





Stellar Populations with MaNGA: Iron Kink and Nitrogen Fuzz

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Abstract

Recent analysis of 2968 MaNGA early-type galaxies has yielded two notable trends with velocity dispersion (σ) not previously discussed in the literature. First, Fe abundance rises with σ but only until $\sigma \approx 100 \text{ km s}^{-1}$, after which it falls. This kink is reproduced by TNG100 simulations, implying that hierarchical merger processes might explain it. Second, astrophysical scatter in N is high for galaxies with $\sigma < 100 \text{ km s}^{-1}$. Due to the restricted list of nucleosynthetic sources for N, it is likely that asymptotic giant branch stars provide most of this N. A varied star formation history (compared to that of massive galaxies) along with variable retention and recycling of N-enriched gas might explain the fuzz of N abundance in low- σ galaxies. Because a timescale argument seems necessary to explain the nitrogen fuzz, and an initial mass function argument is ruled out, similar timescale arguments for the [Mg/Fe] trend as a function of velocity dispersion are supported.

Unified Astronomy Thesaurus concepts: [Galaxy abundances \(574\)](#); [Galaxy stellar content \(621\)](#); [Galaxy ages \(576\)](#); [Galaxy evolution \(594\)](#); [Galaxy chemical evolution \(580\)](#)

Выборка и обработка данных

light of galaxies may be used to infer some limited information about their chemical evolution and star formation histories (S. C. Trager et al. 2000; J. Johansson et al. 2012; C. Conroy et al. 2014; G. Worthey et al. 2014b). Recently, the inclusion of isochrones that respond to individual element abundance changes (G. Worthey et al. 2022) has shifted the measurement of nonsolar abundance ratios from integrated light, which had heretofore been heuristic, to a proper scale relative to the solar mixture. That is, derived quantities such as $[\text{Mg}/\text{Fe}]$ or $[\text{Fe}/\text{H}]$ can now reasonably be expected to be free of zero-point shifts and spurious slope changes wrought by hybrid stellar population models whose spectra shift with elemental mixture but whose underlying isochrones remain static. In this happier situation, it behooves us to reexamine some of the excellent spectra that exist for galaxies.

2. Data, Analysis, and Results

T. Pal & G. Worthey (2025) analyzed 2968 MaNGA low-redshift galaxies from DR17 (Abdurro'uf et al. 2022) with Sérsic index >2 , so that they are, structurally at least, early-type galaxies (ETGs). The spectra have a resolution of $R \sim 2000$ covering a $3000 < \lambda < 10000 \text{ \AA}$. Any galaxy with significant $\text{H}\alpha$ emission was dropped from the sample in order to make mean age estimation more accurate. Elliptical annuli were superimposed to extract radially dependent spectra.

An array of absorption feature indices measured from the galaxy spectra were compared to stellar populations models. The model grid is that of G. Worthey et al. (2022) using an isochrone set assembled from corrected and updated versions

(2014a) with departures caused by changes to chemical composition calculated via synthetic spectra. Single stellar populations (SSPs) were subsequently integrated over an analytic abundance distribution (ADF) function of “normal” width (B. Tang et al. 2014). The resulting composite stellar populations (CSPs) were characterized by single-burst age, the $[\text{Fe}/\text{H}]$ value of the peak of the ADF, and elemental abundances $[\text{C}/\text{Fe}]$, $[\text{N}/\text{Fe}]$, $[\text{Na}/\text{Fe}]$, and $[\text{Mg}/\text{Fe}]$. The philosophy for this MaNGA reduction pass was to derive high-accuracy abundances from easy-to-measure features. For example, oxygen abundance is strongly degenerate with derived age (G. Worthey et al. 2022), but oxygen’s spectral impact is not secure. Oxygen and $[\text{Si}/\text{Fe}]$ were assumed to vary in lockstep with $[\text{Mg}/\text{Fe}]$. A model-inversion program called COMPFIT (G. Worthey et al. 2014b, 2022; G. Worthey & X. Shi 2023) searched for best-fit ages and overall abundance for a trial chemical mixture. The element mixture was altered via linear fits to sensitive features, then the process was iterated. Errors in astrophysical parameters were estimated by altering the input galaxy indices within error envelopes and recomputing. Fifty such Monte Carlo realizations were computed for each annulus in each galaxy.

