GENETIC ALGORITM ECLIPSE MAPPING

A.V. Halevin

Department of Astronomy, Odessa National University
T.G.Shevchenko Park, Odessa 65014 Ukraine, *halevin@odessa-astronomy.org*

ABSTRACT. In this paper we analyse capabilities of eclipse mapping technique, based on genetic algorithm optimization. To model of accretion disk we used the "fire-flies" conception. This model allows us to reconstruct the distribution of radiating medium in the disk using less number of free parameters than in other methods. Test models show that we can achieve good approximation without optimizing techniques.

Key words: methods: numerical - stars: novae, cataclysmic variables - accretion, accretion disks

1. Introduction

Eclipse mapping (EM) techniques are used for reconstruction of accretion disks structure in cataclysmic variables. Eclipse mapping was developed by Horne (1985). One of the most important possibilities of EM is reconstruction of the radial temperature distribution inside accretion disk. It allows to test the different accretion disk models. EM has now many modifications, such as flickering mapping (Bortoletto & Baptista 2004), 3D eclipse mapping (Rutten 1998), stream eclipse mapping with "fire-flies" (Hakala 2002), genetic algorithm EM (Bobinger 1999) and Physical Parameters Mapping by Vrielmann (1997).

In this paper we propose extension of the EM with fire-flies for reconstruction of radiating medium in the systems with flat and optically thin accretion disks.

2. The fire-flies conception and the algorithm.

The idea of fire-flies mapping was developed by Hakala (2002) to reconstruct the structure of accretion flows in eclipsing polars. In this method radiation is modeled by a set of points with angle-dependent emission. Using genetic algorithm techniques it is possible to evolve of fire-flies spatial distribution to fit eclipse light curve by summing the brightness of the fire-flies visible at each phase. The distribution of fire-flies gives us an emission volume. The mostly luminous parts of accretion stream are visible as a larger number of fire-flies placed in a smaller volume.

To model of accretion disk we used the fire-flies with isotropic emission, which reduce the number of variables, associated with single fire-fly to only two plane coordinates. So, in the frame of this conception, we can calculate of emission of accretion disk with formula

$$F_{disk} = \frac{F_0}{n_p} \sum_{j=1}^{n_p} E(\phi), \qquad (1)$$

Here F_0 is uncovered total accretion disk flux, n_p is a number of fire-flies, $E(\phi)$ is an eclipse function, which equal to 0 if fire-fly is eclipsed and equal to 1 if fire-fly is visible (Fig.1).

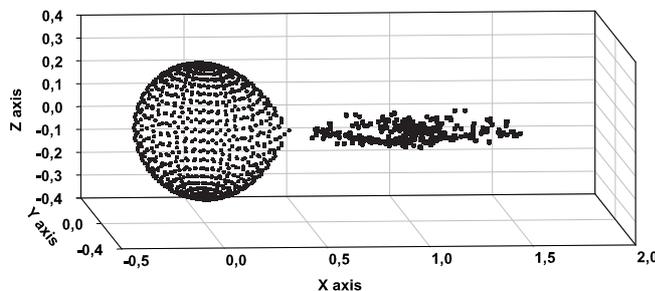As a fitting-function we used χ^2 model parameter with some extension:
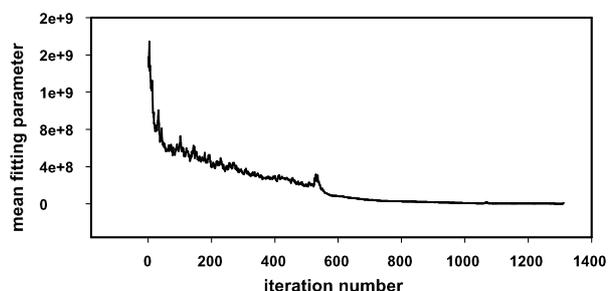

Figure 1: Model scheme.

