A "Secondary" View on Millisecond Pulsars in Globular Clusters

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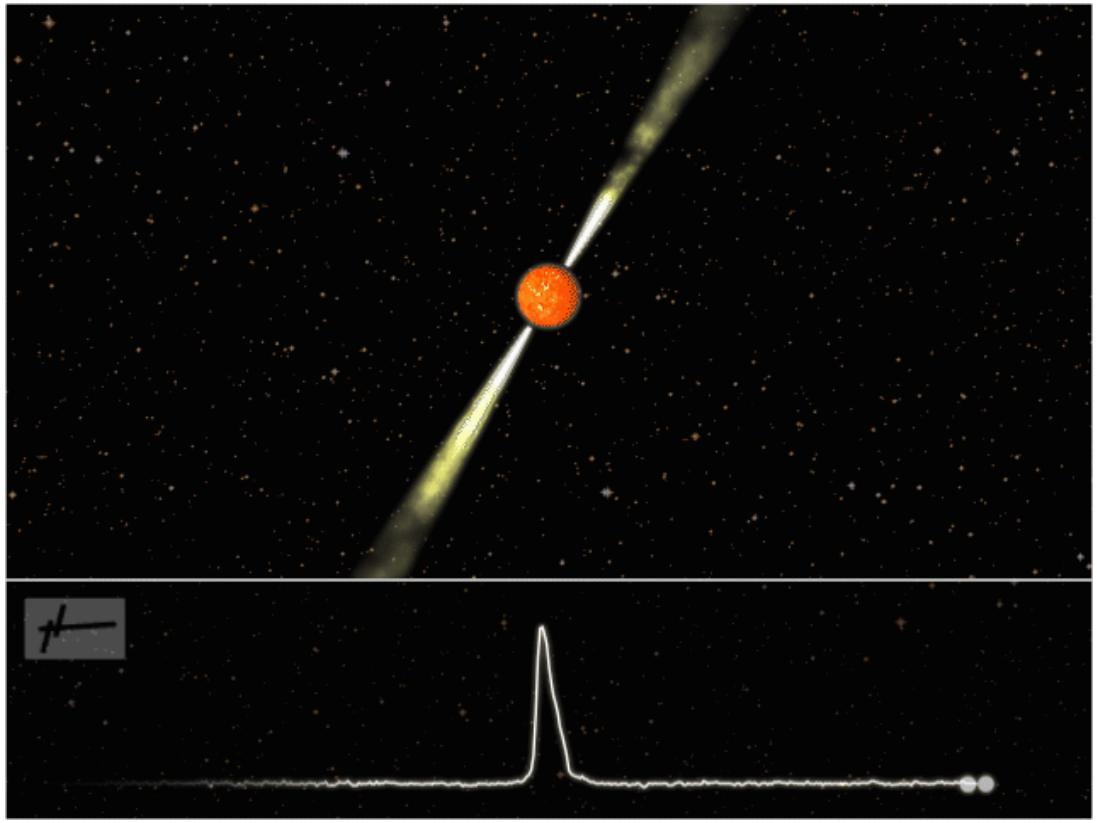
MODEST-18: DENSE STELLAR SYSTEMS IN THE ERA OF GAIA, LIGO & LISA
Fira, June 28th 2018

Pulsars

Pulsars stand for "*Pulsating Radio Sources*".
They are neutron stars, nucleus remnants of massive stars exploded as supernovae.



Credits: Joeri van Leeuwen
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$$M \approx 1.4 M_{SUN}$$

$$R = 10 - 15 km$$

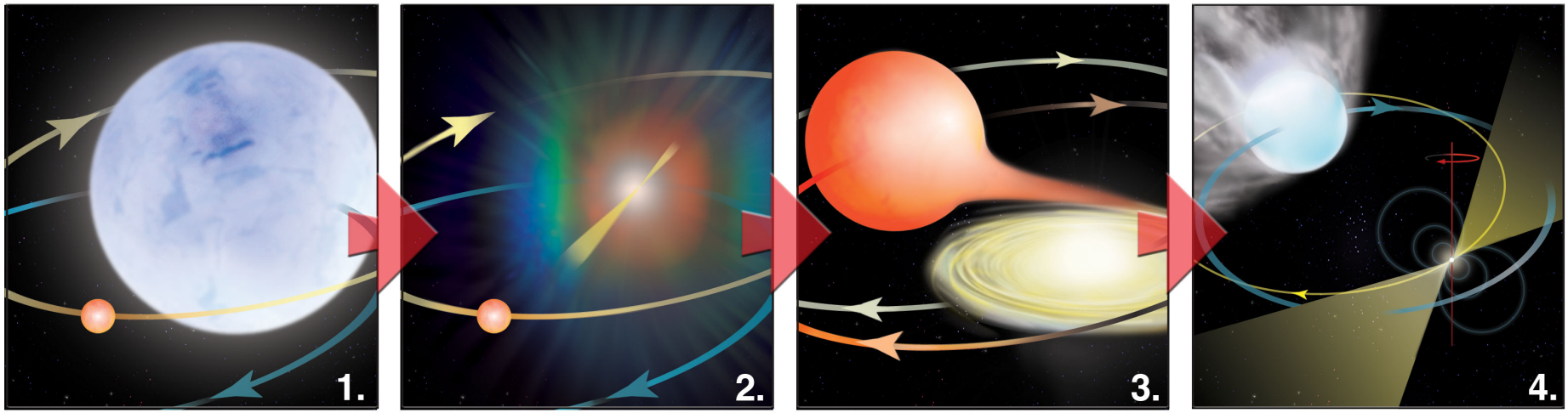
$$\rho \sim 10^{14} g / cm^3$$

$$B = 10^8 - 10^{14} G$$

Emission powered by rotational kinetic energy → spin-down

Canonical Recycling Scenario

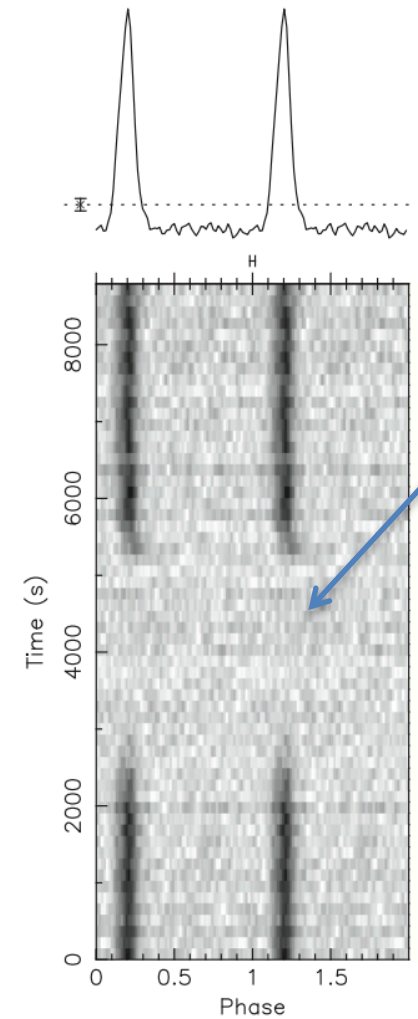
Credits: NRAO



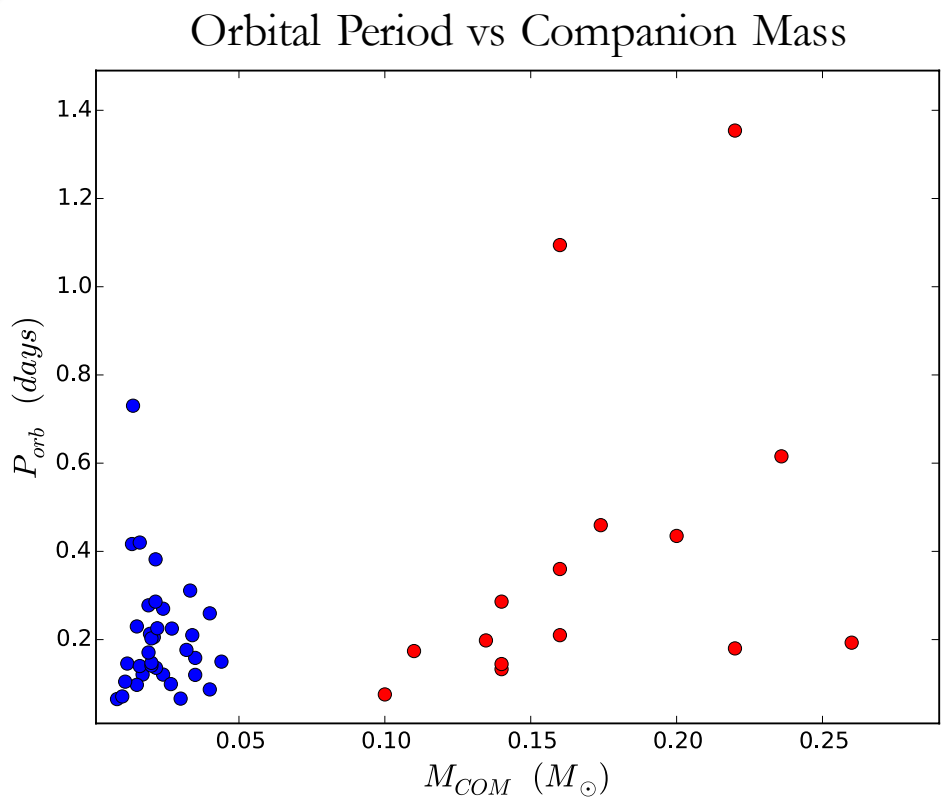
1) Standard evolution of a massive star in a binary system
2) Slowly Rotating Pulsar
3) Low Mass X-ray Binary
4) Millisecond Pulsar (the companion should be a He White Dwarf)

Alpar+82; Bhattacharya+91

Eclipsing Millisecond Pulsars



Periodical Eclipses of Radio Signal → ionized material in the system



Cadelano et al., 2015a

Eclipsing Millisecond Pulsars

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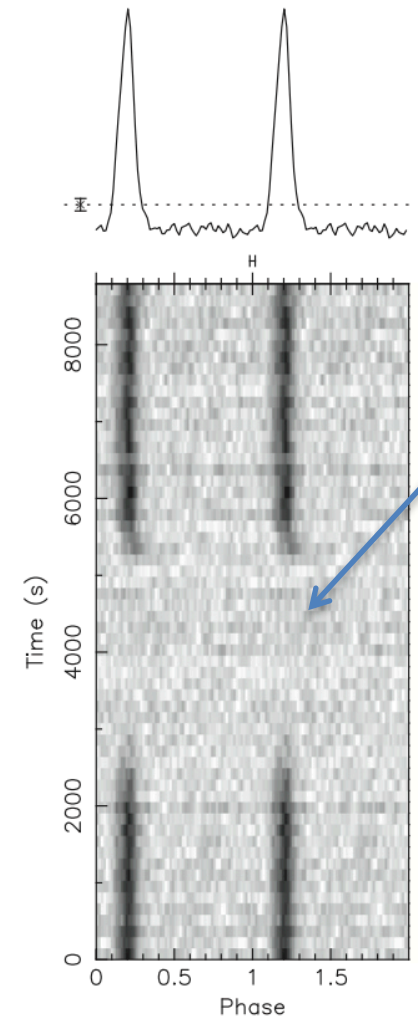

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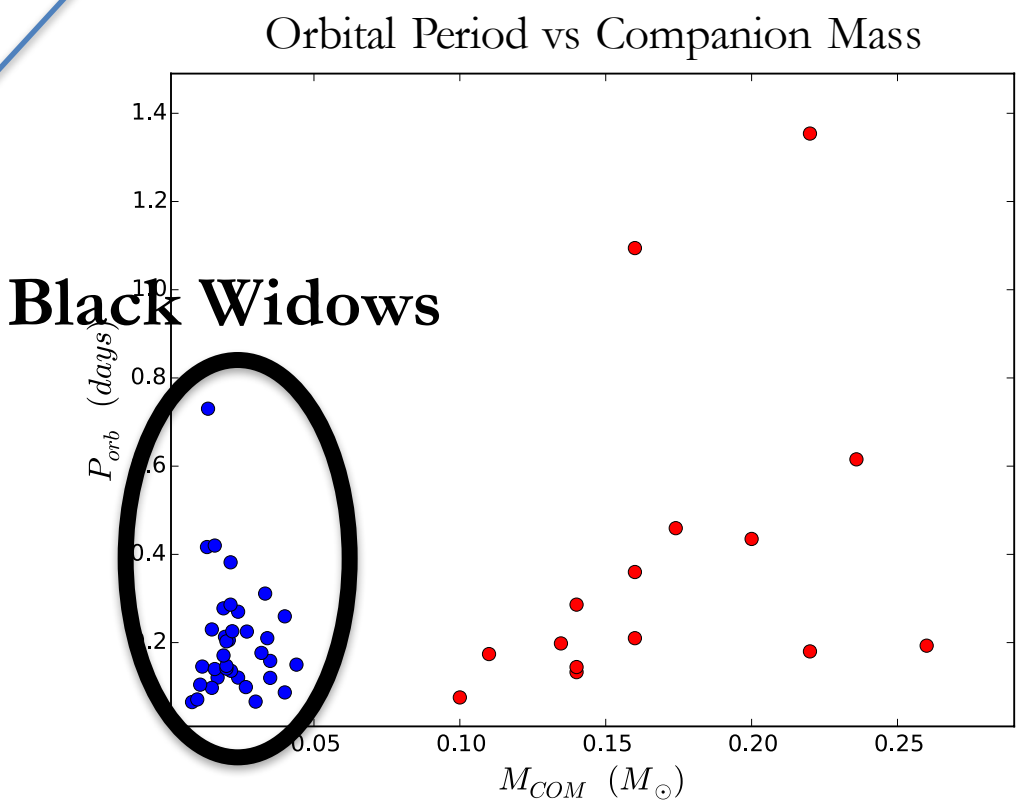
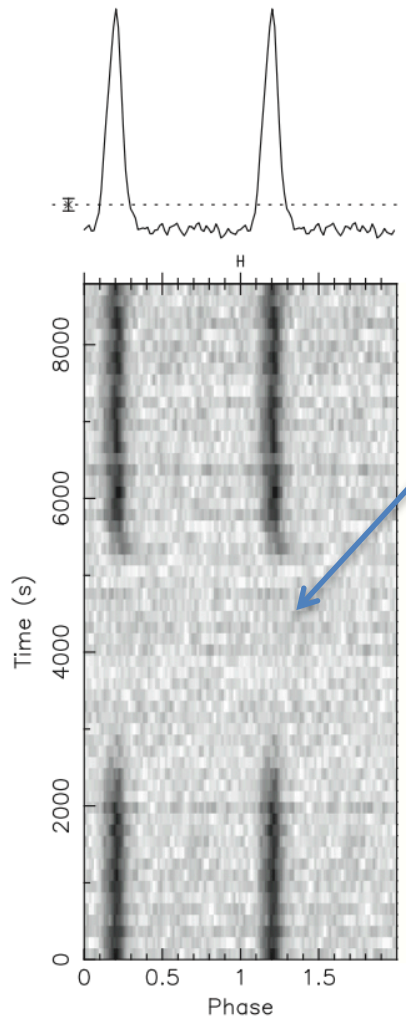


