1 Abstract

We use the radial velocity of NGC 604 obtained with the ISIS instrument (long slit spectroscopy) to study the second order structure function. The H_α emission line is used for being the brightest among the observed lines. To see how the structure function is affected, we change the spatial size (Test 1) and the PDF (Test 2) of the velocity sample. We analyzed not only its form, also the two main parameters obtained with it, the correlation length, l_0, and the slope, m_{2D}. Despite a dependency on our results and the selected samples, the indices obtained and correlations lengths still hold some information on the physics of the region since there is a clear range in the data. For m_{2D} the results encompass 1.2 to 1.8 and for l_0, 28 to 10 pc. Also, our results shows a clearly tendency in the $Length/l_0$ ratio. Finally, we try to fit physical and kinematics information about NGC 604 in our structure functions results.

2 Intro

The structure function has been used as a diagnostic tool to evidence the presence of turbulence in HII regions and giants extragalactic HII regions (GEHRs) (Von Hoerner, 1951; Münch, 1958; Medina-Tanco et al., 1997; Lagrois and Joncas, 2009; Melnick et al., 2019). Multiple investigations have proven is usefulness (Castaneda, 1988; Lagrois and Joncas, 2011) as many others have suggested better methods (Medina et al., 2014; Arthur et al., 2016) for studying the underlying velocity fluctuations in the ionized gas. Spectroscopic observations fits the requirements for a valid structure function analysis based on the number of points they can give. Interpreting the structure function of the ISIS observations have been quite a challenge. Since there are few points (600, many data is discarded), the results obtained by statistical tools need to be examine carefully so we do not arrive to wrong conclusions. Here the importance of knowing what drives the structure function form and what can be attributed to foreign artifacts.

Since the nature of giant HII region is quite a challenge itself, the why it has been measure in these objects (and their galactic counterparts), close values related to turbulent theory still remains a question without answer and we can expect that that none will arrive soon. So our understanding on the limitations of our methods and observations will be necessary to know at what extent our results are valid in the context of theory. As the main goal is to understand how the physics on the GEHRs play a role on turbulence and its related problems, we must first understand what are our methods telling us and how these interpretations are related to what is happening in the region.

For this, we aim to study how the main parameters obtained by a second order structure function change when the analyzed sample has been spatially and statistically reduced. For this we apply what we called 'Test 1' where the complete sample of the region is first used and the is spatially reduced. For the 'Test 2' we start eliminating small brightness values till we arrive to the brightest part of NGC 604.

3 Methods

3.1 Astronomical observations

The archival data used in this work were retrieved from the La Palma archive[1] and reduced again by Pérez-Oregón (2013) using the IRAF (National Optical Astronomy Observatories, 1999) astronomical software. The data used in this work was obtained with the ISIS spectrograph in the 4.2-m William Herschel Telescope of del Roque de los Muchachos Observatory (ORM) in La Palma, Spain. The ISIS observations were used by Maíz-Apellániz et al. (2004) and Tenorio-Tagle et al. (2000). Maíz-Apellániz et al. (2004) provides the details of the observational setup. The spectra were obtained using a position angle of 90° and the slit width was 1". The spectra for the red arm has a range of 6390 and 6849 Å. The slit had a length of 200" and for NGC 604 (Fig. 1[2]) we observed ten positions with an exposure time of 1000 s for every slit.

