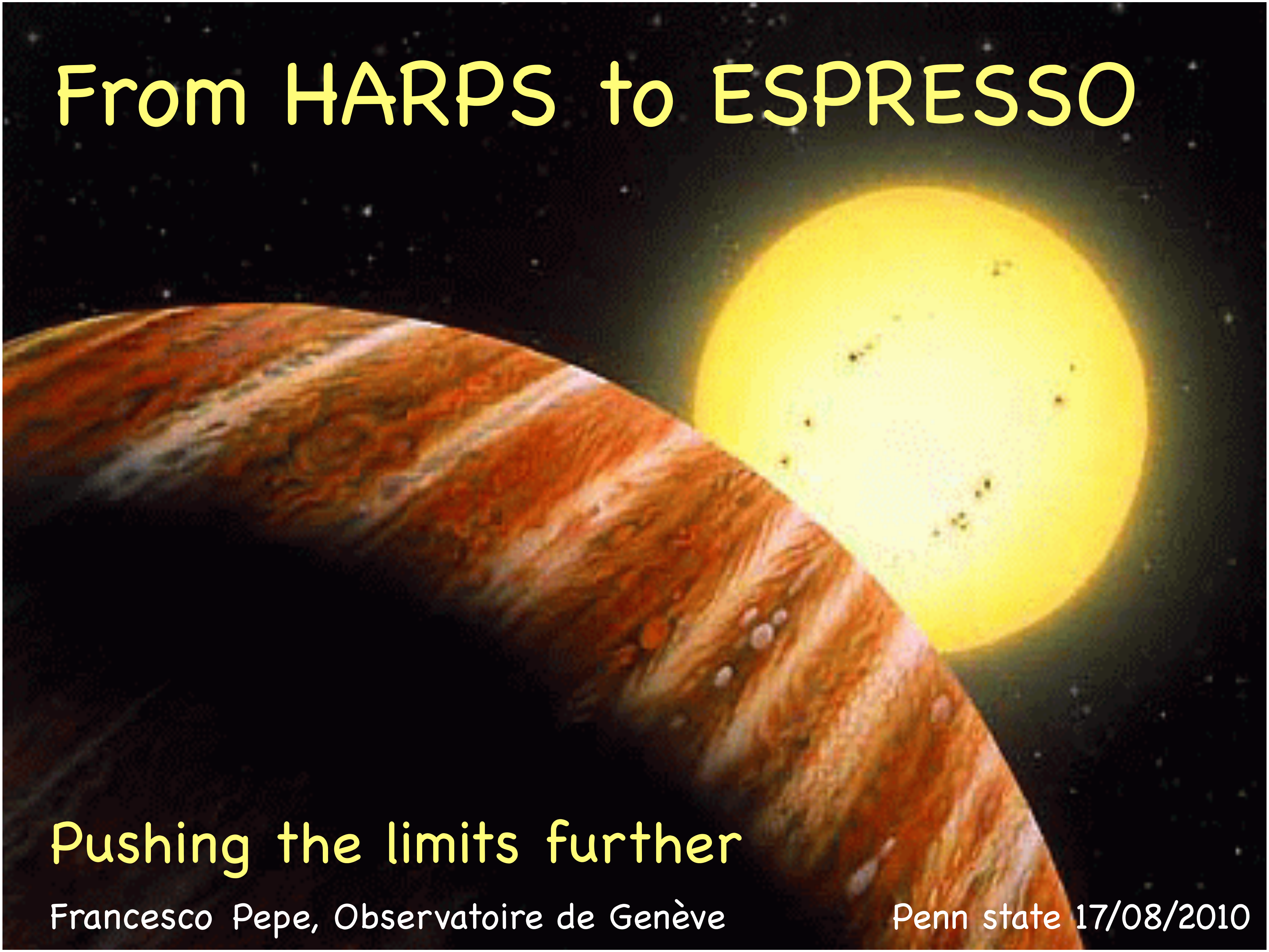
From HARPS to ESPRESSO

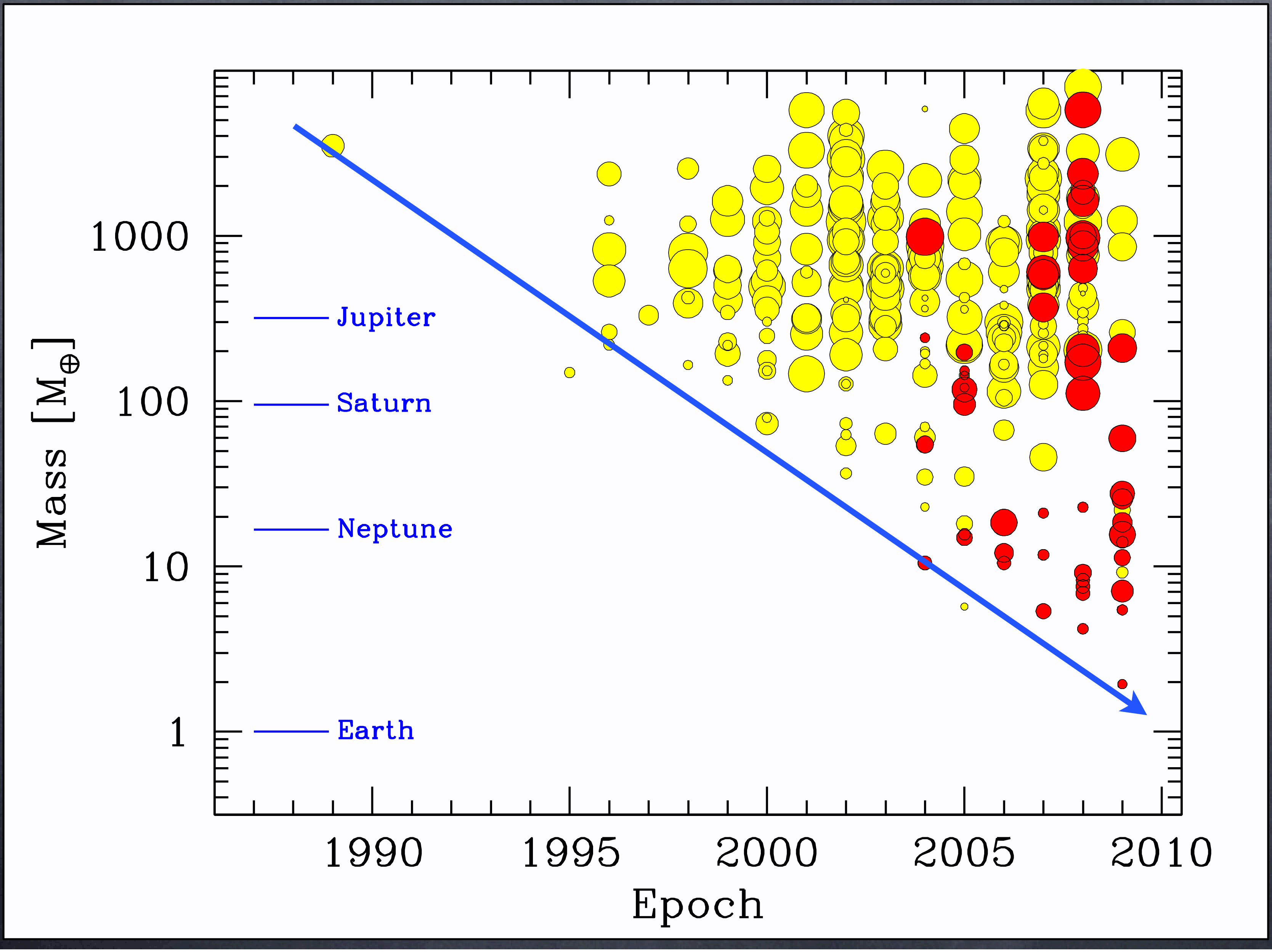


Pushing the limits further

Francesco Pepe, Observatoire de Genève

Penn state 17/08/2010

Where is the limits ?



The HARPS RV machine

+ final quality ‘real-time’ data reduction

Data reduction facts: Keep on moving

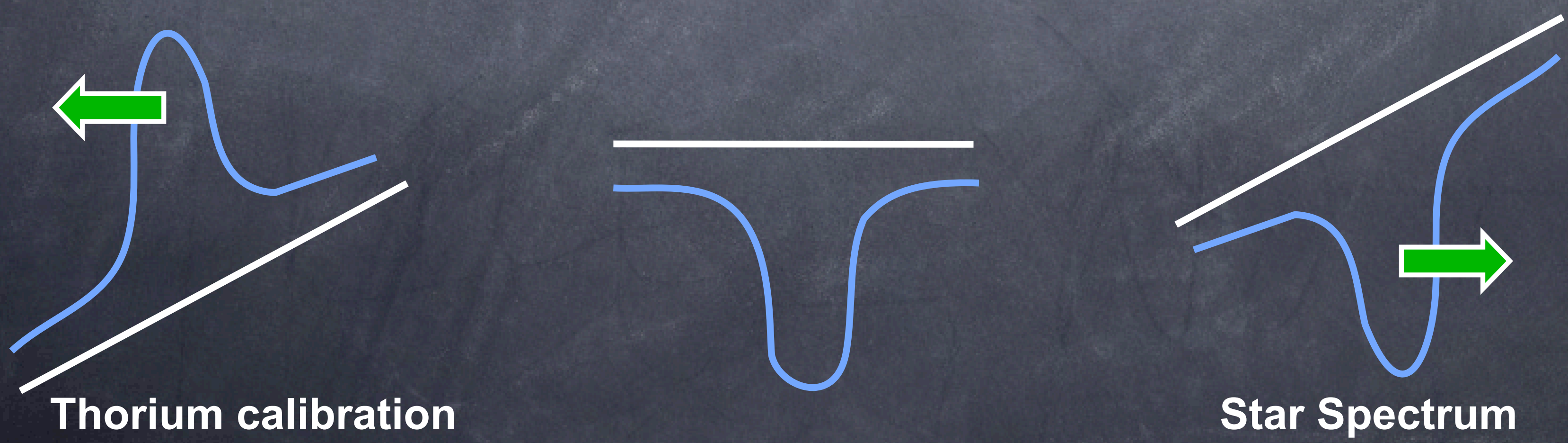
Improvements since 2003:

- Remove atmospheric effects
- Improve barycentric correction
- Correct ThAr lines catalog
- Improve and stabilize wavelength calibration
- Correct for 'color' (continuum) variations and ADC errors
- Correct for lamp aging
- Remove background and contamination
- Improve cross-correlation and masks
- Integrate laser frequency combs and Fabry-Perots
- Blaze function correction

and ... continuously debug SW!

Example: Blaze correction

- Echelle grating = variable diffraction efficiency along order
- Typically 50% less on the border of orders
- This introduces spectral lines deformations
- Should be removed by the calibration but :



