The Structure and Signals of Neutron Stars, from Birth to Death

Optical companions to binary MSPs in GCs:

the case of the transient IGR J18245-2452/PSR J1824-2452I

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S. Ransom, M. Salaris, I. Stairs,

Florence - March 27, 2014

Cosmic-Lab

www.cosmic-lab.eu

erc

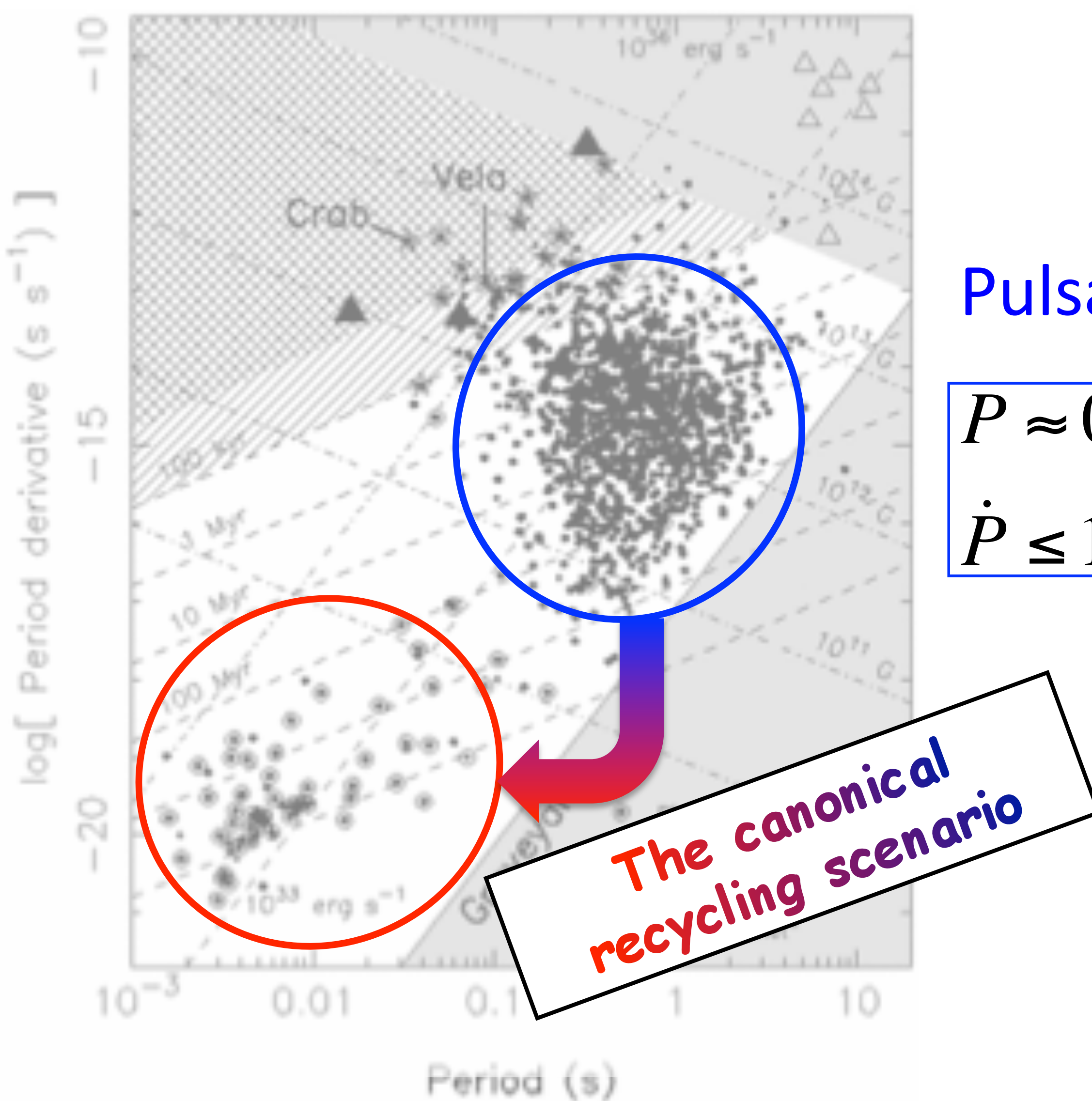
Cosmic-Lab

- 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

Classification of Pulsars



Pulsars (PSRs)

$$P \approx 0.5s$$

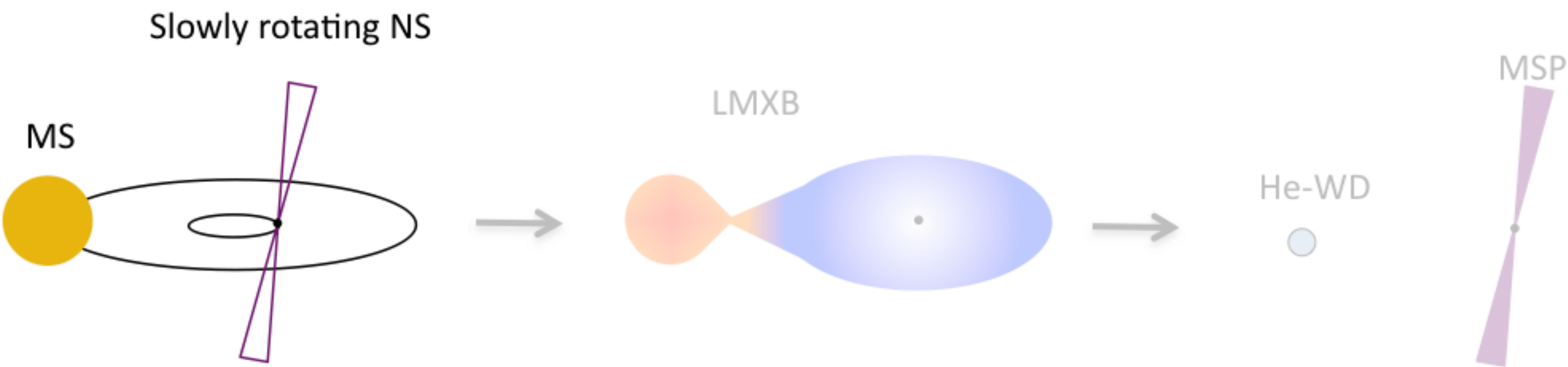
$$\dot{P} \leq 10^{-15}\, s\ s^{-1}$$

Millisecond Pulsars (MSPs)

$$P \approx 3ms$$

$$\dot{P} \approx 10^{-20}\, s\ s^{-1}$$

The canonical recycling scenario



Binary system:

Neutron star (NS)

+ evolving companion

(Bhattacharya et al. 1991)

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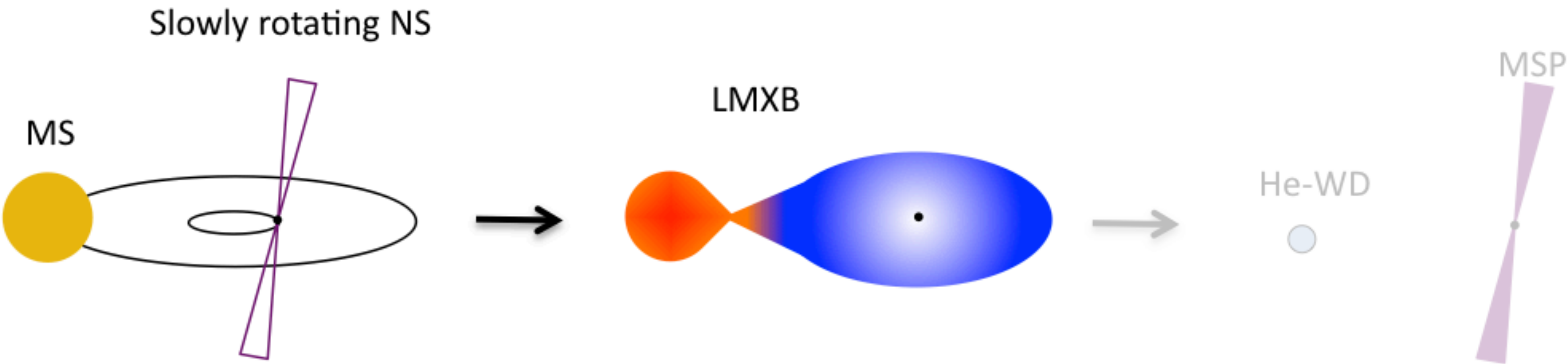

Binary system:
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mass accretion from an
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spin up the NS

