HERMES,
a fibre-fed high-resolution spectrograph at the Mercator telescope

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La Palma, Spain

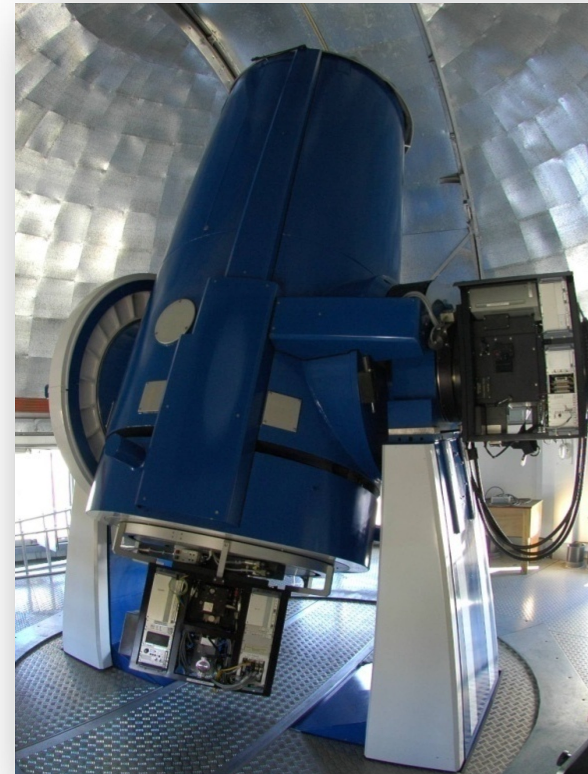
BINA meeting ROB
12/10/2017

Overview

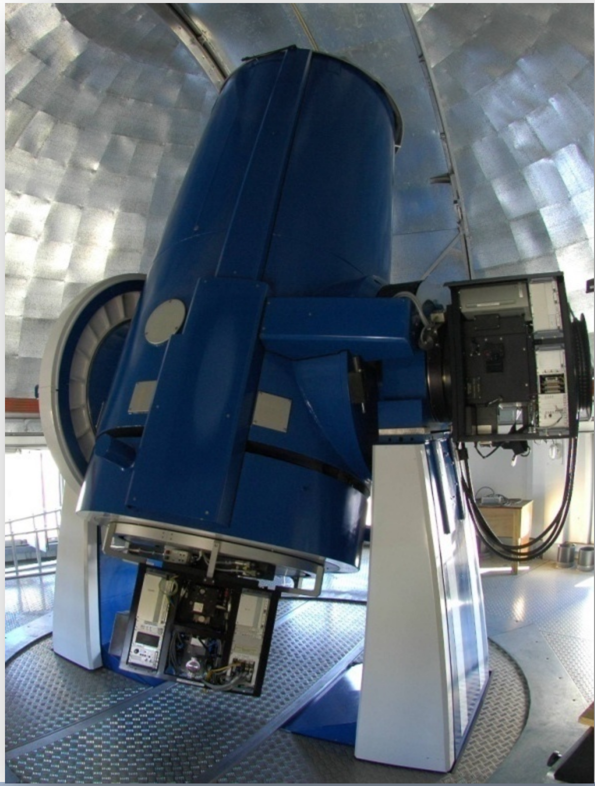
1. Mercator telescope
2. HERMES project
3. Spectrograph design
4. Spectrograph performance
5. Conclusions

The Mercator telescope

- Roque de los Muchachos Observatory, La Palma – Spain
- 1.2 m, F/12 (RC)
- Commissioned in 2001
- Operated by the Institute of Astronomy, KU Leuven Belgium
- Built in collaboration with Observatoire de Genève (Euler twin)
- Niche in telescope market:
    - Permanent and long-term availability
    - Flexible scheduling



The Mercator telescope



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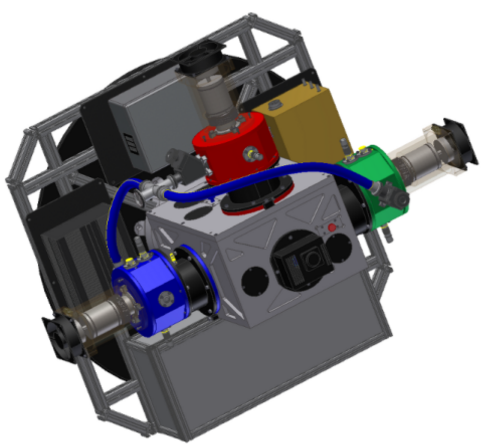
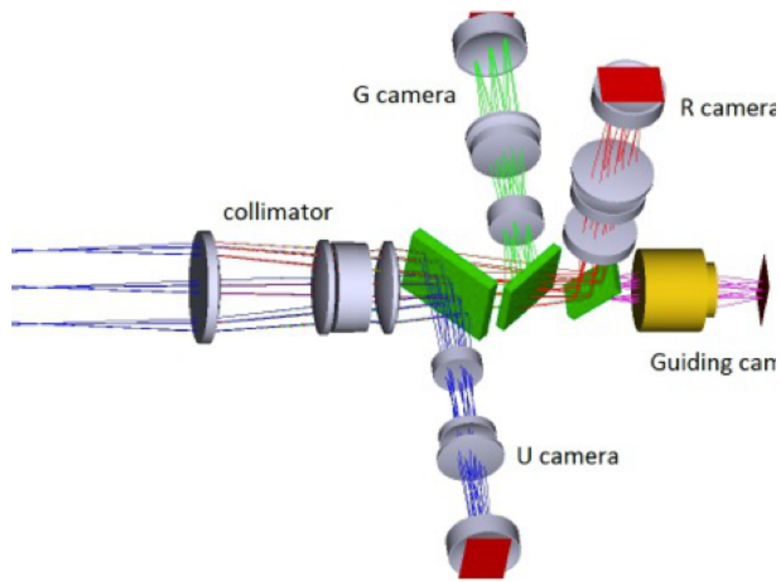
  - Flexible scheduling
- **2016 – 2017: New TCS commissioned**
- **Oct. 2017: Mirrors re-aluminised**

Mercator instrumentation

1. ~~P7-2000 2-channel photometer~~, decommissioned in 2008
2. ~~MEROPE imager:~~
   ~~2003 – 2012~~
   ~~6.5’ x 9’ FOV~~,
   decommissioned
   in 2013

3. HERMES HR spectrograph, commissioned in 2009
4. MAIA 3-channel imager: Fast photometry with large FT CCDs
   Simultaneous **u’**, **g’** & **r’**
   Commissioned in 2013
   9.4 x 14.1 arcmin^2 FOV





The HERMES project

Time series in radial velocities and in individual spectral lines, high SNR, high resolution

=

HERMES: **H**igh-**E**fficiency & high-**R**esolution **M**ercator **E**chelle **S**pectrograph

Requirements:

- High resolution: R = λ/Δλ > 80000
- High stability: < 5 m/s
- Small telescope ⇨ High efficiency!
  - High throughput
  - Broad wavelength coverage in single exposure (380 – 900 nm)
  - Efficient exploitation

    Pooling of observations from a priority driven queue (MESA scheduling software, Merges et al. 2012)

    All HERMES consortium nights are 80% scheduled from pool
- Robust and flexible operation

The HERMES project

- Project Kick-off: January 2005
- First light: November 2008
- Start of science observations: April 2009
- Instrument consortium:

