Imaging Galactic Nuclei: Adaptive Binning with WVT

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J0248-0817, binned to S/N=3
R: 5008 [OIII]
G: 4862 [Hβ]
B: 3728 [OII]
Notice the [OIII] and [OII] emitting regions above and below.

A Brief History of the Entire Universe

Following the Big Bang, the Universe rapidly expanded and cooled, resulting in the neutral hydrogen we see at the end of Recombination, z~1000. Coincident with the emergence of the first galaxies, z~10-20, Cosmic Reionization (the final phase transition of the baryonic component of the universe) occurred. We suspect that these luminous sources are the cause of Reionization and we can examine them by the nebulae that surround them.

Nebulae can either be ionization-bound or density-bound. In the former, also called a Strömgren sphere, a source only has the power to ionize a bubble of gas around it; we would recognize such a nebula by its sharp boundary where the ionized gas is in equilibrium with the neutral gas. A density-bound nebula lacks such a distinctive edge, as the source is able to ionize all of the gas around it and leaks Lyman continuum radiation into the Intergalactic medium.

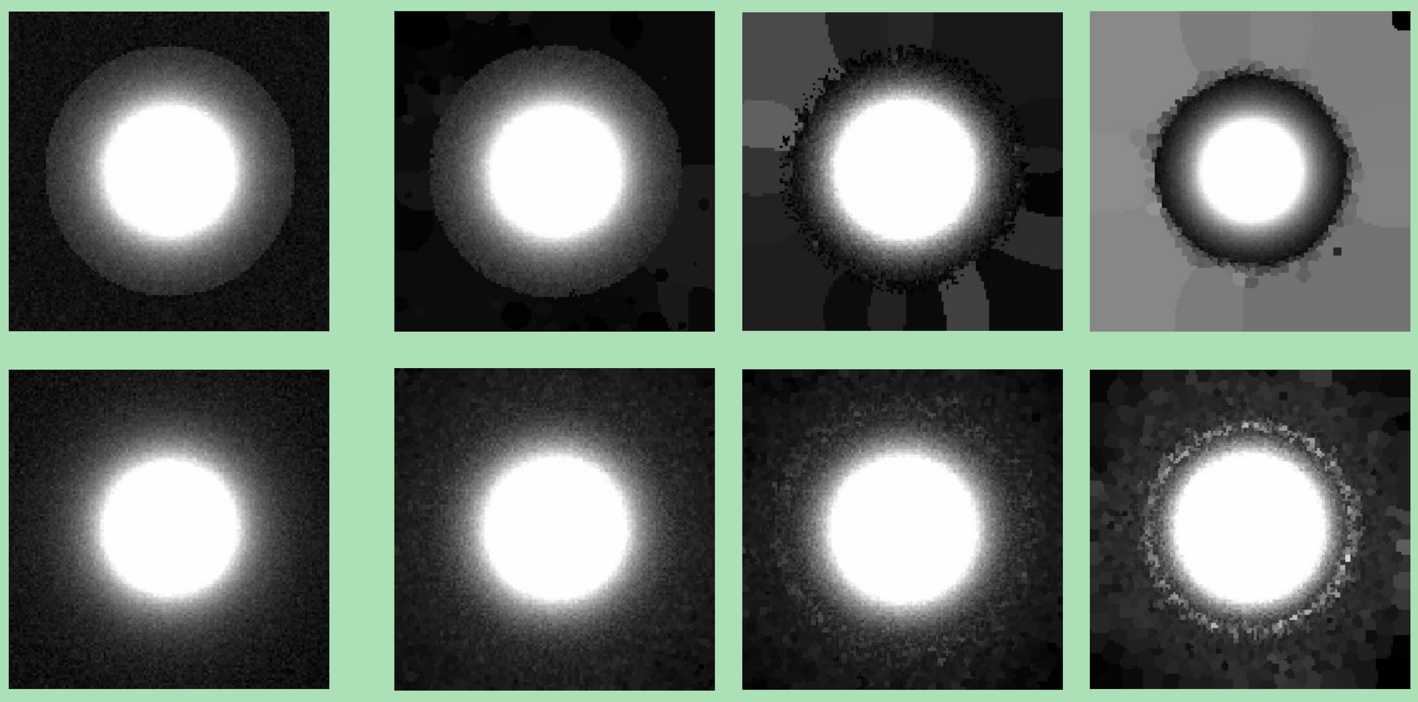
Here, we want to generate a method to detect the presence of nebular edges so we can figure whether or not a galaxy is leaking radiation.

Weighted Voronoi Tessellation (WVT)

Generally, signal-to-noise (S/N) decreases as we move away from the center of a nebula, since those regions are dimmer. We wanted a way to systematically increase the signal to noise to better detect where the nebula ends. We turned to a WVT Adaptive Binning Algorithm by Diehl and Statler[1], based on a method by Cappellari and Copin[2].

The goal is to group pixels together so that their combined S/N exceeds a target we set. The WVT is constructed from a set of points and scale lengths, so starting from a set of bins, we can evaluate whether to expand or shrink the bin by calculating its scale length based on its S/N. We can also recalculate the generator points and use that to construct the next generation, iteratively constructing WVTs until they converge.

Since we are using background-subtracted images, we expect that a nebula with an edge will be surrounded by a region where the signal is symmetrically distributed around zero (due to noise). We modified the WVT algorithm to better handle non-positive data; where the bins fail to achieve net signal, the bins expand until either they have net signal or reach the edge of the image.



Top: edge 50px, Bottom: no edge.
From L→R, unbinned signal, S/N map to 3, S/N map to 5, S/N map to 10.

