Energy Equipartition in Galactic Globular Clusters

Laura Watkins she/her/hers

AURA for ESA, ESA Office, Space Telescope Science Institute

with Roeland van der Marel, Mattia Libralato, Andrea Bellini, Jay Anderson, Mayte Alfaro Cuello

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Globular clusters are dense.
stars interact

Globular clusters are old.
lots of interactions

stars exchange energy

Energy Equipartition

Energy Equipartition

equal kinetic energy

$\frac{1}{2} m v^2$

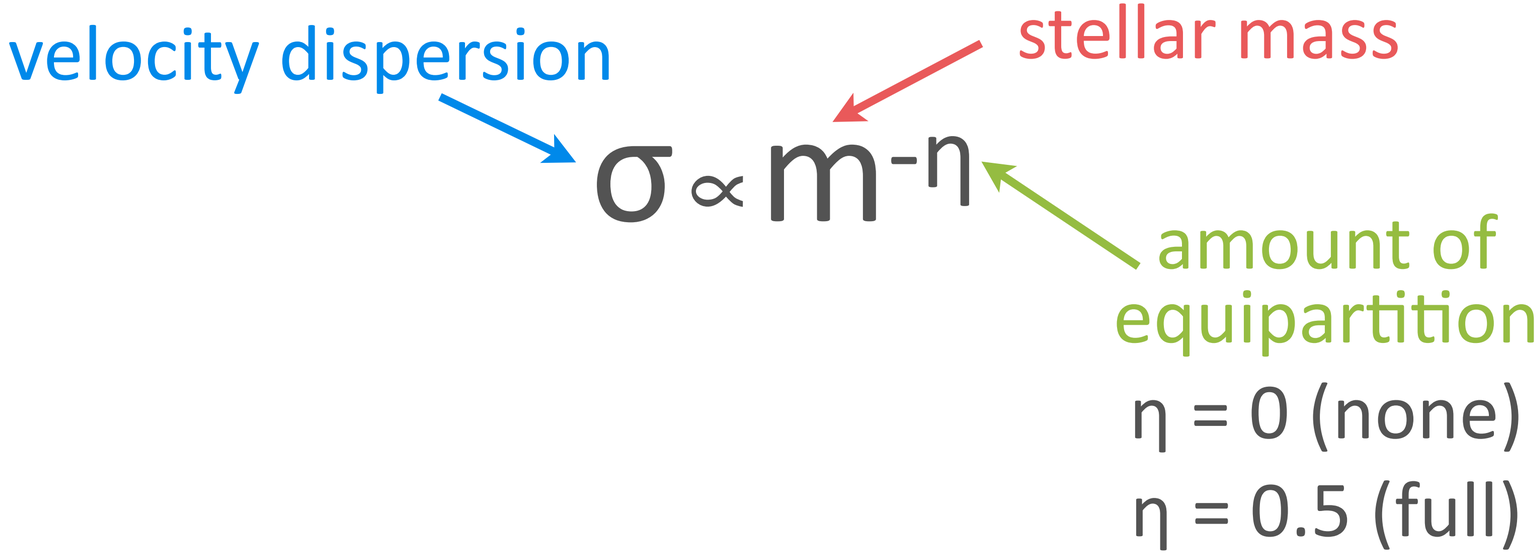
high mass : slow

