# Metallicity Distribution Function for Three Local Group Dwarf Galaxies


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## Abstract


**We present a preliminary metallicity distribution function (MDF) for Leo I, Phoenix, and IC 1613, derived from photometry with the Wide Field Camera 3 (WFC3) aboard the Hubble Space Telescope (HST).**

**We obtained relatively high signal to noise photometry in V (F555W), I (F814W) and Calcium H & K (F390M) filters for giants. Using the medium band filter that covers the Ca H & K lines – the strongest metal absorption lines in the visible spectrum – in conjunction with the V and I band photometry, we calculate the stellar metallicities of individual stars with an accuracy of approximately 0.2 dex.**

**While the metallicity accuracy in our study is lower than spectroscopic measurements, the large number of data points provides some advantages in looking for rarer components of the population and possible substructures.**

**From the photometric metallicities we construct a MDF for Leo I containing almost 4000 stars, 5 times more stellar metallicities than have been obtained from the ground. We measured 1500 stars for IC 1613, and almost 1000 stars for Phoenix. We only used stars with photometric errors < 0.05.**


## Data

**Leo I** is a dwarf spheroidal galaxy at a distance of 254 ± 17 kpc, with a V magnitude of -11.9. The majority of stars were formed between 1 and 7 Gyr ago (Gallart et al. 1999). Though more recent imaging of Leo I supports a much larger population of ancient stars ( >10 Gyr) as reported by Smecker-Hane 2009, Gallart did find some evidence for an older population of stars, which was backed up by Held et al. (2001) who found RR Lyrae stars in Leo I.

**IC 1613** is a one of the nearest gas rich dwarf irregular galaxies at a distance of 721 kpc with an absolute V magnitude of -14.6. The largest burst of star formation happened between 3 and 6 Gyr ago (Skillman et al. 2003), and SF is still occurring now as evidenced by OB associations and H II regions (Garcia et al 2010).

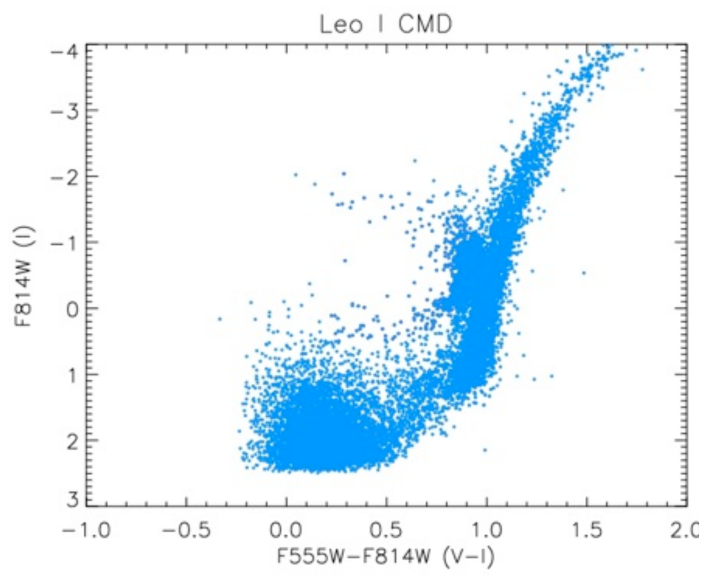
**Phoenix** is a transition galaxy that shows characteristics of both a dwarf irregular, and a dwarf spheroidal galaxy at a distance of 406 kpc with an absolute V magnitude of -10.1. There is no H I emission from Phoenix itself however, H I gas has been found 4.5' to 9' from the center (Young et al. 2007). The star formation has been ongoing, though decreasing; 50% of the stars were formed between initial galaxy formation and 10.5 Gyr ago, 35% of the stars between 10.5 and 6 Gyr, then an even lower SF rate continues to present (Hidalgo et al. 2009).

