The Diversity of Star Formation Efficiencies in Giant Molecular Clouds

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Collaborators:
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Star formation and Giant Molecular Clouds

★ Vast majority of stars are born in Giant Molecular Clouds (GMCs)

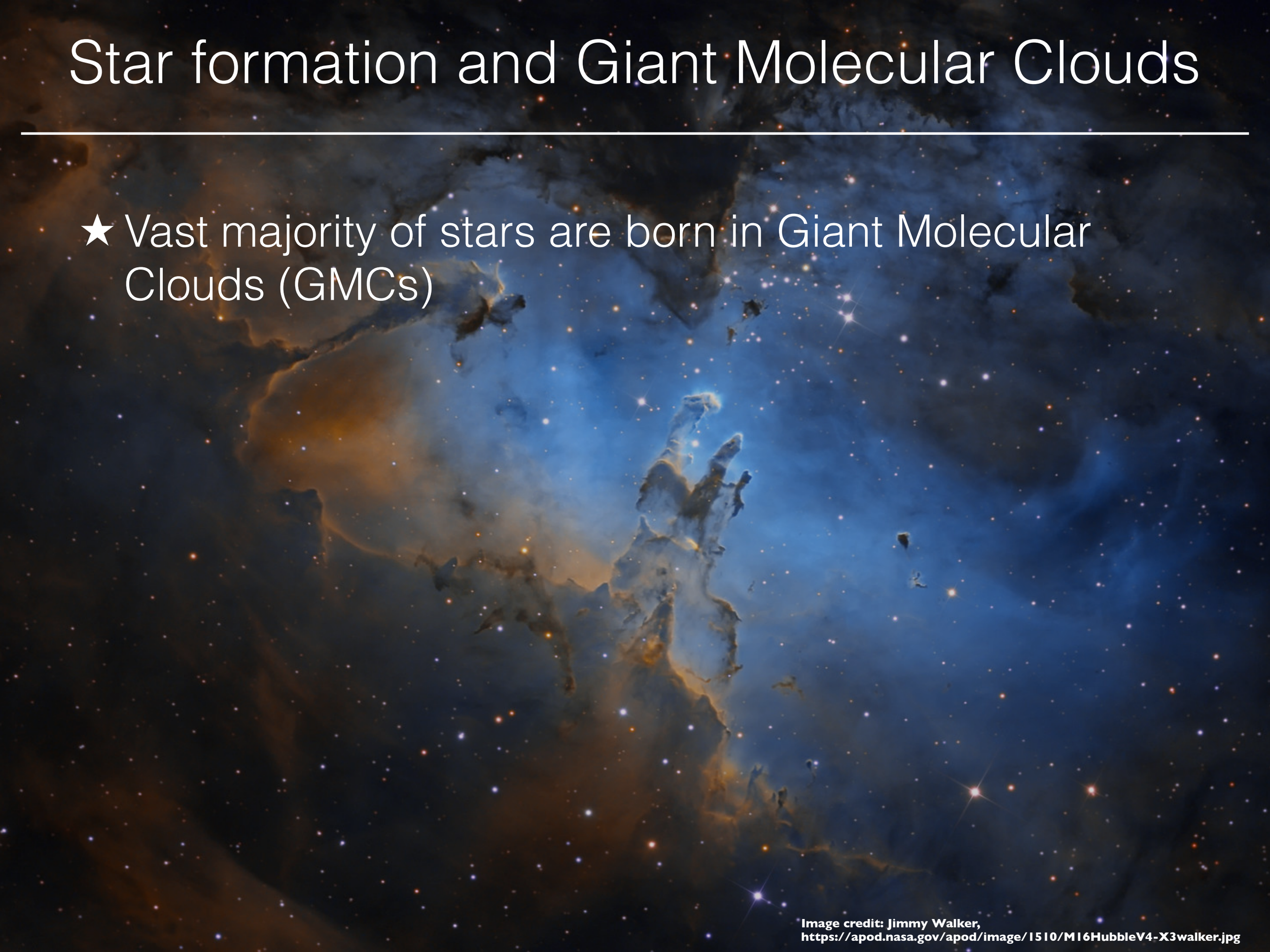

Image credit: Jimmy Walker,
https://apod.nasa.gov/apod/image/1510/M16HubbleV4-X3walker.jpg

Star formation and Giant Molecular Clouds

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★ Observations of GMCs provide Insight into how and where stars form

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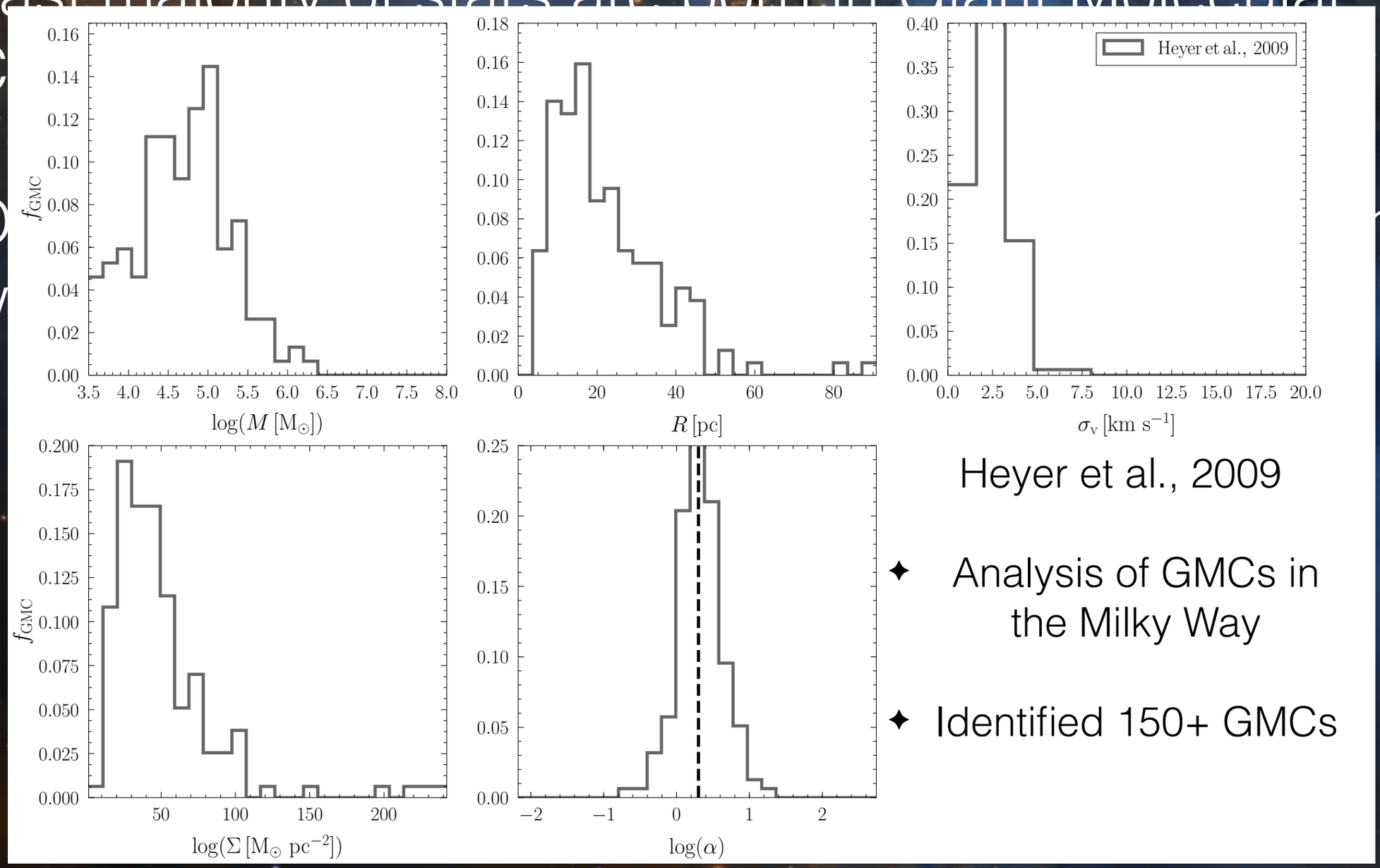

Heyer et al., 2009

- Analysis of GMCs in the Milky Way
- Identified 150+ GMCs

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Star formation and Giant Molecular Clouds

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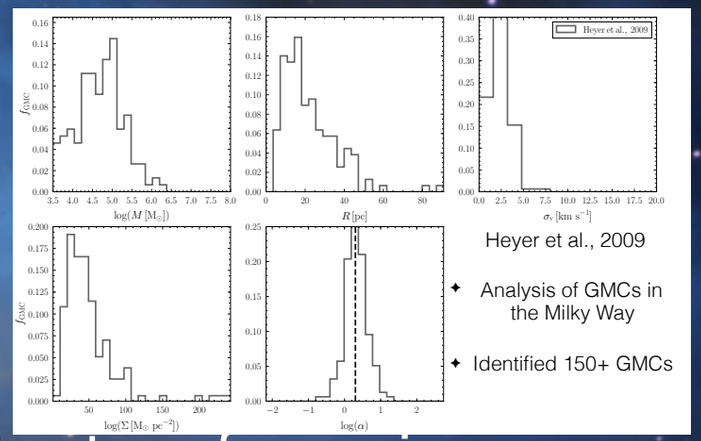
★ No two GMCs are identical

★ GMCs provide a range of different star forming environments



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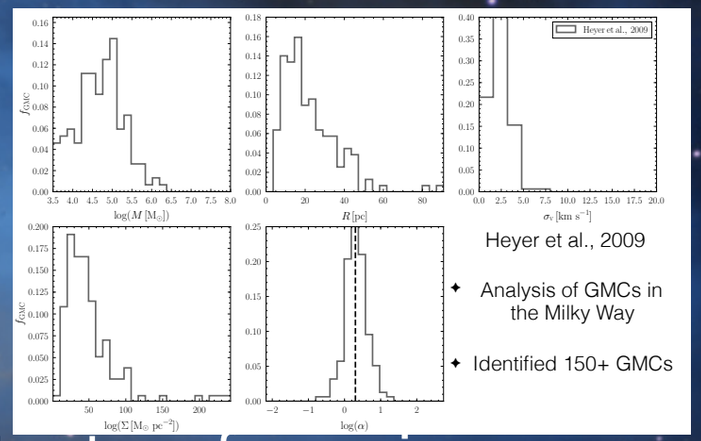
★ Stars shape and change their host GMC



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Star Forming Efficiencies of GMCs

$$\epsilon_{\rm ff} = \frac{t_{\rm ff}}{t_{\star,\rm young}} \frac{M_{\star,\rm young}}{M_{\rm GMC} + M_{\star,\rm young}}$$

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Star Forming Efficiencies of GMCs

Mean free fall time of GMC

Mass in young stars

$$\epsilon_{\rm ff} = \frac{t_{\rm ff}}{t_{\star,\rm young}} \frac{M_{\star,\rm young}}{M_{\rm GMC} + M_{\star,\rm young}}$$

Maximum age of young stars

GMC gas mass

Star Forming Efficiencies of GMCs

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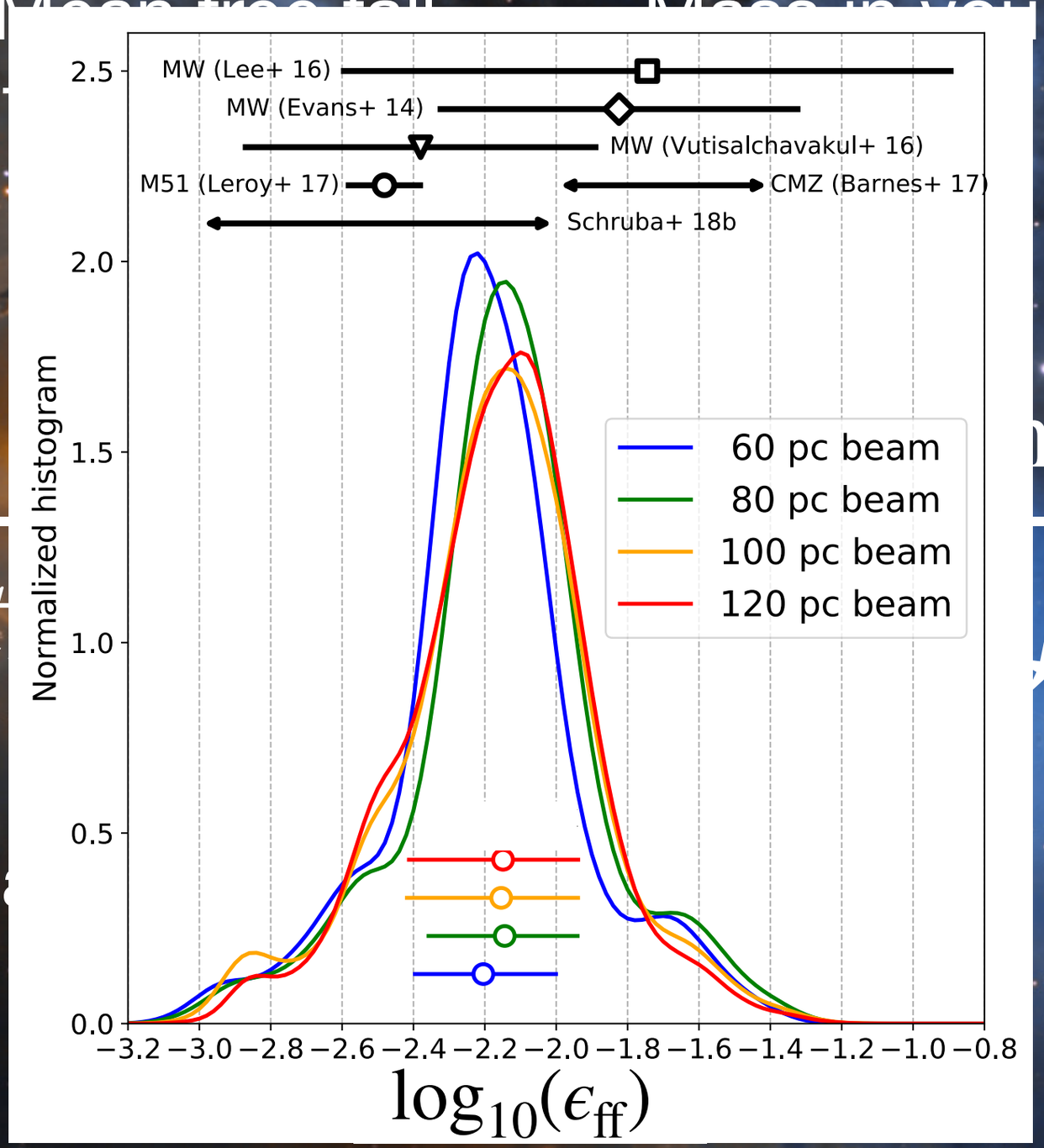


