Gamma-ray excess in the Galactic Center: a closer look to the pulsar interpretation

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The Fermi γ-ray galactic center excess

An excess at the galactic center (GC) at GeV energies is observed in Fermi-LAT data (Hooper&Goodenough 2009, Vitale&Morselli 2009, Hooper&Goodenough 2014, Hooper&Linedn 2011, Abazajian&Kaplinghat 2012, Gordon&Macias 2013, Macias&Gordon 2014, Abazajian et al. 2014, Dylan et al. 2014, Zhou at al. 2014, Calore et al. 2015, Fermi-LAT Coll. 2015)

The excess is likely to be caused by significant emission from the GC and galactic bulge, roughly spherical morphology and is resilient to background systematics (Calore, Cholis, Weniger 2015)

Among many possible explanations, there are **point sources** (Bartels, Krishnamurty & Weniger 2015; Lee, Lisanti, Safdi, Slatyer, Xue 2015) just below the Fermi-LAT threshold, and in particular **millisecond pulsars (MSP)** (Abazajian 2011, Abazajian et al. 2014, Gordon&Macias 2013, Yuan&Zhang 2014)

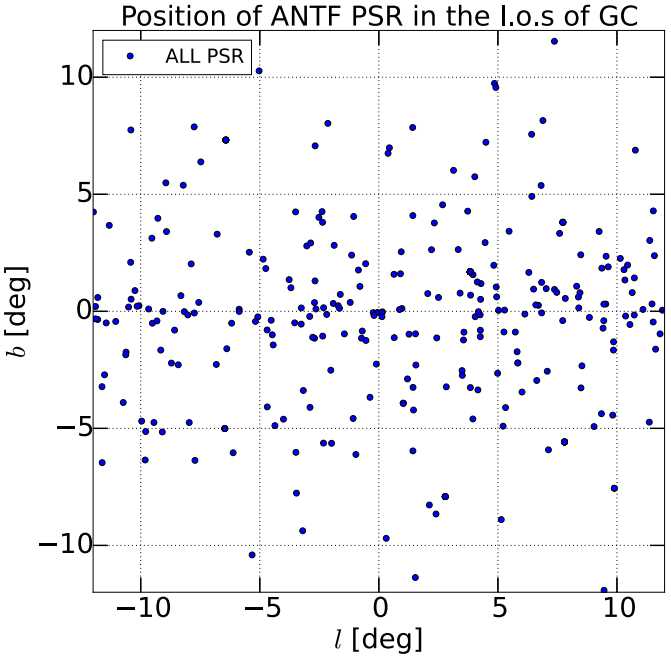
For all the details: talk by C. Weniger!!

and B. Safdi, D. Malyshev

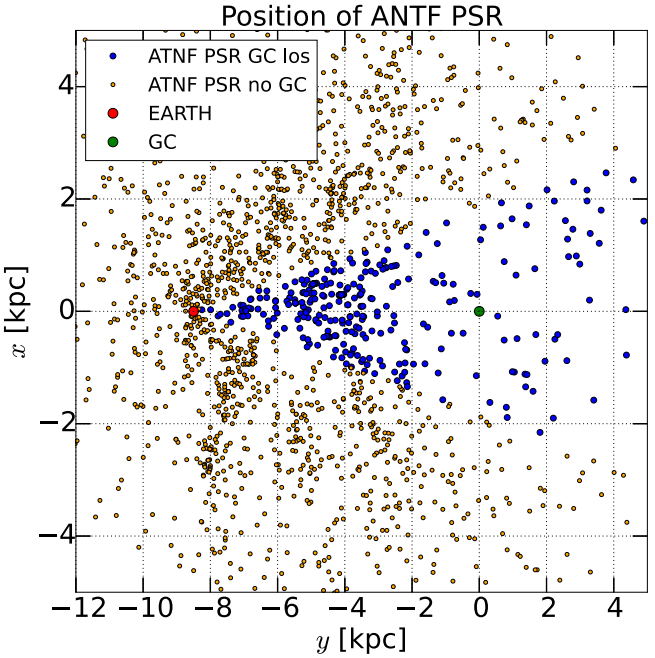
The millisecond pulsar (MSP) interpretation of the GC excess

