Analysis of Metal Distribution in Sc Type Galaxies Using the SDSS-IV DR17 MaNGA Survey

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Abstract: The study of spiral galaxies has yielded fruitful results over the past half-century. The metallicity of a galaxy, the ratio of metal elements to hydrogen and helium, has been shown to decrease as the distance to the center of the galaxy increase. This study verifies the metallicity distribution of Sc type galaxies, with more definite metallicity gradients. In this paper, the author utilized the SDSS-IV MaNGA survey to plot out the metallicity gradient calculated with the O3N2 calibrator. The result shows a large amount of scattering after a certain distance, and that the metallicity gradient is mostly flat, with the exception of a number of galaxies. This shows that the metallicity gradient conforms with the traditional view. The scattering can be explained by the spiral structure of the galaxy, and the exceptions may be due to the observational issues or higher redshifts, which has demonstrated a positive metallicity gradient. These results allowed the confirmation of the metallicity gradient at lower redshifts, and it has given more insight into the metallicity distribution of Sc type galaxies, and thus more insight into the formation of spiral galaxies.

1 INTRODUCTION

Spiral galaxies (SG) have been the centre of astronomical research for decades after Edwin Hubble differentiated galaxies from ordinary nebulae in 1926 (Dobbs & Baba, 2014). Hubble constructed the Hubble Type classification schemes, separating elliptical galaxies, SG's and barred spirals. Hubble then separated SG's, both barred and unbarred, into 3 major types with differing structures: Sa galaxies with a larger bulge, compact arms and higher luminosity; Sb galaxies with smaller bulges loosely wound arms; Sc galaxies with a smaller bulge to arm ratio and generally the loosest arms. SG's allowed researchers to deduce conclusions such as the existence of Dark Matter, from the peculiar shape of the rotation curves all SG's exhibit which was noticed in the 1970s (Rubin, 1983; Rubin, et al., 1985). This utterly important result, which has fuelled many simulations and theories ever since its proposal, has allowed a clearer view of the formation of the entire universe. Another active field of research regarding spirals is the study of the galaxy's metallicity. Metallicity is the ratio between the masses of elements heavier than He to the combined masses of He and H (Henry & Worthey, 1999). Metallicity is an essential part in the investigation of the formation of the Solar System, since the heavier elements such as Silicon, Carbon and Nitrogen would contribute to the formation of planets (Winter, et al., 2024). Thus, the study of metallicity in galaxies allow researchers to understand the formation of stars and planets more thoroughly, thus pushing the boundaries in the studies of the Solar System. SG's have long perplexed researchers and has yielded many fruitful results for the scientific community such as the DM theory and the metallicity results. Thus, this field is of great future prospect, as more theories could potentially arise from the study of SG's.

The focus of this paper is on the metallicity distribution of SG's. Older studies, like the paper published in 1999 by Henry and Worthey focuses on the analysis of the metallicities for all types of galaxies, ranging from the earlier HT's to later HT's, concluding that the metallicity showed a negative correlation with the distance to the centre (Henry & Worthey, 1999). More recent papers focused on analyzing the gas-phase metallicity (GP) by calculating the oxygen abundance. One paper from 2025 used JWST data to analyse the gas-phase metallicity gradient from galaxies of redshift z=0.5 to z=1.7, testifying that the metallicity is lower in the interstellar medium (ISM) of the outer regions of a

