



Status 6/2017

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Potsdam Echelle Polarimetric and Spectroscopic Instrument



Institut
Angewandte Optik
und Feinmechanik

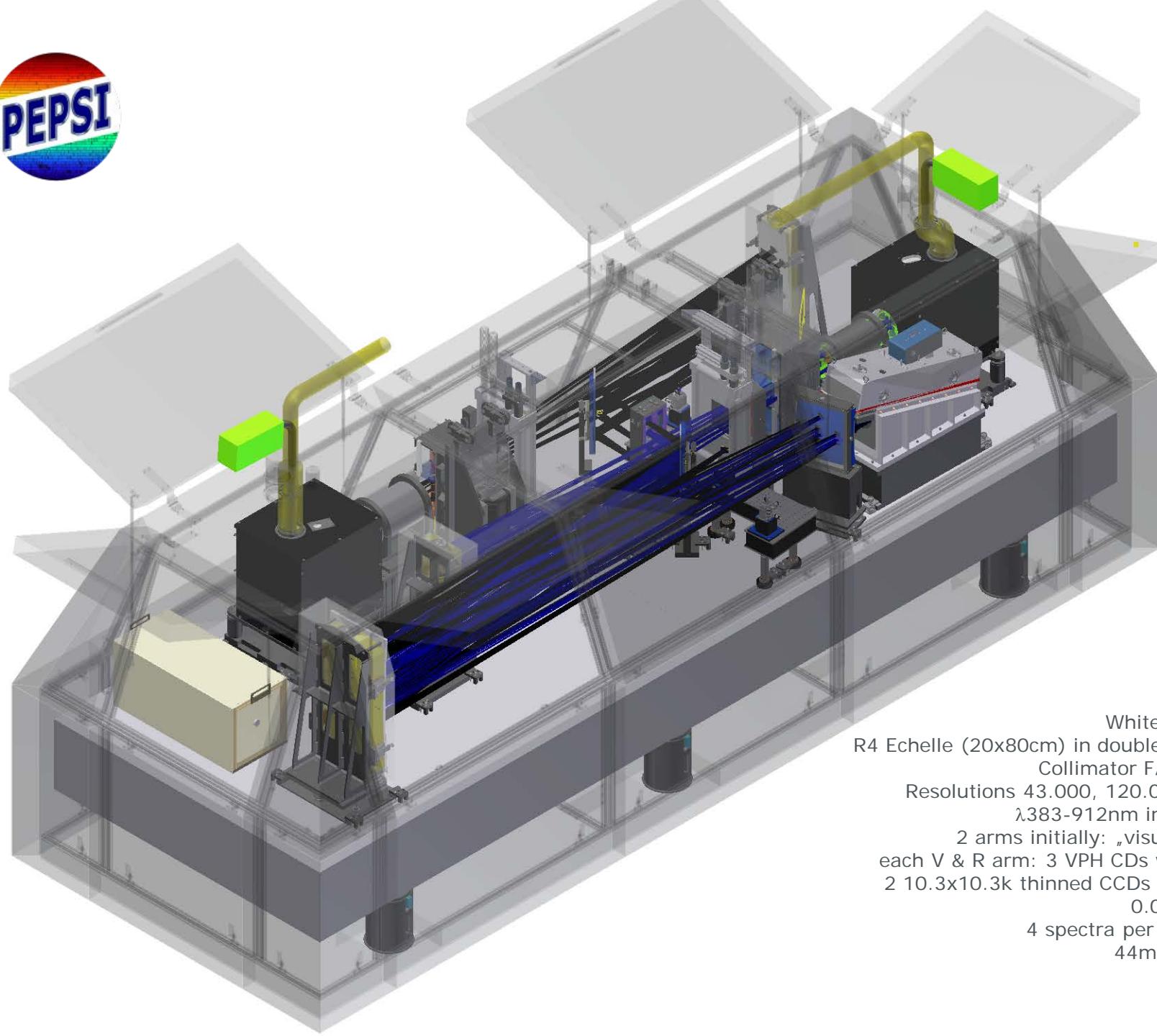
THE UNIVERSITY OF ARIZONA, TUCSON
UA Imaging Technology Laboratory



Visual high-resolution spectrographs at 8-10 m telescopes

Telescope	SALT	Keck I	VLT Kueyen	HET	Subaru	LBT
						
Diameter [m]	10	10	8.2	9.2	8.2	2×8.4
Spectrograph	HRS	HIRES	UVES	HRS	HDS	PEPSI
Maximum R ($=\lambda/\Delta\lambda$)	65,000	84,000	110,000	120,000	160,000	270,000
Wavelengths [μm]	0.37– 0.89	0.3 – 1.0	0.3 – 1.1	0.39 – 1.1	0.3 – 1.0	0.38 – 0.91





White-pupil design
R4 Echelle (20x80cm) in double pass Littrow
Collimator F/14 Maksutov
Resolutions 43.000, 120.000, 250.000
 λ 383-912nm in 3 exposures
2 arms initially: „visual“ and „red“
each V & R arm: 3 VPH CDs with 2 prisms
2 10.3x10.3k thinned CCDs simultaneous
0.073 arcsec/px
4 spectra per echelle order
44m fibre bundle





Issues brief

- 10k CCD **fixed-pattern noise** in three stripes (columns); limits S/N to $\approx 1300:1$ in the affected wavelength regions.
- **Electrical interference** on DX guider CCD; limits guiding on DX currently to 16th mag. SX unaffected.
- Current efficiency in UHR mode dominated by binocular **guiding jitter** (need help from LBTO!)
- **Lower** than expected **efficiency** in the bluest CD (CD#1) suggests there is a remaining coating/glass issue.



Observing experiences

- **Observing** itself is straightforward, no phase-II material or similar is needed. Will work in **remote control** from Potsdam as of 2017B.
- Integrations can be started **10min after sunset** (cc before sunrise).
- **DR** is the (PEPSI-team time) bottleneck. See poster by Ilya Iljin.
- Full and continuous calibration is time consuming (c/o „**Super Master Flats**“). Being done from scripts executed during daytime → competes w/ solar SDI observations.
- So far, **no noteworthy time losses** due to **technical failures**.
- PEPSI is a don't touch system and works even in bad/moderate seeing → **ideal facility instrument**.

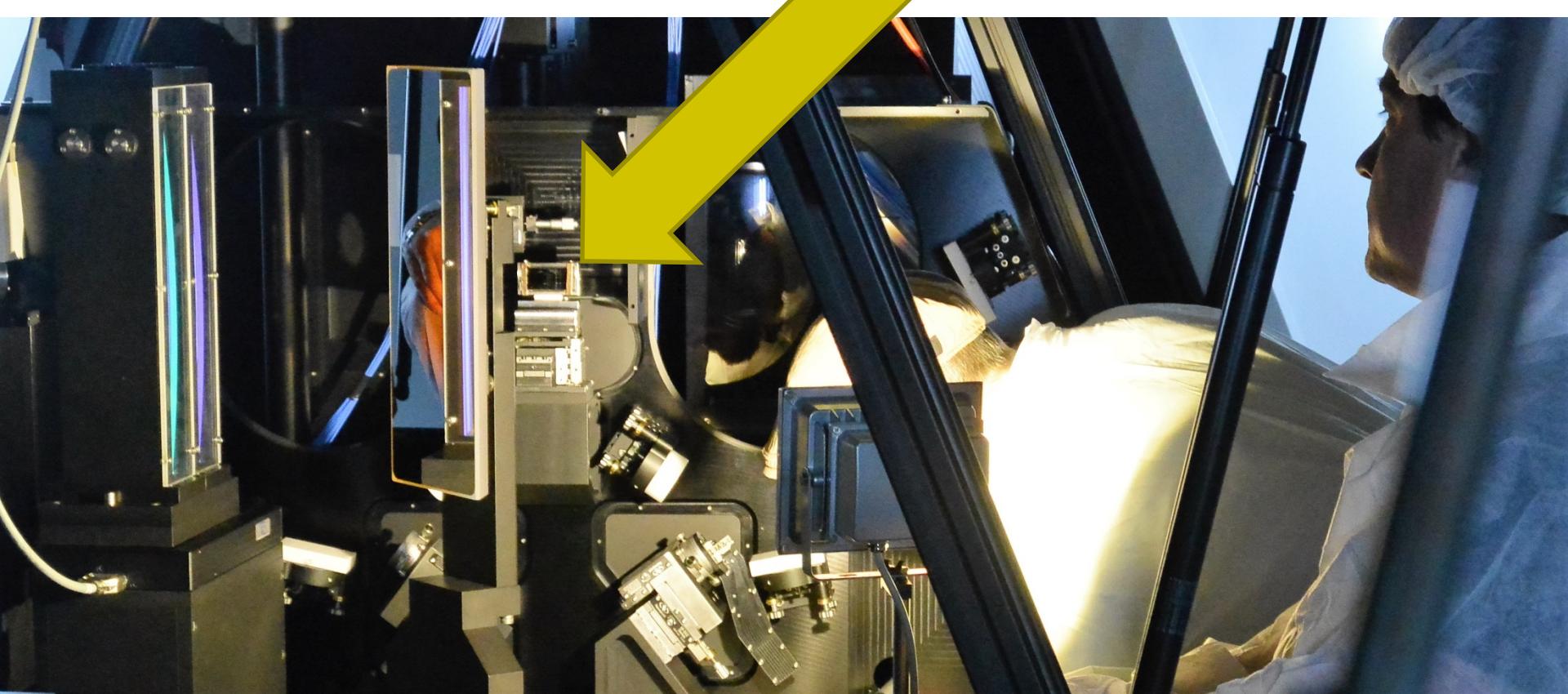


Ongoing work ...