IvS, KU Leuven
H. Van Winckel
G. Raskin

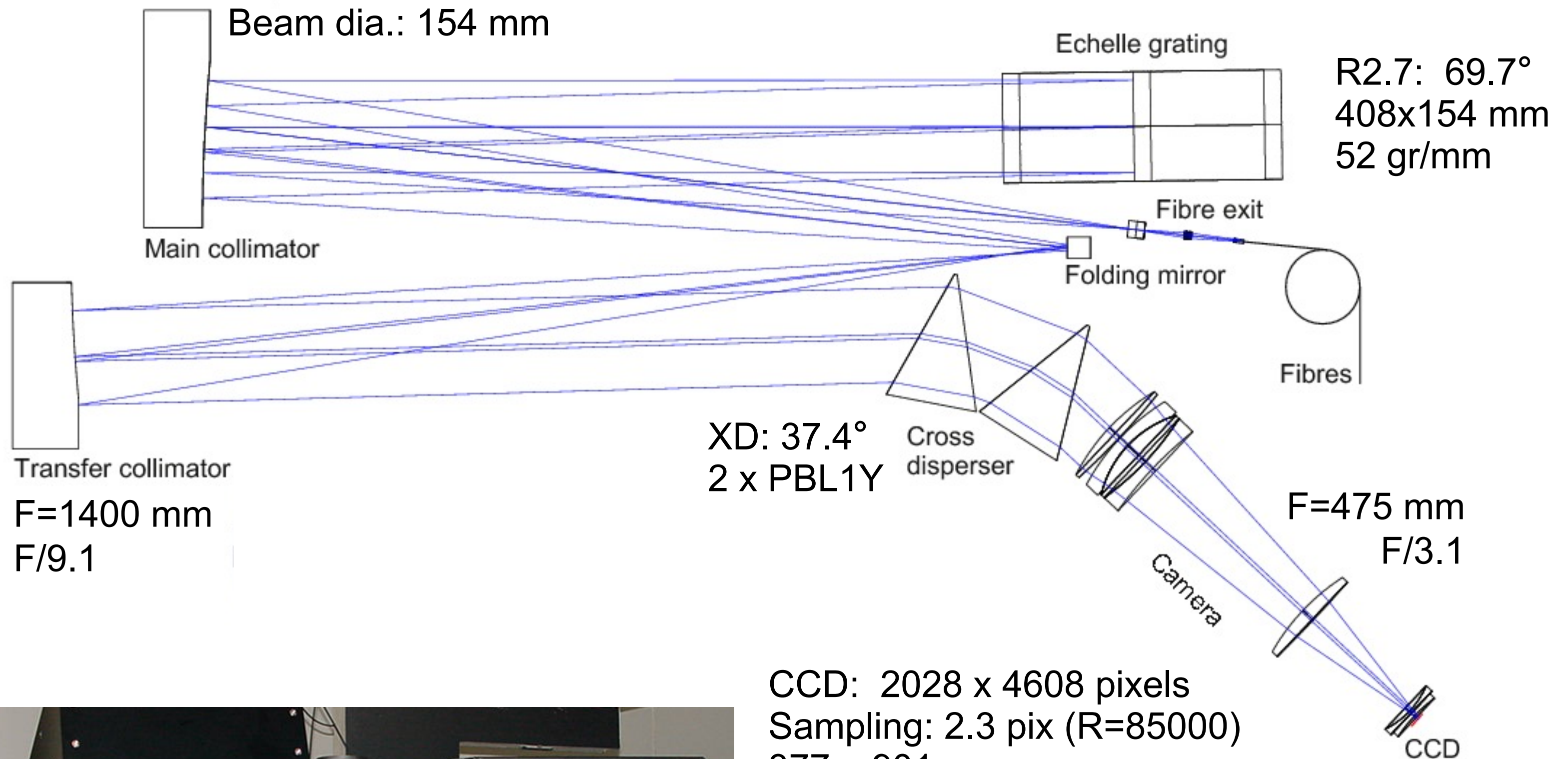
ULB
A. Jorissen

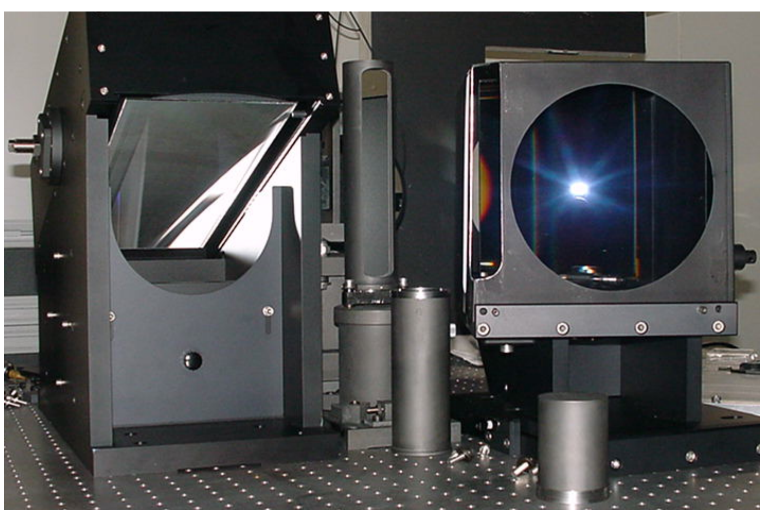
ROB
H. Hensberge

Thüringer Landessternwarte
H. Lehmann

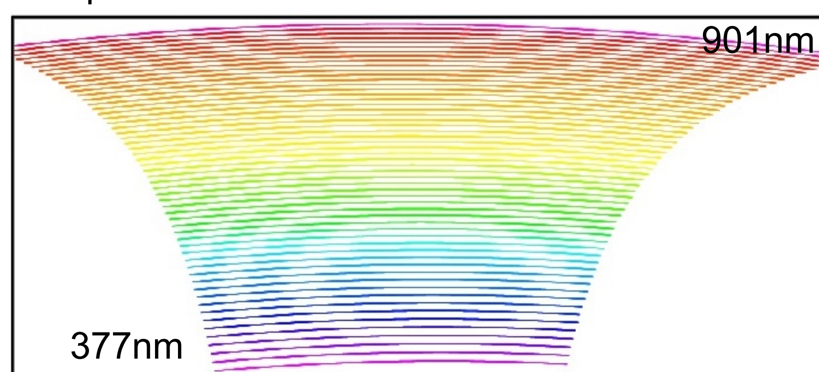
Observatoire de Genève

HERMES white-pupil layout





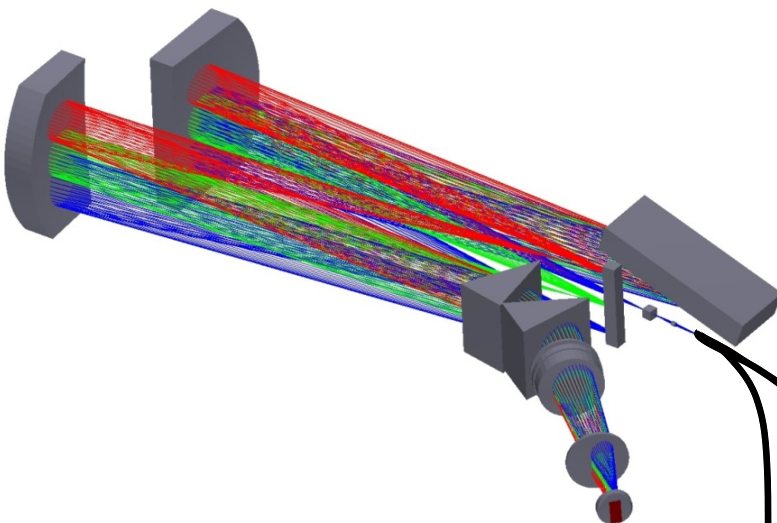
CCD: 2028 x 4608 pixels
Sampling: 2.3 pix (R=85000)
377 – 901 nm
55 spectral orders



Observing modes / optical fibres

2 Observing modes:

- **HRF**: high resolution (R=85000) & high efficiency, with **image slicer**
- **LRF**: low(er) resolution (R=63000), no slicer, **Scrambler** for high illumination stability (70% eff.), interlaced with wavelength reference fibre (WRF)

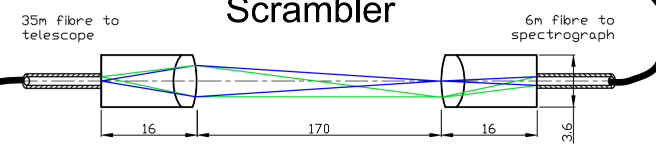


WRF: 60 µm

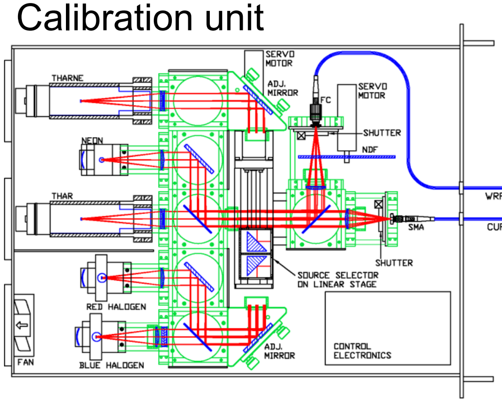
HRF: 80 µm
2.5 arcsec

LRF: 60 µm
2.15 arcsec

Scrambler



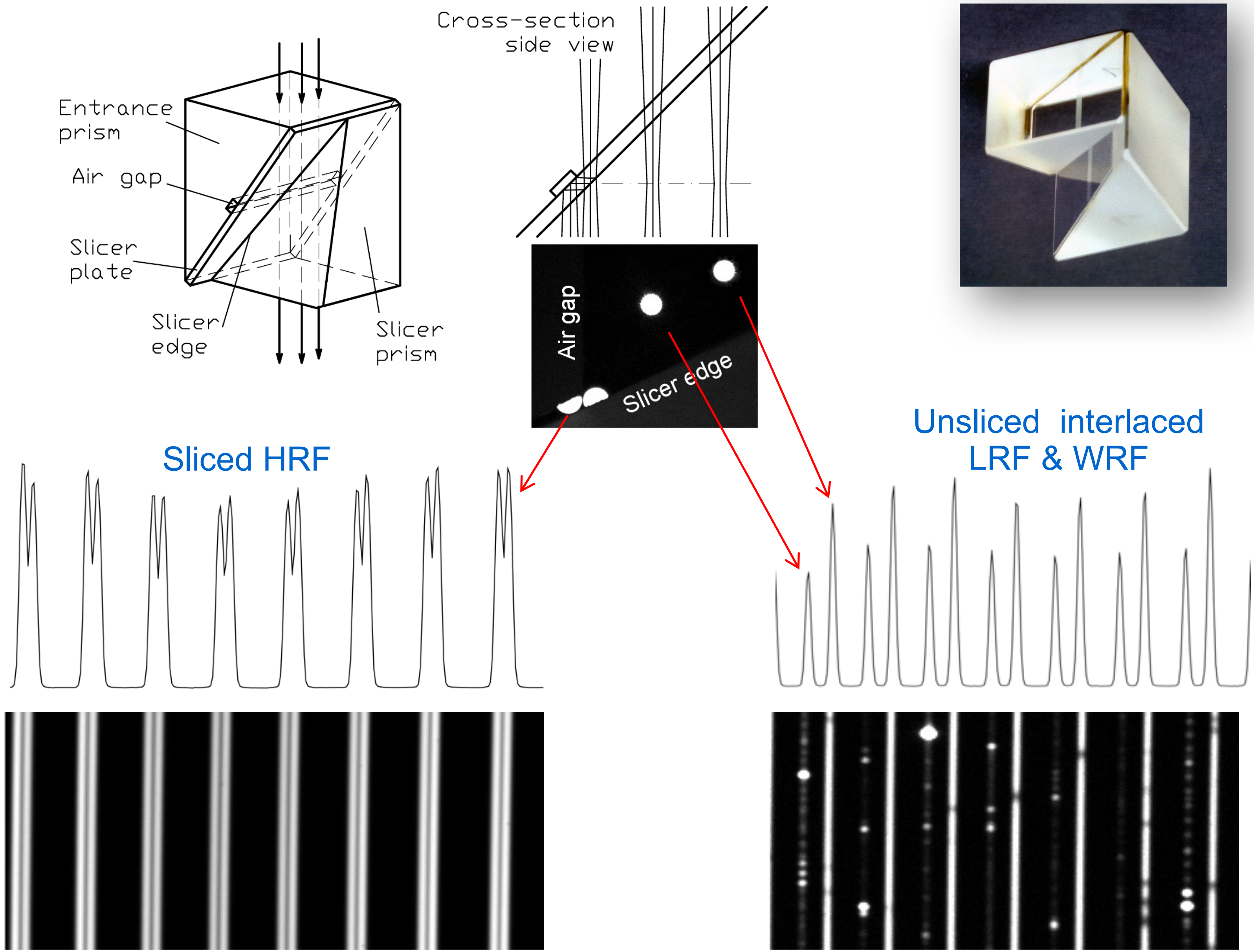
Calibration unit



CF: 300 µm

Telescope interface

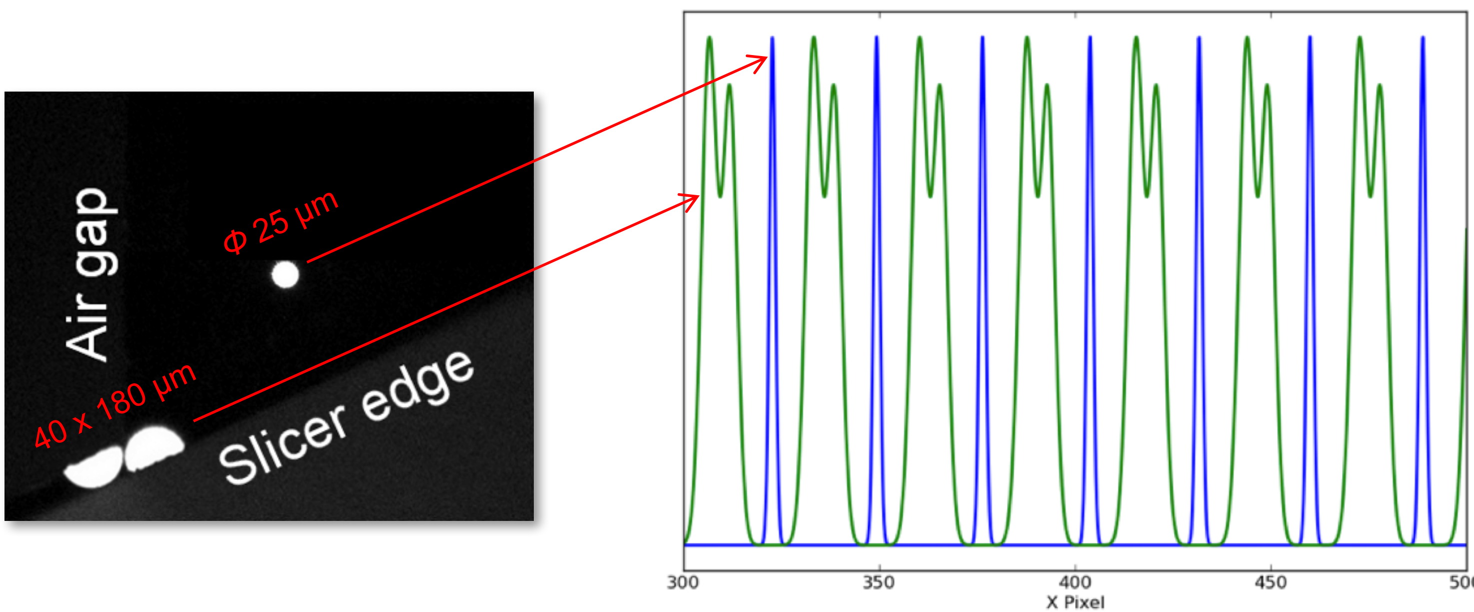
Fibre link: image slicer



Fibre link: upgrade

Use sliced HRF (highest efficiency, highest resolution) in combination with simultaneous wavelength reference:

- Replace 60-µm WRF with narrow unsliced 25-µm or single-mode fibre that fits HRF inter-order space
- Use octagonal fibre for better scrambling of HRF
- Increased throughput (lower FRD for octagonal fibres) ?



