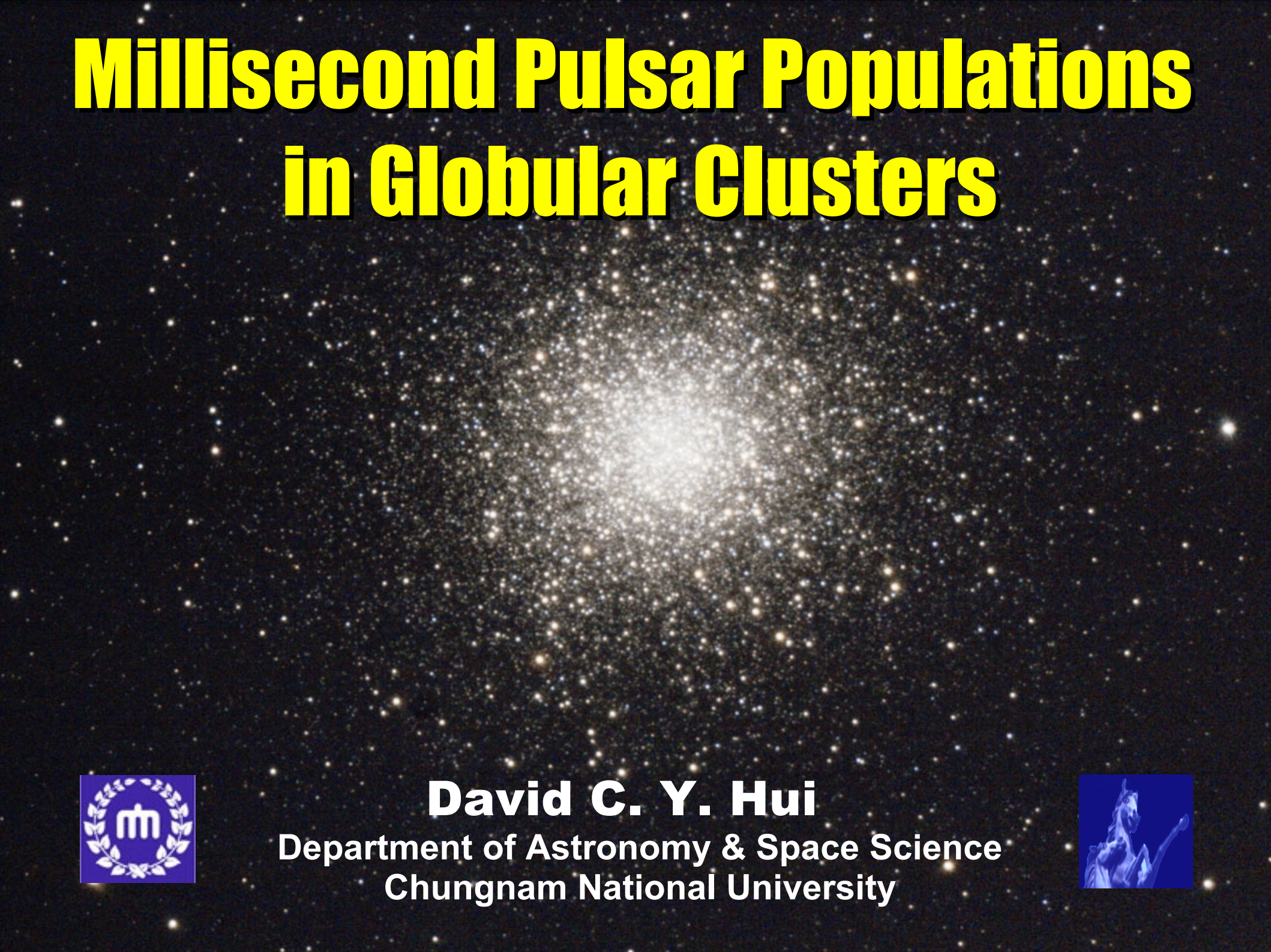
Millisecond Pulsar Populations in Globular Clusters



David C. Y. Hui
Department of Astronomy & Space Science
Chungnam National University

- *1. Introduction*
- *2. Dynamical formation of millisecond pulsars (MSPs) in GCs*
- *3. Multi-wavelength emission properties of GC MSPs*

Globular Clusters

- Stellar systems tightly bounded by gravity
- Composed of late-type metal-poor stars
- Densities of the stars increases toward center
- Stellar encounters are frequent in the cores

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GCs are efficient factories of compact binaries!

Binaries in Globular Clusters

Due to the frequent stellar encounters, the **evolutionary history** of the binary systems in GCs are expected to be different from that in the Galactic field.

Binaries in Globular Clusters

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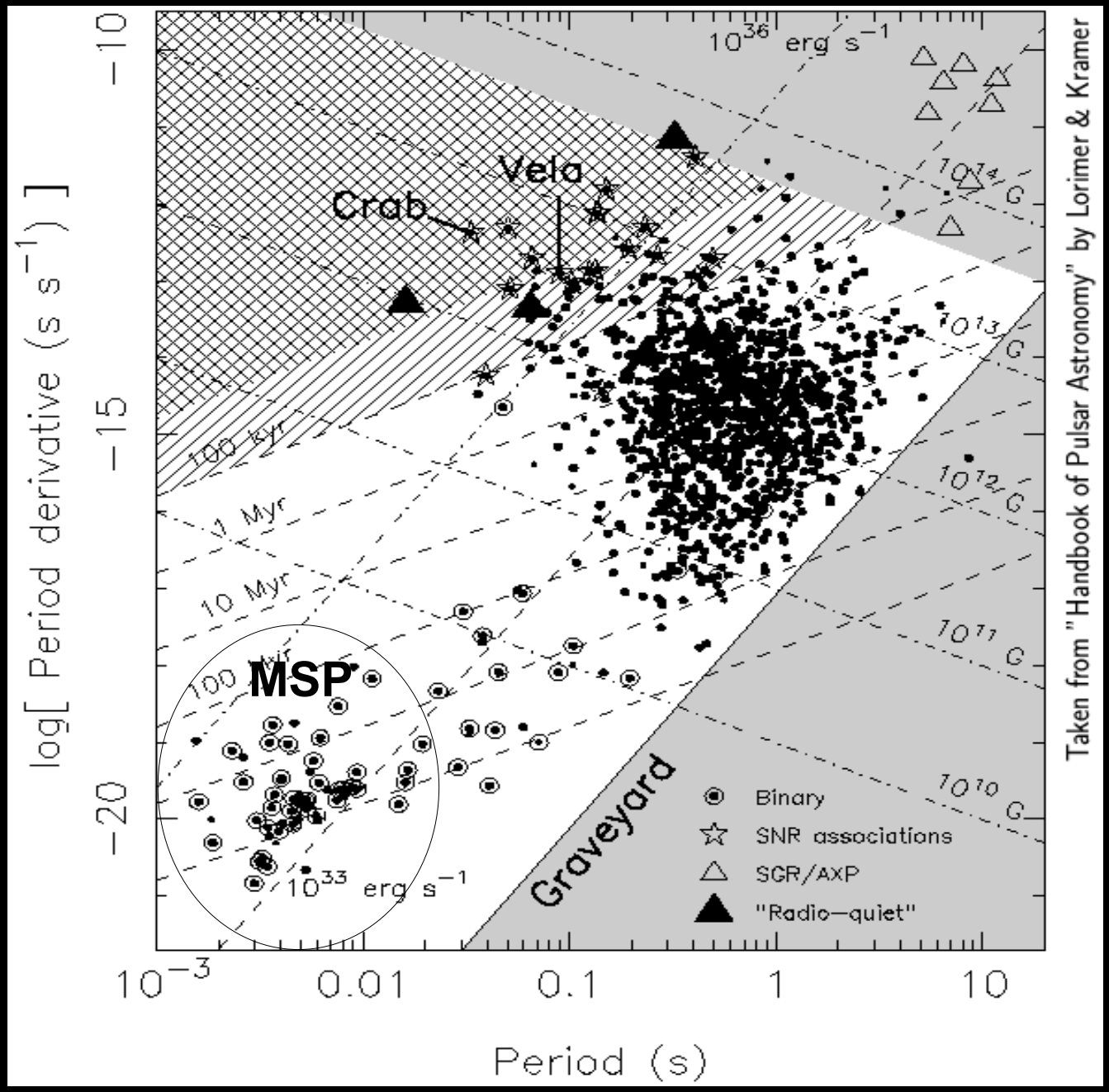
To investigate the binary populations in GCs:

1. Investigate the relations between the binary populations in GCs with various cluster properties.

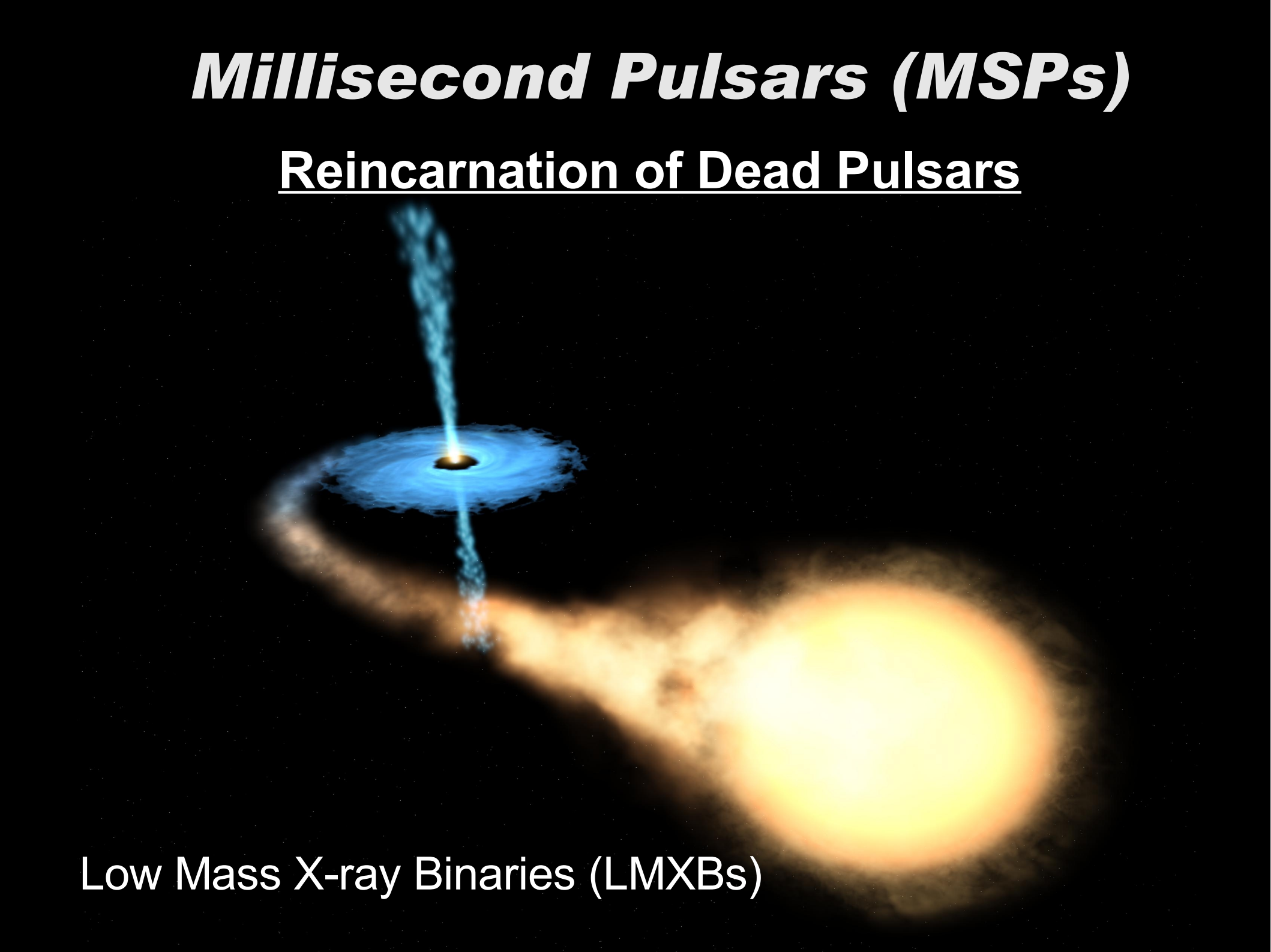
2. Compare the emission properties of the binaries in GCs with those in the Galactic field.

