CONGRESSO NAZIONALE
OGGETTI COMPATTI IX

Optical Companions to Millisecond Pulsars in Globular Clusters

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Monte Porzio Catone, 22-25 Sep 2015

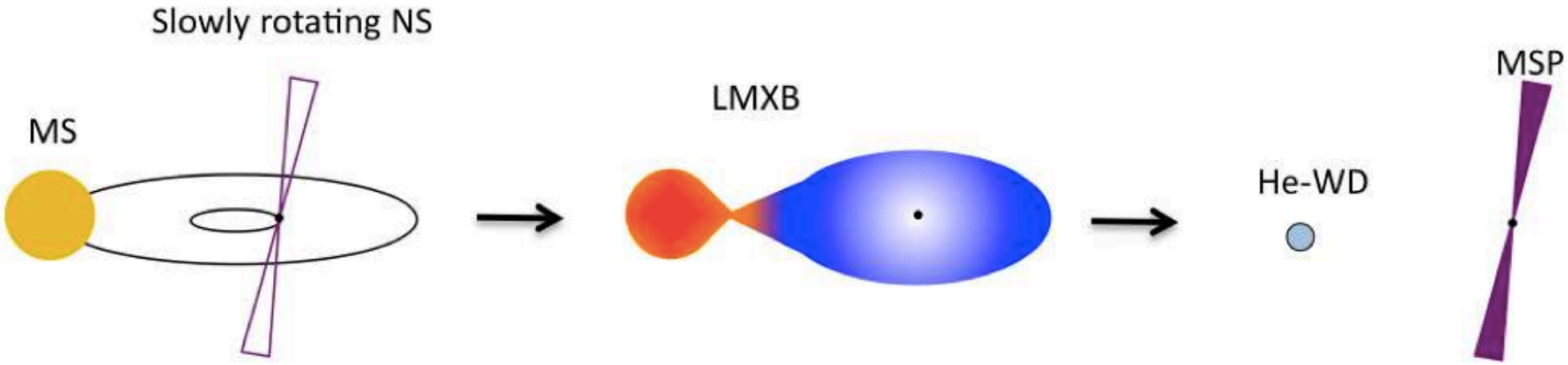
Cosmic-Lab

- 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

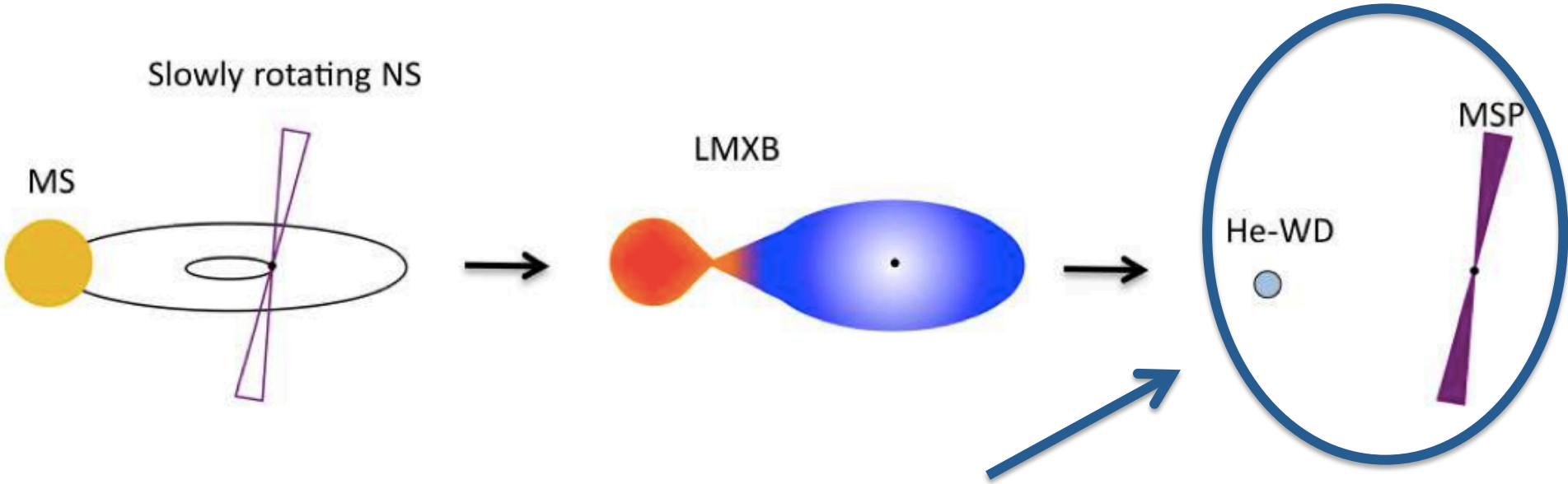
Blue Straggler Stars
Millisecond Pulsars
Intermediate-mass Black Holes

} as probe-particles

Millisecond Pulsars



Millisecond Pulsars



The companion is likely a degenerate star

Eclipsing Millisecond Pulsars (Spiders)

Redbacks

$0.1\ M_\odot < M_{COM} < 0.5\ M_\odot$

Black-Widows

$M_{COM} << 0.1\ M_\odot$

The companion is likely a non-degenerate or a semi-degenerate star

Why searching for the optical counterparts?

The optical band is the only spectral window where the emission is almost entirely dominated by the companion star.

It allows to get insights on the nature of the companion star, thus probing stellar evolution under extreme conditions.

An also to study the evolution and the destiny of the different classes of MSPs.

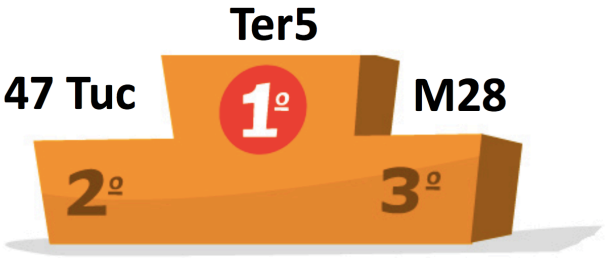
Why Globular Clusters?

- The Galactic Globular Cluster System is **0.01 less massive** than the Galactic Disk
- However, **about 40% of the entire MSP population** is found in Globular Clusters

Galactic Disk → **Evolution of primordial binaries**

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

The study of GC MSPs is crucial to understand the role of dynamical interactions in MSP evolution.



The Optical Companion to the Black Widow System PSR J1953+1846A in the Globular Cluster M71