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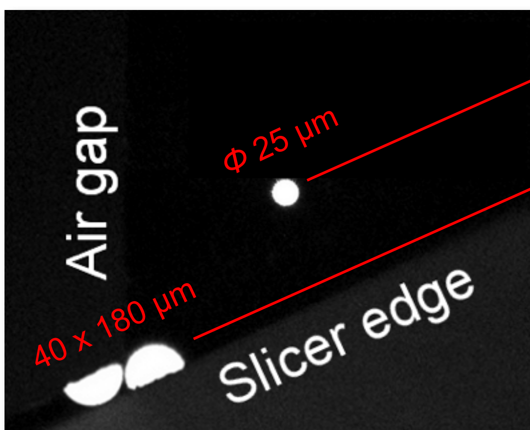
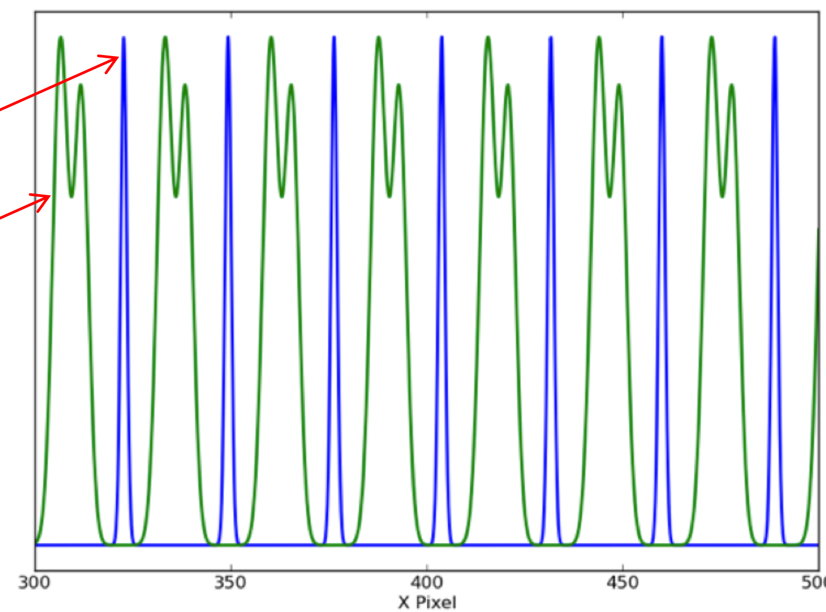
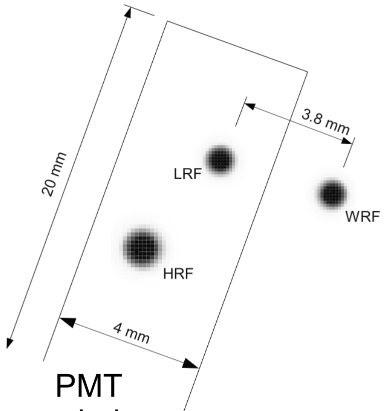
Commissioning planned early 2018

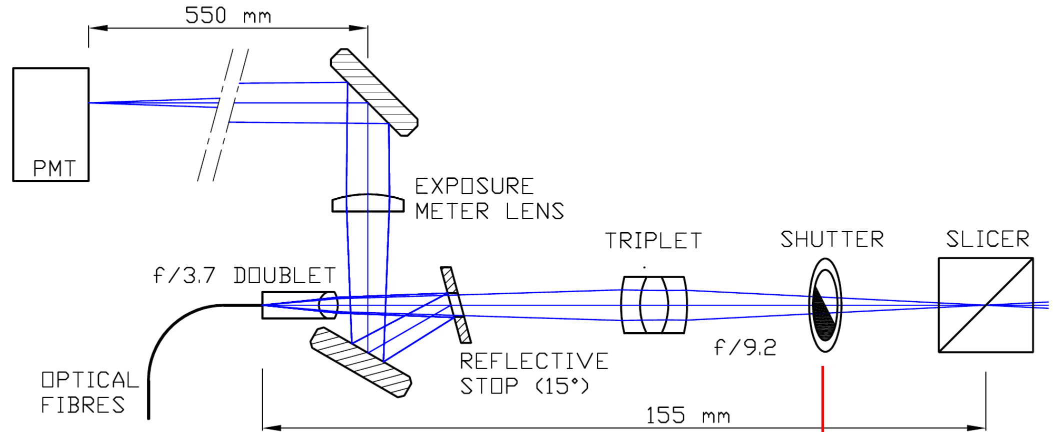


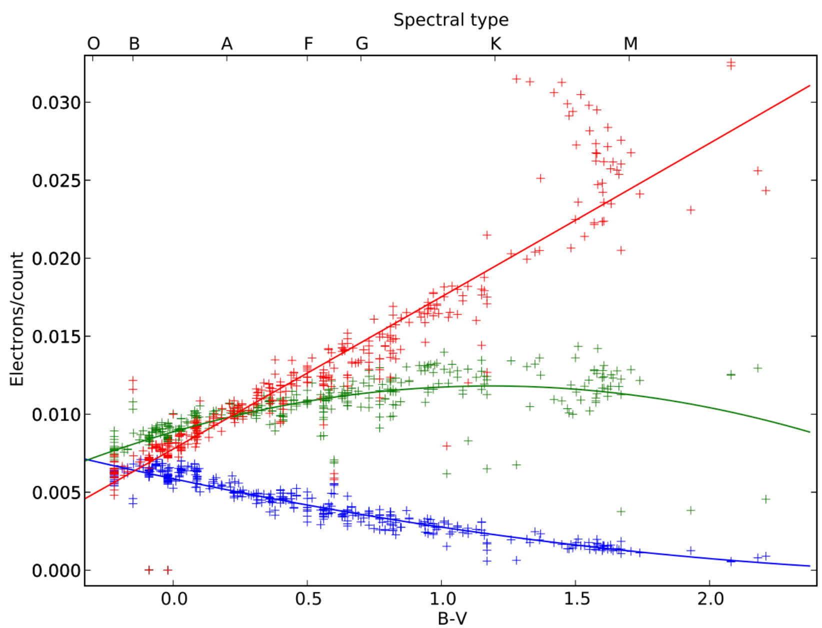


Fibre exit optics / exposure meter

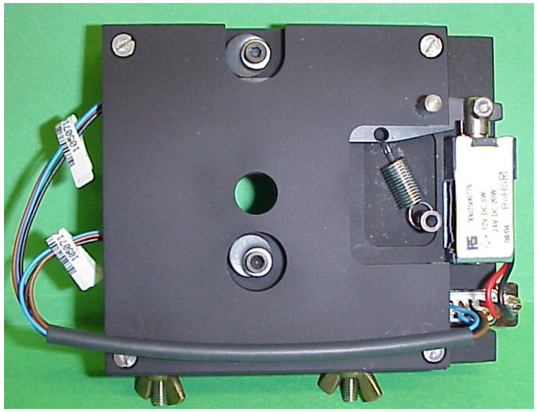


PMT window





CCD – PMT calibration


Compact shutter

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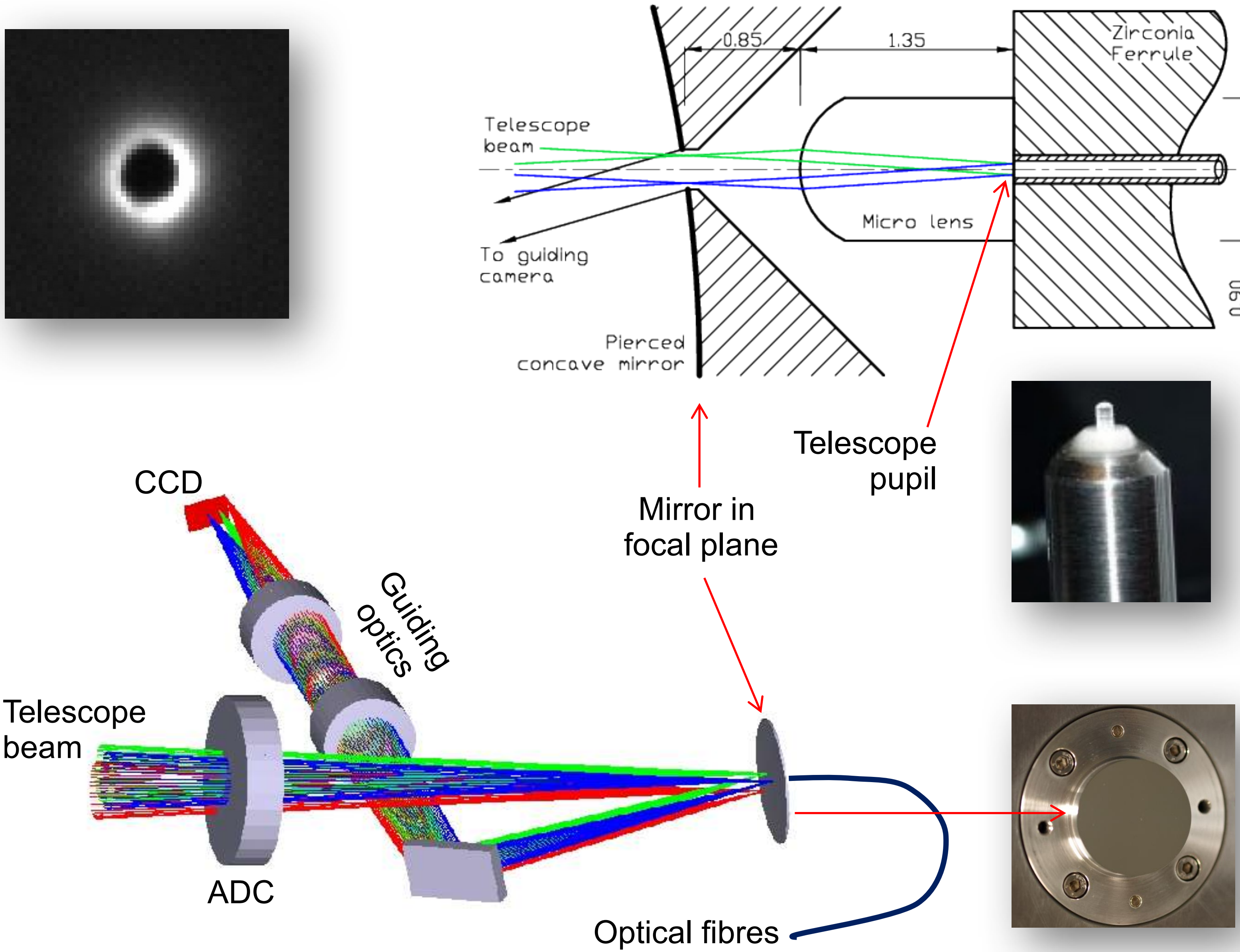
- HERMES project
- Spectrograph design
- Spectrograph performance
- Conclusions

Fibre optics, guiding & acquisition



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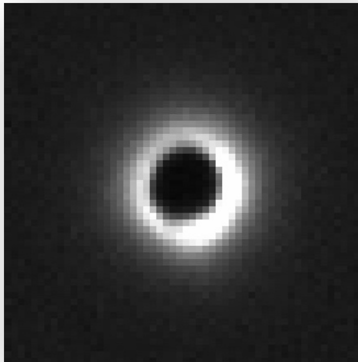
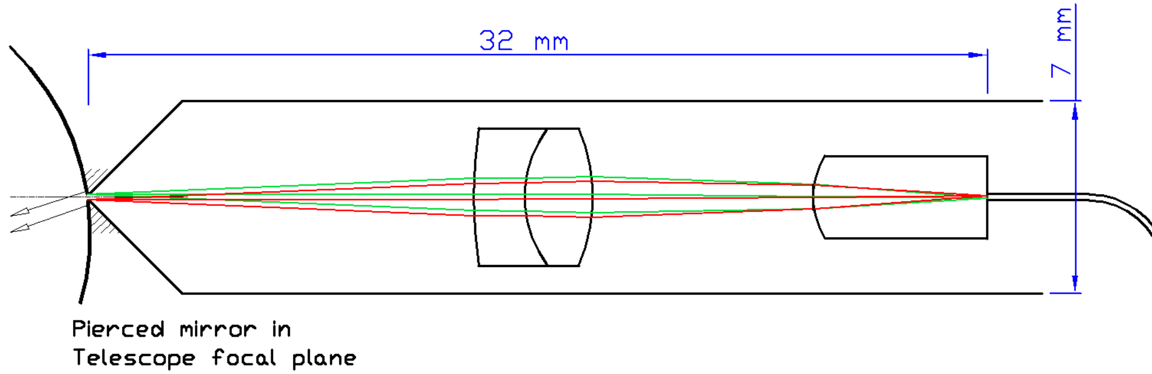
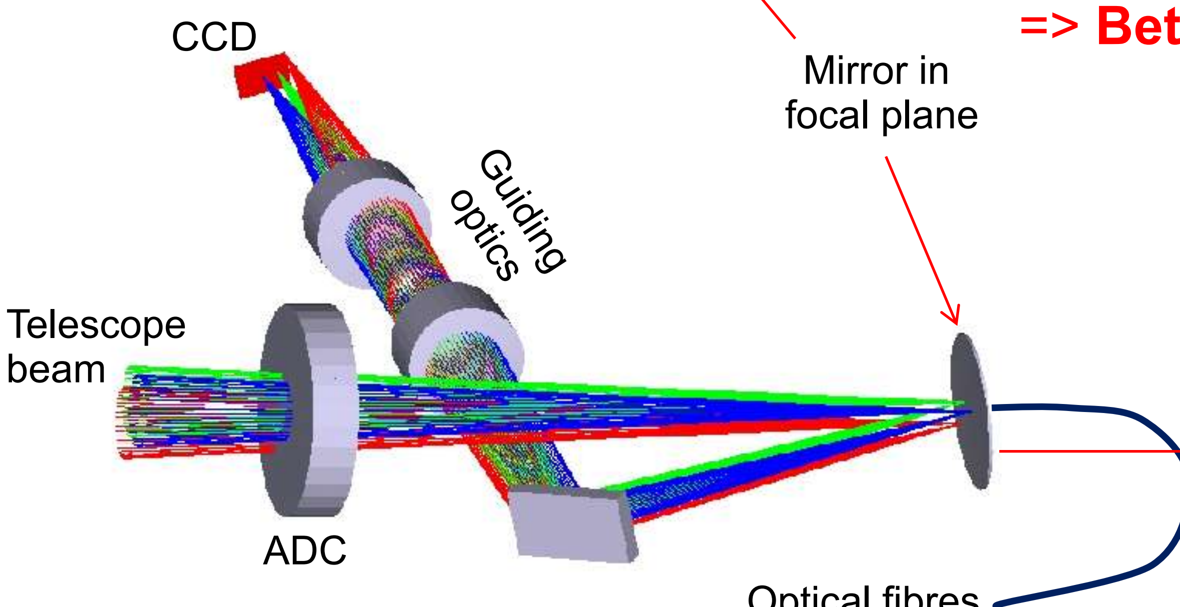
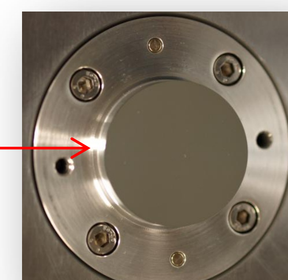


