Introduction to Simba-C: an updated chemical enrichment model

Renier Hough, Douglas Rennehan, Ilani Loubser, Romeel Davé, Arif Babul, Weiguang Cui, Chiaki Kobayashi

North-West University: Potchefstroom Campus

renierht@gmail.com

May 3, 2023

Overview

- Cosmological simulations - The SIMBA simulation
- New chemical enrichment model
- The SIMBA-C simulation
- Global properties
- Metallicity and abundance ratios
- Future science and conclusions

Cosmological simulations and galaxy formation

In modern large-scale structure cosmology, there is a drive to understand the formation and evolution of galaxies and stars, based on their environments.

- Statistical observations.
- Cosmological computer simulations.
  - `SIMBA`
  - `Eagle`
  - `IllustrisTNG`

Simba consist out of two components[1]:

- Gizmo public (a Meshless-Hydrodynamical simulation)
    - Main simulation.
    - Gravity.
    - Hydrodynamics and thermal evolution.
- Simba (Subgrid/sub-resolution models)[2]
    - Stellar and Black-hole formation.
    - Feedback systems and interaction with environments.
    - Chemical evolution, passive dust models, ect.

[1] Davé et.al (2019).
[2] Davé et.al (2016).

Limitations within SIMBA

Many of the physics models are simplified and depend on assumptions!

For example[3]:

- Only 11 elements (H, He, C, N, O, Ne, Mg, Si, S, Ca and Fe) are tracked.
- Instantaneous recycling of the distributed metals.
- A static stellar mass fraction ($f_{\mathrm{SNII}} = 0.18$) lost from SNe.
- Stellar feedback sources, only include SNIa, SNII, AGB, and stellar winds.
- Delayed feedback (not self-consistent) is assumed for SNIa and AGB.

[3] Davé et.al (2019).

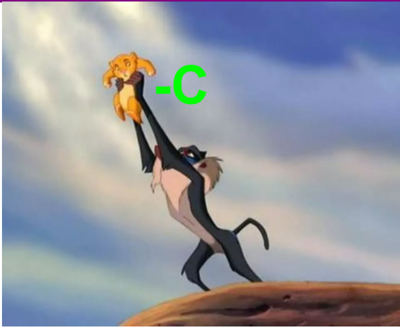
Chem5 cosmic chemical enrichment

We are improving the metal production in SIMBA.

- Chem5 model developed by Kobayashi et.al (2007) and continued improvement[4].
- Self-consistent 3-D chemodynamical model.
- Tracks 34 elements (H $\rightarrow$ Ge).
- Taking these physical processes for metal production into account:
  - Stellar feedback does not use instantaneous recycling!
  - Treats star particles as evolving stellar populations which eject thermal energy, gas mass and heavy elements.
  - More feedback systems for metal production: Super AGBs, HNe, and Failed SNe.

[4] Kobayashi & Nakasato (2011), Kobayashi et.al (2020)

The SIMBA-C simulation is born



SIMBA + Chem5 = SIMBA-C

Implementation, and parameter calibrations[5]

- Chabrier IMF.
- Dust mapping in the simulation.
- $f_{\mathrm{SNII}} = 0$.
- Black hole jet activation range parameter:
  - From $4 \times 10^7\,\mathrm{M}_\odot - 6 \times 10^7\,\mathrm{M}_\odot$
  - To $7 \times 10^7\,\mathrm{M}_\odot - 1 \times 10^8\,\mathrm{M}_\odot$
- Wind velocity scaling:
  - $1.6 \rightarrow 0.85$

[5] Romano et al. (2005), Muratov et al. (2015)

