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Long slit CCD observations of active and normal galaxies

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LONG SLIT CCD OBSERVATIONS OF
ACTIVE AND NORMAL GALAXIES

by

Timothy Edward Carone

A Dissertation Submitted to the Faculty of the

DEPARTMENT OF PHYSICS

In Partial Fulfillment of the Requirements
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DOCTOR OF PHILOSOPHY

In the Graduate College

THE UNIVERSITY OF ARIZONA

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GRADUATE COLLEGE

As members of the Final Examination Committee, we certify that we have read
the dissertation prepared by Timothy Edward Carone
entitled Long Slit CCD Observations of Active and Normal Galaxies

and recommend that it be accepted as fulfilling the dissertation requirement
for the Degree of Doctor of Philosophy.

John T. Stocke
John T. Stocke

May 25, 1990
Date

Robert H. Parmenter
Robert H. Parmenter

5/25/90
Date

Laurence C. McIntyre, Jr.
Laurence C. McIntyre, Jr.

5/25/90
Date

John O. Stoner, Jr.
John O. Stoner, Jr.

6-12-90
Date

Date

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ACKNOWLEDGMENTS

Unfortunately, University regulations force me to refer to this section as the “Acknowledgments”; I would have preferred “Dedication”. When I first realized many years ago that a person must write a dissertation for their Ph.D. I knew instantly to whom it would be dedicated, namely my mother and father. The most painful thought I have had to endure as I wrote this dissertation was that my cherished dream of handing my father this completed work, seeing him smile at me through his cigar and say “Congratulations T, I’m really proud of you kid” would never come to past. Why the Almighty saw it fit to call my father home is a question that has remained burning and unanswered in my consciousness for what seems an eternity. I have been deprived of my father and a life-long dream has been diminished to nothing. Why?

Deep inside us all we have our heroes, though most of us would not be wont to admit to this. Admitting we continually aspire to levels attained by others seems to diminish us as if what we have done up to the present was not good enough, that we had failed to give the canonical “110%”. However, in times of great trouble or dire straits we instinctively think of our heroes, put them in our position or situation and hope we can derive a course of action by determining their response. Viewing my father, his life and the effect he had on his family, friends and co-workers, I realize that in death, as in his life, he epitomizes all that is good. Amidst present day “heroes” I find none whose depth of character, moral convictions and social compassion is comparable to those qualities I found (and still find) in my father. I know of no other “hero” to whom I look up to or to whom I can turn when in need of guidance. I know of no others who can inspire me or fill me with a comparable zeal for life and respect for humanity. A family friend of many years told me once that I reminded him of my father. I later realized that this was the greatest compliment that I could ever hope to receive.

As for my mother, what can I say? To myself, my family and all our friends and relatives, she is a saint who is loved dearly. To paraphrase my paternal grandfather, the smartest thing my father ever did was to “marry that Murphy girl from down the street”. She is now the focal point for our family. Around her is the haven to which her children and grandchildren will always return. Through her, the image of my father is manifest and passed on to their grandchildren.

Therefore, it is with great humility that I dedicate this dissertation to my mother, Elizabeth Murphy, and to my father, Sabino Pupillo. The English language is too inadequate for me to describe the joy and happiness I have derived from being their son.

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ABSTRACT

This work presents a comparative study between a sample of Seyfert galaxies and a control sample of normal galaxies that was done to determine if the presence of an active nucleus would in any way effect its host galaxy. An obvious manifestation of such an effect would be changes in the star formation properties of the Seyfert galaxies relative to the control sample. Since the star formation rate is directly related to the amount of H α emission, the H α luminosity along the major axis of each program galaxy was measured.

The result of this work was twofold. First, a highly optimized CCD camera system was developed for use as a facility instrument. This camera system was then used to spectroscopically survey 15 Seyfert and 15 normal galaxies. H α emission was measured in 12 Seyfert and 12 normal galaxies. It was found that after comparing a number of different quantities all dependent on the star formation process, there was no discernible difference between the sample of Seyfert galaxies and the sample of normal galaxies. In particular, the total H α emission, line ratios and various properties of the sites of star formation and their spatial distribution were similar between the two samples. This implies that the disk regions of Seyferts are identical to the disks of normal spirals as determined by the properties of their giant HII regions.

Chapter 1

Introduction

1.1 Background

Seyfert galaxies comprise about 10^{-4} of all observable galaxies but given the large amount of telescope time devoted to their study, one would find their small numbers hard to believe. Unlike most galaxies, the dominant amount of radiation from Seyferts arises not from their combined stellar populations but from the gravitational and electromagnetic interaction of some centrally condensed object with its surrounding nuclear gas and dust. Twenty-five years of intense study have given us some information but there still remain basic questions about the nature of this centrally condensed object, its evolution and the kinematics and dynamics of the surrounding gas and dust. Disentangling all that goes on in a region that appears as a point source to our telescopes has been likened to determining the nature of a car's engine and transmission by examining only the car's exhaust.

During the Los Angeles blackout of World War II, Carl Seyfert, expanding on earlier work (Fath 1909; Slipher 1917; Hubble 1926), showed conclusively that spectra taken of the centers or nuclei of some galaxies showed emission lines (Seyfert 1943). These spectra contained many high-ionization emission lines whose width was greater than the absorption lines observed from the nuclei of normal galaxies. Combined with the bright

semi-stellar appearance of the nucleus (from which the emission lines arose) and their differences relative to HII region spectra, it was clear that a new class of emission line regions had been found. Some spectra clearly showed that the emission lines were composites because they consisted of spectral lines with disparate values for their full width at half maximum (FWHM). Some emission lines were termed broad ($\text{FWHM} \sim 10^4 \text{ km sec}^{-1}$) and others called narrow ($\text{FWHM} \sim 10^2 \text{ km sec}^{-1}$). Some lines, such as the first two Balmer lines of hydrogen showed both narrow and broad components.

With the advent of larger telescopes and quantum leaps in detector technology the study of active galactic nuclei (Seyfert galaxies, quasars and BL Lac objects) has led to a classification scheme and a first order understanding of these objects. Seyfert galaxies are classified spectroscopically (Khachikian and Weedman 1974). A Seyfert 1 has broad H I, He I and He II emission lines and narrow forbidden lines such as [OIII] $\lambda\lambda 4959, 5007$, [NII] $\lambda\lambda 6548, 6584$ and [SII] $\lambda\lambda 6717, 6731$. A Seyfert 2 also has only narrow H I, He I and He II emission lines along with narrow forbidden lines. There are also intermediate-type Seyferts denoted as 1.5, 1.8 and 1.9. The Seyfert 1.5 has intense broad and narrow H I emission lines that are clearly distinguishable from one another; a 1.8 has weak broad H α and H β components in addition to the narrow components while a 1.9 has only a weak H α broad component and strong narrow components.

This classification of Seyferts based on the width of their emission lines has naturally led to a model for the nuclear or central region that contains a high density ($N_e \sim 10^9$

cm^{-3}) inner region where the broad lines are formed (the broad line region or BLR) and a low density ($N_e \sim 10^4 \text{ cm}^{-3}$) outer region where only the narrow lines are formed (the narrow line region or NLR). This model has withstood the test of time but recent evidence has shown what has been long suspected—this model is an oversimplification.

Since the nucleus of Seyfert galaxies has such strange properties, most studies of these objects have been restricted to this inner region and its immediate environment ($r < 1 \text{ kpc}$ or so). Recent work (Begelman 1984; Chiang *et al.* 1987) has shown that the influence of the nonthermal radiation from the nucleus of Seyfert galaxies and quasars on the large-scale disk structure ($r > 1 \text{ kpc}$) may heat up the interstellar medium leading to large-scale gas motions in the vertical direction. However, observations of HII regions in nearby Seyfert galaxies show that no discernible difference is evident.

This work made a comparative study between a sample of Seyfert galaxies and a control sample of normal galaxies in order to study the possible effects of an active nucleus on its host galaxy. It is natural to speculate that the presence of such a source of radiation in the nucleus may, in fact, influence the interstellar medium of the host galaxy. If so this could alter the star formation rate in the disk region, possibly affect the initial mass function and fundamentally alter the evolution of the host galaxy. However, the effect of nuclear activity on the host galaxy might be minimal, resulting in disk properties like those found in normal galaxies. The characteristics of disk emission in normal galaxies have been well studied, both in terms of individual HII regions and the distribution of HII regions

in their galaxian environment. Any similarities or differences seen in the disk emission of Seyfert galaxies relative to normal galaxies could provide additional information about the origin and evolution of an active nucleus. Does such a nucleus affect its surroundings and if so, what is the radial extent of this influence? Limiting the influence of an active nucleus on its host galaxy will impose constraints on any theoretical explanation. Is nuclear activity and unusual disk emission the result of an external influence? The level of activity in both the nucleus and in the disk would limit the strength of the influence.

In this chapter, we first describe the general characteristics of Seyfert and normal galaxies. This discussion includes what is known about emission in the nuclear and the disk regions of both types of galaxies as well as their local galaxian environment. We also describe the two studies that motivated this work (Dahari 1984; FWS88).

1.2 Normal Galaxies

1.2.1 Global Properties

The vast majority of observable spiral galaxies are termed “normal”. This description implies that the radiation observed from the nucleus and from the spiral arms originates from an aggregate of stars of various spectral types and from HII regions. Observations of HII regions in the disks of nearby late type galaxies (Searle 1971; Smith 1975) showed the existence of a radial abundance gradient. The line ratios $[\text{OIII}] \lambda 5007 / \text{H}\beta$ and $\text{H}\alpha / [\text{NII}] \lambda 6584$ decrease as one moves from the outer to inner galactic regions. The con-

clusion is that the abundance of oxygen relative to hydrogen and the abundance of nitrogen relative to oxygen both increase with decreasing distance from the nucleus.

Recent work (Kennicutt 1989) has shown a threshold exists for star formation. For local gas densities less than some critical value, star formation is suppressed. As the local gas density approaches the critical density, the massive star formation rate increases very fast, much faster than a standard Schmidt model (Schmidt 1959) would allow. However, once above this threshold, the star formation rate is well fit by a Schmidt model. This threshold behavior is well explained by a simple disk stability model (Toomre 1964) and it has been shown that the gas in spiral disks remains near the critical density.

1.2.2 Emission Line Regions

Traditionally, the study of emission-line regions in spiral galaxies has been confined to the spiral arm region because this is where star formation occurs in giant HII regions (HII regions that have their $H\alpha$ luminosities, $L(H\alpha), \geq 10^{37}$ ergs sec⁻¹). The rate and history of star formation in spiral galaxies is one of the more fundamental variables of the Hubble sequence (Searle, Sargent and Bagnuolo 1973; Larson and Tinsley 1978; Kennicutt 1983; Gallagher, Hunter and Tutukov 1984). As one moves along the Hubble sequence from early type S0 galaxies to the late type Sc and Im galaxies, the disks of spiral galaxies become populated with regions of massive star-formation. Previous work (Kennicutt 1988) has shown that the properties of spiral arm HII regions depend on the Hubble

type and on the luminosity of the host galaxy. The HII regions in late type Sc and Im galaxies are more abundant, up to 50 times brighter and several times larger than those found in Sa and Sb spirals of the same absolute magnitude. Their difference might be due to an increase in the number of HII regions in late type spirals relative to early types and to changes to the characteristic sizes of the HII regions. The high Balmer luminosities observed in giant HII regions suggest that they contain from 100–1000 solar mass stars whose spectral type range from late O to early B with effective temperatures ranging from 35,000–40,000 K (Evans and Dopita 1985, 1986; McCall *et al.* 1985).

Recently it has become clear that the nuclei of up to 80% of normal spiral galaxies contain emission line regions that closely resemble HII regions (Keel 1983). The properties of these nuclear emission line regions are similar to the brightest HII regions in the disk (Kennicutt *et al.* 1989) but important differences exist. In particular, the emission line ratios and line profiles indicate that a secondary ionization component exists in addition to the hot stellar continuum. This secondary component is thought to be either an active nucleus (i.e., a non-thermal power law continuum) or large-scale shocks. These results are consistent with the recent conclusions that the nuclei of spiral galaxies are composite in nature. The emission is thought to be the result of a Seyfert-like nucleus ionizing nuclear gas that is surrounded by star forming regions that were themselves induced by the active nucleus.

1.3 Seyfert Galaxies

1.3.1 Global Properties

The majority of all Seyfert galaxies are either Hubble Type Sa, SBa, Sb or SBb. Very few early type (earlier than S0) or late type (later than Sc or SBc) Seyferts are known. Surface photometry of Seyferts (Yee 1983) has shown that the disks of Seyferts have colors similar to those of normal galaxies whose Hubble types range from Sa to Sbc. It has also been shown (Su and Simkin 1987; Simkin *et al.* 1980) that Seyferts seem to possess an abundance of bars and rings. Their presence suggests the existence of a non-axisymmetric potential that could funnel gas and stars into the nuclear region and thereby sustain an active nucleus.

While spiral structure is definitely present it appears at first glance that the disk structure is distorted. In fact examination of the UGC catalogue entries for the Hubble types of the two samples used in this study show that a much greater uncertainty exists in the Hubble types assigned to the Seyfert sample than to those assigned to the normal sample. Inspection of photographic plates taken of Seyferts shows why this is true (Adams 1977). At first, there appears to be a surplus of Seyfert galaxies that are either disturbed or are part of interacting systems. Previous work (Dahari 1984, 1985; Kennicutt and Keel 1984; Keel *et al.* 1985; FWS88) attempted to put this observation on a firmer statistical basis by comparing the environment of Seyferts with the environment of a control sample of normal galaxies. Except for FWS88, there is general agreement that there is an excess of

companions to Seyfert galaxies and that there is a great excess of close companions to Seyferts relative to a control sample of normal galaxies. It was also shown that an excess of Seyfert galaxies are members of interacting pairs of galaxies but that this excess does not exist if the strength of the interaction is very strong. However, FWS88 questioned some of these general conclusions. Their results showed only a slight excess of close companions (identified as low luminosity galaxies with $M_V \geq -18$) and was much smaller than that claimed by others (Dahari 1985). These results will be discussed in more detail below since this present work was motivated by these studies.

1.3.2 Emission Line Regions

The nucleus is the most prominent emission line region of Seyfert galaxies. The nuclear regions of Seyfert galaxies possess a wide range of ionization (OI to Fe X) that are formed in the broad line region and in the narrow line region. As is discussed in Chapter 4, to determine empirically the physical conditions present in a gas cloud, one must measure the spectral lines. It is much more difficult to determine the gas conditions in the broad line region since strong, unambiguous forbidden lines are never seen there. It is possible to determine electron densities and temperatures (as is done in HII regions) in the narrow line region since forbidden lines are formed there due to the lower densities.

Regardless of the current theoretical ideas that explain the origin of the ionizing continuum, there is no disagreement that this continuum is a power law that has the func-

tional form $f_\nu \propto \nu^{-\alpha}$ where $\alpha = 1.0\text{--}1.5$. This means that unlike hot OB stars, the Seyfert nucleus and its near-nuclear regions see a substantial fraction of high energy photons capable of ionizing C, N, O and S. These photons create a partially ionized zone of H because the cross-section for ionization of H by high energy photons decreases with increasing energy. Therefore, there are enough photons present to ionize C, N, O, S and Fe and the densities are low enough to permit forbidden transitions to occur. The emission lines seen in normal galaxies (whether from the nuclear region or from H II regions) contain weak [NII] $\lambda\lambda 6548, 6584$, [SII] $\lambda\lambda 6717, 6731$ and very weak or absent [OI] $\lambda 6300$. This is the distinguishing difference between AGN spectra and HII region spectra. In HII regions, this partially ionized zone is not present.

1.4 Studies of the Environment of Normal and Seyfert Galaxies

An accepted but not unequivocally proven fact pervading the field of active galaxies is that some of the observed nuclear activity in galaxies can be induced by interactions with nearby systems. Much work has been done trying to quantify the effect on active galaxies of all types by their immediate and their non-local environment (Balick and Heckman 1982). Work done over the past ten years points to a correlation between the presence of nearby companions and nuclear activity (Adams 1977; Dahari 1984; FWS88). In his photographic survey of Seyferts, Adams commented on the apparent number of companions

found near Seyfert galaxies. Dahari (1984) undertook a statistical study to determine if Seyferts possessed an enhancement of companions relative to normal galaxies. Such an enhancement, if found, would point to the presence of the companion as a leading reason for the nuclear activity.

More recently, FWS88 undertook a similar study but used very different criteria to choose their control sample, to discriminate against foreground and background galaxies and to quantify the galaxian environment from galaxy counts. They also analyzed their results using a method different than the one used by Dahari. They concluded that Seyferts do not possess a clear excess of luminous companion galaxies when compared to a control sample of normal galaxies. In an effort to understand the differences between these two studies, FWS88 modified their background subtraction technique because it may have been too restrictive. After this modification, a clear excess of companions was found that FWS88 identified as low luminosity galaxies ($M_V \geq -18$). However, this excess was not as large as that found by Dahari.

1.5 Summary

The objective of this dissertation was to implement a CCD camera system operating as a facility instrument on the University of Arizona 2.3 meter telescope at Kitt Peak and then use that camera system to perform a low resolution, long slit study of a sample of

Seyfert galaxies and a sample of normal galaxies (Carone *et al.* 1987). Such a study would allow us to compare a variety of properties of the disk or off-nuclear regions of these samples and search for differences that could be associated with the presence or absence of a Seyfert nucleus. We examined the integrated H α emission along the major axis, the emission line ratios from these regions and the radial position of each emission line region. We also examined the luminosity of the brightest HII region in each galaxy and the relationship between the non-thermal nuclear luminosity from the Seyferts and their disk emission properties.

In Chapter 2, we discuss in detail the CCD camera system used for this study and its optimized characteristics. In Chapter 3 we describe the observational program and the data reduction and analysis methodology. Finally, in Chapter 4, we discuss the results of this study and its implications.

Chapter 2

Charge–Coupled–Devices

2.1 Introduction

The astronomical community has always been quick to adopt new detector technologies for use in both ground–based and space–based observatories. For ground–based work this was true of the photographic plate, the observational mainstay for many years, and the image tube. The introduction of new detector technology is subsequently reflected in the scientific return of many astronomical studies. Not only could previously unattainable observations be done but better data on even well–studied and supposedly well–understood objects showed that they are so not well–understood after all. In the past few years the astronomical community has witnessed the introduction and exploitation of a new detector: the charge–coupled–device or CCD. One of its advantages is its high quantum efficiency ($\geq 60\%$) compared with the image tube (no better than 20%) and the photographic plate (about 4%). The quantum efficiency can be made fairly constant from atmospheric cutoff ($3150 \text{ \AA}$) up to about $8000 \text{ \AA}$. The CCD also has excellent dynamic range with a linear response extending over four decades in counts. In addition, a properly optimized CCD has a low readout noise, negligible dark current and good geometric and photometric

stability. All of these are valuable for astronomical applications.

