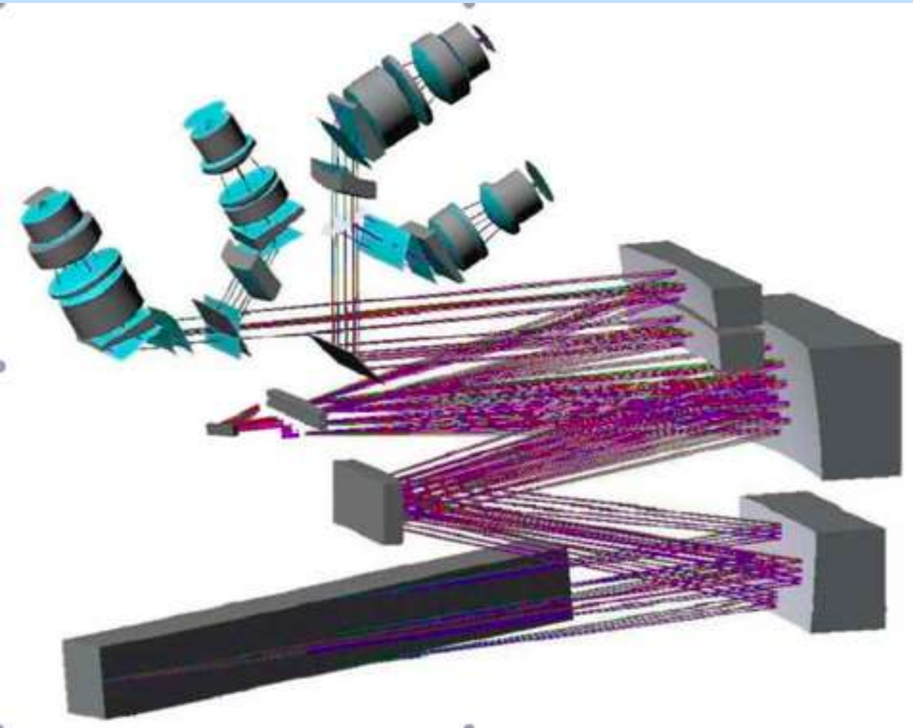
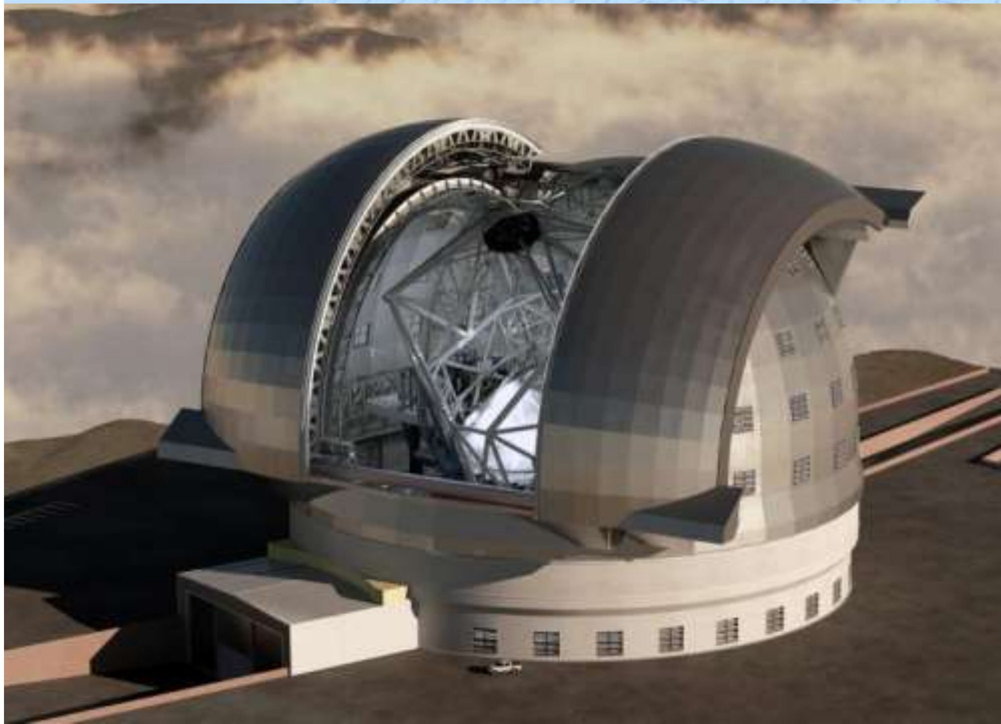
CODEX

the high resolution, ultra-stable spectrograph for the E-ELT

Gaspare Lo Curto, Luca Pasquini





CONSORTIUM

- ESO (L. Pasquini)
- IAC (Ramon Garcia-Lopez)
- IoA Cambridge (Martin Haehnelt)
- INAF (Trieste and Brera) (Stefano Cristiani)
- Observatoire de Genève (Michel Mayor)

Jochen Liske, Bob Carswell, George Becker, Stephane Udry, Francesco Pepe, Christophe Lovis, Dominique Naef, Miroslava Dessauges, Denis Mégevand, Rafael Rebolo, Garik Israelian, Artemio Herrero, María Rosa Zapatero, Valentina D'Odorico, Paolo Molaro, Matteo Viel, Eros Vanzella, Piercarlo Bonifacio, Antonio Manescau, Gerardo Ávila, Hans Dekker, Olaf Iwert, Bernard Delabre, Gaspare Lo Curto, Michel Fleury, Ian Hughes, Fabio Tenegi, Paolo Di Marcantonio, Paolo Santin, Maurizio Comari, Roberto Cirami, Igor Coretti, Filippo Maria Zerbi, Paolo Spanò, Marco Riva.

CODEX web page: http://www.iac.es/proyecto/codex/

What is CODEX ?

CODEX, the COsmic Dynamics and EXoplanet instrument is an

Optical,

High Resolution, Ultra-stable Spectrograph

for the **E-ELT**

An H.R. spectrograph for the E-ELT

The enormous photon collecting power of the E-ELT will allow to open a new parameter space: HIGH PRECISION SPECTROSCOPY

The science cases show as PRECISION is the -add on- Keyword for CODEX

Some History ..

- CODEX was first born as a concept for OWL (2005)
- FP6 - small instrument study (2006)
- E-ELT Phase A study (2008-2009)
- Phase A review (January 2010)

Unique Expertise

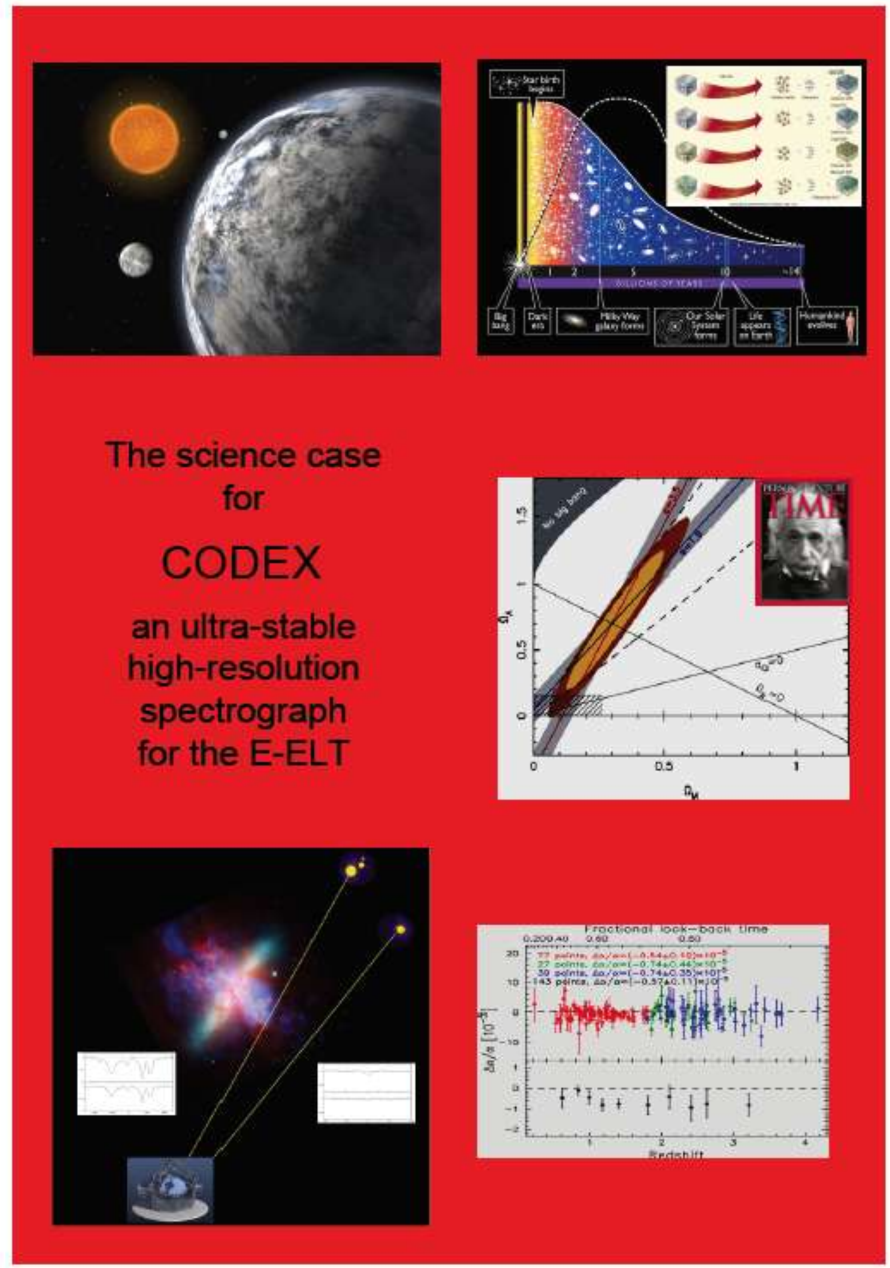
Consortium members participated and had leading roles in most optical H.R. and Radial Velocity spectrographs built in the last 20 yrs in Europe (Elodie, Coralie, Sophie, FEROS, UVES, FLAMES ...)

