The Red Giant Branch Bump: A Sensitive Probe of Mixing in Lower Mass Stellar Models

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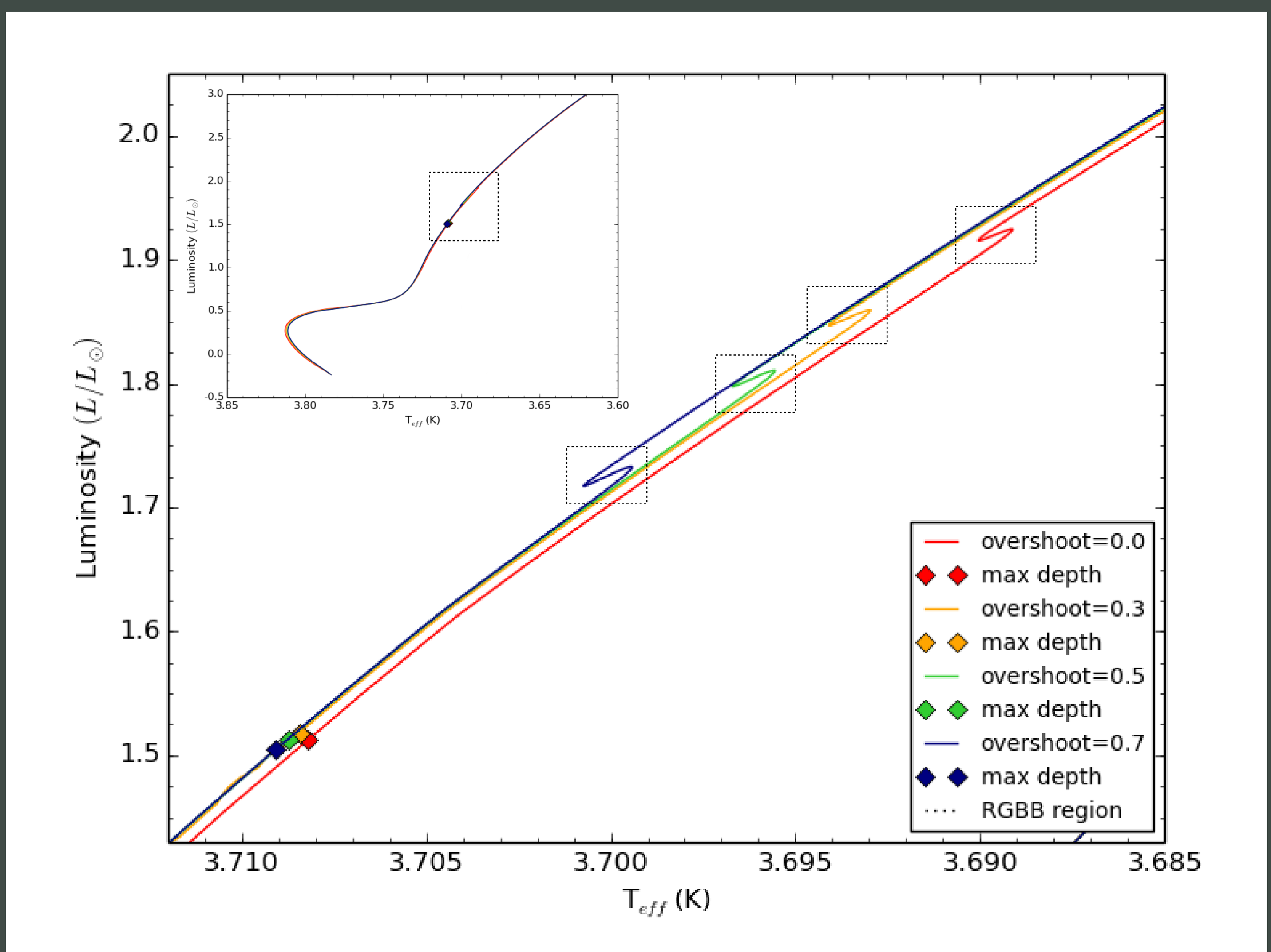
ABSTRACT

The Red Giant Branch Bump is a unique evolutionary feature whose observed properties are direct probes of stars' interior structure. We generate synthetic RGBB magnitudes using the Dartmouth Stellar Evolution Program (DSEP) code (Dotter et al.) and compare these to the 72-cluster, observational sample of Nataf et al. 2013. Our best-fitting DSEP model yields overprediction of the observations by up to -0.35 magnitudes at the lowest metallicities ($[\mathrm{Fe/H}] = -2.3$).

