Lorentz center

Compact Binaries in Globular Clusters

Workshop: 10-14 September 2012, Leiden, the Netherlands

Optical companions to binary MSPs in Globular Clusters

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Cosmic-Lab

www.cosmic-lab.eu

erc

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

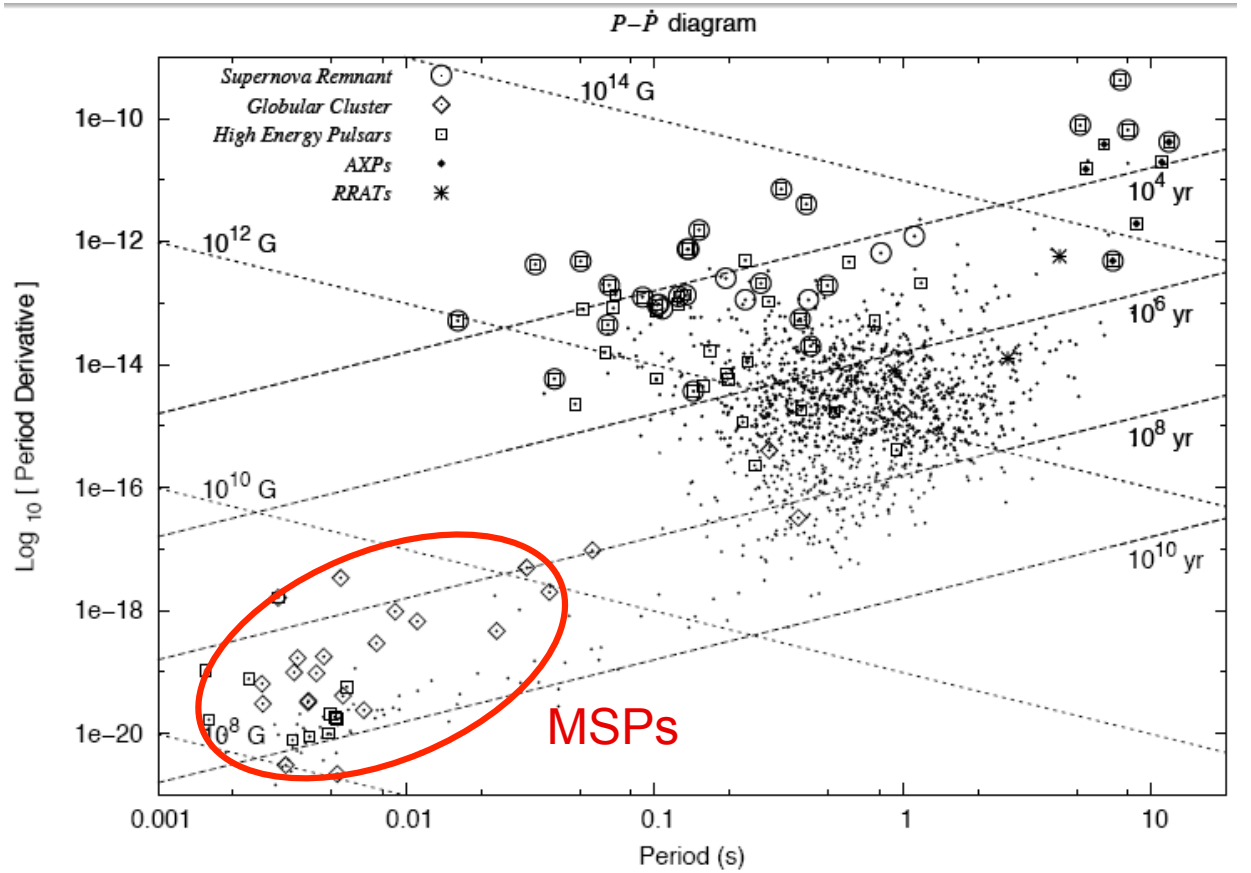
Blue Straggler Stars
Millisecond Pulsars
Intermediate-mass Black Holes

} as probe-particles

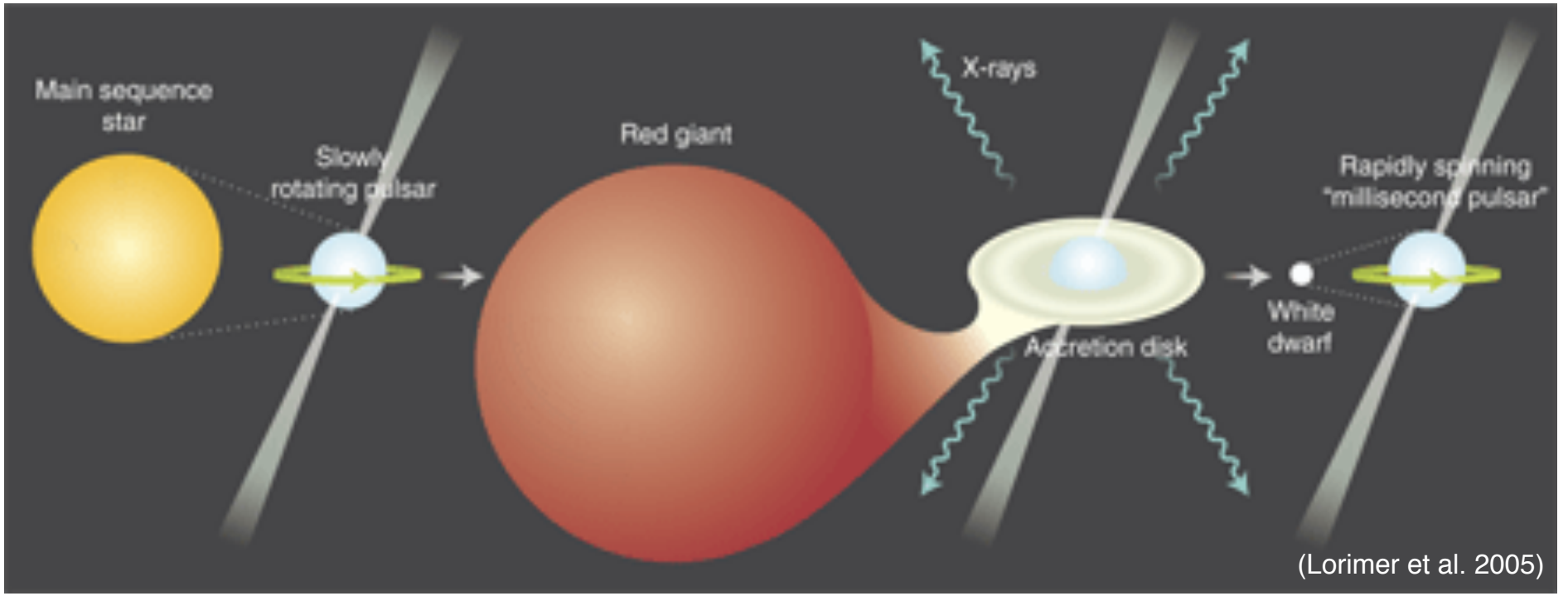
Definition of millisecond pulsars (MSP)

MSPs (recycled-pulsars):

Pulsars with $dP/dt < 10^{-17}$ (OLD) and $P \sim 10^{-3}$ sec (RE-ACCELERATED)



The recycling scenario



Binary system:
NS + evolving companion

mass accretion from an evolving companion spin up the pulsar

fast rotating pulsar (MSP) + an exhausted star

the core of a peeled star = WD

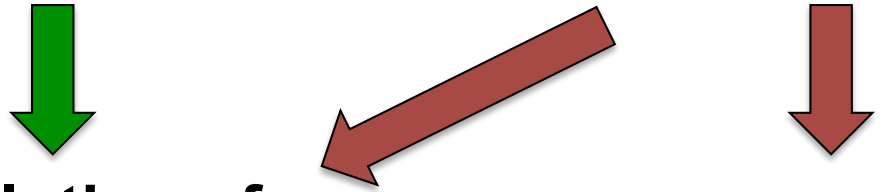
(Bhattacharya et al. 1991)