Millisecond Pulsars (MSPs)



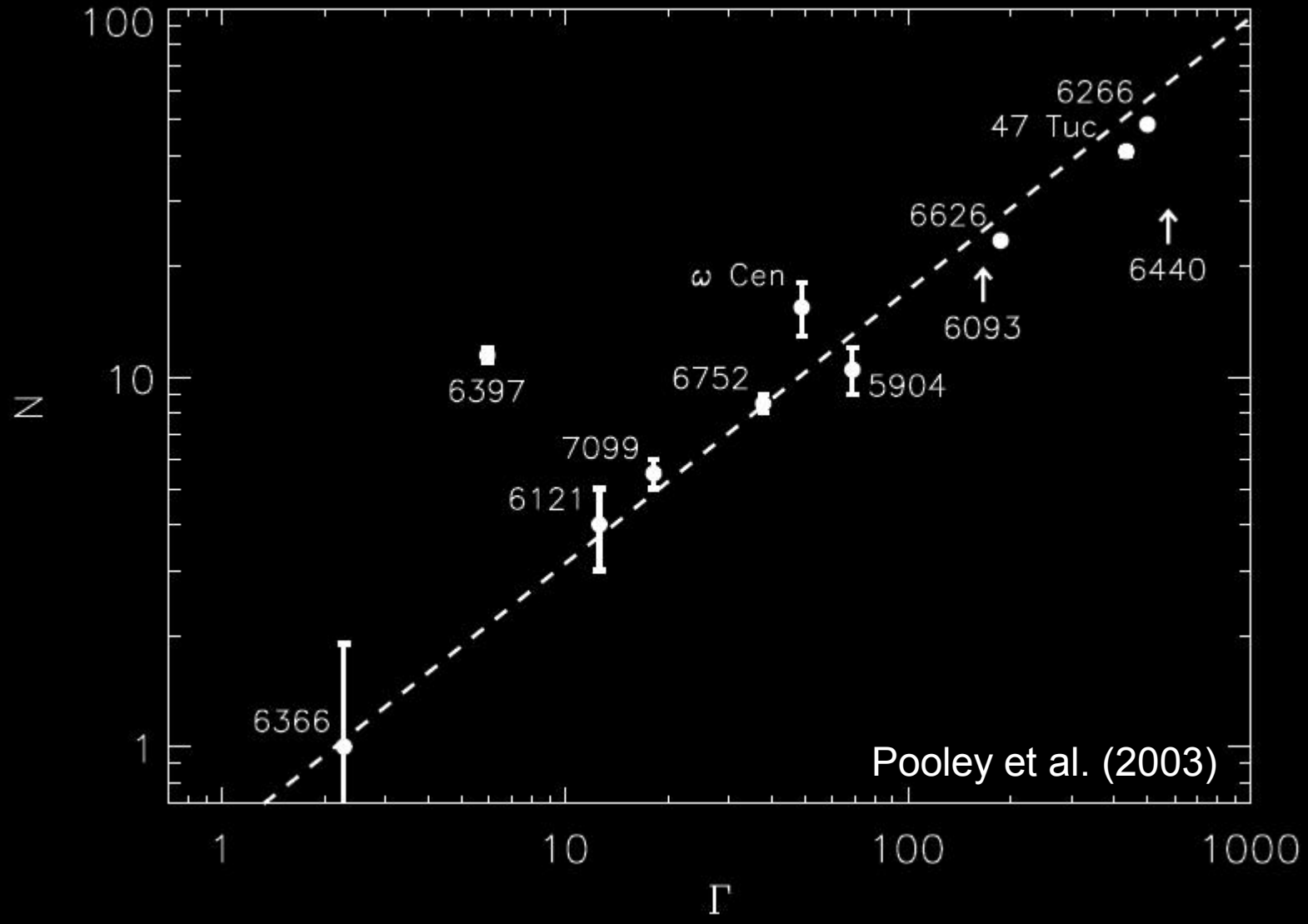
Millisecond Pulsars (MSPs)

Reincarnation of Dead Pulsars



Low Mass X-ray Binaries (LMXBs)

X-Ray Binaries in GCs



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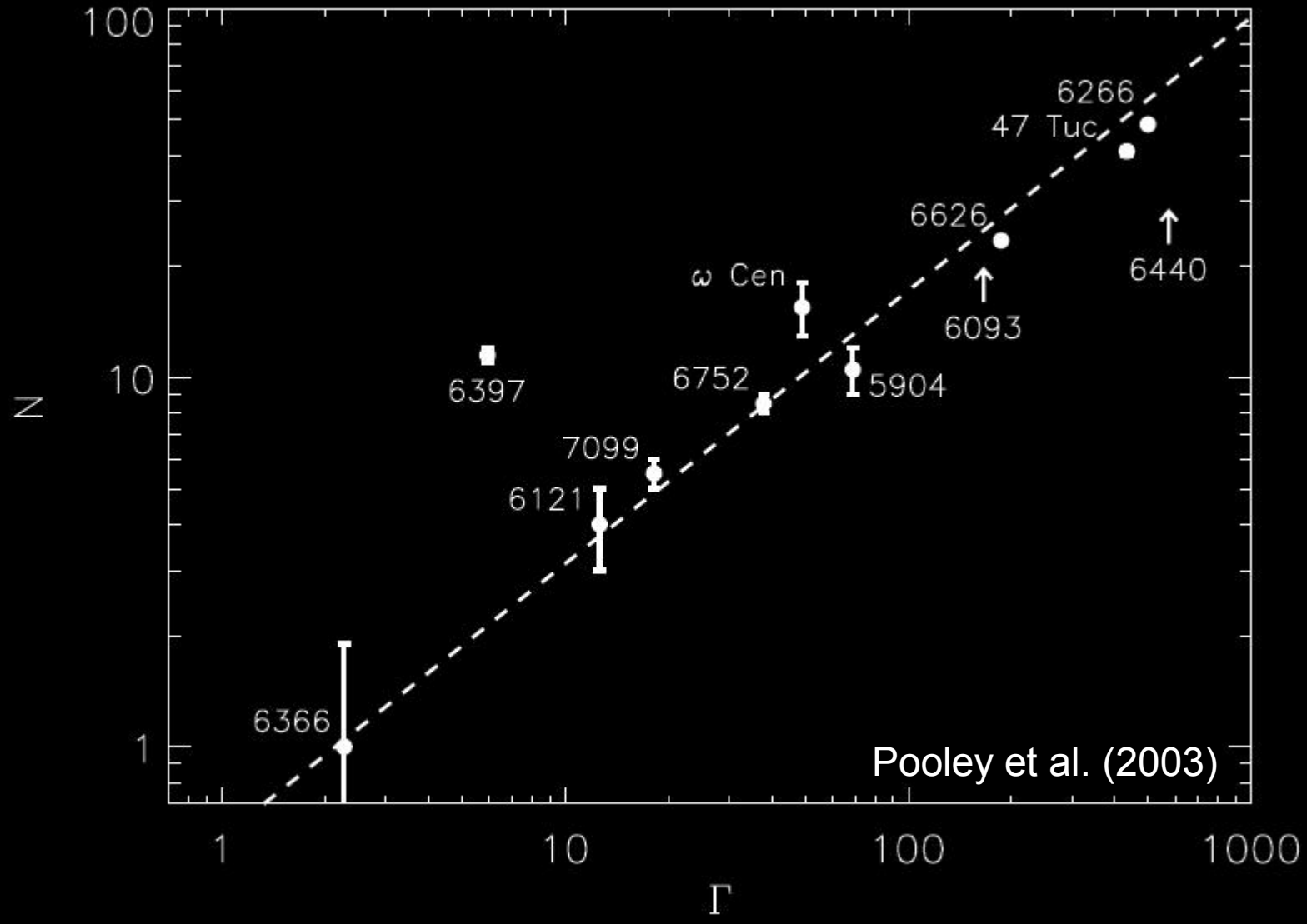
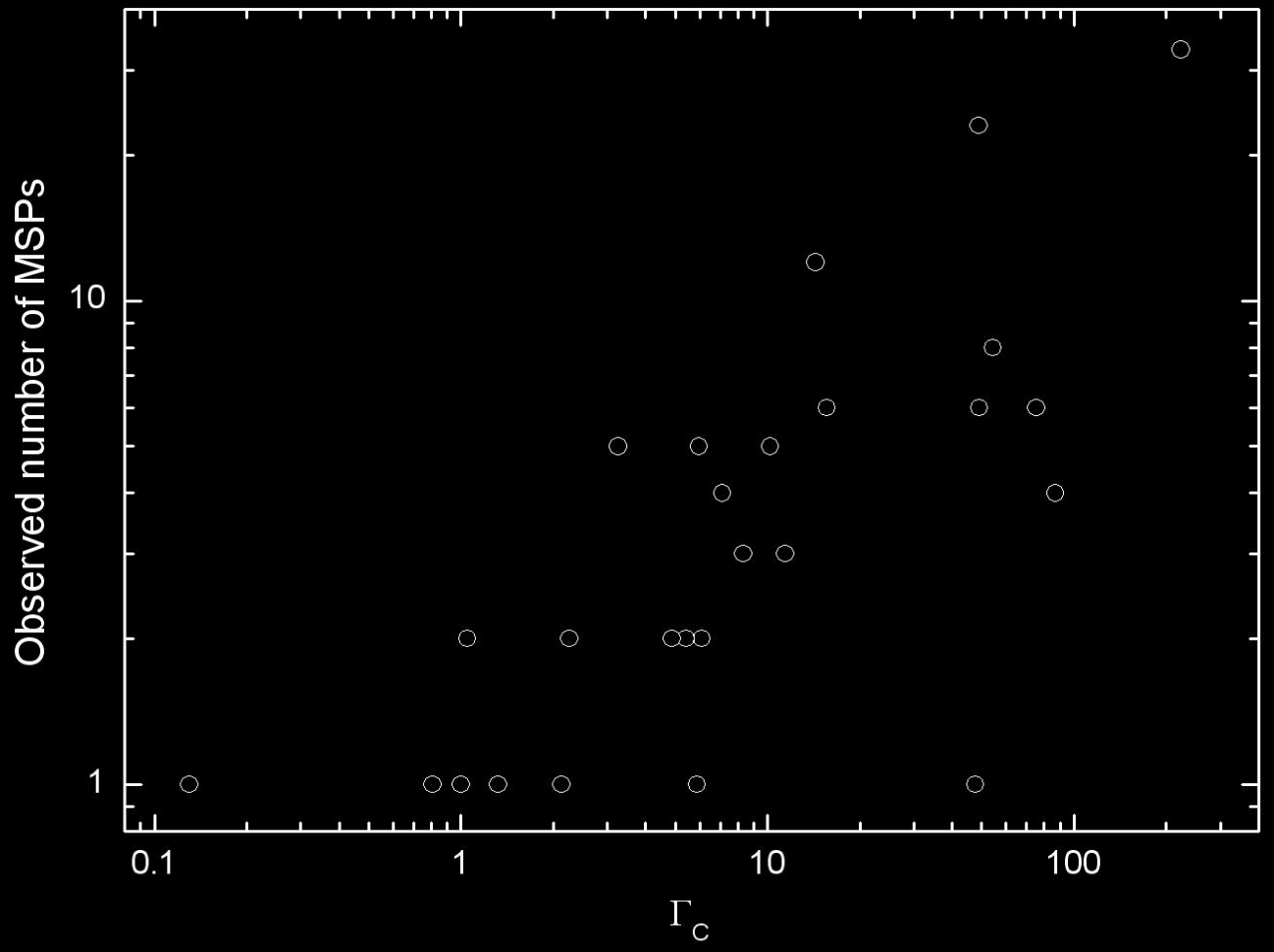


MSPs are also expected to correlate with Γ!

MSPs in Globular Clusters



Hui, Cheng & Taam (2010)

- Many GCs that host a single MSPs have not been searched deep enough

- Observed number of MSPs do not provide an unbiased sample for correlation study

MSPs in Globular Clusters

To alleviate the problem due to selection effects:
Use the cumulative radio luminosity functions (CLFs)

$$N(>L)=N_0 L^q$$

Hui, Cheng & Taam (2010)

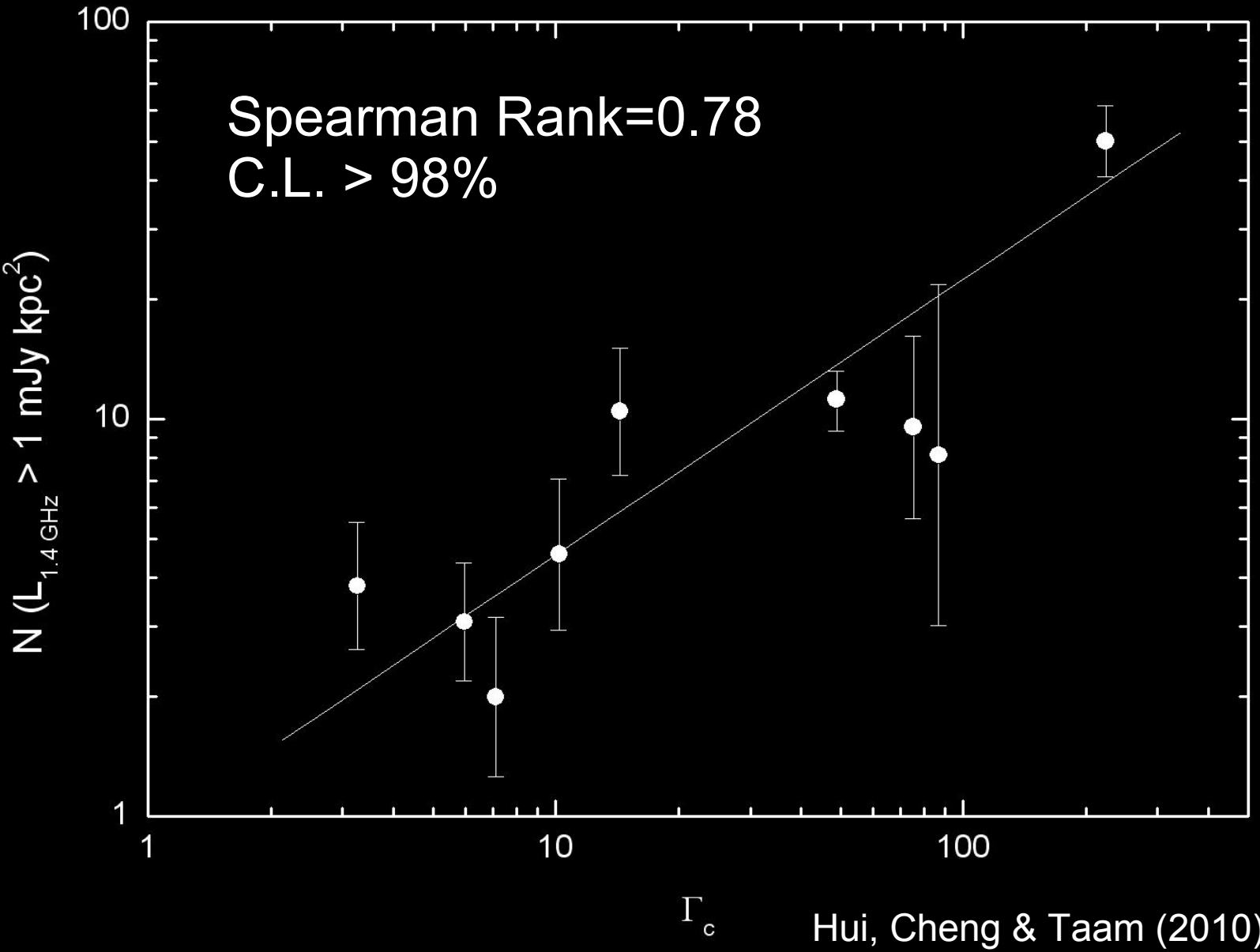
Cluster Name	N_0	q
Terzan 5	$50.12^{+11.54}_{-9.38}$	-0.80 ± 0.12
47 Tuc	$11.22^{+1.96}_{-1.89}$	-0.82 ± 0.19
M 28	$10.47^{+4.66}_{-3.23}$	-0.74 ± 0.26
NGC 6440	$9.55^{+6.67}_{-3.93}$	-0.59 ± 0.27
NGC 6752	$4.57^{+2.51}_{-1.62}$	-0.93 ± 0.50
M 5	$3.09^{+1.27}_{-0.90}$	-0.58 ± 0.31
M 13	$3.80^{+1.69}_{-1.17}$	-0.63 ± 0.34
M 3	$2.00^{+1.17}_{-0.74}$	-1.61 ± 1.09
NGC 6441	$8.13^{+13.75}_{-5.11}$	-0.76 ± 0.52

We are able to estimate the no. of MSPs in these GCs above the same luminosity threshold.

