iGalFit: AN INTERACTIVE TOOL FOR GALFIT

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ABSTRACT

We present a suite of IDL routines to interactively run GalFit whereby the various surface brightness profiles (and their associated parameters) are represented by regions, which the User is expected to place. The regions may be saved and/or loaded from the ASCII format used by ds9 or in the Hierarchical Data Format (version 5). The software has been tested to run stably on Mac OS X and Linux with IDL 7.0.4. In addition to its primary purpose of modeling galaxy images with GalFit, this package has several ancillary uses, including a flexible image display routines, several basic photometry functions, and qualitatively assessing SExtractor. We distribute the package freely and without any implicit or explicit warranties, guarantees, or assurance of any kind. We kindly ask users to report any bugs, errors, or suggestions to us directly (as opposed to fixing them themselves) to ensure version control and uniformity.

Subject headings: methods: data analysis — techniques: image processing — galaxies: structure — galaxies: fundamental parameters

1. INTRODUCTION

The shape, size, and structure of distant galaxies can provide invaluable insight to their formation history. Consequently, many there have been many techniques and codes developed to make these measurements: GIM2D (Marleau & Simard 1998), GalFit (Peng et al. 2002 2010), GASPHOT (Pignatelli, Fasano, & Cassata 2000), and GALPHAT (Yoon, Weinberg, & Katz 2011). While this is in no way meant to be an exhaustive list, it merely highlights the interest in, and emphasis placed on, robustly measuring the properties of the two-dimensional light distributions of galaxies.

As astronomical surveys have grown ever wider, samples of galaxies have become larger, and accordingly these detailed modeling techniques have also evolved. Turning toward a “pipeline approach,” whereby many sophisticated programs are called in concert to streamlining the measurements on large samples (e.g. GALAPAGOS, Haußler, et al. 2011), many authors sacrifice detailed fitting for bulk properties. Naturally, such a paradigm will invariably generate a series of tunable parameters to be set by the User, many of which, can significantly alter the success or reliability of the pipeline. While appropriate settings are likely obvious or easily ascertainment, they are often tailored to a particular sample, and as the sample changes so must the settings. For example, Users often need to provide the shape modeling codes a source list, since rarely do these codes also identify objects. Obviously, this places the utmost importance on the identification scheme, for multiple reasons: First and most obviously, if the object of interest is failed to be cataloged, then clearly the power of the pipeline is for not. Secondly, if the identification software fails to “deblend” a neighboring object, which presumably should be either simultaneously modeled or masked from the fitting, then the results are not to be trusted. Both of these issues (and many others) can be mitigated by human-intervention or supervision throughout the process, which is the primary motivation for this work.

In this article, we present our software, iGalFit, which is a graphical user interface (GUI) for running GalFit. The software is inspired by the successful image display tool, ds9 (and its predecessors), produced and maintained by the Chandra X-ray Science Center. In iGalFit, the Users is expected to place (circular, elliptical, and rectangular) regions on the image to indicate the function to be fit and the initial guesses of the parameters. In this way, the User has complete control over the critical identification step, while abdicating the assembly-line power of a pipeline.

This article should be treated as somewhat of a “User’s Manual” and a reference point for the package. The article is organized as follows: in Section 2 we describe the basics of the code, in Section 3 we briefly describe a second package to integrate SExtractor with GalFit, in Section 4 we discuss potential ancillary uses, and in Section 5 we mention several upgrades for future versions.

2. INTERACTIVE GalFit: iGalFit

2.1. Installing iGalFit

The entire package is written in the Interactive Data Language (hereafter IDL), therefore having IDL installed is an obvious prerequisite. With IDL installed, the installation is relatively straightforward:

1. Obtain the IDL routines for iGalFit from http://dls.physics.ucdavis.edu/~rer/ or by emailing the author.

2. Create an environment variable in your start-up file named igalfit, and set it equal to the full-path of the IDL routines.

3 http://hea-www.harvard.edu/RD/ds9/
4 http://www.ittvis.com/language/en-us/productsservices/idl.aspx
3. Amend the IDL\textsubscript{PATH} variable to include this newly set variable. Obviously, the variable should be set \textbf{ABOVE} the IDL\textsubscript{PATH} setting.

