# Delving Deeper into the Tumultuous Lives of Galactic Dwarfs: Modeling Star Formation Histories

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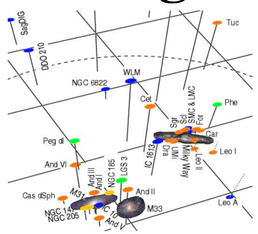
## Missing Satellites Problem

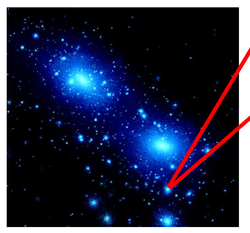



Map of Galaxies in the Local Group

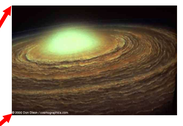
N-body Simulation of Local Group

- The number of observed dwarf galaxies in the Local Group (left) is orders of magnitude fewer than the expected number of dark matter subhalos and mini-halos from N-body simulations (right).
- This discrepancy can be explained through the suppression of gas accretion onto low-mass halos in the early universe (e.g. Gnedin 2000) and through mass stripping from "tumultuous" gravitational interactions (Kravtsov, Gnedin & Klypin 2004; hereafter KGK04).
- In this work we build off of and extend the KGK04 model and compare the predictions of these semi-analytic models to new data.

## Forming Stars in N-body Simulations



Dark Matter Dynamics



Analytic Gas Disk

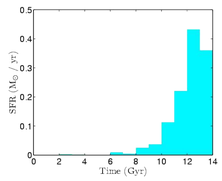
$\Sigma_g(r) = \Sigma_o \exp(-r / r_d)$

= Gas Surface Density

Star Formation Rate

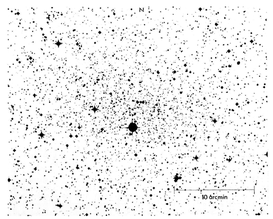
$\dot{\Sigma}_*(r) \sim \Sigma_g^{1.4}$

$SFR(t) = \dot{\Sigma}_* \times Area$

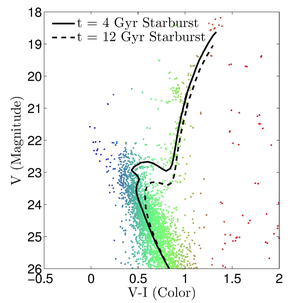


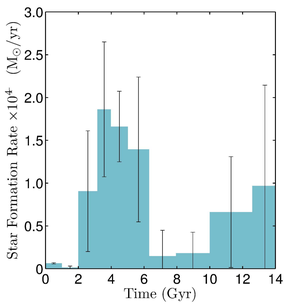

## New Data!

There now exists well-measured star formation histories (SFHs) for most of the Local Group dwarfs. These are obtained through isochrone fitting to deep color-magnitude diagrams.

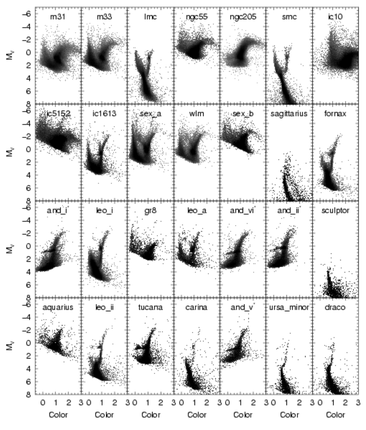


Carina Dwarf Image




## A Local Group SFH census




(Holtzman, Afonzo & Dolphin 2006)

