# PHOTOMETRIC AND SPECTROSCOPIC RESEARCH OF SYMBIOTIC SYSTEM AX PERSEI

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# THE GOALS OF OUR RESEARCH

- Photometric research: analysis of historical light curves of AX Persei in $U$, $B$, $V$, $R_C$, and $I_C$ filters: identification of *active* and *quiescent* phases, outbursts, correlation analysis, period analysis and orbital period determination (Mártonfi et al., 2021).

- Spectroscopic research: period analysis of radial velocity curve of AX Persei and orbital period determination.

# SYMBIOTIC STARS

- Members of the group of eruptive variables.

- Cool (G, K or M star – S-type; Mira variable – D-type) and hot (white dwarf, sometimes neutron star) components.

- Open binaries, the mass is transferred from cool to hot component by stellar wind.

- Outbursts – the sign of activity.



The model of symbiotic system.
Source: Merc et al., 2019
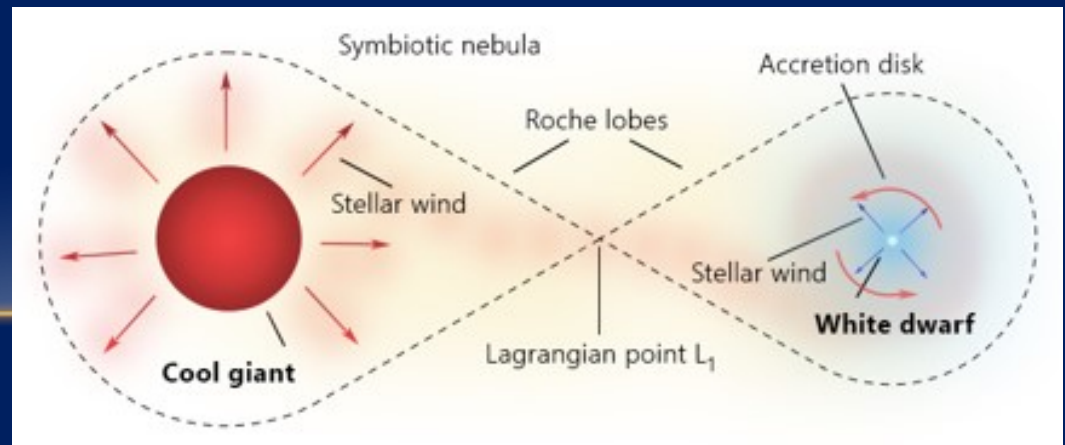
# AX PERSEI

- Symbiotic character discovered by P. W. Merill and L. Humason in 1932.

- Consisting of a M4.5 III giant and a white dwarf.

- Eclipsing binary.
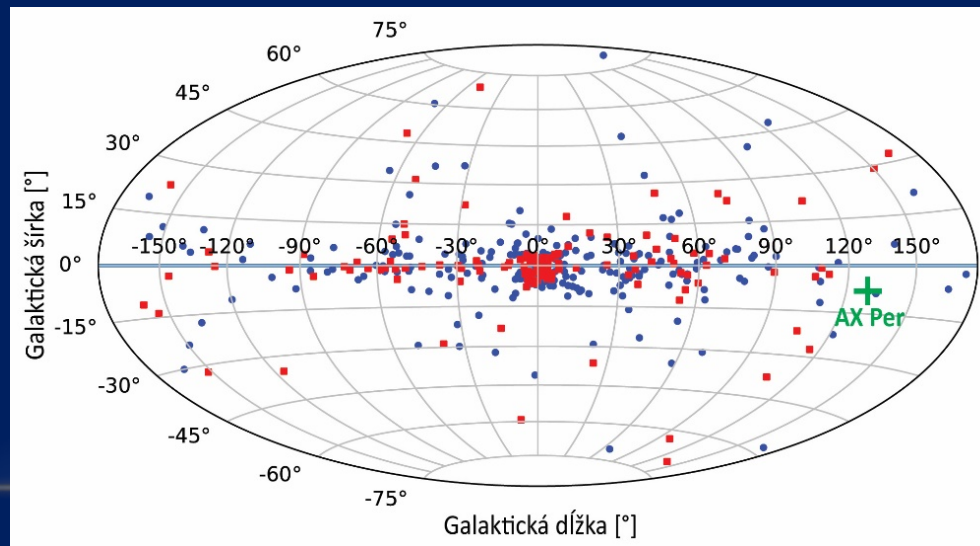


AX Persei – place in our Galaxy.
(Source: Merc et al., 2020)

# PHOTOMETRIC DATA

- Articles (in scientific publications), astronomers' telegrams (Atel, CBET), circulars (IAUC), data from amateur astronomers (AAVSO).