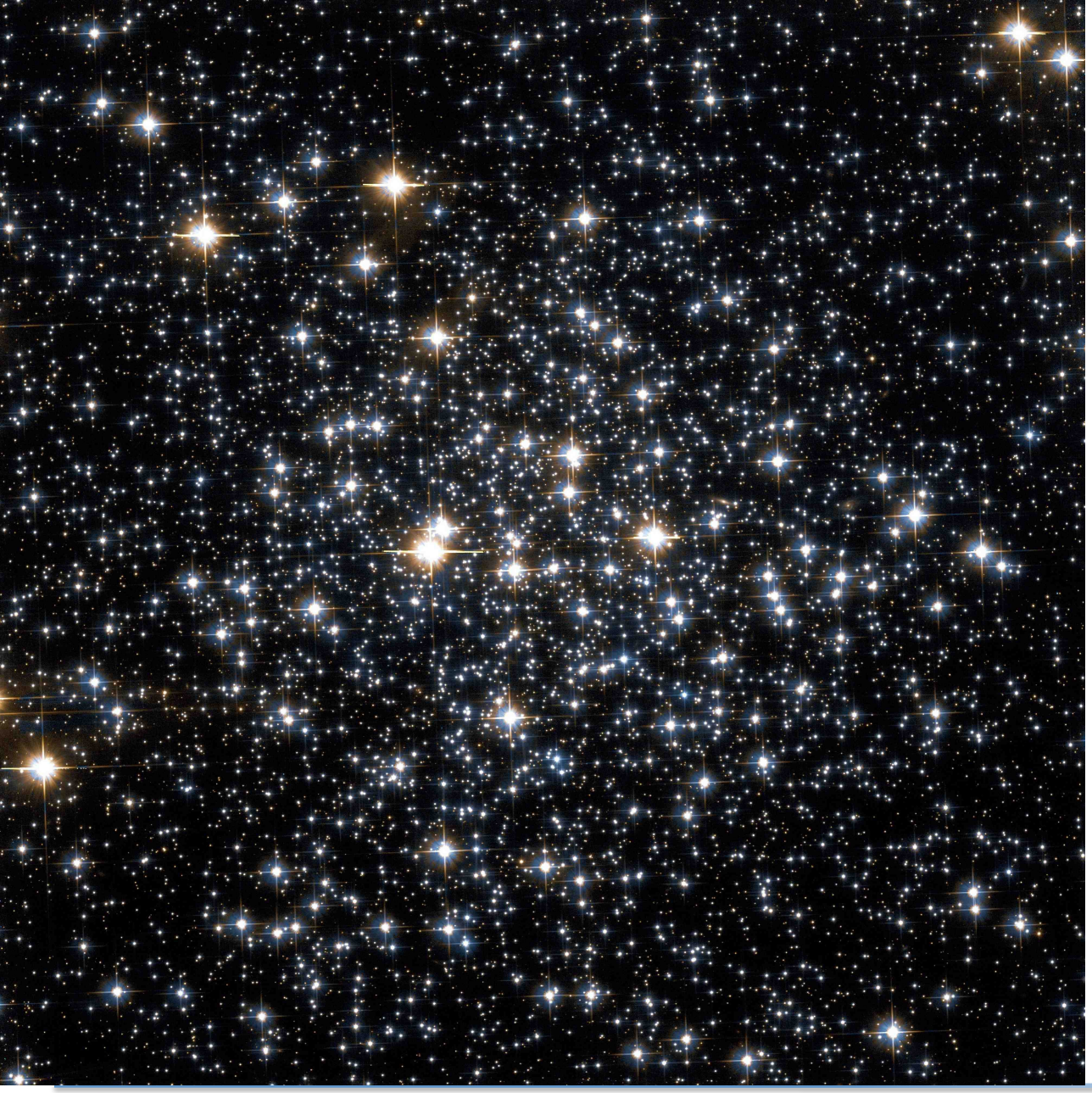
Cadelano et al., 2015a, ApJ, 807-91C

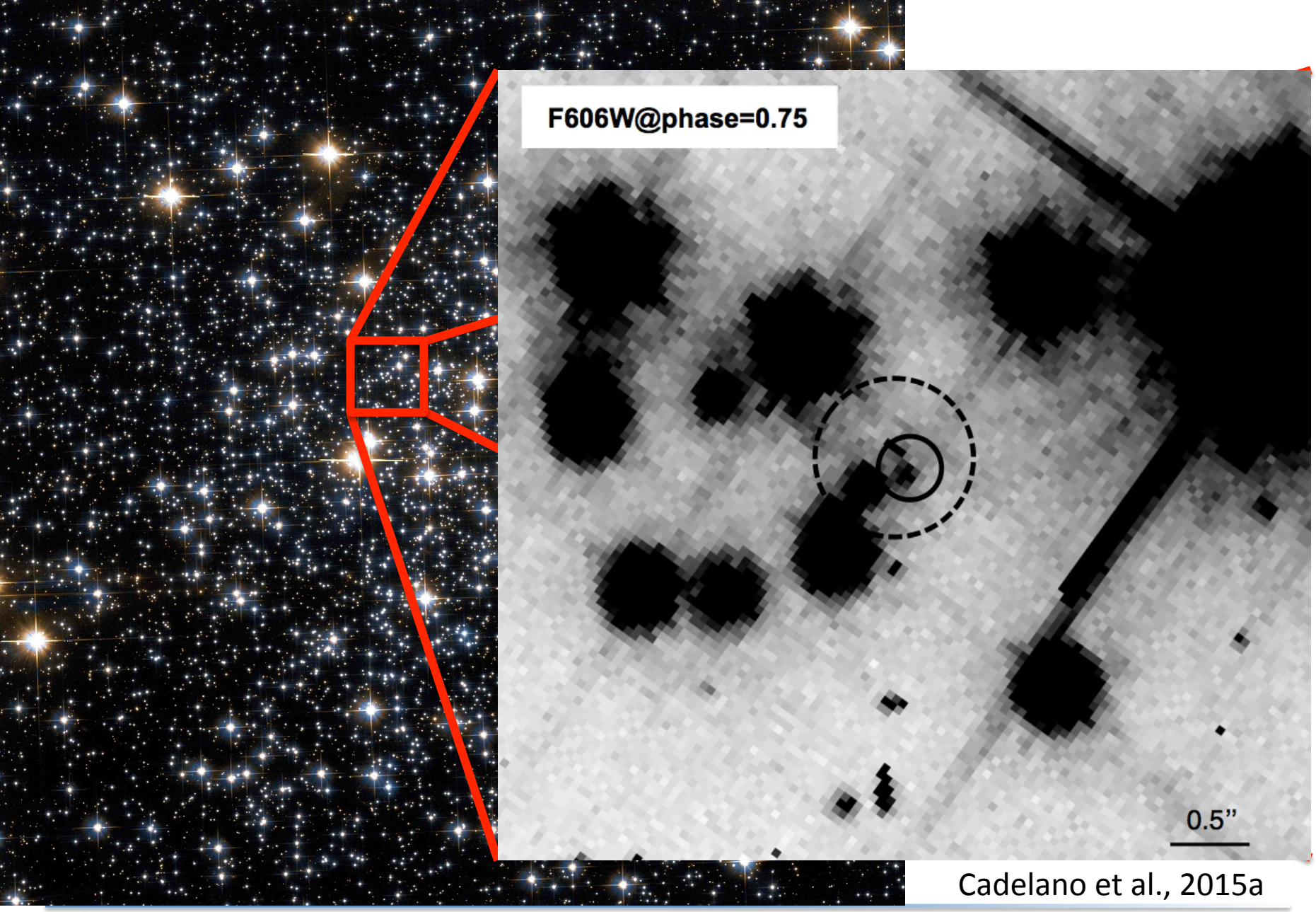
PSR J1953+1846A (M71A)

- Short Orbital Period of ~4 hours. No orbital eccentricity.
- Eclipses for about 20% of the orbital period during the PSR superior conjunction.
- Companion mass of ~0.03 Msun.
- X-ray counterpart. Non thermal emission likely due to an intrabinary shock.

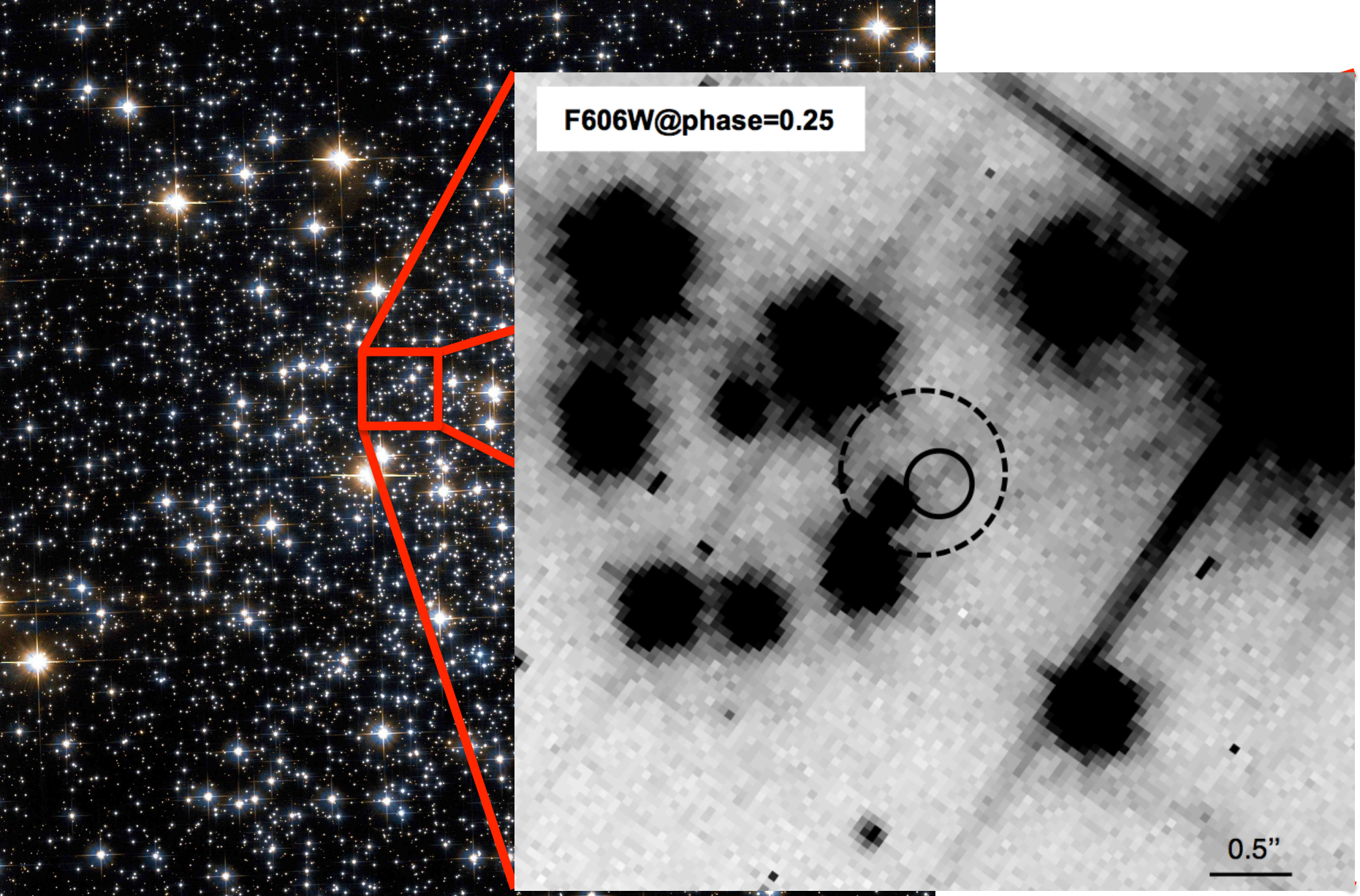
Hessels et al., 07
Elsner et al., 08

We identified the optical counterpart by using deep observation obtained with the ACS@HST

