Billowing Hydrogen: Simulating Turbulence in HII Regions

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Introduction

HII regions are areas of ionized hydrogen surrounding young, hot stars, as pictured in Figure 1. Observing them can help us probe star formation. Most of the visible light is absorbed on it's way to Earth, so we turn to a tracer that isn't absorbed as much by the interstellar medium, radio recombination lines (RRLs). RRLs are generated from hydrogen with high principal quantum numbers (n = ~100) undergoing an electromagnetic emission.

Figure 1: A picture of the HII region M20, otherwise known as the Trifid Nebula [1].

When we do research with RRLs, we need to make special considerations. This is because their emission is sensitive to the density squared of the hydrogen, rather than just the density by itself that is expected for a linear tracer such as the HI 21-cm line.

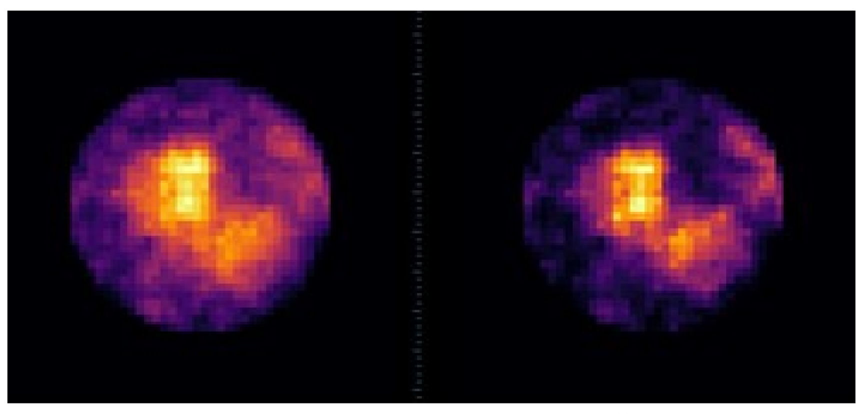

Figure 2: Simulated images showing the difference between a linearly sensitive tracer (left) and a squarely sensitive tracer (right). Brightness of the area represents density.

Looking at Figure 2, we see that there is a noticable difference between the images. More dense areas appear brighter for both cases. However, they differ in that there's more visual sharpness between brighter and darker region in the square sensitivity case. This is due to the squaring effect pronouncing out areas of higher intensity. This clearly is not a negligable effect, so it must be accounted for in simulation.

Research Question

Previous studies [2] have looked at HII regions and concluded rotation may be a good explanation for the motions we see in an HII region. These motions are measured via the first moment map, where each position of the sky in a data cube has an average spectral shift found and used as a velocity. However, later observations of this HII region suggest a different story, as pictured in Figure 3.

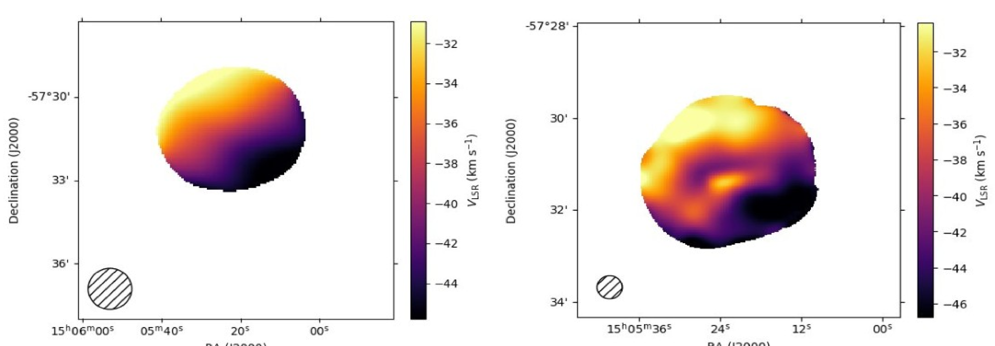

Figure 3: First moment maps of the initial observation and then the follow-up observation. The hatched circles in the corner of the image represent the beam size of the observation and will be used for that for all other figures.

The first image shows the bottom right of the HII region travelling toward the observer faster than the top left side. This creates a gradient and suggests that the region may be primarily undergoing rotation. There are three main types of mass motions of the HII region, being rotation, expansion, and turbulence. The second image does not having that same gradient that we see in the first, thus opening up the question if there is any mass motion that, by itself, can explain the motions of the region.

