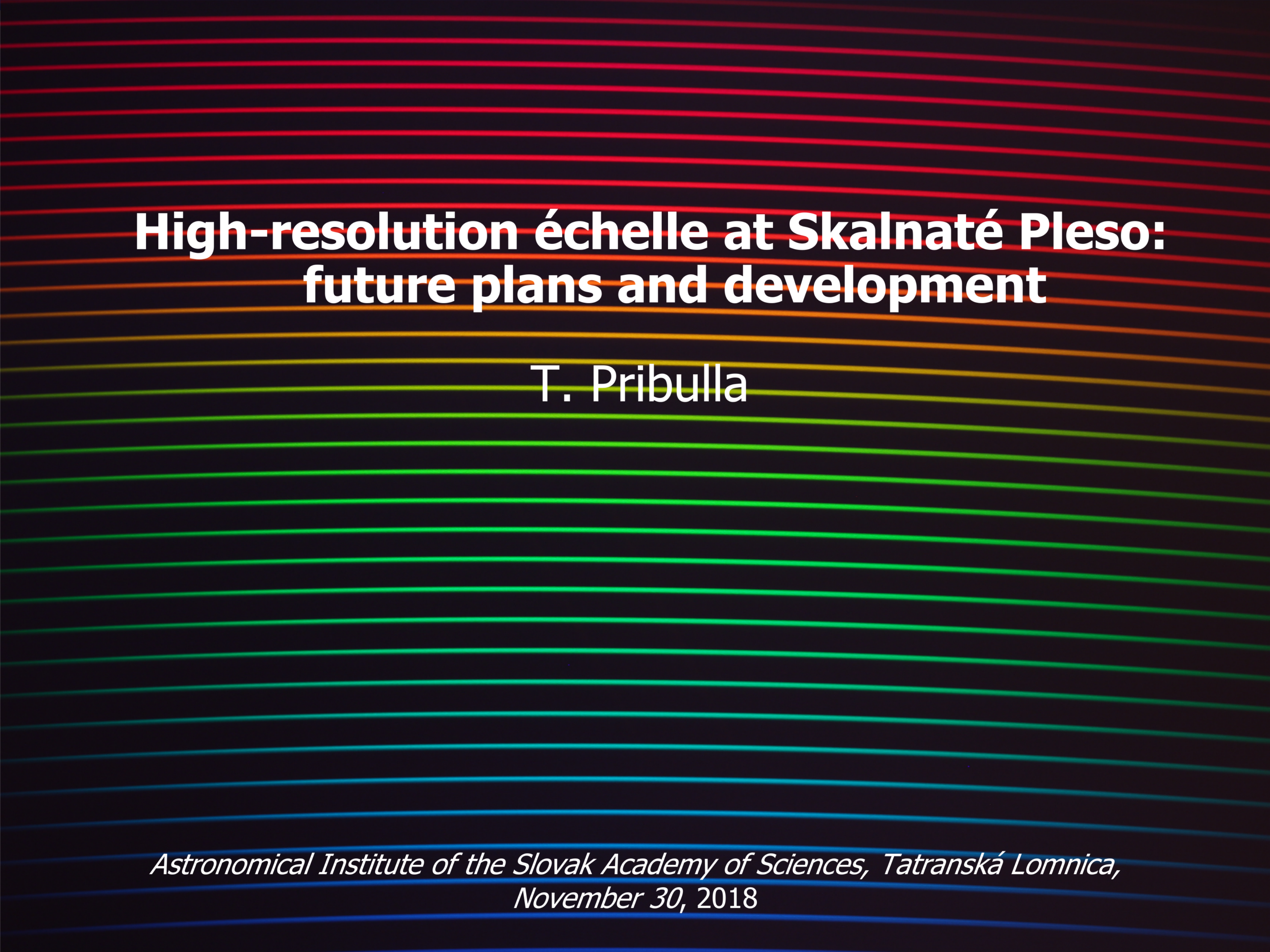

High-resolution échelle at Skalnaté Pleso: future plans and development

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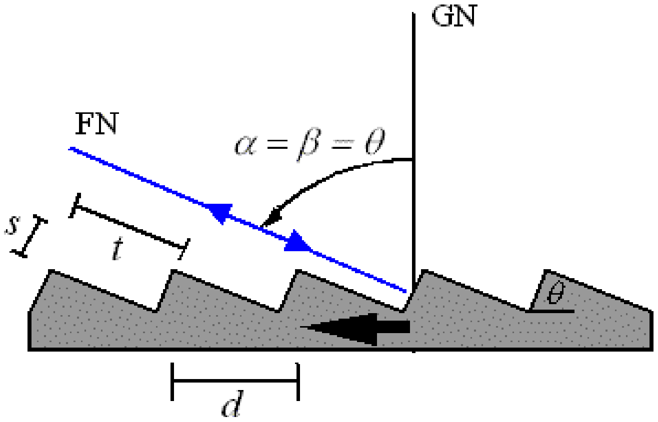
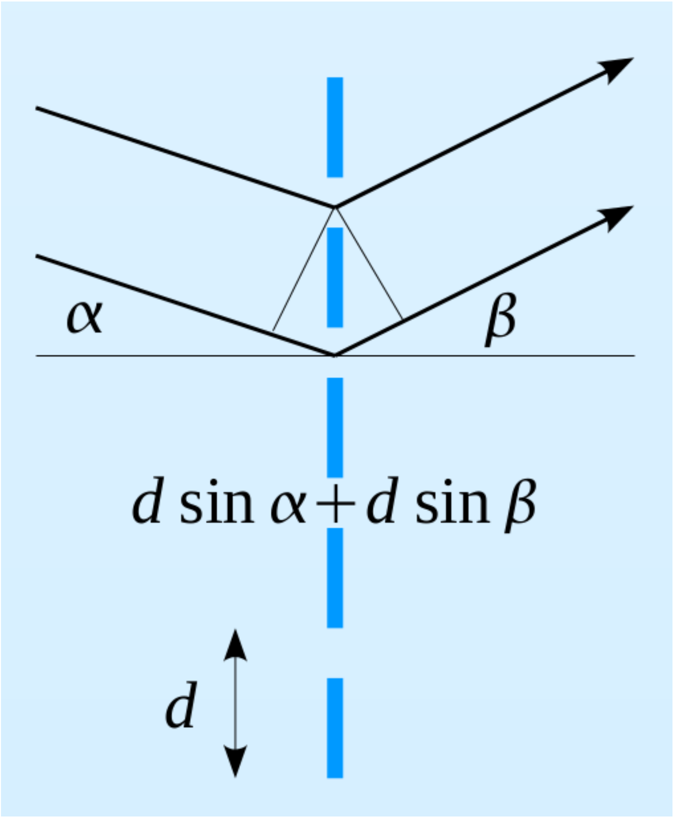
Échelle spectroscopy

