

# A Study of the Spiral Galaxy M101

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## Abstract

We present the results of summer research on the spiral galaxy M101. We have processed and examined images of this object taken from the ground using narrow-band interference filters centered on wavelengths of several bright nebular emission lines. Our study included examining emission from both high and low ionization ions,  $O^{++}$  and  $N^+$  respectively. The presence of HII regions in the galaxy as well as the ionization structure across the galaxy is discussed.

## Introduction

We are student researchers from Elizabeth City State University who participated in the Undergraduate Research Institute in Astrophysics (URIA) program at South Carolina State University (SCSU) during the summer of 2000. URIA is an eight week, residential course of study in astrophysics for underrepresented minority students. It is intended to encourage students to pursue graduate studies or a career in space science. The objectives of this particular study are as follows:

1. To obtain a better understanding of galaxies.
2. To gain experience in image processing.
3. To examine in some detail the spiral galaxy M101.

These objectives have been met as discussed in the following sections.

## Galaxy Types

A galaxy is the largest single unit of stars held together by gravity. There are three different types of galaxies, spiral, elliptical, and irregular. Figures 1a, b, and c show examples of each type. Galaxies have an enormous range in mass and size as indicated in Table 1. Galaxies are separated by vast gulfs of space. For example, our own Milky Way is over 160,000 light years away from its nearest extragalactic neighbor, the Large Magellanic Cloud. Despite these large separations, galaxies interact through gravitational attraction in such a way that they can alter each others shape and evolution.

Current theories on galactic origins say that a galaxy begins with a gravitational collapse of a primordial gas cloud into a protogalaxy. If star formation occurs early in the collapse then it will retain a spherical shape and evolve into an elliptical galaxy. If star formation occurs slowly then it will remain gaseous and form into a disk similar to what we see in a spiral or irregular galaxy.

Components of a **spiral galaxy** are the nucleus, disk, and the halo. Some spirals also have a bar attached to both sides of the nucleus. The arms of the spiral are imbedded in the disk and contain large amounts of dust mixed with bright emission nebulae. The spirals rotate in the sense that the arms trail.

An **elliptical galaxy** displays a smooth distribution of stars in the shape of a squashed sphere with no spiral arms within a cross section of the ellipse. Elliptical galaxies contain mostly old stars and occur in a wide range of sizes and masses, from the largest to the smallest galaxies in the universe.

The third category of galaxy is an **irregular galaxy**. Irregular galaxies are small, low-mass

objects with an irregular or amorphous shape. Irregulars often have regions with high stellar formation rates and numerous young stars embedded in large amounts of gas and dust.



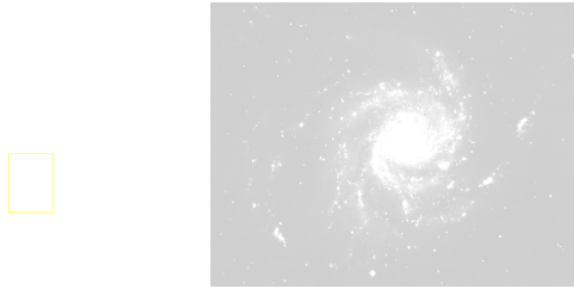
**Figure 1a: A spiral galaxy**

**Figure 1b: An elliptical galaxy**



**Figure 1c: An irregular galaxy, the Large Magellanic Cloud  
M101**

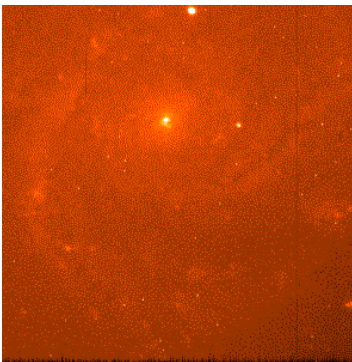
Figure 2 is an image of the spiral galaxy M101. The boxed area to the right of the nucleus is the region covered by some of our San Pedro Matir (SPM) images. Table 2 includes information about M101, which is one of the most prominent spirals in the sky because of a combination of its large size and nearness to Earth. According to Burnham's *Celestial Handbook*, the M101 galaxy was discovered in 1781 by P. Mechain and described by Messier as "... a Nebulae without a star, very obscure and pretty large, between the left hand of Bootes and the tail of the Great Bear." M101 is one of the bluest galaxies known because of the large number of HII regions and young stars in its arms.



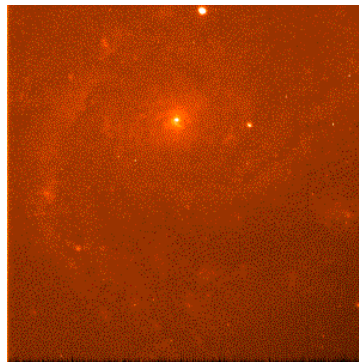
**Figure 2: A wide-field view of M 101**

### **Data Set and Image Processing**

We used images taken at SPM in Baja, Mexico in June 1994. Narrow-band filters isolated select wavelengths of light to allow one to examine the galaxy in detail and look for regions of high and low ionization, including HII regions. Table 3 describes the observing site. The Image Reduction and Analysis Facility (IRAF) is the software that was used for the image reduction process. Image reduction is the process of removing noise and calibrating CCD images. A number of types of noise are introduced into the images during the observing process. These noise sources and the means of correcting them are described in B. Teasdel's paper at this conference. The steps that we took to minimize the effects of cosmic rays, bias, bad pixels and flat field variations are listed in Table 4 along with the IRAF application used in each step. A good example of the results of noise removal are shown in Figures 3a and 3b which are before and after, respectively, cosmic rays and bad pixels have been removed. The images are given a false color to emphasize the results. Close examination of Figure 3a will show dark pixel columns to the upper left and the right of the image as well as numerous small white dots which are cosmic rays. Most of the bad pixels and cosmic ray hits have been removed in Figure 3b.



