Gravitational Microlensing: Ray Traces and Light Curves

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Physics Senior Seminar

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Outline

- General Relativity Background
- Back to Microlensing Basics

- My Project
  - Goals
  - Geometry of my System
- Single Lens
- Binary Lens

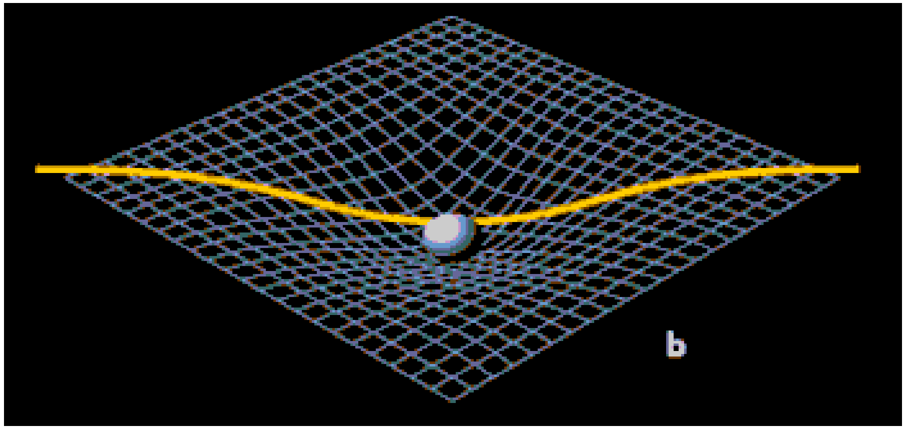
- Conclusions

Background

General Relativity Background

- Developed by Einstein between 1907 and 1915
  - Explains how gravity “warps” space and time

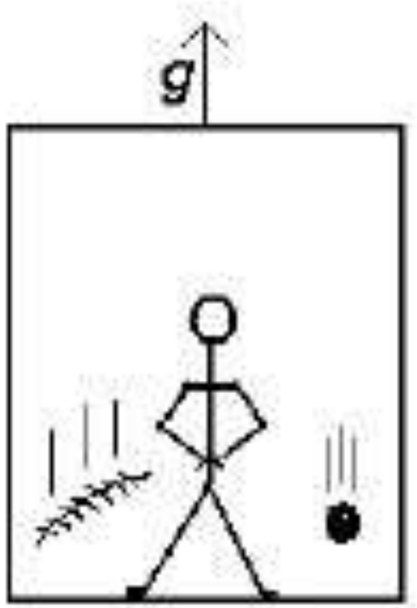
- Equivalence principle
  - It is impossible to distinguish between the effects on an object in an accelerating reference frame and the effects on an object in a gravitational field

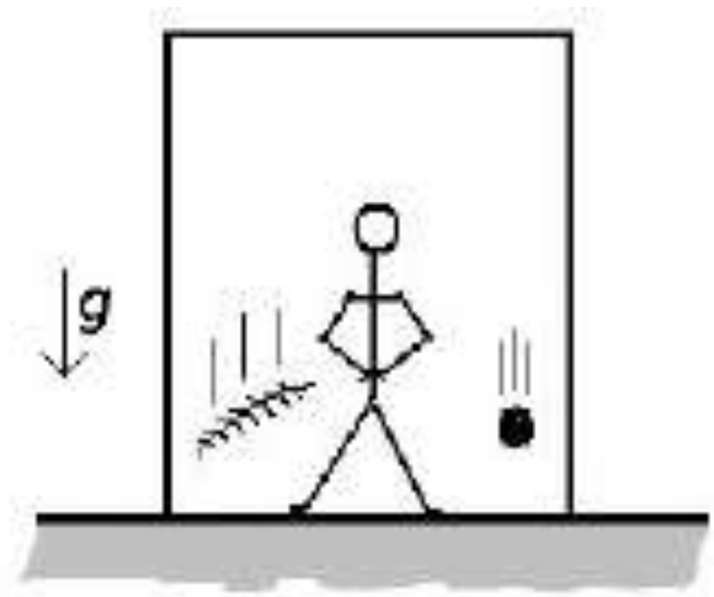


Elevator Thought Experiment

Accelerating Elevator in Zero Gravity

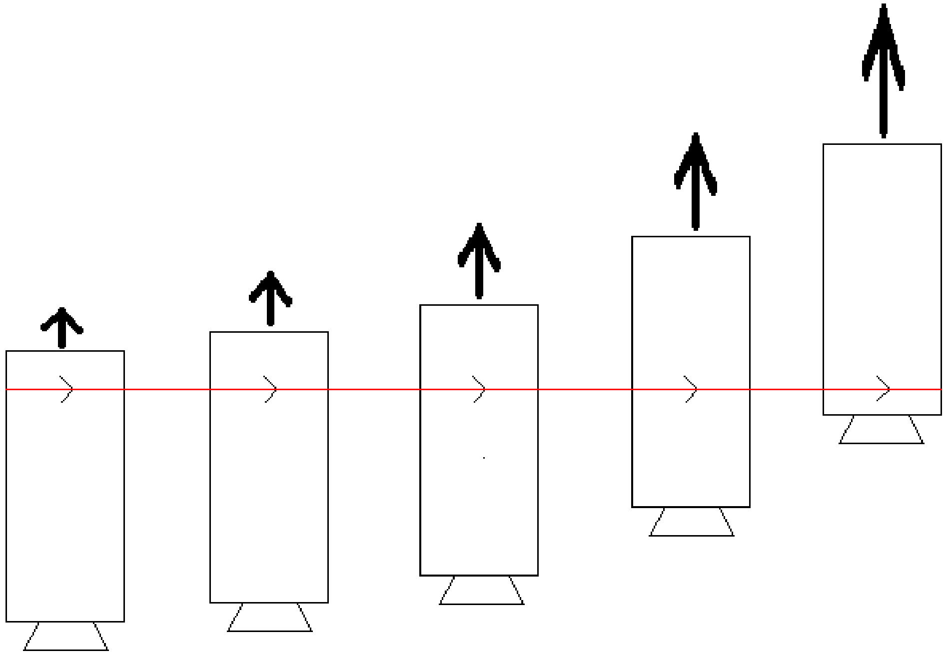
Stationary Elevator in Gravitational Field





Images from "General Relativity"
http://arc-geniuses.blogspot.com/2010/08/general-relativity-genius-of-einstein.html

Elevator Thought Experiment

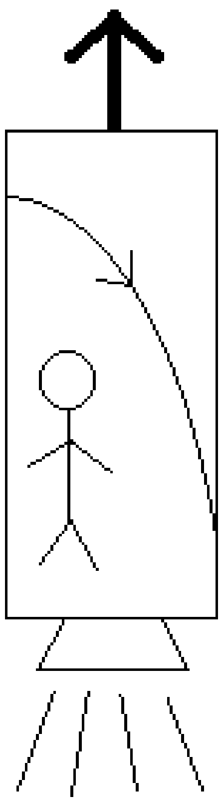


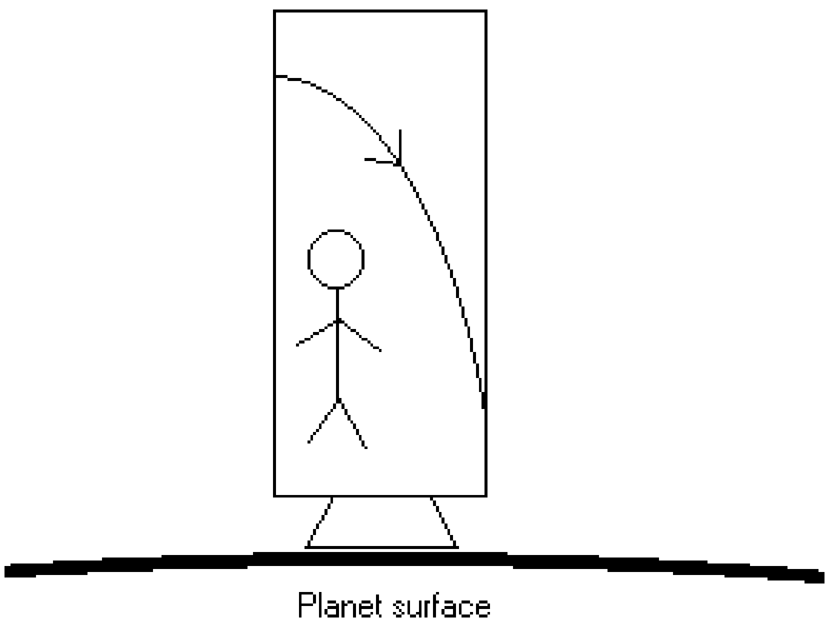
In an inertial reference frame, light travels in a straight path. But to a person inside of the accelerating elevator, the light will appear to bend towards the floor as it moves across the elevator

Images from "General Relativity"
http://www.zamandayolculuk.com/cetinbal/htmldosya1/RVgeneral.htm