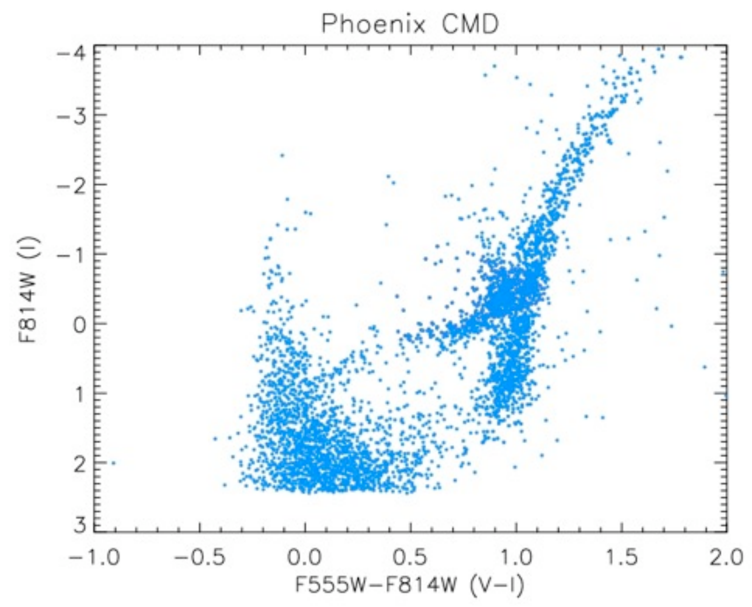
## Motivation

Dwarf galaxies are the simplest types of galaxies known and the most abundant, thus in studying their properties and evolution we gain valuable knowledge to apply to all galaxies. Current formation models argue that galaxies grow through merging events and gas accretion along cold filaments. The widely accepted bottom up formation scenario argues that dwarf galaxies are the building blocks for larger structures, so understanding how they formed and evolved may be key to understanding the larger structures we see today.

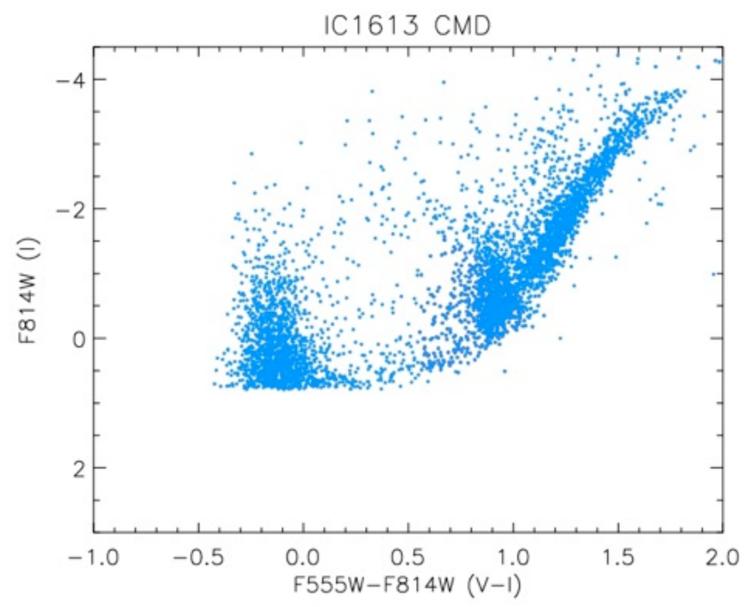
To first order metallicity distribution functions contain information on the star formation history of the galaxy. Star formation is dictated by the inflowing gas, via accretion, the outflowing gas due to supernova winds, and disturbing events such as tidal stirring, ram pressure stripping, and interaction with other galaxies. Thus much of the evolution of the galaxy is reflected in the rate of chemical enrichment, and the MDF.

