Millisecond pulsars and the Fermi GeV excess

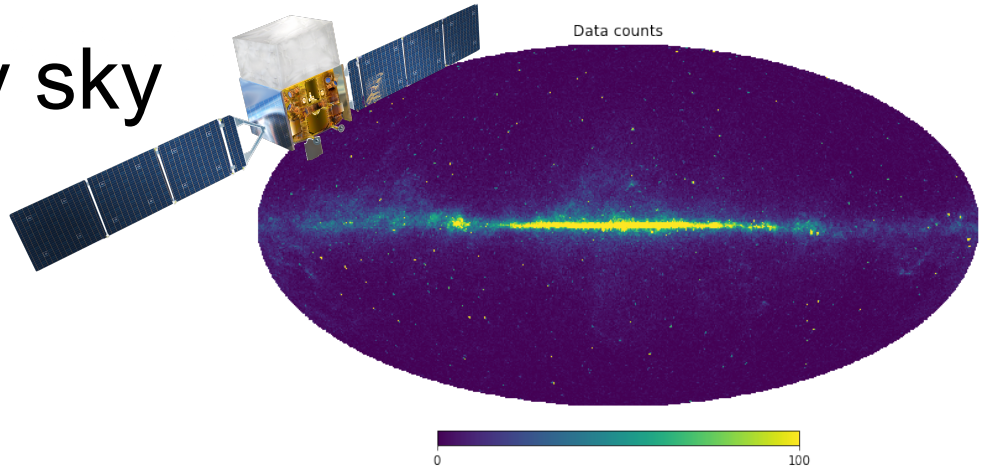
Joanna Berteaud

In collaboration with Francesca Calore and Maïca Clavel

Assemblée générale Enigmass, October 2023

LAPTh cnrs UNIVERSITÉ SAVOIE MONT BLANC IPAG GECO ANR AGENCE NATIONALE DE LA RECHERCHE

The γ-ray sky



https://nptfit.readthedocs.io

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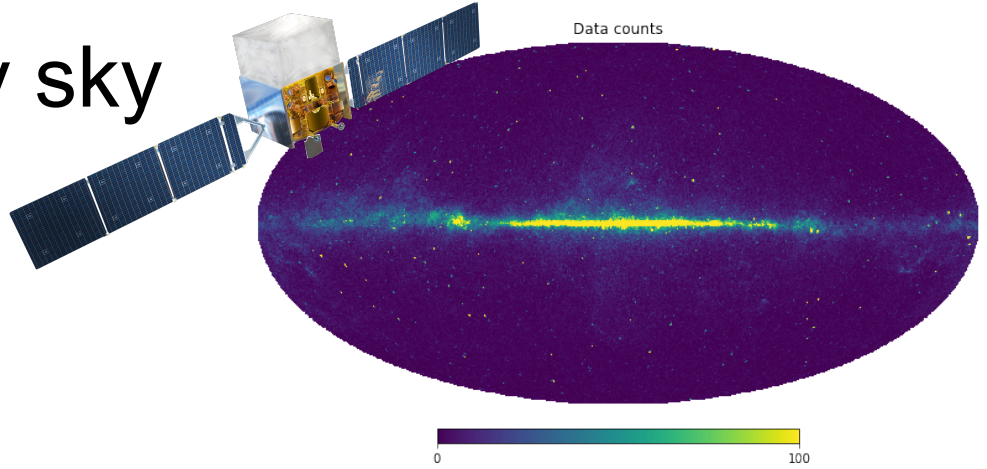

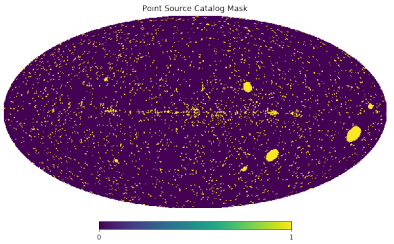

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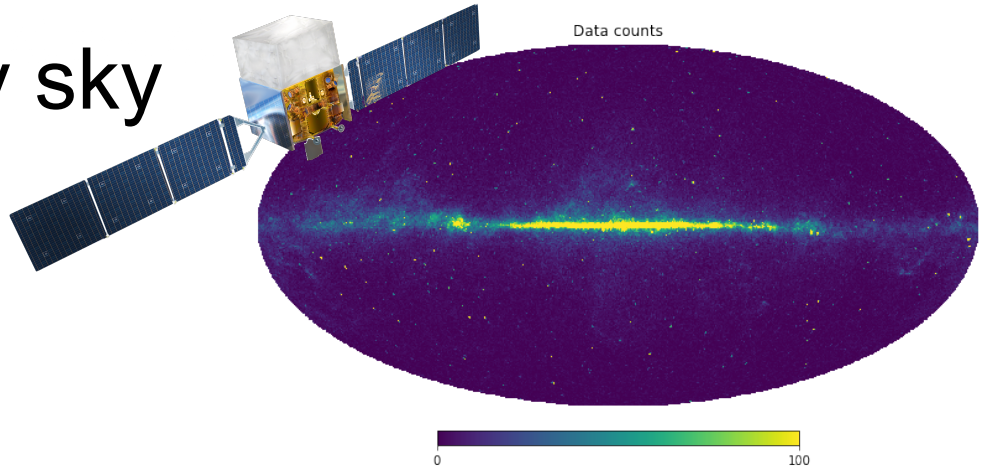
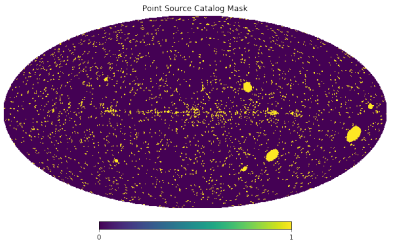
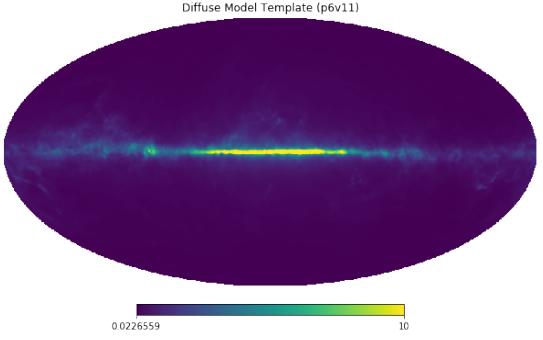
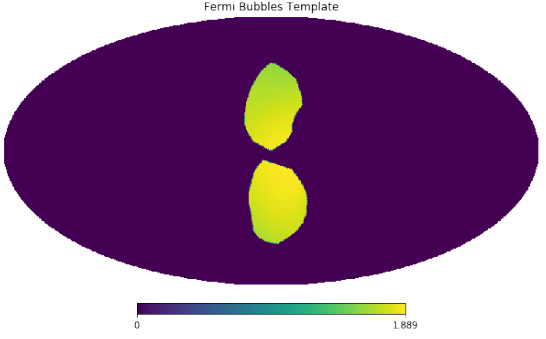