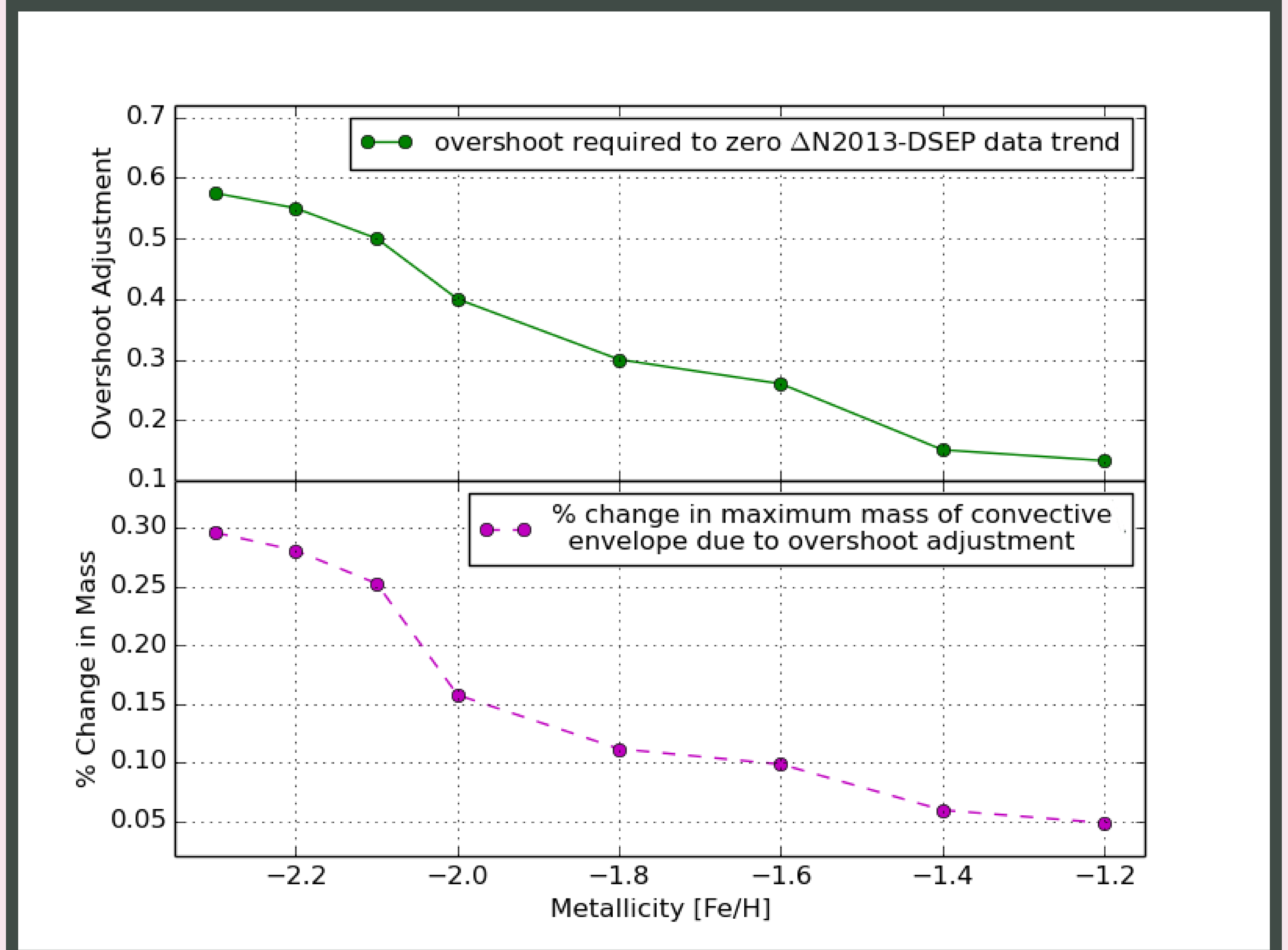
One method of compensating for this overprediction is through adjusting the amount of convective overshoot our models allow. We compute the amount of overshoot required to zero our ΔM_v residuals in the $[\mathrm{Fe/H}] = -1.2$ to -2.3 range, and find a nearly linear, increasing trend ranging from 0.13 scale heights $[(\mathrm{Fe/H}] = -1.2)$ to 0.55 scale heights $[(\mathrm{Fe/H}] = -2.3)$. This corresponds to a physical change of 0.05 to 0.3 per cent in the maximum mass of the convection zone on the red giant branch.

