uGMRT timing of the eccentric binary millisecond pulsar NGC 1851A

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Outline

1) **Introduction**:

- Pulsars in globular clusters (GCs)
- PSR J0514–4002A (a.k.a. NGC 1851A)

2) **uGMRT observations**

- Comparison with previous data

3) **Results**

- Binary component masses
- Proper motion
- Search for pulsations from the companion star

4) **Summary & Outlook**

Pulsars in Globular Clusters

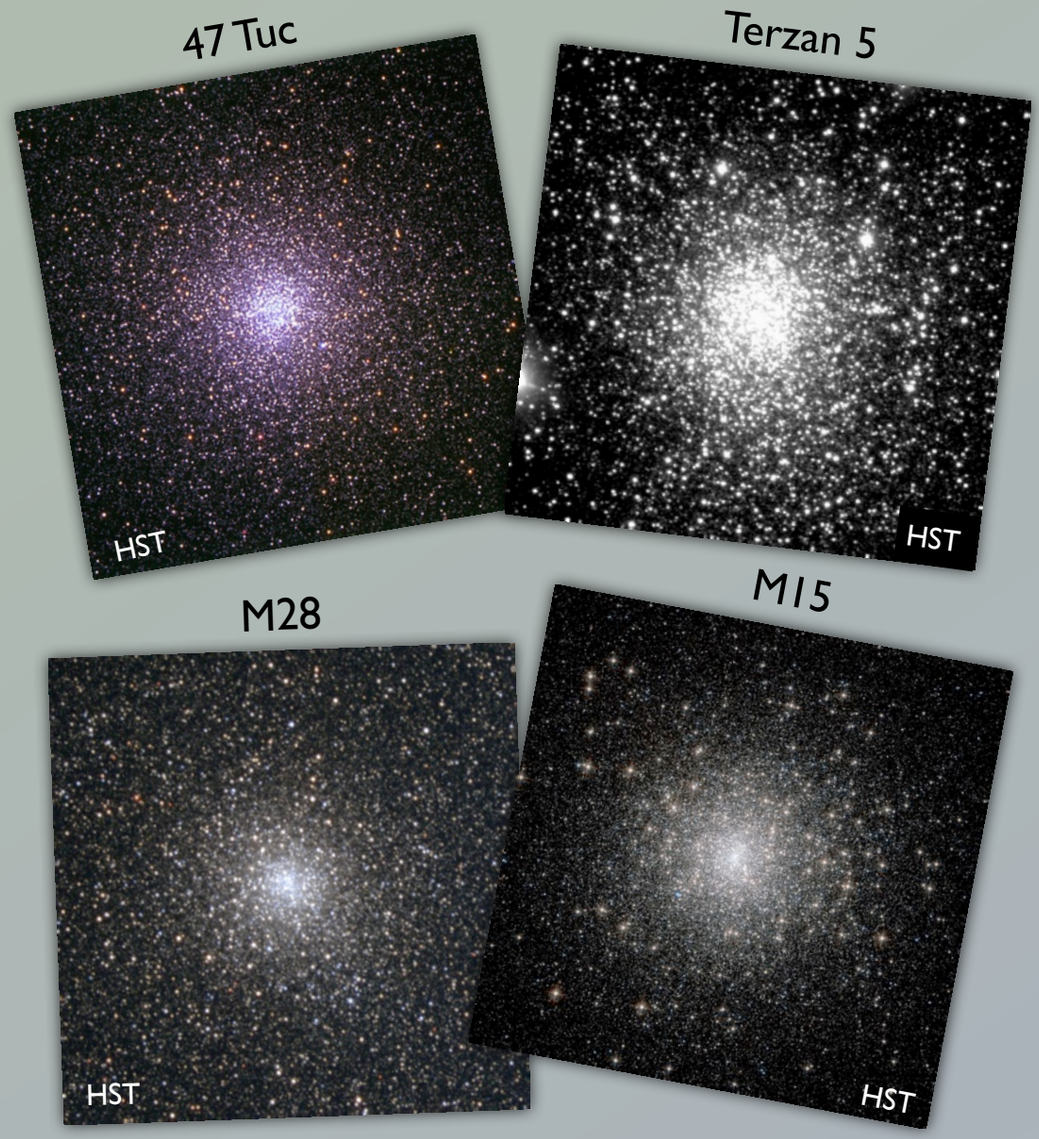
Globular Clusters (GCs) are spherical, gravitationally bound groups of 10^4 - 10^6 stars.

Currently ~150 known orbiting the Milky way.

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

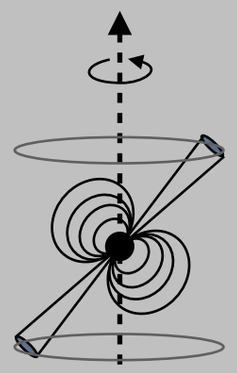
Star densities at the GC cores over 10^3 per cubic parsec.

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.



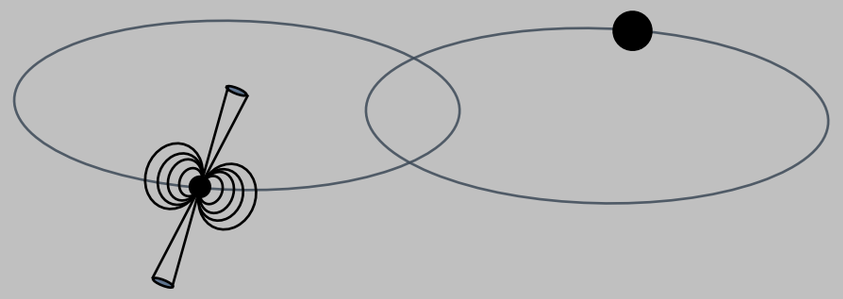
Exciting pulsars can be found in Globular Clusters!

Extremely recycled pulsars



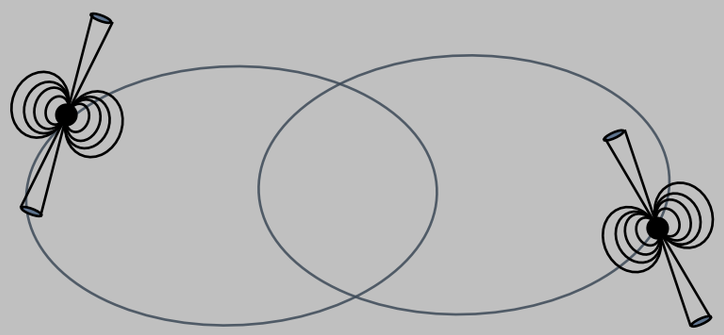
e.g.: Ter 5 ad (Hessels et al. 2006) ✔

Extremely eccentric binaries



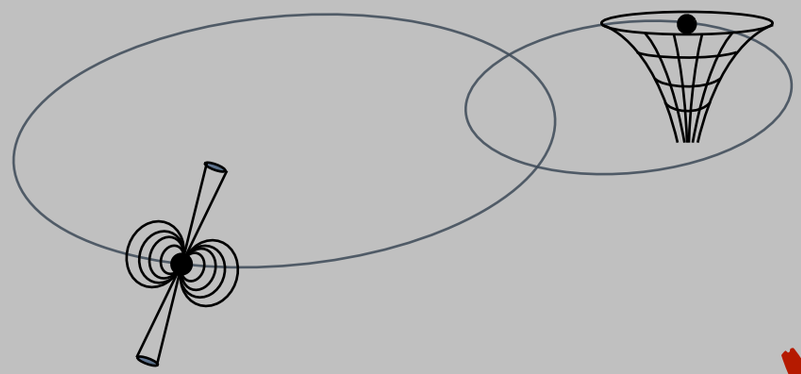
e.g.: NGC 6652 A (DeCesar et al. 2015) ✔

