CRIMSONS TOOL

CRIMSONS (Chemical evolution with the random sampling of the Initial Mass function: Studying the Origin of Nucleosynthesis Stellar products) is a tool to study the chemical enrichment evolution from a single burst of star formation accounting the random sampling of the Initial Mass Function (IMF).

Please cite the following paper if you think that the CRIMSONS TOOL is helpful in writing your paper :) : *"CRIMSONS:Chemical evolution with the random sampling of the Initial Mass function: Studying the Origin of Nucleosynthesis Stellar products" Rossi M. in prep 2024c*

How to run your simulation

First you need to specify our input parameters. In the following the description of parameters

- **N_runs:** is the number of runs you want to perform. After entering the stellar mass of the burst you want to simulate, the code generates a random sampling of the selected Initial Mass Function (IMF). If $N_{runs} > 1$, each run will have a different sampling of the IMF

- $M_\star$: is the total stellar mass of the burst in solar masses. If you are simulating a burst of Population II stars (Pop II), i.e., with stars with metallicity $Z_\star > Z_{crit} = 10^{-4.5} Z_\odot$, the minimum burst mass to enter is $M_\star = 100\ M_\odot$. Otherwise, if the burst consists of Population III stars (Pop III with $Z \leq Z_{crit} = 10^{-4.5} Z_\odot$), the minimum mass to enter is $M_\star = 1000\ M_\odot$. The maximum value that can be entered is $M_\star = 10^9\ M_\odot$

- $Z_\star$: is the metallicity of the stellar burst. Enter the value in the form of $Z_\star = \log(Z/Z_\odot)$. The range of metallicity values varies $Z_\star = [-15, 1]$. If you enter $Z_\star \leq -4.5$ you simulate a burst of Pop III stars; if you enter $Z_\star > -4.5$ you simulate a burst of Pop II stars.

- $\Delta t_{SN\ Ia}$: in the SN Ia time delay express in Myr. $\Delta t_{SN\ Ia}$ represent the time at which you want that SN Ia start to contribuite to the chemical enrichment. Enter a value in the range $\Delta t_{SN\ Ia} = [0,10000]$ Myr

- $f_{SN\ Ia}$: is the fraction of stars with mass $m_\star \leq 8\ M_\odot$ that are in binary system. This fraction varies from 0 (enter 0 if you don't want to account for SN Ia contribution) up to 1 (all the stars with $m_\star \leq 8\ M_\odot$ are in binary systems and evolve as SN Ia)

- **Seed:** The seed allows for generating the sequence of random numbers to sample the assumed IMF. If it is set to 1, the code generates a different sequence of random numbers for each run (recommended if N_runs > 1). If it is set to 0, you can manually enter the seed (the seed can be any number of your choice). It is recommended to choose seed = 0 if, for example, you want to compare the chemical enrichment using different sets of stellar yields or different input parameters, with the same IMF population.

Pop III Selection

If you enter $Z_\star \leq -4.5$ you will access to **Pop III Selection**. In this section, you need to specify your choices for the Initial Mass Function (IMF) and select the stellar yield models available. The mass range of Pop III star is fixed $m_{\star,\mathrm{Pop\ III}} = [0.8,1000]\ \mathrm{M}_\odot$ according to results of Rossi et al 2021

IMF type

For Pop III stars you can choose the shape of the IMF:

1. **Larson type IMF** (Larson 1998): $\phi(m_\star) \propto m_\star^{-2.35} e^{-m_{ch}/m_\star}$, where $m_\star$ is the stellar mass and m_{ch} is the characteristic mass. You can choose the m_{ch} value, for Pop III is recommended $m_{ch} \geq 10\ \mathrm{M}_\odot$ (see Rossi et al 2021, Pagnini et al 2023, Koutsouridou et al 2023)

2. **Exponential IMF** : $\phi(m_\star) \propto m_\star^{-\alpha}$ and you can enter the α value

3. **Flat IMF**: IMF with constant value in the mass range

Yields selection

1. **AGB yields** $m_\star = [2-8]\ \mathrm{M}_\odot$- Selection between three different set of stellar yields:

   - **Van den Hoerk+97**
   - **Nomoto+13**
   - **Meynet&Maeder 02**

2. **SNe yields** $m_\star = [10-100]\ \mathrm{M}_\odot$ - Selection between different stellar yields:

   - **Heger&Woosley+10:**
     By selecting this set of yields, you can make an additional choice: you can choose 'all SNe energies (faint, cc, high, hyper)'. In this case, each time the IMF is populated in SNe mass range, at each SNe is assigned a random energy among faint ($\mathrm{E_{SN}} = [0.3-0.6]\times 10^{51}$erg) , core-collapse (cc, $\mathrm{E_{SN}} = [1.2-1.5]\times 10^{51}$erg), high-energy ($\mathrm{E_{SN}} = [1.8-3]\times 10^{51}$erg), and hypernovae ($\mathrm{E_{SN}} = [5-10]\times 10^{51}$erg). Otherwise, you can select only one type of SNe (only faint/cc/high/hyper). In this case, all SNe in the mass range $m_\star = [10-100]\ \mathrm{M}_\odot$ explode with a fixed energy

   - **Iwamoto+05**: only faint SNe

   - **Nomoto+13/09**: Pop III SNe with explosion energy $\mathrm{E_{SN}} = 1\times 10^{51}$erg

   - **Nomoto+13/09 (HN)** Hypernove models: Pop III SNe with explosion energy of hypernovae $\mathrm{E_{SN}} = [10-60]\times 10^{51}$erg

3. **PISN** (Pair Instability SNe) **yields** - Selection between different stellar yields:

    - **Heger&Woosley+02** in mass range $m_\star = [140 - 260]\ \mathrm{M}_\odot$
    - **Nomoto+13/09** in mass range $m_\star = [140 - 300]\ \mathrm{M}_\odot$

4. **SN Ia yields** - Selection between different models in **Iwamoto+99**: (Model recommended for Pop III is Model W70)

    - Model W7
    - Model W70
    - Model WDD1
    - Model WDD2
    - Model WDD3
    - Model CDD1
    - Model CDD2

Pop II Selection

If you enter $Z_\star > -4.5$ you will access to **Pop II Selection**. In this section, you need to specify your choices for the Initial Mass Function (IMF) and select from the various stellar yield models available. The mass range of Pop II star is fixed $m_{\star,\mathrm{Pop\ II}} = [0.1,100]\ \mathrm{M}_\odot$

IMF type

For Pop II stars you can choose the shape of the IMF:

1. **Larson type IMF** (Larson 1998): $\phi(m_\star) \propto m_\star^{-2.35} e^{-m_{ch}/m_\star}$, where $m_\star$ is the stellar mass and m_{ch} is the characteristic mass. The m_{ch} value is fixed $m_{ch} = 0.35\ \mathrm{M}_\odot$
2. **Exponential IMF** : $\phi(m_\star) \propto m_\star^{-\alpha}$ with $\alpha = 2.35$
3. **Kroupa IMF** (Kroupa 01)

Yields selection

1. **AGB yields** $m_\star = [2 - 8]\ \mathrm{M}_\odot$- Selection between three different set of stellar yields: Van den Hoerk+97, Nomoto+13, F.R.U.I.T.Y (work in progress)
2. **SNe yields** $m_\star = [10 - 40]\ \mathrm{M}_\odot$ - Selection between different stellar yields:

    - **Limongi&Chieffi+18**: Pop II SNe with different rotation velocities v= [0, 150, 300] km/s

- **Nomoto+13/09**: Pop II SNe with explosion energy $E_{SN} = 1 \times 10^{51}$erg
- **Nomoto+13/09 (HN)** Hypernove models: Pop II SNe with explosion energy of hypernovae $E_{SN} = [10 - 60] \times 10^{51}$erg

3. **SN Ia yields** - Selection between different models in **Iwamoto+99**:

- Model W7
- Model W70
- Model WDD1
- Model WDD2
- Model WDD3
- Model CDD1
- Model CDD2

Simulation outputs:

After launching the tool, you can download the simulation outputs in .zip format. Inside the folder, you will find four types of files named (X represents the run number and Y indicates whether it is Pop III or Pop II):

- **SAMPLING_PopY_X.dat**: the first column contains the stellar mass range, the second column contains the number of stars in the resulting mass bin from the sampling, and in the third column there are the theoretical IMF value;
- **SAMPLING_PopY_PLOT_X.dat**: This file contains the data rebinned logarithmically to visualize the sampling of the IMF. The first column is the mass vector, the second one the rebinned IMF counts. To plot the data, use the log-log scale, and the step function in python.
- **Mx_evolution_X.dat**: This file contains columns for time (expressed in Myr) and the masses of elements, Mx, from X=1 (H) to X=30 (Zn) in the ISM in $M_{\odot}$
- **[X_Fe]_evolution_X.dat**: This file contains columns for time (expressed in Myr) and the abundances expressed in [X/Fe] of elements from X=1 (H) to X=30 (Zn). The adopted solar values are those of Asplund+09.
- **stars_evolving_X.dat:** This file lists the stars evolving at a given time step (first column). For each evolving star, it provides the mass (second column), the number of stars (third column), and the energy of the SNe (fourth column) if the mass is within the specified range.