Finding Millisecond Pulsars to Explain the Fermi Gamma-ray Excess

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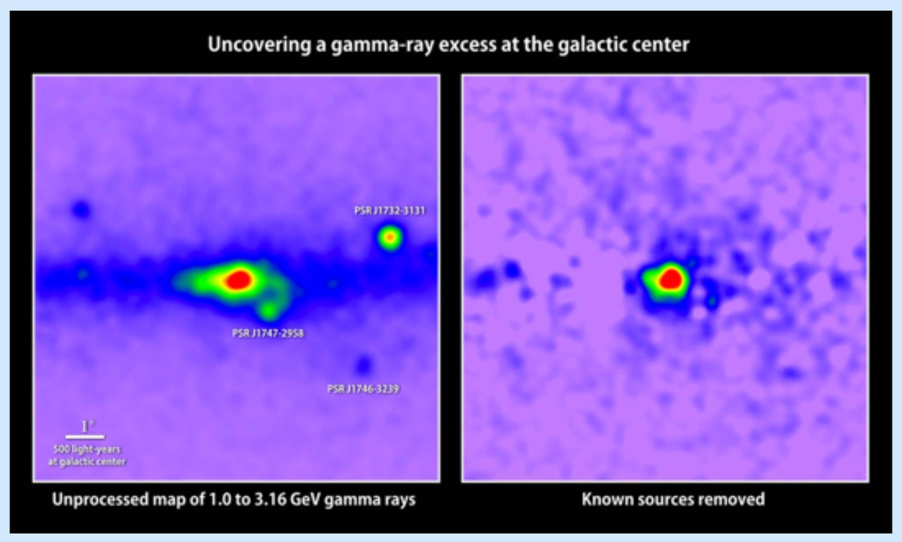
Too Many Gamma-rays

The Puzzle: The *Fermi* Large Area Telescope (LAT) has detected a diffuse excess of GeV gamma-rays coming from the Galactic Center and Bulge (Goodenough et al 2009, Abazajian et al 2014}. This excess extends to roughly 10° from the Galactic Center, but is concentrated in the central 2.5°x2.5° of the Milky Way (Ajello et al, 2016).



Credit: T. Linden, University of Chicago

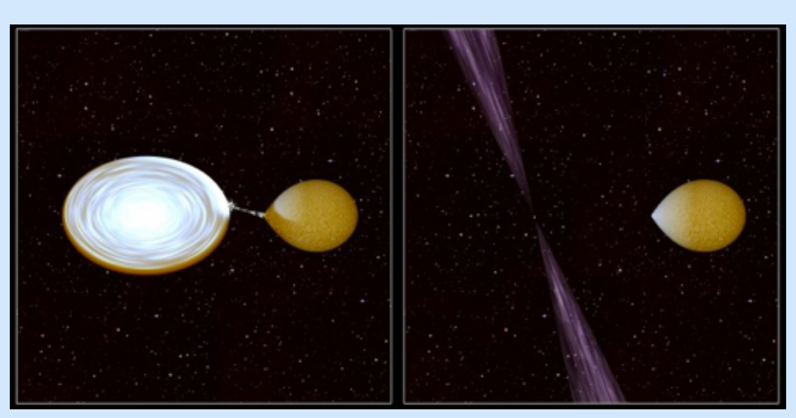
Possible solutions: The two primary explanations for this excess are that it is caused by either the annihilation of dark matter particles (Vitale et al 2009) or by an unresolved population of millisecond pulsars (MSPs) which are known gamma-ray emitters (Abazajian et al 2011).

The difficulties: The ultimate smoking gun for the MSP hypothesis would be the detection of a population of ~1000 MSPs in the Galactic Bulge. This search is complicated by the high electron column density towards the Galactic Center, which smears pulsations by a significant fraction of the pulse period at low frequencies where they emit the most. For targeted searches, longer observations at higher frequencies can be used to reduce the amount of scattering, but surveys at these higher frequencies become telescope-time prohibited because the sensitivity and the field of view *both* drop steeply as the observing frequency is increased.

