Recovering Abundance Ratios and Supernovae Rates with Numerical Chemodynamics

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Abstract

Using numerical hydrodynamics and N-body techniques to simulate cosmological galaxy formation we consider the effect of sub-grid chemical evolution models on the abundance ratios and global supernovae rates of a Milky Way analogue. We show that the abundance of elements in the low metallicity interstellar medium provides a key constraint to the sub-grid chemical evolution models particularly regarding the upper mass limit of type-II supernovae progenitors. Definition of this limit has a knock-on effect upon the constraints that these simulations may place on type-Ia supernovae progenitor models and the slope of the stellar initial mass function.

Introduction

There are numerous cosmological codes on the market but studies of chemical evolution are limited to smoothed particle hydrodynamics with a dearth of Eulerian implementations that include a detailed chemical evolution model. Smoothed particle hydrodynamics codes require additional sub-grid physics to correct for the absence of diffusion between neighbouring gas particles. With the aim of providing a complementary approach to existing chemical evolution codes we present a fully cosmological, chemical evolution code with an adaptive mesh refinement hydrodynamics scheme that traces the formation and subsequent evolution of H, He, C, N, O, Ne, Mg, Si and Fe - RAMSES-CH, [FCG+12]. The results of the initial simulations illustrate how the elemental abundances of the low metallicity ISM provide constraints on star formation treatments in a numerical context.

