The role of MeerKAT in the current renaissance of globular cluster pulsars

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and *many* other people of the MeerTIME and TRAPUM collaborations

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Pulsars in Globular Clusters

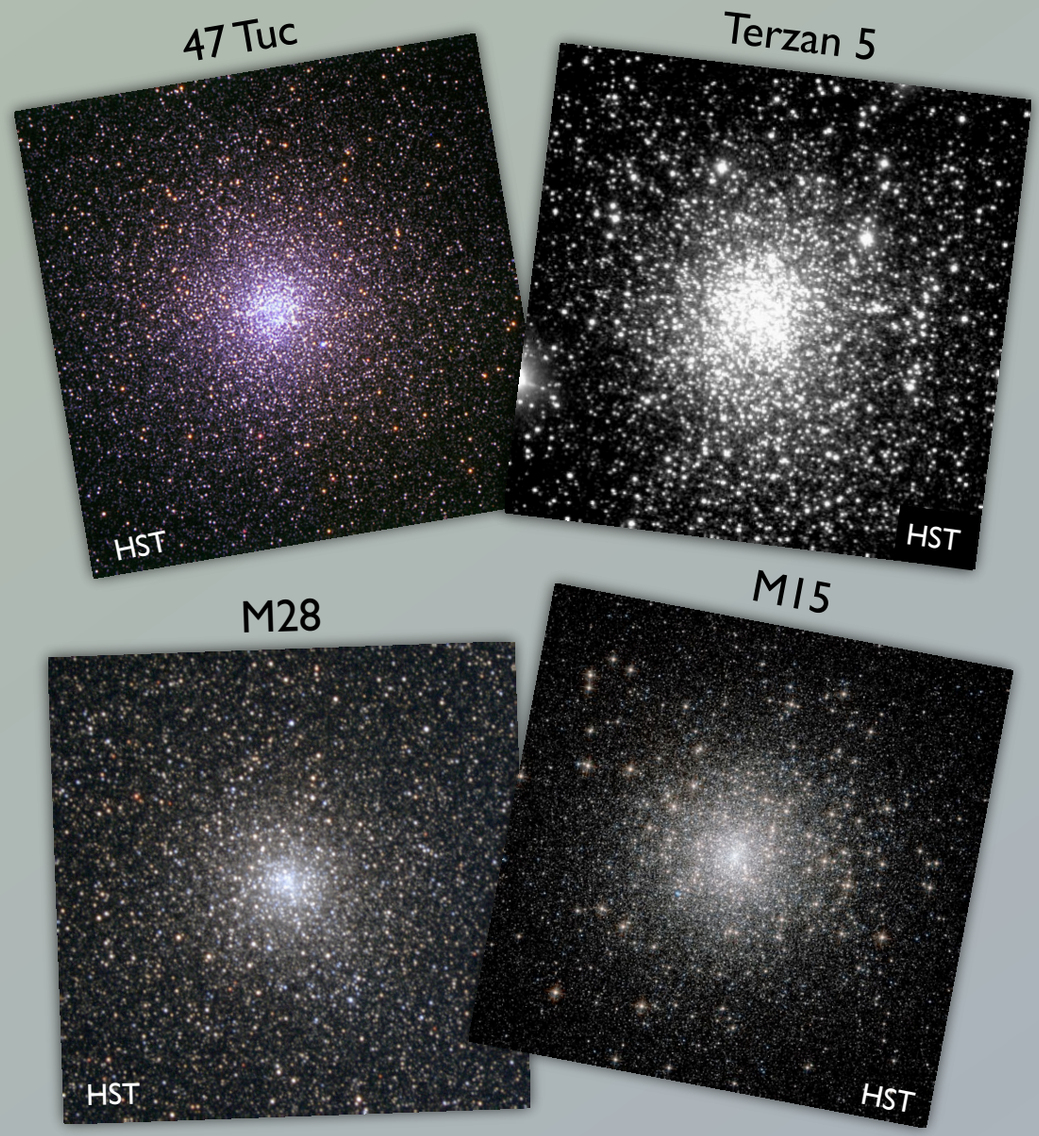
Globular Clusters (GCs) are spherical, gravitationally bound groups of 10^4 - 10^6 stars.

Currently ~150 known orbiting the Milky way.

https://www.physics.mcmaster.ca/~harris/mwgc.dat

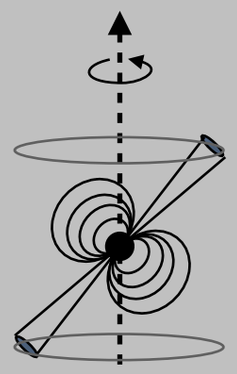
Star densities at the GC cores over 10^3 per cubic parsec.

Ideal environments for formation and disruption of binaries, for the spin-up of pulsars through accretion processes, and the formation of exotic systems through repeated exchange interactions.



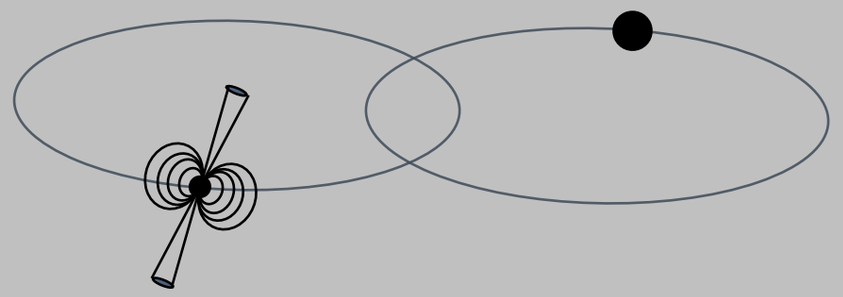
Exciting pulsars can be found in Globular Clusters!

Extremely recycled pulsars



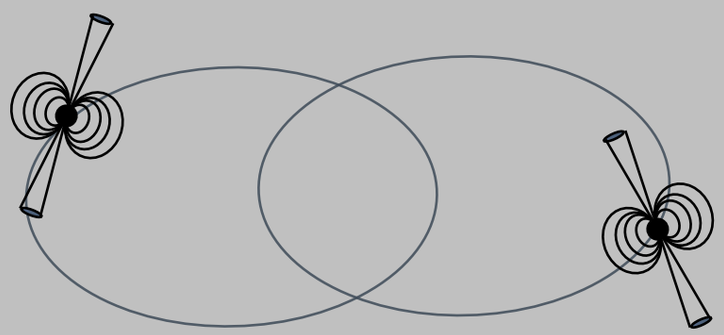
e.g.: Ter 5 ad (Hessels et al. 2006) ✔

Extremely eccentric binaries



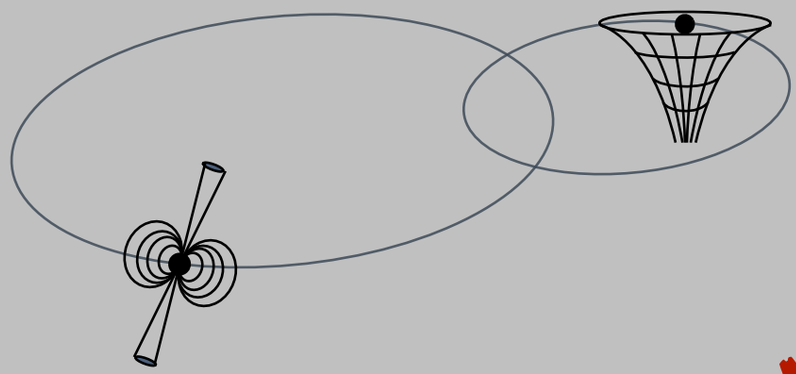
e.g.: NGC 6652 A (DeCesar et al. 2015) ✔