The CSPs we use are “one known bias better” than SSPs along the metallicity dimension, but for this reduction run we still output a single age for systems that, presumably, have much more complex star formation histories. The single age we adopt is approximately equivalent to a photometrically weighted mean age, since young populations are brighter. Naïvely, a U - or B -weighted mean age might be equivalent,

Разброс содержания азота в галактиках с малой дисперсией скоростей

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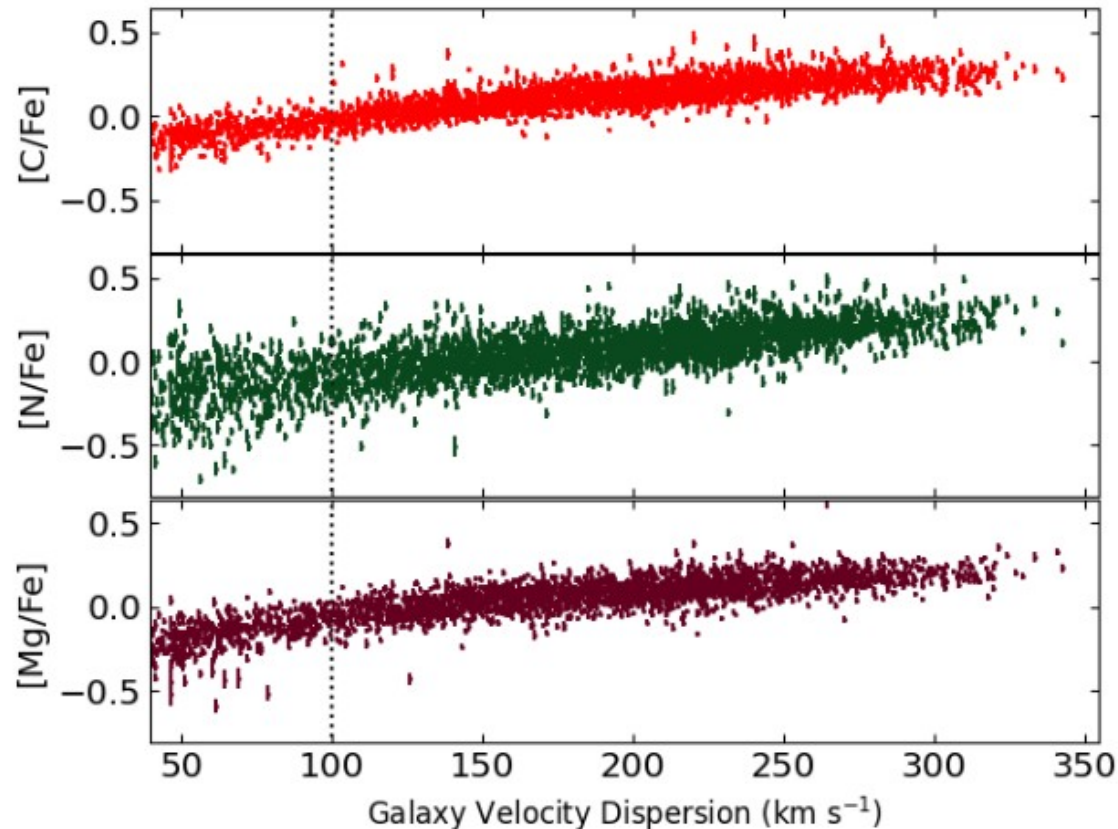


Figure 1. Light element abundances relative to Fe as a function of velocity dispersion. Error bars are Monte Carlo estimates based on random observational noise within a $0.7 \text{ Gaussian } \sigma$ envelope. Galaxies with $\sigma < 100 \text{ km s}^{-1}$ show pronounced scatter in $[\text{N}/\text{Fe}]$ that is not seen in $[\text{C}/\text{Fe}]$ or $[\text{Mg}/\text{Fe}]$.

