Optical companions to Red-Backs and Black-Widows in Globular Clusters

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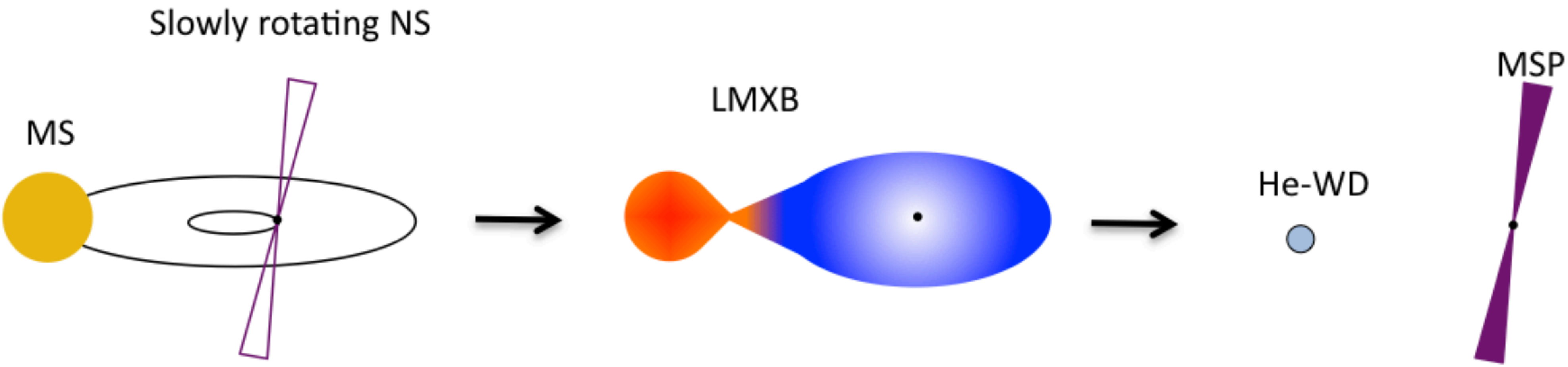
Cosmic-Lab

- 5-year project (web site at **www.cosmic-lab.eu**)
- *Advanced Research Grant* funded by the European Research Council (ERC)
- PI: Francesco R. Ferraro (Dip. of Physics & Astronomy – Bologna University)
- AIM: **to understand the complex interplay between dynamics & stellar evolution**
- HOW: using **globular clusters** as cosmic laboratories and

Blue Straggler Stars
Millisecond Pulsars
Intermediate-mass Black Holes

} as probe-particles

The canonical recycling scenario



Binary system:
Neutron star (NS)
+ evolving companion

mass accretion from an evolving companion spin up the NS

fast rotating pulsar (MSP) + an exhausted star

the core of a peeled star = WD

…but there are a few exceptions…

(Bhattacharya et al. 1991)

A “mass/type” classification of MSPs

High mass
$M_{COM} > 1\ M_\odot$
NSs

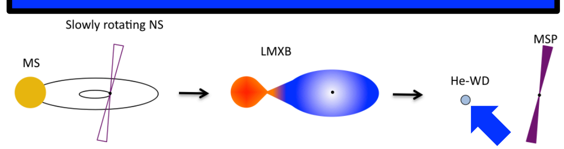
Intermediate mass
$0.5\ M_\odot < M_{COM} < 1\ M_\odot$
CO/ONe-WDs

Low mass
$M_{COM} < 0.5\ M_\odot$

Red-backs
$0.1 M_\odot < M_{COM} < 0.5 M_\odot$
MSs

10 in GCs
7 in the GF

Canonicals
$0.1 M_\odot < M_{COM} < 0.5 M_\odot$
He-WDs



Black widows
$M_{COM} < 0.1\ M_\odot$
MSs/BDs

18 in GCs
17 in the GF

MSP preferred habitats

- Galactic disc 100 times more massive than the GGC System
- About 40% of the entire MSP population found in GGCs

The number of MSPS per unit of mass is significantly higher in GCs

Galactic Field

Evolution of primordial binaries

Globular Clusters

Dynamical interactions can promote the formation of binaries suitable for recycling NSs into MSPs

The study of GC MSPs is crucial to understand the role of dynamical interactions

The optical approach

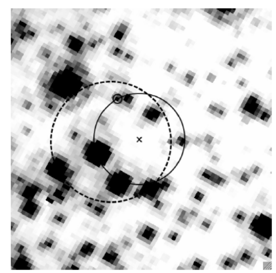
Radio

Optical

Photometry

Astrometry

Very Accurate position →



High resolution

!!! Positional coincidence !!!

CMD position

(Out of sequence)

Deep

Nature and physical parameters

Orbital parameters

Orbital period
Time ascending node ↔

Light curve

(Variability in agreement with the orbital motion)

Multiple epochs

PSR Mass function ↔ i, M_{COM}, M_{PSR}

!!! Orbital variability !!!

Total mass ↔ $M_{PSR}=M_{TOT}-M_{COM}$

The optical approach

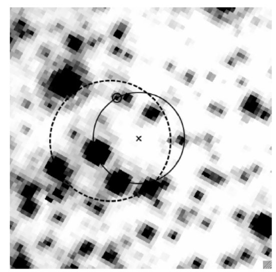
Radio

Optical

Photometry

Astrometry

Very Accurate position



CMD position
(Out of sequence)

Nature and physical parameters

IF
BRIGHT
ENOUGH

Orbital parameters

Orbital period
Time ascending node

Light curve
(Variability in agreement with the orbital motion)

PSR Mass function

i, M_{COM}, M_{PSR}

Total mass

$M_{PSR}=M_{TOT}-M_{COM}$

The optical approach

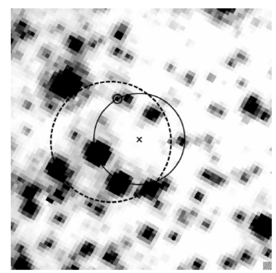
Radio

Optical

Photometry

Spectroscopy

Astrometry



Very Accurate position

Radial Velocity

COM mass function

+

PSR mass function

CMD position

(Out of sequence)

Nature and physical parameters

Orbital parameters

Orbital period

Time ascending node

Light curve

(Variability in agreement with the orbital motion)

Mass ratio

System solved

PSR Mass function

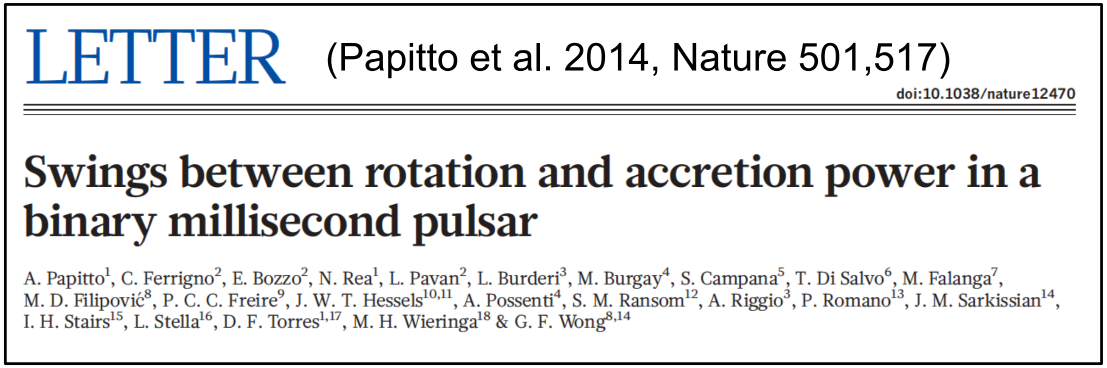
***i*, M_{COM}, M_{PSR}**

Chemical abundances

Total mass

$M_{PSR}=M_{TOT}-M_{COM}$

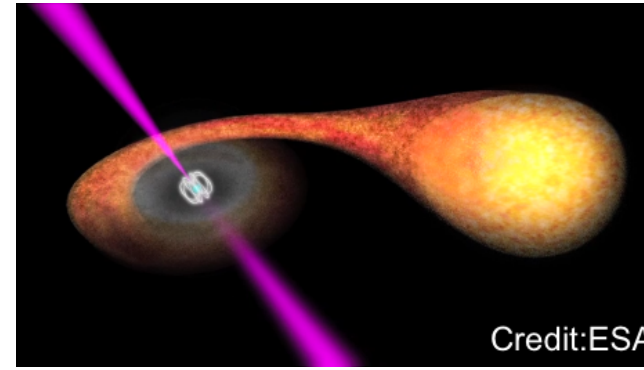
IGR J18245-2452/PSR J1824-2452I


LETTER (Papitto et al. 2014, Nature 501,517)

