

HARPS

The Exoplanet Finder on La Silla

Florian Rodler (ESO)

Introduction

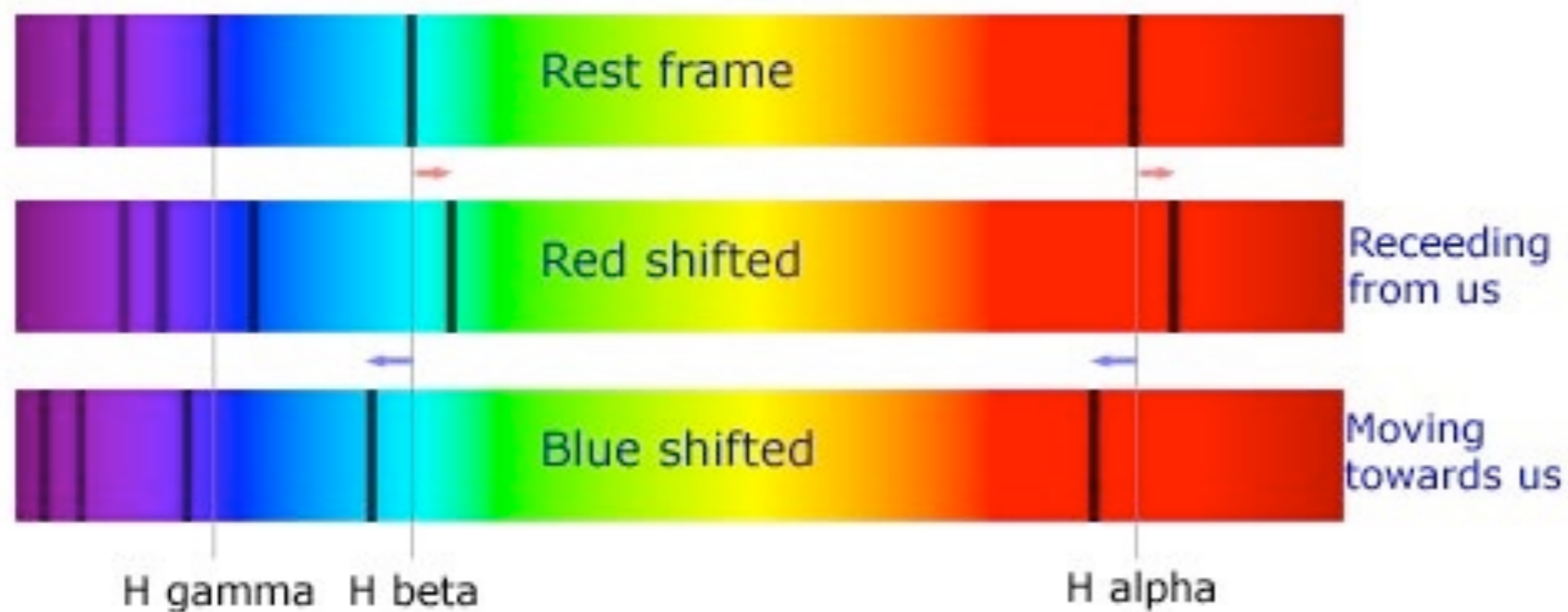


**HARPS =
High
Accuracy
Radial velocity
Planet
Searcher**

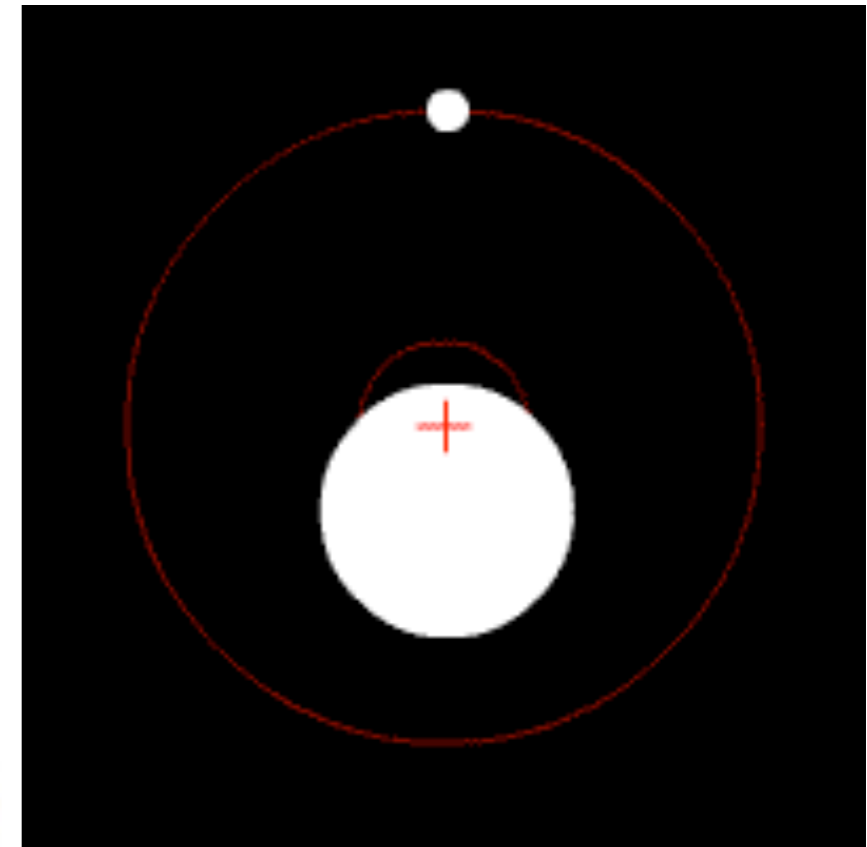
on the La Silla 3.6m telescope

Measure: **stellar absorption lines!**

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

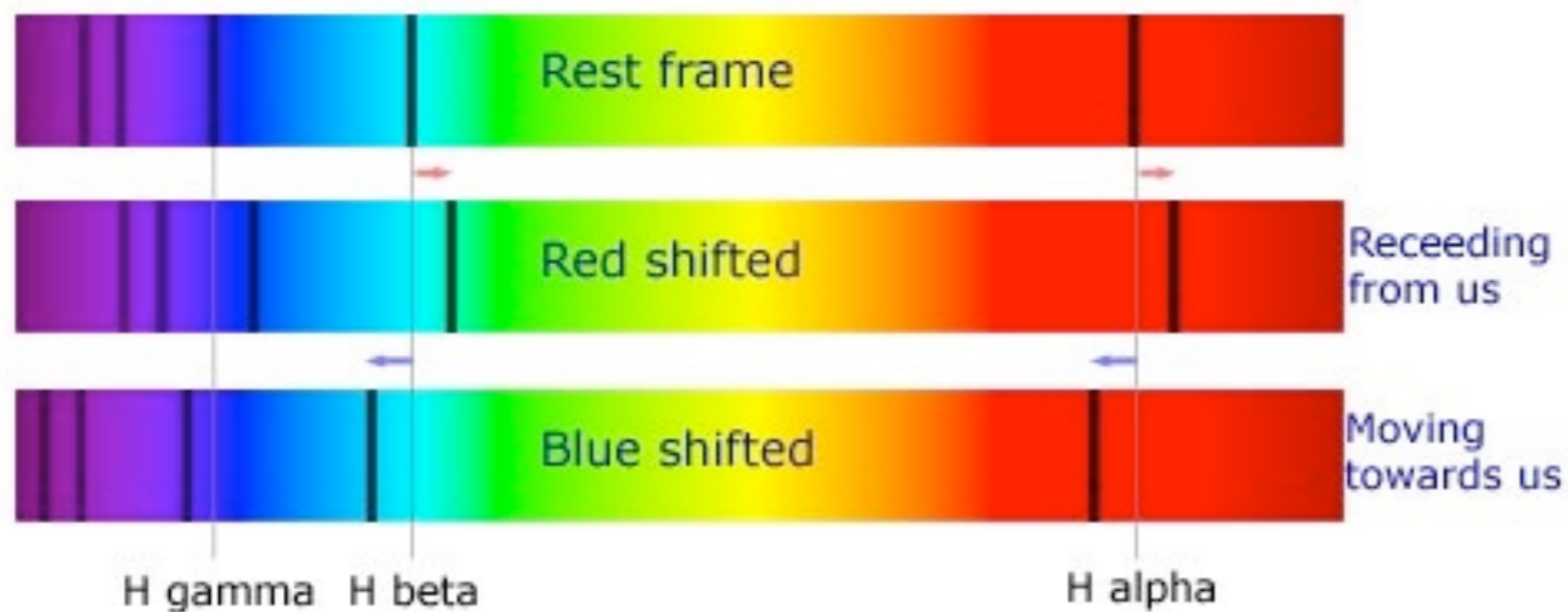