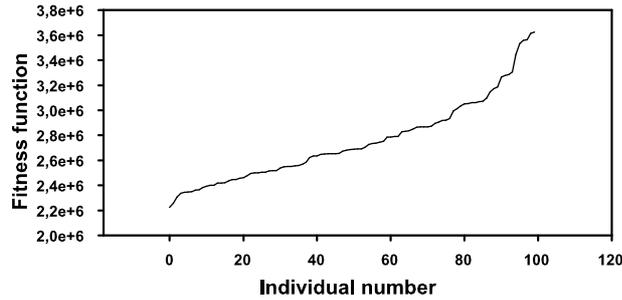Figure 2: Mean fitting parameter evolution.

Figure 3: Distribution of individuals in offspring by the fitting parameter.
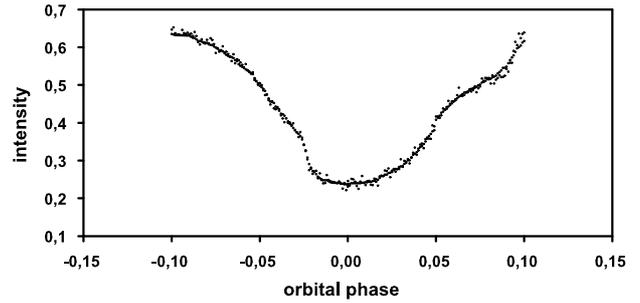

Figure 5: Artificial light curve and fit for hot spot model.
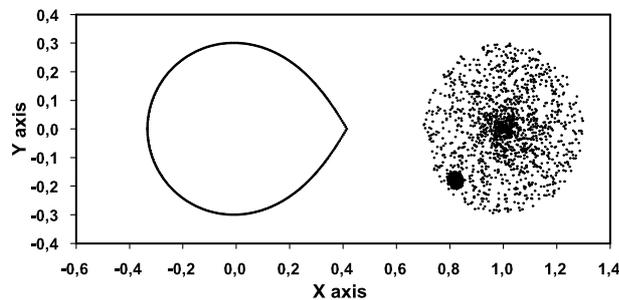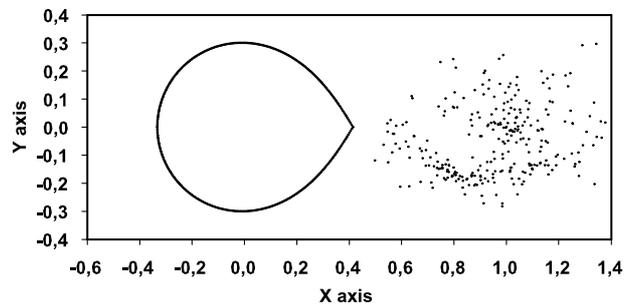

Figure 4: Initial model of accretion disk with hot spot.

Figure 6: Distribution of fire-flies for hot spot model.

$$f_i = \frac{1}{\chi_i^2 + \lambda e_i} \qquad (2)$$

where e_i is an entropy parameter, which we calculate as a mean value of first 100 minimal distances between pairs of particles. λ is some constant which controls the importance of the smoothness for the quality determination.

As a fitting algorithm we have used a Genetic algorithm (Charbonneau 1995) with 100 genes, crossover operations and variable mutation rate. Also we used such additional modes as conservation of the fittest individuals (so-called elitism) and catastrophic and Black Sheep regimes (Bobinger 2000). It takes about $1000 \div 2000$ generations to achieve a good result (Fig.2). During calculations we control the fitting distribution of different individuals (Fig.3), to avoid degeneracy in the offspring.

As a free parameters in our models are used the total disk flux F_0, constant non-eclipsed component and $n \times 2$ parameters of fire-flies coordinates. As usually, in our models we have used $n = 300 \div 400$ to achieve reasonable computational time. Each unknown variable has 6-digits precision. Initial population is generated as a set of points, randomly distributed inside Roche

lobe of the compact star. Actually, we have two heterogeneous sets of parameters: main constants which describe system luminosity and coordinates of the points. To achieve a faster convergence, during first iterations we used increased mutation rate for the first set of parameters.