MSP - MSP



✘

Pulsar - BH



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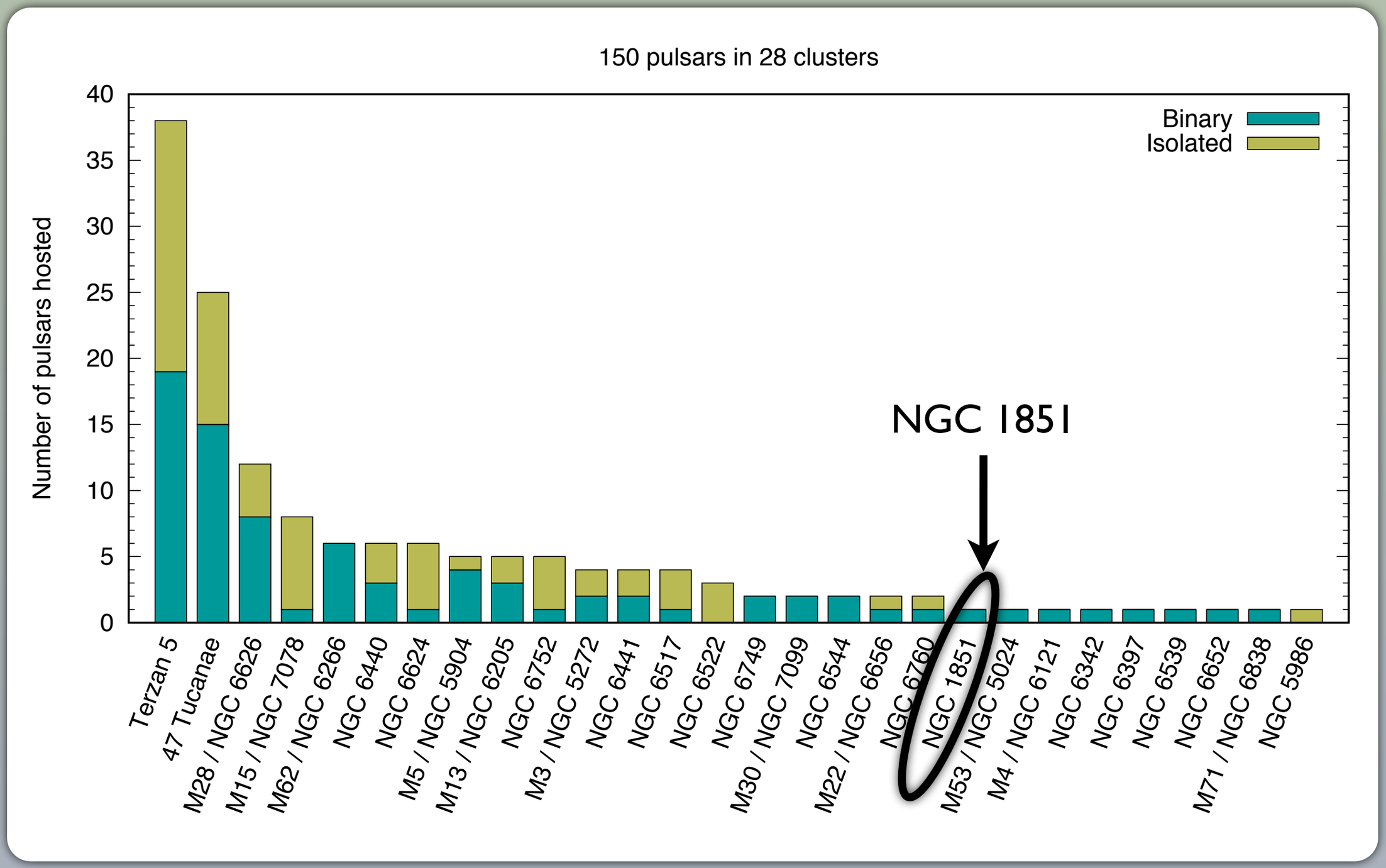
Pulsars in Globular Clusters

150 pulsars in 28 globular clusters

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



Timing of NGC 1851A

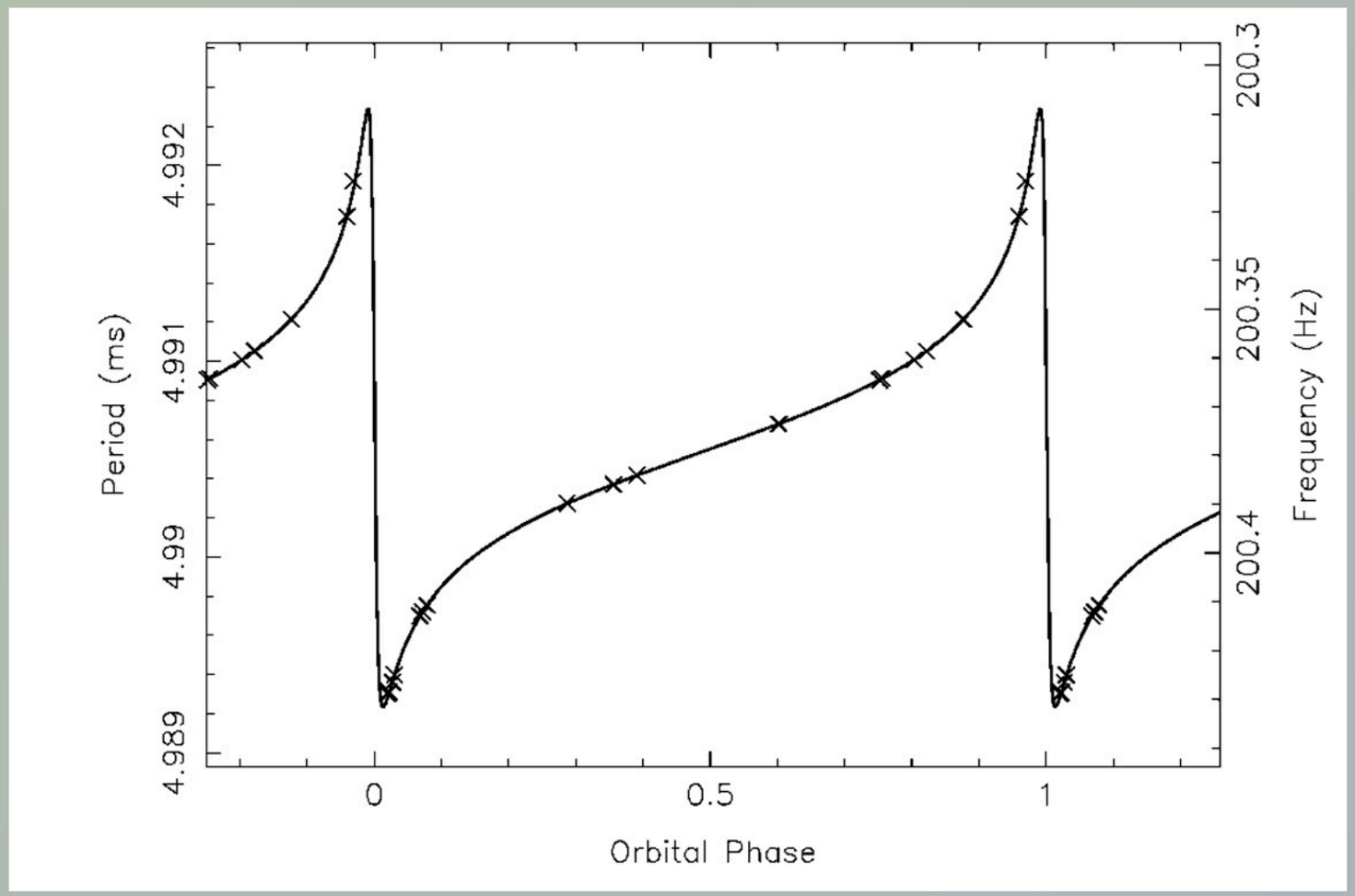
Freire et al. (2004):

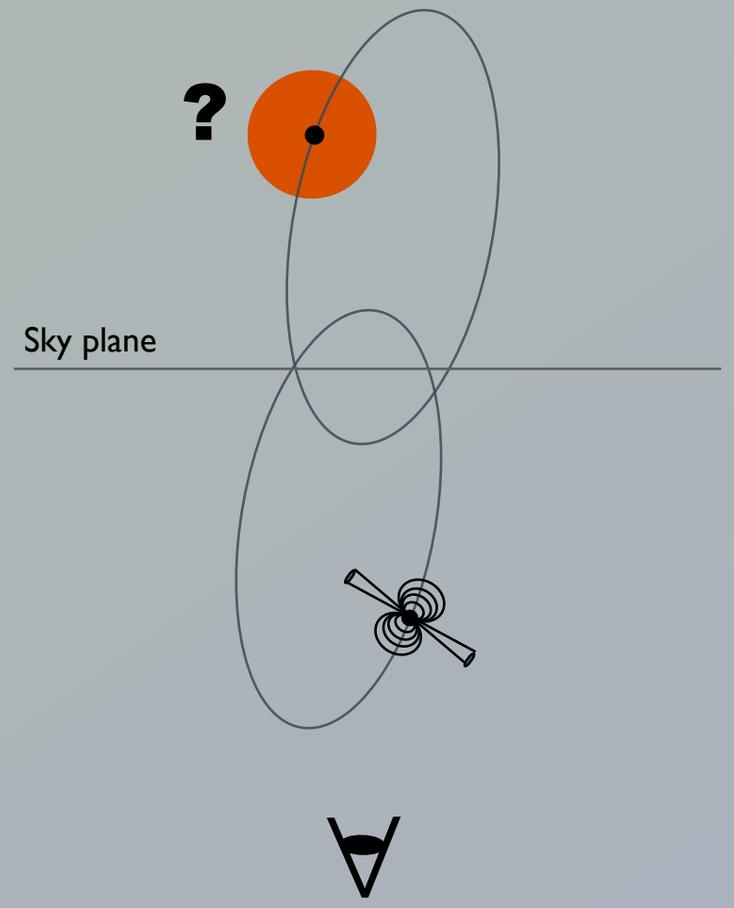
- Discovery with the GMRT at 327 MHz

- Binary characteristics detemined
- Most eccentric binary at the time
- Nature of the companion unclear

