UNIVERSITY OF SURREY

What does M/L_V of globular clusters tell us about the IMF?

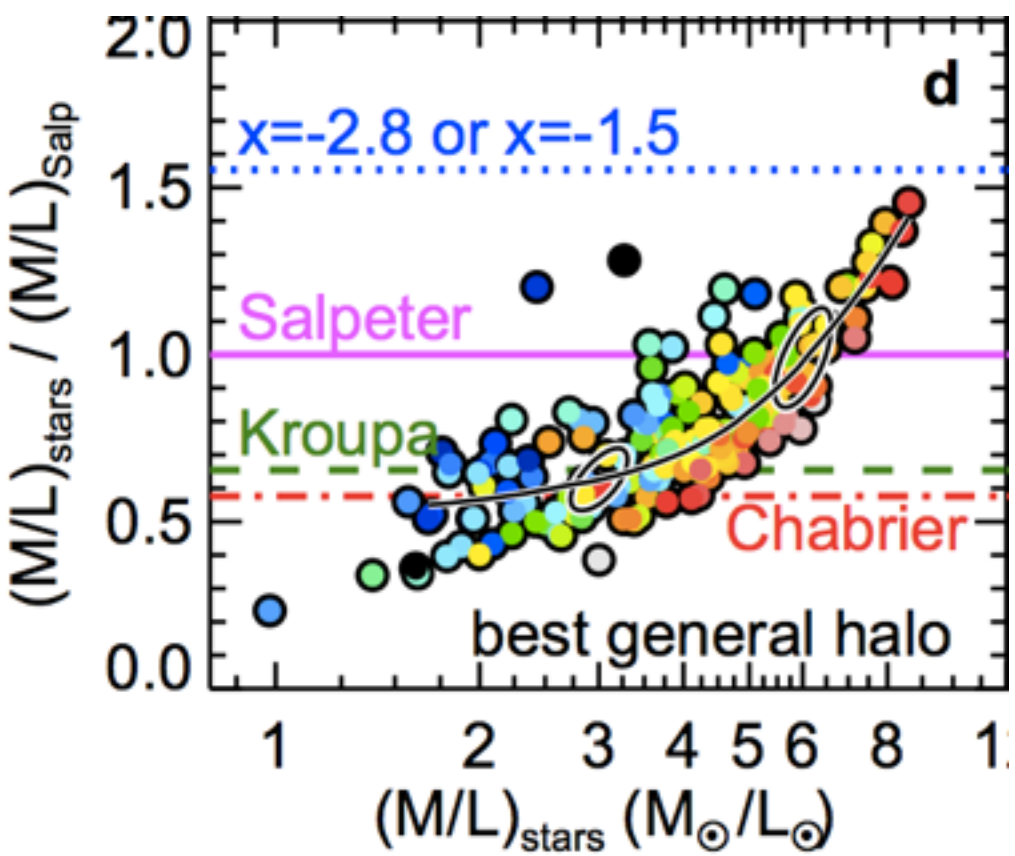
Mark Gieles

Rosemary Shanahan (Edinburgh)
Vincent Hénault-Brunet, Alice Zocchi, Miklos Peuten (Surrey)
Anna Lisa Varri (Edinburgh)

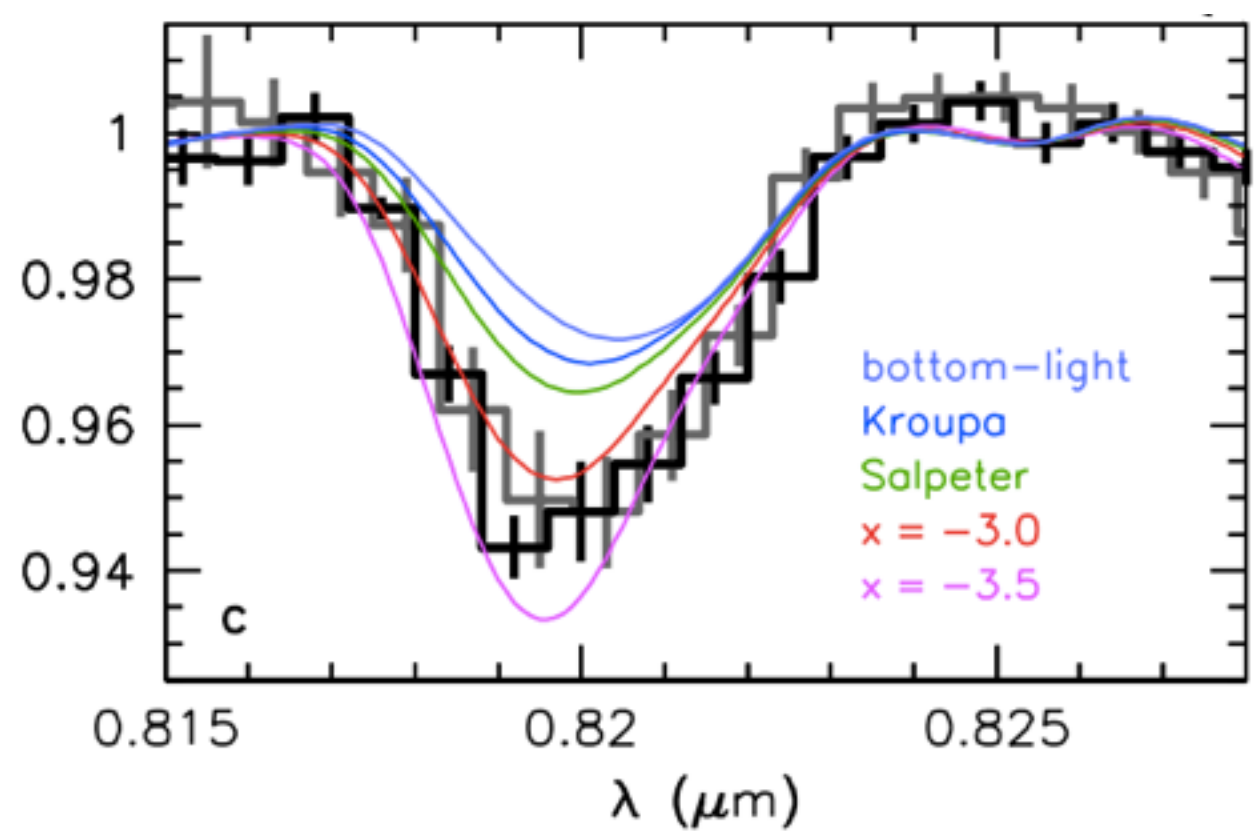
Motivation: IMF variations in early type galaxies?

Kinematics

Direct detection low-mass stars



Cappellari et al. 2012



Van Dokkum & Conroy 2010

M/L_V of GCs: an “easy” probe of the IMF

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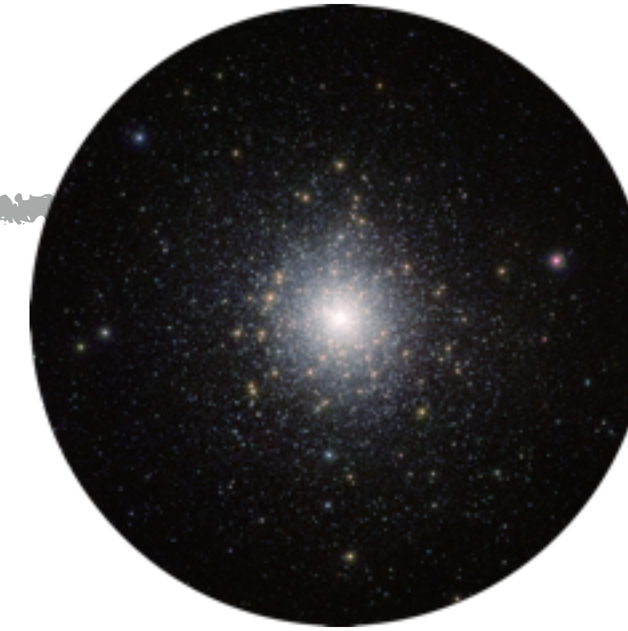

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M/L_V of GCs: an "easy" probe of the IMF

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3 surface brightness profile

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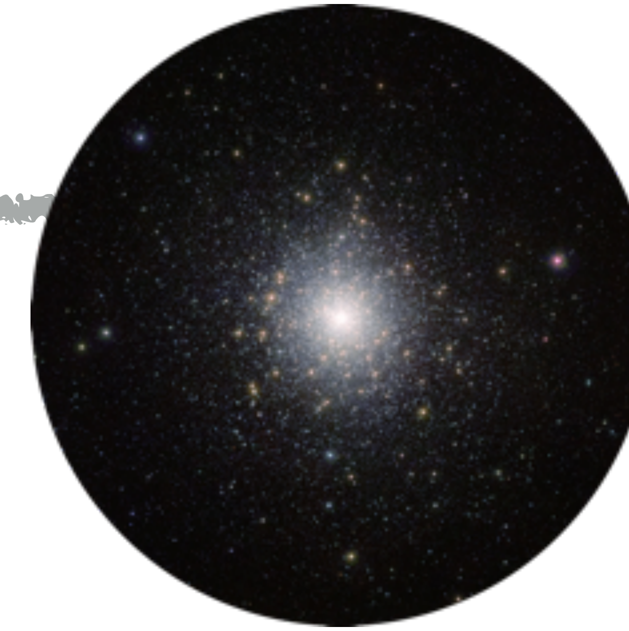

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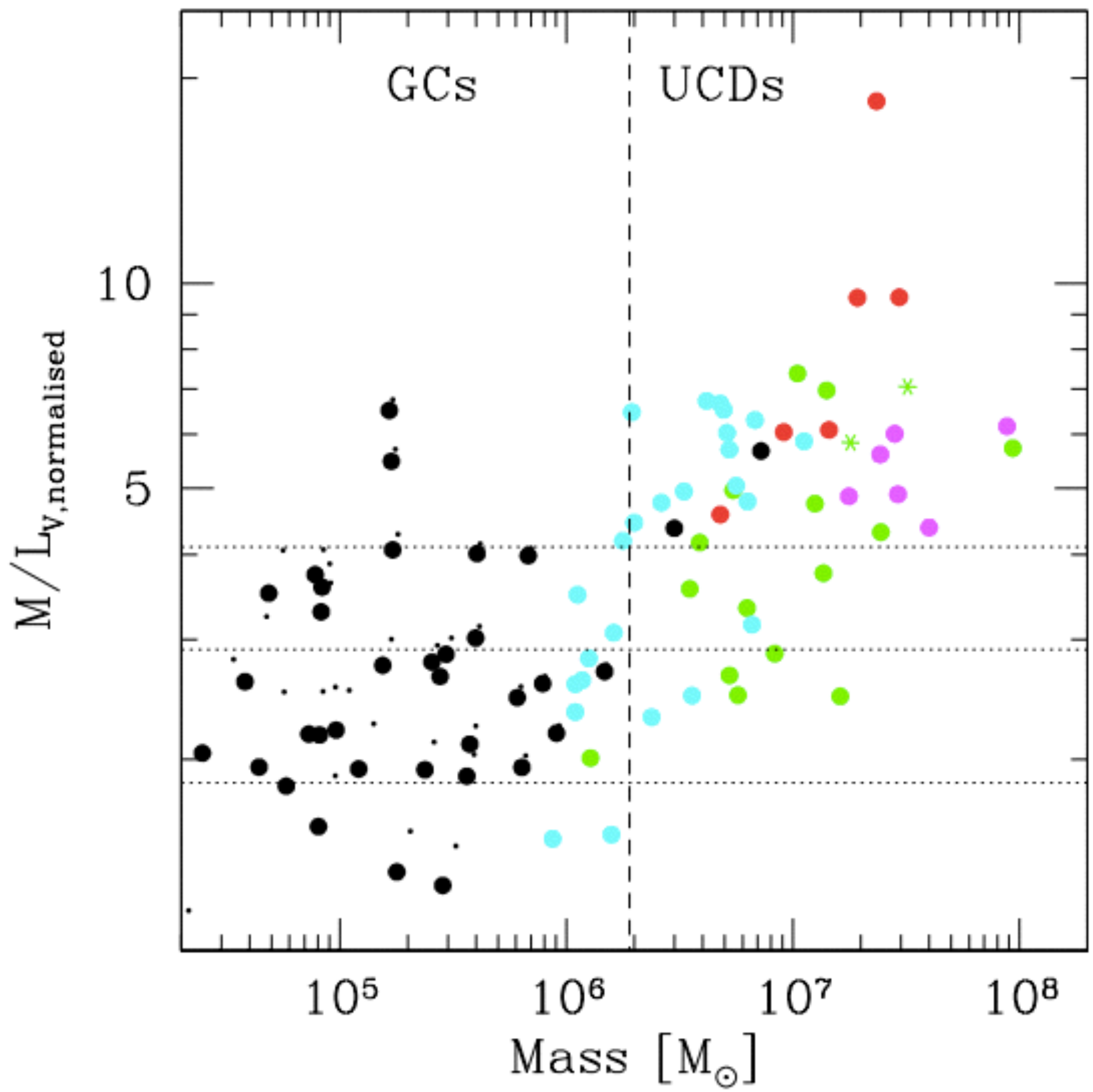
2 kinematics (e.g. RVs)

3 surface brightness profile

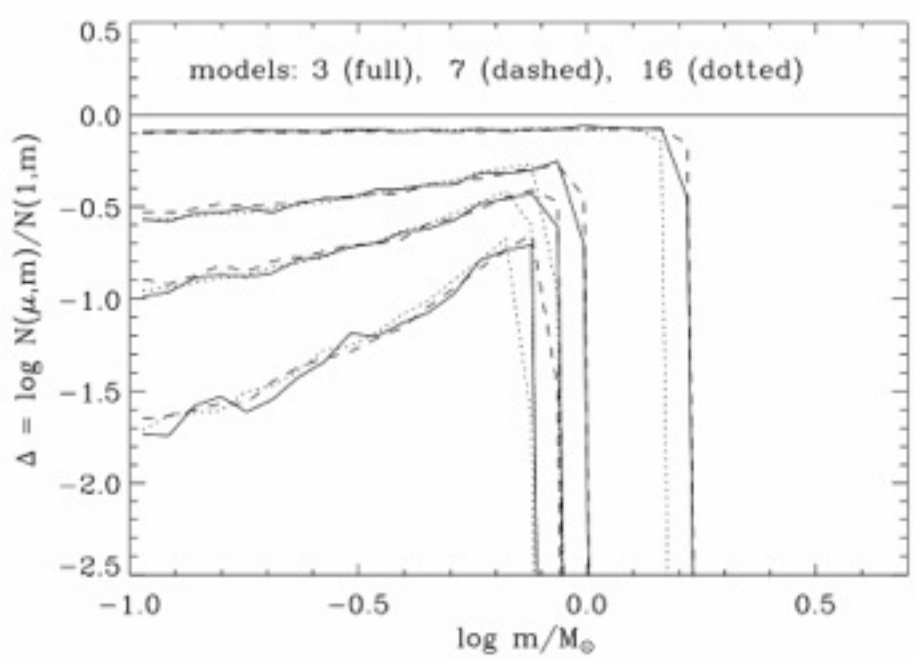
4 measure L_V and compare M/L_V to SSP model

Transition between GCs and ultra-compact dwarf galaxies

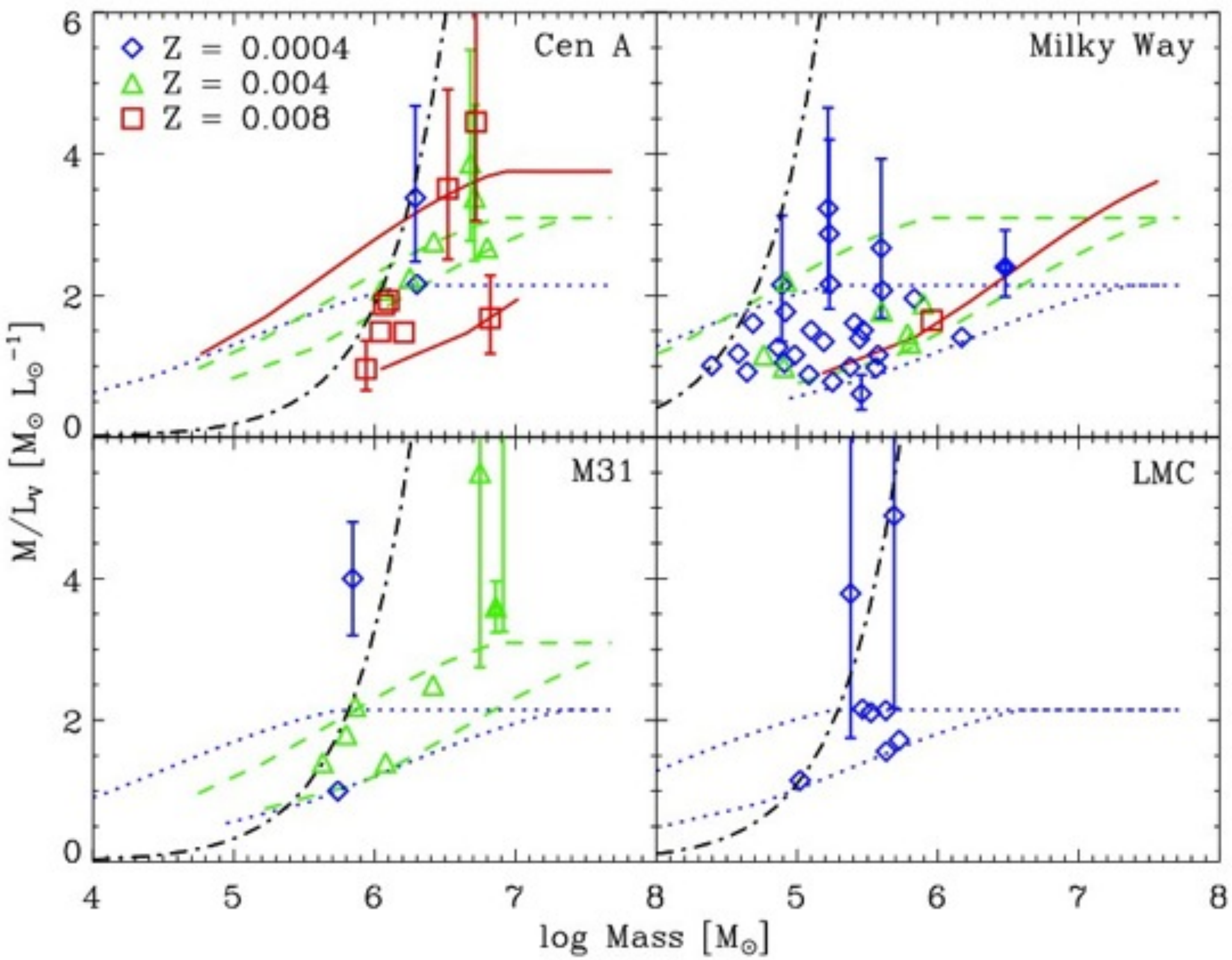


Mieske et al. 2008

Reduced *M/L_V* of GCs: depletion of low-mass stars?



