

CNOC VIII - Ferrara - Palazzo Bevilacqua Costabili - 17-19 Settembre 2013

# Optical companions to binary Millisecond Pulsars in Globular Cluster

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Ferrara - September 19, 2013



- ✦ 5-year project (web site at [www.cosmic-lab.eu](http://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

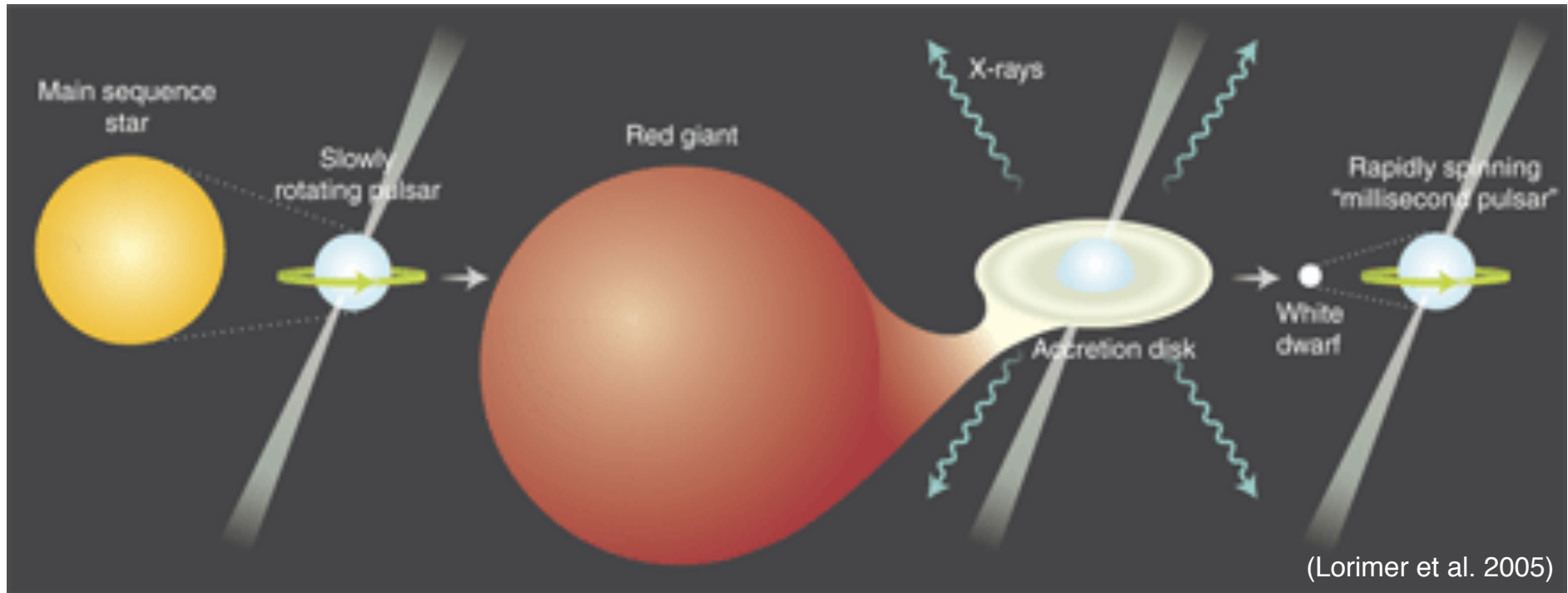
**Blue Straggler Stars**

**Millisecond Pulsars**

**Intermediate-mass Black Holes**

} as probe-particles

