Multiwavelength identification of millisecond pulsar candidates in the Galactic bulge

Joanna Berteaud

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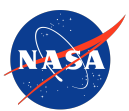
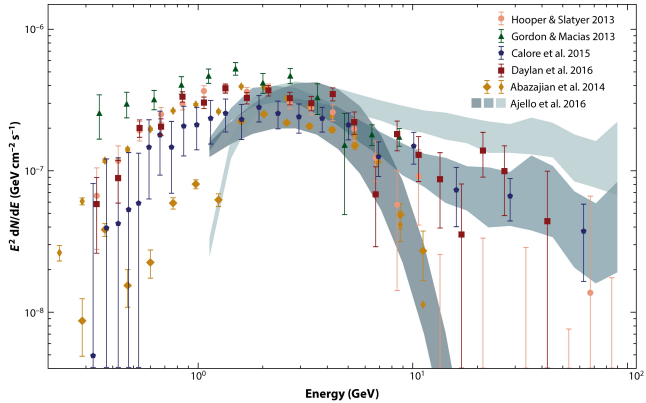


The Galactic center excess



Murgia S. 2020.
Annu. Rev. Nucl. Part. Sci. 70:455–83

See also
B. Safdi's
and
S. Manconi's
talks (Plen. 9)

The Galactic center excess and MSPs

- Spatial distribution traces old stars in the Galactic bulge
- Spectral shape compatible with a cumulative emission from MSPs

See also D. Song's talk (Par. 11B)

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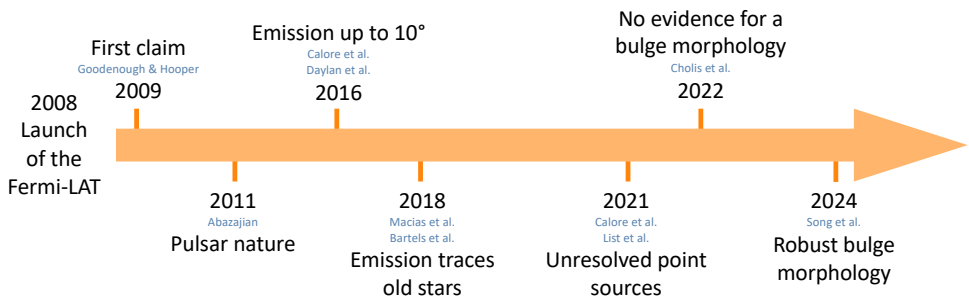


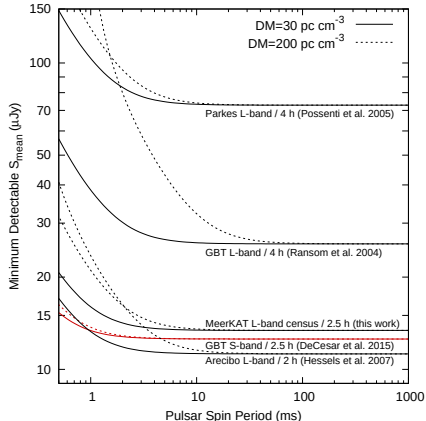
Pulsar detection

Pulsars: **radio**, X-ray and γ-ray emitters

Radio pulsation detections challenging with:

- Small periods
- Highly-dispersed pulses
- Large distances
- i.e. for bulge MSPs

Radio surveys not sensitive enough Calore+16



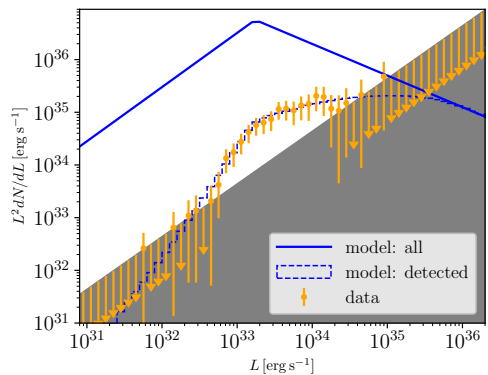
Ridolfi+21.

Are X-ray telescopes sensitive to the bulge MSP population?

