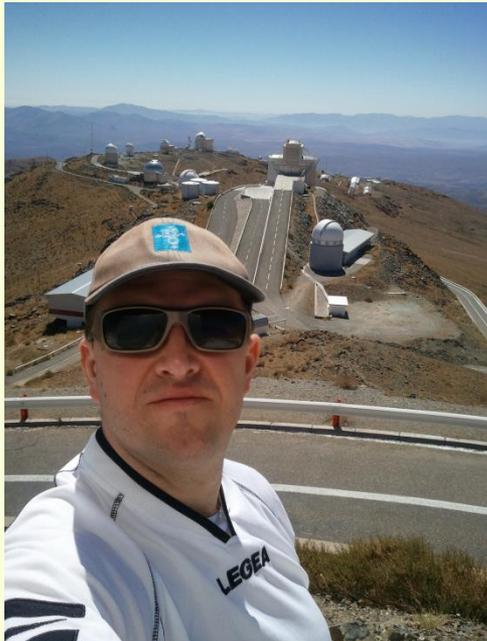


Od hranolu k vysokodisperznímu spektrografu



Jan Janík
ÚTFA PŘF MU

U3V 2. dubna 2024

OD HRANOLU K VYSOKODISPERZNÍMU SPEKTROGRAFU

- Co je to spektrum?
- Co je to spektroskopie?
- Jak vypadají spektrografy?
- Co lze vyčíst ze spektra?

Co je to spektrum?

Spektrum

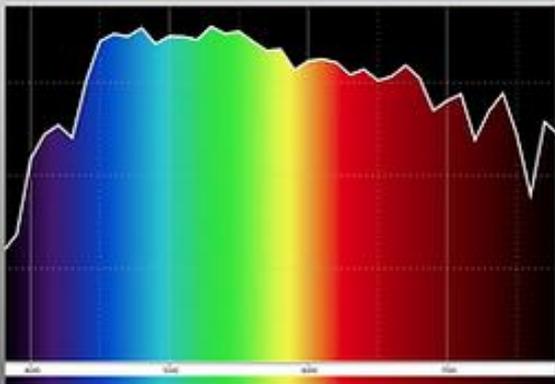
- bílé sluneční světlo (složeno z různých vlnových délek)

Spektrum

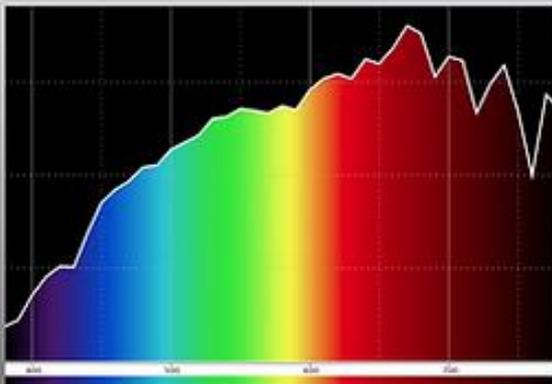
- bílé sluneční světlo (složeno z různých vlnových délek)
- spektrum (rozklad do jednotlivých barev)

Spektrum

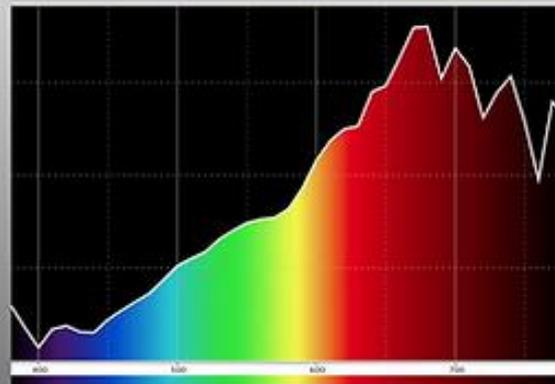
Poledne



1 hodina do Západu



Západ



Spektrum

- bílé sluneční světlo (složeno z různých vlnových délek)
- spektrum (rozklad do jednotlivých barev)
- nejznámější příklad : duha

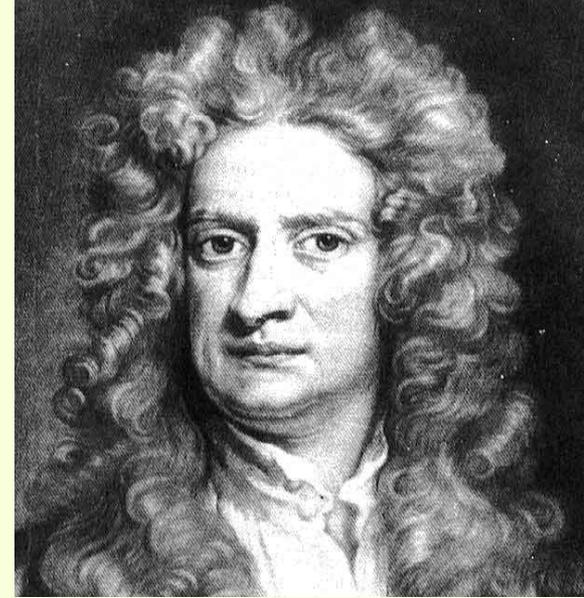


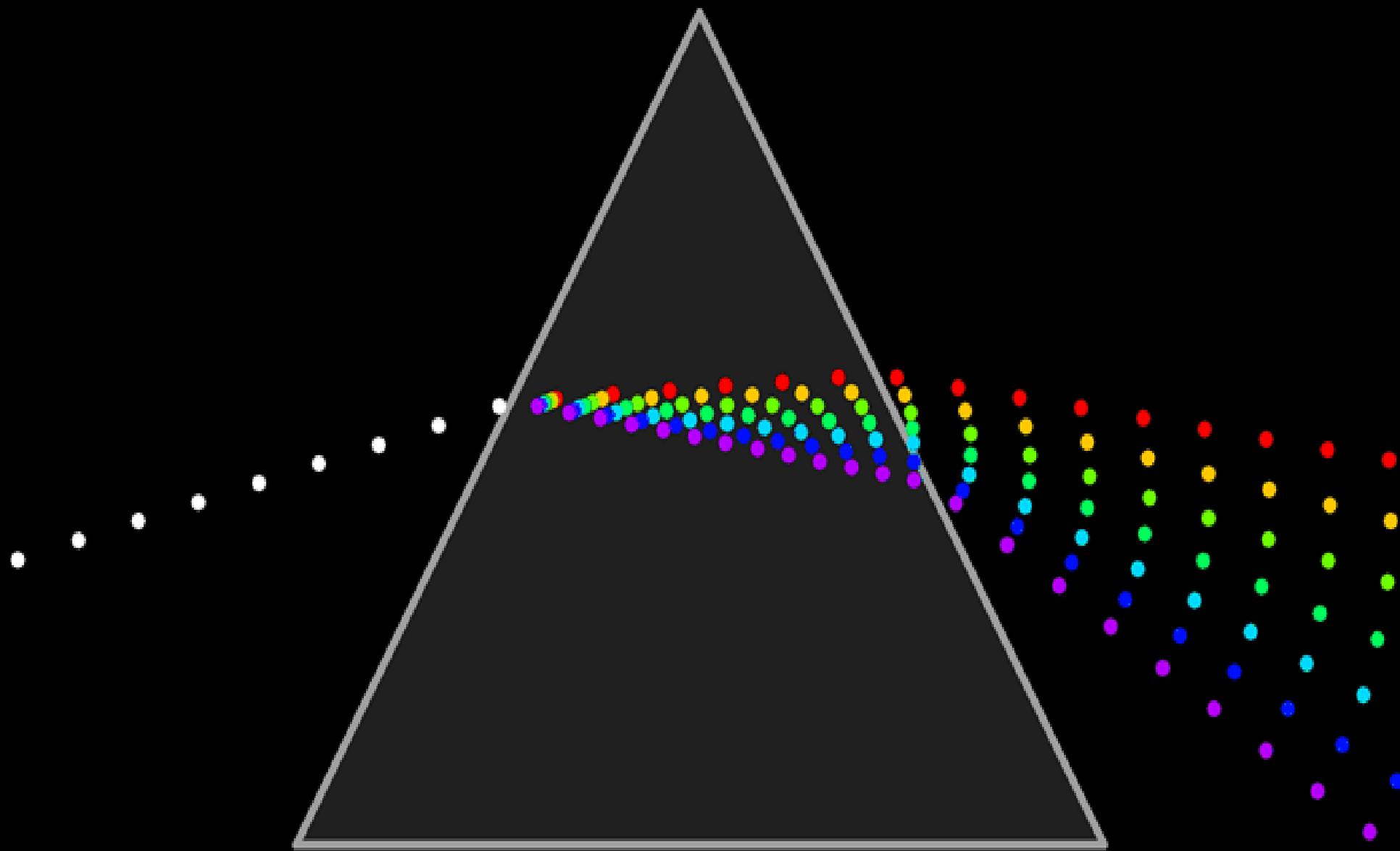
Spektrum

- starověcí Římané znali schopnost hranolu rozložit světlo
- snaha o vysvětlení v 17. století
 - Athanasius Kircher (1646)
 - Jan Marek Marci (1648)
 - Robert Boyle (1664)
 - Francesco Maria Grimaldi (1665)

Spektrum

- I. Newton – *Optics* (1704)
 - experimenty se světlem
 - vysvětlení disperze světla
 - korpuskulární teorie světla (světlo jsou částice)
- Ch. Huygens – *Treatise on Light* (1690)
 - vlnová teorie světla
 - barvy důsledkem různé vlnové délky

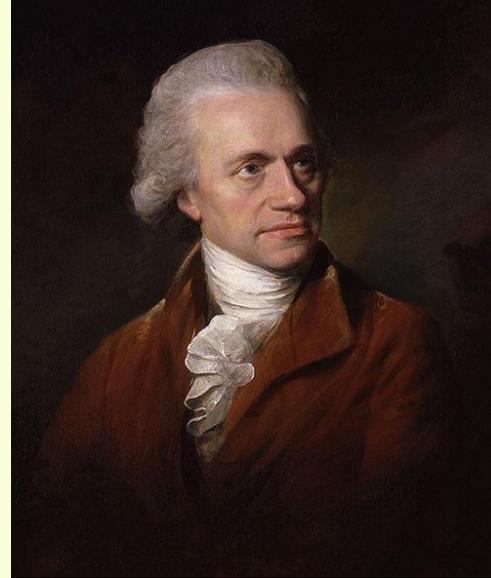


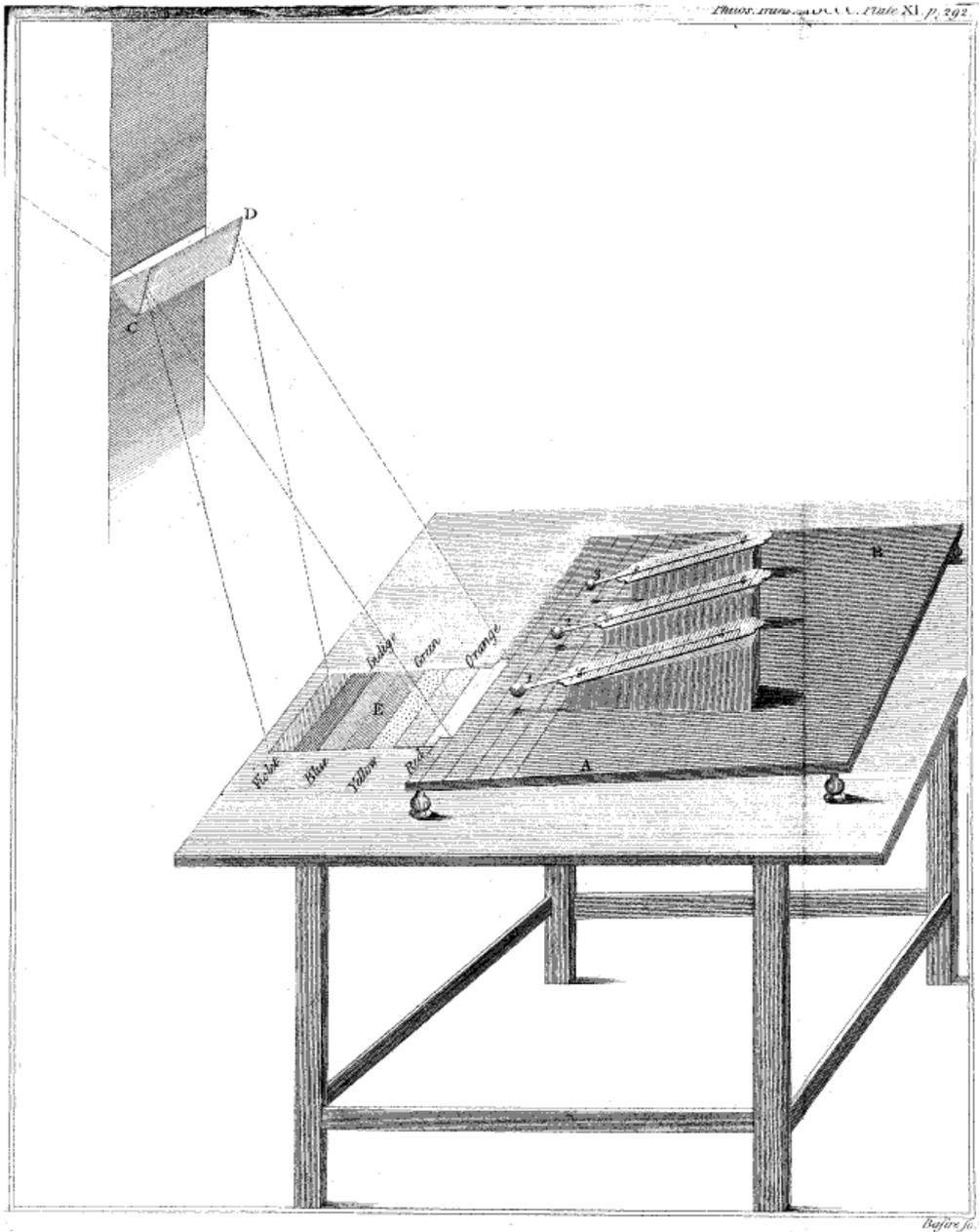


Co je to
spektroskopie?

Spektroskopie

- W. Herschell – test slunečních filtrů (11.2.1800)
 - experiment s teploměry
 - měření teploty v různých částech spektra
 - v místě za červenou barvou vyšší teplota
→ objev (neviditelného) infračerveného záření



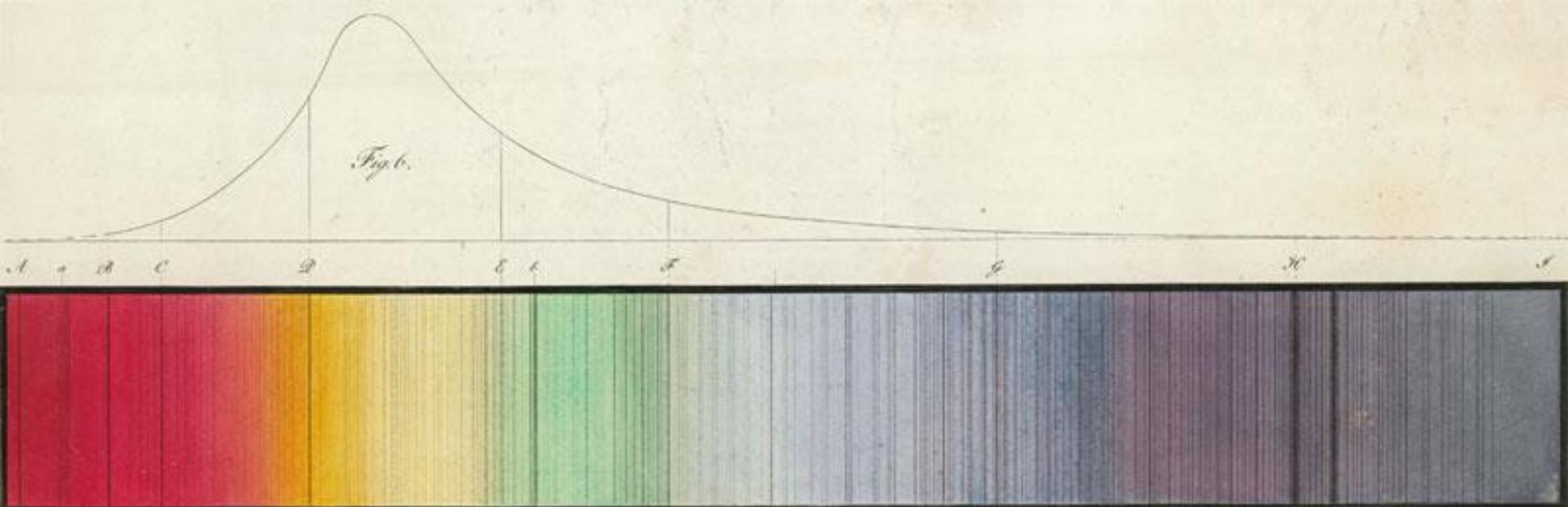


Herschell, W. 1800,
„Experiments on
the refrangibility of
the invisible rays of
the sun“,
Philosophical
Transactions of the
Royal Society of
London. **90**: 284–
292

Spektroskopie



- Josef von Fraunhofer
 - fyzik
 - astronom
 - chemik
- vyvrátil tvrzení Wollastona (1802) – tmavé pásy mezi čarami → přirozená hranice barev
- 1821 difrakční mřížka – lepší rozlišení, měření vlnových délek



