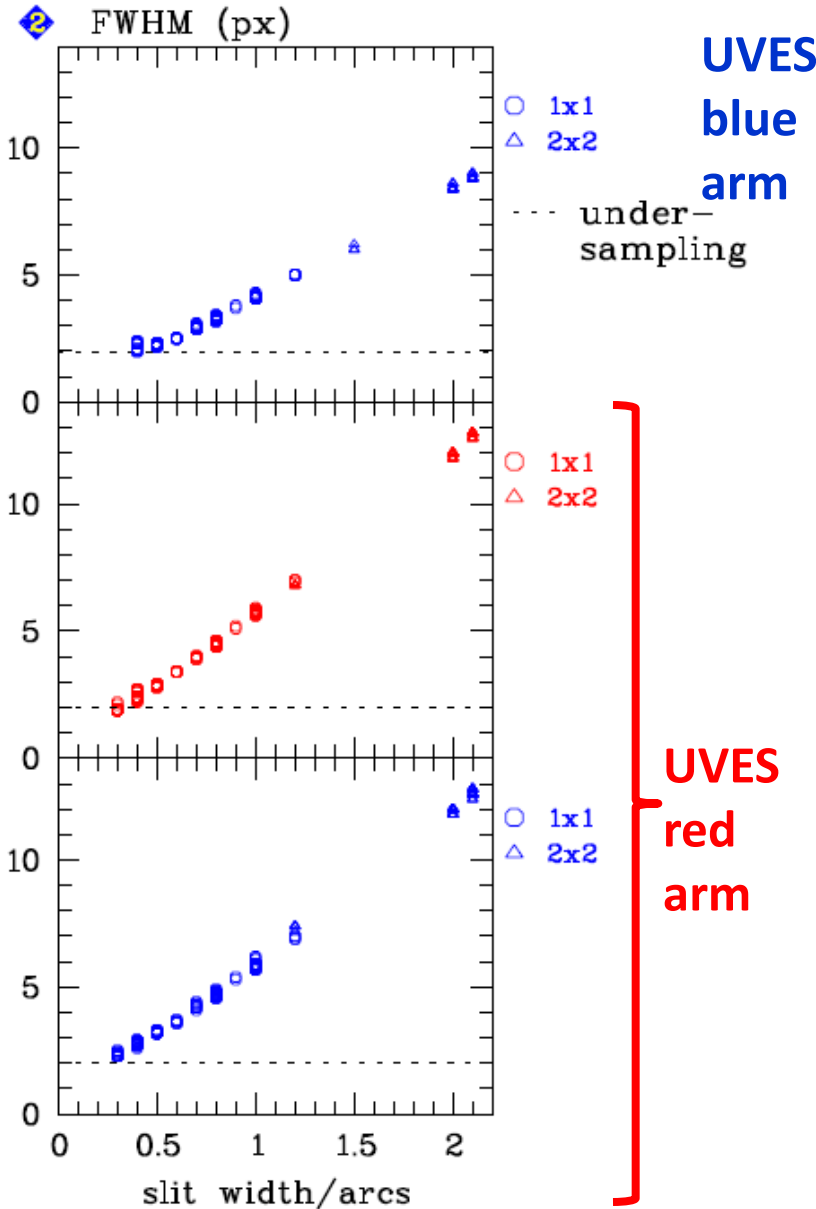
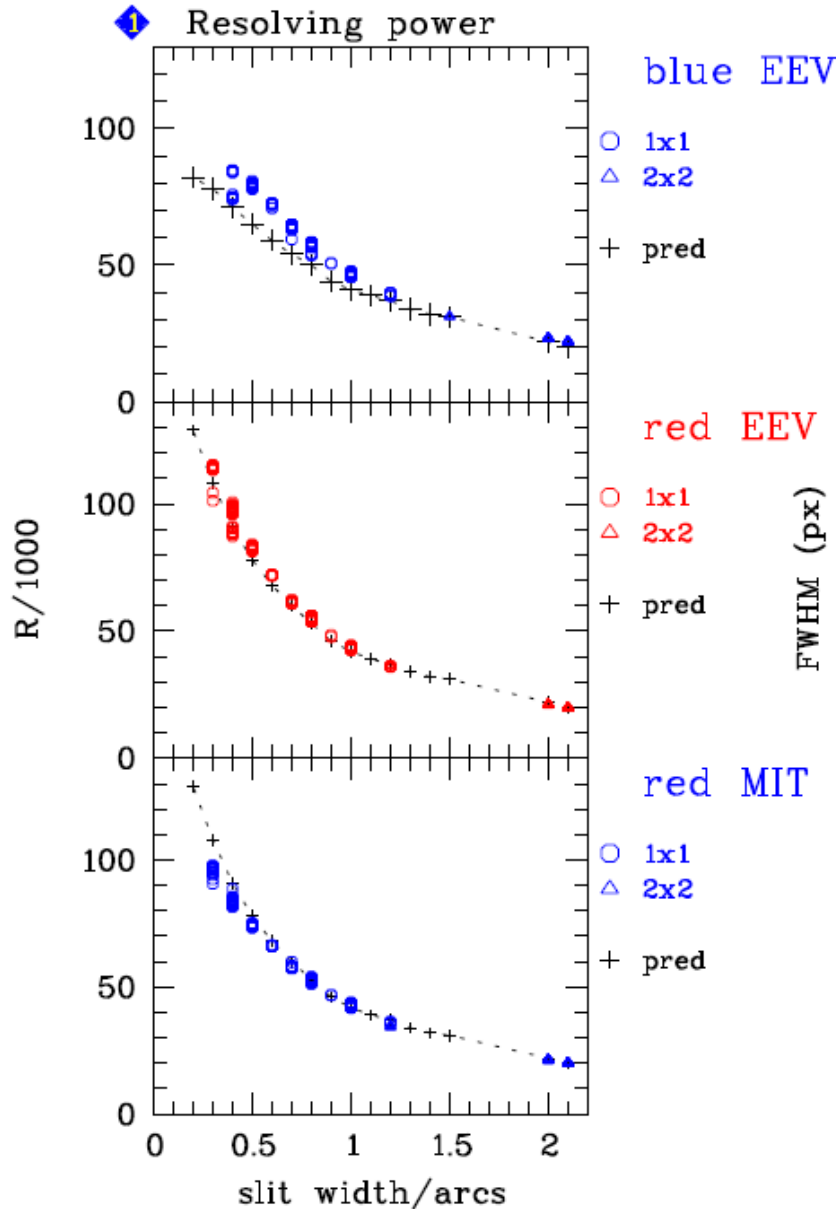
Deckname	Length (")	Width (")	Resolution (calculated)	(measured*)	(measured+)
B1	3.5	0.574	72,000	67,000	66,400
B2	7.0	0.574	72,000	67,000	66,400
B3	14.0	0.574	72,000	67,000	66,400
B4	28.0	0.574	72,000	67,000	66,400
B5	3.5	0.861	48,000	49,000	50,000
C1	7.0	0.861	48,000	49,000	50,000
C2	14.0	0.861	48,000	49,000	50,000
C3	28.0	0.861	48,000	49,000	50,000
C4	3.5	1.148	36,000	37,000	37,500
C5	7.0	1.148	36,000	37,000	37,500
D1	14.0	1.148	36,000	37,000	37,500
D2	28.0	1.148	36,000	37,000	37,500
D3	7.0	1.722	24,000	24,000	24,700
D4	14.0	1.722	24,000	24,000	24,700
D5	0.119	0.179	pinhole		
E1	1.0	0.400	103,000	84,000	86,600
E2	3.0	0.400	103,000	84,000	86,600
E3	5.0	0.400	103,000	84,000	86,600
E4	7.0	0.400	103,000	84,000	86,600
E5	1.0	0.800	51,000	52,000	52,000