$$\sin\alpha + \sin\beta = \frac{n\lambda}{d}$$

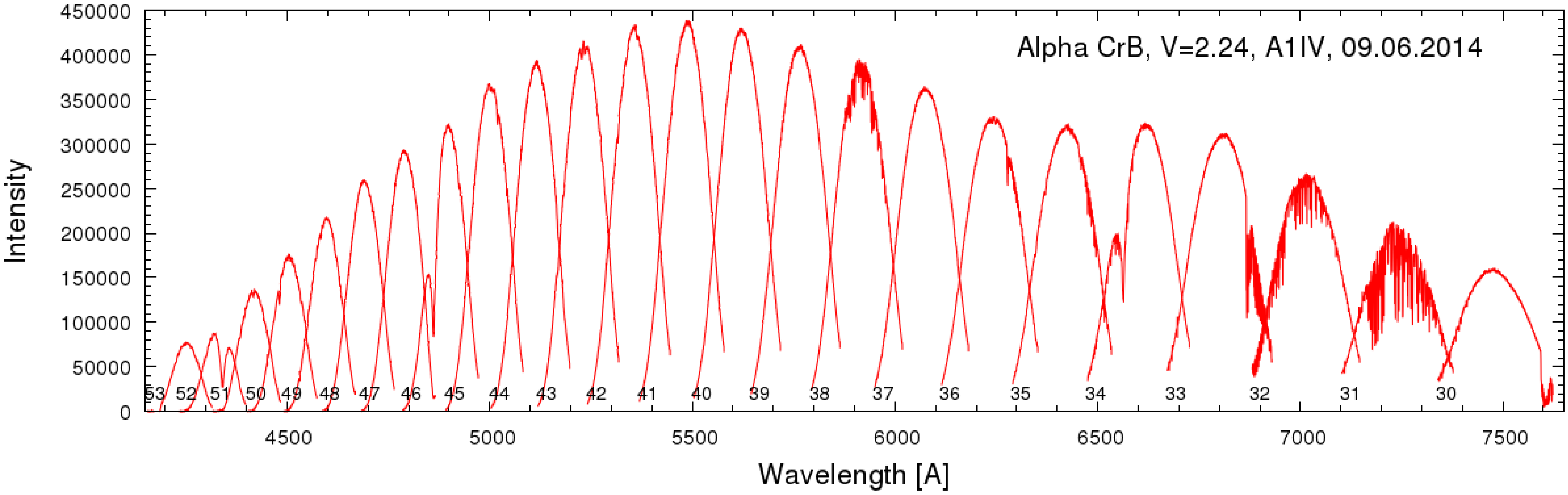
- long-slit spectrographs: usually first or second interference order used, low order overlap
- échelle spectrographs: high orders, total order overlap, cross-dispersers necessary
- High resolution: high order (*n*), or/and small distance between grooves (*d*)
- grating blaze: improvement of efficiency: maximum for specular reflection





Échelle intensity distribution

- Blaze function = distribution of spectrum intensity
- Width of the blaze in wavelength is inversely proportional to the interference order



$$I(\beta) = \left[\frac{\sin(\pi d\cos\theta[\sin(\alpha-\theta)+\sin(\beta-\theta)]/\lambda)}{\pi d\cos\theta[\sin(\alpha-\theta)+\sin(\beta-\theta)]/\lambda}\right]^2$$

MUSICOS @ 1.3m telescope

- MUSICOS = Multi-SIte COntinuous Spectroscopy
- fiber-fed and optical bench-mounted
- Littrow design
- FIGU, fibers & calibration lamps from Shelyak
- 200µm calibration fiber, 50µm object fiber - both multimode
- collimator: f/4 on-axis parabolic mirror
- grating: 31.6 lines/mm, R2 échelle, 128x254mm
- crossdisperser: ZK2 glass prism with 57° apex angle
- camera: Canon FD 2.8/400L
- detector: Andor iKon DZ-936 (ron 2.9e^{-}), with water circulation -100 C
- resolution: R=25000-38500 (FWHM)
- spectral range: 56 orders covering 4190-7200 Å (limited by the chip size)

eShel@60cm in G1

- R=10000 (maximum)
- useful spectral range: 28 orders covering 3920-7100 Å
- magnitude limit V=11, SNR=15 in 15 minutes