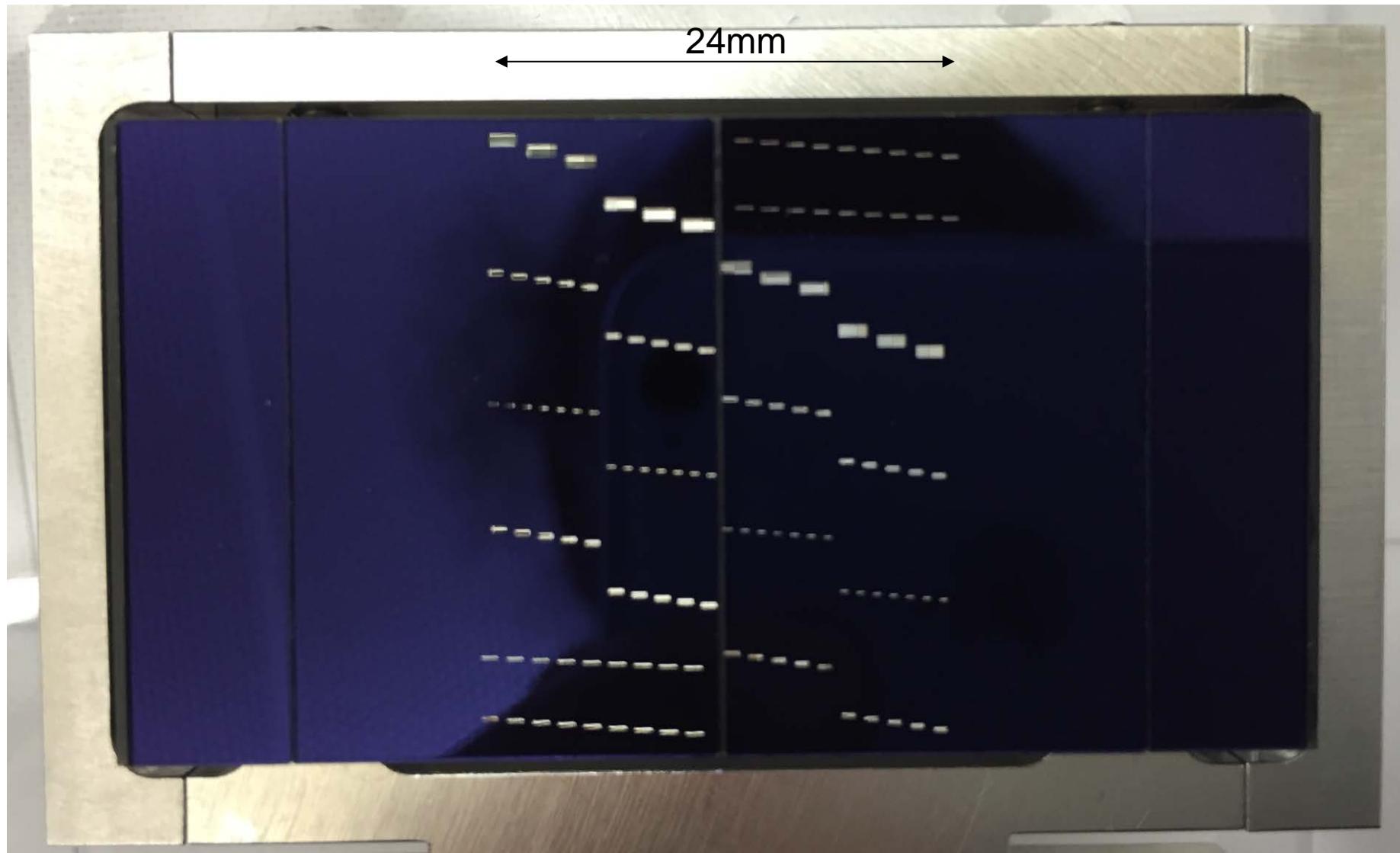


New Image-Slicer block



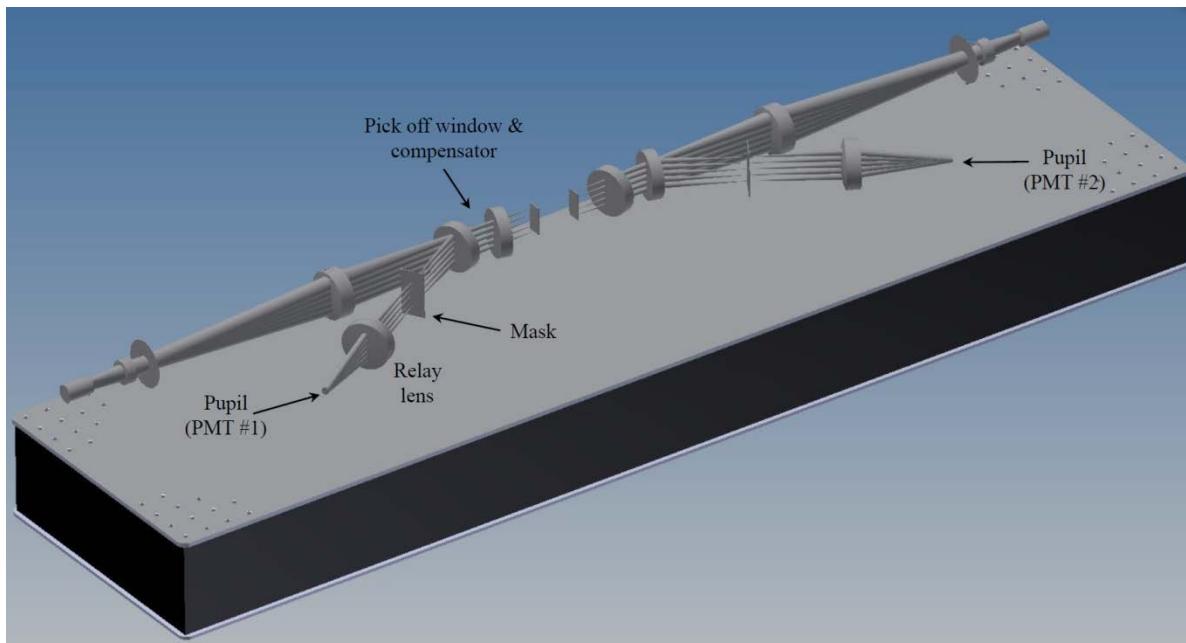


Waveguide IS and its ...





