GALFOR

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Unraveling multiple stellar populations in globular clusters with JWST

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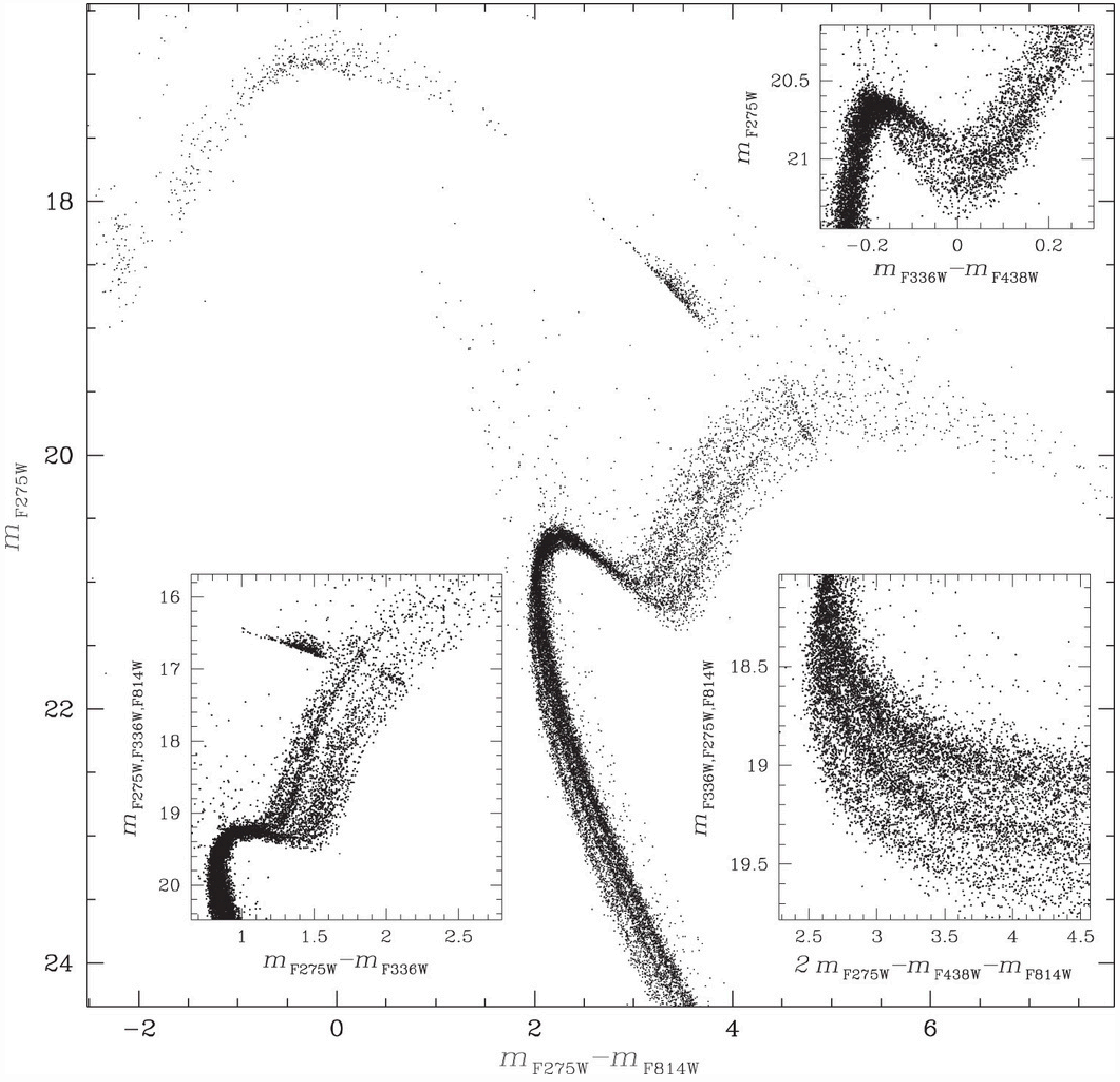
Introduction

Globular clusters host **multiple stellar populations**:

- **First stellar population:** same chemical composition as halo field stars.

- **Second stellar population(s):** enhanced in He, N and Na, and depleted in C and O.



(MILONE ET AL. 2015)

Introduction

Multiple population formation scenarios

I. Multiple episodes of star formation

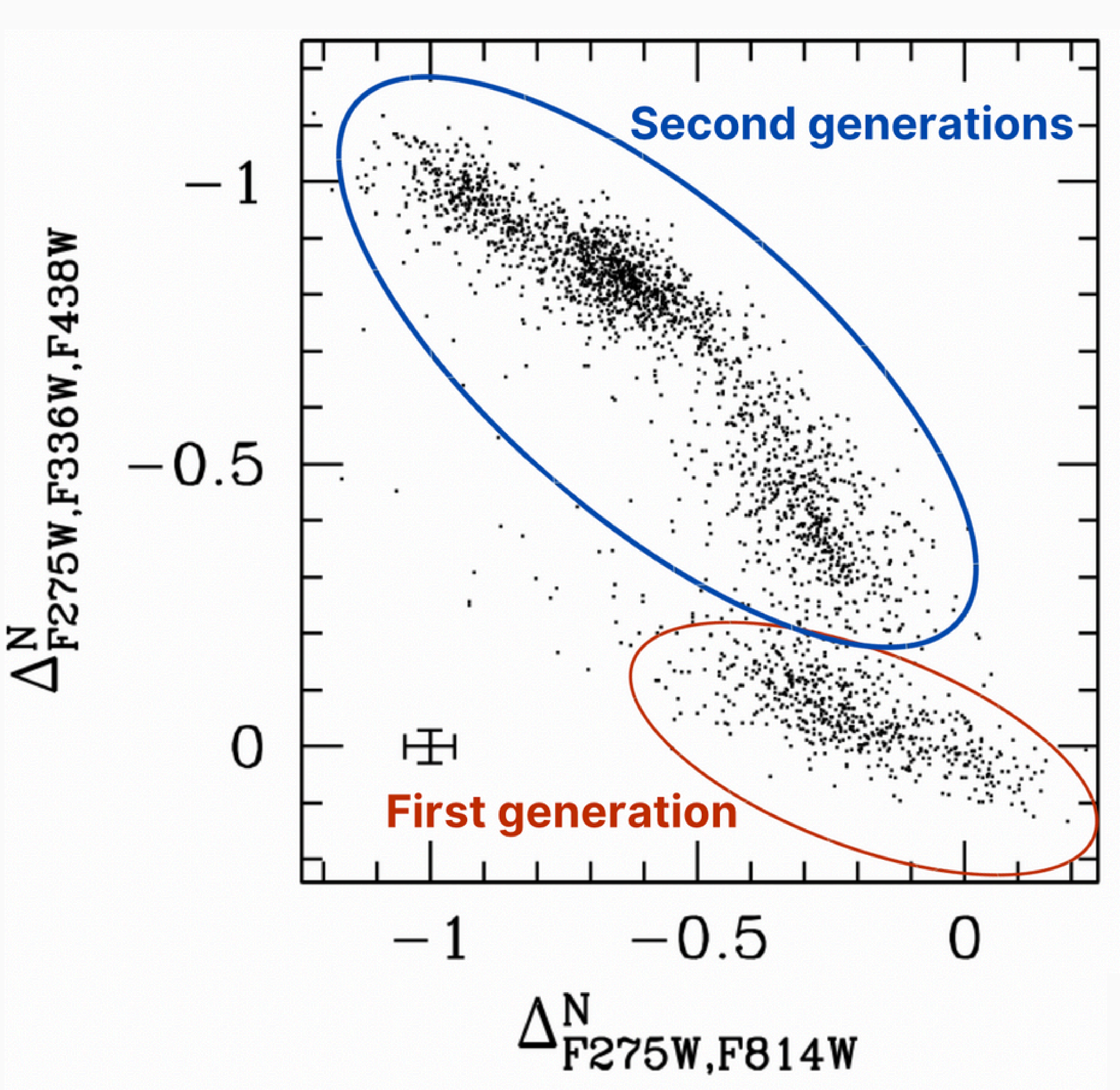
II. Accretion of material onto pre existing stars