Eclipsing Millisecond Pulsars



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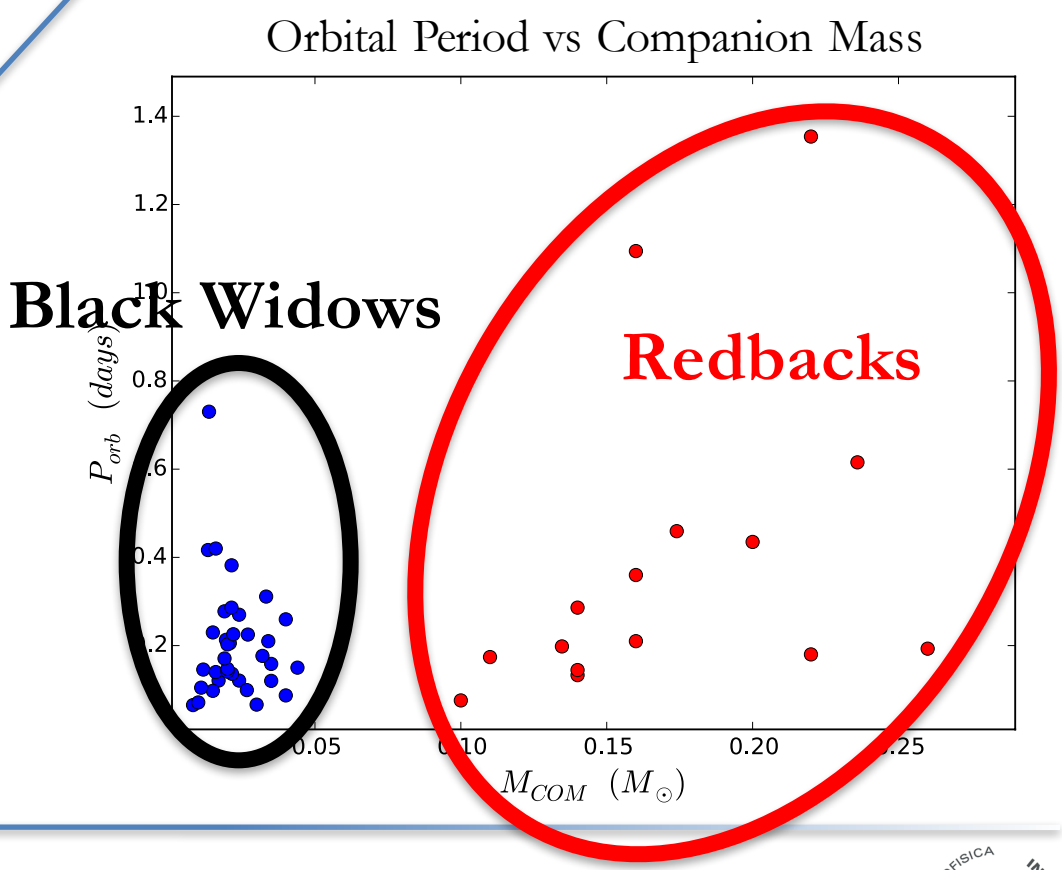
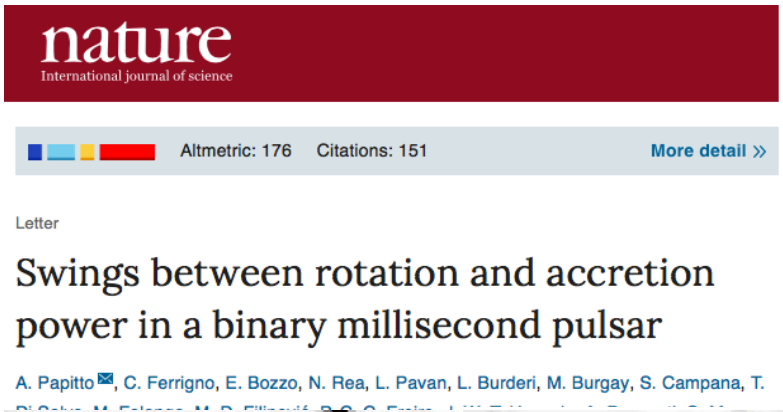


Cadelano et al., 2015a

“Transitional” Millisecond Pulsars

“Swings between accretion powered emission (LMXB stage) and rotation powered emission (MSP stage)”


nature
International journal of science

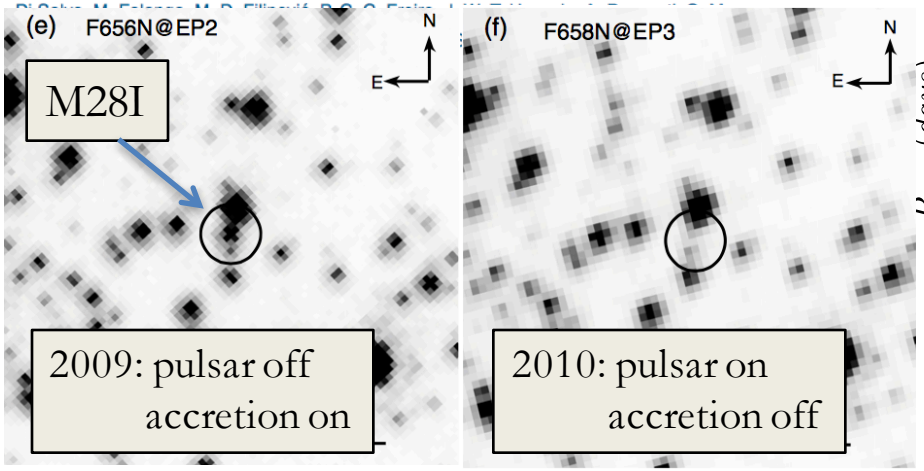
Altmetric: 176 Citations: 151 More detail »

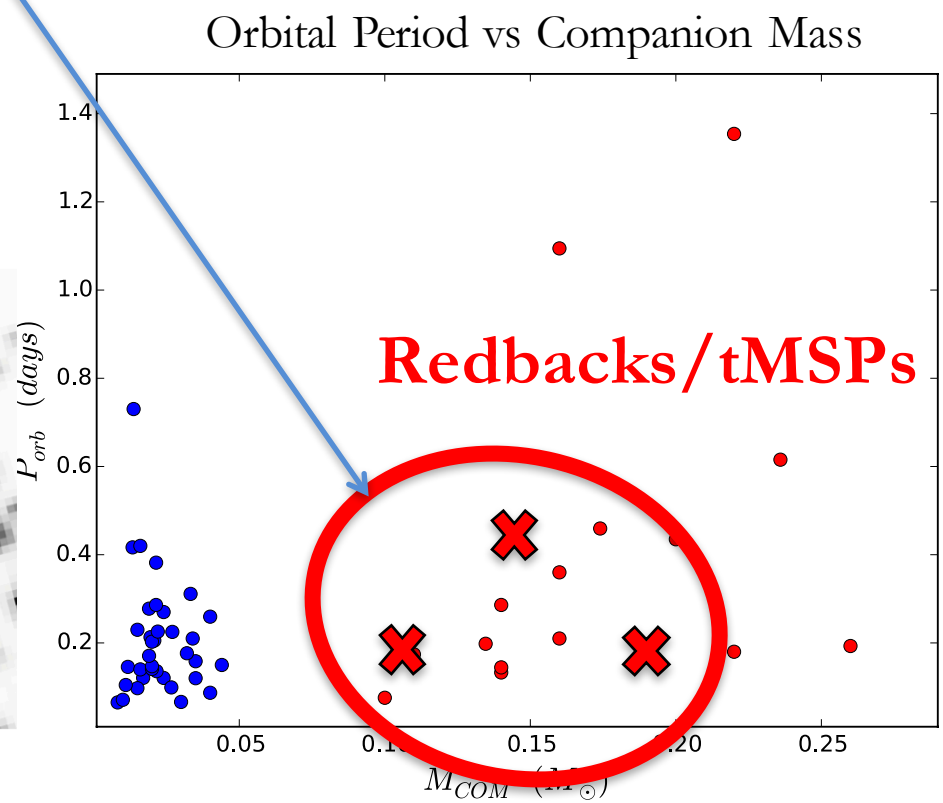
Letter

Swings between rotation and accretion power in a binary millisecond pulsar

A. Papitto, C. Ferrigno, E. Bozzo, N. Rea, L. Pavan, L. Burderi, M. Burgay, S. Campana, T.

MSPs originate from low-mass X-ray binaries!!





Archibald+09, Papitto+13, Pallanca+13, DeMartino+15

Why Globular Clusters?

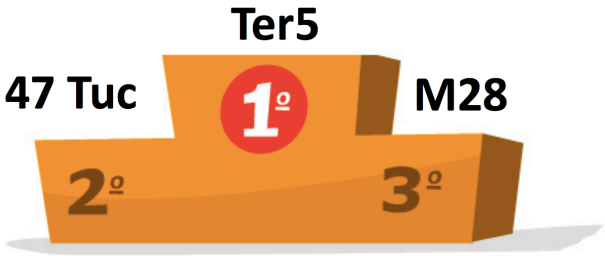
- The Galactic Globular Cluster System is **~1000 less massive** than the Galactic Field
- However, **about 40% of the entire MSP population** is found in Globular Clusters

Galactic Disk → **Evolution of primordial binaries**

Globular Clusters → **Evolution of primordial binaries**

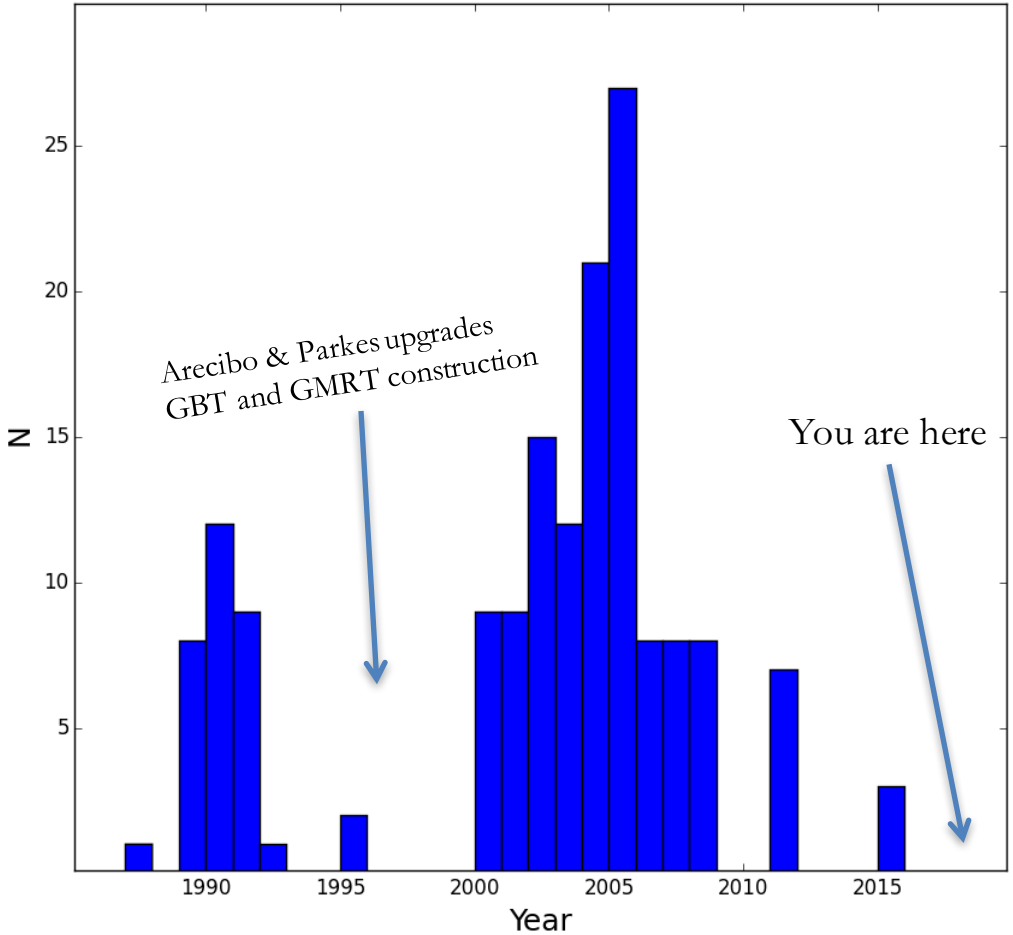
Globular Clusters → **Dynamical interactions promote the formation of binaries suitable for reciclying NSs into MSPs**

Different GCs host different populations of MSPs. Their properties are tightly linked to the cluster dynamical status.



Pulsar discoveries in GCs

Pulsars in globular clusters identified per year



- The number of new pulsars in identified in GCs dropped after ~2010.