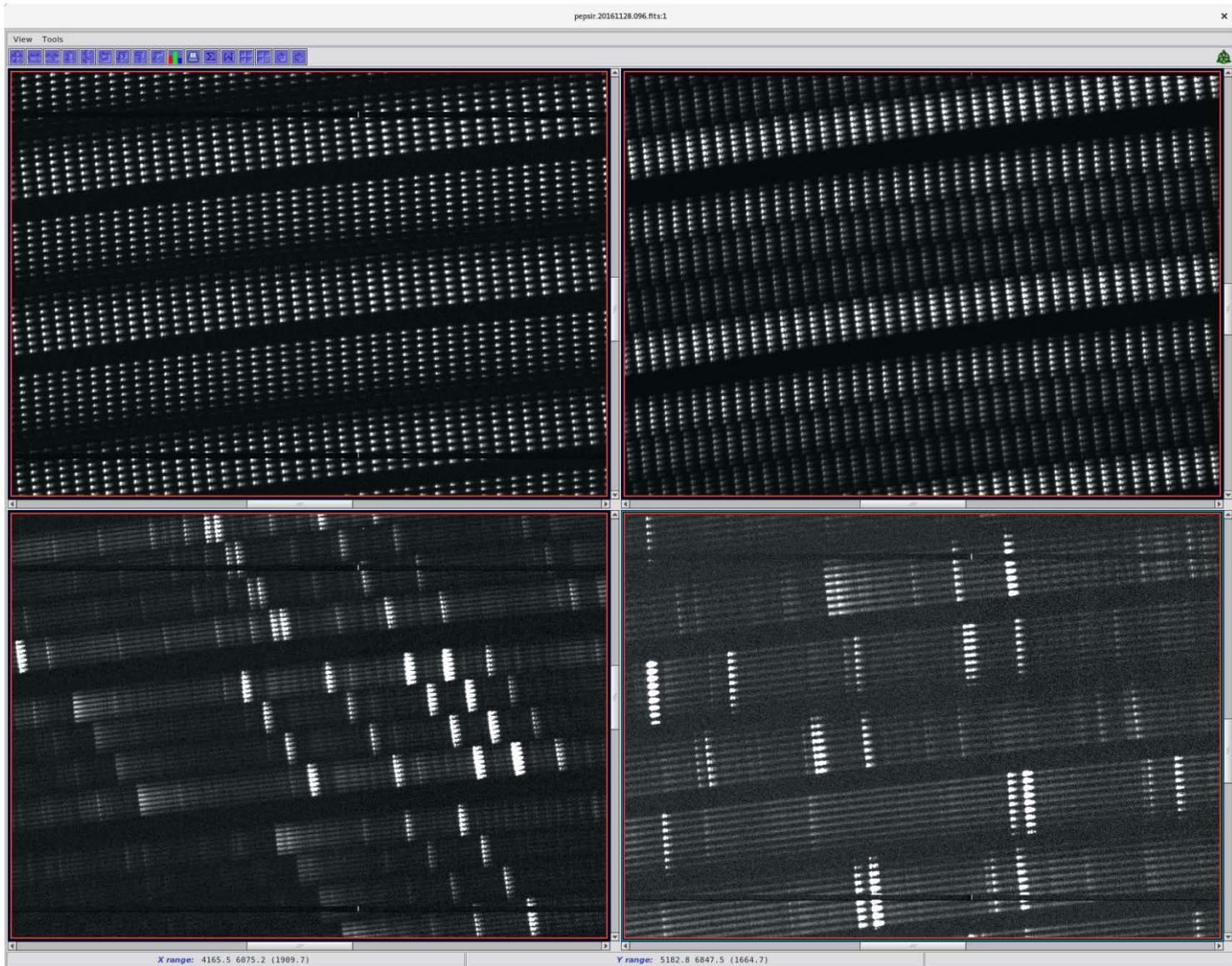
... new fibre coupling





... and what the CCDs see

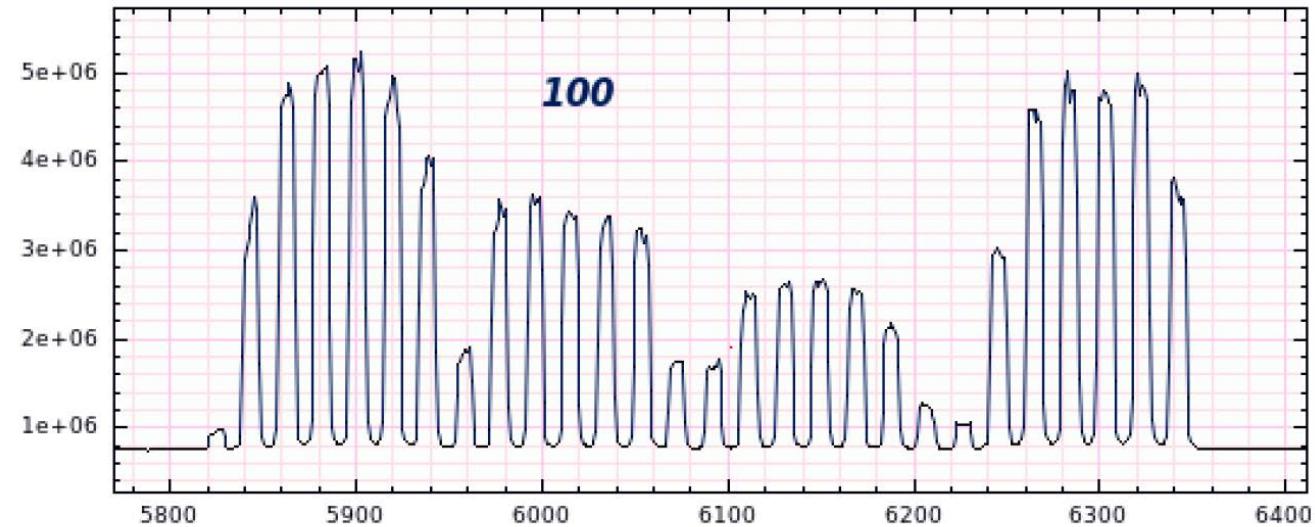
FPE



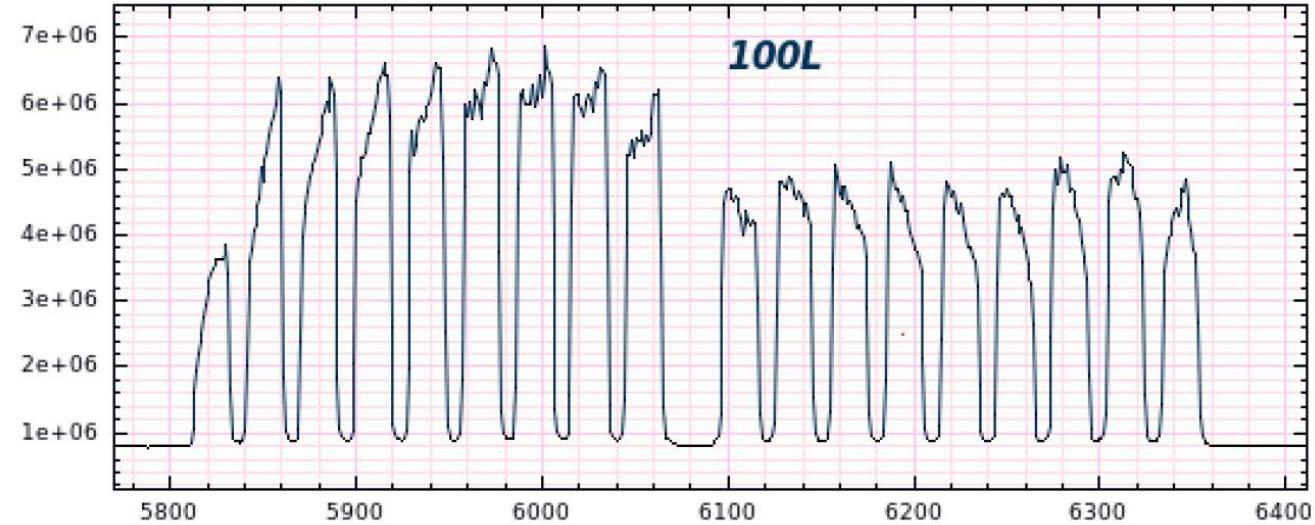


... and what the CCDs see

7-slice IS w/
100 μ m fibre
for use w/ LBT
 $R \approx 270,000$



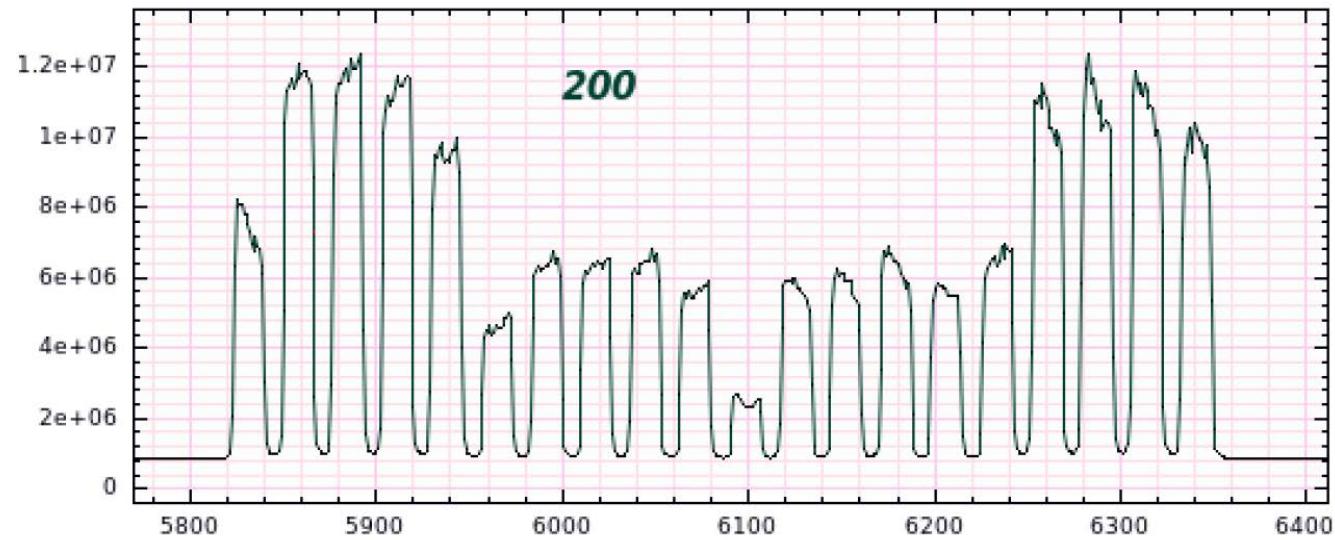
9-slice IS w/
300 μ m fibre
for use w/ VATT
 $R \approx 260,000$



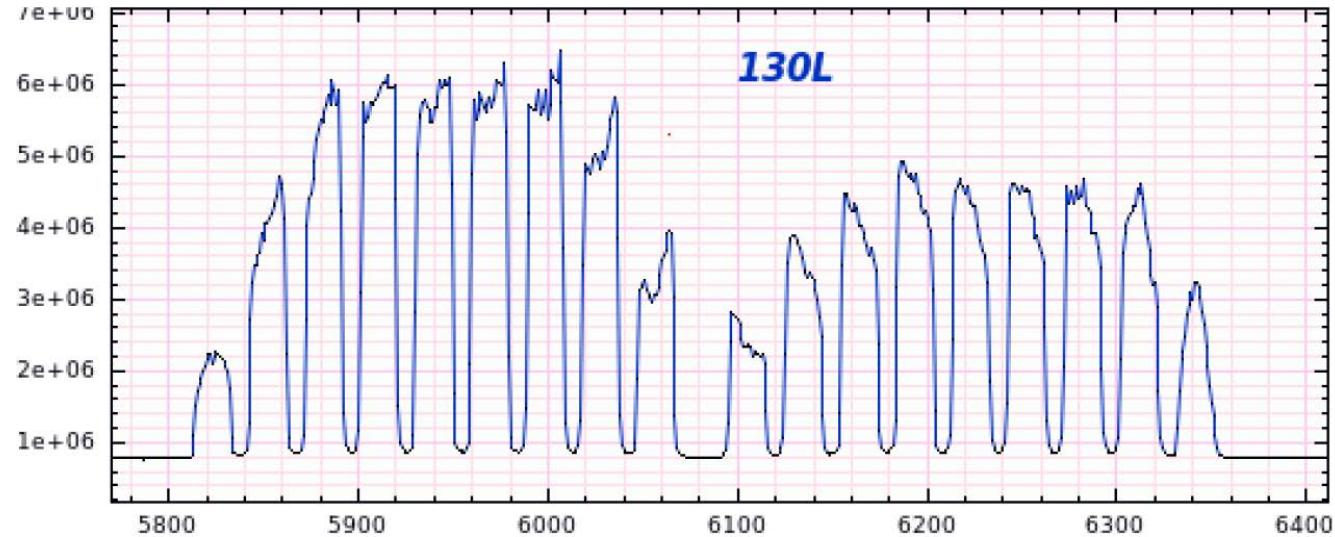


... and what the CCDs see

5-slice IS w/
200 μ m fibre
for use w/ LBT
 $R \approx 120,000$



9-slice IS w/
300 μ m fibre
for use w/ VATT
 $R \approx 200,000$





P.I. key-science projects

- (integral light) PEPSI „**deep spectrum**“ project. Single, high-R, high-S/N spectrum for selected „key“ targets.
- Targets of opportunity (Tabby’s star, TRAPPIST-1 ...)
- (polarimetric light) ZDI of „**The Sun in Time**“; solar-type stars in a series of open cluster stars of various ages sampling the evolutionary „magnetic brake“.

„Deep spectrum project“ ongoing

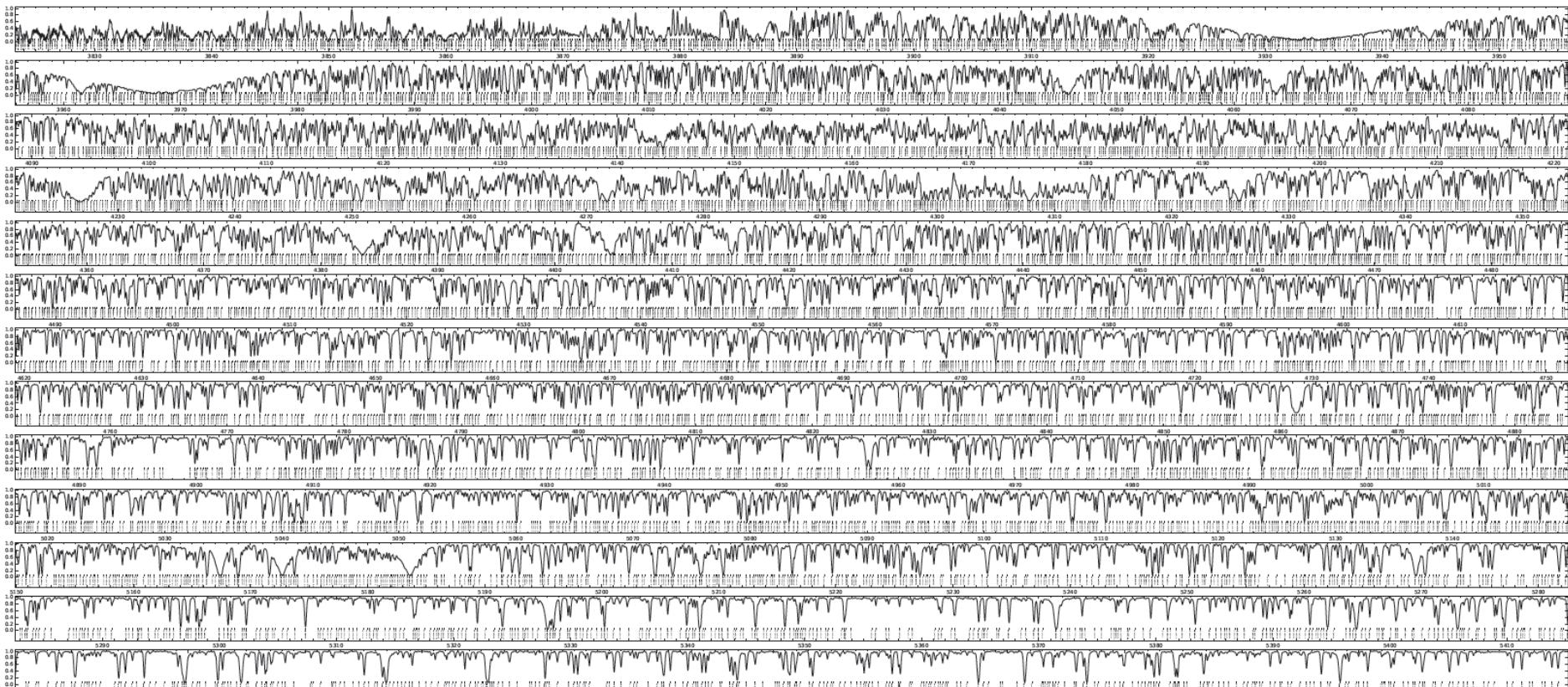


The fingerprint of a star: Arcturus = α Boo

Arcturus ($= \alpha$ Bootis = HD124897) is a prototypical cool red giant of spectral classification K1.5III with a surface temperature of 4290 Kelvin, i.e., 1500 degrees cooler than the Sun but 25x larger. This poster shows the optical spectrum of Arcturus obtained with the Potsdam Echelle Polarimetric and Spectroscopic Instrument (PEPSI) of the Large Binocular Telescope (LBT). It plots the normalized intensity as a function of wavelength λ in Angströms (1 Å = 0.1 nm) from the top left corner to the bottom right corner. The PEPSI spectrum covers the wavelengths between 3820 Å (top left) and 9130 Å (bottom right) with an average spectral resolution of $R = \lambda/\Delta\lambda = 220,000$ or approximately 1.4 km/s. Its average dispersion is 0.007 Å/pixel. The full spectrum is stitched together from six

