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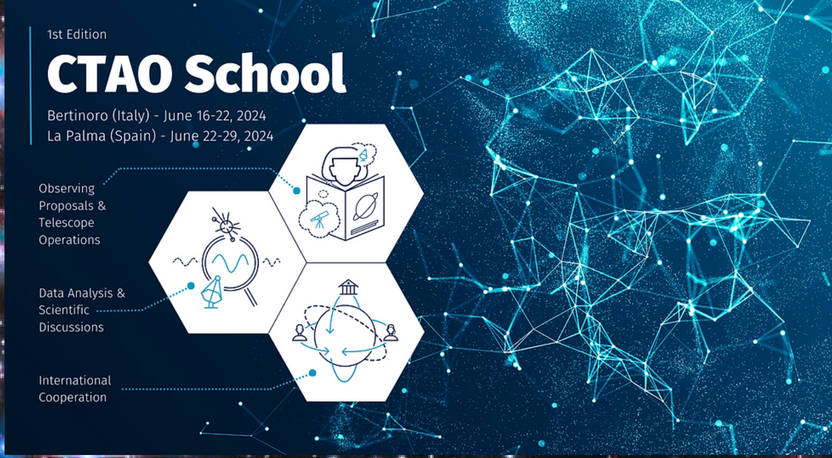


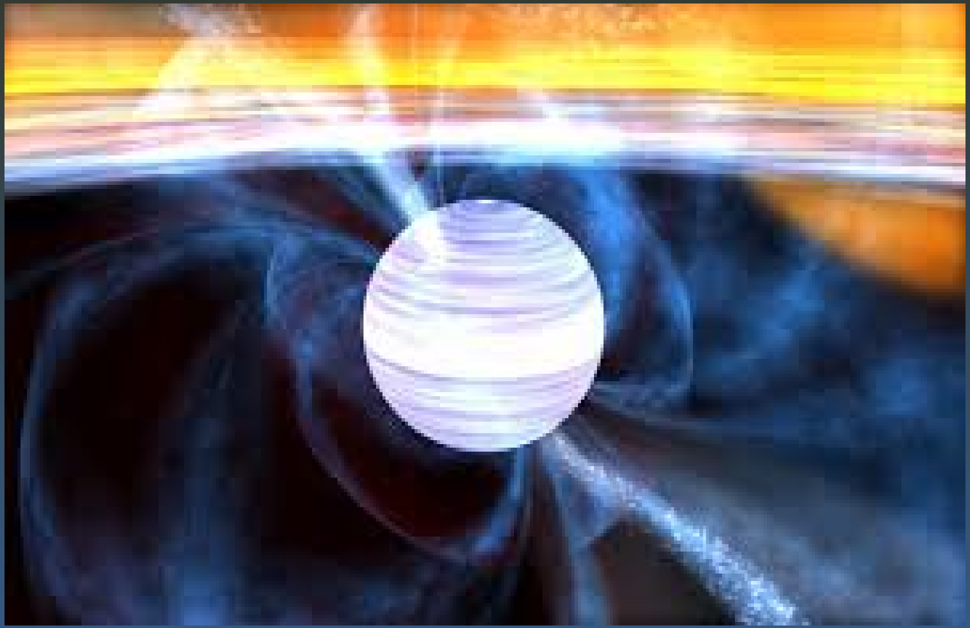

# A Luminosity Function for Millisecond Pulsars in Globular Clusters

With Francesca Calore (LAPTh), Silvia Manconi (LAPTh) and Gabrijela Zaharijas (UNG)

# Millisecond Pulsars

MilliSecond Pulsars (MSPs) are Pulsars with P<30 ms

- Observed for the first time in radio [DOI:10.1038/300615A0]
- We know around 300 MSPs, ~144 of which detected in gamma-rays

