ESPRESSO

and beyond

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The **E**chelle **SP**ectrograph for **R**ocky **E**xoplanets and **S**table **S**pectroscopic **O**bservations

Consortium

- Institutes of four countries (1 PI or Co-PI in each)
  – Portugal: CAUP (N. Santos), Univ. Lisbon
  – Italy: INAF Trieste (S. Cristiani), INAF Brera
  – Spain: IAC (R. Rebolo Lopez)
  – Switzerland: Univ. Geneva (Lead, F. Pepe), Univ. Bern

- Associated Partner (Representative in Executive Board)
  – ESO (H. Dekker)

ESPRESSO

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José Miguel Herreros Linares, Ian Hughes, Olaf Iwert, Jorge Lima, Jean-Louis Lizon, Gaspare Lo Curto, Christophe Lovis, Antonio Manescau, Carlos Martins, Denis Mégevand, André Moitinho, Paolo Molaro, Mario Monteiro, Manuel Monteiro, Christoph Mordasini, Luca Pasquini, Didier Queloz, José Luis Rasilla, Jose Manuel Rebordão, Samuel Santana Tschudi, Paolo Santin, Danuta Sosnowska, Paolo Spanò, Fabio Tenegi, Stéphane Udry, Eros Vanzella, Matteo Viel, Maria Rosa Zapatero Osorio, Filippo Zerbi

ESPRESSO's GTO

The deal: Guarantee Time Observations

- ✓ Capital and manpower investment by Consortium
- ✓ Instrument in exchange for time on large telescopes
- ✓ 'Quality guarantee' by the Consortium since directly interested
- ✓ Direct and indirect benefits for the Community

GTO time distribution

- ✓80% Rocky planets in habitable zone
- ✓10% Variability physical constants
- ✓10% 'Exquisite' science, TBD later

ESPRESSO Science

Other science with ESPRESSO

- ✓Chemical composition of stars in local galaxies
- ✓Investigation of metal-poor stars
- ✓Stellar oscillations, asteroseismology
- ✓Diffuse stellar bands in the interstellar medium
- ✓Chemical enrichment of IGM
- ✓Galactic winds and tomography of the IGM
- ✓Chemical properties of protogalaxies
- ✓Cosmology
- ✓Further extra-solar planet science
  - ✓The Rossiter-McLaughlin effect
  - ✓Transmission spectroscopy
  - ✓Planets in nearby open clusters and galaxies

Planet detectability with RV's

$$k_1 = \frac{28.4\ \mathrm{m\,s^{-1}}}{\sqrt{1-e^2}} \frac{m_2 \sin i}{M_{\mathrm{Jup}}} \left(\frac{m_1 + m_2}{M_{\mathrm{Sun}}} \right)^{-2/3} \left(\frac{P}{1\ \mathrm{yr}} \right)^{-1/3}$$

Jupiter	@ 1 AU	: 28.4 m s^{-1}
Jupiter	@ 5 AU	: 12.7 m s^{-1}
Neptune	@ 0.1 AU	: 4.8 m s^{-1}
Neptune	@ 1 AU	: 1.5 m s^{-1}
Super-Earth (5 $M_{\oplus}$)	@ 0.1 AU	: 1.4 m s^{-1}
Super-Earth (5 $M_{\oplus}$)	@ 1 AU	: 0.45 m s^{-1}
Earth	@ 1 AU	: 9 cm s^{-1}

(M_1 = Sun)

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Earth	@ 1 AU	: 9 cm s^{-1}

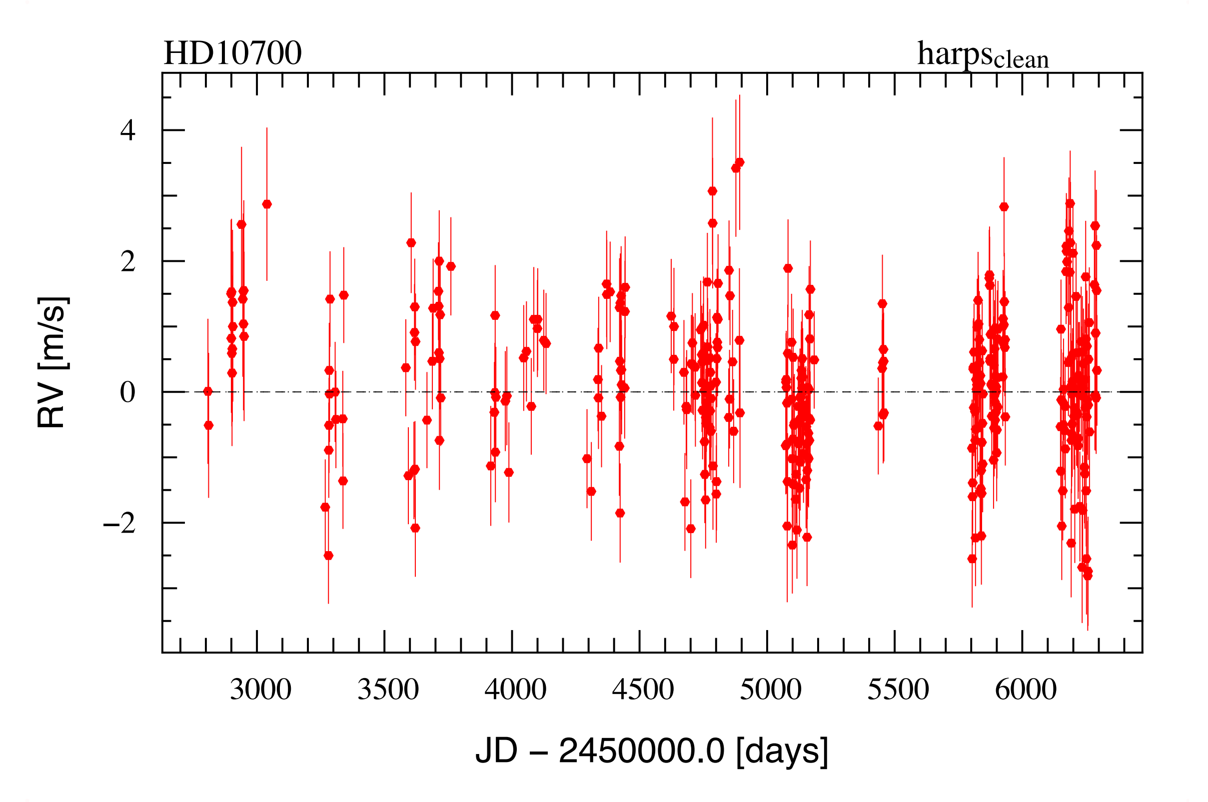
A few m/s precision OK for giant planets
e.g. Jupiters out to > 5 AU

Feasible today with best instruments (e.g. HARPS)

(M_1 = Sun)

HARPS Detection Limits

Tau Ceti:
11 years of measurements
rms = 1.0 m/s



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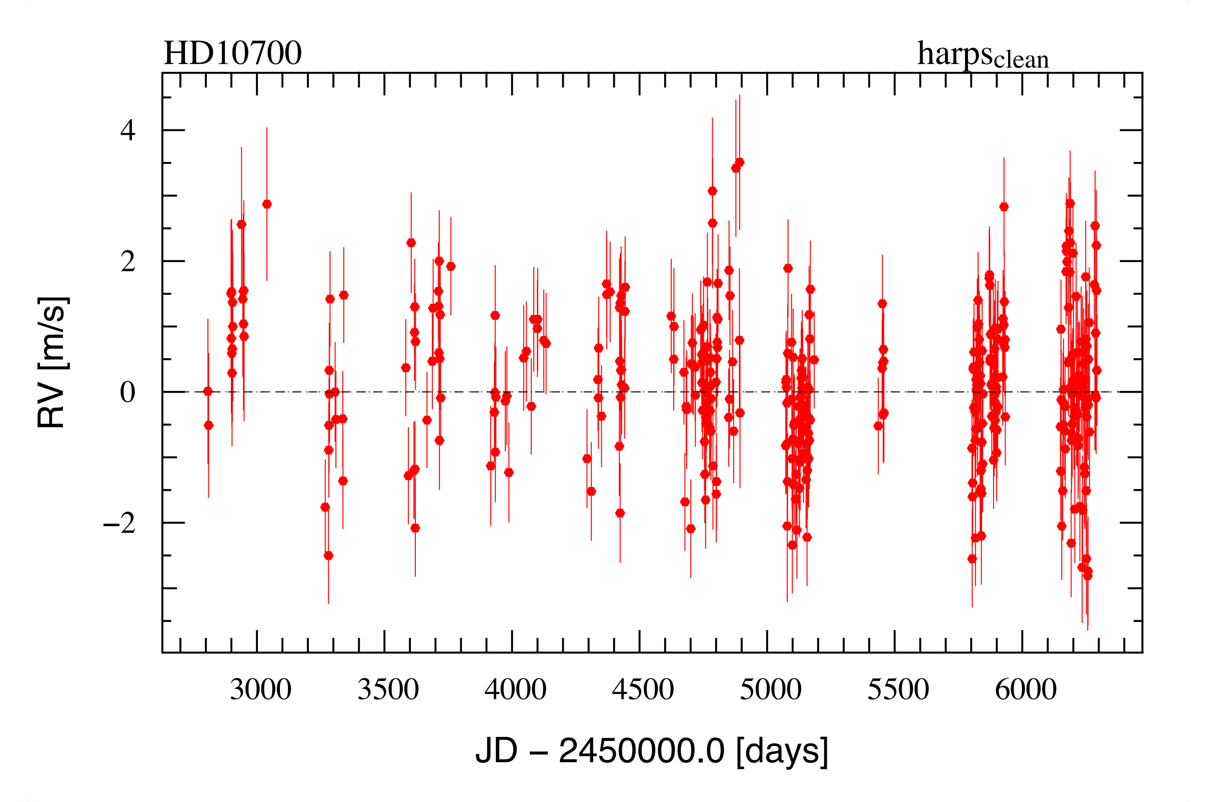
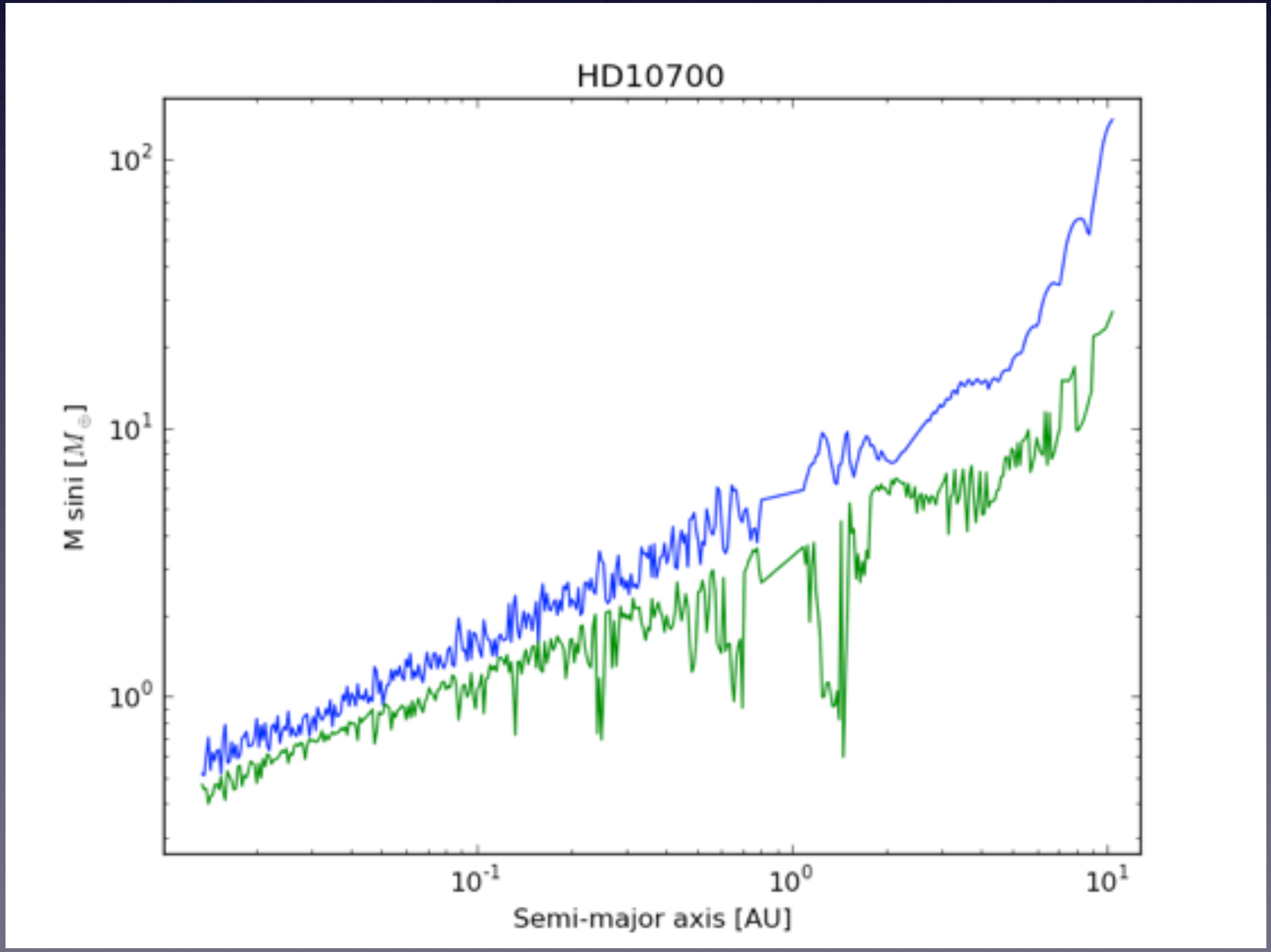




Tuomi et al. 2013, 5 planets?

We would have detected:

- an Earth @ 0.1 AU
- a super-Earth (5 $M_\oplus$) @ 1 AU
- a Neptune @ 5 AU
- a Saturn @ 10 AU

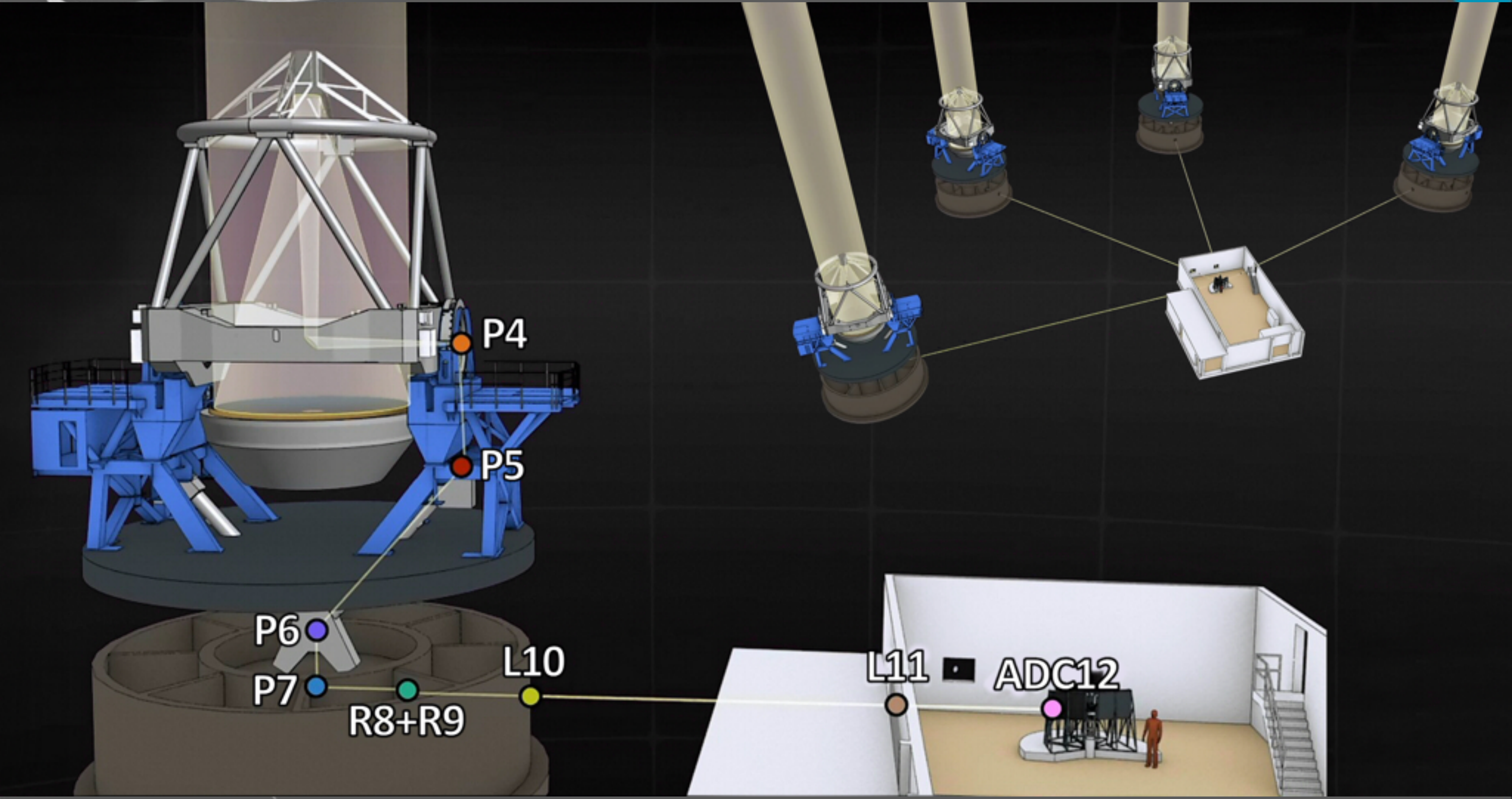
What we need from ESPRESSO

Reduce errors and noise

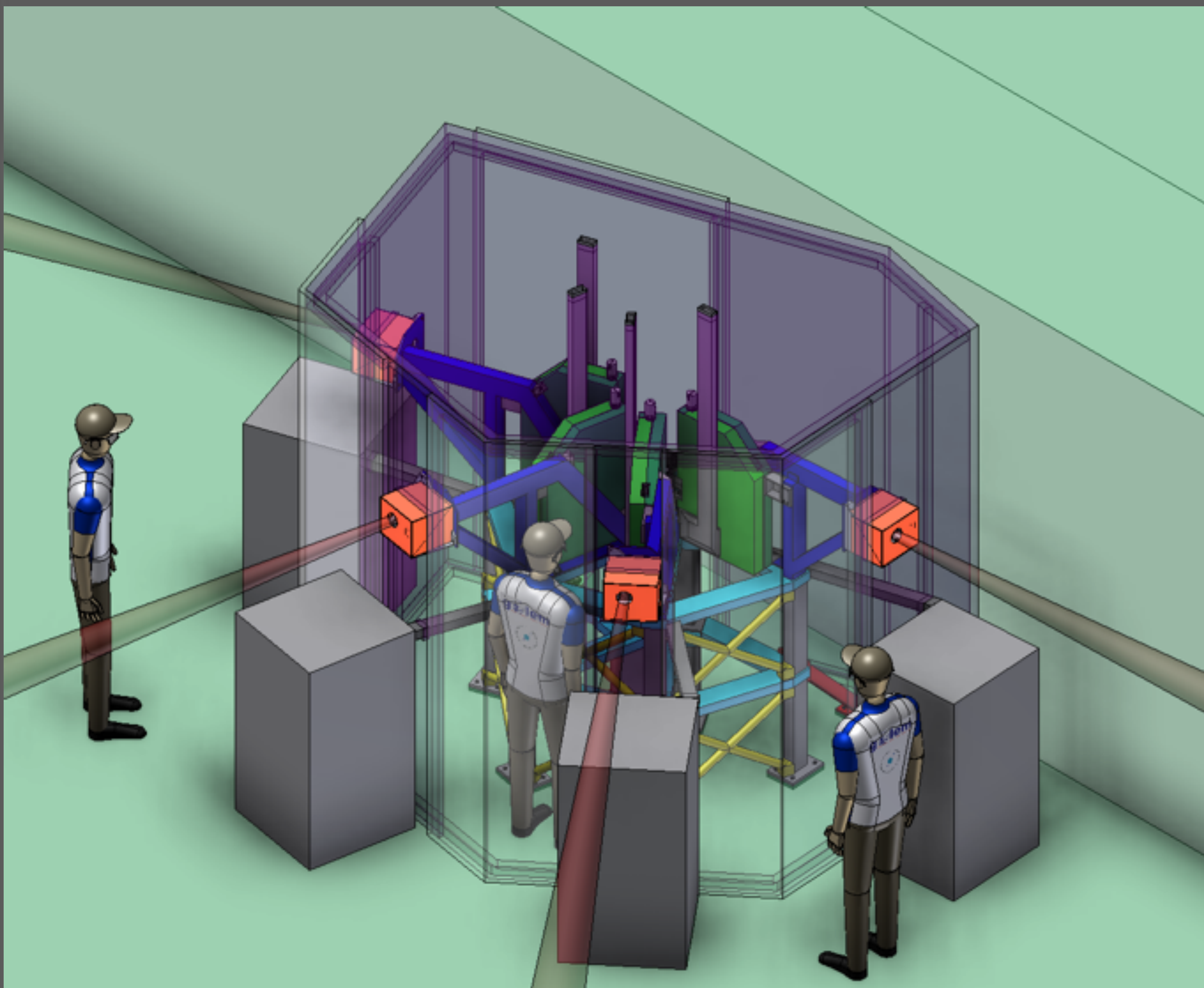
- ✓ Instrumental effects -> better scrambling, better calibration sources, better detectors, improved software
- ✓ Photon noise -> Better efficiency, high spectral resolution, larger telescope(s), efficient observations
- ✓ Stellar noise -> Better understanding, pre-selection, activity indicators, observation strategy

The ESPRESSO instrument

The Coudé Train(s)

