Star Forming Regions in Gas–Rich S0 Galaxies

Richard W. Pogge
Lick Observatory, University of California, Santa Cruz, CA 95064
and
Paul B. Eskridge
Dept. of Astronomy FM–20, University of Washington, Seattle, WA 98195

ABSTRACT

We present the first results of an Hα imaging survey of H I rich S0 galaxies, in which we are searching for H II regions and other sources of emission (*e.g.*, nuclear emission). CCD Hα interference filter images have been made of 16 galaxies. Eight of these galaxies show evidence for on–going star formation (H II regions), one has nuclear emission but no H II regions, and the remaining seven have no emission detected within well defined upper limits. With the exception of one notably peculiar galaxy in which the emission from H II regions appears pervasive, the H II regions are either organized into inner–disk rings or randomly distributed throughout the disk. A few of the galaxies are found to be clearly not S0's, or peculiar objects atypical of the S0 class. Using simple models we have estimated star formation rates (SFRs) and gas depletion times from the observed Hα fluxes. In general, the derived SFRs are much lower than those found in isolated field spiral galaxies (Kennicutt 1983) and the corresponding gas depletion time scales are also longer.

I. Introduction

The gas content of early–type galaxies is a subject of great interest, especially because of its application to understanding the evolution of these systems. Early-type galaxies as a class are deficient in gas and dust relative to later types. For a long time, only a few S0 galaxies and no E galaxies had been detected in 21-cm emission surveys. Recently, however, more sensitive techniques and instruments have increased the number of detected galaxies, and a few E galaxies have now been detected (see the extensive compilations in Wardle and Knapp 1986 for S0 galaxies; and Knapp, Turner, and Cuniffe 1985 for E galaxies). Among S0's with similar properties, there seems to be a broad range in gas content from relatively strong ("H I Rich S0's") to undetected ("H I Poor S0's").

It is of interest to ask to what extent this gas is attended by current star formation. We have used CCD imaging through redshifted Hα interference filters to search for H II regions in a sample of H I rich S0 galaxies selected out of the literature. By subtracting the underlying stellar continuum using images taken through filters sampling emission–free regions of the spectrum, it is possible to isolate not only the brightest H II regions (if any), but also to detect faint H II regions whose surface brightness may be below that of the surrounding starlight.

II. Sample and Observations

From the literature published up to June 1985, a total of 103 S0 galaxies have detectable HI emission, contrasted with about 220 HI poor S0's for which there is either no HI detection or only an upper limit. For the present imaging survey at Lick Observatory, the galaxies must be accessible to our redshifted interference filter set, which excludes all galaxies with V $\gtrsim$ 3800 km sec^{-1}. In addition, the galaxies must be within the declination limits of the 1-meter Anna Nickel telescope at Lick Observatory, which limits the sample to the range $+62° \gtrsim \delta \gtrsim -25°$. The final redshift and pointing limited sample contains 62 HI rich S0's.

Observations were made using the 1-meter Anna Nickel telescope at Lick Observatory using the $f/17$ GEC CCD direct camera during Spring 1985, and using the TI CCD Cassegrain spectrograph in direct imaging mode during Fall 1985. For each program galaxy, two images were taken, the first through an interference filter isolating Hα+[N II]λ6548,6583 emission at the galaxy redshift, and a second through a filter centered on emission–free stellar continuum 40Å redward or blueward of the emission line filter. The filters have a typical width of 22Å and peak transmission of 80%. Reduction and analysis of the images was done using the VISTA image processing program developed at Lick Observatory. Atmospheric extinction corrections were made following Hayes (1970). An approximate flux calibration was accomplished by observing white dwarf standard stars from the lists of Oke (1971) and McCook and Sion (1984). The fluxed continuum image was subtracted from the fluxed emission image to produce an essentially starlight–free Hα+[N II] emission line image of the galaxy. In cases where emission regions were not evident after continuum subtraction, a "detection limit" was evaluated.

III. Results and Discussion

Of 16 S0 galaxies observed so far, eight galaxies have detectable HII regions, and one (NGC 7743) has nuclear emission but no HII regions. The remaining seven galaxies have no emission detected with well defined upper limits. Total Hα fluxes, or appropriate upper limits, are given in Table I. The Hα fluxes have been corrected to account for a contribution due to [N II]λ6548,6583 emission following Kennicutt (1983).

In the S0's with detectable HII regions, we find the star forming regions are either distributed into inner rings near the central regions, or randomly distributed throughout the disk of the galaxy. With the exception of NGC 694, in which the star formation appears to be global, the observed HII regions sparsely populate the disk compared with the covering seen in later type spirals (Hodge and Kennicutt 1983). A few of the galaxies (*e.g.,* NGC 7013) also show signs of nuclear emission. HI maps of NGC 7013 (Knapp *et al.* 1984) and NGC 4138 (Shane and Krumm 1983) suggest that the HI gas rings are associated with the HII region rings. Two galaxies (NGC 4670 and UGC 12713) turn out to be irregular galaxies misidentified as S0's.