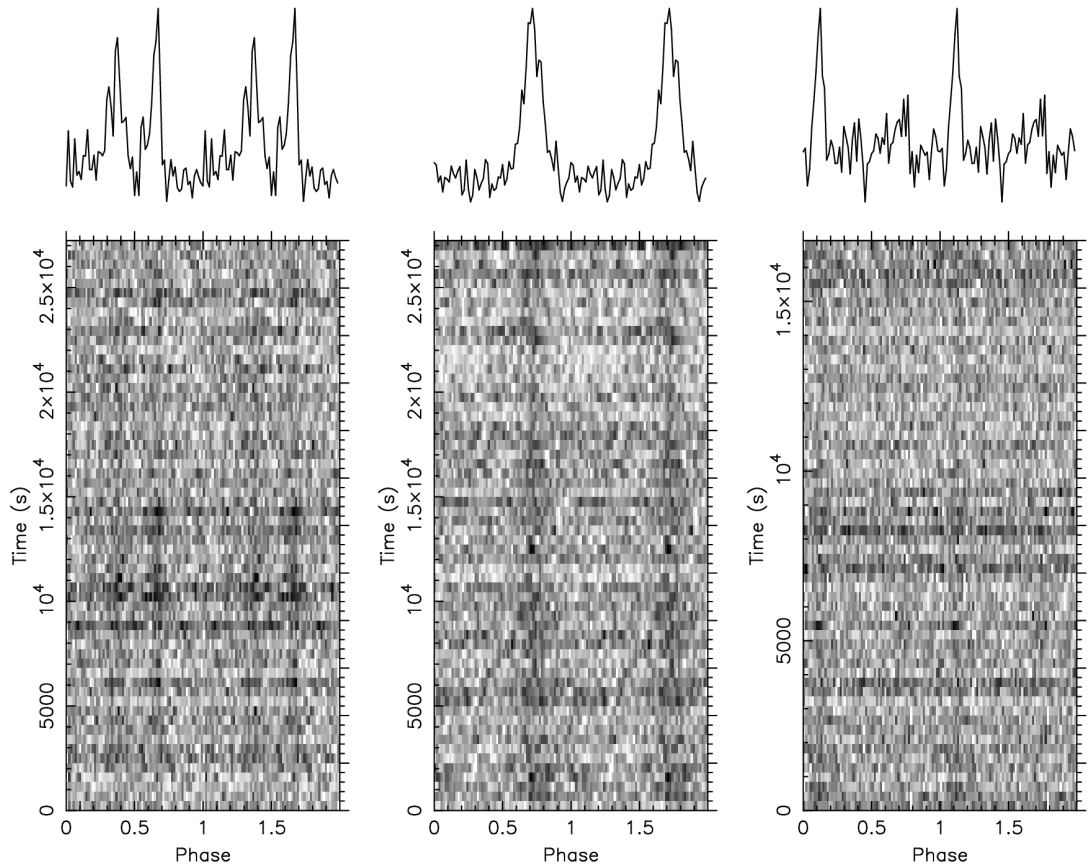
- We reached the maximum sensitivity allowed by the current generation of radio telescopes.

Pulsar discoveries in GCs

Ter5aj
P=2.90 ms

Ter5ak
P=1.89 ms

Ter5al
P=5.95 ms



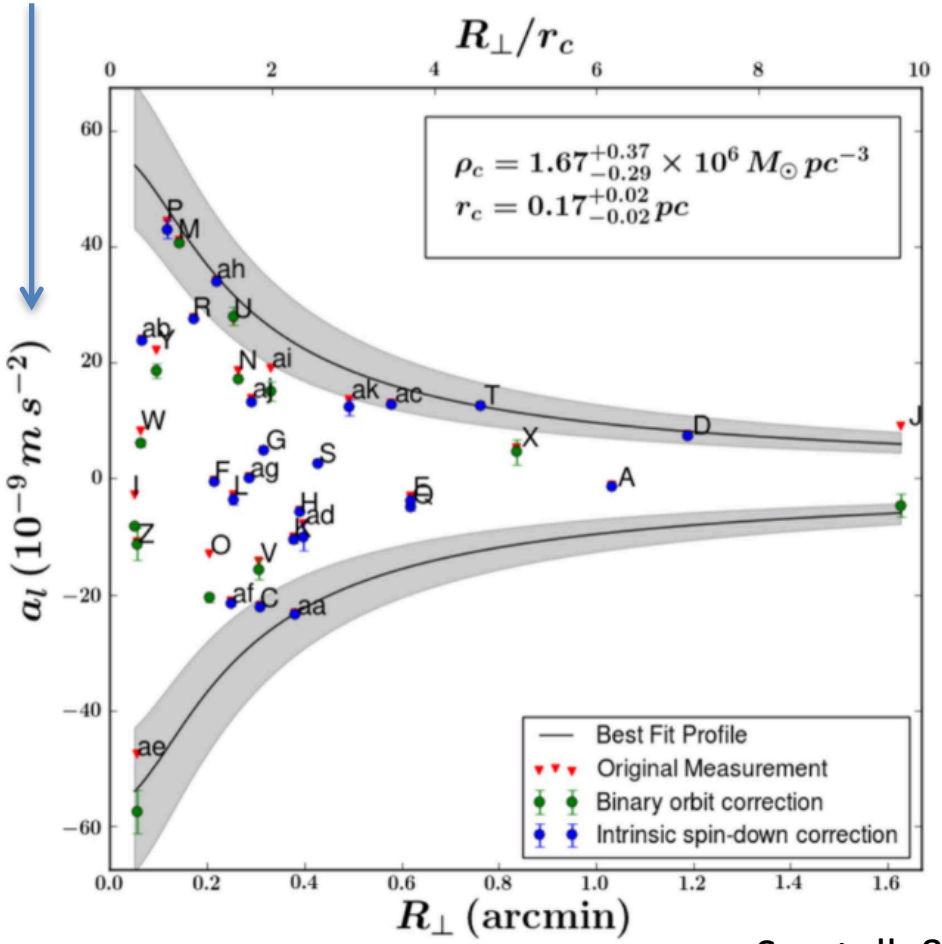
Cadelano, Ransom et al. 2018

3 new pulsars in Terzan 5!!

This cluster now hosts 25% of the entire population in globular clusters.

Pulsar as test particles of the GC structure

Acceleration induced by the GC field



Prager et al. 2017

This cluster now hosts 25% of the entire population in globular clusters.

See talk & poster by F. Abbate

Hunting for the companion stars

WHY:

- Complementary characterization of the systems wrt radio and high energy bands.

- Formation and evolution of binary MSPs: different classes of MSPs appear to have different types of companion stars.

- Study of cooling processes, structure and properties of low-mass white dwarf, usually having a He core.

- Accurate measurements of NS masses, thus possibility of constraining the maximum mass of these objects.

↓

We are leading a long-term program aimed at idenfying the companion stars to millisecond pulsars in GCs. So far, 15 companions out of 81 binaries have been identified.

Searching for MSP optical counterparts

We are searching for an "anomalous" star at a position compatible with that of the neutron star binary

Neutron stars are the most massive stars of the cluster

↓

Mass segregation sink them to the cluster center

↓

PROBLEM 1: crowding!

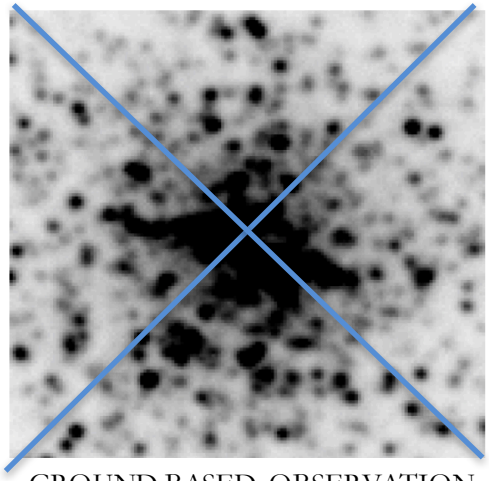
The companion stars are expected to be exhausted and deeply peeled stars

↓

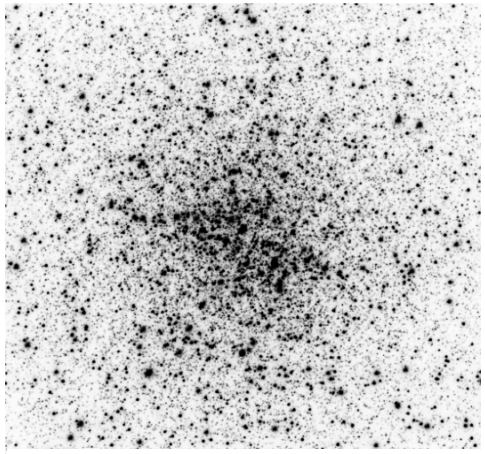
They are extremely faint stars

↓

PROBLEM 2: Need of very deep exposures!



GROUND-BASED OBSERVATION



SPACE-BASED OBSERVATION

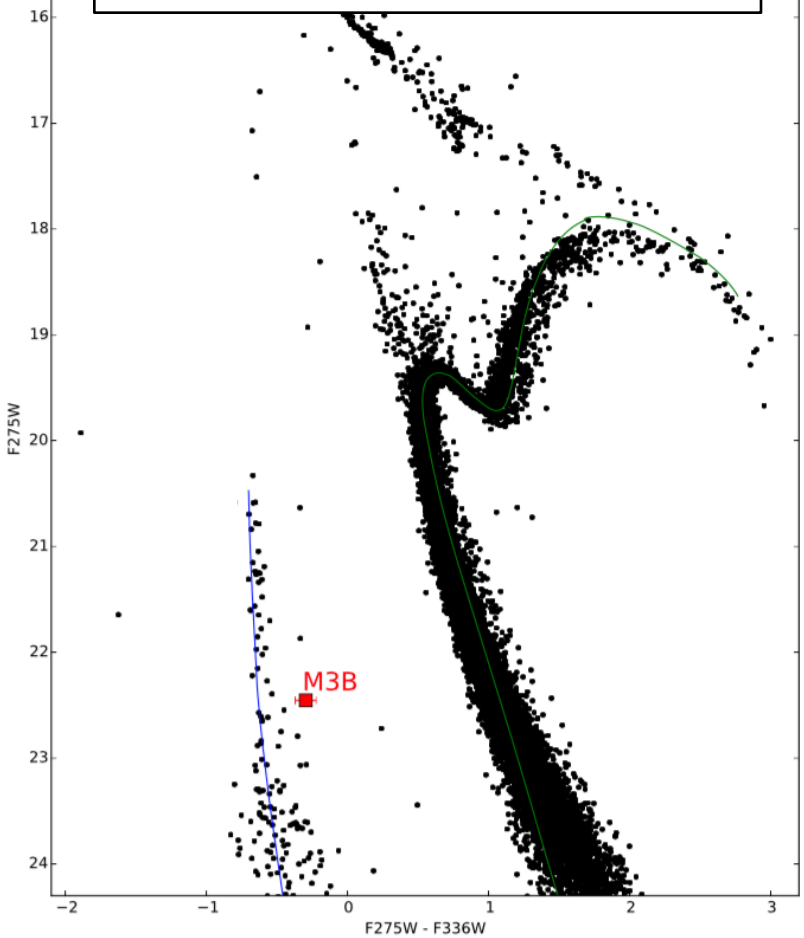
Canonical MSPs

Redbacks

Black-Widows

Canonical MSPs | Redbacks | Black-Widows

Companion to M3B



- Degenerate and usually very <u>low-mass remnants</u>
- Core remnants of stars whose remant has been completely stripped off
- Usually no optical variability
- Comparison with theoretical models can constrain WD and NS properties with accuracy

Cadelano et al., in prep.

Canonical MSPs | Redbacks | Black-Widows

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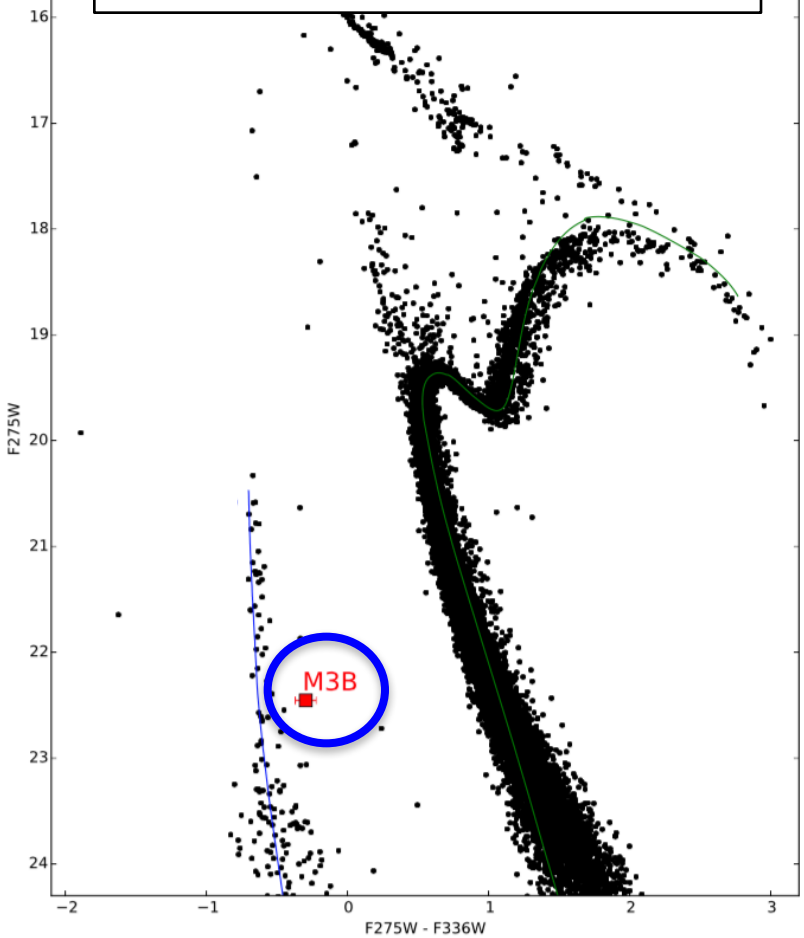