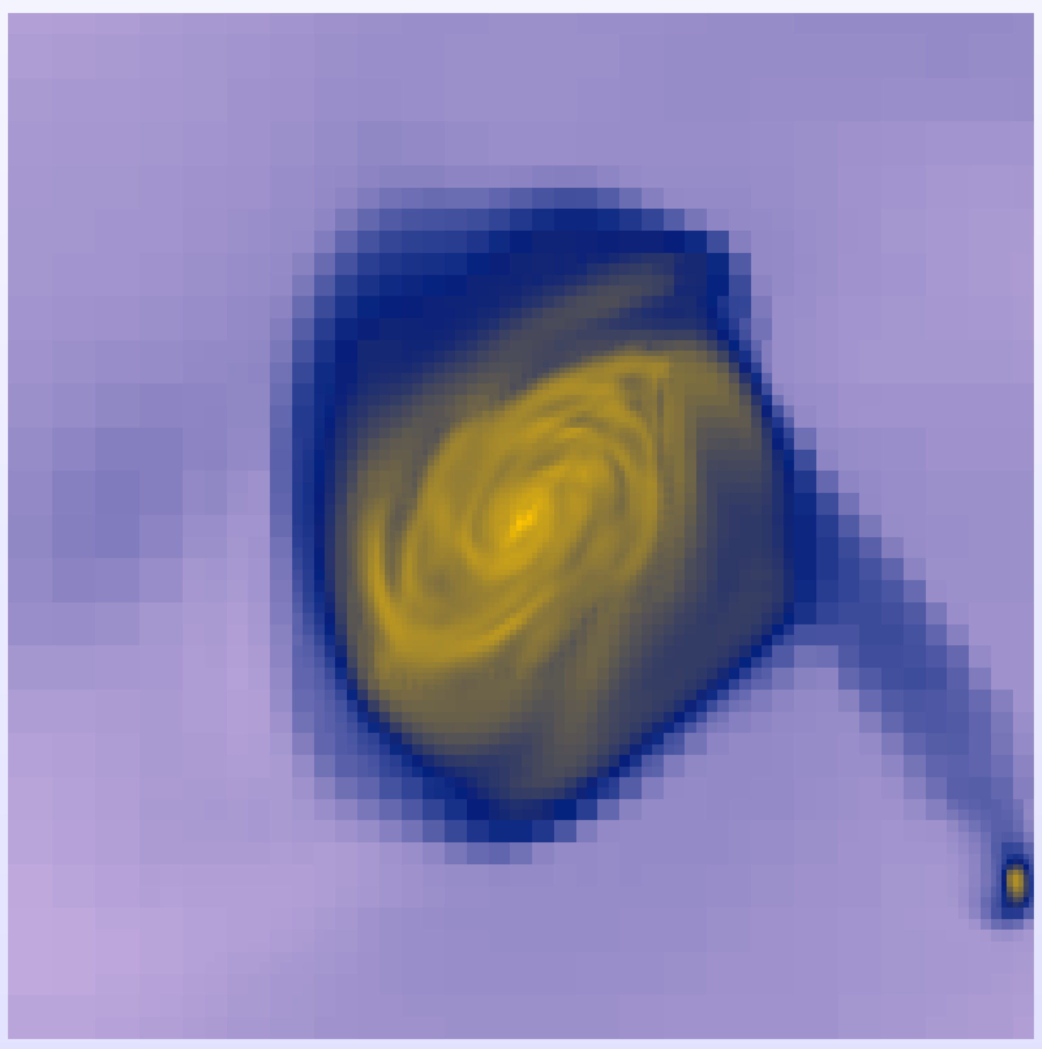

Figure 1: Our code (RAMSES-CH) is applied to cosmological simulations ($20h^{-1}$Mpc cube) of disk galaxies achieving a resolution of 436 pc. The galaxy presented (*109-CH*) is a field spiral galaxy of total mass 6.8×10^{11} $M_\odot$ and a stellar disk mass of 5.3×10^{10} $M_\odot$. Fig. 1 shows the gas column density of a region 40 kpc on a side: the densest regions are shown in yellow with the background in purple. A small satellite can also be seen to the lower right, attesting to the cosmological environment of this galaxy. This galaxy has be used as a fiducial model for a series of test runs that use different initial mass functions (IMFs), upper stellar mass limits and supernovae type-Ia models to ascertain the influence that each of these ingredients has on the abundance ratios of stars, tracing the evolution of the ISM abundances.

