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THE LINK BETWEEN INTERNAL VELOCITIES IN GALACTIC H II REGIONS AND THE EXTRAGALACTIC H II REGIONS

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RESUMEN. La relación entre el tamaño, las velocidades internas de grandes regiones de H II extragalácticas (GRHE) se ha comparado con la posible relación en regiones de H II Galácticas. Hemos utilizado los resultados de estudios de los movimientos internos de ocho objetos Galácticos para calcular las velocidades internas que se habrían determinado de haber sido observados a la misma resolución espacial. Encontramos que los diámetros isofotales en Hα de las GRHE son diez veces mayores que sus contrapartes Galácticos, para la misma velocidad interna. Esta diferencia en tamaño indica que las GRHE son realmente conglomerados de múltiples regiones H II.

ABSTRACT. The relation between the size and the internal velocities of GEHR has been compared with the proposed relation in Galactic H II Regions. I have used the results of studies of the internal motions of eight Galactic objects to determine the internal velocities that would be determined had they been observed at the same spatial resolution. I find that the GEHR Hα isophotal diameters are ten times larger than their Galactic counterparts at the same internal velocity. This size difference indicates that the GEHR are actually conglomerates of multiple H II regions.

Key words: **NEBULAE–H II REGIONS — INTERSTELLAR–KINEMATICS**

I. INTRODUCTION

The use of HII regions for distance determination of galaxies is extremely attractive because of the ability to resolve the largest objects at cosmologically important distances. The critical parameter in their use is the determination of their intrinsic linear size, which was originally simply taken to be the same for all giant spiral galaxies (Sandage and Tammann 1974a,b). This assumption became unnecessary when Melnick (1977) determined that there was a linear relation of size and internal velocity of the Giant Extragalactic HII Regions (GEHR), so named because the extragalactic objects detected are significantly larger than their Galactic counterparts. This relationship of size and velocity has been debated as to its reality (Gallagher and Hunter 1983) and scale (Roy, Arsenault, and Joncas 1986, Melnick et al. 1987) in numerous papers, although the discussion has now evolved to the point that the reality of the relation is not in question, but it is a question of the scale and the appropriate parameters.

The method is to determine the internal velocity dispersion from high resolution spectra taken by Fabry-Perot Interferometer or slit spectrograph, either of which integrate the light from over a substantial portion of the entire nebula. The velocity dispersion is reflected in the residual width of the emission line being observed, after it has been corrected for thermal and instrumental broadening. It can be expressed in several forms, the most direct of which is the half width (β) at which the line is e^{-1} the central intensity, which, when expressed in velocity units is the same as the line of sight velocity dispersion.

The attraction of this approach is that a simple measurement of the width of the emission line tells one the intrinsic linear size of the GEHR, and a simple filtered image produces an angular size. The two facts are then combined to produce a galactic distance. The troubling aspect of this approach is that the relationship is purely empirical, which means that it may possess an unnecessarily broad dispersion through inclusion of the wrong kind of objects and may even be a mixture of different types of objects, which could allow systematic errors when only a limited sample is used. The size of an ionization bounded HII region is determined by the total flux of ionizing photons from the illuminating star and the density of the gas, the case originally worked out by Stromgren (1939). In this case the velocity dispersion would simply reflect the slow expansion of the ionized region (Lasker 1966) and the turbulence that applies. Real nebulae are more complex. We now understand that many of the bright Galactic HII regions represent ionized blisters on the surface of giant molecular clouds, where there can be large outflow velocities. Moreover, the GEHR are possibly mis-named, in that they may actually be complexes of many smaller HII regions. Considering all of these uncertainties, it is remarkable that such a close relationship between velocity width and size does exist. The natural question that arises is "How does this relation compare to that determined for Galactic HII regions, which can be studied in much greater detail?". The answer to this question should provide insight into the application of this distance determinant.

Testing the GEHR relation using Galactic HII regions is made difficult by the fact that the Galactic objects have been observed at much higher spatial resolution, however; but, it is possible to determine how to scale from the observed narrow beam line widths to what they would be if the light from the entire object had been included.