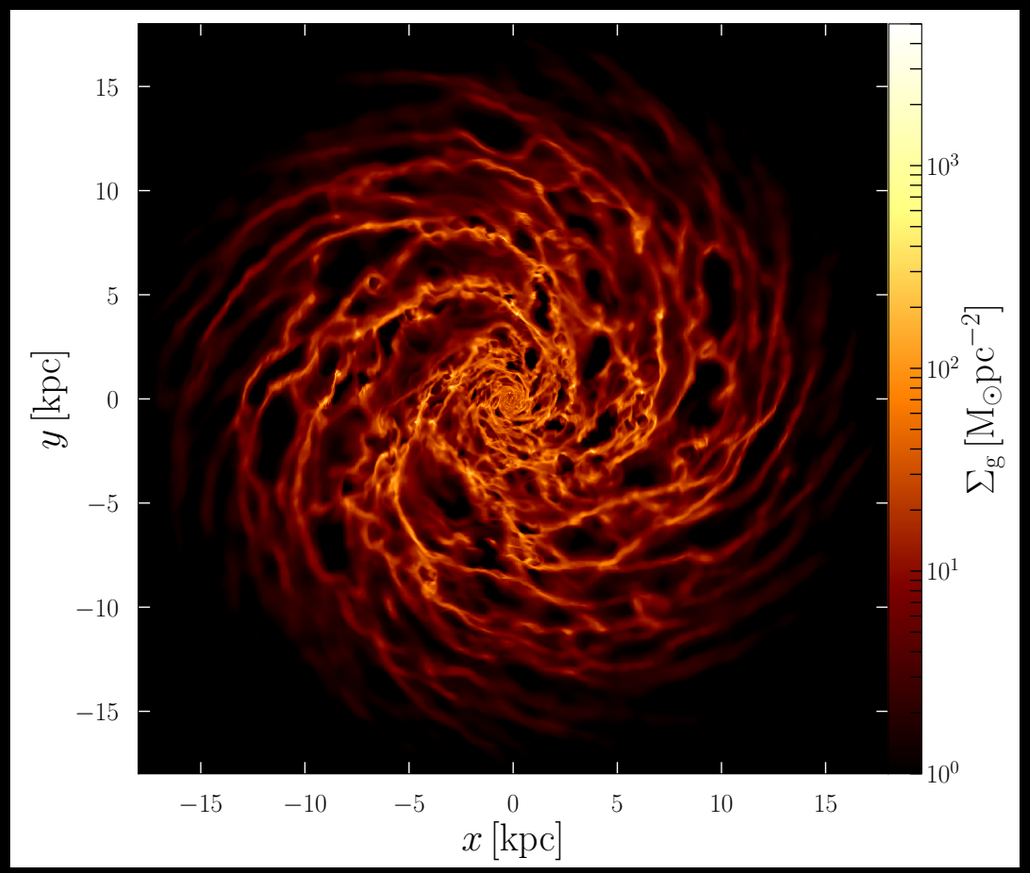
Utomo et al., 2018

Isolated MW-Like Disc Simulation

Gas Stars

AMR-Code Ramses, Resolution =4.6pc, Star particle mass = 300 Msol,
Chabrier IMF, Star formation.
Stellar feedback: Stellar winds, radiation pressure, Type Ia and II supernovae
(Agertz et al., 2013,2015)

GMCs in the Simulation



Two methods to find GMCs: Grisdale et al., 2018

1. 2D: observer based, post-processing, clump finding on surface density
2. 3D: on the fly, clump finding on volume density

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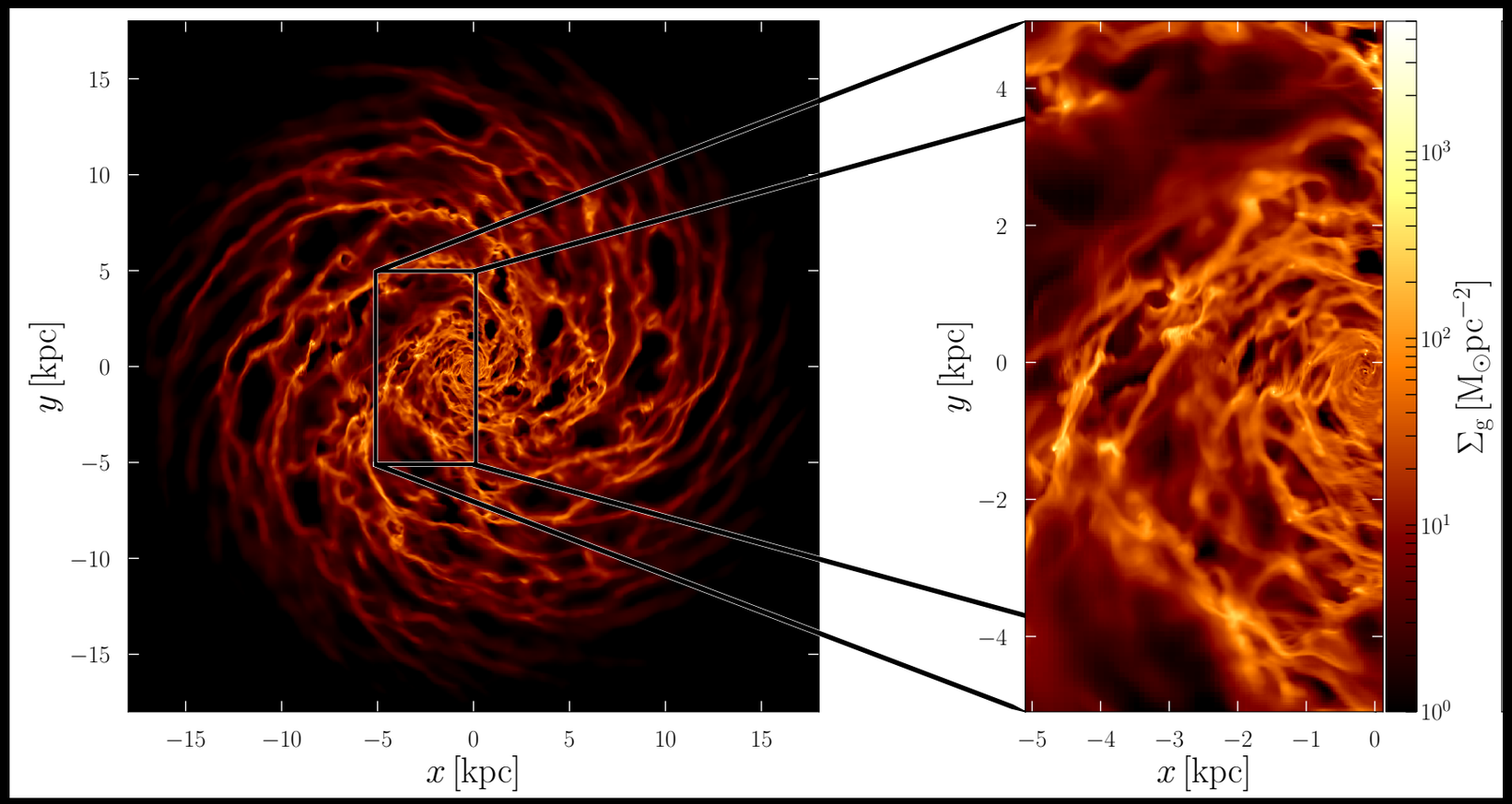

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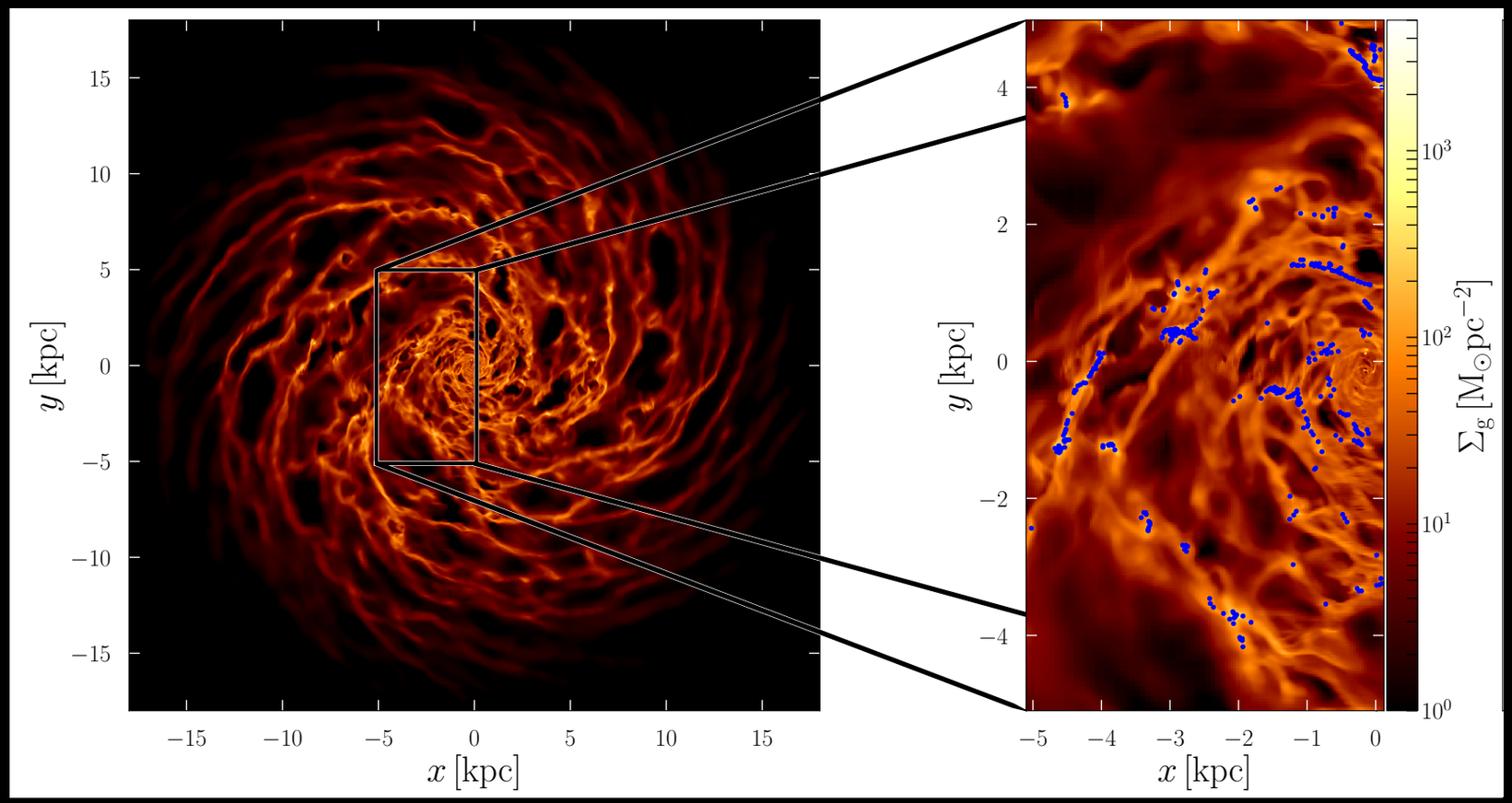

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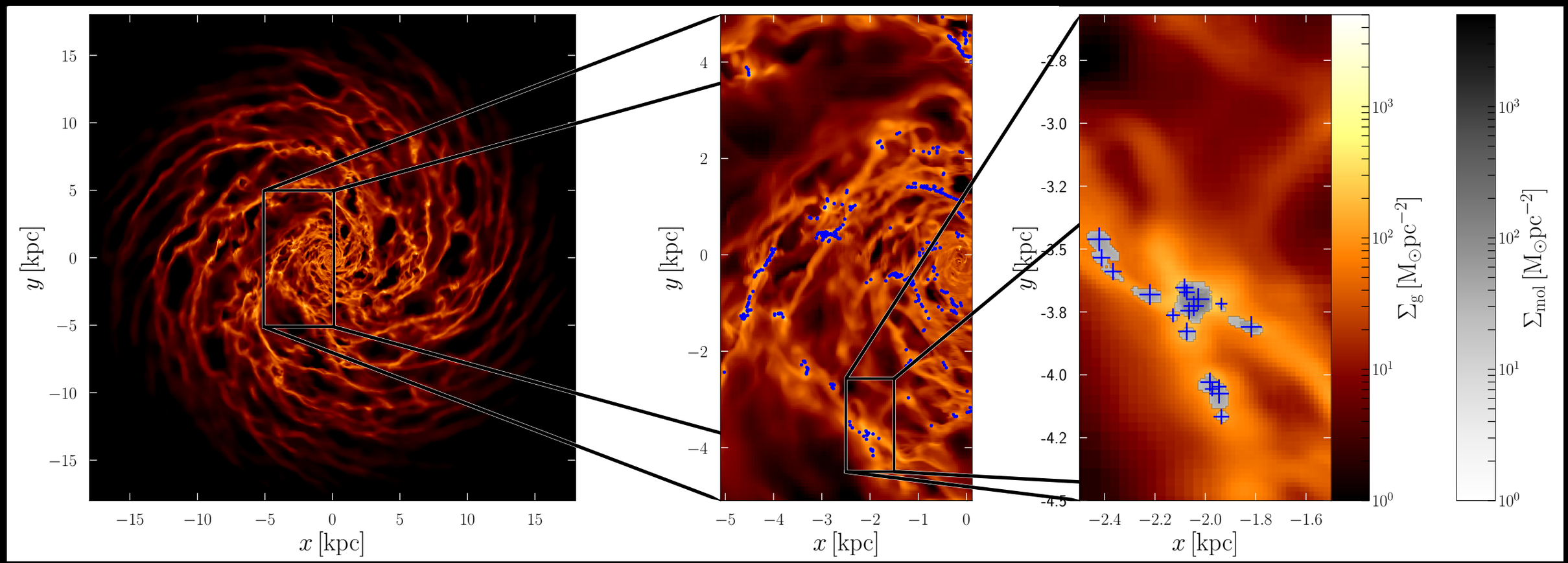

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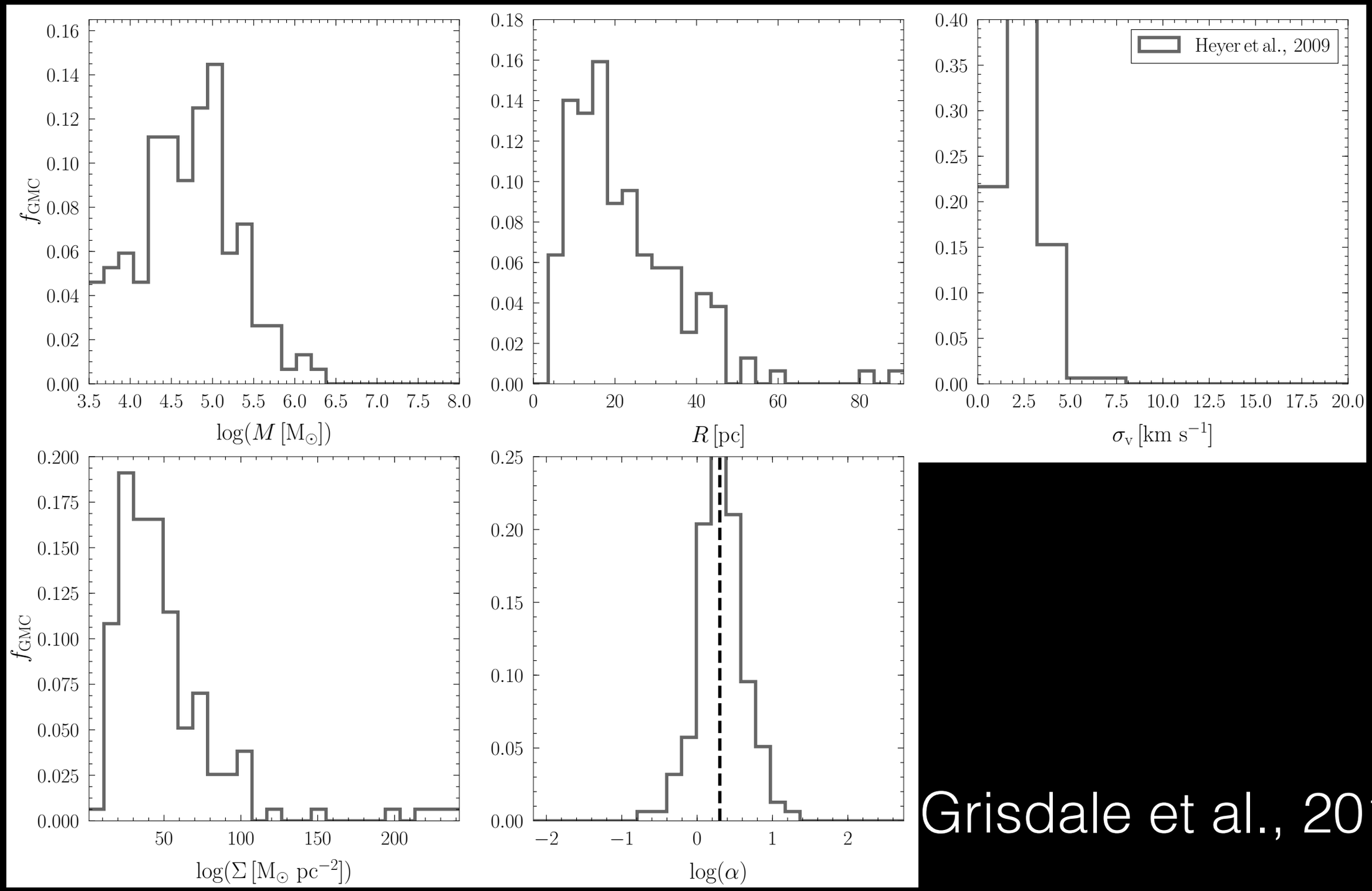