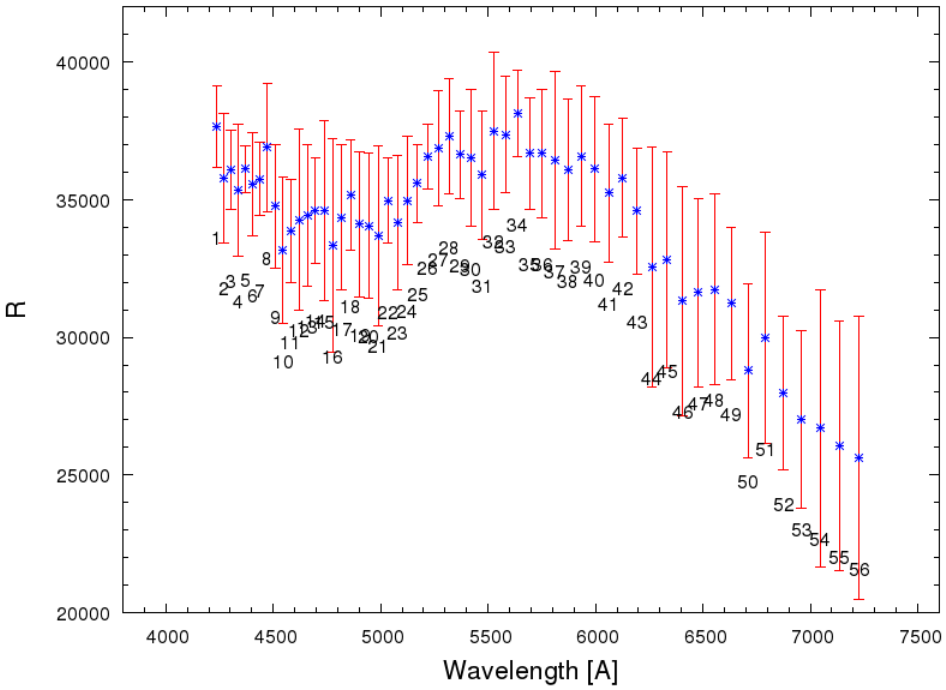
MUSICOS@1.3m at SP

- R=38500 (maximum)
- useful spectral range: 56 orders covering 4220-7200 Å
- magnitude limit V=11, SNR=15 in 15 minutes

$$\sigma = \mathrm{const}\frac{v\sin i}{R^{3/2}B^{1/2}f^{1/2}SNR}$$

Brightness-limited RV precision is about 20 m/s for MUSICOS while only 160 m/s for eShel for a 9 mag star

MUSICOS performance

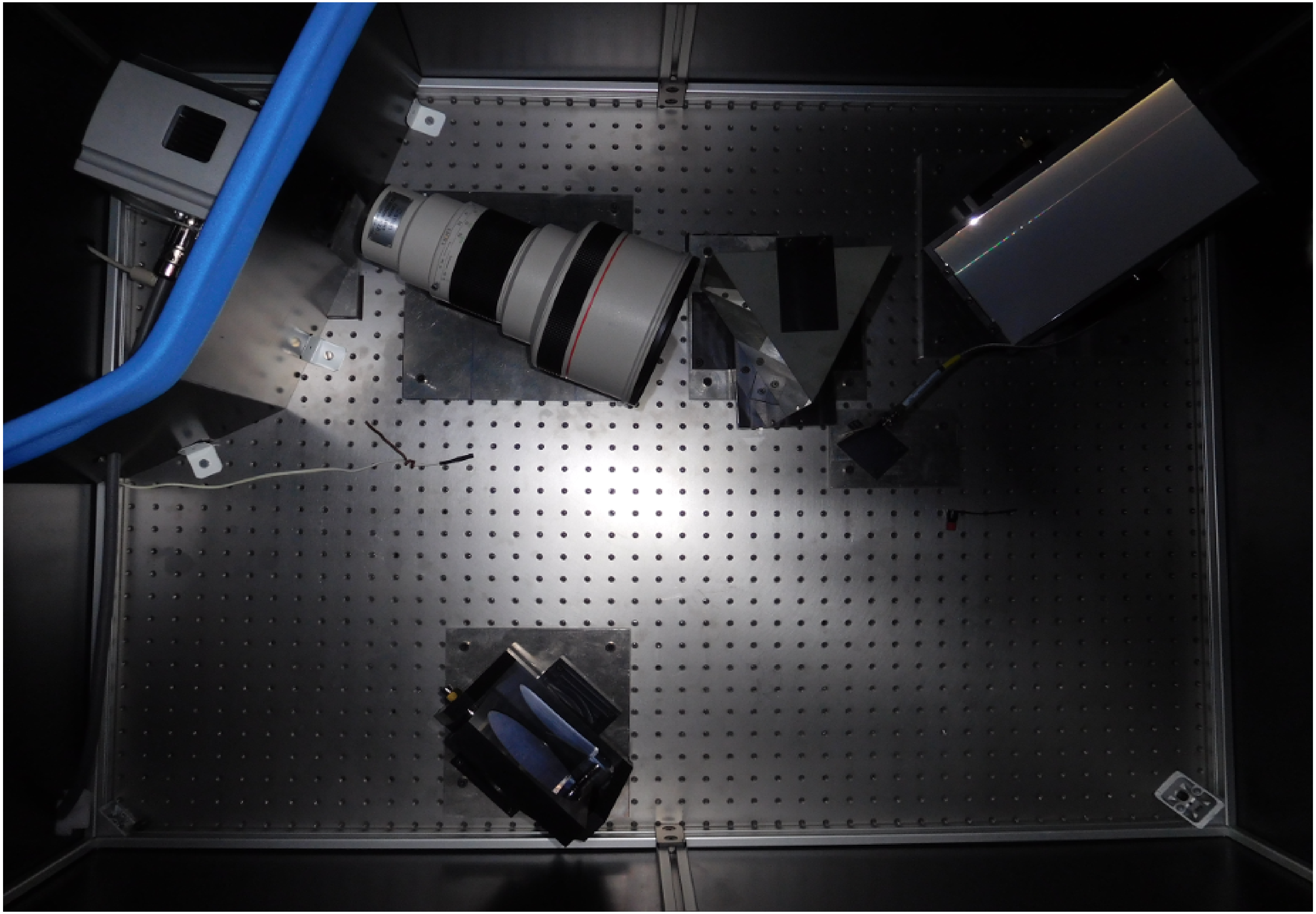


Resolution measured on non-blended ThAr lines, depends on focusing the Canon lens