Elevator Thought Experiment

Accelerating Elevator in Zero Gravity	Stationary Elevator in Gravitational Field





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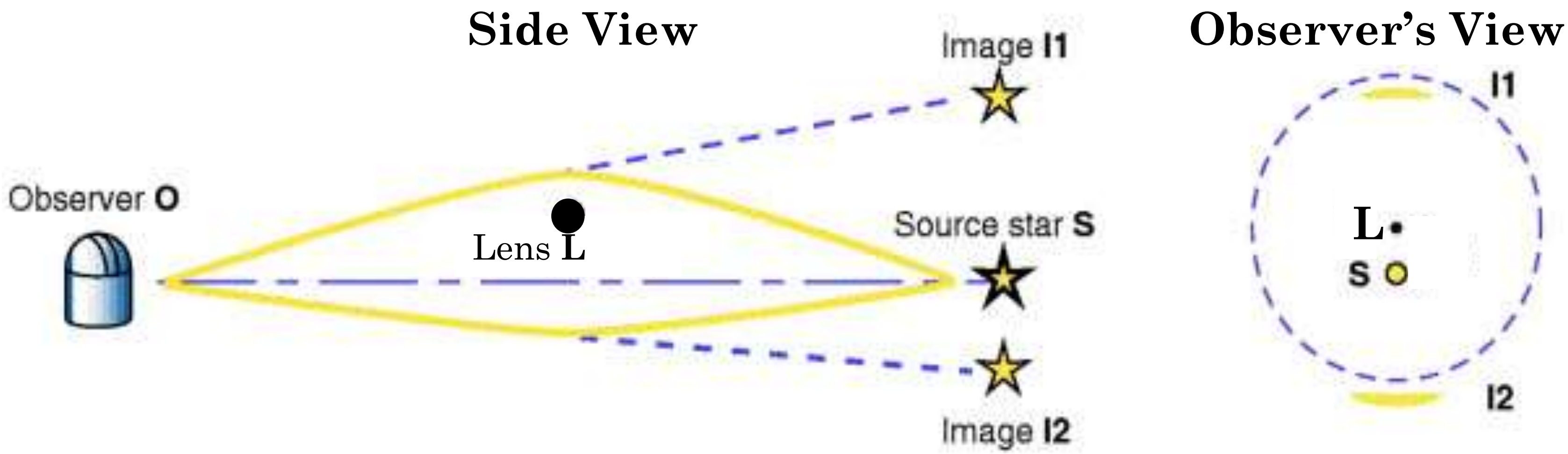
Gravitational Microlensing Basics



A microlensing event is caused by a single object moving between the source object and the observer

Gravitational Microlensing Basics

- The deflection angle for light passing by a mass is given by

$$\alpha = \frac{4GM}{c^2 r}$$

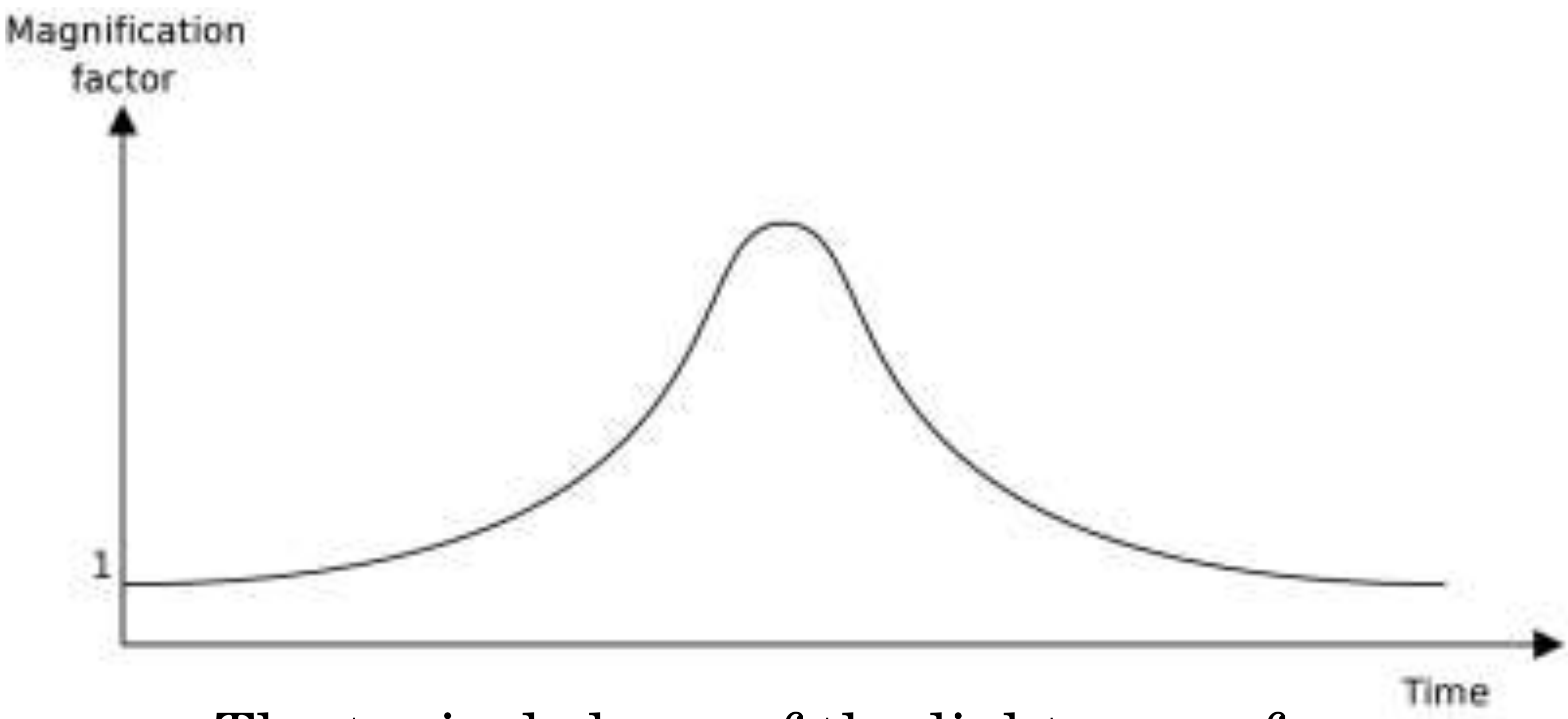
$G = 6.67 \cdot 10^{-11}\ m^3/kg \cdot s^2$

M = mass of star

$c = 3 \cdot 10^8\ m/s$

r = impact parameter

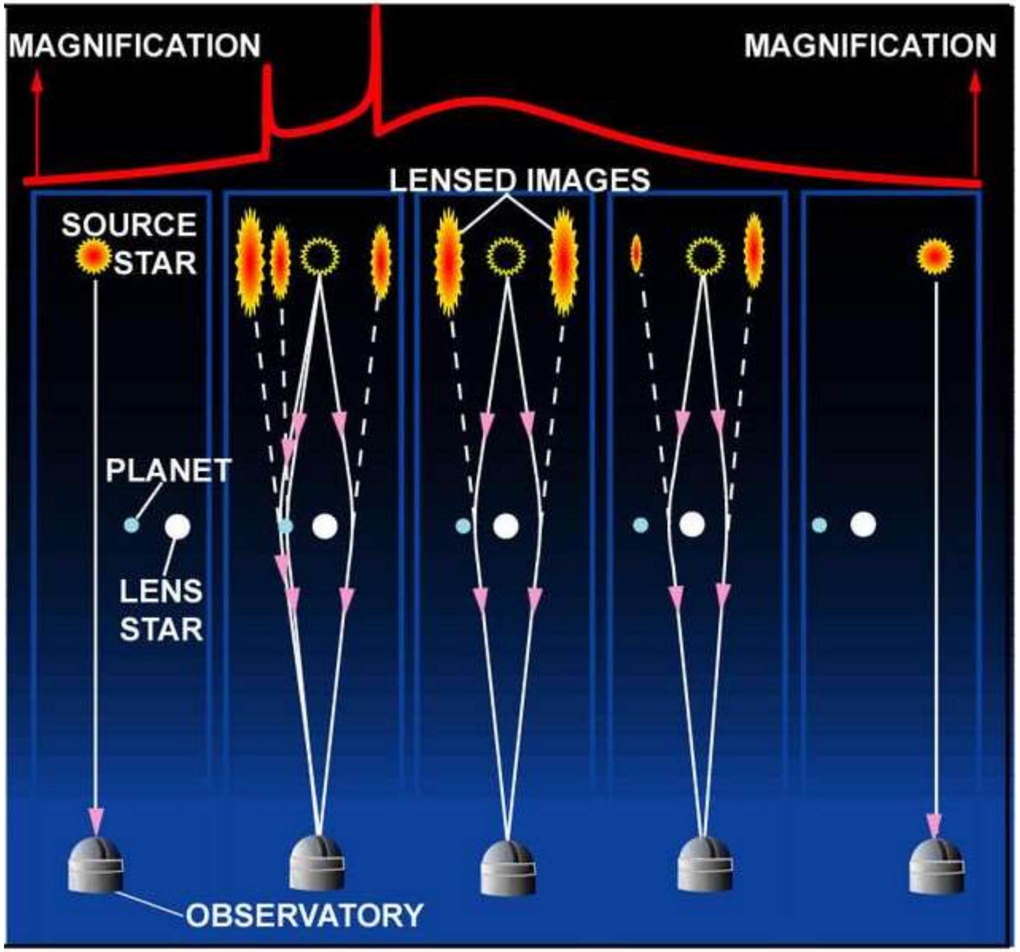
Gravitational Microlensing Basics



The typical shape of the light curve for a microlensing event

Image from "Gravitational Lens"
http://en.citizendium.org/wiki/Gravitational_lens

