Stellar Collisions and HB-morphology (gradients)

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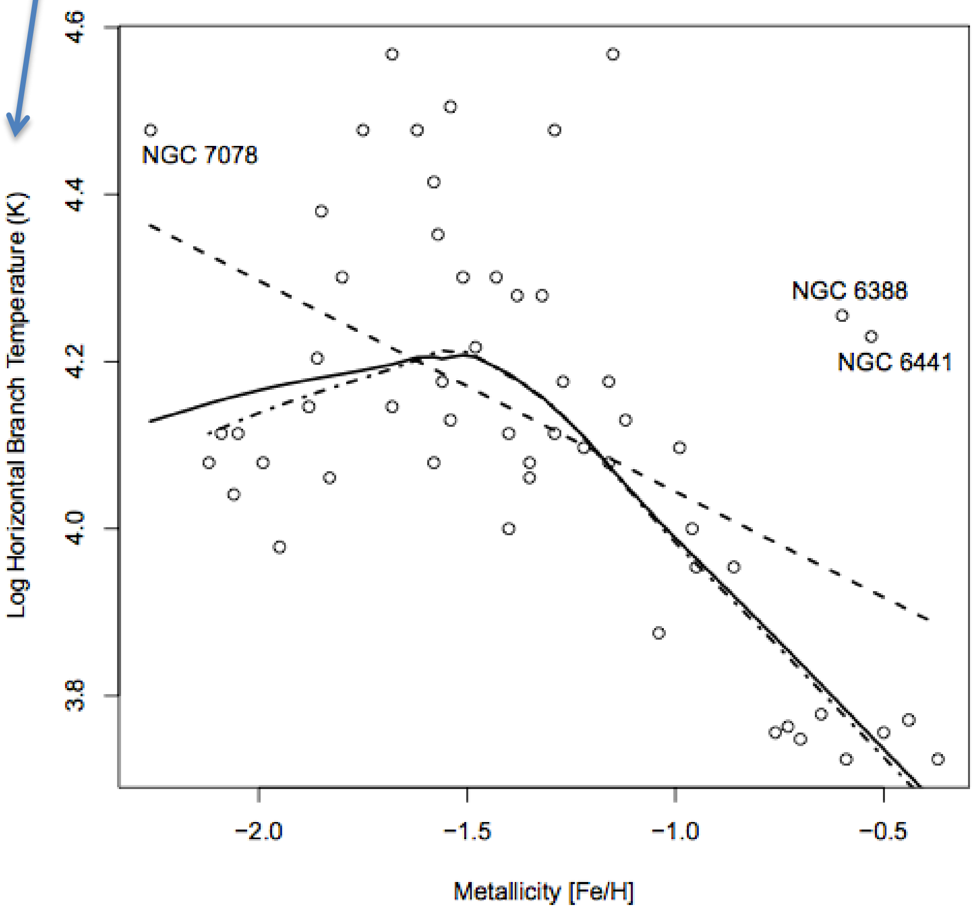
Background I

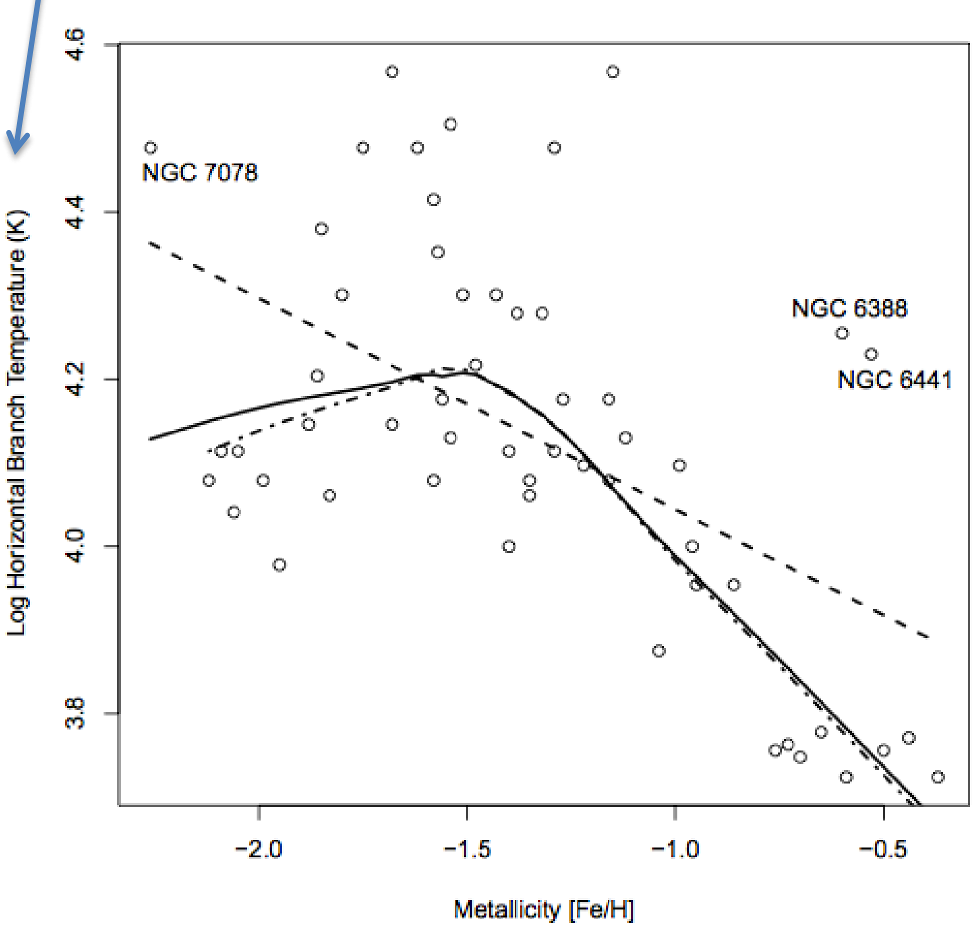
Maximum HB temperature
(Recio-Blanco et al. 2006)