Разброс содержания азота в галактиках с малой дисперсией скоростей

Worthey & Pal

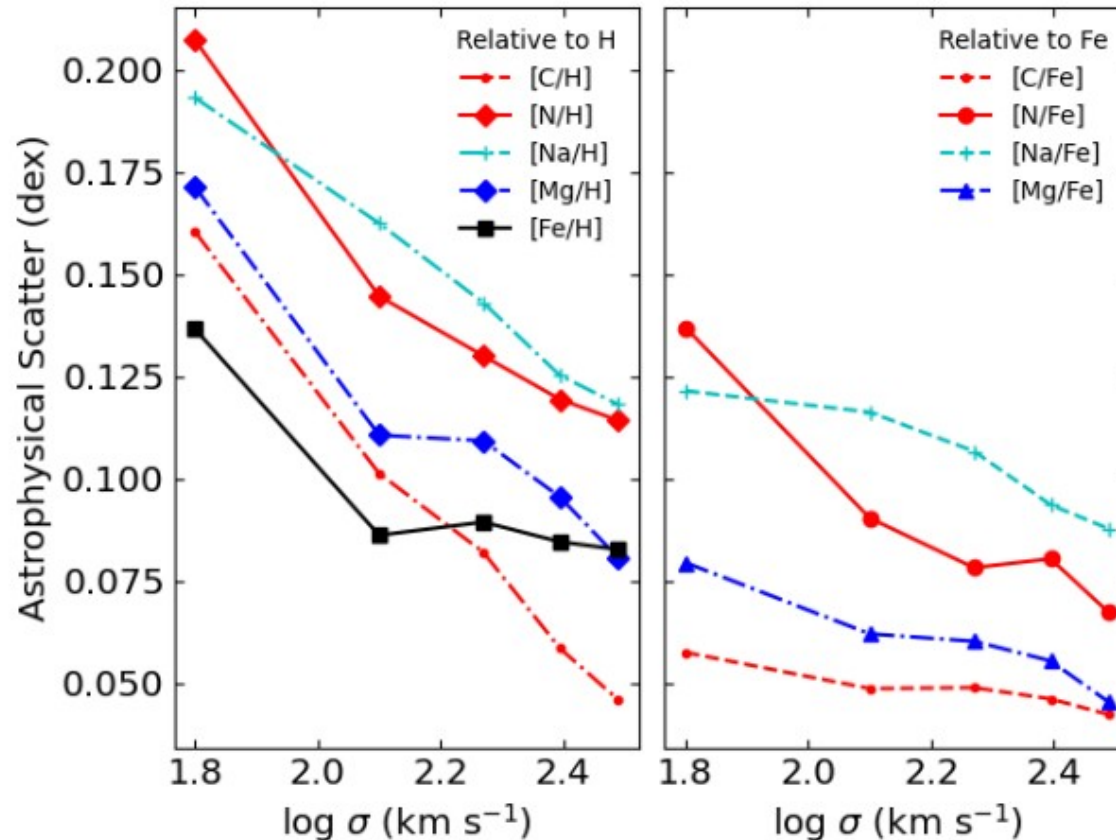


Figure 2. Astrophysical scatter in logarithmic abundances binned by galaxy velocity dispersion. The smallest galaxies have the largest scatter in all quantities, but nitrogen's scatter has the greatest magnitude.