Extreme stability

ΔRV =1 m/s

⇕

Δλ=0.00001 A

⇕

15 nm

⇕

1/1000 pixel

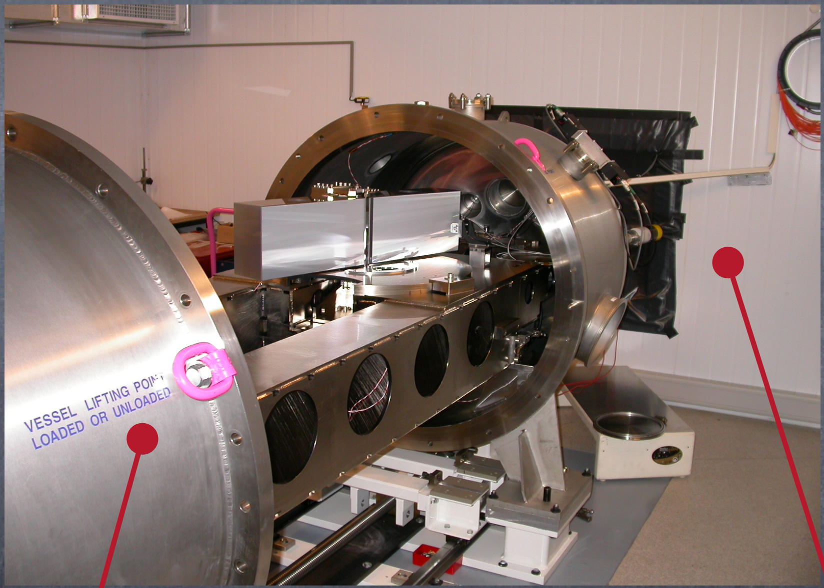
ΔRV =1 m/s

⇕

ΔT =0.01 K

⇕

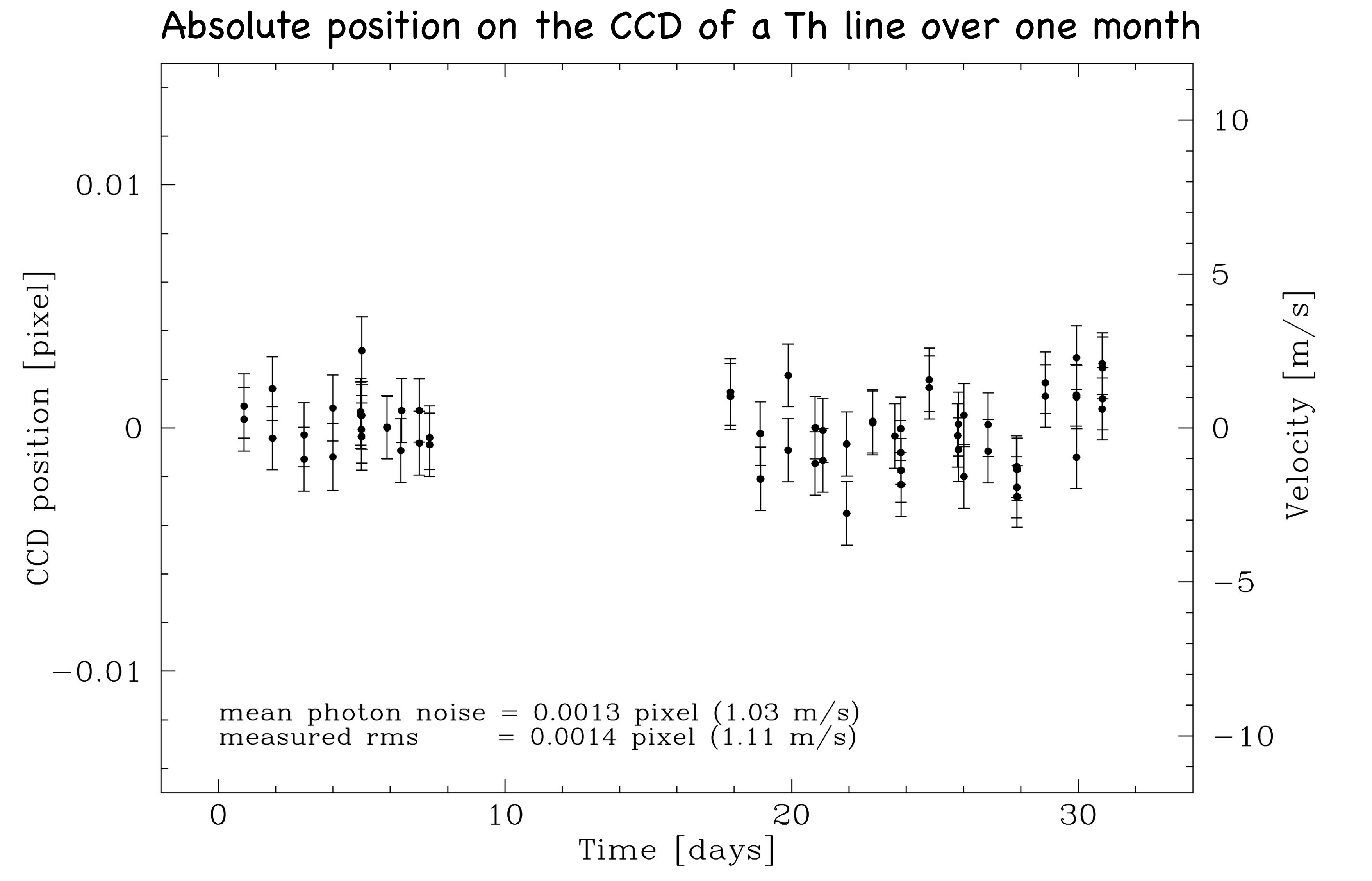
Δp=0.01 mBar



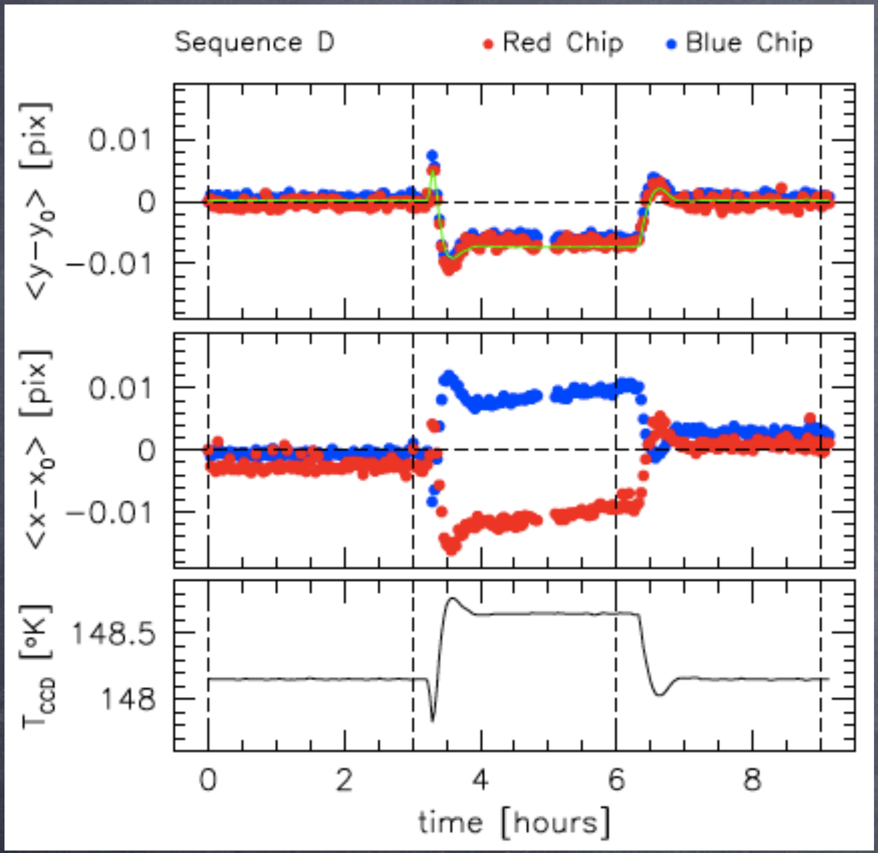
Vacuum operation

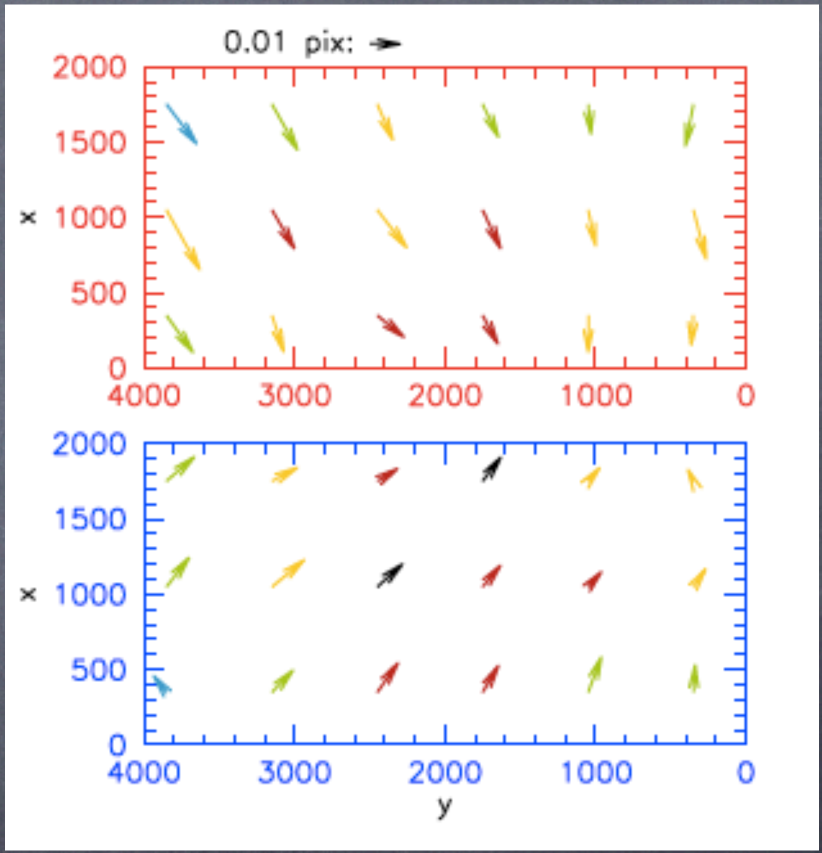
Temperature control

Stability and repeatability



Detector ‘instabilities’





Marco Gullieuszik, ESO

The two main methods ...

Simultaneous reference

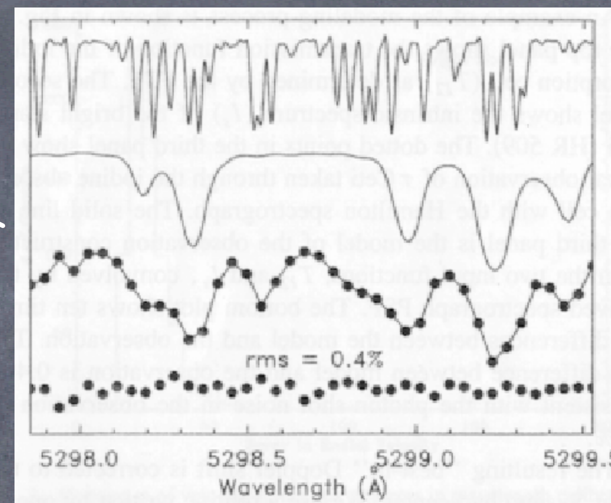
Baranne et al., 1996

'HARPS-like'

- No differential IP changes allowed
- Not suitable for slit spectrographs
- No losses, wide wavelength range
- IP modeling is POSSIBLE