HARPS

Which has a special role for its scientific AND its technical heritage

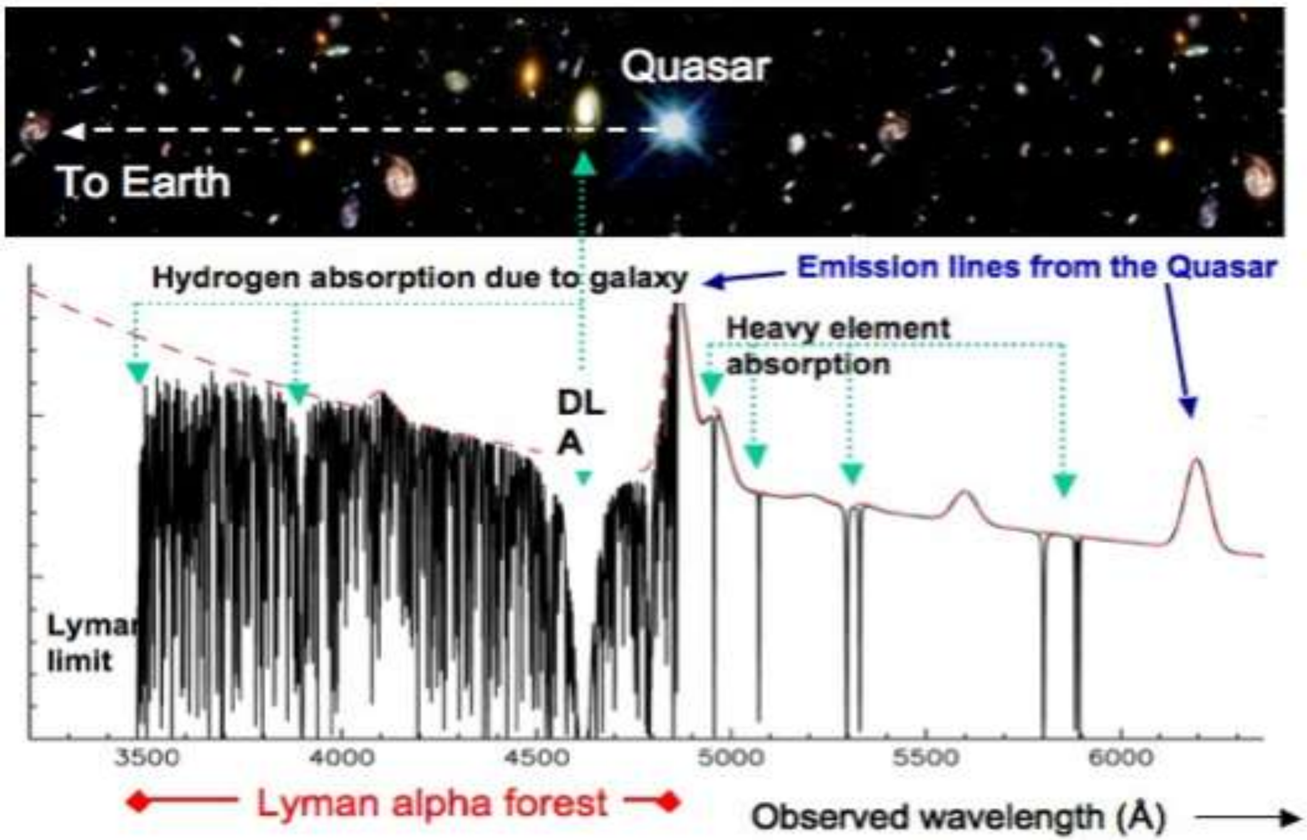
Exciting CODEX Science Cases …

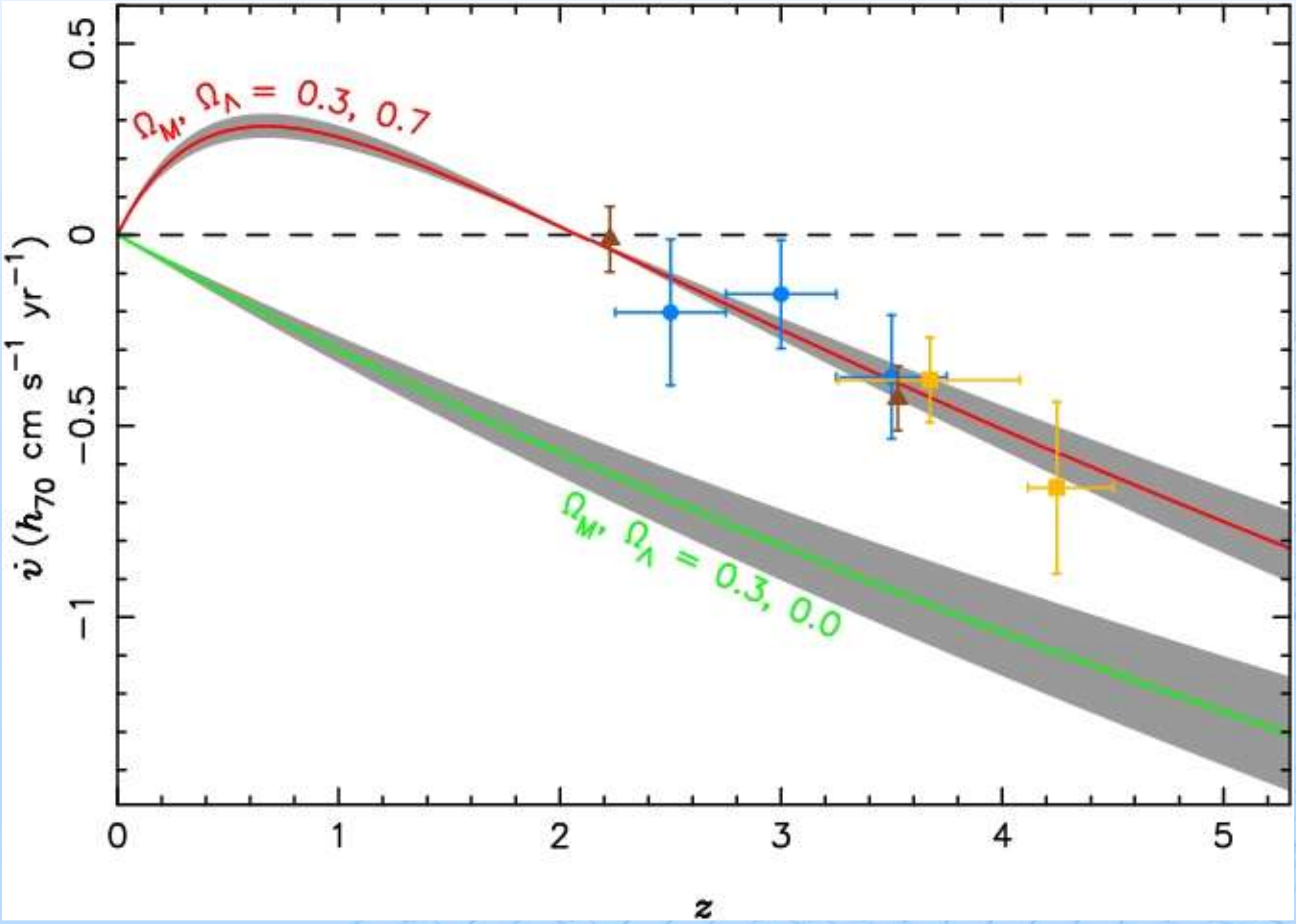
1. Dynamical measurement of the accelerating expansion of the Universe
2. Extra-solar Earth Twins in the habitable zone
3. Variability of Physical Constants
4. Metallicity of the low density IGM
5. Nucleo-chronometry