In 1981, Steward Observatory began construction of a number of CCD camera systems based on the CCD camera systems developed at Kitt Peak National Observatory (Marcus *et al.* 1979). Subsequently, a number of Texas Instruments 3 phase (TI3P) CCDs were given to Steward Observatory by the National Science Foundation and these now in regular use. This thesis began with the construction of an operational camera system based on a CCD built by the General Electric Co. of Great Britain (GEC). We had intended to use it for the long slit study of active and normal galaxies described in this thesis. However, after approximately six months of electronic design work and optimization, when it was on the verge of becoming a usable camera system, the GEC CCD camera system was destroyed because of mishandling by Observatory support personnel. Therefore, the long slit project was carried out with one of the Texas Instruments 3 Phase CCDs (TI 3PCCDs) that was undergoing testing at the same time. This camera system and the optimization work performed on it is described herein. Our work proceeded simultaneously with other similar projects on this and other camera systems which are described elsewhere (Leach 1987; Leach 1988a; Leach 1988b). While there was a common effort because of this, our work was mostly independent of these other studies. However, the results of these different projects were similar which showed that the TI 3PCCD camera system used for the long slit study was properly optimized for use as a general facility instrument.

We discuss the characteristics of the TI 3PCCD in Section 2.2. We then de-

scribe the Steward Camera system in Section 2.3 and its optimization and characterization in Section 2.4. The camera system operating under both laboratory conditions and at the telescope are described.

2.2 Primer on the Texas Instrument 3PCCD

2.2.1 Introduction

The TI 3PCCD was part of a large number of CCDs fabricated by Texas Instruments for use in the Wide Field/Planetary Camera on the Hubble Space Telescope. Though they are no longer in production, these CCDs are in use at most major observatories because of their superior quality. They are also one of the most widely studied CCDs (Janesick *et al.* 1985; Blouke *et al.* 1987) and are, therefore, the fiducial against which all CCDs are measured.

The TI 3PCCD is a buried channel, 3 phase, back (or rear) illuminated 800 x 800 image sensor with 15 x 15 μm pixels. It is 17 x 17 mm with the image-sensitive region occupying the central 12.2 x 12.2 mm. The remaining area of the CCD is occupied by aluminum leads for used to apply the clock voltages necessary for moving the charge packets through the CCD. The image-sensitive area is physically segmented into four 800 x 200 sections with two serial registers present, one at the top and one at the bottom. This allows the charge to be readout in either direction. The TI 3PCCDs were thinned and are backside

illuminated so that the spectral sensitivity is higher and more uniform. However, the thinning process wrinkled the CCD surface. Operationally, these were manifest as slight focus variations across the CCD. The two serial shift registers are identical and are 851 pixels long. Each of the pixels in these registers are $20 \times 15 \mu\text{m}$ and can handle a charge capacity almost twice that of a pixel in the image region. The output well from either of the serial register has increased storage capacity to accommodate on-chip coaddition.

2.2.2 Other Optimization Results Using the TI CCD

The TI 3PCCD has become the CCD against which all others are compared. A tremendous amount of effort has gone into optimizing the operation of this particular CCD which has contributed to the knowledge of CCDs in general. Current and future CCD designs have clearly been influenced by the results of the work done with the TI 3PCCD. Therefore, it will be useful to briefly summarize this knowledge before discussing our efforts at optimization and operation below.

Astronomers are interested in the quantum efficiency of a CCD, its readout noise, charge transfer efficiency, dark current, residual image property and its full well. Optimizing or eliminating these quantities is done in large part by a judicious choice (i.e., trial and error) of the mutually dependent voltages controlling the preamplifier, reset transistors and the parallel and serial clocks. Much of the work done characterizing and optimizing the performance of the TI 3PCCD has been done during the past few years (Janesick

et al. 1985, 1987; Blouke *et al.* 1987; Leach 1987, 1988a, 1988b). The results are low read-out noise (< 7 electrons / pixel), low dark current (a few electrons / pixel / hour), high charge transfer efficiency (0.9999868 electrons / transfer), wide (1–10,000 Å) spectral response that is fairly flat over most of this spectral region, linear response up to 50,000 electrons per pixel and over 4 decades in wavelength, no detectable residual image and acceptable photometric and geometric stability. The device is also shot noise limited over most of its dynamic range. We were able to achieve and sometimes surpass, the performances quoted by other workers. Since no single recipe exists for optimizing a CCD camera system we had to put considerable effort into the Steward Observatory TI 3PCCD camera system even though we were not the first to use a TI 3PCCD for astronomical purposes.

2.3 The Steward Observatory CCD Camera System

The CCD camera systems now in regular use by Steward Observatory were directly derived from the Kitt Peak National Observatory CCD camera systems (Marcus, Nelson and Lynds 1979). These detectors are cryogenically-cooled and operate in a slow scan readout mode ($\sim 20,000$ pixels / second). These camera systems consist of a host computer, a microprocessor camera controller, camera head interface electronics, the camera head electronics and the CCD dewar. The host computer and microprocessor camera controller are located in the room where the observer sits, the camera head interface electronic

box is attached to the telescope, the camera head electronics is mounted on the CCD dewar which is attached to the Boller and Chivens spectrograph. We describe below the CCD camera system that was used on the S.O. 2.3 meter on Kitt Peak to carry out the long slit galaxy study.

The controlling minicomputer is a Data General Point 4 that contains 65,535 words of memory. For a given camera system, the Point 4 uses FORTH to cross-assemble mnemonics into microcode which are then downloaded into a writable control store (WCS) located in the microprocessor camera controller. The host computer and microprocessor camera controller communicate over a 16 bit fast serial data link (Leach 1986). These mnemonics contain all the information necessary for the proper operation of the CCD camera. The WCS is 64 bits wide and 256 words deep. Each word contains bit fields that control the microsequencer and the arithmetic logic unit both of which are also contained in the microprocessor camera controller. The microsequencer determines program flow during the camera operation (e.g., the exposure sequence). From the WCS it reads instructions and addresses needed for program execution as well as arithmetic and logical operation commands, miscellaneous control bits and timing waveforms necessary for proper readout of the CCD. Using this paradigm the sequence and timing of events necessary for optimal CCD operation can be completely specified.

The camera head interface electronic box contains a 16 bit A/D converter, a precision voltage reference, voltage regulators, shutter control, a temperature meter and elec-

tronics necessary for differentially transmitting control and data information between the CCD and the microsequencer. The camera head electronics contains five boards: (1) a voltage reference board, (2) a temperature control board, (3) a horizontal clock board, (4) a vertical clock board and (5) a video processor board. The two clock boards are low impedance drivers with adjustable voltage levels that are used for optimizing the operation of the CCD. The adjustments of these voltage levels, which are not quite independent of one another, comprises most of the work in optimizing the performance this camera system.

The observer initiates an exposure by any one of three FORTH commands. The exposure number, the duration of the exposure and the shutter position are the only parameters that need be specified. Other FORTH commands allow the observer to change the binning parameters for a given exposure as well as specify that portion of the CCD to be read out and stored. Once the exposure command is given but before the exposure starts, the CCD is quickly readout out multiple times. This is done to deplete it of extraneous charge that was left over from the previous exposure (if the source was quite bright) and electrons generated from cosmic rays. Next the optimally correct voltages for charge collection are set for each CCD electrode. Finally the shutter is opened and the CCD exposure is taken. After the shutter is closed, the horizontal and vertical clock boards synchronously move the charge off the chip. Each exposure is stored on a removable disk platter peripheral to the Point 4. The observer can then write the output to a magnetic tape, display the image and examine the image.

2.4 Characterization and Optimization of the S.O. TI 3PCCD Camera System

2.4.1 Preliminaries

The success of any CCD camera system intended for regular use at an observatory depends on how well it has been optimized for (1) high and uniform quantum efficiencies over a wide wavelength range and photometric stability, (2) low detector noise, (3) high (> 0.9999) charge transfer efficiency, (4) no measurable residual image, (5) linearity and (6) low dark current. We discuss each of these in turn. The optimization work occurred both in the laboratory and at the telescope. Therefore, we discuss results for each item obtained under both environments.

2.4.2 Quantum Efficiency

Ideally, it is desirable to have the intrinsic quantum efficiency of a CCD approach its theoretical limits at all wavelengths. A great effort has gone into this area (Leach and Lesser 1987; Janesick *et al.* 1987). At the beginning of this project, the quantum efficiency of the camera system dropped to zero below $\sim 4300 \text{ \AA}$ (Fig. 1). In the midst of the long slit galaxy observations, the quantum efficiency below $4000 \text{ \AA}$ increased significantly by implementing a modified UV flood procedure (Leach and Lesser 1987) (Fig. 1). We

Figure 1. Quantum efficiency of the TI 3PCCD as a function of wavelength.

routinely measured the quantum efficiencies of the TI 3PCCD camera system in the laboratory and before and after observing runs. Laboratory measurements were performed four times over a seven day period and before and after a seven day observing run. These measurements were done before and after the enhancement of its UV response using the quantum efficiency measuring apparatus made available by Dr. Richard Cromwell of Steward Observatory. This apparatus consisted of a set of narrow band interference filters that selected certain wavelengths emitted by a tungsten lamp. This lamp was periodically calibrated with a photodiode radiometer that is referenced to standard light sources provided by the National Bureau of Standards. Fig. 1 shows quantum efficiency measurements done over a period of 7 days. We measured the response of the system in the laboratory using all 11 interference filters and took multiple exposures through each filter. The error bars, determined from the multiple measurements, are smaller than the plot symbols and are not included. From these multiple measurements we estimate that the measurement error is no greater than 1%. The change in the quantum efficiency of the camera system was not significant over the 7 day period. The largest change (1.2% at 3500 Å) occurred between day 2 and 3. This being of the order of the measurement error showed that the photometric stability of the camera system was excellent. We also measured the quantum efficiency of this system in the laboratory before and after the camera system was used on the telescope and found identical results. No significant change occurred in the system during its week on the mountain and during transport. Our results are consistent with other independent quan-

tum efficiency measurements done on this system (Leach 1987; Leach and Lesser 1987).

As is seen in the plot, the quantum efficiency of this system plummets shortward of 4300 Å. After considerable efforts at developing a recipe to use for enhancing the UV response of the TI 3PCCD (Leach and Lesser 1987), the quantum efficiency of the system of the camera system was measured again. As before, we measured the quantum efficiency 4 times over a 7 day period and also before and after a 6 day observing run on Kitt Peak. All measurements were again done in the laboratory. The quantum efficiency plot from one measurement is shown in Fig. 1. As is seen the UV response is greatly enhanced and is close to the theoretical limit of 56%. We again found no temporal changes greater than 1% in the quantum efficiency of the camera system. Our measurements also indicated that the response of the camera was extremely stable over a two week period confirming this system's excellent photometric stability. Subsequent work showed that any variations that had occurred during a 13 month period must be less than 1.0%. This fact was also confirmed from examining observations taken of the calibration star BD+28 4211.

2.4.3 Detector Noise

The intrinsic noise behavior of any CCD camera system determines the minimum detectable signal. There are three types of noise, two of which must be dealt with before a CCD camera system would be considered optimized for use. The first is readout noise. For low illumination levels, readout noise sets the minimum detectable signal. The

second type is the fixed pattern noise which dominates at high illumination levels. The third type is shot noise due to the photon statistics of the signal itself. The fixed pattern noise can be removed by uniformly illuminating the CCD with a continuum light source, normalizing the mean of this image to about 1.0 and then dividing it into all subsequent images. The read noise and shot noise are minimized ($\ll$ fixed pattern noise) at the higher illumination leaving the fixed pattern noise the dominant noise in the image. Therefore, the contributions in the fixed pattern noise image from the other two noise components does not significantly add in quadrature during the division process. For example, for an image of a fixed pattern noise with 24,000 electrons / pixel, the readout noise was 0.027% of the signal and the shot noise was 0.6% of the signal. The fixed pattern noise ranged from 5% to 15% of the signal.

For low light levels, the camera system is limited by those noise sources intrinsic to it. Of a number of sources of noise to be dealt with, one can be dealt with easily and elegantly. This is the noise or uncertainty in the voltage of the output node. After the charge in the output node is read out, the output node is reset to a prescribed voltage. The noise in the voltage of the output node is eliminated through the use of correlated double sampling. The lowest level of noise obtainable depends mostly on the noise of the on-chip output amplifier. We found that the readout noise was most affected by the voltages associated with the preamplifier and reset FET voltages. The preamplifier drain voltage had the most effect on the value of the readout noise; the reset FET drain voltage had less influence

but more so than the reset FET source voltage.

The read noise of the TI 3PCCD camera system was measured using the photon transfer technique (Janesick *et al.* 1985). In this technique, two identical exposures of a uniform illumination source were taken one after the other. The ratios of these images removes the pixel-to-pixel sensitivity variations. A number of exposures that evenly illuminated the CCD were taken at various light levels and their noise level measured after removal of the fixed pattern noise.

In the laboratory, the detector noise was measured from images found by uniform illumination of a white light lamp whose relative intensity could be varied in a reproducible manner. The intensity of the lamp was varied so that each exposure had a different global mean intensity. Fig. 2 shows the noise level in DN plotted against the signal level in DN (note the log-log scale). The signal is proportional to the average number of interacting photons per pixel for a 25×25 array of pixels within the CCD image and the noise is the standard deviation of the 625 pixels. As is seen in Fig. 2, there are three distinct regions to this data. The first is the straight line segment for signal levels between 10 and 10,000 DN. This is simply the shot noise and has a slope of $1/2$. The second region occurs at low illumination levels where the curve flattens out for a signal level < 10 DN. This is due to the noise associated with the readout process. The third region of the curve occurred at a signal level $> 30,000$ DN where the pixels became saturated. These measurements were repeated for a number of 25×25 arrays in each image (i.e., exposure level). Since the

Figure 2. The photon transfer curve for the TI 3PCCD.

adjustable voltages also affected the gain of the system, the above statistical procedure was repeated each time the voltages were varied.

At the telescope, the method was slightly different. Since the detector was part of a spectrograph system, it was important to evenly illuminate all points on the slit. This was done by taking exposures of white light reflected off the inside of the telescope dome. Now each image contained a variety of different light levels since the white light was being dispersed. However, a smaller array of pixels (from 15×15 to 20×20) had to be used because the mean changed for an array of pixels larger than this.

2.4.4 Charge Transfer Efficiency

Besides collecting charge, the other major task of a CCD is transferring the charge to the output amplifier for measurement. The charge transfer efficiency, or CTE, is the efficiency of transferring charge from one potential well to the next potential well. The CTE is most affected by the spurious potential pocket effect. This is the loss of charge during the charge transfer cycle due to an improper potential well shape and/or improper potential well depth beneath the pixel. These are created by any combination of (1) channel width variation, (2) polysilicon edge lifting and (3) typical boron lateral diffusion. As electrons are readout, they can become trapped at these spurious potential pocket sites and then emitted a short time later. This gives rise to the characteristic tail seen on spectral lines from CCDs with poor CTE. The CTE degrades as the operating temperature decreases and

the transfer time decrease.

The CTE in the parallel direction was measured in the laboratory by obtaining an exposure of two slit images, one at each end of the CCD. One of the slit images was read out immediately since it was near the transfer register and this minimized the change in the shape of its slit profile due to charge transfer inefficiency. The second slit was positioned at the opposite end of the CCD so that the change in shape of its slit profile due to charge transfer inefficiency was maximized. The shapes were then compared. Exposures of different intensities were taken as the voltages were varied. This allowed the CTE at various light levels to be studied. These slits were then transposed to measure CTE in the serial direction. By trial and error, the optimal operating conditions for temperature and voltage settings were found. Two fixes were applied that were known to increase the CTE to 0.9999868 (Janesick *et al.* 1987). The first fix was to set the lower voltage of the phase 1 parallel clock to about -10 V. This decreased the size of the spurious potential pockets. The second fix was to lengthen the time between the low-going edge of the parallel phase 2 clock and the high-going edge of the parallel phase 1 serial clock. It was found that a delay of 100 microseconds was optimal. A subsequent study (Leach 1988) showed that the CTE for very low light levels was better in the serial direction than in the parallel direction.

The CTE measurements at the telescope were more subjective than in the laboratory but we found similar behavior. The CTE in the parallel directions was measured by taking long slit exposures of helium/argon arcs and comparing the spectral lines at different

ends of the long slit image. For the CTE in the serial direction, we chose a star bright enough that a few second exposure gave a few thousand counts per pixel. With the star at one edge of the slit, an exposure taken for a few seconds and then halted. The star was then moved about 50 pixels along the slit and the exposure was resumed. Repeating this procedure we got five to six stellar spectra at various points along the slit in one exposure that could be used to examine the CTE in the serial direction. The voltage settings and operating temperature determined in the laboratory were found to give results comparable to those obtained at the telescope.

2.4.5 Residual Image

A major problem of CCDs is that they can, unfortunately, remember their previous image. Pixels saturated by high exposure levels will retain some of the charge at the frontside Si-SiO₂ interface after the charge packet has been transferred. This charge is released very slowly, usually on the order of a few minutes and even up to a few hours (Lauer 1989). Unless this residual image is completely eliminated, it will contaminate subsequent images, especially if low light levels are important. Fortunately, the fix to this problem is rather straightforward.

In general, inverting the clocks of the TI 3PCCD was sufficient for flushing out all photoelectrons from their trapped interface sites. This inversion was implemented on the TI 3PCCD as a two step process. First, between exposures, the TI 3PCCD alternated

between a complete readout at high speed and an inversion of the parallel clocks to -7 V. Then a few seconds prior to exposure, the parallel clocks were again driven to -7 V. We found this procedure to be sufficient for eliminating any vestiges of a residual image even when the previous image and images were severely overexposed.

In the laboratory, a number of methods were used to determine if any residual image was present. The first test for the presence of a residual image was to first heavily expose a wide slit or bar, readout this image and then immediately take another exposure with the shutter closed and the light source off for 1 second. This second image was then examined to see if the region in this second frame that corresponded to the bar in the first frame was statistically different from the surrounding regions. To do this, two strips that

Table 1

TI 3PCCD Voltage Settings

Readout Noise (electrons rms)	6.23 ± 0.02
Conversion Gain (electrons / ADU)	2.92 ± 0.02
Full Well (electrons)	34,000
Dark Current (electrons / pixel / hour)	6.0 ± 0.1
Operating Temperature	-140°C
Vertical Clocks	+9, -7
Horizontal Clocks	+11, 0
Reset FET Drain	+20.0
Reset FET Gate	+15.0, 0
Amplifier FET Drain	+30.0

contained the same number of pixels as contained in the bar were chosen from this second image. The difference between these two regions defines the statistical zero. Then the bar region in the second exposure was compared to one of the other unexposed regions in the second exposure. We found for all exposure levels that no residual image was present since the difference between the two unexposed regions was the same as the difference between an unexposed region and the bar region.

As a second test, the entire chip was heavily overexposed to white light. Subsequent to this, a one second exposure with the shutter closed was taken and compared with a similar image taken before the overexposed image. For all exposure levels, the difference between the overexposed image and the one second exposures was statistically the same as the difference between two one-second exposures.