Self reference

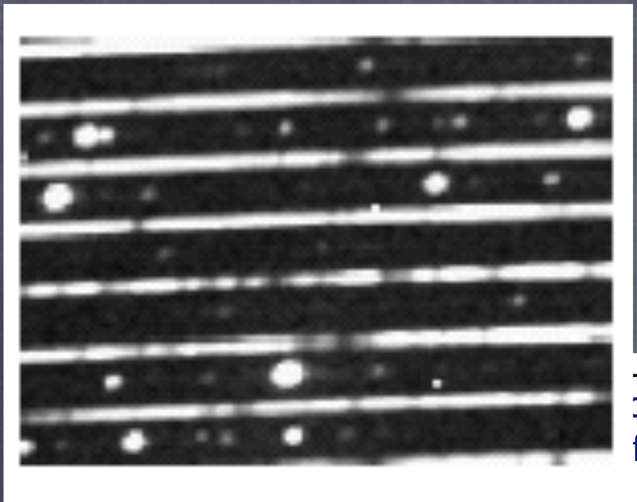
Butler et al., 1996

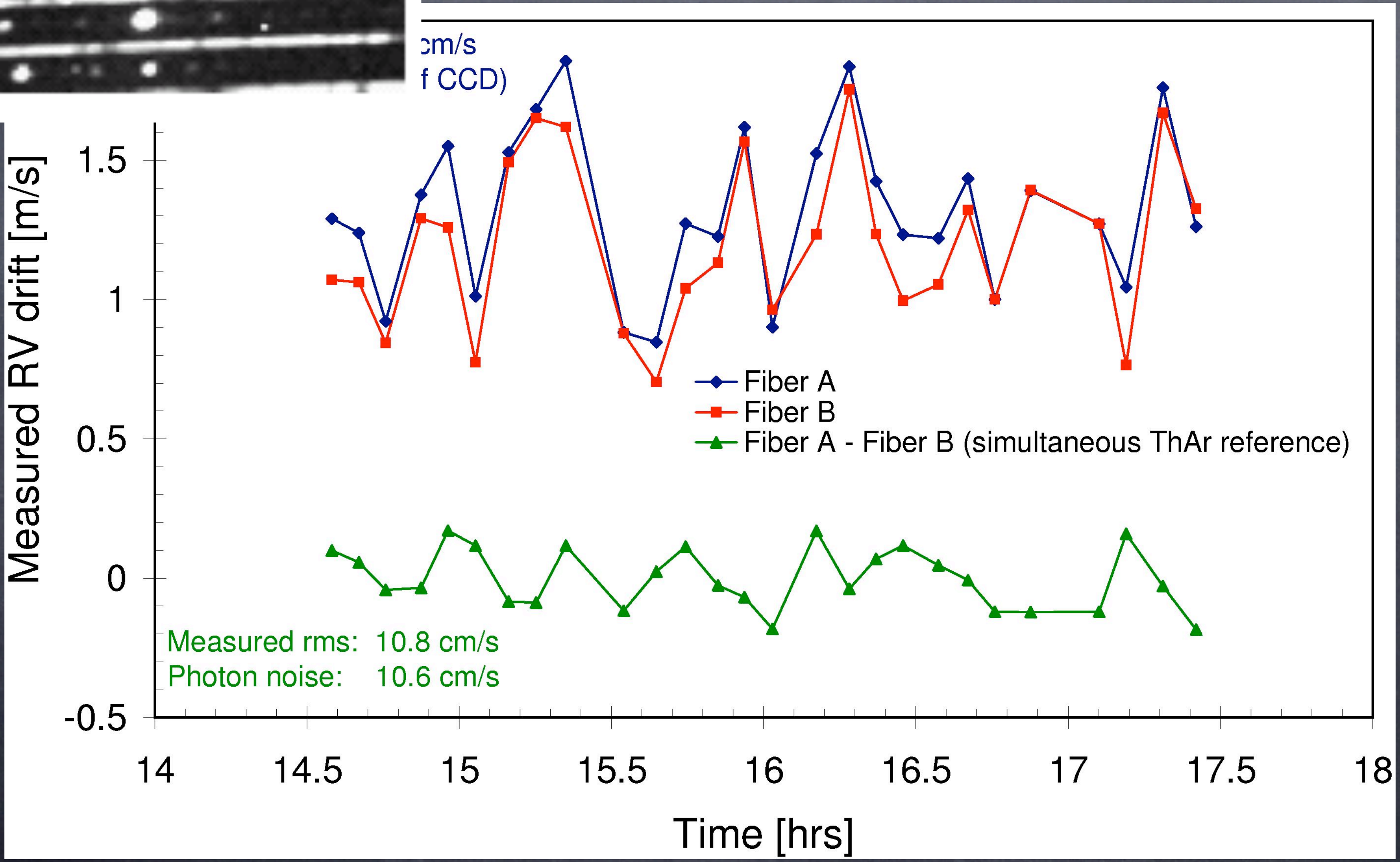


'HIRES-like'

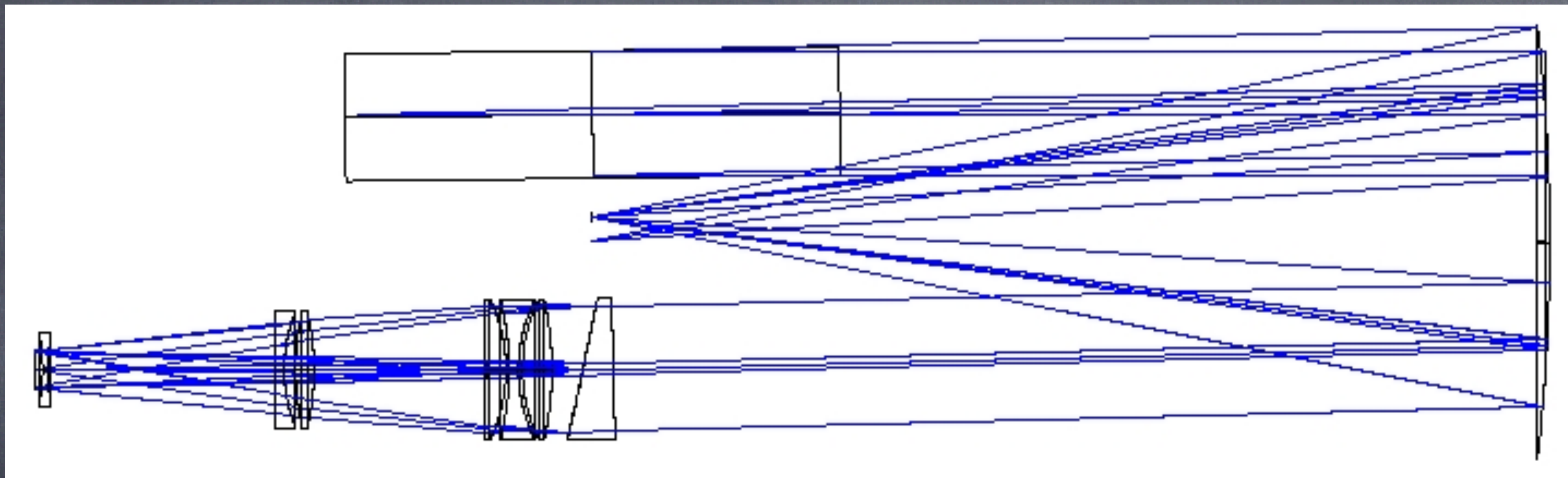
- No differential IP changes allowed
- Suitable for any/slit spectrographs
- Absorption, restricted wav. range
- REQUIRES 'de-convolution'

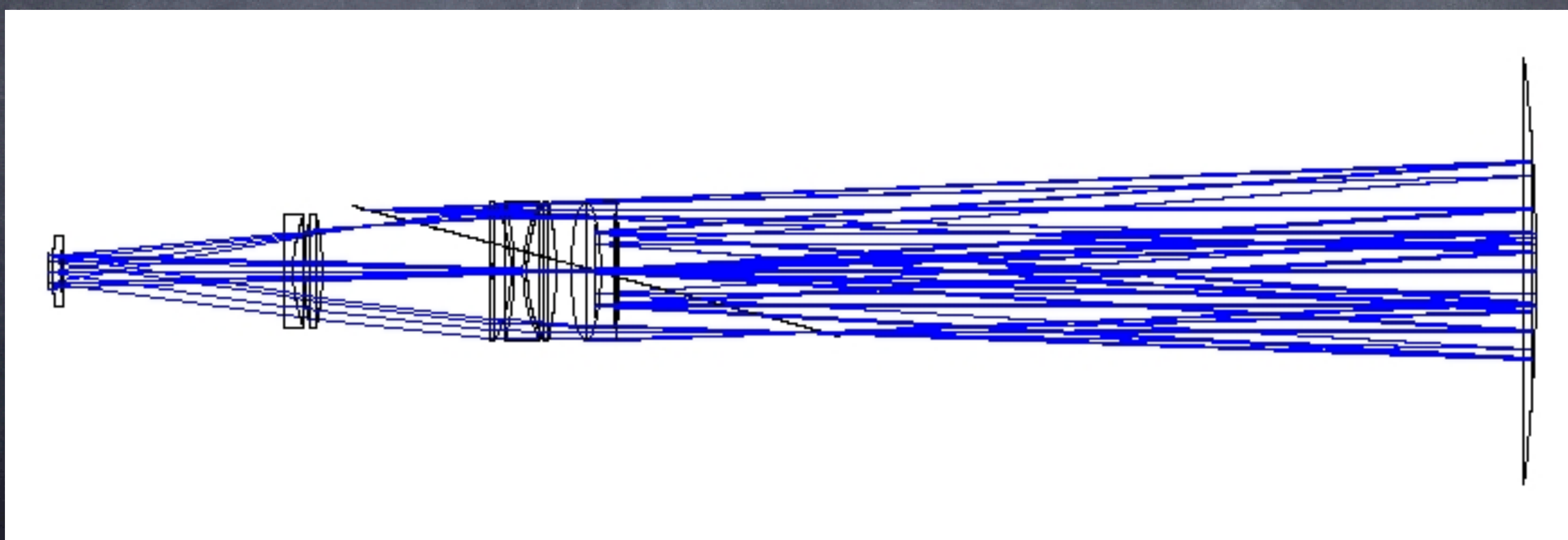
imultaneous reference





No change of instrumental profile (IP)

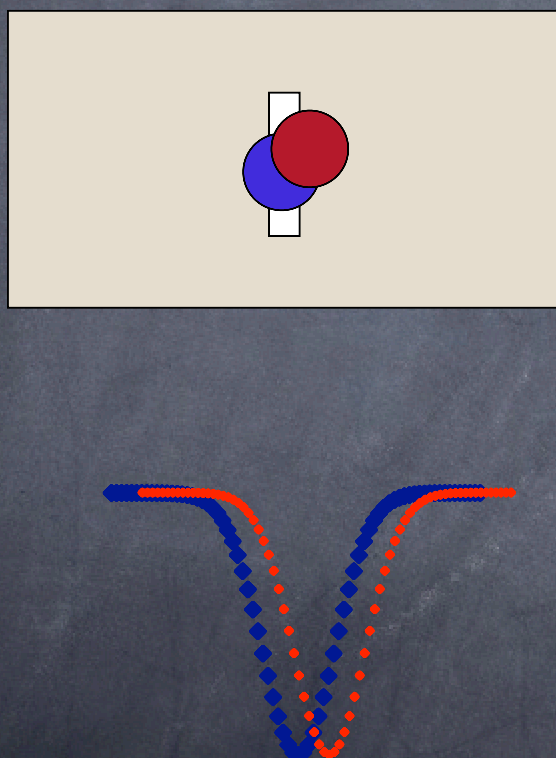


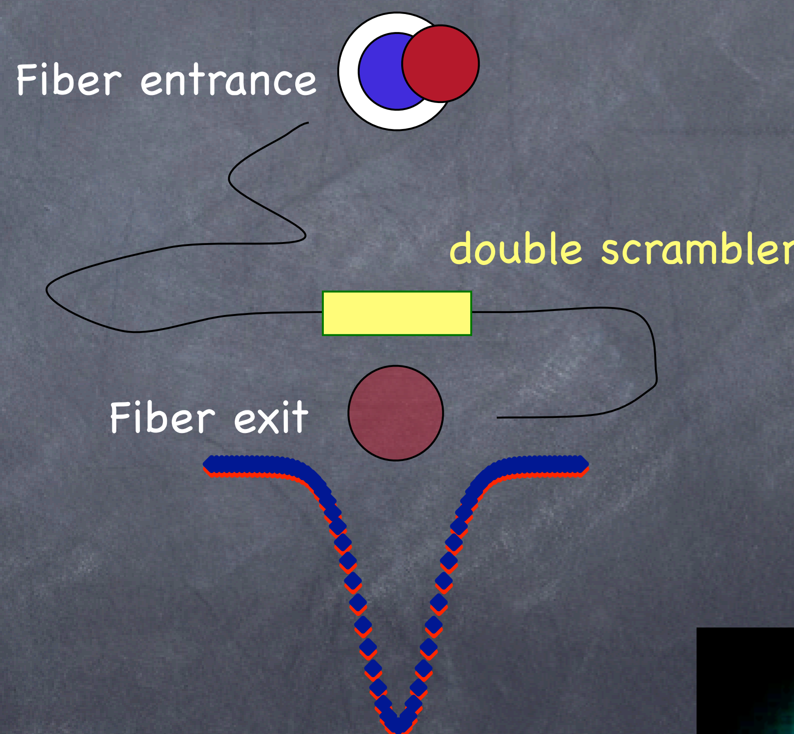


Differential illumination variation

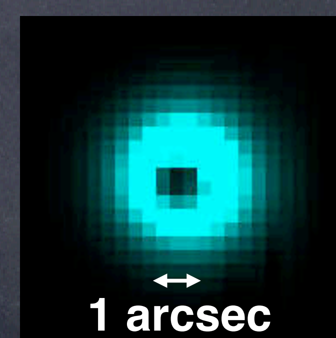
Slit spectrograph

Fiber-fed spectrograph





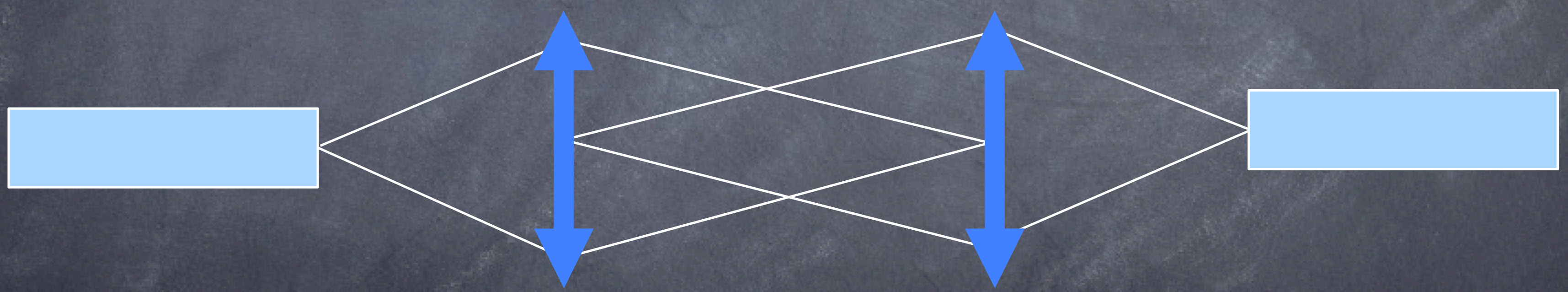
Δ RV up to 3 m/s !