Introduction

Multiple population formation scenarios

I. Multiple episodes of star formation

- The number of 1G stars currently observed is smaller than 2G stars (mass budget problem)
- Globular clusters should have been at least 10 times more massive at the time of their formation
- Contribution to the Galactic halo and possibly to reionization



(MILONE ET AL. 2015)

Introduction

Formation scenarios

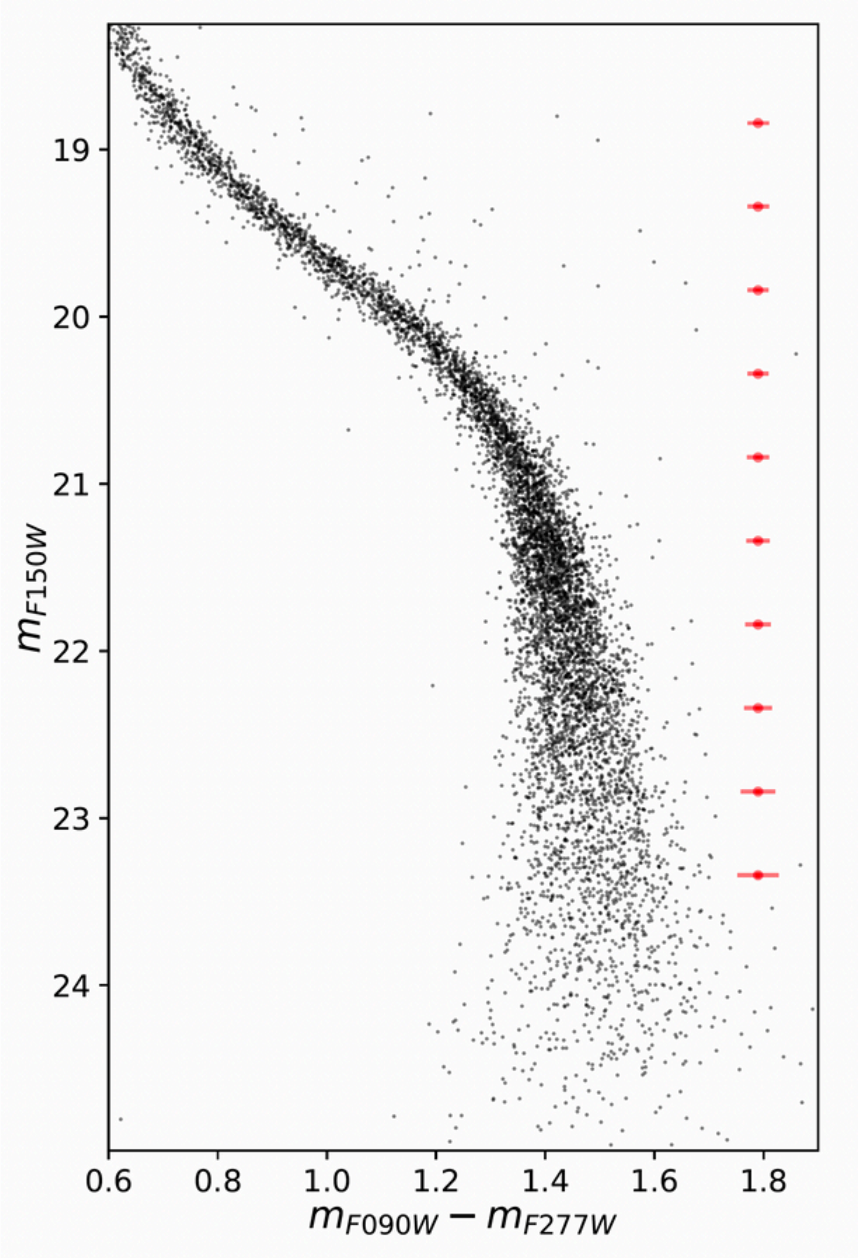
II. Early accretion

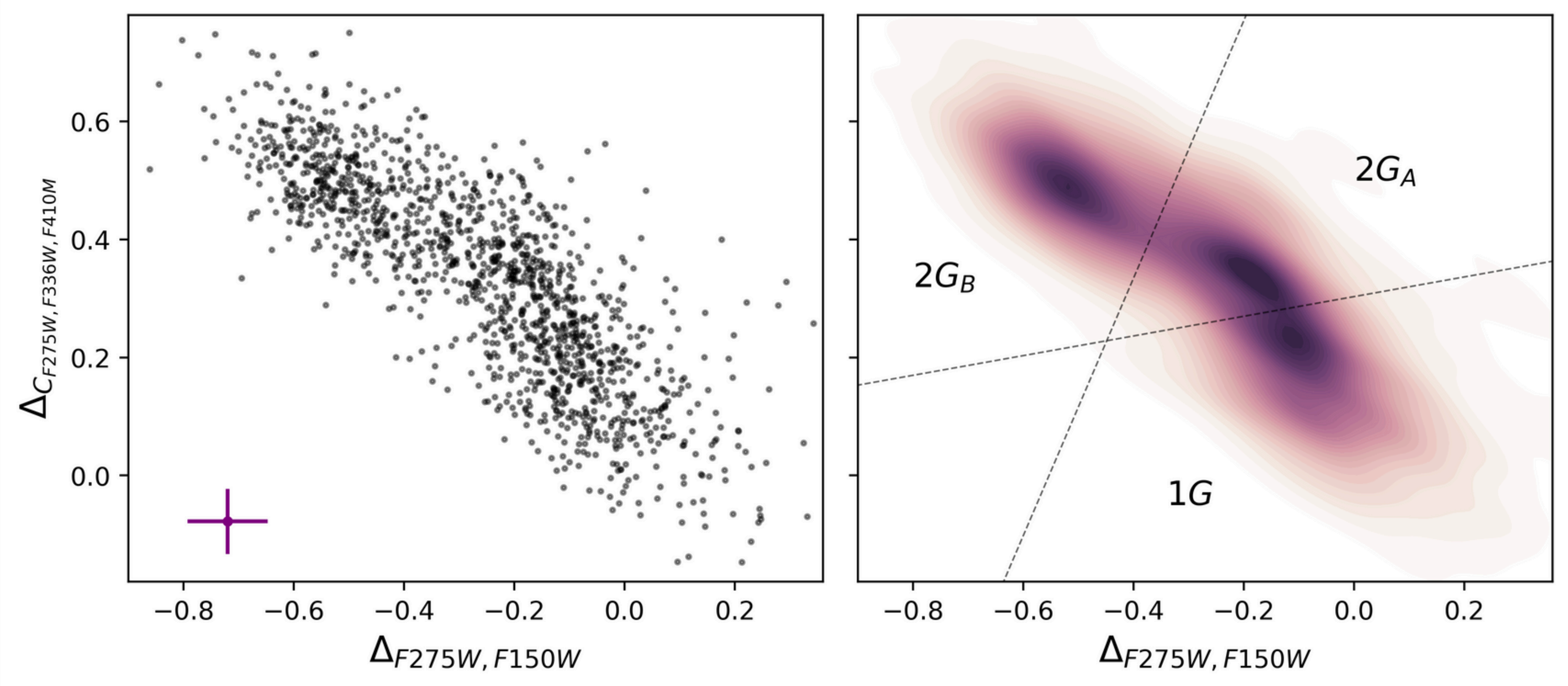
- *Single* star formation episode
- Chemical anomalies are a result of accretion of polluted material onto *pre-MS stars*
- Accretion is proportional to mass: high-mass stars accrete more material than low-mass stars - chemical variations vary with stellar mass

Introduction

Multiple populations with the JWST

- JWST's infrared filters efficiently disentangle multiple populations among very low-mass stars.



