Surface Brightness Relations With The Nancy Grace Roman Space Telescope

Emelly Tiburcio, Matthew Penny, Tabetha Boyajian

Louisiana State University

LSU Department of Physics & Astronomy

Motivation

- Surface brightness relations (SBRs), along with mass–magnitude and mass–color relations, are critical tools for estimating lens masses in microlensing studies.
- SBRs 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.
- SBRs 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 in the Roman era.

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
- Roman Space Telescope filters were used to compute:
  - Surface Brightness Relations
  - Mass–magnitude relations
  - Mass–color relations
- Angular diameters were calculated assuming a distance of 10 pc: [2]

$$\log\theta_{Q=0} = \log\theta_{LD} + 0.2Q$$

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

Surface Brightness Relations

- SBRs 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 SBRs 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 SBRs without knowing [M/H].
- Our results suggest:
  - Broader color baselines yield flatter SBRs (reducing propagation of photometric uncertainty) but also carry greater sensitivity to reddening and metallicity

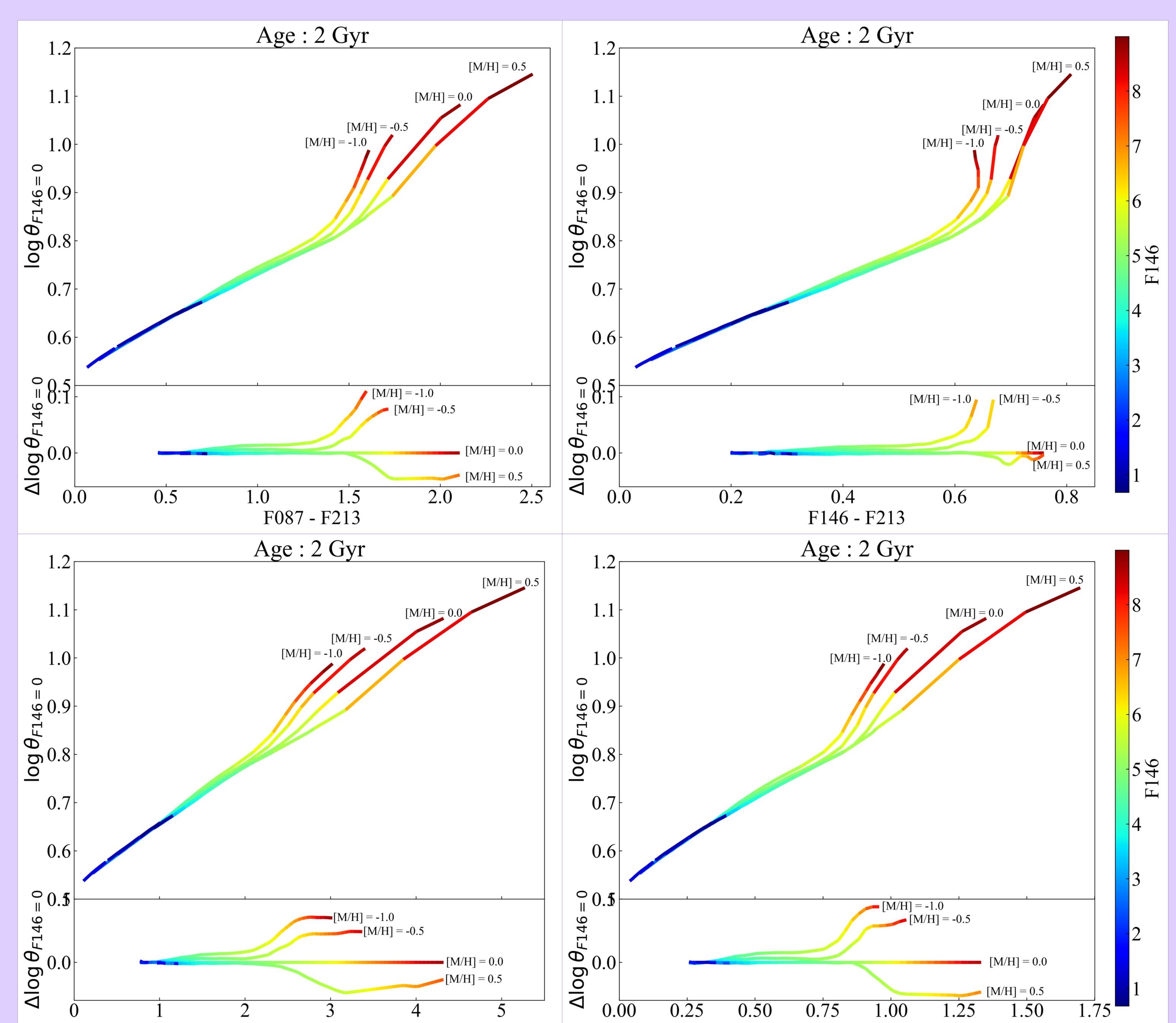

Figure 1. Surface brightness relations (SBRs) for four Roman color indices, F087–F213 (top left), F146–F213 (top right), F062–F184 (bottom left), and F087–F146 (bottom right), evaluated across multiple metallicities using isochrones of main-sequence stars. Each curve is color-coded by F146 magnitude, 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.