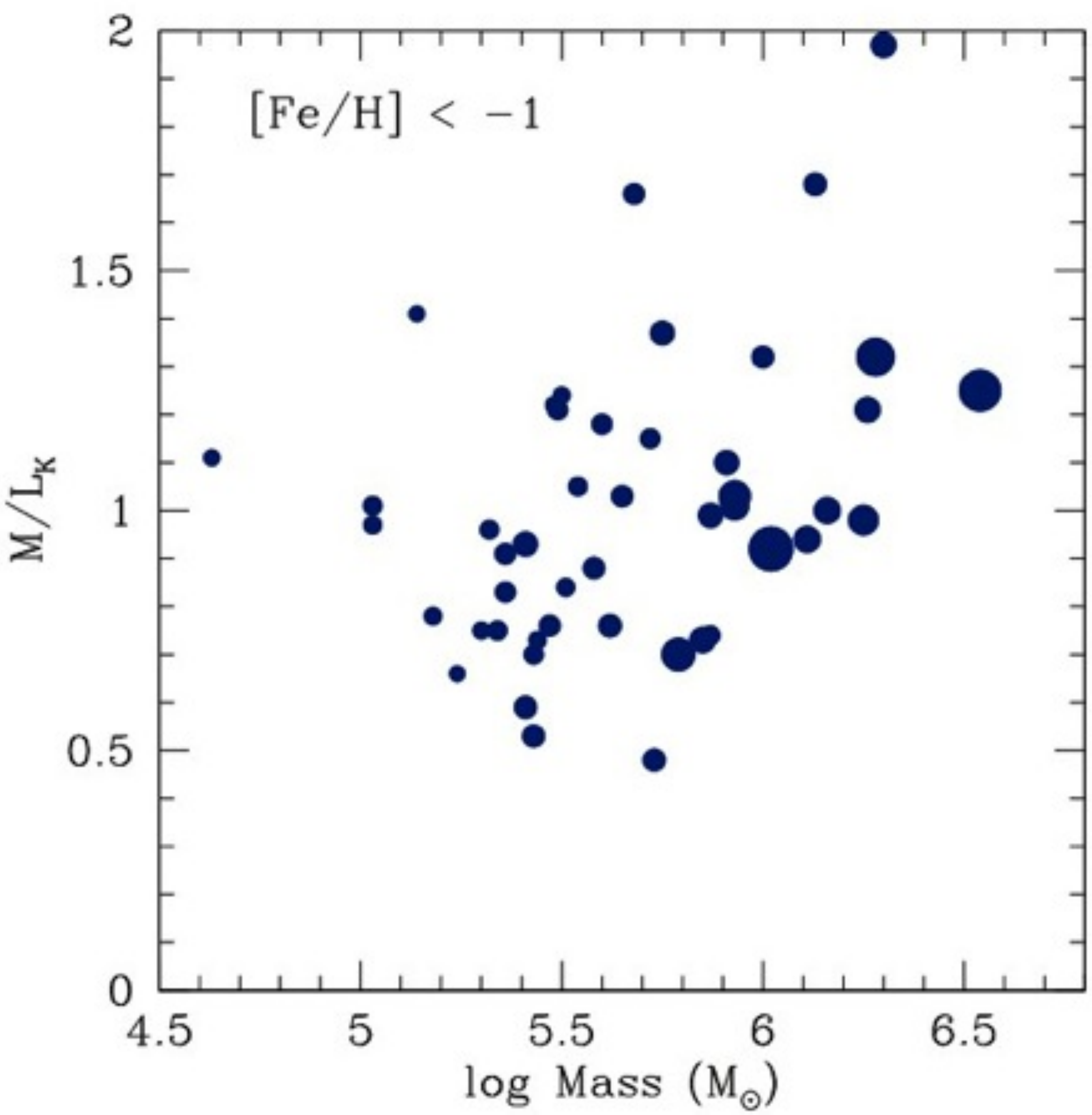
Lamers et al 2013



Kruijssen 2008

Low-mass star depletion?

200 GCs in M31



Strader et al. 2011

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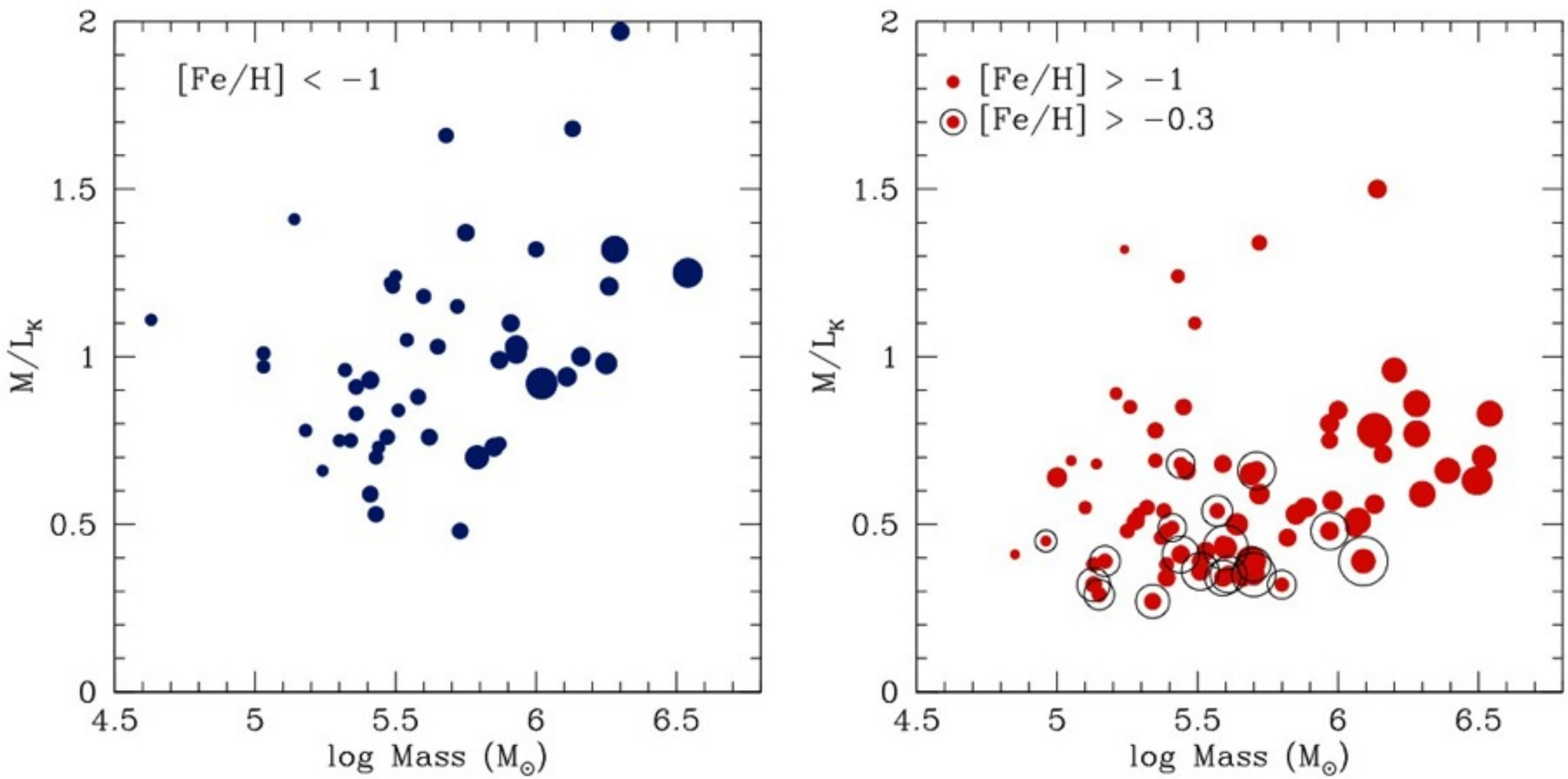

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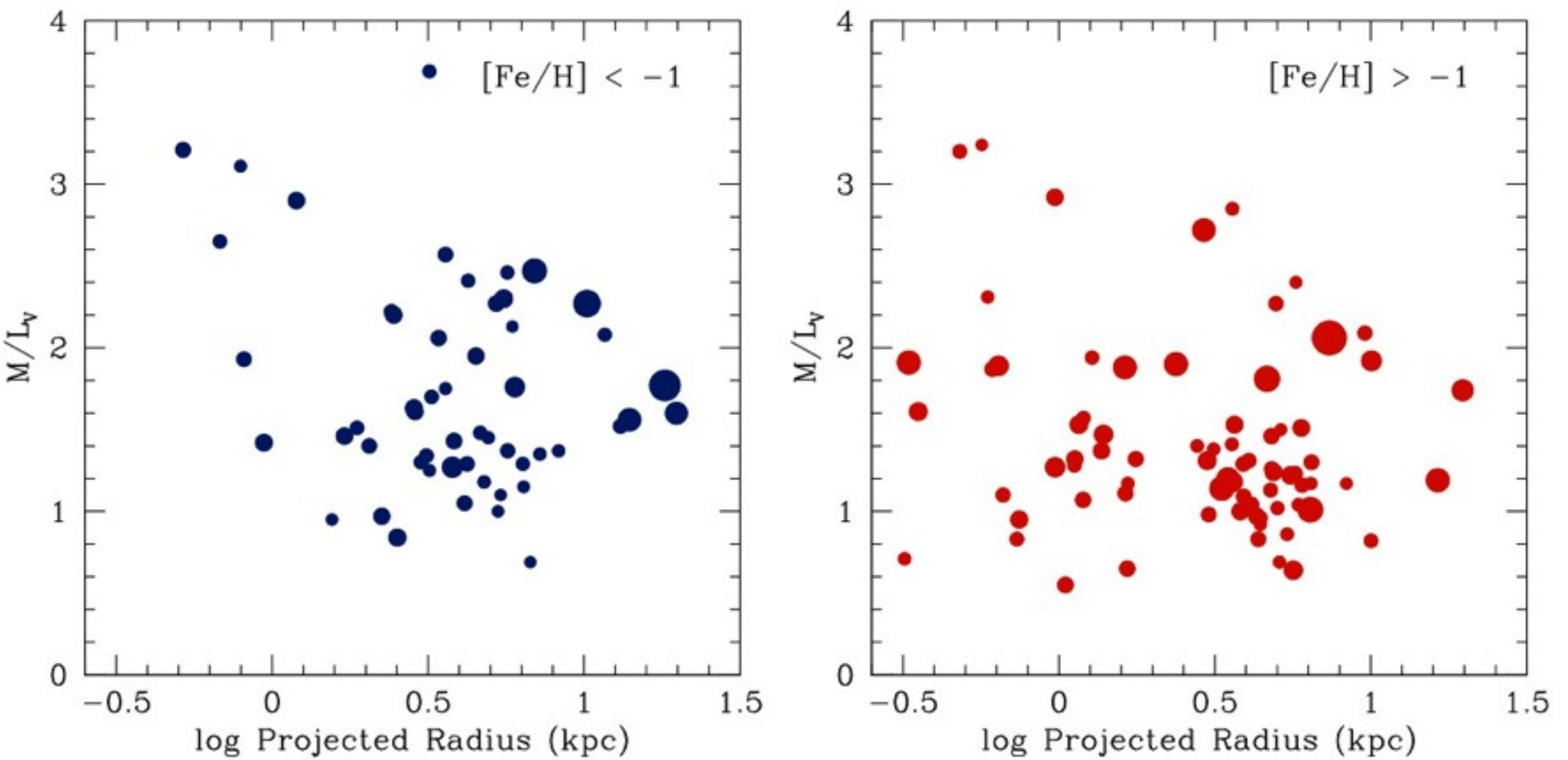
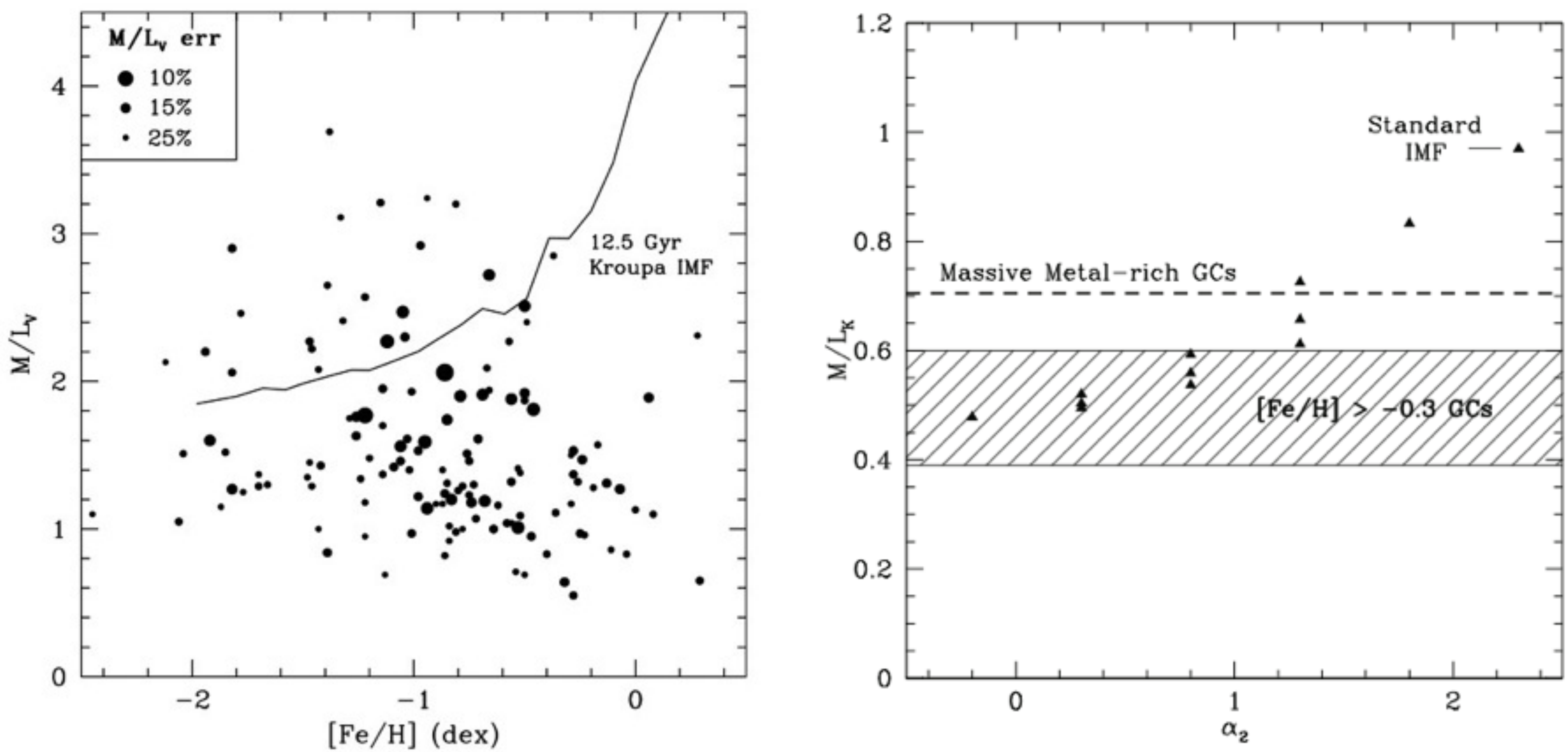


Strader et al. 2011

[Fe/H] dependent IMF?



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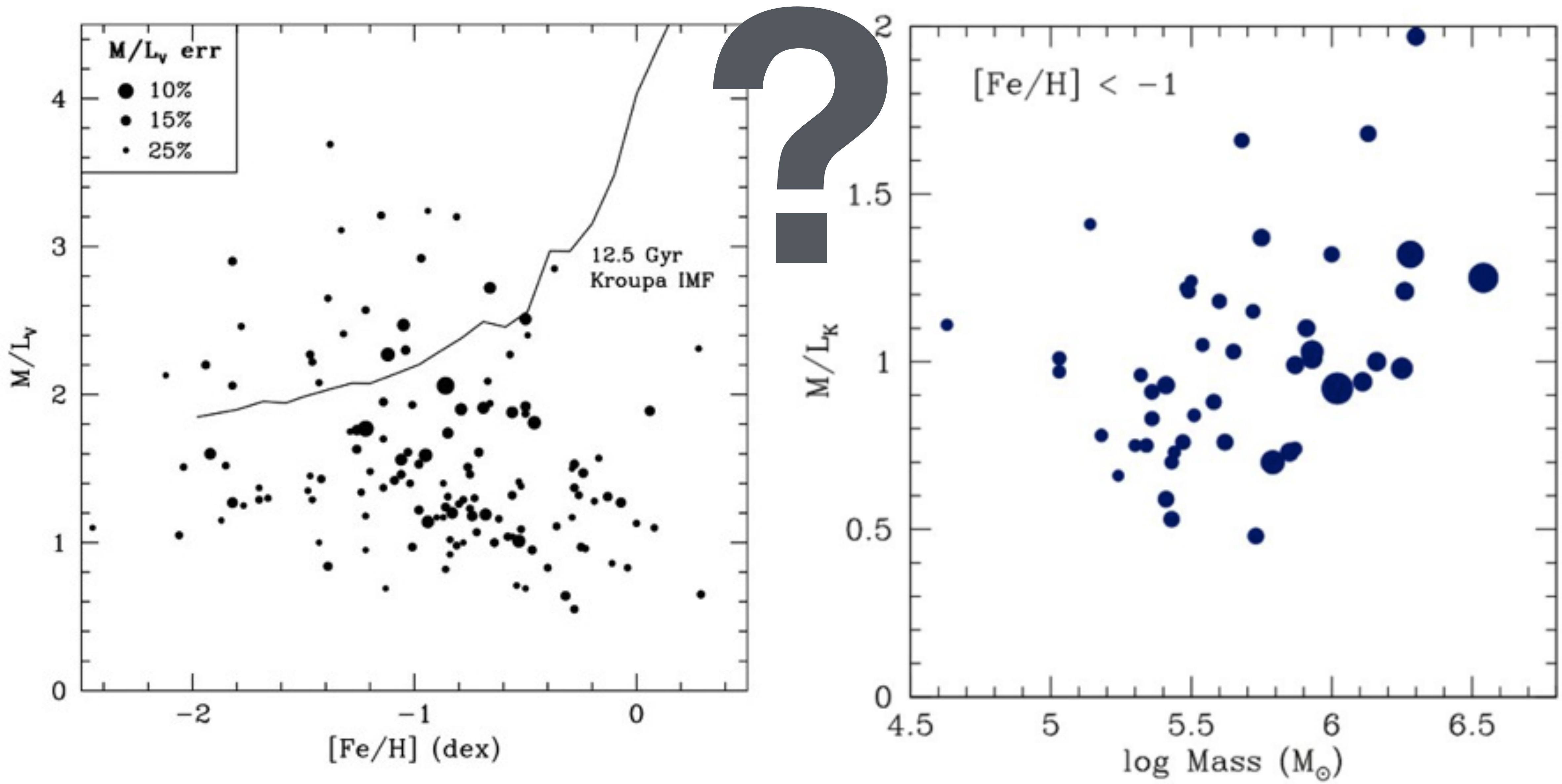
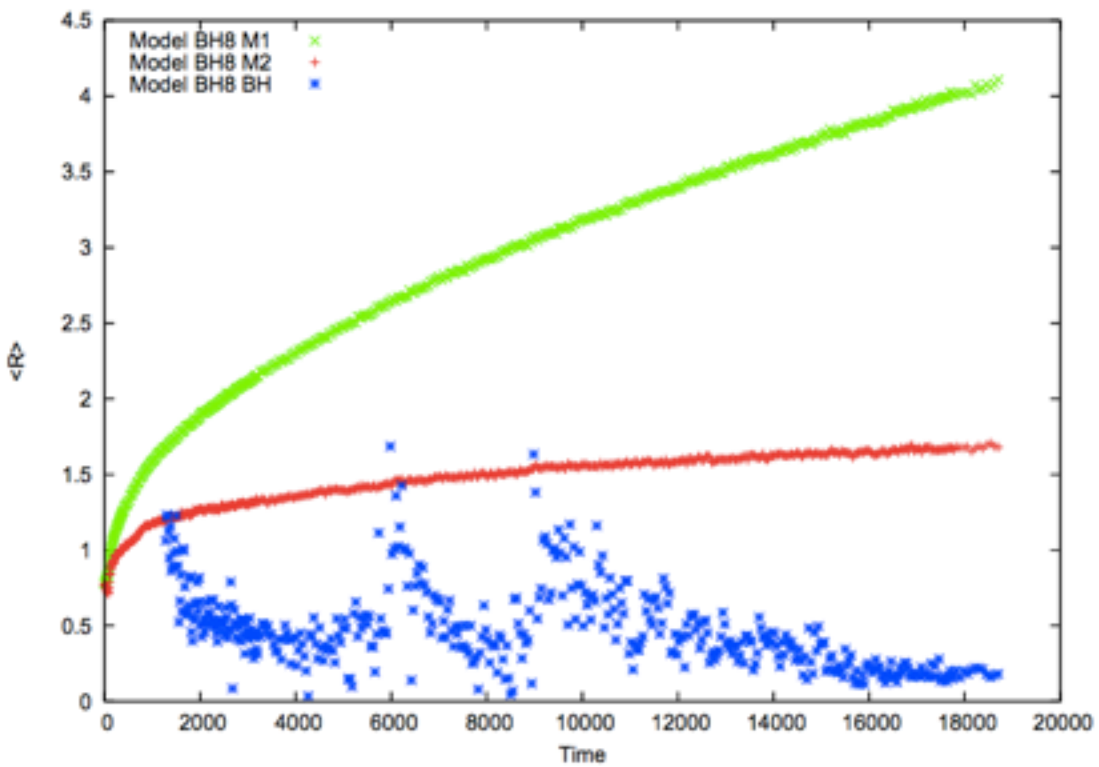