4. For the Mac OS X platform, configure the “Apple Key” for the keyboard accelerators used by \textit{iGalFit}:

   a. In the User’s home directory, there may be a file called \texttt{.Xmodmap} (if not, create one) and add the following lines:

   
   \begin{itemize}
   \item clear mod1
   \item clear mod2
   \item add mod1 = Meta_L
   \end{itemize}

   b. Start the X11 server and open the \textit{Preferences} tab. Under the \textit{Input} dialog, make the following items \textbf{UNCHECKED}:

   \begin{itemize}
   \item Follow system keyboard layout
   \item Enable key equivalents under X11
   \end{itemize}

5. To install the optional Perl script which can call \textit{iGalFit} from the command line, simply include the path to the Perl executable in your start-up file.

6. Restart the X11 server.

\subsection{2.2. Starting \textit{iGalFit}}

Since the code is primarily written in IDL, the simplest way to start \textit{iGalFit} is to issue the command “igalfit” at the IDL prompt:

```
IDL> igalfit, [OPTIONS=options]
```

This of course requires that IDL is running, which can be a nuisance. Therefore we include a brief Perl script, which will initialize IDL and run \textit{iGalFit} and can be run from the command-line in the usual way. There are several optional keywords, which can be set in either the IDL or Perl, to (pre-)set various items. A complete listing can be given by typing “igalfit,/help” in IDL, “igalfit -help” at the command line, or are given in Table \ref{table:Options}.

\begin{table}[h]
\centering
\caption{\textit{iGalFit} Optional Inputs}
\begin{tabular}{|l|l|l|}
\hline
IDL\textsuperscript{1} & Perl & Function \\
\hline
LOADSETTINGS & \texttt{-load} & Load an \textit{iGalFit} save file. \\
SCIFILE & \texttt{-sci} & Load the science image. \\
UNCFILE & \texttt{-unc} & Load the uncertainty image. \\
BPXFILE & \texttt{-bpx} & Load the bad-pixel image. \\
PSFFILE & \texttt{-psf} & Load the PSF image. \\
IMGFILE & \texttt{-img} & Load the output image. \\
MAGZERO & \texttt{-zero} & Set the magnitude zeropoint. \\
\hline
\end{tabular}
\end{table}

\textsuperscript{1}While IDL is not case-sensitive, we follow the convention that optional keywords are in all-caps.

\subsection{2.3. Controls}

The controls to \textit{iGalFit} are largely modeled after those of \textit{ds9}, and so users should be able to seamlessly move between programs. However, we will describe the control system for completeness:

\begin{table}[h]
\centering
\caption{\textit{iGalFit} Keyboard Commands}
\begin{tabular}{|l|l|}
\hline
Key & Function \\
\hline
+ & Zoom in on the center of the display. \\
− & Zoom out on the center of the display. \\
q & Close \textit{iGalFit}. \\
\texttt{DELETE} & Delete the selected region. \\
r & Display a radial profile of object closest to cursor position. \\
m & Display image statistics for a small area around the cursor position. \\
l & Display a line plot for some region around the cursor position.
\hline
c & Display a column plot for some region around the cursor position. \\
h & Display a pixel histogram for some region around the cursor position. \\
e & Display a contour plot for some region around the cursor position. \\
\hline
\end{tabular}
\end{table}

\subsection{File Input/Output::}

While many of the individual files needed to run \textit{GalFit} can be saved/loaded at any time, users may find it convenient to save/load a file which encodes the complete state of \textit{iGalFit}. This facilitates an easy recall or programmatically assigning a state of \textit{iGalFit}. These files are written in the Hierarchical Data Format version 5 (HDF5), though by default named \texttt{igalfit\_save.h5}. These files can be saved/loaded by buttons on the toolbar or the \textit{File} pulldown menu, or with the command line options (see Table \ref{table:Options}).

\subsection{Region Input/Output::}

The regions for \textit{iGalFit} indicate the positions, sizes, and morphologies of the objects to be fit, regions to be masked, and allowable fitting regions (discussed in more detail in § 2.3). Users can save/load regions from the \textit{Regions} pulldown menu, and are meant to be directly compatible with \textit{ds9}.

