OPTICAL HII REGIONS

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1. INTRODUCTION: GALACTIC AND EXTRAGALACTIC HII REGIONS

The ionized hydrogen regions seen on monochromatic Hα photographs of nearby spiral galaxies (e.g. Fig. 1) can be divided into four classes (Monnet, 1971):(1) bright, condensed, classical HII regions; (2) diffuse emission in the arms surrounding and connecting the classical regions (emission measure (EM) $\sim$ 150 cm^{-6} pc, for a gas electron temperature of 6000 K); (3) much fainter, diffuse emission extending over the entire disk (EM $\sim$ 50 cm^{-6} pc) in most Sc and Sd galaxies; (4) diffuse emission in the nuclear region.

In our Galaxy class 4 cannot be detected, class 3 is not yet observed, class 2 (i.e., the general Hα emission produced by a uniformly distributed component of the ionized interstellar medium) has been studied in several optical and radio recombination lines (see Courtès et al., 1978), class 1 is of course well known. The first section of this paper presents the apparent distribution of the galactic HII regions as seen from the Sun. We also point out some large-scale characteristics of the ionized interstellar medium. The second section deals with the distribution of the HII regions in the galactic plane.

2. THE APPARENT DISTRIBUTION: MORPHOLOGICAL CHARACTERISTICS

Since the first photographic surveys of the Milky Way, it has been clear that the classical HII regions (class 1) are distributed along the galactic equator (except for some nearby nebulae). Only recently has the actual appearance of the diffuse emission out of the condensed regions (class 2) been shown by the two following studies: (1) Reynolds et al. (1974) have constructed a new contour map of this emission, from Fabry-Perot Hα observations of the northern Milky Way, with a limiting EM of 4 cm^{-6} pc and a spatial resolution of 5°. (2) Sivan (1974) has carried out a very-wide-field photographic survey of the entire Milky Way which sums up, as completely as possible, the Hα emission features brighter than 20 cm^{-6} pc, with a spatial resolution of 10 arc min.

This survey reveals a number of new large-angular-diameter HII regions and a very extended HII complex in Orion, Eridanus and Cetus

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(Sivan, 1977). Furthermore, it gives a large-scale view of the diffuse Hα emission in excellent agreement with the results of Reynolds et al., and shows the large-scale distribution of the classical HII regions throughout the galactic arms. Owing to the low angular resolution of the wide-field photographs, these arms (Fig. 2) are seen under strictly similar conditions to those of spiral galaxies recorded on large telescope Hα plates. The chaotic and filamentary structure of the diffuse component and the typical ring-like structure of a number of classical regions should be pointed out.

Ring-like HII regions were previously noted in the Galaxy and in other galaxies by Gum and de Vaucouleurs (1953). Owing to improved photographic techniques, numerous extragalactic HII rings have recently been