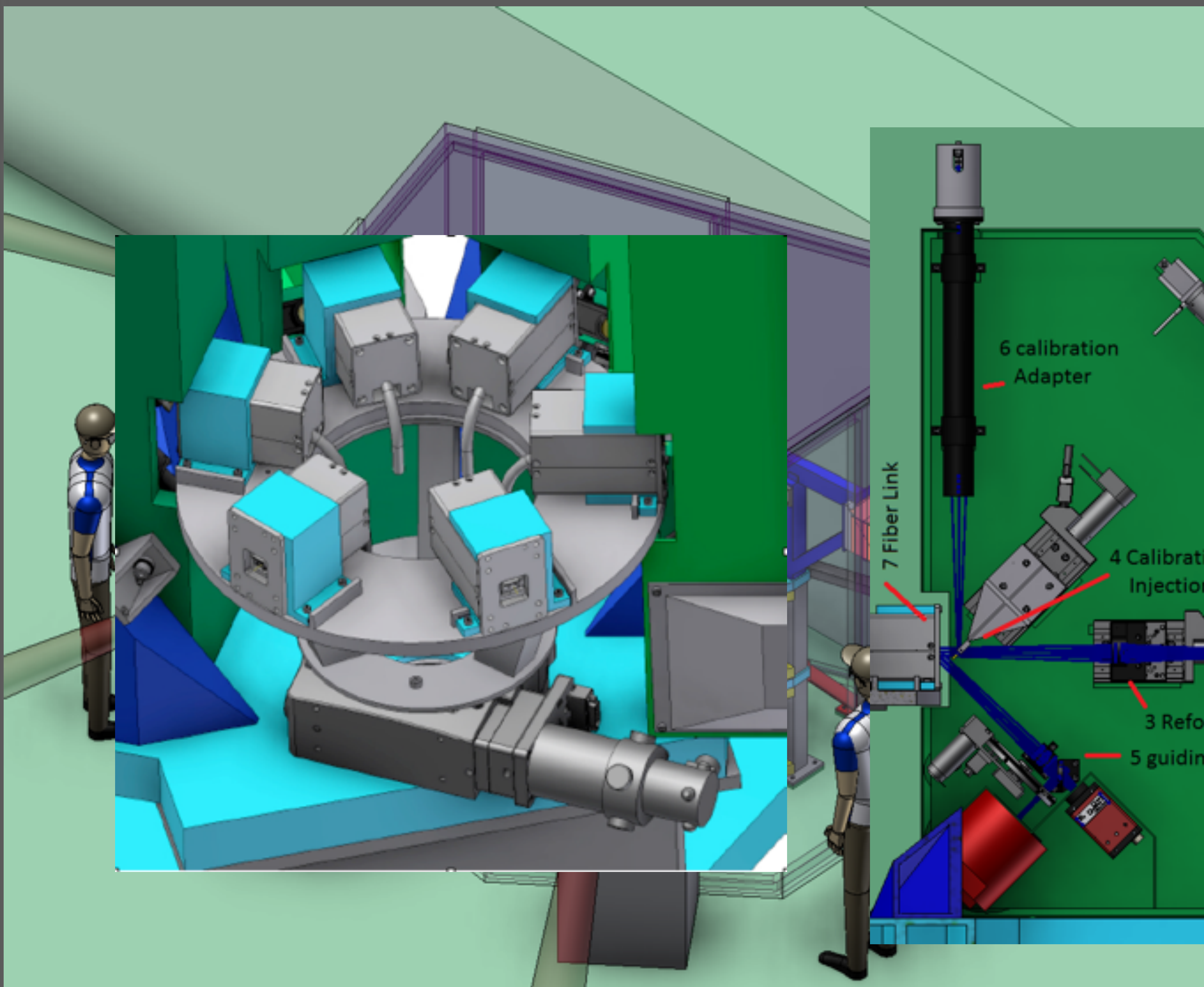


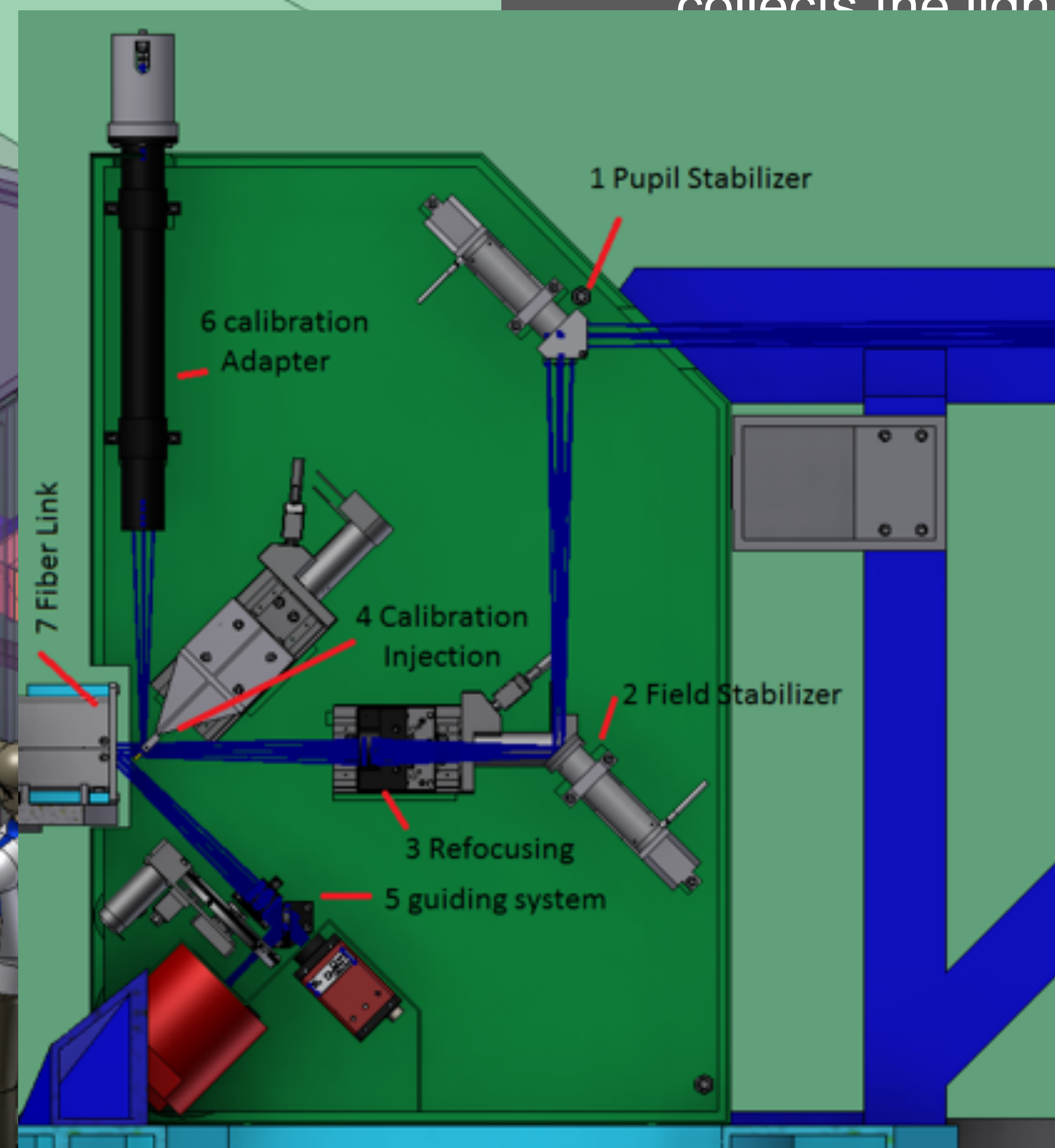
The Front-End Unit



- The Front-End Unit (F/E) collects the light beams transported by the four Coudé Trains
- It performs several functions:
  – Pupil stabilization
  – Field stabilization
  – Calibration light injection
  – Refocalization for injection in the fibers
  – Mode selection
  – UT selection in single UT modes

The Front-End Unit





- The Front-End Unit (F/E)
collects the light beams
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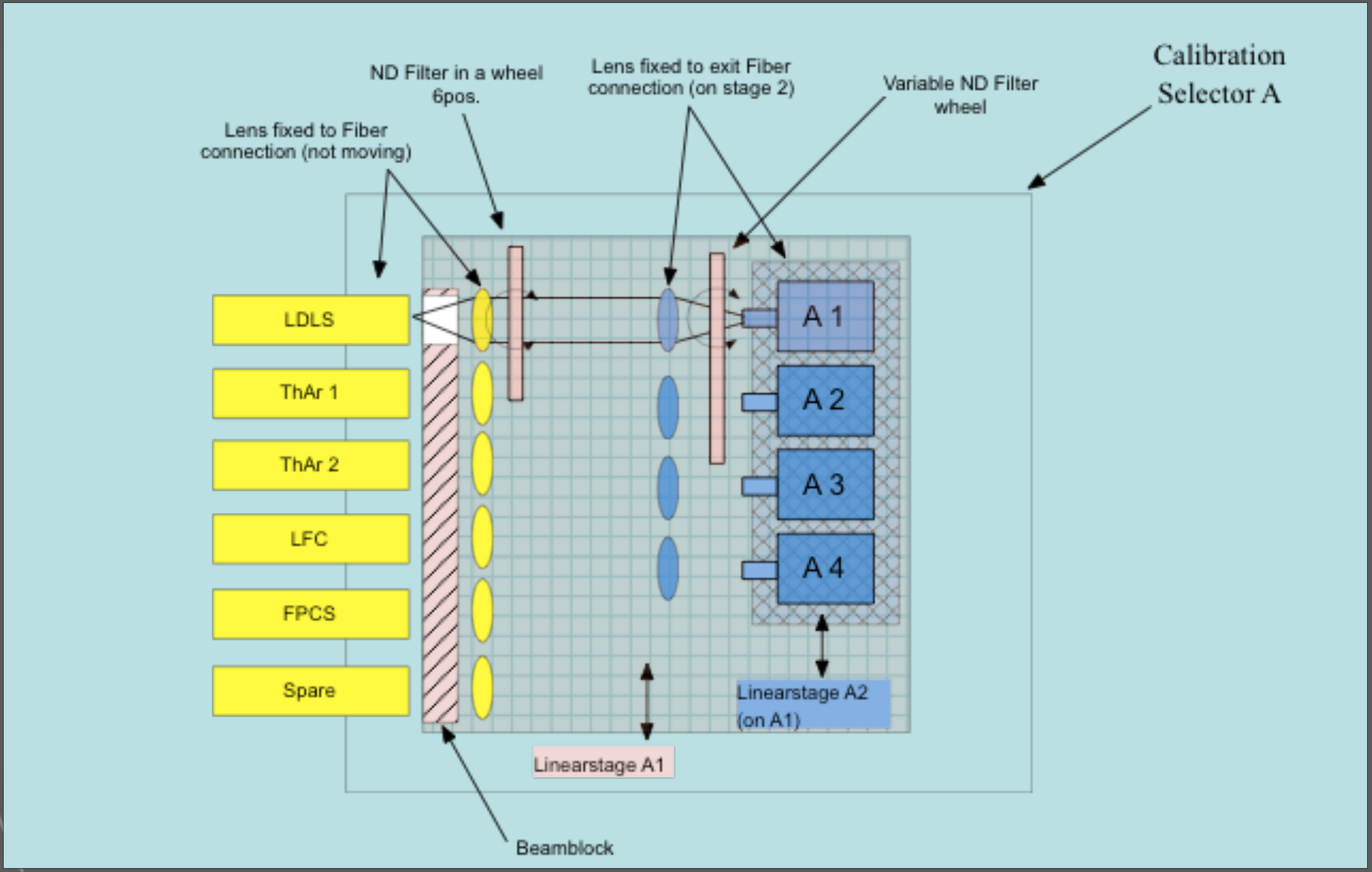
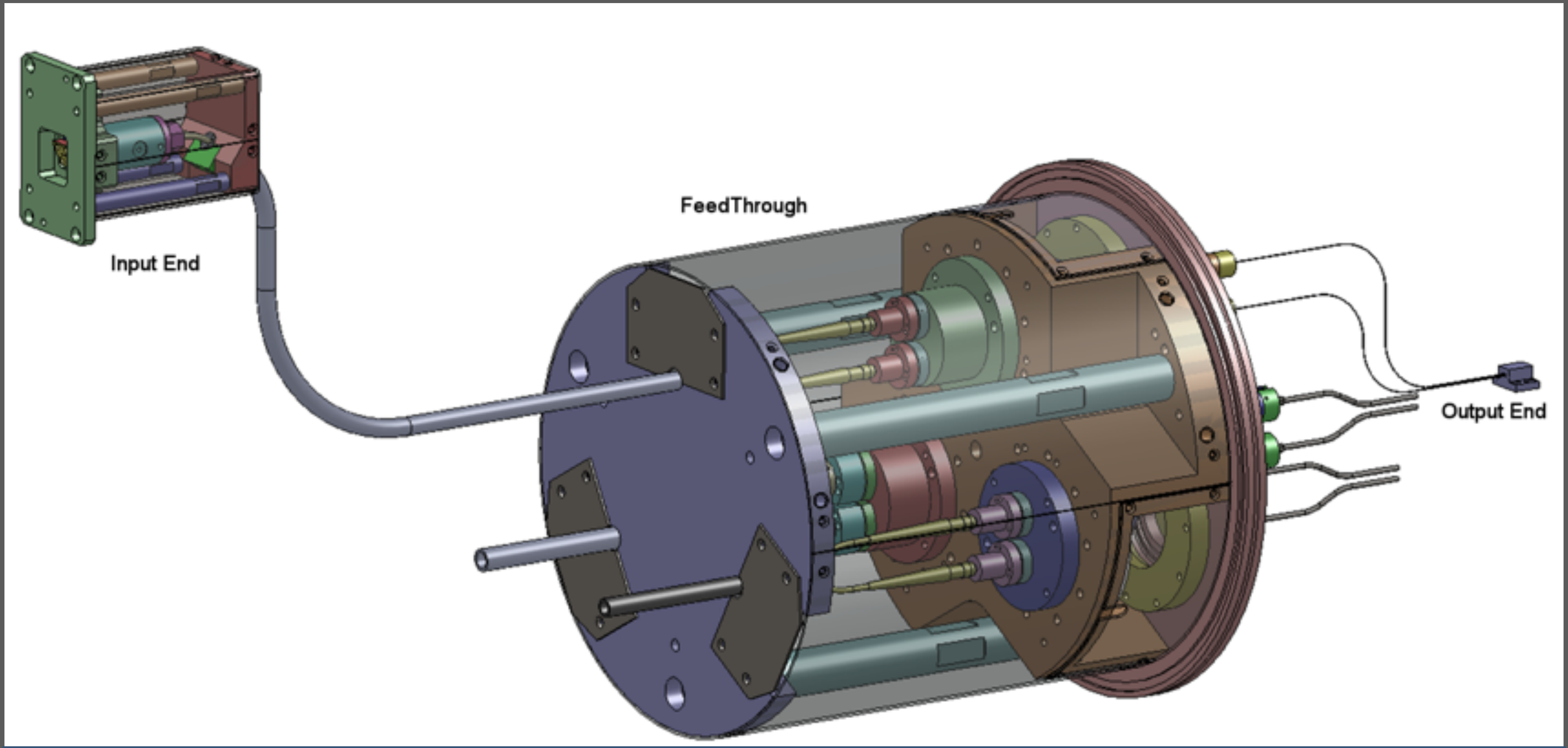
The Calibration Unit

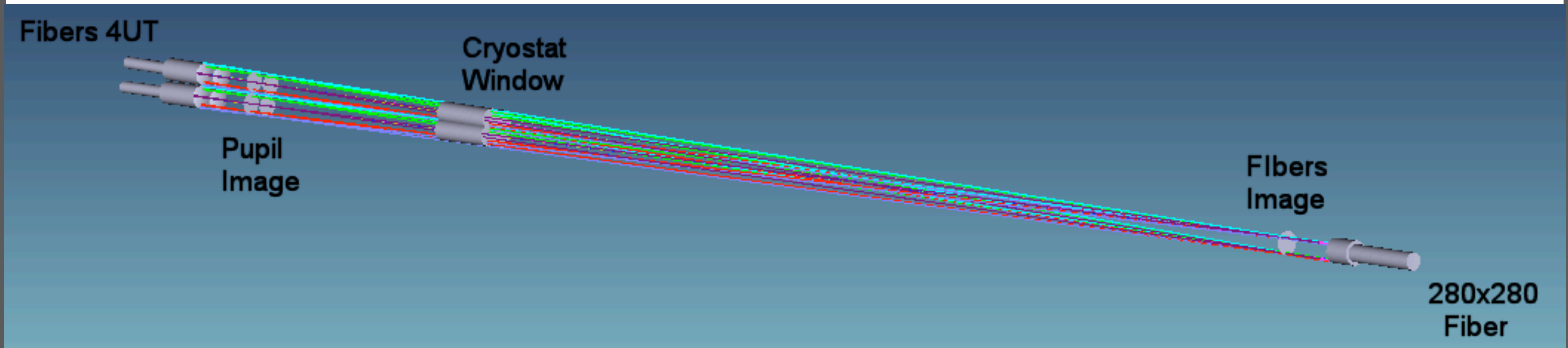


The Fiber Link

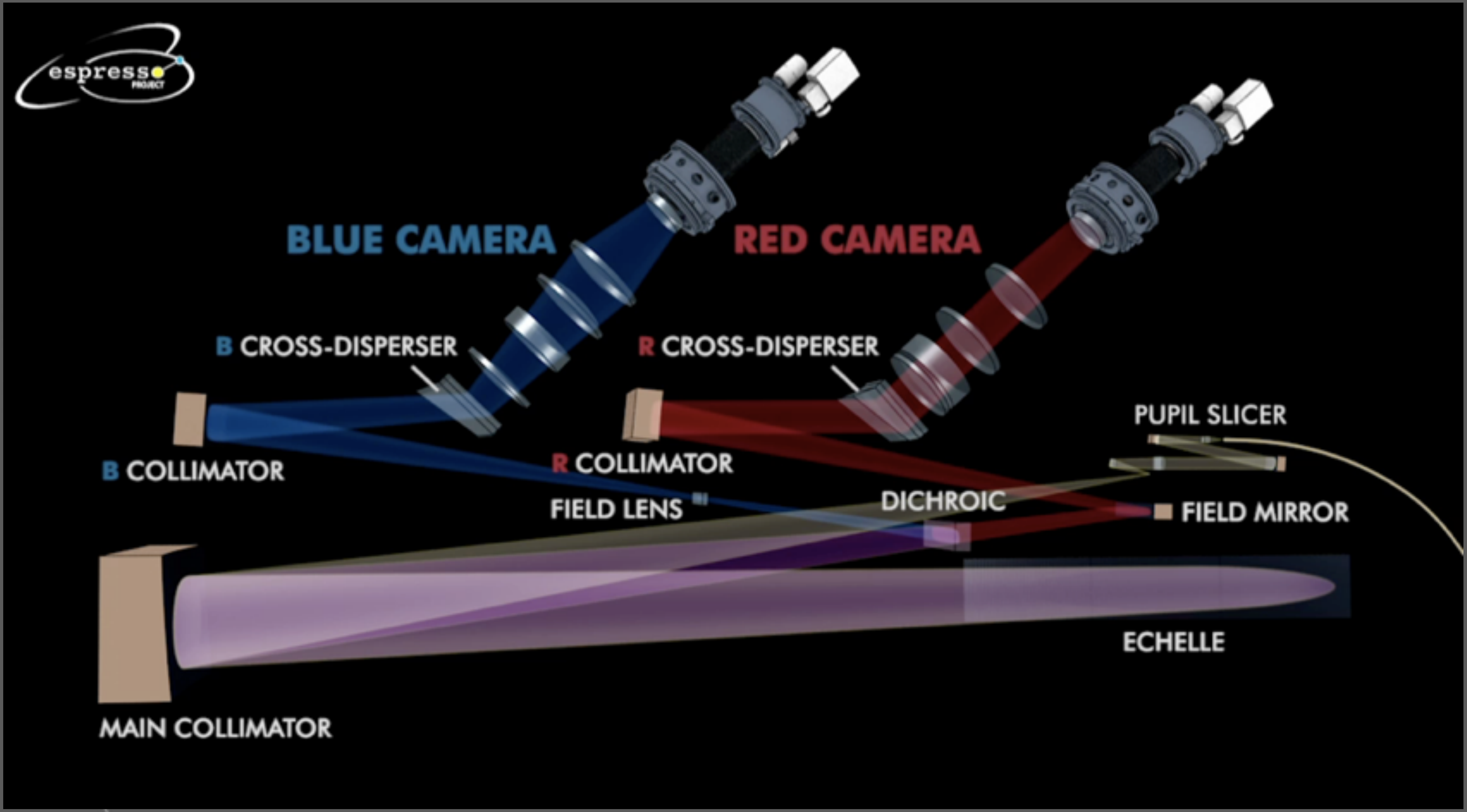
- The Fiber Link has three functions:
  - In multiMR mode, it combines the four fibers into one
  - It transports the selected light from the Front-End to the Spectrograph
  - The vessel feed-through is used to achieve double optical scrambling of the far field (FF) and the near field (NF)
- 2 fiber bundles
  - single-UT (2 octagonal fibers → 2 octagonal fibers)
  - multi-UT (4 octagonal fibers → 1 square fiber)

