BGM FASt: Besançon Galaxy Model for Big Data

Inferring the IMF, the Solar Neighbourhood population density and its SFH

R. Mor[1], A.C. Robin[2], F. Figueras[1], T. Antoja[1]

[1] Dept. Física Quàntica i Astrofísica, Institut de Ciències del Cosmos, Universitat de Barcelona (IEEC-UB), Martí Franquès 1, E08028 Barcelona, Spain. e-mail: rmor@fqa.ub.edu

[2] Institut Utinam, CNRS UMR6213, Université de Bourgogne Franche-Comté, OSU THETA , Observatoire de Besançon, BP 1615, 25010 Besançon Cedex, France

Goal

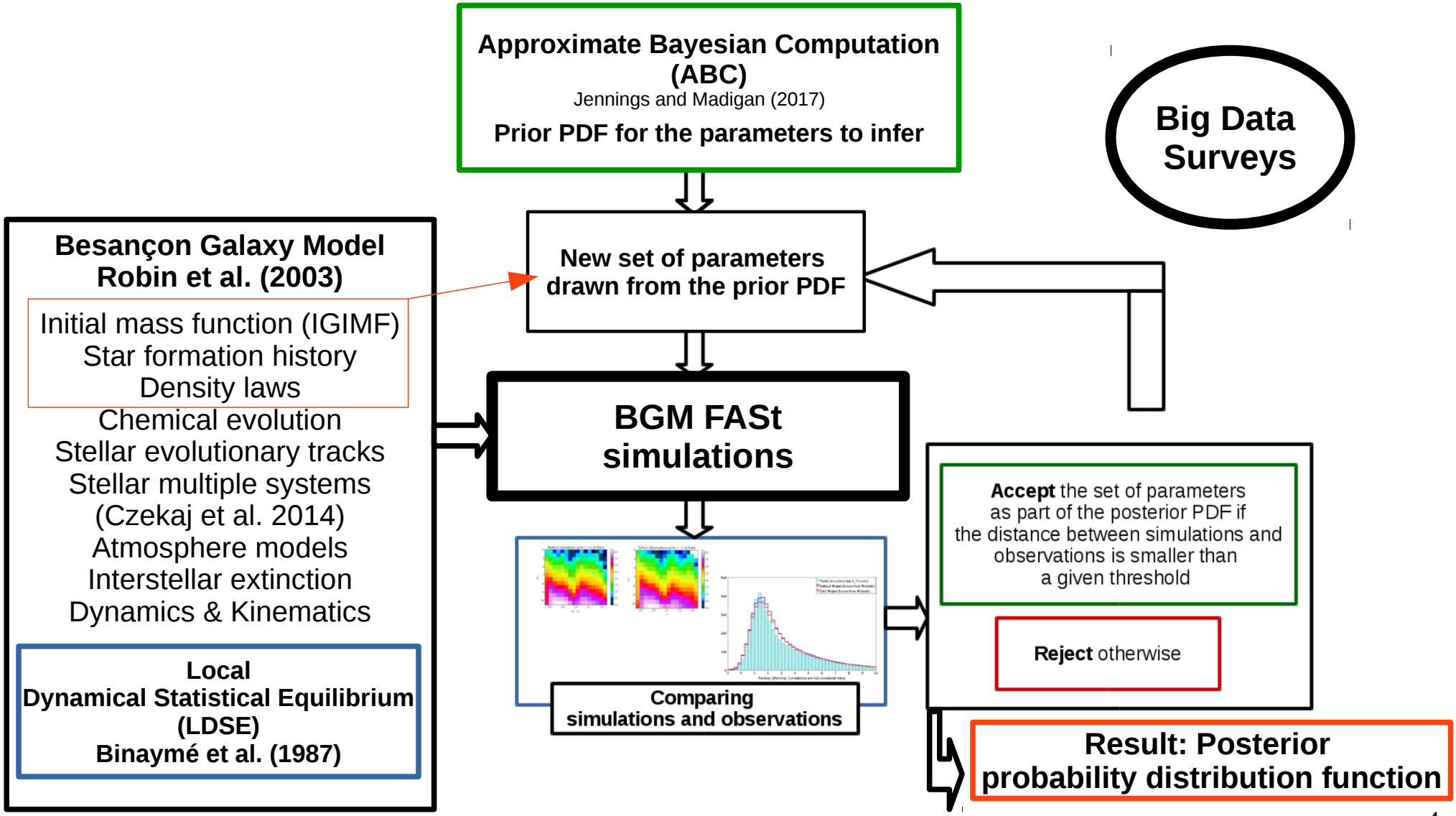
- To perform parameter inference using the Besançon Galaxy Model and Gaia DR2: Starting with the inference of the star formation history (SFH), the integrated Galactic initial mass function (IGIMF) and the density laws.

