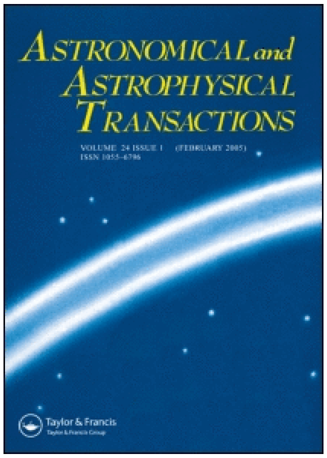

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INTER-LONGITUDE ASTRONOMY PROJECT: SOME RESULTS AND PERSPECTIVES

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The highlights of the recent study of variable stars of different types are discussed. We present some results (out of more than 500 papers) and plans for the further studies within bi- or multi-lateral observational campaigns. Special attention is paid to the polarimetric and photometric monitoring of polars, intermediate polars, superhumpers in dwarf novae and nova-like systems, symbiotic variables, pulsating semi-regular and Mira-type stars and other long-periodic variables, new suspected variables from the Hipparcos–Tycho space observatory and other surveys. To study multi-periodic and aperiodic variability superimposed onto long-term trends, an expert system for time series analysis is briefly referred.

Keywords: Variable stars; cataclysmic stars; AM Her; BY Cam; TT Ari; QQ Vul; pulsating stars; Mira-type stars; semiregular stars; RV Tau

1 INTRODUCTION

The study of short-period variables with complex behaviour requires photometric observations over intervals as long as possible. For this purpose, several networks have been organized with the participation of observatories distributed in longitude. In good conditions, the

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chosen variable star can be observed continuously or with small gaps over several days. The most famous international programmes are the whole Earth telescope (WET), the variable-star net (VSNET) and the Center for Backyard Astrophysics (CBA). The light curves of variable stars as well as monitored brightness estimates are obtained by the members of the associations of variable-star observers in many countries. The international databases of such observations obtained in Europe (Association Francaise des Observateurs d'Etoiles Variables–AFOEV), Japan (VSNET) and USA (American Association of Variable Stars Observers–AAVSO) are available through the Internet. According to the type of data (long runs or monitoring observations), different types of stellar variability have been studied.

In this paper, we present some results (from more than 500 papers) and plans for the studies within bilateral or multilateral observational campaigns.

2 EXPERT SYSTEM FOR ADVANCED TIME SERIES ANALYSIS

The processes taking place in Nature are characterized by the variability of characteristics describing them. The final signal is often a superposition of a few components, the separation of which may be complicated owing to the infinite length of the run, the presence of trends of unknown shape and the possible irregularity of the arguments. It is well known that careless usage of classical mathematical formulae, when the necessary conditions are not justified, may lead to erroneous physical interpretation of the underlying processes. Because of this, dozens of papers, based on elaboration or modification of the analysis, are published annually.

An excellent review of the methods has been presented in the classical monograph by Terebizh (1992). Another monograph on the topic has been recently presented by Andronov (2002). Andronov (1994; 1999a) had described the expert system for the advanced time series analysis with regularly and irregularly spaced arguments. The set of algorithms and programs includes periodogram analysis, using harmonic, multiharmonic or multiperiodic fits with possible prewhitening according to periodic and aperiodic low-frequency trends or with simultaneous determination of the model parameters. For monoperiodic signals with complex shape, fits based on the splines of constant and variable order as well as the set of programmes based on non-parametric methods and the methods based only on characteristic events were developed. For multiple time-scale analysis of signals with arbitrary arguments, a set of algorithms based on the method of running parabolae and the extension of the Morlet-type wavelet was developed. These methods, which have been applied using irregularly spaced arguments, allow one to decrease the statistical noise level by a factor of several dozens. To smooth the signals with a variable period and shape, the following fits are applied: running parabolae, asymptotic parabolae, running sines and self-adapted wavelet smoothing. For multichannel data, the methods are based either on the principal component analysis (non-parametric) method or on channel-dependent parametric fits. The effective colours of periodic and aperiodic components of variability may be statistically estimated even for aperiodic signals of unknown shape, if the shapes (but not the amplitudes) are the same in all channels. For regularly spaced data, the autocorrelation function is being obtained from that biased by an arbitrary trend removal from finite-length data.

