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FREQUENCY DISTRIBUTION OF HII REGIONS RADII AS A DISTANCE INDICATOR

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ABSTRACT

The frequency distribution of HII regions radii in our galaxy has been investigated. The correlation between the number of these regions and their radii has been re-determined, and could be represented by an exponential function. The size distribution of the HII regions in 10 spiral galaxies has been derived and combined with that of our galaxy to derive the distances of these galaxies. It has been found that the distances derived are in a good agreement with the published ones. The interstellar extinction in the galaxies has no influence on the distance estimate when using this geometrical method.

Key words : Galaxies: spiral galaxies- distances, HII regions

I. INTRODUCTION

Catalogues of HII regions of spiral galaxies can be used to obtain a great deal of information on their host galaxies. Sersic (1960) first suggested the possibility that gaint HII regions in galaxies could be used as distance indicators. Sandage and Tammann (1974) derived a correlation between the HII region diameter and the galaxy luminosity class, which can be used to estimate the distances of galaxies for which the luminosity classes are known and the HII regions angular diameters have been measured.

Kennicutt and Hodge (1980) have shown that the dependence of the brightest HII regions diameters and $H\alpha$ luminosities on the absolute magnitude of the galaxy can be predicted on the basis of statistical model and used this dependence to determine the distances of galaxies. There are some obstacles by adopting the size of the three or the five brightest HII regions as a distance indicator. Because the diameter of the HII region has no sharp cutoff, it is difficult to be determined precisely. Its dependence on either the exposure time of the observation or the telescope resolving power cause additional difficulties when considering the diameter of the HII region as a useful calibrator of the distance scale. Accordingly, it is not known whether the largest HII regions are individual or a complex combination of more than one HII region.

Because of these difficulties we suggest a modification of this method depending on the apparent size distribution rather than on the size of the largest HII regions. The advantage of that method is that, it depends on a large number of HII regions instead of the three to the five brightest HII regions. From statistical point of view, such dependence would produce more accurate distance estimate. The difficulties arising from the optical equipment and the exposure time can also be avoided. This geometric method is completely different from the photometric means used to derive the distances of galaxies.(Issa 1981, 1985).

In the present study we use the approach of Issa (1985) after redetermination of the normalization parameter (see in the text, later (section III.a)) and the recent available catalogues for Galactic and extragalactic HII regions. This paper is structured as follows: In section II we present the data sample used in this study and in section III, the geometric method for the distance estimate is explained. In section IV, we give the results of this method and compare them with those achieved so far from other different methods. Finally in section V the conclusion is given.

II. THE DATA

Two Data sets are used for this study to be fulfilling:-

1- A homogenous data sample for Galactic HII regions whose linear and angular diameters as well as the distances are known.

2- A sample of 10 spiral galaxies for each a catalogue of HII regions is published.

(a) Catalogues of Galactic HII Regions

The available published data about accurate linear radii of the Galactic HII regions are rare and scarce. The most available published data are included in the following catalogues:

1- A catalogue published by Murdin and Sharpless (1968) for 60 HII regions whose distances have been derived by the method of the spectroscopic parallax. The published linear diameters are subjected to some uncertainties. The number of galactic HII regions is not adequate to statistical studies and therefore we have not used this catalogue in the calibration.

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2- A catalogue published by Wilson (1970). It includes radio observations of HII regions in the southern hemisphere, which are not suitable for comparison of HII regions in external galaxies whose observations mostly in $H\alpha$ emission line.

3- The Master Catalogue which includes the information from 24, previously published lists and catalogues for 1442 Galactic HII regions. For each object, the catalogue quotes the flux and the diameter, (Paladini et al. 2003). Unfortunately, this catalogue lists the angular diameters of the HII regions without giving any information about their distances. Therefore their linear diameters could not be calculated.

4- A catalogue published by Blitz & Fish (1982) for the radii of 361 Galactic HII regions, from them only 159 HII regions, their distances values are given.