low mass : fast

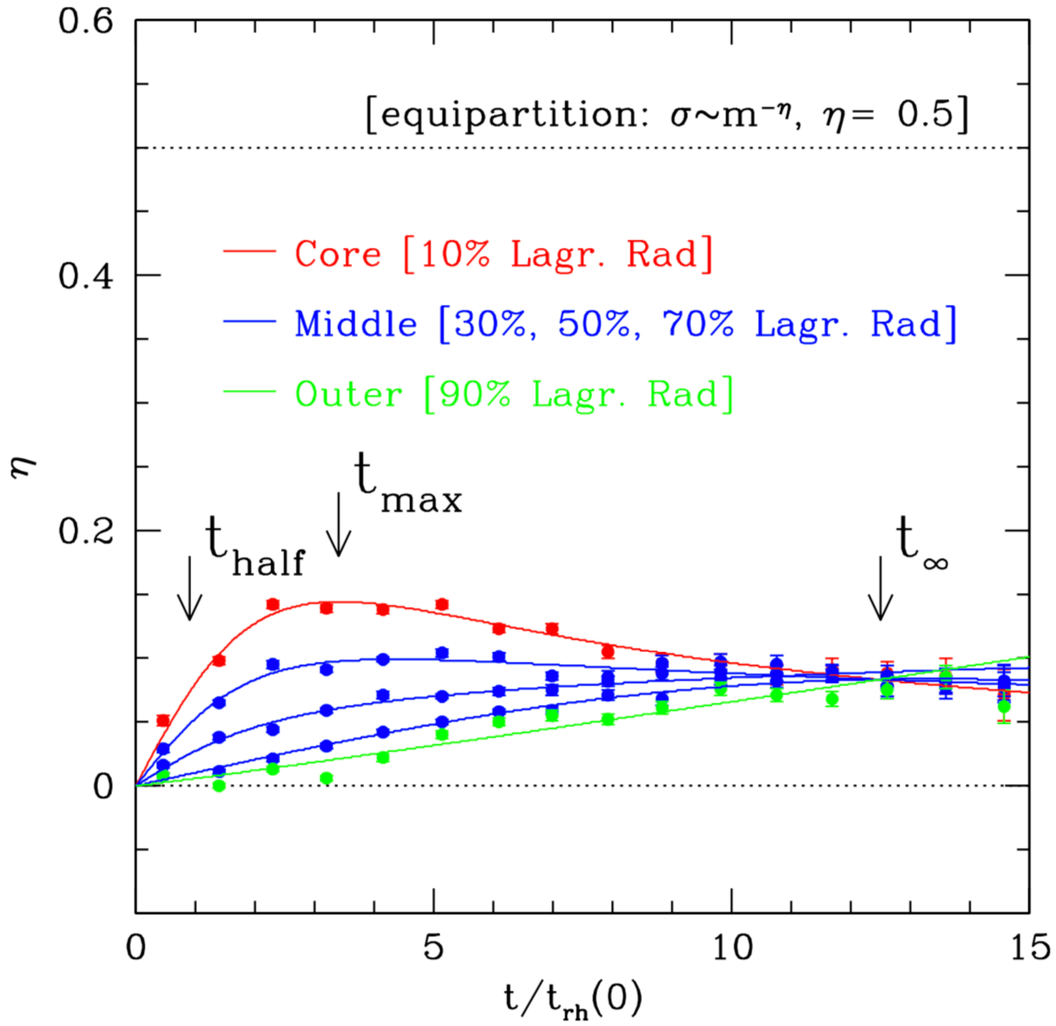
Energy Equipartition

equal kinetic energy

$\frac{1}{2} m v^2$



Simulated Clusters



degree of equipartition

number of relaxation times

does not reach full equipartition

Trenti & van der Marel 2013

Simulated Clusters

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

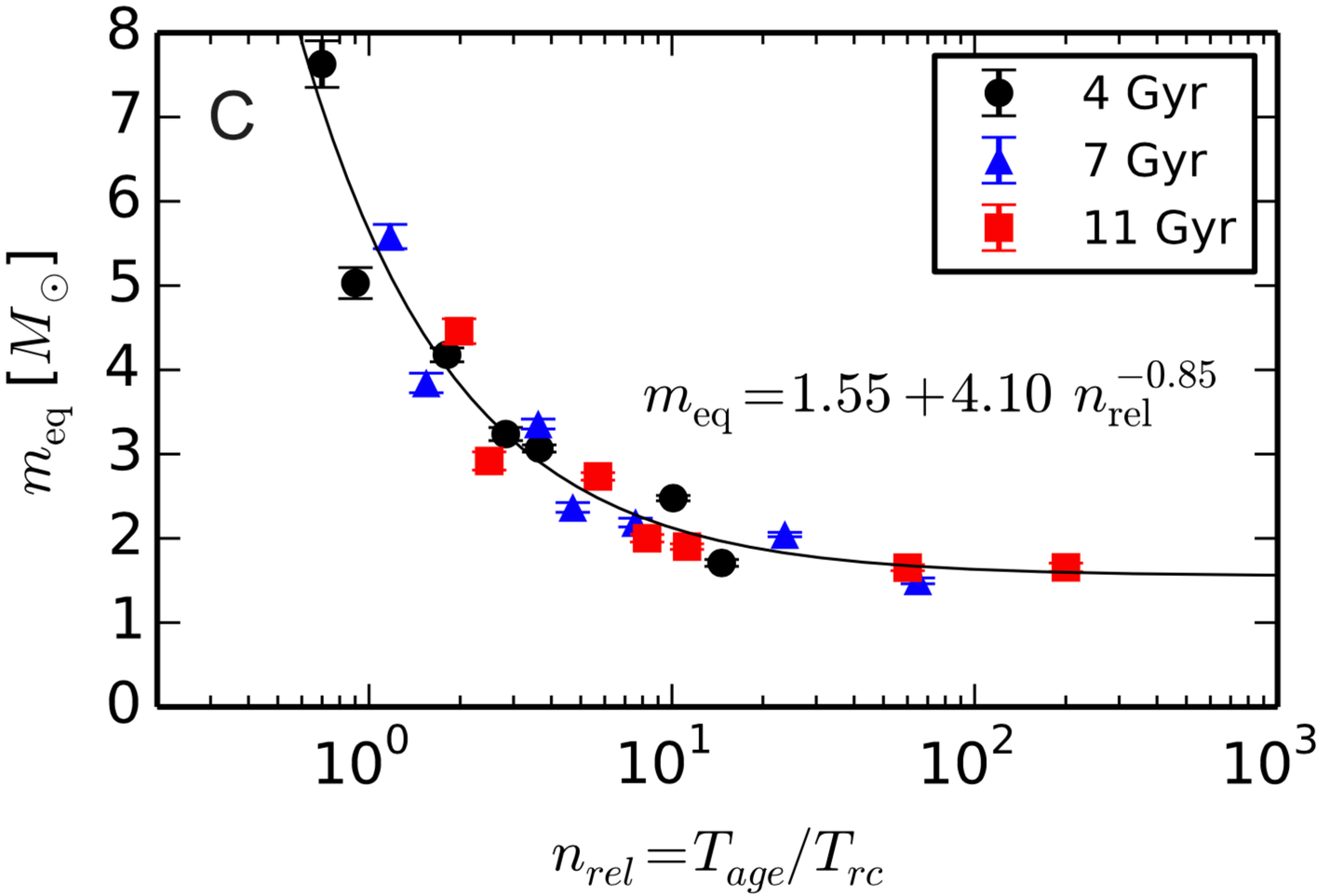
$$\eta(m) = -\frac{d\ln\sigma}{d\ln m} = \begin{cases} \frac{1}{2}\frac{m}{m_{\rm eq}} & \text{if } m \le m_{\rm eq}, \\ \frac{1}{2} & \text{if } m > m_{\rm eq}. \end{cases}$$