- Demonstration case: To infer simultaneously the SFH, the IGIMF and the stellar mass density at the Solar neighborhood using Tycho-2 data.

The triple challenge!

- The efficiency of parameter inference algorithm
- The computational cost of the Milky Way simulations
  - BGM standard to mimic Tycho-2 needs 432 hours of CPU in PCs
  - GUMS (Robin et al. 2012) and GOG (Luri et al. 2014), up to G=20, needs about 200.000 hours of CPU at Mare Nostrum super-computing center
- To deal with Big Data surveys
  - We can jump from the use of about 860.000 stars in Tycho-2 (up to V_T=11) to more than 1 billion stars with Gaia DR-2

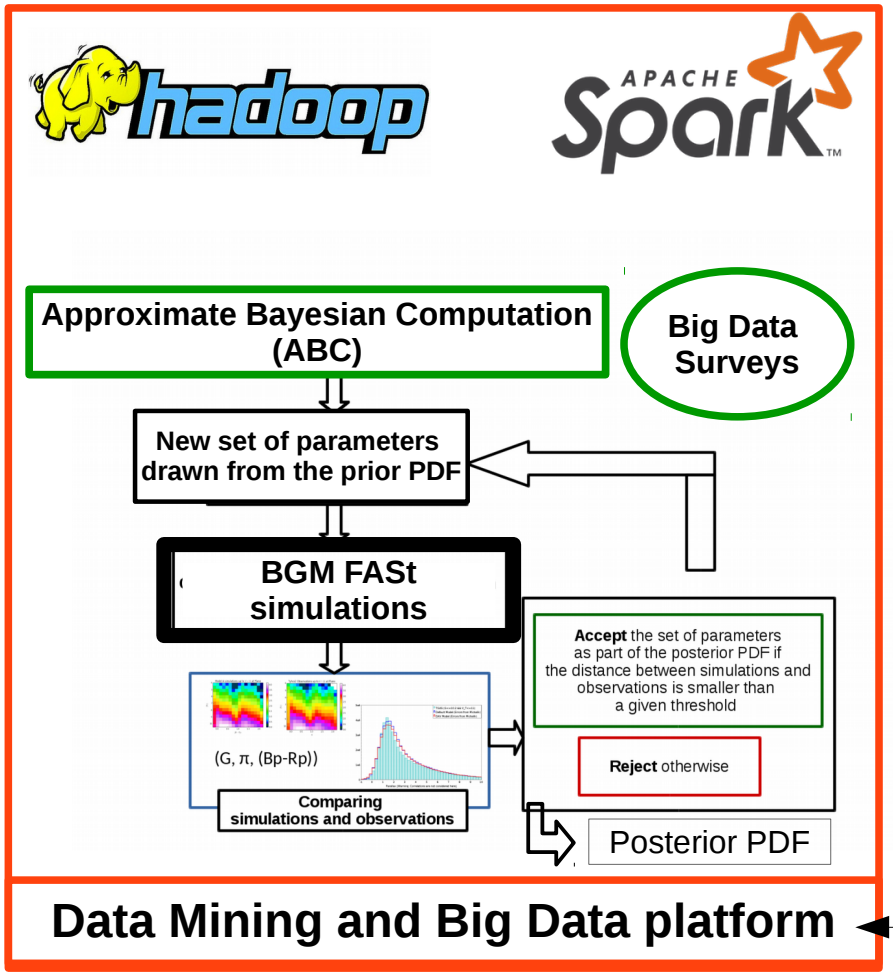
Strategy: BGM FASt + ABC + Big Data platform



Strategy: Data Mining and Big Data platform at University of Barcelona

The full strategy is integrated in the Data Mining and Big Data platform at University of Barcelona

Fast and powerful engines, coming from business science, specially suited for Big Data



Who uses Spark and/or hadoop?