- Globular Cluster (GC) Horizontal Branches (HBs) differ based on metallicity and other parameters (the *second parameter problem*)
- Multiple stellar populations play a key role, through their Helium enhancement [Bedin et al. 2004; Gratton et al. 2004; Piotto et al. 2005; Gratton et al. 2010; Bragaglia et al. 2010; Monelli et al. 2013]

Background II

Maximum HB temperature
(Recio-Blanco et al. 2006)

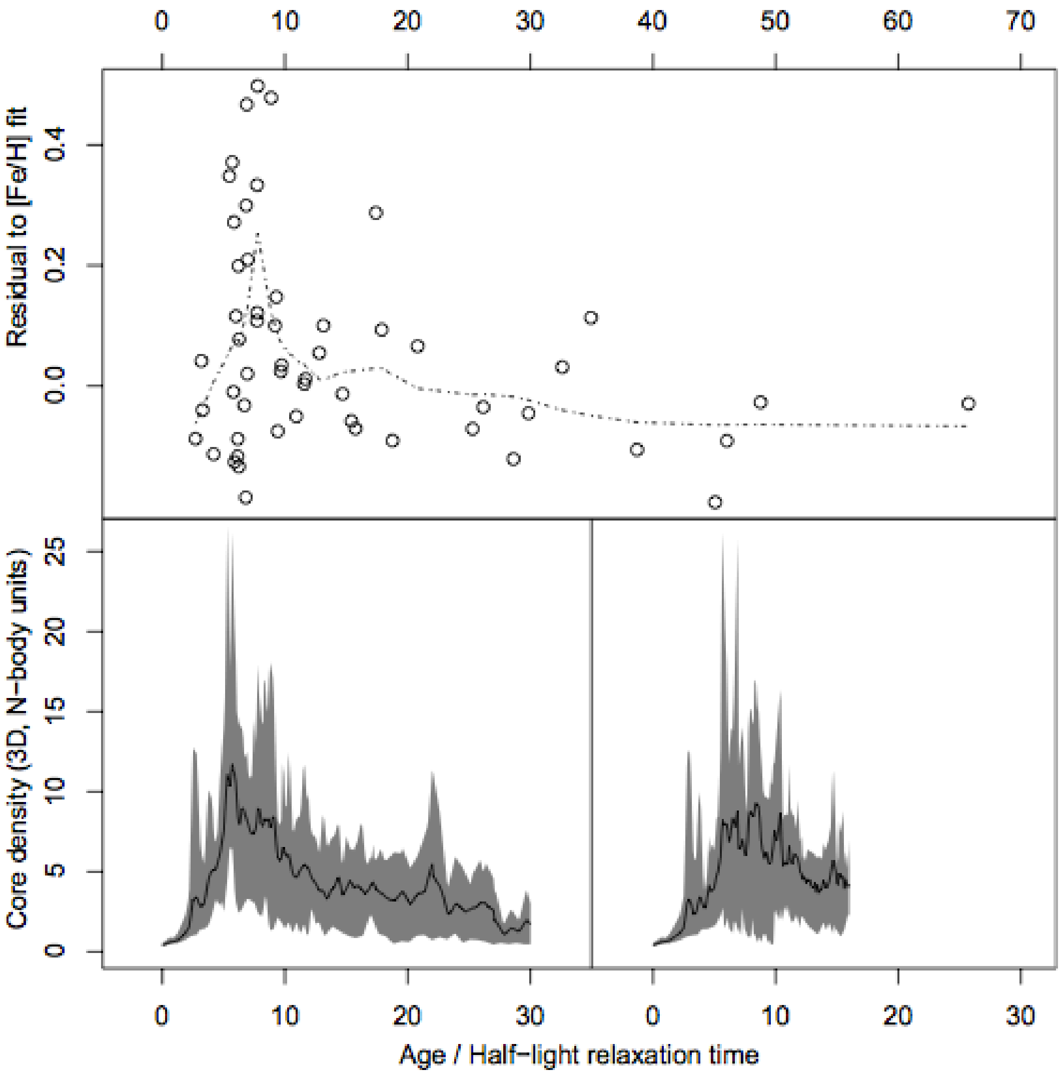


- However, Extreme Horizontal Branches (EHBs) may be difficult to explain in this scenario.
- Do dynamical interactions between stars play a role? Red Giant Branch (RGB) phase may be affected by them, resulting in enhanced mass-loss, with implications for the HB [Lafon & Berruyer 1991; Harper 1996; Origlia et al. 2002, 2007; Dupree et al. 2009; Origlia et al. 2010]

