Study of the Star Formation History and Dust Production Rate of And IX, the Closest Satellite to Andromeda

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Abstract

We studied the evolution of the And IX, one of the metal-poor dSph satellites of M31, using the Isaac Newton Telescope (INT) in two filters, Sloan (i′) and Harris (V). We selected cool and luminous asymptotic giant branch (AGB) stars as easily detectable and reliable indicators of star formation history (SFH) in the galaxy. And IX with a distance modulus of $\sim 24.56^{+0.05}_{-0.15}$ mag ($\sim 816.58^{+19.02}_{-54.50}$ kpc) is quenched $\sim 3.65^{+0.13}_{-1.52}$ Gyr ago with SFR in the order of 0.0002 $M_\odot yr^{-1}$ at redshift < 0.5. We deduced the outside-in galaxy formation scenario by comparing the young and old populations in different radii from the center of And IX. The mass-loss rate for 50 long-period variables (LPV) candidates within two half-light radii with amplitude > 0.2 mag are also estimated by employing the spectral energy distribution (SED) fitting in the range of $10^{-7} \leq \dot{M} \leq 10^{-5}$ $M_\odot yr^{-1}$. The total mass deposition to the interstellar medium (ISM) is $\sim 2.4 \times 10^{-4}$ $M_\odot yr^{-1}$ ($Z = 0.0001$), 1.5×10^{-4} $M_\odot yr^{-1}$ ($Z = 0.0002$), and 1.0×10^{-4} $M_\odot yr^{-1}$ ($Z = 0.0003$) from the C- and O-rich type of dust-enshrouded LPVs. As carbon stars account for 80% of mass return rates in three metallicities, the majority of dust entering the ISM comes from carbon stars. It is estimated that the mass-loss of LPVs in about a billion years could enrich the ISM and revive star formation in the galaxy by estimating the specific mass-loss rate as the total mass return by the total stellar mass. Additionally, we calculate the total stellar mass by integrating the SFRs within two half-light radii $\sim 3.0 \times 10^5$ $M_\odot$ ($Z = 0.0001$), 2.4×10^5 $M_\odot$ ($Z = 0.0002$), and 2.3×10^5 $M_\odot$ ($Z = 0.0003$).

Summary of procedures

- **Reduction** by THELI (Transforming HEavenly Light into Image)
- **Photometry** by DAOPHOT/ALLSTAR package [4]
- **Variable selection** by Stetson variability index (L) estimation routine [3]
- **SFH** by calculation of SFR in different age bins [1, 2]
- **Mass-loss rate estimation** by SED fitting through DUSTY package

Spatial distribution of And IX variable candidates

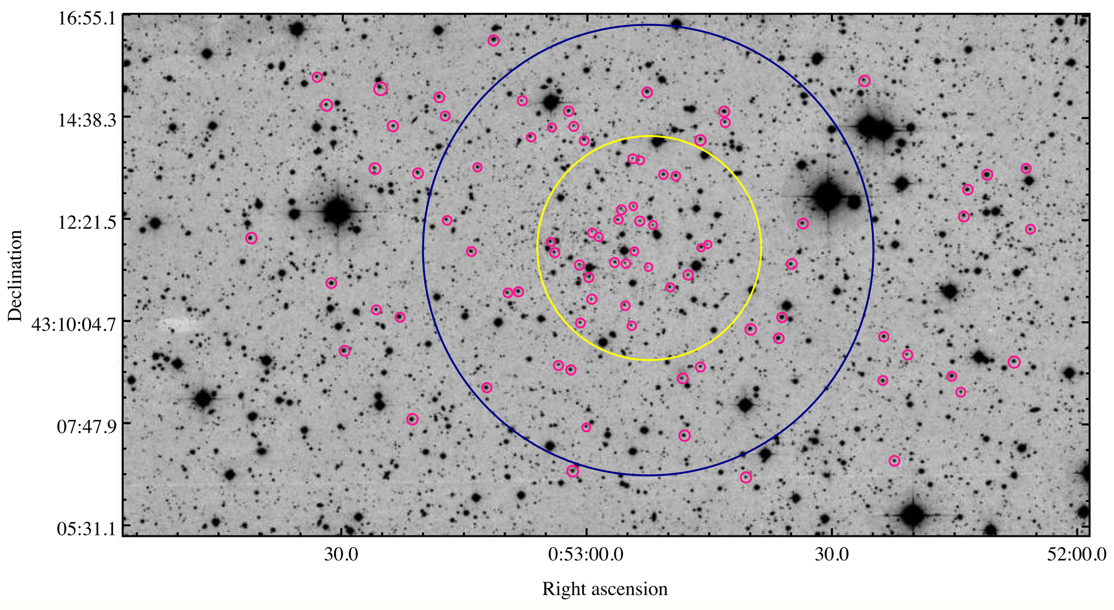

Figure 1: And IX dSph galaxy with variable candidates in pink circles. $r_h \sim 2.5$ arcmin (yellow circle) and $2r_h$ (blue circle).