amazon

IBM

NASA

SAMSUNG

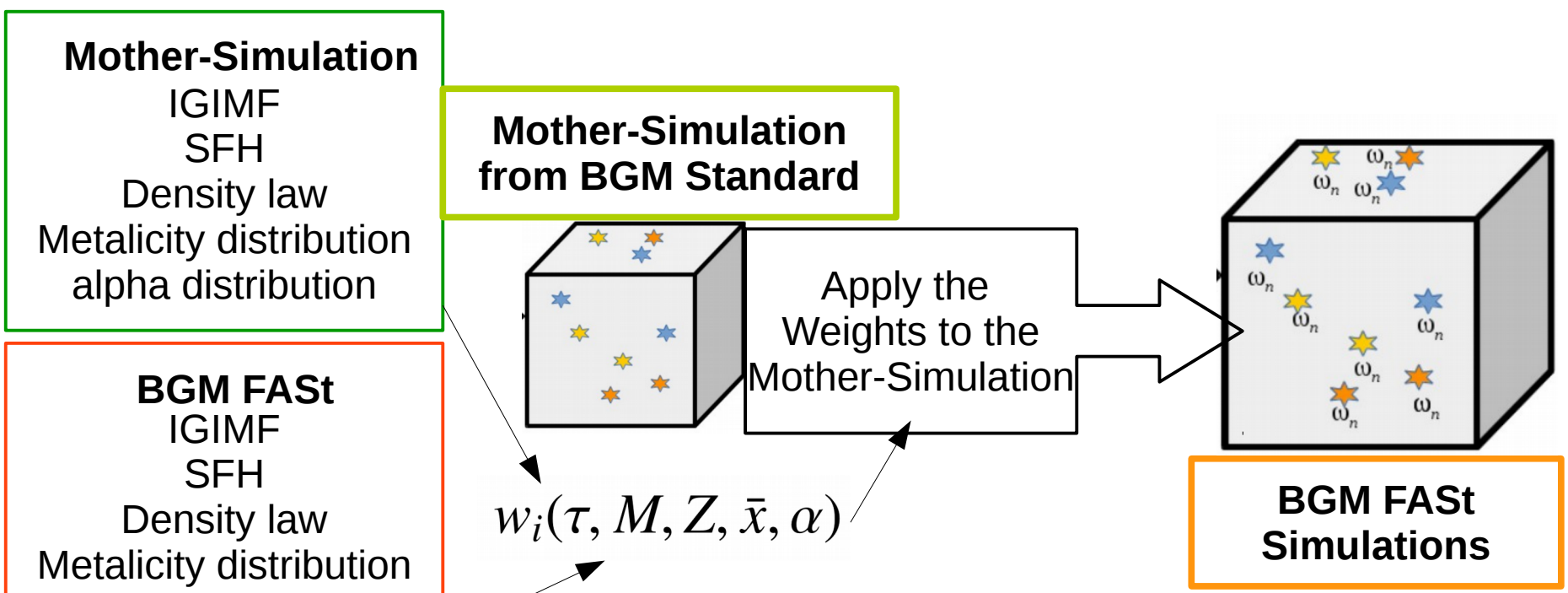
Deep Space Network

(X. Luri, S. Soria, F.Julbe; ICCUB Engineers team)

BGM FASt: Concept

Fast approximate simulations of the Milky Way:

Refining the seed work in Robin et al. (2014)



We are able to perform Milky Way simulations **10^3 to 10^4 times faster**

When comparing CMDs, color, mass and age distributions we find differences between BGM standard and BGM FASt simulations up to 5%

BGM FASt: Analytic expression for the weights

$$w_i(\Delta\tau, \Delta M, \Delta Z, \Delta\bar{x}, \Delta\alpha) \approx \frac{\int_\Delta \frac{\Sigma^i_\odot \cdot \psi^i_\odot(\tau)}{\mathcal{H}_i(\tau)} \cdot \mathcal{R}_i(\tau, \bar{x}) \cdot \xi_i(M) \cdot M \cdot \mathcal{P}_i(Z|\tau, \bar{x}) \cdot P_i(\alpha|\tau, Z, \bar{x}) \cdot d\tau dM\, dZ\, d\bar{x}\, d\alpha}{\int_\Delta \frac{\Sigma^i_\odot \cdot \psi^i_\odot(\tau)}{\mathcal{H}_i(\tau)} \cdot \mathcal{R}_i(\tau, \bar{x}) \cdot \xi_i(M) \cdot M \cdot \mathcal{P}_i(Z|\tau, \bar{x}) \cdot P_i(\alpha|\tau, Z, \bar{x}) \cdot d\tau dM\, dZ\, d\bar{x}\, d\alpha}$$

BGM FASt Simulation

Mother-Simulation from BGM Standard

(Mor et al. 2018 in prep.)