Questions - scientific goals

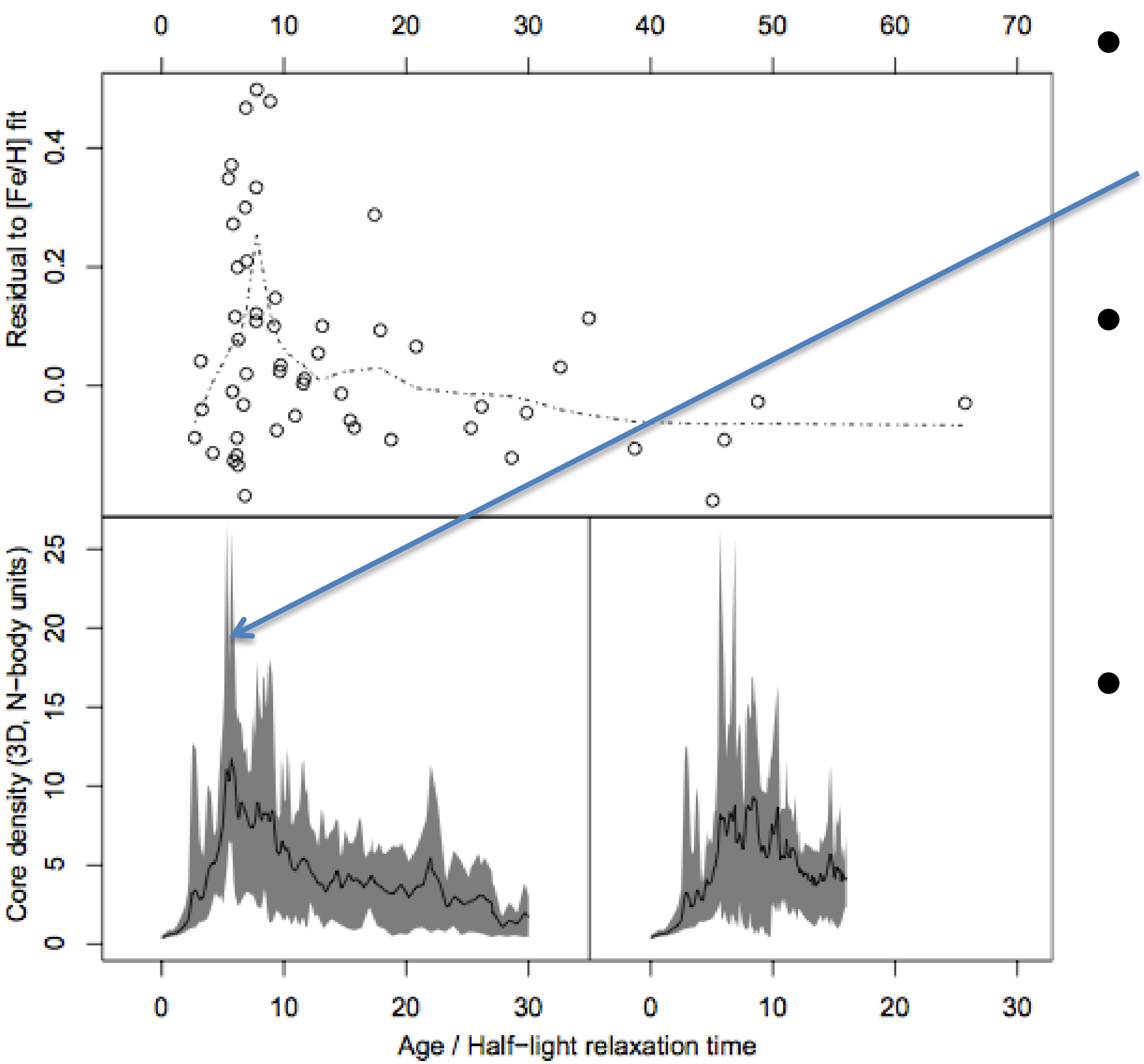
- Can we quantify the effects of dynamical interactions on RGB evolution?
- We need models, to compare with observables. What are the optimal observables?
- We developed a model of RGB mass-loss (Pasquato et al. 2014) and compared it to measured HB mass. Is it better than alternative models?
- Maybe the *smoking gun* observable is the radial dependence of HB morphology? Dynamical interactions are stronger in GC cores.
- Solution (goal): quantify HB morphology in radially binned samples of HB stars in a sample of GCs and compare it with predictions from dynamical models of EHB formation (mass-stripping in stellar collisions, Pasquato et al. 2014; binaries Lei et al. 2012, 2013, 2014)