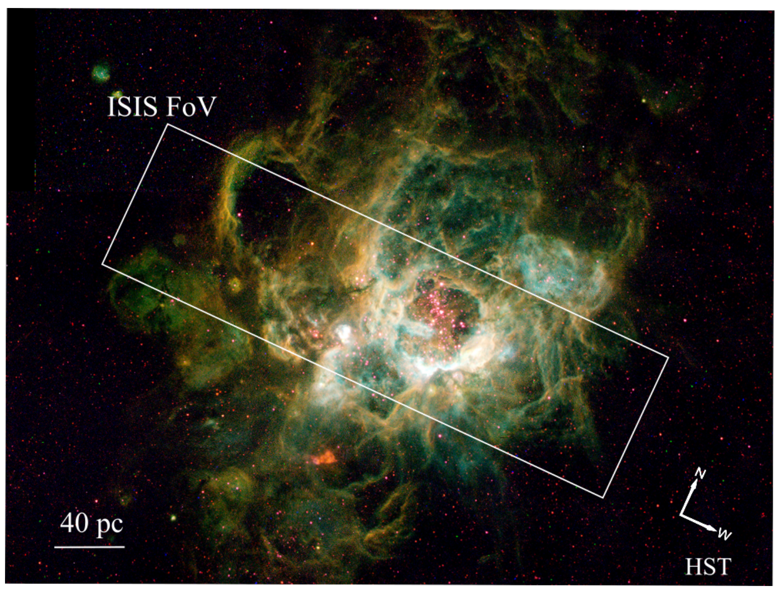

Figure 1: Image of NGC 604 captured with the Hubble Space Telescope with the observations cover by ISIS (Credit: Hui Yang (University of Illinois) and NASA/ESA).

[1] `http://casu.ast.cam.ac.uk/casuadc/ingarch`

[2] `https://esahubble.org/images/opo9627c/`

3.2 Tests

For Test 1 we are changing the spatial area of the sample that is analyzed with the structure function. In Fig. 2 we show with label '0'-'9' the different zones. Also there is a zone named 'a' which corresponds to the brightest area of NGC 604 and some identified shells (Sabalisck et al., 1995; Yang et al., 1996; Tüllmann et al., 2008).

For Test 2 we start getting rid of values wit low emission; this limitation takes into account that ISIS observations are more reliable in high emission pixels. Figures 4 and 5 shows the different emissions zones consider in test 2. Figure 6 shows the histograms of the emission and radial velocity sample, where the change consider values on A.D.U. > 0 , 150, 1 500 and 3 000; this samples are named '0' (same test 1), '10', '11' and '12'.

We are using as main parameters the value of the slope, m_{2D}, obtained with a fit using S(l)=[2-C(l)] where C(l)=1/[1-(l/l_0)$^{m_{2D}}$] and l_0 is the correlation length, the l value where S(l)=σ^2 (Scalo, 1984; Arthur et al., 2016).

4 Results

4.1 Test1

Table 1 shows the results of the fit and the structure function of the areas in Fig. 2. For the value m_{2D} is clear a tendency for the slope to get stepper while there is also a correlation between l_0 and the size of the area. The value of σ also shows a decrease in its value, going from 10.4 to 9.3 km/s.

Figure 3 shows the structure function for all the zones. For all these results, the first point which corresponds to the smallest scales is not consider for the the fit to find the power-law index. The reason is that for scales below 5 pc the seeing is influencing our observations. For zones '0' to '2' the l_0 value is reached at the fourth point. In this case the fit is made only using three points. For zones '3' and '4' there is only two points before l_0, and zones '5' to '8' have just one point. Zones '9' and 'a' can not be fitted with any index. For scales larger than 80 pc, there is an oscillatory pattern for all the zones, though it goes for two complete 'cycles' for zones '0' and '1', at least one cycle is reached with the rest of the zones. This pattern has a 'frequency' of 100 pc.

The ratio L_c/l_0 where L is the length of the zone in parsecs seems to be less affected by the zone reduction having mean value of 13, with a max of 14 for zone '6' and a minimum of 10 for zone 'a'.