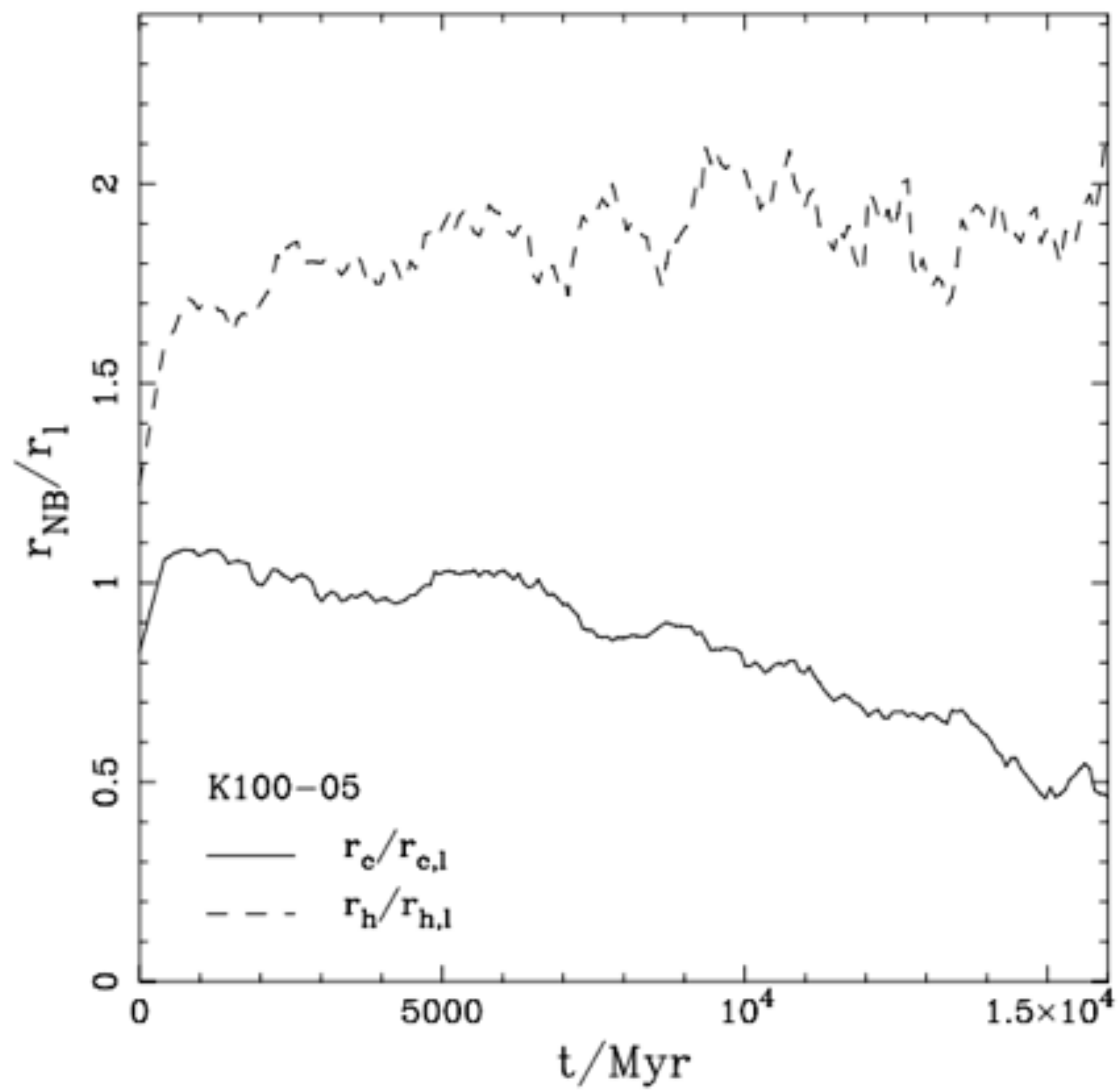
Strader et al. 2011

M/L_V of GCs: an "easy" probe of the IMF?

GCs are collisional systems .. .. which leads to biases!



Aarseth 2012



Hurley 2007

M/L_V of GCs: an "easy" probe of the IMF?

virial equilibrium revisited

3D quantities

$$M = 2\frac{\langle v^2\rangle r_{\rm v}}{G}$$

observable quantities

$$M = 2\frac{\eta}{\eta_r \eta_v}\frac{\langle v_{\rm p}^2\rangle_L r_{{\rm hp},L}}{G}$$

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(Anisotropic) Lowered Isothermal Model Exploration in Python

Isotropic:

$$f_n(\hat{E}) = \begin{cases} A\exp(-\hat{E}), & n = 1 \\ A\left[\exp(-\hat{E}) - \sum_{m=0}^{n-2} \frac{1}{!m}\left(-\hat{E}\right)^m\right], & n > 1 \end{cases}$$

$$\hat{E} = \frac{E - \phi(r_{\mathrm{t}})}{\sigma^2}$$

Davoust 1977

(A)limepy

GAIA CHALLENGE
UNIVERSITY OF SURREY

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“Michie” anisotropy:

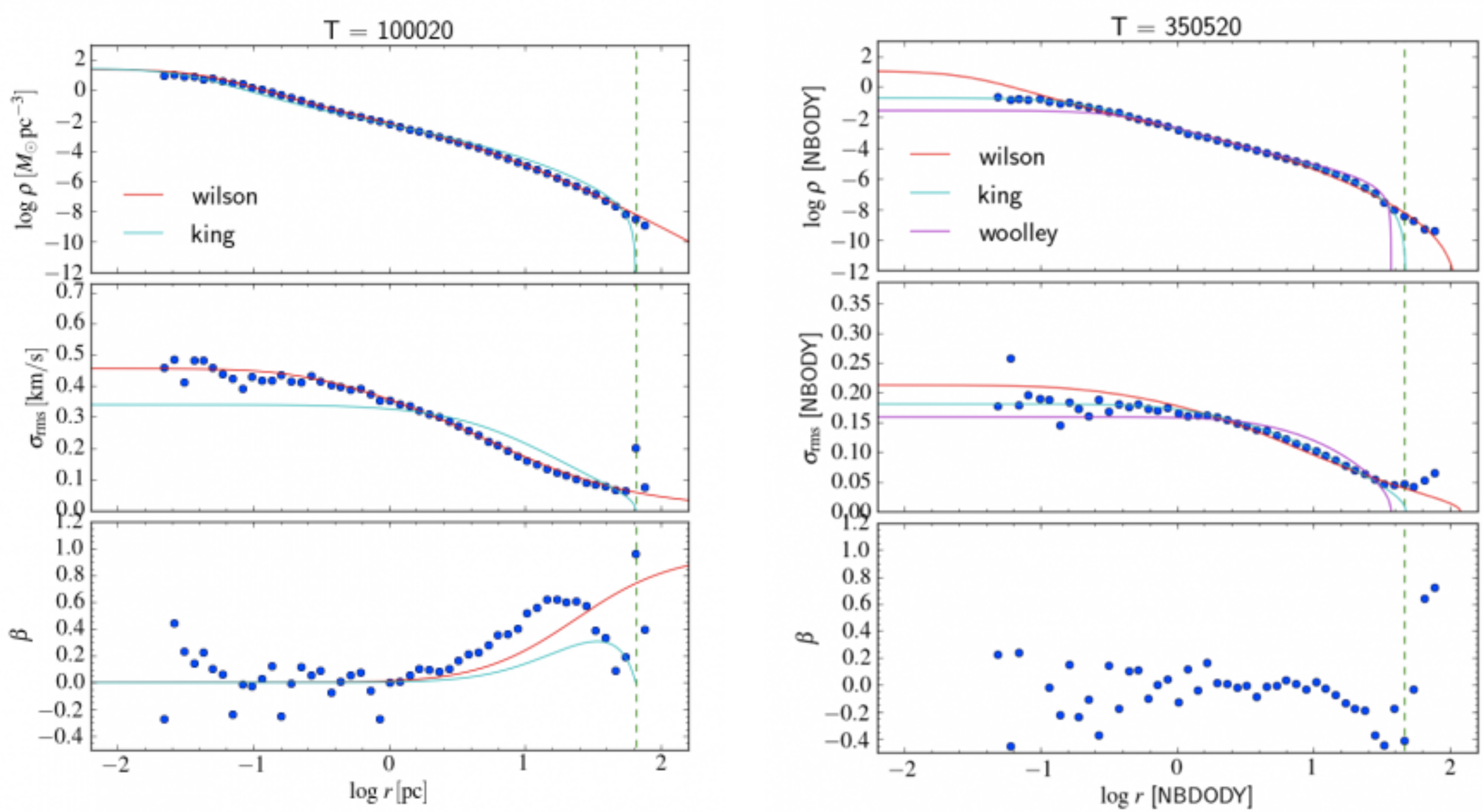
$$f_n(\hat{E}, \hat{J}^2) = \exp\left(-\hat{J}^2\right) f_n(\hat{E})$$

$$\hat{J}^2 = \frac{J^2}{2r_\mathrm{a}^2\sigma^2}$$

Davoust 1977

Comparison to *N*-body simulations

http://astrowiki.ph.surrey.ac.uk/dokuwiki



Zocchi et al. in prep

Multi-mass limepy

Include mass dependence in f in a self-consistent way

Da Costa & Freeman 1976; Gunn & Griffin 1979

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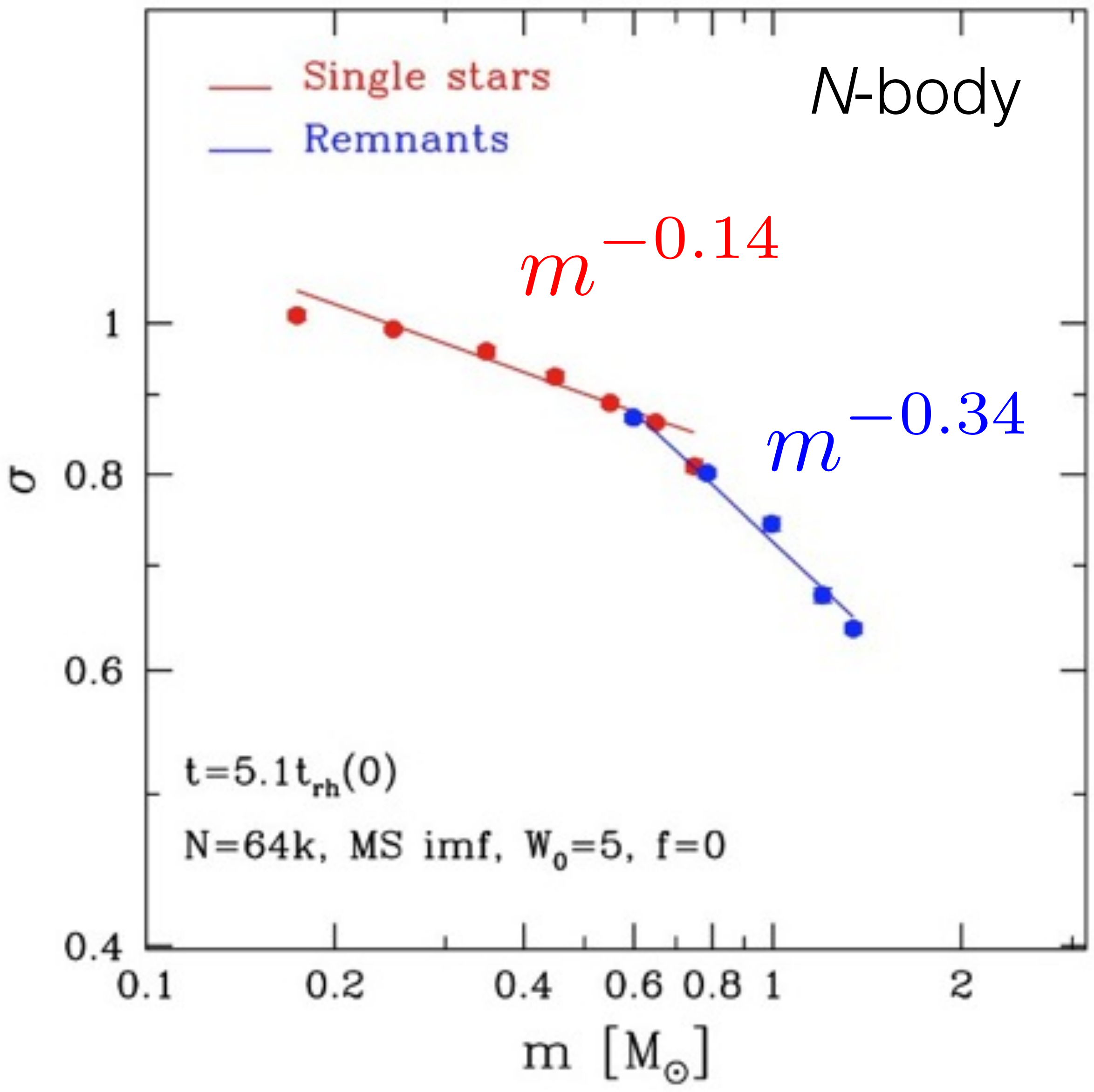
$$\hat{E} = \frac{E - \phi(r_\mathrm{t})}{\sigma_j^2}, \quad \boxed{\sigma_j^2 = v_0^2 \left(\frac{m_j}{\bar{m}}\right)^{-\beta},} \quad \beta = \begin{cases} 0 & \text{single mass} \\ 1 & \text{“equipartition”} \end{cases}$$

Equipartition?

"Modelling techniques that assume equipartition by construction (e.g. multi-mass Michie-King models) are approximate at best."

