High resolution spectroscopy without cross-dispersion

Guillem Anglada-Escude
University of Hertfordshire & Queen Mary University of London
guillem.anglada@gmail.com

Ulrike Lemke
University of Goettingen
ulrike.lemke@phys.uni-goettingen.de

Photonics for planets – Firenze 2014

Outline of the talk

The stabilized echelle spectrometer

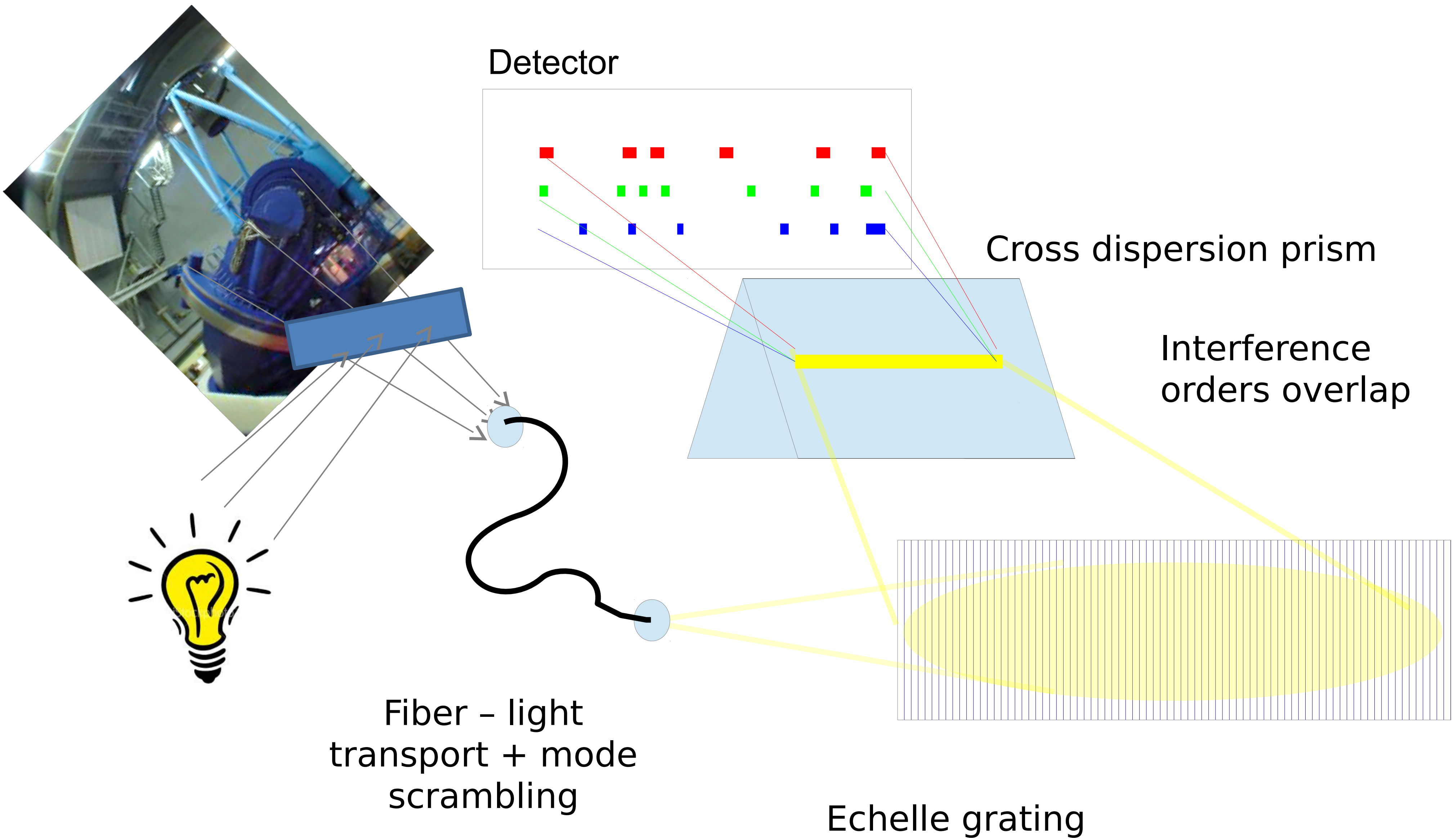
Cross-dispersion using wavelength sensitive pixels