MSP - MSP



✘

Pulsar - BH



✘

Pulsars as probes of GC dynamics

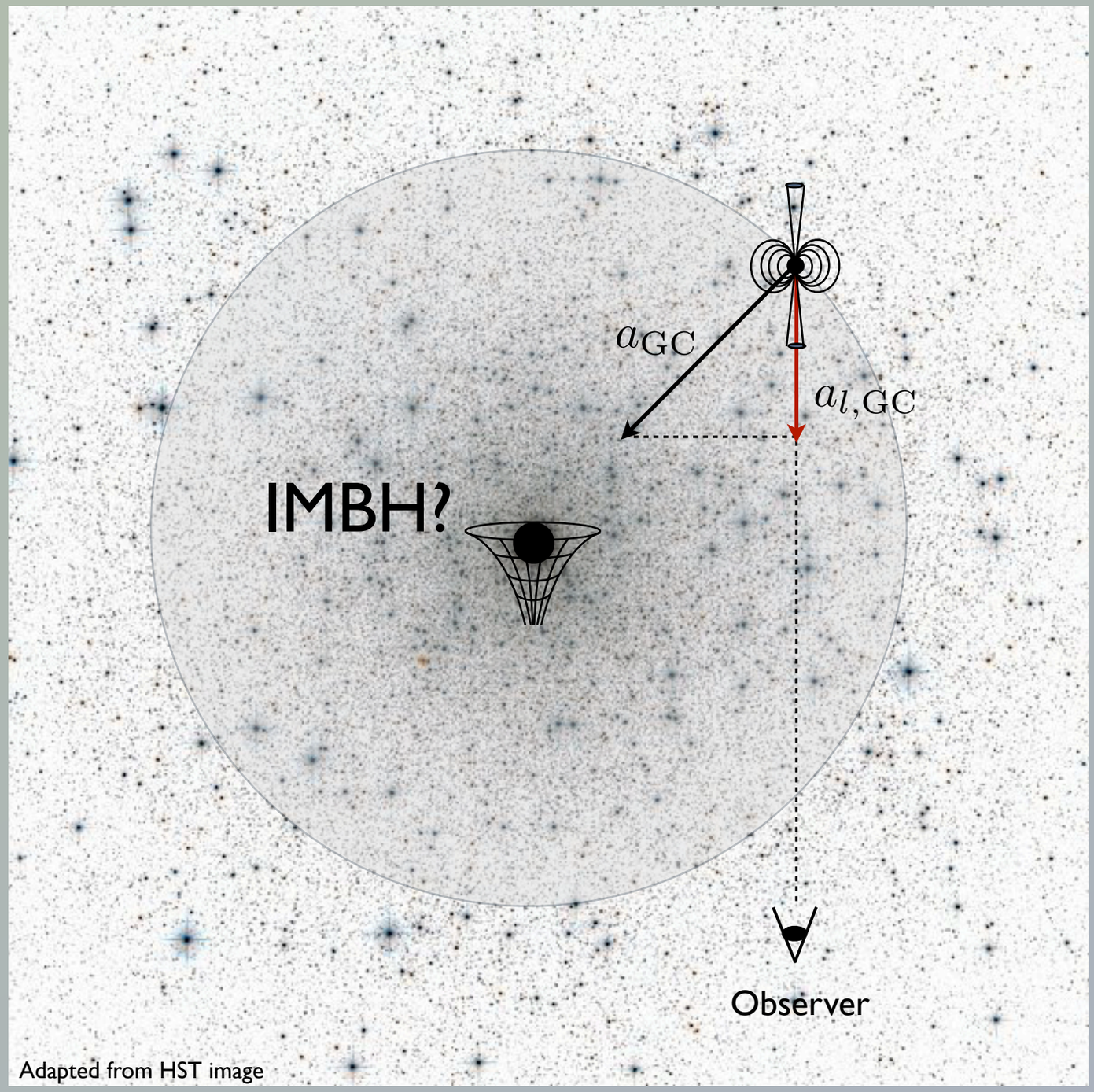
Pulsars in GCs can also be used to study the gravitational **potential of the host cluster** (e.g. Phinney 1993).

And possibly address questions such as:

Is there an IMBH at the center of some clusters?

See e.g. some recent papers:

- Freire et al. (2017)
- Perera et al. (2017)
- Prager et al. (2017)
- Abbate et al. (2018, 2019a, 2019b)
- and others...

