Precise wavelength measurements of Potassium He- and Li-like satellites in a laser plasma of a mineral target.

Ryazantsev S. N.[1,2,@], Skobelev I. Yu.[1,2], Filippov E. D.[2,3], Martynenko A. S.[2], Mishchenko M. D.[1,2], Krus M.[4], Renner O.[4,5,6] and Pikuz S. A.[1,2]

[1]National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe Shosse 31, Moscow, 115409 Russia
[2]Joint Institute for High Temperatures of the Russian Academy of Sciences, Izhorskaya 13 Bldg 2, Moscow, 125412 Russia
[3]Federal Research Center Institute of Applied Physics of the Russian Academy of Sciences, 46 Ulyanov Str., Nizhny Novgorod, 603950 Russia
[4]Laser Plasma Department, Institute of Plasma Physics of the CAS, Za Slovankou 1782/3, Libeň, Prague, 182 00 Czech Republic
[5]Department of Radiation and Chemical Physics, Institute of Physics of the CAS, Na Slovance 1999/2, Prague, 182 21 Czech Republic
[6]ELI-Beamlines, Institute of Physics of the CAS, Za Radnicí 835, Dolní Břežany, 252 41 Czech Republic

INSTITUTE OF PLASMA PHYSICS OF THE CZECH ACADEMY OF SCIENCES

e-mail (speaker): SNRyazantsev@mephi.ru

Motivation.

The atomic models of high-Z deeply charged ions are extremely complex and require experimental validation.

One of the approaches is to measure wavelengths of spectral lines corresponding to transitions in ions with $\geq 2\ e^-$ (He-like, Li, Be-…) which cannot be calculated purely analytically and compare with the values predicted by different models.

Here a method of the wavelength measurements with accuracy of ~0.6 mÅ is described.

General idea.

It is suggested to use minerals of natural origin composed of moderate (15 < Z < 30) and low (< 15) Z elements as laser targets. The emission produced by the latter ones delivers perfect reference lines over a whole range of He- and Li-like moderate-Z emission under examination

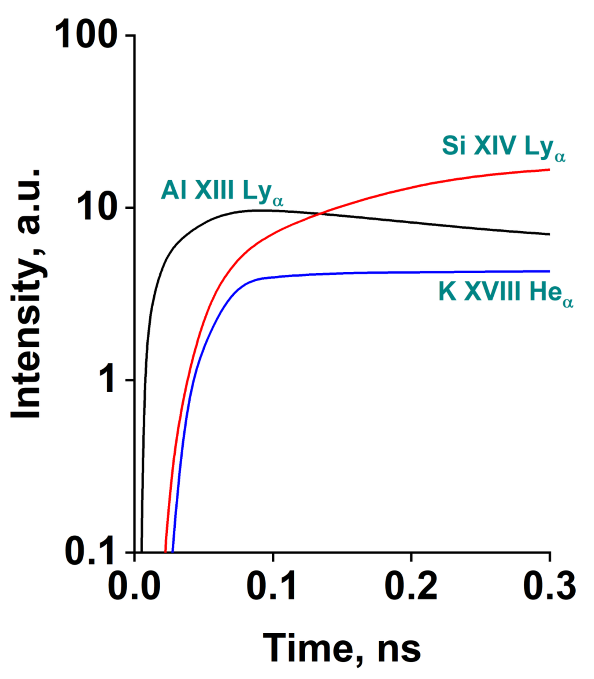
3. Preferred laser parameters.

For T_e=1000 eV measured, and reference spectra have close intensities.

in ~200 ps the steady state is reached so the ***optimal way*** *to use* **sub-nanosecond** pulse with **I~10^16 W/cm²**

in 30–40 ps intensities are comparable so picoseond-pulses also can be used.

Intensities of the concerned lines vs time



Calculated for:
T_e=1000 eV
N_e = 10^{21} cm^{-3}

Orthoclase crystal

4.2. Experiment on the PALS laser facility.

Crystal (1D scheme):

2d = 8.512 Å (*hkl*:100)
R = 150 mm
a = 626 mm

range: 5.8 to 7.2 Å

Three reference lines:

Ly_α (λ = 7.170908 Å), Ly_β (λ = 6.05253 Å) of Al XIII and Ly_α (λ = 6.180428 Å) of Si XIV allowed to obtain the disperse curve.

