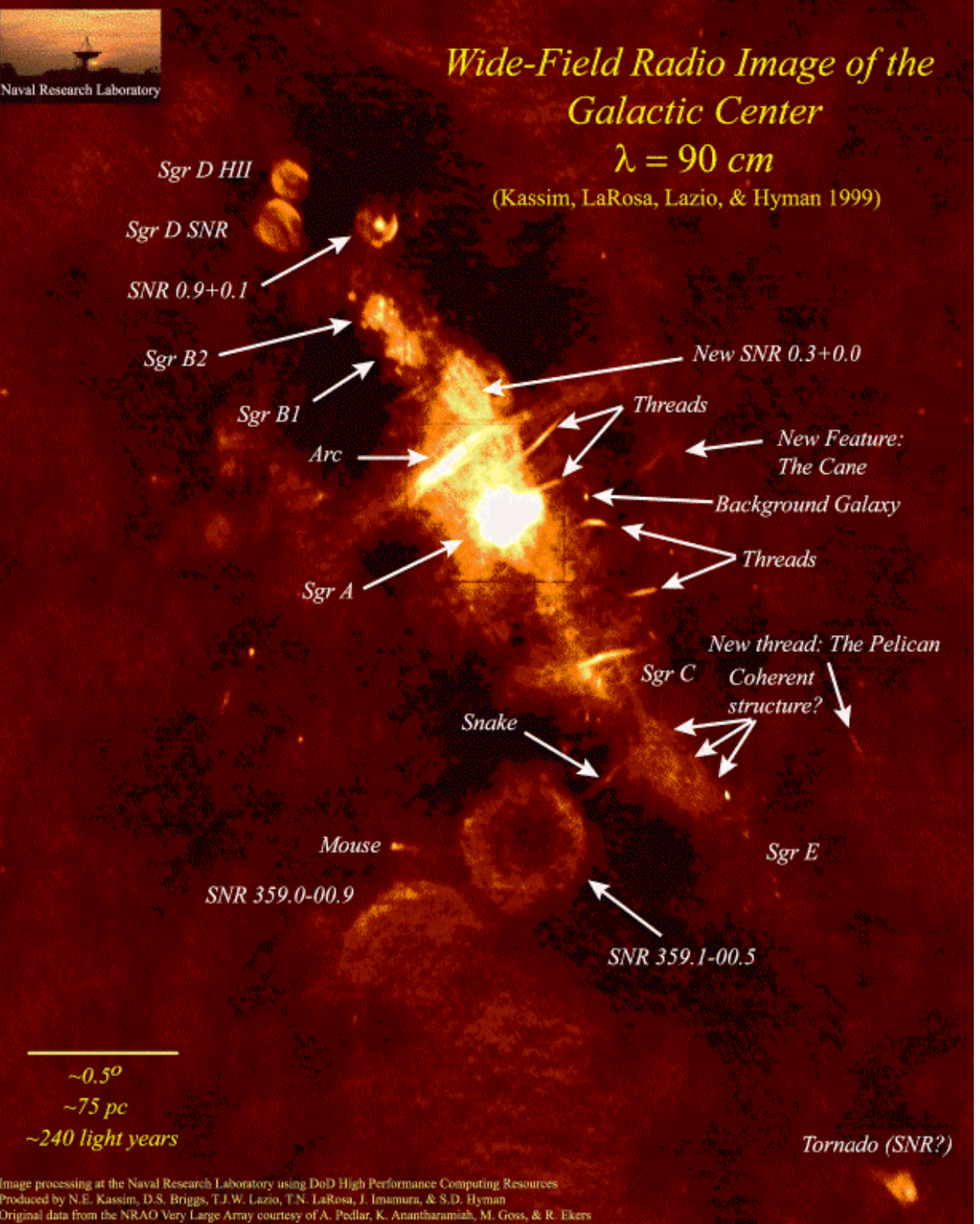
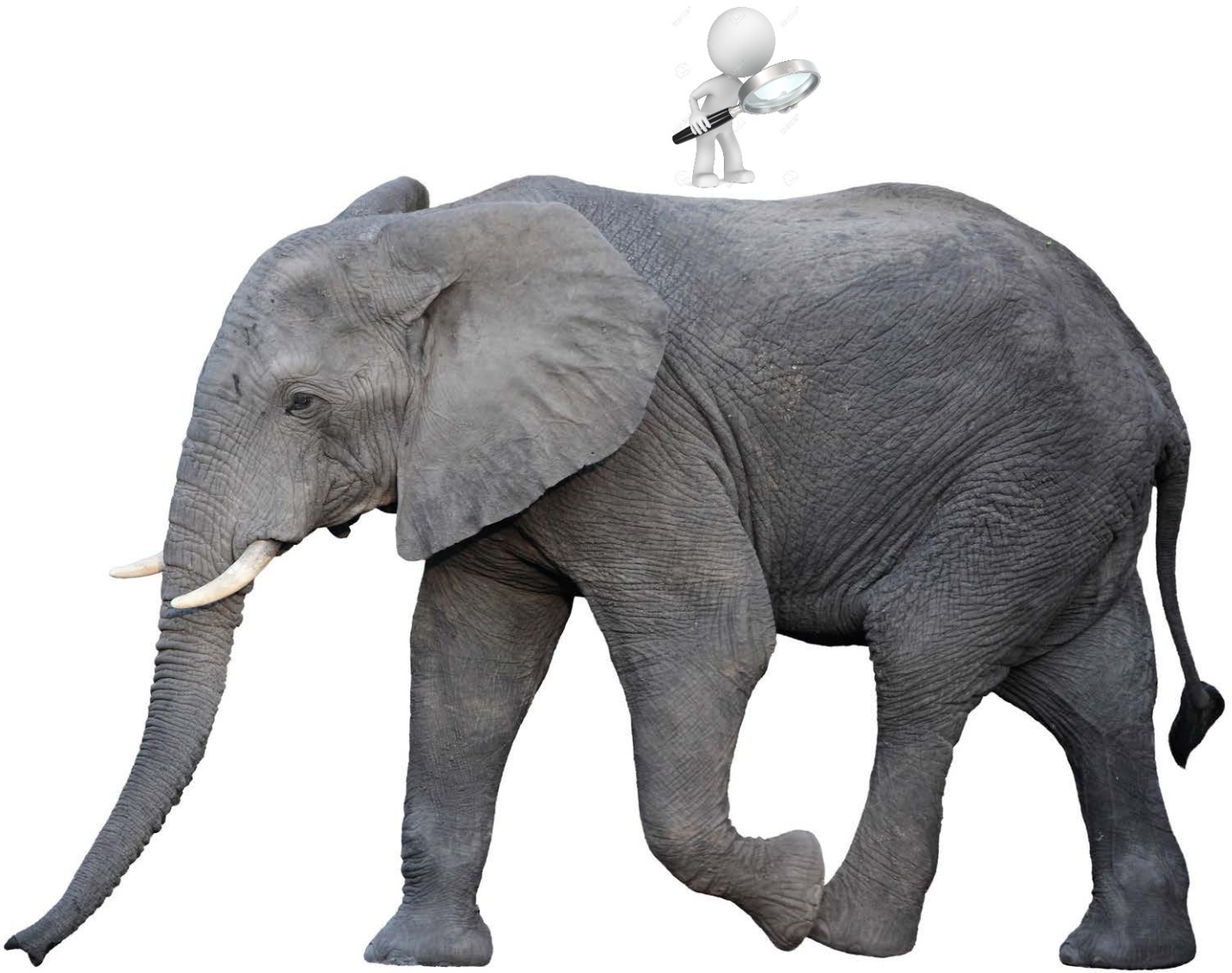