η depends on m

m_{eq} → how much equipartition

$\eta \propto 1/m_{eq}$

degree of equipartition



Bianchini+ 2016

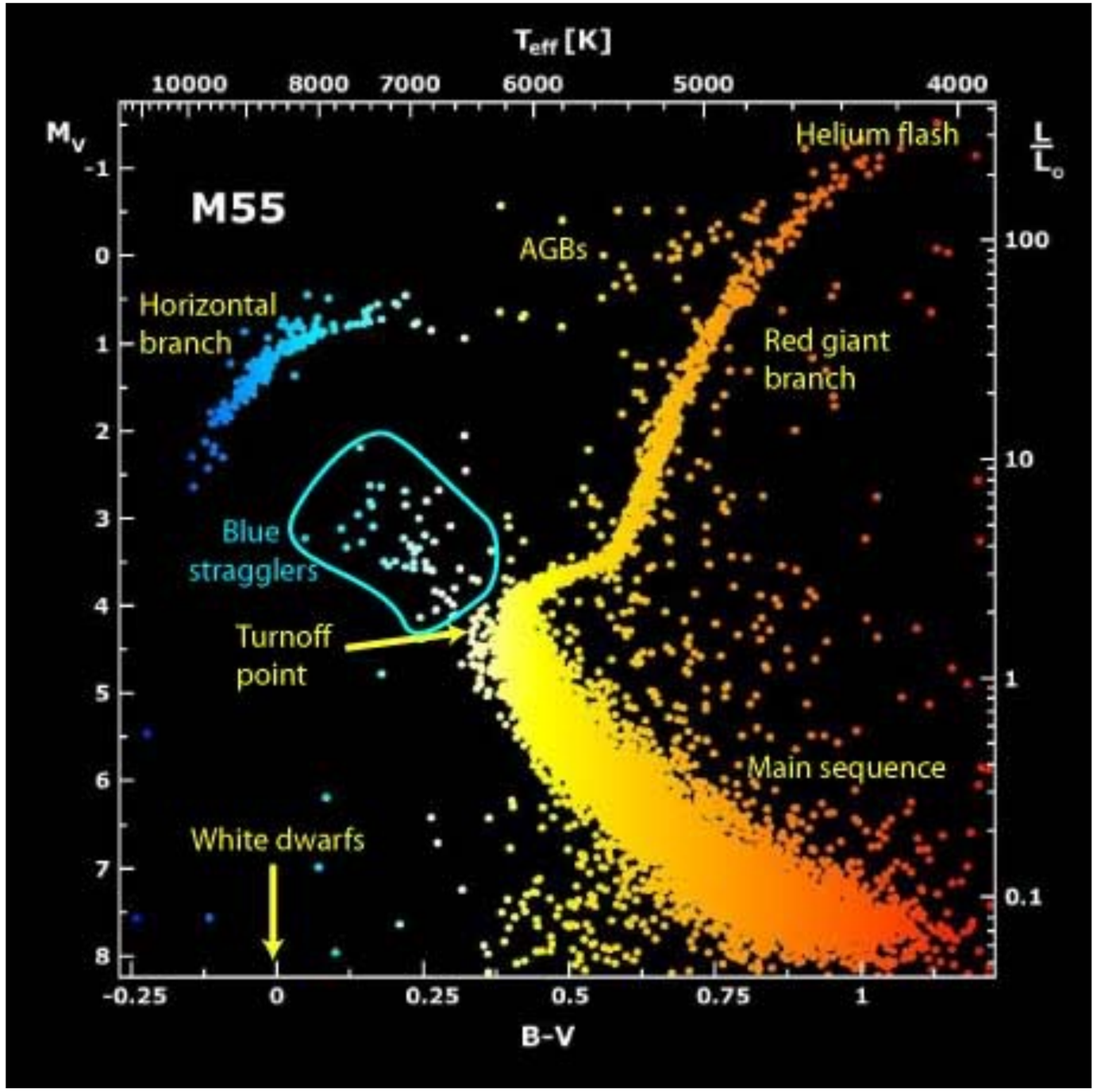
Simulated Clusters

- Equipartition and Multiple Stellar Populations *(Vesperini+ 2021)*
- Equipartition and Anisotropy *(Pavlík & Vesperini 2021)*
- Equipartition and BHs/IMBHs *(Aros & Vesperini 2023)*

see Francisco's talk!

Real Clusters

- Omega Centauri (NGC 5139), $\eta \sim 0.2$ *(Anderson & van der Marel 2010)*
- Omega Centauri (NGC 5139), $\eta \sim 0.16$ *(Trenti & van der Marel 2013)*
- NGC 362, $\eta = 0.114 \pm 0.012$ *(Libralato+ 2022)*



very small mass* range

targets for kinematics

HST

wide mass range

hard to get kinematics

Gaia too bright
JWST too new

*kinematic mass

HST Proper Motion Catalogues

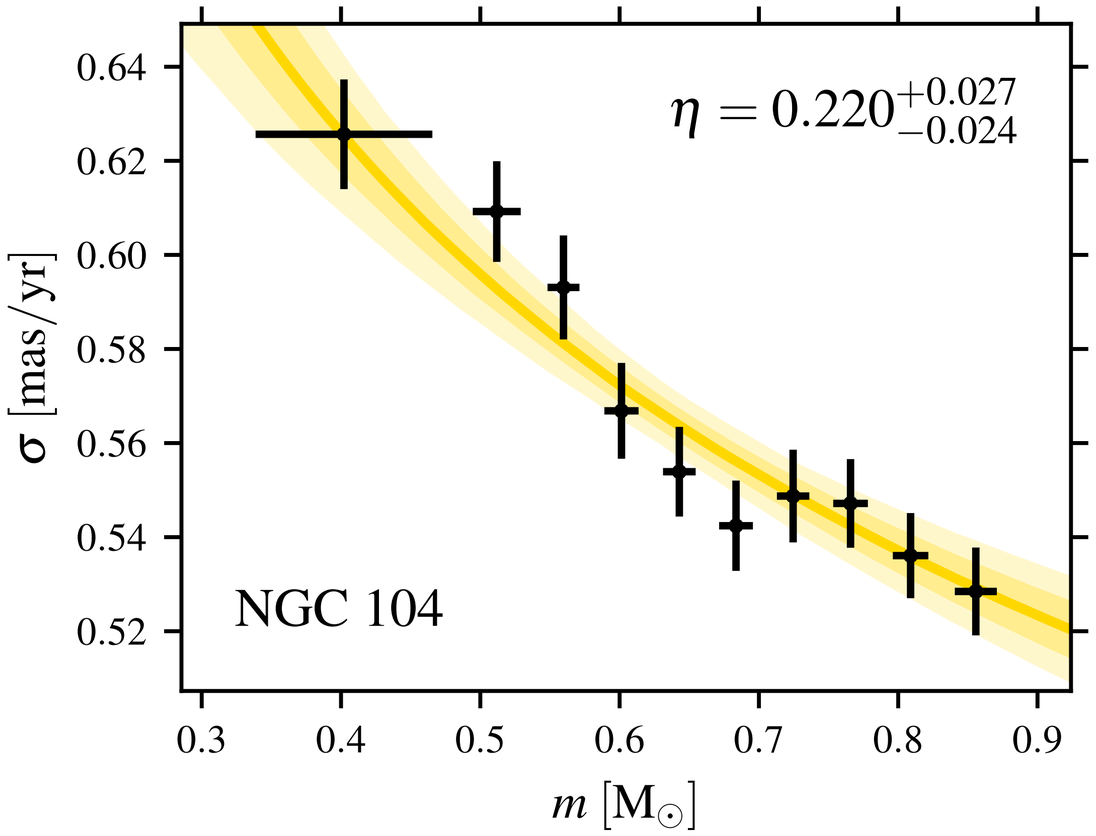
- HST proper motion catalogues for 22 Milky Way globular clusters *(Bellini+ 2014)*
- Quality cleaning (PM fit, PSF fit, PM uncertainties)