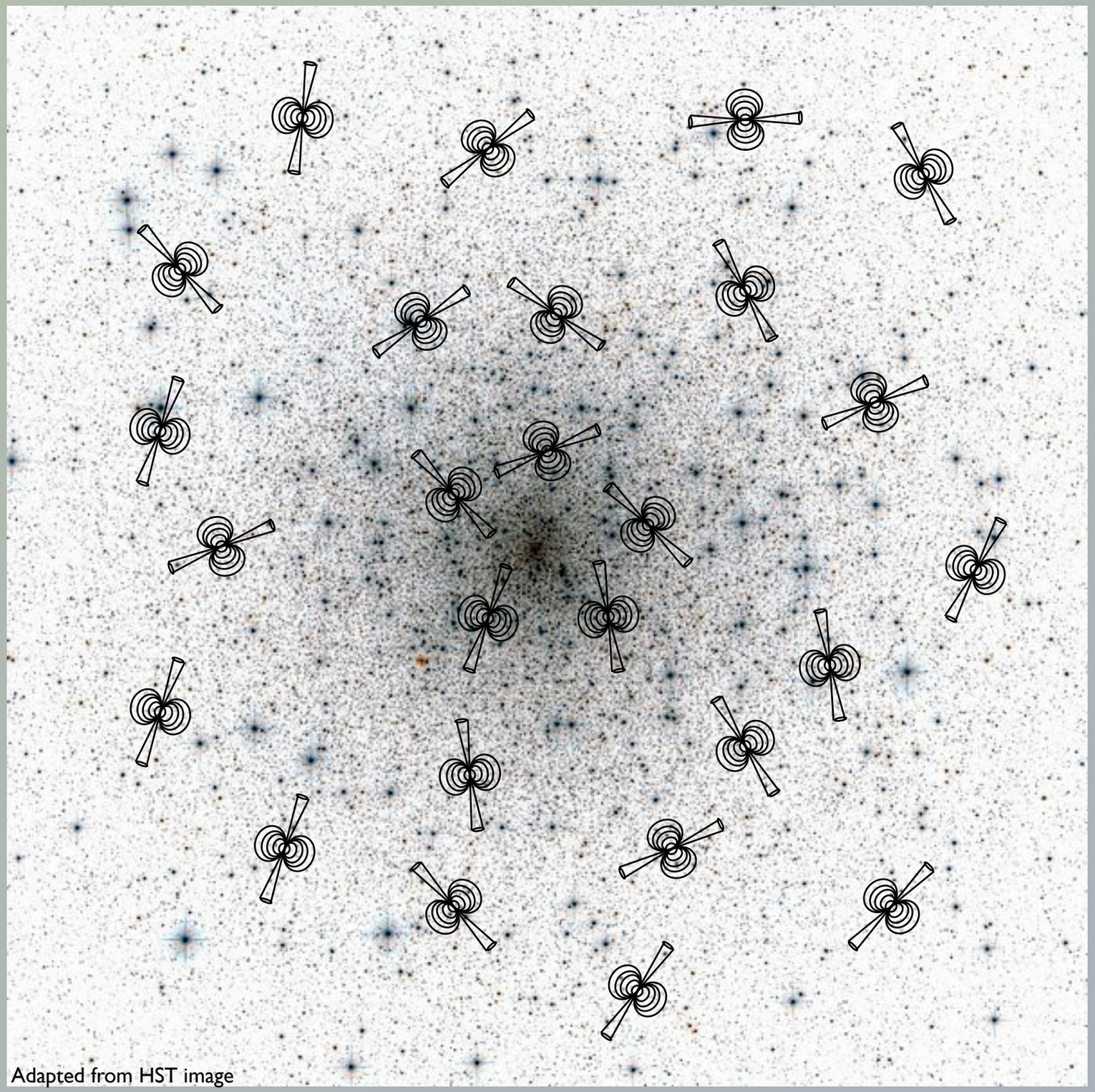


The estimated GC pulsar population

150 pulsars in 28 globular clusters in 2018

However, Turk & Lorimer (2013) estimated a population between **600-3000** potentially observable Galactic GC pulsars.

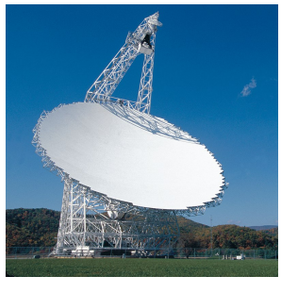
Where are all the others?



Adapted from HST image

Major telescopes for GC pulsar science

Green Bank



MeerKAT

FAST

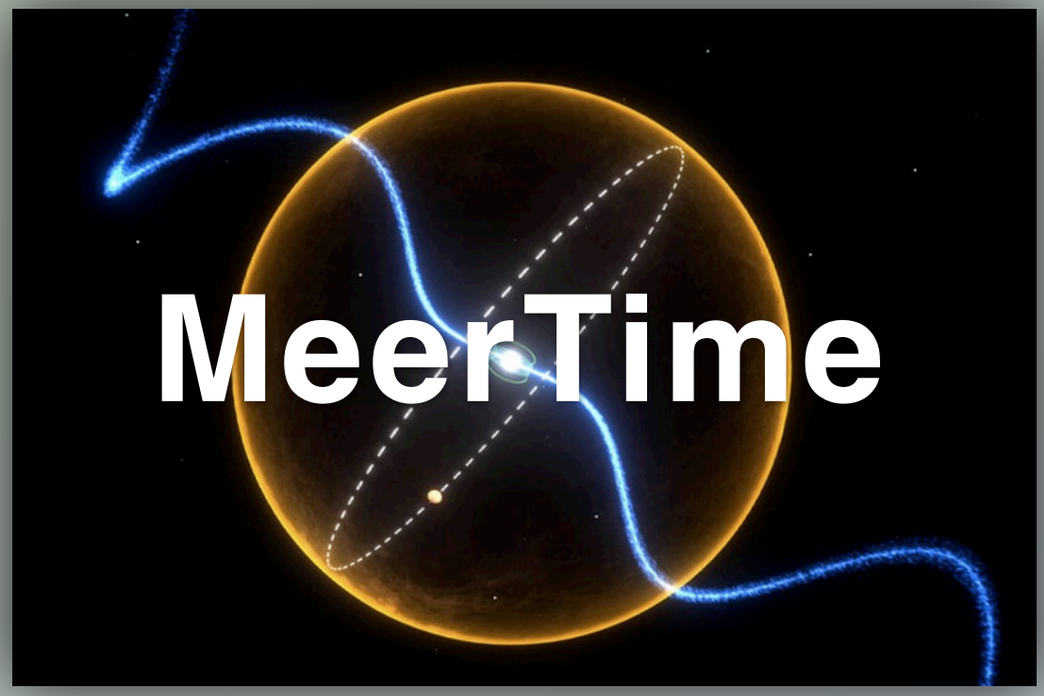
Ar bo

Parkes

The *MeerTime* and *TRAPUM* Large Survey Projects

TRAPUM

Transients and **Pu**lsars with **M**eerKAT



SEARCHING

WG chairs

Ridolfi - globular clusters

Burgay - MWL follow-up

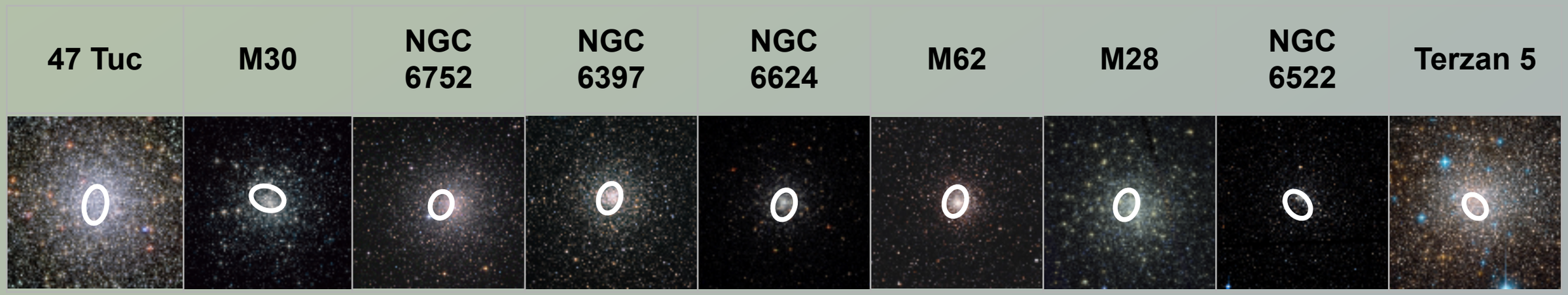
TIMING

WG chairs

Possenti - globular clusters

A first GC census with MeerKAT

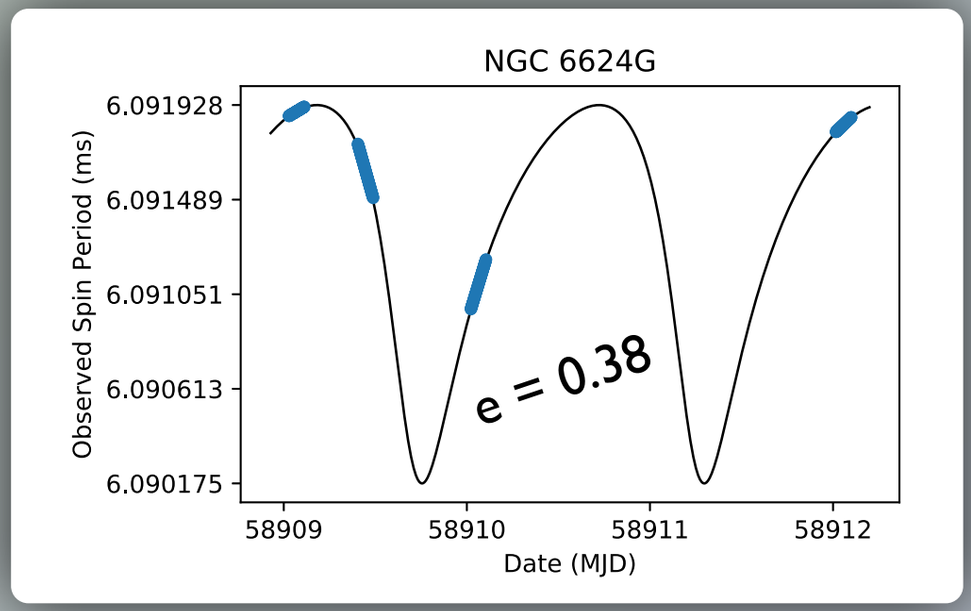
We observed the central regions 9 of different GCs from March 2019 to August 2020



