The Star Formation History of the Leo I dSph Galaxy

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Abstract

We report on results of new deep imaging obtained with the Hubble Space Telescope (HST) Advance Camera for Surveys (ACS) that show the Leo I dwarf Spheroidal (dSph) galaxy has a much larger population of ancient (>10 Gyr old) stars than previously determined with shallower WFPC2 imaging (Gallart et al. 1999, Dolphin 2003), as well as the previously identified component of intermediate-aged stars. Our new imaging is much deeper , which allows us to unambiguously identify the main sequence turnoffs of the ancient population and constrain the star formation rate at the epoch of the formation of the "first stars" in this galaxy. We will determine the galaxy's star formation rate (SFR) as a function of time from the observed density of stars in the color-magnitude diagram (CMD) by comparing with Padova stellar evolutionary models (Girardi et al. 2000). We compare and contrast the star formation histories of the Leo I dSph, which is currently devoid of any gas, with that of the gas-rich Leo A dIrr galaxy, noting that the two are very different.

The Data

We obtained images of our primary field, located near the center of Leo I, using the ACS Wide Field Channel on the Hubble Space Telescope in Jan-Feb of 2006-07. The ACS field covers 3.6' x 3.6'. We obtained 3.3 hrs integration time in the F435W (B) filter and 3.2 hrs in the F814W (I) filter.

In order to facilitate going deep in the blue, we specified that the observations occur when Leo I was in the Earth's shadow. We encountered problems with the pointing of HS, and we had to postpone observations until the next year. However ACS died two days before our scheduled second set of observations. We quickly retooled and mosaiced our primary field with an additional 1.4 hours of integration in each of two pointings with WFPC2 in the F450W filter, which is close but not identical to the ACS F435W filter. We will have plenty of secondary standards in our fields in order to accurately calibrate these to B magnitudes.

Photometry & Results

- ❑ Standard ACS/WFPC2 data reductions were performed on the images.
- ❑ Profile-fitting photometry was performed with DAOPHOT II/ALLFRAME (Stetson 1987, Stetson 1994)
- ❑ Photometry was calibrated to standard B,I magnitudes using bright stars previously observed by Stetson (2008, private communication).
- ❑ The observed CMD containing 170,000 stars from the ACS data is shown in Figure 1.
- ❑ For comparison, a simulated CMD, created by assuming the SFR derived from previous WFPC2 CMD analysis (Dolphin 2002; shown in Figure 4) and our expected photometric errors and completeness is shown in Figure 2.
- ❑ For comparison, the recently observed CMD from Leo A, a dwarf irregular galaxy, from the LCID collaboration is shown in Figure 3. Note that the filters used were not identical to those used for the Leo I dSph.

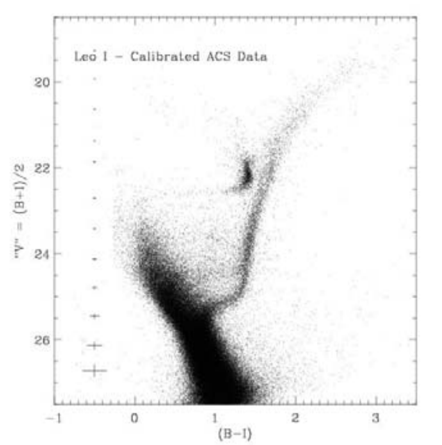

Figure 1. Observed CMD for the Leo I dSph created from our new ACS observations in the F435W and F814W filters. Note the prominence of the main-sequence turnoff for ages >10 Gyr, and the obvious structure in the MSTO region signifying changes in the SFR.

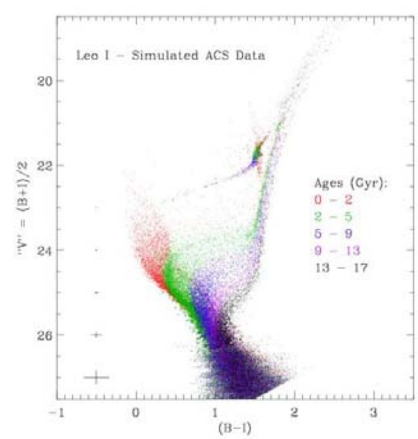

Figure 2. Simulated CMD for the Leo I dSph assuming the SFR shown in Figure 4 and an age−metallicity relationship that was constant at [Fe/H]=−1.35 until 3.5 Gyr ago when it began to rise to reach [Fe/H]=−1.0 when star formation stopped.

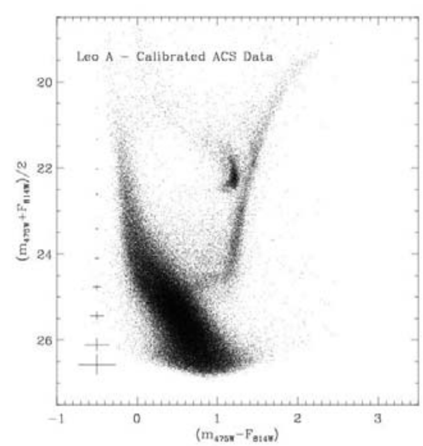

Figure 3. Observed CMD for the dwarf irregular galaxy Leo A, which shows only a small fraction of ancient stars, and a pronounced peak in the SFR for ages < 8 Gyr ago (Cole et al. 2007).

Deriving the SFR

❑ By comparing the density of stars in the observed CMD to predictions from Padova stellar evolutionary models (Girardi, et al. 2000), we will derive the SFR from 0.5 to 14 Gyr ago in Leo I with unprecedented accuracy.

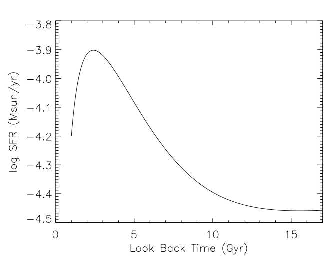

Figure 4. The star formation rate assumed in the creation of the simulated CMD for the Leo I dSph shown in Figure 2, based on the SFR derived from existing WFPC2 photometry (Gallart, et al. 1999, Dophin 2002).

Conclusions & Discussion

- ❑ The large percentage of stars on the ancient (>10 Gyr) main-sequence turnoffs of Leo I was very unexpected, based on the analysis of the earlier WFPC2 CMDs which concluded that most of the stars formed < 7 Gyr ago. Although this dSph did form stars up until quite recently, ending only ~0.5 Gyr ago, it did experience a high rate of star formation at early epochs, 10-14 Gyr ago.
- ❑ The CMDs show that the Leo I dSph and the Leo A dIrr had very different SFRs despite their similar luminosities.
  - Leo I dSph: d = 250 kpc, $M_V = -11.9$ mag, no HI gas
  - Leo A dIrr: d = 690 kpc, $M_V = -11.4$ mag, HI rich
- ❑ The Leo I dSph had a high rate of star formation early on, ~10-14 Gyr ago, while the Leo A dIrr formed only a small fraction of stars
- ❑ Both galaxies show very little evidence of metallicity enrichment; the age-metallicity relationships are very flat based on the CMD analysis and earlier spectroscopy of red giant stars (Bosler, et al. 2007, Koch et al. 2007).
- ❑ Our discovery of a large fraction of ancient stars in Leo I helps explain the high numbers of RR Lyrae stars detected by Held et al. (2001).

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