Laser:

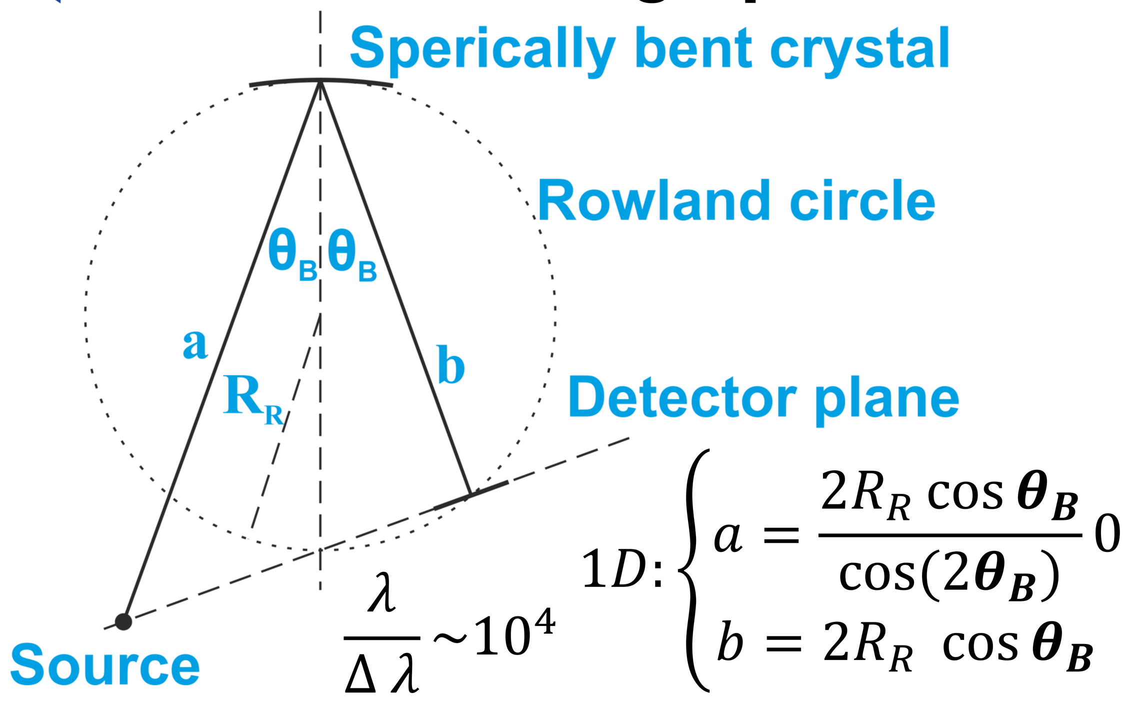
Pulse energy E ~ 600 J
Pulse duration τ = 480 ps
Focal spot R = 100 μm

$$I = 2\times10^{16}\ \frac{W}{cm^2}$$

Detector:

Fuji IX80 X-ray film
Pixel size: 5.29 μm corresponds to ~0.3 mÅ

1. Focusing spectrometer with spatial resolution (FSSRs).



$$1D: \begin{cases} a = \dfrac{2R_R\cos\boldsymbol{\theta_B}}{\cos(2\boldsymbol{\theta_B})}0 \\ b = 2R_R\ \cos\boldsymbol{\theta_B} \end{cases}$$

$$\frac{\lambda}{\Delta\lambda}\sim10^4$$

R_R - Rowland circle radius.
$R = 2R_R$ – spherically bent crystal radius

Bragg diffraction law:

$$2\boldsymbol{d}\cos\boldsymbol{\theta_B} = \boldsymbol{n\lambda},$$

d – interplanar spacing of a crystal,
n – order of reflection.