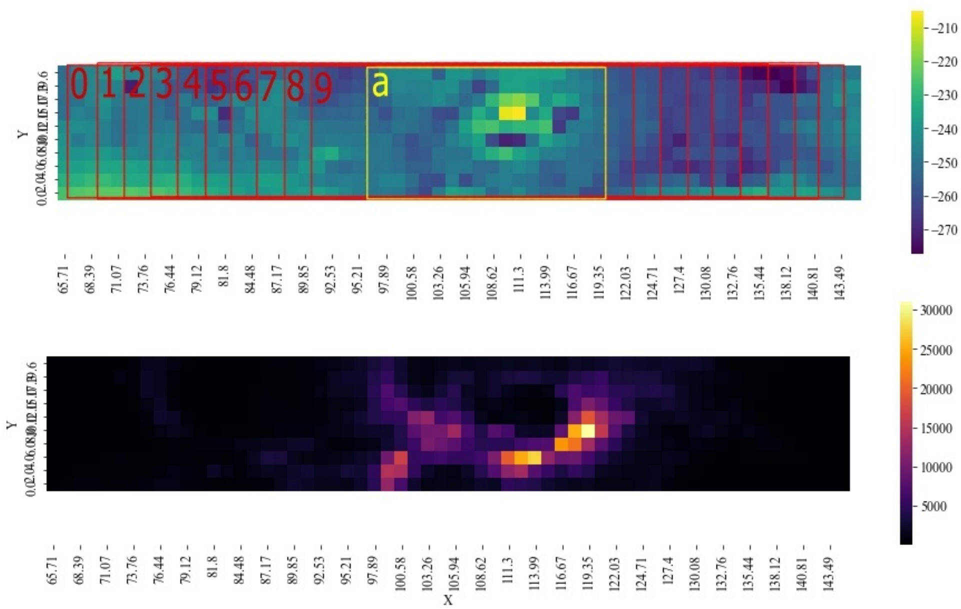

Figure 2: The radial velocity map (above) and the emission map (below) of NGC 604. The radial velocity map shows the different zones, red rectangles, were we apply the structure function ('0'-'9', 'a'). Units are in km/s and A.D.U.

