PROCEEDINGS OF SCIENCE

Re-examining the Gamma-ray Properties of Globular Clusters

Kwangmin Oh[*†]
The Department of Astronomy, Space Science and Geology, Chungnam National University, Daejeon 34134, South Korea
E-mail: min8582046@gmail.com

C. Y. Hui[‡]
The Department of Space Science and Astronomy, Chungnam National University, Daejeon 34134, South Korea
E-mail: cyhui@cnu.ac.kr

We have re-examined the properties of $\gamma-$ray emitting globular clusters (GCs) with the data obtained by Fermi Large Area Telescope in the past nine years. With an updated sample of 19 $\gamma-$ray GCs, we have performed a statistical analysis in the framework set by Hui et al. (2011) [1]. We confirm that the correlation between the $\gamma-$ray luminosities L_γ and the metalicity [Fe/H] is as significant as that between L_γ and the two-body encounter frequencies Γ_c. Correlations between L_γ and the energy densities of the soft photon field $u_{\mathrm{optical}}/u_{\mathrm{IR}}$ at location of the GCs have also been confirmed. With a two-dimensional regression analysis, we have revised the fundamental planes of $\gamma-$ray GCs which relate L_γ, [Fe/H]/Γ_c and $u_{\mathrm{optical}}/u_{\mathrm{IR}}$. The updated relations based on can provide better prediction of the $\gamma-$ray properties of GCs and support the scenario that the $\gamma-$ray emission is originated from the inverse Compton scattering (ICS) between the pulsar wind and the ambient soft photon fields [2].

7th Fermi Symposium 2017
15-20 October 2017
Garmisch-Partenkirchen, Germany

*Speaker.
†Oh Kwangmin is supported by BK21 PLUS Chungnam National University.
‡CYH is supported by the National Research Foundation of Korea grant 2016R1A5A1013277

PoS(IFS2017)106

1. Introduction

Globular clusters (GCs) are efficient factories for producing millisecond pulsars (MSPs) through dynamical formation processes [3]. As MSPs have been established as a new class of $\gamma-$ray emitters, it is not surprise that GCs also emit $\gamma-$ray emission [5]. The $\gamma-$ray properties of GCs have been examined in previous works (e.g. [1], [4]). Apart from the positive correlations for $L_\gamma - \Gamma_c$ and $L_\gamma-$[Fe/H] which are expected from scaling with the MSP population in a GC [3], correlations have also been found between L_γ and the energy densities of the soft photon field at location of the GCs. This supports the scenario that the $\gamma-$rays from GCs are originated from the inverse Compton scattering (ICS) between the pulsar wind and the ambient soft photon fields [2].

In the light of enlarged sample resulted from the uninterrupted observation with Fermi Large Area Telescope (LAT), it is timely to perform a statistical analysis to cross-check the results reported by [1] and, [4]. The results are reported in this paper.

2. Updated Sample

19 $\gamma-$ray GCs are adopted in our sample. They are collected from the 3FGL catalog [5] and Zhang et al. (2016) [6]. Their physical properties are summarized in Table 1. We have excluded NGC6624 and M28 from our sample as their $\gamma-$rays are dominated by a single MSP in the cluster (cf. [5] and the references therein). We have also excluded 2MS-GC01 in our analysis as there is no estimate of [Fe/H] for this GC.

For those $\gamma-$ray GCs reported in Tam et al. (2011) [7] but are excluded in the lists in [5] and [6] (e.g. Liller 1), we have performed searches for their $\gamma-$ray emission with nine years Fermi LAT data. However, we do not found any significant signal from these GCs and therefore they are also excluded in this work. Hence, our adopted sample is different from [6] which include all the GCs reported by [7] in their statistical analysis.

3. Statistical Analysis

In Figure 1, we show the relations between L_γ and four cluster parameters. We have also performed a non-parametric correlation analysis and the Spearman rank coefficients ρ and the corresponding $p-$values are given in each panel. We can see that both [Fe/H] and Γ_c are strongly correlated with L_γ. Although the significance is weaker, evidence for the correlations between L_γ and the ambient soft photon energy densities as suggested by [1] and [4] has also been confirmed.