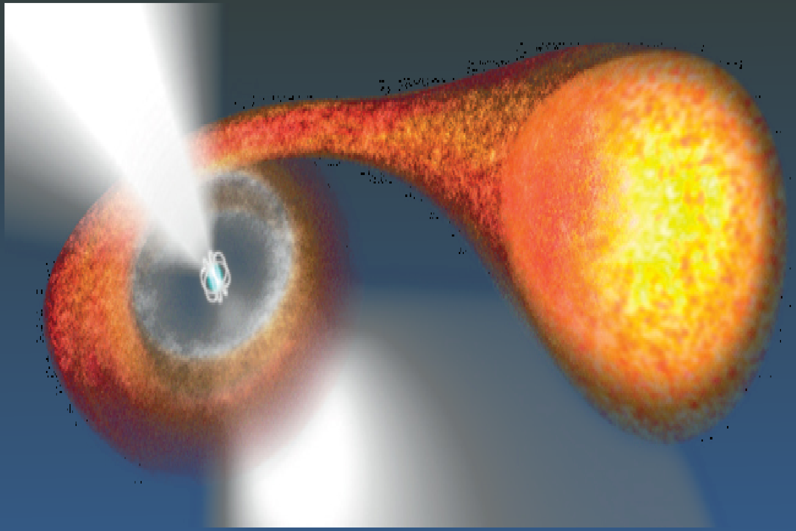


https://svs.gsfc.nasa.gov/10144/

# MSP Formation History

MSPs are considered recycled objects

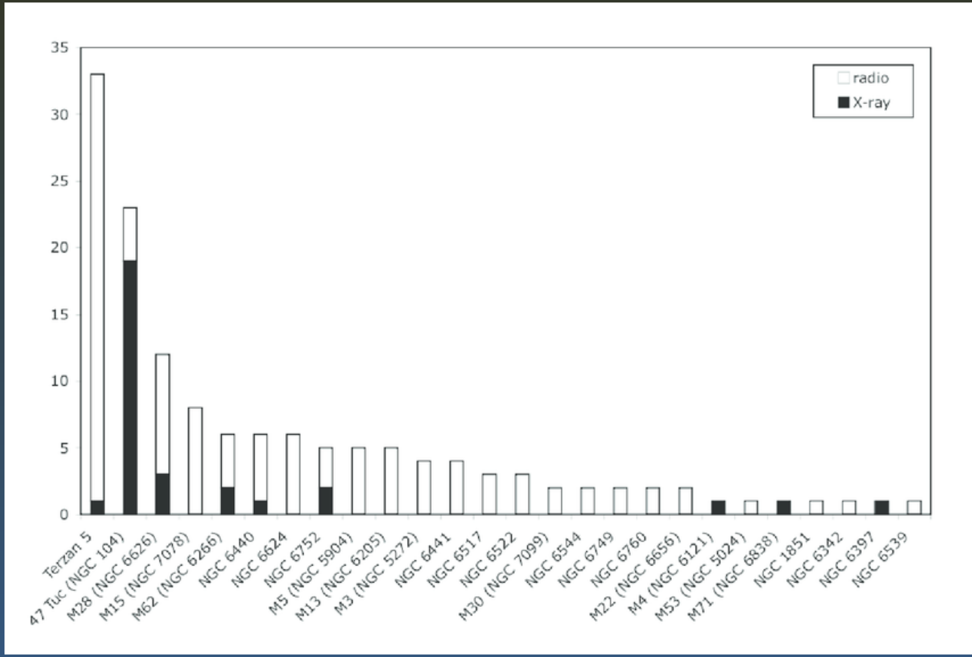
- They are likely related to Low-Mass X-Ray Binaries (LMXB)
- Observations of widows and accreting Neutron Stars (NS) support of this theory