MSP simulation: from γ rays...

- Best fit disk MSP γ-ray luminosity function found to be a broken power-law: Bartels+18

$$\frac{\mathrm{dN}}{\mathrm{dL}} \propto \begin{cases} \left(\frac{\mathrm{L}}{1\mathrm{erg/s}}\right)^{-0.97} & \mathrm{L} \leq 10^{33.24}\mathrm{erg/s} \\ \left(\frac{\mathrm{L}}{1\mathrm{erg/s}}\right)^{-2.6} & \mathrm{L} > 10^{33.24}\mathrm{erg/s} \end{cases}$$



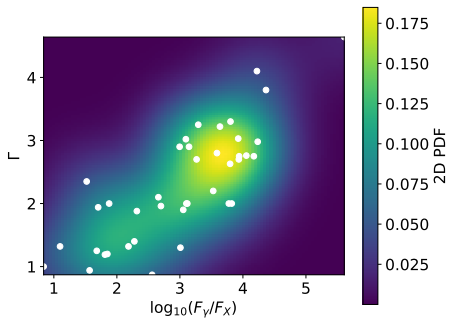
Bartels+18.

MSP simulation: ... to X rays

- 47 MSPs detected in X rays Lee+18
- MSP X-ray spectrum: simple power law:

$$S(E) = A(E/1keV)^{-\Gamma}$$

- 40 of them are also detected by Fermi
- Computation of the γ-to-X flux ratio
- Correlation with the X-ray spectral index Γ



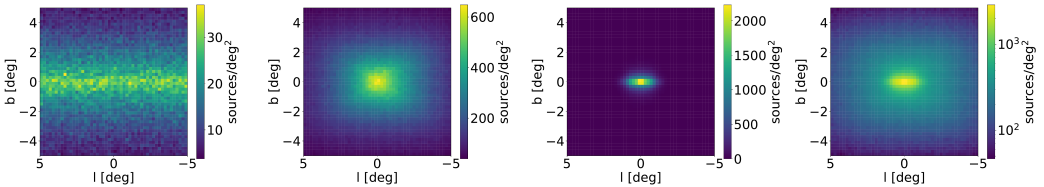
$$F_X = \int_{E_{min}}^{E_{max}} E \cdot S(E) dE = \frac{F_\gamma}{F_\gamma/F_X} = \frac{L_\gamma/(4\pi d^2)}{F_\gamma/F_X}$$

Berteaud+21.

MSP simulation

Available on Zenodo!

Disk	Boxy bulge	Nuclear bulge	Total
$L_\gamma = 1.5e37$ erg/s	$L_\gamma = 1.73e37$ erg/s	$L_\gamma = 1.64e36$ erg/s	
$N_{tot} = 24009$	$N_{tot} = 27674$	$N_{tot} = 2606 + 94$	



Berteaud+21

Each simulated MSP has a position, a γ-ray luminosity and an X-ray flux.

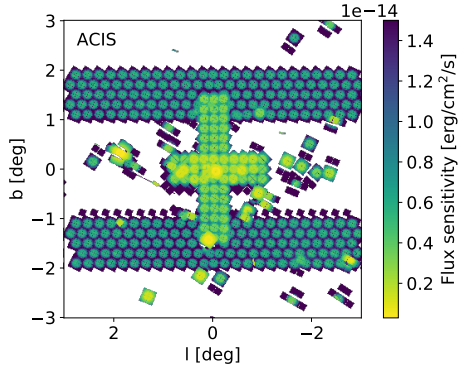
Testing the MSP hypothesis

Chandra X-ray observatory:

- Patchy sky coverage
- Non-uniform sensitivity

Chandra source catalog:

- Position, flux in different energy bands
- Unclassified sources
- Faint sources: incomplete spectral analysis



Berteaud+21.