Feasibility using current technology

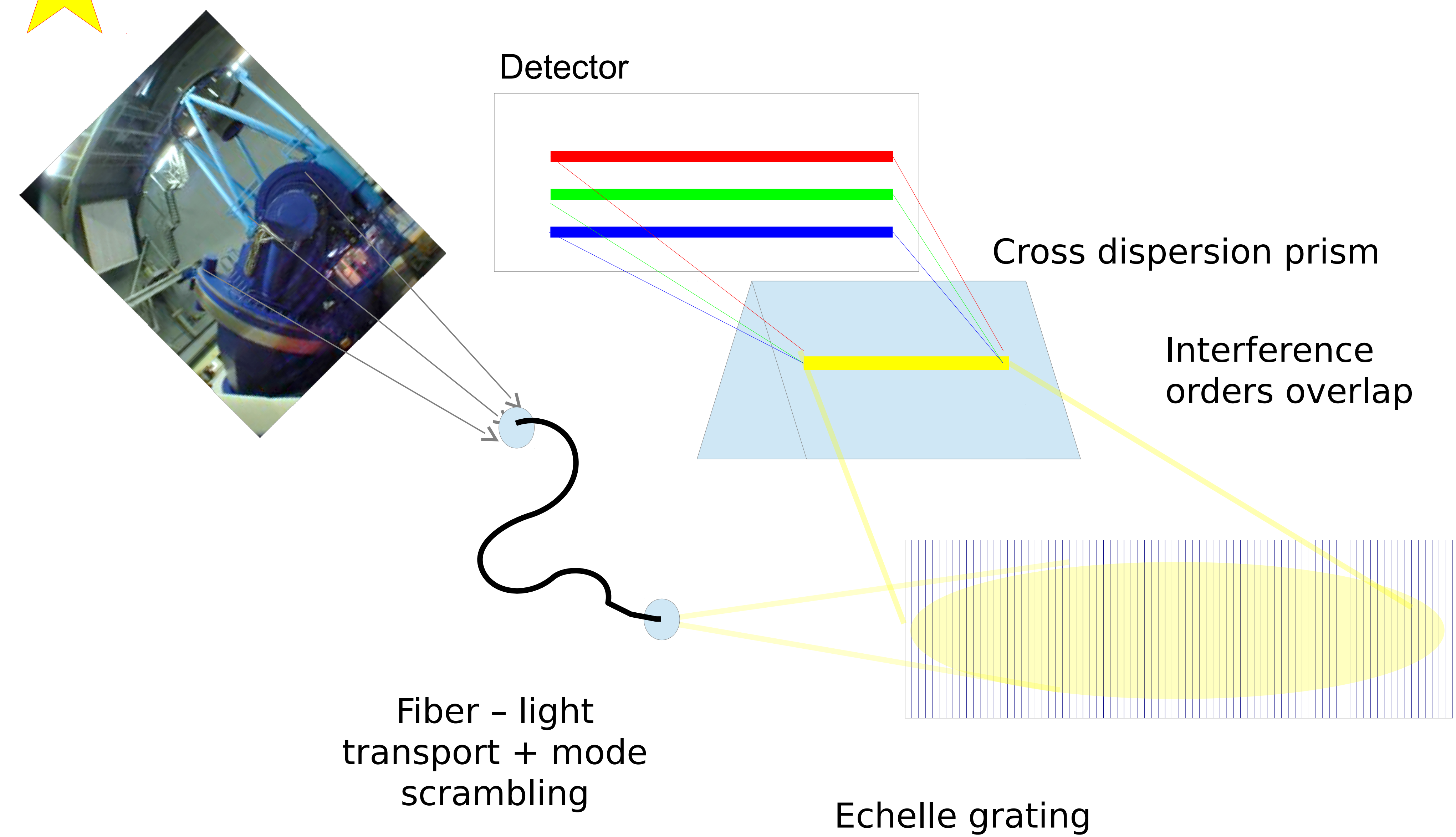
Trade-offs over classic design

Key challenges

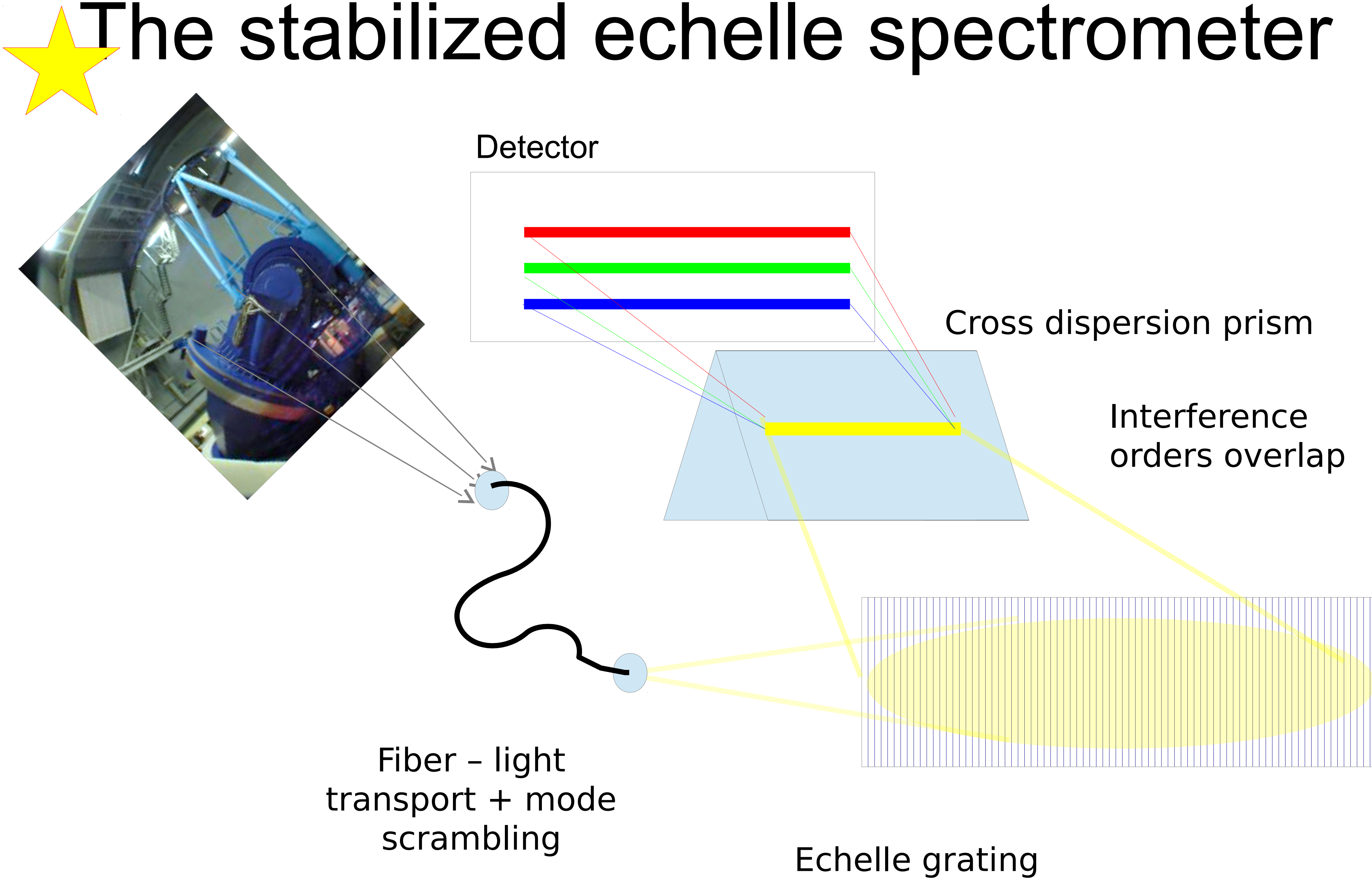
The stabilized echelle spectrometer

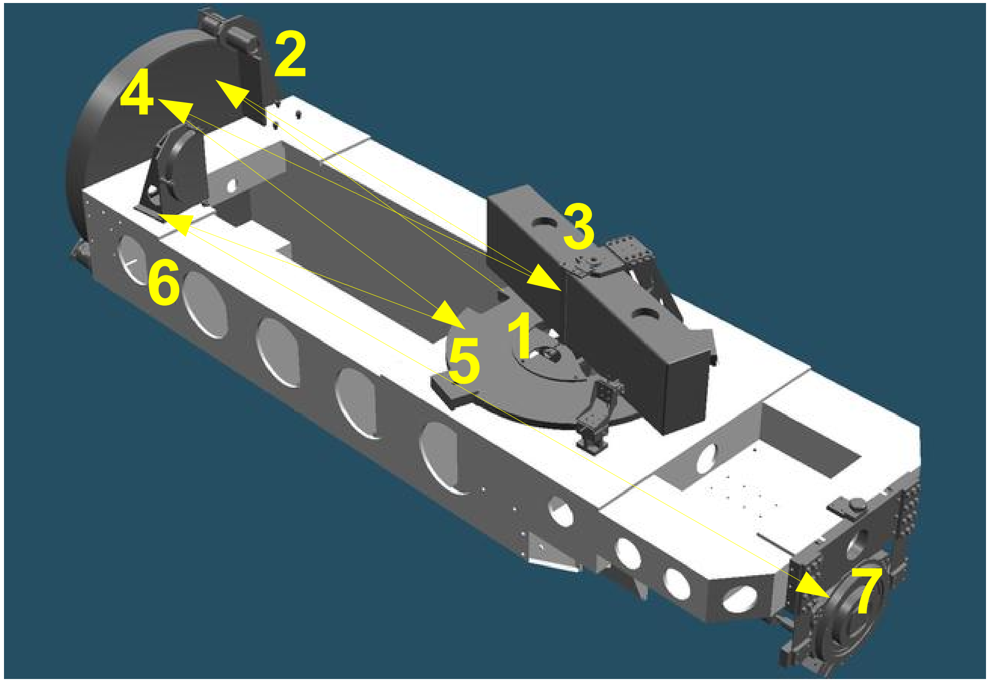


The stabilized echelle spectrometer

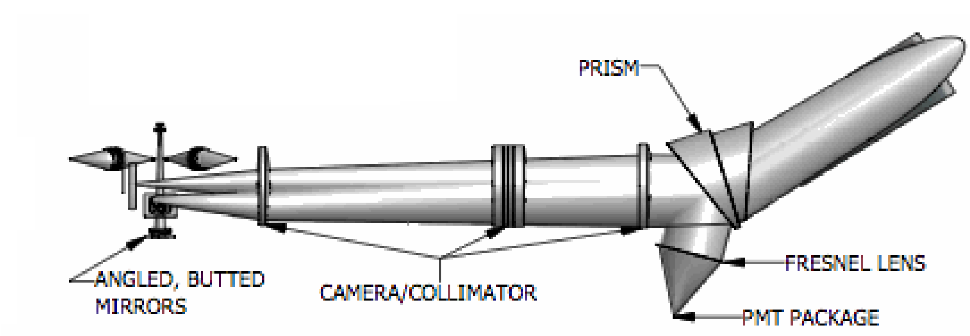