https://cerncourier.com/wp-content/uploads/2013/10/CCast1_09_13.jpg

# MSPs and Globular Clusters

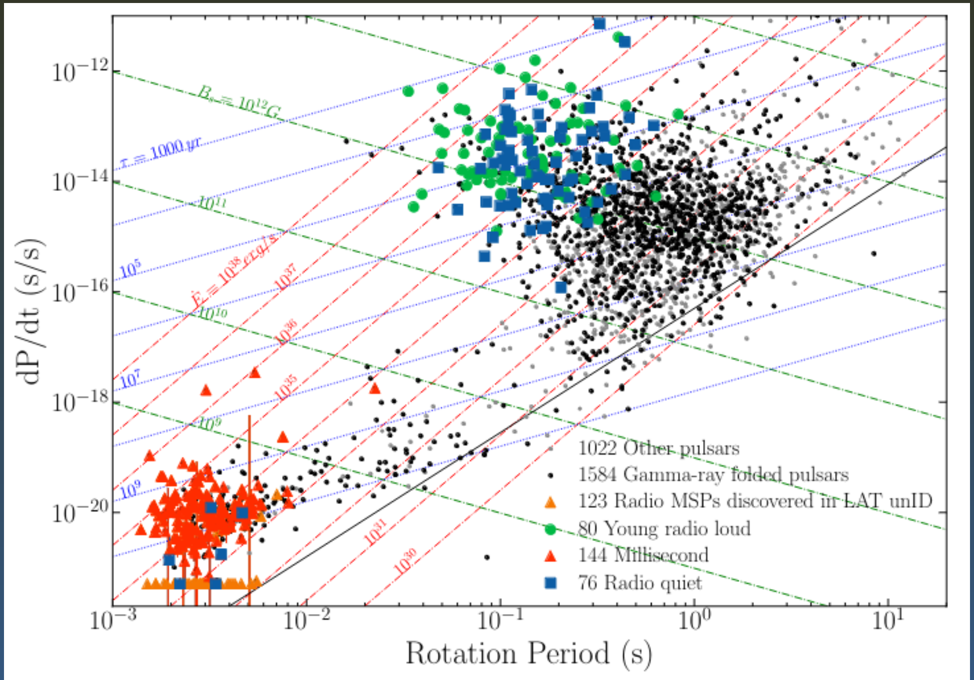
- Globular Clusters (GCs) are rich in MSPs
- Most (~40%) MSPs are found in GCs (similar to LMXBs)
- In GCs LMXBs may be formed by tidal capture
- In GCs pulsars formed from Core Collapse Super Novae (CCSN) can escape
- MSPs in GCs are detected in radio separately




https://www.researchgate.net/figure/A-histogram-of-radio-and-X-ray-detected-millisecond-pulsars-in-globular-clusters_fig1_45921190

# MSPs in Gamma-Rays

- 144 MSPs have been detected in gamma-rays
- They make up most of the gamma-ray emission from GCs
- MSPs represent nearly half of the gamma-ray emitting Pulsars currently detected

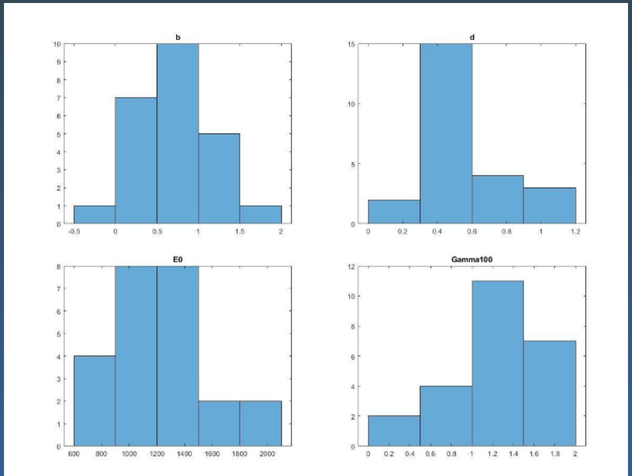



Arxiv:2307.11132

# MSPs Gamma-Ray Spectrum

- Pulsars' Spectral Energy Distributions (SEDs) are well represented by the Power Law Exponential Cutoff 4 (PLEC4) distribution, given as:

$$\frac{dN}{dE} = N_0 \left(\frac{E}{E_0}\right)^{-\Gamma + \frac{d}{b}} \exp\left(d/b^2 \left(1 - \left(\frac{E}{E_0}\right)^b\right)\right)$$



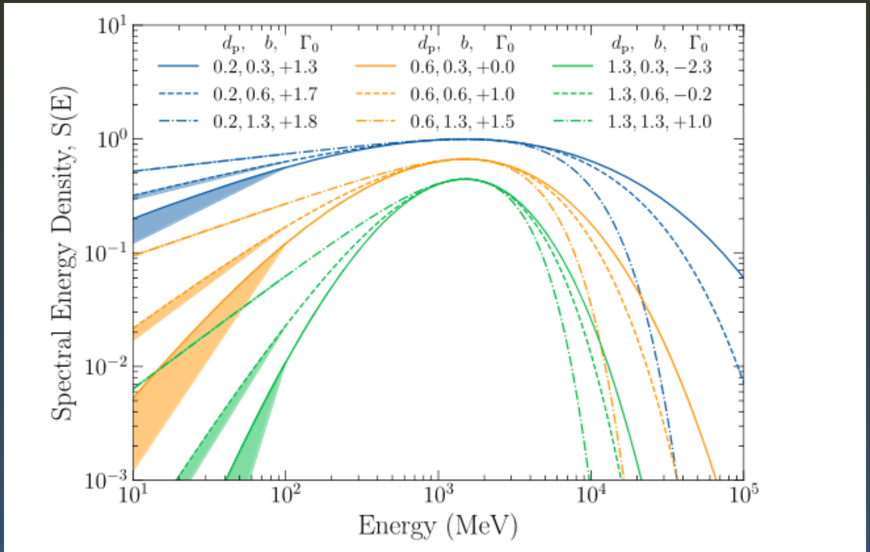

The means are:

d = 0.5473 ± 0.2625

b = 0.7132 ± 0.4491

Γ = 1.907 ± 0.8052

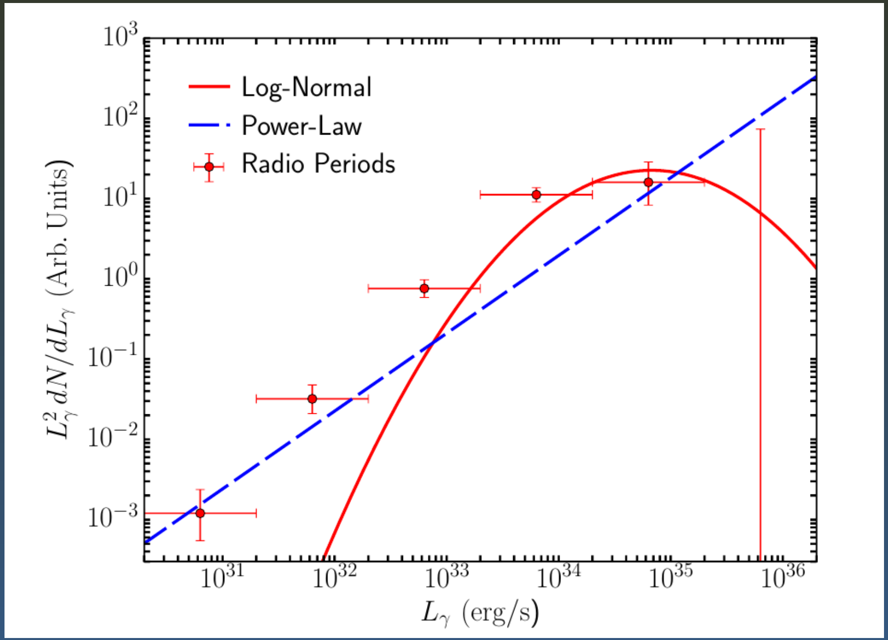
$E_0$ = (1.209 ± 0.3076) GeV




Arxiv: 2307.11132

# MSPs in GCs: Past Studies

- [Arxiv: 1606.09250] found a luminosity function for MSPs in GCs
- They consider 157 gamma-ray emitting GCs
- They use the relationship between Stellar Encounter Rate and number of MSPs



# MSPs in GCs: Past Studies

- This luminosity function underestimate the number of MSPs in GCs
- A linear relation between stellar encounter rate and the number of MSPs is assumed

  We want a luminosity function that uses the information on MSPs' spectra

- It finds 12 MSPs in Terzan 5
- We know of at least 49 MSPs in Terzan 5 [Arxiv: 2403.17799]

# On this Project

**Goal:**

- To find a Luminosity Function for MSPs in GCs

**Methodology:**

- Bayesian Inference with Nested Sampling algorithm to find the parameters of the luminosity function
- GCs’ SEDs are obtained through FermiPy

**Members:**

- Francesca Calore (LAPTh)
- Silvia Manconi (LAPTh)
- Francesco Xotta (UNG)
- Gabrijela Zaharijas (UNG)