380 nm ← wavelength λ → **700 nm**

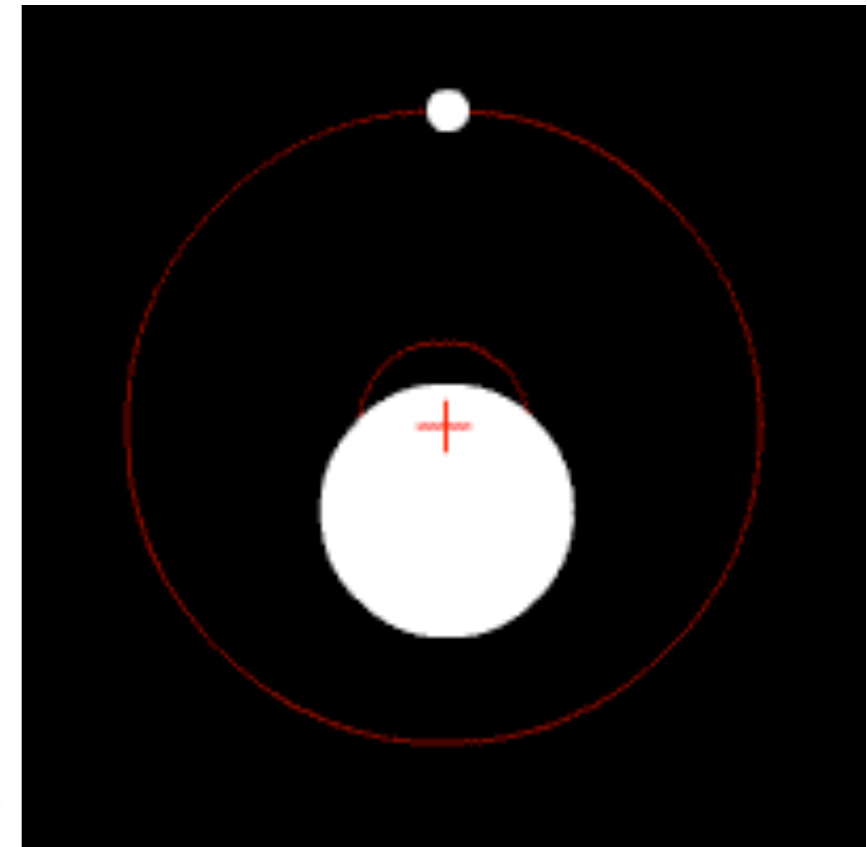


Finding exoplanets with the Radial Velocity technique

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



380 nm ←————→ **700 nm**
wavelength λ

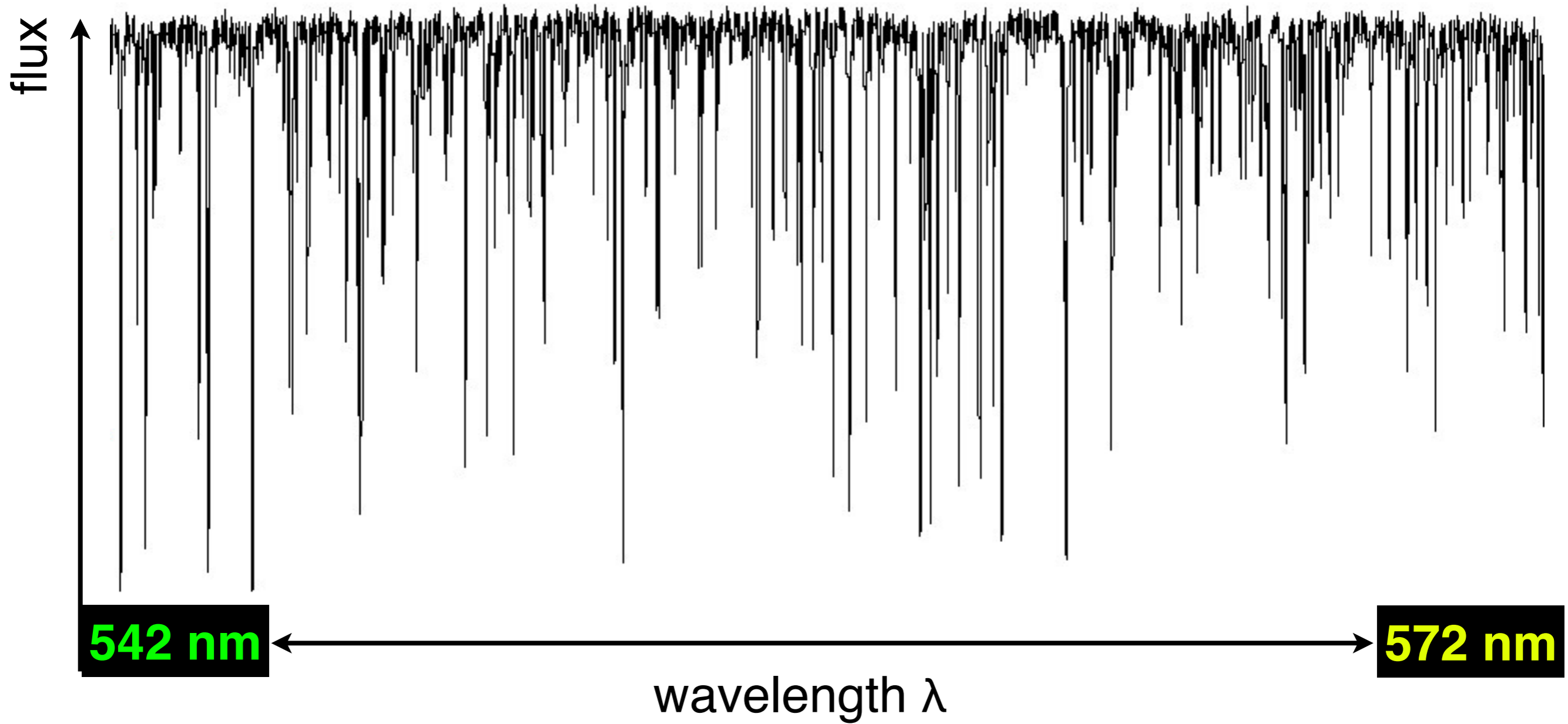




Solar spectrum on the detector of an Echelle spectrograph
(Courtesy Harvard-Smithsonian CfA)

