RR LYRAE STARS AS CALIBRATORS OF THE LOCAL DISTANCE SCALE

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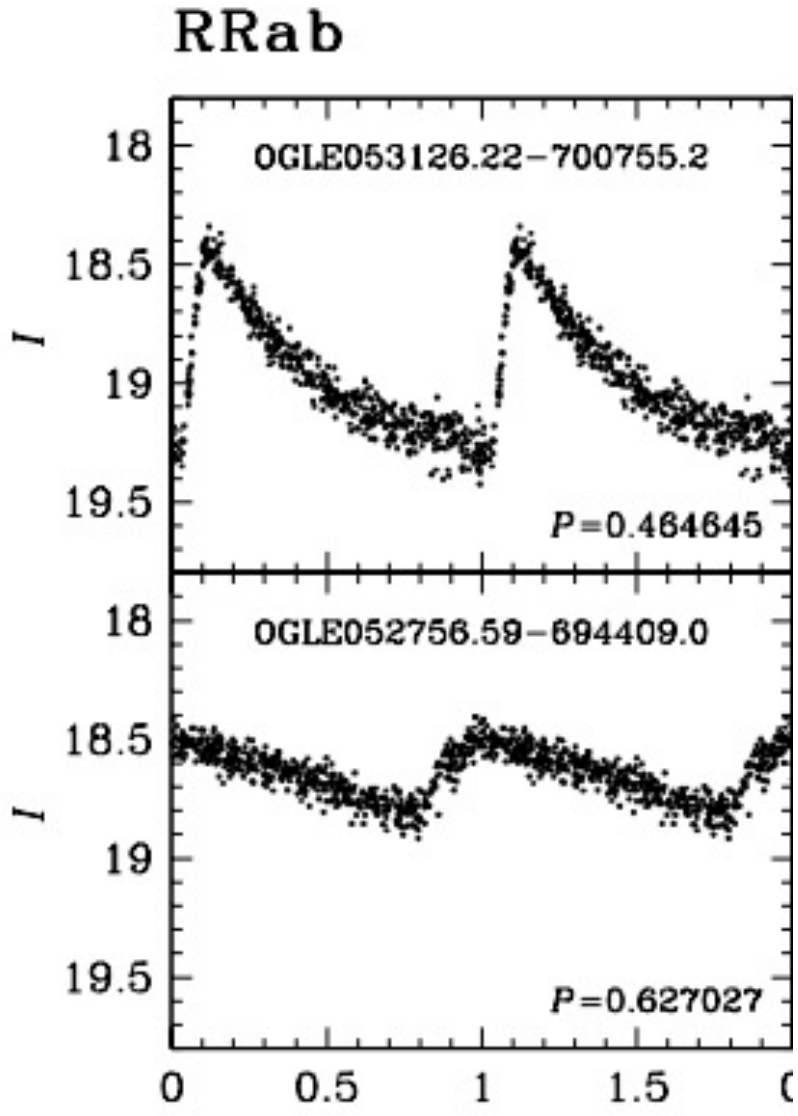
WHAT ARE RR LYRAE STARS

- RR Lyrae are old-metal-poor horizontal branch stars in the instability strip, for which the periodic variations in luminosity and color can inform their instrinsic luminosity, color, and chemistry (e.g. Monson et al. 2017, Kunder et al. 2020).
- These stars are common (e.g. around a million in the Milky Way), intrinsically bright ($M_V \approx 0$), have typical periods of 15 hours, and they trace old stellar populations. They can thus be studied in all nearby galaxies.
- "ab"-type RR Lyrae are "fundamental-mode" pulsators, and have the characteristic ***asymmetric sawtooth pattern*** in the light curve. They're the most widely-studied and best-understood kind of RR Lyrae.



Optical Gravitational Lensing Experiment

WHAT WE CAN DO WITH RR LYRAE – DISTANCES AND SUBSTRUCTURE

Figure 5 from Ripepi et al. (2012), showing a tight period-luminosity relationship for RR Lyrae in the Ks-band. A 1-sigma scatter of 0.10 magnitude is achievable with the period alone.

