

# Creating updated, scientifically-calibrated mosaics for the RC3 Catalogue

## 1. Introduction

The Third Reference Catalog of Bright Galaxies (RC3) (de Vaucouleurs et al. [5]) contains a complete listing of 23,022 galaxies with  $D_{25}$  apparent major isophotal diameter greater than 1 arcminute and with a total B-band magnitude greater than 15.5. There has been existing literature on this subject using data from the Sloan Digital Sky Survey (SDSS). Hogg and Blanton made g,r,i colored images by using data from the SDSS DR6.<sup>1</sup> The FIGI catalog (Baillard et al. [2]), dedicated to studying morphology of galaxies, also obtained a subset of 4458 RC3 FITS and color images by discarding artifacted or missing data by visual inspection and using SDSS DR4 data and . We perform the mosaicing procedures on the whole RC3 catalog using an automated positional update algorithm on the most recent SDSS DR 10 imaging data. In addition, we designed a mosaicing pipeline that creates scientifically-calibrated mosaics, color-band images, as well as a set of updated position values, which can be easily suited for existing surveys such as 2MASS, DSS, or new imaging data release from Dark Energy Survey and Large Synoptic Survey Telescope for larger sky coverage and multiband images.

## 2. Automation Program

### 2.1. Positional Inaccuracy in RC3 Catalog

The principle motivation behind the automation algorithm is to resolve the problem of centering galaxies and finding RC3 galaxy in a given field of view. Initially using the standard mosaicking steps in Montage, we obtained many images whose galaxy are off center or can not be found due to the inherent inaccuracy of the positions in the catalog. The B2000 coordinates are denoted with two different levels of precision: HH MM SS.s, DD MM SS for the positions that has been updated (with accuracy of about 5-8 arcsec) and HH MM.m, DD MM for galaxies whose positional accuracy remain 1-2 arcminutes in the original catalog. In the latest version of the catalog (de Vaucouleurs et al. [4]), there remains 5492 RC3 galaxies that fall in the latter group.

<sup>1</sup><http://cosmo.nyu.edu/hogg/rc3/>

### 2.2. Parameters of Interest

We have decided to record The Catalogue of Principal Galaxies (PGC) number to identify the RC3 galaxy of interest for cases of source confusion, since every RC3 galaxy has a unique PGC number.

### 2.3. Algorithm

The RC3 object contains its PGC number, updated and catalog ra,dec,radius for each galaxy in the RC3 catalog. The practical purpose of modularizing the algorithm in an object-oriented manner is to keep track of the number of iterations in the recursive steps. Some parts of the program needs to be adjusted for survey-specific, but the core concept (and bulk of the code) should stay the same.

### 2.4. Technical Details

Due to the recent popularity of Python in astronomy, we wrote the program in Python 2.7.6 so that the program's dependencies are more widely supported for extending its usage on future datasets. Most of the mosaic steps are done using IPAC's Montage [6] mosaic engine along with the AstroPy Montage wrapper<sup>2</sup> and the final colored image is created using Astromatic's STIFF v.2.4 [3]. Our choice of the two program makes use of the best features from both programs. Montage creates scientifically-calibrated images by retaining the astrometry and photometry of input sources during image reprojection step. STIFF provides the flexibility of adjusting many variables for the final colored image, as well as automatically estimating upper and lower cuts on the dynamic range using statistics derived from a pixel histogram. The source extraction is done using SExtractor v.2.19.5 (? ). If the mosaicking field is chosen correctly, then SExtractor's skylevel estimation is fairly accurate.

## 3. Pipeline

### 3.1. Class Hierarchy

The motivation behind building a class hierarchy is to establish a mosaicking pipeline for any given catalog and survey data. We identify the essential components required for mosaicking program to work. The relationship between these essential steps are reflected in our design of the abstract `Survey`, `Catalog`, and `Server` classes.