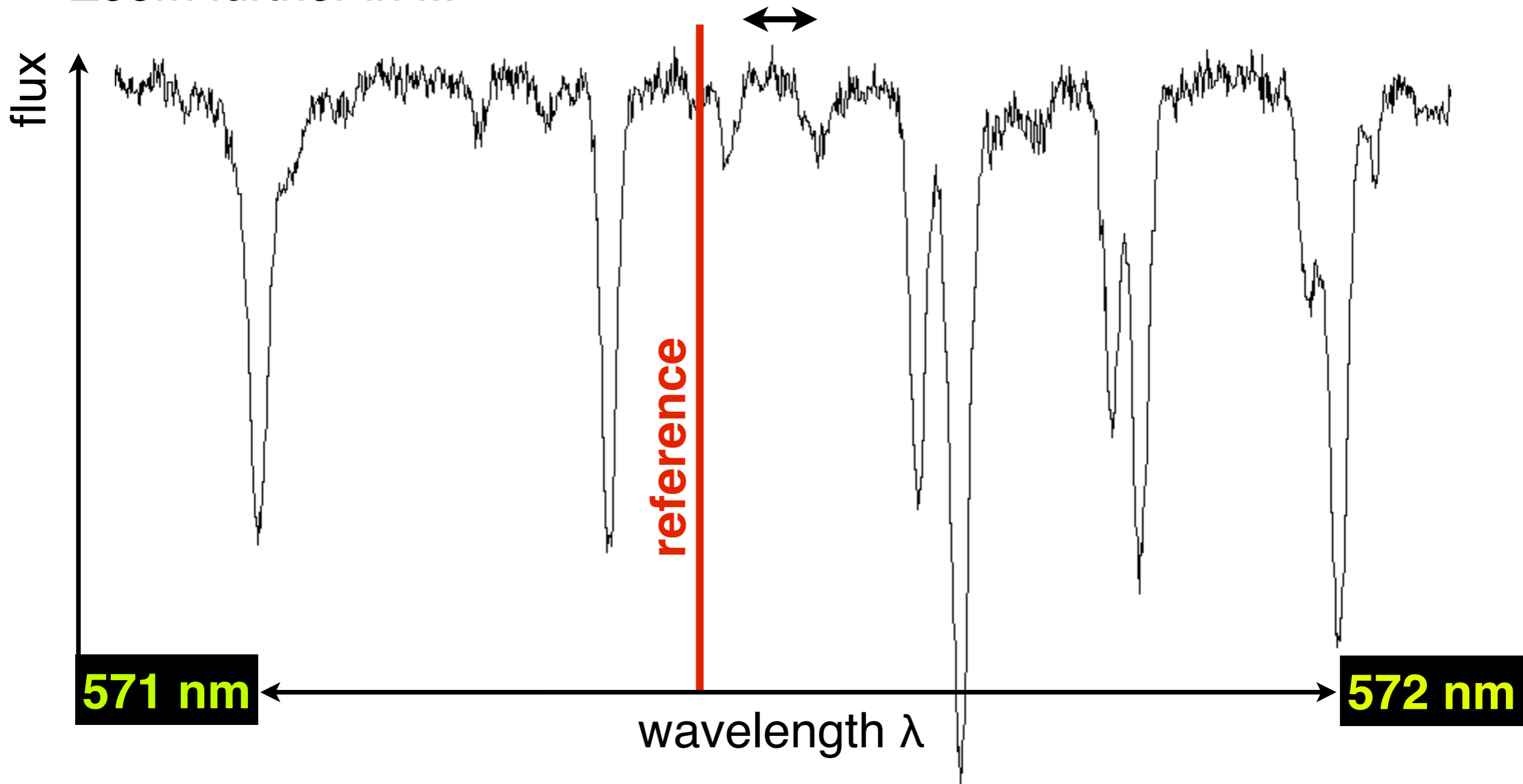
Finding planets with the Radial Velocity technique

Zoom in ...



Finding planets with the Radial Velocity technique

Zoom further in ...

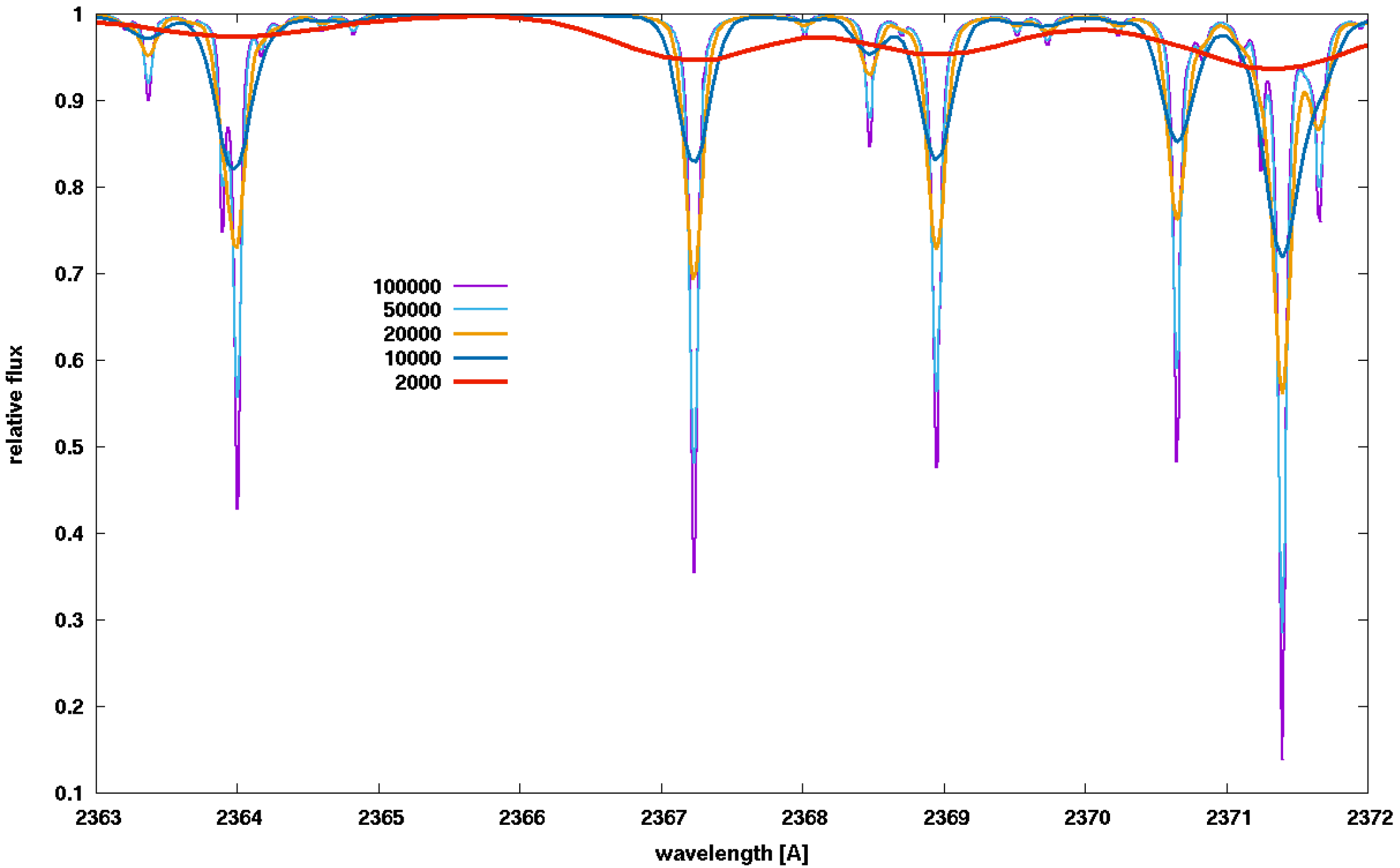


Try to detect Jupiter around the Sun:

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 ... $\sim 1/100$ of a pixel ... over 10 years)



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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)*

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How to achieve such a stability?

What possible error sources do you see?



