Disrupted Globular Clusters as the Source of the *Fermi* Excess

Gamma Rays and Dark Matter

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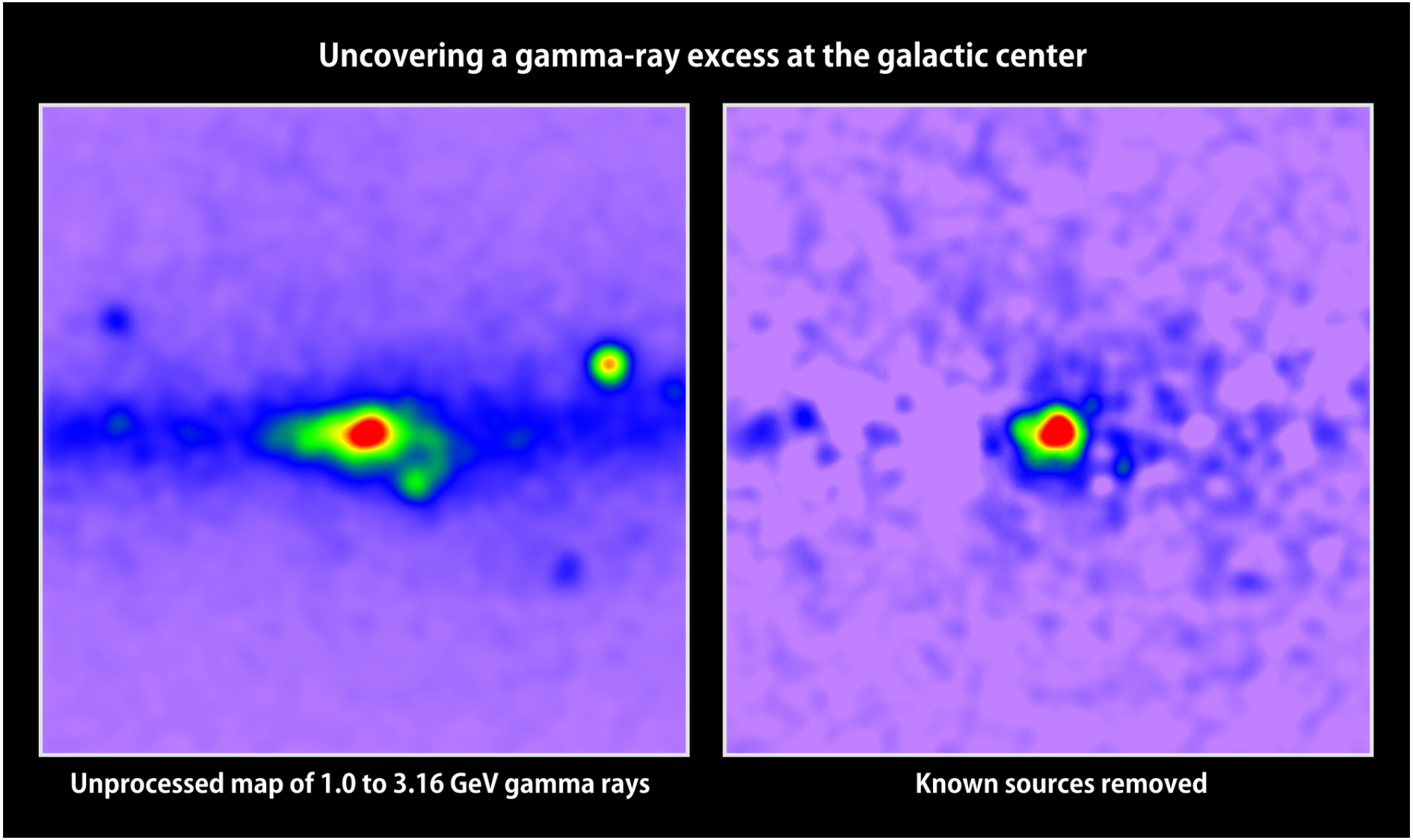
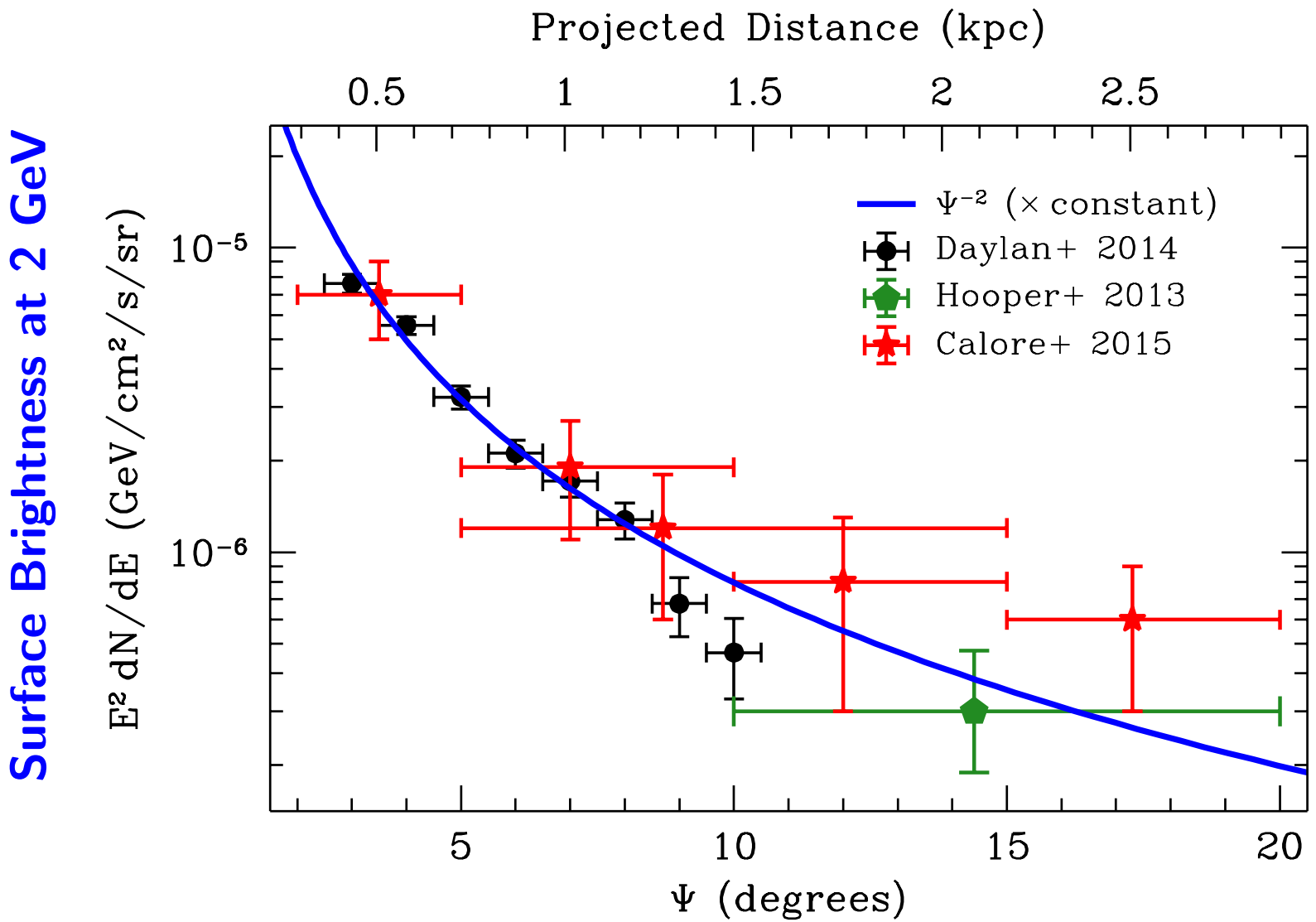
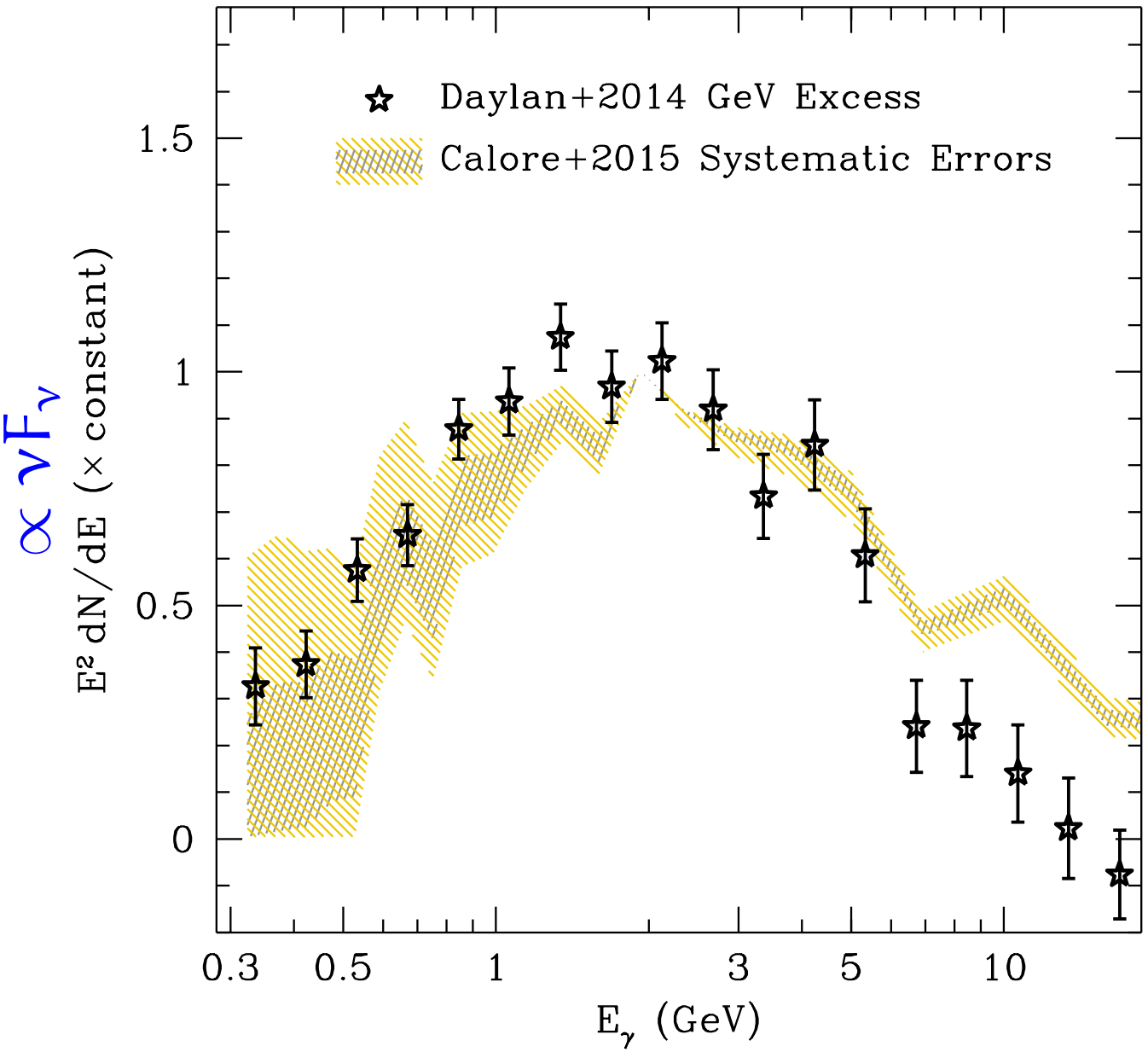
10 December 2015



Daylan et al. (2014)


Surface Brightness at 2 GeV
Projected Distance (kpc)
0.5
1
1.5
2
2.5
$E^2\,dN/dE$ (GeV/cm²/s/sr)
10^{-5}
10^{-6}
Ψ^{-2} (× constant)
Daylan+ 2014
Hooper+ 2013
Calore+ 2015
5
10
15
20
Ψ (degrees)

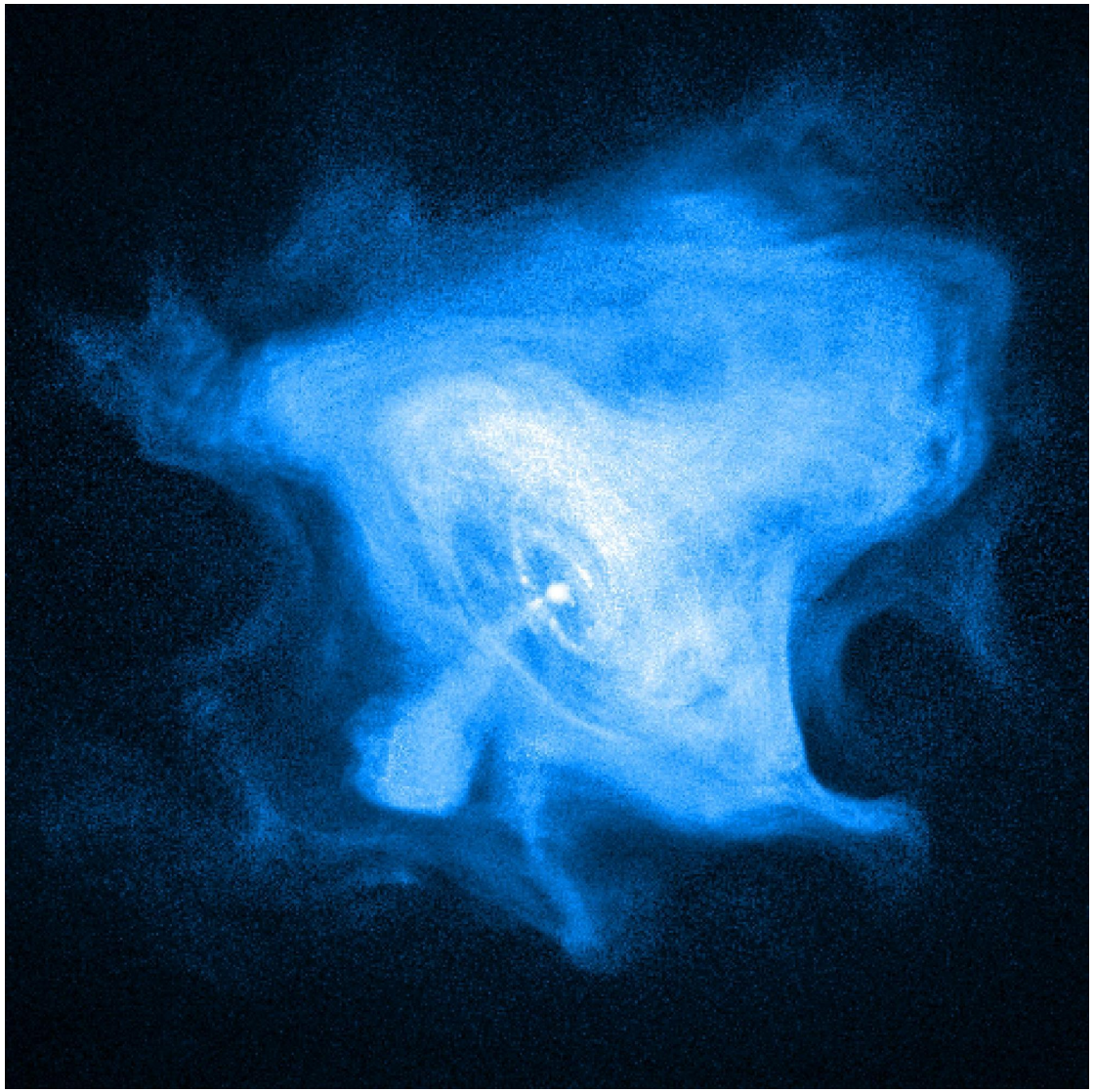

Daylan+2014 GeV Excess
Calore+2015 Systematic Errors
$\propto \nu F_\nu$
$E^2\,dN/dE$ (× constant)
1.5
1
0.5
0
0.3
0.5
1
3
5
10
E_γ (GeV)

- Dark matter annihilation?
- Millisecond pulsars?
- Young pulsars?
- Cosmic ray outbursts?
- Background systematics?