P = 4.99 ms
DM ~ 52 pc cm^{-3}

Pb=18.7 days,
ecc=0.89

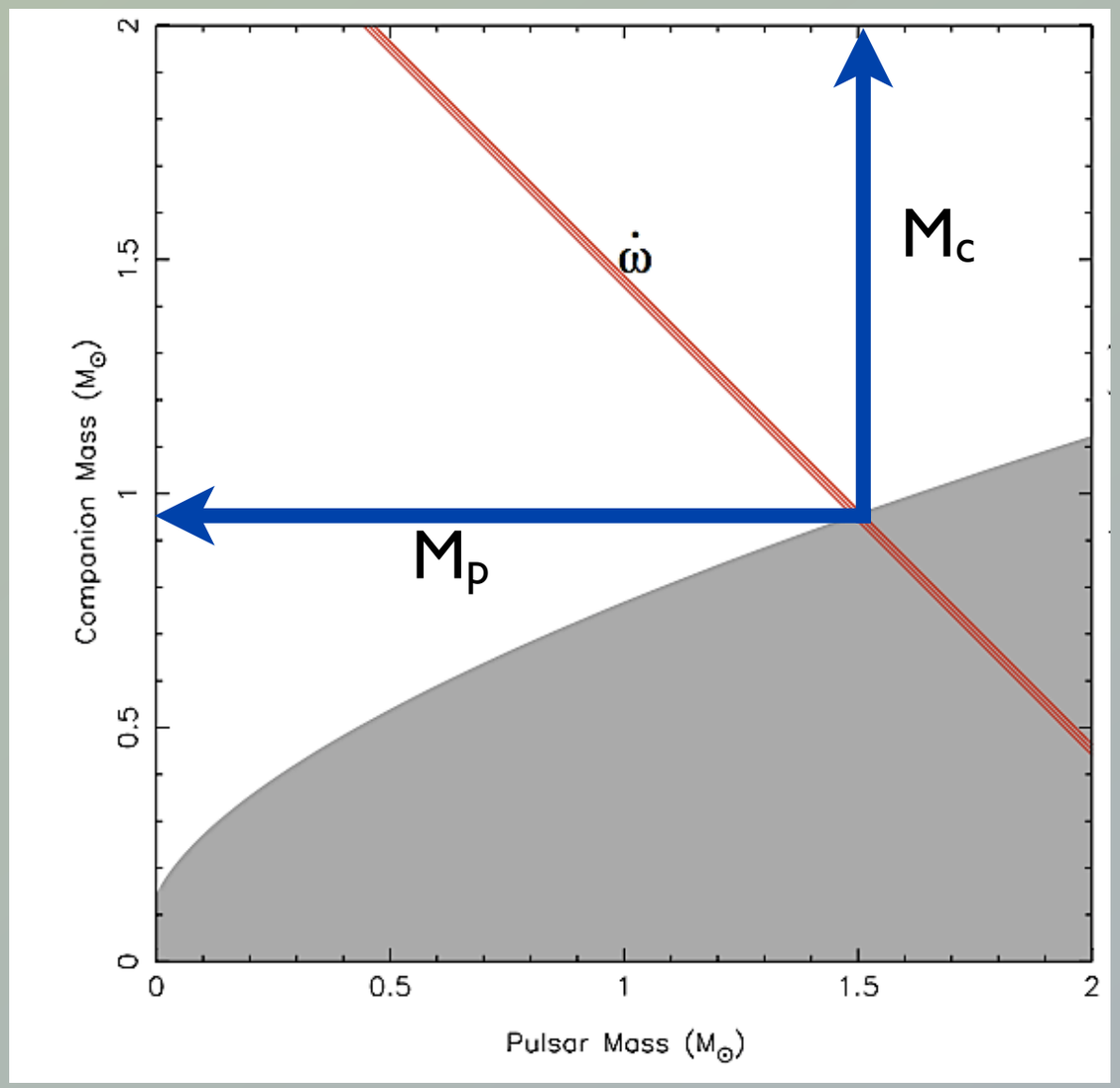


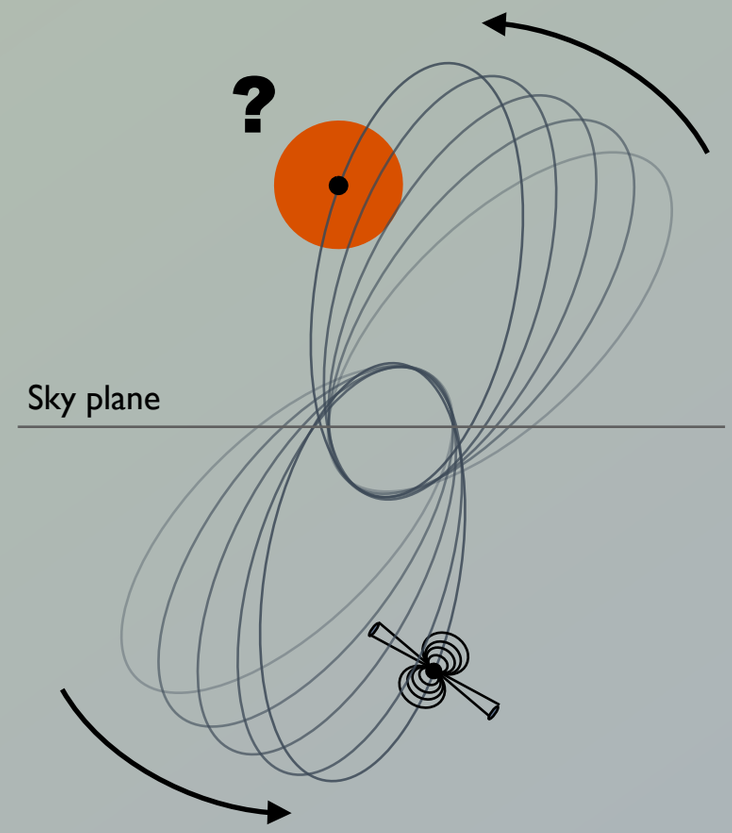


Timing of NGC 1851A

Freire et al. (2007):

- 2-year timing with the GBT
  - ➔ phase-connected timing solution
- No eclipses
  - ➔ no extended companion





- Measurement of rate of advance of periastron, $\dot{\omega}$

➔ $M_{tot} = M_p + M_c = 2.45\ M_{sun}$.

➔ $M_p < 1.50\ M_{sun}$

➔ $M_c > 0.93\ M_{sun}$

The upgraded GMRT (uGMRT)

- New wideband receivers
- New backend with:
  - coherent dedispersion (CDP)
  - up to 400 MHz bandwidth
- 3x better sensitivity!