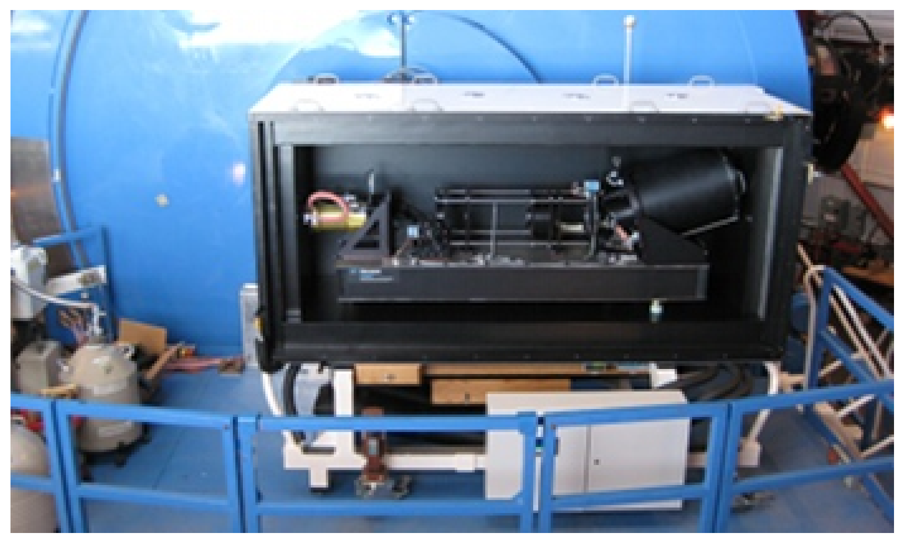
The stabilized echelle spectrometer



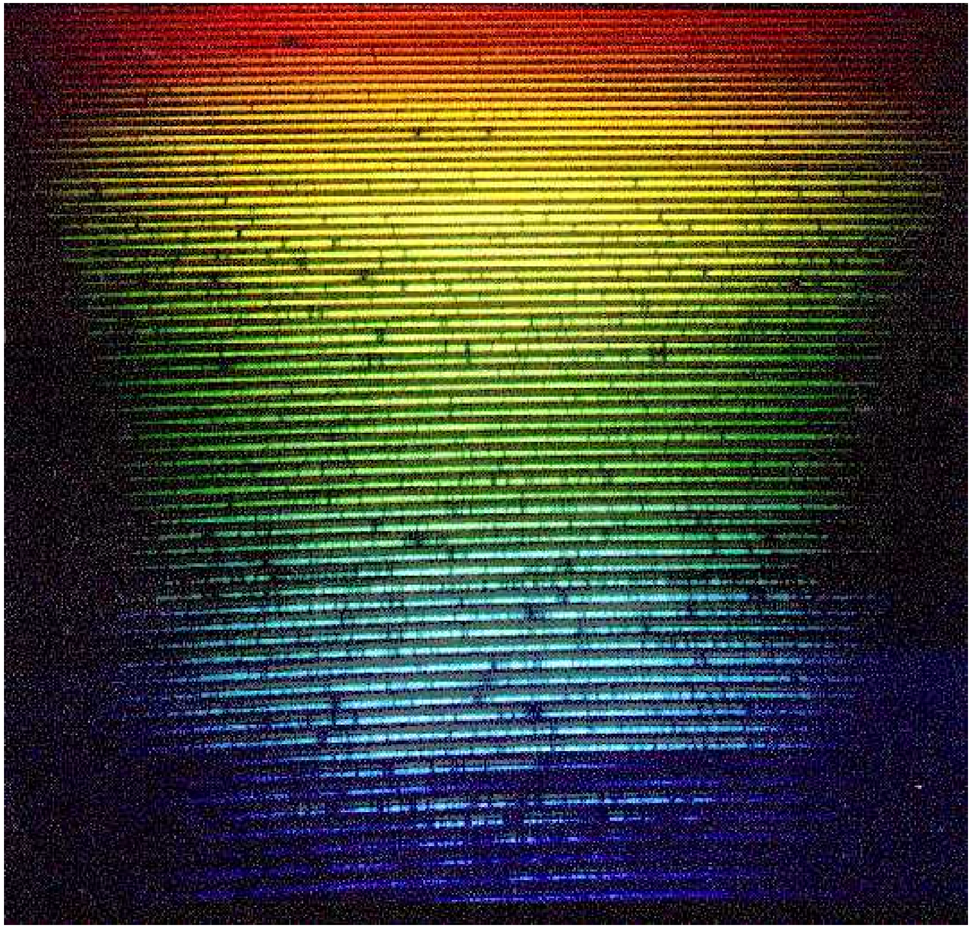


HARPS spectrometer
European Southern Observatory – La Silla

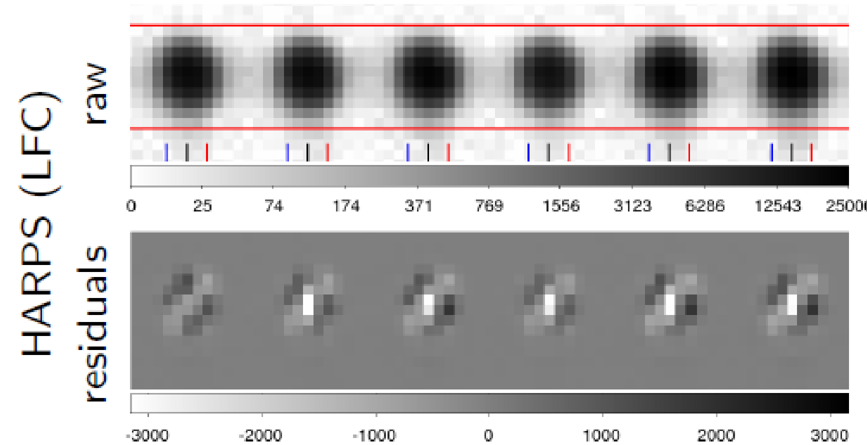




Carnegie's PFS spectrometer
Credits : J Crane. OCIW



Order curvature