- **Millisecond pulsars?**
  1. How do we explain the observed morphology?
  2. Why aren't the millisecond pulsar progenitors there?
  3. Hard luminosity function–shouldn't we have seen individual pulsars?
  4. And the spectrum isn't quite right?

Normal pulsars:

- $P \sim 1$ s
- $B \sim 10^{12}$ G
- Mostly single
- $t_{spindown} \sim 10^5$ years



Crab pulsar, *Chandra* (X-ray)

Normal pulsars:

- $P \sim 1$ s
- $B \sim 10^{12}$ G
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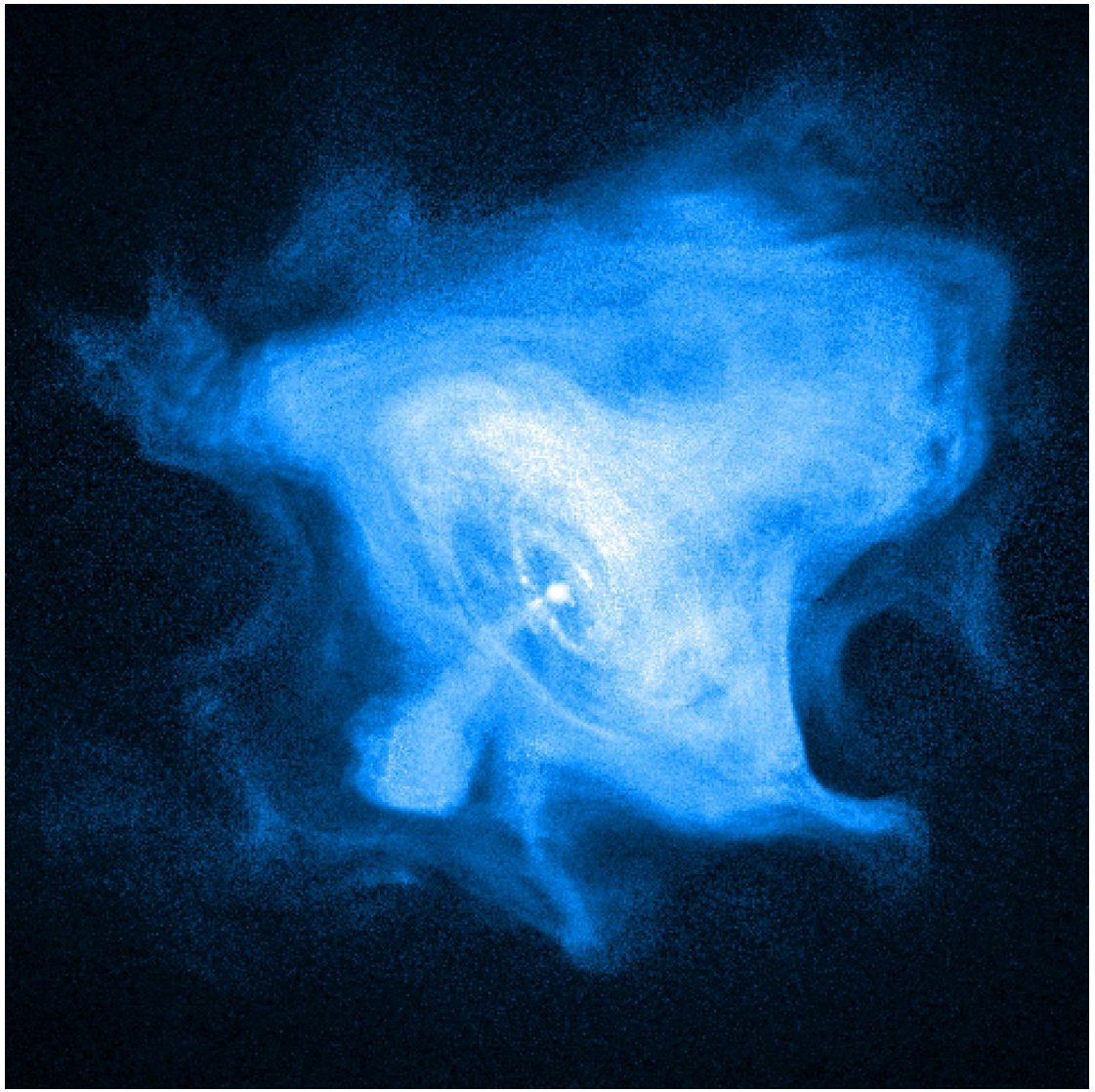
Millisecond pulsars:

- $P \sim 5$ ms
- $B \sim 10^8$ G
- Mostly in binaries
- $t_{spindown} \sim 10^{10}$ years



Crab pulsar, *Chandra* (X-ray)

MSPs: E_{rot} up to 10^{52} erg

"Recycled" pulsars, spun up by mass transfer

Accretion phase: **low-mass X-ray binary (LMXB)**

LMXBs, MSPs **much** more common in globular clusters

47 Tucana, Dieter Willasch

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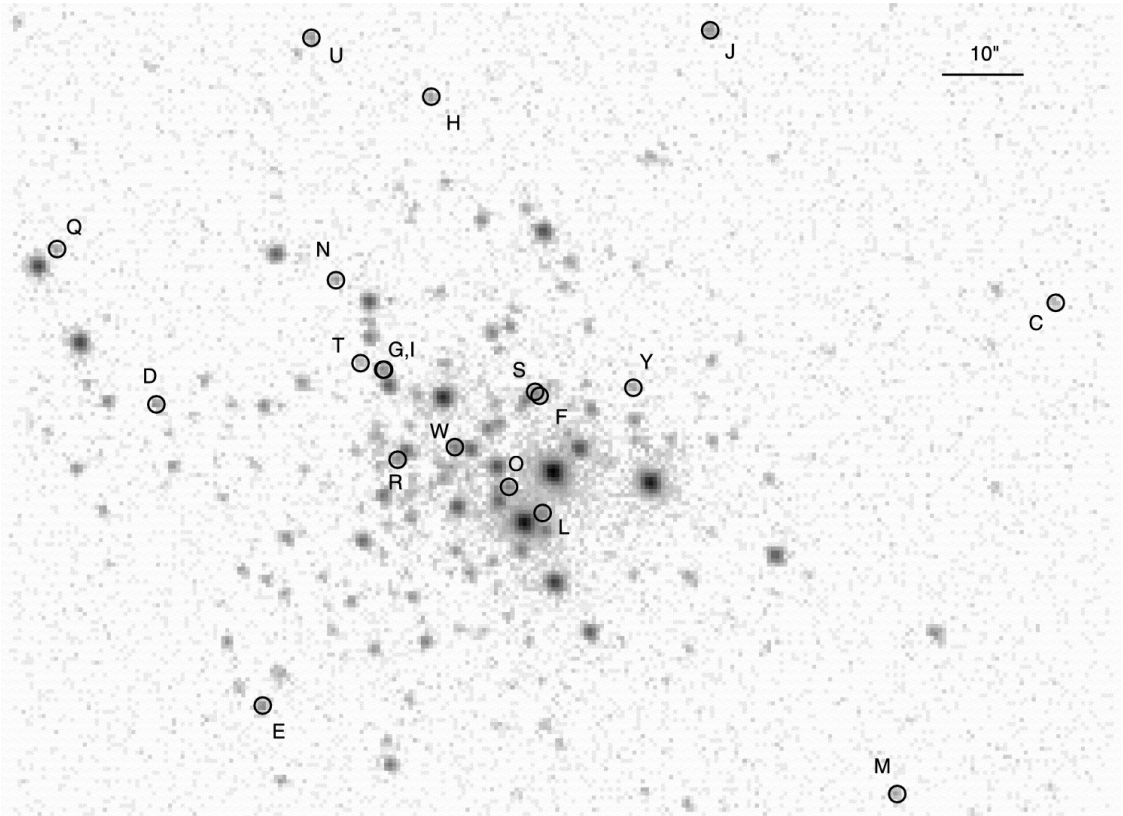
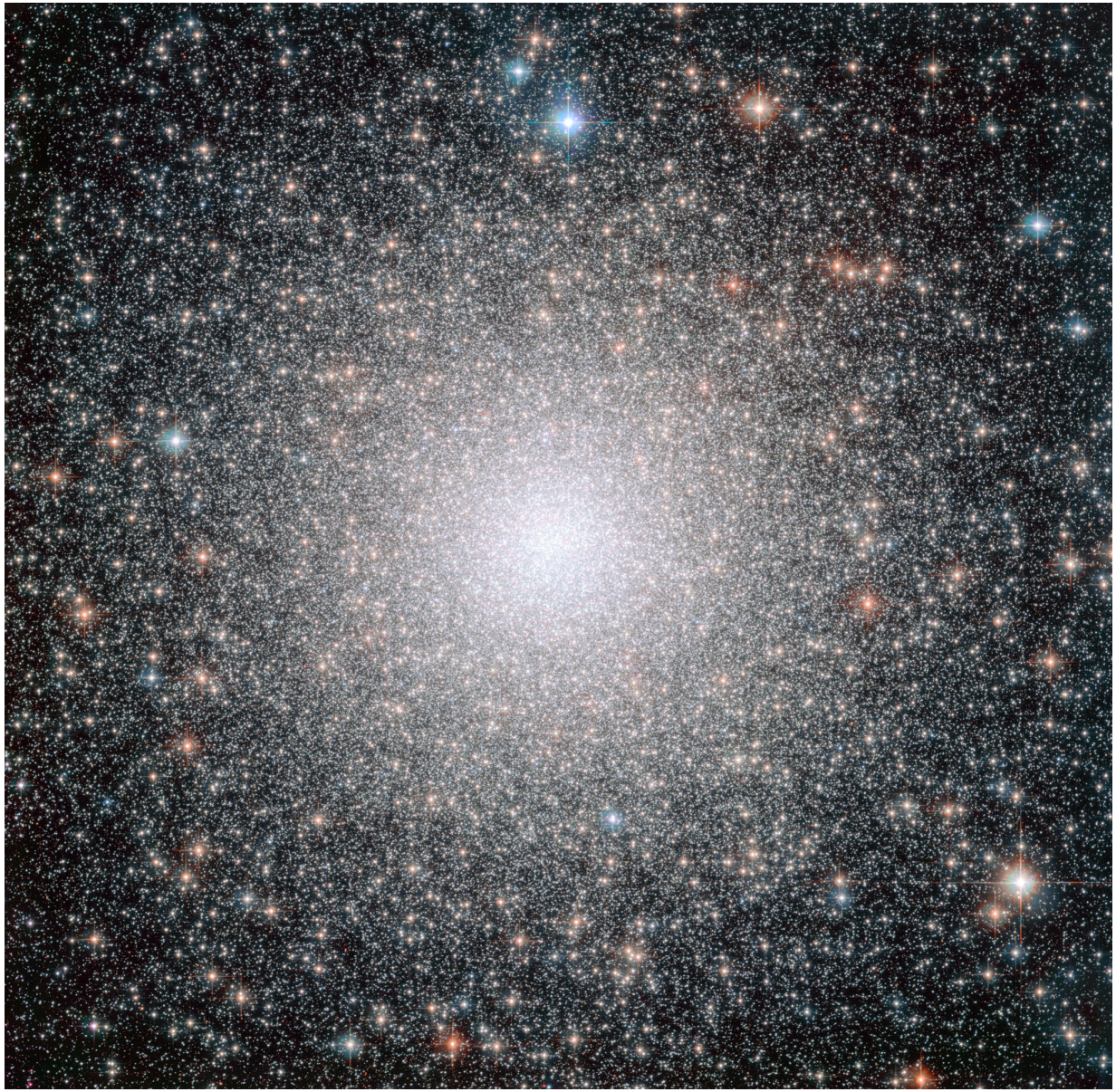