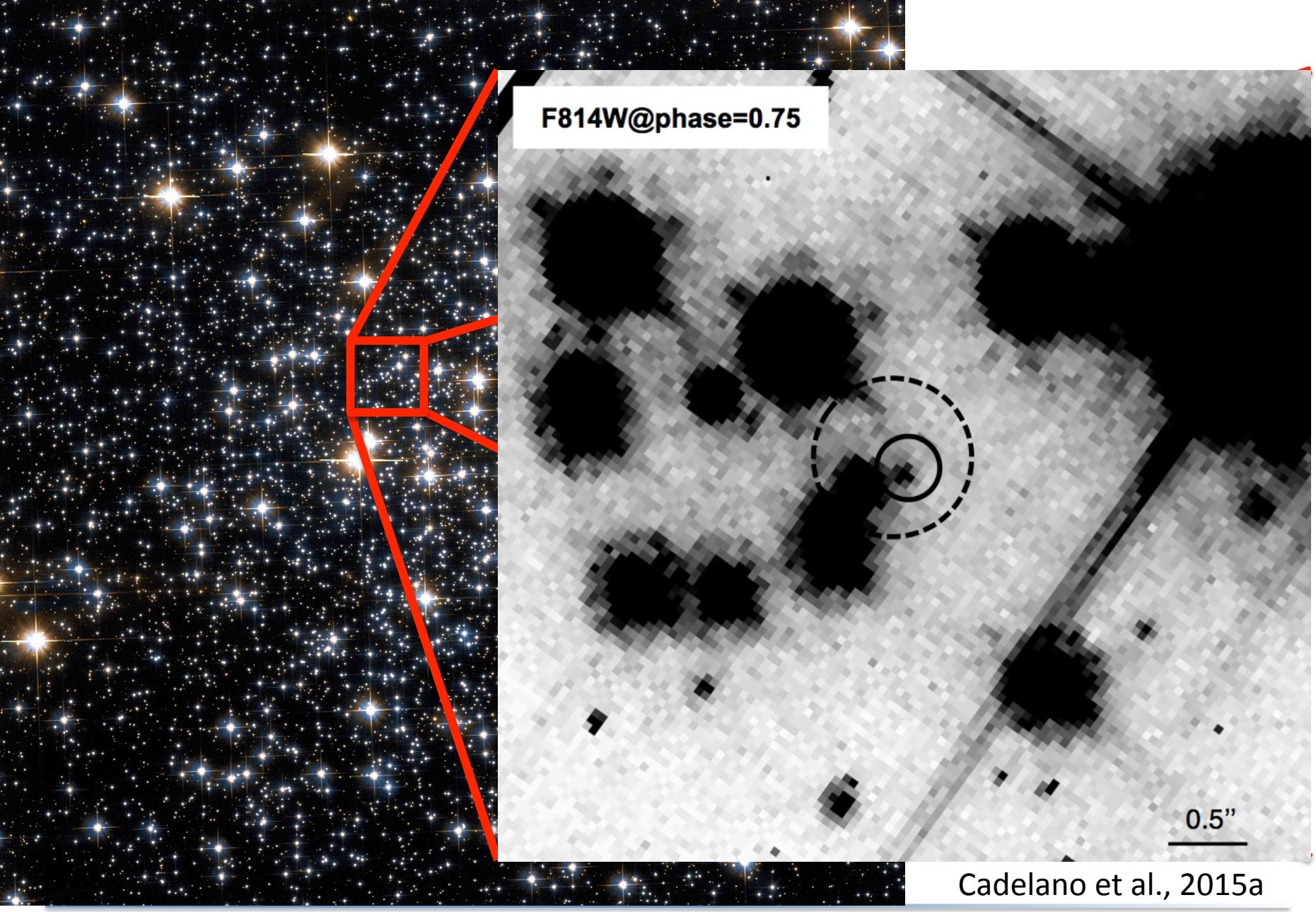




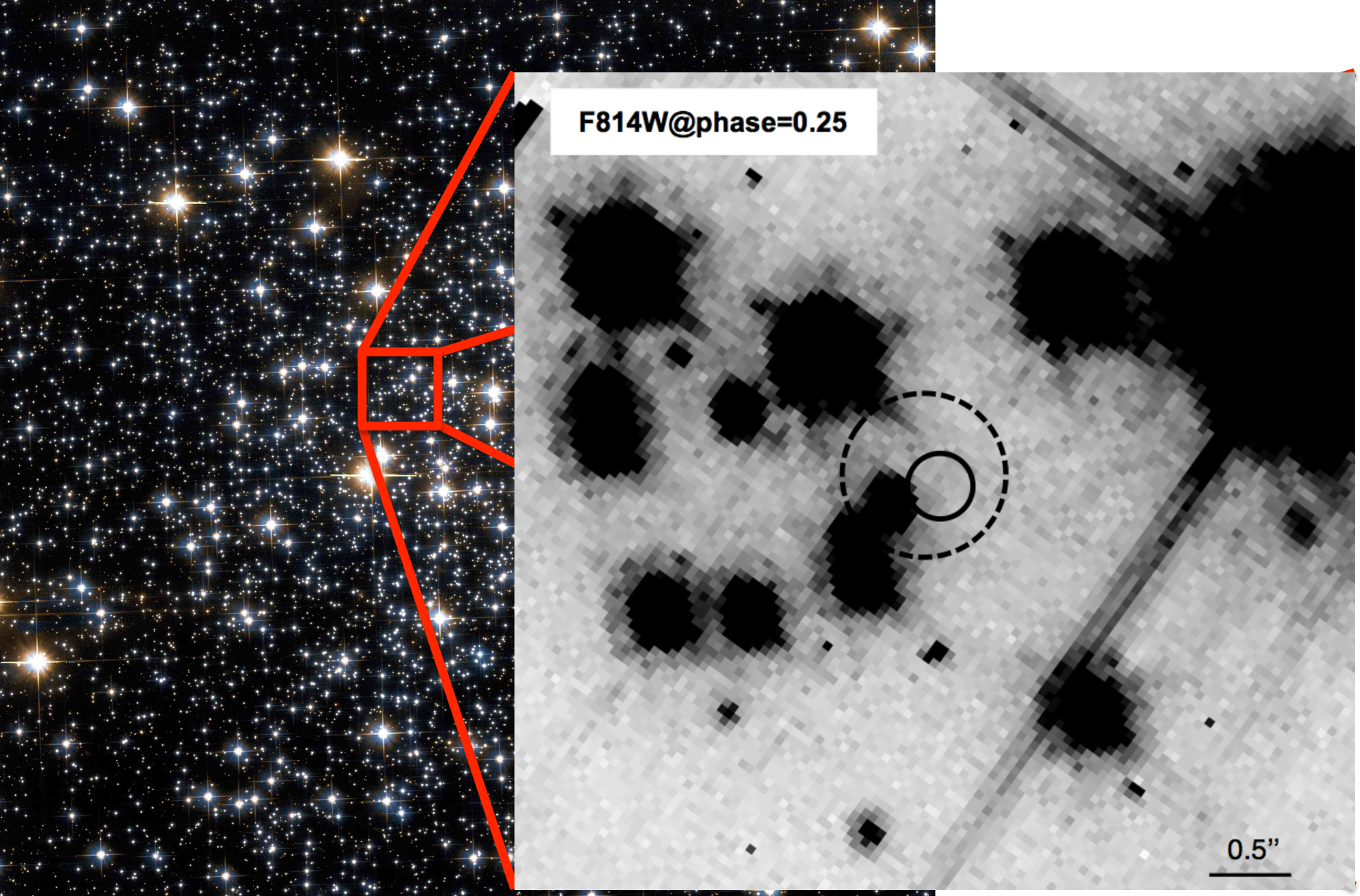
Cadelano et al., 2015a



Cadelano et al., 2015a

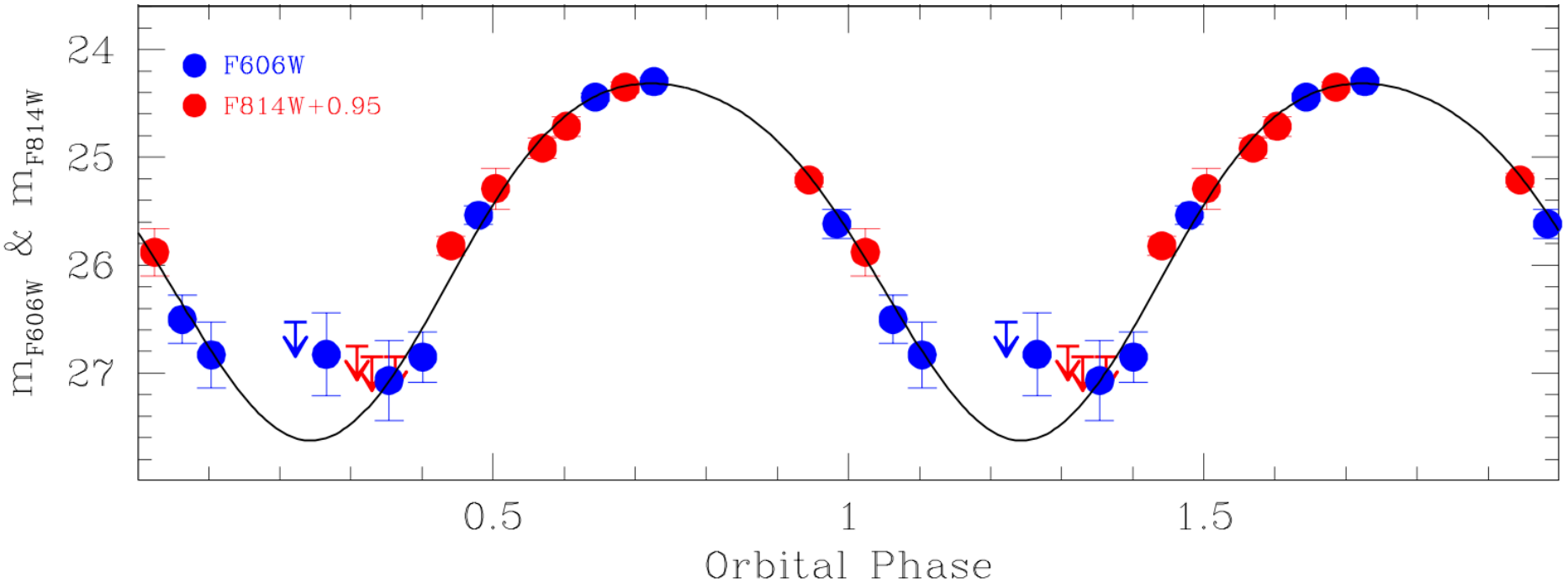


Cadelano et al., 2015a



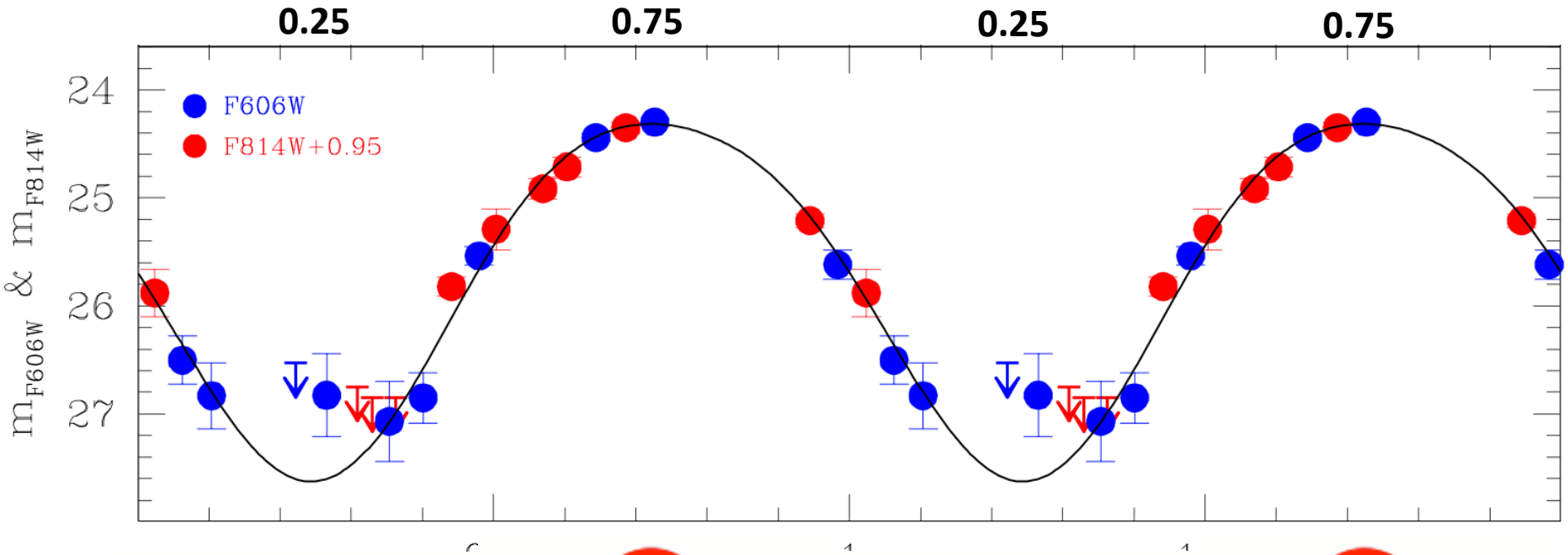
Cadelano et al., 2015a

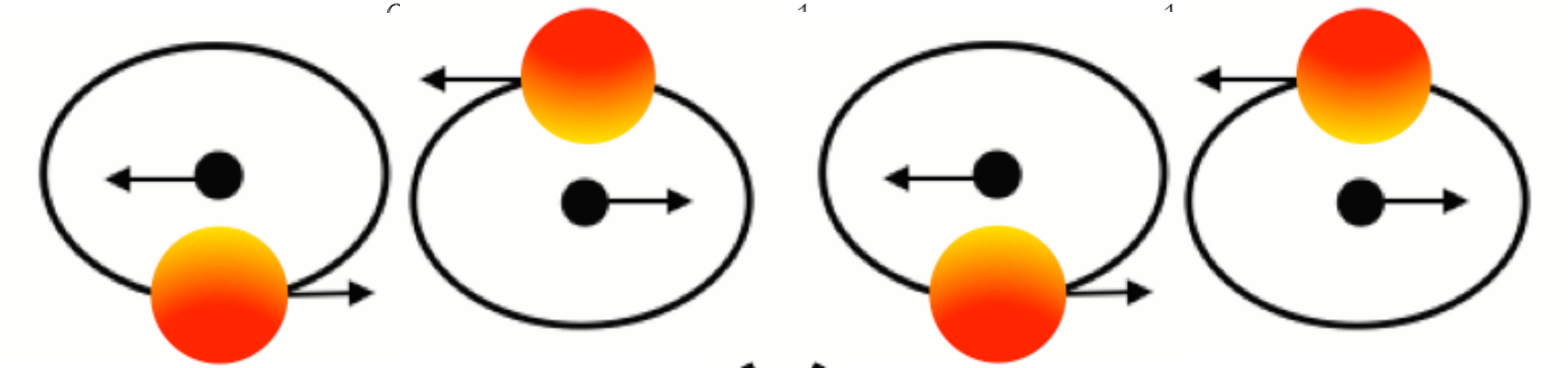
COM-M71A light curve



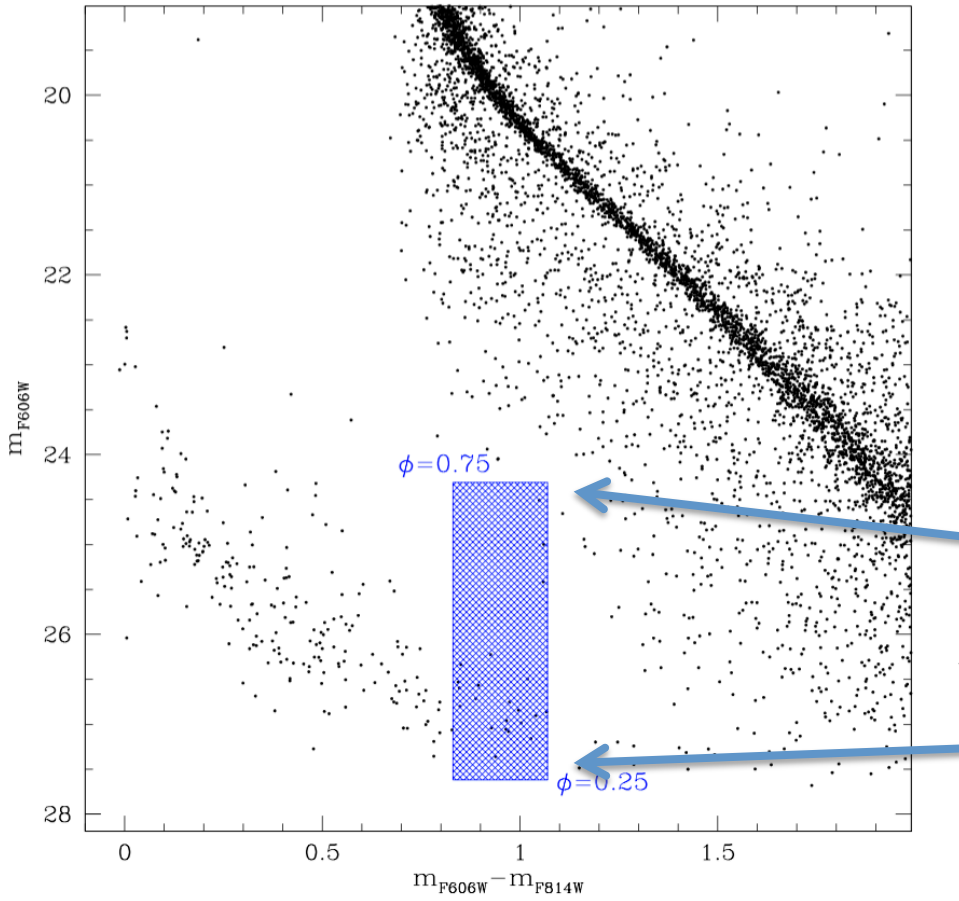
Cadelano et al., 2015a

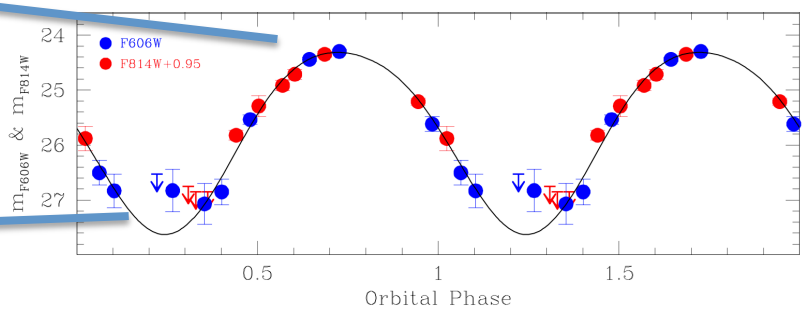
COM-M71A light curve





CMD Position





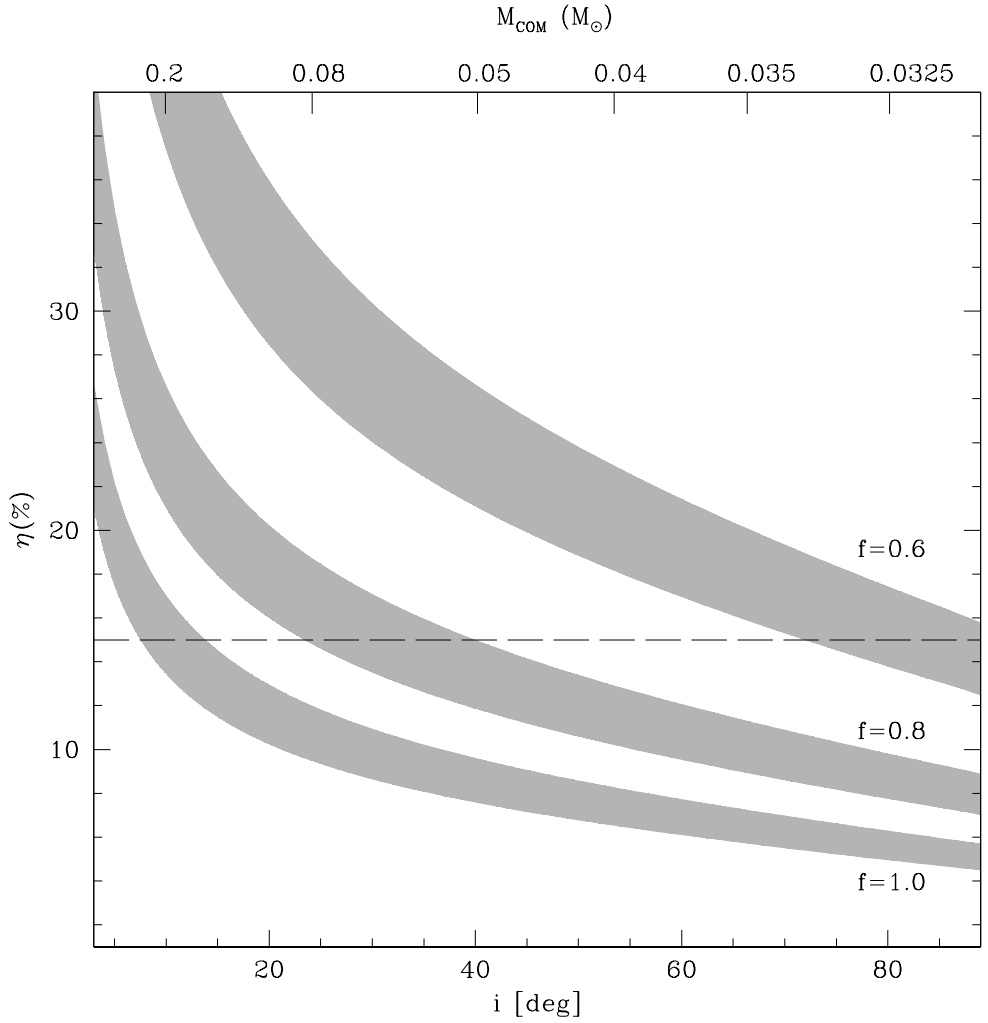
This is a region where no unperturbed stars are expected!

COM-M71A is likely a non-degenerate and highly perturbed star.