Millisecond Pulsars: background

Accretion spins up old neutron stars

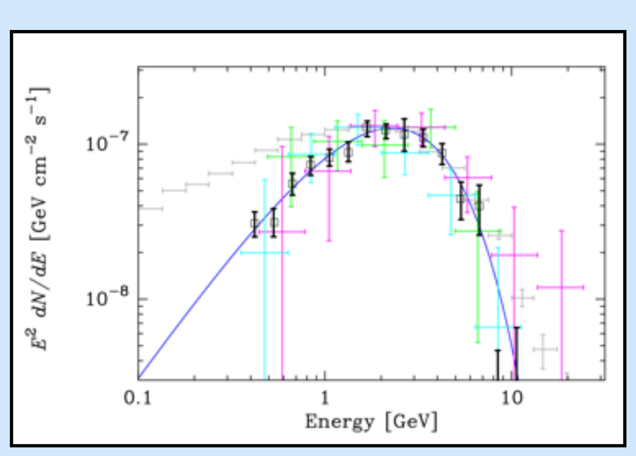
After ~1 Gyr, accretion ends, leaving a recycled millisecond pulsar (MSP)



Left: X-ray Binary *Right*: Millisecond Pulsar
Generated with BinSim
(Credit: J. van Leeuwen, A. Archibald, R. Hynes)

Number of MSPs in Milky Way highly uncertain.

The gamma-ray spectrum of MSPs in globular clusters matches the spectrum of the *Fermi* excess.



Abazajian et al 2011

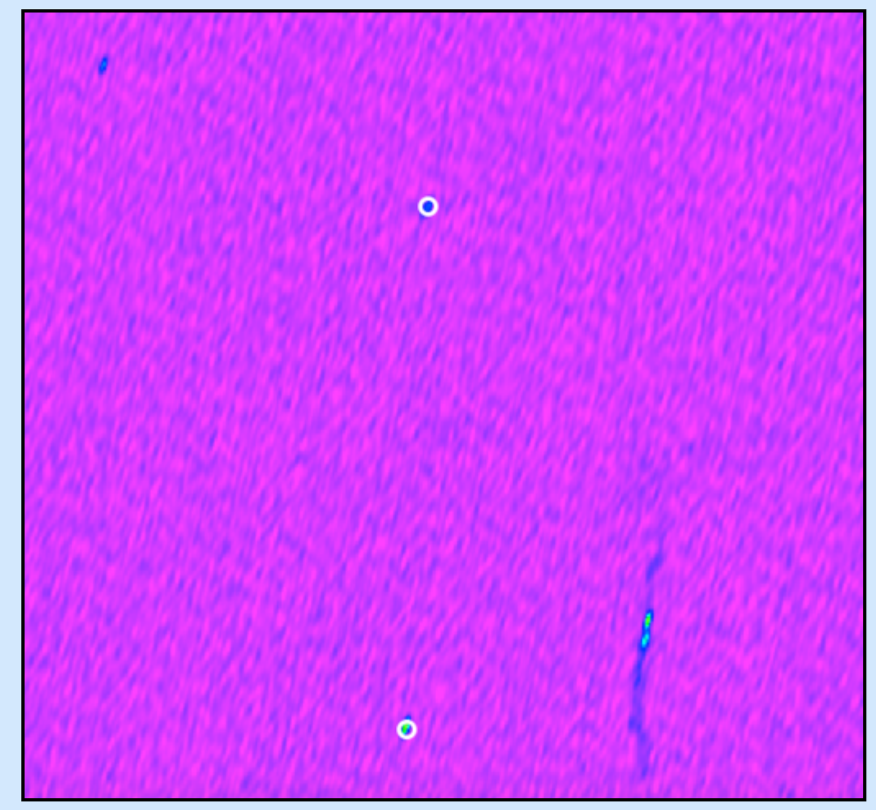
It is possible, however, that the MSP population in globular clusters may have been formed through different channels resulting in different properties.