Designation	Element	Wavelength (nm)	Designation	Element	Wavelength (nm)
y	O ₂	898.765	c	Fe	495.761
Z	O ₂	822.696	F	Hβ	486.134
A	O ₂	759.370	d	Fe	466.814
B	O ₂	686.719	e	Fe	438.355
C	Hα	656.281	G'	Hγ	434.047
a	O ₂	627.661	G	Fe	430.790
D ₁	Na	589.592	G	Ca	430.774
D ₂	Na	588.995	h	Hδ	410.175
D ₃ or d	He	587.5618	H	Ca ⁺	396.847
e	Hg	546.073	K	Ca ⁺	393.368
E ₂	Fe	527.039	L	Fe	382.044
b ₁	Mg	518.362	N	Fe	358.121
b ₂	Mg	517.270	P	Ti ⁺	336.112
b ₃	Fe	516.891	T	Fe	302.108
b ₄	Fe	516.891	t	Ni	299.444
b ₄	Mg	516.733			



Joseph von Fraunhofer
1787-1826

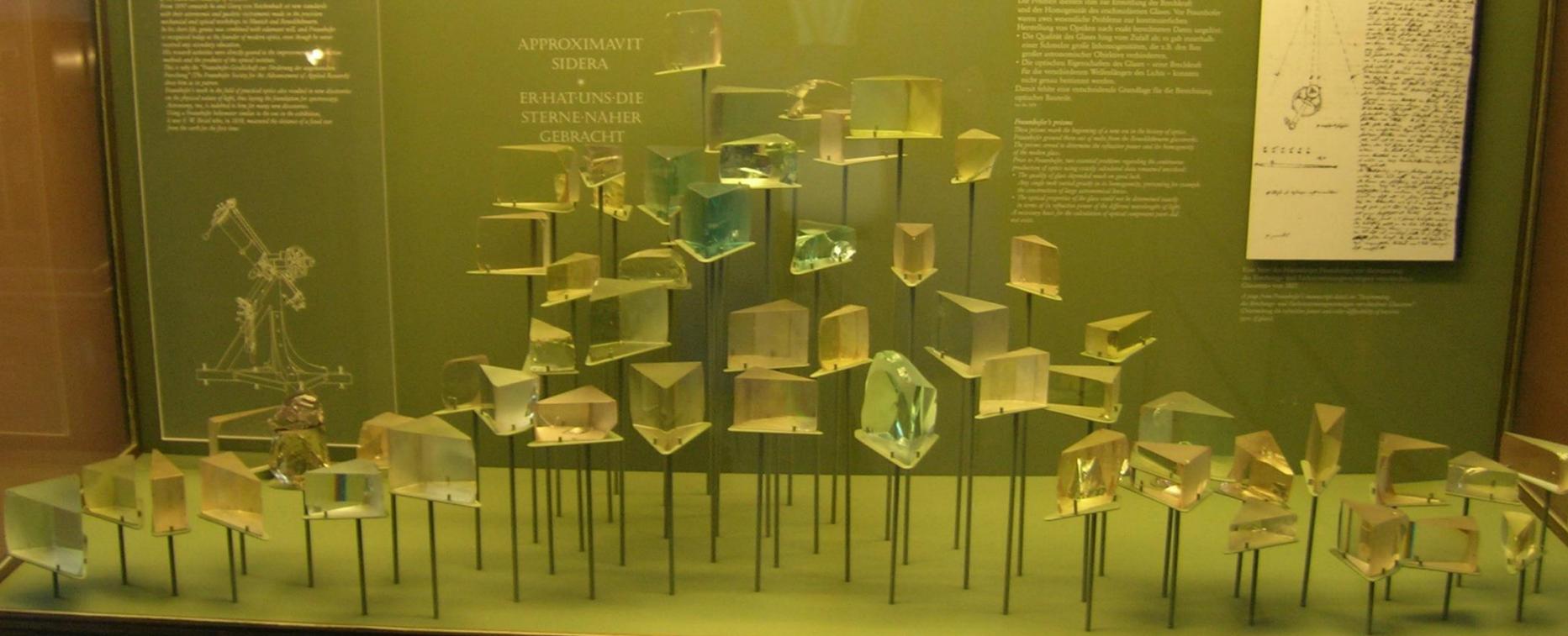
1822 wurde J. v. Fraunhofer zum Professor und zweiten Sekretär der Bayerischen Akademie der Wissenschaften berufen. Ab 1827 leitete er und Georg von Reichenbach, in dem Kaiserlichen russischen Mikroskopie in München und Braunschweig, mit dem Bau von Mikroskopen und optischen Instrumenten einen Meisterkurs in Göttingen, gegen ein eigenes Willen, jedoch Fraunhofer in seinem letzten Leben, wobei er sein letztes Jahr bereits zu haben, sein Hauptziel der wissenschaftlichen Arbeit, seine Forschungsarbeiten auf der Verbesserung der Instrumenten und Entdeckung der optischen Linien abzielte.

Deshalb hat ihn auch die "Fraunhofer-Gesellschaft zur Förderung der angewandten Technologie als Naturwissenschaftler, Erfinder, Konstrukteur, Arbeiter für die praktische Optik berufen aber auch Fraunhofer für seine Entdeckung über die spektrale Natur des Lichts und seine Entdeckung der Fraunhofer'schen Linien nach der Methode von Fraunhofer wurde sein Hauptberuf. Mit einem neuen Mikroskop - ähnlich dem von Fraunhofer - konnte E. W. Brack 1838 erstmals die Entdeckung von Fraunhofer zur Erde bringen.

In 1822, J. v. Fraunhofer was appointed Professor and Second Secretary of the Bavarian Academy of Science.
From 1827, together with Georg von Reichenbach, he was appointed head of the Kaiserlich-russisches Mikroskopie in München und Braunschweig.
In Göttingen, the great work of Fraunhofer was to improve the optical instruments of the time, against his own wishes, but Fraunhofer in his last years, when he was already in his last years, his main goal was the improvement of instruments and the discovery of the optical lines.
Therefore, he was also called "Fraunhofer Society for the promotion of applied technology as a natural scientist, inventor, worker for practical optics, but also Fraunhofer for his discovery about the spectral nature of light and his discovery of Fraunhofer's lines after the method of Fraunhofer, which was his main profession. With a new microscope - similar to that of Fraunhofer - it was possible for the first time to bring the discovery of Fraunhofer to Earth.



APPROXIMAVIT
SIDERA
ER-HAT-UNS-DIE
STERNE-NAHER
GEBRACHT



Fraunhofers Prismen.
schon am Beginn seiner Arbeit in der Geschichte der Optik. Er schiffte sie mit dem Schmelzen der Gläser in Braunschweig. Die Prismen dienten ihm zur Einseitigkeit der Brechung und dem Homogenisieren des einfallenden Lichts. Von Fraunhofer waren zwei wesentliche Probleme zu lösen: einseitige Homogenisierung von Licht und mehr homogenes Licht erzeugen.
• Die Qualität des Glases hing vom Zustand der Luft vor dem Schmelzen.
• Die optischen Eigenschaften des Glases - seine Brechzahl für die verschiedenen Wellenlängen des Lichts - konnten nicht genau bestimmt werden.
Daher legte eine entscheidende Grundlage für die Entwicklung optischer Bauteile.

Fraunhofer's prism.
These prisms were the beginning of a new era in the history of optics. Fraunhofer ground them out of melt, from the Braunschweig glassworks. The prisms served to direct the refractive power and the homogenization of the incident light.
• The quality of glass was greatly dependent on the conditions of production of glass using freshly obtained glass.
• The optical properties of the glass could not be determined exactly in terms of refractive power of the different wavelengths of light.
Therefore, it laid a decisive basis for the realization of optical components parts and tools.

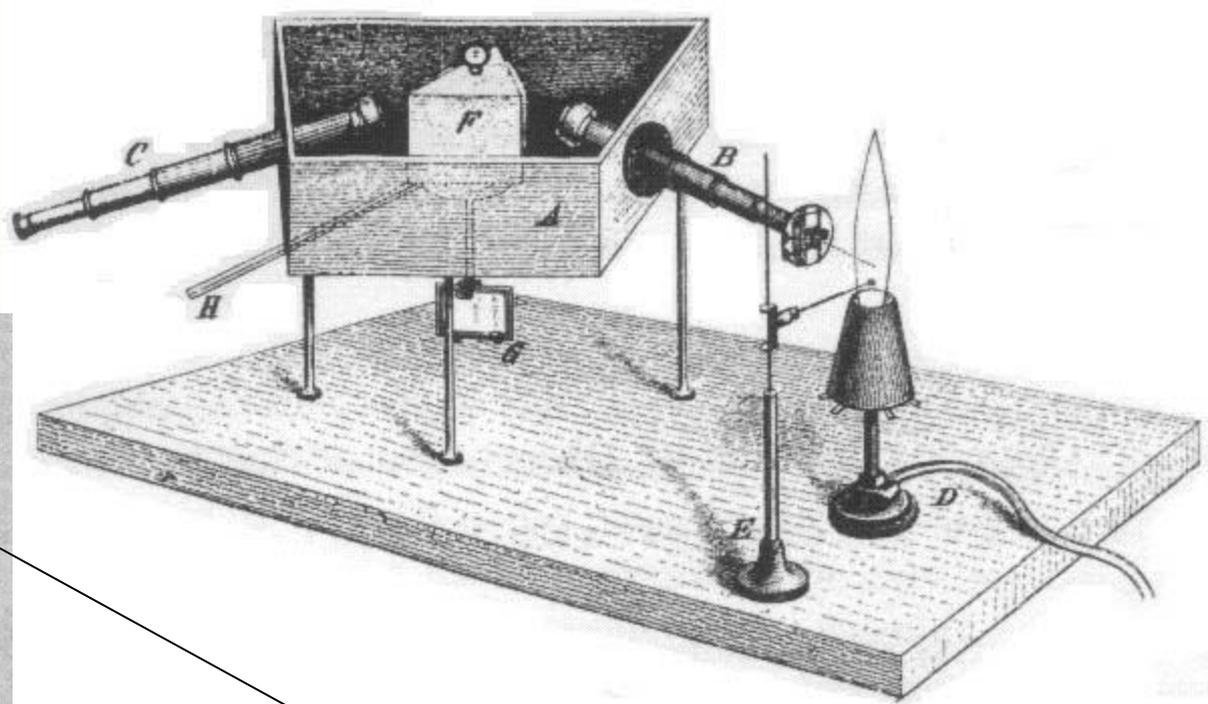
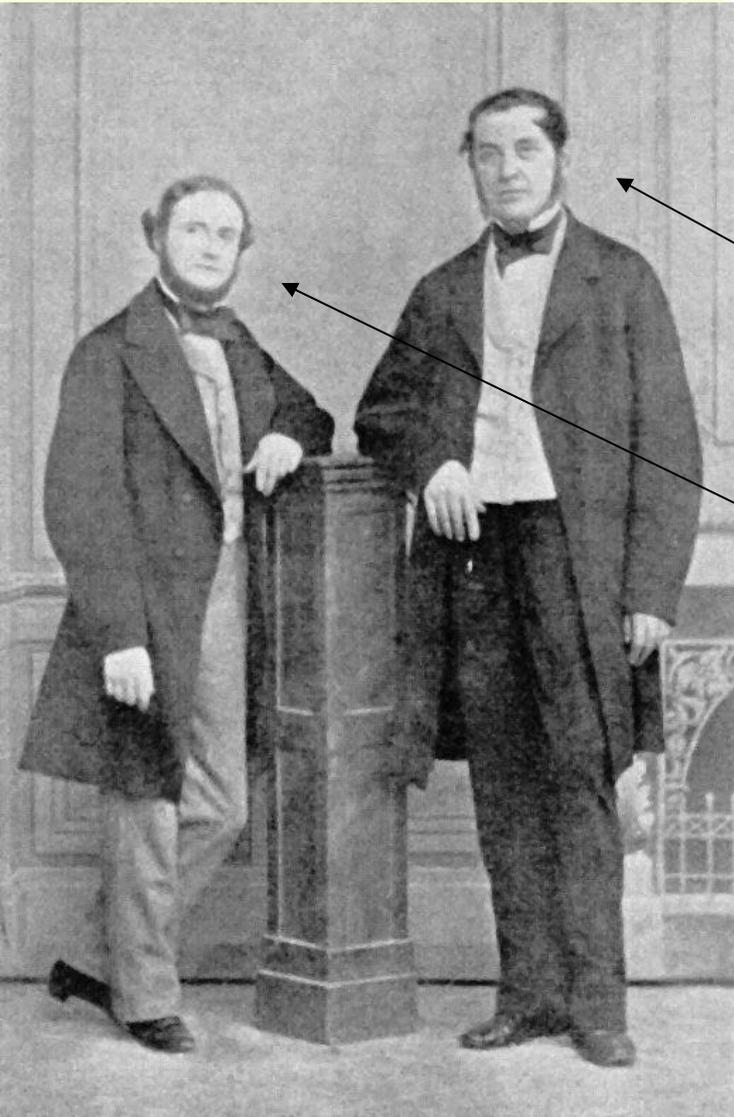
Von Fraunhofer geschmolzenen Prismen zeigten sich auch die Fraunhofer'schen optischen Eigenschaften. Sie waren seine wertvollen Instrumente für die Entwicklung der Brechzahl eines Glases.
Die optischen Eigenschaften des Glases - seine Brechzahl für die verschiedenen Wellenlängen des Lichts - konnten nicht genau bestimmt werden.
Daher legte eine entscheidende Grundlage für die Entwicklung optischer Bauteile.



Ein Blatt des Braunschweiger Protokolls zur Entwicklung der Braunschweiger Gläserwerke, Braunschweig, 1825.
A page from the Braunschweig Protokoll, Braunschweig, 1825.

Spektroskopie

- Robert Bunsen & Gustav Kirchhoff (1861) – korespondence Fraunhoferových čar s čarami v laboratoři
- spojení mezi absorpční a emisní čárou



**Bunsen a Kirchhoff
1859 spektroskop**

Spektroskopie

- Kirchhoffovy zákony tepelného vyzařování
 1. Žárovka, kapalina nebo plyn pod vysokým tlakem vyzařuje spojité spektrum.
 2. Horký plyn pod nízkým tlakem vyzařuje spektrum „jasné čáry“ (emisní čáry).
 3. Spojitý zdroj světla při pohledu přes chladný plyn s nízkou hustotou vytváří ve spektru absorpční čáry.



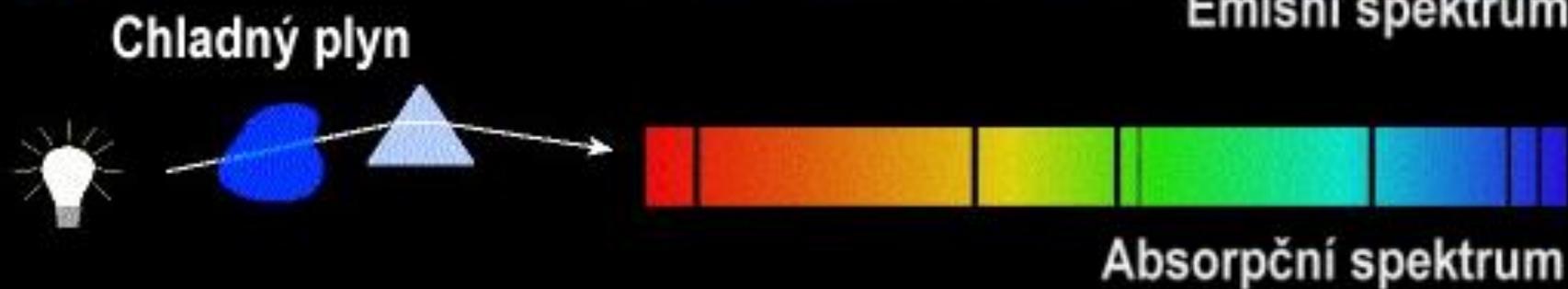
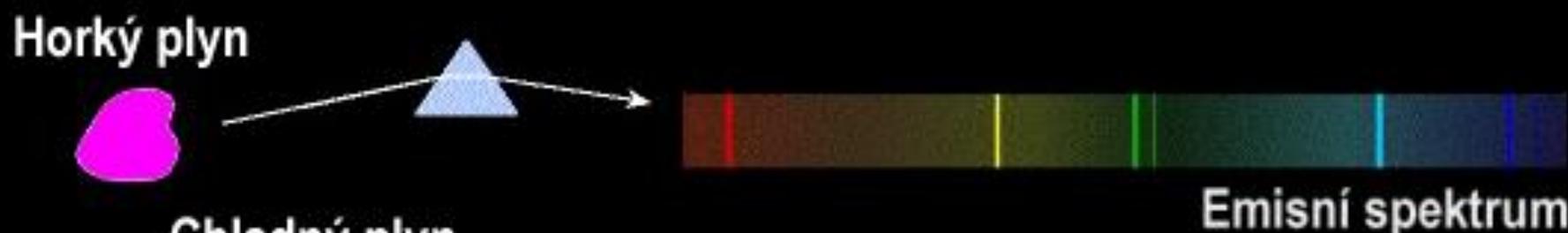
Spojité spektrum