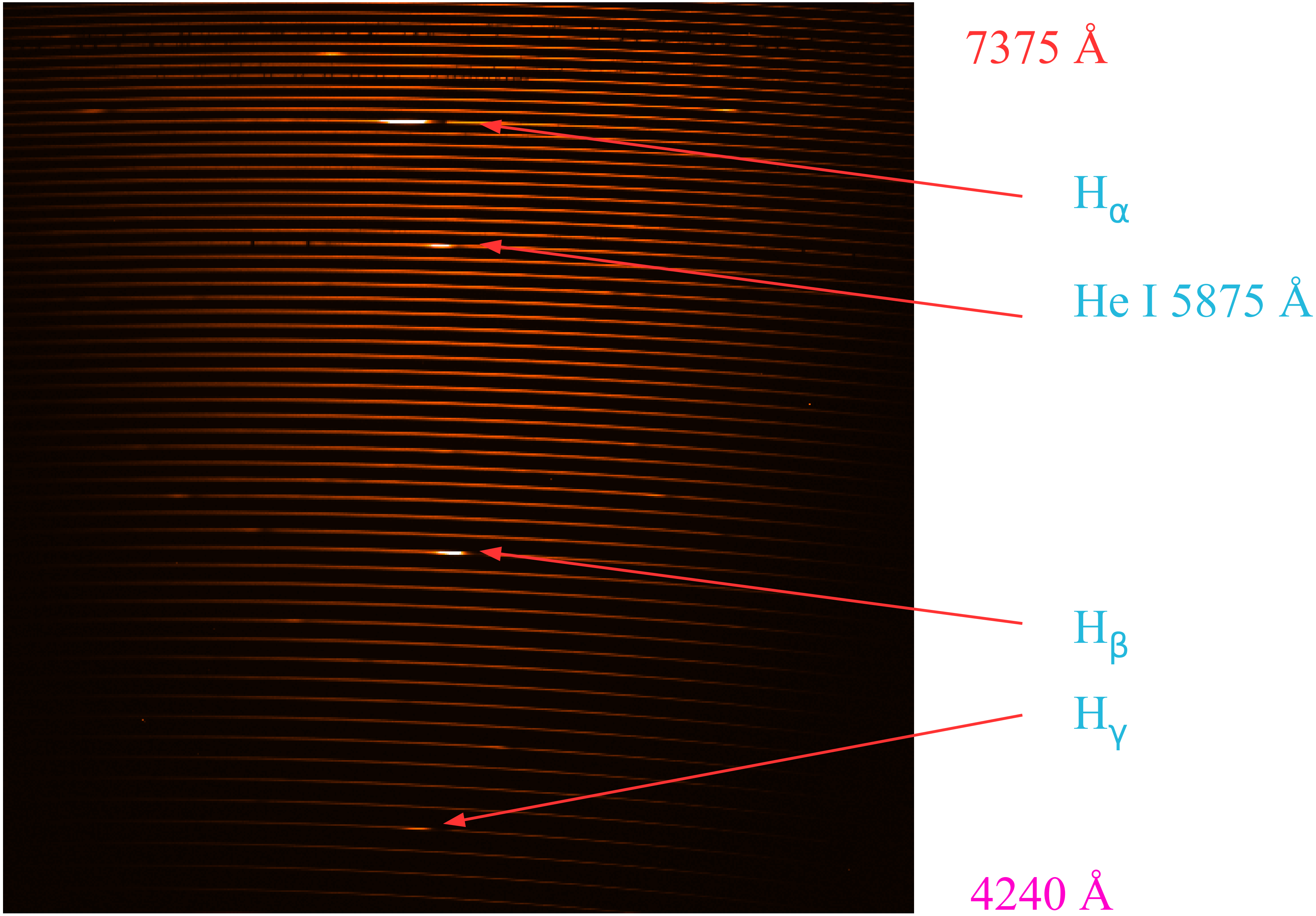
R> 30000 for λ < 6000 Å

Theoretical maximum is R = 38400 (FWHM)