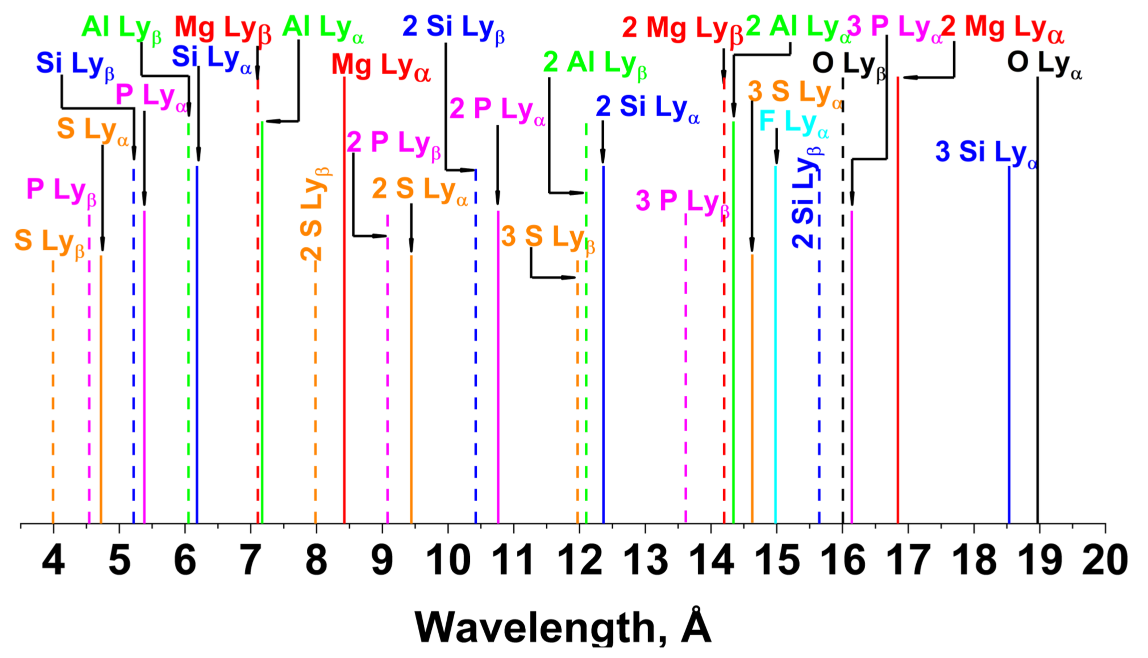
The radiation can be registered in different orders of reflection but **$(n\lambda)_{max}$ limited by $2d$ of a crystal:**

- **$2d_{mica}$ = 19.9149 Å**
- **$2d_{\alpha-quartz\ 100}$ = 8.512 Å**

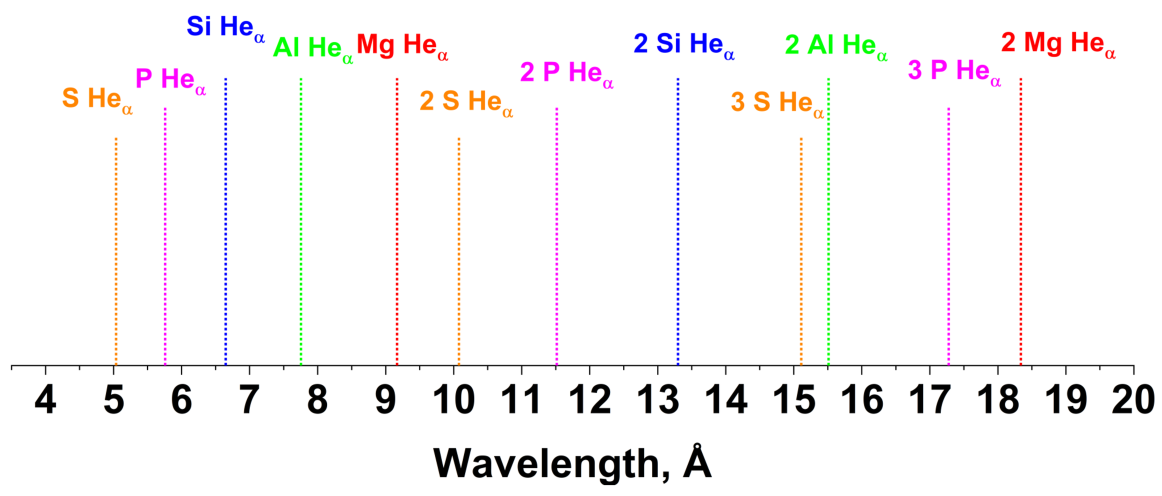
- A **dispersion curve** can be very precisely fitted with a **parabolic function**.
- **Three reference** lines are required to **provide absolute calibration** of the FSSR.