✔ **8** new pulsars

Name	P0 (ms)	Type
47 Tuc AC	2,74	Binary
47 Tuc AD	3,74	Binary
M62 G	4,61	Binary
Ter 5 AN	4,80	Binary
NGC 6522 D	5,53	Isolated
NGC 6624 G	6,09	Binary
NGC 6624 H	5,13	Isolated
NGC 6752 F	8,48	Isolated

- Found in 6 different clusters
- All of them MSPs (P < 10 ms)
- 5 binary, 3 isolated



Omega_dot ➔ $M_{tot} = 2.65 \pm 0.07\ M_{sun}$

The TRAPUM GC survey

Targeting 28 different GCs

NGC 104 (47 Tuc)	NGC 5139 (w Cen)	NGC 6342	Terzan 5	NGC 6522	Mercer 5	NGC 6656 (M22)
NGC 362	NGC 5946	Liller 1	NGC 6440	NGC 6544	NGC 6624	NGC 6717
NGC 1851	NGC 6093 (M80)	NGC 6388	NGC 6441	NGC 6541	NGC 6626 (M28)	NGC 6752
NGC 2808	NGC 6266 (M62)	NGC 6397	NGC 6517	2MS-GC01	NGC 6652	NGC 7099 (M30)

✔ **51** discoveries (in < 10% of data) as of today

http://www.trapum.org/discoveries.html

Spin periods

44 millisecond pulsars

5 mildly recycled

1 long-period (~250 ms)

1 very long-period (2.5 s)

Peculiar objects

3 highly eccentric binaries

Several eclipsing spiders

New pulsars in NGC 1851

NGC 1851

Credits: NASA

1 pulsar known -
discovered by GMRT
by Freire et al. (2004)

Discoveries:

Ridolfi et al. (2022)

Timing:

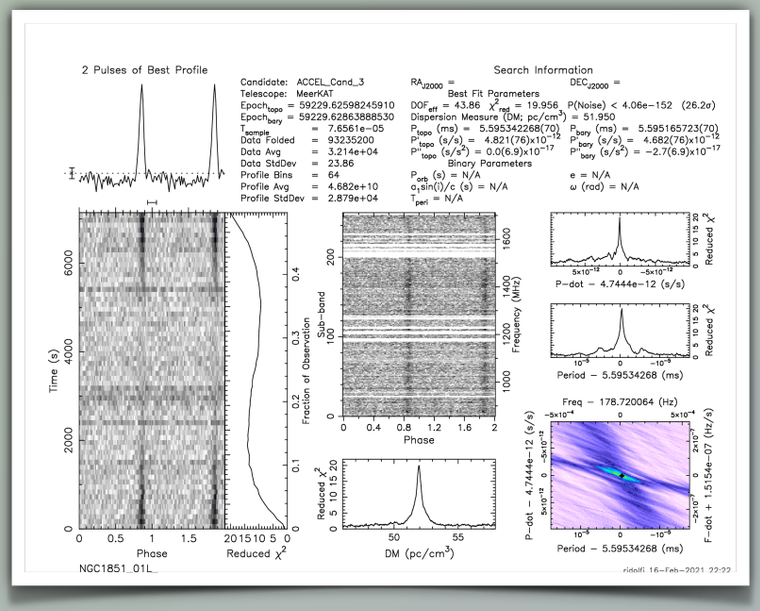
Dutta et al. (in prep.)

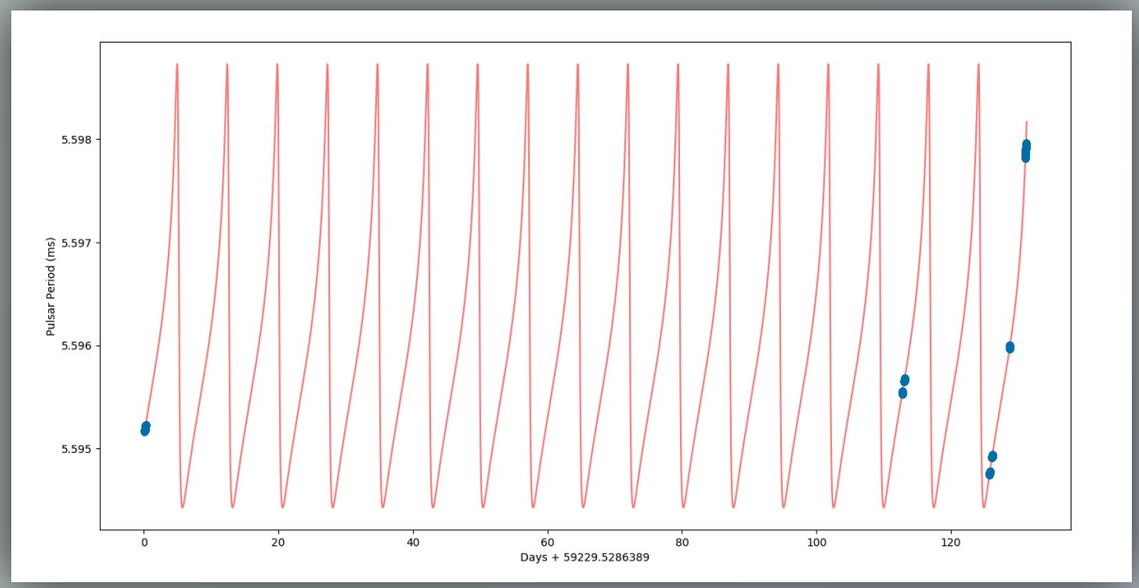
13 new pulsars by MeerKAT

Name	P (ms)	DM (pc cm-3)	Type
NGC 1851B	2,8162	52,07	Isolated
NGC 1851C	5,5648	52,05	Isolated
NGC 1851D	4,5543	52,17	Isolated
NGC 1851E	5,5952	51,95	Binary
NGC 1851F	4,3294	51,63	Binary
NGC 1851G	3,8028	51,01	Binary
NGC 1851H	5,5061	52,26	Binary
NGC 1851I	32,6538	52,42	Binary
NGC 1851J	6,6329	52,06	Isolated
NGC 1851K	4,6920	51,93	Isolated
NGC 1851L	2,9586	51,23	Binary
NGC 1851M	4,7977	51,66	Isolated
NGC 1851N	5,5679	51,11	Isolated

NGC 1851E - an extremely eccentric and massive binary MSP

Barr et al., in prep.