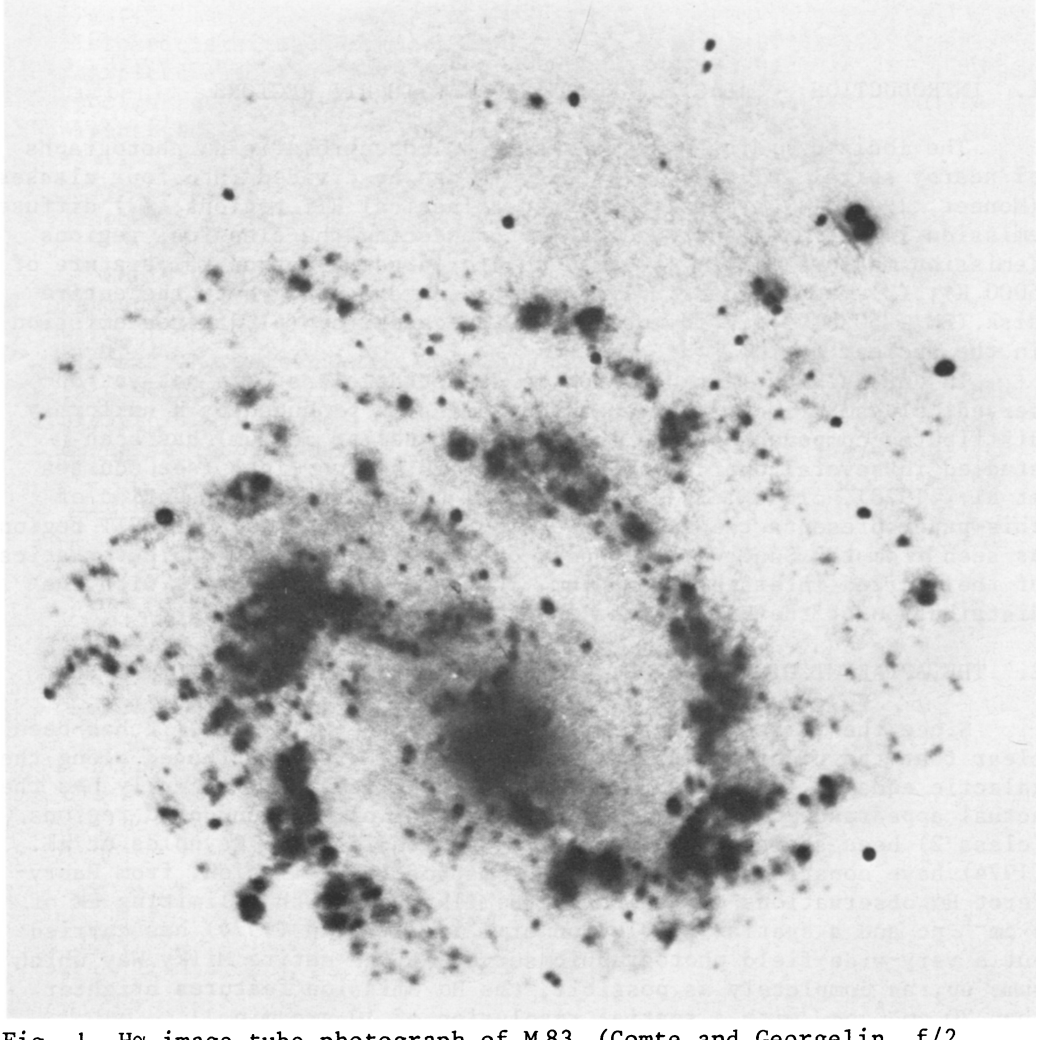

Fig. 1. Hα image tube photograph of M 83 (Comte and Georgelin, f/2 focal reducer of Courtès on the ESO 3.6 m telescope).

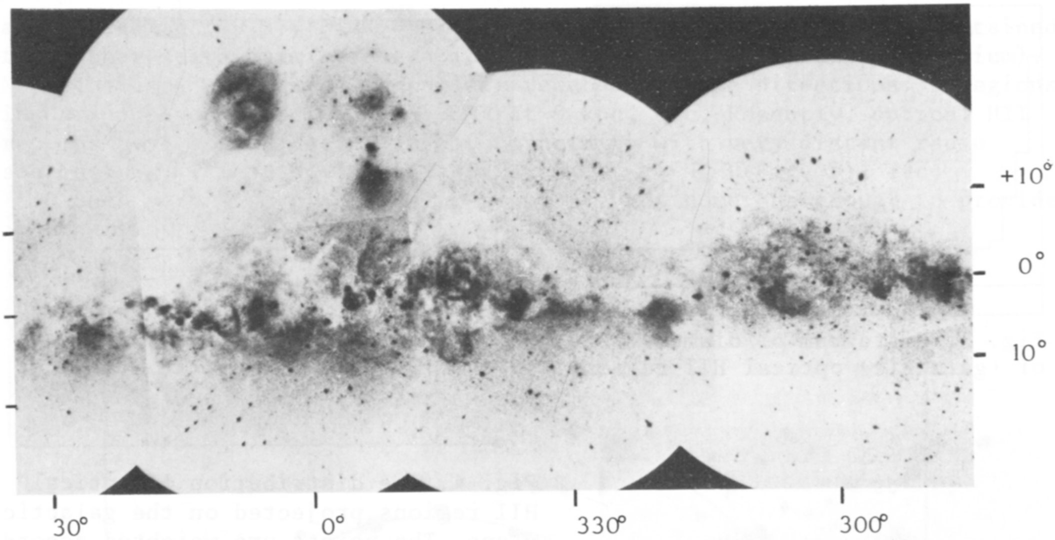

Fig. 2. Section of Sivan's (1974) Hα atlas of the Milky Way (mosaic of 60° field monochromatic plates) showing the entire Sagittarius-Carina arm, and high latitude nearby nebulae.

detected (e.g. Fig. 1; see de Vaucouleurs, 1978). These are good secondary extragalactic distance indicators (de Vaucouleurs, 1978). The following table lists the largest rings visible on the plates of the wide-field Hα survey. The first five regions are single well-defined rings; for the others the ring-shaped structure is more complex (several interlaced rings), or uncertain.