# The 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)

# MSPs in Globular Clusters

More than 50% of known MSPs is found in GCs

Galactic Field

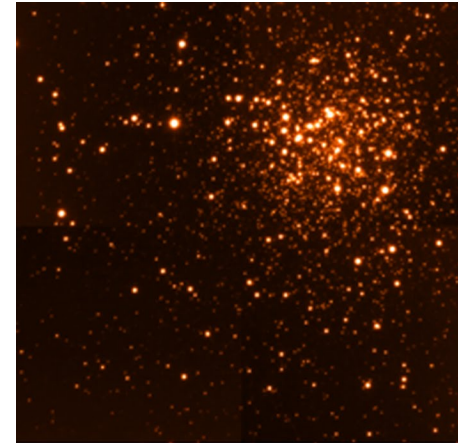


Evolution of  
primordial binaries

Globular Clusters



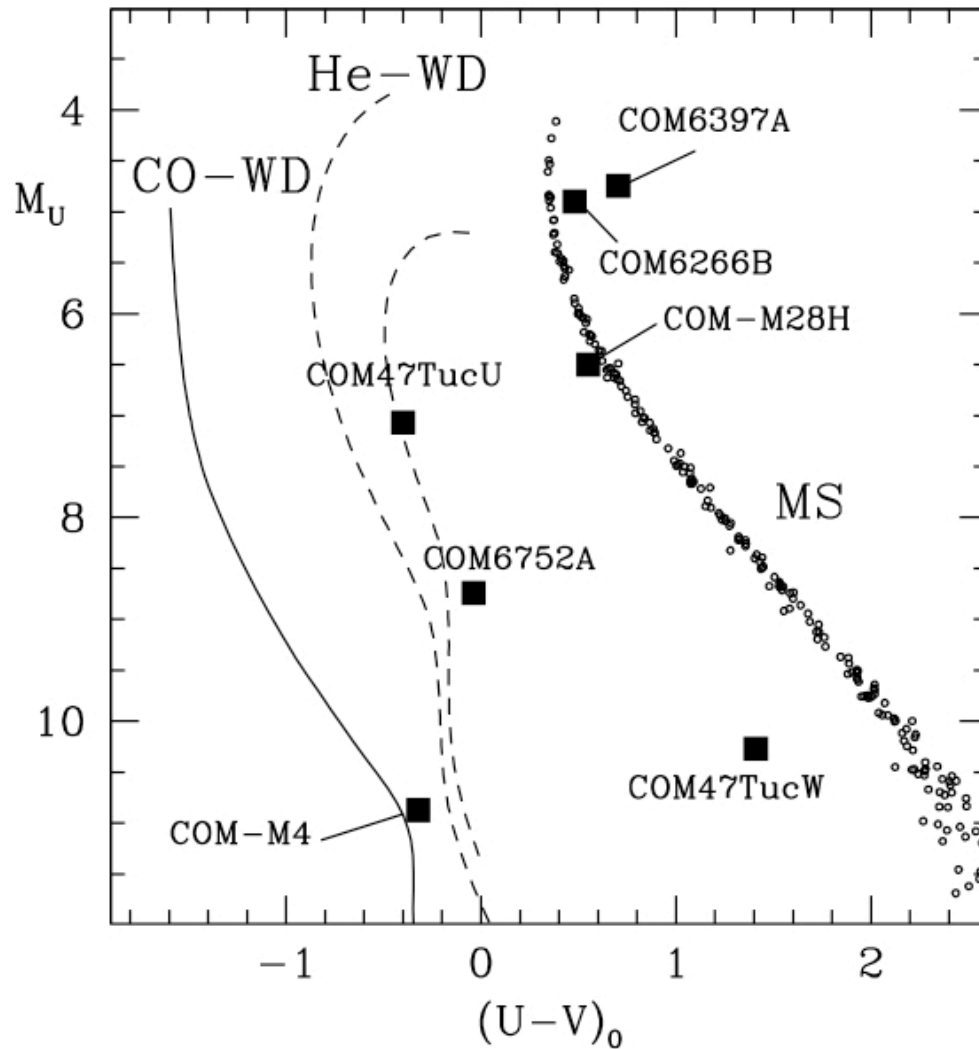
**Dynamical interactions** can  
promote the formation of  
binaries suitable for recycling  
NSs into MSPs



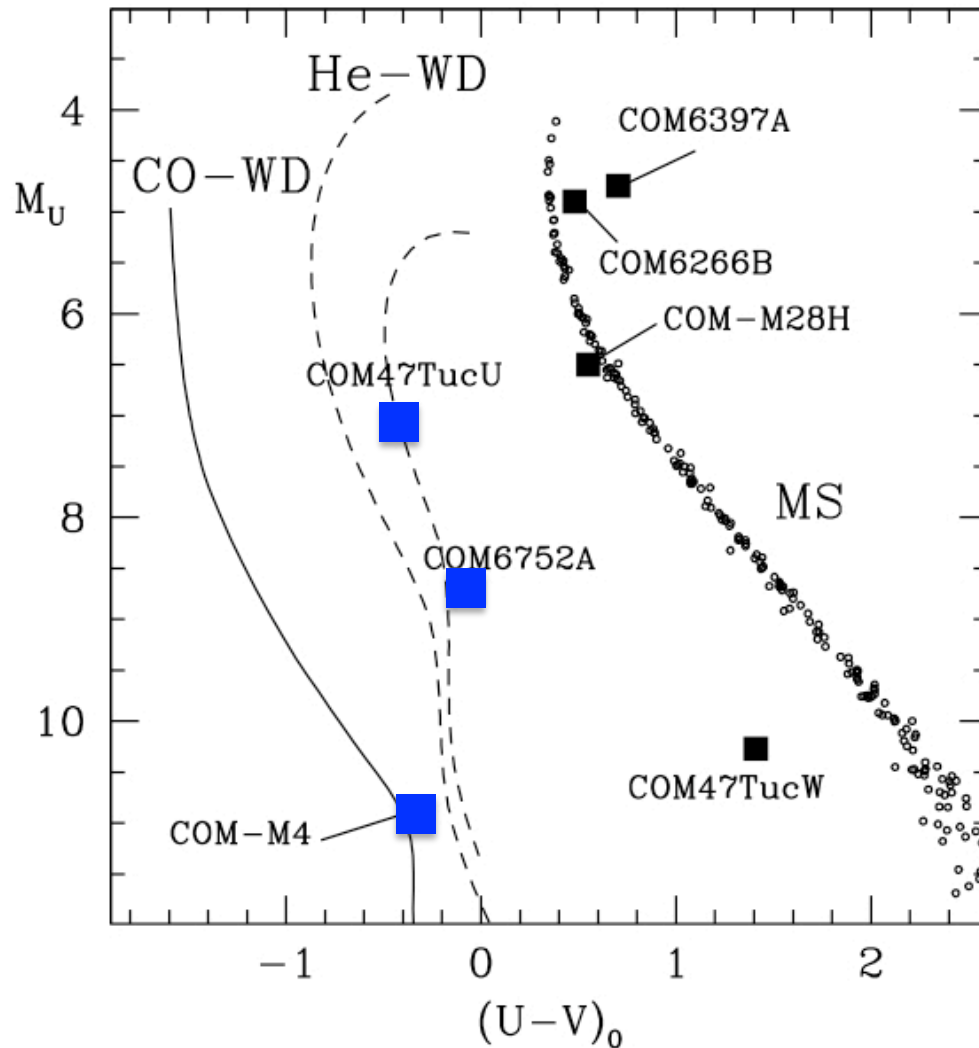
The study of the optical  
companions is crucial to  
understand how  
dynamical interactions  
could modify the standard  
outcome of the recycling  
scenario



