CODEX optics

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ABSTRACT

CODEX is a high resolution spectrograph for the ESO E-ELT. A classical spectrograph can only achieve a resolution of about 120.000 on a 42 m telescope with extremely large echelle gratings and cameras. This paper describes in detail the optical concept of CODEX, which uses only optical elements size similar to those in current high resolution spectrographs. This design is based on slicers, anamorphic beams and slanted VPHG as cross dispersers. In this new version of the CODEX design, no special expensive materials as calcium fluoride or abnormal dispersion glasses are needed. The optical quality is excellent and compatible with 10K x 10K detectors with 10 µm pixels.

Keywords: optical design, spectrograph, high resolution, ELT

1. INTRODUCTION

CODEX is a cross-dispersed spectrograph study for the E-ELT. It should provide a resolution of 120.000 for a 0.8 arcsec object and full wavelength coverage over the range from 370 to 700 nm. The resolution elements must be imaged on 4 pixels of 10µm. A concept similar to Echelle spectrographs built for the 8-10m class telescopes like UVES[1] for the VLT or HIRES[2] for the Keck will require 17 m² grating area (Echelle) and a camera with an F/ratio of 0.26. It is obvious that such requirements associated to these kinds of designs lead to a instrument that is not feasible. More details on the instrument are given in reference 3.

2. PROPOSED CONCEPT

The only possible way to build an instrument for a 42-m telescope, that fulfills the resolution requirement mentioned in the introduction, is to make use of slicing techniques. Combined with anamorphic beam propagation along the instrument, this spectrograph can be built with moderate size optics. The penalty is a detector area that has to be much bigger. Figure 1 illustrates the philosophy of the concept. The propagation of the object and associated pupil are shown at the level of each main optical component.

The rest of the paper will describes in details all optical components from fiber to detector and present the overall performance of the spectrograph. The optical components are:

- The anamorphic pre-slit slicer
- The Echelle disperser Module
- The transfer collimator
- The cross disperser (VPHG)
- The cameras

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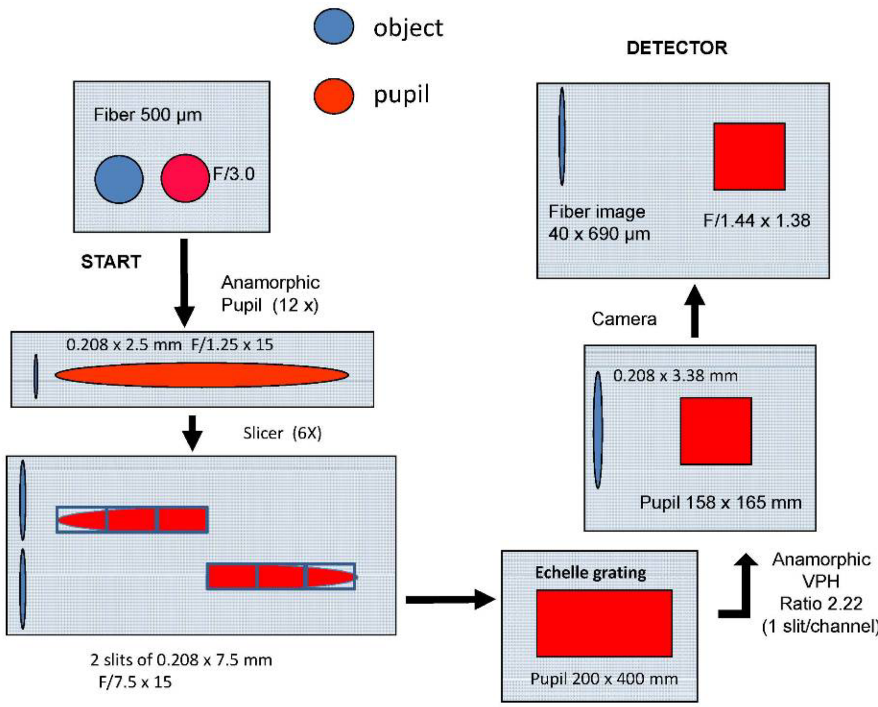


Figure 1.

3. THE ANAMORPHIC SLICER

The two fibers (object and sky/calibration) have both a diameter of 500 μm and are separated by an air gap of 1.4 mm. The fiber diameter is equivalent to 0.82 arcsec on the sky for a 42 m telescope. The output F/N of these fibers is F/3.0. A cemented F=50 mm triplet made of CaF2 - BAL5Y - CaF2 as shown in Figure 2 collimates the beams issued from these fibers and provides a parallel beam of 16.7 mm.

