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 $y_\text{N}^\text{CC} = 4.15 \times 10^{-4}$, $y_\text{N}^\text{Ia} = 0$, and y_N^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 $\sim$ 3). It also appears to be relatively independent of the measurement method.

For the fiducial model, each individual annulus at $R_\text{gal} \geq 2$ 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 $\dot{Z}_\text{x}$ for some element x with delayed enrichment and only affects the time-averaged trend at large R_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_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_N^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 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 selection of radii in the model. This is shown for the Cristallo et al. (2011) (left), Karakas (2010) (middle), and Ventura et al. (2013) (right) AGB star yields. As in previous versions of this model, the Cristallo et al. (2011) yields have been amplified by a factor of 5 to improve agreement with the observed abundances; although this isn't the case for the Ventura et al. (2013) yields, it's likely they'll need amplified as well. In the Cristallo et al. (2011) and Ventura et al. (2013) models, the relation arises out of a series of end-points, having a slightly shallower slope than the relation predicted by the evolutionary track of a one-zone model. The Karakas (2010) yields disagree with this prediction; in that model, the trend arises out of the metallicity dependence of the yields alone - the evolutionary tracks for individual annuli nearly overlap. However, the Karakas (2010) model fails to reproduce the observed trend. Instead, it predicts a trend which is nearly flat at low [O/H], then decreases monotonically at [O/H] $\gtrsim$ 0. This is in tension with the observed trend, with the [N/O] abundances at low [O/H] in tension with the observations at the $\sim$0.5 dex level.

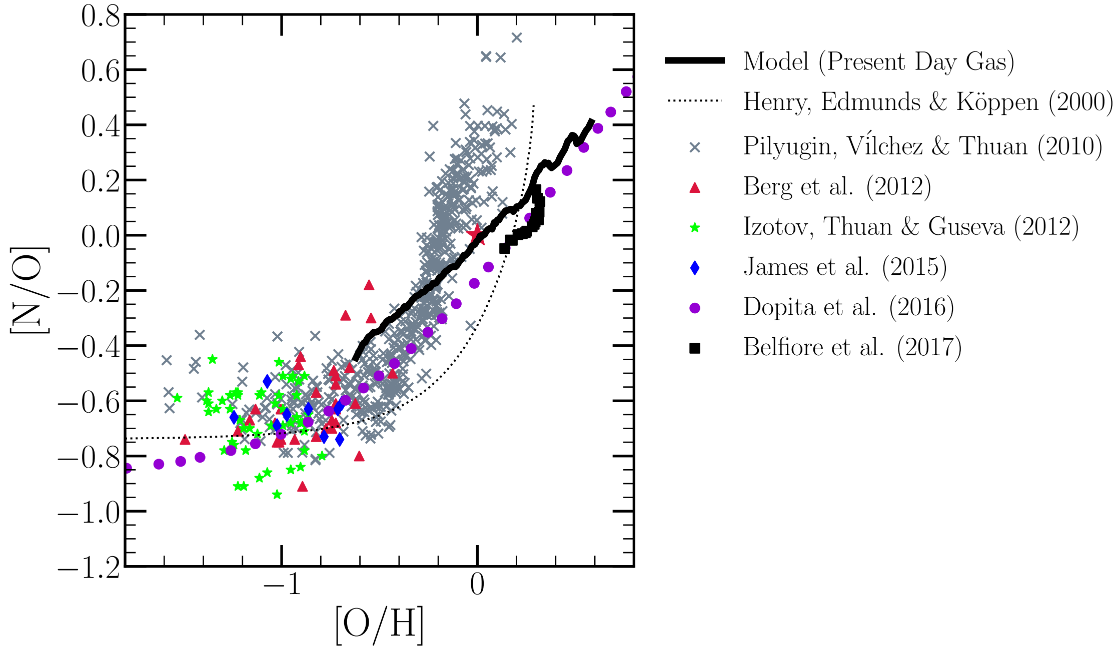

Figure 1: Observational results on the gas-phase [N/O]-[O/H] relation in comparison with a fiducial model at the present day (solid, thick black line). For the fiducial model, each individual ring at a radius of $R_{\text{gal}} \geq 2$ kpc is plotted as a point on the line. The sun (at (0, 0) by definition) is plotted in a large red star. 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). The N/O vs. O/H calibration derived from local stars and HII regions from Dopita et al. (2016) is shown in purple circles. 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.