The MSP population

More than 50% of known MSPs

is found in GCs

Galactic Field **Globular Clusters**



Evolution of primordial binaries

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

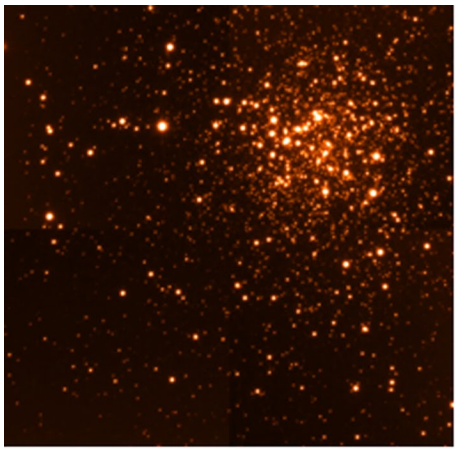
GCs are efficient "furnaces"

Optical companions to binary MSPs

Optical identification of the companion star to binary MSPs

Investigate the recycling mechanism

Could lead to the identification of a very massive NS (6440B - M5B)



Understand the effect of crowded stellar environments on the evolution of binaries

The optical approach

Radio

Very Accurate position

Orbital parameters

Orbital period
Time ascending node

PSR Mass function

Total mass

The optical approach

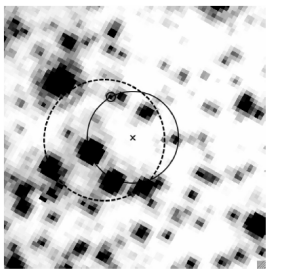
Radio

Optical

Photometry

Positional coincidence

Very Accurate position →



High resolution

CMD position
(Out of sequence)

Deep

Nature and physical parameters

Orbital parameters

Orbital period
Time ascending node

PSR Mass function

↔ Light curve
(Variability in agreement with the orbital motion)
i, M_{COM}, M_{PSR}

Multiple epochs

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

The optical approach

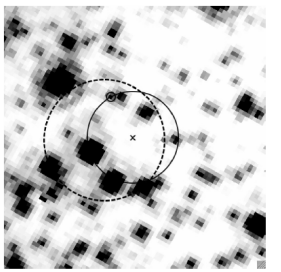
Radio

Optical

Photometry

Positional coincidence

Very Accurate position →



CMD position
(Out of sequence)

Nature and physical parameters

Orbital parameters

Orbital period
Time ascending node

PSR Mass function

↔ Light curve
(Variability in agreement with the orbital motion)
i, M_{COM}, M_{PSR}

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

IF BRIGHT ENOUGH

The optical approach

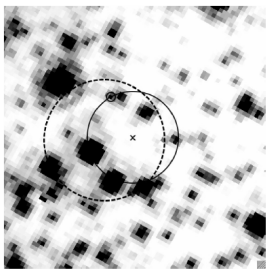
Radio

Optical

Photometry **Spectroscopy**

Positional coincidence

Very Accurate position →



CMD position
(Out of sequence)

Radial Velocity

COM mass function

+

PSR mass function

↓

Orbital parameters

Orbital period
Time ascending node

PSR Mass function

Nature and physical parameters

Light curve
(Variability in agreement with the orbital motion)

i, M_{COM}, M_{PSR}

Mass ratio

System solved

Chemical abundances

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

The state of the art

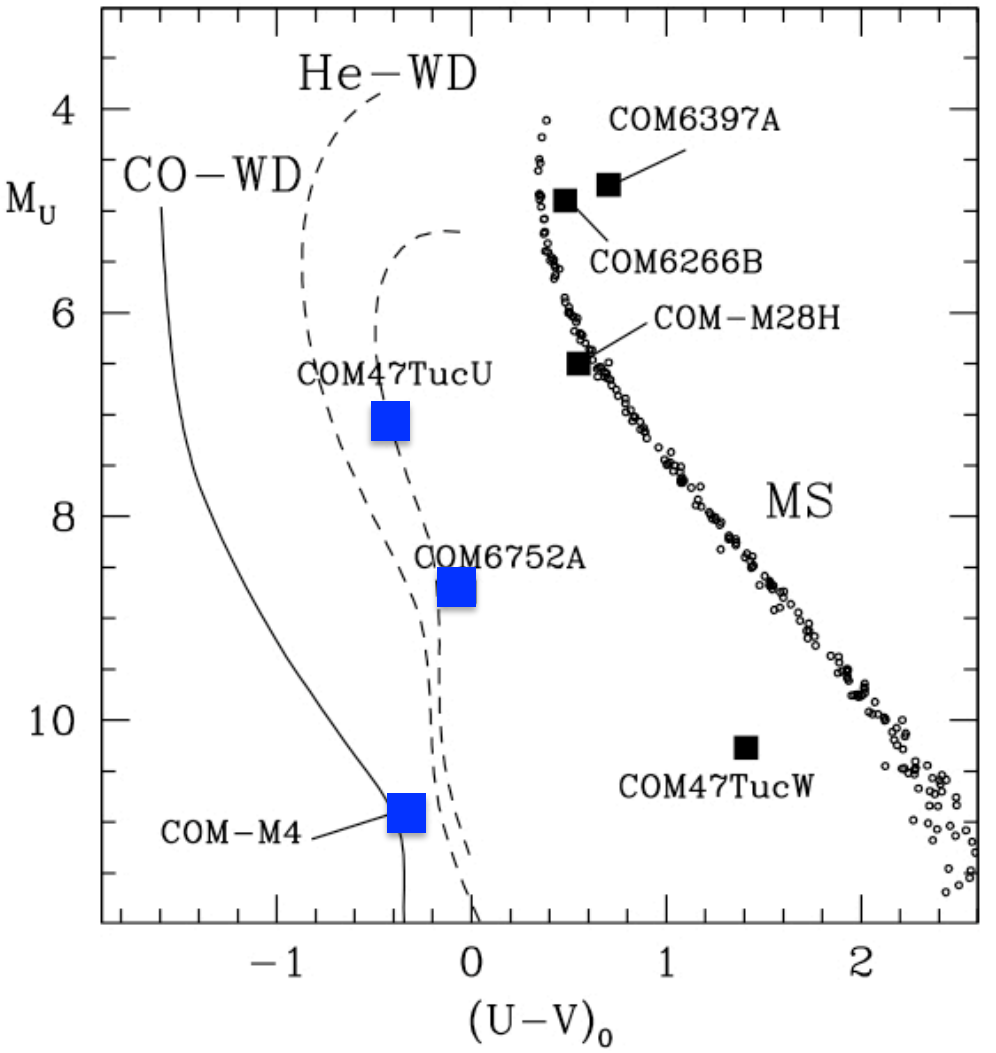
~80 binary MSPs in GCs

7 (<10%) identified companions:

PSR J0024-7203U – Edmonds et al. 2001
PSR B1620-26 – Sigurdsson et al. 2003
PSR J1911-5958A – Ferraro et al. 2003; Bassa et al. 2003

PSR J1740-5340A – Ferraro et al al. 2001
PSR J0024-7204W – Edmonds et al. 2002
PSR J1701-3006B – Cocozza et al. 2008
PSR J1824-2452H – Pallanca et al. 2010

He-WD companions



47TucU – The first identified companion

Edmonds et al. (2001)

M4 – A triple system

Sigurdsson et al. (2003)

6752A – The most off-centre ever observed in a cluster

Ferraro et al. (2003);
Bassa et al. (2003)

Ejected from the core?
Single/double BH?

