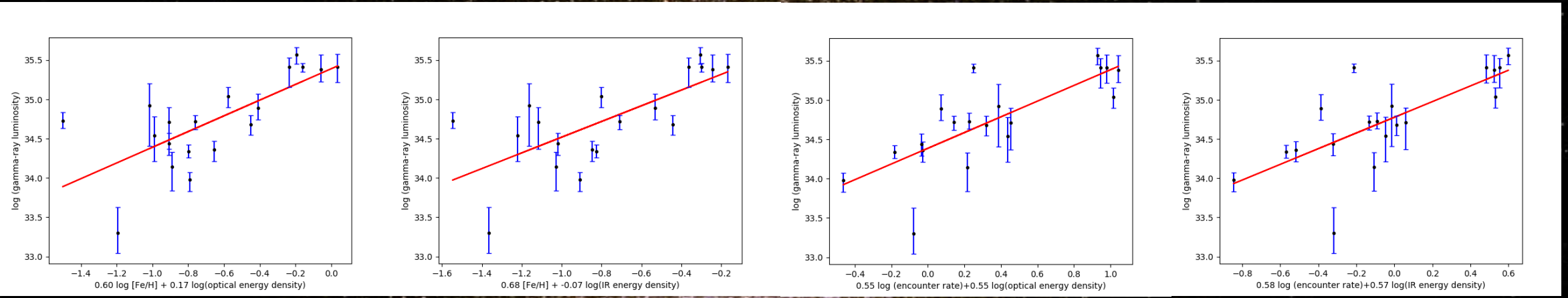
Re-examining the gamma-ray properties of globular clusters



With the updated and expanded sample of gamma-ray emitting globular clusters (GCs), we have reexamined the fundamental plane relation firstly reported by Hui et al. 2011 ApJ 762 100, which depict how does the gamma-ray luminosities of GCs vary with stellar encounter rates, metallicities, and the energy densities of the soft photon fields at their sites. The revised relations with the updated sample can provide a more accurate prediction of the properties of gamma-ray GCs.

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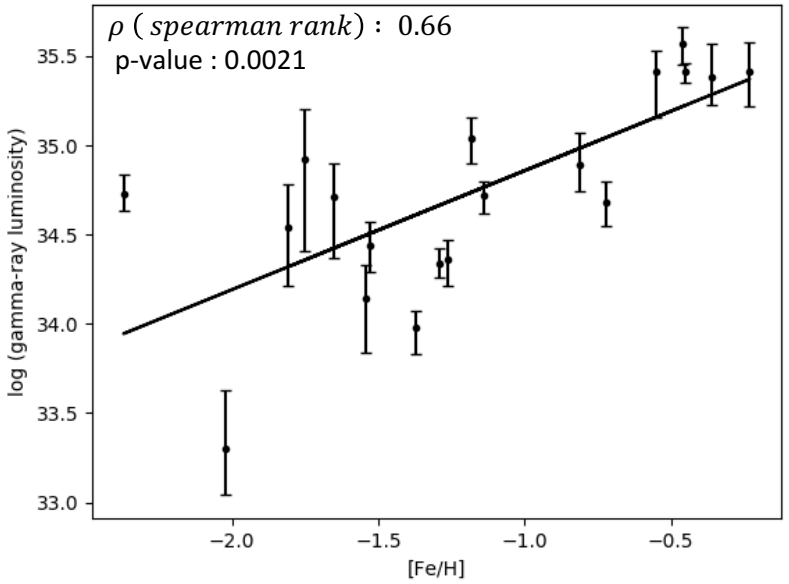
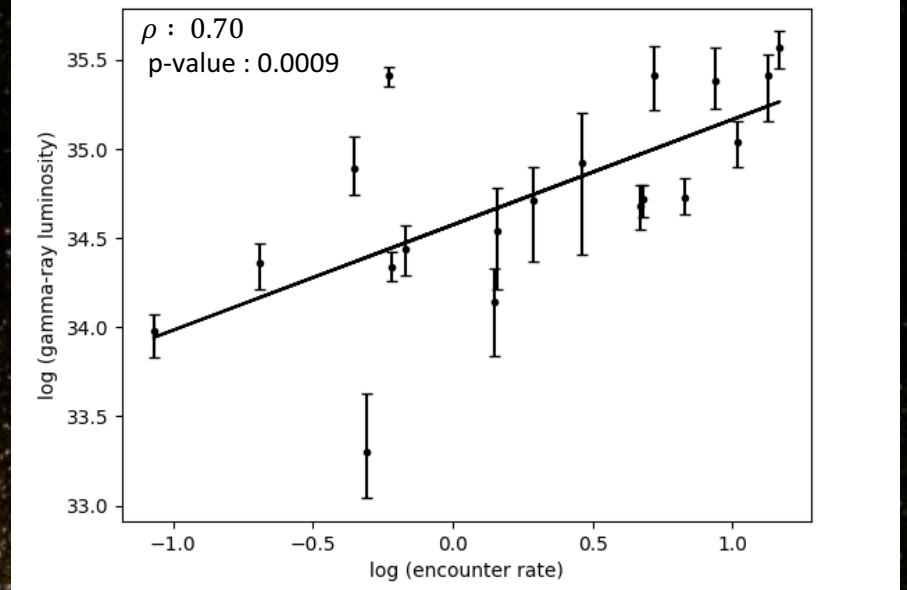
Table 1: Properties of the Gamma-ray emitting GCs

