

The Ionization Structure of the Irregular Galaxy NGC 4449

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ABSTRACT

We present the results of our study of this starburst galaxy using original data taken with the 2.12-meter telescope at San Pedro Matir, Baja, Mexico. The CCD images were taken through narrow band interference filters centered on wavelengths of important nebular emissions lines such as the Balmer series of hydrogen, doubly ionized oxygen and singly ionized nitrogen. The ionization structure of the galaxy is studied through comparison of high and low ionization ratio maps.

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INTRODUCTION

A group of ten students spent the months of June and July 2000 as part of the Undergraduate Research Institute in Astrophysics (URIA) at South Carolina State University (SCSU). NASA/MU-SPIN funded this project through the Network Resource and Training Sites (NRTS) at SCSU, the City College of New York (CCNY), Elizabeth City State University and Tennessee State University (TSU). My own work with URIA included an overview of astronomy, the physics of the interstellar medium, astrophysical image-processing and other computer and web based applications.

The objectives of this particular study were; (1) to better understand galaxies including starbursters; and, (2) examine in detail NGC 4449. These objectives have been met as demonstrated in the sections which follow.

ATOMIC PROCESSES

Clouds of interstellar gas will emit their own light if they are located within the vicinity of young, hot stars, which are the original source of energy for the emission. The major atomic processes which take place in emission nebula are listed below.

Ionization occurs when ultraviolet radiation from the star ionizes the hydrogen in the gas, converting it into a plasma of positive hydrogen ions (protons) and free electrons. Detached protons and electrons move around as free particles in the gas.

Recombination takes place when a proton captures a passing, free electron, becoming neutral hydrogen again. The electron falls through the various energy levels of the hydrogen atom on its way to the ground state, emitting a photon for each jump to a lower energy level closer to the nucleus of the atom.

Excitation occurs when an electron collides with an ion. If the electron gives up some of its kinetic energy to the ion, it excites the ion to a higher state of energy.

Deexcitation occurs in one of two ways; (1) as an ion collisionally deexcites, the free electron that caused the collision takes energy away from the ion and no photon is emitted; (2) in the case of spontaneous decay, a bound electron in the ion drops to a lower energy level spontaneously with the resultant emission of a photon.

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GALAXIES and STARBURSTERS

Galaxies are gravitationally bound aggregations of stars, gas and dust. In the 1920's, Edwin Hubble classified galaxies by their shape into three major types, spiral, elliptical and irregular. Examples are shown in Figures 1a, b and c. More details about galaxies can be found in the article from this conference by K. Banks and I. Lister.

A galaxy which belongs to one of these three types may also belong to a subtype known as a starburst galaxy. Starburst galaxies are the site of an ongoing or recent dramatic rise in the rate of star formation. A normal, non-starburst, spiral galaxy will form 1-10 solar masses per year. Estimates for star formation rates for a starburst galaxy during a burst range from 10-300 solar masses per year and possibly as much as 1000 solar masses per year in a very massive galaxy.

A sudden increase in the star formation rate also results in an increase in the supernovae rate and the amount of energy imparted to the interstellar medium by high-speed winds from young, massive stars. Thus, a starburst galaxy often has a galactic wind, which pushes material up and out of the plane of the galaxy. Starbursters often display superbubbles and large arcs of ionized gas, which are expanding outward to escape the home galaxy.



Figure 1a: A spiral galaxy



Figure 1b: An elliptical galaxy



Figure 1c: An irregular galaxy



**Figure 2: NGC 4449
NGC 4449**

The irregular galaxy NGC 4449 is an example of a starburst. This object is relatively nearby at a distance of only 5 megaparsecs. Table 1 includes some information about this object. In Figure 2 the red glow in NGC 4449 is from the hydrogen balmer emission line which originates in the gaseous nebulae. Perhaps the most striking feature of this galaxy is the incredible number of star forming regions. What appears as stars in Figure 2 are actually clusters, each of which contain hundreds of stars ionizing a very large region of surrounding interstellar gas known as a Giant Extragalactic H II Region (GHER). The GEHR is what looks like a star.

HII REGIONS and GHERs

An H II region is a zone of gas in which all of the hydrogen gas present is ionized. H II regions characteristically include several bright, hot stars whose ultraviolet radiation is converted to visible light as described earlier. A typical H II region in our galaxy has a diameter of a few parsecs, a gas temperature of 10,000 K with a density of about 100 to 10,000 particles/cm³. GEHRs are ionized hydrogen regions as well but on a much grander scale. They are most commonly characterized by diameters greater than 100 pc, a total ionized gas mass of 10⁴-10⁵ M_⊙, and an average density of 1-10 particles/cm³. Typically one finds 100 to 200 ionizing stars within a GEHR.