\subsection{Mouse Functions::}

The mouse controls many aspects of \textit{iGalFit}:

\textbf{Left click and drag::} If on a blank region of the image, then a new region based on the current state of the morphology pulldown menu in the primary toolbar (see Figure \ref{fig:RegionSelection}). If on a valid region, then this will select the region allowing the user to translate or delete the region and initiate the region “handles.” The handles can be selected to adjust the size (left click) and rotate (left click while holding the \texttt{SHIFT} key).

\textbf{Middle click::} Recenter on the current mouse position.

\textbf{Right click and drag::} Adjust the “stretch” of the color map — vertical and horizontal movements adjust the bias and contrast, respectively.

\textbf{Left double-click::} If on a region, then the \textit{Region Information} sub-GUI will open.

\subsection{Keyboard Commands::}

When the cursor is in the main display window there are several actions which can be run by keyboard actions. We briefly describe the valid functions in Table \ref{table:KeyboardCommands}.
Toolbar Functions: Immediately above the main display window is a row of buttons which control several commonly used functions (see Figure 1). We briefly describe the function of each button in Table 3.

2.4. Modeling Galaxy Profiles

The primary motivation for developing iGalFit was to interactively create the input files for GalFit (e.g., bad-pixel masks, constraint files, “galfit.feedme”, and uncertainty maps). In this section, we describe the typical order-of-operations to interactively model galaxy profiles.

1. In principle, iGalFit is capable of displaying large (roughly $10 \times 10$ k pixels). However, manipulating a large number of pixels is computationally expensive and is generally unnecessary (or ill-advised) for running GalFit. Therefore, we recommend operating on images sized for each object (roughly 1 k×1 k pixels).

While GalFit is capable of running without a PSF and uncertainty map, these images are essential for robust estimates of the galaxy profiles. Furthermore, GalFit is more reliable when operating on images which are in the units of counts (cts; Peng priv. comm.), despite the more common convention to process images in count rate (cts/s). Therefore the user should set the appropriate exposure time and unit in the Image Properties tab. Finally, for
2. After loading a science image (and PSF and uncertainty maps), the user is expected to indicate the initial conditions for GalFit by drawing regions, which represent the model that should be fit. In Table 4, we list the currently supported regions and their functions. There are three ways a user may draw regions in iGalFit:

- **Manual**: The primary advantage of iGalFit is the ability to interactively place the model profiles. In this way, the fitting can be done iteratively by modifying properties of the regions, such as the color (see Table 4), position, adding/removing additional regions, or masking objects.

- **Automated**: Despite the obvious advantages with interactively placing regions, this can be very tedious and daunting for large images with many objects. Therefore, we include a second package which will call SExtractor to identify objects and draw the appropriate regions (discussed in more detail in § 8). To determine which fitting function to assume (see Table 4), we have a crude star/galaxy separation algorithm of:

\[
\text{ISOAREA\_IMAGE} \leq A_{\text{crit}} \Rightarrow \text{PSF} \\
\text{ISOAREA\_IMAGE} > A_{\text{crit}} \Rightarrow \text{Mask}
\]  

(2) where we define \( R = \sqrt{ab} \) and \((a,b)\) are the semi-(major,minor) axes, respectively. We consider objects which are considerably smaller in area and extent than the PSF to be likely image defects or unrejected cosmic rays, and in which case, should be masked in the GalFit calculations. All remaining objects are considered to be extended, and are assigned a single fitting function. The tunable parameters \((A_{\text{crit}}, R_{\text{crit}})\) and default extended source function can be set in the Preferences menu in iGalFit. We caution that these classifications are only meant to guide the user in placing the regions, and should not be trusted as a robust morphological indicator.

- **File**: Regions can be loaded from a standard ds9 regions file. In Appendix A, we give an example regions file to illustrate the format.

3. With the fitting regions indicating the initial conditions of GalFit set, the user should consider setting two ancillary regions. First, any pixel which is seriously corrupted by non-object flux (such as cosmic rays, image defects, diffraction spikes, bleeds, etc.) should be masked. If bad pixels are left unmasked, then they will bias the estimate of the sky brightness by GalFit, which will adversely affect other parameters (notably the radius) and/or give incorrect results for the objects directly (such as position, total magnitude, or radius). Second, users should consider setting a Fitting Section region, which restricts the GalFit calculation to the interior pixels. If the fitting section is not set, then iGalFit will fit the entire image.