Global properties - N512L50 simulation volume, excl. dust

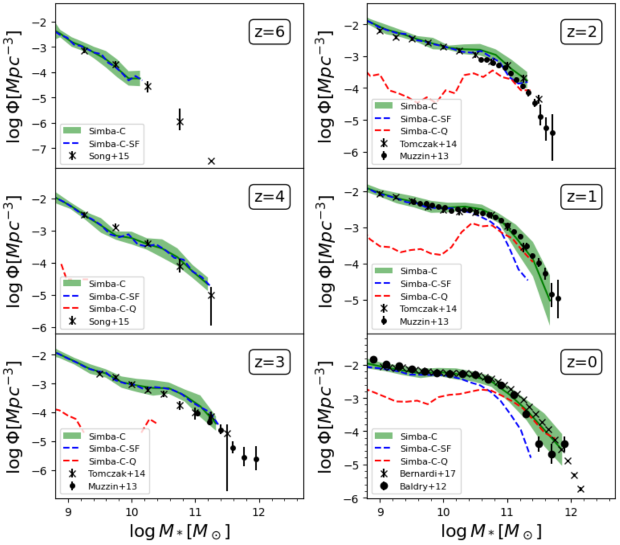


Figure: Evolution of Galaxy Stellar Mass function (GSMF).

Global properties - N512L50 simulation volume, excl. dust

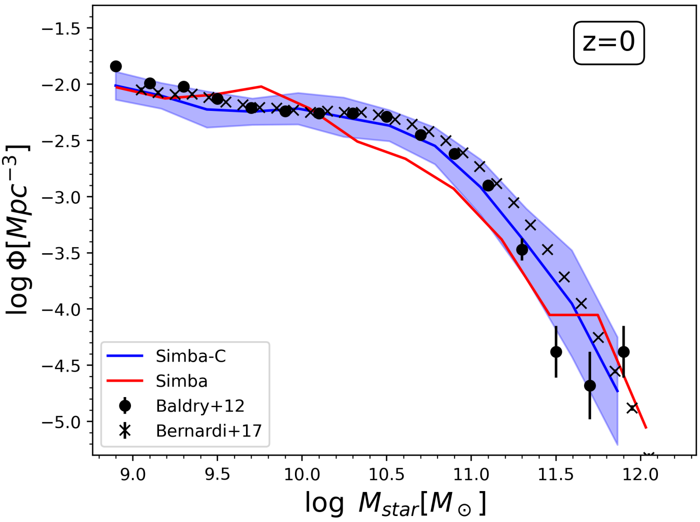


Figure: GSMF at $z = 0$ compared to SIMBA.

Global properties - N512L50 simulation volume, excl. dust

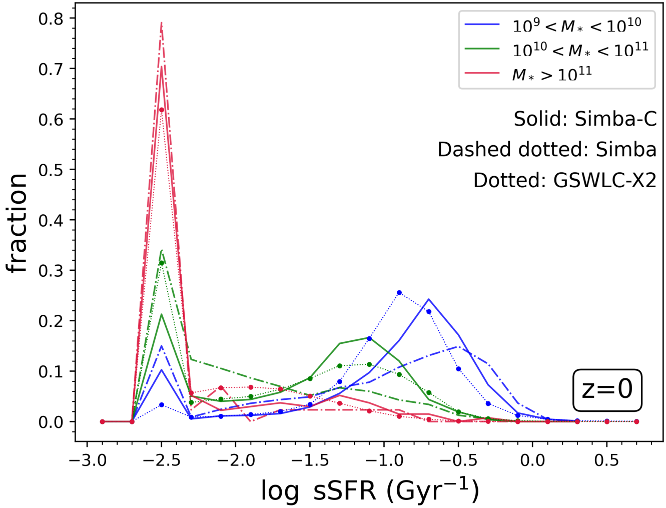


Figure: Histogram of sSFR in three bins of stellar mass at $z = 0$ compared to `SIMBA`.

Metallicity and Abundance ratios

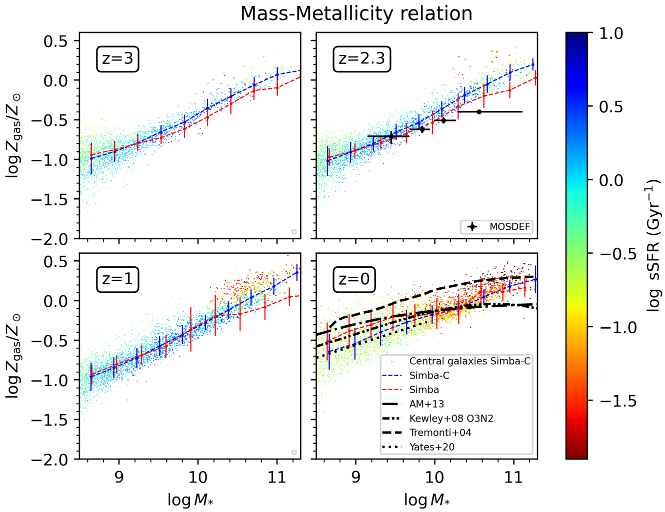


Figure: Evolution of the gas-phase mass-metallicity relation (MZR) compared to `SIMBA`.