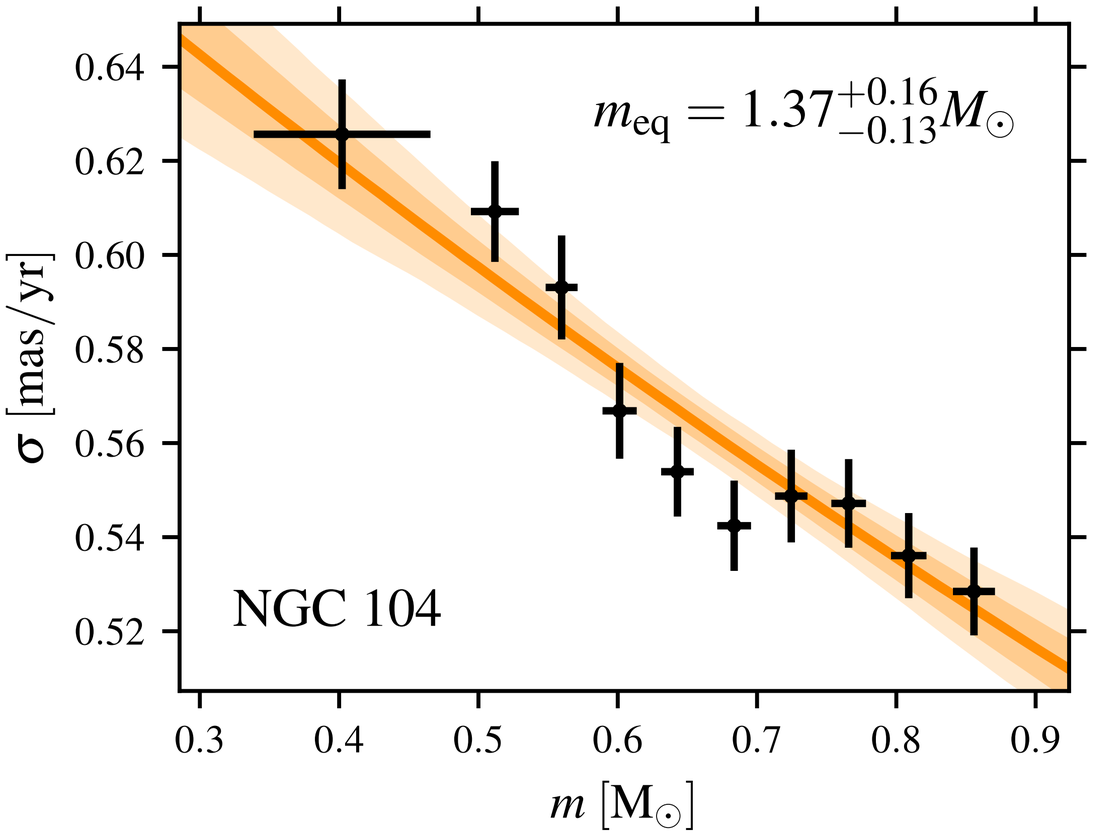
9 clusters

HST: kinematics with stellar mass

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

proper motion dispersion



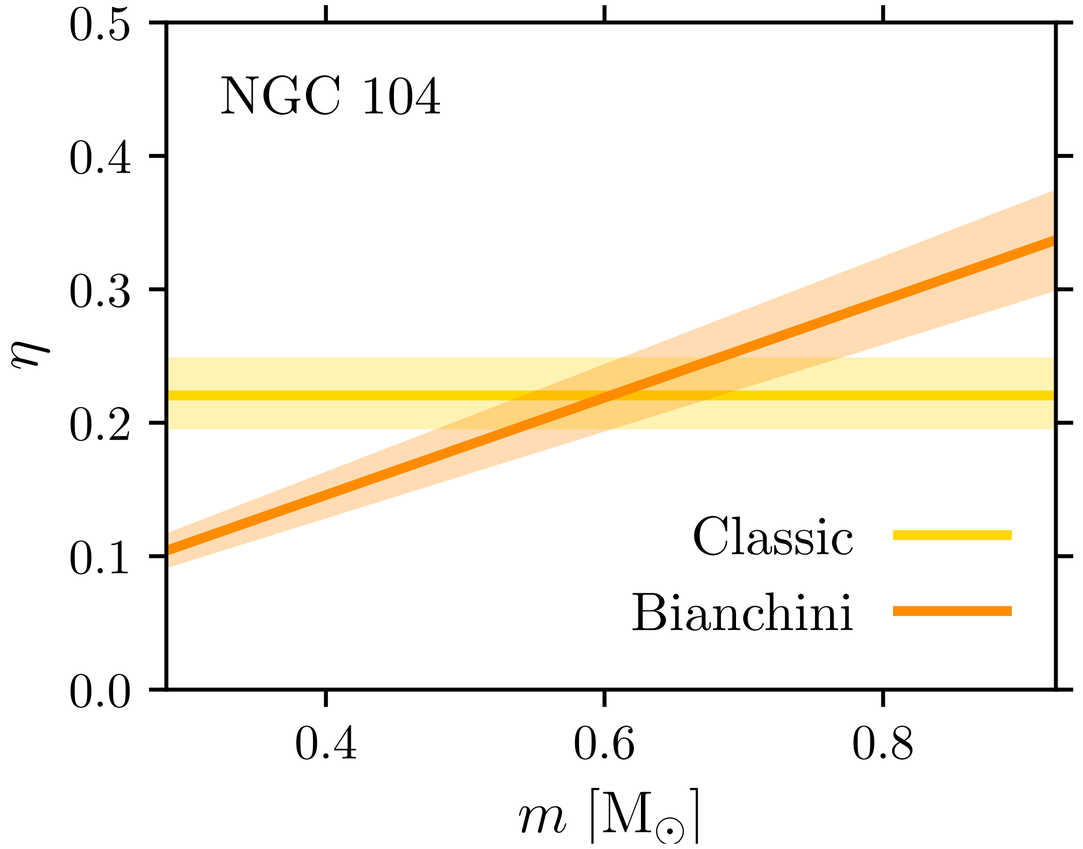


stellar mass

Watkins+ 2022

How do the fits compare?