→ Possibility of measuring additional PK parameters, and more

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1-year observing campaign (Apr 2017 - Mar 2018) of NGC 1851A with the uGMRT

Observation specs:

- Frequency: **300-500 MHz** (Band 3)
- Backend: **GWB** in PA + CDP mode, whenever possible
- Antennas: **12-14** from the central array

Dispersion

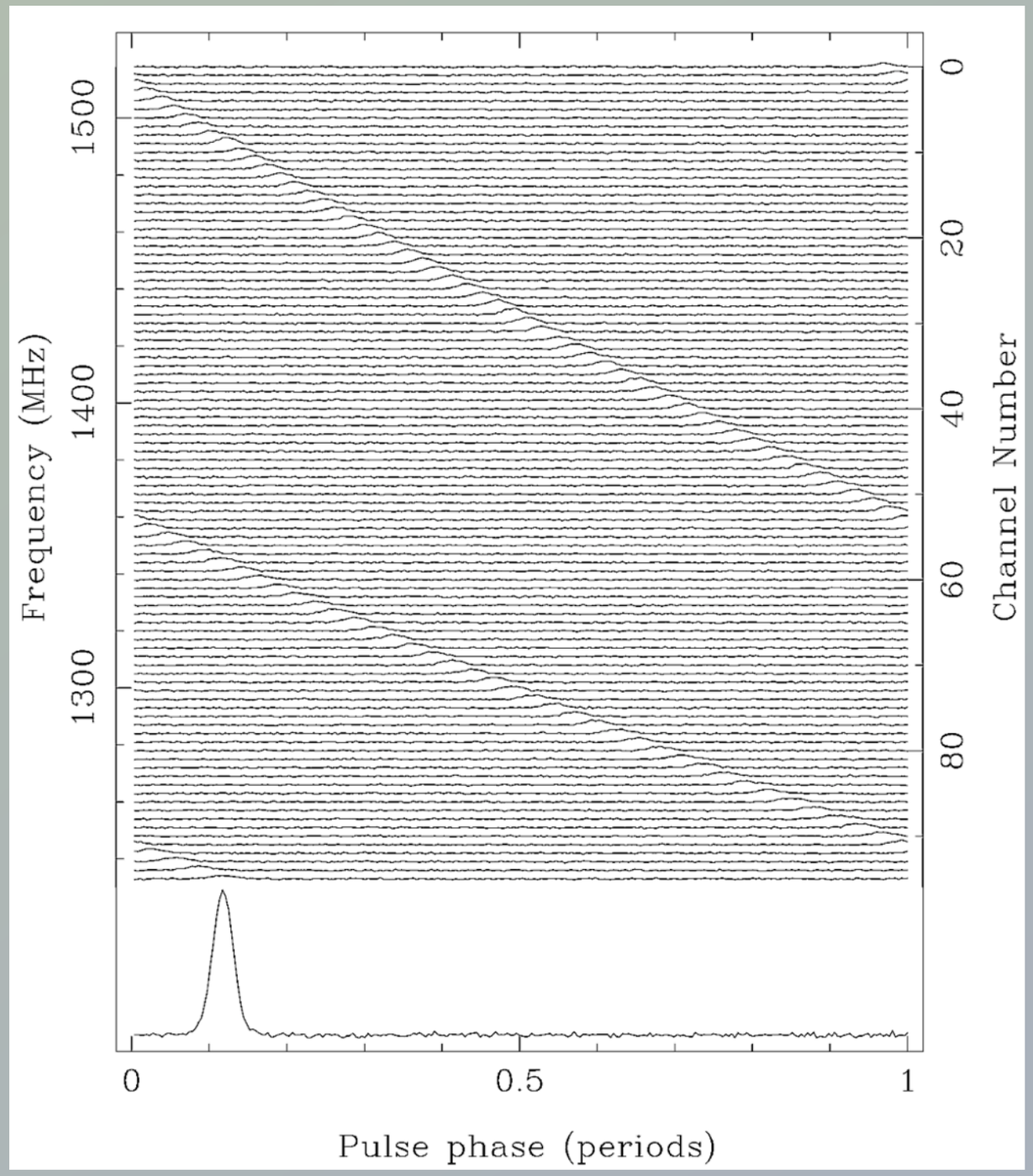
The ionized component of the ISM is a dispersive medium.

$$\Delta t_{(f_1,f_2)} = \frac{e^2}{2\pi m_e c} \cdot \left(\frac{1}{f_1^2} - \frac{1}{f_2^2} \right) \cdot \mathrm{DM}$$

where:

$$\mathrm{DM} = \int_0^d n_e dl$$

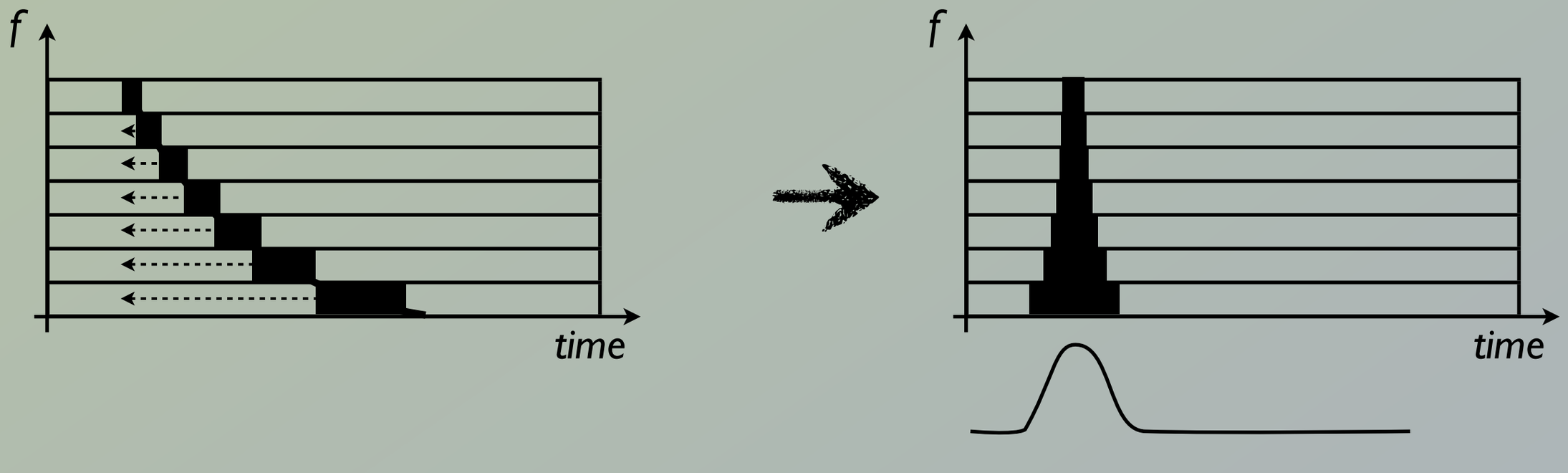
is called “Dispersion Measure”



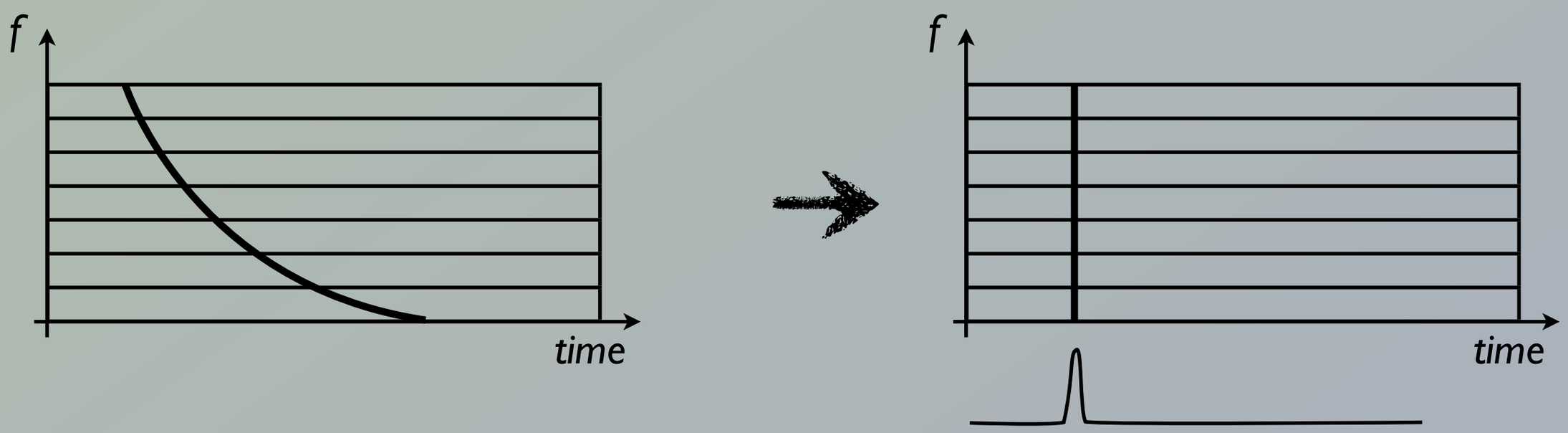
Credits: Andrew Lyne

Incoherent vs coherent de-dispersion

Incoherent de-dispersion:

