# Student Worksheet for the Gravitational Lensing Instant Pack

Astronomers use computers to build mathematical models of gravitational lenses in order to measure the physical properties of the lensing (foreground) and lensed (background) galaxies. In this activity, you will explore how this mathematical model–building works. In this Teen Astronomy Café — To Go Pack, you will use a Python Notebook to interact with simple gravitational lens models and see the computer program that generates the graphics. Python Notebooks are web–based interactive computational environments that contains code, text, and plots.
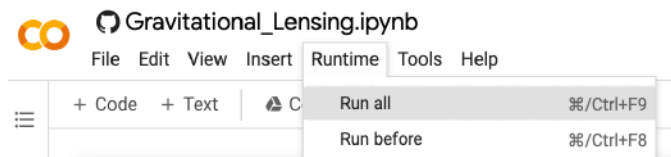

Pre–Activity Setup: Go to the "Runtime" menu and select the option to "Run all." Running all helps to ensure a cell was not skipped and all libraries are imported to help the activities work properly. As you work through the Python Notebook, you may also re-run each cell individually.

Activity 1: The first interactive graphic appears at the bottom of the "Activity 1" section. The graphic represents a simple model for the appearance of a distant galaxy without any gravitational lensing. The sliders adjust the numbers that control how the galaxy looks. Each of the sliders represents parameters (physical properties) that are defined in the notebook. See if you can understand what parameter each slider controls by observing how the graphic changes when you adjust the sliders. It is particularly interesting to attempt to reproduce the same image with a partner or small group and then compare the values obtained.
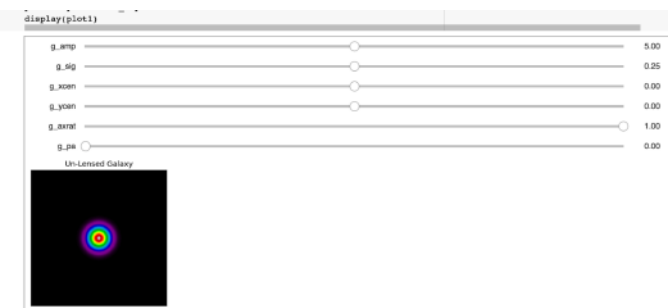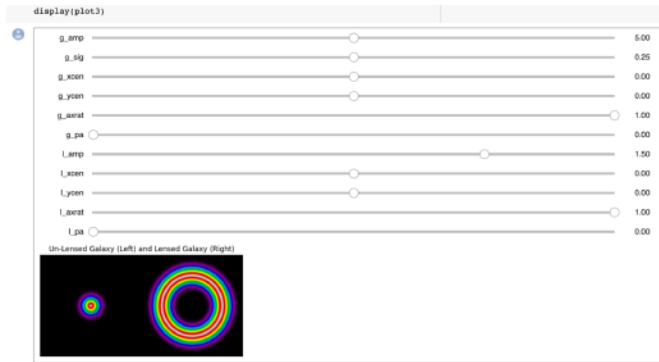

Activity 2: The second interactive graphic appears at the bottom of the "Activity 2" section. The graphic represents the appearance of a gravitationally lensed (background) galaxy. (Note: it does *not* show the image of the lensing galaxy, only the effect of the lensing galaxy on the lensed galaxy.) The sliders adjust numbers that describe how the *mass of the lensing galaxy* is distributed. By adjusting the sliders, see if you can understand how changes in the properties of the lens

- *Hint 1:* The parameter "`l_amp`" is called the "Einstein radius," which changes the overall size of the "Einstein Ring," and is directly related to the total mass of the lensing galaxy.

- *Hint 2:* You may find it easier to understand the effects if you only change the sliders by small amounts or only change a couple of physical properties at a time.

Activity 3: Two more interactive graphics appear at the bottom of Parts 3.1 and 3.2. With these, you can adjust the parameters of both the lensed galaxy *and* the lensing galaxy.

Choose a few of the simulated images (Part 3.1) and real images (Part 3.2), and see if you can find the combinations of values that reproduce them. You can record the values in this table:

	g_amp	g_sig	g_xcen	g_ycen	g_axrat	g_pa	l_amp	l_xcen	L_ycen	l_axrat	L_pa
	peak brightness	how spread out	x position of the center	y position of the center	minor–major axis ratio	major–axis position angle	Einstein radius	x position of the center	y position of the center	minor–major axis ratio	major-axis position angle
Image #:											
Image #:											
Image #:											
Image #:											