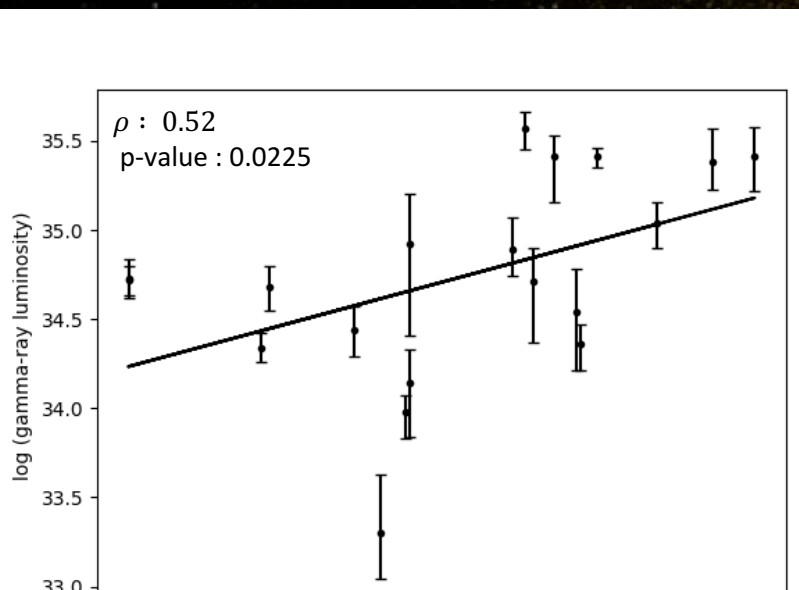
Cluster Name	d^a (kpc)	$[Fe/H]^c$	$log\Gamma^b$	${u_{IR}}^e$ $(eVcm^{-3})$	${u_{optical}}^e$ $(eVcm^{-3})$	${logL_\gamma}^f$ $(ergs^{-1})$
$47Tuc$	4.5	-0.72	0.67	0.22	0.81	$34.68^{+0.12}_{-0.13}$
$OmegaCen$	5.2	-1.53	-0.17	0.41	1.30	$34.44^{+0.13}_{-0.15}$
$M80$	10.0	-1.75	0.46	0.32	1.72	$34.92^{+0.28}_{-0.51}$
$M62$	6.8	-1.18	1.02	0.77	6.55	$35.04^{+0.12}_{-0.14}$
$NGC6388$	9.9	-0.55	1.13	0.66	3.78	$35.41^{+0.12}_{-0.25}$
$Terzan5$	6.9	-0.23	0.72	1.28	11.1	$35.41^{+0.17}_{-0.19}$
$NGC6440$	8.5	-0.36	0.94	0.92	8.96	$35.38^{+0.19}_{-0.15}$
$NGC6441$	11.6	-0.46	1.17	0.73	3.25	$35.57^{+0.09}_{-0.12}$
$NGC6541$	7.5	-1.81	0.16	0.58	4.23	$34.54^{+0.24}_{-0.33}$
$NGC6652$	10.0	-0.81	-0.35	0.48	3.03	$34.89^{+0.18}_{-0.15}$
$NGC6752$	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	$34.73^{+0.11}_{-0.10}$
$NGC6397$	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	$33.98^{+0.09}_{-0.15}$
$NGC6139$	10.1	-1.65	0.29	0.65	3.42	$34.71^{+0.19}_{-0.34}$
$NGC2808$	9.6	-1.14	0.68	-0.92	-0.42	$34.72^{+0.08}_{-0.10}$
$NGC6316$	10.4	-0.45	-0.23	-0.14	0.68	$35.41^{+0.05}_{-0.06}$
$NGC6717$	7.1	-1.26	-0.69	-0.20	0.64	$34.36^{+0.11}_{-0.15}$