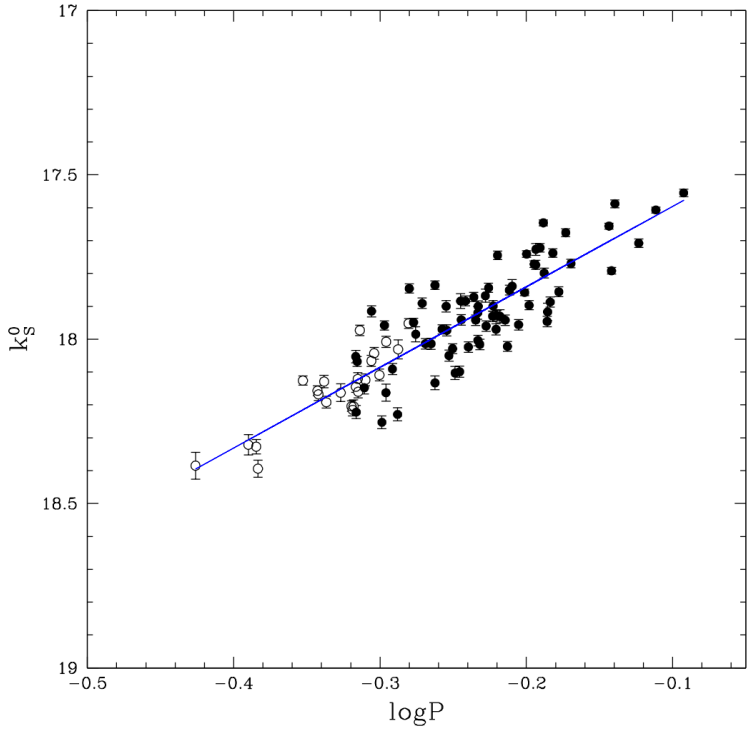
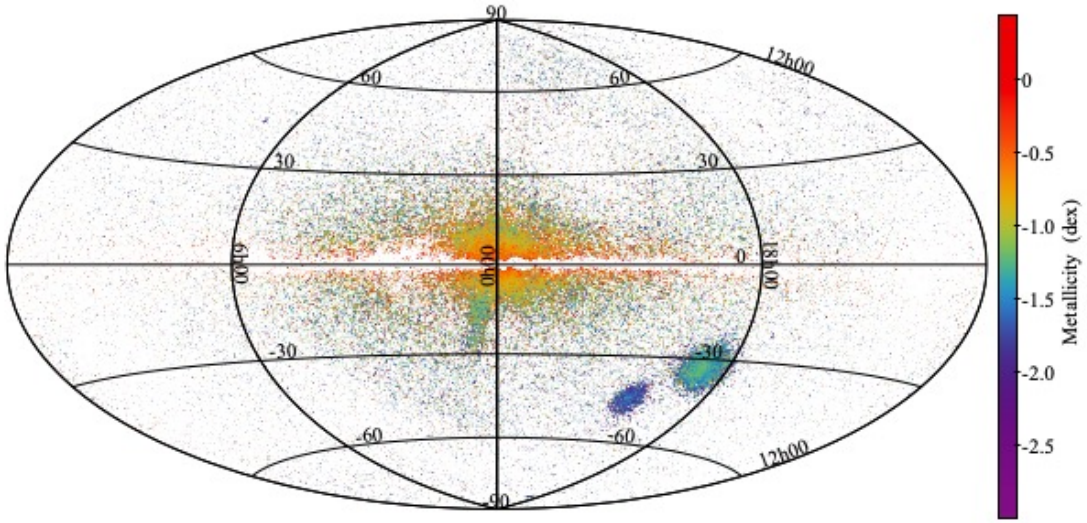


Figure 33 from Clementini et al. [2022], which shows the spatial distribution of RR Lyrae metallicities as inferred from the Fourier coefficients of their Gaia DR3 lightcurves. The incredible relationship between a coarse metallicity indicator and Galactic structure is an argument for an even better calibration.



ON THE USE OF RR LYRAE AS DISTANCE INDICATORS

- RR Lyrae are clearly not as bright as Cepheids, but they are numerous and observable in both young and old galaxies, toward both disks and (less blended, less exintguished) haloes.
- They, they have the potential to anchor the neabry distance scale, for example for the Local Group.

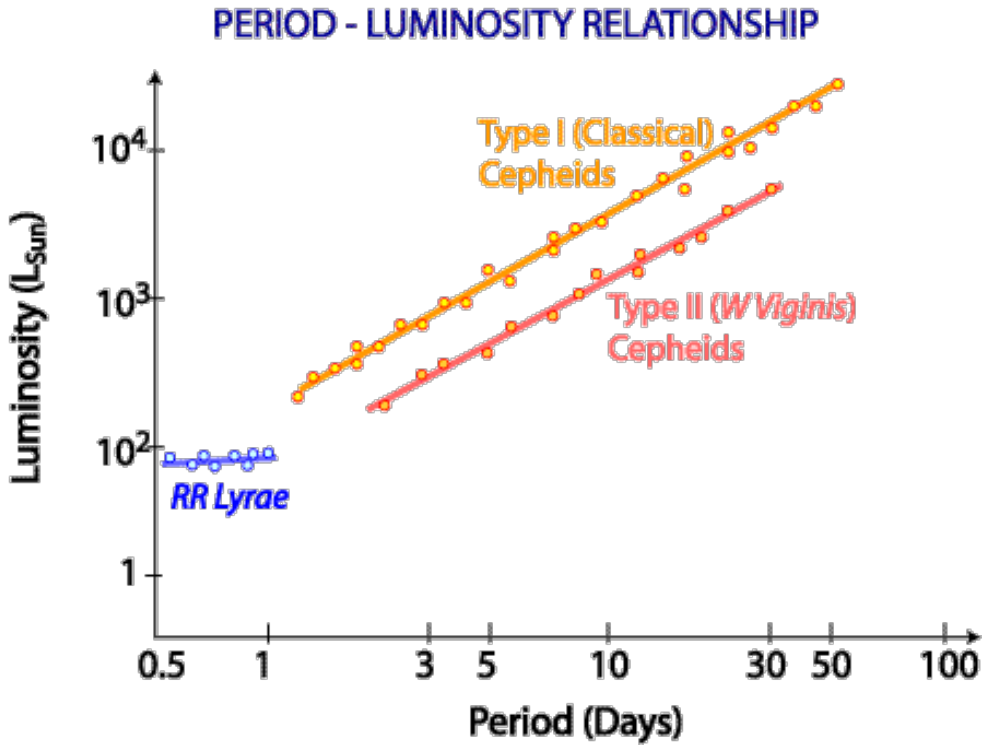


EXHIBIT A – REDDENING ZERO POINT TO THE LARGE (AND SMALL) MAGELLANIC CLOUD(S) AND HUBBLE'S CONSTANT

- The "local" Hubble tension, that between analysis of tip of the red giant branch (TRGB, red) and Cepheids (blue) yield different values for the cosmological expansion, $H_0 = 69.6 \pm 0.8$ (stat) $\pm$ 1.7 (sys) km s^{-1} Mpc^{-1} versus $H_0 = 74.03 \pm 1.42$ km s^{-1} Mpc^{-1}, how can we discuss disagreements with the value inferred from the cosmic microwave background (grey) if we can't agree on the local value?
- The TRGB and Cepheid analyses made different, specific, quantifiable statements and assumptions as to the reddening and extinction zero point to the Large Magellanic Cloud.