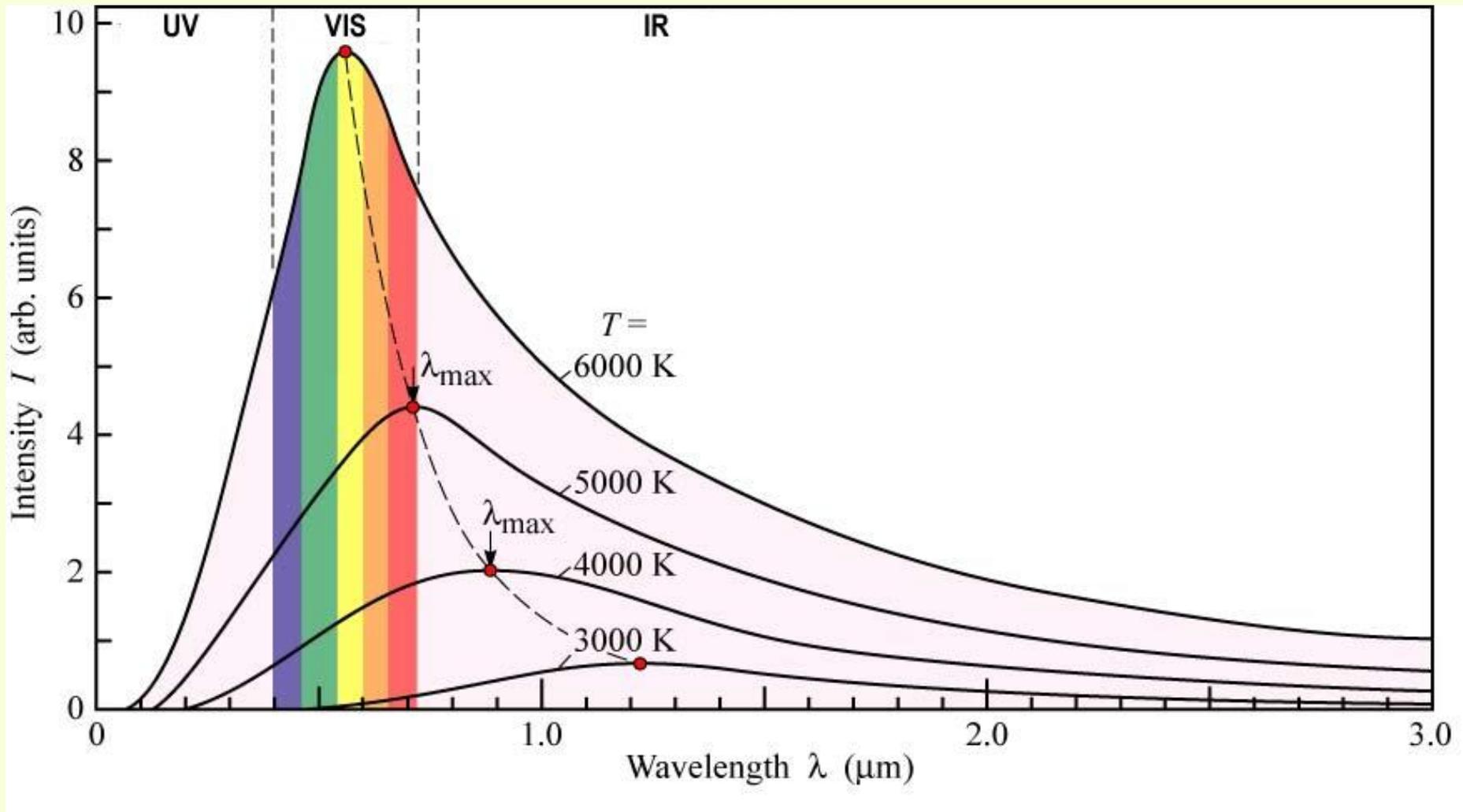


Emisní spektrum



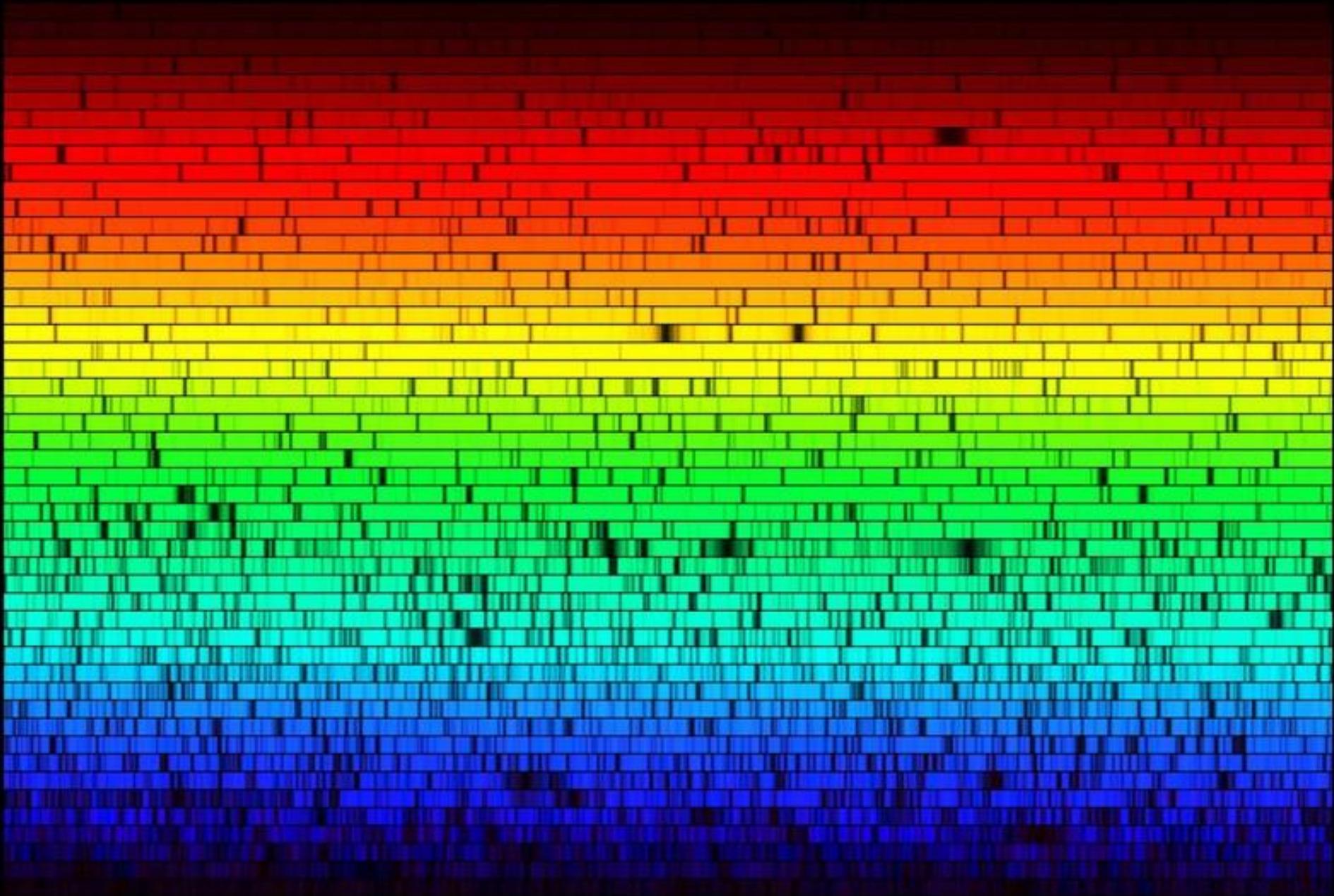
Absorpční spektrum



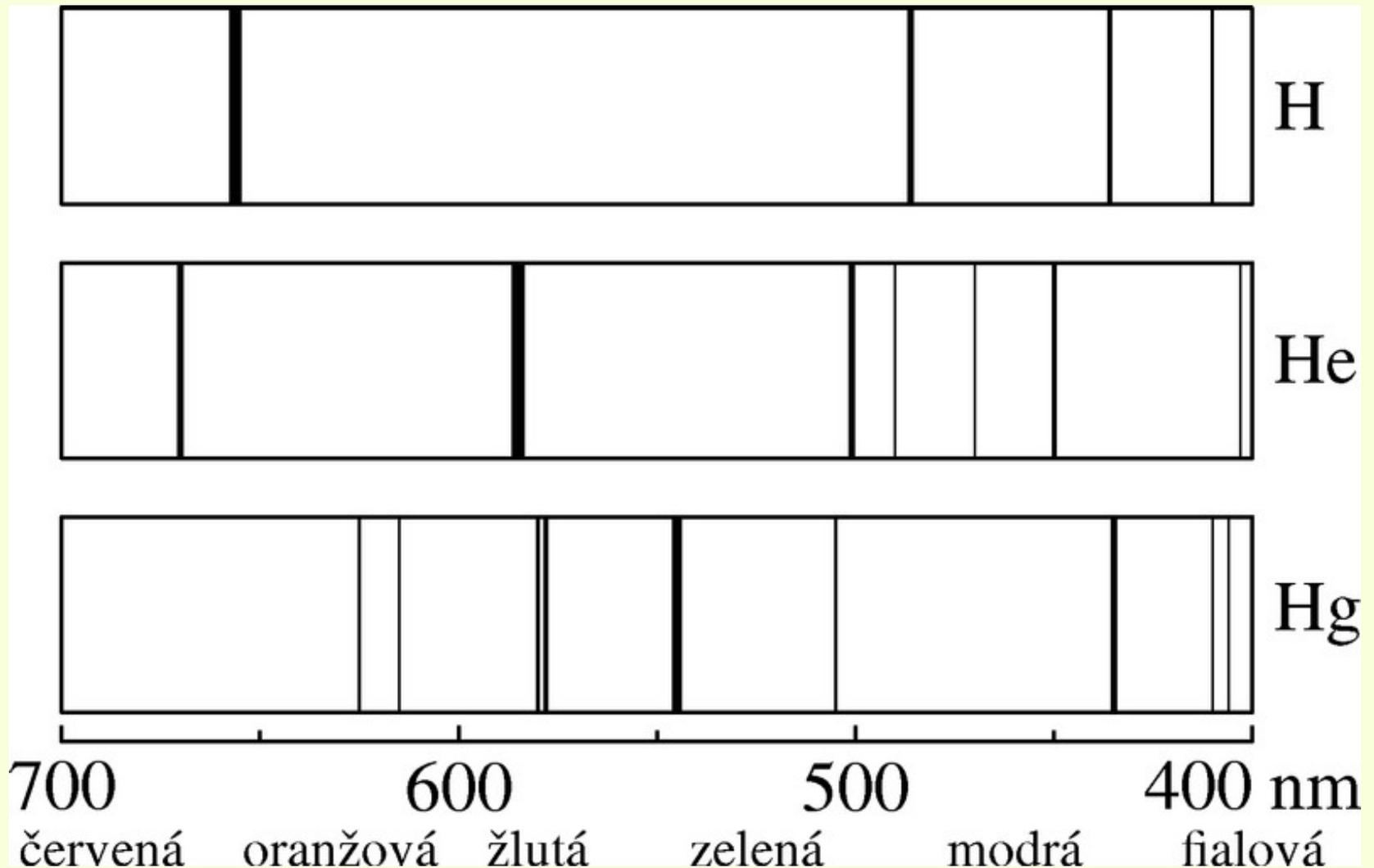


Planckův zákon
$$I(\nu, T) = \frac{2h\nu^3}{c^2} \frac{1}{e^{(h\nu/kT)} - 1}$$

ARCTURUS



Spektrální čáry („otisk prstu“)



HD katalog

- po smrti H. Drapera jeho žena Mary Anne Palmer Draper → peníze na projekt
- publikován mezi lety 1918 – 1924
- první verze 10 351 hvězd v roce 1890 (Williamina Flemming)

ANNALS

OF

THE ASTRONOMICAL OBSERVATORY OF HARVARD COLLEGE.

EDWARD C. PICKERING, DIRECTOR.

VOL. XXVII.

THE DRAPER CATALOGUE

OF

STELLAR SPECTRA

PHOTOGRAPHED WITH THE 8-INCH BACHE TELESCOPE

AS A PART OF

THE HENRY DRAPER MEMORIAL.

CAMBRIDGE:

JOHN WILSON AND SON.

University Press.

1890.

included. Three or four exposures were commonly made upon each plate. The total number of spectra on a single plate sometimes exceeded two hundred. The most sensitive plates obtainable were used. At first the "Allen and Rowell" plates were employed, but later the "Seed" Plates No. 21 were substituted for them. The plan of work was such that the entire sky north of -25° was covered twice in the first cycle of photographs. The plates overlapped so that a spectrum which appeared near the corner of one plate would appear near the centre of another. The work was then repeated by a second similar cycle of plates. Each star should in general appear on four plates. Owing to the overlapping of the regions and the repetition of plates which were not satisfactory, this number is greatly increased for many of the stars, especially for those between $+50^\circ$ and $+85^\circ$. The faintest stars appear on only one plate. In this case a second independent measure was always made.

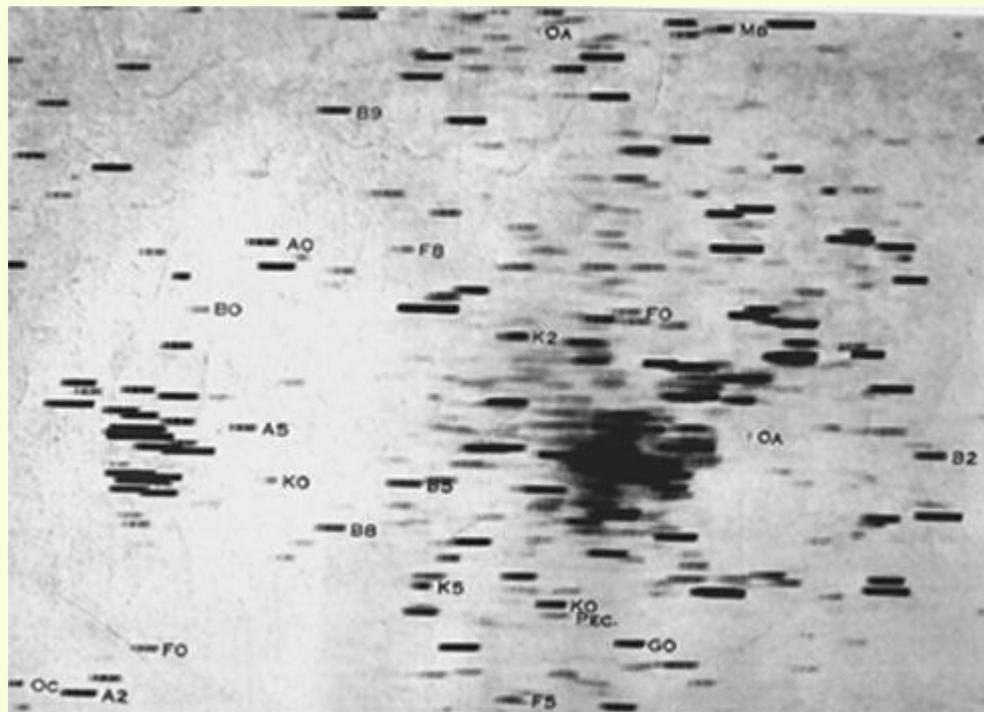
The first of the photographs discussed in this volume were taken by Mr. H. Helm Clayton, the later ones by Mr. Willard P. Gerrish; those taken during the latter part of the night by Mr. R. W. Gifford. The reduction of the plates was begun by Miss N. A. Farrar, but the greater portion of this work, the measurement and classification of all the spectra, and the preparation of the Catalogue for publication, has been in charge of Mrs. M. Fleming. Misses F. Cushman, E. Gill, E. F. Leland, A. E. Masters, J. T. Rugg, M. C. Stevens, L. D. Wells and L. Winlock have at different times aided in the numerical computations and clerical work.