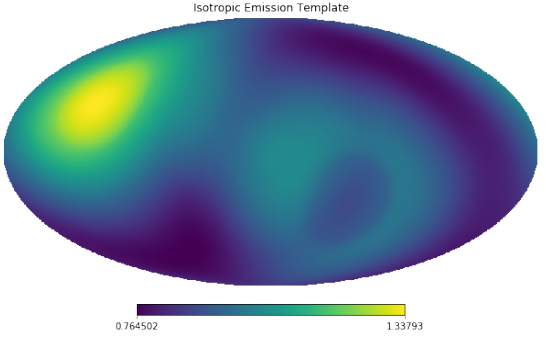


data with point sources masked =

diffuse emission (ICS, Bremsstrahlung, π^0) + Fermi Bubbles + isotropic emission







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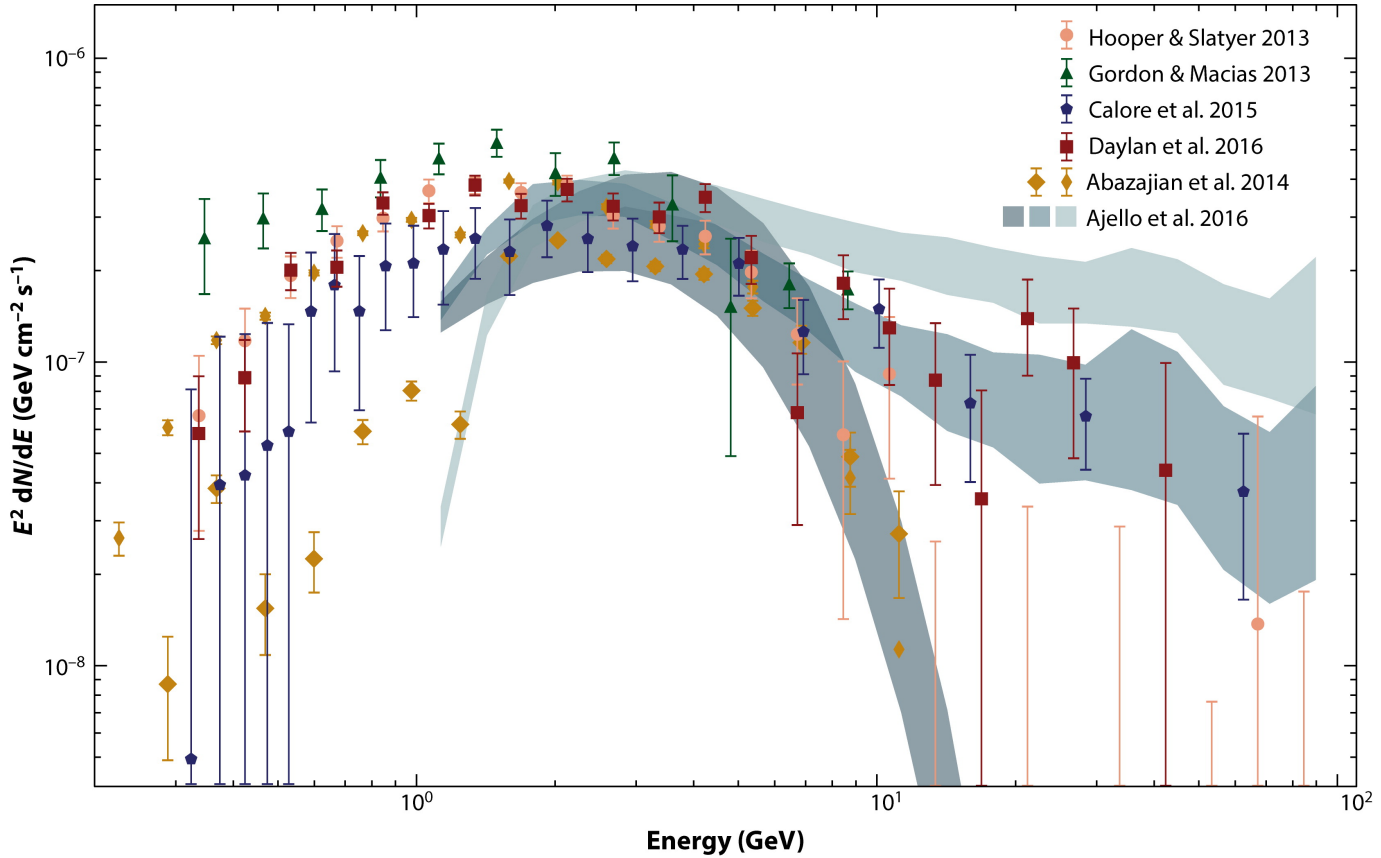
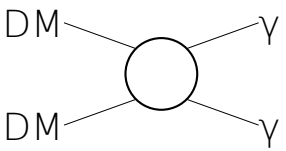
Spectrum of the Fermi GeV excess



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

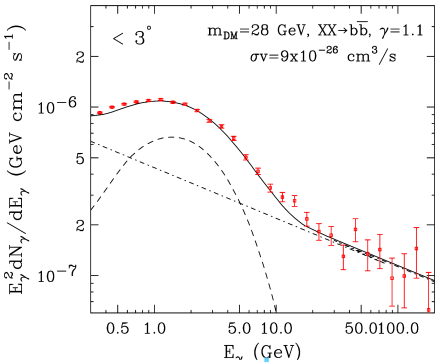
(Non-exhaustive) Timeline of the Fermi GeV excess

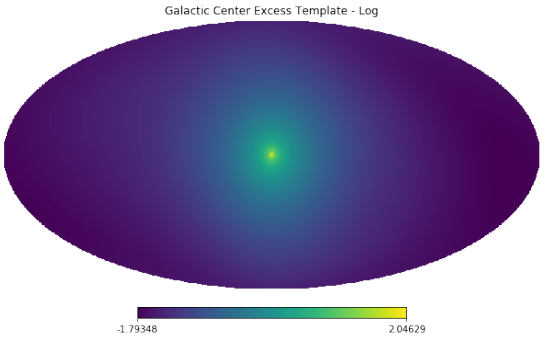


First claim

Goodenough & Hooper

2009





2008 Launch of the Fermi-LAT

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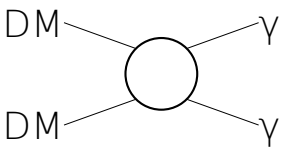

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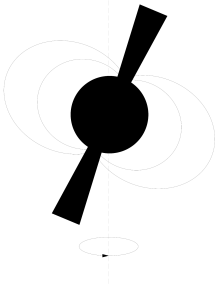

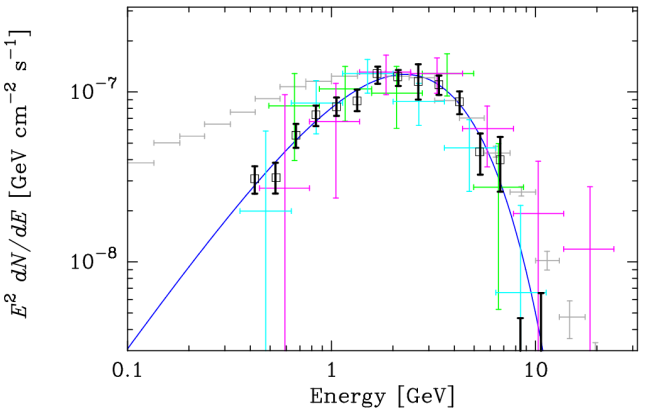

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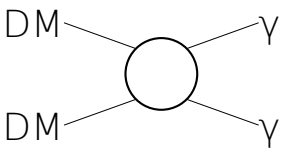

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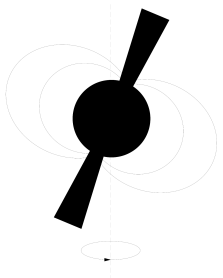

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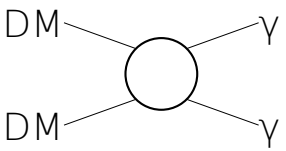

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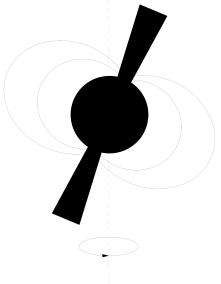

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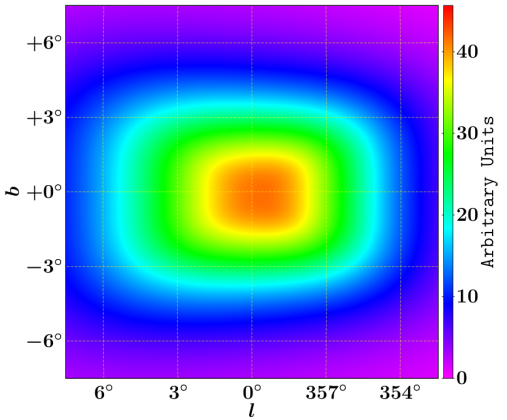