Our question is, can turbulence alone explain both the gradient appearance of the first image as well as the more structured appearance of the second? We will be using simulations in order to test how viable this idea is.

Results

Firstly, we simulate what an HII region would look like if it were homogenous in density and did not move. Figure 4 shows one of these regions without the added turbulence. Adding turbulence to this simulated HII region gives rise to a non-spherical shape, much like what we see with observation. We compare Figures 5 and 7 to see this. In addition, the phenomenon where details are smeared out in such a way that creates a gradient is recreated in the simulation. When a higher resolution is used to observe the region, we get more detail.

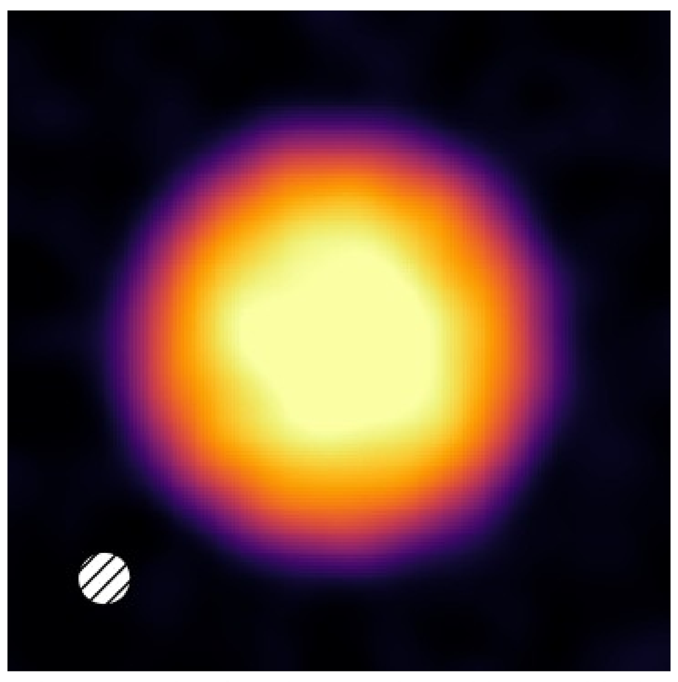

Figure 4: Simulated HII region without added turbulence.