Максимум обилия железа в галактиках с $100 < \sigma < 120$ km/s

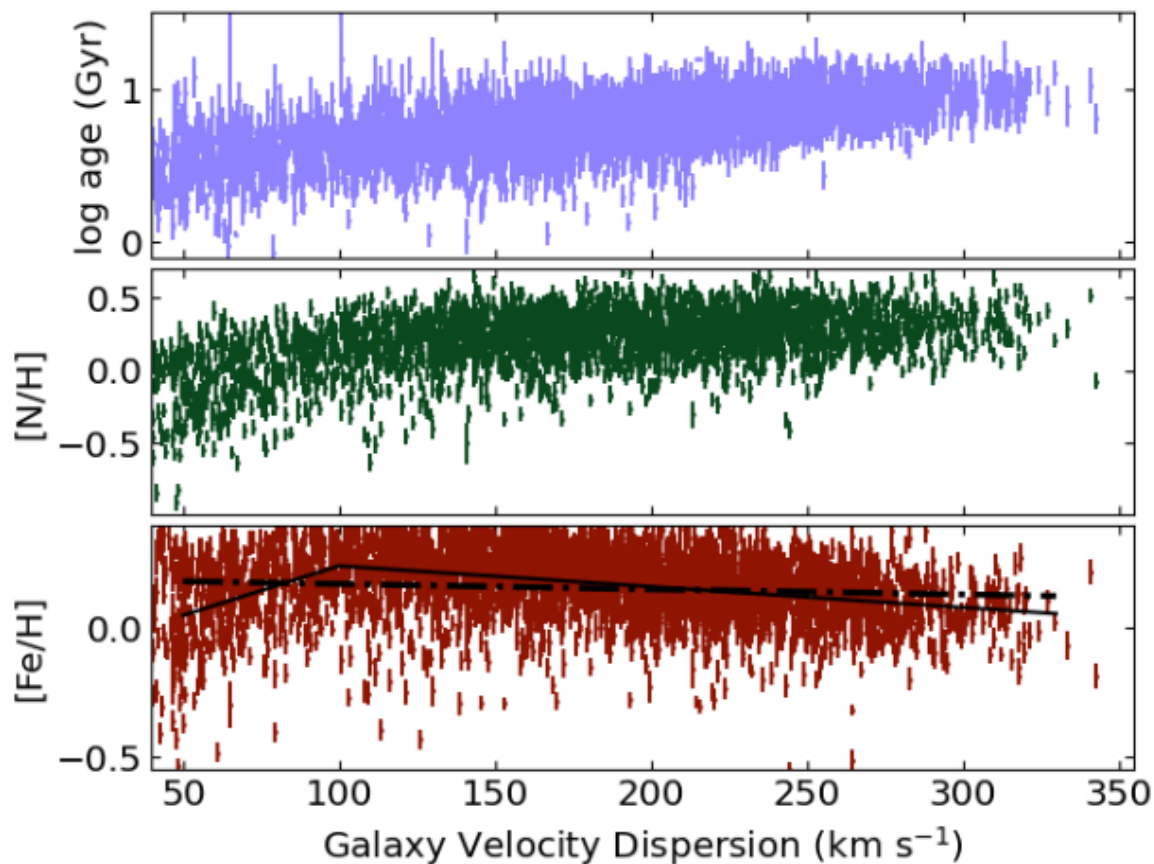


Figure 3. Log age and abundances for N and Fe as a function of σ with error bars as in Figure 1. One-error regressions for a line and a broken line are overplotted in the Fe panel. The top of the Fe panel is set to $[\text{Fe}/\text{H}] = 0.4$, the limit imposed by the model grid.

Источники азота в галактиках

3. Discussion

The iron kink and the nitrogen fuzz are surely clues to the details of galaxy chemodynamical evolution. As presented in some detail by T. Pal & G. Worthey (2025), the TNG100 simulations (F. Marinacci et al. 2018; J. P. Naiman et al. 2018; D. Nelson et al. 2018; A. Pillepich et al. 2018; V. Springel et al. 2018) reproduce the Fe kink at almost exactly the same point ($\sigma \approx 100 \text{ km s}^{-1}$). This agreement is convincing because neither the TNG authors nor we sought to replicate such a thing. The qualitative agreement therefore lends strong support to the hierarchical assembly picture of galaxy evolution in that it can, demonstrably, reproduce this relatively subtle chemical signature.

The nitrogen fuzz, on the other hand, is novel. The TNG100 yield assumptions are generally too high for the observations we present, although both for them and us the $\sigma = 100 \text{ km s}^{-1}$ point is an inflection point in slope for all quantities except mean age, especially apparent when plotted versus $\log \sigma$.

According to K. Nomoto et al. (2013), neither hypernovae, pair-production supernovae, Type Ia supernovae, nor neutron star collisions yield significant amounts of N. Nitrogen therefore has two main nucleosynthetic sources: AGB stars and core-collapse supernovae (Figure 4).

The supernova yield predictions in Figure 4 from K. Nomoto et al. (2013) show a weak dependence on the progenitor mass but a strong dependence on the progenitor metallicity. While noting that supernova yields are notoriously difficult to predict, it seems from the figure that only chemically evolved gas can produce “instant” N-rich ejecta

superimposed (solid line). Note that for galaxies $< 100 \text{ km s}^{-1}$ (to the left of the dotted line), [C/Fe] and [Mg/Fe] lie low, as if these galaxies were enhanced in Fe, but [N/Fe] follows the trend set by high- σ galaxies.

Iron comes in large part from Type Ia supernovae, which require white dwarfs to trigger. Therefore, they come with an inherent time delay, like AGB star enrichment. If the authors could arrange the Universe to their liking, the Type II enrichment would be nearly instant, the Type Ia would follow after some 10^8 yr , and then AGB enrichment would linger the longest. In that case, Mg (Type II), Fe (Type Ia), and N (AGB star) abundances could indicate how long gas lingers in a galaxy before being recycled into stars. Alas, famously, the Type Ia enrichment timescale is not known very well.