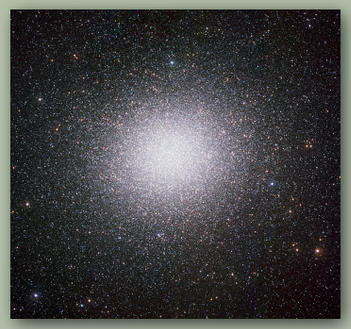
P_b = 7.44 d
e = 0.71
ω_p = 65.4°
x_p = 27.8 s

$M_c > 1.5\ M_{sun}$

(for M_p=1.4 M_{sun})

New pulsars in Omega Centauri

Omega Centauri



Credits: ESO

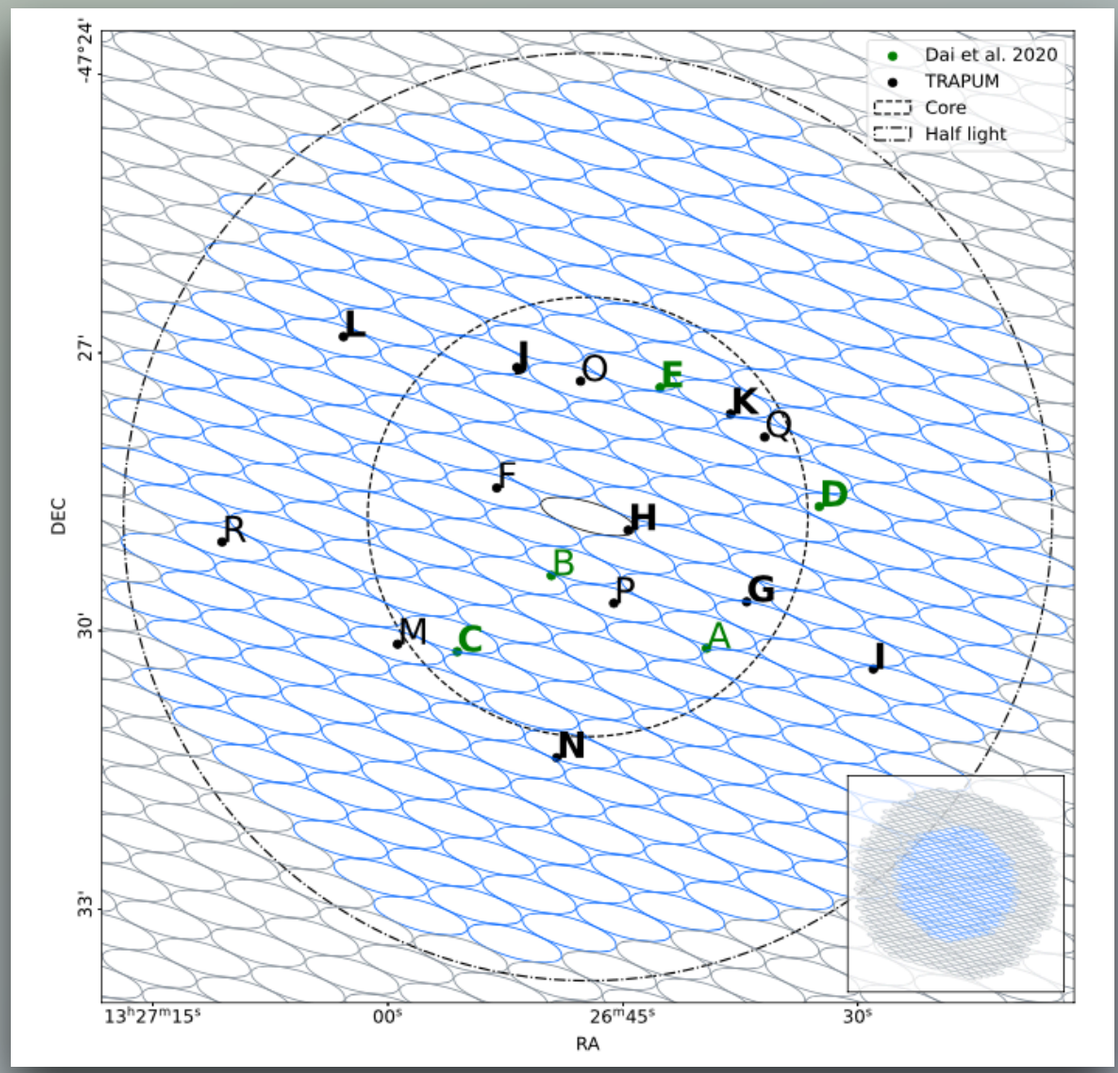
Extensively searched with the Parkes telescope in the 2000's

First 5 pulsars discovered 20 years later (Dai et al. 2020)

13 further pulsars discovered by MeerKAT!

Pulsar	Type	P (ms)	DM (pc cm^{-3})
F	Isolated	2.273	98.29
G	Binary	3.304	99.69
H	Binary	2.520	98.09
I	Binary	18.95	102.2
J	Isolated	1.842	97.28
K	Binary	4.716	94.73
L	Binary	3.537	101.5
M	Isolated	4.603	101.4
N	Binary	6.884	101.2
O	Isolated	6.159	94.27
P	Isolated	2.794	102.1
Q	Binary	4.130	95.92
R	Isolated	10.29	102.1

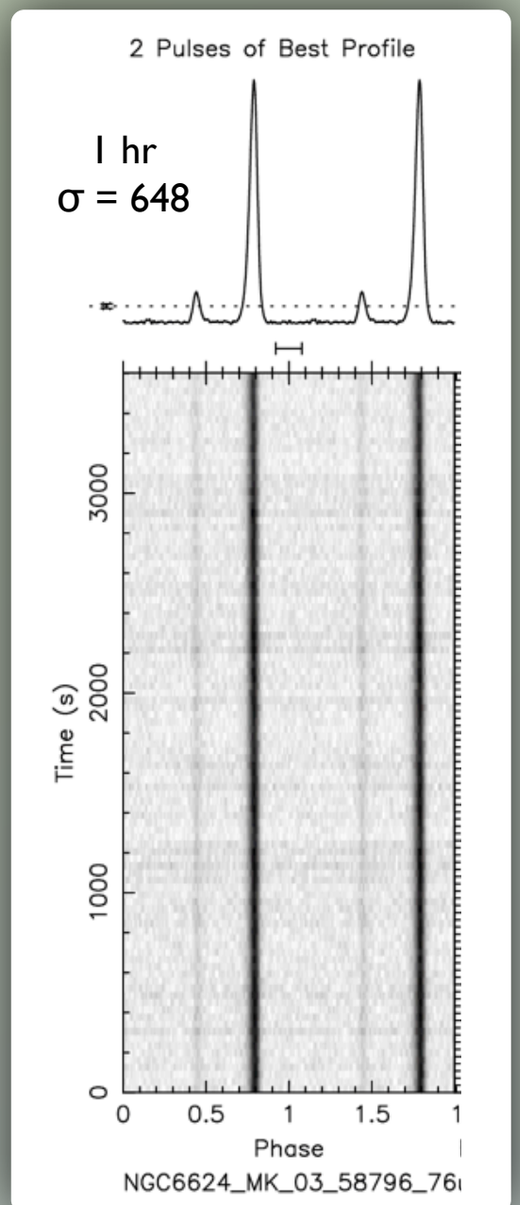
Chen et al., in prep.