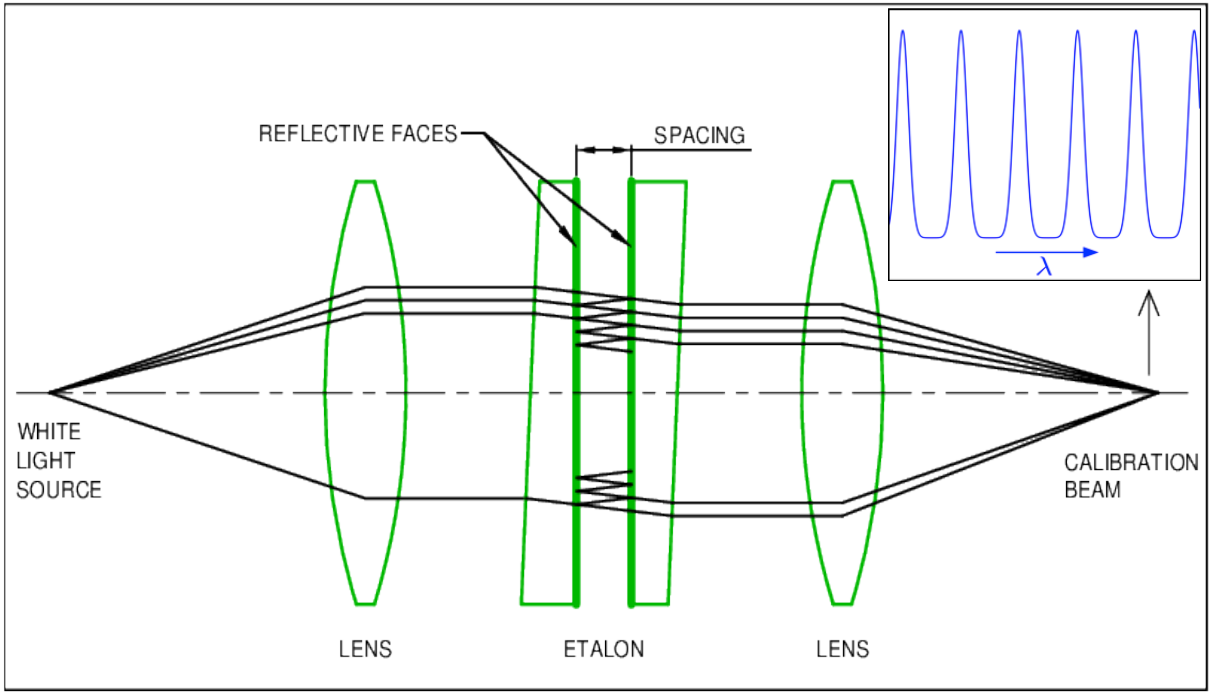


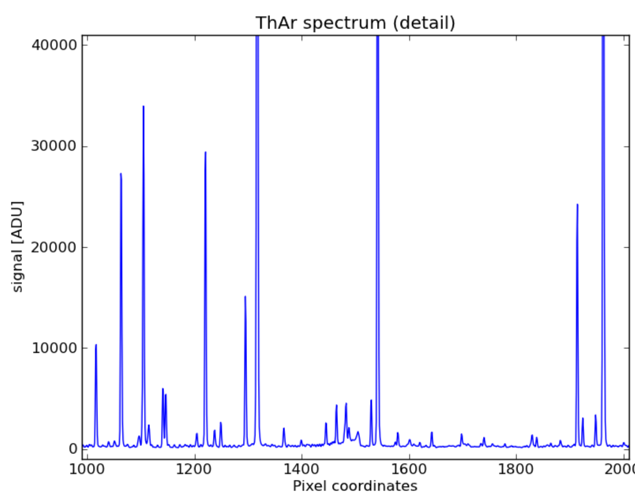
Star image on fibre
Instead of pupil image
=> More complex optics
=> **Better stability**

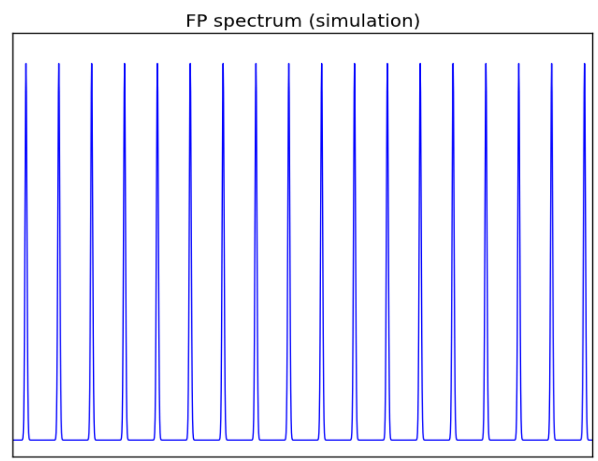




Fabry-Perot etalon wavelength calibration







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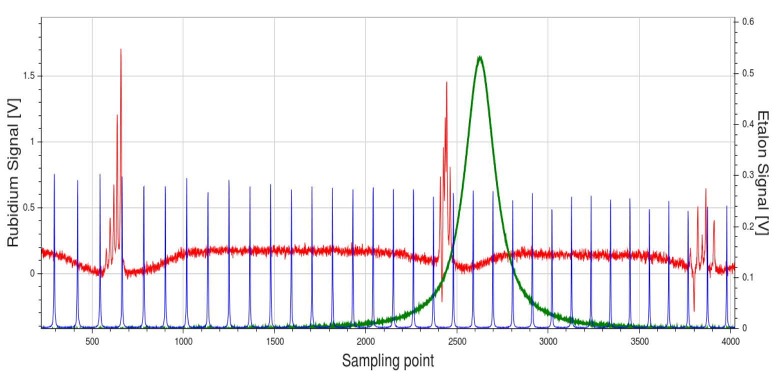
Fabry-Perot absolute stability

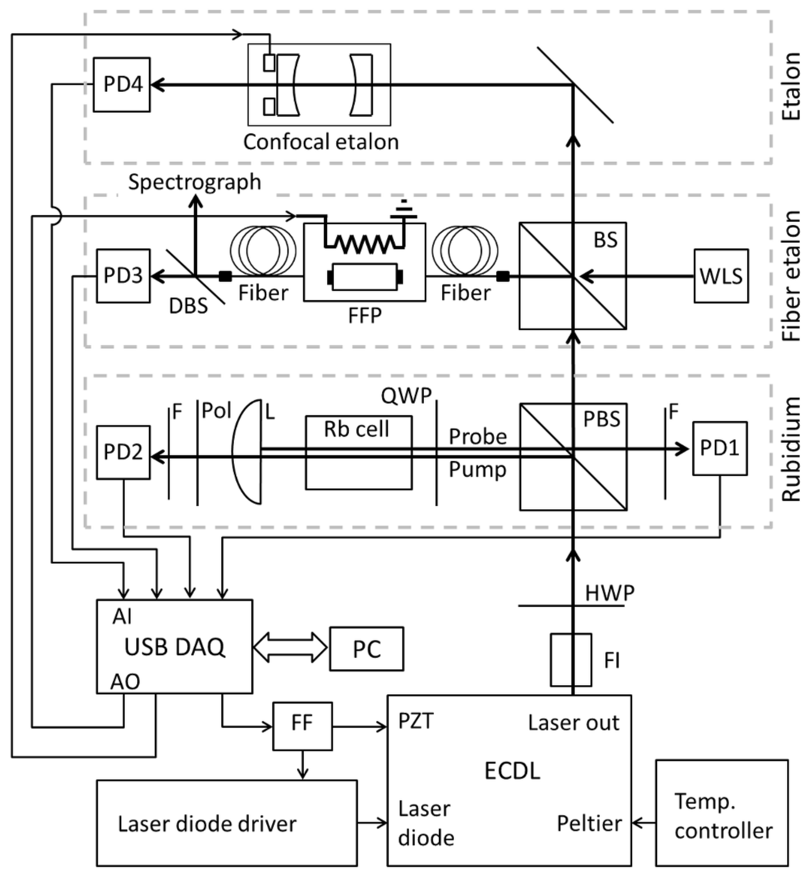
Fabry-Perot spectrum drifts with T and P

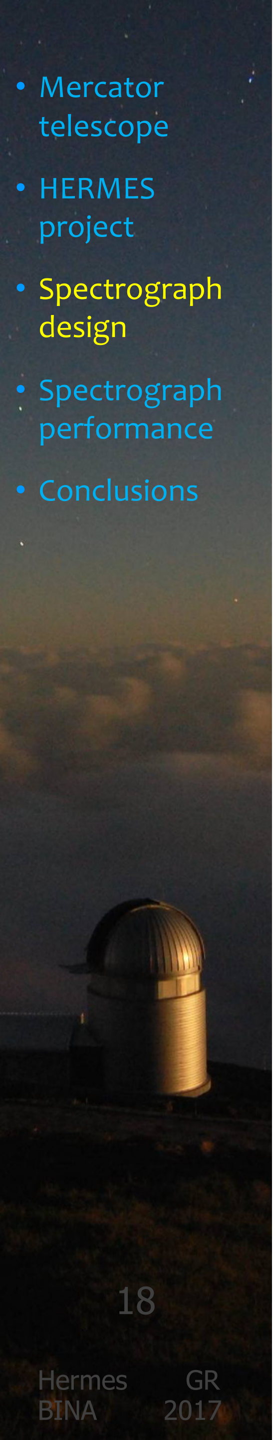
⇒ Install FP in temperature controlled vacuum vessel ?