- Data in time interval of 133 years, 22 550 observations.

- Most of magnitudes in $U$, $B$, $V$, $R_C$ and $I_C$ filters (Johnson-Cousin's system).

- Some other types of magnitudes (photographic, $\Delta R_C$, visual,...).

- Conversion to Johnson-Cousin's system.

- False measurements correction.

# RADIAL VELOCITY DATA

- Articles from other authors (in scientific publications).

- Analysis of the AX Persei spectra from *ARAS database*:

  ❖ based on measuring the Doppler shifts of the sodium doublet absorption lines,

  ❖ using the method of the crosscorrelation analysis of the spectra.

# RADIAL VELOCITY VALUES FROM THE LITERATURE

- Absorption lines rising from the atmosphere of cool component.

- 51 radial velocity values together, the interval of 7 530 days.

- Homogenisation of the data was necessary (the problem of spectrograph zero points).

- The data were fitted by the synthetic curve with the equation:

$$v_r(t) = -116 + 10 \sin\left(\frac{2\pi}{680,83} t + 45717,648\right) \ [km \ s^{-1}]$$

# RADIAL VELOCITY VALUES FROM THE LITERATURE

- Some values from Mikołajewska & Kenyon (1992) are derived from the A-type absorption lines.

- These values are in anticorrelation with others and have higher amplitude, too.
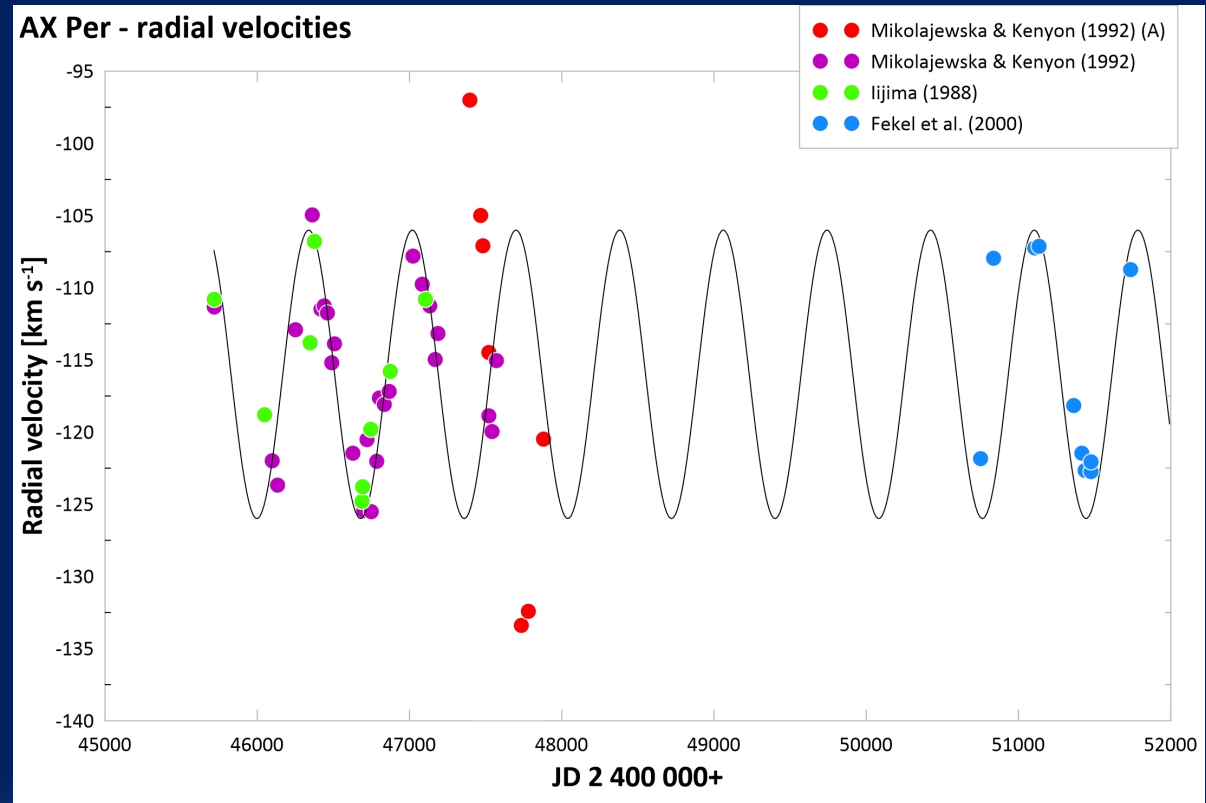