(Colpi et al. 2002, 2003)

The state of the art

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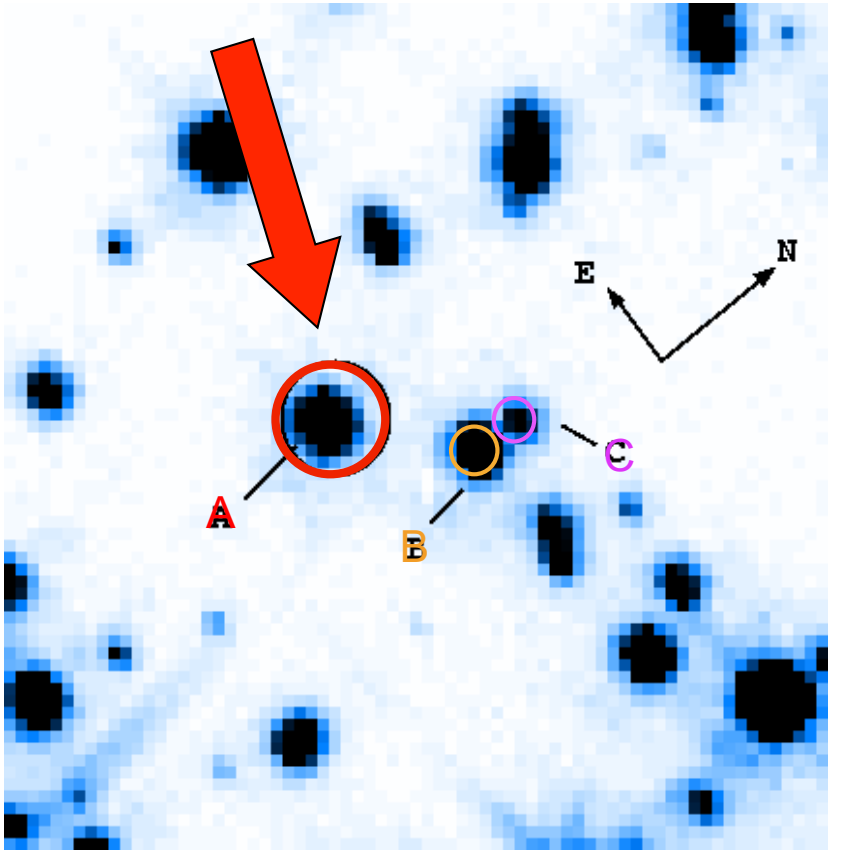
COM 6397A: the first surprise

Member of a binary system with P_b = 1.35 d

Eclipse of the radio signal for about 40% of the orbit *(D'amico et al. 2001)*

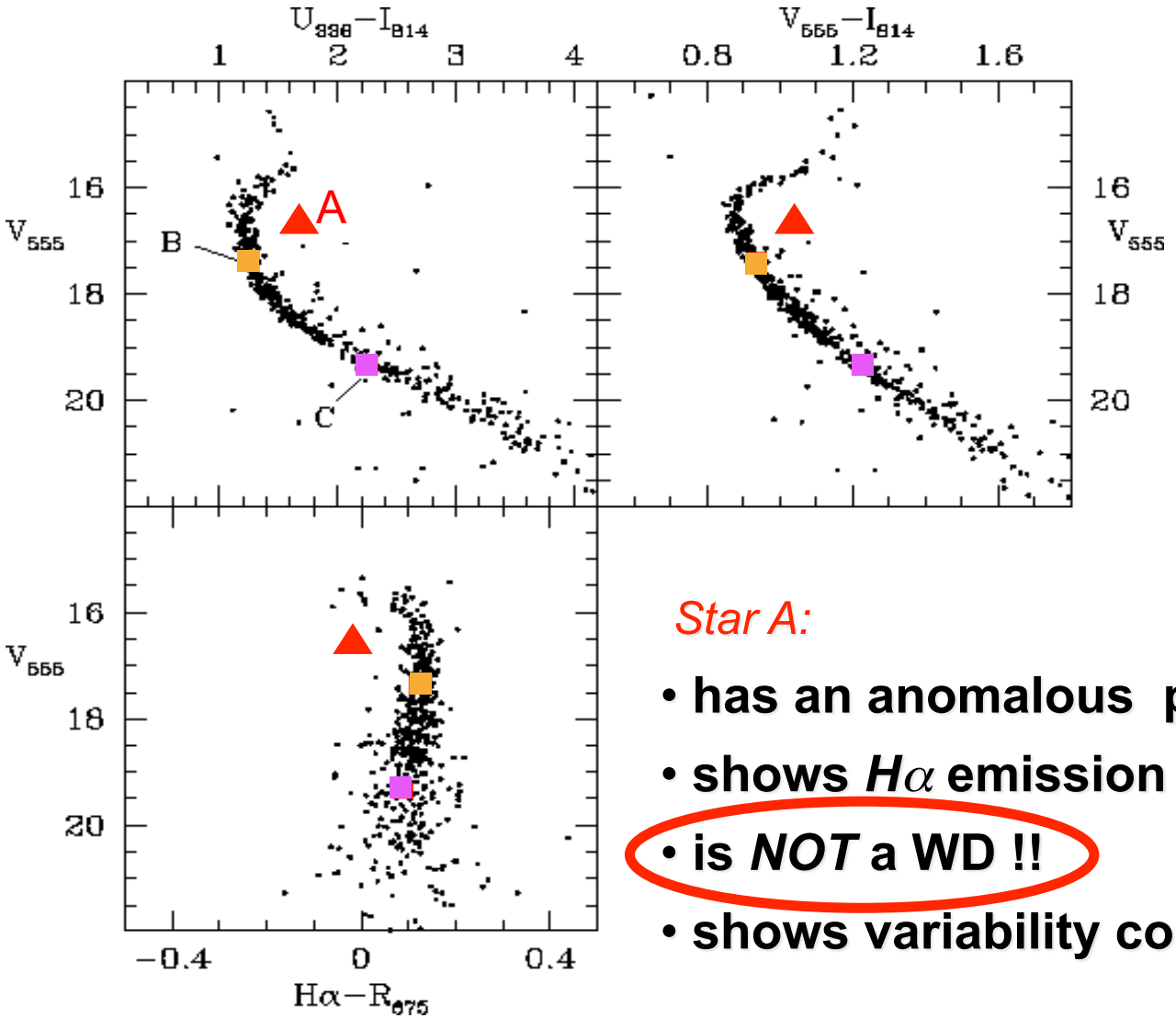
NS orbiting within a large envelope of matter released by the companion

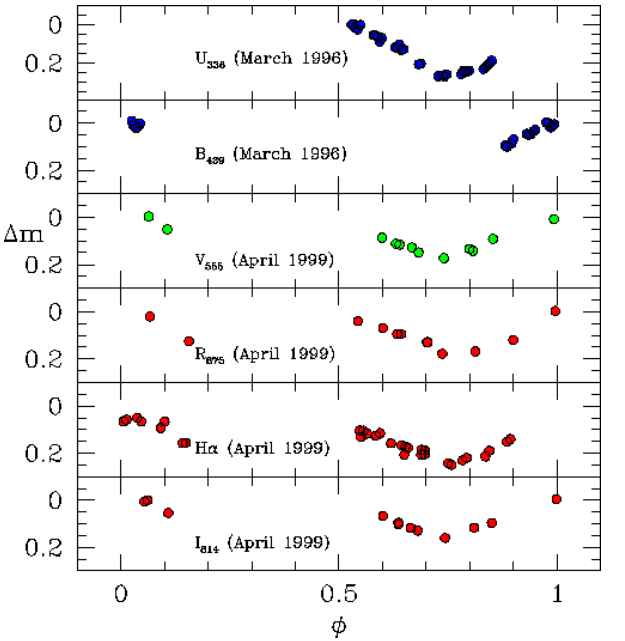
Star A:
a bright variable star nearly coincident with the PSR nominal position



(Ferraro et al. 2001)

COM 6397A: the first surprise





Star A:

- **has an anomalous position in the CMD**
- **shows *Hα* emission**
- **is *NOT* a WD !!**
- **shows variability consistent with the P_b**