Cosmological redshift drift:

$$\dot{z} = (1+z)\, H_0 - H(t_e)$$

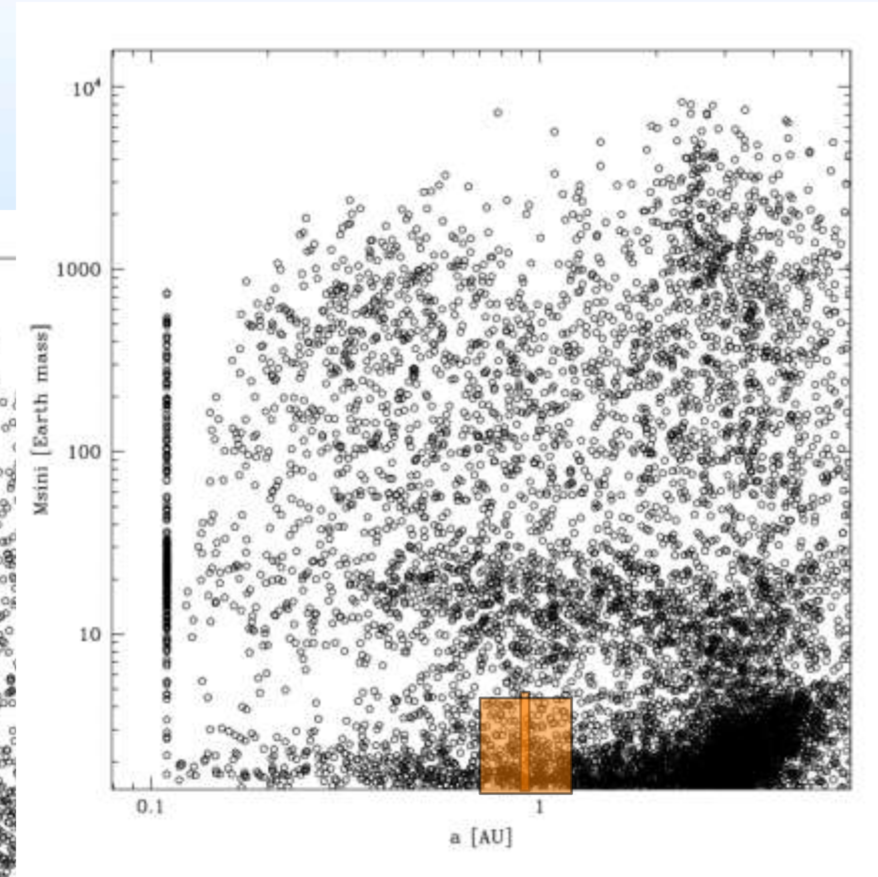




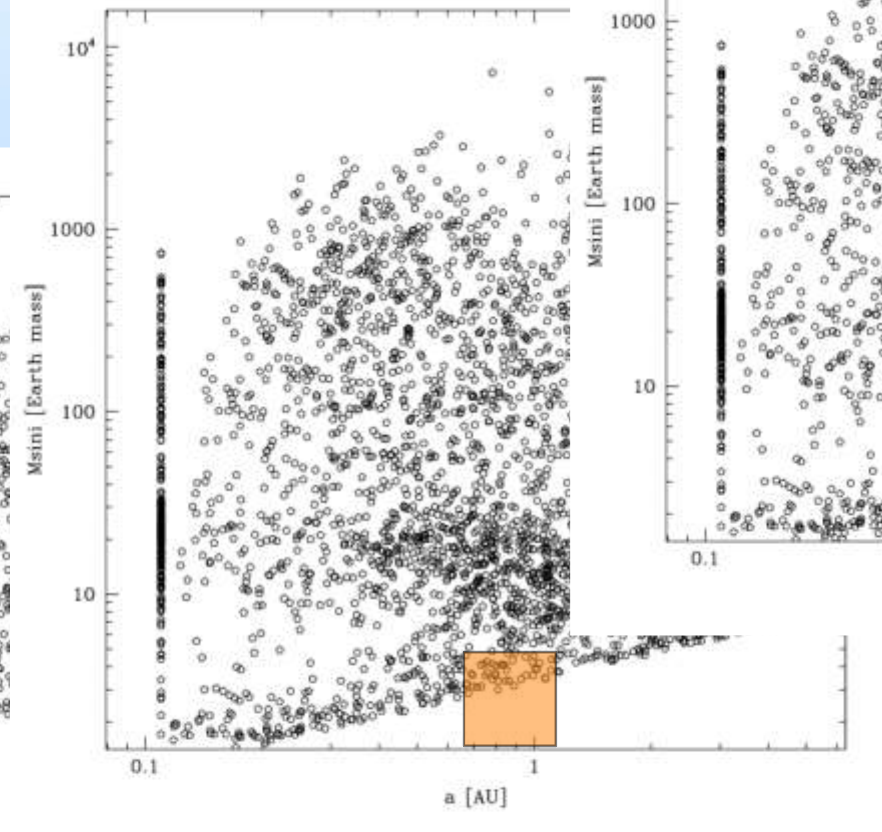
This is what we can expect for a realistic observing campaign.

Searching for the Earth twin

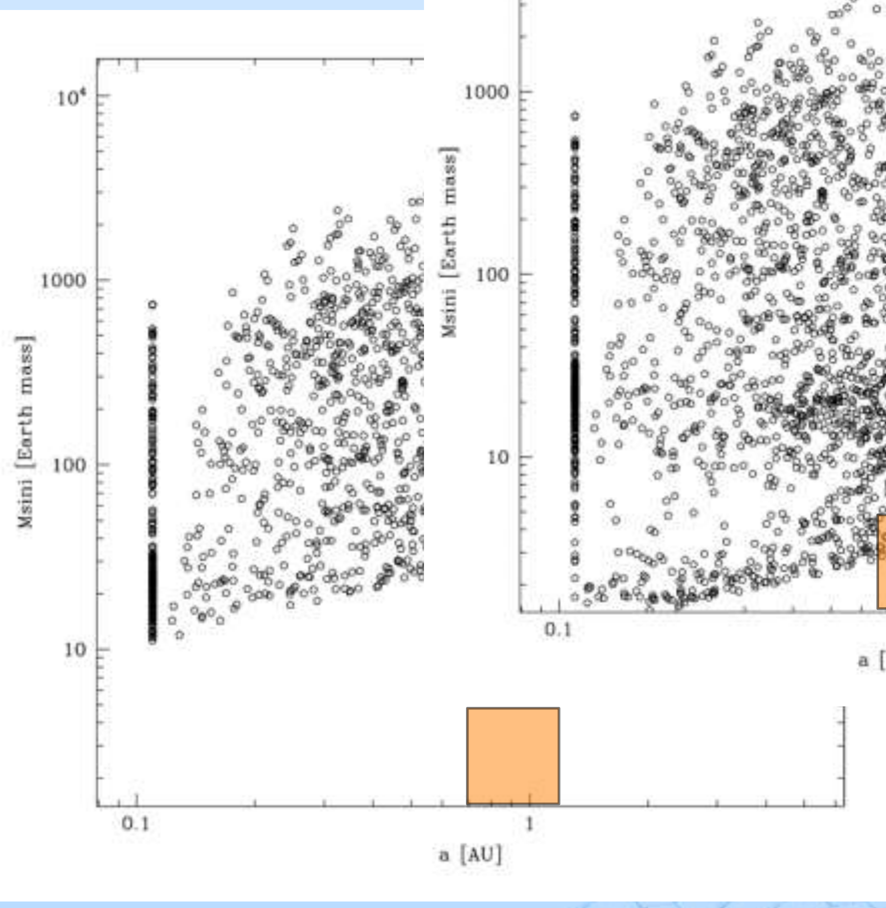
CODEX 2 cm/s



ESPRESSO 10 cm/s



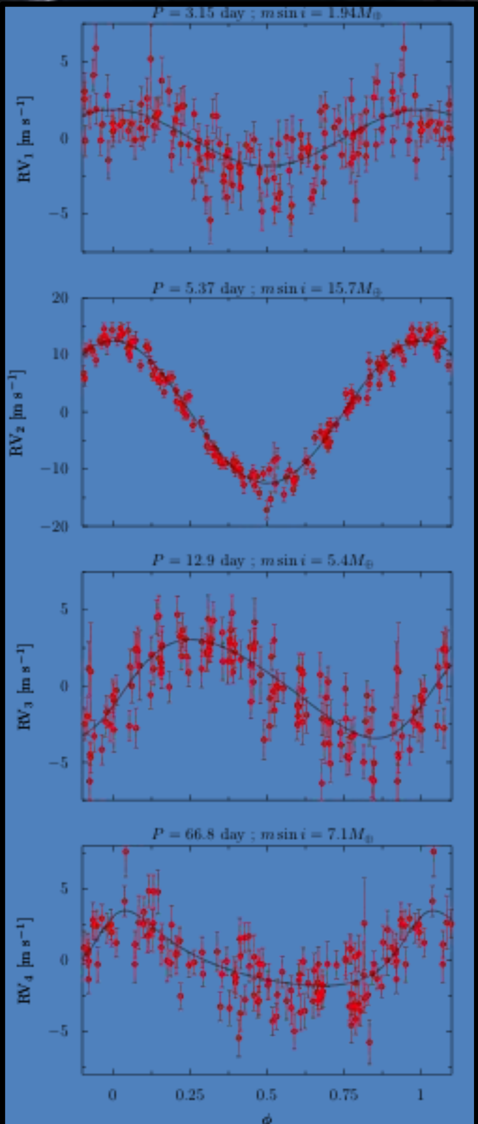
HARPS 1m/s



Mordasini et al., A&A (2009)