Unbiased sample for correlation analysis can be obtained

MSPs in Globular Clusters

Correlation with Stellar Encounter Rate



Hui, Cheng & Taam (2010)

MSPs in Globular Clusters

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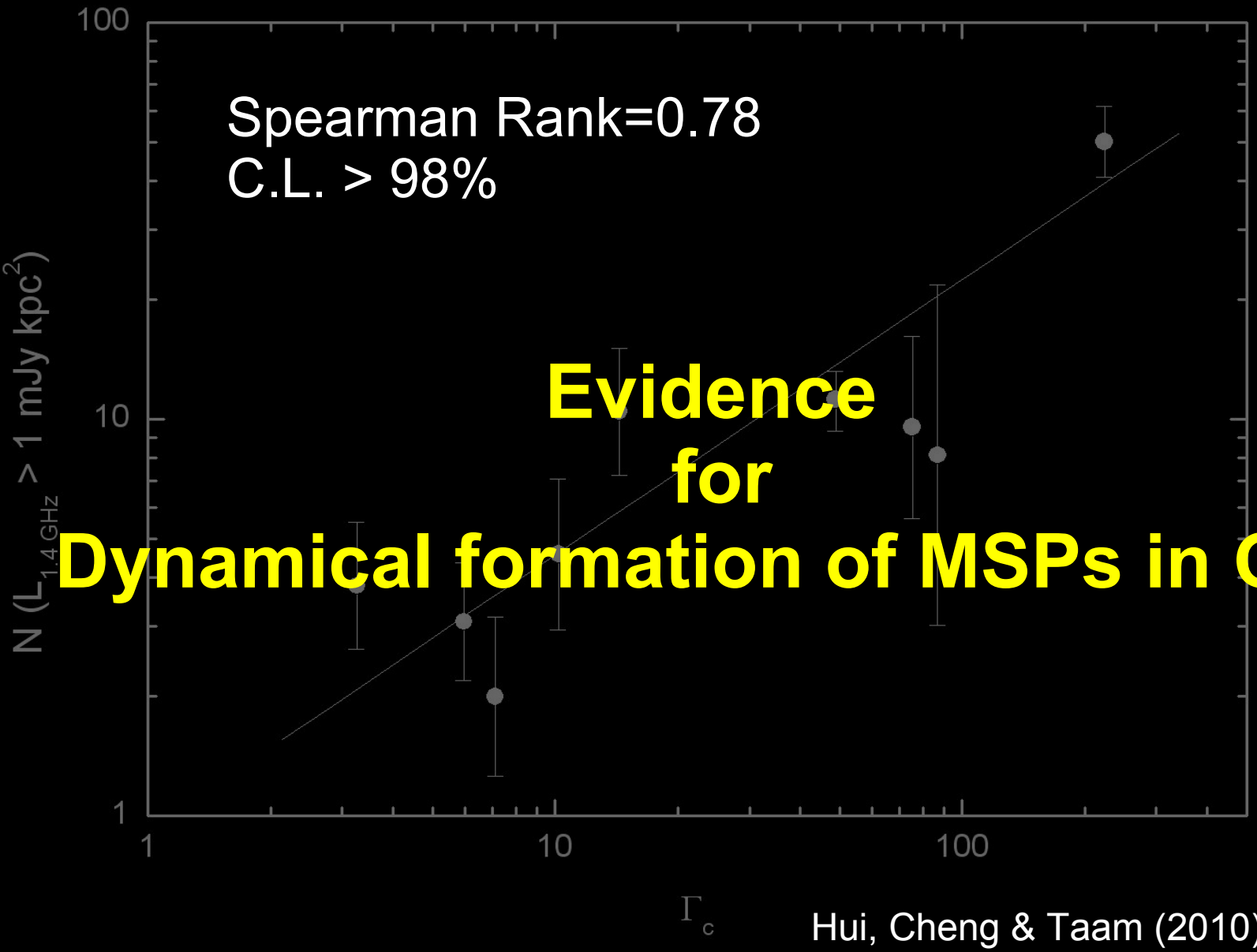
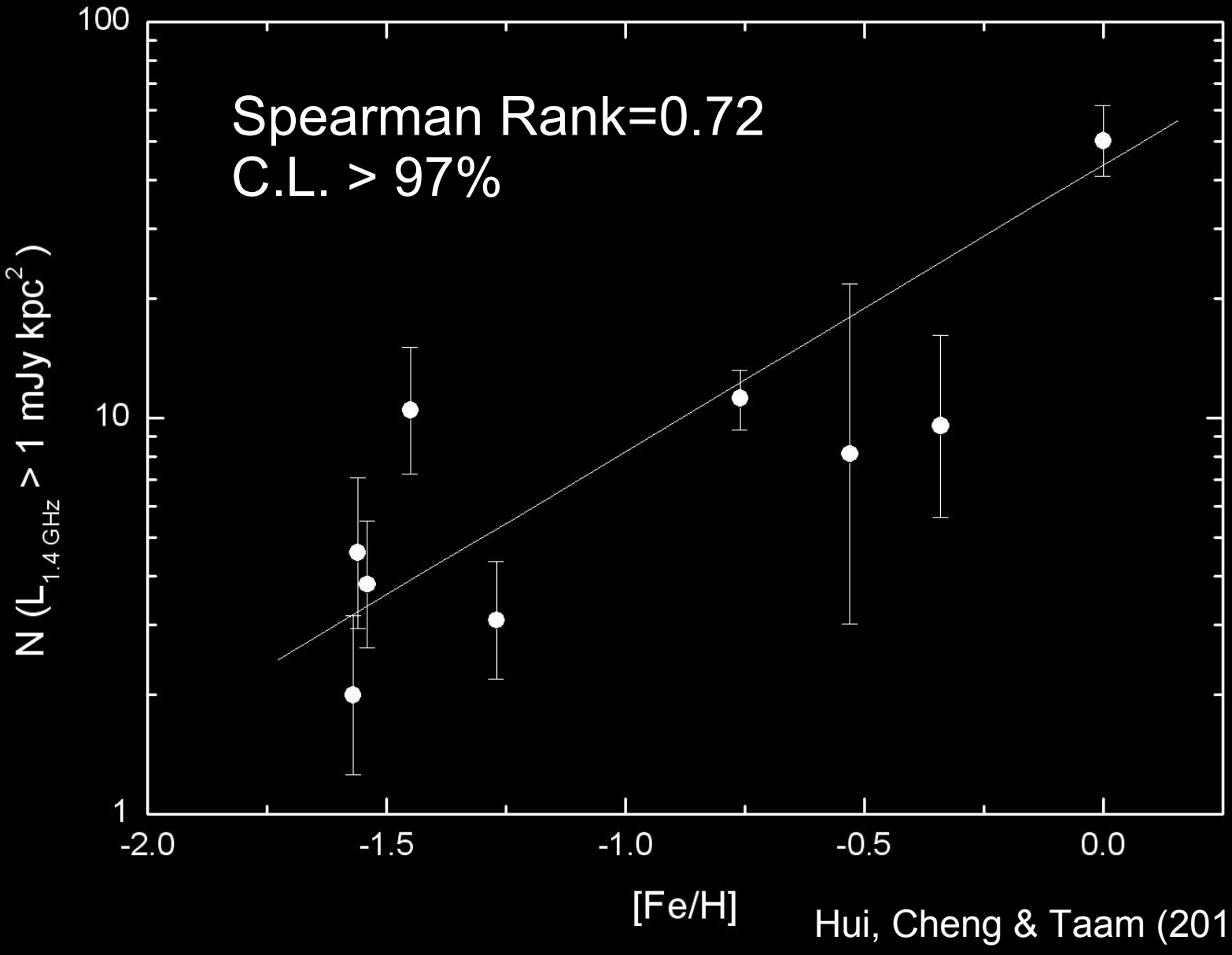


Evidence for Dynamical formation of MSPs in GCs

Hui, Cheng & Taam (2010)

MSPs in Globular Clusters

Correlation with Metallicity

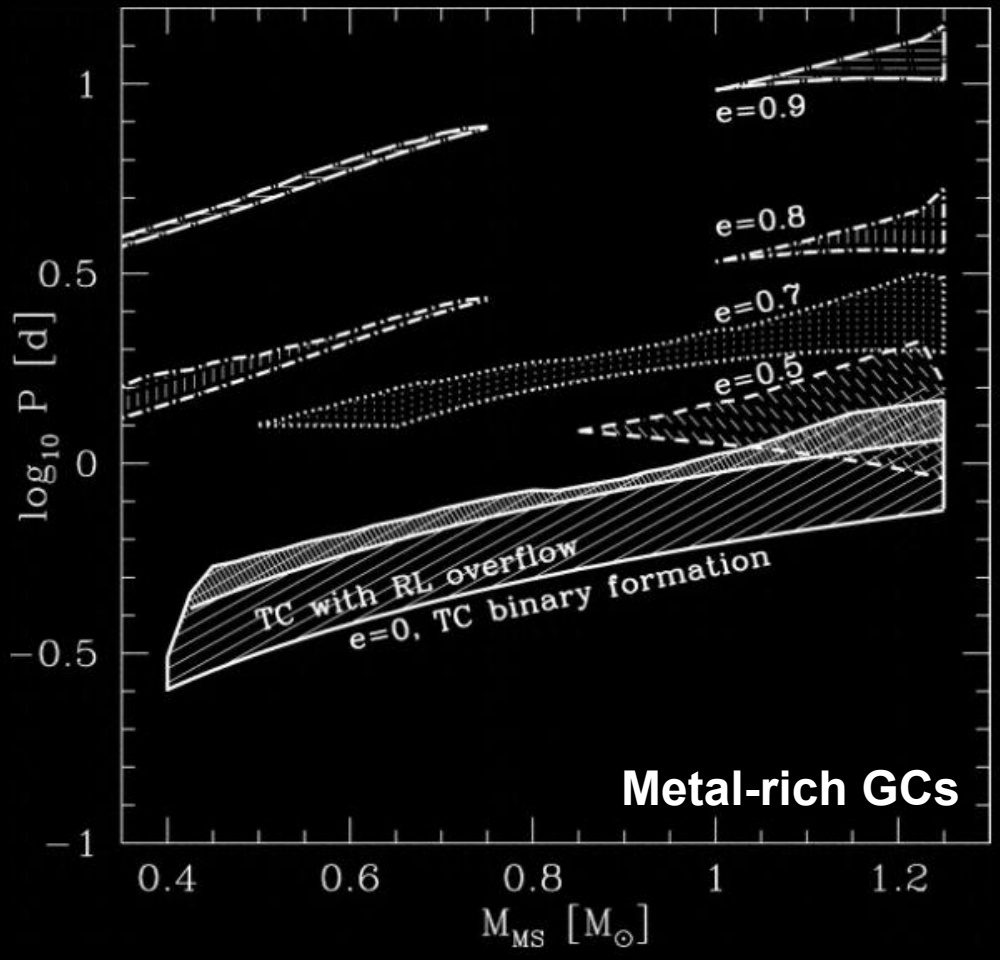


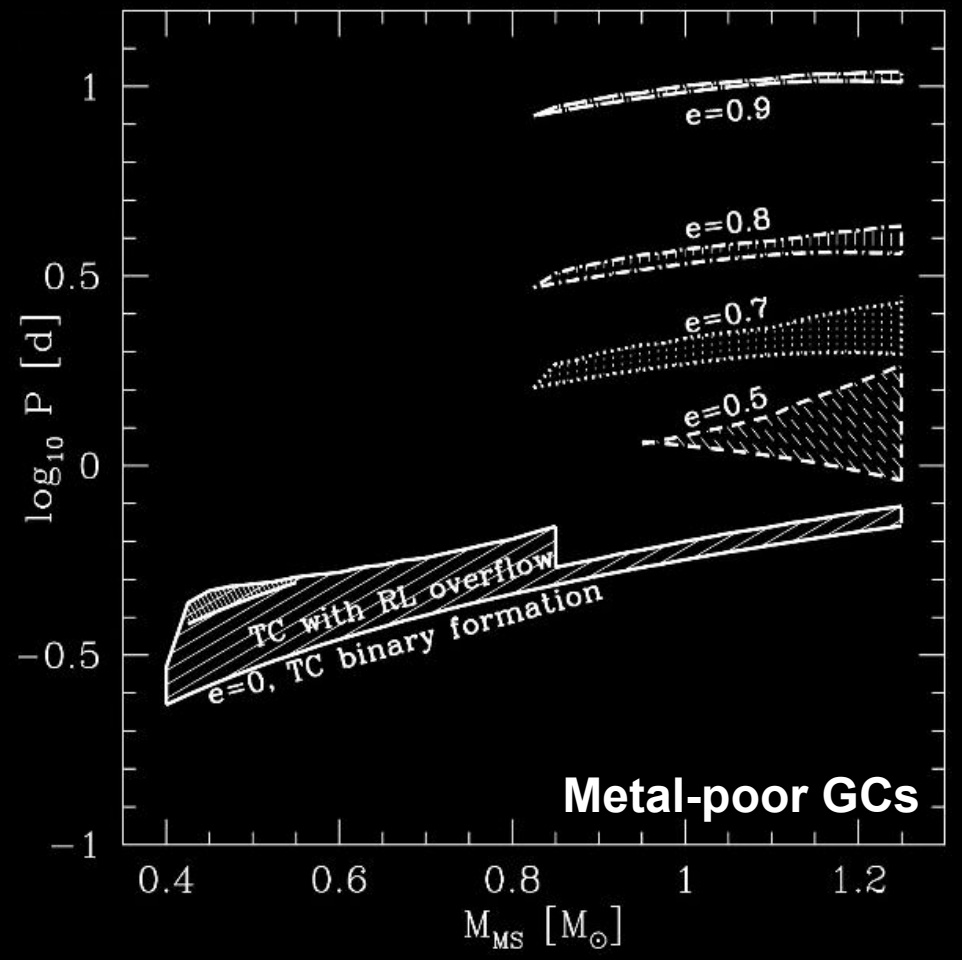
Hui, Cheng & Taam (2010)

