CARBON, OXYGEN, AND THE DESERTIFICATION OF THE GALAXY. E. Gaidos[1], [1]Department of Geology and Geophysics, University of Hawaii at Manoa, Honolulu, HI 96822.

C/O in the Galaxy: Carbon and oxygen are the two most abundant nucleosynthetic elements in the Cosmos and are among the dominant constituents for Earth-size planets and Earth-like life. C and O play crucial roles in determining the chemistry of star-forming molecular clouds and, possibly, the circumstellar disks from which planets emerge [1-3]. Nucleosynthetic yields of C and O vary with stellar mass and metallicity (**Figure 1**) and we expect that the mean C/O ratio of the Galaxy has evolved with mean metallicity, and regions of the Galaxy with different stellar populations will have different average C/O.

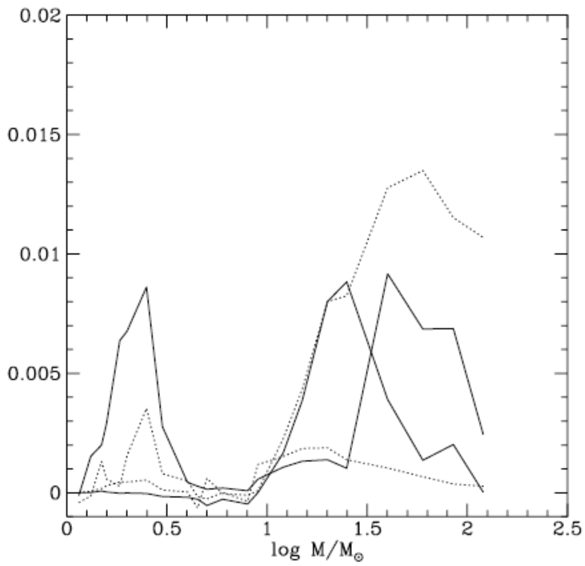

Figure 1. Yields of O (heavy lines) and C (light lines) from stars of solar (dotted) and primordial (solid) metallicity, in units of solar masses, and weighted by a stellar initial mass function $M^{-2.7}$. Increasing metallicity leads to increased carbon and decreased oxygen in the total yields (including winds) form massive stars.

Carbon and oxygen are synthesized in stars more massive than 1.5 solar masses and injected into the interstellar medium through winds and type II supernovae events. (Type I SN contribute less than 0.3% [4]). The yields (net production) from stars with a given initial mass, combined with the initial mass function (IMF) of star formation will determine the relative amounts of C and O. Yield estimates for intermediate-mass (1-5M_{sun}) stars were taken from Marigo et al [5,6] and Renzini & Voli [7]. The supernovae yield calculations of Woosley & Weaver [8] were used for high-mass stars (11-40M_{sun}) and those of Maeder [9] for even more massive (but rare) stars. Maeder has calculated the yields of C and O from the winds of massive stars. The mass loss depends on abundance through its effect on the opacity of outer stellar atmospheres and the impact on their structure. O yields are insensitive to model parameters and are consistent from model to model [8], while the C yield of for intermediate-mass stars depend on the amount of convective ``dredge-up'' [7]. In a metal-poor (0.1Z) stellar population with the IMF of the solar neighborhood, the source of C is evenly divided between ejecta of high-mass (56%) and intermediate-mass stars. The source of C in a solar-metallicity population is radically different; roughly 5% of C is returned to the ISM via the winds of massive stars, 33% is produced in intermediate-mass stars and the remainder in high-mass stars. Oxygen is almost entirely (87%) produced in high-mass stars regardless of metallicity: In a low abundance population the remainder is produced by intermediate-mass stars, in a solar-abundance population the O derives from the winds of massive stars. The increase in C production with initial abundance in intermediate-mass stars, and the ejection of carbon in the winds of high-mass stars produces a trend of increasing C/O production ratio with increasing mean metallicity in a stellar population. For the IMF of the solar neighborhood, the C/O production ratio rises from 0.13 at one-tenth solar abundance to >1 at solar abundance (**Figure 2**). It depends only weakly on the steepness of the IMF power-law index, although the *total* C and O produced depends on this parameter. Maeder [9] and Frayer & Brown [10] have pointed out the implications of the abundance dependence of C/O yields for the chemical evolution of the Galaxy. A universal prediction of chemical evolution models is a low early C/O due to the O-rich composition of ejecta from metal-poor massive stars and a positive correlation between C/O and metal abundance [11-13]. This is driven by the delayed C-rich contribution of intermediate-mass stars (1-10M_{sun}) and the metallicity dependent C/O production ratio described above. Observations of metal-poor galaxies find such a trend [14]. Another expectation is that the C/O of bulge and disk populations diverge due to a combination of differences in the stellar IMF, wind-driven mass loss in the former and the accretion of primordial metal-poor gas in the former. The flatter IMF of bulge stars implies a higher relative production of O from more abundant massive stars. Addition (loss) of mass from a star-forming system will increase (decrease) the amount of star formation required to arrive at a given metal abundance and therefore the C/O at that abundance. There may be local variation in C/O due to selective depletion onto grains [15] or non-steady-state effects [16].