The Fiber Link

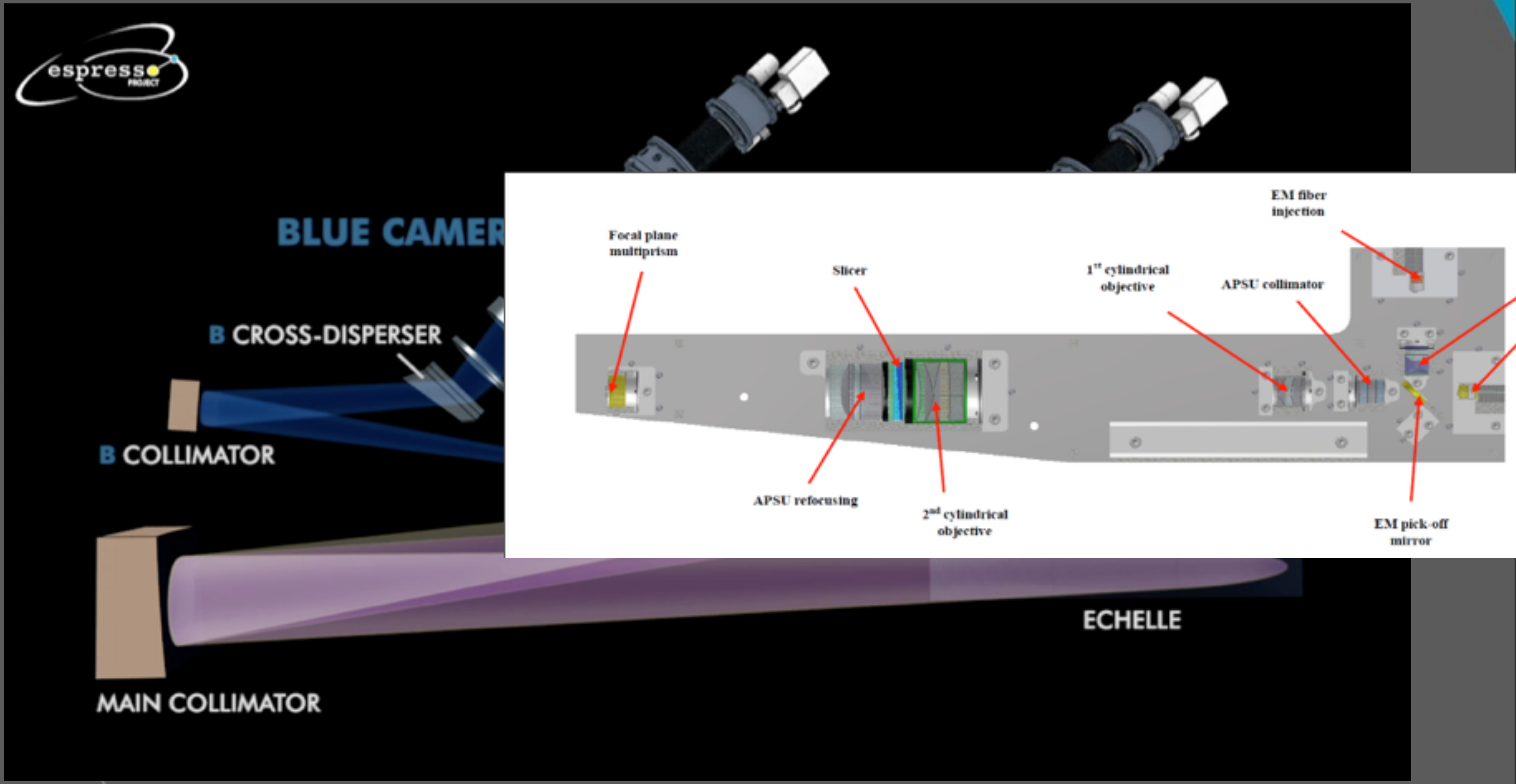




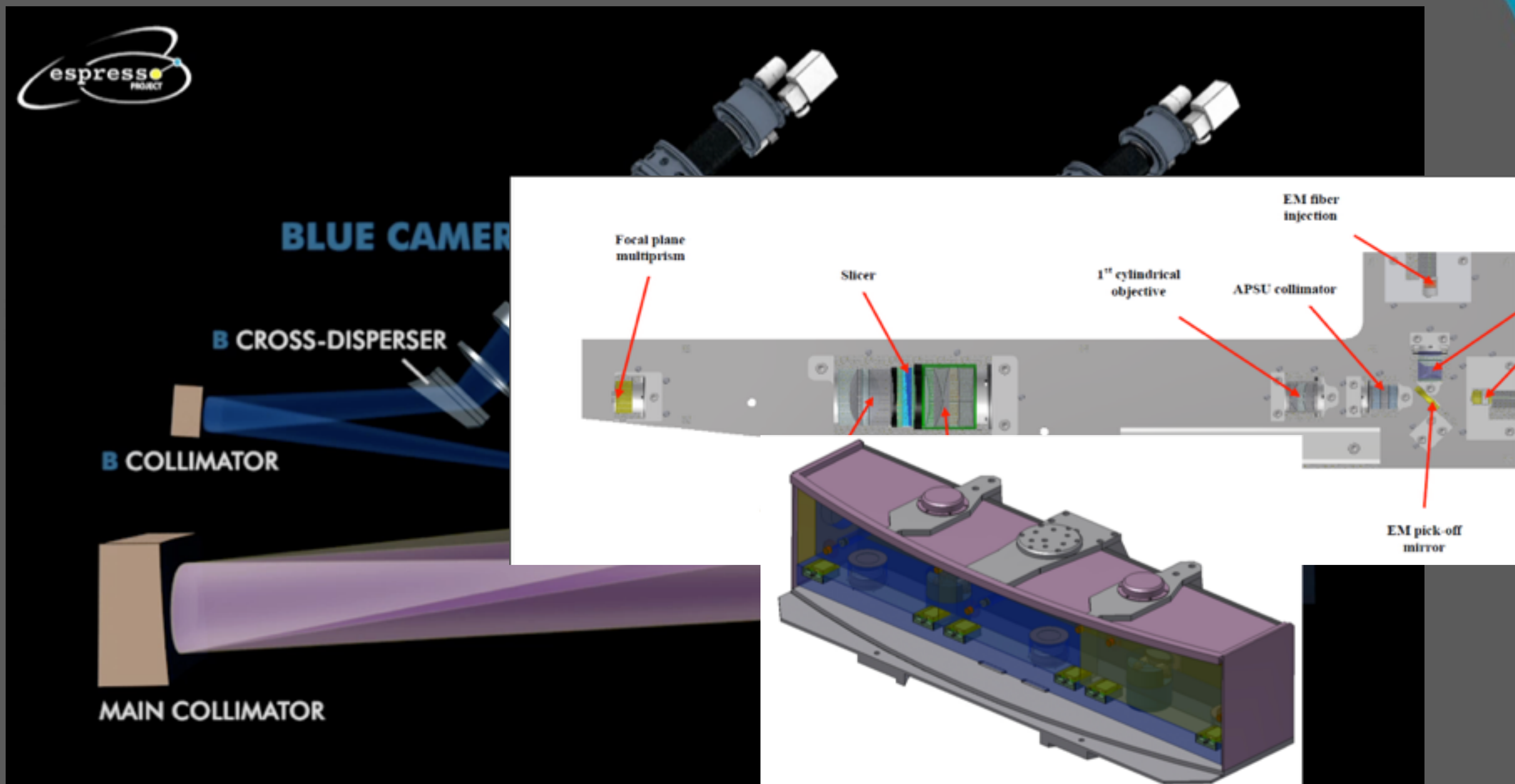
The Spectrograph



The Spectrograph

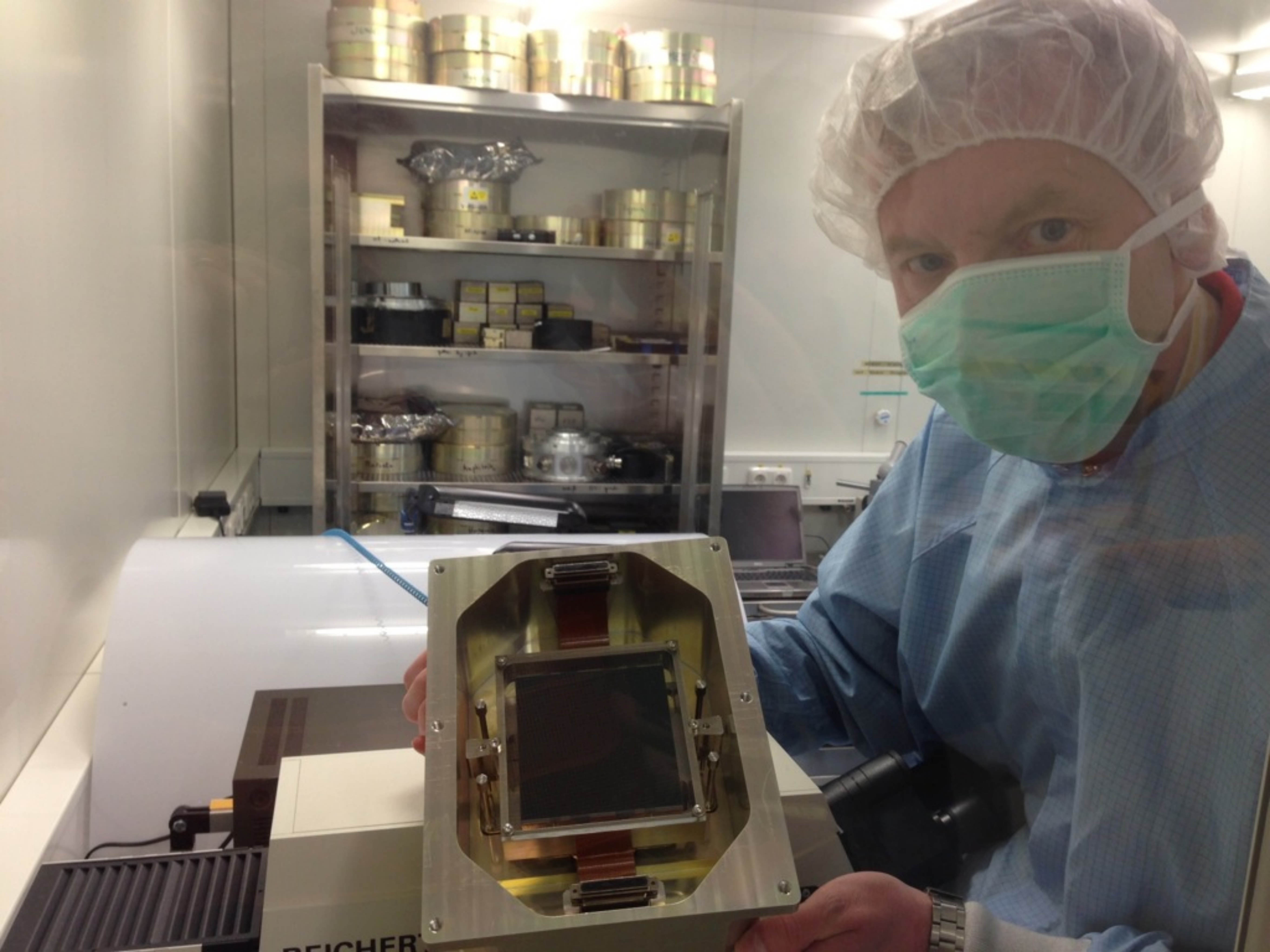


The Spectrograph



CCD detector characteristics

Detector type	Monolithic backside illuminated CCD detectors with 16 output amplifiers
Light sensitive area	~ 92 mm x 92 mm
Pixel size	10 µm
Optical coating	Individually optimized AR coatings for the specific spectral range
Slow read mode	< 60 sec full frame reading with RON < 3 e
Fast read mode	< 20 sec full frame reading with RON < 6 e
CTE	≥ 0.999995, from few e
Full well	> 50’000 e
Dark current	≤ 1 e



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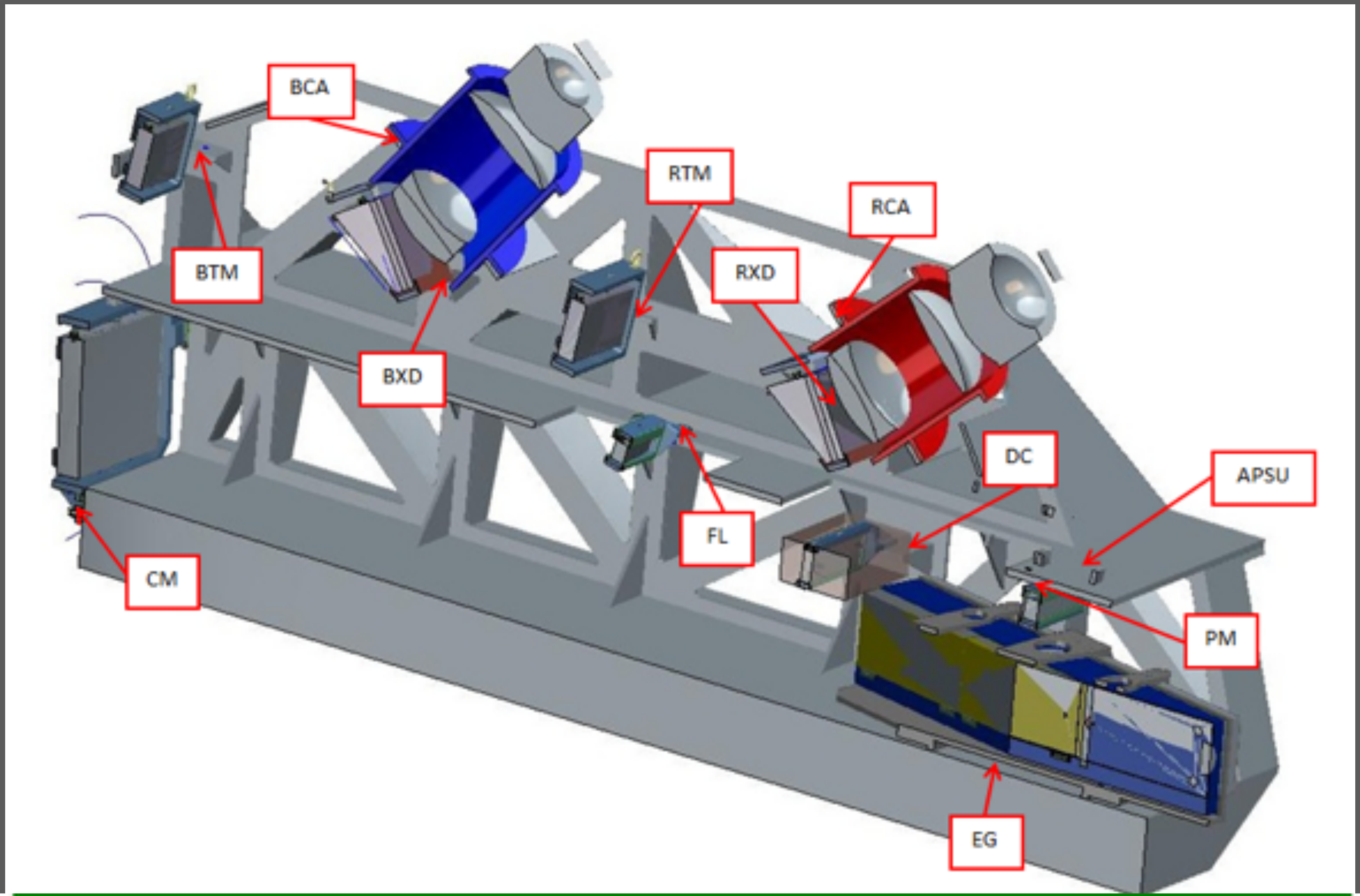
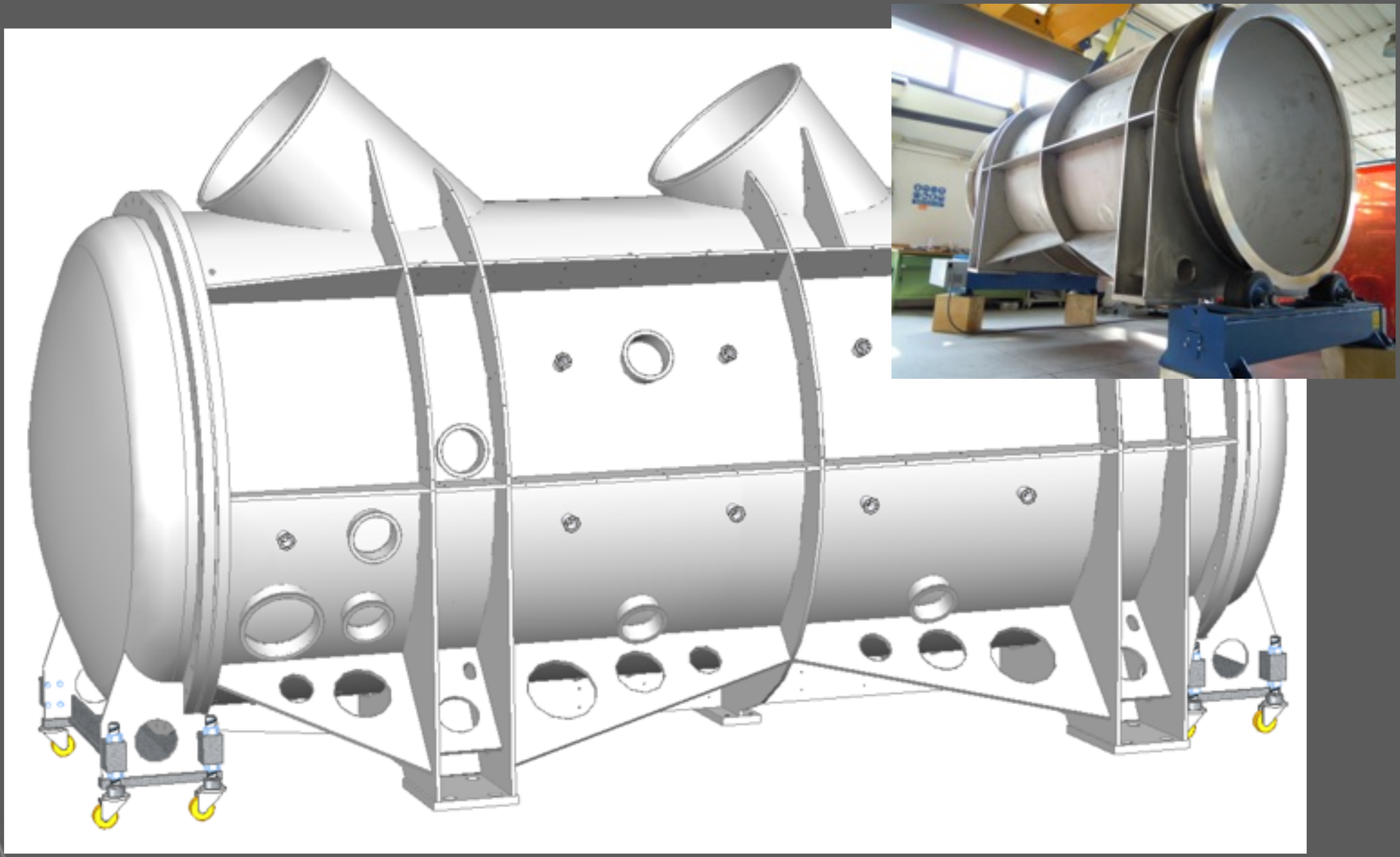
A stabilized environment



Material	Ni-plated structural Steel St-52
Overall dimensions	3400 x 1400 x 1450 mm
Weight	~ 2940 kg
Maximum deformation	62 µm
First Eigen-frequency	91.07 Hz

A stabilized environment



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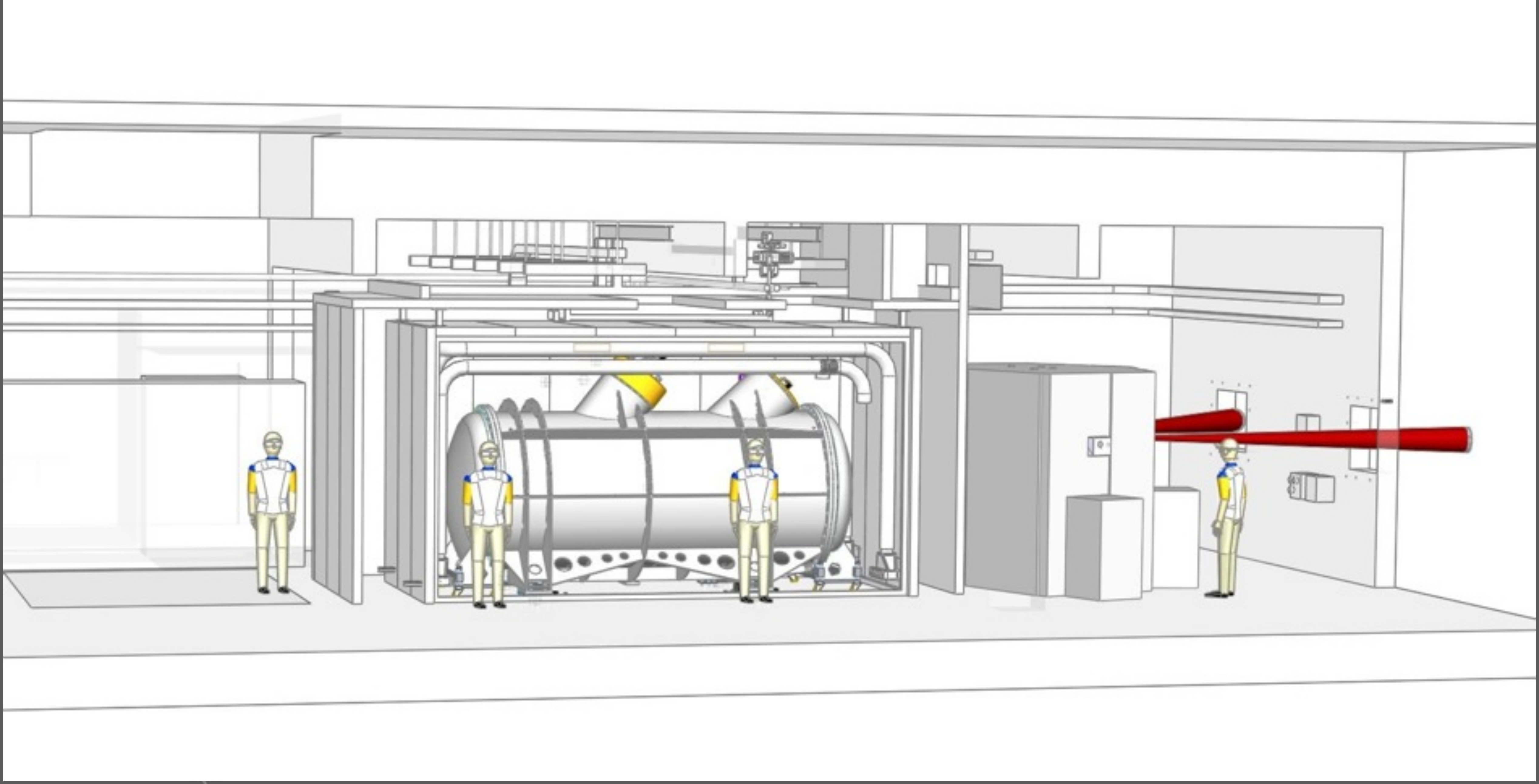
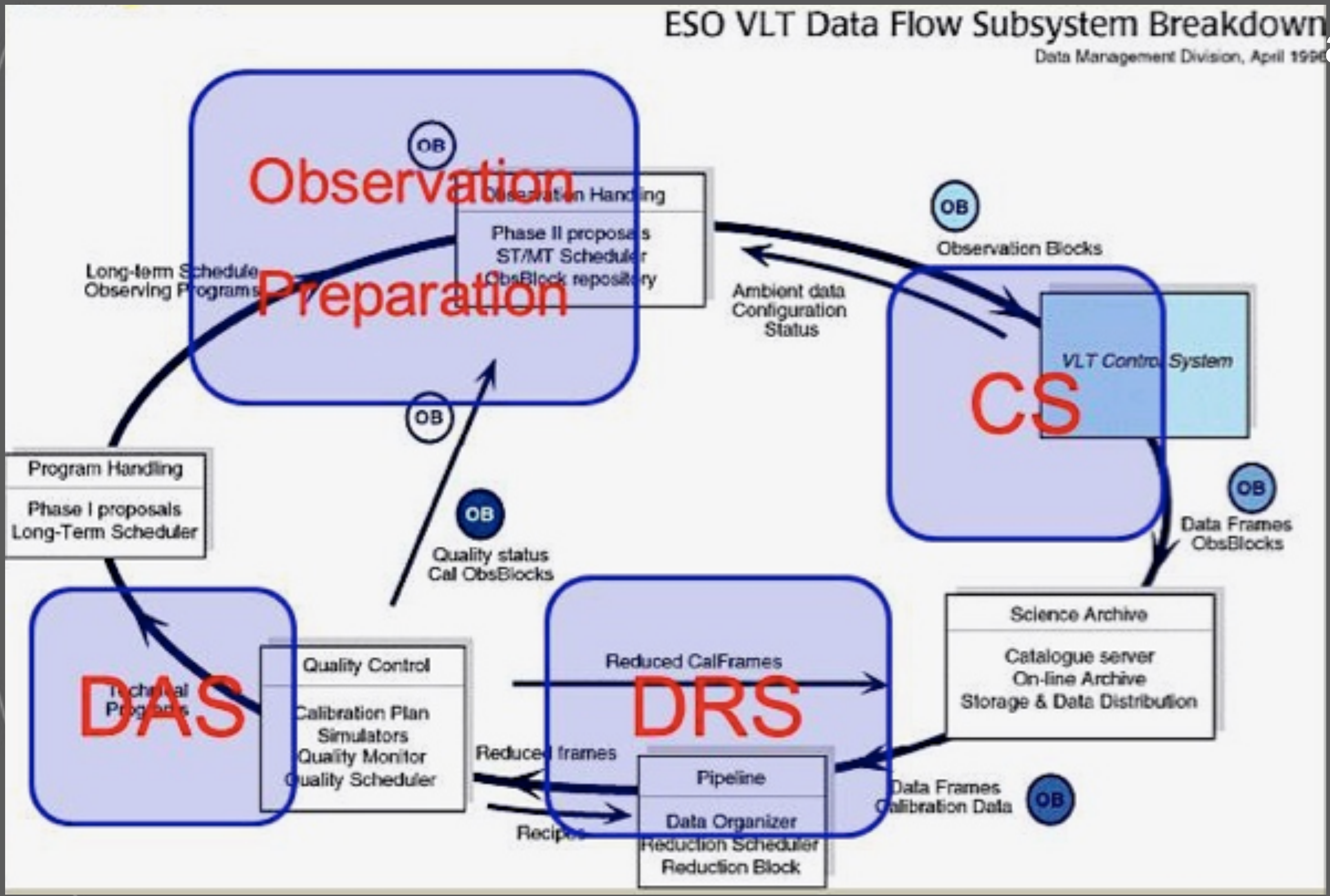