At the telescope, we performed similar tests with the continuum lamp that was used for taking flat field exposures and also flat field exposures using light scattered off the dome. The comparisons were identical to those done in the laboratory. These heavily exposed images were compared to one second exposures with the shutter closed. In all instances, the difference between the heavily exposed image and the one second image were identical to those between two one-second images.

2.4.6 Linearity

The output signal for an imaging device can be expressed in a power series in-

volving the input signal, or $S = \alpha I^n + S_0$ where α is a proportionality constant, I is the input signal, S_0 is the dark current and bias and S is the output signal. The exponent, n , a measure of the linearity of the CCD response, is determined by measuring the signal as a function of exposure time for a constant intensity continuum light source.

The calibration lamps available at Steward Observatory were used to determine the linearity of the TI 3PCCD as a function of wavelength. For each wavelength, we varied the exposure time so that the counts went from a few hundred electrons / pixel to well past full well saturation. For every wavelength, we determined that the best fit line was $n = 1.000 \pm 0.003$ which is identical to that obtained from other TI 3PCCD camera systems (Blouke *et al.* 1987; Janesick *et al.* 1987). This measurement repeated 13 months later gave identical results.

2.4.7 Dark Current

The dark current in any CCD can be created from thermal generation and diffusion from a number of regions in the CCD. Thermal generation of electrons from surface states at the Si-SiO₂ interface, or from the neutral bulk or from the depletion region contribute to the overall dark current. In principle, it is necessary to minimize the dark current in any images sensor. For very long exposures of faint objects or for high time resolution observations on brighter objects, the dark current will increase the apparent noise background and limit the sensitivity of the CCD.

The most obvious way to minimize the dark current is to operate the CCD at temperatures as low as possible but where other characteristics of the system are not adversely affected. We found that operating the TI 3PCCD at -140°C gave a low dark current and acceptable charge transfer efficiency. An elegant method for minimizing the dark current that was shown useful on similar systems, proved the best method for the CCD. It was simply to hold the parallel clocks at negative values (between -10 and -12 V) during the exposure. To avoid dark current build-up in the serial registers, the serial clocks were held at their upper voltage level (Table 1).

At both the laboratory and at the telescope we took many long dark current exposures ranging from 1 hour to 12 hours. From these images we found that the absolute value of the dark current was constant at 6.0 electrons / pixel / hour for all exposures. It was found that the dark current did not change significantly throughout the entire period of optimizing the camera system and during the long slit study. Slight variations occurred across the TI 3PCCD but these were reproducible and could be safely eliminated.

2.5 Summary

The first part of this dissertation was concerned with constructing and optimizing a CCD camera system for facility use on the University of Arizona 2.3 meter telescope. An existing camera design, based on one developed at Kitt Peak National Observatory (Marcus *et al.* 1979), was used to build a camera for a TI 3PCCD. The operating charac-

teristics of this camera were documented and optimized for use as a facility instrument.

This camera system was then used for the long slit galaxy survey.

The optimization of this camera system achieved results consistent and better than previous optimization work. The readout noise was decreased to 6.23 electrons per pixel rms, the dark current was held at 6.0 electrons / pixel / hour for up to two weeks, the charge transfer efficiency was optimized using techniques developed at other sites, the full-well capacity was optimized to 34,000 electrons and no residual image, even for heavily exposed images, was detected. Table 1 lists the settings used for normal operation of the TI 3PCCD camera system.

Chapter 3

OBSERVATIONS and REDUCTIONS

3.1 Introduction

The purpose of this dissertation was to compare the star formation properties of two samples of galaxies whose only difference was the presence or absence of an active nucleus. The data were used to examine what effect an active or Seyfert nucleus has on its host galaxy. In this work, the sample of Seyfert galaxies was compared to a control sample of normal galaxies. The Seyfert sample and the control sample were chosen in an identical manner using criteria to insure that the two samples contained no systematic differences relative to the other. Differences that exist in the disk regions between Seyfert and normal galaxies may very well be manifest as systematic changes in the star formation properties of the Seyferts relative to the normal spirals. Most of this work, therefore, examined the star formation properties of the galaxy samples as traced by $H\alpha$ since $H\alpha$ emission is related to the star formation rate and is an easily observable quantity. It was, therefore, of fundamental importance to push the limits of detection so that the faintest regions of star formation could be measured both in the outer disk regions as well as in the near-nuclear regions. For the latter case, it was necessary to perform additional processing to the sample of Seyfert galaxies in order to remove the contribution of the unresolved nuclear point

source. In this chapter the criteria used to select the Seyfert galaxy sample and the control sample of normal galaxies are discussed. We then describe the methodology behind our observations, data reduction and data analysis. Finally, we describe in detail the method used to eliminate the unresolved nuclear point source from the data. All data processing was done with the Image Reduction and Analysis Facility (IRAF).

3.2 Sample Selection

The samples of active and normal galaxies observed were subsets of the lists used by Fuentes–Williams and Stocke (1988, hereafter known as FWS88). Table 2 contains the list of the control sample of normal galaxies observed and Table 3 lists the Seyfert galaxy sample. In these tables we list the name of the object as we refer to it, its UGC designation, right ascension and declination (epoch 1950), Hubble type and redshift. The criteria used by FWS88 for sample selection attempted to insure that the only difference between the two samples was nuclear activity. The criteria used were:

1. $\delta \geq -10^\circ$
2. $|b^{\text{II}}| \leq 20^\circ$
3. $0.009 \leq z \leq 0.05$

In addition, a restriction on the galaxy morphology or Hubble type was imposed. Seyfert galaxies seem to have disturbed morphologies (Adams 1977) and their Hubble type are sometimes not well determined. FWS88 chose the range of Seyfert galaxy morphology

Table 2
Normal Galaxy Sample

<u>Object Name</u>	<u>UGC Number</u>	<u>Right Ascension</u>			<u>Declination</u>			<u>z</u>
IC 34	351	0	33	0.0	+8	51	0.0	0.018
NGC 182	382	0	35	36.0	+2	27	0.0	0.017
IC 1827	2152	2	37	06.0	+1	20	0.0	0.020
UGC 3403	3403	6	09	18.0	+71	09	0.0	0.014
NGC 2599	4458	8	29	12.0	+22	44	0.0	0.015
NGC 3202	5581	10	17	30.0	+43	16	0.0	0.022
NGC 4500	7667	12	29	00.0	+58	14	0.0	0.010
NGC 5378	8869	13	54	42.0	+38	03	0.0	0.010
NGC 5533	9133	14	14	00.0	+35	35	0.0	0.013
NGC 6032	10148	16	00	48.0	+21	06	0.0	0.014
NGC 6154	10382	16	24	12.0	+49	57	0.0	0.020
NGC 7440	12276	22	56	12.0	+35	32	0.0	0.019
NGC 7570	12473	23	14	12.0	+13	13	0.0	0.016
NGC 7691	12654	23	30	00.0	+15	34	0.0	0.014
NGC 7771	12815	23	48	54.0	+19	50	0.0	0.015

Table 3***Seyfert Galaxy Sample***

<u>Object Name</u>	<u>UGC Number</u>	<u>Right Ascension</u>			<u>Declination</u>			<u>z</u>
Akn 120	959	1	21	54.1	+31	55	26	0.036
Mrk 590	1727	2	12	0.4	−0	59	57	0.027
NGC 1019	2132	2	35	52.3	+1	41	32	0.024
3C 120	3087	4	30	31.6	+5	14	59	0.033
Mrk 618		4	34	00.0	−10	28	36	0.035
UGC 3223	3223	4	56	30.0	+4	54	54	0.018
Mrk 3	3426	6	09	48.4	+71	3	11	0.014
Mrk 6	3547	6	45	43.9	+74	29	10	0.019
Mrk 79	3973	7	38	47.3	+49	55	41	0.022
Mrk 10	4013	7	43	7.4	+61	3	25	0.030
Mrk 382		7	52	3.6	+39	19	7	0.034
Mrk 279	8823	13	51	51.9	+69	33	13	0.031
Mrk 504		16	59	10.4	+29	28	44	0.036
Mrk 506		17	20	45.6	+30	55	40	0.043
NGC 7469	12332	23	00	44.4	+8	36	16	0.017

types from Simkin, Su and Schwarz (1980). Fig. 3 shows the distribution in Hubble types for our program galaxies.

The first criterion was used so that the diameters of the galaxies in both samples could be uniformly measured on the Palomar Observatory Sky Survey. The second criterion excluded areas of high extinction due to the Galactic Plane. This particular criterion was needed by FWS88 not only because of the effects of extinction but also because of confusion with foreground galactic objects. The third criterion, a redshift limit, was necessary so that low luminosity but still significant galaxies would not be excluded. Also FWS88 wanted the redshift to accurately reflect distance in order that the measured galaxian diameters could be converted into physical diameters. Galaxies that are members of the local supercluster, i.e., those with $z \leq 0.009$ or so, have redshifts that have a velocity component due to the anisotropy in the local Hubble flow. This means that their redshift does not reflect their true distance as long as $z \leq 0.009$.

We imposed a fourth criterion involving limits on the Holmberg diameter of the objects in the two samples (Holmberg 1975). We restricted the absolute photographic magnitude, M_B , to be between -18 and -21 . Using the magnitude–diameter relationship (Holmberg 1975) restricted the Holmberg diameter to be between 16 and 49 kpc. This last criterion was included so that the starlight absolute magnitudes were matched between the two samples and not their total absolute magnitudes. Seyfert galaxies have significant nuclear non–thermal luminosities which can dominate the measurement of their absolute

Figure 3. The distribution in Hubble types for both the normal and Seyfert samples of galaxies.

magnitude. Matching only absolute magnitudes between the two samples could bias the Seyfert galaxy sample toward lower starlight luminosities. Therefore, from their diameters, starlight absolute magnitudes (Holmberg 1975) were computed for each sample galaxy and used to choose the two samples. The distribution for our program galaxies is shown in Fig. 4.

The FWS88 study was done to determine whether the environment of Seyfert galaxies was different from the environment of normal spiral galaxies. The FWS88 study selected a total of 53 Seyfert galaxies (Weedman 1977) and 30 normal spirals matched by Hubble type and absolute luminosity to the Seyferts but otherwise randomly chosen from the Center for Astrophysics Redshift Survey (Huchra *et al.* 1983). From these lists we were able to observe 15 normal galaxies and 13 Seyfert galaxies. We also selected and observed two additional Seyferts, UGC 3223 and NGC 1019 (Veron-Cetty and Veron 1985). In this catalogue UGC 3223 is designated as 0456+04. This Seyfert 1 was not known to early studies (Weedman 1977) but it fits all of the above criteria, as did NGC 1019. These objects were included to use the observing time efficiently. Therefore, this study was able to compare equal number of Seyfert and normal galaxies. Figs. 3 and 4 show the distribution of Hubble types and starlight luminosities for each of the two samples used in this study.

The major and minor axes of the galaxies in each of the samples were measured on the two-axis Grant machine at the National Optical Astronomy Observatories using the blue plates of the Palomar Observatory Sky Survey. The major and minor axes of each gal-

Figure 4. The distribution in Holmberg absolute photographic magnitudes for both the normal and Seyfert samples of galaxies.

axy were measured five times. Each measurement consisted of marking the extremes of the major and minor axes of each galaxy. From these repeated measurements we determined that our accuracy was $0.4''$ along either axis, in agreement with FWS88. These apparent diameters were then converted to physical diameters assuming that $H_0 = 75 \text{ km sec}^{-1} \text{ Mpc}^{-1}$ and $q_0 = 0.5$. The expression $D = 19.38 \cdot \vartheta \cdot z$ was used to convert to physical diameters where ϑ is the measured apparent diameter in arcseconds and D is the physical diameter in kpc. These physical diameters were then converted into photometric diameters (Holmberg 1975).

3.3 Observations

The observations were carried out over an 19 month period from December, 1985 to July, 1987. Tables 4 and 5 list the galaxies observed, the date of the observation, the exposure time (in seconds), the slit position angle (in degrees north through east) and the airmass. We used the Boller and Chivens spectrograph on the University of Arizona 2.3 meter telescope on Kitt Peak. Each galaxy was observed in the same manner. A long slit, $2.5''$ by $4.0'$, was placed along the major axis of each galaxy. The value for the major axis position angle was taken from the UGC catalogue (Nilsson 1974). For a number of Seyfert galaxies that had no clear major axis a position angle of 90° was used. The exposure times were chosen to obtain approximately the same signal-to-noise ratio for each galaxy in its strongest emission line, $H\alpha$. An upper limit of 40 minutes for any given exposure

Table 4*Log of Normal Galaxy Observations*

<u>Object</u>	<u>Obs. Date</u>	<u>Exp. Time (sec.)</u>	<u>Pos. Angle</u>	<u>Airmass</u>
IC 34	9 Nov., 1986	2400, 2400	156	1.13, 1.16
NGC 182	5 July, 1987	2400, 2400	75	1.44, 1.30
IC 1827	19 Dec., 1985	2400, 2400	154	1.16, 1.10
UGC 3403	18 Dec., 1985	2400, 2400	27	1.29, 1.32
NGC 2599	18 Dec., 1985	1200, 2400	90	1.03, 1.01
NGC 3202	18 Dec., 1985	2400, 2400	20	1.05, 1.03
NGC 4500	17 April, 1986	2400, 2400	130	1.12, 1.11
NGC 5378	17 April, 1986	2400, 2400	90	1.03, 1.01
NGC 5533	18 April, 1986	1200, 2400	30	1.02, 1.00
NGC 6032	3 July, 1987	2400, 2400	0	1.15, 1.30
NGC 6154	17 April, 1986	2400, 2400	90	1.12, 1.02
NGC 7440	5 July, 1987	2400, 2400	90	1.20, 1.12
NGC 7570	3 July, 1987	2400, 2400	30	1.13, 1.09
NGC 7691	4 July, 1987	2400, 2400	175	1.22, 1.12
NGC 7771	19 Dec., 1985	2400, 2400	68	1.31, 1.40

Table 5*Log of Seyfert Galaxy Observations*

<u>Object</u>	<u>Obs. Date</u>	<u>Exp. Time (secs.)</u>	<u>Pos. Angle</u>	<u>Airmass</u>
Mrk 590	18 Dec., 1985	2400, 2400	90	1.19, 1.23
NGC 1019	18 Dec., 1985	2400, 2400	90	1.27, 1.36
3C 120	19 Dec., 1985	1200, 1200, 1200	130	1.13, 1.13, 1.13
Mrk 618	8 Nov., 1986	2400, 2400	90	1.60, 1.38
UGC 3223	19 Dec., 1985	2400, 2400	80	1.16, 1.16
Mrk 3	19 Dec., 1985	600, 600, 600, 600	90	1.29, 1.29, 1.29, 1.29
Mrk 6	20 Dec., 1985	1200, 1200, 1200, 1200	130	1.36, 1.37, 1.37, 1.38
Mrk 79	19 Dec., 1985	900, 900, 900, 900	90	1.06, 1.05, 1.05, 1.06
Mrk 10	19 Dec., 1985	2400, 2400	130	1.19, 1.25
Mrk 382	9 Nov., 1986	2400, 2400	90	1.05, 1.02
Mrk 279	6 July, 1987	600, 600, 600, 600, 600, 600	33	(3)1.32, 1.34, (2)1.36
Mrk 504	18 April, 1986	2400, 2400	90	1.01, 1.00
Mrk 506	4 July, 1987	900, 900, 900, 900	90	1.01, 1.02, 1.04, 1.05
NGC 7469	19 Dec., 1985	900, 900, 900	125	1.34, 1.47, 1.50
Akn 42	8 Nov., 1986	2400, 2400	60	1.19, 1.31

was imposed because for longer exposure times too many cosmic rays were detected (> 5 in the data region). A number of normal spirals had no clear emission lines even with the coaddition of two 40 minute exposures. For most of the Seyfert sample, multiple (> 2) short exposures were taken and then coadded. This was done because of the large strength of the nuclear emission lines. They were so large that the counts in the pixels at and near $H\alpha$ were close to reaching the non-linear limit of the TI 3PCCD camera system in 10 to 15 minute exposures while those pixels in the continuum regions were still at low signal-to-noise levels.

The 300 line/mm grating blazed at $6690 \text{ \AA}$ in first order was used giving a dispersion of $3.72 \text{ \AA/pixel}$ and a resulting instrumental resolution of between 9 and $10 \text{ \AA}$. The TI 3PCCD, containing 800 pixels in the dispersion direction covers the $4500\text{--}7400 \text{ \AA}$ spectral region. The spatial resolution was, of course, dependent on the seeing. Each pixel is $0.8''$. Since the seeing was typically $1.5 - 3.5''$, the spatial resolution was between 2 and 4 pixels FWHM giving at least 75 spatial bins along the slit.

3.4 Data Reduction and Analysis

3.4.1 Introduction

All data for this study were reduced and analyzed using the Image Reduction and Analysis Facility (IRAF) and the *longslit*, *apextract*, *images* and *onedspec* packages therein. The steps in the reduction procedure were: (1) creation of a mean bias frame, (2)

creation of a dark frame, (3) creation of a flat-field frame, (4) creation of the slit transmission function, (5) determination of the spatial distortion corrections, (6) determination of the two-dimensional wavelength calibration, (7) object image trim and transformation, (8) sky subtraction, (9) extinction correction, absolute flux calibration and dereddening. In the following discussion, we describe the processing necessary for one night's observing run. Each night was reduced separately so that the bias, dark, flat-field and calibration frames were not used on successive nights. In addition to this discussion, we describe how the unresolved nuclear point source was removed from the Seyfert galaxy long slit images. This was done to search for the presence of H α emission in the near-nuclear regions of the Seyfert galaxies.

We made no attempt to replace pixels that suffered cosmic ray hits in any of the object images. Cosmic rays usually resemble strongly peaked emission lines that are localized to a few pixels. The character of a cosmic ray signal depends on its energy and angle of entry. In the end, our approach was not to try and repair bad data but to discard it. We did, however, replace those cosmic ray hits in any of the bias or dark frames because the data values are approximately known. We found that the use of *images.lineclean* was sufficient for this replacement. This task searched for any pixel whose value was a user-selected standard deviation above or below the local mean. It then used a low order polynomial fit to the nearby pixels to determine a value for the bad pixel(s). We found that setting the user-selected standard deviation to $\pm 6\sigma$ was sufficient for deleting cosmic rays in the

bias and dark frames.

3.4.2 Creation of a Mean Bias Frame

The first correction to the raw data was to remove the bias introduced during chip readout. Ideally, a constant could be subtracted from the CCD image in order to account for the bias. However, we found this not to be the case with this particular camera system. There was a slight structure to the bias image that showed about a 4 electron gradient in the dispersion direction and a 0.6 electron change in the cross-dispersion direction. In addition, the mean bias level varied by 20% during the night. To remove the bias structure and the floating bias we adopted the following approach. A mean bias frame was formed by averaging 10 one second dark exposure frames taken at the beginning and end of the night. The TI 3PCCD contained 20 fictitious columns that were used to measure the absolute bias level. These 20 columns are referred to as the overscan region. They are formed by reading out an additional 20 columns after each line is read out. The overscan region of all of these frames was also included in the averaging process. Both the overscan region and the actual bias image changed together in absolute value during the night but their relative differences remained constant at 7.95 electrons. The average of the overscan region in the mean bias frame was subtracted off leaving just the bias structure. We then smoothed this bias structure frame using a 5×5 boxcar. This mean bias frame was then used to remove the bias structure from all other CCD images. Occasionally, a number of

bias frames suffered hits from cosmic rays. Since we knew what the approximate value of the affected pixels should have been, they were replaced using *images.lineclean*. The result of this section then was the mean bias frame containing the relative change in the bias across the chip. This mean bias frame was saved for further processing.