# The state of the art



# The state of the art

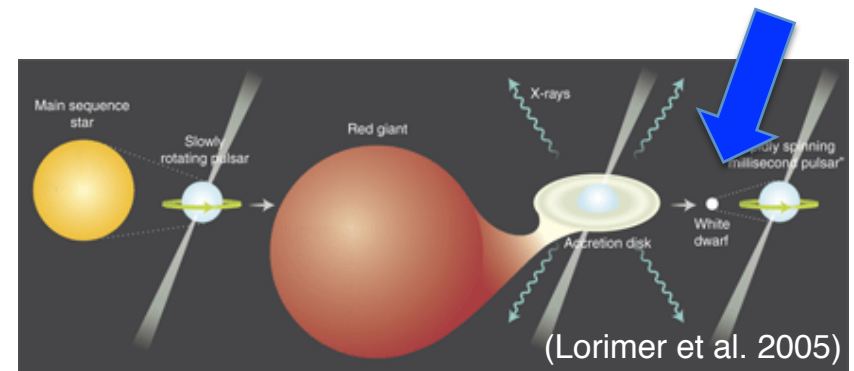


## 3 He WD

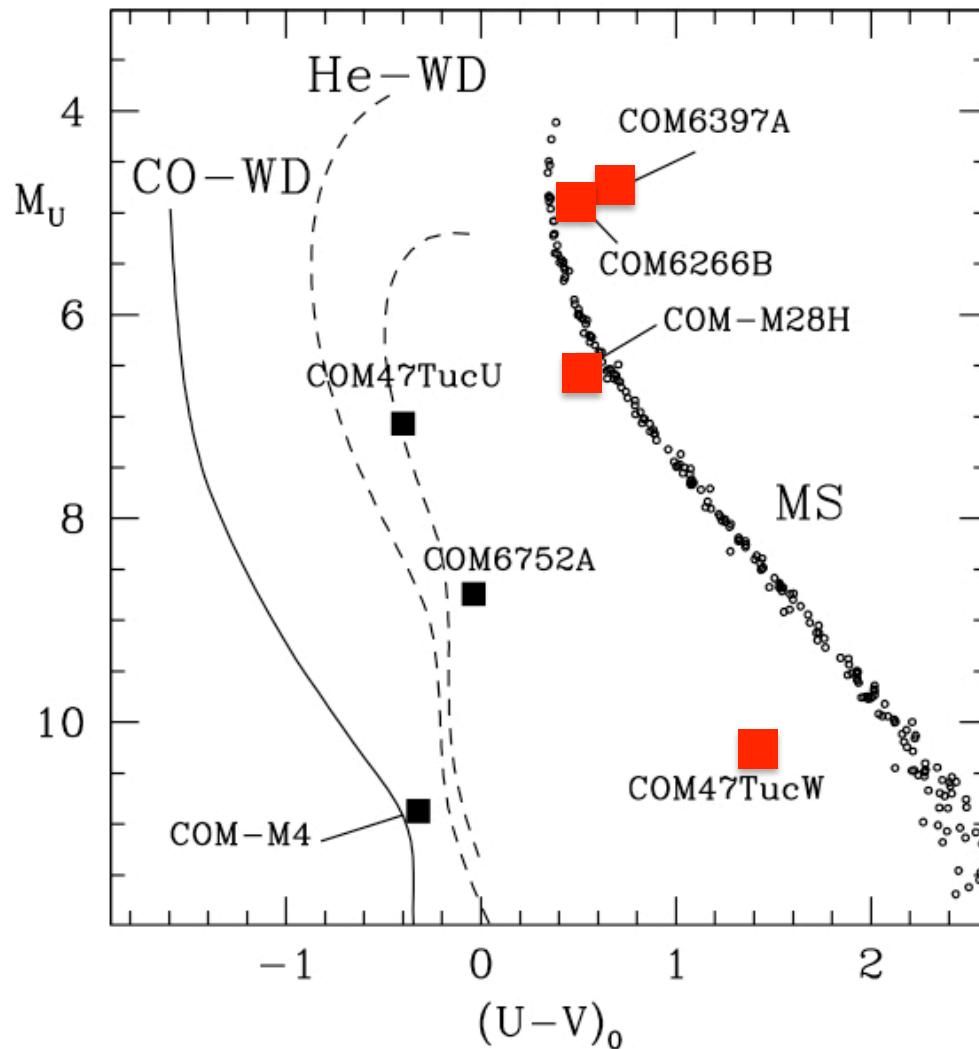
(Edmonds et al. 2001; Ferraro et al. 2003; Sigurdsson et al. 2003)

## CONFIRMATION OF THE RECYCLING SCENARIO:

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

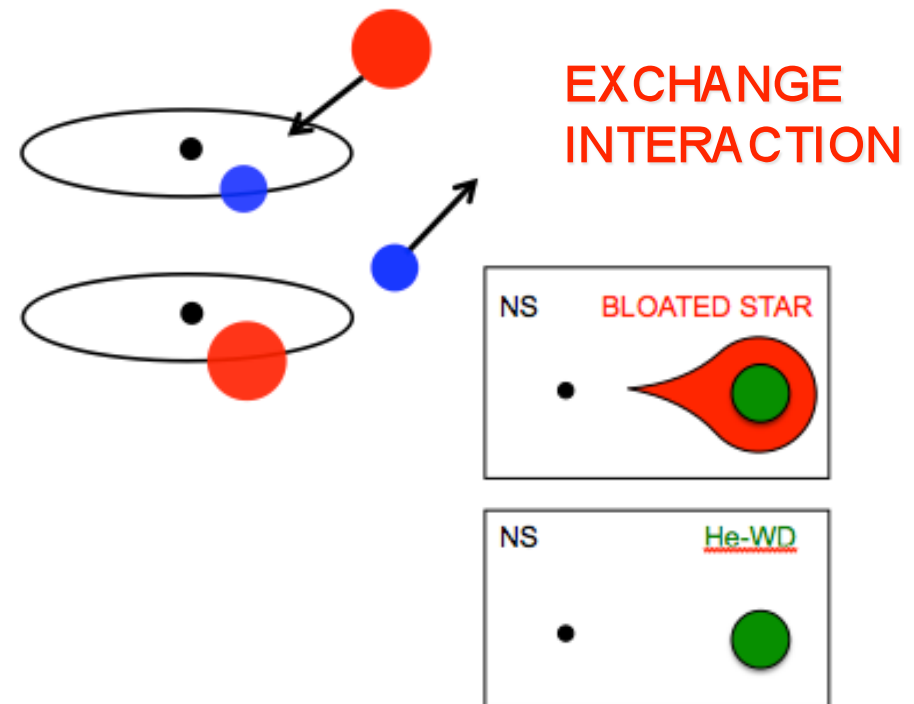


# The state of the art



## 4 NON Degenerate Objects

(Ferraro et al. 2001; Edmonds et al. 2002; Coccozza et al. 2008; Pallanca et al. 2010).