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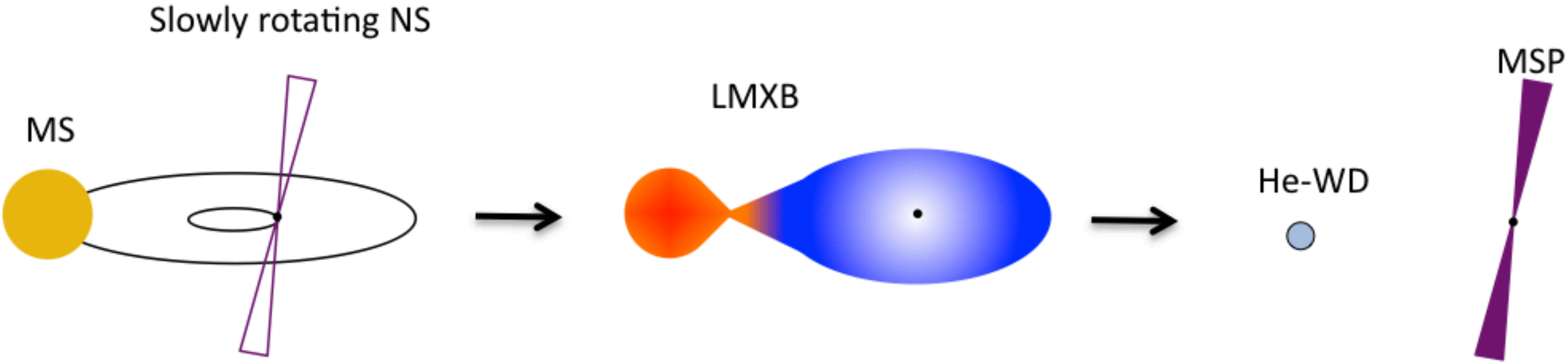

Binary system:
Neutron star (NS)
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mass accretion from an evolving companion spin up the NS

fast rotating pulsar (MSP)
+ an exhausted star

the core of a peeled star = WD

(Bhattacharya et al. 1991)

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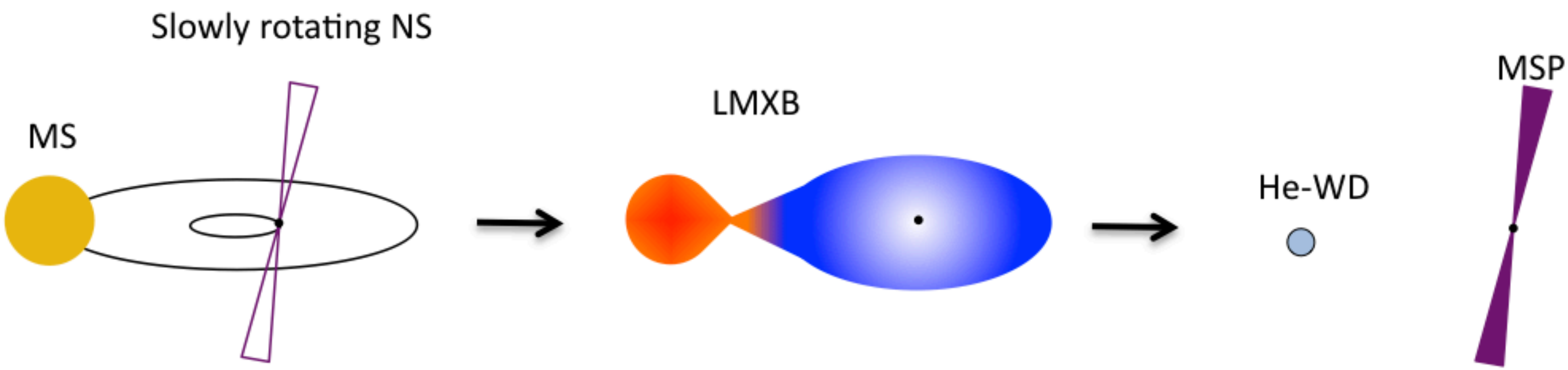

Binary system:
Neutron star (NS)
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mass accretion from an evolving companion spin up the NS

fast rotating pulsar (MSP)
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...but there are a few exceptions...

(Bhattacharya et al. 1991)

MSP preferred habitats

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

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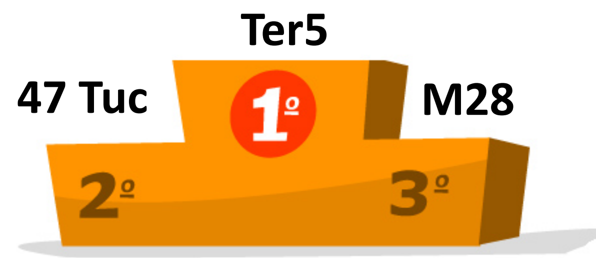
The number of MSPS per unit of mass is significantly higher in GCs



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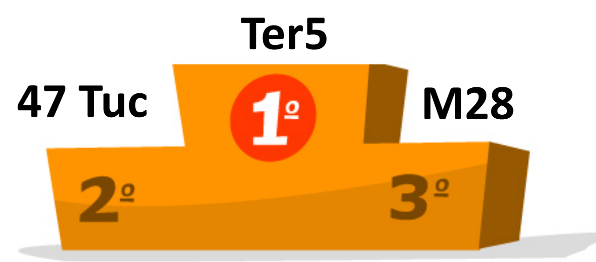
Galactic Field

Globular Clusters

Evolution of primordial binaries



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Evolution of primordial binaries

Globular Clusters

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

Ter5

47 Tuc

M28

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Evolution of primordial binaries

Globular Clusters

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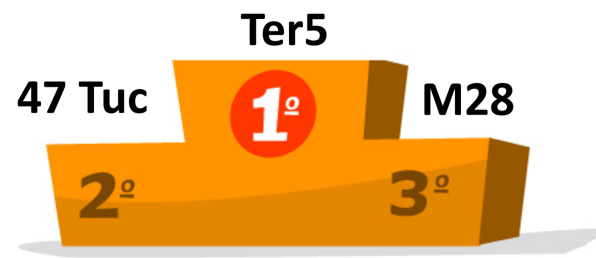


The study of GC MSPs is crucial to understand the role of dynamical interactions

Why are binary MSPs useful?

✓To Characterize the recycling mechanisms

✓If WD companions ⟹ to constrain the spin down theory (characteristic *vs* cooling age)

✓NS masses ⟹ to constrain the EOS of dense matter

✓ Test of general relativity

✓In GCs it is an indirect tool to study the dynamics and the evolution of binaries

The optical approach

Radio

Optical

Photometry

Very Accurate position

Orbital parameters

Orbital period
Time ascending node

PSR Mass function

Total mass

The optical approach

Radio

Optical

Photometry

Very Accurate position

High resolution

Orbital parameters

Orbital period
Time ascending node

PSR Mass function

Deep

Multiple epochs

Total mass

The optical approach

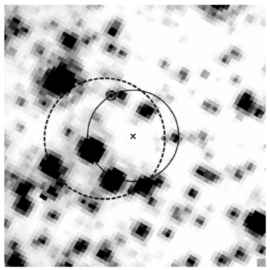
Radio

Optical

Photometry

Astrometry

Very Accurate position →



High resolution

Deep

Multiple
epochs

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Total mass

The optical approach

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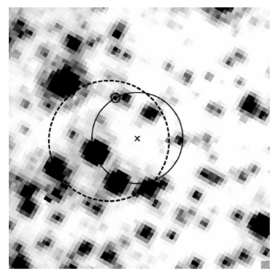

High resolution

CMD position
(Out of sequence)

Deep

Nature and physical parameters

Orbital parameters

Orbital period
Time ascending node

PSR Mass function

Multiple epochs

Total mass

The optical approach

Radio

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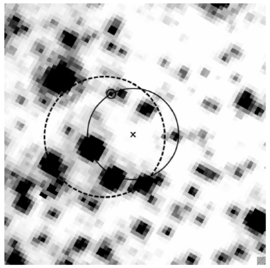

High resolution

Orbital parameters

CMD position
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Nature and physical parameters

Orbital period
Time ascending node ↔

Light curve
(Variability in agreement with the orbital motion)

Multiple epochs

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Total mass

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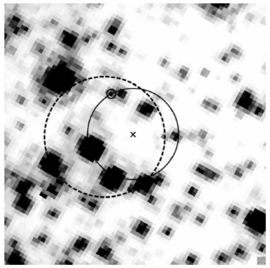

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Multiple epochs

PSR Mass function ↔

i, M_{COM}, M_{PSR}

Total mass

The optical approach

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Optical

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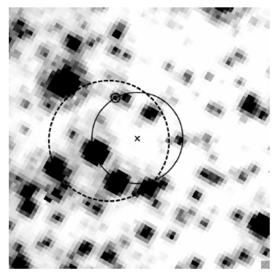

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Nature and physical parameters

Orbital parameters

Orbital period
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Light curve
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Multiple epochs

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

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

The optical approach

Radio

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Photometry

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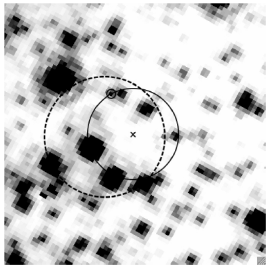

Very Accurate position

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

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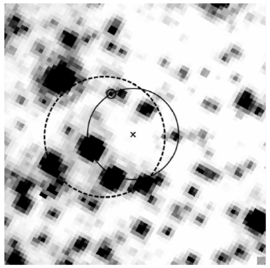
Very Accurate position