Global properties - N512L50 simulation volume, excl. dust

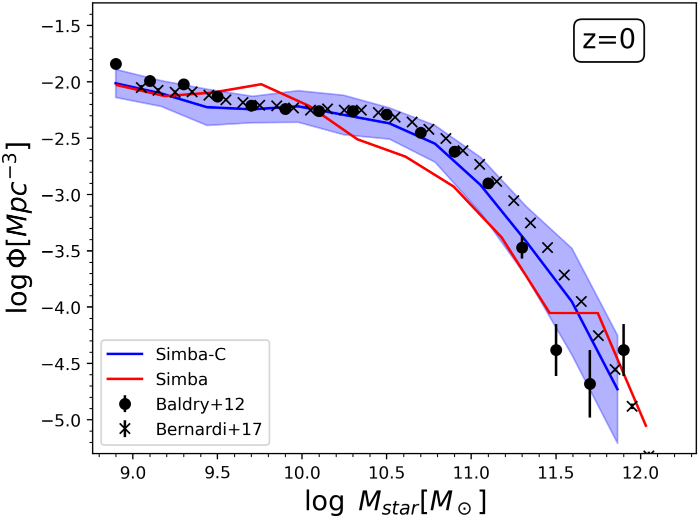


Figure: GSMF at $z = 0$ compared to SIMBA.

Metallicity and Abundance ratios

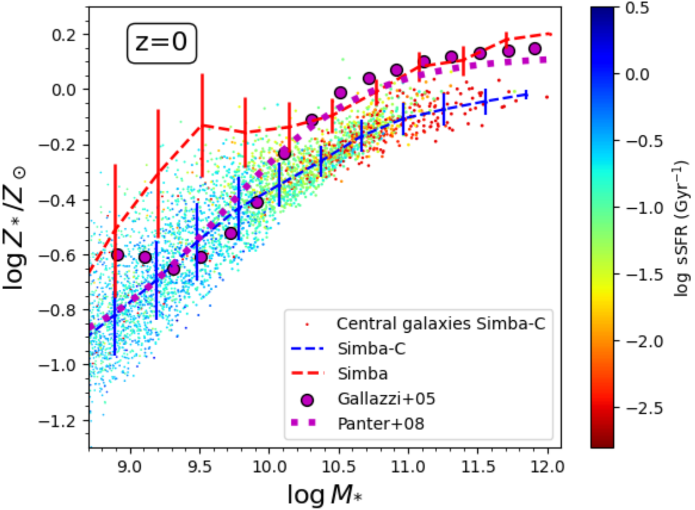


Figure: Stellar mass-metallicity relation at $z = 0$ compared to SIMBA.

Metallicity and Abundance ratios

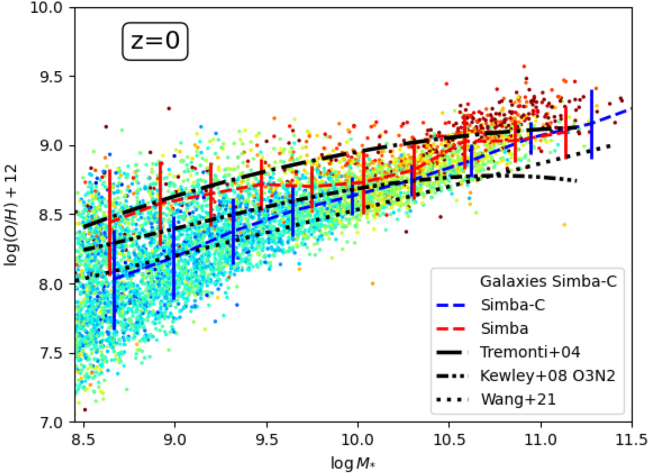


Figure: Gas-phase mass-oxygen abundance relation at $z = 0$ compared to SIMBA.