The Dataflow System



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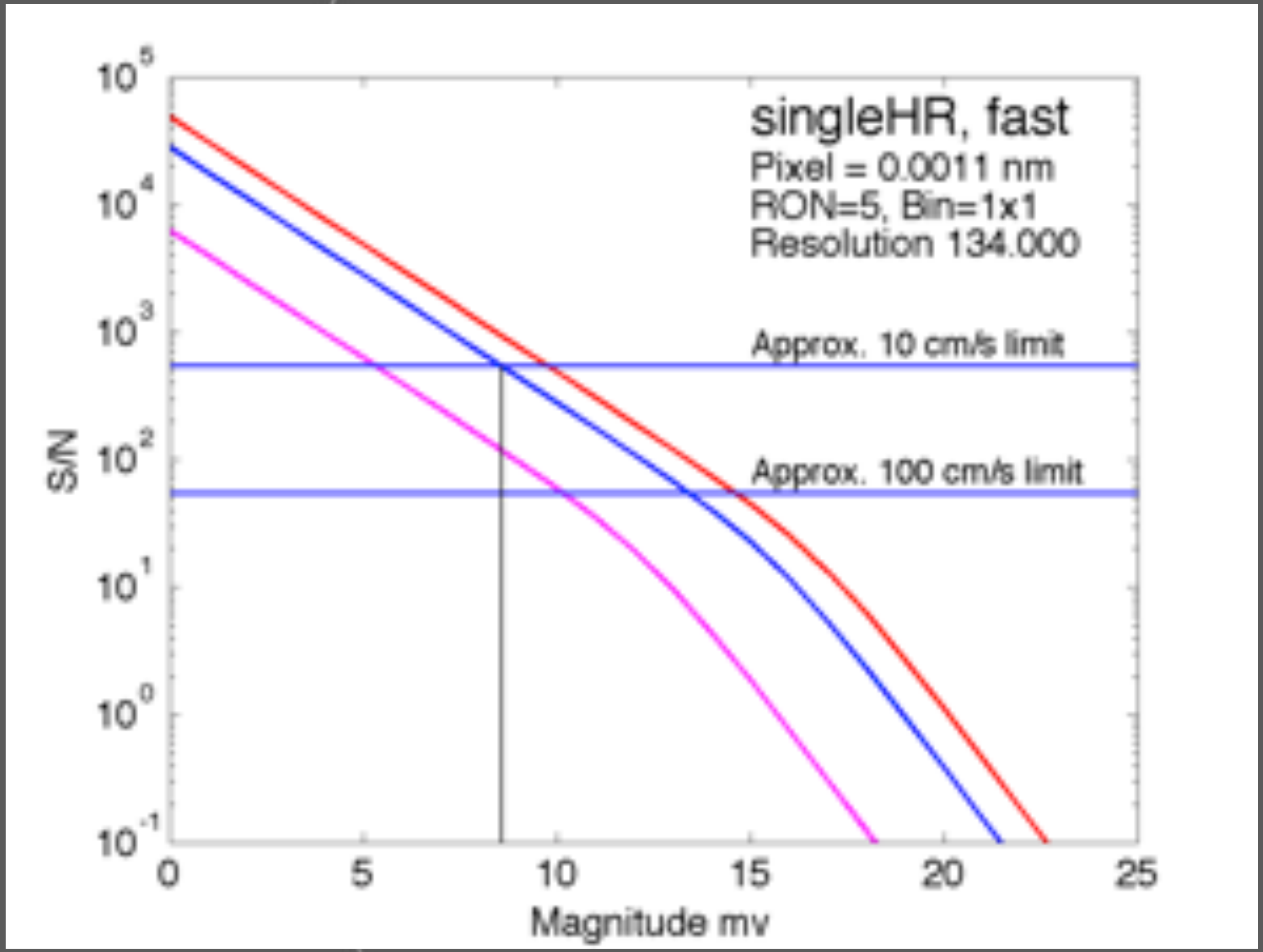
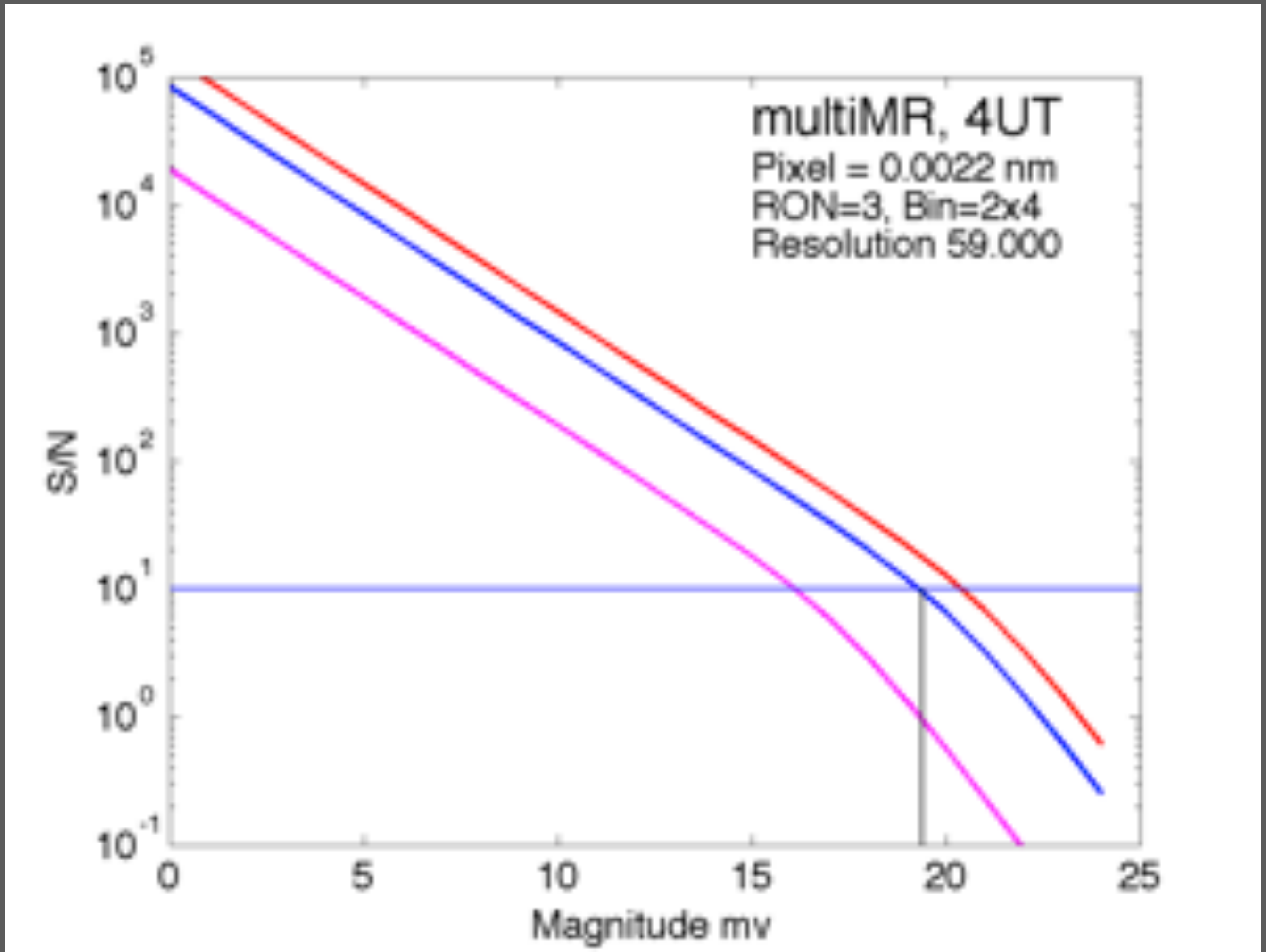
System characteristics

Parameter	*singleUHR*	*singleHR*	*multiMR*
Wavelengths	Blue arm: 380 – 520 nm Red arm: 520 – 780 nm		
Spectral coverage	Full		
Spectra format	Up to 4 spectra per order (2 fibers, 2 spectra / fiber)		
Resolving power	225’000	134’000	59’000
Aperture on sky	0.5 arcsec	1.0 arcsec	4x1.0 arcsec
Spectral sampling	2.5 pixels	4.5 pixels	5.5 pixels (binned x 2)
Spatial sampling	5 pixels	9 pixels	5.5 pixels (binned x 4)
Sky/Simultaneous reference	Yes (mutually exclusive)		
Instrumental RV precision	<10 cm/s	<10 cm/s	~1 m/s

System efficiency



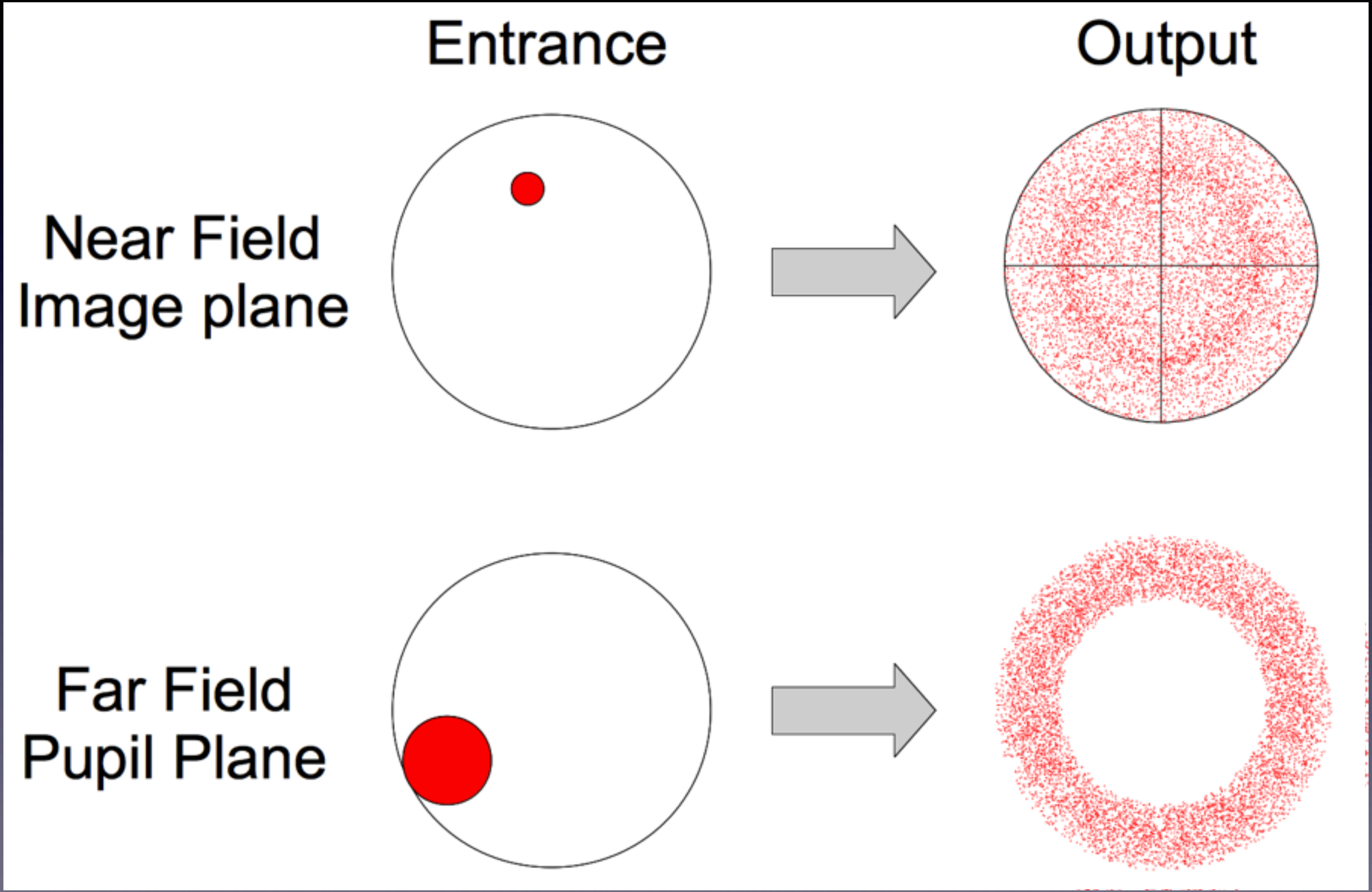


Why should ESPRESSO do better?

Why should ESPRESSO do better?

- Larger Telescope (up to 4 of them! Wow!)
- Monolithic and stabilized detector (9k9 e2v)
- Octoagonal fibers (limitation in HARPS!)
- The adequate calibration source (limitation in HARPS?)
- A fully integrated DRS which showed its capabilities
- New operational flexibility (fast switching between telescopes)! -> Efficiency, time sampling.
- Translate the lessons learned from HARPS into ESPRESSO.

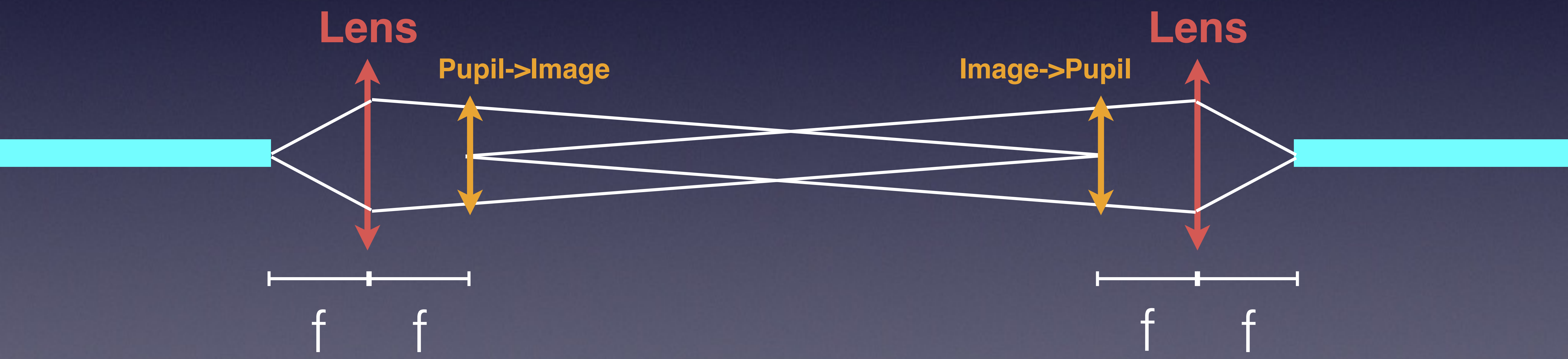
'Scrambling' properties of circular fiber



Chazelas et al. 2008, 2010

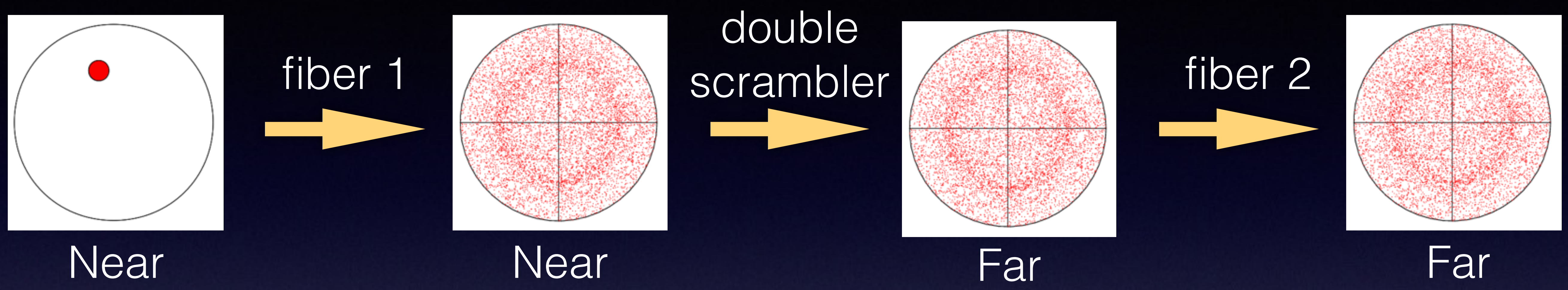
The concept of double scrambling

1) First fiber scrambles near field
2) Optical system exchanges near and far field
3) Second fiber scrambles original far field