Astrometry



Orbital parameters

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i, M_{COM}, M_{PSR}

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IF
BRIGHT
ENOUGH

The optical approach

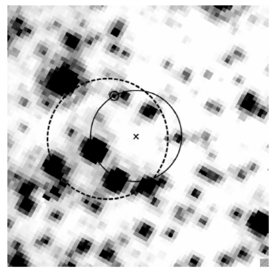
Radio

Optical

Photometry

Spectroscopy

Astrometry



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Radial Velocity

COM mass function

+

PSR mass function

↓

Mass ratio

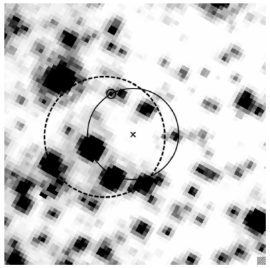
The optical approach

Radio

Optical

Photometry — **Spectroscopy**

Astrometry



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Radial Velocity

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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}

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The optical approach

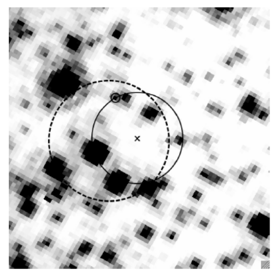
Radio

Optical

Photometry **Spectroscopy**

Astrometry

Very Accurate position →



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System solved

Chemical abundances

The studied targets in PhD Thesis

Photometric identification of:

- The Red-Back PSR J1824-2452H in M28
- The Red-Back PSR J1824-2452I in M28
- The Black-widow PSR J1518+0204C in M5

- The Black-widow PSR J0610-2100 in the GF
- The Intermediate mass PSR J1439-5501 in the GF

Spectroscopic follow-up of:

- COM J1740-5340A in NGC 6397

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IGR J18245-2452/PSR J1824-2452I

LETTER

Papitto at al. 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]

It is thought that neutron stars in low-mass binary systems can accrete matter and angular momentum from the companion star and be spun-up to millisecond rotational periods[1–3]. During the accretion stage, the system is called a low-mass X-ray binary, and bright X-ray emission is observed. When the rate of mass transfer decreases in the later evolutionary stages, these binaries host a radio millisecond pulsar[4,5] whose emission is powered by the neutron star's rotating magnetic field[6]. This evolutionary model is supported by the detection of millisecond X-ray pulsations from several accreting neutron stars[7,8] and also by the evidence for a past accretion disc in a rotation-powered millisecond pulsar[9]. It has been proposed that a rotation-powered pulsar may temporarily switch on[10–12] during periods of low mass inflow[13] in some such systems. Only indirect evidence for this transition has hitherto been observed[14–18]. Here we report observations of accretion-powered, millisecond X-ray pulsations from a neutron star previously seen as a rotation-powered radio pulsar. Within a few days after a month-long X-ray outburst, radio pulses were again detected. This not only shows the evolutionary link between accretion and rotation-powered millisecond pulsars, but also that some systems can swing between the two states on very short timescales.

the rotation-powered stage suggests that, during that phase, most of the matter that the companion transfers towards the neutron star is ejected by the pressure of the pulsar wind[5,28]. A slight increase in the mass transfer rate may subsequently push the magnetosphere back inside the light cylinder[12]. After a disk had sufficient time to build up, an X-ray outburst is expected to take place, as in the case of IGR J18245–2452 during the observations reported here. As the mass accretion rate decreases during the decay of the X-ray outburst, the pressure of the magnetosphere is able to at least partly sweep away the residual matter from the surroundings of the neutron star, and a rotation-powered pulsed radio emission can reactivate. Our observations prove that such transitions can take place in both directions, on a timescale shorter than expected, perhaps only a few days.

The discovery of IGR J18245–2452, swinging between rotation-powered and accretion-powered emission, represents the most stringent probe of the recycling model[1–3], and the existence of an unstable intermediate phase in the evolution of low-mass X-ray binaries, offering an unprecedented opportunity to study in detail the transitions between these two states.

IGR J18245-2452/PSR J1824-2452I

✓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)

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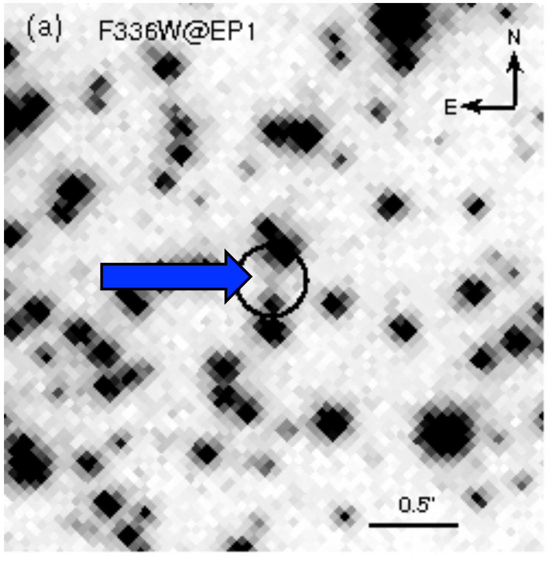
Apr 2009



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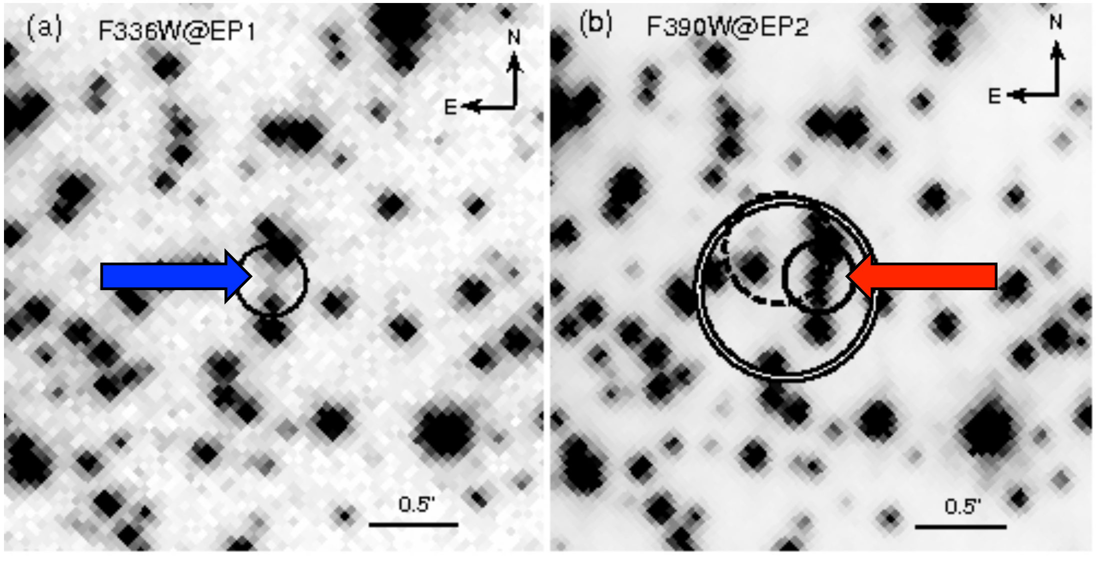

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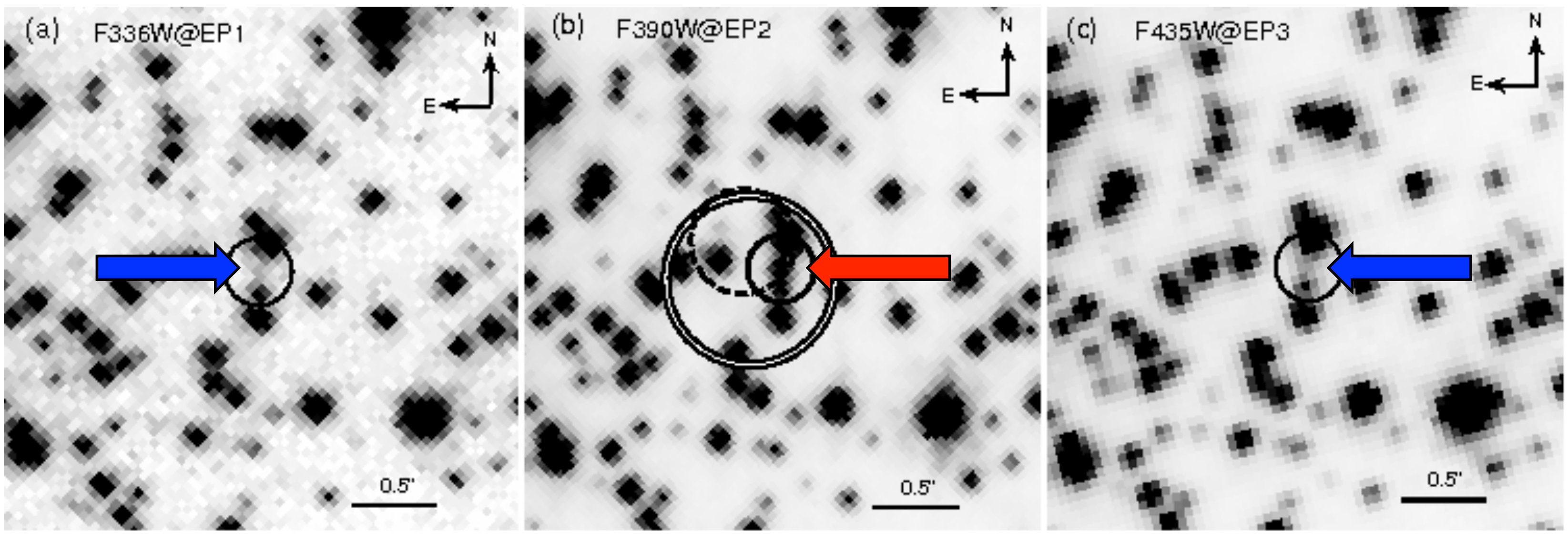