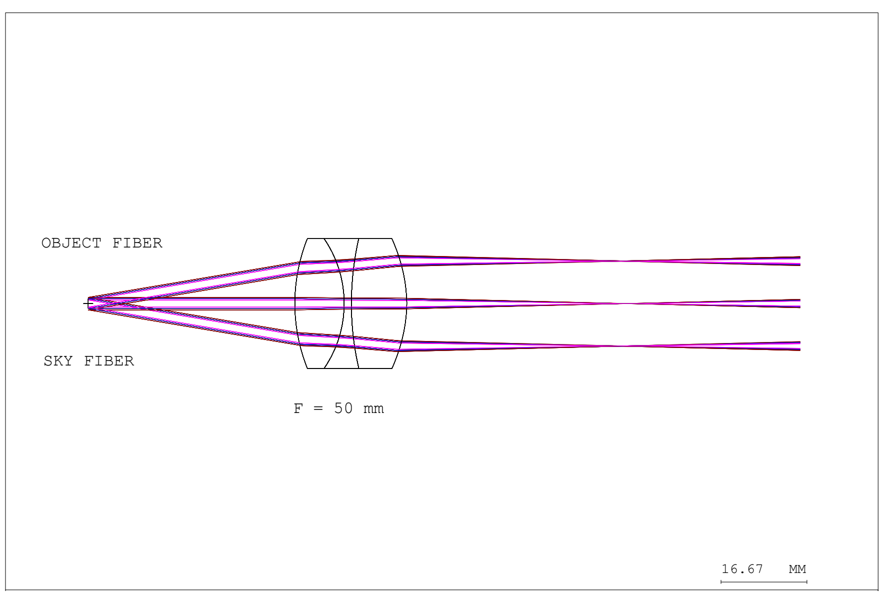


Figure 2. CODEX slicer collimator

A system of 2 mirrors (Figure 3) placed in the parallel beam is used to create the large anamorphic (x12) beam. These mirrors are flat in the plane of the slit separation and parabolic in the perpendicular one.

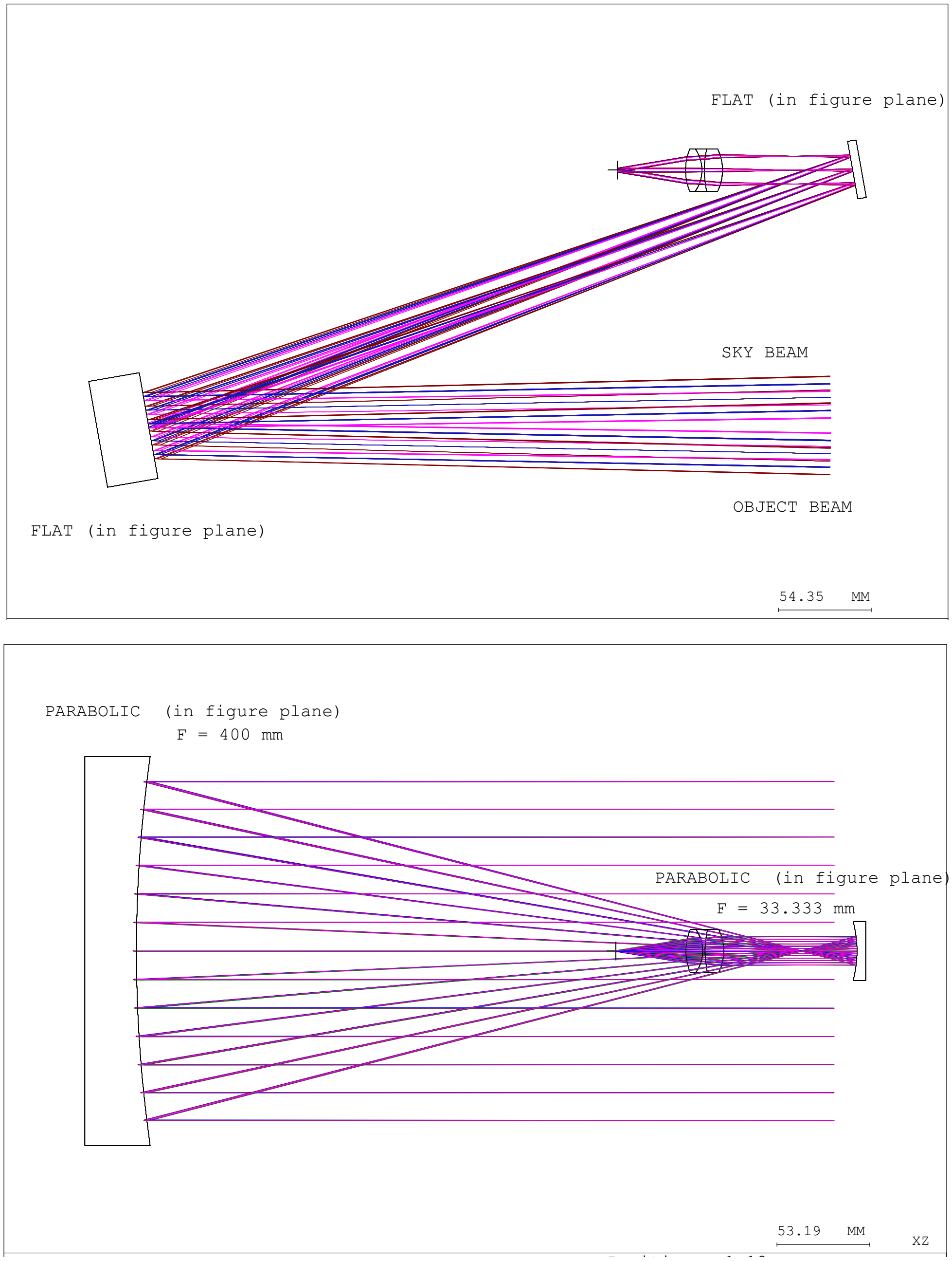


Figure 3. CODEX anamorphic (x12) system

The pupil conjugation on the slicer lens array is only achieved in the plane across the fibers. Along the fibers the pupil is not reimaged at the level of the slicers as shown in Figure 4. This has the advantage to separate the beams issued from the object fibers and the beams issued from the sky / calibration.

