Diffmetal: self-consistent galaxy metallicity and abundance ratio evolution

Kaustav Mitra (*postdoc, Argonne National Lab, email: k.mitra.kaustav@gmail.com*), with Andrew P. Hearin, et al.

WHAT IS DIFFSKY & WHY WE NEED DIFFMETAL

Diffsky is a new differentiable empirical forward-modelling approach to constrain galaxy formation physics from joint multi-wavelength multi-survey data. It parametrically models halo mass assembly and star formation histories of galaxies, correctly capturing the diversity in their assemblies. Based on the star-formation histories it performs stellar population synthesis to generate galaxy SEDs for any mock galaxy lightcone, which can then be compared to observed data to optimize the parameters in the model.

Diffsky has a simplistic empirical prescription to model metallicities: there are a few parameters to set the low metallicity and high metallicity ends of old stars and young stars respectively. For the accuracy requirements of modern surveys we need Diffmetal, a physics-based model for metallicity evolution, that is tied to halo assembly and galaxy star formation history.

DIFFMETAL: HOW IT CURRENTLY WORKS

Similar to a semi-analytic models we track the mass flow rates:

$$\dot{M}_{\rm ISM} = \dot{M}_{\rm cool} - \dot{M}_{\rm reheat} - \dot{M}_{*}$$

$$\dot{M}_{\rm CGM} = f_{\rm b}\dot{M}_{\rm halo} - \dot{M}_{\rm cool} + \dot{M}_{\rm reheat}$$

$$\dot{M}_{\rm reheat} = M_{\rm halo}^{-2/3}\left[\mathscr{F}_{\rm II} + \mathscr{F}_{\rm Ia}\frac{\int_o^t \dot{M}_*(t-\Delta t)\psi(\Delta t){\rm d}\Delta t}{\int_0^t \psi(\Delta t){\rm d}\Delta t}\right]$$

And the metal flow rates between stars, ISM, CGM, tracking different metal species separately, split by type-Ia or type-II SNe contributions (subscripts):

$$\dot{M}_*^{\rm Z,Ia} = Z_{\rm ISM}^{\rm Ia}\dot{M}_* \quad \text{and} \quad \dot{M}_*^{\rm Z,II} = Z_{\rm ISM}^{\rm II}\dot{M}_*$$

$$\dot{M}_{\rm ISM}^{\rm Z,Ia} = Z_{\rm CGM}^{\rm Ia}\dot{M}_{\rm cool} - Z_{\rm ISM}^{\rm Ia}\dot{M}_{\rm reheat} - Z_{\rm ISM}^{\rm Ia}\dot{M}_* + Y_{\rm Ia}\frac{\int_0^t \dot{M}_*(t-\Delta t)\psi(\Delta t){\rm d}\Delta t}{\int_0^t \psi(\Delta t){\rm d}\Delta t}$$

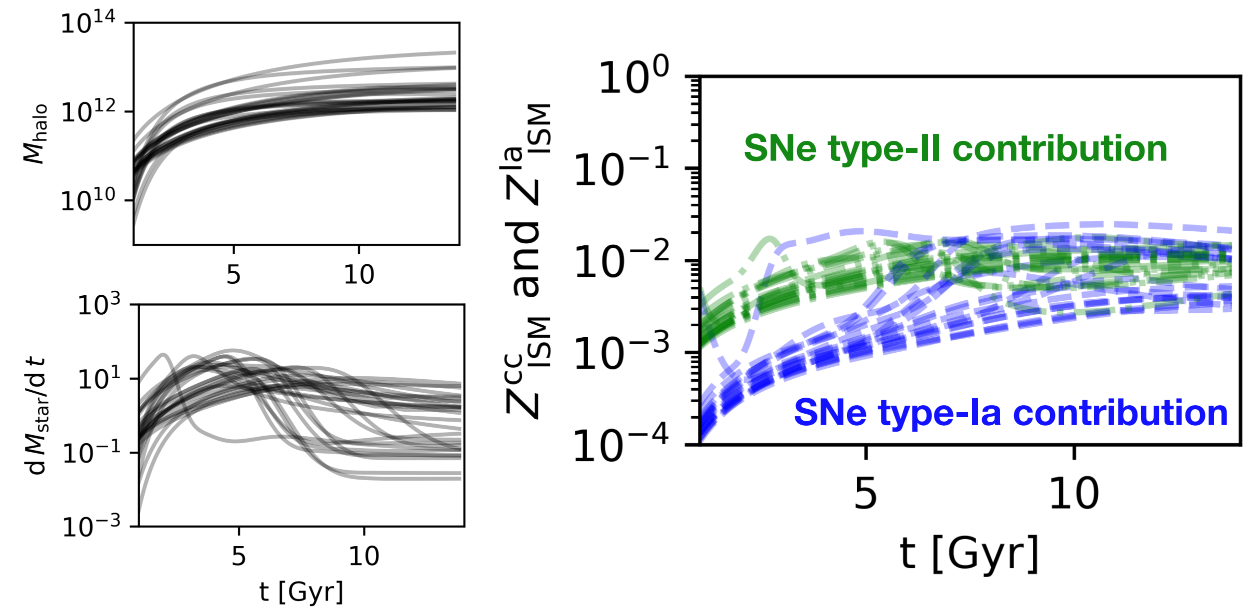
$$\dot{M}_{\rm ISM}^{\rm Z,II} = Z_{\rm CGM}^{\rm II}\dot{M}_{\rm cool} - Z_{\rm ISM}^{\rm II}\dot{M}_{\rm reheat} - Z_{\rm ISM}^{\rm II}\dot{M}_* + Y_{\rm II}\dot{M}_*$$