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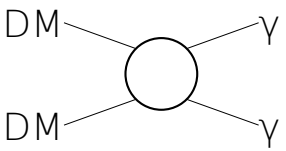

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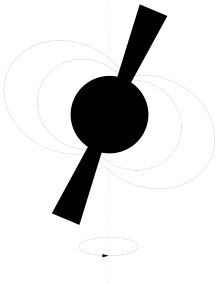

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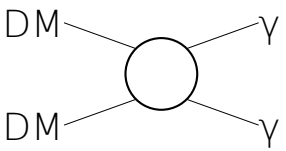

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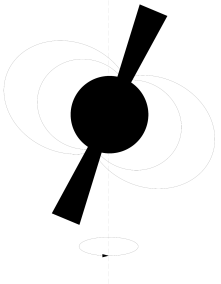

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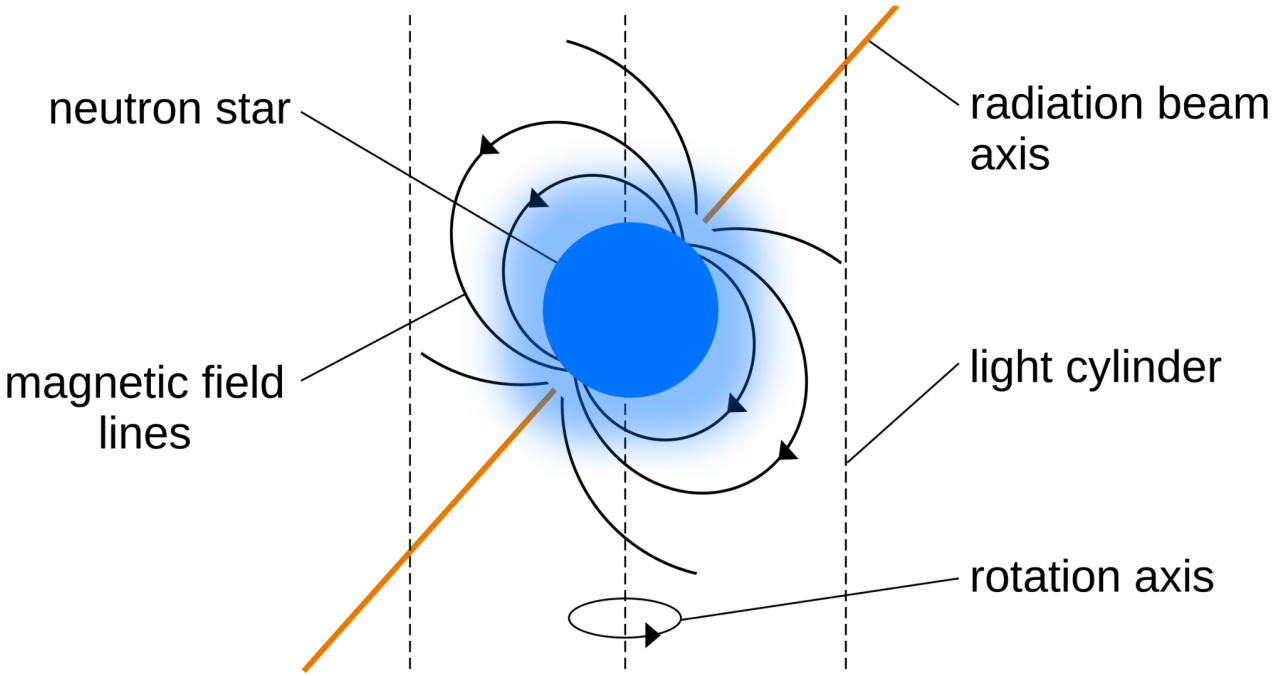
Calore et al.
List et al.

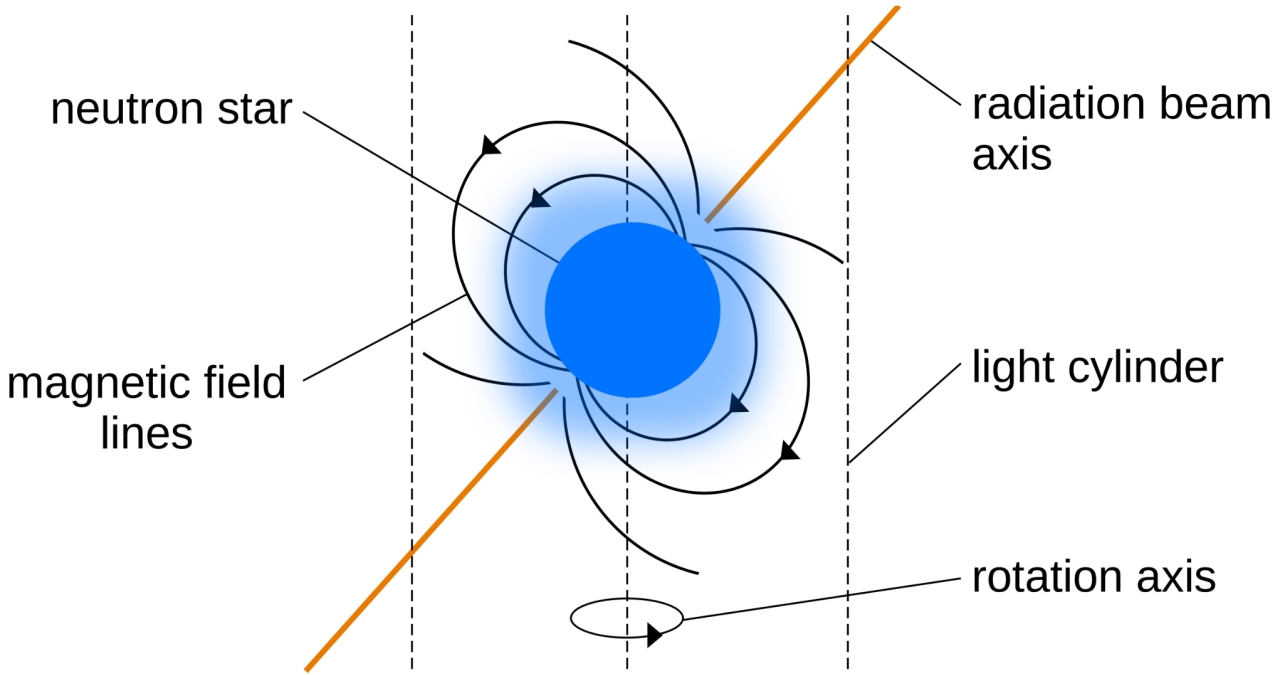
2022
No evidence for a
bulge morphology
Cholis et al.