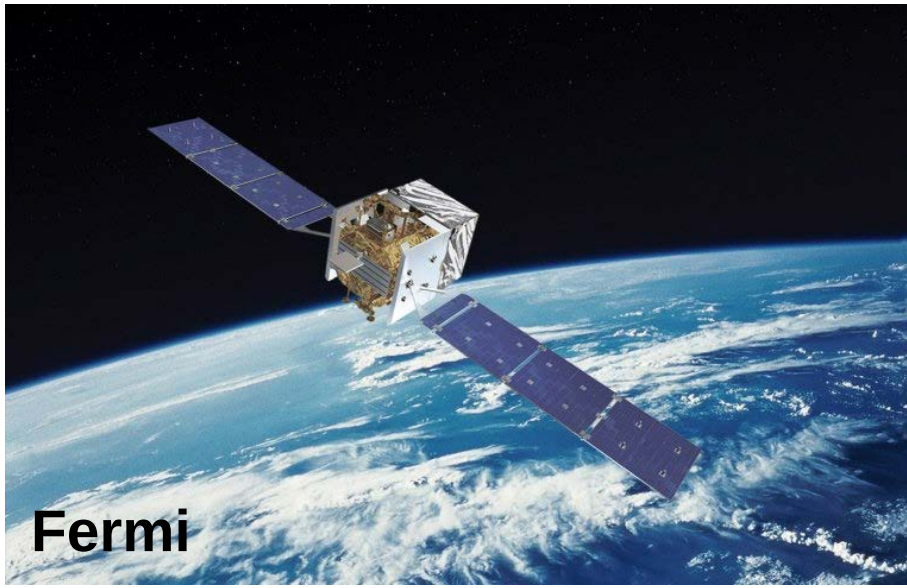
Radio Searches for Pulsars in the Galactic Center

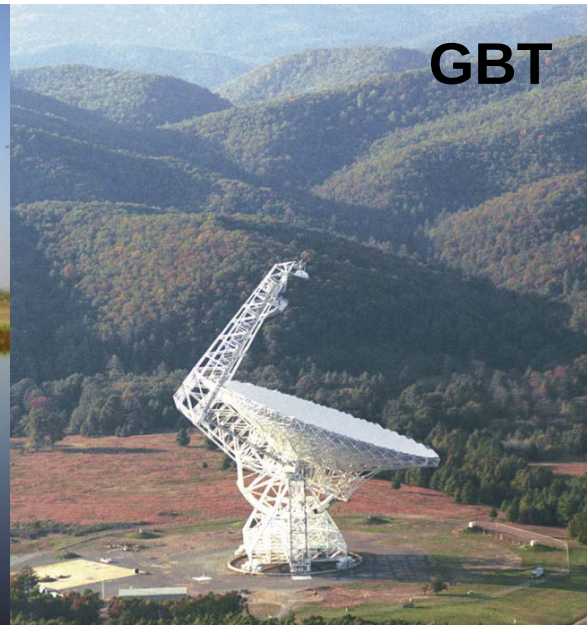
J.Deneva (GMU, resident at NRL), P.Ray (NRL), S.Hyman (SBC), D.Frail (NRAO), N.Kassim (NRL), M. Kerr (NRL), J.Lazio (JPL)



Outline

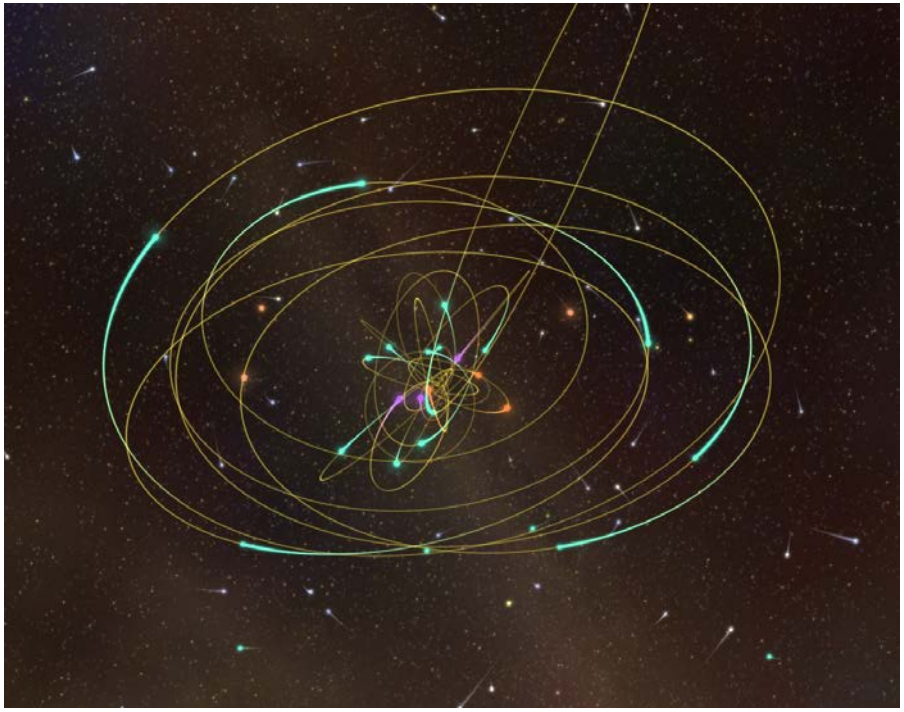
- Motivation.
- Types of surveys.
- Detection biases for pulsars.
- Past surveys in the Galactic Center.
- Known pulsars in the GC.
- “Fracking for pulsars”





Motivation: SgrA* and Gravity

- SgrA*: SMBH and central star cluster.
  - Central cluster consists mainly of young massive stars → NS progenitors.
  - Estimates of 100s – 1000s of active pulsars with Porb < 100 yr around SgrA* (e.g. Pfahl & Loeb 2004).
  - Pulsars orbiting the supermassive BH in SgrA*: measure relativistic effects → mass and possibly spin of the SMBH.
  - Probe the gravitational potential in the central cluster.