MSPs in Globular Clusters

Absence of outer convective layer in metal-poor MS donors precludes the orbital shrinkage through magnetic braking

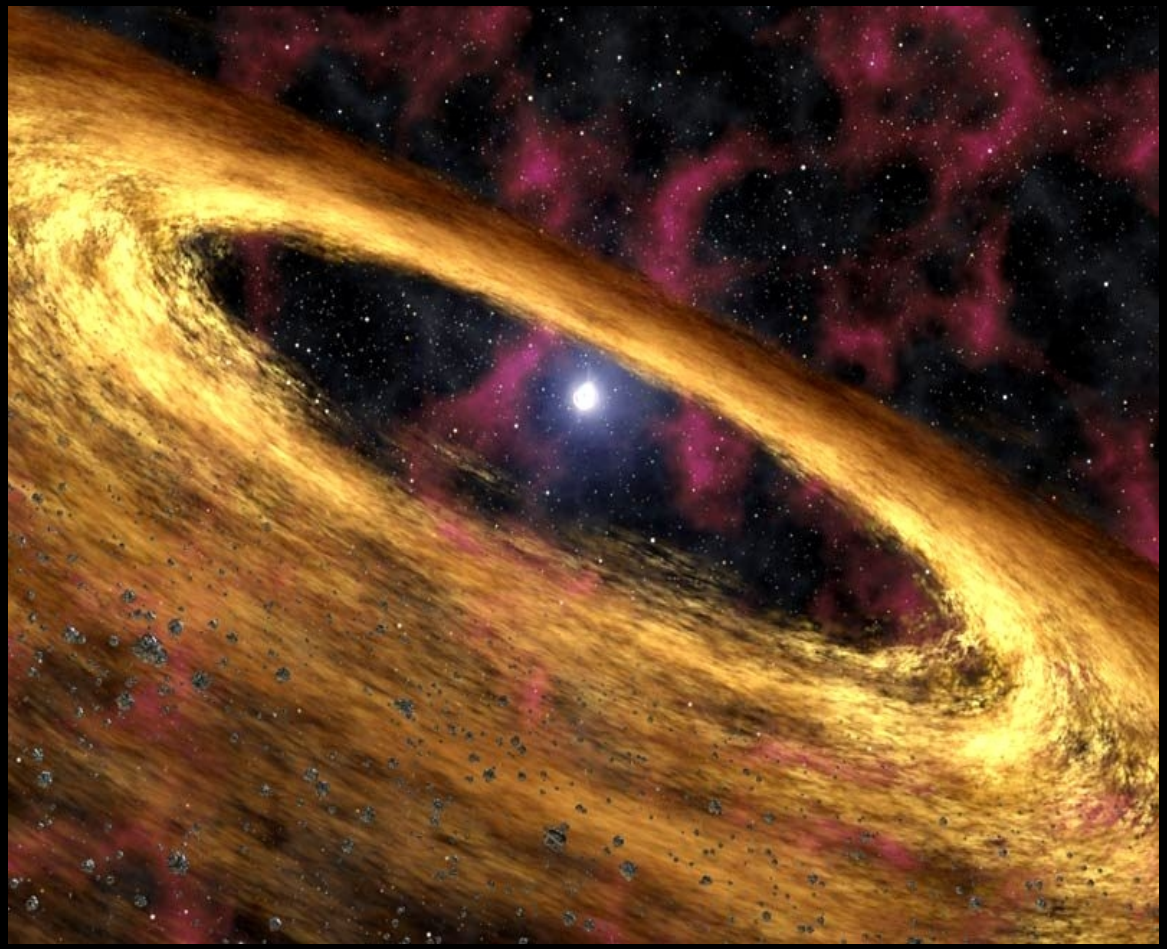
Significantly reduce the parameter space for successful mass-transfer in NS-MS binaries (Ivanova 2006).





MSPs in Globular Clusters

- MSPs in GCs have likely been recycled for multiple times
- In each LMXB phase, accretion might not be in the same plane



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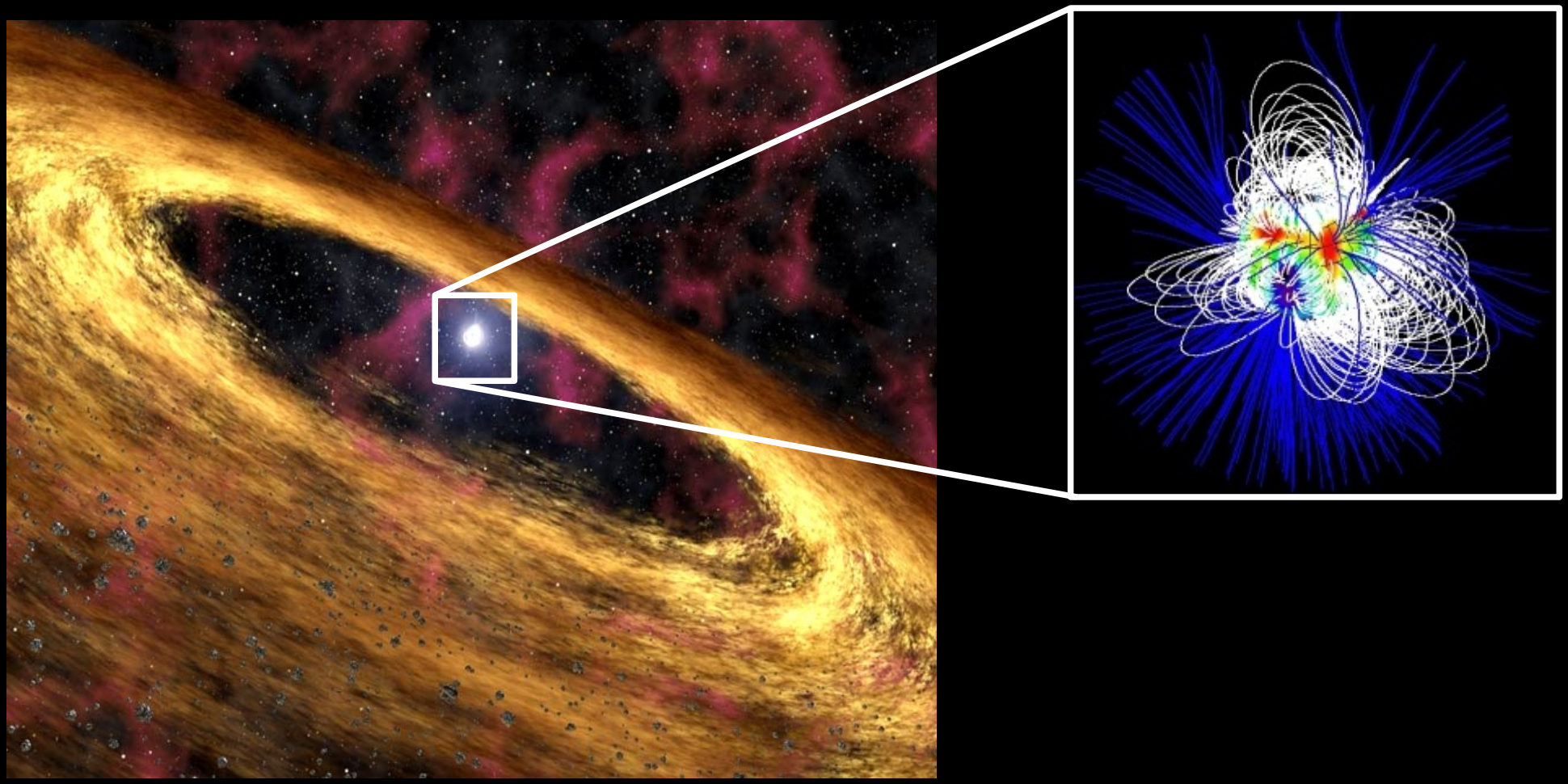

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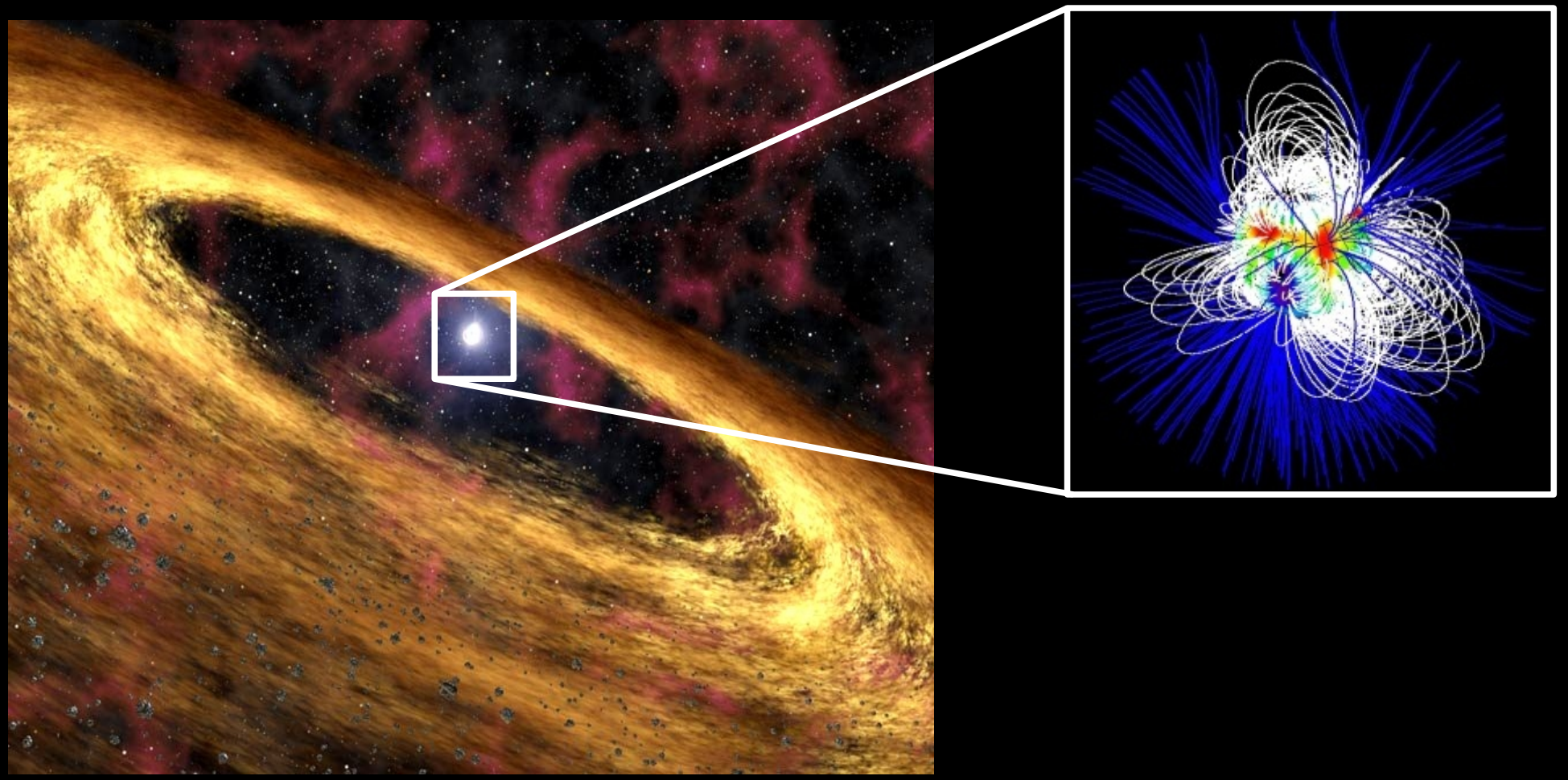
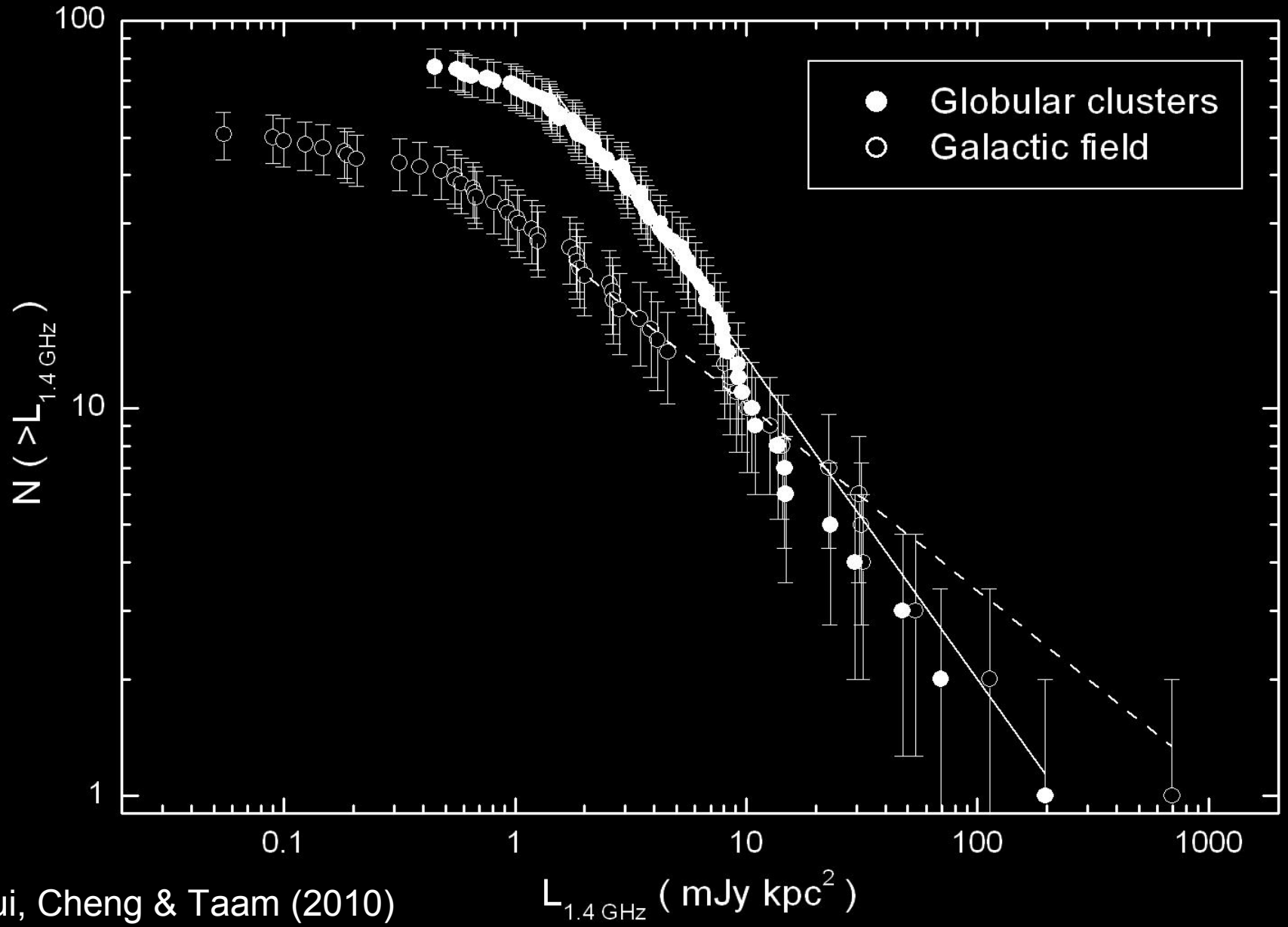
- RESULT: **1.** A complicated B-field on the NS surface (Cheng & Taam 2003)
  2. Different emission properties in comparison the MSPs in the Galactic field