Two super-Earth (5-7 M_{Earth}) in a 4-planet system + a very light planet of 1.94 M_{Earth}

Gl 581, M3V star



Mayor et al, 2009

Bonfils et al.2005

Udry et al.2007

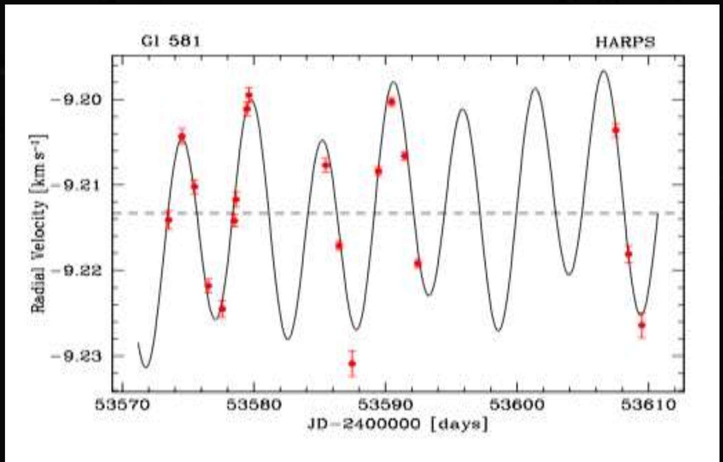
Udry et al.2007
revised in Mayor et al.

P1=3.15d M1=1.94M_{Earth}

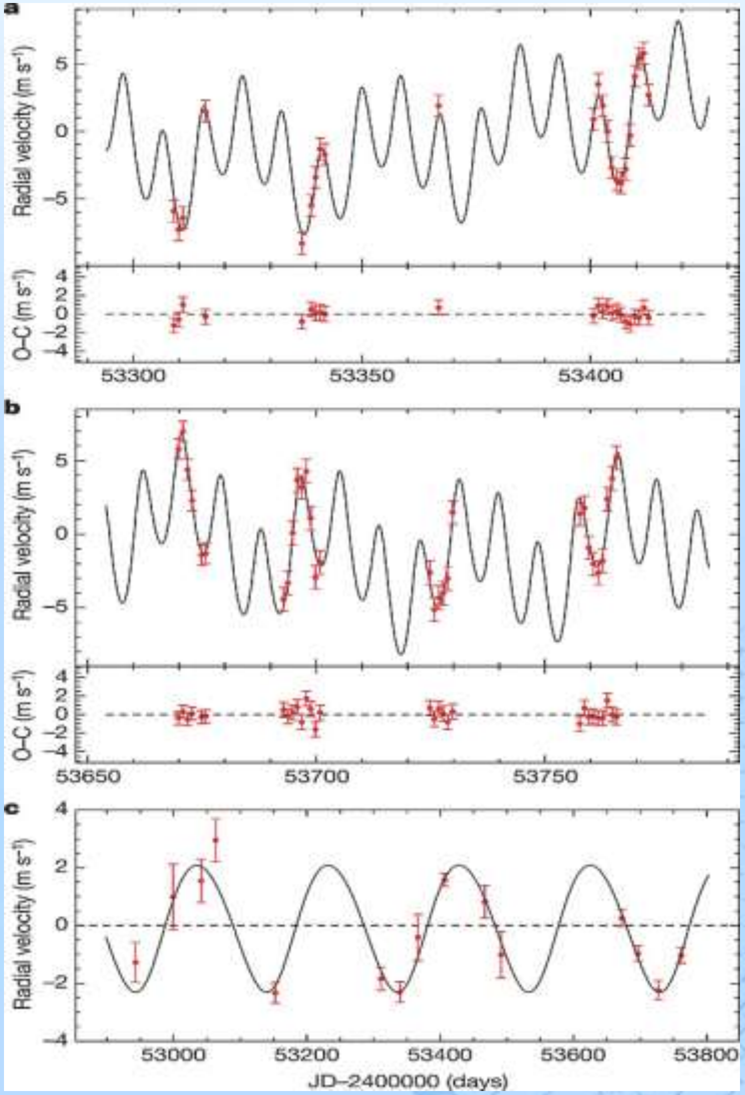
P2=5.37d M2=15.7M_{Earth}

P3=12.9 d M3=5.4M_{Earth}

P4= 66.8 d M4= 7.1 M_{Earth}



The HARPS Precision



3 Neptunes

(Lovis et al. 2006, Nature 441, 305)

σ(O-C) ~ 64 cm s^{-1} for the last (500 Days) group of highest precision observations.

This includes:

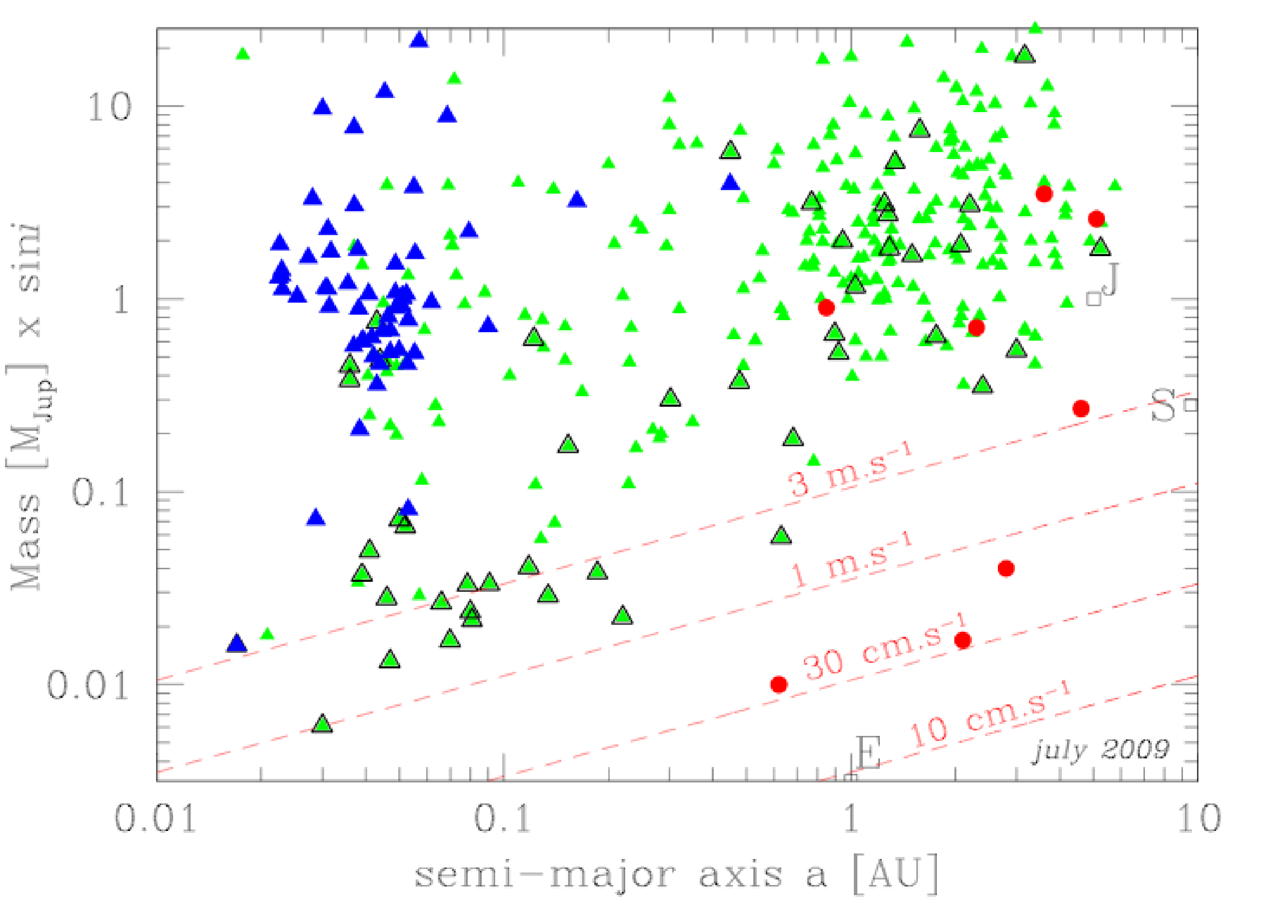
Photon Noise

Stellar "Noise"