See e.g. Hunter and Ramsey 1992; Baranne et al. 1996

Pupil effects



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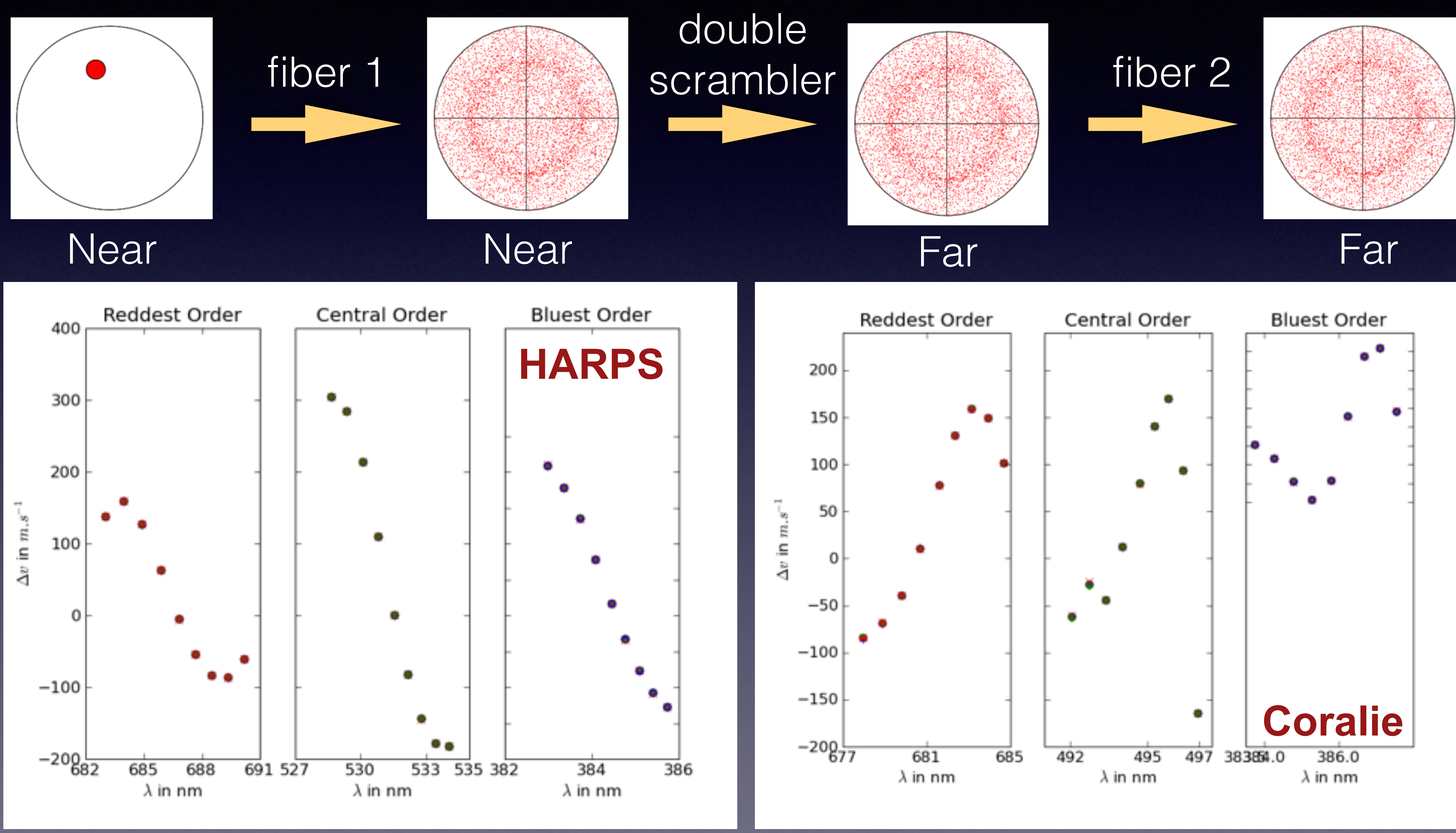
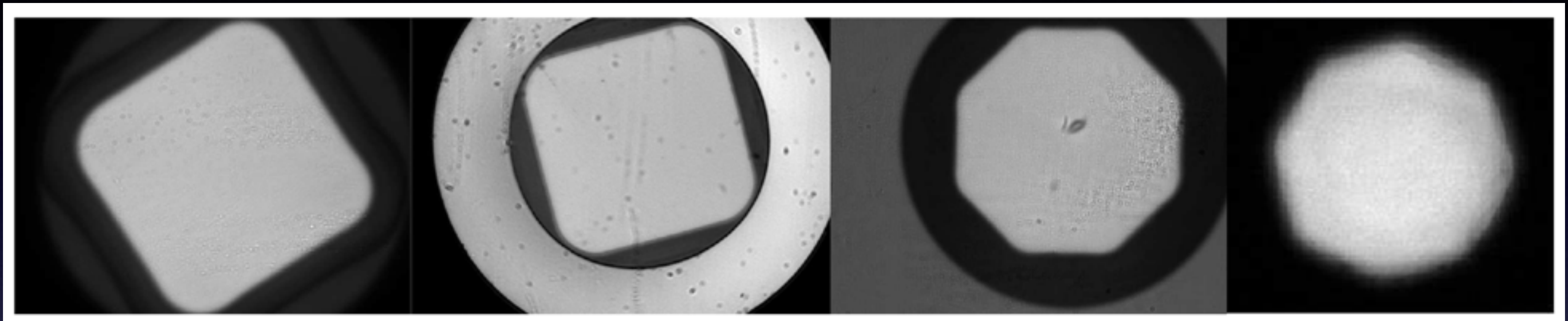
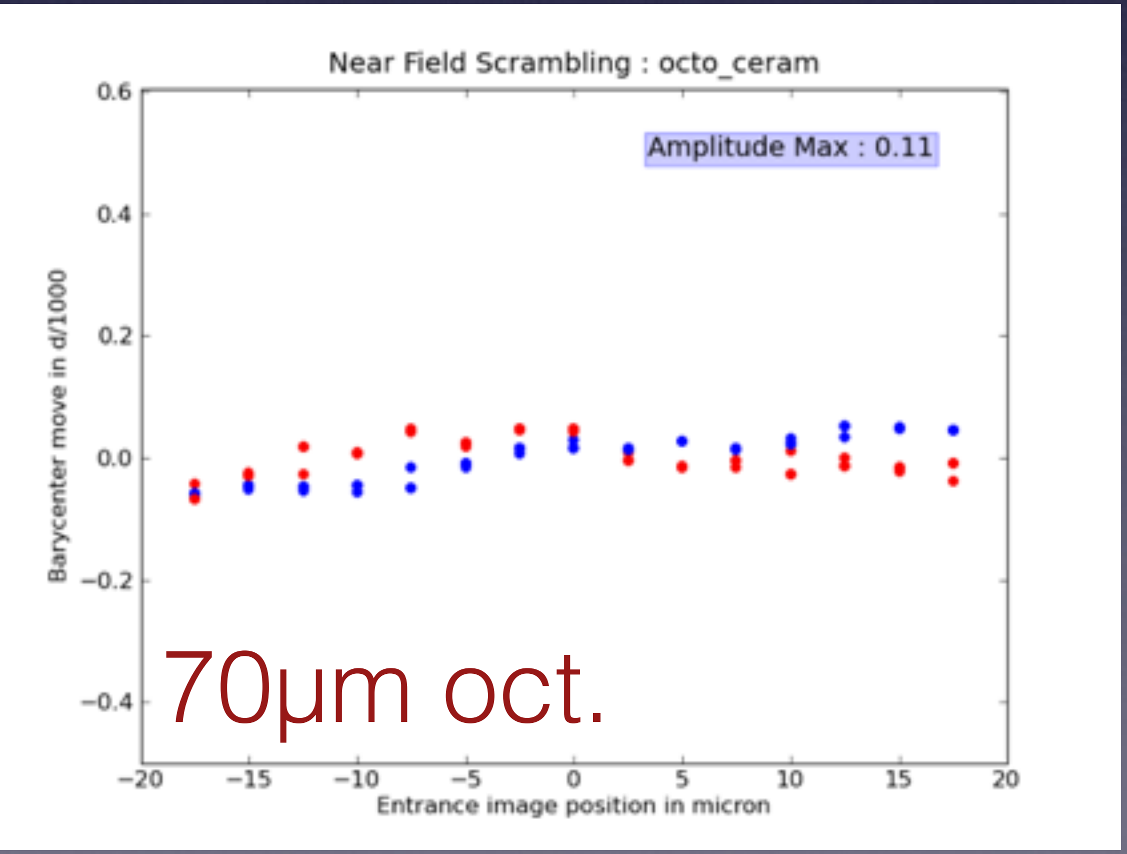
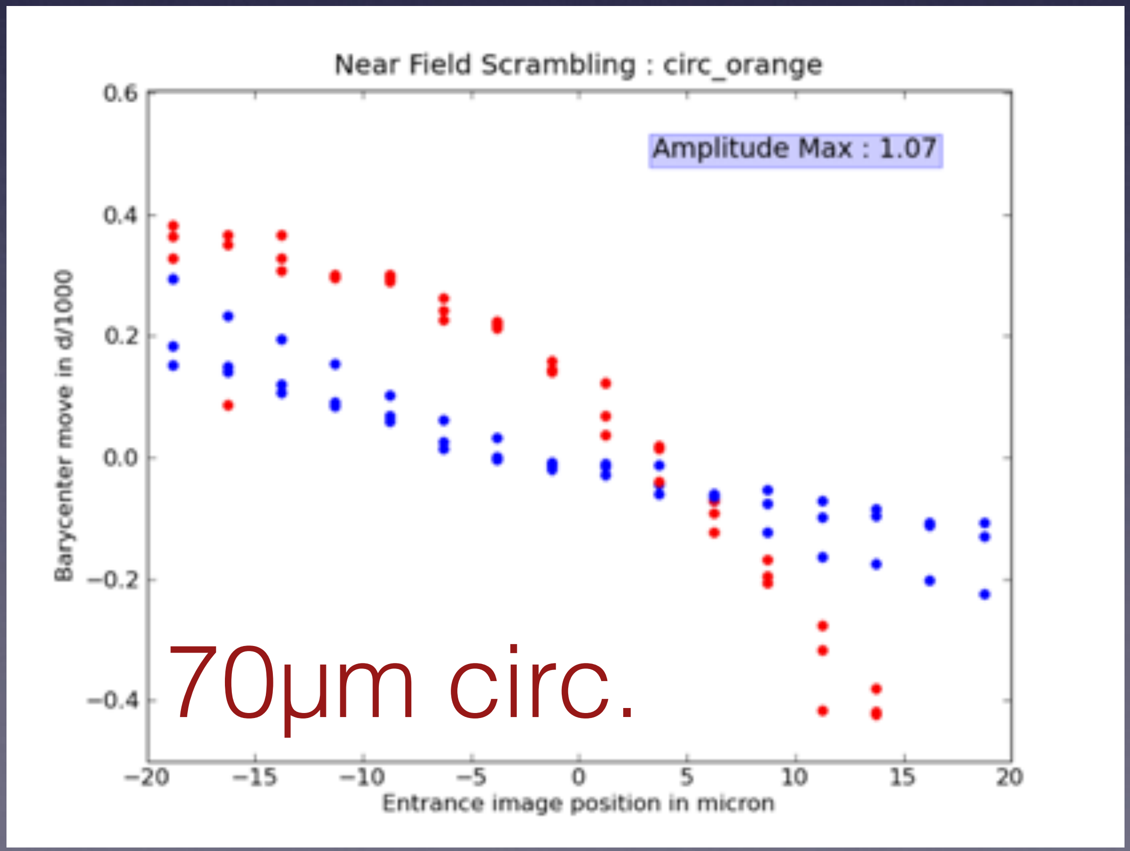


Chazelas et al., 2011; Avila et al. 2011; Perruchot et al. 2011

A new-old idea: Non-circular fiber

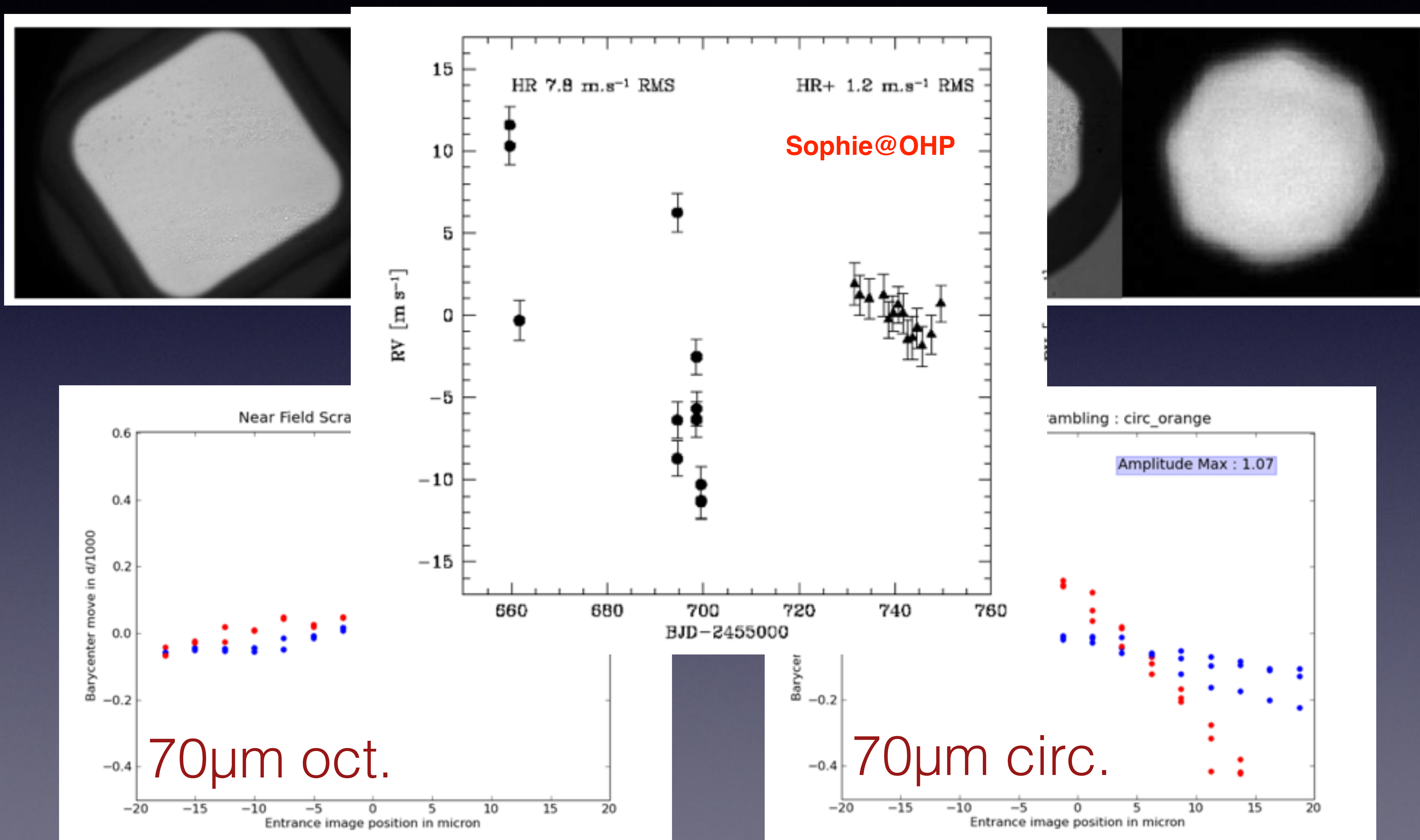




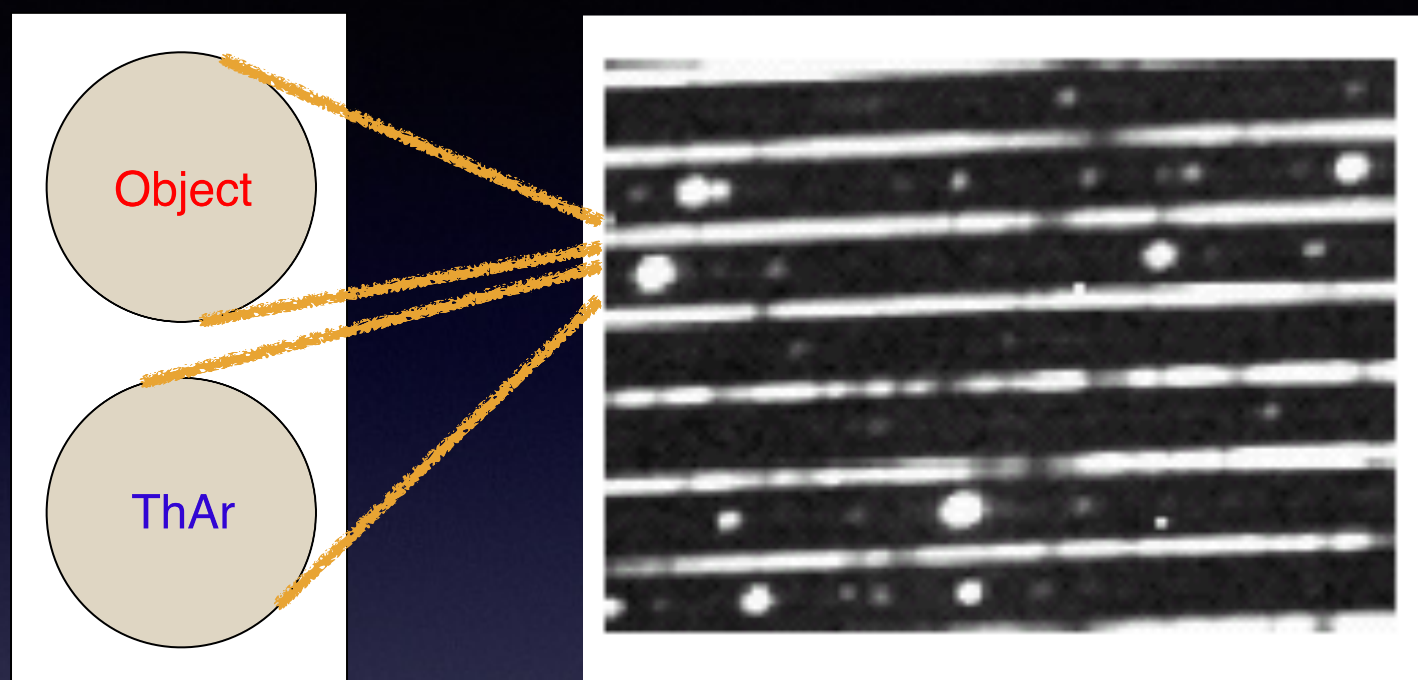


A new-old idea: Non-circular fiber

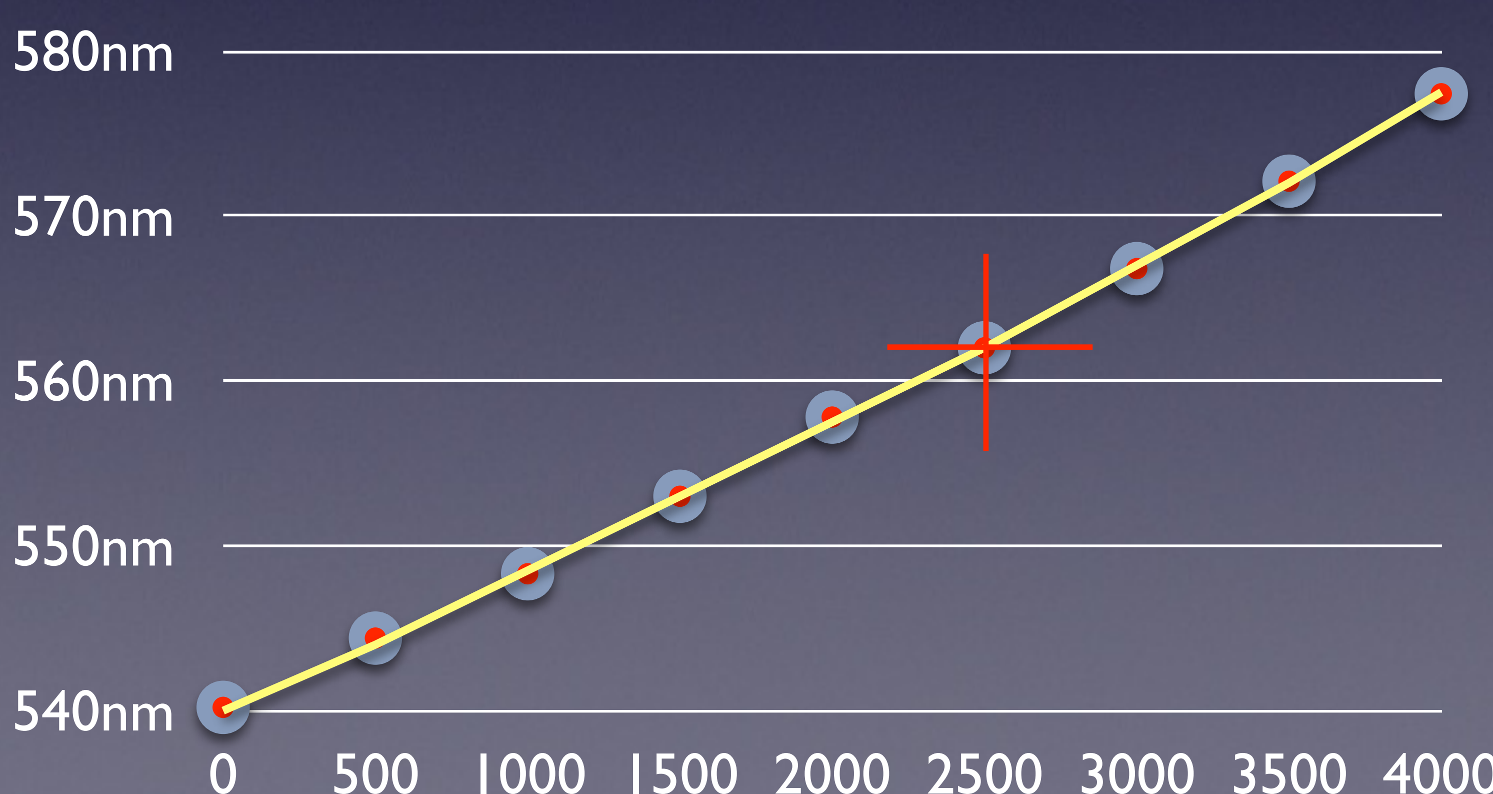
Bouchy et al. 2013



Imaging the 'slit' or fiber



Line position =
Wavelength =
Radial velocity =
etc.

