




Star Formation History of Two Fields in the Halo of NGC 5128

Sima T. Aghdam¹ , Atefeh Javadi¹ , Seyedazim Hashemi^{2,3},
Jacco Th. van Loon⁴, Habib Khosroshahi¹, Roya H. Golshan⁵,
Elham Saremi^{1,6,7} and Maryam Saberi⁸ 

¹School of Astronomy, Institute for Research in Fundamental Sciences (IPM), Tehran, 19568-36613, Iran

email: sima.t.ahdam@gmail.com

²Department of Physics and Astronomy, University of California Riverside, CA 92521, The USA

³Department of Physics, Sharif University of Technology, Tehran, 11155-9161, Iran

⁴Lennard-Jones Laboratories, Keele University, ST5 5BG, UK

⁵Physikalisches Institut der Universität zu Köln, Zùlpicher Str. 77, 50937, Köln, Germany

⁶Instituto de Astrofísica de Canarias, C/ Vía Lactea s/n, 38205 La Laguna, Tenerife, Spain

⁷Departamento de Astrofísica, Universidad de La Laguna, 38205 La Laguna, Tenerife, Spain

⁸Roseland Centre for Solar Physics, University of Oslo, P.O. Box 1029, Blindern, NO-0315, Oslo, Norway

Abstract. NGC 5128 galaxy is a giant elliptical galaxy located in the Centaurus group of galaxies at 3.8 Mpc. We aim to study the star formation history (SFH) of two different fields of the galaxy. The northeastern field (Field 1) is located at a distance of 18.8 kpc, while the southern field (Field 2) is at 9.9 kpc. We use a photometric method that is based on identifying long period variable (LPV) stars and asymptotic giant branch (AGB) stars, as they are strong tracers of star formation and galaxy evolution due to their luminosity and variability; 395 LPVs in Field 1 and 671 LPVs in Field 2 have been identified. These two fields present similar SFHs, although the SF rate of Field 2 is more enhanced. We find that the galaxy has three major star formation episodes $t \sim 800$ Myr ago, $t \sim 3.2$ Gyr ago, and $t \sim 10$ Gyr ago, where t is look-back time. The rate of star formation at ~ 800 Myr ago agrees with previous studies suggesting that the galaxy experienced a merger around that time. Furthermore, NGC 5128 has experienced a lower star formation rate in its recent history which could have been driven by jet-induction star formation and multiple outbursts of AGN activity in this galaxy, as well as a minor merger around 400 Myr ago.

Keywords. stars: AGB and LPV – stars: formation – galaxies: jets – galaxies: nuclei – galaxies: halos – galaxies: evolution – galaxies: star formation – galaxies: individual: NGC 5128

1. Introduction

There is no giant elliptical galaxy (GE) in the local group (LG), so to study the various features of GE galaxies, we must look at the nearest elliptical galaxy in other groups. NGC 5128 (or Centaurus A), with a distance of 3.8 Mpc ($\mu = 27.87 \pm 0.16$ mag; [Rejkuba et al. 2004a](#), and $E(B - V) = 0.15 \pm 0.05$ mag; [Rejkuba et al. 2001](#)) provides for us a distinctive opportunity to study the nearest GE galaxy ([Harris et al. 1999](#);

Charmandaris et al. 2000; Rejkuba 2004b; Rejkuba et al. 2005), located in the Centaurus group of galaxies (Karachentsev 2005).

We aim to find the SFH of two small fields in the halo of NGC 5128 using long period variable stars (LPVs) to better understand the relation between the SFH of the halo and likely recent merger. LPV stars are evolved asymptotic giant branch stars (AGBs) (e.g. Fraser et al. 2005, 2008; Soszyński et al. 2009) which are identified according to high luminosity (1000 to 60,000 L_{\odot}), as well as their variability (~ 100 to 1300 days). In addition, red supergiant (RSG) stars are massive stars with a mass up to $\sim 30 M_{\odot}$, known as a tracer of recent star formation (about 10 – 30 Myr) in the galaxy with a strong radial pulsation (Vassiliadis & Wood 1993; Javadi et al. 2011b; van Loon et al. 1999, 2005).

2. Data

We used the data that was obtained by the ISAAC near-IR imaging spectrometer at the ESO Paranal UT1 Antu 8.2m Telescope (VLT) in two different fields in the halo of the galaxy that were published by Rejkuba et al. (2003), which have been separated into two fields in the halo of the galaxy and identified as Field 1 and Field 2 by Rejkuba et al. (2001) and Rejkuba et al. (2003). Field 1 is on the distinguished north-eastern part of the halo, at a distance of ~ 18.8 kpc from the center of the galaxy whereas Field 2 is located at a distance of ~ 9.9 kpc from the center (Rejkuba et al. 2001). The detected evolved stars to investigate SFH are the LPV stars with periods longer than 70 days (from Rejkuba et al. 2003). Therefore, 395 and 671 LPVs are selected in Field 1 and Field 2, respectively.