Star Formation Histories of Satellite Galaxies of MW and M31

| Galaxy | Alternate Name | Type | Host | $r_{host}$ (kpc) | $\log(M_*/M_\odot)$ | $f_{1G}$ | $f_{2G}$ | $f_{5G}$ | $f_{10G}$ | $\tau$ (Gyr) |
|---|---|---|---|---|---|---|---|---|---|---|
| M33 | NGC598 | Sc | M31 | 203 | 9.9 | 0.093 | | | 0.52 | 8.4 |
| LMC | | Irr | MW | 50 | 9.7 | 0.078 | 0.17 | 0.42 | 0.70 | 6.7 |
| SMC | | Irr | MW | 63 | 9.2 | 0.096 | 0.18 | 0.48 | 0.65 | 6.6 |
| M32 | NGC221 | dE | M31 | 6 | 9.1 | 0.042 | | | 0.50 | 8.5 |
| NGC205 | M110 | dE | M31 | 58 | 9.0 | 0.0049 | 0.0050 | 0.055 | 0.48 | 10.5 |
| IC10 | | dIrr | M31 | 255 | 8.7 | 0.060 | 0.14 | 0.52 | 0.75 | 7.1 |
| NGC6822 | | dIrr | MW | 500 | 8.7 | 0.087 | 0.16 | 0.57 | 0.68 | 6.9 |
| NGC3109 | | dIrr | MW | 1360 | 8.7 | 0.054 | 0.065 | 0.084 | 0.12 | 11.1 |
| NGC185 | | dSph | M31 | 175 | 8.6 | 0.0053 | 0.0053 | 0.090 | 0.51 | 10.5 |
| NGC147 | | dSph | M31 | 101 | 8.4 | 0.032 | 0.036 | 0.050 | 0.17 | 12.4 |
| IC1613 | | dIrr | M31 | 505 | 8.3 | 0.059 | 0.11 | 0.42 | 0.64 | 7.7 |
| WLM | DDO221 | dIrr | M31 | 840 | 8.2 | 0.14 | 0.35 | 0.55 | 0.69 | 6.7 |
| Sex B | DDO70 | dIrr | MW | 1320 | 8.2 | 0.049 | 0.067 | 0.11 | 0.21 | 11.1 |
| Sex A | DDO75 | dIrr | MW | 1440 | 7.9 | 0.15 | 0.29 | 0.38 | 0.41 | 9.3 |
| Sagittarius | | dSph | MW | 28 | 7.7 | 0.0008 | 0.0008 | 0.52 | 0.86 | 6.5 |
| Fornax | | dSph | MW | 138 | 7.5 | 0.013 | 0.059 | 0.33 | 0.73 | 7.4 |
| UGC4879 | VV124 | dIrr | MW | 1100 | 7.3 | | | | | |
| Pegasus | DDO216 | dIrr | M31 | 410 | 7.2 | 0.057 | 0.095 | 0.40 | 0.64 | 7.4 |
| UGCA92 | EGBJ427+63 | dIrr | MW | 1300 | 7.2 | | | | | |
| Sag DIG | ESO594-4 | dIrr | MW | 1060 | 7.1 | 0.11 | 0.17 | 0.20 | 0.20 | 11.6 |
| AndVII | Cassiopia dSph | dSph | M31 | 216 | 7.1 | 0.016 | 0.022 | 0.022 | 0.025 | 12.9 |
| AndII | | dSph | M31 | 48 | 7.1 | 0.0038 | 0.0098 | 0.087 | 0.67 | 8.9 |
| AndII | | dSph | M31 | 160 | 7.0 | 0.0049 | 0.0086 | 0.076 | 0.50 | 9.2 |
| AndVI | Pegasus dSph | dSph | M31 | 266 | 6.9 | 0.0023 | 0.023 | 0.19 | 0.60 | 9.0 |
| Leo A | DDO69 | dIrr | MW | 800 | 6.8 | 0.13 | 0.31 | 0.65 | 0.78 | 6.2 |
| Antlia | | dSph | MW | 1330 | 6.8 | 0.043 | | | 0.43 | 9.0 |
| LeoI | DDO74 | dSph | MW | 270 | 6.8 | 0.0099 | 0.18 | 0.50 | 0.76 | 6.4 |
| Aquarius | DDO210 | dIrr | MW | 950 | 6.7 | 0.037 | 0.083 | 0.12 | 0.12 | 12.0 |
| AndIII | | dSph | M31 | 68 | 6.5 | 0.0022 | 0.0061 | 0.10 | 0.47 | 9.8 |
| Cetus | | dSph | M31 | 680 | 6.4 | 0.0045 | 0.013 | 0.17 | 0.52 | 9.9 |
| LGS3 | Pisces | dIrr | M31 | 284 | 6.3 | 0.015 | 0.046 | 0.16 | 0.43 | 9.8 |
| LeoII | DDO93 | dSph | MW | 205 | 6.3 | 0.0028 | 0.012 | 0.025 | 0.70 | 8.8 |
| Phoenix | | dIrr | MW | 405 | 6.3 | 0.027 | 0.071 | 0.23 | 0.42 | 10.3 |
| Sculptor | | dSph | MW | 88 | 6.3 | 0.010 | 0.016 | 0.026 | 0.14 | 12.6 |
| Tucana | | dSph | MW | 870 | 6.2 | 0.0048 | 0.011 | 0.014 | 0.30 | 11.6 |
| AndXV | | dSph | M31 | 170 | 6.2 | | | | | |
| AndXVI | | dSph | M31 | 270 | 6.1 | | | | | |
| Sextans | | dSph | MW | 86 | 6.1 | 0.00 | 0.00 | 0.00 | 0.00 | 12.0 |
| AndV | | dSph | M31 | 117 | 6.0 | 0.0045 | 0.048 | 0.066 | 0.35 | 10.8 |
| Carina | | dSph | MW | 94 | 6.0 | 0.0065 | 0.0077 | 0.43 | 0.67 | 7.1 |
| Draco | DDO208 | dSph | MW | 79 | 5.9 | 0.0004 | 0.010 | 0.025 | 0.49 | 10.9 |
| Ursa Minor | DDO199 | dSph | MW | 69 | 5.9 | 0.00 | 0.00 | 0.00 | 0.00 | 12.0 |
| AndX | | dSph | M31 | 110 | 5.9 | | | | | |
| AndXIV | | dSph | M31 | 162 | 5.8 | | | | | |
| AndXVII | | dSph | M31 | 44 | 5.8 | | | | | |
| AndIX | | dSph | M31 | 45 | 5.7 | | | | | |

