# High resolution spectrographs

## Instrument Operation Team overview

HARPS, UVES, FLAMES, GIRAFFE, FEROS, CES, EMMI (echelle), CRIRES, VISIR

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# Instrument summary (optical):

HARPS/EGGS: 1”/1.4” fibre, x dispersed, fixed config.

CES: 2” fibre, scanning spectrograph.

FEROS: 2” fibre, cross dispersed, fixed configuration.

EMMI-echelle: slit, (cross) dispersed, order sort., 2-D.

UVES (FLAMES): slit+fibre, cross dispersed, two arms

GIRAFFE: fibre, scanning spectrograph

# Instrument summary (infrared):

CRIRES (NIR): 46” slit, 2-D scanning spectrograph.

VISIR (MIR): 32” slit, 2-D scanning spectrograph, also with a cross dispersed mode.

# Instrument summary (science):

| Instrument | Science |
|---|---|
| HARPS | 79% planets, 16% asteros., 5% others (atm., ISM) |
| FEROS | 46% RV, 24% Abundances, 30% others |
| CES | Line profiles, line splitting (Zeeman), ISM |
| EMMI-ech. | 5% of EMMI scheduled time: ~ 90% stellar atm. and PNs, 5% solar system, 5% others. |
| UVES+<br>UVES-FLAMES | IGM, ISM, circum. ~30%, chemical abund. ~ 30%, RV($I_2$) ~ 10%, others ~ 30%. |
| FLAMES-GIRAFFE | ~85% stellar pop., ~5% planets, ~ 5% kinematic of galaxies, 5% others. |
| CRIRES | 50% planet/star form., 38% stars, 4% ISM, 4% comets, 4% galactic center |
| VISIR | Star formation, obscured sources, UCHII, solar sys. |

# Instrument summary (pipelines):

All HR spectrographs are equipped with online pipelines, which, apart from performing the reduction of the data, supply the basic quality control parameters.

CES and EMMI-echelle only have “quick-look” scripts (SciOps) for online quality control.

HARPS pipeline is developed and maintained by the consortium and apart from delivering science products performs online QC.

# Calibration tasks

- Bias
- Dark
- Order localization
- Flat field
- Wavelength solution
- Absorption cell calibrations
- Flux standards
- Telluric standards
- Radial Velocity standards

# Calibration plan - HARPS

| Calibration | N | Freq. (1/day) | Purpose |
|---|---|---|---|
| Bias | 1 | 1 | Control bias |
| Dark | 3 | 30 | Control dark |
| Order definition | 2 | 1 | Pipeline calib.: order definition |
| Flat | 5 | 1 | Pipeline calib: flat fielding |
| Wavelength solution | 2 | 1 | Pipeline calib.: wavelength sol. |
| Solar spectrum | 1 | ~ 60, when weather allows, on calib. nights | Response to solar spectrum |
| Flux standard | 3 | ~ 30, when weather allows, on calib. nights | Instrument response & eff. |

