HARPS

The Exoplanet Finder on La Silla

Florian Rodler (ESO)

Introduction

HARPS =

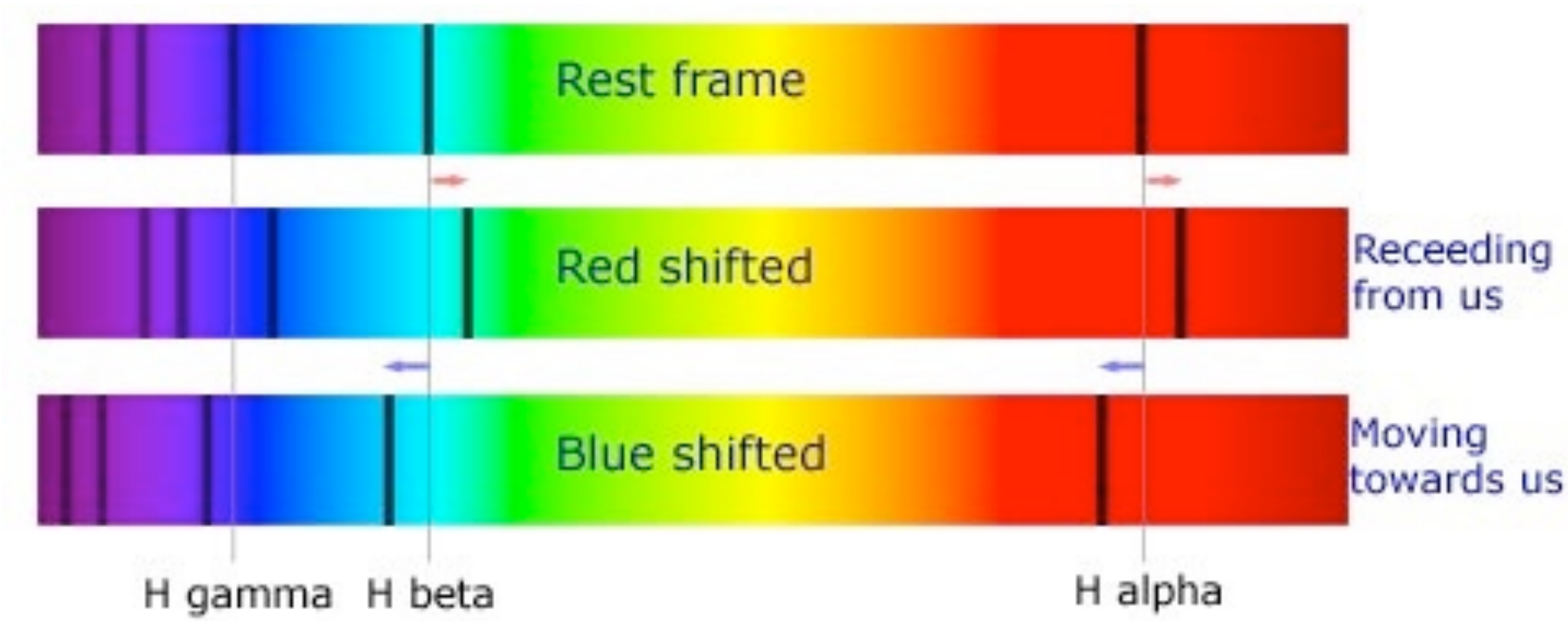
High
Accuracy
Radial velocity
Planet
Searcher

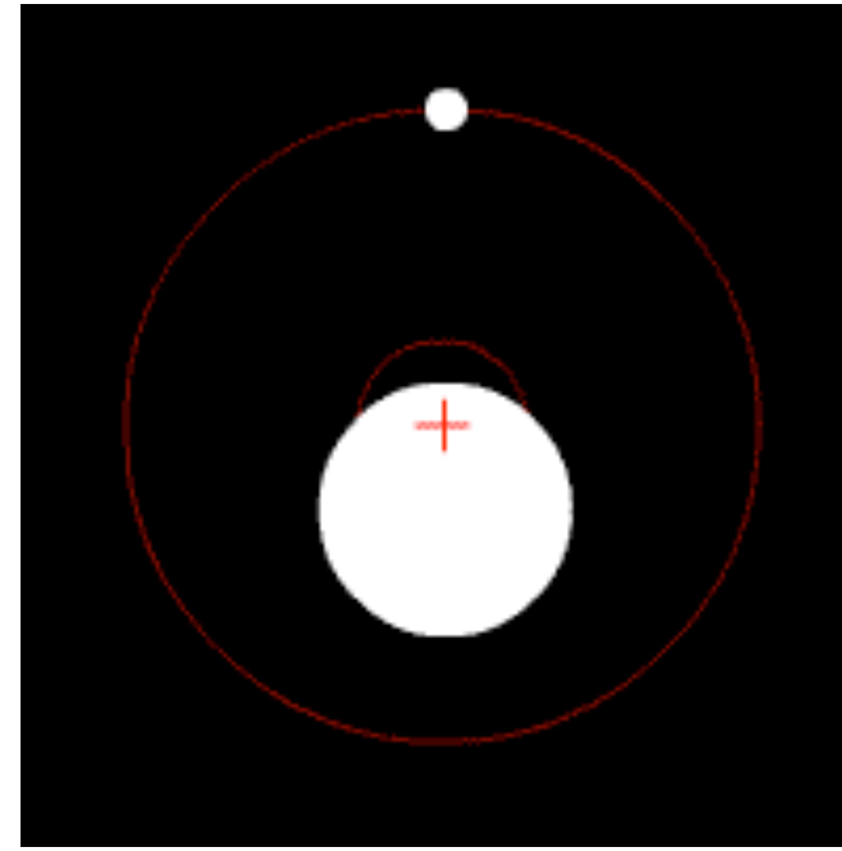
on the La Silla 3.6m telescope

Introduction

Measure: **stellar absorption lines!**

They shift in the line of sight as the star wobbles due to gravitational pull of the unseen planet