Figure 5 points out possible support for such a measurement by fitting lines to [X/Fe] versus σ , but only large ones with $110 \text{ km s}^{-1} < \sigma < 340 \text{ km s}^{-1}$. The extrapolations at low σ miss [C/Fe] and [Mg/Fe], as predicted if extended star formation histories favor Fe over Type II supernova products. But N should also arise plentifully in extended star formation scenarios, and we see it follow the extrapolation of the Fe-N trend. N is being incorporated into stars at about the same rates as Fe for these low- σ galaxies.

This might finger timescales as the driving mechanism, but it might not. G. Worthey et al. (1992) also list IMF as a possible cause. Star formation in massive galaxies should be more dynamically turbulent, and this may favor the formation of massive stars, say $50 M_{\odot}$ relative to $10 M_{\odot}$, producing more Mg (and C). The behavior in Figure 5 might just as easily be caused by an IMF-caused dearth of Type II supernova

Источники азота в галактиках

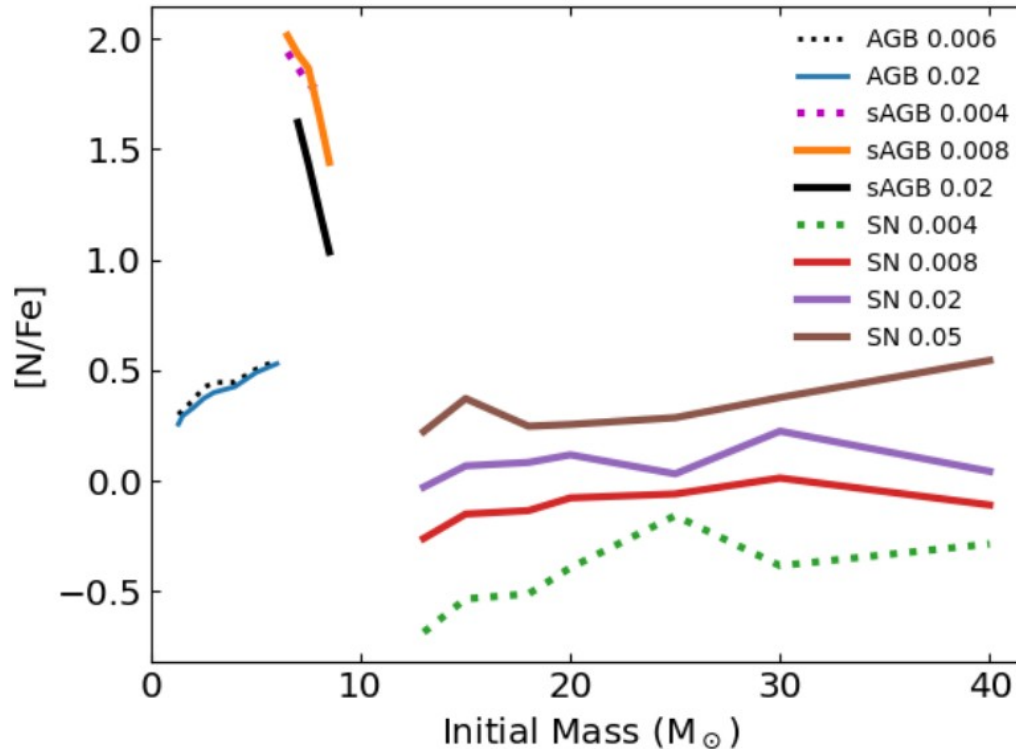


Figure 4. Nitrogen yield relative to iron as a function of initial stellar mass for asymptotic giant branch (AGB) stars (S. Cristallo et al. 2011) at low masses, super-AGB stars (C. L. Doherty et al. 2014) at intermediate masses, and core-collapse supernovae (K. Nomoto et al. 2013) at high masses. Colors indicate initial progenitor heavy element mass fractions (Z) as marked.