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galaxy and also showing that most metallicity gradients are indeed flat (Ju, et al., 2025). They have also found that some galaxies at higher redshifts greater than 0 could demonstrate a positive radial metallicity gradient with sometimes a steep slope, which is consistent with the results from the TNG simulations (Ju, et al., 2025). The metallicity gradient at z=0 could be explained by an inside-out growth model of galaxies, stating that the initial accumulation of matter at the beginning of the galaxy would spread out over time, which would make the gradient less steep (Ju, et al., 2025). This model explains negative, flat slope observed at low redshifts, but fails to account for the situation at higher redshifts (Ju, et al., 2025). This team utilized integral field units(IFU) from JWST observations, thus to construct three dimensional spectroscopies (Ju, et al., 2025). Another paper from 2019 reached a similar conclusion, and also linked the higher metallicity with other values which showed an increase in that region, such as ionization, which led the researchers to conclude that star formation plays a role in the enrichment of the ISM (Kreckel, et al., 2019). Furthermore, another study from 2025 also substantiated the negative metallicity gradient in low-redshift galaxies, using the MaNGA survey. They also found that the slope becomes steep at a mass smaller than 3×10^{10} M_{solar} and then flattens at masses greater than this limit (Khoram & Belfiore, 2025). This study would further examine the radial metallicity gradient as a whole in Sc type spirals using the newer IFU methods to collect data, thus constructing a comprehensive view of larger galaxies, which can further substantiate that the metallicity gradients of SG's are negatively correlated with the radius. The Sc type is particularly selected, as Sc type galaxies are galaxies early in their process of evolution. Being early in its evolution, the Sc's ISM has not yet been supplied with a large amount of metals, which would limit the amount of time available for the redistribution effect achieved by the inside-out growth theory as previously described. This would contribute to a steeper metallicity gradient, benefitting the analysis of metal distribution. Furthermore, as the bulge is smaller, this paper would analyse the combined metallicity in a certain region of a galaxy, using mainly the GP metallicity to compute the metallicity distribution.

In the following part, first, the author will introduce detailed description of SG's. Then, the MaNGA and SDSS would be talked about, giving insight into their technical aspects. Afterwards, the author will talk about the methodology used to analyse the data from MaNGA. The results would follow this, then a discussion of the potential reasons that lie behind the results would be given. Lastly, the paper will discuss the conclusion, limitations and future prospects.

2 SPIRAL GALAXIES AND DETECTION

SG's are essentially a type of galaxy with long arms wrapped around them. As aforementioned, spirals are a Hubble Type with three major categories. Although the Sa type galaxy is commonly called the early type is now thought to be older than Sb and Sc types, due to their star formation rates being lower than that which exists in Sb and Sc types. Thus, indicating that the age should be the oldest for Sa's, then Sb's, with the youngest being the Sc galaxy.

For the data collection part, the author will be using the MaNGA survey from the seventeenth data release from SDSS-IV. The SDSS survey has been carried on for nearly thirty years, beginning in 1998 (Abdurro'uf, et al., 2022). The MaNGA survey is one of the surveys of the SDSS, with the full name Mapping Nearby Galaxies at Apache Point Observer (APO). In the northern hemisphere, SDSS uses the 2.5-meter aperture telescope at the Sloan foundation observatory. They also use the La Campanas Observatory located in Chile to observe the southern hemisphere. This allows for a comprehensive view of the entire night sky.

The MaNGA survey uses IFU, a technology aforementioned, to construct three dimensional, spatially resolved surveys of galaxies and clusters. Thus, MaNGA is capable of constructing full spectroscopic data on a 2D maps, differing it from the traditional spectroscopes, which only allows users to analyze data at a certain region within the galaxy. The MaNGA is capable of taking large field spectroscopic data of entirety of galaxies using integral field units. This, combined with the 2D view, allows a more integral view of galaxies, facilitating future researches (Bundy, 2014).

MaNGA stores data in the form of data cubes, which can be extracted individually from the Marvin API via Python by inputting a specific identification number, for individual data cubes, known as the plate-ifu (Cherinka, et al., 2019). In total, MaNGA made surveys of 10,010 galaxies using the IFU method. The IFU is made up of small packets of fiber optic organized in hexagons (Dory, et al., 2015). In total, 1423 fibers are utilized in the MaNGA. Each of these fibers will form harnesses, which are larger bundles of optic fibers and their corresponding hardware used to hold them in place. The light signals captured by the telescope would be sent to the sensors via the harnesses. The instrument, via this set-up, is capable of resolving lights of wavelength 3600 to 10300Å.

3 METHODOLOGIES

This paper will thus be using the MaNGA survey to construct maps of metallicities of entire galaxies and their corresponding metallicity gradient. The study will be using Marvin as a tool to extract and represent data from the MaNGA survey.