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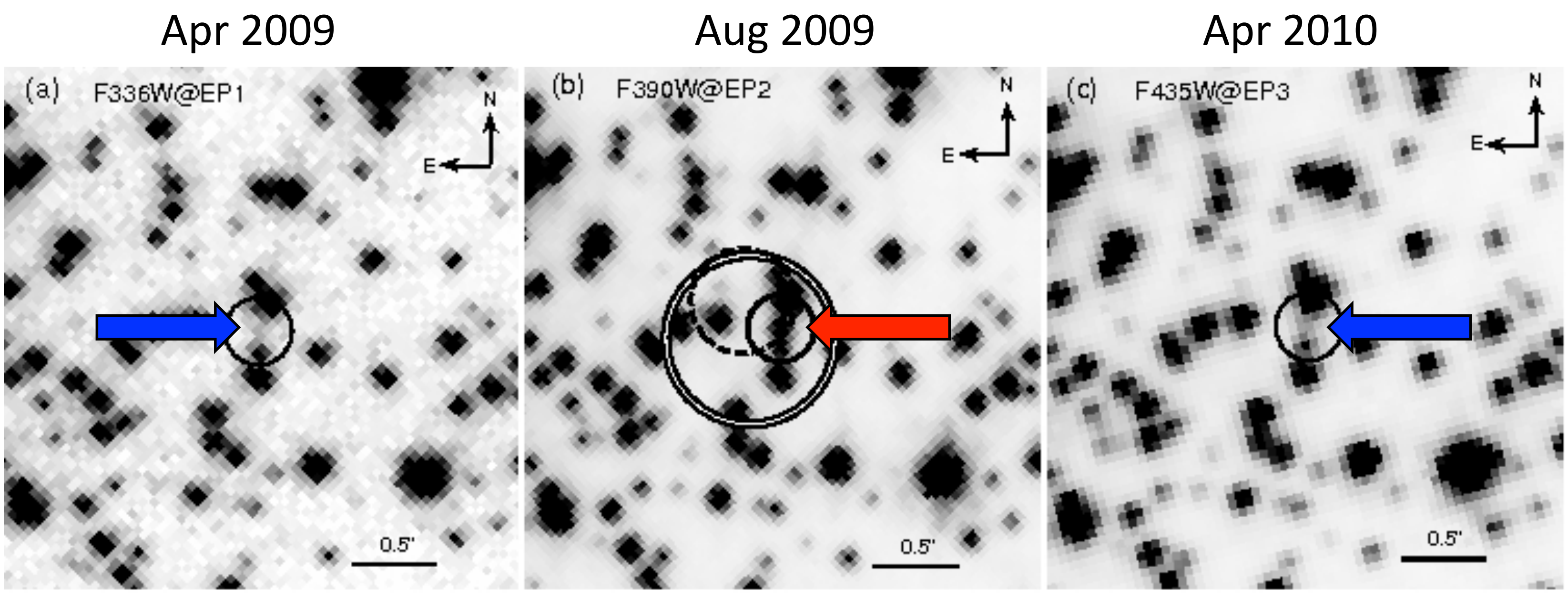

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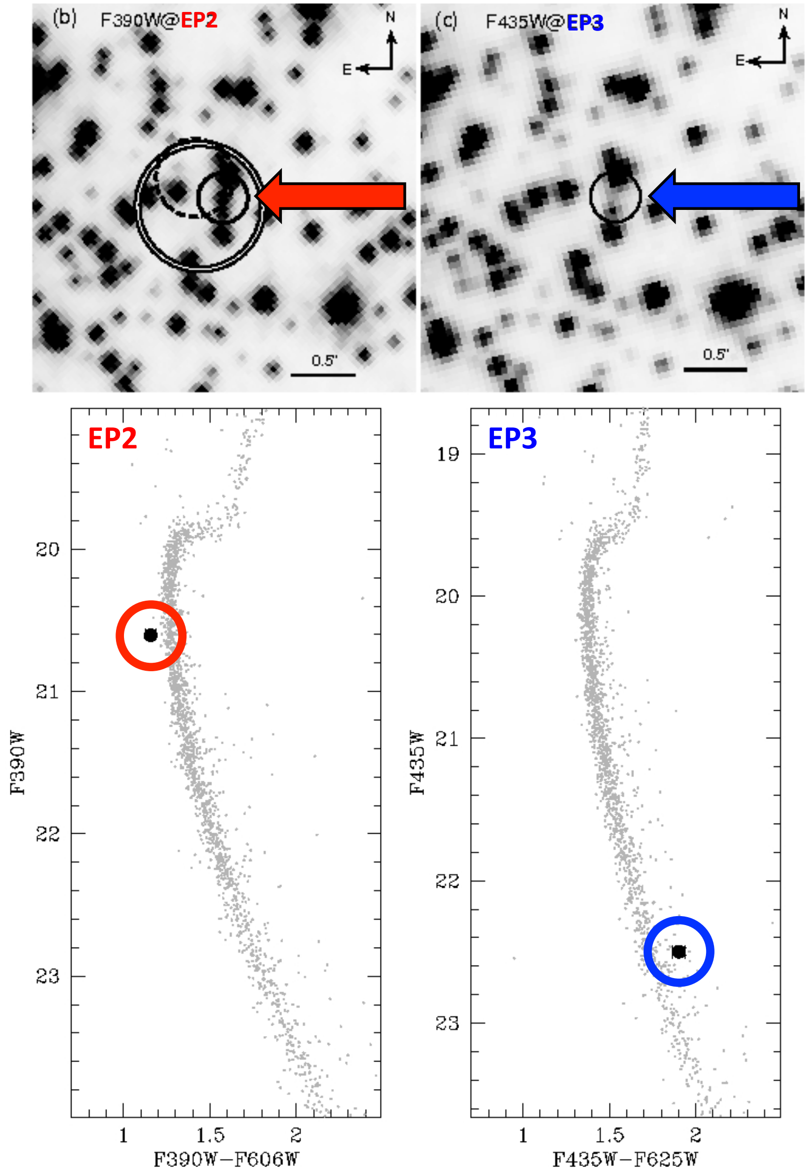

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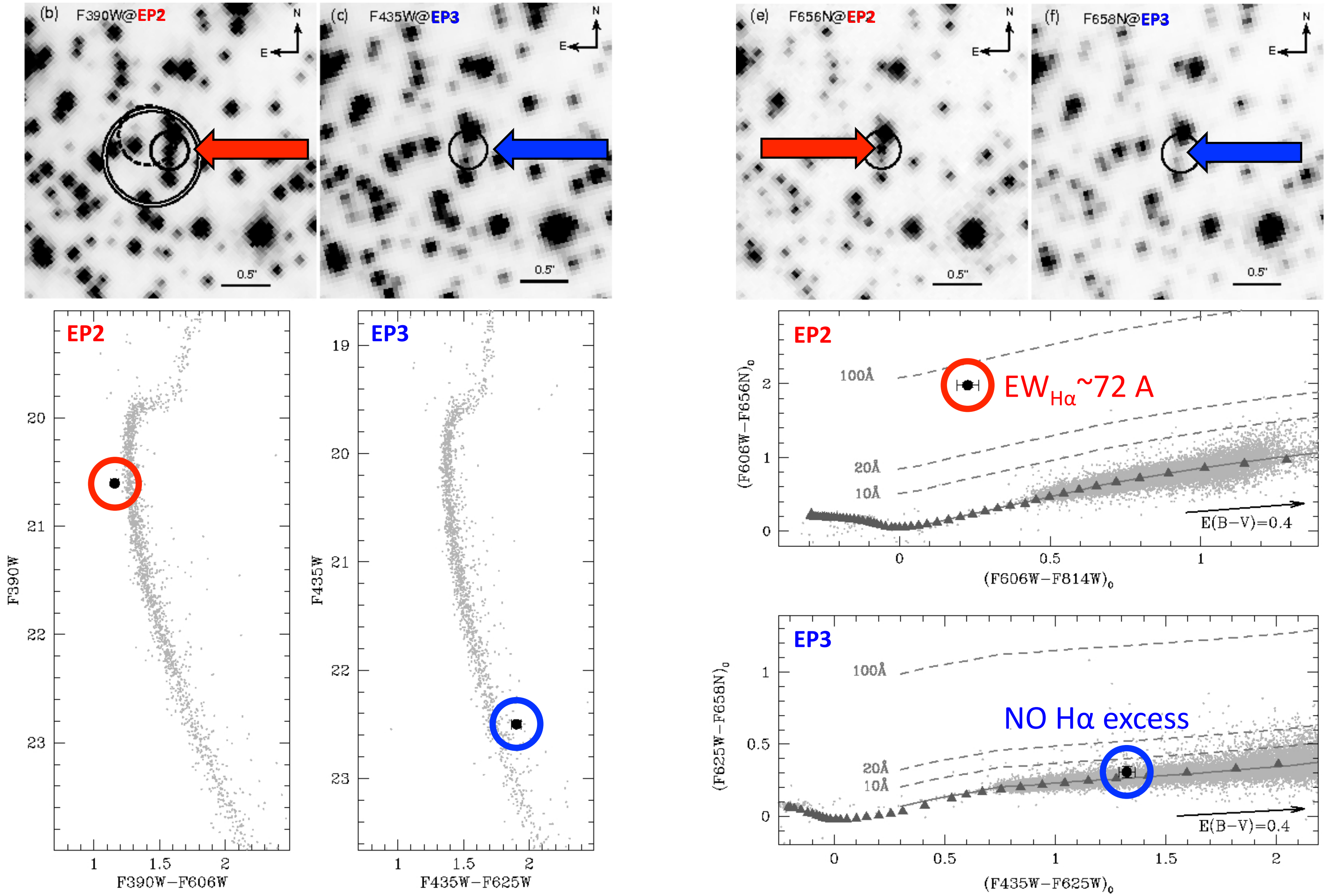