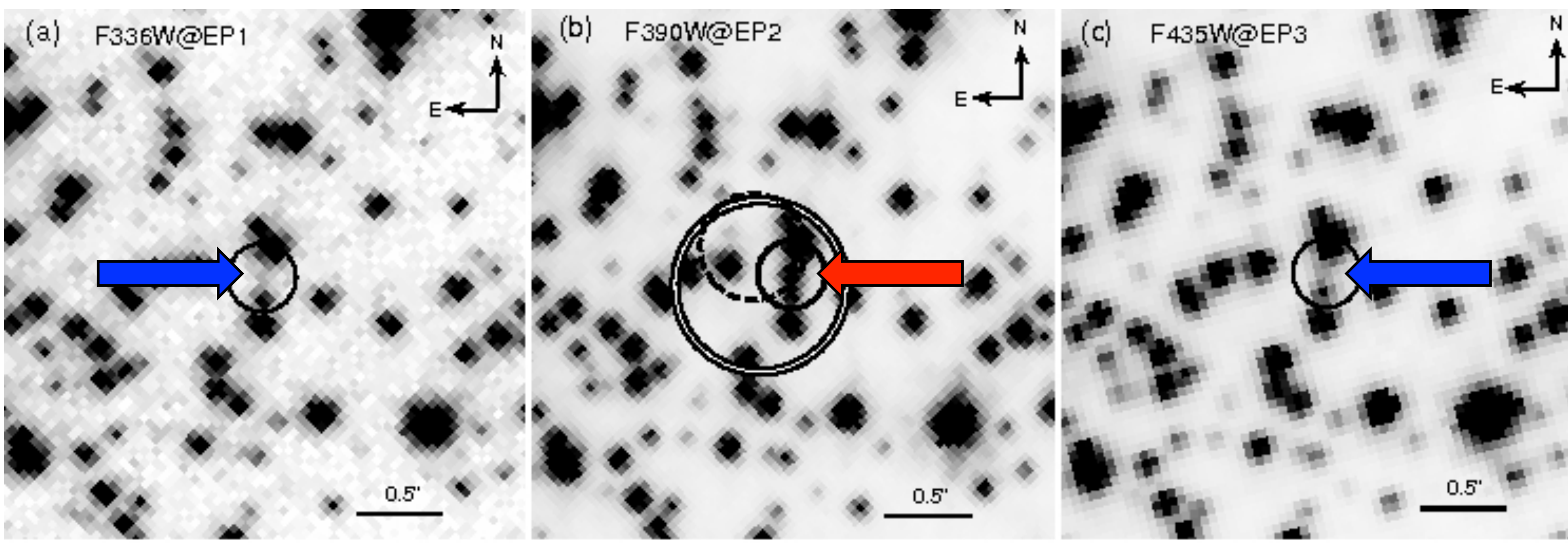
doi:10.1038/nature12470

Swings between rotation and accretion power in a binary millisecond pulsar

A. Papitto[1], C. Ferrigno[2], E. Bozzo[2], N. Rea[1], L. Pavan[2], L. Burderi[3], M. Burgay[4], S. Campana[5], T. Di Salvo[6], M. Falanga[7], M. D. Filipović[8], P. C. C. Freire[9], J. W. T. Hessels[10,11], A. Possenti[4], S. M. Ransom[12], A. Riggio[3], P. Romano[13], J. M. Sarkissian[14], I. H. Stairs[15], L. Stella[16], D. F. Torres[1,17], M. H. Wieringa[18] & G. F. Wong[8,14]

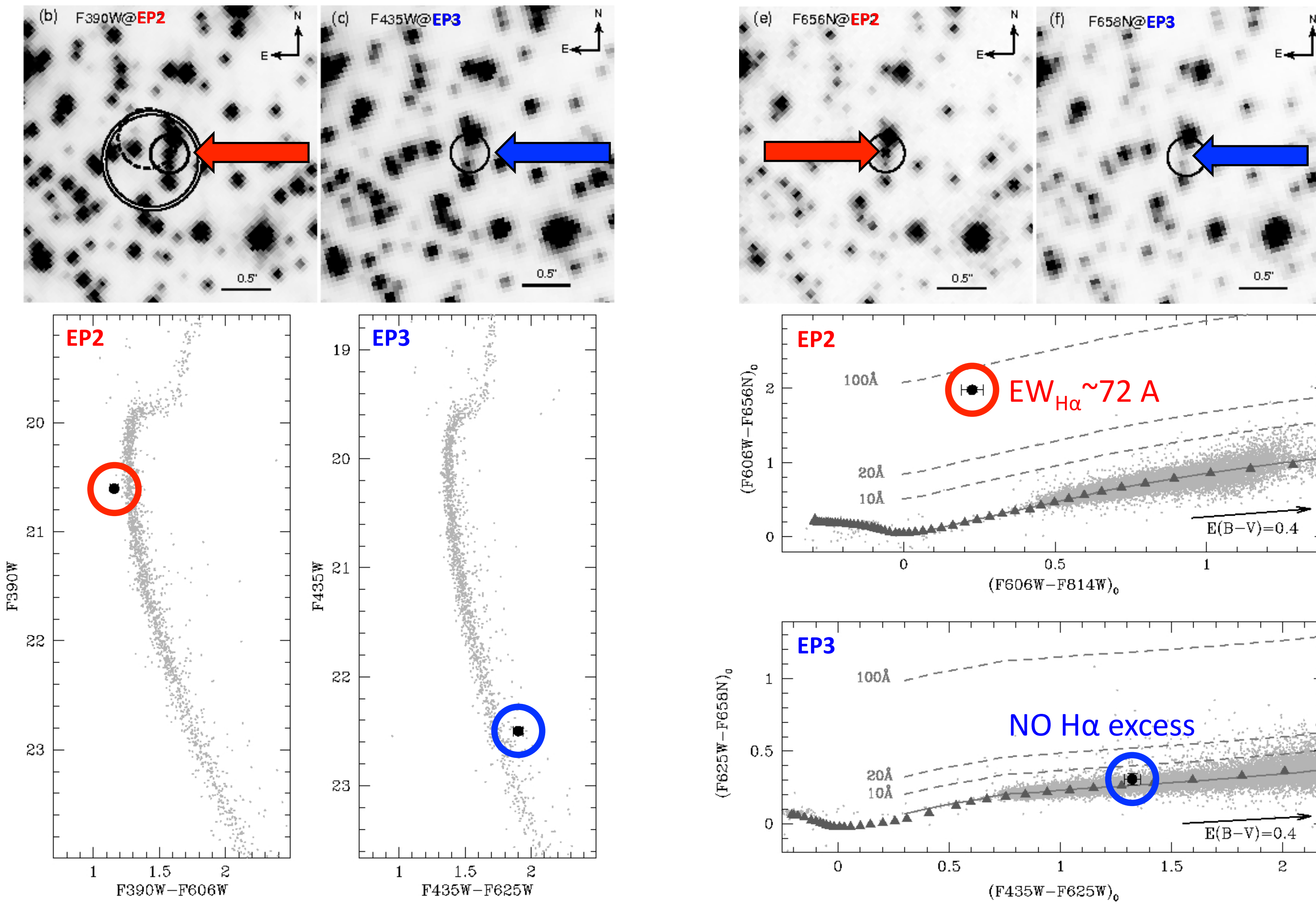


Apr 2009 Aug 2009 Apr 2010



✓We detected the optical counterpart (Atel #5003, Pallanca et al., 2013)