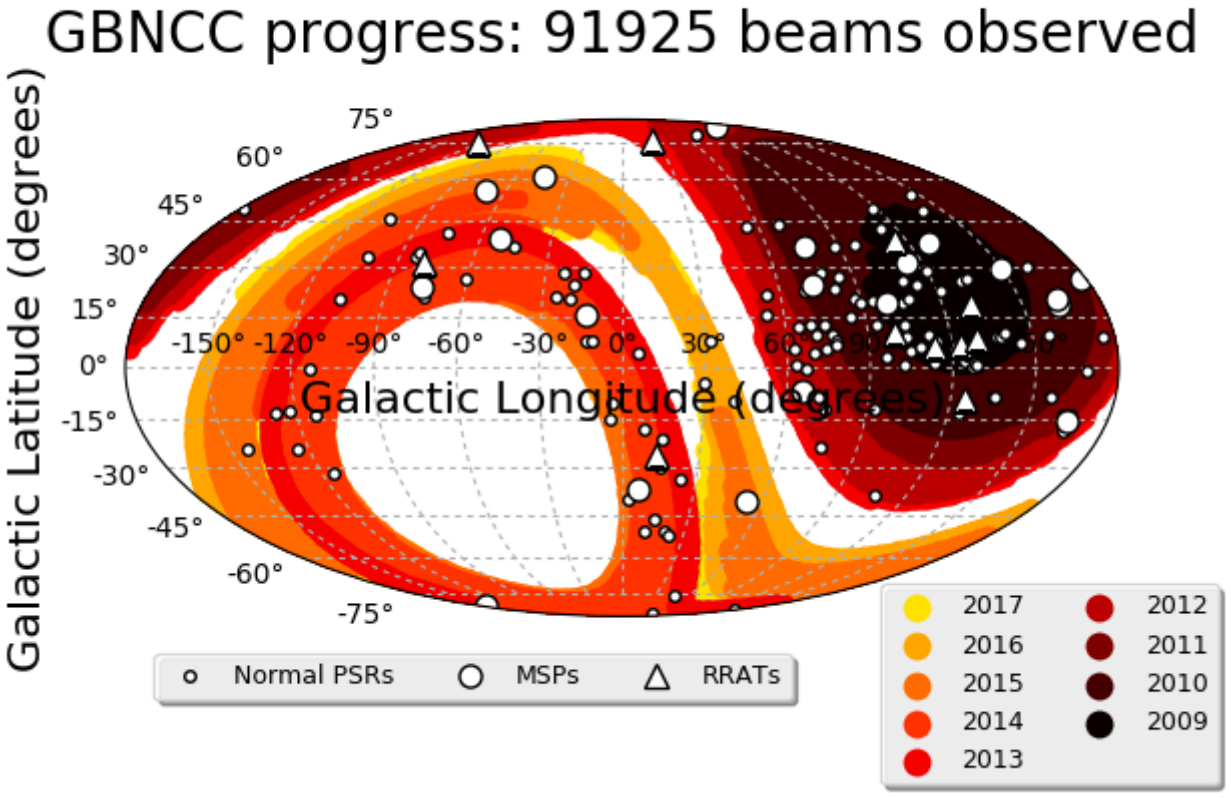
Andrea Ghez UCLA group
NCSA/UCLA/Keck

Pulsars around a SMBH = swarm of GPS satellites around a SMBH

Motivation: Populations and ISM probes

- Central cluster of massive stars.
  - Central cluster of early-type massive stars is unexpected; how did this population get there?
  - Pulsars are the fossil record of their massive star progenitors.
  - Properties of pulsar population in GC can help distinguish between evolutionary scenarios of central cluster of massive stars: collisions and mergers; migration; ongoing star formation.
- High-energy GC emission.
  - Diffuse: EGRET (GeV), HESS (TeV), Fermi (GeV).
  - Spectrum of GeV emission from the GC detected by Fermi consistent with MSP gamma-ray spectra.
  - Discrete: Chandra unidentified X-ray sources.
- Probes of the ISM.
  - Dense, turbulent ionized gas → propagation effects affecting radio pulsar emission.
  - Can map out the gaseous environment around SgrA* → improve Galactic ionized gas models (NE2001, YMW16).

Blind / Untargeted Surveys



- Tile systematically region of interest with many pointings.
- Best for low-frequency (<= 1.4 GHz) as radio beam widths are wider.
- Cover large area with the same sensitivity → good for population studies.

http://astro.phys.wvu.edu/GBNCC/

Targeted surveys

- Types of sources associated with pulsar environments or progenitors:
  - Large star clusters of young, massive stars: Arches, Quintuplet, SgrA*.
  - **Holy Grail of pulsar astronomy: finding MSPs around the supermassive BH at the center of our Galaxy.**
  - SNR, high-energy PWN, high-energy and optical binary systems.
  - Globular clusters: high stellar density, massive stars, exchange interactions → binaries. Terzan 5 has 36 pulsars!
- Sources with pulsar-like properties:
  - Steep-spectrum, compact radio sources.
  - Fermi unidentified sources whose gamma-ray spectra are similar to those of known gamma-ray pulsars (power law with an exponential cut-off).