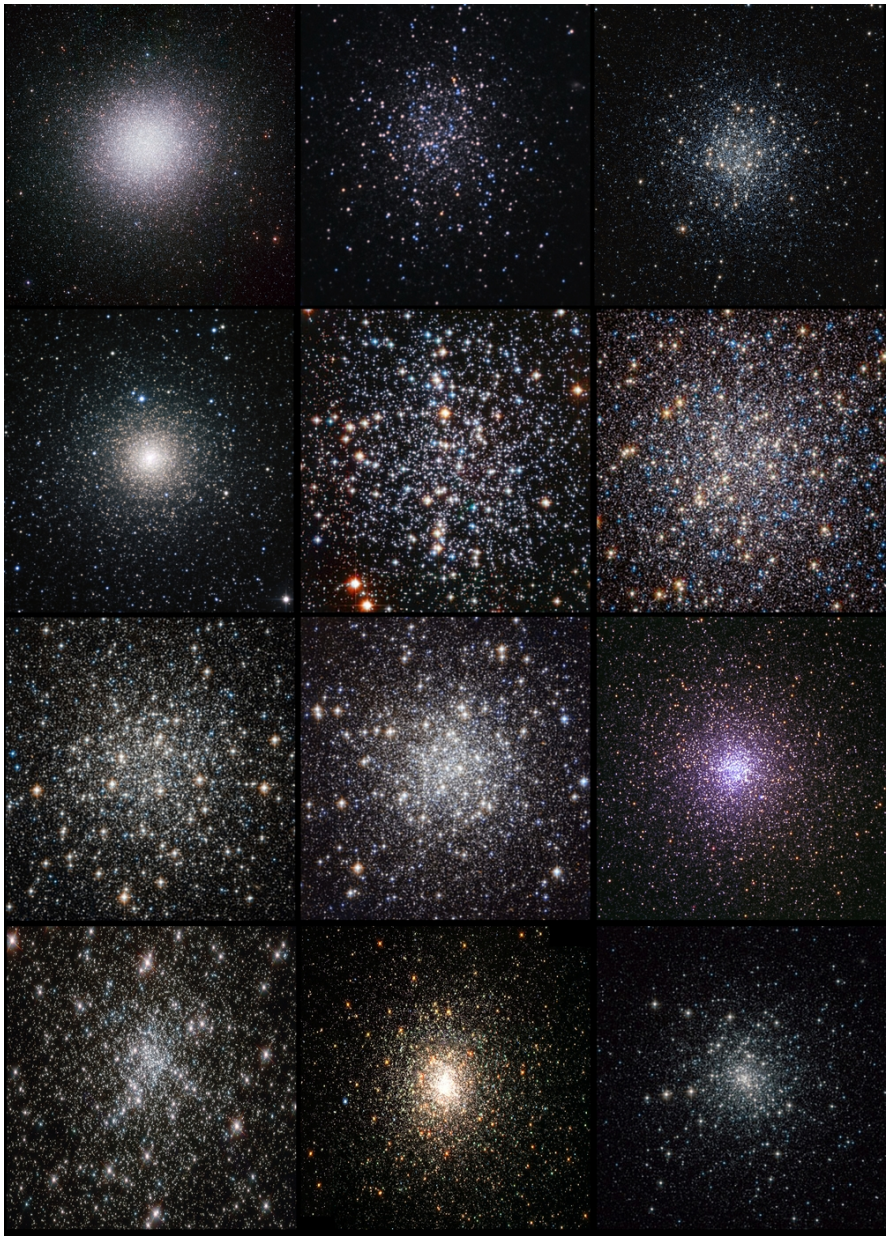
47 Tuc in X-rays, Bogdanov et al. (2006)



NGC 6388, *HST*

~150 known Galactic globular clusters

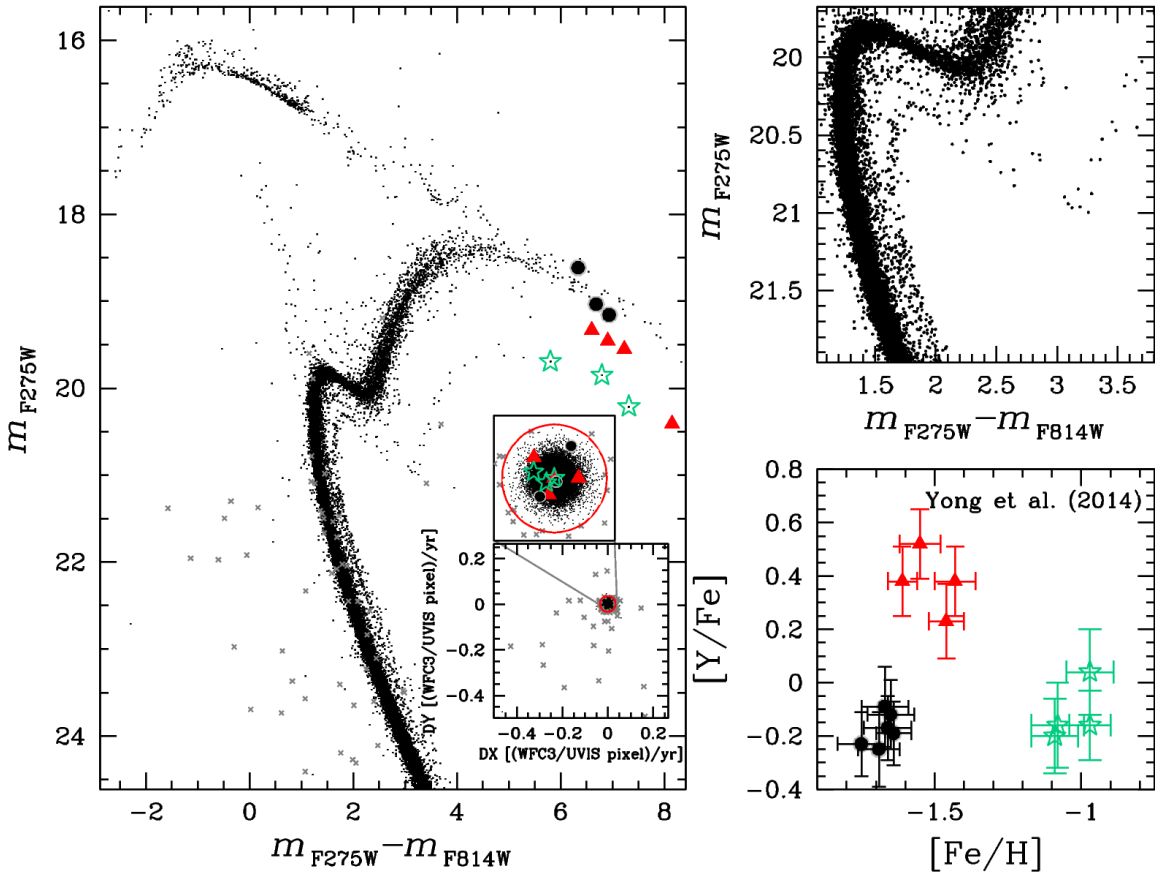
- $\sim 10^4$–10^6 $M_\odot$
- Spherically distributed
- $\gtrsim$10 Gyr old
- Range of metallicities
- Up to $\sim 10^5$ $M_\odot$ pc^{-3}



Credit: Francesco Ferraro

Globular clusters are weird!

- **Exotic objects**
- **Multiple populations**
- Odd abundances



Milone et al. (2015)

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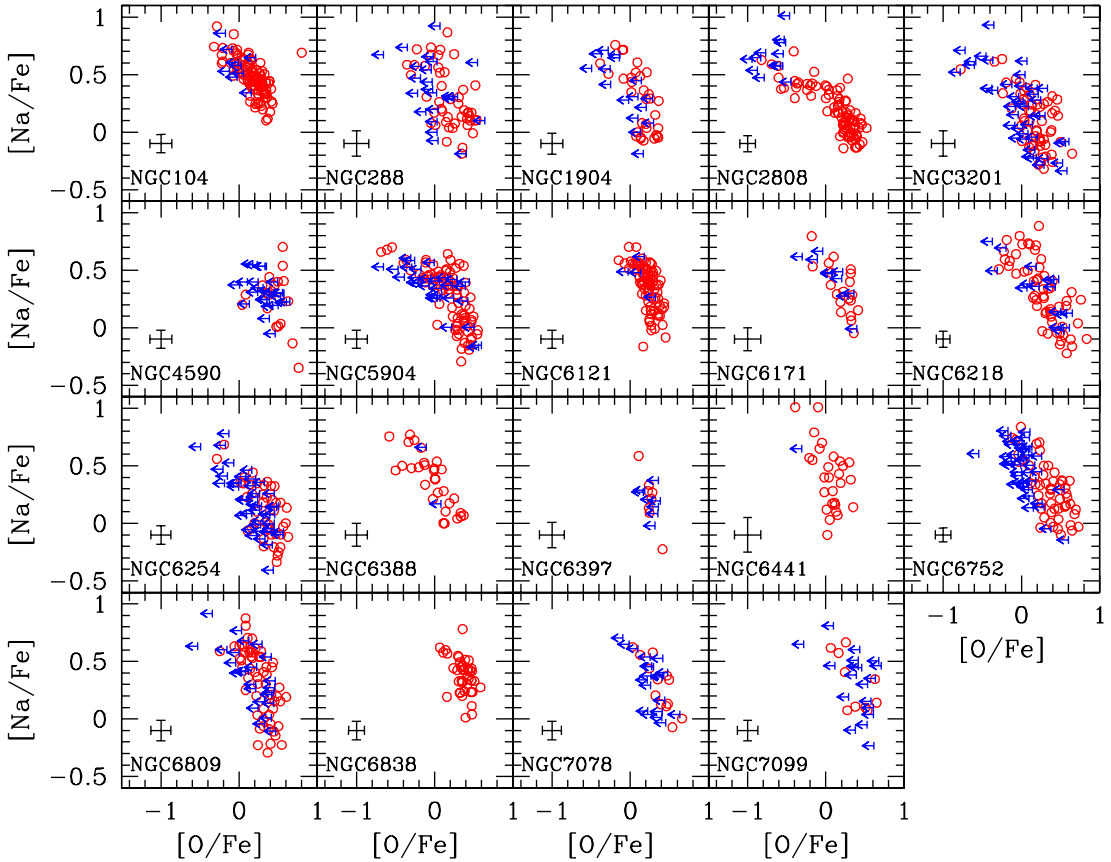


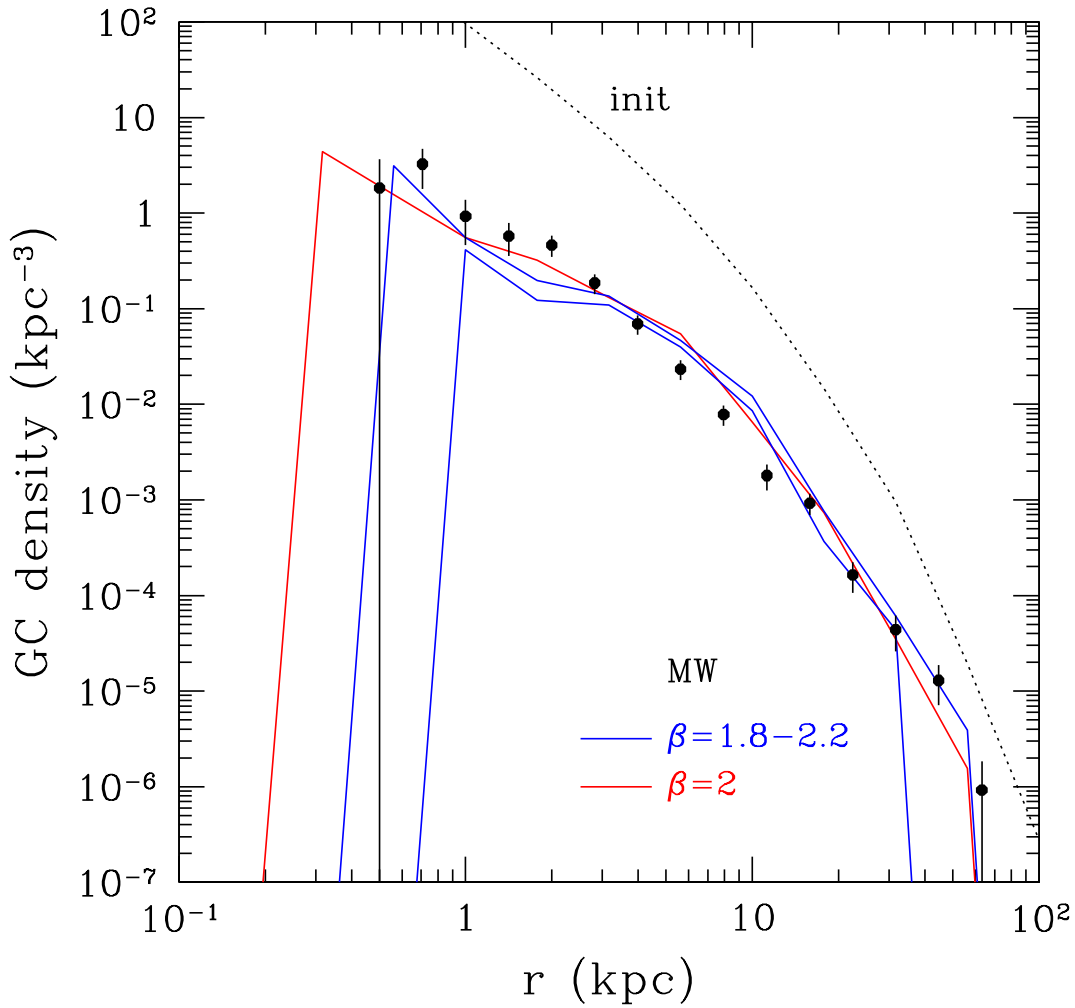
Carretta et al. (2009)

GCs are **dynamical systems** with **long, but finite, lifetimes**

6144 stars, credit Simon Zwart & Frank Summers

Most of the primordial GCs may be gone

- Evaporation
- Dynamical friction
- Tidal disruption



Gnedin et al. (2014)

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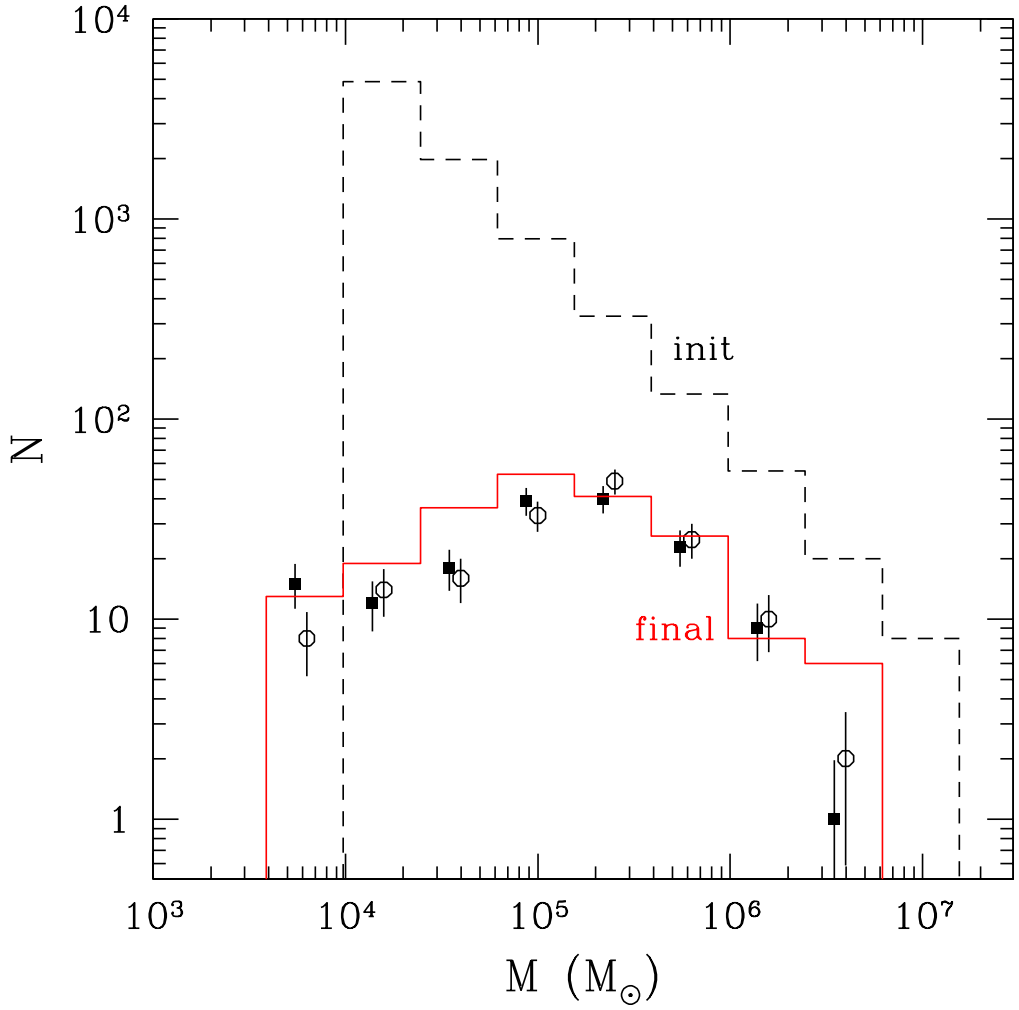