If the spectra of a large number of stars are photographed, one form will be found to predominate. It consists of a nearly continuous spectrum traversed by a series of dark bands or lines arranged with great regularity. The intervals between the lines diminish with the wave-lengths. These lines appear to be due to the presence of hydrogen. They have the following designations and wave-lengths expressed in millionths of a millimetre: — C, 656.3; F, 486.1; G, 434.1; h, 410.2; H, 397.0; a, 388.9; β , 383.6; γ , 379.8; δ , 377.1; ϵ , 375.0; ζ , 373.4; η , 372.2; θ , 371.2. The first of these lines is in the red and does not appear in the photograph. The third is here called G for convenience. It must not be confounded with the adjacent broad band at wave-length 431 which appears in the solar spectrum and was called G by Fraunhofer. Stars having the spectrum described above belong to Type I. according to the usual classification of stellar spectra. The K line 393.4 is also generally visible, but its intensity differs in different stars. This intensity is indicated in Table II. in the column headed FK. When no other lines but those named above are visible the spectrum is indicated by the letter A. When other lines are detected the letter B is used, and the position and intensity of

HD katalog

- po smrti H. Drapera jeho žena Mary Anne Palmer Draper → peníze na projekt
- publikován mezi lety 1918 – 1924
- první verze 10 351 hvězd v roce 1890 (Williamina Fleming)
- Arequipa (Peru) – jižní polokoule (Annie Jump Cannon 1901)
- 225 300 hvězd

HD katalog

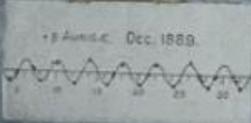


1893, expozice 140 minut



1003B

207316



HD katalog





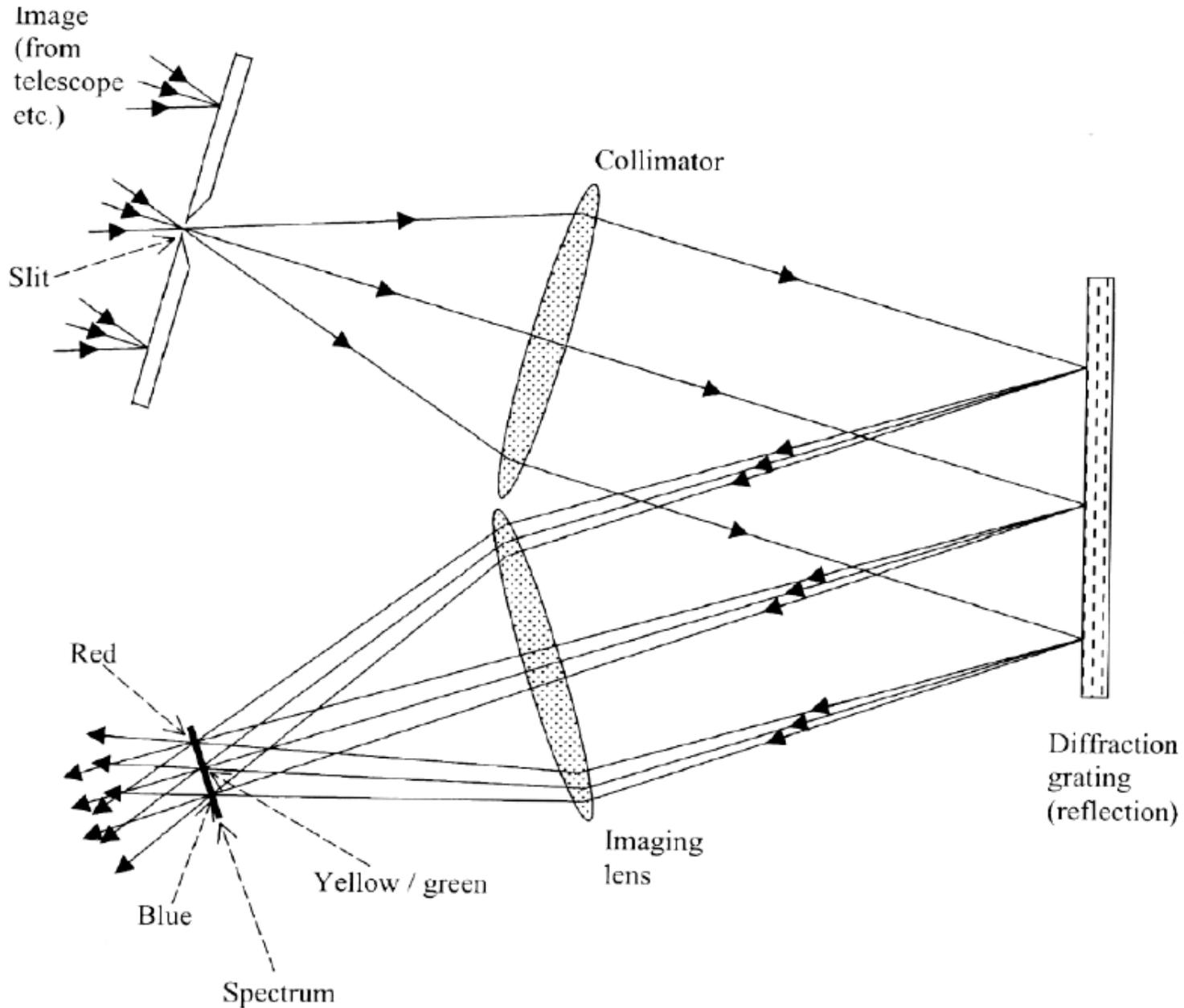


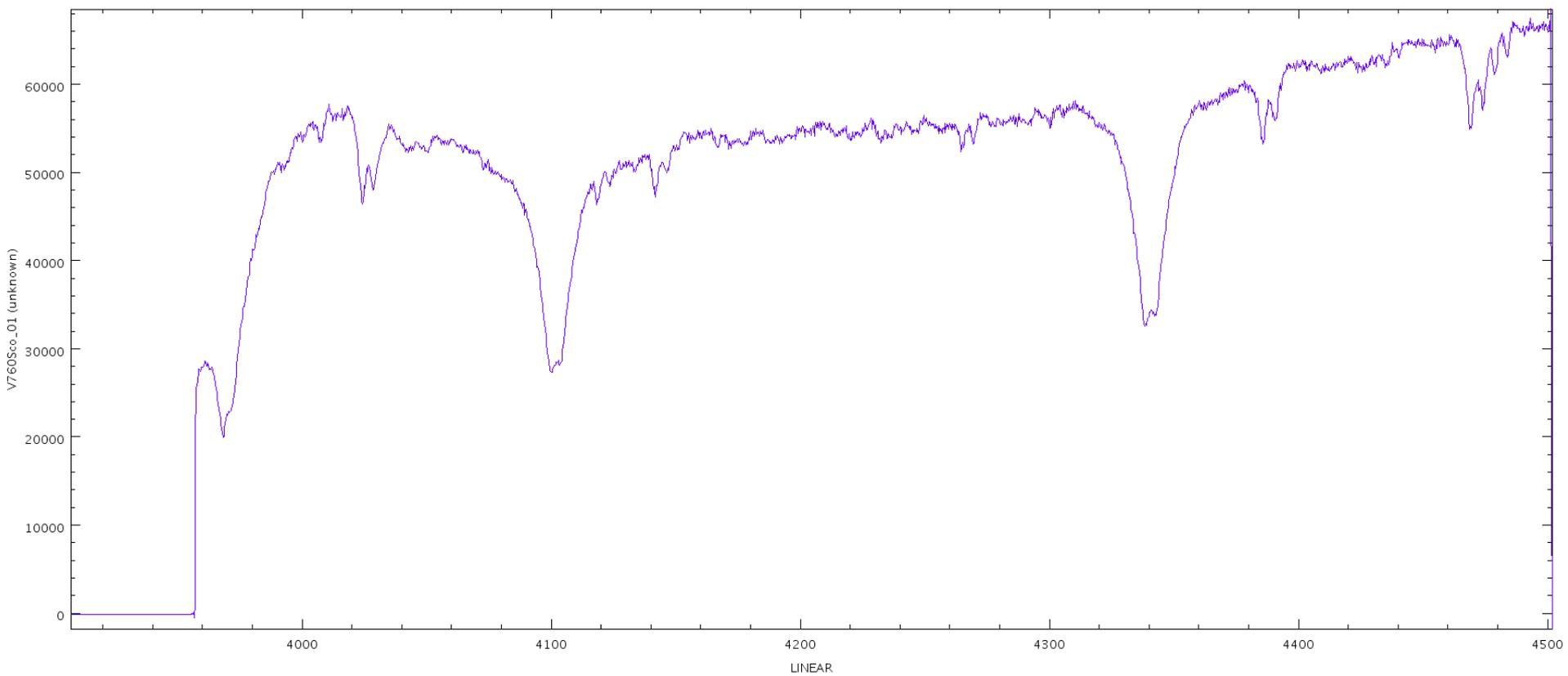
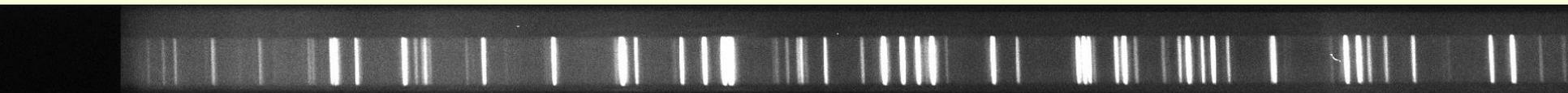
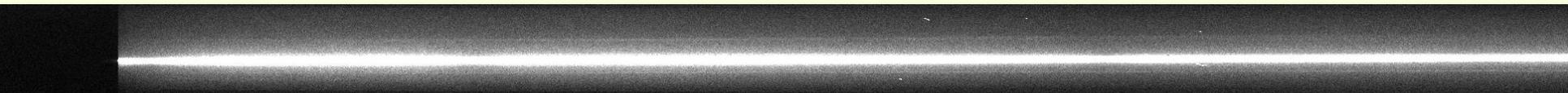
Jak vypadají
spektrografy?

TYPY SPEKTROGRAFŮ

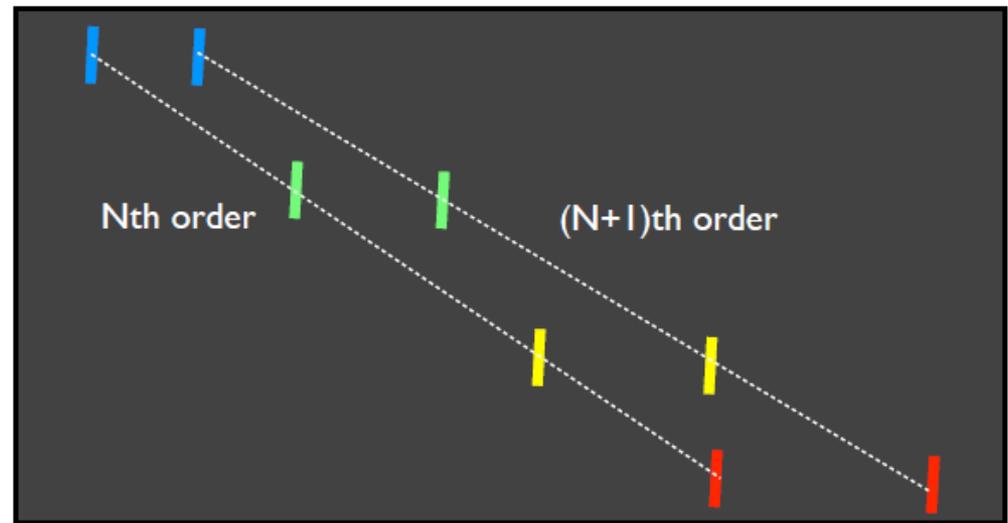
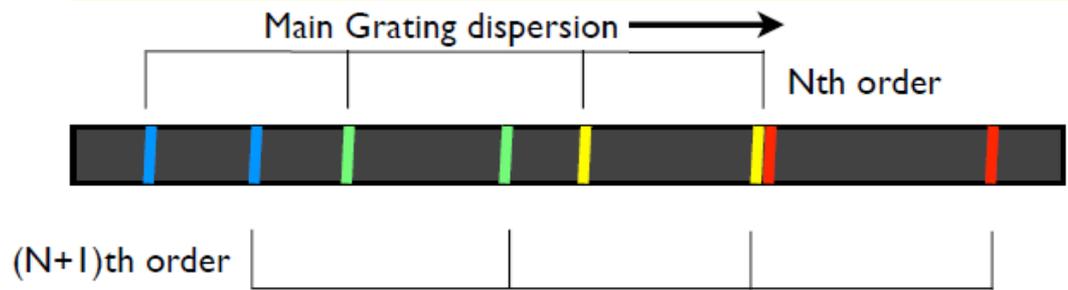
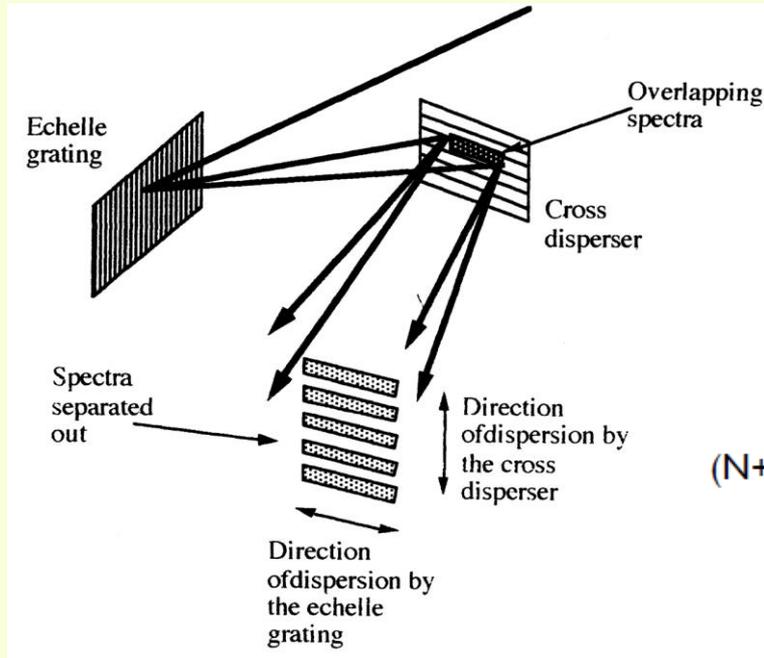
- podle disperzního členu
 - mřížkový, hranolový, propustná mřížka, úzkopásmový filtr
- podle geometrie
 - štěrbinový, aperturní vícevláknový, integrální jednotka pole (integral field unit IFU), laditelné snímače (tunable images)