Trenti & van der Marel (2013)



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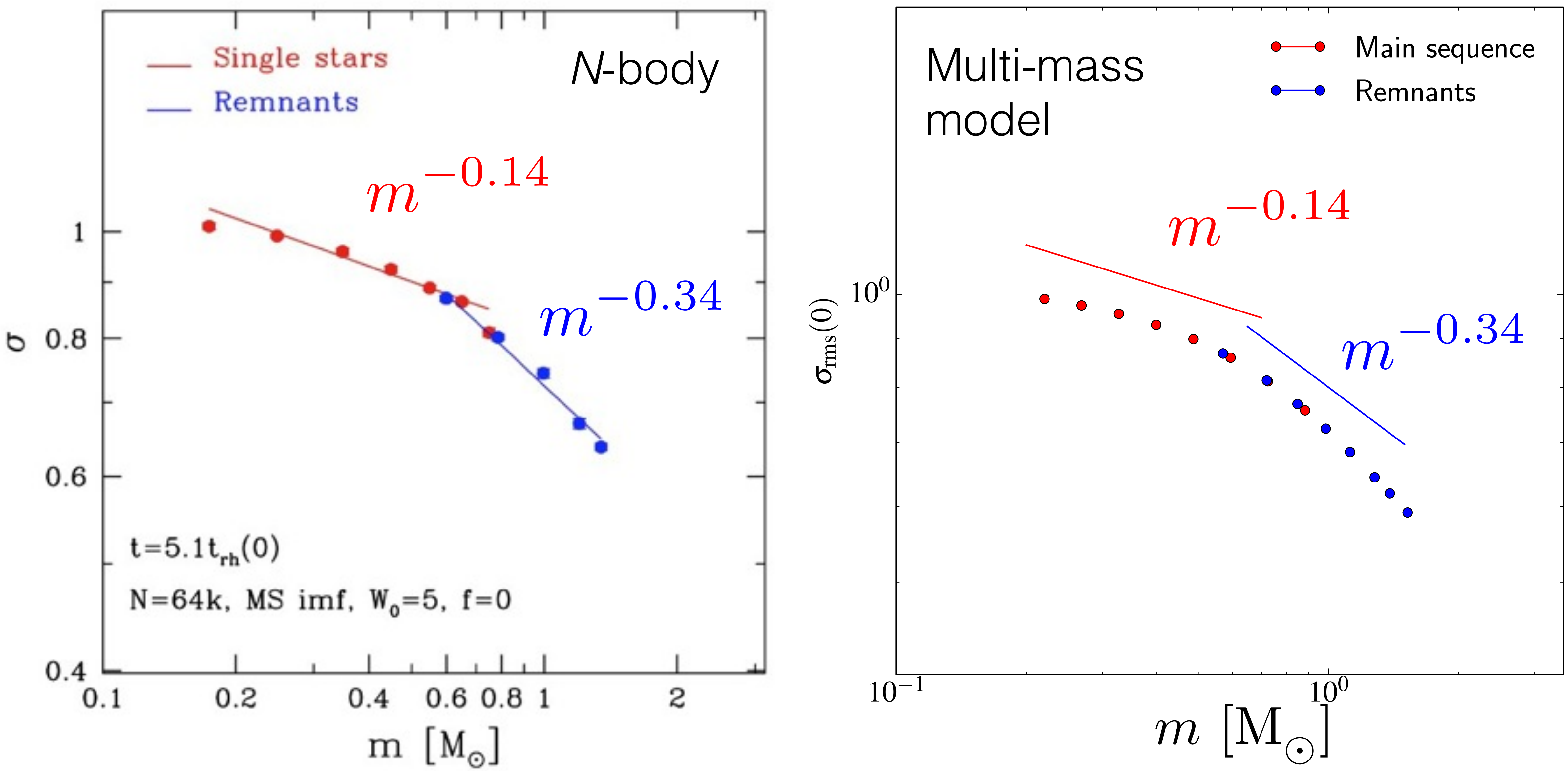
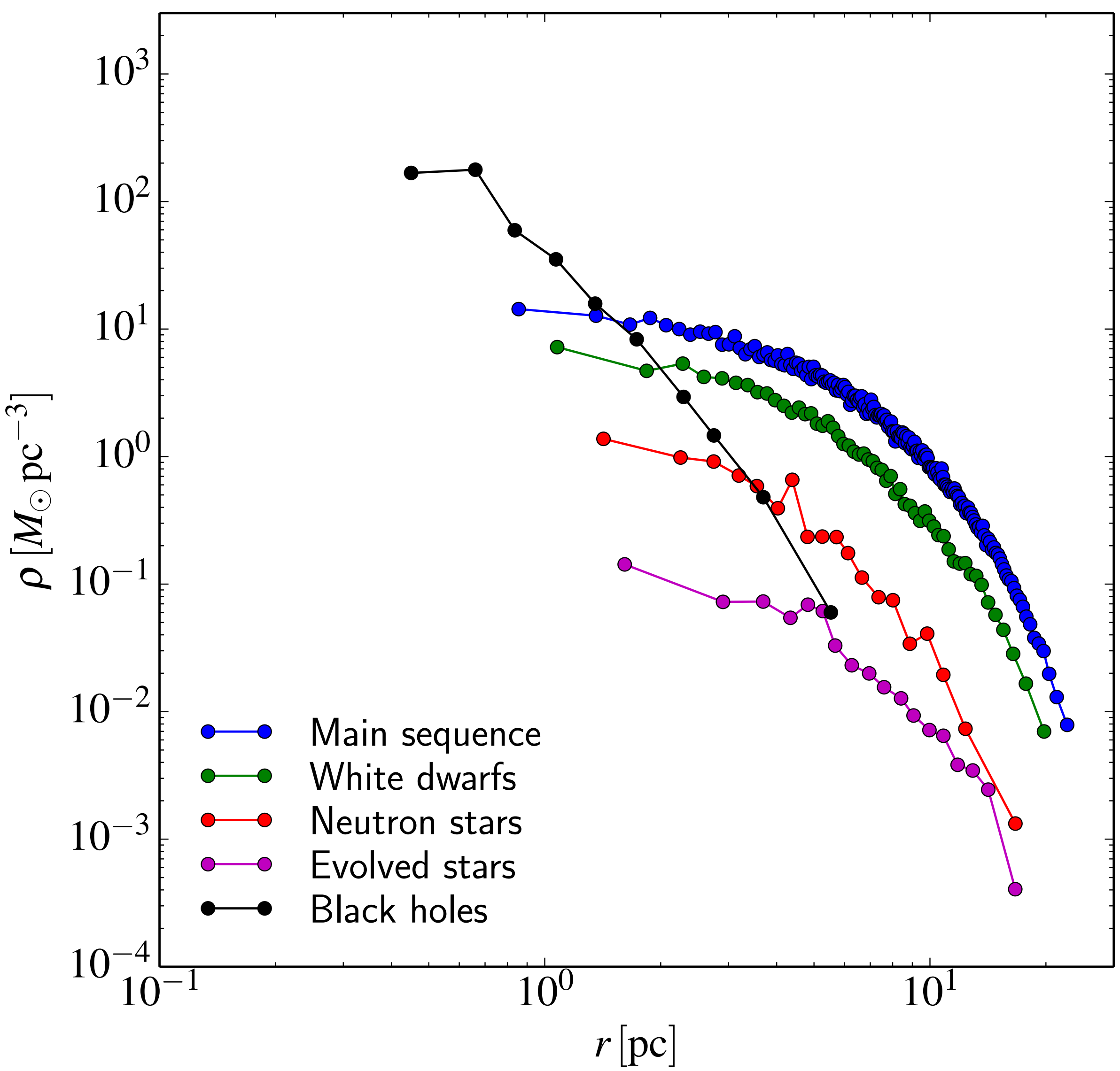


Equipartition?

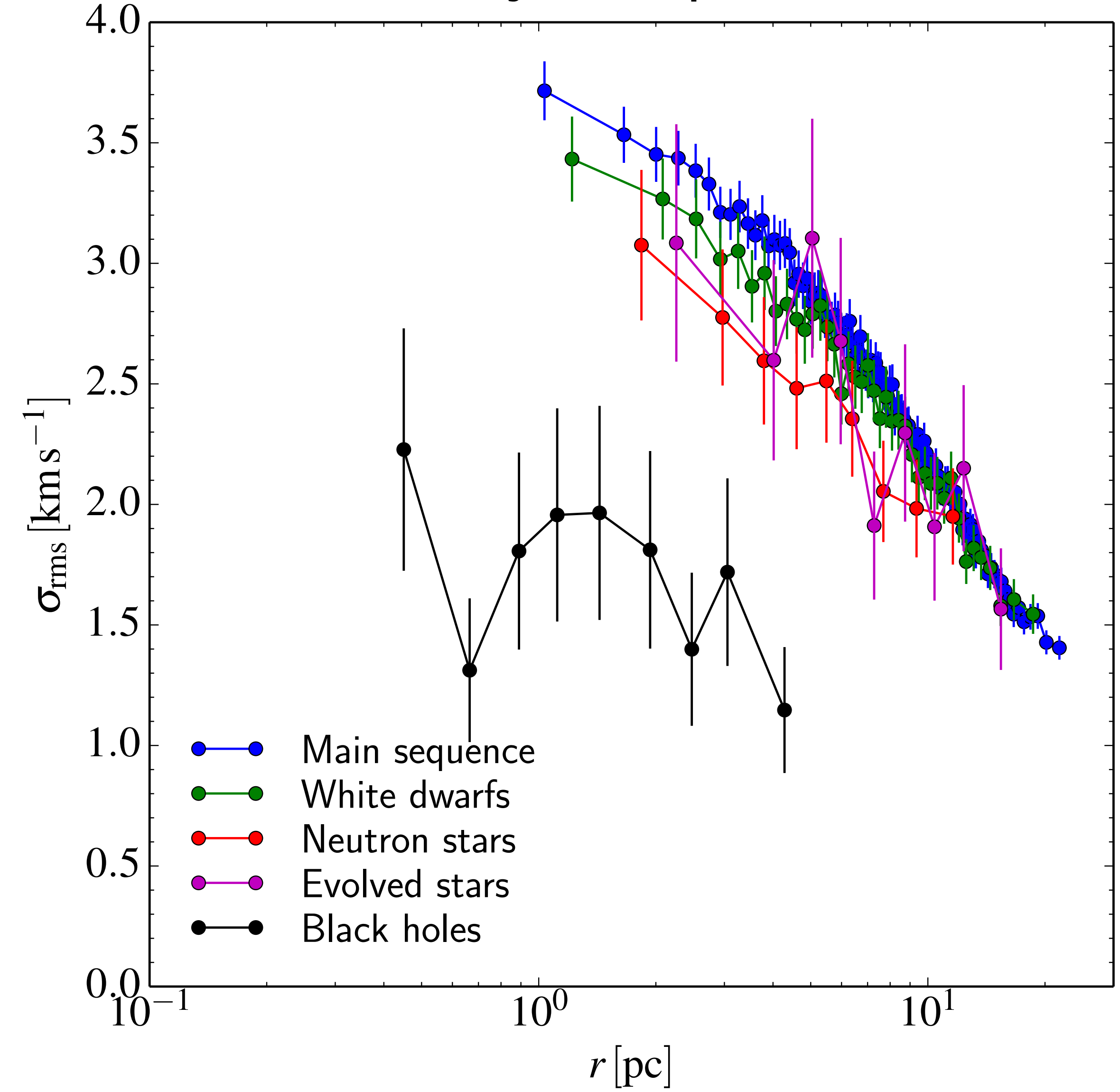
NBODY6 (Aarseth) simulation:

N=10^5, evolved MF, orbit in singular isothermal galaxy, $r_{\mathrm{Jacobi}}/r_{\mathrm{half\text{-}mass}} \simeq 10$

Density



Velocity dispersion



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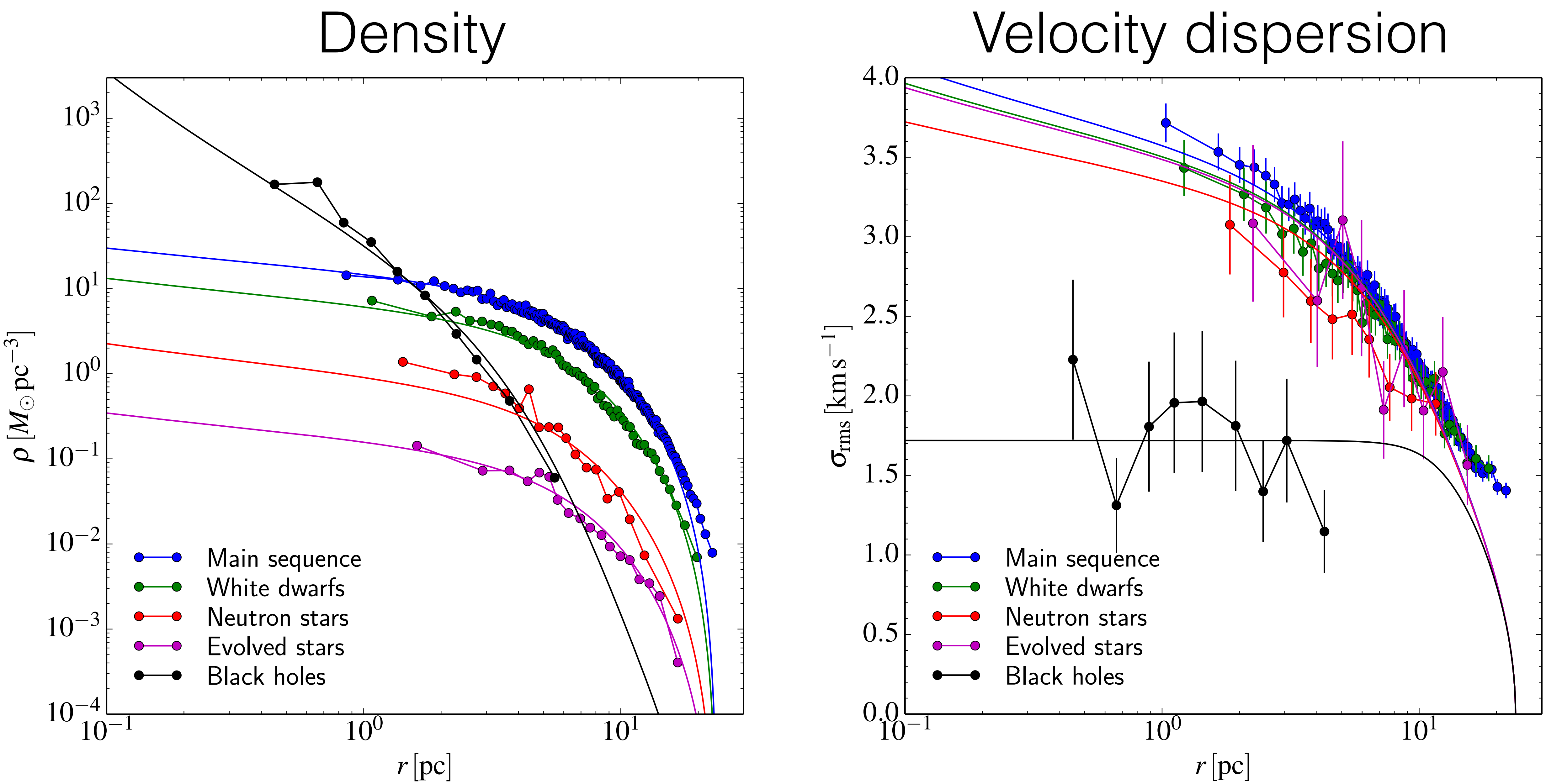

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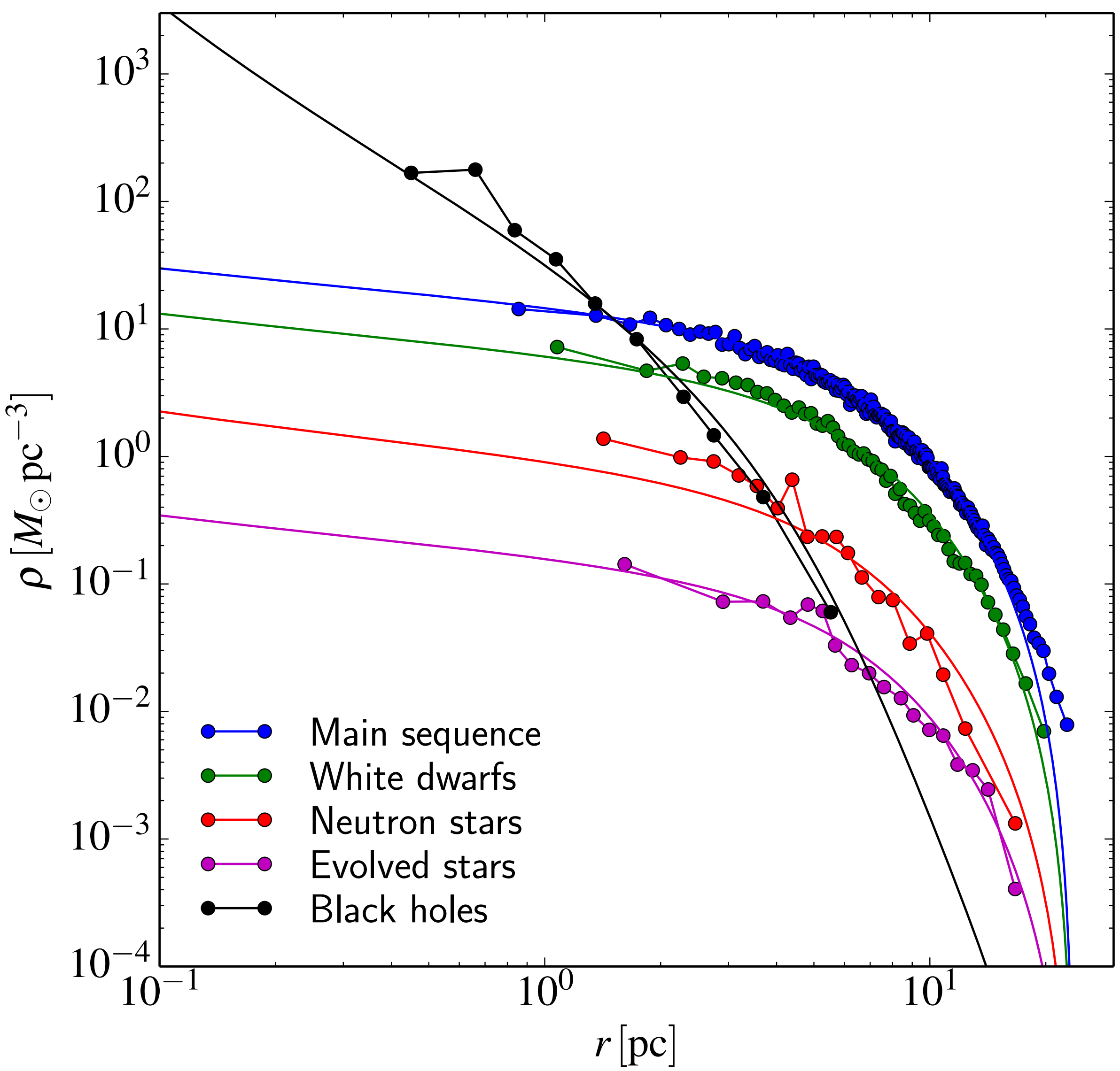