This study intends to use the 12+log(O/H) indicator to calculate the GP metallicity for SG's, using the O3N2 calibrator to eliminate the disruptive effects of dust on the observed light (Boardman, et al., 2023). Furthermore, the O3N2 calibrator has an advantage over the N2 calibrator, as the latter tends to be less accurate with IFU data as mentioned by Marino et al., 2013 (Marino, et al., 2013). Hence, the O3N2 calibrator will be utilized in combination with the 12+log(O/H). The O3N2 calibrator described in Ma2013 takes the value of

$$\mathrm{O3N2} = \log\left(\frac{[\mathrm{OIII}]\lambda 5007}{\mathrm{H}\beta} \times \frac{\mathrm{H}\alpha}{[\mathrm{NII}]\lambda 6583}\right) \quad (1)$$

and the 12+log(O/H) takes the value of

$$12 + \log\left(\frac{\mathrm{O}}{\mathrm{H}}\right) = 8.533 - 0.214 \times \mathrm{O3N2} \quad (2)$$

This paper will not be taking into account the effect of redshift. This is because, firstly, this study will only take samples from regions of low redshift, at $z = 0$, that is, this paper will only account for galaxies at a distance that is near to us. Hence, it will not result in a high redshift. Thus, the effect of the redshift will be minimal. Secondly, the research only desires to acquire the shape of the metallicity distribution across the radius of the SG, discovering the relative distribution of metal elements. Thus, it is unnecessary to determine specific metal elements. For further calculations to be accomplished, the Sc types must be selected first, which can be accomplished by accessing the MaNGA visual morphology catalogue (MVM-VAC). The Sc Type galaxies filtered out is then inputted into a csv file by using the Pandas library in Python. 20 Sc galaxies will be drawn randomly from the 418 Sc galaxies that are included in the MVM-VAC. The 20 Sc galaxies and their corresponding data is visible in Table 1. Then, the plate-ifu of the individual galaxies will be inputted into Marvin, thus to acquire the metallicity data using the aforementioned O3N2 calibrator. And after investigations, due to the messy nature of observational data, the 2D metallicity maps of the SDSS-IV will not be utilized, instead, the metallicity data will be plotted onto a graph with metallicity against radius in kpc. Furthermore, it is also necessary to obtain the radius, which can be easily done by the following code found in the Marvin Documentation (Cherinka, et al., 2019):

radius = 0.7*(galaxy.spx_ellcoo_r_kpc.value) (3)

The 0.7 is multiplied as the radius within the SDSS survey is presented in the units of kpc/h, where h is the dimensionless Hubble parameter(dHp). The h in this paper will be taken as 0.7 as presented by a review in 2013 (Croton, 2013). Multiplying the radius by 0.7 will rid of the dHp thus returning a value in kpc. Then, it is possible to plot the metallicity results against the radius, returning a scatter plot showing the general trend of the metallicity distribution.

Table 1: The 20 Sc galaxies filtered from MVM-VAC. All of these galaxies are randomly selected from 418 samples available in the MVM-VAC. The galaxies are presented with their plate-ifu, the MangaID and their redshifts (Cherinka, et al., 2019).

name	plateifu	MANGAID	Redshift
manga-7443-6101	7443-6101	12-84726	0.03091249
manga-7443-6103	7443-6103	12-84665	0.01834222
manga-7443-9101	7443-9101	12-84660	0.0404705
manga-9871-3703	9871-3703	1-322258	0.018230092
manga-9871-9101	9871-9101	1-321936	0.017267063
manga-9872-12701	9872-12701	1-322161	0.018649809
manga-9872-12702	9872-12702	1-322506	0.04083086
manga-9872-6102	9872-6102	1-322507	0.019473994
manga-9872-6104	9872-6104	1-322353	0.018495463
manga-9876-3703	9876-3703	1-456616	0.016713664
manga-9891-12703	9891-12703	1-593748	0.01753549
manga-9891-6102	9891-6102	1-373878	0.045699038
manga-8145-12704	8145-12704	1-152587	0.023471711
manga-8146-12701	8146-12701	1-604839	0.02784799
manga-8147-12703	8147-12703	1-146028	0.026618272

manga-8149-12701	8149-12701	1-604930	0.042103108
manga-8150-3703	8150-3703	1-390130	0.09668134
manga-8154-12701	8154-12701	1-603920	0.03146515
manga-8154-12703	8154-12703	1-37546	0.03965886
manga-8154-12705	8154-12705	1-37547	0.028330915

4 RESULTS AND DISCUSSIONS

Firstly, one has to eliminate certain results from the data selection, thus to be able to find a general trend that governs metallicity distribution. There are two sets of data that do not show any clear trends, that is, 8146-12701 and 8154-12703. The distribution of data is very loose in these samples; thus, it is more difficult to utilize this data and state any conclusions about the gas-phase metallicity distribution of SG's. Therefore, these samples will not be considered during analysis, as it will confound the results. These anomalies may be due to the data from the SDSS as the ifu itself may be damaged or of low quality.