Line tilt and optical aberrations

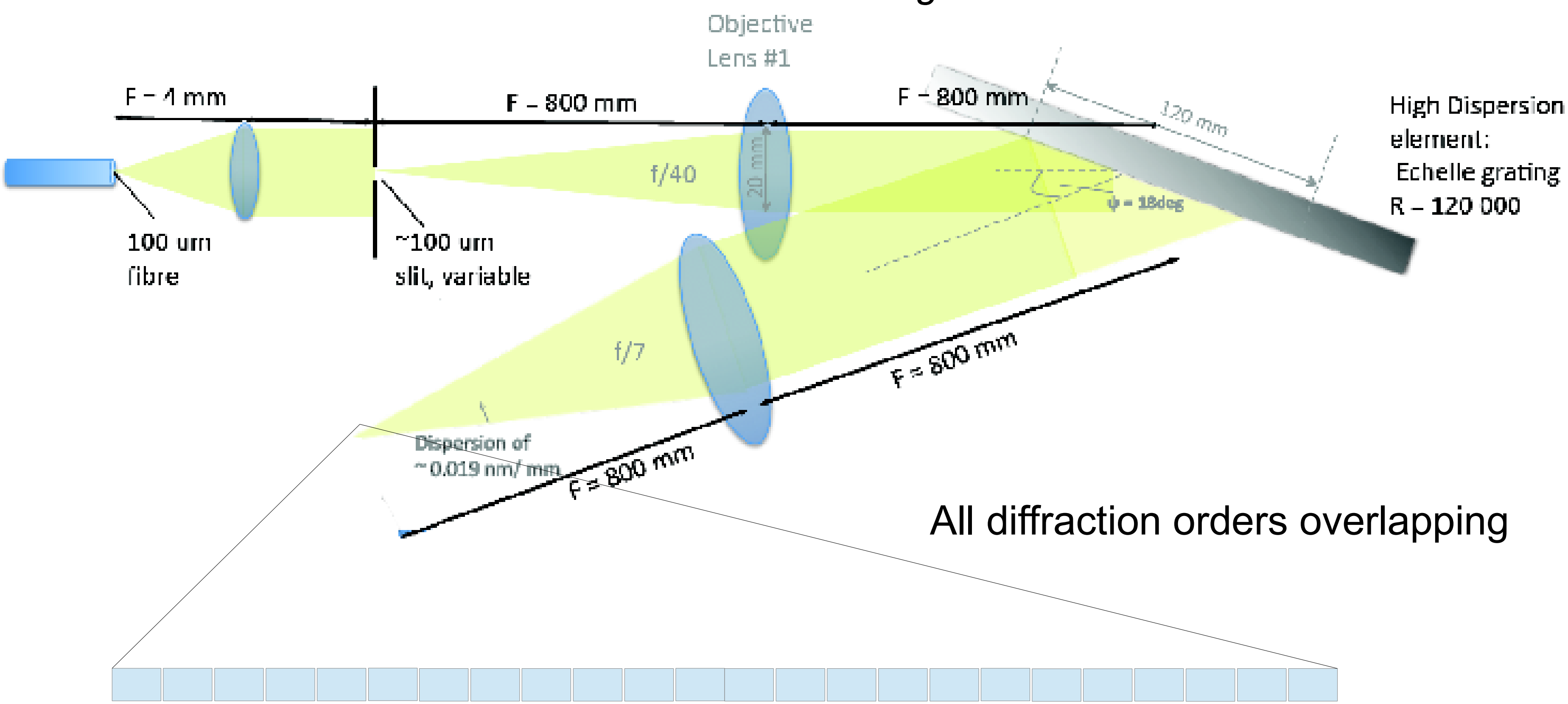
Optimal 2D extraction nightmarish
Modeling the spectra on the detector might be possible but... no success, requires perfectly known :

> PSF maps
> Wavelength maps
> True stellar template

Still get correlated flux measurements if the spectra is to be analyzed.