# Calibration plan - UVES

**UVES Science Data Calibration Plan**
(per instrument and detector setting)

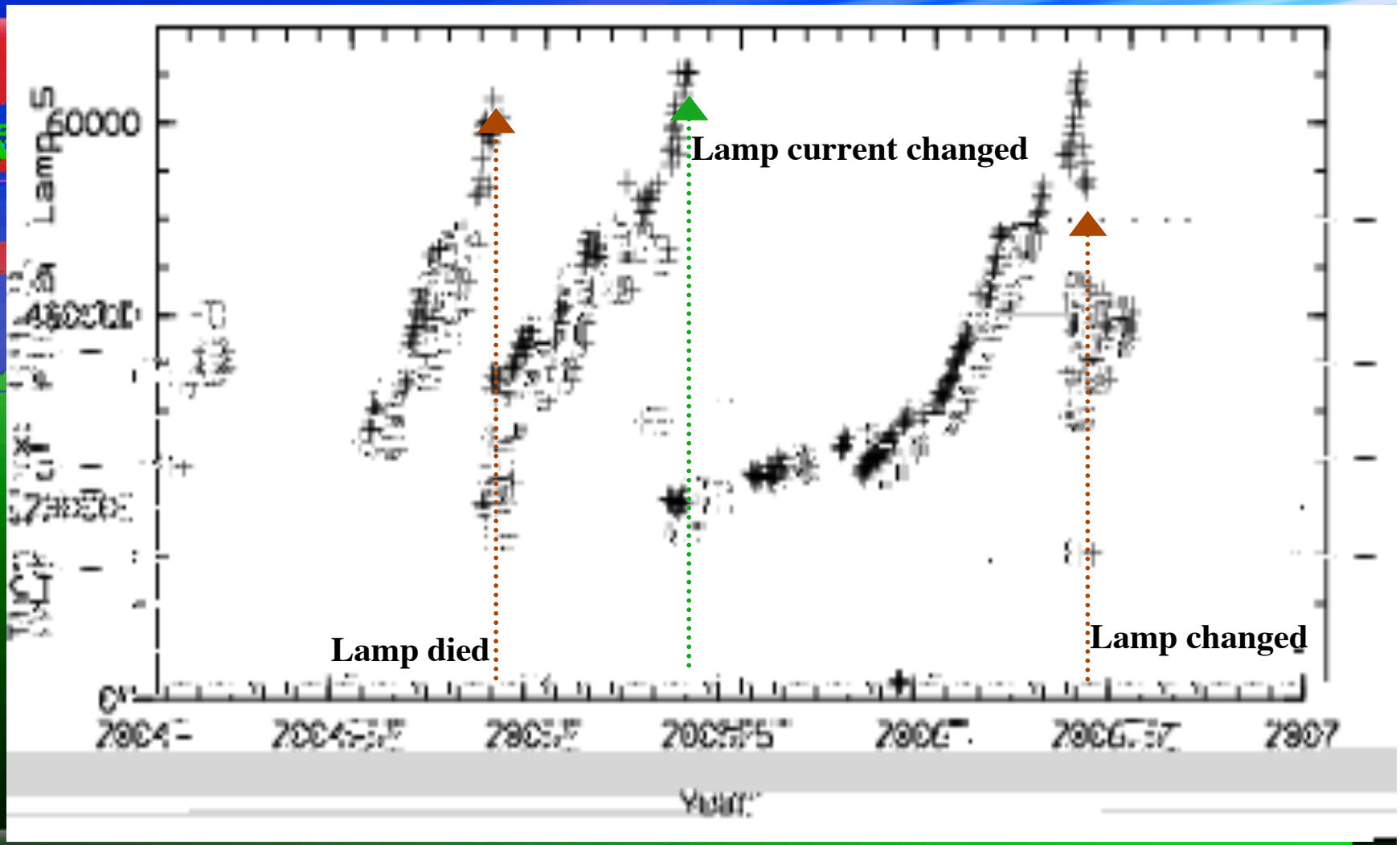
| Calibration | number | frequency [1/days] | purpose |
|---|---|---|---|
| Flatfields | 5 | 1 / 3 | creation of master flats |
| attached Flatfields | $n$ | o.r. | high-precision flatfielding |
| Wavelength | 1 | 1 / 1 | dispersion solution, resolving power |
| attached Wavelength | $n$ | o.r. | high-precision wavelength calibration |
| Order Definition | 1 | 1 / 3 | pipeline calibration: order definition |
| Format Check | 1 | 1 / 3 | pipeline calibration: physical model |
| Bias | 5 | 1 / 7 | creation of master biases |
| Dark | 3 | 1 / 30 | creation of master darks |
| Flux Standard | 1 | 1 / 1 | response correction, flux calibration |
| Telluric Standard | $n$ | o.r. | removal of telluric spectrum |
| Radial Velocity Std. | $n$ | o.r. | absolute radial velocity calibration |
| Iodine Cell Flatfields[1] | 5 | 1 / 1 | master flats for IP reconstruction |