F. Calore, M. Di Mauro, F. Donato, J. Hessels, F. Massaro, C. Weniger, in prep.

The inner Galaxy PSR in the ATNF catalog

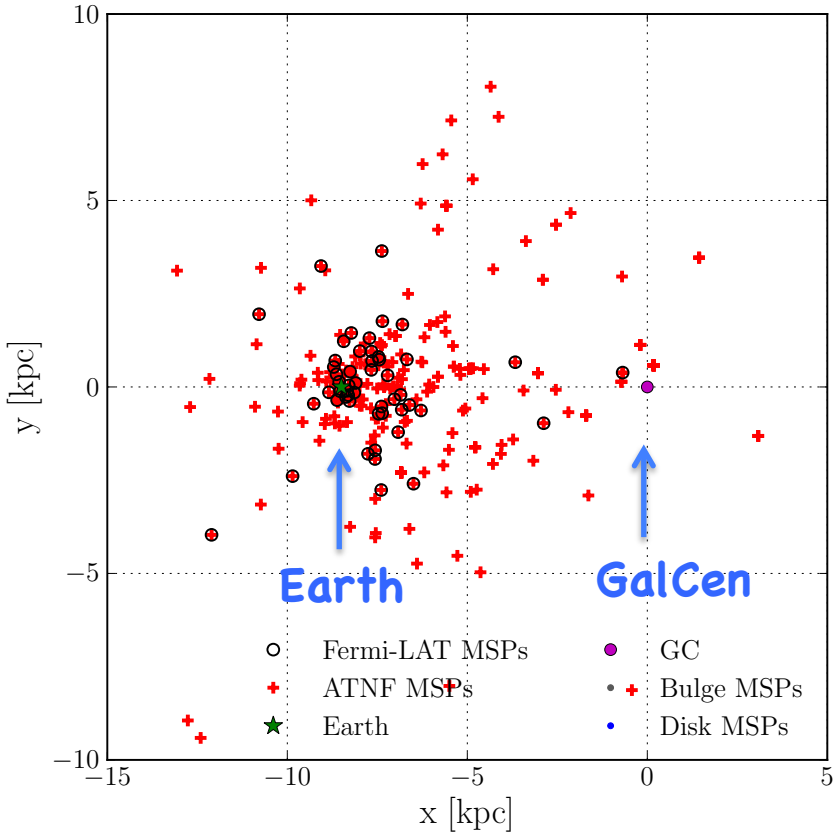


View integrated along l.o.s.
331 PSR with |b|<12°, |l|<12°



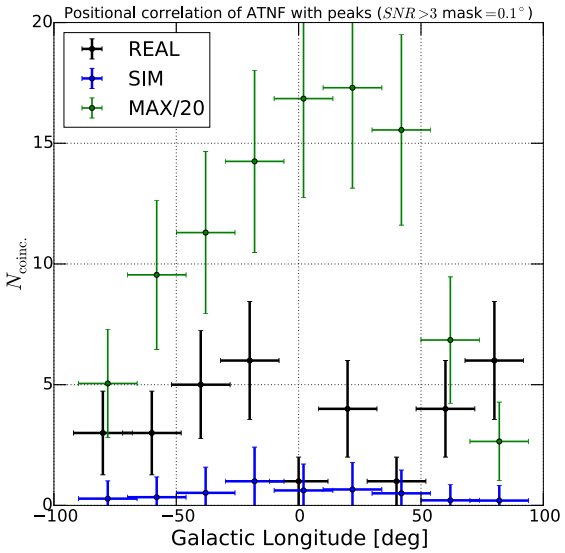
Projection onto the galactic plane
Blue: 2°<|b|<12°, |l|<12° (left panel)
38 PSR are found in the inner 2 kpc

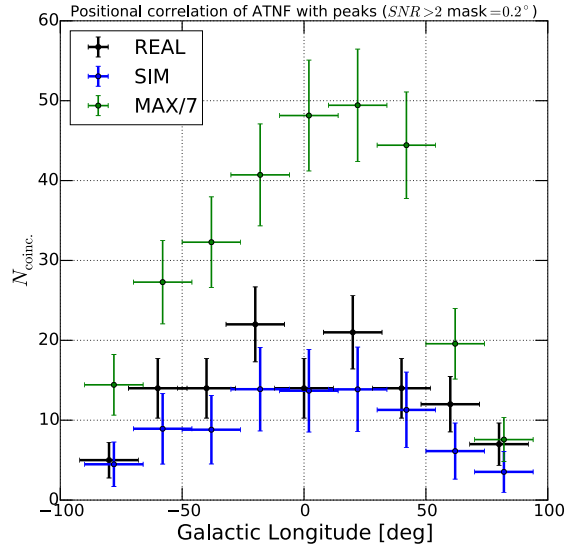
The MSP in the ATNF catalog



- ✓ 328 MSP are detected with rotational period P<30 ms
- ✓ Clustering on 3-4 kpc around the Earth
- ✓ Only few sources in the inner 2 kpc