5- A catalogue published by Georgelin & Georgelin (1970) contains the linear radii of 174 Galactic HII regions. The distance listed in this catalogue is based mainly on the distance of the exciting stars imbedded in each region.

We have used the fourth and fifth catalogues to correlate the frequency distributions of galactic HII regions and their linear radii. These catalogues present a good homogenous data set, adequate for statistical study.

(b) Catalogues of HII Regions for Some External Galaxies

Table 1 lists the basic information for 10 spiral galaxies used in this study: Column 1, the galaxy name, column 2, the galaxy type as obtained from the Third Reference Catalog of Bright Galaxies (RC3), de Vaucoulears et al. (1991), column 3, the number of the HII regions measured in each galaxy, column 4 the radial velocity, taken from RC3. The references of the HII regions data of the galaxies are given in column 5.

HII region is not necessarily circular, so the effective radius of this region is the mean radius of the maximum and minimum radii as measured for each HII region. This method for measuring the radius of HII region is adapted in the all data sample except in M51, NGC 7331, and NGC 1313. In these galaxies, the effective radius of an HII region is defined as the radius of the region measured at half its total flux, corrected for instrumental broadening. The correction is made by comparison with the observed half-flux radius of field star images giving the same integrated flux. In other words, the effective radius is defined according to Milliand and Marcelin (1981) as:

$$r = \frac{k}{\sqrt{\pi}}(A - A^{\star})^{0.5} \qquad (1)$$

where k is a scale factor, A and $A^{\star}$ are the areas contain half of the total flux for the HII region and for a field star of the same total flux respectively.

TABLE 1
BASIC INFORMATION OF THE DATA SAMPLE

GALAXY NAME	TYPE	N-HII	V KM/SEC	REF
M 100	SXS4	1948	1579	1
M 101	SXT6	248	221	2
M51	SAS4P	478	463	3
NGC 0157	SXT4	707	1730	4
NGC 3359	SBT5	547	1008	5
NGC 3631	SAS5	1322	1143	4
NGC 6764	SBS4	348	2412	4
NGC 6951	SXT4	664	1331	4
NGC 7331	SAS3	140	835	3
NGC 7479	SBS5	1009	2394	7

References:- 1- Knapen, J. H. 1998, 2- Scowen, P., et al. 1992, 3- Petit, H., et al. 1998, 4- Rozas, M., et al. 1996, 5- Rozas, M., et al. 2000a, 7- Rozas, M., et al. 1999.

III. THE METHOD

The data analysis has been carried out as follows :-

1- Calculate the frequency distribution function for the Galactic HII regions as a function of their linear radii.

2- Calculate the frequency distribution function for the HII regions as a function of their angular radii in 10 spiral galaxies.

3- The distances to the galaxies are determined based on the fitting parameters of the two distribution functions derived above.

(a) Frequency Distribution of Galactic HII Regions

The catalogue of Blitz&Fish (1982) contains 159 Galactic HII regions, which is nearly adequate for our purposes. In this catalogue, the radii of HII regions are given in arc seconds, we converted them into linear radii in pc using their distances in pc by the following relation:

$$R = D\ tan(r) \qquad (2)$$

Where R and D are the linear radius and distance (in pc) of Galactic HII region respectively and r is angular radius in arc second. We use a MIDAS program to divide the range of data of linear radii into suitable intervals and count the number of HII regions in each interval. The accumulative frequency distributions of the Galactic HII regions radii are shown in 1 and it fits an exponential function in the form:-

$$N(R) = N_o \exp(-K\ R) \qquad (3)$$

Where N(R) is the number of HII regions with a radius larger than R. The fit parameters for the Blitz&Fish