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Canonical MSPs | Redbacks | Black-Widows

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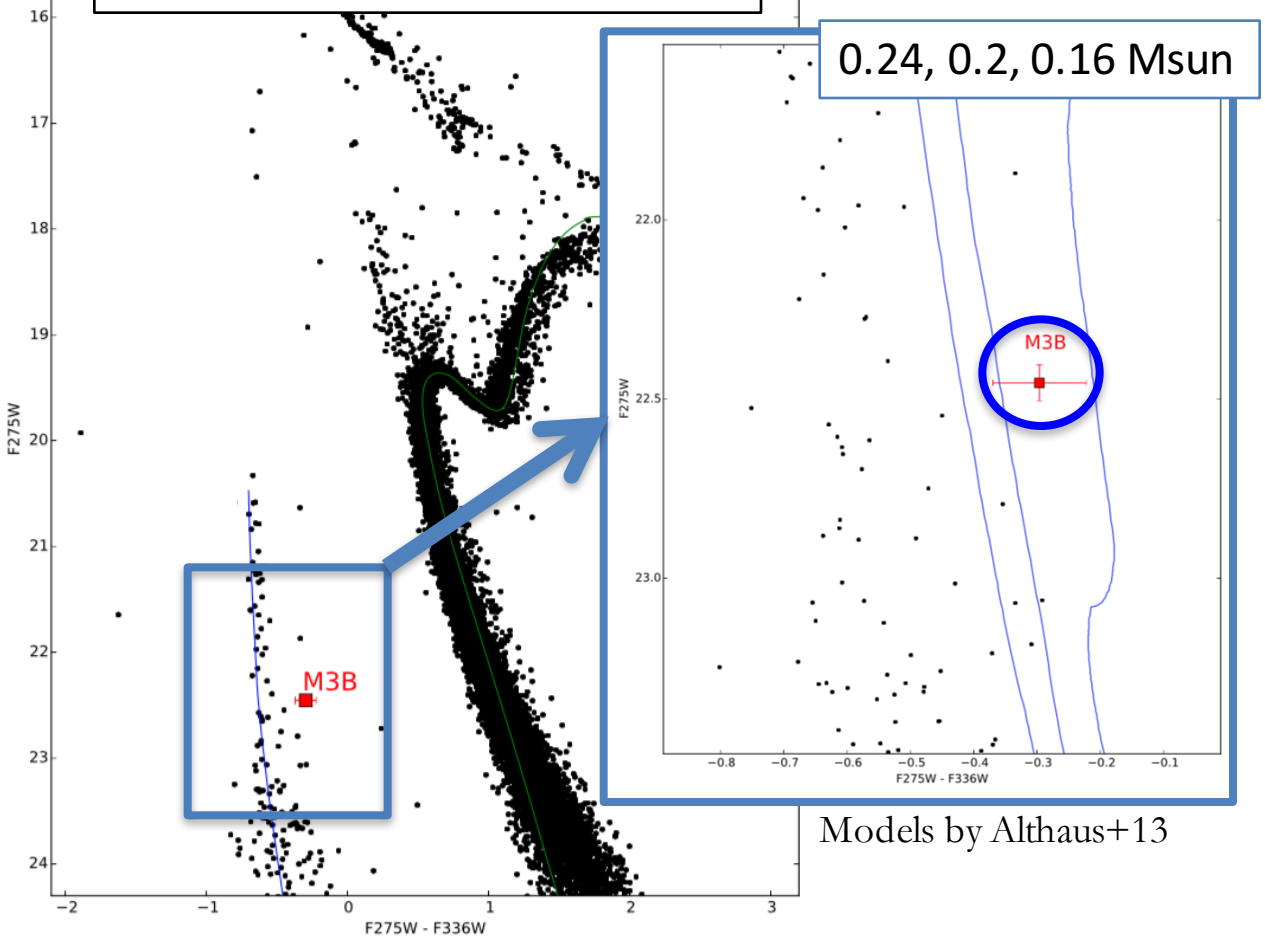

Models by Althaus+13

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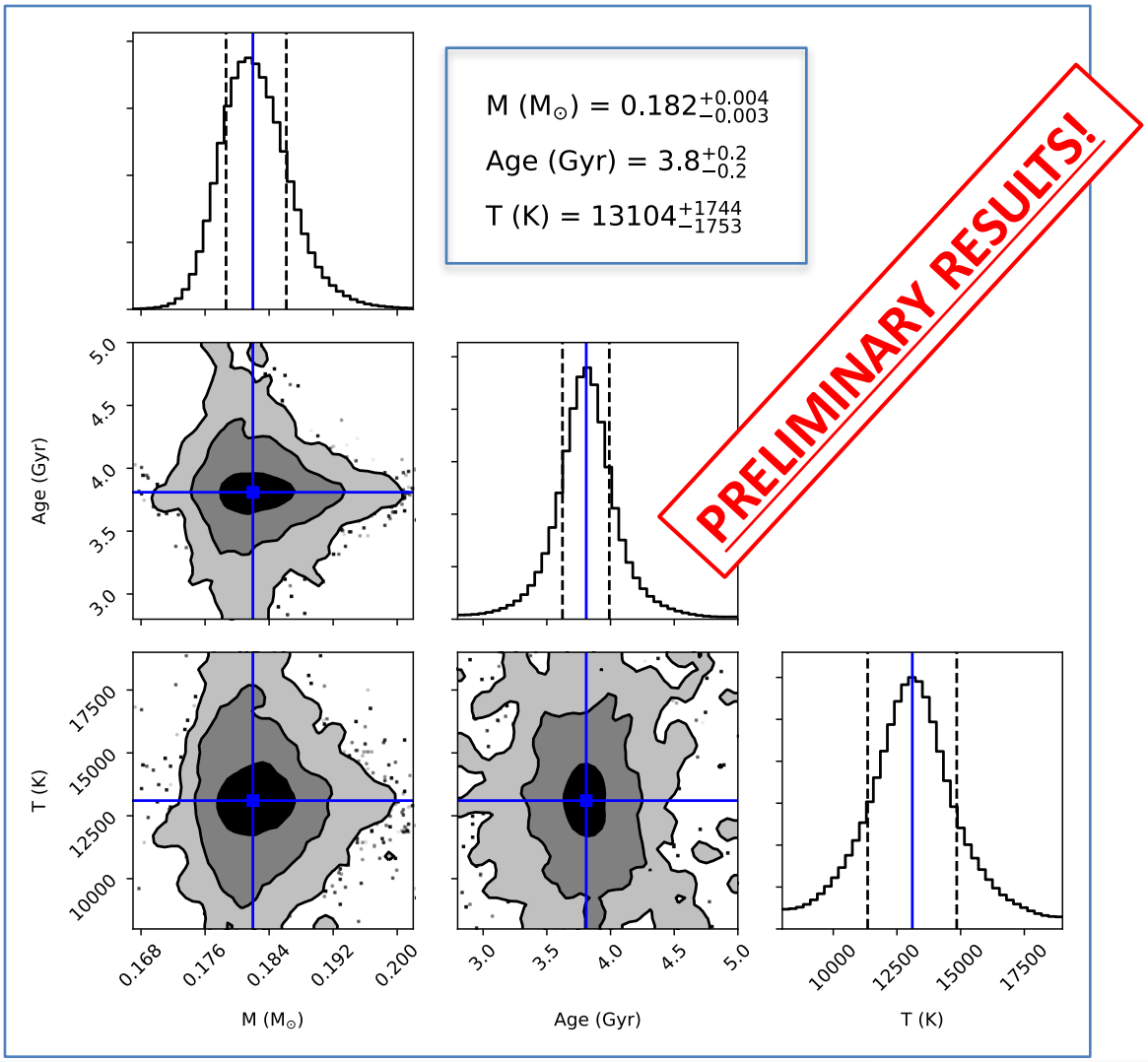
Canonical MSPs

Redbacks

Black-Widows



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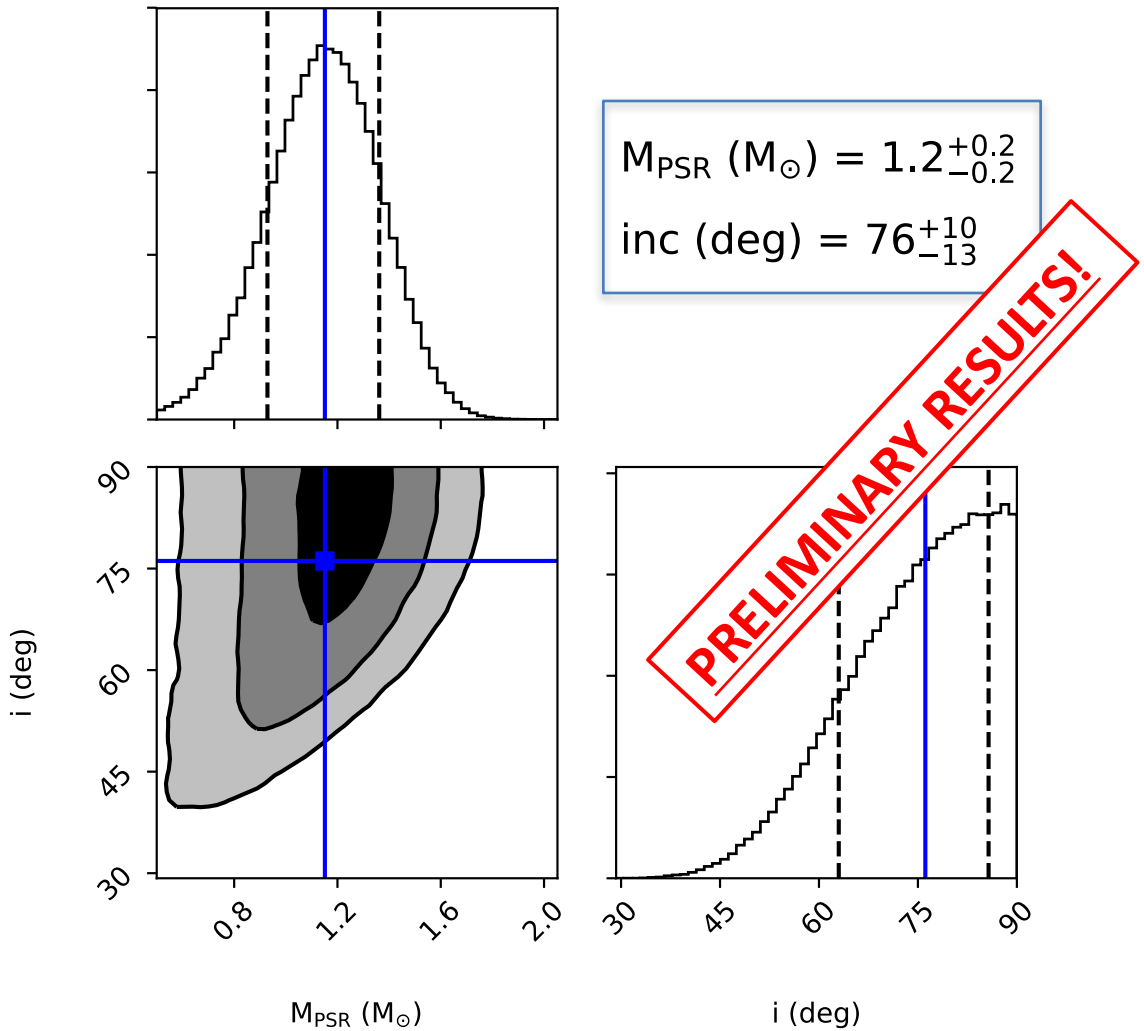

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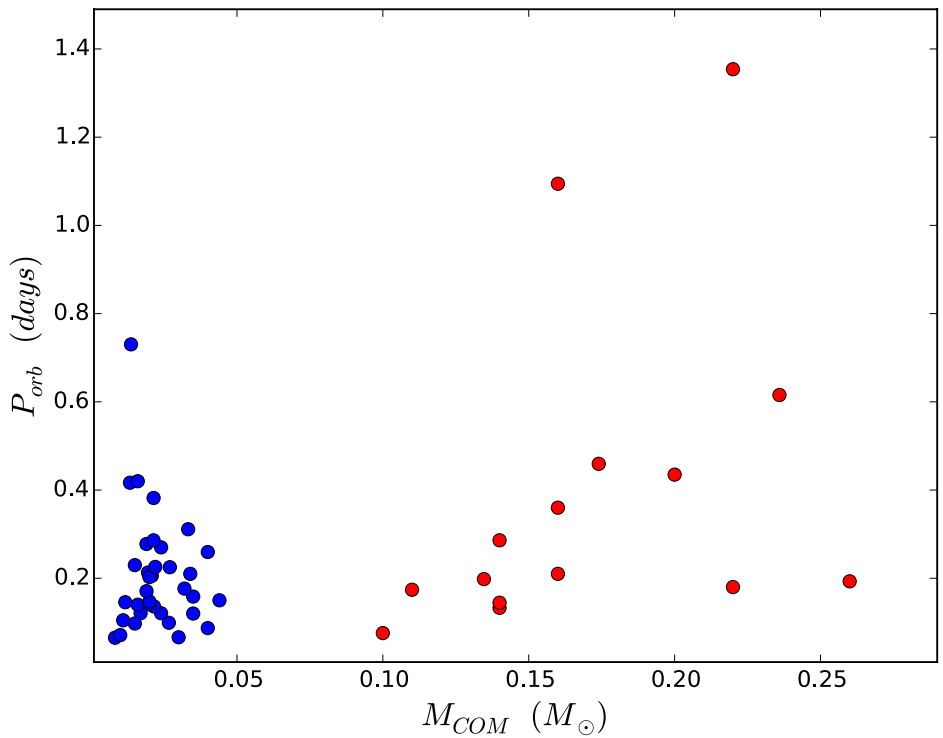
Canonical MSPs

