Astronomie et astrophysique pour physiciens CUSO 2015

Instruments and observational techniques - Spectroscopy

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Course outline

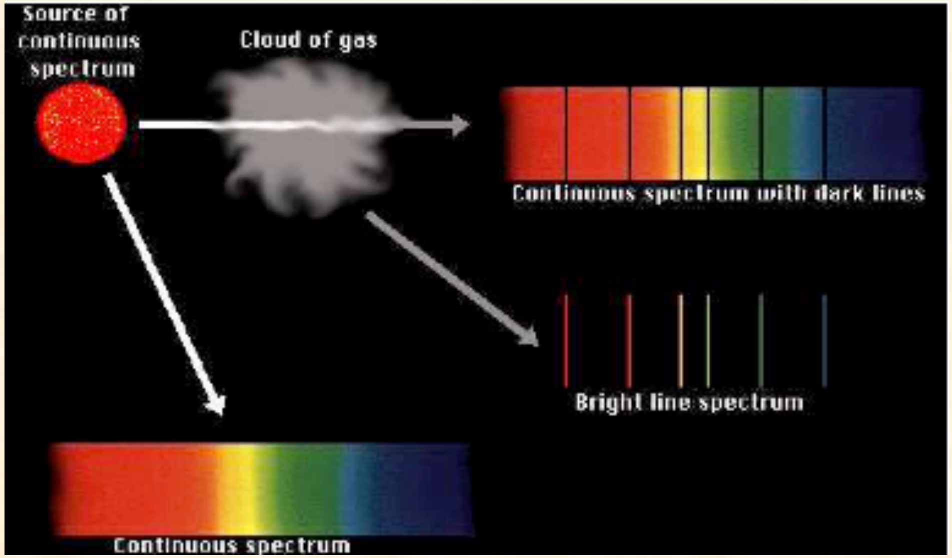
- PART 1 - Principles of spectroscopy
  - Fundamental parameters
  - Overview of spectrometry methods
- PART 2 – 'Modern' spectrographs
  - 'Simple' spectroimager
    - FORS
  - Echelle spectrographs
    - UVES
    - CRIRES
- PART 3 - Spectroscopy on the VLTs
  - Multi-Object spectrographs (MOS) and Intergral-Field Units (IFU) and spectro-imagers
    - Giraffe
    - VIMOS
    - Sinfoni
  - Future instruments
    - X-shooter
    - MUSE
    - ESPRESSO

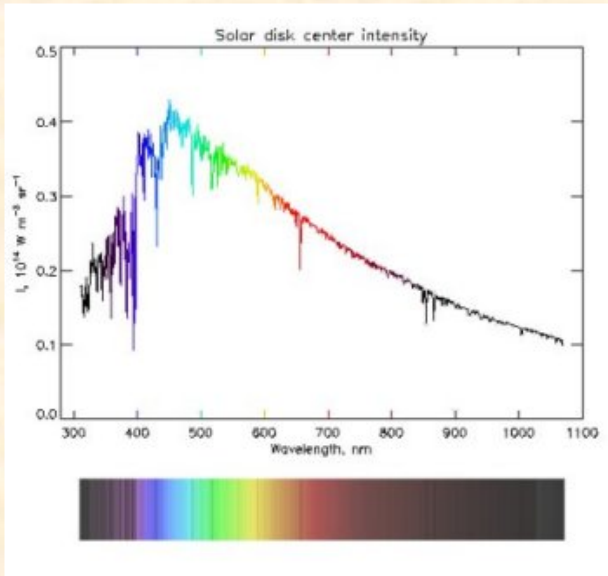
The observables

If we integrate the surface brightness over a given source or sky aperture, we get the spectral flux density F_ν or F_λ at a given light frequency or wavelength:

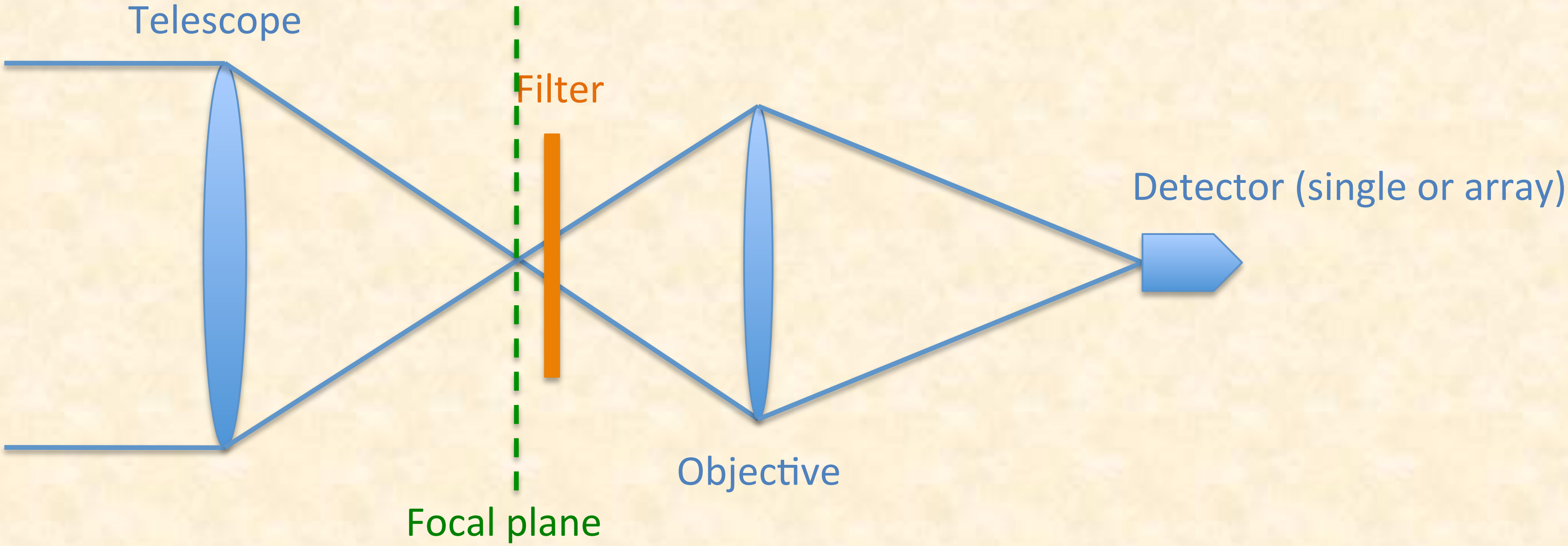
$$F_\nu = F(\nu) = \int S(\nu,(k_x,k_y)) \cdot \cos\Theta \cdot d\Omega \cong \int S(\nu,(k_x,k_y)) \cdot d\Omega$$

$$F_\lambda = F(\lambda) = \int S(\lambda,(k_x,k_y)) \cdot \cos\Theta \cdot d\Omega \cong \int S(\lambda,(k_x,k_y)) \cdot d\Omega$$





Filter spectrometer



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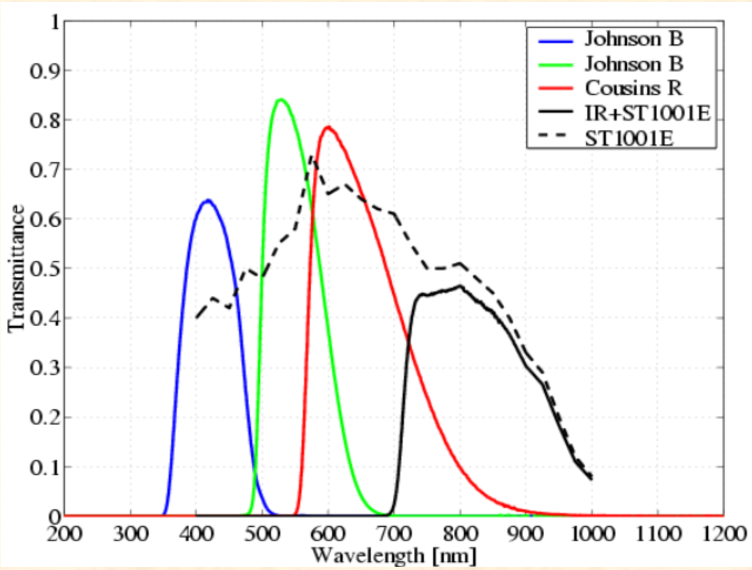
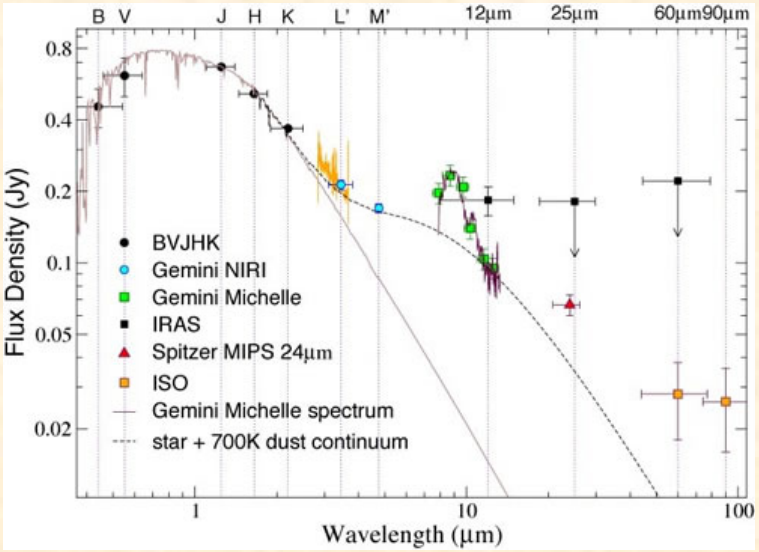
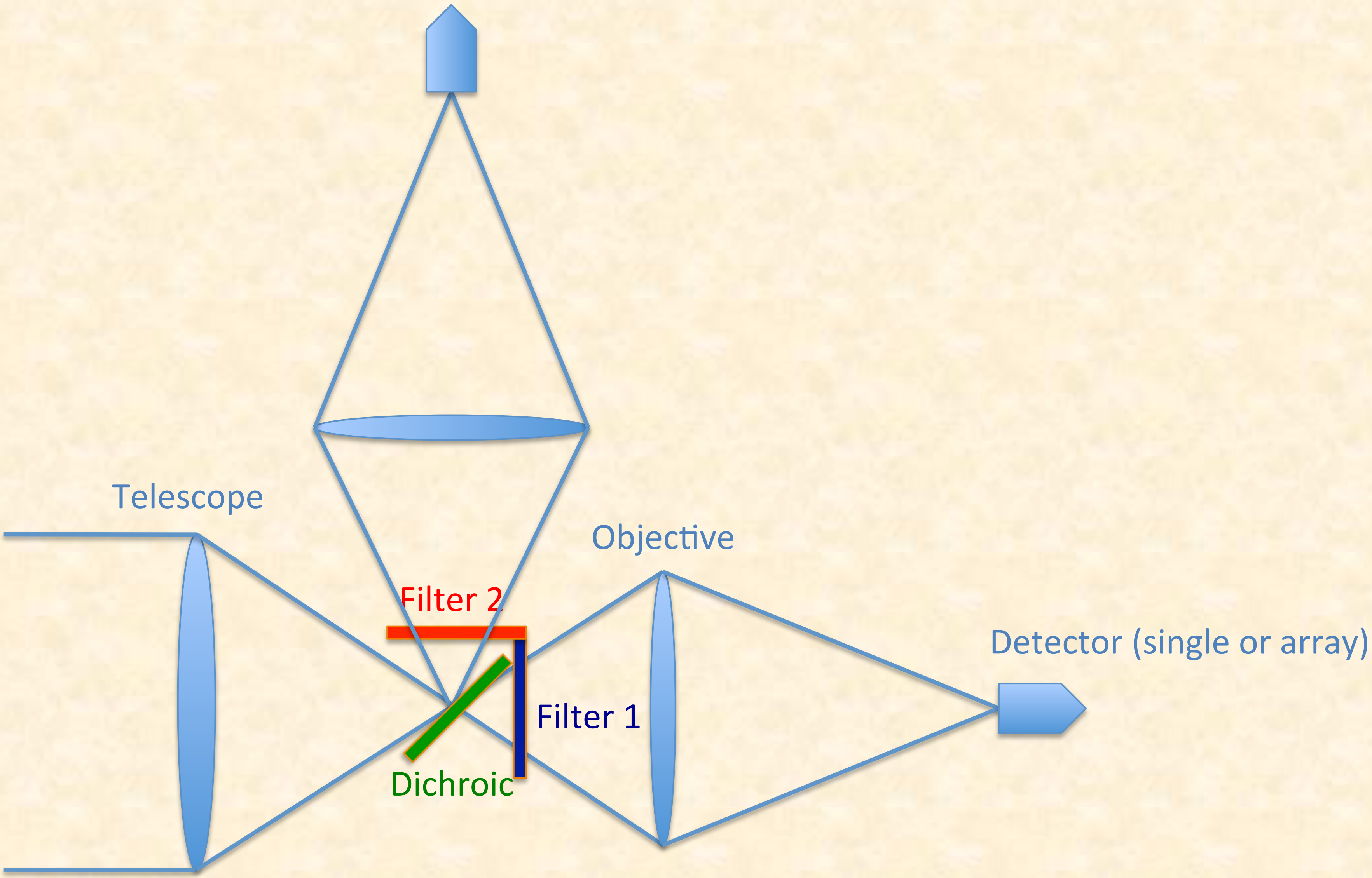


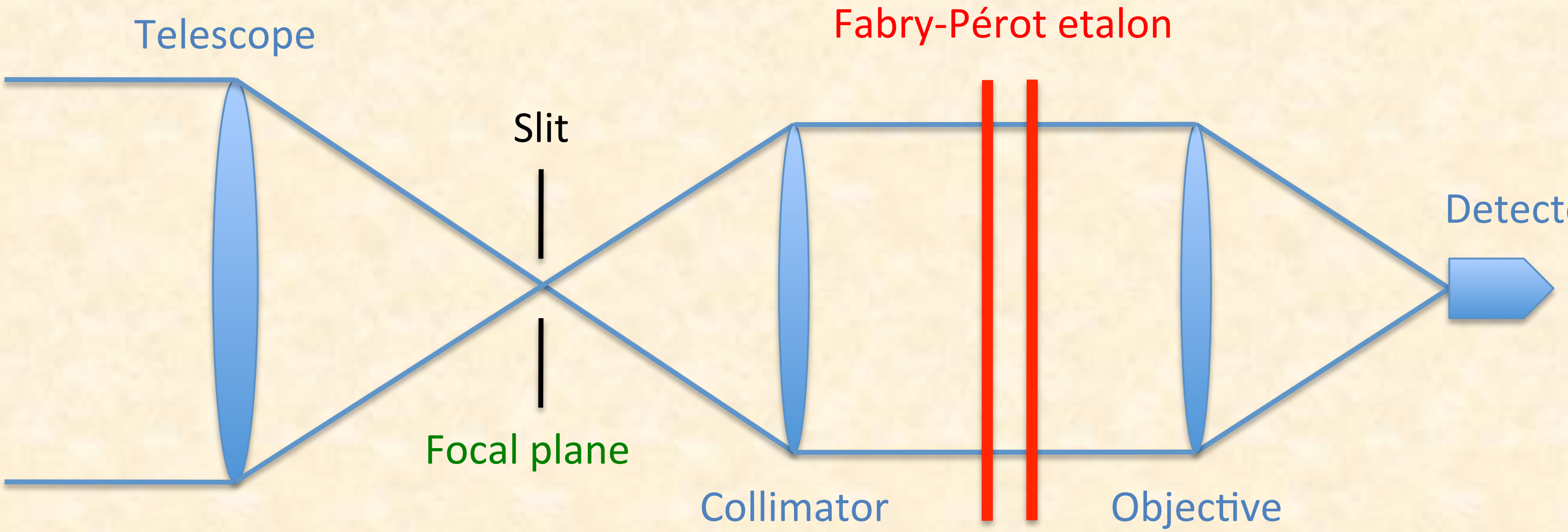


- Detector records I_λ for a given filter with transmittance t_c, central wavelength λ_c, and band width $\Delta\lambda$
- t_c, $\Delta\lambda$ and λ_c need to be calibrated on standard sources
- Appropriate for broad-band spectra
- Only one channel per measurement (unless dichroics are used)

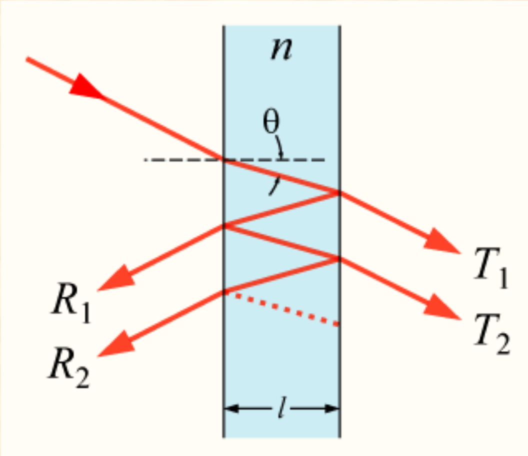
Filter spectrometer

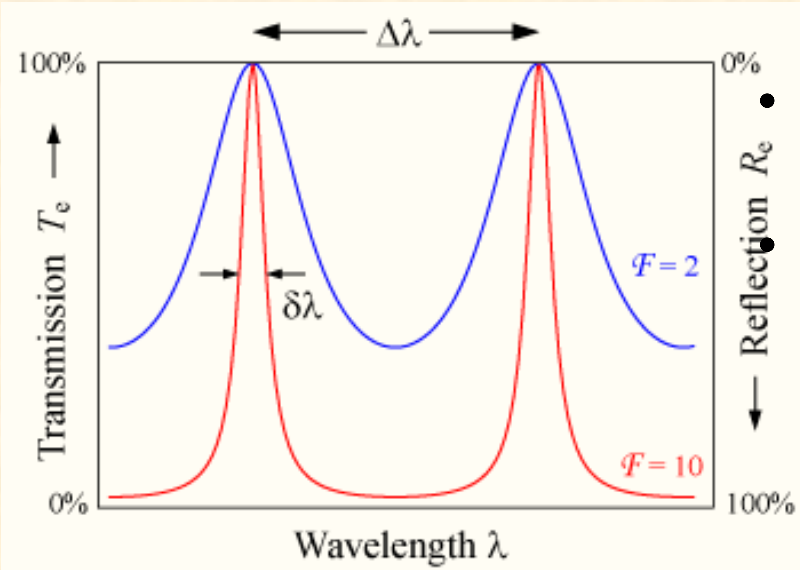


Fabry-Pérot spectrometer



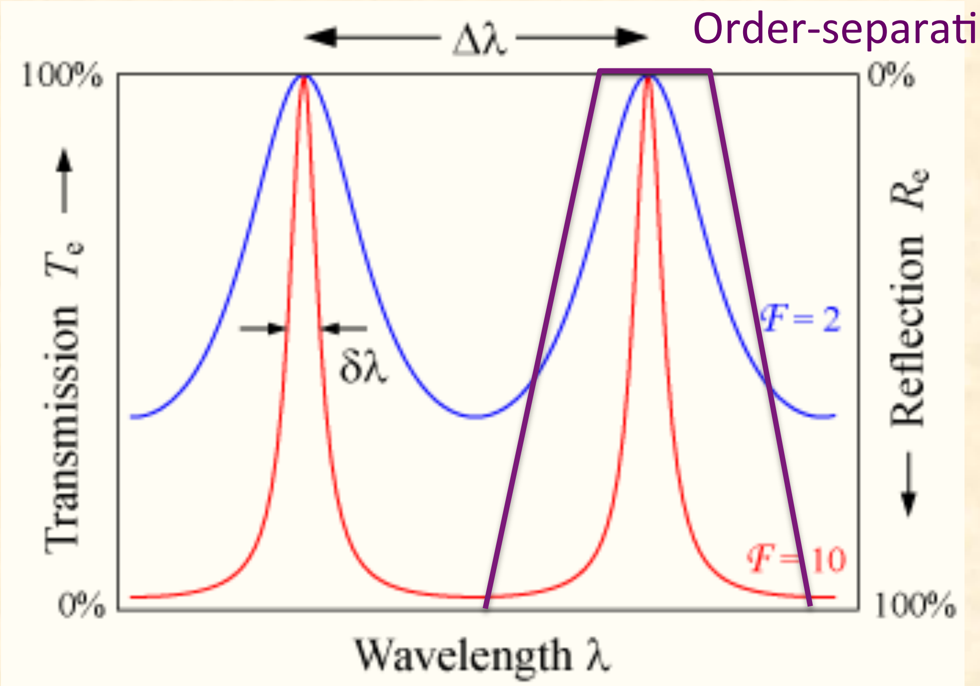
Fabry-Pérot spectrometer





- Similar to filter spectrometer, but spacing can be made tunable
- Detector records I(λ) as a function of the transmitted wavelength $m\lambda=2l$, where m is an integer and enumerates the transmitted order.
- Only one spectral channel per measurement
- Transmittance and wavelength must be calibrated.
- Allows high spectral resolution, if the finesse F or the order m is high. In the latter case, a pre-filtering is required to select only one wavelength (order-selection).

Fabry-Pérot spectrometer



$$T(\lambda) = \frac{1}{1 + (2F/\pi)^2 \cdot \sin^2(\delta(\lambda)/2)},$$

where

$$\delta(\lambda) = \frac{2\pi}{\lambda} 2nl\cos\Theta \ , \ F = \frac{\pi\sqrt{r}}{1-r}$$

(r = mirror reflectance)

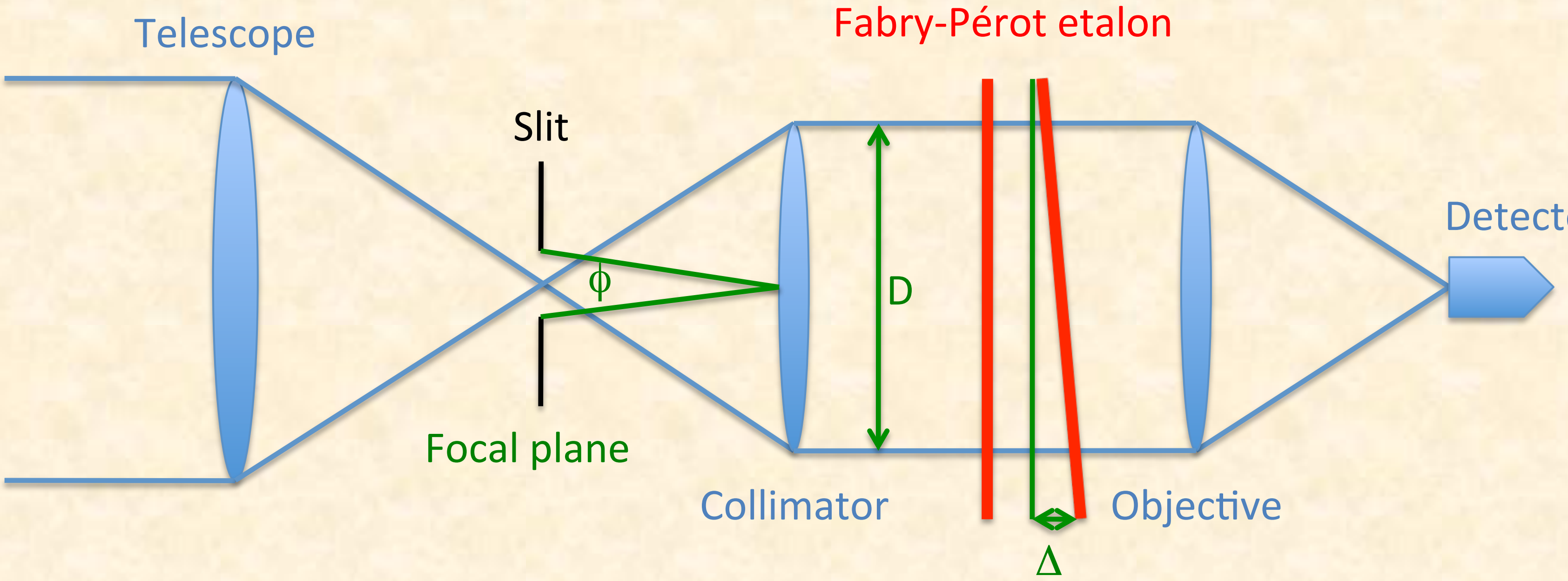
Transmitted wavelength: $\lambda_m = 2nl\cos\Theta / m$

Order separation: $\Delta\lambda = \lambda_{m-1} - \lambda_m \approx 2nl\cos\Theta / m^2$

Finesse: $F = \Delta\lambda / \delta\lambda$

Spectral resolution: $R := \frac{\lambda}{\delta\lambda} = m \cdot F$

Fabry-Pérot spectrometer



Real Fabry-Pérot:

$$T(\lambda) = \frac{1}{1 + (2F_E / \pi)^2 \cdot \sin^2(\delta(\lambda)/2)},$$

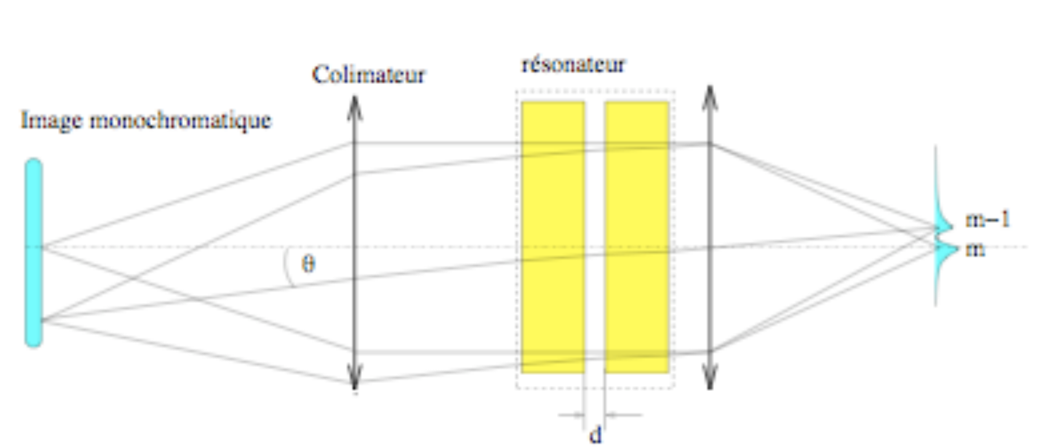
where $\frac{1}{F_E^2} = \frac{1}{F_R^2} + \frac{1}{F_D^2} + \frac{1}{F_P^2} + \frac{1}{F_\phi^2}$

$F_R = \frac{\pi \cdot \sqrt{r}}{1 - r}$, reflectance finesse

$F_D = \lambda / \delta / \sqrt{2}$, defect finesse ($\delta$=defect rms)

$F_P = \lambda / \Delta / 2$, parallism finesse

$F_\phi = \frac{4\lambda}{\phi^2 l}$, aperture finesse

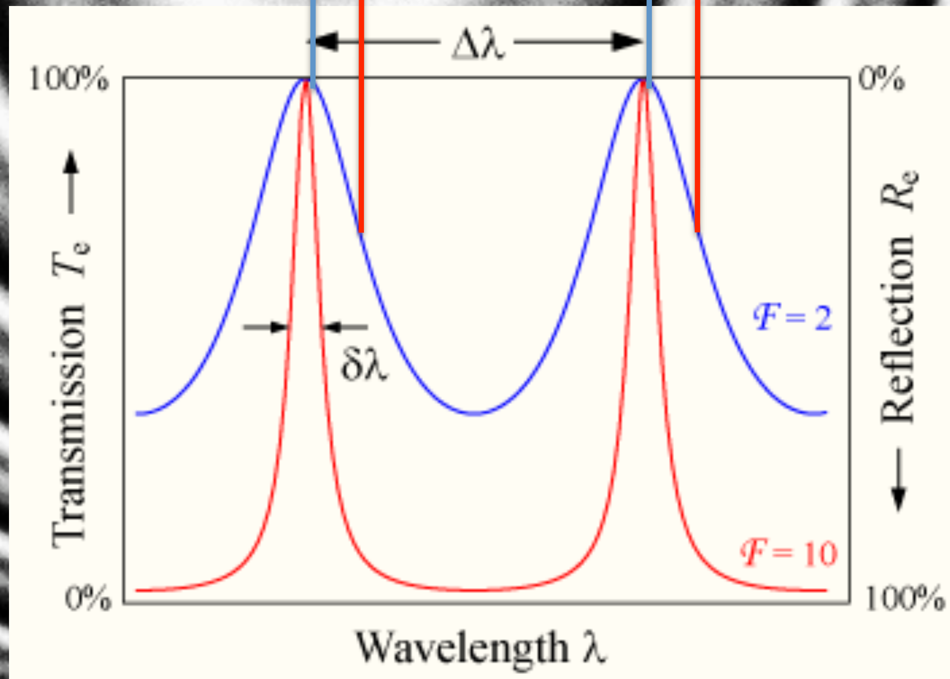


Example of apearture fine

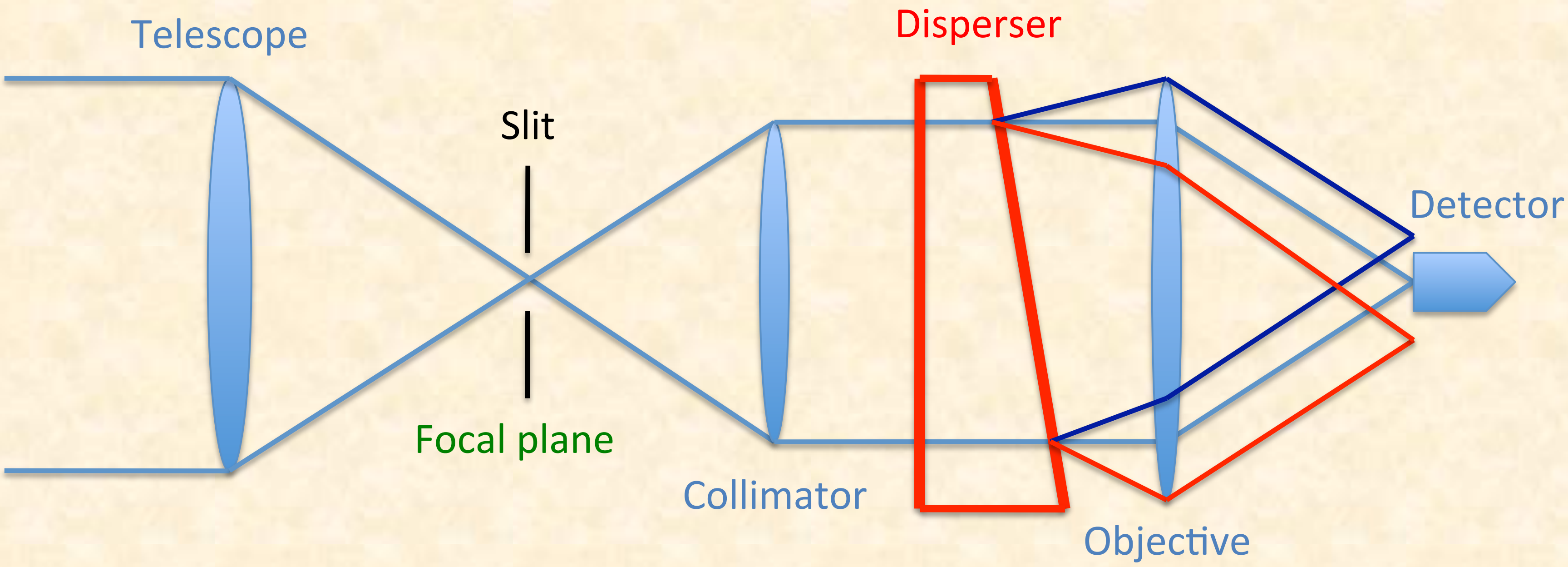
Transmitted wavelength is unique only for given angle T

If slit is too wide, the aperture (angle cone) is enlarged and the range of transmitted wavelength increased.