[1] if iodine cell was used

o.r. = on request only, corresponding OBs to be provided by user

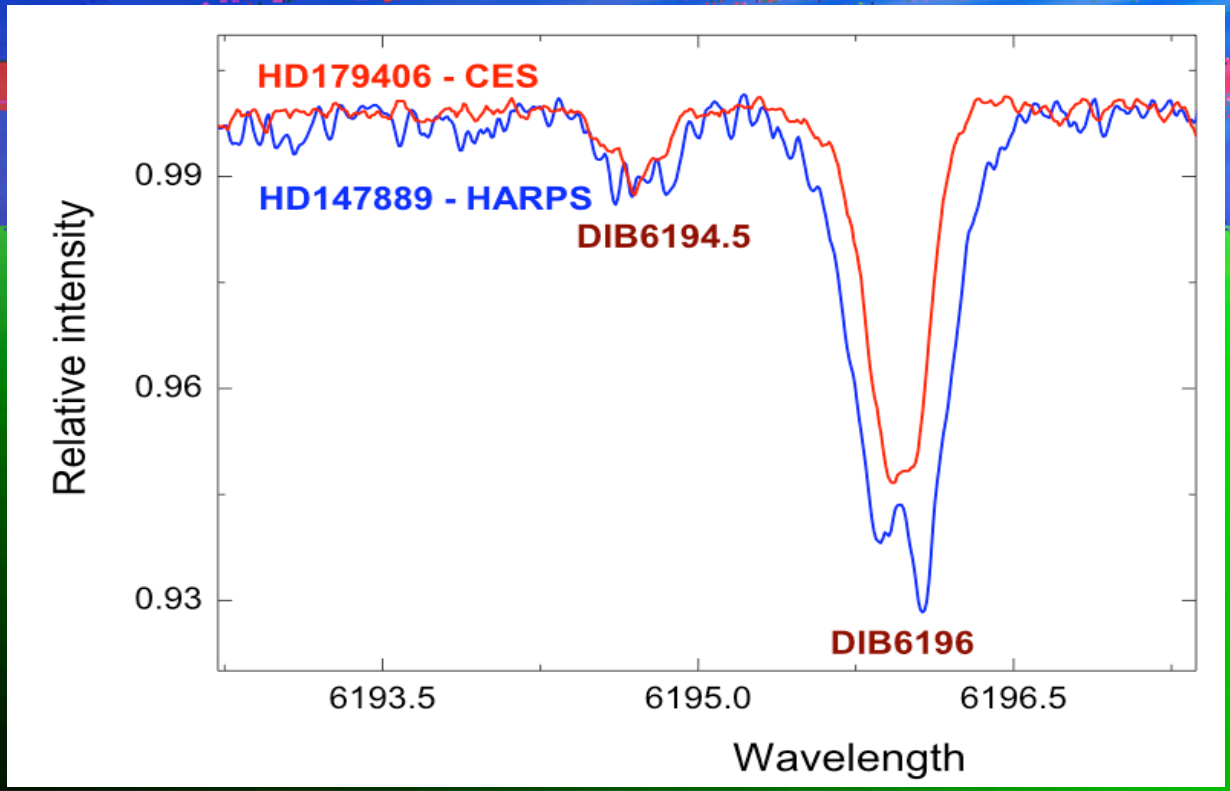
$n$ = number to be defined by user

# Monitoring & trending



# Flat fielding

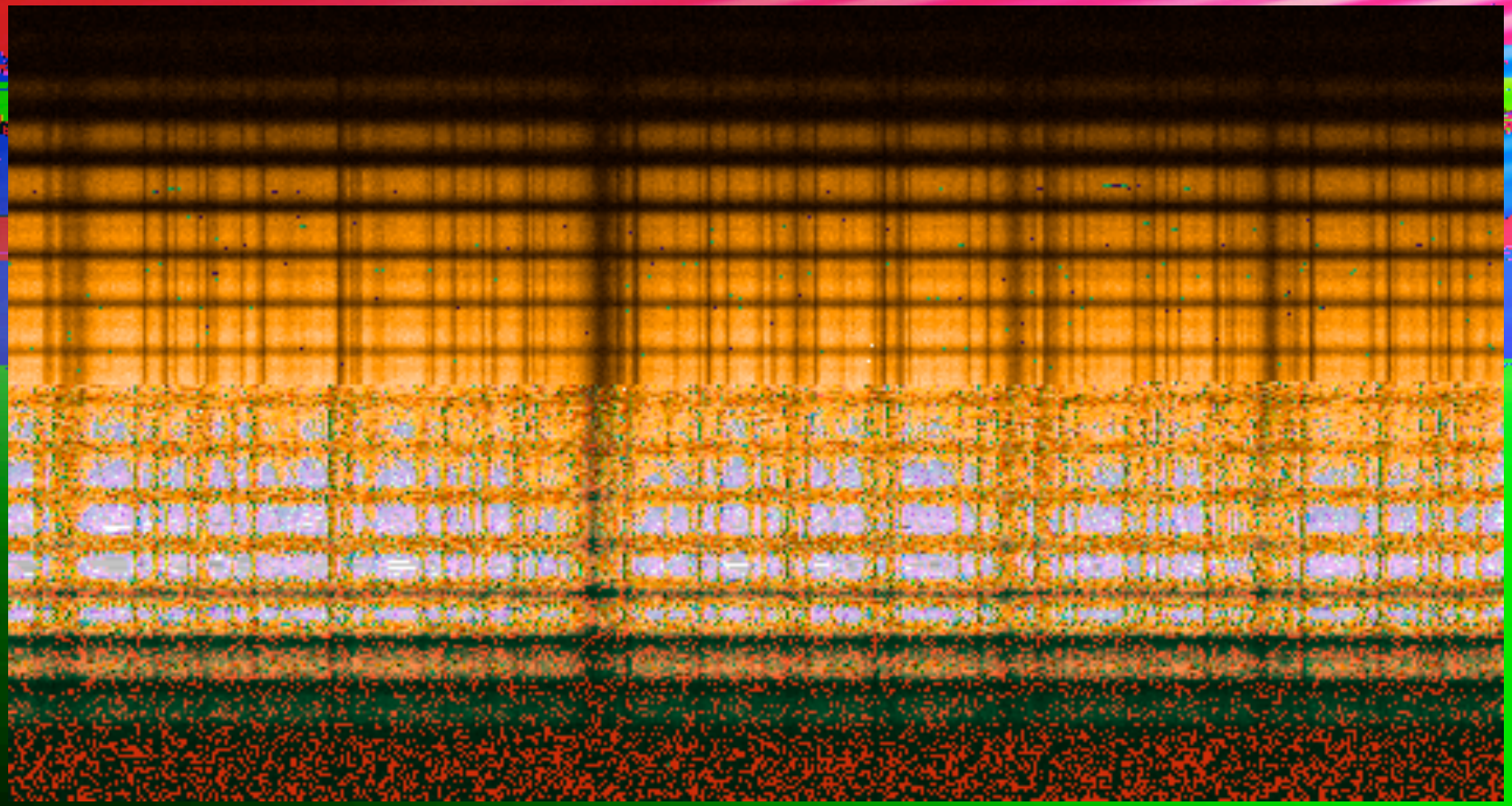
- Need very high signal to noise for specific applications (DIB, extra-solar planets atmospheres ?)




HARPS S/N:
~ 800 - 1200

Flat field:
50 frames of
5s each
(S/N~2000)