Simulations suggest a role of dynamics



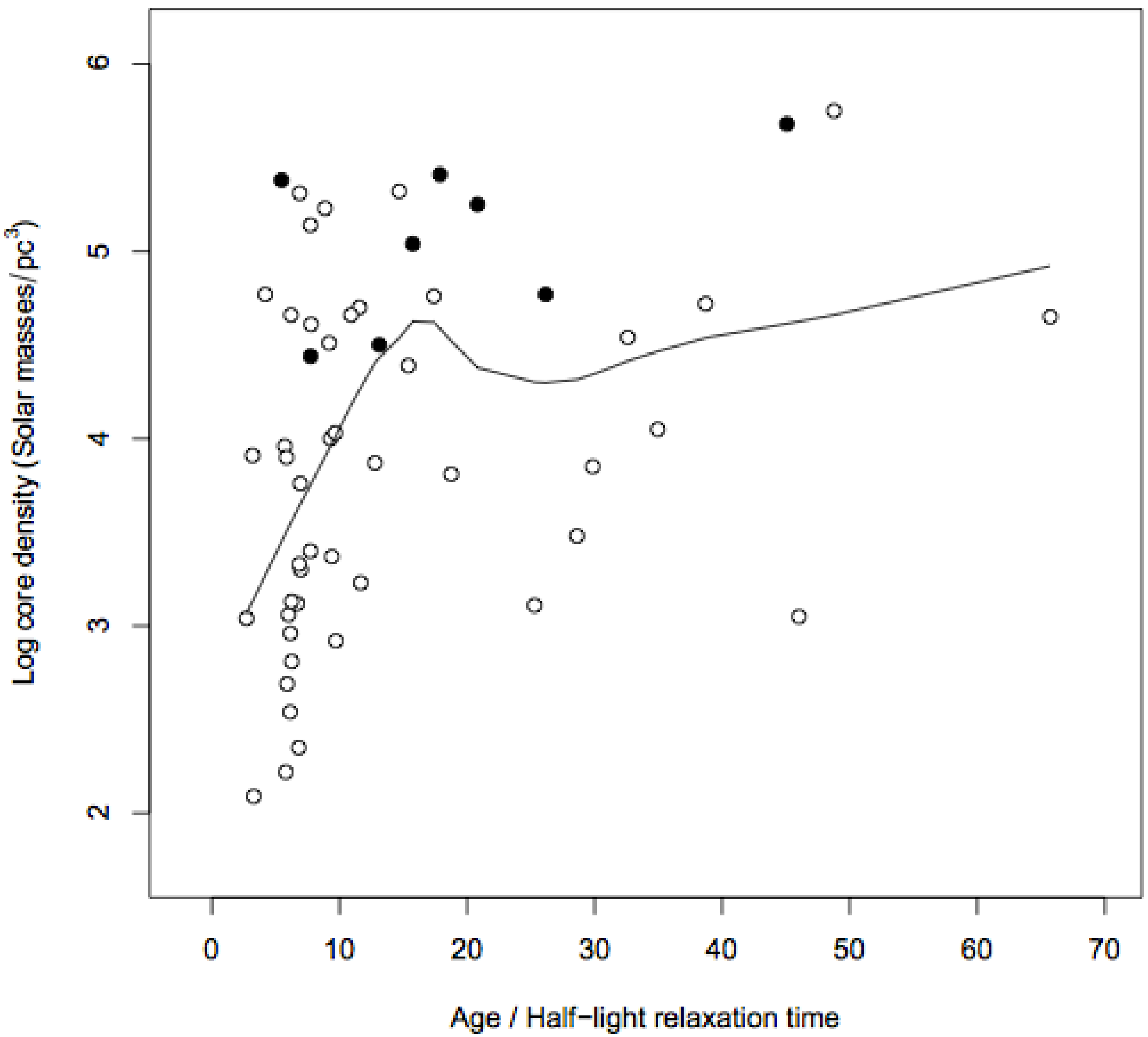
- HB-temperature residuals to [Fe/H] fit show a peak in dynamical age (i.e. age/relaxation time)
- Low-concentration initial conditions in our direct N-body simulations with a mass-spectrum show a similar peak in density, due to core-collapse [Pasquato et al. 2013]

Core-collapse



- Core-collapse (simulation): core density peak
- During core-collapse density increases, binaries are formed/hardened
- RGB stars are big (tens to hundreds of solar radii): high density makes collisions more likely

Observations are difficult to interpret



- Observations, at face value, don't show a strong relation between density and EHBs [Recio-Blanco 2006]
- Core luminosity-density doesn't show a peak in dynamical age
- Core-collapse flag also doesn't help
- Does light trace mass?
- **We need a detailed model!**

Our model of RGB mass-stripping

- We calculate the mass-loss distribution of RGB stars under the hypothesis that it is driven by stellar encounters (parametrized tidal-like interaction)
- A simple analytical model that we plan to extend with simulations (Pasquato et al. 2014, ApJ 789, 28 for details)

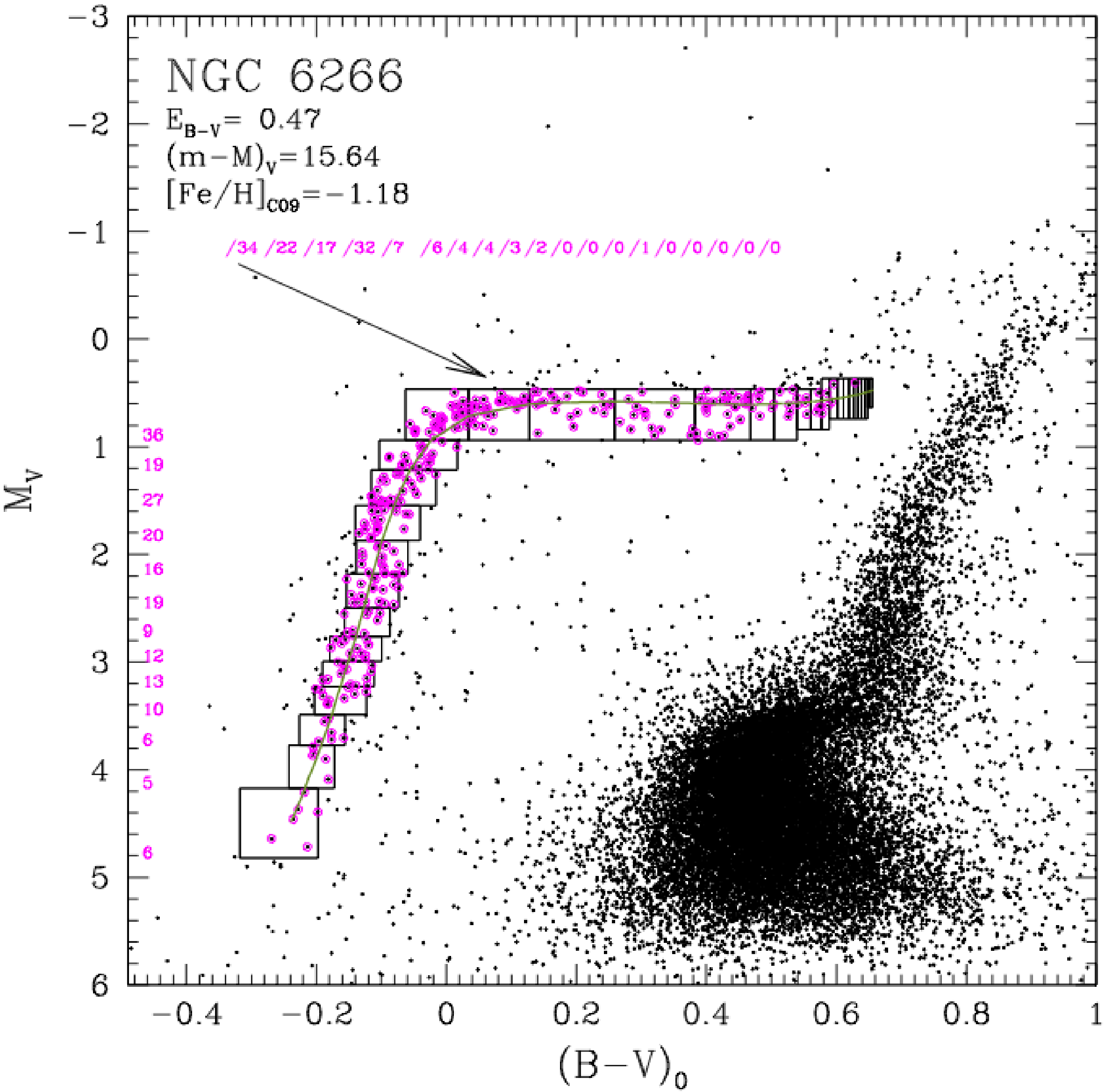
$$\delta M = A\left[1 - \left(\frac{b}{a}\right)^{2/3}\right] + B$$