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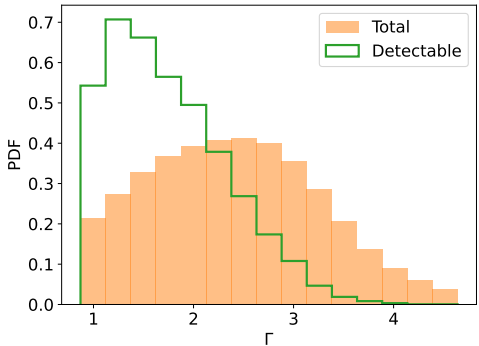
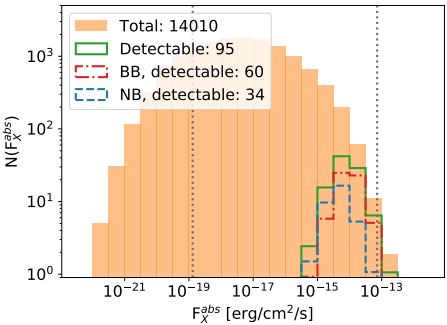


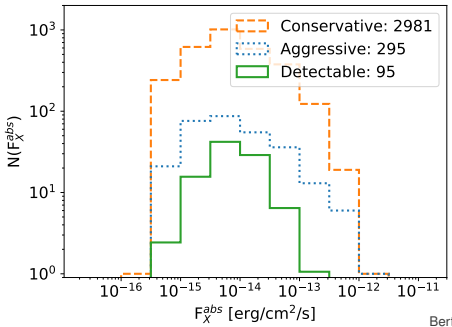
Berteaud+21.

Testing the MSP hypothesis

Simulation



Catalog



Berteaud+21

The MSP hypothesis is not exclued by X-ray data.

Promising candidates

For bulge MSPs, we mainly expect:

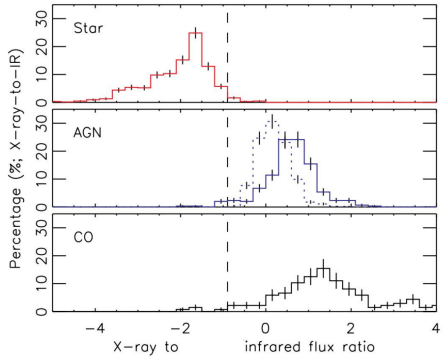
1. No optical counterpart Antoniadis20
2. No UV counterpart

3.a No IR counterpart **or**

3.b Faint IR counterpart Lin+12:

$$\log_{10}(\mathrm{F_X}/\mathrm{F_{IR}}) > 0.5$$

$\sim$ 40 compact objects candidates



Lin+12.

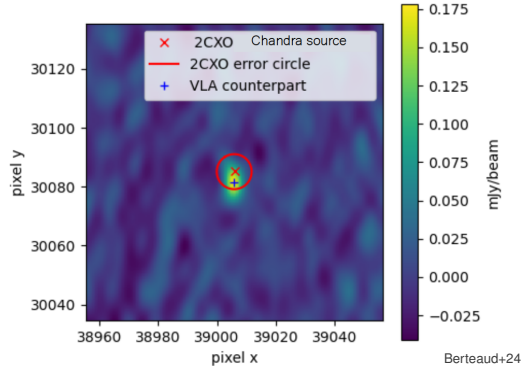
Promising candidates

VLA data (PI: M. Kerr):

- 28h L-band (1.4 GHz) imaging
- About 6 deg^2 overlapping our ROI

Counterpart search:

- Around promising candidates
- Radio flux, size, etc



Berteaud+24

$\sim$ 6 candidates only detected in X-rays and radio

Conclusion

- A population of MSPs in the bulge could explain the Galactic center excess
- We showed that the Chandra data do not exclude the MSP hypothesis Berteaud+21
- We found promising MSP candidates which only emit in X ray and radio Berteaud+24
- See also: pulsar candidates in the MeerKAT bulge survey Frail+24, incl. Berteaud

- Radio observations are ongoing, stay tuned for the outcome!