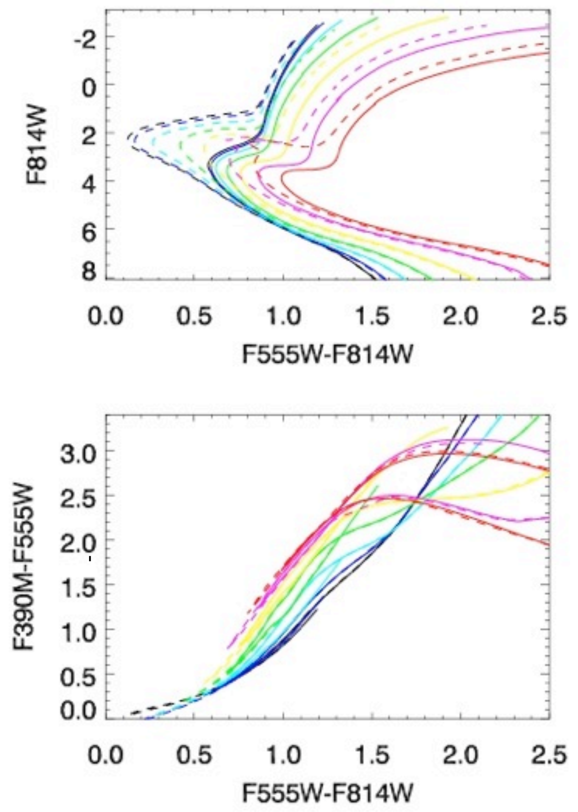
## Photometric Metallicities




Most dwarf galaxy composition studies are carried out spectroscopically; while photometric studies are less precise they offer greater advantages in number of stars surveyed, and in the time required to obtain the data. Most spectroscopic studies use hundreds of stars, while this photometric study resolves thousands of stars. The advantage of more stars means we populate rarer components of the MDF, such as very the metal poor tail of the distribution.




Each color represents a [Fe/H] in steps of 0.5, from -2.5 (black) to +0.5 (red). The solid line's are 12.5 Gyr while the dashed lines are 4 Gyr. The upper plot shows the isochrone tracks to be redder when older or more metal rich. The color-color plot (lower panel) shows the different aged isochrones following the same paths, leaving metallicity as the separating factor thus breaking the degeneracy.

Dwarf galaxies are not a single aged population, so we cannot directly relate fiducial ridge lines from GC's or Isochrones of known metallicity without first breaking the age - metallicity degeneracy. The degeneracy comes from the fact that a star may be redder either because it is older or because it is more metal rich. To address this issue we use color-color plots, namely (F390M-F555W) vs. (F555W-F814W) where (F390M-F555W) is sensitive to metallicity, while (F555W-F814W) is sensitive to temperature. The three color combination is independent of age and therefore breaks the degeneracy. The plot to the left demonstrates how we break the age- metallicity degeneracy using color- color plots.

We've calibrated the WFC3 filters using globular clusters M92, NGC104, NGC 6791, NGC 5927 and open cluster NGC 6752. Empirical corrections were derived from the CMD's. For ($m_{F555W}$ - $m_{F814W}$) vs. $m_{F814W}$ we found:

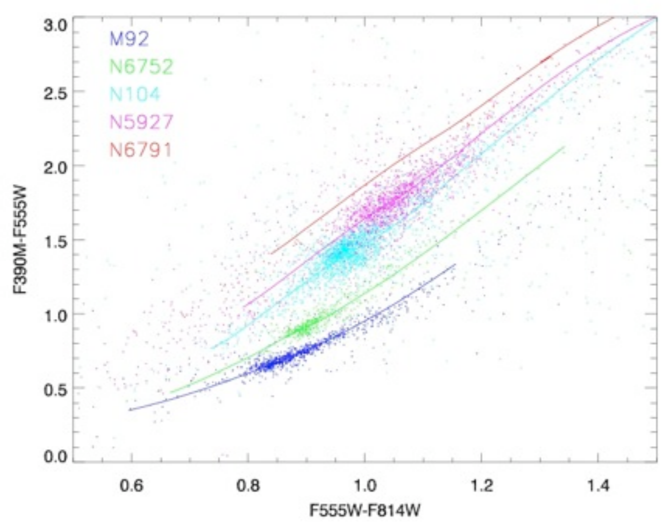
$$(m_{F555W} - m_{F814W})_{new} = 0.905*(m_{F555W} - m_{F814W})_{old} +0.07$$

To be consistent in the color - color plot correction we calibrated the ($m_{F390M}$ - $m_{F555W}$) vs. $m_{F814W}$ :