$$P = n \times \pi h^2 r_{RGB}^2 \nu t_{RGB}.$$

$$f(b) = \frac{3b\sqrt{1 - \frac{b^2}{a^2}}}{a^2}$$

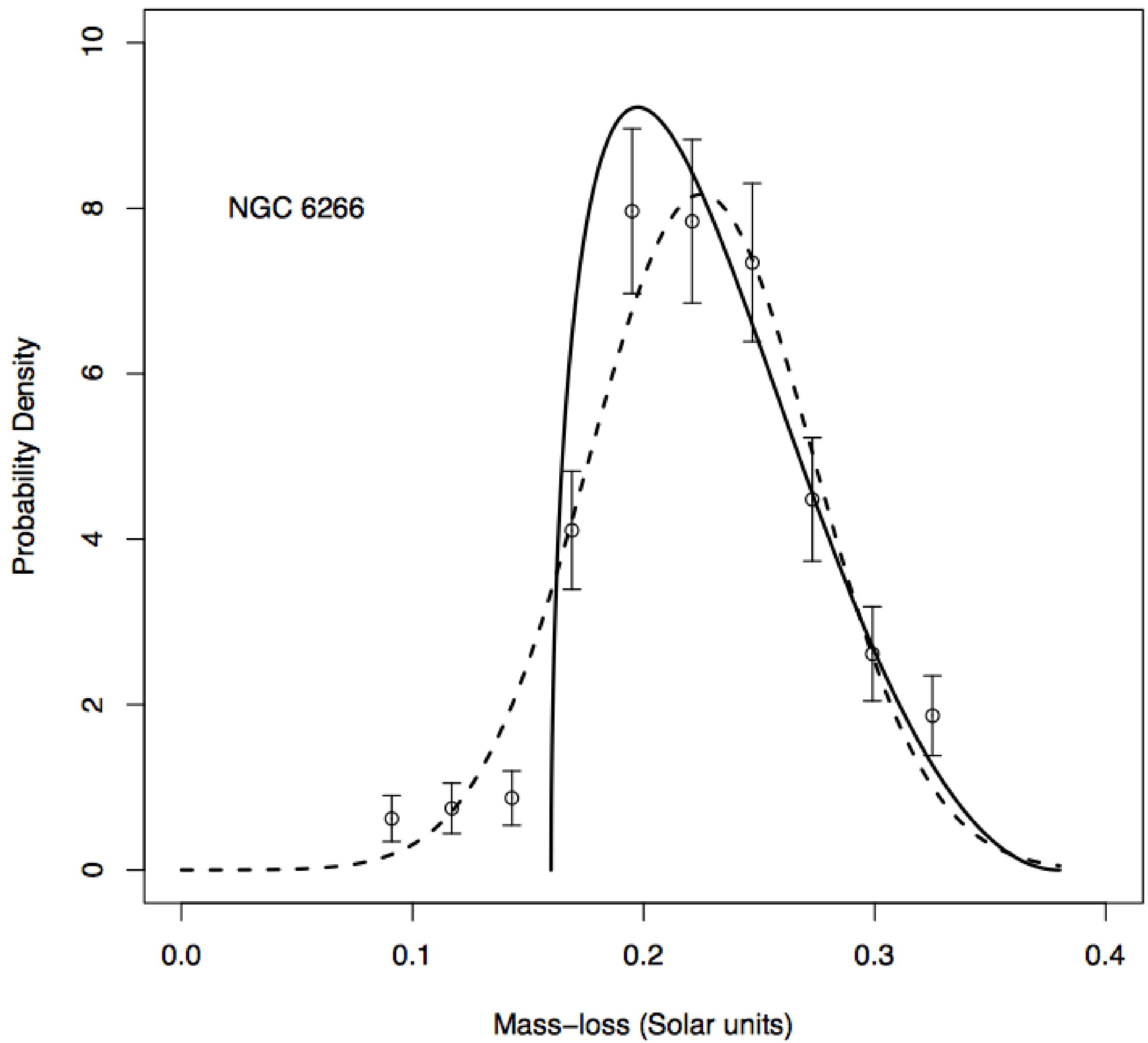
$$g(\delta M) = \frac{9}{2A}\left(1 - \frac{\delta M - B}{A}\right)^2 \sqrt{1 - \left[1 - \left(\frac{\delta M - B}{A}\right)\right]^3}$$