Gravitational Microlensing Basics



The light curve of a microlensing event when a planet is part of the lens

Image from "Planetary Microlensing"
http://www3.nd.edu/~bennett/moa53-ogle235/

My Project

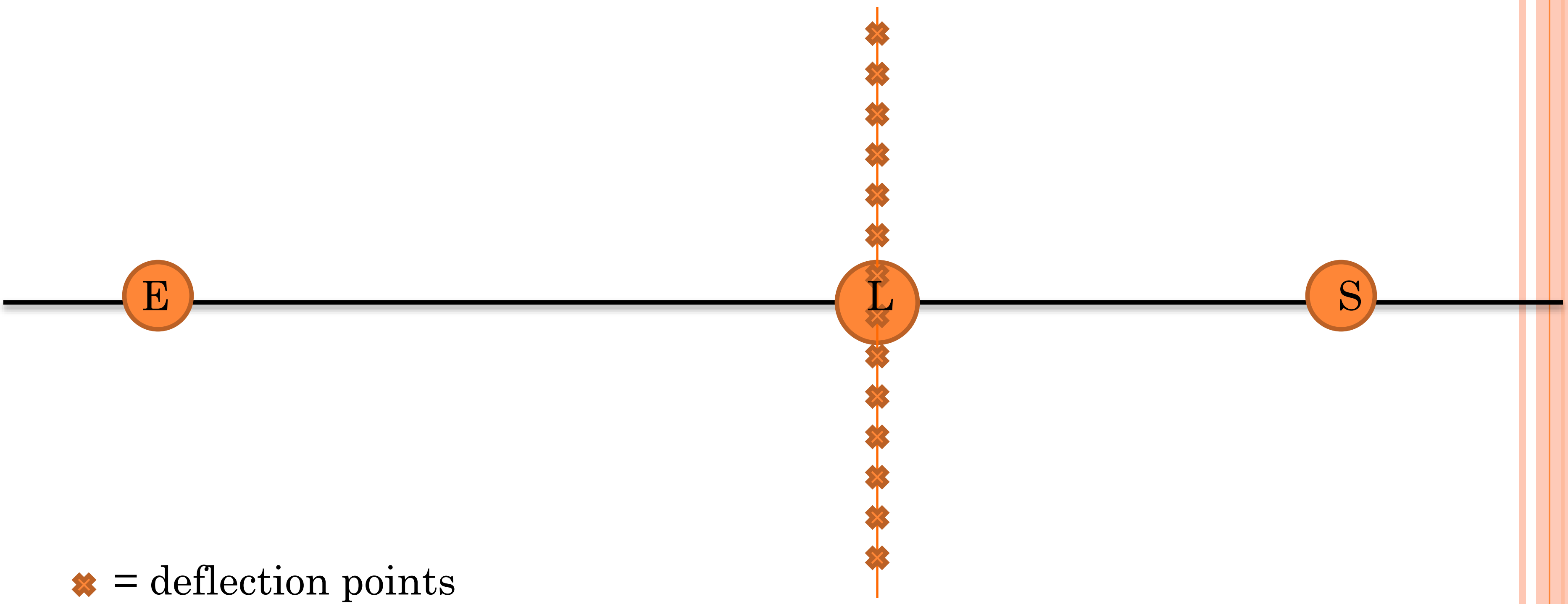
Creating Gravitational Microlensing Simulations

Project Goals

- Single Lens System – Use MatLab to
  - Create a ray trace to see which rays would reach the Earth
  - Create a light curve

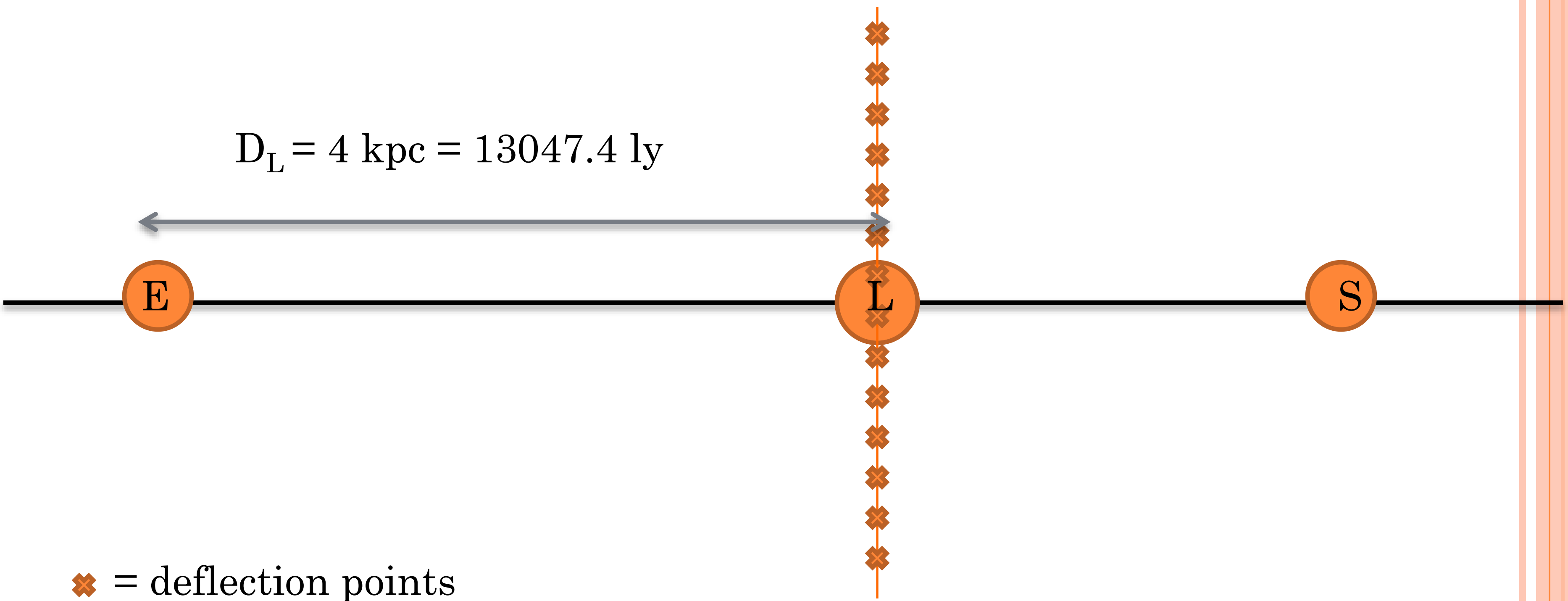
- Binary Lens System – Use MatLab to
  - Create a ray trace to see which rays would reach the Earth
  - Create a light curve
  - Vary the physical parameters of the system to observe the effect on the light curve

Geometry of the Simulation Single Lens System



= deflection points
E = Earth
S = source
L = lens

Geometry of the Simulation Single Lens System



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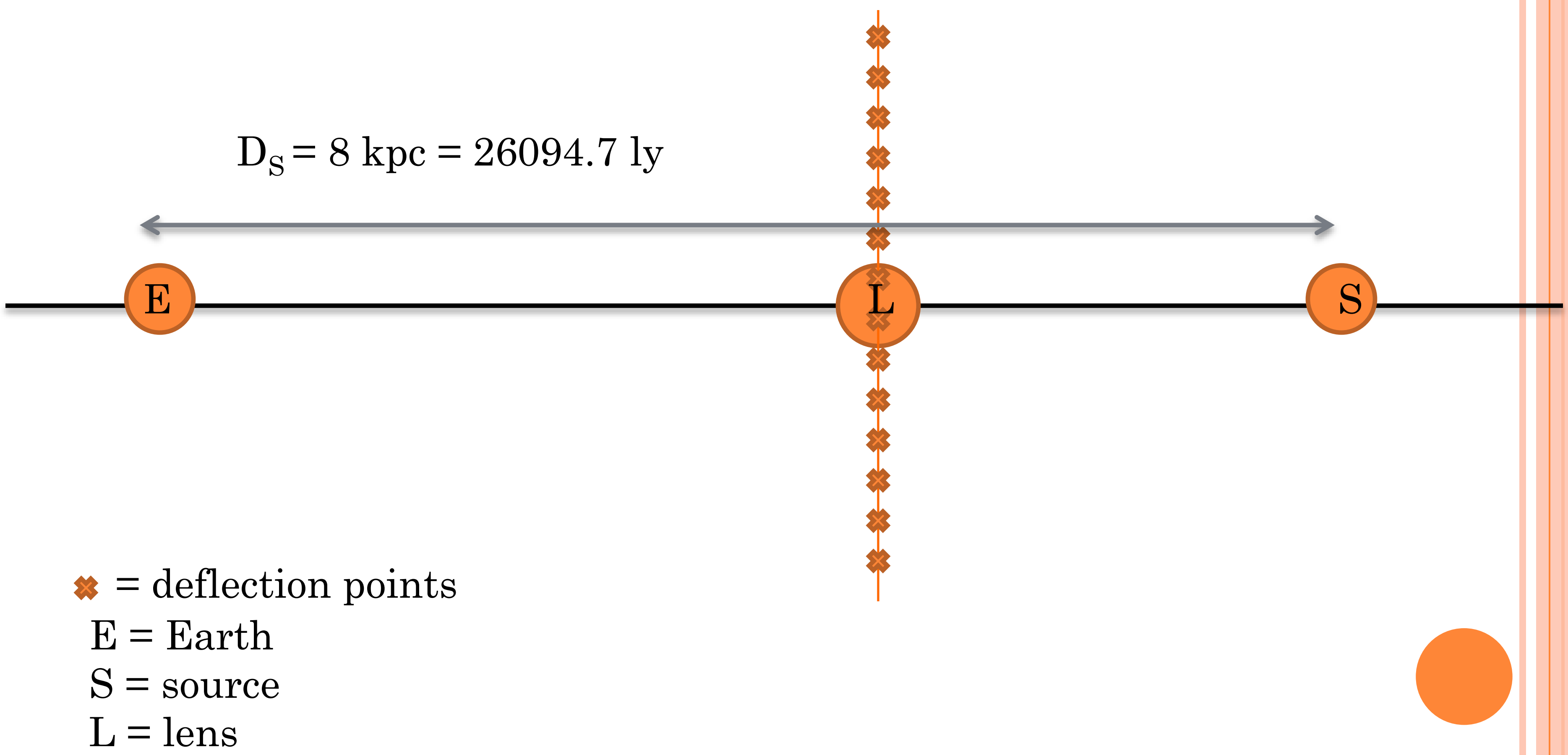
Geometry of the Simulation
Single Lens System