separate spectra in six different wavelength regions. Each wavelength region has its own cross disperser (CD) of which two of them are always exposed simultaneously. The wavelengths for CD-I (3820–4265 Å) and CD-VI (7419–9130 Å) were obtained with the LBT, the others with the much smaller Vatican Advanced Technology Telescope (VATT) and a 450m long fiber to PEPSI at the LBT. The achieved signal-to-noise (S/N) ratio varies with wavelength because CD-III (4800–5441 Å) was employed for only four short VATT exposures while CD-VI included nine LBT exposures (exposure time with the LBT was 3 sec, with the VATT 4 min for similar S/N ratio). At wavelengths longer than ≈ 4000 Å the photon noise is not noticeable anymore, S/N ratio is peaking near 4,000:1 at 700 nm. The

individual exposures took in total 10 minutes and were obtained on April 5, 2015. A subset of spectral absorption lines is identified in the graphics and marked with dashes beneath the spectrum. The annotation indicates the chemical element (e.g., Fe for iron), the ionization state (I for a neutral line, II for an ionized line), and the wavelength in Angstrom. Note that the annotation text appears darker the stronger the line. The line identifications and the wavelengths were taken from the Vienna Atomic Line Database. The original spectrum has been published in *Astronomy & Astrophysics* (Strassmeier, K. G., Iljin, I., & Weber, M. 2017, *A&A*). For further details and for spectra of other stars see <https://pepsi.aip.de/>.





The fingerprint of a star: Arcturus = α Boo

Antares ($\alpha = 16^{\text{h}} 24^{\text{m}} 02\text{s}$) is a spectroscopic cool giant of spectral classification K2-III with an effective temperature of 4200 Kelvin ($\Delta T = 3500$ degrees cooler than the Sun but 22 times larger). Antares shows the optical spectrum of Antares Shakes (Shakes 1960) with the following features: Stellar Polarization at Spectral Type K2-III, the ratio of the intensity of the light polarized at 90 degrees to the unpolarized light is 1.4. A portion of the spectrum from 4000 to 5000 Å has been taken from the bottom-right corner. The FFDG spectrum covers the wavelength range between 3200 Å (purple) and 6550 Å (blue) with an average spectral resolution of $1/\lambda \approx 120,000$ or approximately 1.4 Å/pixel. Averaging dispersion 1.0027 applied. The full spectrum is stitched together from

separate specific to six different nested engI regions. Each nested engI region has its own unique digests which none of them are always resolved simultaneously. The nested engI (CD 10300-10310, 2) and CD 10300-10310 (3) were cut with the *Sph*I, the other nested engI regions with Modified Advanced Technology (MATT) and *Xba*I (CD 10300-10310 at 2). The additional nested engI region with MATT and *Xba*I (CD 10300-10310 (4)) was not employed for only four nested engI regions could be resolved. The nested engI region with *Xba*I and *Pst*I (CD 10300-10310 (5)) was not employed because the *Pst*I signal was too weak. All nested engI regions were resolved with *Sph*I and *Xba*I, the phage lambda (lambda) marker digests, and *Xba*I resulting in new *Xba*I site at 730 nm. The

Individual exposures health related outcomes and were obtained on April 9, 2015. A subset of spectral absorption lines is identified in the graphics and associated with dates from the spectrum. The annotation indicates the chemical element (e.g., Peridotite), the individual state (for example, Ti, Titors or Lockheed Red), and the wavelength (in Angstroms) at which the absorption line appears (closer the stronger the line). The line identifiers and the wavelengths are taken from the Mineralogical Data Database. The original spectrum has been published in Anderson B. Asteroseismology (Brewer, C. E., Dris, L., & Walker, M. 2003, A&A). No further details for spectra of other stars see <http://www.astro-physics.org>.

48 targets;
inc. all northern
Gaia benchmark
stars



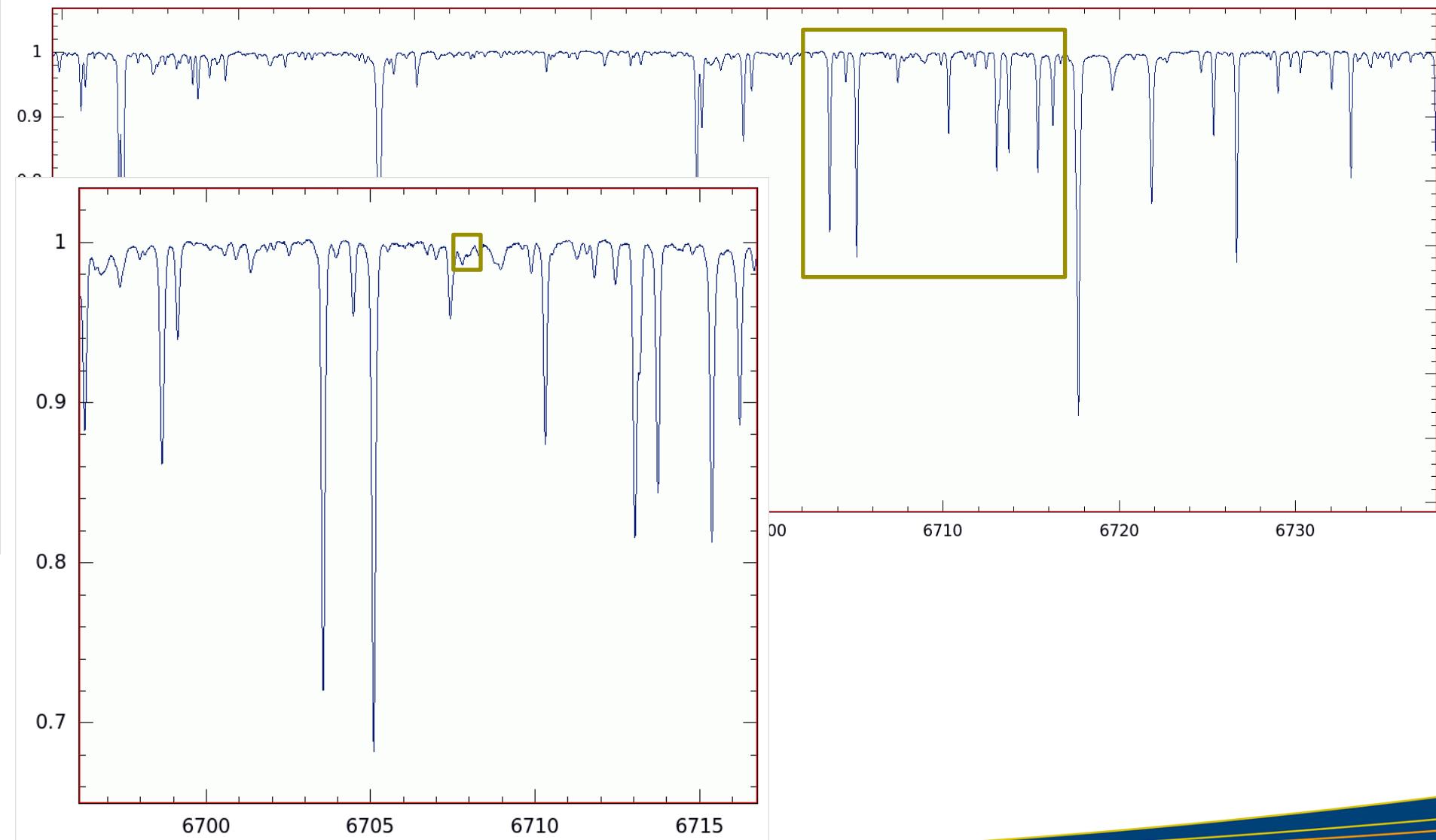
The fingerprint of a star Sun

In 1955, the author had described the case of the *Scutigeridae* in the solar spectra used by Gurney (1953) as being of interest because the solar fluxes were found to be higher than those of the terrestrial sun. The author has now examined the spectra in question, and has shown these areas at nearly the same time in the same manner as Gurney did. The results are given in Table I. The spectra of the terrestrial sun and the spectra of the solar fluxes used by Gurney are given in Fig. 1. The spectra of the terrestrial sun and the spectra of the solar fluxes used by Gurney are given in Fig. 1. The spectra of the terrestrial sun and the spectra of the solar fluxes used by Gurney are given in Fig. 1. The spectra of the terrestrial sun and the spectra of the solar fluxes used by Gurney are given in Fig. 1.

The image is a black and white graphic poster. It features a large, bold, sans-serif font where the letters 't', 's', 'n', 'o', 'r', 't', 'h', 'e', 'r', 'n', 'c', 'h', 'm', 'a', 'r', 'k' are arranged vertically. The background consists of a dense grid of horizontal lines, some of which are slightly curved or wavy, creating a pattern that looks like a stylized map or an architectural floor plan. The overall aesthetic is clean and modern.