3 MULTIDECADE PHOTOMETRIC AND POLARIMETRIC MONITORING OF CATACLYSMIC VARIABLES

The cataclysmic variables exhibit the following types of variability: from seconds to minutes ('red noise'; see Andronov (1999b) for a more detailed description); from minutes to dozens of minutes (periodic variations caused by a rotation of the magnetic white dwarf in intermediate polars or quasiperiodic oscillations in other systems); hours (orbital variability; spin of the magnetic white dwarf in synchronizing polars; negative or positive superhumps in the stars with precessing elliptic discs; slow waves); few days (beat between the variability at orbital and quasiorbital periods); dozens of days (cycles of high- to low-state switches); years and decades (accretion rate variability caused by a magnetic activity of the secondary; swinging dipole in polars; changes in periastron of the third-body orbit).

Contrary to the immediate picture of the system obtained during the short-term campaigns, the variability up to the year and decade scales needs monitoring for an appropriate length of time. The most intensely studied object is AM Her, the photometric monitoring of which was initiated in 1978 by V. P. Tsessevich (1907–1983) in Odessa. Since 1989, this object has been monitored polarimetrically at the 2.6 m Shain and 1.25 m AZT telescopes of the Crimean Astrophysical Observatory. The main results have been briefly summarized by Andronov et al. (2000) and are being prepared for publication in the monograph by N. M. Shakhovskoy, I. L. Andronov and S. V. Kolesnikov entitled Atlas and Catalogue of Photometric and Polarimetric Characteristics of the Magnetic Close Binary System AM Herculis. The highlights are the detection and study of the following: the orientation changes of the magnetic axis of the white dwarf at an approximately 3 year time scale (the theoretical model of the swinging dipole has been introduced by Andronov (1987)); the statistical dependence of the phase light curve on luminosity; variability of the characteristics of the shot noise with phase and luminosity; the statistical dependences of the effective colours of the mean flux, orbital variations and red noise on luminosity; the dependence of the phase curves of polarization on the luminosity. An unprecedented ultraviolet (UV) Cet-type flare of the red dwarf in AM Her has been detected (Shakhovskoy et al., 1993). From coordinated Crimean and International Ultraviolet Explorer (IUE) observations, the two-component character of the UV emission has been shown to originate in the unperturbed atmosphere of the white dwarf and in the hotter polar cap at the base of the column. The results of the recent campaign of the simultaneous optical and X-ray Chandra observations are in preparation.

The magnetic cataclysmic variable BY Cam shows a complicated photometric and polarimetric behaviour. To study this, the Noah project had been organized to obtain at least 40 nights of photometric observations. The polarimetric period corresponds to the spin of the magnetized white dwarf, whereas the photometric wave may be characterized by the spin period with occasional phase jumps due to the accretion switches from one magnetic pole to another of the white dwarf (Mason et al., 1998). The rotational period of the white dwarf with respect to the secondary is about 14 days. As the magnetic axis is not highly inclined to the orbital plane, both poles seems to be equal to the observer from the viewpoint of the formation of the accretion column. The switches occur about every 7 days (Silber et al., 1997). The rotation of the white dwarf synchronizes with the orbital motion on a characteristic time scale of about 200 years, in excellent agreement with a theoretical estimate (Andronov, 1987). Another system showing synchronization is V1500 Cyg (Pavlenko and Malanushenko, 1995). This object has been monitored at the Crimean Astrophysical Observatory since its nova outburst in 1975.

4 SEASONAL CAMPAIGNS OF OBSERVATIONS OF CATACLYSMIC VARIABLES

Contrary to the long-term monitoring of one or few stars, which may be carried out at one telescope in one photometric system, the seasonal observational campaigns of chosen variable(s) are organized in the framework of multilateral cooperation. The members of our project had organized few such campaigns. The most prolonged sequence of observations has been obtained by various groups for the bright nova-like variable TT Ari, for which at least few light curves per year are available since 1965. The most intense campaigns were accomplished in 1986 (Tremko et al., 1996) and 1994 (Andronov et al., 1999). At that time, the system was in its high-activity state and exhibited so-called negative superhumps with an approximately 3 h period, 15–25 min quasiperiodic oscillations (QPOs) and red noise. The colours of different components of the emission correspond to a temperature increase from the mean flux through the superhump variability towards the QPOs. Such behaviour may be explained on the assumption that the QPOs arise in the hotter inner parts of the accretion disc. In 1997, the system underwent a switch to the positive superhump state. Now, it is important to monitor the star to check the time and details of the next reverse switch to negative superhumps. Other nova-like variables, which have been observed during such seasonal campaigns, are BZ Cam, showing a dependence of the photometric period on luminosity (Andronov et al., 2000b), V603 Aql, V795 Her, PX And, BH Lyn, DW UMa, EM Cyg and V1315 Aql. The results are in preparation.