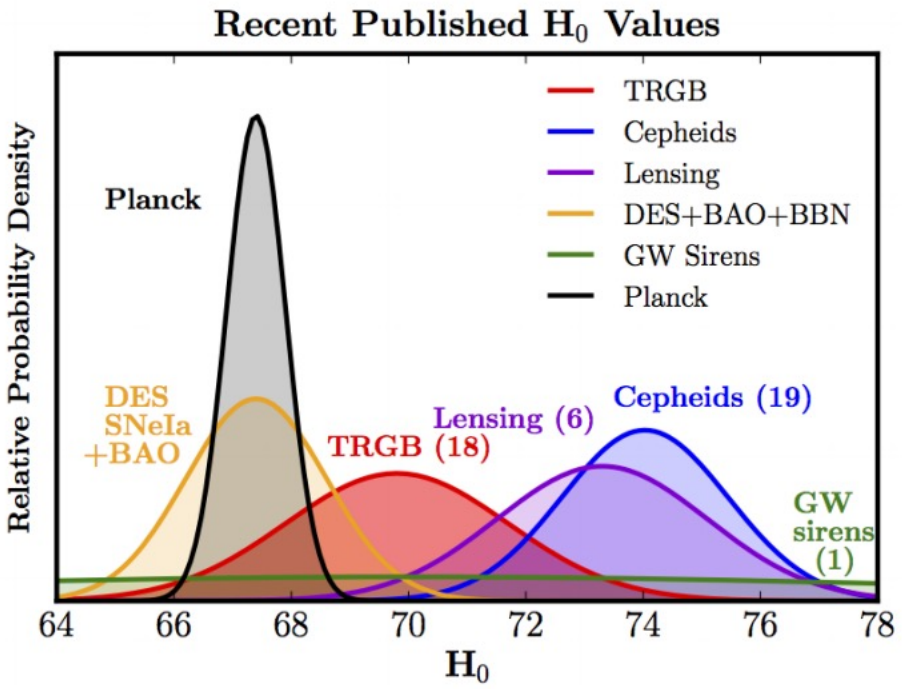
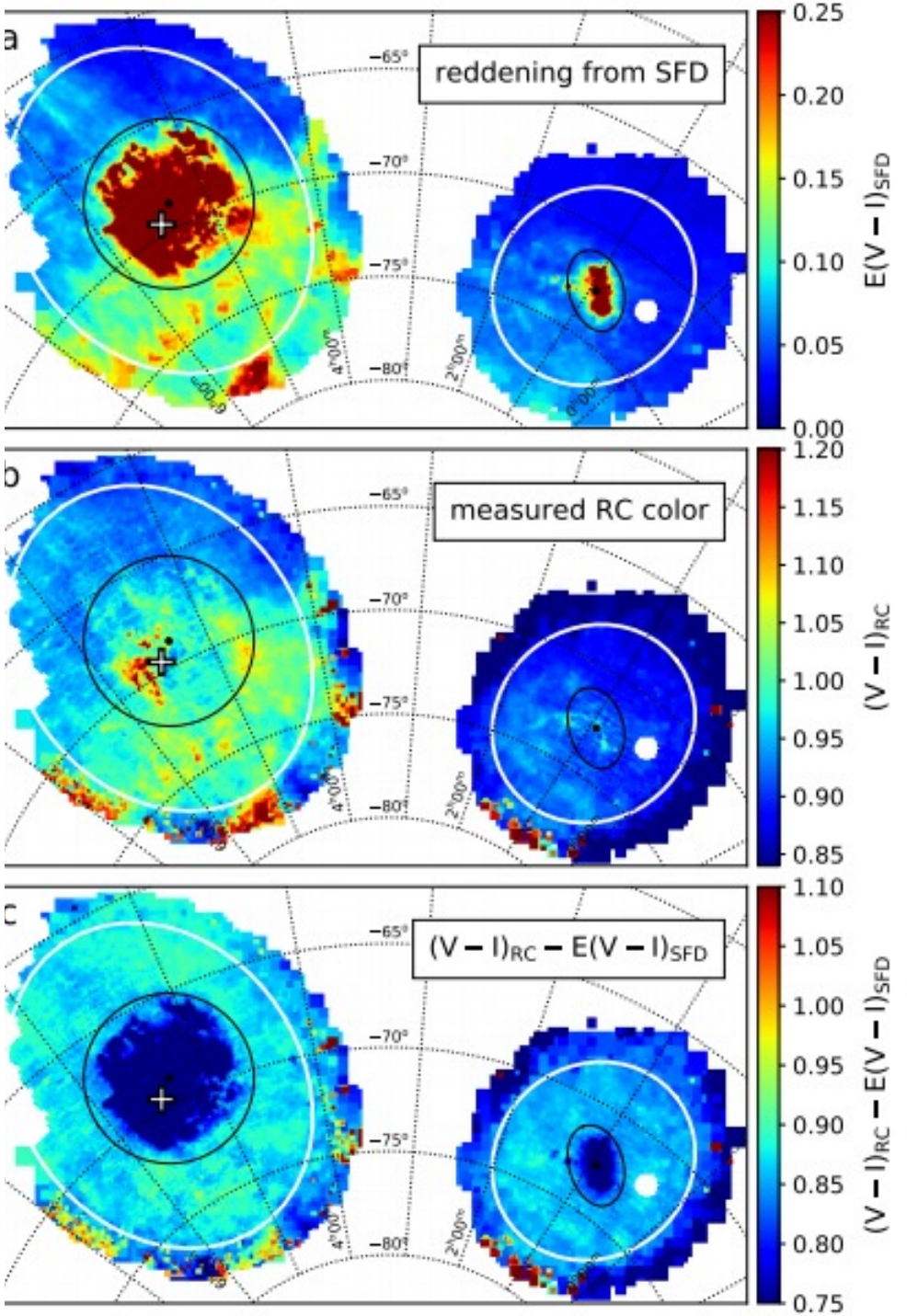