EVOLUTIONARY IMPACT OF OVERSHOOT CORRECTION



We show four stellar tracks (13 Gyr, $[\alpha/\mathrm{Fe}]$= 0.4, $[\mathrm{Fe/H}]$= -1.6) evolved with different overshoot values as indicated. The effect of increased overshoot is, in part, moving the maximum depth of penetration reached by the convective envelope to an earlier point in the star's evolution. More significantly, the effect corresponds to a temporal shift in the occurence of the Red Giant Branch bump.

CHANGE IN MASS



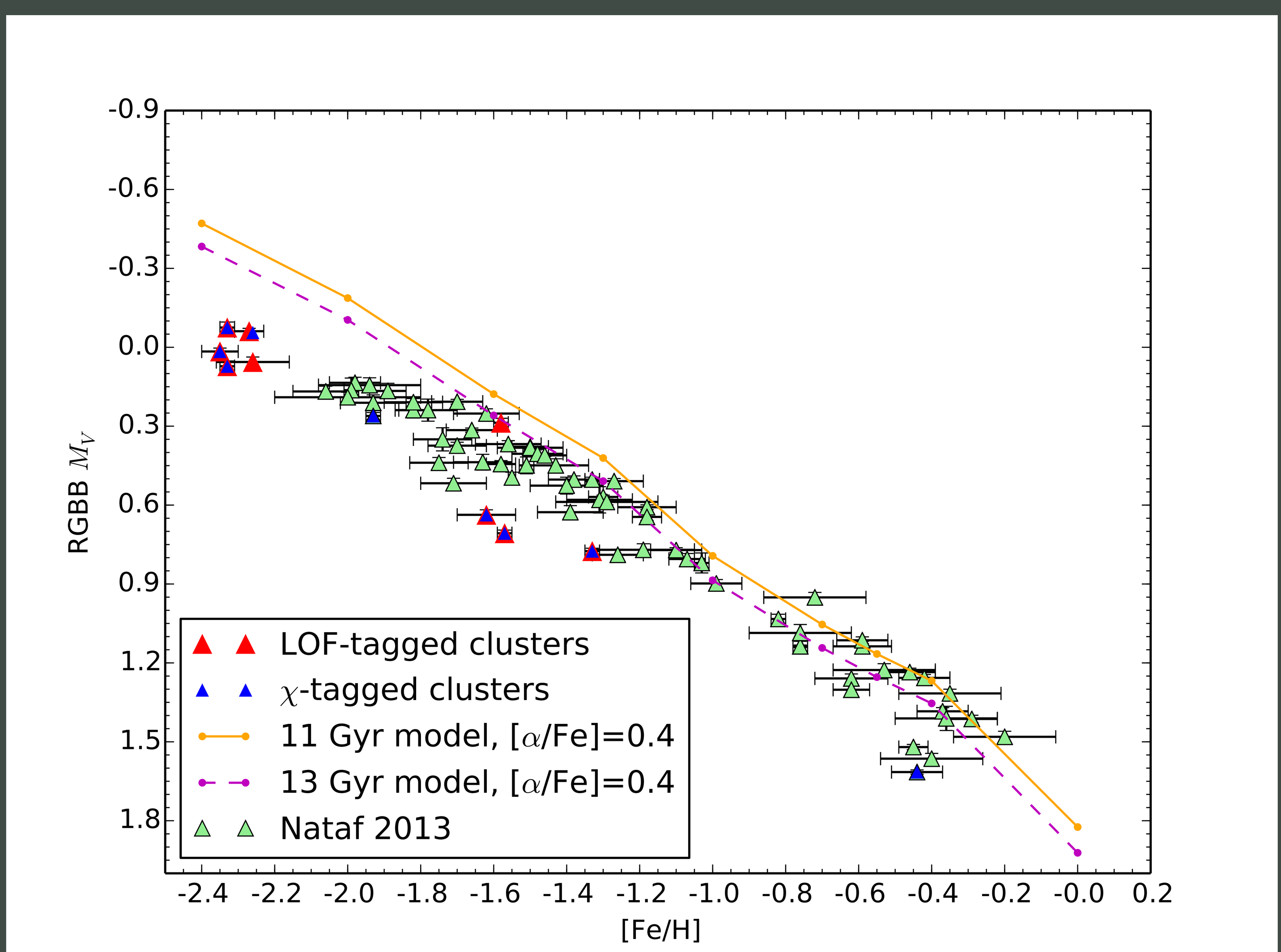
The top panel shows the overshoot adjustment required by DSEP's calculations to zero the model's predictions with N2013's observations. This demonstrates that, in order for DSEP to predict accurately the magnitudes of the most metal-poor stars, overshoot values of up to 0.6 scale heights H may be required.