# The optical approach

Radio

Very Accurate position

Orbital parameters

Orbital period  
Time ascending node

PSR Mass function

Total mass

# The optical approach

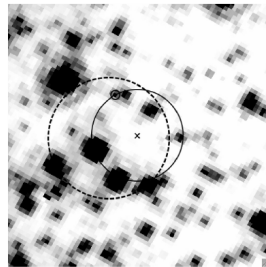
Radio

Optical

Photometry

Astrometry

Very Accurate position



High resolution

Orbital parameters

Orbital period  
Time ascending node

PSR Mass function

CMD position  
(Out of sequence)

Deep

Nature and physical parameters

Light curve  
(Variability in  
agreement with  
the orbital motion)

Multiple  
epochs

$i, M_{\text{COM}}, M_{\text{PSR}}$

Total mass

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



# The optical approach

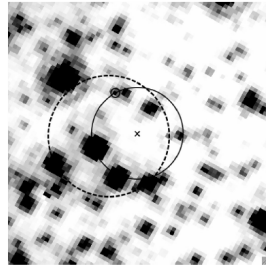
Radio

Optical

Photometry

Astrometry

Very Accurate position



High resolution

!!! Positional coincidence !!!

Orbital parameters

Orbital period  
Time ascending node

PSR Mass function

CMD position  
(Out of sequence)

Nature and physical parameters

Light curve  
(Variability in  
agreement with  
the orbital motion)

$i, M_{\text{COM}}, M_{\text{PSR}}$

Deep

Multiple  
epochs

!!! Orbital variability !!!

Total mass

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

# The optical approach

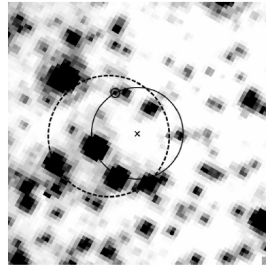
Radio

Optical

Photometry

Astrometry

Very Accurate position



CMD position  
(Out of sequence)

Nature and physical parameters

Light curve  
(Variability in  
agreement with  
the orbital motion)

$i, M_{\text{COM}}, M_{\text{PSR}}$

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

Orbital parameters

Orbital period  
Time ascending node

PSR Mass function

Total mass

IF  
BRIGHT  
ENOUGH

# The optical approach

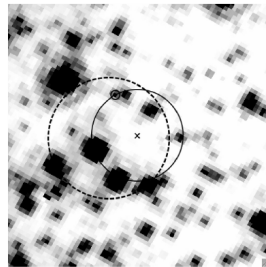
Radio

Optical

Photometry

Spectroscopy

Astrometry



Very Accurate position

Orbital parameters

Orbital period  
Time ascending node

PSR Mass function

Total mass

CMD position  
(Out of sequence)

Nature and physical parameters

Light curve  
(Variability in  
agreement with  
the orbital motion)

$i, M_{\text{COM}}, M_{\text{PSR}}$

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

Radial Velocity

COM mass function

+

PSR mass function



Mass ratio

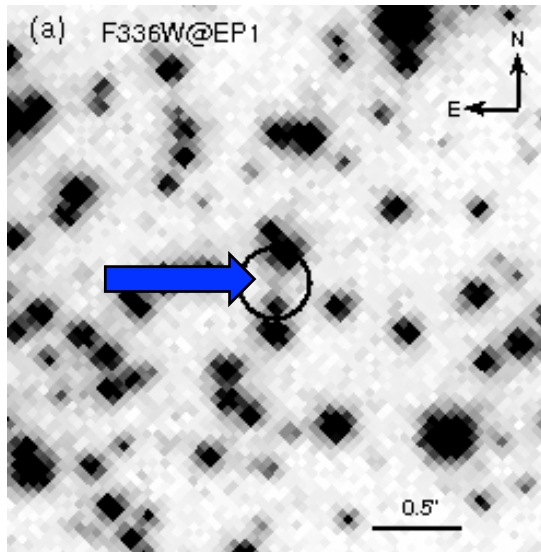
System solved

Chemical abundances

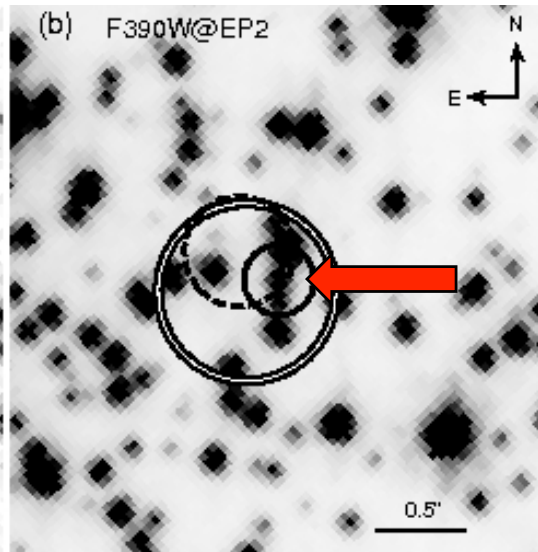
# IGR J18245-2452/M28I

- ✓ 2013 march 28 - A X ray transient in the direction of M28 (ATel #4925)  
It is in the core of M28 (Atel #4927, #4929)  
It is an accreting NS (Atel #4960)  
A radio source associated with the transient has been detected (Atel #4981)
- ✓ We detected the optical counterpart (Pallanca et al., 2013)