Figure 13, Freedman et al. (2020)

EXHIBIT A – REDDENING ZERO POINT TO THE LARGE (AND SMALL) MAGELLANIC CLOUD(S) AND HUBBLE'S CONSTANT, CONTINUED

- An analysis of different tracers by myself (Nataf et al. 2021) and Skowron, (+OGLE Collaboration et al. 2021) used a totalof four different methods, including RR Lyrae, to estimate the reddening and extinction zero point to the Large Magellanic Cloud.
- The zero-point of the mean reddening to the Large Magellanic Cloud stars is measured to lie within a range no broader than $\delta(V\text{-}I)_{0,} \approx 0.03$ mag, corresponding to $\delta H_0 \approx 3$ km s^{-1} Mpc^{-1}.
- The suggested value of the local Hubble's constant is between that has been derived from the TRGB and Cepheids, but approximately three times closer to the latter.



Skowron et al.[5] 2021

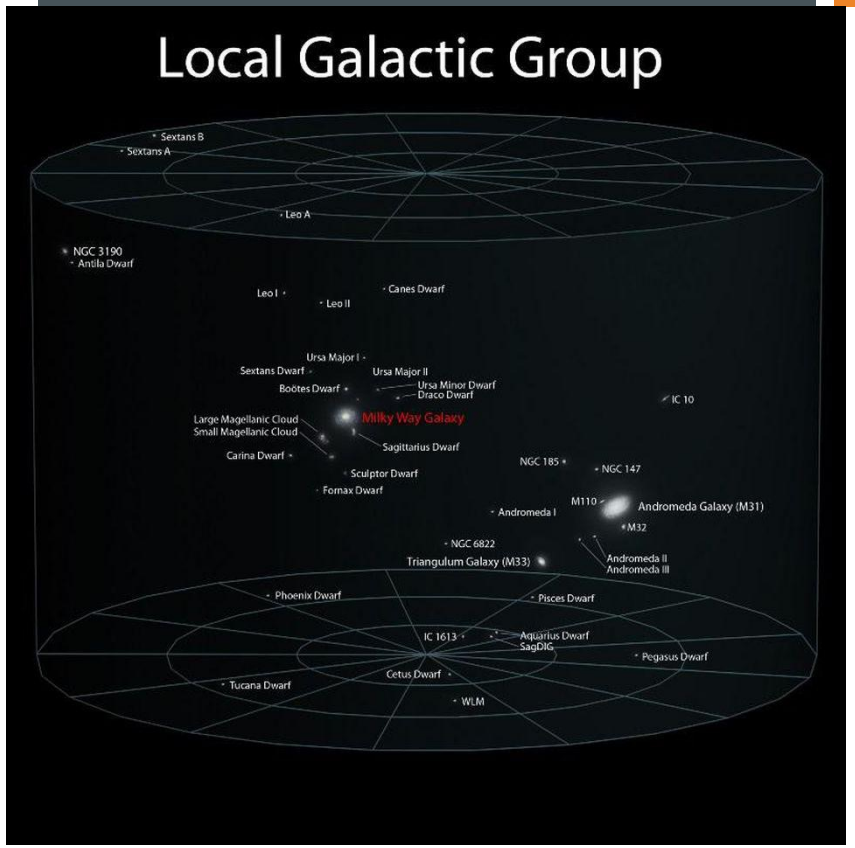
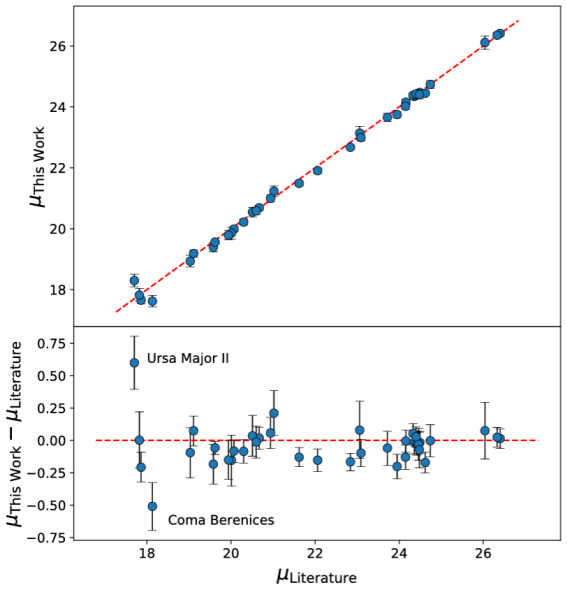
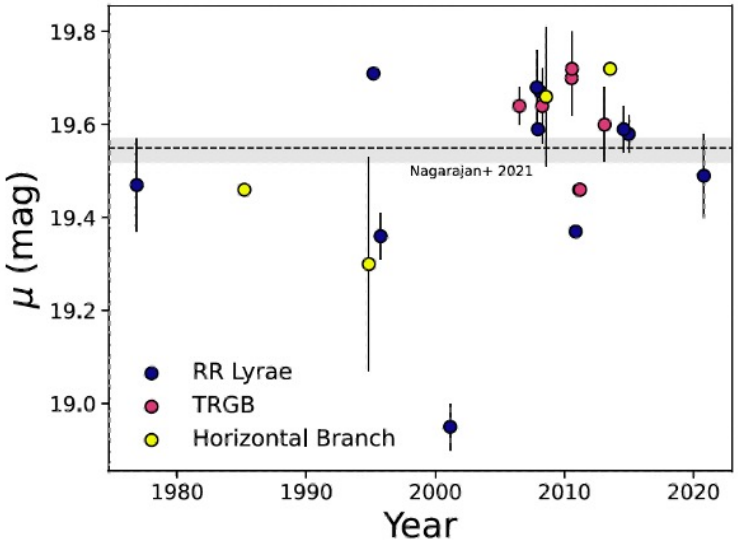