- $\Sigma^i_\odot$ → Surface stellar density at the position of the Sun
- $\psi^i_\odot(\tau)$ → Star formation history at he Solar neighborhood
- $\mathcal{R}_i(\tau, \bar{x})$ → Density laws
- $\xi_i(M)$ → Integrated Galactic initial mass function
- $\mathcal{P}_i(Z|\tau, \bar{x})$ → Metalicity distribution
- $\mathcal{P}_i(\alpha|\tau, Z, \bar{x})$ → alpha elements abundance distribution

First Science demonstration case using Tycho-2 data

ABC

Prior PDF for 6 parameters to be inferred:

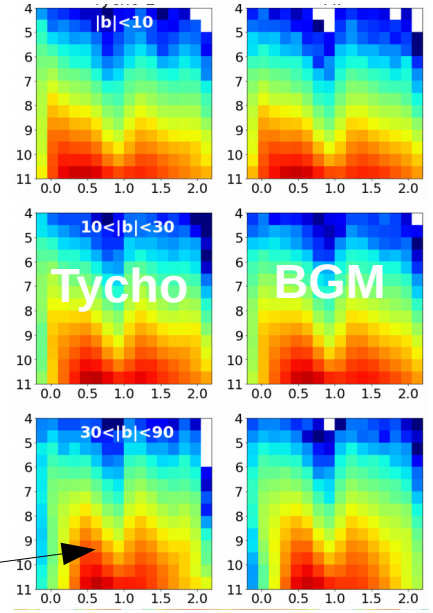
- **3 slopes of the IGIMF assuming a Kroupa-like shape**
- **Inverse of the characteristic time scale for a simple exponential SFH**
- **Stellar volume mass density at the position of the Sun**
- **Thin disc radial scale length**

New set of parameters drawn from the prior PDF

BGM FASt simulation

Best fit model variant from Mor et al. (2017) as Mother-Simulation (+ Drimme/Stylism ext.)

CMDs for three latitude ranges



$$\delta_P(\mathcal{S}_{obs}, \mathcal{S}_{simu}) = \left| \sum_{i=1}^{N} q_i \cdot (1 - R_i + ln(R_i)) \right|$$