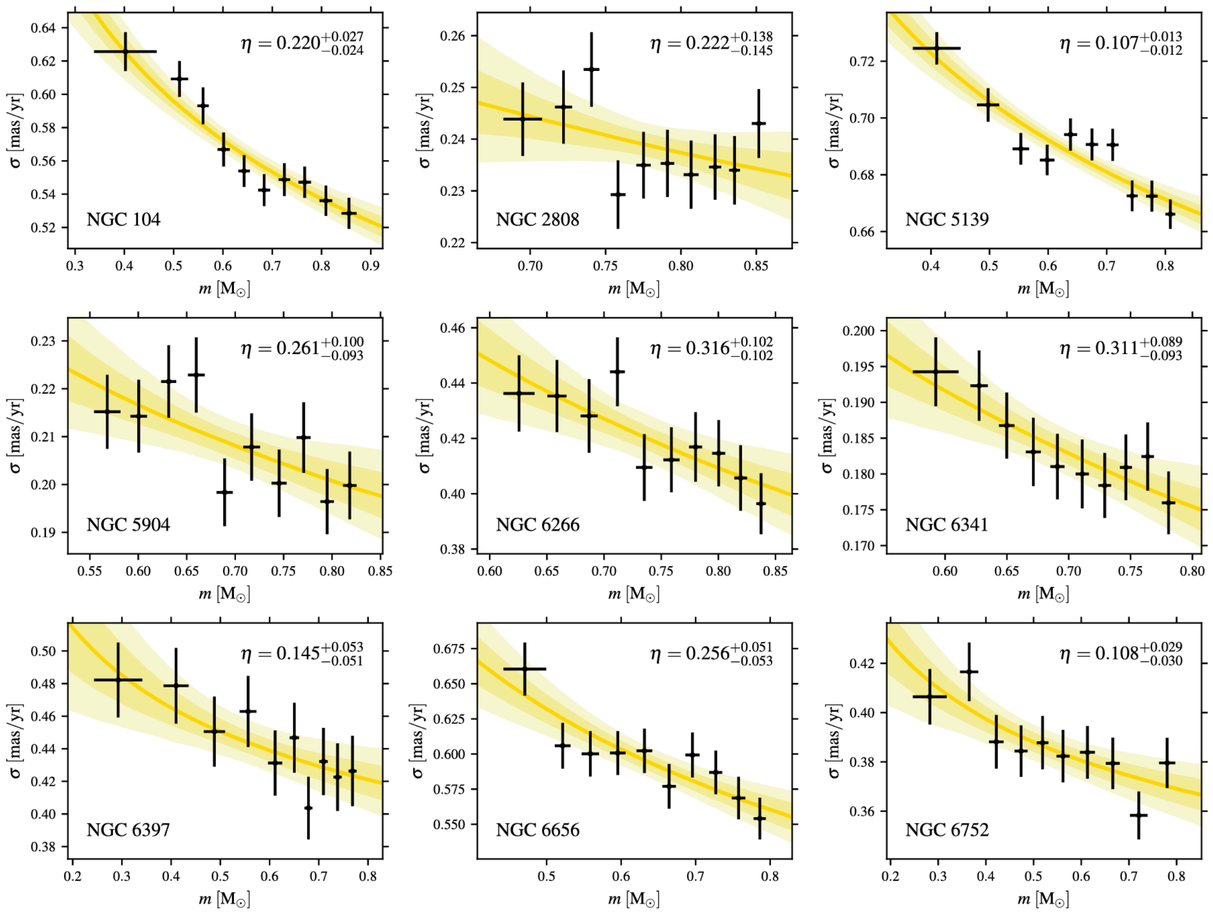
degree of equipartition

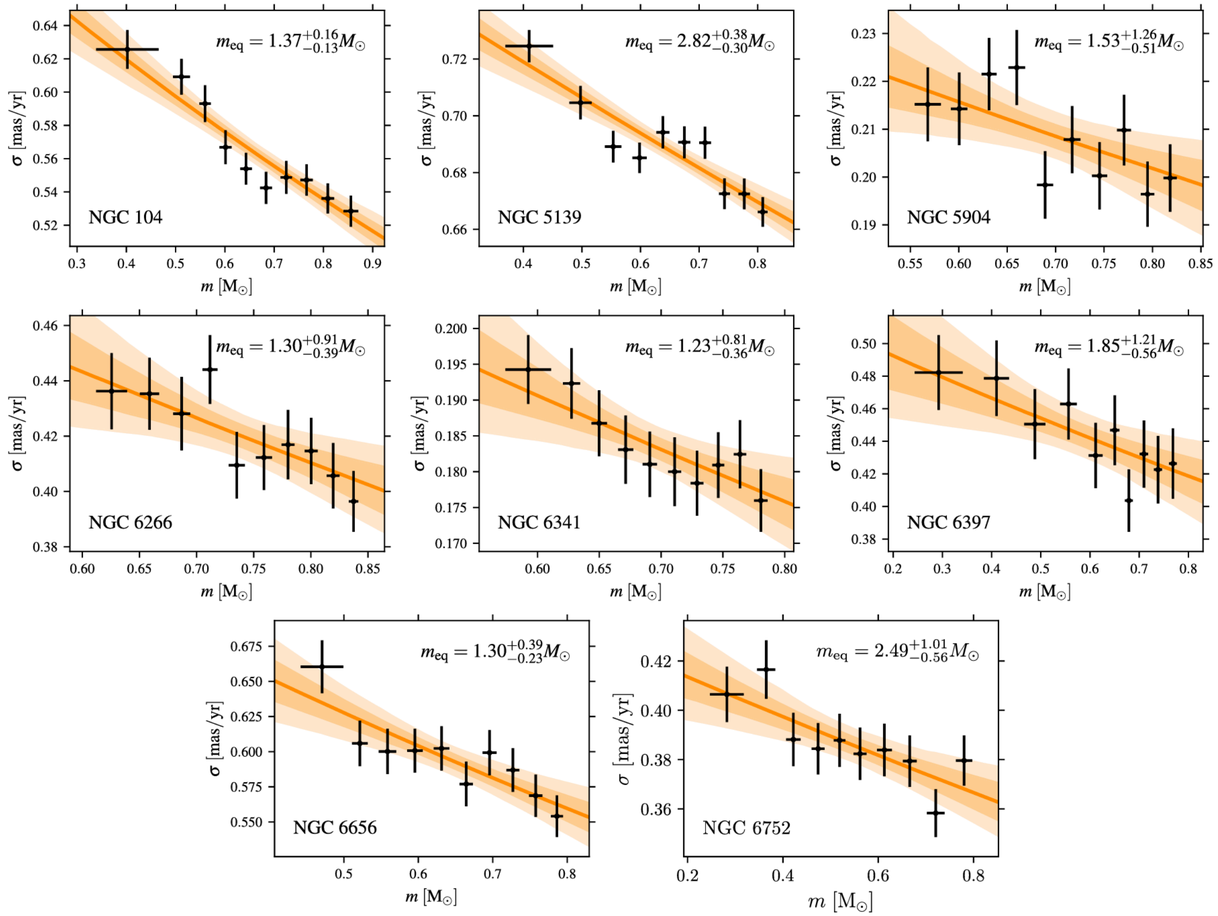


stellar mass

Watkins+ 2022