Science cases, e.g., Li abundances



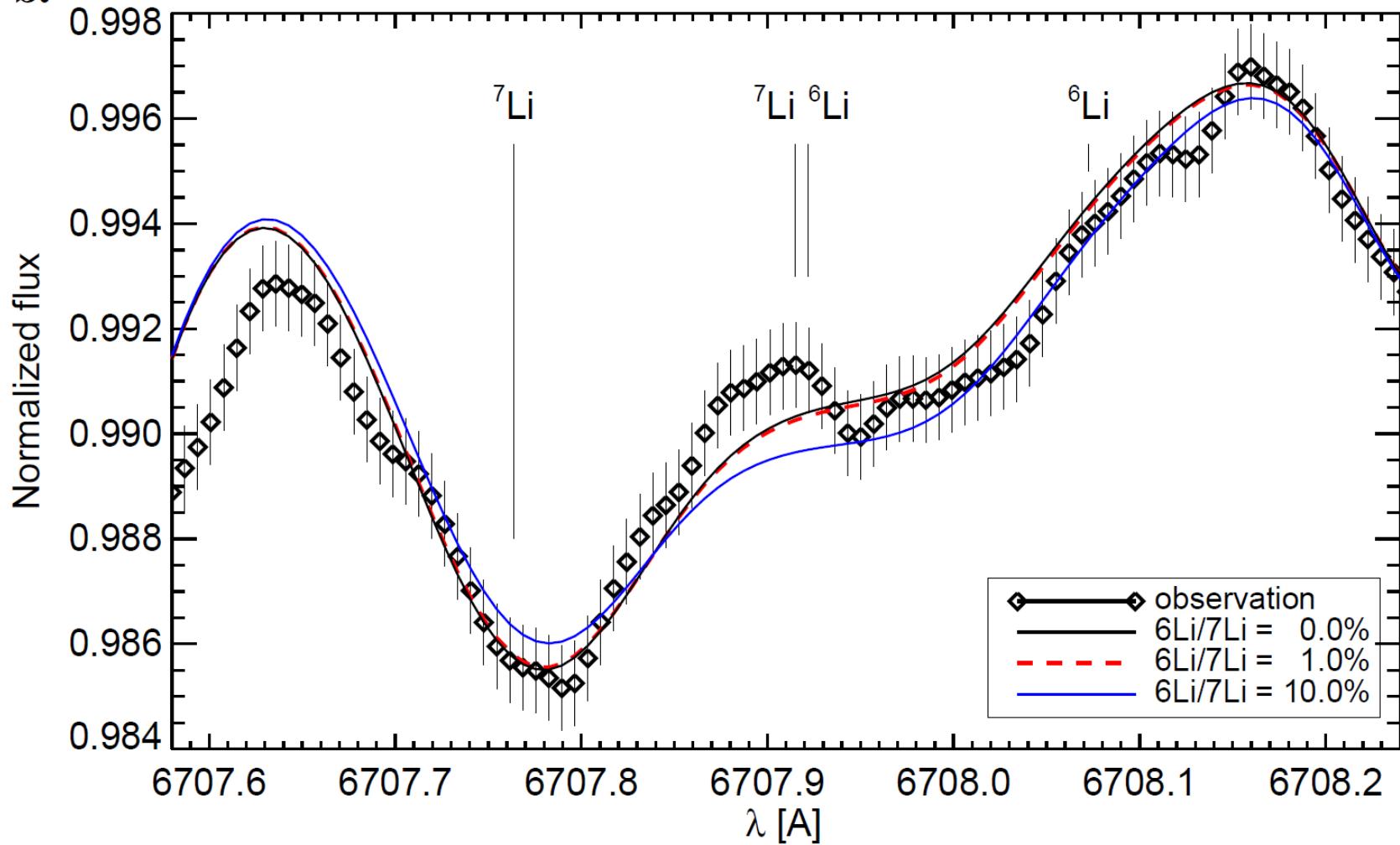


Solar Li abundance 3D-CO5BOLD in NLTE

$W(\text{Li}) \approx 4 \text{ m}\text{\AA}$
 ${}^6\text{Li}/{}^7\text{Li} \approx 1\text{-}10\%$

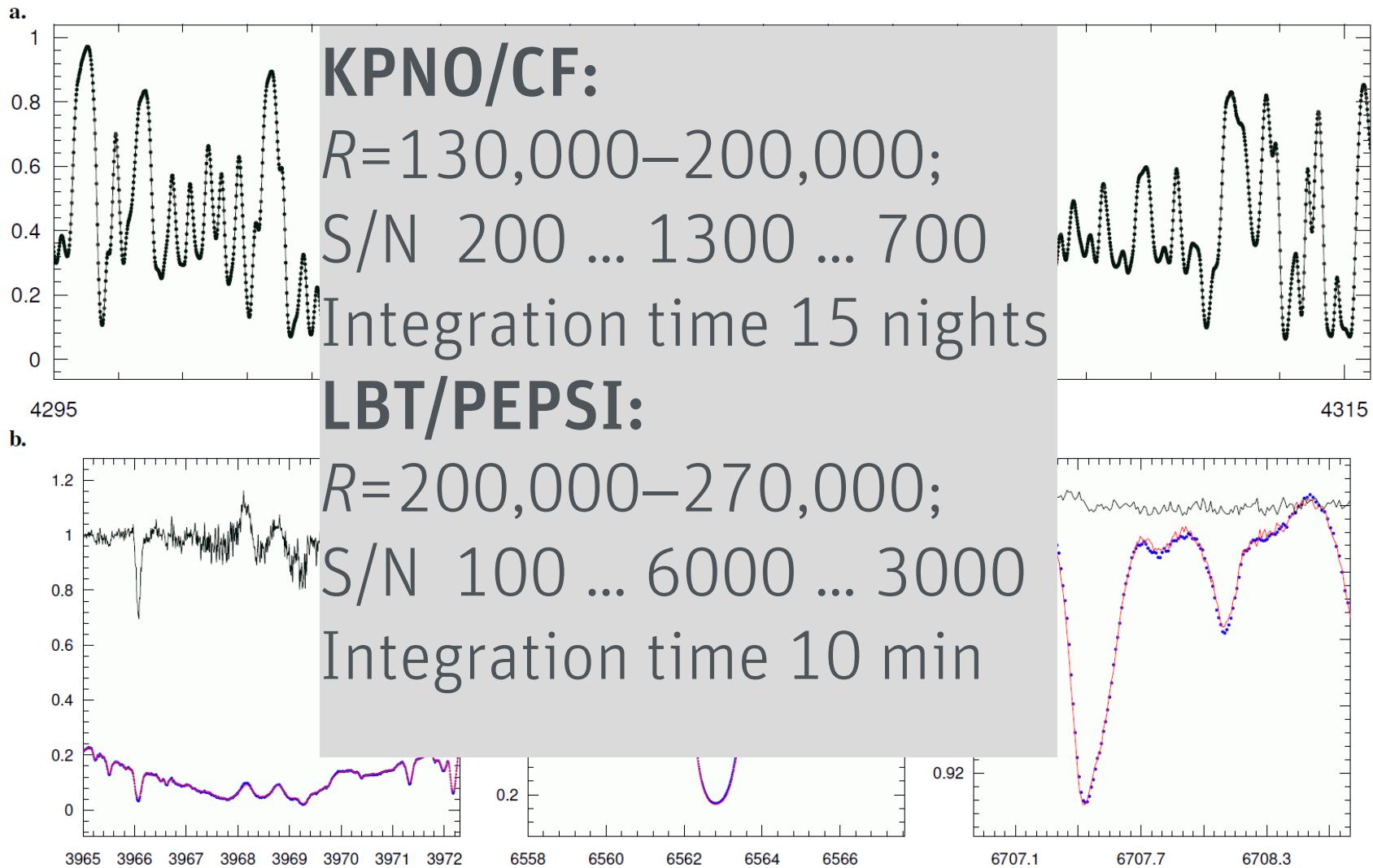
$A(\text{Li}) = 1.11 \pm 0.006^{+0.02}_{-0.06}$

b.



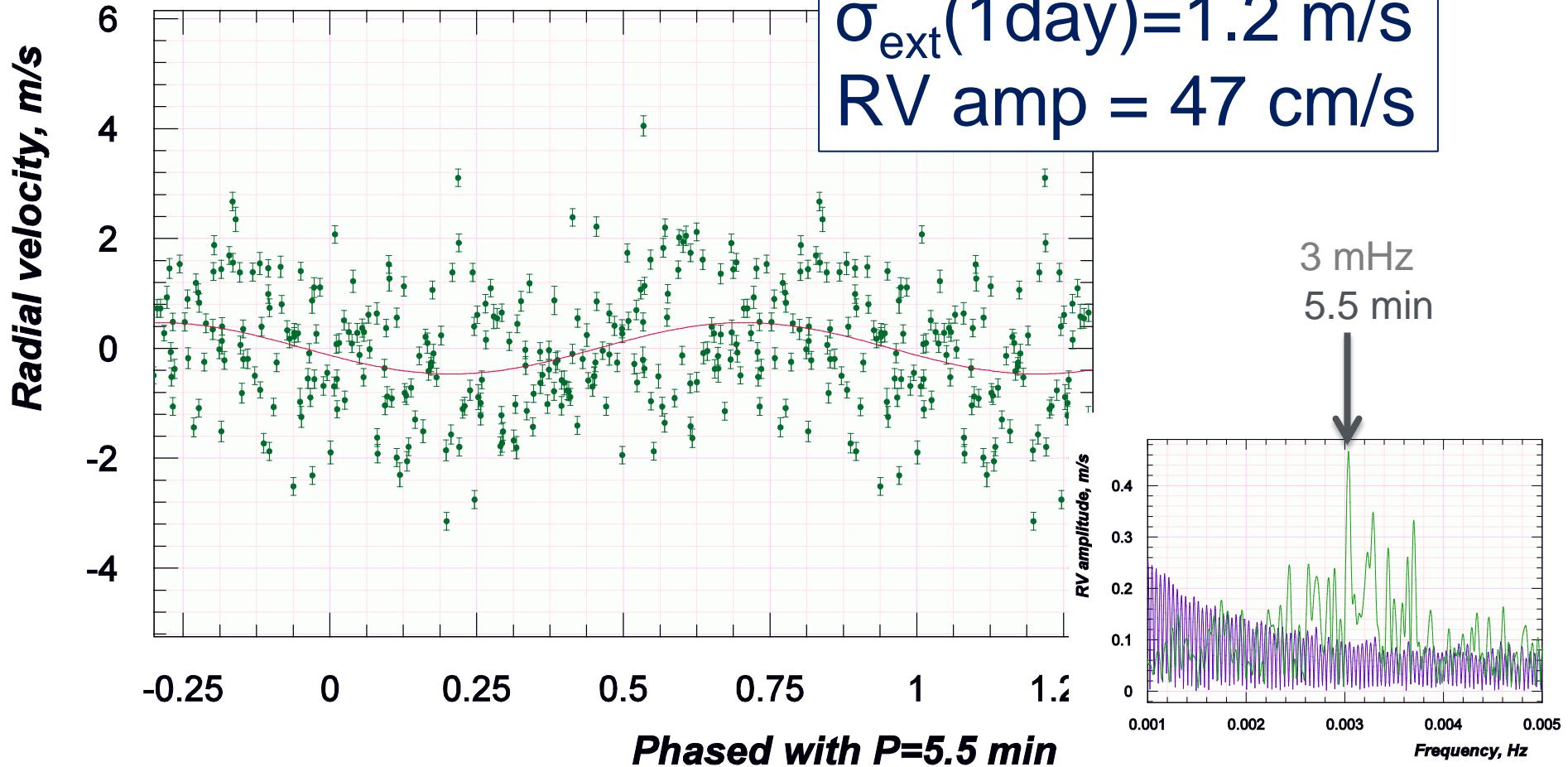


Arcturus: comparison with KPNO atlas (Hinkle et al.)