IGR J18245-2452/PSR J1824-2452I



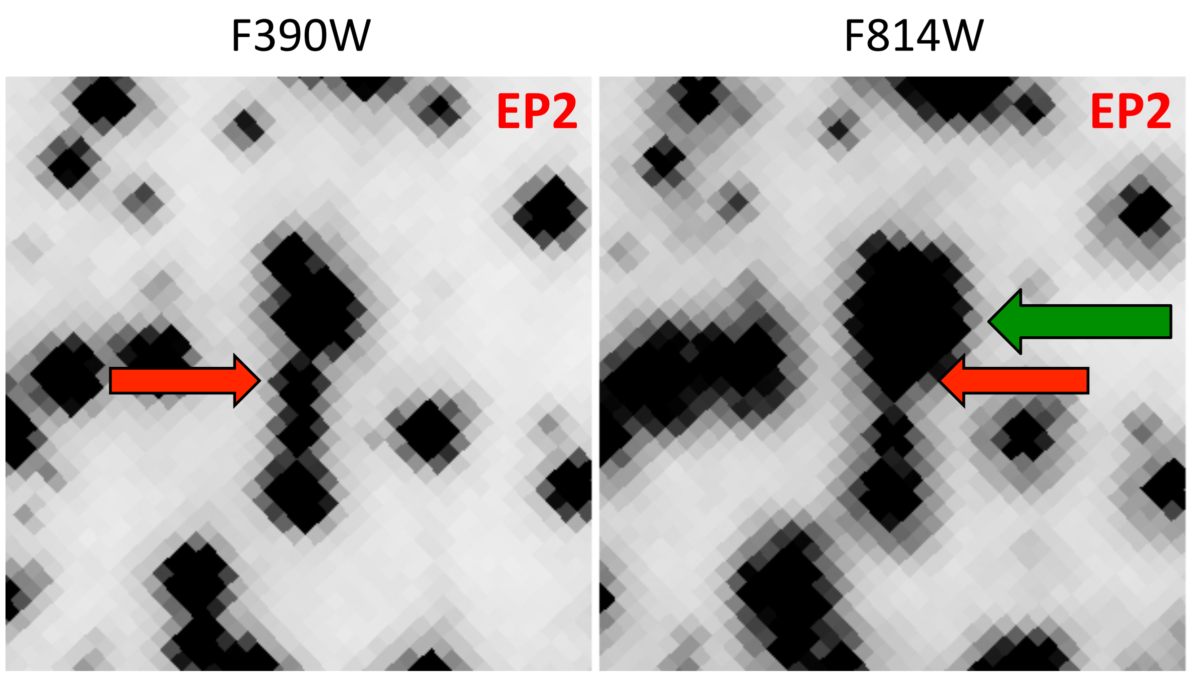
IGR J18245-2452/PSR J1824-2452I

To check if the variability is correlated with the orbital motion of PSR M28I we need a very **accurate photometric analysis** in single images

A faint star close to a brighter star (in particular during the quiescent state)

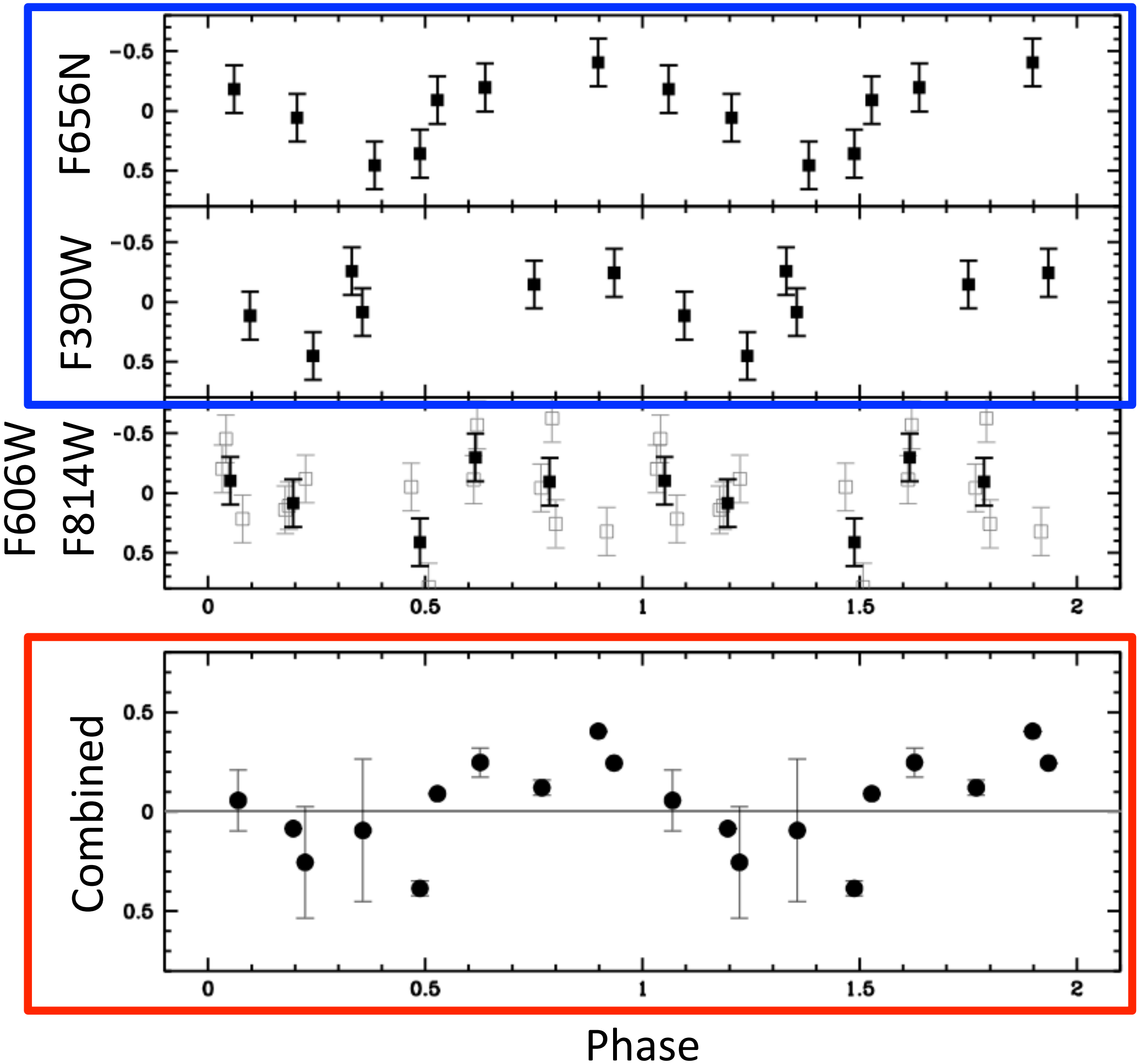
In redder filter the close bright star starts to saturate