4. Once the fitting regions have been placed, the user should consider defining any possible constraints. While the use of constraints are discouraged, they do have some utility — particularly when fitting

\[\text{ISOAREA\_IMAGE} \leq A_{\text{crit}} \Rightarrow \text{PSF} \]

\[\text{ISOAREA\_IMAGE} > A_{\text{crit}} \Rightarrow \text{Mask}\]

\[R \geq R_{\text{crit}} \Rightarrow \text{PSF}\]

\[R \leq R_{\text{crit}} \Rightarrow \text{Mask}\]
composite functions (such as bulge and disk). Obviously, any parameter which is found by \texttt{GalFit} to be fixed on a constraint border is dubious, and the user should relax the constraint. In most cases, if a constraint can be avoided, it is safest to do so.

5. At any point in the process, the user can inspect the \texttt{GalFit} input file (e.g., \texttt{galfit.feedme}) and make any manual modifications. We caution, there are no safe-guards to verify that these files do not contain any errors.

6. If \texttt{GalFit} successfully runs to completion, the default behavior is to load the output file (e.g., \texttt{img-block.fits}) into a sub-GUI to display the results (see Figure 3). This sub-GUI will display the science, model, and residual images (on the same stretch), the best-fit results, and global properties (e.g., degrees of freedom, χ², sky properties, etc.). The various output images can also be displayed in the main GUI.

3. SOURCE EXTRACTOR

Since \texttt{GalFit} does not identify objects, the user is required to indicate approximate positions of all sources, whether to be fit or masked. In many deep galaxy images, the number of objects may be overwhelming to mark every source. Therefore, we include a separate GUI to run \texttt{Source Extractor} (hereafter \texttt{SExtractor}; Bertin & Arnouts 1996). While this package can be run independently of \texttt{iGalFit}, the main features are only accessible through \texttt{iGalFit}. There are a multitude of parameters which govern the operations, however we restrict control to only the few which are most commonly modified.

The \texttt{SExtractor} GUI employs two sub-GUIs to set the measurements (i.e., the *.param file) and build a convolution filter (i.e., the *.conv files). The parameters needed for \texttt{iGalFit} are set by default. The convolution routine allows for several common filters (Gaussian, Mexican hat, top hat, delta-function) and a user-defined function of a single parameter. As of the time preparing this document, \texttt{SExtractor} (version 2.5.0 2009-09-30) did not permit any filters larger than 32 pixels, however \texttt{iSEx} will not warn the use of this potential issue.

4. ANCILLARY USES

While the primary purpose of \texttt{iGalFit} is to model the two-dimensional light distributions of various objects, we suggest other applications which users may find valuable.

4.1. Interactively Assessing \texttt{SExtractor} Settings

\texttt{SExtractor} has become the de facto standard for detecting and measuring a number of properties of faint objects, particularly for deep-field surveys. Not surprisingly, there are a host of tunable parameters to be set by the user which govern the detection, deblending, measurement, memory usage, and outputting. Therefore a typical session involving \texttt{SExtractor} begins with a trial-and-error period of tweaking various parameters until the output catalog satisfies some qualitative property, often times the detection/deblending of the faintest sources. Despite the various manuals (Source Extractor for Dummies: B. Holwerda, \texttt{SExtractor} User’s Manual: E. Bertin), there can be a great deal of confusion on the role of a given parameter and how it can be affected by other parameters, particularly for novice users. Since \texttt{iGalFit} can directly control \texttt{SExtractor} using a separate interface, users are able to experiment with any combination of \texttt{SExtractor} settings and their effects.

4.2. Inspect Images

Since the controls and image display aspects of \texttt{iGalFit} was inspired by \texttt{ds9}, it has a many flexible quick-look tools built-in. The images can be scaled and stretched, zoomed, panned, and separate frames (although this would be implemented by loading additional images into the PSF and Uncertainty fields) for easy display and comparisons. At present, rotations are not supported, but this will likely be included in subsequent versions. As mentioned in §2.3, the display and processing of large images (10k × 10k pixels) is ill-advised.