EXHIBIT B, NAGARAJAN, WEISZ, & EL-BADRY (2022)

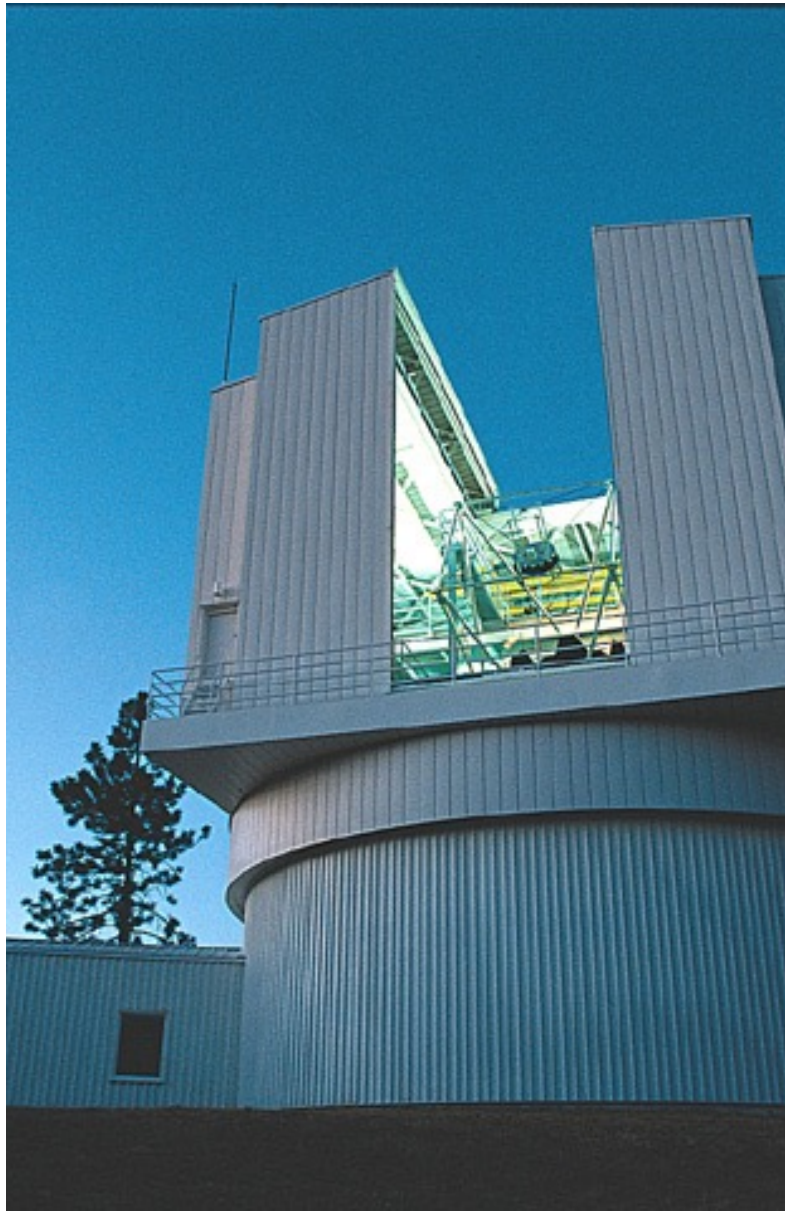


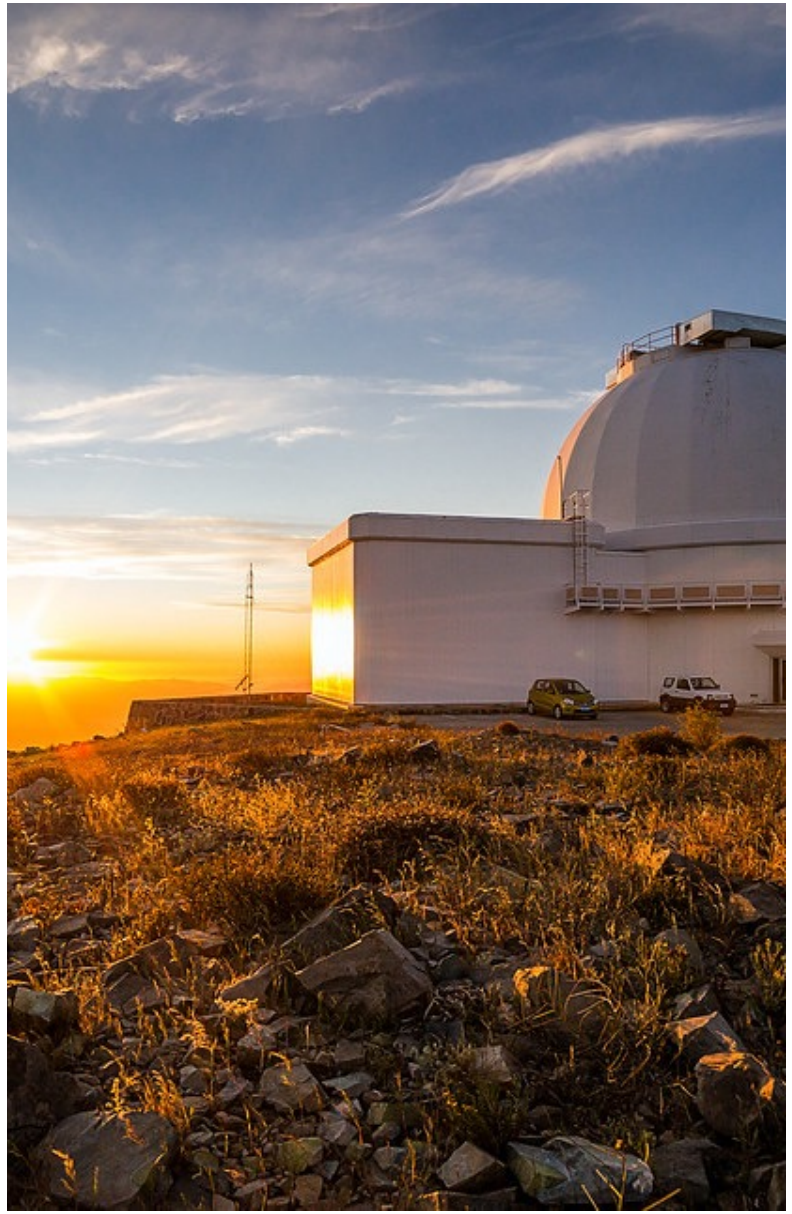


- Nagarajan et al. (2022) apply a Bayesian hierarchical model to determine 5% distances to 39 local group galaxies with ``decent'' time-series photometry, using Gaia DR3 astrometry of 54 Milky Way RR Lyrae stars as an anchor.
- The main limit is that of the Milky Way calibration sample – we need more RR Lyrae with independently-determined metallicities, as the period-luminosity relation has a metallicity dependence.

EARLY FOLLOW-UP

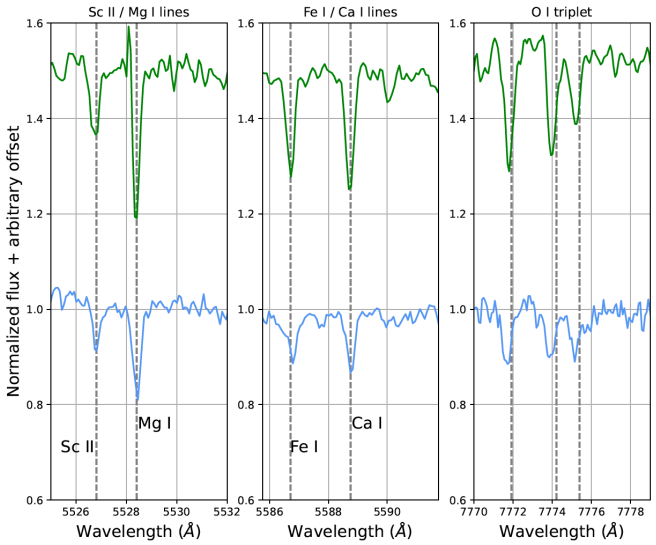
