Color-Surface Brightness Relations with the Nancy Grace Roman Space Telescope

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Motivation

- Color-surface brightness relations (CSBRs) are critical tools for estimating lens masses in microlensing studies.
- CSBRs allow measurement of the angular source size from de-reddened color and magnitude.
- In microlensing events with finite source effects, this angular source size helps determine the angular Einstein radius, which depends on the lens mass and distance.
- Combining this with another constraint, like microlens parallax, yields a unique mass and distance solution.
- While empirical versions of these relations await Roman Space Telescope data, synthetic relations can be modeled using stellar isochrones that include Roman filters.
- CSBRs behave differently for M dwarfs in the infrared compared to FGK stars commonly observed from the ground.
- Understanding these differences is essential for accurate angular diameter estimates and lens mass determinations for Roman.

Method

- We use the Padova and Trieste Stellar Evolution Code (PARSEC)[1] models at 2 Gyr to generate synthetic photometry for main-sequence stars with M < 1.75 $M_{\odot}$ across four metallicities: [M/H]=−1.0, −0.5, 0.0, 0.5
- Angular diameters were calculated assuming a distance of 10 pc:

$$\log\theta_{Q=0} = \log\theta_{LD} + 0.2Q^{[2]}$$

- For each filter pair:
  - Color indices were formed
  - Residuals were computed relative to the solar metallicity track to assess metallicity sensitivity

References

[1] Bressan A. et al., 2012, MNRAS, 427:127
[2] Adams A. et al., 2018, MNRAS, 473:3

Color-Surface Brightness Relations

- CSBRs show a clear, metallicity-dependent trend:
  - Redder colors correspond to larger angular diameters, but higher-metallicity stars consistently lie below lower-metallicity ones in $\log\theta_{F146=0}$.
- This behavior is most pronounced at the red edge of the relation, where metallicity-induced deviations become significant.
- While CSBRs are typically tight and metallicity-insensitive for FGK stars, we observe increased scatter and slope variation in the M-dwarf regime.
- These residuals represent a systematic uncertainty when applying CSBRs without knowing [M/H].
- Our results suggest:
  - Broader color baselines yield flatter CSBRs (reducing propagation of photometric uncertainty) but also carry greater sensitivity to reddening and metallicity.

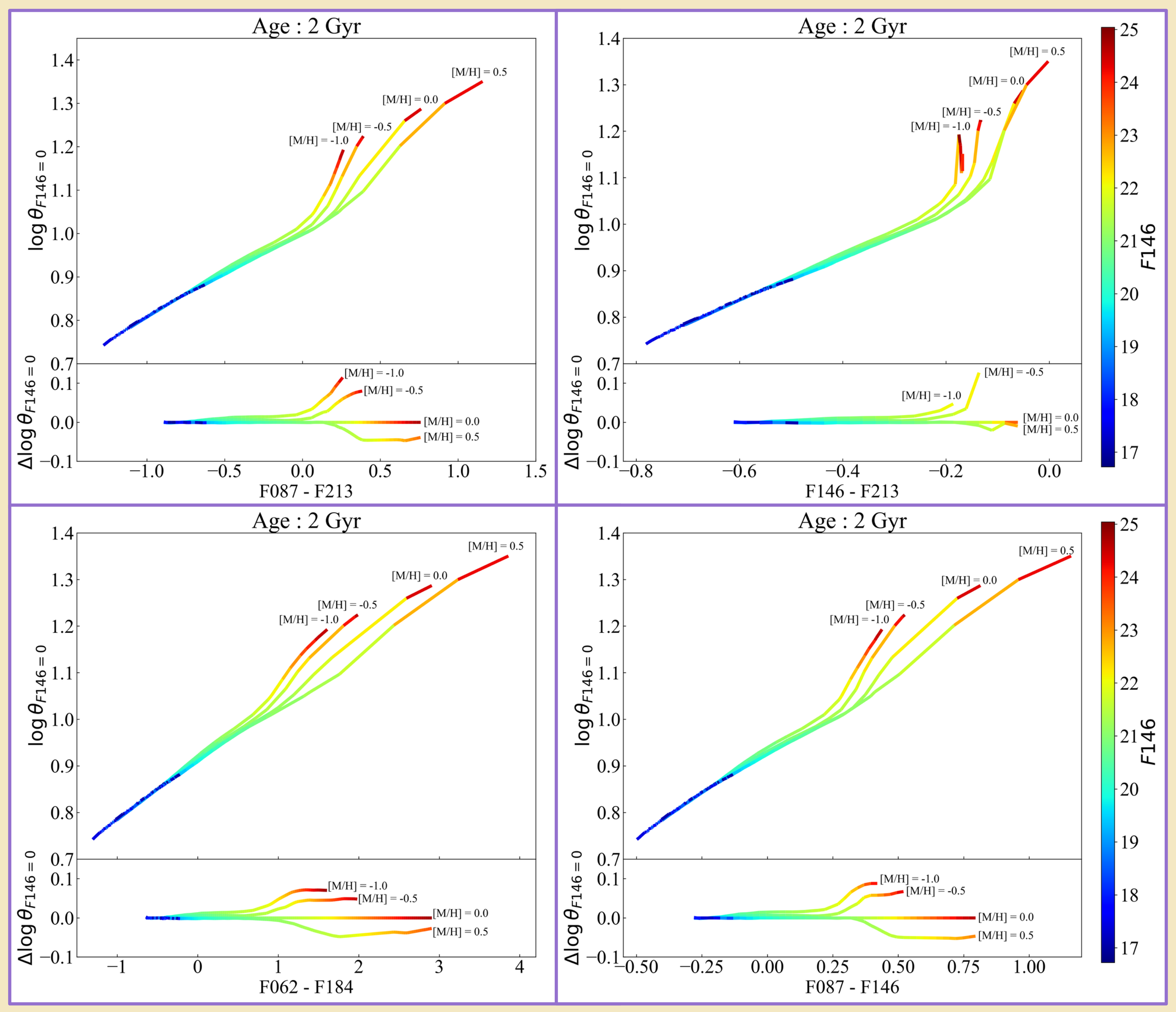

Figure 1. CSBRs for four Roman color indices, F087–F213 (top left), F146–F213 (top right), F062–F184 (bottom left), and F087–F146 (bottom right), evaluated across multiple metallicities using isochrones of main-sequence stars. Each curve is color-coded by F146 magnitude, with dark blue representing brighter stars and red indicating fainter stars. These comparisons highlight differences in slope and metallicity sensitivity across filter pairs, informing the selection of optimal color baselines for the GBTDS.