Region	Ring diameter (pc)	Expansion velocity ($km\ s^{-1}$)	
Cetus Loop	70	23	(HI)
NGC 2237	20	15	(HI)
Barnard Loop	115	9	(HI)
RCW 59	80		
[328.5 - 1.0]	85		
S34 + S35	80		
A0 Cas	90		
IC 1805	35		
(Per OB2)	50	5	(HI)
S264 (λ Ori)	45	8	(HI)
Gum Nebula	∿220	20	(Hα)
[303.5 + 4.0]			
IC4628+RCW113+...	∿200	8	(Hα)
RCW 114			
(Sco OB2)	35	5	(HI)
[354.0 + 5.5]			

For half of these regions there is strong evidence for an expanding shell structure: either an expansion velocity is measured in Hα, or the Hα ring coincides with a 21 cm expanding shell. One million year old supernova explosions may be at the origin of the shells (c.f. Sivan, 1977). However, mechanisms of wind-driven circumstellar bubbles cannot be excluded. In both galactic and extragalactic rings, exciting stars are frequently observed at the edge of the ring. These regions are probably

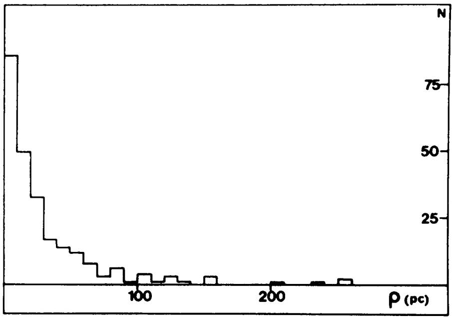

Fig. 3. Histogram of diameters of (galactic) optical HII regions.

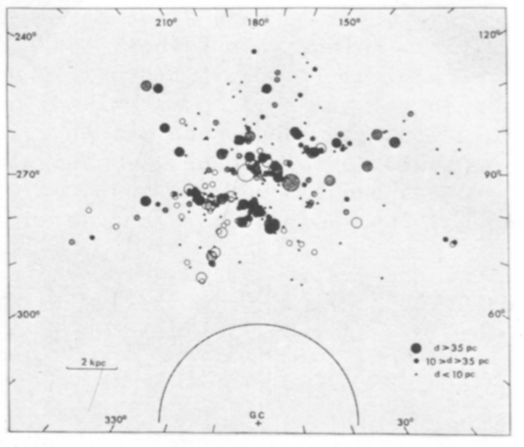

Fig. 4. The distribution of optical HII regions projected on the galactic plane. The points are weighted according to the size and brightness of the regions.

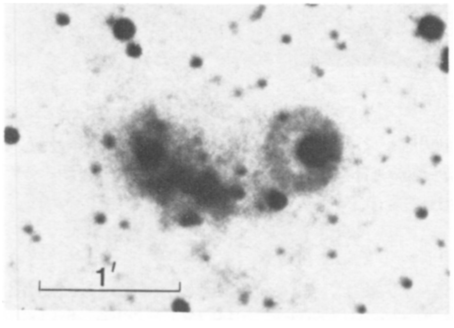

Fig. 5. Hα photograph of G 298.2 - 0.3 (Comte and Georgelin, ESO 3.6 m telescope) distance 11.7 kpc.

a late stage in the life of an expanding ionized region and a second generation of stellar formation may occur (Boulesteix et al., 1974).

Two HII rings (Barnard Loop and Cetus Loop) belong to the Orion-Eridanus-Cetus complex. Spectrophotometric measurements on the whole complex (Sivan, 1977) indicate normal HII region line ratios and a low excitation - i.e., results similar to those obtained by Reynolds (1976) on the Gum Nebula, in agreement with the above interpretation. Also, this complex may be considered as a nearby sample of the uniformly distributed component of the ionized interstellar medium (class 2). The measured low excitation is in agreement with an ionization by *in situ* OB stars (Torres-Peimbert et al., 1974; Comte and Monnet, 1974).