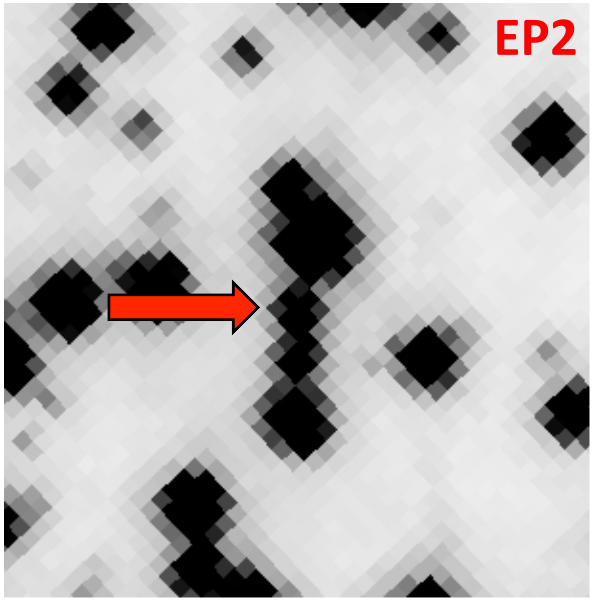
IGR J18245-2452/PSR J1824-2452I

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)

F390W

PSF-fitting is working well



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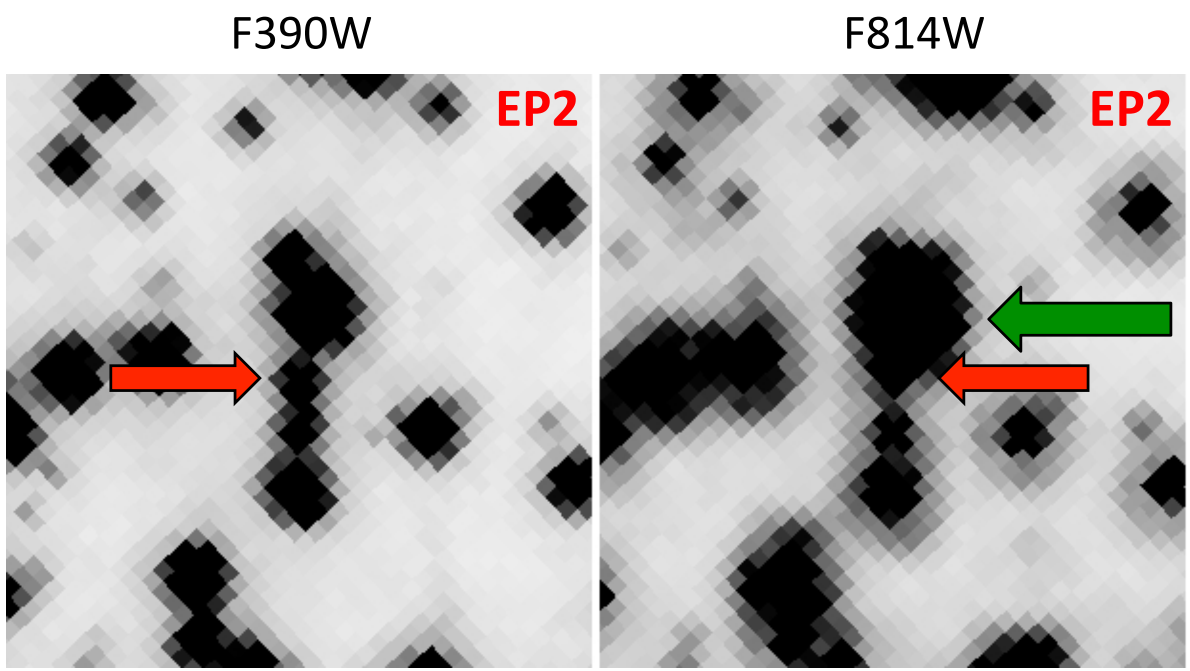
To check if the variability is correlated with the orbital motion of PSR M28I we need a very **accurate photometric analysis** in single images

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

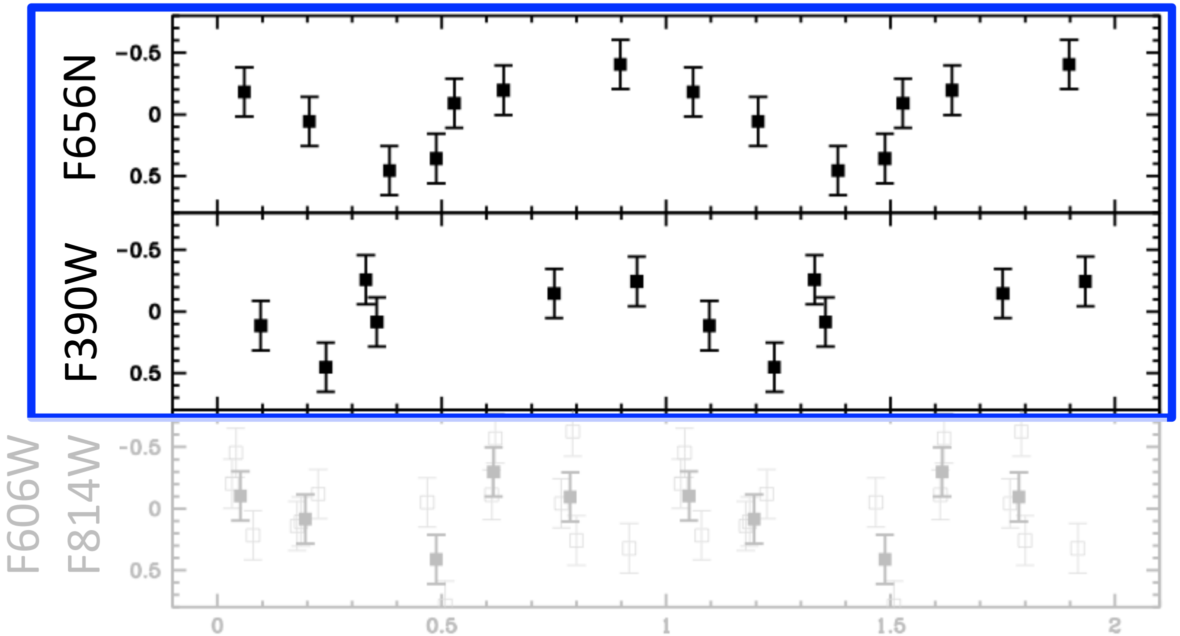
In redder filter the close bright star starts to saturate