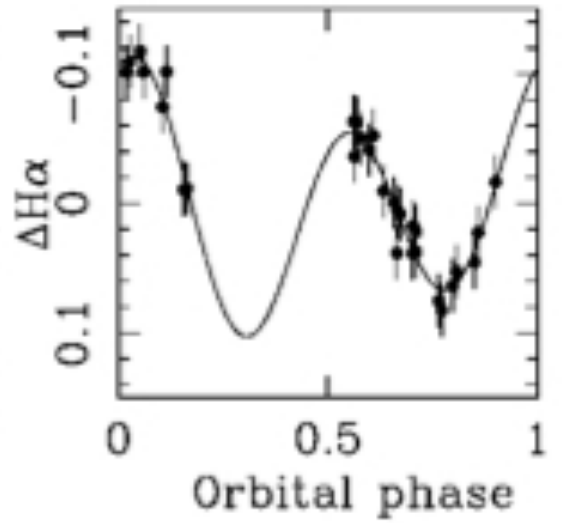
COM 6397A: the first surprise

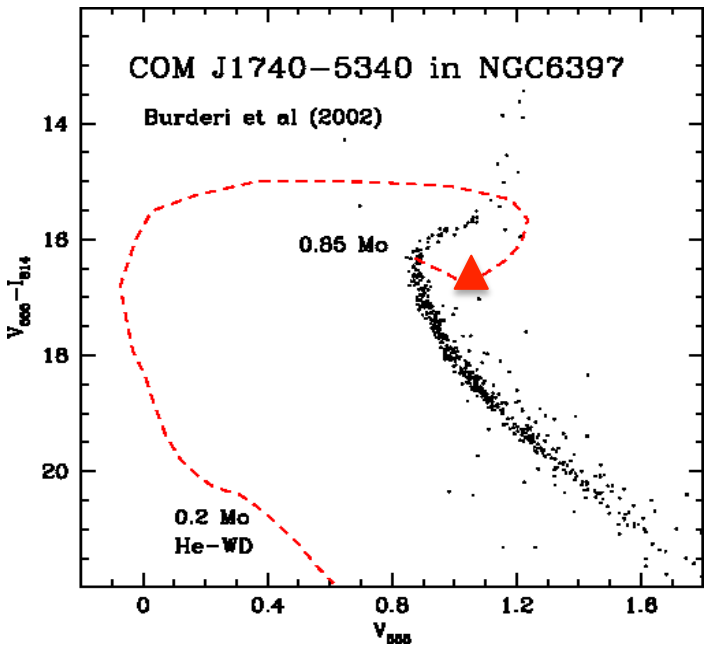
➢ optical light curve shape:

It is *tidally distorted* and loosing mass from its Roche lobe

➢ anomalies in the radio signals + Hα emission:

presence of *ionized matter* along the line of sight





It is consistent with a slightly evolved TO star orbiting the NS and loosing mass

The evolution will generate a He-WD

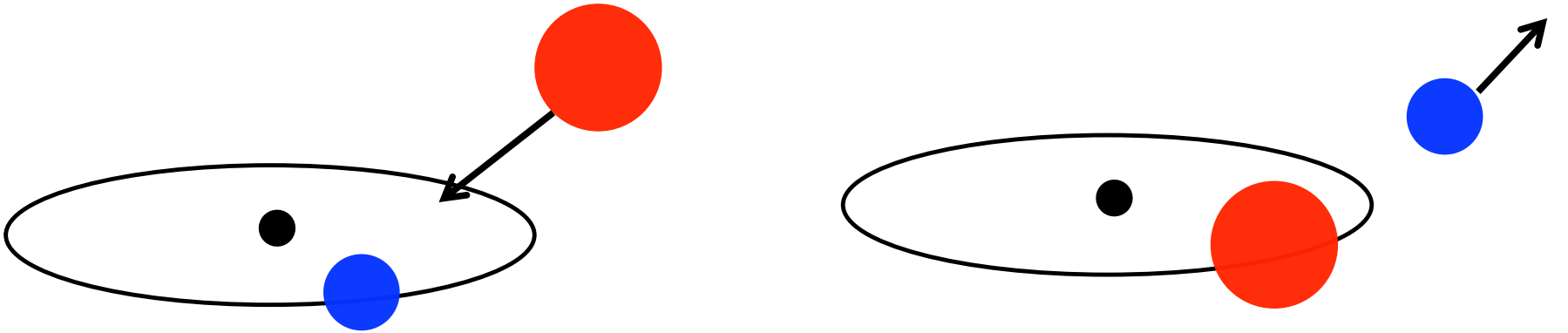
(Burderi et al. 2002)

COM 6397A: the first surprise

Did Star A spin up the PSR ?
(if so, we are observing a JUST-BORN MSP!!!)

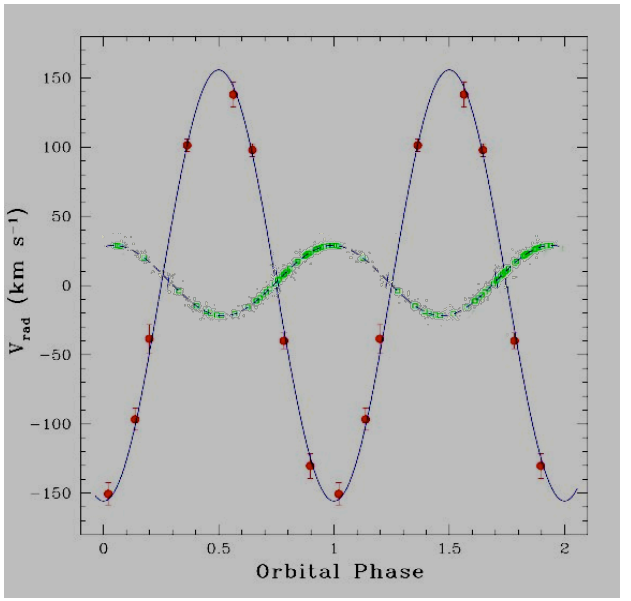
or

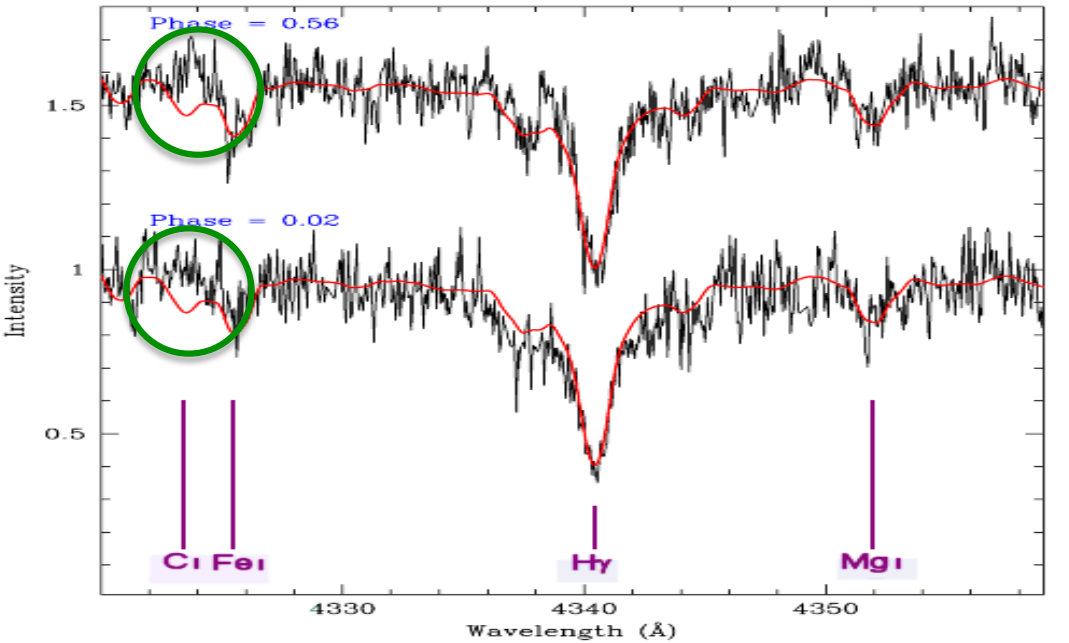
Is this peculiar system the end-product
of an exchange interaction
between the original binary
& an isolated MS star ?