Determination of the distance to the Sun of most of the observed HII regions (§ 3) has allowed us to construct a new histogram of the frequency distribution of the intrinsic diameters for 246 regions (Fig.3): 50% of the regions have linear diameters smaller than 15 pc and 7 regions are larger than 150 pc.

3. THE SPIRAL STRUCTURE OF OUR GALAXY

The distance determination of the optical regions has allowed us to plot them on the galactic plane (Crampton and Georgelin, 1975). The revised diagram in Fig. 4 has been constructed according to more recent data (Crampton et al., 1978). 80% of the regions are plotted using the distances of the exciting stars. 20% are kinematic distances, based upon the Hα radial velocities and the rotation model of the Galaxy of Georgelin and Georgelin (1976). Fig. 4 shows the same distribution as that obtained from other spiral arm tracers (cf. Humphrey's paper at this symposium). Nevertheless, greater distances are reached in some directions: 5 regions in Carina beyond 4.5 kpc, S 99 - 100 at 9 kpc, etc. Recently, optical HII regions have been detected in Hα, coinciding with very distant radio sources: W 51 (Crampton et al., 1978), G 298.2 - 0.3 (Fig. 5), etc.

Such very distant optical regions are not numerous enough to provide

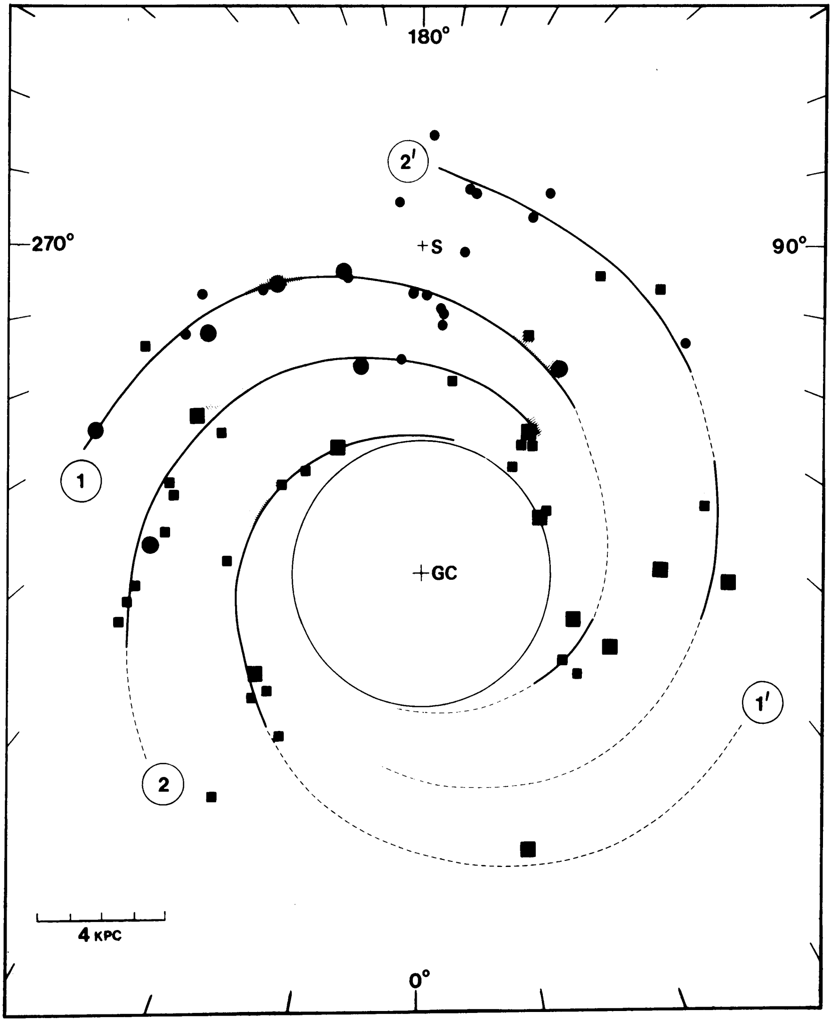

Fig. 6. Spiral model of the Galaxy obtained from high excitation parameter HII regions. Circles = optical; squares = radio regions. Larger symbols : U > 200 pc cm^{-2}; smaller ones : 200 > U > 100 pc cm^{-2}.
1 : Sagittarius-Carina major arm; 2 : Scutum-Crux intermediate arm; 1': Norma internal arm; 2': Perseus external arm. Hatched areas correspond to intensity maxima in the radio continuum and in neutral hydrogen (the arms are seen tangentially at the same longitude as in radio).