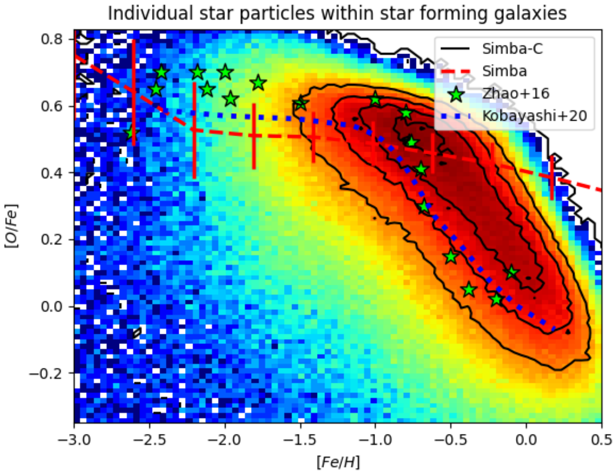


Figure: Stellar chemical abundance $[O/Fe]$ ratio at $z = 0$ compared to SIMBA for stars within MW-like galaxies.

Metallicity and Abundance ratios

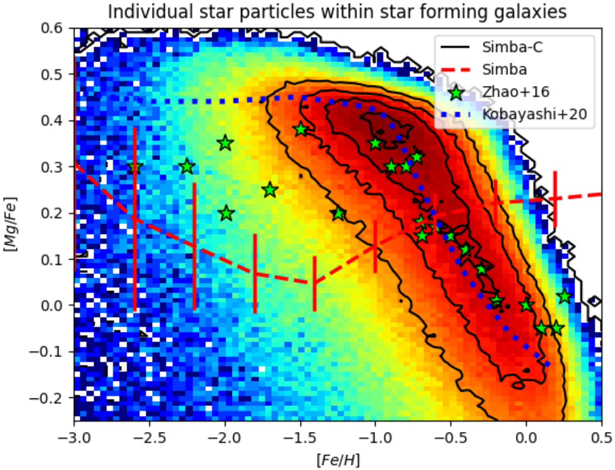


Figure: Stellar chemical abundance $[Mg/Fe]$ ratio at $z = 0$ compared to SIMBA for stars within MW-like galaxies.

Metallicity and Abundance ratios

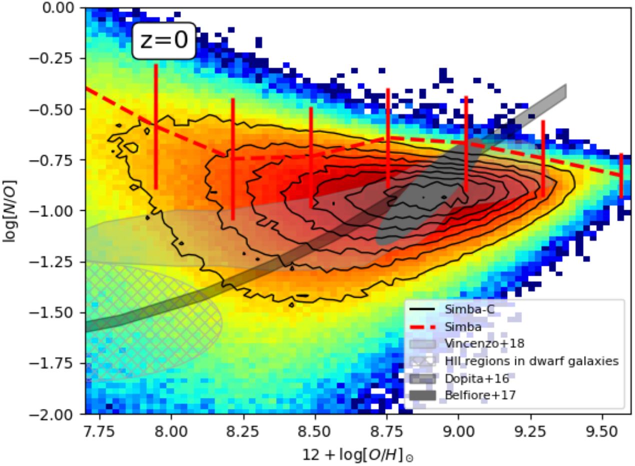


Figure: Gas-phase chemical abundance $[Mg/Fe]$ vs $\log(O/H) + 12$ ratio at $z = 0$ compared to SIMBA in star forming galaxies with stellar masses between $10^9 - 10^{11.5} M_\odot$.