Application

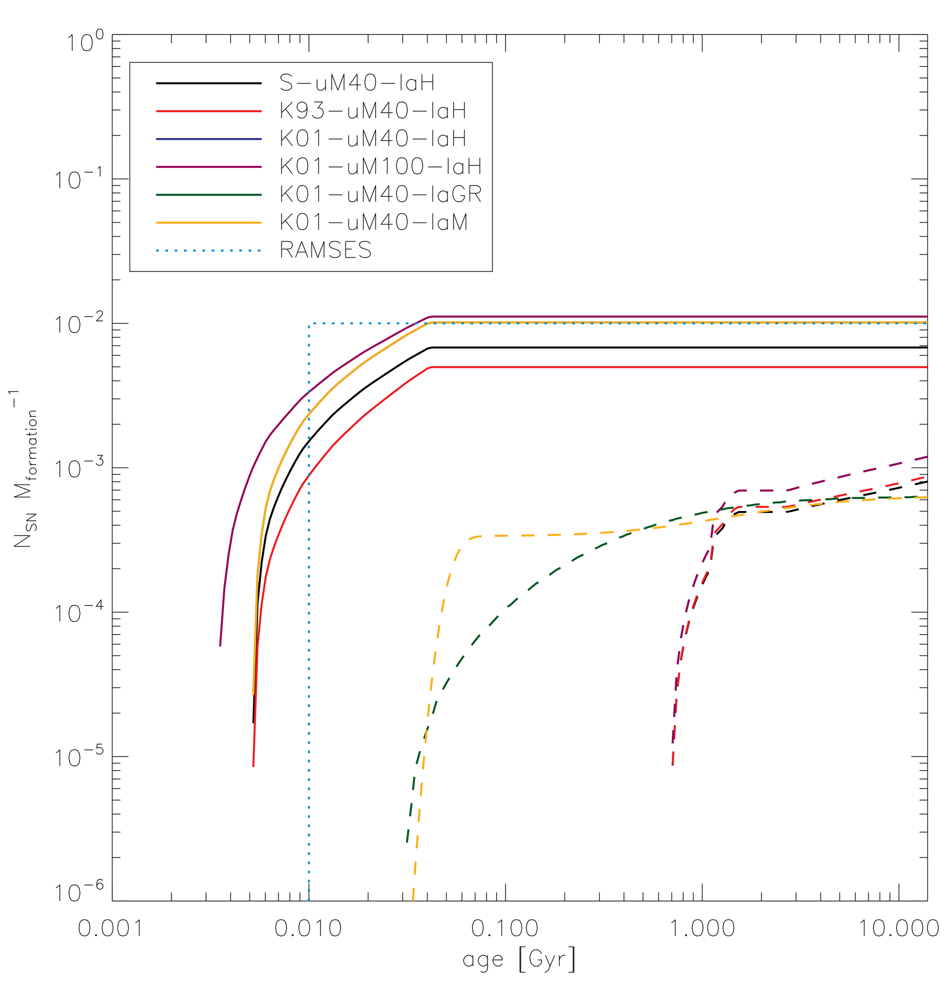

Figure 2: Six different models are presented here with different SNIa progenitor models and IMFs. Fig. 2 illustrates the cumulative SN rates for the different models. The first part of each model name seen in Fig. 2 refers to the IMF of the model (*S* is [Sal55], *K93* is [KTG93] and *K01* is from [Kro01]). The second part of the name (prefixed with *uM*) refers to the upper mass limit of the IMF at either 40 or 100 $M_\odot$ and the last denotes the SNIa progenitor model employed (IaH is based on [HKN99], IaGR is [GR83] and IaM is [MDP06]). All models take nucleosynthetic yields from [IBN+99] (SNIa), [WW95] (SNII) and [vG97] (AGB winds) and stellar lifetimes from [KA97]. A dotted line demonstrates the effective SN rate for a standard RAMSES run.