Millisecond pulsar basics



P < 30 ms

Millisecond pulsar basics



P < 30 ms

Radio

Infrared (IR)

Optical

Ultraviolet (UV)

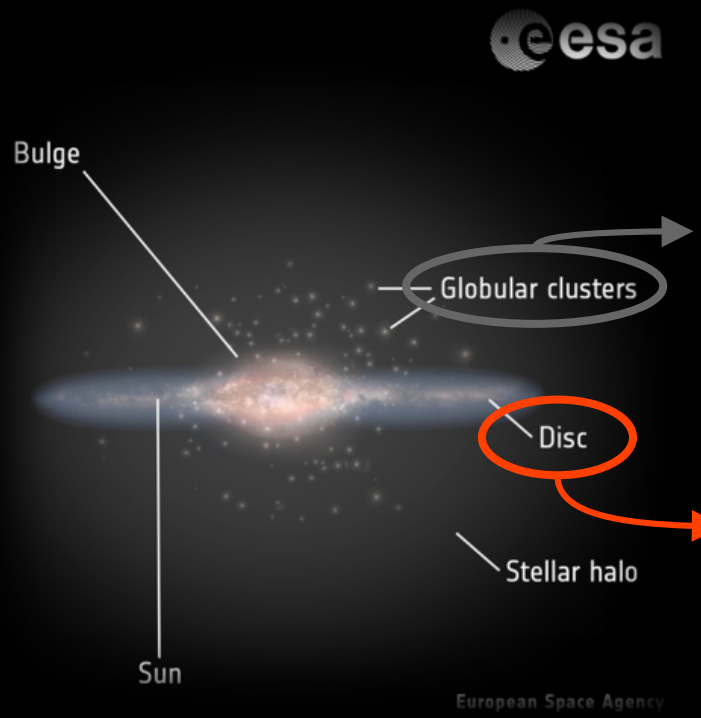
X rays

γ rays

The Galactic MSP population

- More than 250 MSP pulsations detected in radio
- Diffuse γ-ray emission seen by the Fermi-LAT

The Galactic MSP population

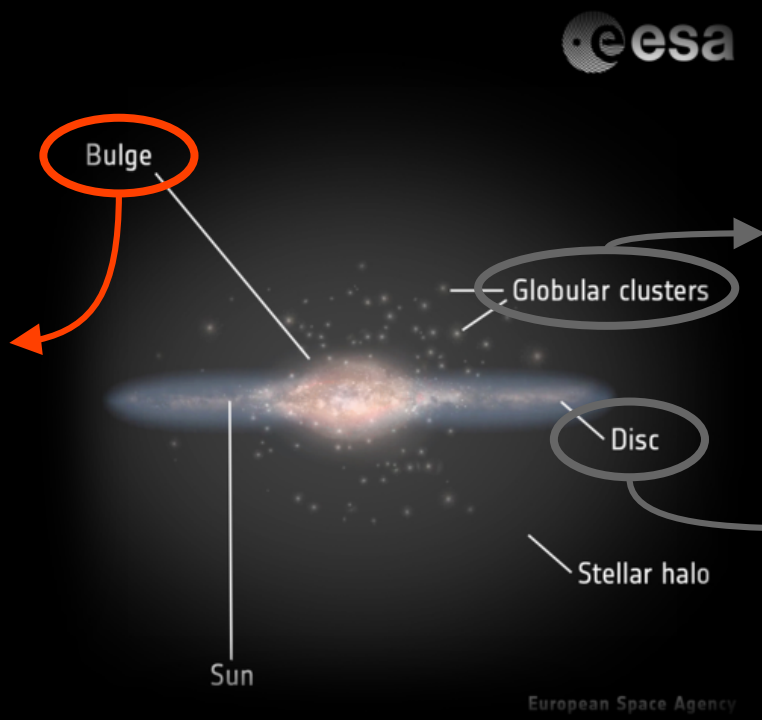


- More than 250 MSP pulsations detected in radio
- Diffuse γ-ray emission seen by the Fermi-LAT

- The rest, more than 300

The Galactic MSP population

- No evidence from individual detections
- Putative origin of the Fermi GeV excess



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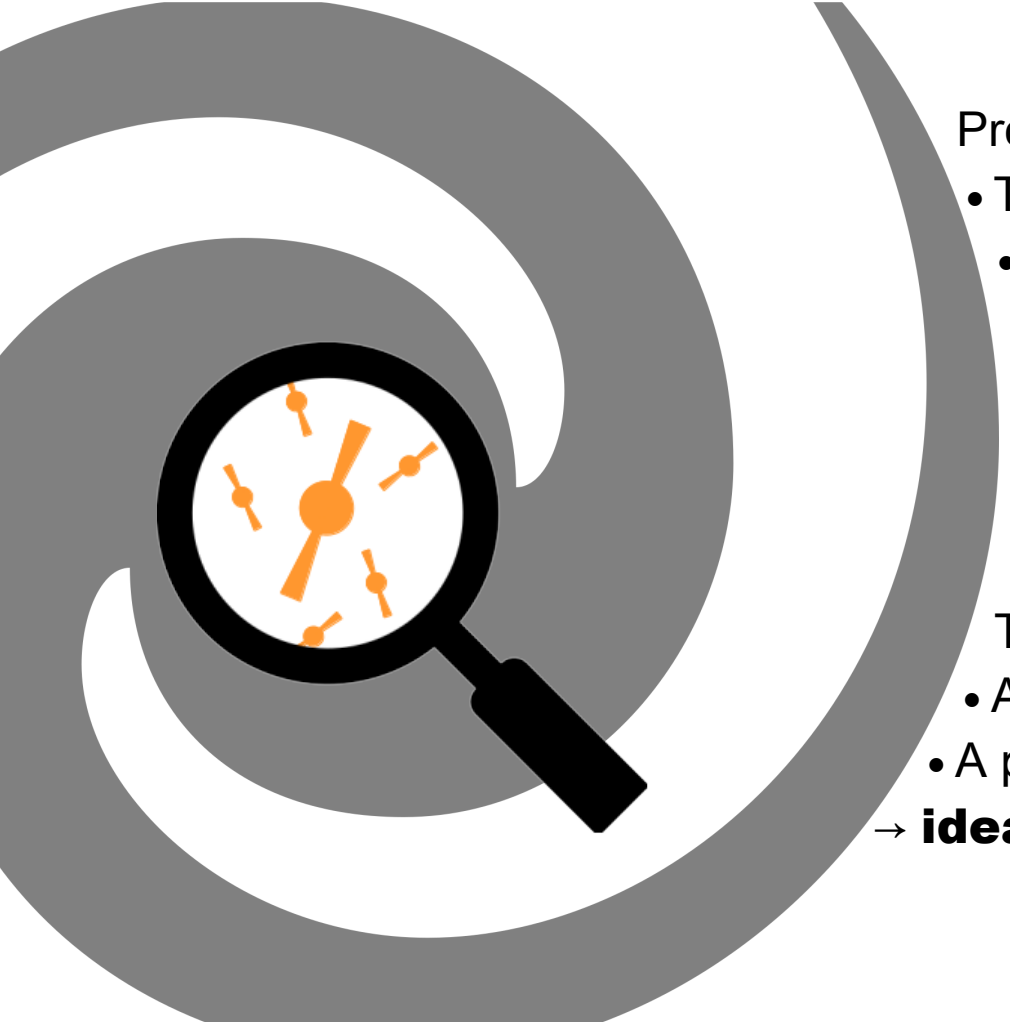
(Millisecond) Pulsars at the Galactic center



Probes of:

- The Fermi GeV Excess, its dark matter origin
- The free electron and cosmic-ray source densities
- The gravitational potential of the region
- Theories of gravity
- ...

The Galactic center shows:

- A large stellar density
- A profusion of massive stars

→ **ideal place to find compact objects**

I. Simulation and X-ray detectability of the Galactic bulge MSP population

Berteaud et al. (2021)

Simulation of the Galactic MSP population

Monte Carlo simulation available on Zenodo!