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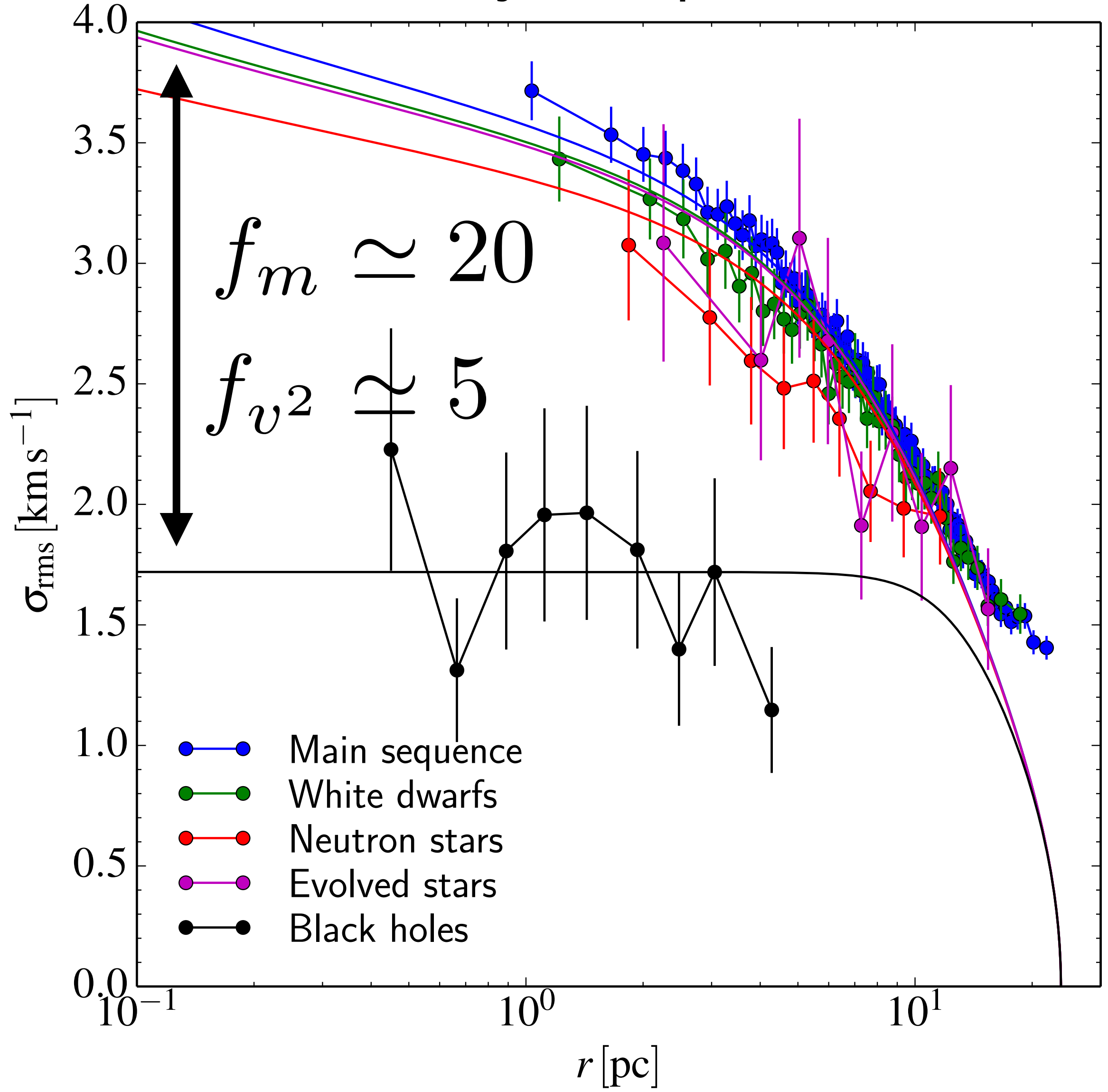
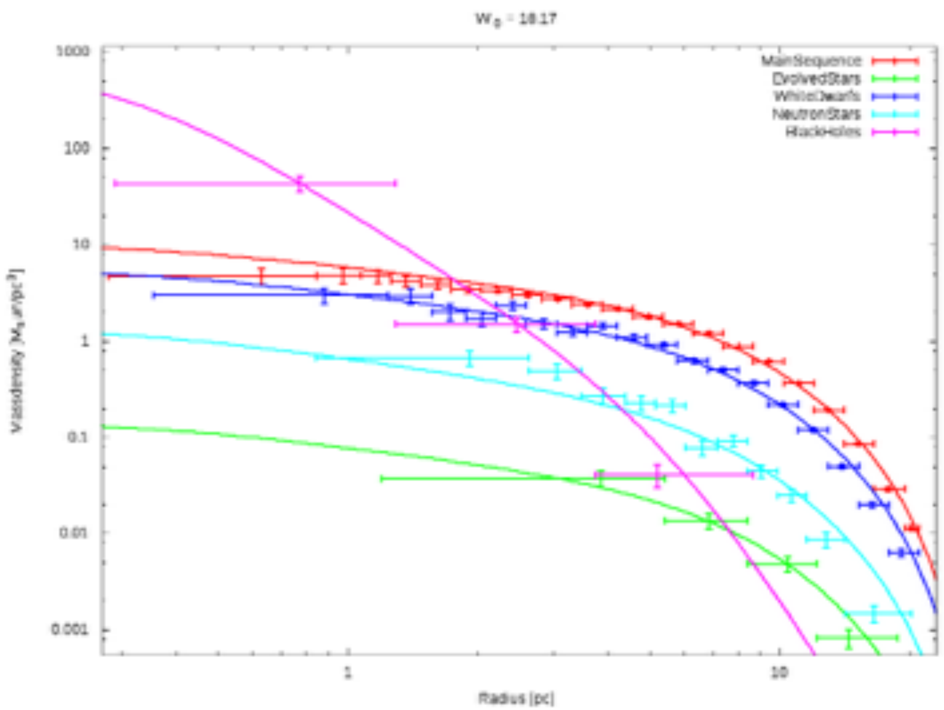
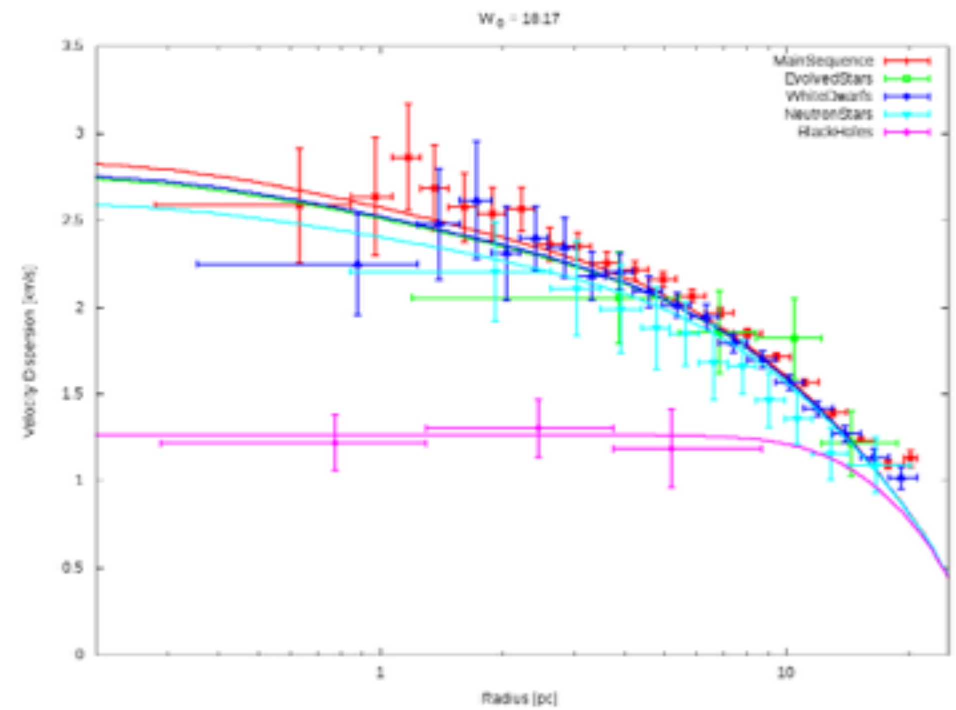


Multi-mass models perfectly describe *N*-body systems

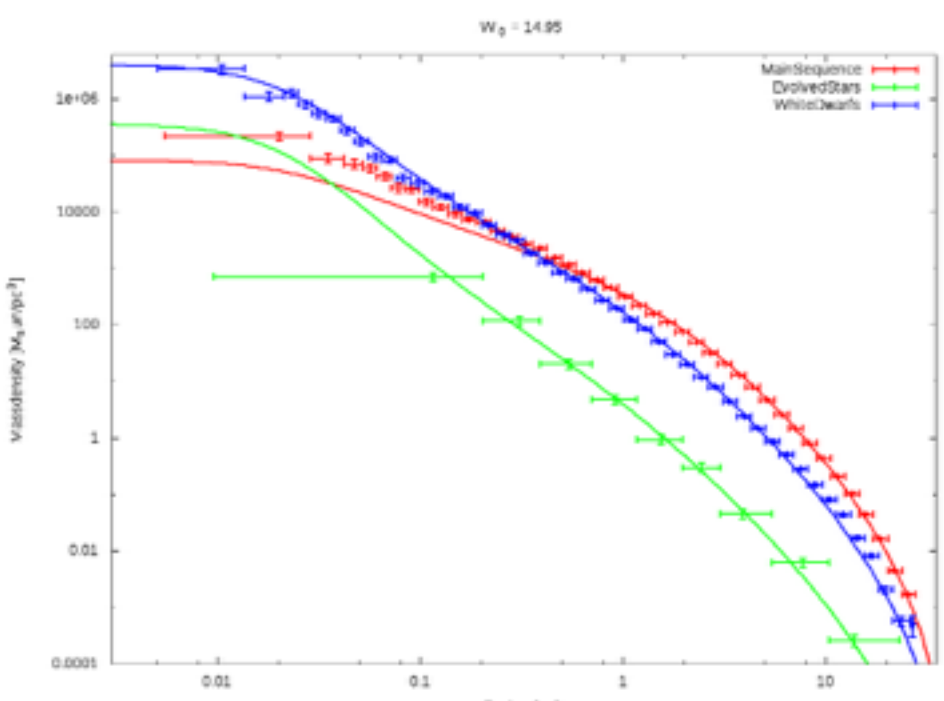
Density | Velocity dispersion

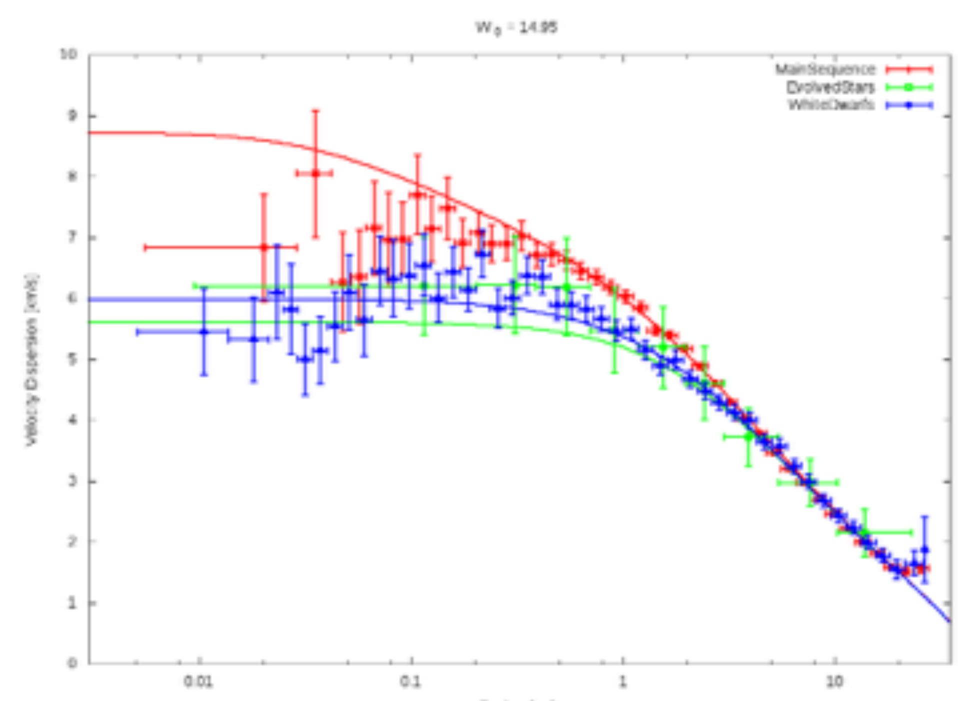
with NSs+ BHs





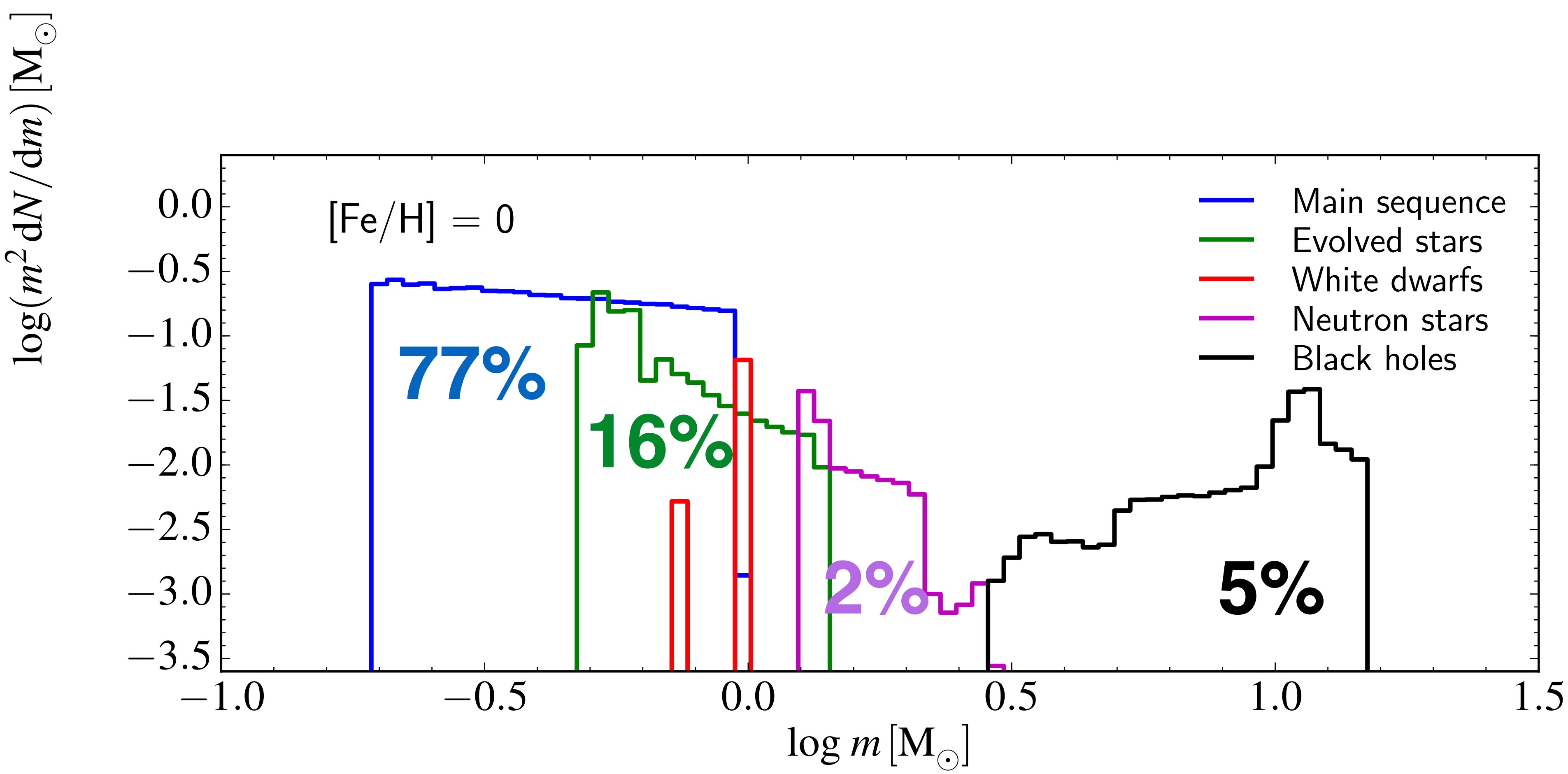
without NSs+ BHs





Peuten et al. in prep

Universal IMF = [Fe/H] dependent MF



Evolve IMF for 12 Gyr with SSE, Hurley et al. 2000

Shanahan et al., to be subm.

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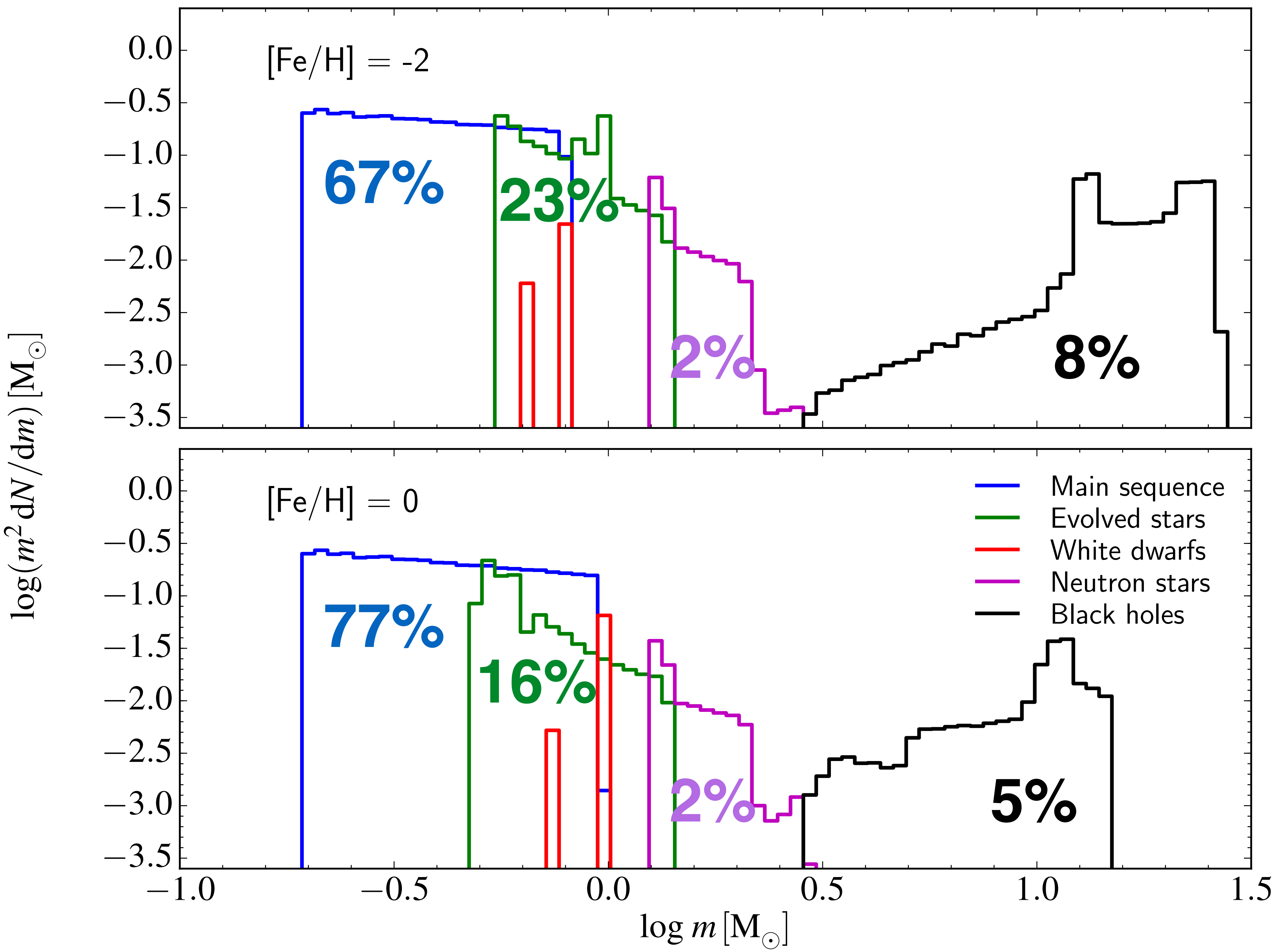