4.3. Quick-Look Photometry

One question that invariably arises in nearly all forms of observational astronomy: What is the brightness of that object? Therefore many astronomical display routines give the user tools to answer this question.
Fig. 3.— Screenshot of the GUI to inspect the GalFit results. All of the information displayed here is taken from the GalFit output file (i.e. the imgblock.fits). This GUI has many of the same controls and mouse functionality as iGalFit.

(e.g. ImExamine in IRAF, atv.pro, idp3.pro Stobie 2000), and iGalFit is no different. However a major advantage to iGalFit is the photometry routines are integrated into an image display tool which combines the flexibility of ds9 with the computational power of IDL and the image processing of SExtractor.

5. FUTURE IMPROVEMENTS

As with most software, iGalFit is a work-in-progress, and there are several additions or improvements we would like to include:

Asymmetry Parameters:: In the latest version of GalFit, there are a bevy of asymmetry parameters (e.g. boxiness, bending modes, fourier components, truncation radii) to model azimuthally asymmetric structures, like bars, spiral arms, or tidal tails. By including these parameters, the user can create far more complex and (perhaps) realistic models.

Additional Morphological Programs:: While this project was conceived to provide a user-friendly interface to GalFit, there are additional modeling programs which can be included as well, for example GALPHAT (Yoon, Weinberg, & Katz 2011), shapelet decompositions (e.g. Refregier 2003; Massey & Refregier 2003), and model-independent estimators (e.g. Conselice et al. 2003; Lotz et al. 2003; Sheth et al. 2003).

6 http://www.physics.uci.edu/~barth/atv/
7 http://mips.as.arizona.edu/MIPS/IDP3
Improved Memory Efficiency and Image Display:

We mentioned in § 2.4, the rendering of large images can be very computationally expensive and dramatically slow down even the most powerful workstations. In future versions, we plan to employ additional advanced graphics capabilities in IDL to improve the real-time image display.

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APPENDIX

A. EXAMPLE REGIONS FILE

iGalFit will read and write regions files in the same format as ds9, allowing users to employ existing tasks to define regions. For completeness, we give an example regions file, as written by iGalFit.

# Region file made by iGalFit on Mon Aug 1 00:31:43 2011
# Filename: psf_f125w.fits
global color=green dashlist=8 3 width=1 font="helvetica 10 normal" select=1 highlite=1 dash=0 fixed=0 edit=1 move=1 delete=1 include=1 source=1 image
circle(593,586,44.019807) # color=magenta
ellipse(456,543,75,28,338.58853) # color=green
ellipse(679,458,40,20,35.134193) # color=red
ellipse(528,476,40,20,330.01836) # color=blue
box(587.5,547.5,369,313,0) # color=yellow
-rect(537.5,605.5,37,59,0) # color=black
-rect(713,607,80,40,0) # color=black

B. BASIC SExtractor CATALOG

As discussed in § 3, iGalFit can call SExtractor to identify objects for later use, but can also take a catalog derived by other means. However to properly interpret the columns, the file should be in the ASCIIHEAD format. here we give an example of a catalog which contains the mandatory fields (additional columns may be present).

# 1 NUMBER Running object number
# 2 ISOAREA_IMAGE Isophotal area above Analysis threshold [pixel**2]
# 3 X_IMAGE Object position along x [pixel]
# 4 Y_IMAGE Object position along y [pixel]
# 5 MAG_AUTO Kron-like elliptical aperture magnitude [mag]
# 6 MAGERR_AUTO RMS error for AUTO magnitude [mag]
# 7 A_IMAGE Profile RMS along major axis [pixel]
# 8 B_IMAGE Profile RMS along minor axis [pixel]
# 9 THETA_IMAGE Position angle (CCW/x) [deg]
# 10 FLAGS Extraction flags

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|----|
| 1 | 17 | 55.004 | 12.177 | -8.3319 | 0.0490 | 1.120 | 0.930 | -21.7 | 0 |
| 2 | 118 | 46.653 | 48.326 | -10.8804 | 0.0100 | 2.262 | 2.078 | -17.9 | 0 |
| 3 | 7 | 22.492 | 47.101 | -7.7120 | 0.0458 | 0.594 | 0.569 | 35.4 | 0 |