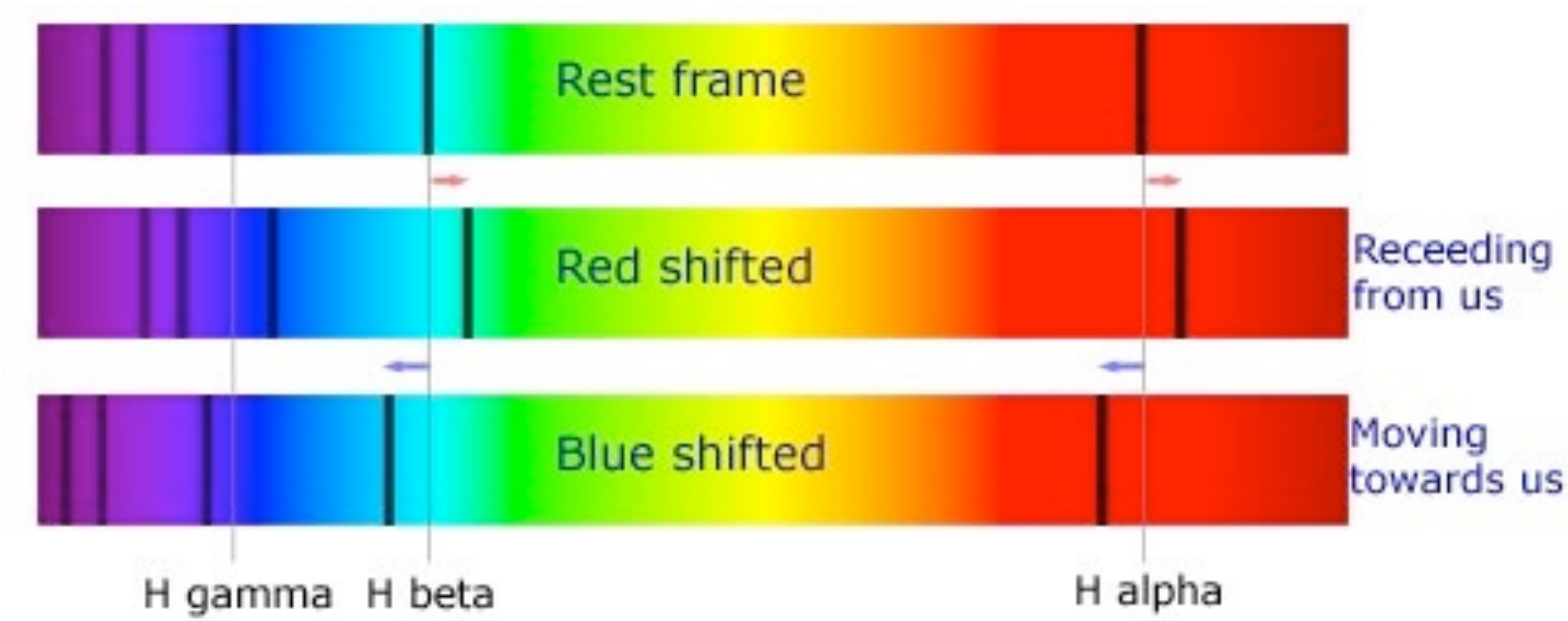


380 nm ⟷ **700 nm**

wavelength λ

Finding exoplanets with the Radial Velocity technique

Doppler effect: $v_{rad} = c\ \Delta\lambda / \lambda$



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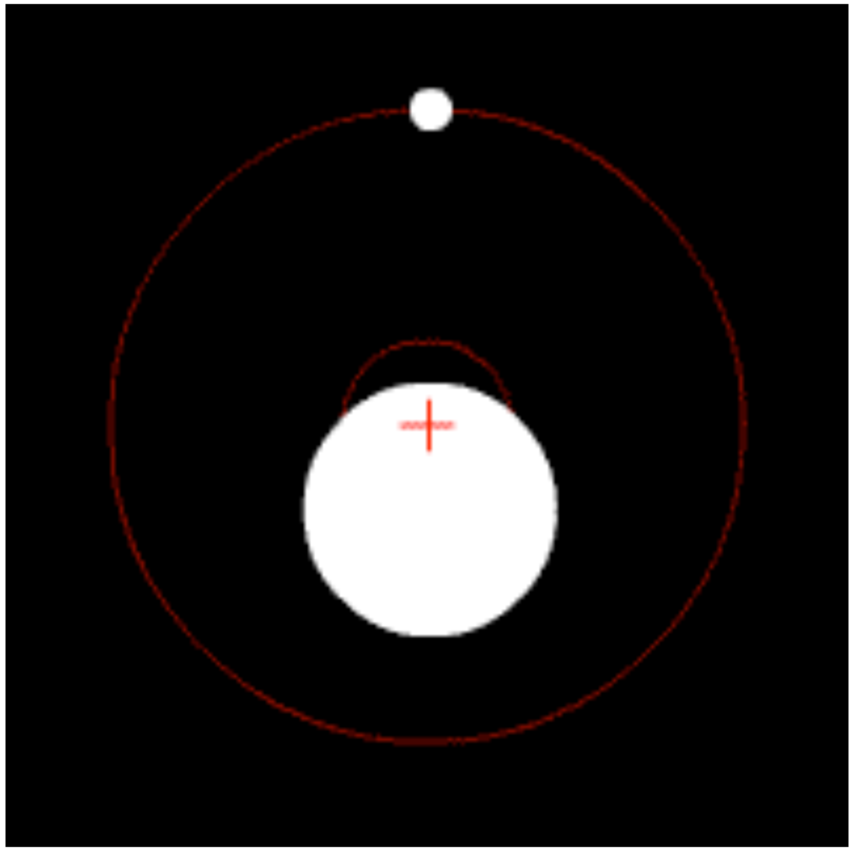
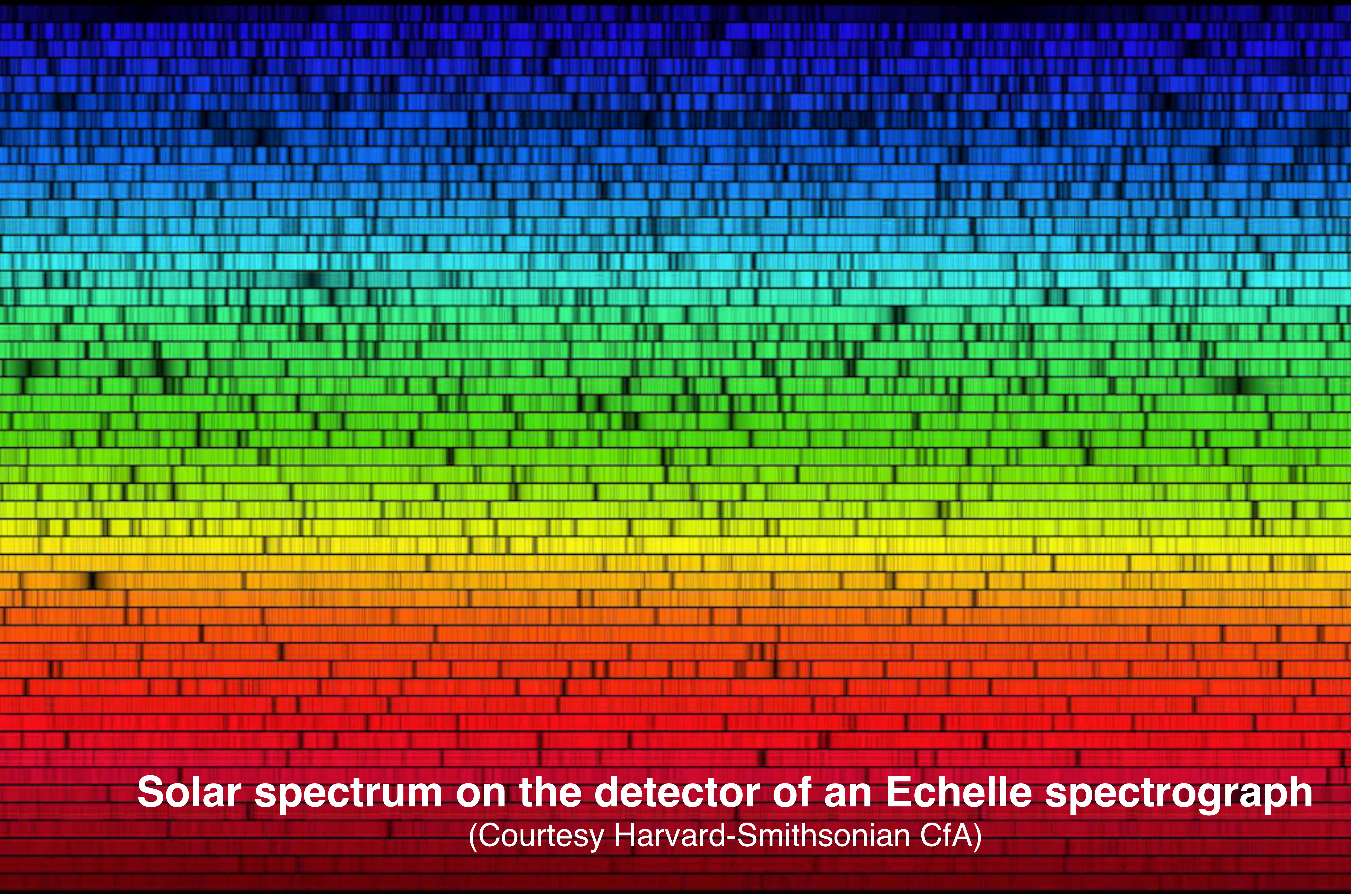
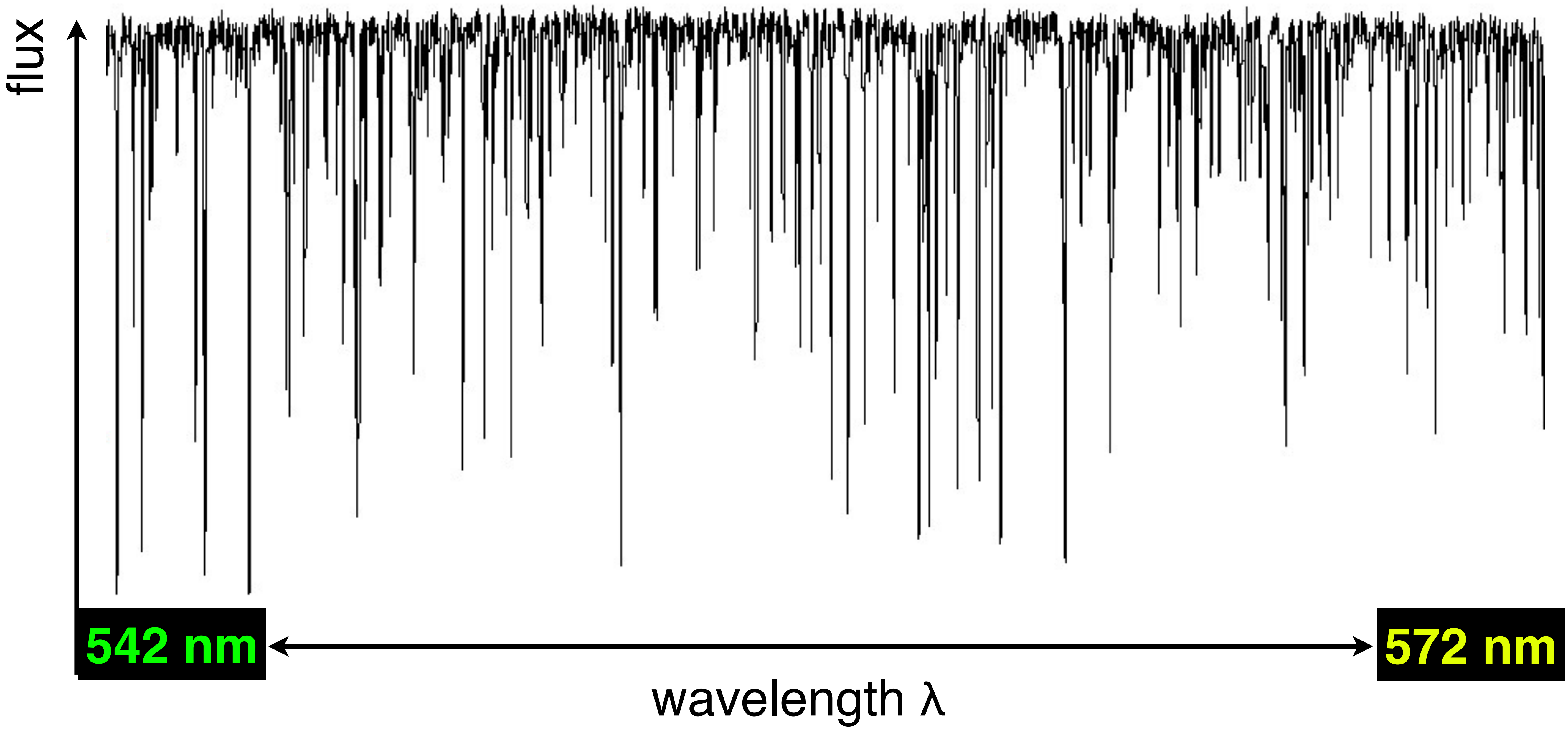