Fitting the observations



- HB is fit with a theoretical ZAHB
- Bins in mass along the ZAHB
- Histogram with star counts: we measure the mass-distribution of stars along the HB
- Caveat: it's model dependent

A case-study: NGC 6266

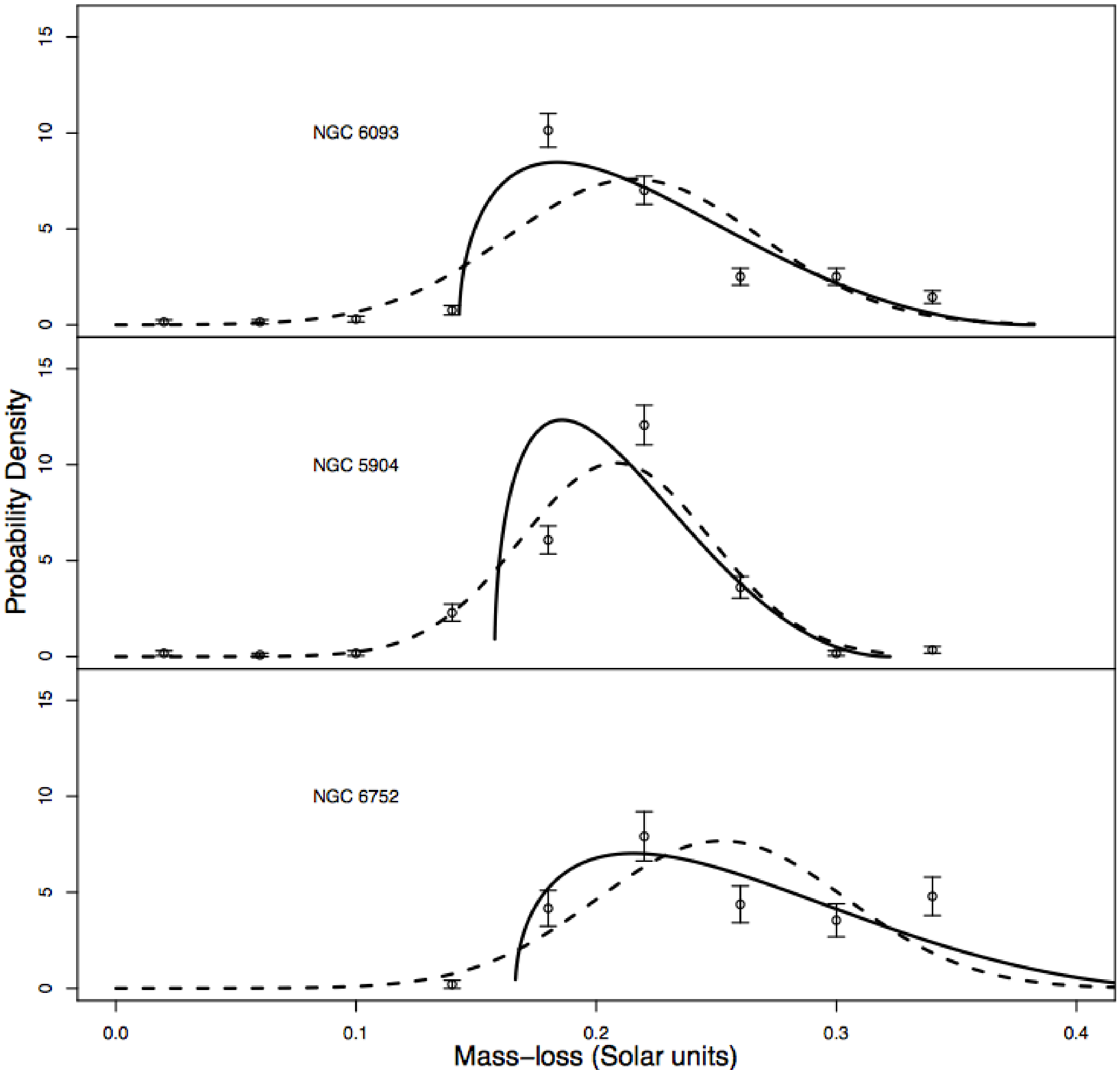


We fit our model to 4 GCs. Here I show NGC 6266 (M62).

Good fit, better than a Gaussian on the high-mass-loss tail

Poor fit on the left tail

A small sample of clusters



A similar behavior is displayed by NGC 6093 (M80), 5904 (M5), 6752 , but the fit is somewhat worse.

Competing (dynamical) model

- Tidally Enhanced Stellar Wind in Binaries (Lei et al. 2013 A&A 549, 145; Lei et al. 2013 A&A 554, 130; Lei et al. 2014 PASJ 66, 82)
- Interaction with a binary companion would be responsible for mass-stripping and EHB formation
- Core-collapse enhances stellar interactions but also binary formation: both models fit the dynamical picture.

Comparing models: role of radial gradients?