The ‘contrast is the reduced, thus the finesse and the spectral resolution



General spectrograph layout



Single detector -> monochromator (may be used with movable part to scan over wavelengths

Array detector -> spectrograph with N wavelength channels (N = number of detectors or pixels)

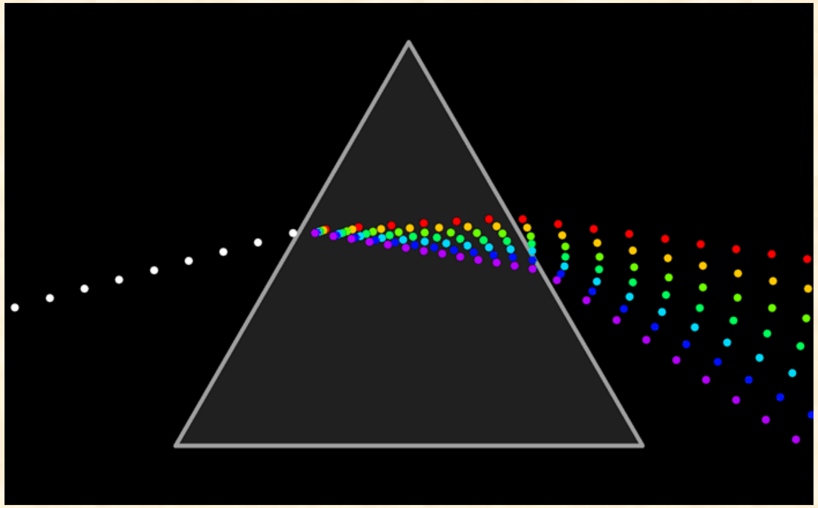
Dispersers

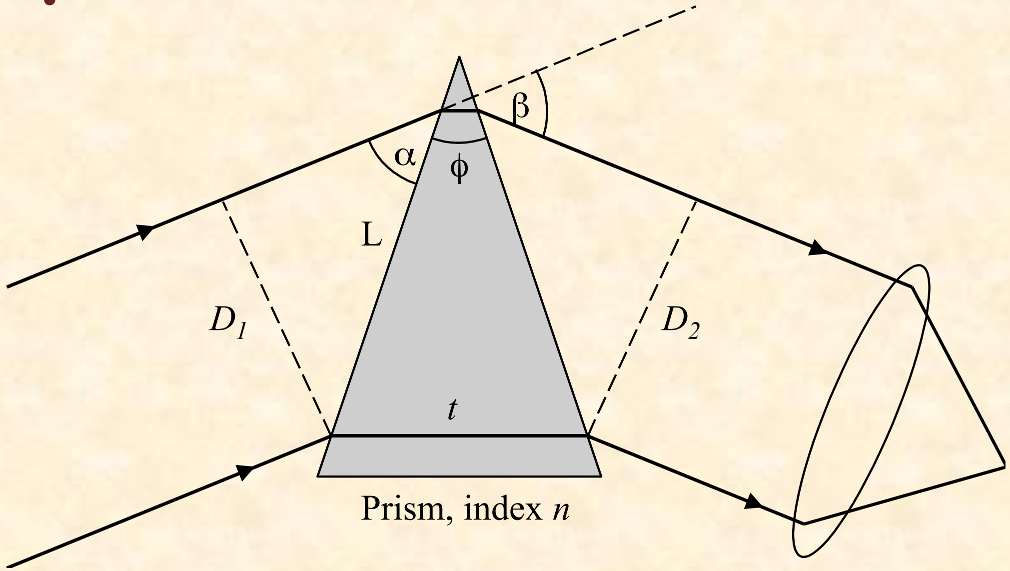
The disperser separates the wavelengths in angular direction. To avoid angular mixing, the beam is collimated. The disperser is characterized by its angular dispersion:

$$D = \frac{\partial \beta}{\partial \lambda}$$

where β is the deviation angle from the un-dispersed direction

The prism





Minimum deviation condition: $\beta = \pi - \phi - 2\alpha$

Fermat priciple: $n \cdot t = 2L\cos\alpha$

$$\Rightarrow \frac{dn}{d\beta} = -\frac{1}{2}\frac{dn}{d\alpha} = \frac{L\sin\alpha}{t} = \frac{D_1}{t}$$

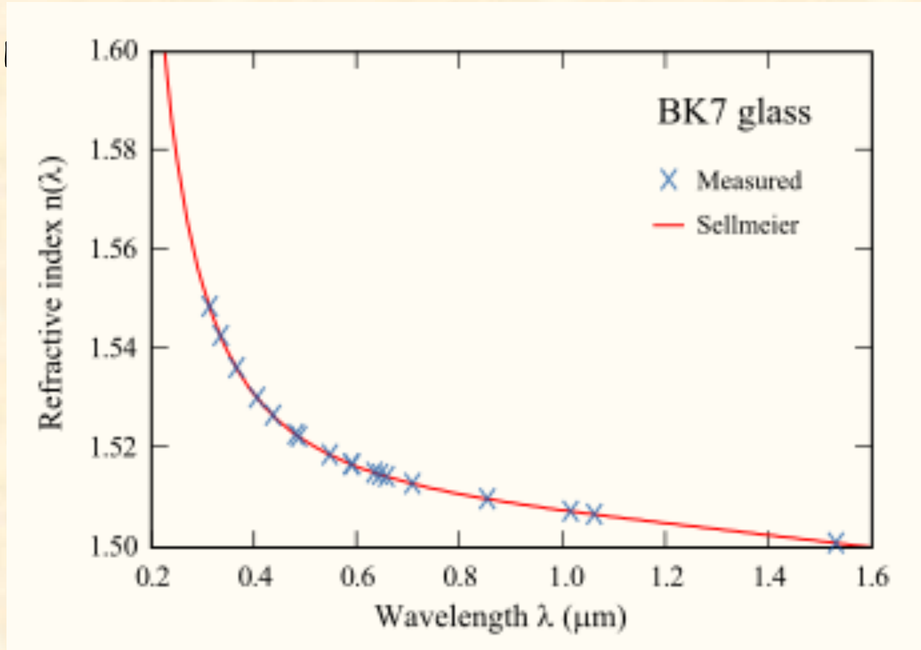
$$\Rightarrow \frac{1}{D_{prism}} = \frac{d\lambda}{d\beta} = \frac{d\lambda}{dn}\cdot\frac{dn}{d\beta} = \frac{D_1}{t}\cdot\frac{d\lambda}{dn} \quad \text{(inverse dispersion)}$$

Prism characteristics

-> High transmittance

-> When used at minimum deviation, compression or enlargement)

-> Produces 'low' dispersion



Prism example: BK7 (normal glass), t = 50 mm, D = 100 mm

$$D_{prism} = \frac{d\beta}{d\lambda} = \frac{t}{D_1} \cdot \frac{dn}{d\lambda} \cong 0.03 \text{ rad/}\mu\text{m @ 550 nm}$$

Prism characteristics

-> Depends mainly on glass material (internal transmittance)

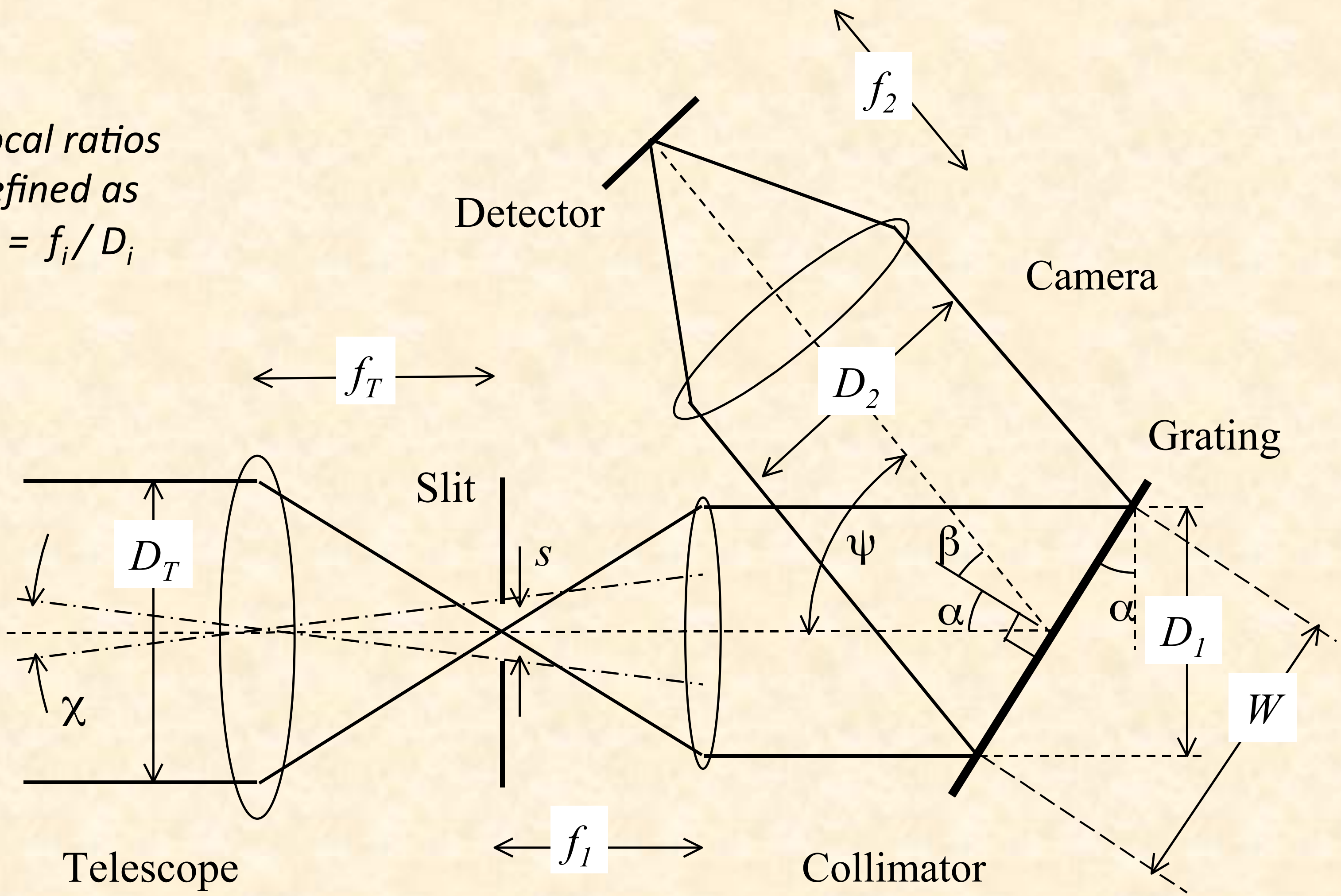
-> Anti-reflection coatings are needed to avoid reflection losses, especially for large apex angles (and large α). The coating must be optimized for the glass and the used angles.

-> Efficiency can be as high as 99%

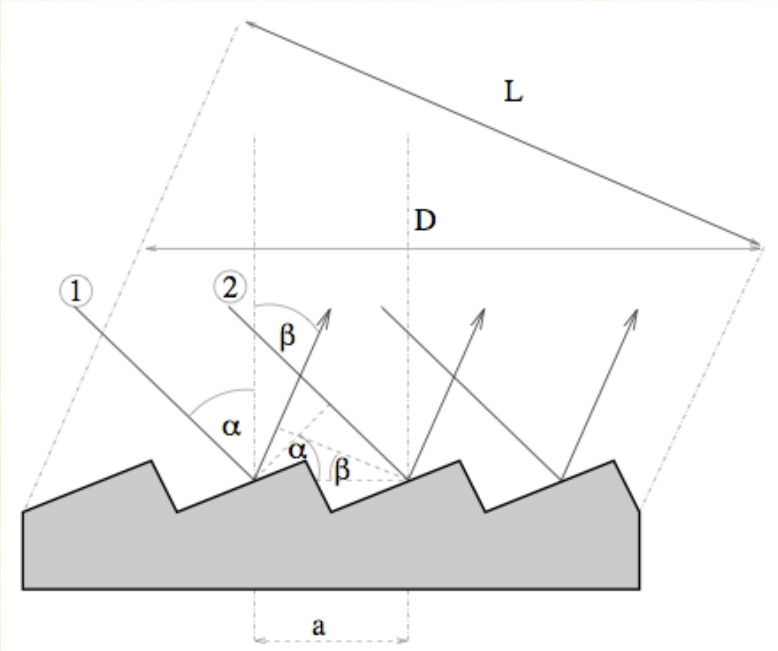
-> The dispersion increases towards the blue wavelengths. For Crown glasses (contain Potassium) the ratio of the dispersion between blue and red is lower than for Flint glasses (contain lead, titanium dioxide or zirconium dioxide) .

Grating spectrograph

Focal ratios defined as $F_i = f_i / D_i$



The diffraction grating



Generic grating equation from the condition of positive interference between various 'grooves':

$$m\rho\lambda = n_1 \sin\alpha + n_2 \sin\beta \quad \text{where} \quad \rho = \frac{1}{a}$$

$$m\rho\lambda = n(\sin\alpha + \sin\beta) \quad \text{reflection grating}$$

$$\text{Angular dispersion}: \quad \frac{d\beta}{d\lambda} = \frac{m\rho}{\cos\beta}$$

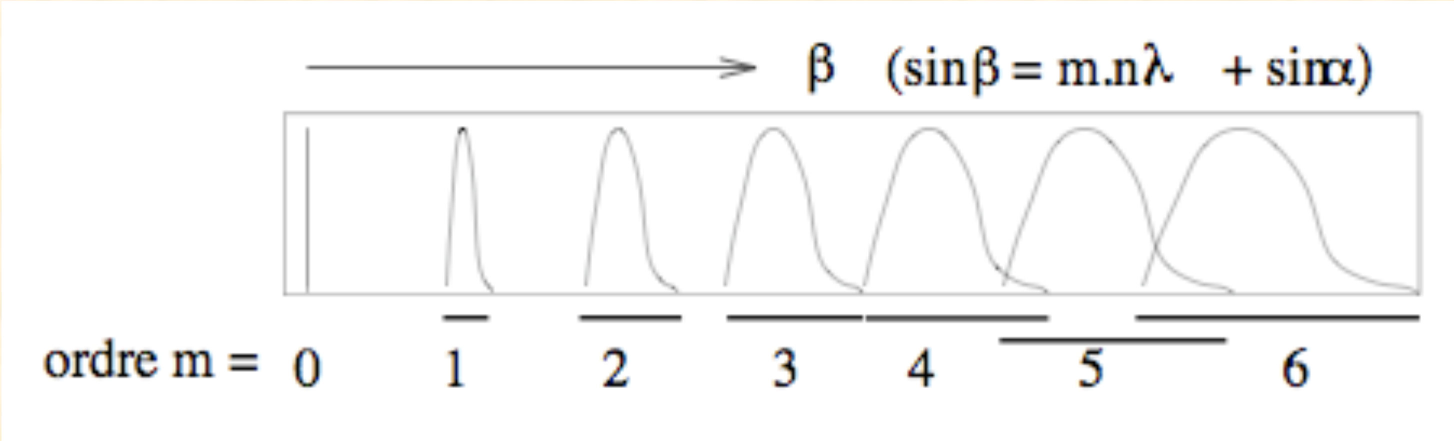
$$\text{Linear dispersion}: \quad \frac{dx}{d\lambda} = \frac{dx}{d\beta}\frac{d\beta}{d\lambda} = f_2 \frac{m\rho}{\cos\beta}$$

Grating characteristics

-> Several orders result for a given wavelength

-> m = 0 for a grating which acts like a mirror -> no dispersion!

-> Orders overlap spatially -> must be filtered or use at m=1

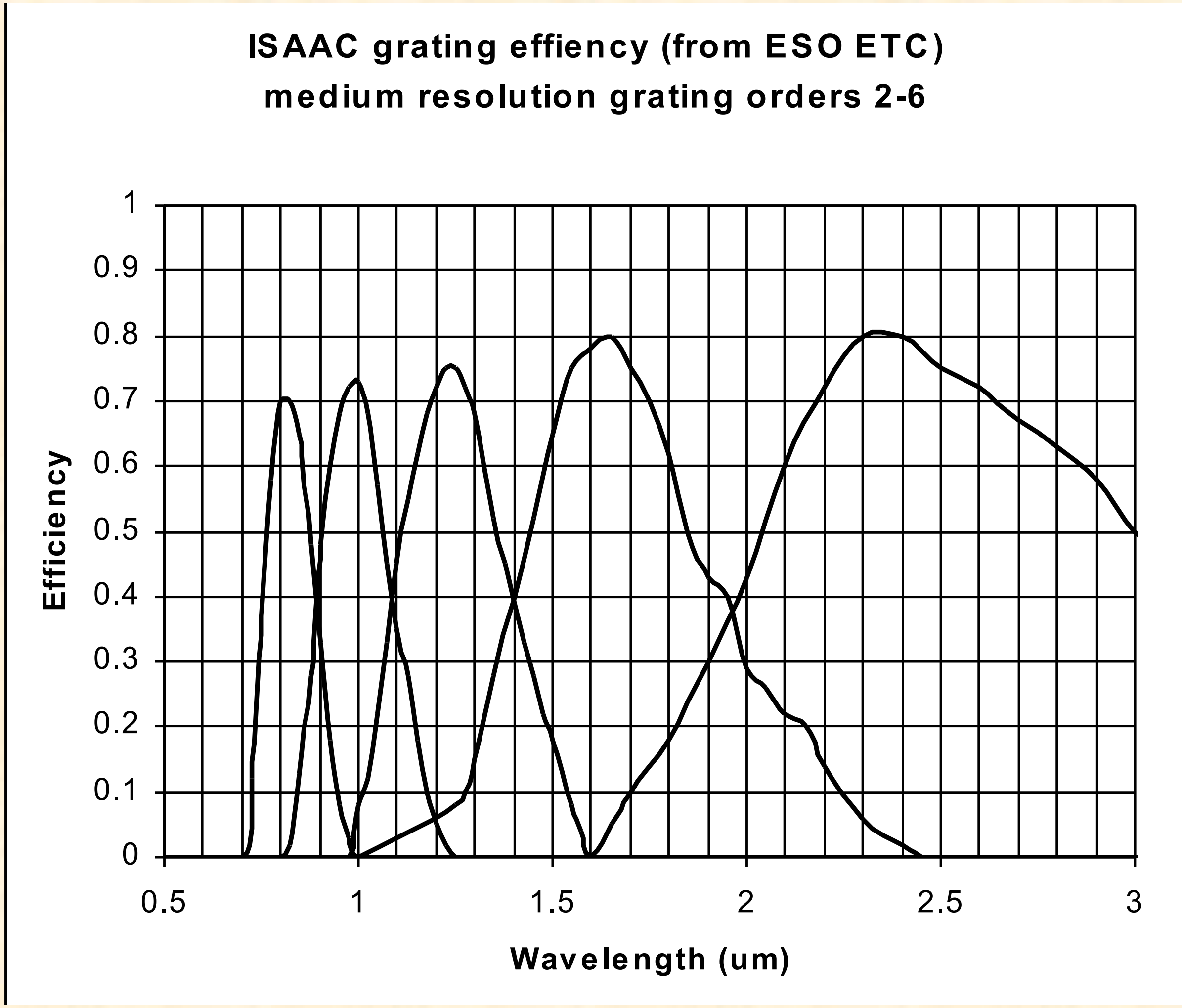


Typical grating example: $m = 1$, $\rho = 1000$ gr/mm, $\sin\alpha + \sin\beta = 1$, $\cos\beta = 1/2$

$$\Rightarrow \frac{d\beta}{d\lambda} = \frac{m\rho}{\cos\beta} = 2 \text{ rad}/\mu\text{m}$$

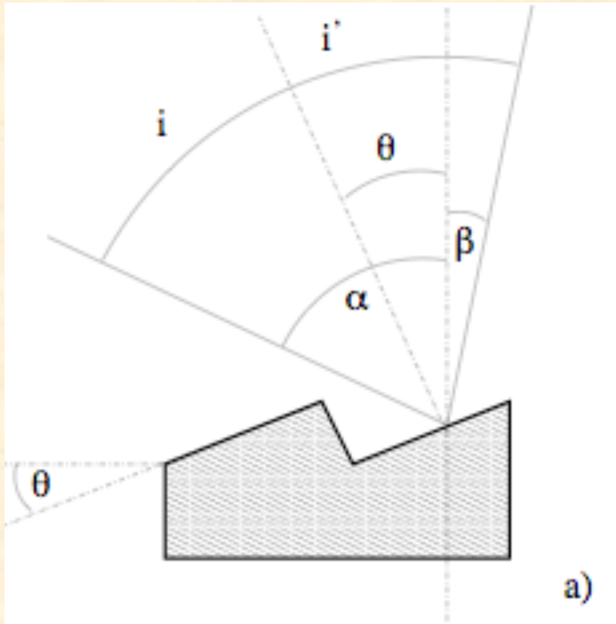
Dispersion typically much higher than for prisms!

Grism efficiency

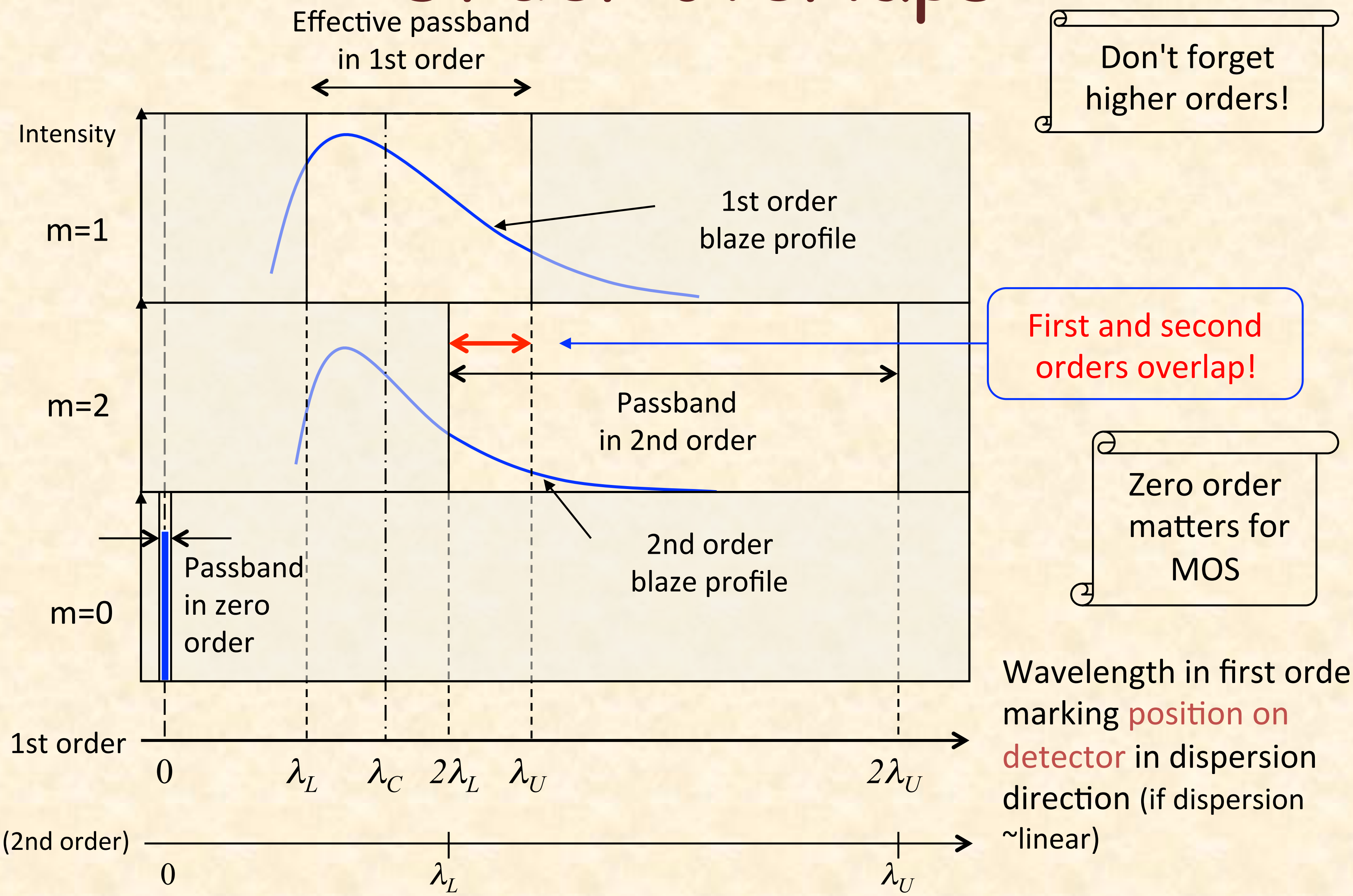


Maximum efficiency obtained when specular groove reflection is matches (Blaze condition):

$$\alpha + \beta = 2\Theta$$



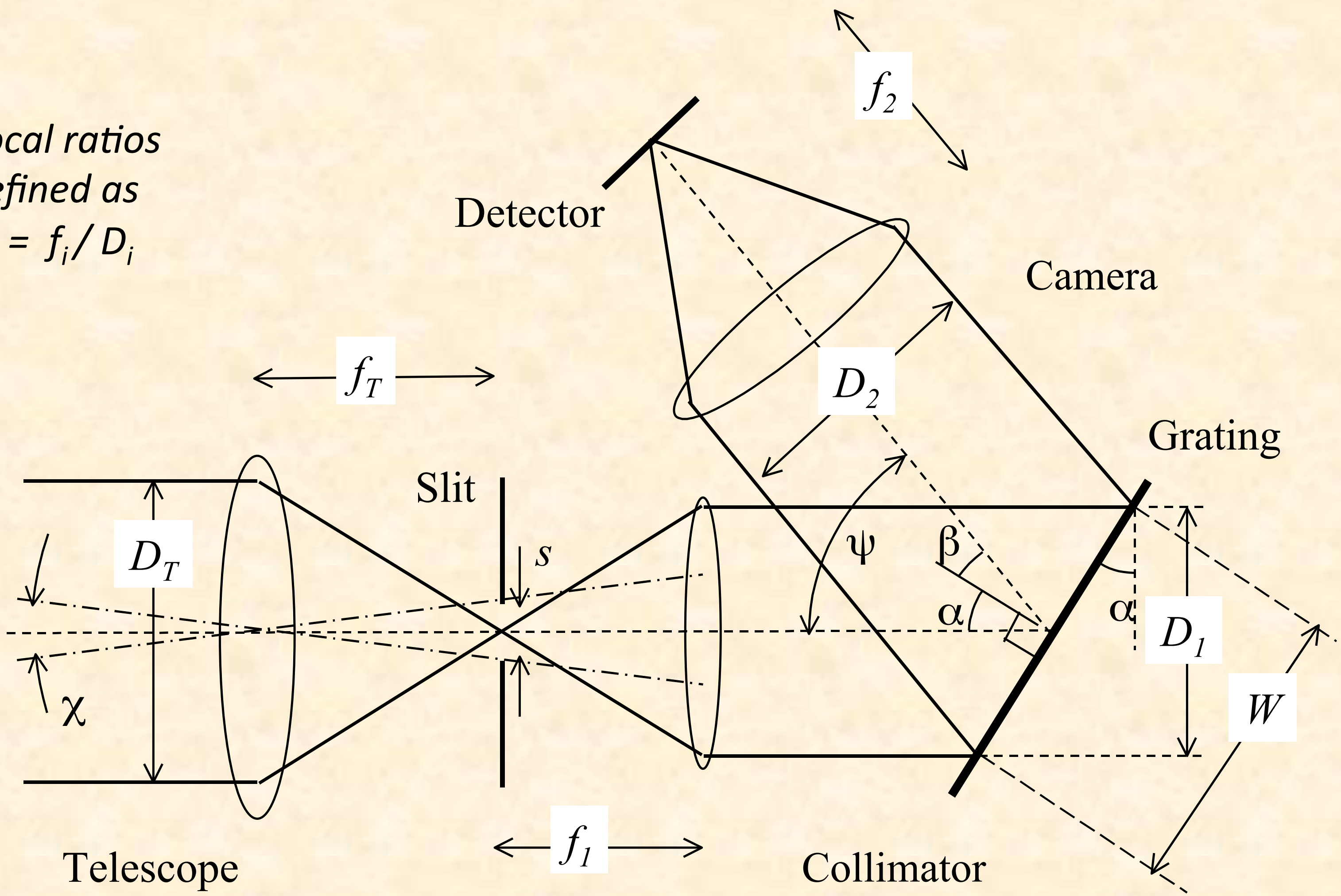
Order overlaps



Wavelength in first order marking position on detector in dispersion direction (if dispersion ~linear)

Resolving power and resolution

Focal ratios defined as $F_i = f_i / D_i$



Resolving power and resolution

The objective translates angles into positions on the detector. Each position (pixel) of the detector 'sees' a given angle of the parallel (collimated) beam

The collimated beam is never perfectly parallel, because either of the limited diameter of the beam, which produces diffraction $\delta\phi = 1.22\ \lambda/D_1$, or because of the finite slit, which produces and angular divergence $\delta\Theta = s/f_1$.