Radio Properties of GC MSPs

Radio Luminosity Function



Hui, Cheng & Taam (2010)

X-ray Properties of MSPs

Galactic Field Population

- Thermal spectral component
  (Heated polar cap)
  +
  Non-thermal PL component
  (Magnetospheric emission)
- Energy dependent pulse profile
  (multiple components)
- Pulsar wind nebulae

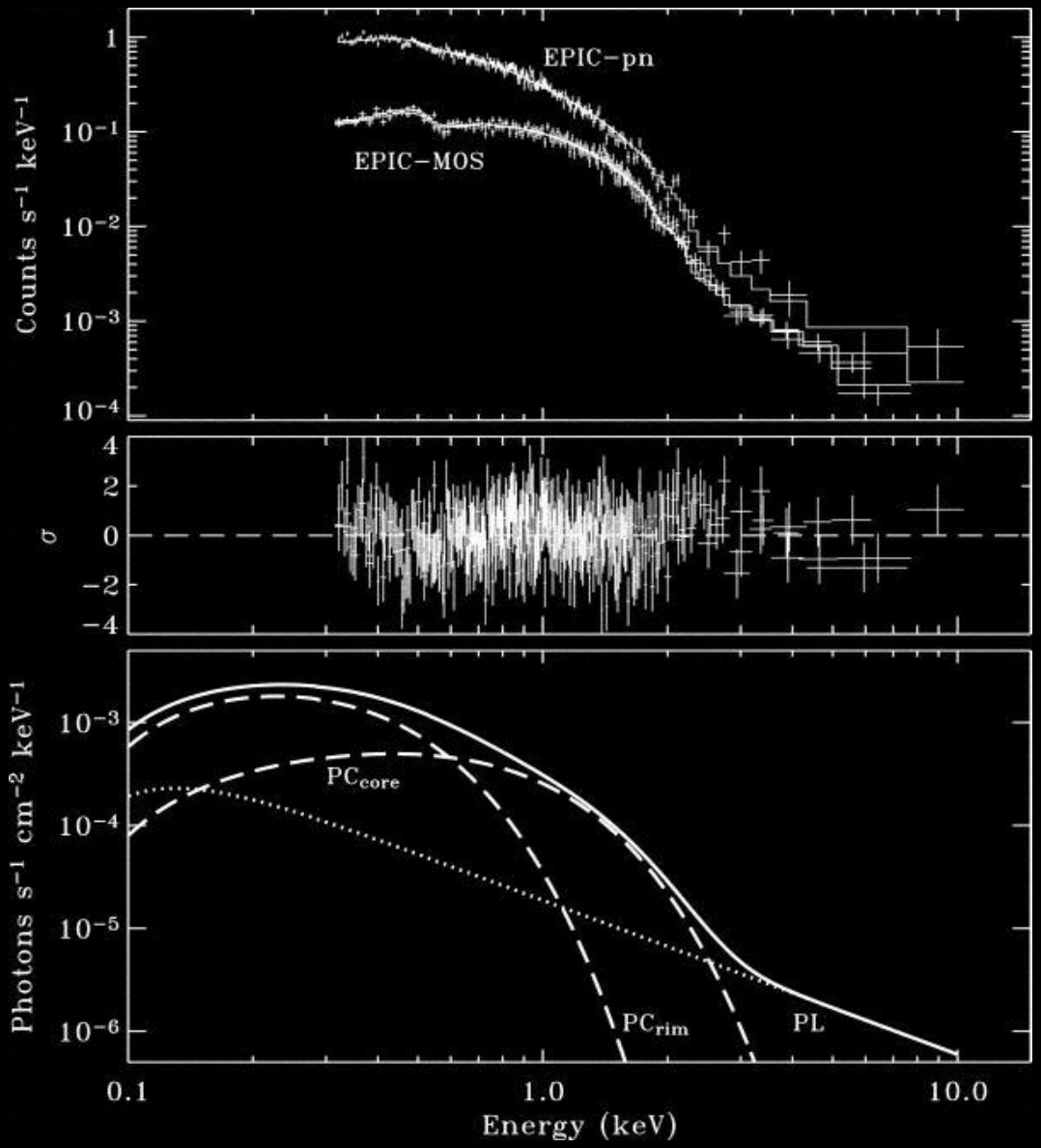
Globular Cluster Population

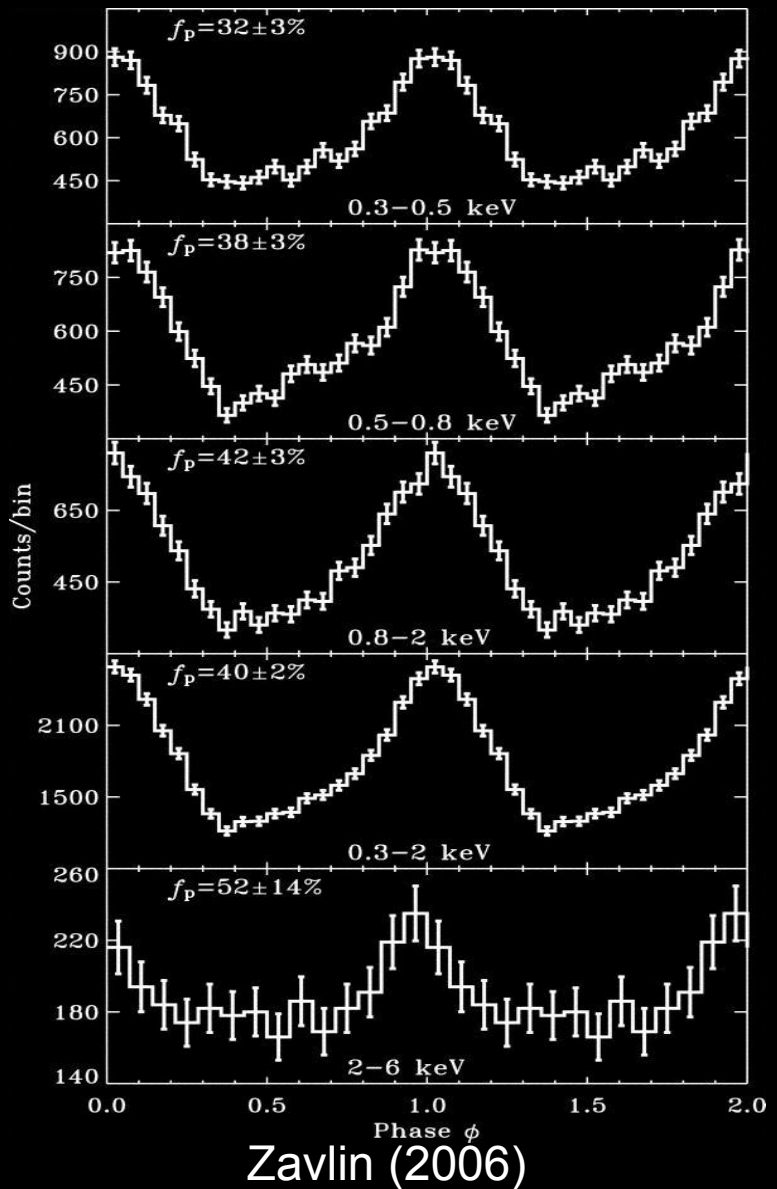
- Majority of the GC MSPs are thermal X-ray emitters
- Pulse profile (unknown)
- No conclusive evidence for pulsar wind nebulae in X-ray

X-ray Properties of MSPs

Examples of MSPs in Galactic Field

Spectrum & energy resolved light curves of PSR J0437-4715



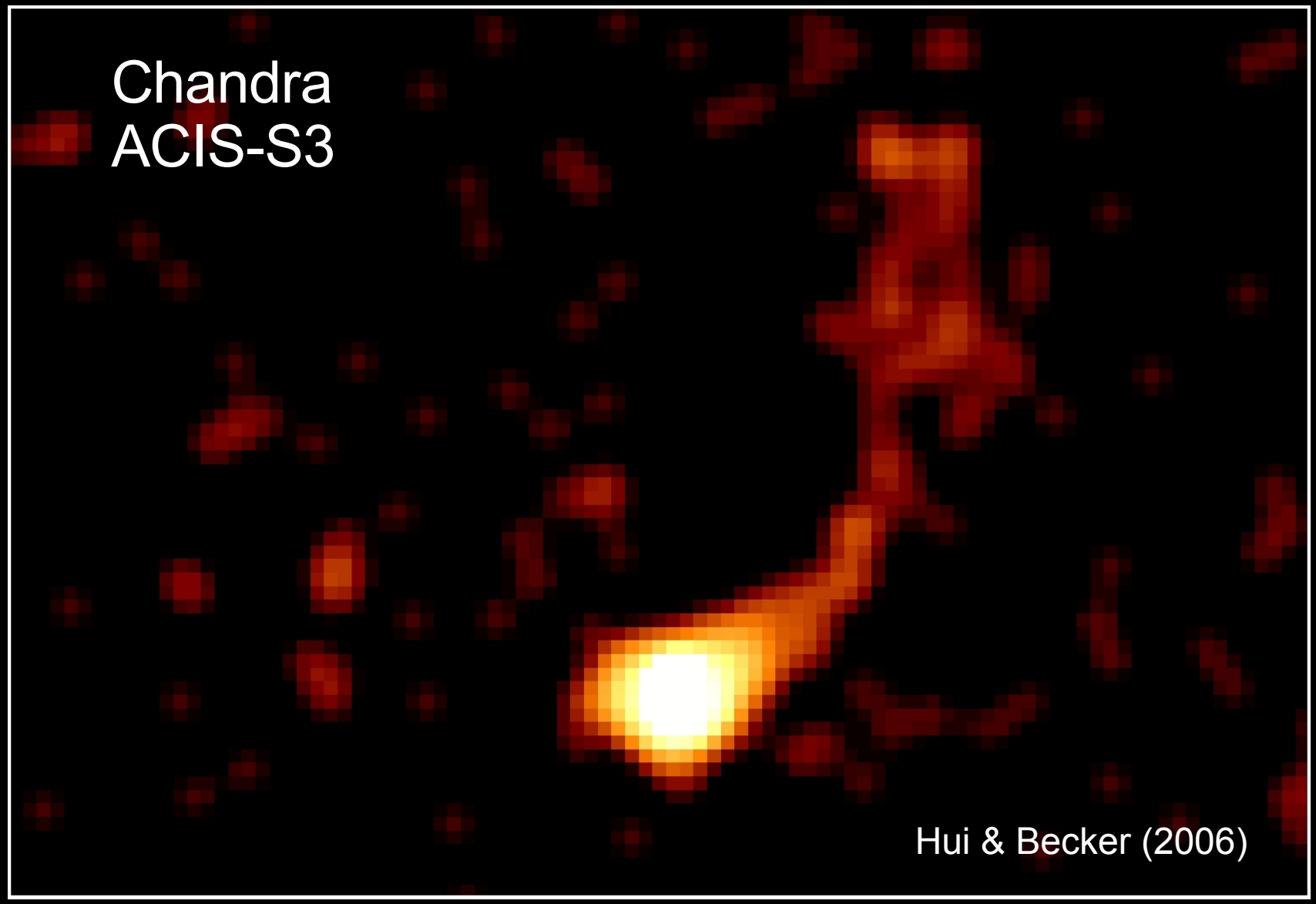


Zavlin (2006)