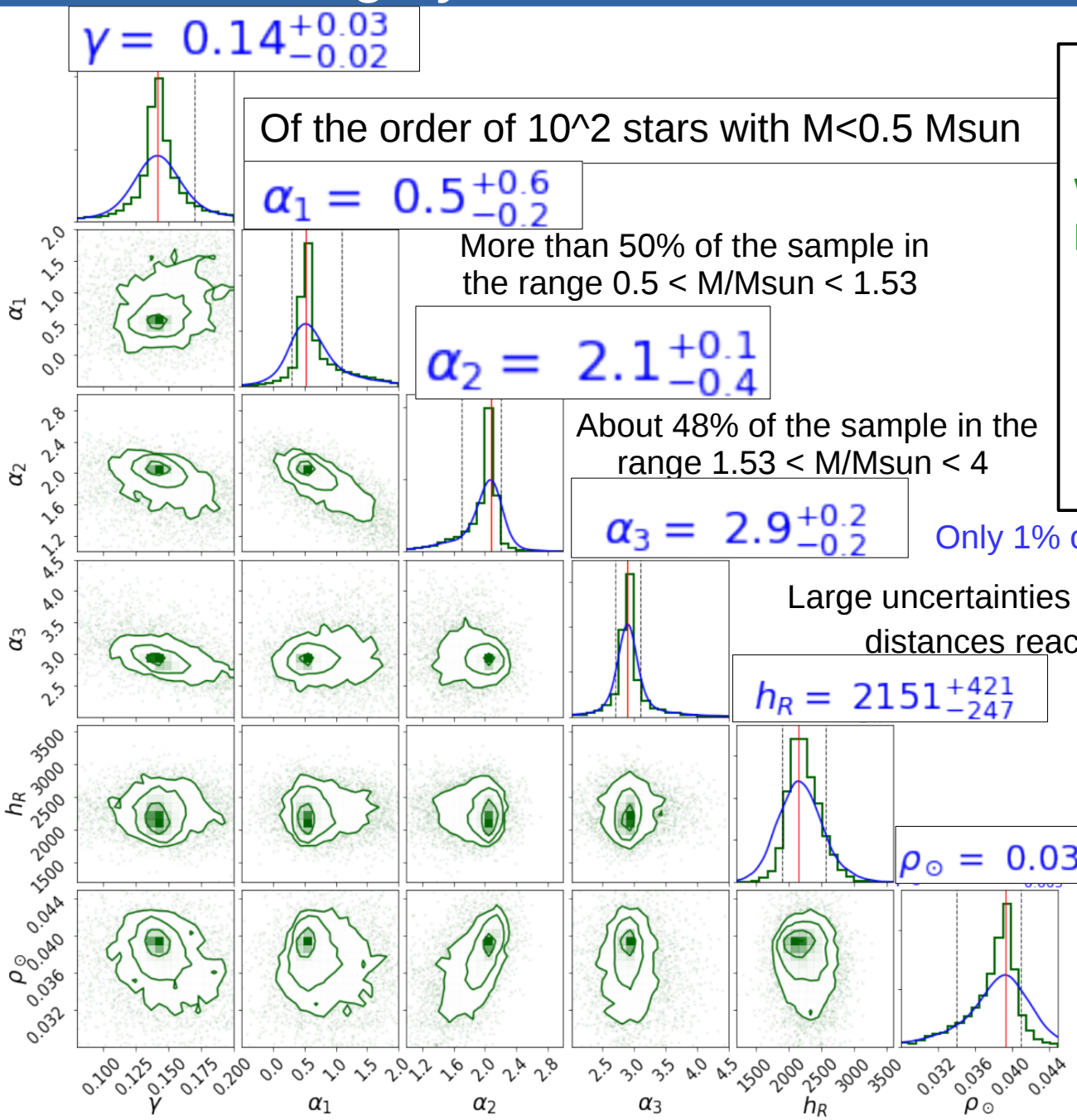
$$(R_i = f_i/q_i)$$

Accept the set of parameters if the distance is below a given threshold

Reject otherwise

Result: Posterior PDF

Simultaneous inference of the SFH, the IGIMF and density using Tycho-2 data: **Results for the thin disc**



Of the order of 10^2 stars with M<0.5 Msun

More than 50% of the sample in the range 0.5 < M/Msun < 1.53

About 48% of the sample in the range 1.53 < M/Msun < 4

Only 1% of the sample with M>4Msun

Large uncertainties in h_R due to the short heliocentric distances reached by Tycho-2 up to V_T=11

Degeneracy with the choice of the 3D extinction model

We get the similar results for the inferred parameters except:

$\alpha_3 = 3.7^{+0.2}_{-0.2}$

$\gamma = 0.09^{+0.03}_{-0.02}$

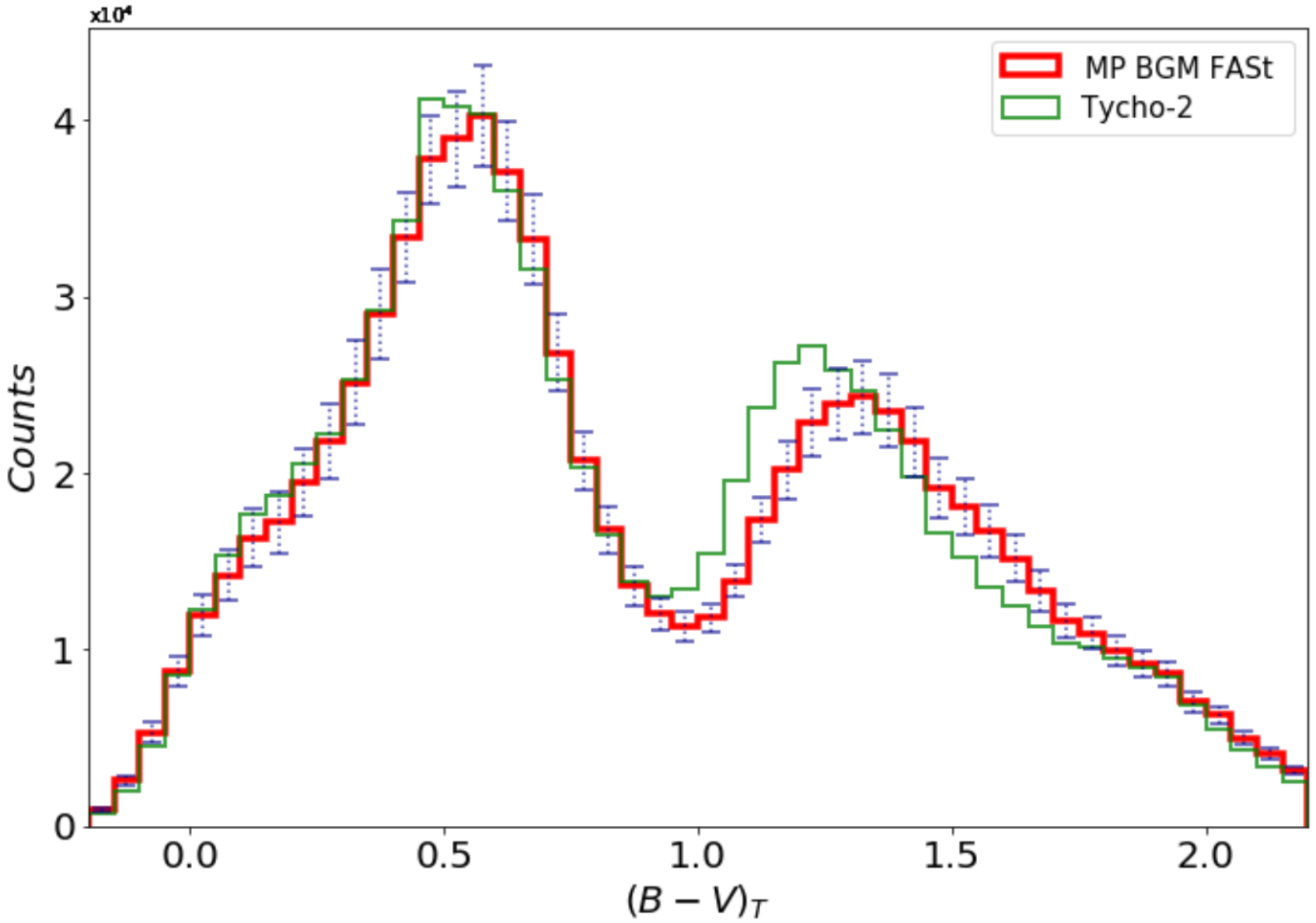
$1.2 \pm 0.2 M_\odot/yr$

$\rightarrow 0.044^{+0.002}_{-0.005} M_\odot/pc^3$

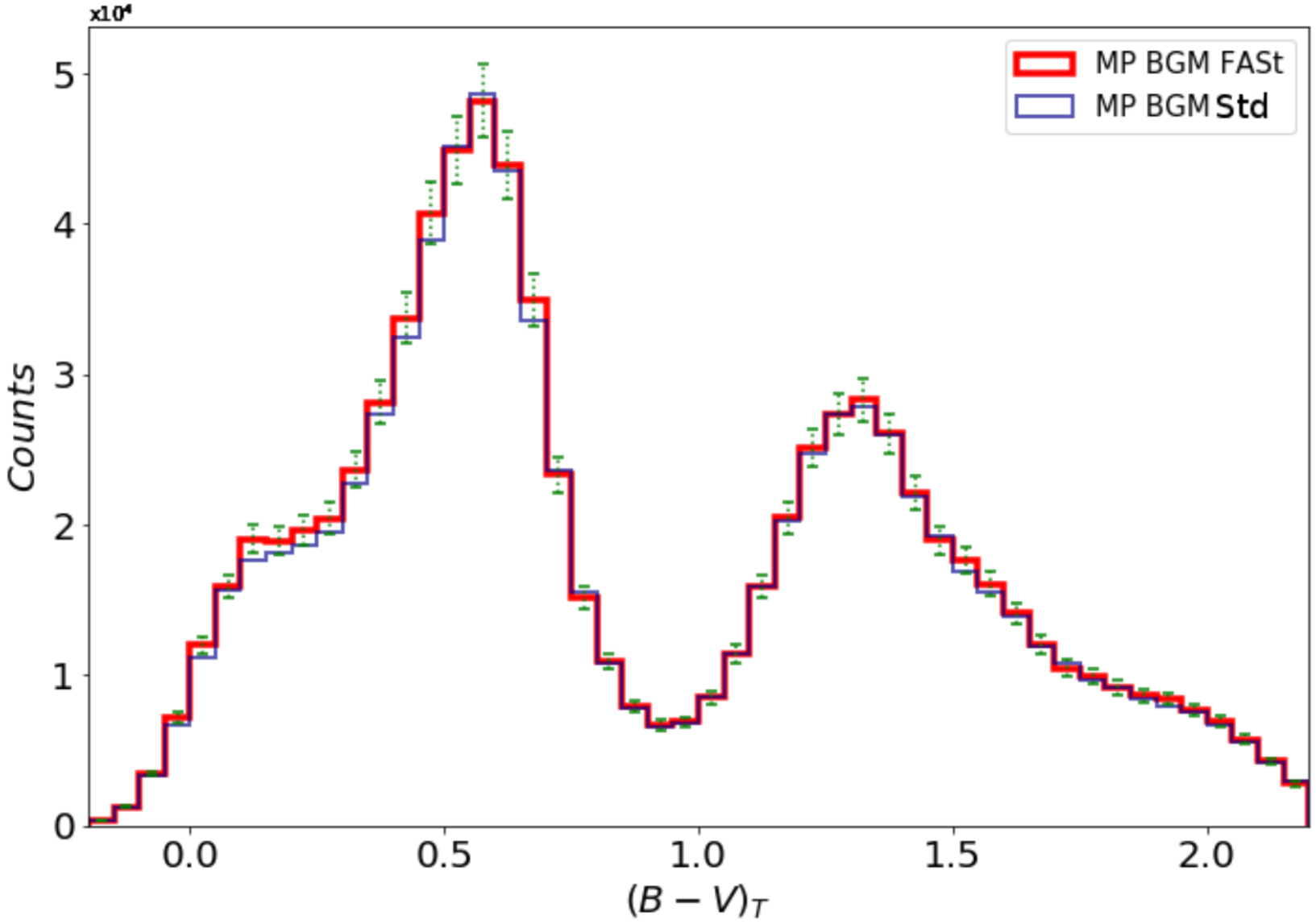
Population density at the SN

Component	Age (Gyr)	$\rho_\odot$ (D)	$\epsilon(D)$	$\rho_\odot$ (Sty)	ϵ (Sty)
thin disc 1	0-0.10	$0.0015^{+0.0001}_{-0.0002}$	0.0140	$0.0013^{+0.0001}_{-0.0002}$	0.0140
2	0.10 -1	$0.0069^{+0.0003}_{-0.0007}$	0.0210	$0.0060^{+0.0003}_{-0.0007}$	0.0209
3	1-2	$0.0055^{+0.0003}_{-0.0006}$	0.0299	$0.0048^{+0.0003}_{-0.0006}$	0.0298
4	2-3	$0.0037^{+0.0002}_{-0.0004}$	0.0451	$0.0033^{+0.0002}_{-0.0004}$	0.0448
5	3-5	$0.0061^{+0.0003}_{-0.0006}$	0.0577	$0.0059^{+0.0003}_{-0.0006}$	0.0574
6	5-7	$0.0060^{+0.0003}_{-0.0006}$	0.0655	$0.0063^{+0.0003}_{-0.0006}$	0.0652
7	7-10	$0.0103^{+0.0005}_{-0.001}$	0.0660	$0.0123^{+0.0005}_{-0.001}$	0.0657
brown and white dwarfs*		0.0071		0.0071	
Total thin disc	0-10	$0.047^{+0.002}_{-0.004}$		$0.047^{+0.002}_{-0.005}$	
young thick disc*	10	0.0036		0.0036	
old thick disc*	12	0.0005		0.0005	
stellar halo*	14	4.1e-05		4.1e-05	
total stellar component		$0.051^{+0.002}_{-0.004}$		$0.051^{+0.002}_{-0.005}$	
ISM*		0.05		0.05	
dark matter halo		$0.012^{+0.001}_{-0.001}$		$0.012^{+0.001}_{-0.001}$	
Total		$0.113^{+0.002}_{-0.004}$		$0.113^{+0.002}_{-0.005}$	