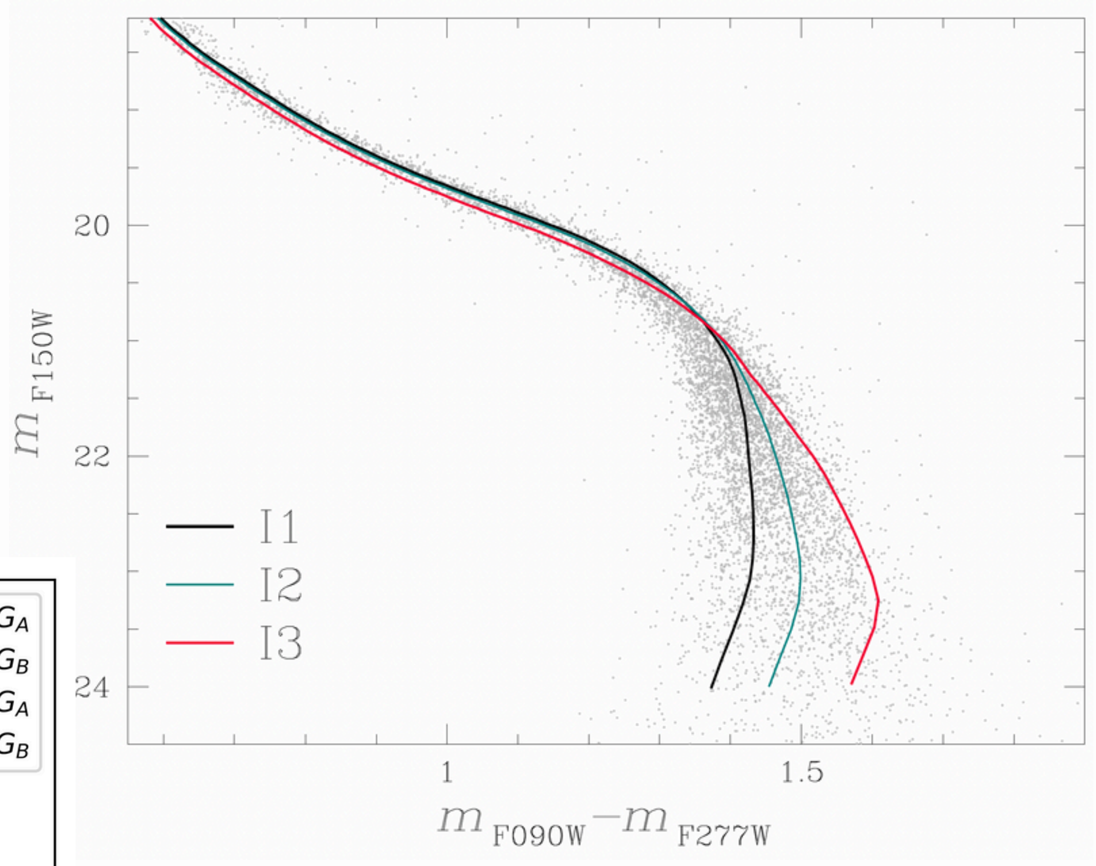


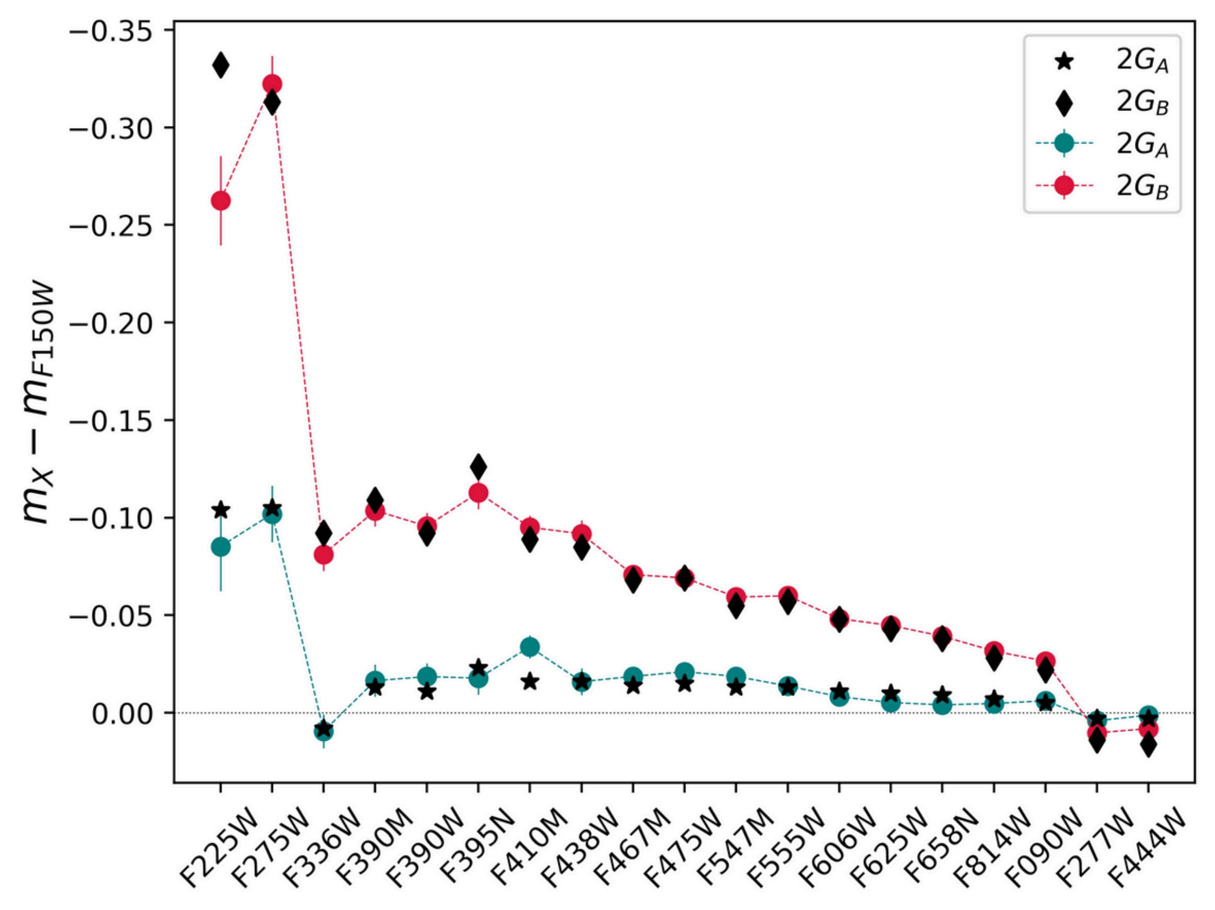
M92 observations (Ziliotto et al. 2023)

Introduction

Multiple populations with the JWST

- Grids of synthetic spectra are compared with observed colors.
- Similar oxygen variations in M-dwarfs, bright MS stars, and RGB stars (Sneden et al. 2000, Meszaros et al. 2015).
- ***Incompatible with predictions from accretion scenarios.***
- Same conclusion from a similar analysis for 47 Tucanae using JWST/NIRCam and JWST/NIRSpec data (Milone+23, Marino+24a,b).





(Ziliotto et al. 2023)

Multiple population kinematics

- Multiple stellar populations differ not only in their chemical properties, but also in their **structural** and **kinematical** properties.

- Hydrodynamical simulations: 2G stars form in a sub-system **more spatially concentrated** and more rapidly rotating than 1G stars.

- Some clusters still preserve signatures of their formation times. For example, 1G and 2G stars may differ in their *anisotropy*, *energy equipartition*, *rotation*, *angular momentum, and velocity dispersion profiles*.

Energy equipartition

- Globular clusters are old, collisional systems;
- Stars interact and exchange energy;
- If you wait long enough, energy starts to equalize, evolving towards a state of energy equipartition.

Energy equipartition

Stellar mass

$$\sigma \propto m^{-\eta}$$

Amount of equipartition:

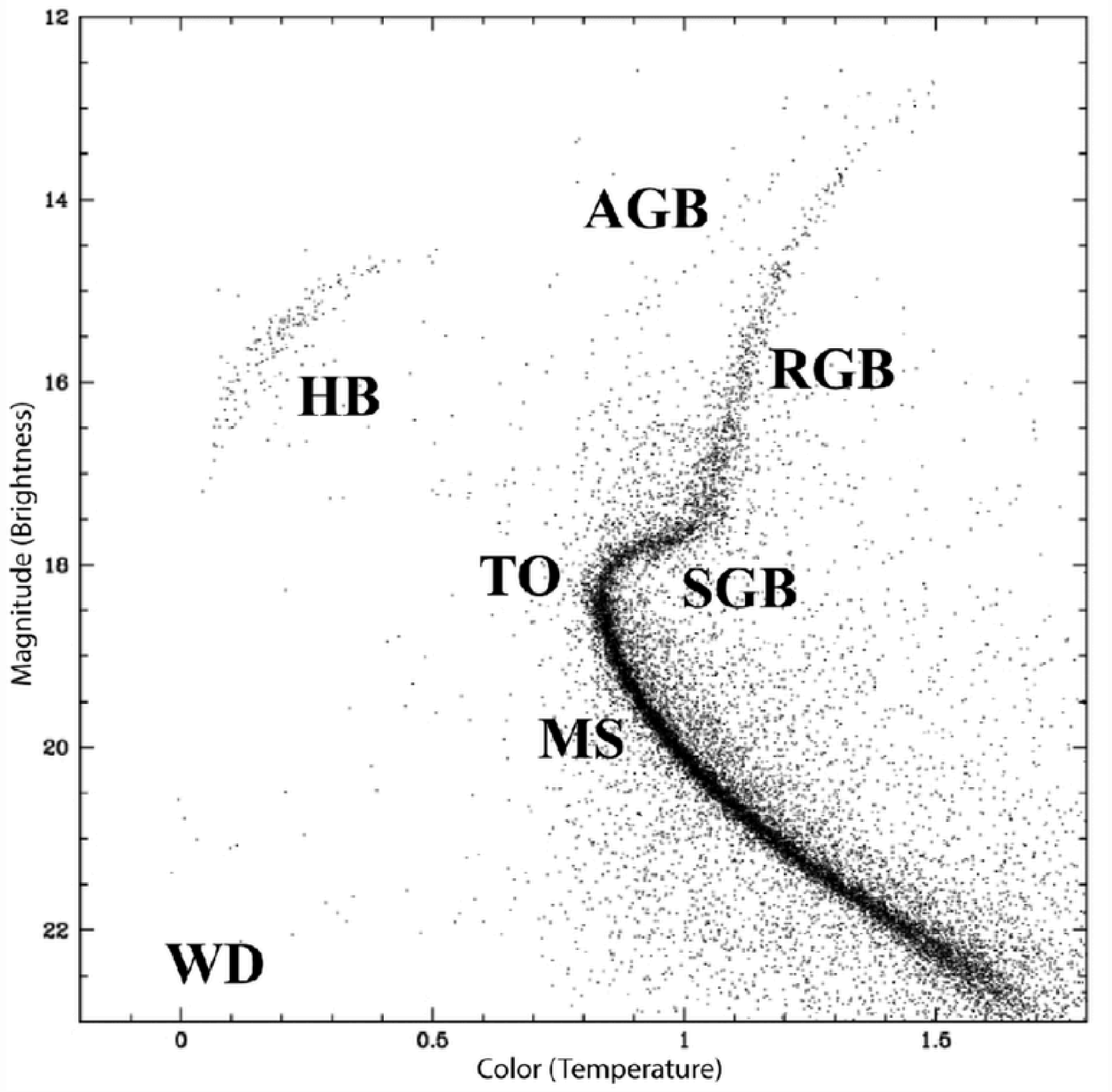
Velocity dispersion

η = 0 : None
η = 0.5 : Full equipartition

Energy equipartition

Brighter stars: small mass range

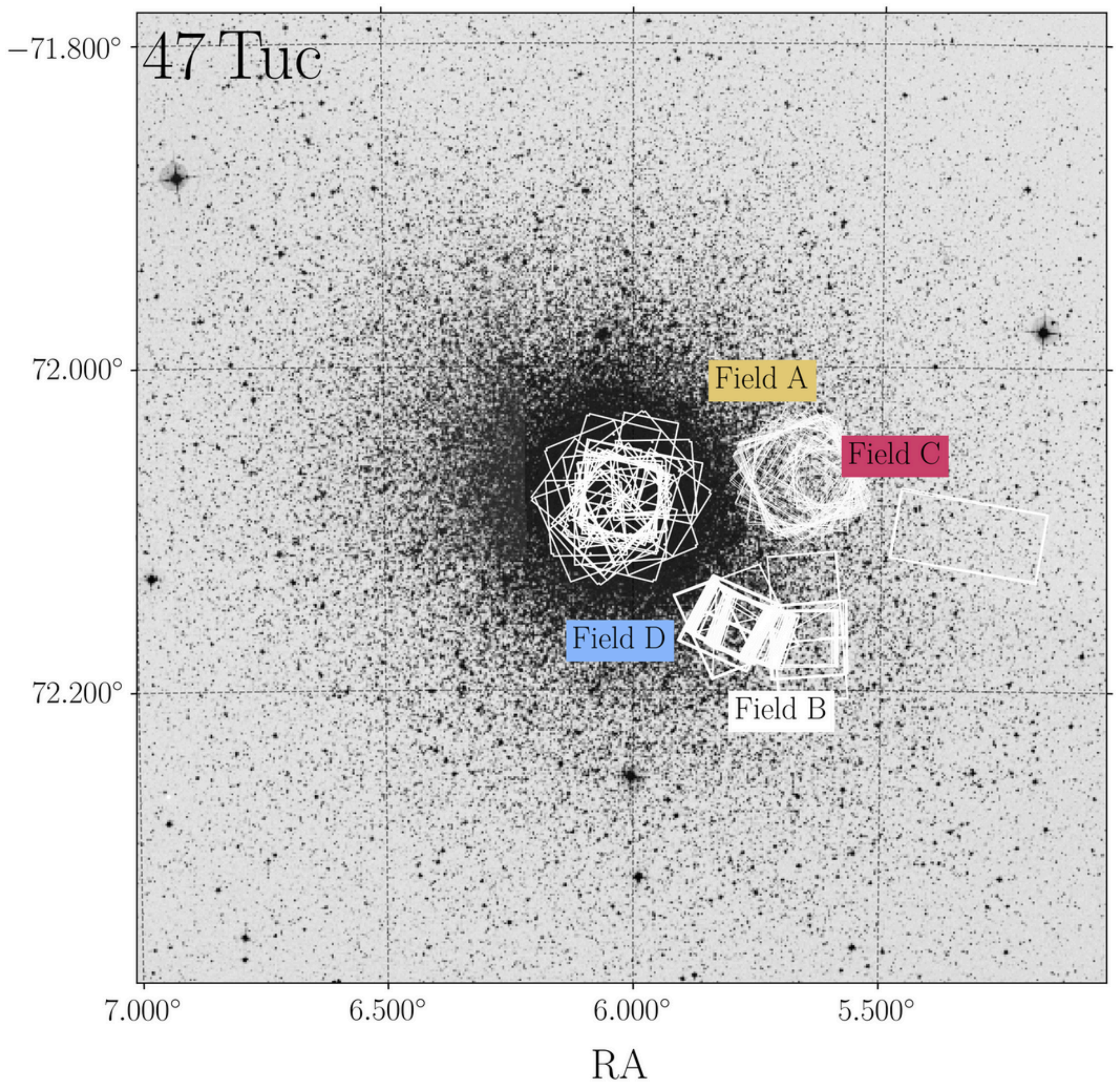
Main sequence stars: wide mass range,
but more challenges in obtaining kinematic data