Cross dispersion using wavelength sensitive pixels

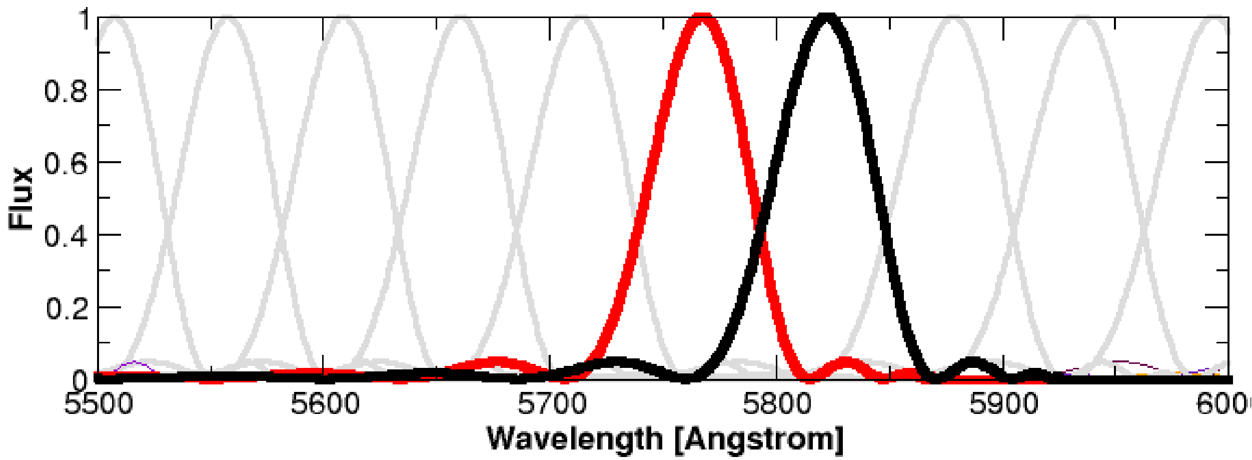
Image credits : Ulrike Lemke

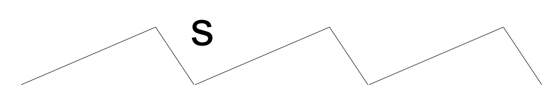


We only need to assign a photon to a diffraction order

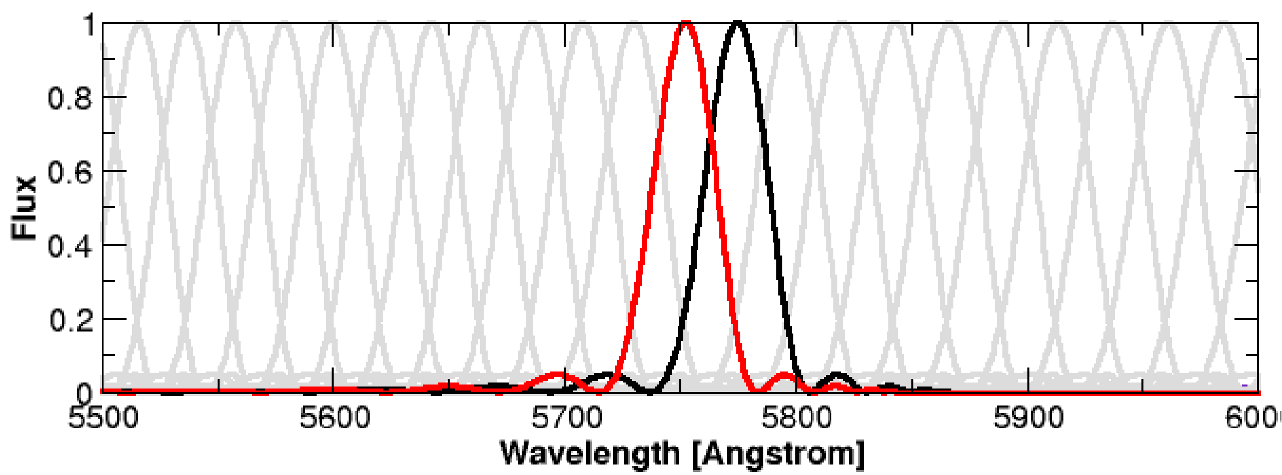
Feasibility using current technology

Grove size is the only key parameter for the echelle grating

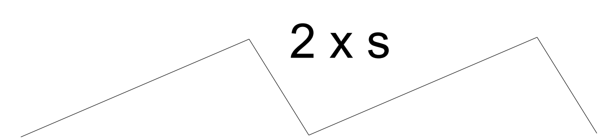




HARPS → 31.6 gr/mm



Coarser grating



16 gr/mm

Packs more orders → less spaxels needed → higher resolution by the post-disperser needed

~also manufactured by Ricardson Gratings

Feasibility using current technology

ARCONS: A 2024 PIXEL OPTICAL THROUGH NEAR-IR CRYOGENIC IMAGING SPECTROPHOTOMETER

Mazin et al. 2013 PASP

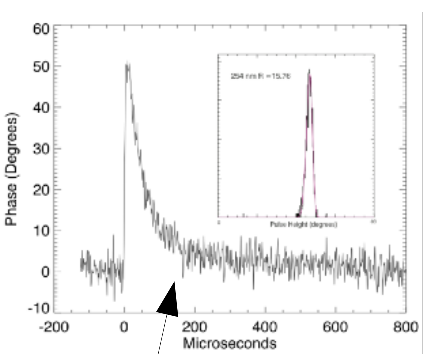
MKIDS

Microwave Kinetic Inductance Detectors

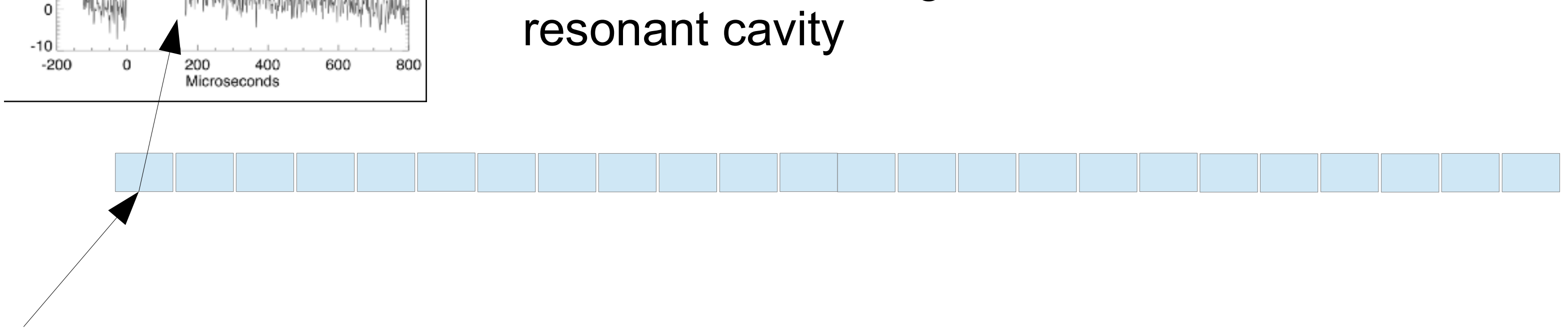
Status : 10 000 element array being produced (Ben Mazin Lab, UCSB)

The typical spectral resolution for the MKIDs used in ARCONS is R∼10 at 4000 Å declining linearly with in-

The achieved spectral resolution is drastically below the theoretical limit for a 100 mK operating temperature of R=100 at 4000 Å (Mazin et al. 2012). We believe the



Measure phase of the microwaves coming from a resonant cavity



Feasibility using current technology

ARCONS: A 2024 PIXEL OPTICAL THROUGH NEAR-IR CRYOGENIC IMAGING SPECTROPHOTOMETER

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MKIDS

Microwave Kinetic Inductance Detectors

Status : 10 000 element array produced and tested on-sky (Ben Mazin, UCSB)

The typical spectral resolution for the MKIDs used in ARCONS is $R \sim 10$ at 4000 Å declining linearly with in-

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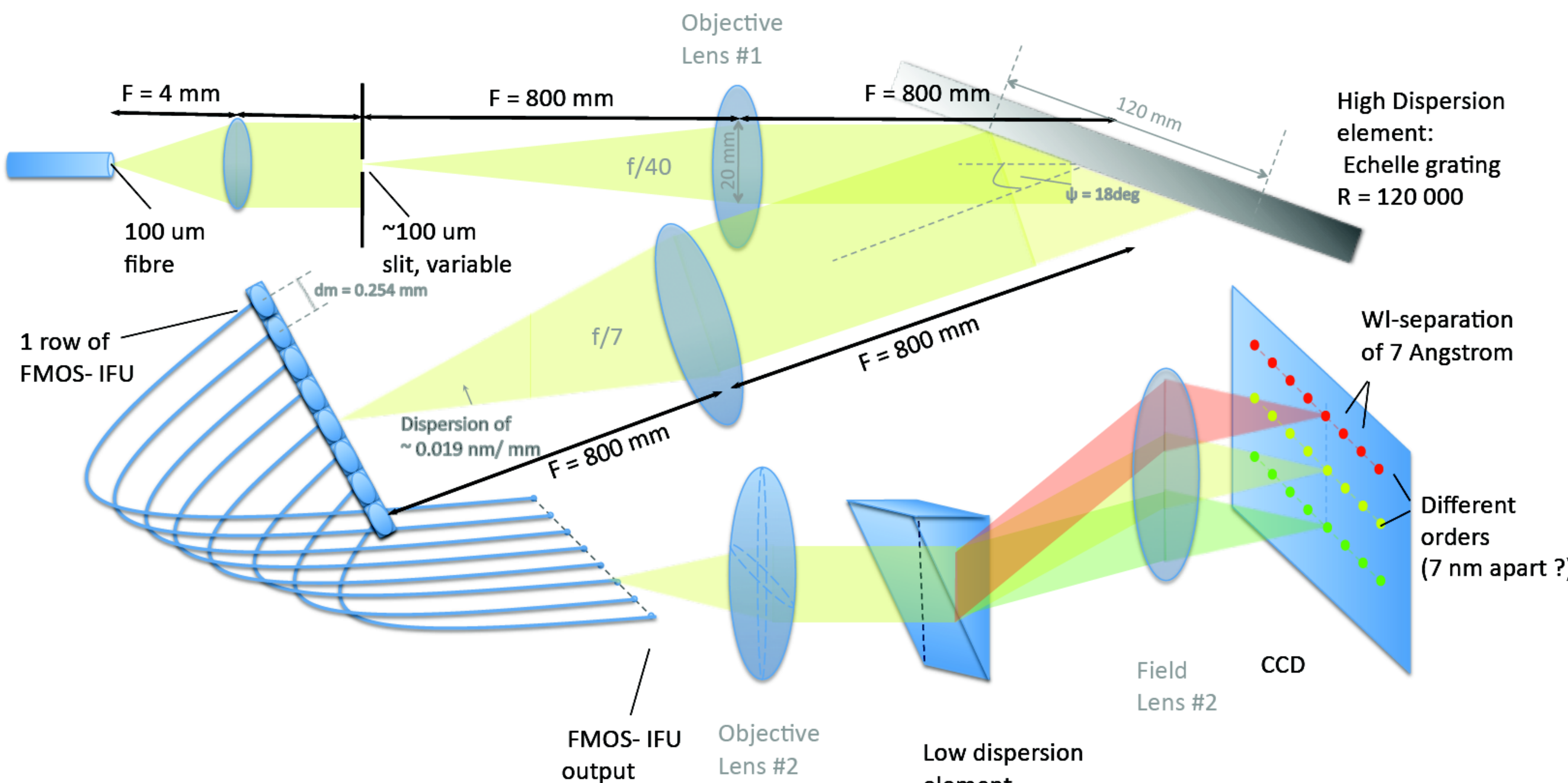
Theoretically limited to order sorting of 40 A