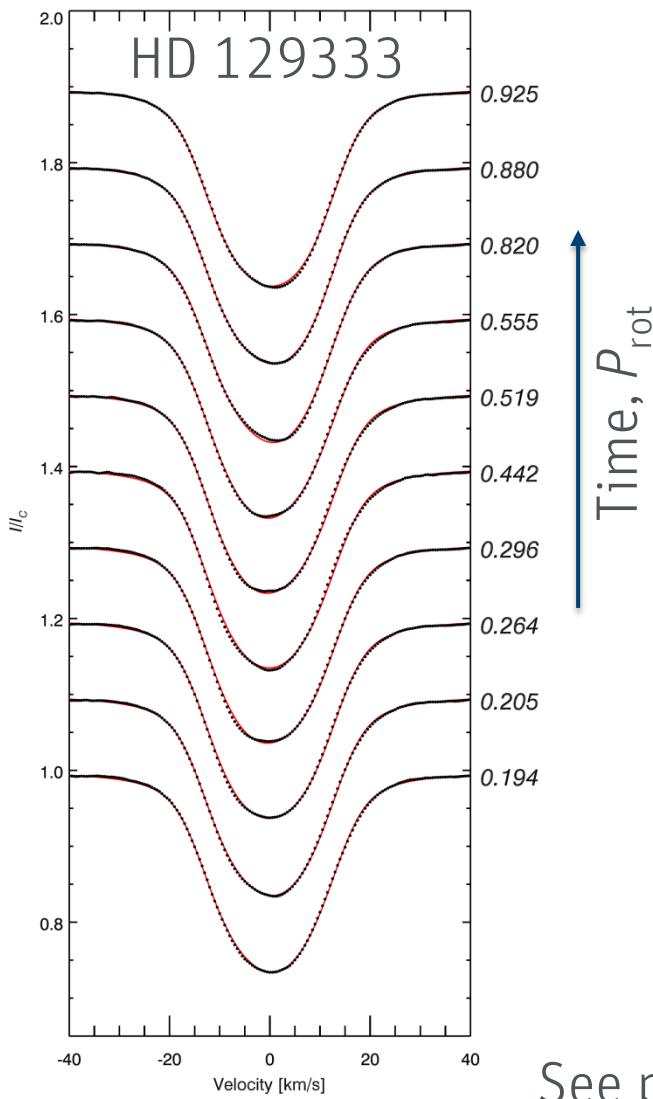


Chamber RV stability reached: Solar p-mode oscillations detected

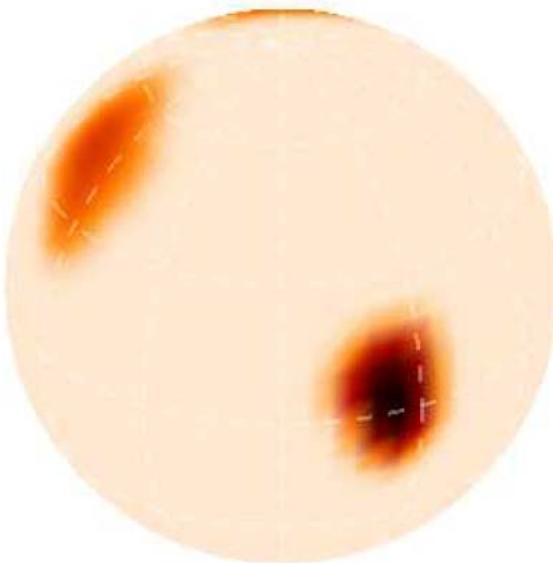




First Doppler images: a young Sun



$\phi = 0.75$



Temperature [K]



$\phi = 0.00$

$\phi = 0.25$

$\phi = 0.50$

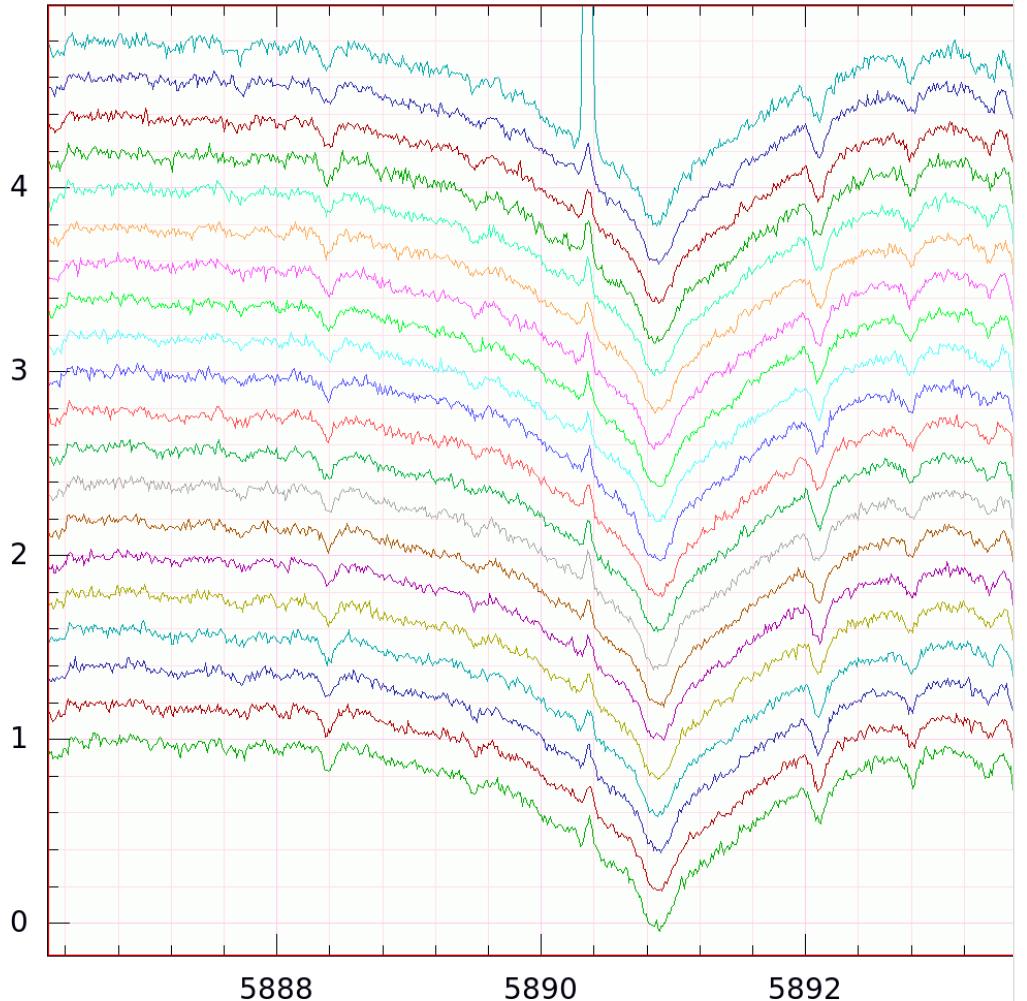
$\phi = 0.75$



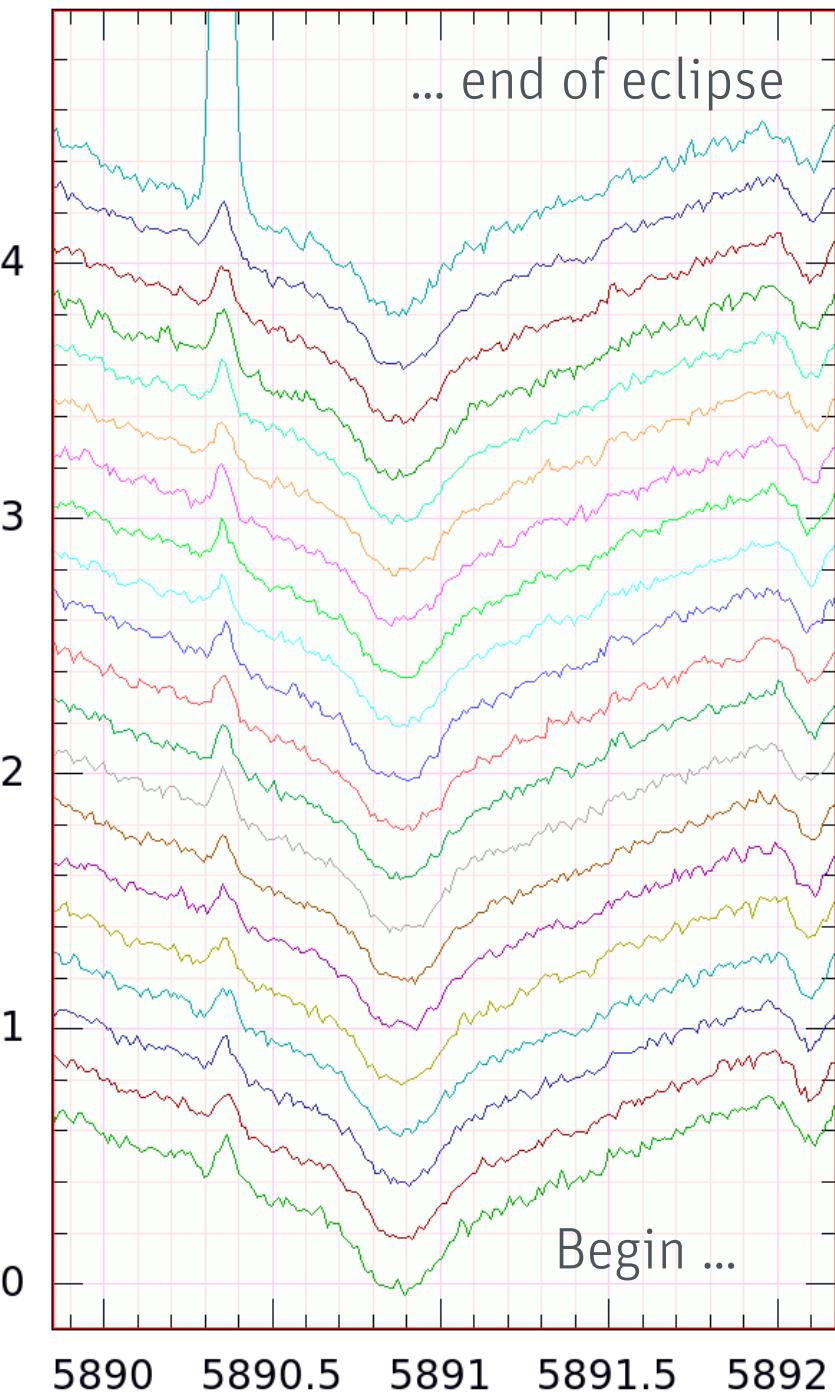
See poster by Silva Järvinen



XO-2b exoplanet



XO-2b transit, 19-11-2015; R=120,000, V=





Partner projects

1. K. Lind (MPIA): **Cosmology with extremely metal-poor stars**, 2N, April 10-11, 2016A --full loss due to bad weather
2. J. Tayar (OSU): **Surface Rotation of the Secondary Clump**, 1N, June 3, 2016A --all targets observed
3. C. Woodward (UM): **LBT (+PEPSI) Observations of Novae**, 1.5N, June 4-5, 2016A --all targets observed
4. M. Johnson (OSU): **Doppler tomography Kelt-3 transit**, 1N, March 2, 2017A --target observed but bad seeing
5. M. Johnson (OSU): **Doppler tomography KC11... transit**, 1N, May 28, 2017A --target observed
6. M. Johnson (OSU): **Doppler tomography Kepler-1514 transit**, 1N, May 29, 2017A --target partially observed
7. C. Woodward (UM): **LBT (+PEPSI) Observations of Novae**, 1N, May 30, 2017A --full loss due to bad weather