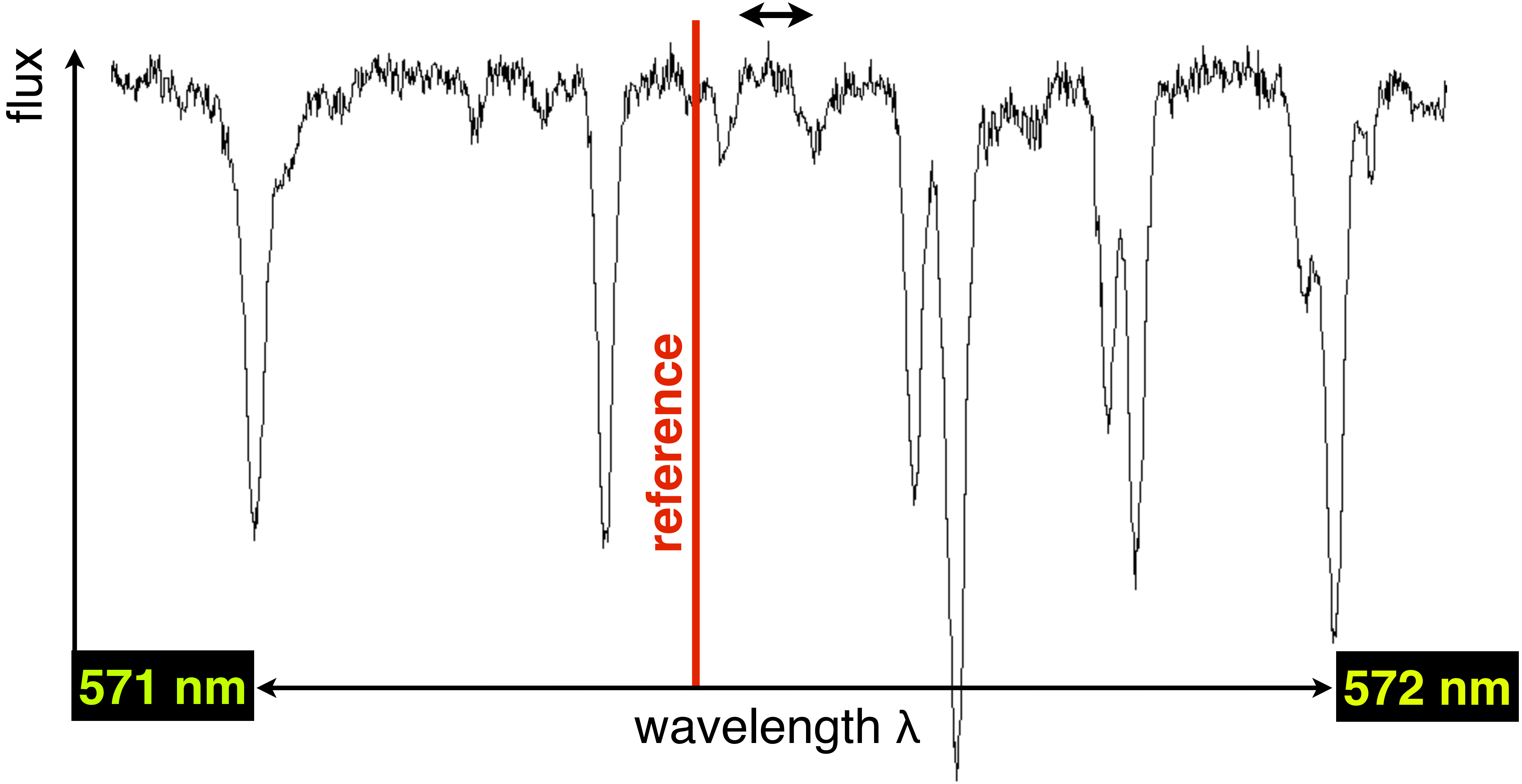


Solar spectrum on the detector of an Echelle spectrograph
(Courtesy Harvard-Smithsonian CfA)

Zoom in ...



Zoom further in ...



Try to detect Jupiter around the Sun:

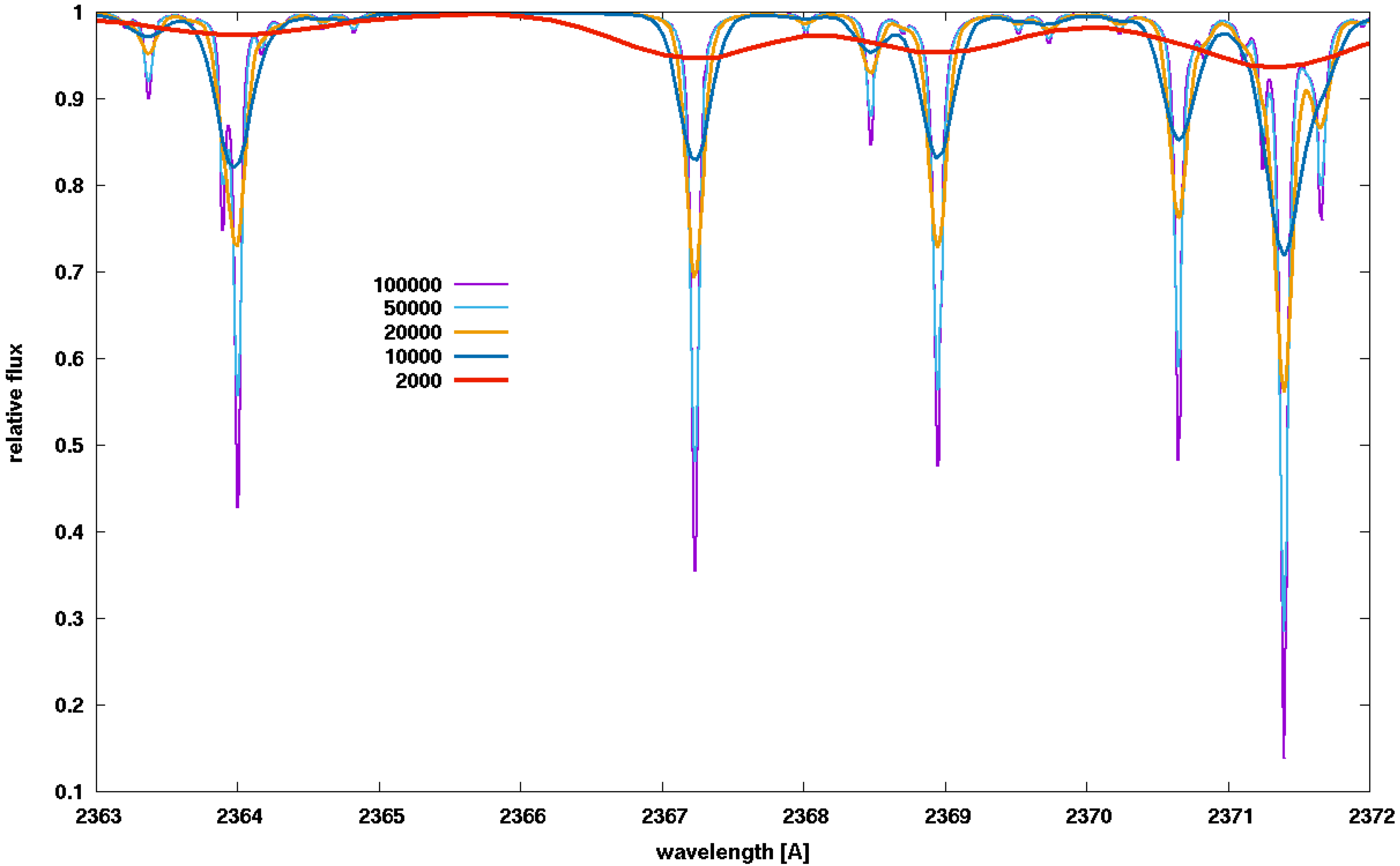
i.e.	an object of	318 Earth masses
	with an orbital period of	11.9 yr
	and causing a stellar RV variation of	**± 12.4 m/s**