Повышенная доля железа(?) в галактиках с малой дисперсией

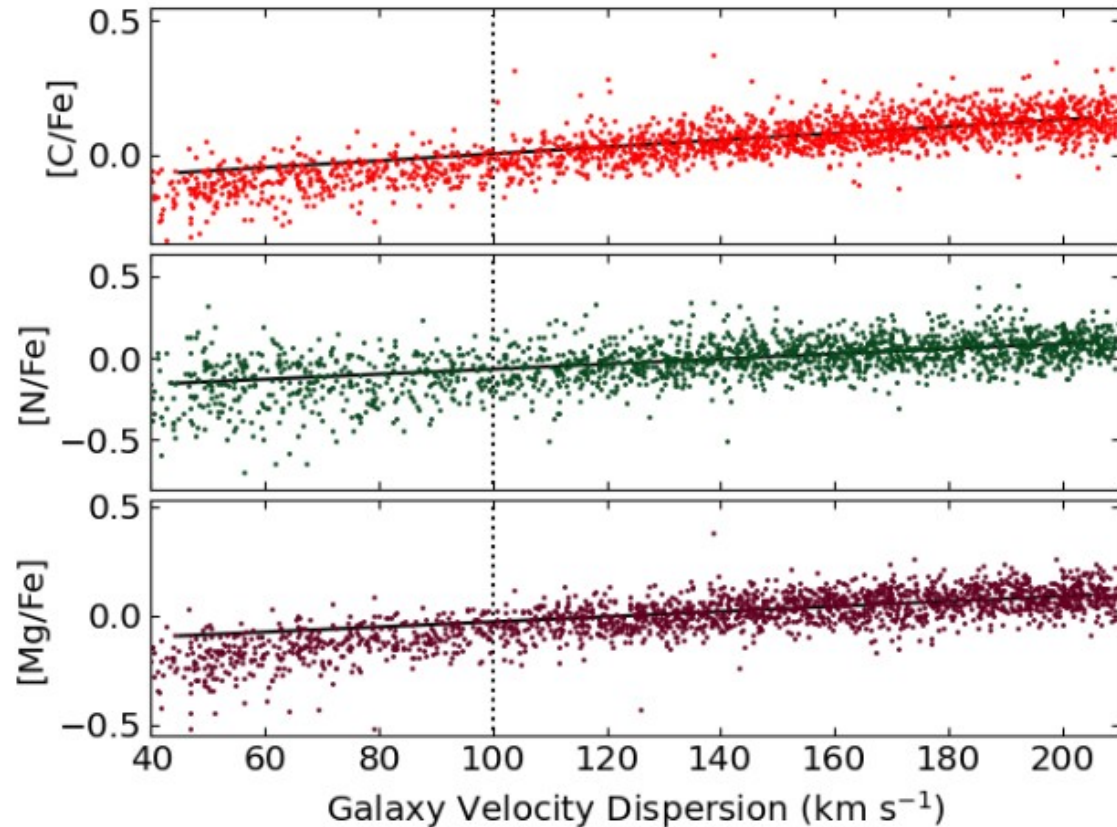


Figure 5. [C/Fe], [N/Fe], and [Mg/Fe] versus velocity dispersion. This version of Figure 1 suppresses error bars and zooms to a narrower velocity dispersion range. A line fit over data in the range $110 < \sigma < 340 \text{ km s}^{-1}$ is superimposed (solid line). Note that for galaxies $< 100 \text{ km s}^{-1}$ (to the left of the dotted line), [C/Fe] and [Mg/Fe] lie low, as if these galaxies were enhanced in Fe, but [N/Fe] follows the trend set by high- σ galaxies.

Связь обилия азота с временной шкалой

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The supernova yield predictions in Figure 4 from K. Nomoto et al. (2013) show a weak dependence on the progenitor mass but a strong dependence on the progenitor metallicity. While noting that supernova yields are notoriously difficult to predict, it seems from the figure that only chemically evolved gas can produce “instant” N-rich ejecta. The AGB stars, on the other hand, eject much N but over timespans of hundreds of millions of years after formation. Therefore, galaxies that quench effectively should not be able to take advantage of the AGB star contributions. Galaxies that have prolonged star formation histories and can retain their gas, however, could be enriched in N, albeit at the whims of gas geometry and the timing of individual bursts of star formation.

Low- σ galaxies are the ones with the youngest mean ages and hence the most evidence for protracted star formation histories. These galaxies are also too dynamically cold to generate coronal, X-ray-emitting gas and therefore lack that mechanism for star formation quenching. Low- σ galaxies are also the ones that exhibit “strong N individualism” or, in other words, [N/Fe] fuzz.

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The nitrogen fuzz therefore gives us indirect support for timescale arguments in chemical enrichment scenarios. While these timescale arguments have long been favorites (D. Thomas et al. 2002; J. Johansson et al. 2012; T. Parikh et al. 2019), it is nice to have a reason to prefer them that is grounded in data.

Future work on the topics addressed in this paper should include attempts to go beyond “mean age” for each galaxy. A more direct connection between N buildup and protracted star formation may then be established. Moreover, measurement of oxygen abundances from the existing MaNGA spectra would inform age via the oxygen–age degeneracy. Inclusion of blue