The graphs are clearly separated into 2 parts, one, the distance nearer to the centre of the galactic bulge, which had less varied metallicity values. This distance took up about half the entirety of each sample. However, 8149-12701, 9891-6102, 9872-12702, 8150-3703 and 8971-12702 showed a different trend, having less of a region with smaller dispersions in metallicity. These exceptions showed a greater range of distribution in the GP metallicity of galaxies. Furthermore, 9871-3703 also showed the exception of having more of its region with GP metallicity scattered across a smaller range of metallicity values. These exceptions are likely due to the properties of individual galaxies being different to each other. This could potentially be explained by the difference in morphology or size of the galaxies, as some of the galaxies with metallicity being more varied tend to also have a larger size, like 9872-12702.

However, the more intriguing result comes from the general trend of scattering after a certain distance. This could be explained by the loose spiral arms of Sc-type galaxies. Therefore, the metallicity, after an initial distance within the central bulge with a more stable metallicity distribution, will tend to scatter as it moves onto the spiral arms. Because, then, the metallicity will be accounting for both the spiral arms with a more compact mass and metal distribution, and the region between the spiral arms with less luminous matter, thus giving rise to the great variation in GP metallicity after about one half the radius. Fig. 1 rom the SDSS-IV data release illustrates the loose spiral arms, and as one can see, the sample includes the entirety of the galaxy, from the centre to the edge (Cherinka, et al., 2019). Fig. 2 shows the scattering of metallicity values after a certain distance.

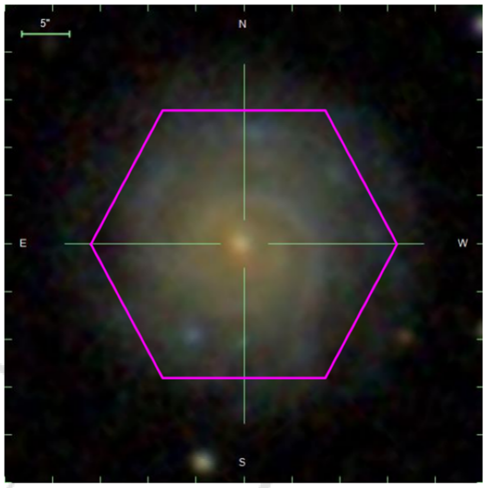

Figure 1: The spiral Sc galaxy from the SDSS-IV survey, plateifu = 8145-12704 (Cherinka, et al., 2019).

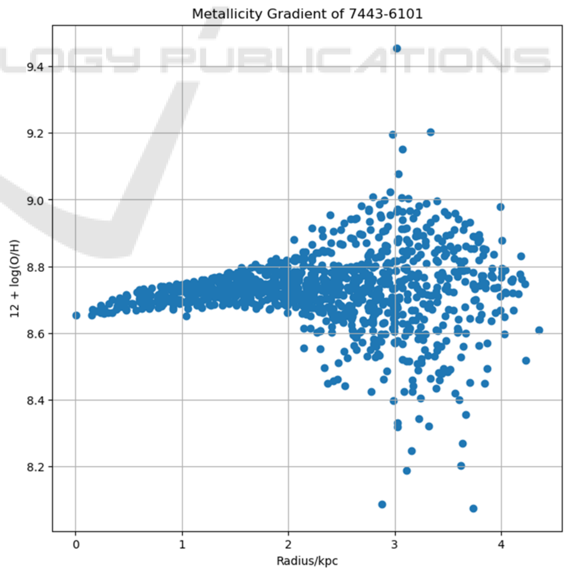

Figure 2: The spiral Sc galaxy from the SDSS-IV survey, plateifu = 7443-6101. The metallicity value stars to scatter above Radius = 2kpc (Photo/Picture credit: Original).