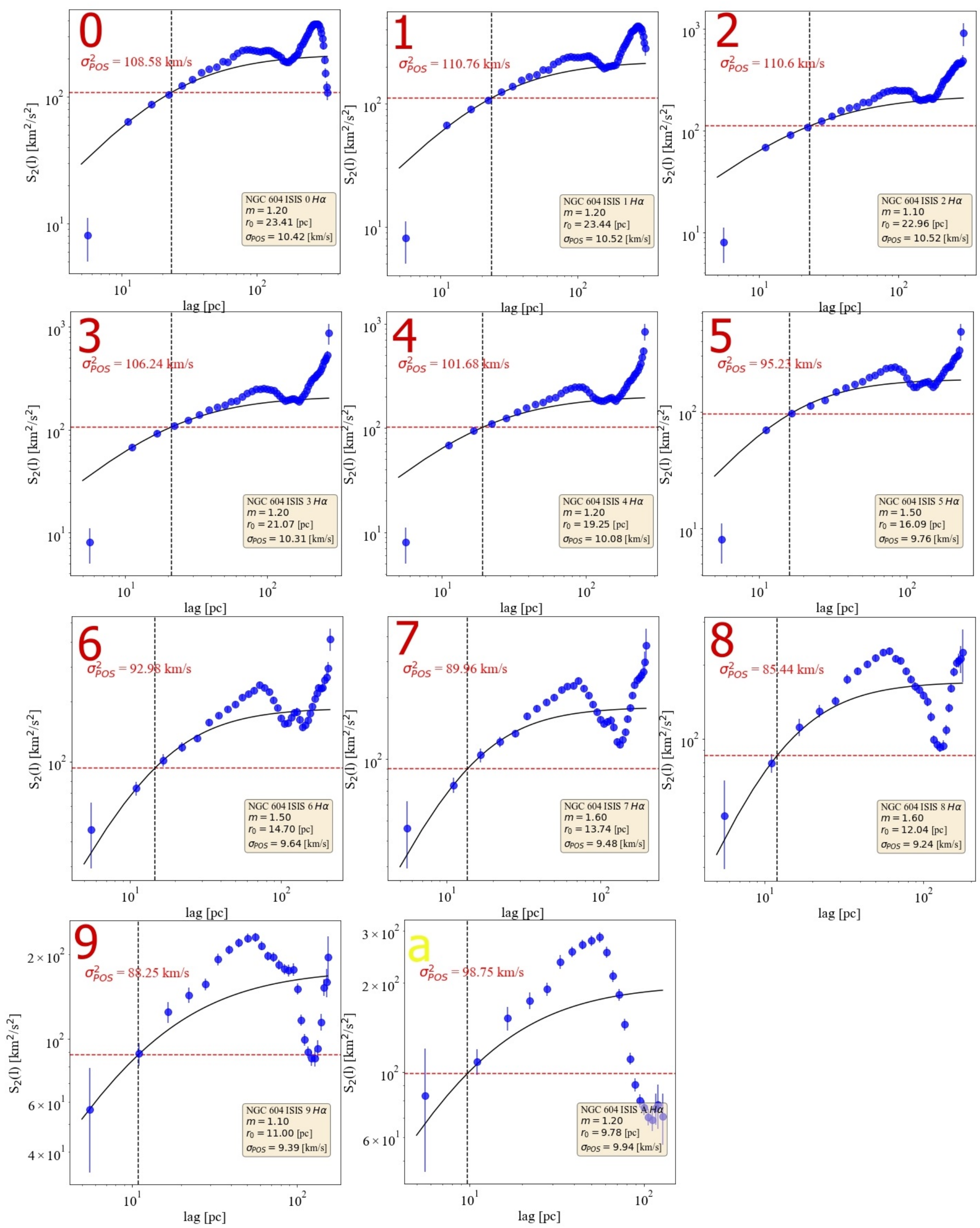

Figure 3: Structure function results for Test 1.

4.2 Test 2

Table 2 shows the results of the fit on the structure function of the areas in Fig. 2 ('0'), Fig. 4 and 5.

The results for the samples '0' and '10' are quite similar mainly because the sample are much alike. Sample '10' considers emission values above 150 A.D.U. The number of masked pixels is 117 and does not have a significant weight on the structure function. The index values goes from 1.2 to 1.1, l_0 increase to 28 pc and related with this we have a increase in σ of 0.42 kms/s, giving us a value of 10.84 kms/s for sample '10'.

From Fig. 6 we can see that sample '0' and '10' show a double peak behavior, previously reported for this GEHR (Rosa and D'Odorico, 1982; Yang et al., 1996; Tenorio-Tagle et al., 2000). This come from the zone between X, 107-118, and Y, 4 and 8 slit, starting from bottom. If we mask this zone (Fig. 4 bottom and Fig. 5) we can get rid of this behavior, as samples '11' and '12' reveal; what it remains has been called, kinematic core because of its 'well' behaved Gaussian fit (Sabalisck et al., 1995; Muñoz-Tuñon et al., 1996).

Sample '11' show the highest m_{2D} value (even considering Test 1) of 1.8. The spatial length of the analyzed zone is 233 pc, between '4' and '5' of Test 1, and as comparison they have 1.2 and 1.5, respectively. σ decrease to 8.8 km/s and the correlation length is 14 pc, half sample '10' shows.

Sample '12' presents the problem that just a single point is behind the correlation length and this can not be used because of seeing, so no fit can be done. The l_0 value is 9 pc with a σ of 7.28 km/s, the lowest of all samples.

For Test 2 the tendency of the ratio L_c/l_0 is to increase towards the brightest samples. The 'periodic' tendency at large scales still is present for samples '10'-'12'. Despite considerable reduction on size (1/3), sample '12' with linear length of 163 pc still shows a periodic form between 80 and 200 pc.