3.4.3 Dark Frame

The second correction to the data was the subtraction of counts due to the dark current present in the TI 3PCCD. At the beginning and end of the night, a one hour exposure was taken with the spectrograph in complete darkness to determine if the dark current changed throughout the night. No evidence for changes were found in the dark current properties of the TI 3PCCD during a night's observing run. For each dark frame, the average of its overscan region and the mean bias frame was subtracted from this dark image. These two frames were then averaged together and using *images.lineclean*, signals from all cosmic rays were removed. After smoothing these frames using a 5×5 boxcar, we found that the dark current was remarkably stable at 6.0 electrons / pixel / hour. This mean dark frame scaled to electrons / pixel / second was used for all subsequent processing. A constant value could not be subtracted from each image to account for the dark current because there existed some very slight global structure to all the dark frames. This structure was independent of the exposure level both in the laboratory and at the telescope.

3.4.4 Flat-fielding and the Slit Transmission Function

The third correction to the data was to remove the pixel-to-pixel sensitivity variations of the TI 3PCCD and determine the slit transmission function. The slit transmission function is structure in the cross-dispersion direction due to different points of the slit not transferring equal amounts of light when evenly illuminated. This occurred because the slit was not machined properly. These sensitivity variations were removed by dividing every image by a very high signal-to-noise exposure whose mean is ~ 1.0 for the case where every pixel was evenly illuminated. The high signal-to-noise insured that the dominant rms noise contribution was from the pixel-to-pixel sensitivity variations and not from the readout noise or shot noise. A true characterization of these sensitivity variations demands that each pixel be evenly illuminated. The frame was normalized so that its mean was ~ 1.0 to insure that counts were conserved when the flat-field image was divided into the object frames. These variations can be as large as 15% but usually averaged 5%.

The pixel-to-pixel sensitivity variations and the slit transmission function can be determined simultaneously by obtaining a high signal-to-noise exposure of diffuse light scattered off the inside of the telescope dome. This insures even illumination of the entire slit. The pixel-to-pixel sensitivity variations can also be determined by taking exposures of a quartz lamp. Even though this lamp does not evenly illuminate the slit, the structure in the cross-dispersion direction can be removed (*twodspec.longslit.illumination*) so that a flat-field frame of mean ~ 1.0 can be created. When a quartz lamp is used the slit trans-

mission function was determined from a blank sky exposure. Tests have shown that both approaches can remove the pixel-to-pixel sensitivity variations to better than 1–2%.

Dome flat exposures were taken at the beginning and at the end of each night while the quartz lamp exposures were taken at every observation position. At all these positions, helium/argon arc spectra were taken to determine if there was flexure of the dewar. Throughout this study, several wavelength calibrations were determined for every night to see if there was significant flexure. Even though the wavelength solutions differed slightly from one telescope position to the next, they did not affect the flat-field results. Coaddition of all of the quartz lamp exposures for one night resulted in an extremely high signal-to-noise flat-field that was comparable to the results obtained for the dome flats.

It is necessary to remove the large scale wavelength variation in the dome flat-field exposures and the quartz lamp exposures. This variation is present because of the color of the lamps used and because of the changing CCD sensitivity with wavelength. The IRAF task *twodspec.longslit.response* averages the pixel values along a user-selected set of columns to form a one dimensional spectrum in the dispersion direction. This spectrum is then fit with an interpolating function. This function is then divided into each column thereby flattening the dome flat/quartz lamp frame in the dispersion direction. In addition, *twodspec.longslit.response* preserved the cross-dispersive shape of the flat-field so that for dome flats, the slit transmission function was present. For the quartz lamp images, their cross-dispersive structure had to be removed using *twodspec.longslit.illumination* (dis-

cussed below). A cubic spline of eight to ten pieces worked best though it was sometimes necessary to perform *twodspec.longslit.response* twice in order to remove the wavelength dependence completely. *twodspec.longslit.response* introduced a discontinuity into the flat-field frame. This discontinuity was traced to the size of the user-selected set of columns. If these columns were selected between columns i and j then the discontinuity occurred between columns $i-1$ and i and j and $j+1$. Increasing the size of the user-selected set of columns reduced this discontinuity. However, if the set of columns was too large the correction in the dispersion direction was poor because the function found from these user-selected columns did not represent the true color dependence. The results of *twodspec.longslit.response* were accepted when the shape of the flat-field in the dispersion direction, fit by a straight line, gave a slope close to 0.0 with a minimum rms error. We used *images.fit1d* to fit a straight line to each column and if necessary, reapplied *twodspec.longslit.response* once to improve the removal of the wavelength variation.

Large amplitude noise was made less influential to the fit by using *twodspec.longslit.response* to fit the function to a set of points that were the median of every 4 points while rejecting all points $1.5-2.0\sigma$ from the fit. An iteration of the fit was performed to reject pixels. This forced the fit to follow the wavelength dependence and not the pixel-to-pixel sensitivity variations. Using an 8 to 10 piece cubic spline gave better results than a Chebyshev polynomial.

We also removed the structure in the cross-dispersion direction caused by un-

even illumination of the slit by the quartz lamp. We used *images.fit1d* because the quartz lamp exposures had very high signal-to-noise making binning unnecessary. In *images.fit1d* we found that the ratio of a 4 to 5 order Chebyshev polynomial fit to the image in the cross-dispersion direction worked best and not a cubic spline. As with *twodspec.longslit.response* we fit this function to the median of every 4 points and rejected those points more than 1.5 to 2.0 σ from the fit. This fit was then divided into the quartz lamp thereby flattening it in the cross-dispersive direction. *images.fit1d* was used again to remove the cross-dispersive structure. As with the removal of the wavelength dependence of the flat-field, the criterion for accepting the normalized quartz flat-field was that the shape of the flat-field in the cross-dispersion direction was fit by a straight line of slope close to 0.0 and that the rms error of the fit was minimized.

The slit transmission function was already present in a dome flat exposure. However, for our first observing run we were not able to take a dome flat so a sky exposure was used with the task *twodspec.longslit.illumination*. This task fits a function to a user-selected set of lines (bins) to determine the slit transmission function. The sky frame had a lower signal-to-noise than the dome flats or quartz lamps. *twodspec.longslit.illumination* summed together all lines in each user-selected bin, fit a function to it, normalized this fit to 1.0 at the maximum point in the fit and then interpolated between all of the fits to form an image that represented the slit transmission function. The fit was to the median of every 4 points and a 4 to 5 order Chebyshev polynomial was found to be adequate. To interpolate

between each of the bins, we found that the cubic polynomial interpolator worked best. We also experimented with the number of bins and found that it was important to use as many as possible—we chose from between 100 and 200 bins (or 8 to 4 lines per bin). The result of *twodspec.longslit.illumination* was a two-dimensional fit representing the slit transmission function. This image was then multiplied by the normalized flat-field determined from the quartz lamp image. This image product was then used in all subsequent image processing to remove the pixel-to-pixel sensitivity variations and the slit transmission function.

There existed another IRAF task called *twodspec.longslit.insurfit* that is intended for use instead of *twodspec.longslit.response* and *twodspec.longslit.illumination*. However, we found that this task did not give satisfactory results. It introduced intermediate frequency structure into a long slit image when used to remove the pixel-to-pixel sensitivity variations and the slit transmission function. For this reason, this task was not used.

The result of this approach was a flat-field frame whose mean was approximately 1.0 and was flat in the dispersion direction. There are two dangers inherent in both these procedures: (1) introducing intermediate frequency structure into the flat-field by not determining a good fit to the wavelength dependence and in the case of the quartz lamp, improper fitting to remove the structure in the cross-dispersion direction as well and (2) removal of some high frequency structure by fitting too well. The latter danger would remove some of the large-scale pixel-to-pixel sensitivity variations.

3.4.5 Distortion Corrections and Wavelength Calibration

Geometric distortions introduced by the spectrograph optics and rotational misalignment (i.e., the dispersion direction not lying exactly along a column) must be removed from all spectra. These corrections were important for a number of reasons. The position and shape of any spectral feature varied in the cross-dispersion direction. Unless this distortion was removed, the resulting wavelength calibration over the entire chip would have been questionable and it would have been difficult to properly subtract the background sky. Since the spatial distribution of given line varies dramatically, subtraction of this line using a single function fit was not appropriate. Rotational misalignment degraded the wavelength resolution because for a given line in the raw CCD image of a star, for example, the flux on one end of the stellar profile would correspond to a slightly different wavelength than the flux at the other side of the stellar profile. Observations of helium/argon arc lamps and bright stars were used to correct the geometrical distortion across the chip and the rotation of the spectrum relative to the column direction, respectively. Correcting the geometrical distortion resulted in a wavelength calibrated image. During most of the observational program the CCD dewar could be rotated at the telescope to align the dispersion and column directions; however, this procedure was never able to produce complete alignment.

Helium/argon arc long slit images were taken at each object position to correct the geometrical distortion and determine the two-dimensional dispersion solution. A three

step approach was used to map the distortion and create a dispersion solution. *twodspec.c.longslit.identify* was used to extract the sum of the central 10 columns of the helium/argon arc. A small number of spectral features (2–3) were identified. We found that the three lines at 5015 Å, 5875 Å and 6678 Å had to be used at this point otherwise the final results were unacceptable. *twodspec.longslit.identify* used these spectral line positions to create a temporary wavelength dispersion solution to locate other spectral features from a list of known helium/argon wavelengths. A one-dimensional wavelength solution was then formed once the positions and identifications were correct. A cubic polynomial fit gave a typical rms error of 0.25–0.30 Å (~ 0.1 of the dispersion).

The columns far from the center of the CCD were curved in the dispersion direction as one moves in the cross-dispersion direction. Summing 10 of these columns together and determining a dispersion solution showed that to achieve an rms error of 0.5 Å, a polynomial of order 5 or more was needed. This meant that the results of *twodspec.c.longslit.reidentify* and consequently, *twodspec.longslit.fitcoords* (both described below) were degraded if only a cubic polynomial was used in *twodspec.longslit.identify*. Therefore, it was decided to fit the central 10 columns with a fifth order Chebyshev polynomial. The danger here was that a higher order polynomial can introduce oscillations into the solution especially since the number of data points was not much greater than the order of the polynomial.

twodspec.longslit.reidentify used the fifth order Chebyshev polynomial found

in *twodspec.longslit.identify* to locate the spectral lines in spectra extracted at other points along the slit. At intervals of 4 columns, 8 columns were summed together to form a one-dimensional spectrum. The position of each spectral features in this spectrum was then identified using the dispersion solution and line identifications found by *twodspec.c.longslit.identify*. The position of each spectral line was then recorded in a database as the triplet (column number, row number, wavelength) or (c,l,λ) , for use by *twodspec.longslit.fitcoords*.

twodspec.longslit.identify was used to map the rotational misalignment from a stellar long slit image. Ideally, this stellar image should contain multiple images of a point source at many positions along the slit. However, results using both multiple stellar spectra and a single stellar spectrum to determine the rotation at every point along the slit were virtually identical indicating that there exists no significant distortion in the spatial direction. The one stellar image for the rotation correction was used since this resulted in more observing time being available for the program objects. *twodspec.longslit.identify* summed together 8 lines in the center of the image and marked the position of the star in the long slit image. *twodspec.longslit.reidentify* determined the position of the star by summing together 8 lines at intervals of 8 lines. The positions of the star were recorded in a database as the triplet (column number, row number, slit position) or (c,l,s) , for use by *twodspec.longslit.fitcoords*.

Once the distortions have been mapped, the task *twodspec.longslit.fitcoords*

was used to determine the transformations needed to remove the geometrical distortions and the rotational misalignment. A two dimensional function was fit to each of the triplets (c, l, λ) and (c, l, s) . These least square polynomials were $f_\lambda(c, l)$ and $f_s(c, l)$ where the function $f_\lambda(c, l)$ is the two dimensional dispersion solution.

twodspec.longslit.fitcoords allowed an interactive, two dimensional fit to either of the triplets (c, l, λ) and (c, l, s) . This interaction was important since there were certain points at the edges of the slit that were always deleted. Usually, we found that for the helium/argon long slit images, 1 to 2 spectra at the edges of the images were deleted since they had a low signal-to-noise level. This meant that their spectral line positions could not be accurately determined by *twodspec.longslit.reidentify*. We found that for f_λ , a Chebyshev polynomial of the form $T(x^5, y^5)$ was sufficient while for f_s , we found $T(x^1, y^3)$ to be adequate. These two functions were stored under a user-selected name for use in transforming images. When applied to a long slit image, these functions removed the geometrical distortion and rotation in the long slit image and rebinned the image onto linear wavelength and spatial scales.

3.4.6 Object Image Trim and Transformation

Once the mean bias frame, dark frame, flat-field frames and slit transmission function were determined and the two distortion corrections found, each of the object

frames (standard star, normal galaxy and Seyfert galaxy) were processed in an identical manner. The average of the overscan region in each long slit image was found using *images.imstatistics* on the image section [305:315,1:800] this number was subtracted from the frame. At the same time, the frame was trimmed from [1:320,1:800] to [40:276,1:800] eliminating those columns of the image that contained the overscan region and those columns that were affected by slit vignetting. Once this was done, the mean bias frame and dark frame (scaled to match the exposure time) were subtracted from the frame and divided by the flat-field and slit transmission frames. Finally, the two distortion corrections were applied using *twodspec.longslit.transform*. *twodspec.longslit.transform* inverted the two functions f_λ and f_s to yield two interpolating functions $u_c(s, \lambda)$ and $v_l(s, \lambda)$, for the column and line positions. This was done by first evaluating the functions f_λ and f_s on a uniform grid of (c,l) and then fitting functions of the same type (in this case the 2 two dimensional Chebyshev polynomials) to produce u_c and v_l . These functions are then used to rectify the input image and create a wavelength calibrated image. The most influential parameter in *twodspec.longslit.transform* was the function that was used to interpolate over the input image. We found that a bicubic polynomial worked best. The bilinear interpolator usually gave a poor wavelength calibration and the biquintic interpolator had the affect of smoothing the data. It was occasionally found that the bicubic spline worked fine. As a check on the accuracy of the transformation, we transformed a number of helium/argon long slit images that were not used in the original transformation determination. These were of limited

use because they tested the interpolation only at those points where the fit was originally determined but they did afford some idea of how good this task worked. *twospec.c.longslit.identify*, *twospec.longslit.response* and *twospec.longslit.fitcoords* applied to a transformed helium/argon long slit image gave acceptable results. At ten points in the cross-dispersion direction, a one-dimensional helium/argon arc spectrum was extracted using *twospec.apextract.apsum*. The wavelengths of the spectral lines were measured and compared to their known values. It was found that the rms error was $0.42 \text{ \AA} \pm 0.04$.

There were a number of blank sky images available for testing the accuracy of the transformation. These afforded a better measure of the accuracy of the transformation since most of the sky lines did not fall exactly near the helium/argon lines. Using a transformed long slit sky image, ten spectra were extracted using *twospec.apextract.apsum*. The wavelengths of the sky lines were measured and compared to their known wavelengths. It was found that the rms error was $0.46 \text{ \AA} \pm 0.05$.

3.4.7 Sky Subtraction

Accurately subtraction of the background emission was now possible since the cross-dispersion direction was aligned along the CCD lines. The background subtraction was done using *twospec.longslit.background*. Even though the images were trimmed to varying sizes, there were always enough columns to determine the level and shape of the spatial distribution of the sky emission. *twospec.longslit.background* was used to inter-

actively fit a polynomial to selected regions in each line of the image. This polynomial was then subtracted from the line. Those regions of the lines containing the object were not used when determining the fit. This procedure had the added benefit of correcting for any residual structure in the sky along the slit. We found that coupled with a good transformation, subtraction of a sky line resulted in residuals comparable to the sky continuum region. The polynomial was fit to the median of every 4 points and points more than 1.5 to 2.0σ away from the mean were rejected.

The similarity in the rms error values between the sky continuum regions and the sky line regions determined the accuracy of the sky subtraction procedure. The spatial distribution of the sky lines was more complicated than the spatial distribution of the sky continuum. It was, therefore, necessary to iterate through the distortion correction – transformation – sky subtraction process to obtain an acceptable removal of the sky lines. This, in fact, was one of the criteria used to decide on accepting the transformed images.

3.4.8 Absolute Calibration, Extinction Correction and Dereddening

The penultimate operation performed on every object image was the application of an absolute flux calibration to convert counts / pixel into $\text{ergs} / \text{cm}^2 / \text{sec} / \text{\AA}$. *twodspec.apextract.apsum*, *onedspec.standard*, and *onedspec.sensfunc* were used to derive a system sensitivity curve and *twodspec.longslit.fluxcalib* was used to apply it to each image after the image had been extinction corrected. Briefly, the spectrum of a standard star was

extracted from its long slit image using *twospec.apextract.apsum*, the absolute calibration was found using this spectrum, *onedspec.standard* and *onedspec.sensfunc*. The observed spectrum was compared to the expected spectrum thereby deriving a system sensitivity curve. *twospec.longslit.fluxcalib* applied this system sensitivity curve to the galaxy long slit images resulting in a calibrated image.

The spectrum of the standard star was obtained using the largest slit available (4.5 ") on the Boller and Chivens spectrograph. This long slit image was processed according to the prescription given above but not extinction corrected. The one dimensional spectrum of this star was extracted using *twospec.apextract.apsum*. This task contains a number of methods for extracting a spectrum but we found that the best results were given by summing those columns that contained the stellar spectrum. Since the calibration stars were quite bright and had a very high signal-to-noise, there was nothing gained by using more sophisticated extraction techniques *twospec.apextract.apsum*.

The task *onedspec.standard* determined the bandpasses in the one-dimensional spectrum used for deriving the calibration curve. IRAF contains tabulated calibration bandpasses for a large number of standard stars. For the standard star selected, *onedspec.standard* defined bandpasses in the calibration star spectrum and converted the counts in this bandpass to a count rate using the exposure time in the image header. We found it necessary to delete those bandpasses affected by strong absorption lines present in the calibration star. For each bandpass, *onedspec.standard* determined the ratio of the count rate in

the bandpass to the absolute flux expected. *onedspec.sensfunc* was then used to interactively fit a function to these bandpasses. The resulting function was the absolute calibration curve. We found that for the TI 3PCCD camera system at low resolution, a 5 piece cubic spline gave the best results. *twodspec.longslit.fluxcalib* then applied this absolute calibration curve to the object images.