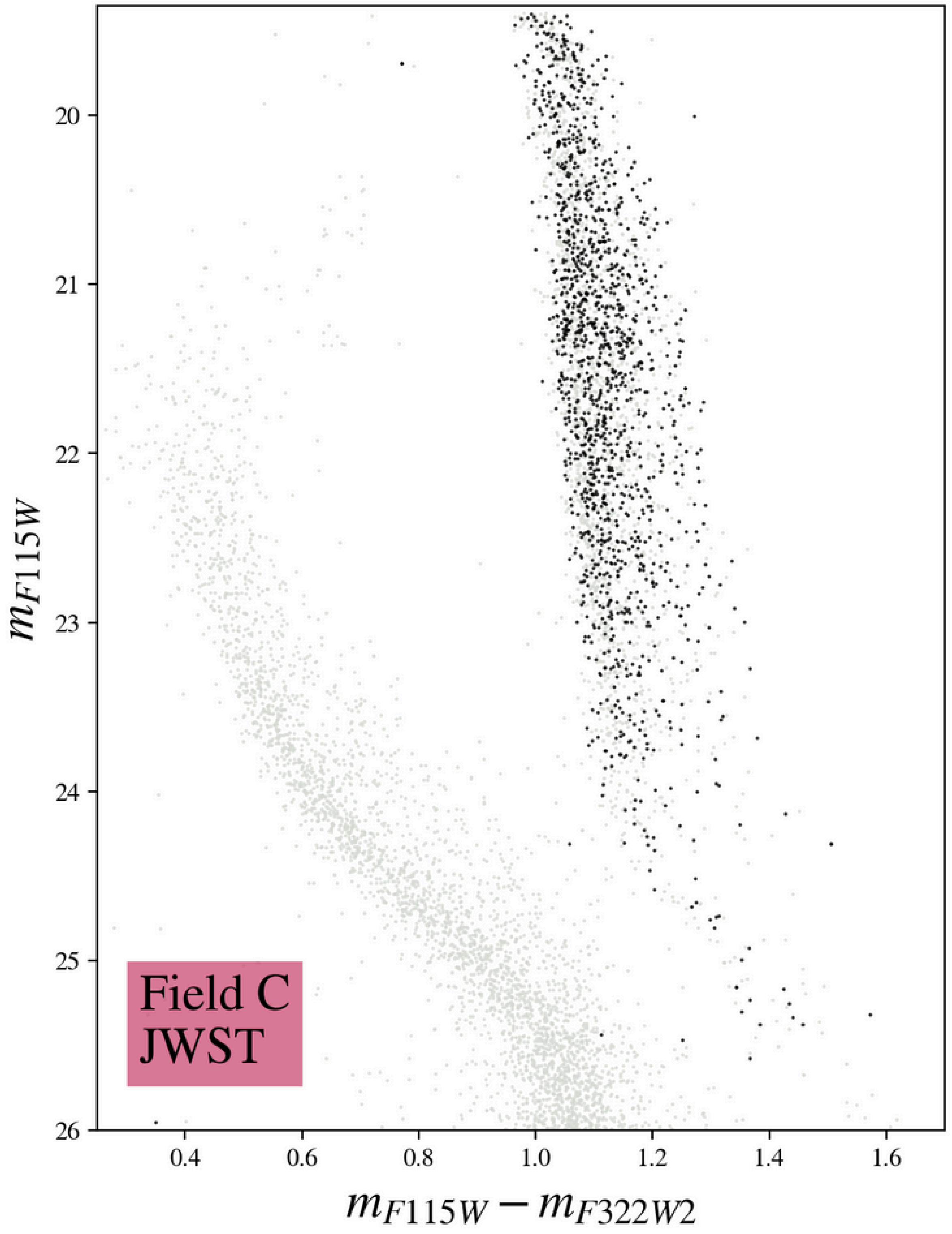


Data: 47 Tucanae

- **HST** and **JWST IR** data are very efficient to characterize multiple populations in the **low-mass regime**;

- **Gaia** provides proper motions for RGB