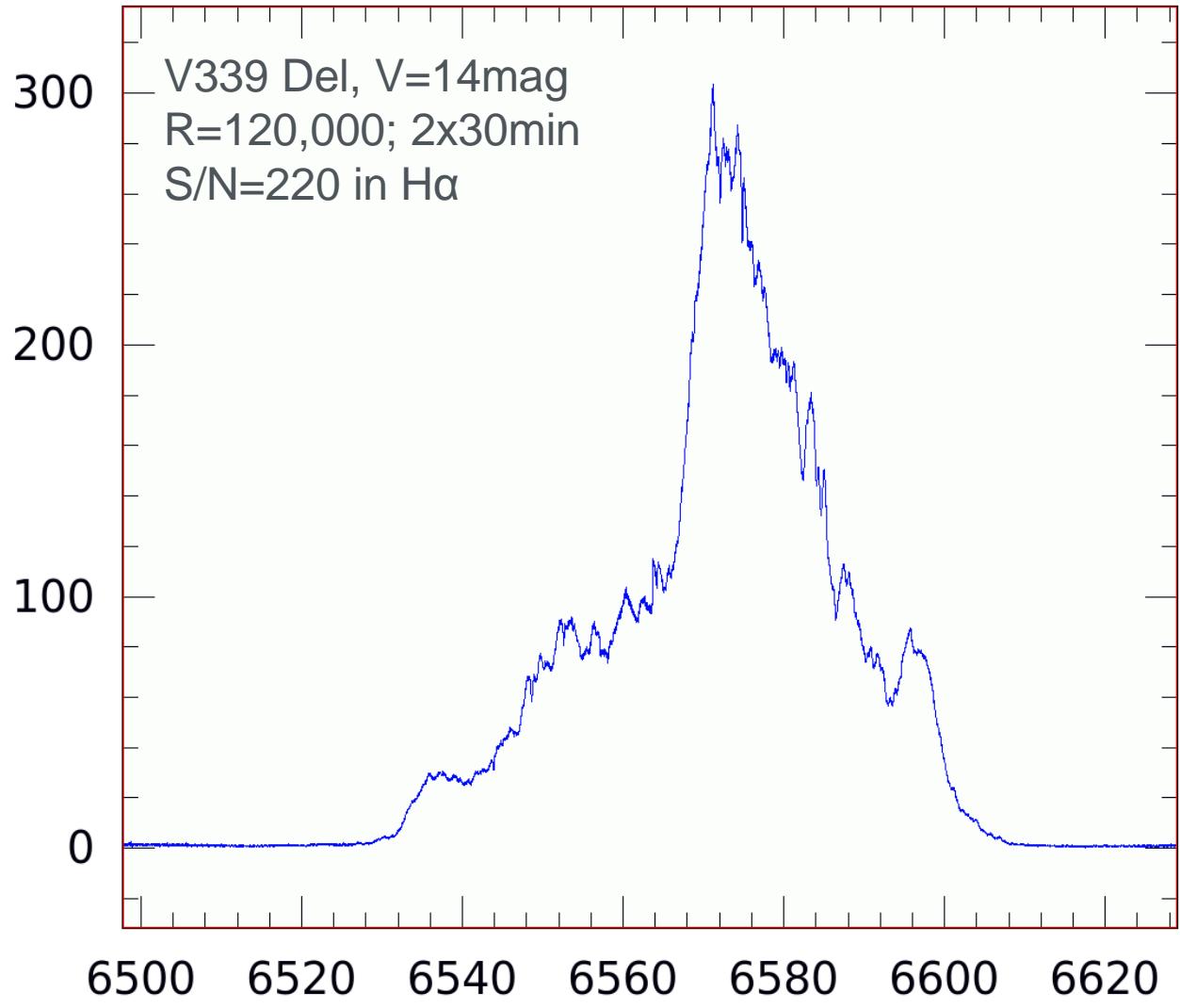
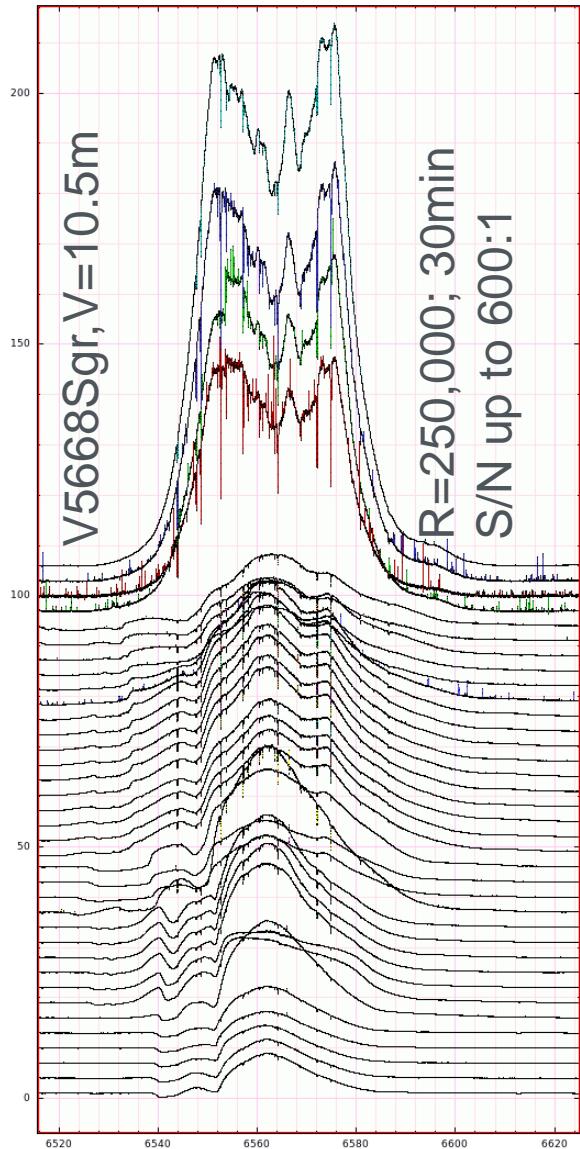


Partner projects

8. M. Johnson (OSU): **Doppler tomography HD222175 transit**, 3hrs, May 31, 2017A --target partly observed
9. T. Beers (UND): **CEMP-i stars**, 4hrs, May 31, 2017A
--full loss due to bad weather
10. J. Crepp (UND): **Kelt-18 deep spectrum**, 4hrs, Jun 1, 2017A
--target partly observed
11. F. Borsa (INAF): **Transmission spectroscopy HD189733, 1N**, Jun 2, 2017A --transit missed, alternative target obs

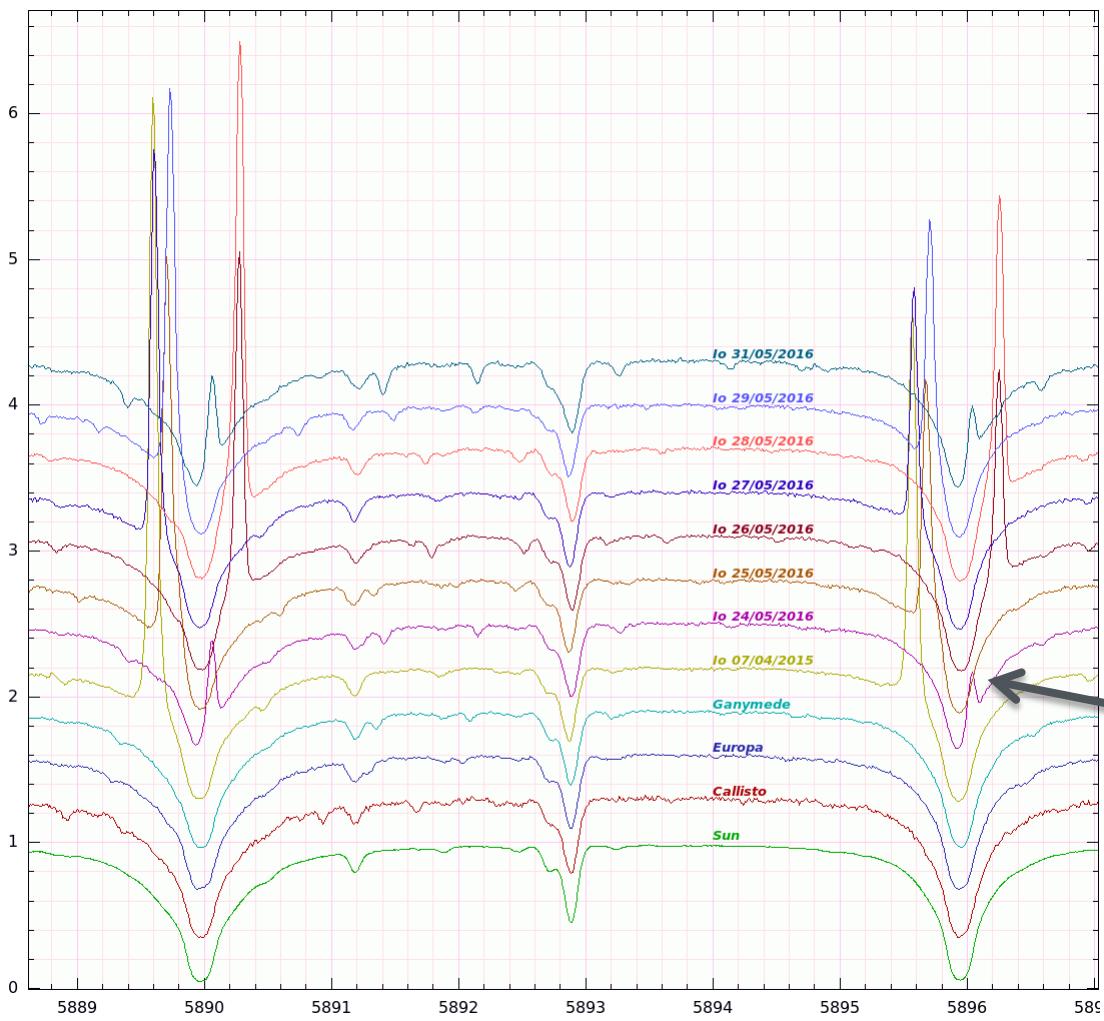


Partner projects: novae (UMinn)