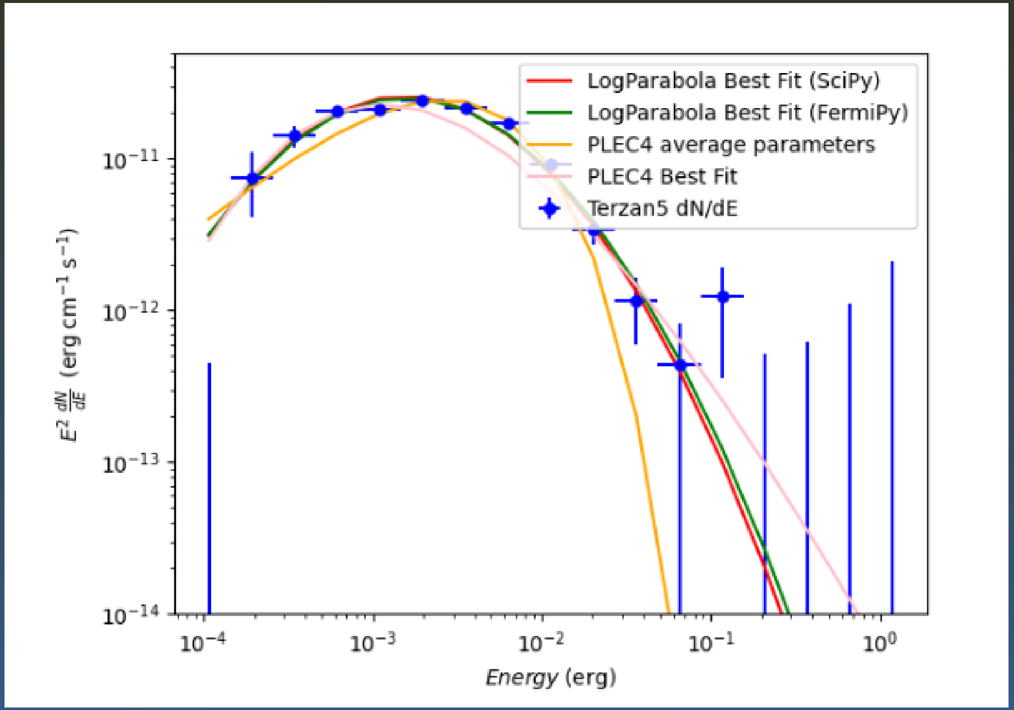
# MSPs in GCs: Terzan5

- Find average parameters of PLEC4 for MSPs

  We then consider Terzan5, the richest GC in MSPs, we check:

- That it can be fit to the PLEC4 distribution
- How its spectrum compares to the PLEC4 with average MSP parameters

  We obtain the flux of Terzan 5 using FermiPy




Fit of Terzan 5 to a LogParabola and to a PLEC4

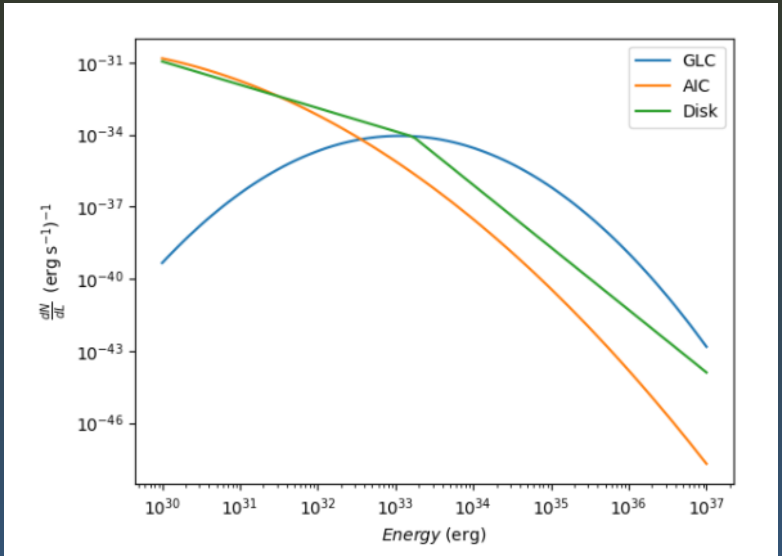
# MSPs in GCs: Expected Result

- We wish to find a luminosity function for the 0.1-100 GeV bin
- We consider the Log-Normal distribution:

$$\frac{dN}{dL}(L; L_0, \sigma) \propto \frac{log_{10}e}{\sigma\sqrt{2\pi}L} exp\left(-\frac{(log_{10}L - log_{10}L_0)^2}{2\sigma^2}\right)$$

A Luminosity Function tells the relative number of MSPs with a given luminosity

- GLC: L0=8.8 × $10^{33}$ erg $s^{-1}$, σ=0.62
- AIC: L0=4.3 × $10^{30}$ erg $s^{-1}$, σ=0.94
- DISK:Lb = 1.7 × $10^{33}$ erg $s^{-1}$, n1 = 0.97, n2 = 2.60