The angular divergence is translated into a distance $\delta\lambda = f_2\ \delta\Theta$ or $\delta\lambda = f_2\ \delta\phi$ on the CCD. This means that over this distances the wavelengths are mixed (cannot be separated angularly.

Resolving power and resolution

Resolving power is the maximum spectral resolution which can be reached if the slit s = 0 and the angular divergence is limited by diffraction arising from the limited beam diameter. For a given Dispersion D we get the resolving power:

$$RP := \frac{\lambda}{\delta\lambda} = \frac{\lambda}{\delta\Phi / D} = \frac{\lambda}{\delta\Phi \cdot \frac{d\lambda}{d\beta}} = \frac{\lambda}{\delta\Phi} \cdot \frac{d\beta}{d\lambda}$$

Spectral resolution is the effective spectral resolution which is finally reached when assuming a finite slit s. For a given Dispersion D we get the spectral resolution:

$$R := \frac{\lambda}{\delta\lambda} = \frac{\lambda}{\delta\Theta / D} = \frac{\lambda}{\delta\Theta \cdot \frac{d\lambda}{d\beta}} = \frac{\lambda}{\delta\Theta} \cdot \frac{d\beta}{d\lambda}$$

Conservation of the ‘étendue’

The étendue is defined as E=A x O, where A is the area of the beam at a given optical surface and O is the solid angle under which the beam passes through the surface.

When following the optical path of the beam through an optical system, E is constant, in particular, it cannot be reduced

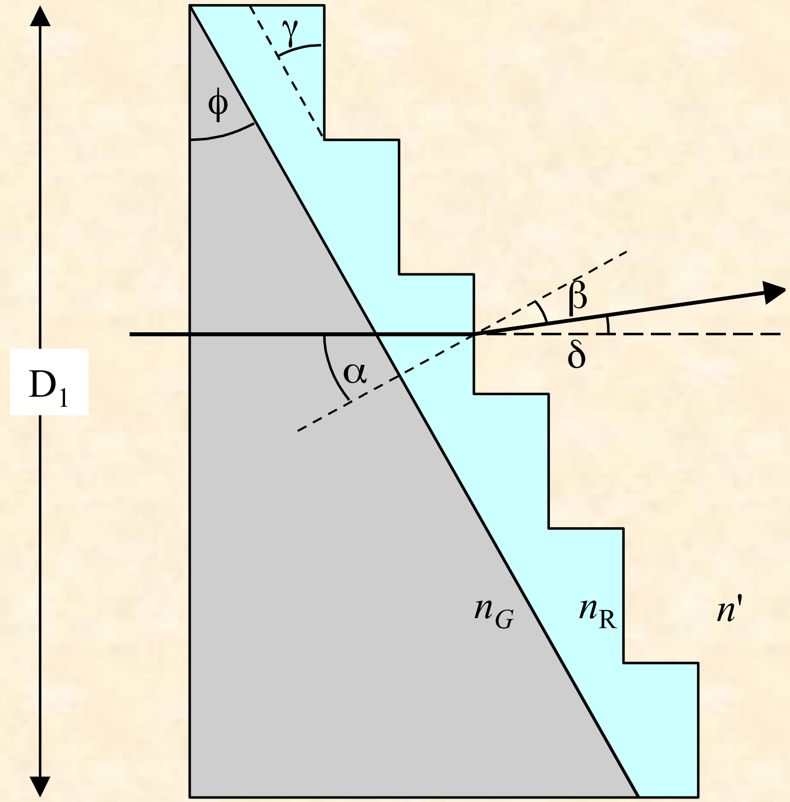
For a telescope, E is the product of the primary mirror surface and the two-dimensional field (in sterad) transmitted by the optical system. Normally, the transmitted field is defines a slit width. When entering spectrograph, the slit x beam aperture at the slit is equal to the etendue E of the telescope. This implies that at fixed spectral resolution, the slit width and the beam diameter cannot be chosen independently, since $d\Theta$ depends on both.

Other dispersers

- Grisms
- VPHG
- Echelle grating

Grisms

- Transmission grating attached to prism
- Allows in-line optical train:
  - simpler to engineer
  - quasi-Littrow configuration - no variable anamorphism
- Inefficient for $\rho > 600/\text{mm}$ due to groove shadowing and other effects



Grism equations

- Modified grating equation:

$$m\rho\lambda = n\sin\alpha + n'\sin\beta$$

- Undeviated condition:

$$m\rho\lambda_U = (n-1)\sin\phi$$

$n' = 1,\ \beta = -\alpha = \phi$

θ = phase difference from centre of one ruling to its edge

- Blaze condition:

$$\theta = 0 \Rightarrow \lambda_B = \lambda_U$$

- Resolving power
  (same procedure as for grating)

$$R = \frac{m\rho\lambda W}{\chi D_T}$$

$$W = D_1 / \cos\phi$$

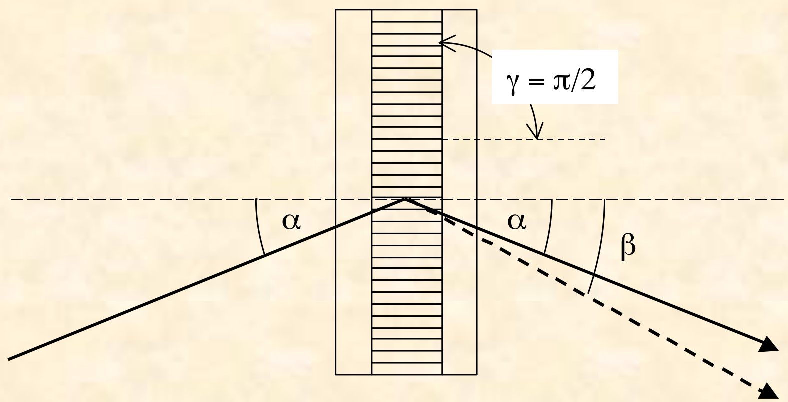
$$R = \frac{(n-1)\tan\phi D_1}{\chi D_T}$$

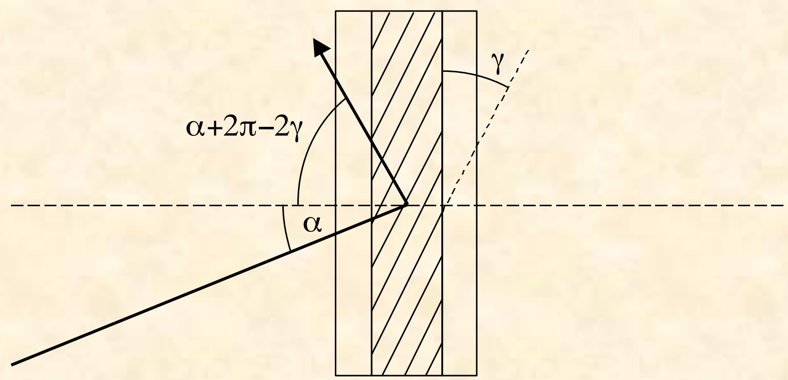
Volume Phase Holographic gratings

- So far we have considered *surface relief* gratings
- An alternative is *VPH* in which refractive index varies harmonically throughout the body of the grating:
- Don't confuse with '*holographic*' gratings (SR)
- Advantages: $n_g(x,z) = n_g + \Delta n_g \cos\left[2\pi\rho_g\left(x\sin\gamma + z\cos\gamma\right)\right]$
  - Higher peak efficiency than SR
  - Possibility of very large size with high ρ
  - Blaze condition can be altered *(tuned)*
  - Encapsulation in flat glass makes more robust
- Disadvantages
  - Tuning of blaze requires *bendable spectrograph!*
  - Issues of wavefront errors and cryogenic use

VPH configurations

- *Fringes* = planes of constant *n*
- Body of grating made from *Dichromated Gelatine* (DCG) which permanently adopts fringe pattern generated holographically
- Fringe orientation allows operation in transmission or reflection

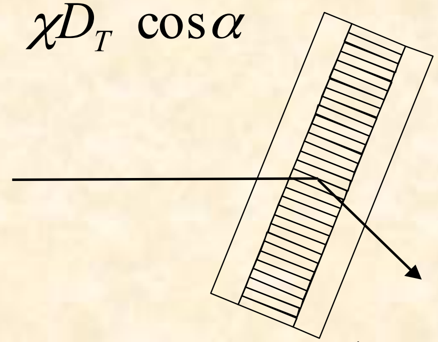




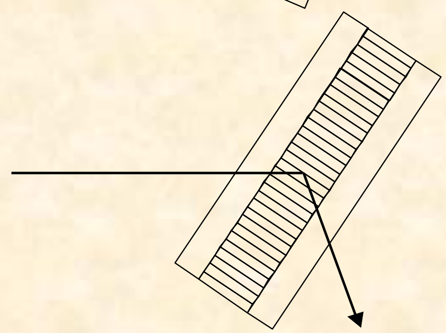
VPH equations

- Modified grating equation: $$m\rho\lambda = \sin\alpha + \sin\beta$$
- Blaze condition: $$m\rho\lambda_B = 2n_g \sin\alpha_g = 2\sin\alpha$$

  = *Bragg* diffraction $$n_g \sin\alpha_g = \sin\alpha$$
- Resolving power: $$R = \frac{m\rho\lambda W}{\chi D_T} = \frac{m\rho\lambda}{\chi D_T}\frac{D_1}{\cos\alpha}$$
- Tune blaze condition by tilting grating (α)

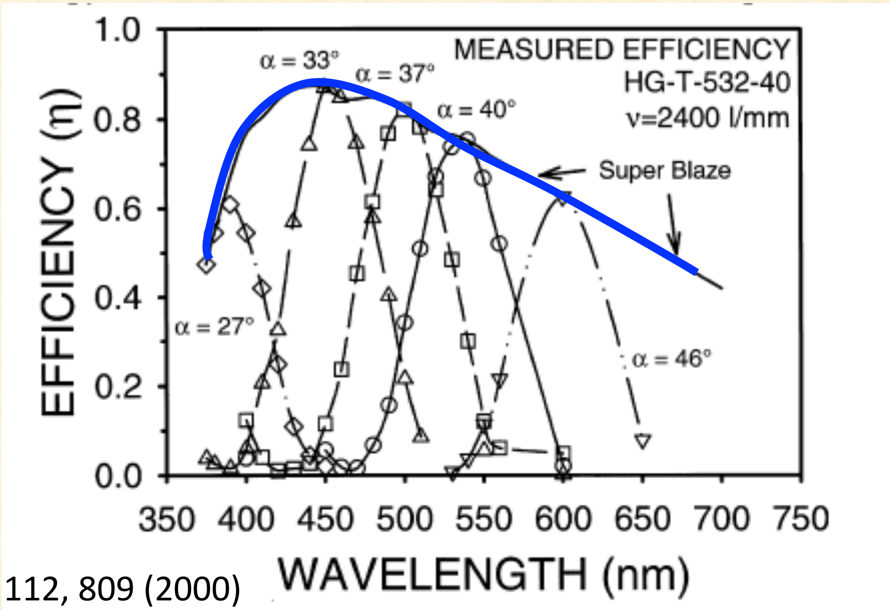


- Collimator-camera angle must also change by 2α $\Rightarrow$ mechanical complexity



VPH efficiency

- Kogelnik's analysis when: $$\frac{2\pi\lambda d\rho_g^2}{n_g} . > 10$$
- Bragg condition when: $$\Delta n_g d . \approx \frac{\lambda}{2}$$
- Bragg envelopes (efficiency FWHM):
  - in wavelength: $$\Delta\lambda \propto \left(\frac{1}{\rho_g \tan\alpha_g}\right)\Delta n_g = \left(\frac{1}{\rho_g \tan\alpha_g}\right)\frac{\lambda}{d}$$
  - in angle: $$\Delta\alpha \propto \frac{1}{\rho_g d}$$
- Broad blaze requires
  - thin DCG
  - large index amplitude
- *Superblaze*



Barden et al. PASP 112, 809 (2000)

Resolving power and resolution

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$$RP := \frac{\lambda}{\delta\lambda} = \frac{\lambda}{\delta\Phi / D} = \frac{\lambda}{\delta\Phi \cdot \frac{d\lambda}{d\beta}} = \frac{\lambda}{\delta\Phi} \cdot \frac{d\beta}{d\lambda}$$

Spectral resolution is the effective spectral resolution which is finally reached when assuming a finite slit s. For a given Dispersion D we get the spectral resolution:

$$R := \frac{\lambda}{\delta\lambda} = \frac{\lambda}{\delta\Theta / D} = \frac{\lambda}{\delta\Theta \cdot \frac{d\lambda}{d\beta}} = \frac{\lambda}{\delta\Theta} \cdot \frac{d\beta}{d\lambda}$$

Example of spectrographs

Basic Parameters

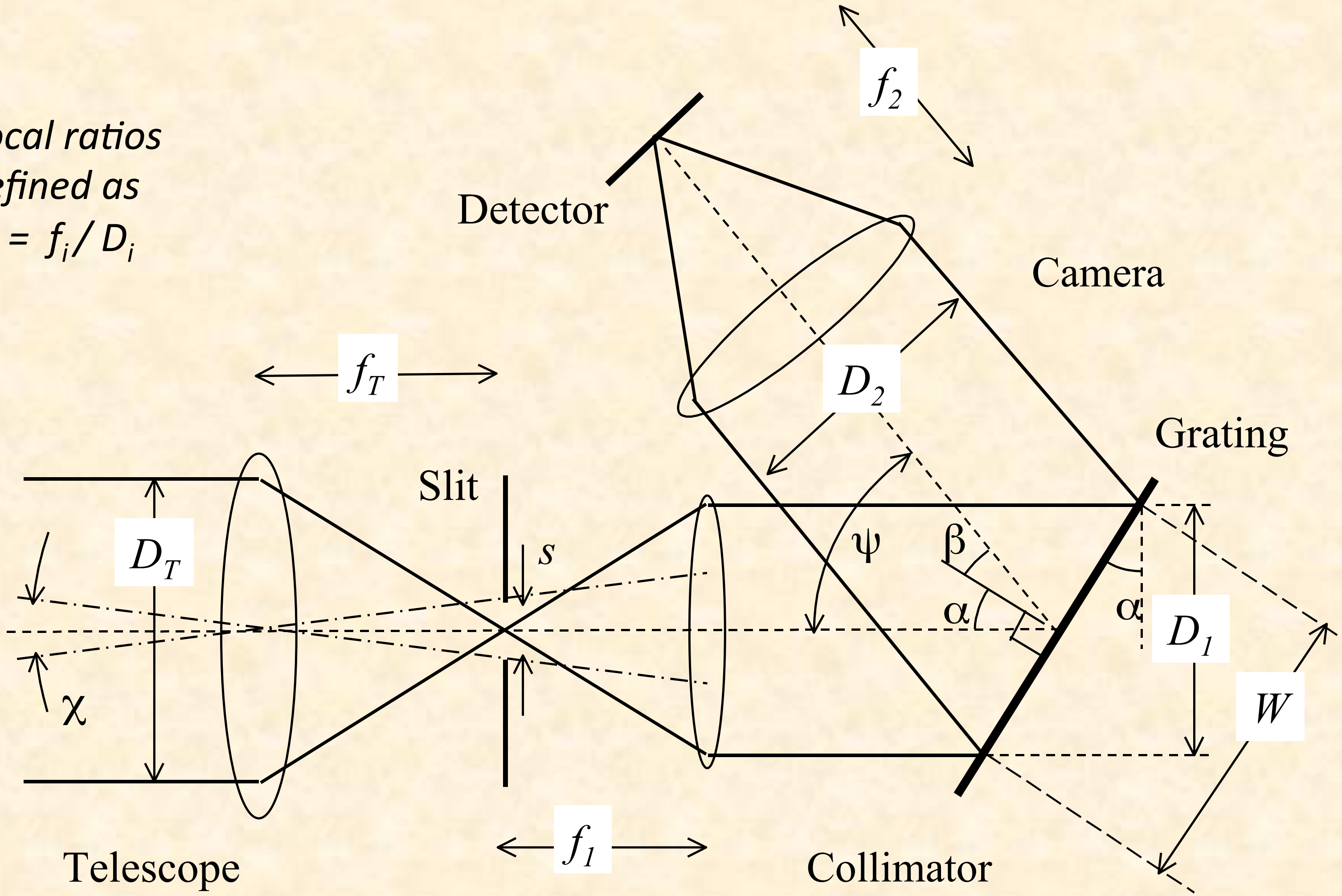
- Telescope diameter: D_T
- Source/seeing/slit: s_{sky}
- Collimated beam of the spectrograph: D_1

Other parameters:

- Telescope focal length: f_T
- Telescope F-number (focal ratio): $F_T = F = f_T/D_T$
- Physical slit/fiber width: $s = f_T \times s_{sky}$
- Collimator focal length: f_1
- Objective focal length: f_2

Grating spectrograph

Focal ratios defined as
$F_i = f_i / D_i$



Example of simple spectrographs

Spectral resolution:

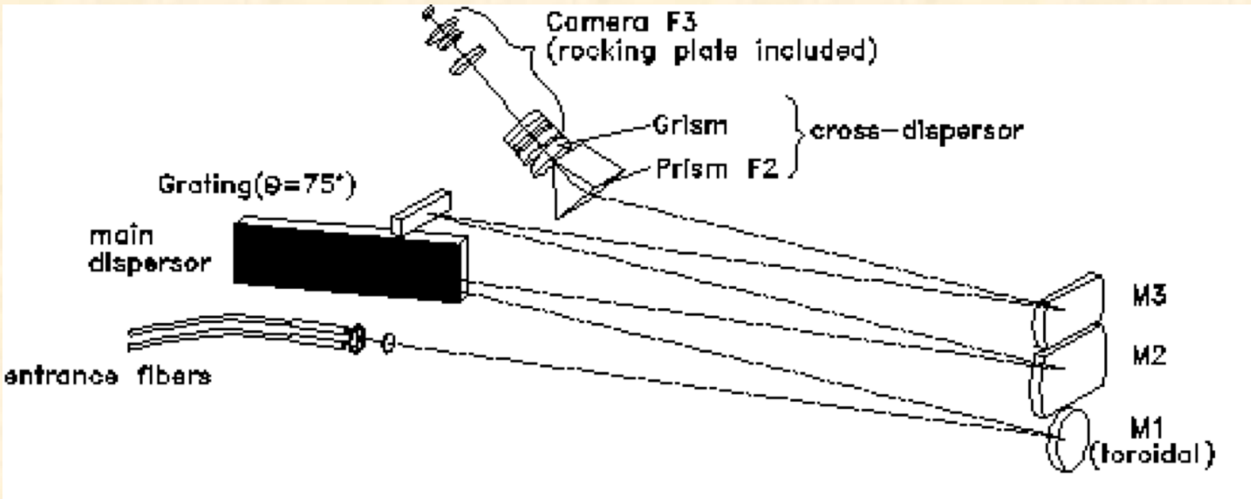
$$R := \frac{\lambda}{\delta\lambda} = \frac{\lambda}{\delta\Theta} \cdot Disp = \frac{\lambda}{\frac{s}{f_1}} \cdot Disp = \frac{\lambda}{\frac{f_T \cdot s_{Sky}}{\frac{f_T \cdot D_1}{D_T}}} \cdot Disp = \lambda \cdot \frac{D_1}{D_T} \cdot \frac{Disp}{s_{Sky}}$$

where $$Disp = \frac{d\beta}{d\lambda}$$

Example of 'simple' spectrographs

Coralie@Euler:

- Telescope diameter: D_T = 1.2 m
- Source/seeing/slit: s_{sky} = 1 arcsec
- Collimated beam of the spectrograph: D_1 = 75 mm



Example of 'simple' spectrographs

With prism: BK7 (normal glass), t = 50 mm

$$D_{prism} = \frac{d\beta}{d\lambda} = \frac{t}{D_1} \cdot \frac{dn}{d\lambda} \quad \cong \ 0.04 \text{ rad/}\mu\text{m @ 550 nm}$$

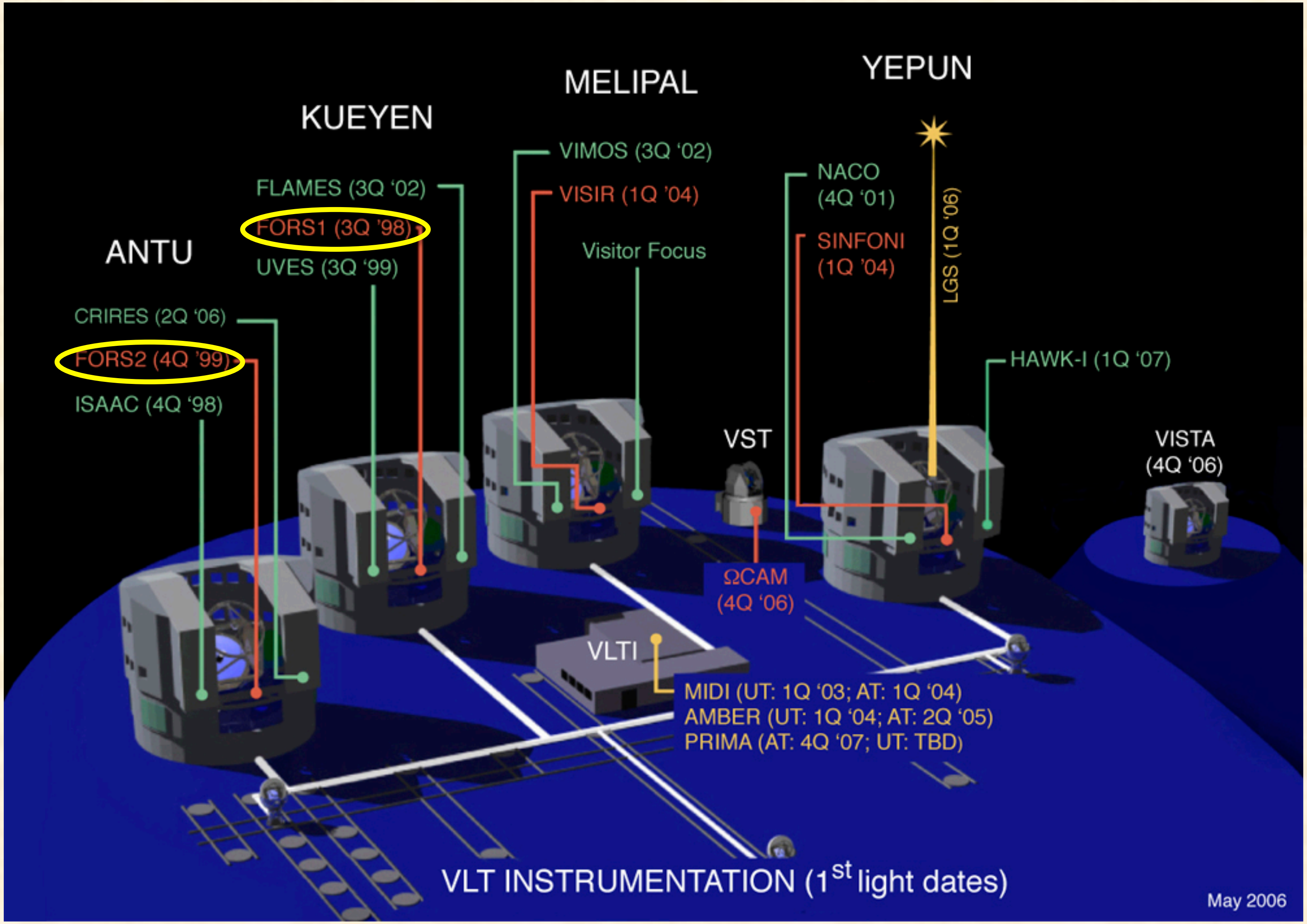
$$R_{prism} = \frac{\lambda}{\delta\lambda} = \lambda \cdot \frac{D_1}{D_T} \cdot \frac{D_{prism}}{s_{Sky}} = 0.55 \cdot \frac{0.075}{1.2} \cdot \frac{0.04}{5 \cdot 10^{-6}} \approx 275$$

With grism: m = 1, ρ = 150 gr/mm, cosβ=1

$$D_{grism} = \frac{d\beta}{d\lambda} = \frac{m\rho}{\cos\beta} = 0.15 \text{ rad/}\mu\text{m}$$

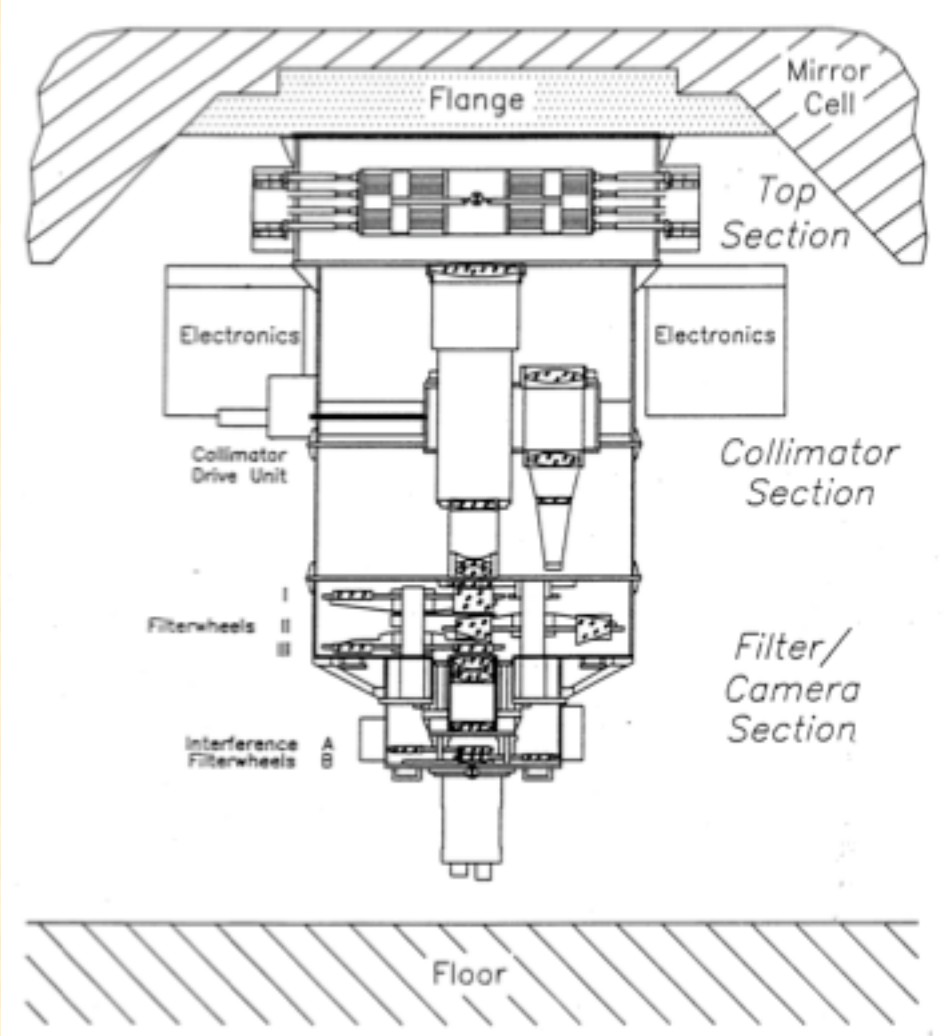
$$R_{grism} = \frac{\lambda}{\delta\lambda} = \lambda \cdot \frac{D_1}{D_T} \cdot \frac{D_{grism}}{s_{Sky}} = 0.55 \cdot \frac{0.075}{1.2} \cdot \frac{0.15}{5 \cdot 10^{-6}} \approx 1000$$