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

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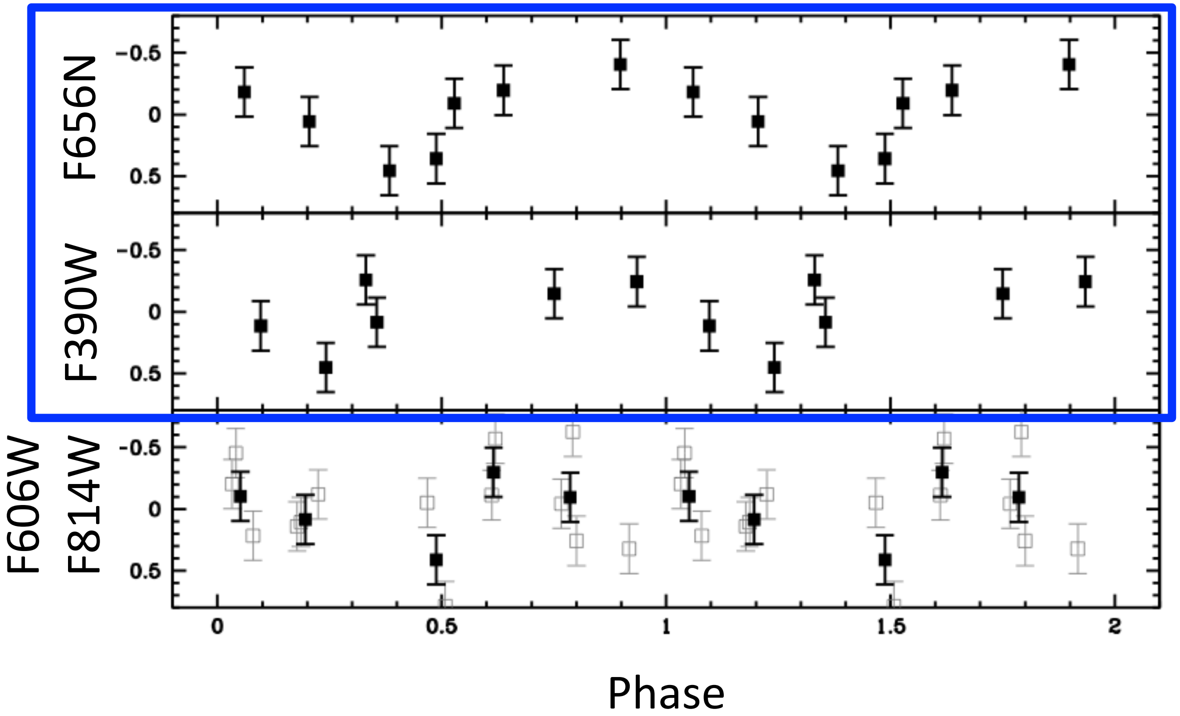

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We combined the F606W and the F814W magnitudes likely dominated by random scatter

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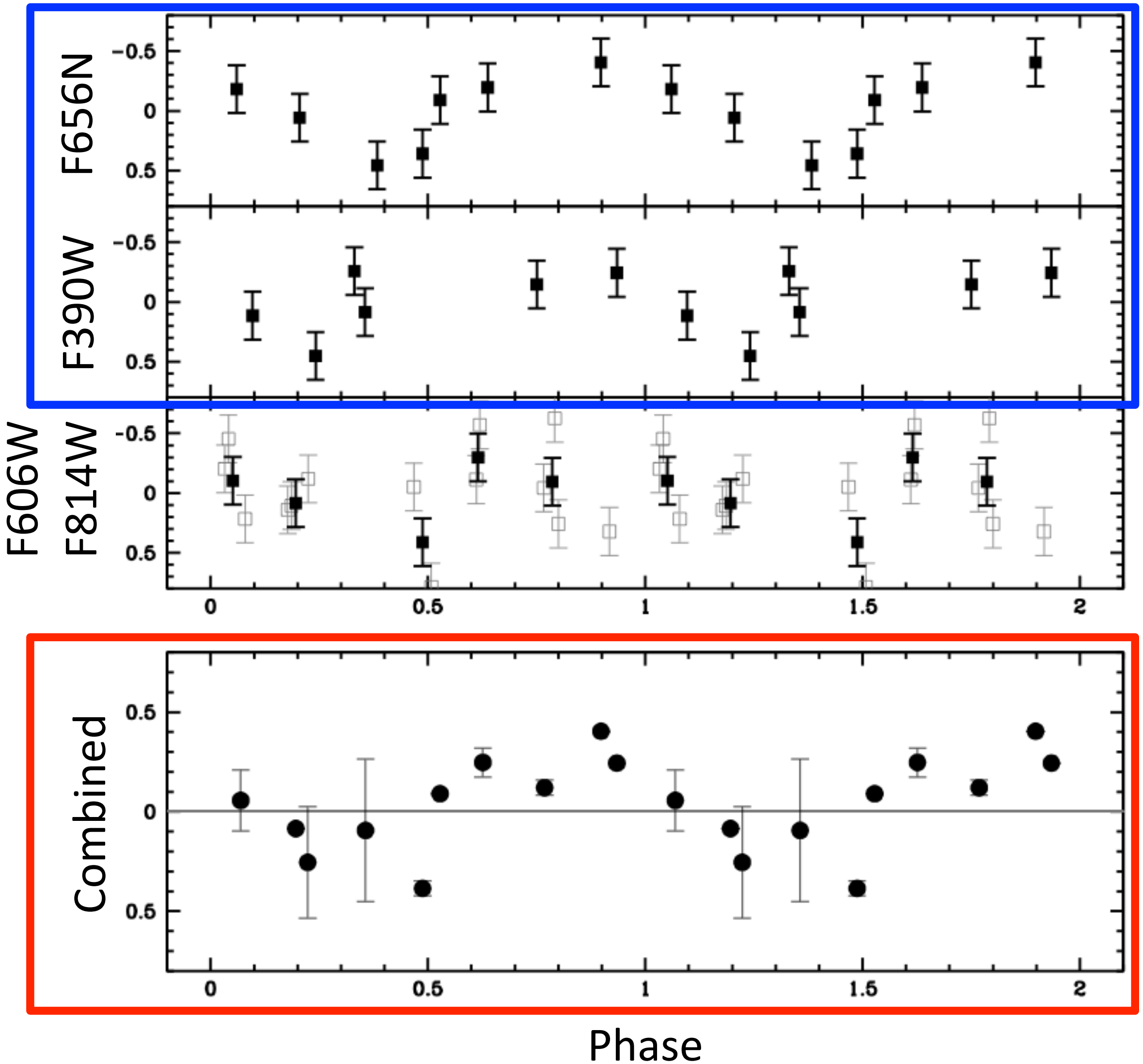

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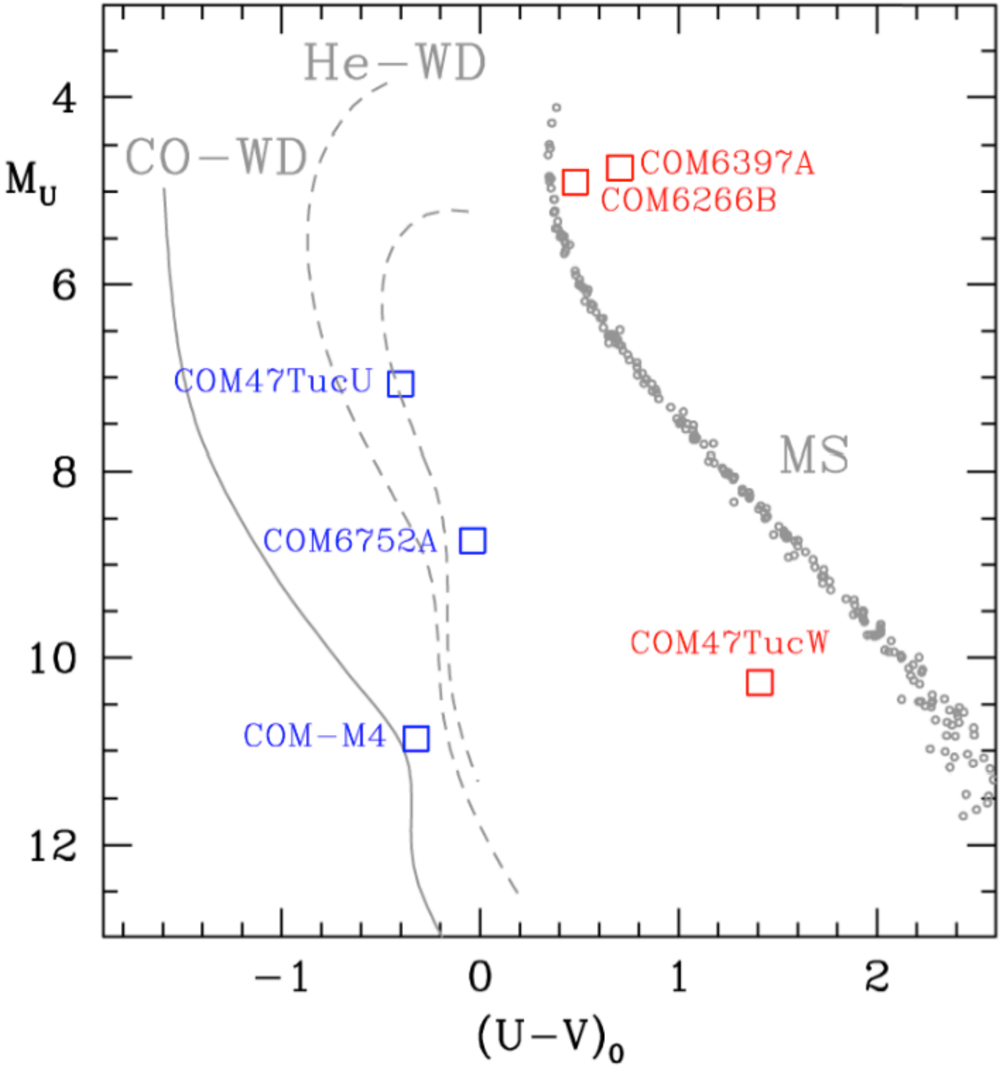
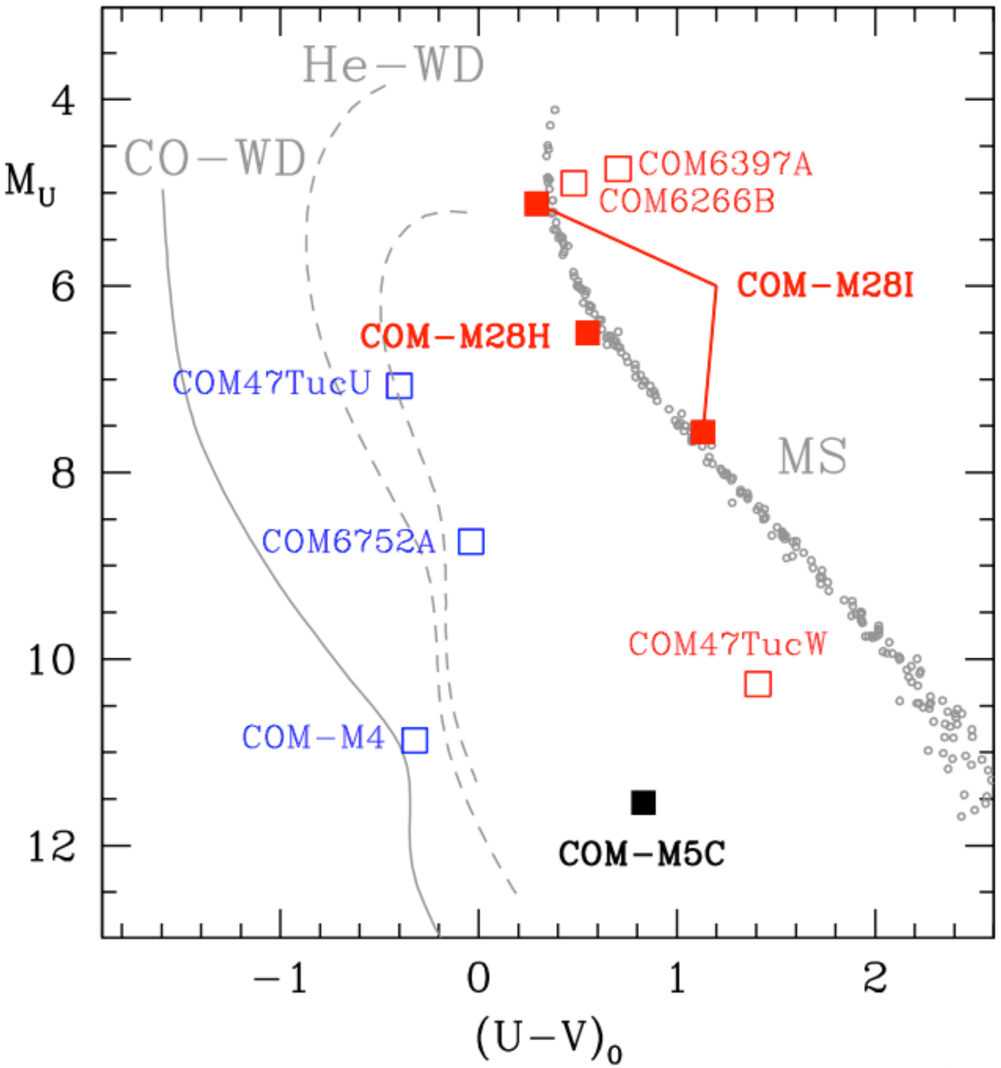
Combined light curve obtained by averaging in bins of 0.1 in phase all the available measures