Results

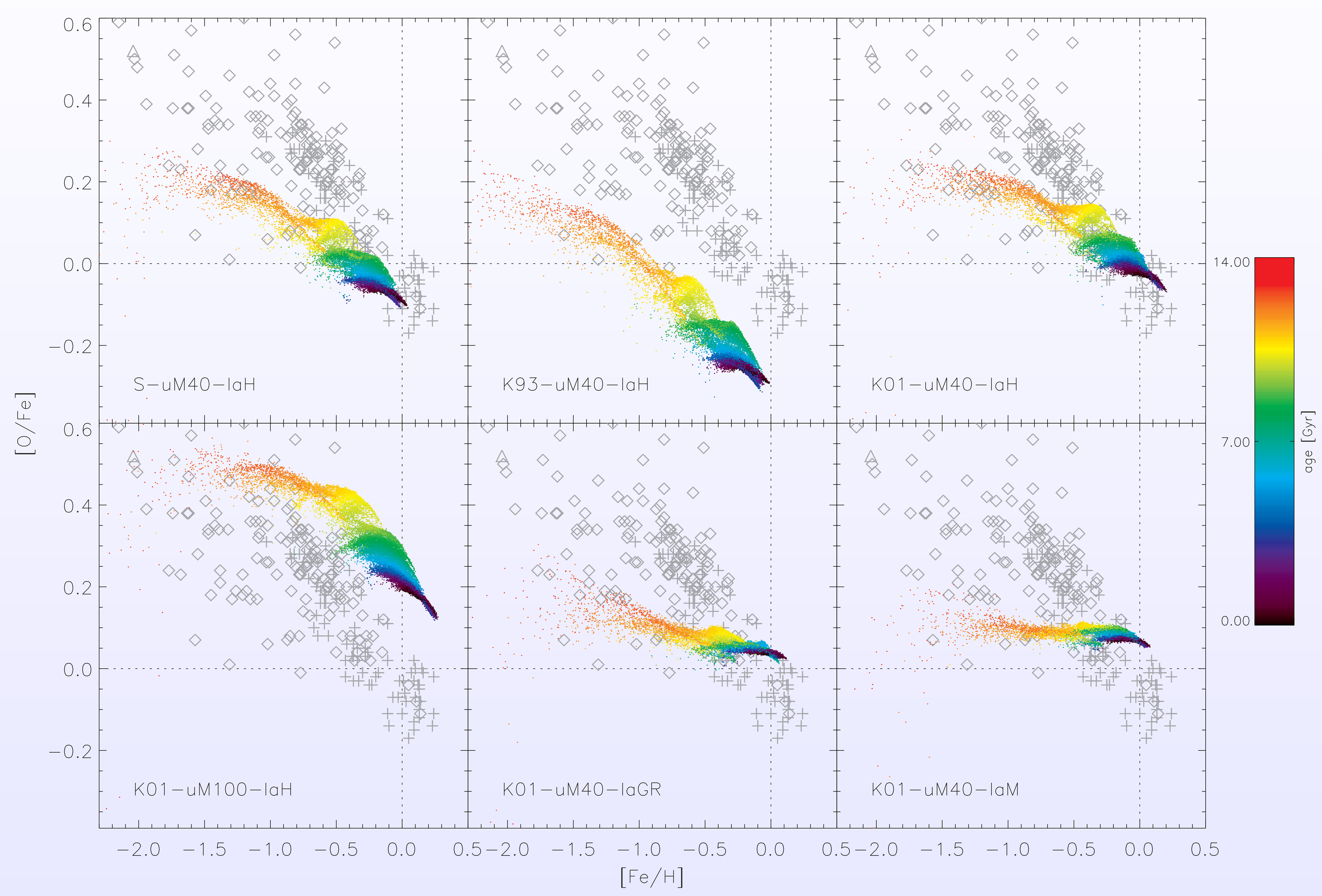

Figure 3: [O/Fe] is plotted against [Fe/H] for disk stars. The age of the stars is denoted by colour and dotted lines indicate solar abundances. Observational data is plotted in grey, triangles are very metal-poor stars from [CDS+04], diamonds are thick disc and halo stars from [GCC+03], plusses are disc dwarf stars from [EAG+93].

Fig. 3 shows the abundance ratios of stars that trace the evolution of the ISM. The model that best reproduces the metallicity of the solar neighbourhood is *K01-uM40-IaH* however this model underestimates [O/Fe] at low metallicities. The models with steeper IMFs (*S-uM40-IaH* and *K93-uM40-IaH*) or a lower mass limit (*K01-uM40-IaH*) produce fewer SNII and thus have a lower [O/Fe]. Models using SNIa models IaM and IaGR produce SNIa on shorter timescales than those using IaH models, leading to the relatively constant [O/Fe]. Only one model successfully reproduces the low metallicity [O/Fe], *K01-uM100-IaH*, which has the most top-heavy IMF and the greatest upper mass limit. This suggests that either the simulations mix gas too efficiently or that a variable IMF (one that is more top heavy at low metallicities) should be invoked.

Summary

- We present a small suite of chemical evolution models applied to a Eulerian cosmological disk galaxy framework and test how the abundance ratios of the tracer stars vary depending upon the intial mass function and SNIa model.
- A great deal of variation in abundance ratios is seen under changes in IMF slope, upper mass limit and supernovae type-Ia delayed time distribution.
- Reasonable SN rates are recovered, however this conflicts with the excessive stellar mass fraction of the galaxies which should be carefully considered.
- Only models that give the highest SNII rates are capable of reproducing the quantity of [O] required to match low metallicity observations while other models produce excessive quantities of [Fe] which nevertheless lead to recovery of the solar abundance ratio. There is also an underprediction in the spread of abundance ratios, both these results suggest that a variable IMF should be considered or that metal diffusion throughout the galaxy is too efficient in the simulations.
- Future work will explore a full range in parameter space to constrain the chemical evolution of disk galaxies and determine the key degeneracies. High resolution simulations will be undertaken employing large-scale magnetic fields to study the role that turbulence plays in metal diffusion within the ISM.

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