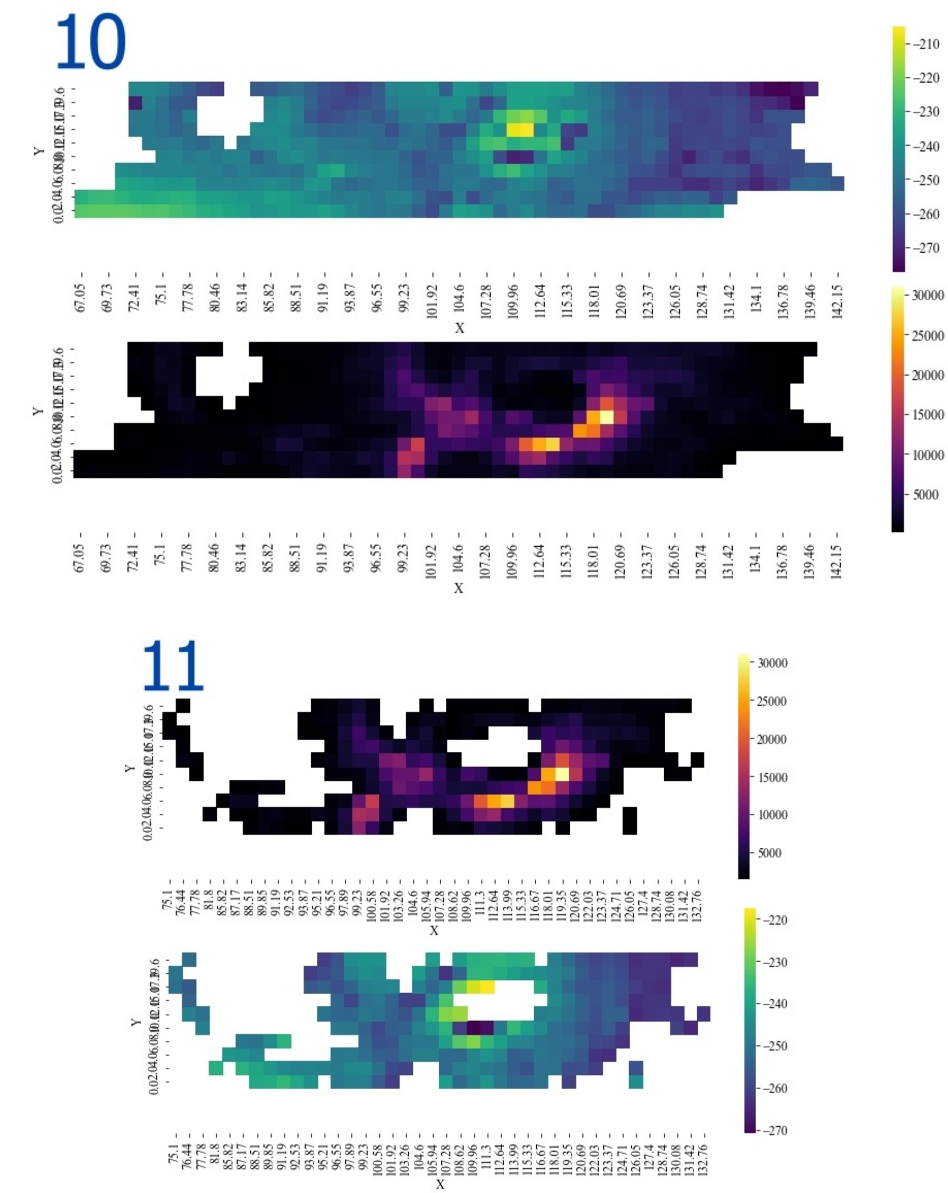

Figure 4: The radial velocity maps and the emission maps of samples '10 (above)' and '11' (below). Units same as in Fig. 2.

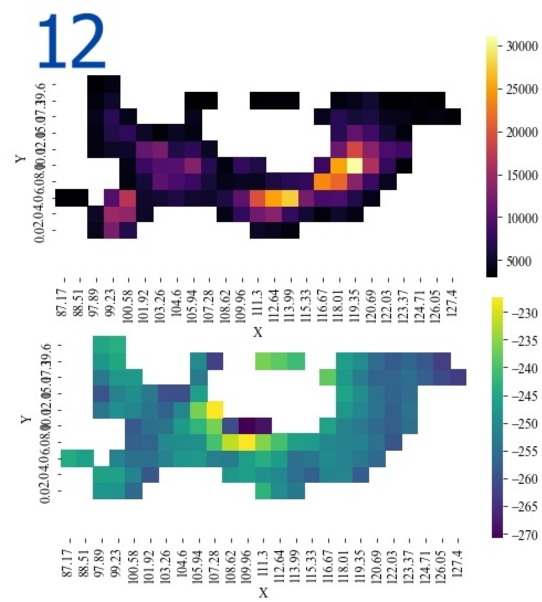

Figure 5: The radial velocity map and the emission map of samples '12'. Units same as in Fig. 2.