(a shift in λ of 0.000023 nm at 550 nm)

Requirements for such a spectrograph:

- very high **spectral resolving power** ($R = \lambda/\Delta\lambda > 50\,000$)

- very high **instrumental stability** over many years
  (error in RV ~ 1 m/s ... ~1/100 of a pixel ... over 10 years)



relative flux
wavelength [A]
100000
50000
20000
10000
2000
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
2363
2364
2365
2366
2367
2368
2369
2370
2371
2372

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  (error in RV ~ 1 m/s ... ~1/100 of a pixel ... over 10 years)

Always know your instrument!
Think of possible error sources!

(Murphy's law applies: your nice planet signal just might turn out to be instrumental variations)

Finding planets with the Radial Velocity technique

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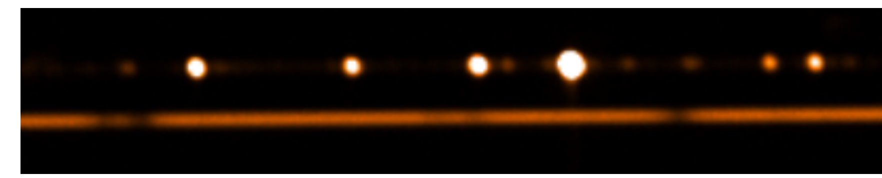
- very high **spectral resolving power** ($R = \lambda/\Delta\lambda > 50\,000$)

- very high **instrumental stability** over many years
  (error in RV ~ 1 m/s ... ~1/100 of a pixel ... over 10 years)

How to achieve such a stability?
What possible error sources do you see? **?**

Very high instrumental stability:

- **simultaneous wavelength calibration**



- **no moving parts** in the spectrograph, fixed spectral format, spectrograph not moving

- **in vacuum** (P and T stabilized)

HARPS

- build by a consortium led by Geneva Observatory

- commissioned in 2003

- **wavelength range: 381 - 691 nm**;
  fixed spectral format, 72 orders,
  simultaneous wave calibration

- **spectral resolving power: 115,000** in HAM mode
  80,000 in EGGS mode

- Spectrograph in Coudé-room, connected via fibers to 3.6m telescope
- Pressure stability: $<10^{-3}$ mbar
- Temperature stability: 1 mK / day

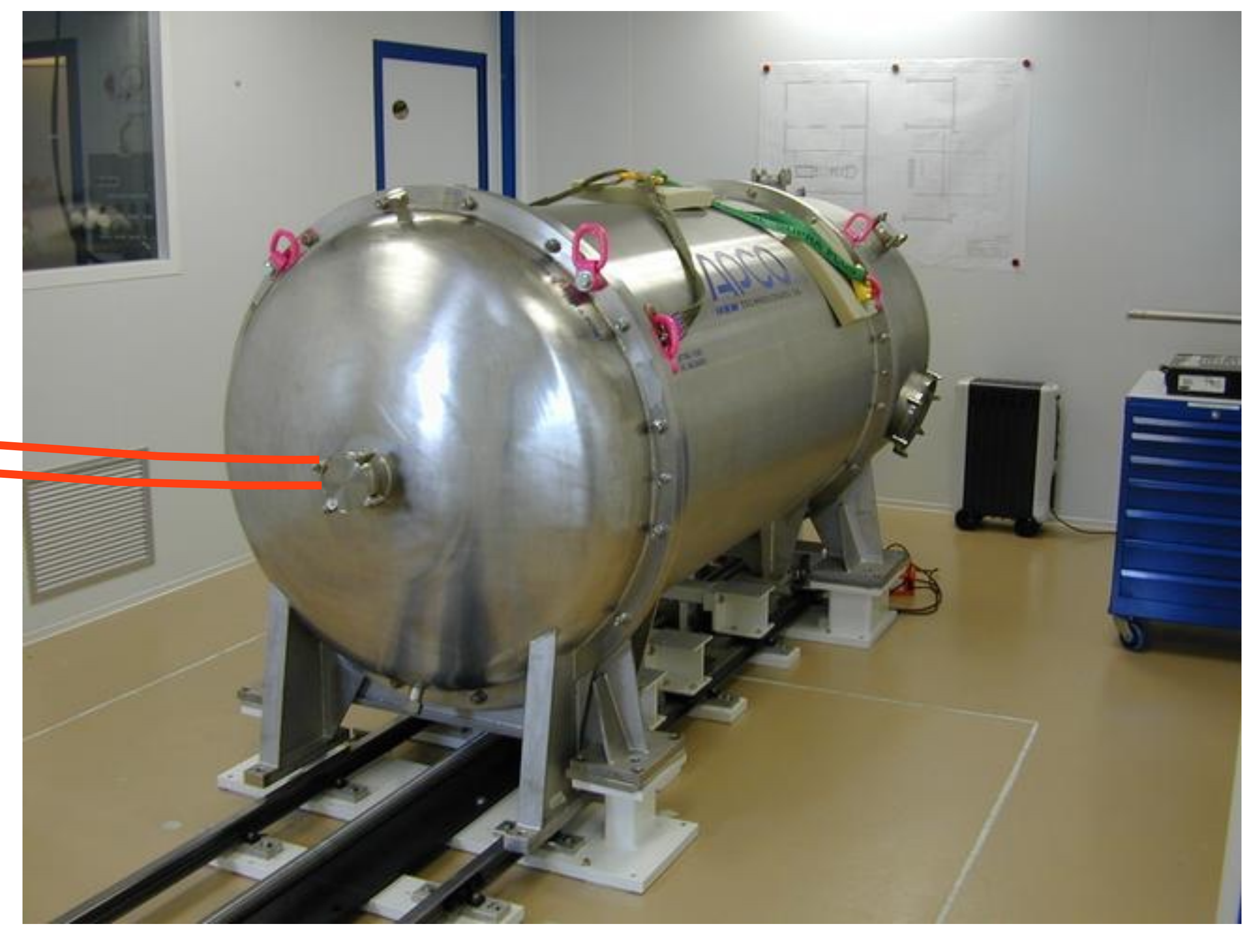
HARPS

Telescope

Guiding system

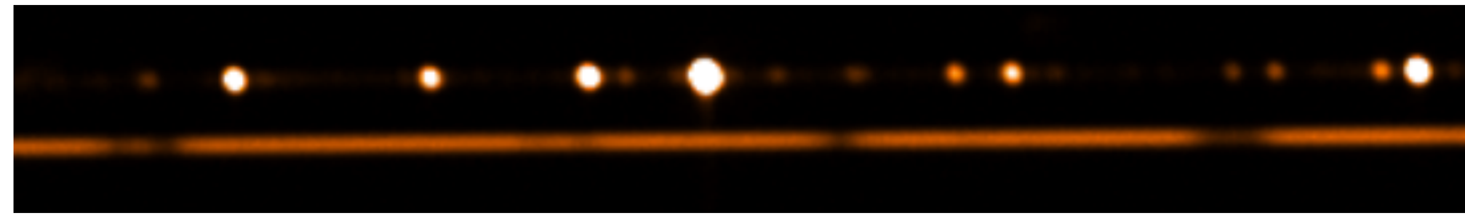
Calibration lamps (ThAr, Tun)
Fabry-Perot
Laser Frequency Comb