Diffraction Grating Spectrograph

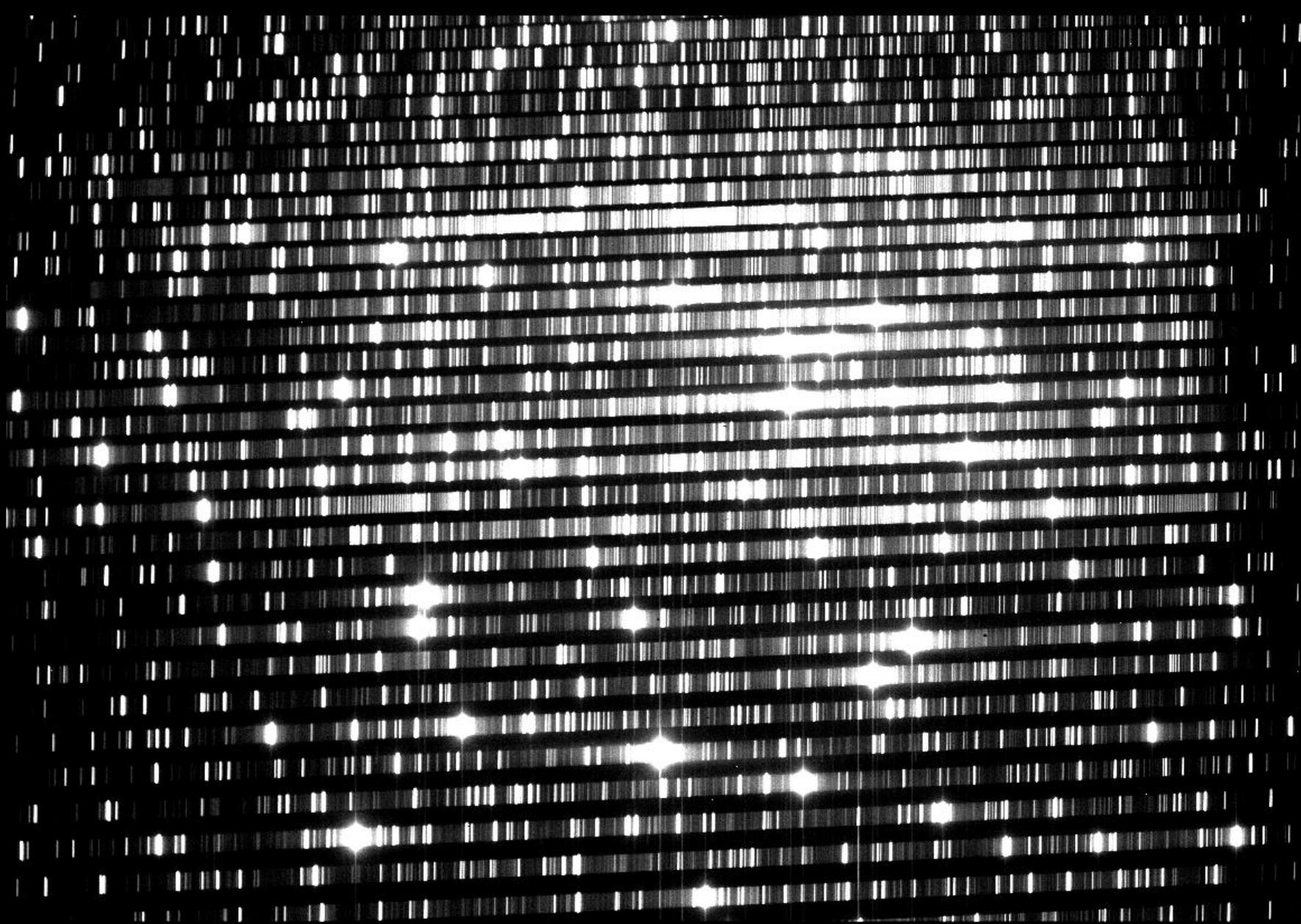




ECHELLE SPEKTROGRAF



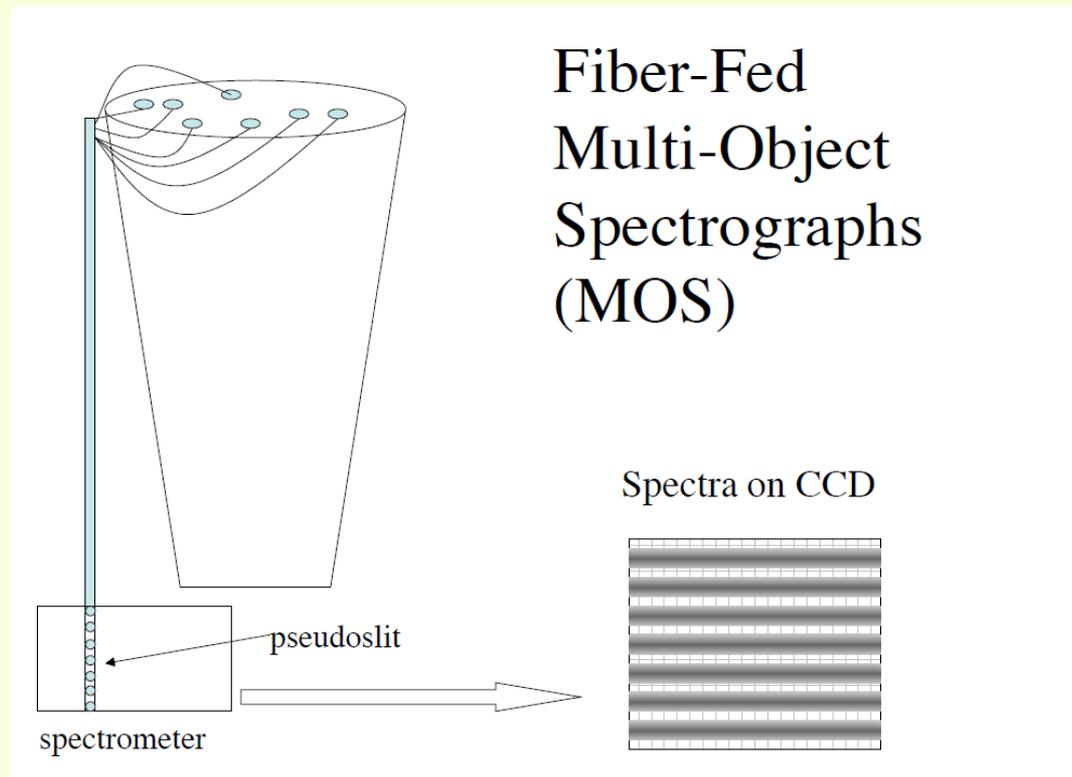
Cross-disperser dispersion ———>



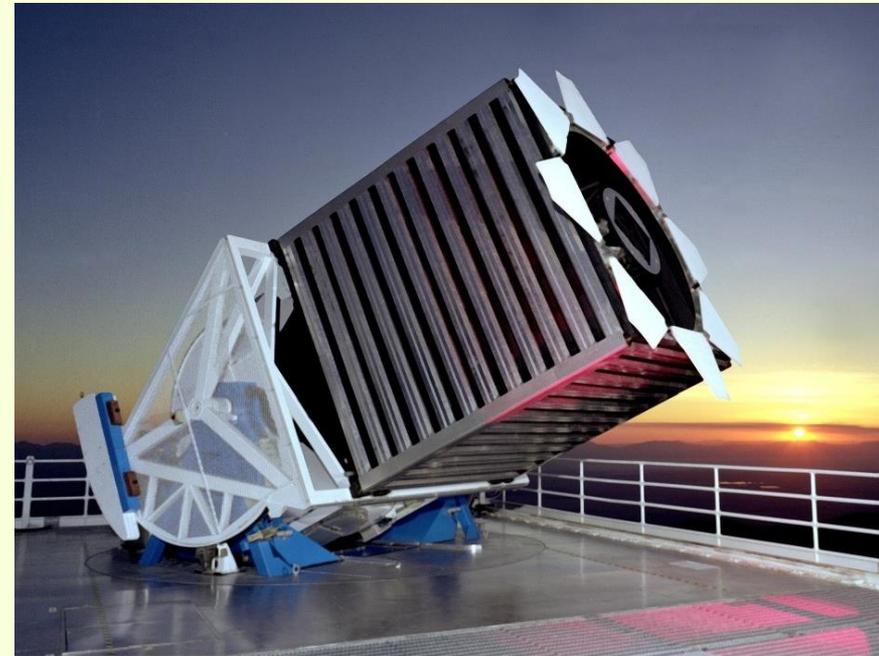
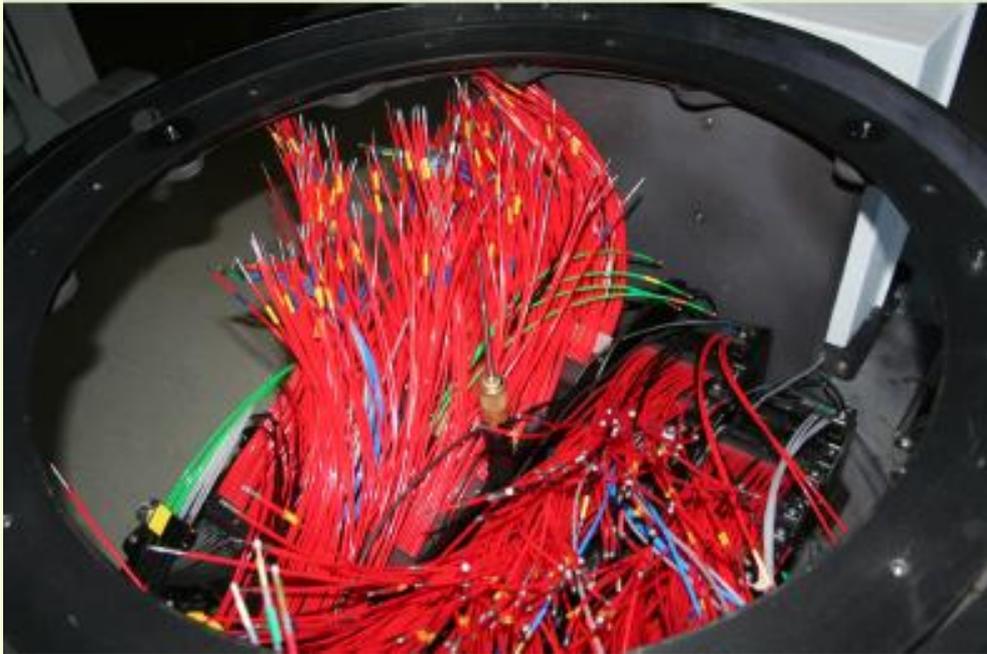
kalibrační spektrum UVES

APERTURNÍ VÍCEVLÁKNOVÉ

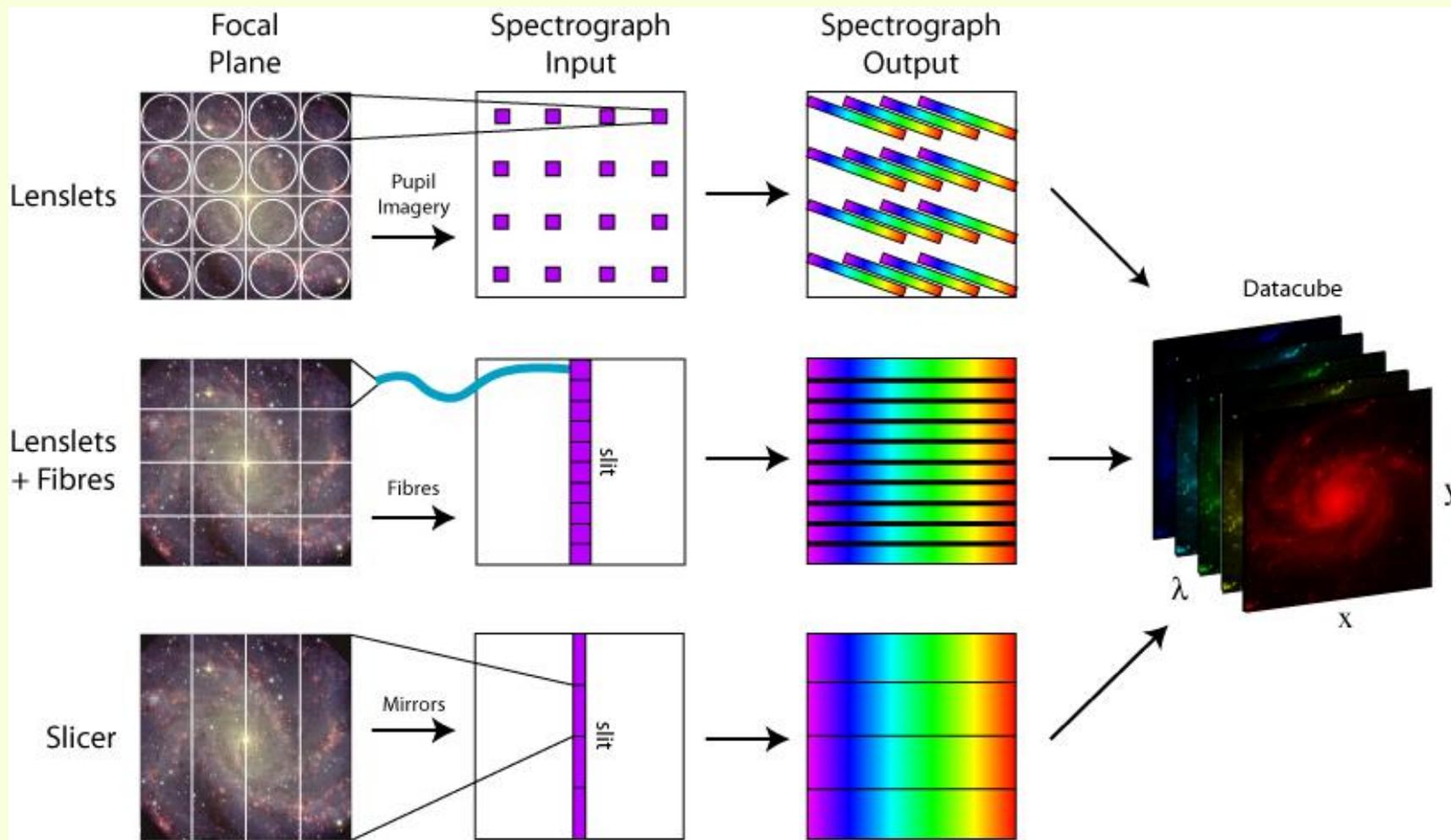
- nastavení optických vláken v ohniskové rovině na měřené cíle
- optická vlákna vedou světlo na štěrbinu



SDSS (Apache Point Observatory)



INTEGRÁLNÍ JEDNOTKA POLE



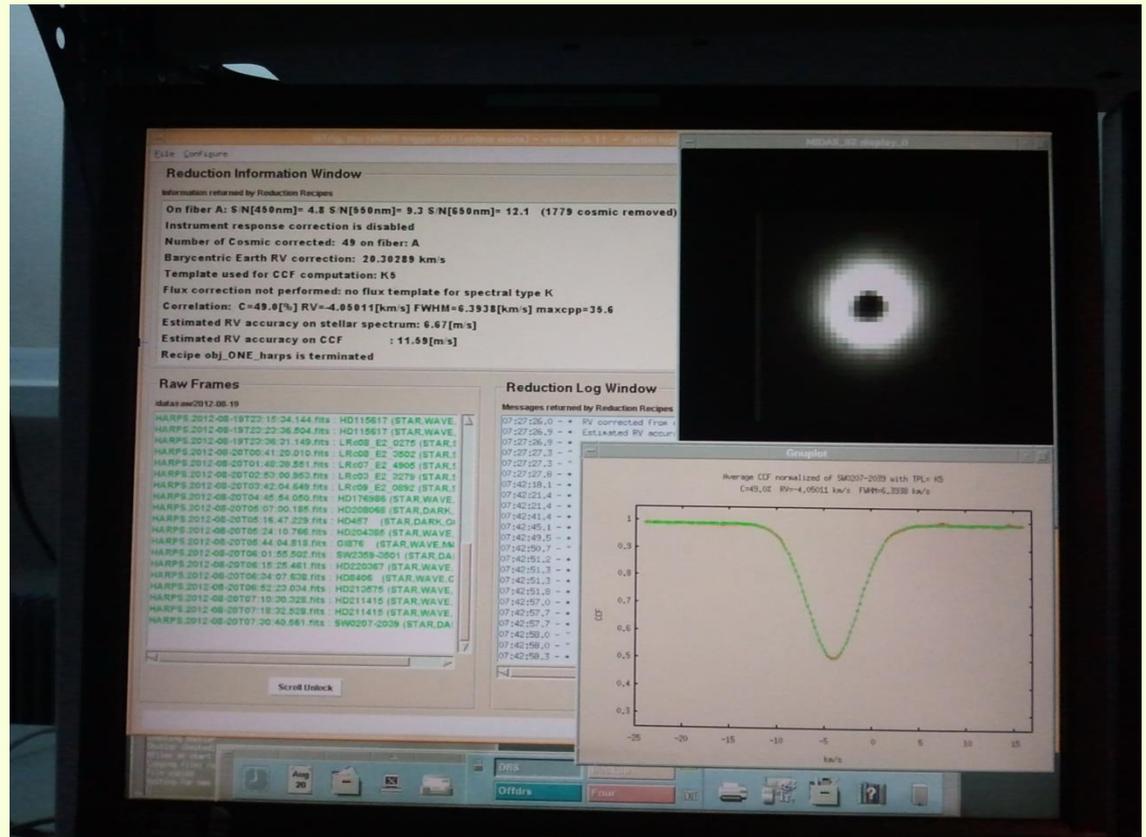
MÁLO SVĚTLA

- seeing – rozmazání do větší plochy
- AdO + AcO



MÁLO SVĚTLA

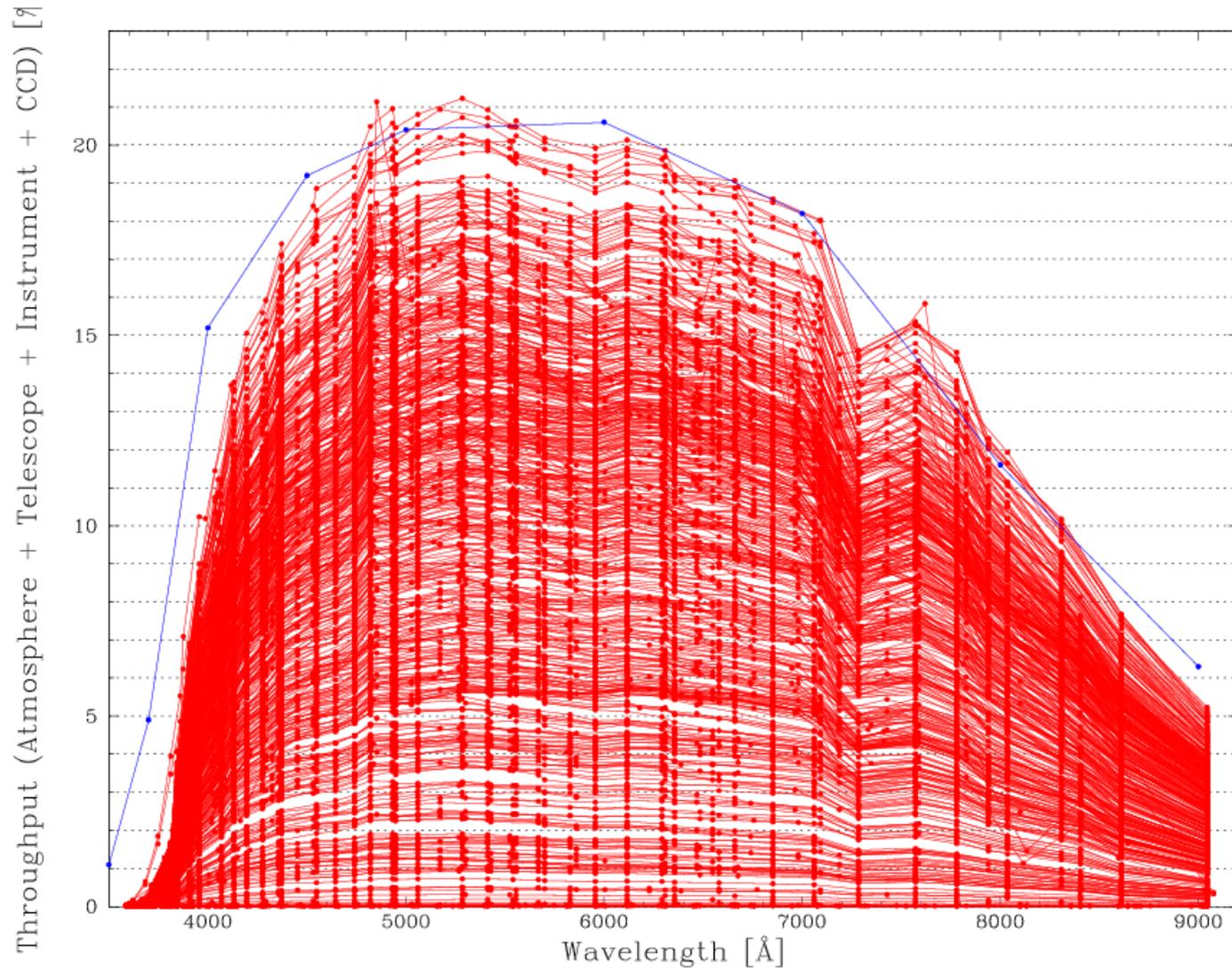
- seeing – rozmazání do větší plochy
- AdO + AcO



MÁLO SVĚTLA

- seeing – rozmazání do větší plochy
- AdO + AcO
- větší průměry dalekohledů
- mnoho optických části ve spektrografu (ztráta světla) → dlouhé expoziční časy

MÁLO SVĚTLA



Co lze vyčíst
ze spektra?