FORS@VLT



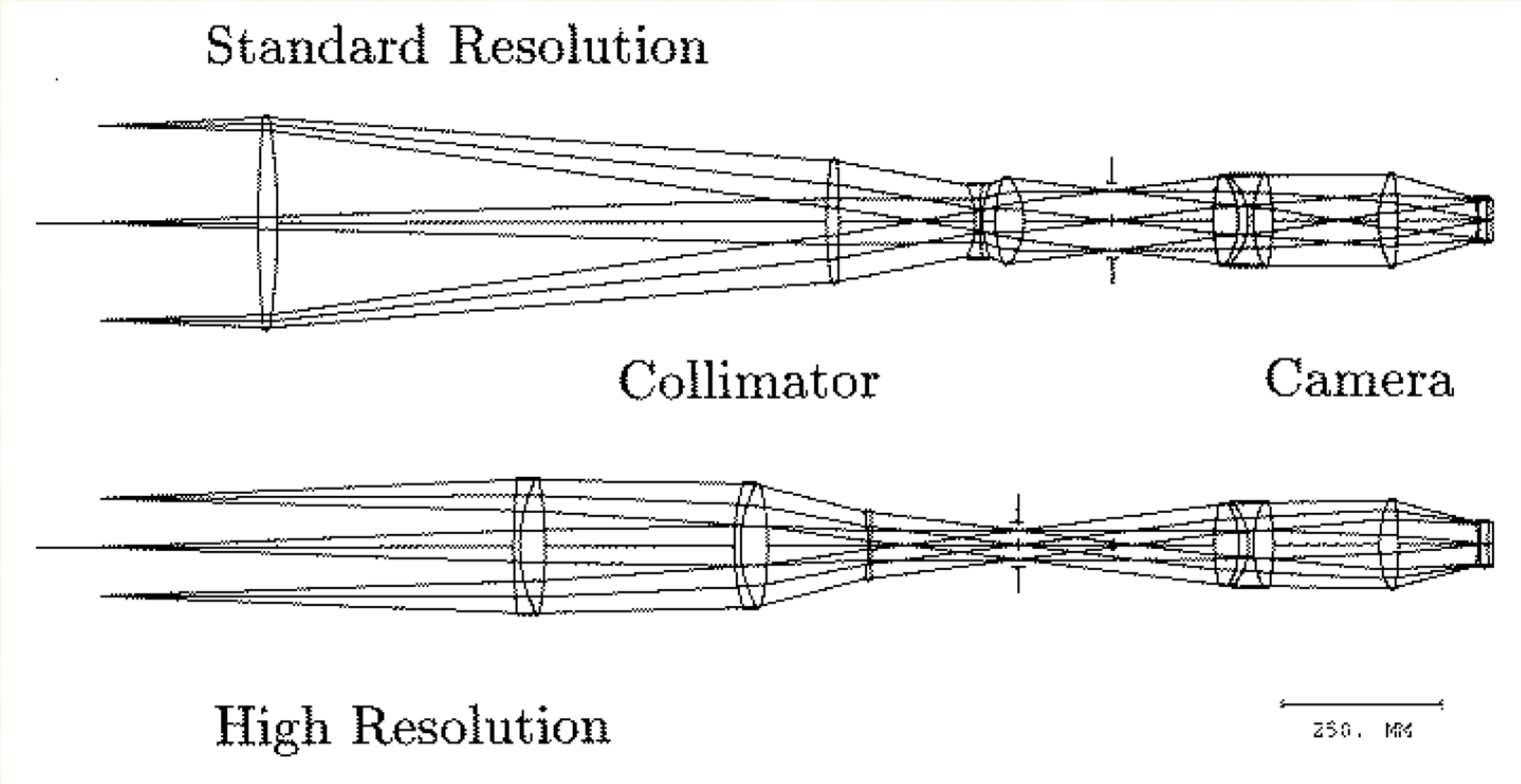
YEPUN
MELIPAL
KUEYEN
ANTU
VIMOS (3Q '02)
VISIR (1Q '04)
Visitor Focus
FLAMES (3Q '02)
FORS1 (3Q '98)
UVES (3Q '99)
CRIRES (2Q '06)
FORS2 (4Q '99)
ISAAC (4Q '98)
NACO
(4Q '01)
SINFONI
(1Q '04)
LGS (1Q '06)
HAWK-I (1Q '07)
VST
VISTA
(4Q '06)
ΩCAM
(4Q '06)
VLTI
MIDI (UT: 1Q '03; AT: 1Q '04)
AMBER (UT: 1Q '04; AT: 2Q '05)
PRIMA (AT: 4Q '07; UT: TBD)
VLT INSTRUMENTATION (1st light dates)
May 2006

FORS@VLT



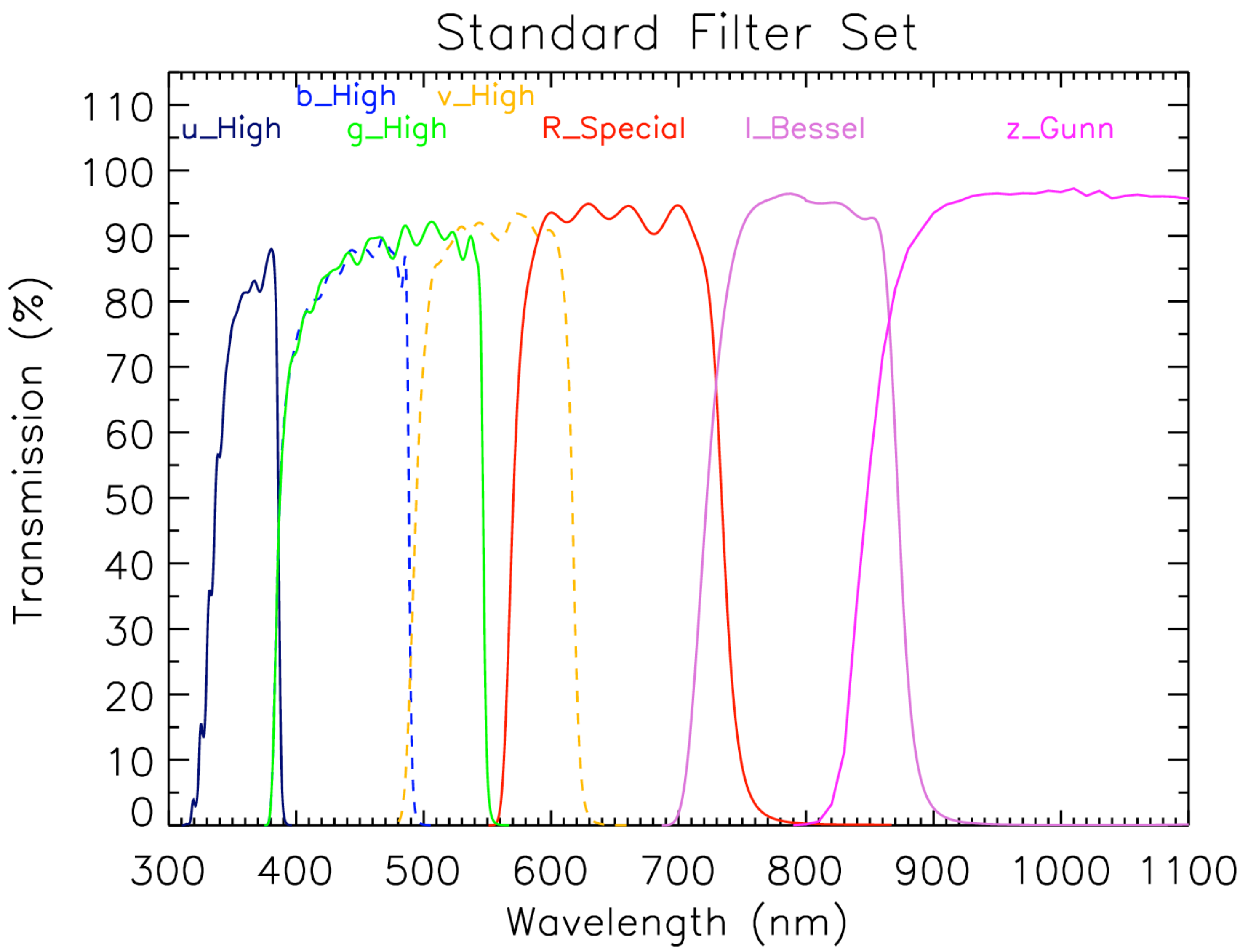
Mirror
Cell
Flange
Top
Section
Electronics
Electronics
Collimator
Drive Unit
Collimator
Section
Filterwheels
I
II
III
Filter/
Camera
Section
Interference
Filterwheels
A
B
Floor

FORS@VLT



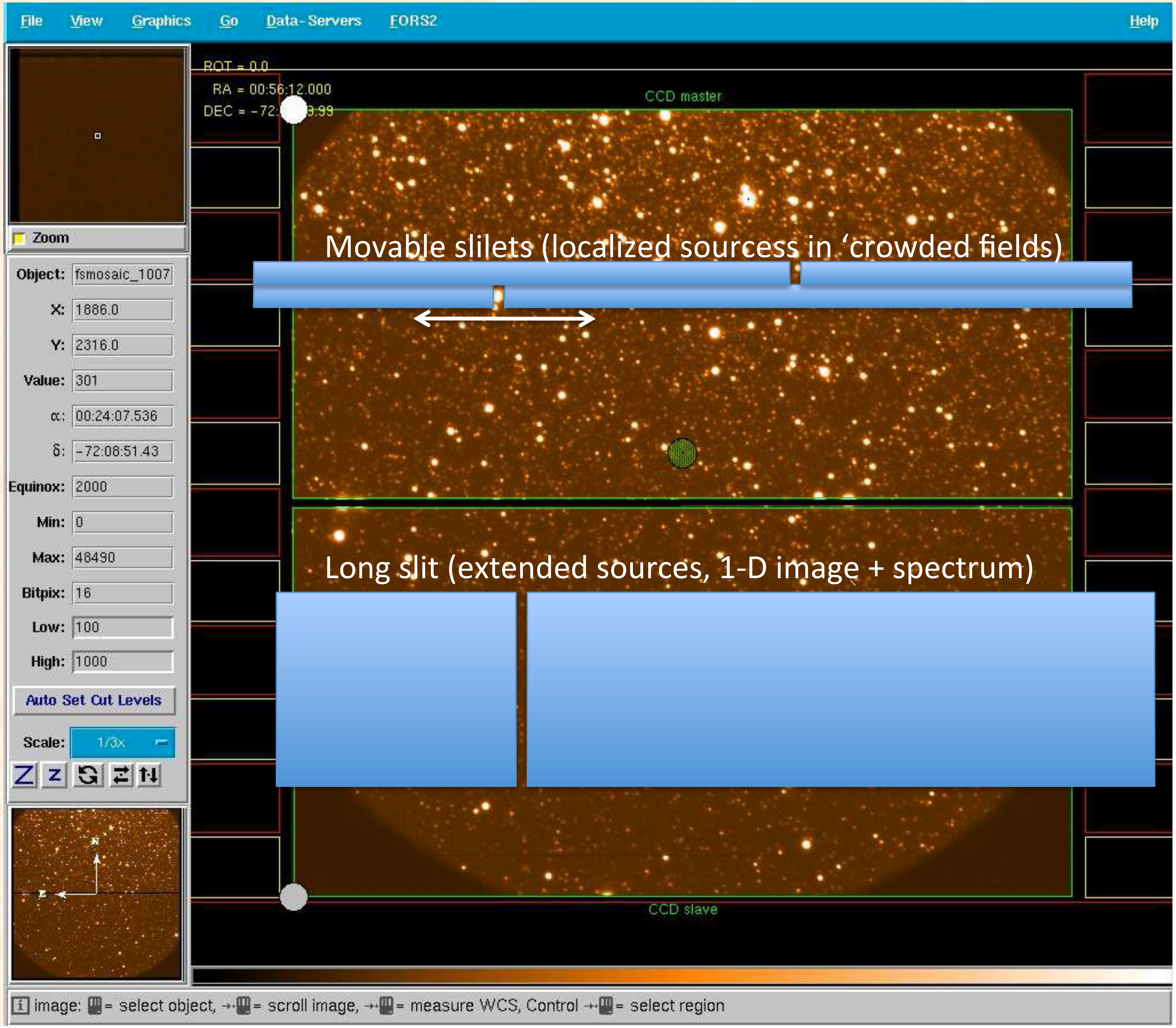
Standard Resolution
Collimator
Camera
High Resolution
250. MM

FORS: Filter mode

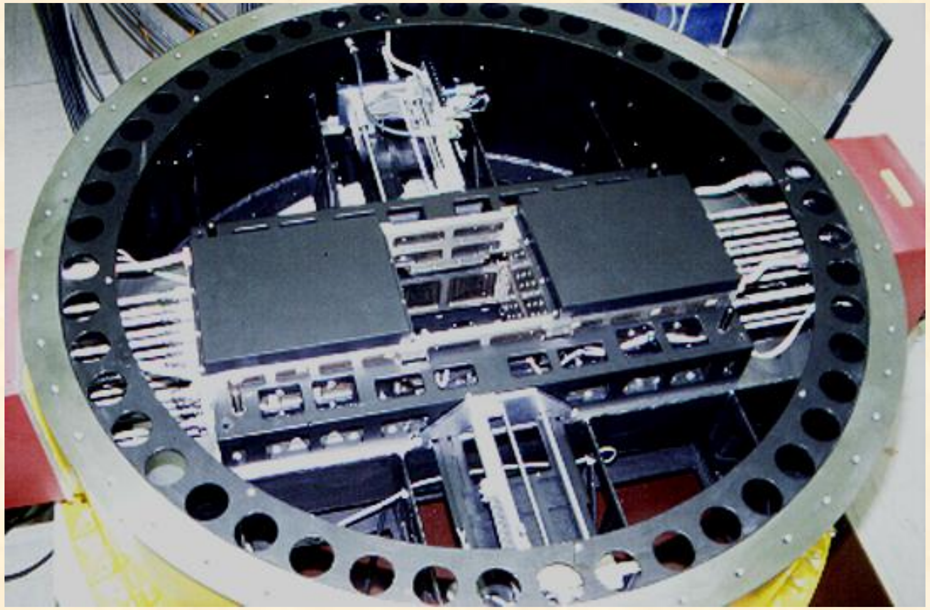


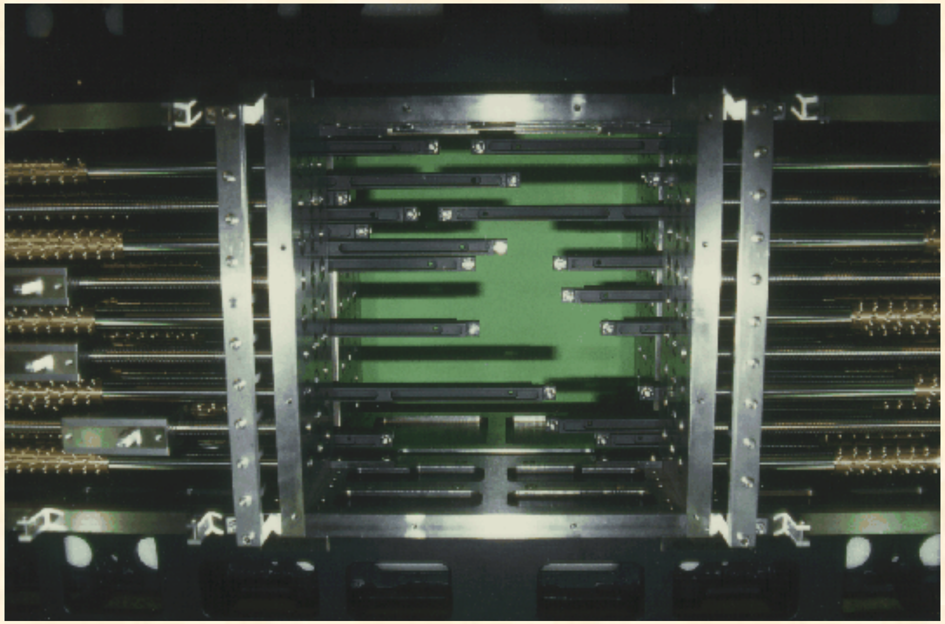
FORS: Grism mode

- Grisms from 150 gr/mm to 1400 gr/mm
- Spectroscopic modes
  - 'slitless' MOS mode (R is given by seeing)
  - Mask with up to 9 'long slits' of 0.3" x 6.8'
  - Up to 19 movable 'slitlets' of 0.3" x 22.5"
  - MOS-MXU: Laser-cut masks (any format)
- Spectral resolution depends on grism dispersion and slit width in dispersion direction.

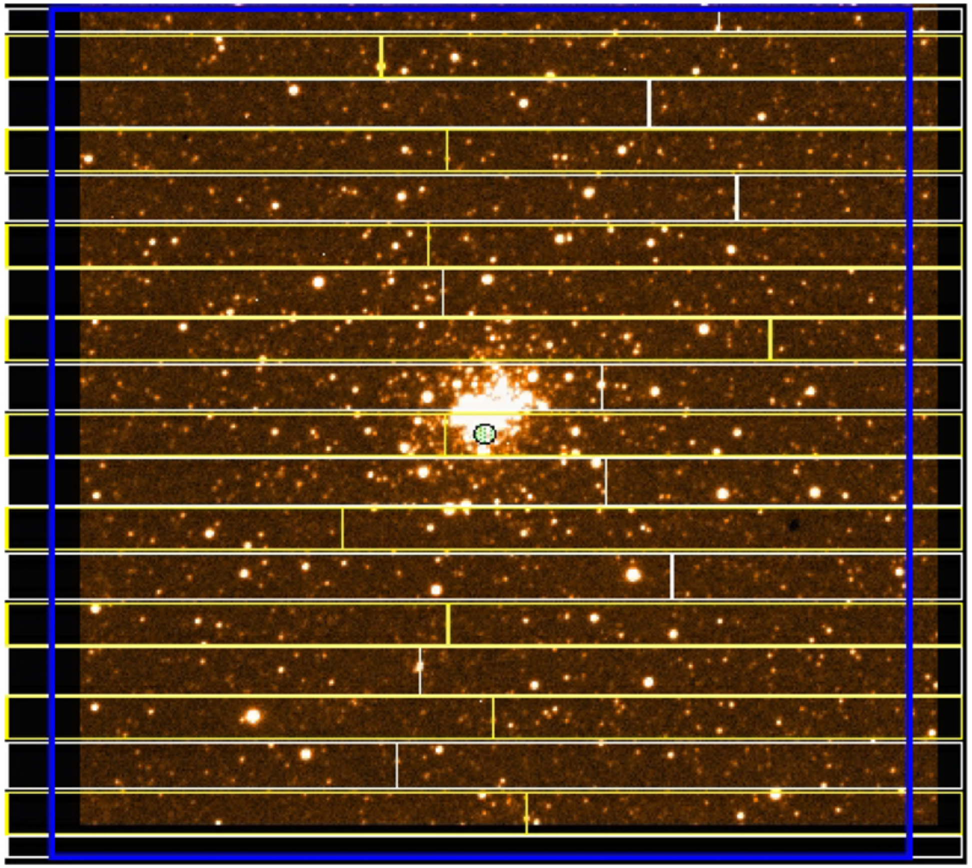

File
View
Graphics
Go
Data-Servers
FORS2
Help
ROT = 0.0
RA = 00:56:12.000
CCD master
Zoom
Object: fsmosaic_1007
X: 1886.0
Y: 2316.0
Value: 301
α: 00:24:07.536
δ: -72:08:51.43
Equinox: 2000
Min: 0
Max: 48490
Bitpix: 16
Low: 100
High: 1000
Auto Set Cut Levels
Scale: 1/3x
Movable slilets (localized sourcess in 'crowded fields)
Long slit (extended sources, 1-D image + spectrum)
CCD slave
image: = select object, = scroll image, = measure WCS, Control = select region

FORS: MOS mode



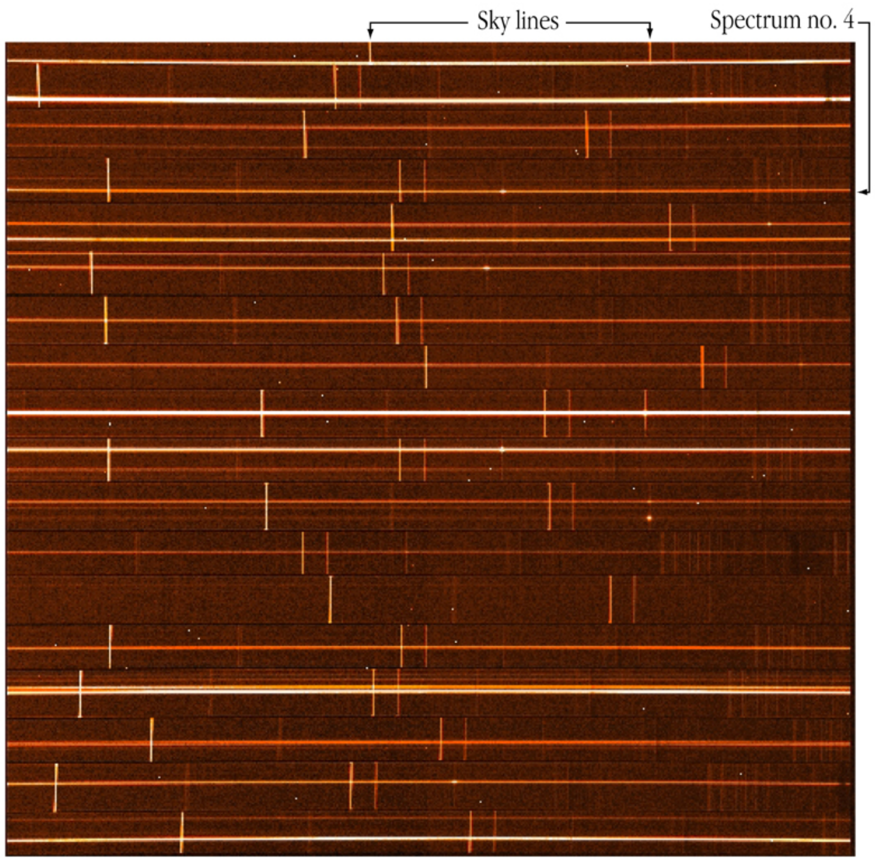


FORS@VLT



Open Cluster NGC 330 in SMC - VLT UT1 + FORS1 (MOS-mode)

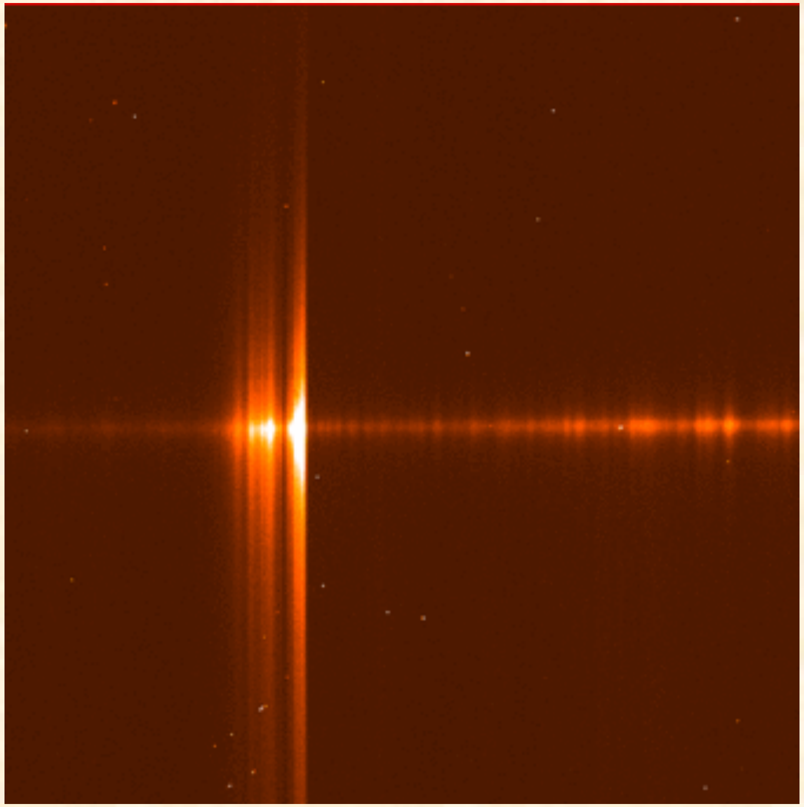
ESO PR Photo 38c/98 (7 October 1998)



Spectra of Stars in Open Cluster NGC 330 in SMC - VLT UT1 + FORS1 (MOS-mode)

ESO PR Photo 38d/98 (7 October 1998)

FORS@VLT



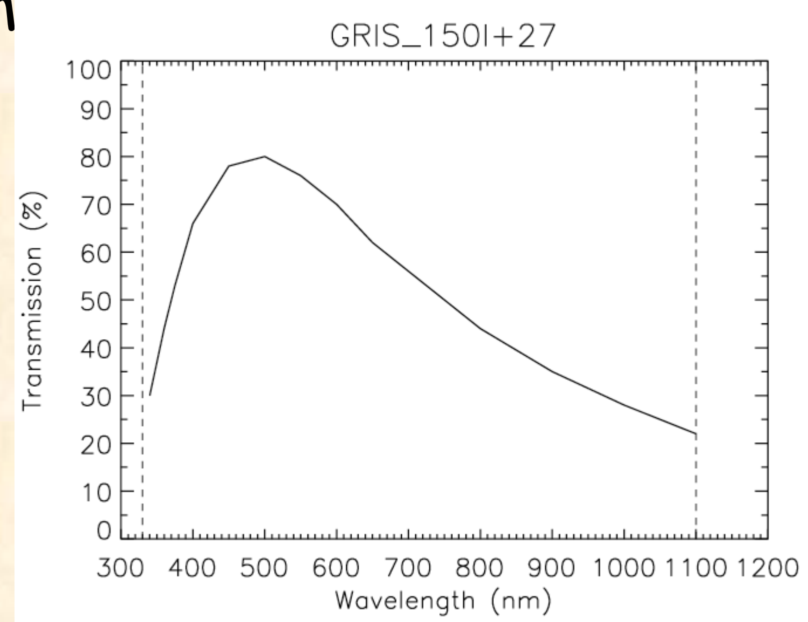
This image shows the first spectrum obtained of the comet 1995 Q1. The spectral coverage extends from about 3650 Angstrom (left) to 4100 Angstrom (right) in the violet region. The spectrograph slit was oriented along the main tail at position angle ~ 145 degrees. The total slit length was 5.6 arcminutes. The spectrum is typical for a comet at Comet Bradfield's current distance from the Sun (0.5 A.U., or about 75 million kilometres).

FORS: Spectral resolution

- Telescope diameter: D_T = 8.2 m
- Source/seeing/slit: s_{sky} = 0.3 arcsec
- Collimated beam : D_1 = 125 mm

FORS2 cross disperser grisms for the HITS mode

Grism	$\lambda_{central}$ [Å]	λ_{range} [Å]	dispersion [Å/mm]/[Å/pixel]	$\lambda/\Delta\lambda$ at $\lambda_{central}$	filter
XGRIS_600B+92	4452	3300 - 6012	50/0.75	780	
XGRIS_300I+91	8575	6000 - 11000	108/1.62	660	OG590+32
XGRIS_300I+91	8575	5032 - (6600)	108/1.62	660	



With grism: m = 1, ρ = 1400 gr/mm, cosβ=1

$$D_{grism} = \frac{d\beta}{d\lambda} = \frac{m\rho}{\cos\beta} = 1.4 \text{ rad/}\mu\text{m}$$

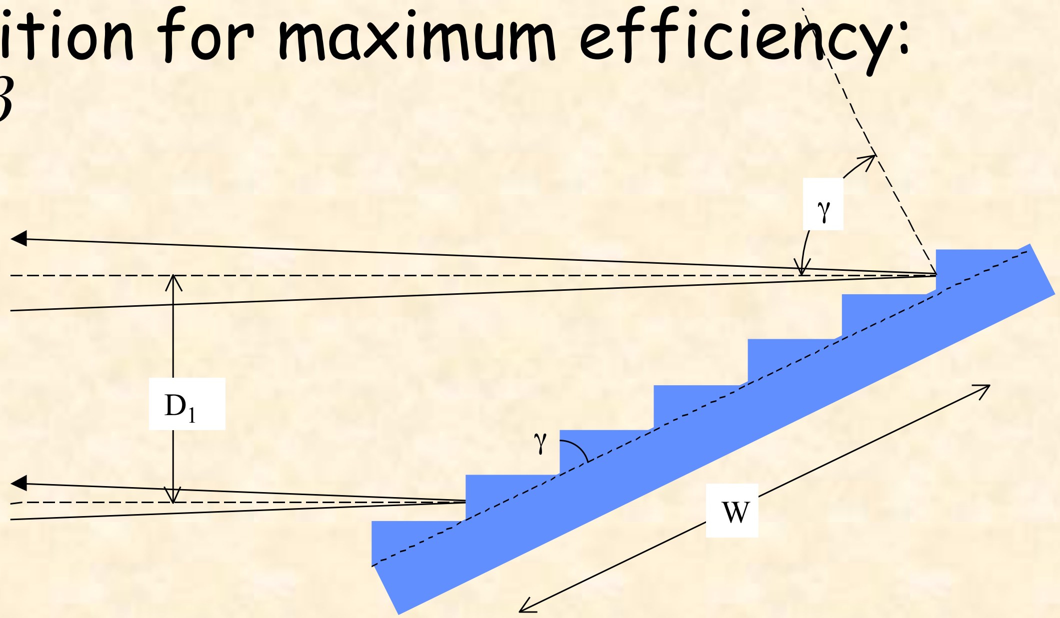
$$R_{grism} = \frac{\lambda}{\delta\lambda} = \lambda \cdot \frac{D_1}{D_T} \cdot \frac{D_{grism}}{s_{Sky}} = 0.55 \cdot \frac{0.125}{8.2} \cdot \frac{1.4}{5 \cdot 10^{-6}} \approx 2350$$

Example of 'simple' spectrographs

- With single prisms resolution remains small
- Possibility to increase dispersion by adding up several prisms
- With gratings or grisms, the spectral resolution is up to several 1000 but still modest.
- Other 'tricks' required

Echelle grating

- Increase dispersion of the ordinary greating by increasing the difference between entrance and exit angle
- The use in Littrow condition will make the mounting symmetric and maximize $\alpha + \beta$, since a is set equal to β: $\alpha = \beta$
- Use in blaze condition for maximum efficiency: Groove angle $\gamma = \beta$



Echelle grating

From the grating equation we derive the dispersion law of an echelle grating:

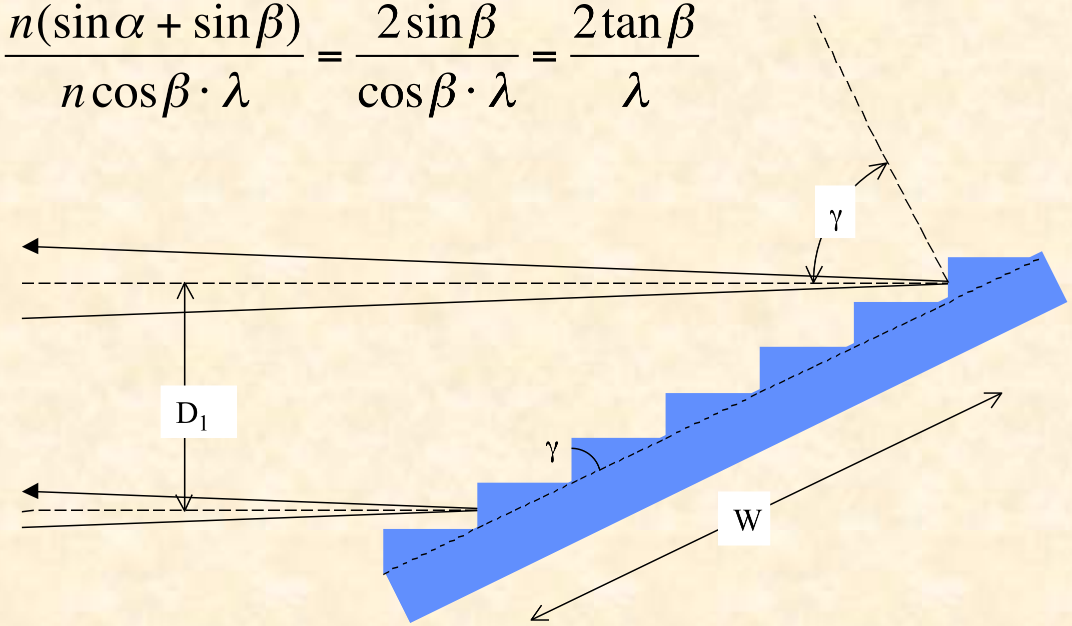
$$n\sin\beta(\lambda) = m\rho\lambda - n\sin(\alpha) \;\Big|\, d/d\lambda$$

$$\Rightarrow n\cos\beta \cdot \frac{d\beta}{d\lambda} = m\rho$$

$$\Rightarrow \frac{d\beta}{d\lambda} = \frac{m\rho}{n\cos\beta} = \frac{n(\sin\alpha + \sin\beta)}{n\cos\beta \cdot \lambda} = \frac{2\sin\beta}{\cos\beta \cdot \lambda} = \frac{2\tan\beta}{\lambda}$$

Example: R = 4 grating:

$$\Rightarrow \frac{d\beta}{d\lambda} = \frac{8}{\lambda} \cong 15 \text{ rad } \mu\text{m}^{-1} \text{ !!!}$$



Characteristics of Echelle grating

- High dispersion -> high resolution
- Spectrum becomes VERY long and efficiency drops because of blaze function
- Alternative: use at high order, e.g. m = 100 (ρ = 30 gr/mm)
- -> Orders overlap spacially and must be separated (filtering, pre-dispersion or cross-dispersion)

Free spectral range: $$F_\lambda = \frac{\lambda}{m}$$

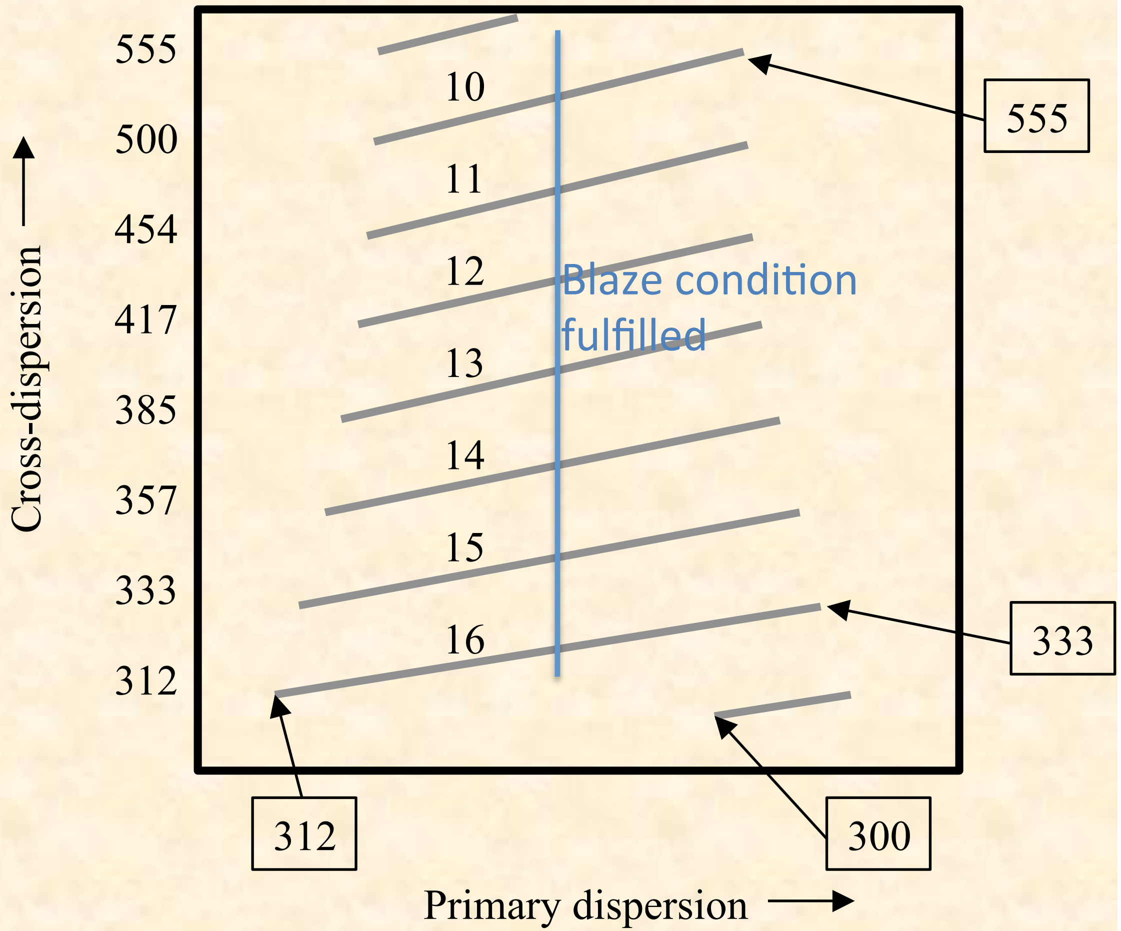
Numbers of orders for full 'octave': $$N = \frac{m}{2}$$

Multiple orders

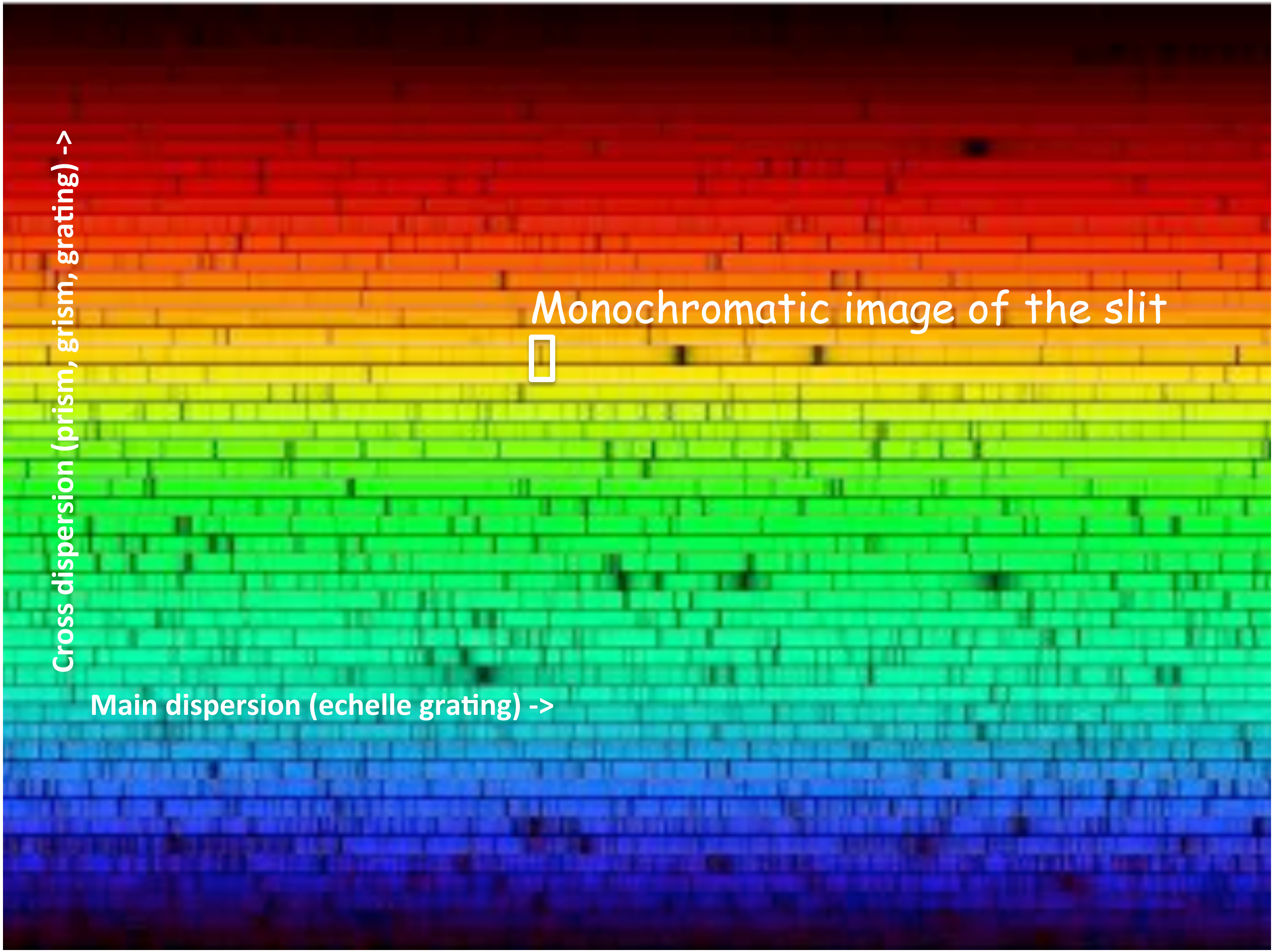
- Many orders to cover desired $\lambda\lambda$: *Free spectral range*

  $F_{\lambda} = \lambda/m$
- Orders lie on top of each other:

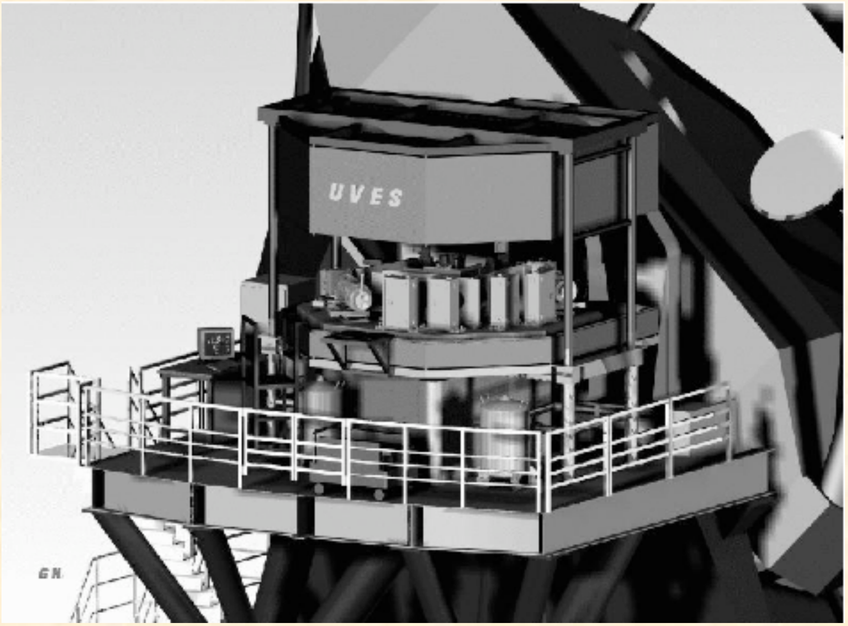
  $\lambda(m) = \lambda(n) \times (n/m)$
- Solution:
  - use narrow passband filter to isolate one order at a time
  - cross-disperse to fill detector with many orders at once

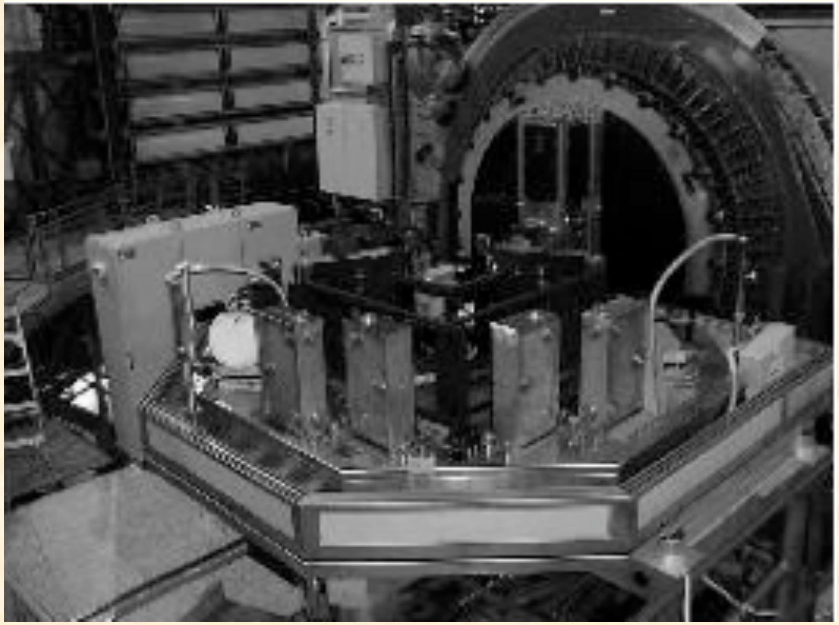


Cross dispersion may use prisms or low dispersion grating

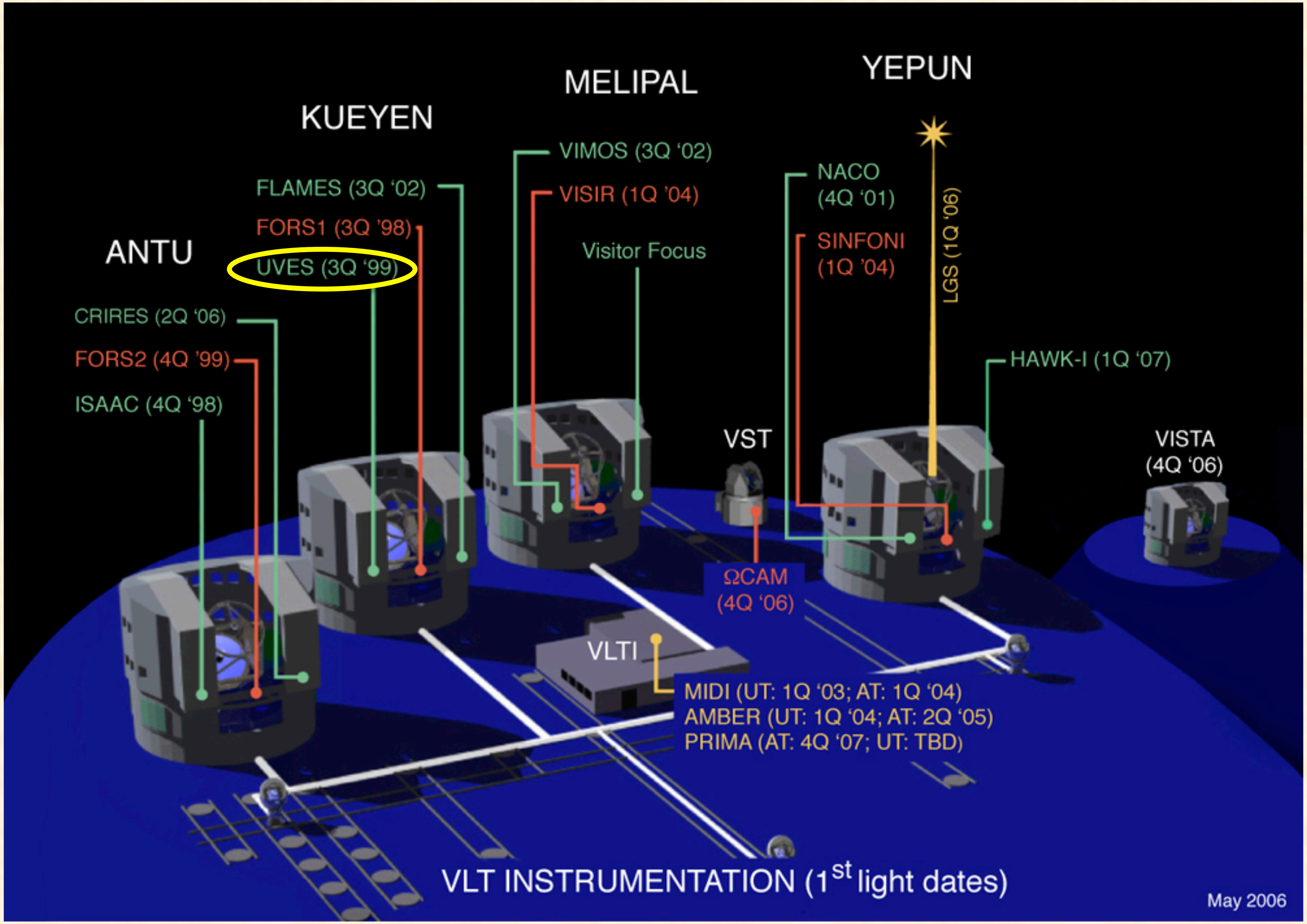

Monochromatic image of the slit
Cross dispersion (prism, grism, grating) ->
Main dispersion (echelle grating) ->

UVES@VLT





UVES@VLT



YEPUN
MELIPAL
KUEYEN
ANTU
VIMOS (3Q '02)
VISIR (1Q '04)
FLAMES (3Q '02)
FORS1 (3Q '98)
UVES (3Q '99)
Visitor Focus
NACO
(4Q '01)
SINFONI
(1Q '04)
LGS (1Q '06)
CRIRES (2Q '06)
FORS2 (4Q '99)
ISAAC (4Q '98)
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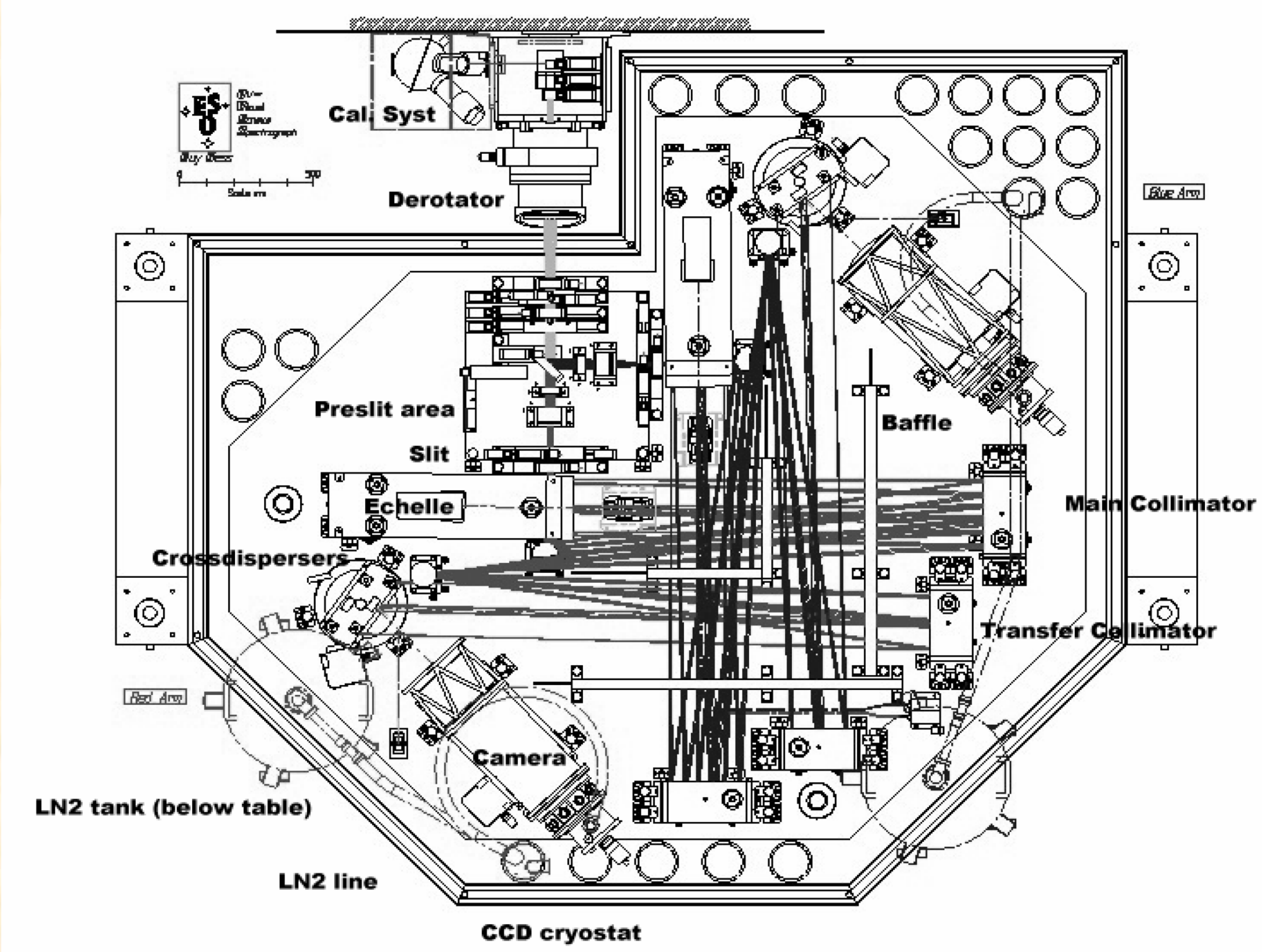
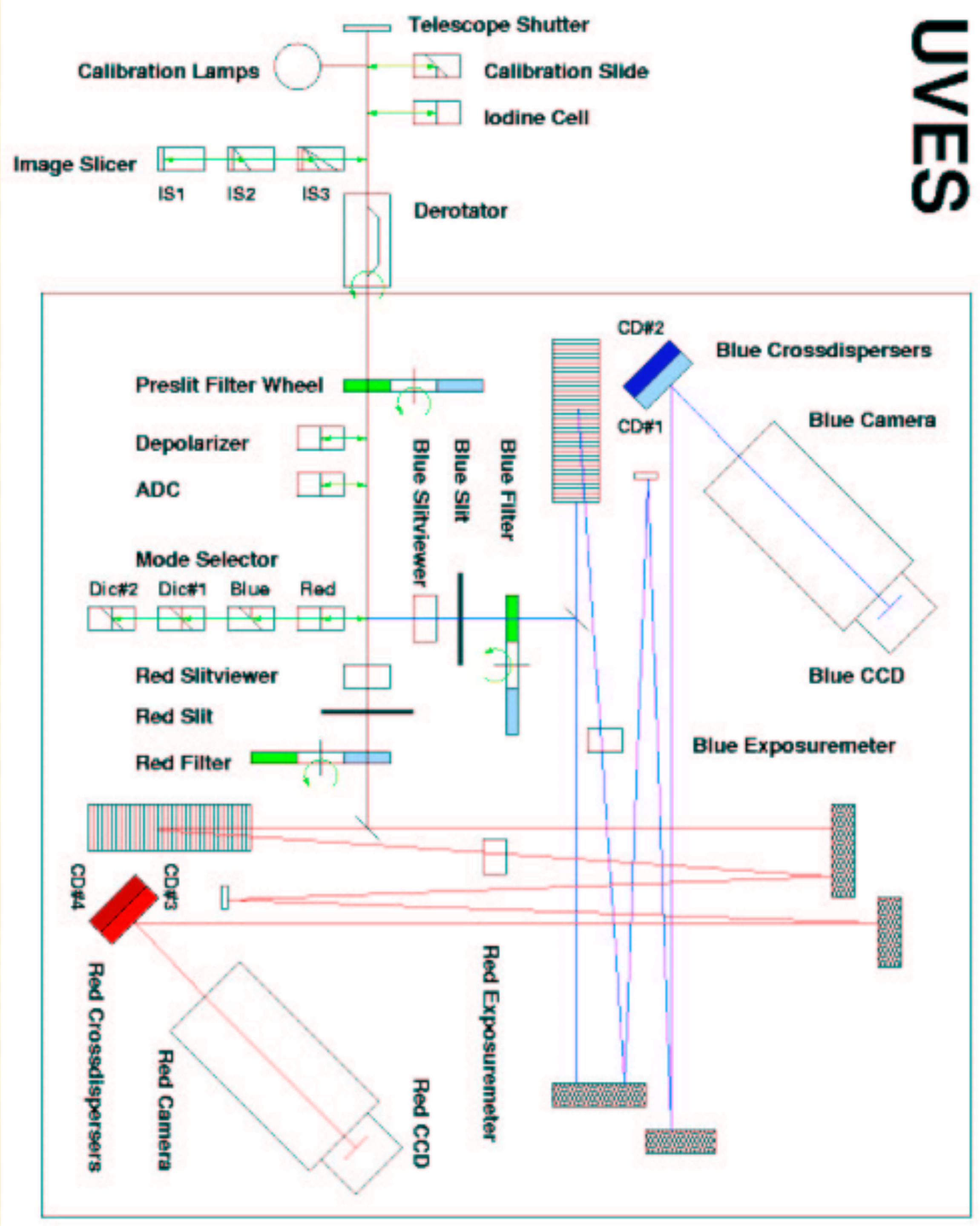
VST
VISTA
(4Q '06)
ΩCAM
(4Q '06)
VLTI
MIDI (UT: 1Q '03; AT: 1Q '04)
AMBER (UT: 1Q '04; AT: 2Q '05)
PRIMA (AT: 4Q '07; UT: TBD)
VLT INSTRUMENTATION (1st light dates)
May 2006

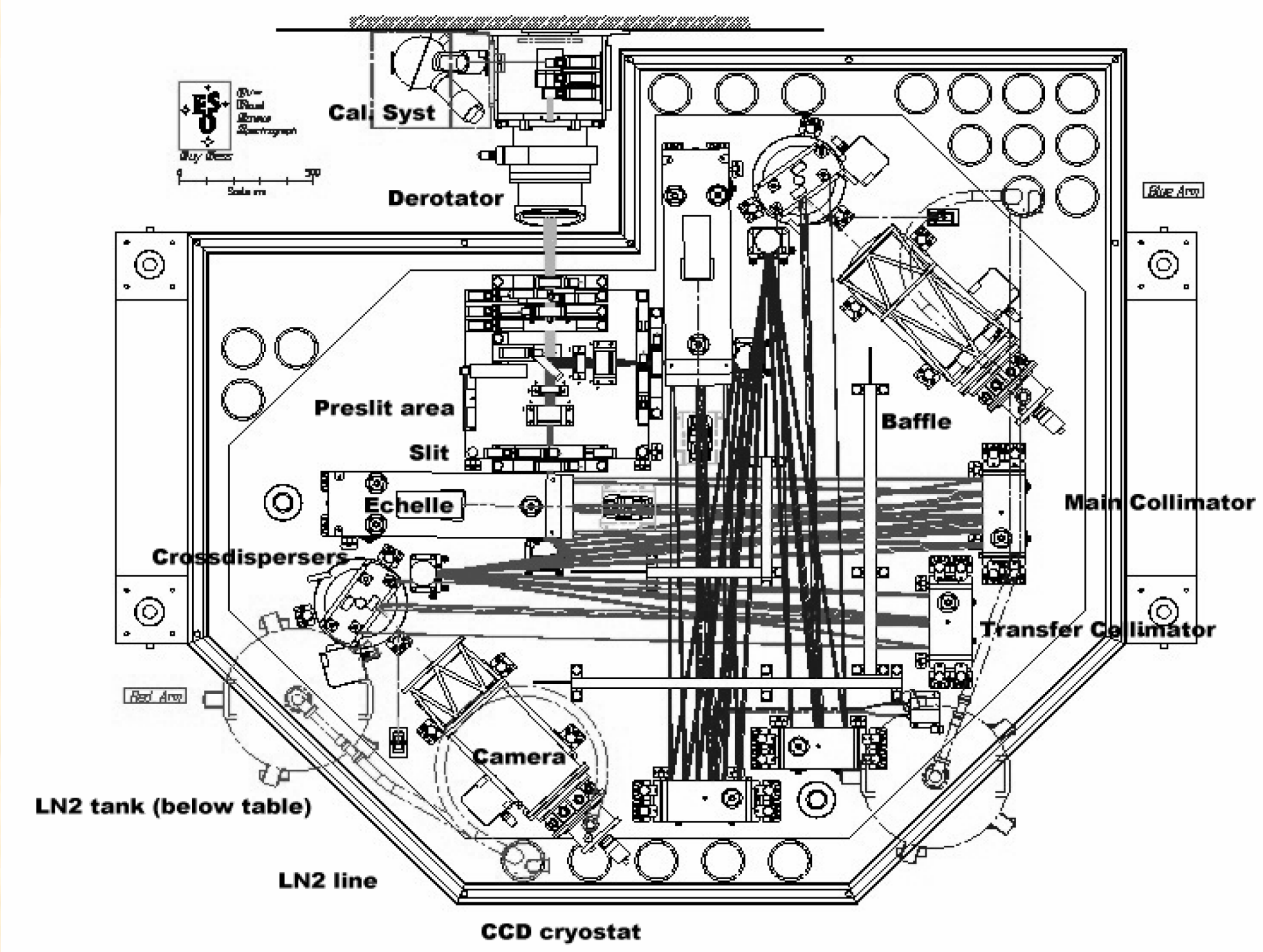
UVES@VLT



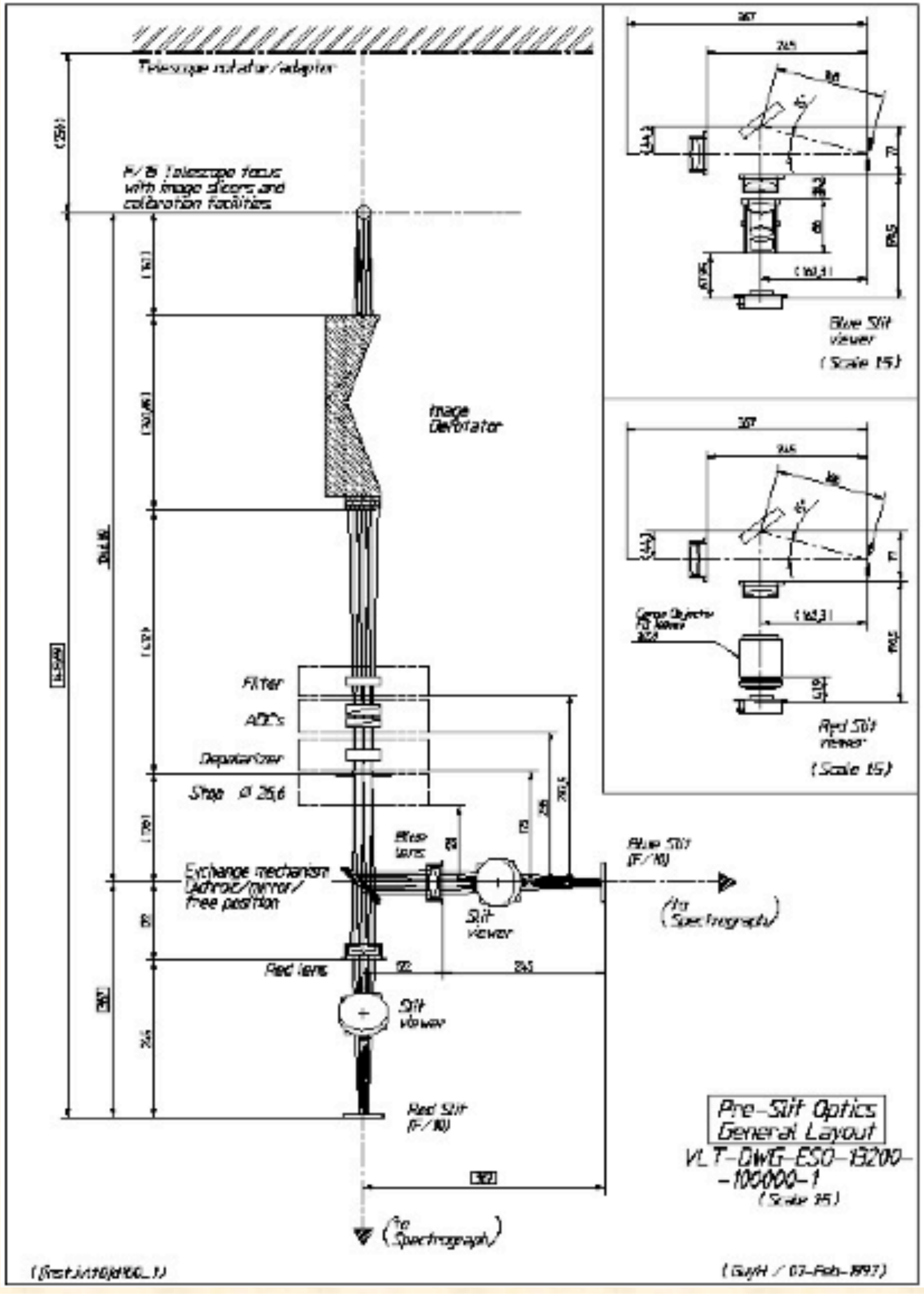
Cal. Syst
Derotator
Preslit area
Slit
Echelle
Crossdispersers
Baffle
Main Collimator
Transfer Collimator
Camera
LN2 tank (below table)
LN2 line
CCD cryostat