stars, providing a **wide mass and radial range.**





Degree of energy equipartition

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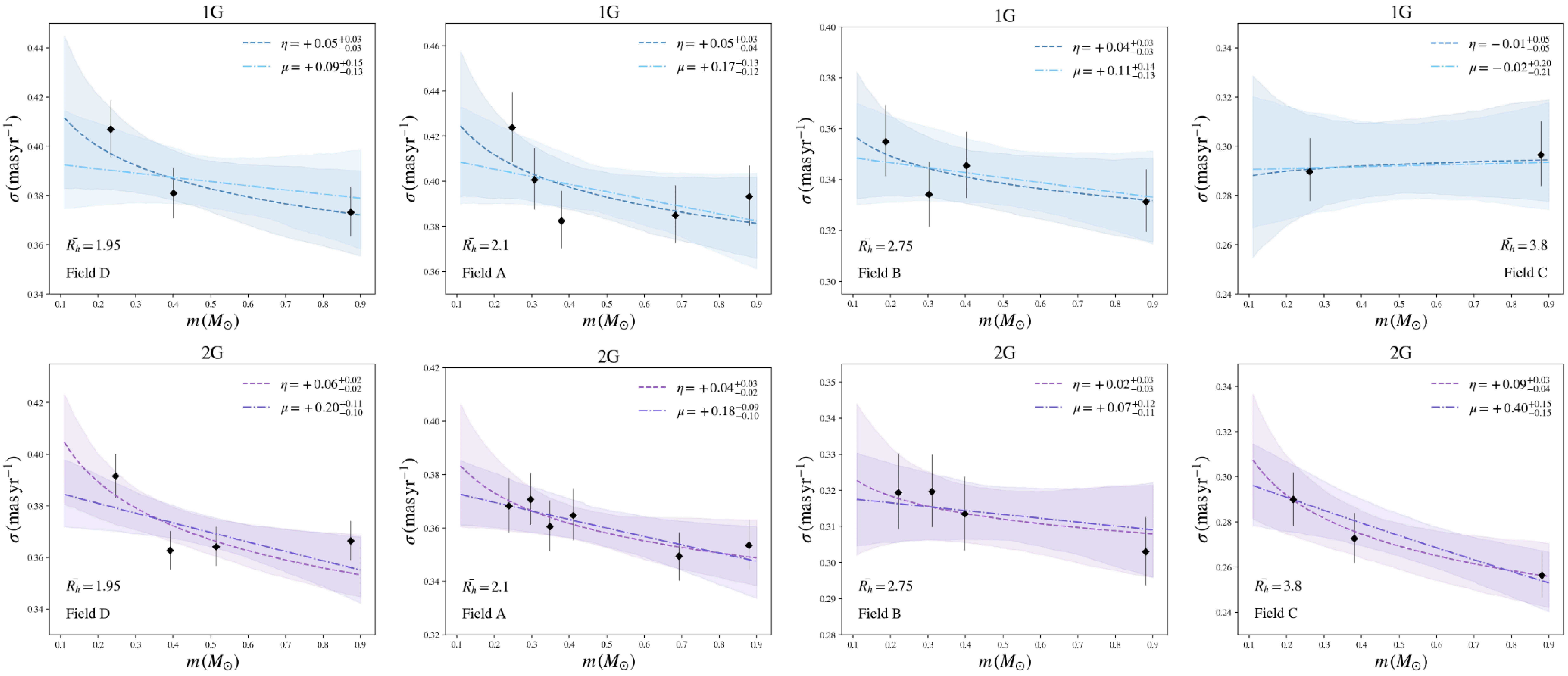
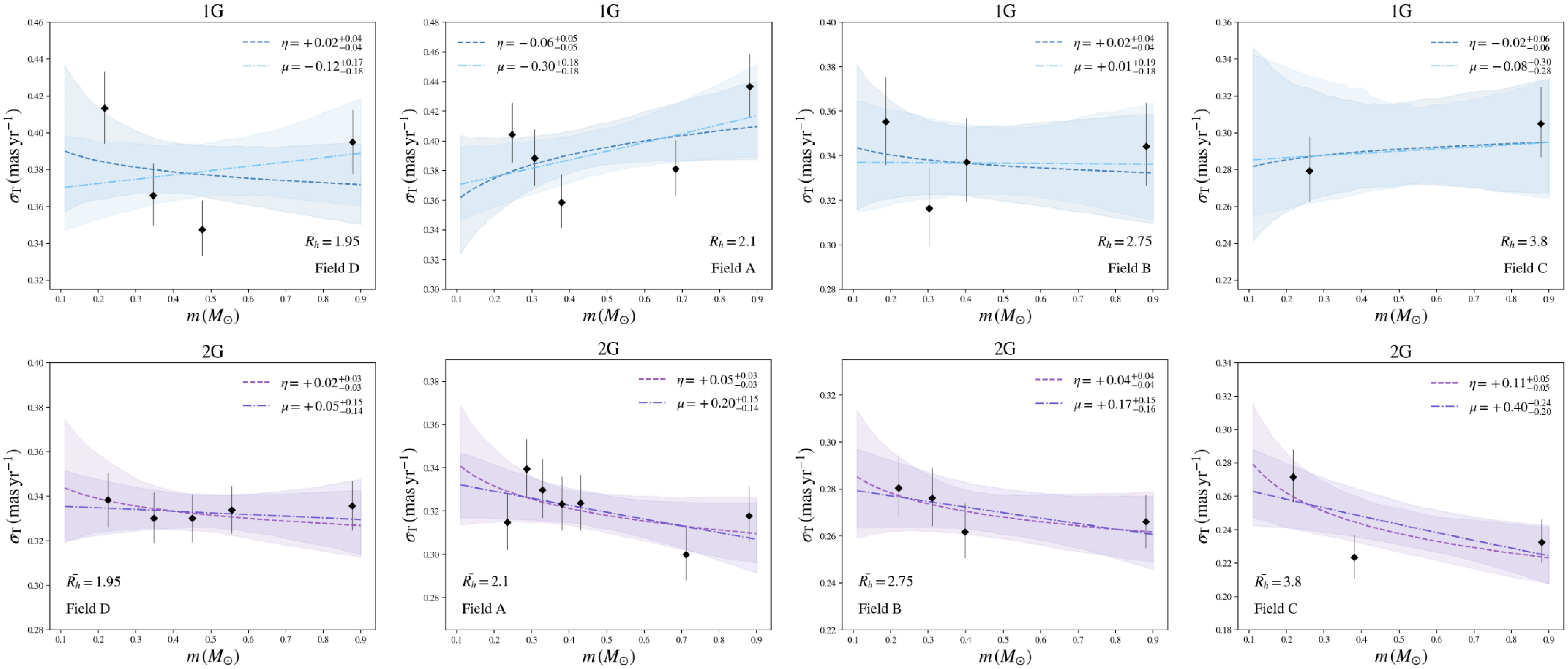