2. Possible reference lines.

H-like ions resonance lines wavelengths are known from QED-involved calculation with accuracy several order of amplitude higher than experimentally achievable, which makes them **the best references.**

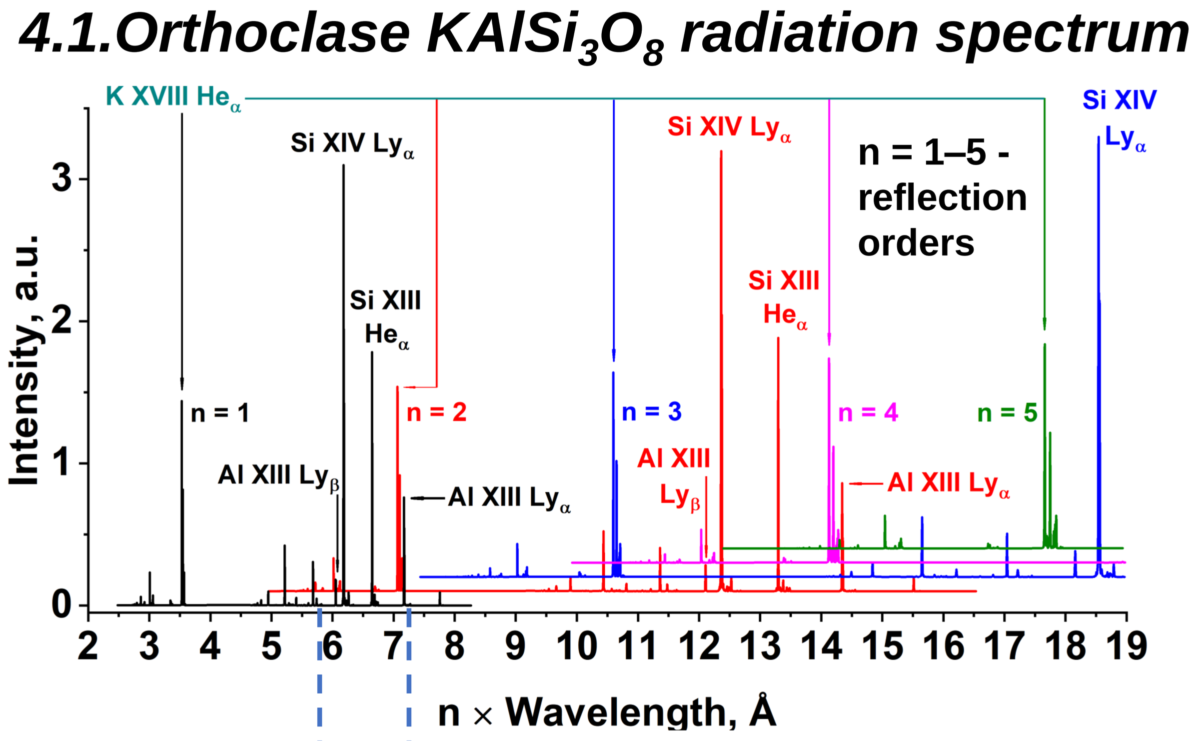


He-like ions spectral lines are the most convenient to be used as references, because such ions exist for a wide plasma electron temperature range, but their wavelengths should be measured preliminary with the high accuracy using lines of H-like ions as references.



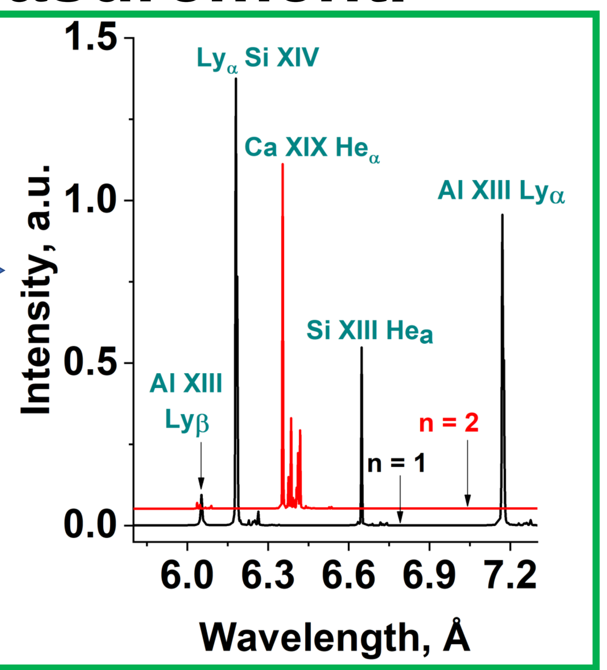
4. Potassium and Calcium He- and Li-like lines measurement.