ThAr solution zero-point shifts show about 200 m/s scatter



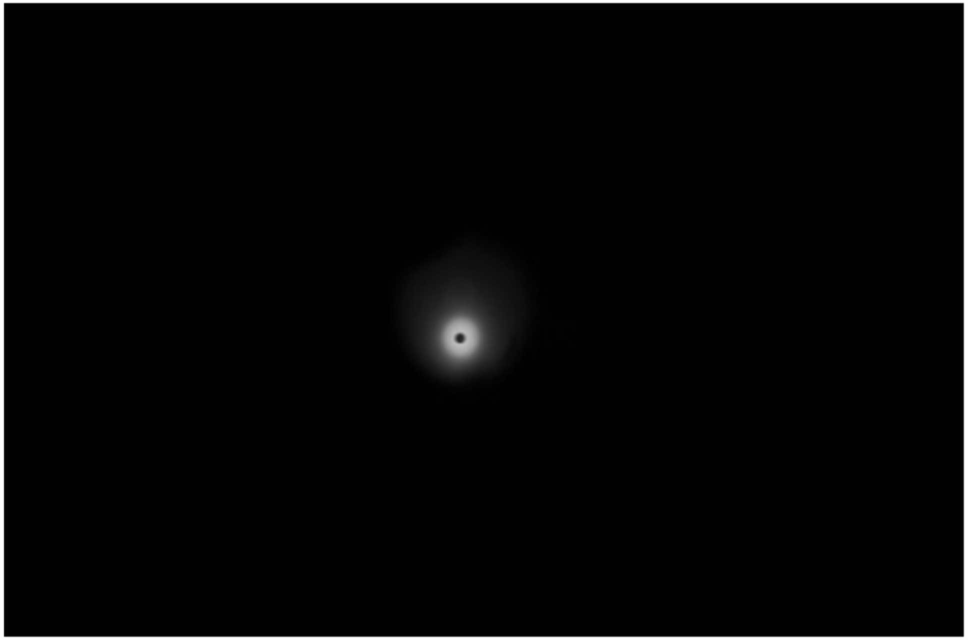
MUSICOS on the optical bench



Format of echelle spectrum on the Andor 2k x 2k CCD (P Cygni, 90-sec exposure)

FIGU - Fiber Injection and Guiding Unit

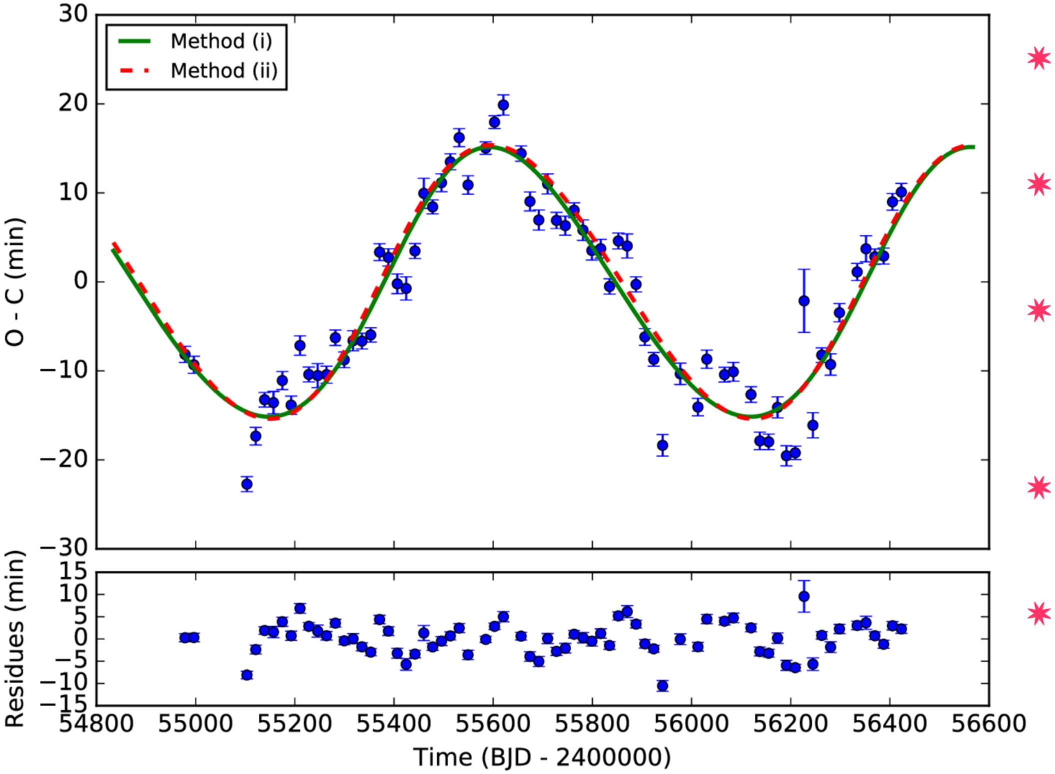
- FIGU optimized for f/6 but run at f/4
- focal reducer from f/8 to f/4
- inclined mirror reflects telescope image to a video camera , WATEC 120N
- no image slicer used at the fiber end