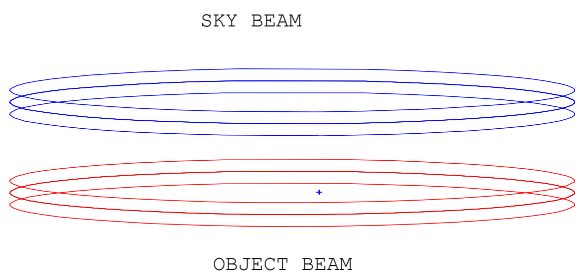


Figure 4. Beam arrangement at the slicer level (F/15 x F/1.25)

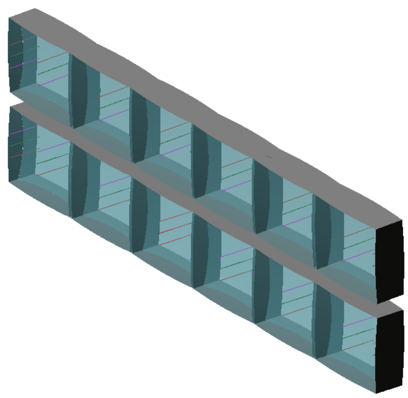


Figure 5. Slicer lens array

Two one dimensional arrays of 6 x1 lenses located one on the object beam and the other on the sky / calibration beam are used to create 6 object images and 6 sky / calibration images.

The 6 objects and the 6 sky / calibration images are rearranged by means of 12 flat mirrors along the spectrograph common entrance slit as shown in Figure 6. The respective F/Ns are now F/15 along the fiber slit and F/7.5 across.

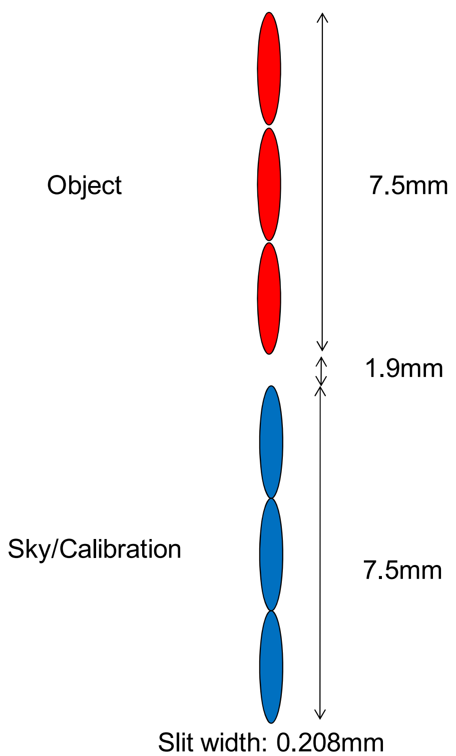


Figure 6. Slit arrangement

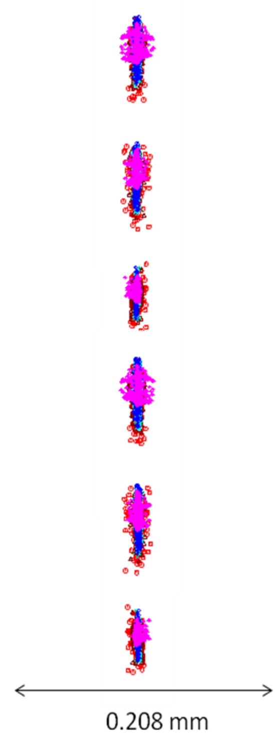


Figure 7. Spot diagrams of the anamorphic slicer

The images of the slices are arranged by means of 12 tilted mirrors along the spectrograph slit. Although the first part of the instrument related to the main Echelle dispersion is common, the rest of the instrument is divided in two identical units after the intermediate spectrum. Each spectrograph accepts 3 object slices and 3 sky / calibration slices.