⇒ Lock one FP transmission peak to a hyperfine atomic (Rb) transition through saturated absorption spectroscopy

- Poor man’s laser frequency comb
- Relative accuracy $< 10^{-10}$ (< 10 cm/s)
- PhD student starts next week
- Commissioning: 2020

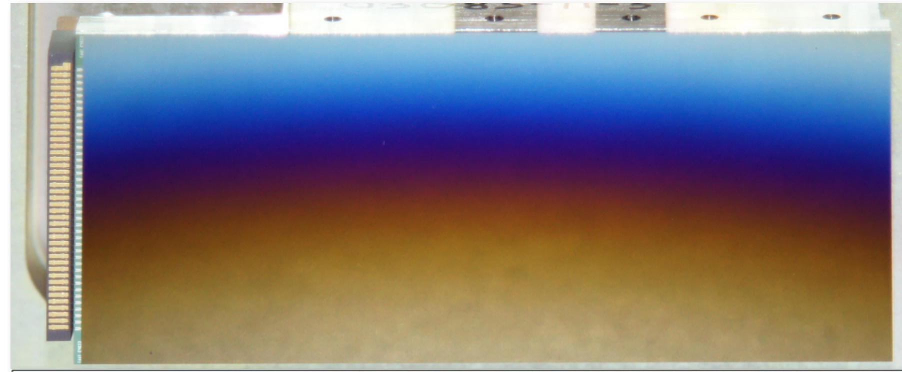


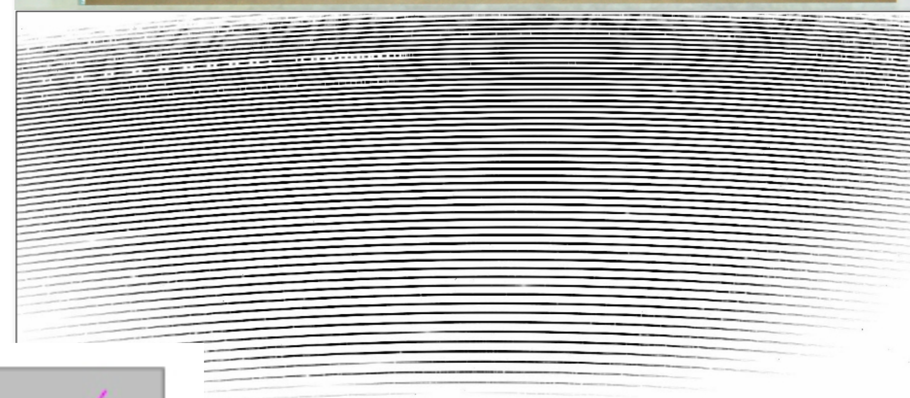


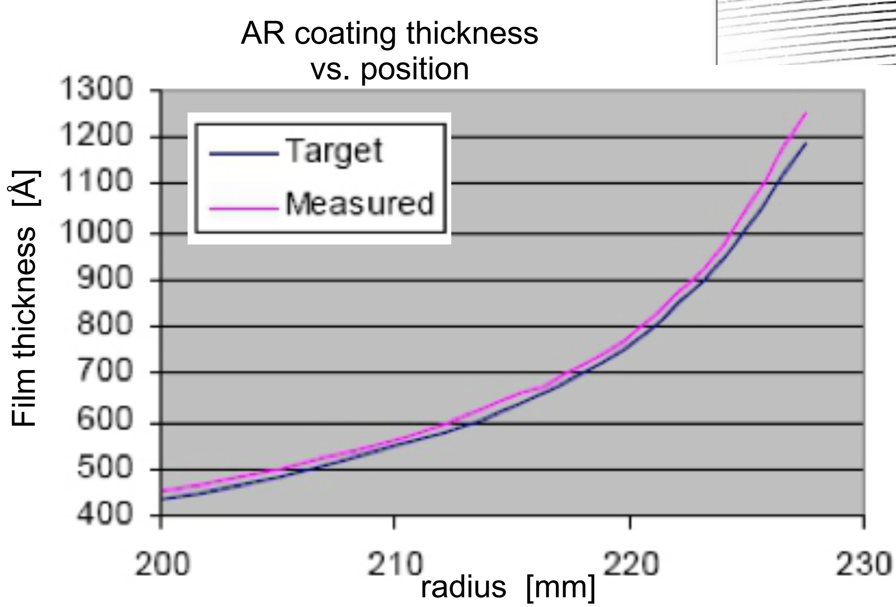


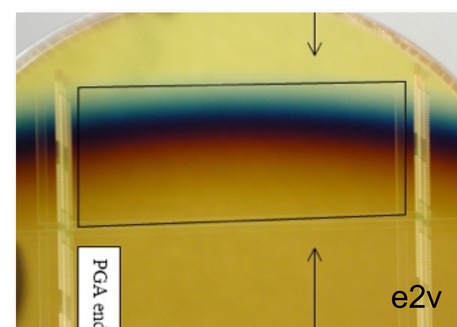
CCD with graded AR coating

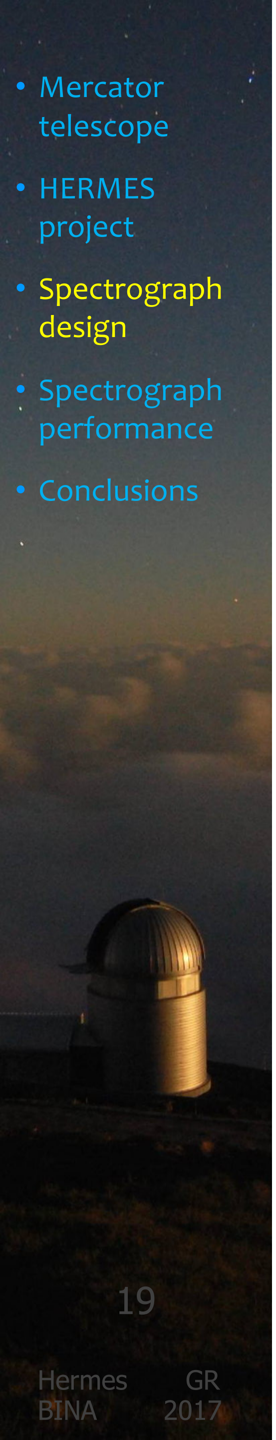
- HERMES was 1st HR spectrograph with graded AR coating (e2v)
- Coating thickness matched to local λ
- Follows curved echellogram











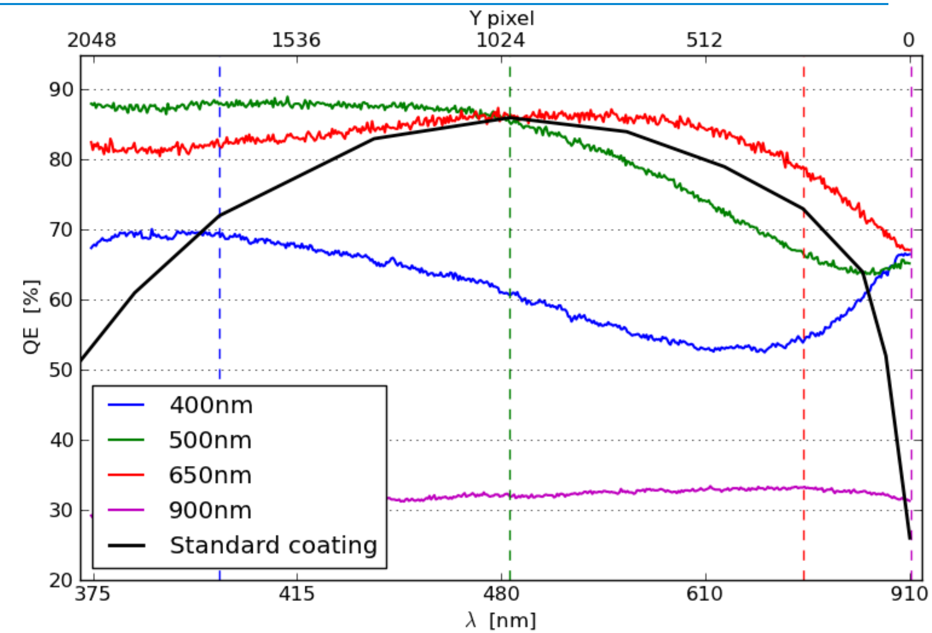
CCD with graded AR coating: does it work?

Increases QE ?

⇨ Not in the blue

Our engineering CCD with standard astro-broadband coating performs better at 380 – 400 nm

Why?

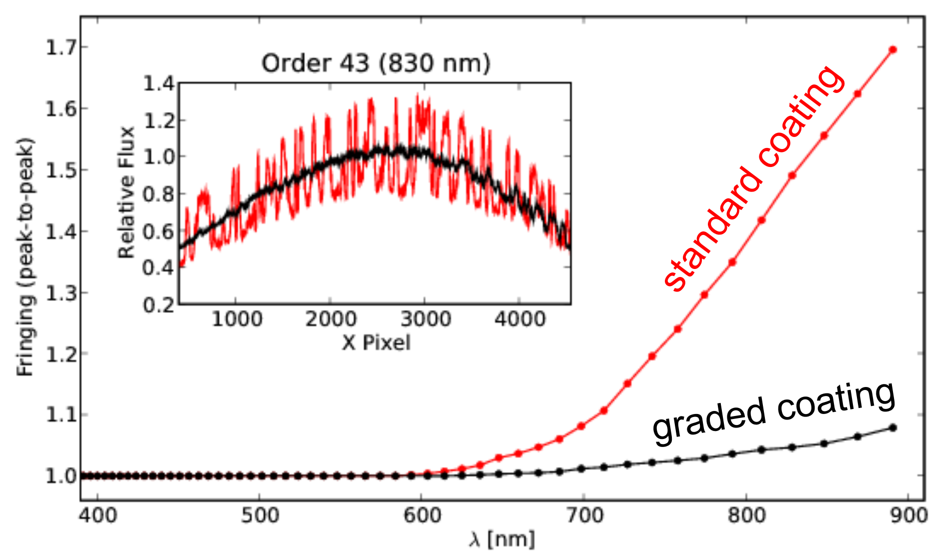


Reduces fringing ?

⇨ Yes

~ 9 times @ 900nm

Better than deep-depletion CCD with standard coating !



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CCD with graded AR coating: does it work?

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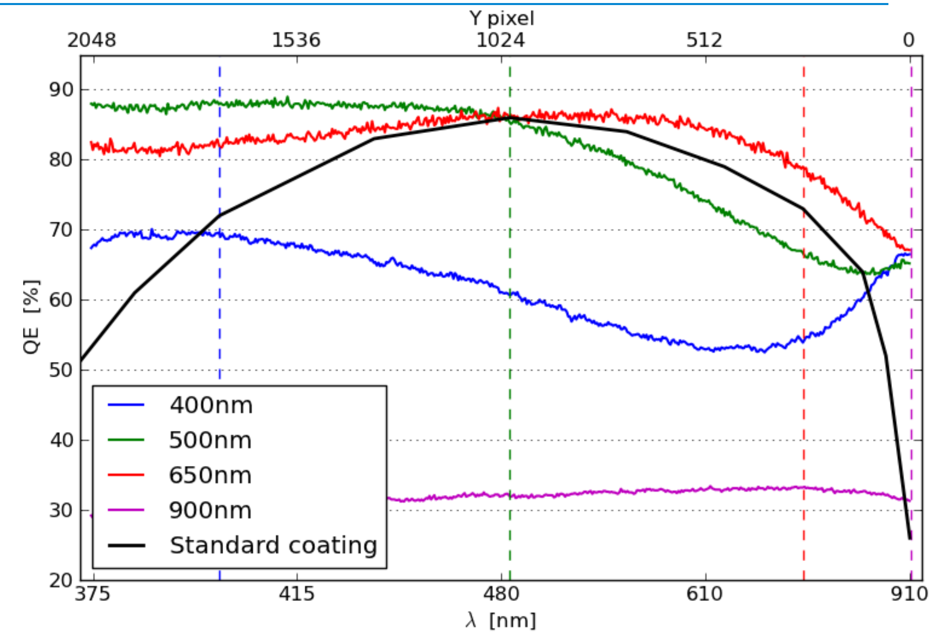
Better solution: Fringe-suppression CCD with standard AR coating

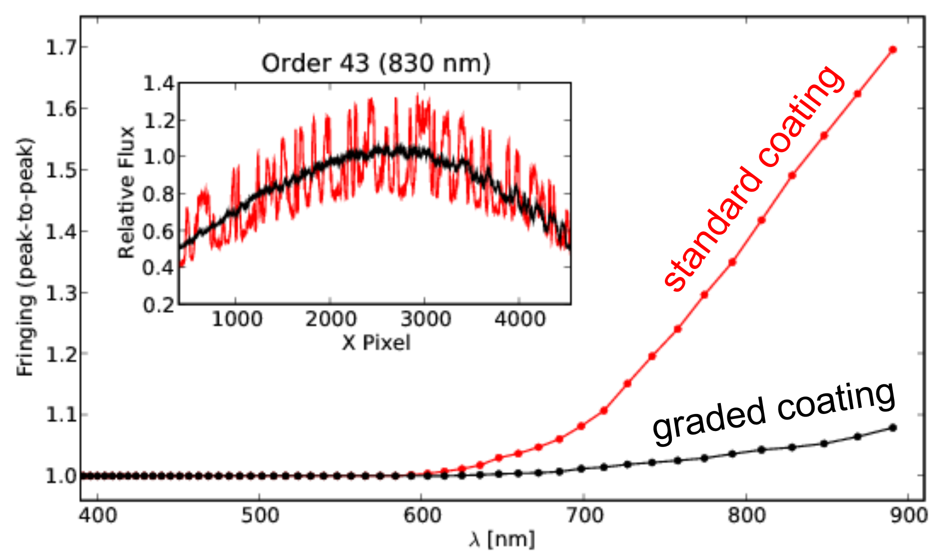
Reduces fringing ?