Very high instrumental stability:

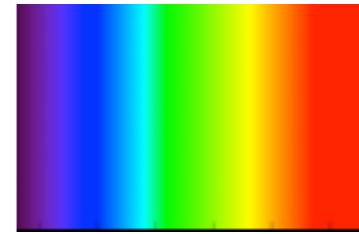
- **simultaneous wavelength calibration**
- **no moving parts** in the spectrograph, fixed spectral format, spectrograph not moving
- **in vacuum** (P and T stabilized)



HARPS

- *build by a consortium led by Geneva Observatory*
- *commissioned in 2003*

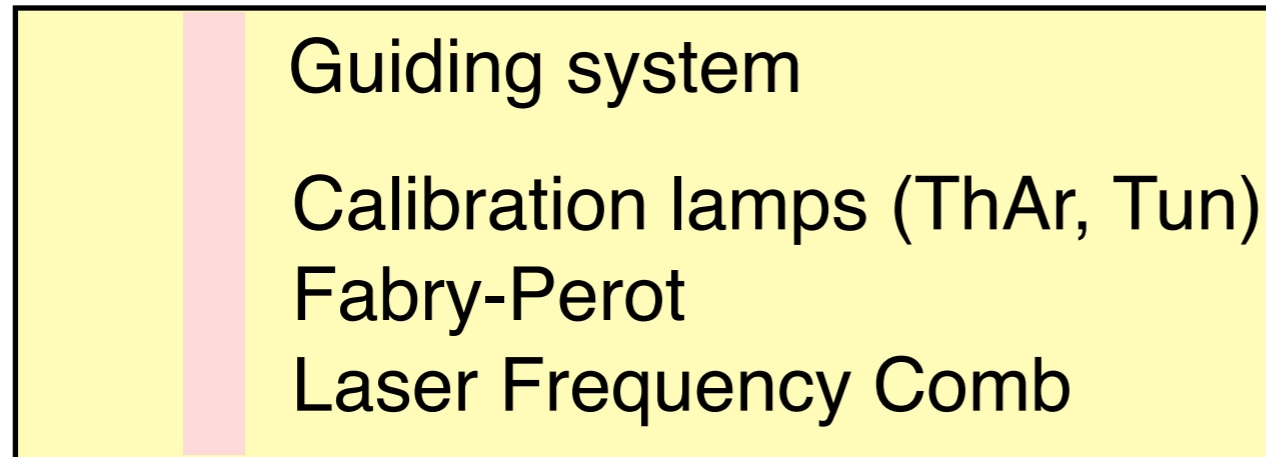
- **wavelength range: 381 - 691 nm;**
fixed spectral format, 72 orders,
simultaneous wave calibration



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

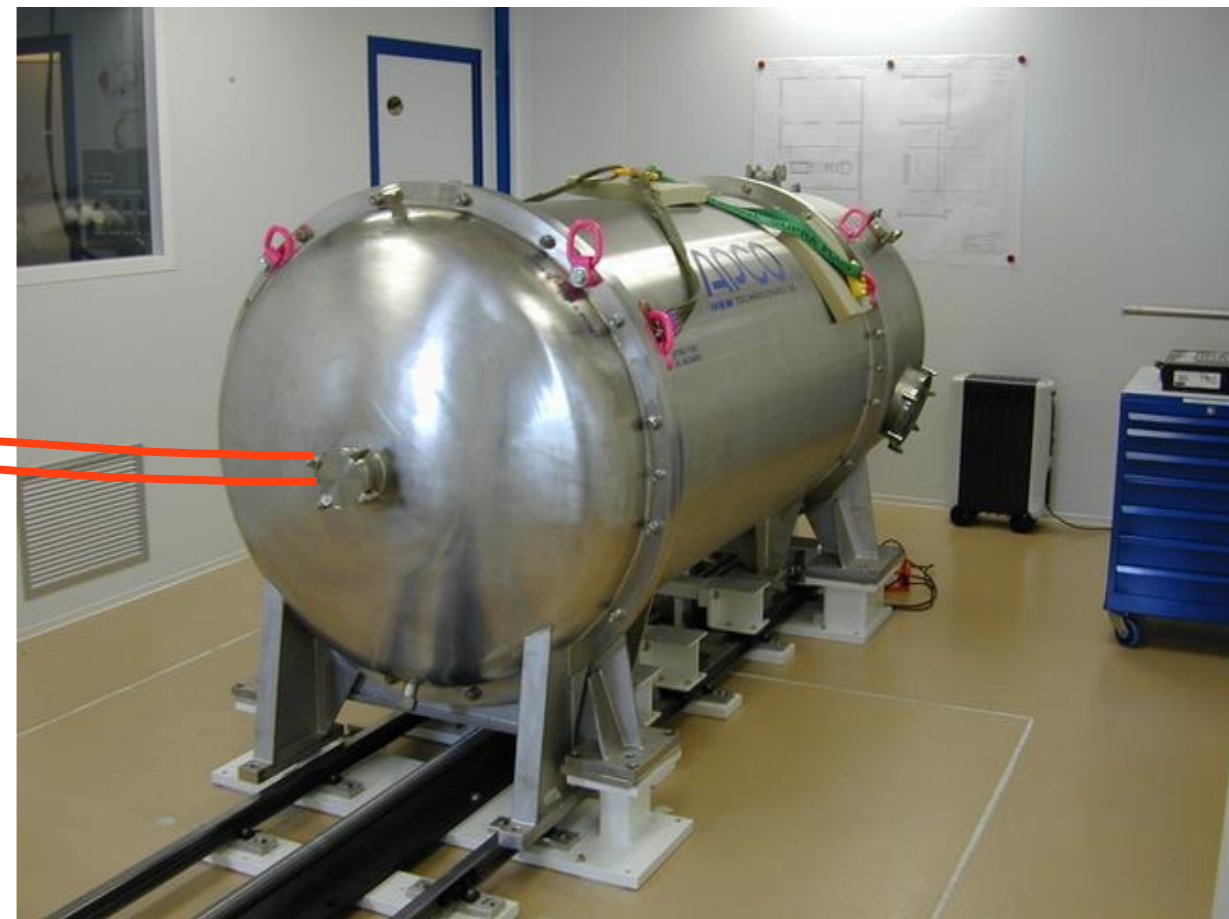
- Spectrograph in Coudé-room, connected via fibers to 3.6m telescope
- Pressure stability: $<10^{-3}$ mbar
- Temperature stability: 1 mK / day