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useful information on the spiral structure beyond 4 kpc. To compensate for this lack of optical data and in order to establish a coherent picture of the spiral structure of our Galaxy, Georgelin and Georgelin (1976) have combined optical and radio data, making extensive use of the H 109α radial velocities observed principaly by Reifenstein et al. (1970) and Wilson et al. (1970). This was quite possible because (1) there is excellent agreement between Hα and H 109α velocities, (2) H 109α sources must be considered not as independant regions but as parts of extended optical HII regions . This study uses a homogeneous population (HII regions + exciting stars). It is based upon a method of analysis which has been fully described elsewhere (Georgelin and Georgelin, 1976).

Fig. 6 shows the spiral model obtained from 60 high excitation parameter ($U > 100$ cm^{-2} pc) HII regions - i.e., giant regions as defined by Mezger. These are class 1 regions (§ 1) similar to those observed in external galaxies and which are known to define spiral arms (Fig. 1). The diagram in Fig. 6 differs from the previously published one only by the higher limit put on the U's. As a consequence of the selection of the HII regions according to their U's, our local region is practically insignificant. Two symmetrical pairs of arms are found - i.e., 4 arms altogether - with a pitch angle of 12°. The continuous curves are the best fits to the plotted regions; the dashed curves are their symmetric images. No arm is observed to go all the way around the Galaxy, in agreement with observation of spiral structure in external galaxies.

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DISCUSSION

de Vaucouleurs: On two slides you showed the diameter of the Gum Nebula to be 220 and 250 pc; is this due to different definitions or different distance scales?

Sivan: This is due to different definitions. For the study of the frequency distribution of intrinsic diameters of the galactic HII regions, I use the diameter of the outer limits of the Gum Nebula (250 pc). But in the tables listing the ring-like regions, the diameter is measured at the maximum intensity of the ring (about 220 pc).

Crampton: It is obvious that several spiral features or arms must continue in the longitude range $25° < l < 90°$ but they are not seen either in the optical or radio observations of HII regions. There must be more HII regions there, and I urge radio astronomers to try to fill in this longitude range with deeper surveys. Optically, the region is quite obscured but there are some holes, and because this direction is so important to our understanding of spiral structure, a major effort is warranted.

Heiles: I was pleased to see that many of the HII regions are rings. A great many HI rings exist in the galactic plane which have similar properties.

Terzian: Have you made a comparison of the distribution of HII region sizes in our Galaxy with those of other galaxies like M33 and M31?

Sivan: I have compared my galactic results with those obtained using the same observational techniques, by Pellet et al. (A.&A. Suppl. 31, No. 3) for M31, and by Boulesteix et al. (1974, A.&A. 37, 33) for M33. The Galaxy is closer to M31 than to M33. Half of the galactic regions of M31 have diameters of 40 pc or less. We do not observe in the Galaxy a most probable value, as is observed in M33. The diameters of the largest regions are 220 pc for M31, 250 pc for the Galaxy, and 350 pc for M33.

Rubin: Do you see HII regions in the anticenter direction, beyond the Perseus arm?

Sivan: The outer Perseus arm appears to be more tenuous than the others. We do not see HII regions beyond it. The most distant region in the Georgelins' diagram in the anticenter direction, is IC 410. It is situated on the outer part of the Perseus arm at 3.4 kpc from the Sun (spectrophotometric distance).

Bok: Congratulations to Dr. Sivan and Dr. Georgelin for the beautiful spiral diagram of our Galaxy that we have just seen. My colleagues Roberta Humphreys, Juan Carlos Muzzio, and Ellis Miller, and I, have long tried to obtain an overall spiral diagram and found this most difficult. Dr. Georgelin drew a diagram three years ago and while it was a good one the spiral structure was ambiguous. Now we have a diagram, based mostly on optical data but in agreement with radio data, which shows the spiral structure of our Galaxy in its full scope.