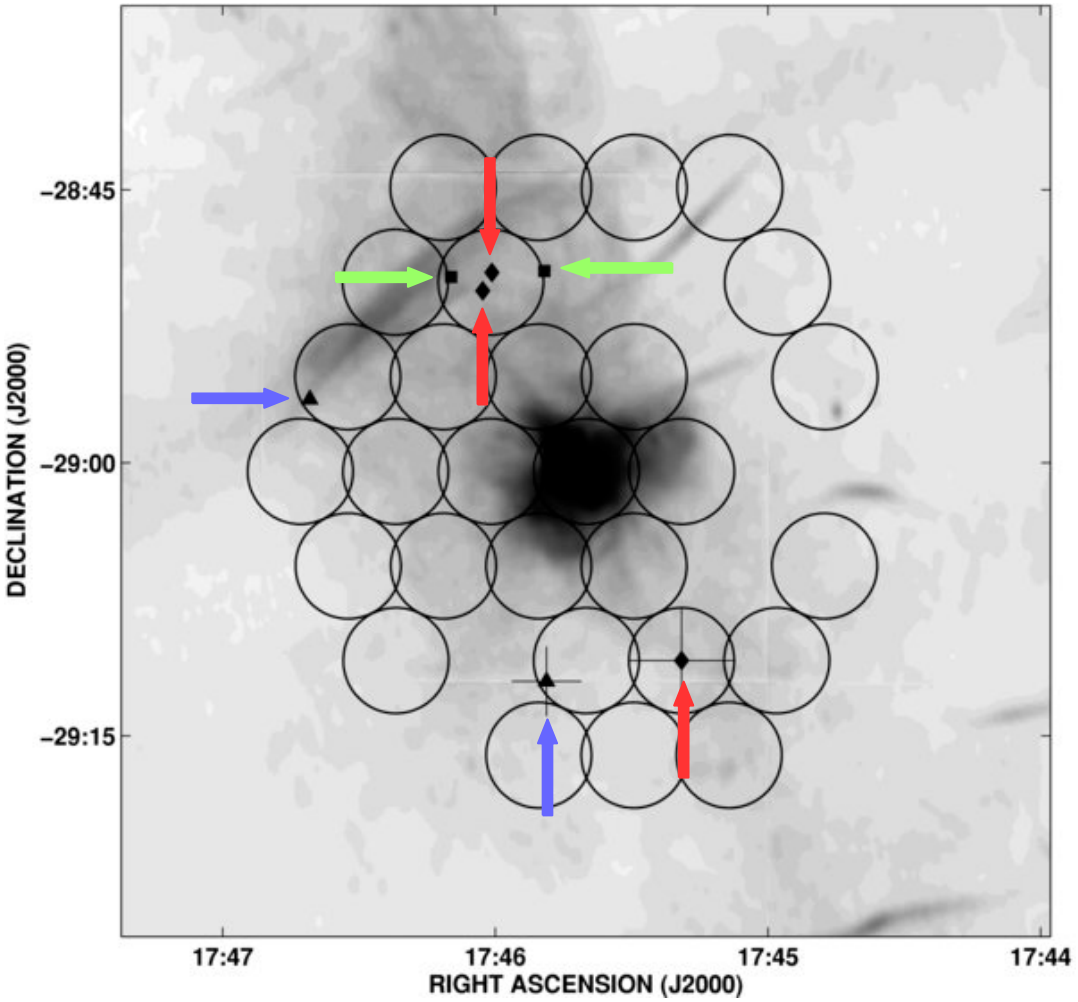
Crab Nebula:
1054: SN recorded.
1700s: Nebula identified.
1920s: Nebula, SN related.
1960s: Pulsar predicted.
1968: Pulsar found.

Obstacles and biases in pulsar detection

- All pulsars:
  - Dispersion (~ν^{-2}); correctable → Brute force search over dispersion measure (DM), proxy for distance.
  - Scattering (~ν^{-4}); not correctable.
  - Scintillation in time and EM frequency (worse for nearby pulsars).
  - Pulsar spectra are steep: $S \sim \nu^{-1.7}$ on average

- MSPs and binary pulsars:
  - MSP spectra are *really* steep: $S \sim \nu^{-2.1}$ on average
  - Line of sight acceleration: Doppler effect from orbital motion modulates observed P. Worse for short P_{orb} and massive companions (e.g. NS-BH).
  - Free-free absorption from dense companion wind (Redback and Black Widow systems) → undetectable for more than 50% of orbit in some cases.

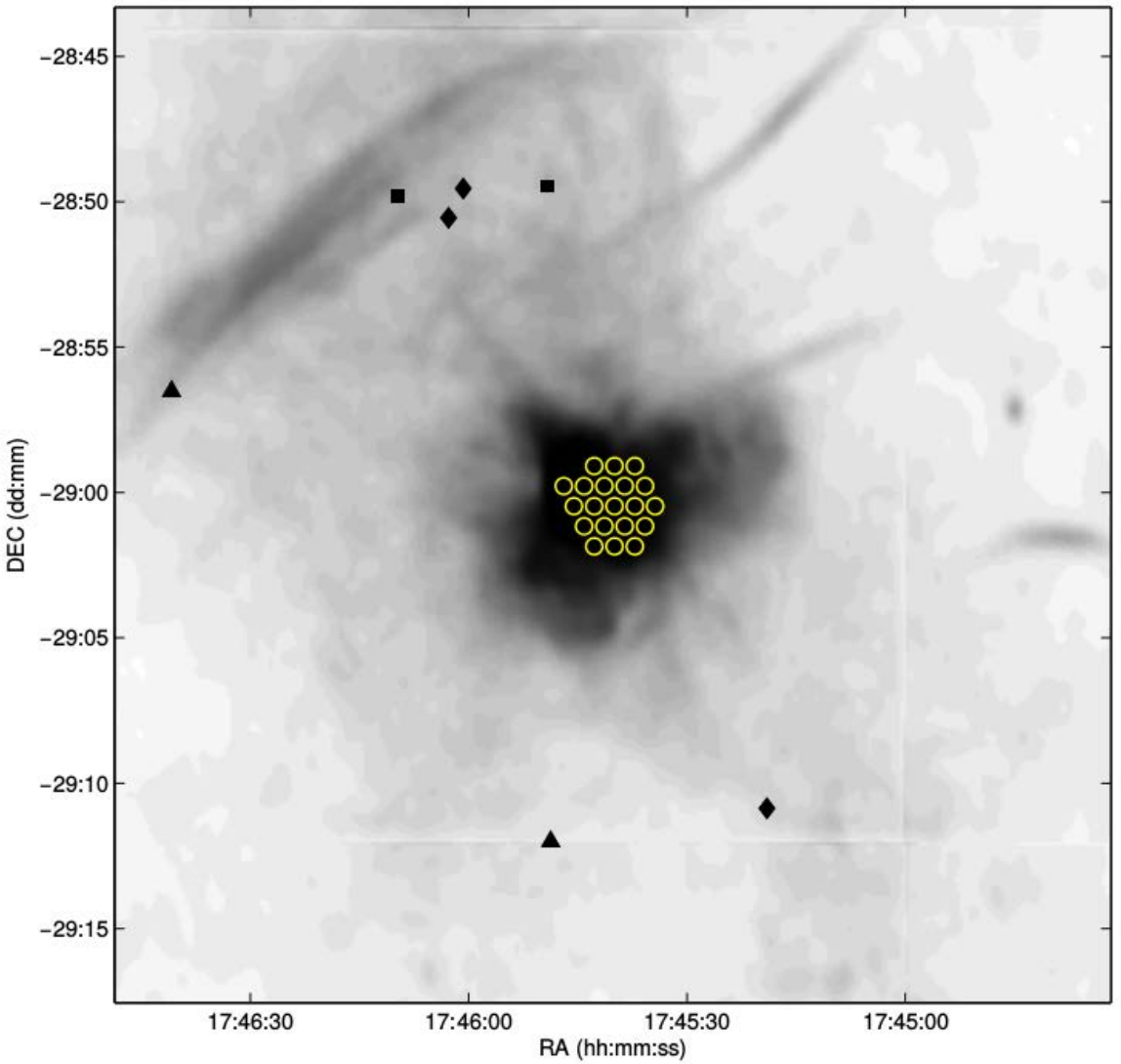
Searches in SgrA* and Vicinity: 2-3 GHz



Deneva et al. (2009)