PSF-fitting is working well



We need to accurately subtract the profile of the bright star

IGR J18245-2452/PSR J1824-2452I



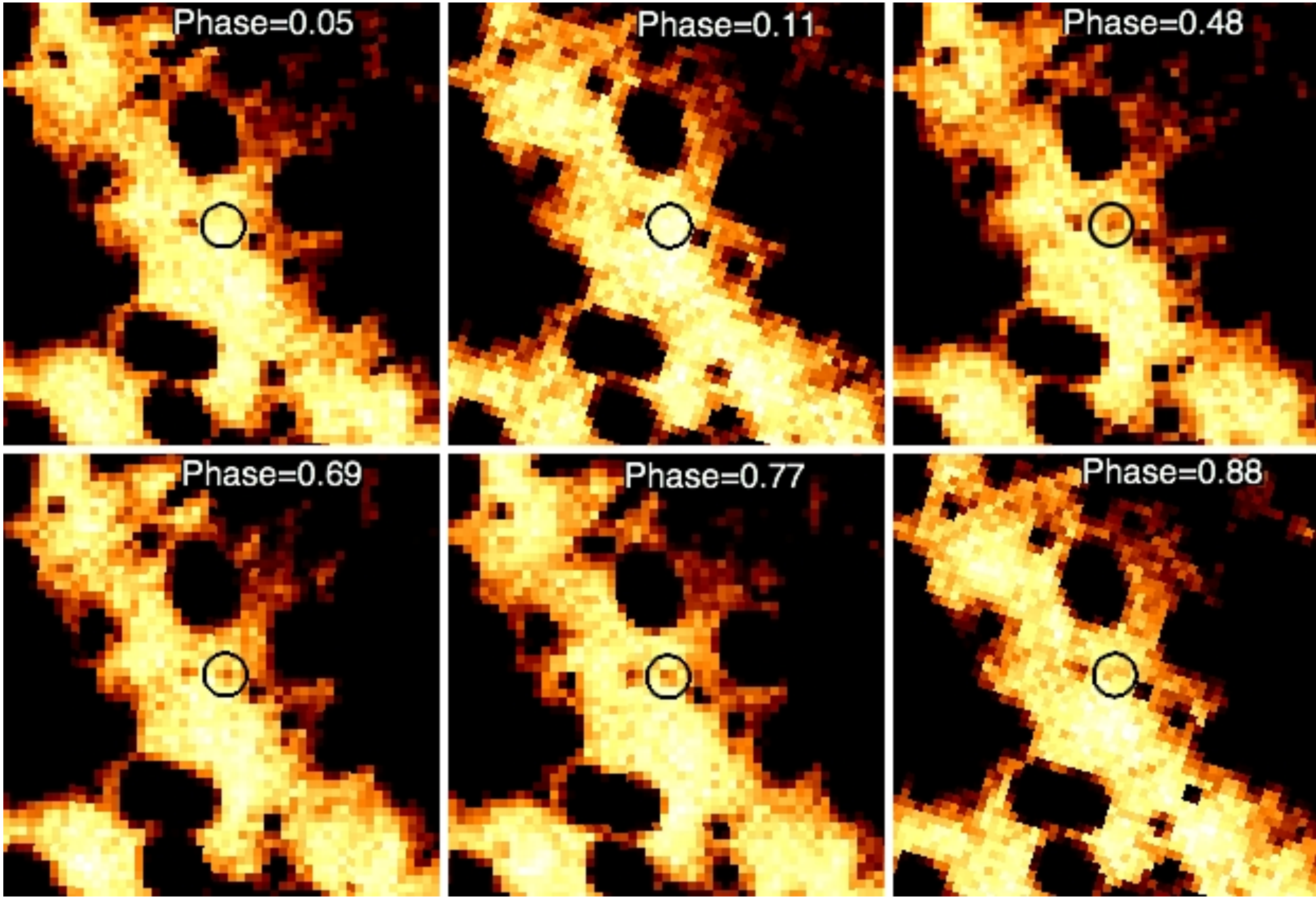
We adopted the orbital parameters of M28I

In the F656N and F390W filters the star is brighter and the closest star does not saturate

We combined the F606W and the F814W magnitudes likely dominated by random scatter

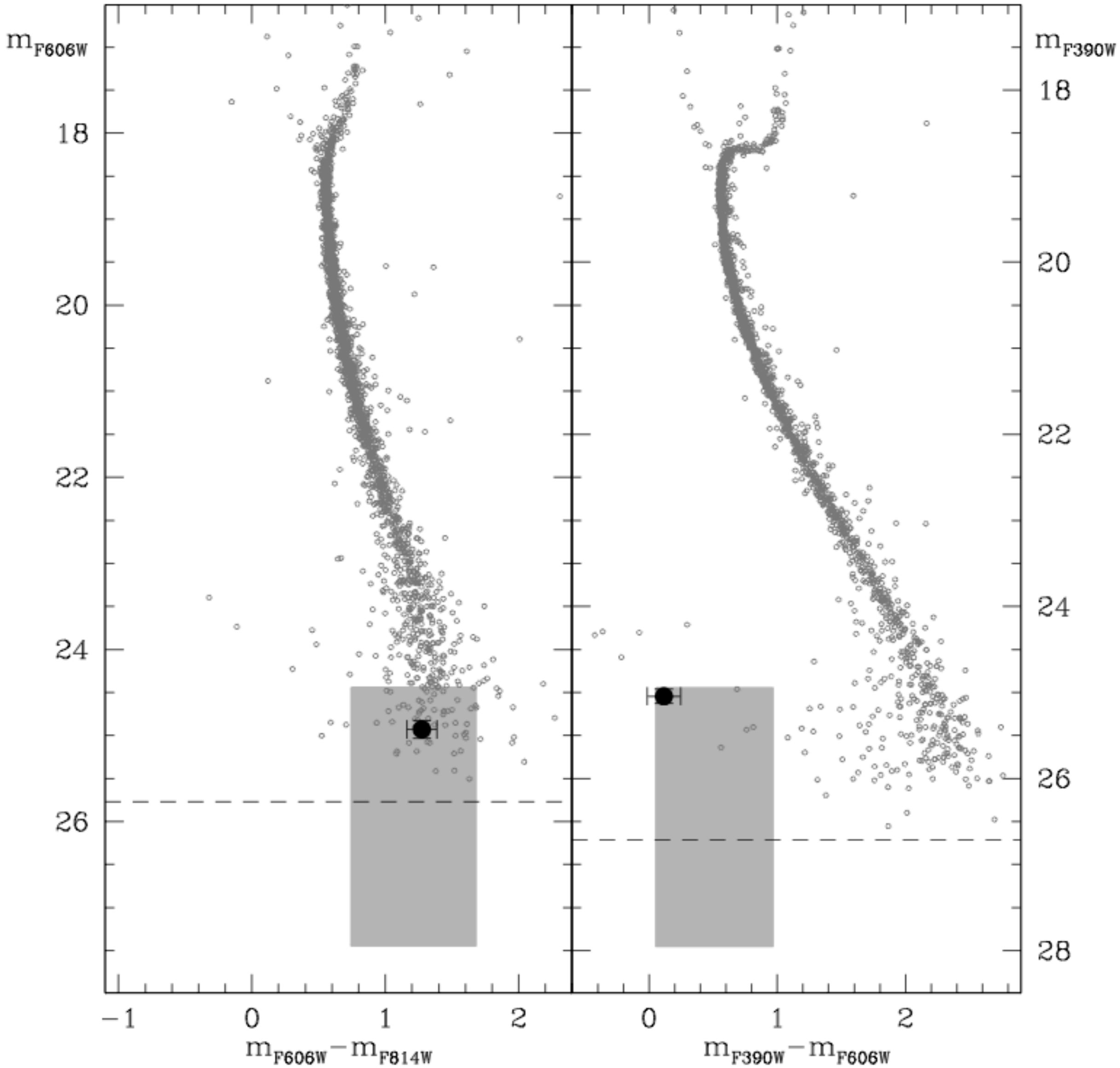
Combined light curve obtained by averaging in bins of 0.1 in phase all the available measures