[1] M. Cappellari and Y. Copin. Adaptive spatial binning of integral-field spectroscopic data using voronoi tessellations. *Monthly Notices of the Royal Astronomical Society*, 342(2):345–354, Jun 2003.
[2] S. Diehl and T. S. Statler. Adaptive binning of x-ray data with weighted voronoi tessellations. *Monthly Notices of the Royal Astronomical Society*, 368(2):497–510, May 2006.

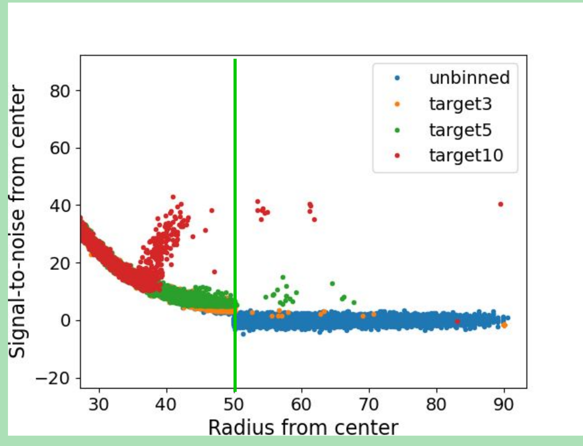
Testing the Algorithm

We expect that the WVT Binning Algorithm should raise the overall S/N and we expect it converge towards this result. We test our procedure on data simulated from a Circular β profile[3], with and without edges.

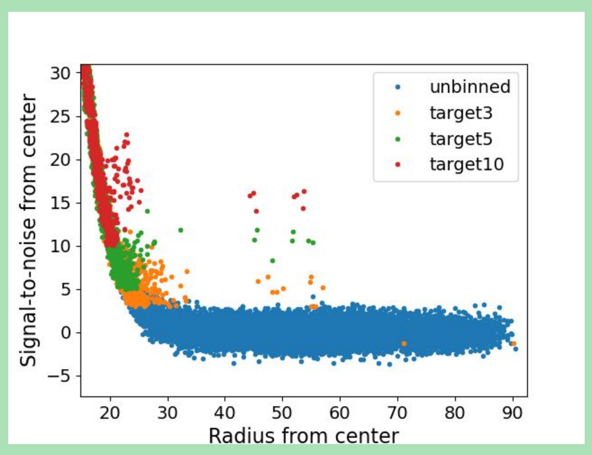
Overall, we do find that binning raises the S/N of our images, but can often create a false "S/N edge" due to inadequate S/N in certain regions. This is more pronounced in steeper nebulae or larger binnings, obfuscating the location of true edges. Alterations that prioritize compactness over S/N might be more illustrative of the true structure of the nebulae.

Especially for steeper nebulae, we find that convergence can take many more iterations, implying that our initial seeding wasn't great. This comes from our negative-S/N modifications: convergence is a bit at odds with finding signal in signal-less regions since bin growth perturbs the surrounding bins.

Generally, we find that low S/N binning better preserves low brightness structures, though evidently, higher S/N binning results in more pronounced edges, if it can achieve its minimum S/N.



β=0.9. We see 3,5 suggestive of true edge (green) but 10 suggests early edge

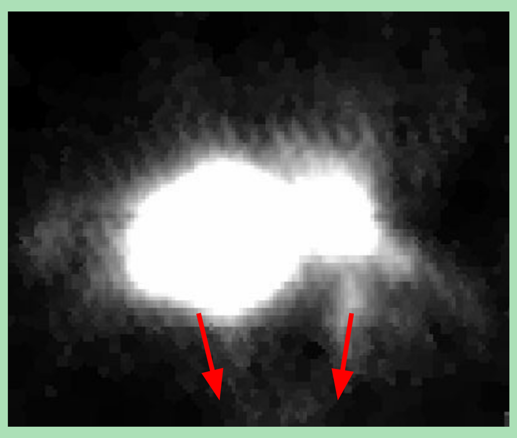


β=1.8 (steeper). Edgeless, but each binning suggests an edge → "S/N edge"

[3] Sarazin C. L., 1988, Cambridge Astrophysics Series, X-Ray Emission from Clusters of Galaxies. Cambridge Univ. Press, Cambridge

Local Analogues of Early Galaxies

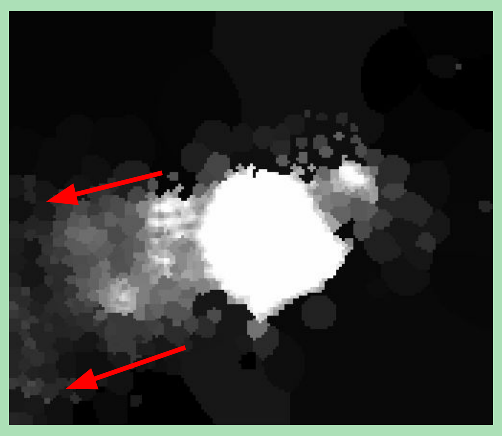
We are examining multiple-wavelength KCWI images of [OIII] rich dwarf galaxy nebulae. These systems are similar to the ones that we suspect reionized the universe, but are closer and easier to study. So far, application of our methods to real galaxies has been frustrated due to the "S/N edges," though, binning allows us to identify regions where we believe ionizing radiation is escaping:



Escaping Radiation

Left: J1044+0353
wavelength 5006
binned to S/N=5

Right: J1238+1009
wavelength 3727
binned to S/N=5



Acknowledgements

I would like to acknowledge Dr. Crystal Martin for her incredible mentorship. Additional thanks to Sarah Polizzotto and Zixuan Peng for assistance with software. Thank you to my CCS advisor Dr. Sathya Guruswamy. This CCS SUF project was made possible due to the generosity of John and Susan Axline.