\* Using UV cross-disperser.  
Average of 5 Th/Ar lines near  
4100 Å.  
+ Using Red cross-disperser.  
Average of 4 Th/Ar lines near  
5240 Å.

$$R = \frac{\lambda}{\delta\lambda_0} = \frac{\lambda}{r_{\text{an}} \sigma \cos \theta} \frac{m}{W_s} \frac{f_{\text{COL}}}{W_s}$$

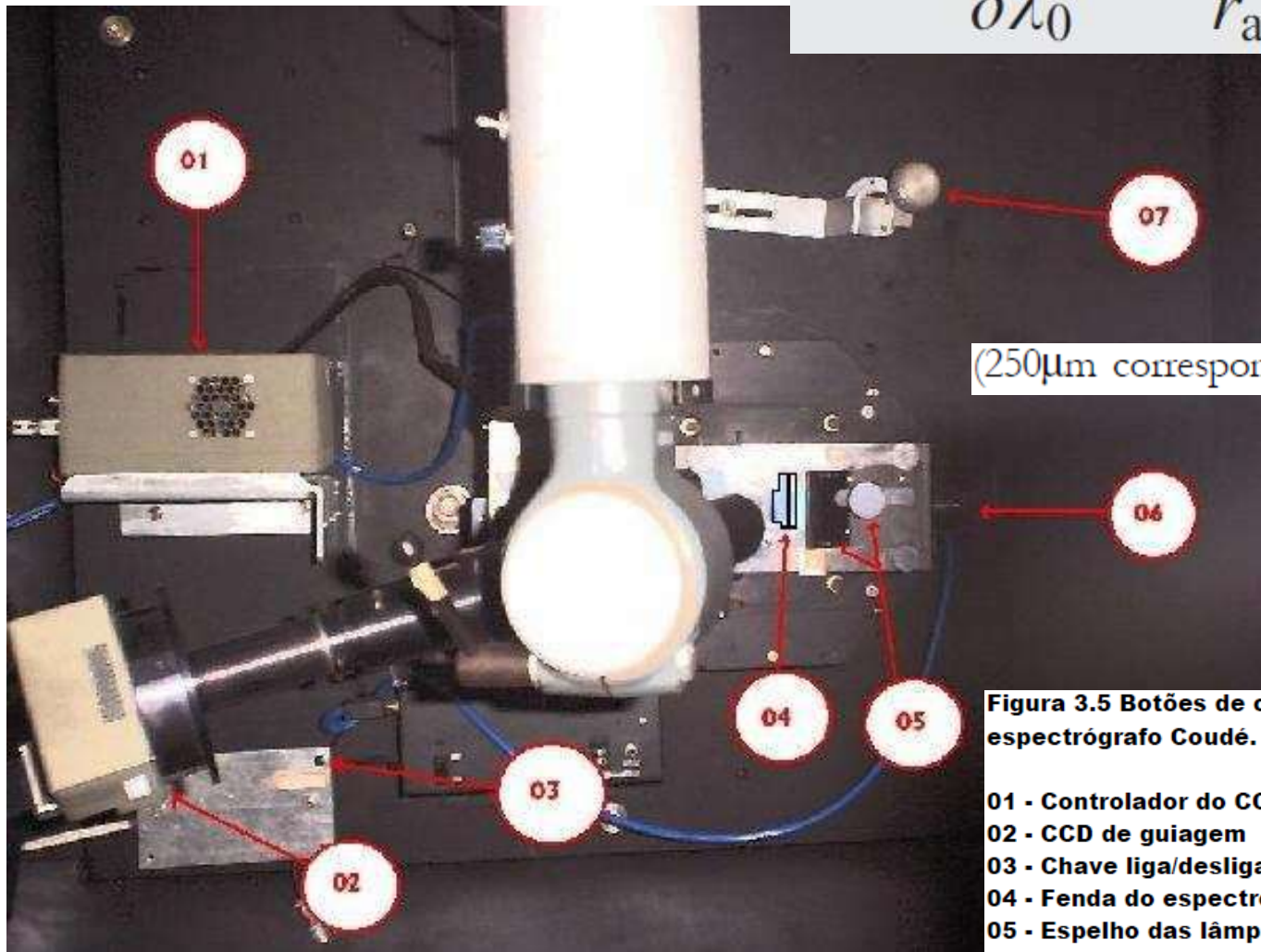
# UVES spectrograph on 8m VLT telescope

## Resolution vs. slit width