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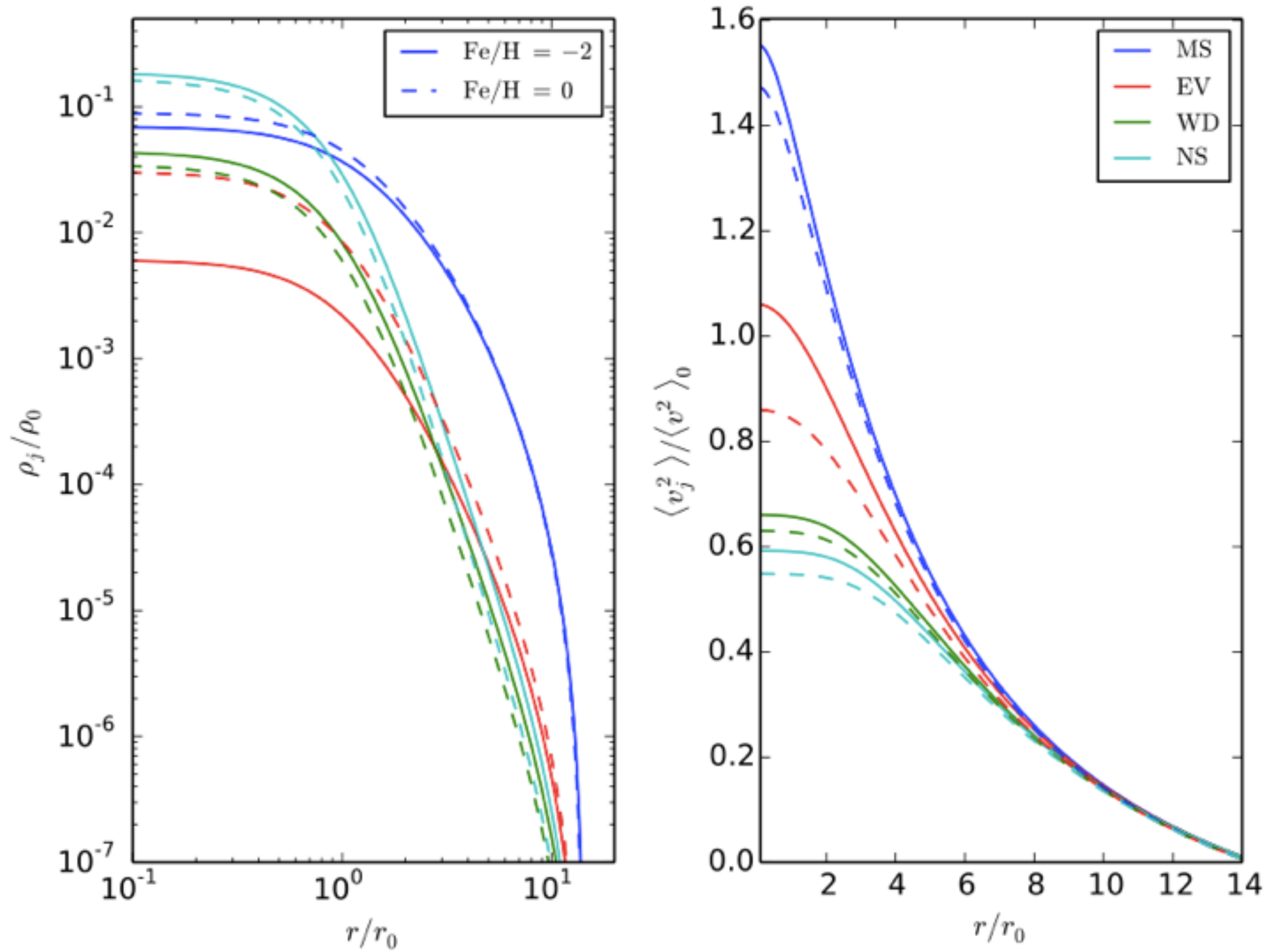

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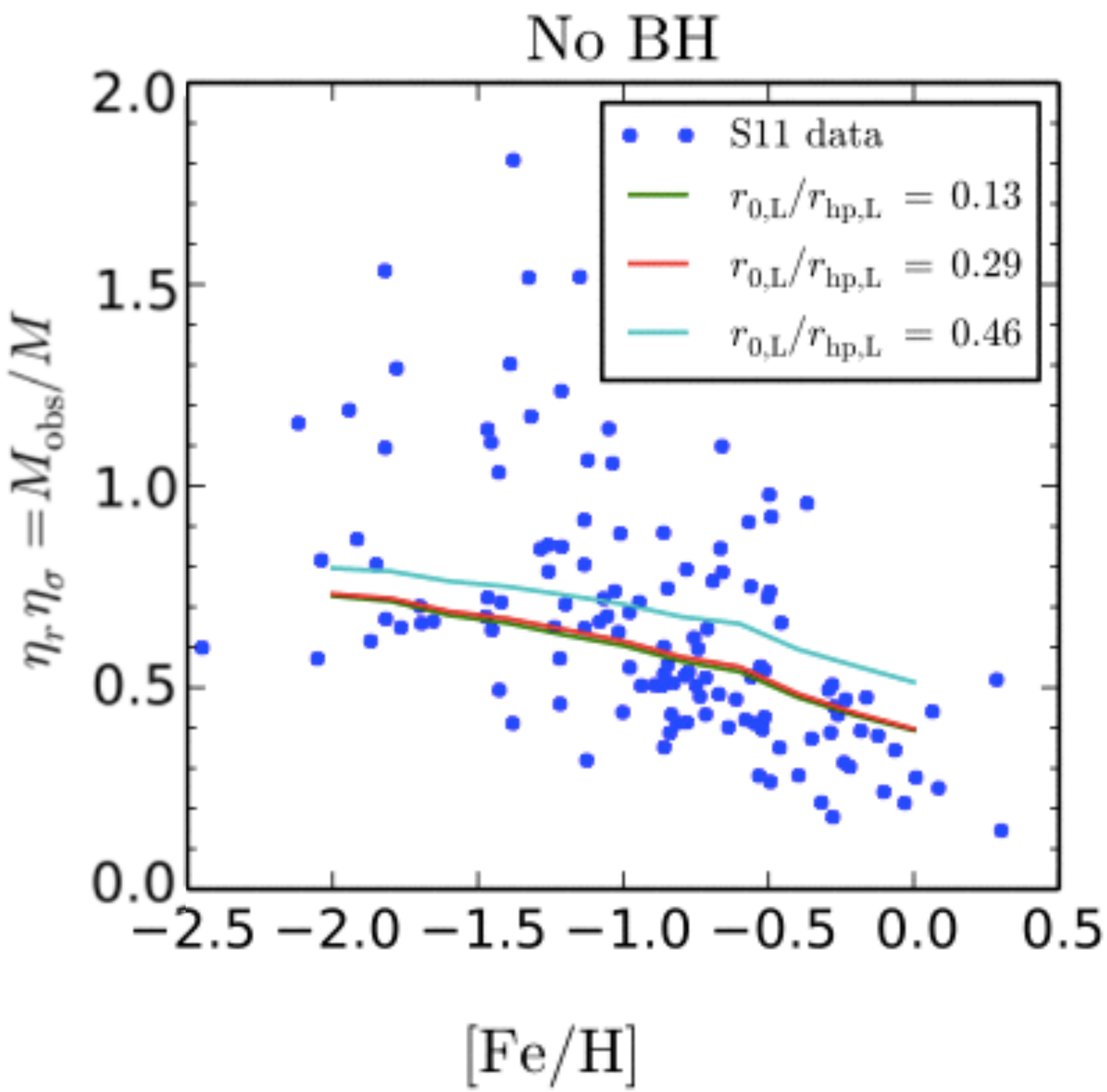

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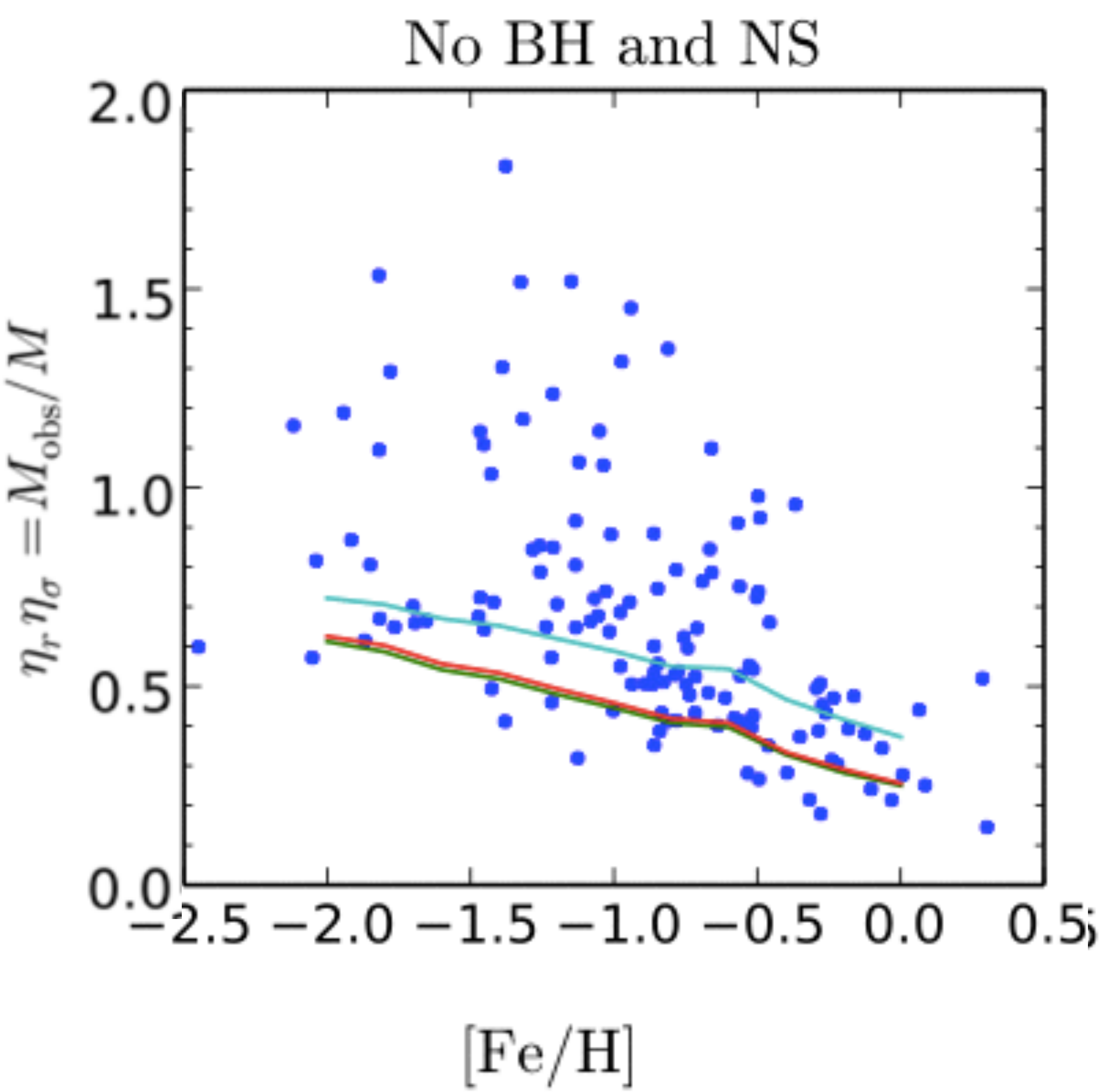

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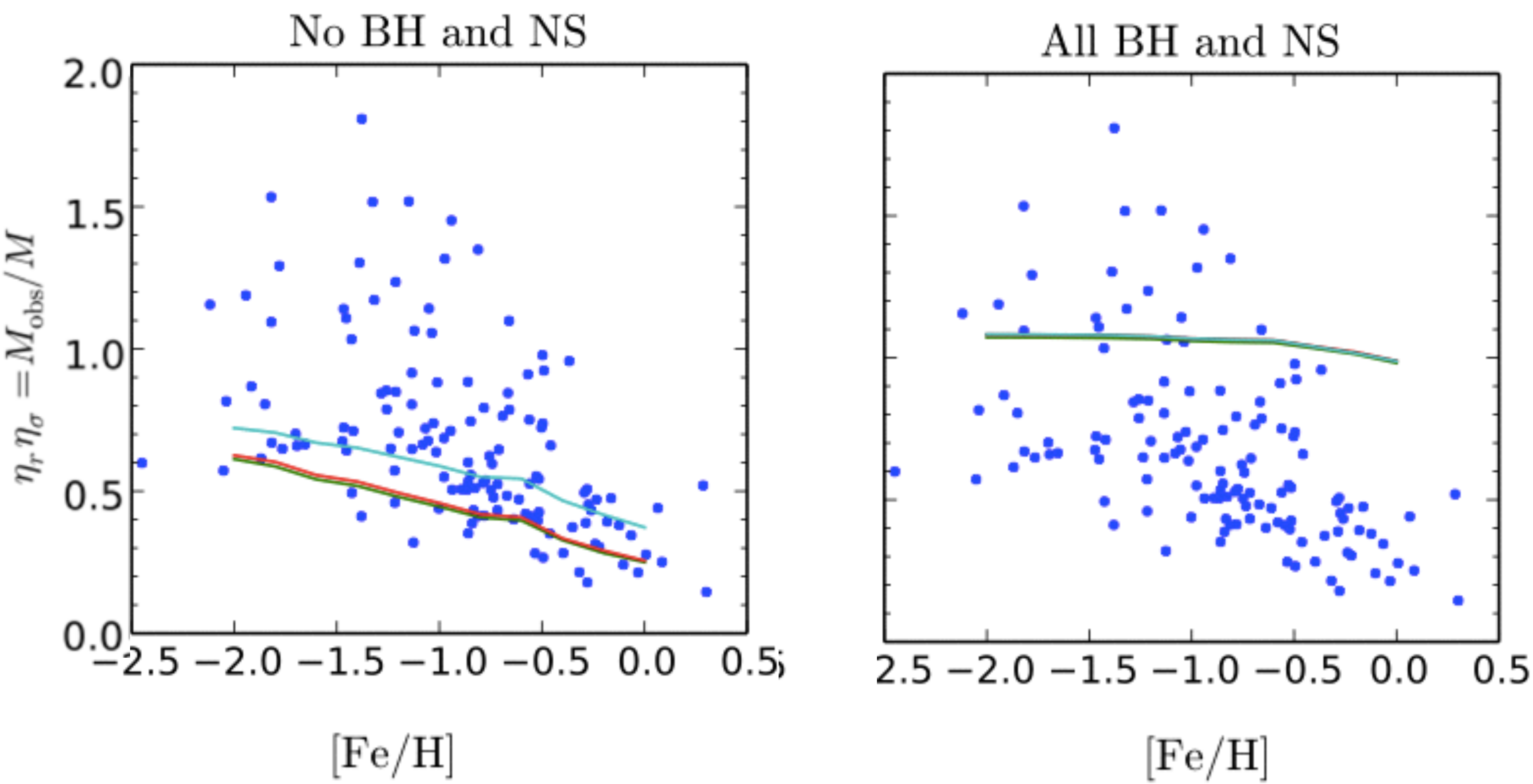
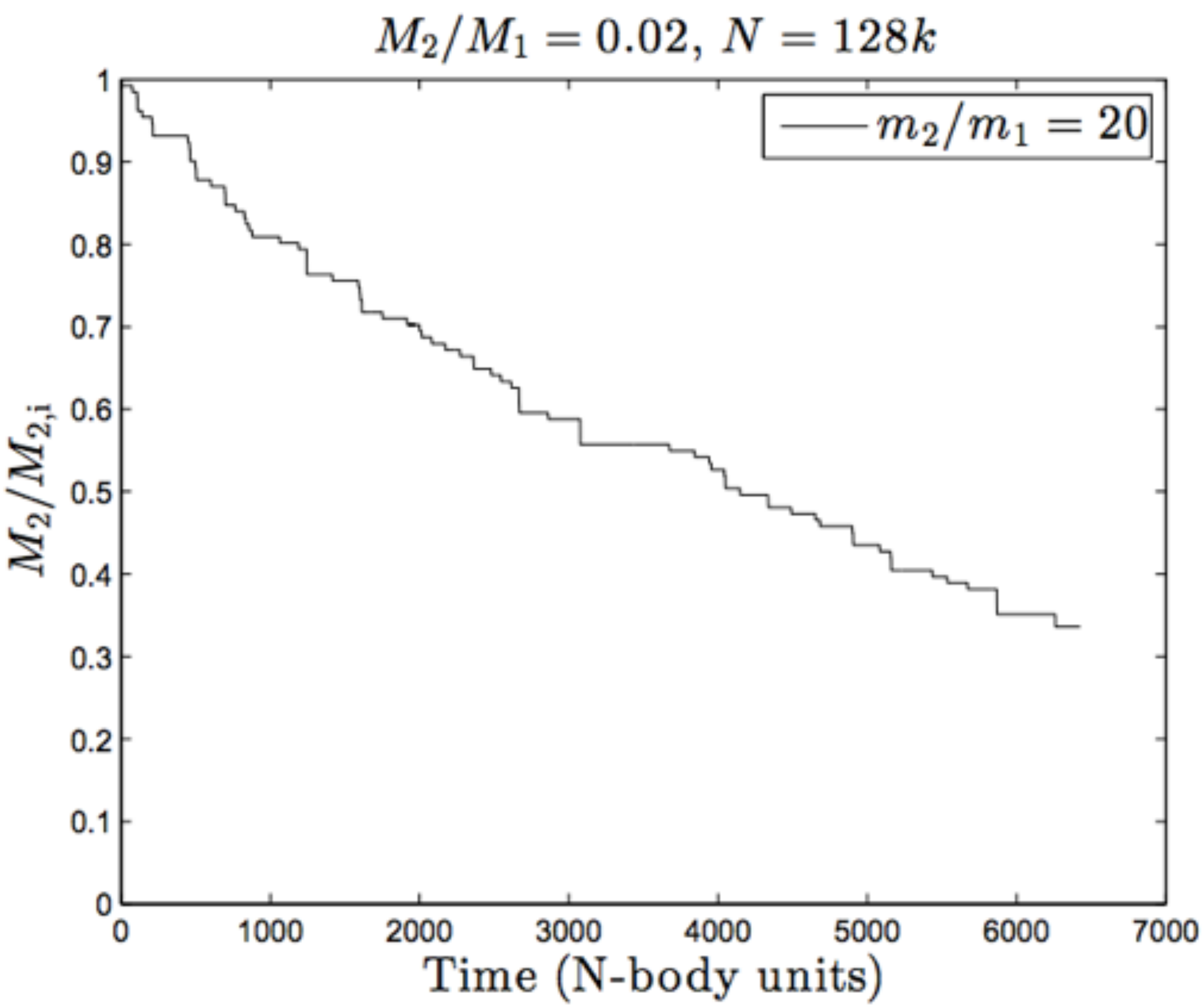


Shanahan et al, to be submitted

BH subsystem can survive in GC!