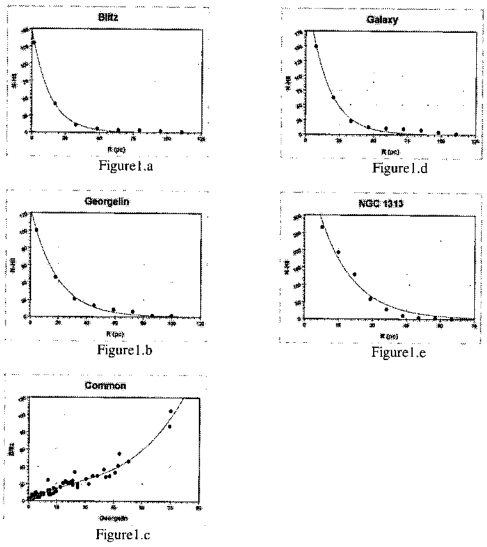

Fig. 1.— Frequency distribution of the HII regions as a function of their radii (dots). An exponential functions fits well the distribution(solid line).

(1982) Data are $N_o = 148.2$ and K = $0.075{\pm}0.007\ pc^{-1}$ while that for Georgelin et al(1970) Data are $N_o =$ 124.4 and K = $0.054{\pm}0.001\ pc^{-1}$ (see Figures 1a and 1b).

In order to benefit both data sets, common HII regions in them are searched to correlate the two data sets; (Blitz et al 1982. and Georgelin et al.1970). A 74 common HII regions are found in the two catalogues, and they are used to correlate the linear radii of the HII regions in the two catalogues. Figure 1c shows this correlation and its mathematical form is:-

$$\begin{aligned} R(B) &= 0.305 + 1.229R(G) \\ &- 0.0236R^2(G) + 0.00033R^3(G) \end{aligned} \qquad (4)$$

Where R(G) and R(B) are the radii of HII regions in Georgelin and Blitz catalogues respectively.
Finally 299 HII regions have been used to calibrate the size distribution function of Galactic HII regions. This function fits well an exponential law, see Figure 1d, with size parameter; K = $0.067{\pm}0.004\ pc^{-1}$.
We assume that the size distribution function is universally function and fits well an exponential function either in our Galaxy or in the external galaxies. Therefore, we did the same calculation for the HII regions in the galaxy NGC 1313, using a catalog for 375 HII regions, which is presented by Marcelin and Condoin (1983), see Figure 1.e.

It is found that the size parameter for HII regions in NGC1313 is K =$0.067{\pm}0.005\ pc^{-1}$, exactly equal to that of Galactic HII regions. Without contradiction, the assumption of the universality of the size distribution function of the HII regions is true, and it could be used as a distance indicator of the galaxies.

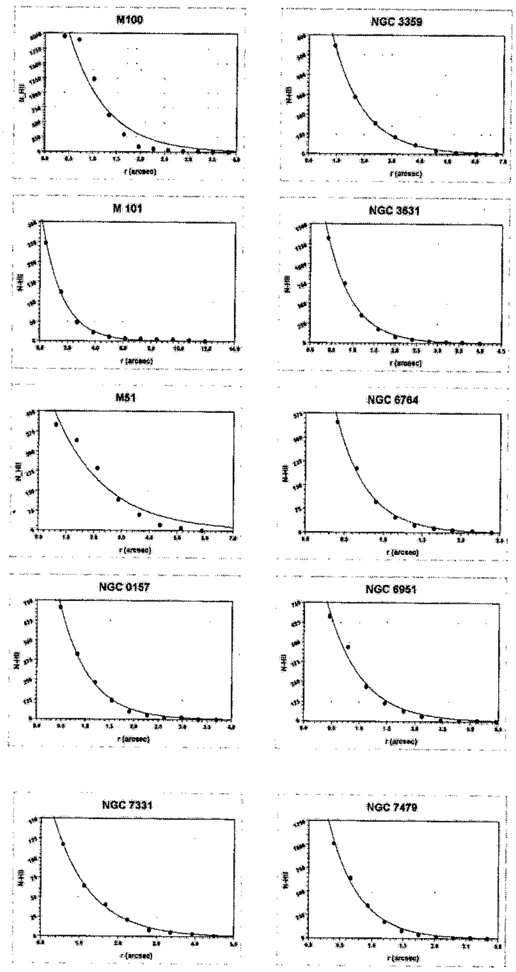

Fig. 2.— Frequency distribution of the HII regions of 10 spiral galaxies (dots) and their fitting functions (solid line).