X-ray Properties of MSPs

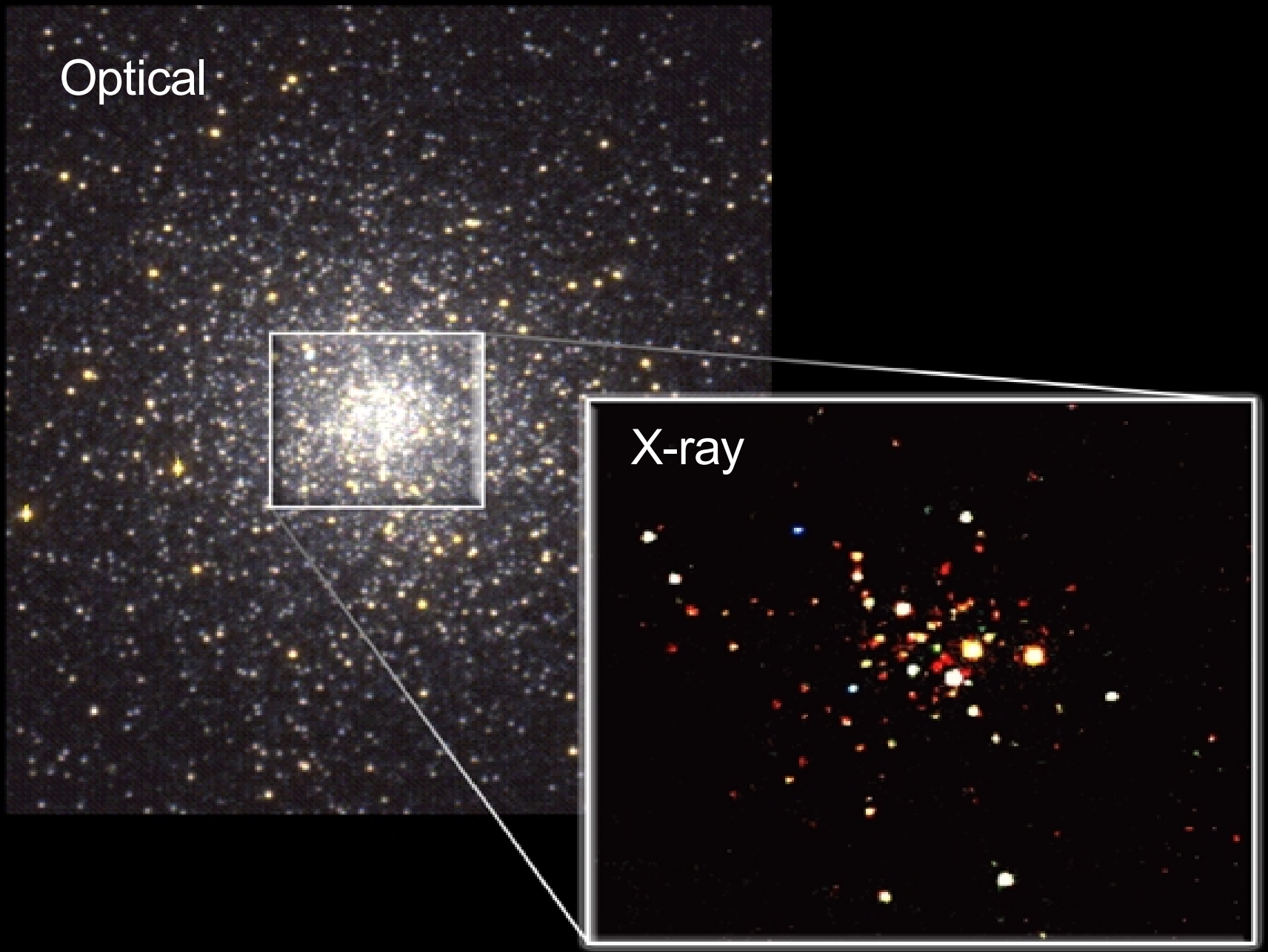
Examples of MSPs in Galactic Field

Pulsar wind nebulae associated with isolated PSR J2124-3358



X-ray Properties of MSPs

MSPs in Globular Clusters – 47 Tuc



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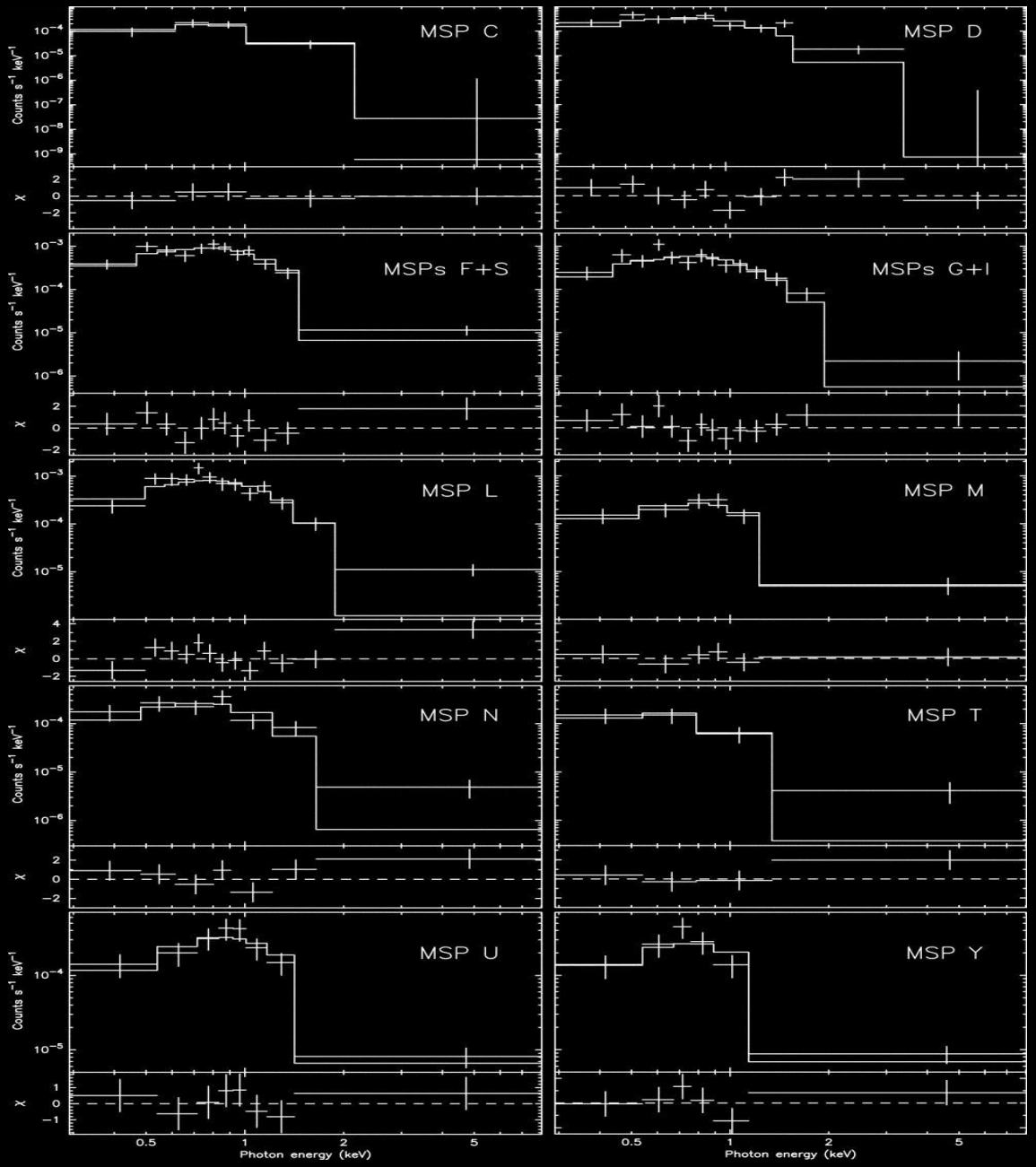

Bogdanov et al. (2006)

X-ray Properties of MSPs

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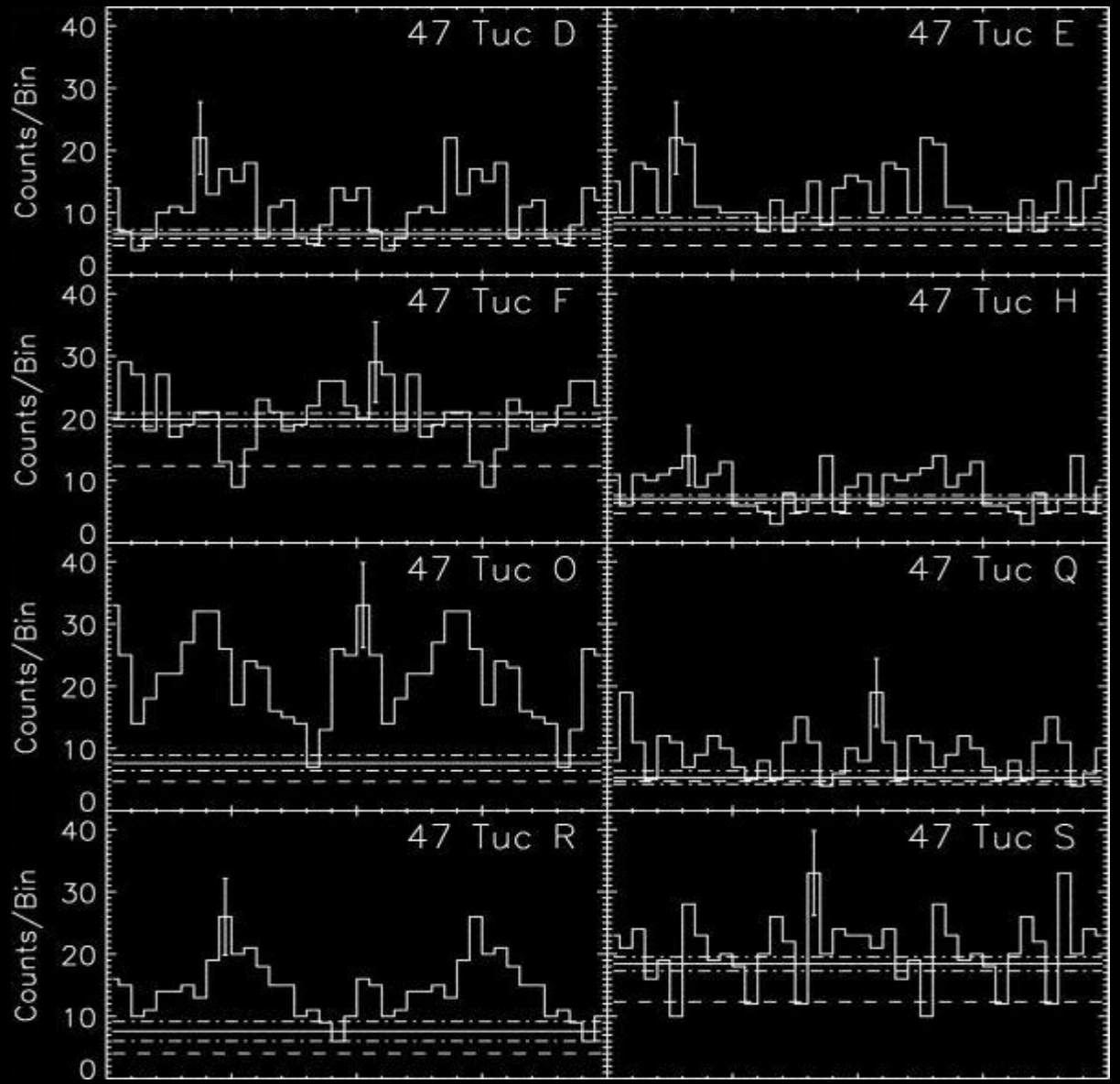


Cameron et al. (2007)

X-ray Properties of MSPs

Evidence for Pulsar Wind in GCs?

Intracluster gas density

Difference of dispersion measures of MSPs in 47 Tuc suggests tenuous plasma in the center:

$$n_e = (0.067 \pm 0.015)\ \mathrm{cm}^{-3}$$ (Freire et al. 2001)