While known MSPs remain too rare to explain the *Fermi* excess, the number of known systems has exploded into the hundreds in recent years.

Our approach

Small cutout of survey area. Pulsar Candidates outlined in white.

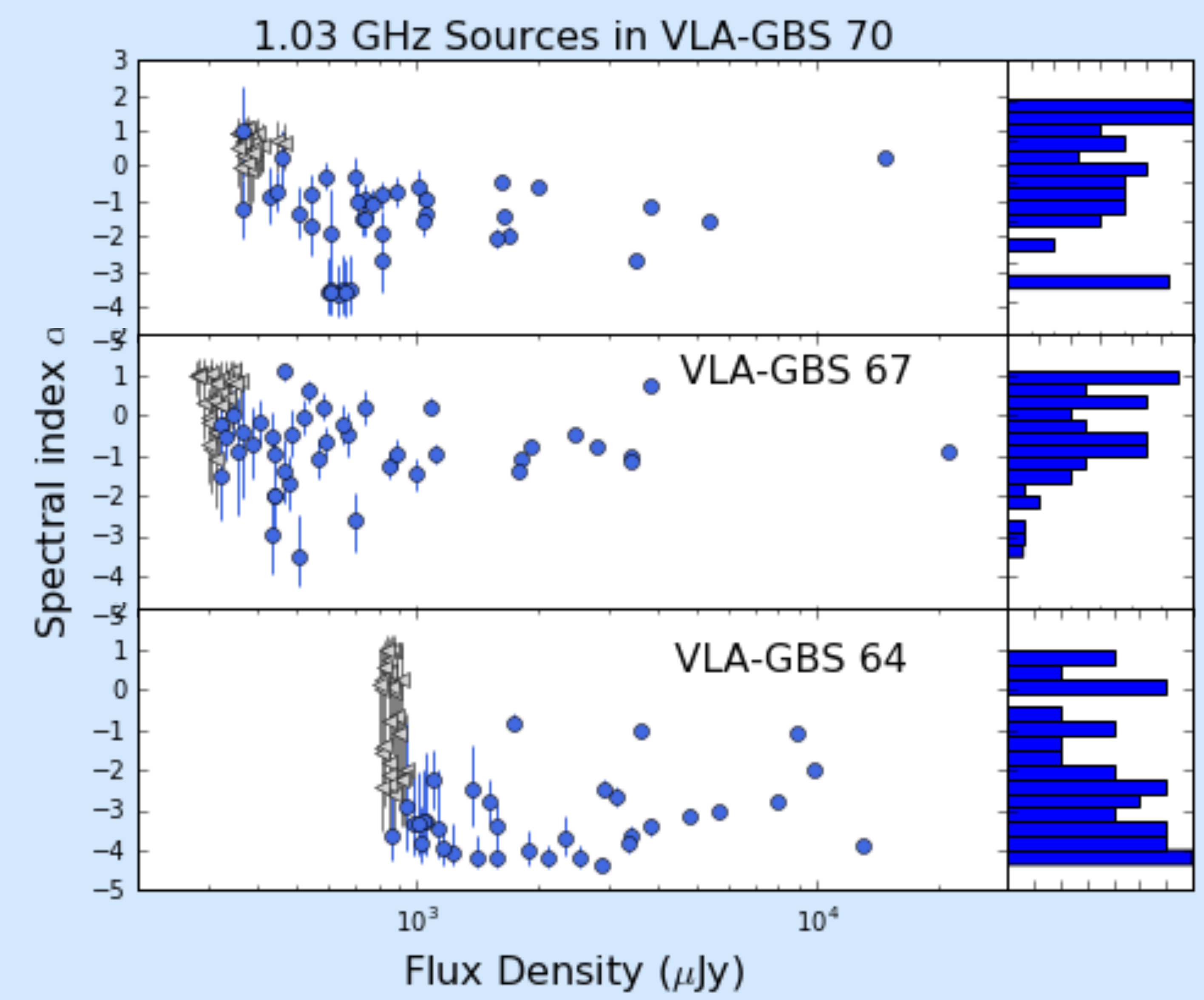
Pilot survey is 3 L-band pointings covering ~0.5 square degrees.



