Multi-wavelength probes of the Fermi GeV excess:

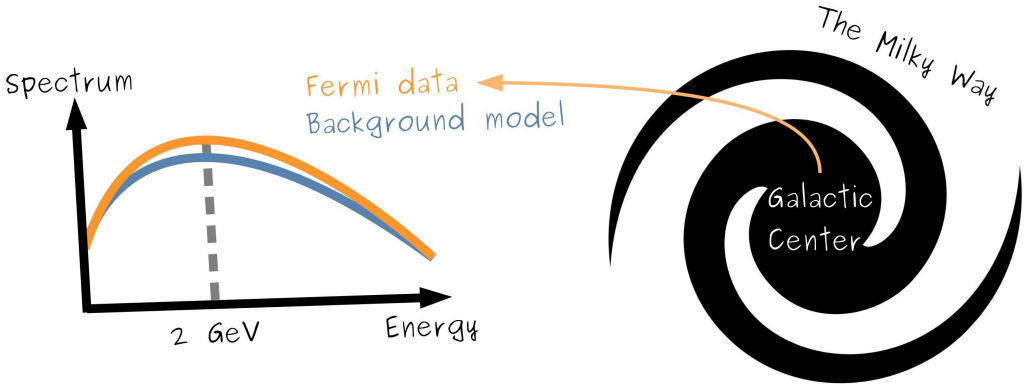
A multi-wavelength search for bulge millisecond pulsars

International Cosmic Ray Conference
July 2021

Joanna Berteaud

Francesca Calore
Maïca Clavel

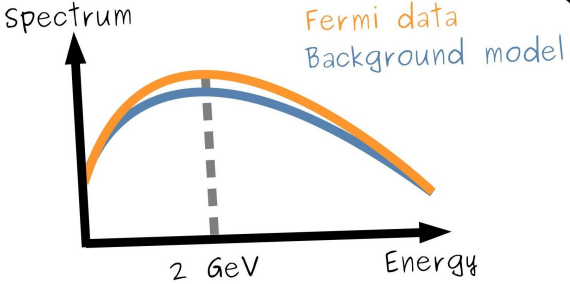
Introduction
What is the Fermi GeV excess?



Goodenough+09

Introduction

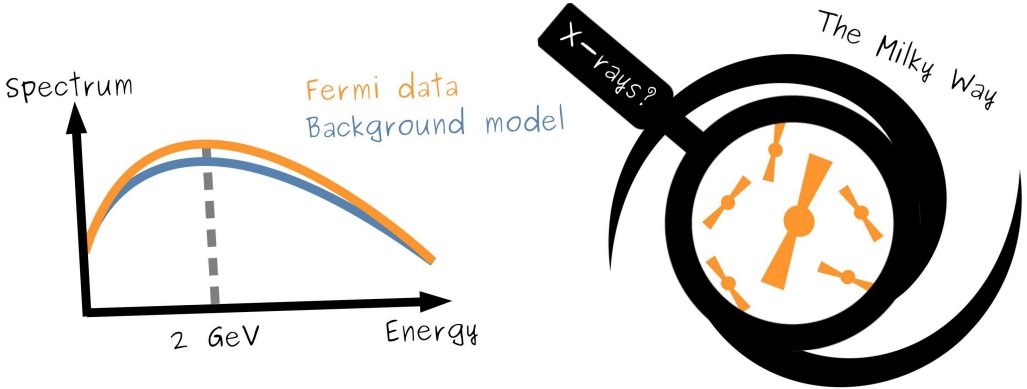
Millisecond pulsars as an explanation to the Fermi GeV excess



Abazadjian10

Introduction

Millisecond pulsars as an explanation to the Fermi GeV excess



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Introduction

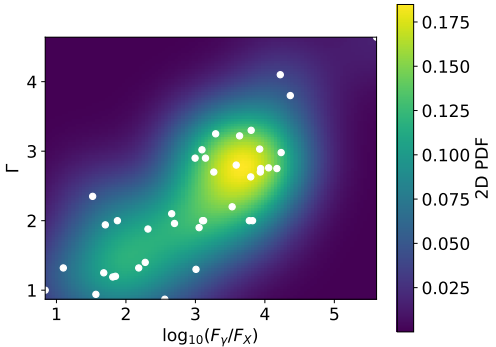
Millisecond pulsars as an explanation to the Fermi GeV excess

Simulation of the MSP population:

- Same morphology as the GeV excess
- Same total γ-ray luminosity as the GeV excess

Simulation of the X-ray emission:

- Computation of the γ-to-X MSP flux ratio
- Correlation with the X-ray spectral index Γ



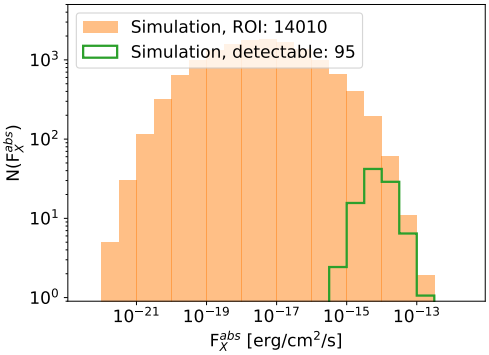
Berteaud+20.