- We’re working to better refine the RR Lyrae - based calibration, we now have high-resolution, high signal-to-noise ratio ECHELLE spectra on 35 stars. We are aiming for 150 stars.
- Collaborating with Henrique Reggiani, Andrea Kunder, and Rosemary Wyse



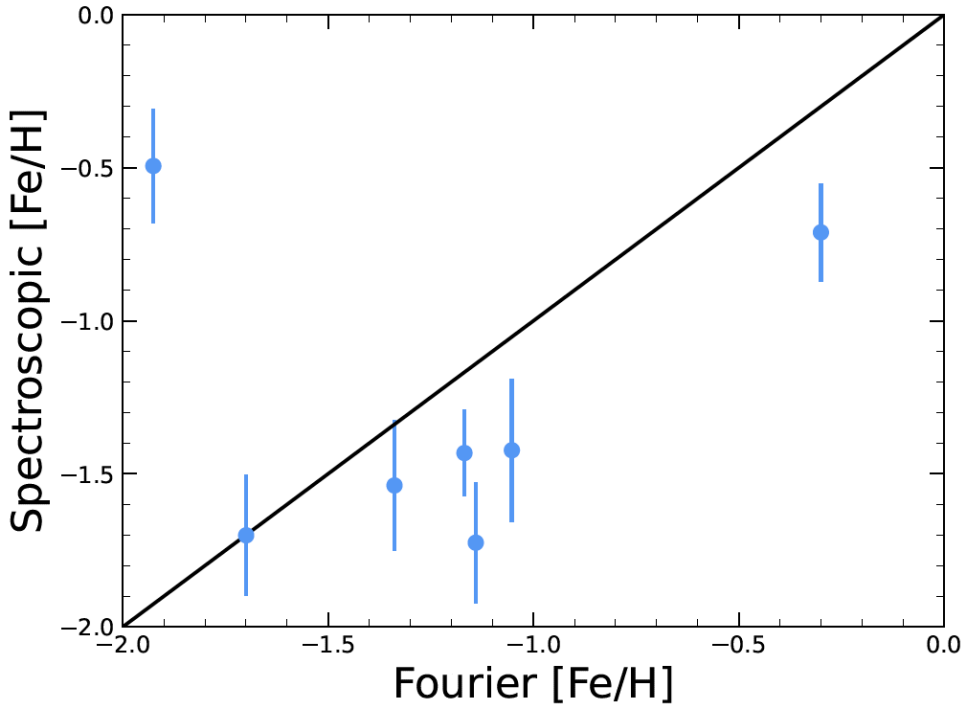


EARLY FOLLOW-UP, CONTINUED

- Early analysis shows significant discrepancies between photometric and spectroscopic metallicity determination.
- We are aiming to establish a new zero-point foundation for RR Lyrae calibration, one based off of high-signal-to-noise ratio, high-resolution spectra of RR Lyrae that infer multiple abundances.