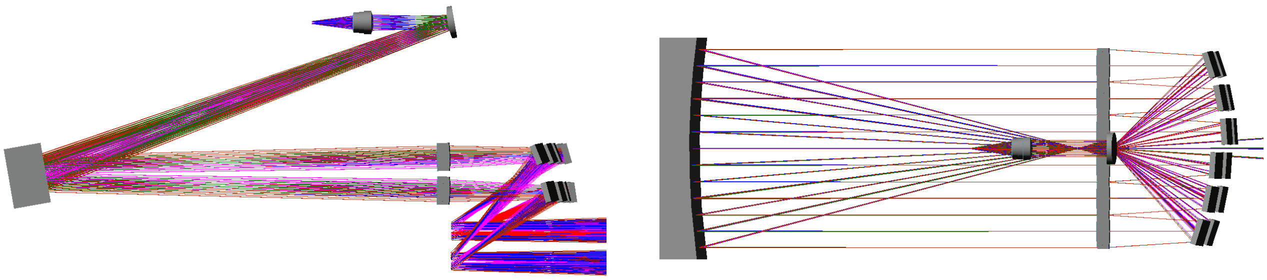


Figure 8. Front and upper view of the entire anamorphic slicer

The image quality of the system is excellent as shown in spot diagrams (Figure 7). The 3 upper spots represent the 3 sliced object images and the 3 bottom spots the 3 sky / calibration images. The spot diagrams are the image of a single point of the entrance fibre. The scale of the 0.208 mm represents a resolution element of CODEX, defined by the width of the spectrograph slit.

4. THE ECHELLE DISPERSER MODULE

The total slit length of 37 mm plus a gap between the 2 slits is too large to use a module like UVES (2 parabolas). The best solution is here a three mirrors anastigmat used in double path. This system gives a very good image quality and is relatively compact. The size of each individual mirrors are for the larger one (M1) 920 mm x 400 mm and for the other two ones 430 mm x 180 mm and 660 mm x 300 mm (respectively M2 and M3). All three mirrors are conic surfaces.

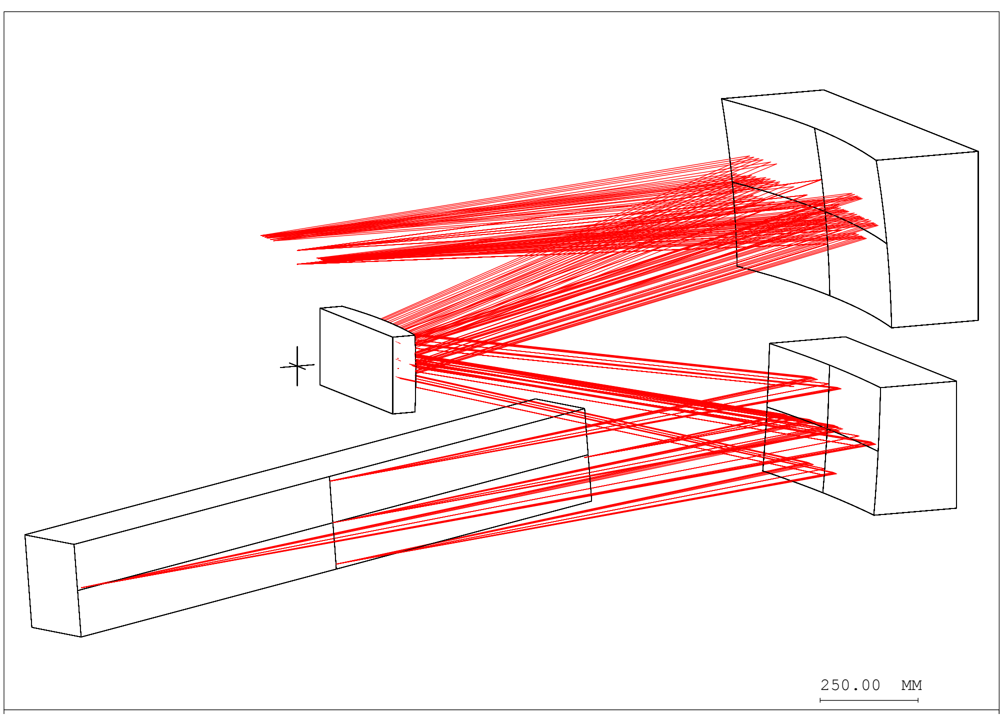


Figure 9. Echelle disperser module

The grating is a 41.6 mm-1 echelle blazed at 76º. Its dimension is 1600 x 200 mm2. It consists of a 4 x 1 mosaic of 408 x 200 mm2 grating segments, the double of each of the UVES arms. The grating characteristics require the same master as the one used to produce the UVES Echelles. The efficiency is well known: blaze peaks are about 70%

The linear and angular tolerances required for the segment alignment have not been calculated, however in our experience the grating spectral resolution, as measured, is much better than the one required for the spectrograph. For instance in the case of the UVES grating (with two segments), which could be considered as a first step for the CODEX grating, its theoretical spectral resolution for a monolithic piece (840 mm ruled length) is 2.5 million; the measured spectral resolution was 2.1 million; both values are well above the spectral resolution for CODEX. The expected spectral degradation due to a non perfect alignment of the segment will be negligible; in addition the instrument itself is not working at diffraction limit.

5. THE TRANSFER COLLIMATOR

The long slit as shown in paragraph 3 is too long for a single Echelle format on the detector. The cross dispersion required to separate the orders is impossible to achieve with a beam size below 200 mm. It is more convenient to split the slit in two parts and send the light on two spectrographs. This will also ease the design of the cameras. The separation of the 2 slits has already been set up by the anamorphic slicer. As the Echelle disperser module operates at magnification one, this separation is achieved at the level of the intermediate spectrum. The pupil relays mirrors near the focus of the intermediate spectra are used to direct the beams to the selected spectrograph.