Assuming one proton for every free electron: $M_{gas} \sim 0.1\ M_\odot$

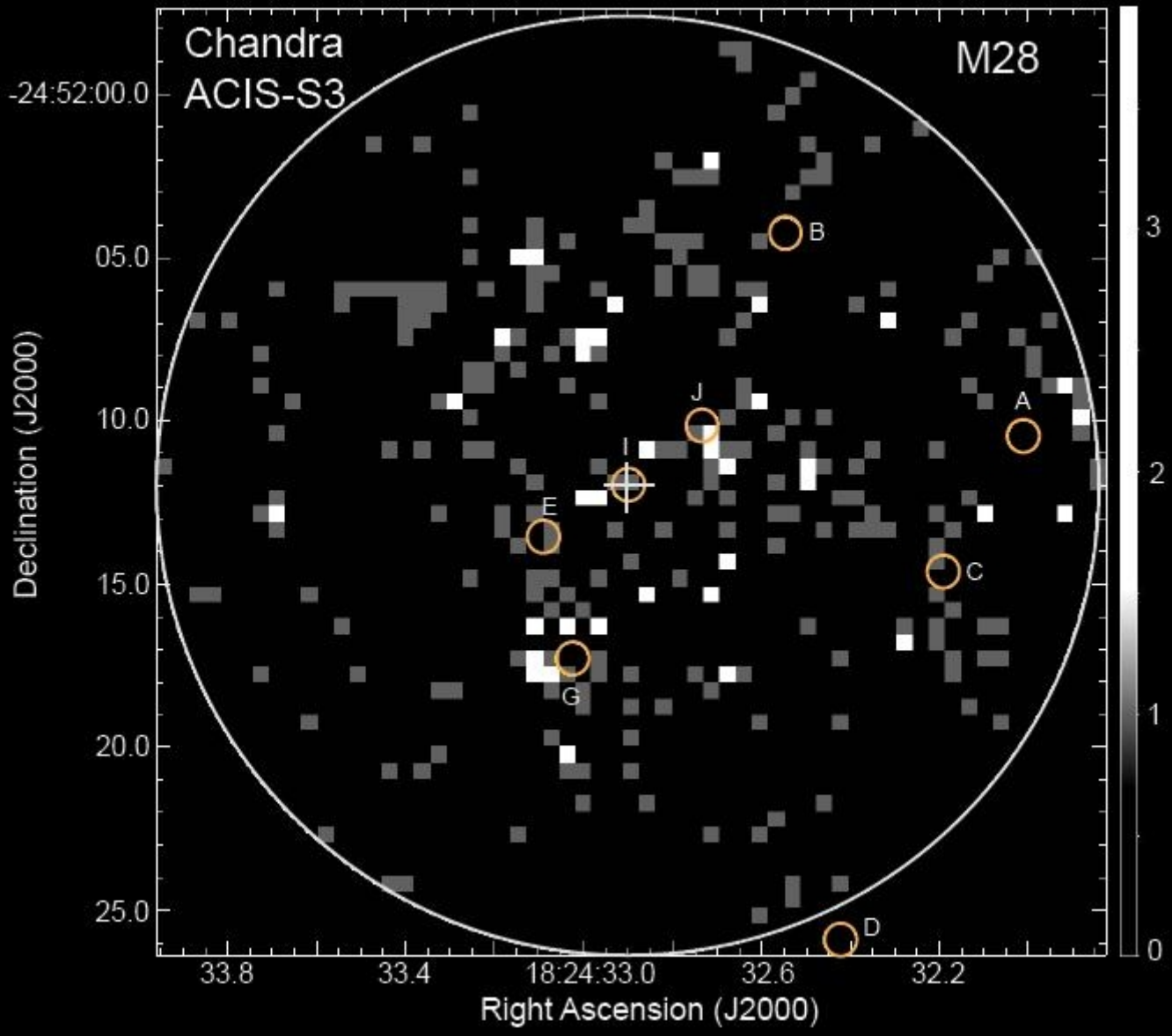
$100\ M_\odot$ expected to accumulate when GC past through the Galactic disk in ~$10^{7\text{-}8}$ yrs

Spergel (1991) proposed that the relativistic wind of MSPs expel most of the gas

X-ray Properties of MSPs

Evidence for Pulsar Wind in GCs?

Diffuse X-rays in GC cores



Detailed investigations show that the diffuse X-rays in the clusters are the blend of unresolved point sources.

No evidence for PWNe can be found in X-ray observations.

Hui, Cheng & Taam (2009)

X-ray Properties of MSPs

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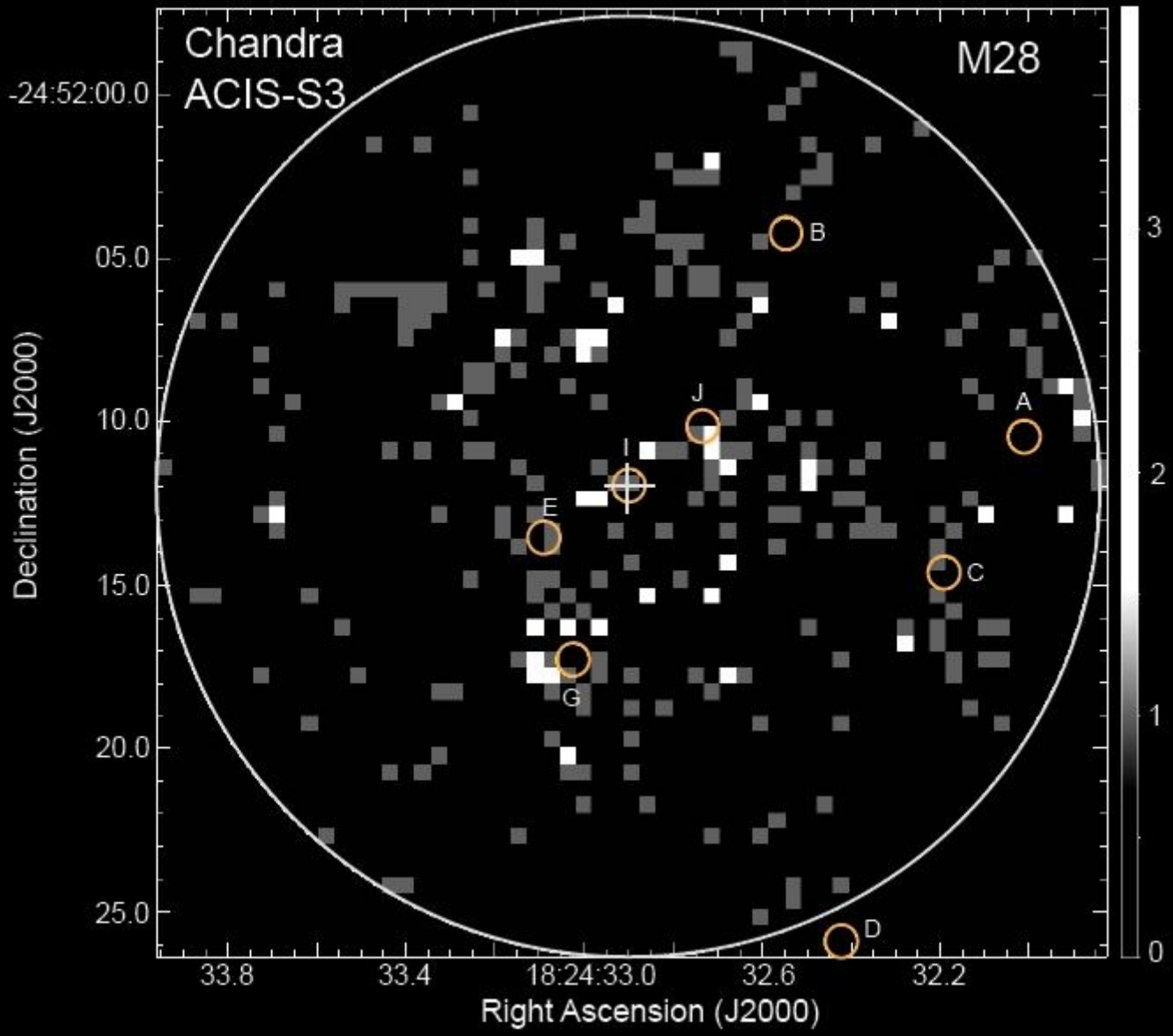

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Where does the energy of pulsar wind go?

Hui, Cheng & Taam (2009)

Cooling of the Relativistic Particles

Synchrotron Cooling vs Inverse Compton Scattering

$$\frac{P_{\rm ICS}}{P_{\rm syn}} = \frac{U_{\rm rad}}{U_{\rm B}}$$

For intracluster *B*-field of few μG and the typical starlight energy density in the core:

$$\frac{U_{\rm rad}}{U_{\rm B}} \gtrsim 100$$

ICS predominates in GC cores!

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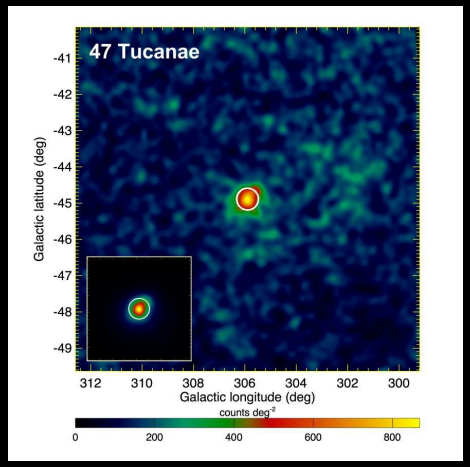
Mean energy gain in a single collision: $\left\langle \Delta E_\gamma \right\rangle \sim \gamma^2 \beta^2 E_\gamma$

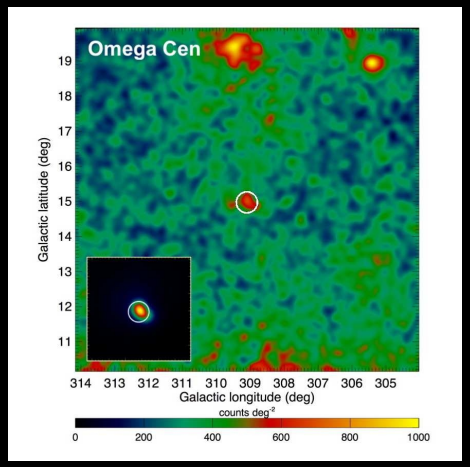
Pulsar wind can easily boost a soft photon to γ-ray regime

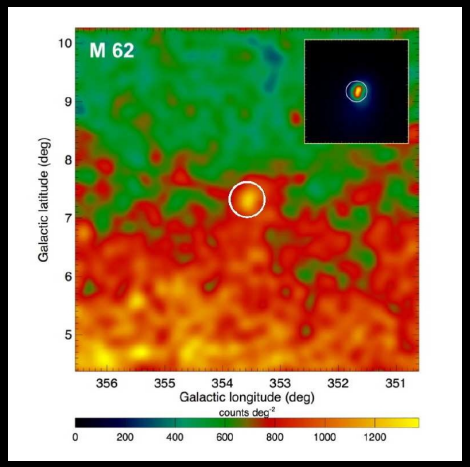
Gamma-ray Emission from GCs

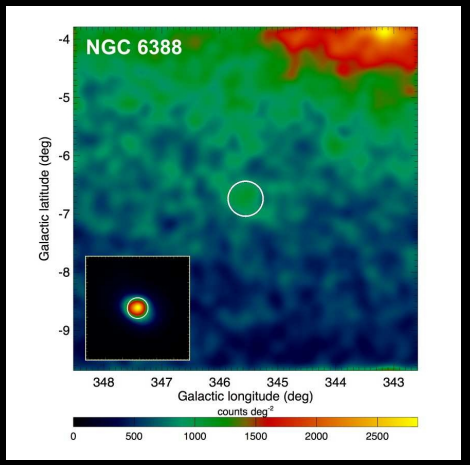
Significant Detections of 8 GCs

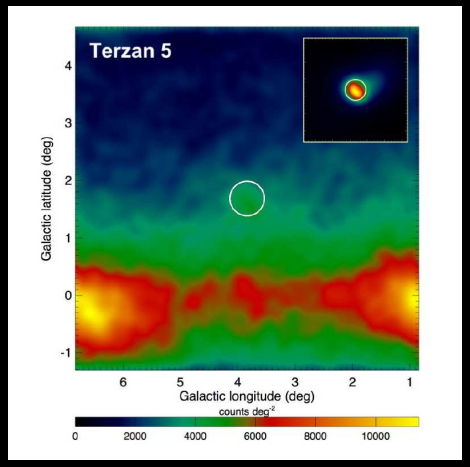
Abdo et al. (2010)