Not only new pulsars...

Giant pulses (GPs) from NGC 6624A

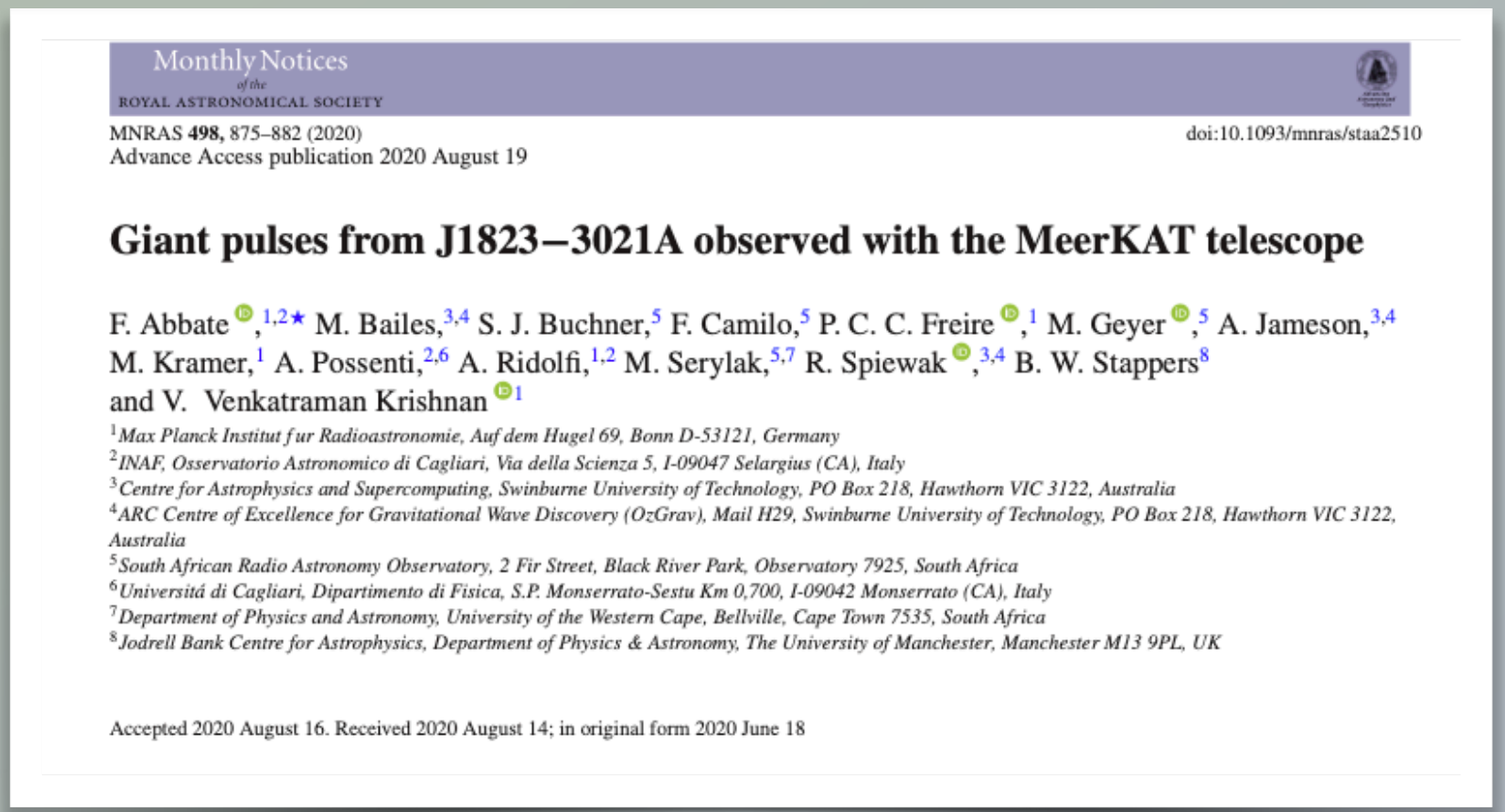
40 antennas
@L-band



5 h of MeeKAT obs ➔
14350 GPs (~0.8 GP/s)

→

Most active known GP emitter amongst MSPs



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MNRAS **498,** 875–882 (2020)
Advance Access publication 2020 August 19

doi:10.1093/mnras/staa2510

Giant pulses from J1823−3021A observed with the MeerKAT telescope

F. Abbate [1,2★] M. Bailes,[3,4] S. J. Buchner,[5] F. Camilo,[5] P. C. C. Freire [1] M. Geyer [5] A. Jameson,[3,4] M. Kramer,[1] A. Possenti,[2,6] A. Ridolfi,[1,2] M. Serylak,[5,7] R. Spiewak [3,4] B. W. Stappers[8] and V. Venkatraman Krishnan [1]

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[8] *Jodrell Bank Centre for Astrophysics, Department of Physics & Astronomy, The University of Manchester, Manchester M13 9PL, UK*

Accepted 2020 August 16. Received 2020 August 14; in original form 2020 June 18

Abbate et al. (2020b)

A super-long observation of 47 Tuc

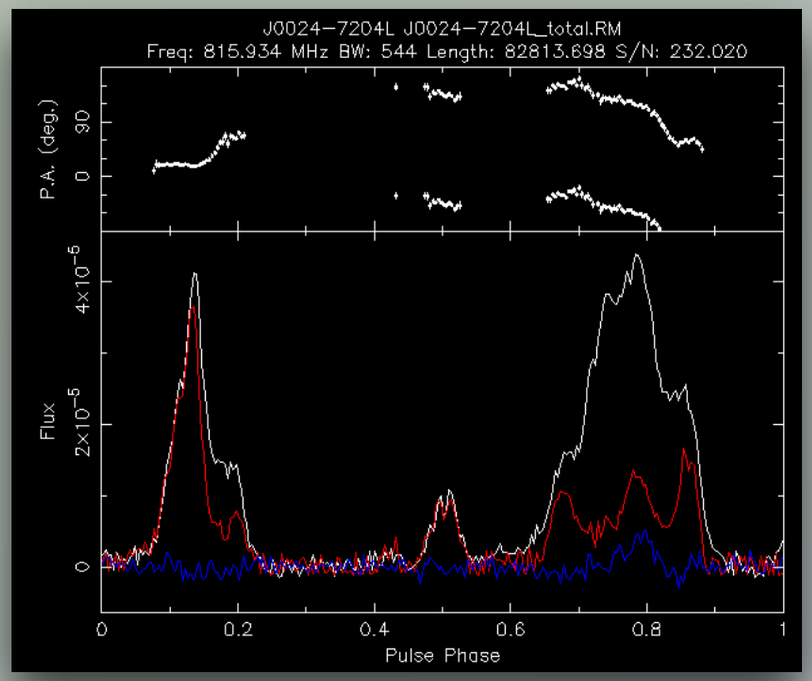
29 pulsars known in the cluster

16-hour observation of 47 Tuc with the UHF receivers

Longest observation of a GC of all time

Scientific goals:

- Measure polarization profile with much better precision than Parkes
- Try and detect the Shapiro delay of several pulsar-WD binaries
- Discover many additional pulsars



Most precise DM and RM measurements to date

Evidence of turbulence in the intracluster medium
Likely driven by the motion of wind-shedding stars

Abbate et al., submitted

The relativistic binary NGC 6752A

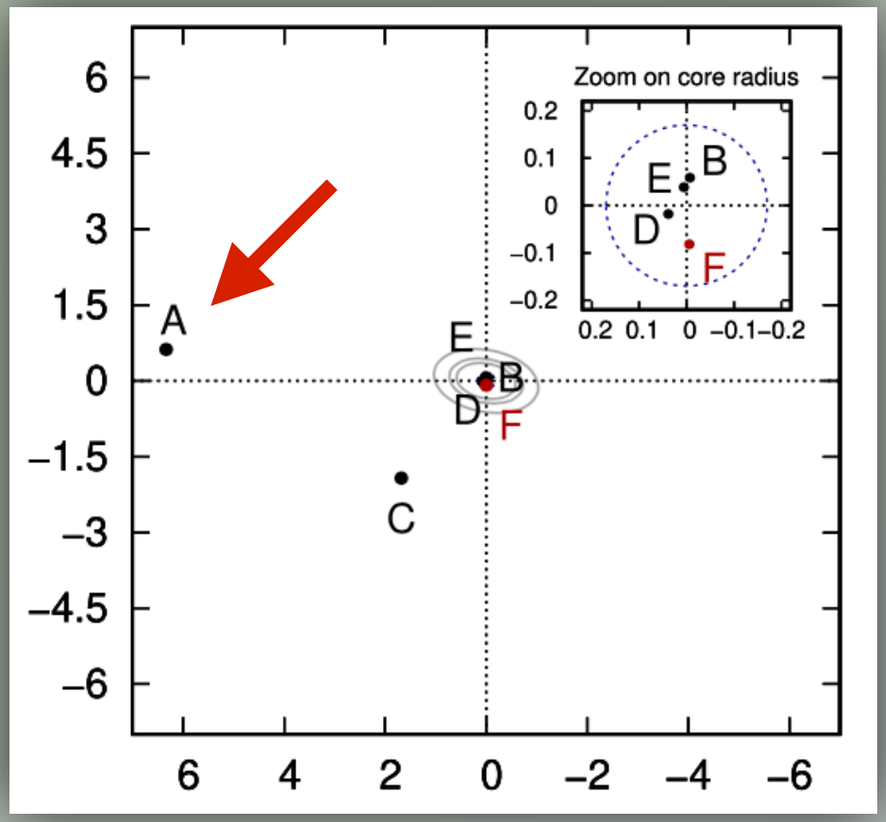
P = 3.26 ms

Pb = 0.84 days

He WD companion

74 r_{core} from center

Does it really belong to the cluster?



Timing with Parkes + MeerKAT

- Shapiro delay
- Orbital decay
- Proper motion
- M_p=1.55 Msun
- M_c=0.202 Msun

3D velocity < GC escape velocity → **Yes, it belongs to NGC 6752!**

Parameter	Symbol
Mass ($M_\odot$)	M_C
Distance (kpc)	D
Reddening (mag)	$E(B-V)$
U–band magnitude (mag)	m_U
B–band magnitude (mag)	m_B
V–band magnitude (mag)	m_V
Surface temperature (K)	T_{eff}
Surface gravity (c.g.s.)	$\log_{10} g$