Radial velocity curve constructed by using the values obtained from the literature. The values from different sources are colourfully distinguished.

# MEASURING THE DOPPLER SHIFTS OF THE SODIUM DOUBLET ABSORPTION LINES

- Radial velocity determination based on the Doppler effect.

- Spectra from ARAS database with the resolution higher than 6000.

- Software *PlotSpectra*: visual inspection, processing and analysis of the spectra.

- Measuring the line position by using 3 methods: *center position, flux weighted position, peak position*.

# CROSSCORRELATION ANALYSIS OF AX PERSEI SPECTRA

- Principle: observed and synthetic spectrum are divided to *K* equidistant steps *Δλ.* They are shifted by *j* steps *Δλ* to each other, *j = -K,...,K*. We have to find the shift with the highest Pearson's correlation coefficient $r_j$ (Zverko et al., 2007):

$$r_j = \frac{\sum_{i=1}^{K-j}\left(F_i^{syn}-\overline{F^{syn}}\right)\left(F_{i+j}^{obs}-\overline{F^{obs}}\right)}{\sqrt{\sum_{i=1}^{K-j}\left(F_i^{syn}-\overline{F^{syn}}\right)^2 \sum_{\hat{i}=1}^{K-j}\left(F_{i+j}^{obs}-\overline{F^{obs}}\right)^2}}$$

$F^{syn}$ – radiative flux of synthetic spectrum
$F^{obs}$ – radiative flux of observed spectrum
*j* – number of steps, by which were the spectra shifted to each other

# CROSSCORRELATION ANALYSIS OF AX PERSEI SPECTRA

- Resulting radial velocity value is derived by using the formula for the relativistic Doppler effect.

- Programming language Python.

- Observed spectrum – ARAS, synthetic spectrum – POLLUX (according to well known parameters of cool component).

- Resampling of the spectra, choosing of suitable interval of wavelengths (without emission lines) and suitable step.