Telescope



Fibers A+B

Spectrograph

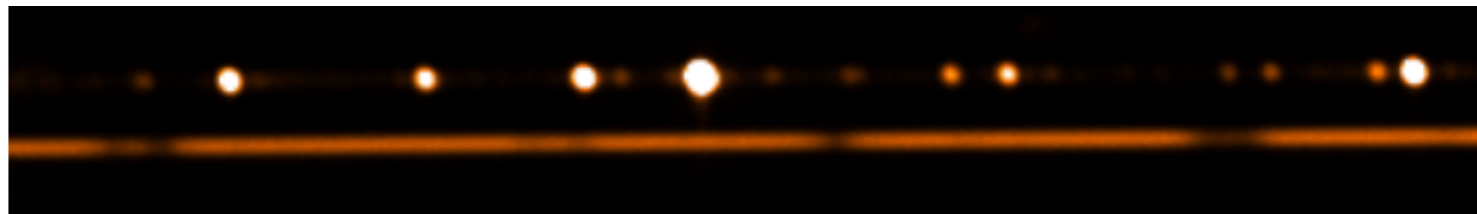


star sky,
 wave calib



Fibers A+B

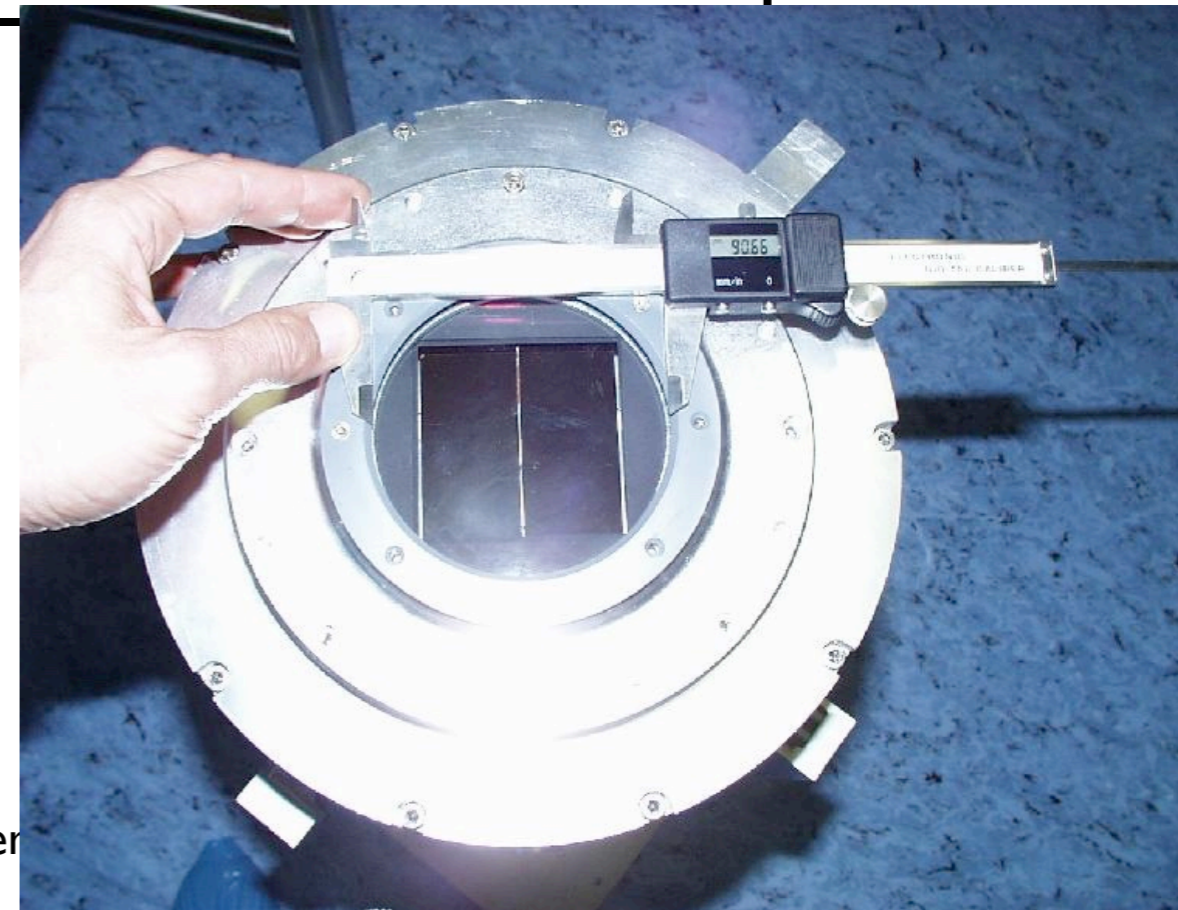
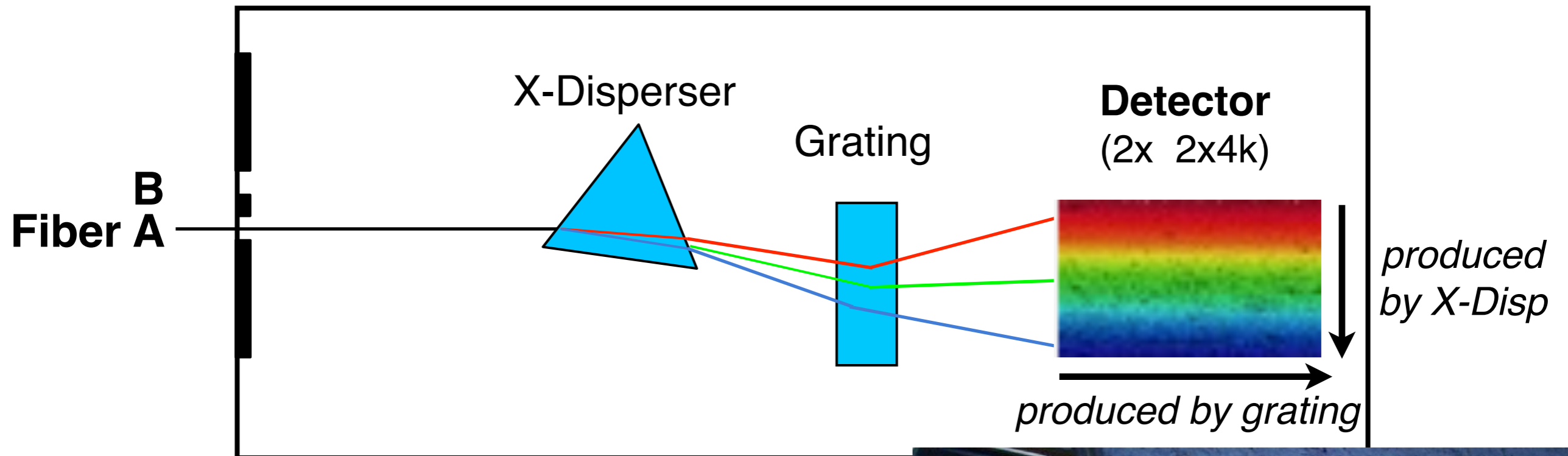
B
A