II. OBSERVATIONS OF GALACTIC AND EXTRAGALACTIC HII REGIONS

My colleagues and I have been observing Galactic HII regions at high spatial and velocity resolution for over ten years (Fountain, Gary and O'Dell 1979, 1983a,b, Mufson et al. 1981, Castañeda and O'Dell 1987, O'Dell, Townsley and Castañeda 1987,O'Dell and Townsley 1988). Initially the angular resolution was about one minute of arc, when the emphasis was on the general flow of gas; but we shifted to higher angular resultion when it became apparent that there was ordered-chaotic motion (turbulence) present. This has resulted in good velocity maps across the face of eight nebulae. In addition to line-of-sight velocity variations, we were also able to measure the line widths. These results

TABLE 1
Expected Velocity Widths of Galactic HII Regions

Object	Diameter (pc) studied	Diameter (pc) total	Log D (total)	β_{OBS} (km s^{-1})	Standard Deviation*	$\sqrt{\beta_{OBS}^2 + SD^2}$	References+
NGC1499	9.55	9.55	0.980	15.8	2.34	15.97	1
NGC7000	40.7	40.7	1.610	16.9	5.13	17.66	1
S252	19.5	19.5	1.290	19.3	4.79	19.89	2
NGC6611	20.1	20.1	1.303	16.5	4.62	17.13	3
IC131813/C	52.4	52.4	1.719	31.2	--	31.2	1
NGC6523	1.0	11.6	1.064	7.42	5.65	9.33	4
NGC1976 A+B	0.3	1.0	0.0	7.05	7.29	10.14	5
NGC1976 C	0.3	1.0	0.0	18.5	6.82	19.74	5
NGC6514	0.71	7.0	0.845	8.8	2.48	9.11	4

*Calculated standard deviation in all radial velocities, scaled to the full size of the nebula.

+(1) Fountain, Gary and O'Dell 1983a, (2) Fountain, Gary and O'Dell 1983b, (3) Mufson et al., 1981, (4) O'Dell, Townsley & Castañeda 1987, (5) Castañeda 1988

are summarized in Table 1. The line widths are the average values derived from fitting Gaussian profiles to each observed region. NGC 1976 (the Orion Nebula) was found to actually be three velocity systems (Castañeda 1988), one of which is so broad it would not have been noticed in the low signal-to-noise ratio studies of GEHR. NGC 6523 was found to have two velocity systems (O'Dell,Townsley, and Castañeda 1987). In both of these nebulae we have quadratically added the line widths of the two systems.

The observed line widths at high angular resolution will be less than expected when observing the entire nebulae because there can be additional random motions reflecting turbulence and flow. In the study of the individual nebulae we determined how the standard deviations varied with angular sample size, which allows one to project to the full size of the nebulae, even for those that were observed only in their central portions. The line widths expected in observations of the entire nebulae would then be the quadratic sum of the observed high spatial resolution line widths and the full nebula standard deviation of line-of-sight velocities. The results of these calculations are shown in Figure 1. We see that there is a loose correlation of logarithims of the size and expected line width ($\log D = -0.455 + 1.4269 \log \beta$, correlation coefficient 0.83), with the exception of NGC 1976 (Castañeda 1988). NGC 1976 is probably different from the rest of the objects in the sample in that its small size means that its blister nature manifests itself in unusually high internal velocities. NGC 6611 is also a blister type HII region, but its much larger size must diminish the relative role of the outflow velocities (Mufson et al. 1981).

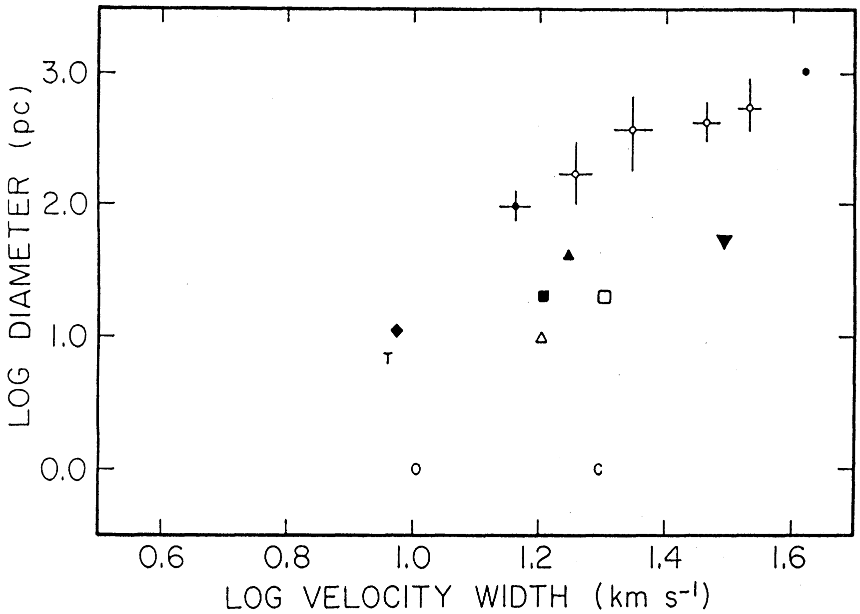

Figure 1 --- The relation between size and e^{-1} velocity width is shown for GEHR(filled circles), and the Galactic HII regions NGC 1499 (open triangle), NGC 7000 (filled triangle), S252 (open square), NGC 6611 (filled square), NGC 6514 (T), IC 1318B/C (filled triangle on its point), NGC 6523 (filled diamond), NGC 1976 A and B (O), and NGC 1976 C (C).

