Relationship of Hα velocity & H_2 fraction in Galaxies

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Abstract

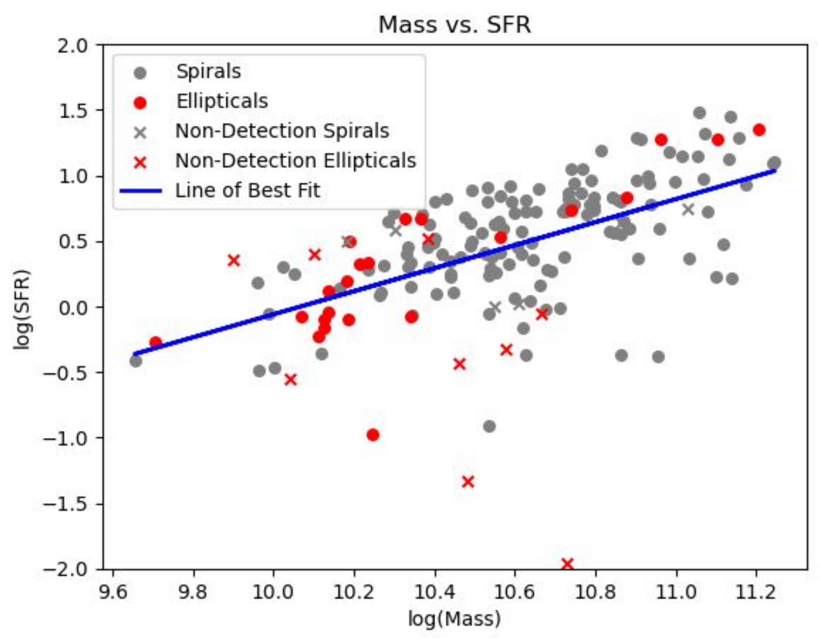
The molecular hydrogen gas fraction has been observed to correlate with a multitude of galactic characteristics, among which are color, star formation rate, and stellar mass. In this study, we assess a possible relationship between the aforesaid value with asymmetry in the Hα velocity dispersion of galaxies, using a set of 170 spirals and ellipticals from the MASCOT survey, whose morphology was previously identified by Galaxy Zoo. Employing Python computational techniques, outliers within the customary interval of 3σ were removed from our dataset. Hα velocity dispersion maps were then acquired from IFUs, with which we computed the asymmetry indices of our sample. This technique proved to be unfruitful in the determination of any perceptible pattern, so we resorted to investigating a correlation between the H_2 gas fraction and quantitative asymmetry as computed by kinemetric methodology. This procedure, likewise, failed to detect any nonrandom relationship between our values of interest. Contrary to what might be predicted by reasoning on theoretical axioms alone, our data thus appear to suggest that there may be no significant empirical correlation between the H_2 gas fraction and the asymmetry of a galaxy.