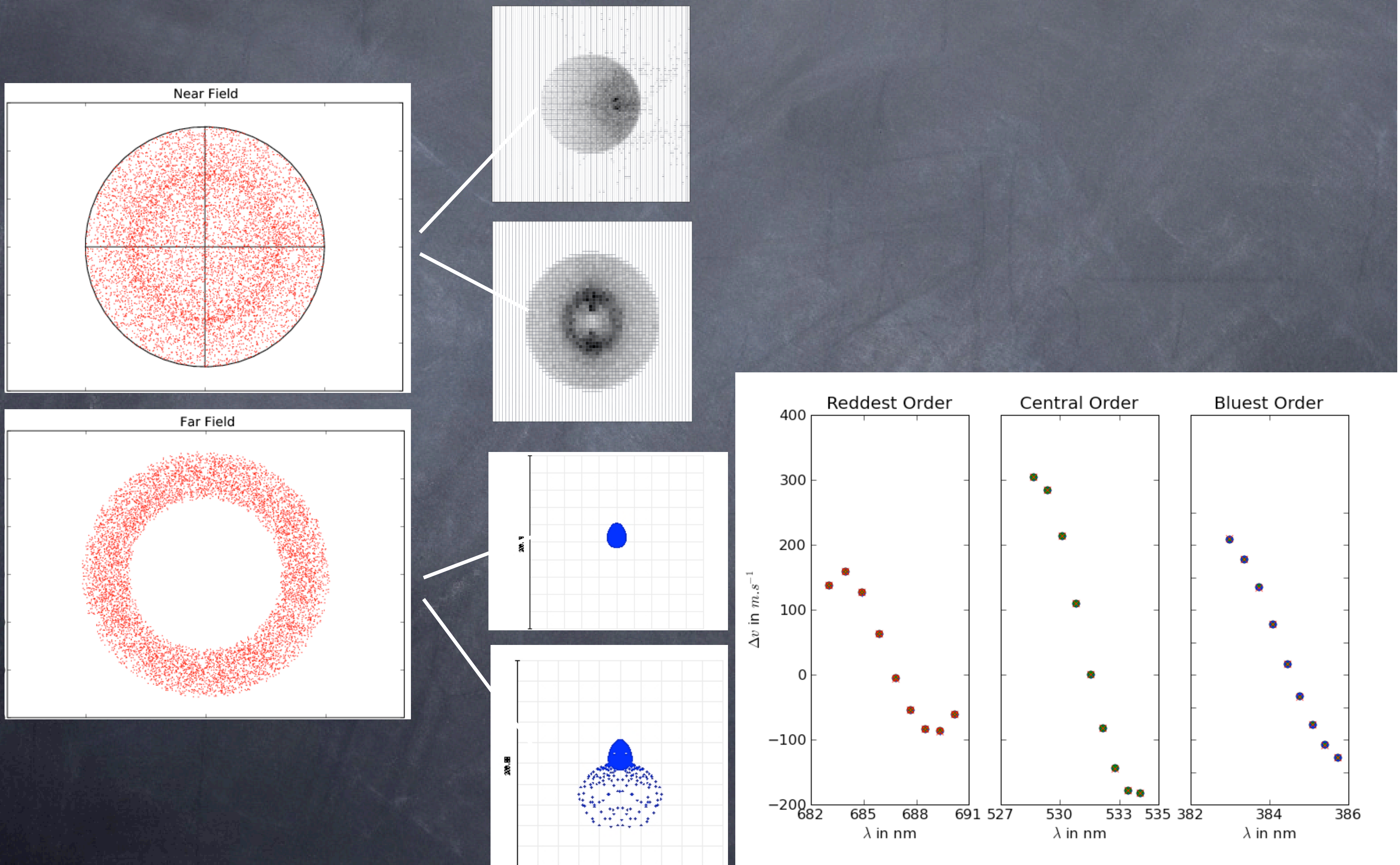
The concept of double scrambling

1) Scramble stellar image

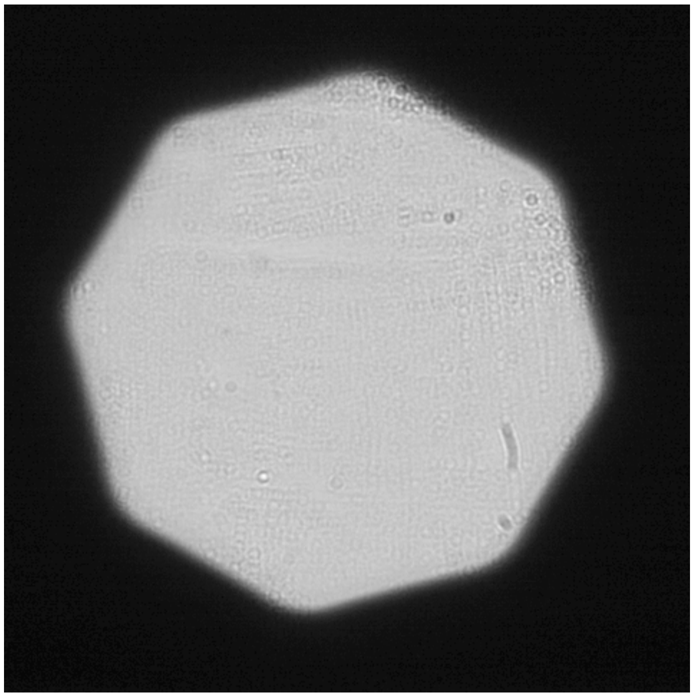
2) Use telescope pupil as new entrance illumination