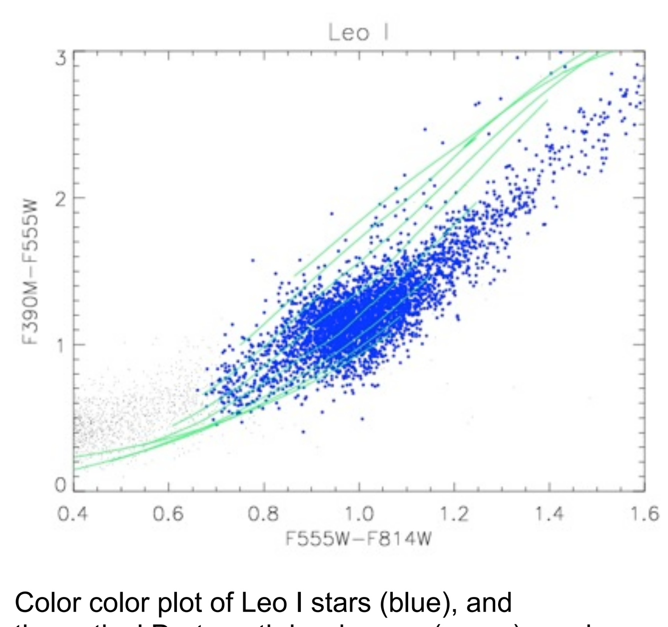
$$(m_{F390M} - m_{F555W})_{new} = 1.035*(m_{F390M} - m_{F555W})_{old} +0.04$$

The color - color plot to the right and above shows the corrected literature valued isochrones and the clusters of known metallicity.

The lower color-color plot is for Leo I with isochrones of [Fe/H] from -2.5 to +0.5. The color-color plots are used to assign metallicities to stars for each dwarf galaxy.

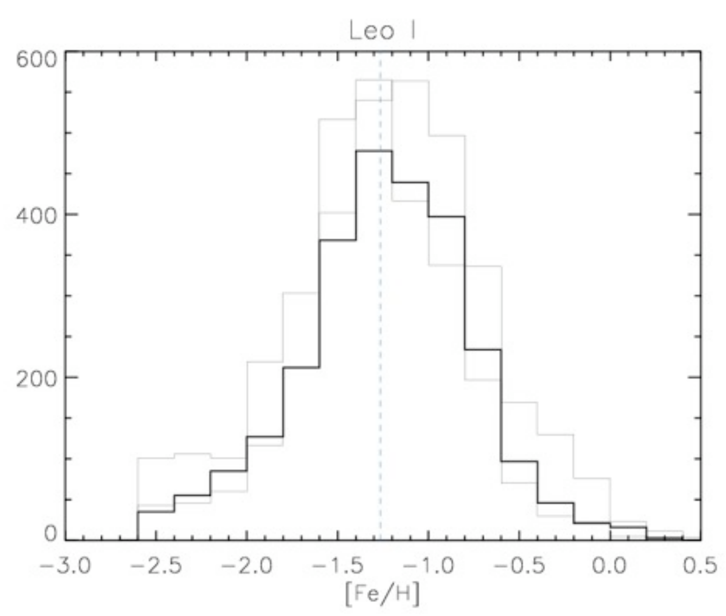


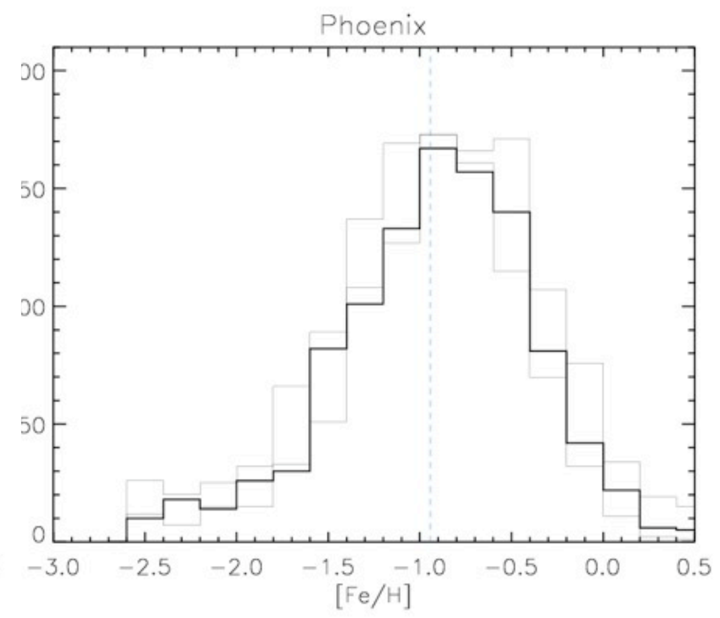

The color-color plot of the calibrating clusters [Fe/H] ranges from -2.25 to +0.3. Only giant branch stars have been plotted.