5 'ALERT' CAMPAIGNS OF OBSERVATIONS OF CATACLYSMIC VARIABLES

This type of campaign is close to the seasonal campaigns, but they are initiated by the detection of some rare event such as dwarf nova superoutburst. We acknowledge the excellent service of email alerts provided by the VSNET.

The most intensively studied object is WZ Sge. In 2001, it underwent an unexpected superoutburst 23 years after the previous outburst, despite three earlier intervals equal to 33 years. An unprecedented coverage during 3 months with almost no gaps took place by the members of VSNET, CBA, AAVSO, our group and other observers. Our results showed the excitation of the true superhumps a day after the top of the outburst (Andronov et al., 2001) and 24 days before they dominate the orbital variability (Ishioka et al., 2002).

The superhumps of the star V368 Peg had a variable period. Ostrova et al. (2001) had suggested a superhump period – luminosity dependence rather than the simple frequency doubling expected, when the hot spot disappears leaving the elliptic accretion disc. Other examples of the variations in the superhump parameters have been listed by Kuznetsova et al. (1999).

6 MONITORED PHOTOMETRIC OBSERVATIONS: NEW RESULTS FROM THE OLD PLATES AND ESTIMATES

Long-term variability of the objects needs monitored observations over decades. We have made photographic brightness estimates of dozens of cataclysmic, symbiotic and long-periodic pulsating variables using the extensive plate collections in Odessa, Sonneberg, Moscow and Asiago. The international databases published by the AFOEV and Variable Star Observers League of Japan (VSOLJ) have been used for the time series analysis of the individual characteristics of pulsational cycles of 173 semiregular variables (Chinarova and Andronov, 2000), 58 Mira-type stars (Marsakova and Andronov, 1998, 2000), 36 RV Tau-type stars (in preparation). The interrelations between the mean characteristics of 62 Mira-type stars have been studied (Kudashkina and Andronov, 1996). The UBVRI polarimetric monitoring of three Mira-type stars has been presented by Efimov and

Kudashkina (2001). The multicomponent variability of symbiotic binaries has been studied in a series of papers (see Chochol et al. (1999), Chinarova (1998) and references therein). These data are used for reclassification of long-period variables into groups according to the number and stability of the variability components.

The monitored observations allowed us to study the solar-type activity in the close binary systems, the brightness variations of old nova and nova-like variables and the year-scale variations of the outburst cycle length in dwarf novae. Andronov and Chinarova (2002) introduced an additional mechanism of the modulation of the accretion rate in cataclysmic variables, caused by the variations in the orbital separation between the components due to the presence of the third body.

7 HUNTING THE NEW VARIABLES FROM ALL-SKY WIDE-FIELD SPACE AND GROUND-BASED SURVEYS

Because of the huge number of stars observed during such surveys, hundreds of new stars are suspected variables. From the Hipparchos-Tycho mission, 783 such new objects have been selected and tested. The programme for periodogram analysis have been extended to weighted two-colour observations, the main method being the third-order trigonometric polynomial fit. However, for stars with abrupt phase curves, a class of variable-order splines have been introduced, separately for eclipsing binary systems (EA catcher) and pulsating variables with highly asymmetric phase curves (RR catcher). The preliminary results of automatic classification have been presented by Andronov et al. (2000a).

8 PLANS AND PERSPECTIVES

The following are planned:

(i) polarimetric and photometric monitoring of magnetic cataclysmic variables at different stages of the influence of the magnetic field on accretion: classical polars (AM Her, QQ Vul, MR Ser); synchronizing polars (BY Cam, V1500 Cyg); intermediate polars (V405 Aur);

(ii) multicolour monitoring of nova-like cataclysmic variables with complicated behaviour (TT Ari, MV Lyr, BZ Cam, V603 Aql, V795 Her, BH Lyn, DW UMa and PX And);

(iii) monitoring of dwarf novae during outbursts and especially superoutbursts for study of the evolution of the superhump characteristics with luminosity;

(iv) time series analysis of the stars suspected to show variability as a result of sky surveys from space and ground-based observatories; charge-coupled device, photographic and visual observations of selected objects;

(v) time series analysis of extensive databases of observations of astronomical objects using the expert system of methods already developed;

(vi) development of new algorithms and programmes for the advanced analysis of the multicomponent processes of any nature.

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