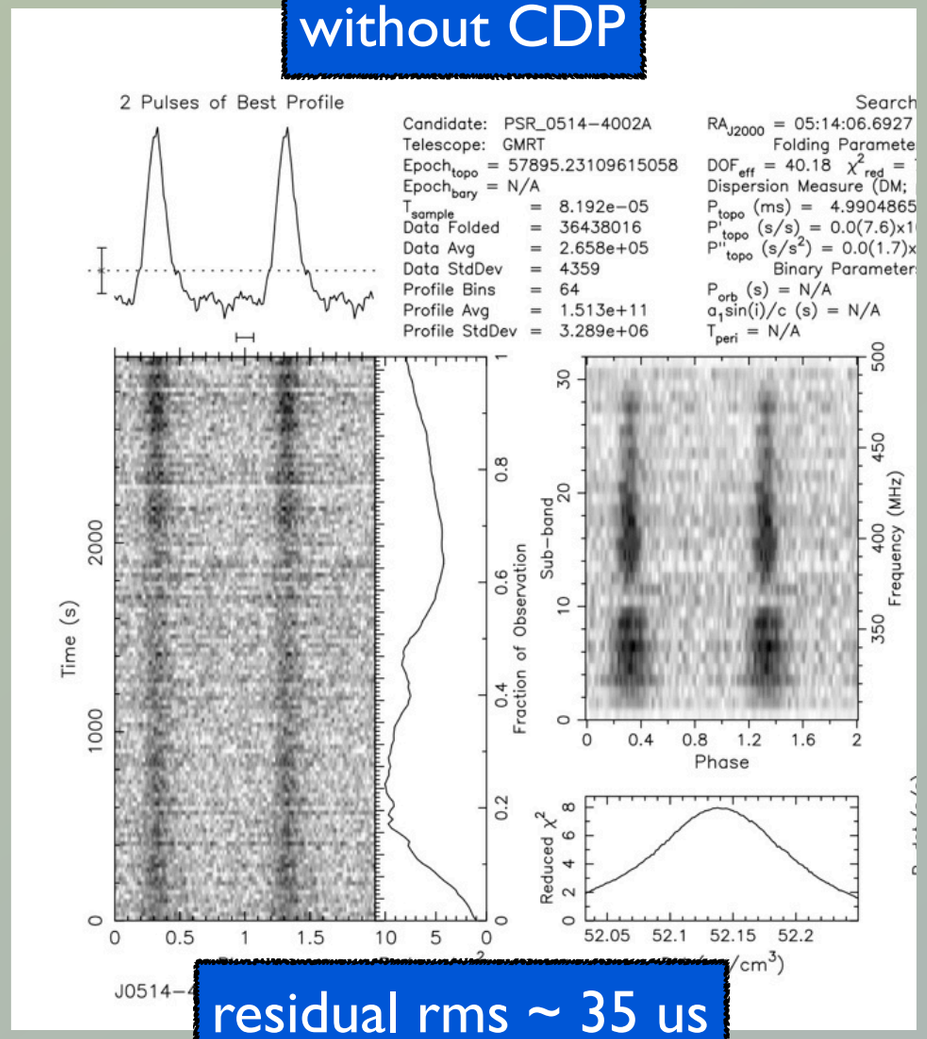


Coherent de-dispersion:



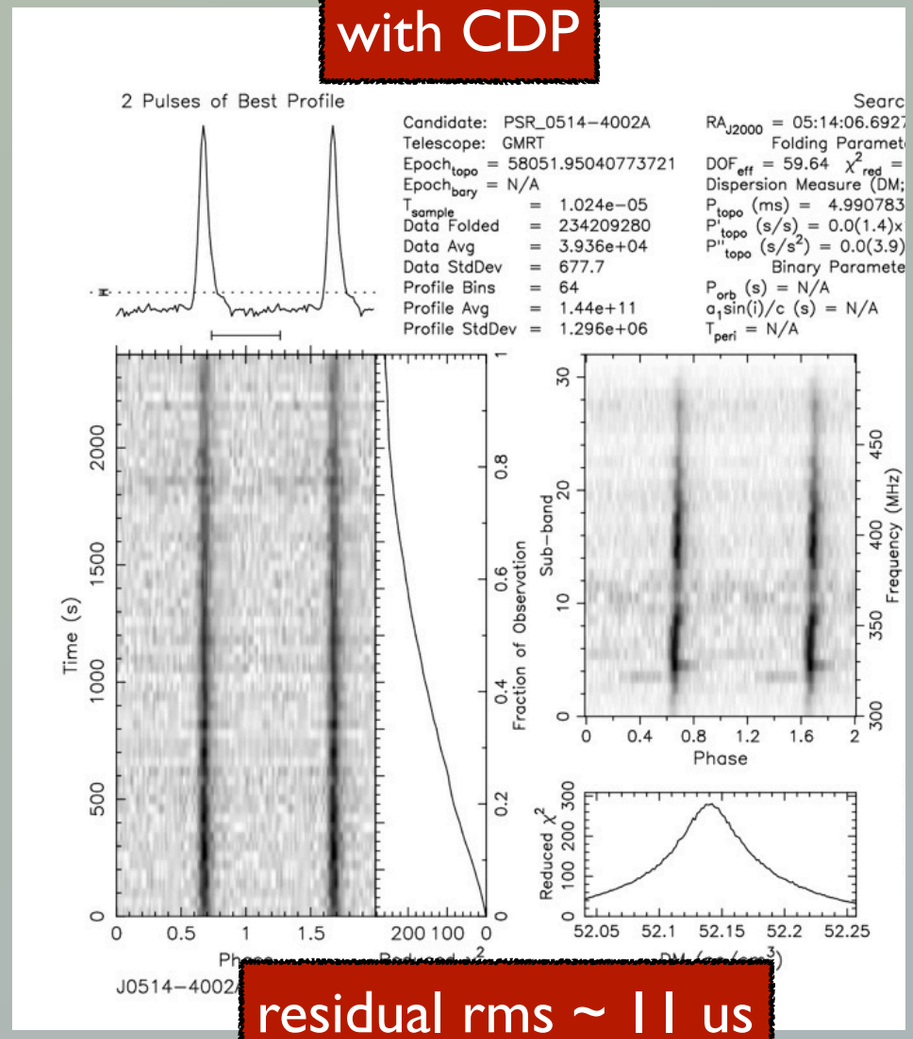
Impact of coherent dedispersion (CDP) on NGC 1851A