HST: kinematics with stellar mass for all clusters





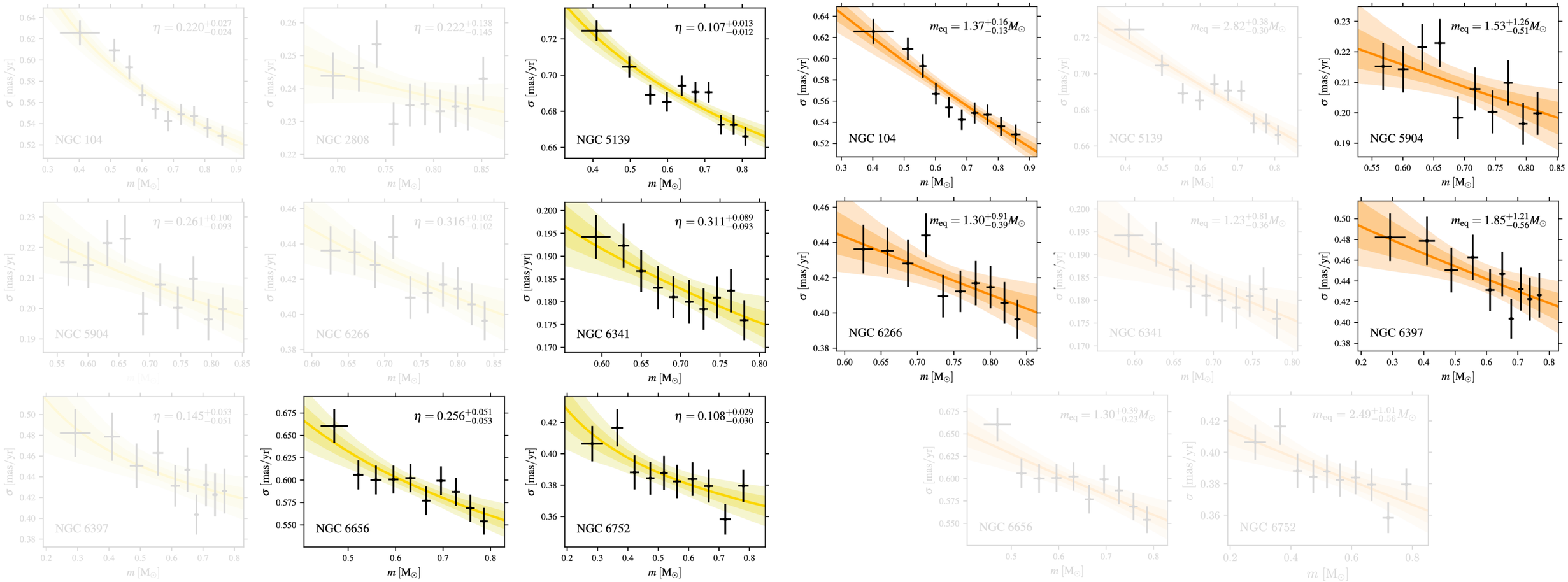
Watkins+ 2022

Which function fits best?