- For one radial velocity value – different doppler shift at different wavelengths (necessary to take into account during preparing the algorithm).
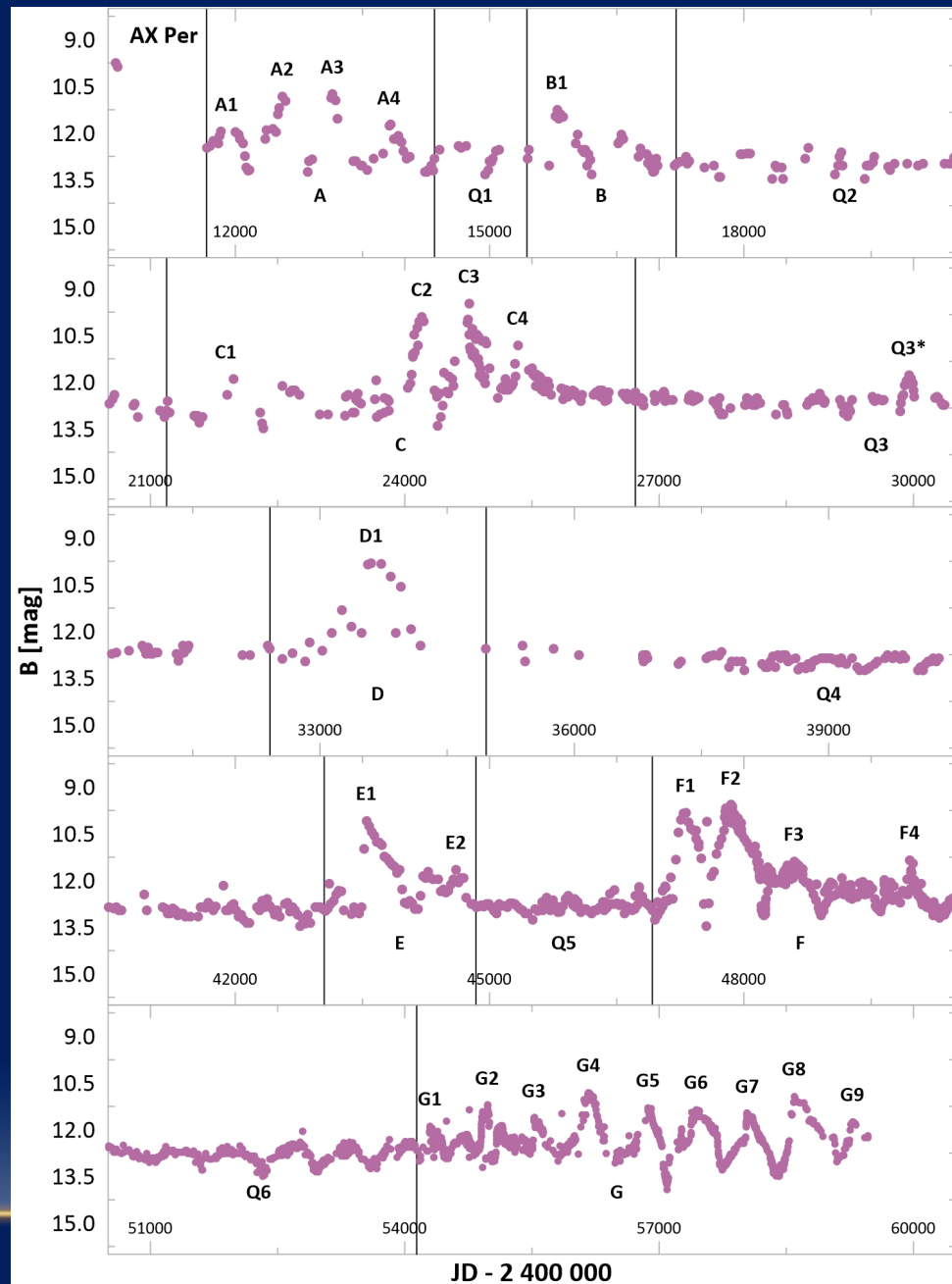
# PERIOD ANALYSIS

- *Peranso* software.

- *Lomb-Scargle* (LS) method, *Phase dispersion minimization* (PDM) method.

- Aliases, spectral window.

# RESULTS OF OUR RESEARCH

## THE HISTORICAL LIGHT CURVE OF AX PERSEI

- The most of magnitude data in *B* filter.

- 7 active, 6 quiescent phases.

- 26 outbursts.

- Our determination of active and quiescent phases is not definitive.



The light curve of AX Persei in *B* filter.

# CORRELATION ANALYSIS OF THE LIGHT CURVES

- *CorrLAB* software, classical and discrete correlation analysis.

- Higher correlation coefficients in *active phases* than in *quiescent one* – smaller variations in quiescent phases and higher influence of measure errors.

- Lower correlation coefficients with the light curves in $R_C$ and $I_C$ filters – different source of variations at longer wavelengths than in shorter ones.

|     | U    | B    | V    | $R_C$ | $I_C$ |
|-----|------|------|------|-------|-------|
| U   | 1.00 | 0.88 | 0.88 | 0.83  | 0.50  |
| B   | 0.88 | 1.00 | 0.94 | 0.86  | 0.61  |
| V   | 0.83 | 0.94 | 1.00 | 0.93  | 0.74  |
| $R_C$ | 0.83 | 0.86 | 0.93 | 1.00  | 0.75  |
| $I_C$ | 0.50 | 0.61 | 0.74 | 0.75  | 1.00  |

Phase G – classical correlation analysis

|     | U    | B    | V    | $R_C$ | $I_C$ |
|-----|------|------|------|-------|-------|
| U   | 1.00 | 0.86 | 0.78 | 0.72  | -     |
| B   | 0.86 | 1.00 | 0.83 | 0.71  | -     |
| V   | 0.78 | 0.86 | 1.00 | 0.70  | -     |
| $R_C$ | 0.72 | 0.71 | 0.70 | 1.00  | -     |
| $I_C$ | -    | -    | -    | -     | -     |

Phase Q6 – classical correlation analysis

# PERIOD ANALYSIS OF THE LIGHT CURVES

- Analysis for complete interval of the light curves and particularly for each phase.