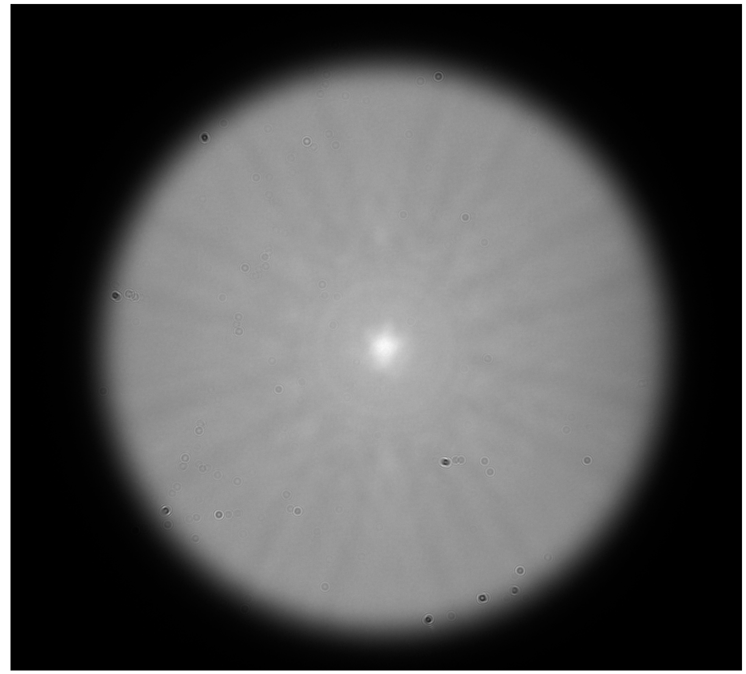
Fibers alone do not scramble enough



Octagonal Fiber

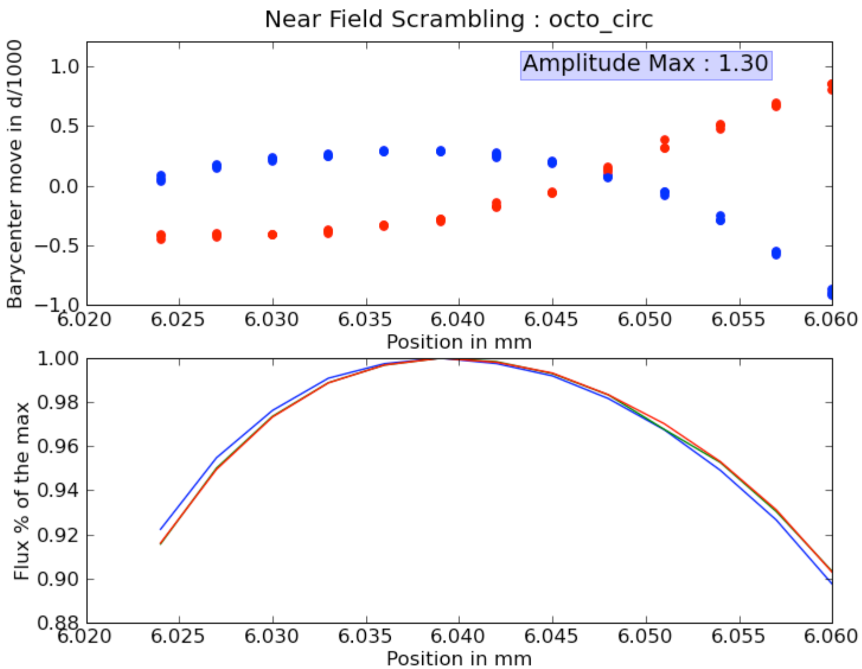


Near Field

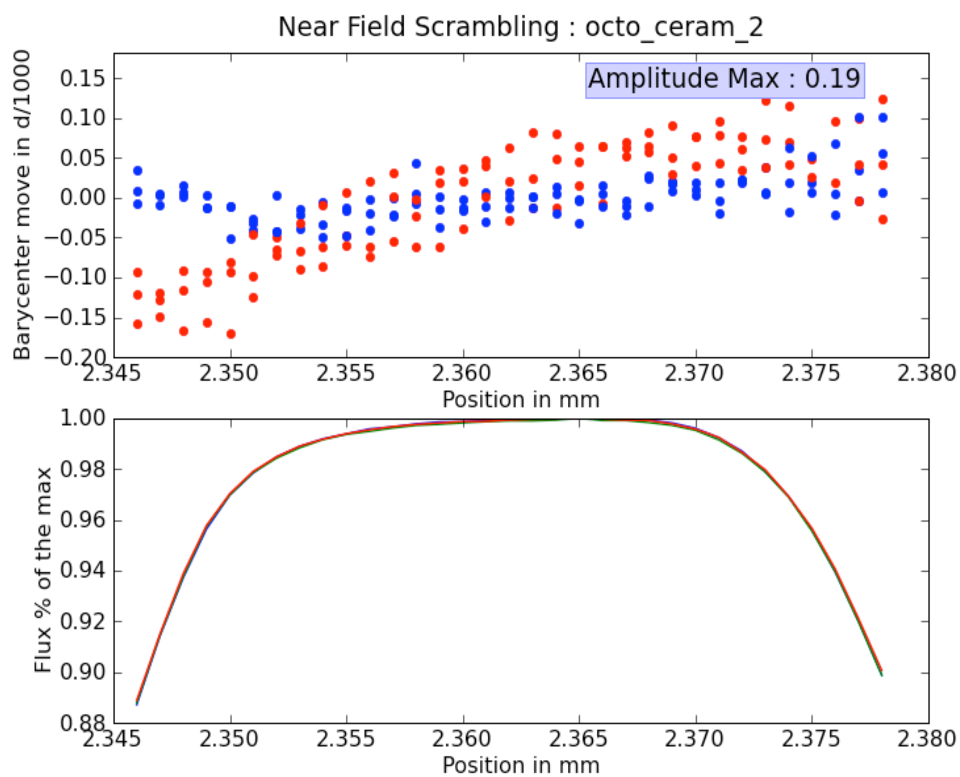


Far Field

Scrambling in the near field

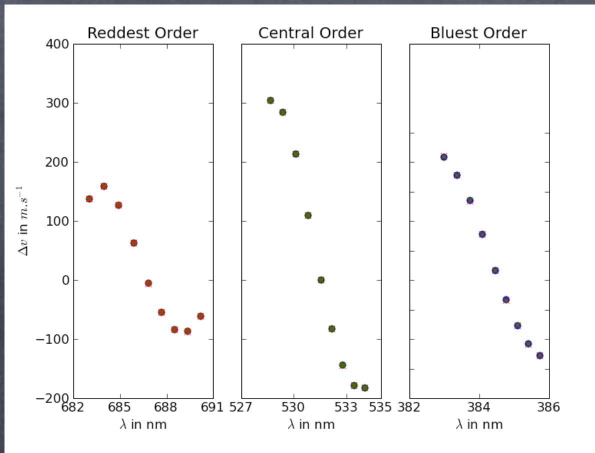


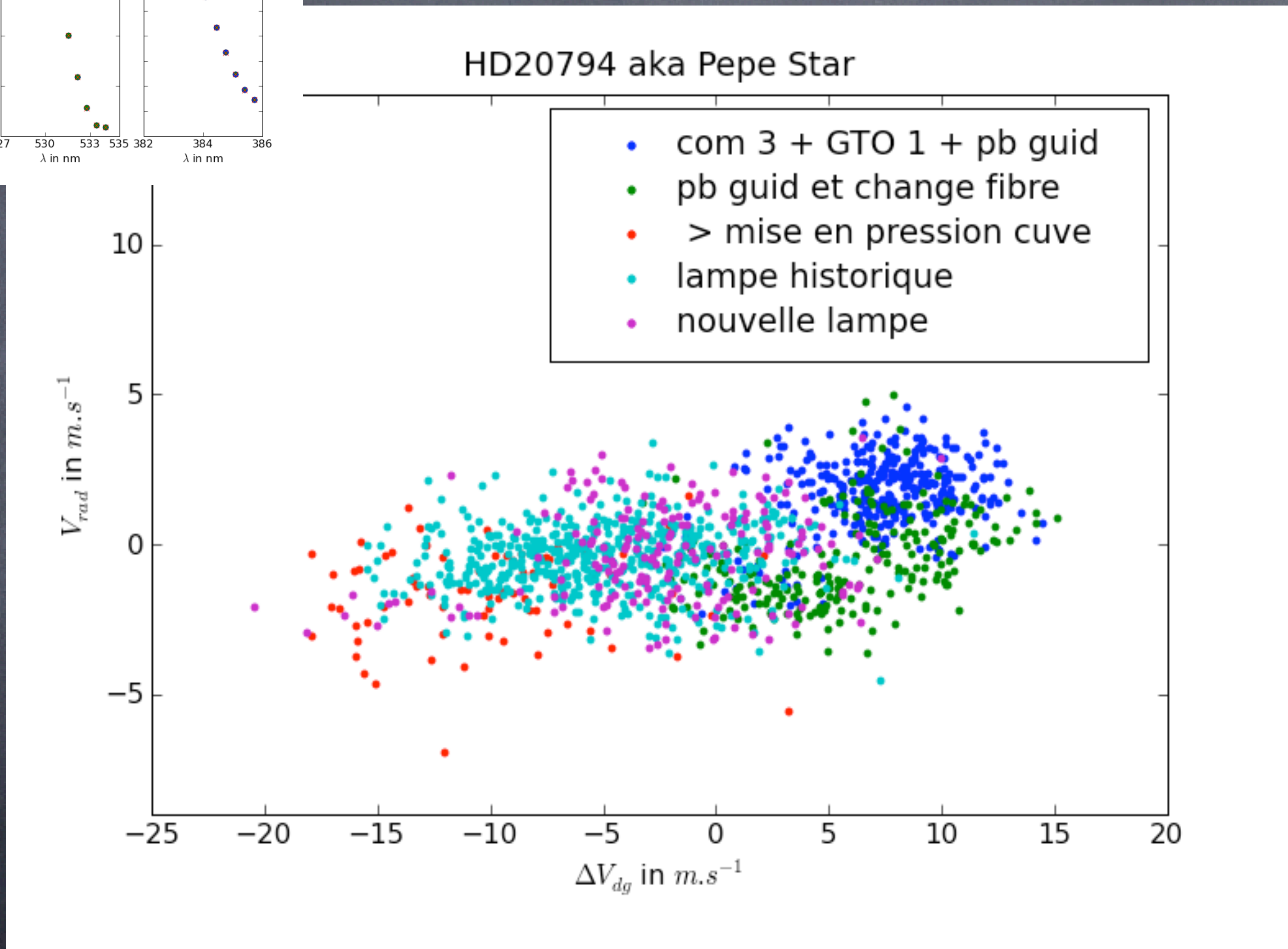
Circular fiber :
Diameter : 70 microns
Star size : 35 microns



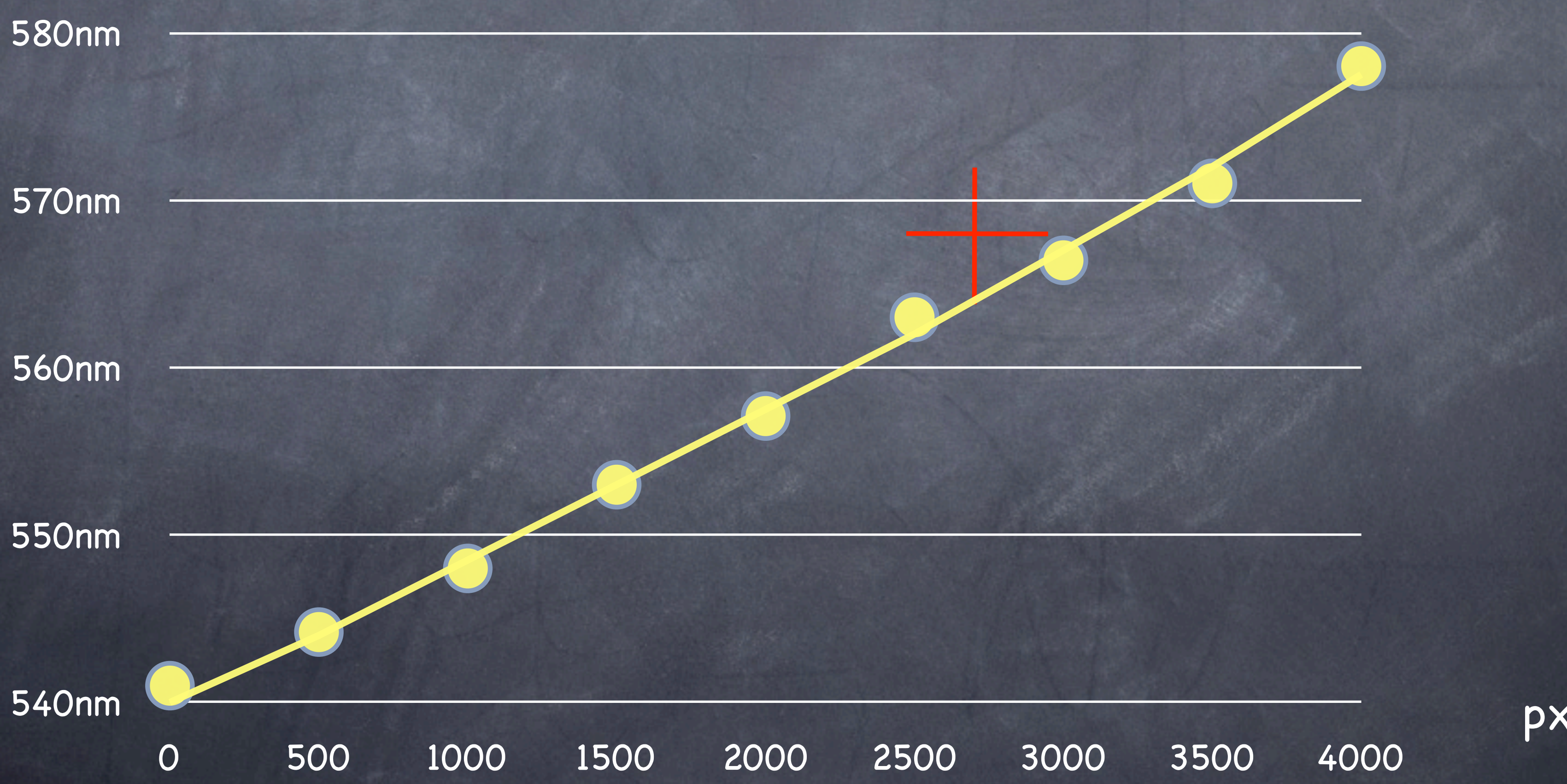
Octagonal fiber :
Diameter : 70 microns
Star size : 35 microns