3. Test models

To test of our method we have made several artificial configurations of accretion disks. The most typical situation for low luminosity states is the presence of three main radiation sources: the accretion disk, hot spot where accretion stream couples with disk and filled its Roche lobe secondary star (Fig.4). In the Fig.5 one can see resulted light curve with added noise and the best fit (Fig.6) represents eclipse map, which have found with eclipse mapping method. One can see that main radiation sources are traced very well. Distortions of the image are typical for eclipse mapping techniques (see Horne 1985). So this method allows resolve compact sources in accretion disk.

Several cataclysmic variables show significant asymmetry of their disks which arise due to tidal effects.
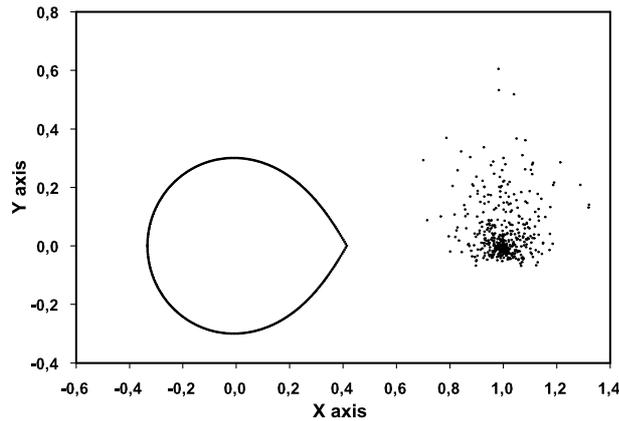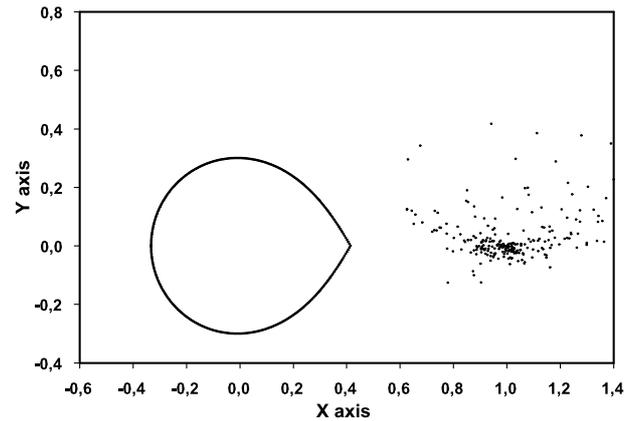
Figure 7: Model of elliptical accretion disk.

Figure 9: Reconstructed fire-flies distribution for elliptical accretion disk model.
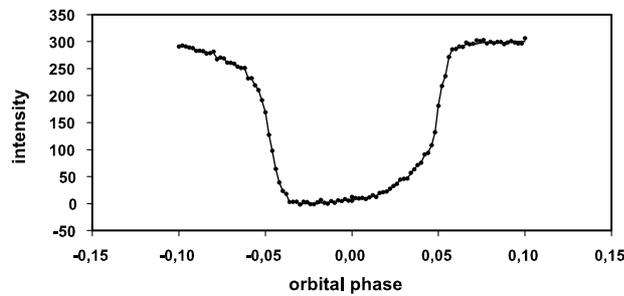

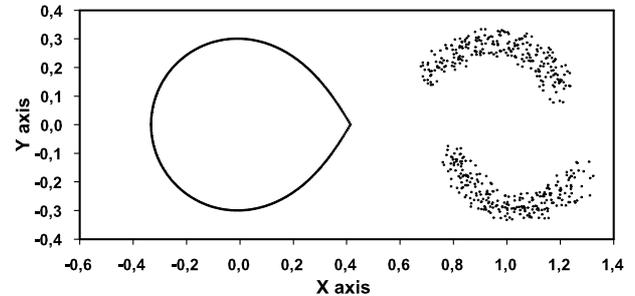Figure 8: Artificial light curve and fit for elliptical accretion disk model.