- Orbital period:
  (680.4 ± 4.3) days.

- Harmonic and subharmonic periods and periods related to morphology of analysed interval.

- Periods of unknown origin.
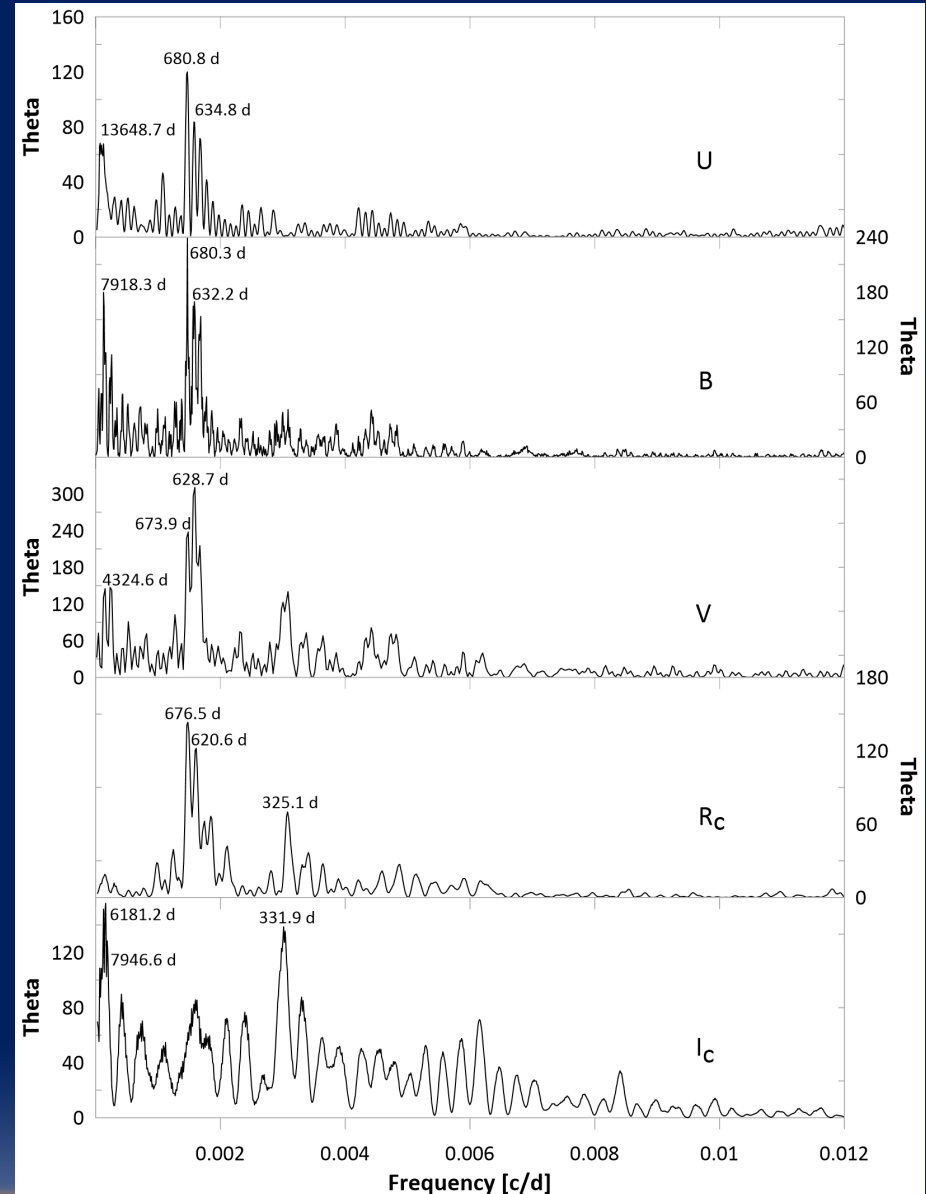


Power spectra of the light curves of AX Persei in different filters.

# CONCLUSIONS – PHOTOMETRY OF AX PERSEI

- Data covering the interval of 133 years, 22 550 observations.