The state of the art in GCs



The "updated" state of the art in GCs



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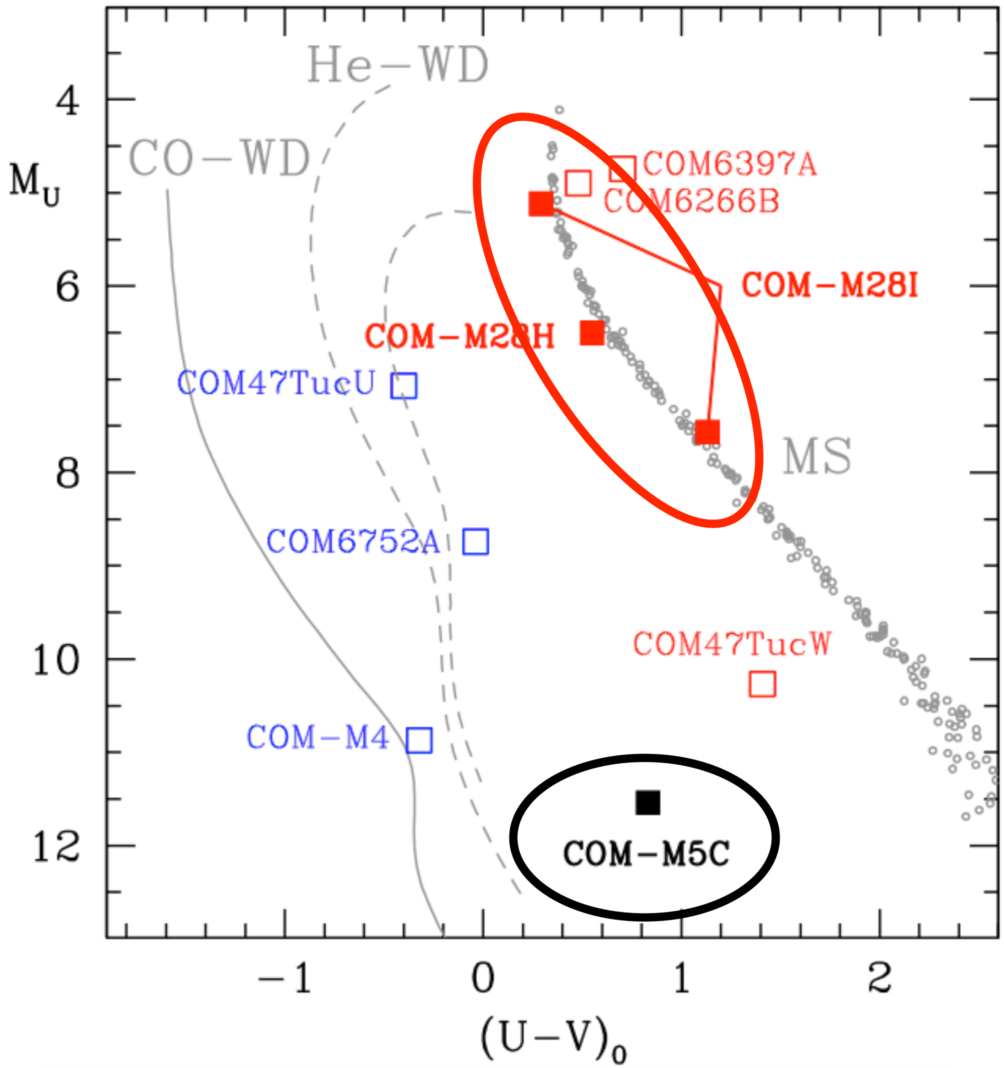
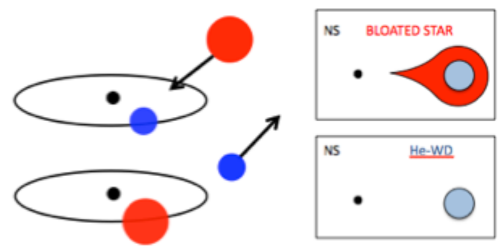


3 new NON Degenerate Objects
(Pallanca et al. 2010, 2013a, 2013b)



