GAMMA-EM: Emulating Galactic Chemical Evolution Models to Explore the Galactic Origins of the Elements

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INTRODUCTION

- The life cycles of stars and the evolution and recycling of heavy elements (metals) in galaxies is referred to as **galactic chemical evolution**.

- **Galaxy Assembly with Merger Trees for Modeling Abundances (GAMMA)** is an existing computational model of this process. It orchestrates the generation and combination of chemical evolution models of stellar populations to reproduce galactic chemical abundances based on merger trees provided by cosmological dark matter simulations (Côté et al. 2018).

- **Newly available chemical abundance observations** for the Milky Way and its satellites have the potential to give insight to the murky chemical evolution history of the Milky Way and its satellite galaxies (Abolfathi et al. 2018, McConnachie et al. 2012).

- We aim to obtain **a set of GAMMA input parameters** that **produce the best model fit** to this new observational data.
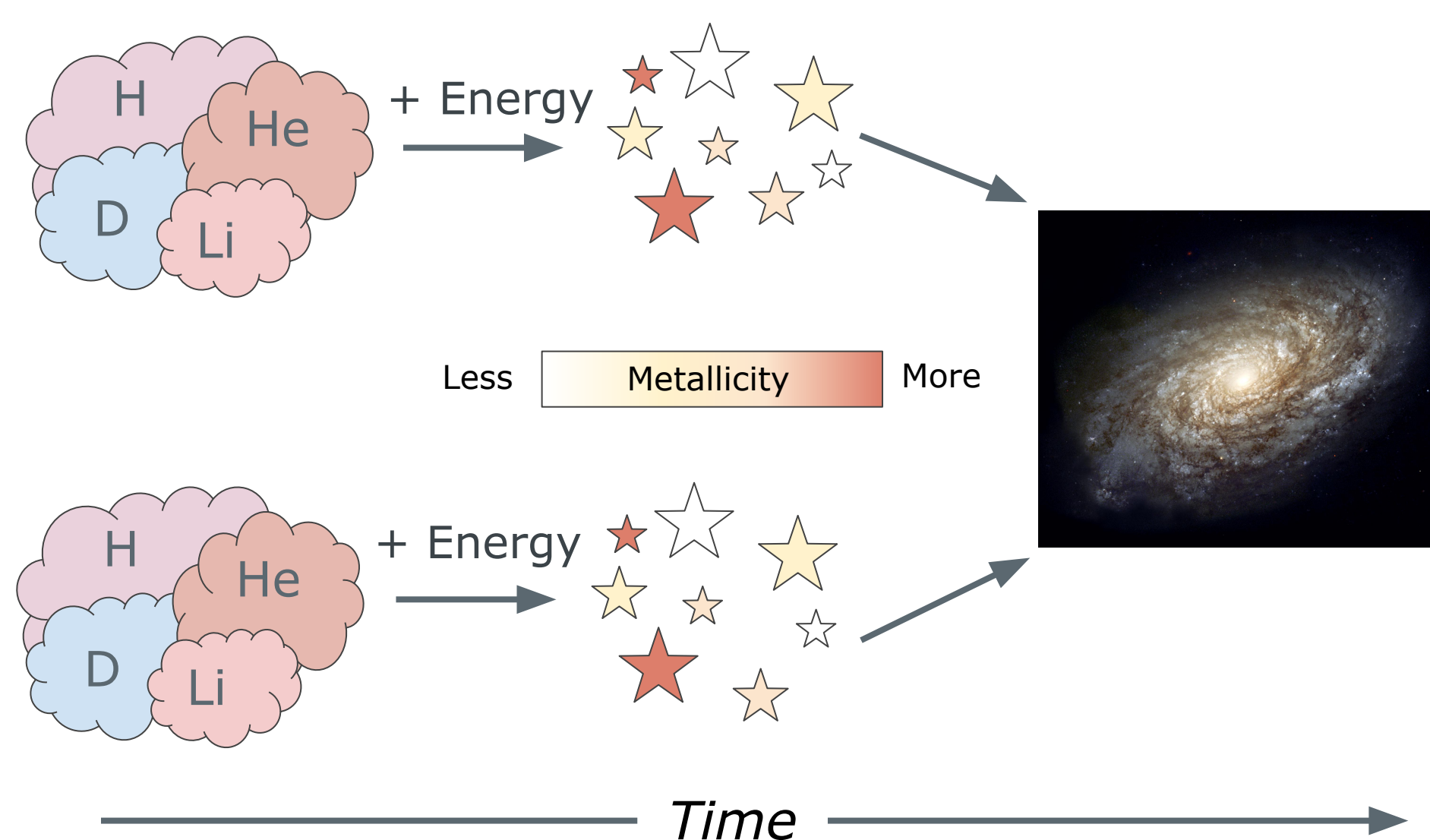

Figure (1): A representation of how GAMMA models galactic chemical evolution over time. Galaxy image credit: NASA - The Hubble Heritage Team (AURA/STScI/NASA)

METHODS

- GAMMA's computation time is **too large** to efficiently search the model's parameter space for a set of best-fit parameters.