The BW PSR J1518+0204C in M5



WFC3/UVIS@HST images in the F814W at different epochs

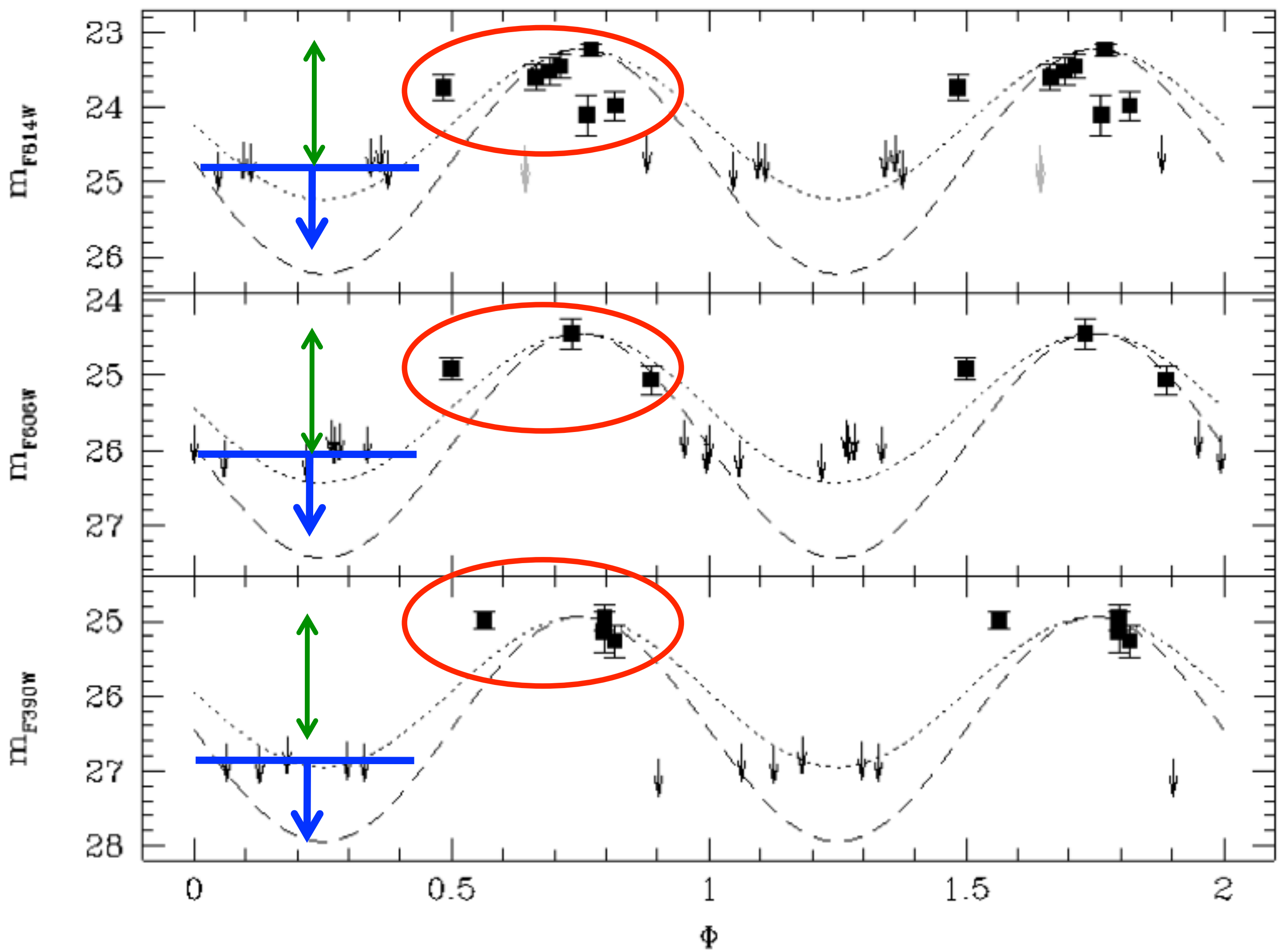
The BW PSR J1518+0204C in M5



CMD position consistent with a location between the WDs and the MS

$M_{COM} < 0.2 M_{\odot}$

The BW PSR J1518+0204*C* in M5

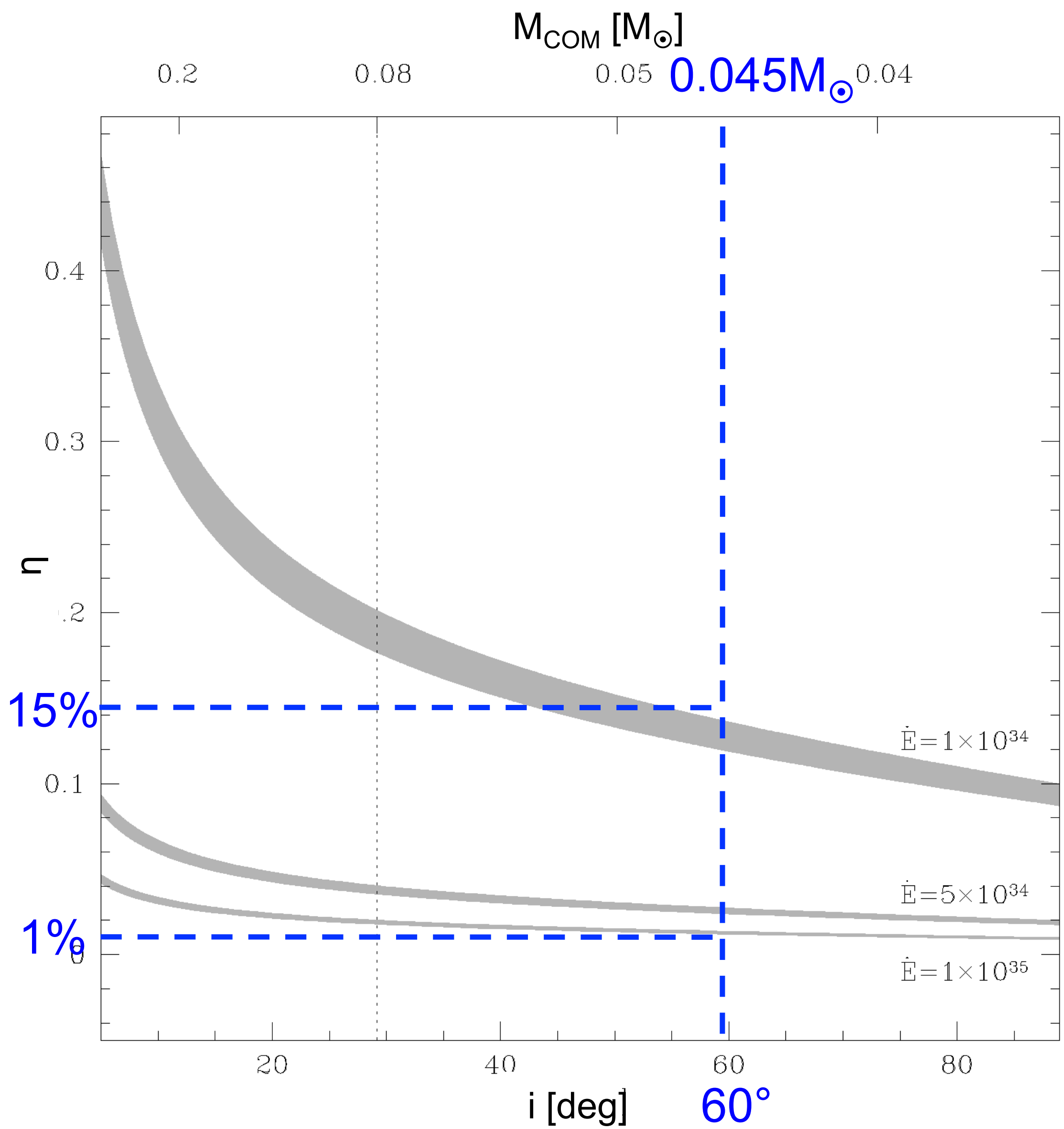


Detected at the PSR inferior conjunction

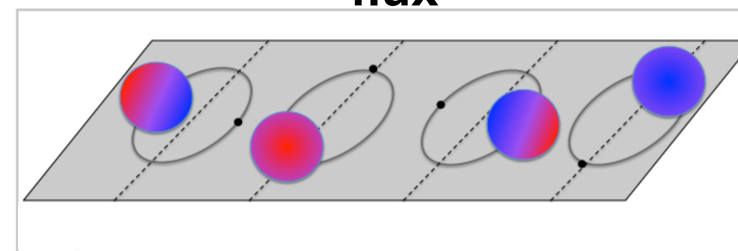
Under the detection limit at the PSR superior conjunction