Instrumental Noise

Exoplanets: the HARPS Scientific Heritage

16/20 Neptune mass planets have been discovered by HARPS in 5 yrs of operations
(Bouchy et al. 2009 A&A 496, 527)



CODEX main characteristics

- ✓ High resolution (120000)
- ✓ ultra-stable (vacuum, cryostat etc.)
- ✓ fiber fed (scrambling)
- ✓ echelle
- ✓ cross dispersed (slanted VPHG)

- ✓ stabilized light injection
- ✓ laser frequency comb calibration
- ✓ E-ELT

CODEX characteristics

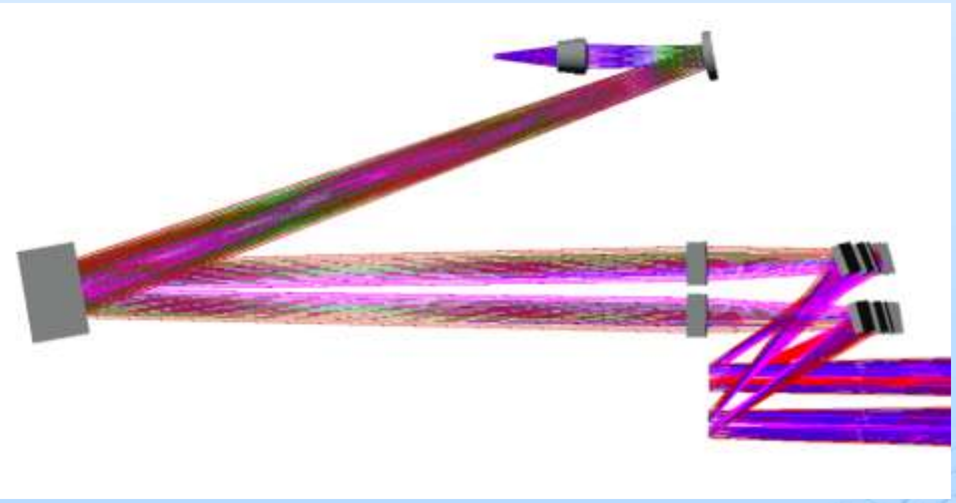
Aperture on the sky	*0.82 arcsec, with a Ø 500 μm fibre at F/3; 80% of flux are collected assuming the model E-ELT PSF of 0.65" square fibres*
Feeding	*2 fibres, one for object, one for sky or simultaneous calibration*
Wavelength range	*370-710 nm, split in two arms by dichroics BLUE: 370-500 nm; RED: 490-710 nm*
Doppler Precision	*< 2 cm/sec over 30 years*
Wavelength Precision	*< 1 m/sec (absolute wave length calibration of each spectral pixel)*
Resolving Power	*120000 for square fibre, ~135000 for circular fibre*
Sampling	*4 pixel/spectral element*
Spectral format	*cross-dispersed echelle*
Echelle	*R4, 41.7 l/mm, 1700x200 mm, 4x1 mosaic*
Order separation	*>30 pixels (>300 μm) between adjacent orders*
	30 pixels (300 μm) between object and sky fibre
Order height	*0.705mm x 2 (141 pixels of 10 μm size)*
Camera focal ratio	*F/1.5 (on-axis)*
Detector focal plane	*Four CCDs (2 in Blue Camera, 2 in Red Camera), each with 9 x 9 K 10 μm pixels*
Total efficiency	*24.9% (maximum), 8.5% (minimum) from telescope to detector focal plane, slit losses are not included*
Auxiliary functions	*Exposure meter system, CCD flatfield, LEDs for maintenance*

CODEX optical design (B. Delabre et al.)

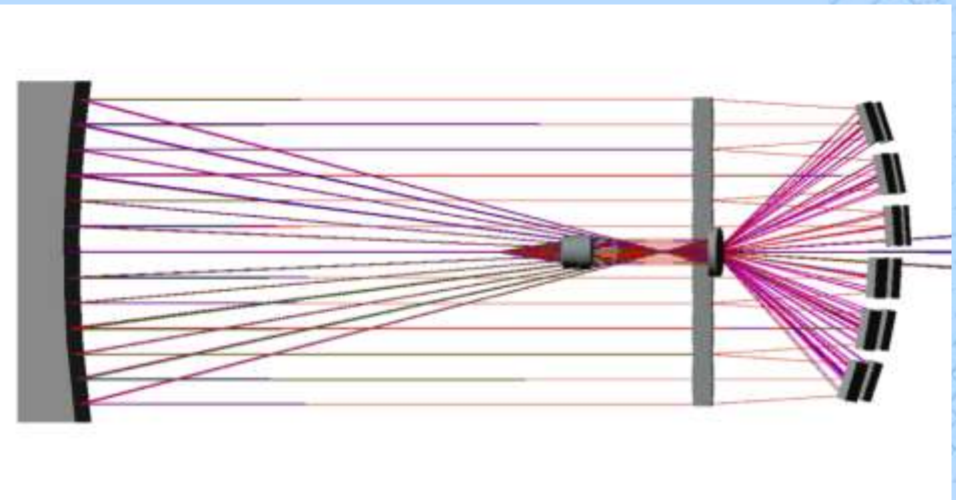
- Anamorphic beams (x12)
- Pupil slicing (x6)

Pre-slit optics

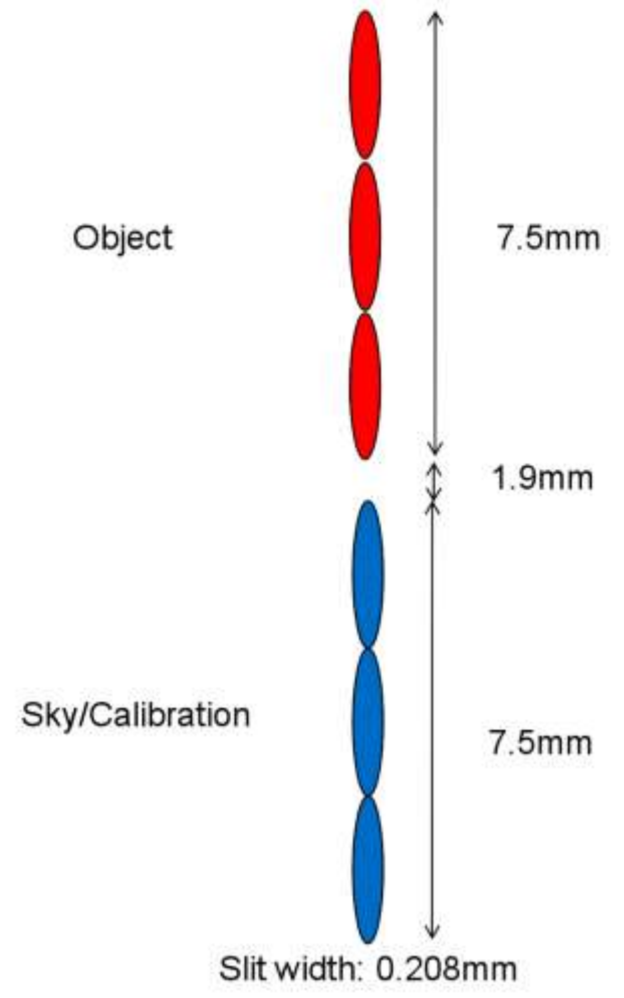
Slit (x 2)