3800-6800 A → 75 orders

HARPS 72 orders x 4096 pixels

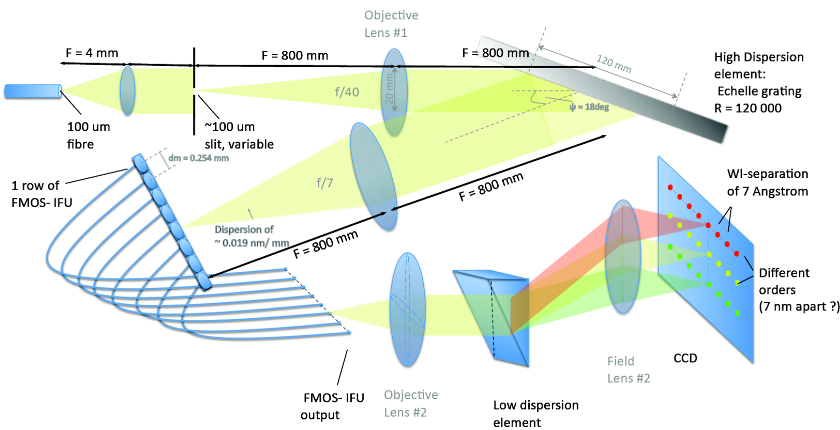
Feasibility using current technology



Use IFU technology?

Image credits : Ulrike Lemke

Feasibility using current technology



VIRUS: a massively-replicated IFU spectrograph for HET

Gary J. Hill[a*], Phillip J. MacQueen[a], Carlos Tejada[b], Francisco J. Cobos[b], Povilas Palunas[a], Karl Gebhardt[c], and Niv Drory[c]

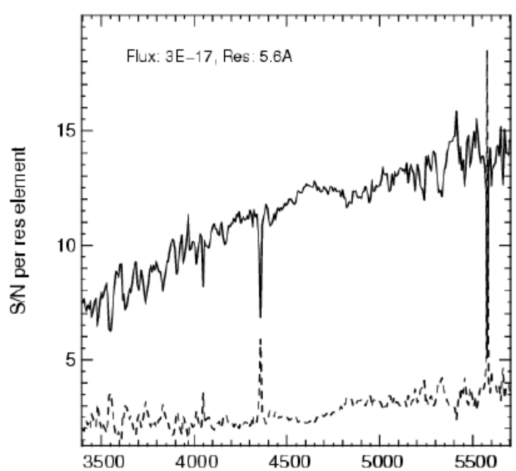
[a]McDonald Observatory, University of Texas at Austin, 1 University Station, C1402, Austin, TX 78712 -0259, USA

[b]Instituto de Astronomía de la Universidad Nacional Autónoma de México, Apdo. Postal 70-264, 04510 México

[c]Department of Astronomy, University of Texas at Austin, 1 University Station, C1402, Austin, TX 78712 -0259, USA

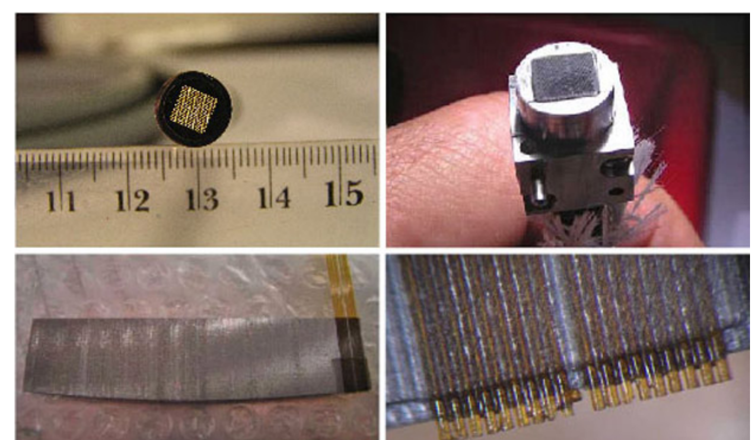
ABSTRACT

We investigate the role of industrial replication in the construction of the next generation of spectrographs for large telescopes. In this paradigm, a simple base spectrograph unit is replicated to provide multiplex advantage, while the engineering costs are amortized over many copies. We argue that this is a cost-effective approach when compared to traditional spectrograph design, where each instrument is essentially a one-off prototype with heavy expenditure on engineering effort. As an example of massive replication, we present the design of, and the science drivers for, the Visible IFU Replicable Ultra-cheap Spectrograph (VIRUS). This instrument is made up of 132 individually small and