An off-axis Maksutov type collimator is used to re-collimate the beams. This collimator type has been preferred to other collimators mainly for its field curvature characteristics which fully cancel the one produced by the Echelle disperser module and the pupil relay lens. The mirror has 800 mm x 116 mm aperture and the off axis meniscus, which completes the system, has an aperture 260 mm x 110 mm and is made in fused silica. The pupil relay mirror (spherical) has a 450 mm x 20 mm aperture.

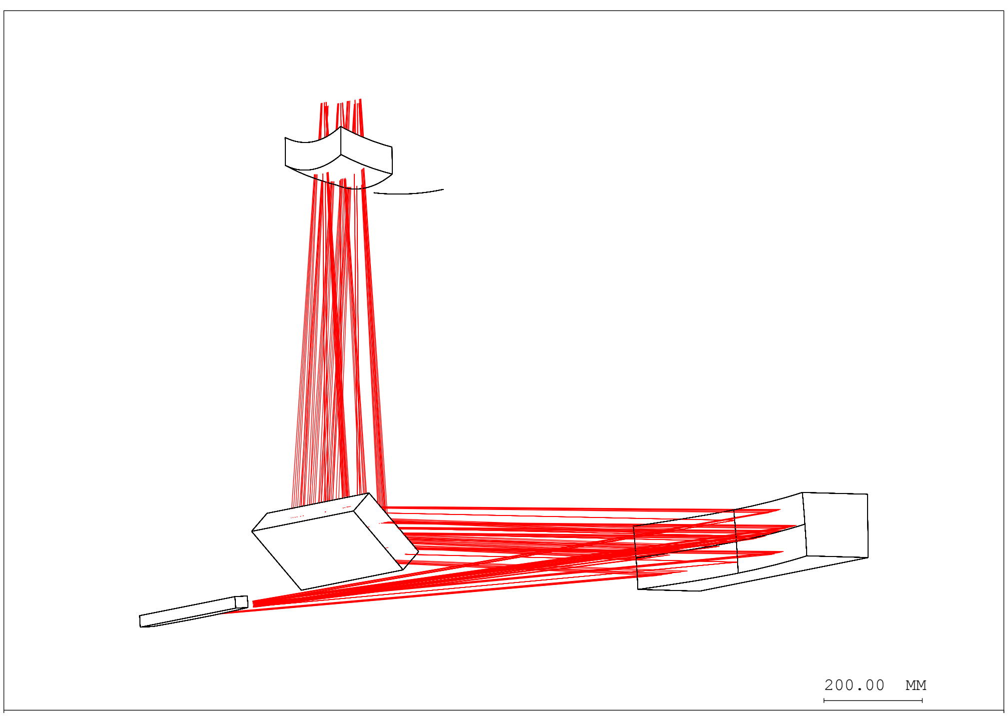


Figure 10. Transfer collimator

6. THE CROSS DISPERSER GRATING

The collimated beam is now dispersed in the perpendicular direction (across the orders). To cancel the anamorphic effect introduced previously to keep the Echelle grating height below 200 mm, the VPH is not used in Bragg condition but with a diffracted angle smaller than the incident angle. This will produce an anamorphic effect of 2.22. This anamorphic effect increases the parallel beam diameter from 74 mm to 165 mm. This different mode of operation of the VPH is still in prototyping phase, in case of non successful results, the VPH will be uses closer to pure Bragg conditions and the anamorphic effect will be produced by one or more prisms. The groove densities of the blue and red VPHG are respectively 2600 and 1500 mm^{-1}.

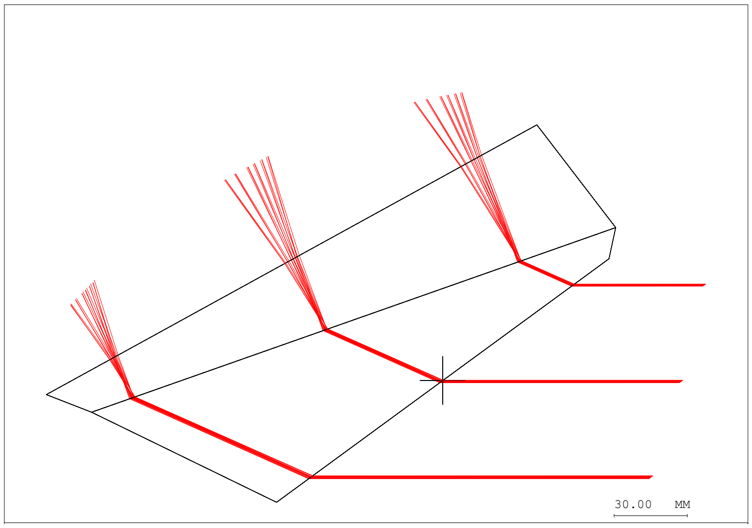


Figure 11. CODEX VPHG

7. THE CAMERA

The requirements on the cameras are very demanding:

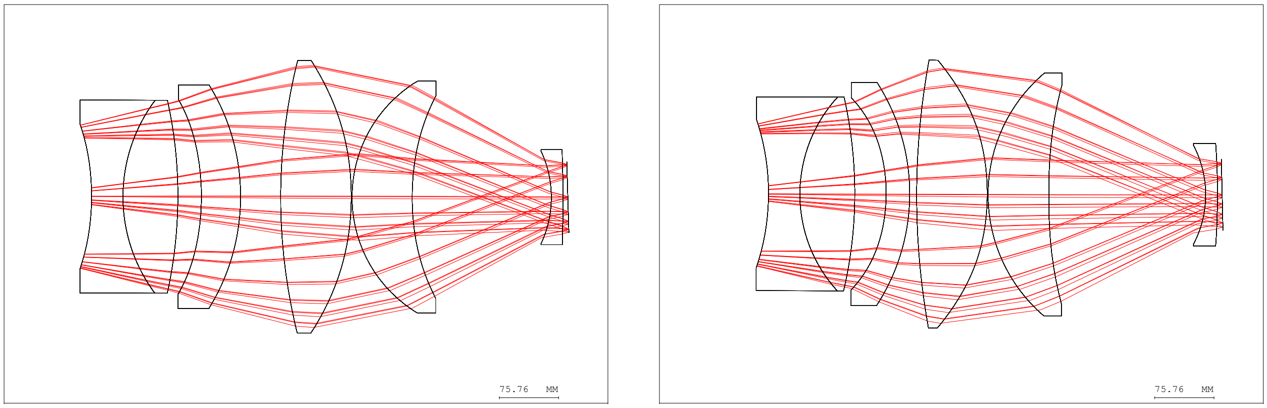
- Fast F/N: 1.44 (spectral) x 1.38 (spatial)
- Large field of view: 30°
- Excellent image quality to be compatible with 10 µm pixel.

Dioptric cameras are proposed for both arms. The design for both cameras is very similar. During the design phase of the cameras several possible designs have been investigated. For the final choice priority has been given to transmission efficiency. As this instrument will operate with a unique spectral format, the cameras do not need to be fully achromatic (this would have required expensive materials like Caf2 or Ohara SFPL51). The residual chromatism can be compensated by a detector tilt along the cross dispersion. As aspheric polishing has considerably improved over the last few years, aspheric lenses are also used to minimize the number of optical components.

Both cameras are now made of only 6 lenses in 5 groups. One of the lenses is used as cryostat window. Four aspheric surfaces are needed, one on each of the 4 groups of the camera body. Both cameras provide a very good image quality fully compatible with the small 10µm pixels.

The lens glasses of the blue camera (Figure 12-a) have been selected to maintain a high internal transmission in the UV region: Ohara PBL25Y, BSM51Y, PBL6Y, S-FSL5Y (2) and fused silica for the cryostat window lens. The camera covers the range 370 nm to 510 nm, its effective focal length is 231 mm, its total length 607 mm and the diameter of the largest lens is 340 mm.

The glasses of the red camera (Figure 12-b) are Ohara PBM2Y S-LAL7, S-TIH10, S-NSL3 (2) and fused silica. The camera covers the spectral range from 490 nm to 710 nm and has an EFL of 231 mm, its total length is 578 mm and the diameter of the largest lens is 330 mm.



(a) (b)

Figure 12. CODEX blue (a) and red (b) cameras

8. THE COMPLETE SPECTROGRAPH

The instrument fits on a bench of 2.9 m by 2.4 m. The layout is shown in Figure 13. The slit arrangement on the detector is shown in Figure 14.