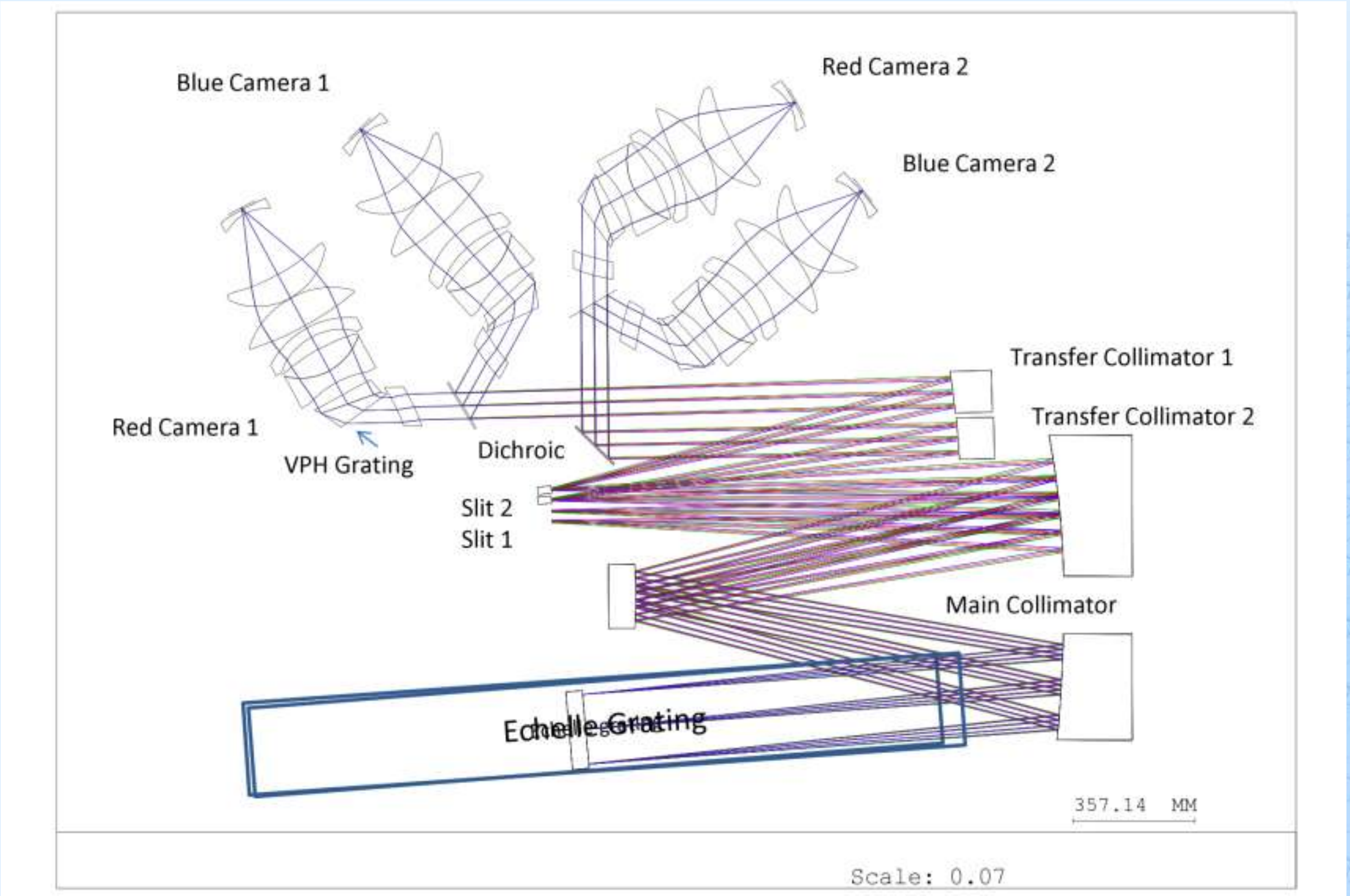
Front view



Upper view



CODEX optical design



Instrumental Contribution comes from:

- Wavelength calibration
- Thermo-mechanical Stability of the spectrograph
- Thermo-mechanical Stability of the detector
- Stability of the light injection

Other Contribution comes from:

- Photon Noise
- Astronomical Sources of Noise

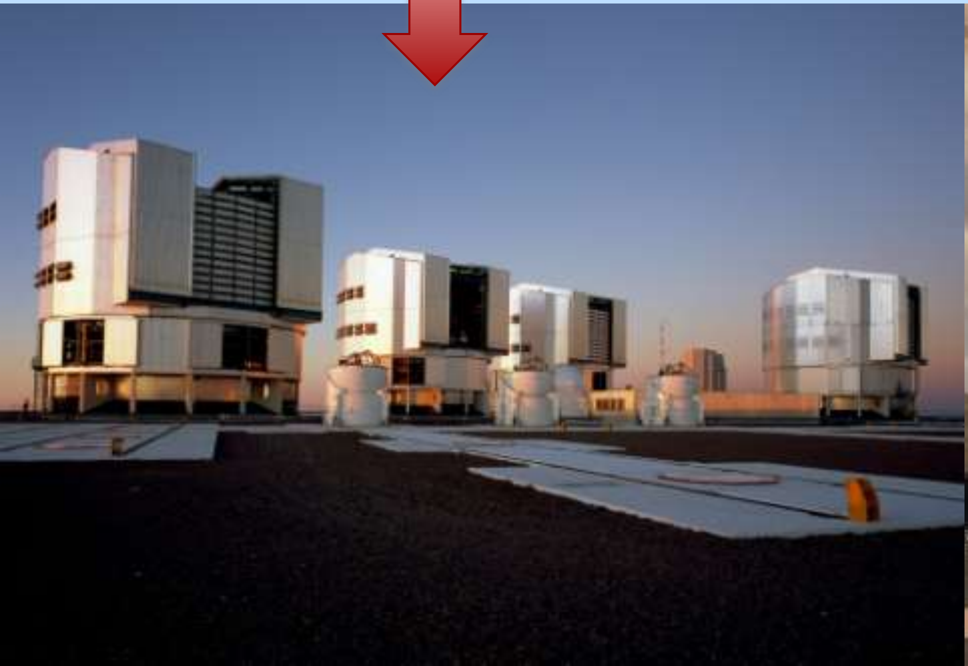
	HARPS	ESPRESSO	CODEX
RV precision	1 m/s	10 cm/s	2 cm/s
Distance on CCD	17 nm	16 Å	3.2 Å

Silicon lattice constant: 5.4 Å

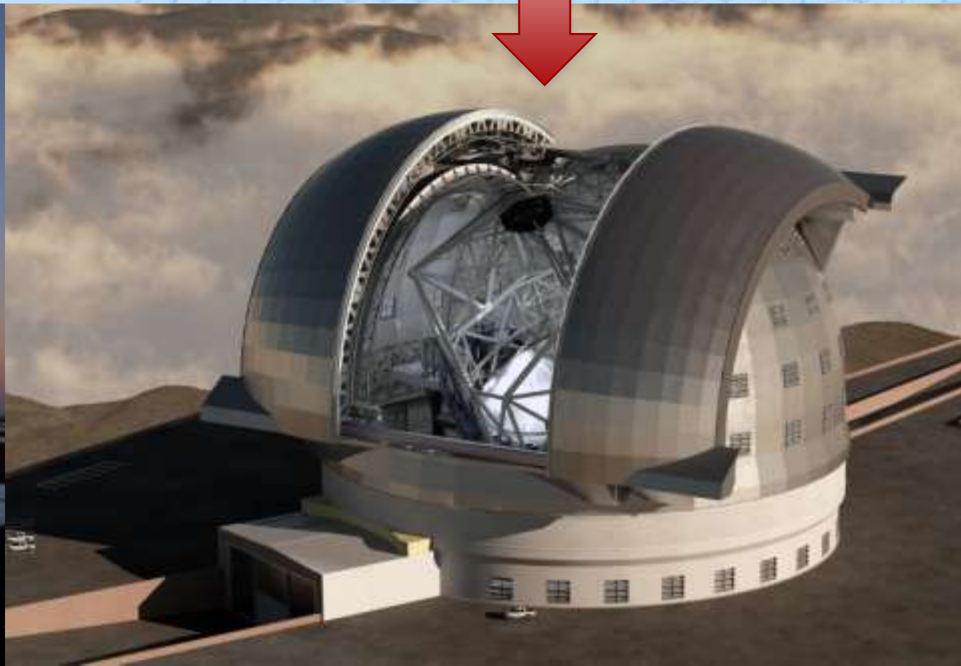
$$\delta RV = \frac{c}{Q \cdot \sqrt{N_{e^-}}} \propto \frac{1}{R}$$

S/N ~ 100 => RV ~ 1m/s

ESPRESSO, 10cm/s



CODEX, 2 cm/s



HARPS: stability at 1 m/s

⊗RV =1 m/s

⇕

⊗L =0.00001 A

⇕

15 nm

⇕

1/1000 pixel

Pressure and temperature control !!!