After providing an explanation to one trend observed in the graphs, it is then possible to organize the other samples into two groups: those with decreasing or flat trends of metallicity, and those with increasing metallicity. The majority of galaxies, of about 12 galaxies, had a rather flat metallicity, with very small amounts of fluctuations near the centre of the galaxy. And two of the galaxies had an increase and then abrupt decrease in metallicity. These are expected results, as most SG's do show either decreasing or flat trends across its radius as a result of inside-out growth. Similar results are present in Ju et al. and furthermore, their results also included a galaxy with an increasing then decreasing metallicity trend (Ju et al., 2025). This is due to the inside-out growth model as aforementioned. The inside-out growth model enriches the centre with more metal elements; because the model suggests that the centre of the galaxy is where the galaxy begins growing, meaning that the initial star formation occurs in the centre, thus resulting in higher metallicity. The smooth decreasing curve or flat curve is a result of the later diffusion and spreading of metal elements after the initial formation at the centre.

Table 2: the galaxies categorized with the trend of their graphs.

Galaxy	Trend
7443-6101	Flat
7443-6103	Decrease after increase
7443-9101	Decrease after increase
9871-3703	Flat
9871-9101	Flat
9872-12701	Flat
9872-12702	Flat
9872-6102	Flat
9872-6104	Flat
9876-3703	Flat
9891-12703	Flat
9891-6102	Flat
8145-12704	Increase
8146-12701	Discarded
8147-12703	Flat
8149-12701	Flat
8150-3703	Increase
8154-12701	Increase
8154-12703	Discarded
8154-12705	Increase

The samples with the increasing metallicity as radius increase demands different explanations as it opposes the classic results from the inside-out growth model. High redshift regions could result in a positive metallicity gradient. However, the values in Table 2 indicate that most of the samples do not have a high redshift. Only one galaxy 8150-3703 has a relatively high redshift of 0.967, and simultaneously, its radius and metallicity have a weak positive correlation, rendering it the only galaxy that could be potentially explained by the high redshift proposition. The other galaxies mostly have lower redshifts below 0.5. Therefore, it may be the issues with the data, or the individual morphological characteristics of these Sc normal spirals.

5 LIMITATIONS AND PROSPECTS

It is no doubt that this paper has reached some results. However, there were many issues and limitations with the methodology and the data. Firstly, there were flaws in the method. The author did not account for issues with the data cubes, for instance, potential data that were corrupted, or cannot be used, or lacks validity. The paper can be improved if masks were to be used in the Python code to decrease the number of spaxels that contained unreliable data, thus increasing the reliability and confidence with the final results. Furthermore, this paper focused only on using the oxygen abundance to derive the GP, which has been shown by Fraser-McKelvie et al. in 2021 to be only a rough estimate of the GP in a galaxy, as other elements are also present in the ISM (Fraser-McKelvie, et al., 2021). Potentially, in the future, stellar metallicity should also be considered so to acquire the overall metallicity of the entire galaxy, giving new insights into the inside-out model, as the inside-out model is proposed based upon GP metallicity, examining it using a stellar metallicity result might yield valuable results.

This field also has many limitations currently. Due to the lack of better means of probing the universe and the limitations in the technique, the data sent from all-sky surveys still has uncertainties. Surveys like such may lack details when probing galaxies, hence limiting the current researches. Furthermore, the existence of dust, nebulae and other matter in the Milky Way can also impede further inspections on extragalactic objects. Although there are algorithms that can reduce noise and other sources of uncertainty, there exists, still, a physical constraint on further investigating objects at distant locations like galaxies.

This field is still an active one. In the future, it is also possible that the observation techniques improve. SDSS is in fact starting to release their new SDSS-V, making the data more reliable and more accurate, which can offer newer insights in the formation and evolution of galaxies. Furthermore, more accurate simulations, such as Illustris TNG and Thesan can also be integrated with actual observations so to further test the understanding of galaxies and the universe. These simulations, in the future, could be used to test the validity of galaxy formation theories, if fed with more accurate results from observations. The development of machine learning in the past few years can also be used to analyse and interpret data from surveys and simulations, providing more solutions to issues like the price and time for simulations. This can and will improve the results from the field, making researches more fruitful.

