The Empirical Delay Time Distributions of Type Ia Supernovae From Galaxy Star Formation Histories

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ABSTRACT

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1. introduction

2. Description of the Data

3. Delay Time Distributions from Star Formation Rate Densities

4. Delay Time Distributions from Star Formation Histories

This is an evaluation of the maximum likelihood delay time distribution following the prescription of Maoz et al. (2012) but performed on the GOODS/CANDELS galaxies. In a given galaxy, the total expected rate of SNe Ia per year will be:

$$R_i = \int_0^t \Psi(t') * \Phi(\tau)\, dt' \tag{1}$$

where $\Psi(t)$ is the star formation history of the galaxy (mapped in forward time), and $\Phi(\tau)$ is the delay time distribution model, also forward in time. The product of the integrated rate and the control time, $t'_{c,i}$, which contains all the information on the temporal sampling and depth of the survey,

$$m_i = R_i \times t'_{c,i} \tag{2}$$

which is the expected number of SN Ia events from that galaxy over the duration of the survey. The probability distribution of observed events is likely Poisson, where of catching n_i SNe Ia from that galaxy when m_i are expected is

$$P(n_i|m_i) = \frac{m_i^{n_i} e^{-m_i}}{n_i!}. \tag{3}$$

The product of probabilities for all galaxies in the survey would then serve as the likelihood of a given delay-time distribution model. The log-likelihood, convenient for MCMCs, is then expressed by:

$$L = \prod_{i}^{N} P(n_i|M_i) \Rightarrow \ln L = -\sum^{N} m_i + \sum^{N} \ln\left(\frac{m_i^{n_i}}{n_i!}\right) \qquad (4)$$

in which the last term is zero for galaxies which do not host SNe Ia during the survey.

Following Strolger et al. (2010), we can continue to test a robust delay-time model, capable of reproducing the theoretical distributions for SD and DD models at one extreme, and δ-function delay times at the other. The unimodal, skew-normal $\Phi(\tau)$ function is defined as:

$$\Phi(\tau) = \frac{1}{\omega\pi}\exp\left(\frac{-(\tau-\xi)^2}{2\omega^2}\right)\int_{-\infty}^{\alpha\left(\frac{\tau-\xi}{\omega}\right)}\exp\left(\frac{-t'^2}{2}\right)dt', \qquad (5)$$

where location (ξ),[1] scale (ω^2), and shape (α) define the mode time ($\bar{\tau}$, as defined in the previous tests), variance (σ^2), skewness (γ_1), and kurtosis (γ_2) of the model function by,

$$\begin{aligned}
\bar{\tau} &= \xi + \omega\delta\sqrt{\frac{2}{\pi}}, \\
\delta &= \frac{\alpha}{\sqrt{1+\alpha^2}}, \\
\sigma^2 &= \omega^2\left(1-\frac{2\delta^2}{\pi}\right), \\
\gamma_1 &= \frac{1}{2}(4-\pi)\frac{(\delta\sqrt{2/\pi})^3}{(1-2\delta^2/\pi)^{3/2}}, \\
\gamma_2 &= 2(\pi-3)\frac{(\delta\sqrt{2/\pi})^4}{(1-2\delta^2/\pi)^2}.
\end{aligned}$$

[1]Different from the initial mass function, $\xi(M)$.

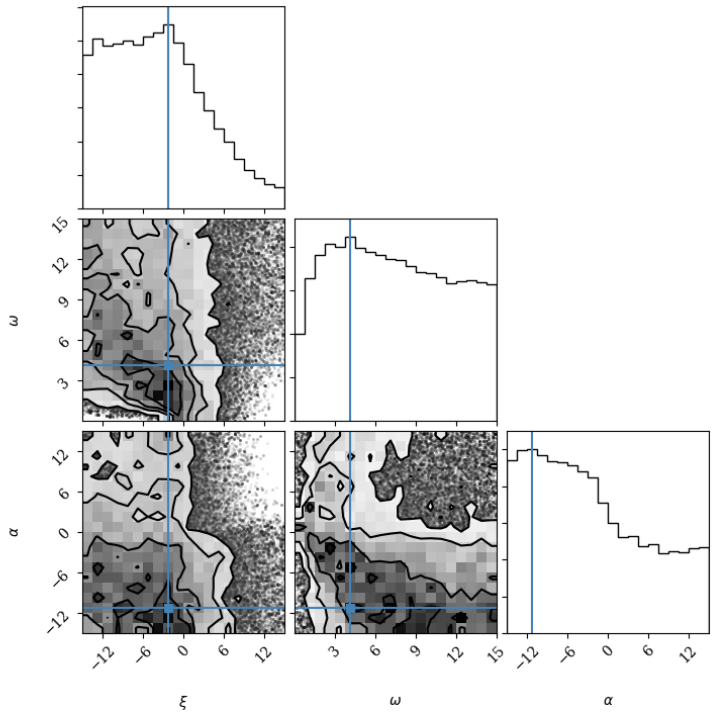

Fig. 1.— MCMC results on 147 galaxies in CANDELS, 49 of which are SN Ia hosts. Plot generated using `corner.py` (Foreman-Mackey 2016).

The model parameters, ξ, ω, and α are explored in an Affine Invariant Markov-chain Monte Carlo using `emcee.py` (Foreman-Mackey et al. 2013). As for priors, we restrict the parameters to the space:

$$\begin{aligned} -15 < \quad & \xi \quad \leq 15 \\ 0 < \quad & \omega \quad \leq 15 \\ -15 < \quad & \alpha \quad \leq 15 \end{aligned}$$

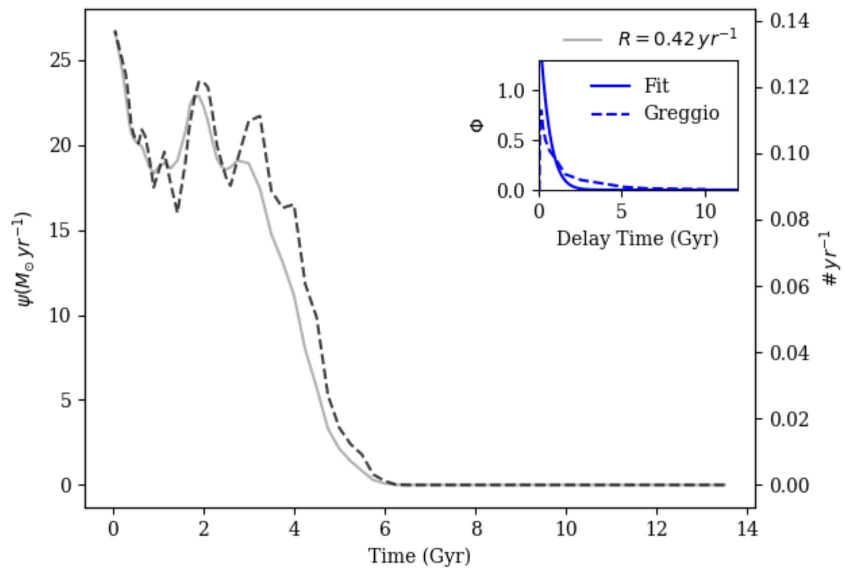

Fig. 2.— Example of best-fit delay-time distribution (inset) on the SFH of a sample host galaxy.

5. discusssion

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