We tested the accuracy and stability of the calibration in two ways. Each night two standard stars were observed, one at the beginning and one at the end of the night. A system sensitivity curve was found for one of the stars and applied to the other calibration star. A system sensitivity curve was also derived using the other calibration star. It was found that when the first calibration was applied to the second star and then compared to the expected spectrum we found a relative error of 10% or less. The two system sensitivity curves were found to differ by no more than a few percent. We also used observations of the same calibration star taken at different points in the slit of the same image to determine how well the relative calibration was in the cross-dispersed direction. For example, in one case, three observations of BD+28 4211 were taken using three different points in the slit, one in the center and the other two an arcminute to either side of the center. The center spectrum was used to determine the absolute calibration and then this was applied to the other two. Their extracted spectra were then compared and it was found that the relative error was 16% for one of the slit positions and 14% for the other. To determine the loss of flux from the use of the smaller long slit, observations of the same calibration star using

both slits were compared. We found that the 2.5" slit gave a light loss of 24% on average relative to the 4.5" slit.

A correction to the long slit images before absolute calibration must be made in order to account for extinction or the loss of light through the atmosphere. This loss is dependent on wavelength and on the path length through the atmosphere. The strength of the effect increases with decreasing wavelength. The IRAF task *twodspec.longslit.extinction* used the value of the airmass of the observation and determined a correction factor of the form $10^{0.4 \cdot E_{\lambda} \cdot \sec z}$ where E_{λ} is the extinction function tabulated for Kitt Peak and z is the angle between the vertical and the telescope optical axis.

The flux calibrated images were corrected for foreground Galactic extinction (Burstein and Heiles 1984) but not for extinction in the program galaxies. Large variations in reddening and extinction are known to exist in external giant HII regions (McCall, Rybski and Shields 1985) and since H β could not be measured everywhere, it was decided not to correct for reddening internal to the program galaxies. The unknown amount of internal reddening in all of the sample members was one of the major sources of error in the interpretation of the final long slit images. Fig. 5 shows an example of a flux calibrated long slit image of NGC 7691, one of the control sample galaxies. The spatial distribution of H α is shown along with the spatial distribution of a nearby continuum region. The spatial scale is shown in both arcseconds from the nucleus and in kpc.

Figure 5. Long slit image of the normal galaxy, NGC 7691. Shown are the H α and nearby continuum spatial emission.

3.5 Point Source Removal and The Measurement of Spectral Lines

It is necessary to remove the emission due to the unresolved nuclear source from the long slit image to determine the amount of circumnuclear emission in the Seyfert galaxy sample. This must be done so that any residual emission remaining after removal can unambiguously be assigned to either circumnuclear emission or scattered nuclear emission. One approach to removing the nuclear emission is to use a scaled nuclear spectrum and subtract it from every column. However, this approach would result in all of the nuclear emission being removed thereby precluding determination of the presence of scattered nuclear emission. Another approach would be to fit a gaussian to the spatial profile of the Seyfert galaxy since the central part of the seeing profile is gaussian and then subtract this profile from the long slit image. A more proper function to use is the actual point spread function of the telescope–spectrograph–detector system. This function is just the profile due to a point source such as a star. Therefore, the approach taken here is to use the high signal-to-noise stellar profile from one of the calibration stars to extract the spectrum of the unresolved nuclear point source. This extracted profile was then subtracted from the Seyfert galaxy long slit image. This removed the contribution from the unresolved nuclear point source. This approach is similar to that employed by DAOPHOT.

The IRAF package *apextract* contains the task *apstrip* which was used to fit the stellar profile to the spatial profile of the Seyfert galaxy. The point spread function of a galaxy is not, in general, similar to that of a star since the brightest part of a galaxy, its bulge, is

extended. However, in a Seyfert galaxy, the emission line component corresponding to nuclear $H\alpha$ emission arises from an area so small that, at its distance, it is essentially a point source. Therefore, to determine the spatial extent of the nuclear emission line region, the point spread function due to a point source was fit to the Seyfert galaxy point spread function at $H\alpha$. The point spread functions used were from the calibration stars observed on the same night as the galaxies. To account for the slight seeing variations that occurred throughout the night, the stellar profile was changed slightly by convolving the profile with a circular gaussian.

As a first test of the efficacy and correctness of this method, the spatial profile of one of the calibration stars was used as a template to extract itself. This gave the ultimate accuracy for point source removal that can be expected from this method. As a second test the spatial profile of one of the calibration stars was used to extract another calibration star. This result gives a more appropriate limit to the accuracy of the point source removal when the unresolved nuclear point sources are extracted from the Seyfert galaxies. Though many calibration stars were used throughout this study, for purposes of example, the results from using just one star to extract itself and then using it to extract another calibration star taken on the same night are discussed. The results from other nights are similar to those discussed here.

As the first test, the calibration star Feige 15 was used to extract itself. This test might seem superfluous since it would be expected that the fit would be exact. However,

this test proved the existence of a number of software problems in IRAF that were subsequently fixed. Also, *twodspec.apextract.apstrip* averages together a number of profiles at wavelengths local to the profile being fit. This averaged profile forms the template profile that is fit to the data but it means that the template profile will not exactly match that of the profile being extracted even if they are from the same long slit image. Finally, it was always necessary to shift the extracted profile a slight amount in order to subtract the extracted profile from the long slit image. Therefore, this first test proved useful in understanding how good the extraction would be and if it would be good enough for this study. If the numerical techniques employed in IRAF were inadequate, this test would show this.

Since the spatial profile of Feige 15 was very well defined, there was nothing gained by summing together more than a few profiles local in wavelength space. The relative error ($[\text{Feige 15} - \text{extracted Feige 15}] / \text{Feige 15}$) in the cross dispersion direction at one wavelength was determined and its relative rms error of the fit was 0.011. For all of the lines in the image, the mean relative rms errors was 0.016 with a dispersion about this mean of 0.001. As a second test we used the profile from Feige 15 to extract the spectrum of another of the calibration stars, Feige 34. The relative rms error for one particular wavelength was 0.029 and for all of the lines in the Feige 34 long slit image, the mean relative rms errors was 0.036 with a dispersion about this mean of 0.007.

The next step was to use the profile of one of the calibration stars and fit it to the H α spectral region in the Seyfert galaxy, Markarian 10. The profile of the calibration stars

were taken from long slit images with short exposure times. Therefore, changes in the seeing and guiding errors were not present. The 40 minute galaxy exposures, however, possessed slightly different point spread functions (with respect to the calibration stars) due to changes in the seeing and guiding errors. From the observing log, it was noted that the seeing did not change significantly throughout the night. However, an estimated change of $\pm 0.5''$ in the seeing may have occurred during these long exposures. In addition, there may have been slight guiding errors of a similar magnitude since no autoguider was present. Therefore, there is some uncertainty and ambiguity in the true shape of the point spread function for the galaxy long slit images. This concern was dealt with by modifying the point spread function of the calibration star through convolution with a circular gaussian. The profile fit to the galaxy was modified within the bounds of the estimated errors due to seeing changes and guiding errors. The profile was chosen using the criteria that the rms error of the fit was minimized and that the shape of the nuclear spectrum be invariant across the profile.

A column from each wing was scaled to match the column at the peak of the profile to insure that the profile extracted from the Seyfert galaxy contained emission just from the nuclear region and that the wings of the profile did not contain emission line contributions from the circumnuclear region. This provided another constraint on the fitting process.

The emission lines were measured using the IRAF task *splot*. This task allows the emission lines to be measured by fitting each marked line with a gaussian function. *splot*

allows the user to fix the position(s) and width(s) of the lines being fit and then allows the user to subtract the fit to determine the accuracy of the fit. Each of these approaches were tested to determine if one type of fitting constraint worked best. The criteria used to determine the best approach was to at least match the rms of the fit with the rms in the local continuum. In addition, the long slit galaxy data used in this study afforded a way of testing the accuracy of the fit. The [NII] $\lambda\lambda 6548,6584$ and [OIII] $\lambda\lambda 4959,5007$ spectral lines are always in the ratio of 1.0 : 3.0 and 1.0 : 2.89, respectively. The [NII] $\lambda 6548$ line was measured whenever possible in all of our two samples and it was found that at worst, the relative error in the fit was 23%. The few times we were able to measure the [OIII] $\lambda\lambda 4959,5007$ spectral lines showed similar results.

In Tables 6 through 17 we present the data for the sample of Seyfert galaxies while Tables 18 through 29 contain the data for the control sample of normal galaxies. Listed are the radial distance (in kpc) at which the H α , [NII] $\lambda\lambda 6548,6584$ and [SII] $\lambda\lambda 6717,6731$ lines were measured. The H α luminosity shown in the tables is the logarithm of the luminosity in ergs/second. The negative sign in front of the radial distance is used to differentiate between the two sides of the galaxy. We were able to detect H α emission in 12 of the 15 galaxies from both samples.

Table 6				
Markarian 590				
Position (kpc)	$\frac{[\text{NII}]\lambda 6584}{\text{H}\alpha}$	$\frac{[\text{SII}](\lambda 6717+\lambda 6731)}{\text{H}\alpha}$	$\frac{[\text{SII}]\lambda 6717}{[\text{SII}]\lambda 6731}$	Log(H α)
-4.39				37.91
-4.00				38.04
-3.60	0.52			38.14
-3.20	0.61			38.22
-2.80	0.80			38.23
-2.40	0.53			37.92
1.20	0.57			38.28
1.60	0.83			38.17
2.00	0.74			38.07
2.40	0.09			37.82
2.80	0.87			38.06
3.20	0.59			38.01
3.60	0.52			38.04
5.19	0.29			37.98
5.59	0.40			37.98
5.99	0.44			37.78
6.39				37.70
6.79				37.67
8.39				37.69
9.59				37.81
9.99				37.60

Table 7				
NGC 1019				
Position (kpc)	$\frac{[\text{NII}]\lambda 6584}{\text{H}\alpha}$	$\frac{[\text{SII}](\lambda 6717+\lambda 6731)}{\text{H}\alpha}$	$\frac{[\text{SII}]\lambda 6717}{[\text{SII}]\lambda 6731}$	$\text{Log}(\text{H}\alpha)$
-5.00				37.87
-4.64	0.42			37.92
-4.28	0.70			37.96
-1.78	1.40			37.86
-1.43	0.64			38.42
-1.07	0.68			38.58
1.07	0.84			38.76
1.43	0.65			38.68
1.78	0.47			38.22
2.14	0.77			38.08
2.50	1.08			37.91
3.57	0.65			38.02
3.93	0.69			38.16
4.28	0.35			38.34
4.64	0.43			38.32
5.00	0.55			38.32
5.35	0.57			38.17
5.71	0.59			38.15

Table 8				
3C 120				
Position (kpc)	$\frac{[\text{NII}]\lambda 6584}{\text{H}\alpha}$	$\frac{[\text{SII}](\lambda 6717+\lambda 6731)}{\text{H}\alpha}$	$\frac{[\text{SII}]\lambda 6717}{[\text{SII}]\lambda 6731}$	Log(H α)
-3.38	0.39			38.97
-3.87	0.48			38.90
-4.35	0.41			38.71
-2.90	0.31	0.70		38.89
-2.42	0.31	0.34	1.72	39.24
-1.93	0.35	0.31	1.39	39.48
-1.45	0.27	0.35	1.34	39.40
1.45	0.37	0.27	1.44	39.52
1.93	0.36	0.38	1.56	39.23
2.42	0.55	0.59	1.56	39.05
2.90	0.39			38.78
3.38	0.31			38.48
3.87	0.29	0.27	1.14	38.85
4.35	0.39			38.78
4.83	0.42	0.58	1.85	38.72
5.32	0.29			38.76
5.80	0.33	0.39	2.93	38.77
6.28	0.47			38.86
6.77	0.40			38.79
7.25	0.46	0.79		38.62
7.73	0.40			38.50

Table 9				
Markarian 618				
Position (kpc)	$\frac{[\text{NII}]\lambda 6584}{\text{H}\alpha}$	$\frac{[\text{SII}](\lambda 6717 + \lambda 6731)}{\text{H}\alpha}$	$\frac{[\text{SII}]\lambda 6717}{[\text{SII}]\lambda 6731}$	Log(H α)
-9.20				38.24
-8.69	0.34	0.56	1.35	38.75
-8.17	0.34	0.37	1.44	39.23
-7.66	0.37	0.28	1.38	39.48
-7.15	0.36	0.27	1.55	39.47
-6.64	0.36	0.34	1.44	39.28
-6.13	0.38	0.36	1.77	39.09
-5.62	0.44	0.46	1.57	38.97
-5.11	0.40	0.51	1.80	38.99
-4.60	0.42	0.32	1.77	38.98
-4.09	0.37			38.96
-3.58	0.39	0.43	1.58	38.93
-3.07	0.53	0.46	1.28	38.90
-2.55	0.57			38.67
-2.04	1.23			38.17
3.58	0.46			38.60
4.09	0.52	0.57	1.71	38.84
4.60	0.47	0.41	1.31	38.97
5.11	0.47	0.44	1.81	39.00
5.62	0.46	0.50	1.67	38.91
6.13	0.53			38.75
6.64	0.60			38.49
7.15	0.49			38.37
7.66				38.23
8.17	0.39			38.56
8.69	0.27	0.44	1.96	38.81
9.20	0.27	0.36	1.13	38.85
9.71	0.33			38.61
12.26				37.91
12.77				37.84
13.28				38.50
13.79				38.65
14.31				38.05

Table 10				
UGC 3223				
Position (kpc)	$\frac{[\text{NII}]\lambda 6584}{\text{H}\alpha}$	$\frac{[\text{SII}](\lambda 6717+\lambda 6731)}{\text{H}\alpha}$	$\frac{[\text{SII}]\lambda 6717}{[\text{SII}]\lambda 6731}$	Log(H α)
-10.01	0.43			37.88
-9.74	0.57	0.85		37.86
-9.47	0.52			37.87
-8.66	0.44	0.67		37.79
-8.39	0.45	0.54		37.93
-8.11	0.56	0.60	0.81	38.15
-7.84	1.00	0.52	0.91	38.41
-7.57	0.45	0.44	0.97	38.67
-7.30	0.48	0.36	1.27	38.87
-7.03	0.45	0.35	1.23	38.93
-6.76	0.42	0.29	1.32	38.92
-6.49	0.42	0.34	1.25	38.84
-6.22	0.43	0.30	1.17	38.66
-5.95	0.52			38.40
-5.68	0.75	0.37		38.06
-5.41	0.64	0.37		37.95
8.11	0.63			37.96
8.39	0.65	0.72		38.12
8.66	0.51	0.73	1.50	38.34
8.93	0.57	0.56	1.07	38.42
9.20	0.50	0.61	1.39	38.43
9.47	0.58	0.46	1.20	38.28
9.74	0.58	0.68	1.45	37.98
10.01	0.56	0.22	1.40	37.63

Table 11				
Markarian 6				
Position (kpc)	$\frac{[\text{NII}]\lambda 6584}{\text{H}\alpha}$	$\frac{[\text{SII}](\lambda 6717+\lambda 6731)}{\text{H}\alpha}$	$\frac{[\text{SII}]\lambda 6717}{[\text{SII}]\lambda 6731}$	Log(H α)
1.14	0.73			38.75
1.43	0.77			38.35
1.71	1.21			37.96
2.00	0.91			37.74

Table 12				
Markarian 79				
Position (kpc)	$\frac{[\text{NII}]\lambda 6584}{\text{H}\alpha}$	$\frac{[\text{SII}](\lambda 6717 + \lambda 6731)}{\text{H}\alpha}$	$\frac{[\text{SII}]\lambda 6717}{[\text{SII}]\lambda 6731}$	Log(H α)
-9.85	0.79			37.92
-9.52				37.93
-9.19	0.47			38.00
-8.87	0.47			38.02
-8.54	0.62			38.19
-8.21	0.53			38.21
-7.88	0.42			37.99
-7.55	0.60			38.10
-7.22	0.81			38.16
-6.90	1.08			38.12
-6.57	0.51			38.22
-6.24	1.35			38.30
-5.91	0.88			38.28
-5.58	0.74			37.99
-1.31	1.49			38.16
1.31	1.70	1.76	1.70	38.81
1.64	1.79	1.39	1.44	38.58
1.97	1.28			38.17
5.25	0.58			38.29
5.58	0.48			38.59
5.91	0.44			38.67
6.24	0.47			38.59
6.57	0.39			38.47
6.90	0.41			38.27
7.22	0.63			38.07

Table 13				
Markarian 10				
Position (kpc)	$\frac{[\text{NII}]\lambda 6584}{\text{H}\alpha}$	$\frac{[\text{SII}](\lambda 6717 + \lambda 6731)}{\text{H}\alpha}$	$\frac{[\text{SII}]\lambda 6717}{[\text{SII}]\lambda 6731}$	$\text{Log}(\text{H}\alpha)$
-13.69	0.59			39.72
-13.25	0.53	0.24		39.80
-12.81				39.76
-12.37	0.29			39.52
-11.92		0.26		39.31
-10.60	0.69			39.70
-10.16	0.41			40.14
-9.72	0.28	0.09		40.22
-9.27	0.38			40.36
-8.83	0.38			40.28
-8.39	0.46			40.18
-7.95	0.60			39.97
-7.51	0.56			40.04
-7.07	0.45			40.06
-6.62	0.58	0.05		39.81
6.18	1.01	0.16		39.82
6.62	0.54	0.58		40.09
7.07	0.55			40.10
7.51	0.72			40.05
7.95	0.67			39.83
8.39	0.86			39.71
9.72	0.76			39.59
10.16	0.40			39.67
10.60	0.47	0.38		40.04
11.04	0.35	0.40	1.00	40.24
11.48	0.30	0.52		40.14
11.92	0.31	0.41	1.09	40.05
12.37	0.42	0.06	1.05	39.88
12.81	0.36	0.46	0.44	39.63
13.25	0.70			39.62
13.69	0.46			39.48

Table 14				
Markarian 382				
Position (kpc)	$\frac{[\text{NII}]\lambda 6584}{\text{H}\alpha}$	$\frac{[\text{SII}](\lambda 6717+\lambda 6731)}{\text{H}\alpha}$	$\frac{[\text{SII}]\lambda 6717}{[\text{SII}]\lambda 6731}$	Log(H α)
-5.97	0.69			38.60
-5.47	0.59			38.86
-4.97	0.81			38.80
-4.47	0.69			38.89
-3.98	0.69	0.45	0.52	38.99
-3.48	0.77	0.46	0.41	38.87
2.49	0.93			38.51
2.98	0.79	0.29	0.98	38.61
3.48	0.56	0.82	1.19	38.95
3.98	0.62	0.86	1.25	38.90
4.47	0.71	0.02	1.43	38.68
4.97	0.72	0.55	1.45	38.42
5.47	0.60			38.42