$$T \approx 5100K$$

Cadelano et al., 2015a

Reprocessing efficiency and RL filling factor



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

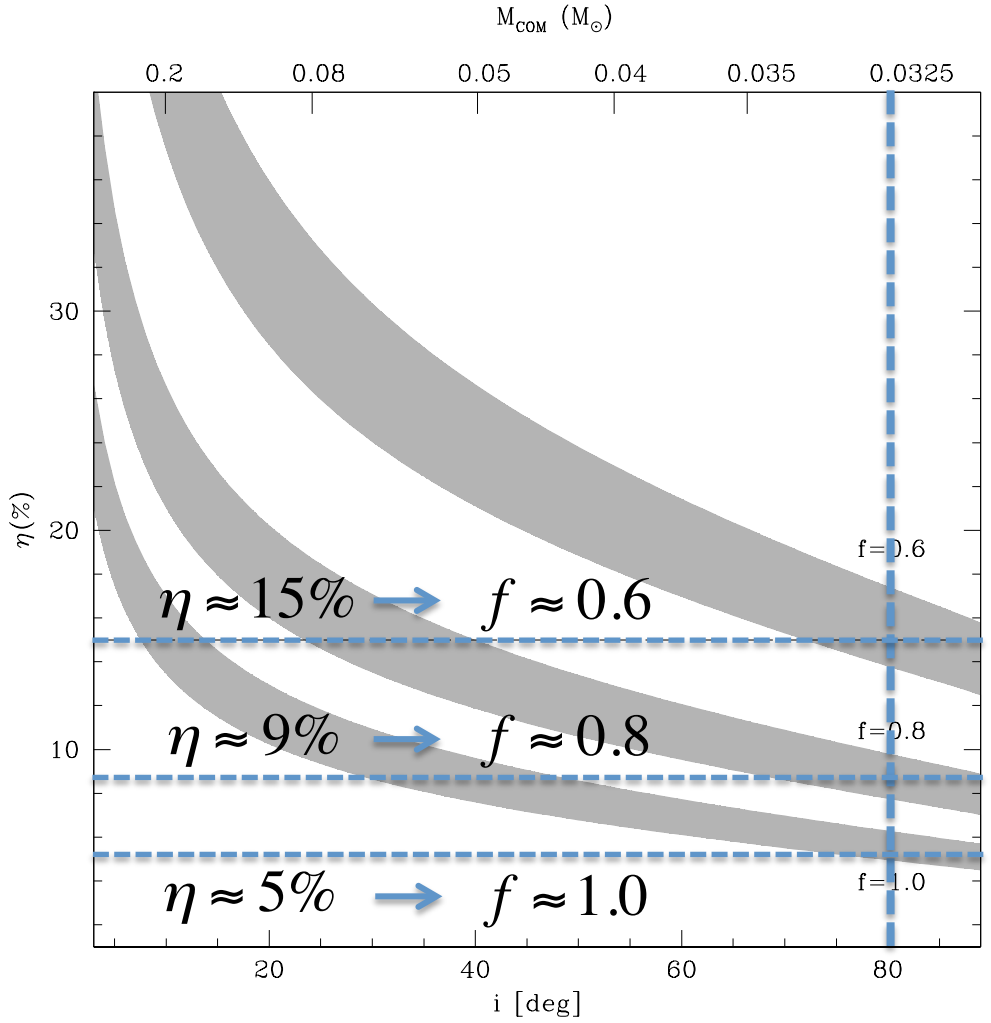
$$\dot{E}_{rot} \cong 4.6 - 5.8 \times 10^{33} ergs/s$$

$$\Delta F_{\exp}(i) = \eta \frac{\dot{E}_{rot}}{a^2} (fR_{RL})^2 \frac{\varepsilon(i)}{4\pi d_{PSR}^2}$$

Flux difference between the minimum and the maximum.

Cadelano et al., 2015a

Reprocessing efficiency and RL filling factor



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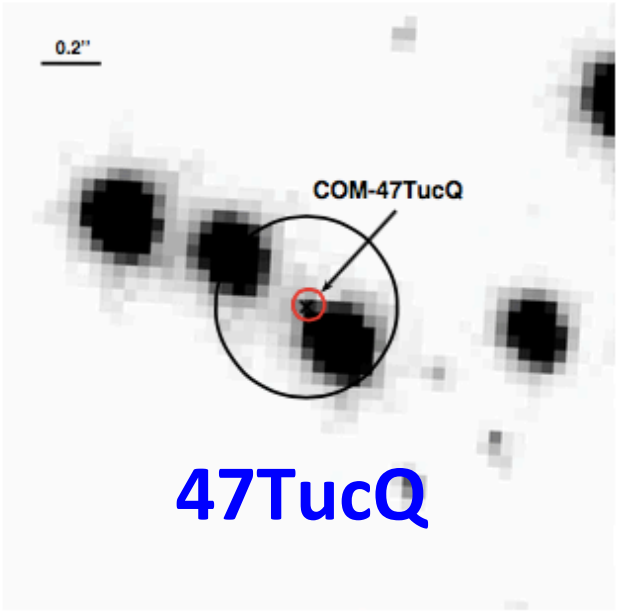
Flux difference between the minimum and the maximum.