# Resolution vs. slit width $w_s$ - Coudé OPD

$$R = \frac{\lambda}{\delta\lambda_0} = \frac{\lambda}{r_{\text{an}}} \frac{m}{\sigma \cos \theta} \frac{f_{\text{COL}}}{w_s}$$



Regule a largura da fenda  
(250 $\mu\text{m}$  correspondem a aproximadamente 1")

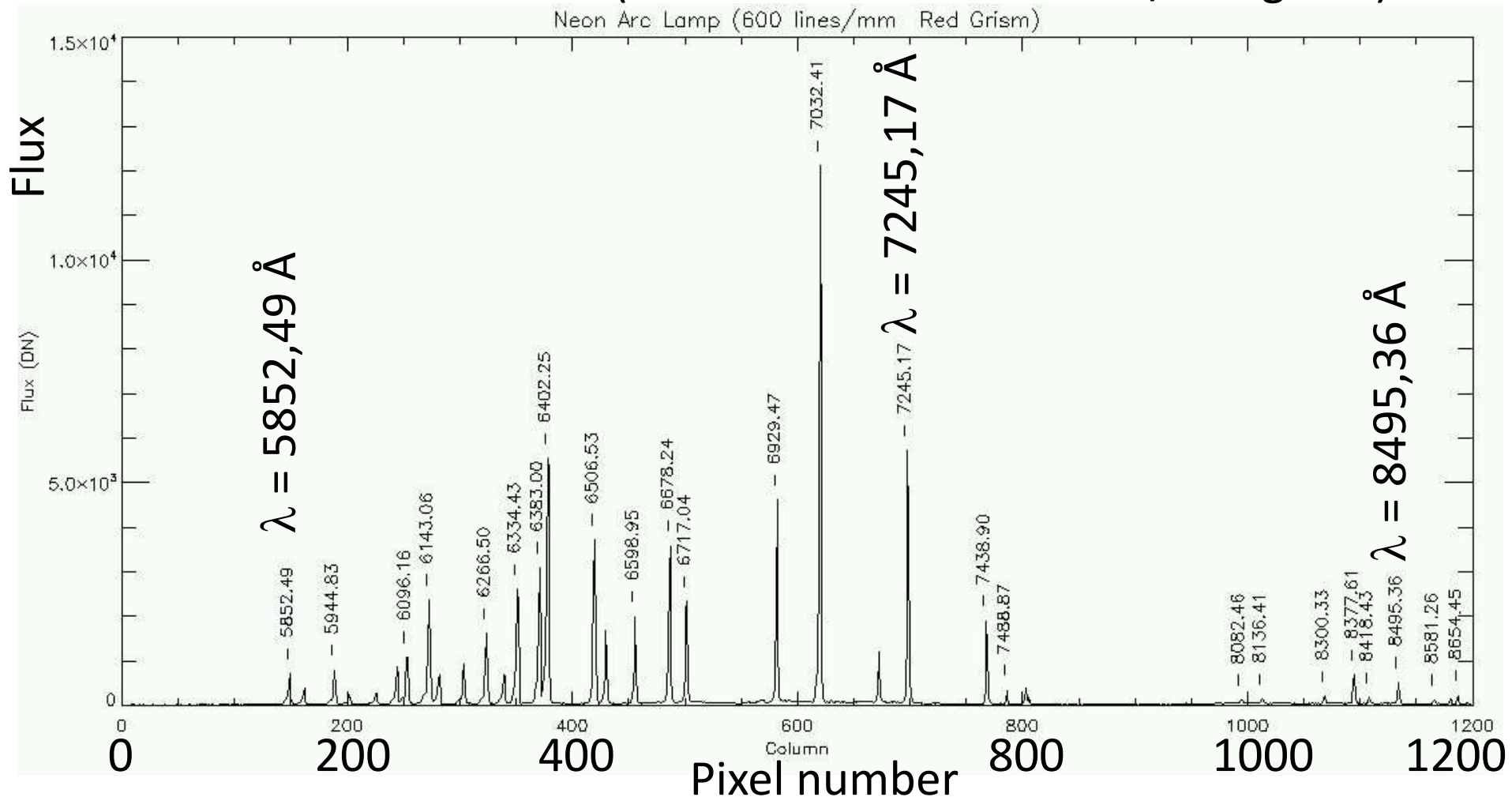
Figura 3.5 Botões de controle do espectrógrafo na ante-sala do espectrógrafo Coudé.