without CDP

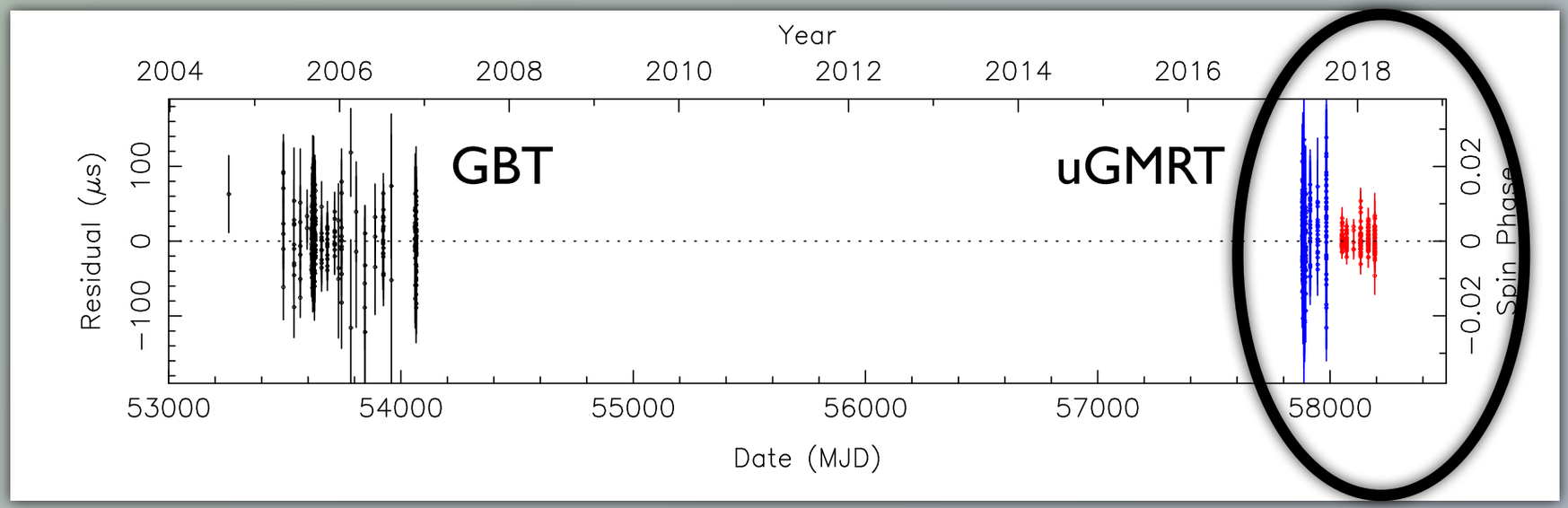


residual rms ~ 35 us

with CDP



residual rms ~ 11 us



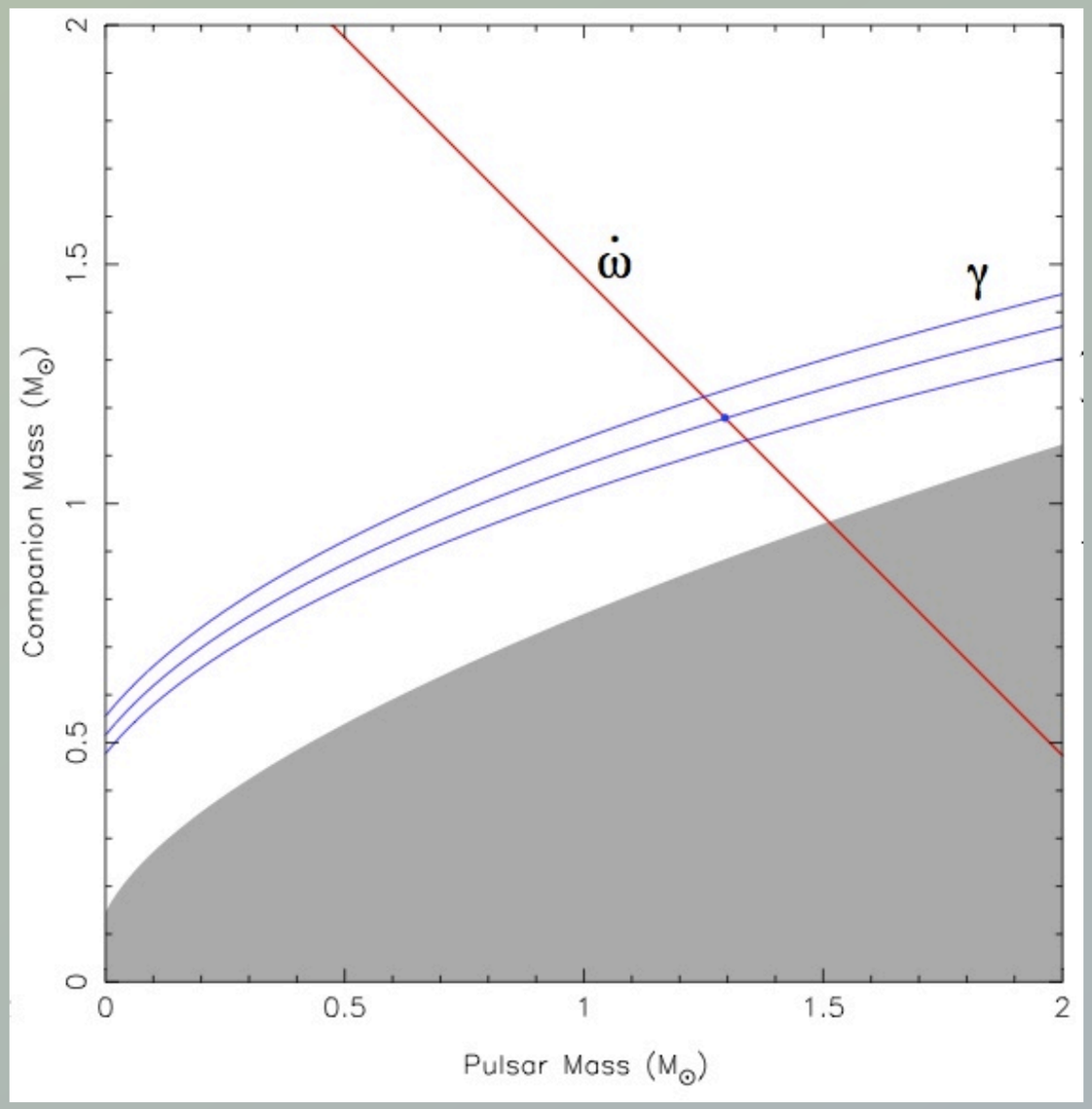
3x better timing precision!

Post-Keplerian parameters

Freire et al. (2007): $\dot{\omega}$ = 0.01289(4) deg/yr → M_{tot} = 2.453(14) M_{sun}

Ridolfi et al., in press: $\dot{\omega}$ = 0.0129592(16) deg/yr → M_{tot} = 2.4730(6) M_{sun}

γ = 0.0216(9) s



Measurement of component masses!

M_p = 1.25 ± 0.05 M_{sun}

M_c = 1.22 ± 0.05 M_{sun}

Lightest MSP with a precisely measured mass!

Proper Motion

The much larger baseline allowed us to measure the proper motion of the system

NGC 1851A (Ridolfi et al., in press):

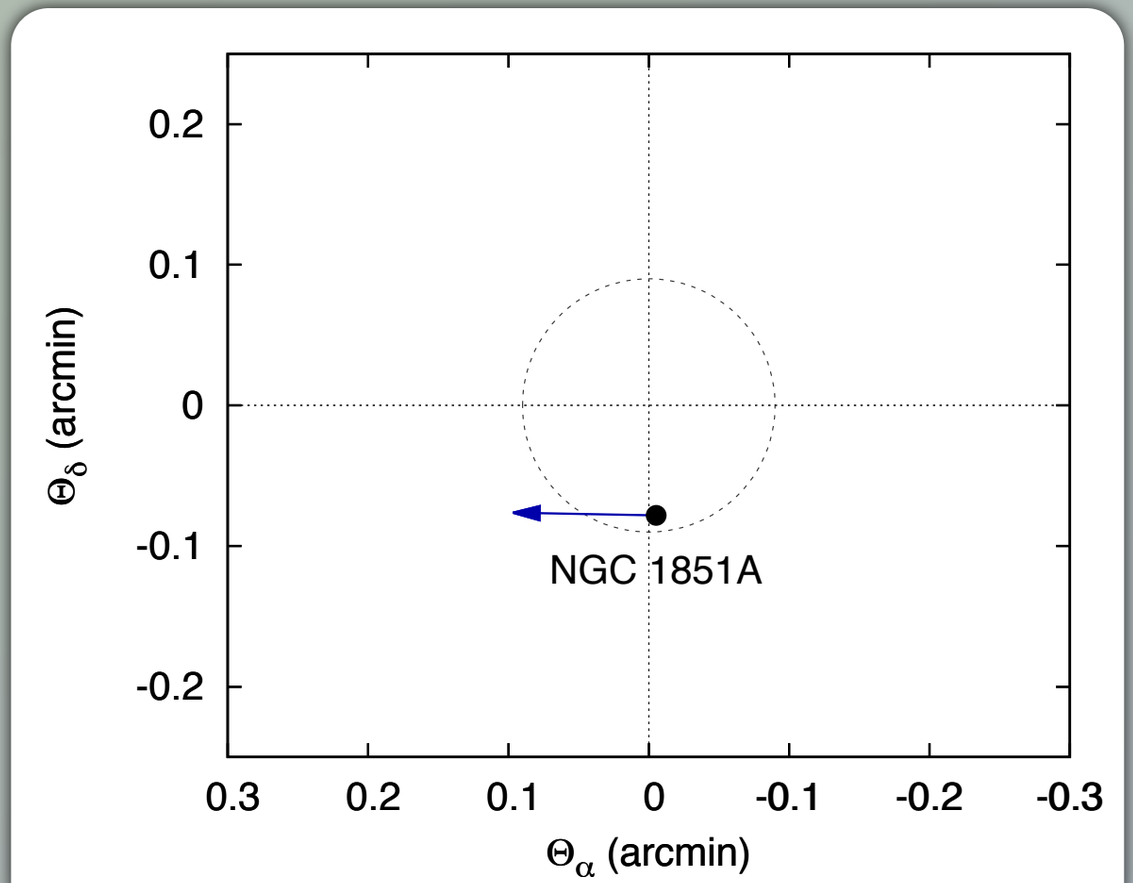
$$\mu_\alpha = +5.19 \pm 0.22 \text{ mas yr}^{-1}$$

$$\mu_\delta = -0.56 \pm 0.25 \text{ mas yr}^{-1}$$

Cluster (GAIA Collab. 2018):

$$\mu_\alpha = +2.1308 \pm 0.0037 \text{ mas yr}^{-1}$$

$$\mu_\delta = -0.6220 \pm 0.0040 \text{ mas yr}^{-1}$$



Relative linear velocity: ~173 ± 13 km/s (assuming d = 12.1 kpc)