	Disk	**Bulge**
Number density		
γ-ray luminosity function		
X-ray emission model		

Simulation of the Galactic MSP population

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	Disk	**Bulge**
Number density	~100 γ-ray detected MSPs Bartels et al. 2018b	Fermi GeV excess data Bartels et al. 2018a
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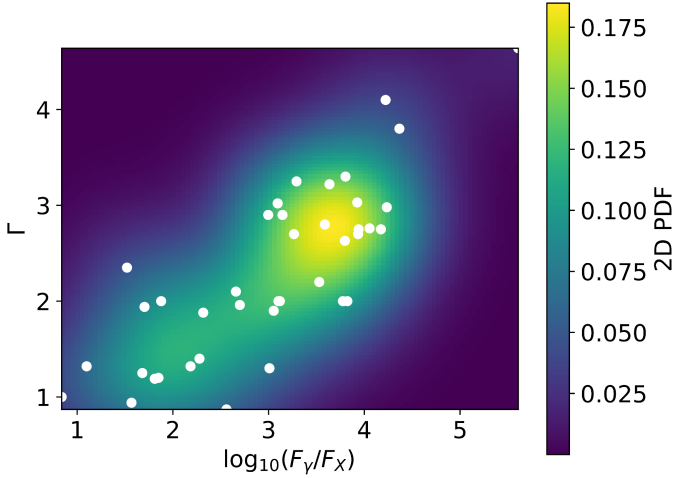

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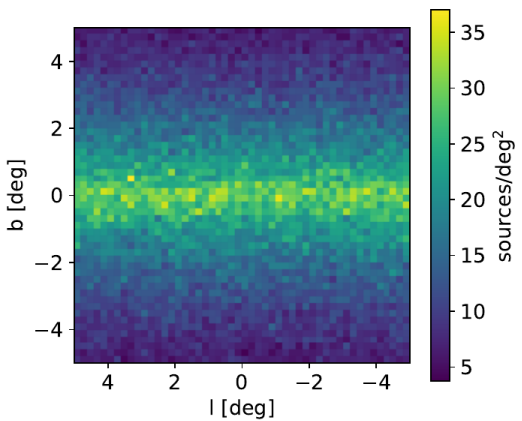
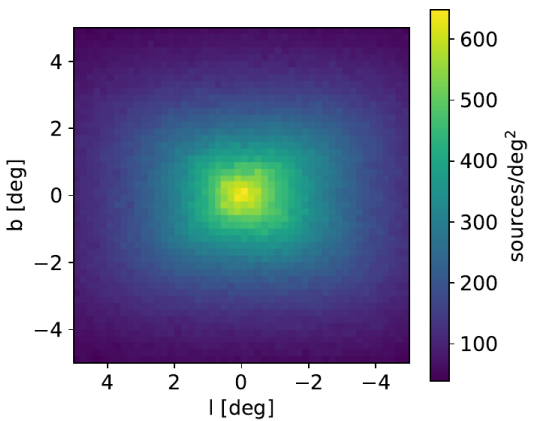
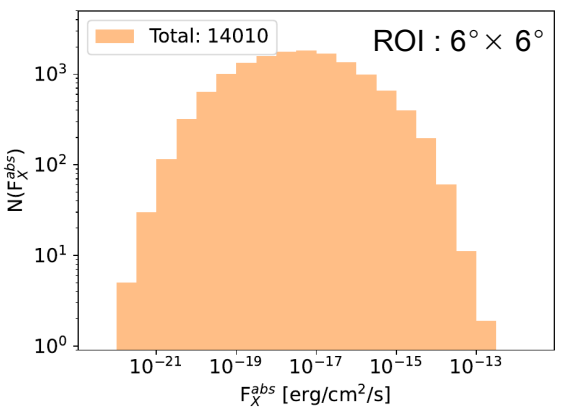
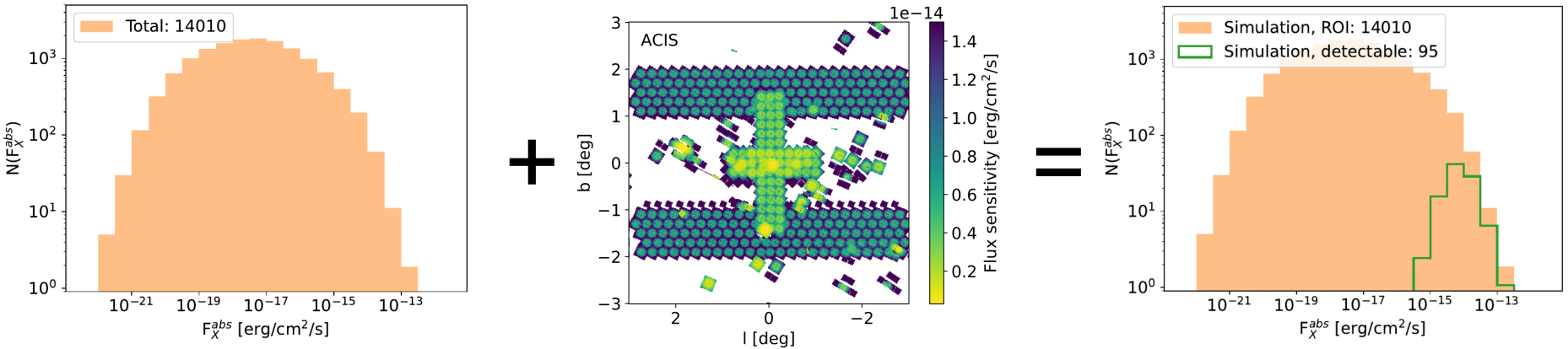






X-ray detectability of the Galactic MSP population



- Detectable simulated MSP: MSP simulated flux > Chandra sensitivity
- **About 100**, minor contribution from the disk (**Berteaud** et al. 2021)

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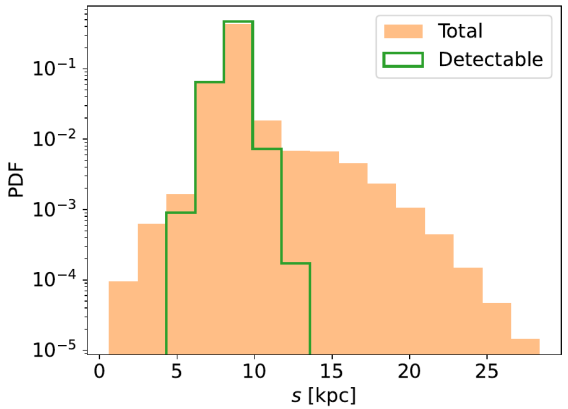
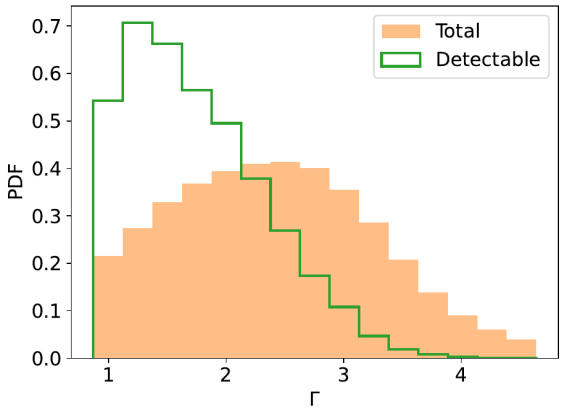




- Detectable simulated MSP: MSP simulated flux > Chandra sensitivity
- **About 100**, minor contribution from the disk (**Berteaud** et al. 2021)

- Between 5.2 and 11.9 kpc, at 8.5 kpc on average
- Hard X-ray sources

II. Selection of MSP candidates

Berteaud et al. (2021 & 2023, in prep.)