Metallicity and Abundance ratios

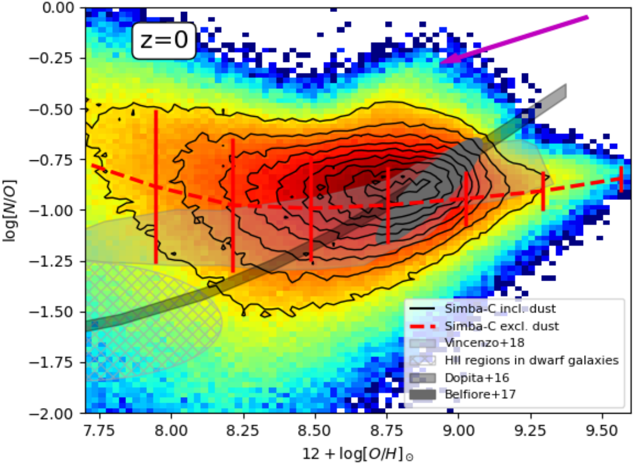


Figure: Gas-phase chemical abundance $[Mg/Fe]$ vs $\log(O/H)+12$ ratio at $z=0$ compared to SIMBA in star forming galaxies with stellar masses between $10^9 - 10^{11.5}\mathrm{M}_\odot$.

Future science with SIMBA-C

Now that SIMBA-C has been fully tested on galactic scales, we can study the:

- Global **intragroup** X-Ray halo properties (including metallicities and abundance ratios) using the XIGrM python package.
- Metallicity and abundance ratio properties in **clusters** part of The 300 project
- ect.

Summary and conclusions

We discussed the following:

- Cosmological simulations - `SIMBA`
- Cosmic chemical enrichment model - `Chem5`
- Introduced `SIMBA-C`
- Global stellar and galaxy properties
- Metallicity and abundance ratios (new types of tests)
- Future science we can do with `SIMBA-C`.

Acknowledgements

I would like to thank my supervisor Prof. S.I. Loubser, Prof. A. Babul, Prof. R.S. Davé and lastly Dr. D. Rennehan for the assistance with my project. I would also like to thank the NRF for the funding I received for this project (Grand number 146053), as well as the Centre for Space Research (NWU), the Royal Society travel grant, and the Flatiron Institute for my attendance at the Simba Collaboration Workshop 2023.

THANK YOU!!!

References

- Davé R., Thompson R., Hopkins P. F., 2016 MNRAS, 462, 3265.
- Davé R., Anglés-Alcázar D., Narayanan D., Li Q., Rafieferantsoa M. H., Appleby S., 2019, MNRAS, 486, 2827
- Kobayashi C., Springel V., White S. D. M., 2007, MNRAS, 376, 1465
- Kobayashi C., Nakasato N., 2011, ApJ, 729, 16
- Kobayashi C., Karakas A. I., Lugaro M., 2020, ApJ, 900, 179
- Muratov A. L., Kerěs D., Faucher-Giguère C.-A., Hopkins P. F., Quataert E., Murray N., 2015, MNRAS, 454, 2691
- Romano D., Chiappini C., Matteucci F., Tosi M., 2005, A&A, 430, 491

References - Observations

Andrews B. H., Martini P., 2013, ApJ, 765, 140

Baldry I. K., et al., 2012, MNRAS, 421, 621

Belfiore F., et al., 2017, MNRAS, 469, 151

Bentz M. C., Manne-Nicholas E., 2018, ApJ, 864, 146

Bernardi M., Meert A., Sheth R. K., Fischer J. L., Huertas- Company M., Maraston C., Shankar F., Vikram V., 2017, MNRAS, 467, 2217

Dopita M. A., Kewley L. J., Sutherland R. S., Nicholls D. C., 2016, Ap&SS, 361, 61

Gallazzi A., Charlot S., Brinchmann J., White S. D. M., Tremonti C. A., 2005, MNRAS, 362, 41

Kewley L. J., Ellison S. L., 2008, ApJ, 681, 1183

Kormendy J., Ho L. C., 2013, ARA&A, 51, 511

Muzzin A., et al., 2013, ApJ, 777, 18

Panter B., Jimenez R., Heavens A. F., Charlot S., 2008, MNRAS, 391, 1117

Salim S., Boquien M., Lee J. C., 2018, ApJ, 859, 11

Sanders R. L., et al., 2015, ApJ, 799, 138

Tomczak A. R., et al., 2014, ApJ, 783, 85

Tremonti C. A., et al., 2004, ApJ, 613, 898

Vincenzo F., Kobayashi C., 2018, A&A, 610, L16

Wang E., Lilly S. J., 2021, ApJ, 910, 137

Yates R. M., Schady P., Chen T. W., Schweyer T., Wiseman P., 2020, A&A, 634, A107

Zhao G., et al., 2016, ApJ, 833, 225