Preliminary Results: Mass-Magnitude and Mass-Color Relations

- In microlensing events where the lens and source are separately detected, the lens's brightness can be used to constrain its mass, using mass–magnitude–distance relations that account for extinction.
- These relations define mass–distance curves, helping break degeneracies when combined with microlensing observables like parallax and proper motion.
- The mass–magnitude relation follows a broken power law, with a break near log(M/M⊙)≈−0.4
- In cases where direct lens flux is unavailable, mass–color relations become valuable.
- A lens star's color, combined with microlensing constraints, can inform its mass and distance.
- We interpolated mass–color relations across metallicities and computed residuals from the solar-metallicity track.
- These deviations show how metallicity affects inferred mass, improving lens modeling for varied stellar populations.

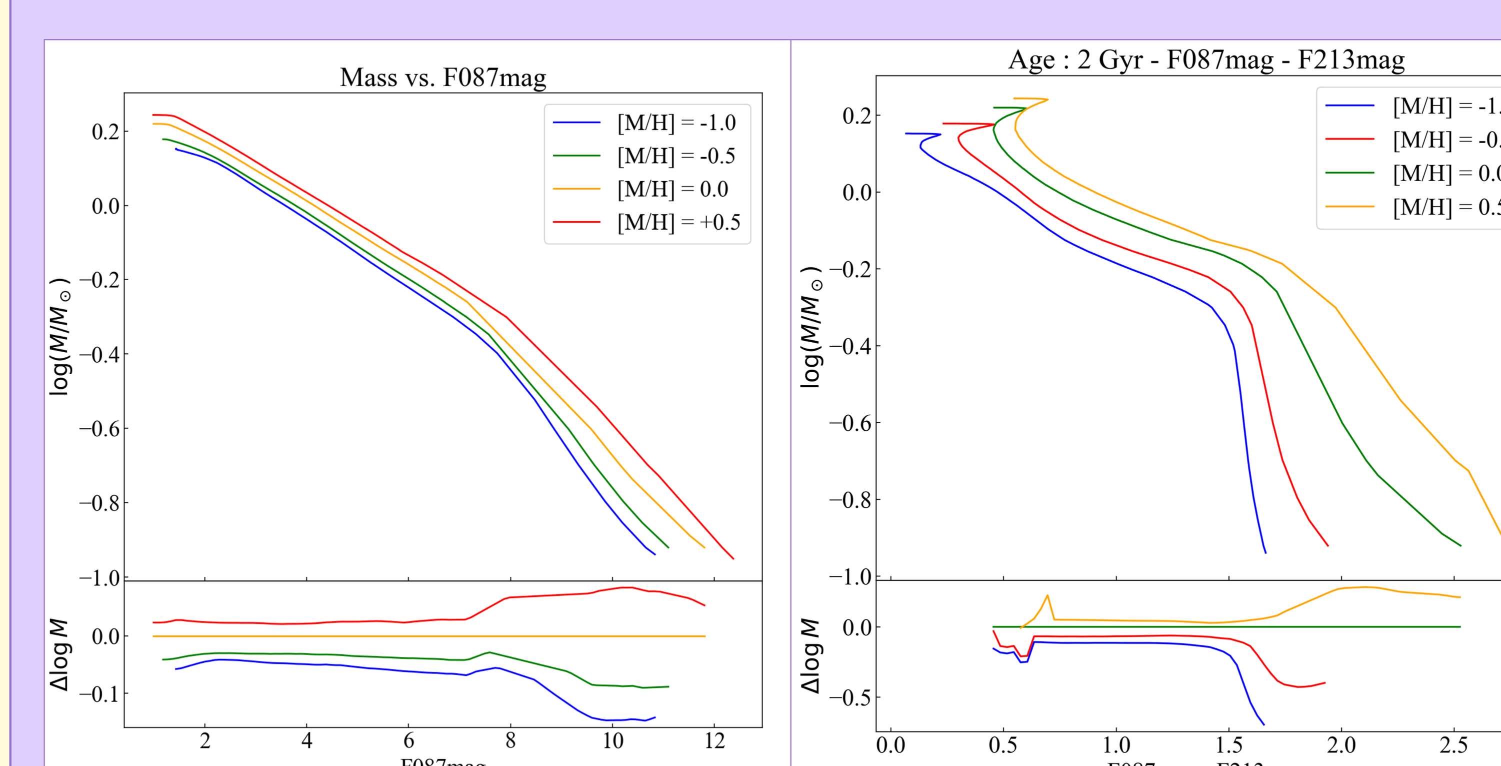

Figure 2. Stellar mass as a function of absolute magnitude in the F146 filter for main sequence stars at 2 Gyr (left). Stellar mass as a function of color index for main sequence stars at 2 Gyr across various metallicities (right). Each curve represents a different [M/H] value, highlighting how the mass-magnitude and mass-color relation shifts with chemical composition.

References

[1] Bressan A. et al., 2012, MNRAS, 427:127

[2] Adams A. et al., 2018, MNRAS, 473:3