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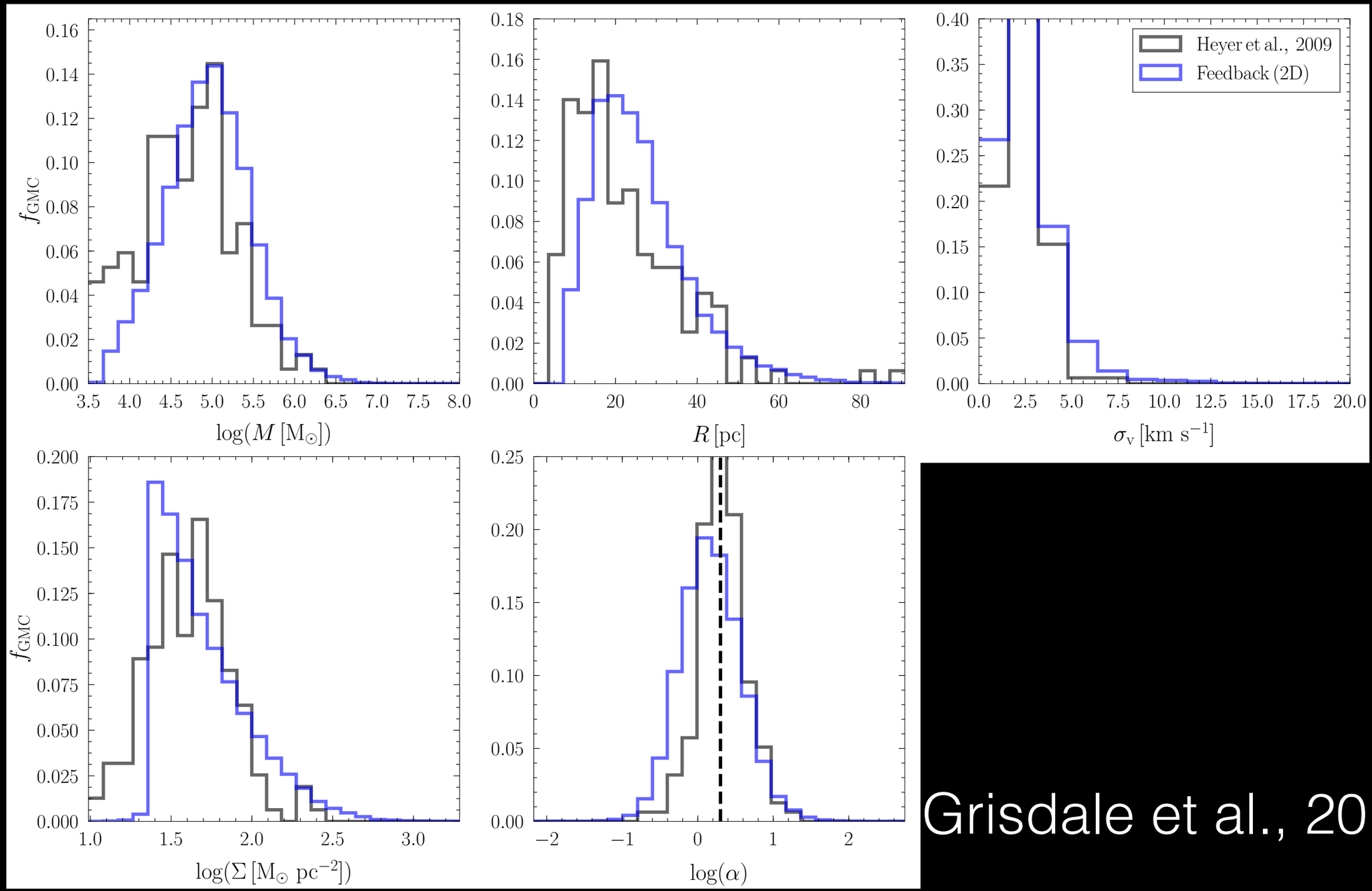

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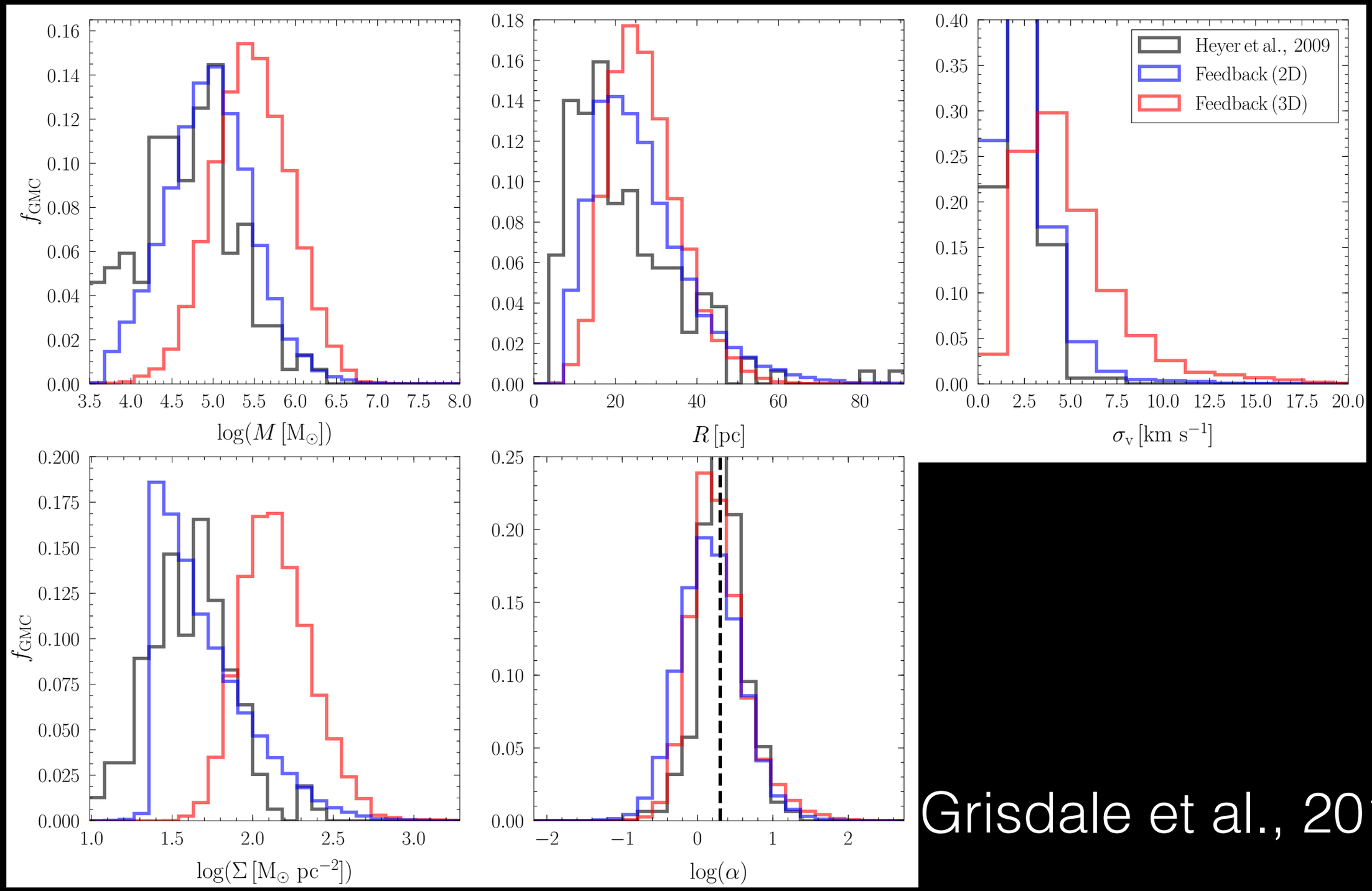

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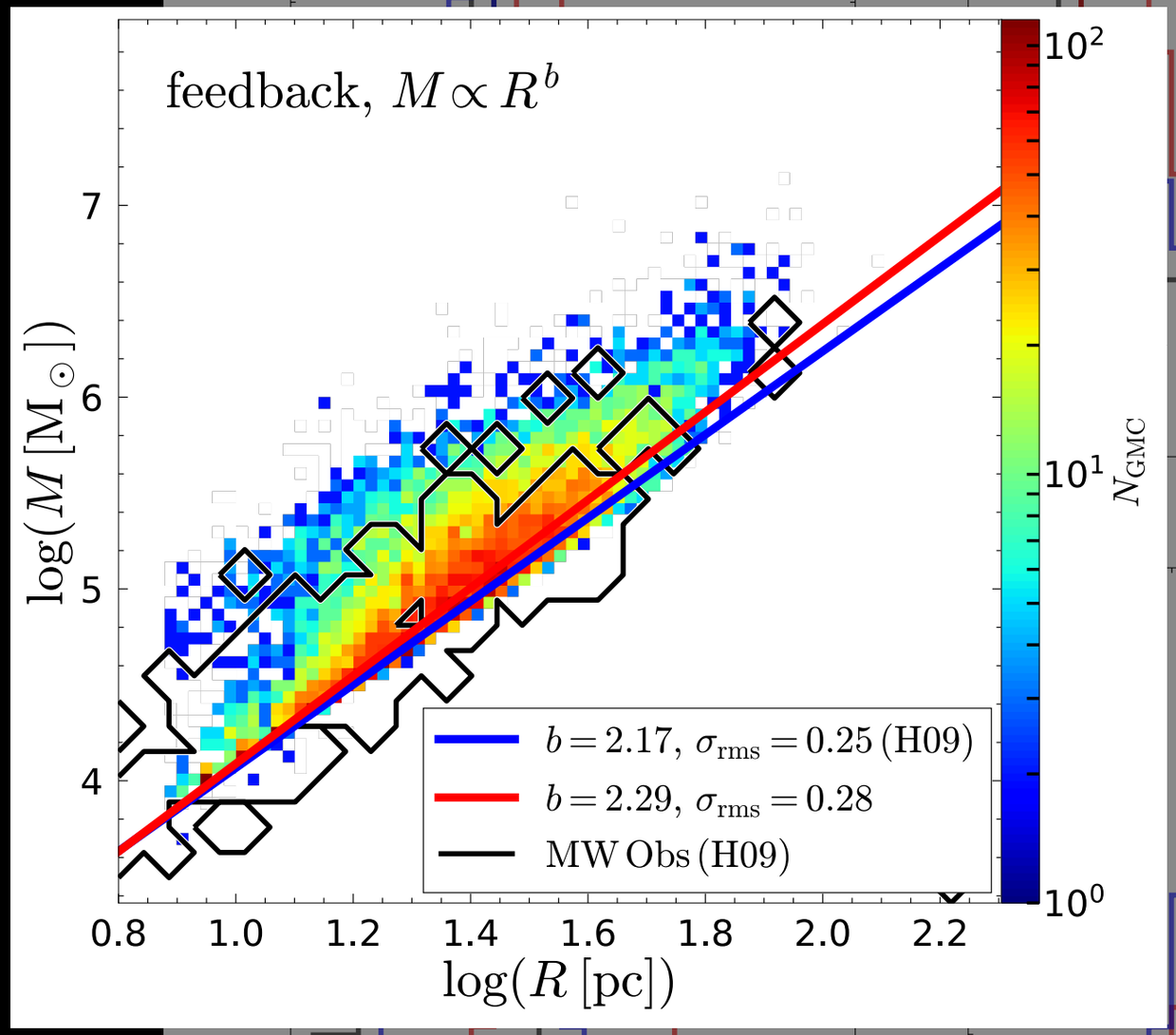