4 preferred Classic

4 preferred Bianchini

EXTREMELY low statistical significance



(1 could not compare)

Watkins+ 2022

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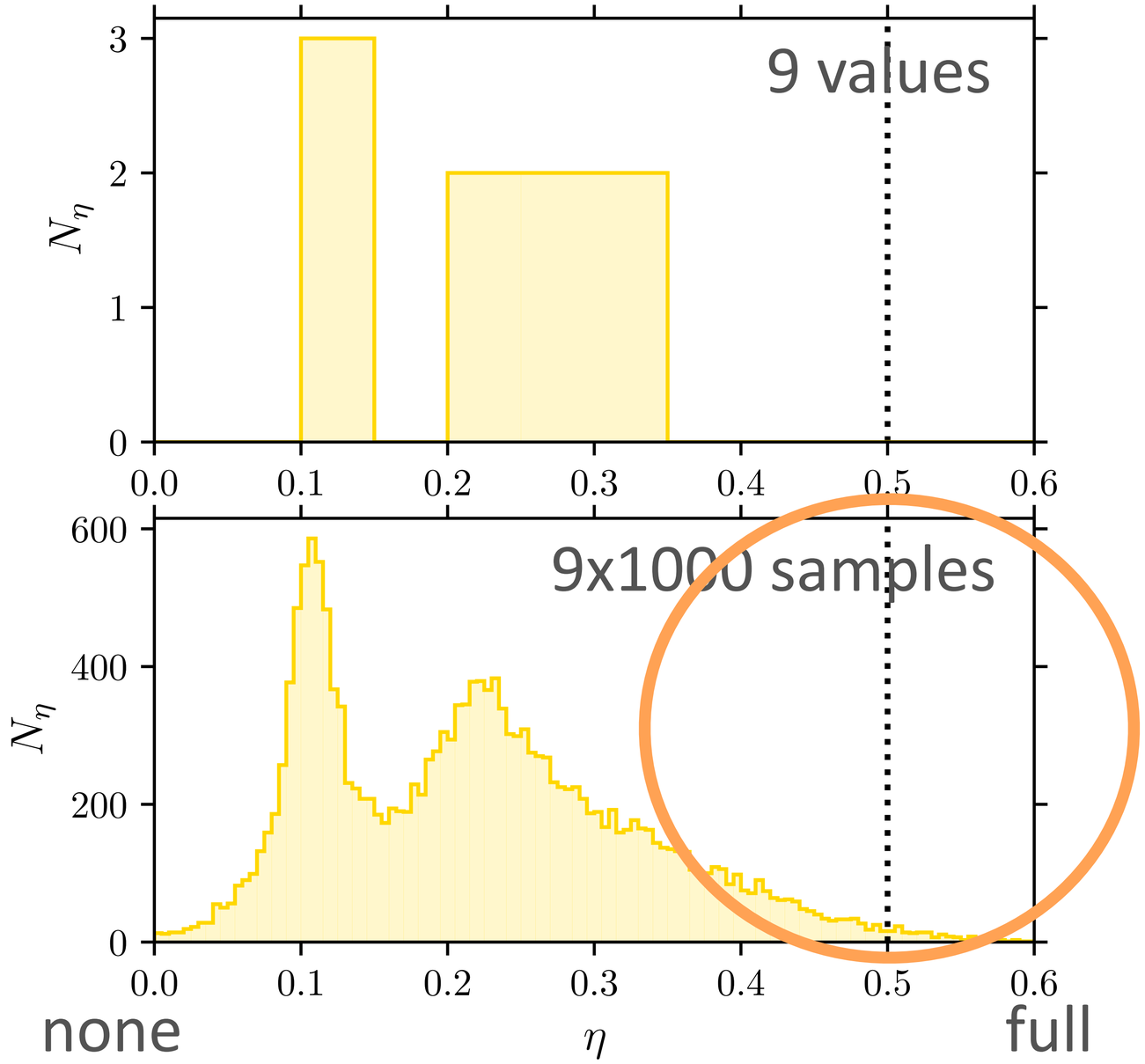
Watkins+ 2022