Test of M-R relations of WD models

Corongiu et al., submitted

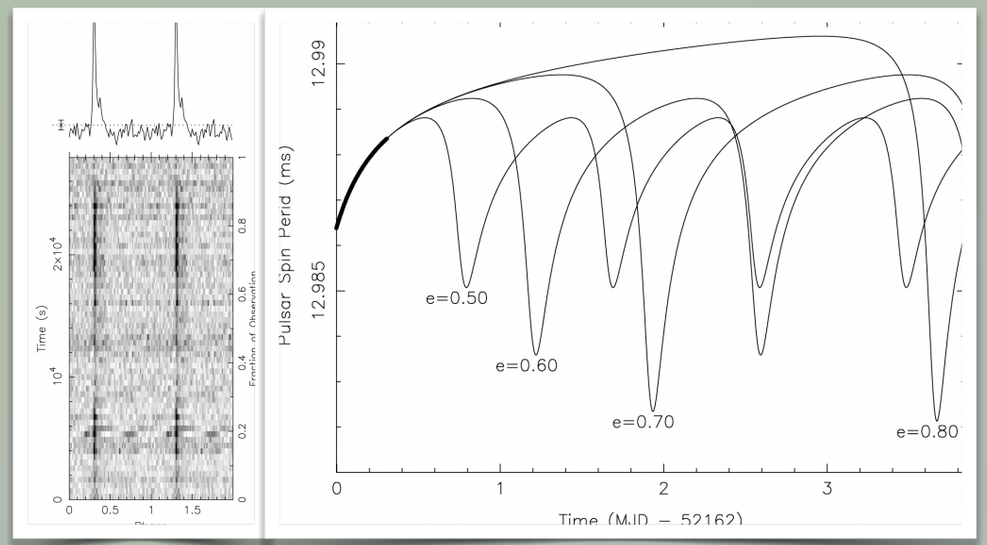
Revisiting M30B... 20 years later

Discovered by Ransom et al. (2004) with the GBT

P = 13.0 ms

Pb = ~ days

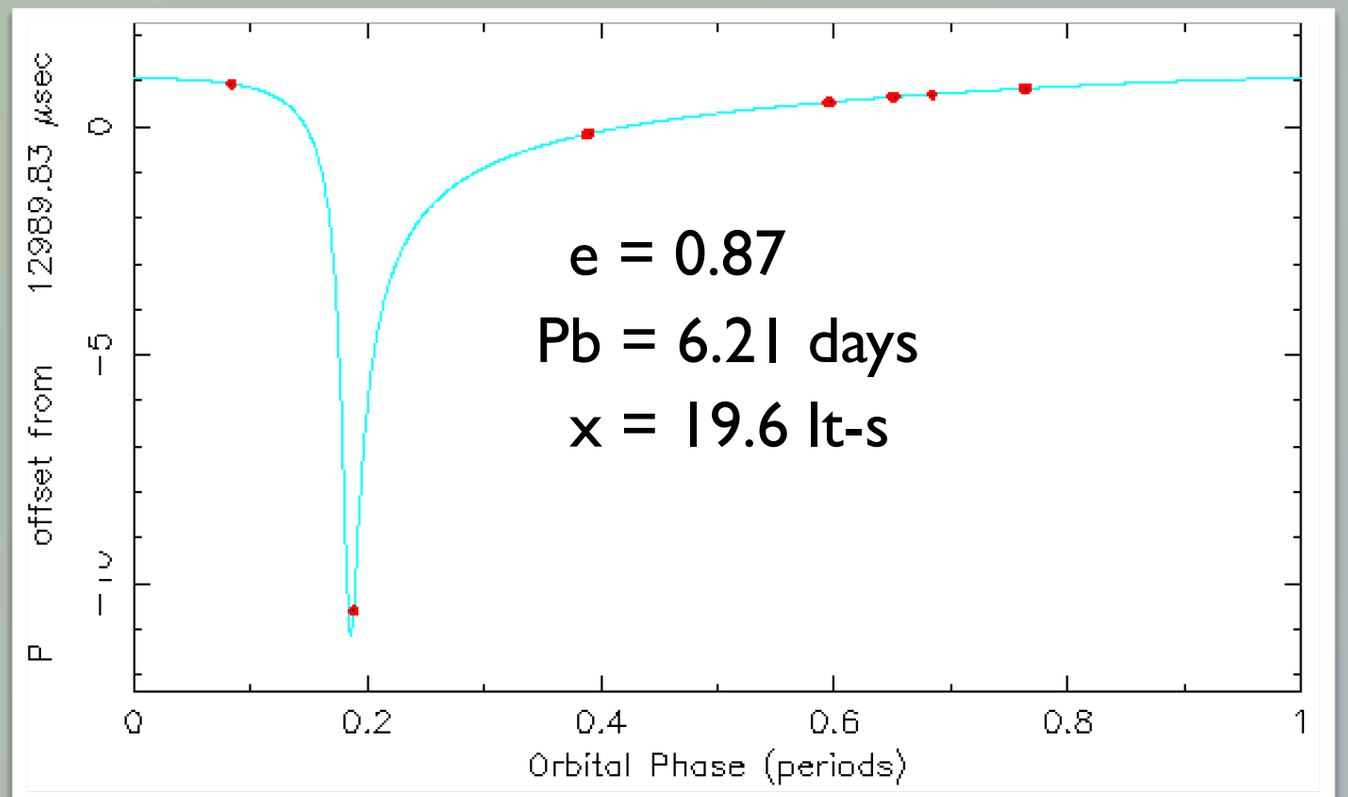
e > 0.45



Credits: Ransom et al. (2004)

Never detected again....

until MeerKAT!



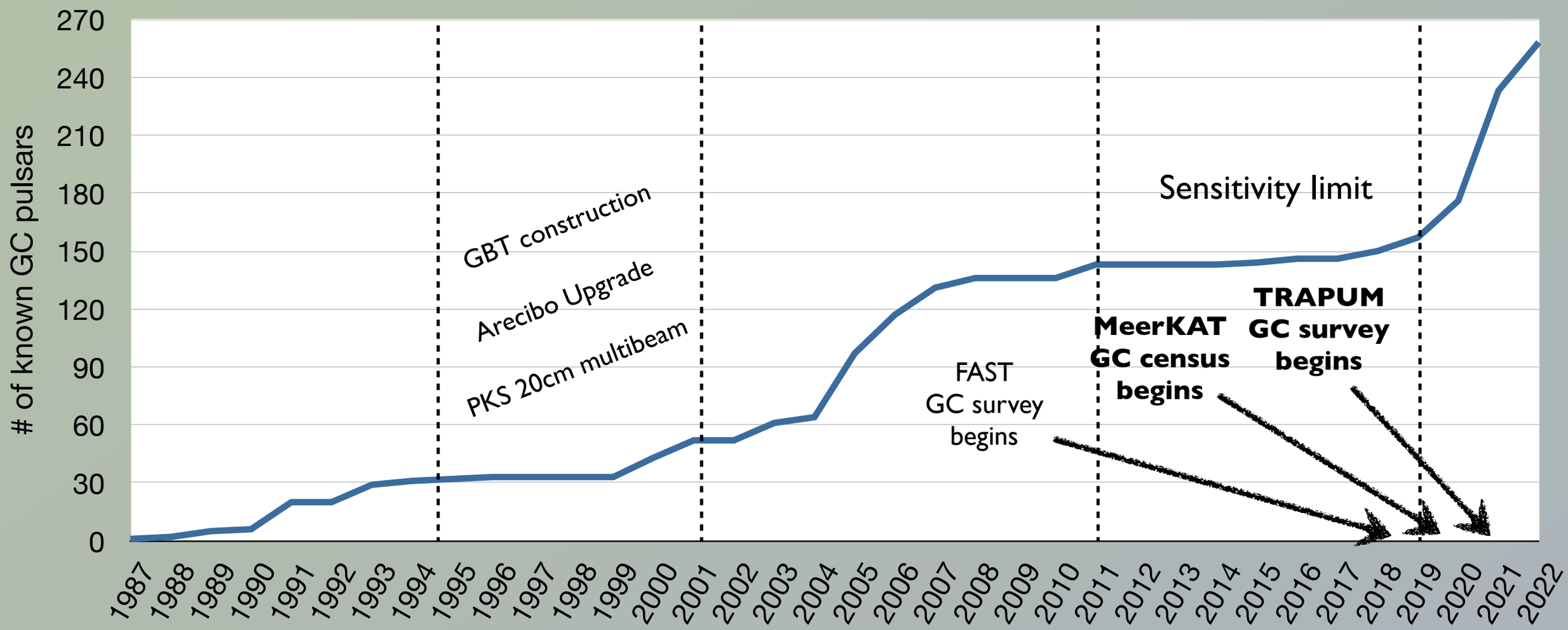
Credits:Vishnu Balakrishnan

→ Mc > 1.08 Msun

Omega_dot
with archival GBT data

Balakrishnan et al., in prep.

Where are we now?



MeerKAT	FAST	GBT	Parkes	GMRT
+59	+36	+7	+6	+1
Ridolfi et al. (2021) Vleeschower et al. (2022) Douglas et al. (2022) Ridolfi et al. (2022) Abbate et al. (2022) more in prep...	Pan et al. (2020) Wang et al. (2020) Pan et al. (2021a, b) Qian & Pan (2021) Yan et al. (2021)	De Cesar et al. (in prep)	Dai et al. (2020) Zhang et al. (2022)	Gautam et al. 2022)

http://www.naic.edu/~pfreire/GCpsr.html

Outlook

Today	2024	~2028
MeerKAT (64 dishes) (S-band in 2023)	**MeerKAT+ (76 dishes)**	**SKA1-mid (197 dishes)**
300 GC pulsars?	400 GC pulsars?? MSP-MSP binary??	1000 GC pulsars??? Pulsar-BH binary???

In any case....

These are very exciting times for GC pulsar astrophysics!

Summary

- MeerKAT is a game changer for GC pulsar astrophysics
  - Enables observations of southern GCs with unprecedented sensitivity
  - Up to 2x more sensitive than GBT, > 4x more sensitivity than Parkes
  - Paves the way for **SKA1-mid**

- Exciting results from the first 2.5 years of data
  - 59 new GC pulsars discovered
  - 13 new pulsars in NGC 1851
  - 13 new pulsars in Ω Centauri
  - At least three very eccentric MSPs
  - NGC 1851E is a massive binary
  - Most detailed study of giant pulses from an MSP to date
  - Characterization of M30B after two decades

THANK YOU!

MeerKAT GC publications:

Abbate et al. (2020b)
Ridolfi et al. (2021)
Vleeschower et al. (2022)
Douglas et al. (2022)
Ridolfi et al. (2022)
Abbate et al. (2022)
Corongiu et al. (submitted)
Abbate et al. (submitted)
Barr et al. (in prep.)
Chen et al (in prep.)
Dutta et al. (in prep.)
Balakrishnan et al. (in prep.)
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