Introduction

Millisecond pulsars as an explanation to the Fermi GeV excess

X-ray detectability of the MSP population:

- Chandra X-ray observatory
- Region of interest: $6^\circ \times 6^\circ$ about the Galactic Center
- MSP flux $>$ telescope sensitivity $\implies$ detectable
- A few hundred of detectable MSPs



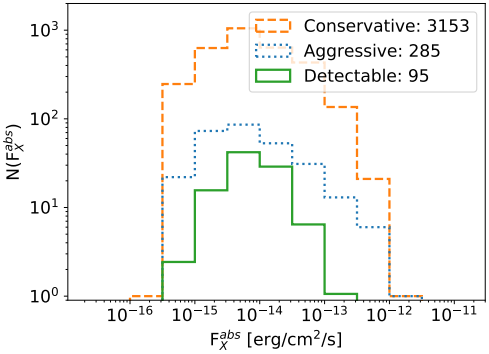
Berteaud+20.

Introduction

Millisecond pulsars as an explanation to the Fermi GeV excess

Comparison with data:

- Chandra data: unidentified sources
- Candidates properties:
  1. Power-law X-ray spectrum
  2. Intermediate distance
  3. Very faint or no optical counterpart
- MSP hyopthesis not excluded by the data
- Few hundreds of promising candidates kept for follow-up studies



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Multi-wavelength cross-matches
MSP criteria

For bulge MSPs, we expect:

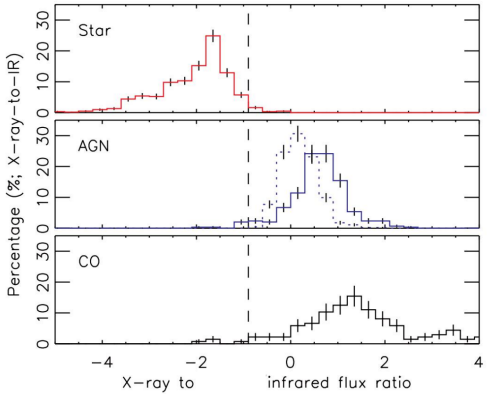
1. No optical counterpart (Antoniadis20)

2.a No IR counterpart **or**

2.b Faint IR counterpart (Lin+12):

$$\log_{10}(F^{abs}_{0.1;10keV}/F_{IR}) > 0.5$$

3. No UV counterpart



Lin+12.

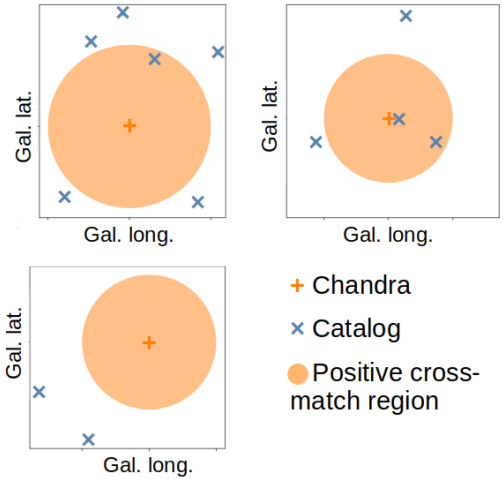
Multi-wavelength cross-matches
Goal and method

The goal of the multi-wavelength cross-matches is:

- **not** to find the true counterpart
- to exclude all candidates that **potentially** don't respect our criteria
- to keep only the most promising candidates

Method:

- Positive cross-match according to the angular separation
- Maximum separations depend on the positional uncertainties



Multi-wavelength cross-matches
Results

Ultraviolet:

- XMM-OM: 7 positive cross-matches
- 7 exclusions

Infrared:

- 2MASS: 10 positive cross-matches, no compact object
- VVV: 23 positive cross-matches, no compact object
- GLIMPSE: 5 positive cross-matches, no compact object
- 38 exclusions

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The 158 remaining promising candidates are only detected in X-rays so far.

Radio luminosity predictions
Motivations and method

Motivations:

- A pulsation is needed to confirm an MSP detection
- Little hope to detect an X-ray pulsation, more chances to detect a radio pulsation
- Radio predictions can help motivate radio observations

Method:

- Construct a relation between the X-ray and radio luminosity of observed MSPs
- Predict the radio luminosity of our candidates using this relation
- If the luminosity is larger than the telescope sensitivity, it is worth observing!

Radio luminosity prediction

$l_X - l_R$ relation

X-ray data:

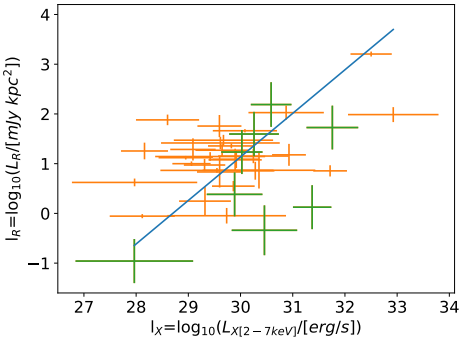
- Lee+18: 47 MSPs detected in X-rays
- Energy band: 2-7 keV

Radio data:

- ATNF pulsar catalog
- Frequency: 1400 MHz or 400 MHz (+ conversion)

Relation:

$$l_R = (0.88 \pm 0.21) l_X + (-25.13 \pm 6.29)$$



Conclusion and future prospects

- Some bulge MSP, unresolved in γ-rays, could be seen in X-rays
- The MSP hypothesis explaining the GeV excess is consistent with Chandra data

- More than 3000 MSP candidates found among Chandra unidentified sources
- About 160 promising candidates found, only seen in X-rays so far

- We computed a relation between the X-ray and radio luminosities of MSPs
- This relation will be used to motivate observations needed for pulsation detections

Bibliography

Thank you for your attention!

- Goodenough+09: arXiv:0910.2998
- Abazajian10: arXiv:1011.4275
- Berteaud+20: arXiv:2012.03580
- Lin+12: ApJ 756 27
- Antoniadis20: arXiv:2011.08075
- Lee+18: arXiv:1807.06505