Comparison of three benchmark luminosity functions, two of which (GLC and AIC) use a Log-Normal luminosity function, while the third (Disk) uses a Broken-Power Law luminosity function

# MSPs in GCs: Procedure

Given N GCs, we have N+2 free parameters:

- $N_l$ with l=1,....,N: number of MSPs in the l-th GC
- $L_0$
- $\sigma$

We follow the steps below:

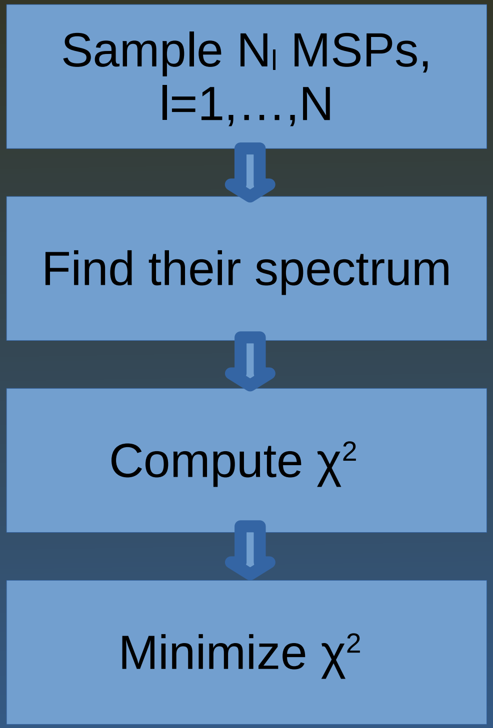
- We sample for each GC $N_l$ MSPs' luminosities from the luminosity function
- We find the normalization of the PLEC4 with average MSPs parameters

$$F_i \equiv \int k_i \times \frac{dN}{dE}(E) \times E\, dE \equiv \frac{L_i}{4\pi {d_{GC}}^2}$$

- We compute the $\chi^2$

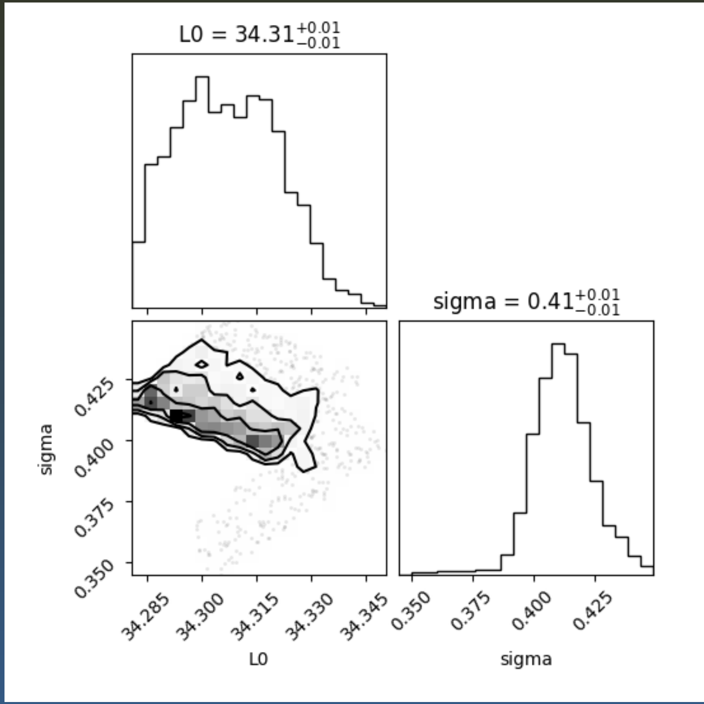
$$\chi^2_k = \left(\frac{F_{\rm MSP} - F_{\rm GC}}{\Delta F_{\rm GC}}\right)^2_k$$

- We minimize it to find the best parameters using a Nested Sampling Algorithm



# MSPs in GCs: Some Results

- Here we assume the same relationship of [Arxiv: 1606.09250]



# MSPs in GCs: Additions

In the future, we intend to make the following changes:

- Sample every PLEC4 parameter instead of just the normalization
- Consider possible relationship to the Stellar Encounter Rate
- Consider the number of MSPs detected in Globular Clusters

# Thank You!

# MSPs in GCs: Sampling

- Example of Sampling of MSPs
- The number of MSPs however can be very small, leading to big uncertainties in the $\chi^2$