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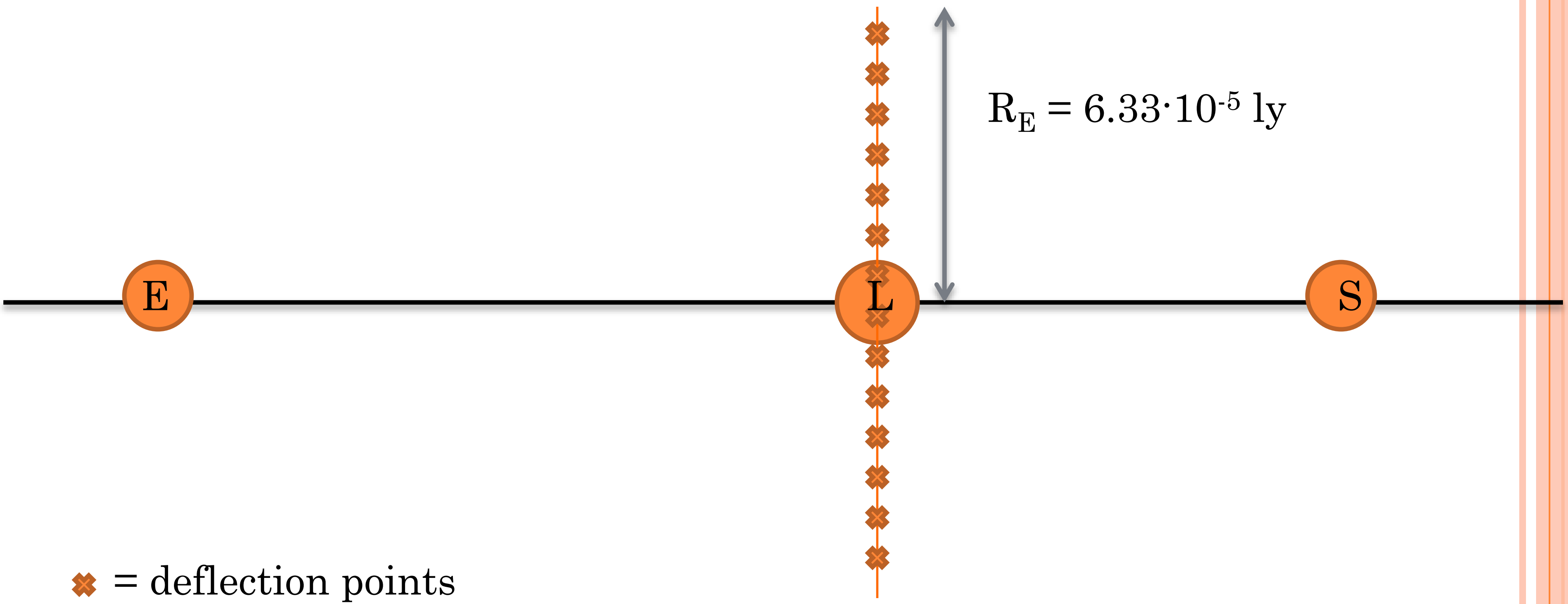
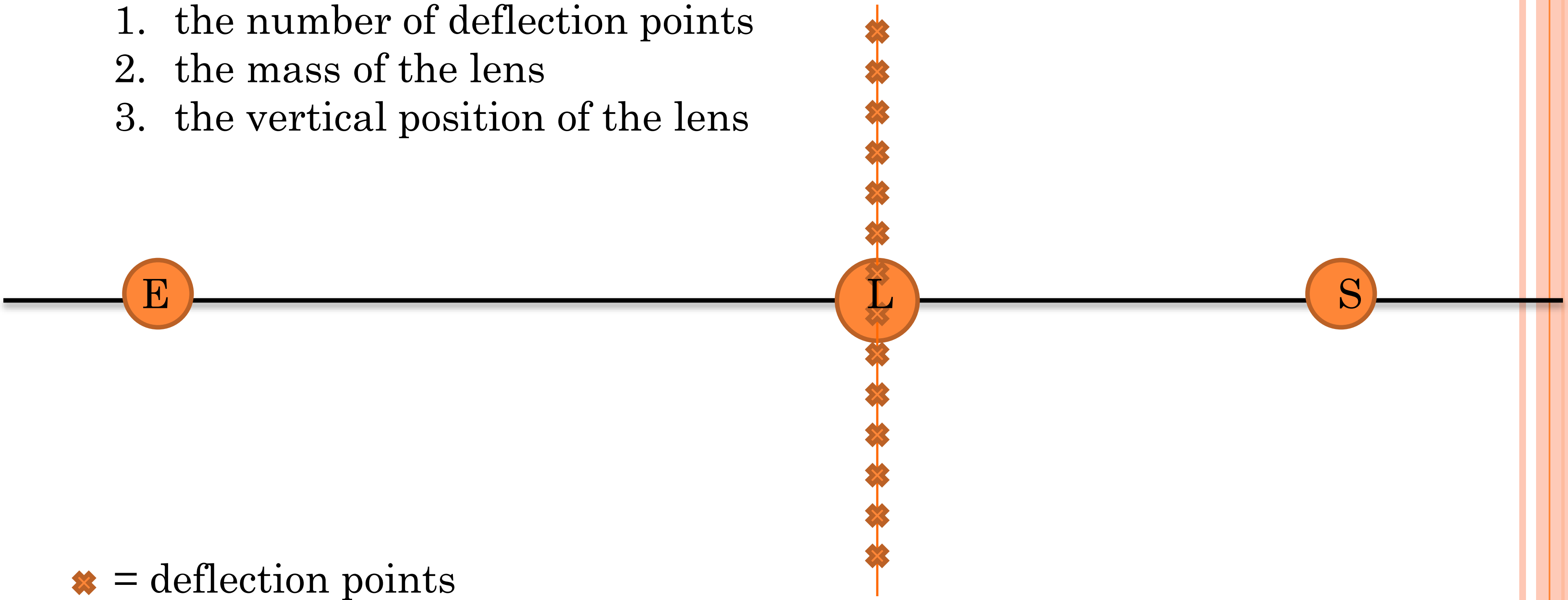


✖ = deflection points
E = Earth
S = source
L = lens

Geometry of the Simulation
Single Lens System

User inputs:

1. the number of deflection points
2. the mass of the lens
3. the vertical position of the lens



✖ = deflection points

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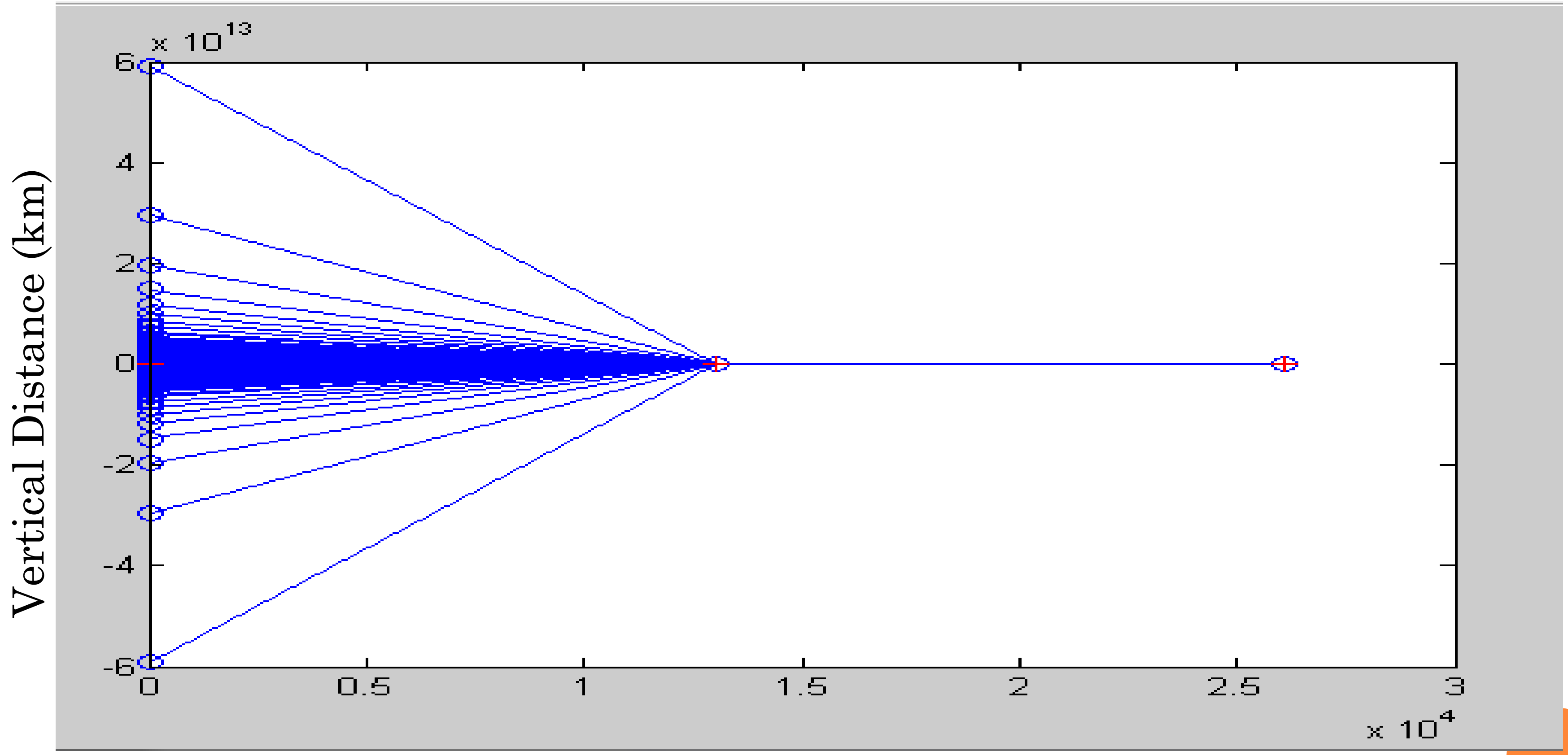
L = lens