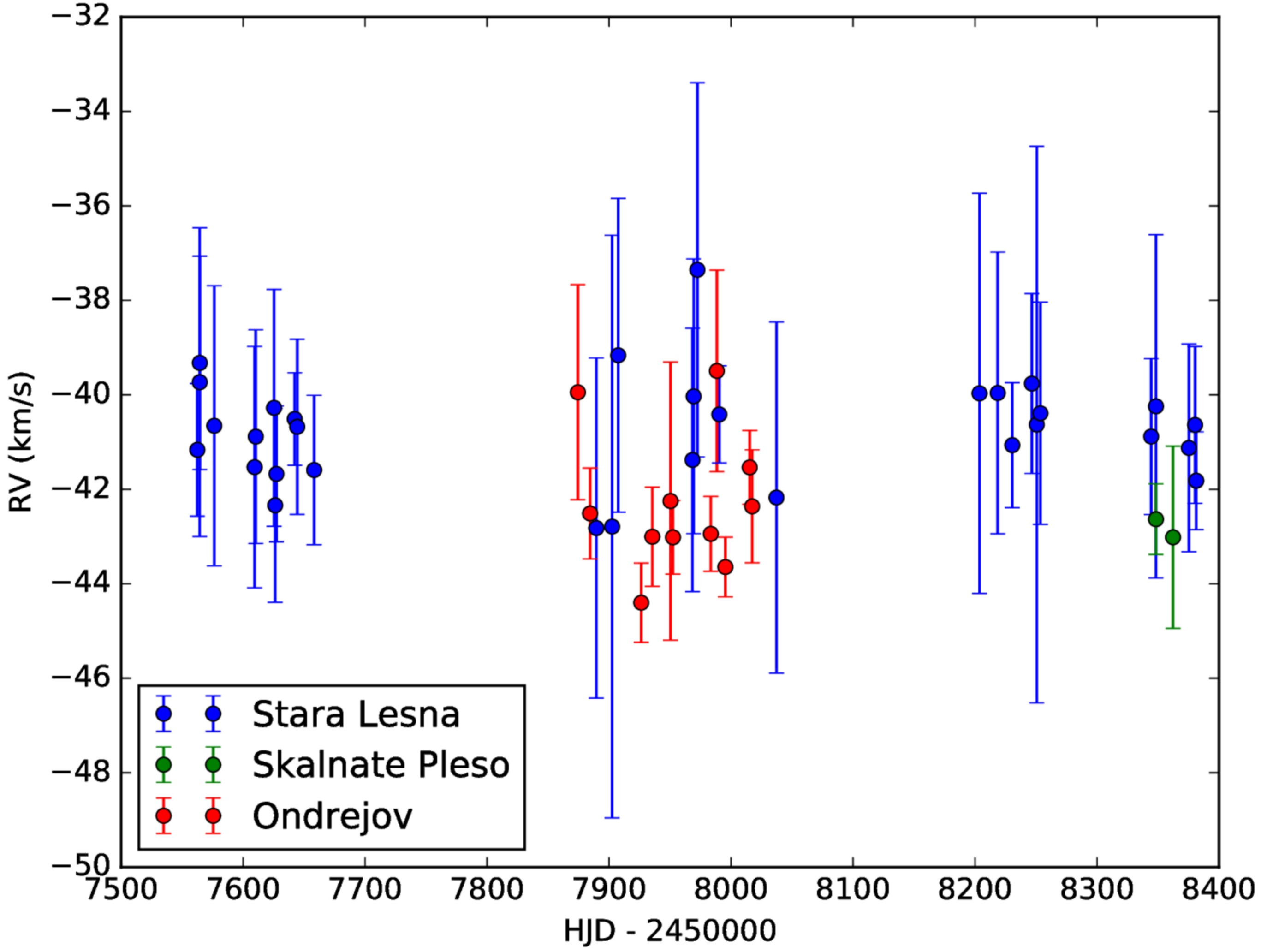
Observing projects

- symbiotic stars and novae
- close binaries, multiple systems of stars
- T Tauri objects
- CP stars (mostly for Ernst Paunzen)
- exoplanet host stars
- follow-up observations for BRITE satellite objects

Kepler-410Ab



- Kepler-410Ab = HD175289, F6IV parent star
- Neptune-sized planet on a 17.8336 d orbit
- TTV variability observed with about 15-minute amplitude and 970-day orbit seen in the Kepler data
- The perturber must be a star with M > 0.9 Msun
- Expected RV amplitude K ~ 30 km/s (Gajdoš et al., 2017, MNRAS 469, 2907)