Correlation between wavelet analysis (Bartels, Krishnamurty & Weniger 2015) and ATNF sources





REAL = number of coincidences between the peaks found with the wavelet analysis and the ATNF PSRs

SIM = number of coincidences between a simulated Isotropic distribution of sources and the ATNF PSRs

MAX = number of maximal correlations: 100% of the Wavelet peaks are correlated with ATNF PSRs

SNR is ~ peak statistical significance, and the correlation is found in angles of 0.1º or 0.2º.

Lack of a significant spatial correlation between wavelet peaks and ATNF PSRs ➔ the gamma-ray seeds interpretation as sources in the GC is not invalidated

Bulge MSP population: radio detection

We estimate the number of radio MSPs of the bulge population required to explain the GC excess

- Number density of the MSP bulge population follows the GC excess(Calore, Cholis, Weniger 2015):

$$\propto r^{-\Gamma} e^{-r/R_{\rm cut}} \qquad \Gamma = 2.5 \qquad R_{\rm cut} = 3\,{\rm kpc}$$

- Energy spectrum (McCann 2015):

$$dN/dE \propto e^{-E/E_{\rm cut}} E^{-\gamma} \qquad E_{\rm cut} = \quad 3.60 \pm 0.21\,{\rm GeV} \text{ and } \gamma = 1.46 \pm 0.05$$

- Total gamma luminosity: $L_\gamma^{\rm bulge} \simeq (2.7 \pm 0.5) \times 10^{37}\,{\rm erg\,s^{-1}}$

- The MSPs in the bulge and in **globular clusters** have the same gamma ray and radio emission properties

- All the gamma-ray emission from **globular clusters** comes from MSPs

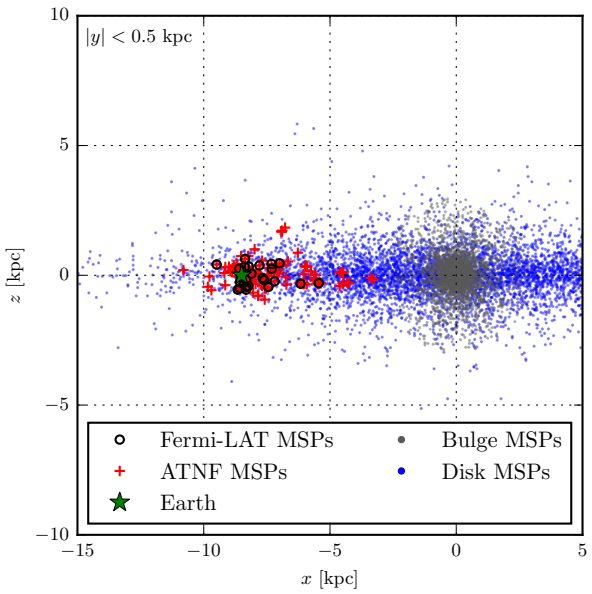
Number of radio MSPs in the galactic bulge

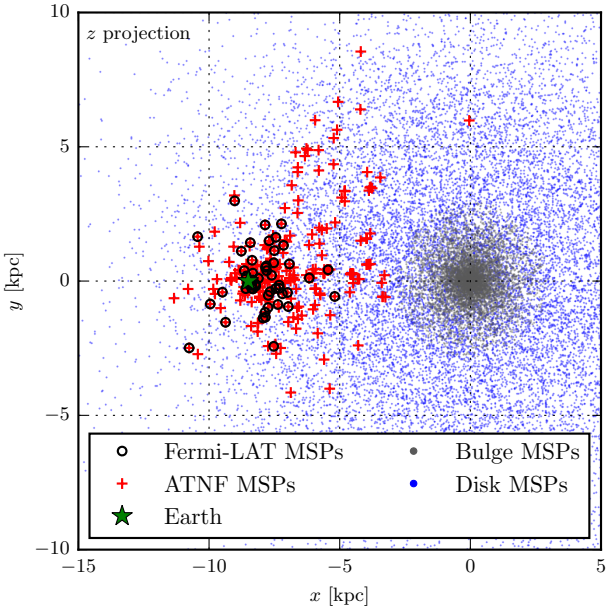
1. Estimated number of radio MSPs in globular clusters from radio luminosity function (Bagchi, Lorimer, Chennamangalam 2011)
2. Total gamma-ray luminosity in globular clusters from Fermi-LAT observations (Acero + 2015)

→ gamma-ray luminosity per source.