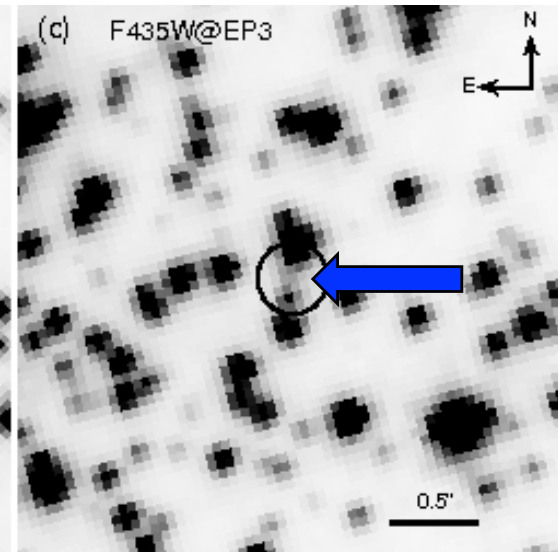
Apr 2009



Aug 2009



Apr 2010

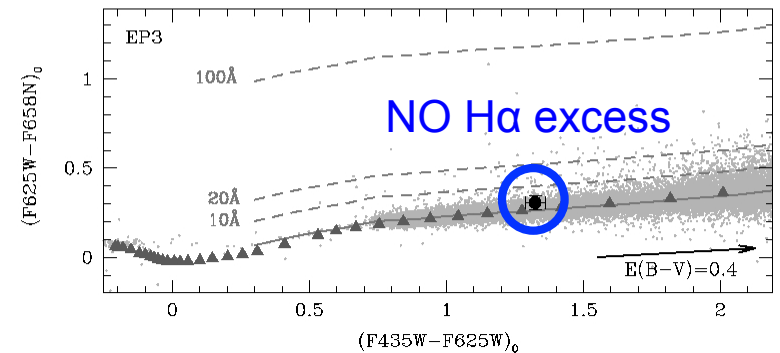
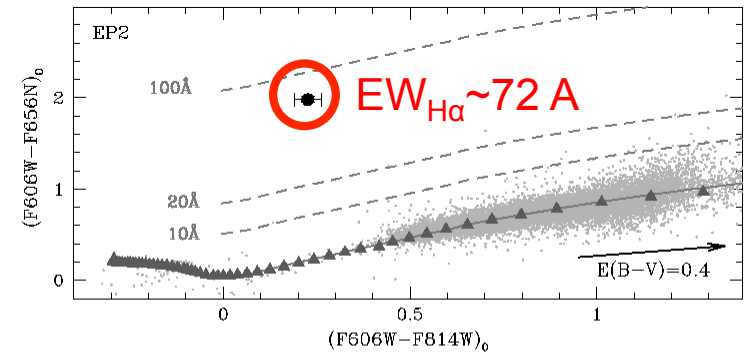
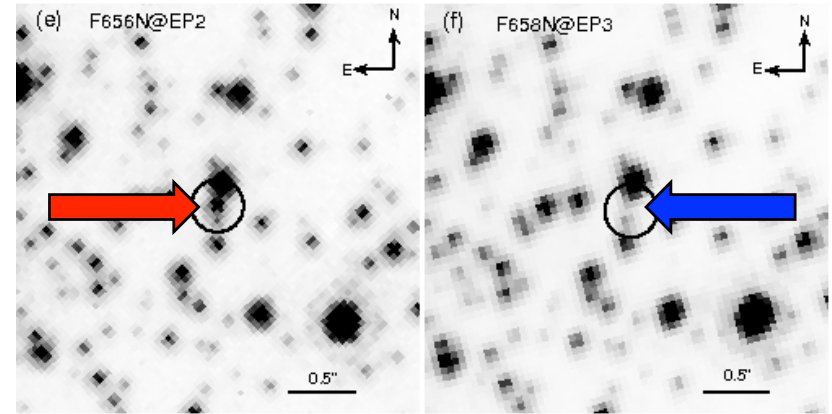
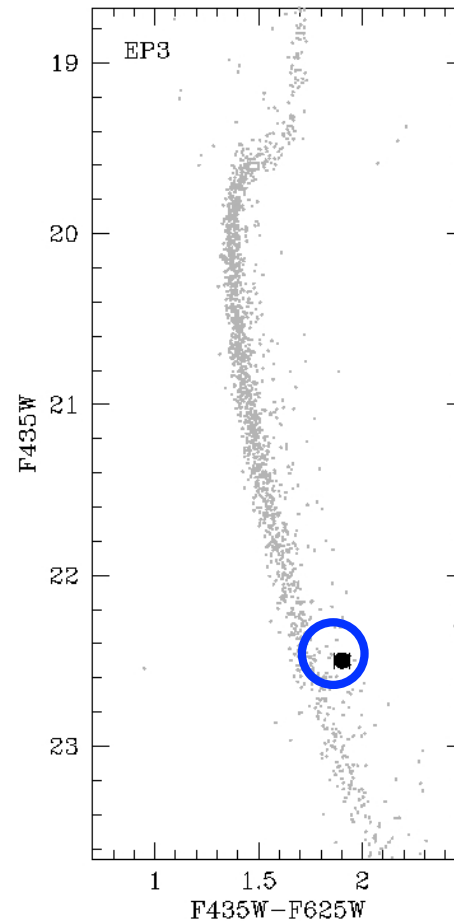
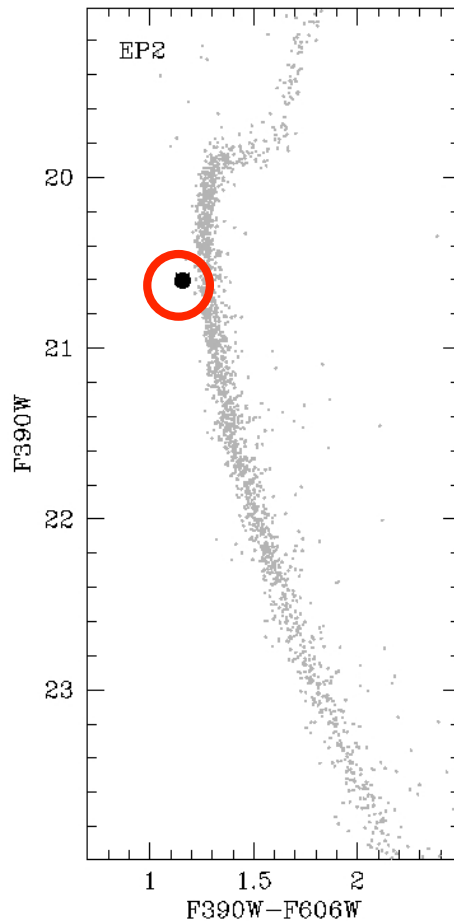