- Johnston et al. (2006): 3 GHz, Parkes
  - 2 new pulsars
- Deneva et al. (2009): 2 GHz, GBT
  - 3 new pulsars
  - 1 is young, magnetar-like B, flat spectrum, long periods without radio emission (Dexter et al. 2017)
- Deneva (2010,PhDTh): 2 GHz, GBT
  - Deep searches of Arches and Quintuplet clusters.
  - No new pulsars.
- All are slow pulsars.

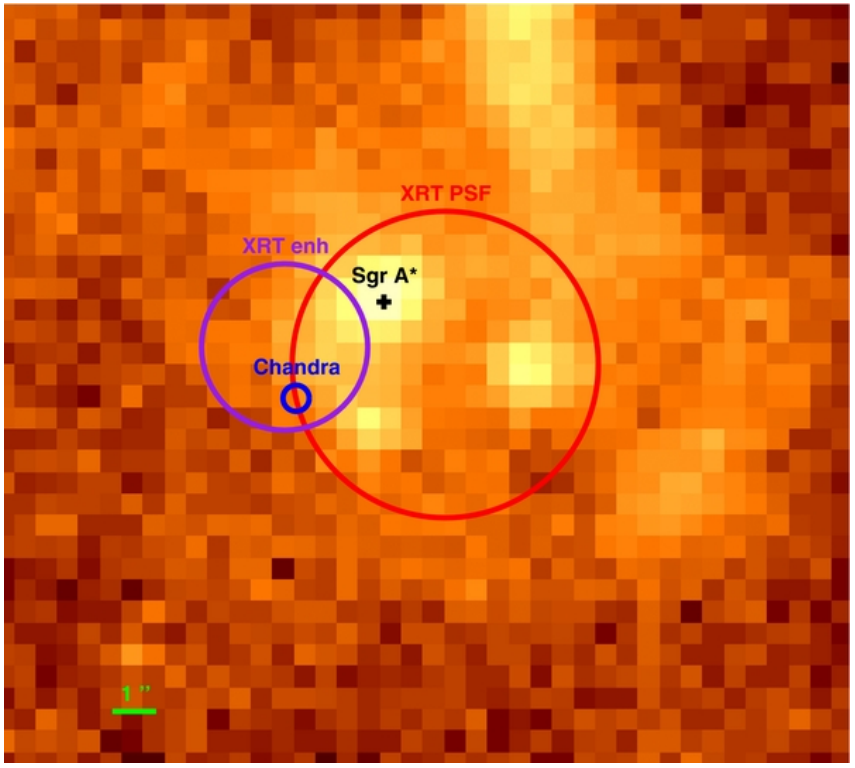
Searches in SgrA* and vicinity: 5-15 GHz



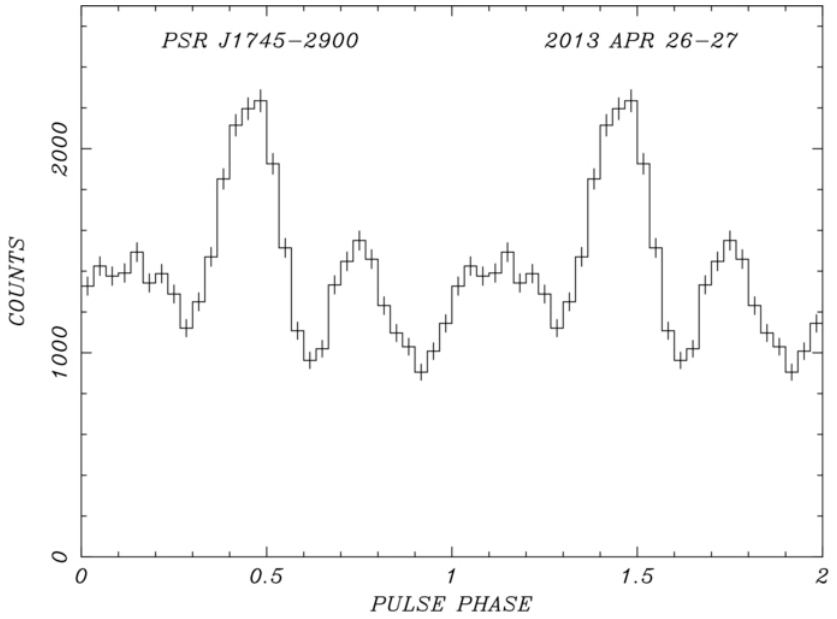
Deneva (2010, PhDTh)

- Deneva (2010, PhDTh): GBT
  - Grid SgrA* central cluster (9 GHz)
  - 15 steep-spectrum compact radio sources within 1 deg of SgrA* (9 GHz) – from 2LC catalog (Lazio et al. 2008)
  - Deep search of SgrA* (5 and 9 GHz)
- Macquart et al. (2010): 15 GHz, GBT
  - Deep search of SgrA* (central parsec)
- No new discoveries.

SGR J1745-29 / PSR J1745-2900 (The Galactic Center Magnetar)



X-ray flare detected by Swift (Kennea et al. 2013)



X-ray pulsations detected by NuSTAR (Mori et al. 2013)