Spectrograph



Fibers A+B

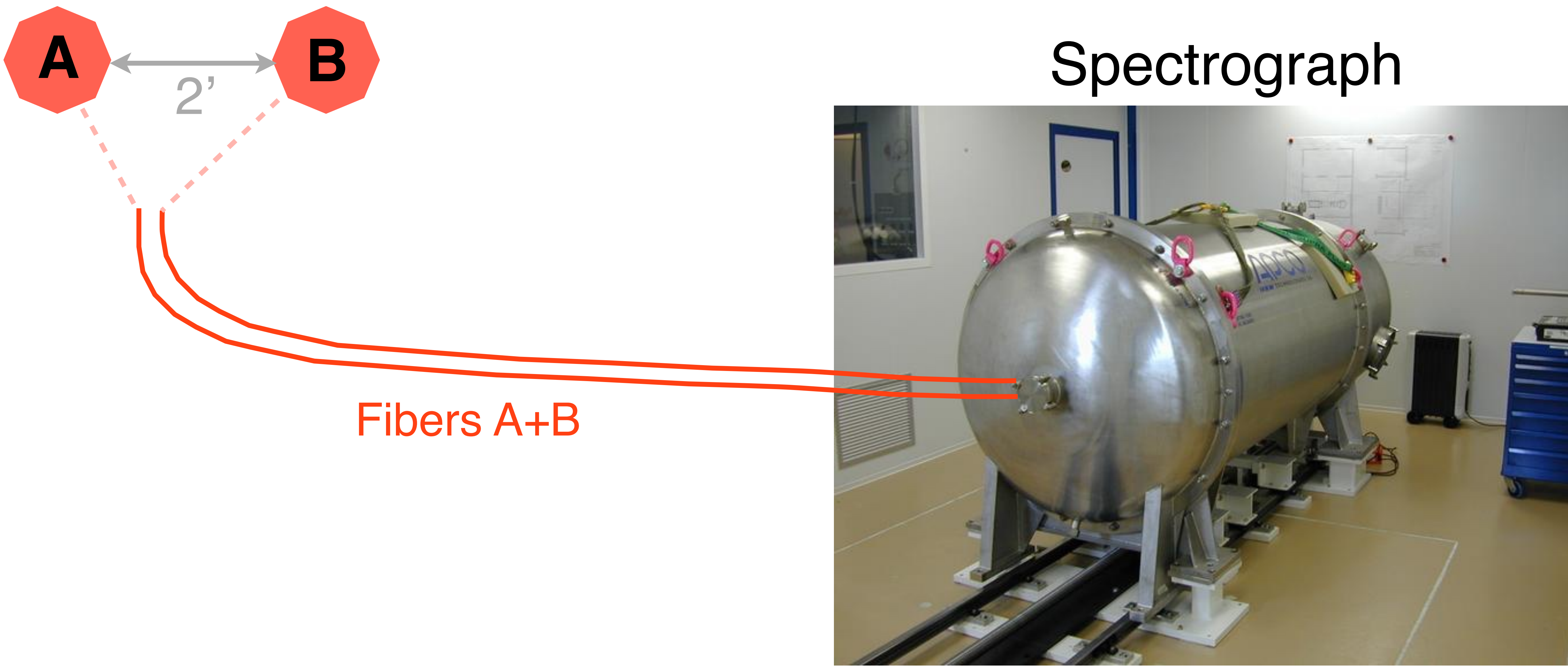
B
A



star

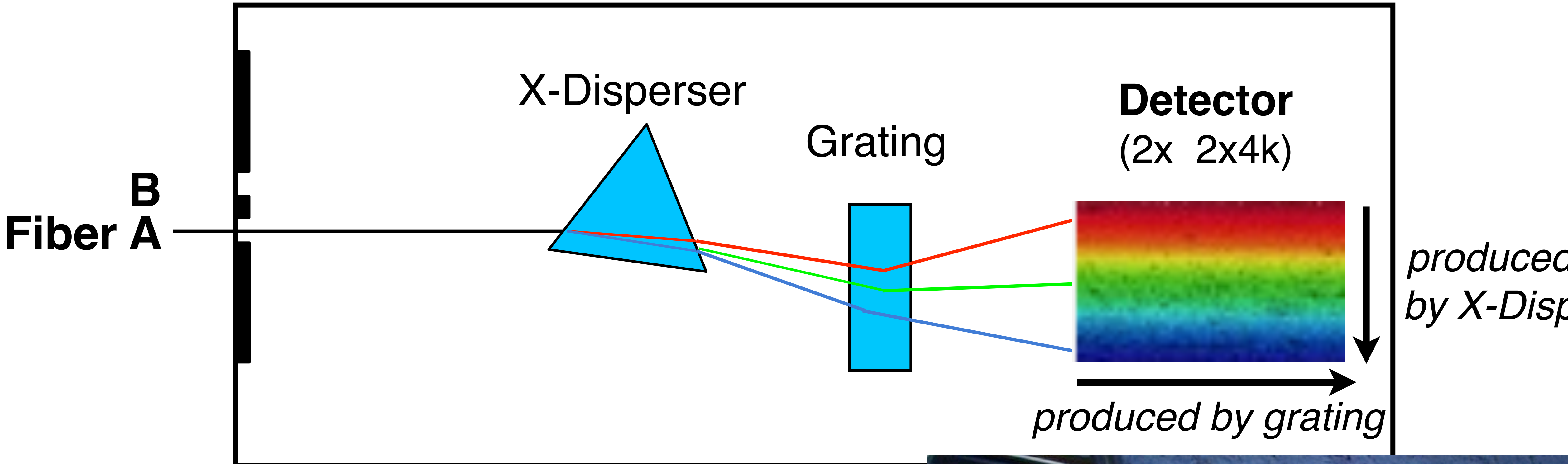
sky,
wave calib

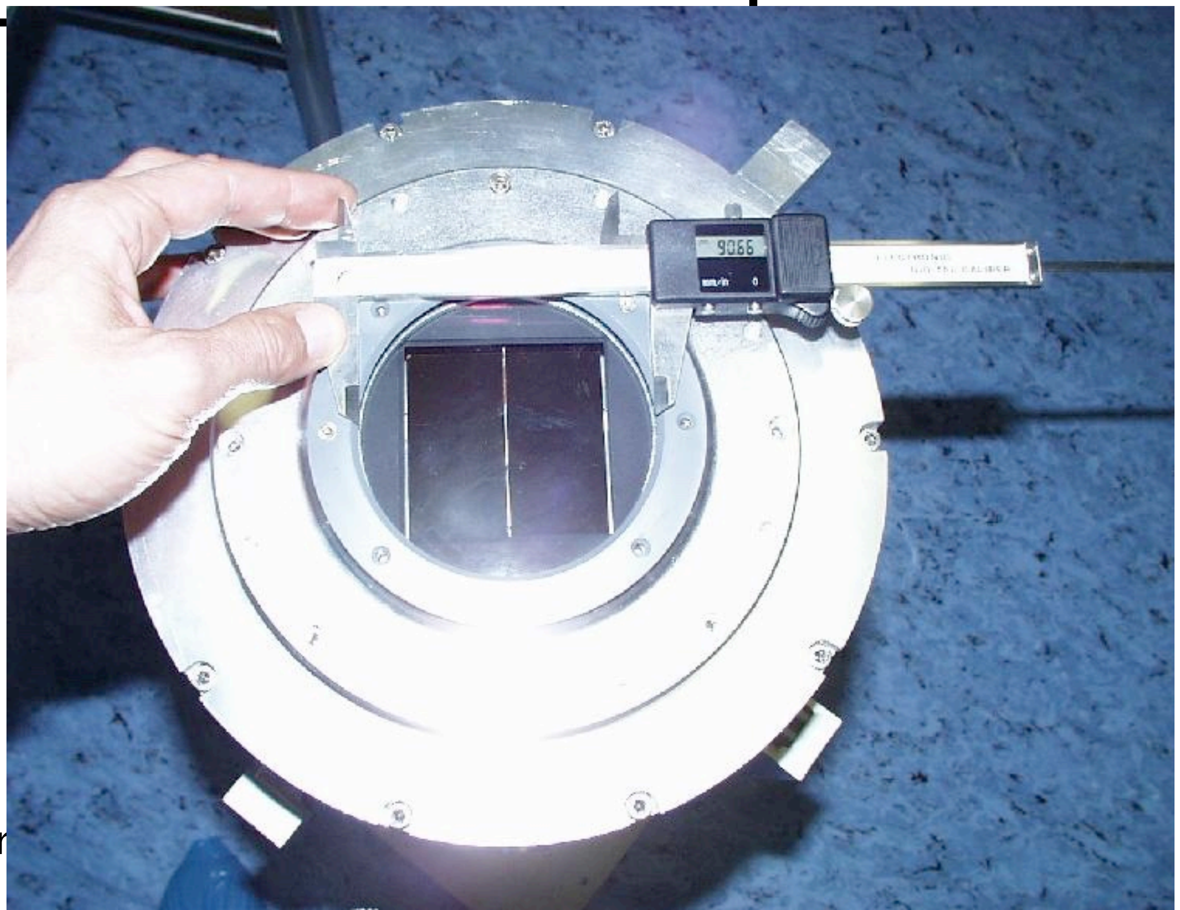
Spectrograph

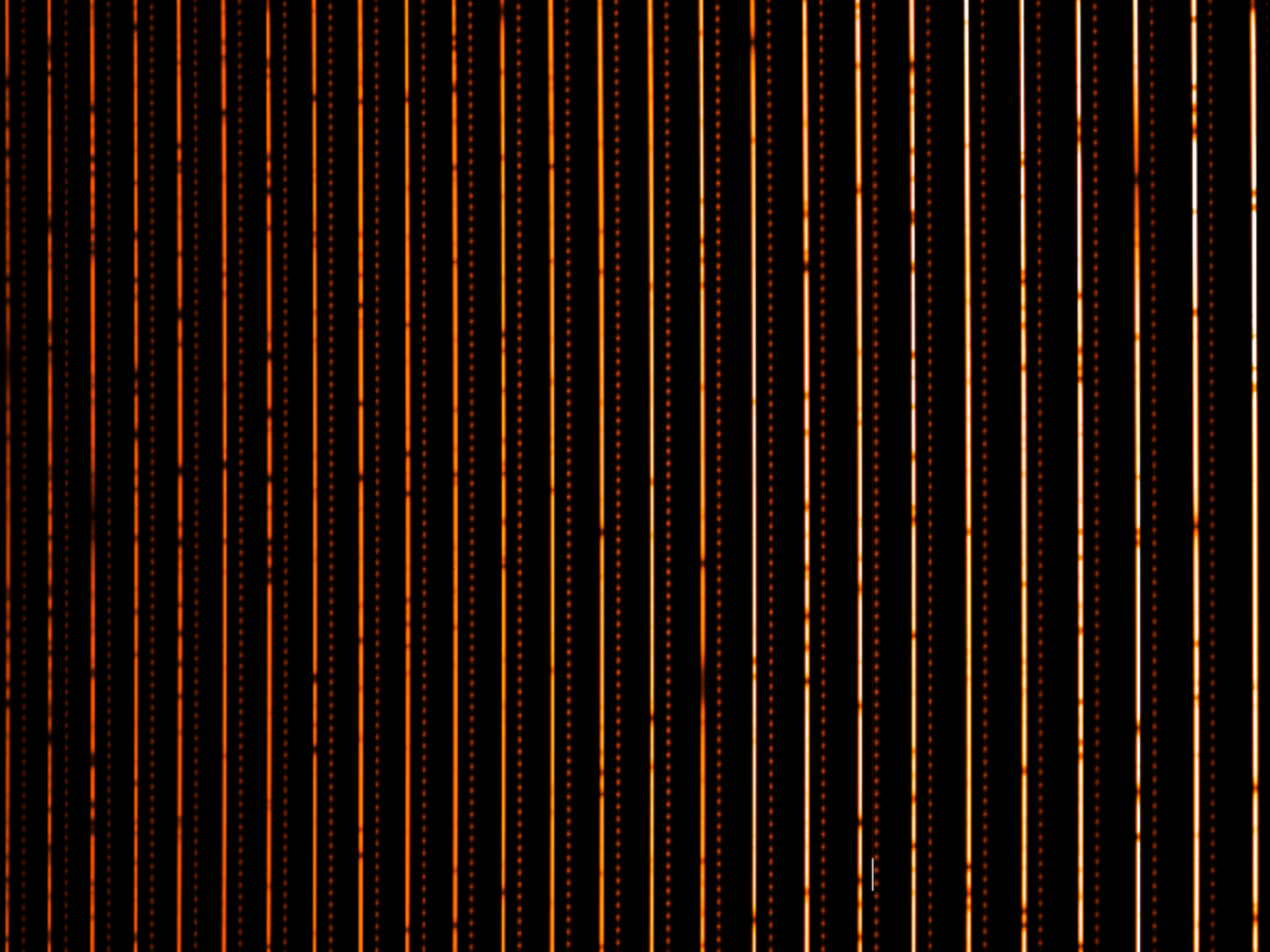


HARPS

Concept of Echelle Spectrograph