Breen & Heggie 2012

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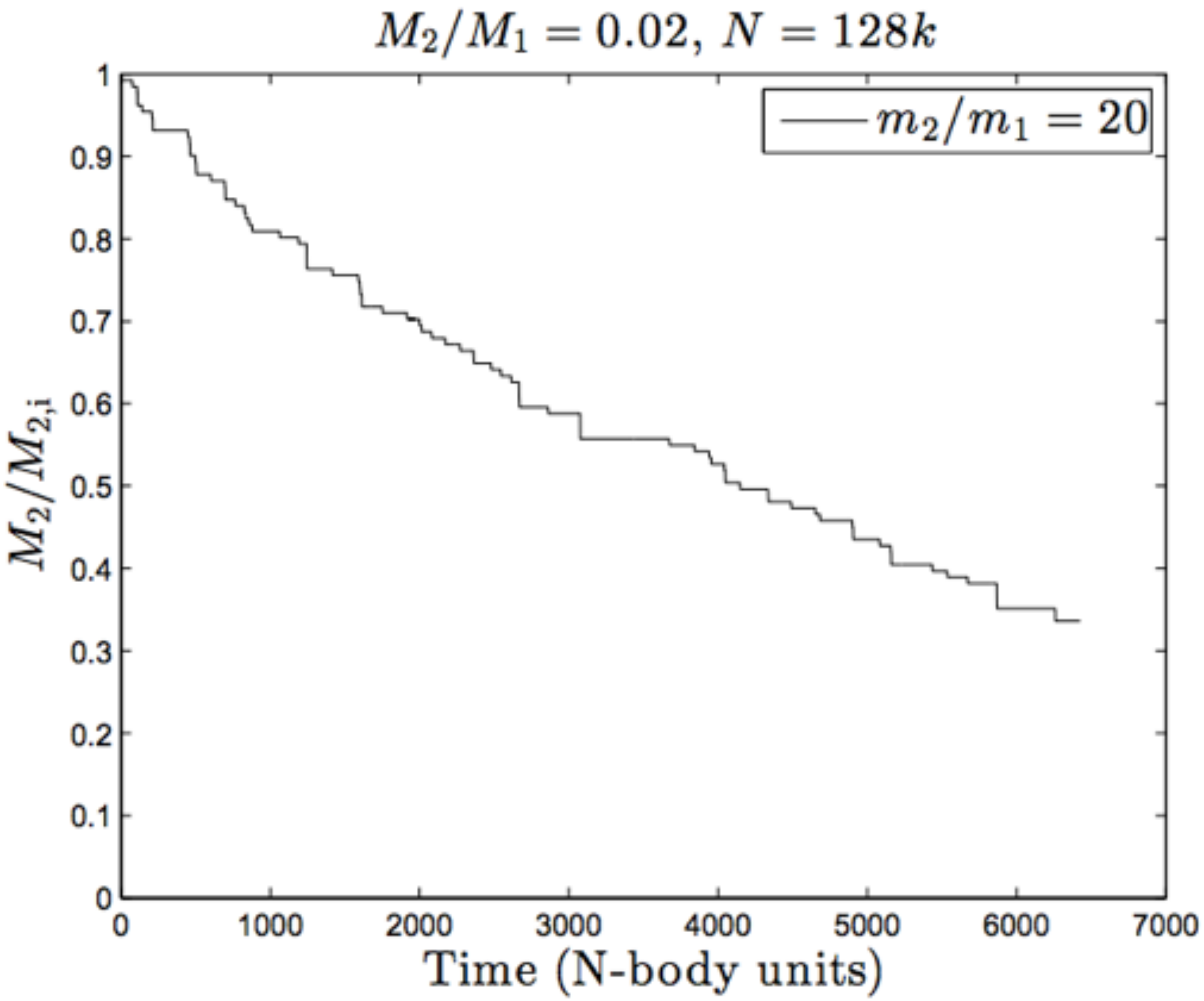
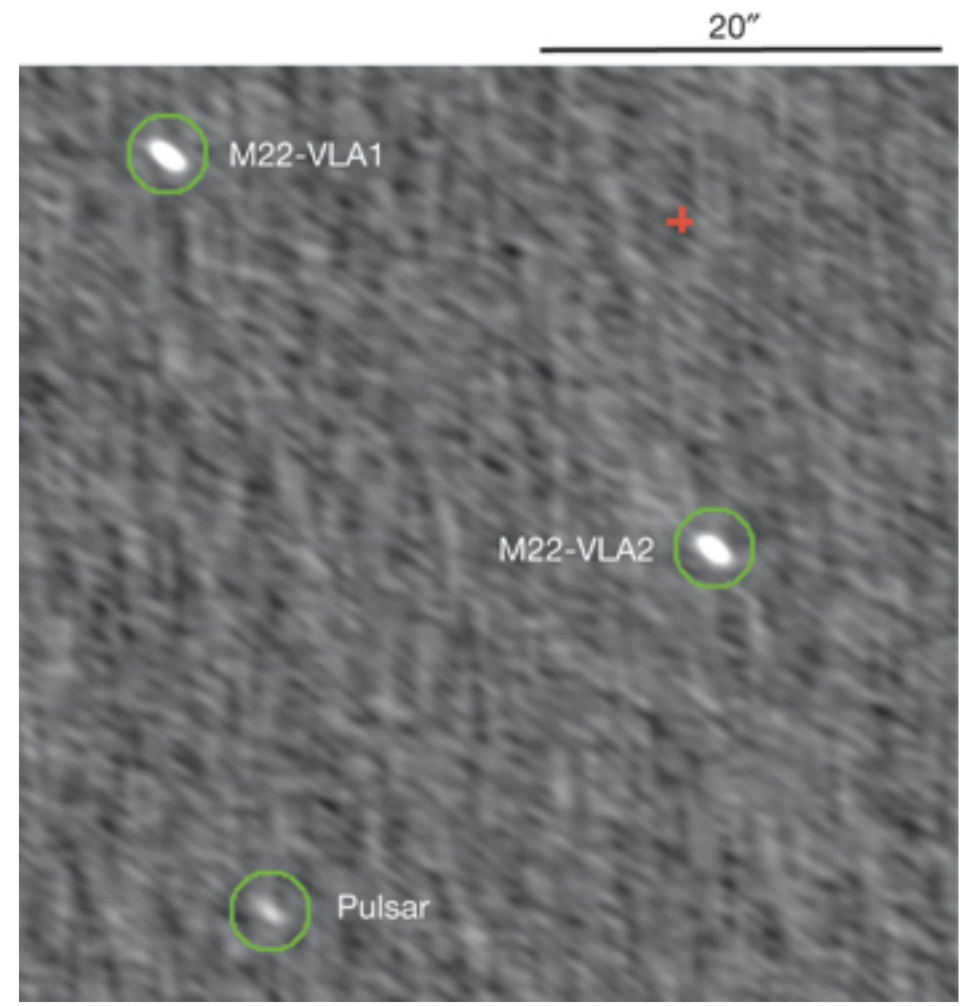


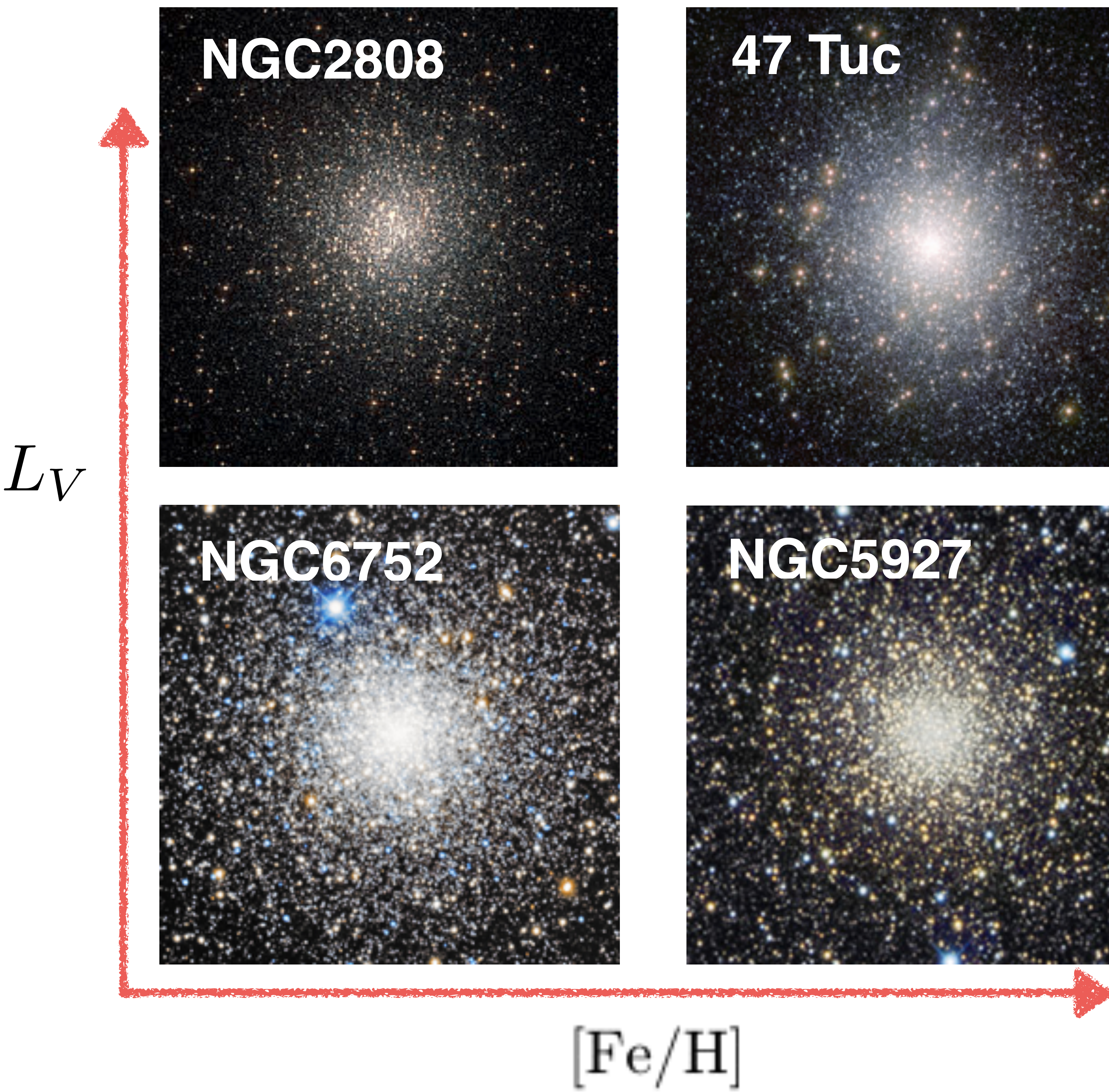
Breen & Heggie 2012

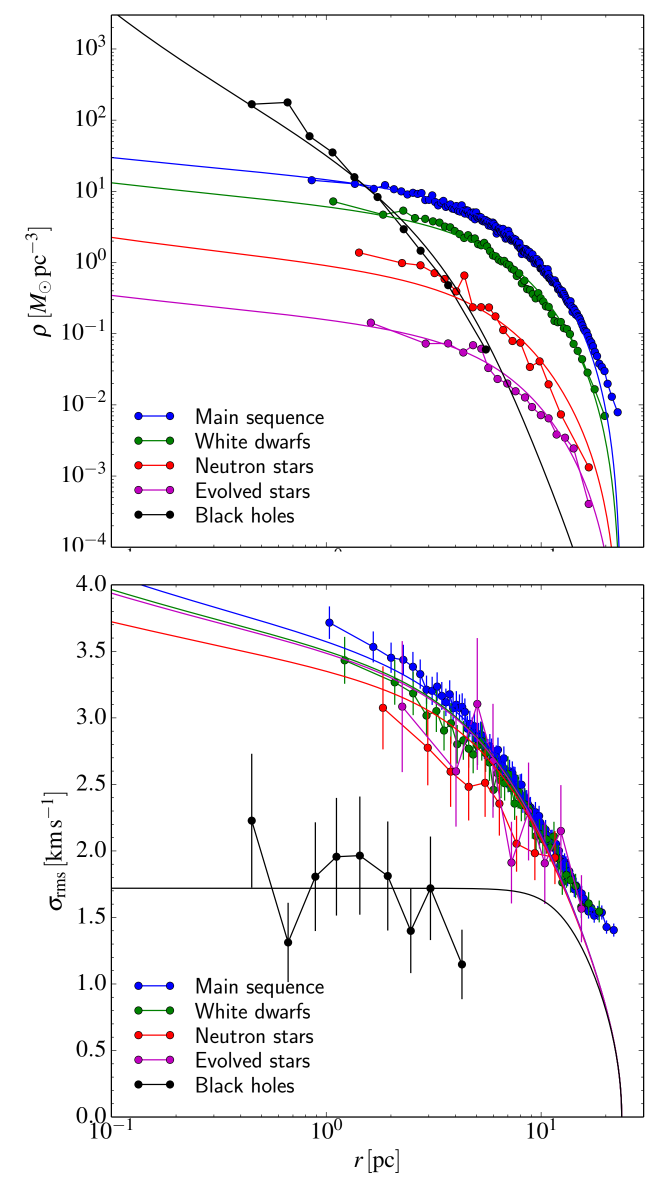
BH candidates in M22



Strader et al. 2012

Can we weigh the dark remnants with Gaia-ESO?

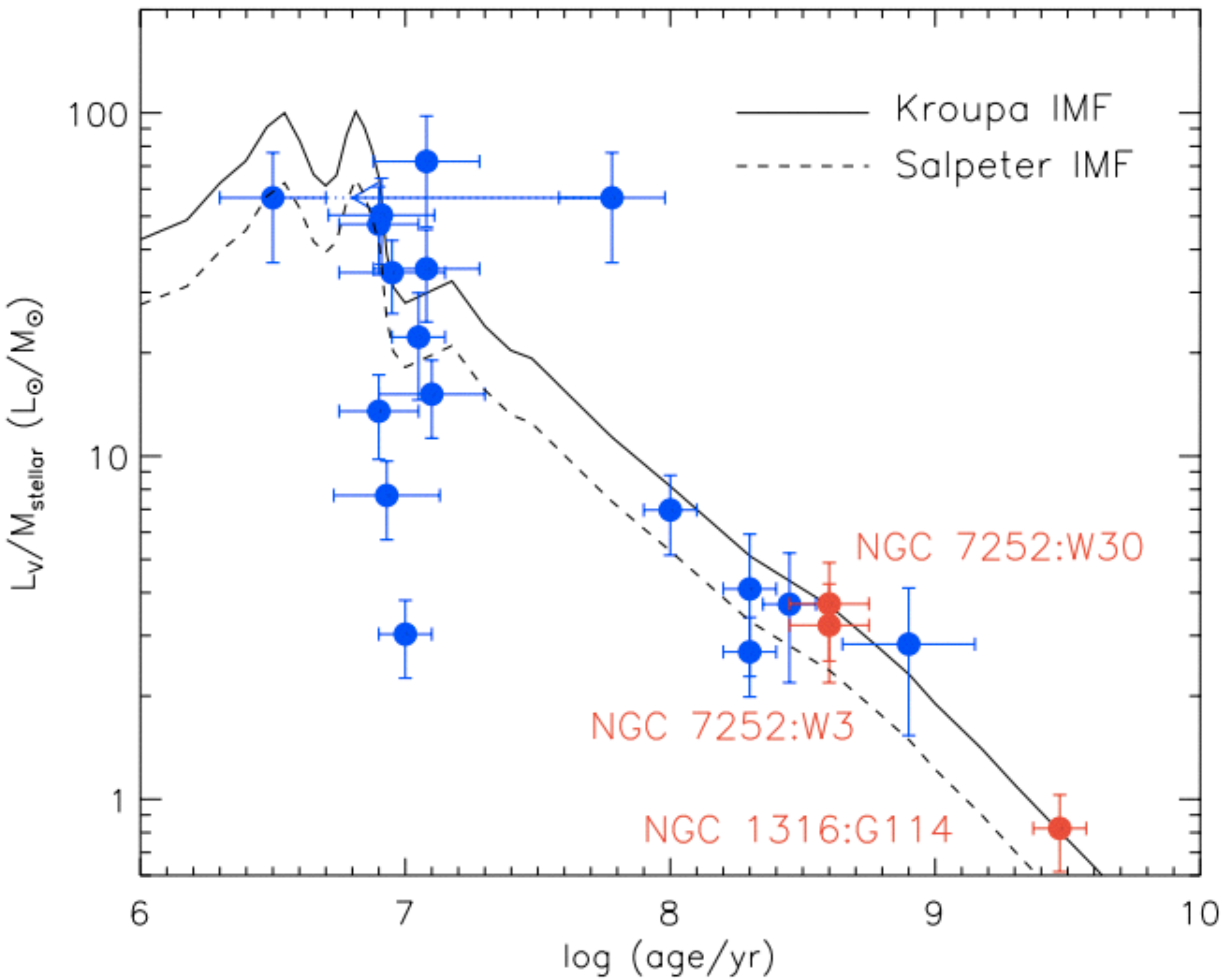




What does M/L_V of globular clusters tell us about the IMF?