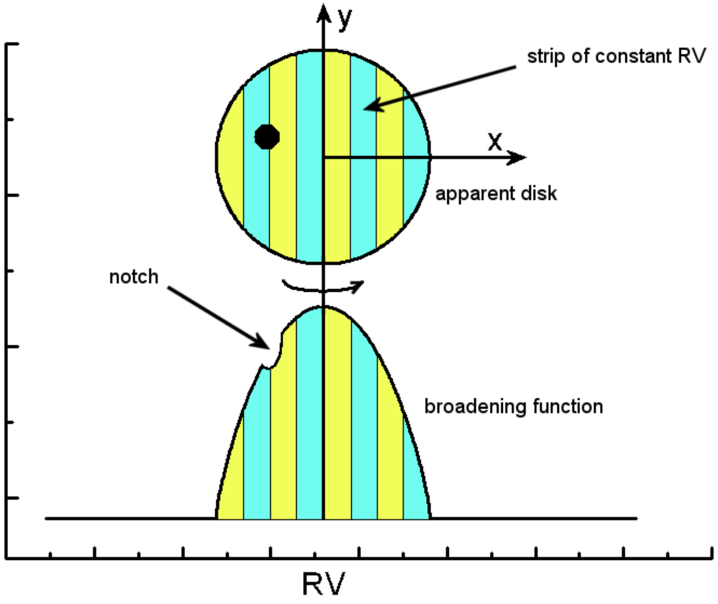


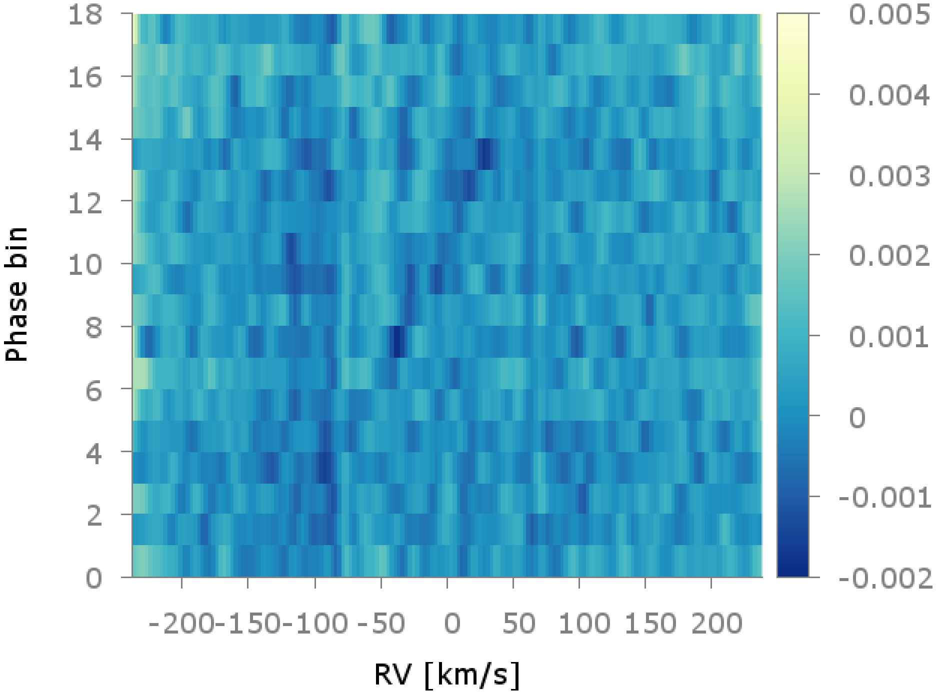
Now almost one cycle covered, observed RV variability < 3 km/s...

Possible explanation of TTV: resonance with a low mass planet

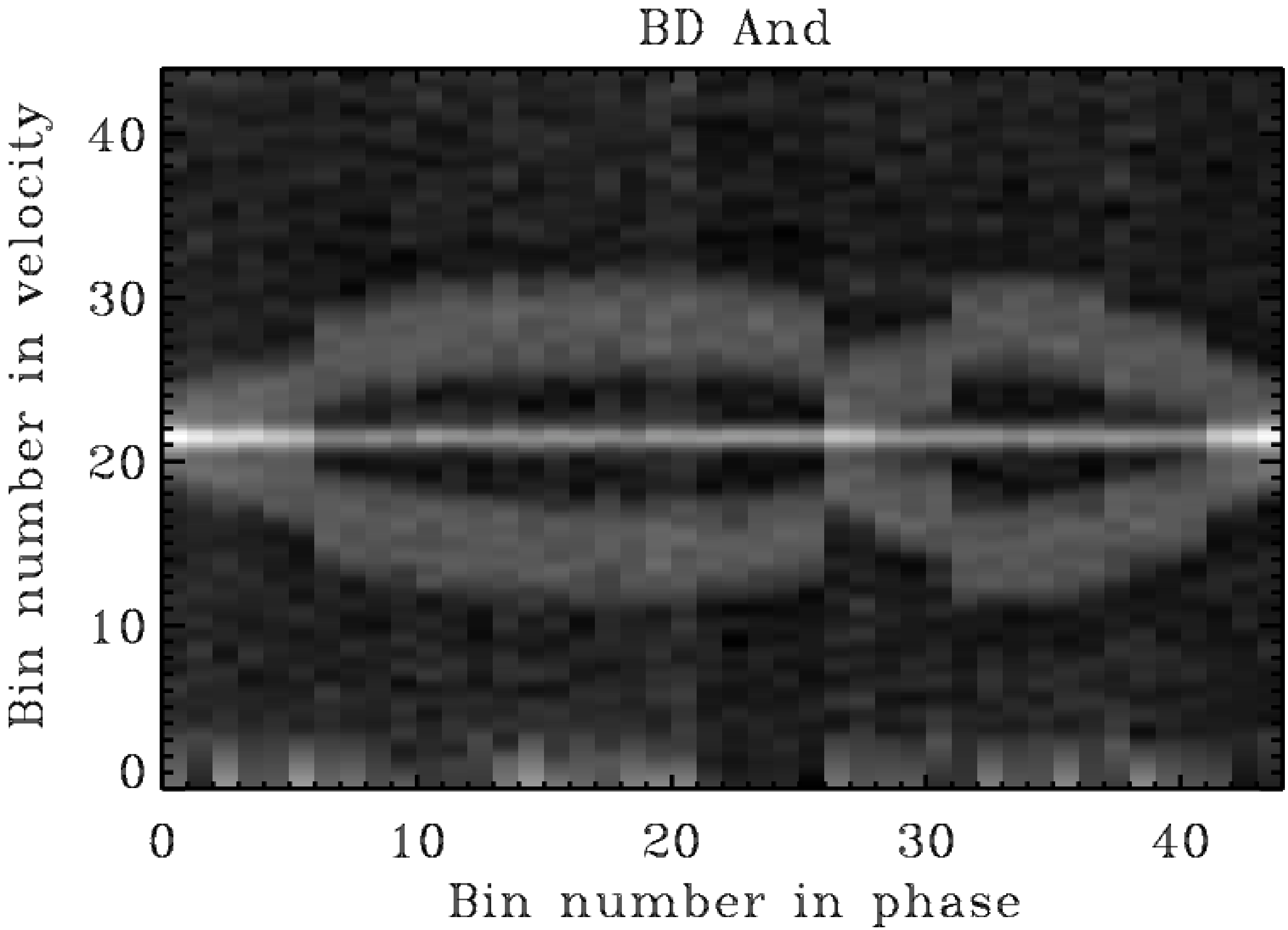
Doppler tomography of exoplanet transits

- Measuring spin-orbit misalignment
- requires v sin i » c/R
- Line profile modeled by limb-darkened rotational profile





- Kelt-7b = HD 33643, V=8.54
- F2V fast rotating parent star, v sin i = 74 km/s
- Transiting hot Jupiter P = 2.7347785 d, duration 210.7 minutes
- Spectroscopy with 15-min exposures, typical SNR = 40, 1.3m telescope
- BF = LSD profiles using HD102870 as a template and 4900-5600 Å range