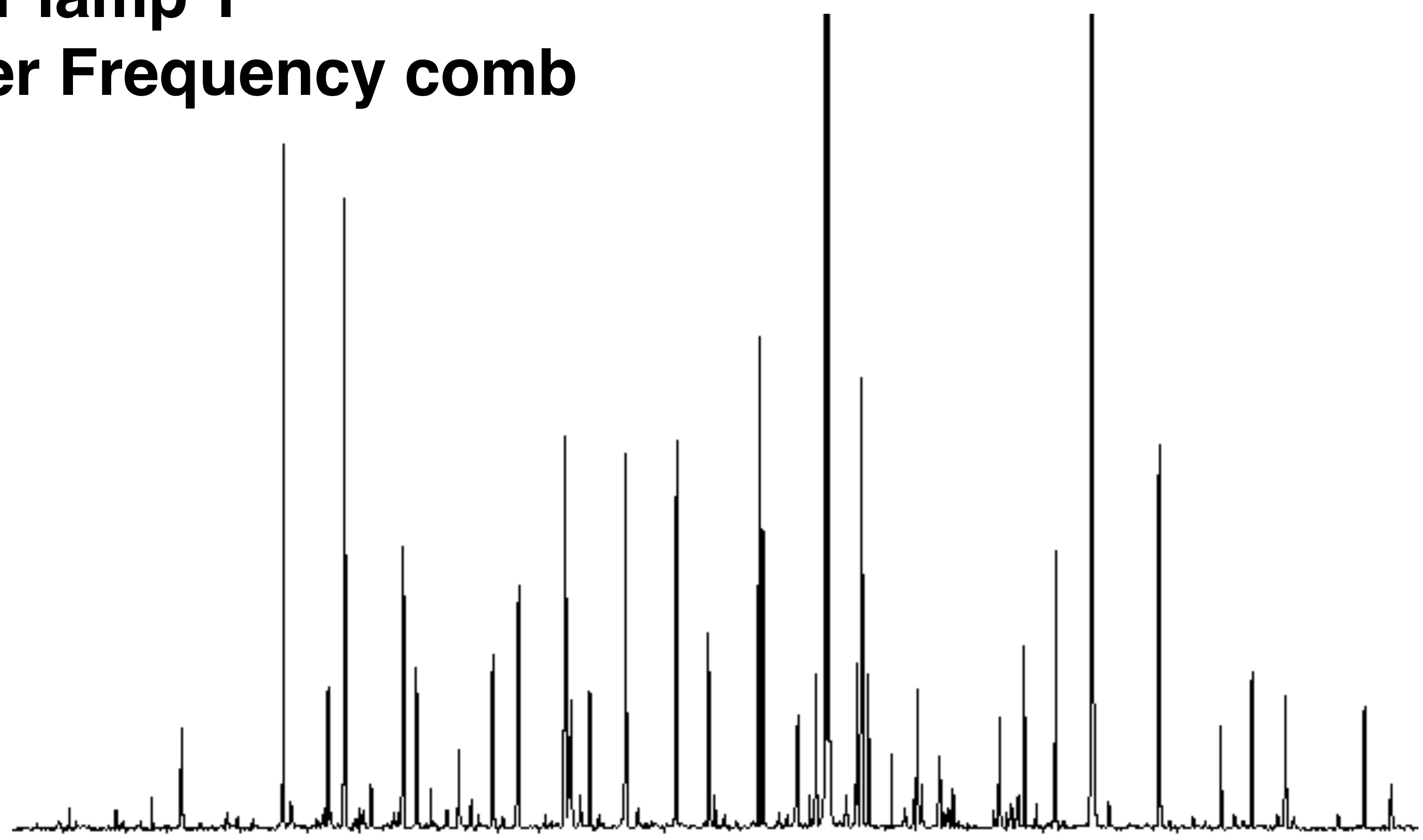




Daily Calibrations (afternoon before the observations!)

Two **long-term absolute wavelength references** (only used during afternoon to preserve lifetime):

- **ThAr lamp 1**
- **Laser Frequency comb**



Daily Calibrations (afternoon before the observations!)