We can translate a change in the degree of convective overshoot directly into an impact on the size of the star's convection zone. The bottom panel shows the change in the maximum mass of the star's convective envelope due to overshoot adjustment as a function of metallicity. The overshoot adjustments required to force consistency between DSEP's predictions and N2013's observations correspond to changes of 0.1 to 0.3% in the model stars' convection zone.

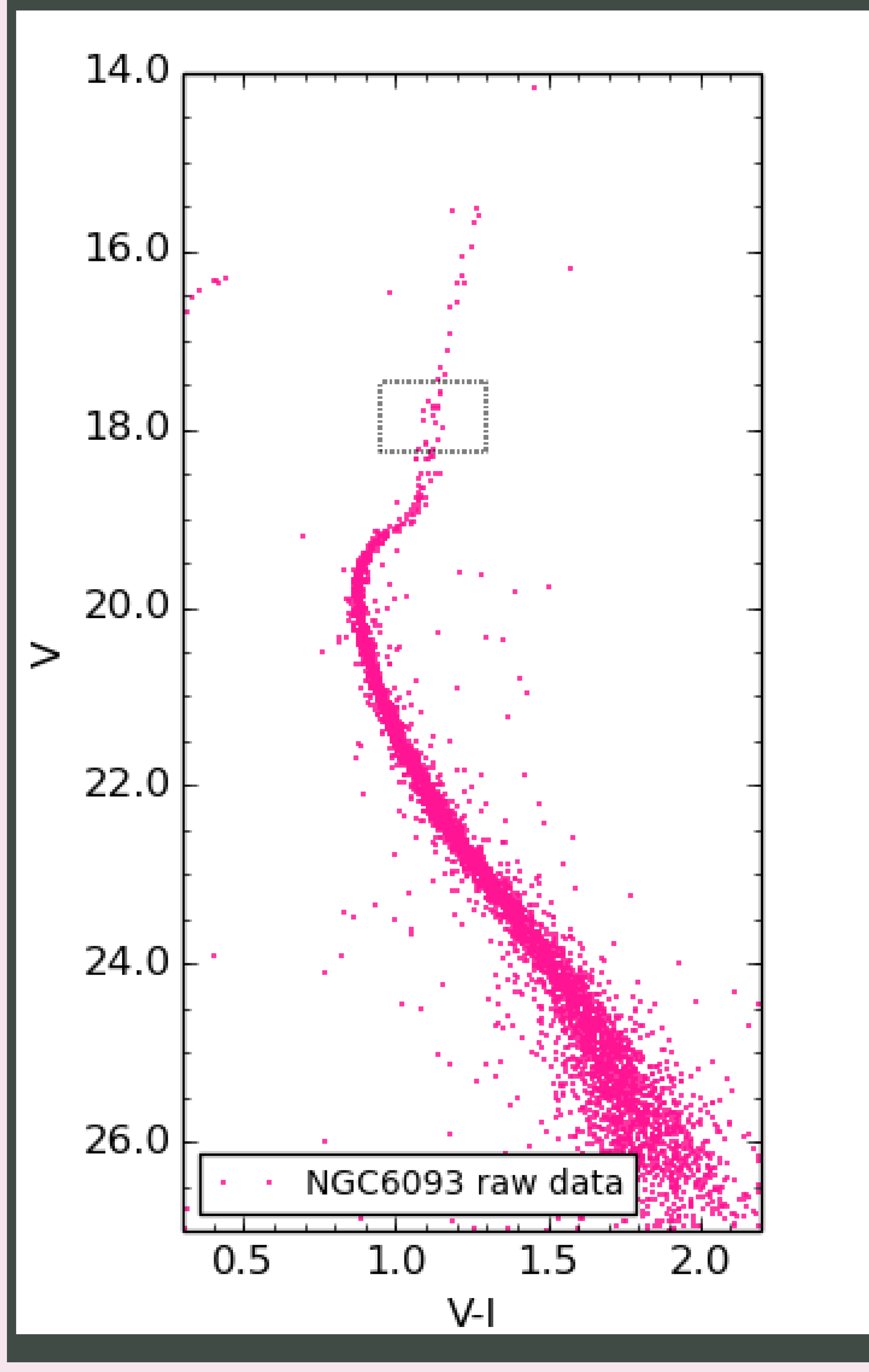
BEST FIT: 13 Gyr, α-enhanced DSEP model

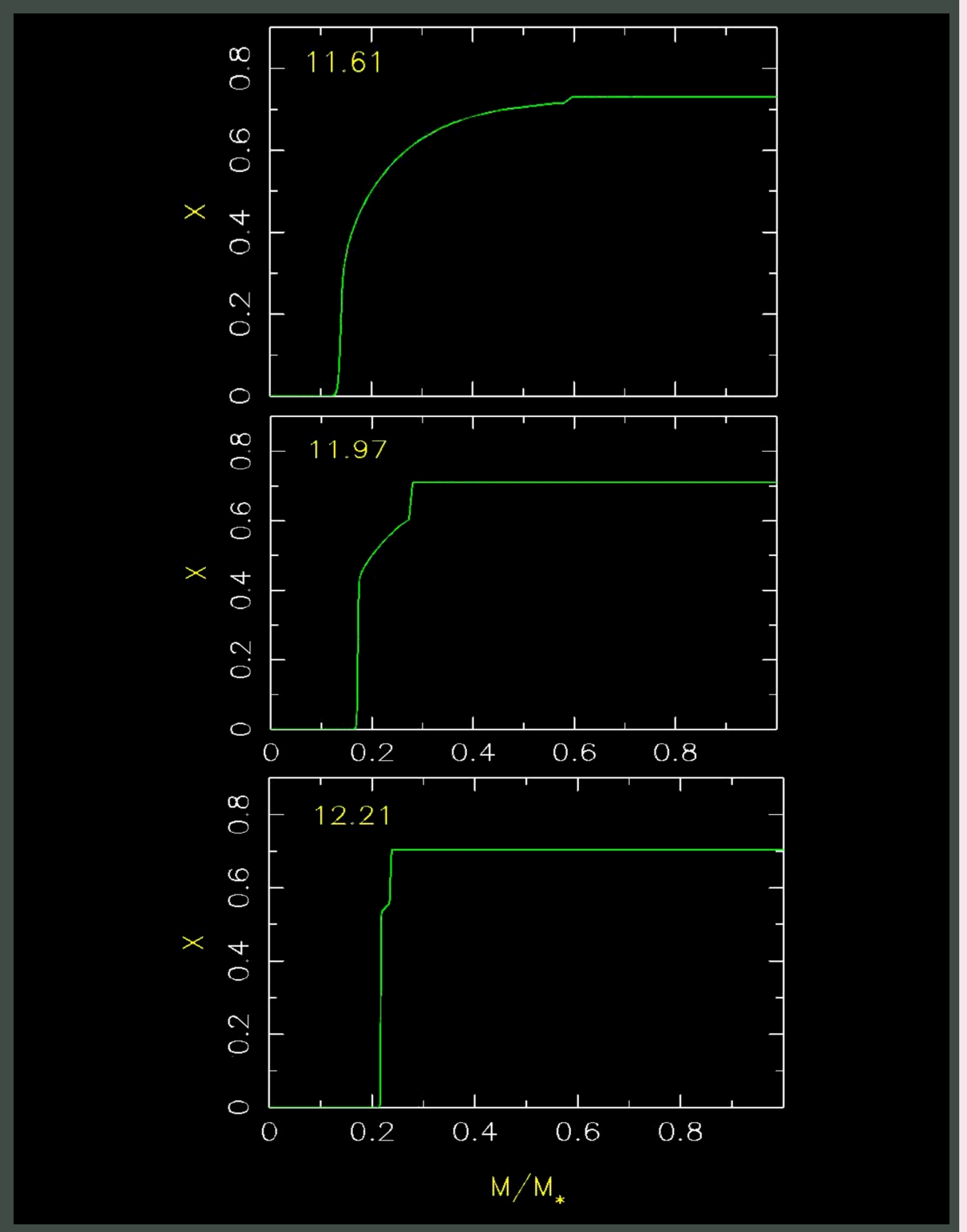
We implement a χ^2 minimization routine to assess the goodness of fit of our best model to N2013's data (Joyce & Chaboyer, 2015). The reduced χ^2 score for the fit to the entire sample is 1.38, corresponding to a p-score of 0.0175, computed via