Table 15				
Markarian 504				
Position (kpc)	$\frac{[\text{NII}]\lambda 6584}{\text{H}\alpha}$	$\frac{[\text{SII}](\lambda 6717 + \lambda 6731)}{\text{H}\alpha}$	$\frac{[\text{SII}]\lambda 6717}{[\text{SII}]\lambda 6731}$	$\text{Log}(\text{H}\alpha)$
-4.72	0.58			38.56
-4.20	0.97			38.38
4.20	0.97			38.45
3.67	1.20			38.30
4.72	0.76			38.53
5.25	0.80			38.34

Table 16				
Markarian 506				
Position (kpc)	$\frac{[\text{NII}]\lambda 6584}{\text{H}\alpha}$	$\frac{[\text{SII}](\lambda 6717 + \lambda 6731)}{\text{H}\alpha}$	$\frac{[\text{SII}]\lambda 6717}{[\text{SII}]\lambda 6731}$	Log(H α)
−4.95				38.50
−4.33				38.66
−3.72				38.90
−3.10				39.00
−2.48				39.11
1.86				38.96
3.72				38.72
4.33				38.49
4.95				38.67

Table 17				
NGC 7469				
Position (kpc)	$\frac{[\text{NII}]\lambda 6584}{\text{H}\alpha}$	$\frac{[\text{SII}](\lambda 6717 + \lambda 6731)}{\text{H}\alpha}$	$\frac{[\text{SII}]\lambda 6717}{[\text{SII}]\lambda 6731}$	Log(H α)
-9.98				37.64
-9.72				37.62
-9.47				37.72
-9.21				37.94
-3.58	0.45			38.28
-3.33	0.74			38.55
-3.07	0.54			38.50
-2.81	0.48			38.47
-2.56	0.82			38.46
-2.30	0.84			38.30
-2.05	0.84	0.68	1.24	38.53
-1.54	1.64			38.21
-1.28	0.97	0.19	1.36	38.66
-1.02	0.54	0.43	1.66	39.19
1.54	0.72	0.49	1.03	38.88
1.79	0.91			38.51
2.30	0.79			38.47
2.56	0.68			38.51
2.81	0.67			38.53
3.07	0.52			38.48
3.33	0.53			38.37
3.58	0.72			37.98

Table 18				
NGC 182				
Position (kpc)	$\frac{[\text{NII}]\lambda 6584}{\text{H}\alpha}$	$\frac{[\text{SII}](\lambda 6717 + \lambda 6731)}{\text{H}\alpha}$	$\frac{[\text{SII}]\lambda 6717}{[\text{SII}]\lambda 6731}$	Log(H α)
-12.80				37.63
-12.54				37.94
-12.28	0.54			38.36
-12.03	0.40	0.54	0.86	38.56
-11.77	0.45	0.42		38.66
-11.52	0.42	0.50		38.67
-11.26	0.56			38.57
-11.00	0.42	0.59	1.26	38.35
-10.75				38.03

Table 19				
UGC 3403				
Position (kpc)	$\frac{[\text{NII}]\lambda 6584}{\text{H}\alpha}$	$\frac{[\text{SII}](\lambda 6717+\lambda 6731)}{\text{H}\alpha}$	$\frac{[\text{SII}]\lambda 6717}{[\text{SII}]\lambda 6731}$	Log(H α)
10.38				37.32
10.59	0.27			37.56
10.80	0.20			37.60
11.02				37.50
11.23				37.33
11.44				37.03
-9.96				37.21
-10.17				37.37
-10.38				37.51
-10.59				37.61
-10.80				37.62
-11.02				37.31

Table 20				
NGC 2599				
Position (kpc)	$\frac{[\text{NII}]\lambda 6584}{\text{H}\alpha}$	$\frac{[\text{SII}](\lambda 6717 + \lambda 6731)}{\text{H}\alpha}$	$\frac{[\text{SII}]\lambda 6717}{[\text{SII}]\lambda 6731}$	Log(H α)
-2.27	0.87			37.65
-2.04	0.91			37.60
-1.81	1.07			37.56
-1.59	0.75			37.82
-1.36	0.79			37.92
-1.13	0.97			37.95
1.13	1.57			37.80
1.36	0.77			38.01
1.59	0.69			38.00
1.81	0.48			38.00
2.04	0.76			37.88
2.27	1.36			37.53
3.17				37.72
3.40				37.78
3.63				37.57
3.85				37.41

Table 21				
NGC 3202				
Position (kpc)	$\frac{[\text{NII}]\lambda 6584}{\text{H}\alpha}$	$\frac{[\text{SII}](\lambda 6717+\lambda 6731)}{\text{H}\alpha}$	$\frac{[\text{SII}]\lambda 6717}{[\text{SII}]\lambda 6731}$	Log(H α)
-6.24				37.81
-5.91				37.83
-5.58	0.30			38.06
-5.25				38.16
-4.93	0.51			38.15
-4.60	0.67			38.12
-4.27	0.31			38.11
-3.94				37.86
-3.61				37.91
6.90	0.35			37.96
7.22	1.29			37.84
7.55	0.71			37.77

Table 22				
NGC 4500				
Position (kpc)	$\frac{[\text{NII}]\lambda 6584}{\text{H}\alpha}$	$\frac{[\text{SII}](\lambda 6717 + \lambda 6731)}{\text{H}\alpha}$	$\frac{[\text{SII}]\lambda 6717}{[\text{SII}]\lambda 6731}$	Log(H α)
-6.40	0.18			38.17
-6.25	0.66			38.42
-6.09	0.16	0.25		38.87
-5.94	0.05	0.30	1.03	39.18
-5.64	0.18	0.08		38.86
-5.49	0.23	0.95		38.83
-4.42	0.46			38.54
-4.27	0.72	0.53		37.93
-4.11	0.90			37.84
-3.66	1.44			38.08
-2.44	0.19	0.11		38.92
-2.29	0.46	0.39	0.23	39.17
-2.13	1.24	0.09	8.28	39.01
-1.98	0.73	0.47	1.65	39.39
-1.37	0.47	1.82	4.15	39.64
-1.22	0.65	0.74	0.34	40.21
-1.07	0.64	0.76	1.52	40.13
1.07	1.15			38.22
1.22	0.34			38.26
1.37	0.86			37.67
1.52	1.97			37.93
1.68	0.21			38.95
1.83	0.02			39.27
1.98	0.13	0.09	1.95	39.19
2.13	0.76	0.26	0.42	39.02
2.44	0.57	1.62	0.46	38.64

Table 22 (continued)				
NGC 4500				
Position (kpc)	$\frac{[\text{NII}]\lambda 6584}{\text{H}\alpha}$	$\frac{[\text{SII}](\lambda 6717 + \lambda 6731)}{\text{H}\alpha}$	$\frac{[\text{SII}]\lambda 6717}{[\text{SII}]\lambda 6731}$	Log(H α)
3.05	0.37			38.49
3.20	0.16			38.68
3.35	1.52			37.34
4.11				38.19
4.27				38.15
4.42				35.28
4.57	2.14			37.37
4.88				37.98
5.03				37.63

Table 23				
NGC 5378				
Position (kpc)	$\frac{[\text{NII}]\lambda 6584}{\text{H}\alpha}$	$\frac{[\text{SII}](\lambda 6717+\lambda 6731)}{\text{H}\alpha}$	$\frac{[\text{SII}]\lambda 6717}{[\text{SII}]\lambda 6731}$	Log(H α)
-7.47				37.38
-7.31	0.37			37.77
-7.16	0.31			37.99
-7.01	0.36			37.99
-6.86	0.41			37.79
-6.70	0.55			37.41
-3.81	1.11	0.05	1.08	37.98
-3.66	1.13	0.66	1.16	38.56
-3.50	1.18	0.55	1.18	38.71
-3.35	1.14	0.63	1.20	38.75
-3.20	1.17	0.61	0.99	38.21
-3.05	1.15	0.63		37.77
-2.89	1.12			37.48

Table 24				
NGC 5533				
Position (kpc)	$\frac{[\text{NII}]\lambda 6584}{\text{H}\alpha}$	$\frac{[\text{SII}](\lambda 6717+\lambda 6731)}{\text{H}\alpha}$	$\frac{[\text{SII}]\lambda 6717}{[\text{SII}]\lambda 6731}$	Log(H α)
-7.09				37.60
-6.90				38.03
-6.70	0.26			38.20
-6.50	0.33			38.23
-6.31	0.55			38.02
-6.11	0.84			37.61
-2.36	0.17	0.27	1.09	38.13
-2.17	1.21	0.27	1.07	38.50
-1.97	1.30	0.38	1.20	38.94
-1.77	1.10	0.41	1.20	38.86
-1.58	1.28	0.94	1.01	38.46
-1.38	1.41	0.73	1.31	38.14

Table 25				
NGC 6032				
Position (kpc)	$\frac{[\text{NII}]\lambda 6584}{\text{H}\alpha}$	$\frac{[\text{SII}](\lambda 6717 + \lambda 6731)}{\text{H}\alpha}$	$\frac{[\text{SII}]\lambda 6717}{[\text{SII}]\lambda 6731}$	Log(H α)
-10.17	0.98	0.35		37.05
-8.69				37.54
-8.47				37.44
6.99	0.49			37.71
7.20	0.44			38.04
7.41	0.52			38.20
7.63	0.38			38.22
7.84				37.59

Table 26				
NGC 6154				
Position (kpc)	$\frac{[\text{NII}]\lambda 6584}{\text{H}\alpha}$	$\frac{[\text{SII}](\lambda 6717 + \lambda 6731)}{\text{H}\alpha}$	$\frac{[\text{SII}]\lambda 6717}{[\text{SII}]\lambda 6731}$	Log(H α)
-8.09	0.59			38.21
-7.79	0.67			38.21
-7.49	0.59			38.07
7.79	0.56			38.31
8.09	0.55			38.36
8.39	0.63			38.31
8.69	0.52			38.48
8.99	0.53			38.52
9.28	0.43			38.63
9.58	0.66			38.65
9.88	0.42			38.69
10.18	0.58			38.59
10.48	0.50			38.32
10.78	0.58			37.91
11.08	0.58			37.91
12.58				38.08
12.88	0.26			38.20
13.18	0.45			38.09
13.48				38.04

Table 27				
NGC 7570				
Position (kpc)	$\frac{[\text{NII}]\lambda 6584}{\text{H}\alpha}$	$\frac{[\text{SII}](\lambda 6717 + \lambda 6731)}{\text{H}\alpha}$	$\frac{[\text{SII}]\lambda 6717}{[\text{SII}]\lambda 6731}$	Log(H α)
-1.69	0.95			38.11
-1.45	0.60			38.76
-1.21	0.52	0.33		39.10
1.21	0.46	0.29		39.11
1.45	0.53	0.39		38.85
1.69	0.65			38.29
6.51	0.55			38.51
6.76	0.47	0.34		38.91
7.00	0.54	0.37	0.86	38.92
7.24	0.49			38.66
7.48	0.57			38.54
7.72	0.73	0.39	1.50	38.53
7.96	0.46			38.45
8.20	0.56	0.38		38.30
8.44				38.16
8.69				37.90
8.93	0.52			37.73

Table 28				
NGC 7691				
Position (kpc)	$\frac{[\text{NII}]\lambda 6584}{\text{H}\alpha}$	$\frac{[\text{SII}](\lambda 6717+\lambda 6731)}{\text{H}\alpha}$	$\frac{[\text{SII}]\lambda 6717}{[\text{SII}]\lambda 6731}$	Log(H α)
-12.29				39.85
-12.07	0.36	0.32	0.54	40.52
-11.86	0.17	0.05	0.18	41.12
-11.65	1.08	0.66	0.71	40.23
-7.63				40.34
-7.41				40.38
-5.93	0.64			40.47
-5.72	0.90			39.67
-3.39				40.54
-3.18	0.83			40.53
-2.97				38.42
-2.75				40.57
-2.54				40.05
-2.33				40.51
-2.12	0.28			39.94
-1.06	0.87			40.23
1.91	0.30			40.40
2.12	0.93			40.47
2.33	1.13			40.39
2.54	0.60			40.52
10.80				40.46

Table 29				
NGC 7771				
Position (kpc)	$\frac{[\text{NII}]\lambda 6584}{\text{H}\alpha}$	$\frac{[\text{SII}](\lambda 6717+\lambda 6731)}{\text{H}\alpha}$	$\frac{[\text{SII}]\lambda 6717}{[\text{SII}]\lambda 6731}$	Log(H α)
-8.16	0.37			37.54
-7.93	0.35			37.86
-7.70	0.24			37.86
-7.48	0.22			37.96
-7.25	0.34			38.06
-7.02	0.57			38.01
-6.80	0.39			38.18
-6.57	0.41	0.32	0.97	38.28
-6.34	0.48	0.23	1.23	38.34
-6.12	0.43			38.38
-5.89	0.46	0.66	1.23	38.38
-5.66	0.42	0.36	1.33	38.38
-5.44	0.36			38.41
-5.21	0.33	0.33	1.35	38.41
-4.98	0.35	0.34	1.19	38.50
-4.76	0.36			38.57
-4.30	0.34			38.62
-4.08	0.34			38.59
-3.85	0.37			38.55
-3.63	0.40			38.50
-3.40	0.44			38.50
-3.17	0.44	0.25	1.15	38.49
-2.95	0.40	0.30	0.75	38.45
-2.72	0.40			38.43
-2.49	0.47			38.42
-2.27	0.47			38.32
-2.04	0.38			38.20
-1.81	0.49			38.19
-1.59	0.56			38.15
-1.36	0.49			38.10
-1.13	0.61	0.73	0.65	38.07

Table 29 (continued)				
NGC 7771				
Position (kpc)	$\frac{[\text{NII}]\lambda 6584}{\text{H}\alpha}$	$\frac{[\text{SII}](\lambda 6717+\lambda 6731)}{\text{H}\alpha}$	$\frac{[\text{SII}]\lambda 6717}{[\text{SII}]\lambda 6731}$	Log(H α)
1.13	0.50	0.23	1.25	39.06
1.36	0.48			39.24
1.59	0.45	0.24	1.08	39.27
1.81	0.45	0.28	1.29	39.34
2.04	0.45	0.20	1.32	39.41
2.27	0.41	0.23	1.11	39.39
2.49	0.43	0.22	1.11	39.38
2.72	0.41	0.19	1.18	39.27
2.95	0.44	0.19	1.27	39.10
3.17	0.43			38.93
3.40	0.56			38.69
3.63	0.55			38.57
3.85	0.55			38.44
4.08	0.57			38.35
4.30	0.70			38.33
4.53	0.53			38.40
4.76	0.57			38.30
4.98	0.54	0.40	0.95	38.27
5.21	0.82			38.16
5.44	0.71			38.09
5.66	1.00			37.95
5.89	0.77			38.00
6.12	0.55			37.88
6.34	1.22			37.97
6.57	0.75			38.01
6.80	0.57			38.15
7.02	0.73			38.16
7.25	0.72			38.15
7.48	0.56			38.22
7.70	0.57			38.30
7.93	0.56		0.80	38.43

Table 29 (continued)				
NGC 7771				
Position (kpc)	$\frac{[\text{NII}]\lambda 6584}{\text{H}\alpha}$	$\frac{[\text{SII}](\lambda 6717+\lambda 6731)}{\text{H}\alpha}$	$\frac{[\text{SII}]\lambda 6717}{[\text{SII}]\lambda 6731}$	Log(H α)
8.16	0.45	0.44	1.00	38.37
8.38	0.46			38.40
8.61	0.40			38.35
8.84	0.40			38.34
9.06	0.47			38.49
9.29	0.45			38.50
9.52	0.43			38.45
9.74	0.45			38.39
9.97	0.50			38.39
10.20	0.41	0.43	1.15	38.40
10.42	0.38	0.33	1.54	38.50
10.65	0.41			38.62
10.88	0.40	0.32	1.10	38.72
11.10	0.40	0.29	1.66	38.79
11.33	0.35	0.27	1.13	38.83
11.56	0.38	0.28	0.59	38.80
11.78	0.36			38.67
12.01	0.35	0.39		38.55
12.24	0.39	0.35	1.52	38.42
12.46	0.40			38.32
12.69	0.40			38.19
12.91	0.43			38.14
13.14	0.45	0.31	1.18	38.22
13.37	0.40			38.30
13.59	0.40			38.38
13.82	0.35			38.31
14.05	0.47			38.08
14.27	0.43			37.83
14.50				37.34

Chapter 4

RESULTS and DISCUSSION

4.1 Background

The motivation for this project was to determine what similarities and/or differences exist in the galaxian environment of Seyfert and normal galaxies. One prominent global feature of a galaxy is the amount of star formation occurring in its disk regions. In fact, the star formation rate and the history of star formation is a primary underlying variable along the Hubble sequence. Most S0 and Sa galaxies contain large amounts of gas but their star formation rates are quite low. The star formation rate as well as the characteristics of the sites of massive star formation change markedly as one moves to the late type Sbc galaxies through to the Irregular class. The HII regions in early type galaxies are about 50 times less bright and certainly less numerous than those found in the late type galaxies of the same absolute magnitude. Therefore, theories of galaxy formation and evolution must explain why comparable amounts of gas in galaxies produce drastically different rates of star formation and also why the characteristics of the star formation sites change. Fortunately, one direct tracer of star formation activity, namely H α emission, is easily observable.

A relationship exists between the massive star formation rate (SFR) and the density and dynamics of the interstellar gas (Schmidt 1959; Kennicutt 1989). For 30 years, a sim-

ple power law relationship between the SFR and the local gas density (Schmidt 1959) was assumed though frequently questioned. Recently it has been shown that the dependence of the SFR on the local gas density is very non-linear and that star formation cannot occur unless the local gas density is close to or above a critical density that depends on the dynamics of the gas (Kennicutt 1989). Massive star formation is suppressed at densities well below this critical density while at or near this critical density, there is an abrupt increase in the star formation rate that is greater than that predicted by the Schmidt law. Far enough above this critical density the star formation rate is well reproduced by a Schmidt law. HI radio maps and H α emission surveys clearly indicate that over many decades in gas density, the gas density is at or near the critical density everywhere in a galaxy.

Since the radial distribution of gas in a galaxy is close to the critical density everywhere, any modification to the local gas density may affect the SFR. Though star formation can occur when the local gas density is slightly below the critical density any mechanism that significantly depletes/enhances the local gas density will decrease/increase the SFR. This in turn will be evident by a decrease/increase in the number and morphology of HII regions. Observations of interacting systems (Kennicutt *et al.* 1987) showed that both the H α emission and the far infrared emission were systematically enhanced in these systems relative to a control sample of normal spirals of the same Hubble type. These interacting systems also had a wider dispersion in their emission properties. However, the degree of this enhancement varied dramatically and was shown to be due to the characteristics of the

interaction rather than with the internal properties of the galaxies. These types of observations, when coupled with theoretical work (Struck–Marcell and Scalo 1987) that shows that even a modest perturbation of the disk could lead to very large increases in the global star formation rate, provides another approach to studying the affect of an active nucleus on its host galaxy. Measurement of the HII emission, and the H α emission in particular, in Seyfert galaxies will be a useful indicator of possible modification to their interstellar medium when compared to a sample of normal galaxies.