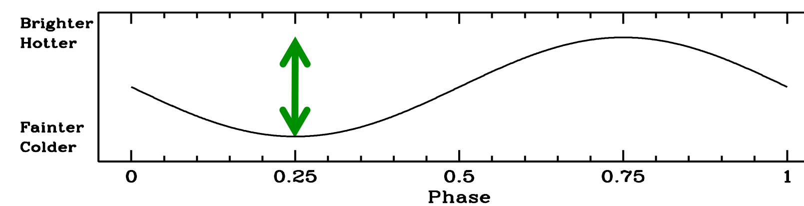
Δmag>1.5 mag

The BW PSR J1518+0204C in M5



Magnitude modulation is due to
the **reprocessing of the PSR flux**

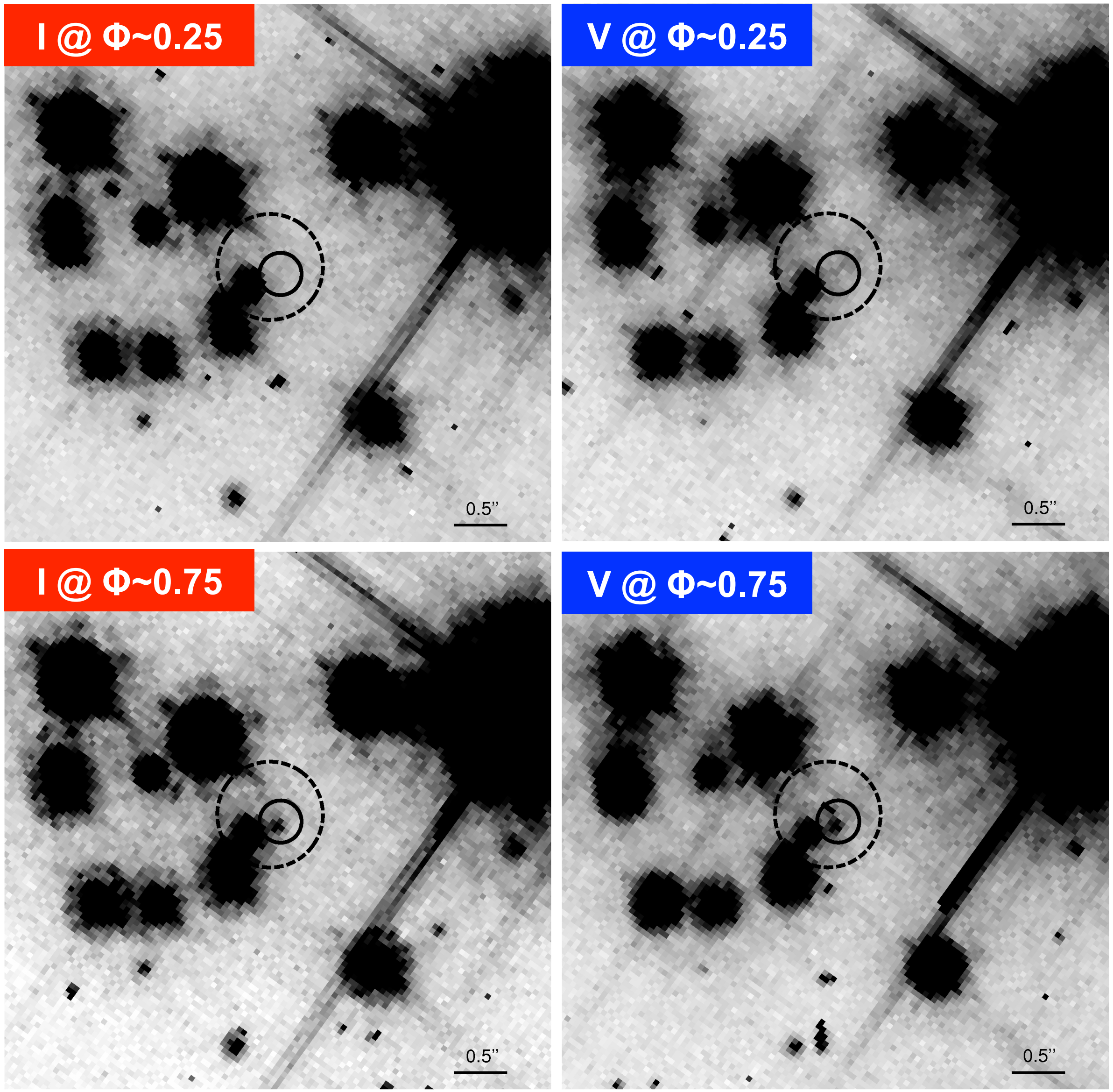




We estimated a lower limit to the **reprocessing efficiency (η)**

$$\Delta F_{\exp}(i) = \eta \frac{\dot{E}}{a^2} R^2_{COM} \frac{1}{4\pi d^2_{PSR}} \varepsilon(i)$$

The BW PSR J1953+1846A in M71



X-ray position
r~0.5"

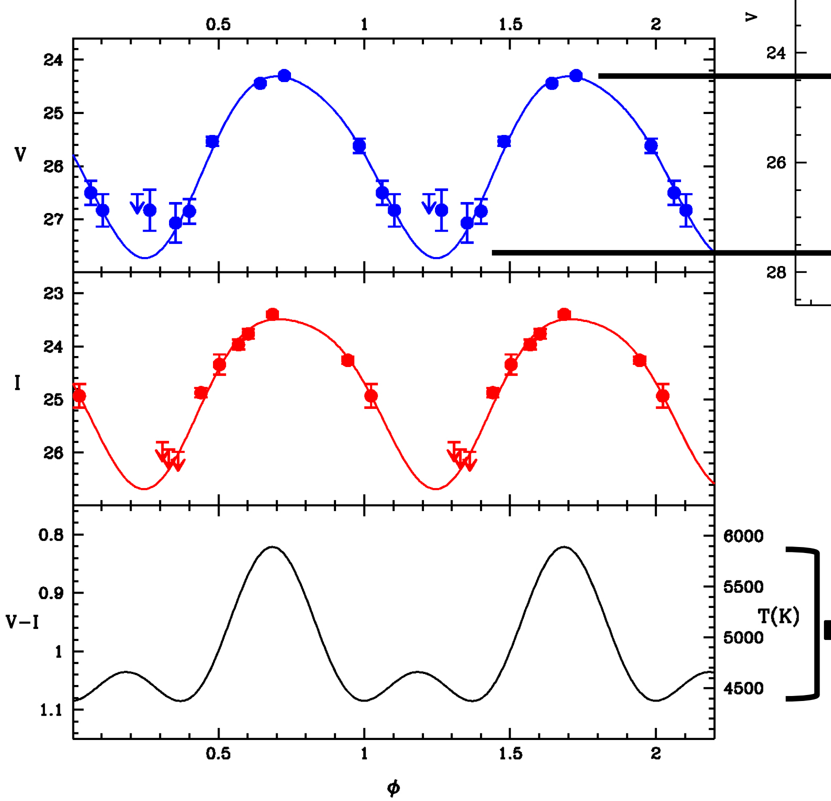
Radio position
r~0.2" (optical astrometric uncertainty)