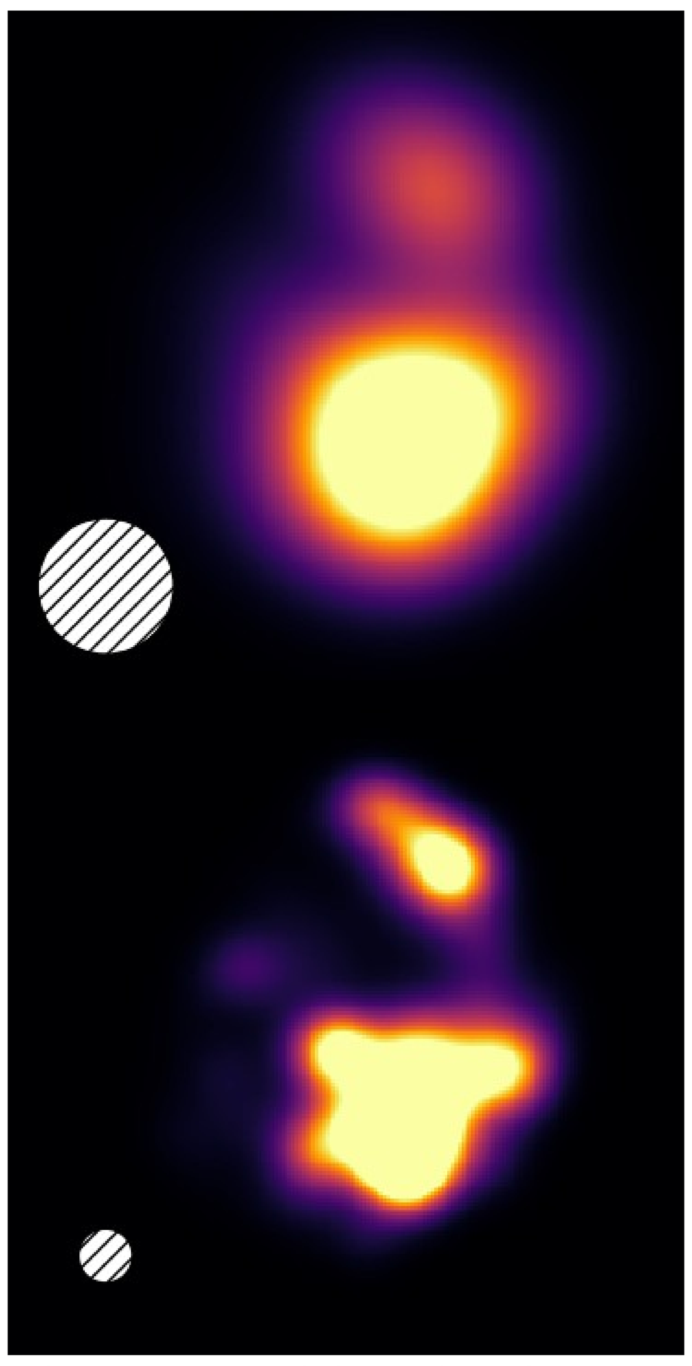

Figure 5: Generated observations of an HII region's RRL, integrated over frequencies nearby the frequency of the RRL.

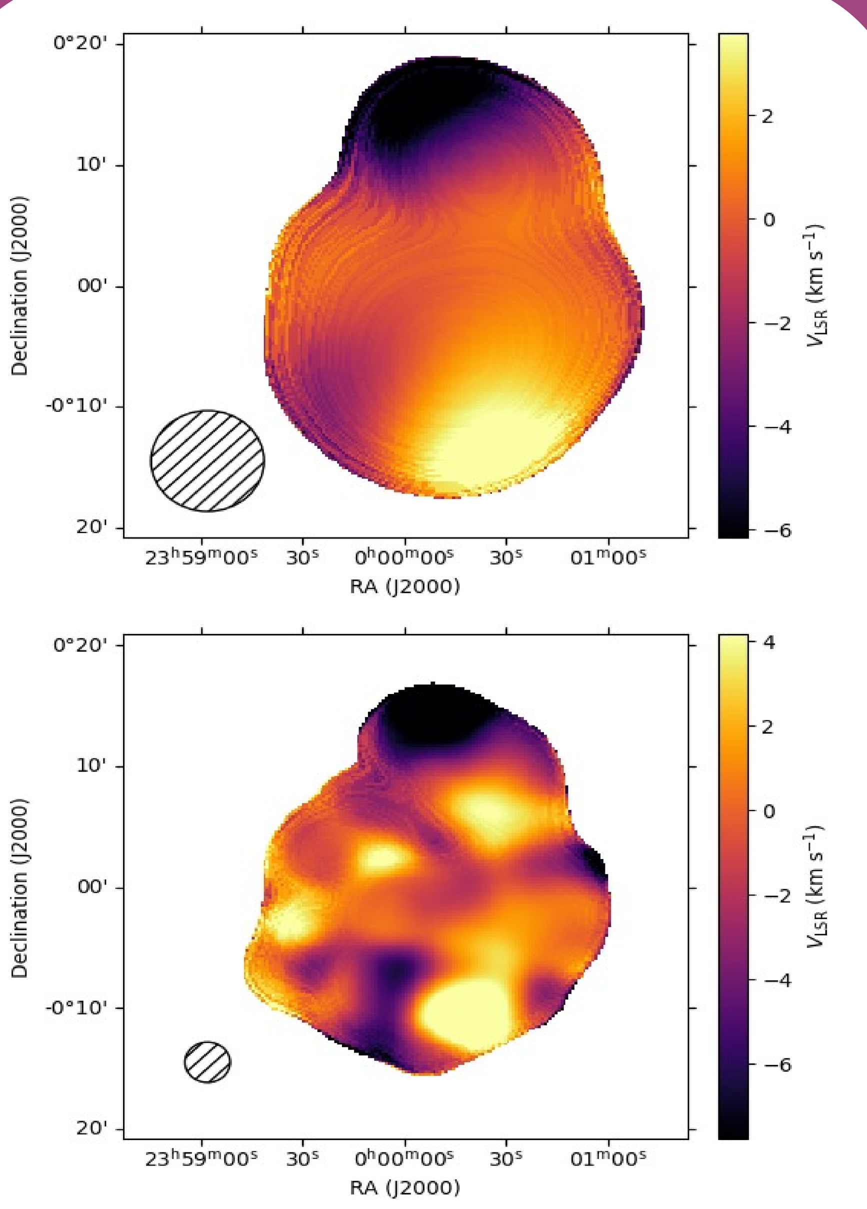

Figure 6: The first moment maps for our generated regions for two different resolutions.