- **Gaussian Process regression** was used to create model emulators for GAMMA, trained on two sparsely sampled sets of input parameters across two model emulator generations.

- An affine-invariant ensemble sampler for **Markov chain Monte Carlo** was used to explore the parameter space to find probabilities for best-fit variable values to the observational data (Foreman-Mackey et al. 2013).

We have identified the **likely conditions** under which the chemical composition of the **Milky Way and its satellite galaxies** evolved.

Probability Densities of GAMMA Parameters

Figure (3): A plot of the observations GAMMA's results using set of the best-fit parameters found through the probability densities. **Host galaxy not shown** because it was not used in finding best-fit parameters.
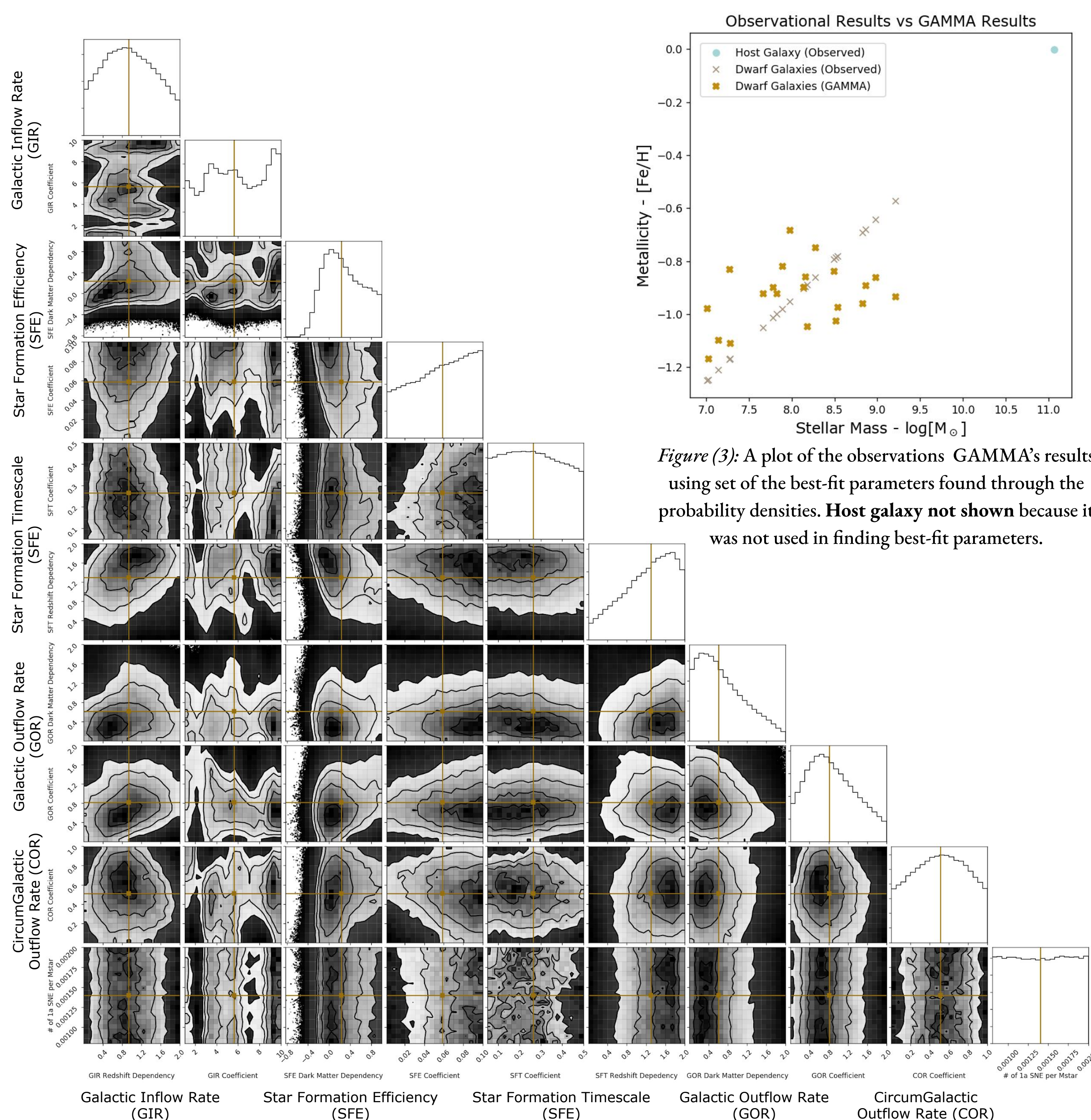
Figure (2): Diagonal plots represent the probability density functions of each parameter of GAMMA that is labelled along the x-axis, with all other parameters marginalized. All other plots represent two-dimensional projections of parameter space between two independent variables, and they display confidence intervals of where the best fit value is located in that section of parameter space.
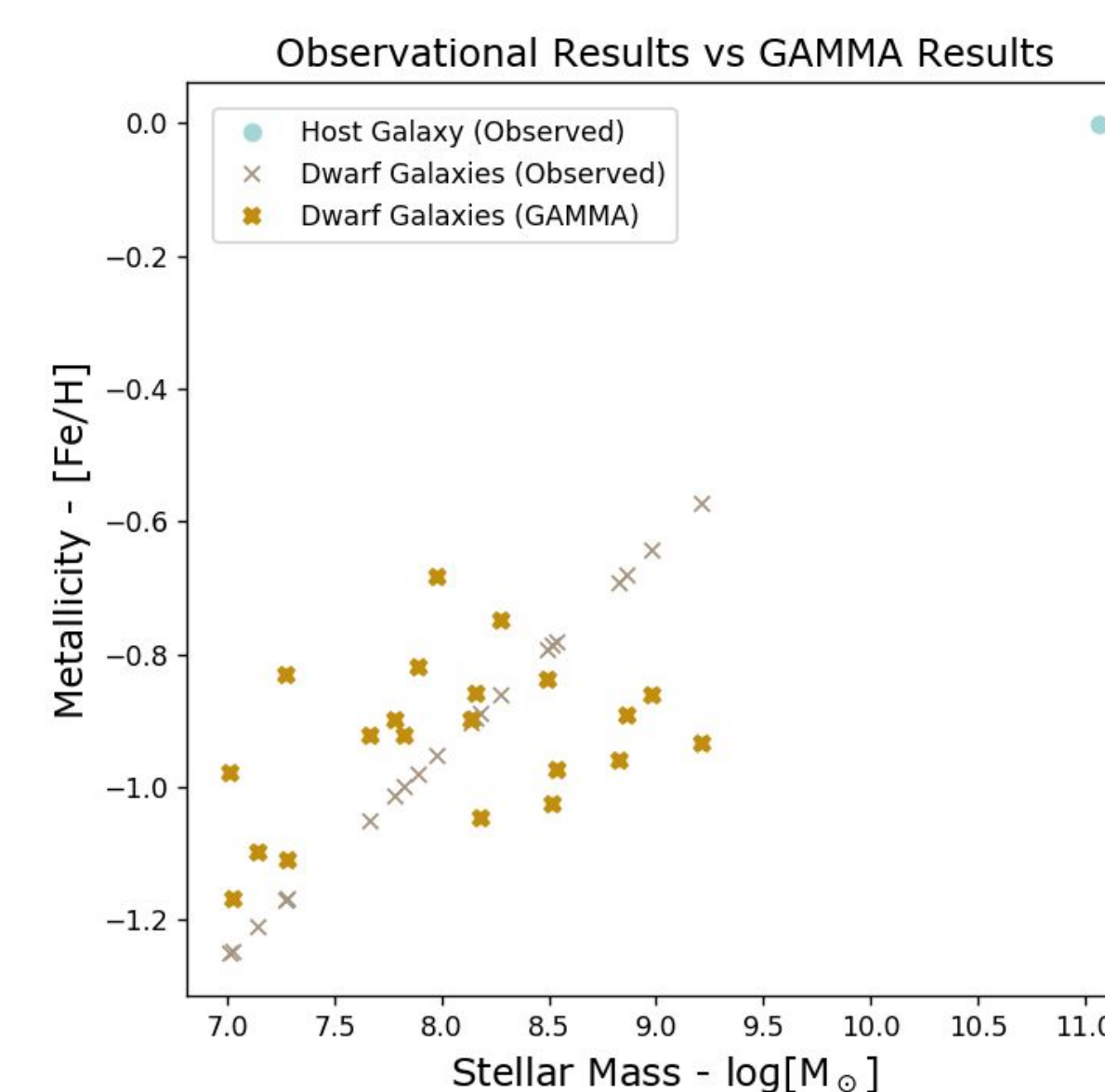
DISCUSSION

- The model emulators cut computation time by **3000x** (50 hours to 60 seconds for 10000 GAMMA samples)

- The peaks in the probability density function of certain model parameters (see Fig. (2) and caption) indicate values of that parameter that have a **high probability** of being the best value to shape the stellar mass-metallicity distribution to reflect the observations.

- The varying number of Type 1a supernovae per stellar mass was not included in the GAMMA calculations, which is why a flat probability density function is produced. This works as a consistency check to verify whether the MCMC simulations were correctly run, because it suggests the parameter values have a **negligible impact** on shaping the modelled distribution.

- The multiple peaks in the probability density function of the GIR coefficient show **multiple best-fit values** for the parameter. Further investigation is needed to determine if the PDF is truly multi-modal.

FUTURE WORK

- Additional Markov Chain Monte Carlo simulations comparing to other observational values, such as the **stellar mass versus dark matter mass relationship.**

- Integrate the many **cosmological dark matter simulations** from the Caterpillar Project (www.caterpillarproject.org) as an additional parameter.

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