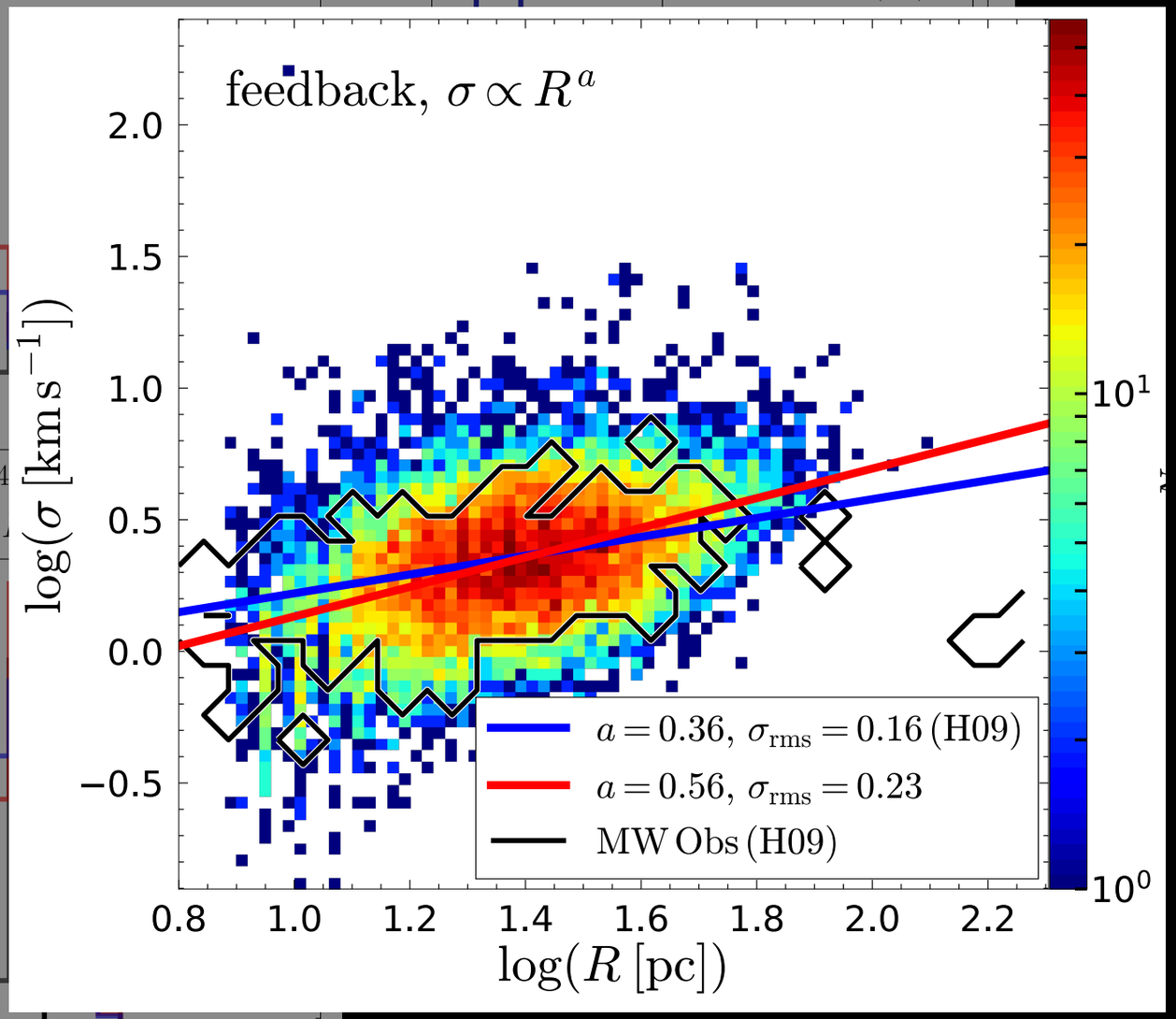

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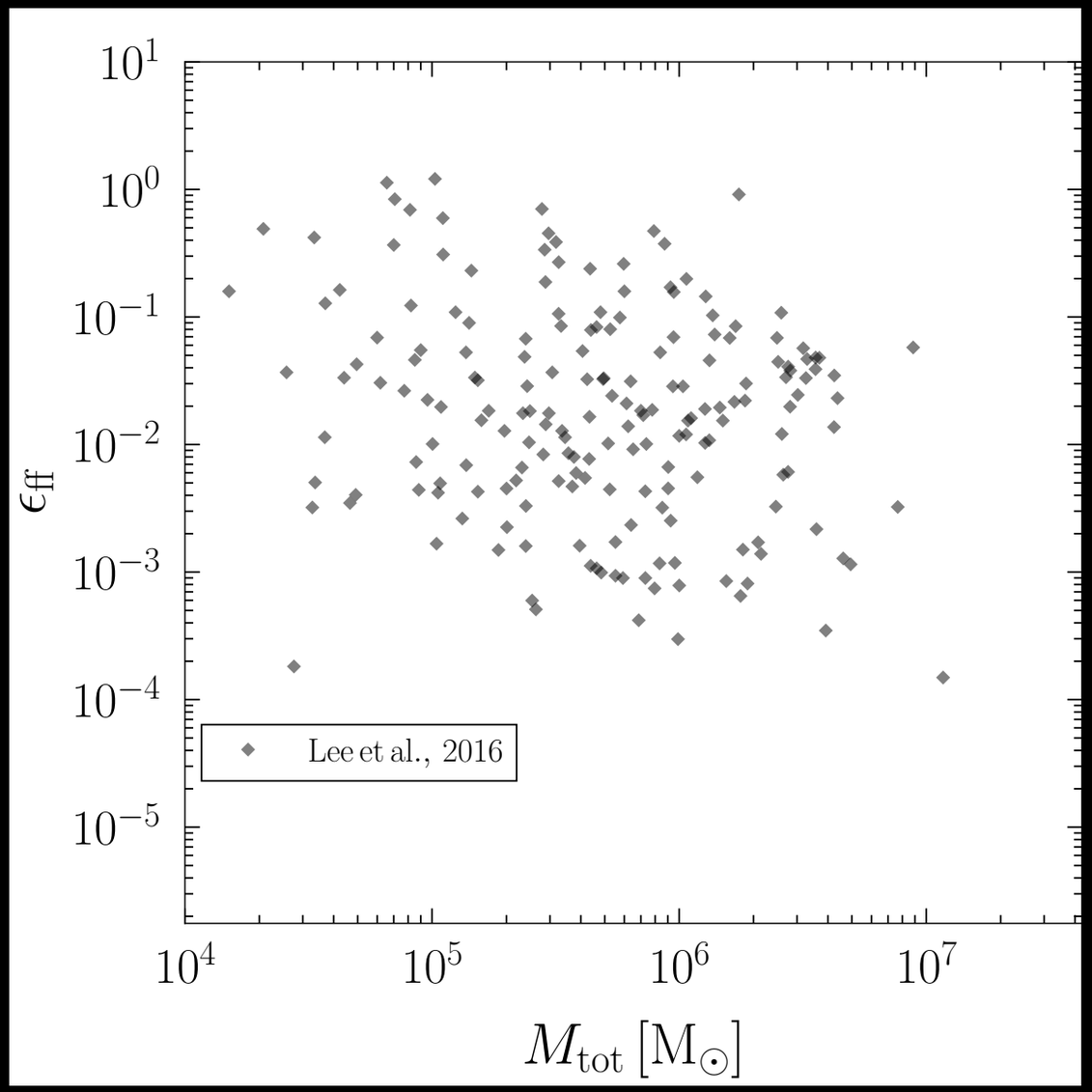

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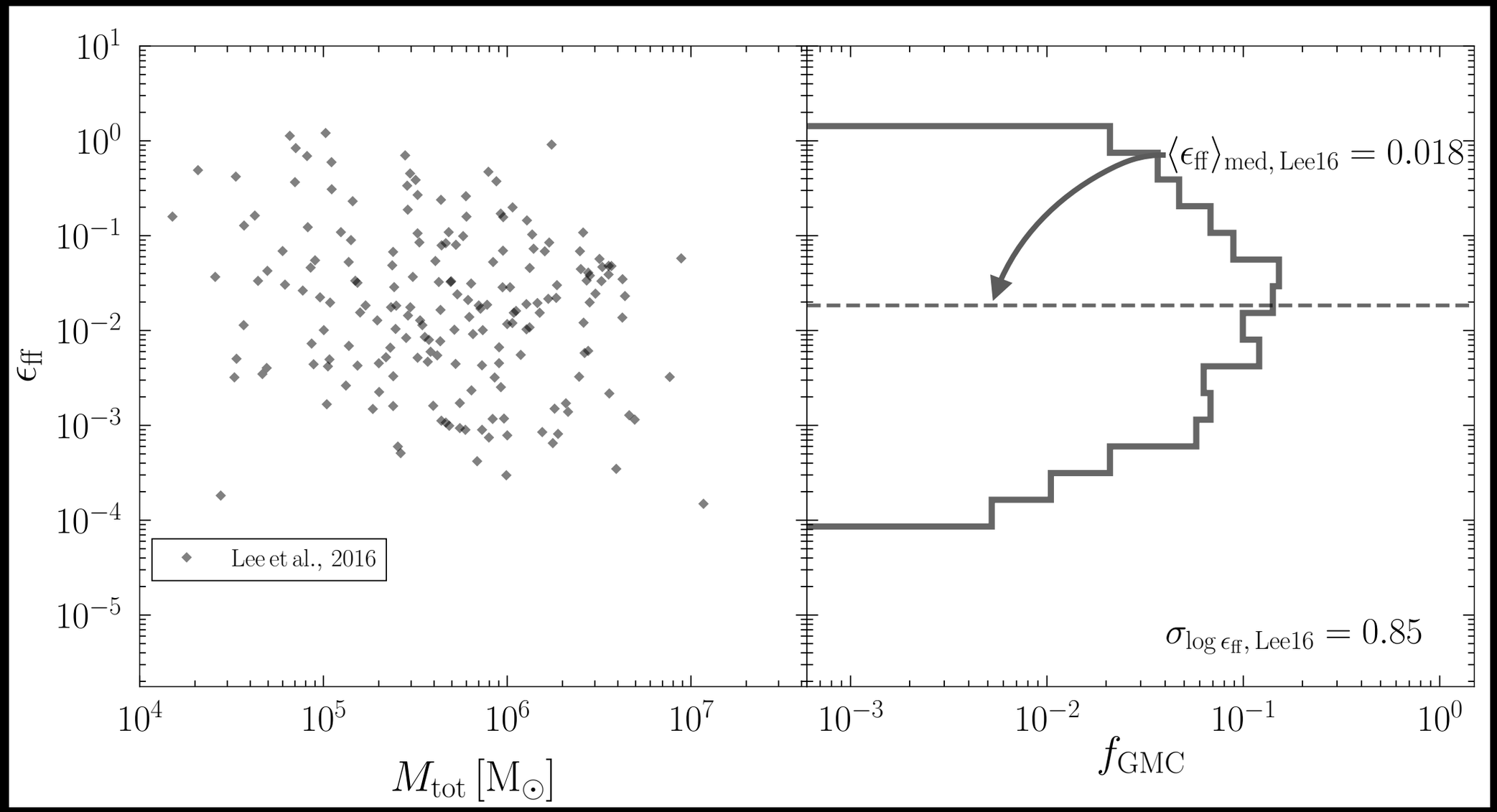

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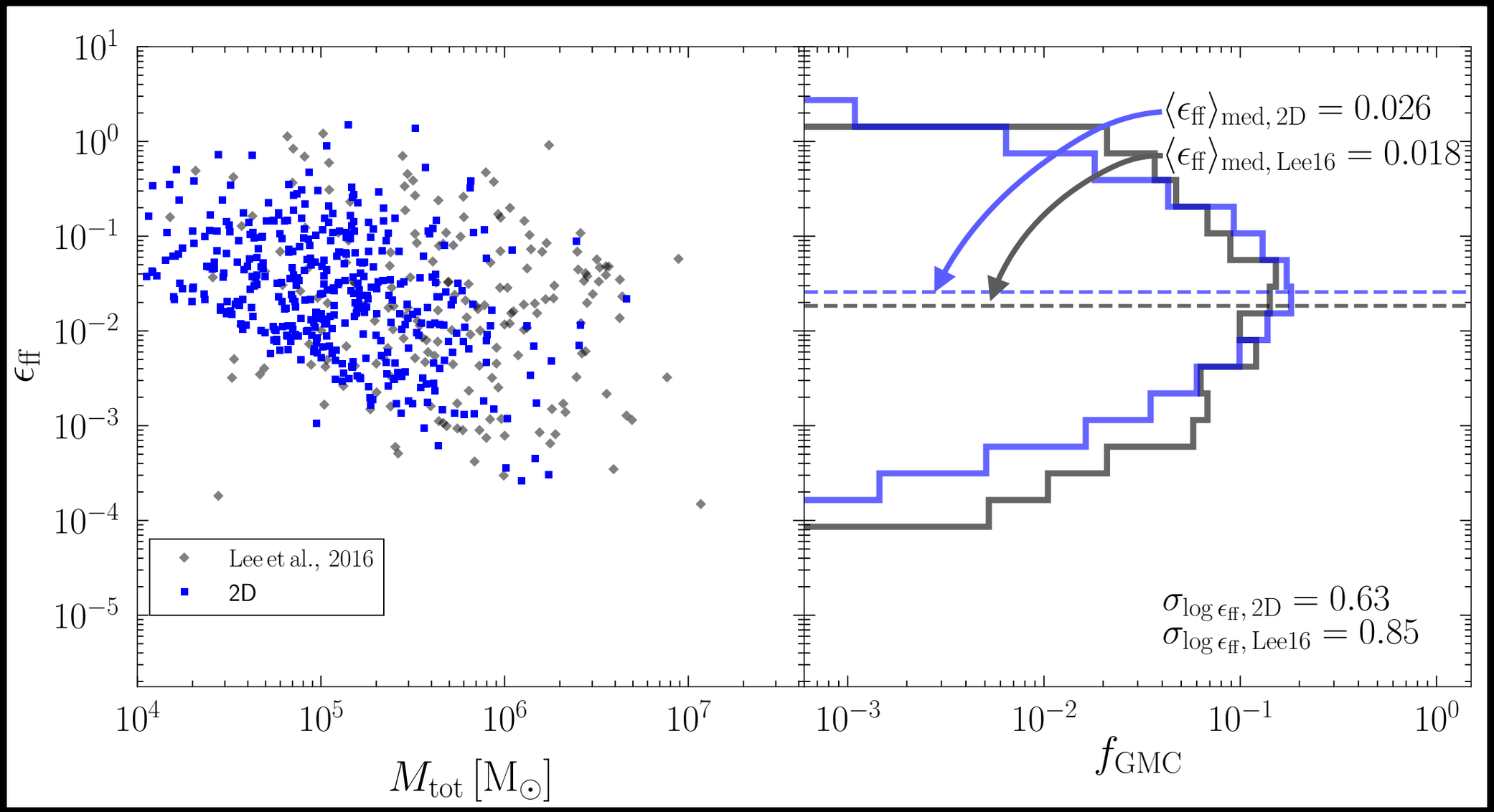

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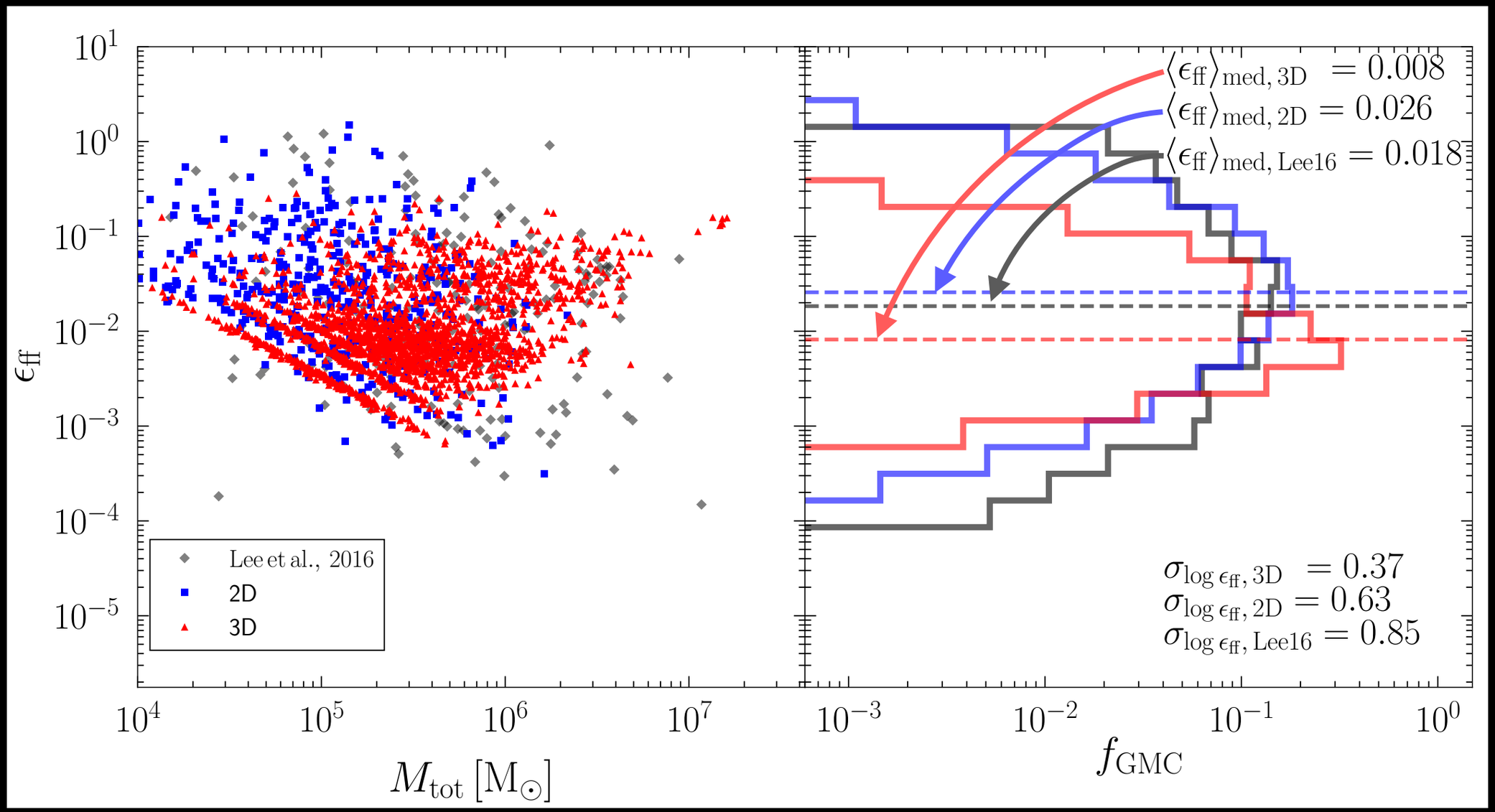