Evolution of And IX

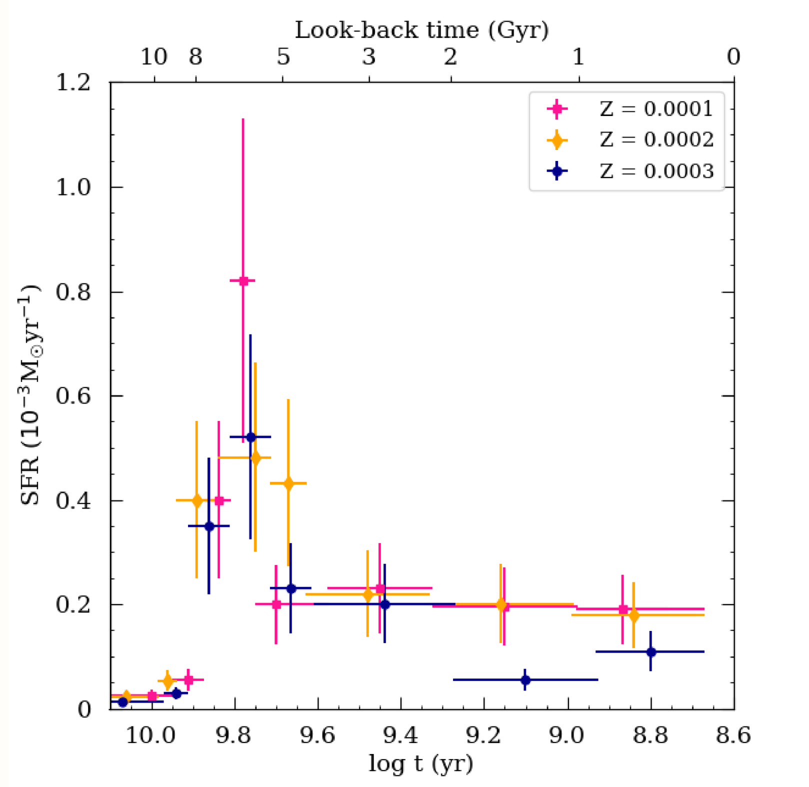

Figure 2: SFRs within two half-light radii of And IX.

SED fitting

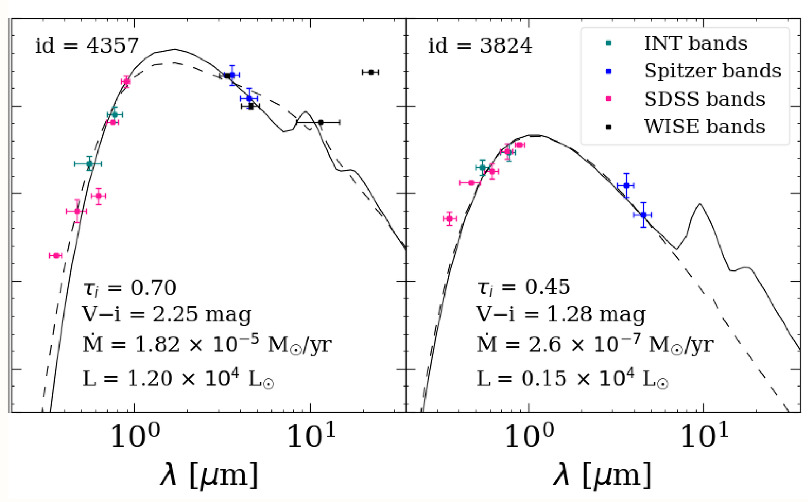

Figure 3: SEDs with the best fit of the C- and O-rich (dashed and solid black lines) flux.