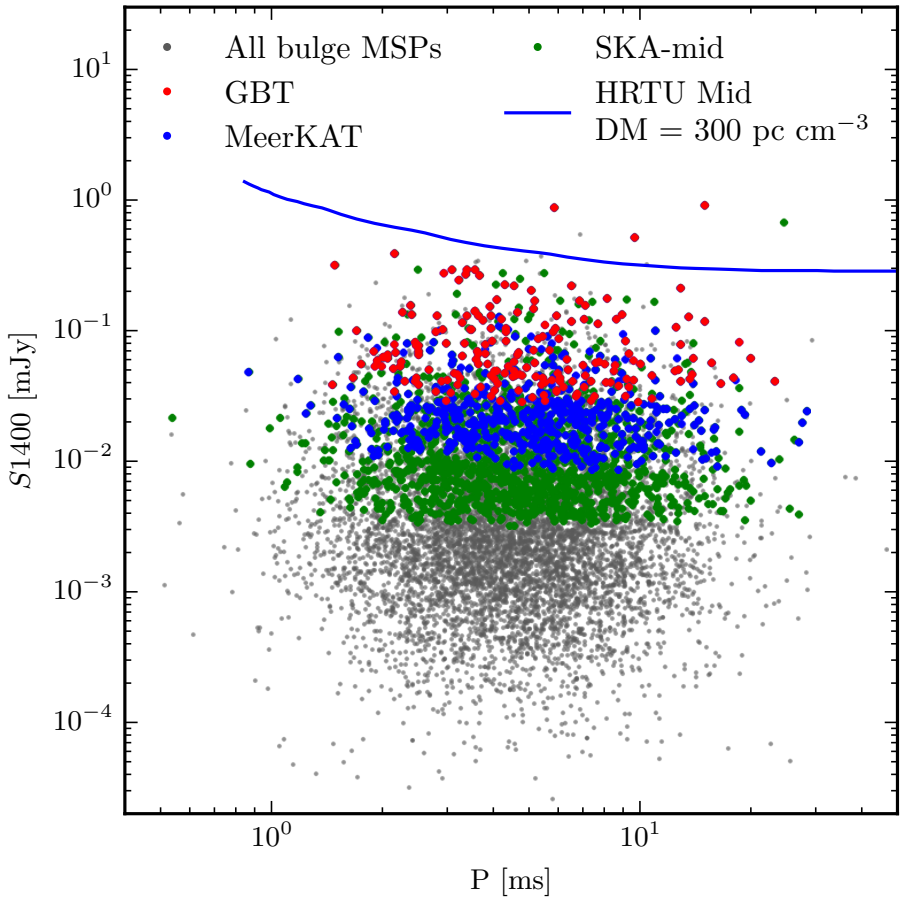
3. From total (GalCen) gamma-ray luminosity:

$$N_{\rm rad}^{\rm bulge} \sim (9.1 \pm 4.2) \times 10^3$$





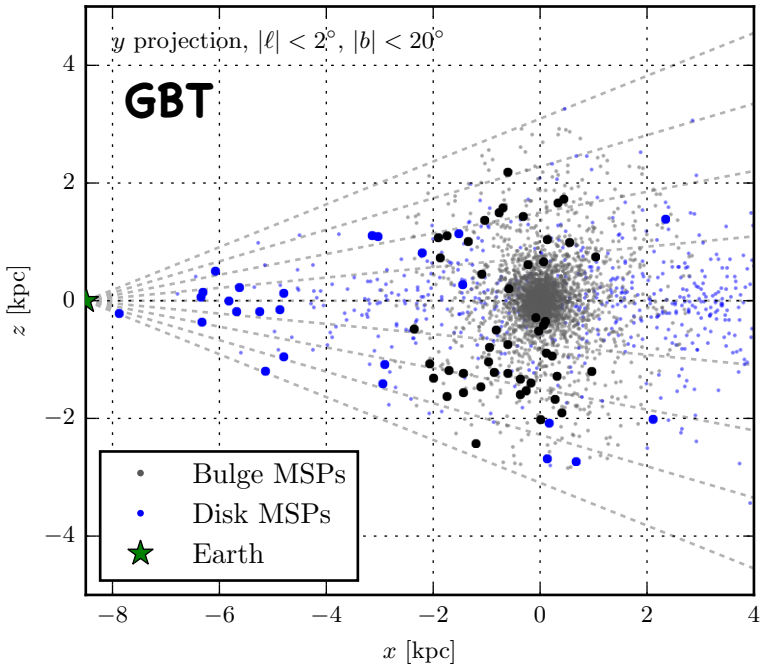
Radio MSP bulge population detectability: flux density vs period