- *7 active* and *6 quiescent phases*, *26 outbursts*.

- Correlation analysis: high correlation coefficients of light curves, different source of variations on different wavelengths.

- Period analysis: *orbital period* (680.4 ± 4.3) days, in the good agreement with previous estimations; the periods of unknown origin.

# RADIAL VELOCITIES DETERMINED FROM ABSORPTION LINES

- Data fitted by synthetic curve.

- Unexpected result: the values are in opposite phase with values from literature and the curve have higher amplitude.

- The spectral lines does not rise in the cool giant's atmosphere – more research about that result is necessary.
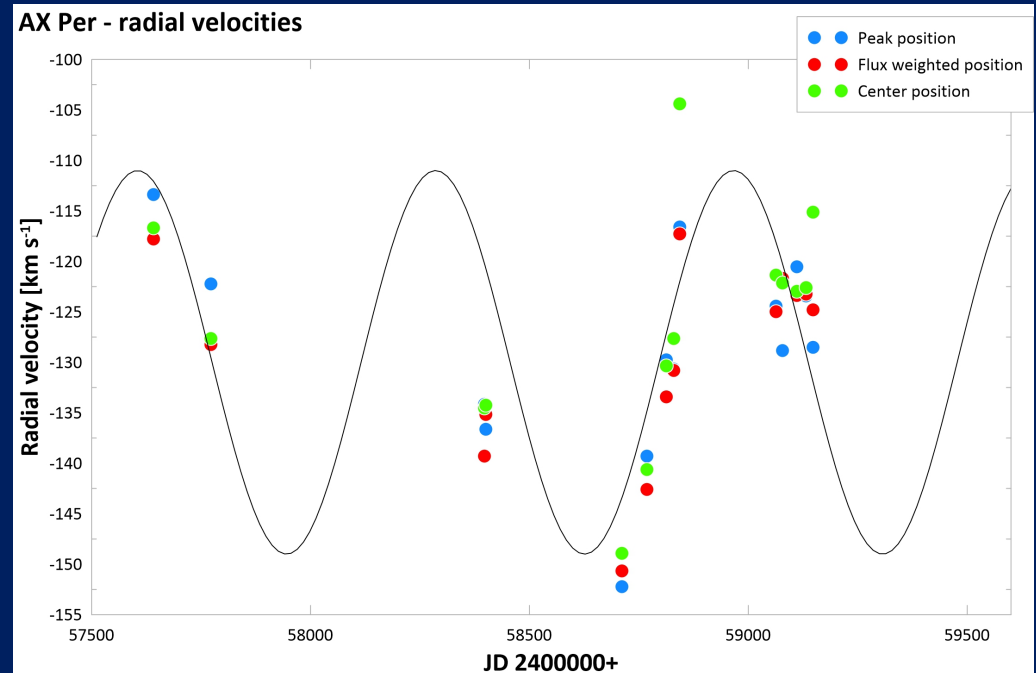


Radial velocity curve containing the values determined from absorption lines of sodium doublet. The values determined by different methods are represented by points with different colours.