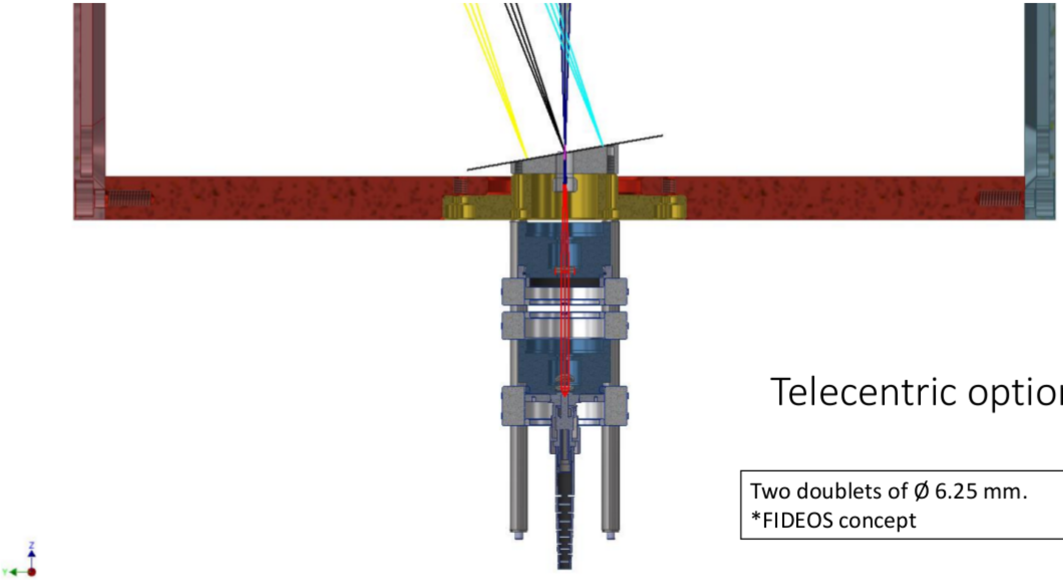
Vmax=10.84, G1V+G1V+G7V, P=0.9258 days, eclipsing binary, difficult object, short period and low brightness

Future plans

Improving magnitude limit

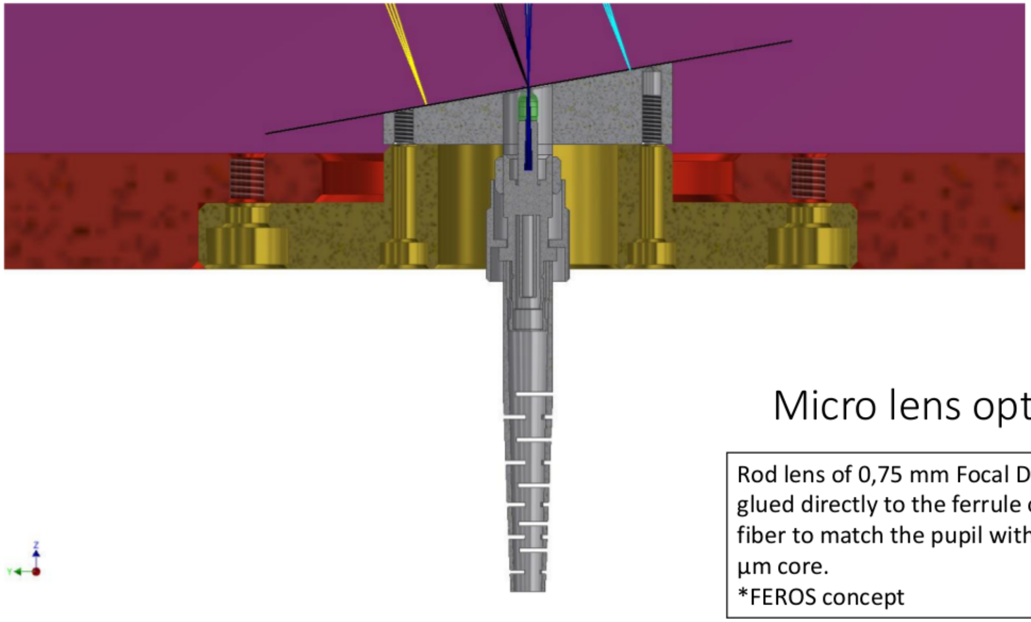
- Telescope losses: 3 mirrors + focal reducer <70% efficiency ⇒ fiber to the primary focus ?, but then f/2.8 to f/5, silver coating
- FIGU and seeing losses: fiber + FIGU: 42 % efficiency (measured by Shelyak) ⇒ possibly fiber reformaters, microlense ?
- collimator: now on axis + Al-coated ⇒ off-axis collimator and dielectric coated or silver-coated
- grating: ~10% losses by overfilling (+extra modal noise) ⇒ changing f/4 to f/5

Fiber injection possibilities (From FIDEOS and FEROS)



Telecentric option

Two doublets of Ø 6.25 mm.
*FIDEOS concept



Micro lens option

Rod lens of 0,75 mm Focal Distance glued directly to the ferrule of the fiber to match the pupil with the 50 µm core.
*FEROS concept

Improving RV stability: towards exoplants

- The RV precision is now stability-limited even for V=9 objects
- Thermal stability of the room is $\Delta T \approx 1$ K within in one night ⇒ temperature regulation and thermal insulation
- Modal noise and aperture obscuration: ⇒ additional image scrambling + decreasing numerical aperture
- Simultaneous ThAr calibration ⇒ using bifurcated fiber input

Enabling remote observations

- Fixing the dome -slit opening
- Controling WATEC camera parameters, possible via RS232 to TP convertor + dedicated software

Thanks for your attention !