<sup>2</sup><http://www.astropy.org/montage-wrapper/>

### Pipeline Class Hierarchy

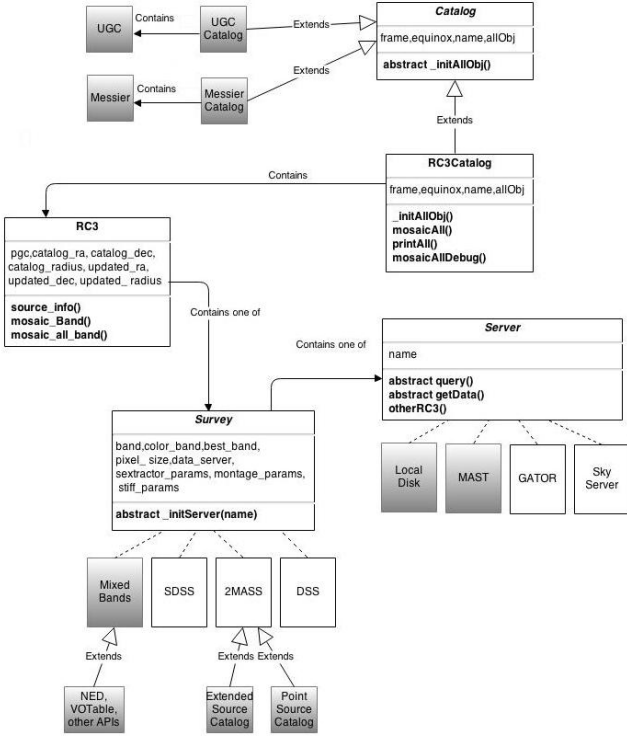


Figure 1: Greyed out boxes are possible extensions of this pipeline

**Server.** Data acquisition is composed of two main tasks: querying imaging data and retrieving data from server. Most surveys have an API that enables data access by SQL or customized query. Figure out how to convert positional values (ra,dec) to record-keeping parameters dependent on the survey’s telescope. (tiles, frames...etc) For example, SDSS image frames are uniquely identified by a particular combination of run,camcol,field. Usually this step can be done using the SQL search. Our choice of using a server instead of a data object enables code reusability across various surveys that uses common server tools, such as IPAC’s GATOR query service (Alexov et al. [1]) or Astroquery.

**Catalog.** The **Catalog** class contains a list of objects that lies inside the catalog. Although the use of the Catalog container class seem unnecessary, it enables a clear separation between basic mosaicking functionality for individual galaxies. This can be used to study some particular object, executed on all objects in a **Catalog**, or simply used for debugging purposes. This abstraction barrier ensures minimal changes to the code in both classes when an investigator decides to input data from a new survey in the future.

## 4. Result from SDSS run

There are ~ RC3 galaxies within the footprint. on average the program processes 1.21 galaxies per minute

### 4.1. Known Errors

Even though a series of exception handling and error prevention mechanisms were put in place,

- mProjectExec is the montage Mosaic procedure that creates the reprojected image from the raw FITS files. Sometimes reprojected images are not created even when Montages’ debug statement clearly shows that the reprojection was successful and table and header files are corrupted. This results in an error in later mosaicing steps. We have implemented error prevention mechanism to ensure that mosaic procedures terminates correctly in such cases and wrote the problematic galaxy into failed\_projection, which can be examined later.
- Montage’s background rectification module is not used in creating the FITS mosaics. Attempts were made in implementing these procedure, however it is sometimes stuck in the step where the background model is applied to the projected images and produces huge difference images files (50GB) for reason that we have not figured out yet. This should not affect the astrometric quality of the data product. The only visible difference is observed in the color images for 2MASS, so will likely affect the photometric quality of the resulting 2MASS mosaics.(?)

### 4.2. Performance

We accelerate the mosaicing process by performing the recursive algorithm on only a single band FITS file designated as **best\_band**, then mosacking all bands only once per object. For SDSS, we use the image obtained by the r band filter since transmission curve in Stoughton et al. [7] shows that r band has the highest quantum efficiency.

Most of the computation time is spent on downloading the raw FITS files from the survey’s specific server. Therefore, even though Montage’s modular design enables its performance to scale with number of processor (Jacob et al. [6]), the process would not be significantly sped up by the use of Message Passing Interface (MPI). Therefore, the speed depends more on the bandwidth (downloading rate) rather than the number of cores in the machine. On jbigdog spec machine, the program processes on average about 80 RC3 objects per hour using SDSS data. This average runtime would also depend on the sky coverage of the particular survey, the speed of query ...etc.

This process can be significantly sped up if the investigator already has imaging data stored locally on a disk or have access to running the mosaic program alongside the survey’s datacenter. We have designed our class hierarchy such that this can be written as a subclass of **Server** with user-defined details of where the images are stored. The Montage mBgExec takes a long time.

## 5. Possible Uses of Data Product

Can be incorporated in the photo pipeline in future survey to make pretty rc3 images. with larger focal plane more photon such as the LSST saturation especially with the DSS data, full coverage of the sky map out where bright objects are.

The scientifically calibrated FITS images can be used as for individual studies. It can be used for improved astrometry (as we did) in updating the catalog. Can also do photometry to determine galaxy property

Another possible usage is to combine the calibrated mosaics into multiband color images with mosaics from single/double band surveys such as POSS-I and GALEX.

## 6. Conclusion

Can talk about here how LSST and future telescope can mask theses so that image not saturated

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