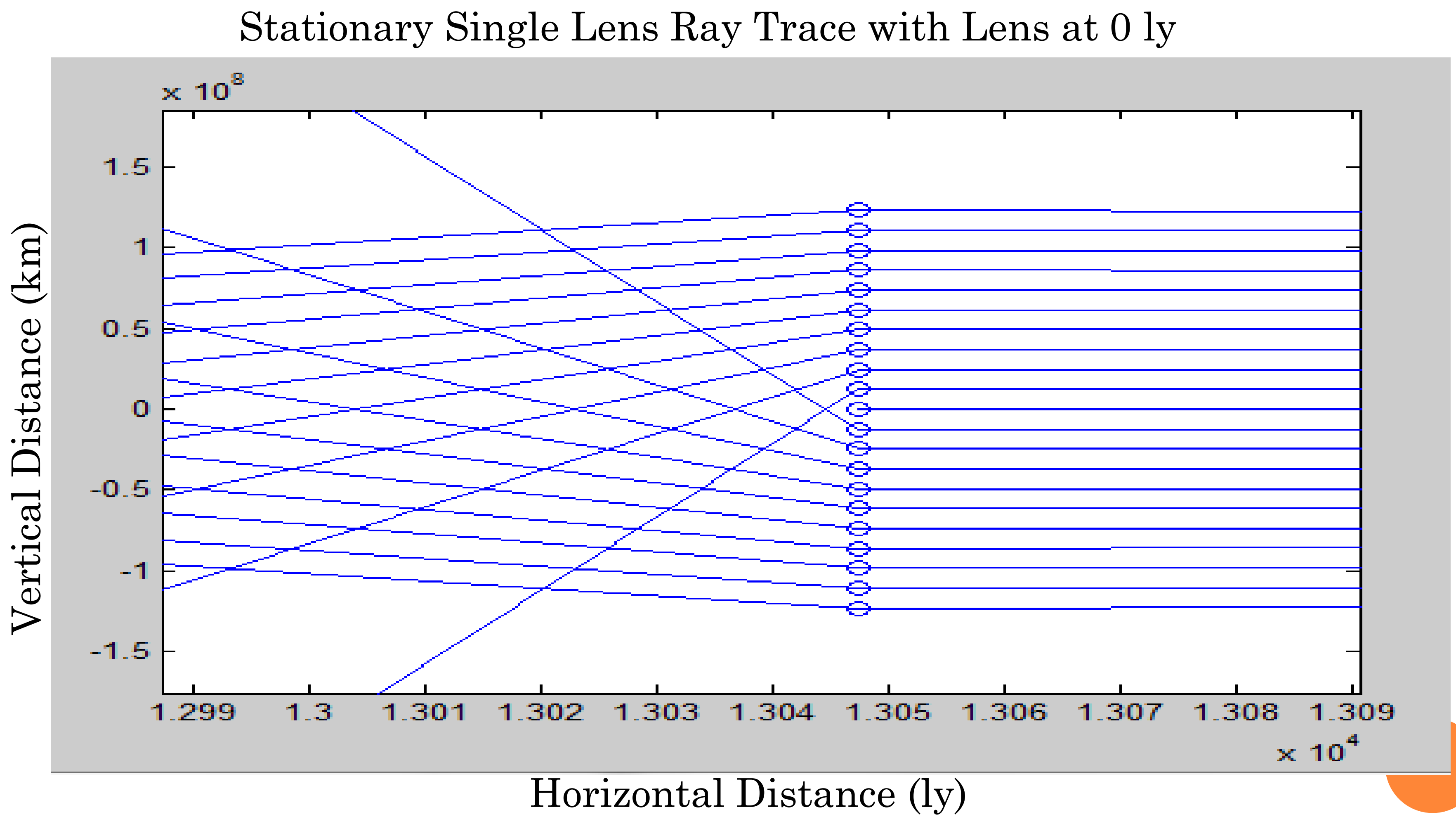
Simulation Ray Trace
Single Lens System

Stationary Single Lens Ray Trace with Lens at 0 ly

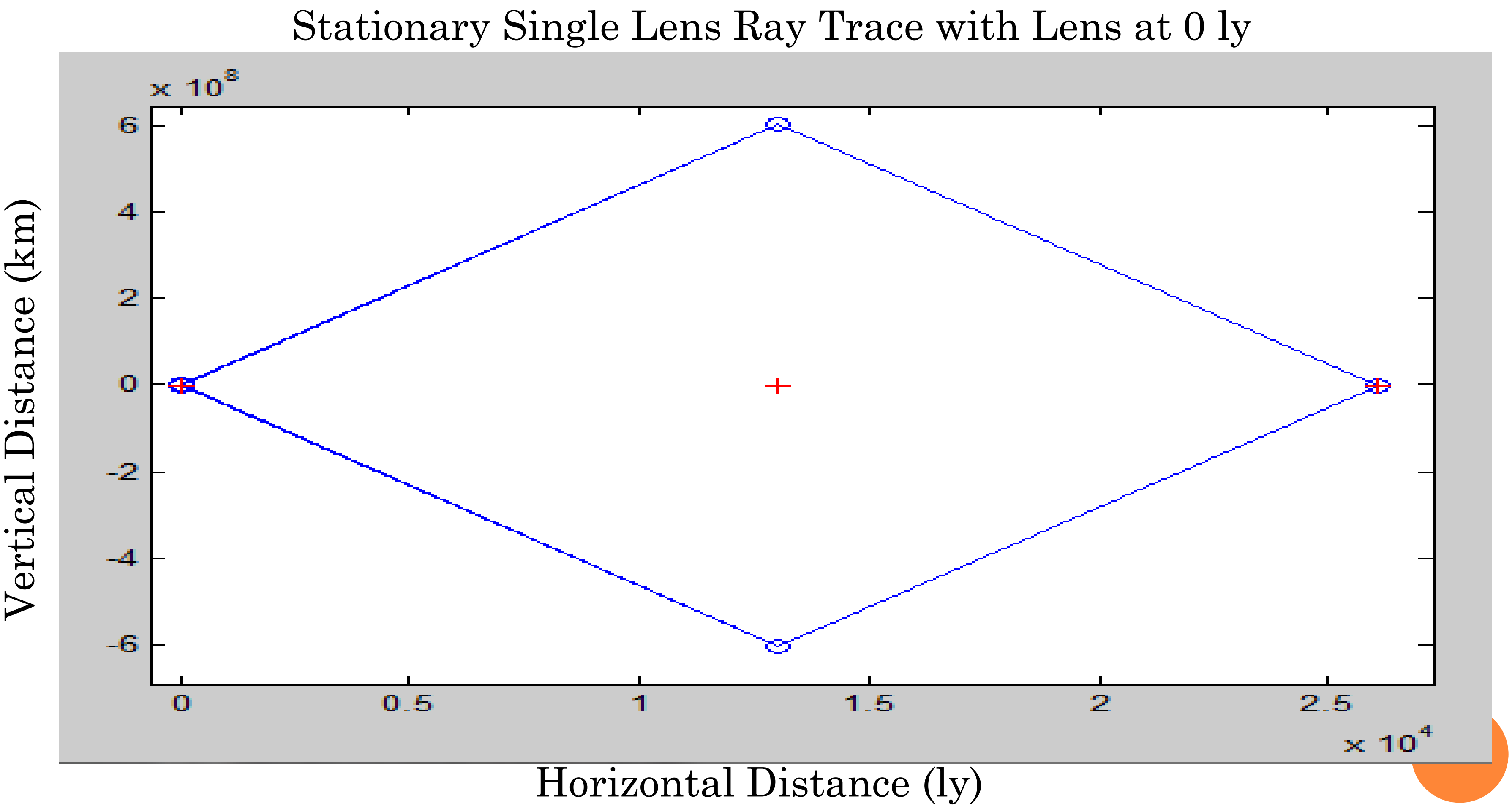


Horizontal Distance (ly)