Redbacks

Black-Widows

Orbital Period vs Companion Mass



-> Radio Eclipses: Ionized material

-> Hard X-ray emission: Intrabinary shocks

The companion is unlikely to be a degenerate star

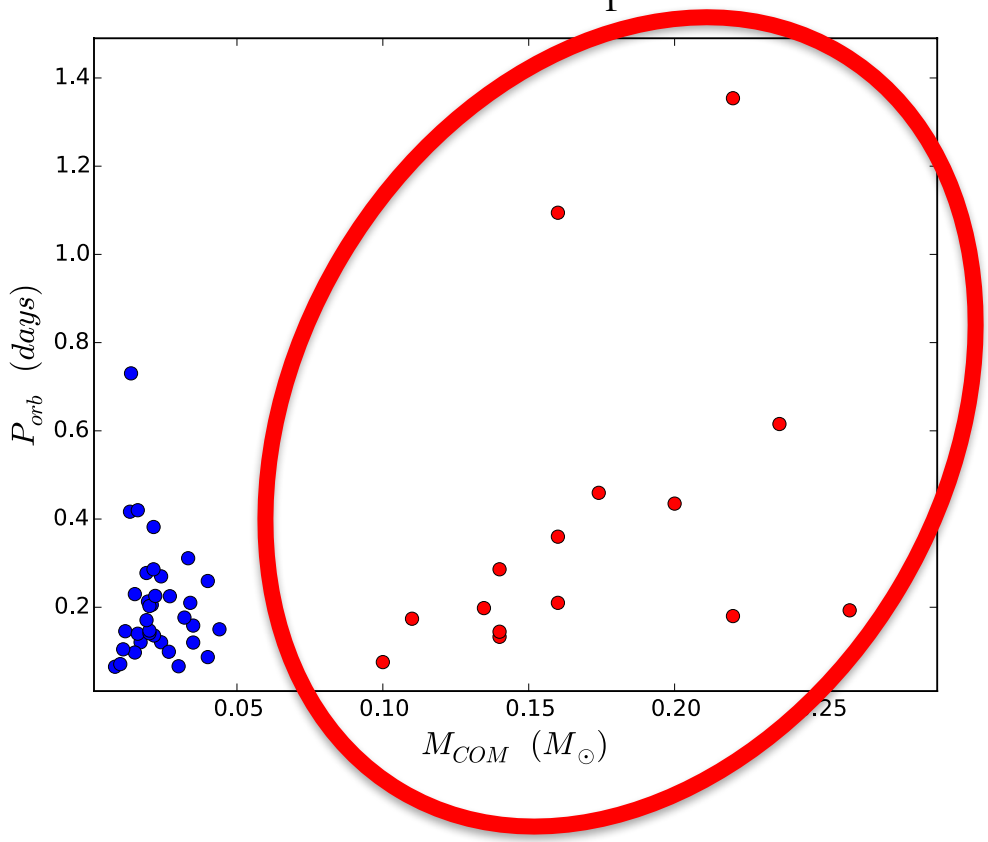
Pallanca+10,13

Canonical MSPs

Redbacks

Black-Widows

Orbital Period vs Companion Mass



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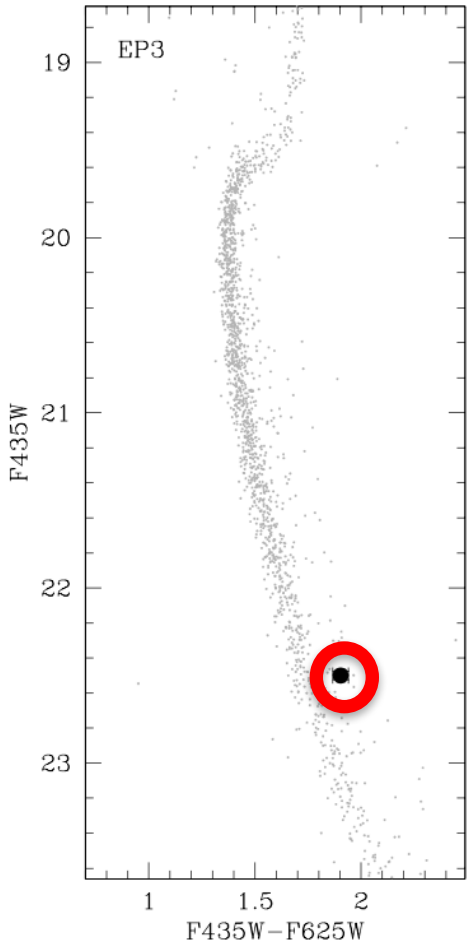
Canonical MSPs

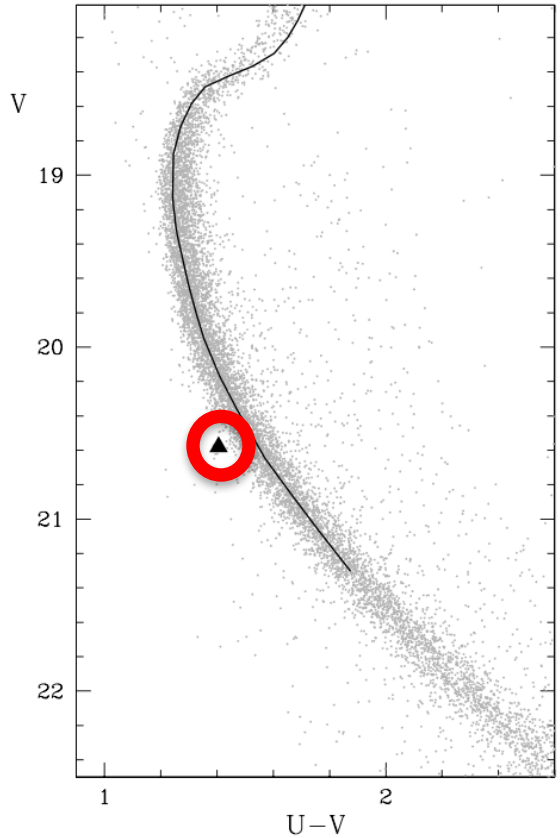
Redbacks

Black-Widows

Companion to M28I



Companion to M28H

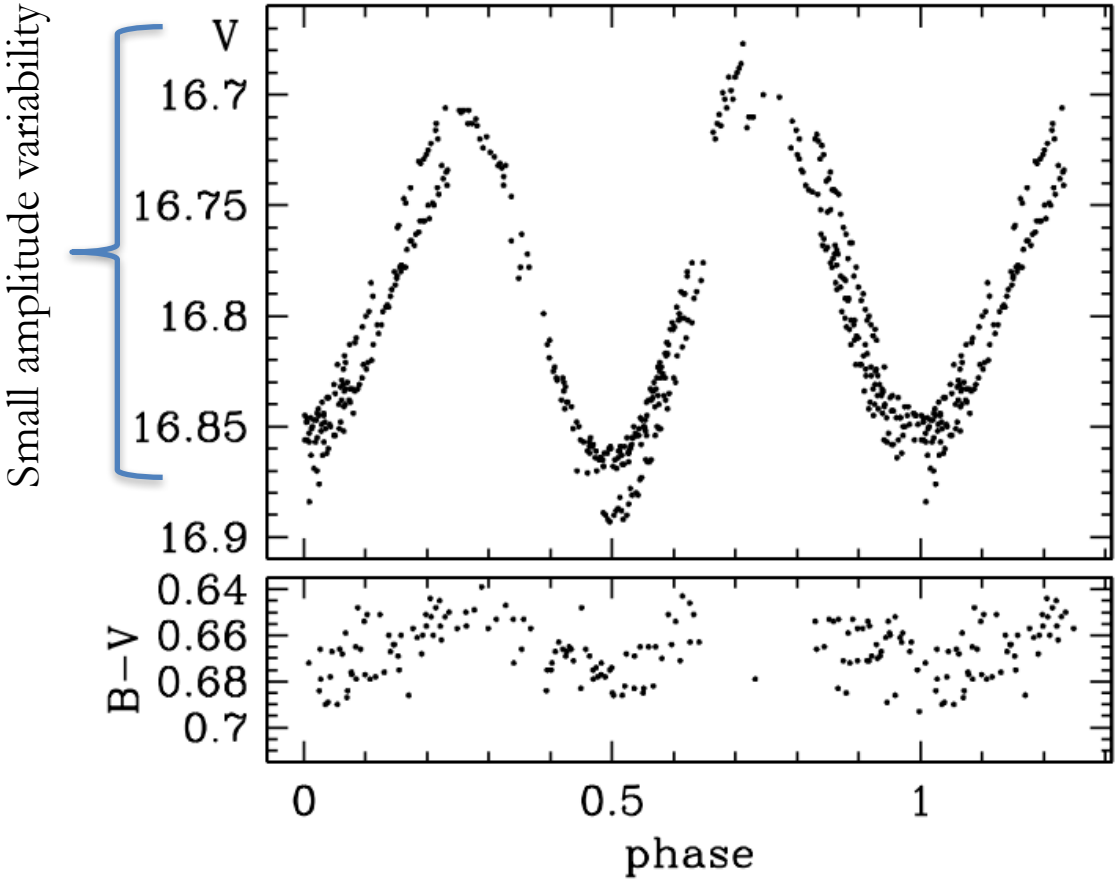


- Non degenerate, main-sequence like stars
- Roche-Lobe filling stars
- Usually optical varibility due to tidal deformations (<u>but not always!</u>)
- Radio eclipses
- Hard X-ray spectra: intra-binary shocks

Pallanca+10,13

Canonical MSPs | **Redbacks** | Black-Widows

Companion to 6397A light-curve



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Kaluzny+06, Ferraro+01

Canonical MSPs

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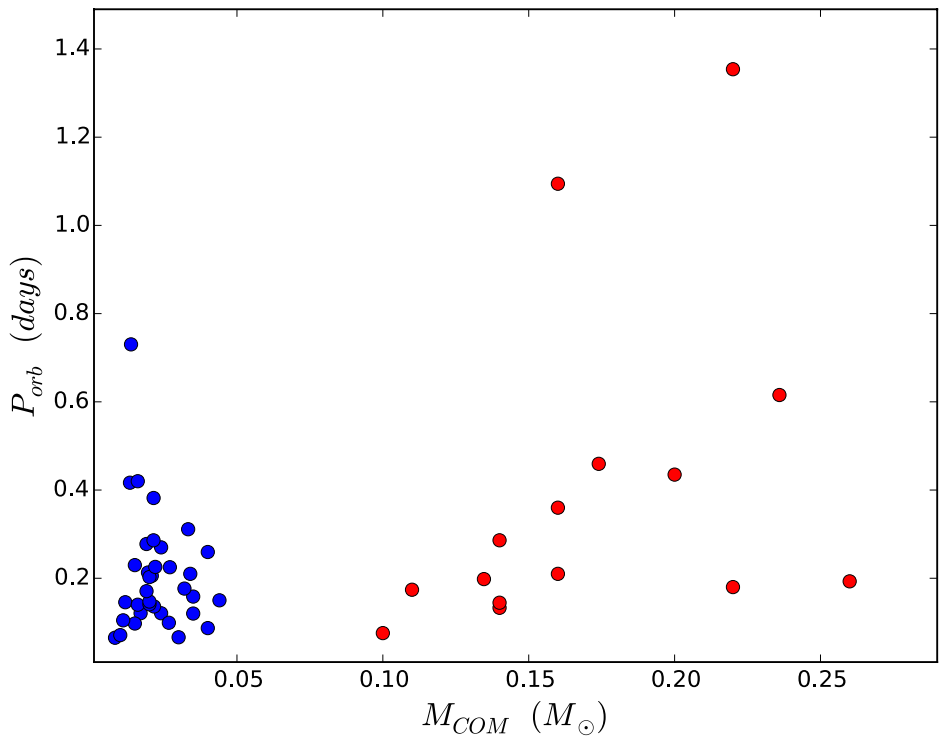
Black-Widows

Orbital Period vs Companion Mass



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Black-Widows

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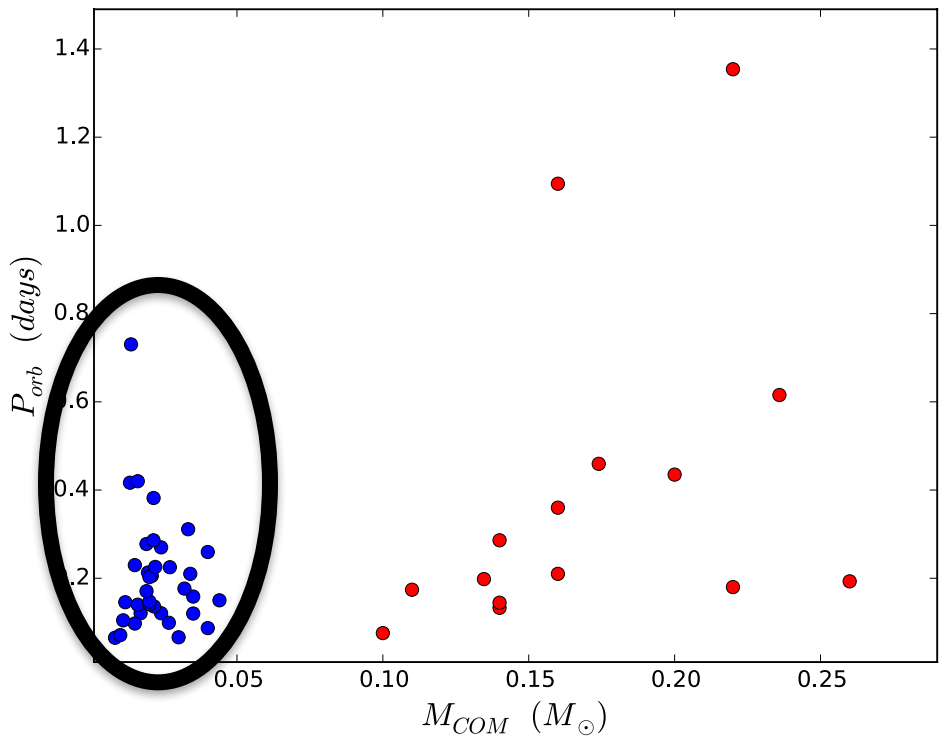

