The Distribution of Young Stars and Metals in Simulated Cosmological Disk Galaxies

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Abstract. We examine the distribution of young stars associated with the spiral arms of a simulated L^{*} cosmological disk galaxy. We find age patterns orthogonal to the arms which are not inconsistent with the predictions of classical density wave theory, a view further supported by recent observations of face-on Grand Design spirals such as M51. The distribution of metals within a simulated ~0.1 L^{*} disk is presented, reinforcing the link between star formation, the age-metallicity relation, and the metallicity distribution function.

1. Star Formation

We make use of fiducial L* simulated disk galaxy (g15784) from the McMaster Unbiased Galaxy Survey (MUGS) (Stinson et al. 2010). Our earlier work with this simulation has focused on the temporal evolution of its metallicity gradient (Pilkington et al. 2012a) and metallicity distribution function (Calura et al. 2012). Here, we examine briefly the distribution of recent star formation within the simulation, with an emphasis on the location of the young stars with respect to the simulation's most prominent spiral arm.

A detailed description of the g15784 can be found in Stinson et al. (2010) and Pilkington et al. (2012a); here, we simply provide a brief overview of the star formation prescription. The MUGS simulations were run with the gravitational N-Body + SPH code GASOLINE (Wadsley et al. 2004). Stars particles are formed with a user-specificed efficiency from gas particles when the latter are sufficiently cool (<15000 K), dense (>1 cm⁻³), and taking part in a convergent flow ($\nabla \cdot v_i < 0$). Energy feedback from supernovae adheres to the Stinson et al. (2006) blastwave formalism.

Figure 1 (left panel) shows the young stellar population (in this case, stars born in the last 300 Myr, at redshift z=0) of the g15784 simulation. The prominence of the centrally-concentrated star formation has been commented upon already by Stinson et al. (2010), Pilkington et al. (2012a), and Calura et al. (2012). Three 100 Myr age bins are denoted, with the youngest in blue, the intermediate in green, and the oldest in red. The right panel of Figure 1 isolates the most prominent spiral feature within the simulation (noted by the box inset to the left panel of Figure 1). We find that the younger (older) stars tend to lie on the inside/trailing (outside/leading) parts of the arm. This age 'gradient' in the young stellar populations orthogonal to the arm is consistent with the basic predictions of classical density wave theory, where star formation has been triggered by gas shocked by the passage of a spiral density wave, ¹ see Dobbs & Pringle (2010). A more thorough examination of the issues pertaining to spiral arm age gradient/offsets can be found in Grand et al. (2012).

The offsets we see in the stellar populations associated with the spiral arm are most prominent in the 'upper' part of the figure, before the arm opens up to its full extent. To achieve a fairer comparison with both the high-resolution models of Dobbs & Pringle (2010) and the observations which show very similar trends (e.g. for M51, as in Sánchez-Gil et al. 2011), we would need much finer temporal resolution (where the age ranges probed are 0-10 Myrs, rather than 0-300 Myrs); having said that, the gross trends in orthogonal age gradients/offets do appear to extend to ~100 Myr old stellar populations (e.g. Calzetti et al. 2005) and so perhaps the result highlight here is not obviated by the larger age bins.

2. Chemical Properties

Finally, we wish to show our most recent work on the distribution of metals in a suite of $\sim 0.1 \text{ L}^*$ disk simulations undertaken with a wide range of feedback prescriptions (including supernovae and thermal energy from OB-stars during their pre-supernovae phase), initial mass functions, and metal diffusion efficiencies. We focus here on our fiducial simulation, 11mKroupa, which was first introduced in a different context by Brook et al. (2012). This simulation, like g15784, was realized with the GASOLINE code, but with an upgraded version to take into account the chemical enrichment histories of broader spectrum of elements beyond just oxygen and iron.

The left-most panel of Figure 2 shows the age-metallicity relation of the 'solar neighborhood' (an annulus ~ 3 disk scalelengths from the center, lying within a kpc of the mid-plane) associated with 11mKroupa. The middle panel shows the the corresponding relationship in the solar neighborhood of the Milky Way, as derived from the Geneva-Copenhagne Survey (GCS) by Holmberg et al. (2009). The right-most panel shows the associated metallicity distribution functions (MDFs) for these respective 'solar neighborhoods'; the (indistiguishable) overlaid curves on the right-most MDF within the panel correspond to two 'cuts' of the GCS (effectively, 'volume-limited' and 'open', in some sense - details provided in Pilkington et al. 2012b), while the left-most MDF is that constructed from 11mKroupa.

What should be readily apparent from Figure 2 is that the age-metallicity relation for the solar neighborhood of 11mKroupais significantly more correlated than that of the Milky Way's solar neighborhood and that it is very tight at a given age. The former should not be surprising, in that the star formation and infall histories of the two are not the same. Regardless, this tight correlation has an inexorable effect on the resulting MDF, in the sense that it is more negatively skewed, possesses greater kurtosis, while the MDF's 'peak' component is quite narrow (due to the minimal dispersion in [Fe/H] at a given age convolved with the

 $^{^{1}}$ At least within co-rotation. We emphasise that we are *not* claiming that this is necessarily what we are witnessing within the simulation simply that it is consistent with the predictions of the basic theory.



Figure 1. The star particles born in the last 300 Myr (at z=0) of the g15784 simulation. The particles are separated into three age bins: 'young' (with ages 0–100 Myr, shown in blue), 'intermediate' (100–200 Myr, shown in green), and 'old' (200–300 Myr, shown in red). The black box in the left panel identifies the most prominent spiral feature, for which an expanded view is provided in the right panel. The black points in the latter represent the stars born in the last 300 Myr that are not part the spiral arm.



Figure 2. The left-most panel shows the age-metallicity relation for the stars situated in the 'solar neighborhood' of the 11mKroupa simulation. The stars are colored by age where red is the youngest and purple is the oldest. The middle panel, for comparison, shows the observed age-metallicity relation for the solar neighborhood of the Milky Way (Holmberg et al. 2009). The right-most panel shows the resulting metallicity distribution functions for these age-metallicity relations, along with simple single Gaussian fits to their respective 'peak' regions (with the FWHM noted in the inset).

simulation's star formation history). A deeper analysis is provided by Pilkington et al. (2012b).

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