The exponential representation for the size distribution of the HII regions in galaxies has been found by Isaa (1981), Hodge and Kennicutt (1983), Hodge (1987), Rozas et al (1999) and Knapen (1998).

(b) Distance Determination

The size parameter (K), obtained from the size distribution function of Galactic HII regions and the HII regions catalogues of 10 spiral galaxies, gathered from the Literature are used to determine the distance to these galaxies.
For each galaxy, the apparent size distribution of its HII regions is plotted as a function of the apparent radius. From this plot, we chose two frequency values at two different radii (the minimum and the mean radii), the distance of the galaxy can be determined. From equation 3 we get:

$$N(R1) = N_o \exp(-K\ R1) \qquad (5)$$

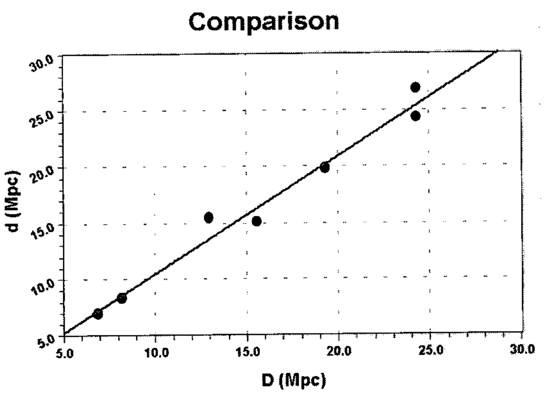

Fig. 3.— A comparison between the calculated distances (D) using our method and the puplished distances (d) for the same galaxies.

$$N(R2) = N_o \exp(-K\ R2) \tag{6}$$

Where R is the linear radius of HII region.

$$\ln N(R2) - \ln N(R1) = K(R1 - R2) \tag{7}$$

where $R = D\tan(r) = rD\tan(1'') = rD$.

$$\ln N(r2) - \ln N(r1) = K\ D\ (r1 - r2) \tag{8}$$

$$D = \frac{\ln N(r2) - \ln N(r1)}{K(r1 - r2)} \tag{9}$$

Where N(r1), N(r2) are the numbers of HII regions at the apparent radii r1 and r2 (the minimum and the mean radii) respectively and D is the distance of the galaxy.

IV. RESULTS

The size distributions of the HII regions in the 10 spiral galaxies are calculated and presented in Figure 2, and their fitting curves are overplotted as solid curves in the same Figure. They fit very well the exponential mathematical function. The distance to these spiral galaxies are determined and listed in Table 2 in comparison with that given in the literature.

The relation between these two distance determinations is plotted in Figure 3 and the relation could be fitted well by a linear equation in the form:

$$D = 0.04 + 1.04d \tag{10}$$

In Table 2, the distance values and their error of determination, (D±δD), where the error in the distance determination is defined as follows;

$$\frac{\delta D}{D} = \frac{\delta K}{K} \tag{11}$$

TABLE 2
THE DISTANCE DETERMINATION OF 10 SPIRAL GALAXIES

Galaxy Name	D±δD Mpc	d Mpc	Ref
M 100	19.3±1.3	19.8±3.0	1
M 101	6.9±0.5	6.95	2
M51	8.2±0.6	8.4±0.6	3
NGC 0157	24.6±1.6		
NGC 3359	13.0±0.9	15.5	4
NGC 3631	24.3±1.6	24.3	5
NGC 6764	37.4±2.5		
NGC 6951	24.3±2.2	26.8	6
NGC 7331	15.6±1.0	15.1	7
NGC 7479	31.1±2.1		

References:- 1- Bartel et al. (2003), 2- Stetson et al. (1998), 3- Feldmeyer et al. (1997), 4- Sandage and Tamman (1975), 5-Kennicutt, R.C. (1979), 6- Valentini et al. (2003), and 7- Hughes et al. (1998)

are given in column 2, while the published distance values (d) and their sources (Ref.) are listed in columns 3 and 4.