Previous work on the disk components of Seyfert galaxies has indicated that their star formation rates and stellar populations are similar to those found in normal spiral galaxies. Observations of a sample of 27 HII regions in four Seyfert galaxies have shown that there is no evidence for unusual emission line strengths, unexpected emission line ratios or abnormal N/O or S/O abundances (Evans and Dopita 1987). These authors found that the presence of nuclear activity is not a significant factor for understanding the interstellar medium for distances greater than about 2 kpc from the nucleus. Surface photometry of Seyferts (Yee 1983; MacKenty 1985) has shown that the disk components of Seyfert galaxies were similar to normal spirals of Hubble types ranging from Sa to Sbc. It was found that the colors of the host galaxies were comparable to normal spirals. However, no systematic study of global massive star formation in Seyferts has been done to our knowledge.

Most previous studies of star formation activity in Seyfert galaxies have concentrated on just their inner few kpc (Heckman 1987). Within a few kpc of the active nucleus both

optical emission line gas and radio continuum measurements indicate that Seyfert galaxies contain dual gas components (Wilson 1986). One component are HII regions with emission line strengths due to hot OB stars and they partake in the galactic disk rotation. The other component are emission line regions whose line strengths are due to a non-thermal continuum. This component exhibits non-circular motions. While previous work showed that star formation exists in Seyferts and that there are probable differences between the circumnuclear gas in Seyferts relative to normal spirals, no detailed study has been made of the global star formation activity occurring in Seyfert galaxies relative to normal spiral galaxies. This type of study has the potential for determining the limits of the large-scale influence of the non-thermal continuum on the galaxy as a whole and the effect of a possible non-axisymmetric potential set up by the active nucleus; this approach is not limited to just the central few kpc. If the nucleus does not affect or perturb the host galaxy to some minimum observational level, then we would expect to find no differences in the star formation properties between Seyfert and normal galaxies. On the other hand, if, for example, gas was funneled into the nuclear region due to the non-axisymmetric potential set up by the active nucleus or if the Seyfert galaxy underwent a tidal interaction with a nearby galaxy, then there may be a discernible change in the gas density that is subsequently reflected in the star formation rate of the host galaxy (Bushouse 1987; Cutri and McAlary 1985).

Measurement of the total H α flux of a galaxy gives a measure of the current global rate of star formation since the presence of HII regions is the one obvious manifestation of

star formation activity. In addition, the relative strengths of optical emission lines arising from clouds photoionized by hot OB stars are distinct from the relative strengths of those same lines when the ionizing continuum arises from a non-thermal source. These line ratios are, therefore, very useful in determining the extent of the influence of an active nucleus on its host galaxy when considered in parallel with the global H α emission level.

There are a number of other quantities that can be derived from long slit images that give useful information on star formation activity in galaxies. Systematic differences in any these quantities between the two galaxy samples would indicate that the galaxian environment in Seyferts has been modified. The maximum critical density associated with the threshold in star formation activity is one such quantity. Clouds begin collapsing when their density exceeds some critical density that depends on the dynamics of the gas. The onset of star formation can be viewed in terms of whether the spiral disk is stable to axisymmetric perturbations. Instability to such perturbations will cause the gas to self-gravitate thereby initiating star formation. Consider a differentially rotating thin, isothermal disk. If motion is confined to the $z = 0$ plane and a simple equation of state is adopted, then the equations of motion can be linearized. This yields a dispersion relation that provides the necessary criterion for determining if the disk is stable to an imposed potential. It can be shown (Binney and Tremaine 1987) that the disk is stable (i.e., no star formation will occur) if the local surface gas density is always less than some critical density

$$\Sigma < \Sigma_c := \alpha \kappa c / (3.36 G)$$

This is known as the Toomre stability criterion (Toomre 1964). If the imposed potential is strong enough then the change in the surface gas density due to this imposed potential makes it greater than the critical density then this change may very well be manifest as an overall enhancement/depletion of the massive star formation rate. This type of change would be reflected in changes in the H α emission of the galaxy since H α traces the sites of massive star formation and the H α luminosity is proportional to the massive star formation rate. However, these type of changes must occur on scales of kpcs if we are to detect them in our long slit study.

In the inner regions of normal spirals the rotation curve is proportional to R while in the outer regions of spiral disks, the rotation curve is fairly constant or flat. The critical density in the inner regions of a spiral galaxy is, therefore, a factor of $\sim \sqrt{2}$ greater than that for the outer regions of a spiral galaxy. Since we can measure V(R) and R and can make an estimate of the slope of V(R), we can determine $V_{\max} / R_{\max}$, where $V_{\max}$ and $R_{\max}$ are the velocity and radial position where the outer edge of the H α emission is detected in the spiral disk. This ratio is a measure of the critical density for both galaxy samples. Differences in the distribution of the critical densities between the two samples would be strong evidence for differences in the dynamics of the disks in Seyfert galaxies.

Another quantity of interest is the number and luminosity of HII regions. Though the

spatial resolution in this study is not good enough for counting individual HII regions, it is possible to isolate complexes of HII regions in these data. If star formation is enhanced/depleted in the Seyfert sample relative to the normal sample, there should be discernible changes in the number and luminosity of these HII region complexes. For these same reasons, we can compare the brightest HII region complex and the radial distribution of HII emission. Finally, the distribution in the values of the line ratios $[\text{NII}] \lambda 6584 / \text{H}\alpha$, $[\text{SII}](\lambda 6717 + \lambda 6731) / \text{H}\alpha$ and $[\text{SII}] \lambda 6717 / [\text{SII}] \lambda 6731$ can be examined.

The following sections describe the results of a long slit study that examined the HII emission in a sample of Seyfert galaxies and compared these results to a control sample of normal spiral galaxies. A number of quantities, all of which depend on the global star formation rate, were determined for each sample and then compared. The quantities examined and compared were (1) the total integrated $\text{H}\alpha$ emission line luminosity along the major axis of each program galaxy, (2) the magnitude of the critical density for star formation, (3) the number and luminosity of each emission line region (4) the brightest off-nuclear emission line region from each galaxy, (5) the radial distribution of the emission line regions and (6) the line ratios $[\text{NII}] \lambda 6584 / \text{H}\alpha$, $[\text{SII}](\lambda 6717 + \lambda 6731) / \text{H}\alpha$ and $[\text{SII}] \lambda 6717 / [\text{SII}] \lambda 6731$.

4.2 Total $\text{H}\alpha$ Luminosity

4.2.1 Introduction

The total $H\alpha$ luminosity of a galaxy is an important quantity because it is directly related to the star formation rate. Any perturbation introduced could be enough to initiate star formation since the gas density in galaxies is everywhere close to the critical density and so the circumnuclear gas is only marginally stable. One possible origin for a perturbation is an active nucleus. Efforts to understand the origin and evolution of nuclear activity have involved examining the interaction of the by products of an active nucleus (e.g., jets and energetic particles) with the circumnuclear regions and on the host galaxy interstellar medium. Star formation or enhanced star formation in these regions could be an effect of nuclear activity, induced by the above mechanisms. On the other hand, there is no way to rule out the possibility that star formation and nuclear activity have a common cause (e.g., interaction with a close companion - see Adams 1977, Dahari 1984, 1985 and FWS88). If an active nucleus results because a perturbation causes inflow of gas and stars into the nuclear regions thereby providing accreting material around the supermassive black hole, then this perturbation could also provide the necessary impetus to cause clouds to begin collapsing in other parts of the affected galaxy, whether the clouds are in the nucleus, circumnuclear region or in the disk itself. Regardless of the origin of any detected differences, if the disks in Seyfert galaxies are fundamentally different than those of normal galaxies then these differences may be observable as differences in the SFR (i.e., $H\alpha$ luminosity) if the effects are strong enough. Since the line ratio analysis above indicated that the emission line regions in the Seyfert disks appear photoionized by hot OB stars only, it seems apparent that the

HII regions in both samples are similar; however, it may be that the global amount of H α emission shows systematic differences, either in strength or in radial position.

4.2.2 Results and Discussion

Fig. 6 presents the histograms of the logarithms of the total H α luminosities (in ergs sec⁻¹) for both the normal galaxy sample and the Seyfert galaxy sample. The distribution of values for the sample of normal galaxies ranges between 38.53 and 40.90 while the distribution for the Seyfert galaxies range from 38.97 to 41.50. The distribution in the logarithms of the total H α luminosities for individual HII regions (Kennicutt et al. 1989) ranges between 37.0 and 41.0 with a peak around 39.5 while for an entire galaxy, the range of values is from 40.0 to 42.0 (Kennicutt and Kent 1983). One member of the Seyfert sample, Markarian 10, was found to have the highest amount of disk emission in either sample. It is natural to ask if this is due in some obvious way to the presence of the Seyfert nucleus. Examination of the radial distribution in the disk of H α emission in this object shows that the emission arises in the disk component and not in the near-nuclear regions. Since the amount of disk emission is comparable to that of an entire galaxy, it is may be that for Markarian 10, most of the disk HII emission was sampled. If the large amount of emission were due to the Seyfert nucleus, then it would be difficult to explain why all of the other Seyfert galaxies only have H α luminosities comparable to the sample of normal galaxies.

Figure 6. The distribution in the total H α luminosity for each sample of the galaxy samples.

The apparent similarity between these two distributions was tested using the Kolmogorov–Smirnov test or KS test. The KS test measures the maximum value of the absolute difference between two cumulative distribution functions. The distribution of the KS statistic when applied to data sets drawn from the same distribution can be approximated analytically. The null hypothesis that the data sets are drawn from the same distribution can be accepted or rejected based on the significance of a nonzero value of the KS statistic. The null hypothesis can be accepted for confidence levels approaching 100%.

Application of the KS test showed that these distributions were similar and that the null hypothesis can be accepted at the 97% level. The effect on these results of errors in the absolute calibration were done using a Monte Carlo simulation with the KS test. 100,000 simulations were run with errors of up to $\pm 40\%$ introduced into the values for the total H α luminosities in both samples. The KS test was run for a given data set generated from the Monte Carlo simulation. Even with this large error estimate introduced, the null hypothesis that these distributions are identical was accepted at the 92% level. Therefore, the total H α luminosities between Seyfert and normal galaxies appear identical at our level of detection. If differences do exist then they must be at levels not grossly affecting the global star formation rate. There is no evidence for either an increased amount or a noticeable depletion in the star formation activity in Seyfert galaxies. If there does exist any perturbation on the disk regions due to the Seyfert nucleus, it must be at a sufficiently weak level so as not to change dramatically the star formation properties of the disk.

4.3 *The Distribution of the Critical Density*

4.3.1 *Introduction*

A non-linear relationship exists between the massive SFR (as traced by the H α emission) and the local gas density and its dynamics (Kennicutt 1989). For the past 30 years a power law relationship between the massive SFR and the local gas density, known as the Schmidt law (Schmidt 1959), has been used. In dense regions (surface densities ≥ 4 solar masses / pc²), the Schmidt law (star formation rate $\propto$ (gas density)^N where $N = 1.3 \pm 0.3$) appears valid. However, for surface densities below this value, the SFR drops rapidly to zero and for densities less than about 3 solar masses / pc², there is no star formation occurring as evidenced by no detectable H α emission.

The existence of this threshold in the process of forming stars is understandable from gravitational stability arguments. For a thin, isothermal gas disk, the disk is unstable to the growth of density perturbations if the local gas density exceeds the critical value $\Sigma_c = \alpha \kappa c / 3.36 G$ where c is the velocity dispersion of the gas and has a measured value of 6 km/sec. in our local interstellar medium, κ is the epicyclic frequency and α is a dimensionless quantity with a value near unity. For the outer disk regions of spiral galaxies where the rotation curve is flat, Σ_c (solar masses / pc²) $\propto V(\text{km/sec}) / R(\text{kpc})$ where $V(R)$ is the rotation curve at radius R . The radial dependence of the ratio of the gas surface density to the critical density is similar for a large number of galaxies. This ratio was found not to change

by more than a factor of 2 to 3 over several decades in actual gas densities (Kennicutt 1989).

The radius that corresponds to the outer edge of the HII emission in any one galaxy is approximately the same radius where the gas surface density becomes less than the critical density. From our long slit data, this radius and the rotational velocity at this radius can be measured, thereby enabling a measurement of the critical surface density to be found for all those galaxies in our two samples that contain observable HII emission. Any systematic differences between the two samples would imply that in general, the critical density has been modified thereby directly influencing whether global star formation will be inhibited or enhanced.

For each of the galaxies with detectable HII emission, the wavelength at the emission farthest from the nucleus was converted into a rotational velocity ($V_{\max}$) and its angular position converted onto a linear scale ($R_{\max}$). The ratio $V_{\max} / R_{\max}$, which is proportional to the critical density, was then compared between the two samples. A correction to the epicyclic frequency in the case that the rotation curve was not flat was estimated by approximating the derivative $dV(R)/dR$ by the ratio of the difference in velocity and distance in the region near $R_{\max}$.

4.3.2 Results and Discussion

Fig. 7 shows the distribution in critical density values for each sample. For the sample of normal galaxies, the values of $V_{\max} / R_{\max}$ ranged from 10.96 to 48.23 while for the

Figure 7. Distribution in the critical density measures.

Seyfert sample these values ranged from 6.82 to 56.01. The two distributions are quite similar and application of the KS test shows that the null hypothesis can be accepted at the 91% level. To determine the affect of errors from the wavelength calibration and from the spatial position on the results, a Monte Carlo simulation was run for 100,000 trials. The wavelength calibration and spatial position were both accurate to about 10% so that the total error was about 15%. This then allows the null hypothesis to be accepted at the 87% level.

Since the range of critical densities in the Seyfert galaxies closely matches that in the normal sample, it follows that the local surface density of the gas everywhere in the disk region of the Seyfert galaxies is similar to that in normal galaxies. The gas density in normal spirals is very close to the critical density and even a modest perturbation of the interstellar gas is enough to noticeable modify the star formation rate (Struck–Marcell and Scalo 1987). Had there been a significant redistribution of gas to the inner regions of the Seyfert galaxy in order to power the active nucleus, for example, then the local gas densities would have increased/decreased thereby increasing/decreasing the global star formation rate. On the other hand, if the critical density had been modified due to a systematic difference in the rotation curves of Seyfert galaxies relative to normal spirals then star formation would have been suppressed. However, these results show that no such scenarios are evident and that there is no noticeable systematic change in the dynamics of the interstellar medium of the active galaxies compared to an otherwise similar sample of spirals without an active nucleus.

4.4 Number and Luminosity of HII Emission Line Complexes

4.4.1 Introduction

Another indicator of the massive star forming properties of galaxies is the number and luminosity of individual HII regions. In general, early type spirals contain fewer HII regions than late type spirals or irregular galaxies. The HII regions in early type spirals are also less luminous with very few or no highly luminous ($> 10^{39}$ ergs / sec) HII regions. Compared to the late type spirals, the luminosity function of early type spirals is more steep indicating that the dominant number of HII regions have luminosities $< 10^{39}$ ergs / sec. The luminosity function has an upper cutoff or turnover implying a virtual absence of very massive and very luminous HII regions. In early type galaxies, the large majority of massive star formation occurs in small HII regions photoionized by a few OB stars. In addition, for a given luminosity, fewer HII regions are present in early type spirals relative to late type galaxies. The conclusion is that along the Hubble sequence, there exists a strong gradient in the underlying masses of the parent cloud. Any perturbation modifying this characteristic mass would certainly modify the number and luminosity of HII regions.

Previous work that studied the number and spatial distributions of HII regions required good spatial resolution between HII regions and so have been necessarily limited to samples of nearby galaxies. Since the galaxies observed for this study were not nearly close enough to resolve their individual HII regions, the measured HII emission arises from mul-

multiple HII regions or complexes. However, it is still possible to isolate individual complexes throughout both samples and compare these. Though it is no longer meaningful to construct an HII luminosity function for each galaxy and sample, it is useful to determine the integral luminosity function for each sample and then compare these two. The integral luminosity function, $N(L) dL$, is the total number of HII regions with a luminosity greater than L .

In this section then, we examined the number of HII regions detected in each sample and the luminosity of these detections. Since the majority of the individual HII regions cannot be resolved in our samples, we instead looked at isolating regions of HII emission that clearly arise from multiple HII regions. For each galaxy, the emission arising from an isolated complex was summed together spatially and its luminosity determined. Determining single or multiple complexes for each galaxy was not without ambiguity. However, the spatial resolution was sufficient enough that in most galaxies, the individual complexes could be identified unambiguously from surrounding HII complexes. It was necessary to extract these complexes in a manner similar to the way in which the unresolved nuclear point source was extracted in Section 3.5. For those galaxies in which the source was clearly embedded in other emission, we found it helpful to extract the other less bright HII complexes first and subtracting them off before extracting the brightest HII complex. As a third method, we also simply used *splot* to fit multiple gaussians to these embedded regions. The results from all three methods were similar and gave a useful error estimate on how well

the luminosity of the brightest region was known.

4.4.2 Results and Discussion

Fig. 8 shows the luminosity distribution for each sample. For the sample of normal galaxies, the values of the logarithm of the $H\alpha$ luminosity (ergs sec^{-1}) for individual HII region complexes ranged from 38.21 to 40.63 while for the Seyfert sample these values ranged from 38.19 to 40.98. The two distributions were quite similar and application of the KS test shows that the null hypothesis can be accepted at the 98% level. To determine the effect of errors on the results due to errors in the absolute calibration, a Monte Carlo simulation was run for 100,000 trials. We assumed errors of $\pm 40\%$. This allowed the null hypothesis to be accepted at the 94% level.

The number of HII region complexes and the luminosity distributions of Fig. 8 are very similar to those with larger samples of normal spirals (Kennicutt et al. 1989). The Seyfert sample contained 42 individual complexes while the normal sample contained 40. The luminosity of individual disk HII regions from such studies ranged from about 37.5 to 41.0 with a peak at 39.5. The distributions from both samples were clearly not starbursts since these distributions ranged from 39.0 to 42.0 with a maximum at 41.0. Therefore, we can conclude that the number and luminosities of the HII regions in Seyfert galaxies are not skewed to one or a few dominant HII regions but appear distributed in a manner similar to

Figure 8. Distribution in the $\text{H}\alpha$ luminosities for the HII emission line complexes.

normal spirals and there is no evidence that Seyfert and starburst phenomena are correlated.

4.5 Brightest HII Emission Line Complexes

4.5.1 Introduction

There exists a strong dependence of the properties of HII regions on Hubble type. Since the $H\alpha$ luminosities of HII regions increase as one progresses towards later type galaxies, increases in the luminosities of the brightest HII region(s) are also expected and in fact are evident. These changes arise due to the physical differences in the size of the HII regions and the number of embedded ionizing stars (Kennicutt 1988). The brightest HII regions in late type galaxies have masses that are 1–2 orders of magnitudes greater than those in early type spirals. If it is assumed that the efficiency of star formation is constant in all galaxies, the change in the luminosities of the brightest HII regions with Hubble type implies that the masses of the parent clouds also increase with Hubble type. Therefore, significant changes in the size and masses of the parent clouds would be reflected in the formation of very bright HII regions over and above what would be expected for a given Hubble type. In this section we compared the brightest (i.e., largest $H\alpha$ luminosity) individual HII complex from each galaxy.

