Multi-Zone Milky Way Models

The Resultant [N/O]-[O/H] Relation

Any viable model for nitrogen production in the Milky Way must accurately reproduce the observed abundances and their correlations with other elements. Here we test a fiducial model for nitrogen yields. The model has $y_{\rm N}^{\rm CC}=4.15\times 10^{-4},\,y_{\rm N}^{\rm Ia}=0,\,{\rm and}\,y_{\rm N}^{\rm AGB}$ described by the Cristallo et al. (2011) yields amplified by a factor of 5. Otherwise, the model is the same as the inside-out SFH model with diffusion migration from Johnson et al. (2021). Its predictions for the present day are shown in comparison to observational samples from a wide variety of astrophysical environments in Fig. 1. As discussed in Vincenzo et al. (2016), the observed [N/O]-[O/H] relation is more or less universal between systems; the comparison to the Dopita et al. (2016) measurements further suggests that this extends to high redshift as well (z ~ 3). It also appears to be relatively independent of the measurement method.

For the fiducial model, each individual annulus at $R_{\rm gal} \geq 2$ kpc is represented by a point on the line. In general, it is more linear than the observed data. This suggests that at high metallicities, the model is under-predicting nitrogen production relative to oxygen, whereas it over-predicts it at low abundances. Since stellar migration only induces variability in $Z_{\rm x}$ for some element x with delayed enrichment and only affects the time-averaged trend at large $R_{\rm gal}$ and early times, the late-time abundances should be reasonably described by the late-time equilibrium abundance of a one-zone model with similar parameters as one of the rings at a given $R_{\rm gal}$. Multiple studies focusing on the yields of AGB stars suggest that the nitrogen yields should depend more or less linearly on the initial mass of the progenitor (Cristallo et al., 2011; Ventura et al., 2013), although the tables published by Karakas (2010) provide circumstantial evidence that they could be much higher for the most massive AGB stars, particularly at low metallicity. Since these studies largely agree on this qualitative result, the simplest way to recalibrate the yields is most likely by adjusting $y_{\rm N}^{\rm CC}$ and its dependence on Z, whose values span a much wider dynamic range between the Limongi & Chieffi (2018), ?, Nomoto, Kobayashi & Tominaga (2013), and Woosley & Weaver (1995) results.

Is the resultant [N/O]-[O/H] relation the result of the metallicity dependence of the yields only, or is the time-delay sufficiently important that it is instead a superposition of endpoints? This question is addressed in Fig. 2, which plots the present-day [N/O]-[O/H] relation in the gas-phase (parameterized by radius) as well as the evolutionary tracks (parameterized by time) for a selction of radii in the model. Since the evolutionary tracks show a noticeable dependence on $R_{\rm gal}$ at all times, it's quite clear from this that the time-dependence of AGB star nucleosynthesis is playing an important role in shaping the relation. The metallicity dependence is important as well, but this suggests that the time-dependence is strong enough that at least in this model, the [N/O]-[O/H] relation is arising out a superposition of endpoints. This further suggests that these gas-phase abundance correlations should not be described by one-zone models reproducing the trend.

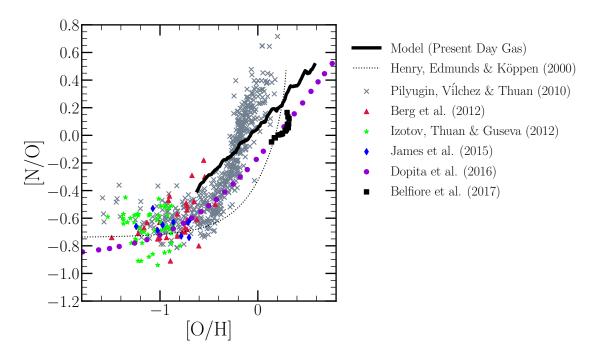


Figure 1: Observational results on the gas-phase [N/O]-[O/H] relation in comparison with a fiducial model at the present day (solid, thick black line). For the fiducial model, each individual ring at a radius of $R_{\rm gal} \geq 2$ kpc is plotted as a point on the line. The fit to an analytic chemical evolution model using data from Galactic HII regions, main sequence and halo stars, and damped lyman alpha systems from Henry et al. (2000) is shown in a dotted black line. Abundances derived from electron temperatures of HII in nearby NGC spiral galaxies at shown in grey X's (Pilyugin, Vílchez & Thuan, 2010). Measurements from blue, star forming diffuse dwarf galaxies probing the low metallicity regime are shown in red triangles (Berg et al., 2012), green stars (Izotov, Thuan & Guseva, 2012), and blue diamonds (James et al., 2015). Emission line measurements from high-redshift HII regions are shown in purple circles (Dopita et al., 2016). A sample of star-forming galaxies from MaNGA are shown in black squares (Belfiore et al., 2017). The Pilyugin, Vílchez & Thuan (2010), Berg et al. (2012), Izotov, Thuan & Guseva (2012), and James et al. (2015) measurements are for individual systems, while the Dopita et al. (2016) and Belfiore et al. (2017) data represent a population-averaged trend. Error bars are omitted for visual clarity.

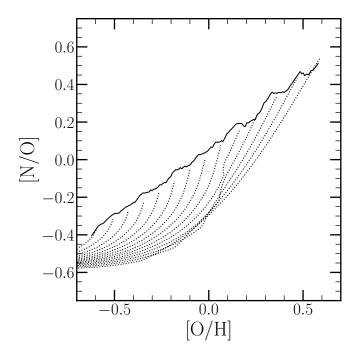


Figure 2: The present-day gas-phase [N/O] relation as a function of [O/H] in the fiducial model for $R_{\rm gal} \geq 2$ kpc (solid), shown alongside the gas-phase evolutionary tracks (i.e. parameterized by time) for $R_{\rm gal} = 2, 3, 4, \ldots, 13, 14$, and 15 kpc rings.

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