UVES
Telescope Shutter
Calibration Lamps
Calibration Slide
Iodine Cell
Image Slicer
IS1
IS2
IS3
Derotator
CD#2
Blue Crossdispersers
Preslit Filter Wheel
CD#1
Blue Camera
Depolarizer
ADC
Blue Slitviewer
Blue Slit
Blue Filter
Mode Selector
Dic#2
Dic#1
Blue
Red
Red Slitviewer
Blue CCD
Red Slit
Red Filter
Blue Exposuremeter
CD#4
CD#3
Red Crossdispersers
Red Camera
Red CCD
Red Exposuremeter

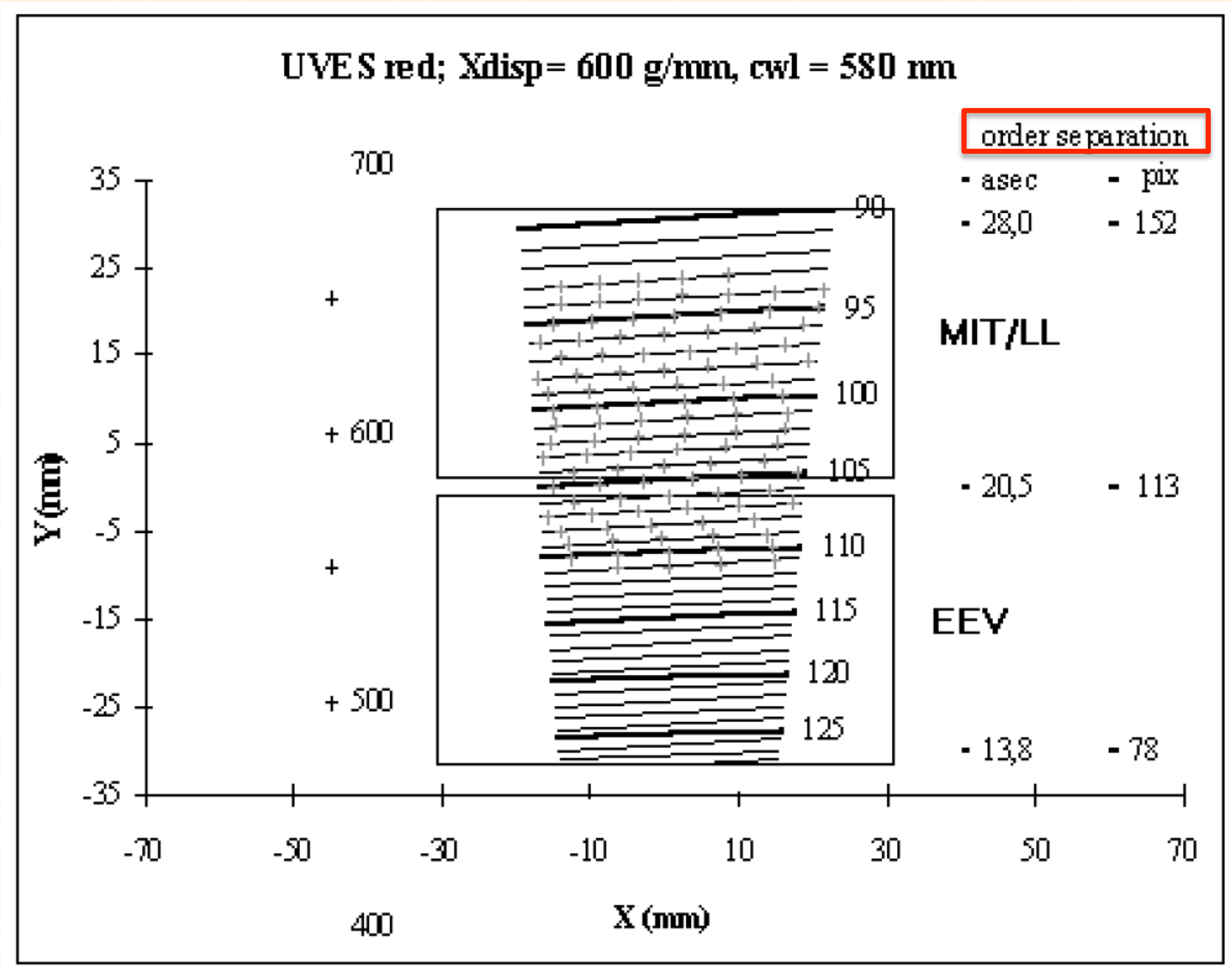
UVES@VLT



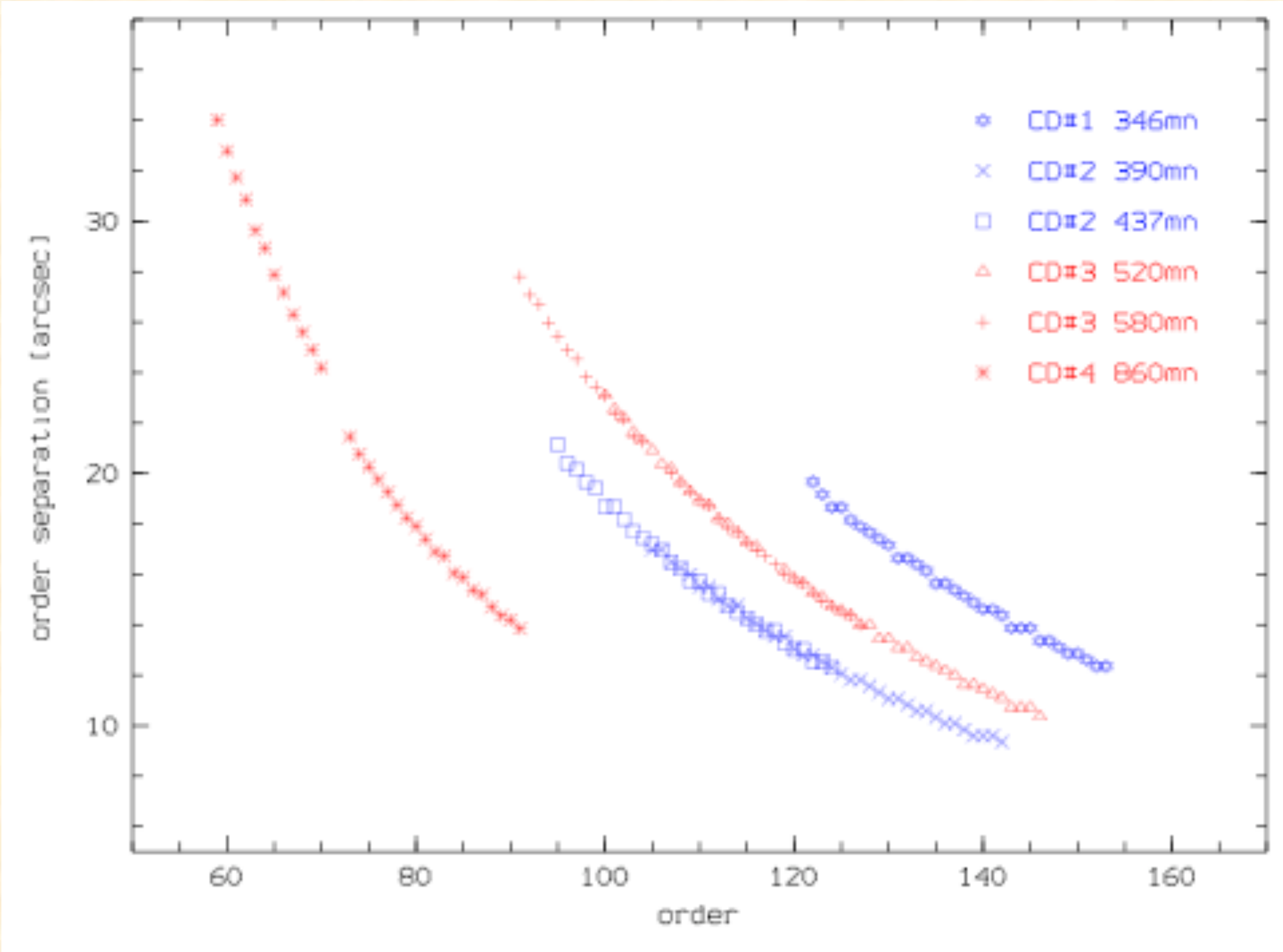
Cal. Syst
Derotator
Preslit area
Slit
Echelle
Crossdispersers
Baffle
Main Collimator
Transfer Collimator
Camera
LN2 tank (below table)
LN2 line
CCD cryostat
Blue Arm
Red Arm


Telescope rotator/adapter
Telescope focus with image slicers and calibration facilities
Image Derotator
Filter
ADC's
Depolarizer
Stop Ø 25,6
Blue lens
Exchange mechanism (dichroic/mirror/ free position)
Slit viewer
Blue Slit (F/10)
(To Spectrograph)
Red lens
Slit viewer
Red Slit (F/10)
(To Spectrograph)
Blue Slit viewer
(Scale 1:5)
Red Slit viewer
(Scale 1:5)
Pre-Slit Optics
General Layout
VLT-DWG-ESO-13200-
-100000-1
(Scale 1:5)
(GuyH / 07-Feb-1997)

UVES: Spectral format



UVES: Order separation



UVES: Spectral resolution

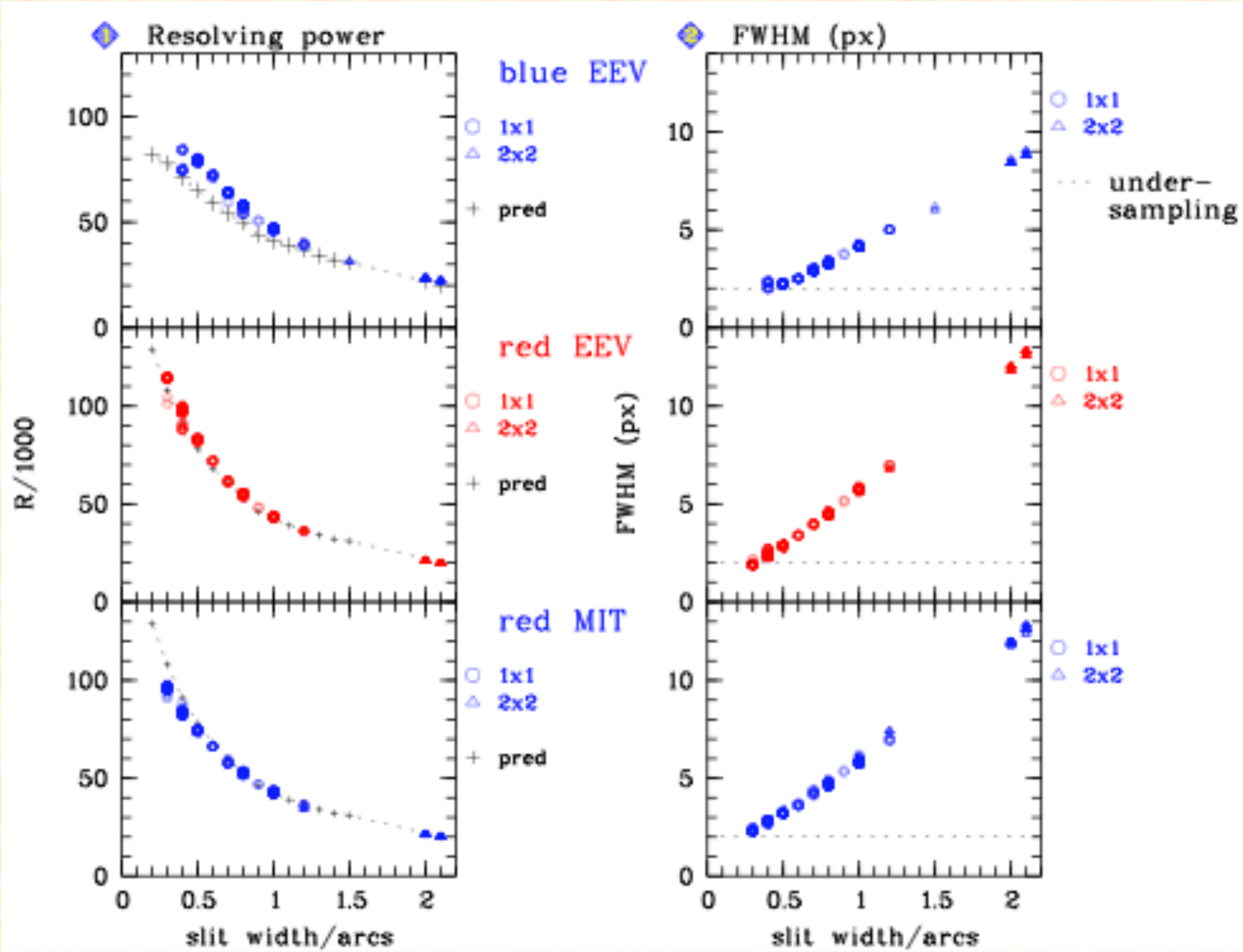
- Telescope diameter: D_T = 8.2 m
- Source/seeing/slit: s_{sky} = 0.3 arcsec
- Collimated beam of the spectrograph: D_1 = 200 mm

Echelle grating: R4 -> tanβ = 4, D_1 = 200 mm

$$D_{echelle} = \frac{d\beta}{d\lambda} = \frac{2\tan\beta}{\lambda} = \frac{8}{0.55} = 14.5 \text{ rad/}\mu\text{m}$$

$$R_{UVES} = \frac{\lambda}{\delta\lambda} = \lambda \cdot \frac{D_1}{D_T} \cdot \frac{D_{prism}}{s_{Sky}} = 0.55 \cdot \frac{0.2}{8.2} \cdot \frac{14.5}{0.3 \cdot 5 \cdot 10^{-6}} \approx 130'000$$

UVES: Sampling and resolution

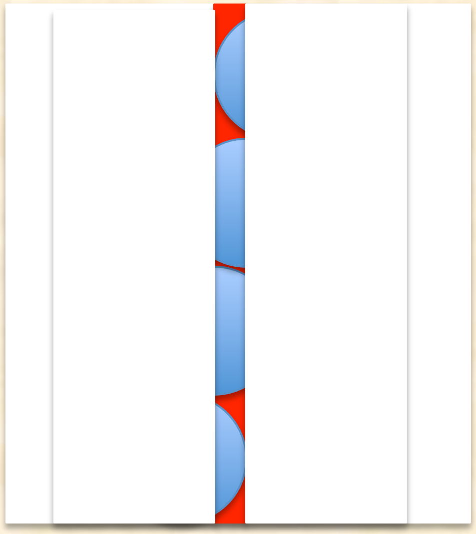


UVES: Image slicer 'trick'

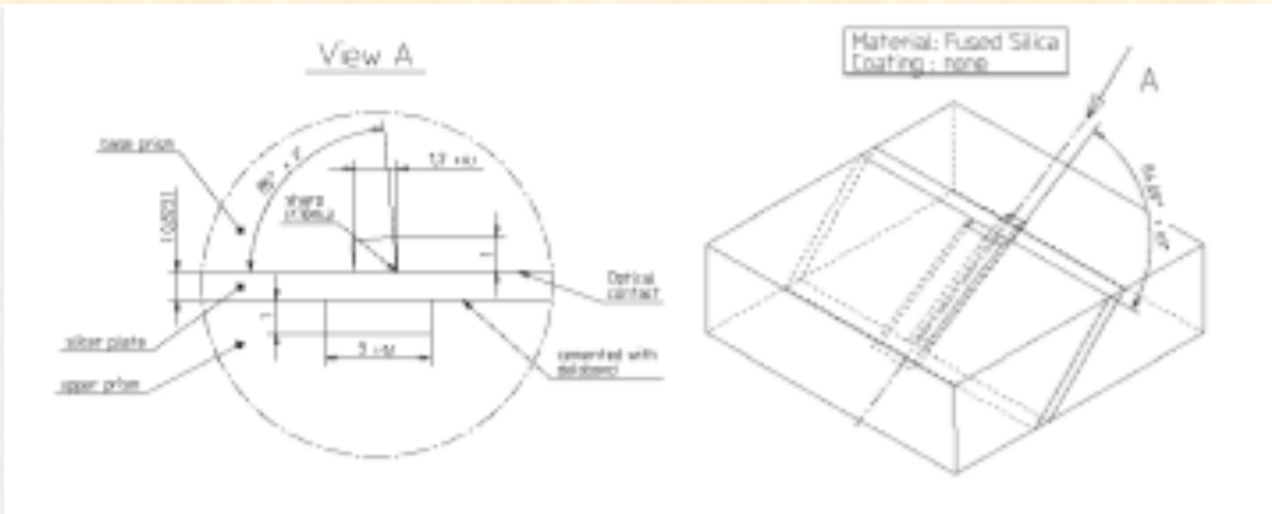
Long slit

Image slicer

Increase of efficiency at give R, or vice versa



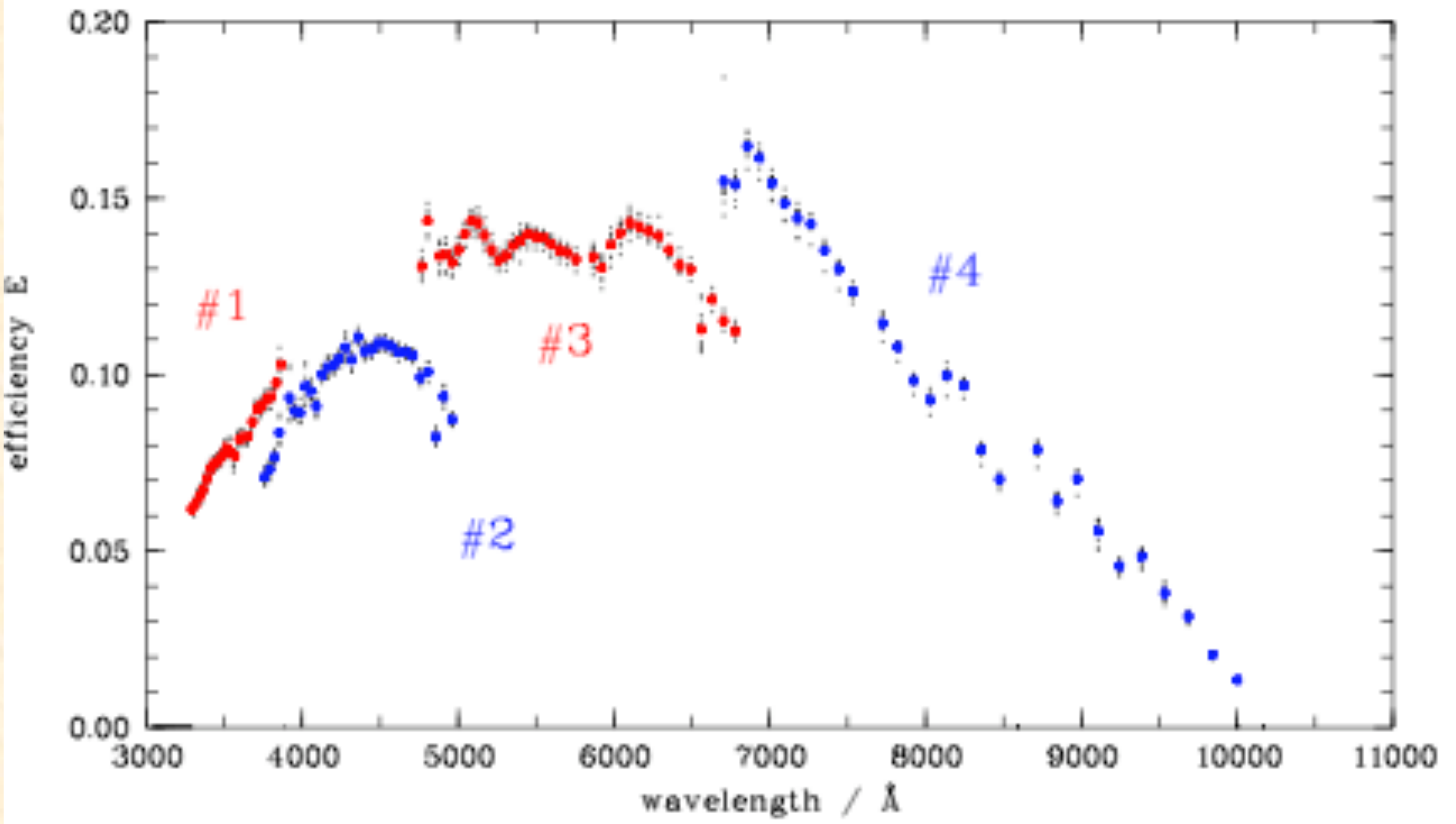
Slicer	*Entrance*	*Slit*	N_{slices}
1	*2.1x2.6"*	*0.68x7.9"*	*3*
2	*1.8x2.0"*	*0.44x7.9"*	*4*
3	*1.5x2.0"*	*0.30x10.0"*	*5*

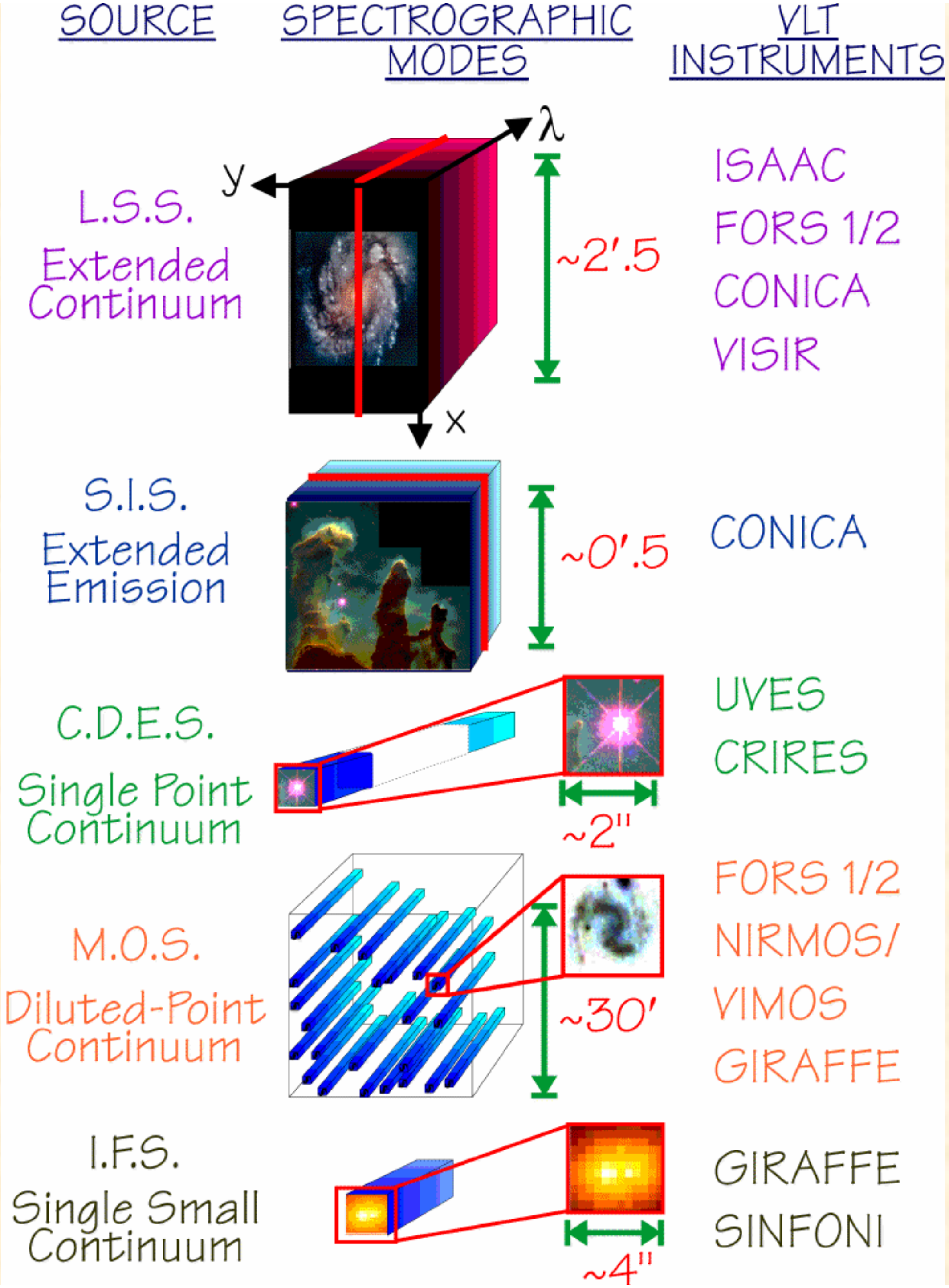


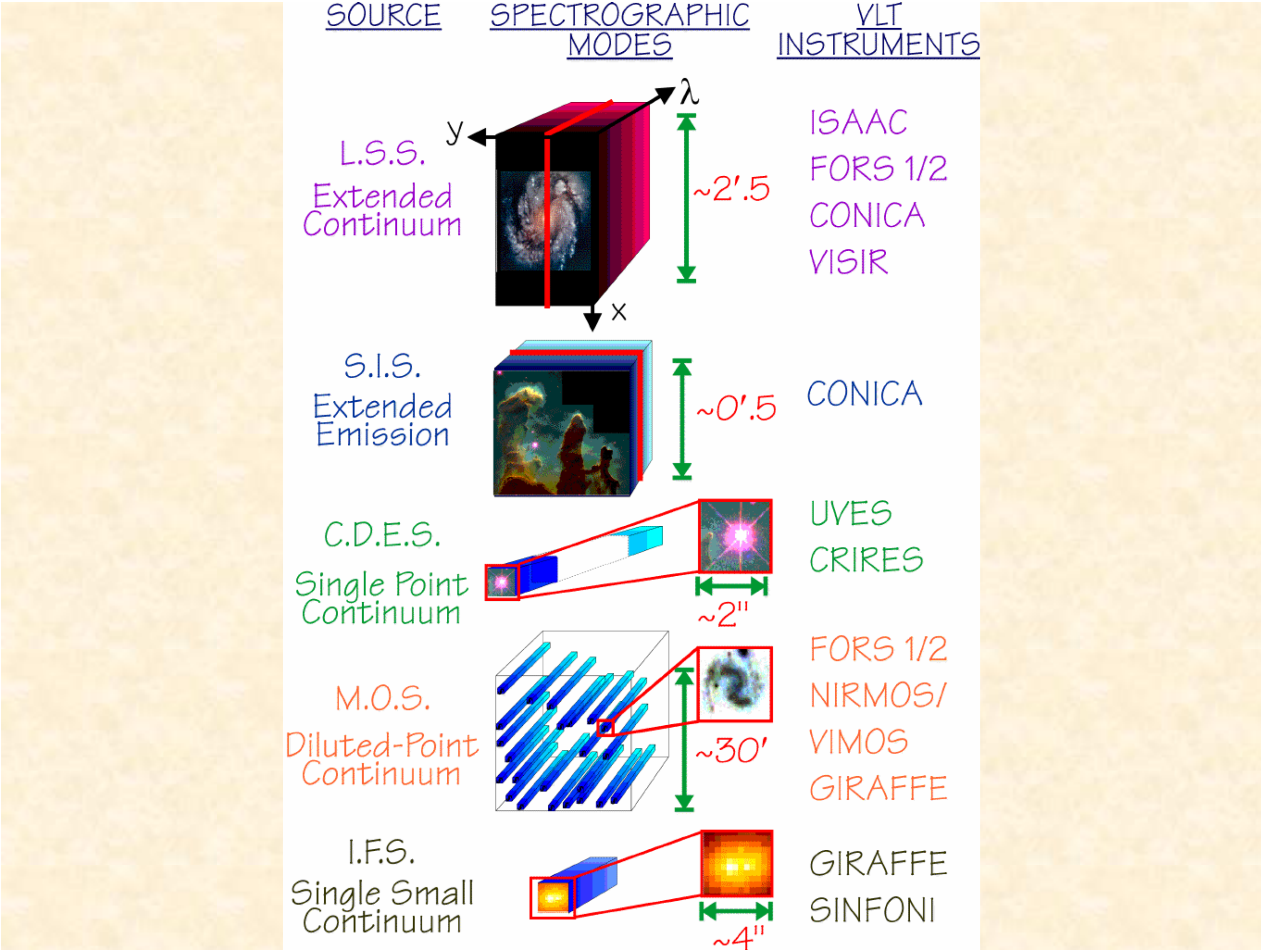
UVES params

	Blue	Red
Wavelength range	300 - 500 nm	420 - 1100 nm
Resolution-slit product	41,400	38,700
Max. resolution	~80,000 (0.4" slit)	~110,000 (0.3" slit)
Limiting magnitude (1.5hr integration, S/N=10, seeing 0.7")	18.0 at R=58,000 in U (0.7" slit)	19.5 at R=62,000 in V (0.7" slit)
Overall detective quantum efficiency (DQE) (from the top of the telescope, wide slit)	12% at 400 nm	14% at 600 nm
Camera	dioptric F/1.8, 70 μm/arcsec field 43.5 mm diam.	dioptric F/2.5, 97 μm/arcsec field 87 mm diam.
CCDs (pixel scale)	EEV, 2Kx4K, 15 μm pixels (0.22 arcsec/pix)	mosaic of two (EEV + MIT/LL), 2Kx4K, 15 μm pixels (0.16 arcsec/pix)
Echelle	41.59 g/mm, R4 mosaic	31.6 g/mm, R4 mosaic
Crossdispersers: g/mm and wavelength of max. efficiency	#1: 1000 g/mm, 360 nm #2: 660 g/mm, 460 nm	#3: 600 g/mm, 560 nm #4: 312 g/mm, 770 nm
Typical wavelength range/frame [CD#1(#2) and CD#3(#4)]	85 (126) nm in 33 (31) orders	200 (403) nm in 37 (33) orders
Min. order separation	10 arcsec or 40 pixels	12 arcsec or 70 pixels