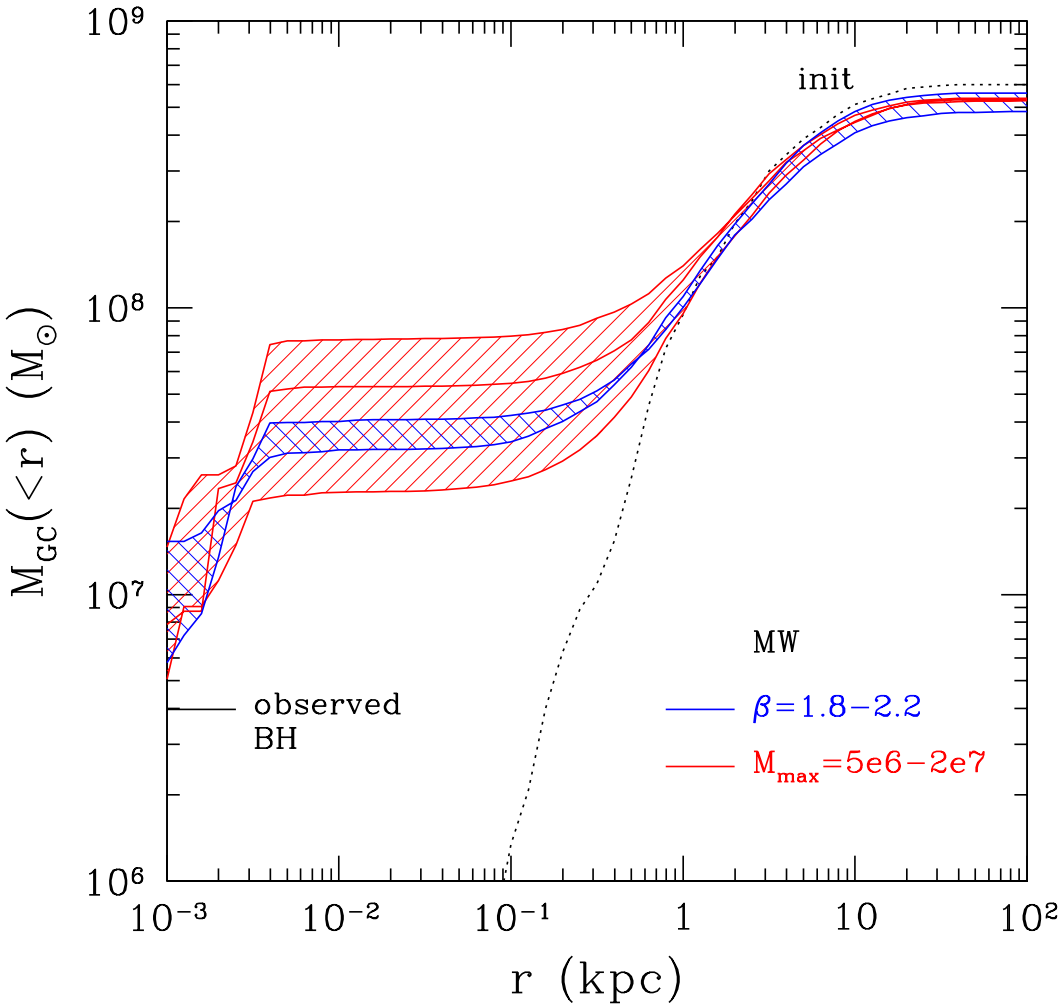
Gnedin et al. (2014)

The clusters may be gone,
but the stars and MSPs remain.

Where are they now?

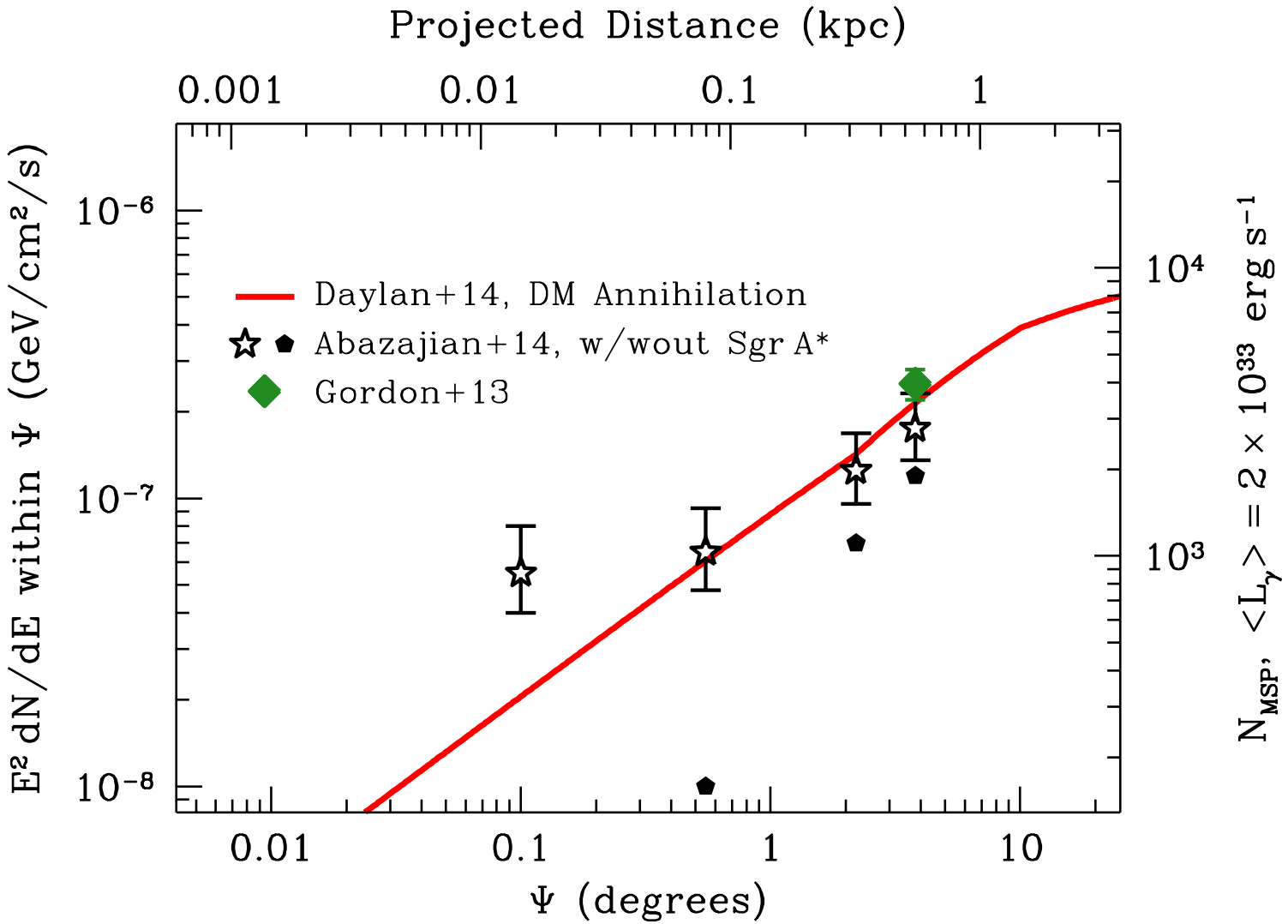
Take results of toy model to recover **current** GC properties

Scale to L_γ/M_* of extant GCs



Gnedin et al. (2014)

Results: 2 GeV Flux Within a Circular Aperture of Radius Ψ



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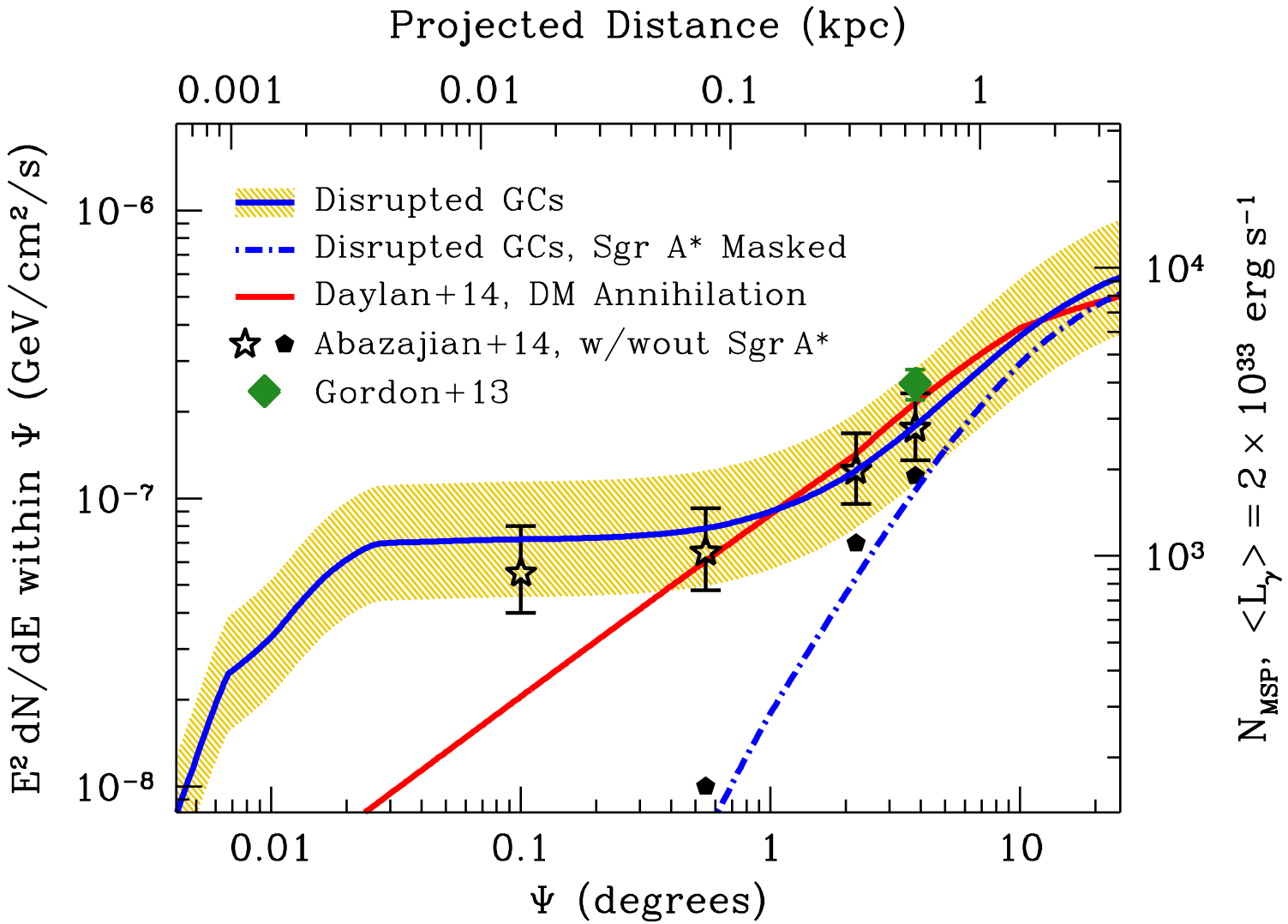

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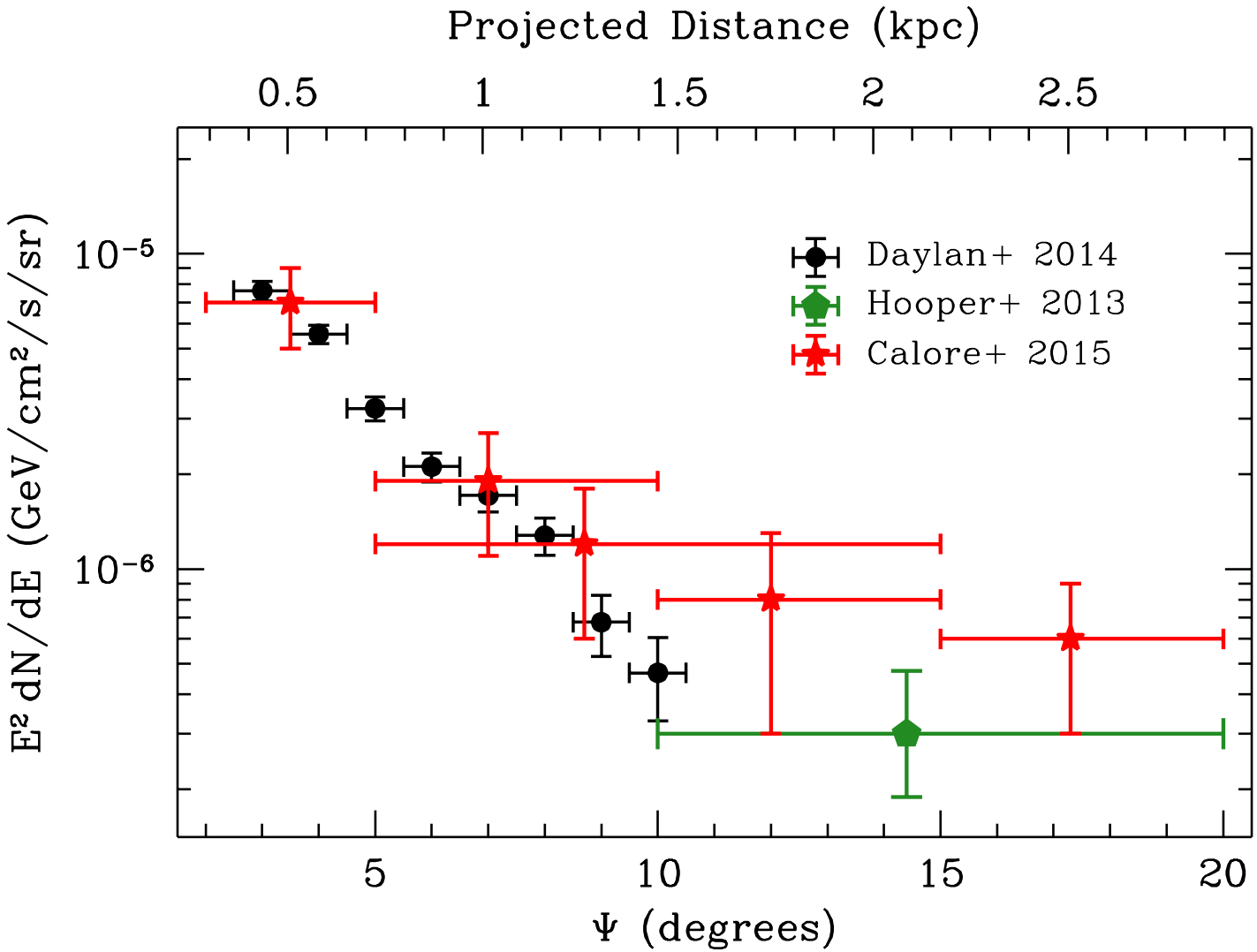

