Visualization of Gravitational Lenses

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INTRODUCTION

Gravitational Lens phenomena are presently playing an important role in astrophysics. These lenses deflects the light rays coming from distant objects and allow the origination of multiple images of the same source object. This effect opens the possibility of determining not only the parameters of the lens (mass) but also the computation of Hubble's constant provided that the time delay of a pair of images is known. Using C, Xforms, Mesa (free version of Open GL) and Imlib a computer program to visualize this phenomenon has been developed. This program has been applied to generate sequences of images of a source object and its corresponding images. It has also been used to visually test different models of gravitational lenses.

THE VISUALIZATION PROGRAM

Description of the program

The program was written in C and the *Mesa graphic libraries* (free version of the Open GL) have been used. These graphic subroutines are available for Unix and Linux systems. The *XForms Library* was used to design the control panel program (see fig. 1). The *Image Library* permits to load an image file on the program. These libraries can be found at the following addresses:
`http://world.std.com/~xforms/ftp/ftp.html`
`http://www.mesa3d.org/`
`ftp://ftp.enlightenment.org/pub/enlightenment/imlib/`
The program creates a window: the *Control Panel* (see fig. 1). The user is able to control all items on it just by clicking. A second window, the *Image window*, appears when the Image Window button is clicked on this panel (see fig. 1). On this window the events (images, ray plot, etc.) are displayed. All variations of

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the parameters on the control panel are shown on-line on this window. The Help button on the panel gives the user a concise program guide.
A version of this program employing the SGI *Graphic Libraries* and the *Forms Library* is also available. The author prepared websites for downloading this program:
`http://lia.efis.ucr.ac.cr/~frutos/`
`http://www.tat.physik.uni-tuebingen.de/~frutto/`

APPLICATIONS

From both the didactical and scientific point of view a program to visualize the gravitational lenses is useful. This versatile program works quickly and interactively with the mouse. With this computer program the user has a tool to visualize and to visually model gravitational lenses. Two of many applications of the program are:
- *Sequences of images*
- *Easy visual modeling*

The user can produce sequences of images for a chosen gravitational lens model (see fig. 2). Through the variation of model parameters he or she can investigate the structure of the images. The user can also attempt to visually model observed gravitational lenses. The observed position data can be input and the model parameters can be easily varied in order to approximate the observed images (see fig. 3). So the user can quickly obtain model parameter estimations. Some observed lenses have already been modeled and the user can compare those results with the output from a chosen model of the control panel.

FUTURE WORK

The program can be improved by the inclusion of some additional subroutines:
- *Contour subroutine for the isochrones (time delay)*
- *Light curves subroutine (dependence of brightness with time)*
- *Subroutine for computing the image magnification*
- *Subroutine to calculate critical curves and caustics*
- *Fitting subroutine*
- *Root finder subroutine*
- *Subroutine to load images of observed gravitational lenses*
- *Subroutine with more complex (elliptical) models*
- *Subroutine for superposition of models in different lens planes*
- *Subroutine with cosmic string lens models*
- *Subroutine for non-parametric reconstruction*
- *Kaiser-Squires Subroutine*

The author is actually working on the implementation of some of the abovementioned improvements.

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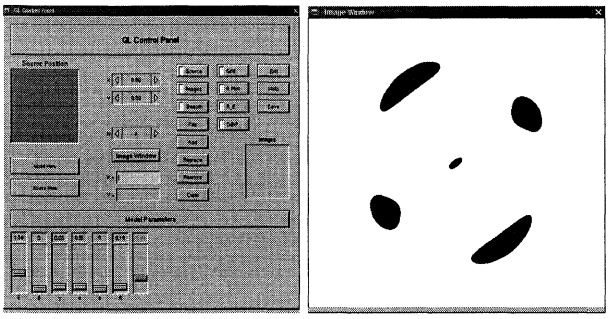

FIGURE 1. Control Panel and Image Window

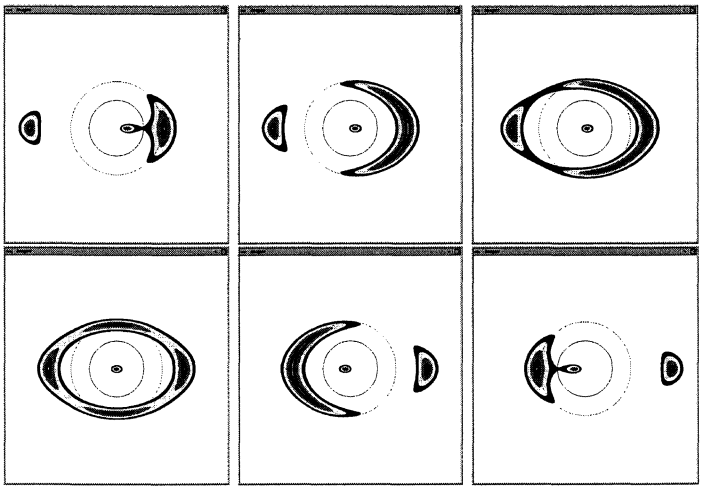

FIGURE 2. An elliptical lens

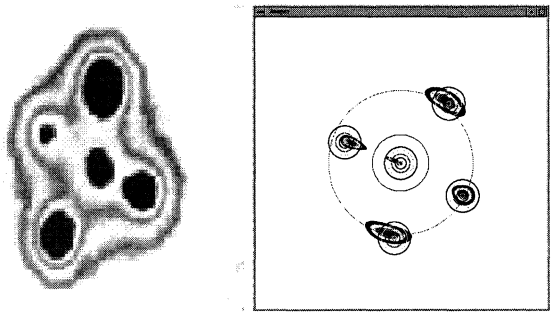

FIGURE 3. Gravitational lens $2237 + 0305$

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