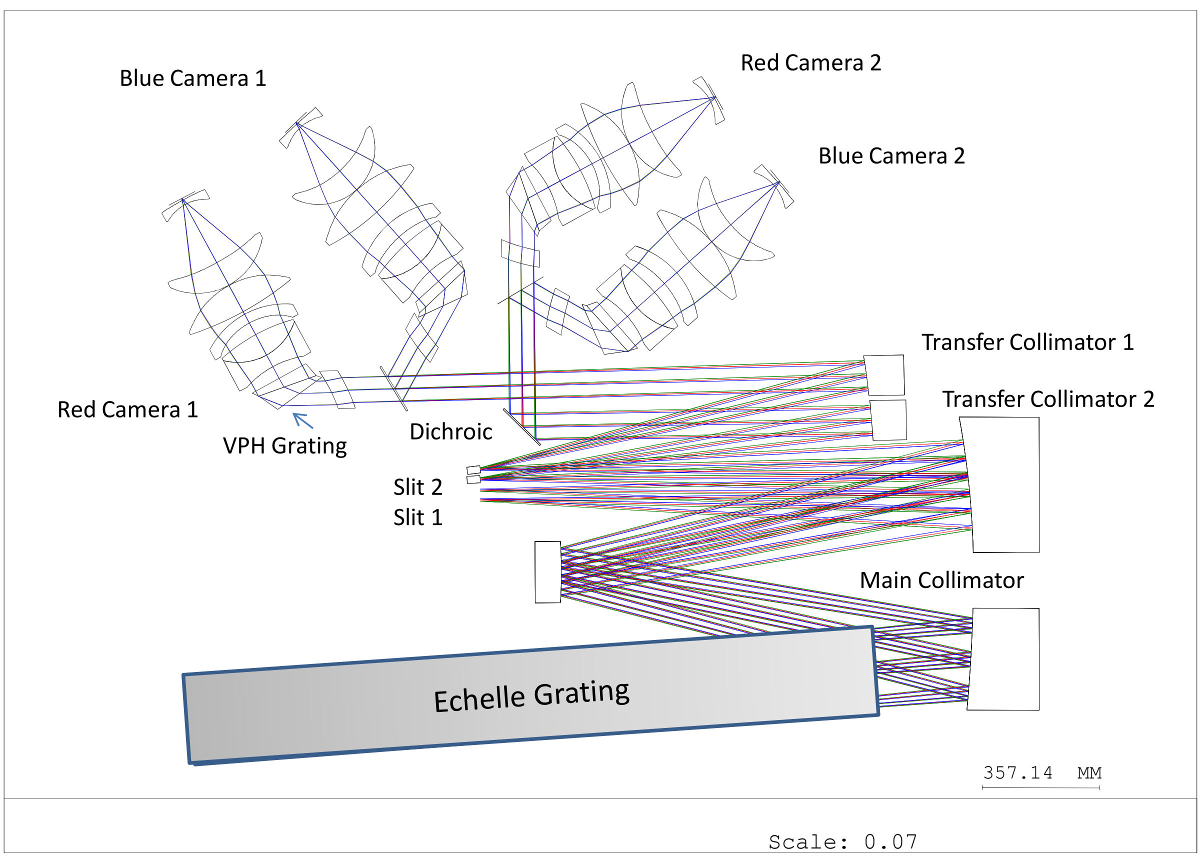


Figure 13. CODEX spectrograph layout

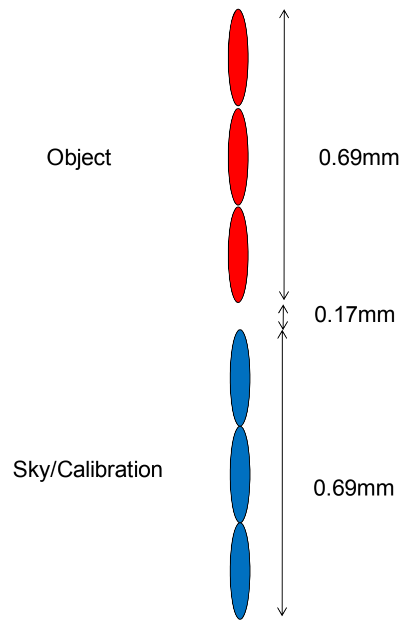


Figure 14. Image slit on the detector

8.1 Spectral Format

The wavelength range is split around 500 nm. Orders 92 to 95 are common to both detectors. This corresponds to a recoverage of 20 nm. The minimum order separation is 1.73 mm on the blue detector and 1.83 mm on the red one. Spectral format on each detector is shown in Figure 15 and order separation curves are shown in Figure 16.

