Two Distinct Populations in Dwarf Spheroidal Galaxies

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Sagittarius Dwarf Galaxy (HST, NASA, ESA)

Two Distinct Ancient Populations in the Sculptor Dwarf Spheroidal Galaxy


• The First Result from DART (Dwarf Abundances and Radial velocity Team)

Spatial Distribution of BHB and RHB Stars in the Sculptor dSph
Radial Metallicity Gradient of RGBs

Kinematical Properties of Scl dSph Stars

metal-rich
metal-poor
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• The Sculptor dSph contains two distinct stellar components, one metal-rich, 
  
$-0.9 > [\text{Fe/H}] > -1.7$,

and one metal-poor, 

$-1.7 > [\text{Fe/H}] > -2.8$.

• The metal-rich population is more centrally concentrated than the metal-poor one, and on 
  average appears to have a lower velocity dispersion \( \sigma = 7 \pm 1 \text{ km/s} \), whereas metal-poor 
  stars have \( \sigma = 11 \pm 1 \text{ km/s} \).

What Mechanism Can Create Two Ancient Stellar Compositions in a Small dSph Galaxy?

• The formation of these dSph galaxies began with an initial burst of star formation, resulting in a stellar population with a 
  mean \([\text{Fe/H}] < -2\). Subsequent supernovae explosions would have been sufficient to cause gas and metal loss such that star 
  formation was inhibited until the remaining gas could sink deeper into the center and begin star formation again (Mori et 
  al. 2002).

• Another possible cause is external influences, such as minor 
  mergers, or accretion of additional gas at later epoch.

• Events surrounding the epoch of re-ionization strongly 
  influenced the evolution of these small galaxies and resulted in 
  stripping of photo-evaporation of the outer layers of gas in 
  the dSph galaxy, meaning that the subsequent more metal-
  enhanced star formation occurred only in the central regions 
  (Susa & Umemura 2004).
Origin of Two Distinct Populations in Dwarf Spheroidal Galaxies

Hierarchical Growth (DM=287,491, gas=233,280)

Kawata, Arimoto, Cen & Gibson (2006)

Galactic Chemodynamics Code (GCD+)


• Three dimensional tree N-body/smoothed particle hydrodynamics (SPH) code which incorporates
• Self-gravity,
• Hydrodynamics,
• Radiative cooling,
• Star formation,
• Supernovae feedback,
• Metal enrichment by SNeII and SNe Ia,
• Mass-loss from intermediate mass stars,
• Chemical enrichment history of gas and stars.
Evolution of the distribution of the dark matter (top), gas density (2nd), and K-band observed frame luminosity (bottom).

Evolution of the distribution of the gas density (top), the gas temperature (2nd), the iron abundance of gas (3rd).
Although some minor mergers are involved, the system is forming through the smooth accretion.

No Star Formation at $z < 5.9$ due to re-ionization and/or galactic wind. SNe feedback has a strong effect on the gas dynamics, and continuously blows out the gas from the system. Continuous gas accretion, however, leads to further star formation but with low rate.

Metallicity Distribution

G-dwarf problem

Sculptor dSph

Fornax dSph

$r < 0.25$ kpc

$r > 0.25$ kpc
Strong Radial Metallicity Gradient

The MDF for the inner (outer) region has a peak at \([\text{Fe/H}] \approx -1.4\) (\([\text{Fe/H}] \approx -1.9\)). We find this is just due to the metallicity gradient in the simulated system.

Velocity Dispersion Profile

Within the radius of about 0.6 kpc, the metal poor population have larger velocity dispersion than the metal rich one.
Our simulation demonstrates that a system formed at a high redshift can reproduce the two stellar populations whose chemical and dynamical properties are distinctive.

**Caveats**
- In the observational data, there are no stars at $[\text{Fe/H}]<-2.8$, while the simulated galaxy has a significant fraction of stars with such low metallicity (G-dwarf problem).
- The velocity dispersion of our simulated galaxy is too small compared with the observed values.
- The V-band magnitude of the simulated galaxy ($M_v=-7.23$) is also small compared with the Sculptor dSph ($M_v=-10.7$).

However, Tolstoy (2005) astro-ph, 0506481

Star formation stopped at <1Gyr, well before SNeIa started to contribute significantly.

Scatter is very large, indicating a serious problem of the current chemical evolution model in the particle based simulation.
Role of Intermediate Mass Stars

The enriched gas is blown out at a high redshift around $z=17$, due to a strong feedback by SNeII and relatively shallow potential of subgalactic clumps. As a result, the chemical enrichment by the massive stars becomes less important and the enrichment from intermediate mass stars ($4$-$8M_\odot$) becomes important.

In the simulation dwarf spheroidals formed via hierarchical clustering, but stars formed from cold gas and stars at the galaxy center tend to form from metal-enriched infall gas, which builds up the metallicity gradient. Infalling gas has larger rotational velocity and small velocity dispersion.