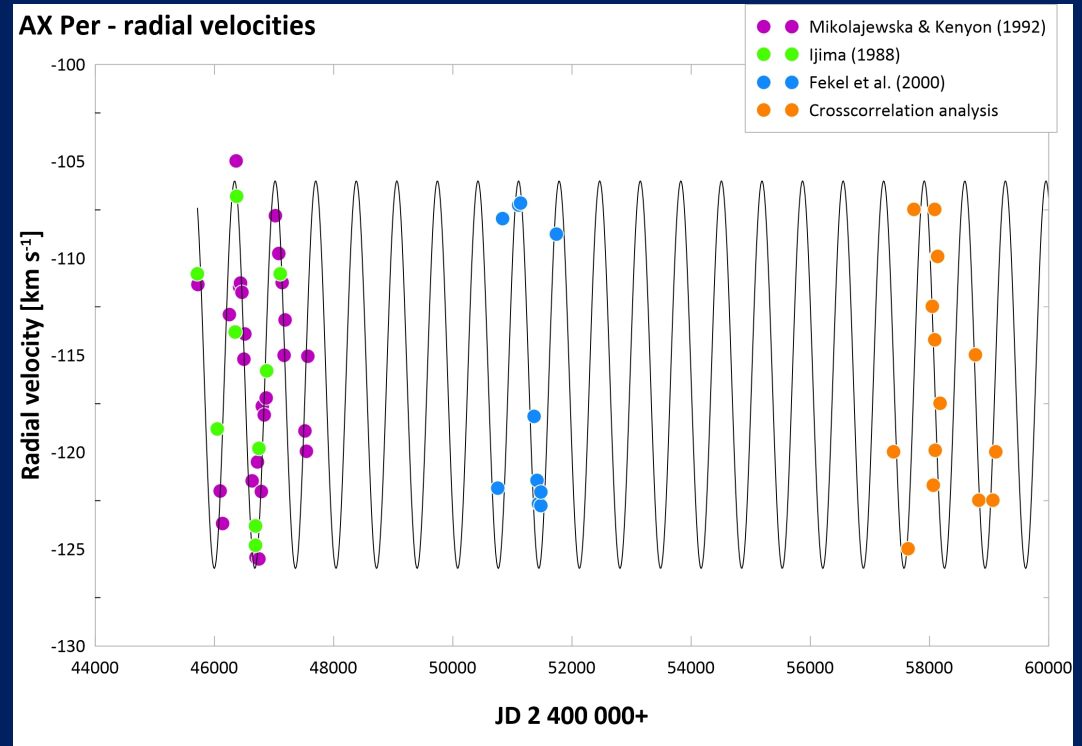# RADIAL VELOCITIES DETERMINED BY CROSSCORRELATION ANALYSIS

- 34 new radial velocity values.

- Data were fitted with the same synthetic curve as the data from the literature and were in good agreement with them.
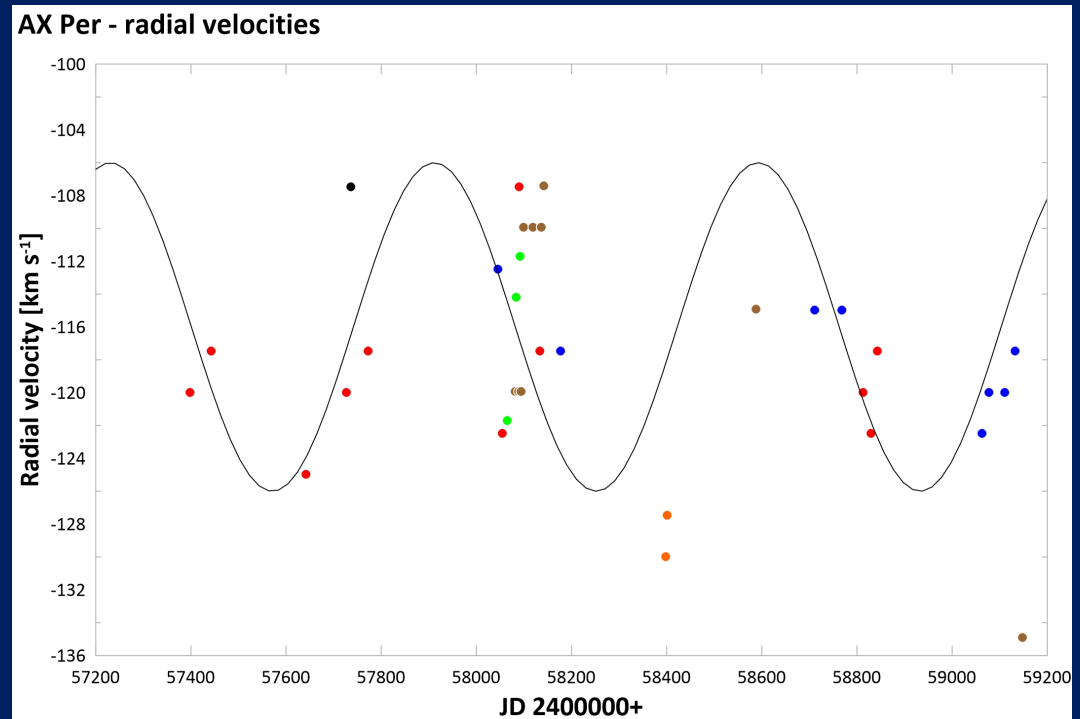


Radial velocity curve containing the values determined by crosscorrelation analysis. Determinations of radial velocity values from the spectra from different observers are colourfully distinguished.