COM 6397A: the first surprise

*B*right object (V=16.5) => High-resolution spectroscopy with UVES/VLT





Mass ratio q=5.85±0.13
V_{rad} amplitude of Star A: 155.8±3.6 km/s

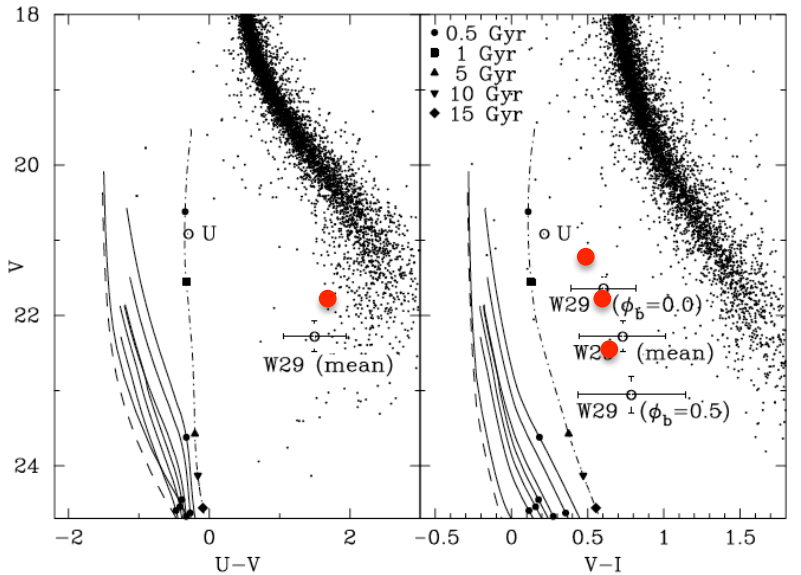
Mass of MSP	1.30 : 1.90 $M_\odot$
Mass of Star A	0.22 : 0.32 $M_\odot$
Inclination angle	56 : 47 deg
Orbital separation	6.1 : 7.0 $R_\odot$
Roche lobe radius	1.5 : 1.7 $R_\odot$

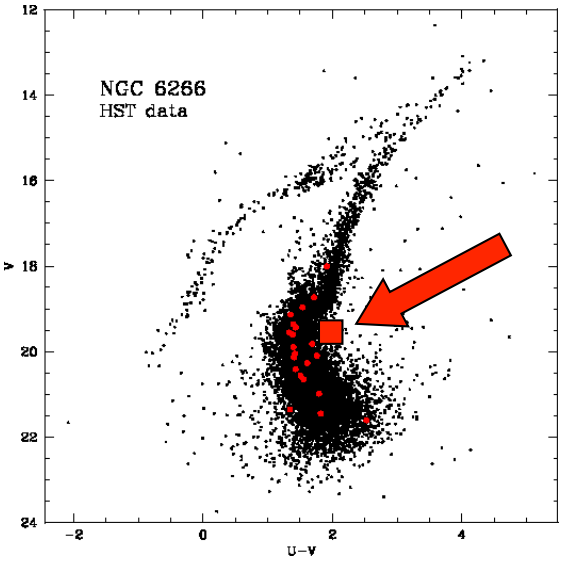
STAR A has the same chemical composition of SGB stars

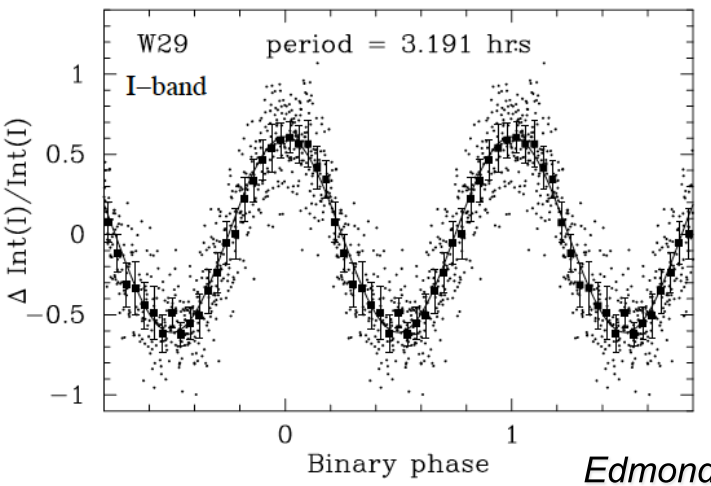
No C in its atmosphere => material processed by CNO-burning => deeply peeled star

(Ferraro et al., 2002; Sabbi et al., 2003)

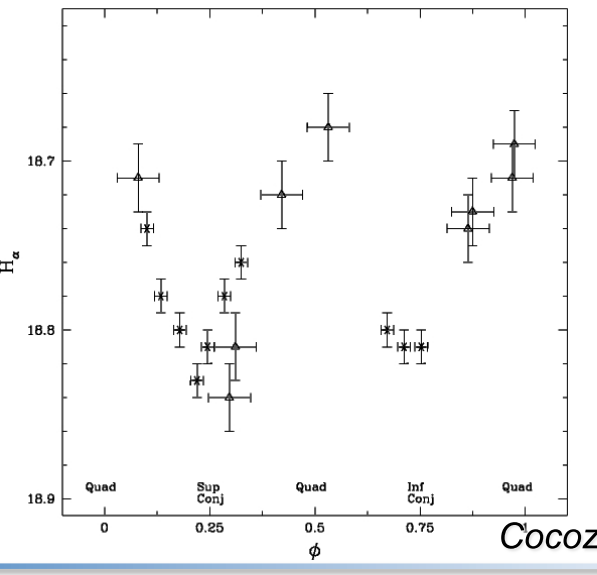
COM 47TucW - COM 6266B





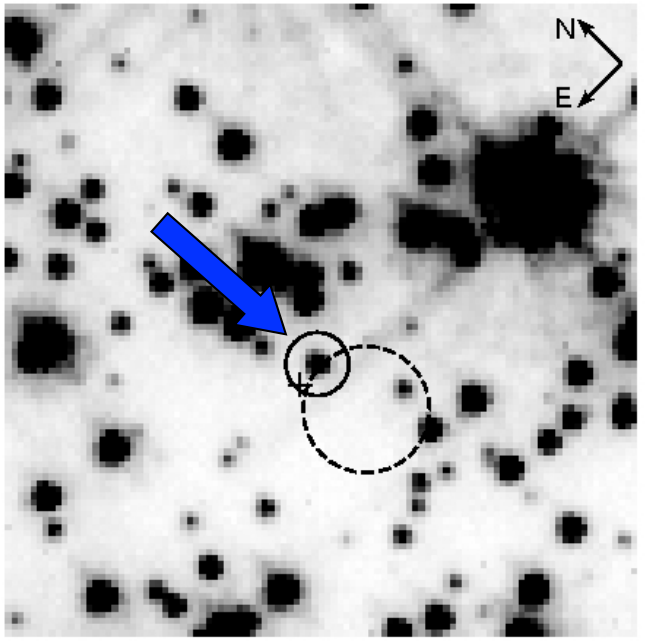


Edmonds et al. (2002)