Mass-loss *vs.* luminosity

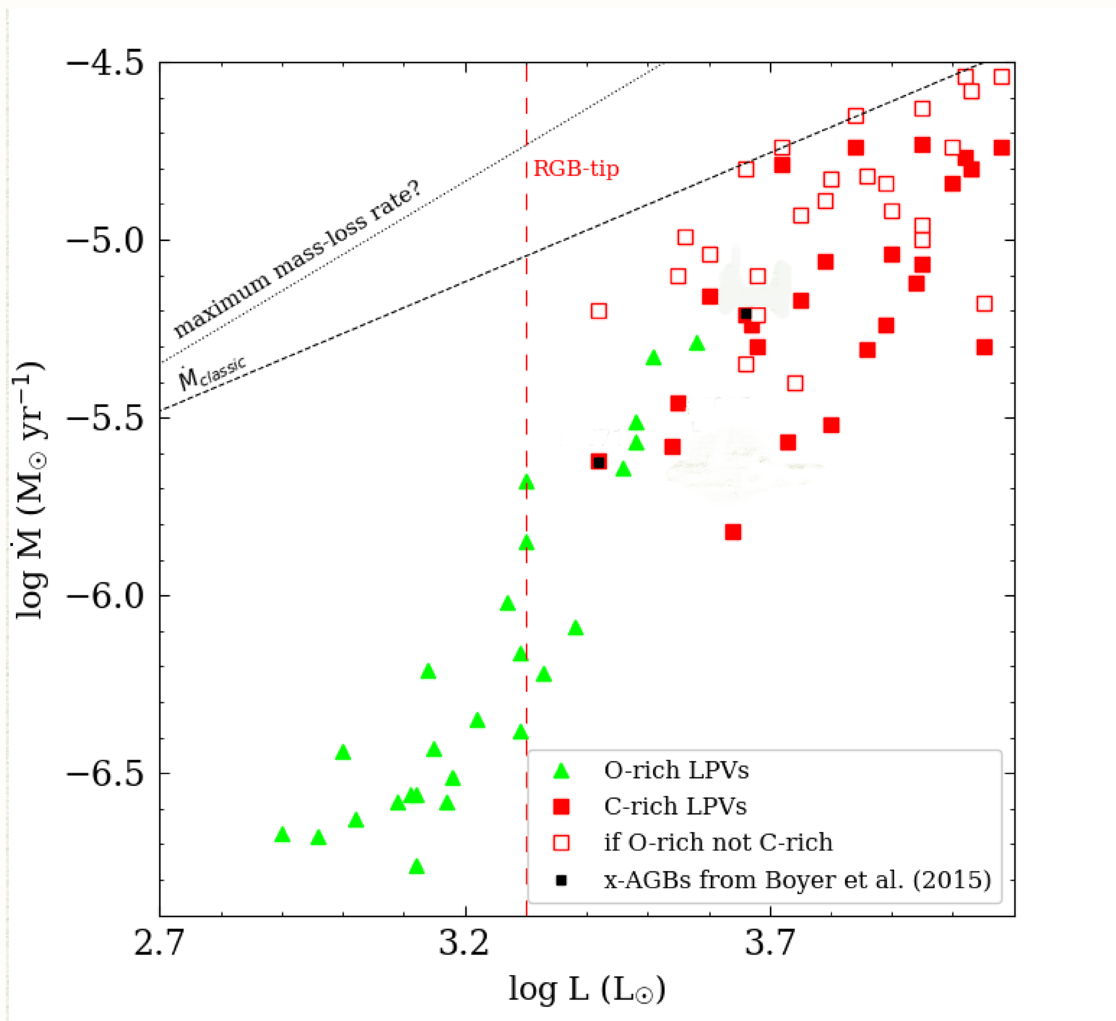

Figure 4: Mass-loss rate as a function of luminosity for C-rich (red squares) and O-rich (green triangles) LPVs within two half-light radii of And IX. The open red squares show the results if the carbon stars are assumed instead to be O-rich.

Summary

Metallicity	1×10^{-4}	2×10^{-4}	3×10^{-4}
M_{Total} (10^6 $M_\odot$)	0.30	0.24	0.23
$\dot{M}_{Total}$ (10^{-4} $M_\odot$/yr)	2.4	1.5	1.0
SFR_{max} (10^{-4} $M_\odot$/yr)	8.2 ± 3.1	4.8 ± 1.8	5.2 ± 2.0
t_{90} (Gyr)	$3.65^{+0.13}_{-1.52}$	$3.29^{+0.97}_{-1.16}$	$3.07^{+1.00}_{-1.39}$
t_{50} (Gyr)	$7.02^{+0.39}_{-0.56}$	$6.15^{+0.77}_{-1.02}$	$6.10^{+0.36}_{-0.97}$

References

[1] Javadi A., van Loon J. T., Khosroshahi H. G., Tabatabaei F., Hamedani Golshan R., Rashidi M., 2017, MNRAS, 464, 2103
[2] Javadi A., van Loon J. T., Mirtorabi M. T., 2011b, MNRAS, 414, 3394
[3] Stetson P. B., 1996, PASP, 108, 851
[4] Stetson P. B., 1987, PASP, 99, 191