Color color plot of Leo I stars (blue), and theoretical Dartmouth isochrones (green) ranging from -2.5 < [Fe/H] < +0.5. Only stars with errors < 0.05 are shown

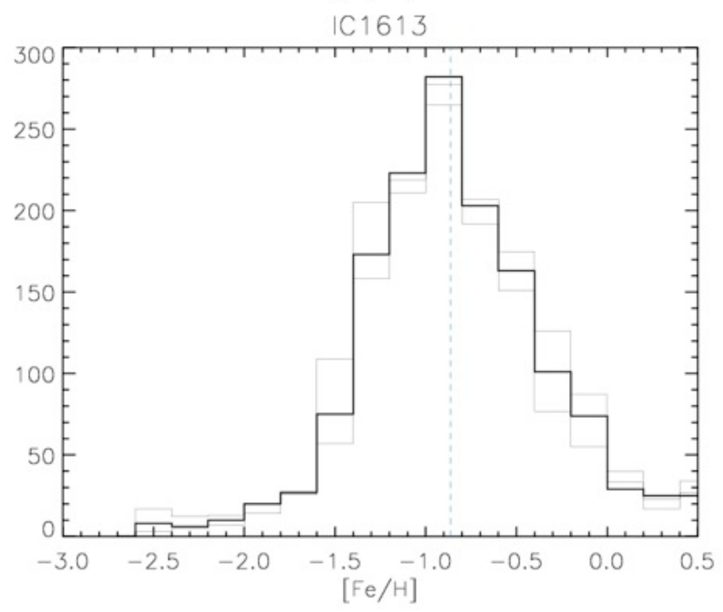
## Metallicity Distribution Function




Using 4306 stars from Leo I, we have produced a MDF peaked at [Fe/H] = -1.26. The MDF used bin sizes of 0.2 dex, to reflect the accuracy of the metallicity determination. The shape is nearly gaussian with a slightly extended tail on the metal poor end of the distribution. The isochrone grid did not extend below [Fe/H] = -2.5 therefore we cannot determine the extent of the metal poor tail.

Both the shape and peak are consistent with previous results by Kirby et al. (2009) who found a median [Fe/H] of -1.42 with a dispersion of 0.36 dex; Gullieuszik et al. (2009) found the mean metallicity to be [M/H] = -1.2 with a dispersion of 0.2 dex.




Leo I average [Fe/H] = -1.26 Fit with ~4000 stars

IC1613 average [Fe/H] = -0.86 Fit with ~1500 stars

Phoenix average [Fe/H] = -0.94 Fit with ~1000 stars

We found Phoenix has an average [Fe/H] of -0.94, more metal rich than the literature values of [Fe/H]= -1.37 (Martinez-Delgado et al. 1999) and ~ -1.7 (Holtzman et al. 2000). We are investigating further sources for this discrepancy.

In IC 1613 we found a [Fe/H] = - 0.77 which agrees with literature values of -0.67 +/- 0.09 (Tautvaisiene et al. 2007) who spectroscopically measured 3 supergiants. Skillman et al. 2003 who derived the SFH, found the oldest stars to have an [Fe/H] = ~-1.3 which evolves to [Fe/H] = ~-0.7 at present.

The metal poor tail is of particular interest since the presence of very metal poor stars may have bearing on the possibilities for dwarfs to have contributed to the halos of larger galaxies. However, the possibility of mis-assigning metallicities at the metal poor end is greater since the isochrones are closer together here, thus the errors in this region are higher than the rest of the MDF. Also the grids do not extend farther than [Fe/H] = -2.5, though we do see stars beyond the isochrone grid.

## Future work

We plan to run chemical evolution models for all our dwarf galaxies in order to constrain their star formation, gas inflow, and galactic winds. MDF's are useful when matched against analytical models of chemical evolution. The basic comparison provides a diagnostic measure of the gas as stars form. Chemical evolution models prescribe star formation rates and inflow and outflow rates which are related to galactic winds. Considering inflow and enrichment as vital to galaxy evolution, we can piece together the histories of the dwarf galaxies stars from trends seen in the chemistry

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