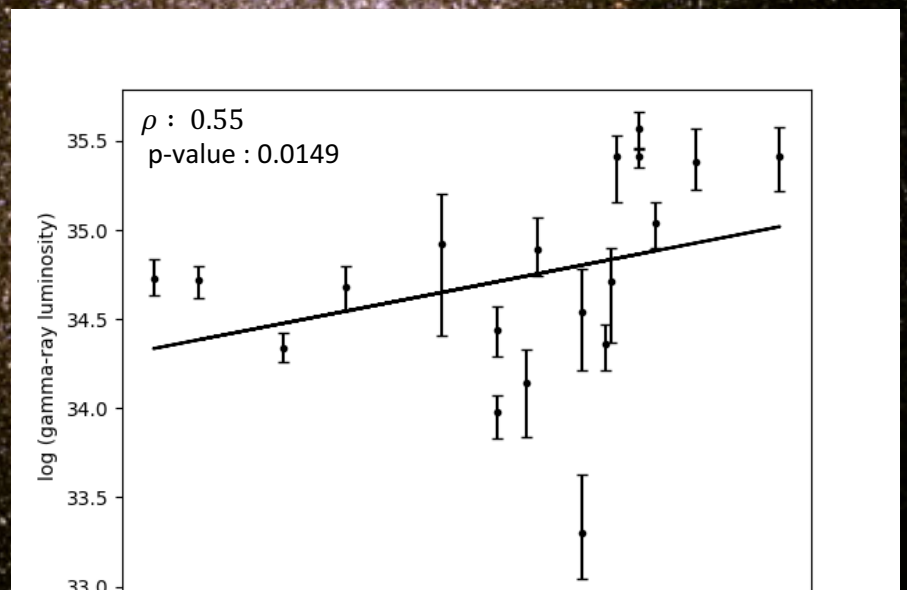
a : cluster distance from sun in Harris catalogue.
b : Two-body encounter rate.
c : Metallicity.
e : Energy densities of soft-photon field
f : γ-ray luminosity

1. 19 gamma-ray GCs included in our sample are selected from 3FGL catalog (Acero et al. 2015 ApJS 218 23) and Zhang et al. 2016 MNRAS 459 99.
2. Energy densities of optical and infrared photons estimated by using GALPRO code (Strong & Moskalenko 1998).
3. Stellar encounter rates Γ_c are estimated by ${\rho_0}^{1.5}$ ${r_c}^2$.
4. NGC6624 and M28 were excluded in our sample since the gamma-rays from those clusters are dominated by the single pulsar (Freire et al. 2011 Science 334 1107; Wu et al. 2013 ApJ 765 L47).
5. GC 2MS-GC01 in the 3FGL has also been excluded since the metallicity has not detected yet.
6. For those reported by Tam et al. 2011 ApJ 729 90 but were excluded in 3FGL and Zhang et al. (2016) (e.g. Liller 1), we are searching for the gamma-rays with ~9 years Fermi LAT data. In the preliminary analysis, we do not identify any significant signal from them. Therefore, they are excluded in our sample.