CO LZE VYČÍST ZE SPEKTRA

- chemické složení a metalicita
- teplota
- povrchové zrychlení
- perioda rotace
- rychlost rotace
- radiální rychlost
- magnetické pole
- rozložení prvků na povrchu (skvrny)

CHEMICKÉ SLOŽENÍ A METALICITA

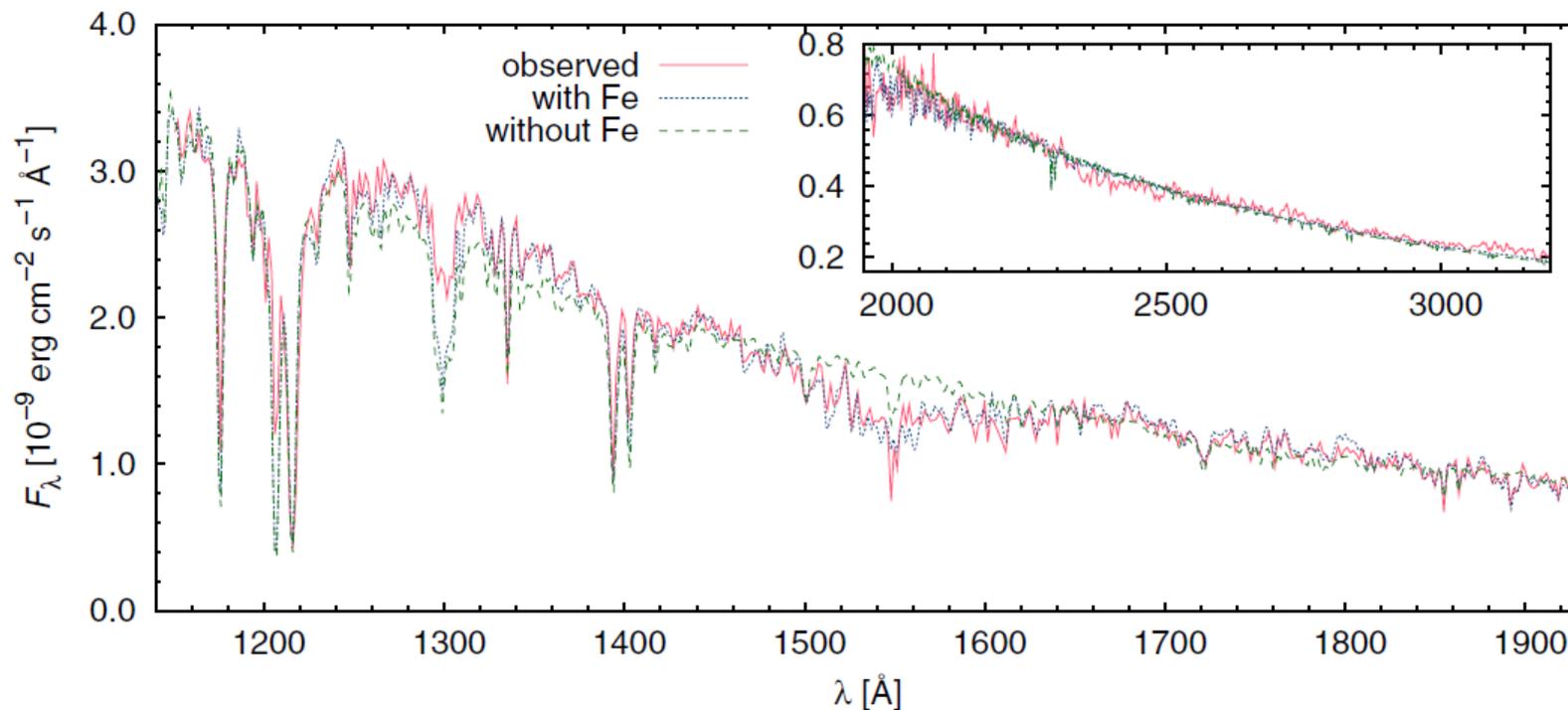
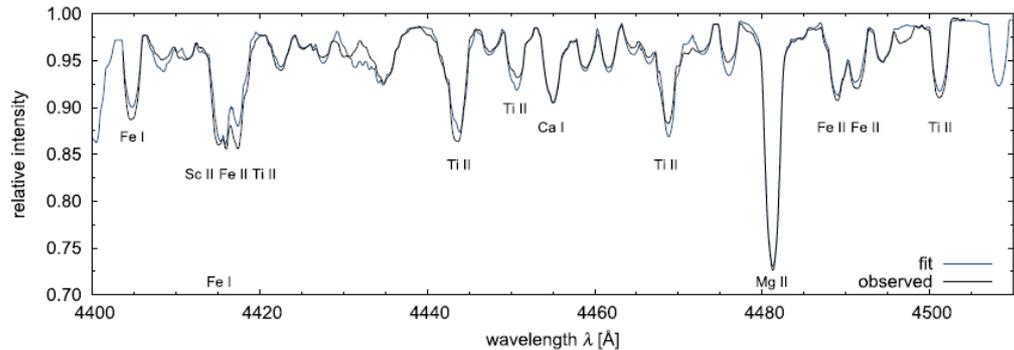


Fig. 3. Comparison of observed UV flux (IUE, mean low spectral resolution spectrum) with flux from model atmospheres for solar iron abundance $\varepsilon_{\text{Fe}} = -4.6$ and for a model without iron (the abundance of helium and silicon is $\varepsilon_{\text{He}} = -1.0$, $\varepsilon_{\text{Si}} = -4.3$). The depression at 1550 \AA is a clear signature of iron. Both model fluxes were multiplied by a constant factor to match the observed spectrum and convolved with a Gaussian filter with a dispersion of 1.3 \AA . The LWP12335 spectrum and predicted near-UV fluxes are overplotted in the *upper right*.

TEPLOTA, POVRCHOVÉ ZRYCHLENÍ



$$T_{\text{eff}} = 8\,700 \pm 125 \text{ K}$$

$$\log g = 4,11 \pm 0,05$$

Figure 4. Comparison of the observed spectrum and the fit by the synthetic spectrum in a selected region of a FEROS spectrum.

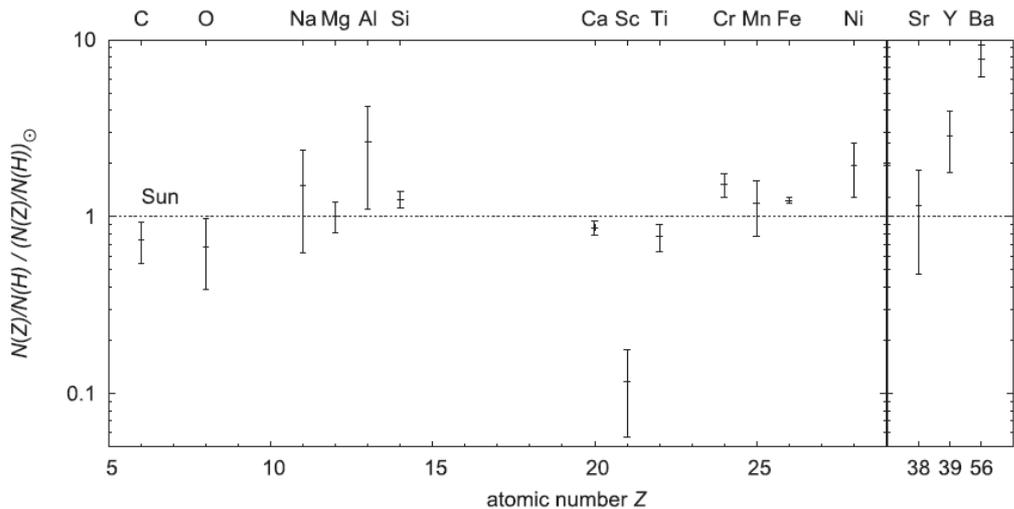
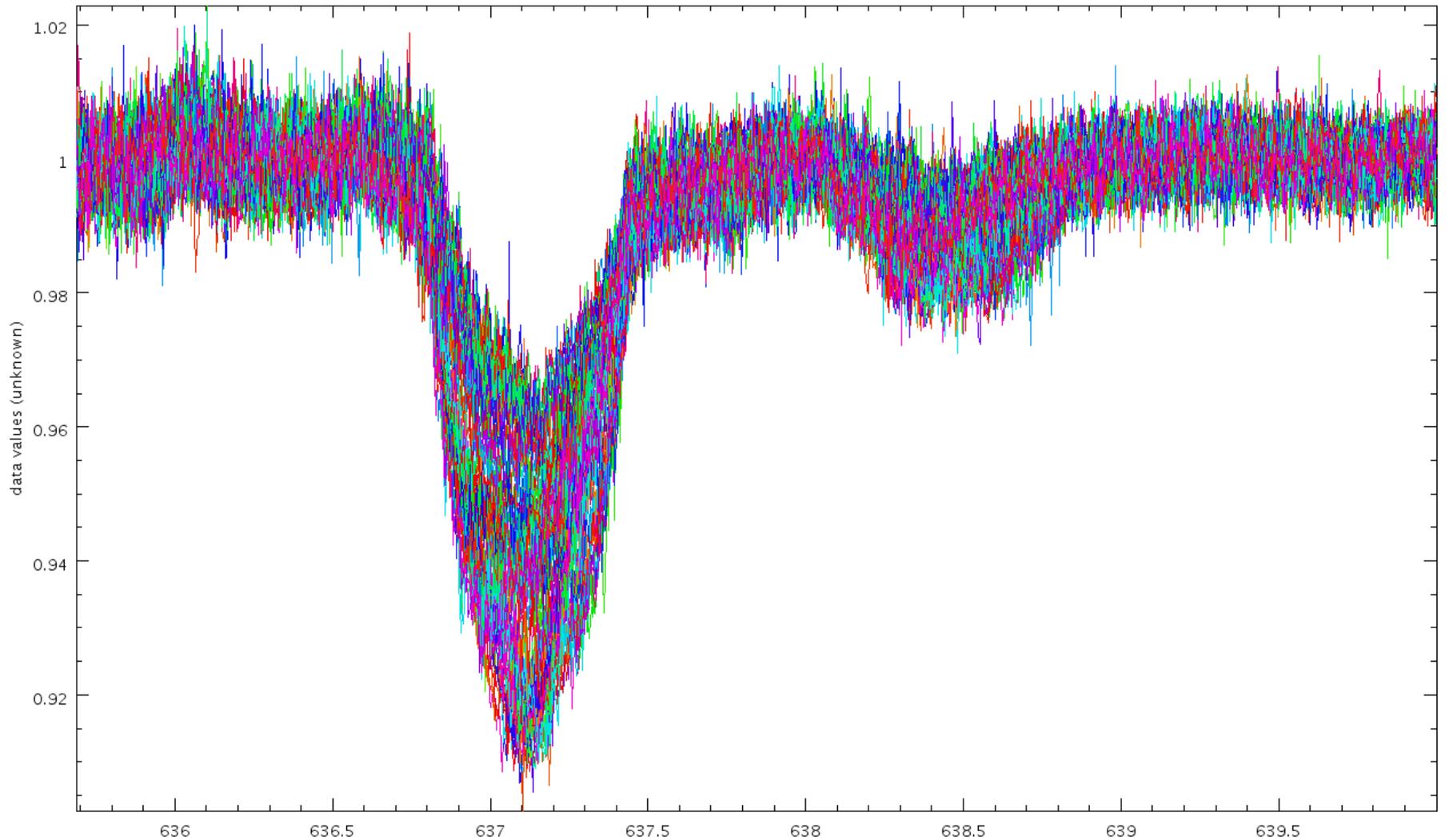


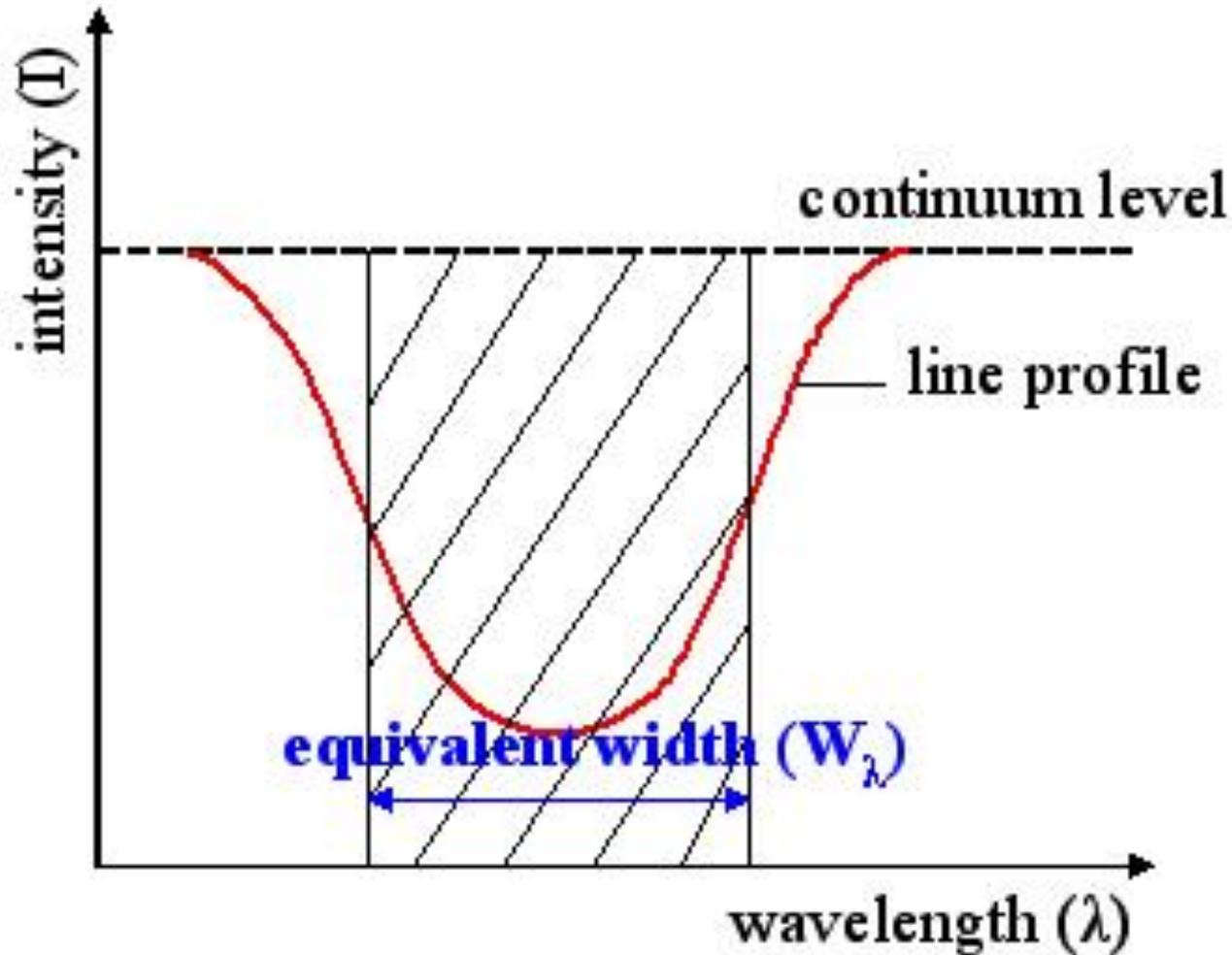
Figure 5. Derived σ Scl abundances relative to the Sun.