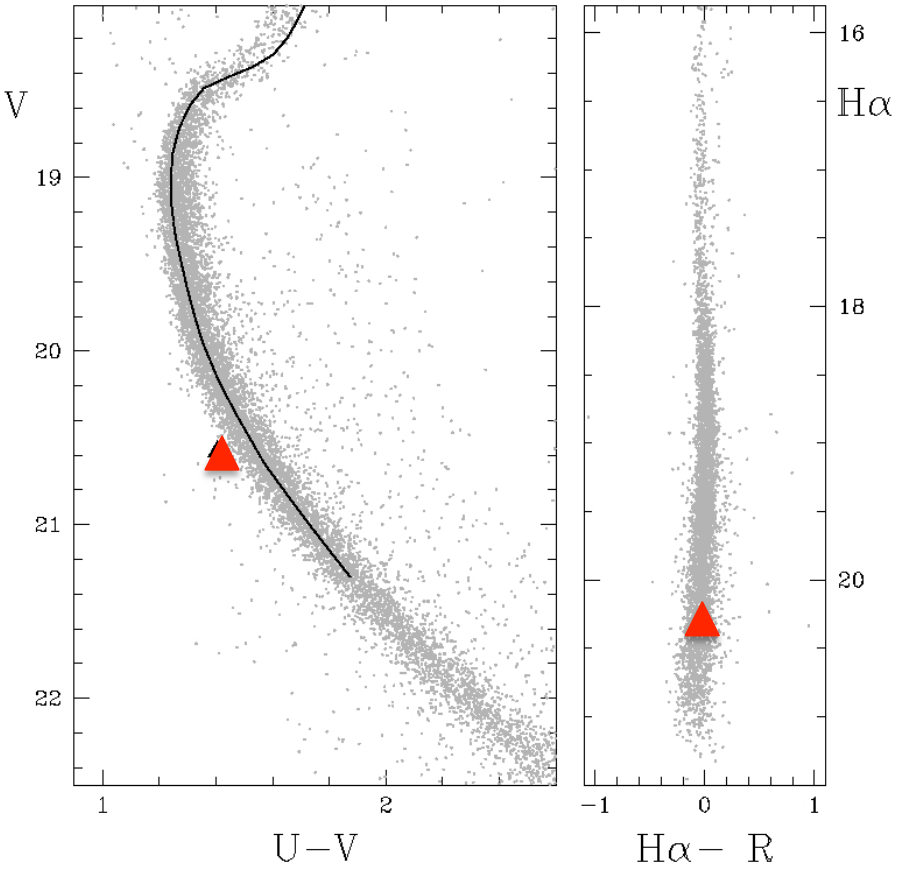
Cocozza et al (2008)

COM M28H: an exchange interaction?



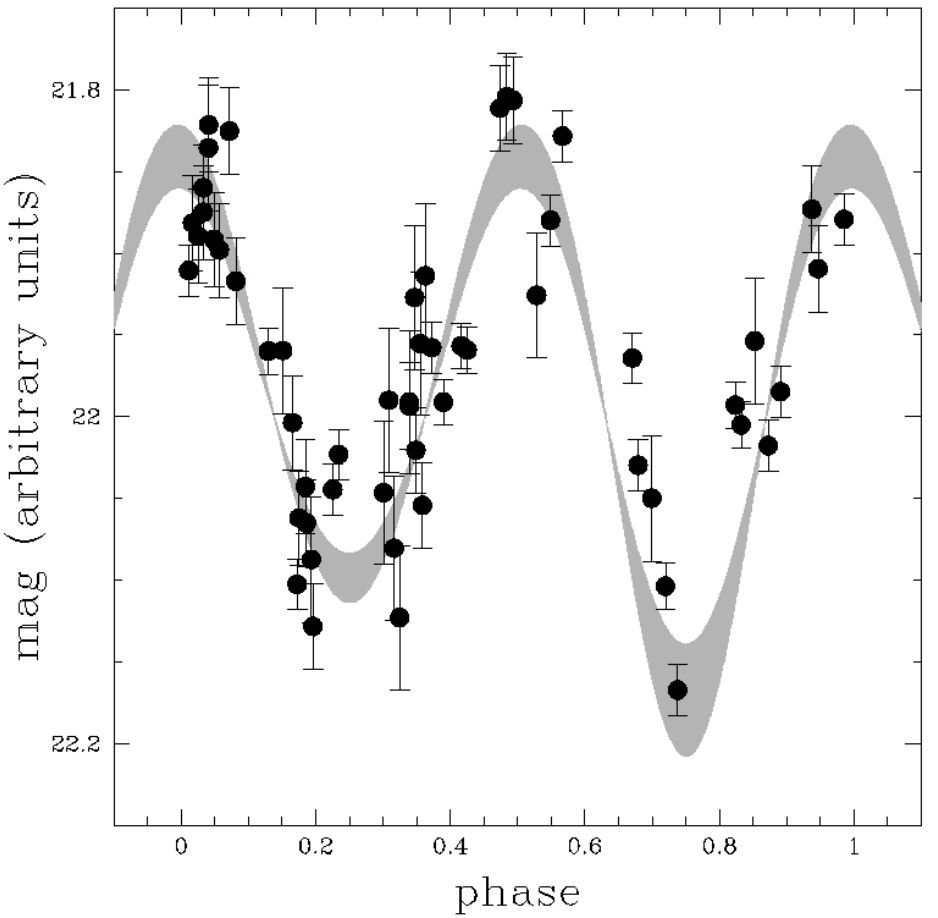
Another
NOT-DEGENERATE
companion

The companion star is located at *0.17" from the radio source* (+) and ~0.4" from the X-ray source (dashed circle)



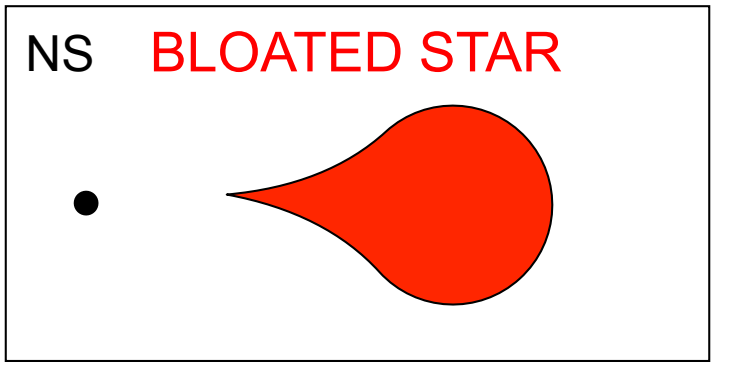
COM M28H: an exchange interaction?

The variability is associated with the pulsar binary motion

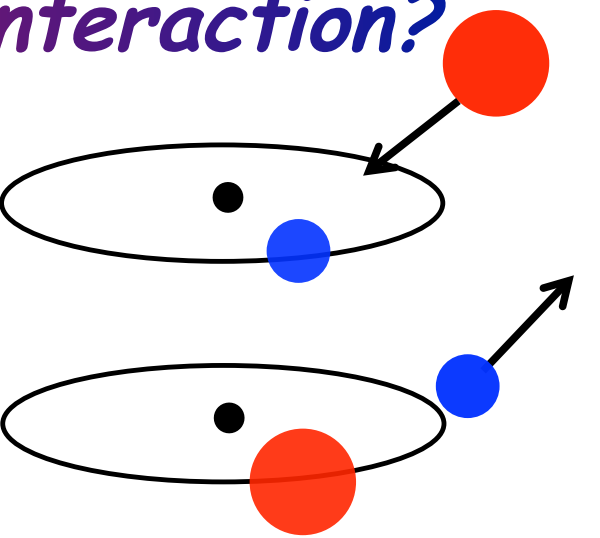


Two distinct and asymmetric minima

Such a shape is a clear signature of ellipsoidal variations induced by the NS tidal field on a highly perturbed bloated star



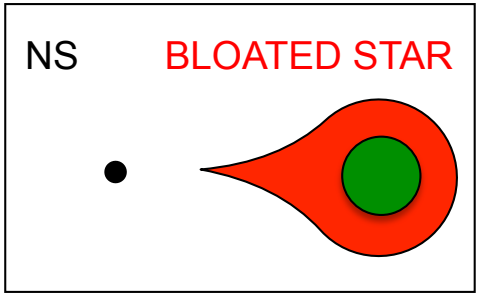
COM M28H: an exchange interaction?