Galilean moons w/ PEPSI@VATT

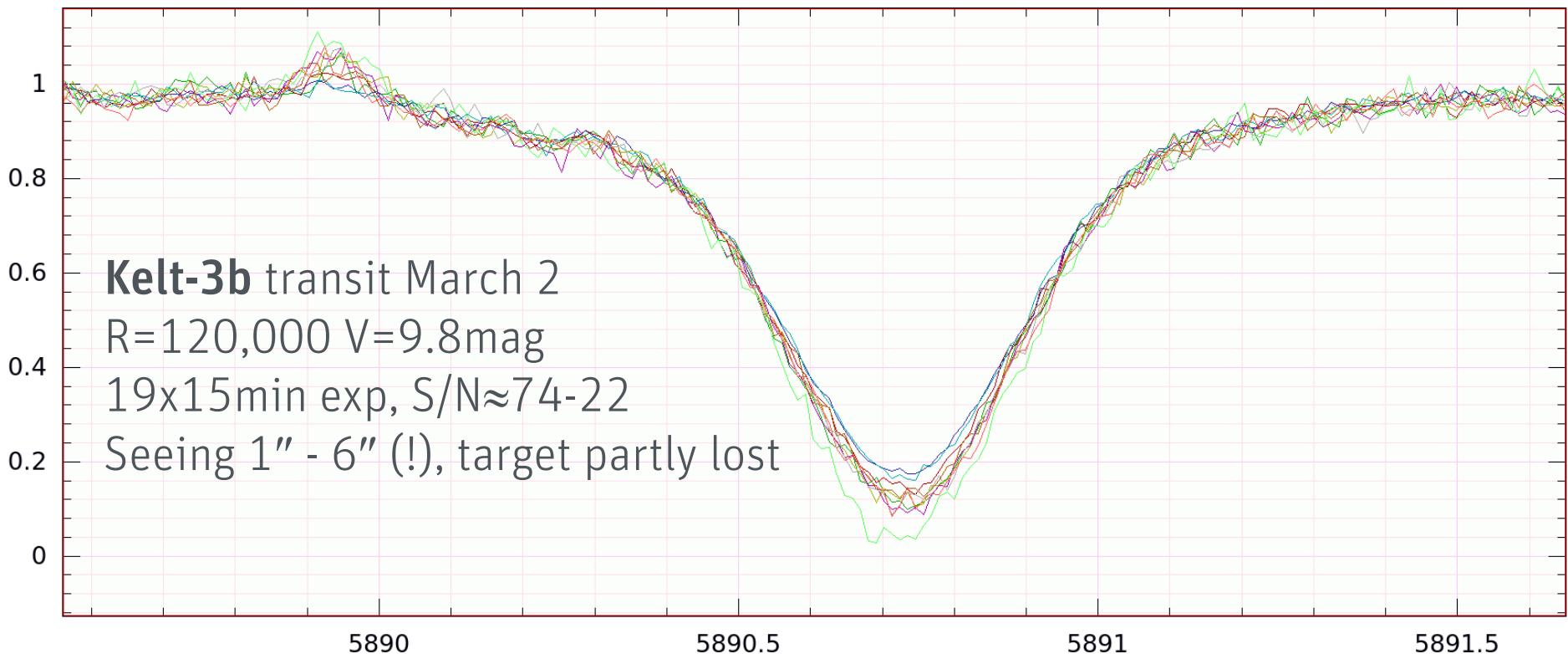


Na D doublet
R=120,000 mode
1.8m VATT
30 min exposures
S/N \approx 340

Sodium jet launch;
took less than a day to
travel from 6 \rightarrow 50 R_J

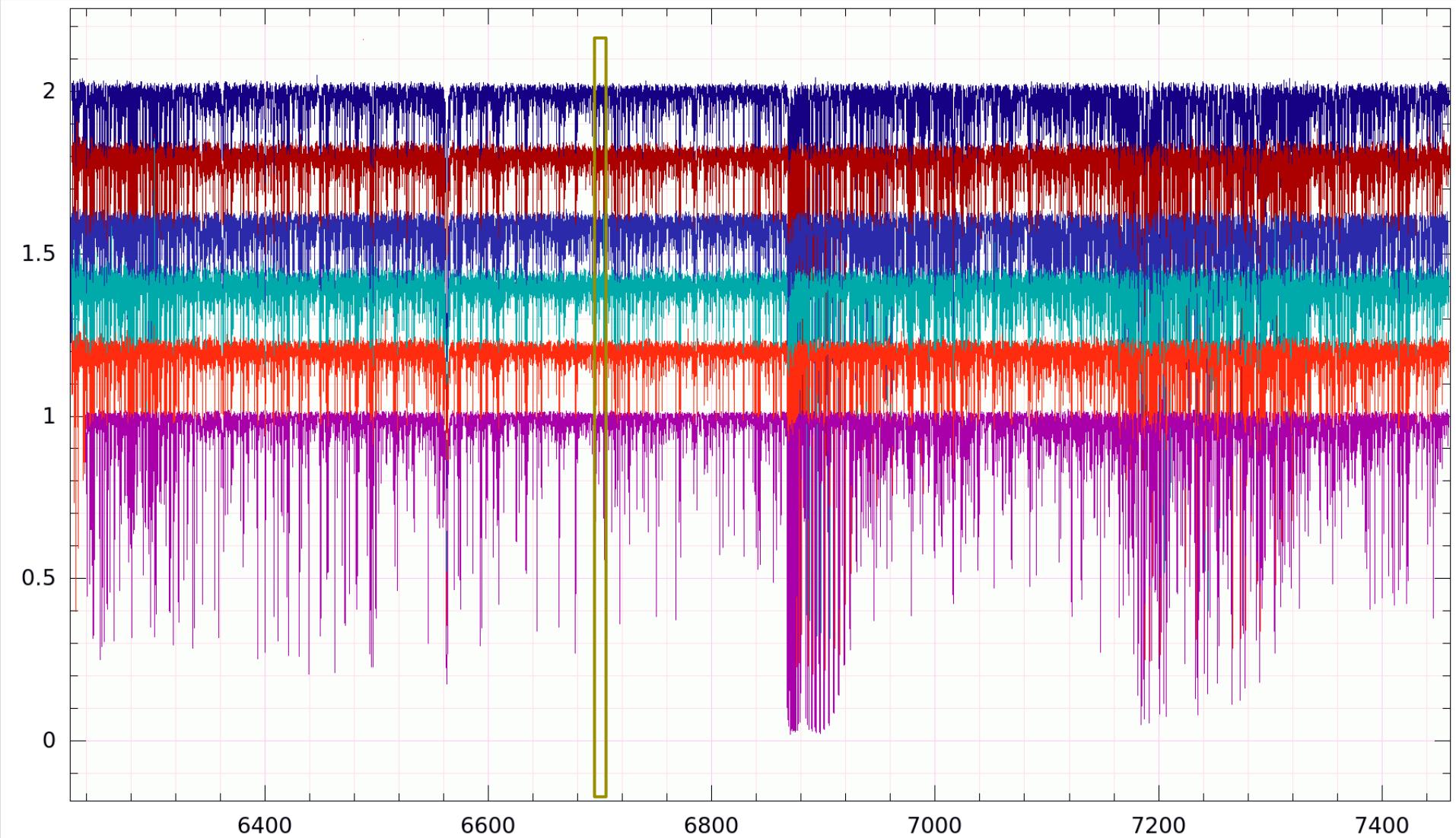


Partner projects: exoplanet transits (OSU)



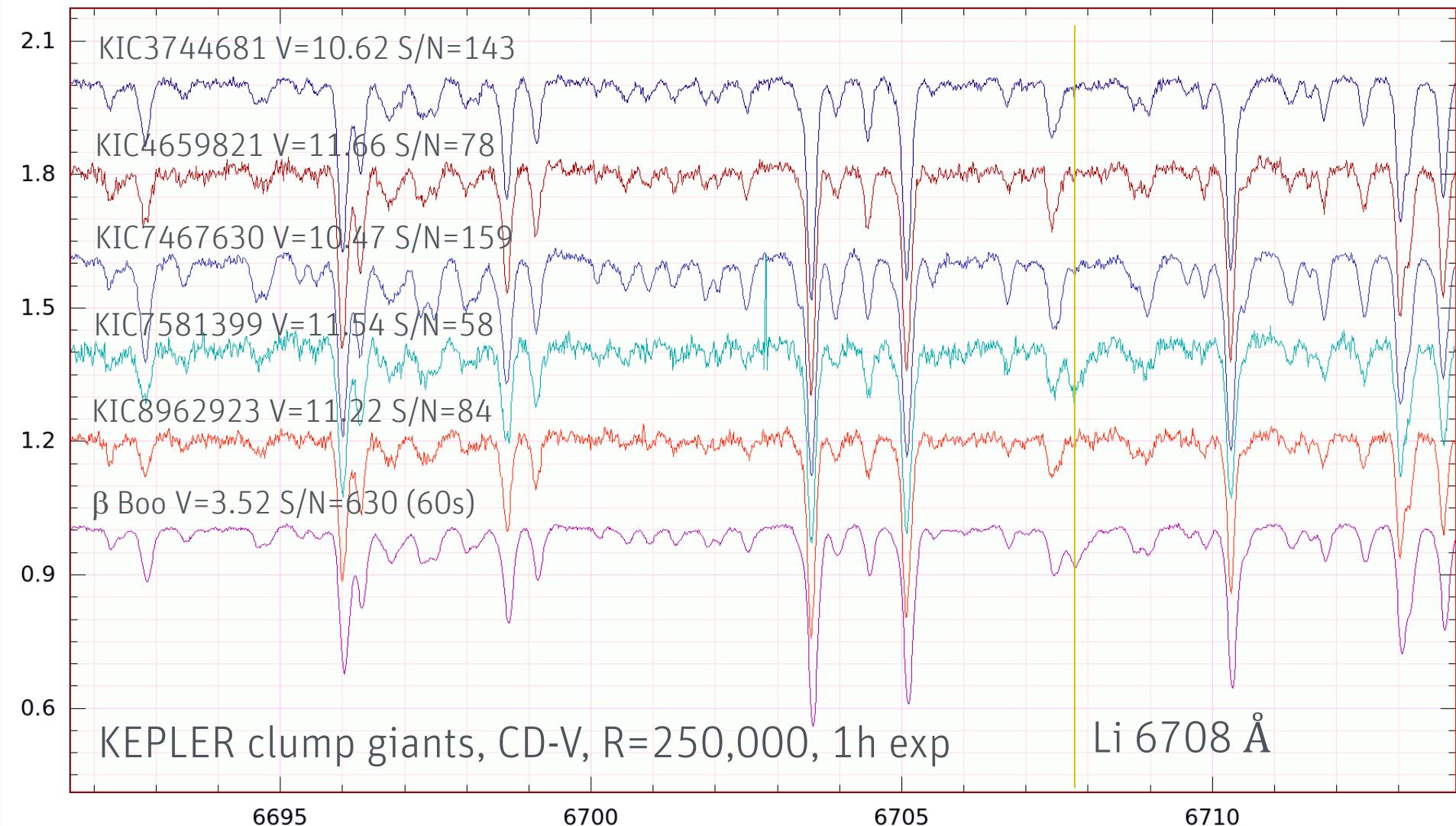


Partner projects: Kepler stars (OSU)





Partner projects: Kepler targets





Outlook

- LBTO observer as of 2017B (Shane Walsh)
- Partner representatives as points of contact
- SDT will continue until 2018B
- Polarimeters as of 2018A (only Stokes facility on any 8m class telescope)



Polarimeters

Commissioning Sept. 5-12, 2017