Far field effects

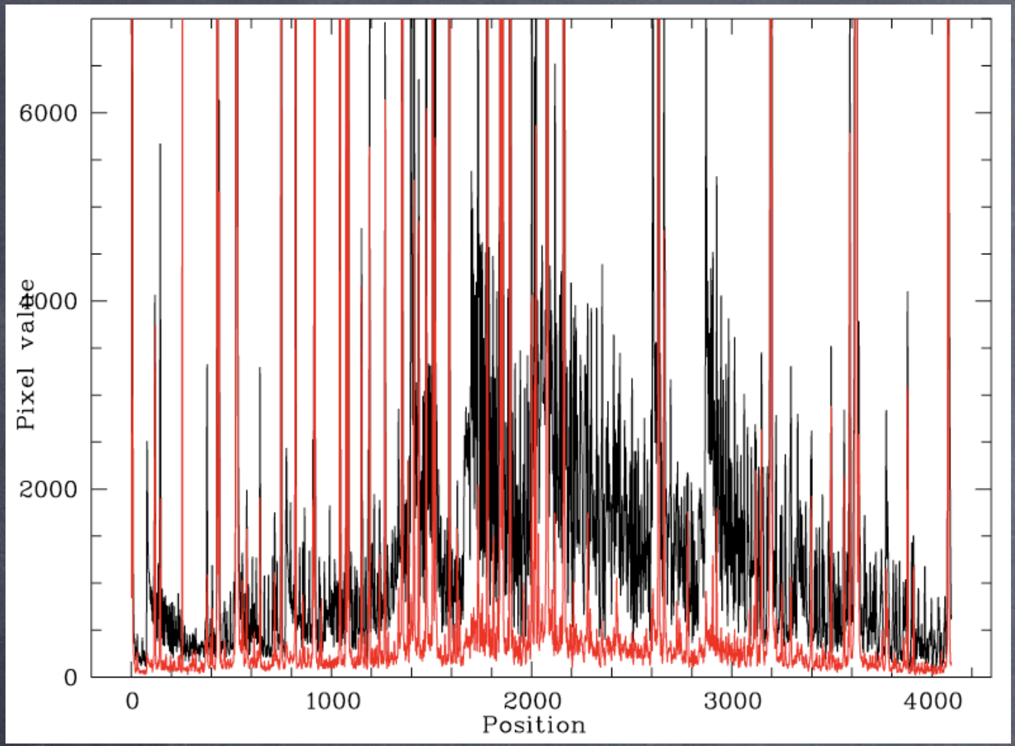


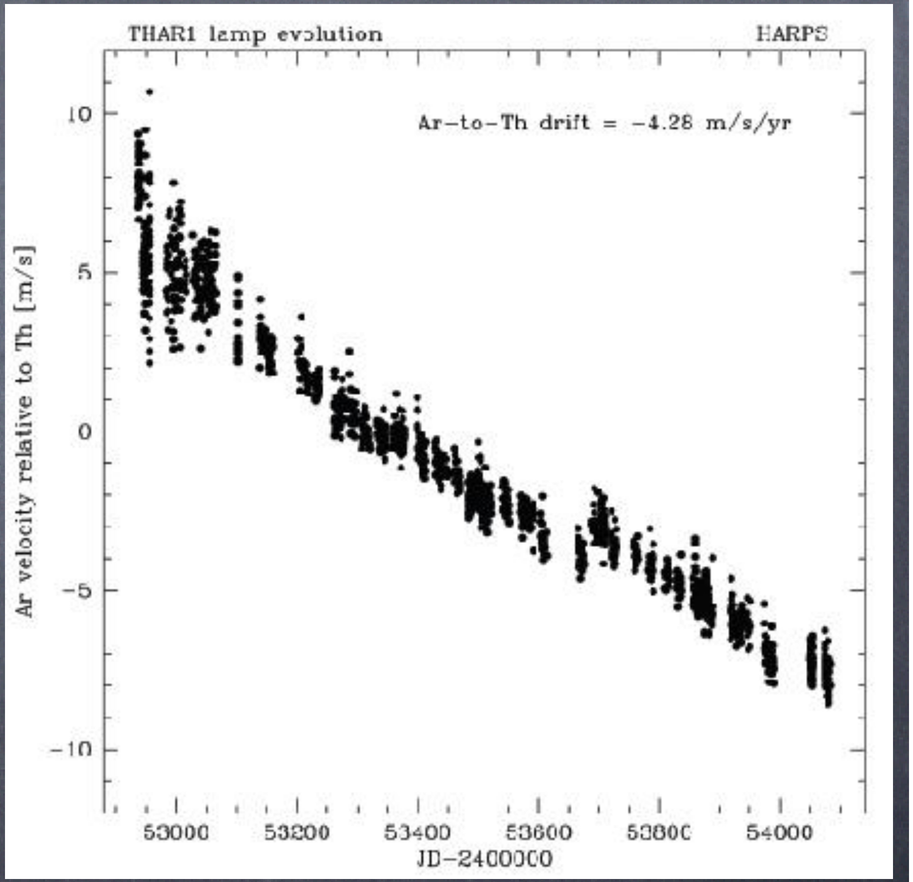


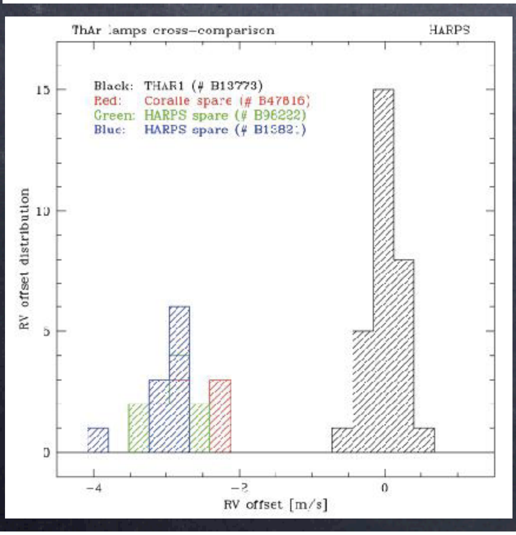
The wavelength calibration



Thorium lamps issues

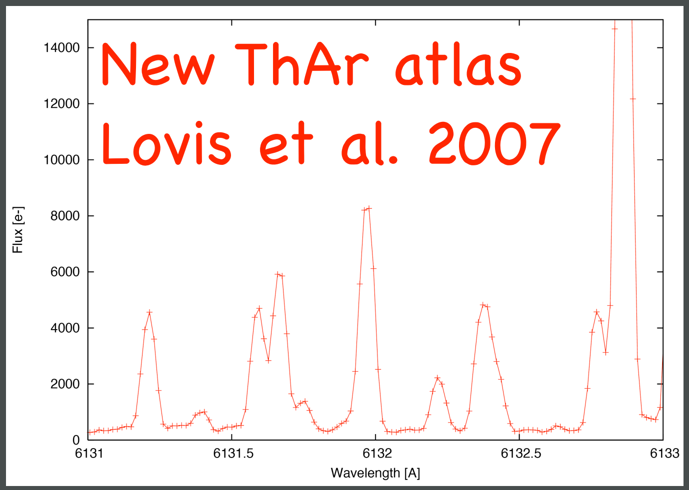




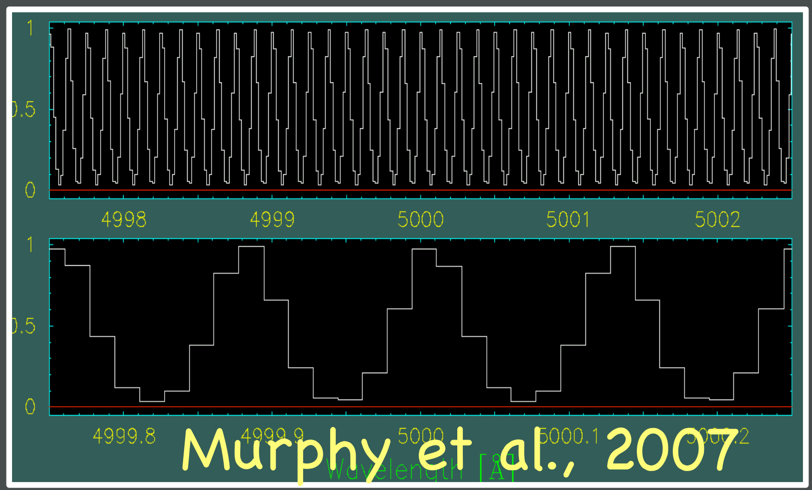


Improving the calibration

- ✓ Cover full spectral range
- ✓ High spectral resolution (again)
- ✓ Equally dense and unresolved lines
- ✓ No blends
- ✓ Knowledge of theoretical wavelengths
- ✓ Stability (repeatability) of 10^{-11} over > 20 years