Empirical Calibrations of Color-Surface Brightness Relations

- Synthetic CSBRs require empirical validation before they can be applied with confidence.
- Long-baseline optical interferometry provides direct, model-independent measurements of stellar angular diameters.
- Combining interferometric diameters with precise photometry enables empirical color–surface brightness relations.
- We are using the Center for High Angular Resolution Astronomy Array (CHARA) to observe photometric standard stars spanning a wide range of colors and luminosities.
- The current sample (Figure 2) represents our observational progress toward building an empirical calibration dataset.
- The measured angular diameters will be compared with our synthetic CSBRs to test their zero points, slopes, and scatter.
- Differences may reveal systematic effects caused by metallicity, surface gravity, extinction, or stellar atmosphere models.
- A broad calibration sample helps ensure that CSBRs remain accurate for the diverse stellar populations that will be observed by Roman.

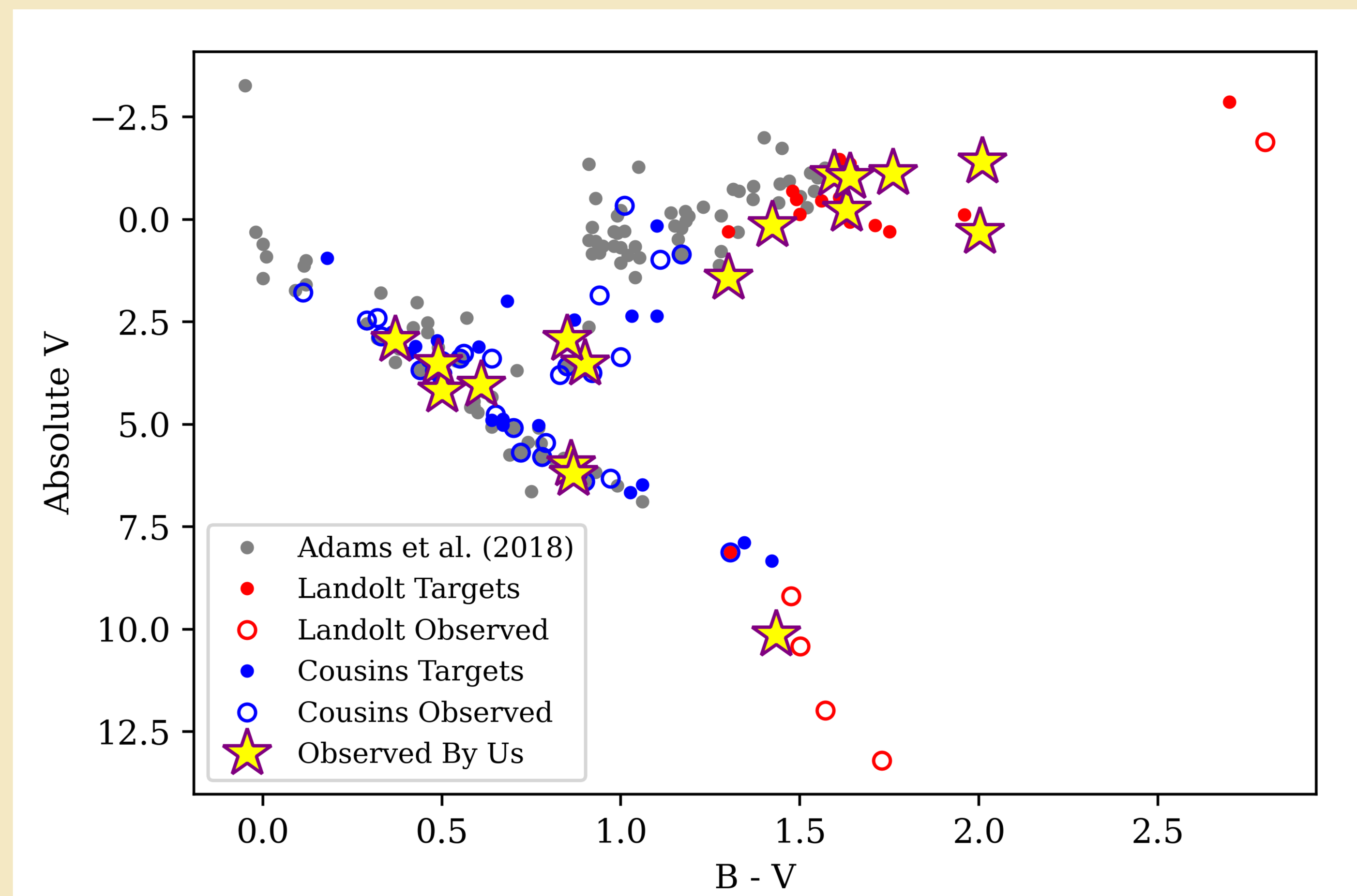

Figure 2. CHARA target sample**.** Color–magnitude diagram showing literature stars, selected photometric-standard targets, previously observed targets, and stars observed by us.