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Redbacks

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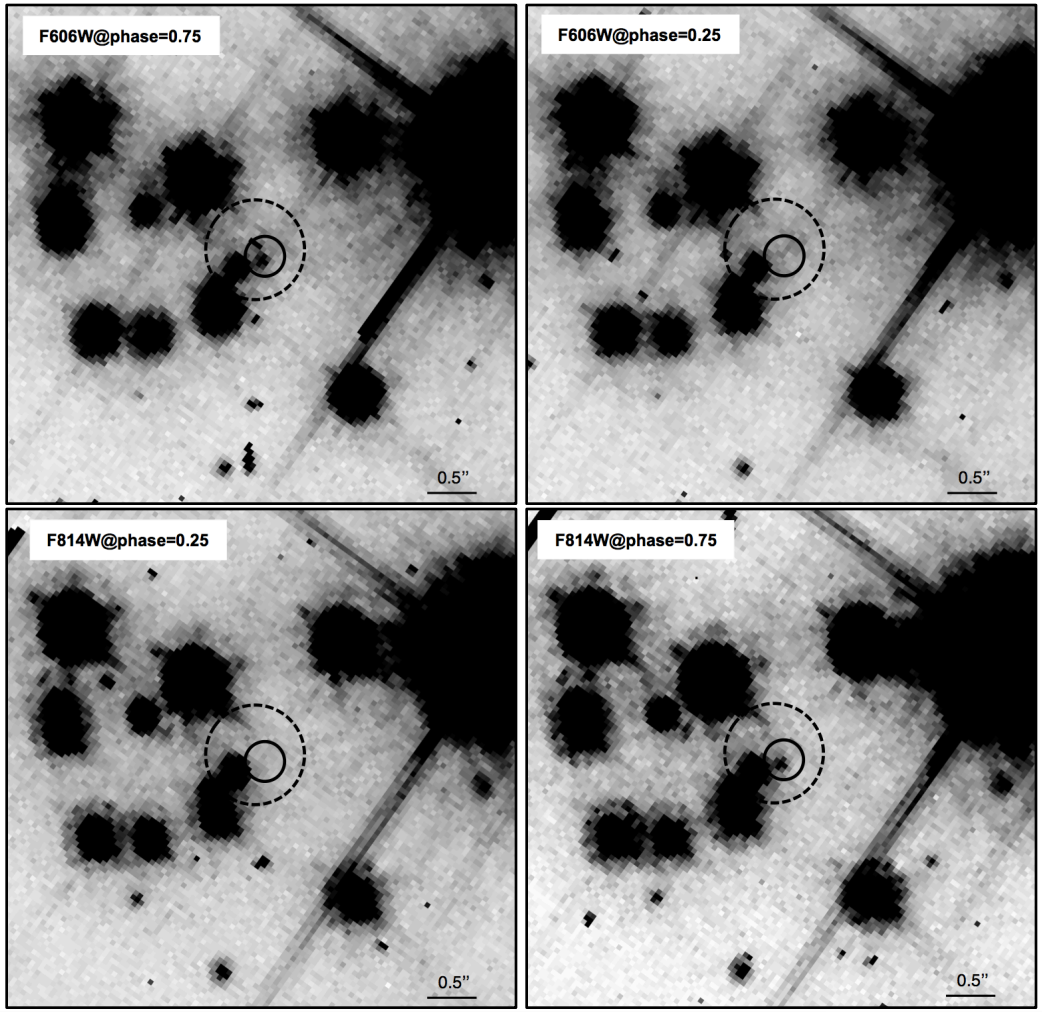


Companion to M71A

- Extremely faint, low-mass objects.
- Large amplitude variability.
- Progressive strong irradiation/vaporization due to the PSR injected flux.

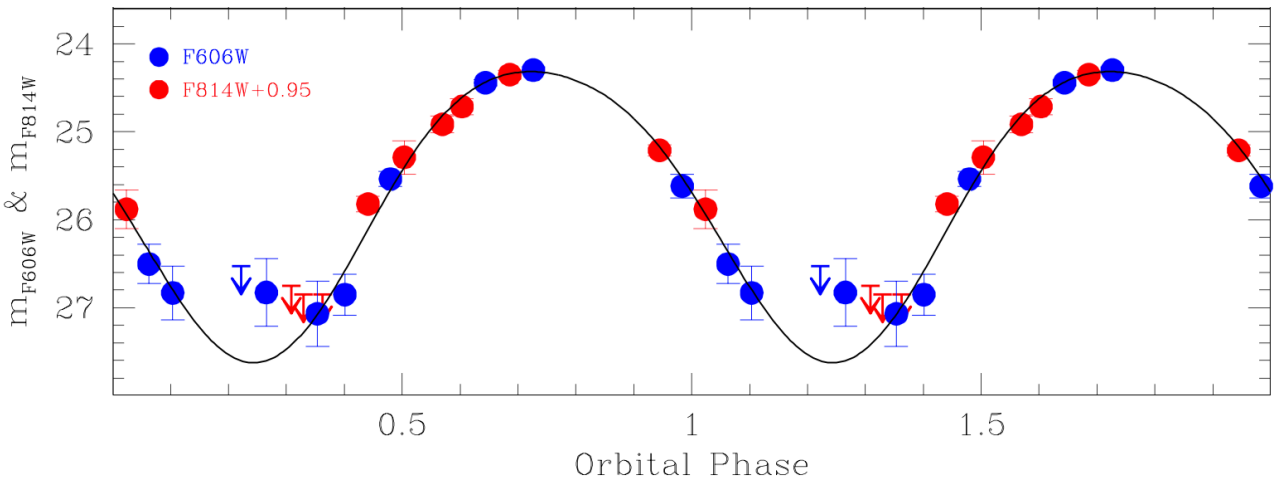
Cadelano+15a

Canonical MSPs

Redbacks

Black-Widows

Companion to M71A



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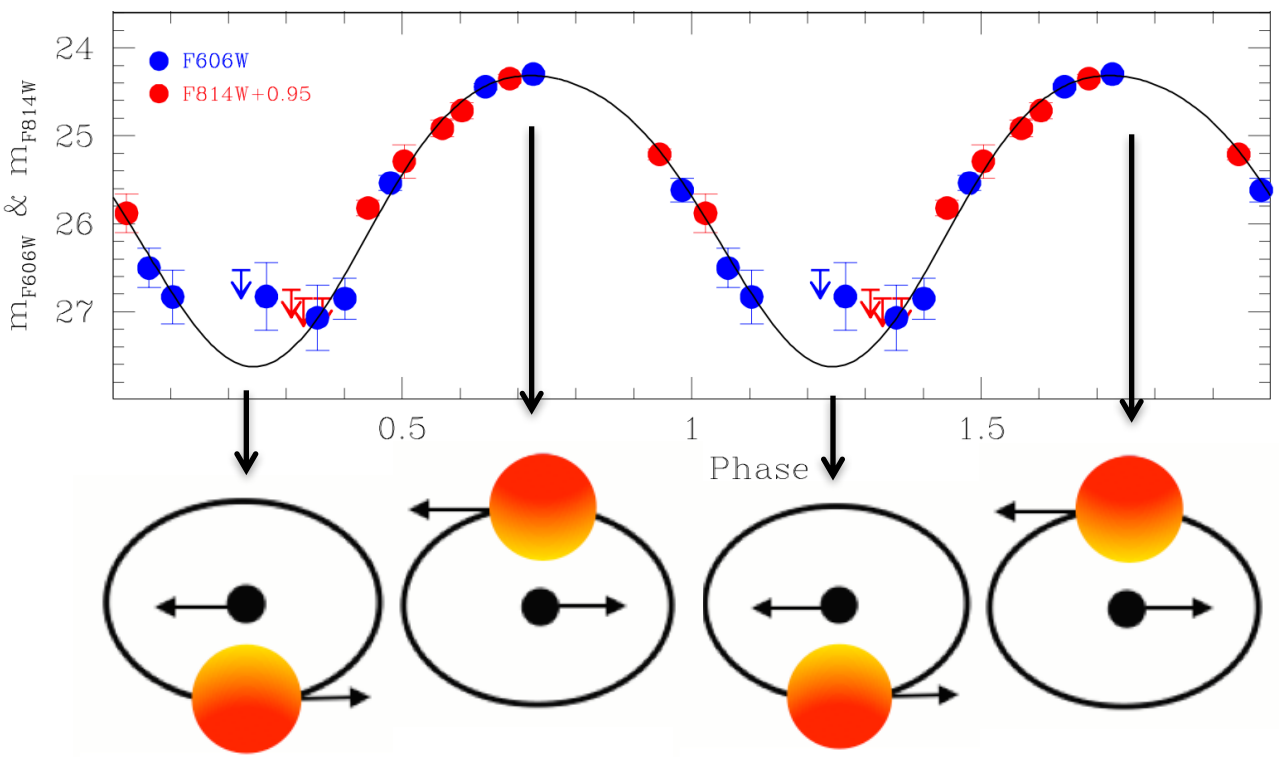

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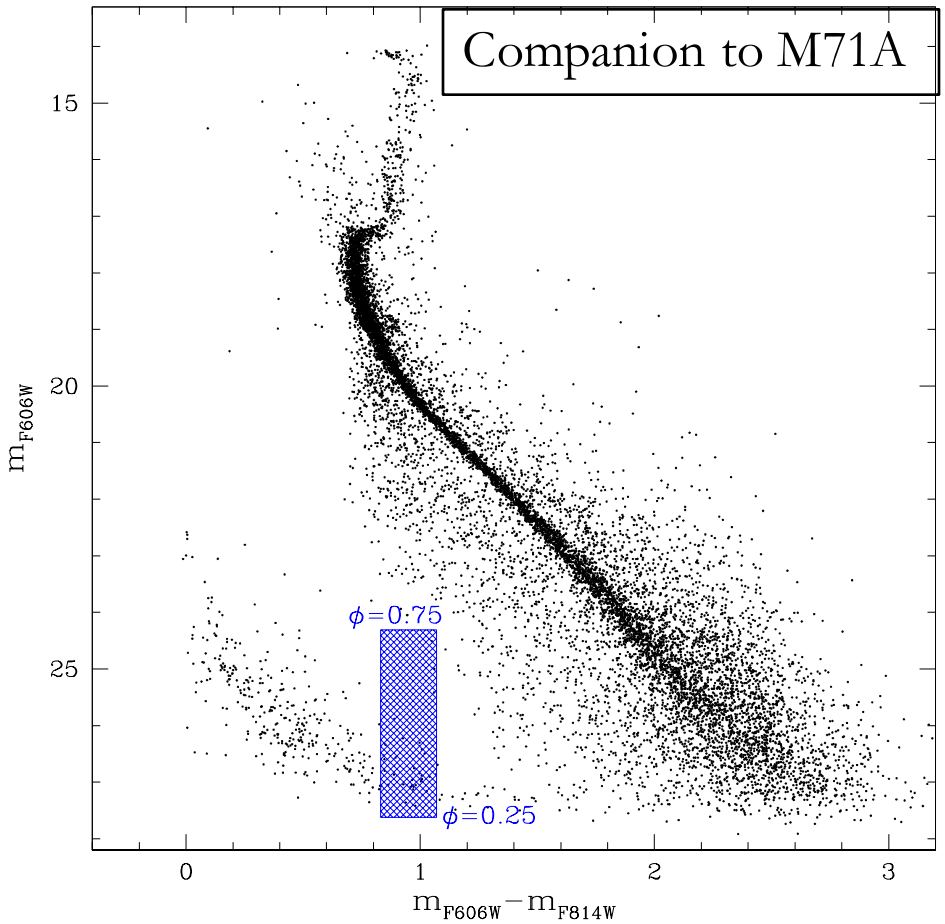

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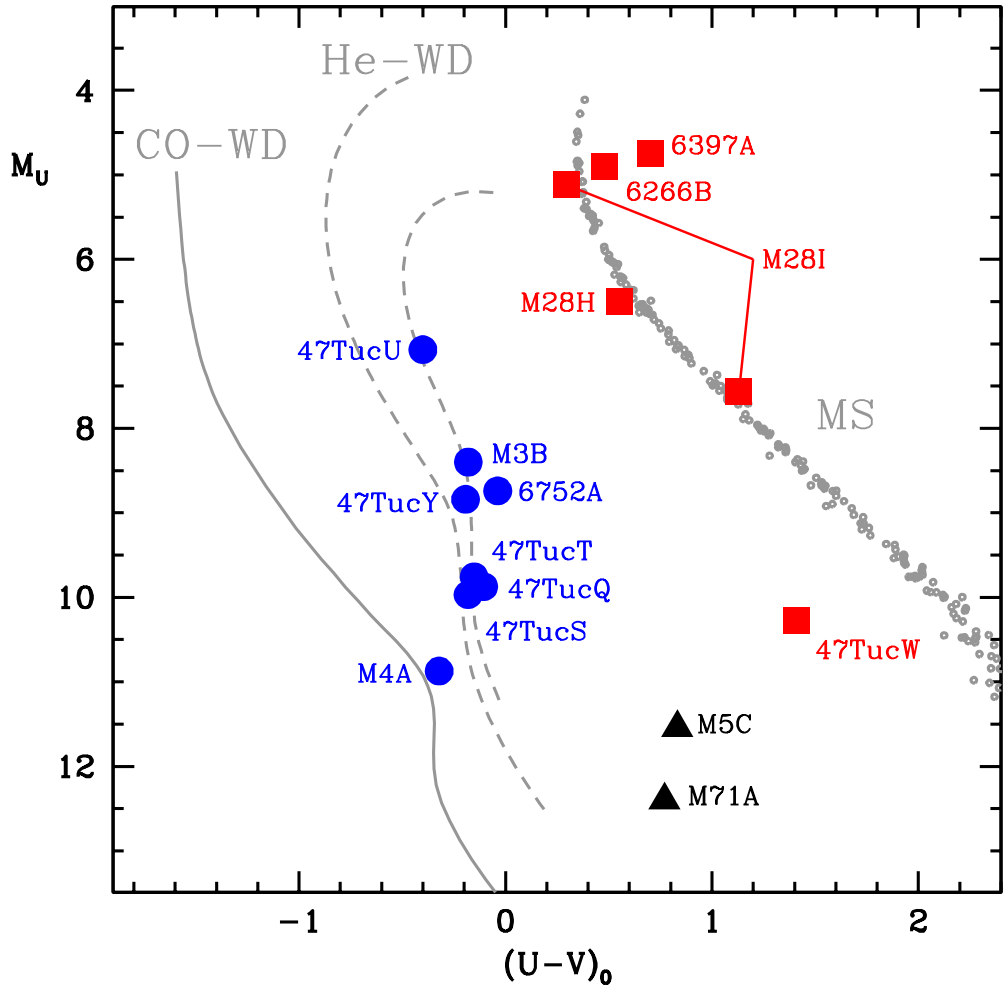
The Zoo of MSPs in GCs

MSP companion positions in an absoulte CMD



A classification based only on the optical properties of the companion star is now clearly emerging.