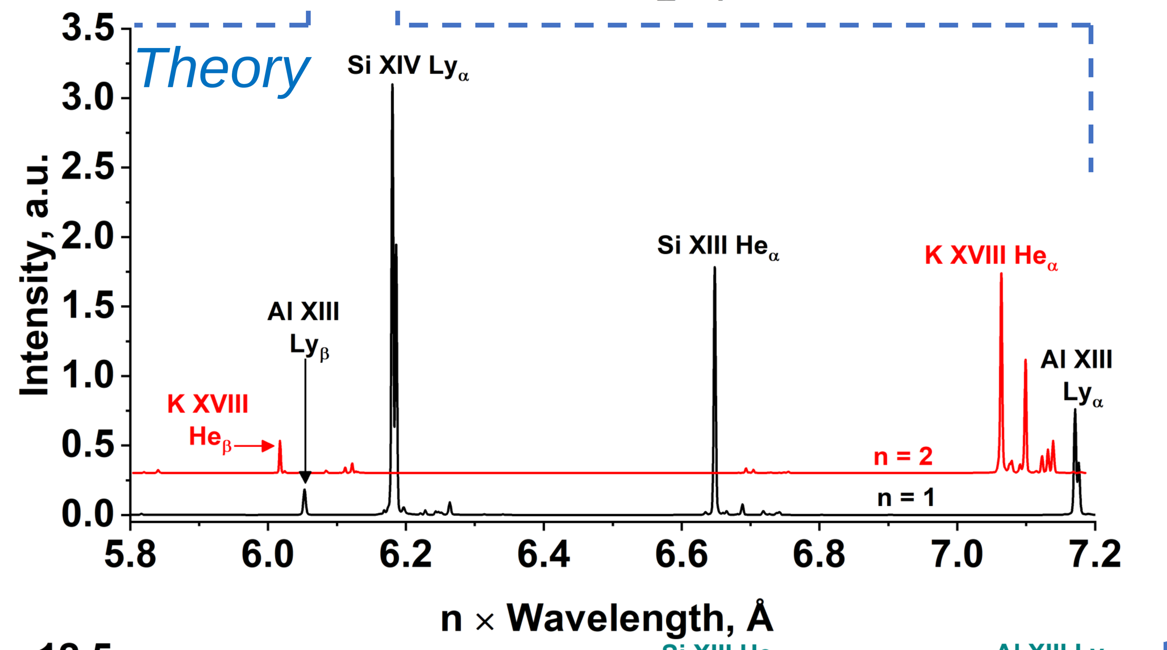
4.1.Orthoclase $KAlSi_3O_8$ radiation spectrum