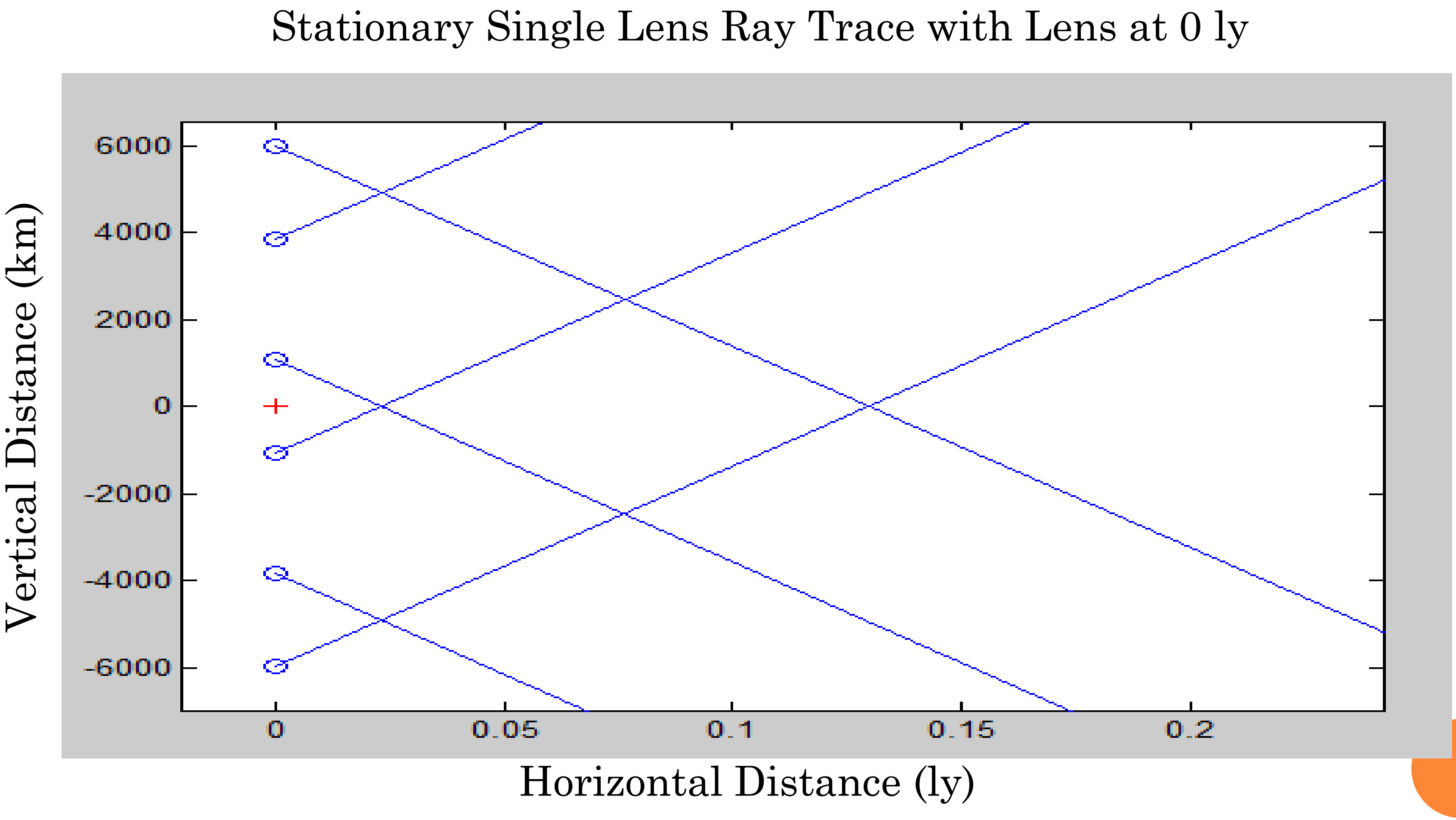
Simulation Ray Trace
Single Lens System



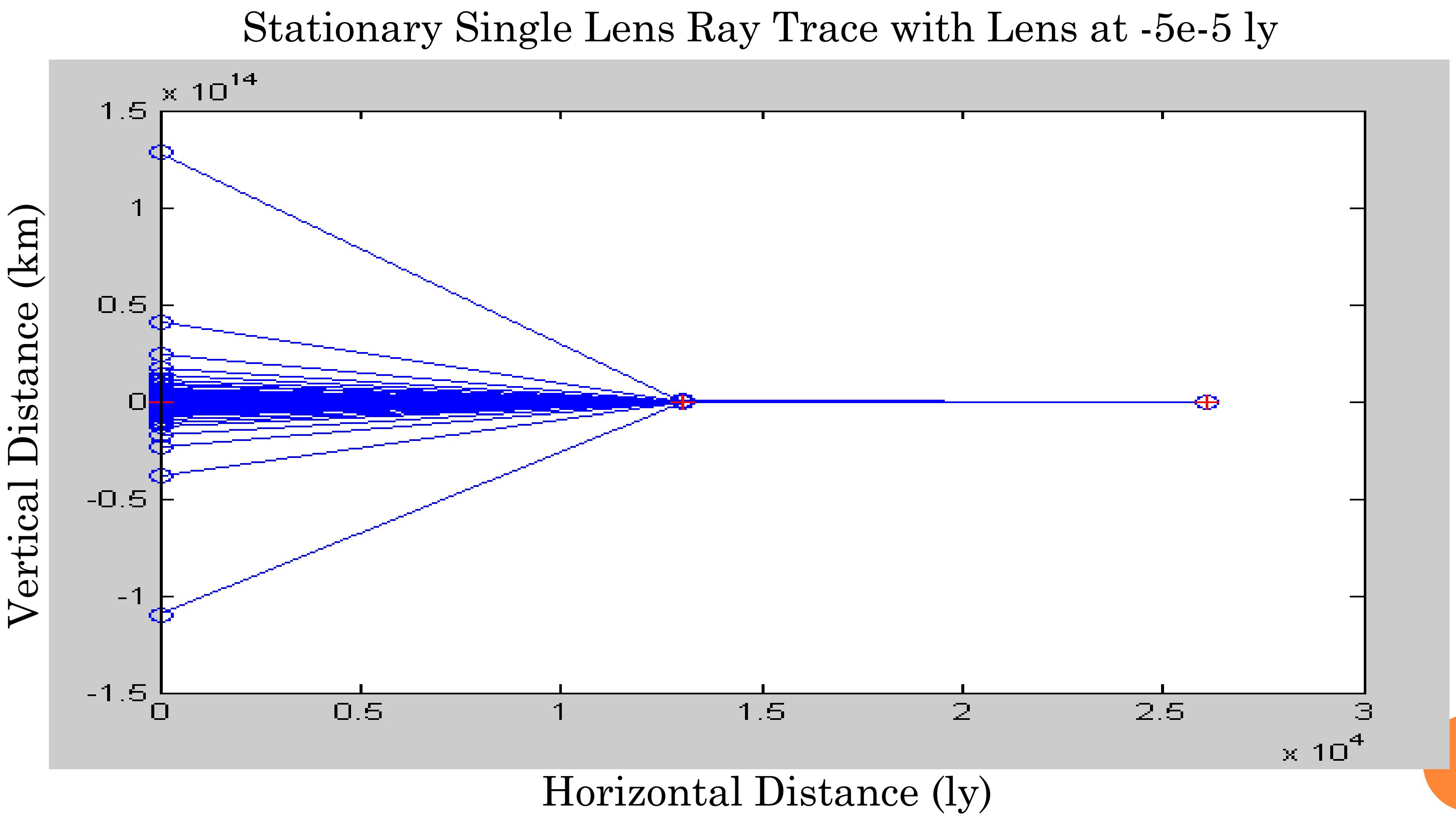
Simulation Ray Trace Single Lens System



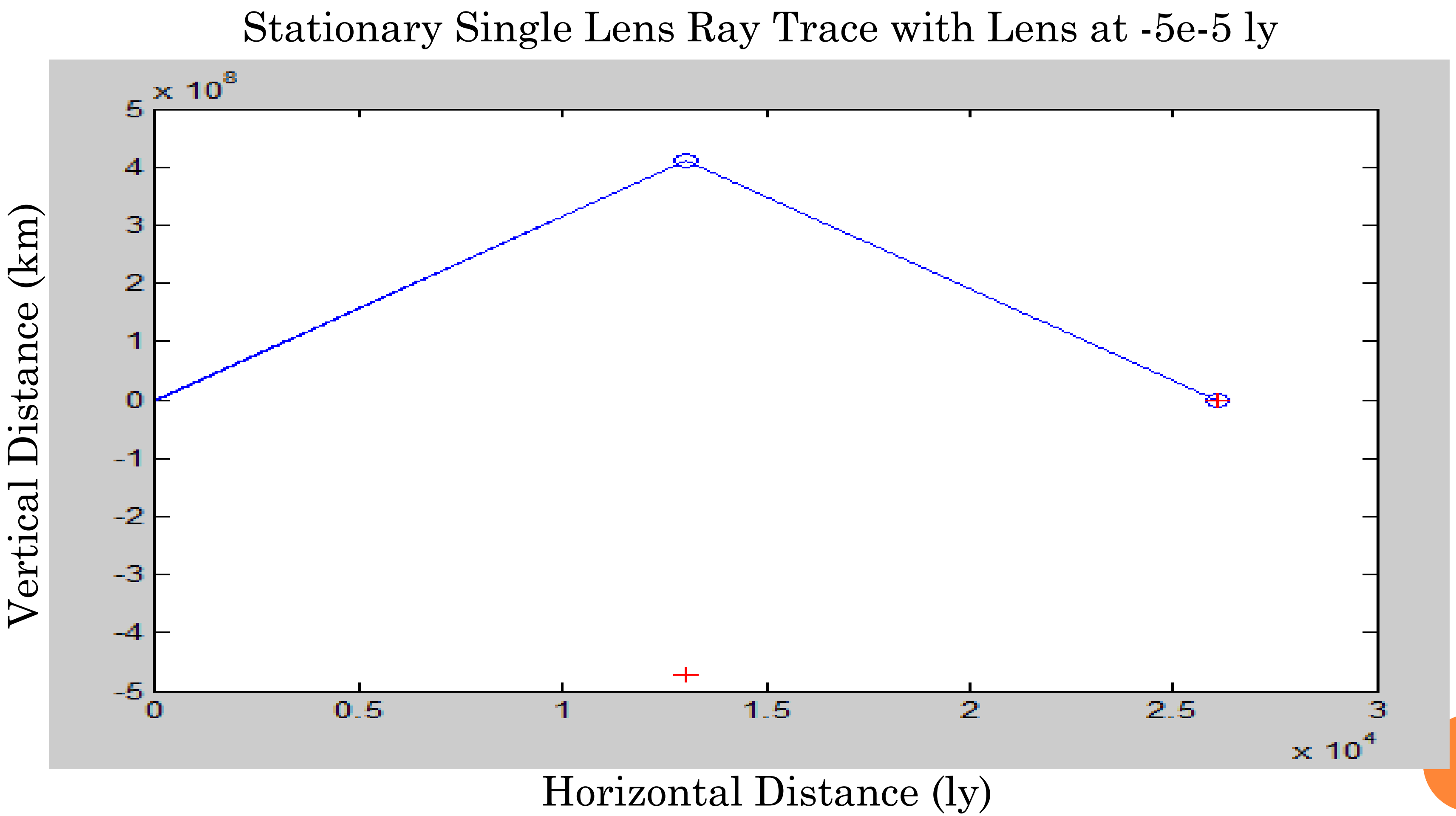
Simulation Ray Trace
Single Lens System



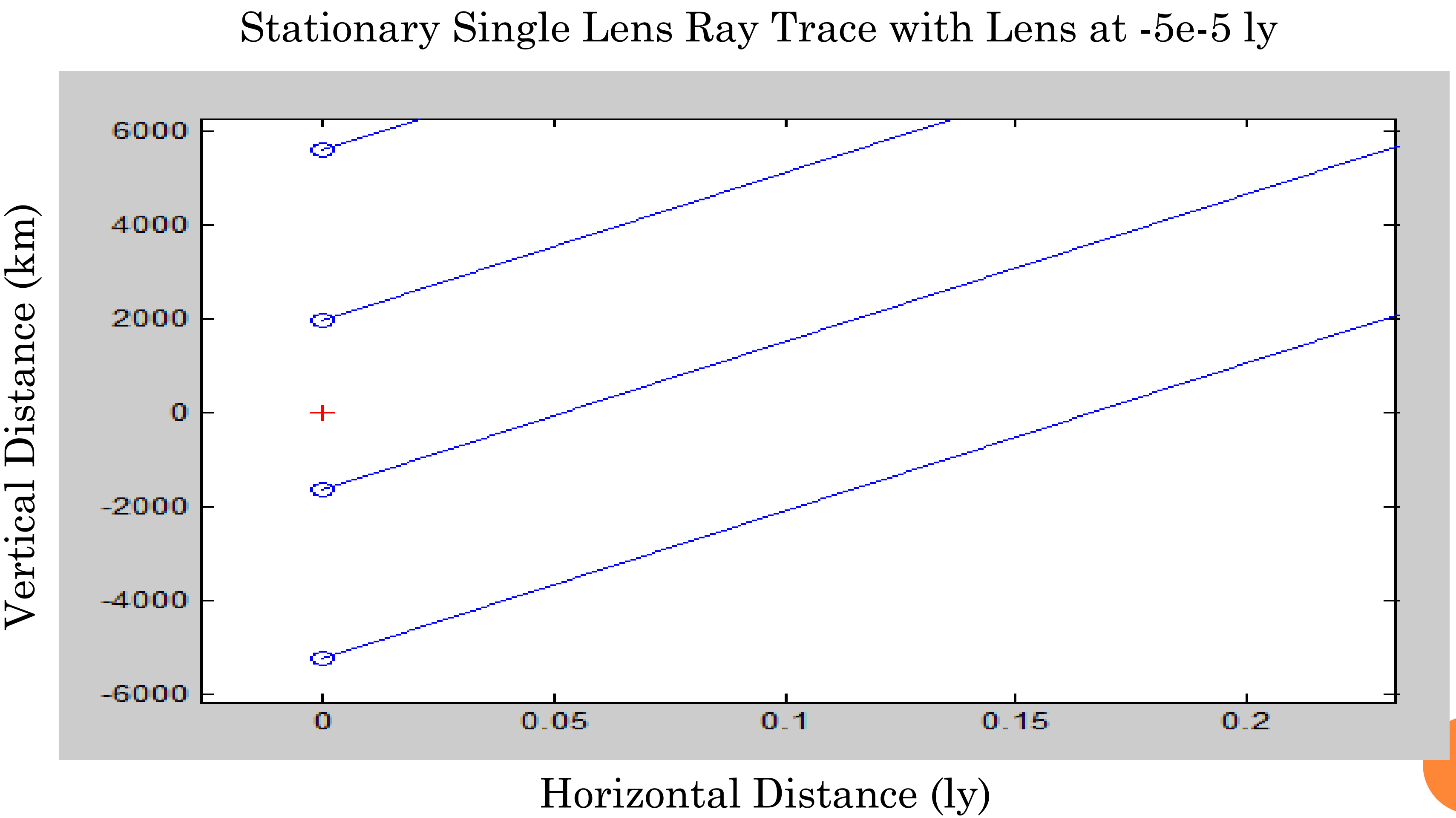
Simulation Ray Trace
Single Lens System



Simulation Ray Trace
Single Lens System