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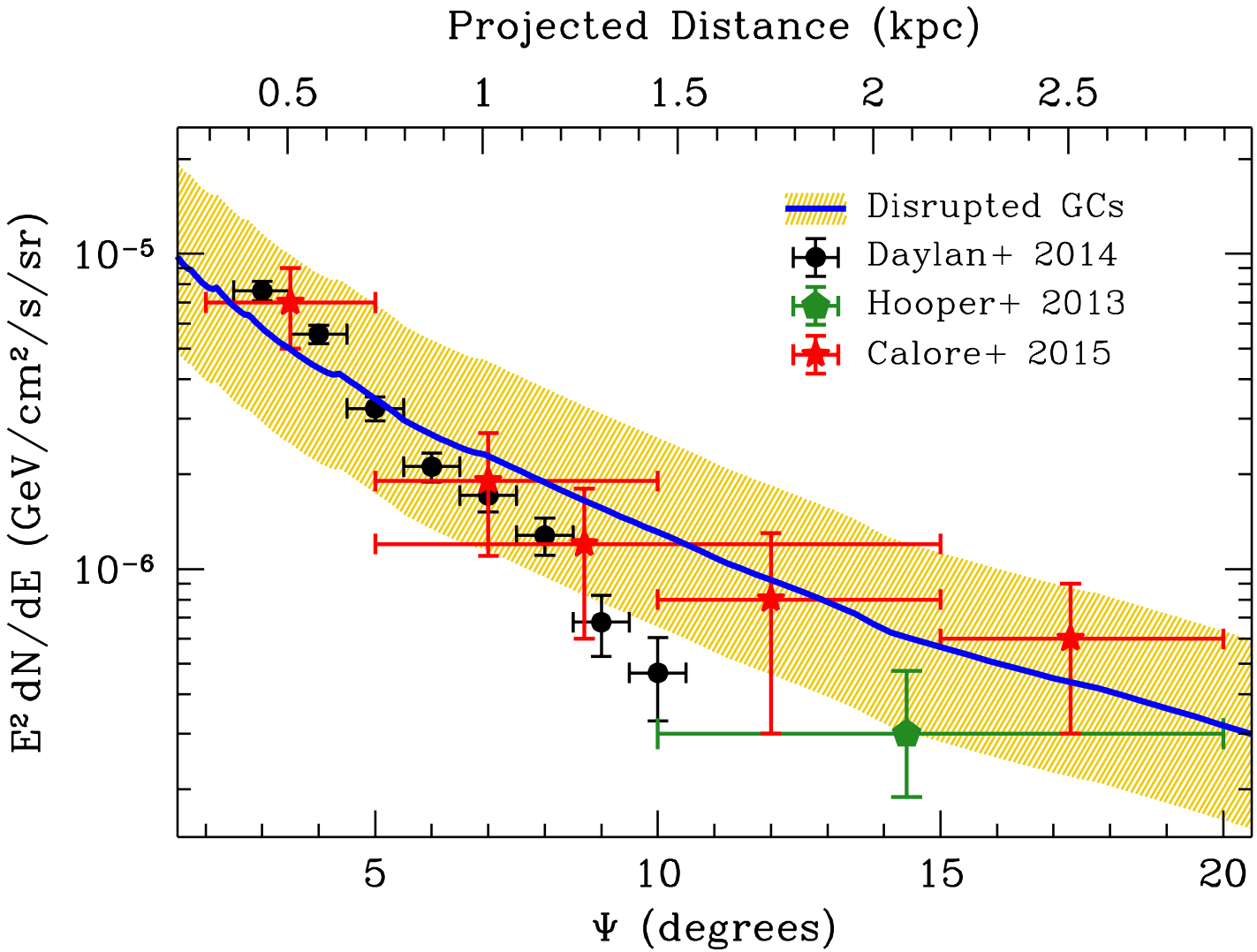

Objections to Millisecond Pulsars

1. No theoretical reason to expect observed distribution out to ~2 kpc
2. Pulsar progenitors (LMXBs) aren't there
3. Luminosity function is hard–should have seen individual pulsars
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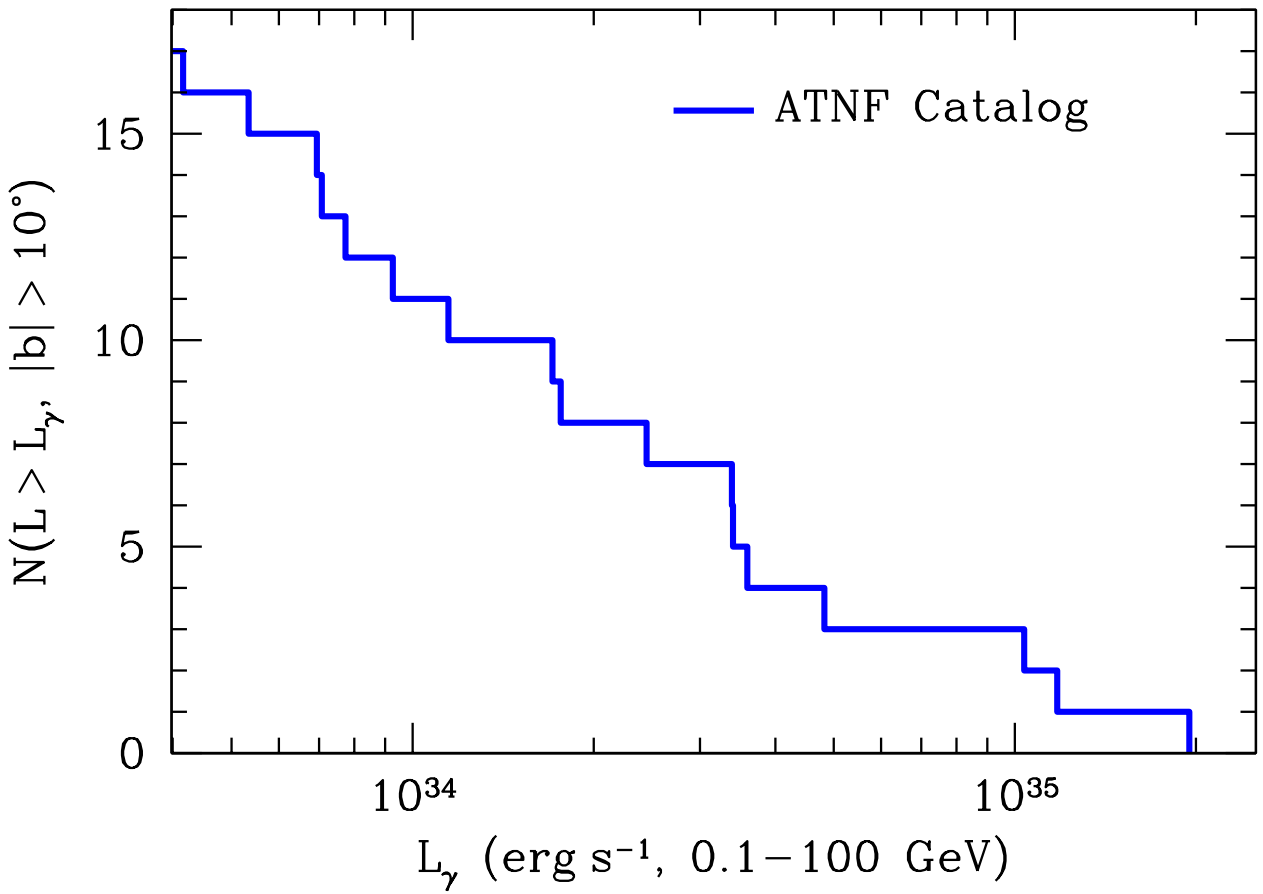

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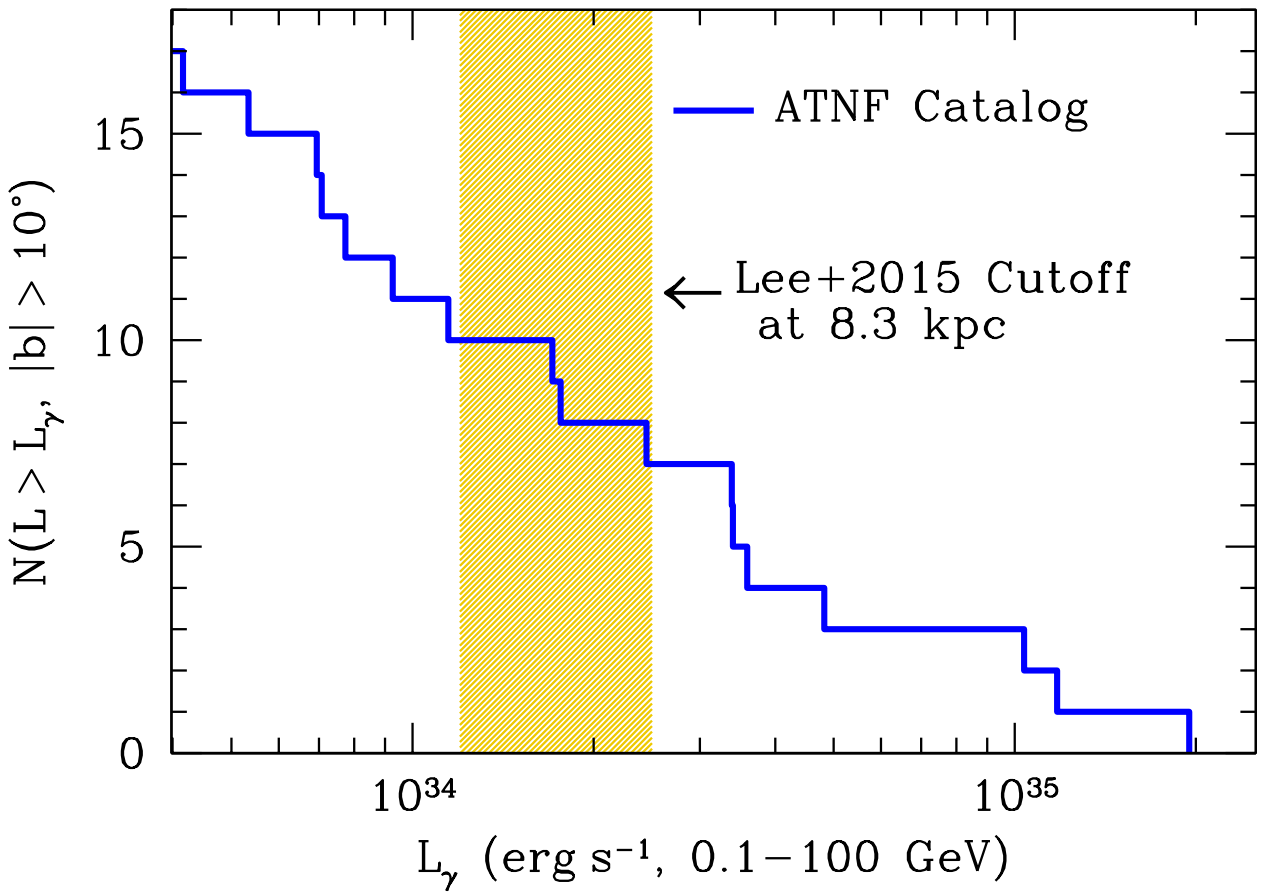

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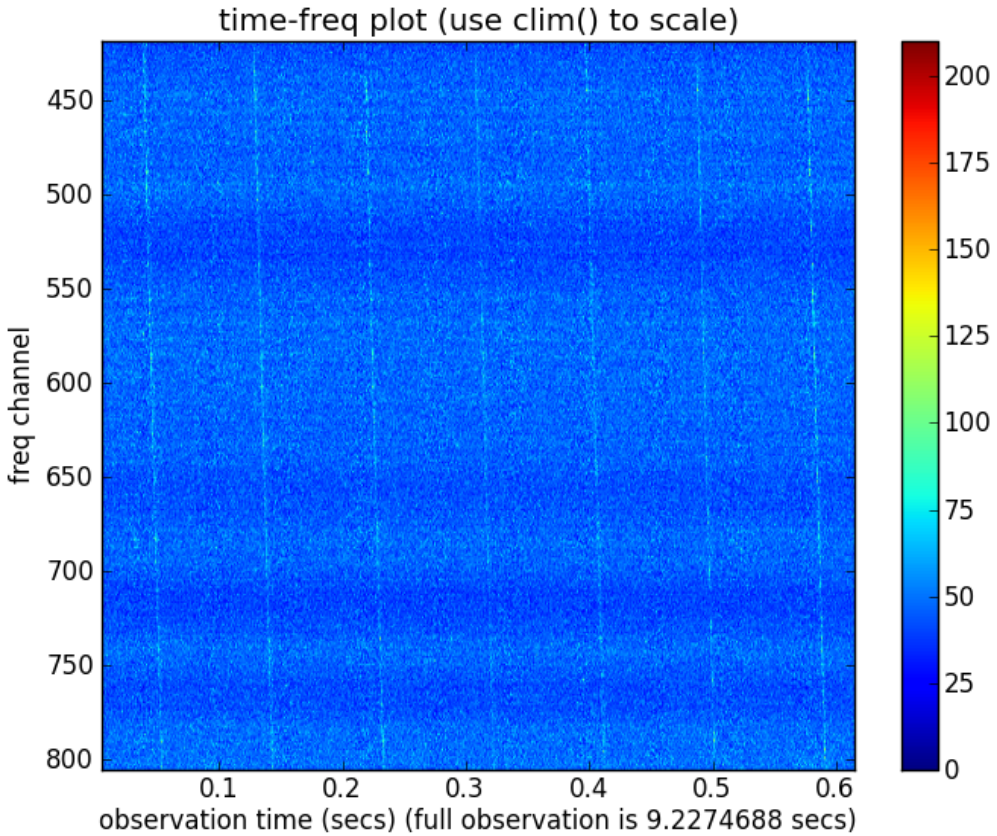
dispersion measure