2–fiber fed

⊗RV =1 m/s

⇕

⊗T =0.01 K

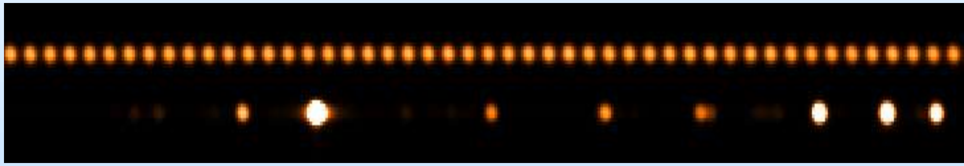
⇕

⊗p=0.01 mBar

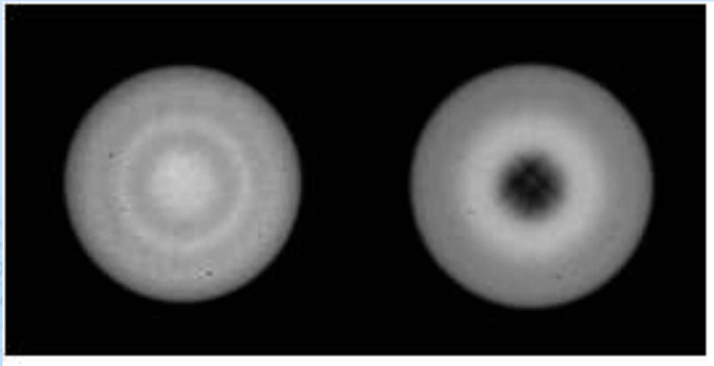
CODEX: 2cm/s => 3.2Å

Critical areas

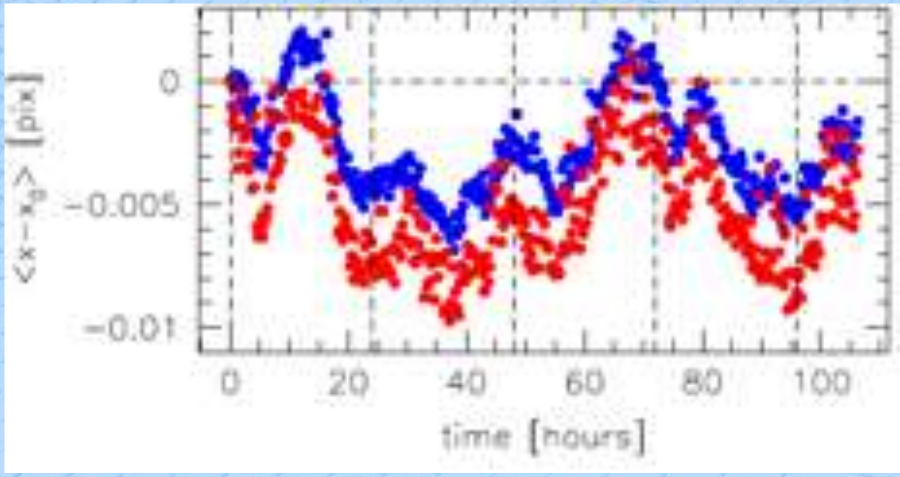
Wavelength Calibration:
Development of LFC Calibration System
in collaboration with MPQ (T. Udem talk)



Light injection:
Tests on FRD and Scrambling on different
types of fibers

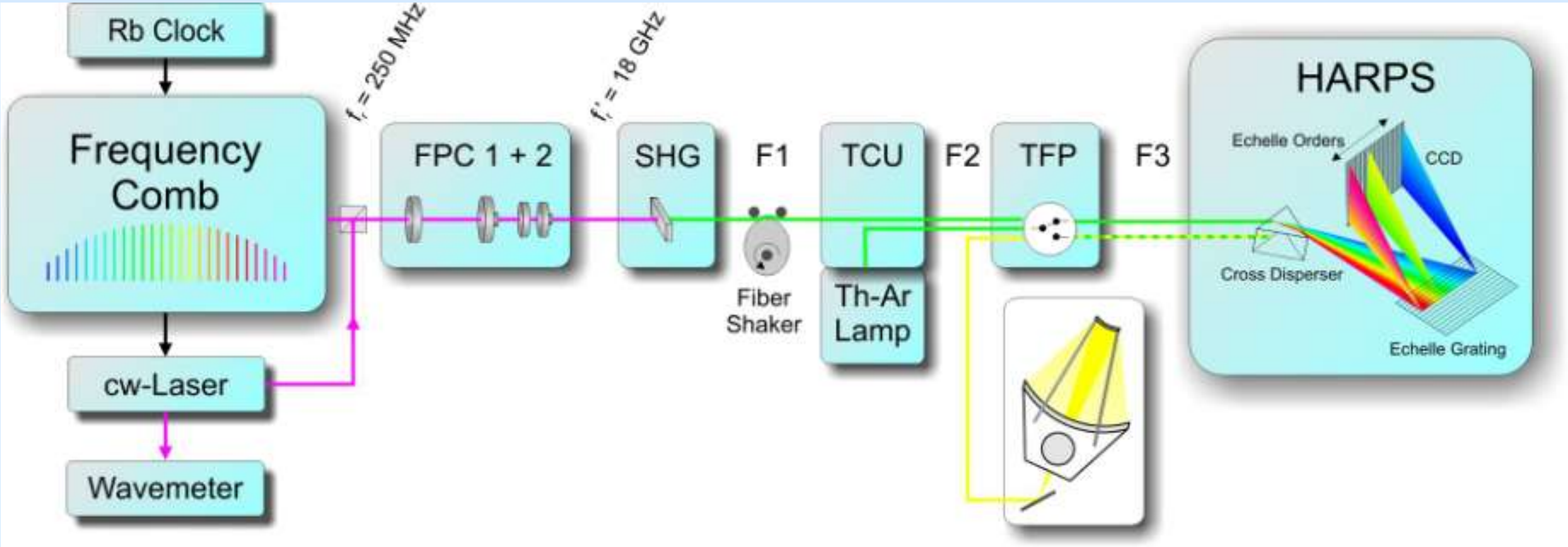


Detector Stability:
Analysis and modeling of HARPS tests and
Development of super stable cryostat (FP7)
Ad-Hoc Test Campaign and development

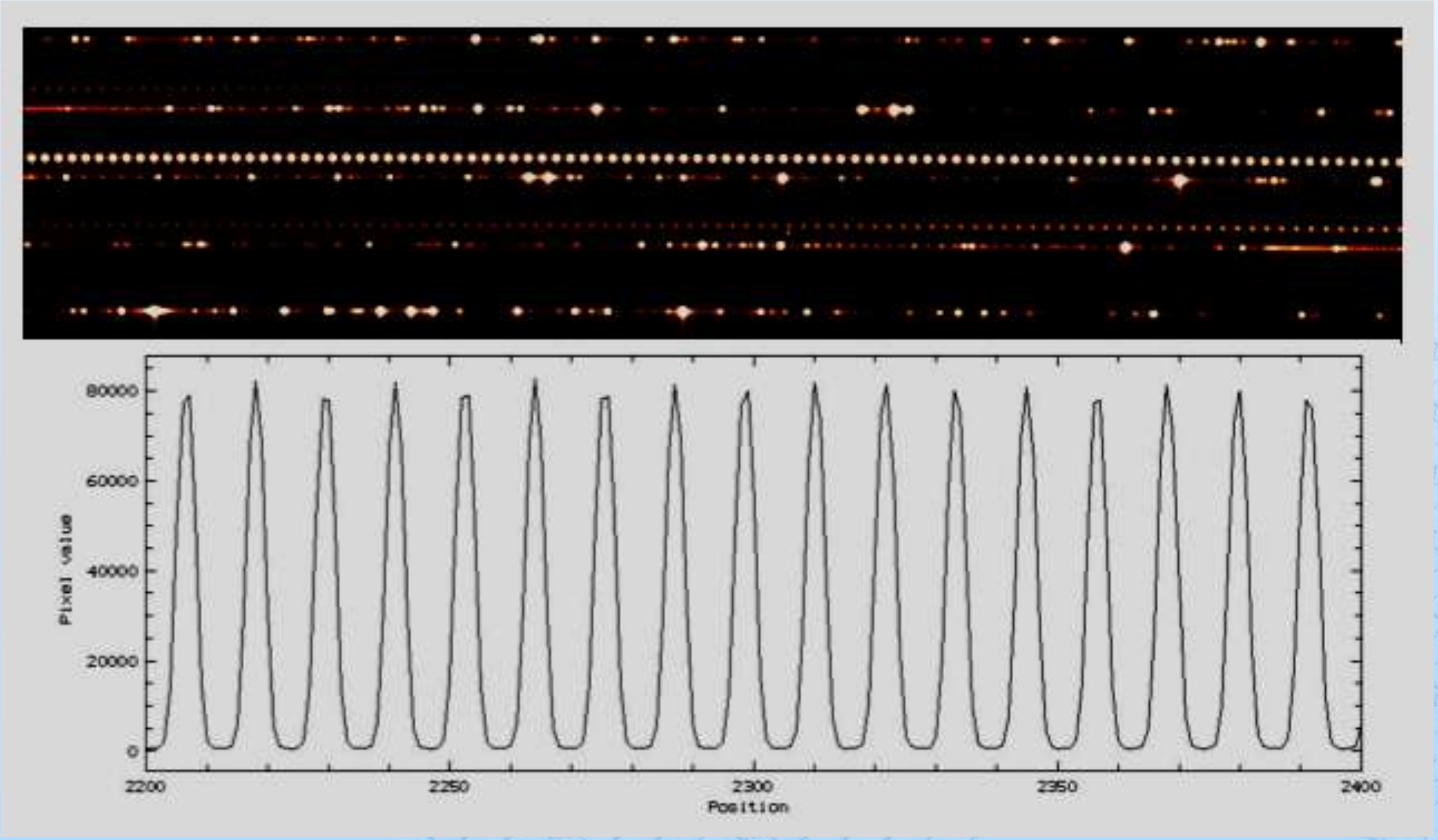


Astro-comb

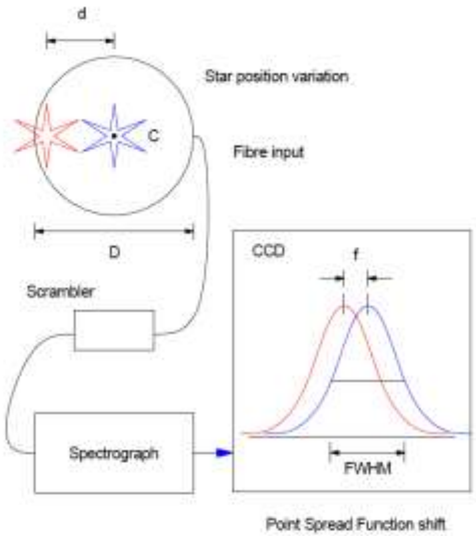
Wilken et al, MNRAS, 405, L16 (2010),
see also T. Udem' talk