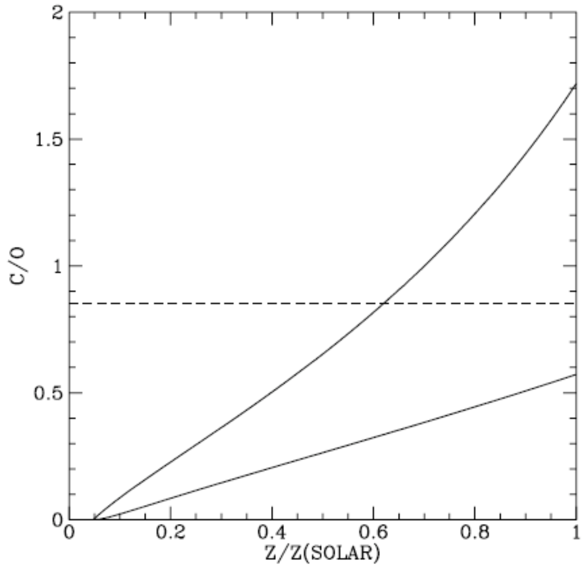

Figure 2. C/O ratio of stellar SN ejecta and winds (top) and the ISM (bottom) as a function of metallicity.

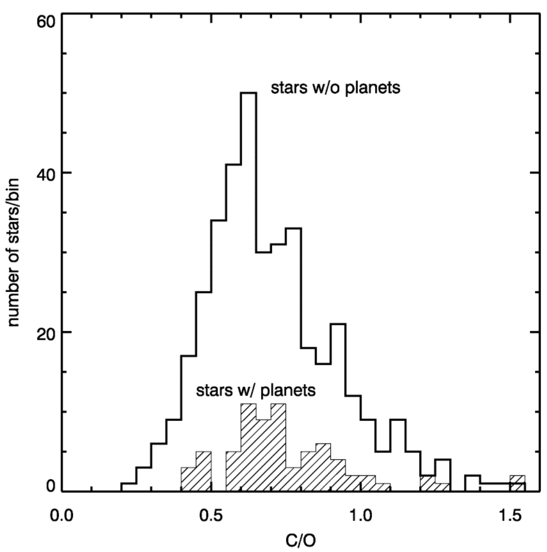

Figure 3. Distribution of C/O for stars with and without planets; data from [17].

C/O and planets. Gaidos [1] proposed that C/O influences the abundance of water in a planetary system because the formation of CO is thermodynamically favored and whether H_2O forms will depend if O is in excess of C. Thus as the galactic disk evolves from an O-rich to a C-rich state its propensity to form water-bearing planets may be evaporating. Furthermore the tendency of systems to include gas giants may depend on C/O if the core-accretion mechanism of giant planet formation is correct and if core formation is accelerated by a concentration of water ice at a "snowline". This prediction is that, for a given metallicity, stars with low C/O (and hence more water) are more like to host giant planets. Several studies have analyzed the spectra of planet-search targets solar-type and derived the abundances of C and O. The most recent included 941 FGK stars [17]. Distributions of C/O for stars with and without known planets are shown in **Figure 3**. The two-sided Kolmogorov-Smirnov and Kuiper probabilities are 0.022 and 0.13, respectively, indicating that the hypothesis that the two distributions are drawn from the same population cannot be ruled out. Median values for stars w/ and w/o planets are 0.7 and 0.66, respectively. Metallicity and C/O may trade against each other but a plot of the data shows no discernable trend. C/O may only weakly influence H_2O abundance; the abundance of H_2O may not control giant planet formation; or the selection for close-in, detectable planets may mask any effect.

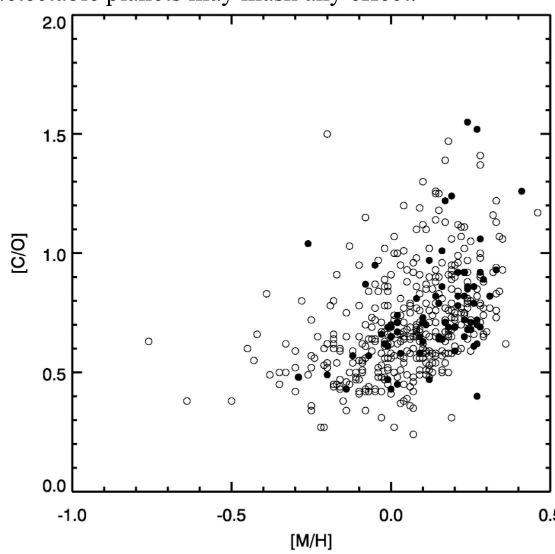

Figure 4. C/O vs. metallicity for stars w/ (filled points) and w/o (open points) planets; data from [17].

References: [1] Gaidos E. J. (2000) Icarus 145, 637. [2] Kuchner M. & Seager S. (2005) arXiv:0504214. [3] Bond J. C. et al. (2010) ApJ 715, 1050. [4] Gehrz R. D. et al. (1998) PASP 110, 3. [5] Marigo P. et al. (1995) A&A 313, 545. [6] Marigo P. et al. (1998) 331, 564. [7] Renzini A. & Voli M. (1981) A&A 94, 175. [8] Woosley S. E. & Weaver T. A. (1995) ApJSS 101, 181. [9] Maeder A. (1992) A&A 264, 105. [10] Frayer D. T. & Brown R. L (1997) ApJ 113, 221. [11] Tinsley B. M. (1980) 5, 287. [12] Timmes et al. (1995) ApJSS 98, 617. [13] Cescutti G. et al. (2009) A&A 505, 605. [14] Garnet D. R. et al. (1995) ApJ 443, 64. [15] Cardelli J. A. et al. (1993) ApJ 402, L17. [16] Xie T. et al. (1995) ApJ 440, 674. [17] Petigura E. A. and Marcy G. W. (2011) ApJ 735, 41.