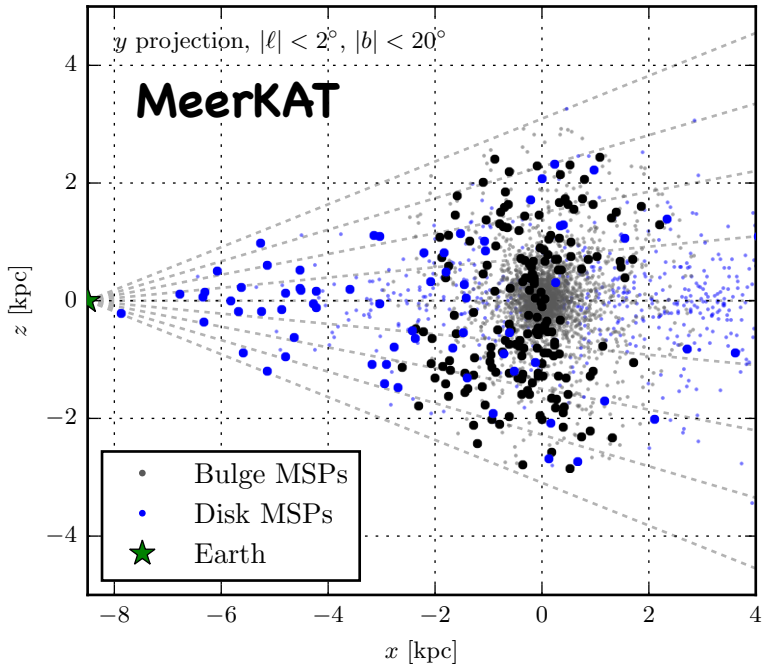


- ✓ Current Parkes HTRU survey cannot probe the bulge population
- ✓ Flux density is for 1400 MHz
- ✓ Reference observation time per pointing is 60 – 120 – 60 min for GBT – MeerKAT – SKA
- ✓ **Green Bank Telescope and upcoming telescopes could detect hundreds of sources**