- ✓ After the submission of the paper, XMM observations suggested that  
**IGR J18245-2452 is the radio PSR M28I** (Papitto et al., arXiv:1305.3884)

# IGR J18245-2452/M28I

Aug 2009

Apr 2010





# IGR J18245-2452/M28I

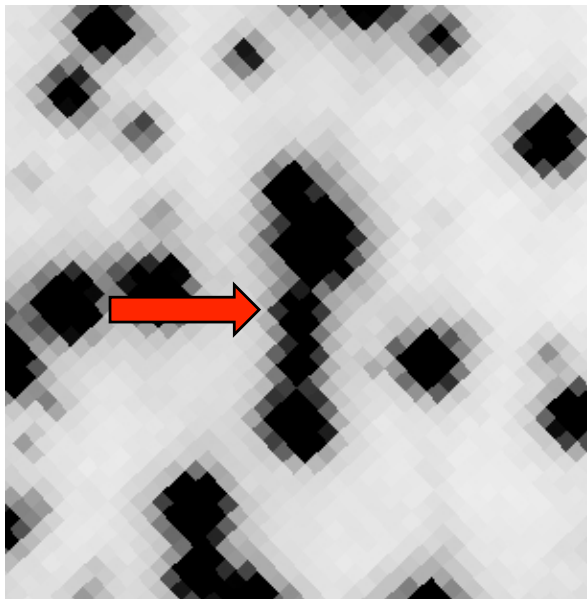
To check if the variability is correlated with the orbital motion of PSR M28I  
we need a very **accurate photometric analysis** in single images