6 CONCLUSIONS

In conclusion, this research has discussed the metal distribution in normal Sc type galaxies by utilizing the SDSS-IV DR17 MaNGA survey. The research has concluded that most galaxies do follow a nearly flat metallicity gradient, thus indicating the validity of the inside-out growth model of galaxies, further substantiating the theory. Furthermore, the data used in the paper has also yielded some anomalous results, showing 4 galaxies with a clear increasing trend and a positive gradient, and most of which do not necessarily have a satisfactory explanation, since only one out of 4 has a redshift greater than 0.5. In the future, this field still holds many potentials, as machine learning develops and new technology arises. The study of SG's is capable of ridding of more physical constraints in the near future. And, this field also has great potential and significant meaning. Integrating results from metallicity gradients can also provide more insight into DM, for metallicity is a very fundamental characteristic of galaxies and could potentially have connections with DM, which plays a significant role in spiral galaxies.

REFERENCES

Abdurro'uf, A., K., Aerts, C., Silva Aguirre, V., et al., 2022. The seventeenth data release of the sloan digital sky surveys: Complete release of Manga, MaStar, and apogee-2 data. *The Astrophysical Journal Supplement Series*, 259(2), 35.

Boardman, N., Wild, V., Heckman, T., Sanchez, S. F., Riffel, R., Riffel, R. A., Zasowski, G., 2023. Gas metallicity distributions in SDSS-IV manga galaxies: What drives gradients and local trends? *Monthly Notices of the Royal Astronomical Society*, 520(3), 4301–4314.

Bundy, K., 2014. Manga: Mapping nearby galaxies at apache point observatory. *Proceedings of the International Astronomical Union*, 10(S311), 100–103.

Cherinka, B., Andrews, B. H., Sánchez-Gallego, J., et al., 2019. Marvin: A tool kit for streamlined access and visualization of the SDSS-IV manga data set. *The Astronomical Journal*, 158(2), 74.

Croton, D. J., 2013. Damn you, little H! (or, real-world applications of the Hubble constant using observed and simulated data. *Publications of the Astronomical Society of Australia*, 30.

Dobbs, C., Baba, J., 2014b Dawes Review 4: Spiral structures in disc galaxies. *Publications of the Astronomical Society of Australia*, 31.

Dory, N., MacDonald, N., Bershady, M. A., et al., 2015. The manga integral field unit fiber feed system for the sloan 2.5 m telescope. *The Astronomical Journal*, 149(2), 77.

Fraser-McKelvie, A., Cortese, L., Groves, B., et al., 2021. The Sami Galaxy Survey: The drivers of gas and stellar metallicity differences in Galaxies. *Monthly Notices of the Royal Astronomical Society*, 510(1), 320–333.

Rubin, V. C., 1983. Dark matter in spiral galaxies. *Scientific American*, 248(6), 96–108.

Rubin, V. C., Burstein, D., Ford, W. K., Thonnard, N., 1985. Rotation velocities of 16 SA galaxies and a comparison of SA, SB, and SC Rotation Properties. *The Astrophysical Journal*, 289, 81.

Henry, R. B. C., Worthey, G., 1999. The distribution of heavy elements in Spiral and elliptical galaxies. *Publications of the Astronomical Society of the Pacific*, 111(762), 919–945.

Ju, M., Wang, X., Jones, T., Barišić, I., Nanayakkara, T., Bundy, K., Faucher-Giguère, C. A., Feng, S., Glazebrook, K., Henry, A., Malkan, M. A., Obreschkow, D., Roy, N., Sanders, R. L., Sun, X., Treu, T., Zhou, Q., 2025. MSA-3D: Metallicity gradients in galaxies at Z ∼ 1 with JWST/NIRSpec slit-stepping spectroscopy. *The Astrophysical Journal Letters*, 978, 2.

Khoram, A. H., Belfiore, F., 2025. Direct-method metallicity gradients derived from spectral stacking with SDSS-IV manga. *Astronomy & Astrophysics*, 693.

Kreckel, K., Ho, I. T., Blanc, G. A., et al., 2019. Mapping metallicity variations across nearby Galaxy Disks. *The Astrophysical Journal*, 887(1), 80.

Marino, R. A., Rosales-Ortega, F. F., Sánchez, S. F., et al., 2013. The O3N2 and N2 abundance indicators revisited- improved calibrations based on CALIFA and Te-based literature data. *Astronomy & Astrophysics*, 559.

Winter, A. J., Benisty, M., Andrews, S. M., 2024. Planet formation regulated by Galactic-scale interstellar turbulence. *The Astrophysical Journal Letters*, 972, 1.