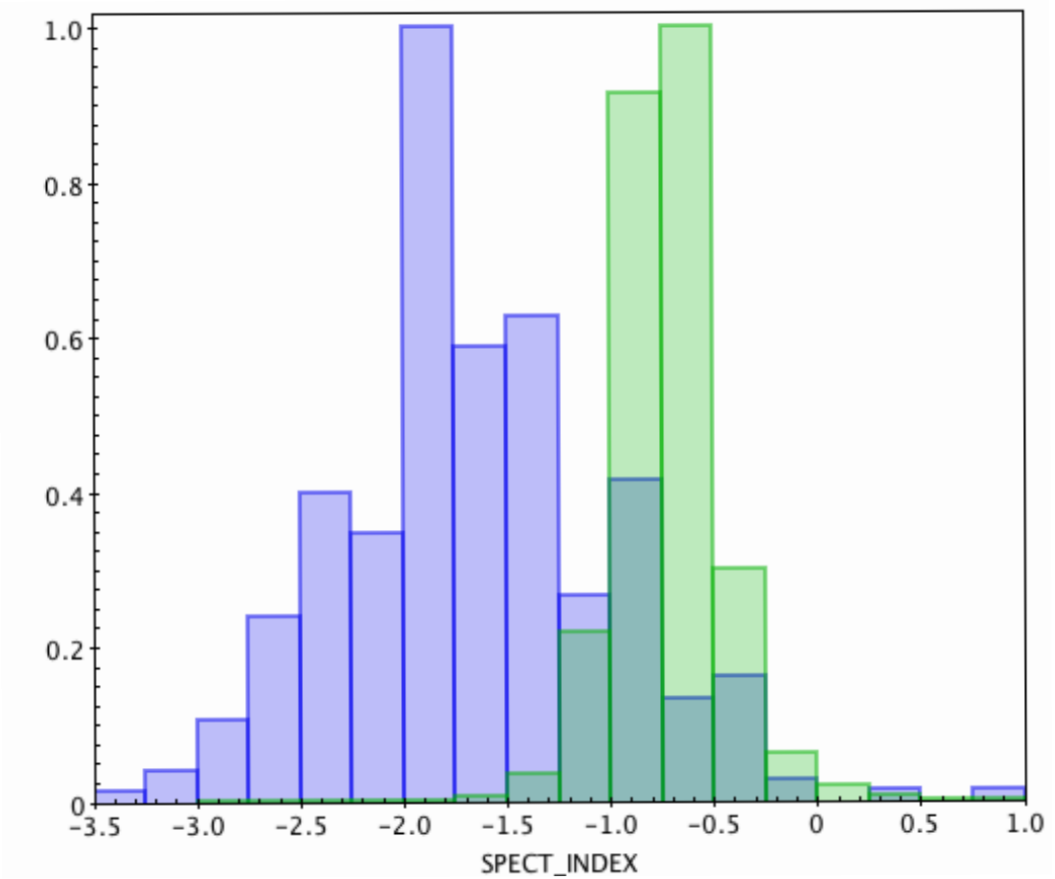
- Source is ~2.4 arcsec from SgrA*; ~0.1 pc at D=8.25 kpc.
- Radio pulsations at 5,7,8 GHz (Atels 5040, 5043, 5053)
- P = 3.8 s, DM = 1778 pc/cc (highest pulsar DM to date).

“Fracking for pulsars” (coined by D.Frail)

- Several concurrent projects form a conceptual pipeline for finding the progenitors of the Fermi GeV excess:

1) Image unidentified Fermi sources in the GC region with the VLA (N.Kassim; accepted Fermi GI proposal).
2) Use radio images for at least 2 frequencies to identify compact, steep-spectrum sources (D.Frail, S.Hyman) → in the GC region in general, not only Fermi error boxes.
3) Search for radio pulsations from sources whose properties are most pulsar-like (J.Deneva, P.Ray, GBT proposal submitted Aug. 2017).

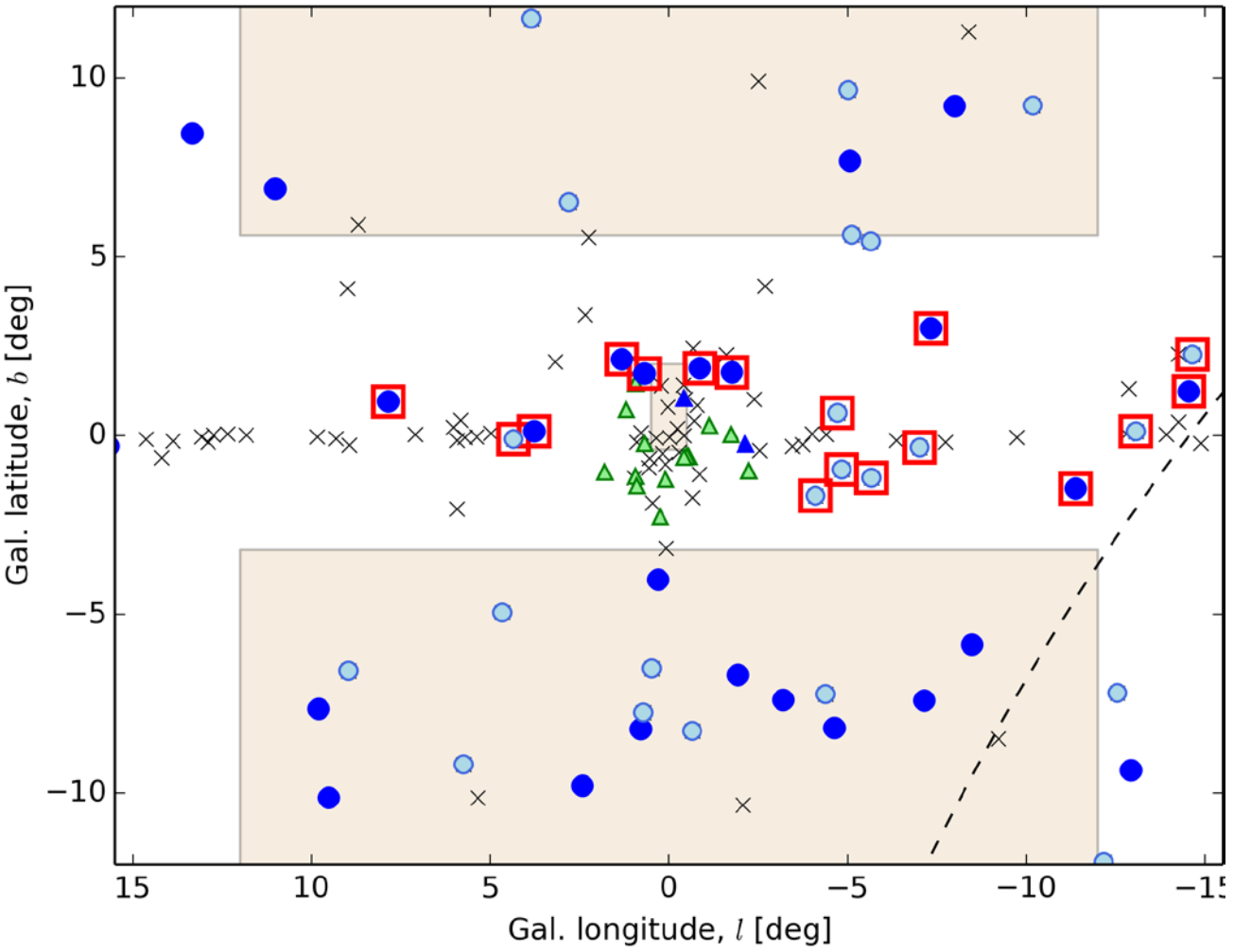
Image Unidentified Fermi sources in GC (N.Kassim)



Normalized radio spectral index distributions:
Blue: 416 known pulsars from ATNF database (median: -1.8)
Green: ~1M radio sources from TGSS and NVSS surveys (median: -0.75)

- Steep-spectrum radio sources are rare, except for pulsars.
- Use VLA at 1-2GHz to Image Fermi unidentified sources with pulsar-like gamma-ray spectra.
- This provides accurate in-band spectra (instead of using two different surveys).
- Much better positions for pulsation searches than (usually large) Fermi source error boxes.
- Result: Multi-wavelength “sieve” for pulsar-like sources to be searched for pulsations.