Degree of energy equipartition: Tangential velocity dispersion



Degree of energy equipartition: Radial velocity dispersion

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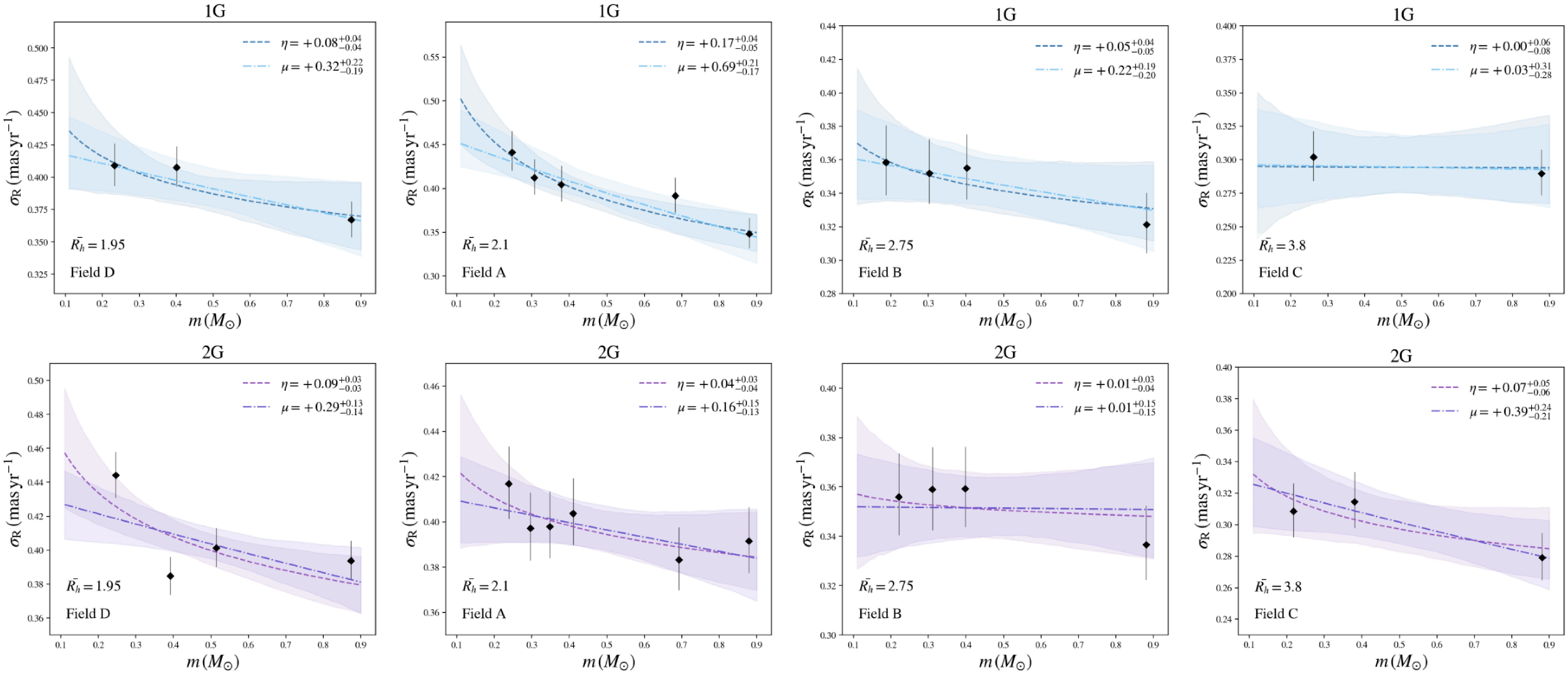