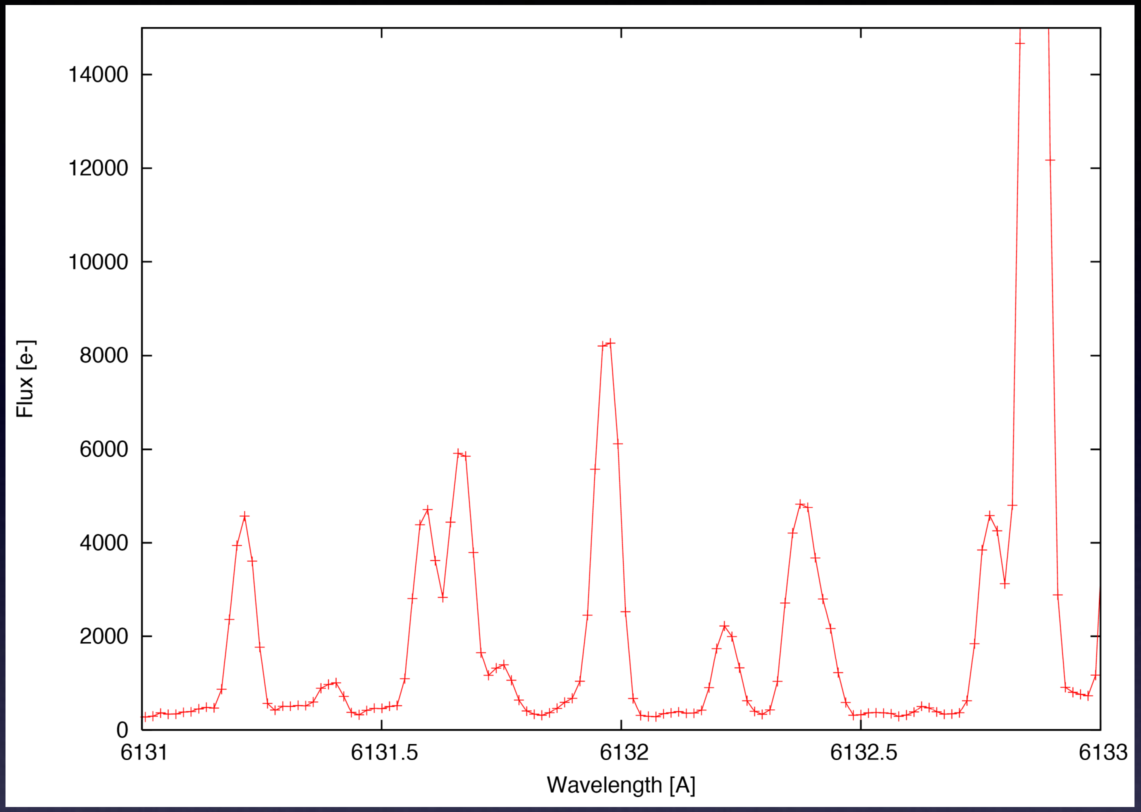


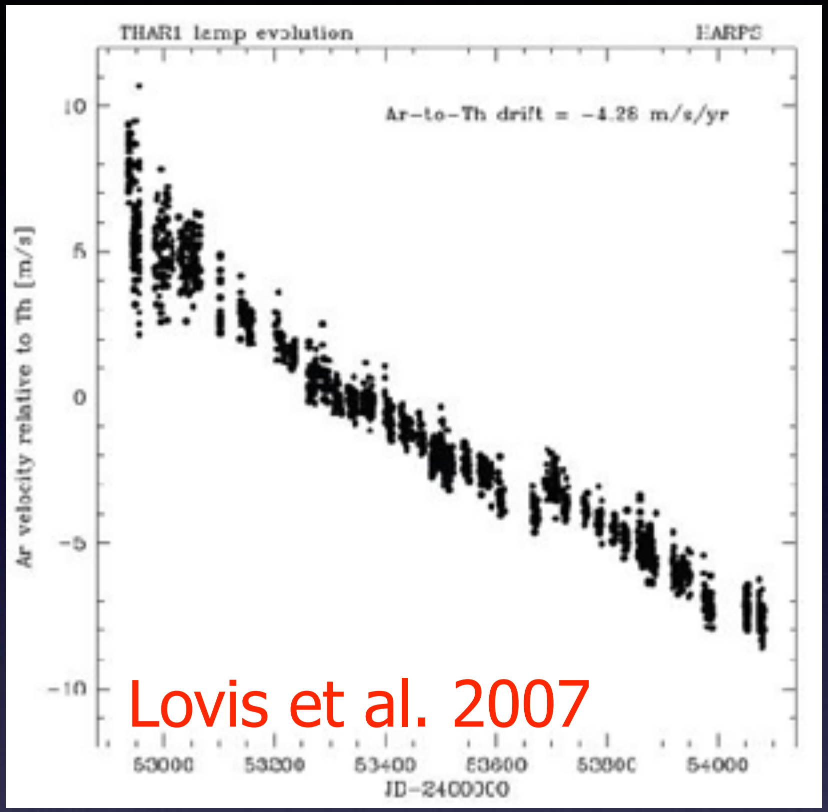
IP distorsion:
Biased wavelength calibration

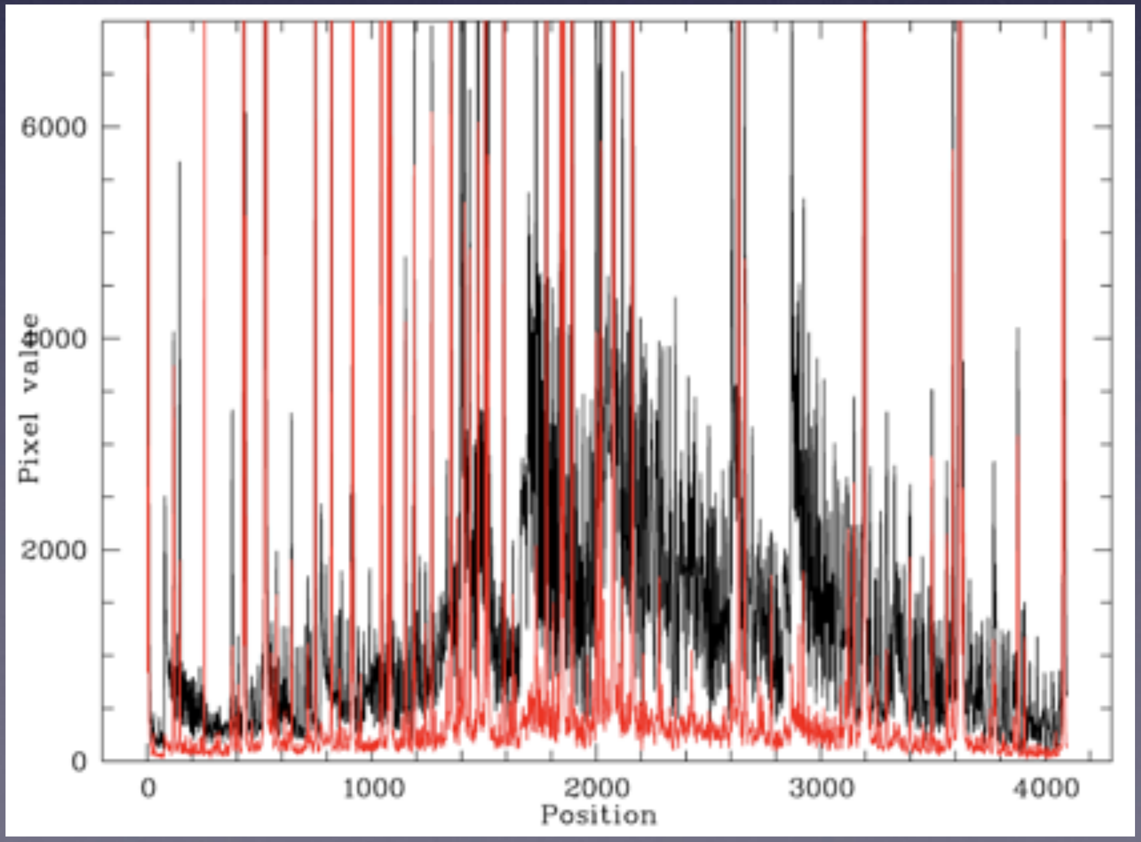
IP variation:
Loss of repeatability

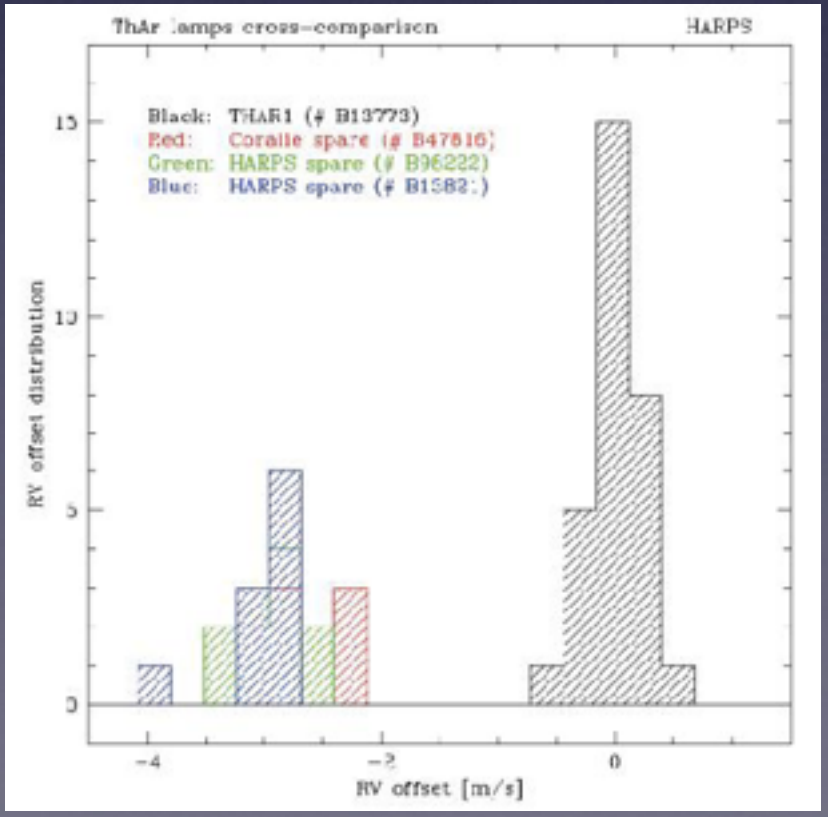
All about IP !!!!