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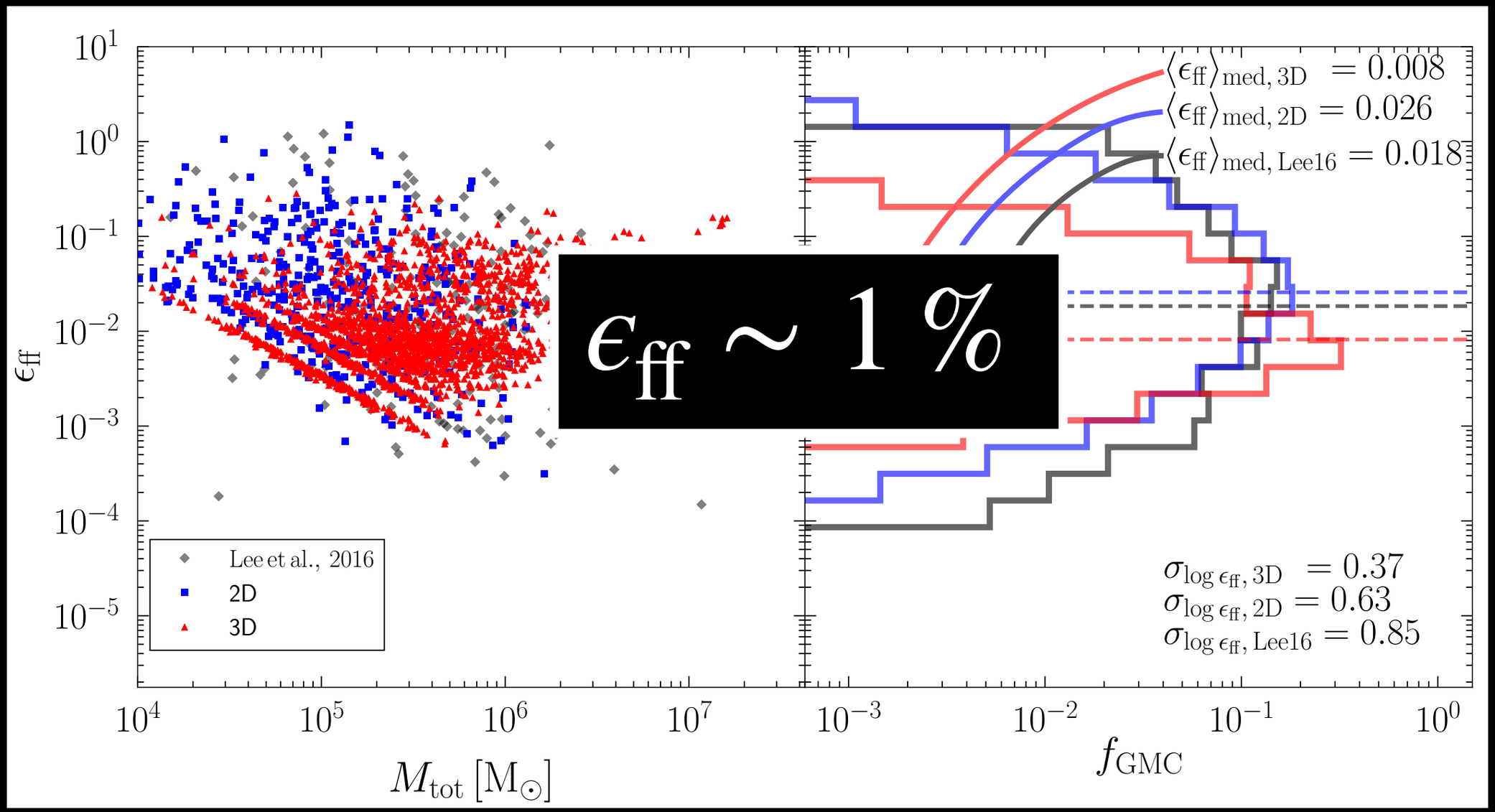

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Intrinsic Efficiency

Star Formation per cell:

$$\dot{M}_\star = \epsilon_{\mathrm{ff,SF}} \frac{M_{\mathrm{mol}}}{t_{\mathrm{ff}}}$$

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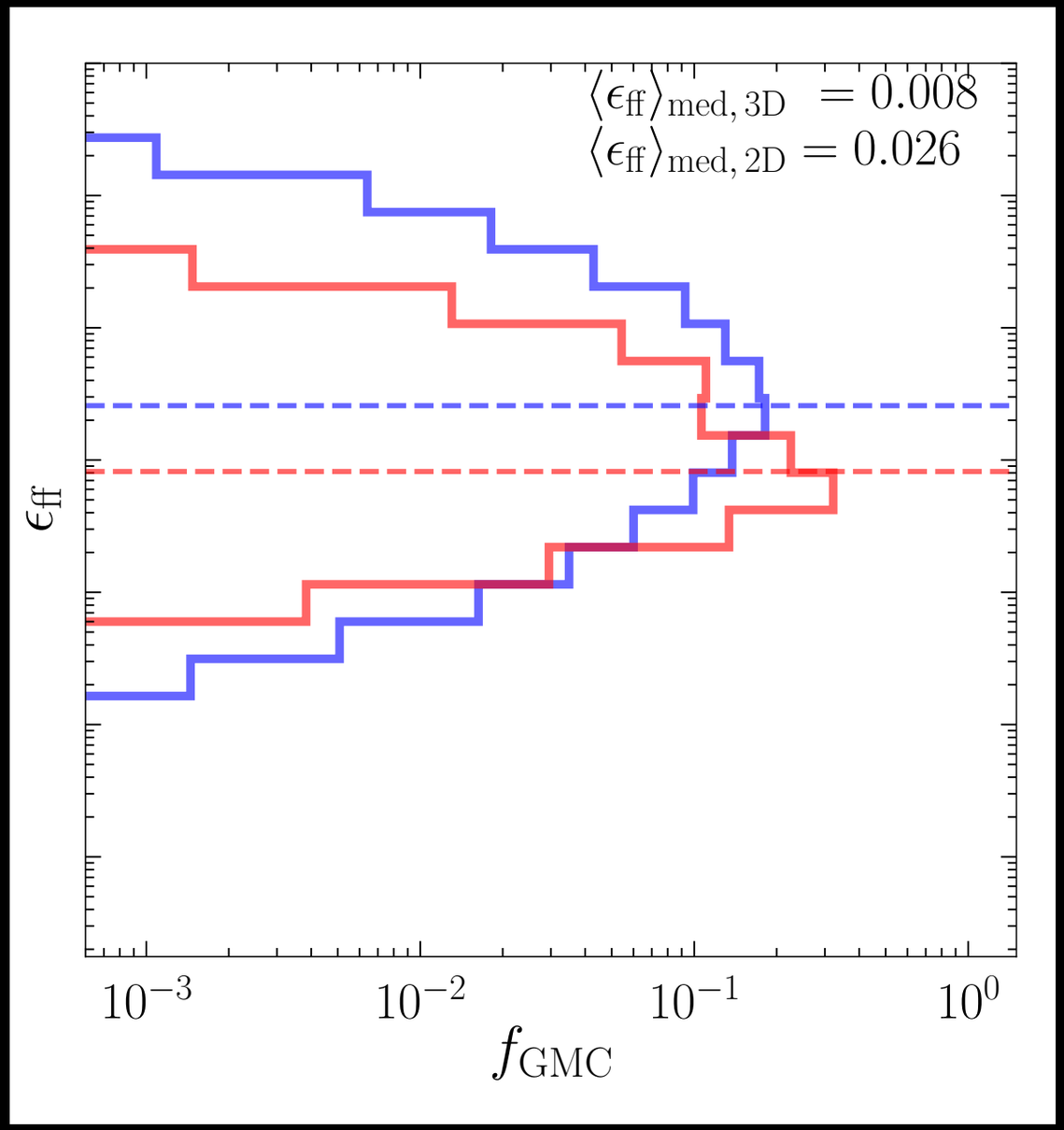

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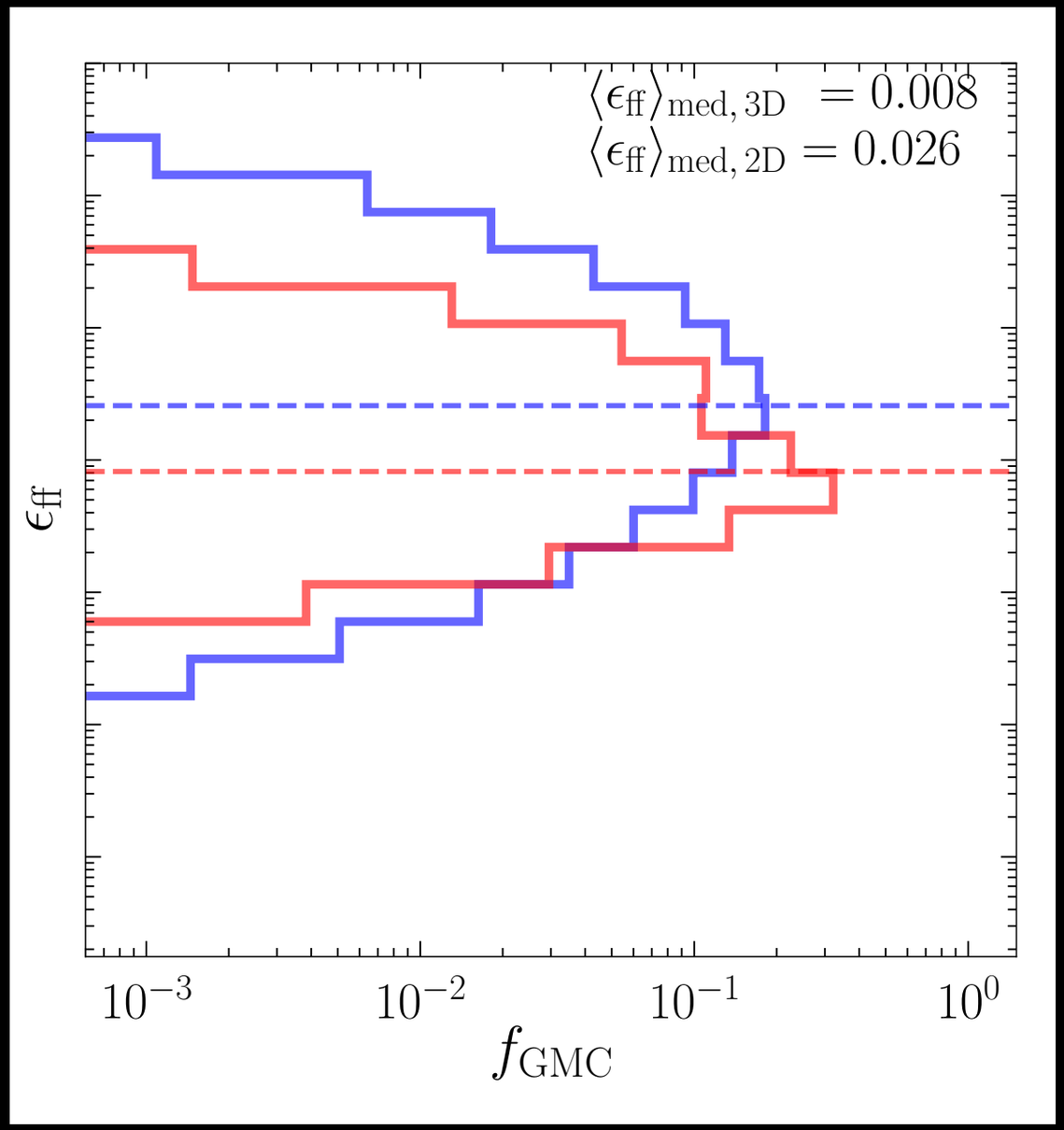

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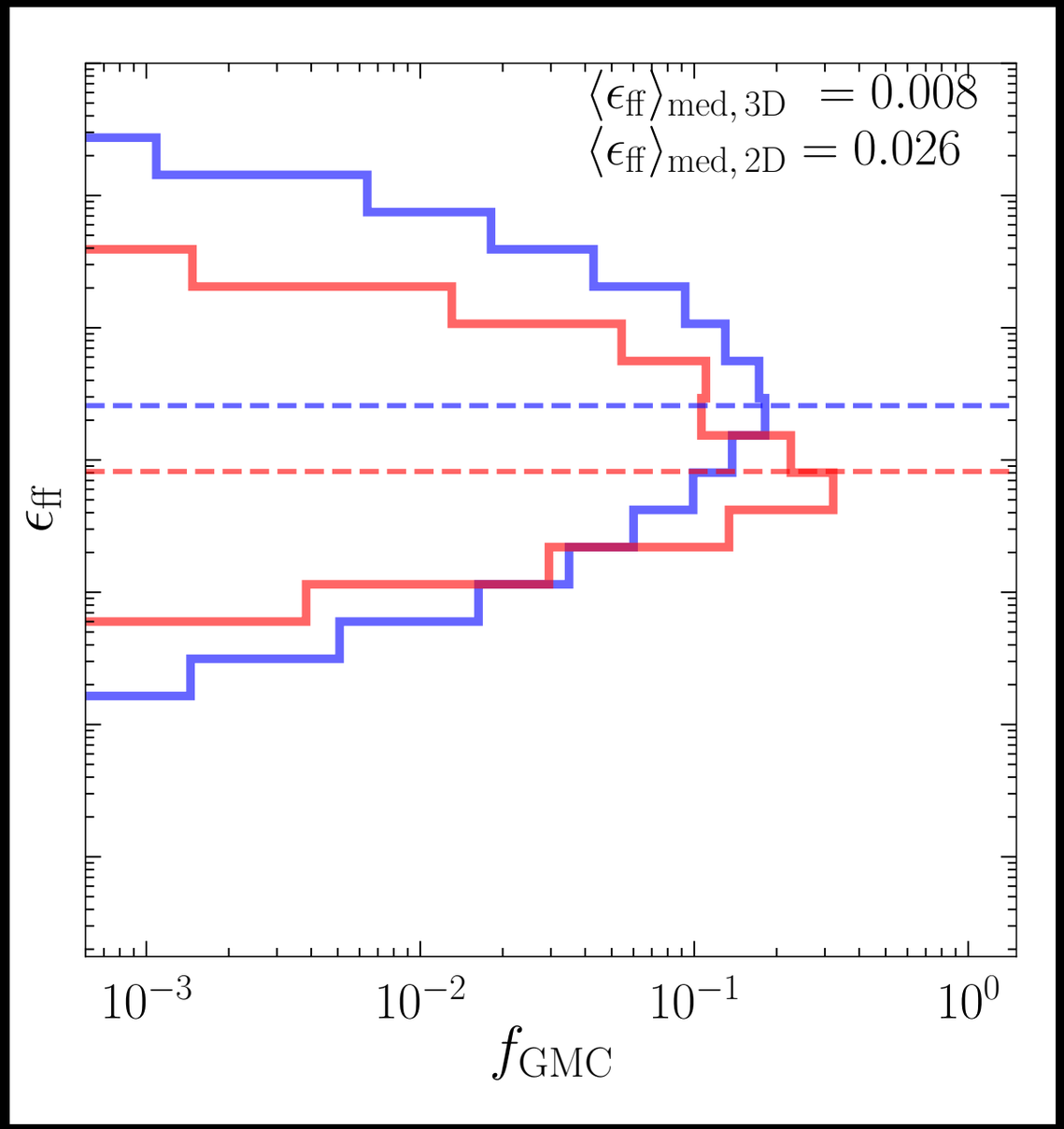