1. M/L_V variations explained by mass segregation, no need for IMF variations
2. Potential: derive the present day MF of stars and remnants of clusters

3. Young Massive Clusters

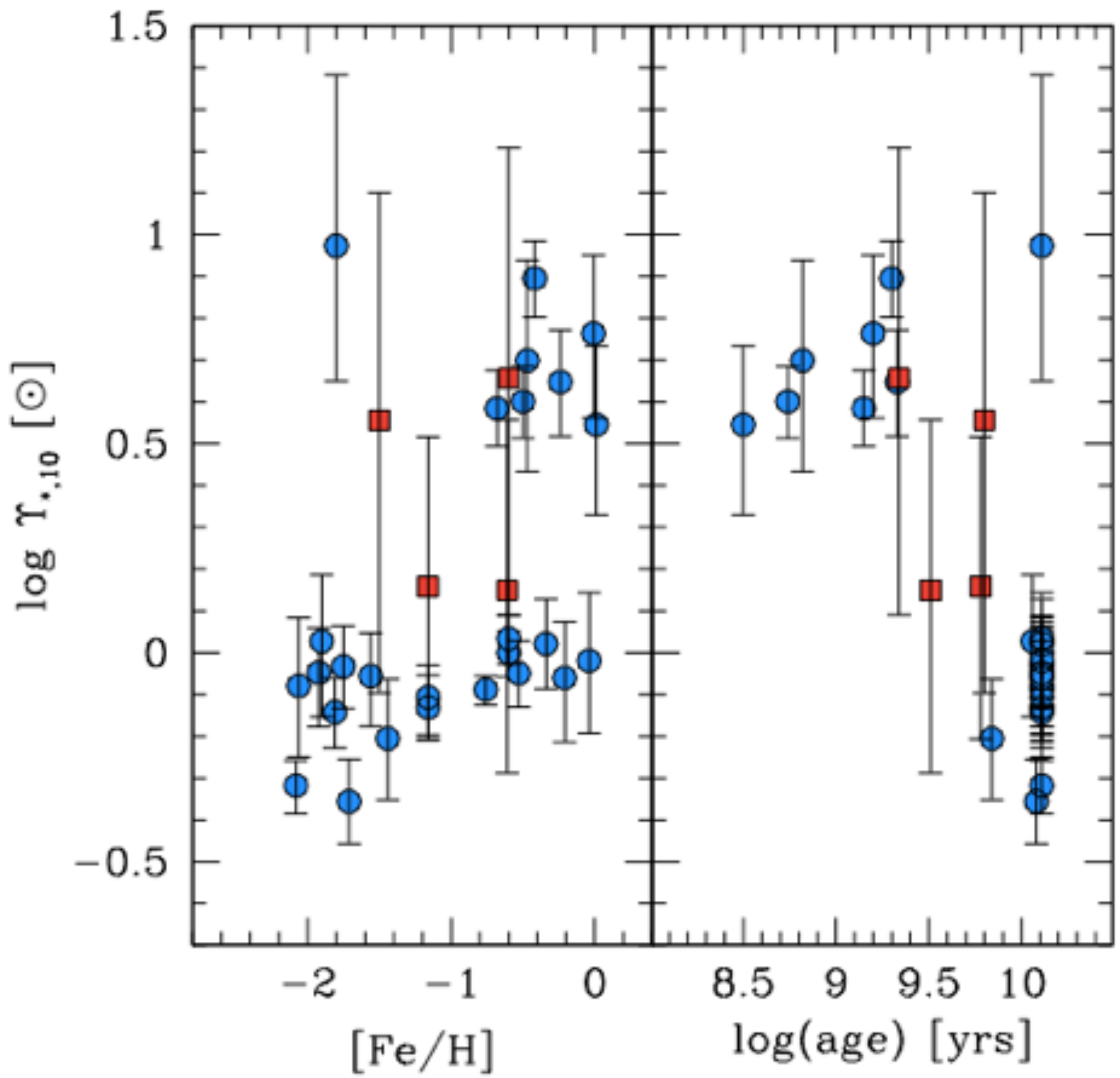


Bastian et al. (2006)

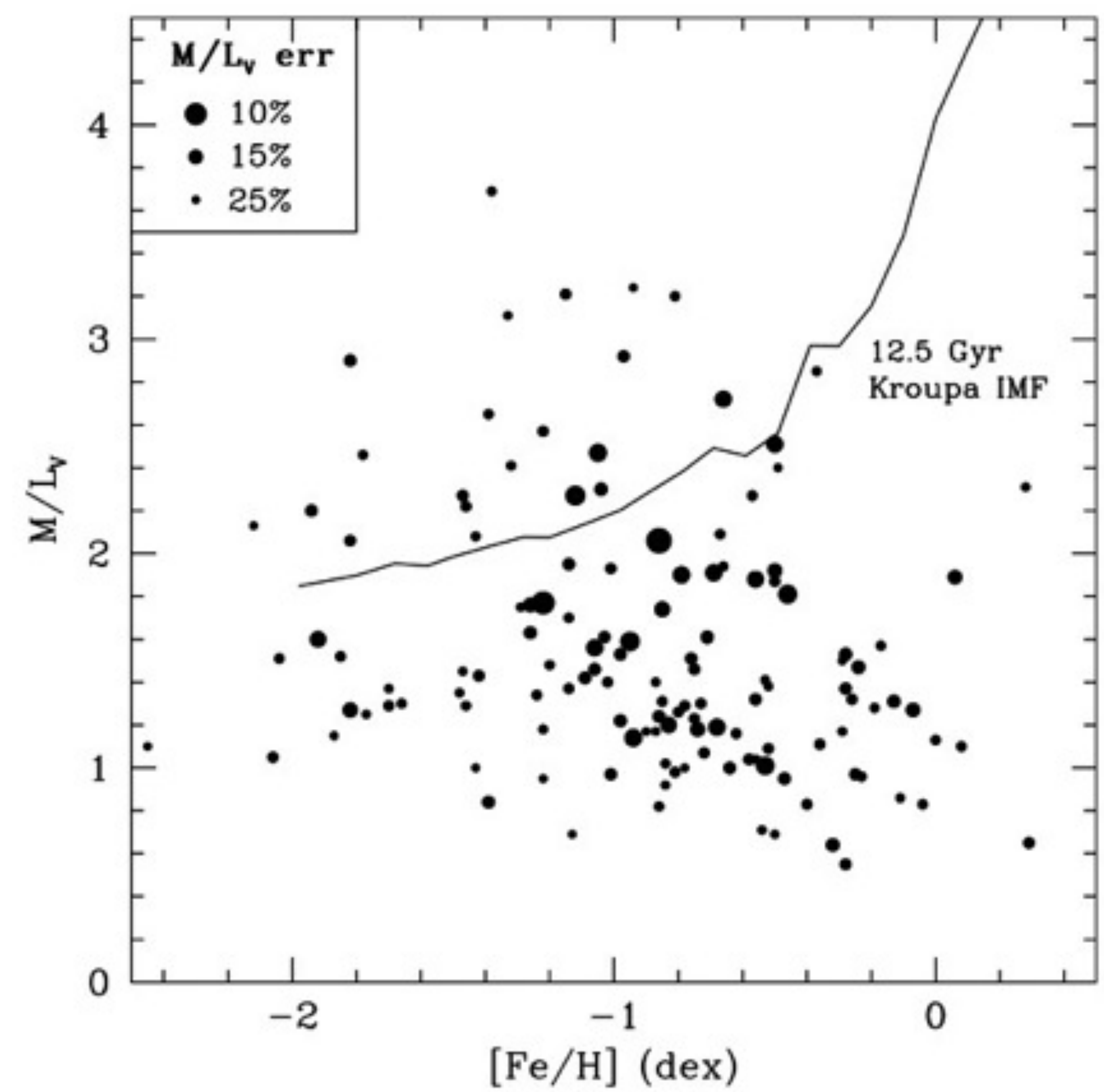
M/L_V of GCs: an "easy" probe of the IMF?

MW, LMC, Fornax

M31



Zaritsky et al. 2012, 2013, 2014



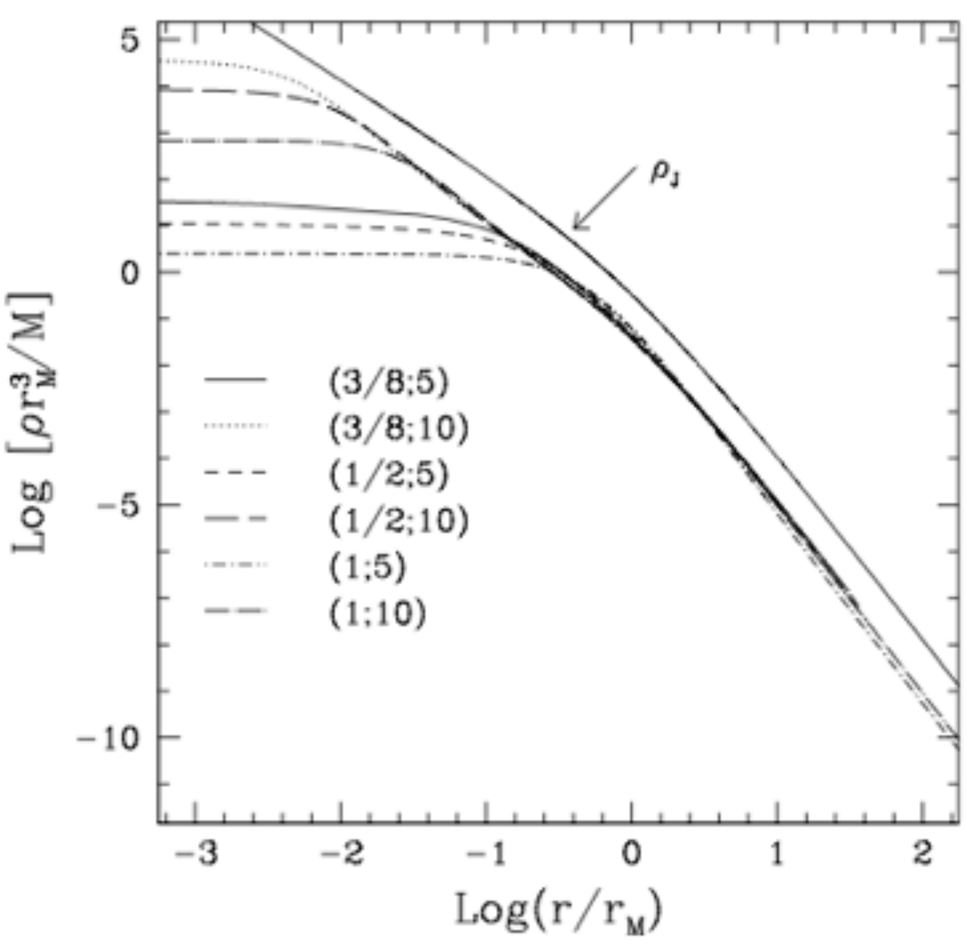
Strader et al. 2011

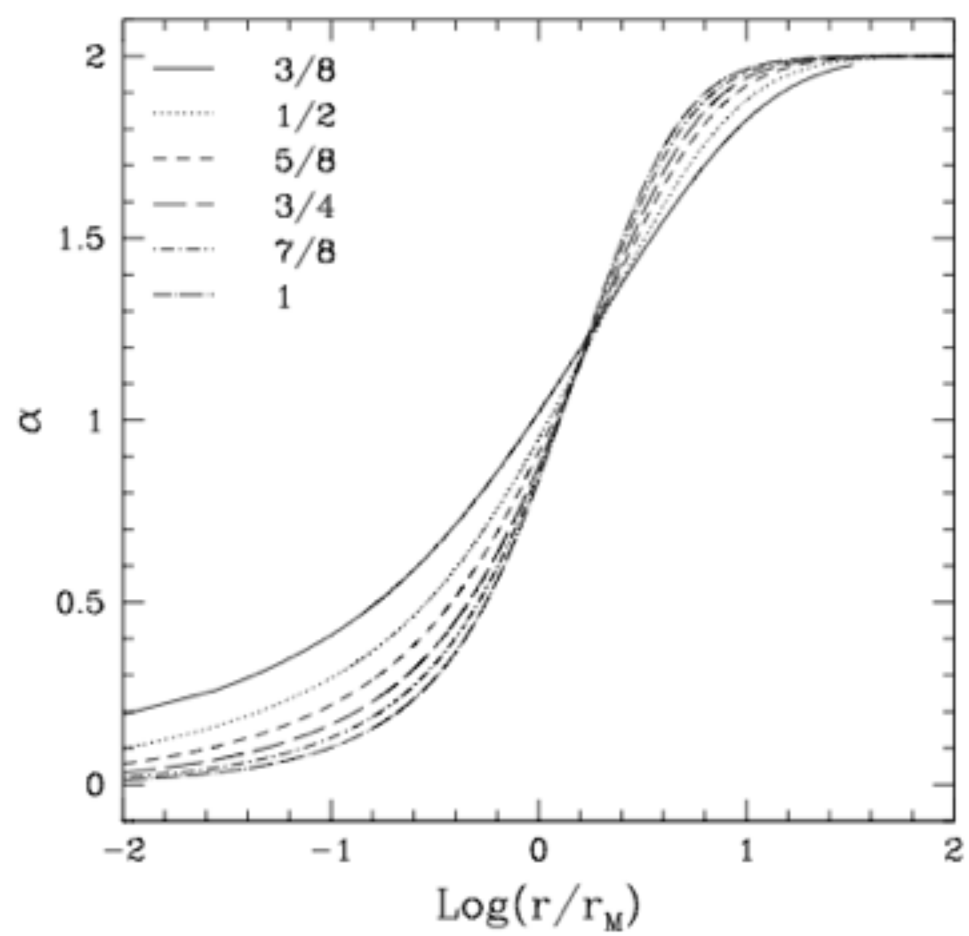
1. Which model to choose? Zocchi et al.

A. "efnú" models

Bertin & Trenti 2003

$$f_\nu(E, J^2) = A \exp\left[-\frac{E}{\sigma^2} - d\left(\frac{J^2}{|E|^{3/2}}\right)^{\nu/2}\right]$$

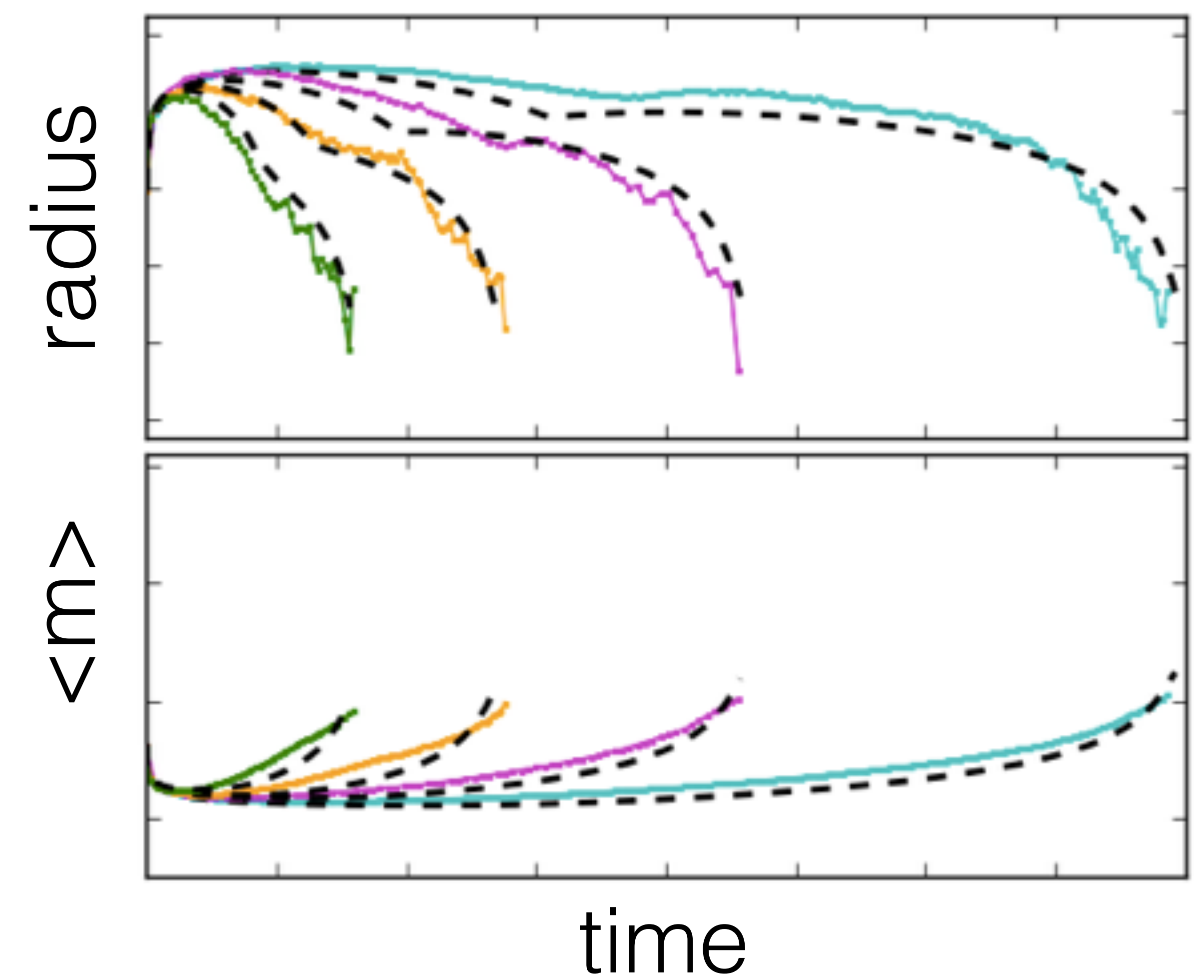




4. What next?

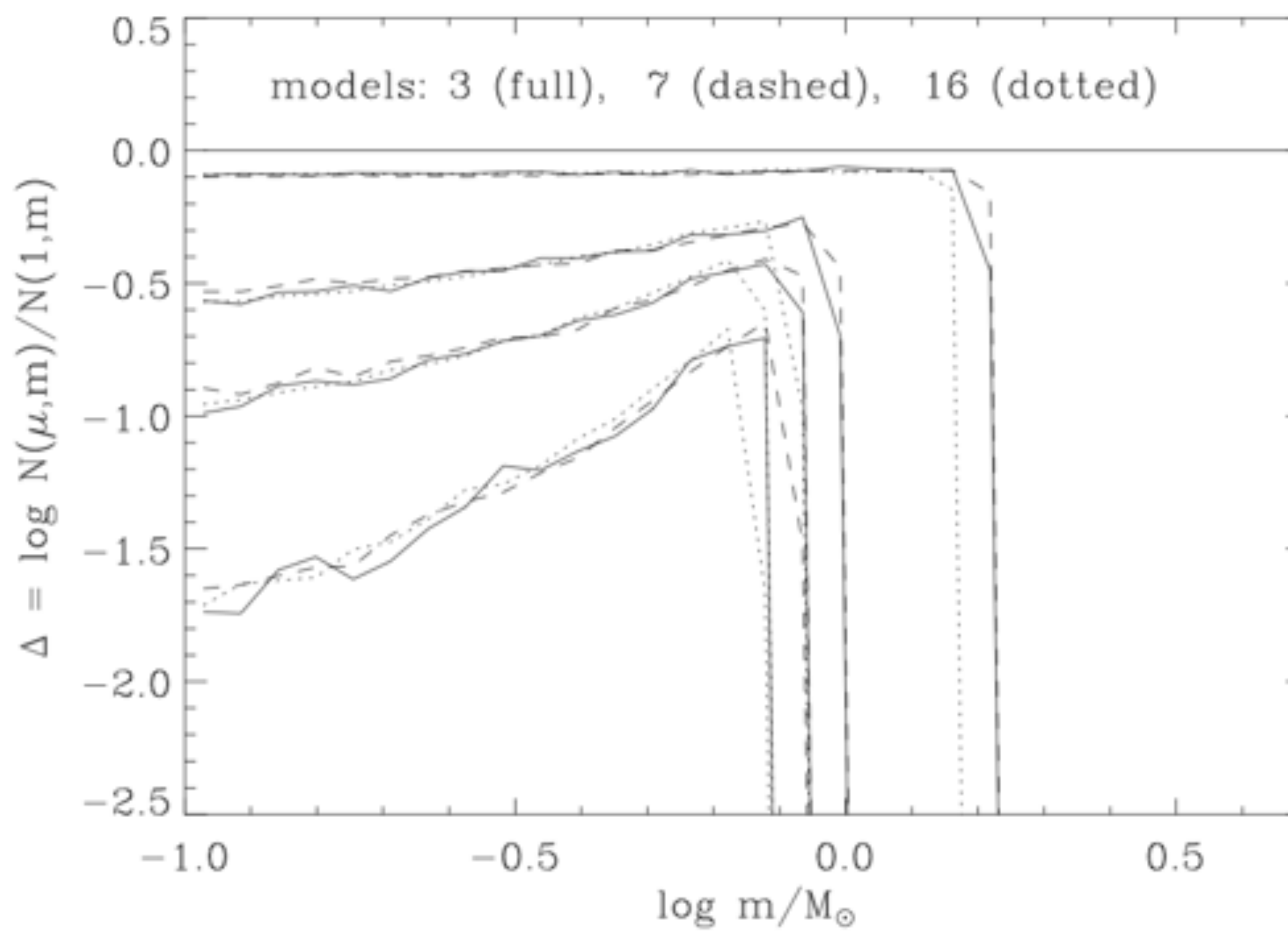
Couple multi-mass model to:

(fast cluster) evolution code



Alexander & G 2012; G+ 2013; Alexander+ 2014

Evolution of mass function



Lamers, Baumgardt & G 2013