Radio detection perspectives: GBT and MeerKAT-like

Spatial distribution of the bulge and simulated disk MSP population



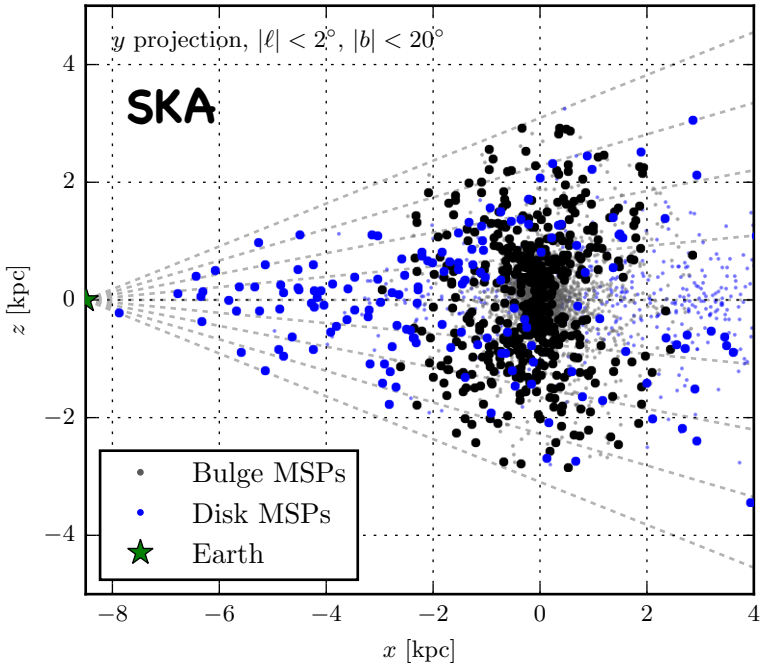


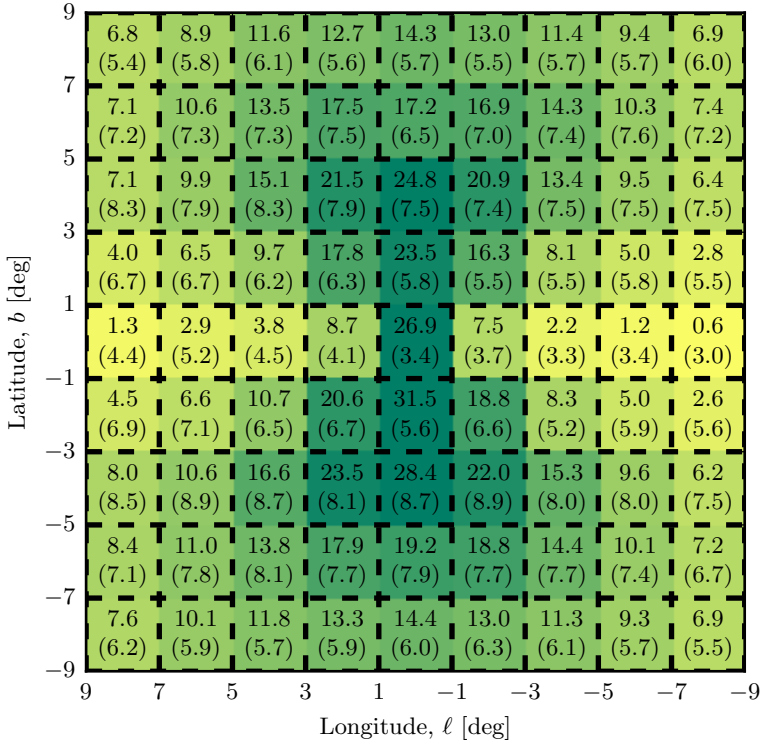
Thick dots: sources detected by GBT and MeerKAT in |l|<2° and |b|<20°, assuming that Pixels of 2 × 2 are covered by 100 h observation

Contamination of disk sources – Difficulty in survey the true GC sources

Radio detection perspectives: SKA & best sky explorable regions

Spatial distribution of the bulge MSPs and of simulated MSP disk population



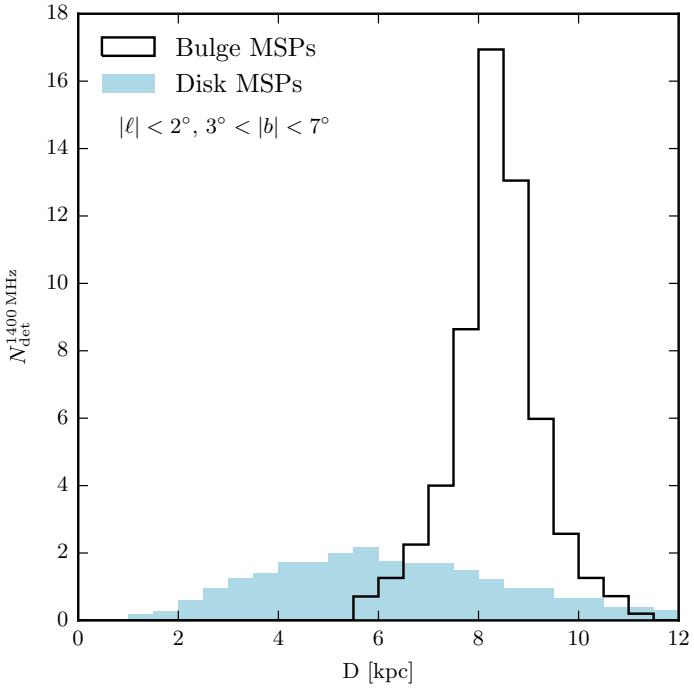


Thick dots: sources detected by SKA in |l|<2° and |b|<20°, 100 h /pixel

The most efficient survey would be ~ 5° about the galactic center

Role of the scattering of the radio signal

Discrimination between disk and bulge MSP populations



Histogram of distances of detected disk (blue) and bugle MSPs, assuming a MeerKAT reference survey.

The two populations can be clearly separated

Conclusions

- We investigate the possibility the all the gamma-ray galactic center excess might be due to **a bulge population of field millisecond pulsars**
- We estimate the **number** of these MSPs in the **radio** band, passing through the gamma and radio properties of globular clusters
- This putative radio MSP bulge population could be investigated by ongoing and future **radio surveys**
- The best region to look for bulge MSPs is few degrees around the galactic center, where tens of sources could be detected by SKA
- Our predictions, as well as their intrinsic interest, could help to reduce the **ambiguity between the MSP and the dark matter** interpretation of the GC excess.