BGM FASt: Fit with Tycho-2



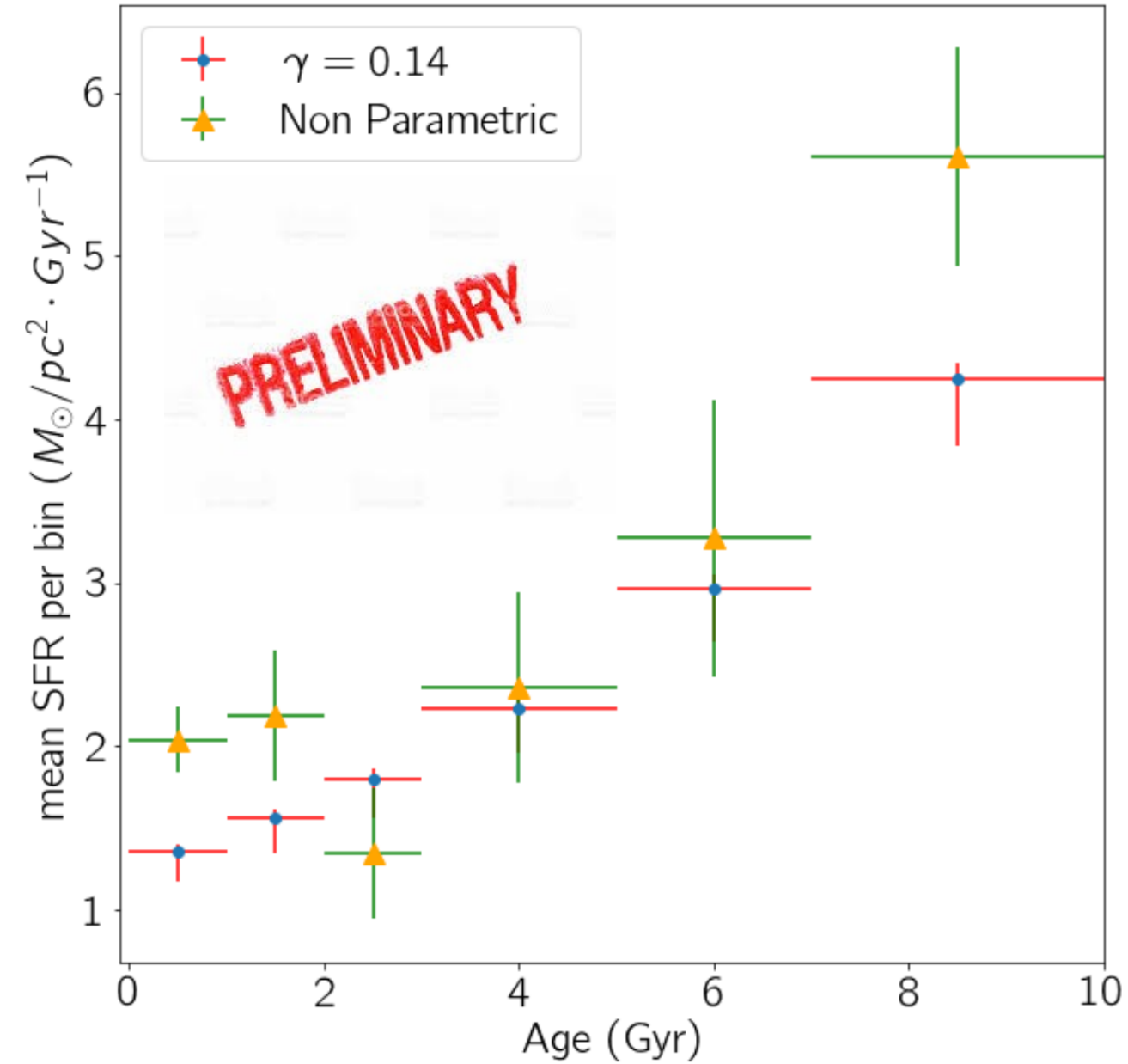
BGM FASt versus BGM Std



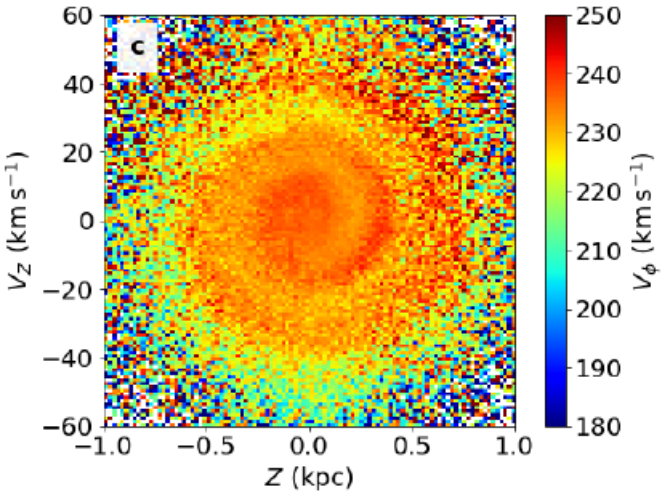
Main conclusion

- **We have a robust strategy that allow us to simultaneously infer the Integrated Galactic initial mass function, the star formation history and the density laws using Gaia DR-2 data**

Hints of a recent reactivation of the Star Formation in the last 2Gyr



Are these signatures coming from the same perturbation of the disc?



Antoja et al. (2018)

Bimodal distribution WD Mass, R...

Fran Jiménez-Esteban et al.

Thanks for attending!