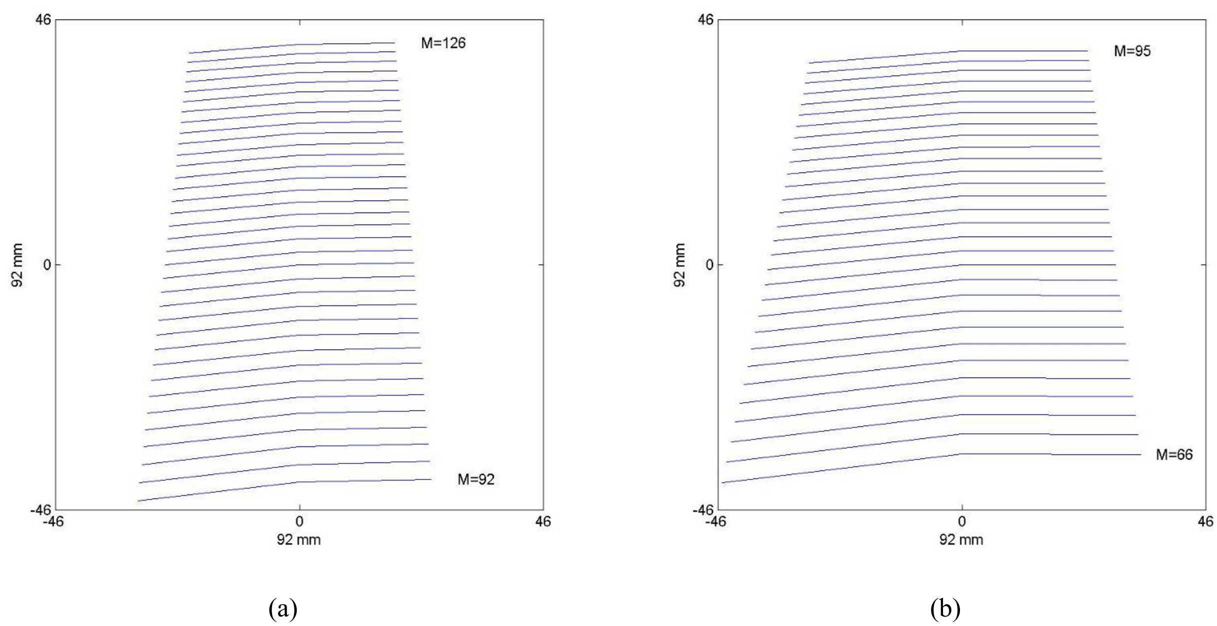


Figure 15. Spectral format on the blue and red detector

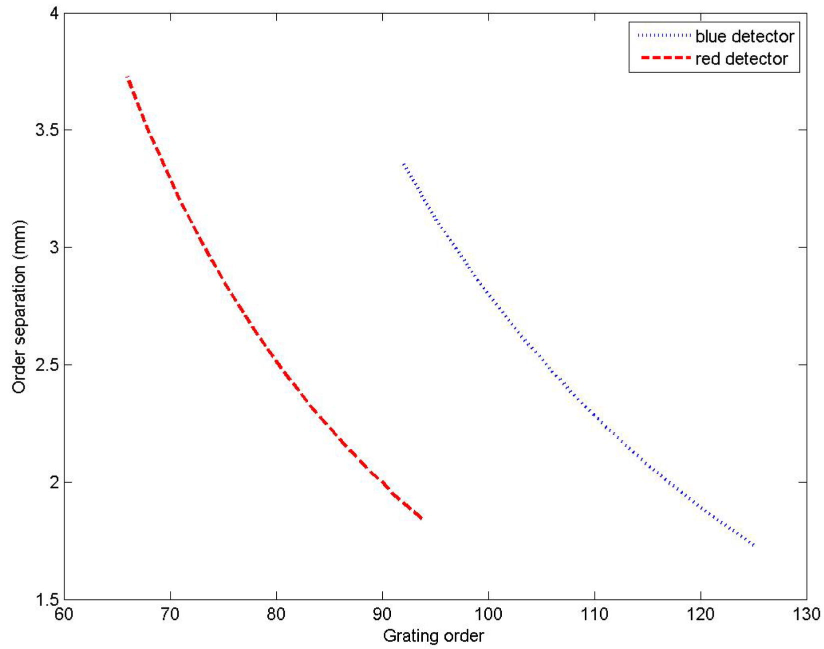


Figure 16. Order separation on the blue (doted line) and red (dashed line) detectors

8.2 Optical Performance

The optical quality given by the complete spectrograph is excellent and fully compatible with small pixel size of 10µm. The Figure 17 gives the diameter of the image spots (80% geometrical energy) for 3 wavelengths of all Echelle grating order. The three wavelengths are right edge, center and left edge of each order. The wavelength range for the blue spectrograph is 370 to 510 nm and for the red spectrograph 485 to 715 nm

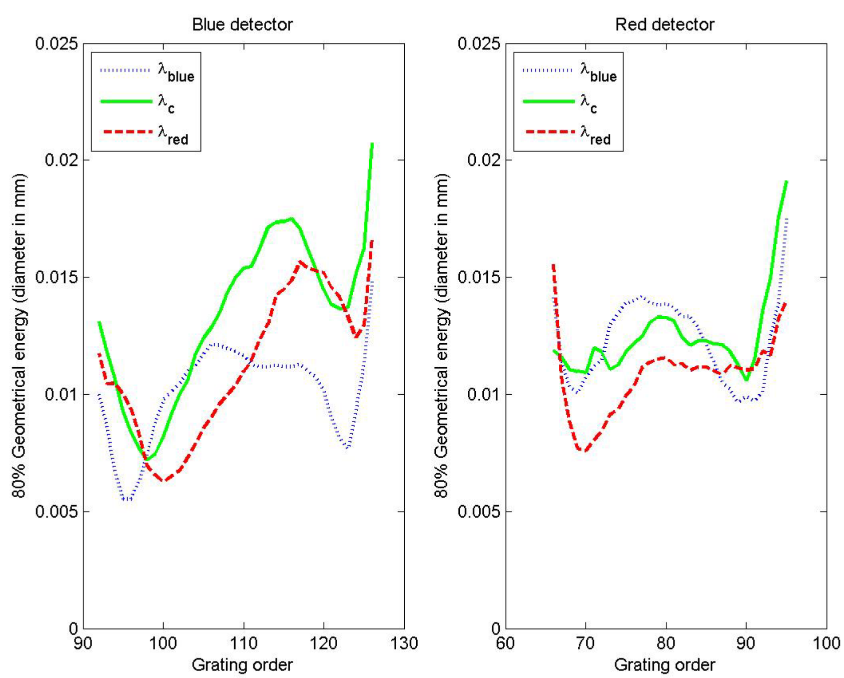


Figure 17. Image quality for each detector

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