Ferraro+01,03; Bassa+03; Edmonds+01,02; Sigurdsson+04; Cocozza+06; Pallanca+10,13,14; Cadelano+15a,15b, in prep; Rivera-Sandoval+15.

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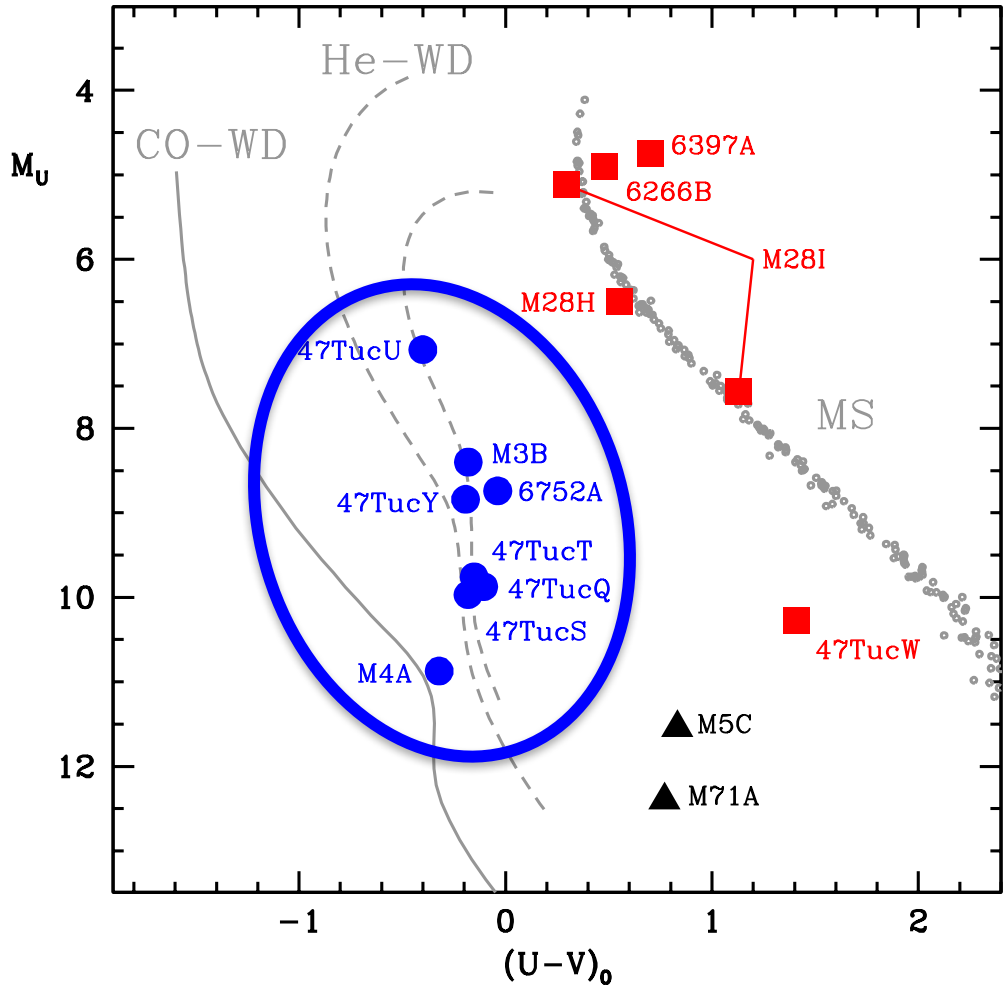

A classification based only on the optical properties of the companion star is now clearly emerging.

The companion to **canonical MSPs** are He-WDs, as expected from the canonical recycling scenario.

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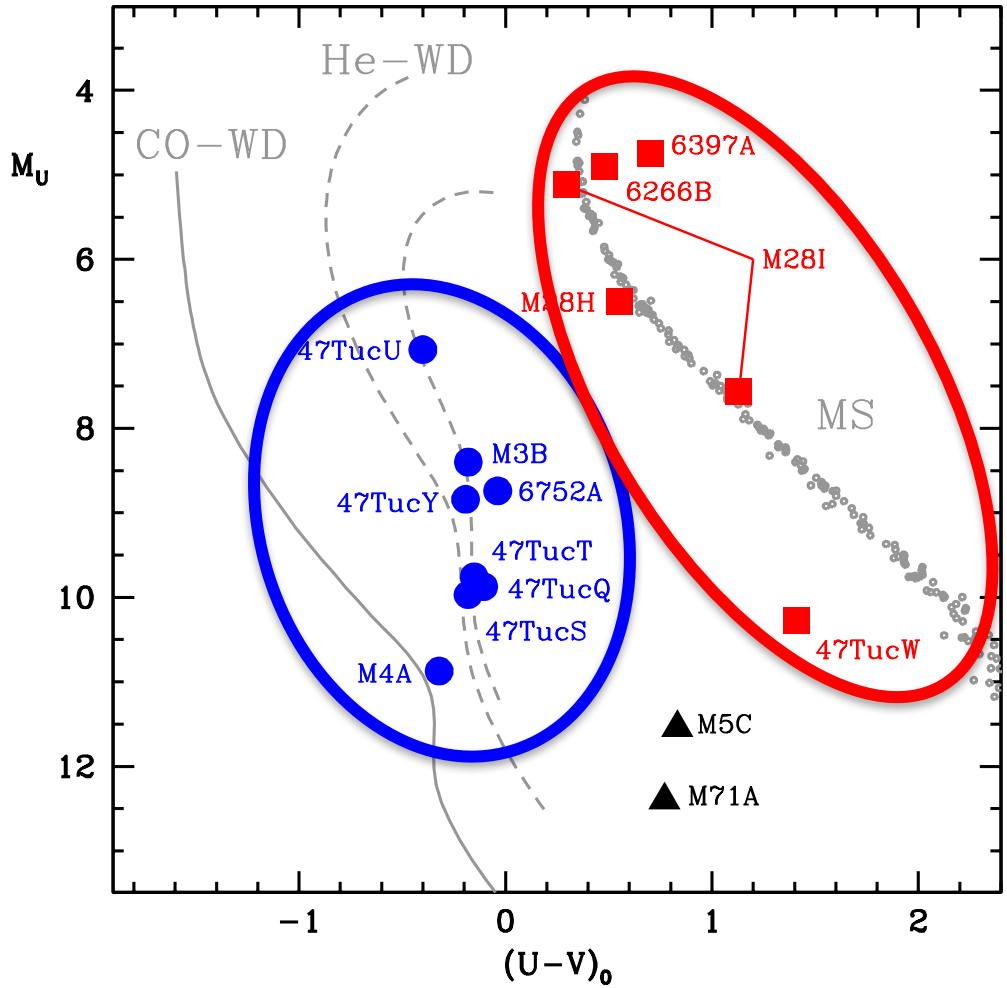

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The companion to **redback** systems are main sequence-like stars.

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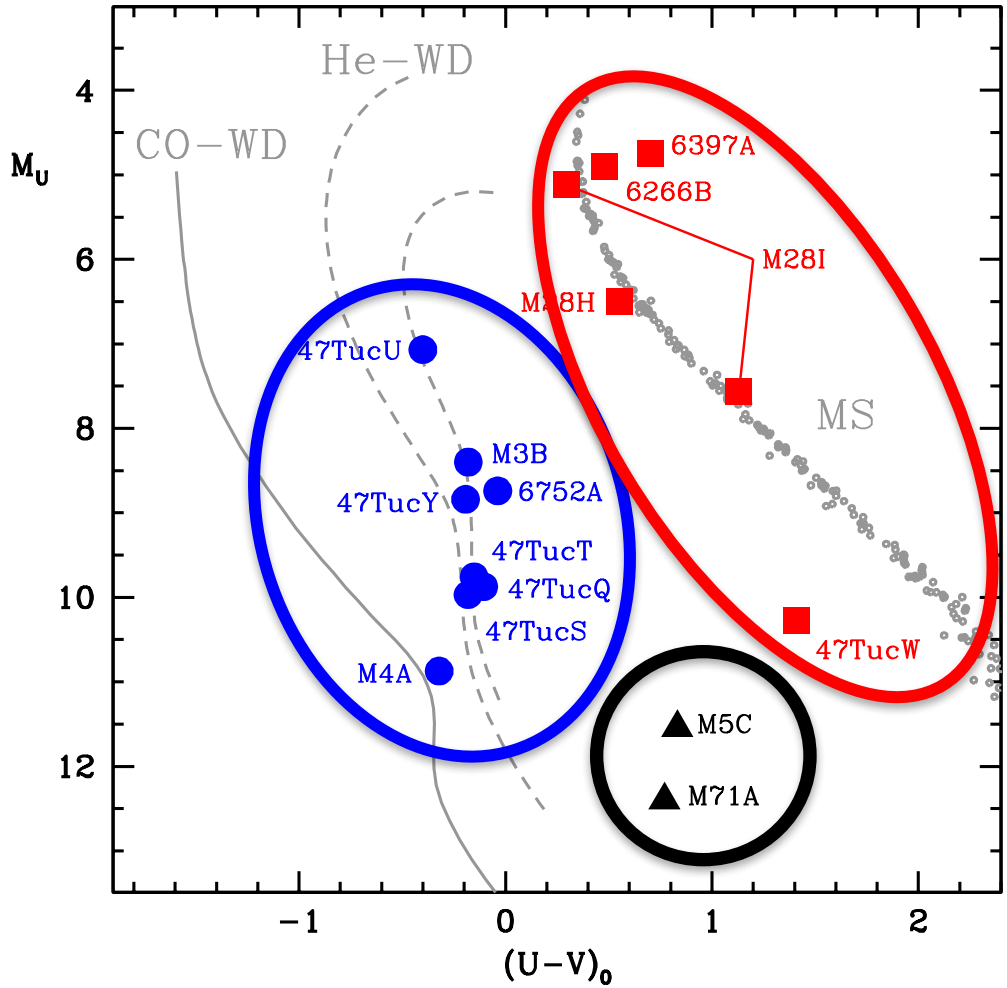

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The companion to **black-widow** systems are very faint, deeply perturbed stars.

The Zoo of MSPs in GCs

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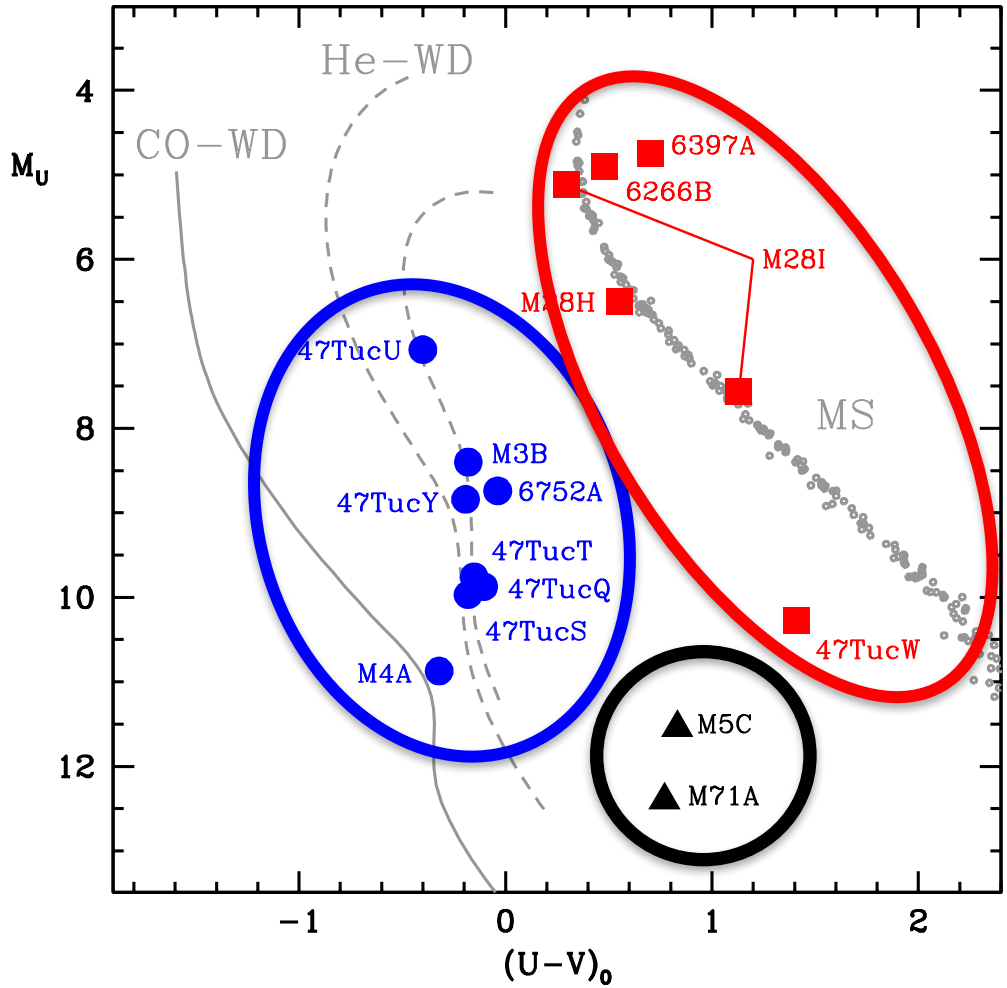

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The companion to **redback** systems are main sequence-like stars.