Limitations from present calibration sources

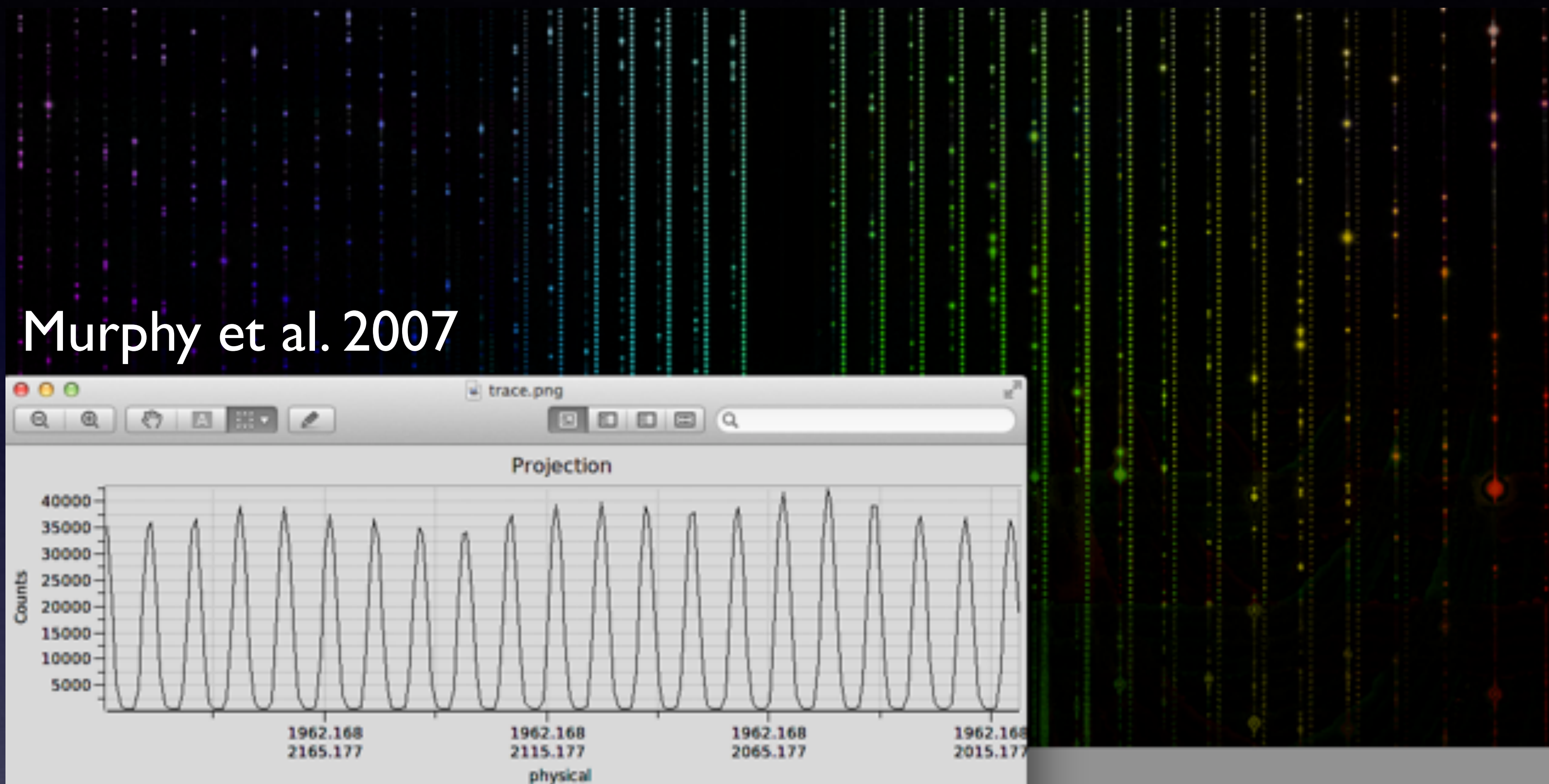




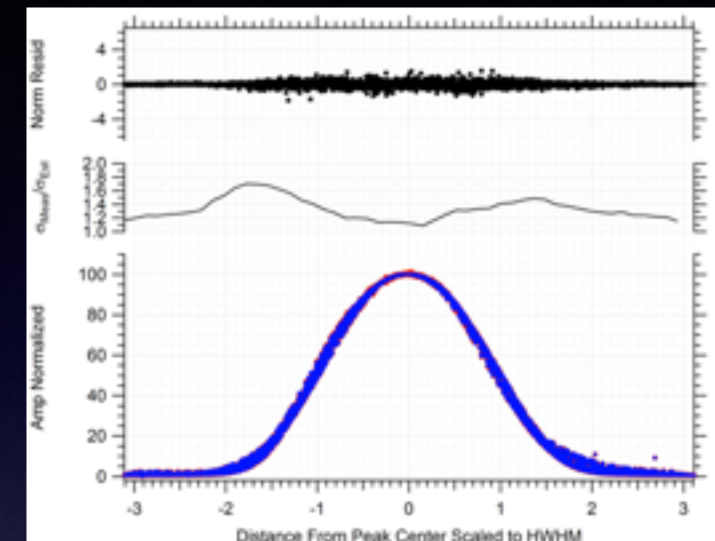




The HARPS-N LFC

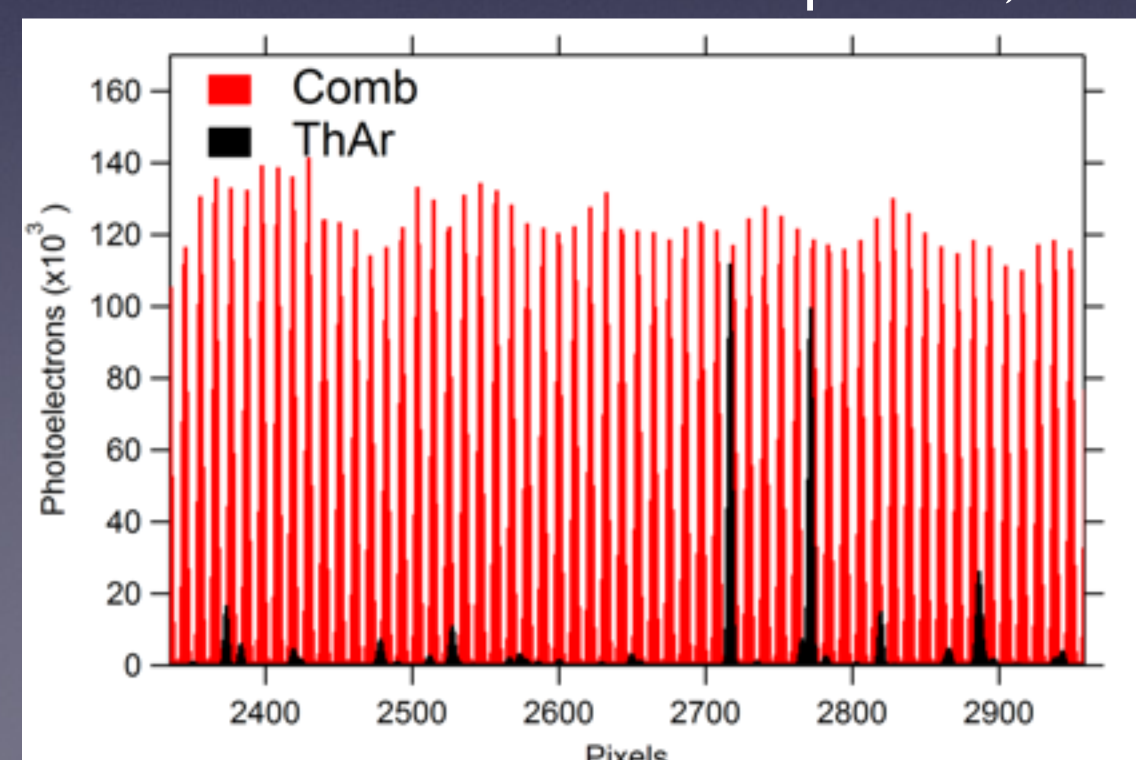


Murphy et al. 2007

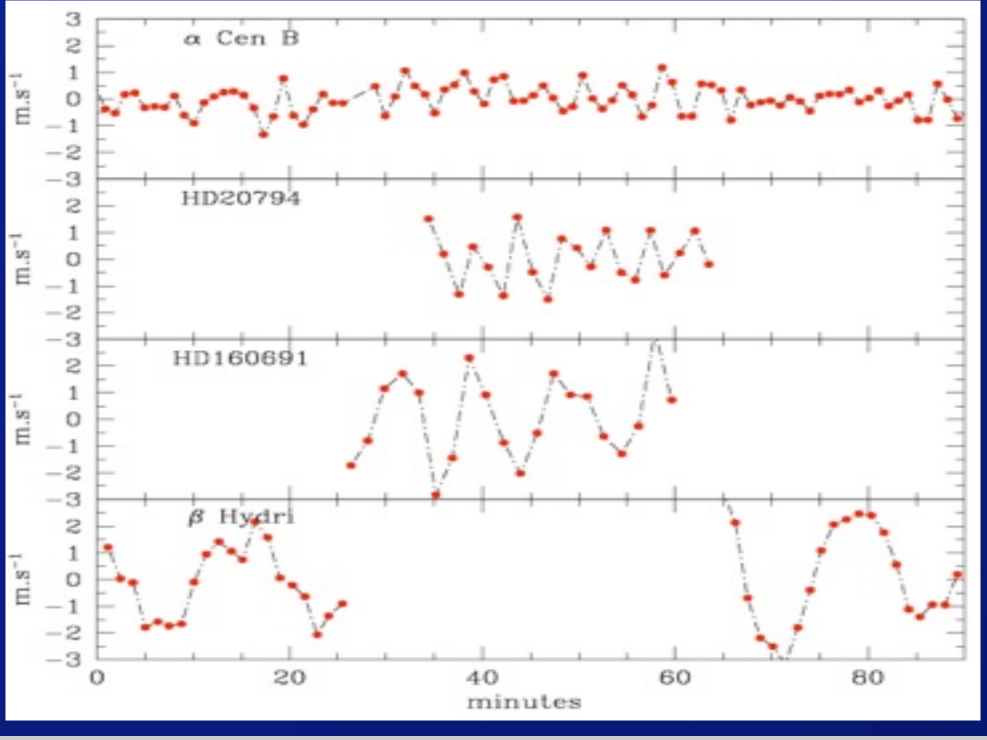


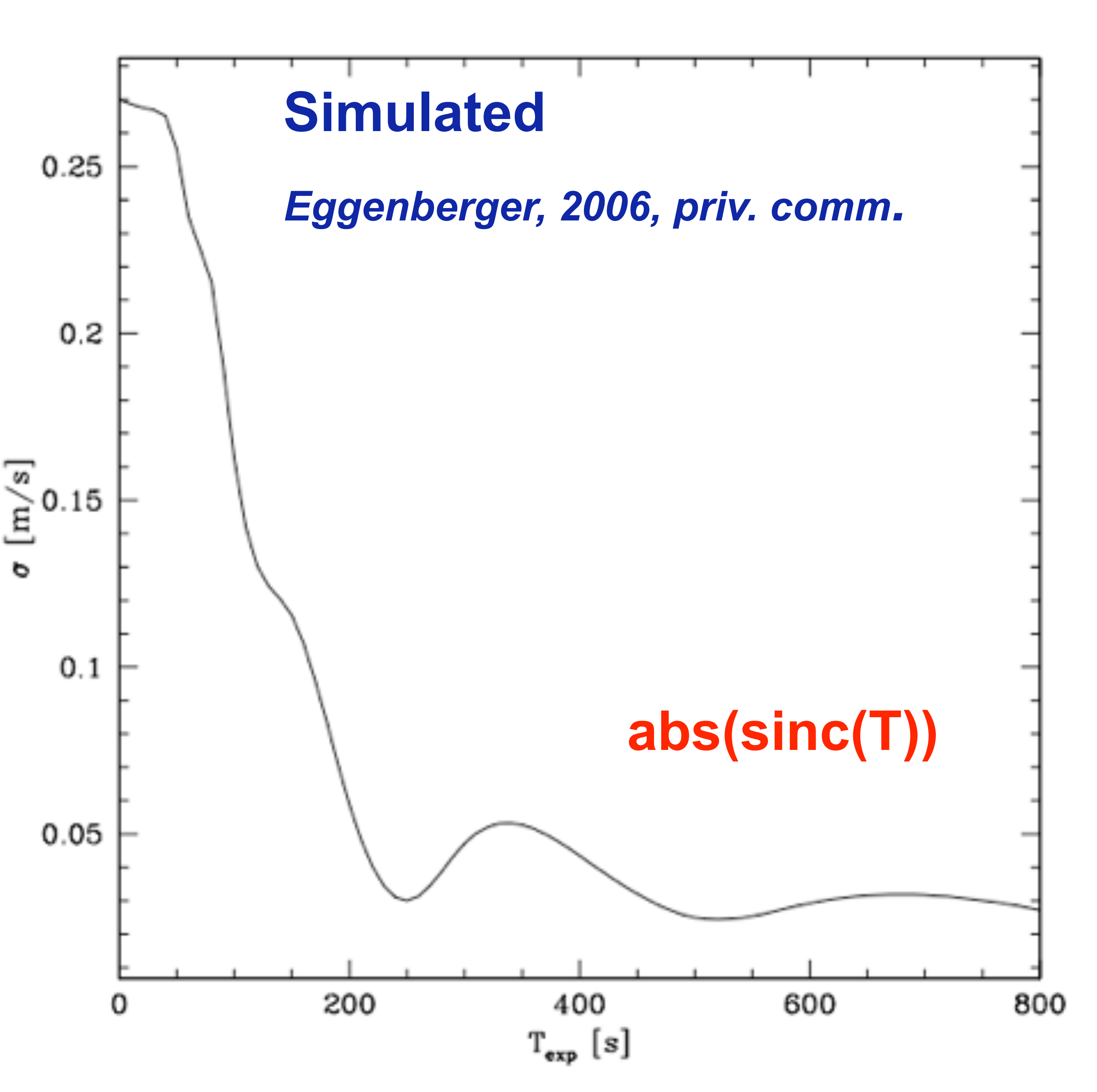
Courtesy of Alex Glenday, CfA

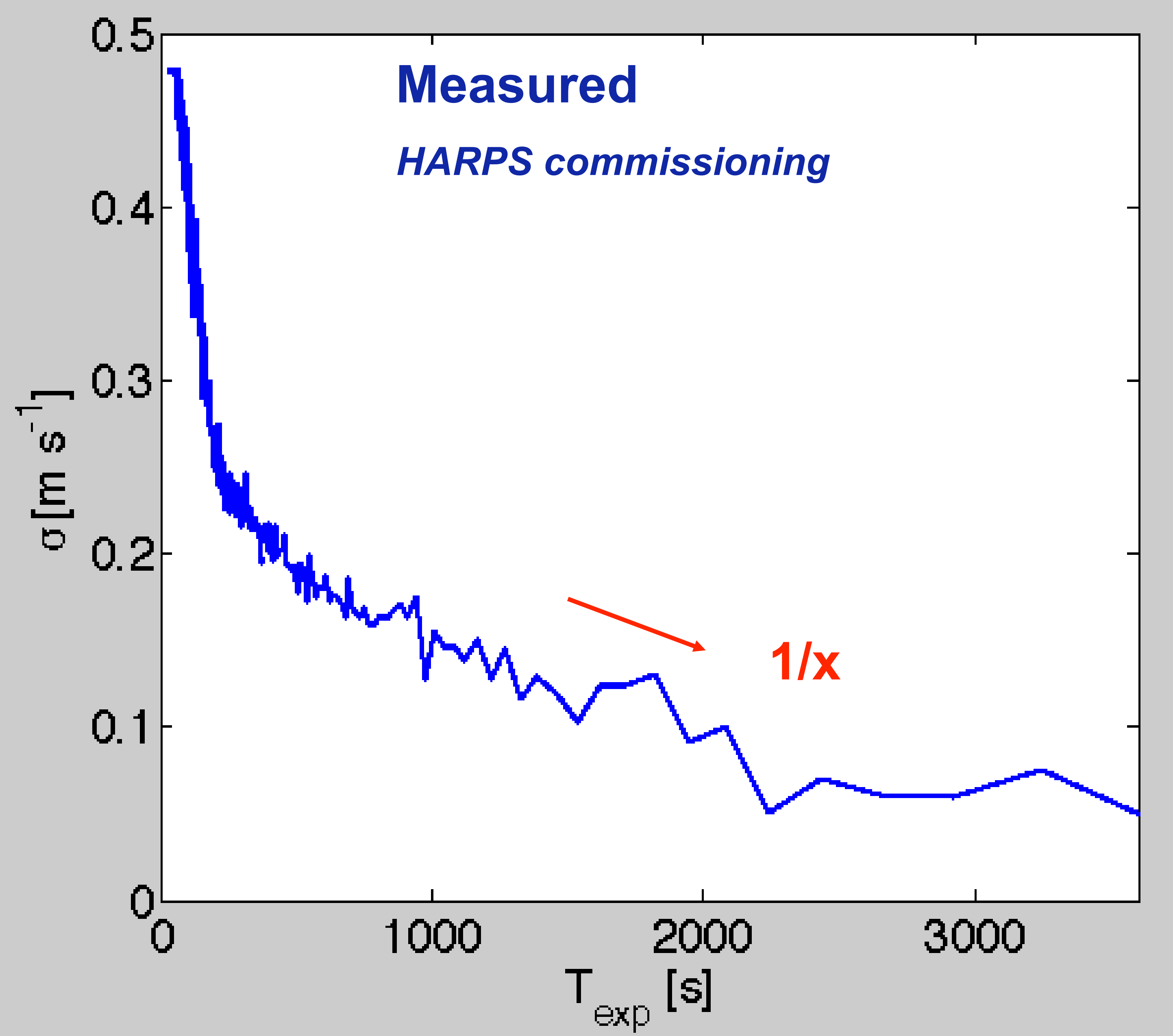
Phillips et al., 2012

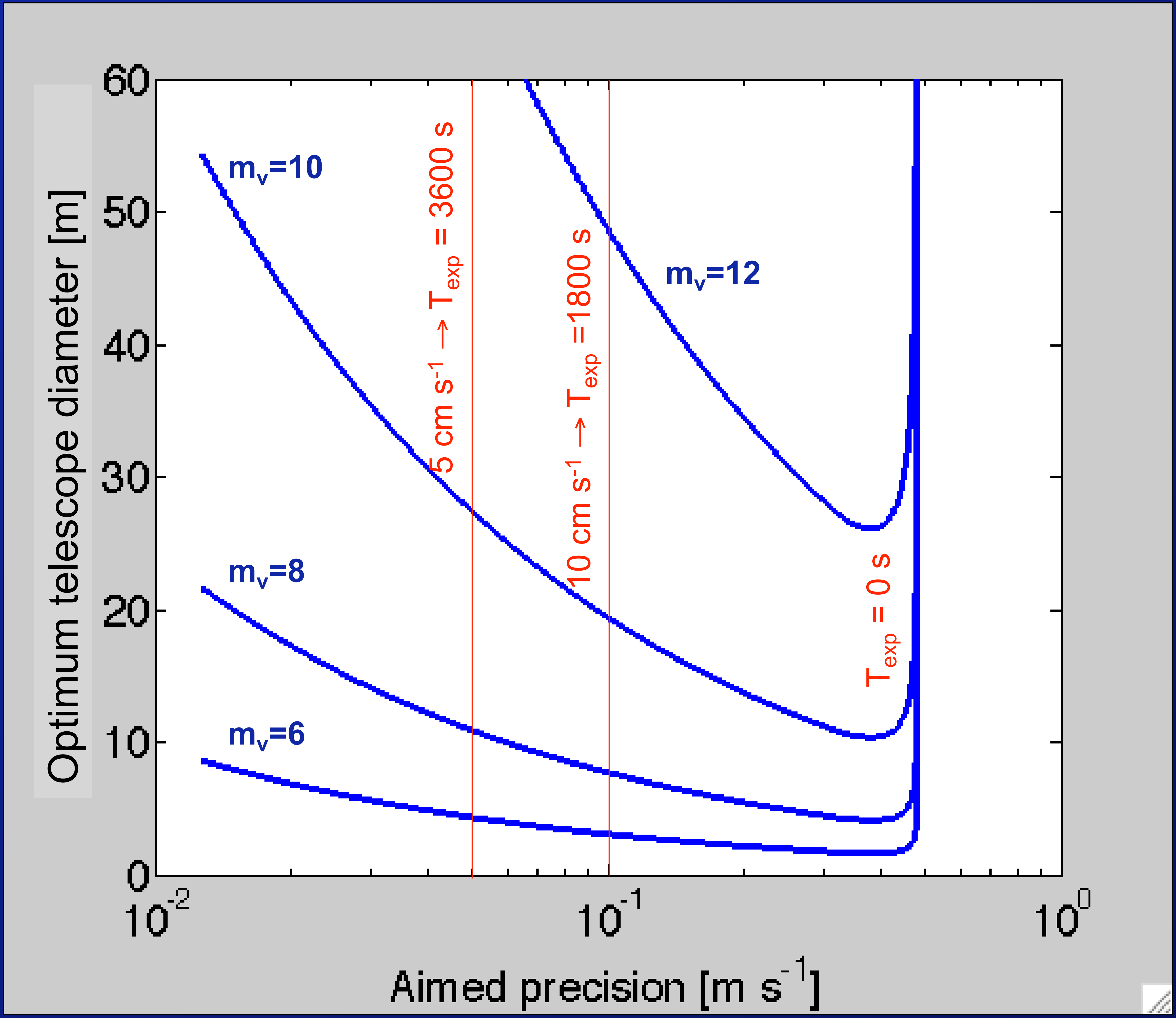


Averaging periodic signals



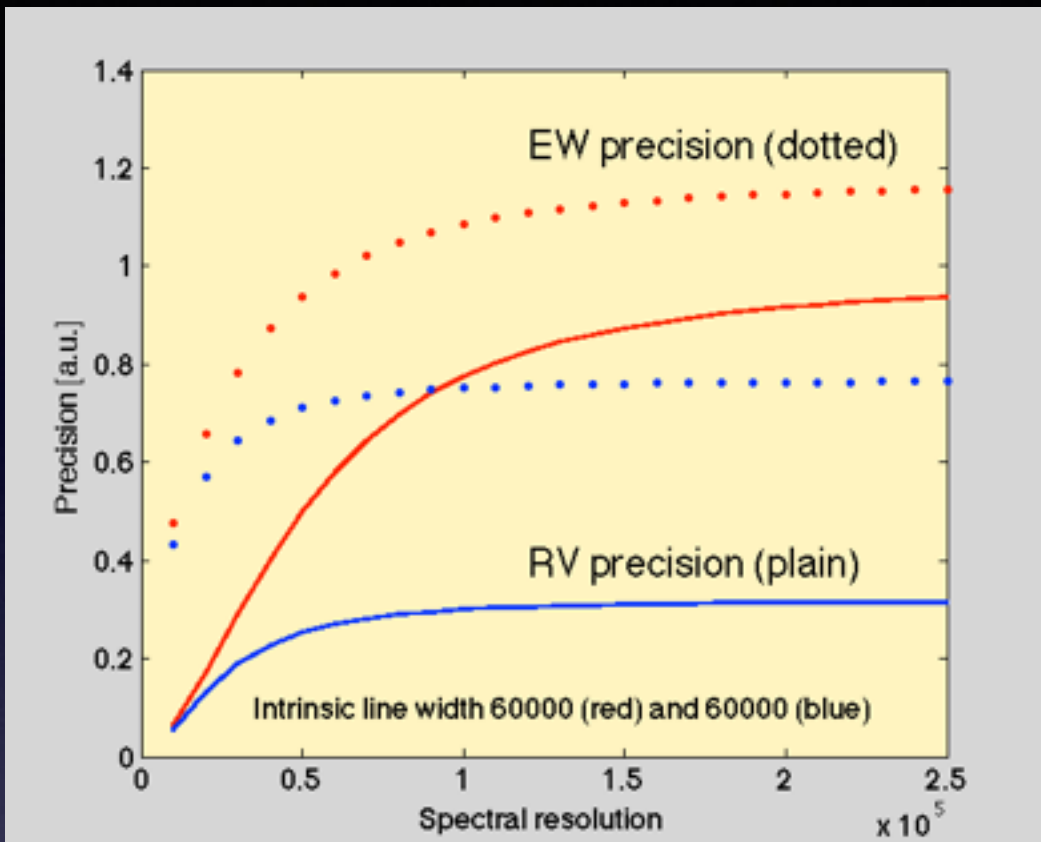


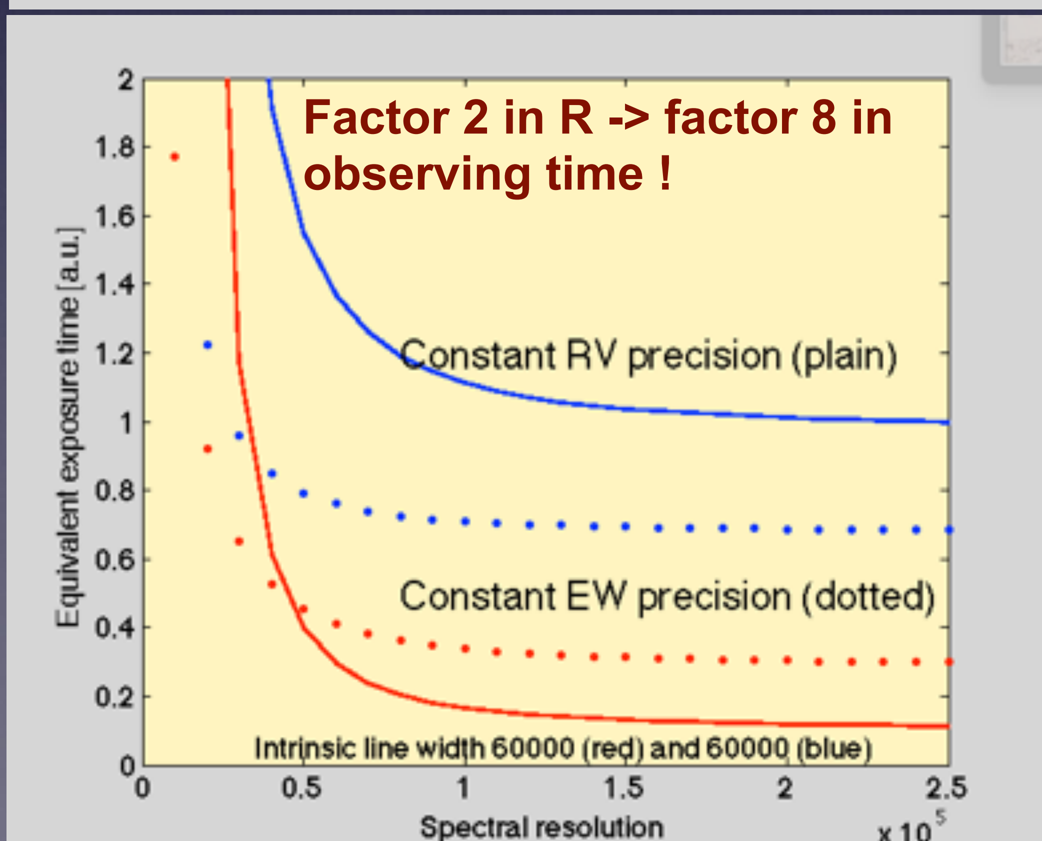


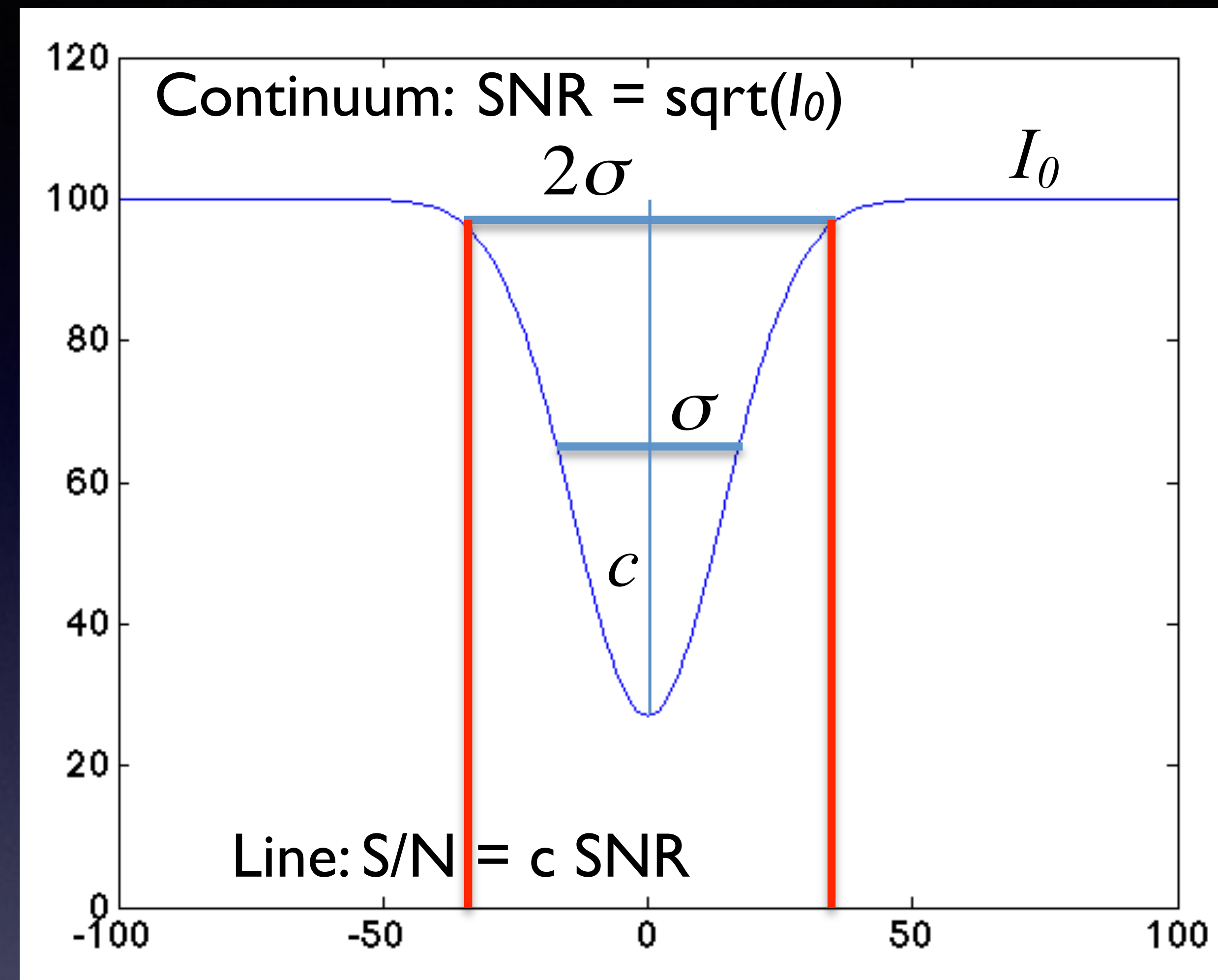


Optimum telescope diameter [m]
Aimed precision [m s^{-1}]
60
50
40
30
20
10
0
10^{-2}
10^{-1}
10^{0}
m_v=10
m_v=12
m_v=8
m_v=6
5 cm s^{-1} → T_{exp} = 3600 s
10 cm s^{-1} → T_{exp} =1800 s
T_{exp} = 0 s

SNR, precision & Co.