DATA REDUCTION and RESULTS

The data for this research project came from the observations taken at the San Pedro Matir Observatory in Baja, Mexico in June 1994. Table 2 includes information on the specific images used in this study. For image processing, we utilized the IRAF software package to remove noise sources and to create our ratio maps. For more information on CCD noise see the article at this meeting by B. Teasdel; for details on IRAF and image processing, see the paper by K. Banks and I. Lister.

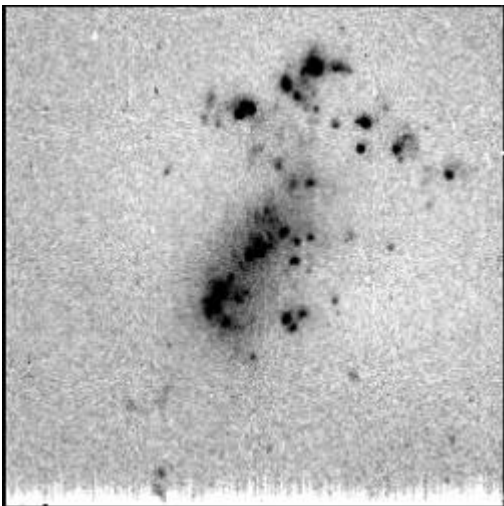


Figure 3: OIII/H β Ratio Map

Figure 3 is a ratio map in which our image taken with the [O III] filter at 5007 Å was divided by the image taken through the H β filter at 4861 Å. The dark areas are regions of high ratio values of 3.0–3.5 which correspond to high ionization regions at the center of the GEHR, closest to the cluster of ionizing stars.

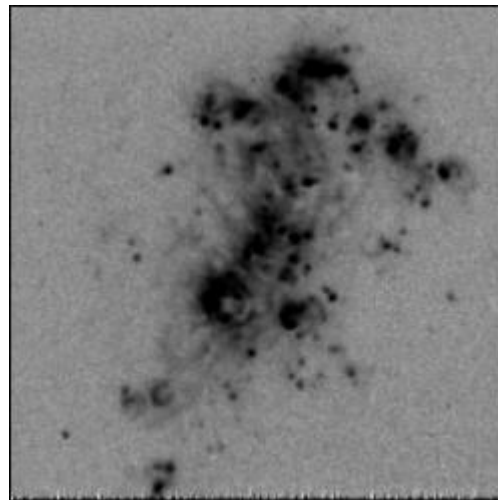


Figure 4: NII/H α Ratio Map

Figure 4 is also a ratio map in which the image taken of the [N II] line at 6584 Å was divided by the image taken through the H α line at 6563 Å. The dark areas have large [NII]/H α values of around 0.2. These are the low ionization regions in and between adjacent GEHRs. The low ionization regions cover a larger area of each GEHR, which is obvious when comparing the size of each GEHR in both Figure 3 and 4. Furthermore, the fact that Figure 4 shows far more ionization *between* the GEHRs than in Figure 3 confirms that most of the high energy photons are absorbed in the inner part of the GEHRs leaving only low energy photons to travel further out into the galaxy.

SUMMARY

The four major atomic processes which occur in gaseous nebulae have been discussed. These processes form the foundation for understanding the nature of H II regions, GEHRs and the interstellar medium in galaxies. New ground-based imagery of NGC 4449 has been processed and are ready for further study.

ACKNOWLEDGEMENTS

We wish to acknowledge funding for this research from NASA to Medgar Evers College through its PAIR and Partnership awards and from NASA/MU-SPIN through NCC 5-98 to the CCNY, NCC 5-116 to SCSU and NCC 5-228 from NASA-URC to TSU. The author also wishes to thank Dr. Leon Johnson at Medgar Evers, Dr. Shermane Austin at CCNY and Dr. Donald Walter at SCSU.

REFERENCES

Bishop, Roy 1998, Observer's Handbook 1998

Hirshfeld, Alan & Sinnott, Roger W. 1998, Sky Catalogue 2000.0, Volume 2.

Kennicutt, R.C. 1983, Astrophysical Journal, 272, 54

Telesco, Charles 1988, Annual Review of Astronomy and Astrophysics, 26, 343

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TABLE 1

Properties of NGC 4449

Galaxy Type	Magellanic Irregular
DDO Luminosity	III
Right Ascension (α 2000.0)	12 ^h 28.2 ^m
Declination (δ 2000.0)	+44° 06'
Constellation	Canes Venatici
Distance	5.0 Mpc
Size Major diameter	5.1' (angular), 7.42 kpc (linear)
Size Minor diameter	3.7' (angular), 5.38 kpc (linear)
B (Blue) Magnitude	9.85
V (Visual) Magnitude	9.44
B-V (Color Index)	0.41
Radial Velocity	+262 km/s

TABLE 2
SPM Data Log for NGC 4449

Image Name	Filter Central λ	Ion	Ionization Potential
n4n44003	6563 Å	H II	13.6 eV
n4n44013	6584 Å	N II	14.5 eV
n3n44005	5007 Å	O III	35.1 eV
n3n44006	4861 Å	H II	13.6 eV