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Star F

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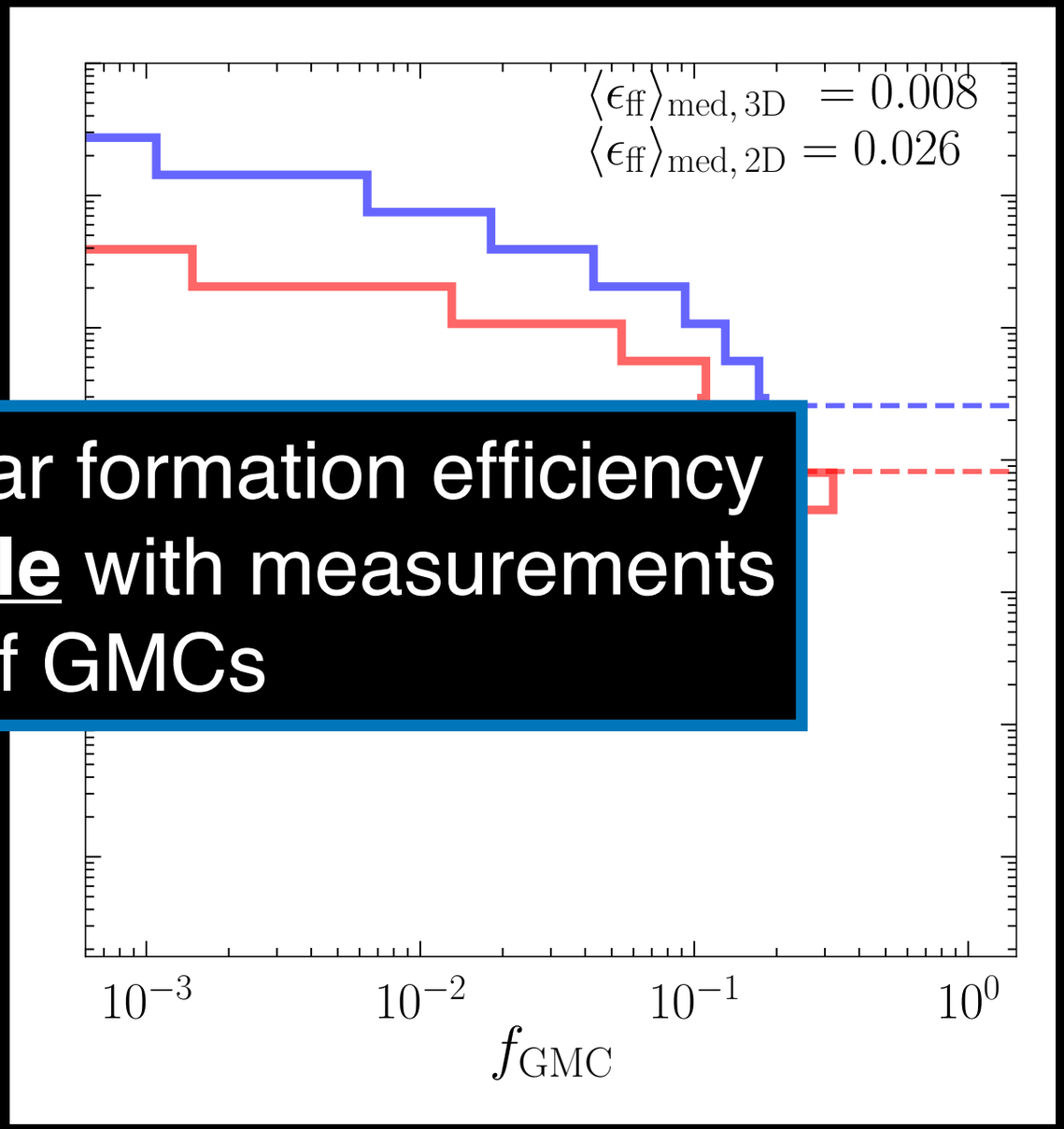
Measuring the intrinsic star formation efficiency of Universe is **not possible** with measurements on scales of GMCs



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Evolution and Efficiency

Toy Model:

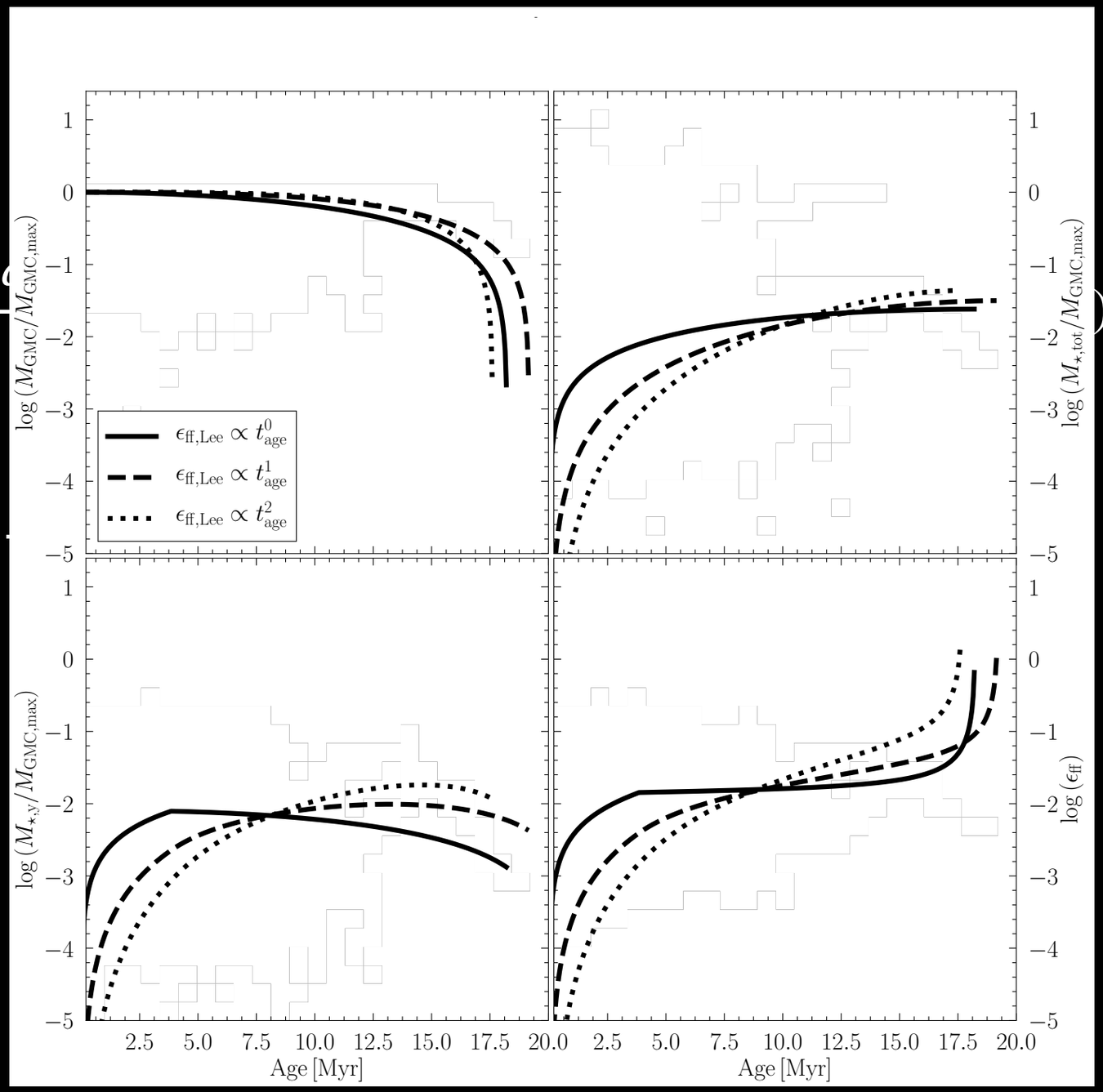
$$\frac{dM_{\rm GMC}}{dt} = -\epsilon_{\rm ff,0}\left(\frac{t_{\rm age}}{t_{\rm ff}}\right)^{\delta}\frac{M_{\rm GMC}(t_{\rm age})}{t_{\rm ff}} - \alpha M_{\star,\rm tot}(t_{\rm age})$$

$$\frac{dM_{\star,\rm tot}}{dt} = \epsilon_{\rm ff,0}\left(\frac{t_{\rm age}}{t_{\rm ff}}\right)^{\delta}\frac{M_{\rm GMC}(t_{\rm age})}{t_{\rm ff}}$$

$$t_{\rm ff} = 6.7\,{\rm Myr}\,({\rm fixed})$$

$$\epsilon_{\rm ff,Lee} = \epsilon_{\rm ff,0}\left(\frac{t_{\rm age}}{t_{\rm ff}}\right)^{\delta}$$

Evolution and Efficiency



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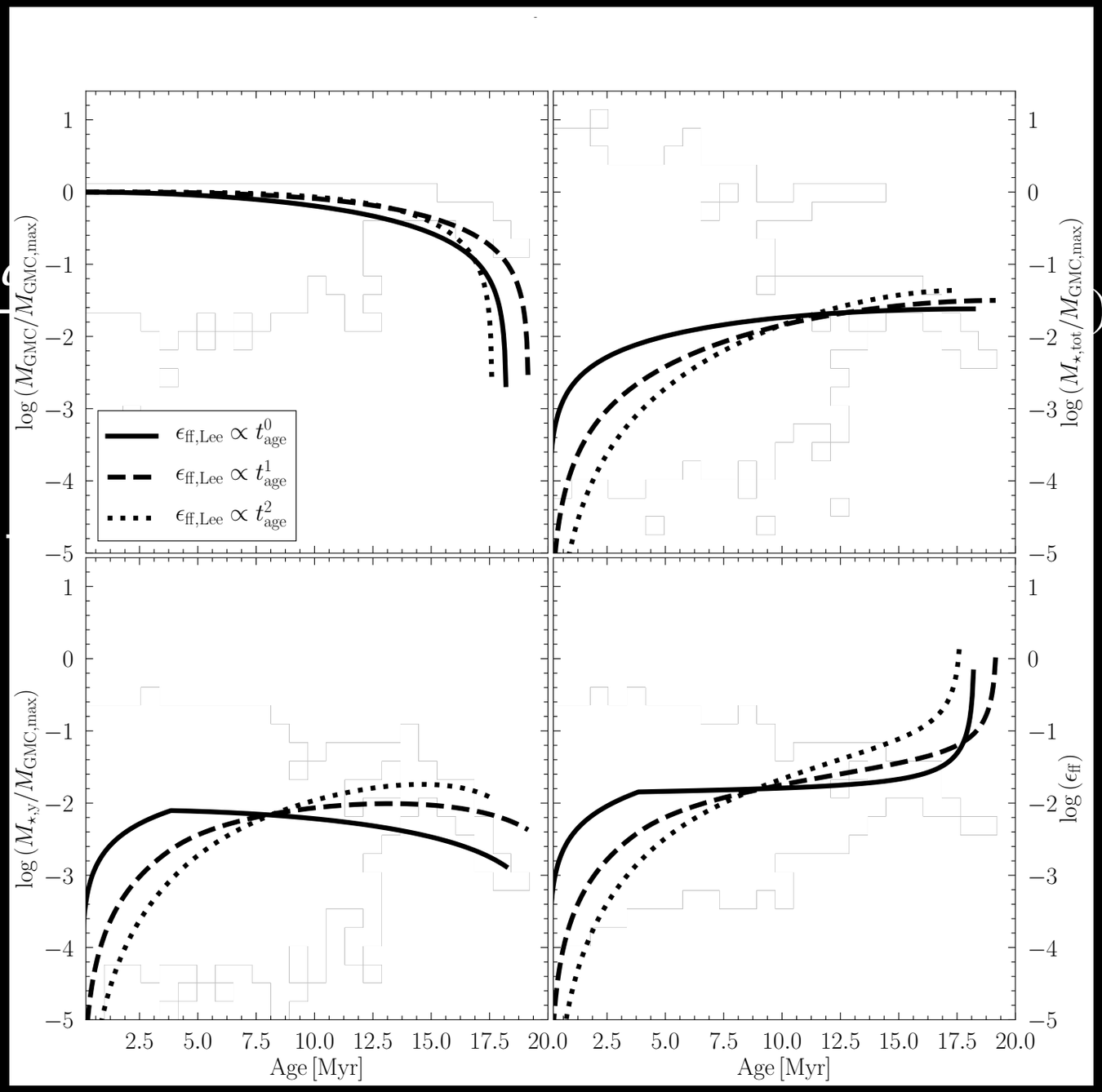
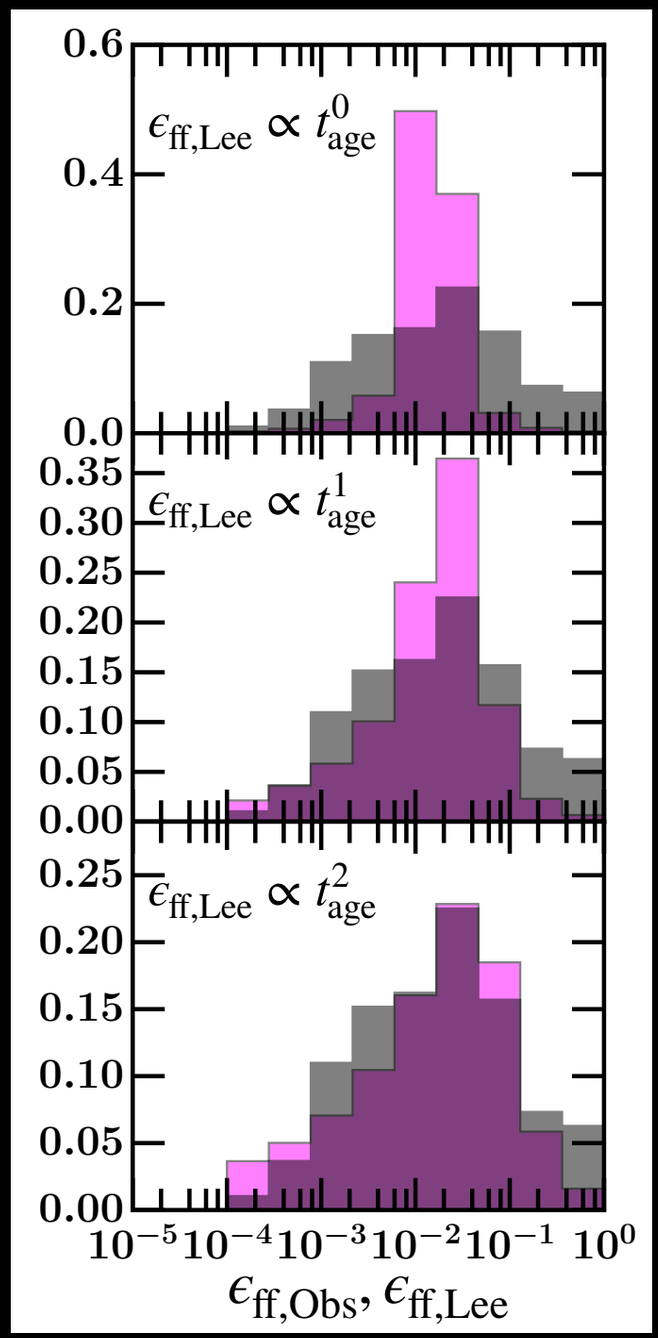
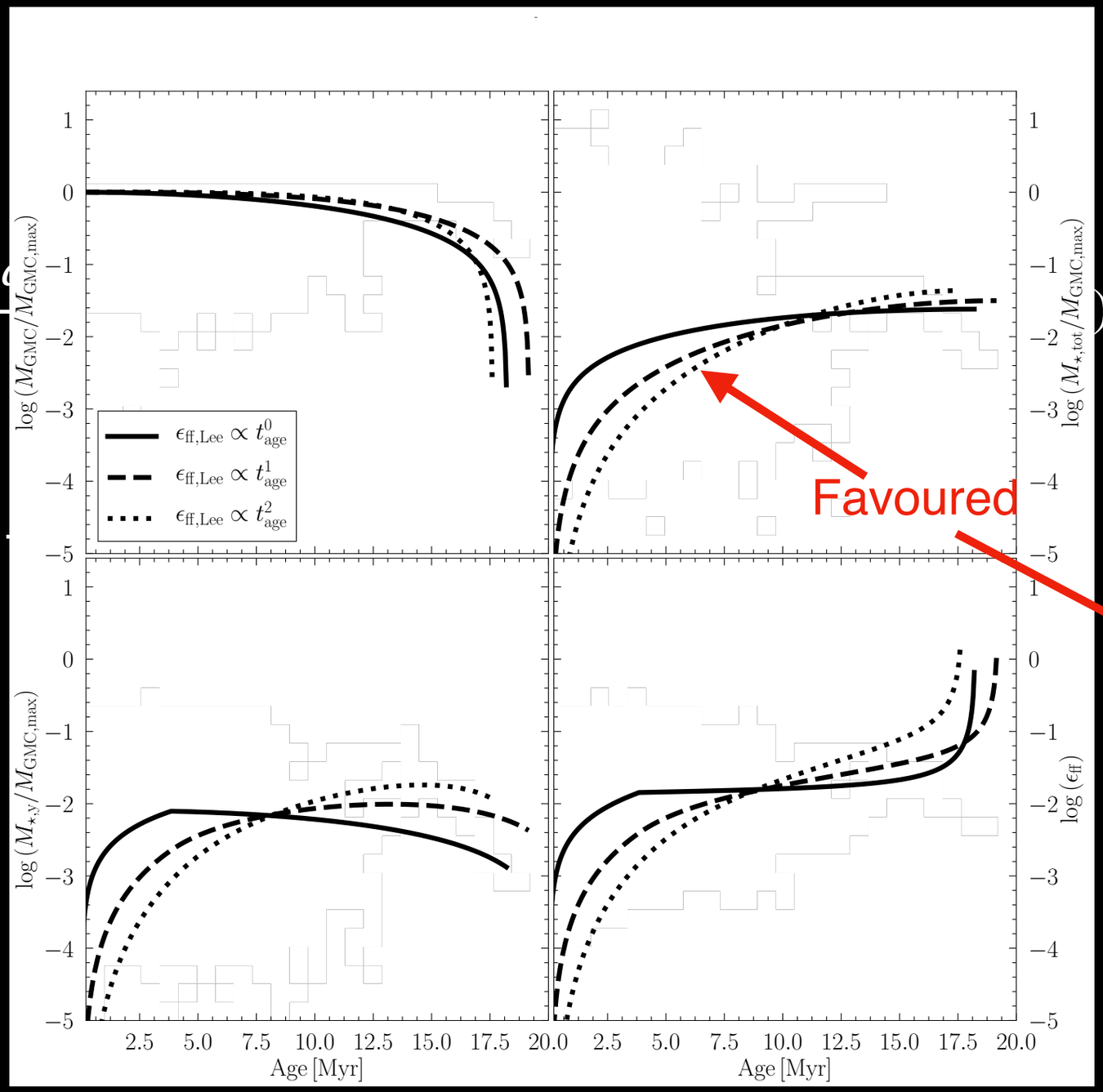