- 01 - Controlador do CCD de guiagem
- 02 - CCD de guiagem
- 03 - Chave liga/desliga lâmpada halógena do *flat field* interno
- 04 - Fenda do espectrógrafo
- 05 - Espelho das lâmpadas de comparação
- 06 - Controle da abertura da fenda
- 07 - Seletor do ângulo da rede de difração (ajuste fino)

# Calibration lamps (a.k.a. arcs)

(para calibrar o comprimento de onda)

NEON arc (observed with a 600 lines/mm grism)



$\lambda = 3650,146 \text{ \AA}$

$\lambda = 5460,735 \text{ \AA}$

# SOAR Goodman HgAr

$\lambda = 6965,431 \text{ \AA}$

$\lambda = 8667,944 \text{ \AA}$

3  
6  
5  
0  
1  
4  
6

4  
0  
4  
6

4  
0  
7  
7

4  
0  
9  
4



5  
6  
0  
7  
3  
8

5  
7  
6  
9

5  
7  
6  
9

5  
5  
6  
4



6  
9  
6  
5  
4  
3  
1

7  
1  
4  
7  
0  
3  
2

7  
2  
5  
3  
8  
6  
9

7  
5  
0  
4  
5

7  
7  
6  
1



7  
8  
9  
8  
6  
7  
6

8  
1  
0  
3  
5  
1  
3

8  
8  
1  
1  
6  
3  
1

8  
8  
2  
4  
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3

8  
8  
6  
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6  
0

8  
8  
4  
8  
4  
1

8  
8  
4  
5  
6

8  
8  
2  
2  
6

8  
8  
4  
1  
7



300

600 Blue

600 Mid

600 Red

1200 M1

1200 M2

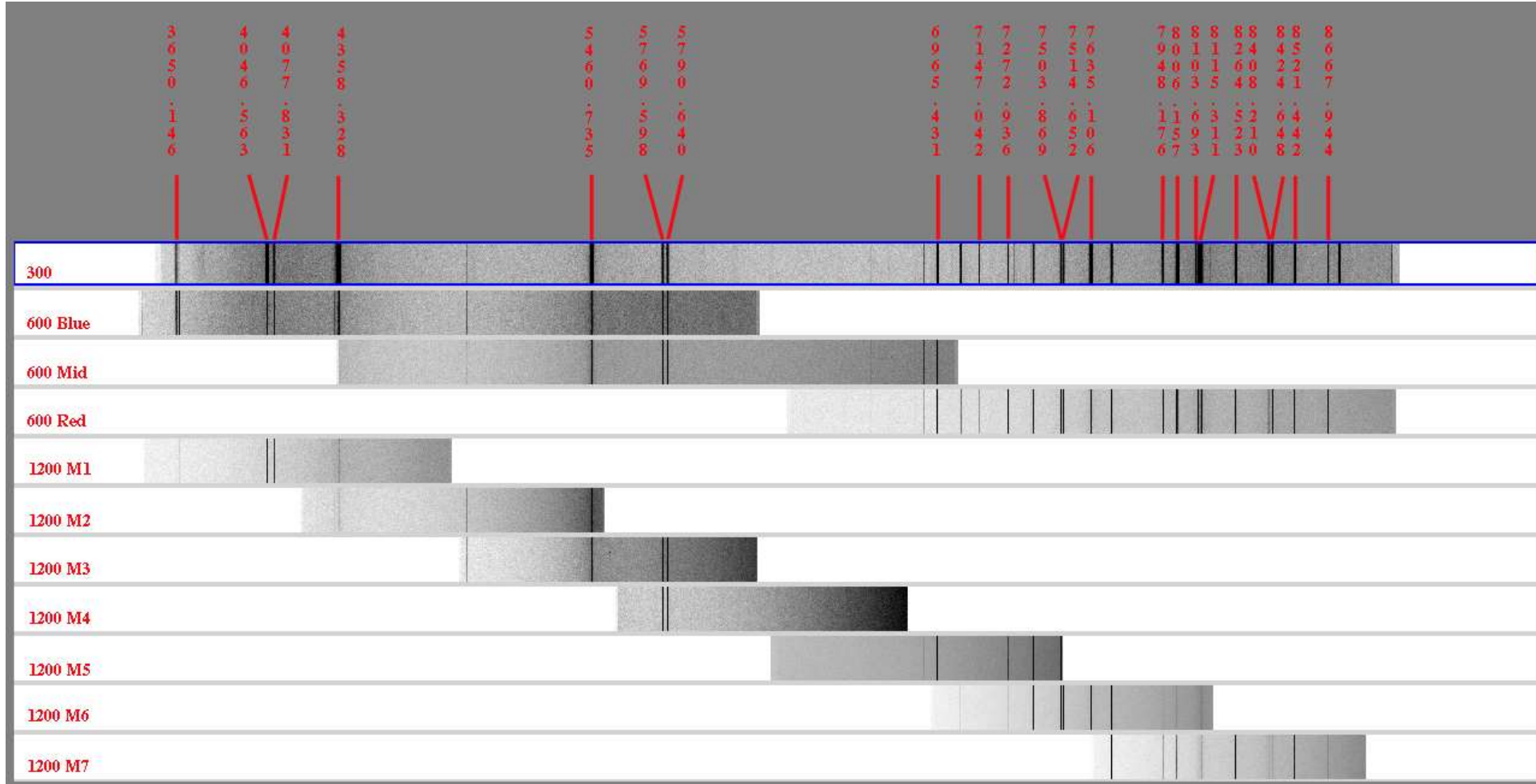
1200 M3

1200 M4

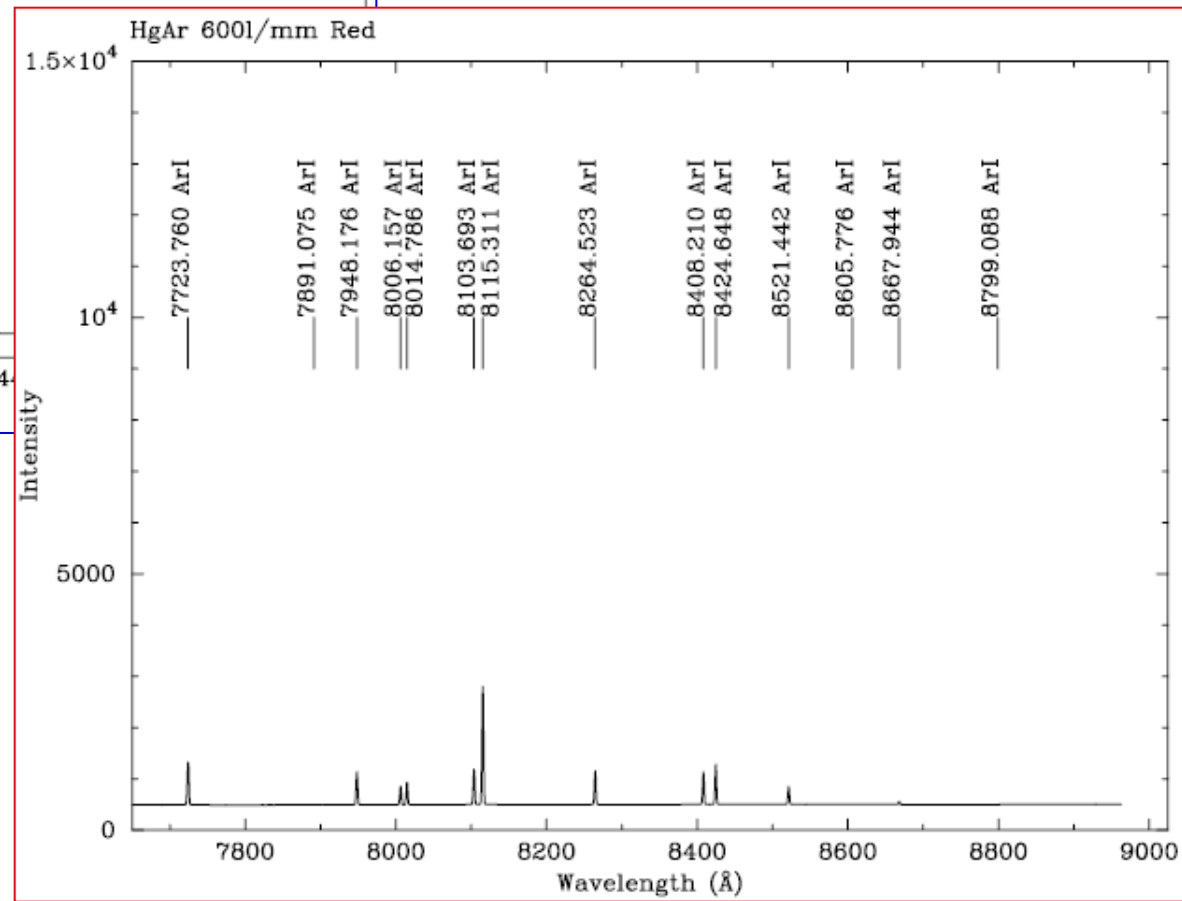
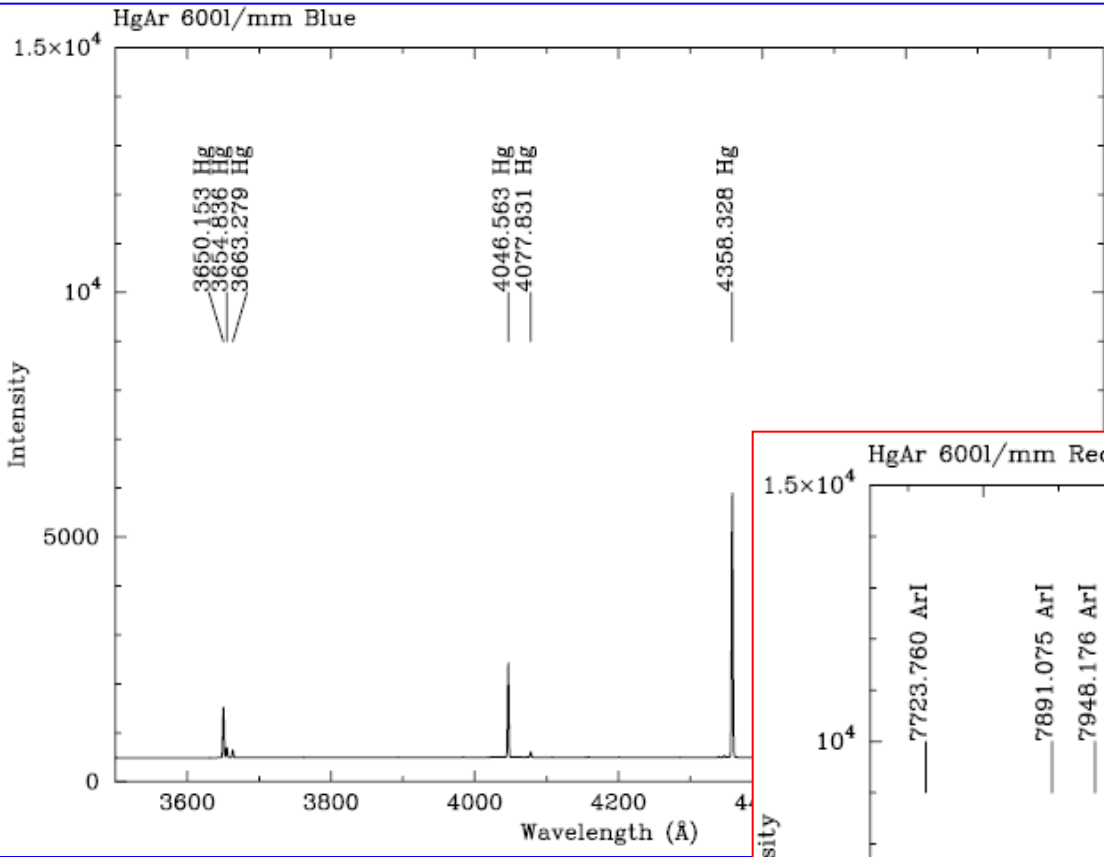
1200 M5