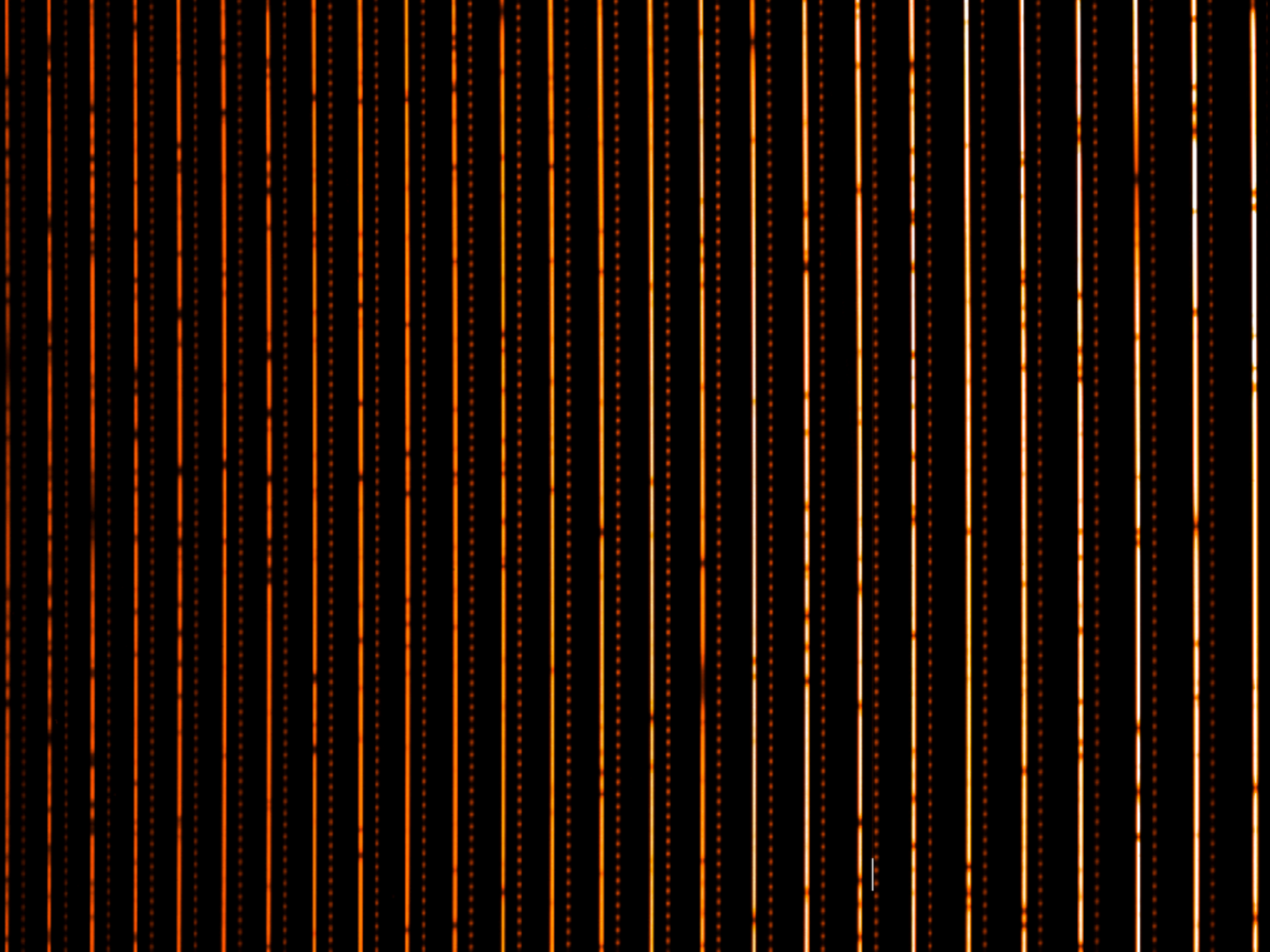


Spectrograph



Concept of Echelle Spectrograph

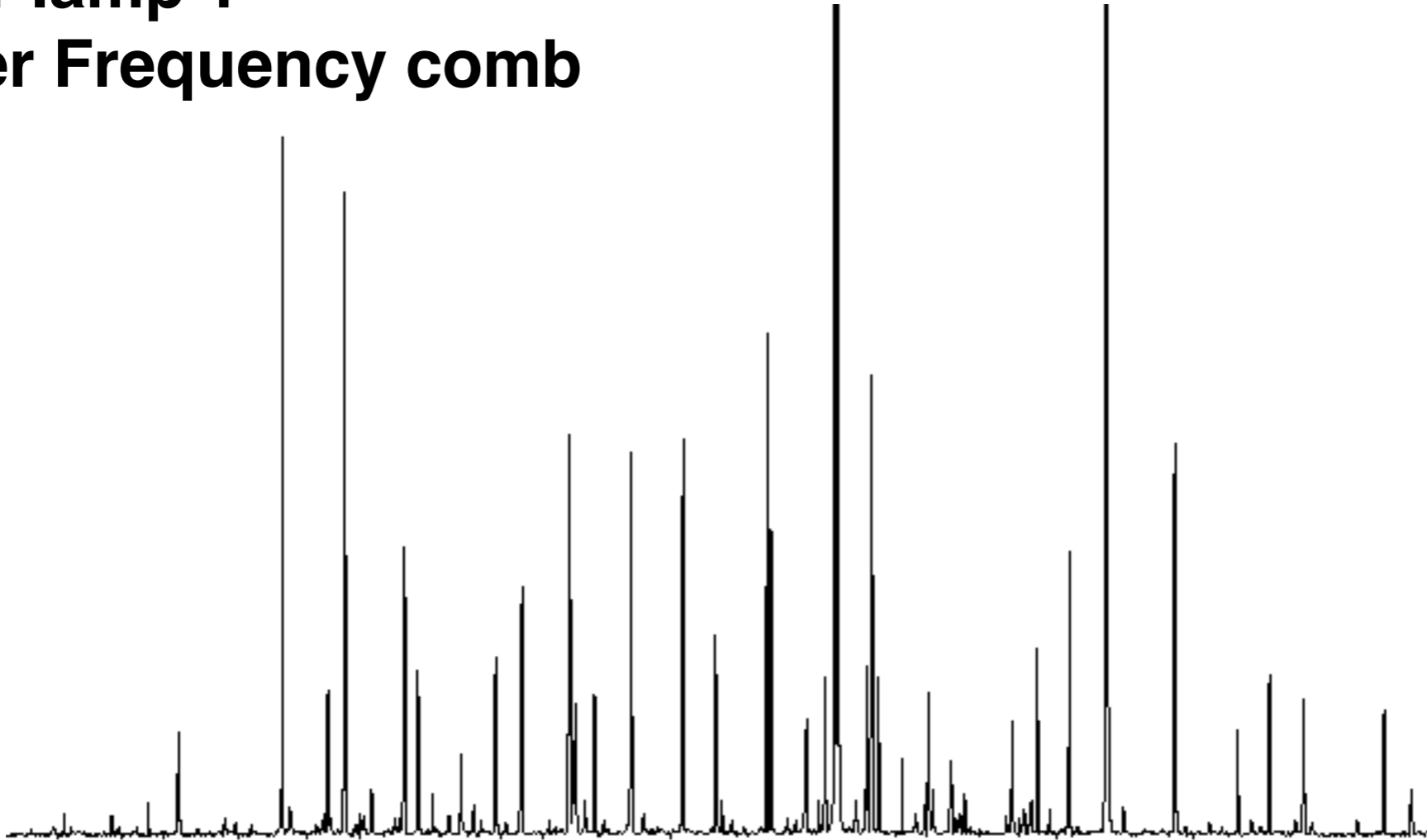




Daily Calibrations (afternoon before the observations!)

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

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



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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),