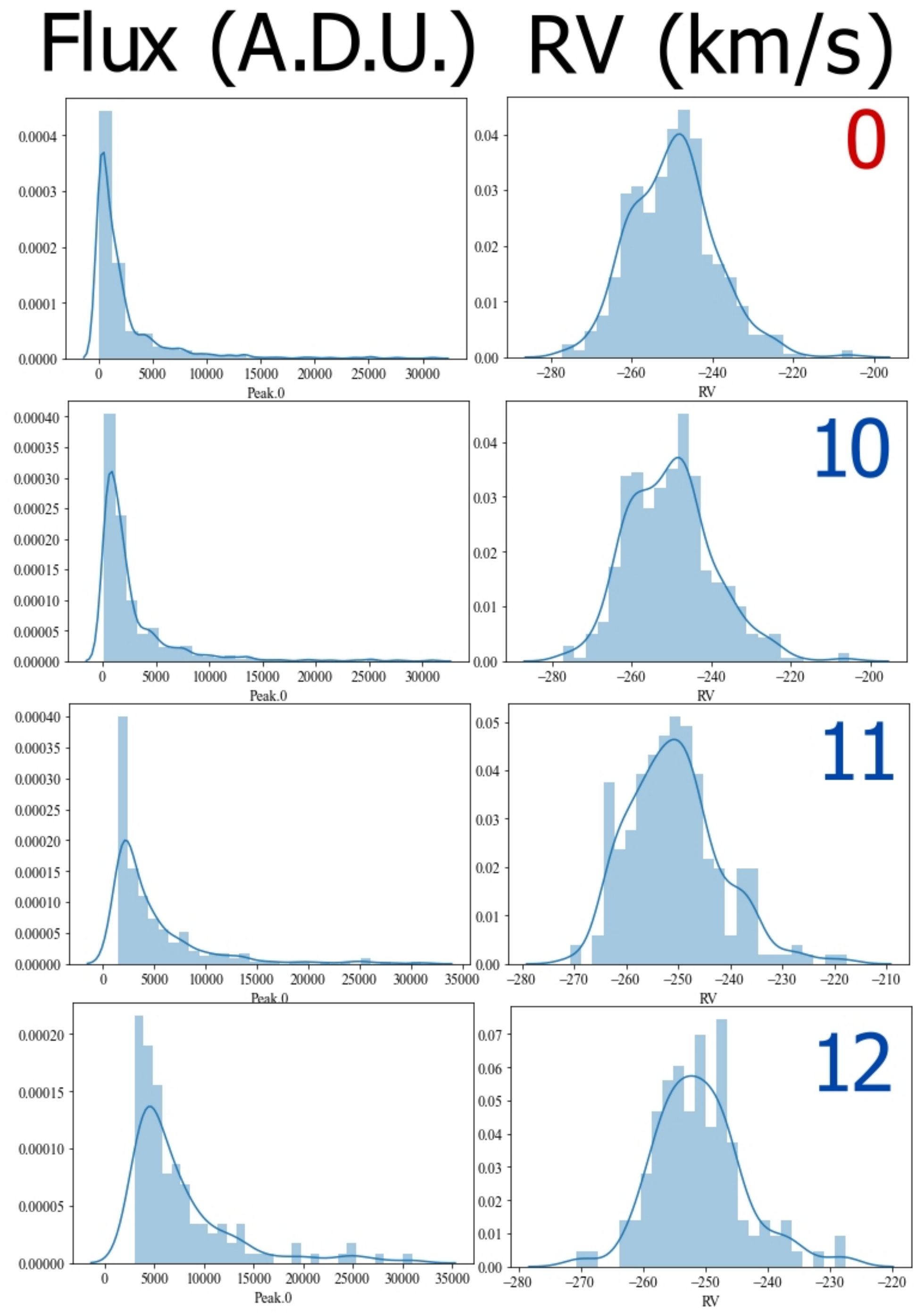

Figure 6: Histograms of the emission and radial velocity samples; 0, 10, 11 and 12. Samples 0 and 10 shows a double peak behavior. This is eliminated in samples 11 and 12.