UVES: Efficiency

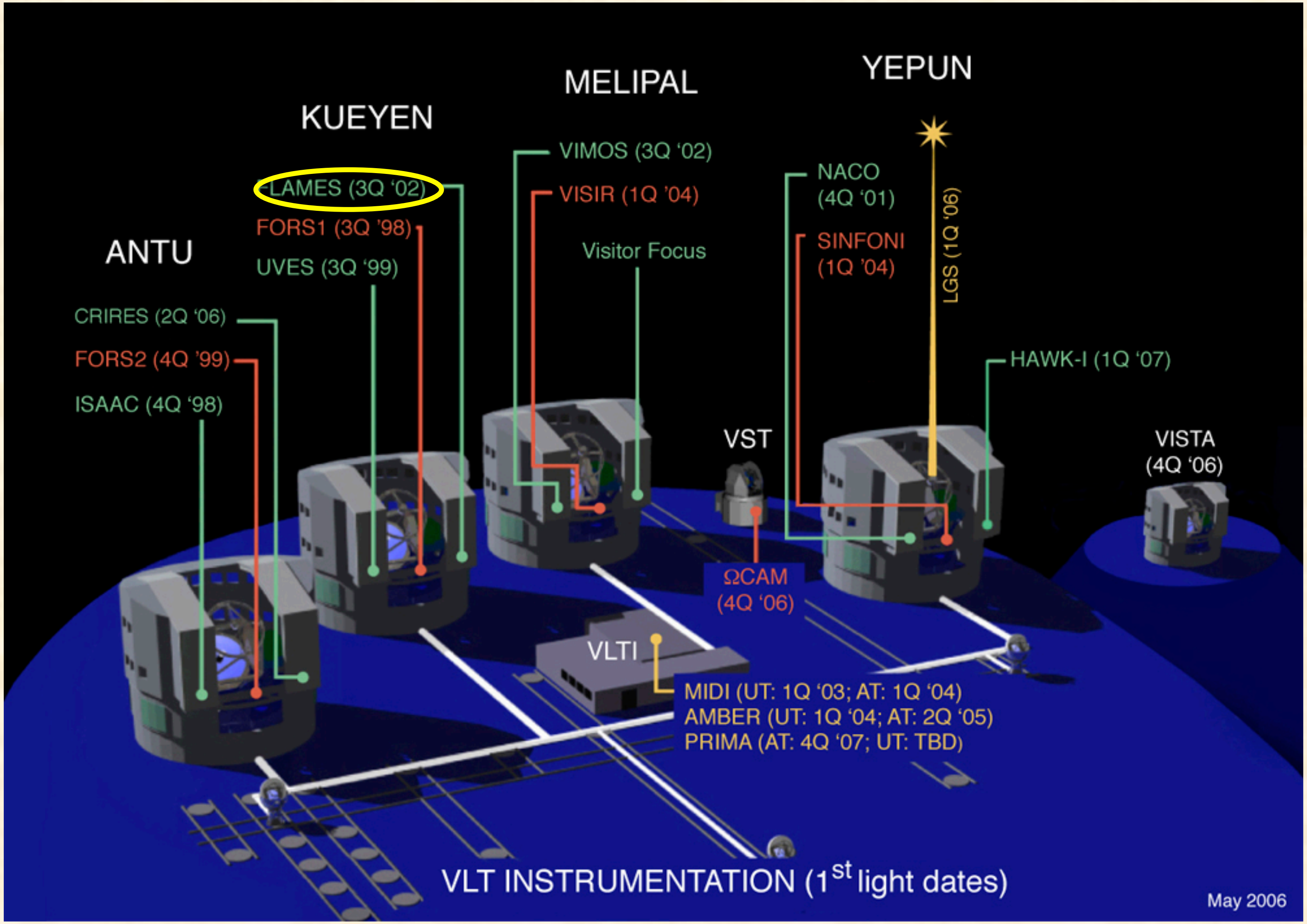



SOURCE
SPECTROGRAPHIC MODES
VLT INSTRUMENTS
L.S.S.
Extended Continuum
y
λ
x
~2′.5
ISAAC
FORS 1/2
CONICA
VISIR
S.I.S.
Extended Emission
~0′.5
CONICA
C.D.E.S.
Single Point Continuum
~2″
UVES
CRIRES
M.O.S.
Diluted-Point Continuum
~30′
FORS 1/2
NIRMOS/
VIMOS
GIRAFFE
I.F.S.
Single Small Continuum
~4″
GIRAFFE
SINFONI



SOURCE
SPECTROGRAPHIC MODES
VLT INSTRUMENTS
L.S.S.
Extended Continuum
y
λ
x
~2′.5
ISAAC
FORS 1/2
CONICA
VISIR
S.I.S.
Extended Emission
~0′.5
CONICA
C.D.E.S.
Single Point Continuum
~2"
UVES
CRIRES
M.O.S.
Diluted-Point Continuum
~30′
FORS 1/2
NIRMOS/
VIMOS
GIRAFFE
I.F.S.
Single Small Continuum
~4"
GIRAFFE
SINFONI

Flames@VLT



KUEYEN
MELIPAL
YEPUN
ANTU
FLAMES (3Q '02)
FORS1 (3Q '98)
UVES (3Q '99)
VIMOS (3Q '02)
VISIR (1Q '04)
Visitor Focus
NACO
(4Q '01)
SINFONI
(1Q '04)
LGS (1Q '06)
CRIRES (2Q '06)
FORS2 (4Q '99)
ISAAC (4Q '98)
HAWK-I (1Q '07)
VST
VISTA
(4Q '06)
ΩCAM
(4Q '06)
VLTI
MIDI (UT: 1Q '03; AT: 1Q '04)
AMBER (UT: 1Q '04; AT: 2Q '05)
PRIMA (AT: 4Q '07; UT: TBD)
VLT INSTRUMENTATION (1st light dates)
May 2006

Flames – various links

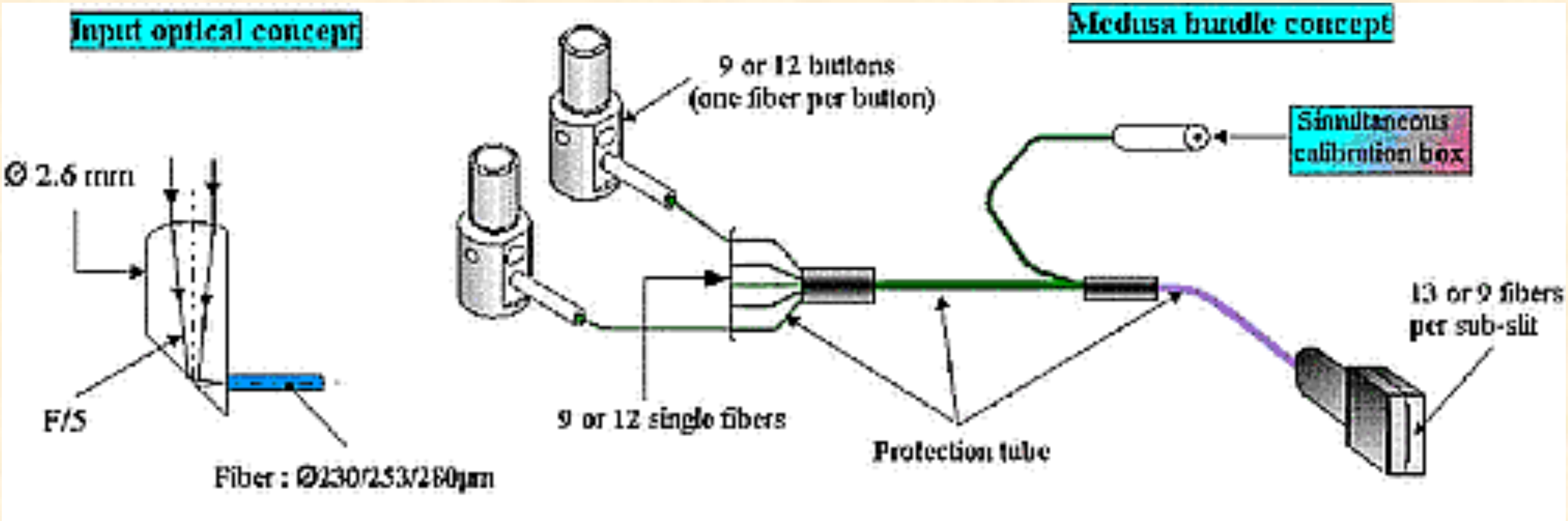
Mode	Number of Buttons	Fibers per Buttons	Sky Buttons	Total fibers
UVES	8	1 -	8	
Medusa	132	1 -	132	
IFU	15	20	15	315
ARGUS	1	14x22 (-8)	15	315

UVES

Giraffe

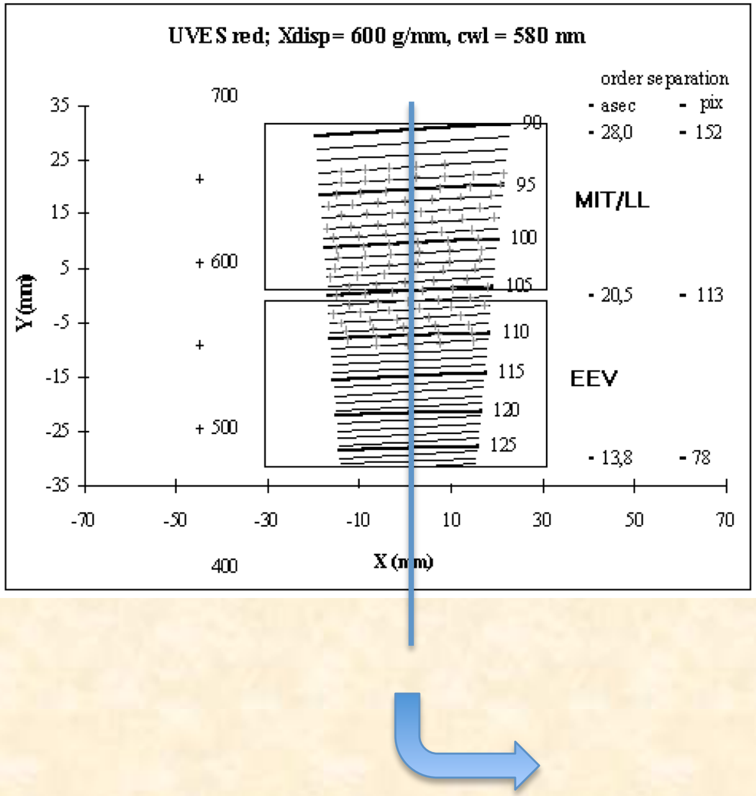
Flames – UVES link

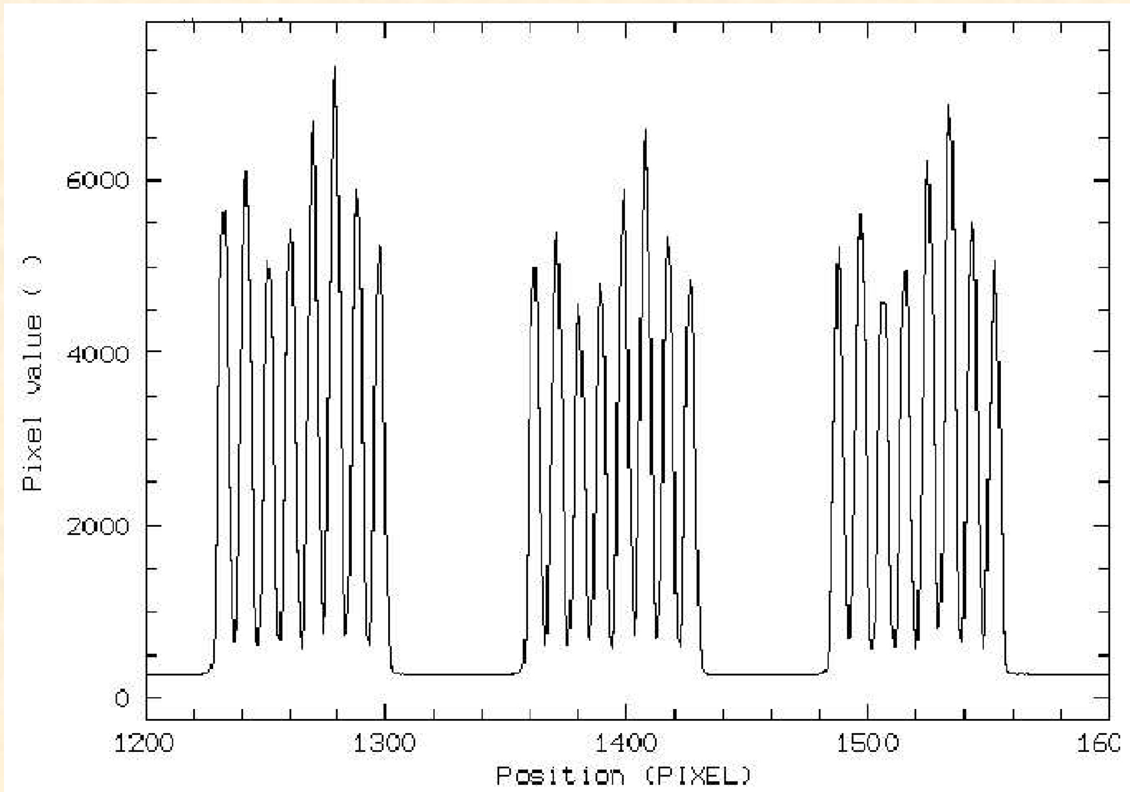
Mode	Number of Buttons	Fibers per Buttons	Sky Buttons	Total fibers
UVES	8	1 -	8	
Medusa	132	1 -	132	
IFU	15	20	15	315
ARGUS	1	14x22 (-8)	15	315



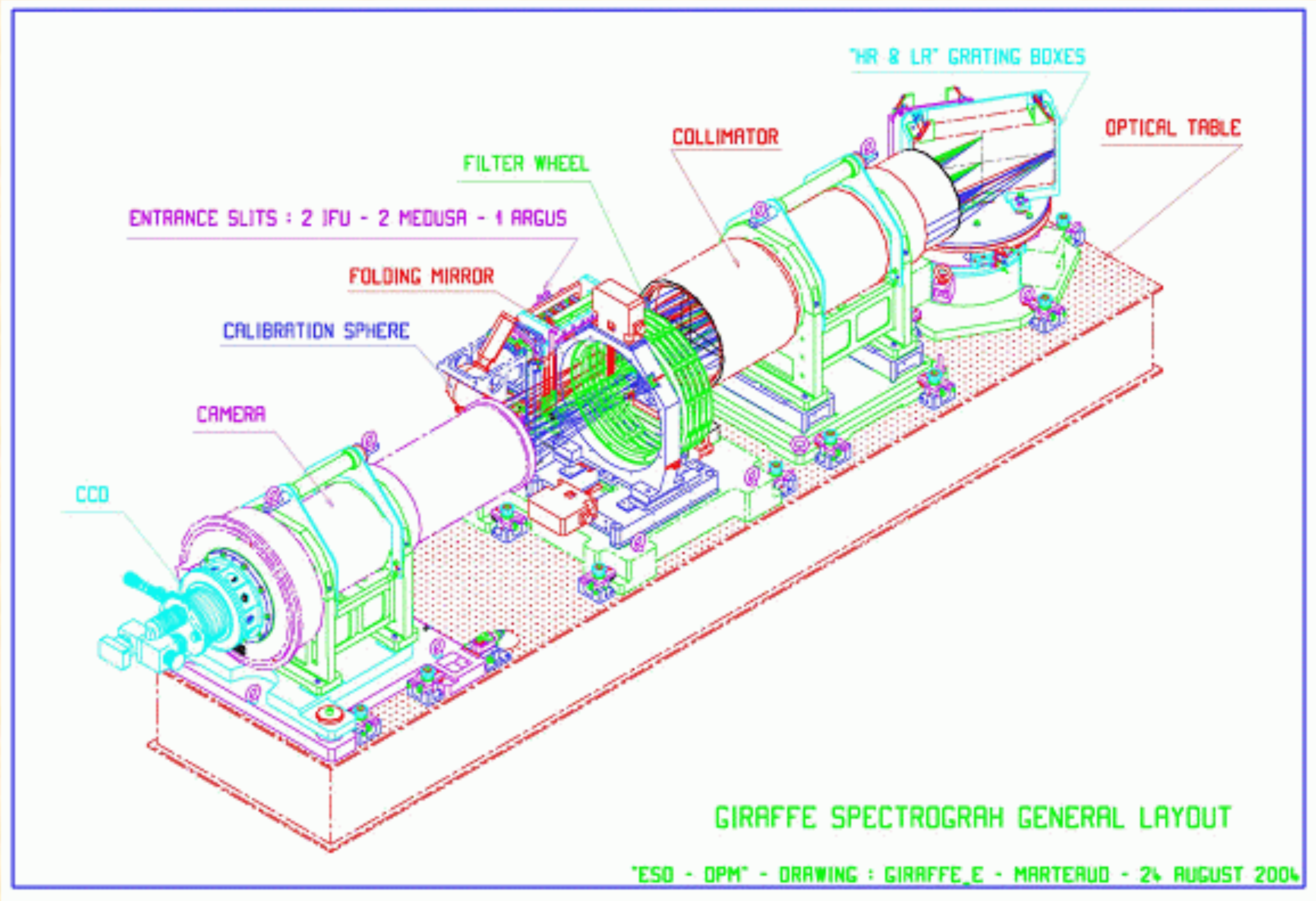
Flames – UVES link

Mode	Number of Buttons	Fibers per Buttons	Sky Buttons	Total fibers
UVES	8	1 -	8	
Medusa	132	1 -	132	
IFU	15	20	15	315
ARGUS	1	14x22 (-8)	15	315



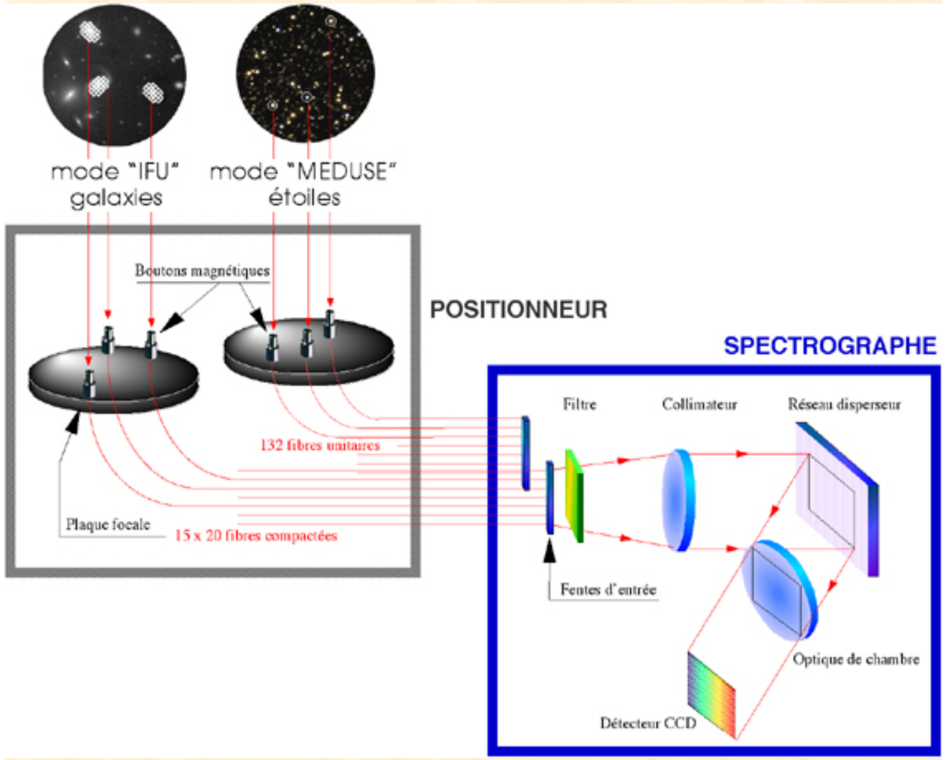


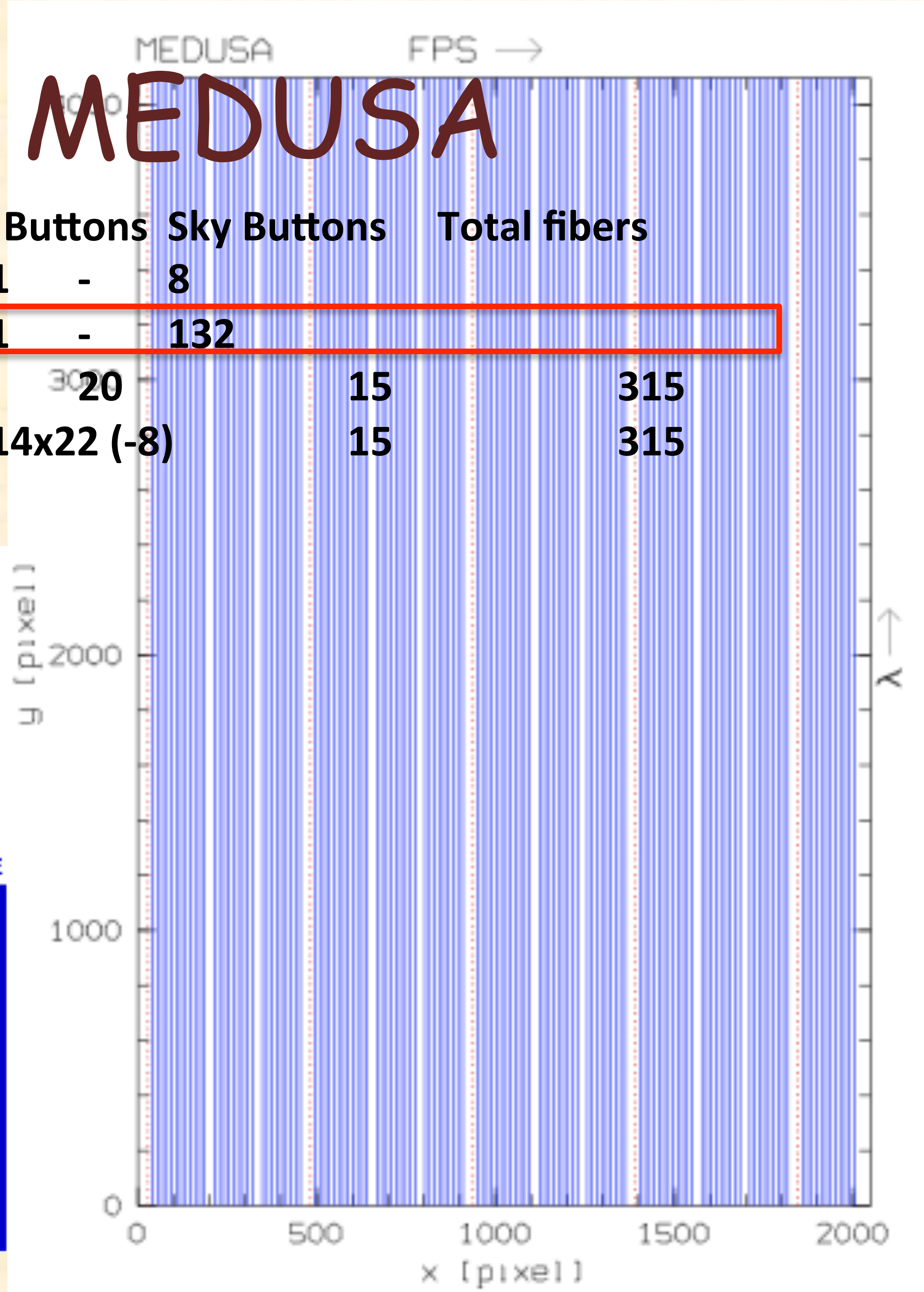
Flames – Giraffe



Flames - MEDUSA

Mode	Number of Buttons	Fibers per Buttons	Sky Buttons	Total fibers
UVES	8	1	-	8
Medusa	132	1	-	132
IFU	15	20	15	315
ARGUS	1	14x22 (-8)	15	315