(Orban et al. 2008 − arXiv:0805.1058)

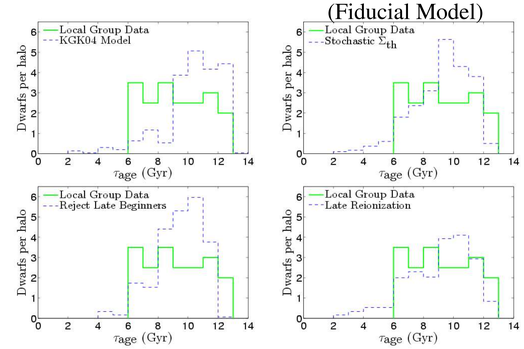
SFH data summarized by

$f_{xG}$ = fraction of stellar mass formed in last x Gyr

$\tau_{age}$ = mean age of the stellar population

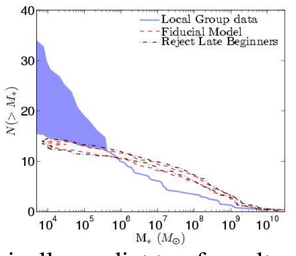
## Results

(Fiducial Model)




- KGK04 model (top left) needs much more late-time SF; adding stochasticity to the minimum density threshold (top right) largely fixes this problem.
- Changing the reionization scenario (bottom right) makes little difference in the predicted SFHs.
- Models generically predict a small population of anomalously young dwarfs.

## Ultra-Faint Dwarf Projections




- Models generically predict too few ultra-faint dwarfs.
- Brighter dwarfs are typically too massive (in stars), however, models do not include supernovae feedback or winds.

## Acknowledgments

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