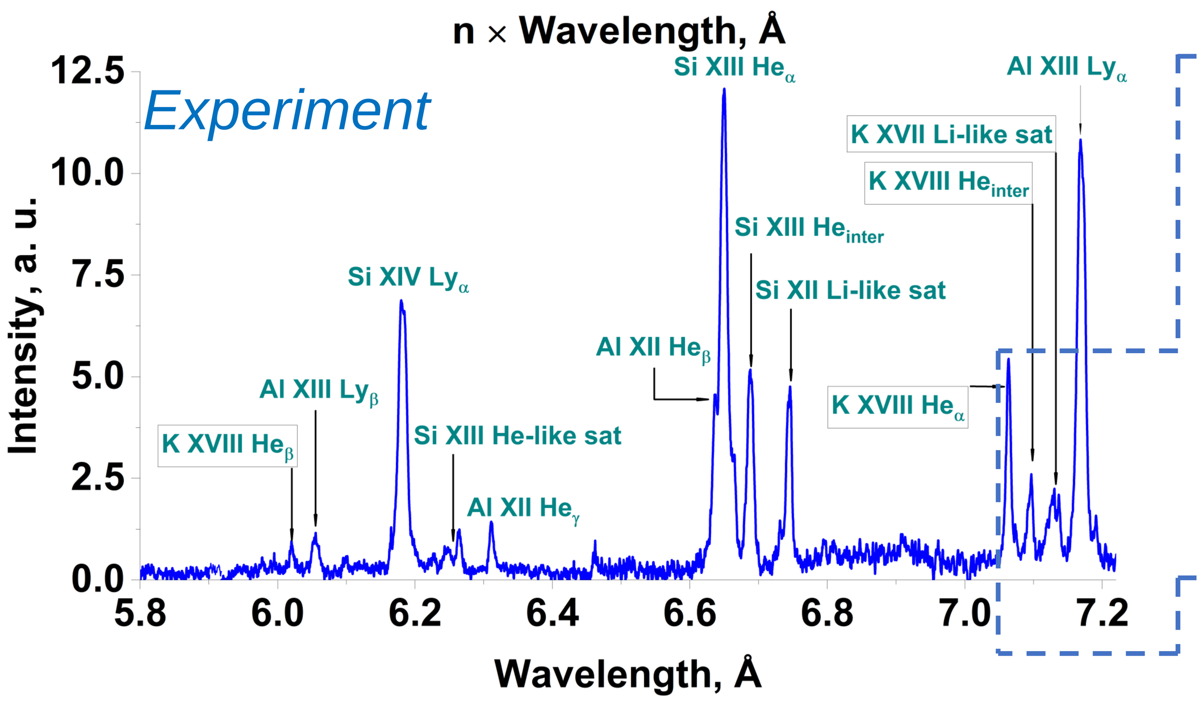


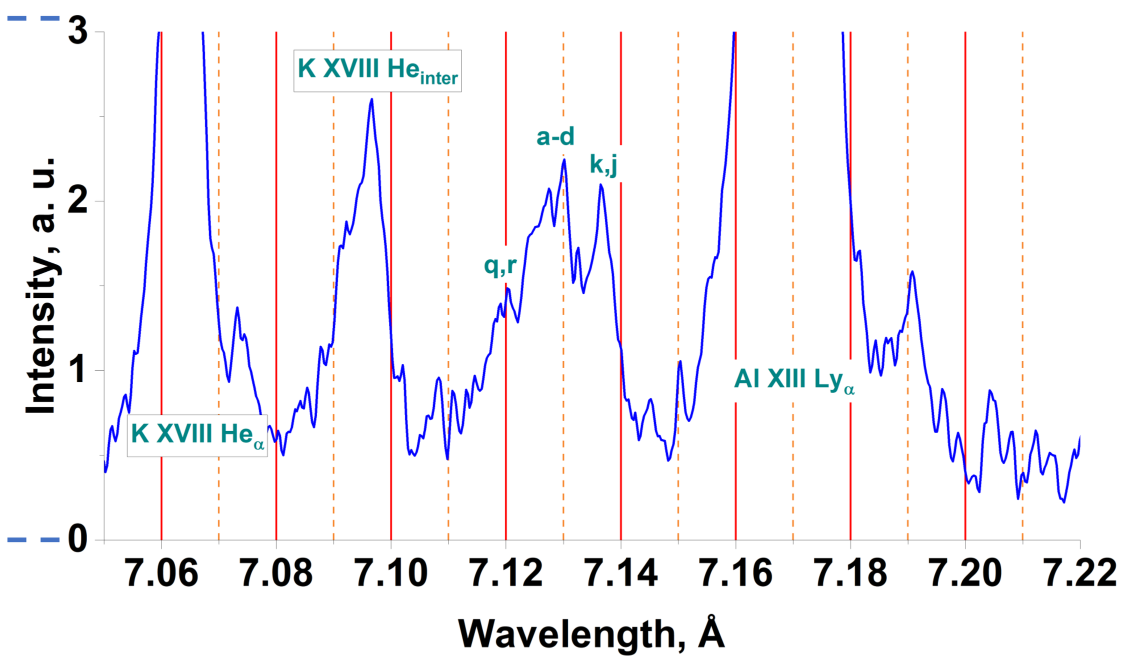
The same scheme of measurements can be implemented for Ca ions lines.

Mineral Anorthite $CaAl_2Si_2O_8$ should be used as a laser target.









4.3. Measured Potassium lines wavelengths

Line label (transition(s))	λ, mÅ	Δλ, mÅ
$K\ He_\beta(1s3p\ ^1P_1 \to 1s^2\ ^1S_0)$	3010.26	0.6
$K\ He_\alpha(1s2p\ ^1P_1 \to 1s^2\ ^1S_0)$	3532.55	0.6
$K\ He_{inter}(1s2p\ ^3P_{2,1} \to 1s^2\ ^1S_0)$	3549.35	0.6
q,r $(1s2p\ [\ ^1P]2s\ \ ^2P \to 1s^22s\ \ ^2S)$	3560.87	0.6
a-d $(1s2p^2\ \ ^2P \to 1s^22p\ \ ^2P)$	3565.06	0.6
k,j $(1s2p^2\ \ ^2D \to 1s^22p\ \ ^2P)$	3569.1	0.6

The reported study was funded by RFBR, project number 19-32-60050