Cadelano et al., 2015a

Optical Identification of He White Dwarfs Orbiting Four Millisecond Pulsars in the Globular Cluster 47 Tucanae

Cadelano et al., 2015b, ApJ, in press (arXiv:1509.01397)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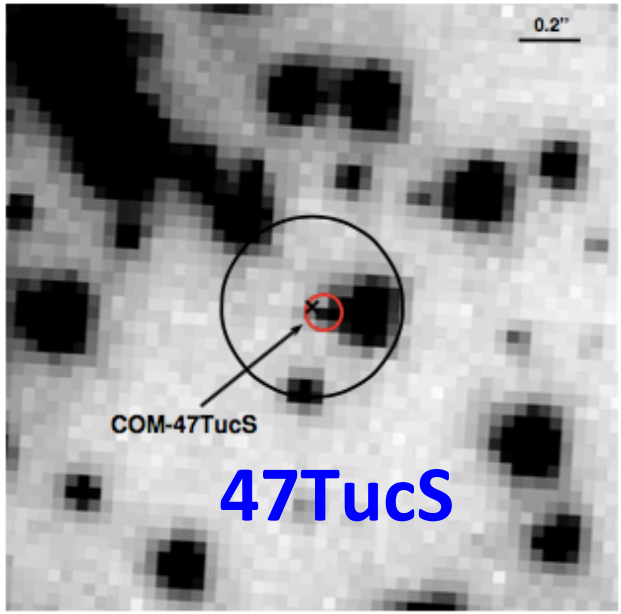
COM-47TucQ
47TucQ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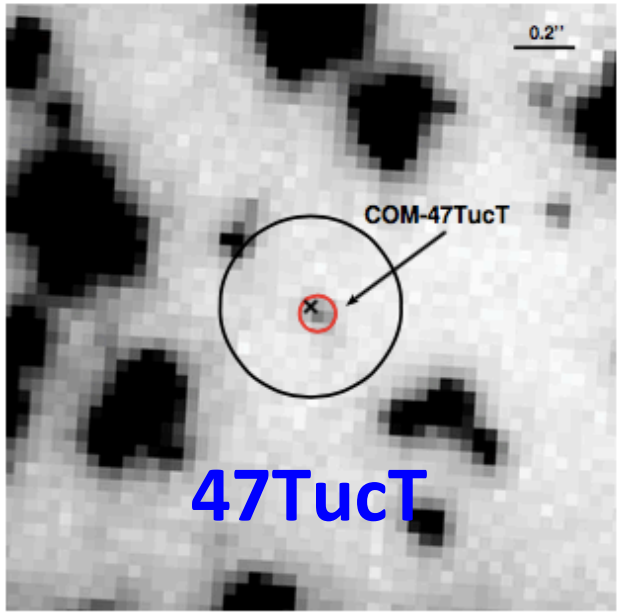
COM-47TucS
47TucS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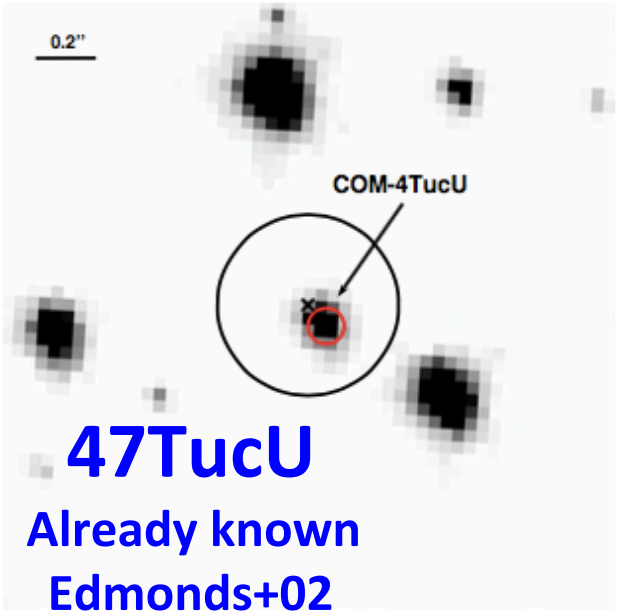
COM-47TucT
47TucT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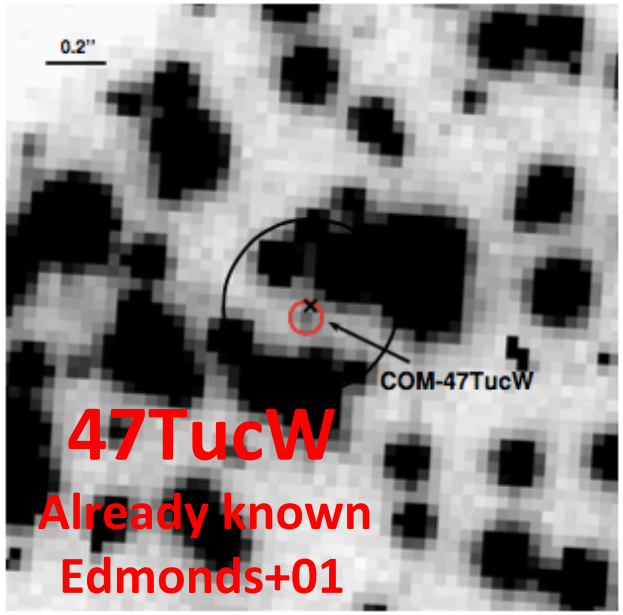
COM-4TucU
47TucU
Already known
Edmonds+02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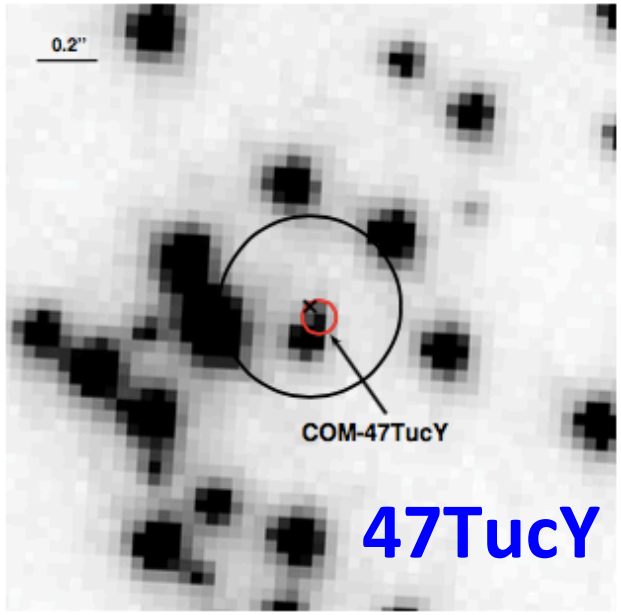
COM-47TucW
47TucW
Already known
Edmonds+01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COM-47TucY
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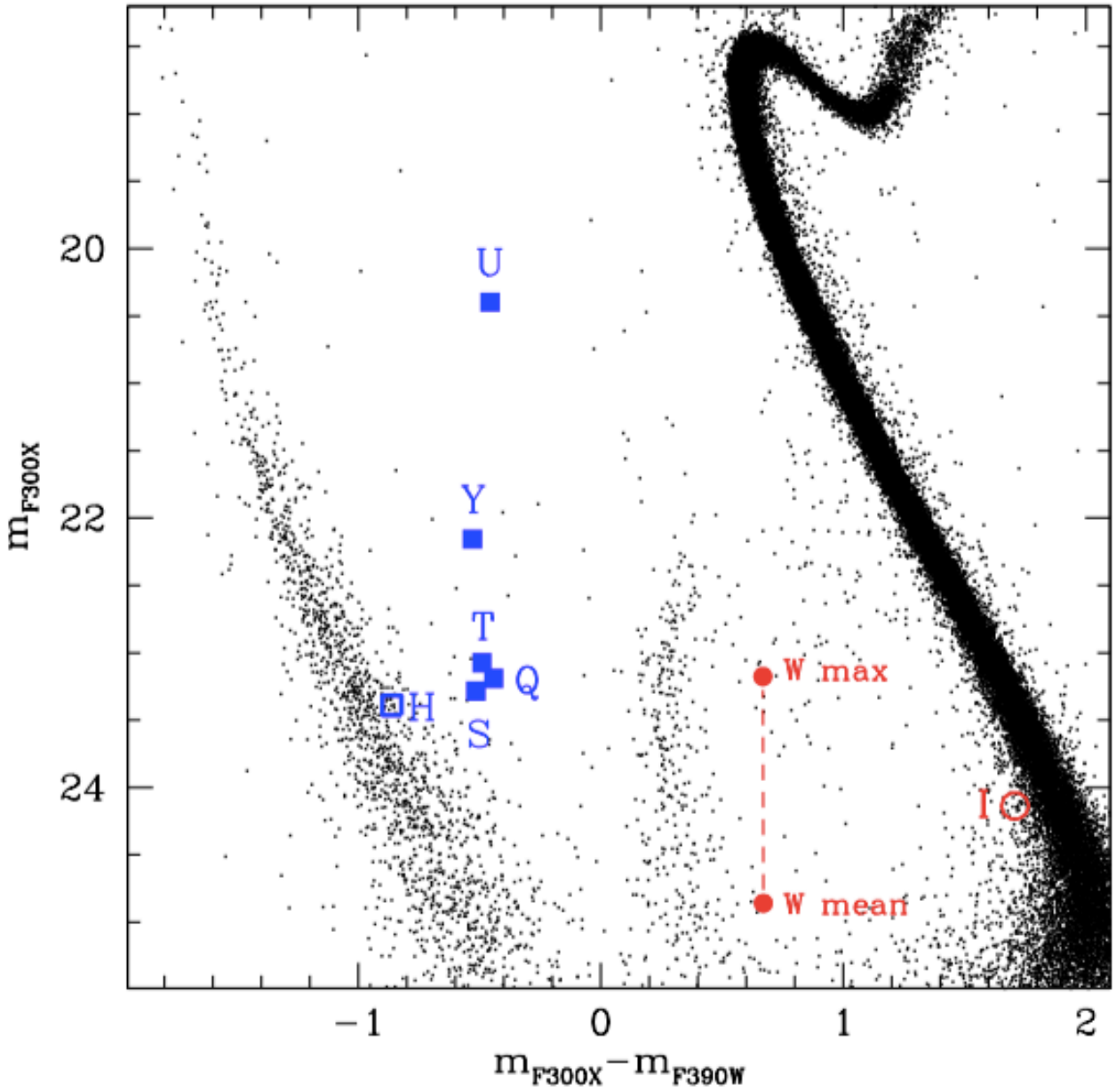
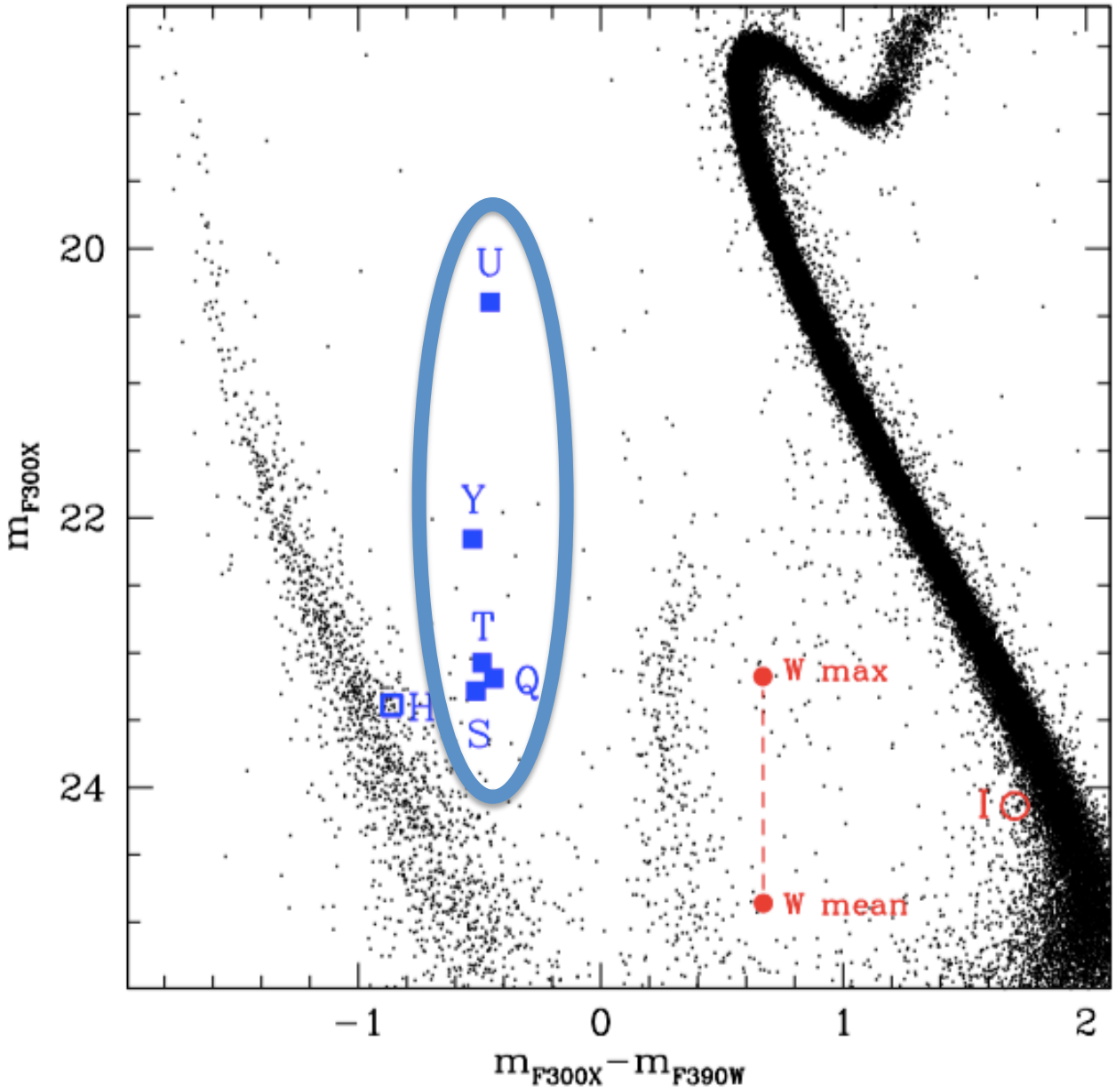