1200 M6

1200 M7

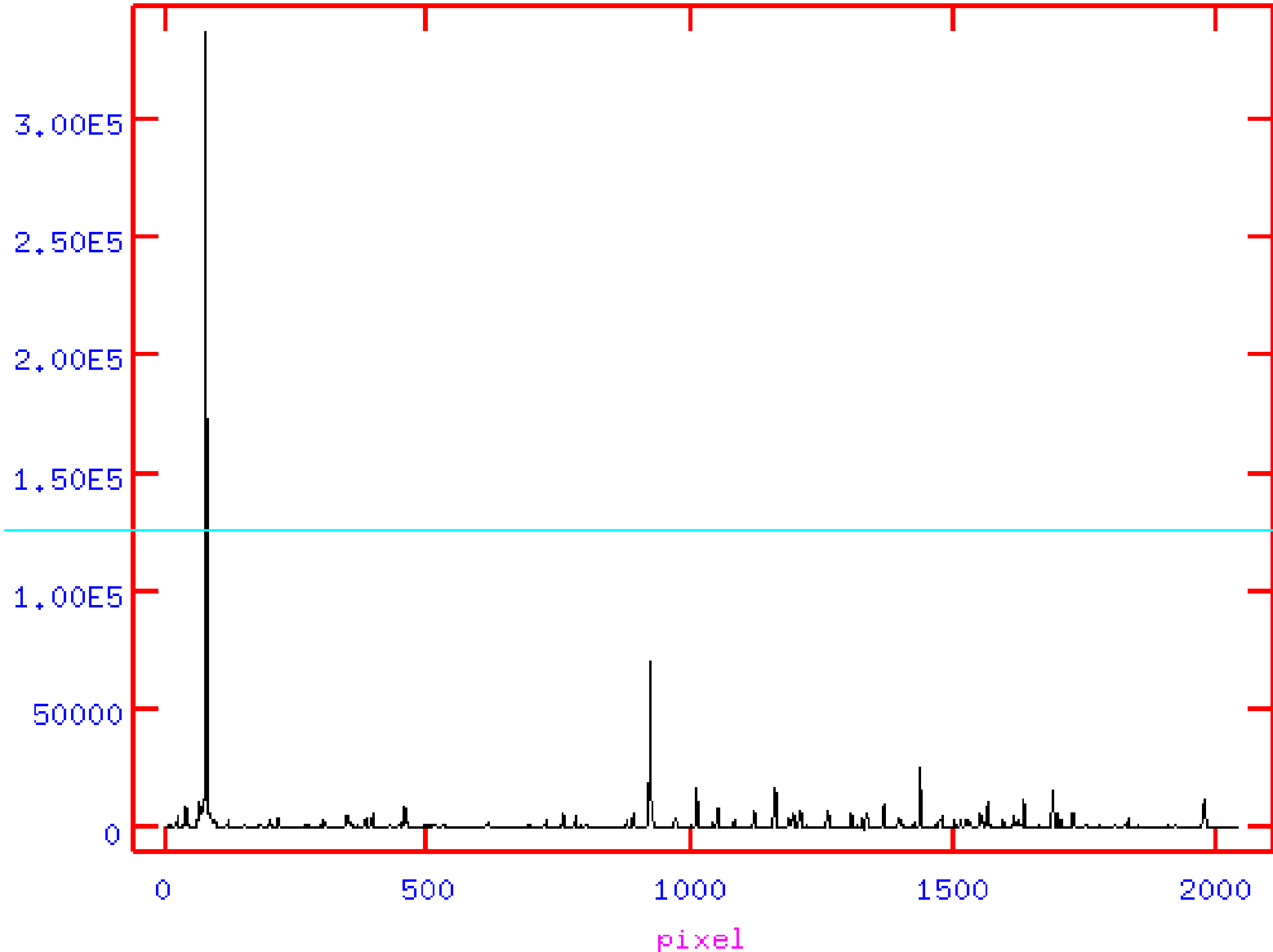


# HgAr arc 600 l/mm Goodman /SOAR

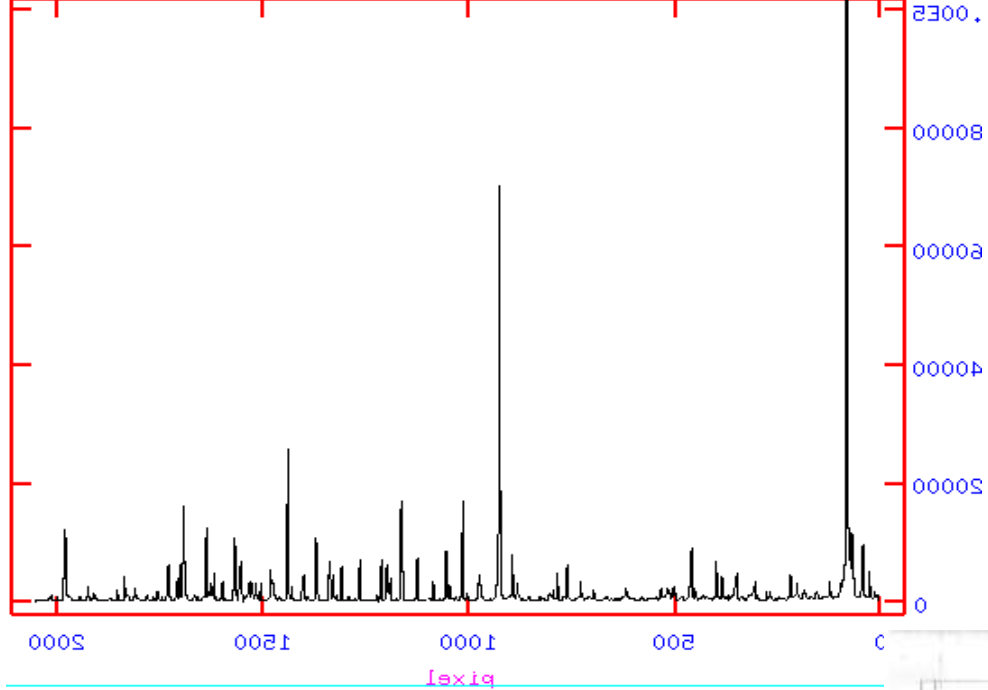


# He-Ar, espectrógrafo