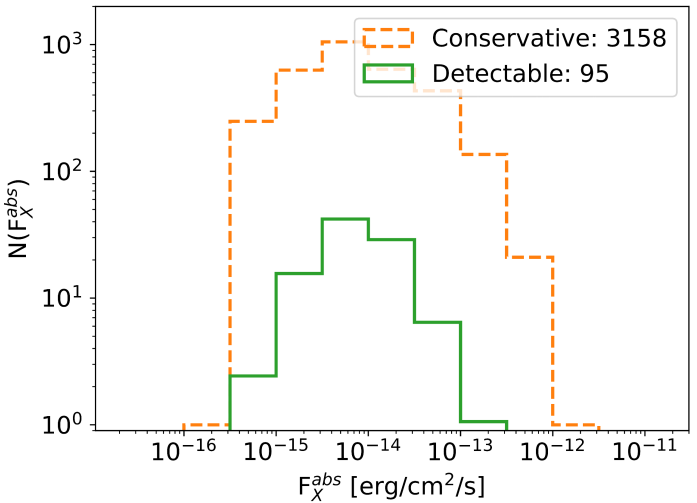
Selection of MSP candidates

1. From the Chandra catalog:
   - Non-variable
   - Non-extended
   - Hard sources

2. Distance constraints with Gaia:
   - at bulge distance (Bailer-Jones, 2021)

   ~3200 candidates > 95 expected

Selection of MSP candidates



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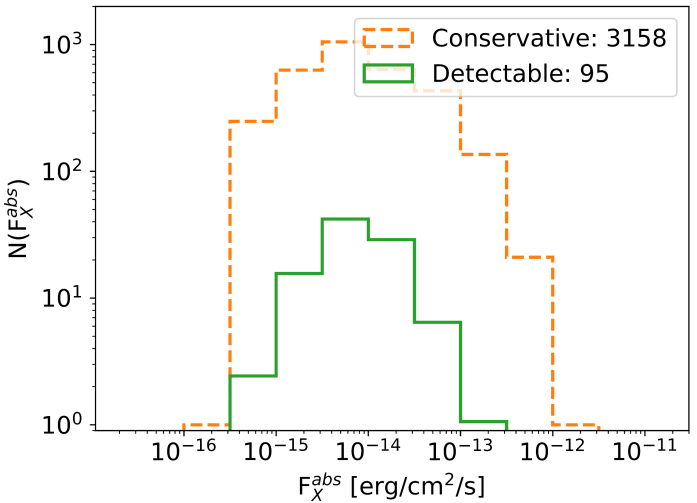

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   ~3200 candidates > 95 expected

3. Neither optical nor UV counterarts:

   ~2300 candidates

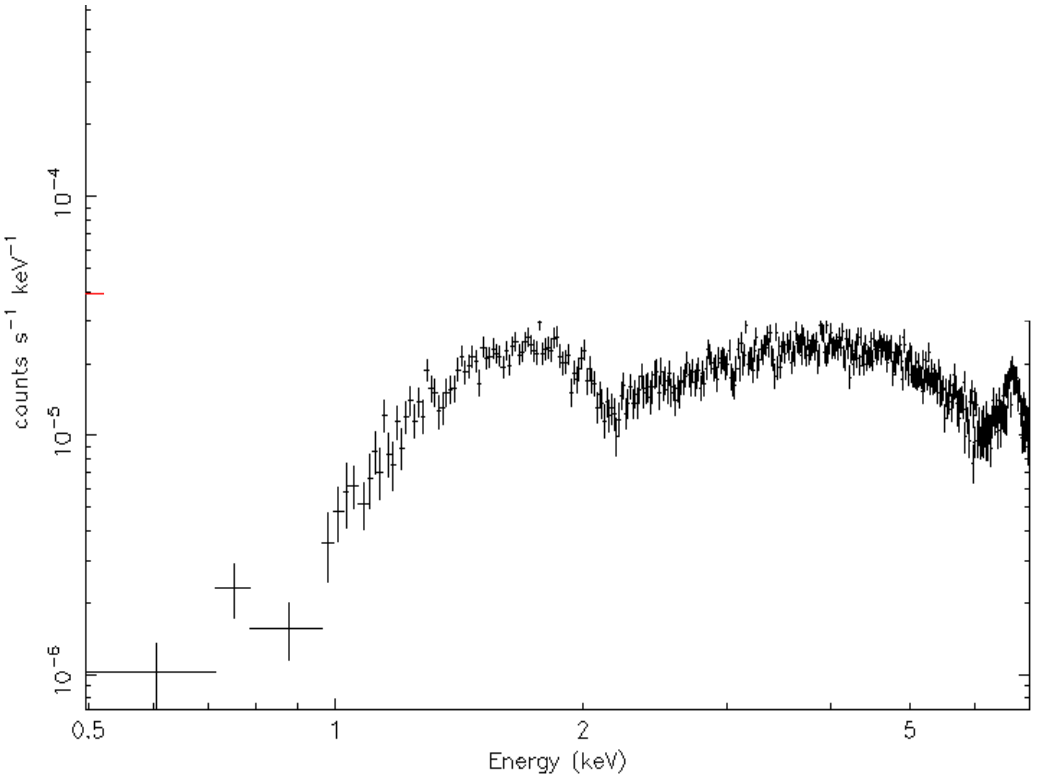
4. No strong IR counterpart:

   ~1400 candidates

   ~50 compact objects (CO, Lin et al. 2012):

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

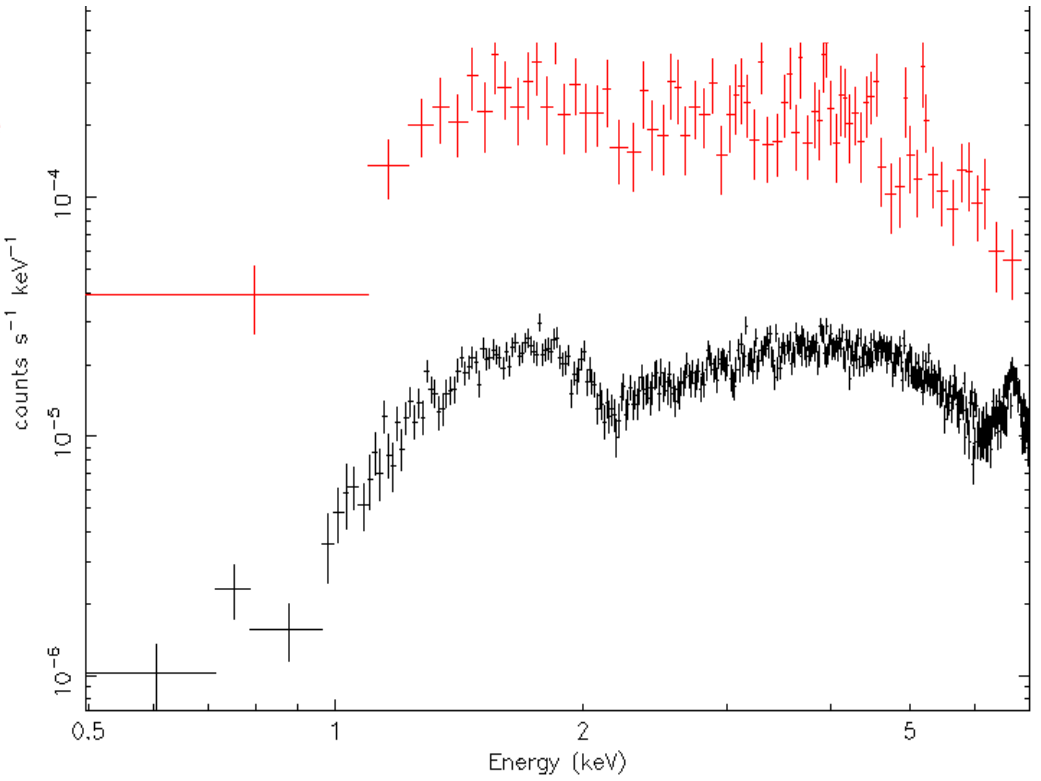
Cumulative X-ray emission of MSP candidates



~1400 MSP candidates: contaminated by cataclysmic variables (CVs)