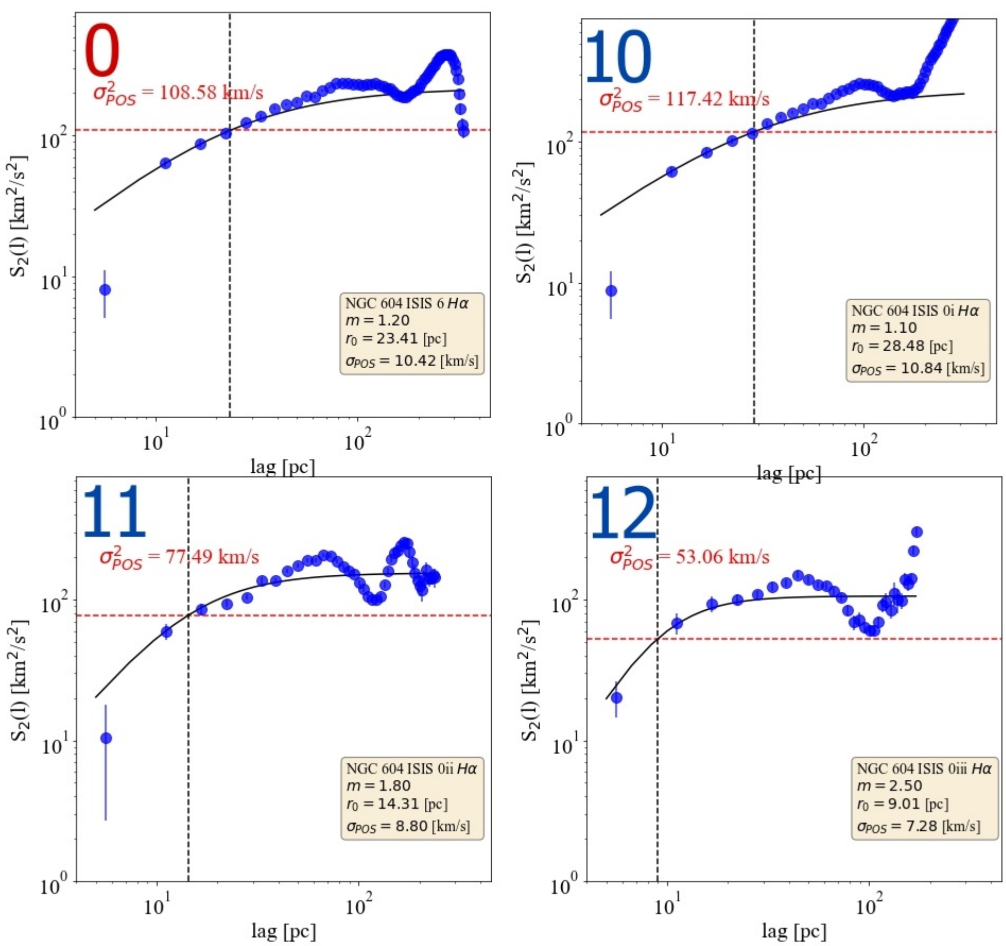

Figure 7: Structure function results for Test 2.

5 Discussion

The large range of values of m_{2D} between samples shows that this parameter is not reliable as a single diagnosis for the turbulent state of the ionized gas, the same goes for l_0. Despite showing a strong dependency on the sample these values still hold information that can be used. The index goes to a maximum of 1.8 at a length of 233 pc and considers the brightest part of the region. In this case the observations are not just centered in the bright emission zone, they cover some extent of the outside region, which can give us insight is something is going on through all the nebula that can be related. It has been mentioned that hot gas that has escaped the hot supper bubbles, consequences of the stellar winds, is flowing 'freely' inside the region (Tüllmann et al., 2008).