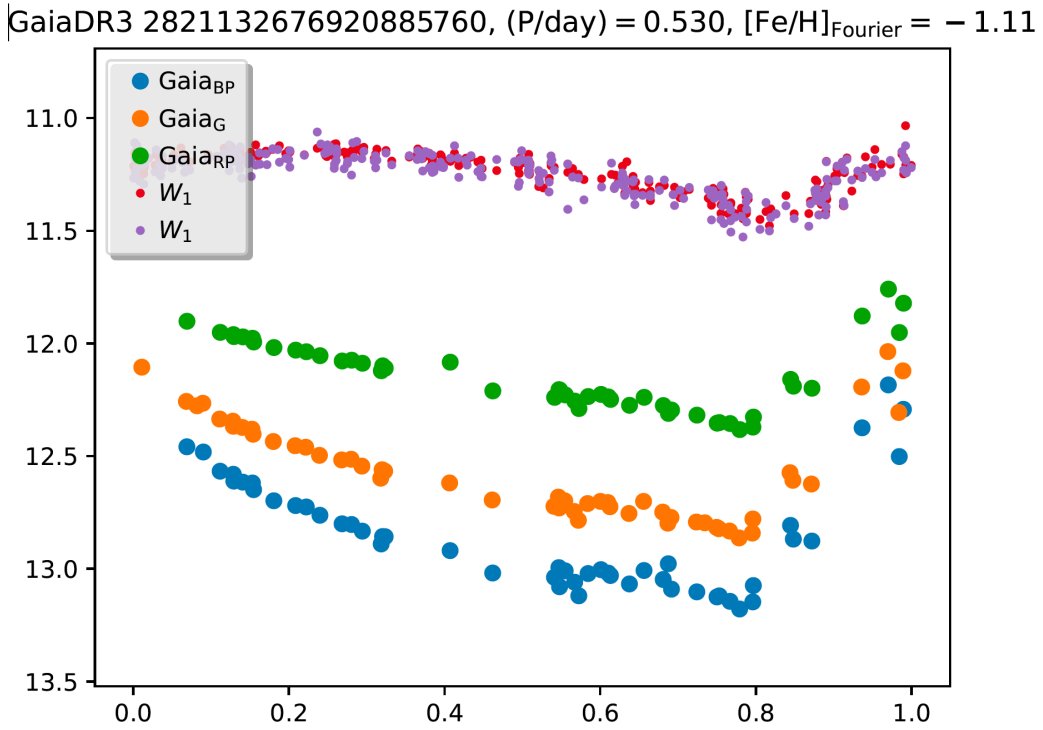


The star in the top panel has deeper lines, and thus a higher spectroscopic metallicity (by 0.63 dex), but a Fourier metallicity lower (by 0.93 dex), indicating an error in the calibration.