Cassegrain do OPD

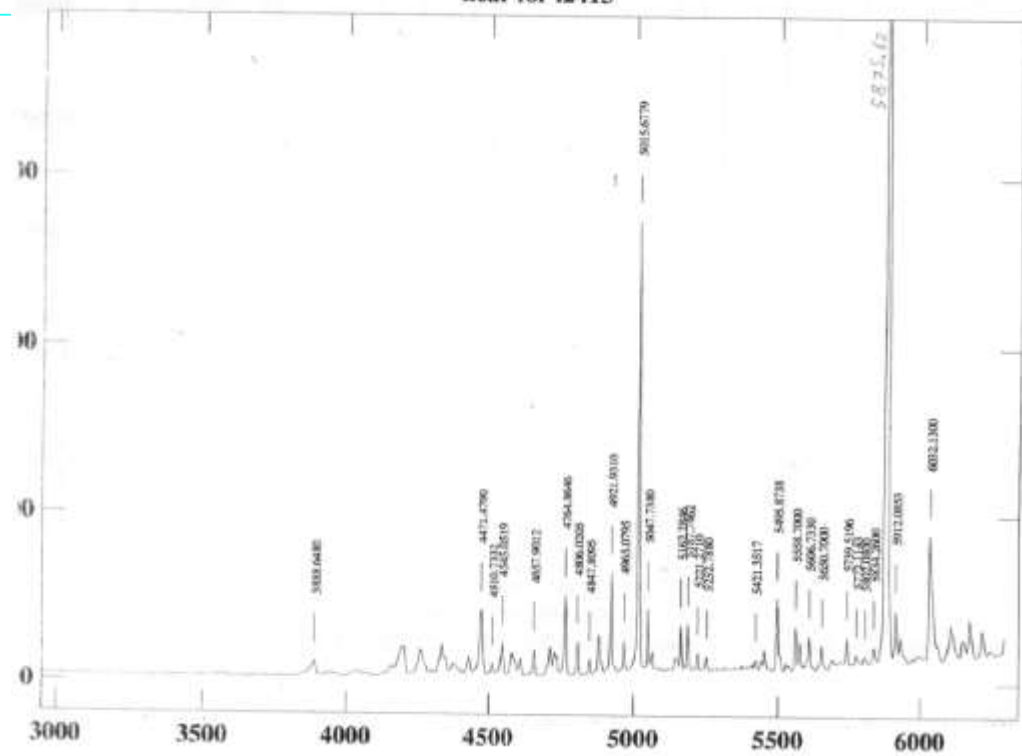
NOAO/IRAF V2.14.1 jorge@ubuntu1010 Sun 00:41:25 21-Apr-2013  
[hear\_opd\_101f.fits]: He-Ar 30, ap:1 beam:1