Conclusion

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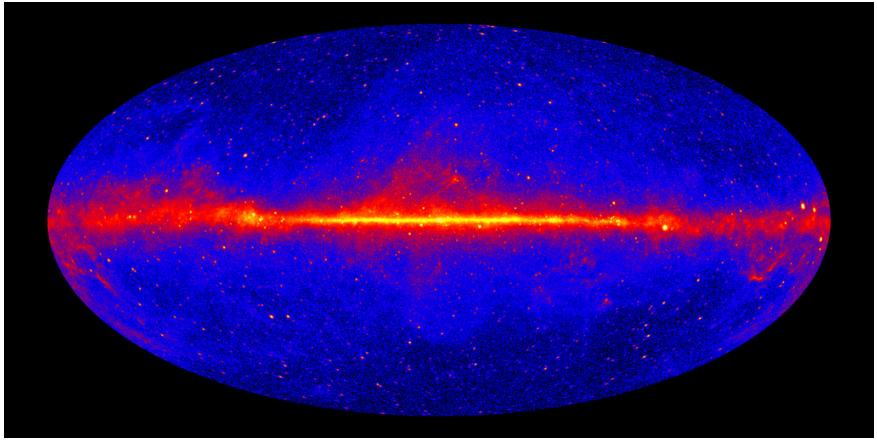
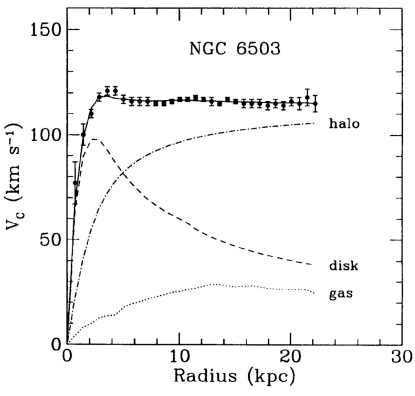
Thank you for your attention!

The Galactic center excess



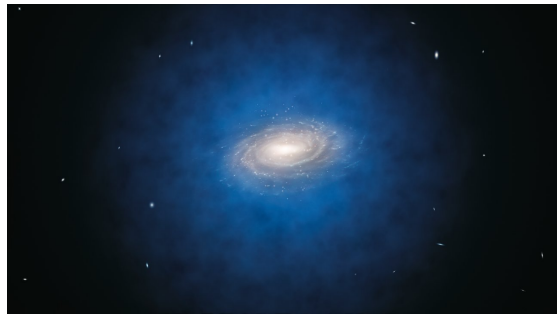
NASA GSFC

Dark matter: the missing mass



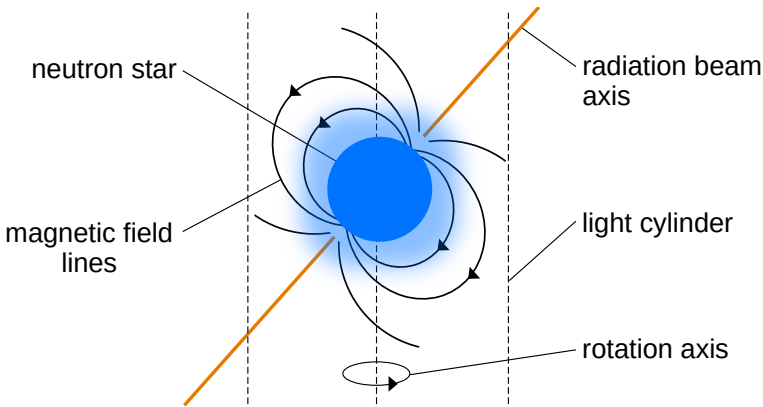
Freese+08.

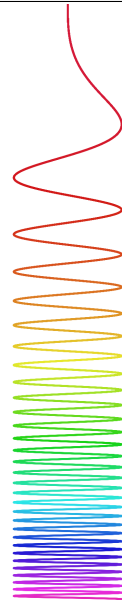
Spherical halo of non-luminous matter:



ESO/L. Calçada.