Background

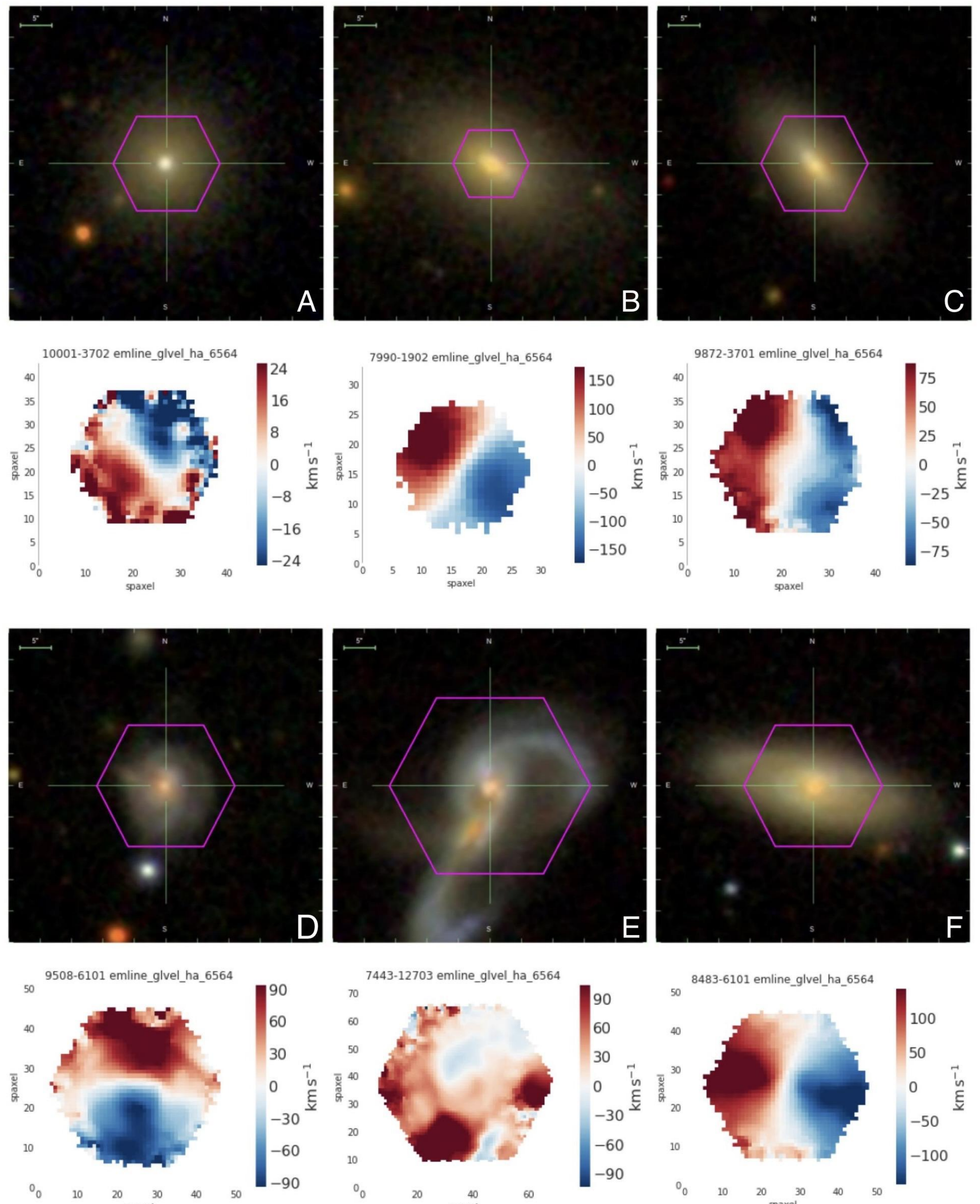
Atomic hydrogen is the most abundant gas in the universe and therefore is abundant in galaxies. Over time this atomic hydrogen begins to condense to form a protostar, and during this process, molecular hydrogen, or cold gas, is created. This cold gas is essential for star formation and is what powers fusion in the core of stars. As a star begins to undergo fusion and rises in temperature, its hydrogen becomes ionized, creating "warm gas" which produces Hα emission. This Hα emission is indicative of recent star formation because of this. Asymmetries in velocity dispersion are a trait commonly associated with star forming galaxies because the high concentration of hydrogen content slows regions of the galaxy by dynamical friction. These high cold gas levels also cause star formation which produces warm ionized (HII) gas. Integral Field Units (IFUs) are utilized to analyze the signal from individual pixels or cells from a 2D image and form a comprehensive spectroscopy from it. IFUs provide the spectroscopy necessary for analyzing asymmetry. The asymmetry index (computation seen in equation (1)) was utilized as opposed to visual morphology, because measuring red- and blueshifts within a galaxy presents the variances in gas morphology more so than looking at an individual image would. Quantifying asymmetry is a technique others have used, usually in the context of images containing all the light in a galaxy, as opposed to light of one wavelength.

Sample Selection

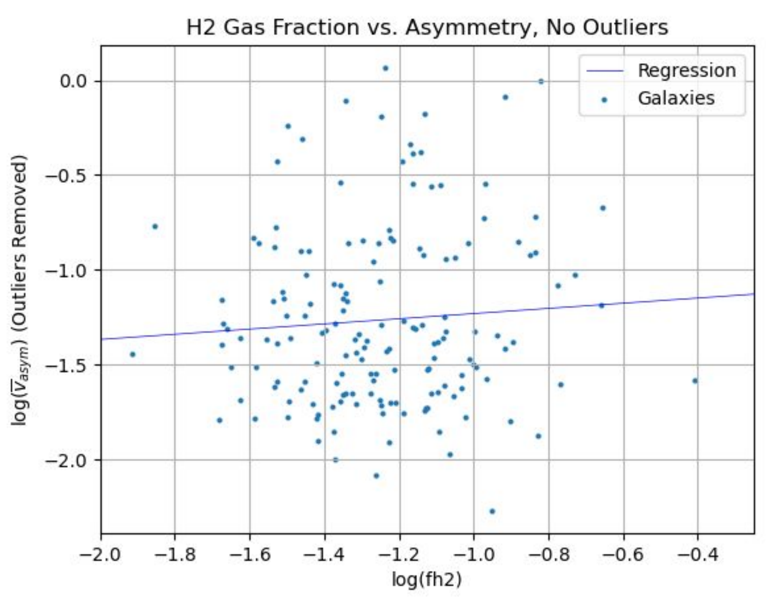
The Galactic Main Sequence is defined as the stage of a galaxy's life in which star formation is occurring, which is important to us because this galactic stage follows a typical star formation to mass ratio. As most of a galaxy's gas mass is due to atomic and molecular hydrogen, galaxies on the galactic main sequence are the best candidates for our study of molecular hydrogen's effects on morphology. We used the Galaxy Zoo survey to determine the morphology of a galaxy. To determine the molecular hydrogen content, the MASCOT survey was used. The MASCOT survey targeted a sample of MaNGA galaxies. MaNGA was a large galaxy survey that mapped the kinematic structure of thousands of galaxies. The sample had a low redshift, in addition to mainly mapping galaxies with a stellar mass greater than $10^{9.5}$ $M_\odot$. Our results featured primarily main sequence galaxies, missing quiescent, elliptical galaxies. We filtered outliers that were three standard deviations from the mean of our results. Our graph (1) then verifies that the filtered galaxies mostly all lie within the Galactic Main Sequence.