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

In redder filter the close **bright star starts to saturate**

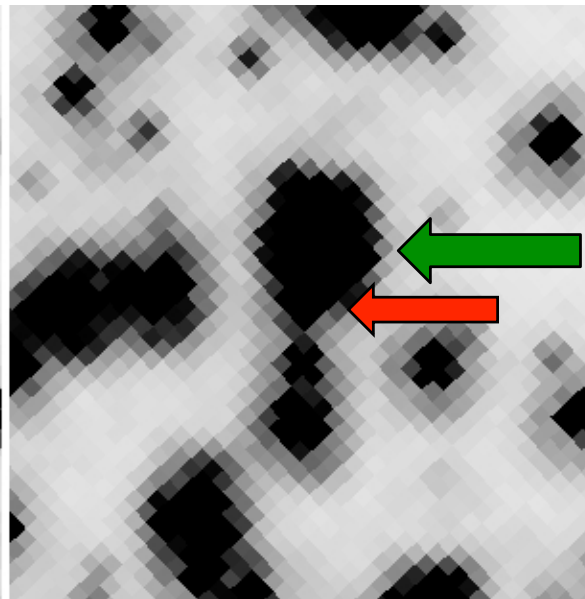


F390W



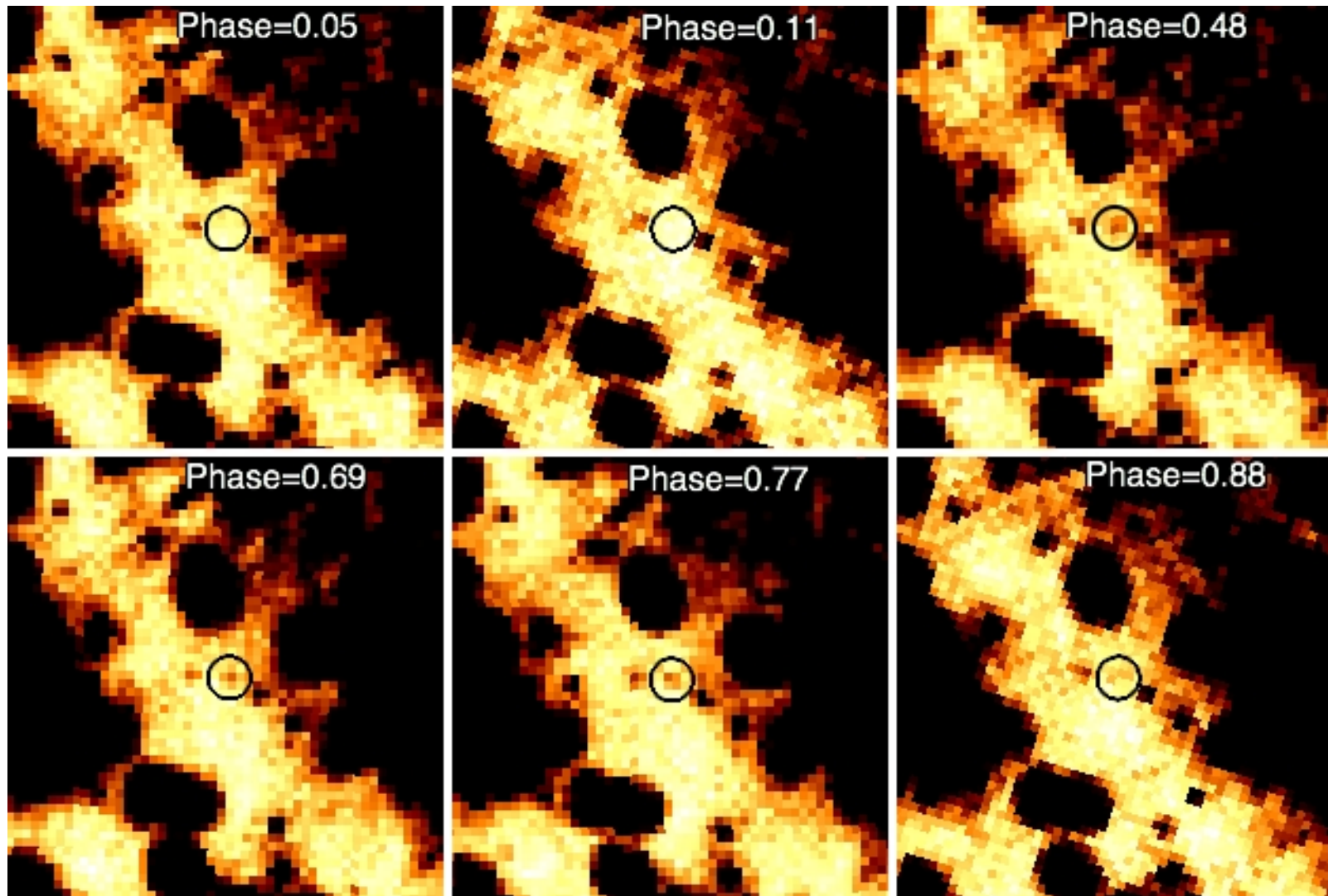
PSF-fitting  
is working  
well

F814W



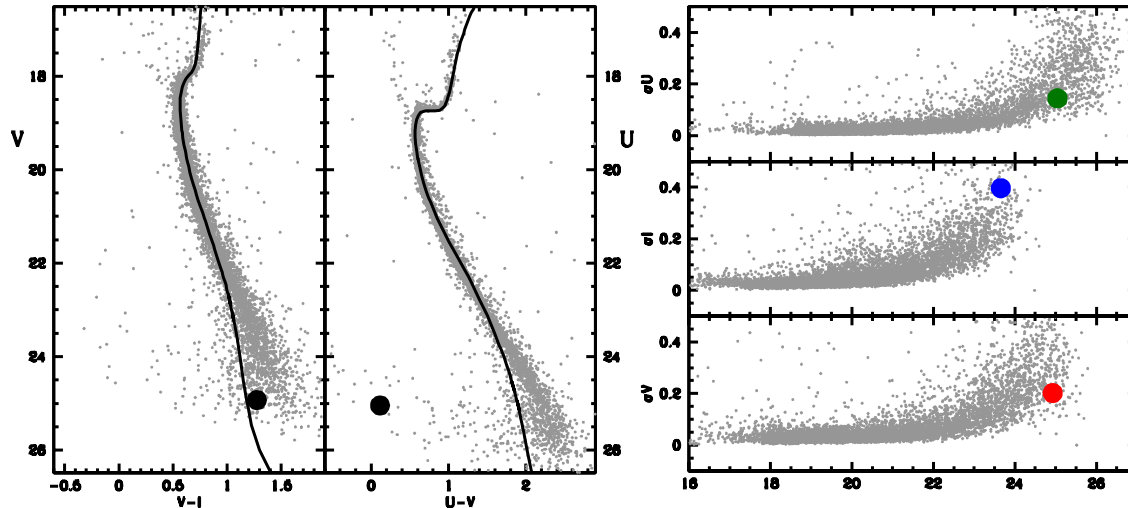
We need to  
accurately subtract  
the profile of the  
bright star