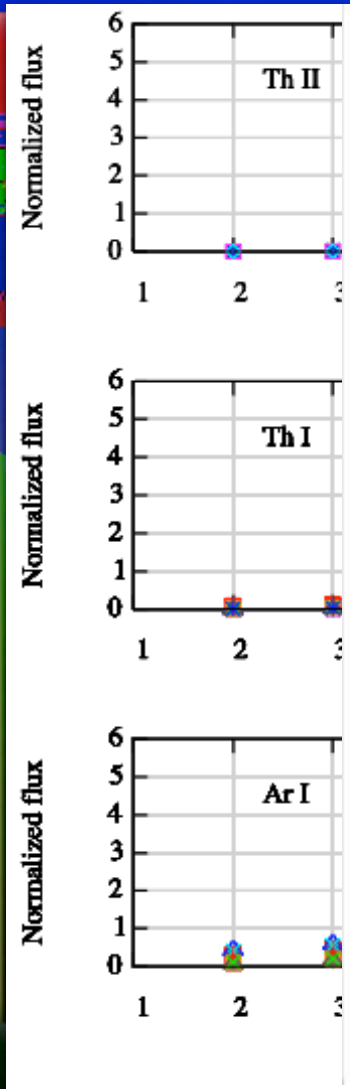
# Flat fielding

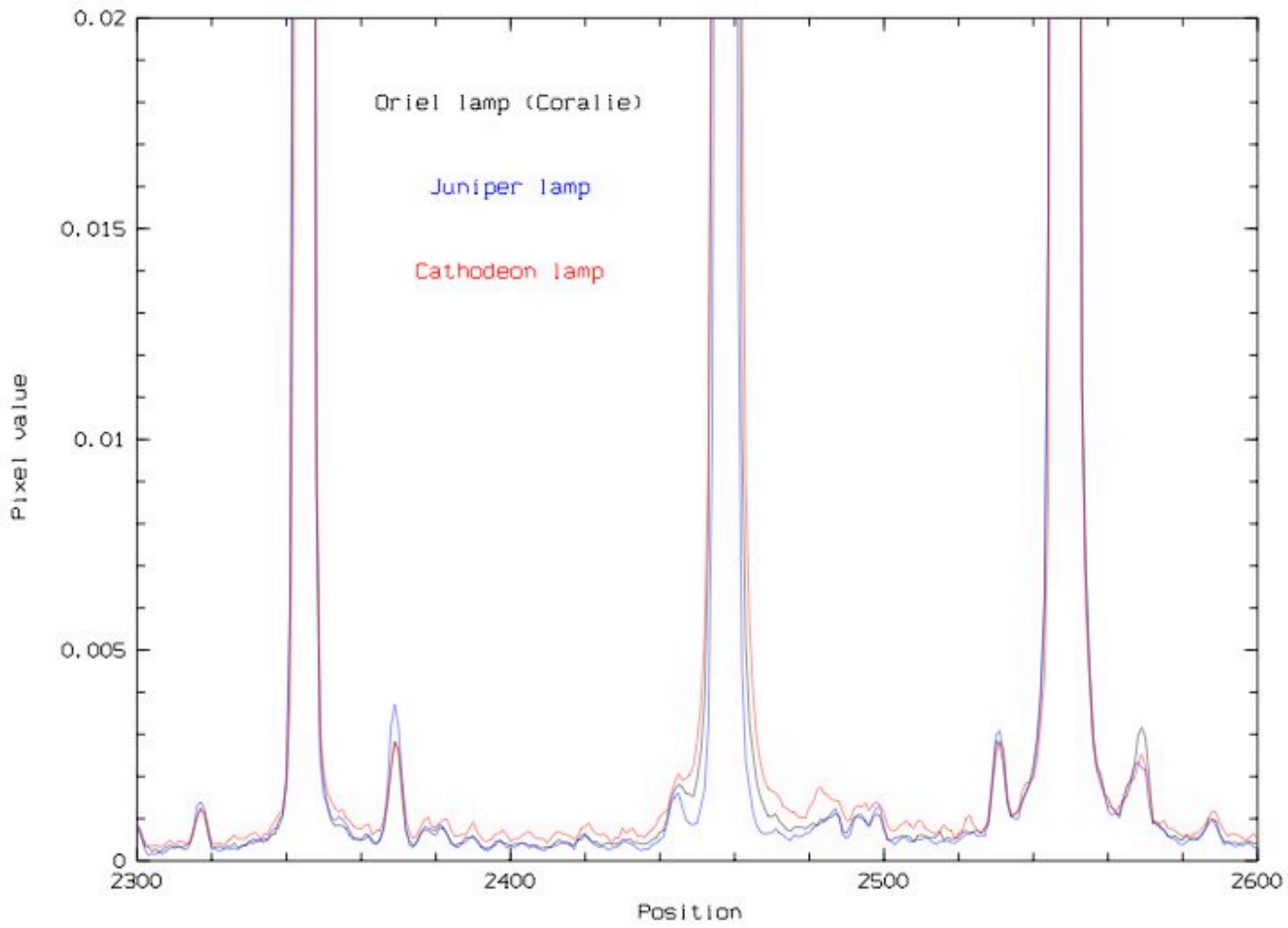


# Wavelength calibration

- Critical for high precision radial velocity determination (RV “content” of one pixel is ~ 900m/s for HARPS and UVES).
- Troublesome at some wavelengths (NIR, MIR) for lack of lines from an adequate calibrator.