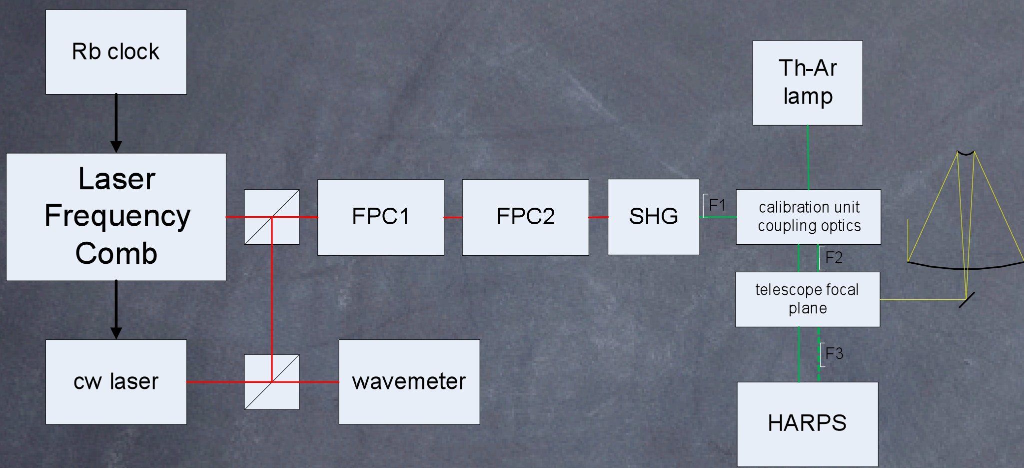


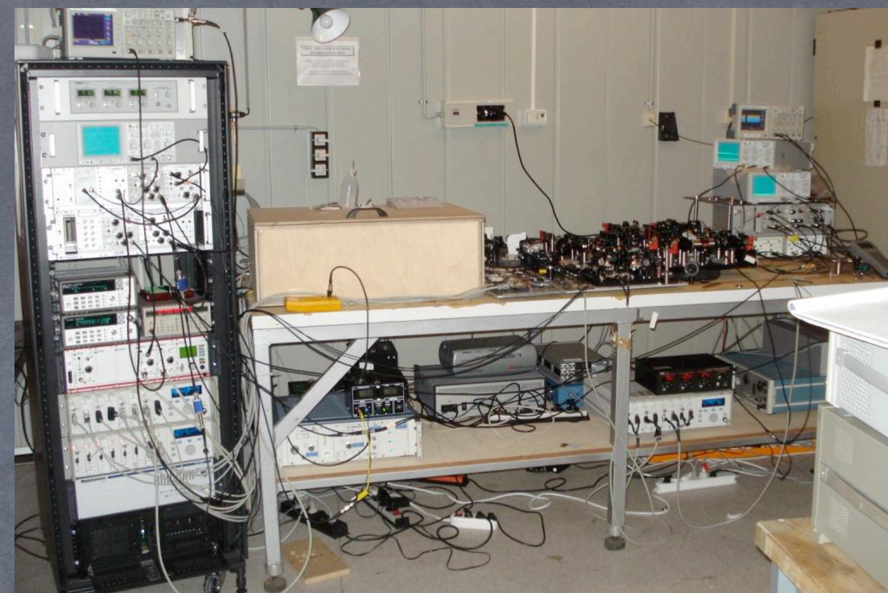
ThAr lamp

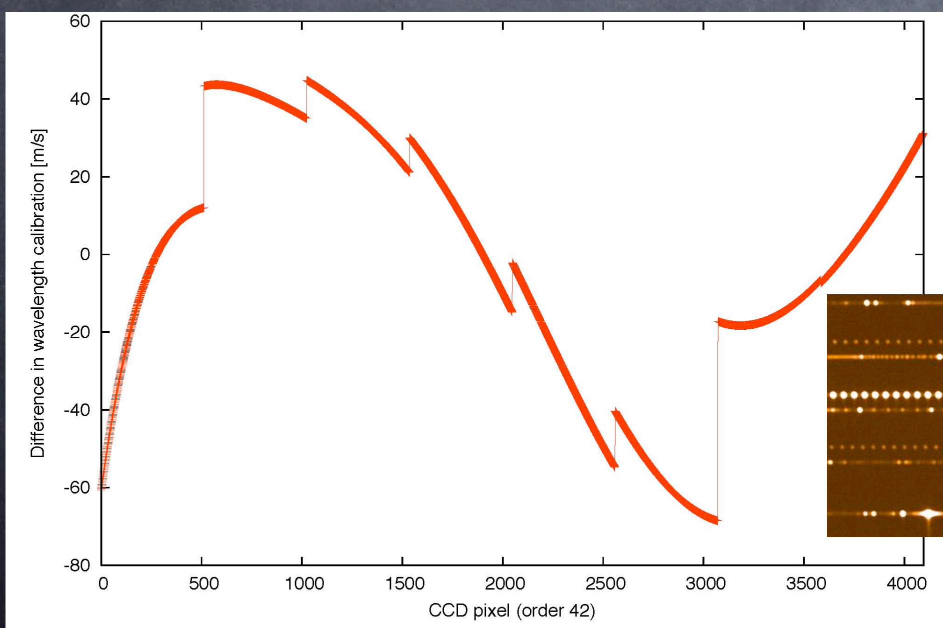


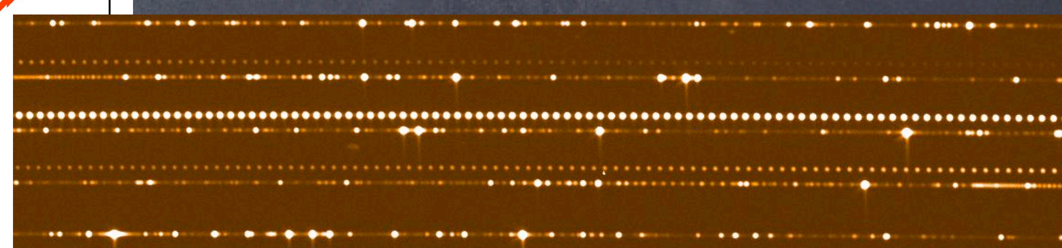
Laser comb or etalon

Laser frequency comb



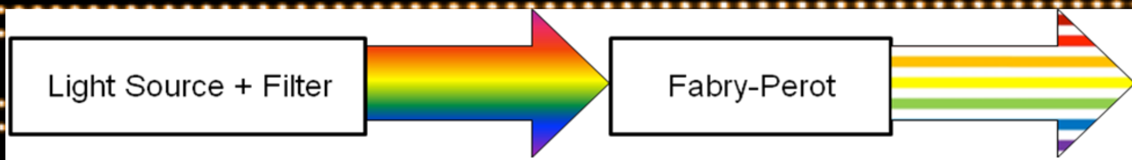


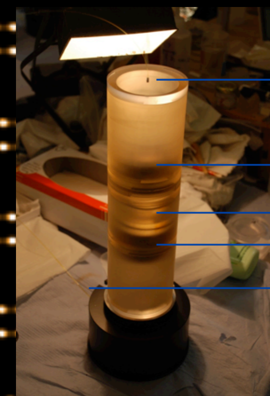


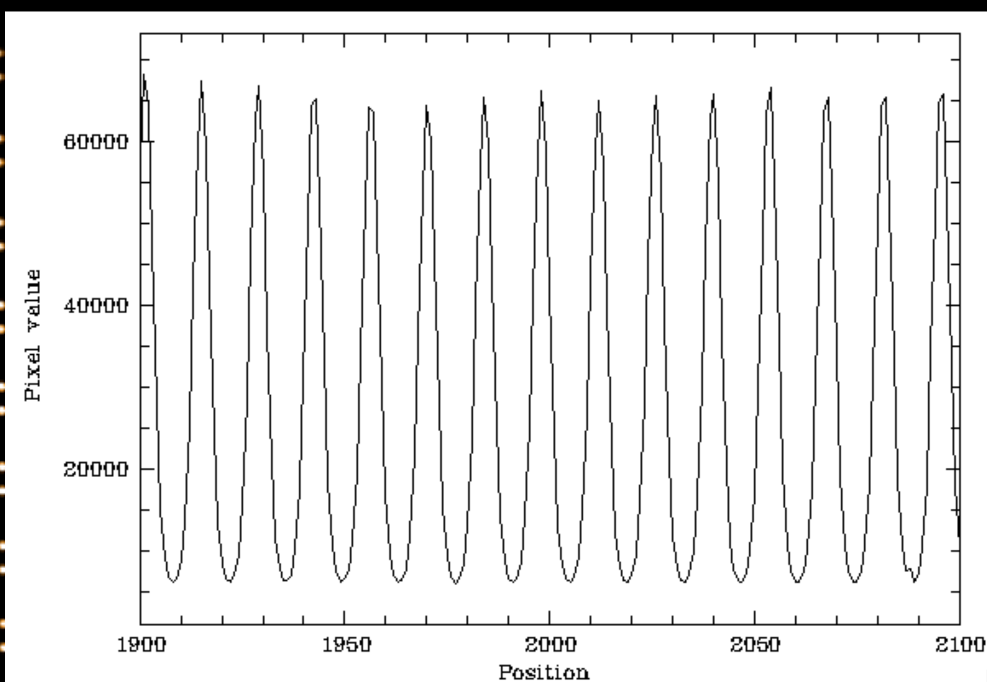


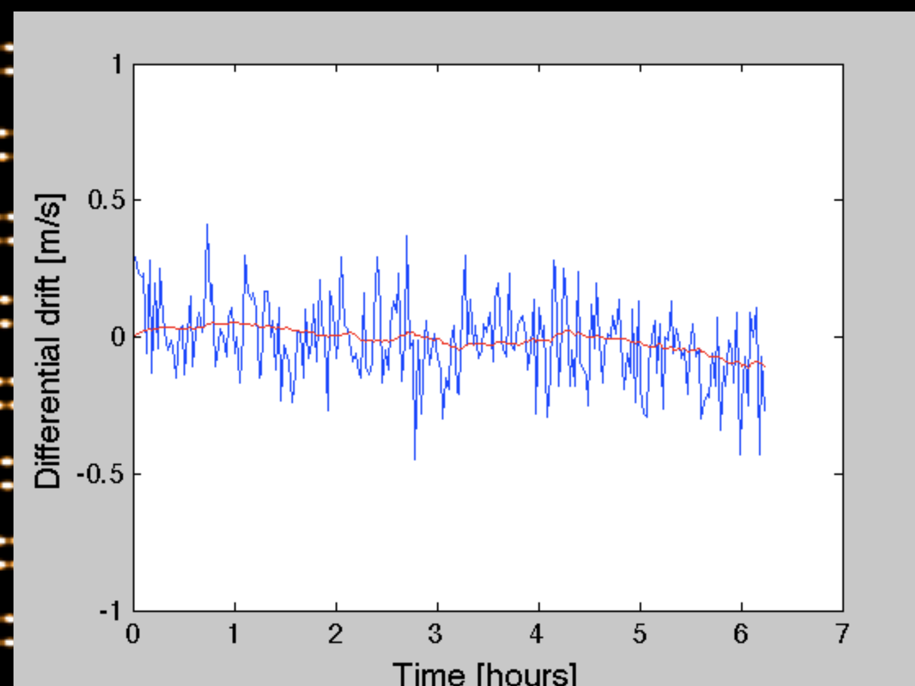
Steinmetz et al., 2008

Fabry-Perot Calibrator

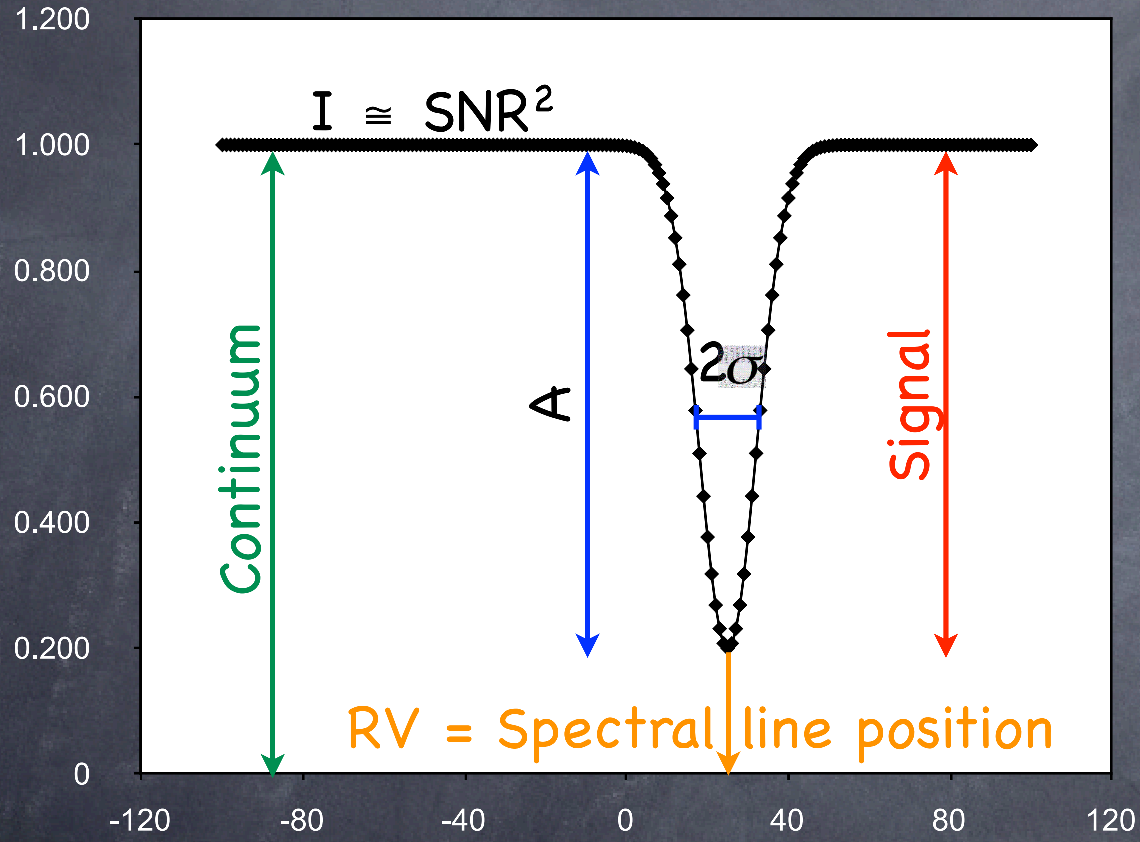








Better photons or resolution?



For exact formulae see:

Butler et al. 1996

Bouchy et al. 2001

etc.

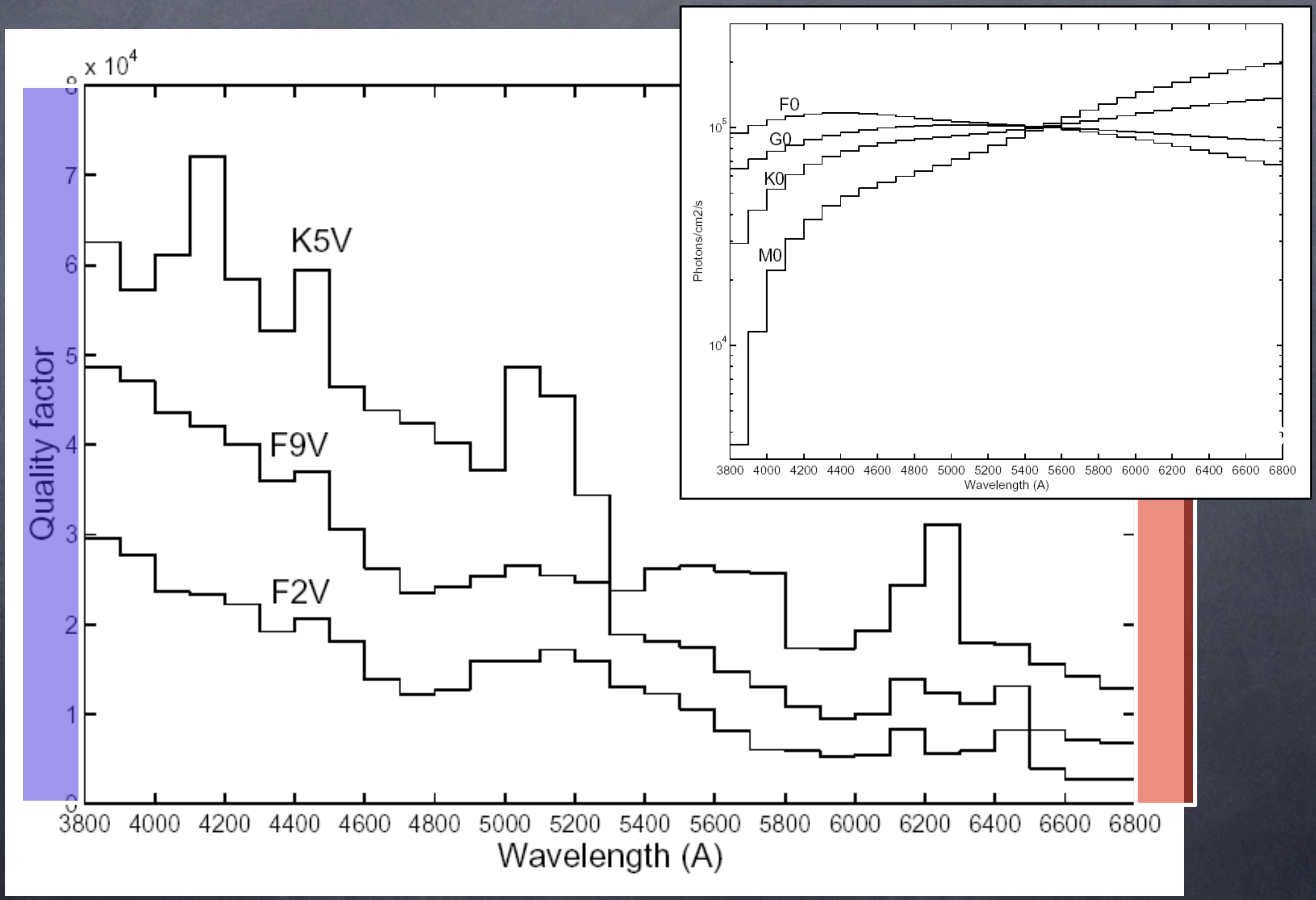
Approximation:

$$\varepsilon_{\text{single line}} = \frac{\sqrt{2 - A}}{2} \cdot \frac{\sqrt{\sigma}}{A} \cdot \frac{1}{SNR}$$

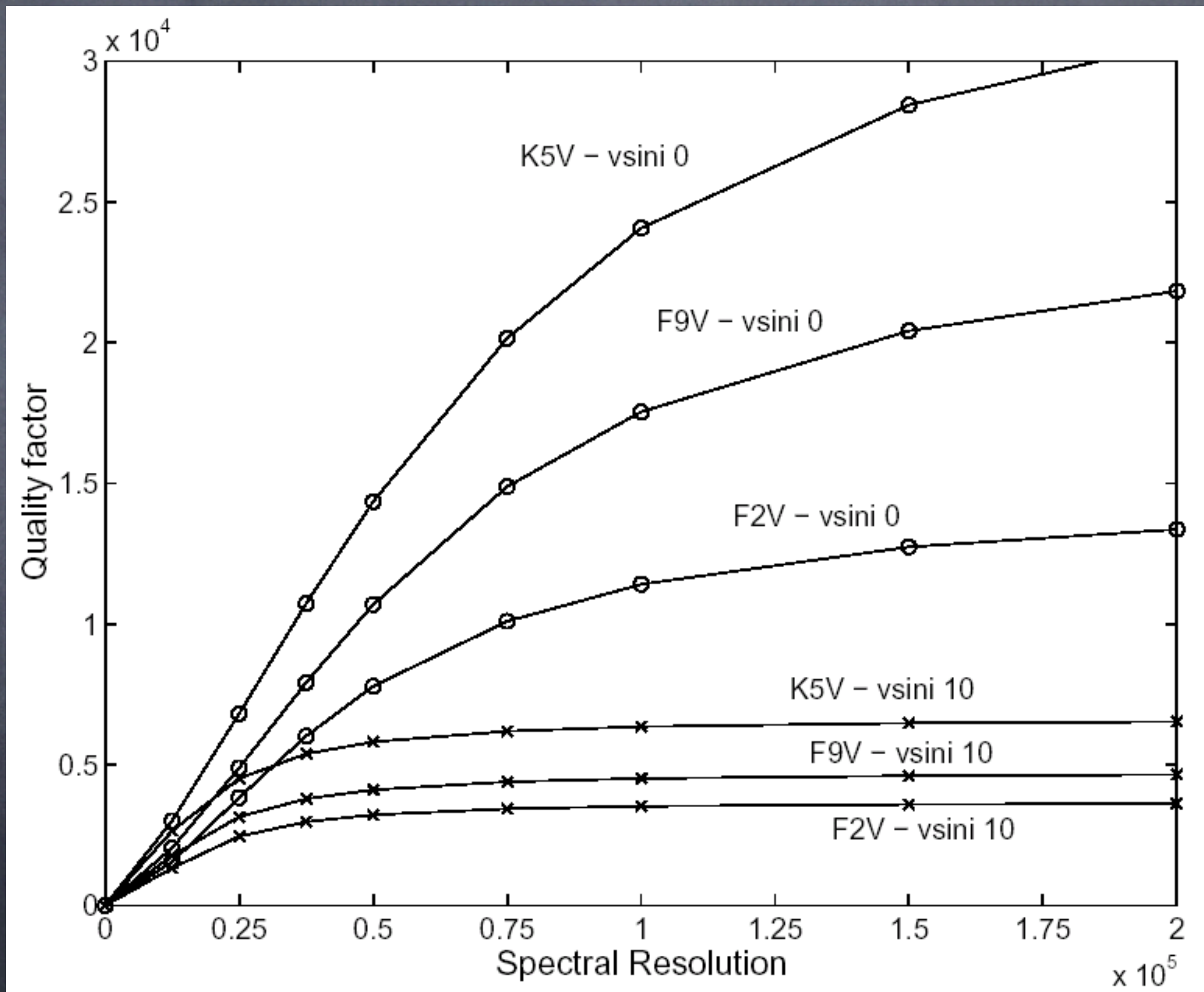
- Fixed-delay Interferometer (Ge et al.)
- Dispersed FT spectrograh (Hajian et al., 2005, Monnet)
- Fourier Transform spectrograph (Maillard et al., 2009)