20
22
24
m_{F300X}
U
Y
T
Q
H
S
W max
W mean
I
−1
0
1
2
$m_{F300X} - m_{F390W}$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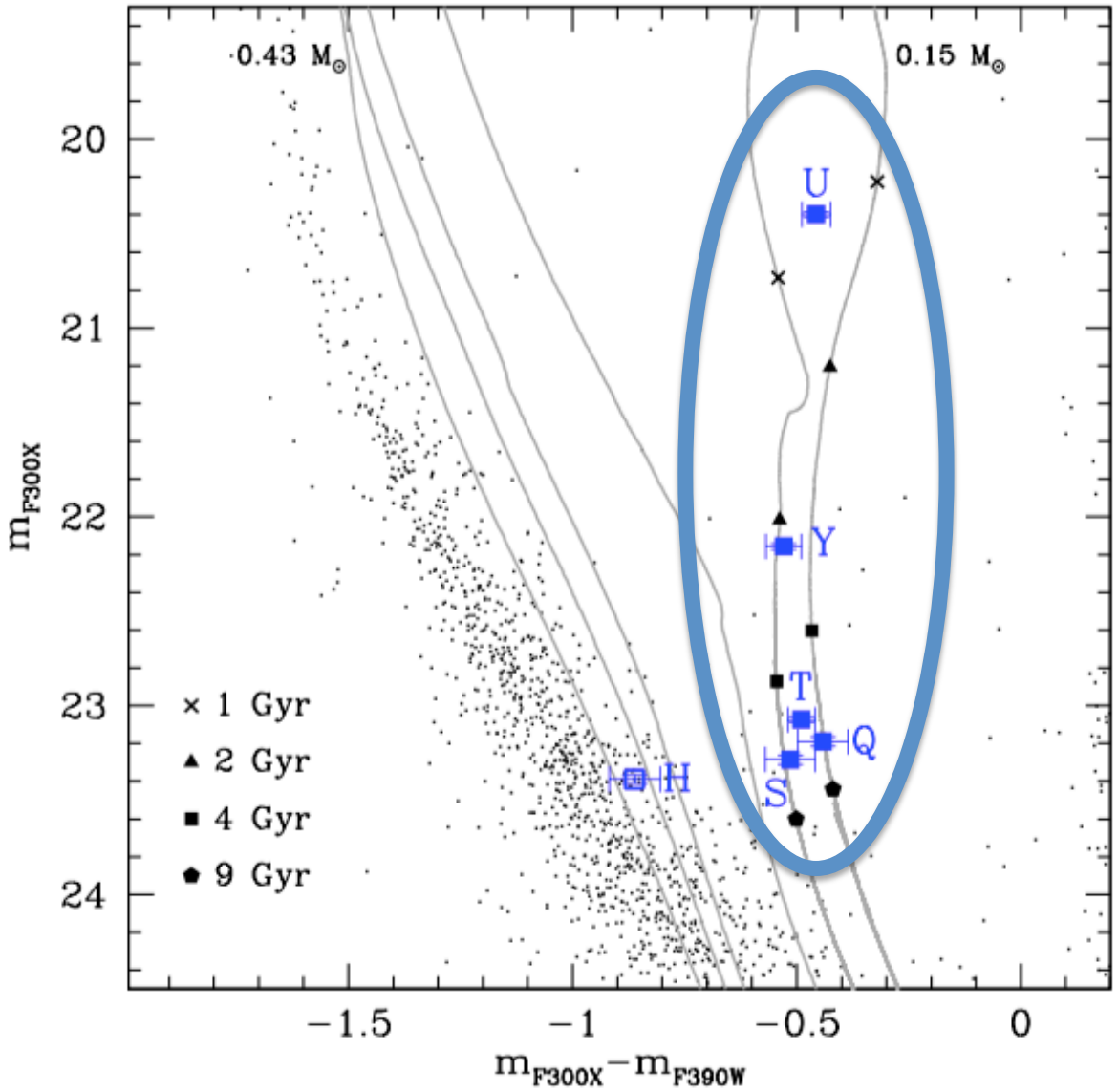
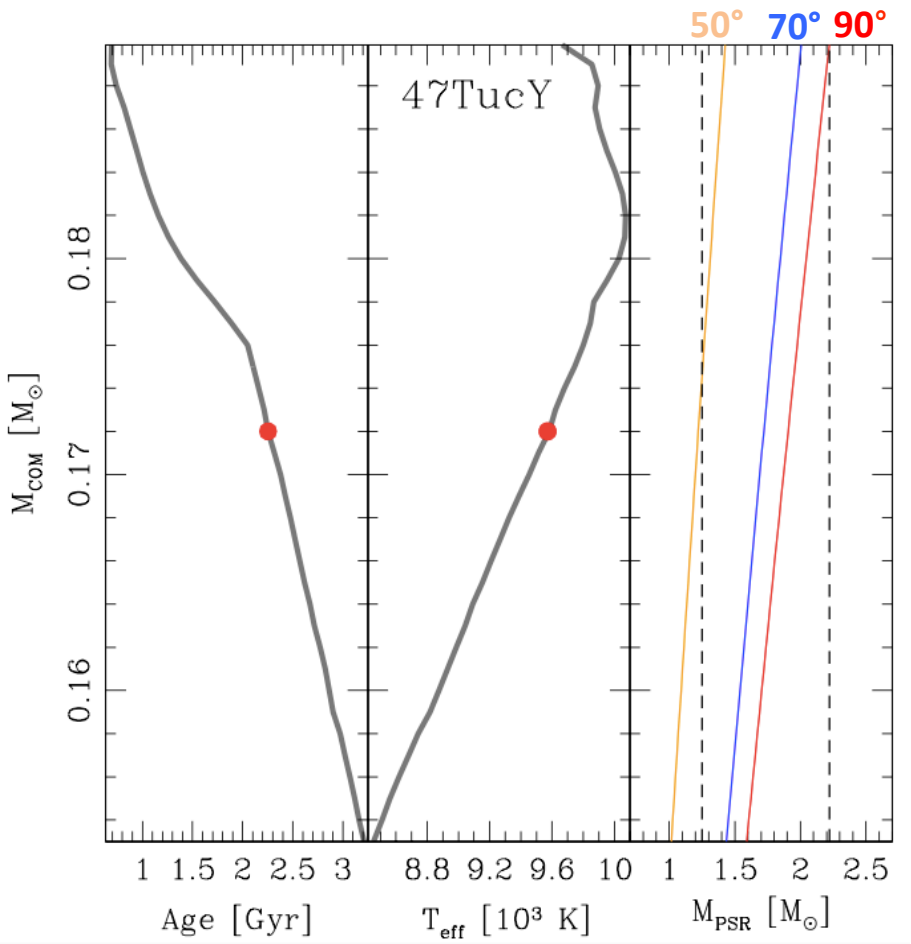
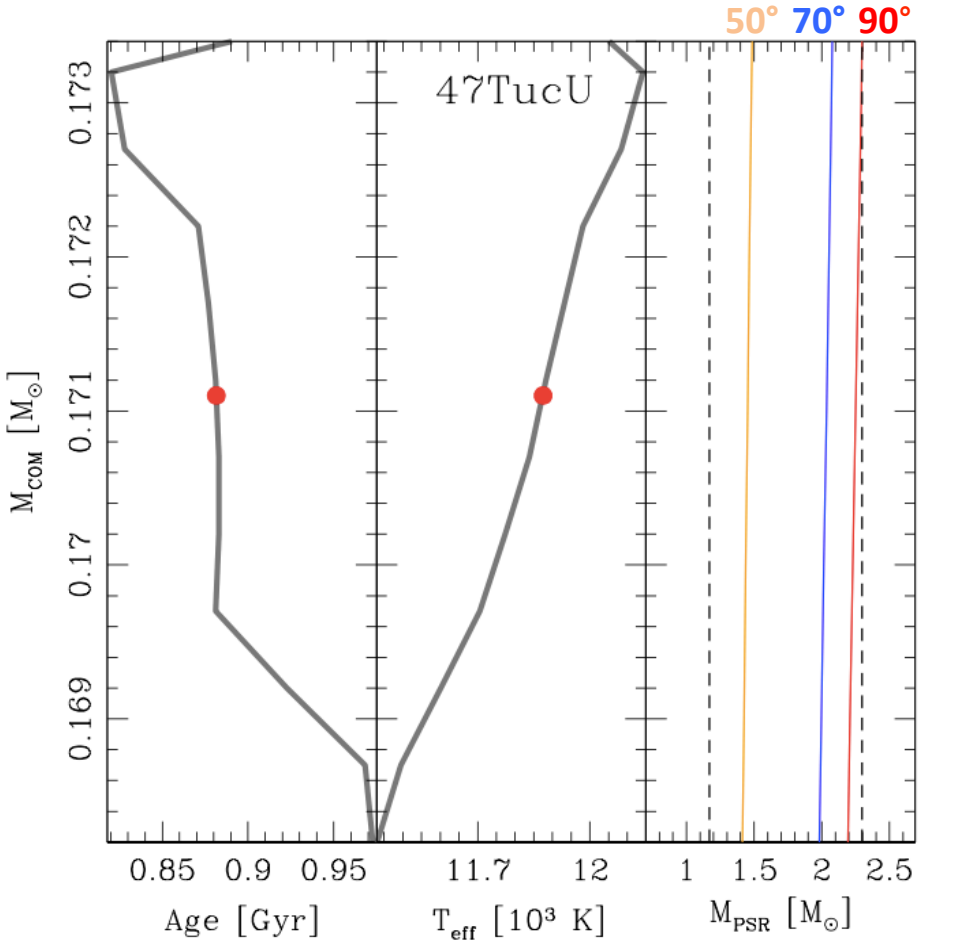