V. CONCLUSIONS

Verfication of the proposed method has been achieved employing the data of NGC 1313, in addition to that of 10 spiral galaxies. The size distribution function for the HII regions either in our Galaxy or in the 11 spiral galaxies (10 + NGC 1313), could be represented very well by an exponential function. The coincidence of this property for such large number of galaxies let us strongly to consider that the size distribution function of the HII region could be a universal function. In addition, the equality of the size parameter (K) for the Galactic and extragalactic HII regions makes it sure that this size parameter is a universal attribute, which could be benefit to determine the distance to the galaxy. The good agreement between our result and the previous one concerned with the distance estimate could be a strong indication for the consideration that the size distribution function of the HII regions may be used as a distance indicator.

REFERENCES

Bartel, N., Bietenholz, M. F., & Michael F. 2003, SN 1979C VLBI: 22 Years of Almost Free Expansion, ApJ, 591, 301

Blitz, L., & Fish, M. 1982, Catalog of CO radial velocities toward galactic H II regions, ApJS, 49, 183

De Vaucouleurs, G., de Vaucouleurs, A., Corwin, H. G., Buta, R. J., Paturel, G., & Fouque, D. 1991, Third

Reference Catalogue of Bright Galaxies, Springer, New York. (RC3)

Feldmeier, J. J., Ciardullo, R., & Jacoby, G. H. 1997, Planetary Nebulae as Standard Candles. XI. Application to Spiral Galaxies, ApJ, 479, 231

Georgelin, Y. P., & Georgelin Y. M. 1970, Vitesses radiales et distances des regions HII galactiques, A&A 6, 349

Hodge, P. W. 1987, Size distributions of H II regions in galaxies. - Spiral Galaxies, PASP, 99, 915

Hodge, P. W, & Kennicutt, R. C. 1983, An atlas of H II regions in 125 galaxies, AJ, 88, 296

Hughes, S. M. G., Han, M., Hoessel, J., Freedman, W. L., Kennicutt, R. C., Jr., Mould, J. R., Saha, A., Stetson, P. B., Madore, B. F., Silbermann, N. A., Harding, P., Ferrarese, L., Ford, H., Gibson, B. K., Graham, J. A., Hill, R., Huchra, J., Illingworth, G. D., Phelps, R., & Sakai, S. 1998, The Hubble Space Telescope Extragalactic Distance Scale Key Project. X. The Cepheid Distance to NGC 7331, ApJ, 501, 32

Issa, I. A. 1981, The size distribution of HII regions as a new variant to determine the distances of galaxies, Astron. Nachrichten, 302, 251

Issa. I. A. 1985, Distance estimate of M31 based on the size distribution of H II regions and dark clouds, Ap&SS, 113, 317

Kennicutt, R. C. Jr. 1979, H II regions as extragalactic distance indicators. II - Application of isophotal diameters, ApJ, 228, 696

Kennicutt, R. C. Jr. 1979, H II Regions as Extragalactic Distance Indicators. III. Application of H II Region Fluxes and Galaxy Diameters, ApJ, 228, 704

Kennicutt, R. C. Jr., & Hodge , P. W. 1980, H II regions in NGC 628. III - H_α luminosities and the luminosity function, ApJ, 241, 573

Knapen, J. H. 1998, Statistical properties of H II regions in the disc of M100, MNRAS, 297, 255

Marcelin, M., & Condoin, P. 1983 A&AS, 51, 353

Milliard, B., & Marcelin, M. 1981, Morphology and kinematics of the ionized gas in NGC 2997, A&A 95, 59