Following roughly the procedures used by Gallagher, Hunter and Tutukov (1984) and Kennicutt (1983), we have used these fluxes to estimate the total star formation rates (SFRs) in these galaxies. Details of the derivation may be found in Pogge and Eskridge (1986). The total star formation rates in $M_\odot$/year are given in Table I. By comparison, Kennicutt (1983) found that for field Sa and Sb spiral galaxies the mean SFR is $\sim$ 1.6 $M_\odot$/yr, and for field Sbc and Sc spirals it is $\sim$ 3.5 $M_\odot$/yr. (Kennicutt's method of estimating the SFR differs slightly from ours, so it was necessary to multiply his estimates by 0.64 to bring the two methods into agreement.) For the detected S0 galaxies the SFRs are typically $\sim$ 0.4 $M_\odot$/yr, smaller than for field spirals.

In Table I, we give estimates of the total gas depletion time in years for the S0 galaxies with detected HII regions assuming that all of the HI gas is available for star

TABLE I. HII Regions in HI Rich S0 Galaxies.

Galaxy	Type[1]	D (Mpc)[2]	M_{HI} (10^9 $M_\odot$)[3]	H II Dist[4]	log F(Hα)[5]	SFR ($M_\odot$/yr)	τ (yr)
NGC 473	S0	45.4	...[6]	R	−12.33	0.66	...[6]
NGC 680	S0	56.6	2.96		< −15.4	<0.0006	
NGC 694	S0p	60.0	4.20	G	−12.42	0.94	1.1×10^{10}
NGC 936	SB0	31.6	1.80		< −15.7	<0.0001	
NGC 1023	SB0	15.2	3.72		< −15.1	<0.0001	
NGC 4138	S0	8.6	0.8	R	−12.39:	0.02:	9.5×10^{10}:
NGC 4385	SB0	50.4	11.7	P	−11.36:	7.6:	3.9×10^{9}:
NGC 4670	SB0p	24.6	1.84	G	−11.51	1.28	3.6×10^{9}
NGC 5631	S0	40.2	2.40		< −14.9	<0.0015	
NGC 6501	S0	60.0	5.96		< −15.4	<0.0006	
NGC 7013	S0/a	20.0	2.04	R	−11.88	0.36	1.4×10^{10}
NGC 7180	S0/a	30.4	0.18		< −16.2	<0.00003	
NGC 7280	S0	41.2	1.08		< −15.4	<0.0003	
NGC 7742	S0p	35.2	4.16	P	−14.75	0.016	6.5×10^{11}
NGC 7743	SB0	38.2	1.00	n	< −15.5	<0.0001	
UGC 12713	S0/a	9.2	0.26	G	−13.11	0.0044	1.5×10^{11}

Notes:

A colon (:) means fluxes are uncertain to greater than 20%, hence greater uncertainty in SFR and τ.

1.) From de Vaucouleurs *et al.* (RC2) or Sandage and Tammann (RSA).

2.) Based on H_0 = 50 km/sec/Mpc and V_{Virgo} = 1350 km/sec.

3.) From literature, see references in Pogge and Eskridge (1986).

4.) Emission Region Distribution Codes: R=Ring, G=Global, P=Patchy, n=nuclear.

5.) Log of integrated Hα flux in erg/cm^2/sec.

6.) Promised updated value of M_{HI} not available at press time.

formation. The total gas mass is found by correcting the observed HI mass to account for helium, molecular gas, and gas recycling by evolved stars (see Kennicutt 1983; Larson *et al.* 1980). The gas depletion time (τ) is the amount of time required to use up the available gas at the current SFR. For field spirals, the median value of τ is $\sim 4 \times 10^9$ yr (Kennicutt 1983). For our detected S0's τ varies from 1.1×10^{10} yr for NGC 694 to as high as 6.5×10^{11} yr for NGC 7742. A bright nuclear starburst in NGC 4385 makes its estimate of τ uncertain as our simple SFR models may not be valid. If all of the HI gas is not be available for star formation, then our estimates of τ would be reduced. For example, if only the gas in the inner regions of NGC 7013 ($M_{\rm HI} = 1.92 \times 10^9$ $M_{\odot}$– Knapp *et al.* 1984) is available for star formation, this implies that $\tau \sim 5 \times 10^9$ yr, compared with $\sim 1.4 \times 10^{10}$ yr using the total HI mass.

Both the SFRs and gas depletion times suggest that on–going star formation in most of these systems is likely to have little impact on their subsequent evolution unless the SFRs increase dramatically. This is consistant with the evolutionary theory of Larson *et al.* (1980), suggesting that S0's may be fossil spiral galaxies with only vestigial star formation continuing to the present.

IV. Conclusions

We have demonstrated that in at least a few HI rich S0 galaxies, the gas is accompanied by current star formation. Much work remains. In particular, it is essential to have detailed HI maps made of more of these systems to be able to determine to what extent the gas is directly associated with the star forming regions.

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