- Radio Pulsars:
  - have unusually steep, inverted radio spectra
  - are radio point sources
- AGN:
  - have flatter spectrum if point sources
  - have extended radio lobes with steep spectrum
  - can have IR counterparts with characteristic colors
- Follow up candidates with pulsation search
- Work 1-2 degrees above Galactic Midplane, where stellar density remains high, but ISM is reduced.
- Leverage previous X-ray, Optical, and IR surveys.

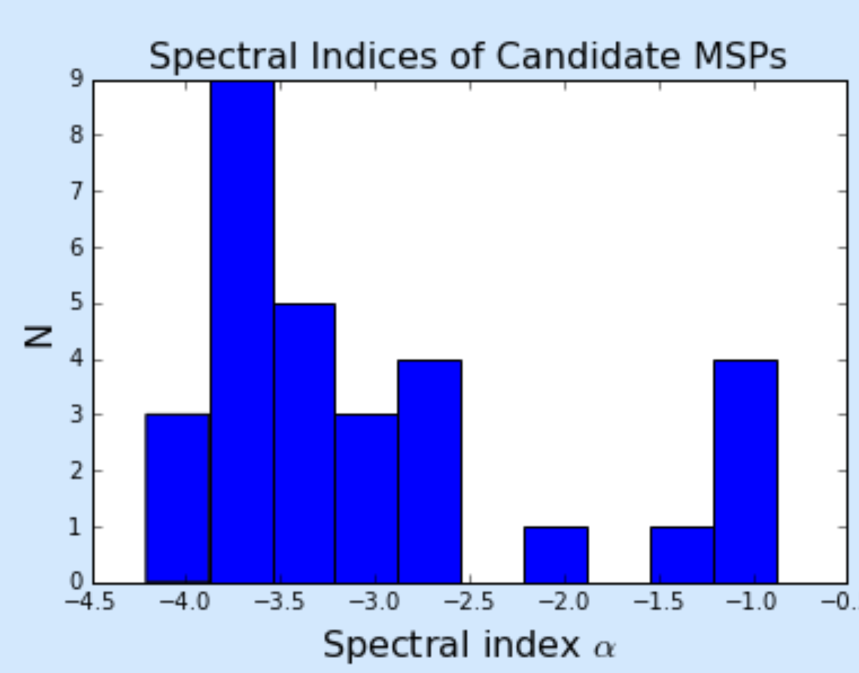
Identifying Pulsar Candidates

Fields are imaged in multiple frequency bands. Source detection and flux measurements made with JMFIT. Source is "real" if detected at >5 sigma at any one pass-band or >3.5 sigma at any two.



MSP Candidates

We designate all point sources with α < -1.0 and 2-sigma lower than -0.75 as candidate MSPs. We find 30 point sources spread over the ~0.5 sq. degree survey area which meet those criteria.



The number of candidate MSPs in our pilot survey is consistent with the presence of an unresolved MSP population in the Galactic Bulge large enough to explain the *Fermi* GeV excess.

Search for X-ray, IR Counterparts and optical variability

Previous surveys in X-ray (Chandra Galactic Bulge Survey [GBS; Jonker et al. 2011], optical variability to *r'*<23 (Britt et al. 2014), WISE and *Spitzer*.

Search for X-ray, optical, and IR counterparts to identify AGN or other sources.

3 radio sources are also GBS X-ray sources:

- CX63: CV undergoing radio flaring
- CX78: may be a radio pulsar detected in the X-ray
- CX392: likely background AGN

Searching for pulsations

Timing data from the Green Bank Telescope in hand for candidate pulsars to confirm the MSP nature.

References

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