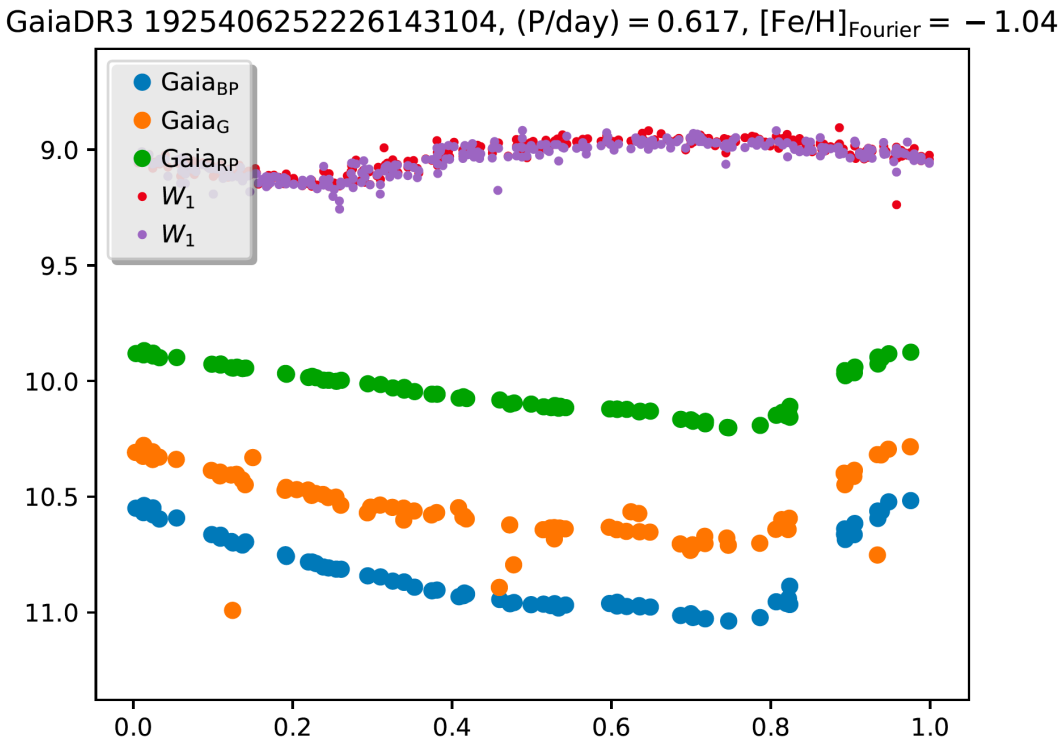
EARLY FOLLOW-UP, CONTINUED

- One example of a star in our program. The Fourier metallicity from the lightcurve parameters is [Fe/H]=-1.11, but our inferred spectroscopic metallicity is [Fe/H]=-1.42.
- With its 4% parallax precision (as of Gaia DR3), this star will be a great addition to any calibration sample.



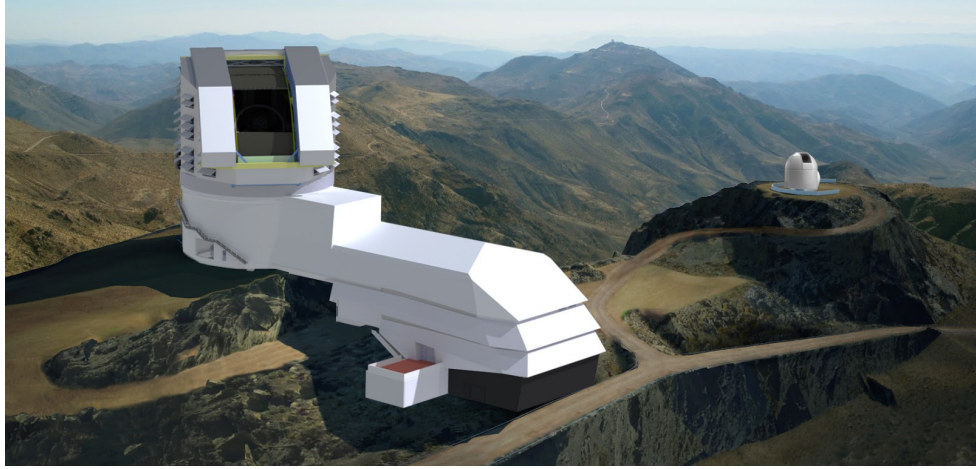
EARLY FOLLOW-UP, CONTINUED

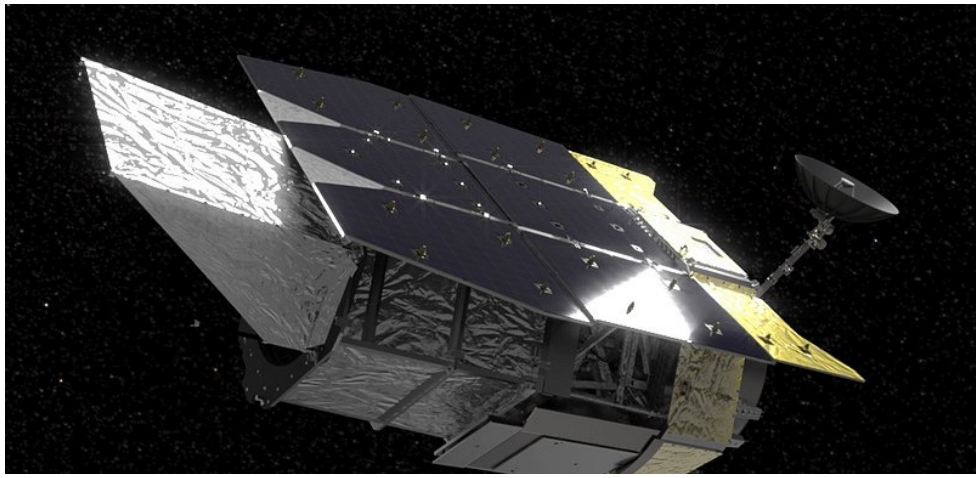
- Another example of a star in our program. The Fourier metallicity from the lightcurve parameters is [Fe/H]=-1.04, but our inferred spectroscopic metallicity is [Fe/H]=-1.73.
- The Parallax precision is only 17%, but that will eventually tighten as Gaia DR3 (34 months of data) yields to Gaia DR4 (66 months) and then Gaia DR5 (120 months).



WHAT WE WILL BE ABLE TO DO WITH RUBIN, ROMAN, AND UVEX

- Each of these three surveys will be able to image RR Lyrae to the ends of the Local Group and beyond. The different colors will constrain the metallicity and reddening to the RR Lyrae, and also constrain our understanding of stellar physics.
- Meanwhile, Gaia will eventually have 120 months of data on astrometry, photometry and spectroscopy.
- The UVEX sample, in particularly, will open a completely new discovery space.
- This panchromatic dataset, with its incredibly precise Milky Way anchor, will enable an exquisite calibration of the Local Group distance scale, reddening, and the chemodynamic substructure of the oldest stellar populations.





CONCLUSIONS

- RR Lyrae stars, by virtue of being bright, numerous, and representative of old stellar populations, have great potential as standard candles and standard crayons to trace the Local Group's distance scale – and substructure.
- We can already do much better with Gaia DR3 and medium-sized spectroscopic facilities … now is the time to derive the best calibrations we can given the upcoming deluge of spectacular data from Rubin, Roman, UVEX, and even Gaia DR5.
- Our own survey (Nataf, Reggiani, Kunder, & Wyse) will improve the calibration in the relationship between metallicity, light curve shape, and luminosity.