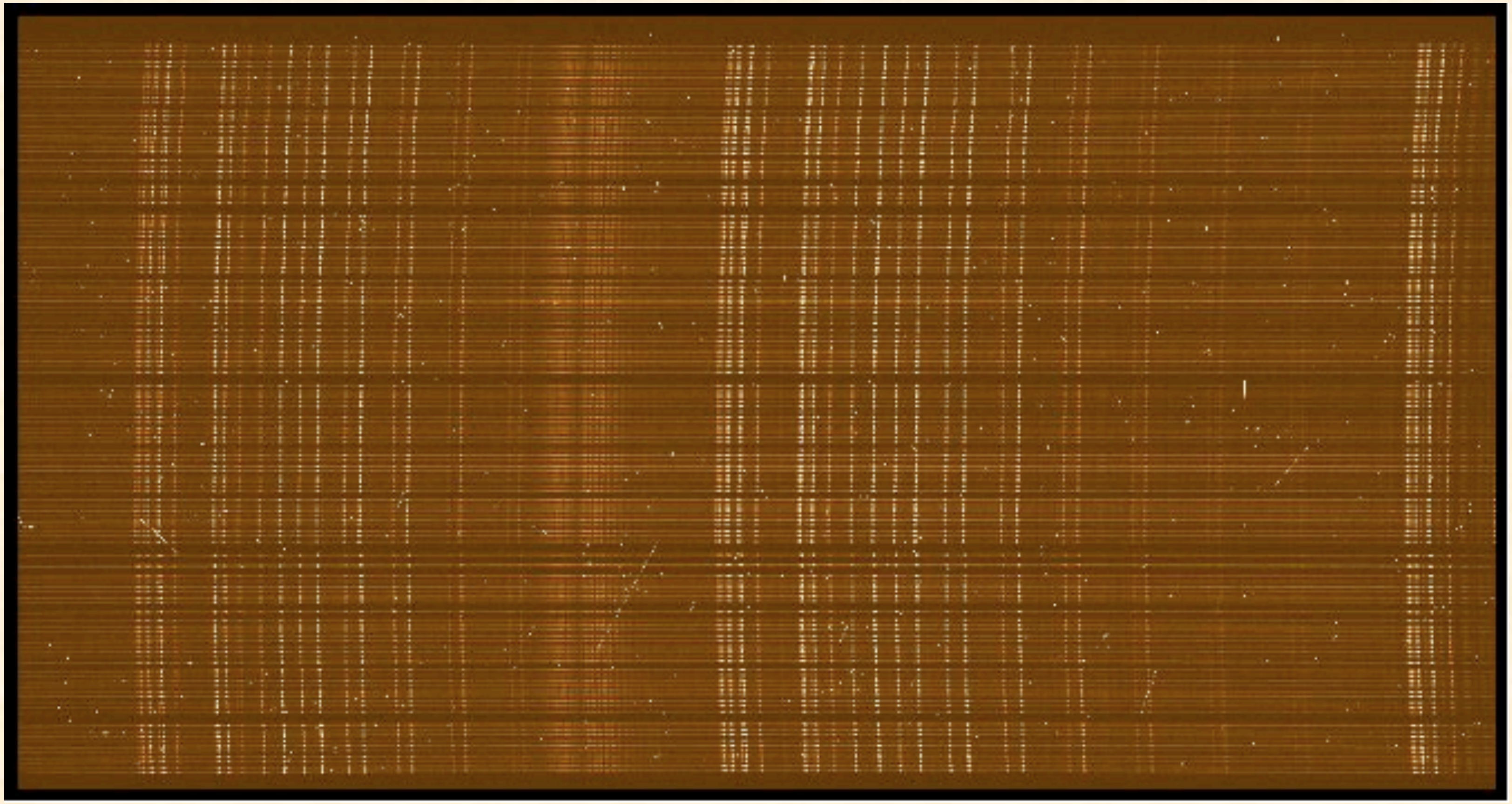


Flames – MEDUSA

OzPoz fiber positioner

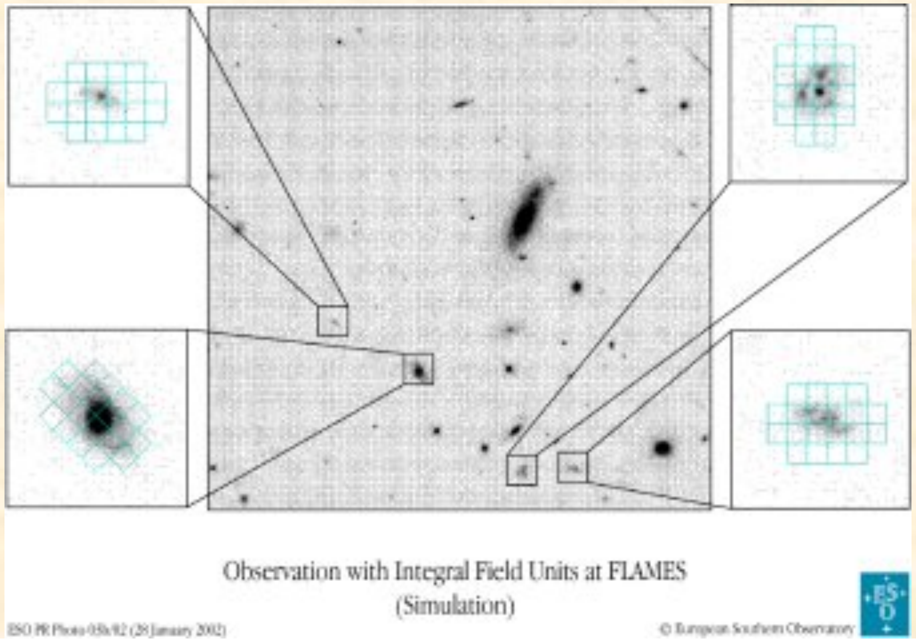
Flames – MEDUSA

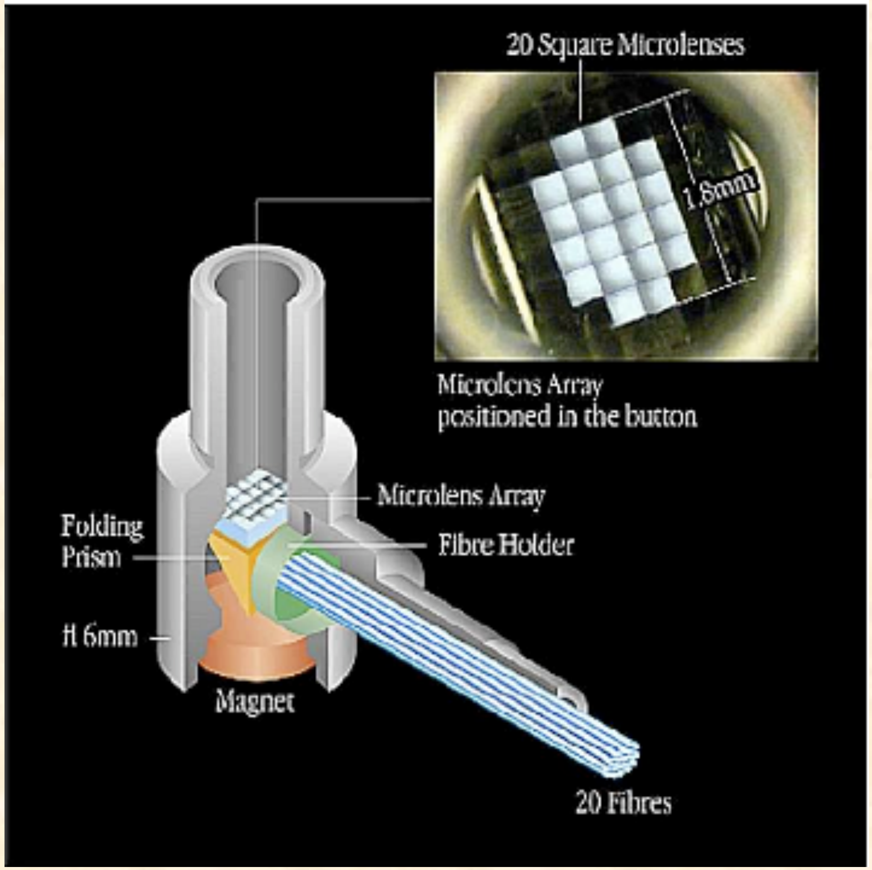
Mode	Number of Buttons	Fibers per Buttons	Sky Buttons	Total fibers
UVES	8	1 -	8	
Medusa	132	1 -	132	
IFU	15	20	15	315
ARGUS	1	14x22 (-8)	15	315



Flames - IFU

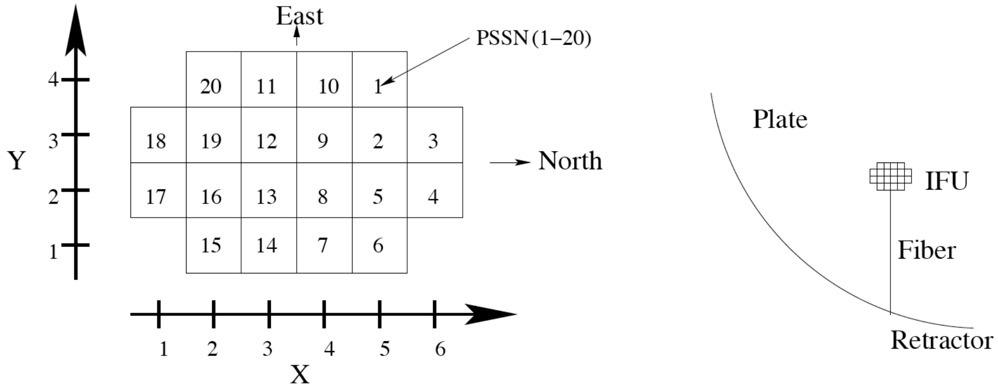
Mode	Number of Buttons	Fibers per Buttons	Sky Buttons	Total fibers
UVES	8	1 -	8	
Medusa	132	1 -	132	
IFU	15	20	15	315
ARGUS	1	14x22 (-8)	15	315



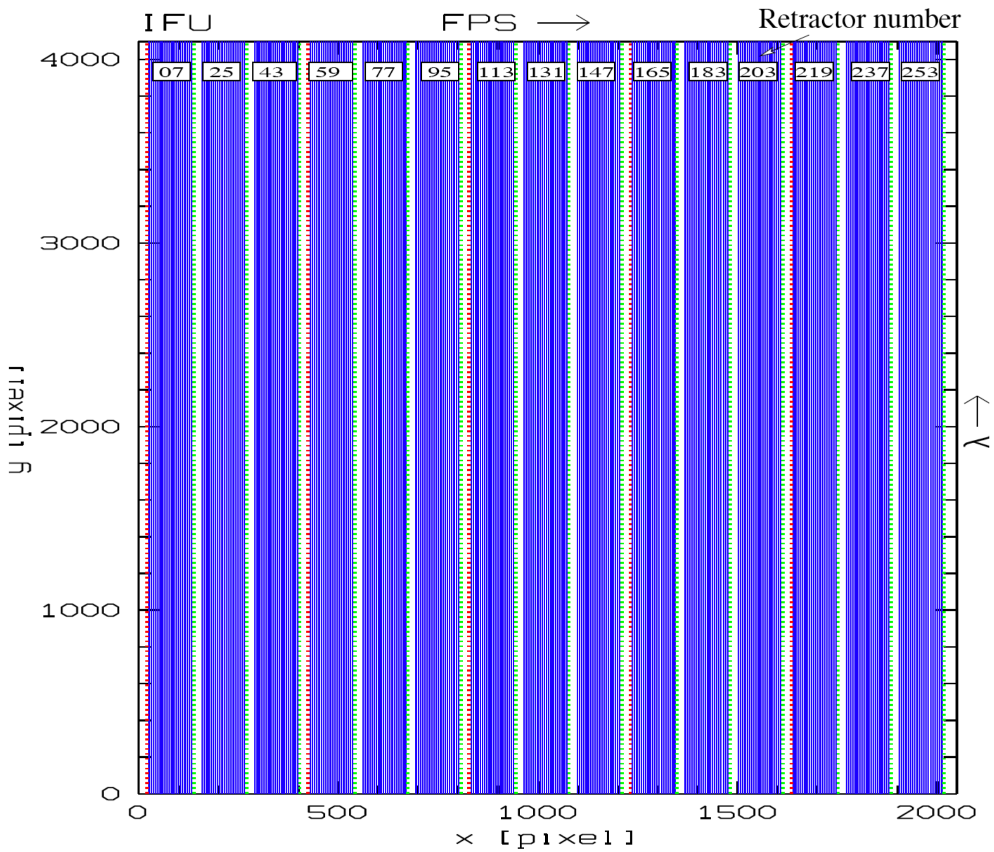


Flames - IFU

IFU configuration shown for PA=0 deg.

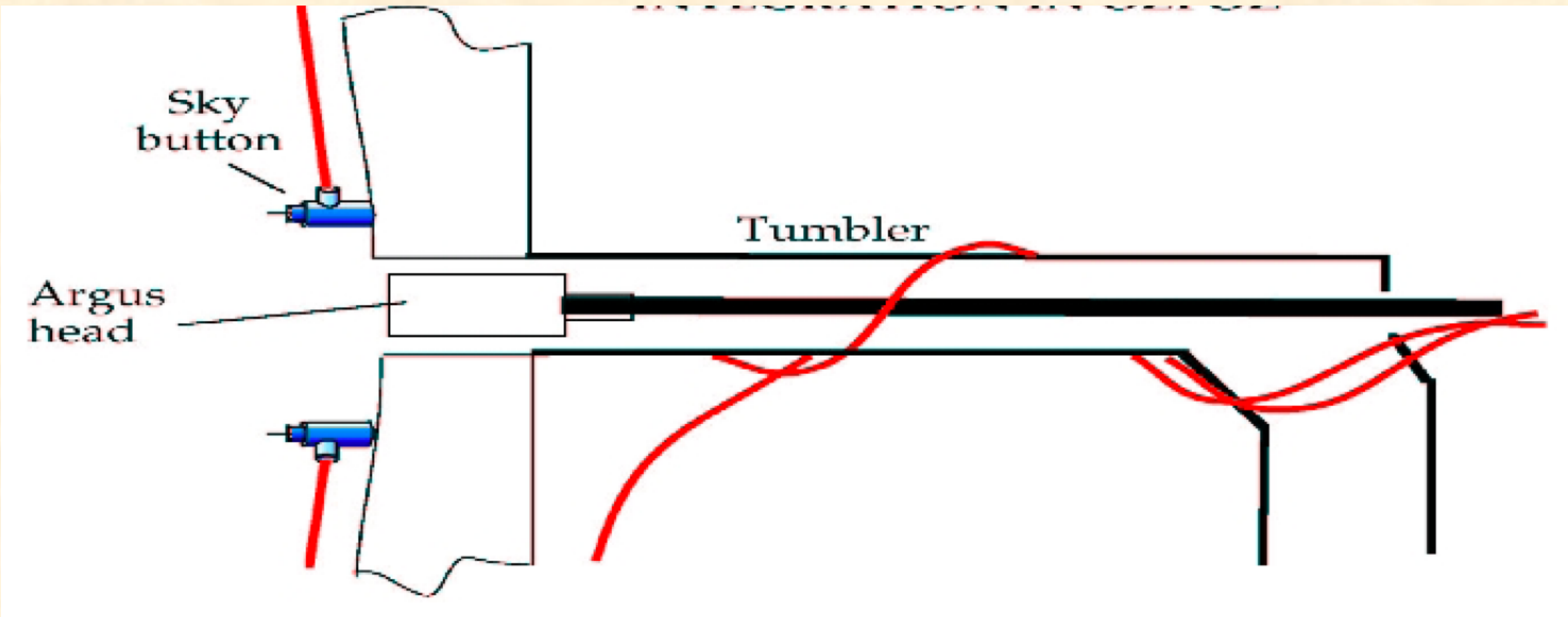


Notes: 1) Position Angle PA = 315 deg − ORIENT in binary OzPoz table. PA=North−East.
2) For IFUs with SKY fibers, the PSSN numbers should be increased by 1.
3) X,Y and PSSN can be found in the binary FLAMES FIBER table.



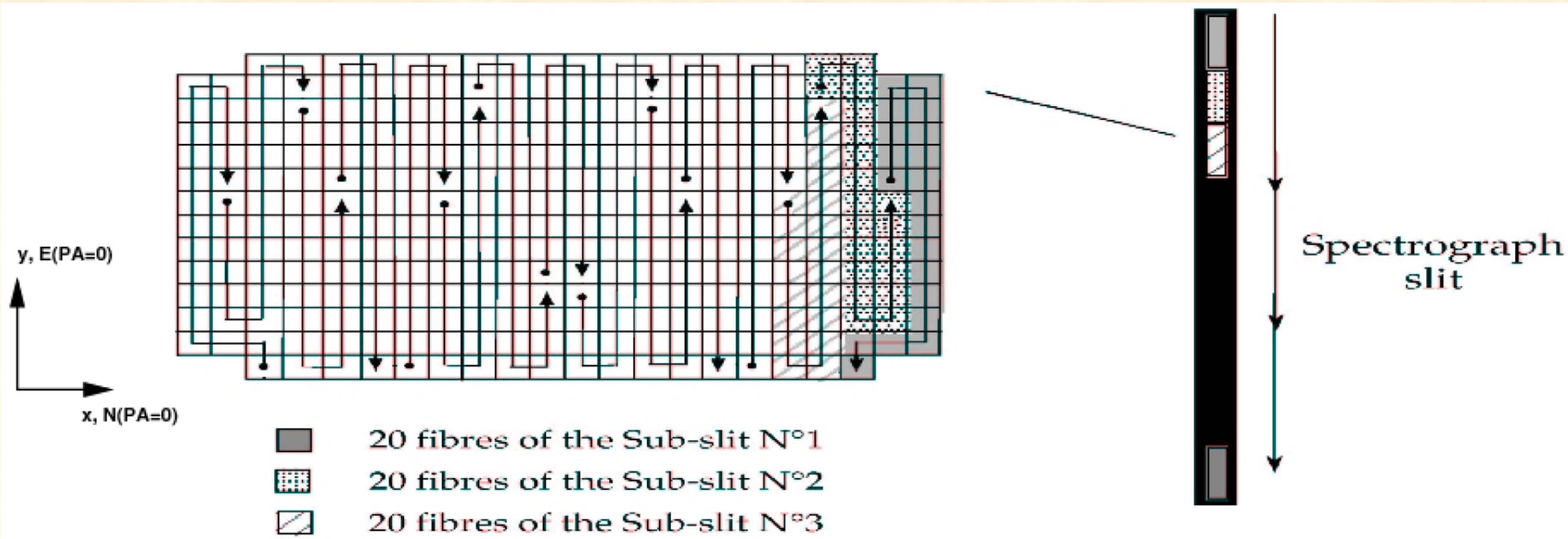
Flames – ARGUS

Mode	Number of Buttons	Fibers per Buttons	Sky Buttons	Total fibers
UVES	8	1	-	8
Medusa	132	1	-	132
IFU	15	20	15	315
ARGUS	1	14x22 (-8)	15	315

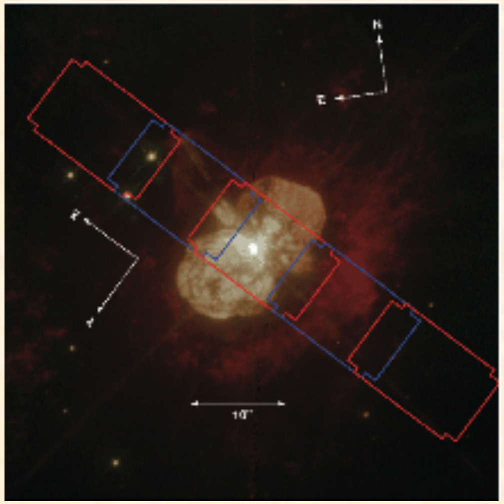


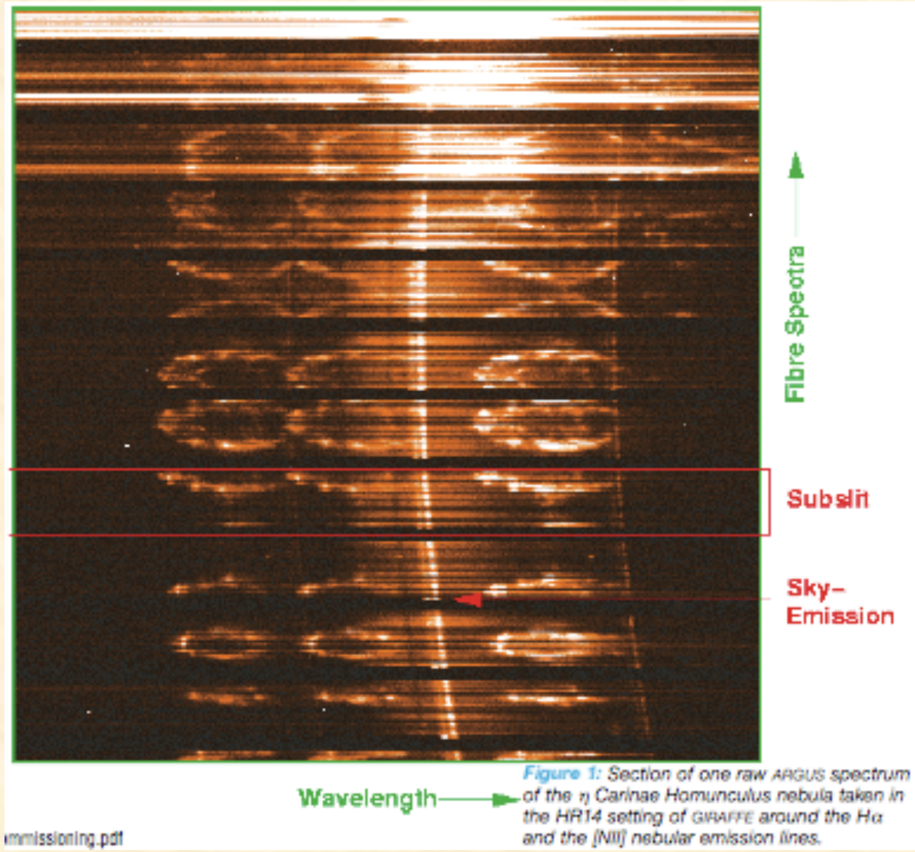
Flames - ARGUS

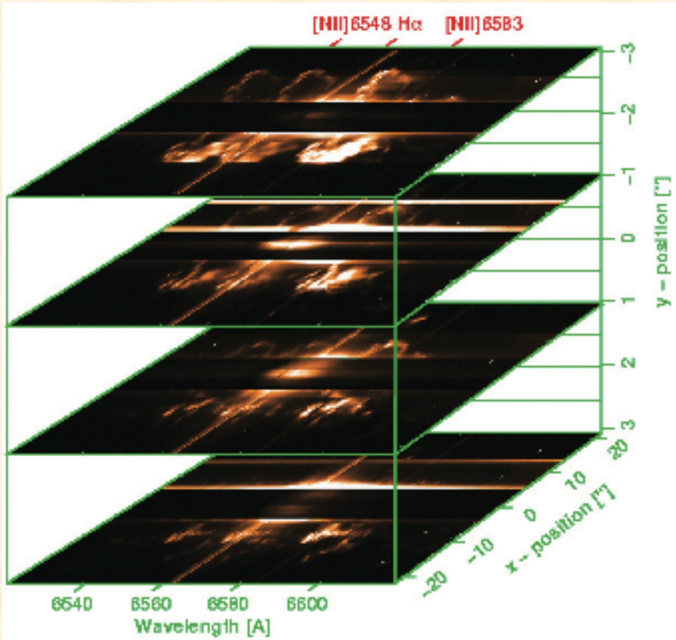
Mode	Number of Buttons	Fibers per Buttons	Sky Buttons	Total fibers
UVES	8	1 - 8		
Medusa	132	1 - 132		
IFU	15	20	15	315
ARGUS	1	14x22 (-8)	15	315



Flames - ARGUS



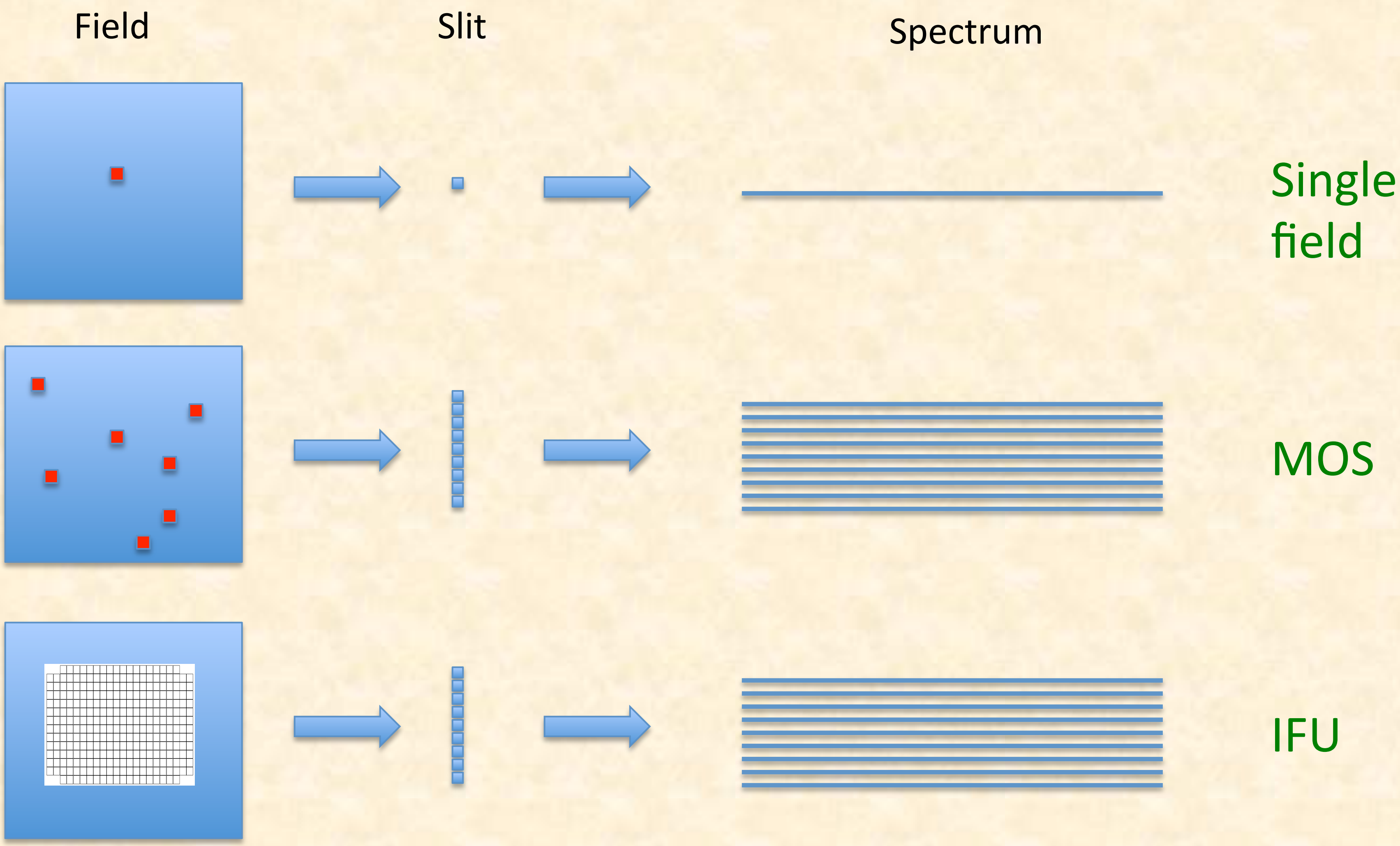




Flames – Summary

Spectro.	Mode	N. Objects	Aperture [″]	R	Cover.
UVES	RED	8 (with sky)	1.0	47000	200
UVES7	RED	7 (with sky) +1 Simul. Calib.	1.0	47000	200
GIRAF HR	MEDUSA	131[a] (with sky)	1.2	19000[†]	$\lambda/22 - \lambda/12$
GIRAF LR	MEDUSA	131[a] (with sky)	1.2	7000[†]	$\lambda/9.5$
GIRAF HR	IFU	15 (+15 sky)	2×3	30000[†]	$\lambda/22 - \lambda/12$
GIRAF LR	IFU	15 (+15 sky)	2×3	11000[†]	$\lambda/9.5$
GIRAF HR	ARGUS	1	11.5×7.3 or 6.6×4.2	30000[†]	$\lambda/22 - \lambda/12$
GIRAF LR	ARGUS	1	11.5×7.3 or 6.6×4.2	11000[†]	$\lambda/9.5$

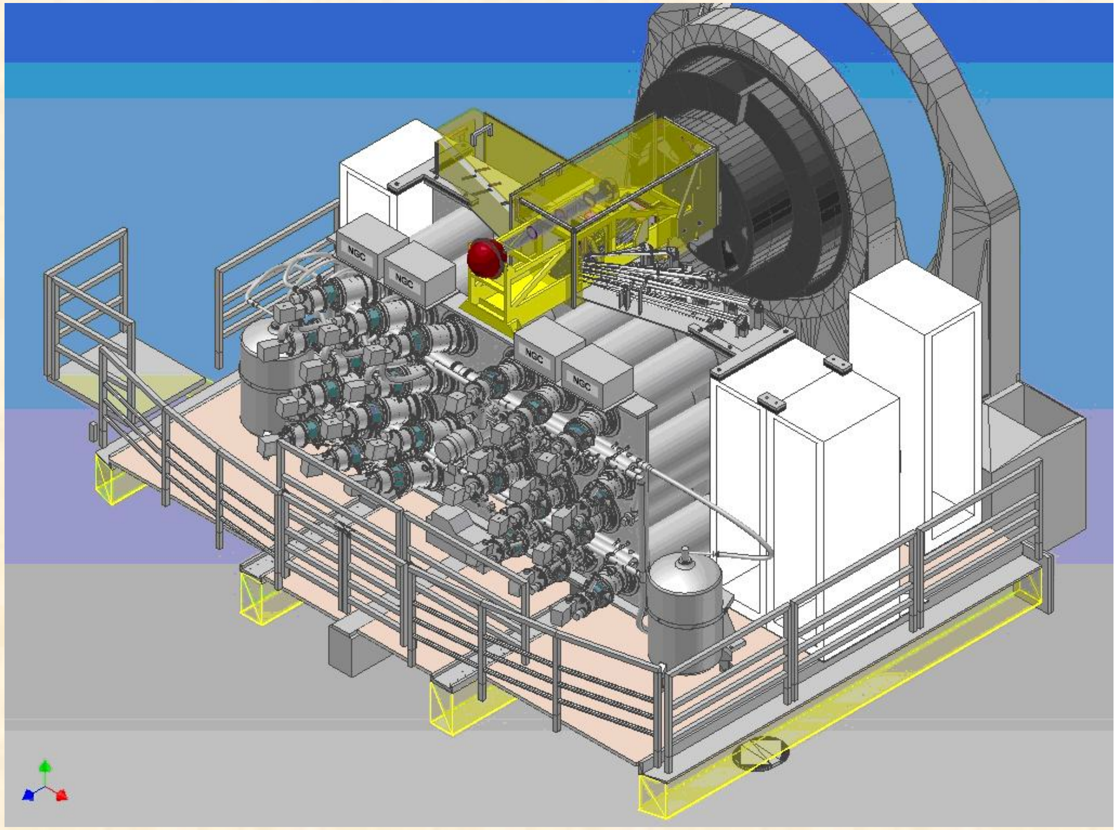
Flames - Summary



Future VLT spectrographs

MUSE:

- AO
- IFU with 1′ x 1′ (0,2″ sampling) or 7.5″ x 7.5″ (0,025″ sampling)
- Array of 24 fields organized in 24 spectrographs
- Resolution 2000 – 4000 @ NIR
- Available in 2011



Challenges for ELT spectrographs

- Huge telescope -> huge instrumentations (conservation of étendu)
- Or, massive adaptive optics (very complex and demanding with increasing telescope size, difficulty increases with D and with ~1/λ
- Location of the instruments (trade-off between stability and efficiency)
- Costs