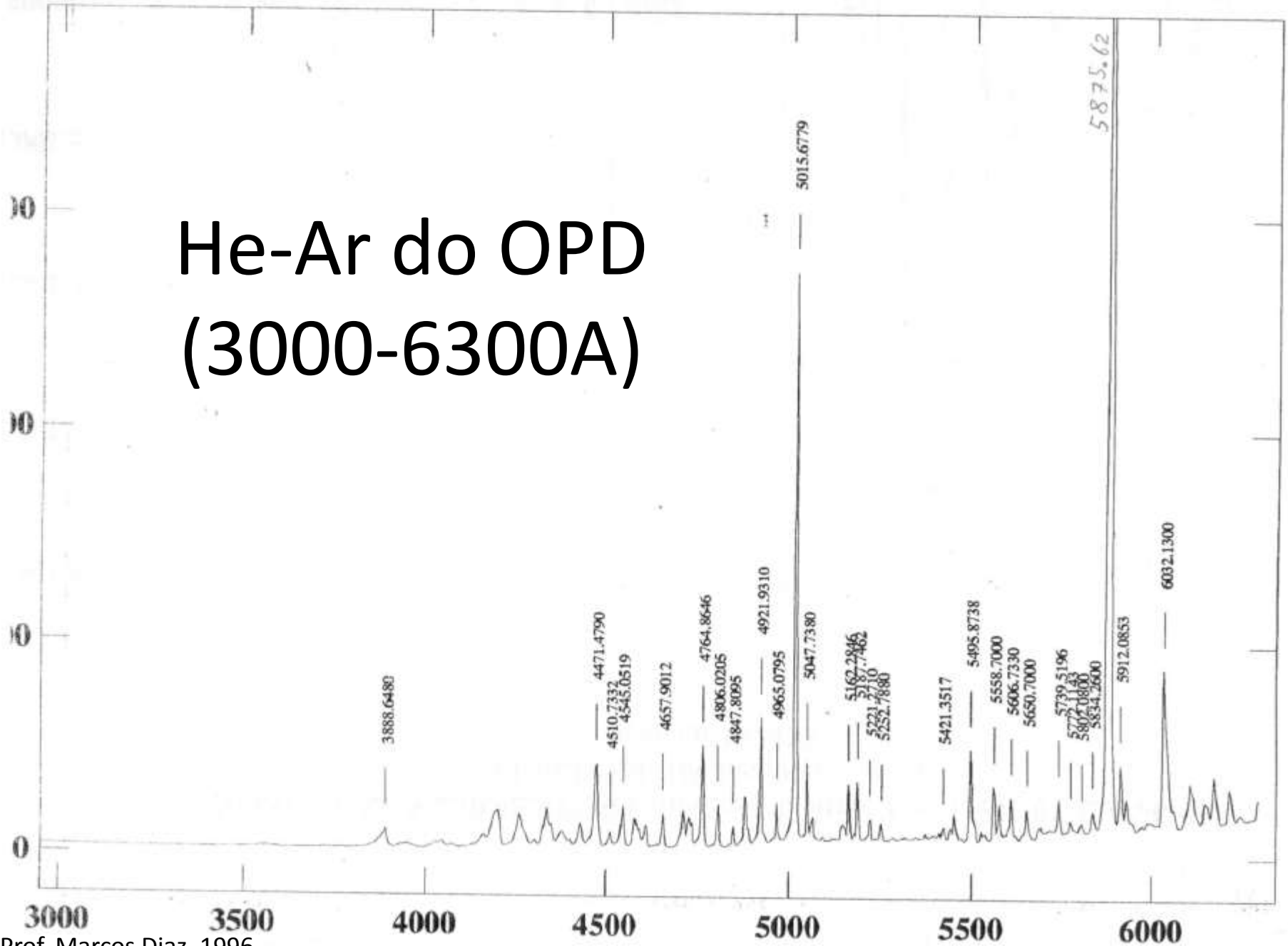




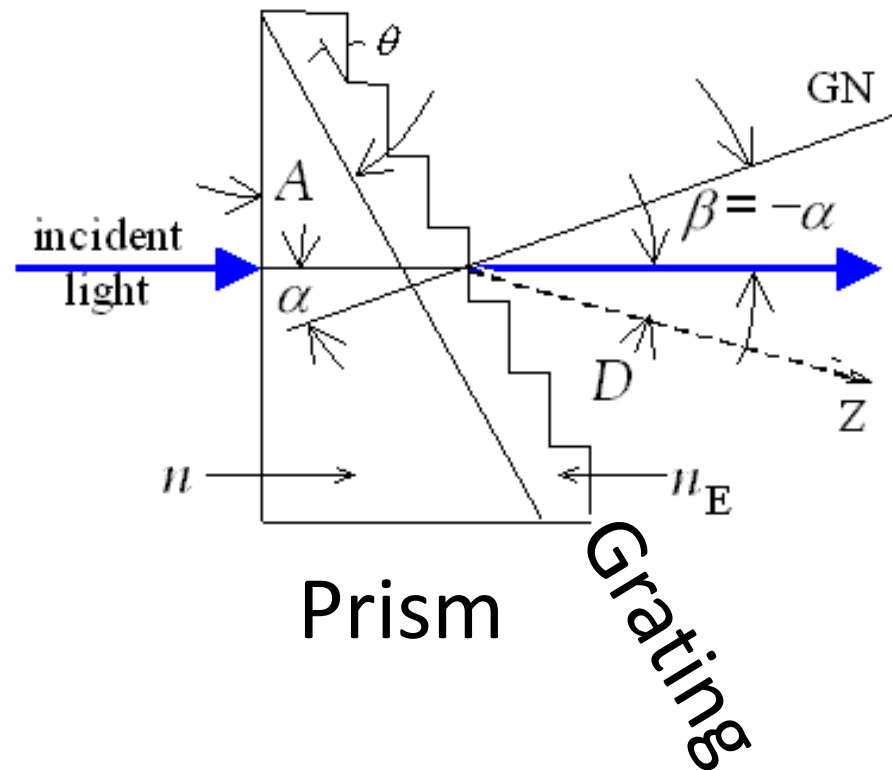
identify I244000.heav.0001 - Ap 1  
hear for I2415



# He-Ar do OPD (3000-6300A)

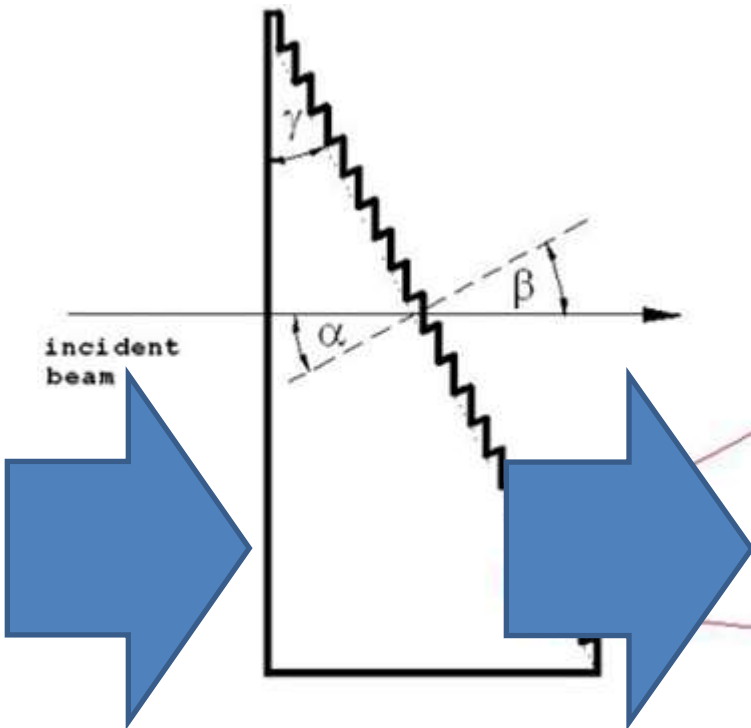


Além de *prisms* e *gratings*, o dispersor também pode ser um *grism*



# Grism = Grating + Prism

Para uma faixa de comprimento de onda, o desvio do feixe de luz to prisma é contrarestado pelo desvio da rede, portanto o feixe segue reto



O instrumento pode servir para imageamento apenas retirando o grisma do caminho optico.