Vela pulsar, KAT-7 (radio)

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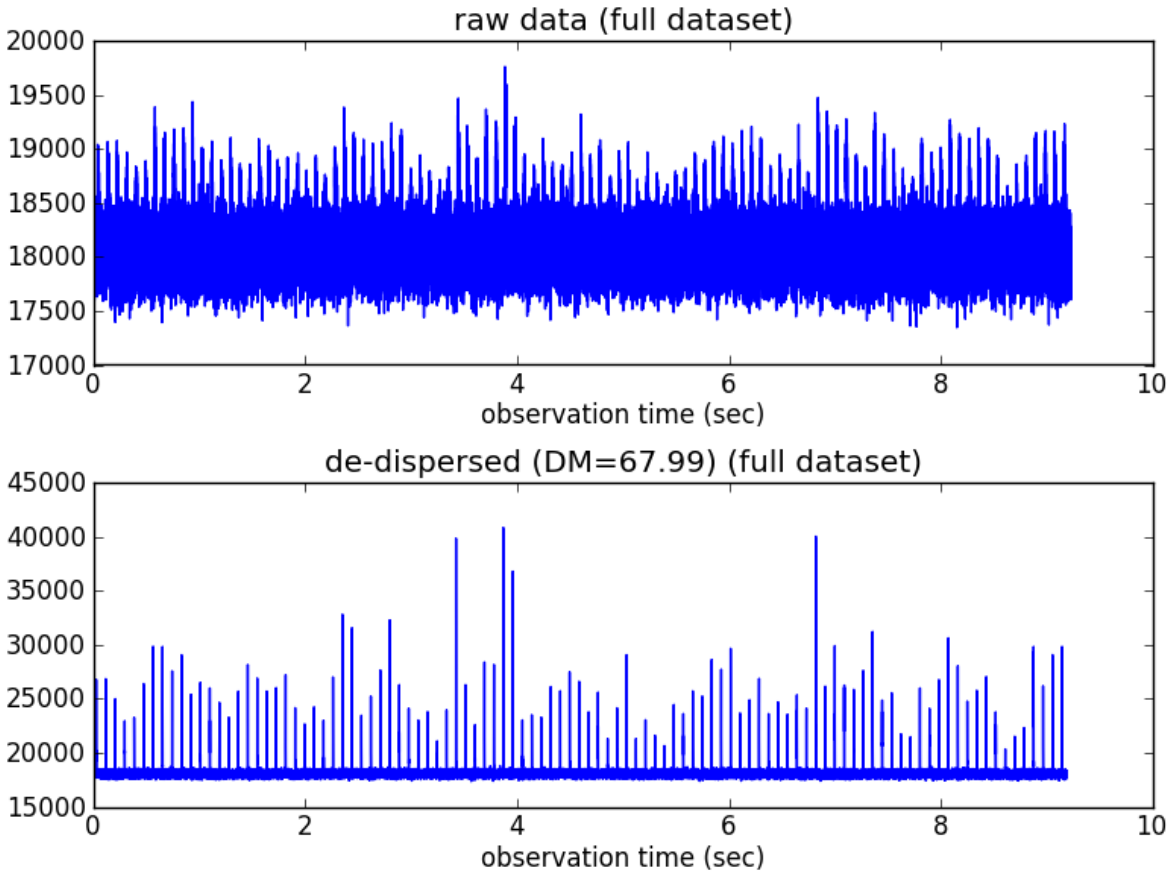

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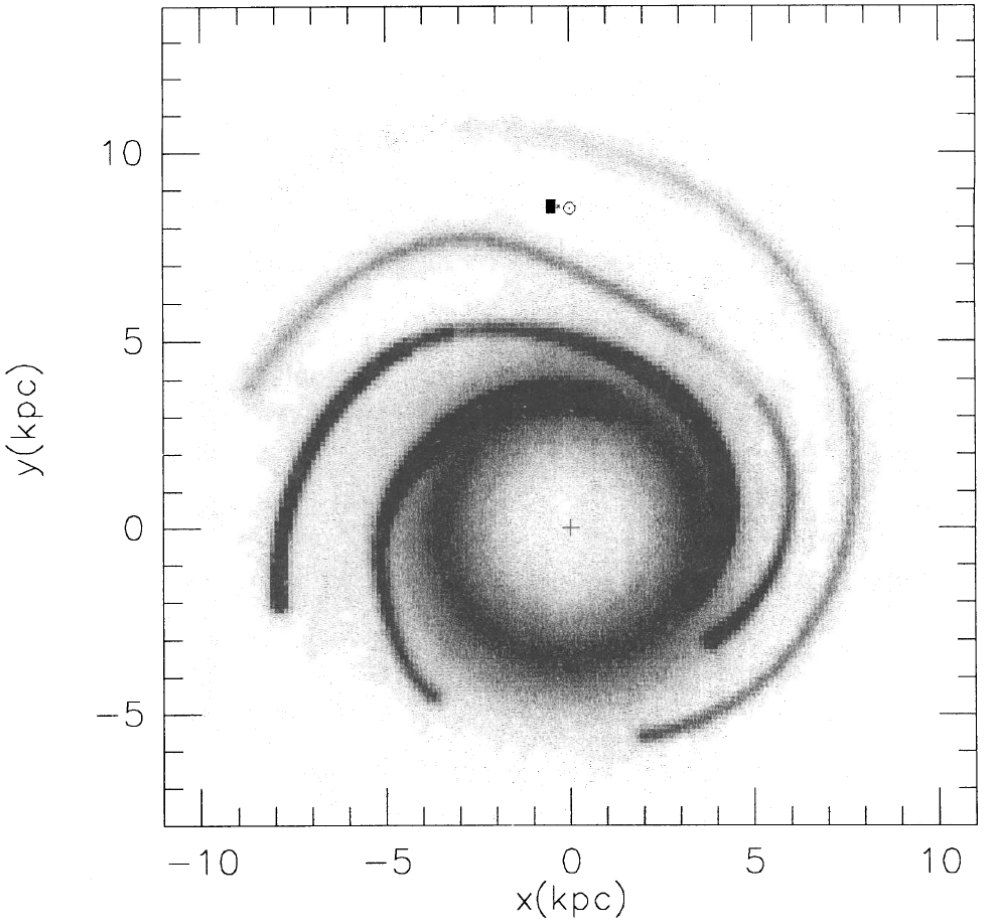
Distances almost always from dispersion measures

$$\mathrm{DM} = \int_0^{\mathrm{dist}} n(e^-)\,\mathrm{d}s$$

Requires modeling free electron density



Taylor & Cordes (1993)

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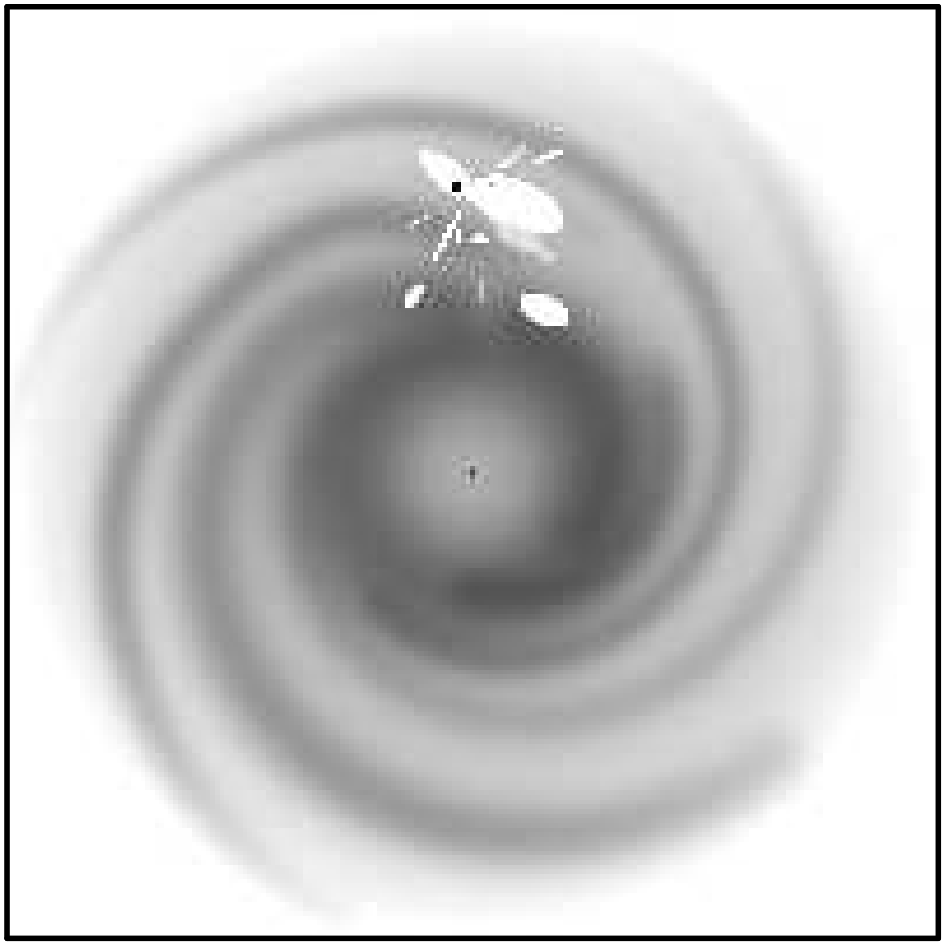

Cordes & Lazio (2002)

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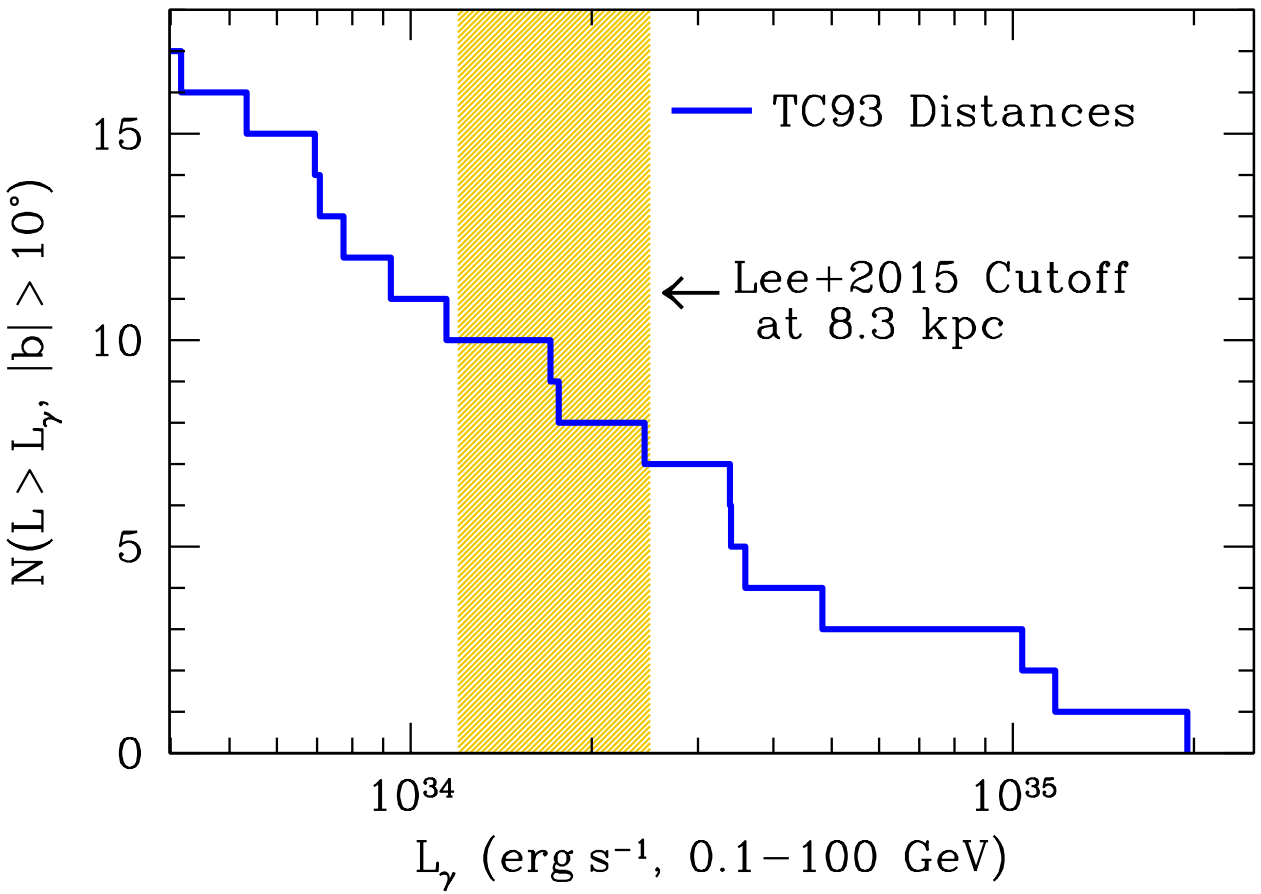