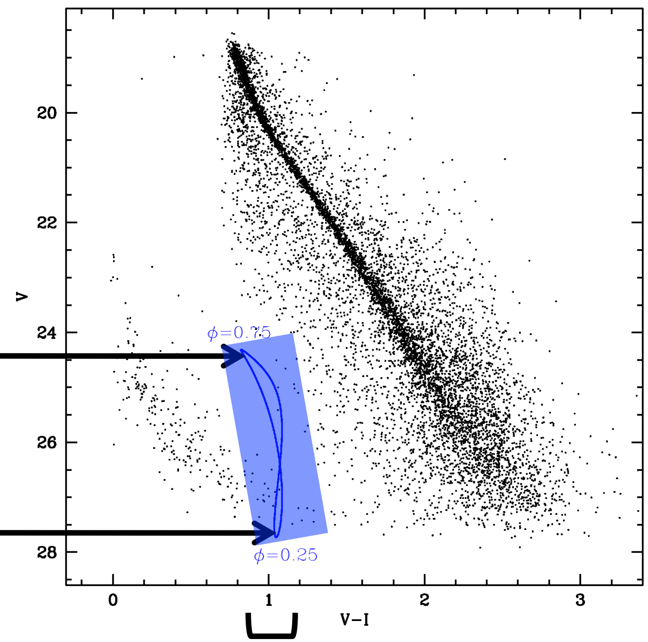
No star detected within the astrometric uncertainty at the PSR superior conjunction

The companion star is visible at the PSR inferior conjunction

The BW PSR J1953+1846A in M71

We built the light curve by fixing the orbital parameters known by radio

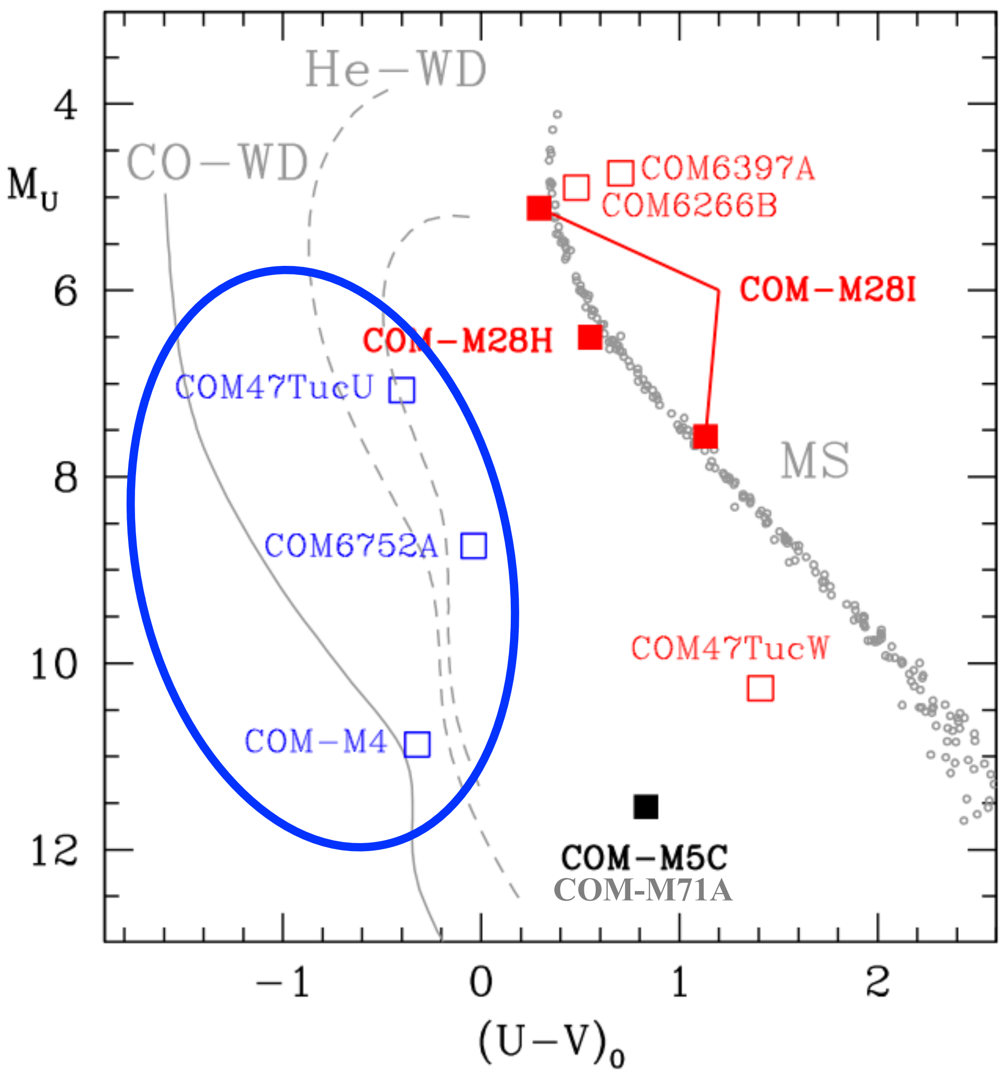




We reported the position in the CMD taking into account the magnitude and the color variations

From the modeling of the light curve it will be possible to constrain some parameters as the inclination angle, the reprocessing efficiency etc…