Janík et al. 2018,
PASP, **130**, 4203

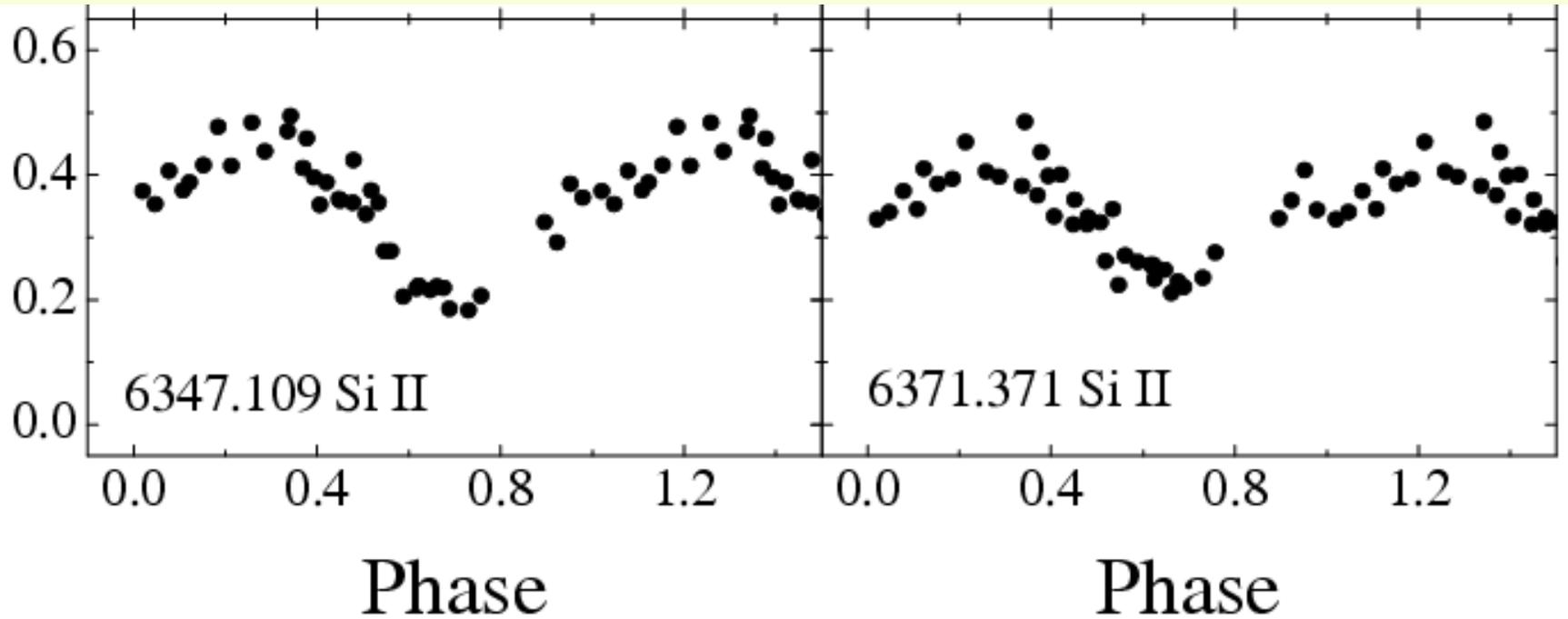
PERIODA ROTACE



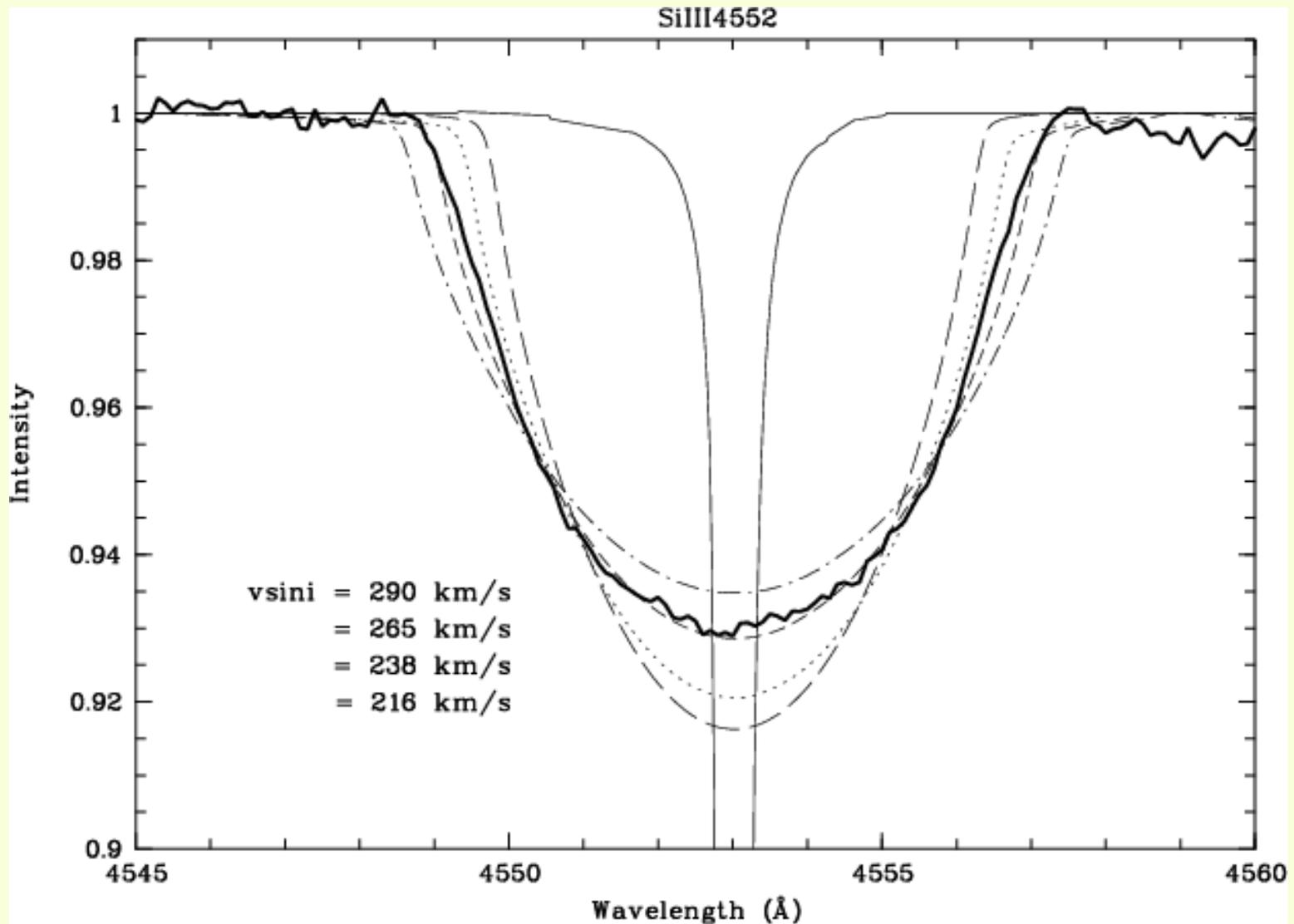
PERIODA ROTACE



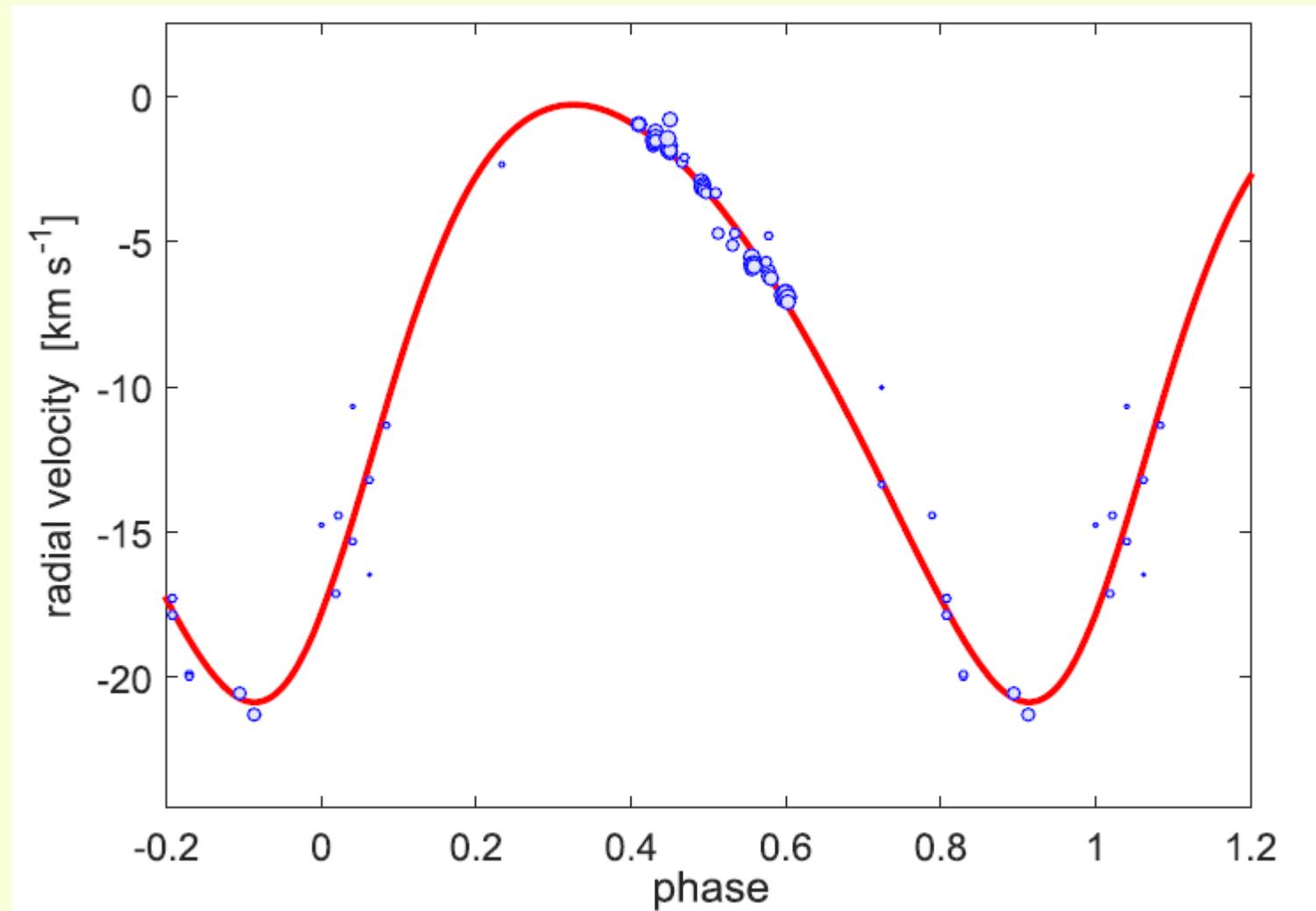
PERIODA ROTACE



RYCHLOST ROTACE



RADIÁLNÍ RYCHLOST



RADIÁLNÍ RYCHLOST

HD 137496

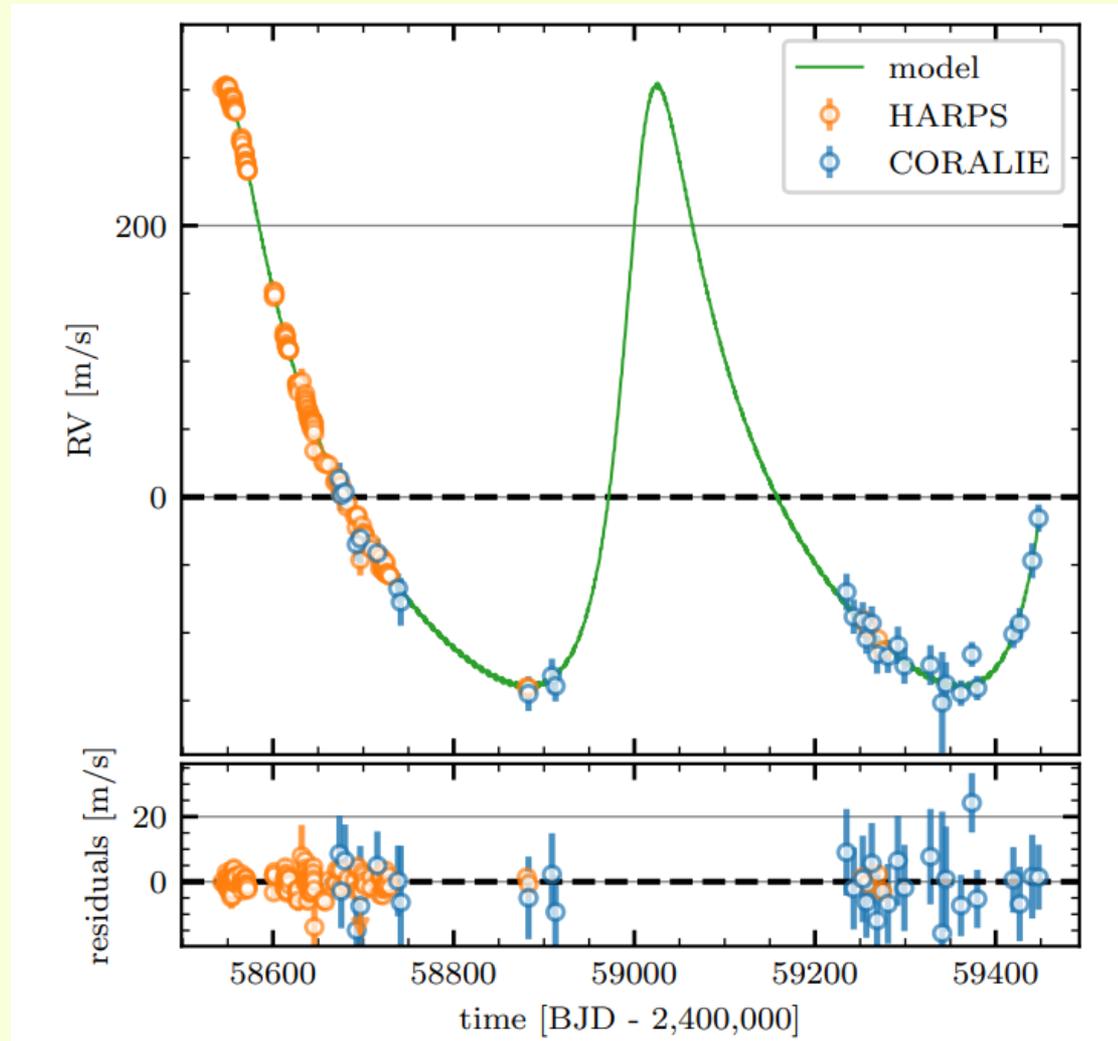
($R = 1,587 R_{\odot}$,
 $M = 1,035 M_{\odot}$,
 $T_{\text{eff}} = 5800 \text{ K}$)

HD 137496b

($M = 4,04 M_{\oplus}$)

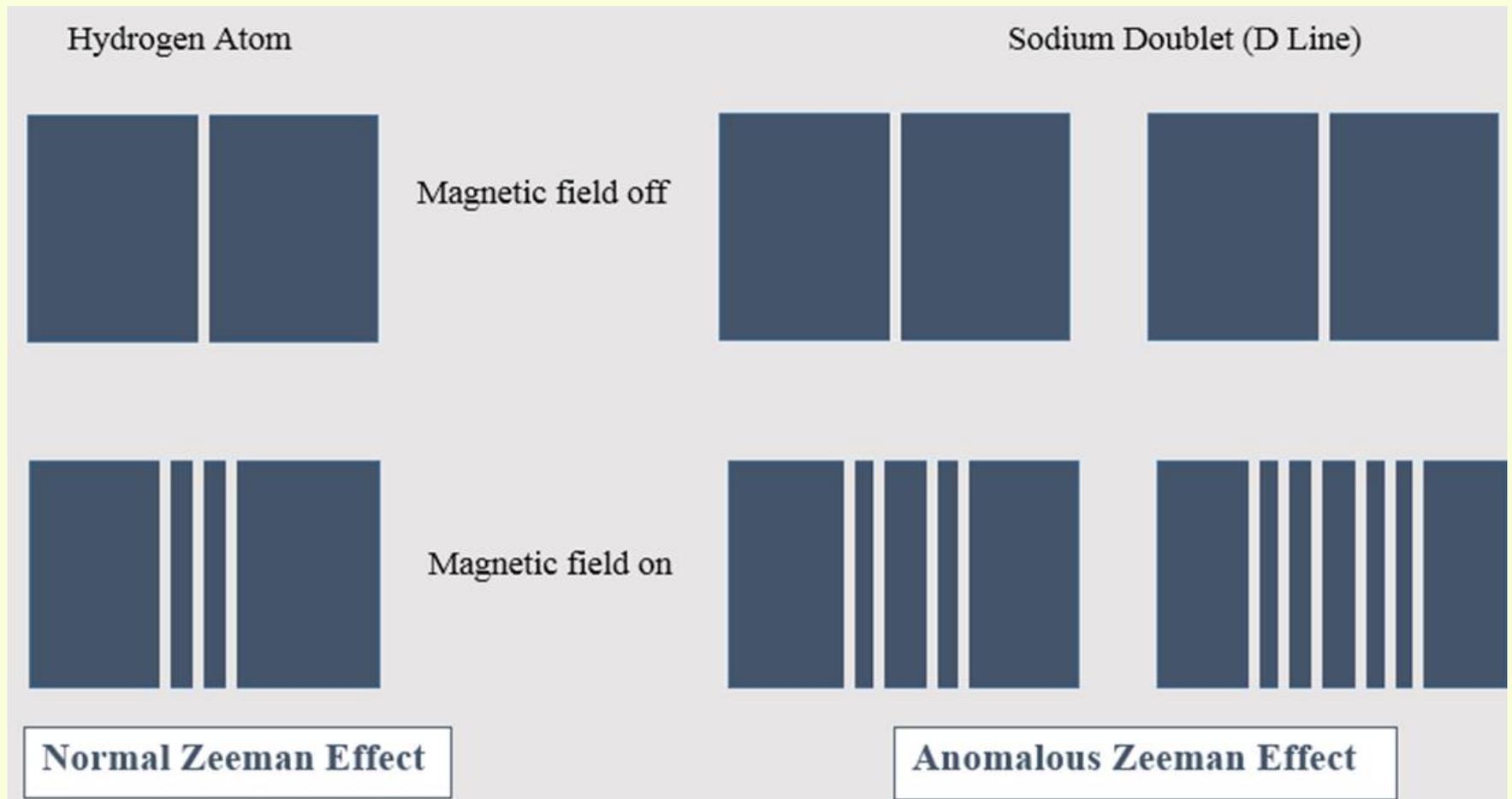
HD 137496c

($M = 7,66 M_{\text{J}}$)