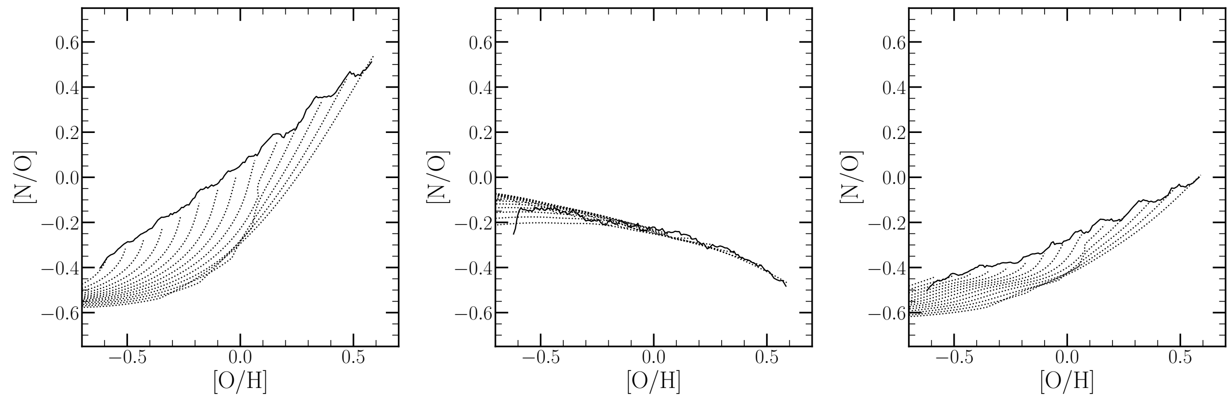

Figure 2: The present-day gas-phase [N/O] relation as a function of [O/H] in the fiducial model for $R_{\rm gal} \geq 2$ kpc (solid), shown alongside the gas-phase evolutionary tracks (i.e. parameterized by time) for $R_{\rm gal} = 2, 3, 4, \ldots, 13, 14$, and 15 kpc rings. Each panel shows a different set of AGB star yields: Cristallo et al. (2011) on the left, Karakas (2010) in the middle, and Ventura et al. (2013) on the right.

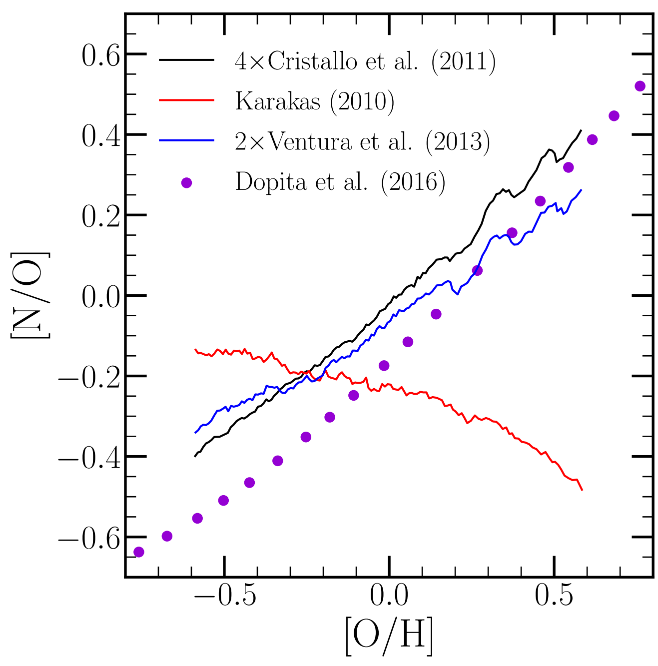

Figure 3: The present-day gas-phase [N/O]-[O/H] relation in the fiducial model for $R_{\rm gal} \geq 2$ kpc assuming three different AGB star yield prescriptions for N: the Cristallo et al. (2011, 2015) sample amplified by a factor of 4 (black), the Karakas (2010) sample (un-amplified, red), and the Ventura et al. (2013) sample amplified by a factor of 2 (blue). For reference, the Dopita et al. (2016) calibration is plotted in purple points.

Can we distinguish between the different AGB star yield sets? In Fig. 3, we compare the predicted present-day gas-phase [N/O]-[O/H] relation in the inside-out SFH model ran with a few different prescriptions for the AGB star yield. Both the Cristallo et al. (2011, 2015) and Ventura et al. (2013) sets can reproduce the observed trend within the scatter to a reasonable accuracy, though a multiplicative prefactor is required to do so, suggesting that these models under-predict nitrogen production. The Karakas (2010) model, however, fails to reproduce the trend, instead predicting an [N/O]-[O/H] relation which is montonically *decreasing*. There is no multiplicative prefactor which can be added to this yield set to reproduce the observed relation.

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