# M5C: a black widow

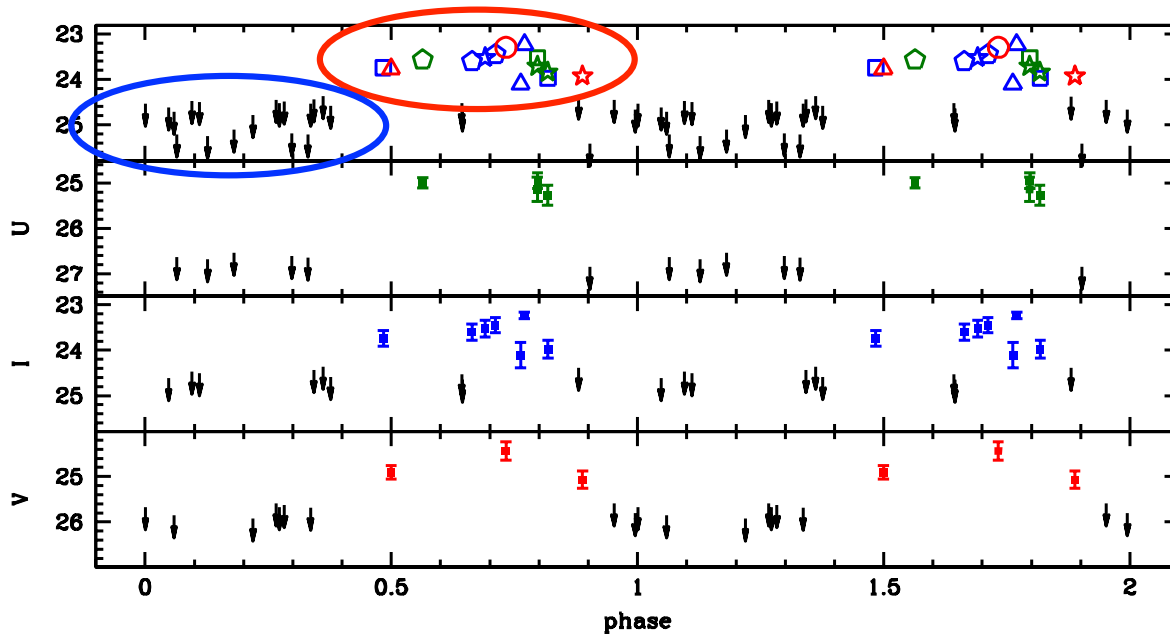


WFC3/UVIS@HST images in the F814W at different epochs

# M5C: a black widow



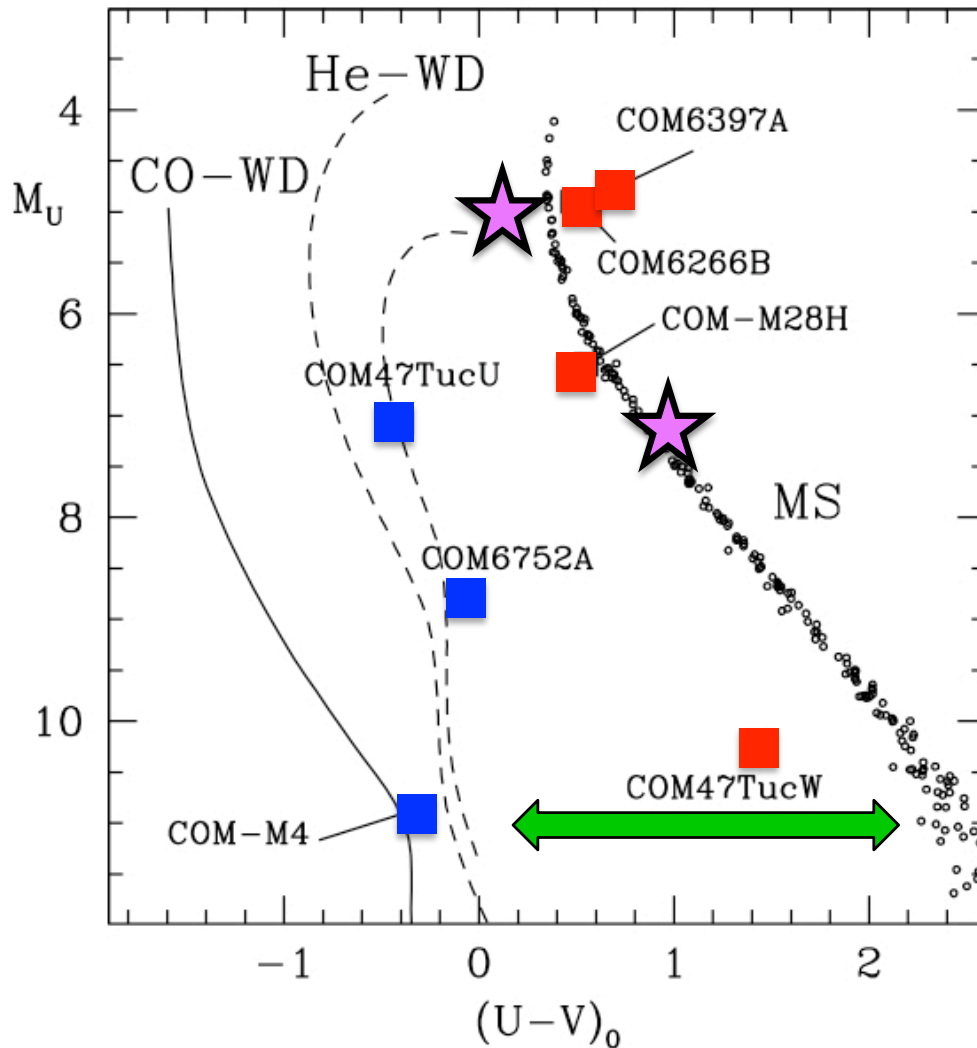
Low mass star  
 $M < \sim 0.2 M_{\odot}$



- Detected at the PSR inferior conjunction
- Under the detection limit at the PSR superior conjunction

$\Delta mag > 1.5 mag$   
 Heating ?

# Conclusions



2 new non degenerate companions

Indirect tool to understand how dynamical interactions can affect the evolution of binary MSPs in GCs (How **exchange interactions** are **efficient**)

✓ PSR M28I: an accreting MSP

We detected M28I both in a quiescent and outburst state

✓ PSR M5C: a black widow

We detected the companion during the PSR inferior conjunction

# Future

## HST cycle 20 - GO 12932 - PI: Ferraro

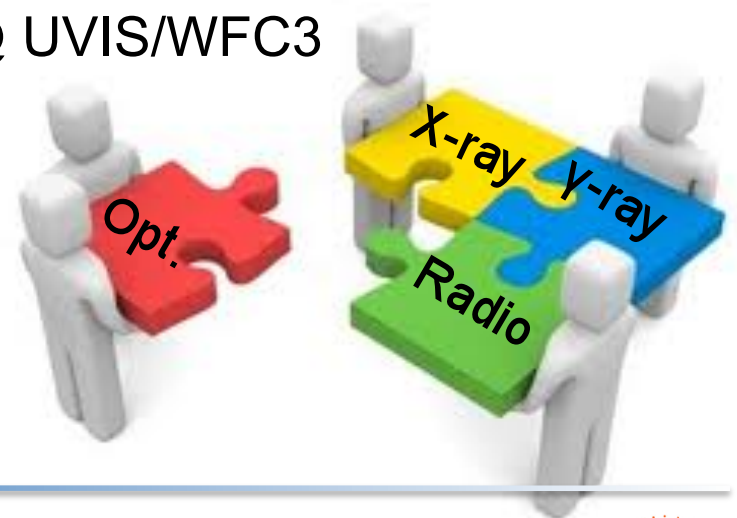
- NGC 6838 4 orbits @ WFC/ACS
- NGC 6544 6 orbits @ UVIS/WFC3
- M28H 8 orbits @ G750L/STIS

**ACQUIRED A FEW WEEKS AGO**

## HST cycle 21 - GO 13410 - PI: Pallanca

- NGC 6440 15 orbits @ UVIS/WFC3

**APPROVED FOR THE UPCOMING CYCLE**







# Thanks

You can visit our web-site: [www.cosmic-lab.eu](http://www.cosmic-lab.eu)