Two **long-term absolute wavelength references** (only used during afternoon to preserve lifetime):

- **ThAr lamp 1**
- **Laser Frequency comb**

They are used to calibrate the nightly simultaneous wavelength reference:

- **ThAr lamp 2**
- **Fabry-Perot** (has a drift of <0.1 m/s per night)

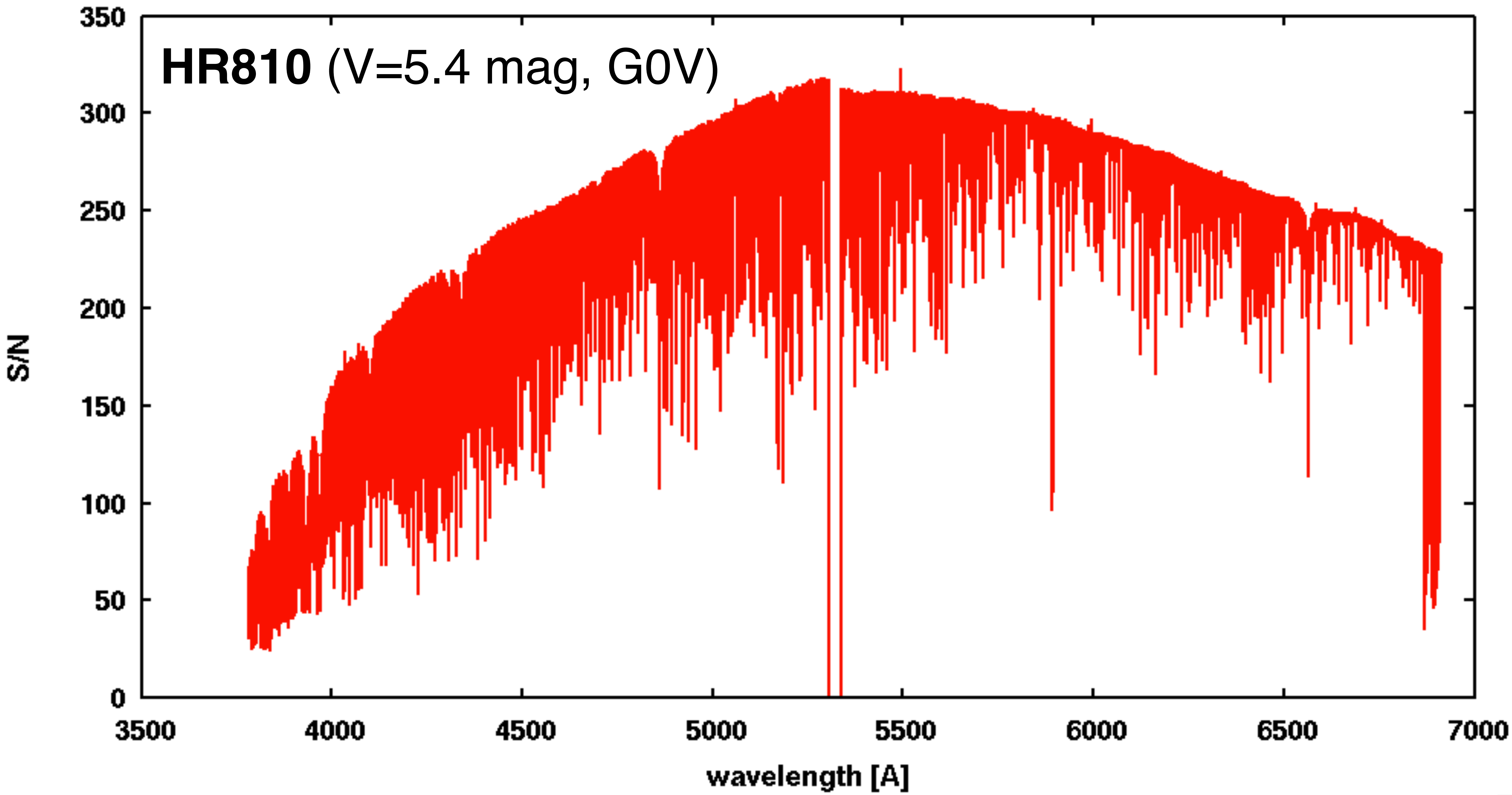
Observing modes:

HAM: High accuracy mode,
R~115,000
RV precision 1 m/s, 1” fibers A+B
For faint targets (V>12) no simultaneous wave calib!

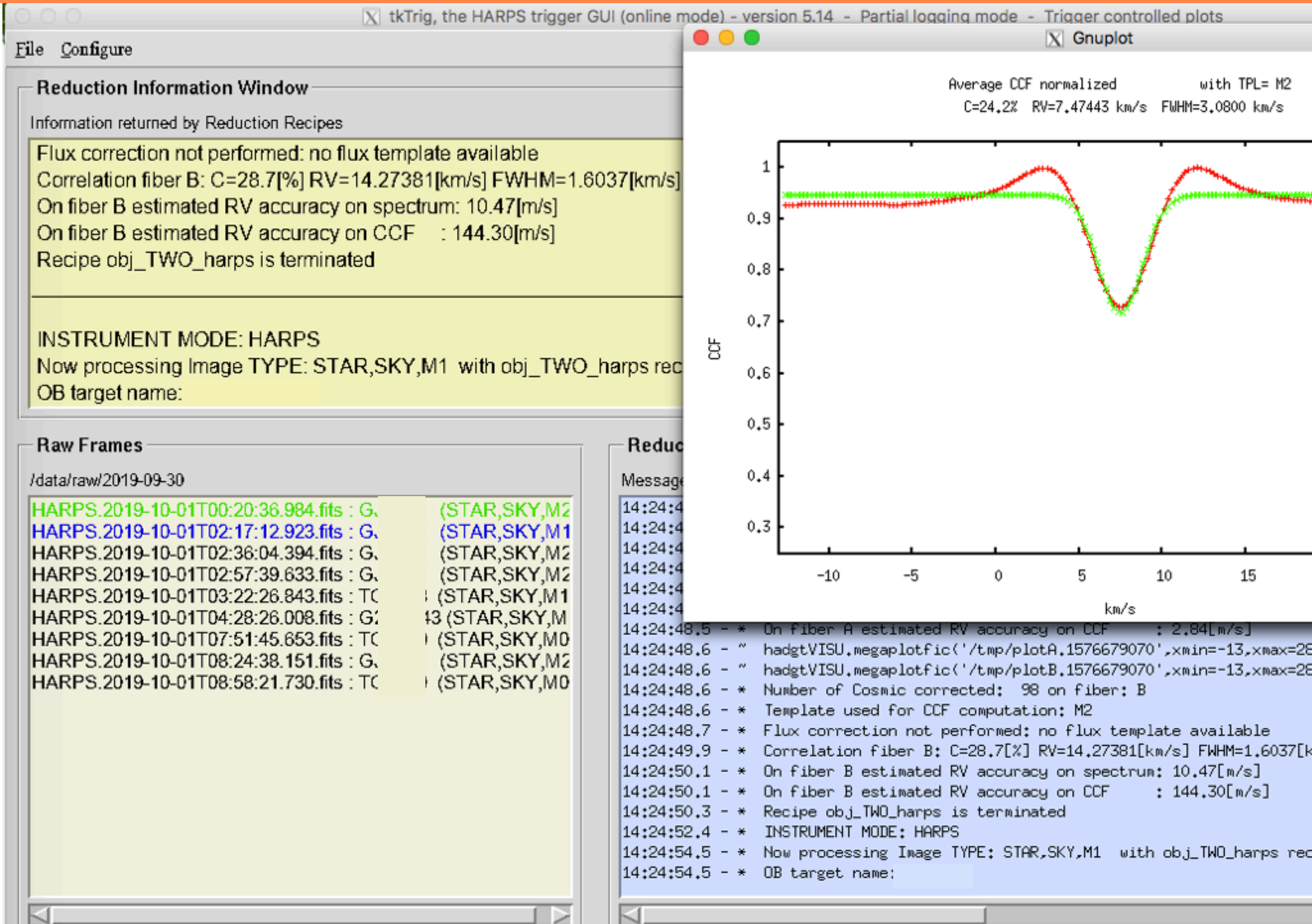
EGGS: High efficiency mode (faint targets),
R~80,000
RV precision 3 m/s, 1.4” fibers A+B

Polarimetry: 1” fibers A+B

Example: HAM mode, 240 sec, 1” seeing, X=1.1:



Observing with HARPS



HARPS Pipeline (DRS)