Theoretical models from Althaus et al. 2013

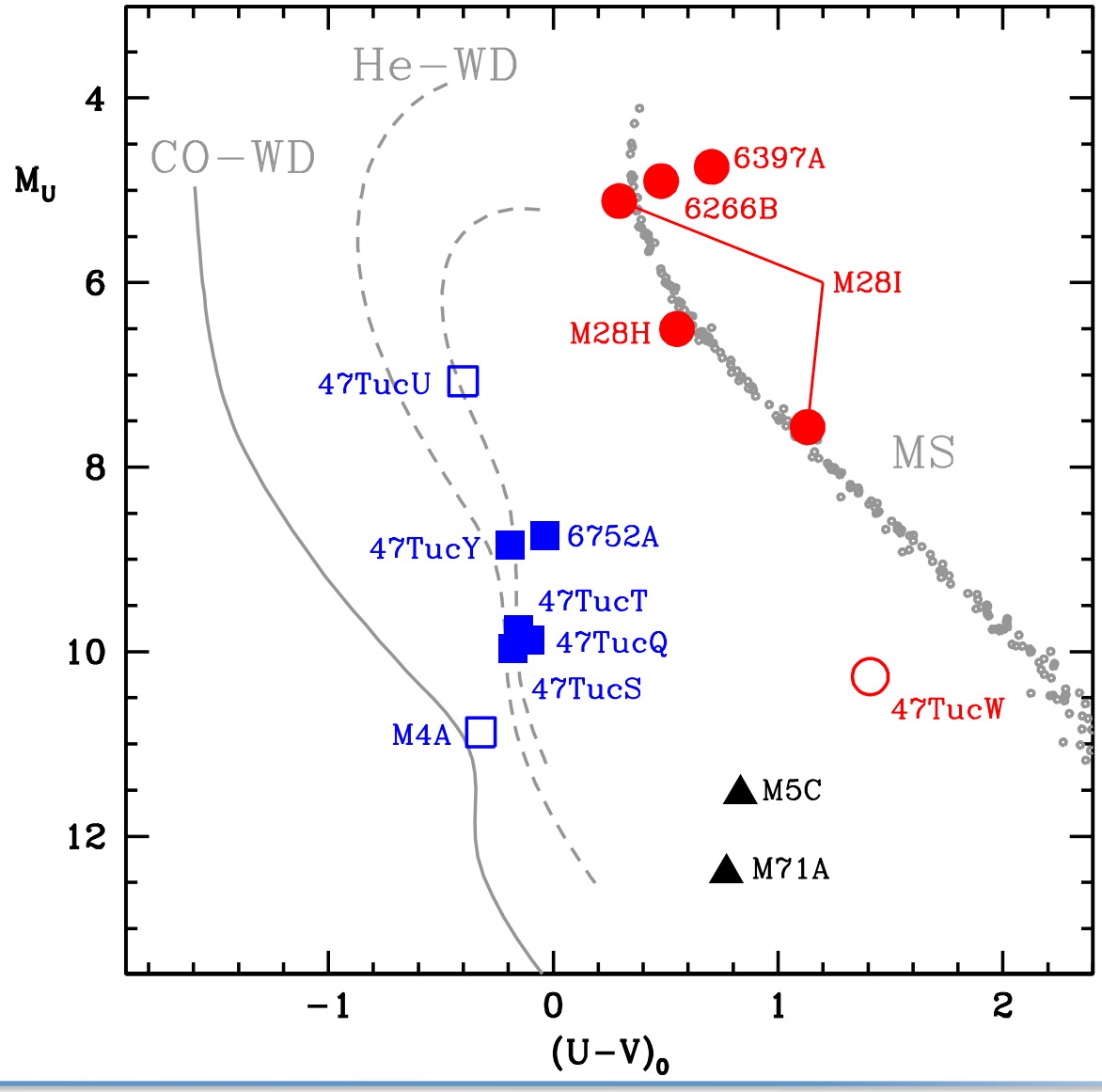




Conclusions:

- Companion masses between **0.15 Msun and 0.2 Msun**
- Cooling ages significatively **younger the cluster stellar population age**
- No massive neutron star for **47TucQ** and **47TucT** (**M_{NS}<1.6 Msun**)
- **47TucU** past accretion stages likely proceeded in a **Sub-Eddington rate** (M/Medd~0.02)

The Globular Cluster Companion Zoo

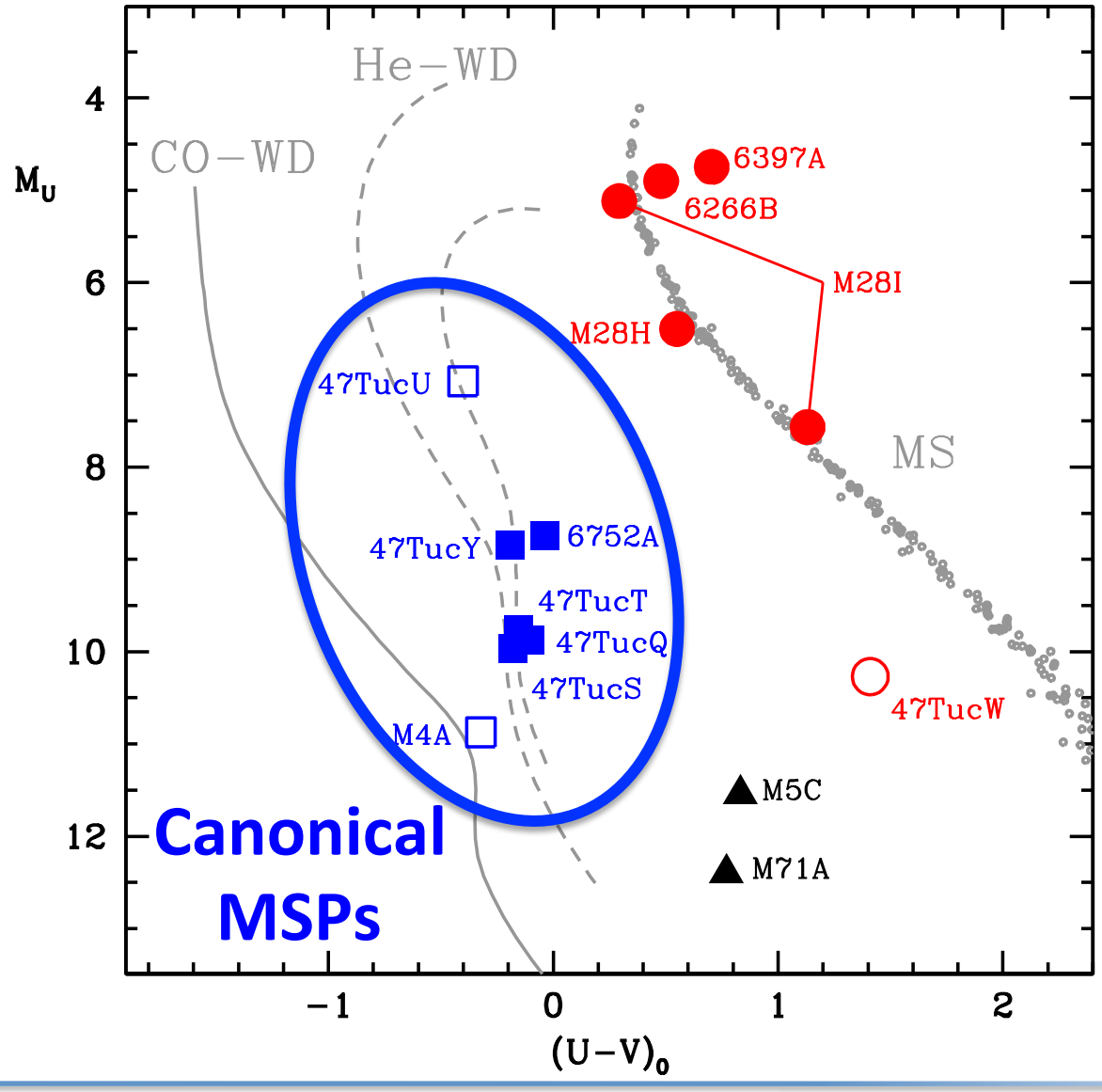


47TucU :Edmonds et al.,02
6752A: Ferraro et al.,03
M4A: Sigurdsson et al., 03
47TucQ,S,T,Y:
Cadelano et al.,15b
Rivera-Sandoval et al.,15

6397A: Ferraro et al., 01
47TucW: Edmonds et al., 01
6266B: Cocozza et al., 08
M28H: Pallanca et al. 10
M28I: Pallanca et al. 13

M5C: Pallanca et al., 14
M71A: Cadelano et al, 15a

The Globular Cluster Companion Zoo



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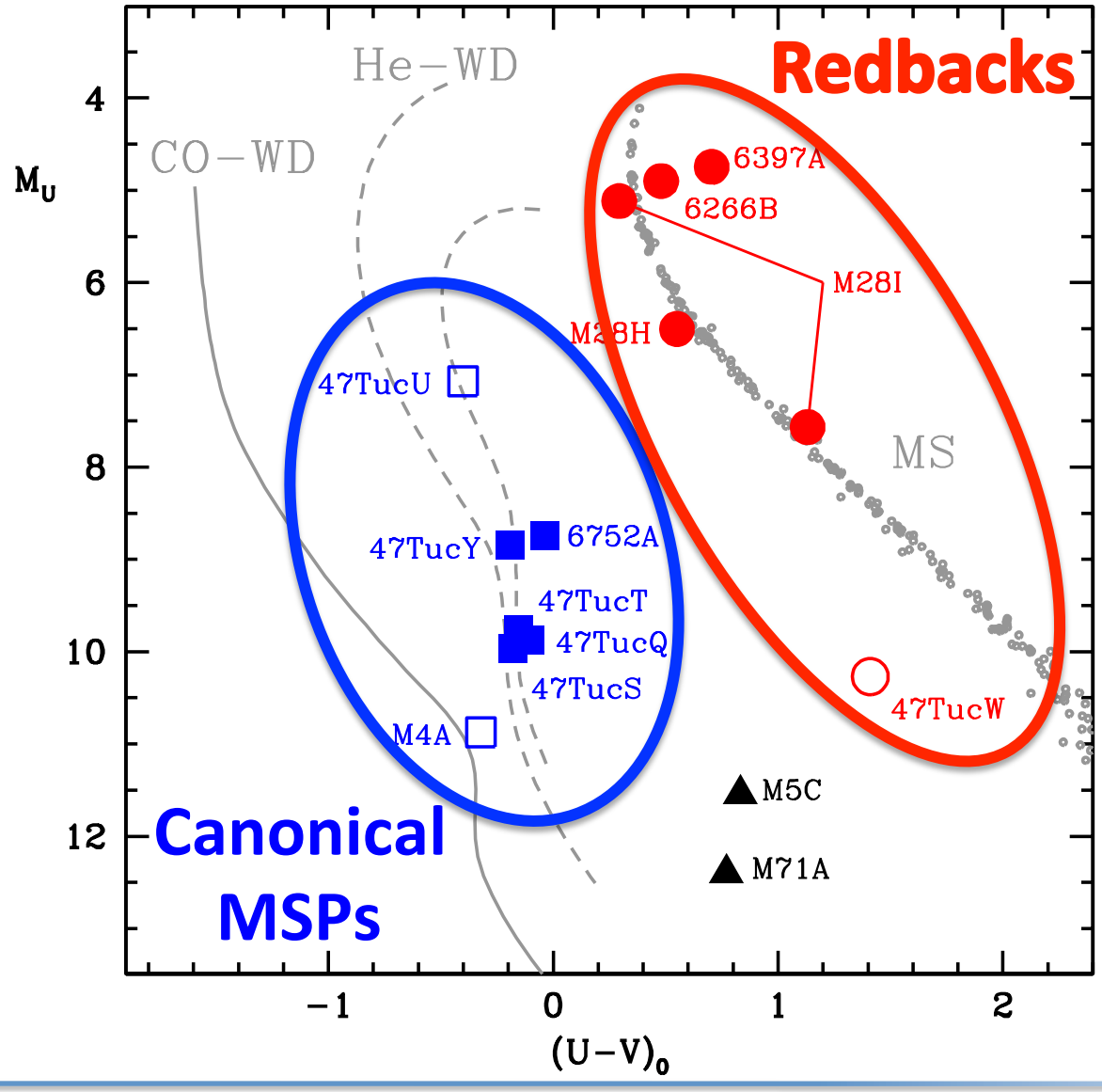