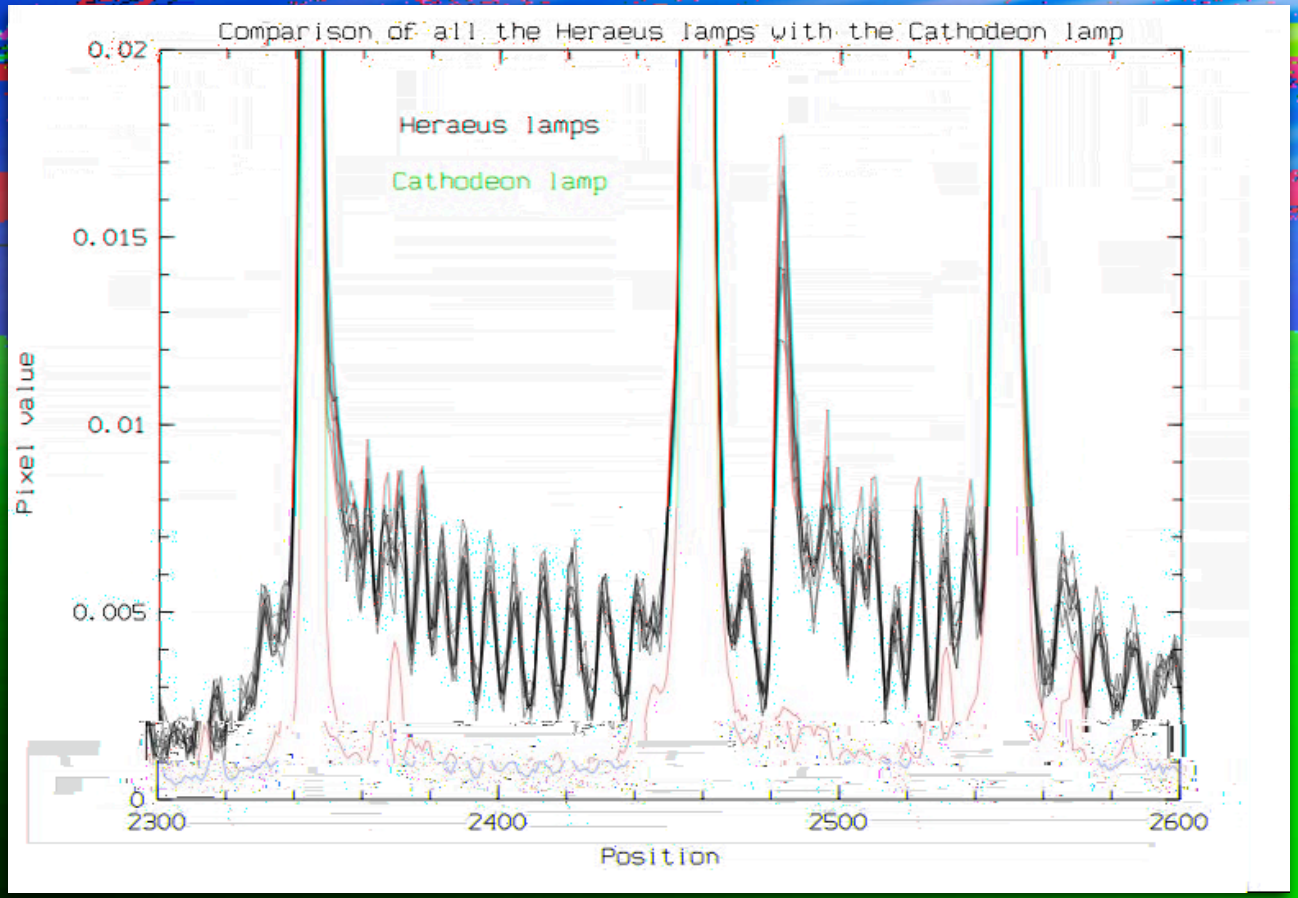
# Wavelength calibration



# Wavelength calibration

- Choice of source is critical



## Wavelength calibration (HARPS, FEROS, FLAMES)

HARPS FEROS and FLAMES (coupled with both UVES or GIRAFFE) make use of the method of simultaneous calibration with ThAr lamps to correct for variations of the Instrument Response Function (IRF) due to temperature or pressure changes within the spectrograph.
RV accuracy better than 1m/s has been reached with this method (HARPS).

# Wavelength calibration (EMMI echelle)

Exposure times for the arc in echelle mode is 30 minutes at minimum. It takes up to 8 hours blueward of 500nm (with ech. 14 and grism 3). An integrating

# Wavelength calibration (CRIRES - NIR)

There is not a single calibration source.
Depending from the wavelength and the density of lines, the most appropriate source is chosen.
An effort is being made to increase the number of identified Th lines (ESO-NIST).

| | | | |
|---|---|---|---|
| 950nm | -> | 2000nm | ThAr lines |
| 2000nm | -> | 4000nm | $N_2O$ absortpion cell |
| 4000nm | -> | 5400nm | Sky lines |

# Wavelength calibration (VISIR - MIR)

- Wavelength calibration: sky lines (comparison with atmospheric models)
- Movable grating, i.e. needs to calibrate each time it is used
- Problem: the grating moves during the exposure due to the limited accuracy of the scanner. Solutions: more accurate sensor or pipeline to correct with sky lines on each frame (before co-addition).

# Fringing

Fringing is an issue for UVES, CES (~ 30% redward of 650nm) and VISIR.

For UVES and CES FF exposures attached immediately before or after the science exposure correct well the effect (~5% residual fringing).

For VISIR fringing is corrected by divison of the extracted spectrum by the STD spectrum.

# Flux calibration

- Spectro-photometric standards are part of the calibration plan for the optical and the IR spectrographs.
- In the MIR the most accurate calibration is achieved via the normalization to the IRAS photometric fluxes (Cohen et al. 1999, AJ 117, 1864).

# Telluric standards

- HARPS: ignored, range 390nm-690nm.
- For the other spectrographs telluric standards are not part of the calibration plan and are left to the users to request (although spectro-photometric standards in VISIR at low resolution mode have mostly the role of telluric).