Astro-comb: Successful implementation on HARPS

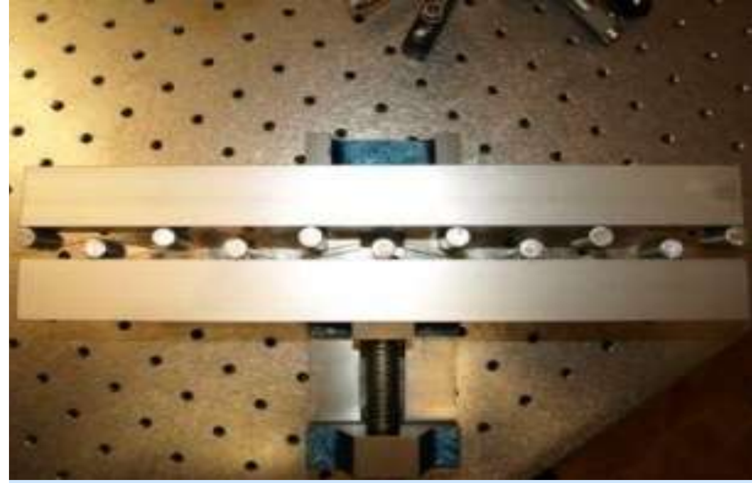


8cm/s, photon noise limited, repeatability;
8cm/s, photon noise limited, wavelength calibration precision achieved using only one comb order



Scrambling Gain:

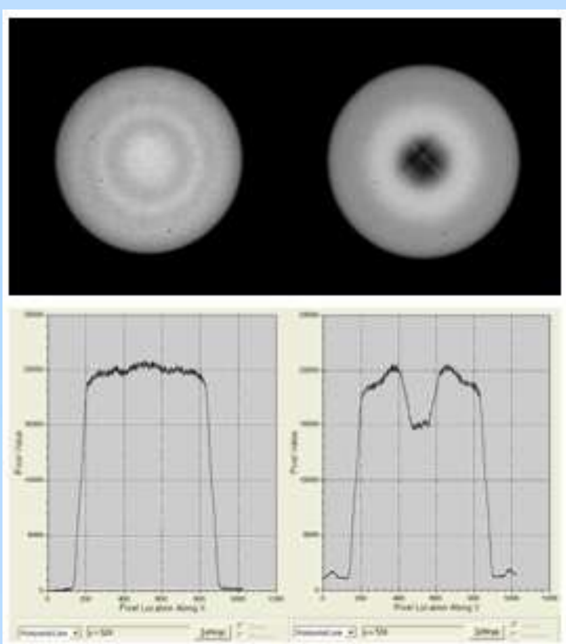
$$G = \frac{d / D}{f / FWHM}$$

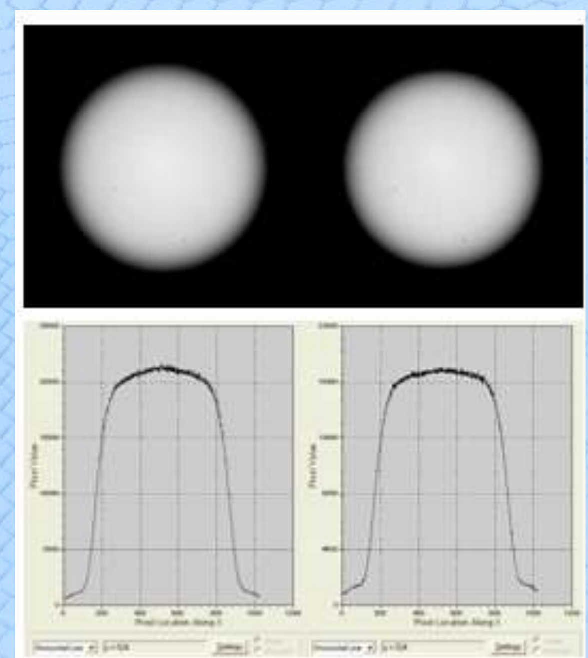


Scrambler

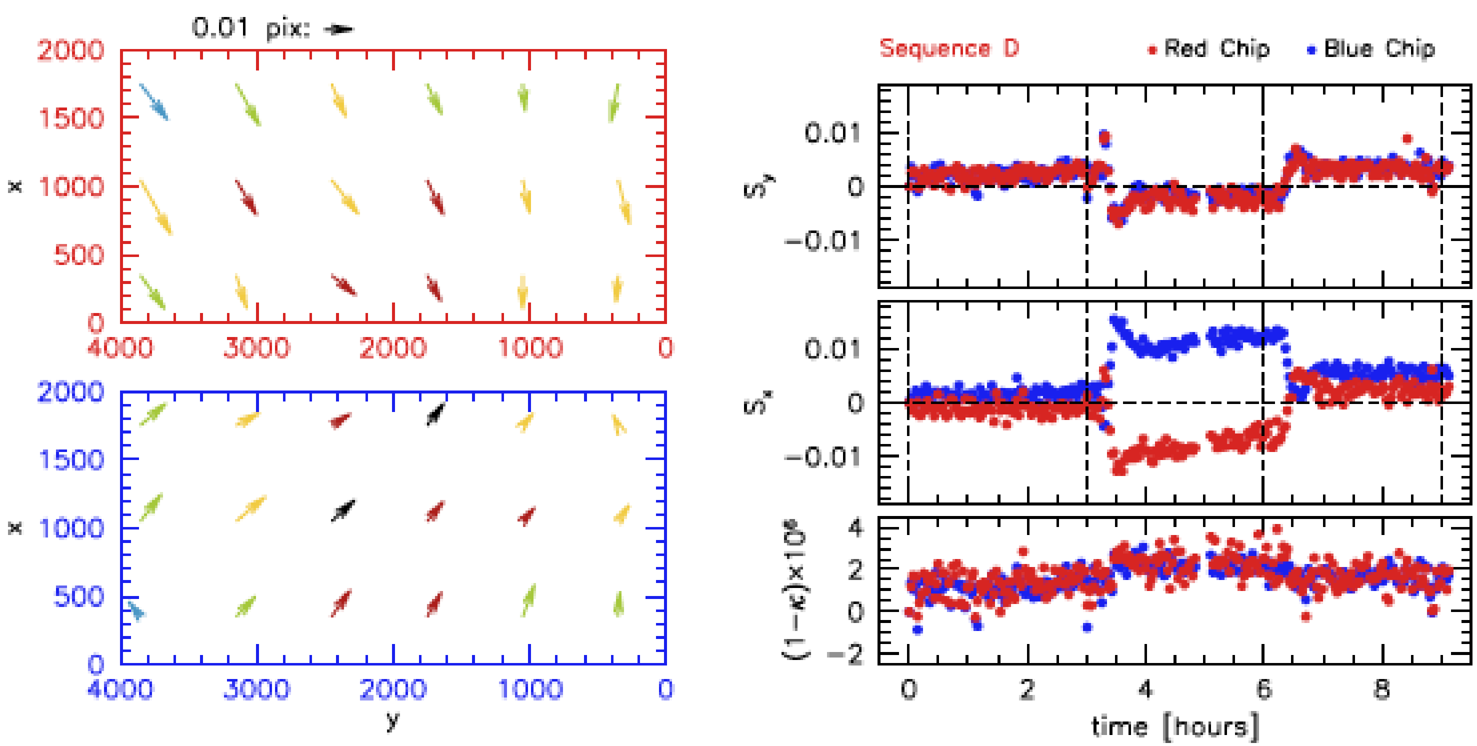
Tests in the lab proved the achievability of very high gains.

Template gains in the study have been G=1500 and G=3500





Detector Stability



Movements of the Th-A lines in the detector: ~0.005 pixel/K (right)
Left: the detector expands around the attachments of the mosaic to the support
After modeling, a new cryostat/system will be designed. Differential movements within ~150 pixels: ~ one order of magnitude less ~10^{-3} pixel/K

Conclusions

- CODEX targets several high profile science cases:
    - direct measurement of the accelerated expansion of the Universe
    - detection of exo-Earths in the habitable zone of solar type stars
    - measure the variation of the fundamental constants α, μ to an unprecedented precision.
    - ...

- CODEX is the high resolution, optical spectrograph for the E-ELT, capable to achieve a RV precision of 2cm/s.

- The main technological challenges are:
    - Wavelength calibration
    - Stability of the light injection (scrambling)
    - Detector stability

  these triggered R&D activities which are well under way.

- Preliminary results from the R&D activities are very positive