⇨ Yes

~ 9 times @ 900nm

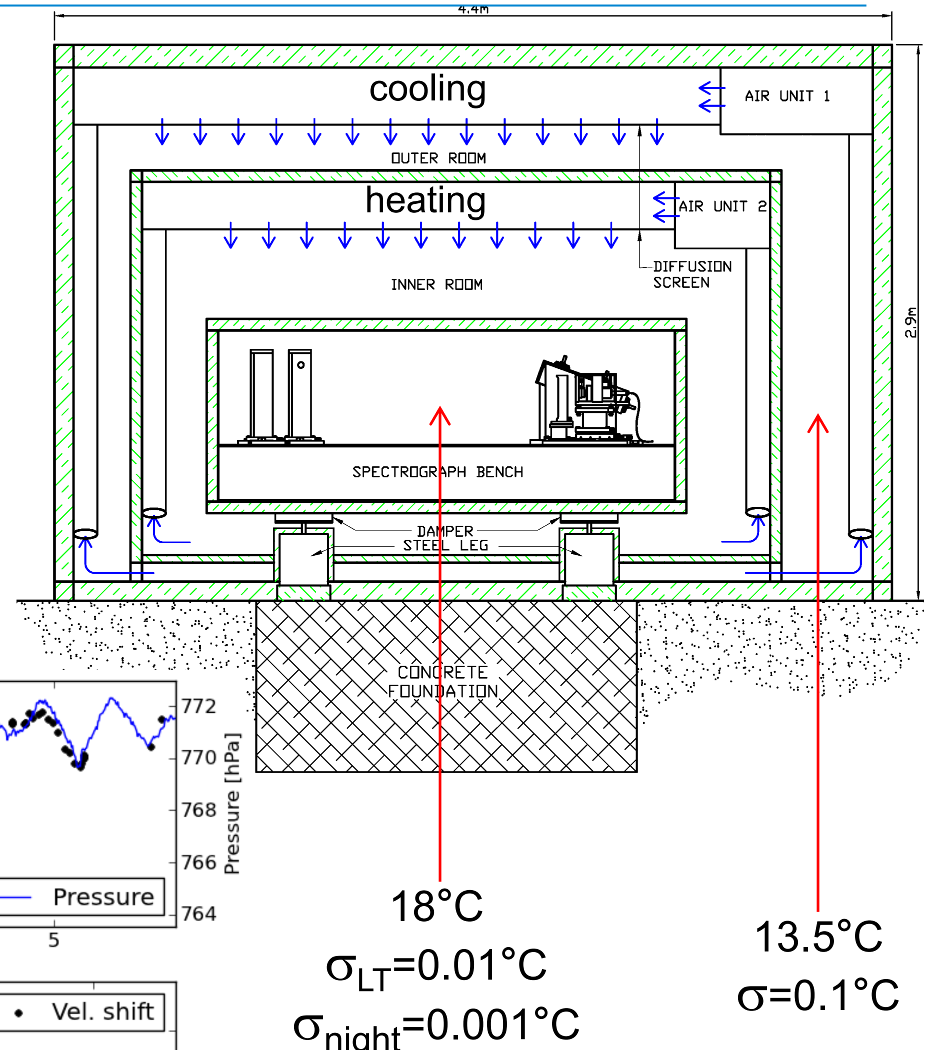
Better than deep-depletion CCD with standard coating !

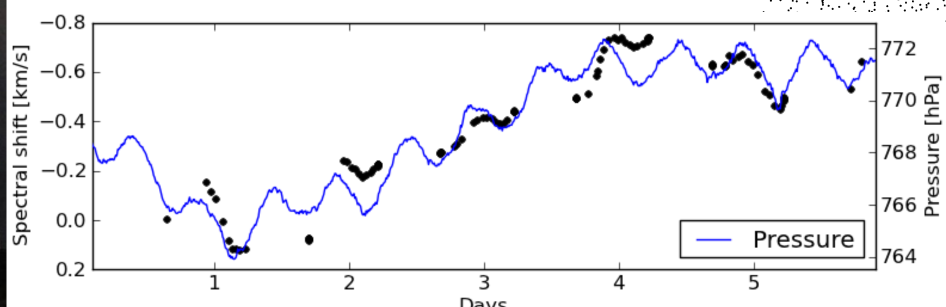


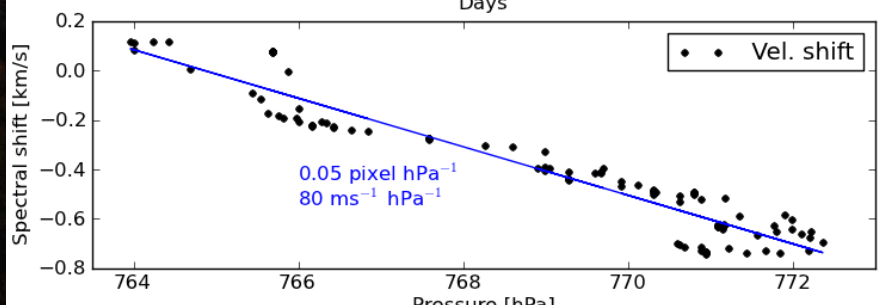


Spectrograph room

- Triple isolation of spectrograph bench
- Instrument temperature stable to $\sigma < 0.01°C$
- Pressure control to be implemented… (over-pressure: 0 – 20 mbar)







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Spectrograph room

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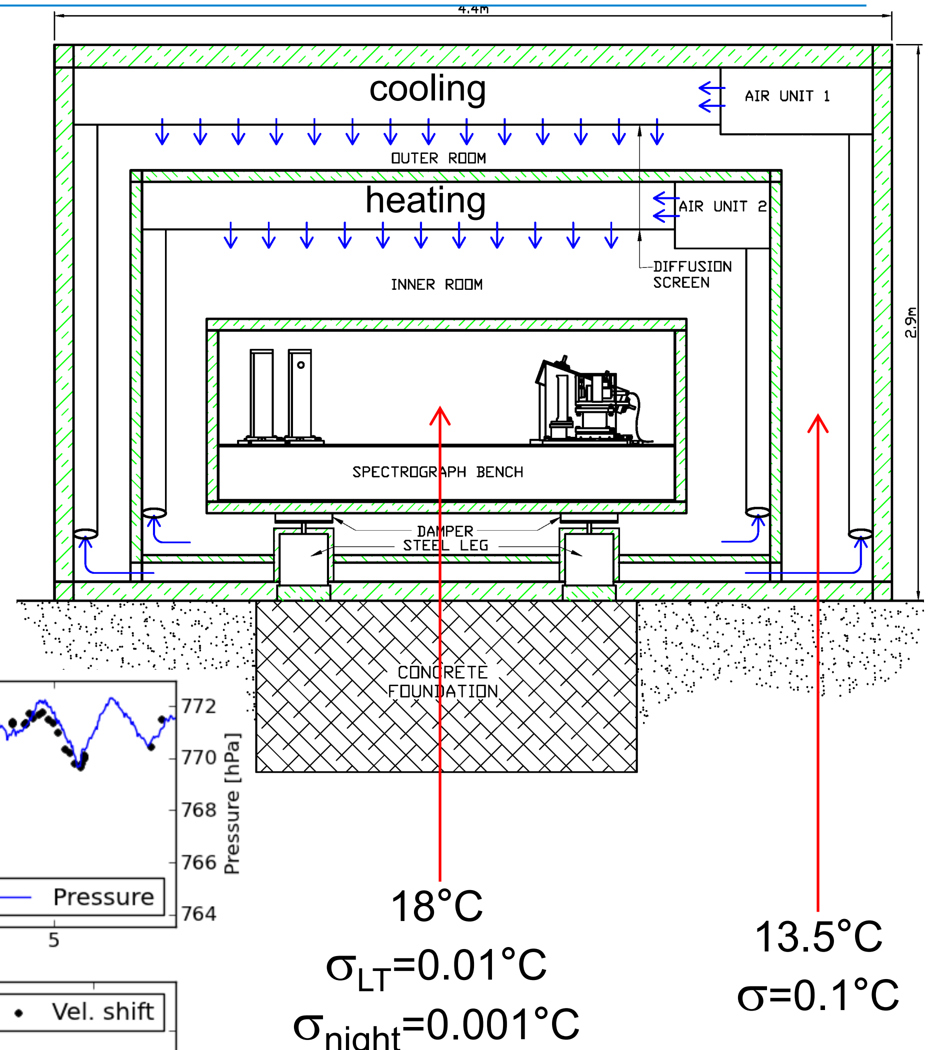
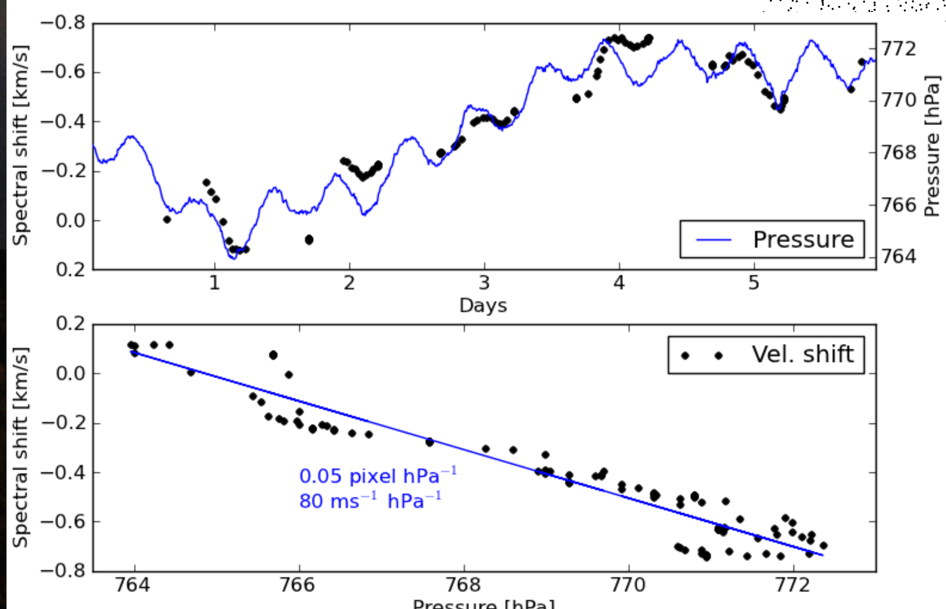
- ~~Pressure control to be implemented (over-pressure: 0 – 20 mbar)~~

Better solution:
Install in vacuum tank





Spectral resolution

Sampling:

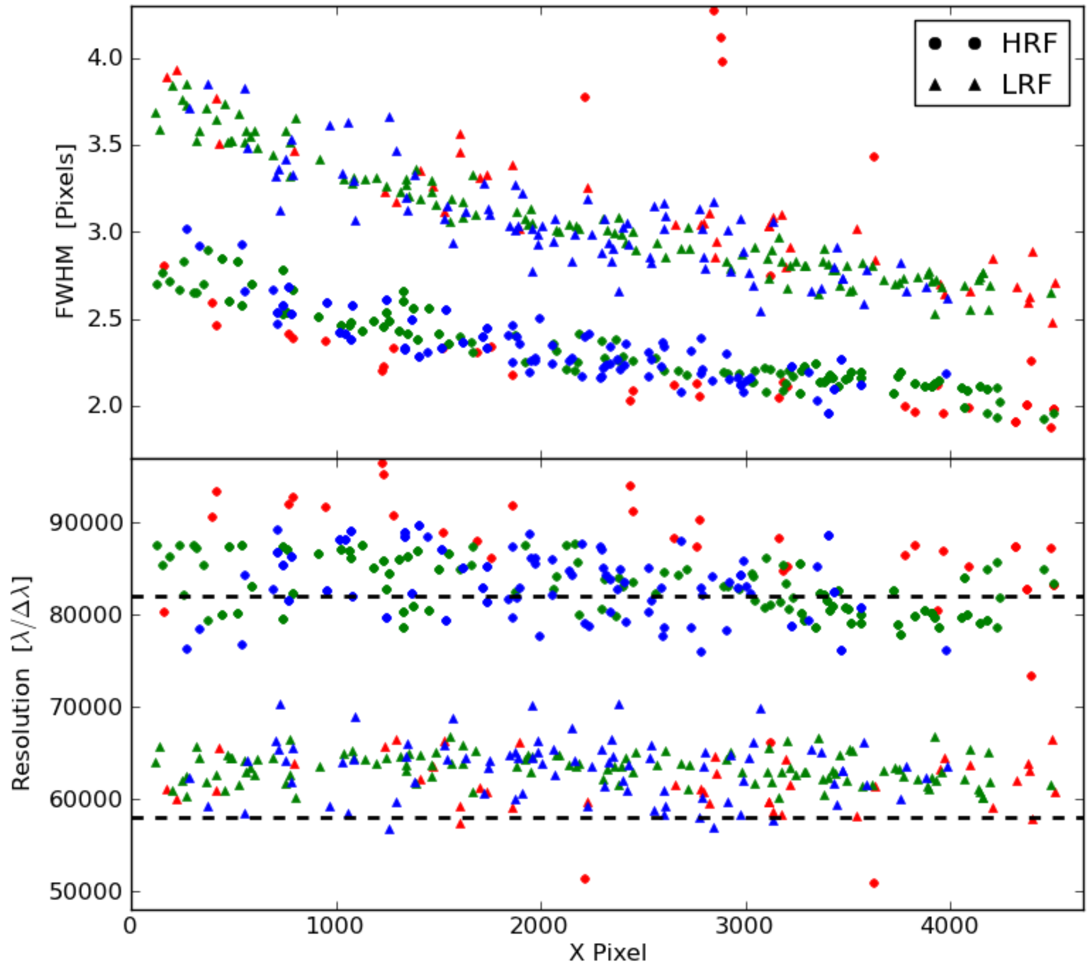
LRF: 2.7 – 3.7 pix.

HRF: 2 – 2.7 pix.

Resolution:

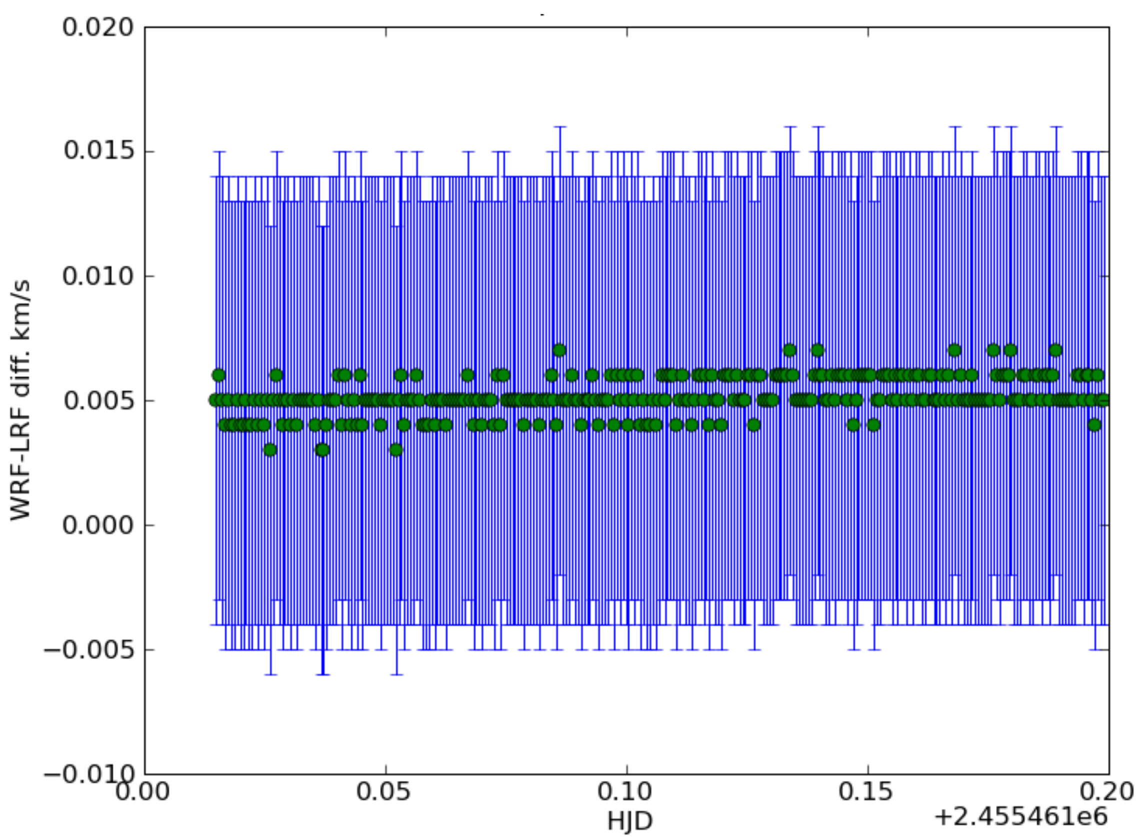
R_{HRF} ≈ 85000
(Design: 82000)

R_{LRF} ≈ 63000
(Design: 58000)



Radial velocity accuracy

- Most data taken in HRF mode with wavelength calibration only at beginning and end of night: σ_{RV} **= 50 – 100 m/s**
- HRF + regular Th reference spectrum: $\sigma_{RV} <$ **3 m/s**
- LRF + WRF simultaneously: $\sigma_{RV} <$ **3 m/s**



LRF + WRF
RV Standard
Texp = 10 s
300 exposures
4.5 hours

σ **= 1 m/s**

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Throughput

HRF efficiency:

28% peak (500 – 600 nm)

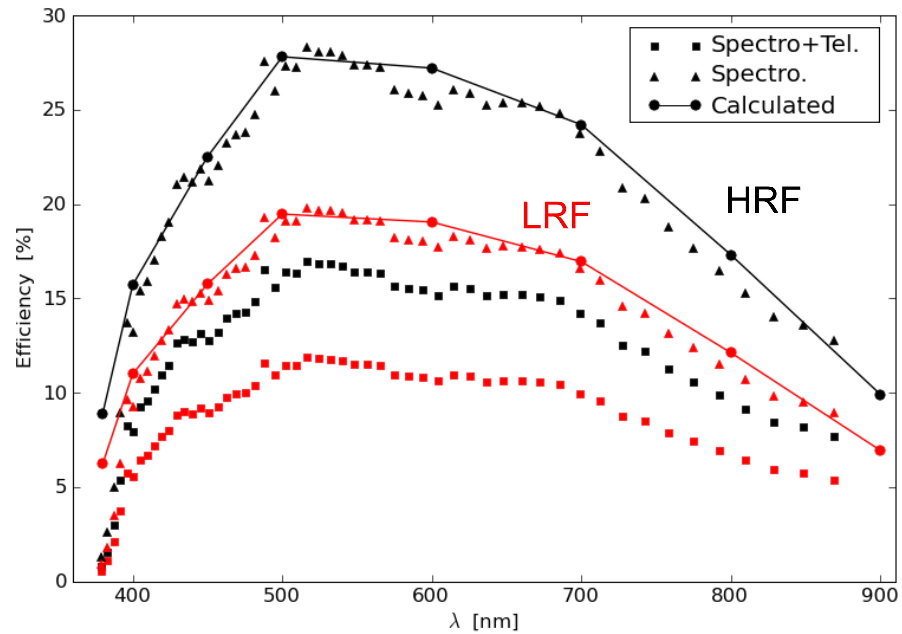
18% including telescope

LFR efficiency:

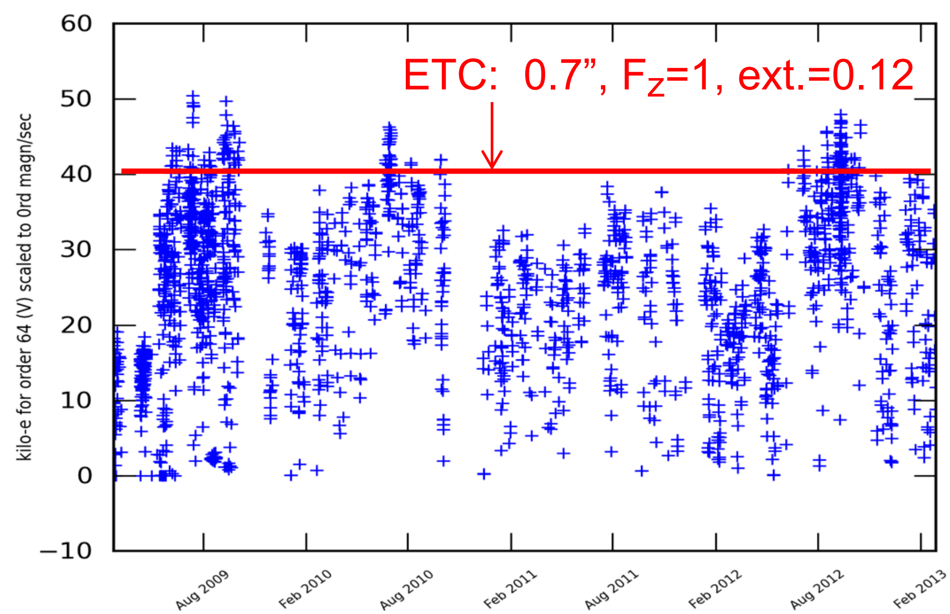
20% peak

13% including telescope

Sub-specifications below 400nm



Flux measured from standard stars (blue) and calculated from exposure time calculator (red line), normalised to M_V=0 (ke^-/s @ 550nm)

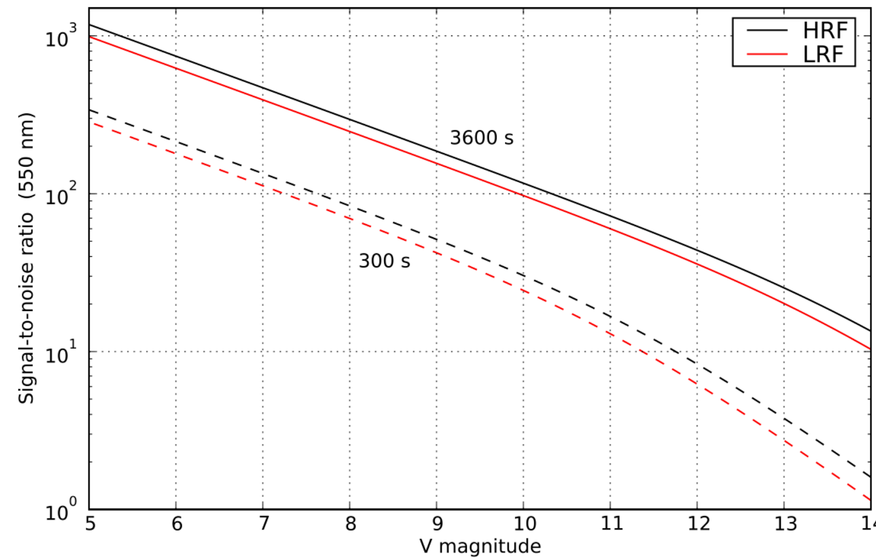


Throughput and limiting magnitudes

SNR & limiting magnitudes (1” seeing, 1 hr exposure):

Mv = 10.5 ⇨ SNR = 100

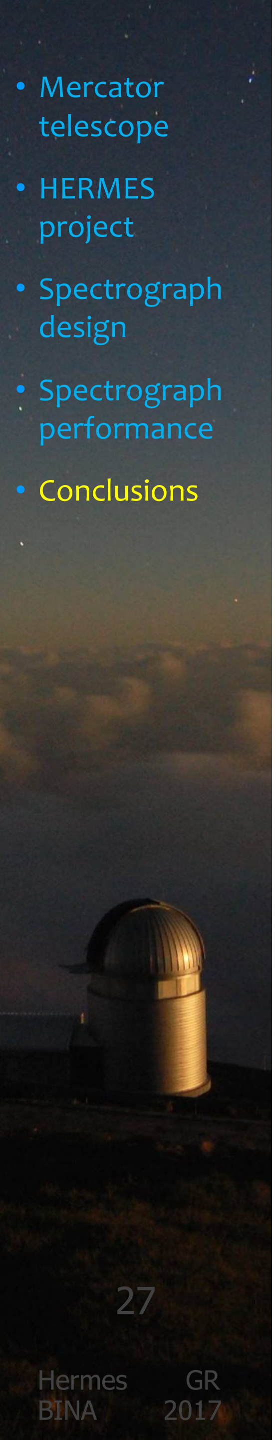
Mv = 13.5 ⇨ SNR = 20



Comparison with other HR spectrographs on La Palma:

Instrument	Telescope diameter	R (λ/Δλ)	Flux (e^-/Å/s)	
			0.6”	1.2”
HERMES	1.2 m (1.05m^2)	85000	1050	1000
FIES (NOT)	2.5 m (4.5m^2)	67000	1200	700
HARPS-N (TNG)	3.5 (9m^2)	115000	4000	2000

Flux @ 550nm from ETCs (M_V=8)



How to obtain high efficiency

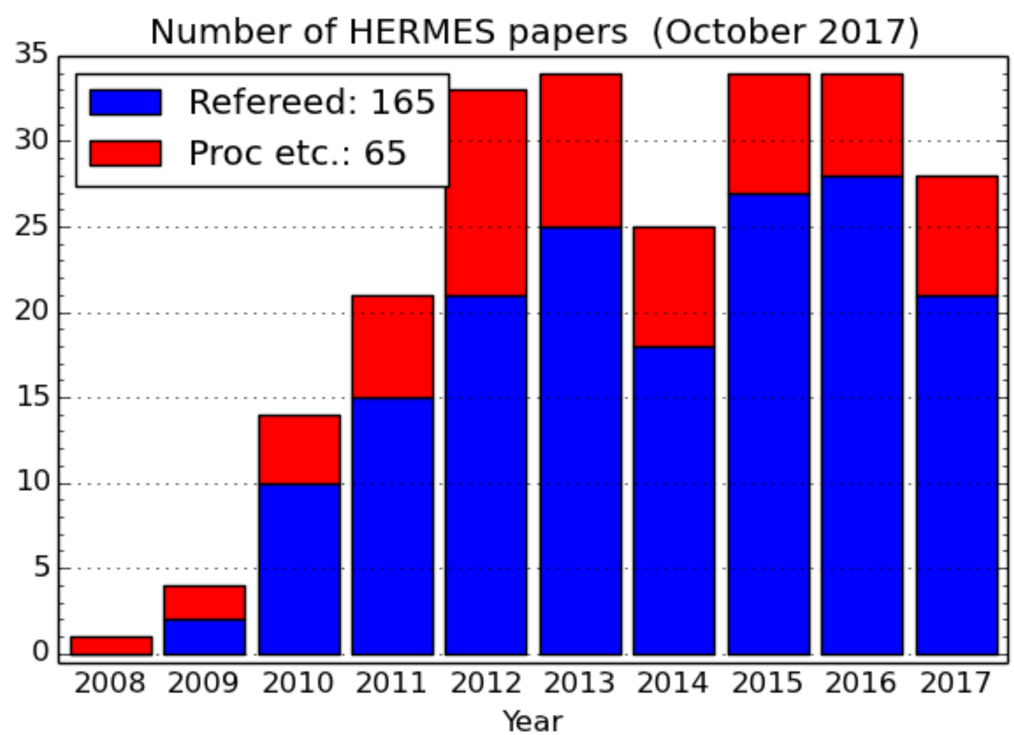
- Optimise mirror and AR coatings
- Minimise number of optical surfaces
- Use a prism as cross disperser instead of a grism or diffraction grating
- Sky aperture larger than seeing disk (1.5" – 2")
  => Use image slicer to increase resolution
  => Large telescope implies large optical components
  Use largest echelle grating (800 x 200 mm^2)
- Do not use a double scrambler
- **Limit focal ratio degradation => Pay extreme caution to quality of optical fibre confectioning**
- Regularly clean and re-aluminise telescope mirrors

- Highest efficiency is often incompatible with highest RV stability!

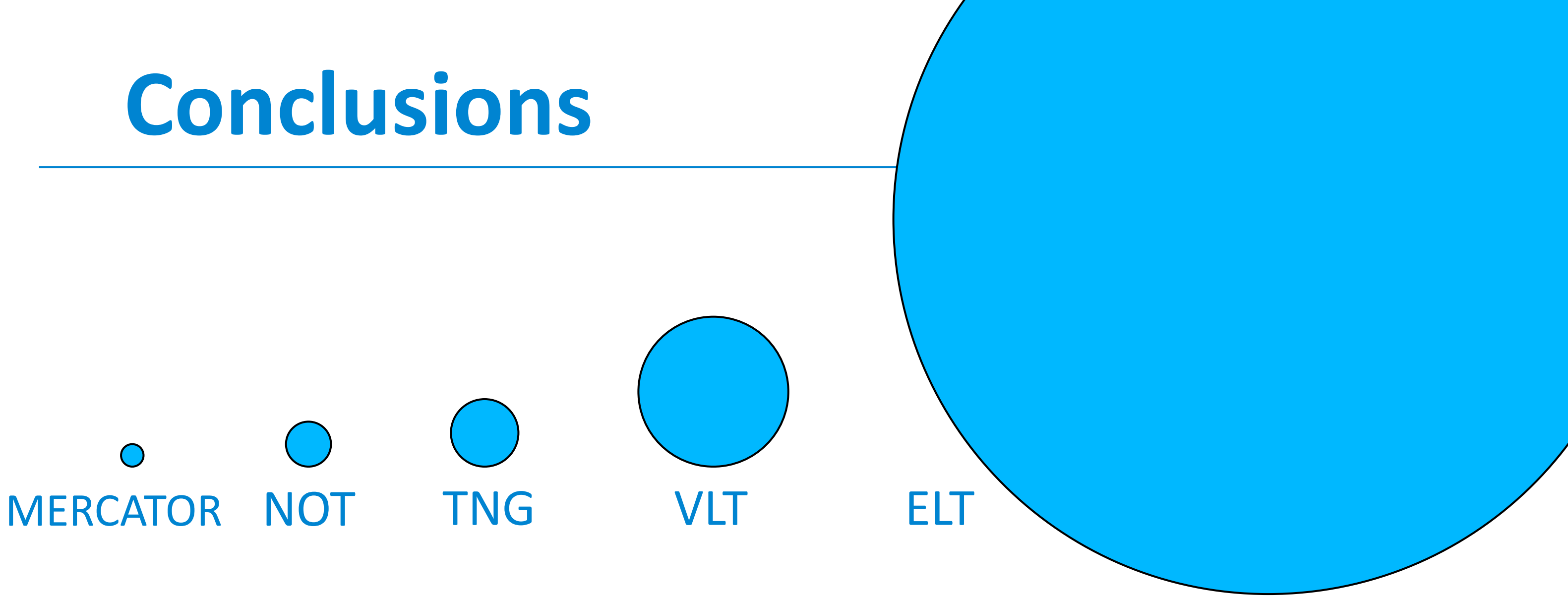
HERMES productivity

Since start of HERMES observations in 2009:

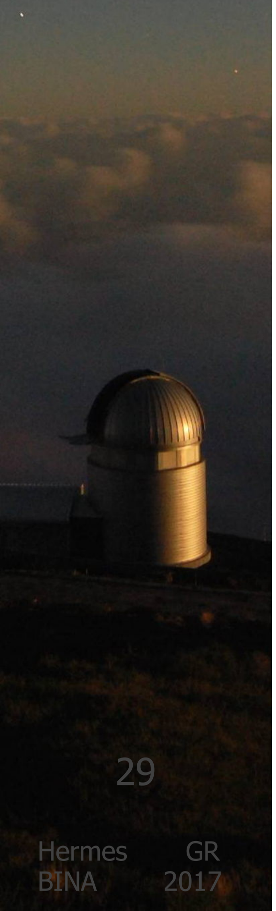
- 2500 nights with spectra over 8.5 years
- 75k HRF science spectra
- 5k LRF spectra with simultaneous wavelength reference
- 280k spectra including calibrations
- 230 Papers, 165 Refereed



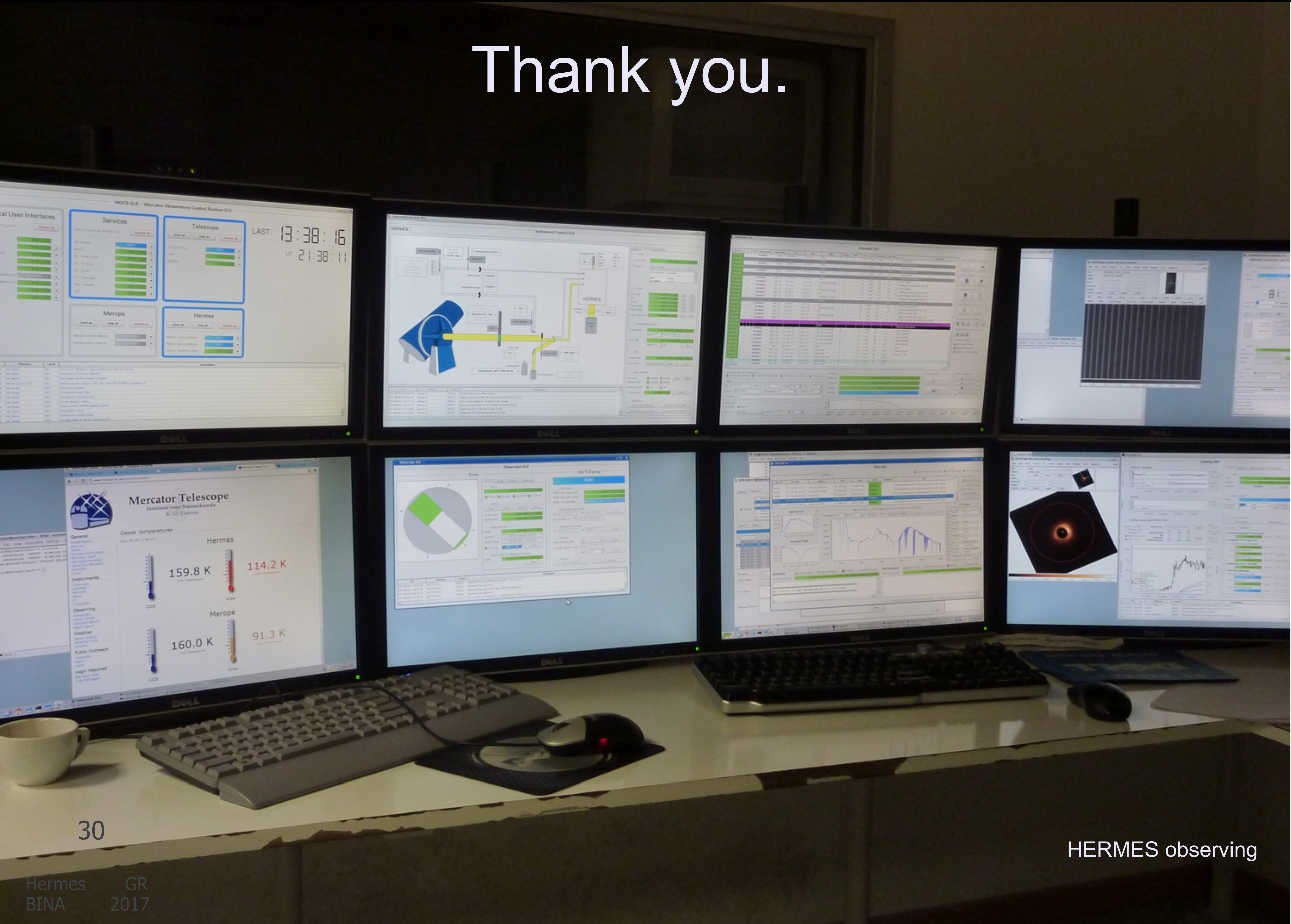
Conclusions



- A small but dedicated telescope with an efficient spectrograph can still be used for competitive science.
- HERMES is a very efficient HR spectrograph with good stability.
- HERMES productivity is a key element in many of the science programs at the Institute of Astronomy at KU Leuven.
- HERMES is available through Spanish TAC (20%) or through collaboration with a consortium member.



Thank you.



HERMES observing