$$\chi^2 = \sum_i \frac{(M_{V_{i,t}} - M_{V_{i,o}})^2([\mathrm{Fe/H}]_{i,t} - [\mathrm{Fe/H}]_{i,o})^2}{[(M_{V_{i,t}} - M_{V_{i,o}})^2 + ([\mathrm{Fe/H}]_{i,t} - [\mathrm{Fe/H}]_{i,o})^2]\sigma_i^2} \quad \text{with } \sigma_i = \sqrt{\delta^2_{\mathrm{obs}_i} + \delta^2_{[\mathrm{Fe/H}]_i} + \delta^2_{\mathrm{dist}_i}}$$



BACKGROUND



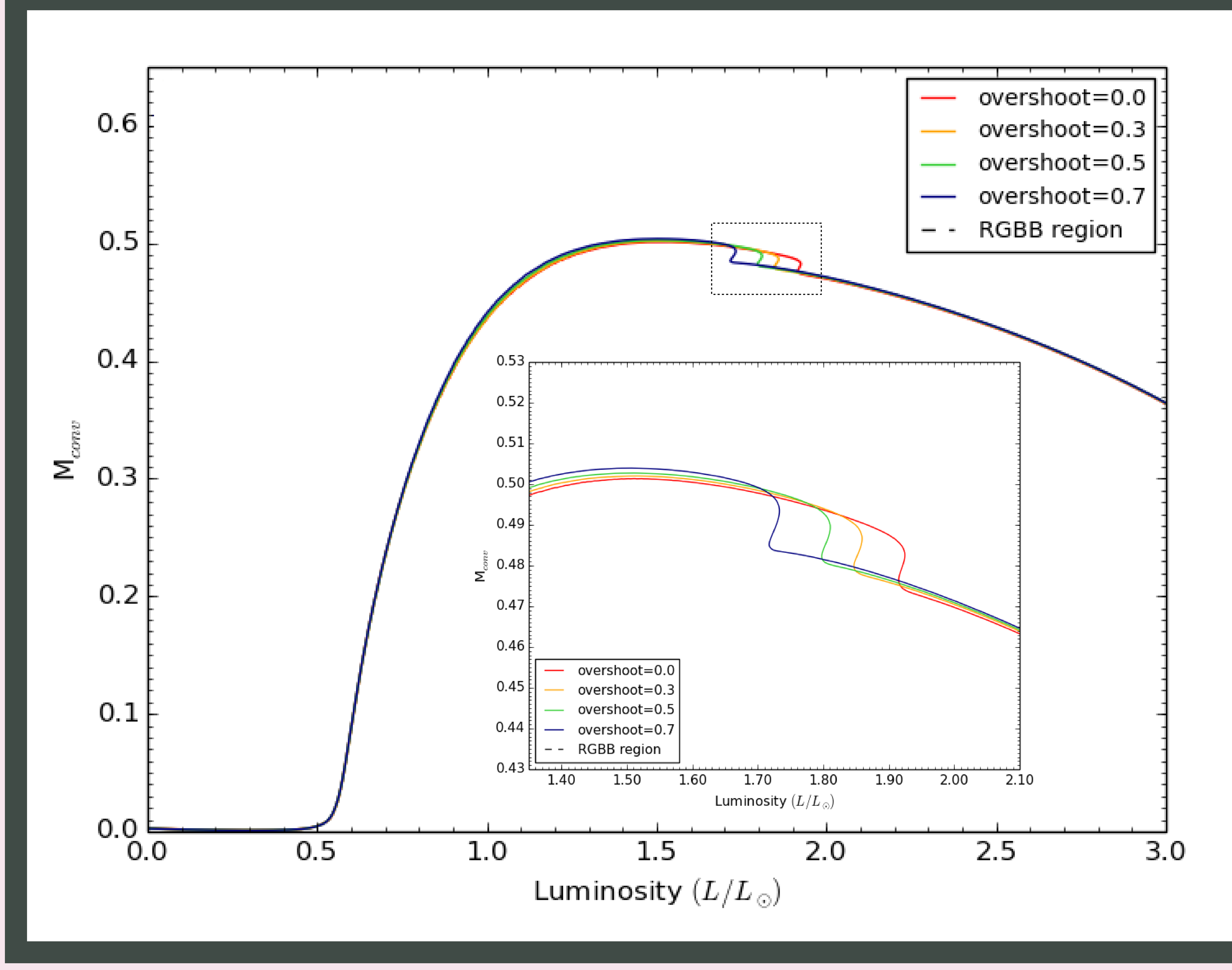


Left: Raw data from globular cluster NGC 6093 with RGBB in dashed box (HST, 2013)

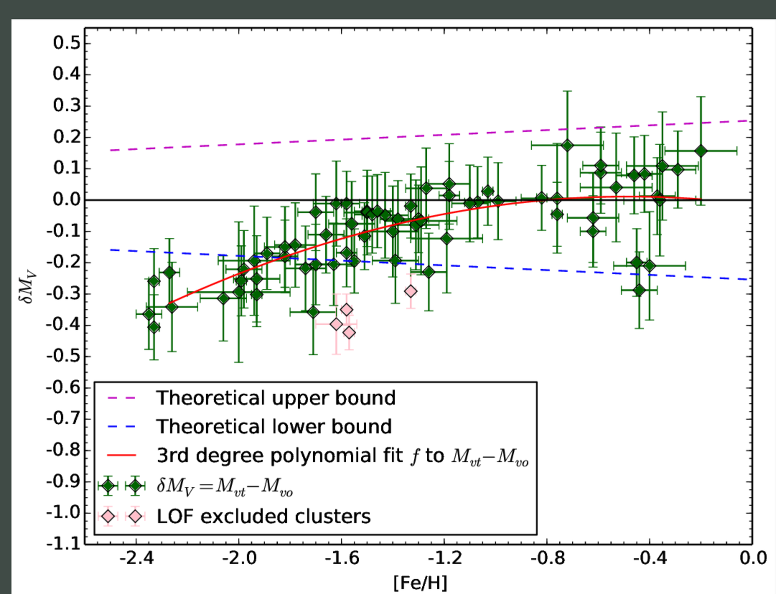
Right: Diagram showing the change in Hydrogen abundance during the mixing phase that causes the RGBB

THE RGBB IN TERMS OF CONVECTIVE ENVELOPE MASS

The mass of the convective envelope is shown against luminosity for the same four overshoot values and baseline model parameters used in the central panel. Evolutionary time is traced along the luminosity curve from left to right, where the discontinuity near the center represents the RGBB. The highest point reached along the M_{conv} corresponds to the mass of the convective envelope at its maximum penetration depth.



QUANTIFYING RESULTS



We quantify the trend by fitting a cubic polynomial (red) to the magnitude differences. We exclude the four anomalous clusters (pink) from the calculation. Theoretical uncertainties from BC2006 are shown. Our model agrees with N2013's data over the metallicity range $[\mathrm{Fe/H}] = (0, -1.5)$ dex, but disagreement amplifies in the most metal-poor regime.

Identifying Outliers

A GC may be classified as an outlier in two ways:

(1) if its contribution to the total reduced χ^2 score, or χ^2_i score, is sufficiently large

(2) its o-score computed using the 4D Local Outlying Factor (LOF) algorithm is sufficiently large.

The 4D LOF routine (Breunig et al., 2000) identifies the most anomalous clusters based on a given point's distance from the bulk distribution. Results are model-independent, but non-uniform density can cause an issue!

"Anomalous" vs Outlying

We reserve the special designation of "anomalous cluster" for GCs that

(1) do not belong to the isolated cluster of 5 GCs in the lowest metallicity regime, but

(2) still rank in the highest 10% for discrepancy as defined by either method.

This leaves us with clusters that are not impacted by the LOF routine's sampling issue and are not subject to the model-dependent inflation of their χ^2_i scores.

ACKNOWLEDGEMENTS

This work is supported by grant AST-1211384 from the National Science Foundation.

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Hubble Space Telescope database and collaboration

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