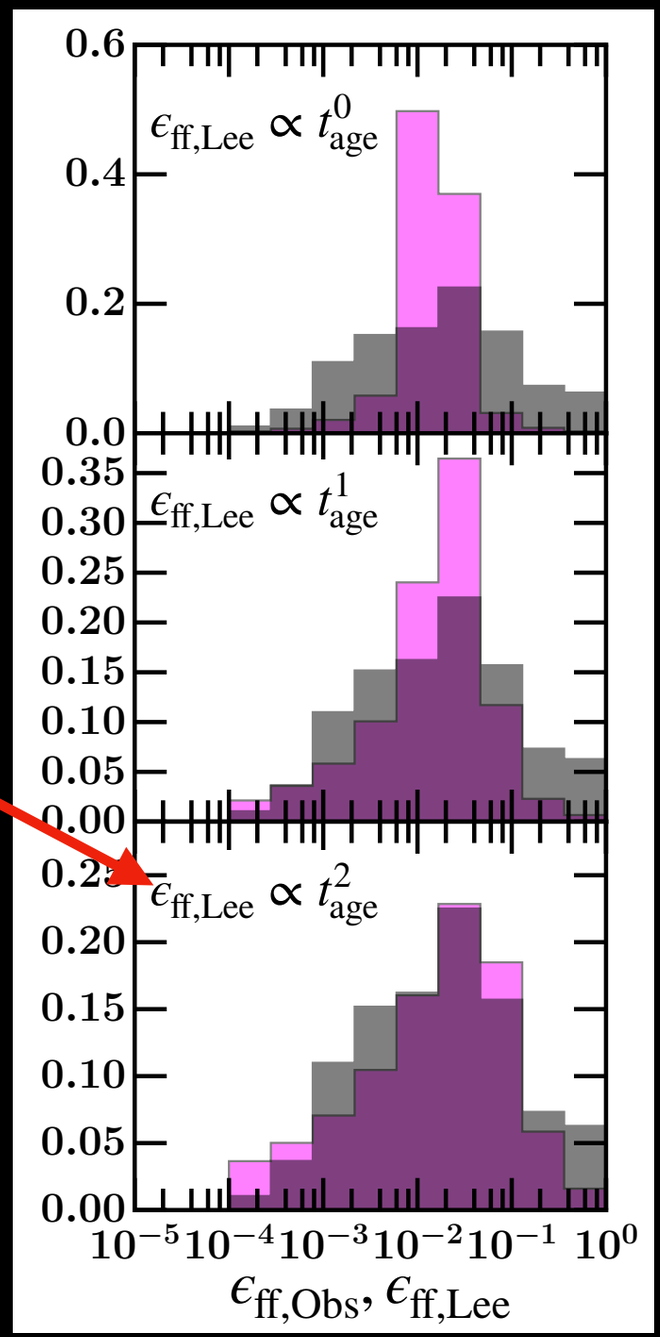


Lee et al., 2016

Evolution and Efficiency



Favoured



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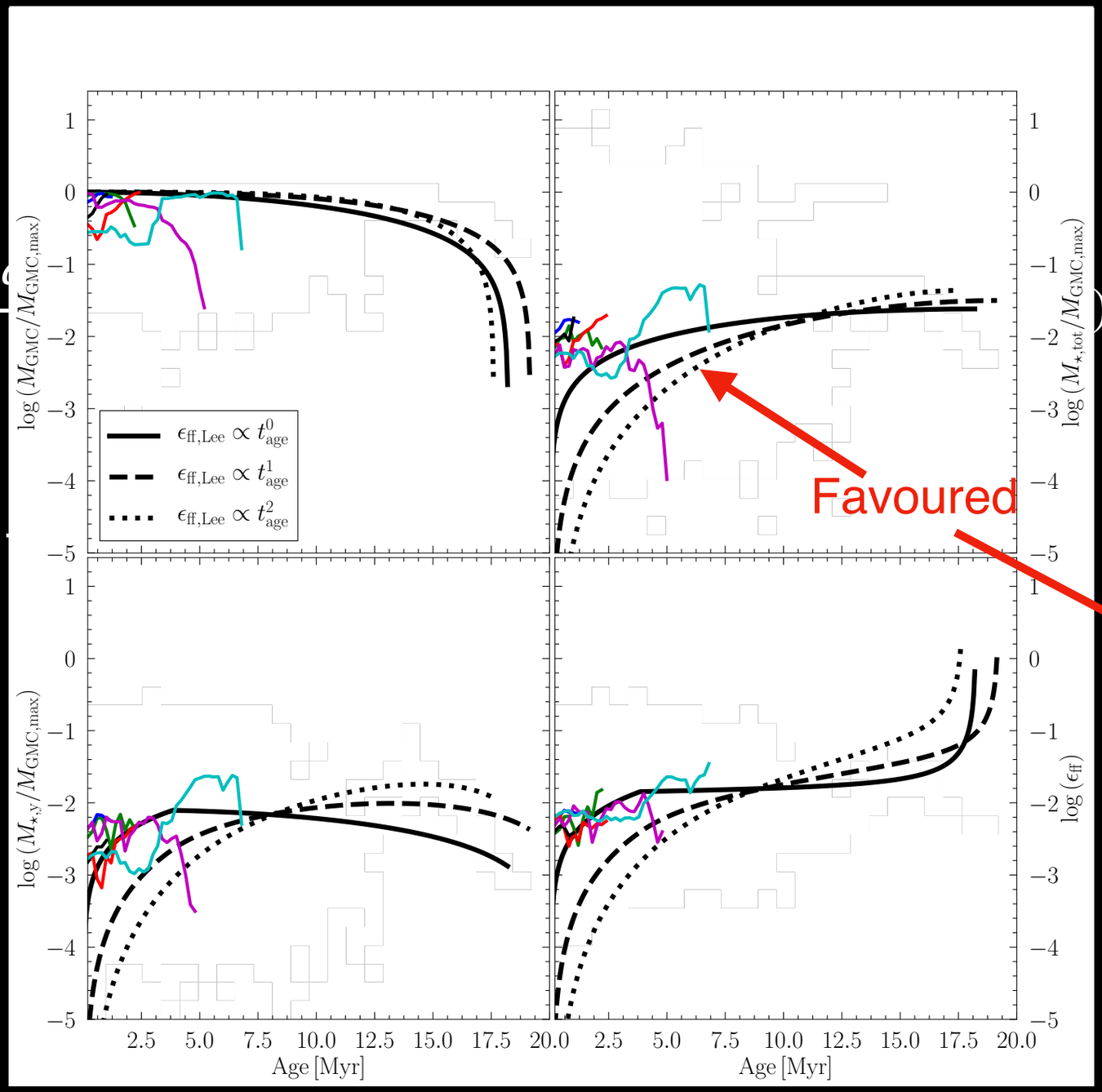

Grisdale et al., (in prep.)

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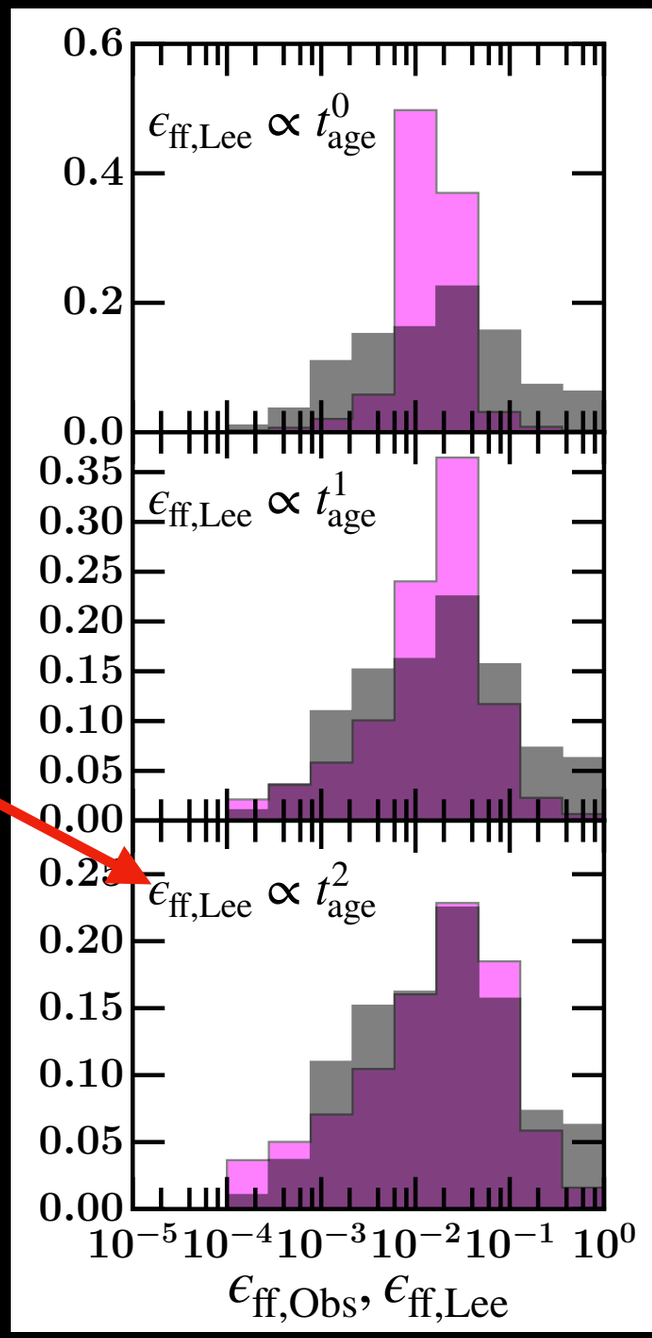

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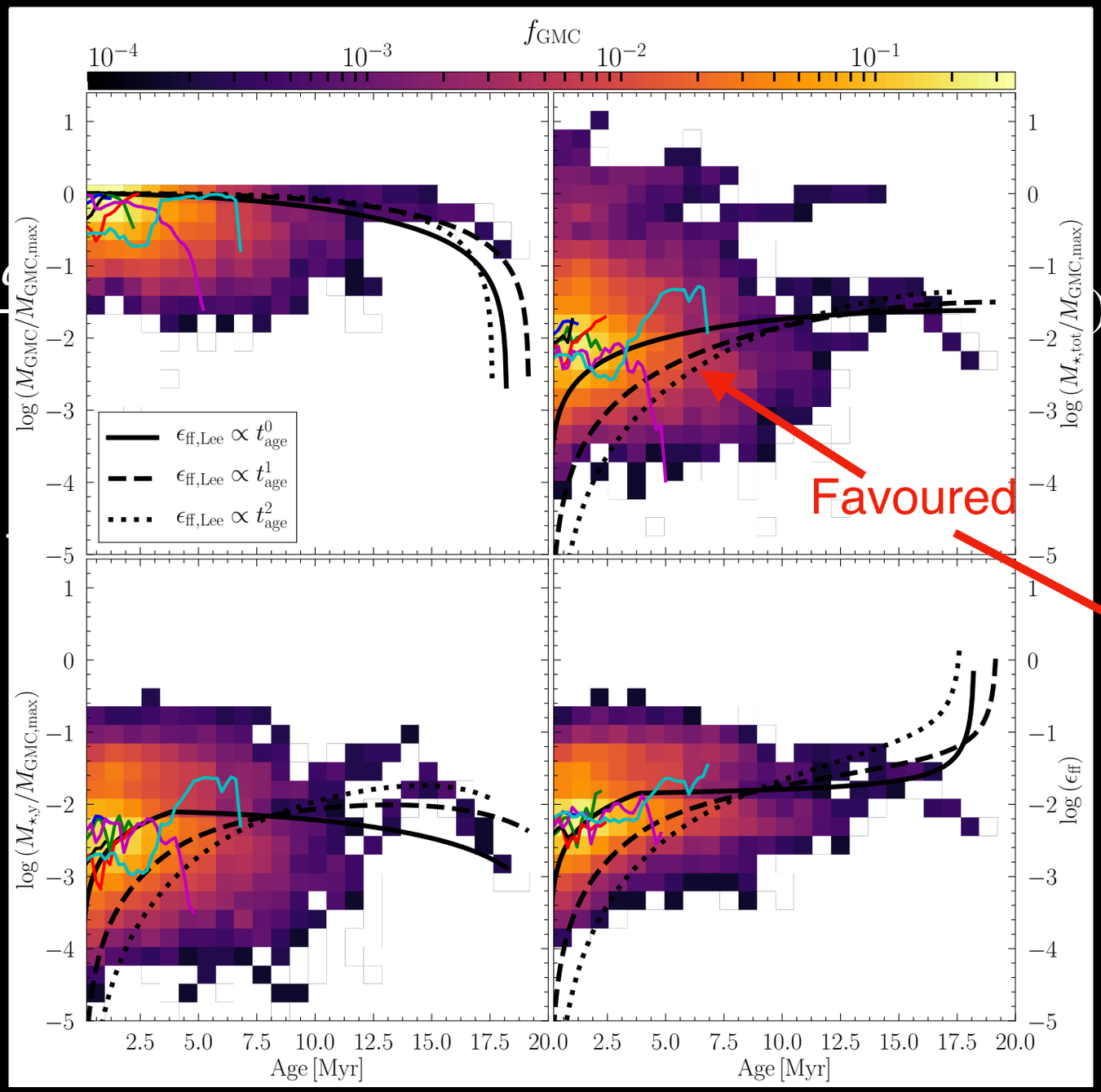