Multiplex 'DIS'advantage

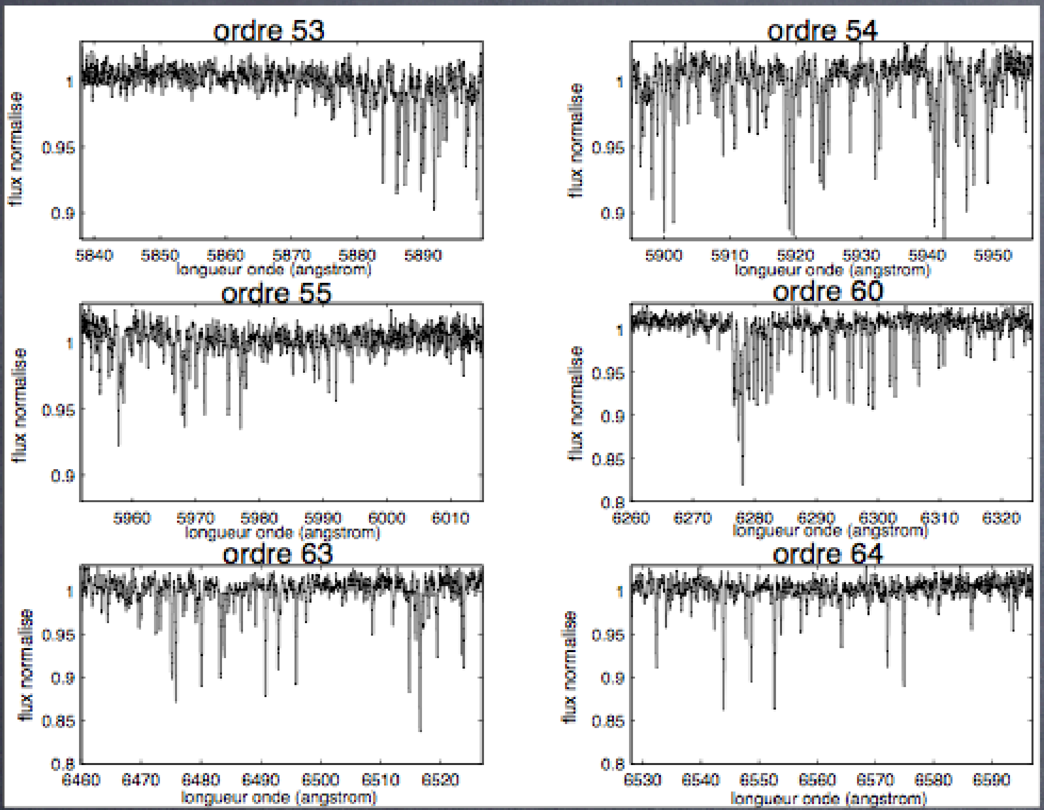
Better photons or resolution?



Better photons or resolution?



Care about ... atmosphere



Assumptions:

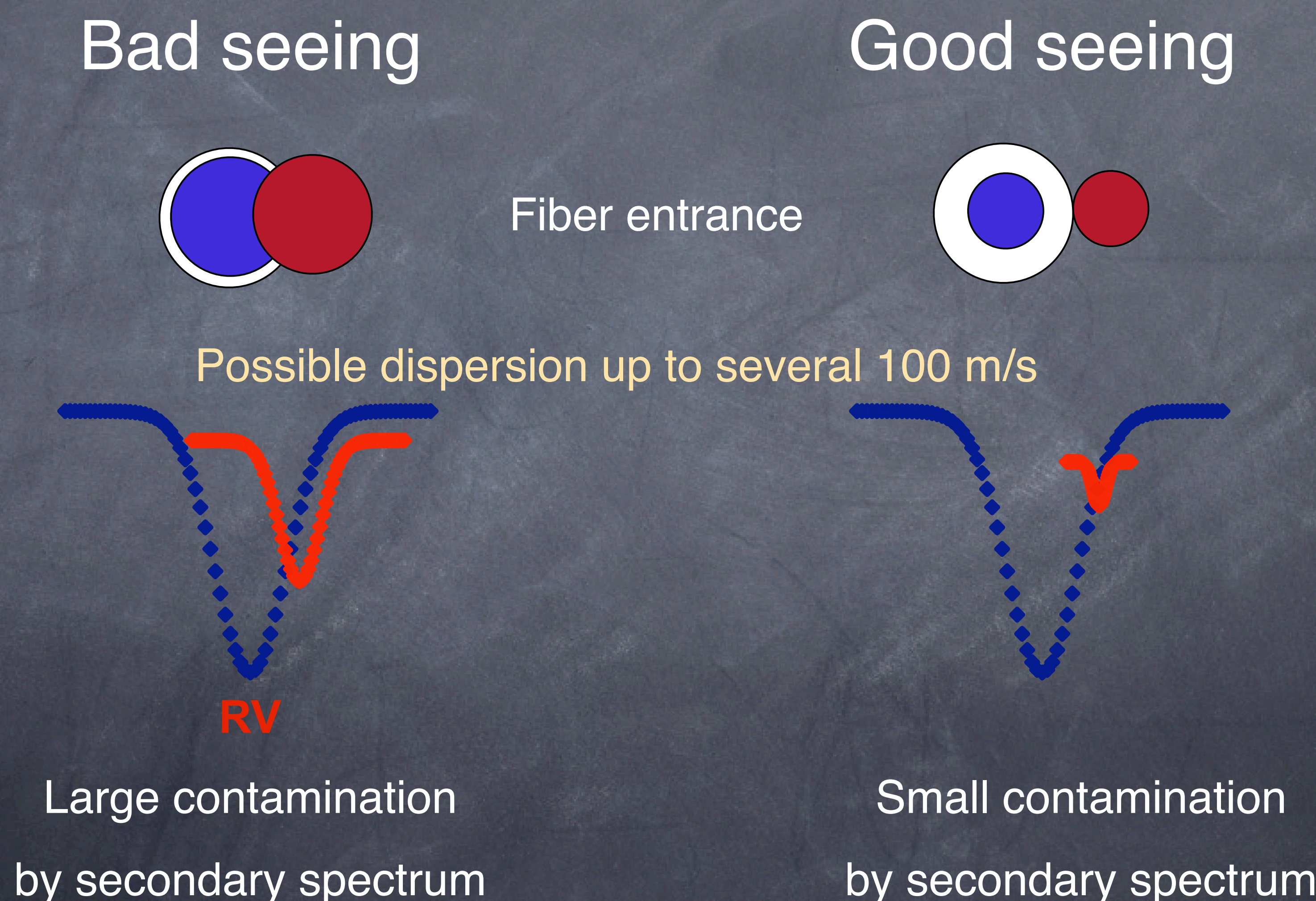
- 3% telluric line or (10% error on model depth)
- R = 100'000
- 3000 stellar lines, 30% average depth

-> 10 cm/s RV error with 1 year period, if one line affected

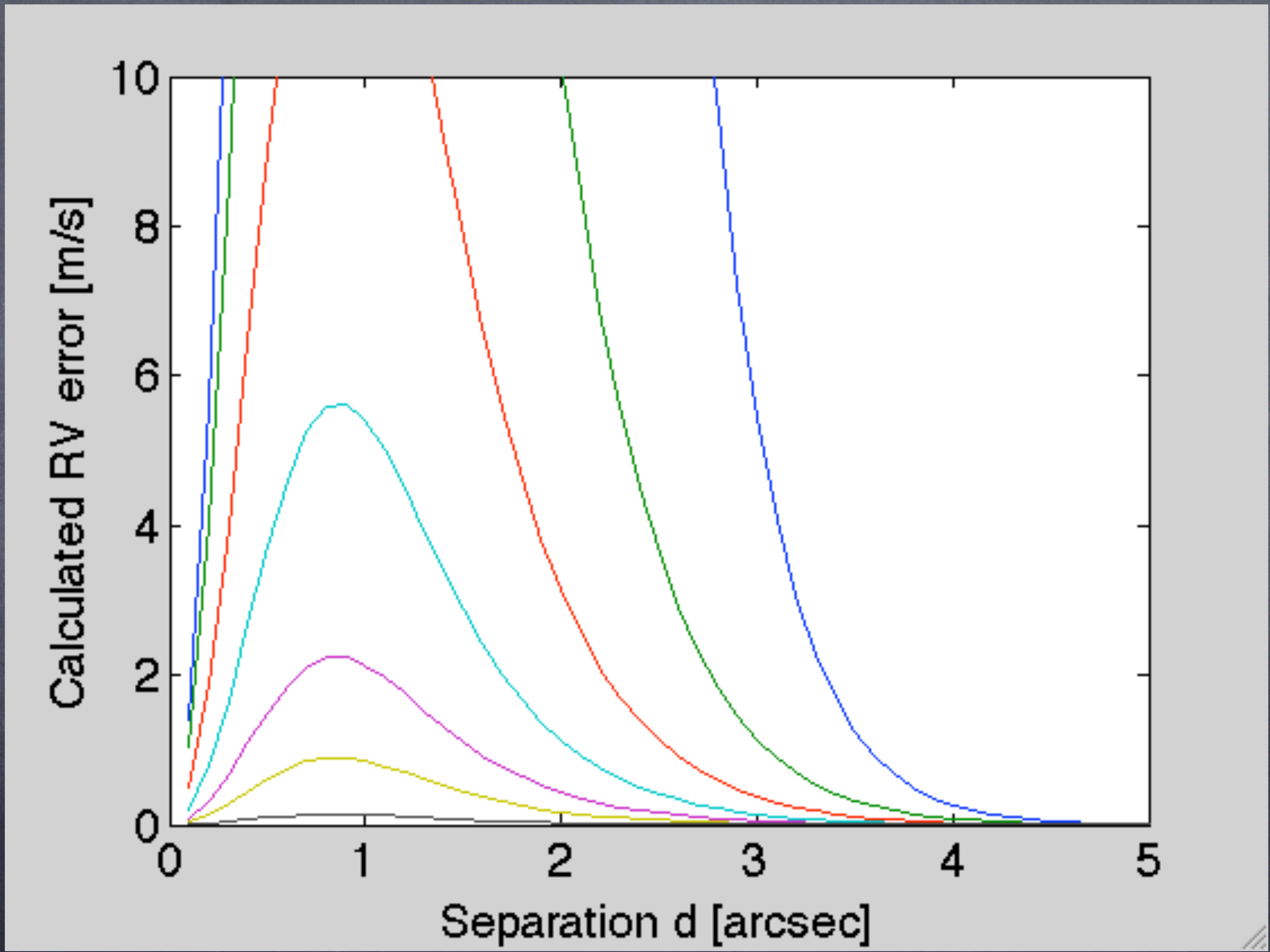
Recommendations

- Remove 'generously' the spectral domains affected by telluric lines
- Or model the atmosphere

Contamination by faint background sources



Contamination by faint background sources



Steps towards ESPRESSO et al.

For precise RVs a lot of photons are required -> bigger telescopes and better efficiency. But sometimes efficiency is in competition with instrumental precision.

Improve instrumental precision by

- Optimize simultaneous reference technique e.g. by further improving stability, in particular of CCDs
- Reduce illumination effects (scrambling required)
- New calibration reference needed
- Understand and master effects by atmosphere, moon, and other contaminants
- Optimize observation strategy to reduce stellar noise effects
- Increase spectral resolution (stability, telluric lines, SNR)