Image Unidentified Fermi sources in GC (N.Kassim)

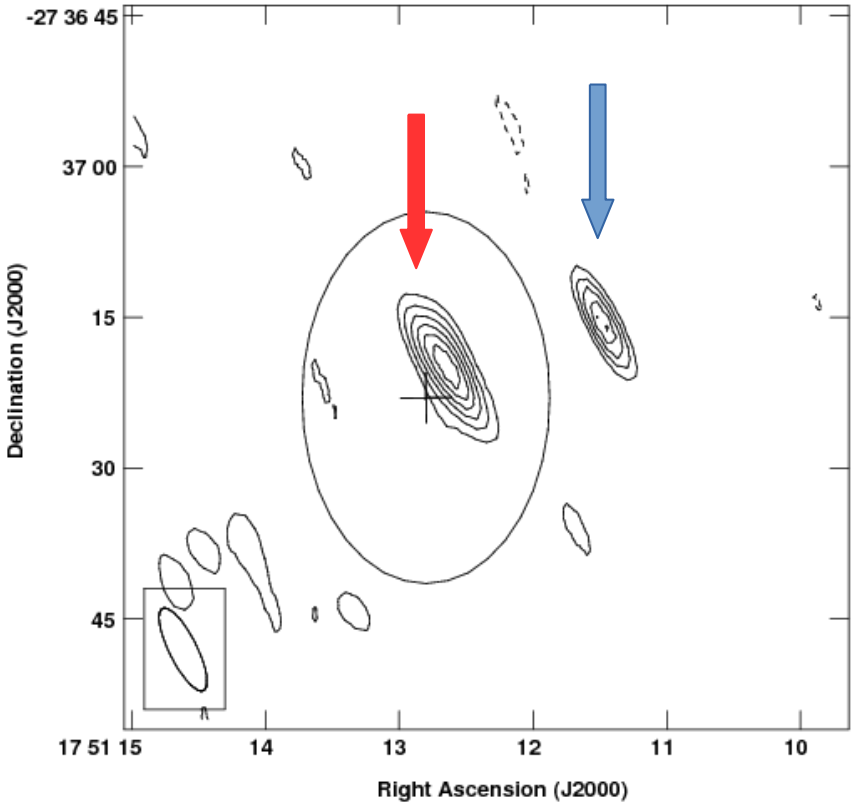


- 17 targets (red squares).
- Blue circles: Fermi un-id sources with pulsar-like gamma-ray specra. (Dark blue: 3FGL; light: 7-yr)
- Black crosses: other Fermi sources.
- Shaded and green: concurrent proposal sources.
- Dashed: VLA declination lower limit (-41 deg)

VLA Source Selection (D.Frail, S.Hyman)

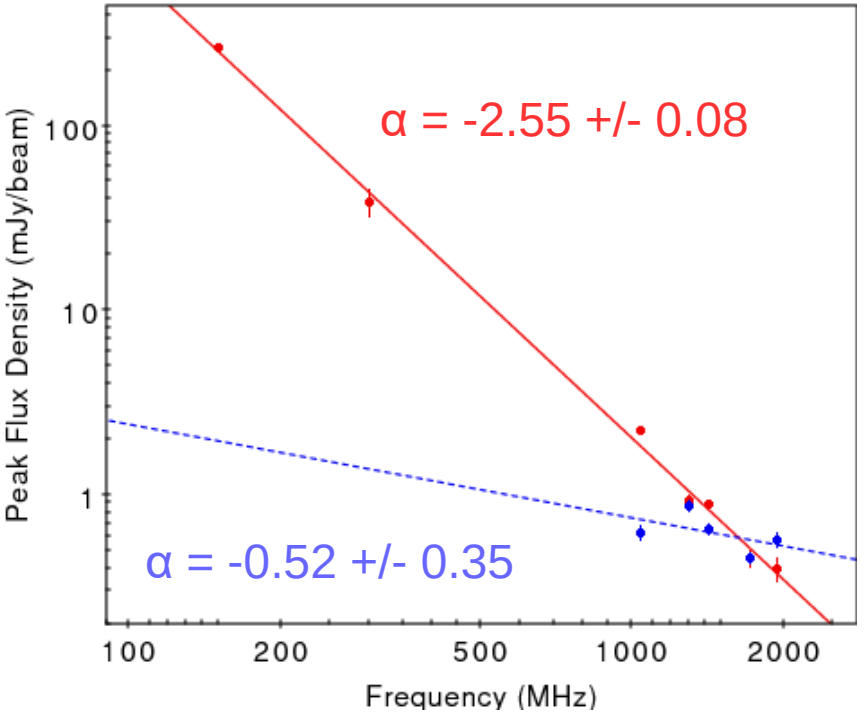
- Select unidentified sources within a few deg of GC from detected in two or more of:
  - TGSS survey at 150 MHz, Giant Metrewave Radio Telescope (Intema et al. 2016).
  - VLA 330 MHz survey (Nord et al. 2004).
  - NRAO VLA Sky Survey at 1.4 GHz (NVSS, Condon et al. 1998).
- Pulsars have on average $\alpha = -1.8 +/- 0.2$ at low frequencies ($S \sim \nu^{-\alpha}$)
- The only other type of source with similar steep spectra are luminous, high-z galaxies.
  - Distinguished by resolved extended structure.
- Image ambiguous sources at 5 GHz with the VLA (angular resolution ~0.5”).
- Pilot project:
  - R < 2.5 deg from GC
  - Require sources to have $\alpha < -1.7$
  - Criteria reduced initial pool of 220 radio sources to 2.
  - One has extended structure typical of radio galaxies.