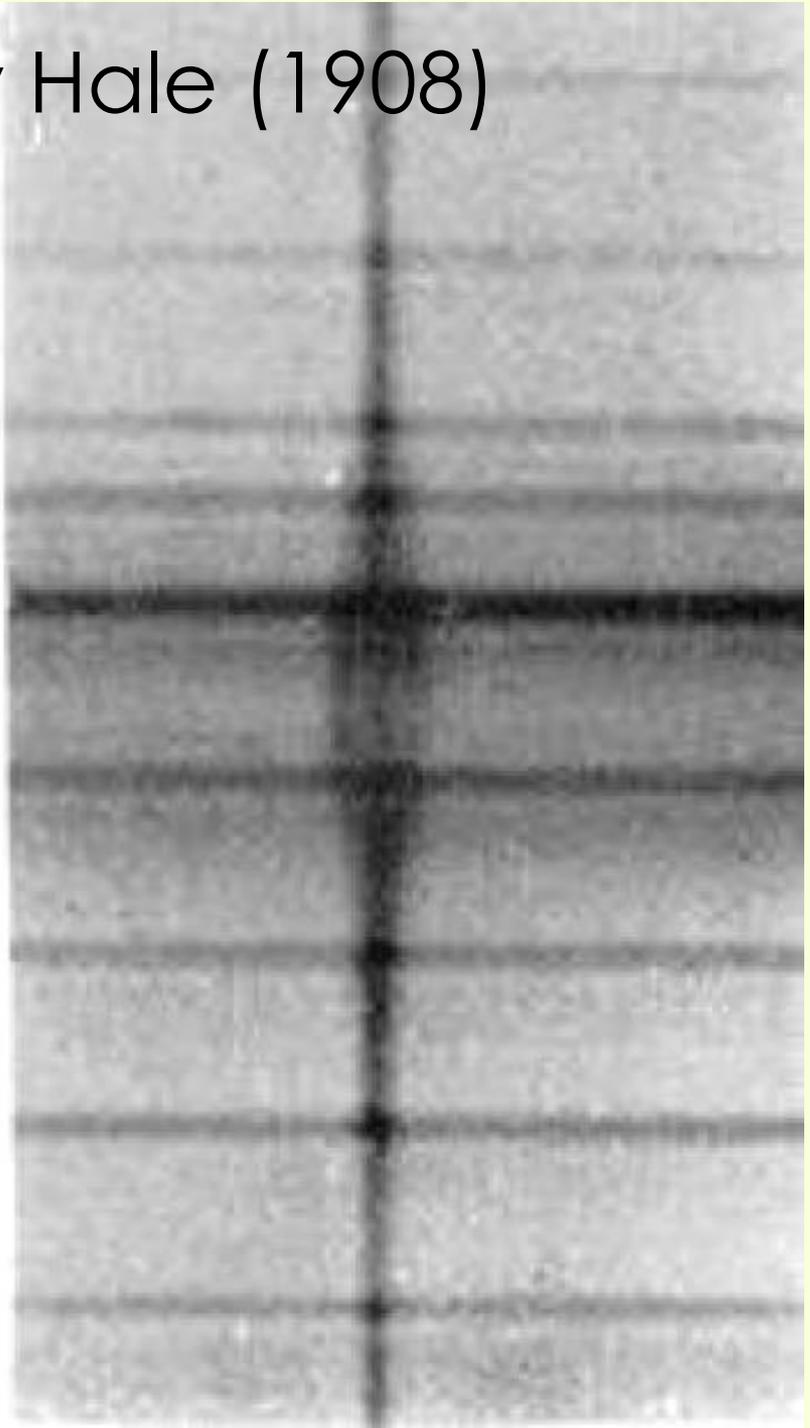
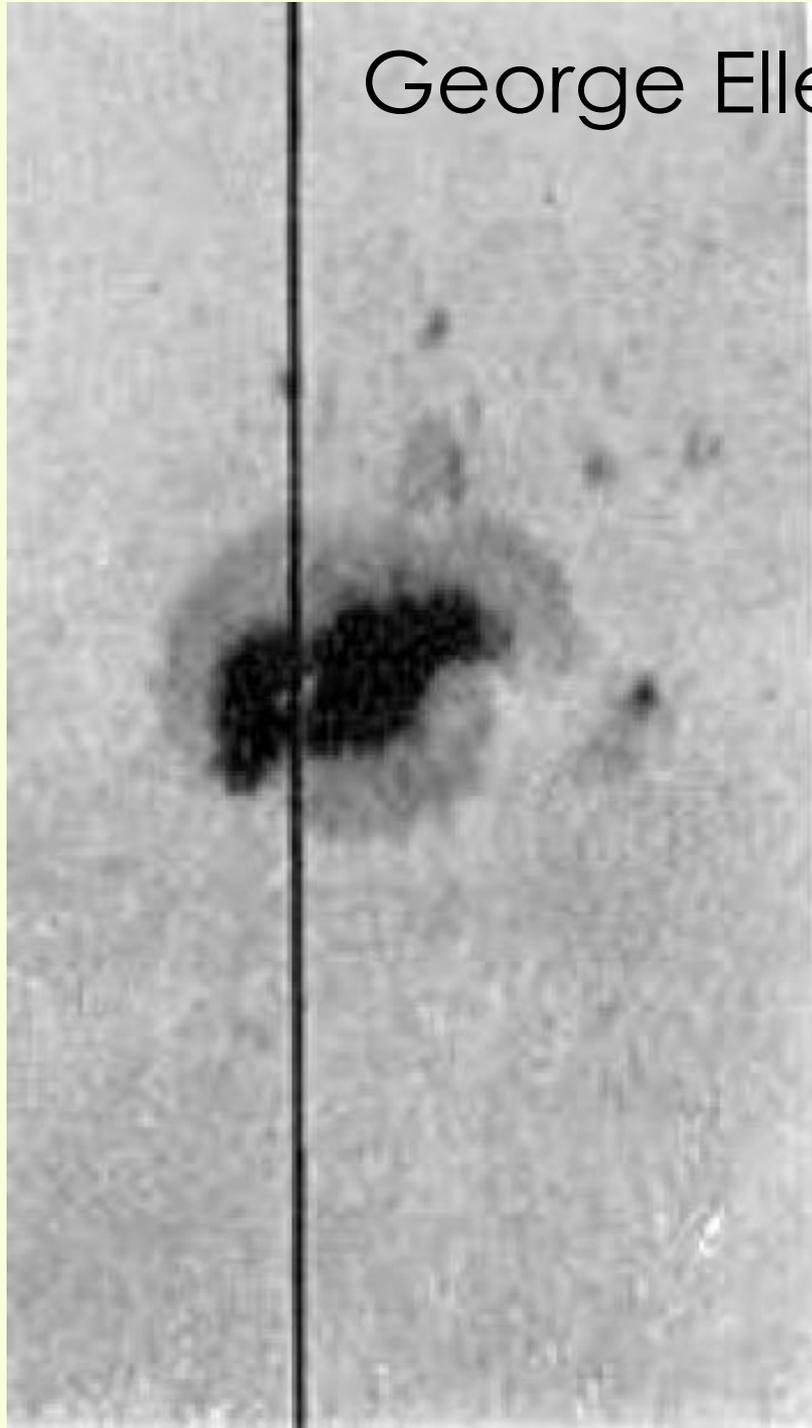


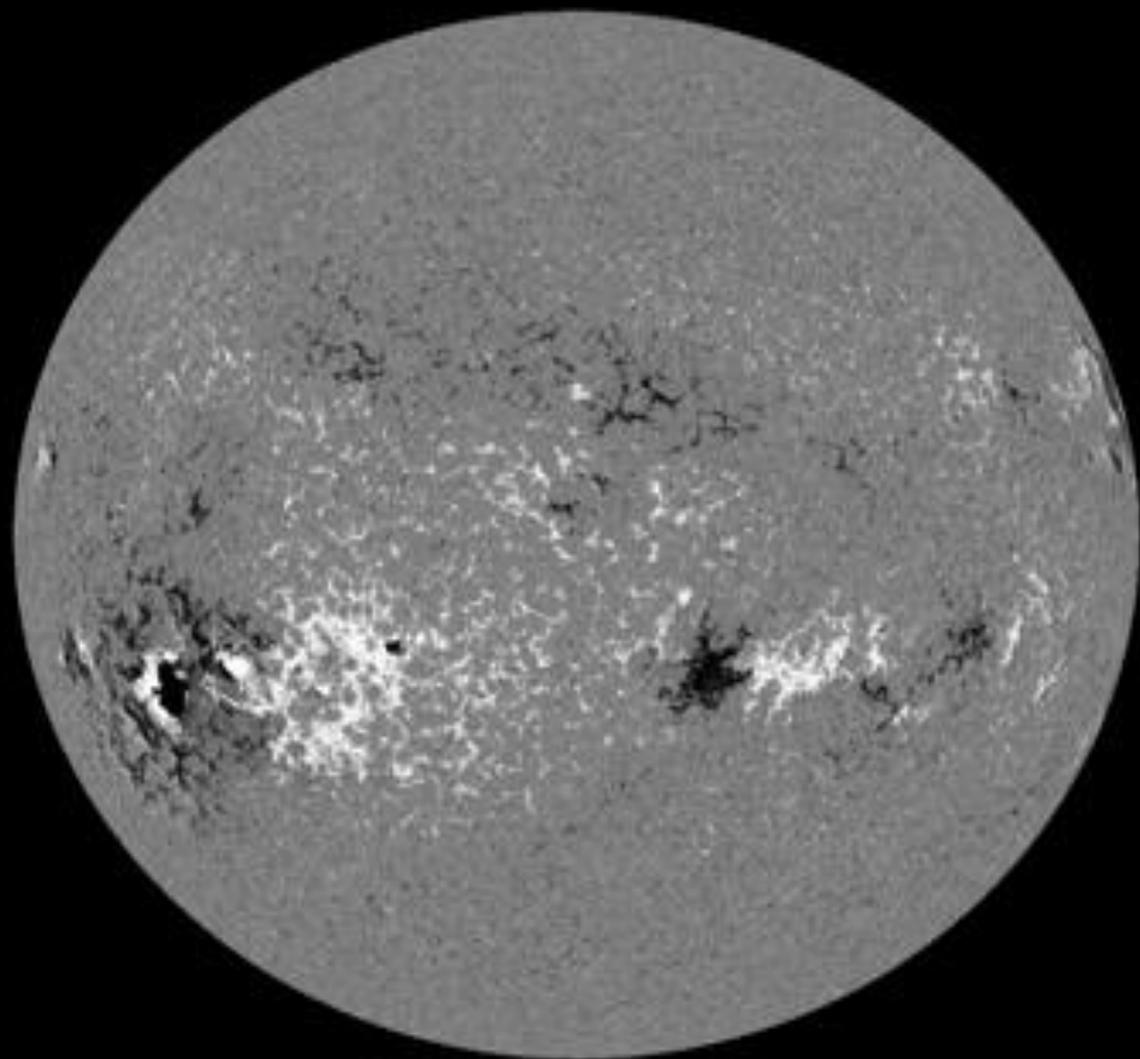
MAGNETICKÉ POLE

- rozštěpení čar – Zeemanův jev



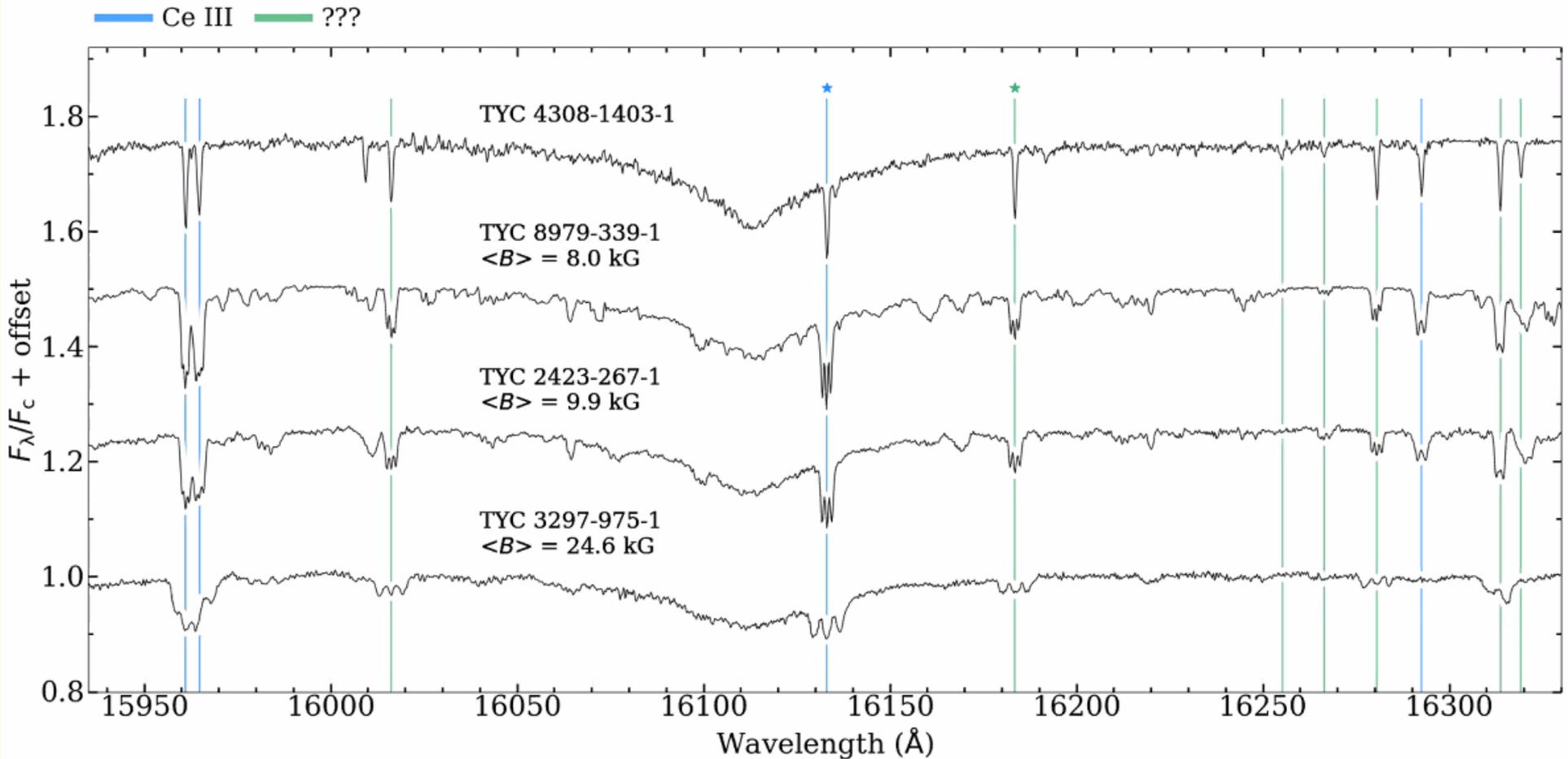
George Ellery Hale (1908)





SSO/148 044-044 Register: 20141118_131500

MAGNETICKÉ POLE



DOPPLEROVSKÉ MAPOVÁNÍ

- Vogt et al. (1987) – dopplerovské zobrazení rotujících hvězd – rekonstrukce obrazu
 - chladné skvrny RS CVn, FK Com
 - nerovnoměrné rozložení prvků CP hvězdy

DOPPLEROVSKÉ MAPOVÁNÍ

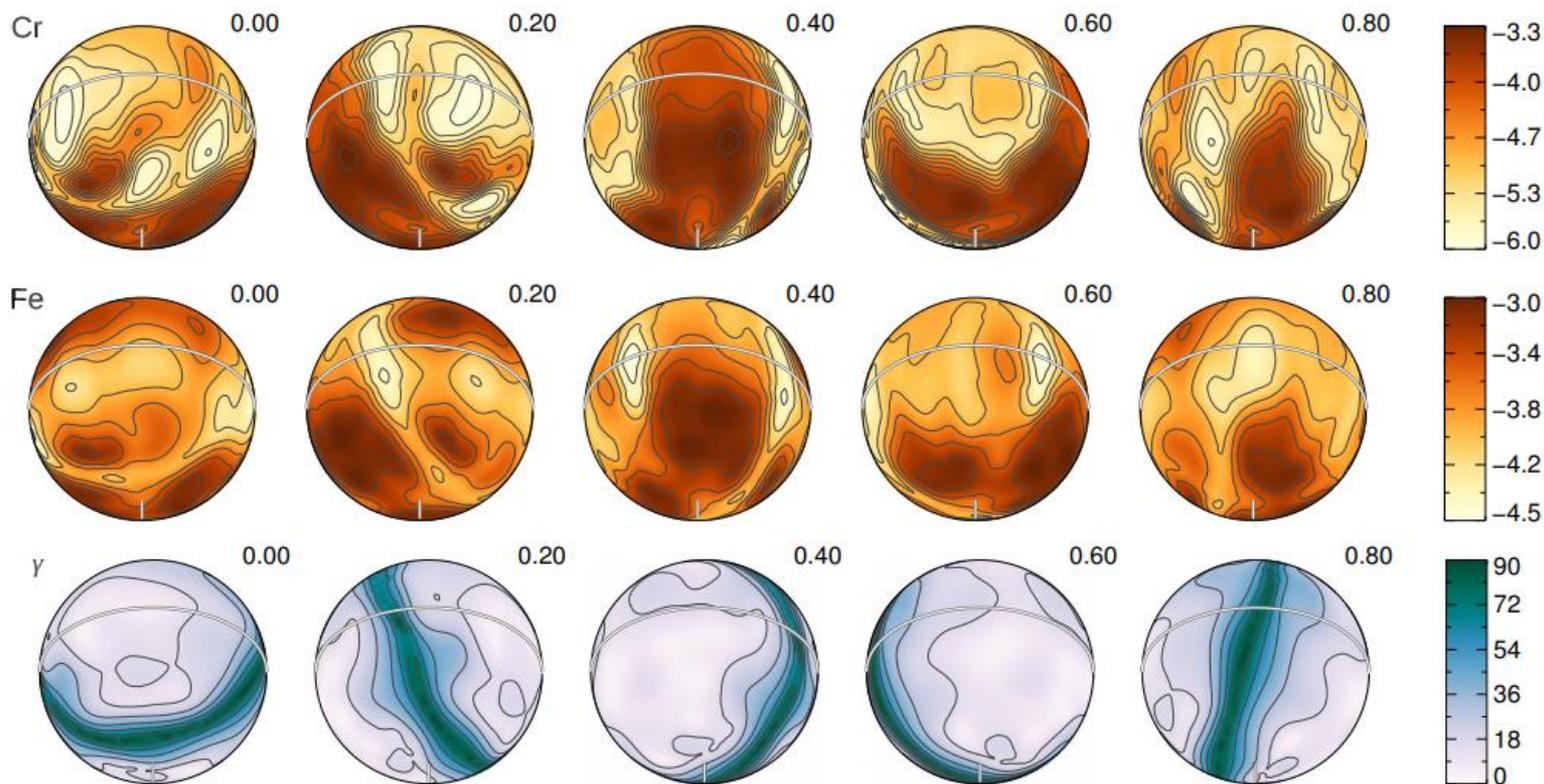


Fig. 11. Chromium and iron surface abundance distributions (*top and middle rows*) of θ Aur compared to the local magnetic field inclination (*bottom row*). The star is shown at five rotational phases, as indicated next to each plot. The contours are plotted with a 0.2 dex step for the abundance maps and with a 15° step for the field inclination map. The side colour bars give element abundances in the $\log N_{\text{el}}/N_{\text{tot}}$ units and field inclination in degrees.

Děkuji vám
za pozornost