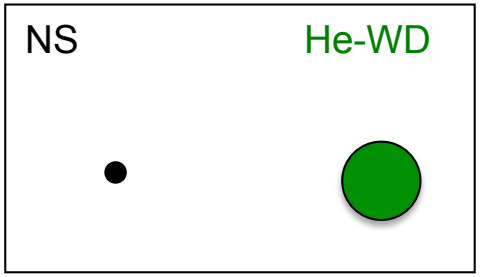


M28H is outside the cluster core

Such an offset position may suggest that the NS was recycled by another companion

The new companion started to suffer heavy perturbations (bloating, mass loss…) induced by the MSP and we currently observe it as COM-M28H



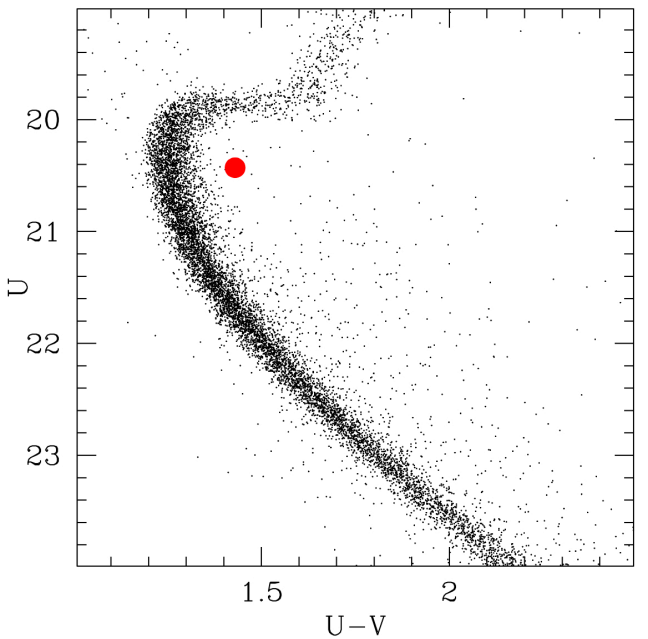


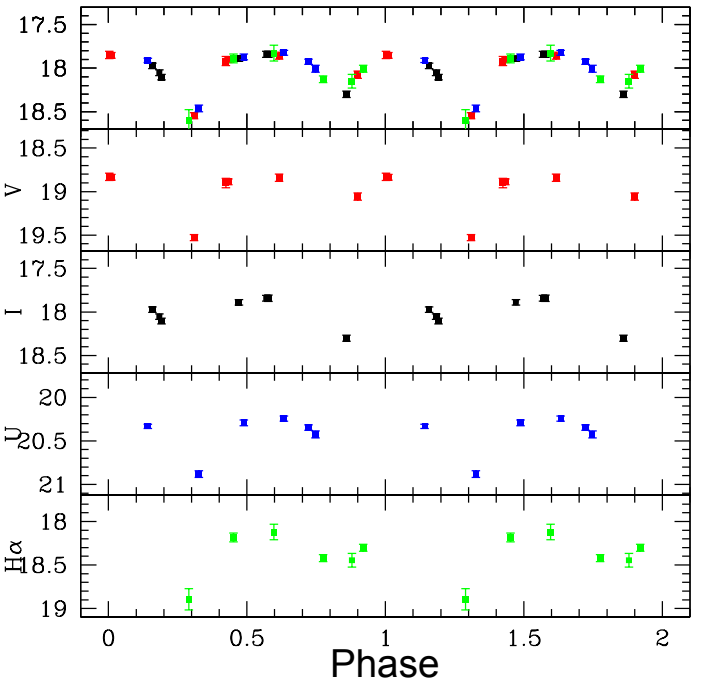
It eventually will become a helium WD

Work in progress

COM M28I: a candidate companion

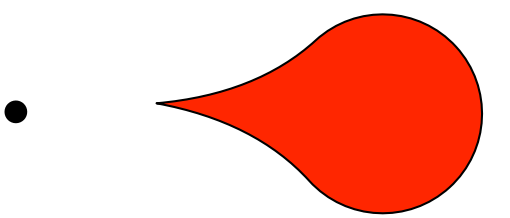
No radio position !
Eclipsing system
P_b~0.459 d



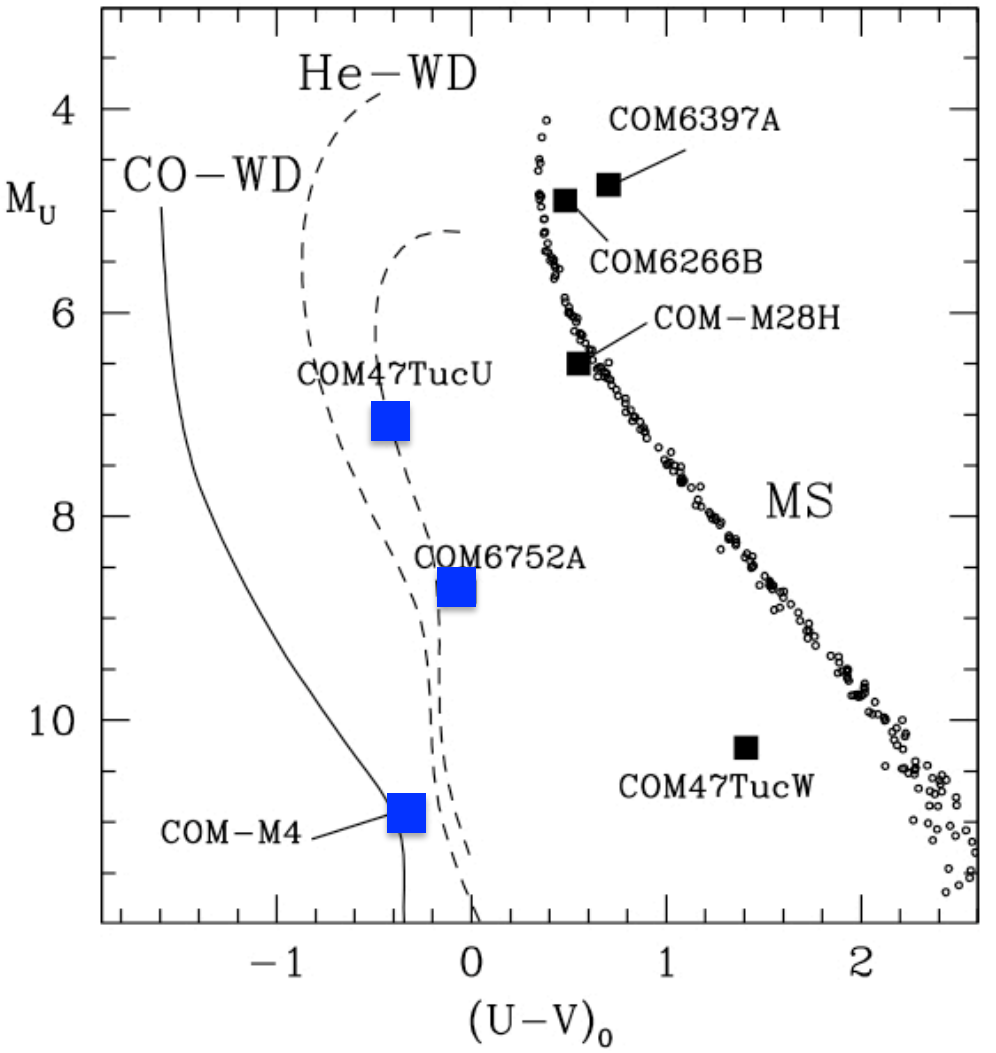


Spectroscopical analysis ?

NS BLOATED STAR ?