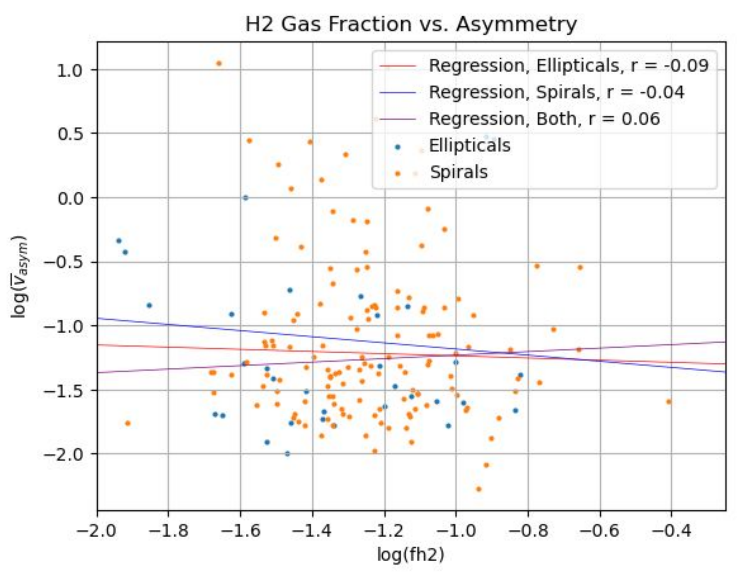
Plot 1: Mass vs Star Formation Rate
The star formation rate plotted against the stellar mass displays a proportional relationship.



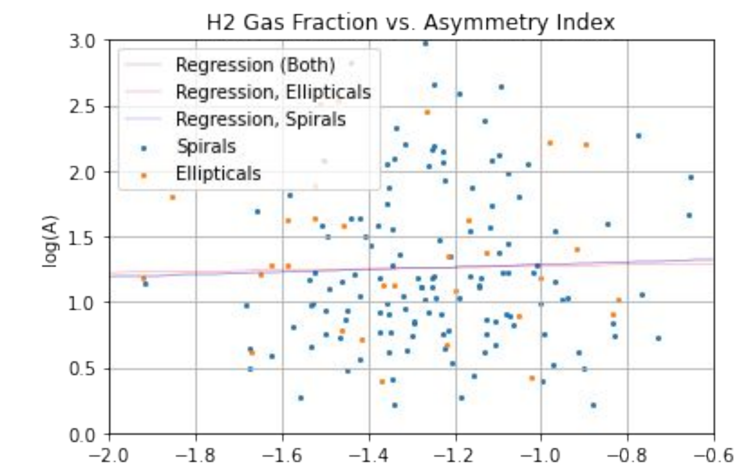
Plot 2: Galactic Images and Velocity Dispersion Graphs
Images A, B, and C are elliptical galaxies and their corresponding Hα velocity dispersion graphs are below, while images D, E, and F are spiral galaxies with their corresponding Hα velocity dispersion graphs.



Plot 3: Kinemetric Asymmetry (Cleaned)
Scatterplot of the molecular hydrogen gas fraction against the asymmetry as computed by kinemetric methods, with points more than 2σ removed. Note that the slope of the regression line changes from - to + after removing outliers, intimating poor correlation. Indeed, Pearson's r = 0.07.



Plot 4: Kinemetric Asymmetry (Detailed)
There exists virtually no qualitatively perceptible or numeric distinction between the kinemetric asymmetries of elliptical galaxies and spiral galaxies.



Plot 5: Asymmetry Indices (Detailed)
Asymmetry, as calculated by the Conselice method, plotted against the molecular hydrogen gas fraction. See discussion for Pearson r values. Note the scarcely perceptible difference between the regression lines.