Figure 10: Model of spiral arms structure in accretion disk.

This feature is shown as so called superhumps on light curves. To test such situation we modeled elliptical accretion disk with radiation concentrated near white dwarf (Fig.7). Eclipsing profile and model fit for such configuration one can see in the Fig.8. Resulted distribution of fire-flies in the Fig.9 shows very close to initial distribution picture. There is also some distortion along x-axis.

Sometimes in accretion disk we can observe spiral arms, which are also product of tidal forces. This feature is traced only by emission lines. We tried to test reconstruction of such configuration using our modification of eclipse mapping. Light curve with fit and initial emission distribution are in Fig.10 and Fig.11. Fig.12 shows that we can determine the presence of this feature.

4. Discussion

Here we see that the fire-flies based eclipse mapping allows reconstruct of accretion disk structure with some x-axis distortions, which are typical for this class of methods. It is interesting that we do not used any regularization techniques to achieve appropriate result. We must say that our method has good convergence because several consecutive calculations for the same light curve gave the same results. The only one important restriction for such approach is demand to accretion disk to be optically thin. Significant opacity in accretion disk is observed as non-eclipse mid-time scale variability because short time scale variability, so called flickering, is the consequence of unstable processes in active regions of accretion disk. Previous investigators in their works used de-trending of eclipsing part of light curve to avoid an influence of covering effects in the disk. So, we can reconstruct only visible directly before and after the eclipse parts of accretion disk. It is obvious that we can see source which are mainly close to the secondary star due to opacity effect.

So the most adequate model could be the combination of radiating fire-flies with some opaque medium.
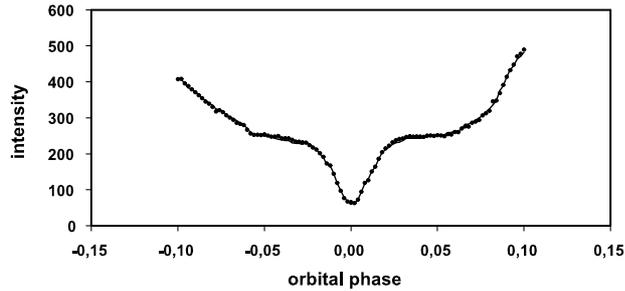
Figure 11: Artificial light curve and fit for model of spiral arms in accretion disk.
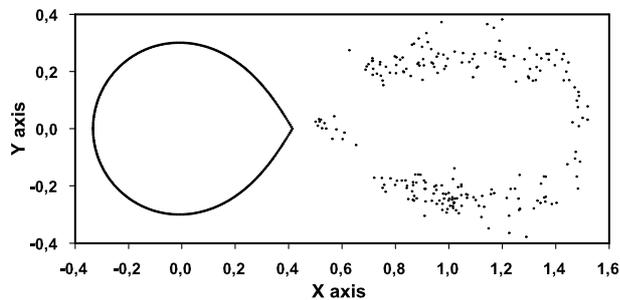

Figure 12: Reconstruction of spiral arms in accretion disk.

The main problem is how we must model of this opaque medium. If we use it distribution as a free parameter the model will be poorly conditioned. If we use some predetermined configuration of an opaque medium it dramatically simplifies the model. In our next papers we are going to use some models for opaque medium to fit also non-eclipsing parts of light curves.

5. Conclusions

Using several artificial configurations typical for accretion disks of cataclysmic variables we tested fire-flies conception based eclipse mapping technique. Our results show that we can use it successfully to reconstruct of radiating medium distribution in optically thin flat accretion disks.

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