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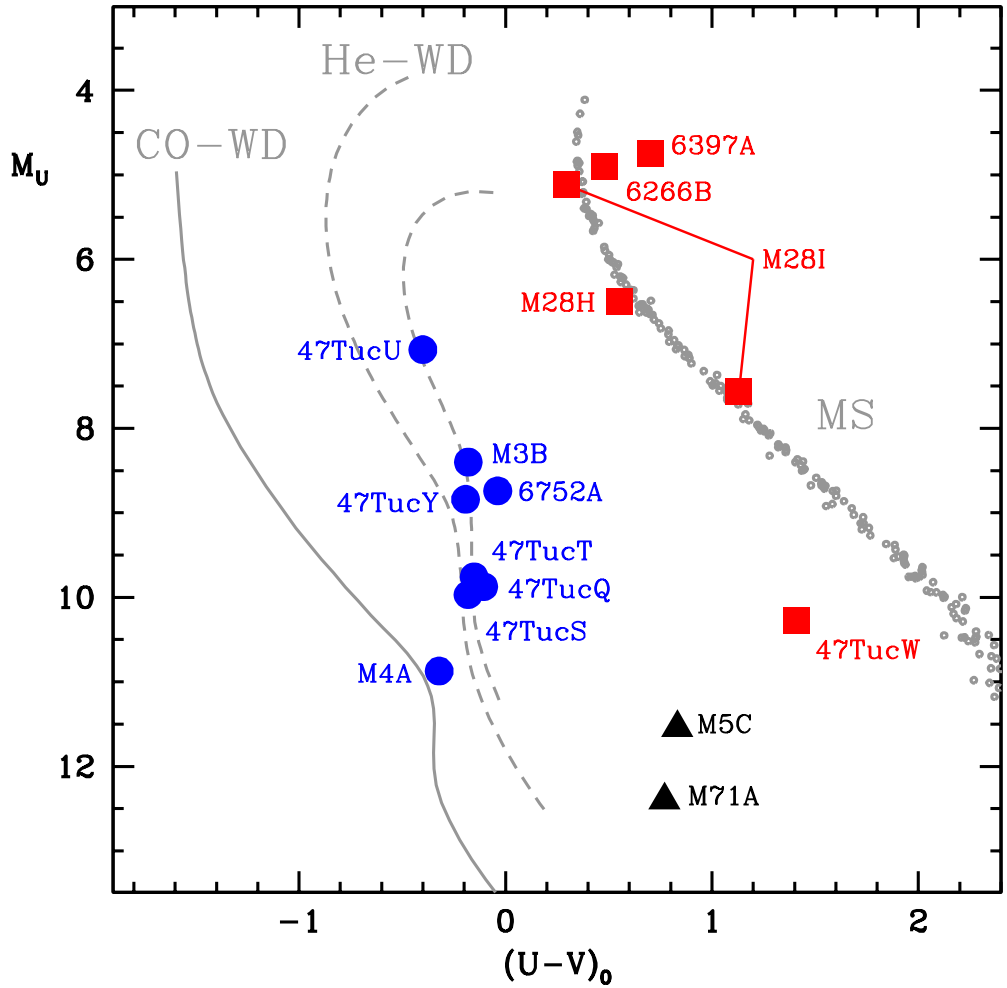
From the optical identification, alone, we are able to classify the binary MSP!

The Zoo of MSPs in GCs

MSP companion positions in an absoulte CMD



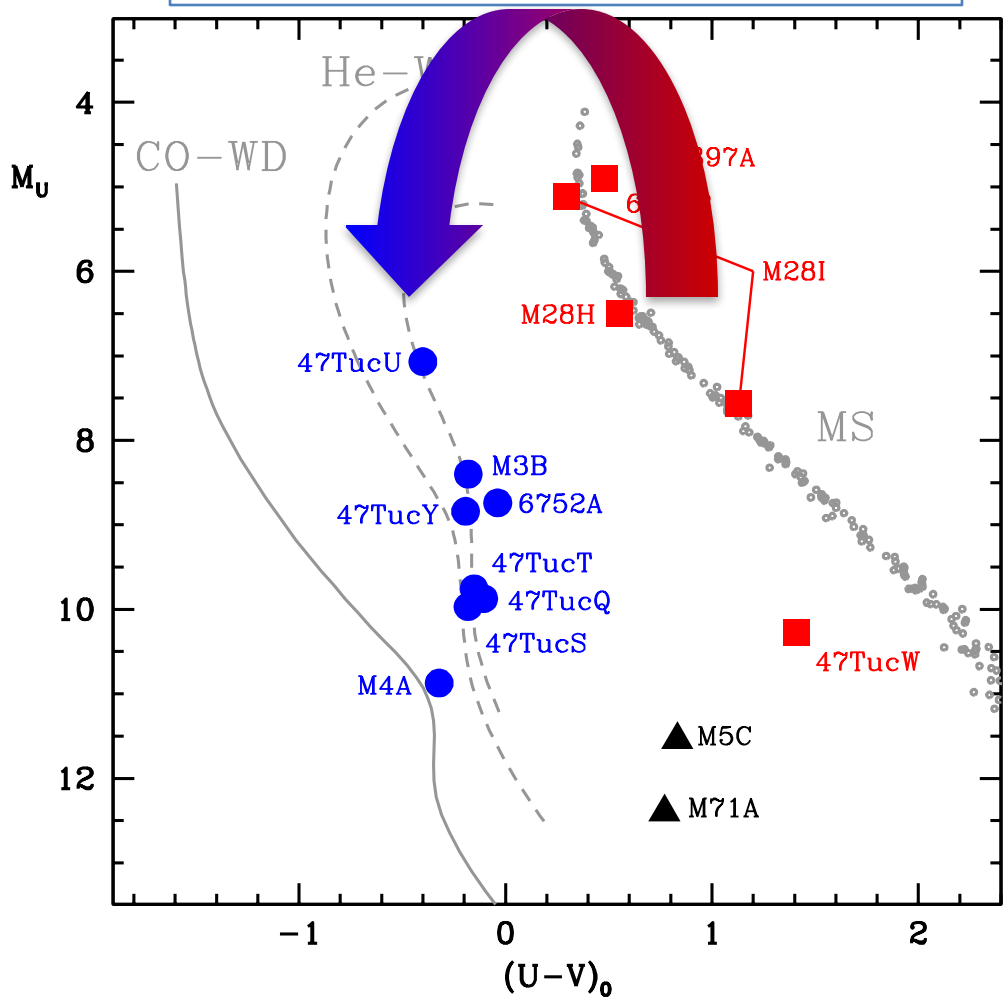
Can we infer something more about the evolution of these objects?

Benvenuto+14,15 suggested that Redbacks can evolve to both He WD systems and Black-Widow systems.

However, such a possiblity is still debated. See for example Chen+13.

The Zoo of MSPs in GCs

MSP companion positions in an absoulte CMD



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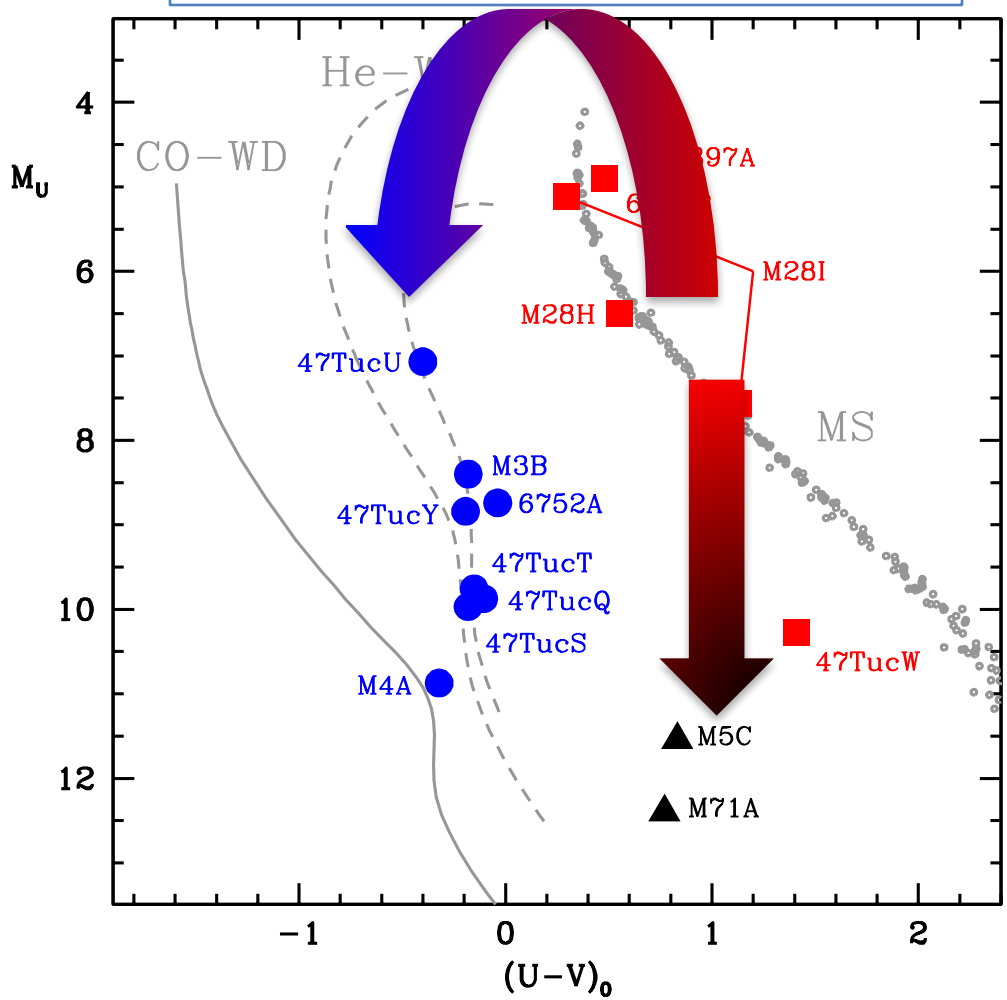
However, such a possiblity is still debated. See for example Chen+13.

We lack systems in an intermediate stage between Redbacks and He WD systems.

The Zoo of MSPs in GCs

MSP companion positions in an absoulte CMD



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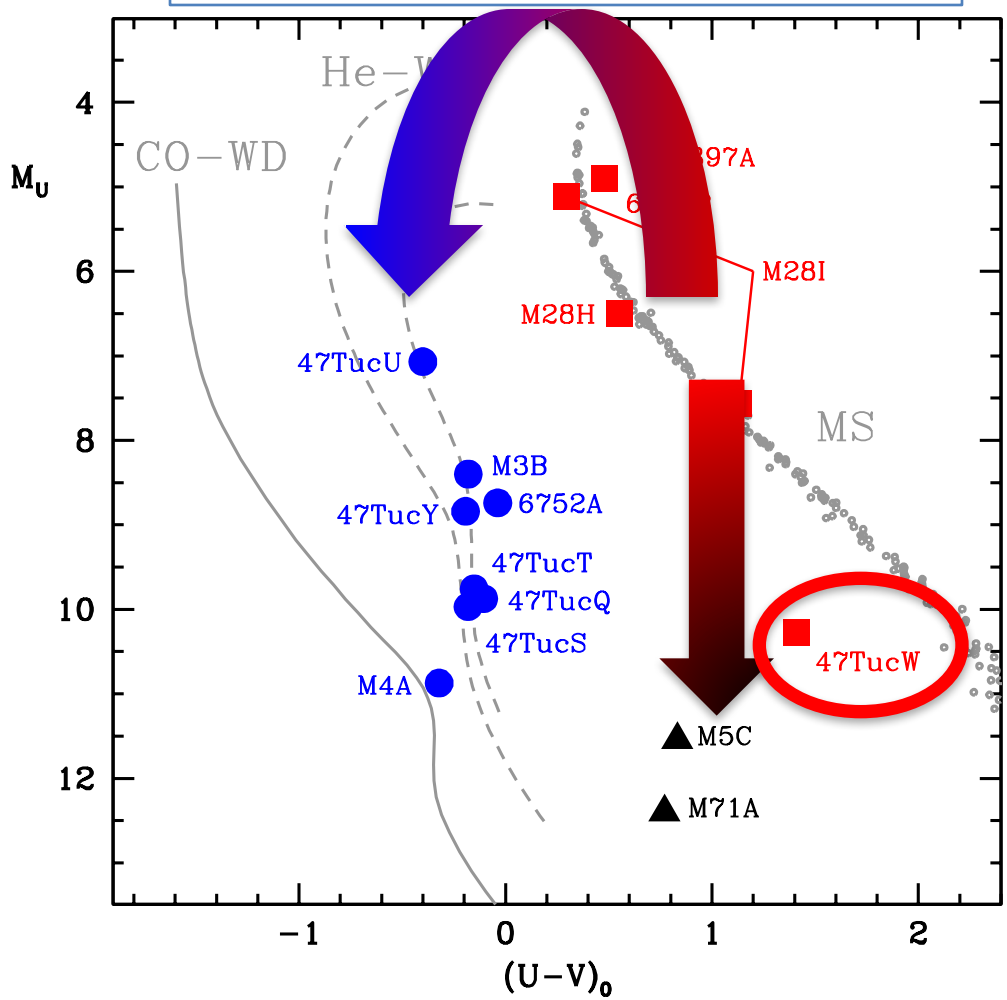

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Take home messages

1) The study of MSP optical counterparts is a powerful complementary tool to characterize binary MSPs. We are studying stellar evolution under extreme conditions.

2) The optical identification and characterization of the companion star is enough to classify the binary MSP.

3) The study of the companion stars allow to get insight on the still obscure evolution of these systems.

4) The combinination of the radio timing analysis and optical photometry allows to measure the masses of both the WDs and NSs…chances to find massive NSs?

Thanks for your attention