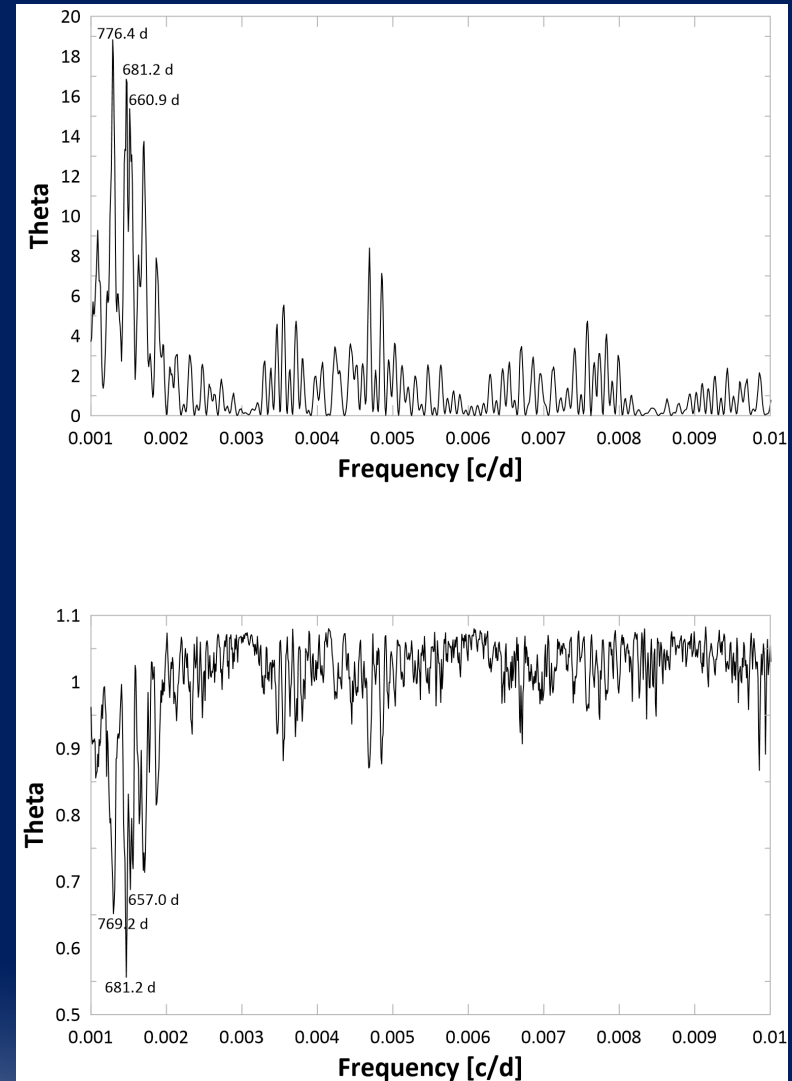# COMPLETE RADIAL VELOCITY CURVE FOR PERIOD ANALYSIS

- The curve contains the values extracted from literature and the values determined by crosscorrelation analysis.

- 75 radial velocity values.

- The values are in good agreement with the synthetic curve fitting the data from the literature.



Radial velocity curve containing the radial velocity values extracted from the literature and the values determined by crosscorrelation analysis.

# PERIOD ANALYSIS OF RADIAL VELOCITY CURVE

- *LS method*: 2 significant periods: 776.4 days and 681.2 days.

- *PDM method*: orbital period (681.2 ± 4.2) days is dominant.

- The period of 776.4 days is also detected by *LS method*. The question of its origin is still open.



The results of period analysis – the power spectrum and the periodogram.

# CONCLUSION – RADIAL VELOCITIES

- Period analysis of totally 75 radial velocity values of AX Persei.

- Data were extracted from literature and determined by crosscorrelation analysis.

- Measuring the position of sodium doublet – unexpected result – more analysis of this data necessary.

- Orbital period: (681.2 ± 4.2) days, in good agreement with the literature.

- The period of unknown origin 776.4 days – we need more analysis to determine this origin.

- **Next research:** analysis of strong emission lines of AX Persei.

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**THANK YOU FOR YOUR ATTENTION**