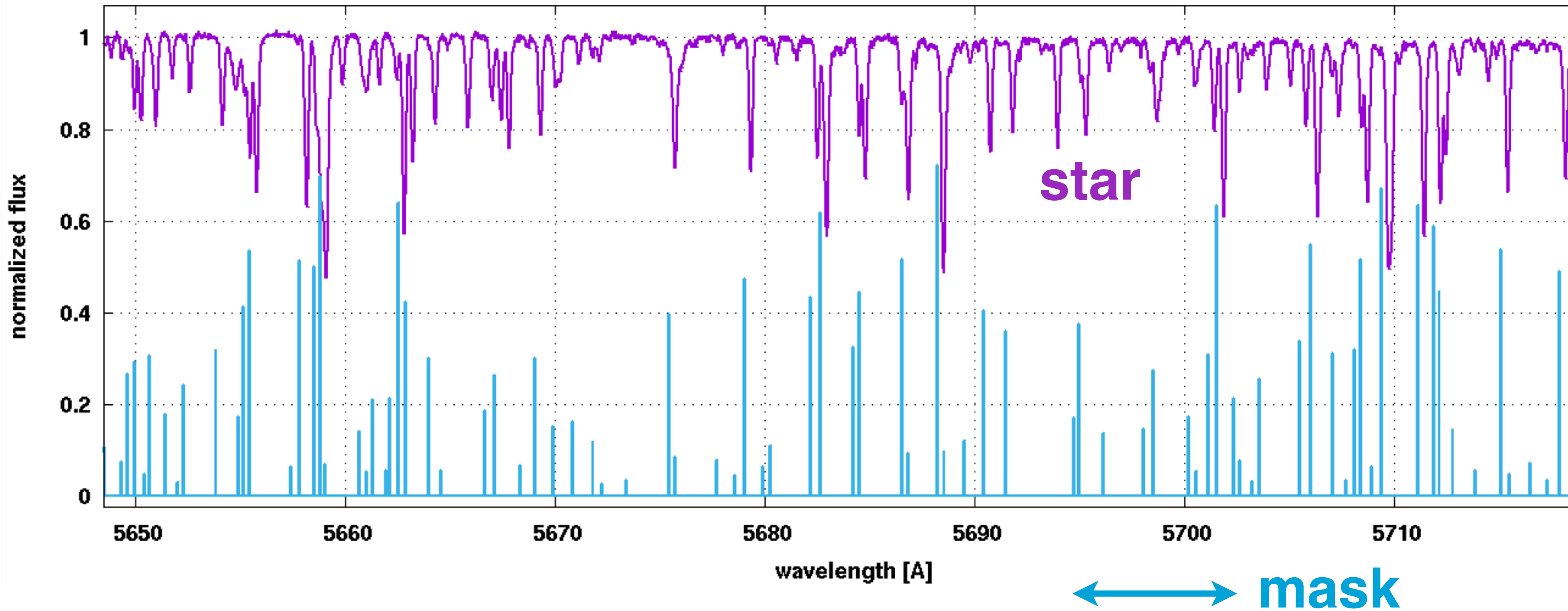
- **standard steps:** bias, flat-field, cosmic-rays correction

- **extraction of spectral orders** from frame + **wavelength solution**

- **cross-correlation** with suitable reference mask (G2, K5, M2) to calculate radial velocity of target. Barycentric correction.

- Bi-sector analysis of stellar line-profile (star spots?)

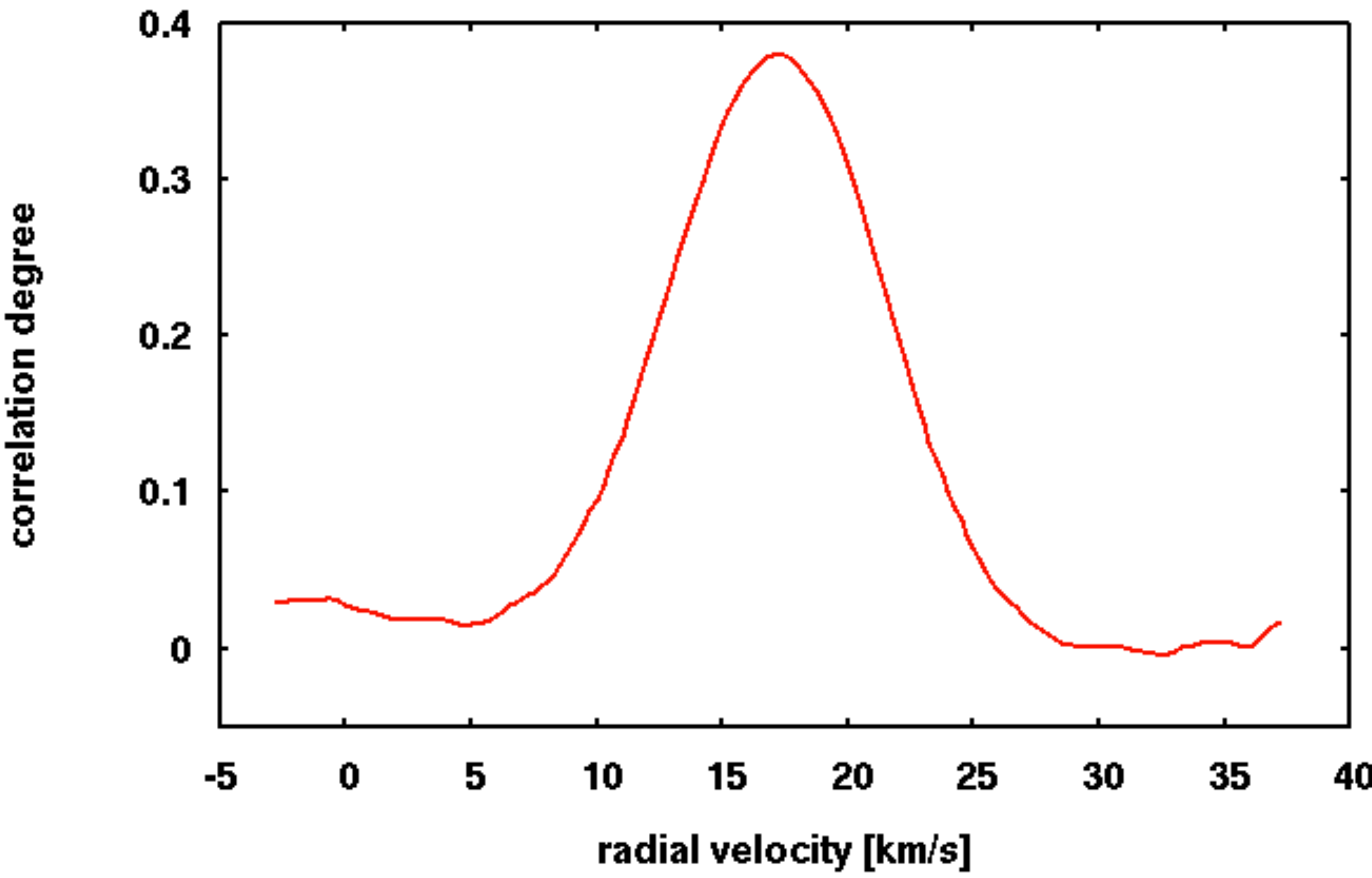
- **cross-correlation** with suitable reference mask (G2, K5, M2) to calculate radial velocity of target.



Result: cross-correlation function (CCF):

$$v_{rad} = c\ \Delta\lambda / \lambda$$

$$C(v) = \frac{\sum_k (M_k(v) O_k)}{\sqrt{\sum_k M_k(v)^2 \sum_k O_k^2}}$$



Raw science frame:

/data/raw/<date>/HARPS*.fits

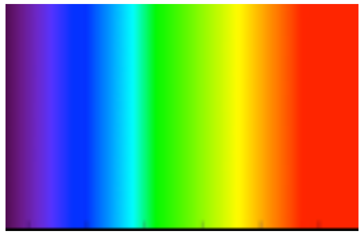
Reduced data products:

/data/reduced/<date>/

HARPS*_ccf_G2_A.fits ..... *CCF*
HARPS*_ccf_G2_A.tbl ..... *extracted RV per spectral order (72 orders)*
HARPS*_e2ds_A.fits .... *extracted spectrum, per order, fiber A*
HARPS*_s1d_A.fits .... *extracted and merged spectrum, fiber A*
HARPS*_bis_G2_A.fits ..... *bi-sector analysis*
HARPS*_INT_GUIDE.fits ... *integrated image of the guide camera*

OUTLOOK: HARPS+NIRPS

HARPS



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NIRPS

λ=381-691 nm
R~115,000, 1 m/s
80,000

λ=970-1810 nm
R~100,000, 1 m/s
80,000

simultaneous operations (2021)!