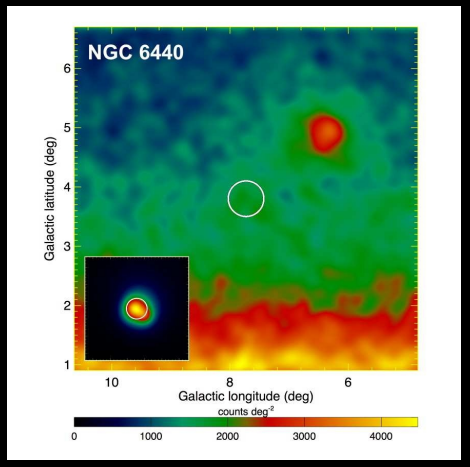


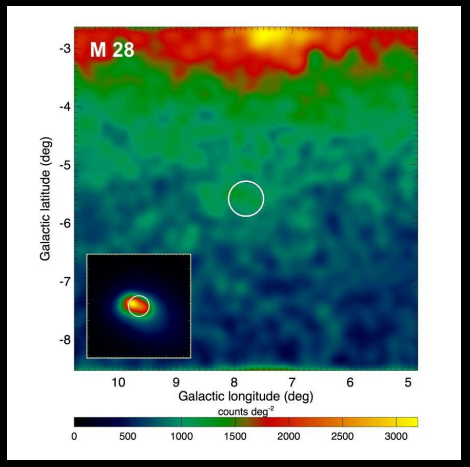


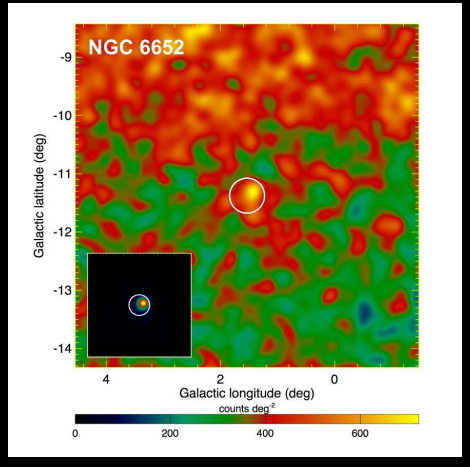




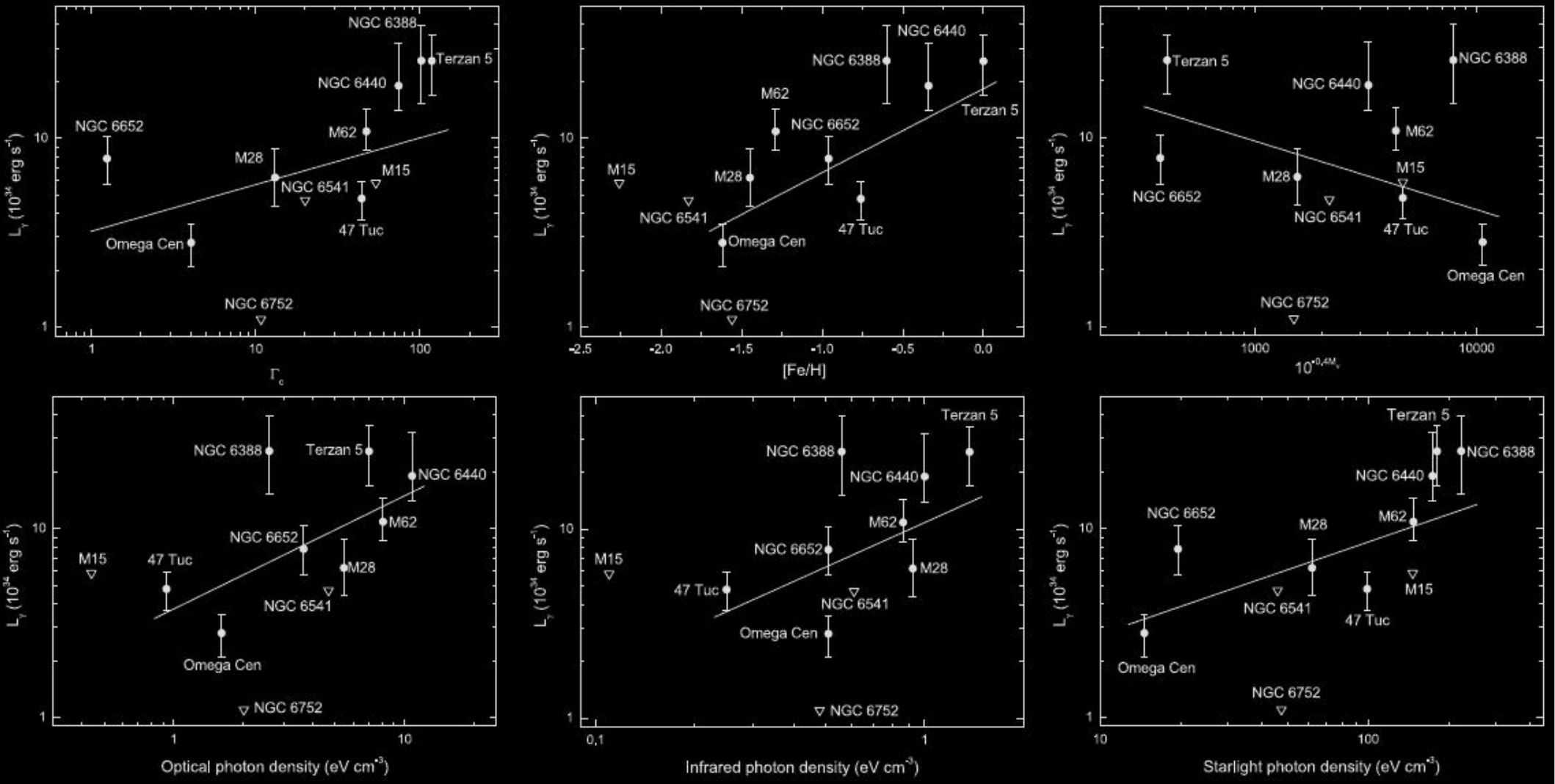








Gamma-ray Emission from GCs

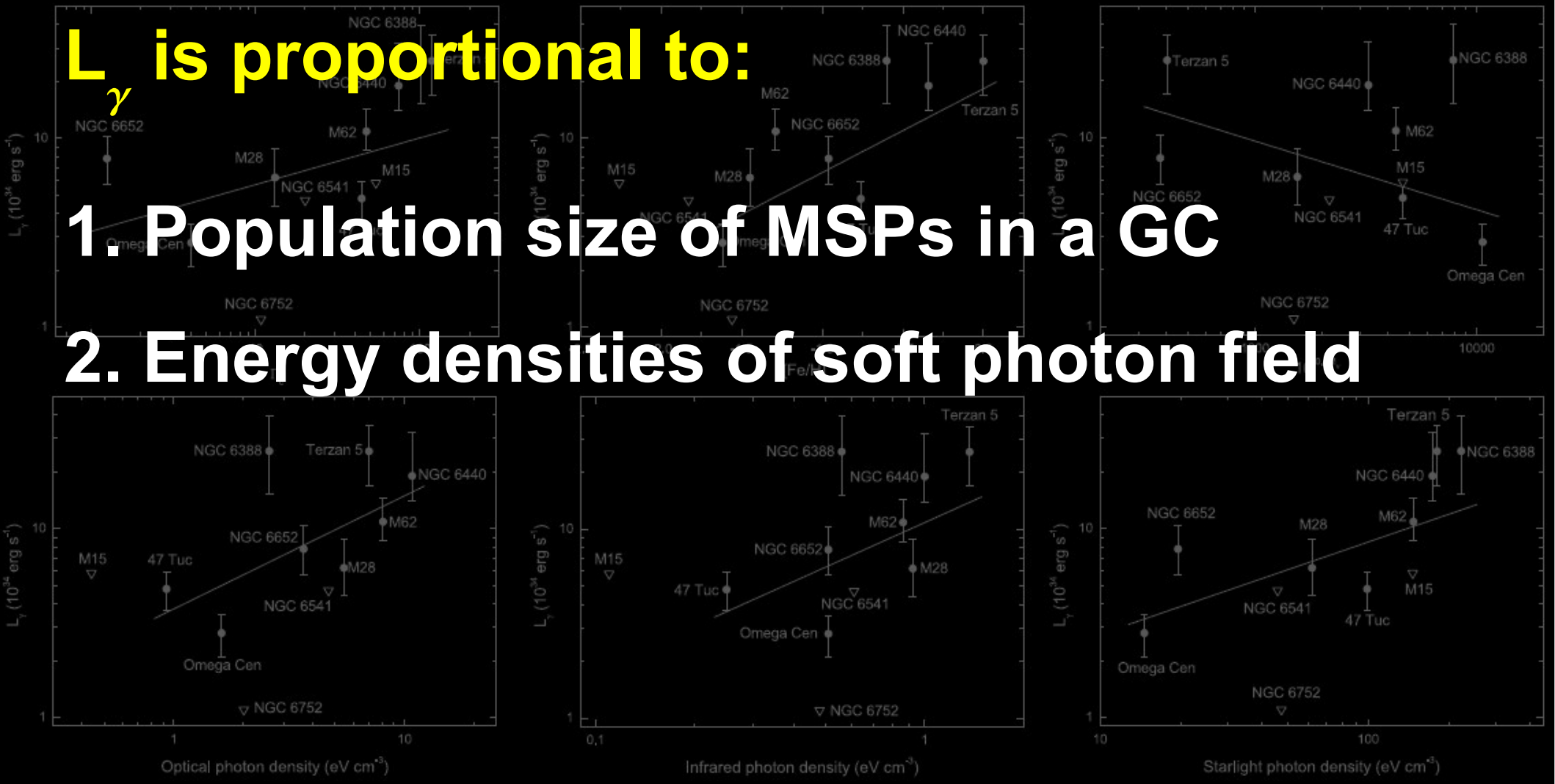


Hui et al. (2010b)

Gamma-ray Emission from GCs

L_γ is proportional to:

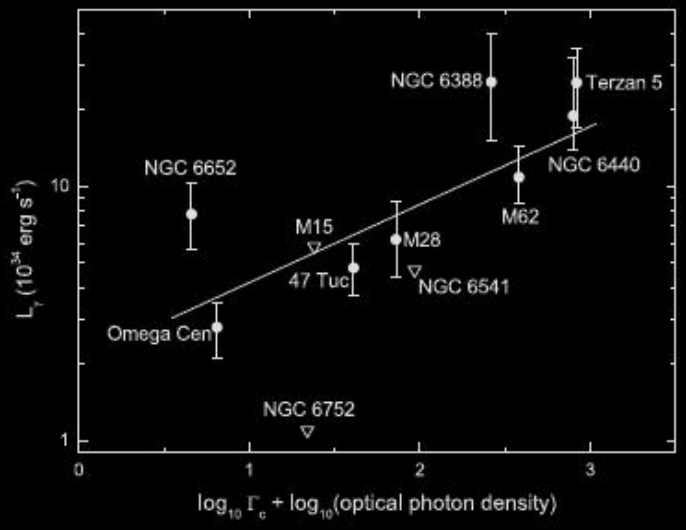
1. Population size of MSPs in a GC
2. Energy densities of soft photon field

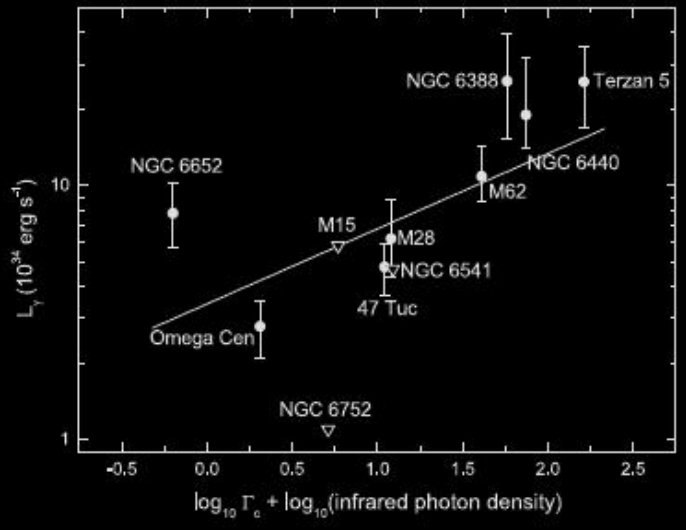


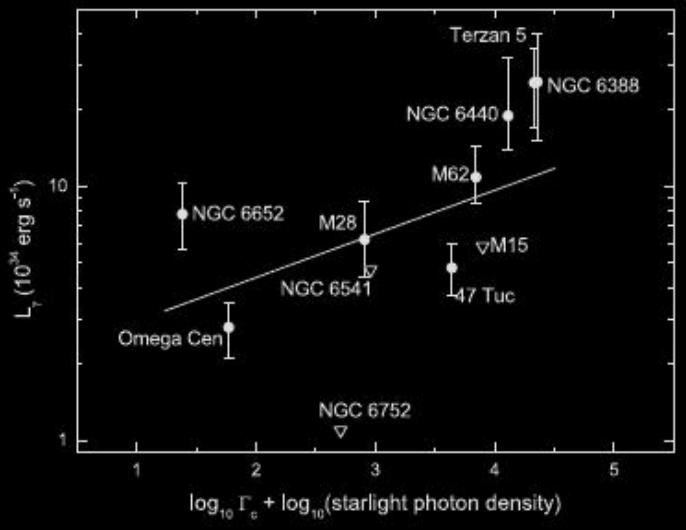
Hui et al. (2010b)

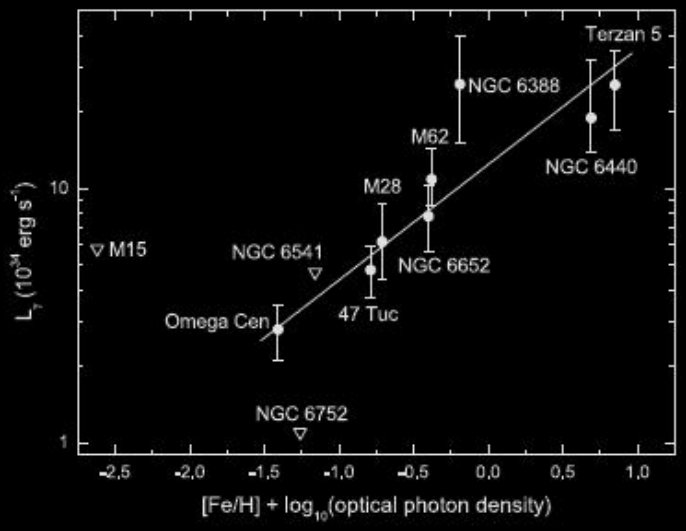
Gamma-ray Emission from GCs

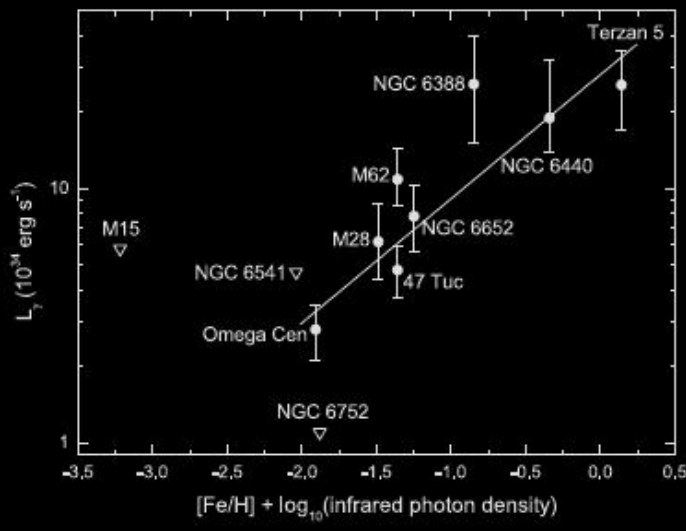
Fundamental Plane of γ-ray Globular Clusters

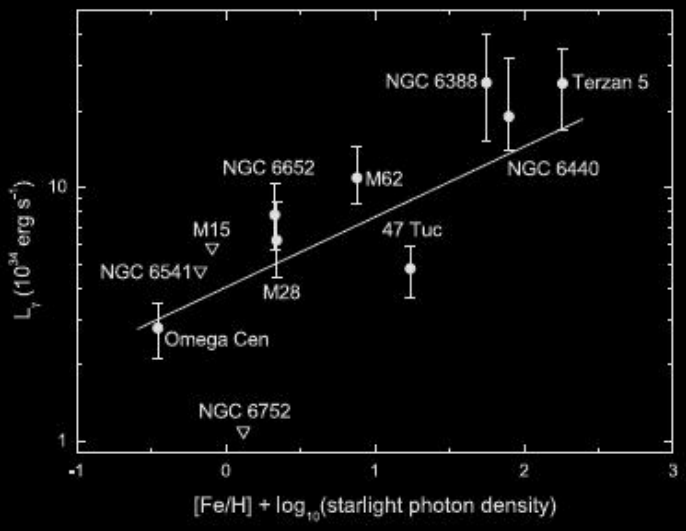












Hui et al. (2010b)

Collaborators

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Albert K.H. Kong (NTHU)

Ronald Taam (TIARA; Northwestern U.)

Thomas P.H. Tam (NTHU)

Y. Wang (HKU)