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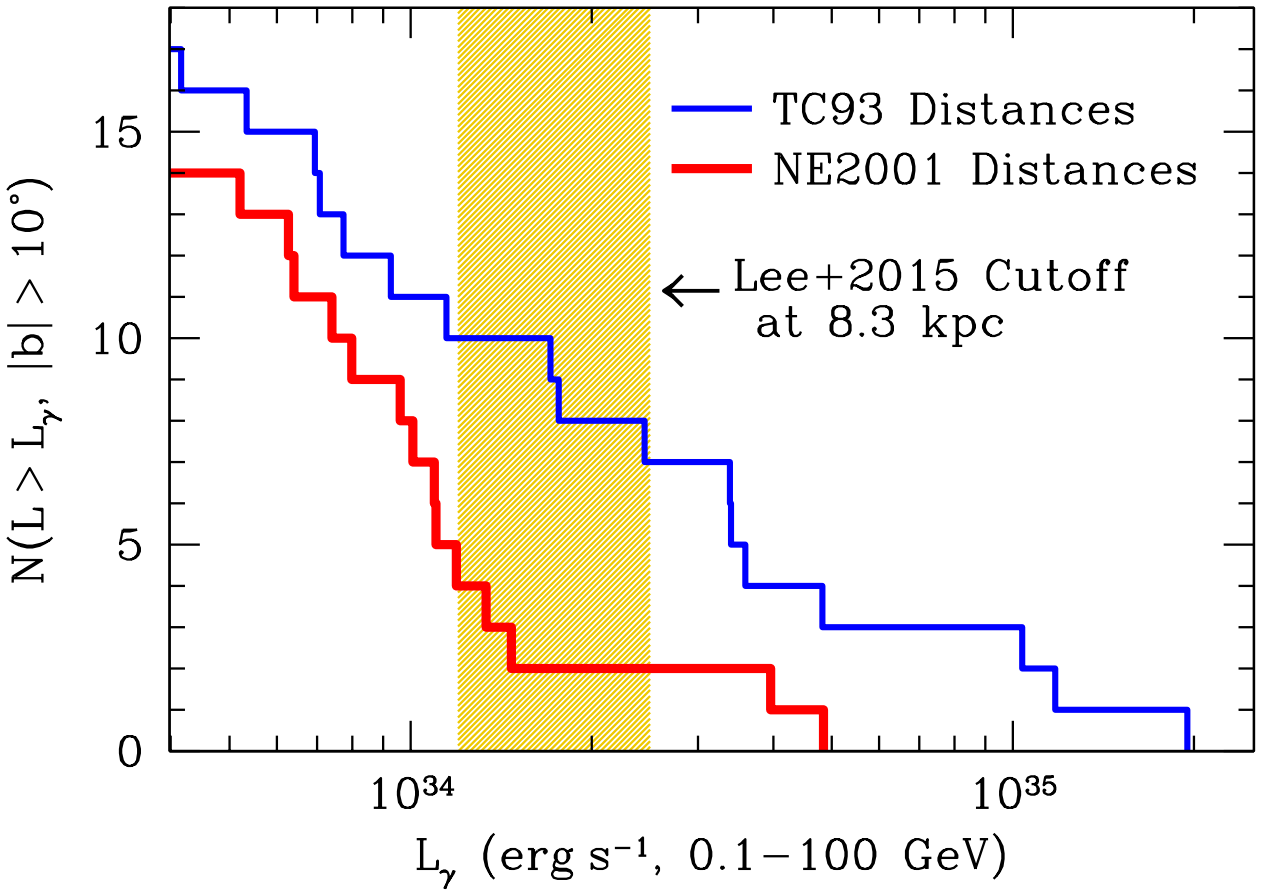
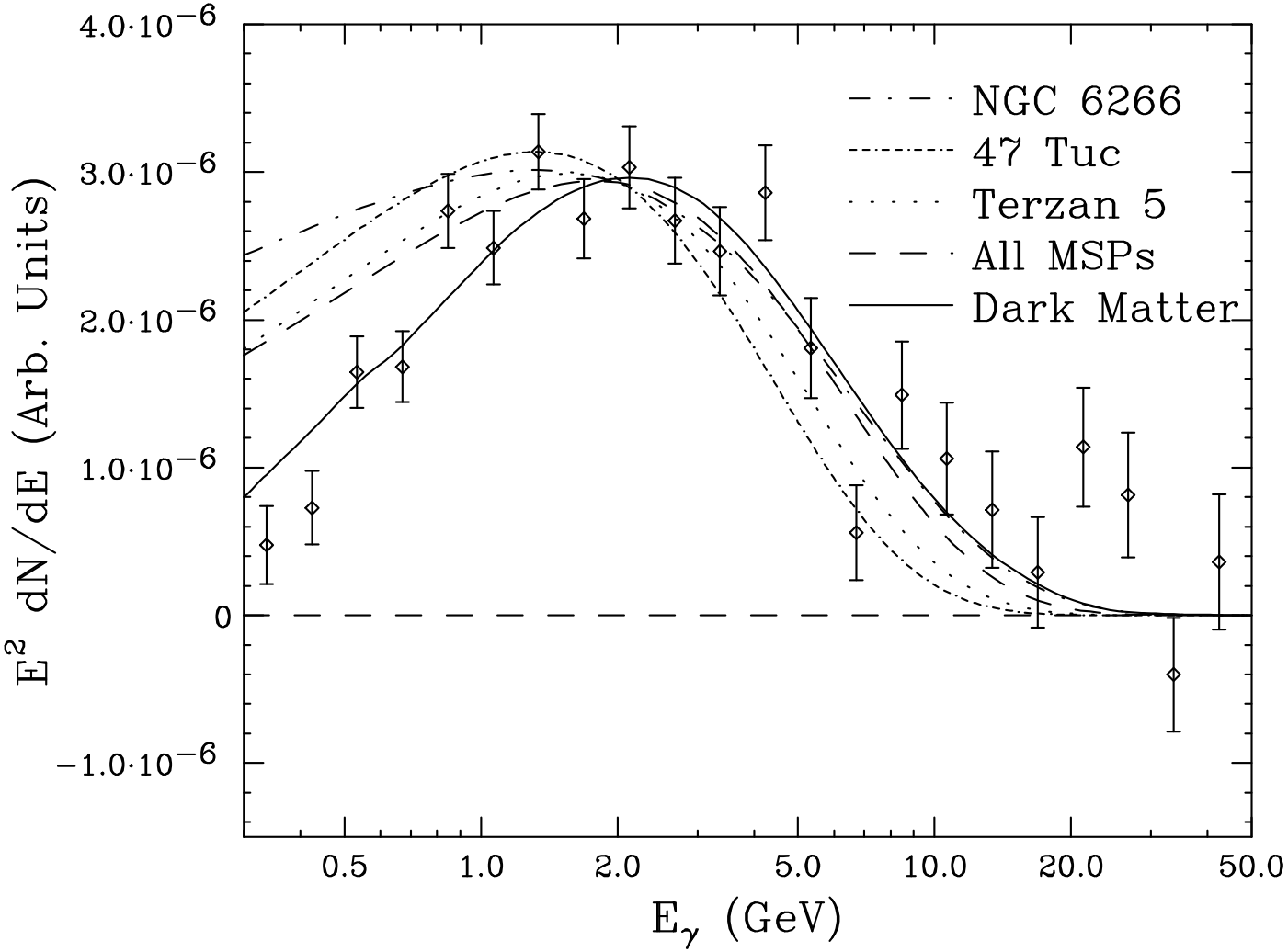


Only a problem with questionable dispersion measure distances

Objection: spectrum of GeV excess is too soft to be MSPs



Daylan et al. (2014)

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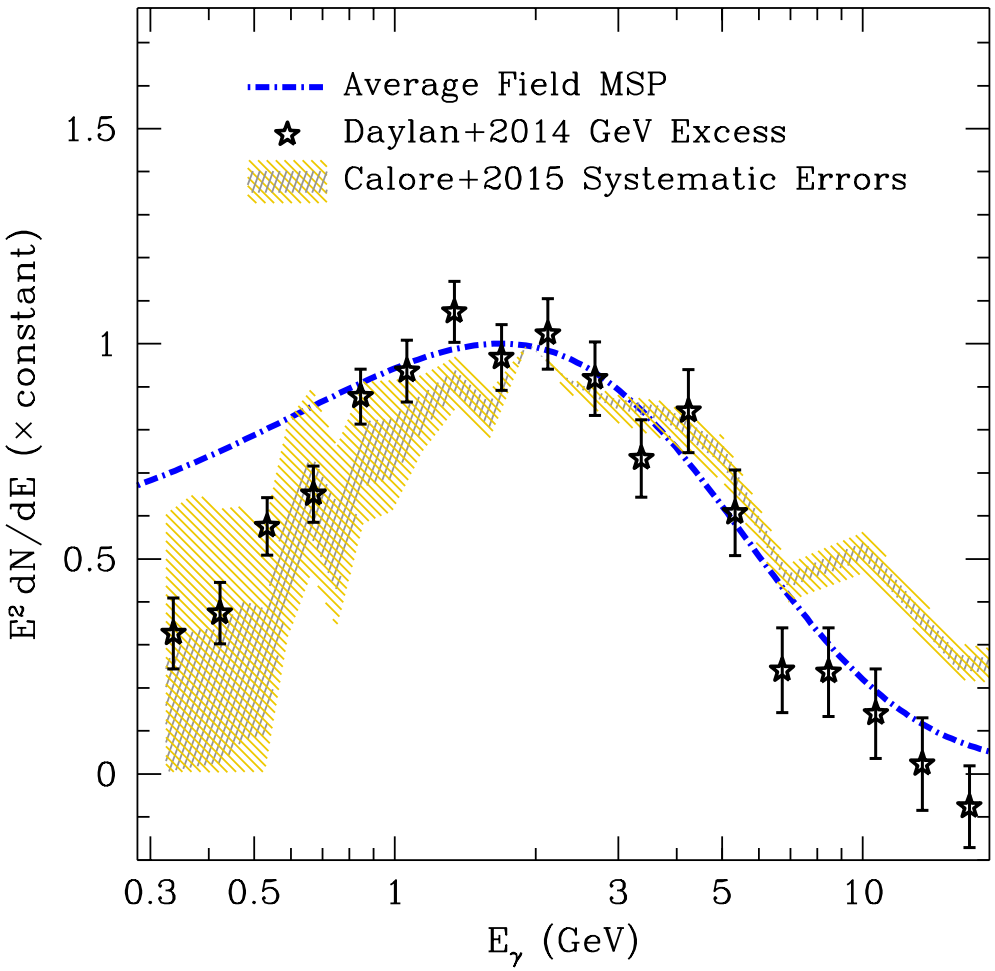

Unweighted average of *Fermi* MSPs

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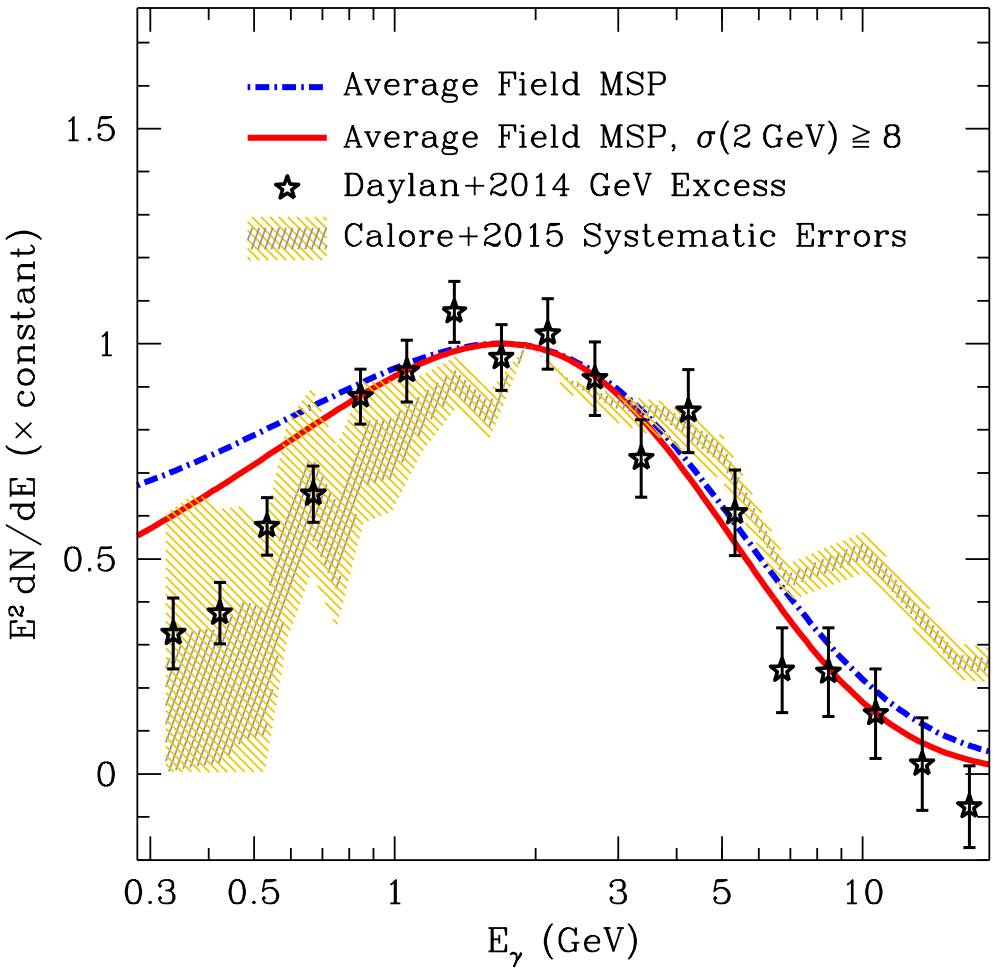

2 GeV-Selected, Luminosity Weighted

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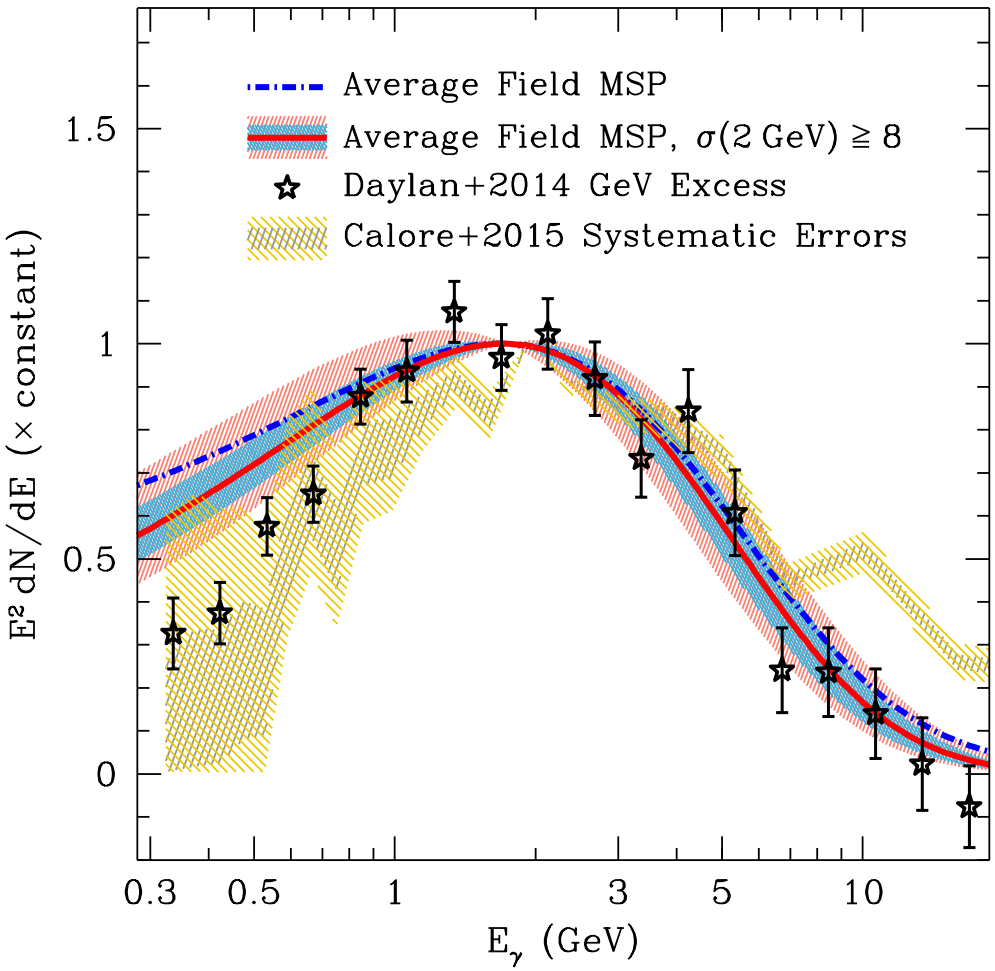