The consistency of the periodic behavior at larger scales can be consider as a real 'motion' since it has proven to be omnipresent in our results. The oscillation in the range of 100 pc should also mark some limit where energy injection can be happening. For this regions it have been determined gradients in the east west direction that have been attributed to the rotation of the region (Hippelein and Fried, 1984).

The maximum and minimum values of l_0 may be used to determined some limits where the energy injection is happening; this if we consider the classic Kolmogorov cascade model. The scales 28 to 10 pc can be attributed to many things, among others, they correspond to the radius of the expanding shells present in NGC 604 (Yang et al., 1996). Though, there is no clear correlation, far by a causation it worth pointing it out. We already mentioned that samples 0 and 10 show a double peak behavior. The elimination of this to a more Gaussian fit does not influence in a considerable way the results. Which raise the question: At what extent this shells play a role in the structure function?

However, the power-law indices show a clear tendency between 1.2 and 1.8 which far from been concluding also are telling something relevant; that we can limit our astronomical observations to this range of values.

If we compute the m_{3D} index through projection smoothing and a sheet-like distribution limits it is possible to use; $m_{2D} - 1 < m_{3D} < m_{2D}$, having $0.8 < m_{3D} < 1.2$, been m_{3D} above the Kolmogorv prediction. This shouldn't be a surprise since physical conditions in GEHRs are different from the homogeneous and incompressible ideal model, as many authors have mentioned (Münch, 1958; Castaneda, 1988; Lagrois and Joncas, 2011; Arthur et al., 2016).

As for the L_c/l_0 ratio can be seen how much smaller is in tendency the correlation length related to the sample area. The diminution in l_0 is correlated with the σ, since lower σ impose smaller correlation lengths. The issue with this change in σ is that clearly shows that there isn't statistically homogeneity in our data.

Also, the numbers of points have show that there is a limit where the fit can be done to the structure function. Samples '9', 'a' and '12', which respectively have 260, 200 and 124 where unable to give reliable information.

Table 1: Main results from Test 1.

Name	Length [pc]	m_{2D}	l_0 [pc]	σ [km/s]	L_c/l_0	No. points
0	318	1.2	23	10.42	13.8	600
1	296	1.2	23	10.52	12.8	560
2	274	1.1	23	10.52	11.9	520
3	258	1.2	22	10.39	11.7	480
4	241	1.2	19	10.08	12.6	450
5	220	1.5	16	9.76	13.75	410
6	197	1.5	14	9.64	14	370
7	175	1.6	13	9.48	13.4	340
8	153	1.6	12	9.24	12.7	300
9	131	-	11	9.39	11	260
a	99	-	10	9.94	10	200

Table 2: Main results from Test 2.

Name	L_c [pc]	m_{2D}	l_0 [pc]	σ [km/s]	L_c/l_0	No. points	Peak> [A.D.U.]
0	318	1.2	23	10.42	13.8	600	0
10	318	1.1	28	10.84	11.3	483	150
11	233	1.8	14	8.8	16.64	239	1500
12	163	-	9	7.28	18.1	124	3000

6 Conclusions

The variation on the m_{2D} indices and the correlation length can be attributed to the variation in the analyzed samples. Since no two samples where the same, our results show dependency on the velocity field and the structure function form. The m_{2D} index goes from 1.2, for a sample with length 318 pc that considers all the points, to a value of 1.8 for a 233 pc length for a sample who considers only a bright region. Since the σ of the sample is getting smaller, the same is happening to the correlation length, l_0. This breaks possibility of determining the scale where energy injection is happening using this method, thought is seems rarely that this is the case on this or any other GEHR. Also, there is nothing conclusive regards if stellar winds, champagne flows, or other kinematic assumptions, are registered through the structure function. The change in the form and in the two main diagnostic parameters make this method no as reliable as one would have wanted, but it impose some constraints where we can expect other results for GEHR.

ISIS long-slit spectroscopic observations have been proven useful in obtaining the structure function for NGC 604. The second order structure form has a dependency on its input data, but this does not weight enough to overlook the information that it can give, but also is recommendable that others methods are used in determining turbulent information of a GEHR.

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