The Asymmetry Index

This project began with a merged dataset created in TOPCAT using galaxies that have data from both Galaxy Zoo and MaNGA. From this, the Hα velocity maps of every galaxy were downloaded and analyzed using Python. This gave us 170 galaxies to work with. The images were cropped to only include the map with no axes. The images were converted to grayscale so that the Hα velocity values can be compared to a copy of the images flipped 180° to compare their symmetry. Using OpenCV, the backgrounds of the maps were removed and the difference in pixel values were calculated, revealing the error of the images overlaid on each other. The logic for image subtraction follows this equation:

$$\log A = \log std\left(\frac{\Sigma|I_0 - I_{180}|}{\Sigma|I_0|}\right) \tag{1}$$

Where I_0 is the original image and I_{180} is the same image flipped 180°. Each pixel is evaluated for its difference in values and divided by the original pixel value. The asymmetry indices of each galaxy were added to the dataset sheet. The galaxies were separated into their respective morphologies using the data from Galaxy Zoo. The asymmetry indices for each morphological type were averaged to find that the average for elliptical galaxies was 22.814 and for spiral galaxies was 25.002. Taking the log of these errors gives us 1.358 and 1.398 respectively.

This shows that elliptical galaxies are more symmetrical than spiral galaxies, but not by enough to make a conclusion about the relationship between galaxy morphology and Hα velocity.

Kinematic Asymmetry

In looking at the asymmetric degree of velocity maps of ionized gas' emission lines, we looked for a correlation between this degree–also called kinematic asymmetry–and a galaxy's characteristics, proving a relationship between Hα velocity and H_2 gas fraction. We combine the MASCOT data set and a "kinemetry" Python package[9] for our code. The velocity maps are divided into elliptical annuluses through the "kinemetry package," which are determined by the position of the galaxy center, position angle, and ellipticity. Provided by the Feng paper[8], we use the amplitude equation (2), where "a" is the semi-major axis, and "A" and "B" denote amplitudes of harmonic expansion of the n^{th} ellipse. When n=1, it notes a symmetric pattern in the velocity map or contribution of rotational motion. When n>1, it notes asymmetric patterns in the velocity map or the contribution of non-rotational motion. In understanding this equation, we gather an asymmetric velocity equation (3), which gives the ratio of several asymmetric patterns of non-rotating motion averaged against the symmetric pattern of rotating motion.

We ran into inconsistencies with this calculation. Provided with some example galaxies and their $\log(v_{asym})$ values[8], we noticed some of our values were off. The assumed reasoning for this difference is in the radii we use compared to the paper; where we use all non-zero radii, the paper uses the effective radius.

$$k_n(a) = \sqrt{A_n^2 + B_n^2}, \tag{2}$$

$$v_{\text{asym}} = \frac{k_2 + k_3 + k_4 + k_5}{4k_1}. \tag{3}$$

Discussion

Asymmetry Index (A): Using the method of asymmetry indices as outlined in Conselice 2014[10], no significant correlation was observed between the molecular hydrogen gas fraction and the asymmetry index, with both spirals and ellipticals distributed haphazardly ($r = 0.034$, $p = 0.7$ for both spirals and ellipticals; $r = 0.02$, $p = 0.91$ for ellipticals alone; and $r = 0.04$, $p = 0.66$ for spirals). These values did not improve significantly after removing outliers within two sigma ($r = 0.042$, $p = 0.6$, universal set). Boundary values varied wildly, with a minimum of 0.33 and a maximum of 1430, 2/3rds of the galaxies possessing an $A < 30$ (recall that asymmetry index is calculated by the standard deviation of the velocity dispersion throughout the galaxy).

Kinematic Asymmetry (v_{asym}): After iterating the function over our data set and graphing these galaxies on a $\log(v_{asym})$ versus $\log(fH_2)$ graph, there were no consistencies or trends in relating asymmetric velocity and the molecular gas fraction. Even when looking at morphological differences of elliptical galaxies versus spiral galaxies, all showed "across-the-board" behavior, with $-0.1 < r < 0.1$ (see the graphs for more detailed results), and a corresponding $p \gg 0.05$. Similarly, after culling those points which lay only within 2σ of our median, no greater than a change of 0.01 in the Pearson correlation coefficient was observed, with $p = 0.83$.

Future Work

Kinematic Asymmetry: Given how recently we got the "kinemetry" Python package to work with the MASCOT data set, in future work, we would like to alter our code to more closely match what is provided in the Feng paper[8]. Specifically, with changing the radii we use from all non-zero values to the effective radius. The hope is that this will result in our $\log(v_{asym})$ becoming more accurate to the paper's provided value so we may gain a deeper, and possibly different understanding of the relationship between asymmetric velocity and the molecular gas fraction.

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