We also note the range of velocities we get in Figures 3 and 6. For the upper and lower bounds of the regions pictured (first and last 5% of velocities), we get a range in the lower tens of kilometers per second for a velocity for a typical average velocity of the gas.

Our key findings are:

- Turbulence can explain the gradient existing at low resolution and details at high resolution.
- The velocity ranges of the regions are realistic for the simulation.

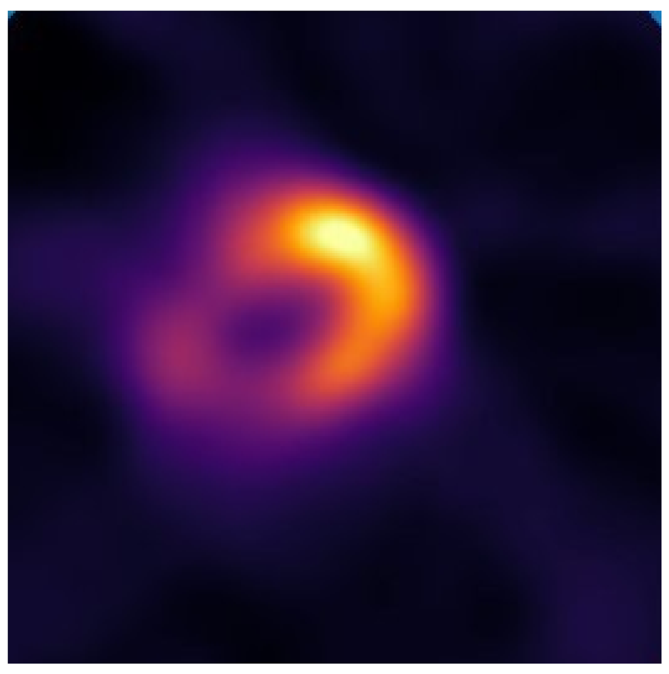

Figure 7: Region that was observed in order to create the moment maps shown in Figure 3.

Conclusion

We find that turbulence alone can explain the visual behavior of HII regions when they are resolved and unresolved. This is because the gradient-like behavior is recreated for unresolved and the granular features show for the resolved. Additionally, the ranges of velocity for the motions of the cloud in the simulation are realistic.

Future Work

Currently, we are working to predict the velocity of the gas contained by the HII region by looking at the residuals of a plane fit to quantify the "smoothness" of the image, as well as some other tests. These findings will help us to better our understanding of the motions of the gas within. Additionally, we will compare these simulations to more images similar to the one provided in Figure 2 to get a better understanding of how our simulation responds to different conditions.

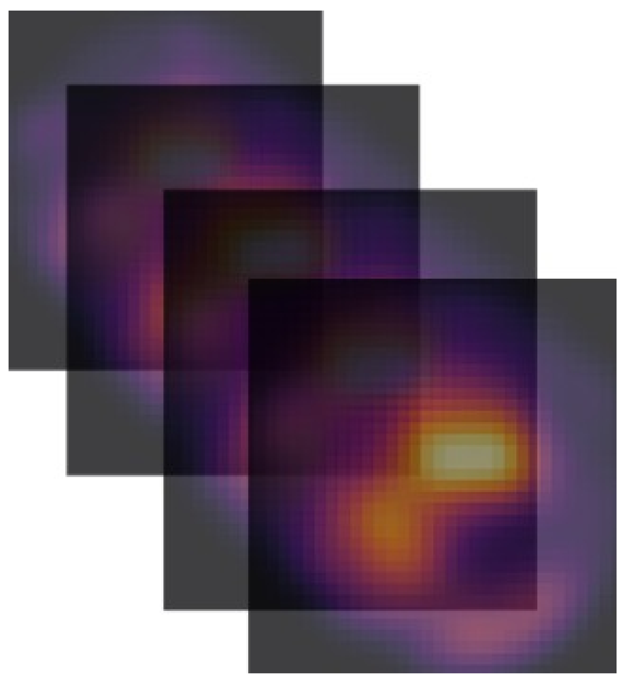

Figure 8: More simulations to come.

References

[1] M20 | Trifid Nebula HII Region in Sagittarius 6° from Kaus Borealis (top of the teapot) taken by R Jay GaBany.

[2] Balser, D. S., Wenger, T. V., Anderson, L. D., et al. 2021, The Astrophysical Journal, Vol. 921 (American Astronomical Society), 176, http://dx.doi.org/10.3847/1538-4357/ac1db3

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