3. Method

We used a method to study the SFH based on LPVs and it was developed by Javadi et al. (2011b) which was explained in the previous papers in details (M33: Javadi et al. 2011b, 2011c, 2016, 2017; LMC & SMC: Rezaei et al. 2014; NGC 147 & NGC 185: Hamedani Golshan et al. 2017; IC 1613: Hashemi et al. 2019; Andromeda VII: Navabi et al. 2021; Andromeda I: Saremi et al. 2021). In the first step, we should obtain mass, age, and pulsation duration of LPVs (the duration that stars are in the LPV phase) by applying Padova evolutionary models (Marigo et al. 2017) for various constant metallicities. Furthermore, for studying the star formation history of the galaxy, we consider $Z = 0.039$ (Woodley et al. 2010; Rejkuba et al. 2011). By assuming all mentioned parameters, the SFRs for different bins with specified intervals in age and mass as follows:

$$\xi(t) = \frac{dn'(t)}{\delta t} \frac{\int_{\min}^{\max} f_{\text{IMF}}(m)m \, dm}{\int_{m(t)}^{m(t+dt)} f_{\text{IMF}}(m) \, dm} \quad (3.1)$$

where m is mass, $f_{\text{IMF}}(m)$ is Kroupa initial mass function (IMF) (Kroupa 2001), dn' is the observed LPVs in each bin, and δt is the pulsation duration.

The statistical error bars for each bin come from the Poisson distribution:

$$\sigma_{\xi(t)} = \frac{\sqrt{N}}{N} \xi(t) \quad (3.2)$$

where N is the number of stars in each age bin.

Stellar evolution in the AGB phase causes that LPV stars inject dust into the interstellar medium (ISM). Therefore, the light from the LPVs will be detected with a fainter magnitude (Javadi et al. 2011b; van Loon et al. 1999, 2005). To correct the circumstellar extinction, we should do a de-reddened process by plotting the color-magnitude diagram and overlaying the theoretical isochrones by Marigo et al. (2017).

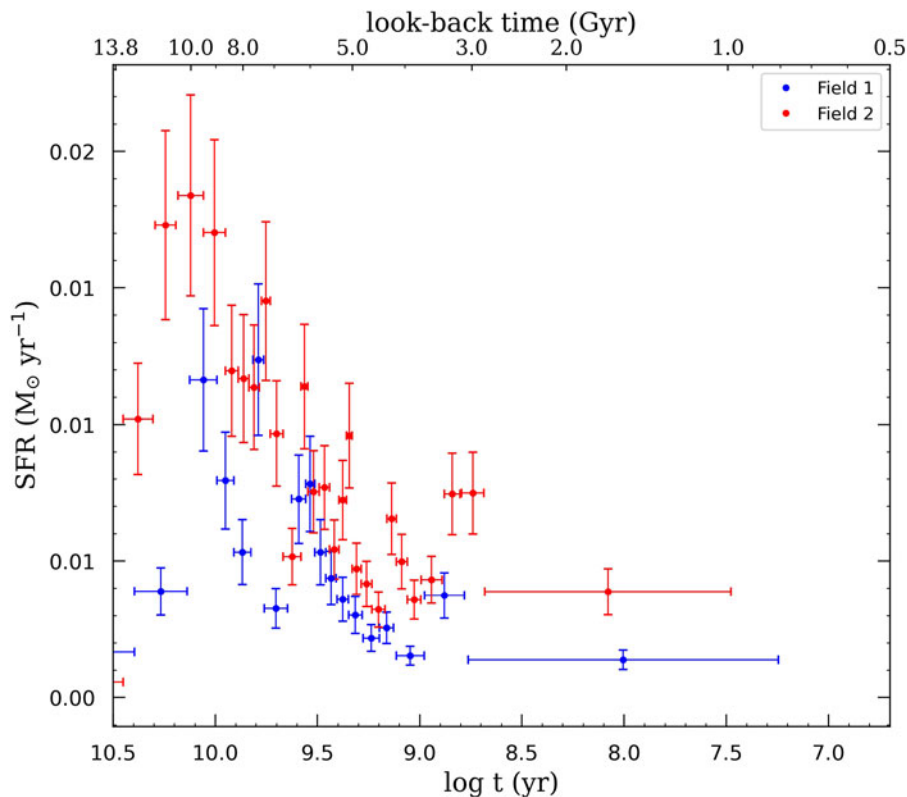


Figure 1. The SFH of Field 1 and Field 2 for $Z = 0.039$. *The blue* represents the SFH of Field 1, while *the red* one indicates the SFH of Field 2.

Furthermore, since NGC 5128 is a distant galaxy, it is unlikely to detect all of the LPVs in the galaxy. According to Rejkuba *et al.* (2003) study, they simulated variable stars by using 3 crucial parameters which are the mean magnitude of each star, period, and amplitude. By considering their simulation, we applied the detection probability of each star to our results. It should be noted that it is a key point in the presented method due to its dependency on the number of detected LPVs.