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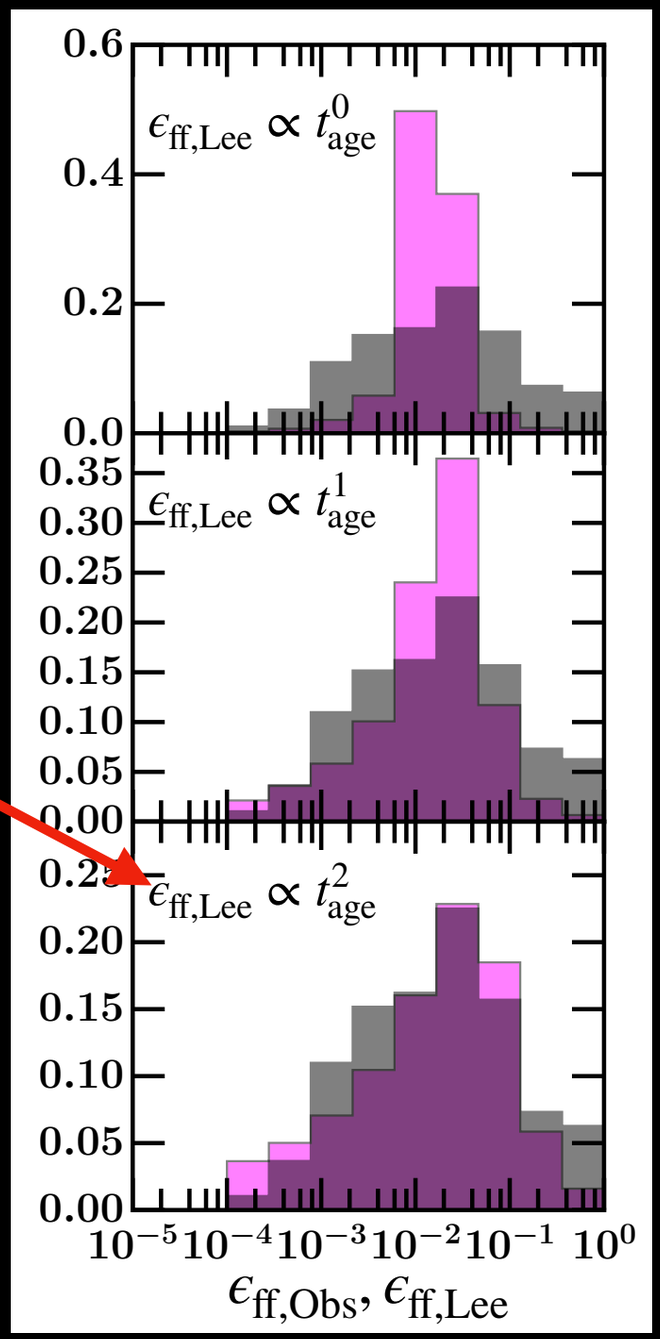

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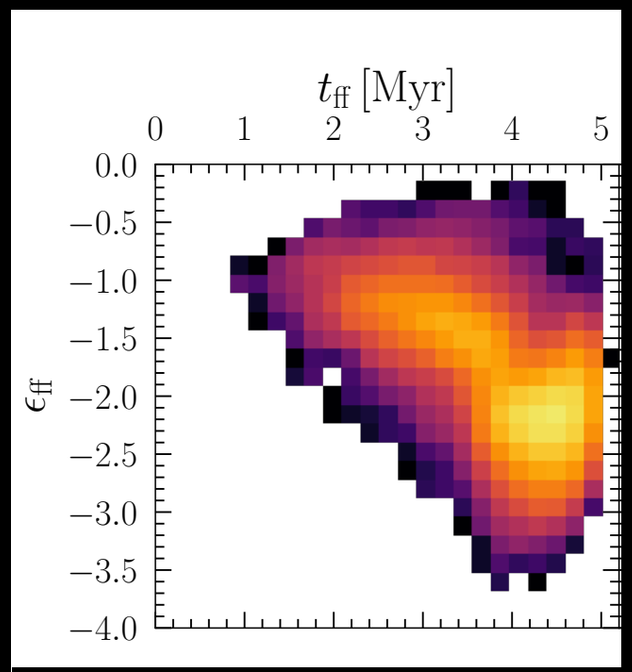
Source of the Variation



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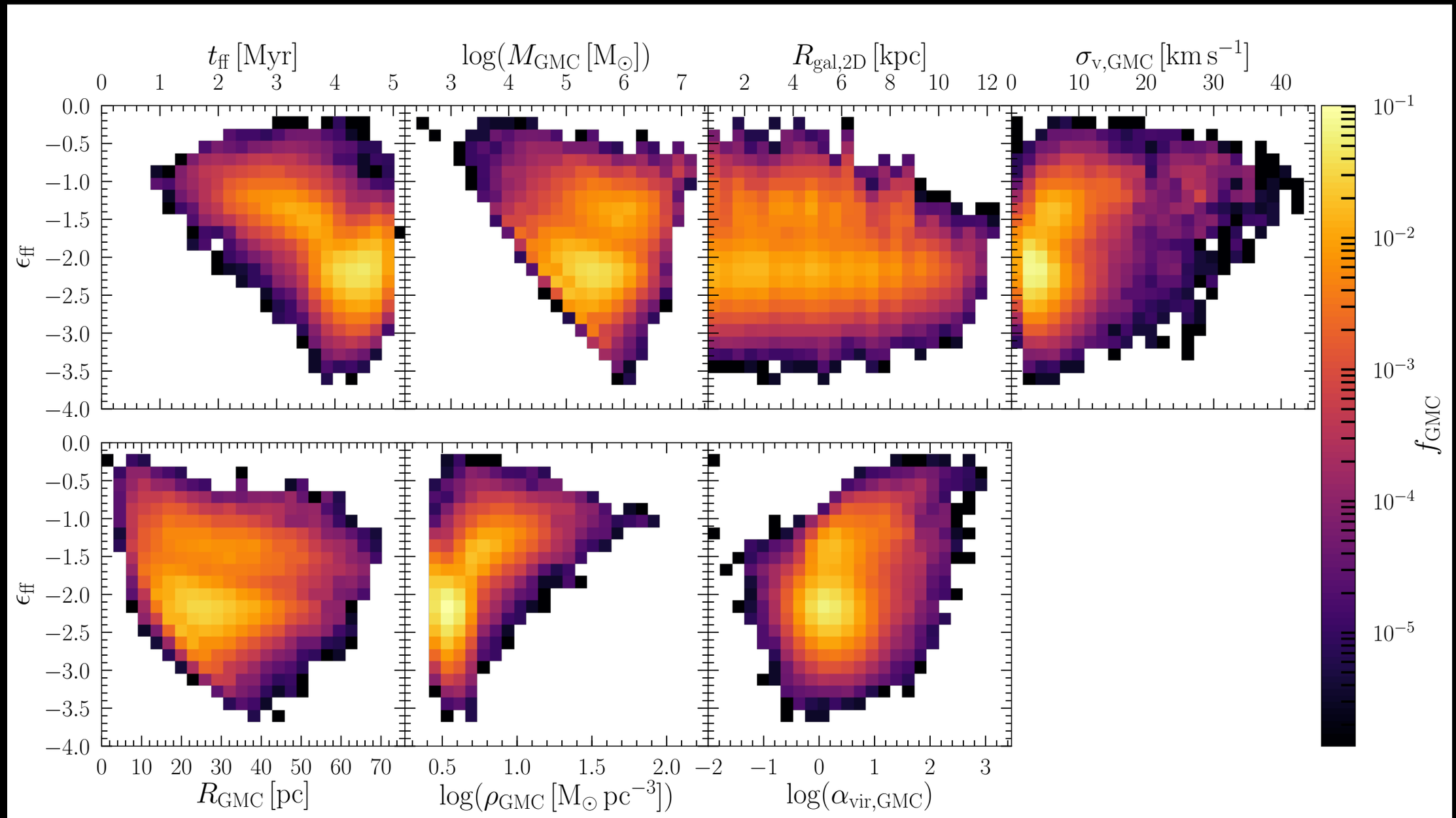

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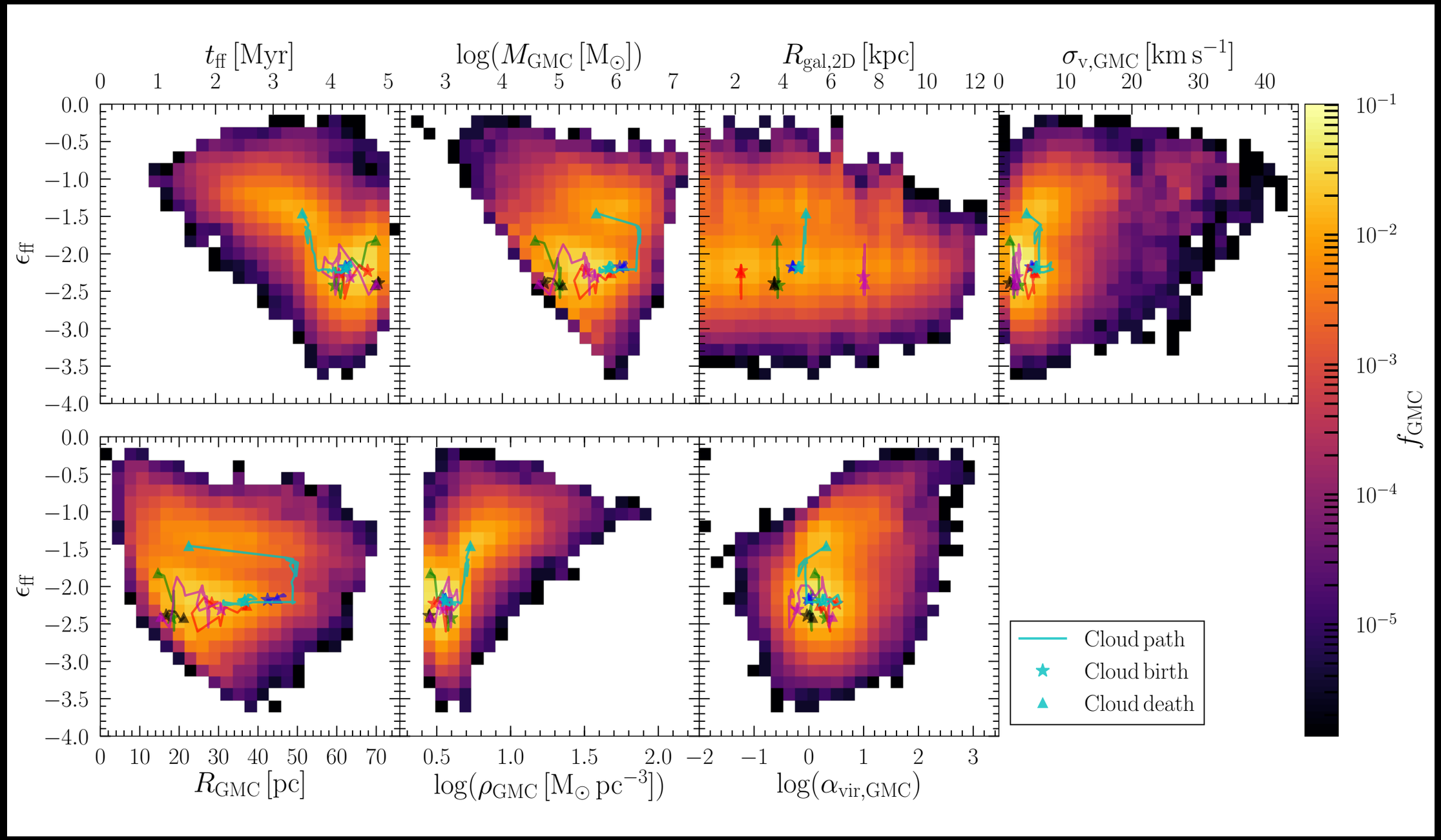

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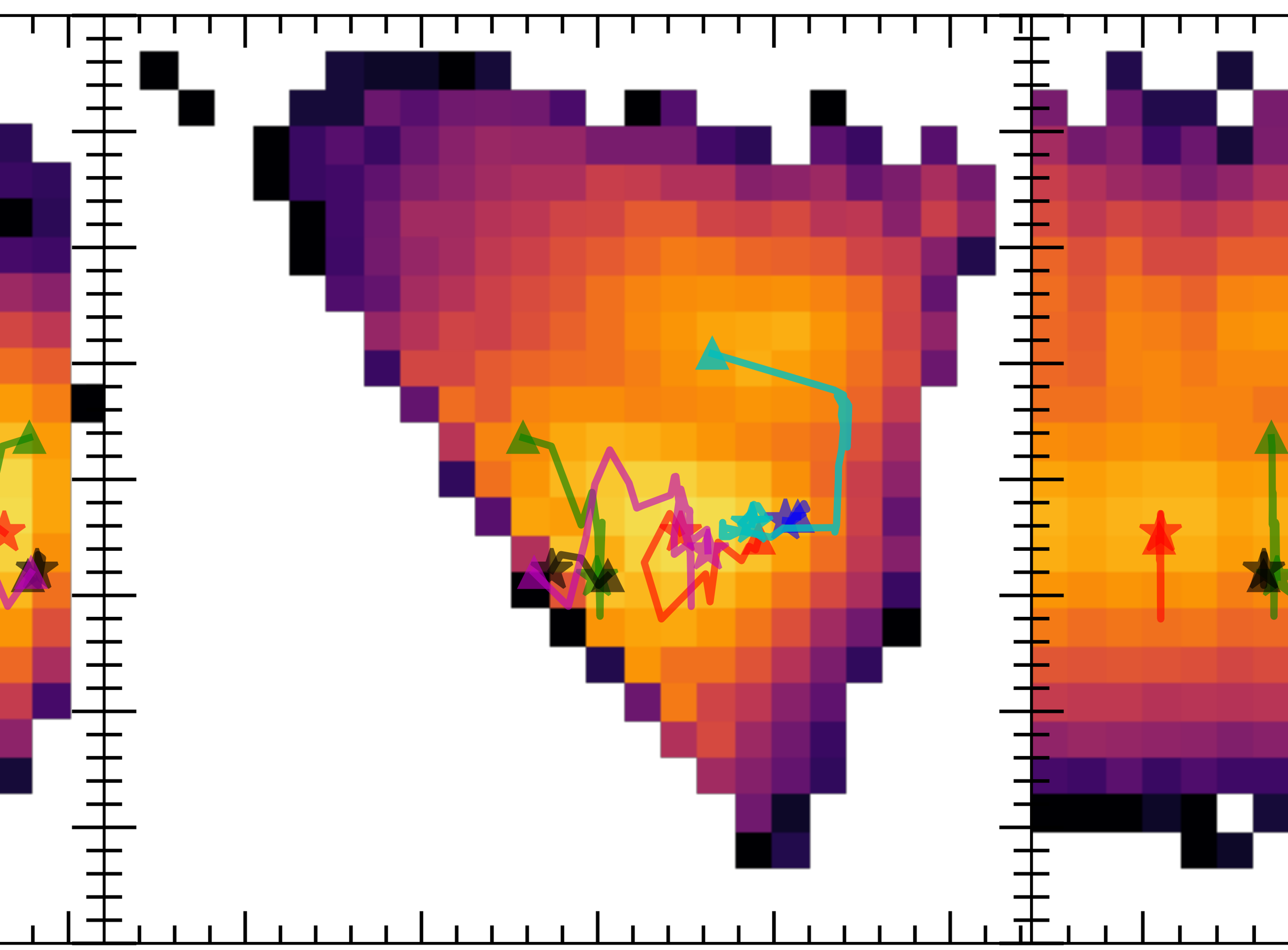

Summary

★ Observations show that there is a range of star forming efficiencies (per free fall time) which can be reproduced in observations.

★ This variation is not a result of the method used to measure efficiency.

★ If there is an intrinsic star formation efficiency, it cannot be measured by observations of GMCs.

★ Every GMC has a unique evolution and it is this evolution that leads to the variation in star formation.