Millisecond pulsars





MSP simulation: positions in the bulge

The bulge, fitted to the excess data, gets contributions from two components:

- The boxy bulge (BB): Cao+13

$$n(r_{BB}) = K_0 \left(\left[\left[\left(\frac{x_{BB}}{x_0} \right)^2 + \left(\frac{y_{BB}}{y_0} \right)^2 \right]^2 + \left(\frac{z_{BB}}{z_0} \right)^4 \right]^{\frac{1}{4}} \right)$$

- The nuclear bulge (NB) is composed of the: Launhard+02
  - nuclear stellar disk (NSD):

$$n(r, z) = \begin{cases} n_0 \left(\frac{r}{1\,pc} \right)^{-0.1} e^{-\frac{|z|}{45\,pc}} & r \leq 120\,pc \\ n_1 \left(\frac{r}{1\,pc} \right)^{-3.5} e^{-\frac{|z|}{45\,pc}} & 120\,pc < r \leq 220\,pc \\ n_2 \left(\frac{r}{1\,pc} \right)^{-10} e^{-\frac{|z|}{45\,pc}} & r \geq 220\,pc \end{cases}$$

  - nuclear stellar cluster (NSC):

$$n(r) = \begin{cases} \frac{\rho_0}{1+\left(\frac{r}{r_0}\right)^2} & r \leq 6\,pc \\ \frac{\rho_1}{1+\left(\frac{r}{r_0}\right)^3} & 6\,pc < r \leq 200\,pc \\ 0 & r \geq 200\,pc \end{cases}$$

MSP simulation: positions in the disk

MSP number density in the Galactic disk: Lorimer+06, Bartels+18

$$n(r, z) = \frac{NC^{B+2}}{4\pi R^2 z_s e^C \Gamma(B+2)} \left(\frac{r}{R}\right)^B \times \exp\left(-C\left(\frac{r-R}{R}\right)\right) \exp\left(-\frac{|z|}{z_s}\right)$$

- Based on observations of γ-ray detected pulsars
- May represent an important foreground, it is the case in γ-rays
- Important to model, even if we look for bulge MSPs!

Selection of MSP candidates

MSP simulation

$6^\circ \times 6^\circ$about the GC
MSP flux > threshold at the MSP position

- 95 ± 9 detectable MSPs

Chandra sources

Exclude extended sources
Exclude variable sources
$6^\circ \times 6^\circ$about the GC

Source flux > threshold at the source position

- 6918 candidates

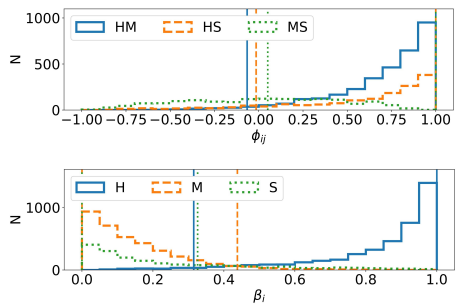
Testing the MSP hypothesis

Spectral cuts:

- Bands: broad, hard, medium, soft
- Flux ratio and band fraction:

$$\phi_{\rm ij} = \frac{\rm F_i - F_j}{\rm F_i + F_j} \qquad \beta_{\rm i} = \frac{\rm F_i}{\rm F_B}$$

- $\phi_{\rm ij}^{\rm cand} \in [\phi_{\rm ij}^{\rm min}, \phi_{\rm ij}^{\rm max}]$, $\beta_{\rm i}^{\rm cand} \in [\beta_{\rm i}^{\rm min}, \beta_{\rm i}^{\rm max}]$



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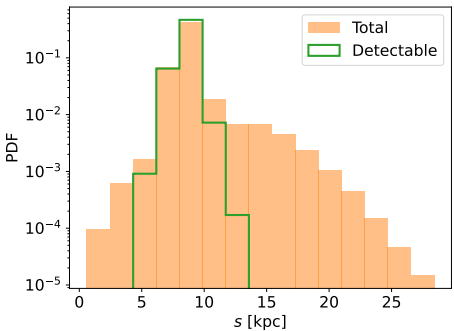

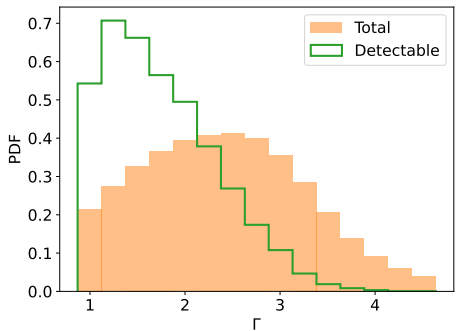

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