Proof of concept: TGSSJ175112.8−273723 (Bhakta et al. 2017)



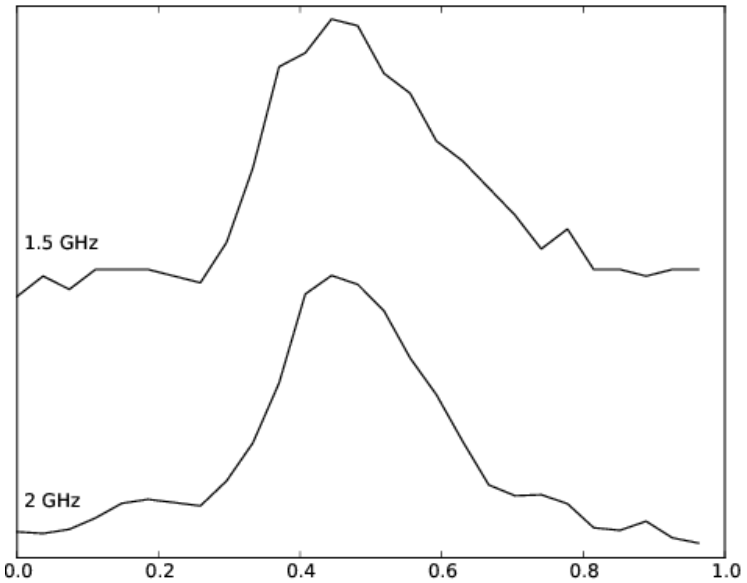
VLA 1.5 GHz image of TGSSJ175112.8−273723

Large ellipse: TGSS beam.
Small ellipse in lower left: VLA synthesized beam.



Continuum spectra of the two sources on left

Proof of concept: TGSSJ175112.8−273723 (Bhakta et al. 2017)

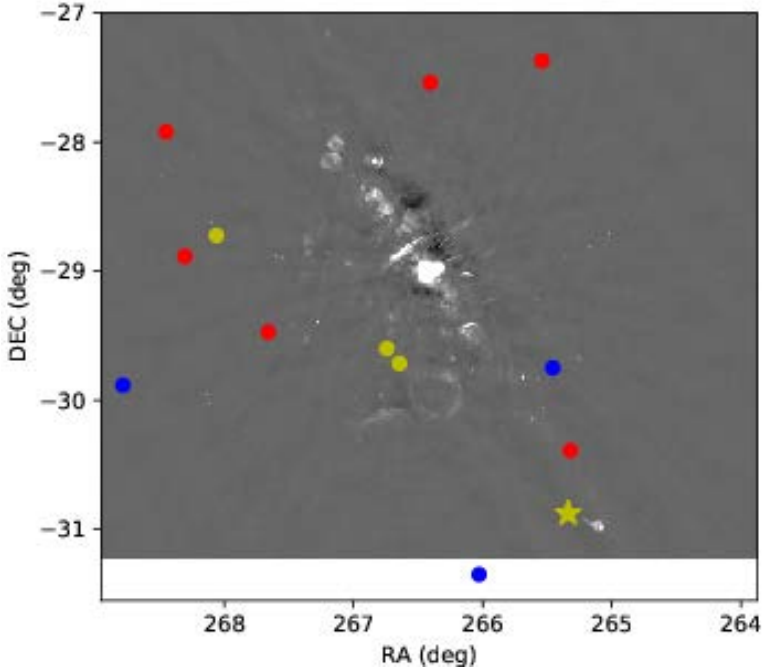


Radio pulsations detected with the GBT (averaged pulse profiles vs. phase, normalized to same height)

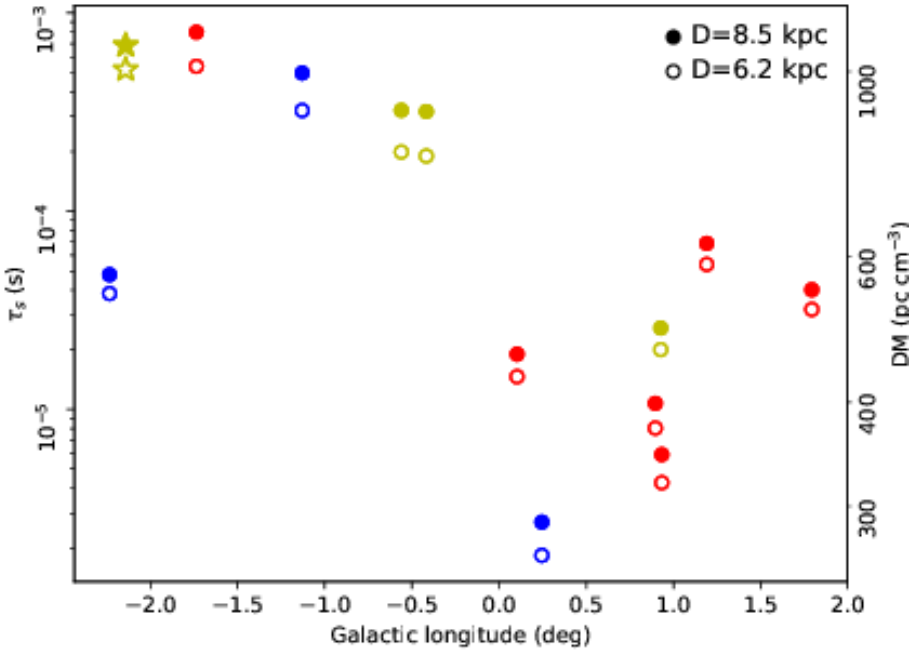
- MSP discovery: J1751-2737
- P=2.23 ms
- DM=260 pc/cc (foreground object)
- D=3.4 kpc (YMW16), 4 kpc (NE2001)
- Isolated
- Radio pulsations detected at 1.5 and 2 GHz, non-detection at 5 GHz.
- From non-detection, limit on radio spectrum: $\alpha < -2.2$.

- Two more MSP discoveries in sources selected by this method, in error boxes of Fermi un-id sources (away from the GC).

Pulsation searches (J.Deneva, P.Ray)



Red: α < -1.4
Yellow: α < -1.4 above 1 GHz, α > -1.4 below.
Blue: 1σ spans α = -1.4
Star: in Fermi un-id source error box.



Scattering broadening (τ_s) at 5 GHz and DM for a nominal SgrA* distance (D=8.5 kpc) and the near edge (D=6.2 kpc) of a population extent equal to that of the GeV excess (15 deg).

GBT proposal submitted on 1 Aug. 2017, awaiting review.

To (Re)submit

- Priority radio pulsation searches of Fermi un-id sources within the GeV excess GC region.

- Deep image of the inner 2 deg around SgrA* at L and S band with the VLA to narrow down steep-spectrum point sources for future pulsation searches. → better sensitivity than existing catalogs.

This work was in part supported by the NASA Fermi program.