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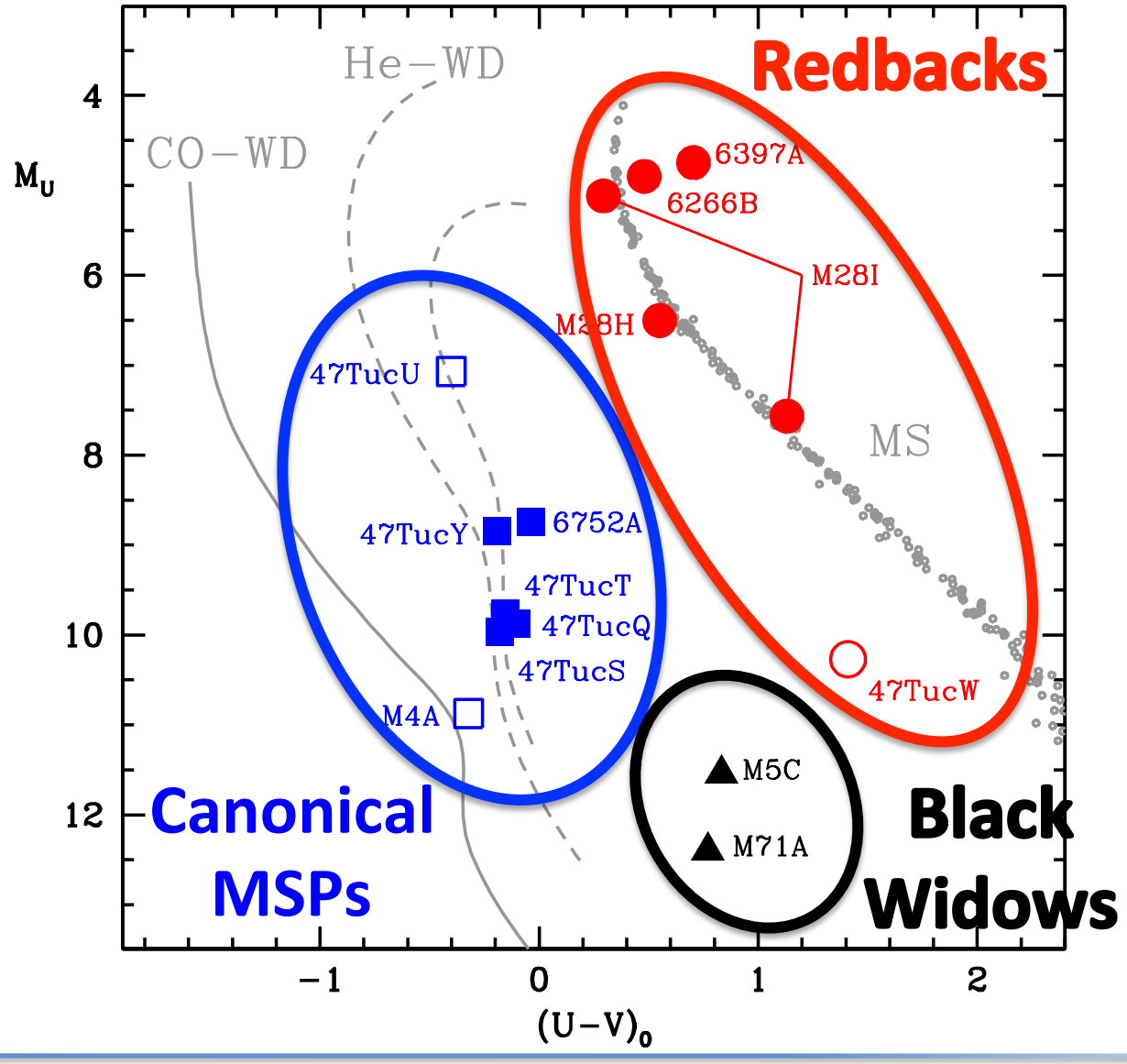

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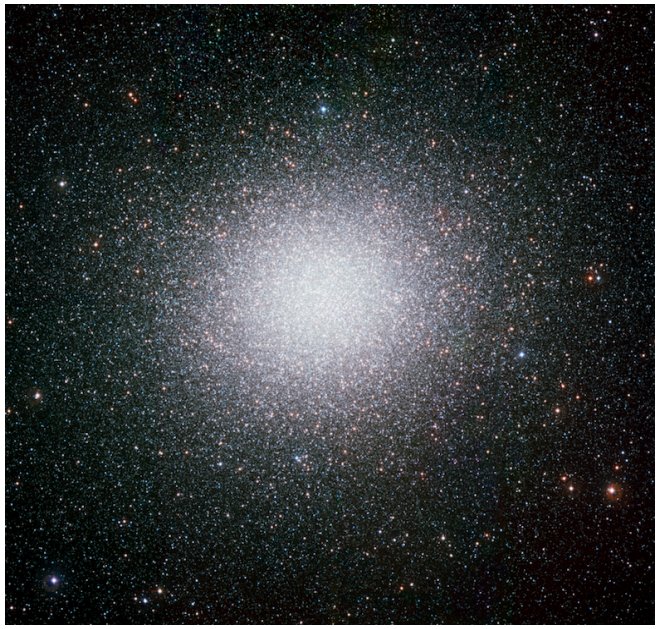
A New Deep Survey for Millisecond Pulsars in Globular Clusters

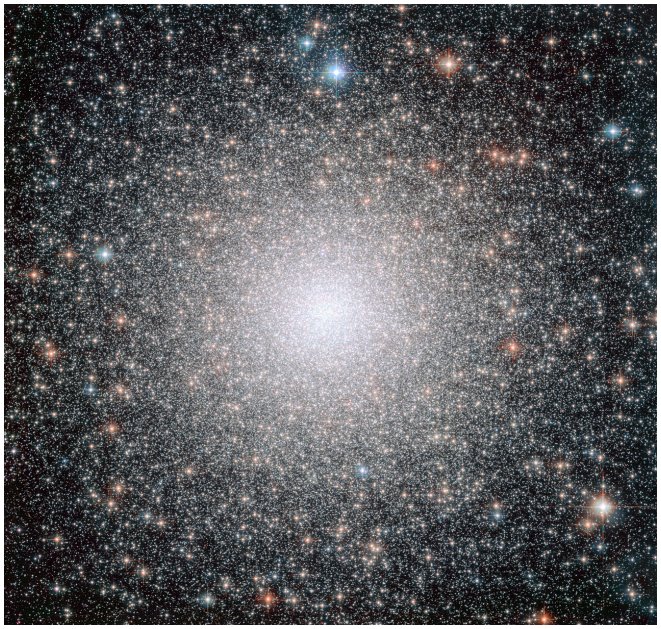
ω Centauri



- ✓ Gamma-ray emission
- ✓ Large stellar mass
- ✓ Multiple stellar populations

Acceleration search at 20 cm and 10 cm
DM = 0-600 pc/cm^3

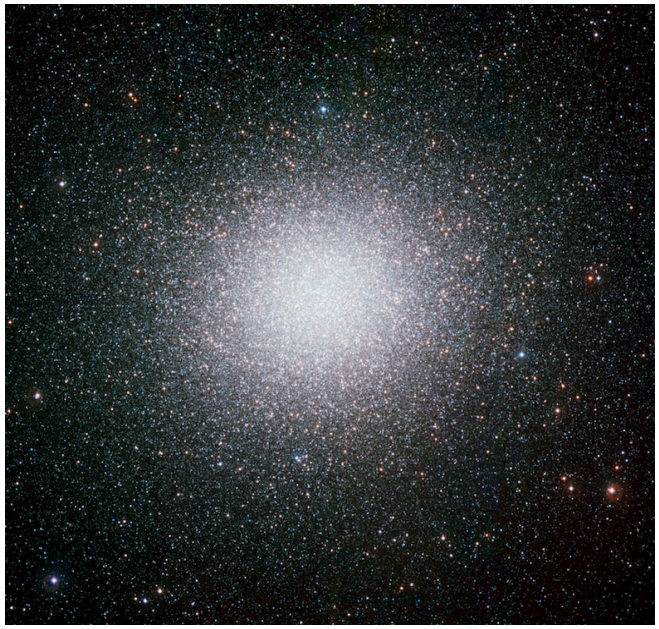
NGC 6388



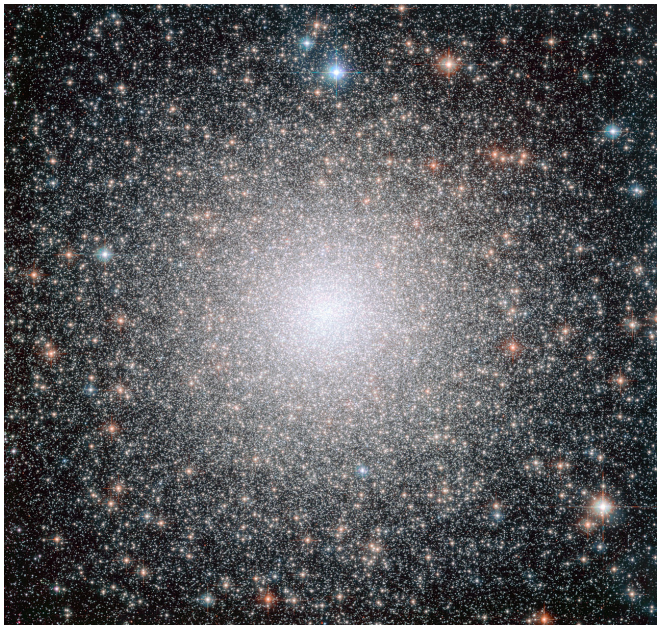
- ✓ Gamma-ray emission
- ✓ Large stellar mass
- ✓ High stellar encounter rate

Acceleration search at 20 cm and 10 cm
DM = 0-800 pc/cm^3

ω Centauri



NGC 6388



WORK IN PROGRESS…

Thanks for your attention!