Bootstrap Sample Variances Added

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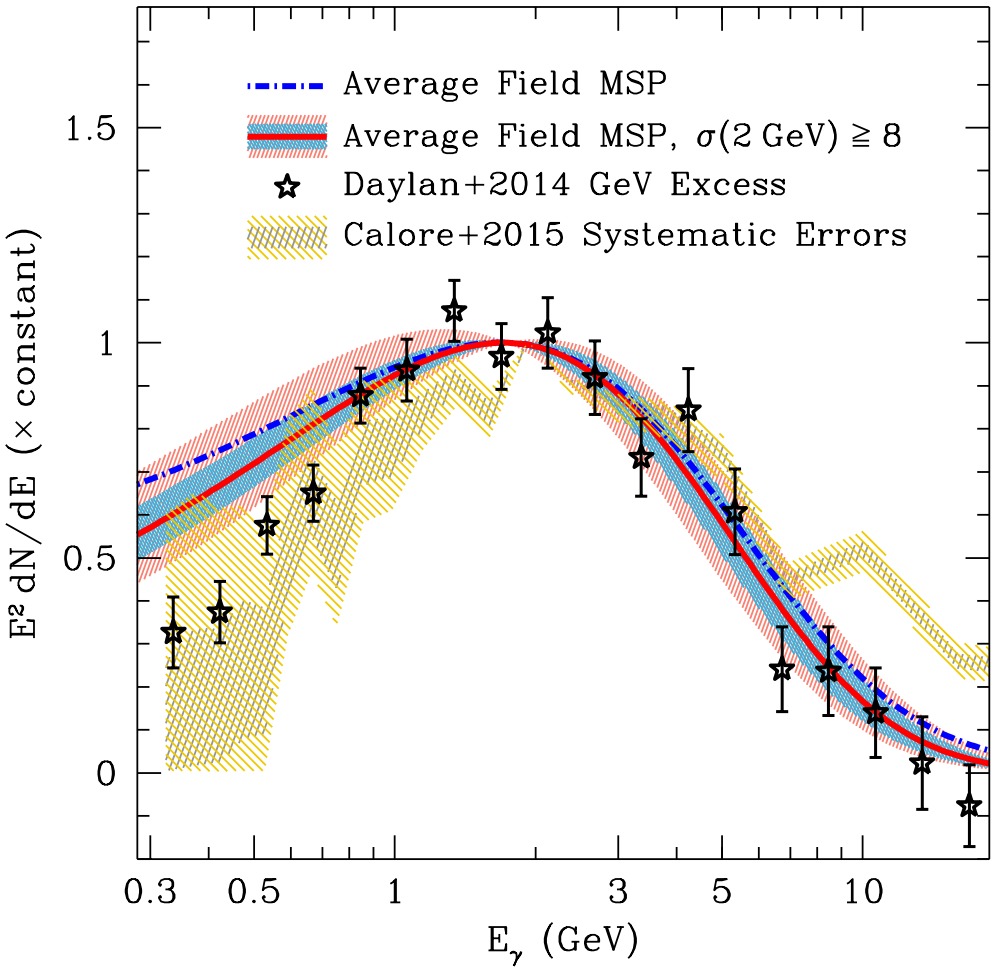

Biases, systematics, etc. $\Rightarrow \lesssim 2\sigma$ discrepancy

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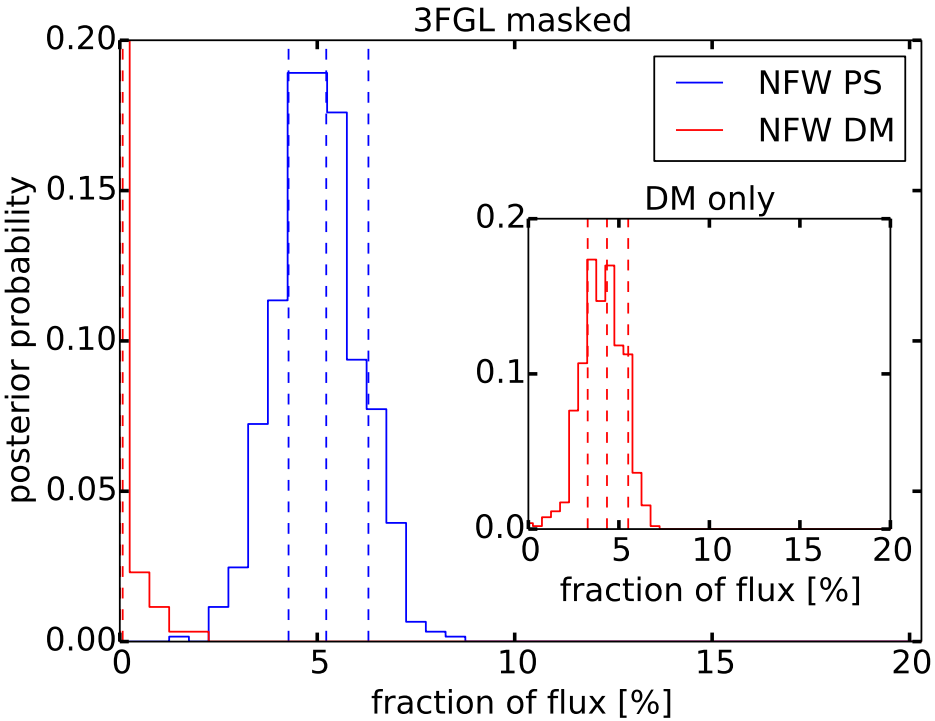
   - $\sim 1.5\sigma$ or 2σ discrepancy

Other Evidence:

Fermi excess looks like unresolved point sources

- Lee et al. (2015)
- also Bartels et al. (2015), talks by Daylan, Zechlin, Portillo



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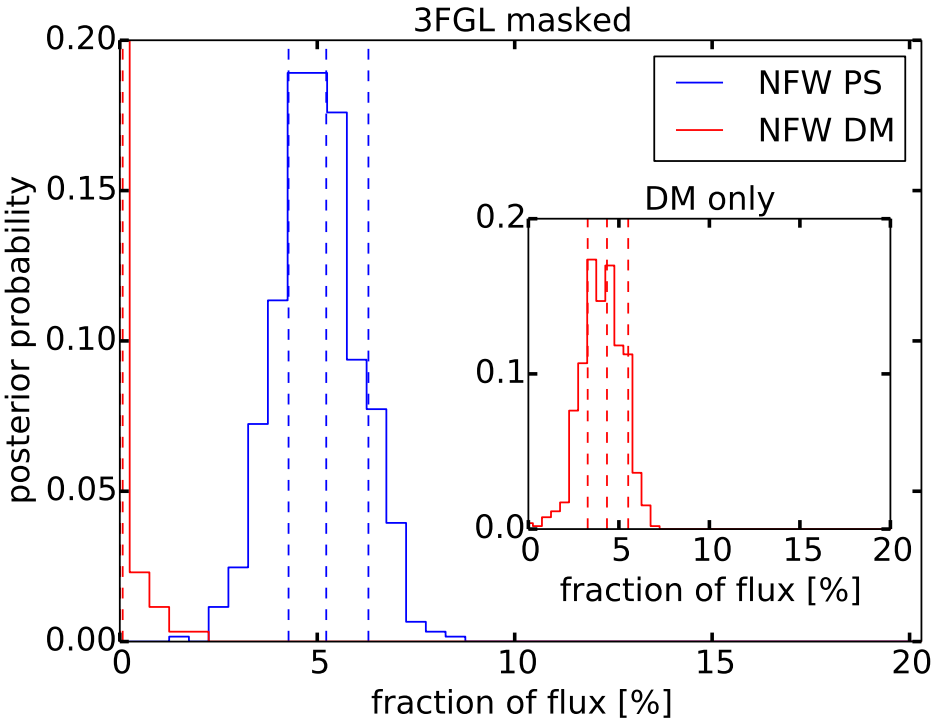
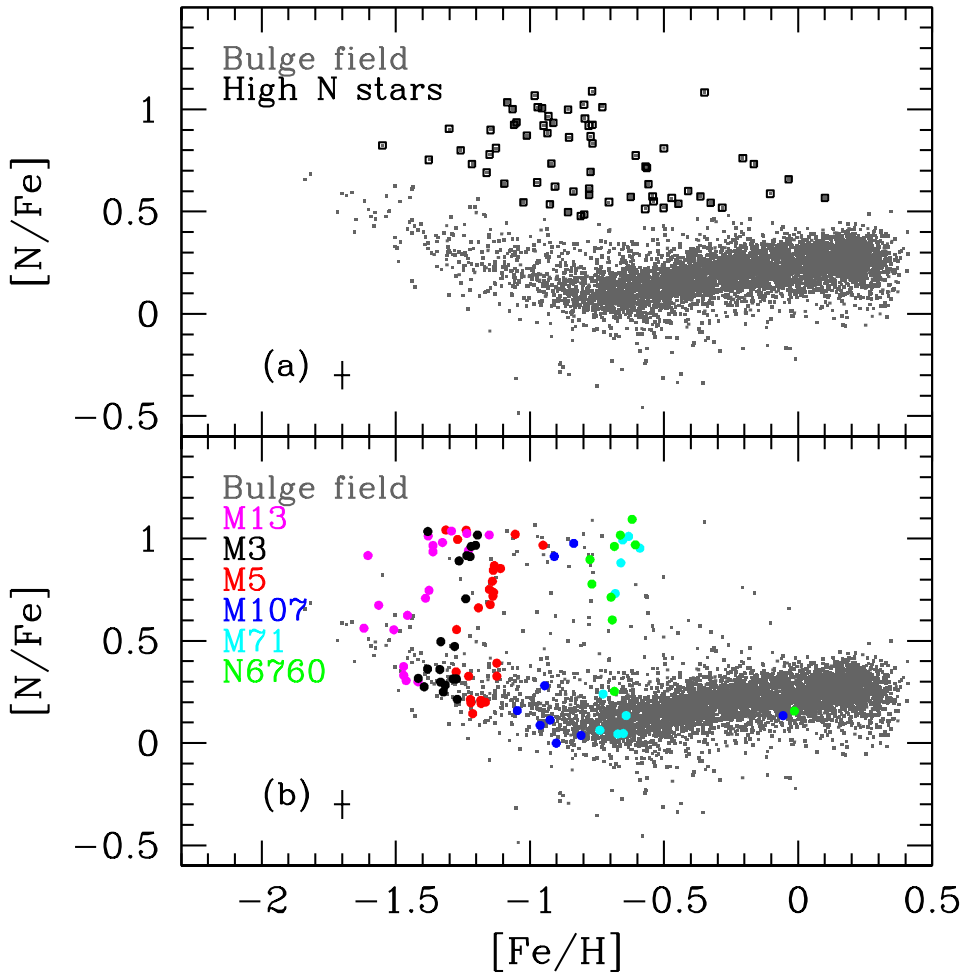


If you are allowed a population of point sources with the right spatial distribution, the favored (diffuse) dark matter contribution is **zero**.

Bulge Chemistry

- ~1% of bulge stars show strong Al, N enhancements
- $\sim\frac{1}{2}$ of globular cluster stars show similar enhancements

$\Rightarrow$ ~2% of bulge is dissolved globular clusters?



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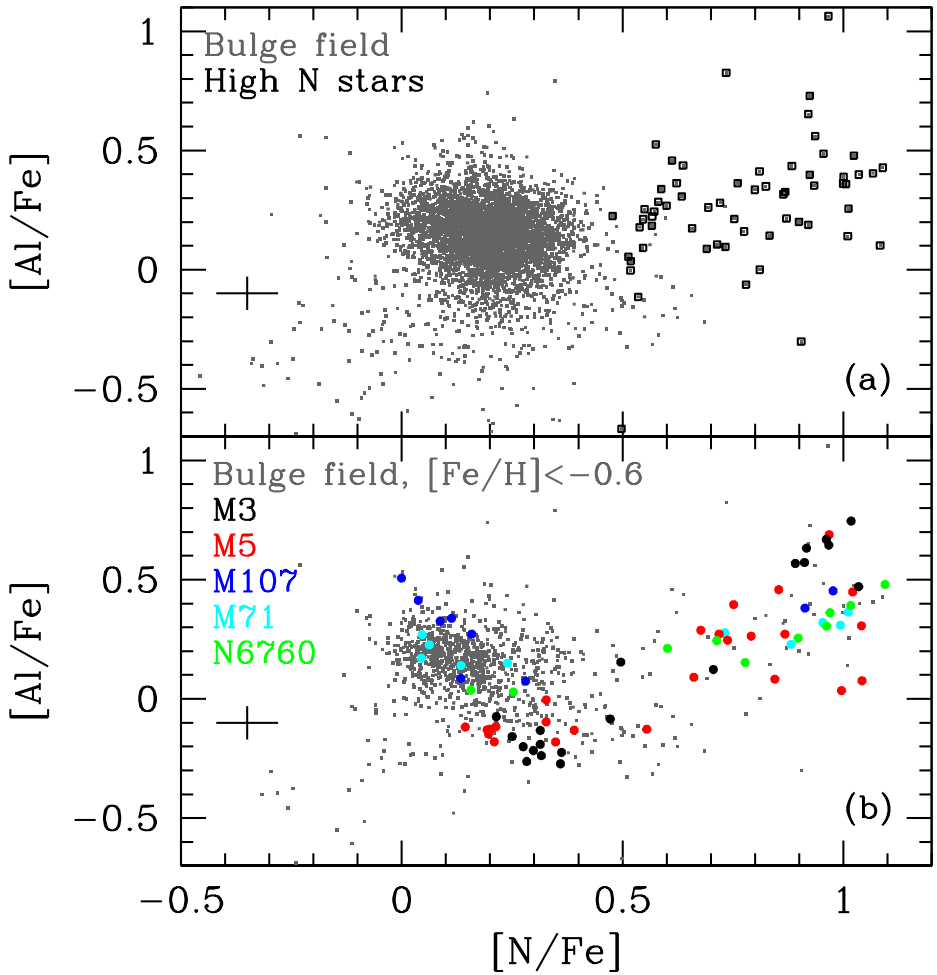

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How can we confirm this scenario?

1. Better models of GC, MSP formation
2. Find the MSPs! (pulsing γ rays, radio)
3. Other (chemical?) evidence of dissolved GCs

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Is the *Fermi* excess the first **direct** evidence for globular cluster destruction?