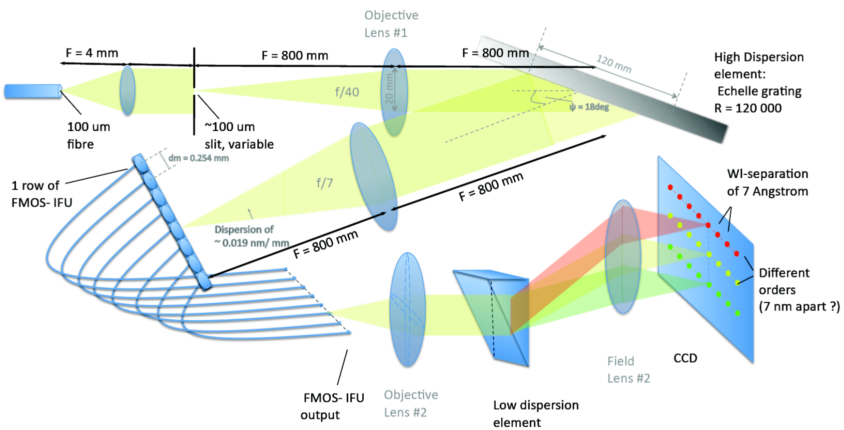
VIRUS HET →500$ per pixel

R~1000

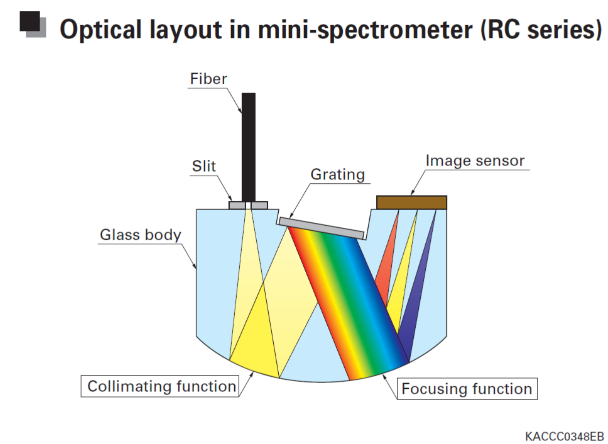


http://hetdex.org/hetdex/virus.php

Feasibility using current technology



Minispectrometers

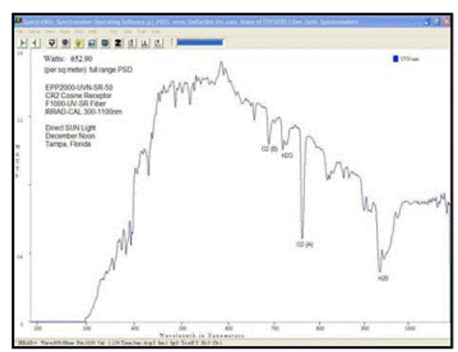


Optical

Hammamatsu catalog

Mini-spectrometers

StellarNet - GreenWave (2000 $/unit)



UVN spectra of sunlight

Satisfy all design requirements!

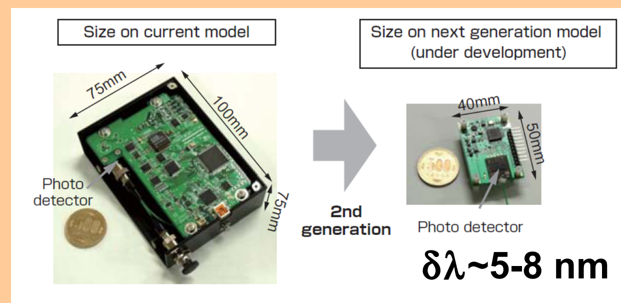
Range 350-1150 nm
Resolution for a 50micron fiber : 16 A →
500 echelle orders
http://www.stellarnet.us/p

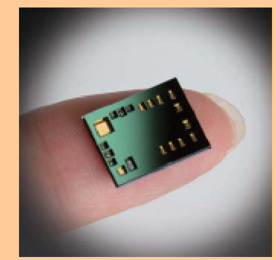
Feasibility using current technology

Near infrared

MEMS

Micro-Electro-Mechanical Systems





MEMS-nIR
Fourier Transform Spectrograph
HAMAMATSU
(2000 $/unit)