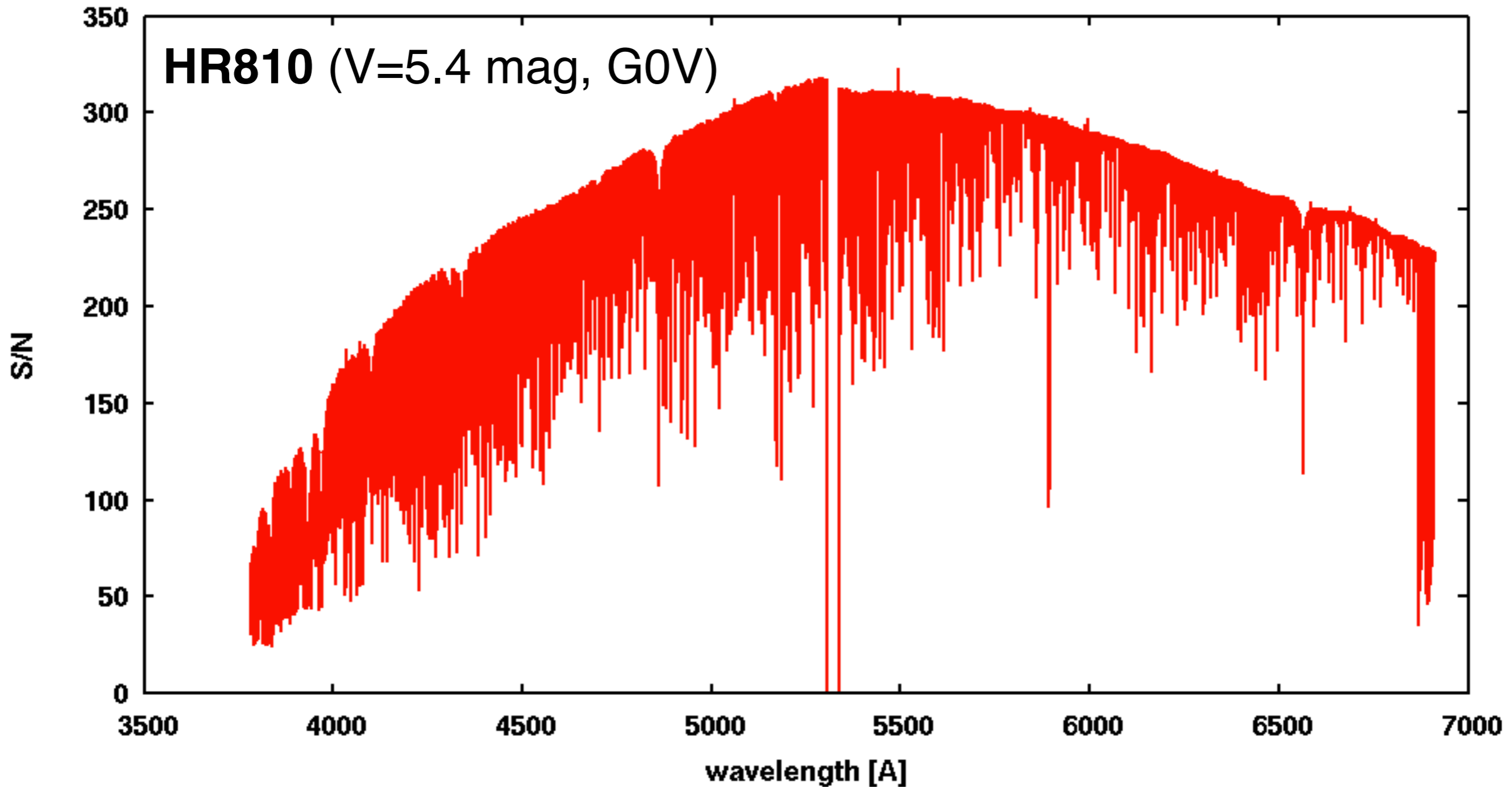
R~80,000

RV precision 3 m/s, 1.4" fibers A+B

Polarimetry: 1" fibers A+B

Observing with HARPS

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



Observing with HARPS

tkTrig, the HARPS trigger GUI (online mode) - version 5.14 - Partial logging mode - Trigger controlled plots

File Configure

Reduction Information Window

Information returned by Reduction Recipes

Flux correction not performed: no flux template available
Correlation fiber B: C=28.7[%] RV=14.27381[km/s] FWHM=1.6037[km/s]
On fiber B estimated RV accuracy on spectrum: 10.47[m/s]
On fiber B estimated RV accuracy on CCF : 144.30[m/s]
Recipe obj_TWO_harps is terminated

INSTRUMENT MODE: HARPS

Now processing Image TYPE: STAR,SKY,M1 with obj_TWO_harps rec
OB target name:

Raw Frames

/data/raw/2019-09-30

HARPS.2019-10-01T00:20:36.984.fits : G.	(STAR,SKY,M2
HARPS.2019-10-01T02:17:12.923.fits : G.	(STAR,SKY,M1
HARPS.2019-10-01T02:36:04.394.fits : G.	(STAR,SKY,M2
HARPS.2019-10-01T02:57:39.633.fits : G.	(STAR,SKY,M2
HARPS.2019-10-01T03:22:26.843.fits : TC	(STAR,SKY,M1
HARPS.2019-10-01T04:28:26.008.fits : G.	13 (STAR,SKY,M
HARPS.2019-10-01T07:51:45.653.fits : TC	(STAR,SKY,M0
HARPS.2019-10-01T08:24:38.151.fits : G.	(STAR,SKY,M2
HARPS.2019-10-01T08:58:21.730.fits : TC	(STAR,SKY,M0

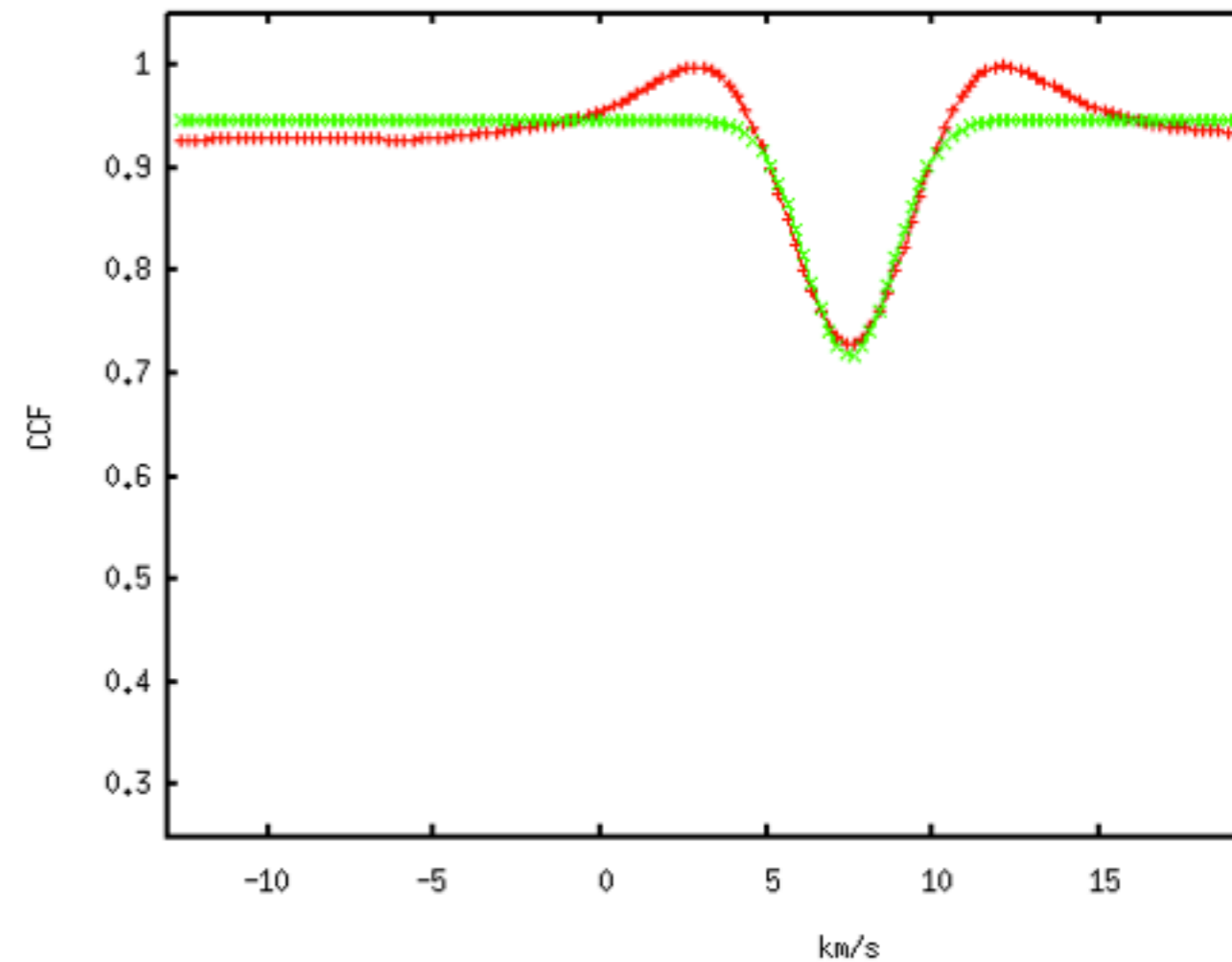
Reduction

Message

```
14:24:48.5 - * On fiber A estimated RV accuracy on CCF : 2.84[m/s]
14:24:48.6 - ~ hadgtVISU.megaplotfic('/tmp/plotA.1576679070',xmin=-13,xmax=28)
14:24:48.6 - ~ hadgtVISU.megaplotfic('/tmp/plotB.1576679070',xmin=-13,xmax=28)
14:24:48.6 - * Number of Cosmic corrected: 98 on fiber: B
14:24:48.6 - * Template used for CCF computation: M2
14:24:48.7 - * Flux correction not performed: no flux template available
14:24:49.9 - * Correlation fiber B: C=28.7[%] RV=14.27381[km/s] FWHM=1.6037[km/s]
14:24:50.1 - * On fiber B estimated RV accuracy on spectrum: 10.47[m/s]
14:24:50.1 - * On fiber B estimated RV accuracy on CCF : 144.30[m/s]
14:24:50.3 - * Recipe obj_TWO_harps is terminated
14:24:52.4 - * INSTRUMENT MODE: HARPS
14:24:54.5 - * Now processing Image TYPE: STAR,SKY,M1 with obj_TWO_harps rec
14:24:54.5 - * OB target name:
```