# Absorption cells

Two uses:

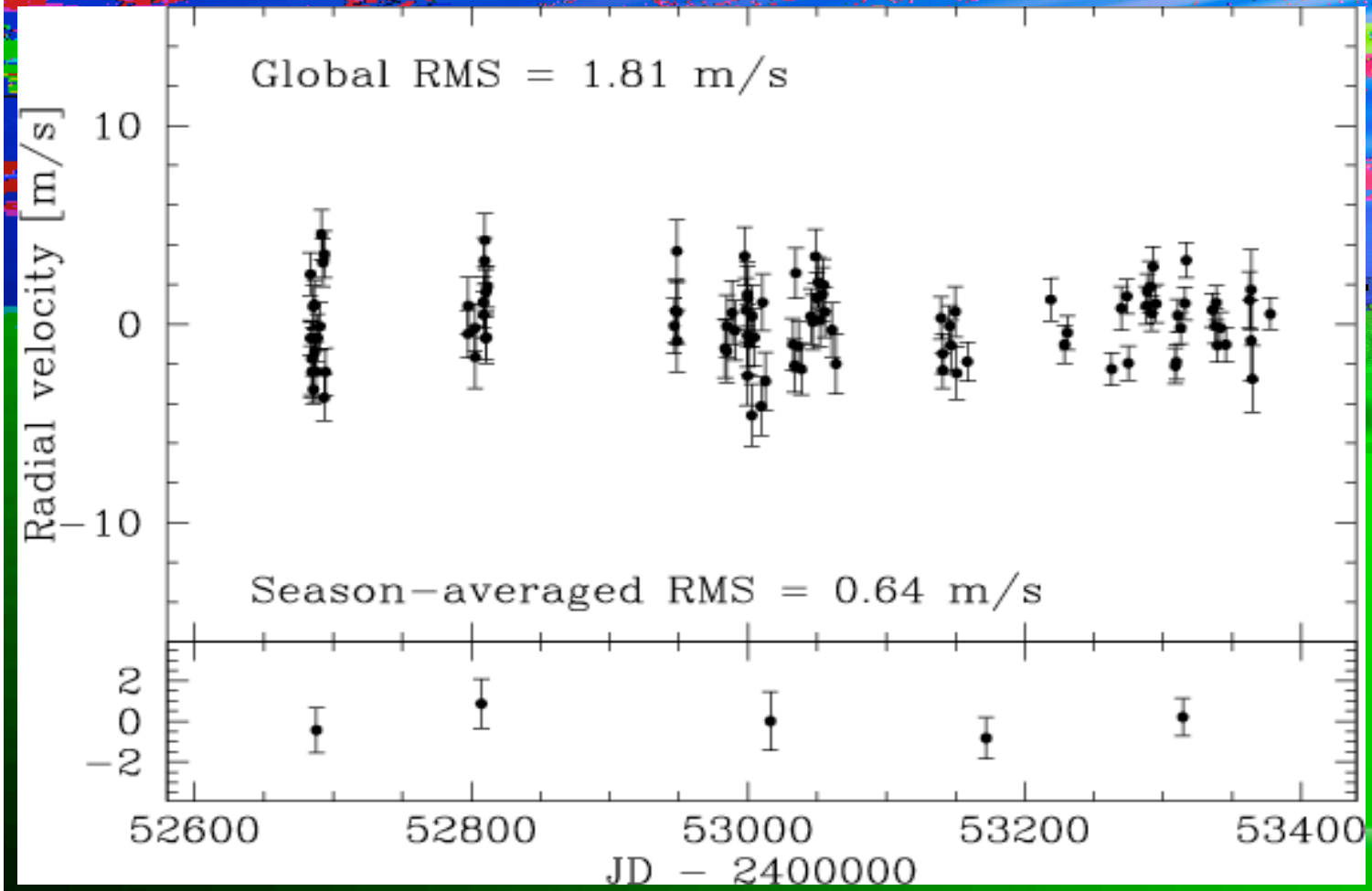
- wavelength calibration ($N_2O$, CRIRES)
- IRF tracking (for accurate RV: CRIRES, UVES with $I_2$)

Formerly $I_2$ cells were also used in HARPS and CES for planet searches.