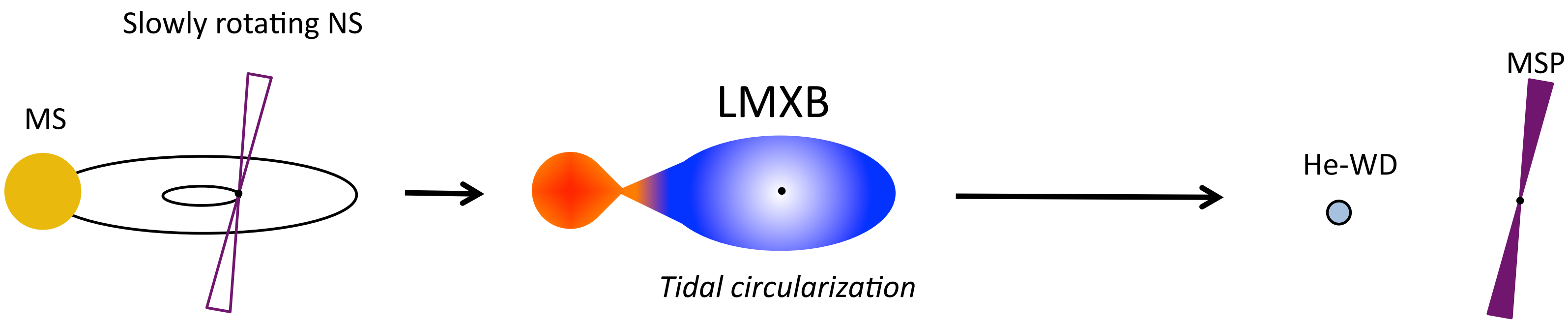
EXCHANGE INTERACTION

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

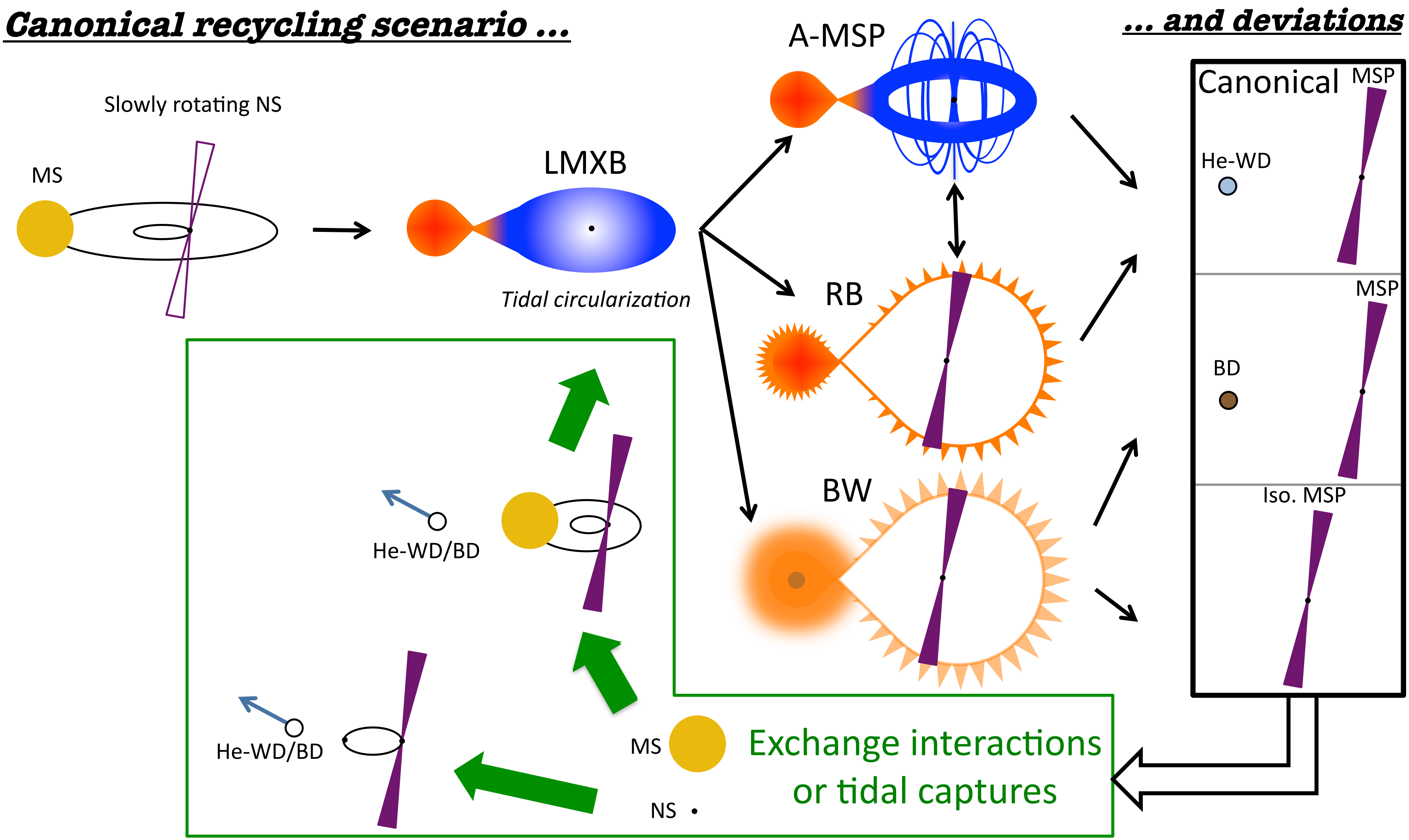
A cartoon of the evolutionary scenario

Canonical recycling scenario ...

... and deviations



A cartoon of the evolutionary scenario



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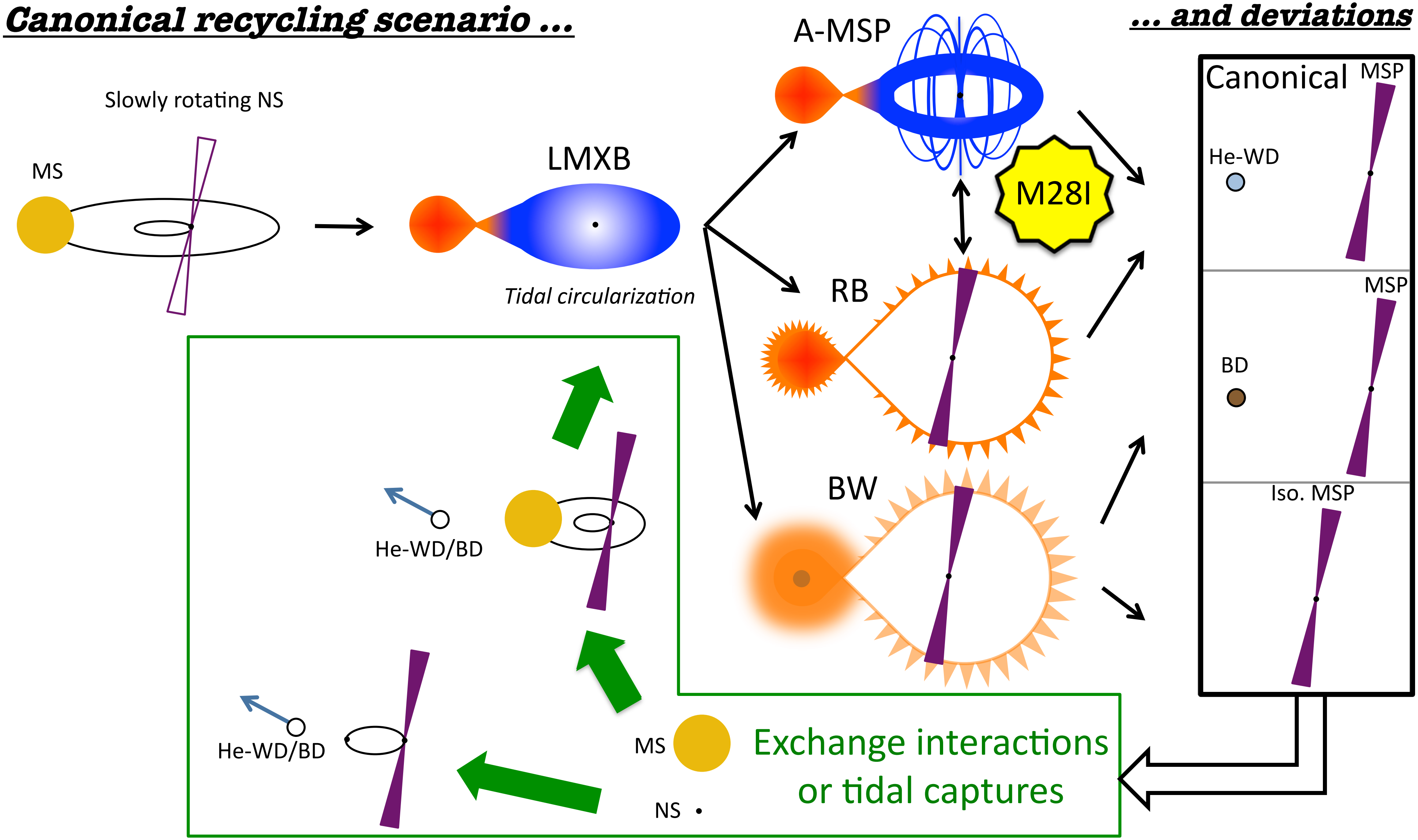


Future

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

→ see Cadelano's poster

RECENTLY ACQUIRED

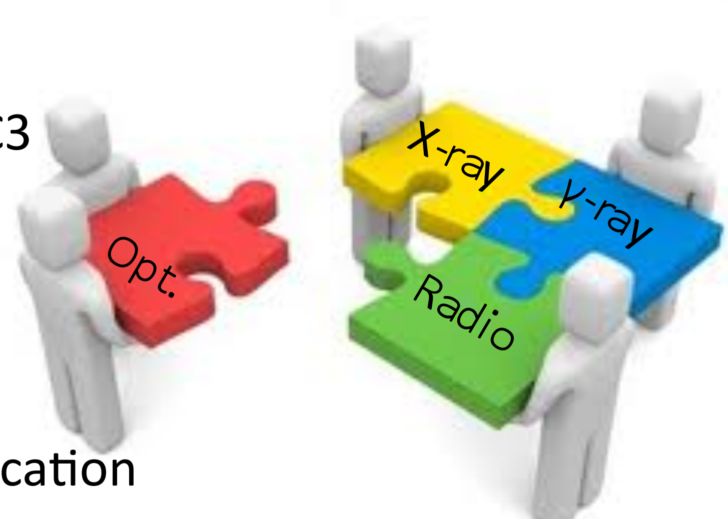
HST cycle 21 - GO 13410 - PI: Pallanca

- NGC 6440 — 15 orbits @ UVIS/WFC3

CURRENTLY ONGOING

HST cycle 22 - Deadline April 14

- M28I — variability analysis
- NEW MSPs — photometrical identification



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