Murdin, P., & Sharpless, S. 1968, Space Distribution of HII Regions, in Y. Terzian (ed), interstellar ionized Hydrogen, P. 249

Paladini, R., Burigana, C., Davies, D. R., Maino, D., Bersanelli, M., Cappellini, B., Platania, P., & Smoot, G. 2003, A radio catalog of Galactic HII regions for applications from decimeter to millimeter wavelengths, A&A, 397, 213

Petit, H. 1998, Catalogue of HII regions in NGC 7331 at the 6 meter telescope, A&AS, 131, 317

Rozas, M., Beckman, J. E, & Knapen, J. H. 1996, Statistics and properties of H II regions in a sample of grand design galaxies I. Luminosity functions, A&A, 307, 735

Rozas, M., Zurita, A., Heller, C. H., & Beckman, J. E. 1999, Global properties of the population of HII regions in NGC 7479 from photometric H_α imaging, A&AS, 135, 145

Rozas, M., Zurita, A., & Beckman, J. E. 2000, The ionized gas in the spiral galaxy NGC 3359. I. Photometry, A&A, 354, 823

Sandage, A., & Tamman, G. A. 1974, Steps Toward the Hubble Constant. Calibration of the Linear Sizes of Extra-Galactic H II Regions, ApJ, 190, 525

Sandage, A., & Tamman, G. A. 1974, Steps towards the Hubble constant. II. The brightest stars in late-type spiral galaxies, ApJ, 191, 603

Sandage, A., & Tamman, G. A. 1974, Steps toward the Hubble constant. III - The distance and stellar content of the M101 group of galaxies, ApJ, 194, 223

Sandage, A., & Tamman, G. A. 1974, Steps toward the Hubble constant. IV - Distances to 39 galaxies in the general field leading to a calibration of the galaxy luminosity classes and a first hint of the value of H_0, ApJ, 194, 559

Sandage, A., & Tamman, G. A. 1975, Steps toward the Hubble constant. V - The Hubble constant from nearby galaxies and the regularity of the local velocity field, ApJ, 196, 313

Sandage, A., & Tamman, G. A. 1975, Steps toward the Hubble constant. VI - The Hubble constant determined from redshifts and magnitudes of remote SC I galaxies: The value of Q_0, ApJ, 197, 265

Scowen, P. A., Dufour, R. J., & Hester, J. J. 1992, The H II regions of the galaxy M101, AJ, 104, 92

Sersic, J. L. 1960, The H II Regions in Galaxies. With 2 Figures in the text, Zeitschrift fur Astrophys., 50, 168

Stetson, P. B., Saha, A., Ferrarese, L., Rawson, D. M., Ford, H. C., Freedman, W. L., Gibson, B. K., Graham, J. A., Harding, P., Han, M., Hill, R. J., Hoessel, J. G., Huchra, J. P., Hughes, S. M. G., Illingworth, G. D., Kelson, D. D., Kennicutt, R. C. Jr., Madore, B. F., Mould, J. R., Phelps, R. L., Sakai, S., Silbermann, N. A., & Turner, A. 1998, The Extragalactic Distance Scale Key Project. XVI. Cepheid Variables in an Inner Field of M101, ApJ, 508, 491

Valentini, G., Di Carlo, E., Massi, F., Dolci, M., Arkharov, A. A., Larionov, V. M., Pastorello, A., Di Paola, A., Benetti, S., Cappellaro, E., Turatto, M., Pedichini, F., D'Alessio, F., Carattio Garatti, A., Li Causi, G., Speziali, R., Danziger, I. J., & Tornambé A. 2003, Optical and Near-Infrared Photometry of the Type Ia Supernova 2000E in NGC 6951, ApJ, 595, 779

Wilson, T. L., Mezger, P. G., Gardner, F. F., & Milne, D. K. 1970, A Survey of H 109cc Recombination Line Emission in Galactic H N Regions of the Southern Sky, A&A, 6, 364