Degree of energy equipartition: comparison of the fits

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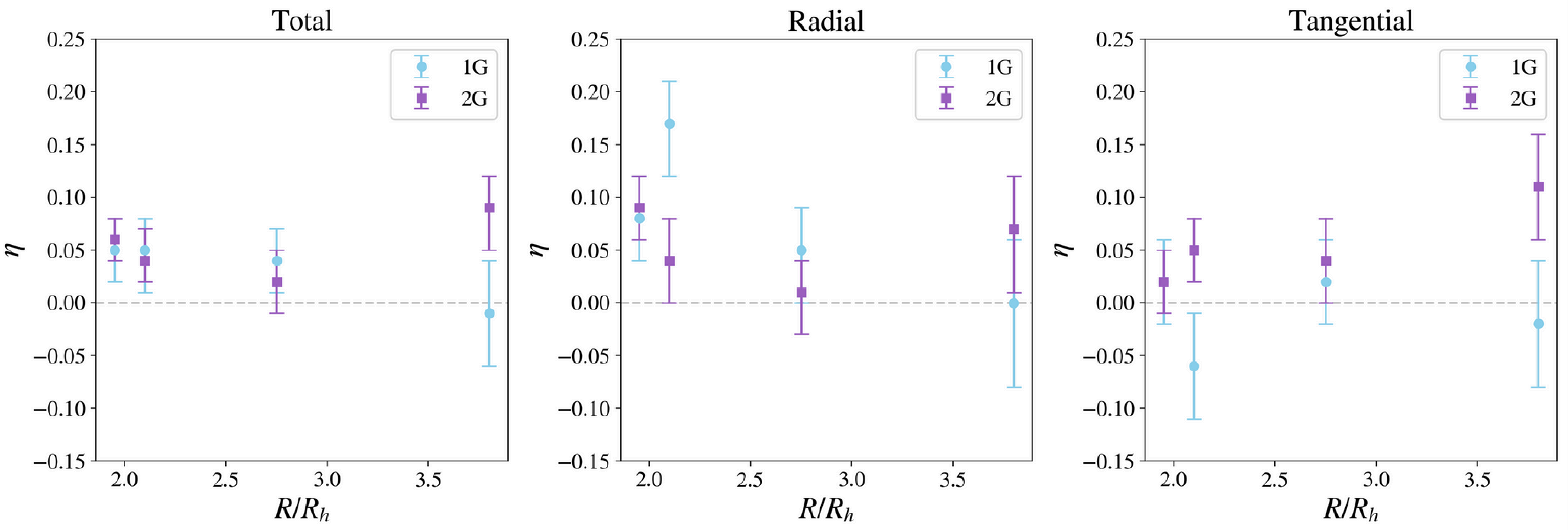
- Recent results from hydrodynamical simulations (Livernois+2024) indicate that 2G stars are always closer to energy equipartition in the tangential velocity component than 1G stars, which agrees with our results.



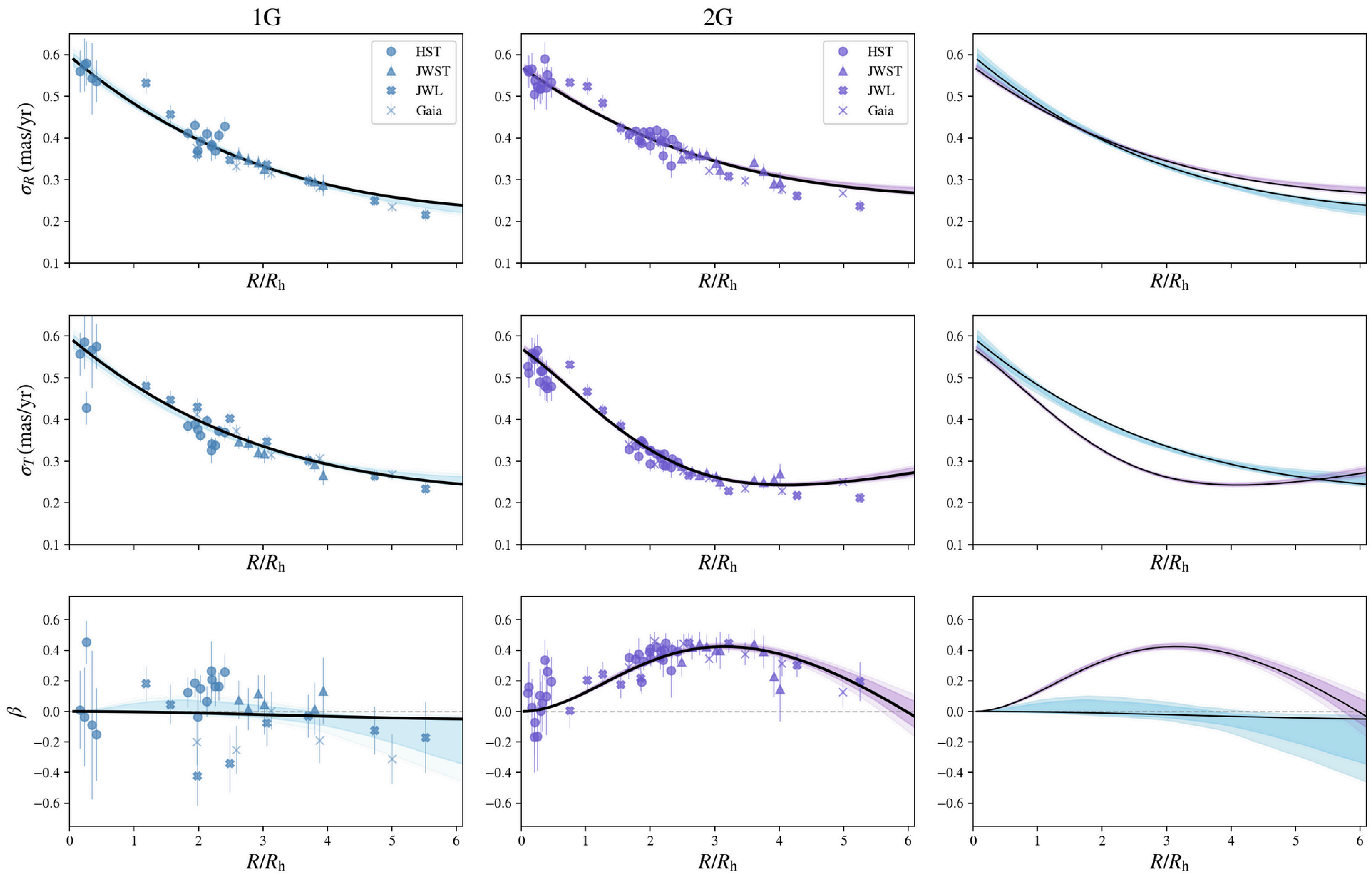
Anisotropy

- The anisotropy of the internal motion of first and second population stars can also provide information about the differences between these populations.

$$\beta_{2D}(R) = 1 - \frac{\sigma_T^2}{\sigma_R^2}$$

β = 0: isotropic
β > 0: radial anisotropy
β < 0: tangential anisotropy

Anisotropy



Conclusion

- The evolution towards energy equipartition is anisotropic and proceeds at different rates in the tangential and radial directions;
- Second generation stars are more radially anisotropic than first generation stars;
- Our results support scenarios involving multiple episodes of star formation within the same cluster;
- This could imply that Globular Clusters contributed substantially to the baryonic mass of the Galactic Halo and possibly played a significant role in reionization.