**Figure 3a: Unprocessed M 101 image**

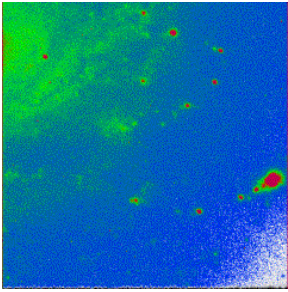


**Figure 3b: Processed M 101 image**

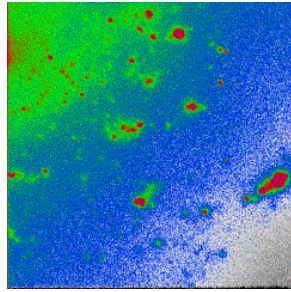
### **Results**

The results of our initial image reduction is shown in Figures 3b, 4 and 5. Figures 3b and 4 were taken through a filter centered on the  $O^{++}$  ion's emission line at 5007 Å. Figure 5 was taken through a filter centered on the  $N^{+}$  ion's emission line at 6584 Å. Figure 3b is an underexposed image of the nuclear region of M101. Of greater interest are Figures 4 and 5 which show a portion of one of the spiral arms of M101 enclosed in the box in Figure 2. Figures 4 and 5 are shown in false color to emphasize the regions of emission of their respective ion. The dark red color in both figures locate HII regions in the galaxy. For more information on HII regions and the

atomic processes which give rise to the emission by these ions, see T. Battle's paper at this conference.



**Figure 4: O<sup>++</sup> emission in M 101**



**Figure 5: N<sup>+</sup> emission in M 101**

The most obvious difference between the two images is that the nitrogen ion shows far more regions of emission than the oxygen. This is in part due to dust in the galaxy which will preferentially dim the 5007 line more than the 6584 line. Another reason is that the singly ionized nitrogen shows regions of lower ionization than the doubly ionized oxygen. While both ions will be found in emission in HII regions, the oxygen can only be doubly ionized in the highest ionization regions which are fewer in number and smaller in physical size than the lower ionization regions.

### **Summary**

We have conducted a review of galaxies and examined the spiral galaxy M101 in detail. Previously unpublished imagery of M101 has been partially reduced and is ready for calibration. The spiral structure and HII regions in the arms are readily visible in light emitted by the ions of O<sup>++</sup> and N<sup>+</sup>.

### **Acknowledgements**

The authors gratefully acknowledge funding provided by NASA-MU-SPIN to Elizabeth City S

### **References**

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- Burnham, Jr. Robert, 1978, Burnham's Celestial Handbooks Vol. 3. pp. 2000-2001.
- Bishop, Roy. Observer's Handbook 2000, 2000, p.156
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**Table 1**

## General Characteristics of Galaxies

(Source: The Universe Revealed by Chris Impey &amp; William K. Hartman)

Characteristic	Spirals	Ellipticals	Irregulars
Mass ( $M_{\odot}$ )	$10^9 - 10^{12}$	$10^6 - 10^{13}$	$10^8 - 10^{11}$
Luminosity ( $L_{\odot}$ )	$10^8 - 10^{11}$	$10^5 - 10^{11}$	$10^8 - 10^{11}$
Diameter (kpc)	5 - 50	1 - 200	1 - 10
Stellar populations	Old halo and intermediate age bulge, young disks	Old halo	Young and intermediate age
Interstellar material	Gas and dust in disk	Small amounts of gas and dust	Copious amounts of gas, some dust
Large-scale galaxy environment	Small groups, low-density regions	Rich clusters	Low-density regions

**Table 2**

## Properties of M101

Quantity	Value
Right Ascension (2000)	$14^{\text{h}} 03.13^{\text{m}}$
Declination (2000)	$54^{\text{h}} 21.0^{\text{m}}$
Size	$4.86 \times 10^5 \text{pc}$
Galaxy Type	Sc I
Distance from Earth	7.6 Mpc
Constellation	Ursa Major
Blue magnitude	8.18
Visual magnitude	7.72
Color index B-V	0.46
Radial Velocity	$+372 \text{ km/s}$
Other Names	Pinwheel Galaxy, NGC 5457, UGC 8981

**Table 3**

## San Pedro Matir Observatory

<b>Observatory Location</b>	Baja, Mexico
<b>Telescope</b>	2.12 Meter Telescope
<b>Elevation</b>	2800 Meters
<b>Latitude</b>	31°2'39" north
<b>Longitude</b>	115°27'49" west
<b>CCD Chip Size</b>	1024 x 1024
<b>Binned Data</b>	512 x 512
<b>Filters Central Wavelength (Å)</b>	4770, 4861, 5007, 6450, 6563, 6584

**Table 4**  
IRAF Steps Used

<b>Step</b>	<b>Task Name</b>	<b>Result</b>
1	cosmicrays	removes cosmic rays
2	fixpix	fixed bad columns
3	imarith	average bias frames
4	imarith	subtract bias frames
5	imarith	divide by flat field
6	imarith	divide by exposure time