Disrupted globular clusters explain gamma-ray excess in the Galactic Center

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Uncovering a gamma-ray excess at the galactic center

Unprocessed map of 1.0 to 3.16 GeV gamma rays

Known sources removed

Daylan et al. (2014)
• Dark matter annihilation?
• Young pulsars?
• Cosmic ray outbursts?
• Background systematics?
• Millisecond pulsars?
Millisecond pulsars?

• How do we explain the observed morphology?
• Why aren’t the millisecond pulsar progenitors there?
• Shouldn’t we have seen individual pulsars?
• Is the spectrum consistent?
Normal pulsars

- $P \sim 1$ sec
- $B \sim 10^{12}$ G
- mostly single
- $t_{\text{spindown}} \sim 10^5$ yr

Crab pulsar, *Chandra* (X-ray)
**Normal pulsars**
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- $B \sim 10^{12}$ G
- mostly single
- $t_{\text{spindown}} \sim 10^5$ yr

**Millisecond pulsars**
- $P \sim 10$ ms
- $B \sim 10^8$ G
- Mostly in binaries
- $t_{\text{spindown}} \sim 10^{10}$ yr

Crab pulsar, *Chandra* (X-ray)
Origin of millisecond pulsars

- “recycled pulsars” spun up by mass transfer
- accretion phase: $10^6$ yr
  low mass X-ray binary (LMXB)
- MSPs, LMXBs
  much more common in globular clusters
Origin of millisecond pulsars

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47 Tuc in X-rays, Bogdanov et al. (2006)
GCs are dynamical systems with long but finite lifetimes
Most of the primordial GCs may be gone

- Evaporation
- Dynamical friction
- Tidal disruption
The clusters may be gone but the stars and MSPs remain.

Where are they now?
• Utilize evolutionary models which recover current GC properties
  Gneden, Ostriker, Tremaine (2014)

• Scale $L_\gamma/M_*$ of extant GCs

• Zero free parameters!

![Graph showing mass deposited by disrupted GCs](image_url)
Results: 2GeV Flux within aperture of radius $\Psi$
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Results: 2GeV Surface Brightness

Projected Distance (kpc)

$E^2 \frac{dN}{dE}$ (GeV/cm$^2$/s/sr)

Daylan+ 2014
Hooper+ 2013
Calore+ 2015

$\Psi$ (degrees)
Results: 2GeV Surface Brightness

Projected Distance (kpc)

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- Disrupted GCs
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Should we have seen individual MSPs at 2 GeV?
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Based on known pulsars in the galactic field: two *could* have been seen in the GC
But these 2 have large systematic distance errors. → OK if we see none at 2 GeV
Is the spectrum consistent?

- Yes! 1GeV – 20 GeV
- Slight (2σ) discrepancy at <800 GeV
  - Note: correlated errors
  - low signal-to-noise
  - biases/confusion not included
Millisecond pulsars?

✓ How do we explain the observed morphology?
  Disrupted globular clusters

✓ Why aren’t the millisecond pulsar progenitors there?
  Density is no longer high enough to form new LMXBs

✓ Shouldn’t we have seen individual pulsars?
  Not with the latest estimates of dispersion measures

✓ Is the spectrum consistent?
  Less than $2\sigma$ discrepancy
Other evidence

**Bulge chemistry**
- 1% of bulge stars show Al, N enhancements
- ½ of globular cluster stars show Al, N enhancements
- $\Rightarrow$ 2% of bulge mass from GCs?

**Flux statistics**
- Of Fermi excess looks like unresolved point sources
  - Diffuse contribution is zero

(Lee et al. 2015, see also Bartels et al. 2015)
How can we confirm this scenario?

• Find the MSPs within ~ 1 kpc
  • high-radio frequency radio surveys
  • pulsing X-rays, gamma-rays

• Further chemical evidence of dissolved GCs?
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Is the Fermi excess the first direct evidence for globular cluster destruction?