Escape velocity at the cluster core: ~42.9 km/s (Baumgardt & Hilker 2018)

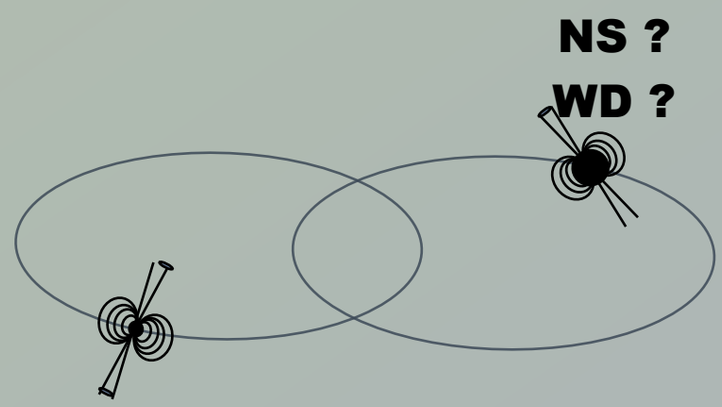
Is the system bound to the cluster?

Nature of the companion

Companion to NGC 1851A is:

- Compact
- Massive

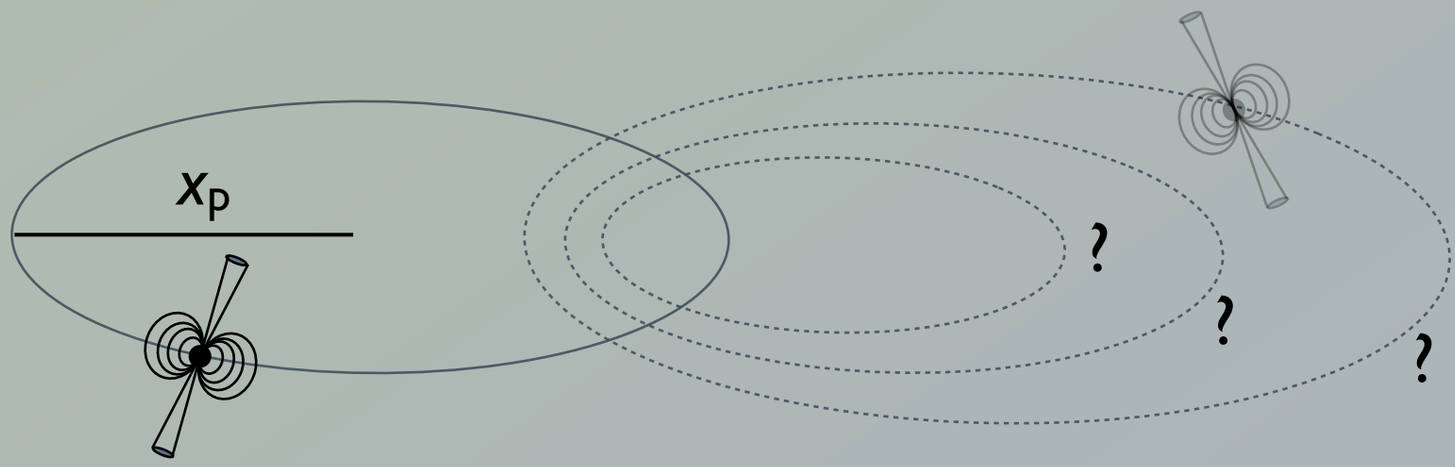
➔ either a WD or a NS



➔ If it is a NS, it could also be a pulsar!

→ We searched for radio pulsation from the putative companion pulsar

Timing of the pulsar → Projected pulsar orbit (x_p , P_b , e, ω_p , T_0)



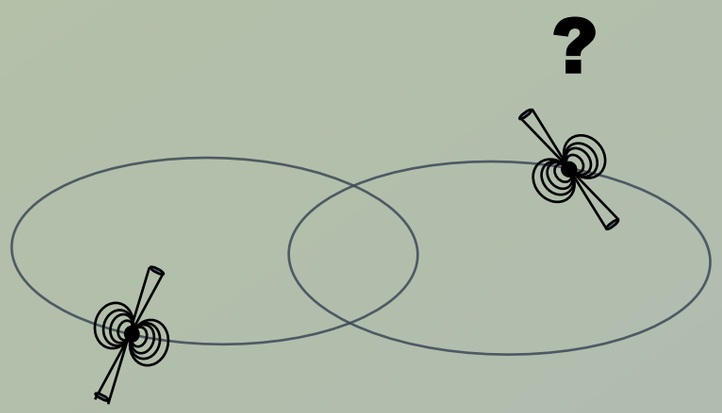
P_b , e, $\omega_p + 180°$, T_0

x_c ???

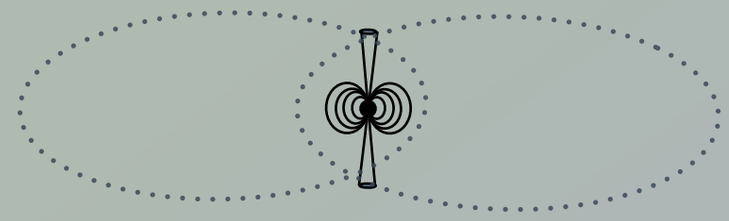
$$x_c = \frac{M_p}{M_c} x_p$$

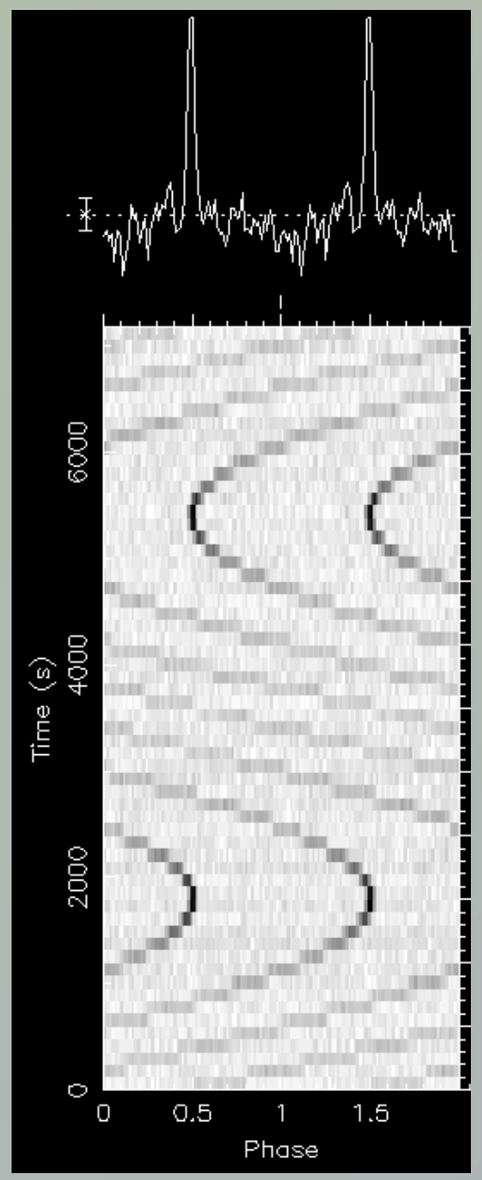
2 PK parameters → M_p , M_c → x_c → **Projected companion orbit!**