Gnuplot

Average CCF normalized with TPL= M2
C=24.2% RV=7.47443 km/s FWHM=3.0800 km/s

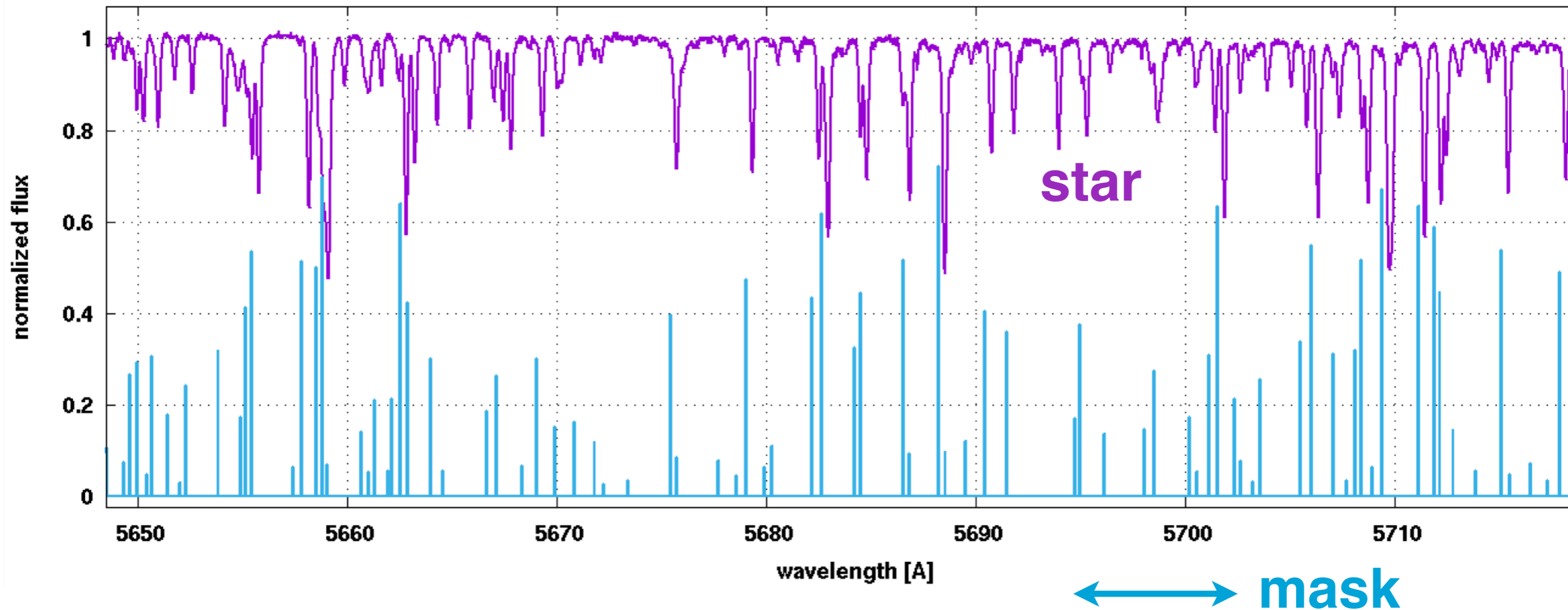


HARPS Pipeline (DRS)

- **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?)

Observing with HARPS

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

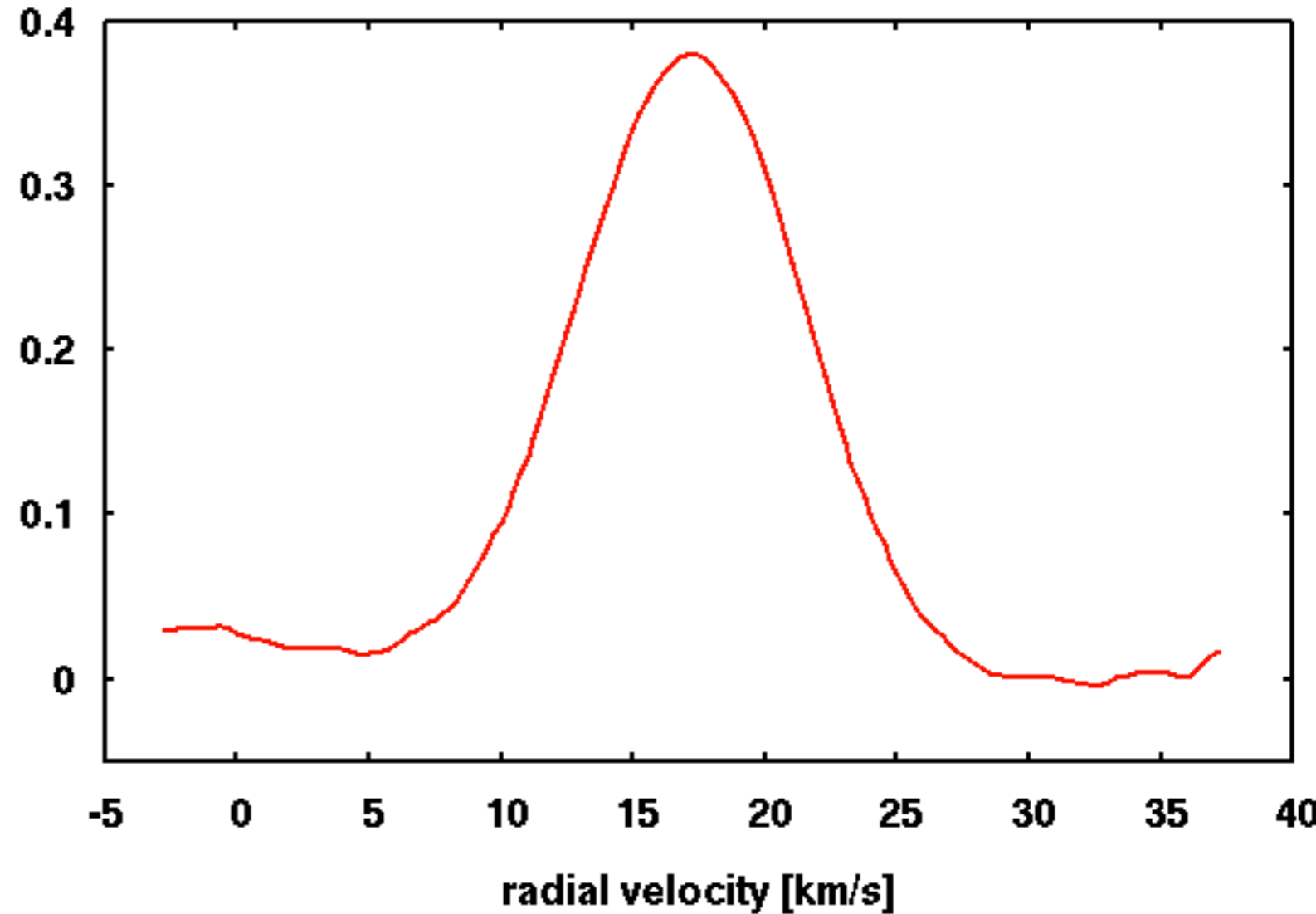


Result: cross-correlation function (CCF):

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

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

correlation degree



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)*

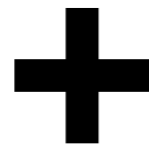
HARPS*_e2ds_A.fits *extracted spectrum, per order, fiber A*

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*

HARPS



NIRPS



$\lambda=381-691$ nm

**R~115,000, 1 m/s
80,000**

$\lambda=970-1810$ nm

**R~100,000, 1 m/s
80,000**

simultaneous operations (2021)!