Conclusions



7 companions in 6 GCs

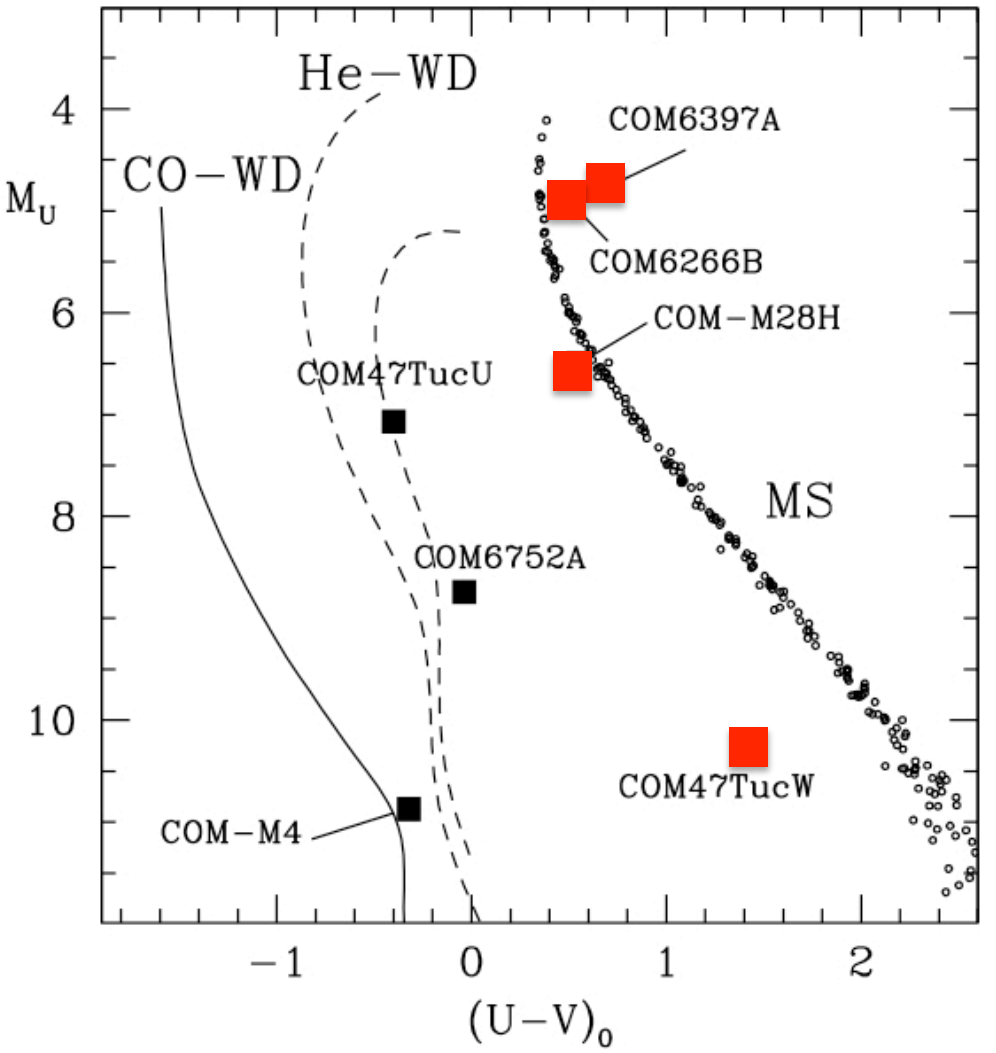
3 He WD

(Edmonds et al. 2001; Ferraro et al. 2003; Sigurdsson et al 2003)

CONFIRMATION OF THE RECYCLING SCENARIO:

low mass He-WD is the "final stage" of the pulsar recycling process

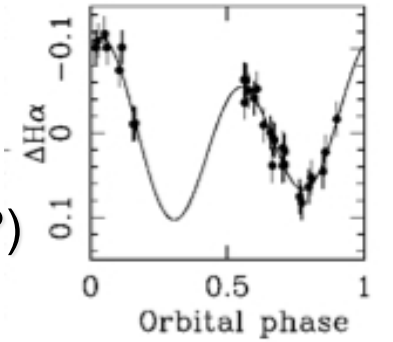
Conclusions



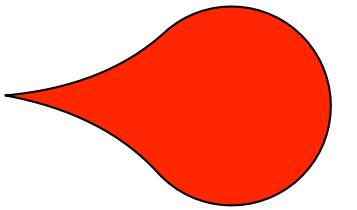
7 companions in 6 GCs

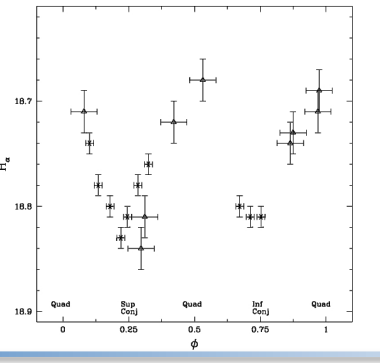
1 low-mass MS

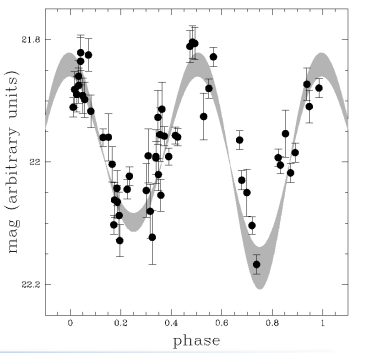
3 deformed MS
(pre He-WD stage?)



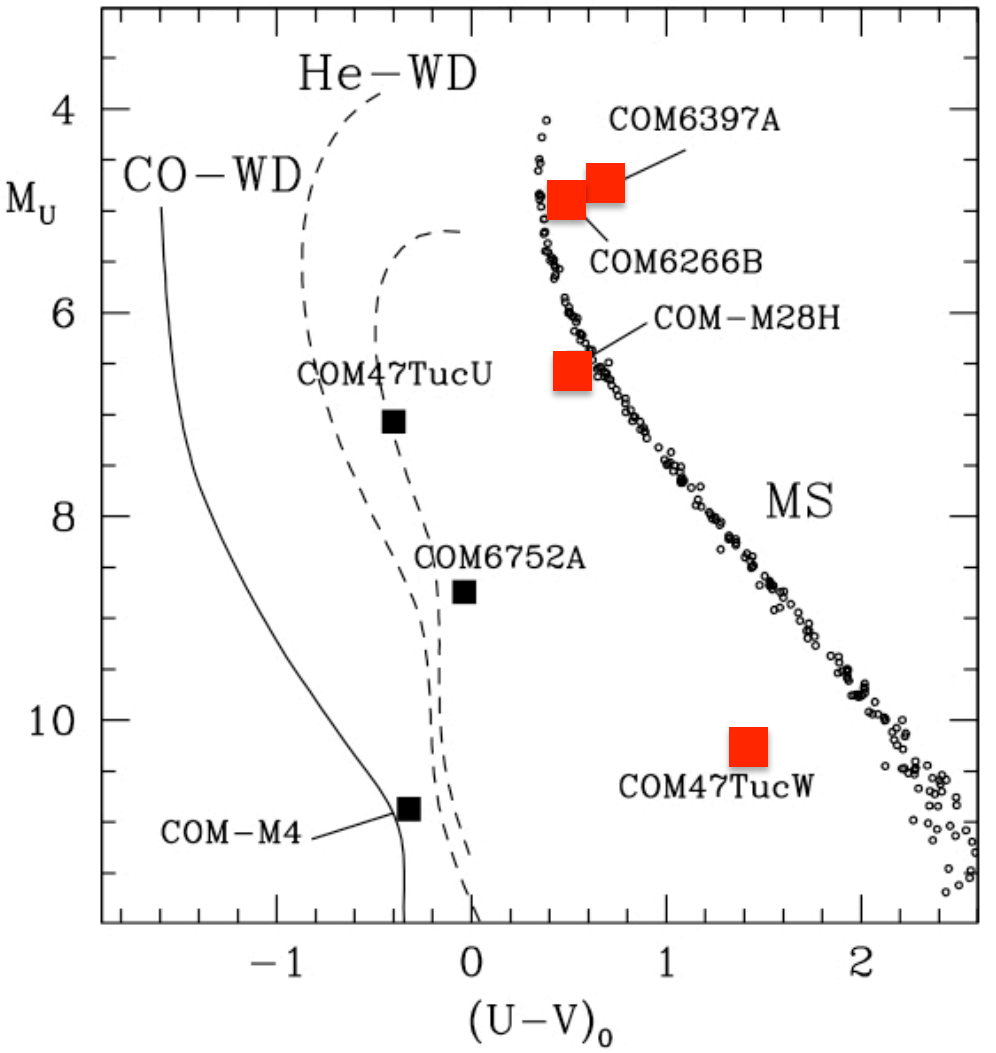
NS BLOATED STAR







Conclusions



7 companions in 6 GCs

4 NOT Degenerate Objects
(Ferraro et al. 2001; Edmonds et al 2002; Cocozza et al 2008; Pallanca et al. 2010).

EXCHANGE INTERACTIONS?
the high-density enviroment favours exchange interactions

Future

HST cycle 19 - GO 12517 - PI: Ferraro

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

ALREADY ACQUIRED

HST cycle 20 - GO 12932 - PI: Ferraro

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

SCHEDULED FOR THE END OF 2013

Visit our web-site: **www.cosmic-lab.eu**

The End