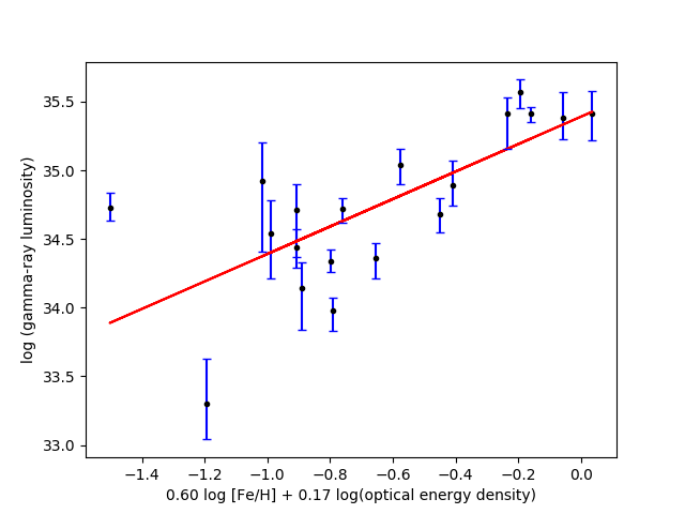


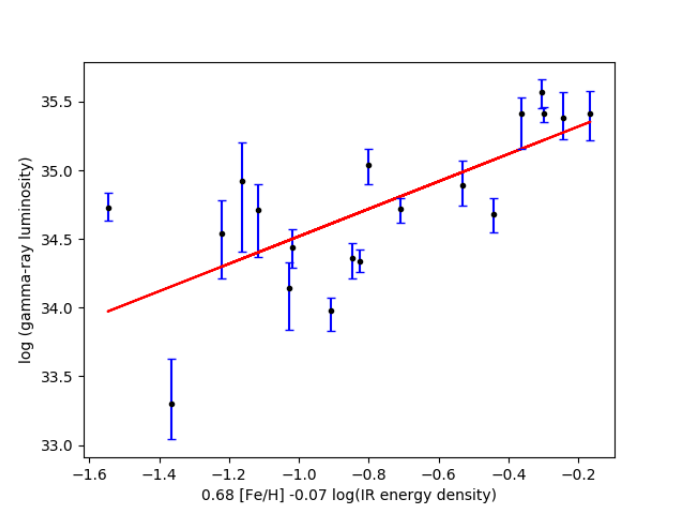


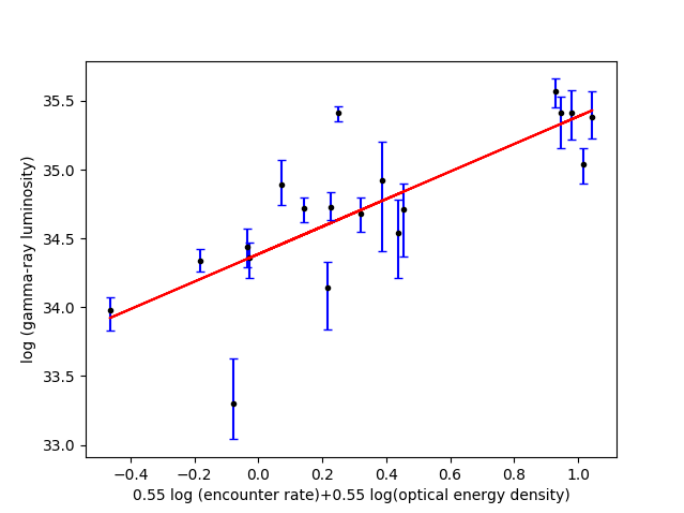


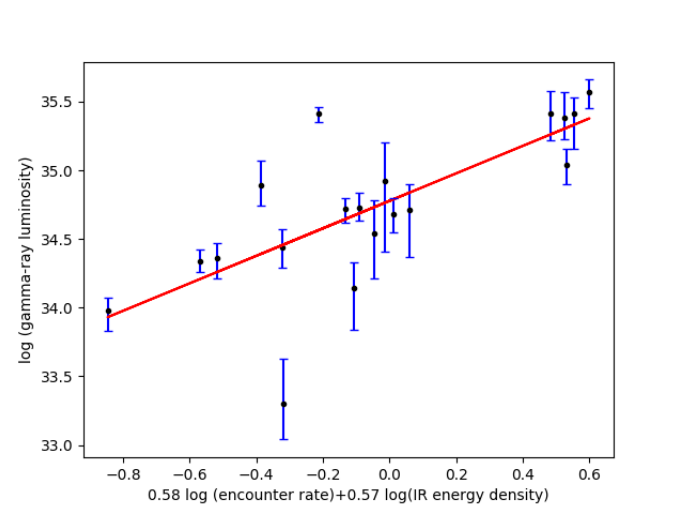
γ-ray luminosity vs individual GCs properties. Straight lines represent best-fit line from the linear regression. Also Spearman ranks and p-values are given in the plots.

Fundamental plane relation between Gamma ray luminosity and GCs properties









Edge-on views of the fundamental-plane relations of globular clusters based on the updated and expanded samples.

Table 2: Parameters of Best-fit Fundamental-plane Relationship

Parameter	Best-fit Values
a_1	34.77
a_2	0.55
a_3	0.55
a_4	34.38
a_5	0.58
a_6	0.57
a_7	35.39
a_8	0.60
a_9	0.17
a_{10}	35.52
a_{11}	0.68
a_{12}	-0.07

For obtaining the best-fit parameters, we have used following relationships with samples.

$$\log L_\gamma = a_1 + a_2 \log\Gamma_c + a_3 \log u_{optical}$$
$$\log L_\gamma = a_4 + a_5 \log\Gamma_c + a_6 \log u_{IR}$$
$$\log L_\gamma = a_7 + a_8[\mathrm{Fe/H}] + a_9 \log u_{optical}$$
$$\log L_\gamma = a_{10} + a_{11}[\mathrm{Fe/H}] + a_{12} \log u_{IR}$$