- Radial gradients of HB morphology (of EHB abundance) predicted in all dynamical models:
- Binary stars (Lei et al. model) mass-segregate to the center, so EHBs should be more concentrated in the core, except for dynamically young, non-mass-segregated GCs
- Dynamical interactions are more likely near the core (high density)
- Multiple populations can be radially segregated as well!

Naïve prediction (collision model)

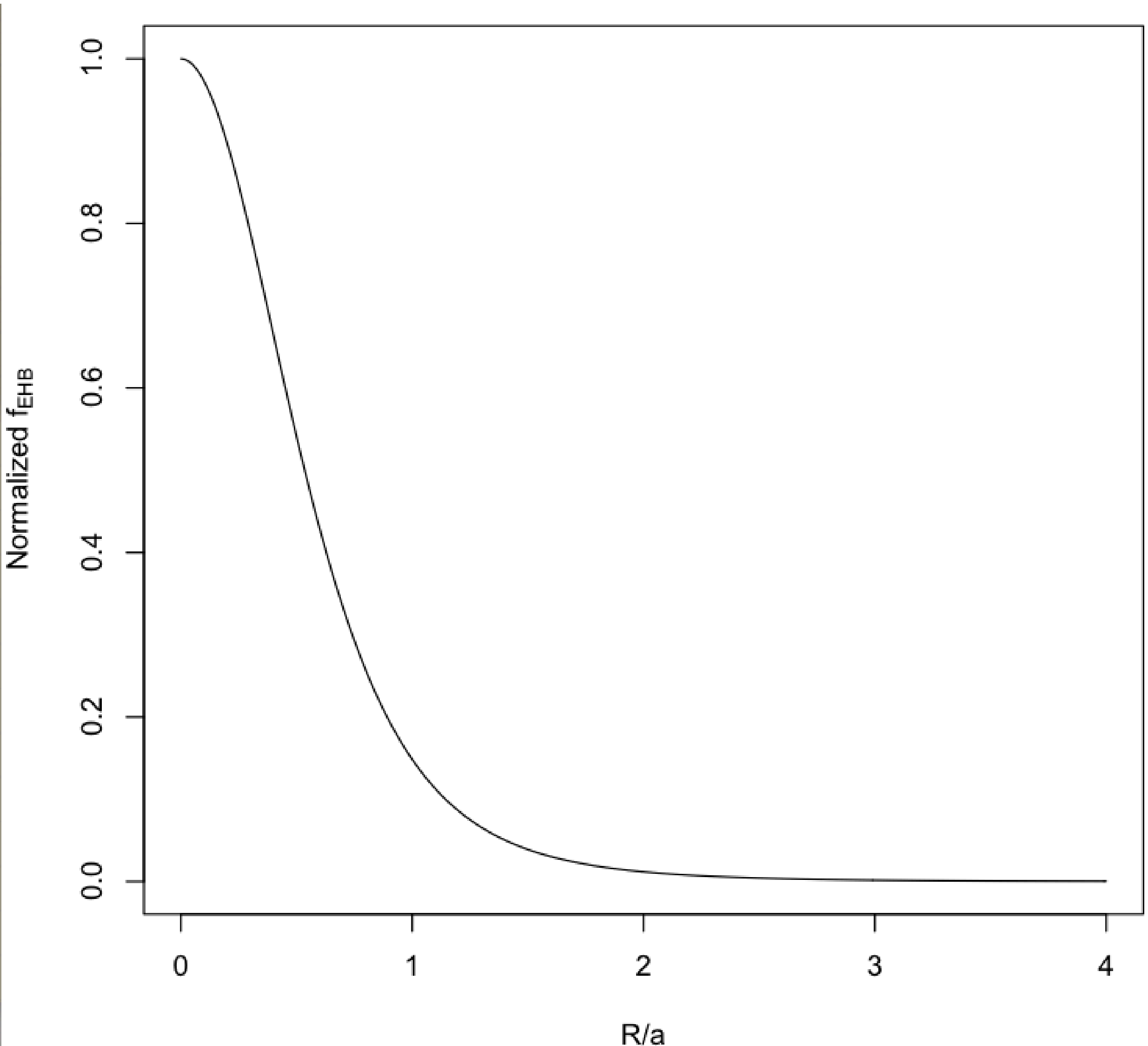
$$n(r) = n_0 \frac{1}{\left(1+\frac{r^2}{R^2}\right)^{5/2}} \qquad v(r) = v_0 \frac{1}{\left(1+\frac{r^2}{R^2}\right)^{1/4}}$$

$$P(r) = n_0 v_0 \langle\sigma\rangle T_{RGB} \frac{1}{\left(1+\frac{r^2}{R^2}\right)^{11/4}}$$

$$P(\iota) = n_0 v_0 \langle\sigma\rangle T_{RGB} \frac{\int_0^\infty \left(1+\xi^2+\iota^2\right)^{-21/4} d\xi}{\int_0^\infty \left(1+\xi^2+\iota^2\right)^{-5/2} d\xi}$$

$$P(\iota) = n_0 v_0 \langle\sigma\rangle T_{RGB} \frac{A}{\left(1+\iota^2\right)^{11/4}}$$

Naïve pred: normalized EHB fraction



Normalized ratio of EHB to HB stars. Analytical prediction based on a Plummer model (core radius = a) and geometric cross section for collisions.

A morphology gradient is predicted.

COMPARE WITH OBSERVATIONS!