# Radial velocity standards

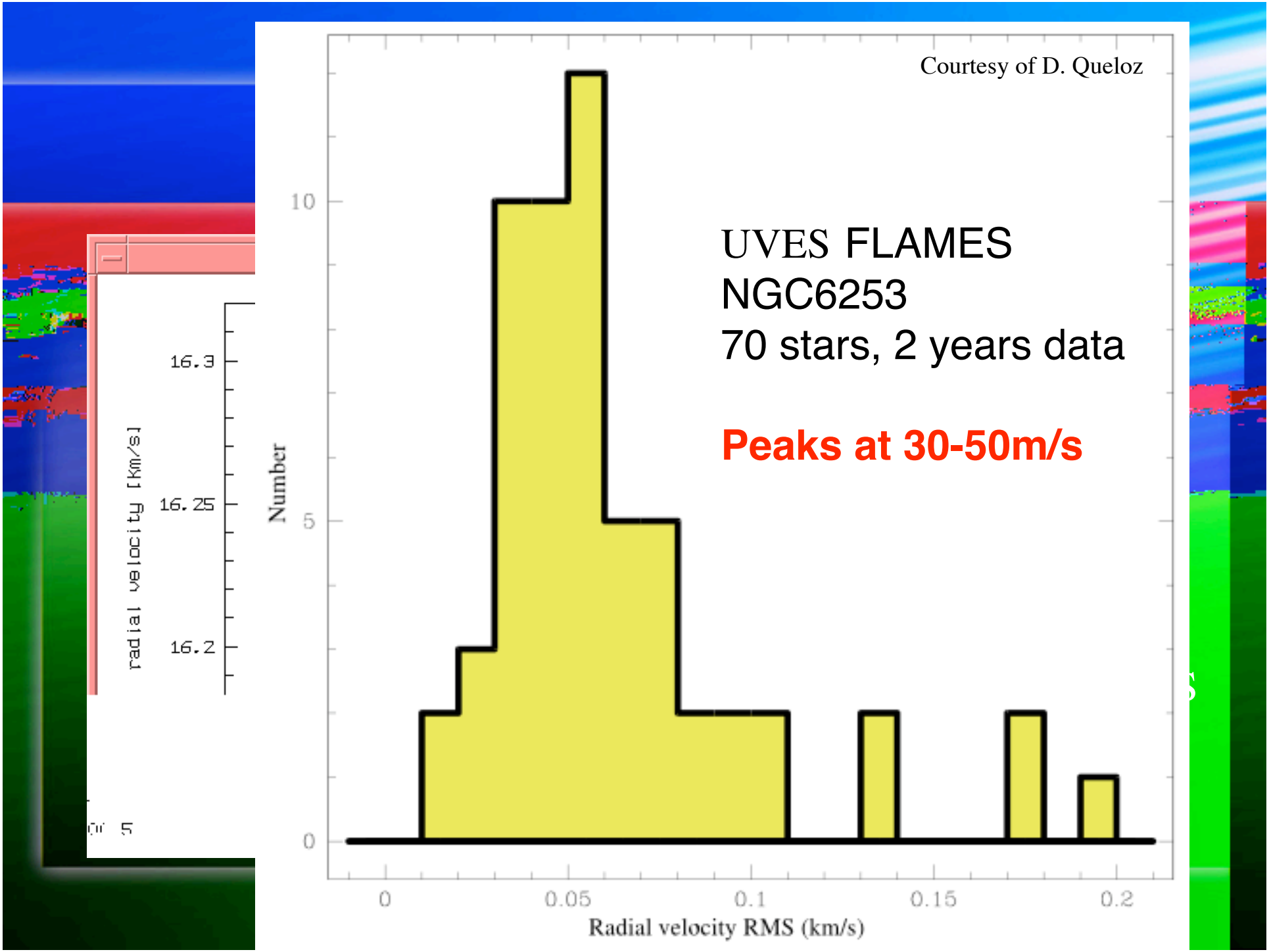
- HARPS: do they exist ?
- Others: use Coralie (accurate to ~ 5m/s) or Elodie (accurate to ~ 10m/s) standards.

# Radial velocity accuracy (the HARPS case)




2006)

C. Lovis et al., A&A 437, 1121 (2005)


Courtesy of D. Queloz
UVES FLAMES
NGC6253
70 stars, 2 years data
Peaks at 30-50m/s
Number
10
5
0
0
0.05
0.1
0.15
0.2
Radial velocity RMS (km/s)
radial velocity [Km/s]
16.3
16.25
16.2

# Conclusions

- Standard calibration plans suffice for most of the applications.
- Standard calibration plans allow to reach the top RV accuracies achievable for the instruments.
- Difficulty of a precise wavelength calibration is a common issue of several high resolution spectrographs.
- Still, we have a dream…

# The dream…

An alternative wavelentgh calibration source satisfying the requirement of **extreme stability** and **high density of spectral features from the optical to the IR** wavelength ranges.

# Instrument pipelines (HARPS):

The HARPS pipeline is a "living being", going towards several steps of evolution.

A reduction machine is installed in Garching to re-reduce all archived data anytime there is a new release of the software.

The idea is not to "leave behind" the general users, but rather to have them benefit from the experience accumulated.

# Calibration plan - FEROS

| Calibration | number | frequency [1/days] | purpose |
|---|---|---|---|
| Internal Flatfields | 10 | 1 / 1 | creation of master flats |
| attached Flatfields | $n$ | o.r. | high-precision flatfielding |
| Dome Flatfields | $n$ | o.r | Fringe correction in red orders |
| Internal Wavelength | 12 | 1 / 1 | dispersion solution, resolving power |
| attached Wavelength | $n$ | o.r. | high-precision wavelength calibration |
| Bias | 5 | 1 / 1 | creation of master biases |
| Dark | 1 | 1 / 10 | creation of master darks |
| Flux Standard | $n$ | o.r. | response correction, flux calibration |
| Telluric Standard | $n$ | o.r. | removal of telluric spectrum |
| Radial Velocity Std. | $n$ | o.r. | absolute radial velocity calibration |

o.r. = on request only, corresponding OBs to be provided by user

$n$ = number to be defined by user

# Calibration plan - CES

| Calibration | N | Freq. (1/day) | Purpose |
|---|---|---|---|
| Bias | 5 | 1 | Bias calibration |
| Dark | 3 | 1/run | Dark calibration |
| Flat/order def. | 5 | 1* wavelength change*X | flat fielding |
| Wavelength solution | 1 | 1* wavelength change*X | wavelength sol. |
| Telluric | 1 | 1, when obs. at $\lambda$>650nm | Telluric removal |
| Flux standard | 3 | ~ 90, when weather allows, on calib. nights | Instrument response & eff. |

