Gamma-ray properties of globular clusters and the “fundamental planes”

P. Tam, A. Kong
Institute of Astronomy and Department of Physics, National Tsing Hua University, Hsinchu, Taiwan

C. Y. Hui
Department of Astronomy and Space Science, Chungnam National University, Daejeon, Republic of Korea

K S. Cheng
Department of Physics, University of Hong Kong, Pokfulam Road, Hong Kong

We report on the discovery of gamma-ray emission from several globular clusters (GCs), including Terzan 5, the second known gamma-ray GCs. By now, more than a dozen GCs are known to emit gamma-rays of energies above 100 MeV, thus enabling us to carry out the first detailed correlation study with several cluster properties. We found strong correlations between the observed gamma-ray luminosities and four cluster parameters: stellar encounter rate, metallicity [Fe/H], and energy densities of the soft photons at the cluster locations. These “fundamental planes” of gamma-ray GCs put an intimate relation of the observed gamma-rays to the underlying millisecond pulsar population and have important implications on the origin of the gamma-ray emission of GCs.

I. INTRODUCTION

Radio and X-ray observations have revealed about 140 millisecond pulsars (MSPs) in 26 globular clusters [GCs; 1]. However, the presence of much stronger X-ray emitters can contaminate the X-ray observations of MSPs. Because MSPs are the only known steady γ-ray sources in GCs [2], γ-ray observations of GCs serve as an alternative channel in studying the underlying MSP populations in GCs.

Using the Large Area Telescope (LAT), γ-rays from 8 GCs [3] have been discovered, including 47 Tucanae [4] and Terzan 5 [5].

II. MODELS OF γ-RAYS FROM GLOBULAR CLUSTERS

The radiation mechanism of γ-rays is unclear. In the pulsar magnetosphere model, e.g. [5], γ-rays up to a few GeV come from the MSPs through curvature radiation. On the other hand, inverse Compton (IC) processes resulted from energetic particles up-scattering low-energy photons, such as starlight and infrared light, may give rise to γ-rays of MeV to TeV energies, e.g. [6]. In either model, it is expected that the γ-ray luminosity of a GC is proportional to the stellar encounter rate, a measure of the number of MSPs in a GC.

III. NEW γ-RAY GLOBULAR CLUSTERS UNCOVERED

Terzan 5 contains the largest number of known MSPs among all GCs. It was discovered as the second known γ-ray emitting GC after 47 Tucanae [3] (see Figure 1). We note that 47 Tucanae was discovered in the bright source list [8], while the discovery of Terzan 5 in γ-rays was announced [5] before the release of the first Fermi/LAT catalog [9] and the report of the 8 GCs [3].

Like 47 Tucanae, the γ-ray spectrum of Terzan 5 also shows a cutoff at ~3 GeV [3, 5]. After the discovery of other six γ-ray emitting GCs [3], we also identified a group of GCs with high encounter rate. Using more than two years of data taken from LAT, we found γ-ray emission from the directions of Liller 1, NGC 6624, and NGC 6752 [10]. The test-statistic maps of the regions around these 3 GCs are shown in Figures 2 and 3. For M80, NGC 6139, and NGC 6541, the detection is marginal (4–5σ) when it was first reported [10].

For the cases where the γ-ray emission is offset from the core (i.e. Liller 1 and NGC 6624), the γ-ray spectra in the energy range of 200 MeV to 100 GeV are presented in Figure 4. The photons above ~20 GeV are detected at significance levels of 3–4. Once the existence of these high-energy photons is established, it will be easier to be reconciled in the IC models than in the pulsar magnetosphere model. In the latter case, spectral cut-offs at several GeV are expected.

IV. THE FUNDAMENTAL PLANES OF γ-RAY GLOBULAR CLUSTERS

We have investigated the properties of the γ-ray emitting globular clusters [11]. By correlating the observed γ-ray luminosities with various cluster properties, we probe the origin of the high energy photons from these GCs. We found that the γ-ray luminosity is positively correlated with the encounter rate and the metallicity [Fe/H] which places an intimate link
between the γ-ray emission and the MSP population. We also found that the γ-ray luminosity increases with the energy densities of the soft photons at the cluster location. When combining two parameters at the same time, the correlation is even stronger. The edge-on fundamental plane relations of γ-ray GCs are depicted in Figure 5.

This finding strongly suggests that models that incorporate optical or infrared photons should be taken into considerations in explaining the γ-ray emission from GCs, e.g. the IC models [7].

Acknowledgments

P. Tam acknowledges the support of the Formosa Program of Taiwan, NSC100-2923-M-007-001-MY3, and the NSC grant, NSC100-2628-M-007-002-MY3. AK is supported by a Kenda Foundation Golden Jade Fellowship.
FIG. 3: The test-statistics maps of NGC 6624 (left) and NGC 6752 (right) [10].

FIG. 4: Spectra of Liller 1 (left) and NGC 6624 (right). The solid and dashed lines represent the best-fit power law and power law with exponential cutoff, respectively [10].

[1] http://www.naic.edu/~pfreire/GCpsr.html

[2] Abdo, A. A., et al. (Fermi/LAT Collaboration) 2009, Science, 325, 848.

[3] Abdo, A. A., et al. (Fermi/LAT Collaboration) 2010, A&A, 524, 75.

[4] Abdo, A. A., et al. (Fermi/LAT Collaboration) 2009, Science, 325, 845.

[5] Kong, A. K. H., Hui, C. Y., & Cheng, K. S. 2010, ApJL, 712, L36.

[6] Venter, C. & de Jager, O. C. 2008, ApJL, 680, L125.

[7] Cheng, K. S., Chernyshov, D. O., Dogiel, V. A., Hui, C. Y., & Kong, A. K. H. 2010, ApJ, 723, 1219.

[8] Abdo, A. A., Ackermann, M., Ajello, M., et al. (Fermi/LAT Collaboration) 2009, ApJS, 183, 46.

[9] Abdo, A. A., et al. (Fermi/LAT Collaboration) 2010, ApJS, 188, 405.

[10] Tam, P.H.T., Kong, A.K.H., Hui, C. Y., Cheng, K. S., Li, C., & Lu, T.-N. 2011, ApJ, 729, 90.

[11] Hui, C. Y., Cheng, K. S., Wang, Y., Tam, P. H. T., Kong, A. K. H., Chernyshov, D. O., & Dogiel, V. A. 2011, ApJ, 726, 100.
FIG. 5: The edge-on views of the fundamental plane relations of γ-ray GCs. The straight lines in the plots represent the projected best-fits [11].