HST: kinematics with stellar mass



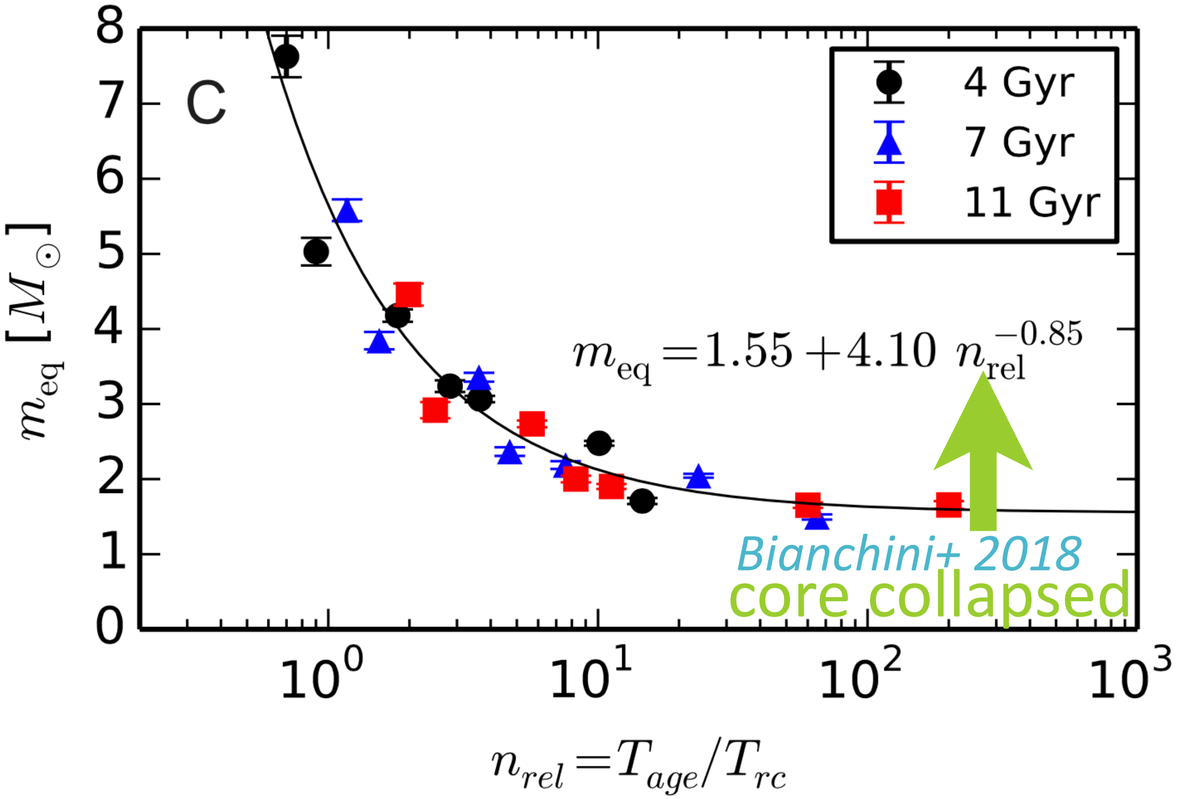
full equipartition (0.5) very unlikely

Watkins+ 2022

HST: kinematics with stellar mass

pre-core-collapse

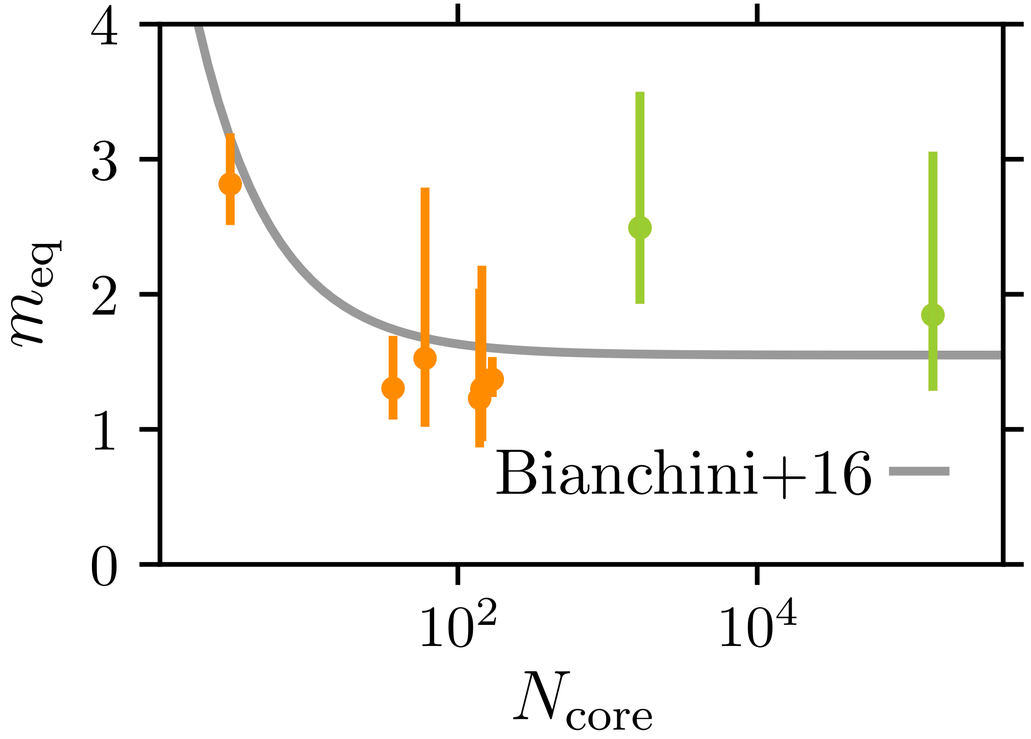
Bianchini+ 2016



Bianchini+ 2018

core collapsed

Watkins+ 2022

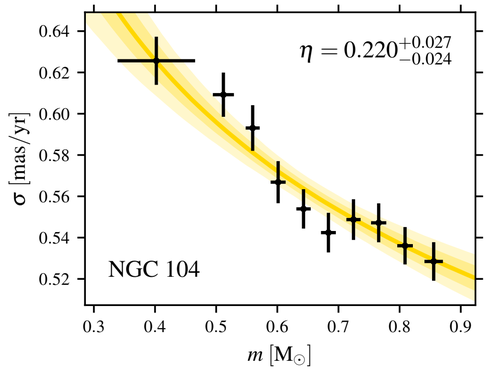


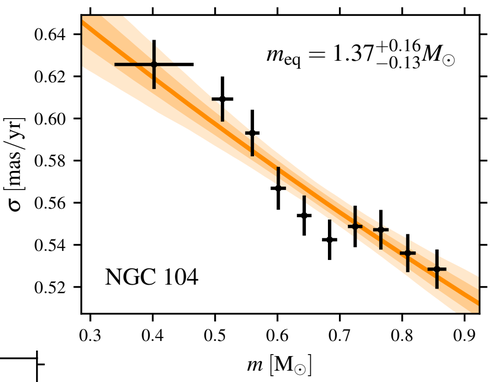
pre-core-collapse

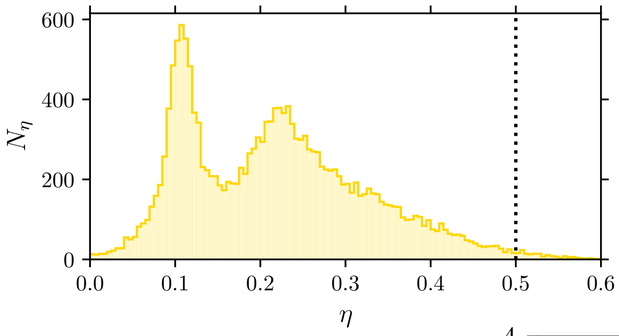
core collapsed

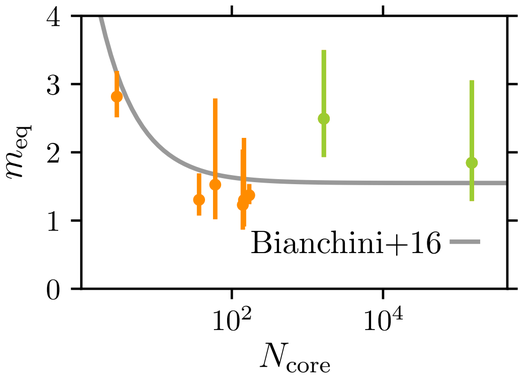
Energy equipartition in MW GCs with HST proper motions.

- Studied 9 clusters — first study of multiple clusters.
- All showed some equipartition.
- None in full equipartition.
- Amount of equipartition changes with number of relaxation times.
- Agrees with theory for pre- and post- core collapse.









Lots more in the paper!

Watkins+ 2022 ApJ 936 154

Laura Watkins · ESA-AURA, STScI