Simulation Ray Trace
Single Lens System

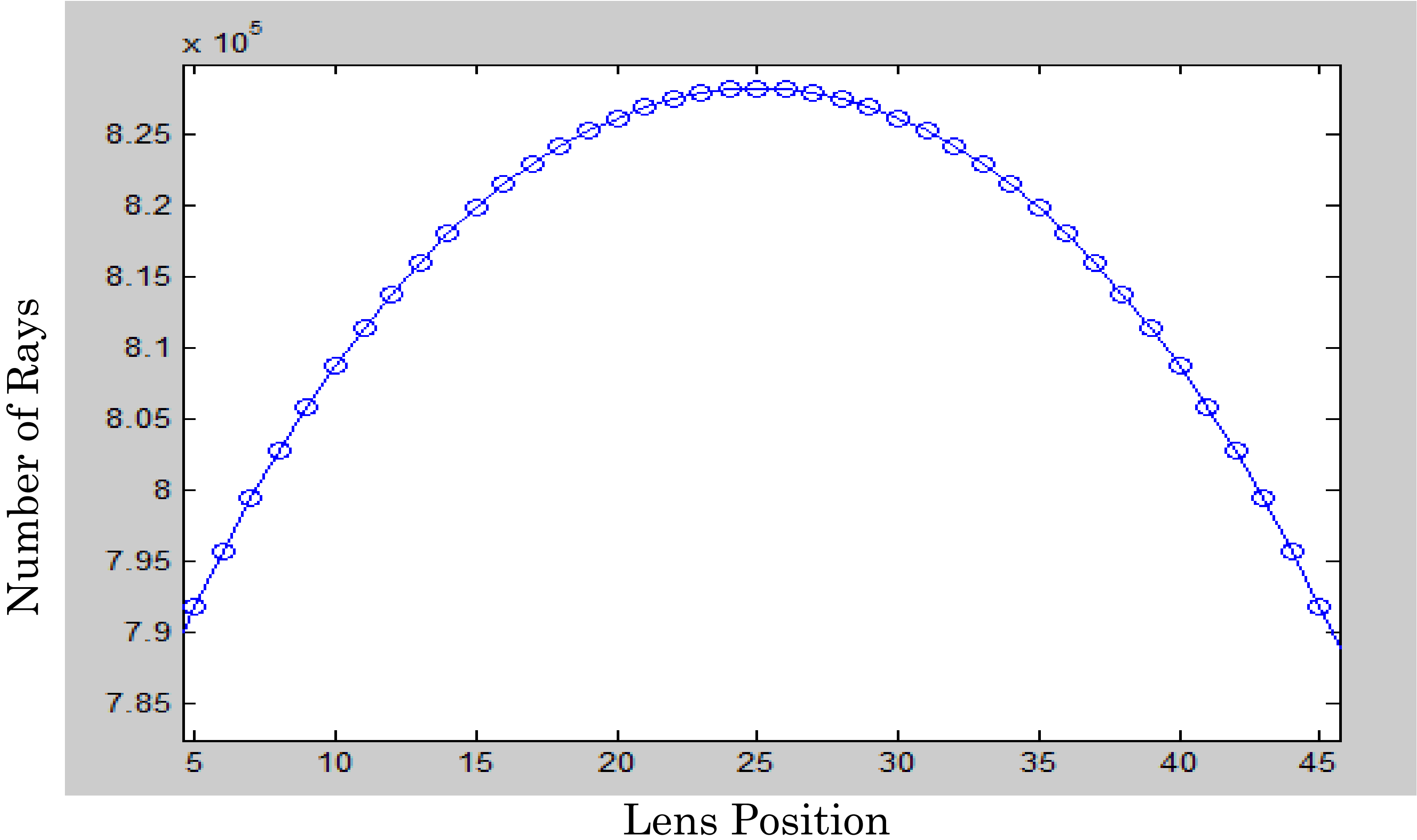


Simulation Light Curve Single Lens System

- Needed to change the physical set up of system for MatLab to give good results

- $D_S = 100$ ly
- $D_L = 50$ ly
- $M_L = 1.989 \cdot 10^{27}$ kg
- $R_E = 2.4 \cdot 10^{-7}$ ly

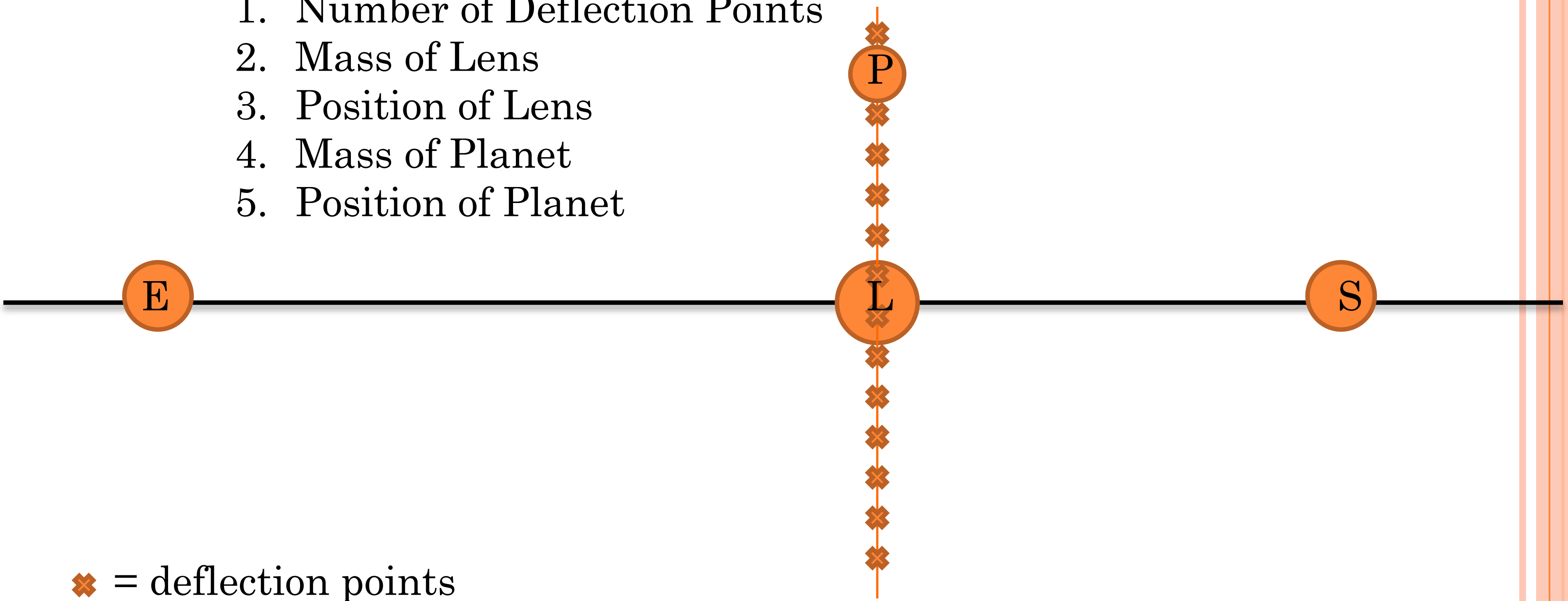
Simulation Light Curve
Single Lens System