X < 4: whenever the spectrum drift more than 0.2 pixels

# Calibration plan - EMMI echelle

| Calibration | N | Freq. (1/day) | Purpose |
|---|---|---|---|
| Bias | 5 | 1 | Bias calibration |
| Flat | 3/setup | 1 | flat fielding |
| Wavelength solution | 3 | 1 | wavelength sol. |
| Spectrophotom. STD | 1 | 1/setup | Flux calibration |

# Calibration plan - FLAMES-UVES

**FLAMES – UVES Science Data Calibration Plan**

(per instrument setting, i.e. plate, fibre mode, and central wavelength)

| Calibration | number | frequency [1/days] | purpose |
|---|---|---|---|
| Fibre Flatfields | 3 | 1 / 1 | pixel-to-pixel sensitivity vari |
| | | | fibre-to-fibre transmission |
| | | | fibre localisation |
| | | | fibre PSF modelling |
| | | | blaze correction |
| Slit Flatfields | 3 | 1 / 7 | pixel-to-pixel sensitivity vari |
| attached Fibre Flatfields | $n$ | o.r. | high-precision flatfielding |
| Wavelength | 1 | 1 / 1 | dispersion solution |
| | | | resolving power |
| Sim. Fibre Order Definition | 1 | 1 / 1 | order and background defini |
| Sim. Fibre Format Check | 1 | 1 / 1 | dispersion guess solution |
| Bias | 5 | 1 / 1 | master biases, bias characte |
| Dark | 3 | 1 / 30 | master darks, dark current, |

# Calibration plan - FLAMES-GIRAFFE

FLAMES—GIRAFFE Science Data Calibration Plan

(per instrument setting, i.e., plate, fibre mode, resolution and central wavelength)

| Calibration | number | frequency (1/days) | purpose |
|---|---|---|---|
| Flatfields | 1 | 1 / 1 | pixel-to-pixel sensitivity vari<br>fibre-to-fibre transmission<br>fibre(=spaxel) localisation |
| shifted Flatfields | n | n.r. | high-precision flatfielding |
| Wavelength | 1 | 1 / 1 | dispersion solution<br>resolving power<br>slit geometry |
| Bias | 5 | 1 / 1 | master biases, bias characteri |
| Dark | 5 | 1 / 30 | master darks, dark current, |
| IFU: Flux Standard | n | n.r. | response correction, flux cali |
| ↳ shifted Flats | n | n.r. | rel. trans. IFU away / Sky |
| ARGUS: Flux Standard | 1 | 1 / 1 | response correction, flux cali |
| ↳ shifted Flats | 5 | 1 / 1 | rel. trans. ARGUS away / S |

n.r. = on request only, corresponding CRs to be provided by user

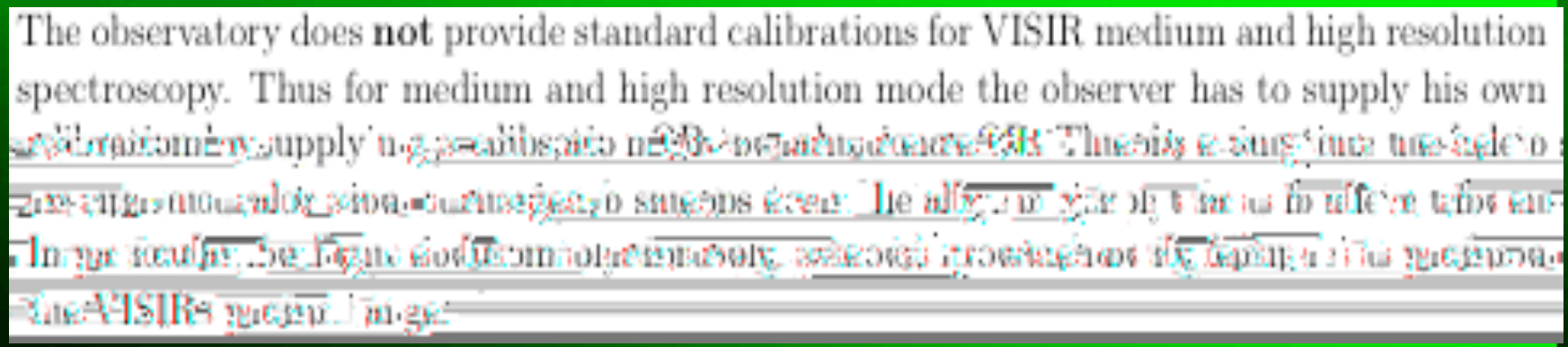
n = number to be defined by user

# Calibration plan - CRIRES

| Calibration | Frequency | Purpose |
|---|---|---|
| Dark | 1/day | Dark subtraction |
| Flat field | 1/day | Flat field calibration |
| Distortion map<br>photon transfer | 1/year<br>1/warmup | System characterization |

# Calibration plan - VISIR

Photometric standards from a subsample (12) of: Cohen et al. 1999, AJ 117, 1864
every three hours during the night (in SM).


The observatory does **not** provide standard calibrations for VISIR medium and high resolution spectroscopy. Thus for medium and high resolution mode the observer has to supply his own