Cumulative X-ray emission of MSP candidates

~50 CO candidates:
spectrum compatible with simulation



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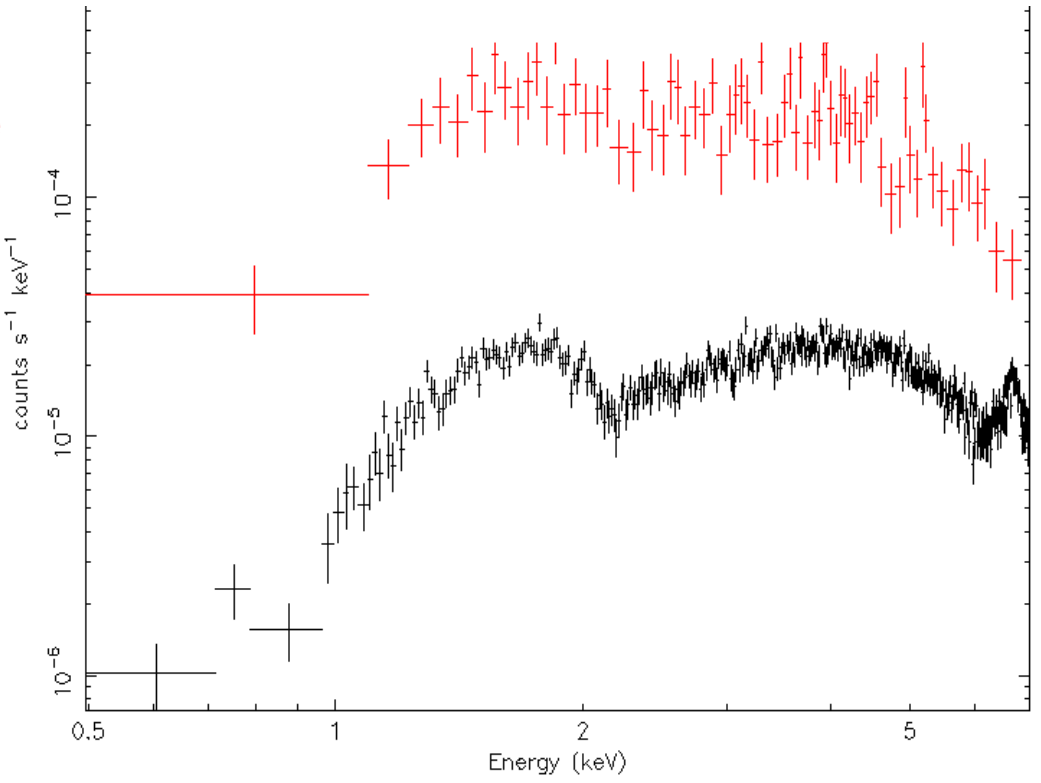

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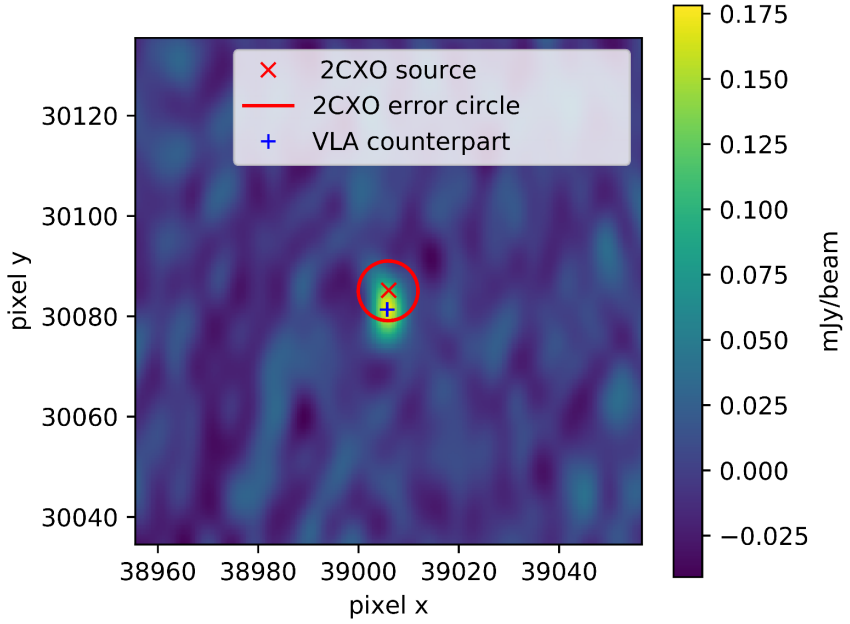
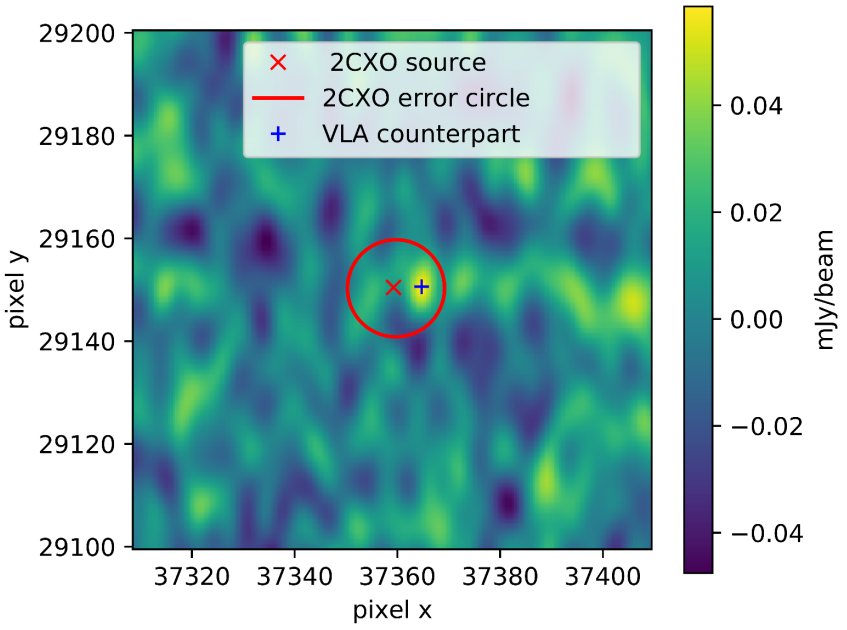
Interesting population of X-ray sources without optical/UV/IR emission. What are they?

Radio counterparts

- NRAO VLA Sky Survey: sources above 2.5 mJy, too high for bulge MSPs
- Unpublished VLA data (PI: M. Kerr): 18 radio counterparts

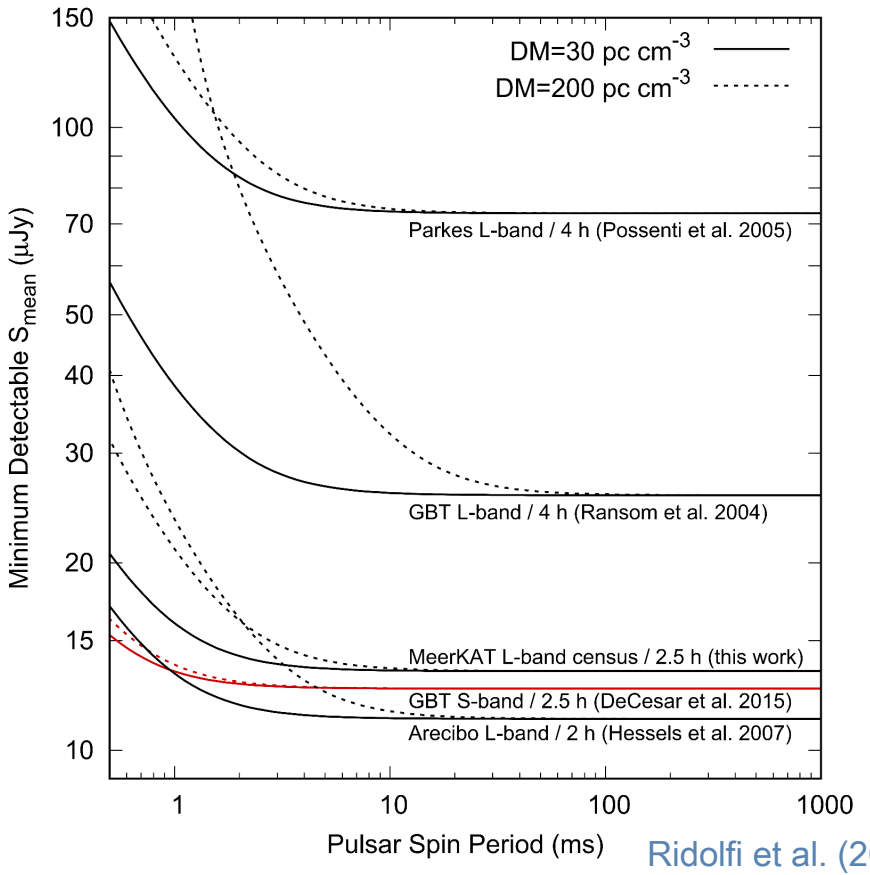




→ 6 interesting candidates selected for follow-up studies

III. Radio timing follow-ups

Radiometer equation



Ridolfi et al. (2021)