I present the results for the GEHR in Figure 1 also. This data was taken from Arsenault and Roy (1988). For clarity and mathematical convenience, we have grouped their nebulae according to intervals in $\log \beta$. Again, we see that there is a good correlation of size and velocity, although the slope is now 2.0 instead of 1.4. The least squares fit gives $\log D = -0.257 + 1.99 \log \beta$. The most important difference is that the GEHR are almost exactly a factor of ten larger at the same velocity dispersion. Put inversely, The Galactic HII regions show much more dispersion in velocity for the same linear size.

III. DISCUSSION

Why this difference in the relationship? It must lie in the fact that the GEHR are different types of HII regions than those we study in the Galaxy. Clearly they are different in scale, for the largest Galactic object (IC 1318B/C) included in this study is still smaller than the smallest sample size of the GEHR. We don't see HII regions in our Galaxy that are as large as in the other spirals. Perhaps they are not there, but it seems more likely that they are simply not discovered because of our unfavorable location in the plane of the obscuring interstellar dust.

TABLE 2
Grouped GEHR Data from Arsenault and Roy

Interval in log β	<Log β>	<Log D (pc)>	Weight
1.1 - 1.2	1.162 ± 0.025(4)	1.979 ± 0.216(4)	2
1.2 - 1.3	1.257 ± 0.023(7)	2.228 ± 0.235(9)	3
1.3 - 1.4	1.346 ± 0.030(19)	2.561 ± 0.316(9)	3
1.4 - 1.5	1.462 ± 0.022(13)	2.628 ± 0.171(13)	4
1.5 - 1.6	1.532 ± 0.019(13)	2.744 ± 0.207(13)	4
1.6 - 1.7	1.620 -- (1)	3.013 -- (1)	1

Errors are standard deviations with the number of objects shown in parentheses.

Part of the resolution of the differences may rise with the method of determining the size. We have followed the example of Arsenault and Roy (1988) in using the outer Hα isophotal diameters of Kennicutt which reach down to a faint limiting surface brightness which is much lower than the characteristic brightnesses of the Galactic HII regions. Our objects are much more like the cores of the GEHR. The fact that the core sizes may be a more closely related to the internal velocities is shown by the lower dispersion in the size-velocity relationship as determined by Melnick et al. (1987). The core sizes are less convenient to use because they subtend smaller angular sizes and are subject to the vagaries of atmospheric seeing, but they certainly are more characteristic in size and surface brightness to the Galactic HII regions. This is not the simple answer, however, because Arsenault and Roy (1988) show in their Figure 1 that the isophotal diameters are only about a factor of three larger than the core diameters.

The remainder of the discrepancy probably lies in the fact that the GEHR are not what their name implies. They are probably complexes of HII regions found in and about giant molecular clouds such as we find in our Galaxy rather than being giant single HII regions. In this case, the light we see is from multiple HII regions, each having a size-velocity relation like their Galactic counterparts. The integrated signal would represent a composite of individual regions and their random motions with respect to one another. The much smaller velocity at a given size argues that random motions of the constituent individual extragalactic HII regions is small so that the primary result of the blending of the images is simply to build up a larger and larger apparent GEHR size without increasing the velocity width. The mathematical formulation of this relation would be very model dependent and has not yet been done, but it should be tractable since we know the dispersion-size relation already from the Galactic HII regions.

The data in Figure 1 shows that the surveys of GEHR have not reached down to the size of the Galactic HII regions and that all of the present GEHR are composites, mostly composed of individual regions having significantly smaller sizes. If this statement is true, then a search for smaller GEHR will produce a wider range of velocities as the group becomes a mix of the more numerous composite objects and a few large single HII regions.

The other work that needs to be done is two part and observational. They could hardly be more different in nature. The first is a study of the Galactic HII regions at very low spatial resolution but high velocity resolution, so that they are observed under the same basic conditions as the GEHR. This would eliminate all modeling in scaling from our present high spatial resolution results. The other work demands the highest spatial resolution on the GEHR, to resolve the problem of whether or not these objects are actually composites of multiple HII regions like those found in the Galaxy. This program is one of those that I will pursue in the early years of operation of the Hubble Space Telescope.

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