We proceeded to perform the 2-D regression to obtained the updated fundamental plane relations, which are given as follows:

$$\log L_\gamma = (34.39\pm0.12) + (0.55\pm0.14)\log\Gamma_c + (0.55\pm0.22)\log u_{\rm optical}$$

$$\log L_\gamma = (34.78\pm0.16) + (0.58\pm0.15)\log\Gamma_c + (0.57\pm0.33)\log u_{\rm IR}$$

$$\log L_\gamma = (35.39\pm0.32) + (0.60\pm0.20)[\mathrm{Fe/H}] + (0.17\pm0.29)\log u_{\rm optical}$$

$$\log L_\gamma = (35.52\pm0.22) + (0.68\pm0.19)[\mathrm{Fe/H}] + (-0.07\pm0.40)\log u_{\rm IR}$$

The edge-on views of these relations are given in Figure 2.

Table 1: Properties of the Gamma-ray emitting GCs

Cluster Name	$d^{(\mathbf{a})}$ (kpc)	[Fe/H]$^{(\mathbf{a})}$	$\log\Gamma^{(\mathbf{a})}$	$\log u_{\rm IR}{}^{(\mathbf{b})}$ (eV cm^{-3})	$\log u_{\rm optical}{}^{(\mathbf{b})}$ (eV cm^{-3})	$\log L_\gamma{}^{(\mathbf{c})}$ (erg s^{-1})
47 Tuc	4.5	-0.72	0.67	0.22	0.81	$34.68^{+0.12}_{-0.13}$
Omega Cen	5.2	-1.53	-0.17	0.41	1.30	$34.44^{+0.13}_{-0.15}$
M80	10.0	-1.75	0.46	0.32	1.72	$34.92^{+0.28}_{-0.51}$
M62	6.8	-1.18	1.02	0.77	6.55	$35.04^{+0.12}_{-0.14}$
NGC 6388	9.9	-0.55	1.13	0.66	3.78	$35.41^{+0.12}_{-0.25}$
Terzan 5	6.9	-0.23	0.72	1.28	11.1	$35.41^{+0.17}_{-0.19}$
NGC 6440	8.5	-0.36	0.94	0.92	8.96	$35.38^{+0.19}_{-0.15}$
NGC 6441	11.6	-0.46	1.17	0.73	3.25	$35.57^{+0.09}_{-0.12}$
NGC 6541	7.5	-1.81	0.16	0.58	4.23	$34.54^{+0.24}_{-0.33}$
NGC 6652	10.0	-0.81	-0.35	0.48	3.03	$34.89^{+0.18}_{-0.15}$
NGC 6752	4.0	-1.54	0.15	0.46	1.75	$34.14^{+0.19}_{-0.30}$
M15	10.4	-2.37	0.83	0.1	0.38	$34.73^{+0.11}_{-0.10}$
NGC 6397	2.3	-2.02	-0.31	0.57	1.48	$33.30^{+0.33}_{-0.26}$
M5	7.5	-1.29	-0.22	0.17	0.77	$34.34^{+0.08}_{-0.08}$
M12	4.8	-1.37	-1.07	0.41	1.71	$33.98^{+0.09}_{-0.15}$
NGC 6139	10.1	-1.65	0.29	0.65	3.42	$34.71^{+0.19}_{-0.34}$
NGC 2808	9.6	-1.14	0.68	-0.92	-0.42	$34.72^{+0.08}_{-0.10}$
NGC 6316	10.4	-0.45	-0.23	-0.14	0.68	$35.41^{+0.05}_{-0.06}$
NGC 6717	7.1	-1.26	-0.69	-0.20	0.64	$34.36^{+0.11}_{-0.15}$

Note:**(a)** GC properties collected from Harris (1996, 2010 revision) [8]. The two-body enounter rate is estimated as $\Gamma_c \equiv \rho_c^{1.5} r_c^2$ where ρ_c is the central luminosity density and r_c is the core radius.**(b)** The soft photon densities are estimated by using GALPROP code[9]. **(c)** L_γ in 0.1-300 GeV [5][6].

4. Conclusion

With the updated and enlarged population of $\gamma-$ray GCs, we have re-examined the relations of L_γ with a number of physical parameters. Our results support the assertion which have been previously made by [1], [2] and [4]: The $\gamma-$rays from a GC is a result of ICS between the relativistic wind from its MSPs, which are formed dynamically, and its ambient soft photon field.

References

[1] C.Y. Hui, et al. *The Fundamental Plane of Gamma-ray Globular Clusters* *ApJ, 726, 100* (2011) [arXiv:1101.4107].

[2] K.S. Cheng, et al. *The Origin of Gamma Rays from Globular Clusters* *ApJ, 723, 1219* (2010) [arXiv:1009.2278].