Also useful for nIR integral field spectroscopy

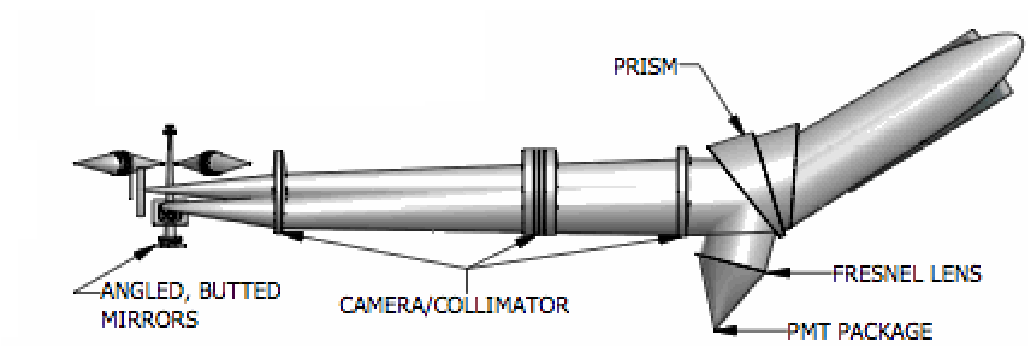
Same, but with InGaAs 1D array

10 000 EUR/unit

http://www.stellarnet.us/pricelist.htm

Feasibility using current technology

Very simple optical layout



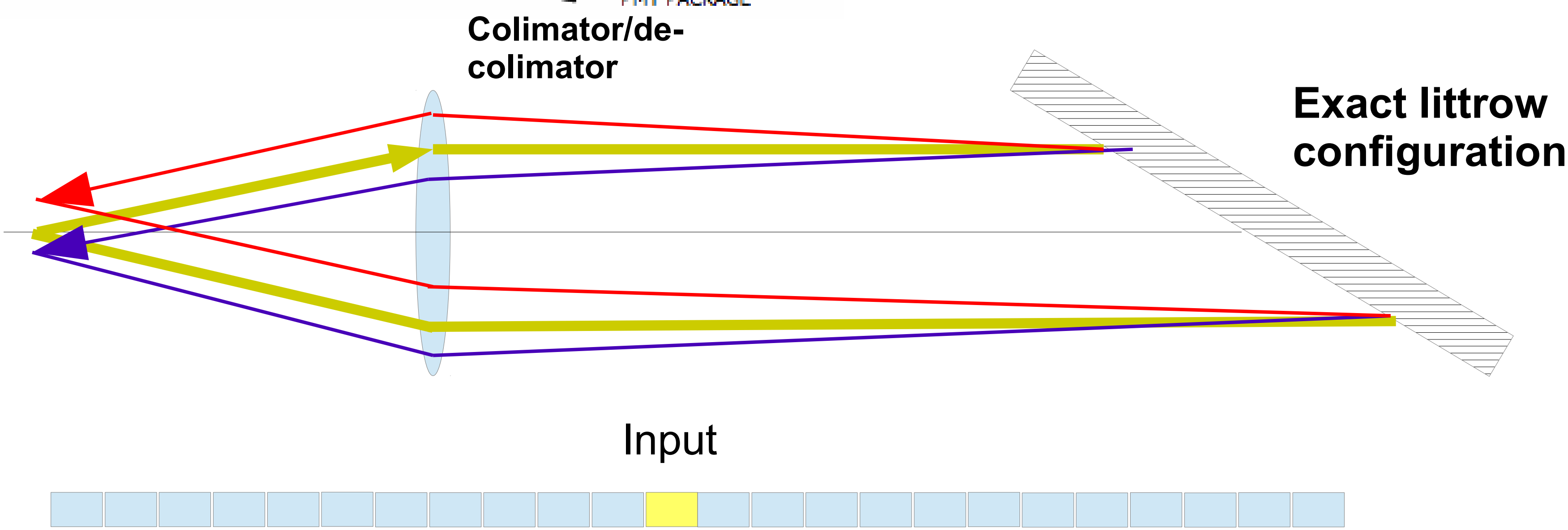
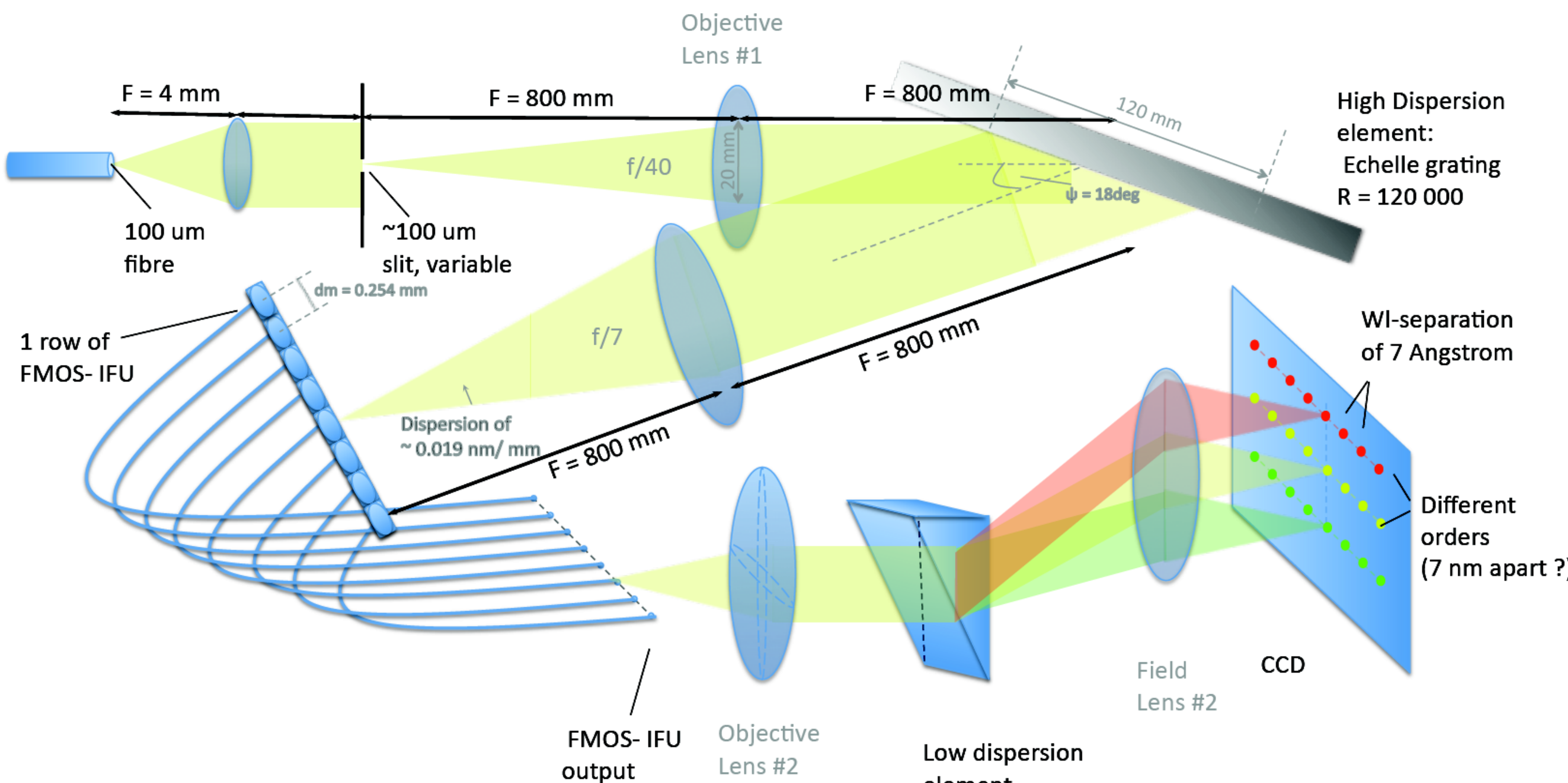


Image credits : Ulrike Lemke

Feasibility using current technology



Trade-offs over classic design

The promise

Very simple stabilized optics
No optical aberrations, order tilting or spectral line tilts
Detector decoupled from stabilized body
Detectors upgradeable at any time
No stability requirements for detectors
Very fast read-out, minimal read-out noise
Off-the-shelf technology
Minimal stray-light
Ultra-broad wavelength range

The challenges

2000 EUR x 4000 → 8 MEUR
Fabrication of ultrastable 1D fiber coupling
Performance of mini-spectrometers unknown

Unsolved issues

Large echelle grating → Slicing? Reformating?
Input stabilitzation : scrambling

Funding proposals being submitted, collaborations are VERY WELCOME

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Ask Ulrike Lemke,
ulrike.lemke@phys.uni-goettingen.de
Fiber input feed and detailed optic designs

The challenges

2000 EUR x 4000 → 8 MEUR
Fabrication of ultrastable 1D fiber coupling
Performance of mini-spectrometers unknown

Guillem Anglada-Escude
guillem.anglada@gmail.com
Overall instrument concept and echelle design

Unsolved issues

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Input stabilitzation : scrambling

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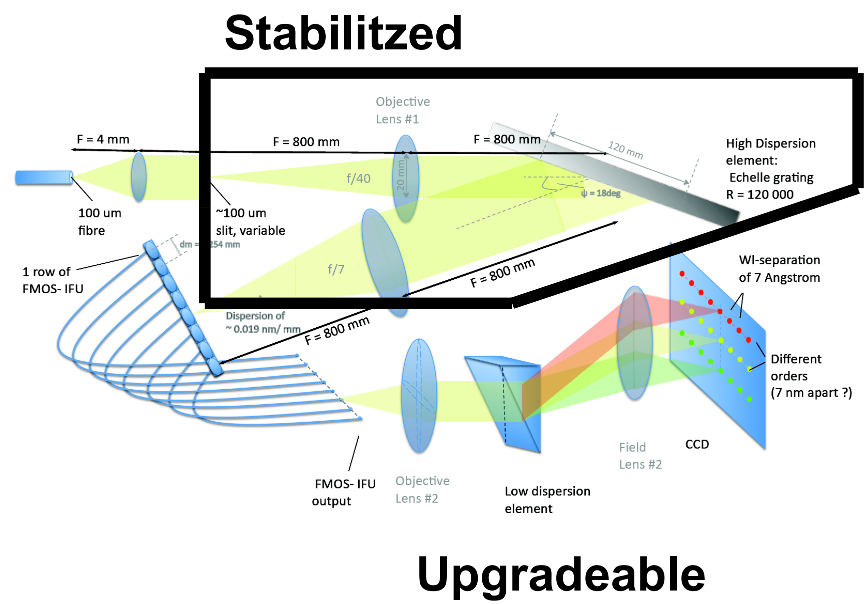
Summary

- The post-multiplexed spectrometer can be built today
- Many advantages over classic echelle design
- All technology available. Very few key elements need testing → mini-spectrometers, 1D fiber array couplings
- Upgradeable detectors
- **Project on-hold, funding pending**



Candidate technology for a optical+nIR ultra-stabilized ELT-HIRES spectrometer for the E-ELT?