Geometry of the Simulation
Binary Lens System

User Inputs:

1. Number of Deflection Points
2. Mass of Lens
3. Position of Lens
4. Mass of Planet
5. Position of Planet



✖ = deflection points

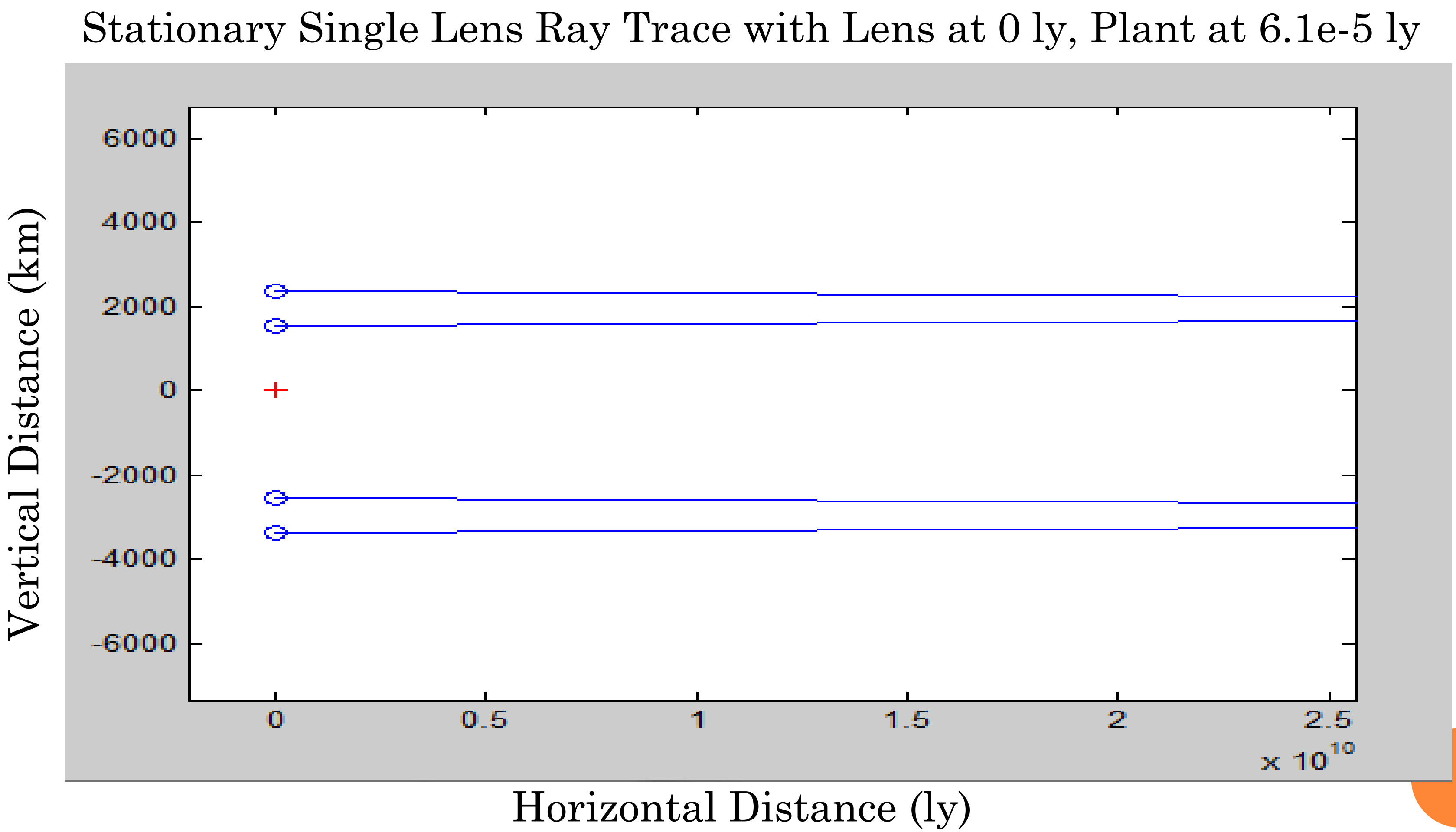
E = Earth

S = source

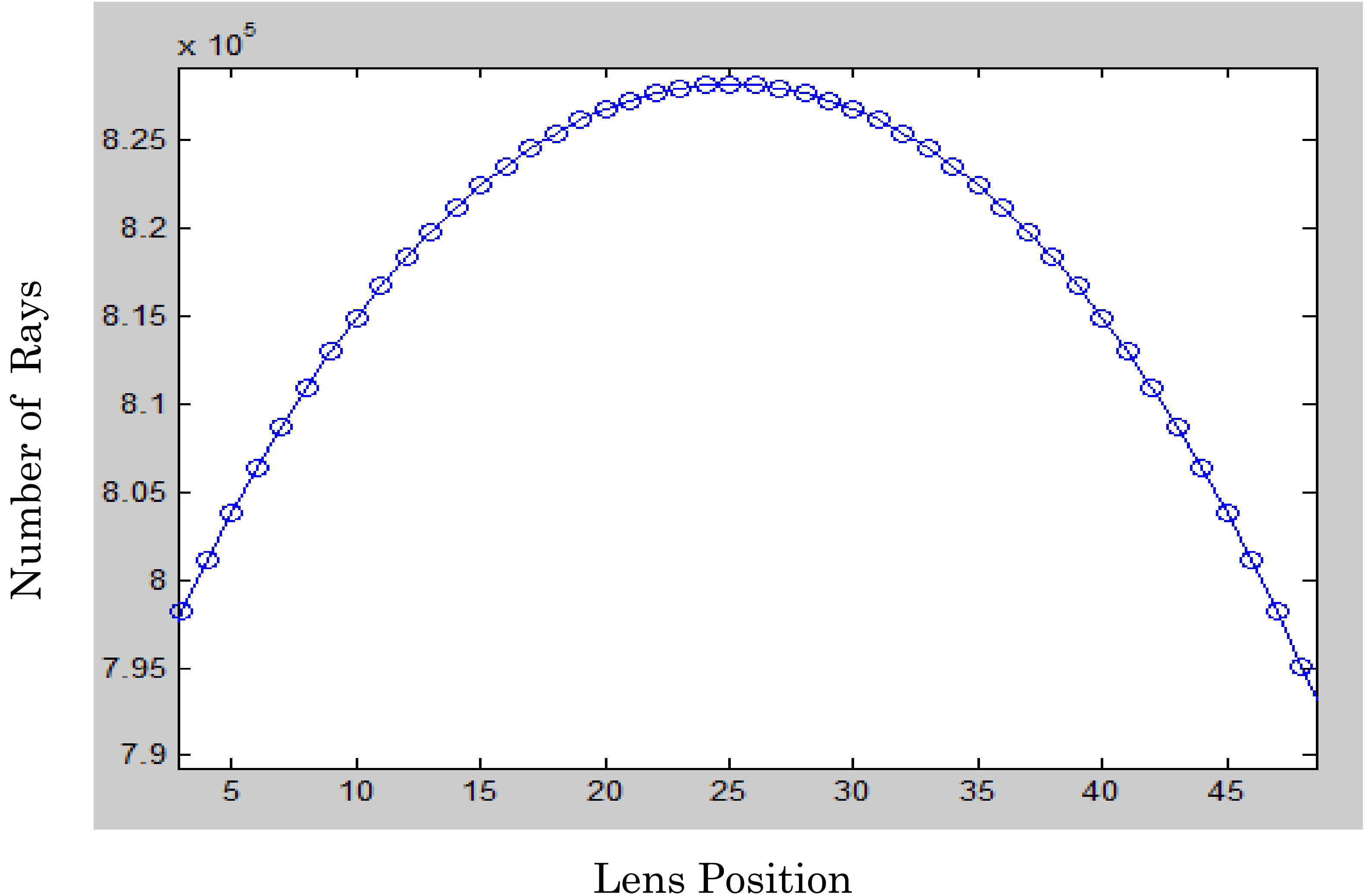
L = lens

P = Planet

Simulation Ray Trace
Binary Lens System



Simulation Light Curve Binary Lens System



Conclusions

- MatLab was able to be used to trace the rays of both single and binary lensing event
- Due to the scale of gravitational lensing systems, MatLab could not accurately create light curves
- By rescaling the system, MatLab could create light curves for the single lens events
- Not able to see the effect of the binary system in the light curve

Acknowledgements

- Dr. Fleisch

References

- http://arxiv.org/pdf/1002.0332v2.pdf
- http://www.springerlink.com/content/t6qh54735l5tx1u7/fulltext.pdf
- http://articles.adsabs.harvard.edu/cgi-bin/nph-iarticle_query?1991ApJ...374L..37M&data_type=PDF_HIGH&whole_paper=YES&type=PRINTER&filetype=.pdf
- http://nd.edu/~bennett/moa53-ogle235/
- http://arc-geniuses.blogspot.com/2010/08/general-relativity-genius-of-einstein.html
- http://www.zamandayolculuk.com/cetinbal/htmldosya1/RVgeneral.htm
- http://en.citizendium.org/wiki/Gravitational_lens

Questions