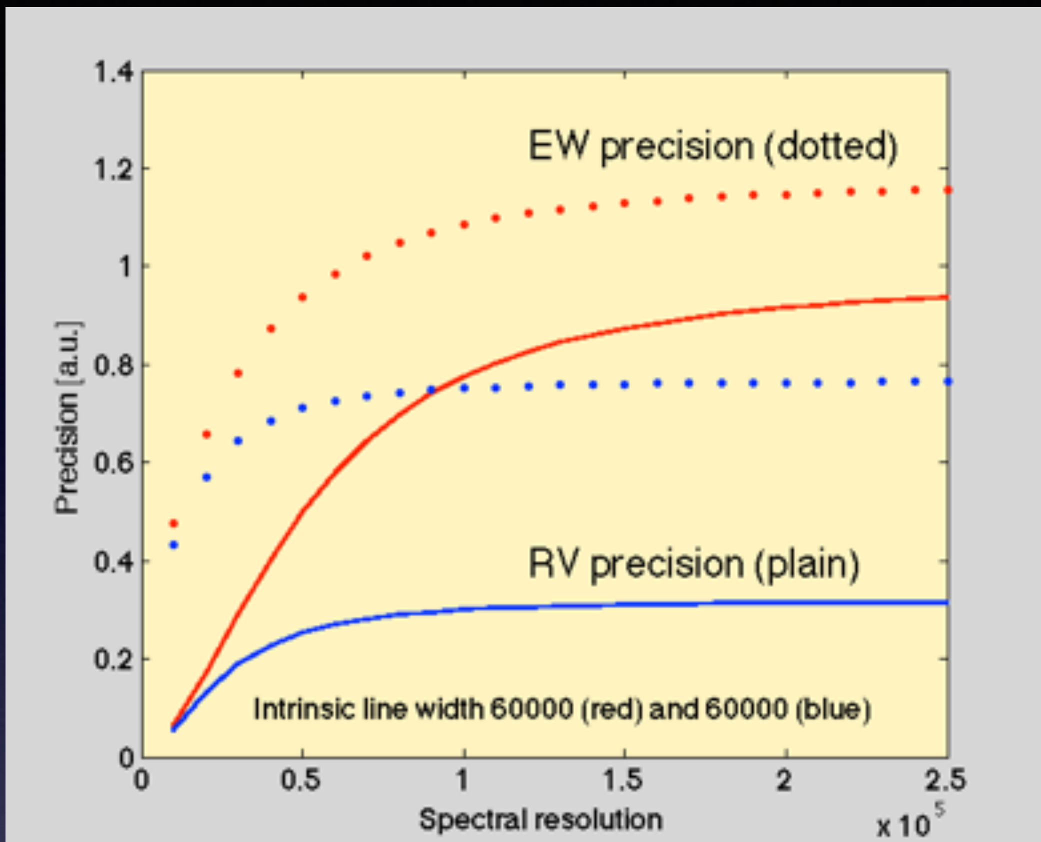


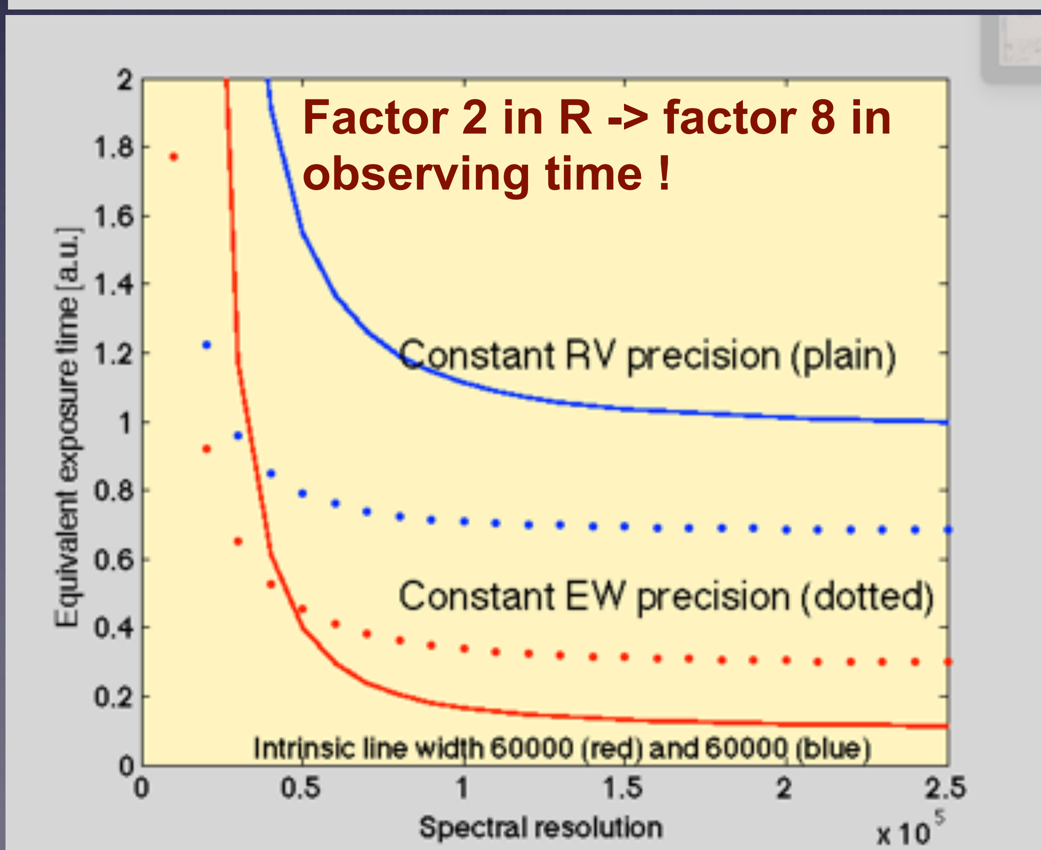


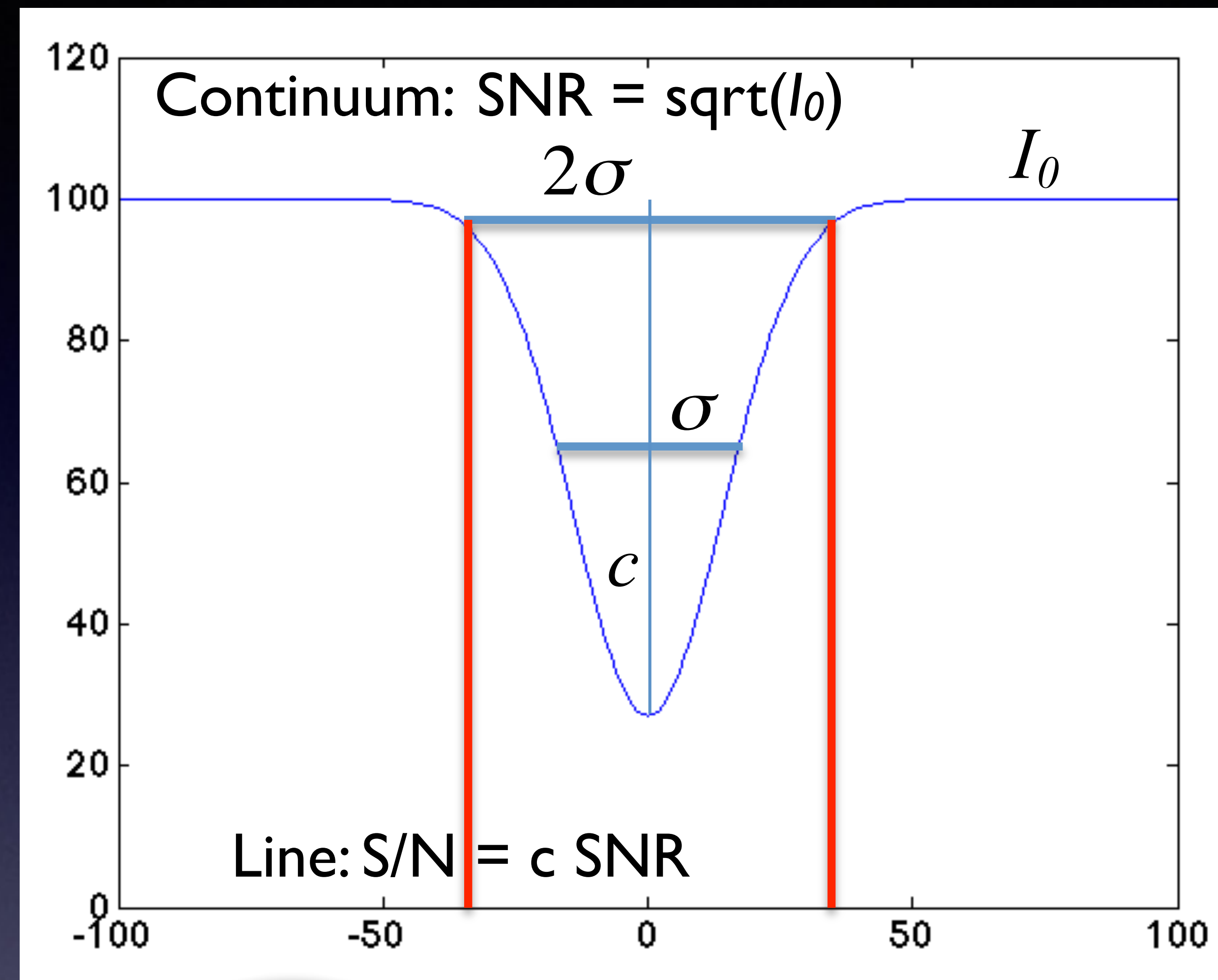
$$\varepsilon_x = \frac{\left(\sqrt{\sigma_{ix}^2 + \sigma_{Rx}^2}\right)^{1.5}}{\sqrt{2I'_0} \cdot EW_x} \cdot \sqrt{\left(1 - \frac{c}{2}\right) + n_c \cdot \left(\frac{I_D}{I'_0} \cdot t + \frac{1}{b_c \cdot b_R} \cdot \frac{RON^2}{I'_0}\right) + \frac{I'_S}{I'_0}}$$

$$\varepsilon_{EW} = \frac{\sqrt{2}\left(\sqrt{\sigma_{ix}^2 + \sigma_{Rx}^2}\right)^{0.5}}{\sqrt{I'_0} \cdot EW_x} \cdot \sqrt{\left(1 - \frac{c}{2}\right) + n_c \cdot \left(\frac{I_D}{I'_0} \cdot t + \frac{1}{b_c \cdot b_R} \cdot \frac{RON^2}{I'_0}\right) + \frac{I'_S}{I'_0}}$$

SNR, precision & Co.







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$$\varepsilon_{EW} = \frac{\sqrt{2}\sqrt{\sigma_{ix}^2 \ldots}}{\sqrt{I'_0} \cdot EW_x} \cdot \sqrt{\ldots \left(\frac{I_D}{I'_0} \cdot t + \frac{1}{b_c \cdot b_R} \cdot \frac{RON^2}{I'_0}\right) + \frac{I'_S}{I'_0}}$$

Butler et al., 1996
Bouchy et al., 2001

The ‘annoying’ equations for large telescopes (no AO assumed)

$$R \cdot \frac{D_T \cdot FOV}{D_C \cdot \tan\beta} = const$$

$$N_{Pixels} \propto \frac{D_T^2 \cdot FOV^2}{D_C^2 \cdot \tan\beta}$$

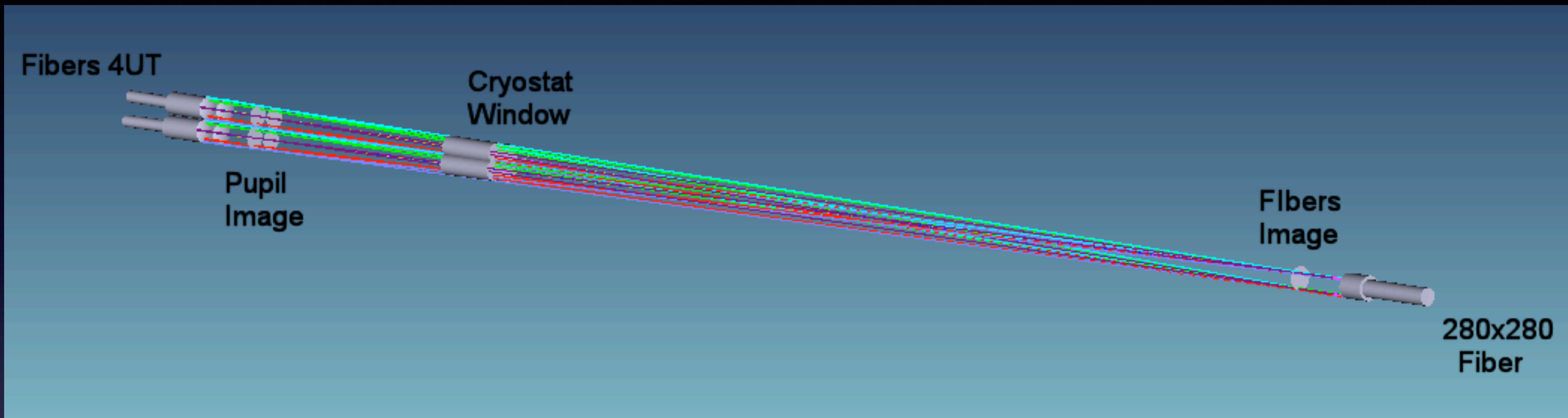
at fixed R & sampling

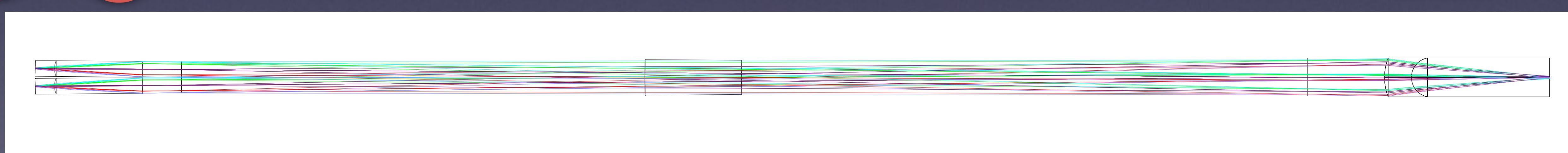
AO would actually be useful for cost reduction, not sure about ‘precision’…

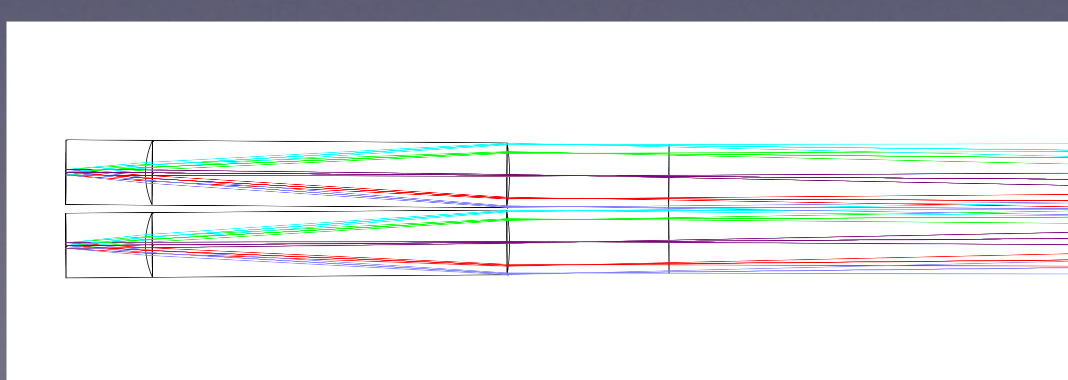
Moving towards ELTs

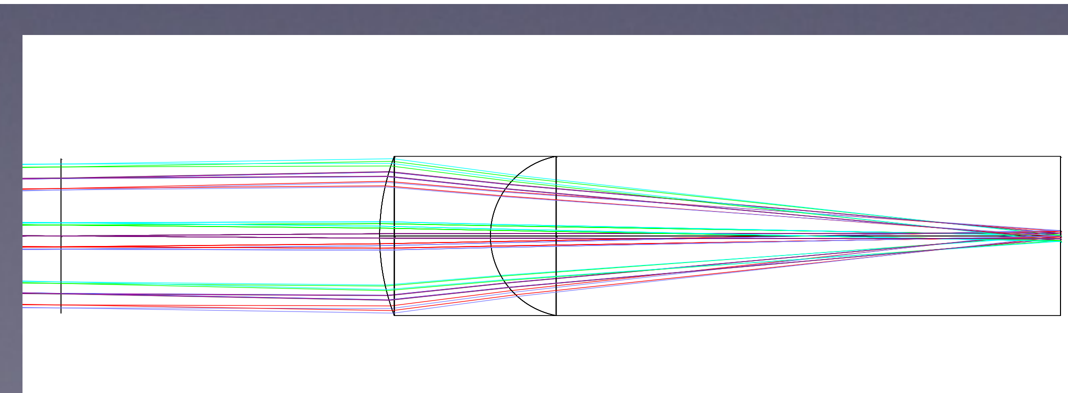
- Adopt HARPS' principles (intrinsically stable and 'clean' in order to avoid using signal recovering 'tricks')
- Larger collecting areas (Photons)
- Efficient instruments (Photons)
- High spectral resolution (Photons + Precision: photon noise, instrumental 'stability', calibration, atmosphere,)
- Expand wavelength range (Photons + new information: late spectral types, sensitivity to spots and plages)
- Use of AO (reduce size and costs)

ESPRESSO 4-UT image combiner/scriser









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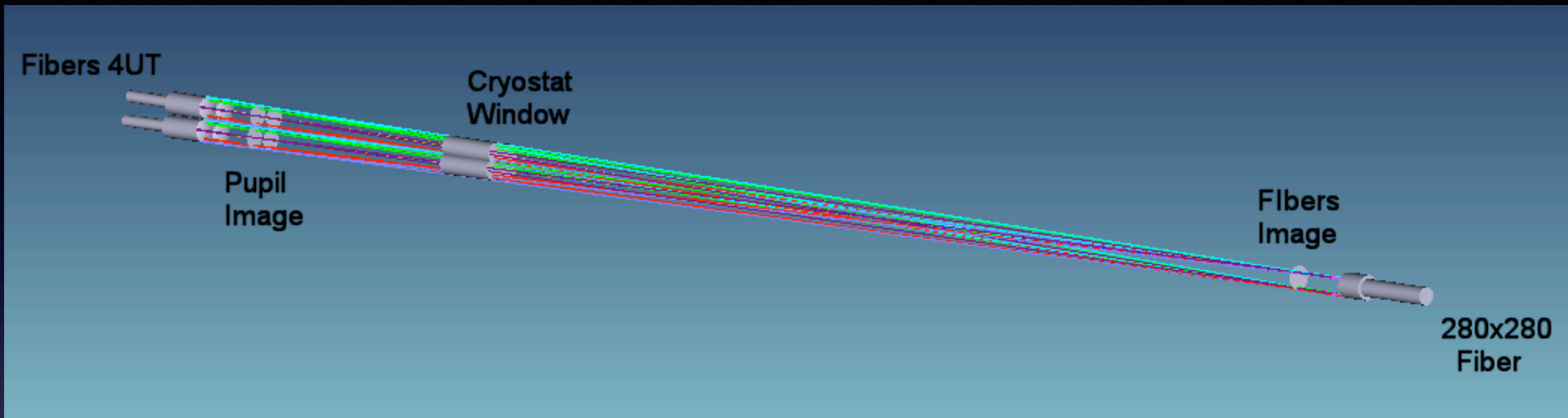

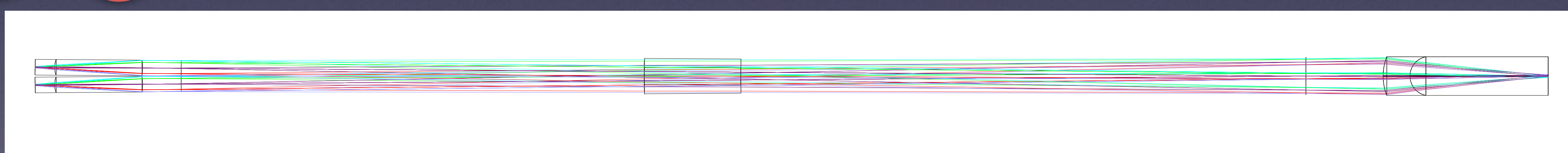

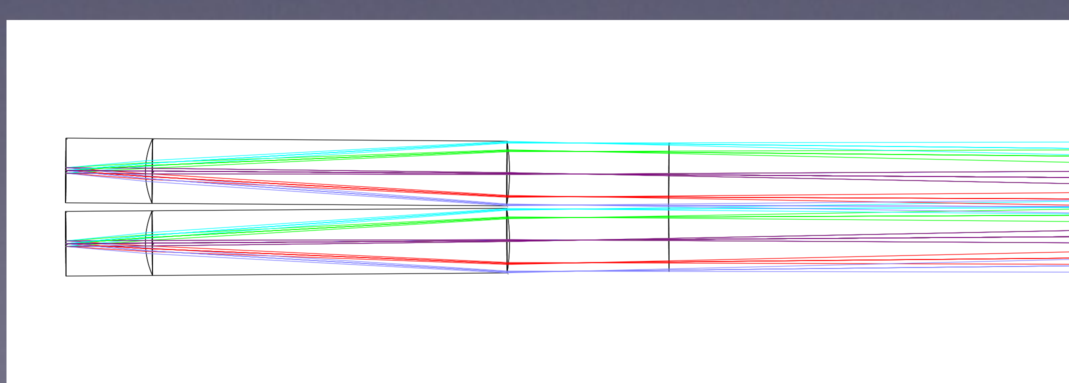

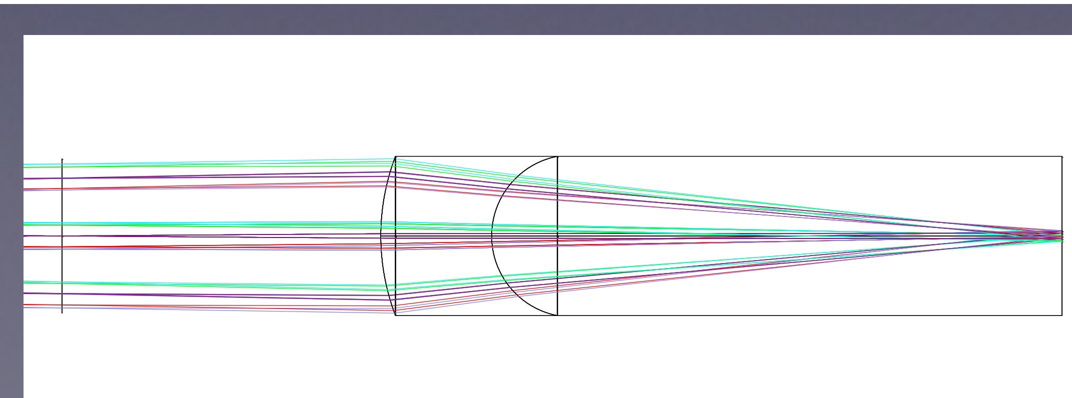

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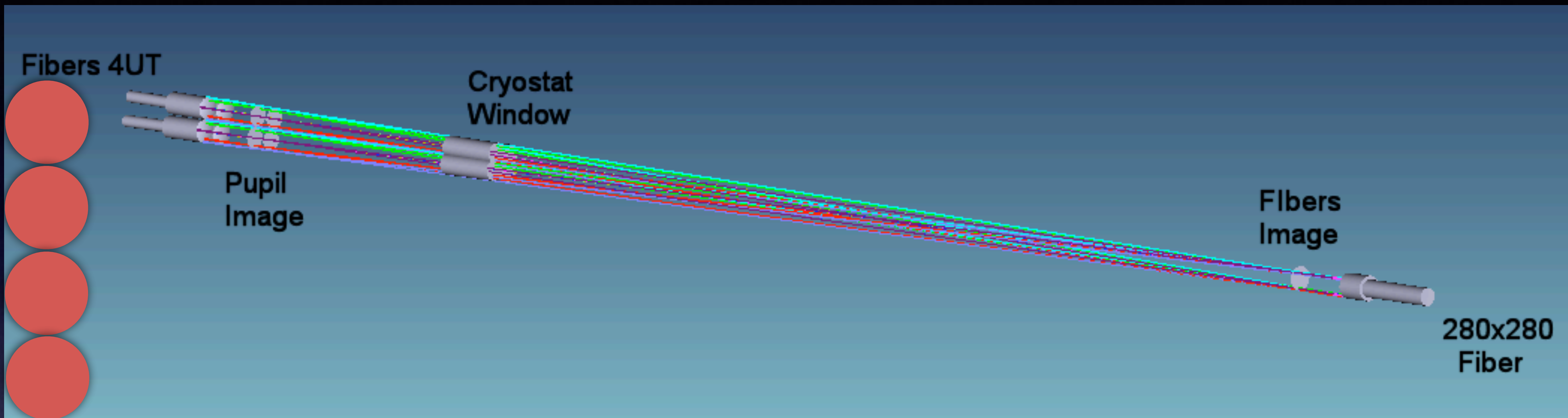

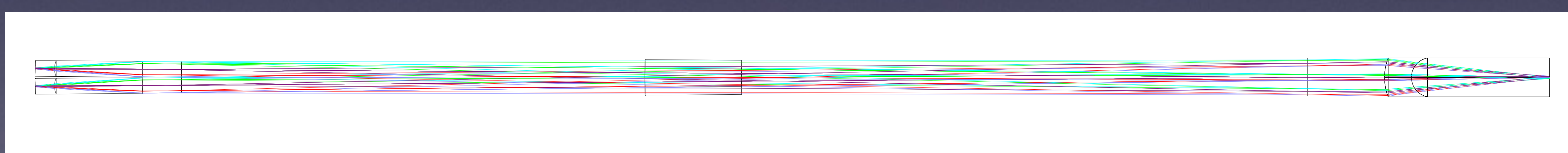

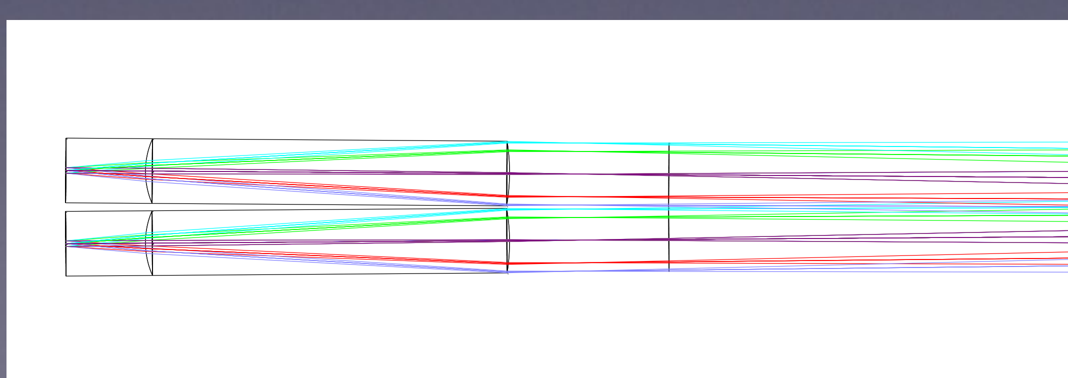

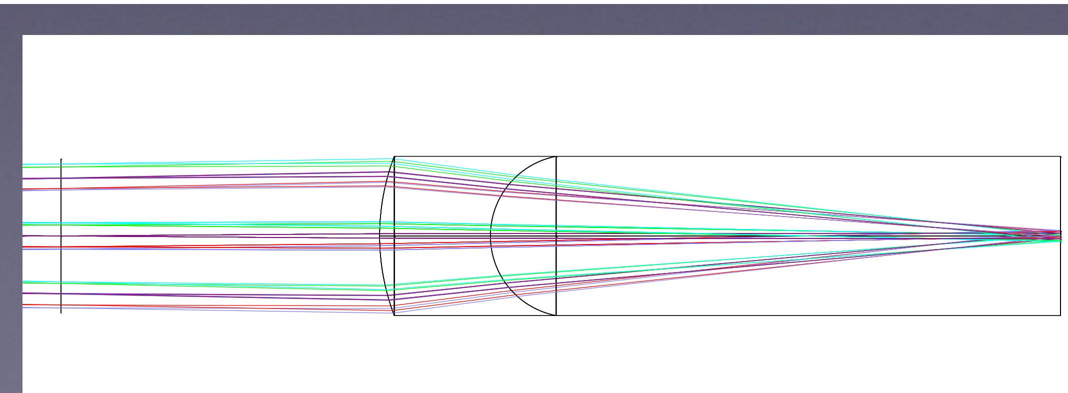

ESPRESSO 4-UT image combiner/scriser