$$\dot{M}_{\rm CGM}^{\rm Z,Ia} = Z_{\rm ISM}^{\rm Ia}\dot{M}_{\rm reheat} - Z_{\rm CGM}^{\rm Ia}\dot{M}_{\rm cool} \quad \text{and}$$

$$\dot{M}_{\rm CGM}^{\rm Z,II} = Z_{\rm ISM}^{\rm II}\dot{M}_{\rm reheat} - Z_{\rm CGM}^{\rm II}\dot{M}_{\rm cool}$$

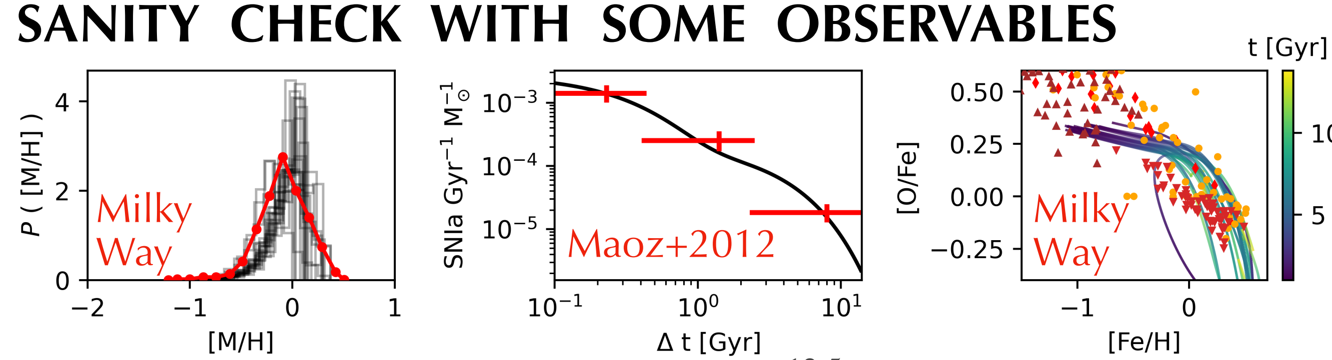
ψ is SNIa delay time distribution, Ys are metal yields, $\mathscr{F}$s are mass loading efficiencies for supernova feedback, and $f_{\rm b}$ is the cosmic baryon fraction.

DIFFMETAL: WHAT IT DOES



Based on the halo mass assembly (from Diffmah) and star formation history (from Diffstar), Diffmetal models the type-Ia and type-II SNe rates over cosmic history for those halos and galaxies, models the ISM mass, CGM mass, heating and cooling rates between ISM and CGM, and finally predicts the metal evolution in CGM, ISM and stars. **Diffmetal is a tool to self-consistently paint galaxy metallicity and abundance ratio evolution over cosmic time, physically informed by the star formation history and halo assembly history.** It is flexible and general, and can be applied to extended press-schechter merger trees, or to dark matter only simulations.

SANITY CHECK WITH SOME OBSERVABLES



Simulating halos of mass roughly around $10^{12.5}\,{\rm M}_\odot$, so that it is somewhat reasonable to compare with Milky Way observations, but the model is in no way tuned for Milky Way. Left: metallicity PDF at $z = 0$. Middle: SN-Ia delay time distributions. Right: abundance ratio [O/Fe] versus metallicity. Although the comparisons are for Milky Way, **Diffmetal is primarily for large extragalactic survey science. It is important for accurate SED predictions in Diffsky framework, required by the next-generation science goals, and especially for cross-survey analyses of DESI, Rubin, Roman, etc.**