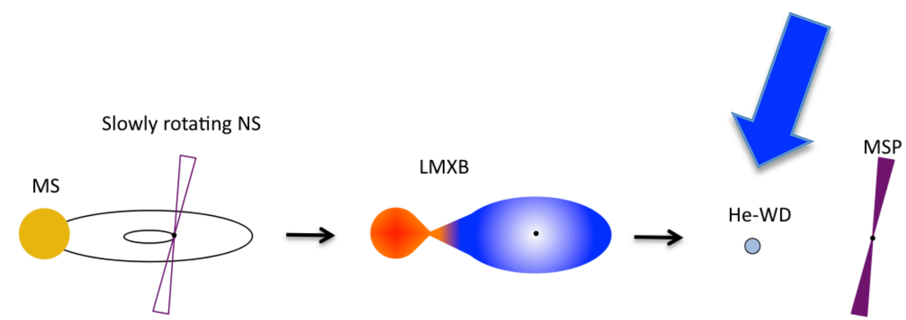
Different types of companions



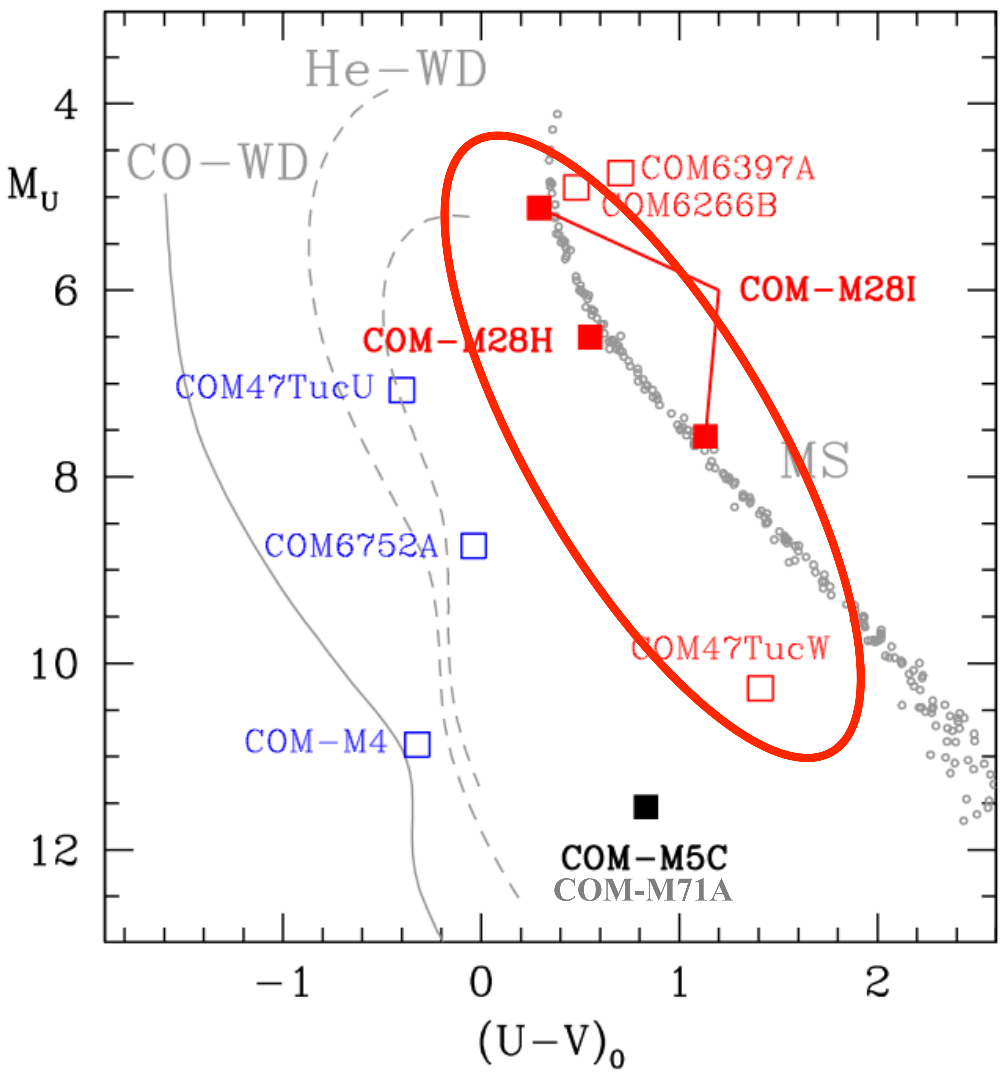
3 WDs
(Edmonds et al. 2001; Ferraro et al. 2003; Bassa et al. 2003; Sigurdsson et al 2003)

CONFIRMATION OF THE RECYCLING SCENARIO:

Low mass WDs:
The "final stage" of the pulsar recycling process

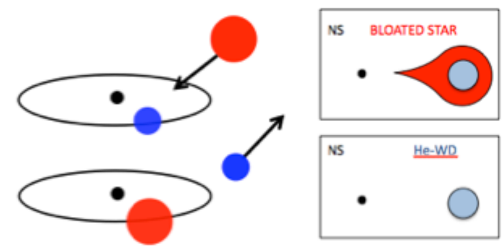


Different types of companions



5 NON Degenerate Objects
(Ferraro et al. 2001; Edmonds et al 2002; Cocozza et al 2008;Pallanca et al. 2010; 2013)

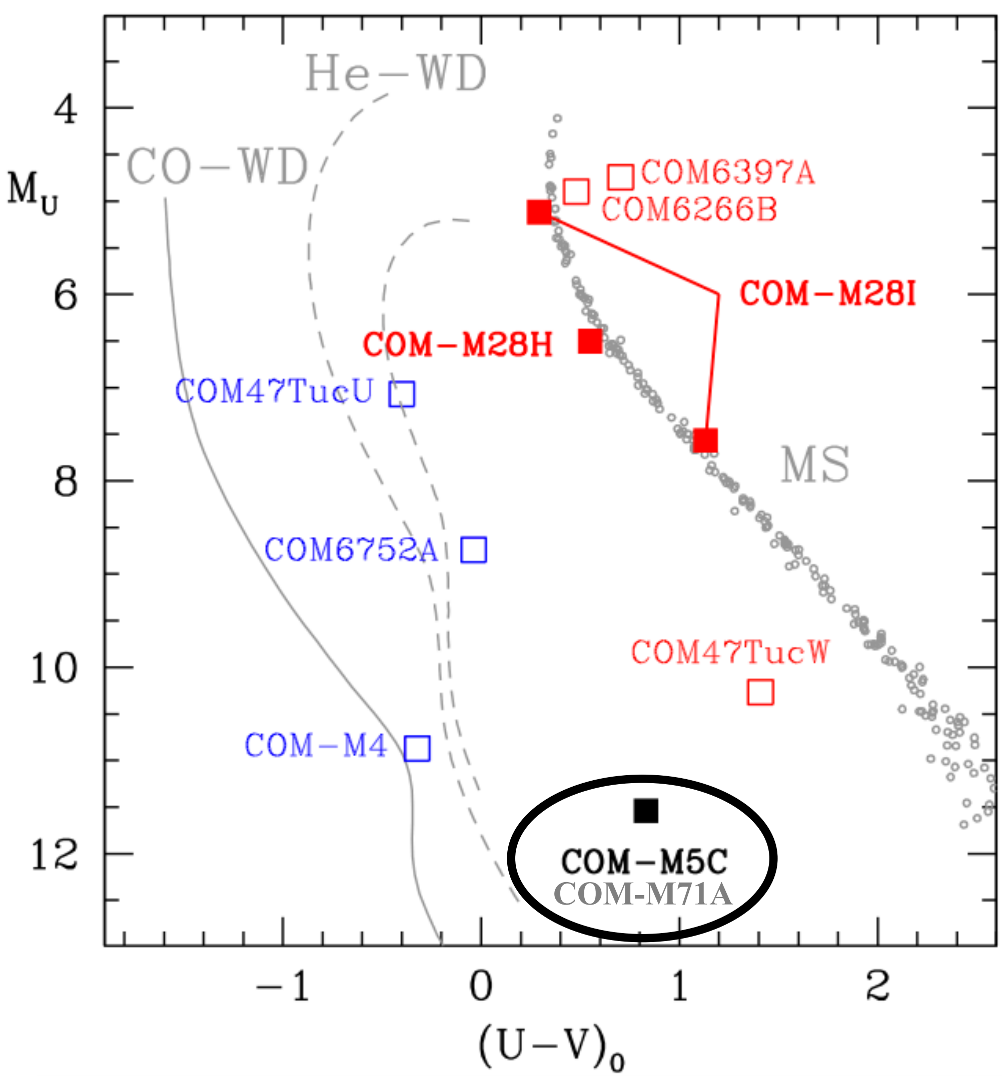
Variables (tidal distortion and/or heating)



EXCHANGE INTERACTION

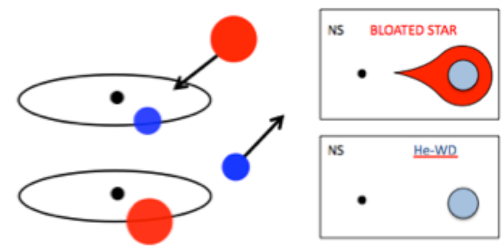
However the increasing number of exotic objects in the GF suggests that **also the evolution of primordial binaries** could lead to the formation of such objects

Different types of companions



2 very low-mass companions
(Pallanca et al. 2014, to be submitted; Cadelano et al., in prepararion).

- Strongly variables
- Likely heated by the PSR flux



EXCHANGE INTERACTION

However the increasing number of exotic objects in the GF suggests that **also the evolution of primordial binaries** could lead to the formation of such objects

Future

HST cycle 19 - GO 12517 - PI: Ferraro

- NGC 6440 — 11 orbits @ UVIS-IR/WFC3
- M5 — 4 orbits @ UVIS/WFC3

→ Pallanca et al. in prep.

HST cycle 20 - GO 12932 - PI: Ferraro

- NGC 6838 — 4 orbits @ WFC/ACS
- NGC 6544 — 6 orbits @ UVIS/WFC3
- M28H — 8 orbits @ G750L/STIS

→ Cadelano's master degree thesis

RECENTLY ACQUIRED

HST cycle 21 - GO 13410 - PI: Pallanca

- NGC 6440 — 15 orbits @ UVIS/WFC3

CURRENTLY ONGOING

HST cycle 22 – Waiting for the TAC decision

- M28I — variability analysis

Thanks for the attention

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www.cosmic-lab.eu

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