4. Results and Discussion

By considering metallicity $Z = 0.039$ and applying the probability functions, the SFHs of Field 1 and Field 2 are presented in Fig. 1. Despite being located in very different parts of the galaxy, these two fields have very similar SFHs, as well as the higher rates of star formation for Field 2. There is a similar supply of gas to stars during their evolution. In each field, the consistent patterns of SFRs is seen that are comparable for Field 1 and Field 2 in increasing in $\log t(\text{yr}) \sim 8.9$ ($t \sim 800$ Myr), $\log t(\text{yr}) \sim 9.5$ ($t \sim 3.2$ Gyr), and $\log t(\text{yr}) \sim 10$ ($t \sim 10$ Gyr) where t is look-back time.

Additionally, an increase in star formation in Field 1 and Field 2 around 800 Myr ago is consistent with the idea of recent merger of NGC 5128 with a small gas-rich galaxy (Israel 1998; Fassett & Graham 2000; Mould *et al.* 2000; Rejkuba *et al.* 2001). After $\log t(\text{yr}) \sim 8.5$, the rate of recent star formation stays constant according to the recent merger which happened around 400 Myr ago (Peng *et al.* 2002). Furthermore, NGC 5128 has experienced AGN activity based on the central supermassive black hole (SMBH). There

is an acceptable scenario leading to starbursts and AGN activity which is the interaction of gas-rich galaxies during mergers (Mo, Van den Bosch & White 2010).

References

- Charmandaris V., Combes F., van der Hulst J. M., 2000, *A&A*, 356, L1
- Fassett C. I., & Graham J. A., 2000, *ApJ*, 538, 594
- Fraser O. J., Hawley S. L., Cook K. H., Keller S. C., 2005, *AJ*, 129, 768
- Fraser O. J., Hawley S. L., Cook K. H., 2008, *Astron. J*, 136, 1242
- Hamedani Golshan R., Javadi A., van Loon J. Th., et al. 2017, *MNRAS*, 466, 1764
- Hashemi S. A., Javadi A., van Loon J. Th., 2019, *MNRAS*, 483, 4751
- Harris G. L. H., Harris W. E., Poole G. B., 1999, *Astron. J*, 117, 855
- Israel F., 1998, *A&A Rev.* 8, 237
- Javadi A., van Loon J. Th., Mirtorabi M. T., 2011a, *MNRAS*, 411, 263
- Javadi A., van Loon J. Th., Mirtorabi M. T., 2011b, *MNRAS*, 414, 3394
- Javadi A., van Loon J. Th., Mirtorabi M. T., 2011c, in: *Why Galaxies Care About AGB Stars II*, eds. F. Kerschbaum, T. Lebzelter & R. F. Wing, ASPC, 445, 497
- Javadi A., van Loon J. Th., Khosroshahi H., Mirtorabi M. T., 2013, *MNRAS*, 432, 2824
- Javadi A., van Loon J. Th., Khosroshahi H., 2016, *Memorie della Società Astronomica Italiana*, 87, 278
- Javadi A., van Loon J. Th., Khosroshahi H., et al., 2017, *MNRAS*, 464, 2103
- Karachentsev I. D., 2005, *Astron. J*, 129, 178
- Kroupa P., 2001, *MNRAS*, 322, 231
- Marigo P., Girardi L., Bressan A., et al. 2017, *ApJ*, 835, 77
- Mo H., Van den Bosch F., White S. D. M., 2010, *Galaxy formation and evolution*. Cambridge University Press
- Mould J. R., Ridgewell A., Gallagher J. S., et al. 2000, *ApJ*, 536, 266
- Navabi M., Saremi E., Javadi A., et al. 2021, *ApJ*, 910, 127
- Peng E. W., Ford H. C., Freeman K. C., White R. L., 2002, *Astron. J*, 124, 3144
- Rejkuba M., Minniti D., Silva D., Bedding T., 2001, *A&A*, 379, 781
- Rejkuba M., Minniti D., Silva D., 2003, *A&A*, 406, 75
- Rejkuba M., Greggio L., Zoccali M., 2004, *A&A*, 415, 915
- Rejkuba M., 2004, *A&A*, 413, 903
- Rejkuba M., Greggio L., Harris W. E., et al. 2005, *ApJ*, 631, 262
- Rejkuba M., Harris W. E., Greggio L., Harris G. L. H., 2011, *A&A*, 526, A123
- Rezaei Kh S., Javadi A., Khosroshahi H., van Loon J. Th., 2014, *MNRAS*, 445, 2214
- Saremi E., Javadi A., Navabi M., et al. 2021, *ApJ*, 923, 164
- Soszyński I., Udalski A., Szymański M. K., et al. 2009, *ACTA*, 59, 239
- van Loon J. Th., Groenewegen M. A. T., de Koter A., 1999, *A&A*, 351, 559
- van Loon J. Th., Cioni M.-R. L., Zijlstra A. A., Loup C., 2005, *A&A*, 438, 273
- Vassiliadis E., & Wood P. R., 1993, *ApJ*, 413, 641
- Woodley K. A., Harris W. E., Puzia T. H., et al. 2010, *ApJ*, 708, 1335