[3] C.Y. Hui, et al. *Dynamical Formation of Millisecond Pulsars in Globular Clusters* *ApJ, 714, 1149* (2010) [arXiv:1003.4332].

[4] P.H.T. Tam, et al. *Gamma-ray Emission from Globular Clusters* *JASS, 33, 1* (2016) [arXiv:1207.7267].

[5] F. Acero, et al. *Fermi large area telescope third source catalog* *ApJS, 218, 23* (2015) [arXiv:1501.02003].

[6] Zhang P, et al. *Detection of Gamma-ray Emission from Globular Clusters M15, NGC 6397, 5904, 6218 and 6139 with Fermi-LAT* *MNRAS, 459, 99* (2016) [arXiv:1603.02358].

[7] P.H.T. Tam, et al. *Gamma-ray Emission from the Globular Clusters Liller 1, M80, NGC6139, NGC 6541, NGC 6624, and NGC 6752* *ApJ, 729, 90* (2011) [arXiv:1101.4106].

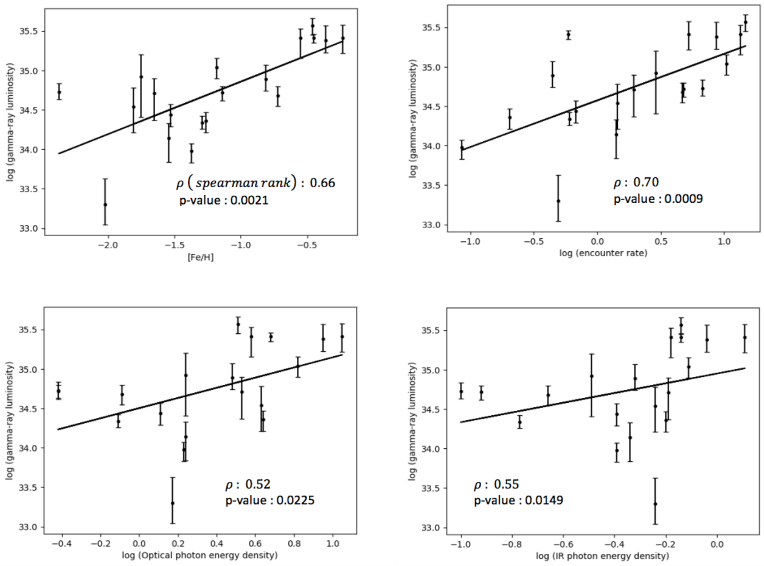

Figure 1: γ-ray luminosity vs individual GCs properties. Straight lines represent best-fit lines from the linear regression. The Spearman rank coefficients and the corresponding $p-$values are given in each panel.

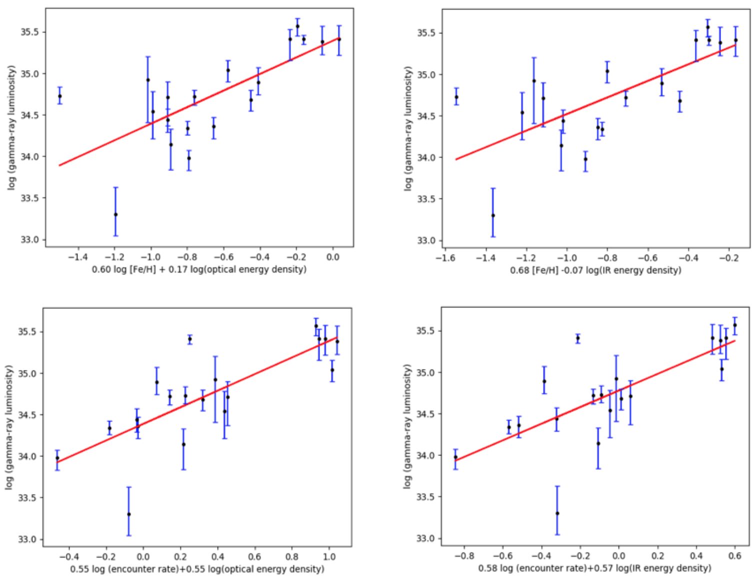

Figure 2: Edge-on views of the fundamental-plane relations of $\gamma-$ray GCs based on the updated and expanded sample.

[8] W.E. Harris, *A Catalog of Parameters for Globular Clusters in the Milky Way* *AJ, 112, 1487* (1996)

[9] Strong AW, & Moskalenko IV, *Propagation of Cosmic-Ray Nucleons in the Galaxy* *ApJS, 509, 212* (1998)[arXiv:astro-ph/9807150].