4.5.2 Results and Discussion

Fig. 9 shows the luminosity distribution for the brightest HII region complex for both samples. For the sample of normal galaxies, the values of the brightest luminosity HII re-

Figure 9. The distributions of the brightest HII emission line complexes.

gion complex ranged from 38.24 to 40.63 while for the Seyfert sample these values ranged from 38.97 to 40.98. The two distributions were quite similar and application of the KS test shows that the null hypothesis can be accepted at the 98% level. To determine the affect of errors (mainly from the absolute calibration) on the results, a Monte Carlo simulation was run for 100,000 trials. This allowed the null hypothesis to be accepted at the 93% level.

Studies of samples of normal galaxies (Kennicutt 1988) show that the brightest individual HII region have luminosities that range from 38.0 to 41.0 with a peak in the luminosity distribution of just over 39.0. It is clear that the distributions for the two samples in this study were similar. There do not appear to be any supergiant HII regions or starburst activity present. These results imply that the parent clouds from which massive star formation occurs in Seyfert galaxies are quite similar to those in normal galaxies. Has there been a large-scale shift in the characteristic size of these parent clouds, the distribution in Fig. 9 for the Seyfert galaxies would be skewed to the brighter end and would have their brightest HII luminosities greater than those found in normal spirals. The lack of any indication of changes in the dominant HII region complex further supports the conclusion that the star formation activity in Seyfert galaxies is quite comparable to normal spirals.

4.6 Radial Distribution of HII Emission Line Complexes

4.6.1 Introduction

The radial distribution of HII regions are also correlated with Hubble type. In general, the distribution found in early type galaxies show that either the radial number distribution decreases exponentially or has a ring shape coupled with a deep, minimum central area. In late type galaxies, another radial number distribution evident is one in which the surface number density of HII regions oscillate with decreasing density outwards (Hodge and Kennicutt 1983). This quantity is less useful for comparing the two samples in this study because we are only sampling the HII region distribution along the major axis and not azimuthally averaging the distribution. In addition, we cannot sample individual HII regions. Also, this quantity is not as an objective quantity for discriminating differences between the two samples as some of the other quantities. The differences in those galaxies with different star formation properties is not as distinct here. However, this quantity is still useful in that it will show if the Seyfert sample has grossly different sites for star formation due to large-scale redistribution of the gas or if the near nuclear regions have enhanced star formation activity relative to those regions in normal galaxies.

4.6.2 Results and Discussion

Fig. 10 shows the radial distribution of the number of H α detections and Fig. 11 shows the radial distribution in luminosities. The values shown in these two figures is the radial distribution of the total fraction of H α detections and H α luminosity. Fig. 10 shows that most of the detections from both samples were within 12 kpc of the nucleus. Fig. 11 is more intriguing in that it seems to show a difference. However, the Seyfert sample is

Figure 10. The radial distributions of the H α detections.

Figure 11. The radial distributions of the H α luminosities.

dominated by the contribution from Markarian 10. If this object is eliminated then the distributions were very similar. Application of the KS test showed that the null hypothesis can be accepted at the 93% level. To determine the affect of errors on the results, a Monte Carlo simulation was run for 100,000 trials. This allowed the null hypothesis to be accepted at the 89% level.

For the sample of normal galaxies, the radial luminosity distribution ranged from 39.36 to 40.59 while for the Seyfert sample these values ranged from 32.58 to 40.63. The two distributions were quite similar and application of the KS test shows that the null hypothesis can be accepted at the 96% level. To determine the affect of errors on the results, a Monte Carlo simulation was run for 100,000 trials. This allowed the null hypothesis to be accepted at the 91% level.

These results show that the sites for star formation of the Seyfert galaxies is comparable to the normal galaxy sample and that there is no global modification to the sites of star formation activity due to the presence of the active nucleus. In particular, the near –nuclear regions are very similar between the two samples indicating that if there is an enhancement to the star formation activity in Seyferts, it must be confined to within 1 kpc of the nucleus.

In addition to there being no discernible changes to the locations of star formation, there are no global differences in the strength of the star formation activity. It might be expected that if the local gas density in the near–nuclear regions in Seyferts was modified due to the presence of the active nucleus, that there would be more/less sites of star formation

Figure 12. The integrated luminosity function for each sample of galaxies.

closer to the nucleus and that the characteristic luminosity would be different. However, these results show that no such differences exist.

Fig. 12 shows the integrated luminosity function. This is not a true HII luminosity function since the spatial resolution does not allow most of the individual HII regions to be separated. However, it does show that the approximate number of HII regions in each sample are similar. The slight difference in the zero-point for the two distributions can be attributed to how the individual HII region complexes were counted. It is important that the shape of the integrated luminosity functions be similar and they clearly are.

4.7 *Spectral Line Ratios*

4.7.1 *Introduction*

The use of line ratios to determine the physical conditions present in emission line regions is a very powerful method. It is well-known that the relative strengths of spectral lines can be used to discriminate between emission line regions photoionized by hot OB stars, non-thermal continua and shock heating (Baldwin, Philips and Terlevich 1981, hereafter known as BPT; Veilleux and Osterbrock 1987, hereafter known as VO). These studies found that a classification scheme involving the line ratios $[\text{OII}] \lambda 3727 / [\text{OIII}] \lambda 5007$, $[\text{OIII}] \lambda 5007 / \text{H}\beta$, $[\text{NII}] \lambda 6584 / \text{H}\alpha$, $[\text{SII}] (\lambda 6716 + \lambda 6731) / \text{H}\alpha$ and $[\text{OI}] \lambda 6300 / \text{H}\alpha$ allowed a fairly clean separation of the type of ionizing continuum to be made. Some of these ratios, since they involve the ratio of spectral lines close to each other in wavelength, had

the added attraction of minimizing the effects of reddening as well as errors in the absolute flux calibration. The [OI] $\lambda 6300$ / H α ratio is known to be especially useful because it is most sensitive to the shape of the ionizing continuum. As an example of the utility of line ratios, it was shown (Baldwin *et al.* 1986) that in the Seyfert 2 galaxy NGC 1068, the emission line regions studied could be described as gas photoionized by hot OB stars projected in front of gas photoionized by a power law. This is consistent with (1) observations of an early stellar population present in the low excitation gas, (2) differences in the spatial distribution of the various emission line regions and (3) differences in the line profiles and velocity fields between narrow H β and [OIII] $\lambda 5007$.

The fundamental difference between an HII region and an AGN is the shape of their ionizing continuum. An HII region is photoionized by OB stars of effective temperature between 35,000–40,000 K. This continuum peaks at about 800 Å and then falls off at shorter wavelengths. The ionizing continuum of an AGN has the functional form $f_{\lambda} \propto \lambda^{\alpha-2}$ where $\alpha \sim 1.0$ – 1.5 . For decreasing wavelengths, the OB star continuum contains fewer and fewer high energy photons while the AGN continuum rises and so more high energy photons are present. Therefore, unlike an OB stellar continuum, the AGN continuum has a significant fraction of its energy in the X-ray spectral region ($\lambda \leq 100$ Å). The presence of these photons alters the ionization structure of the gas by creating a high ionization zone and a partially ionized or transition zone. The former contains highly ionized species (Ne V, Fe VII, Fe X). The latter region arises because the absorption cross sections of HI, HeI

and HeII decrease with increasing photon energy and so the mean free path of these photons increases. The end result is a partially ionized region that contains H, He and a number of metals (N, O and S) in various ionization stages. The ionization state of the metals are those with ionization potentials comparable to that of H so that in this partially ionized zone, the dominant ionization stages of the metals present are OI, SII and NI with smaller amounts of NII and OII. These are in addition to HI, HII, HeI and free electrons. These electrons are extremely important because they enhance the strength of those lines produced by collisional excitation (e.g., [OI] λ 6300 and [SII] $\lambda\lambda$ 6717,6731).

The usefulness of line ratio diagrams was made clear by BPT and VO. In their work BPT used the ratio [OII] λ 3727 / [OIII] λ 5007 plotted against the ratios [OIII] λ 5007 / H β , [NII] λ 6584 / H α , [OI] λ 6300 / H α , He II λ 4686 / H β , [Ne V] λ 3426 / [OII] λ 3727, [Ne V] λ 3426 / [OIII] λ 5007 and [NII] λ 6584 / [OIII] λ 5007. They also examined the diagram [NII] λ 6584 / H α vs. [OIII] λ 5007 / H β . Their work showed that it was quite easy to determine the photoionizing continuum present in an emission line region. For HII regions, there is a well-defined relationship followed as the excitation changes. If any new object is found to lie more than 0.5 dex away from the locus of HII regions then its photoionizing continuum must be something other than hot OB stars.

However, the one problem with the use of [OII] λ 3727 and [Ne V] λ 3426 is that they are far enough away in wavelength from most of the other optical emission lines that errors associated with misapplied reddening corrections or errors in the absolute flux calibration

could result in an improper location on the line ratio diagram and, therefore, an incorrect conclusion regarding the kind of ionizing continuum present. In their work, VO explored other combinations of line ratios that were insensitive to instrumental, observational and data handling errors but still capable of distinguishing the type of ionizing continuum present. They established that the ratios $[\text{OIII}] \lambda 5007 / \text{H}\beta$ vs. $[\text{NII}] \lambda 6584 / \text{H}\alpha$, $[\text{SII}] (\lambda 6716 + \lambda 6731) / \text{H}\alpha$ and $[\text{OI}] \lambda 6300 / \text{H}\alpha$ were good enough to allow the photoionizing continuum to be uniquely determined while remaining insensitive to the strength of the errors present.

The separation between emission line regions photoionized by hot OB stars and those photoionized by a power law is quite large, being 0.5 dex at a minimum. A region ionized purely by hot stars will never be found in that part of the line ratio diagram populated by AGNs and vice versa. However, it is not too surprising that some objects do fall in between pure HII objects and pure AGNs. These include LINERs, narrow line radio galaxies and narrow emission line galaxies. The emission lines in these objects could also be photoionized by several continua. For example, for circumnuclear HII regions, their line strengths, and consequently their ratios, could possess two components, one due to the hot OB stars and a second due to a somewhat weakened power law continuum arising from the nucleus. Using the photoionization code CLOUDY (Ferland and Netzer 1983) we varied the relative strengths of two continua (hot OB stars and a power law) and discovered that the resulting line ratios did indeed clearly reflect the presence of dual components. How-

ever, we also found that for a given location in that region of the line ratio diagram lying between HII region objects and power law photoionized objects, there was no unique combination of OB stars and power law continua that characterized that point. What can be said is that the location of these points can be explained by dual continua known to exist and not some third type of heretofore unknown type of continuum.

Therefore, our aim here was to examine the properties of as many emission line regions as could be identified in both samples of galaxies. Examination of the line ratios present indicated how normal these regions are in Seyfert galaxies. If there was a non-thermal or power law ionizing continuum present, then it would be manifest as a systematic shift in the location of these points in the line ratio diagrams towards the power law region. However, if the distribution of the ratios were similar to those found in normal galaxies then this supports the claim that the disks of Seyferts is normal and that the effects of an AGN are confined to the circumnuclear region.

The one major disappointment in this project was the lack of lines detected other than $H\alpha$, $[NII] \lambda 6584$, $[SII] \lambda 6716$ and $[SII] \lambda 6731$. Over 1600 spectral lines were measured but only a very small percentage of these were not one of the above four lines. It was therefore, not possible to produce flux ratio diagrams that could unambiguously determine if multiple ionizing continua were present in an emission line region. Instead, the line ratios were compared between the two samples and it was found that the $[NII] \lambda 6584 / H\alpha$ ratio was quite sensitive to the amount of Balmer absorption present. Due to the affects of un-

derlying Balmer absorption, the strength of the $H\alpha$ emission can decrease relative to the [NII] $\lambda 6584$ line. This arises due to a large population of intermediate age stars (A, F and G stars). Therefore, examining the [NII] $\lambda 6584 / H\alpha$ ratio gave direct information on the emission mechanism and on the stellar populations present. In the following sections we examine the [NII] $\lambda 6584 / H\alpha$, [SII] $(\lambda 6716 + \lambda 6731) / H\alpha$, and [SII] $\lambda 6716 / [\text{SII}] \lambda 6731$ ratios.

4.7.2 [NII] $\lambda 6584 / H\alpha$

Fig. 13 shows the distribution of the [NII] $\lambda 6584 / H\alpha$ values for both galaxy samples. The ratios fall predominantly at values normally expected for HII region emission, i.e., gas photoionized by hot stars. However, a significant number in both samples were on the order of or greater than 1.0. Normally, this value for the [NII] $\lambda 6584 / H\alpha$ ratio indicates the presence of a different ionizing continuum other than just host stars. In the narrow line region of Seyfert galaxies, for example, this ratio reaches a value of 1.0 or greater. However, in this case, the ratios that were greater than 1.0 were not due to a change in the ionizing continuum but can be explained by a decrease in the $H\alpha$ emission due to an increase in the underlying Balmer absorption. These ratios all arise at distances greater than a few kpc from the nucleus so it is difficult to explain them any other way. Also, these ratios occur in low luminosity emission line regions, i.e., HII regions photoionized by only a small number of OB stars. It is the intermediate age stars that have strong Balmer absorption lines. In fact, it is possible to estimate the equivalent width of the underlying absorp-

Figure 13. The distribution in the $[NII] \lambda 6584/H\alpha$ line ratio.

tion by assuming that the true value of the ratio is similar to nearby emission regions not affected by Balmer absorption. The difference between the two ratios gives the equivalent width of the absorption. Doing this, we find that the absorption equivalent widths were on the order of from 2–5 Å, exactly that measured in Galactic HII regions known to contain these intermediate–age stars.

Even though the errors were quite small here ($\pm 20\%$) the KS test and the Monte Carlo simulations were still run. The two distributions were quite similar and application of the KS test shows that the null hypothesis can be accepted at the 93% level. To determine the affect of errors on the results, a Monte Carlo simulation was run for 100,000 trials. This then allows the null hypothesis to be accepted at the 89% level.

In the near–nuclear regions, there does not seem to be any indication of abnormally high $[\text{NII}] \lambda 6584 / \text{H}\alpha$ line ratios relative to the normal sample. This fact rules out any significant influence of the non–thermal continuum of the Seyfert nucleus on the interstellar medium at distances greater than a kpc or so.

4.7.3 $[\text{SII}] (\lambda 6717 + \lambda 6731) / \text{H}\alpha$

The distribution in this ratio is shown in Fig. 14 for both galaxy samples. The values range from 0.09 to 0.99 in the normal sample and from 0.08 to 0.98 in the Seyfert sample. The KS test again indicates that these two samples were identical and that the null hypothesis can be accepted at the 96% level. A Monte Carlo simulation of 100,000 events shows that for 20–25% errors, the KS test indicates that these samples were identical.

Figure 14. The distribution in the [SII] ($\lambda 6717 + \lambda 6731$)/H α line ratio.

As with the previous section, there were some ratios that were higher than expected due to the presence of underlying Balmer absorption. However, most fall within the values expected for HII region emission. The positions of the larger ratios in the Seyfert sample were in the disk regions and not in the near–nuclear regions so that it is difficult to believe that the origin of these ratios are from a non–thermal continuum and not from an increase in the Balmer absorption due to a large population of intermediate age stars.

4.7.4 $[SII] \lambda 6717 / [SII] \lambda 6731$

The distribution in this ratio is shown in Fig. 15 for both galaxy samples. The values range from 0.19 to 1.63 in the normal sample and from 0.40 to 1.98 in the Seyfert sample. These values span a range greater than that expected for normal HII region emission. We looked into this further and determined that the large spread in values was due to the inherent difficulty in cleanly separating the two [SII] lines. We found that the errors here were larger than that for the other line ratios. The KS test again indicates that these two samples were identical and that the null hypothesis can be accepted at the 91% level. A Monte Carlo simulation of 100,000 events shows that for 40–45% errors, the KS test indicates that these samples were identical.

4.7.5 *Results and Discussions*

The overriding result from the study of the line ratios was that there is no discernible difference between the distribution of the line ratios in either sample. At least along the

Figure 15. The distribution in the $[\text{SII}] \lambda 6717 / [\text{SII}] \lambda 6731$ line ratio.

major axis, the influence of the active nucleus is limited to within a kpc or so of the central region. No abnormally high ratios were found for the near–nuclear regions of the Seyfert sample relative to the normal sample. We also examined the radial distribution of these ratios and found that there was no predilection for certain values at any one radius as might be expected for the near–nuclear regions. These results reinforce and are consistent with the previous sections that the emission line properties in the disk region of Seyfert galaxies are similar to those in normal galaxies and that the star formation activity is not enhanced in any dramatic fashion.

4.8 Final Results and Discussion

The one common thread running through this work and its results is that there appear to be no discernible differences between the disk regions of Seyfert galaxies and the disk regions of a control sample of normal galaxies. We have measured a number of quantities that were all related to the star formation activity occurring in galaxies. If the Seyfert nucleus had caused any global changes in the distribution or local densities of the gas or if the Seyfert nucleus was a result of some external event (e.g., an interaction with a close companion), these changes should have been manifest as changes to one or more quantities such as the global star formation rate, the critical density for initiating star formation, the radial distribution of the HII regions, their luminosities and number the most highly luminous HII region and in the values of certain line ratios that are capable of discerning between various

ionizing continua or mixtures of ionizing continua. In none of the quantities studied were we able to find unequivocal evidence for fundamental differences in the disk regions of Seyfert galaxies relative to normal spiral galaxies. Therefore, it would appear from our work that the affect of an active nucleus on its host galaxy is minimal. There appear to be no large-scale changes to the local gas density at points throughout the disk and this implies that the dynamics of the gas (and stars) in Seyfert galaxies cannot be very different than in normal spirals.

The results of this work complement work done on comparing the effects of interactions between galaxies with their disk star formation rates. The integrated H α emission and IRAS far infrared colors of samples of interacting galaxies shows that the disk star formation rates in these galaxies is enhanced relative to a control sample of isolated galaxies. These star formation rates can be explained by bursts of star formation involving a few percent of the mass in the disk. Galaxies with strong disk starbursts almost always possess strong nuclear emission while the reverse is not generally true (Kennicutt *et al.* 1987). We have found that strong nonthermal nuclear activity was not accompanied by enhanced star formation activity in the disk. This is consistent with the conclusions reached by FWS88 that Seyferts only very marginally possess an excess of comparably sized companions like those in the sample of interacting galaxies (Kennicutt *et al.* 1987). If Seyfert galaxies possessed bright companions then it would have been expected that their disk star formation rates would have been higher relative to the control sample. The results presented here are

also consistent with the fact that low-level Seyfert activity may be present in all normal galaxies (Keel 1984).

An obvious follow-up to this work would be emission-line imaging of this same sample as well as HI and CO observations. We were restricted to just the major axis of these galaxies. It would be important to determine the true total H α emission in these two samples as well as the spatial distribution of the sites of star formation. The HI and CO observations would allow the relationship between the critical density and the local gas density to be explored further.

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