Search for pulsations from the companion

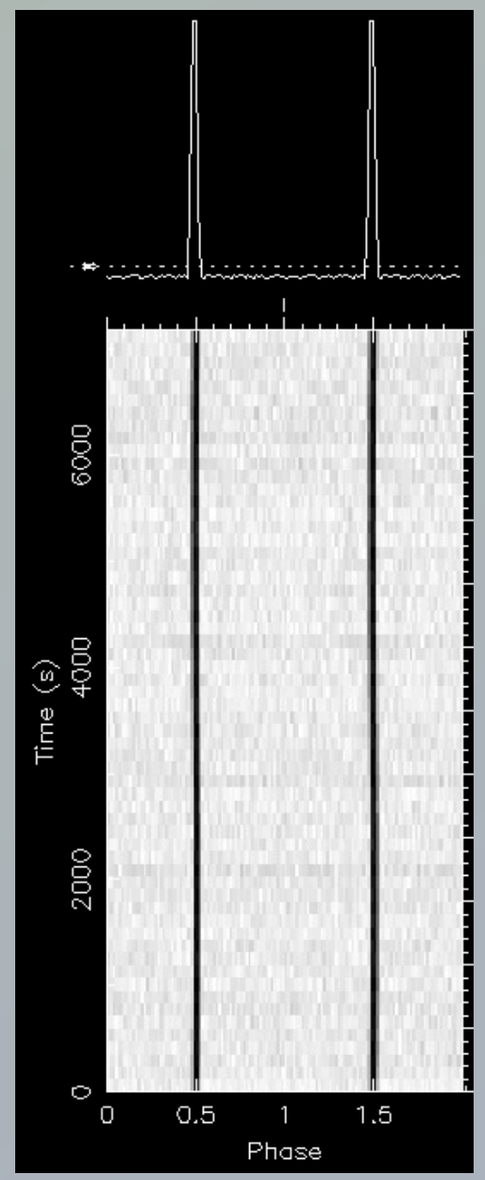


isolated companion

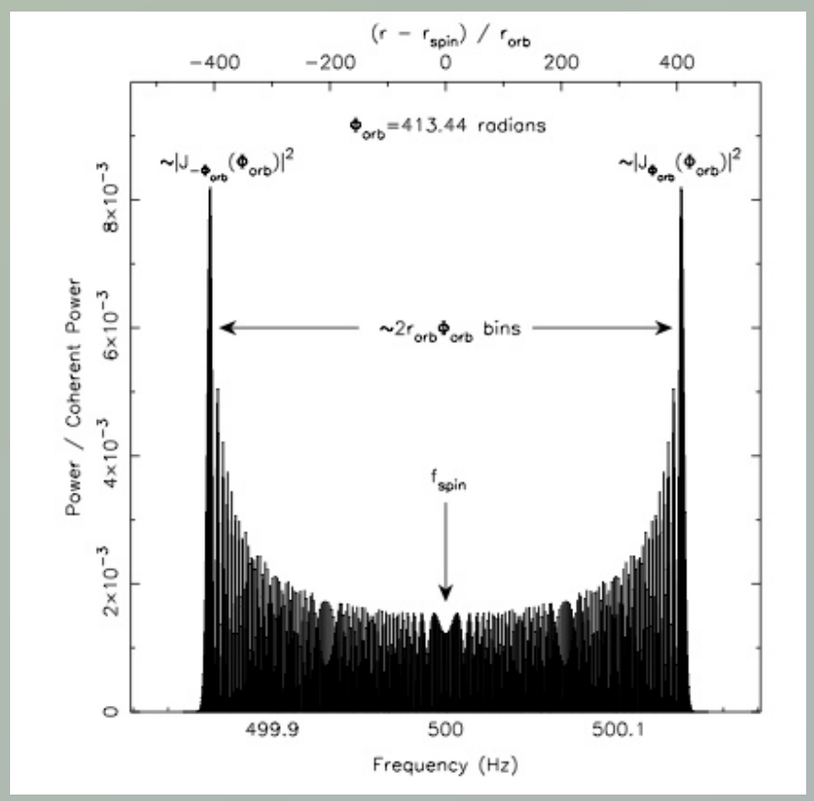




https://github.com/alex88ridolfi/pysolator



Search for pulsations from the companion



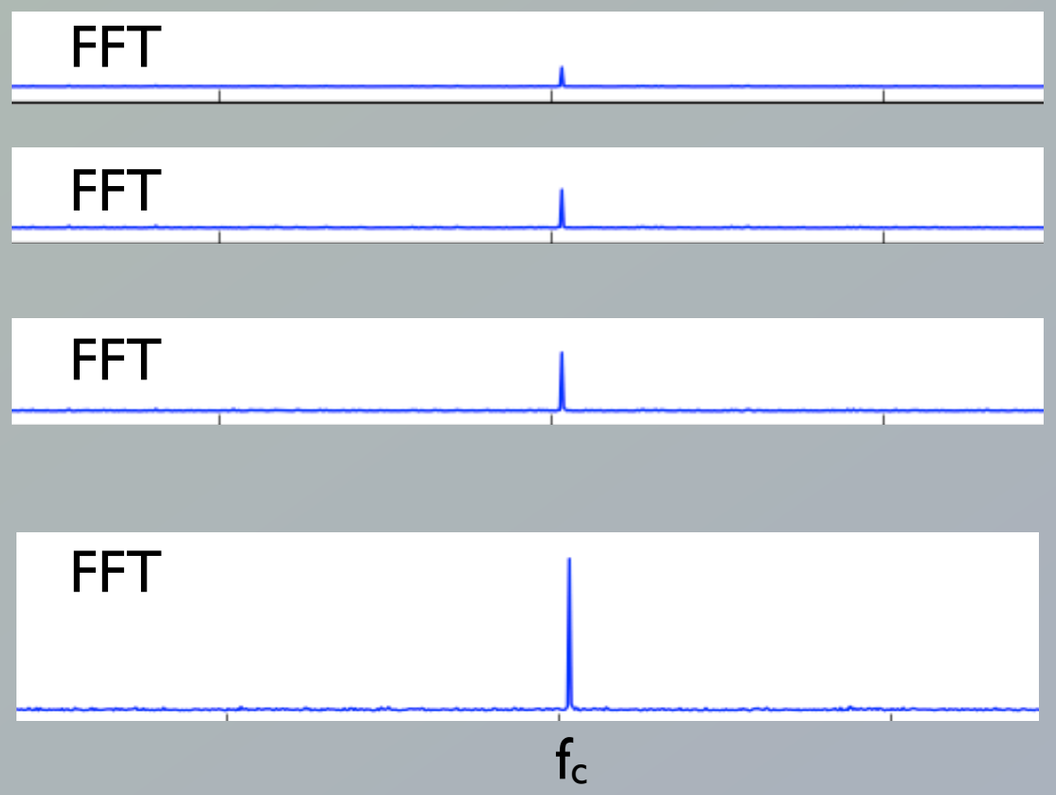
Ransom et al. (2003)

Obs 1

\+ Obs 2

\+ Obs 3

\+ Obs N



No pulsar-like signals detected

Summary

- Timing NGC 1851A with the uGMRT, together with old GBT data, allowed us to:
  - Greatly improve the measurement of $\dot{\omega}$
  - Measure the Einstein delay, γ
  - Measure the system's proper motion

→ $M_p = 1.25 \pm 0.05\ M_{sun}$
$M_c = 1.22 \pm 0.05\ M_{sun}$

- Recycling can be achieved with a very small amount of matter!
- No radio pulsations were detected from the companion star

Outlook

- New uGMRT proposal submitted for follow-up timing to:
  - Solve the mistery of the proper motion
  - Increase the precision of the Einstein delay, γ
  - Possibly detect the Shapiro delay

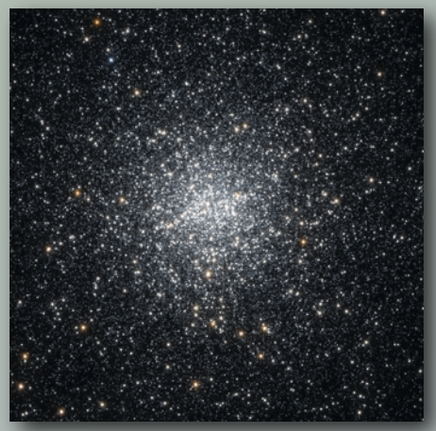
One more thing...

- Many more clusters observed with the uGMRT are currently being searched


NGC 1851


NGC 6539


Terzan 5


NGC 6440


NGC 6652


NGC 6441


M30

Image credits: Hubble Space Telescope

➔ many more exciting pulsars to be discovered soon!

See Tasha Gautam's poster!

Poster