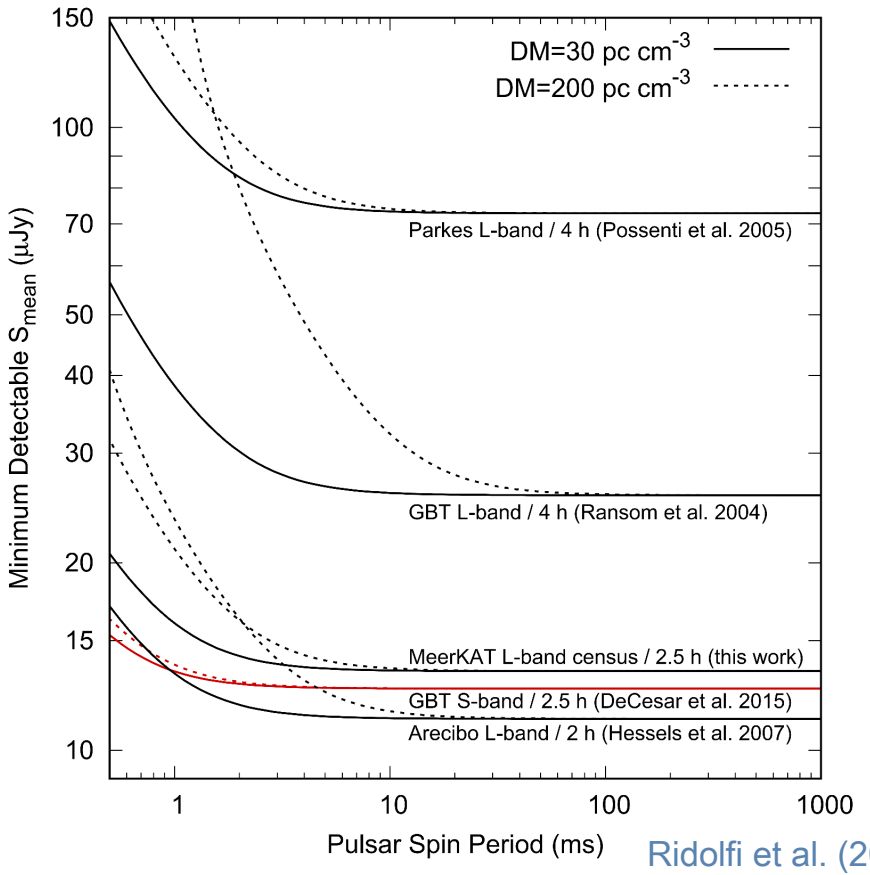
Radiometer equation:

→ minimum detectable flux S_{min}

→ as a function of pulsar period P

$$S_{min}(P)\,\alpha\sqrt{\frac{w}{T_{obs}(P-w)}}$$

Radiometer equation



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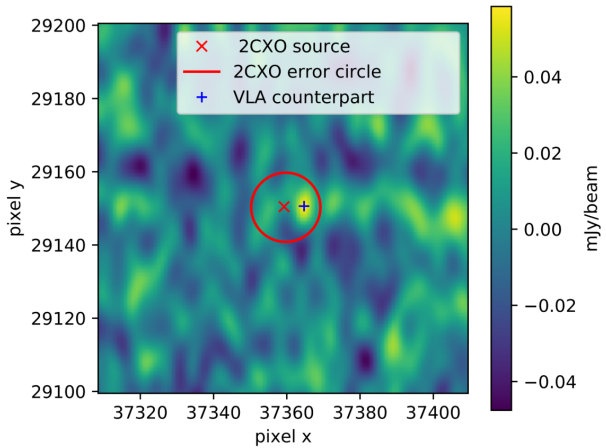
Hardest detections:

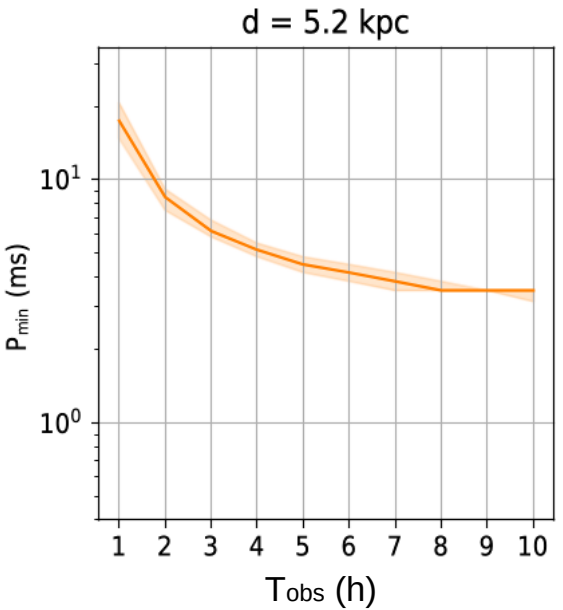
- High electron column density (DM)
- Short pulsar period
- Binary system
- Low flux

See also Calore et al. (2016)

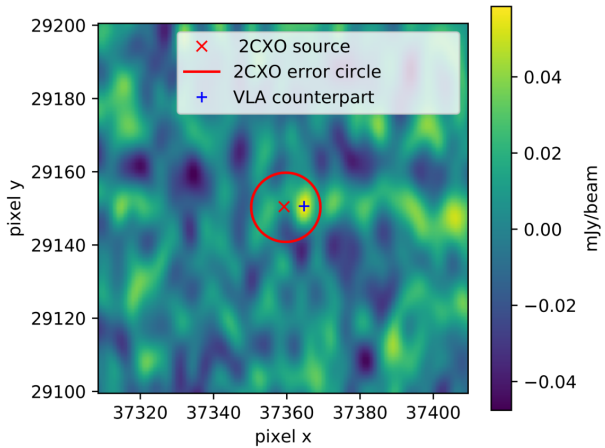
Observations with Parkes and the GBT



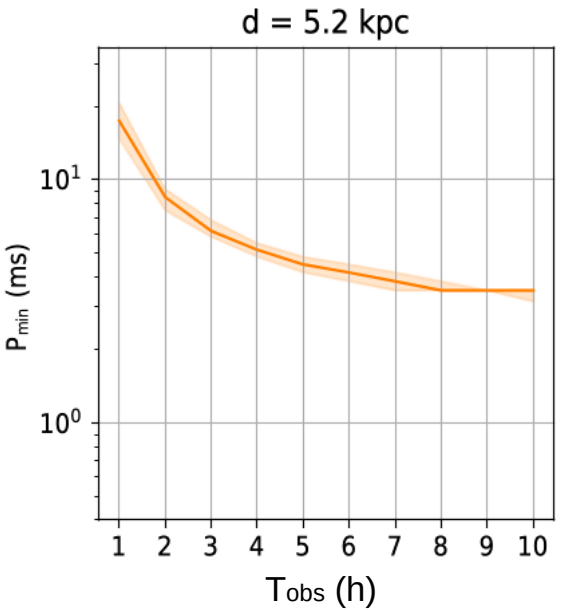
$$S_{min}(P)\,\alpha\,\sqrt{\frac{w}{T_{obs}(P-w)}}$$



Observations with Parkes and the GBT



$$S_{min}(P)\,\alpha\,\sqrt{\frac{w}{T_{obs}(P-w)}}$$



~60h of observations

Take-home messages

- The Galactic center is a perfect place to look for **compact objects**
- Chandra **likely detected** bulge MSPs in past observations
- Enough Chandra sources are MSP candidates: the MSP hypothesis **cannot be excluded**
- Deep targeted pulsation searches are ongoing, preliminary results are encouraging

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Thank you for your attention!