Binary distribution from simulations

- What is the distribution of EHBs if their progenitors are binaries, as in the Lei et al. scenario?
- We run a large set (hundreds) of direct N-body simulations with different mass-classes, different spectra, initial King concentrations
- Hard binaries treated as dynamically inert particles
- We distilled a fitting formula for the binary distribution
- Compare it with EHB abundance to test binary scenario!

Conclusions (not over yet!)

- Dynamics may play a role in EHB formation: RGB mass- stripping either through interactions or within a binary
- Core-collapse is likely to enhance both effects
- We have an analytical model predicting EHB formation from encounters and simulations predicting the binary distribution under mass-segregation
- Comparison with observations coming soon!

Future prospects

- Why is our model naïve and hot to improve?
- How to get radial HB-morphology gradient data?
- How to compare model and data?

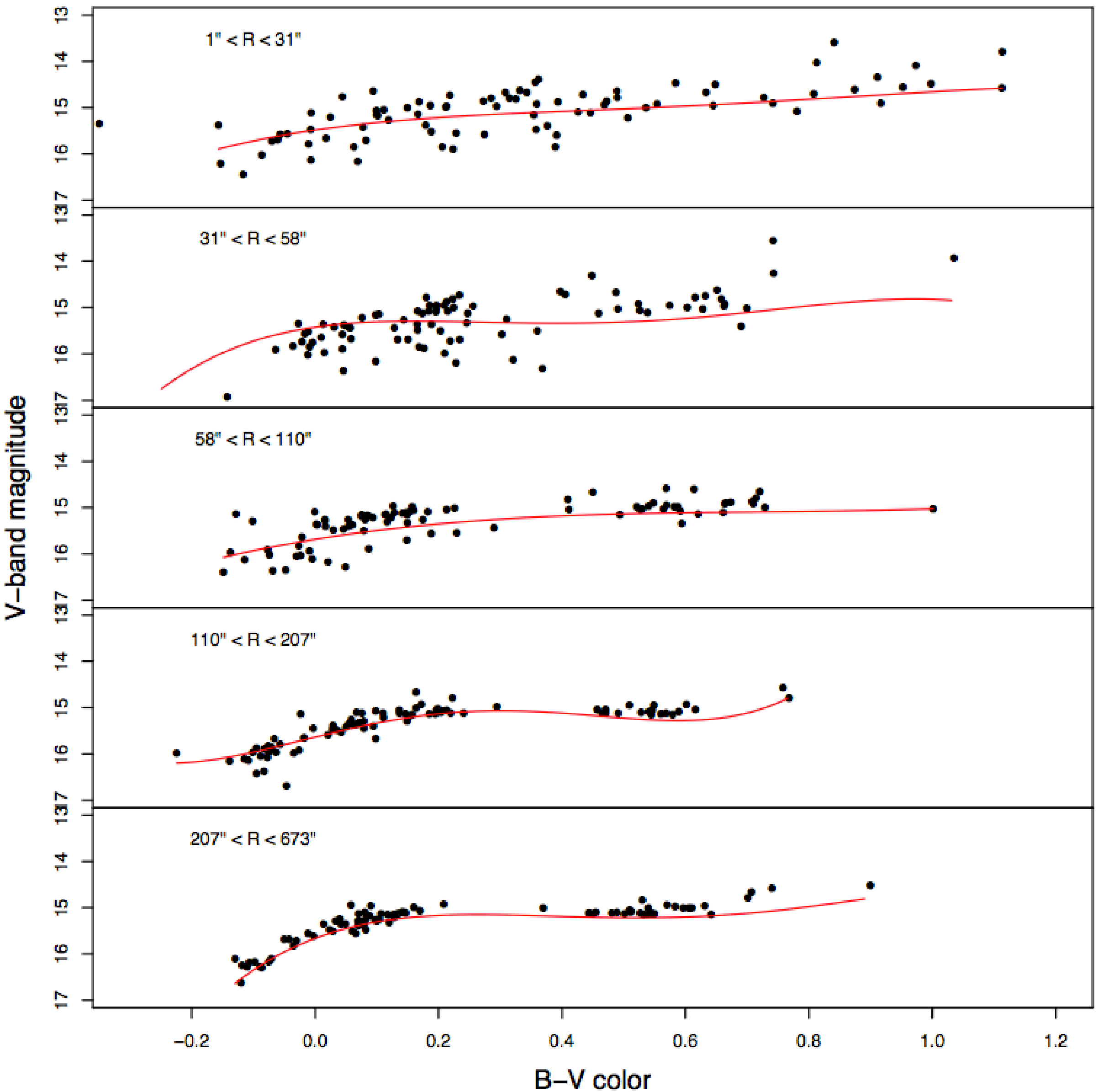
Why the prediction is naive

- Stars move, possibly on elongated orbits. RGB loses mass in the core, then becomes HB in the periphery
- Actual cross-section should include gravitational focusing!
- Stars that lose too much mass may fail to ignite He and become white dwarfs
- Need to include other effects: He-enhanced multiple populations
- **A kitchen-sink simulation?** Anyway, simulations are likely more useful in the binary scenario.

Clusters with HB data

- Several clusters have photometric data for HB stars measured across a large interval in projected radius: M5 (Sandquist & Bolte 2004), M55 (Vargas & Sandquist 2007), M13 (Sanquist et al. 2010), NGC 288, 362, 1851 (Bellazzini et al. 2001)
- More data is being reduced from observing runs (Lim et al. in prep.)

Example: NGC 5904 (M5)



Non-variable HB stars out to > 10’ (complete to 8’)

CTIO, CHFT, HST (the latter are the same as the core data we used for our model fit)

Thank you

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- Questions?