CHANDRA X-RAY SOURCES IN OLD STAR CLUSTERS: SIGNATURES OF BINARY FORMATION & DESTRUCTION

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MAIN COLLABORATORS

- Globular clusters: Josh Grindlay, Phyllis Lugger, Haldan Cohn, Craig Heinke, Slavko Bogdanov
- Old open clusters: Luigi Bedin, Frank Verbunt, Bob Mathieu, Imants Platais
- PhD students (Amsterdam): Smriti Vats, Liliana Rivera Sandoval ... check out their posters!

MOTIVATION

- why binaries in clusters?
  - primordial binary frequency is a fundamental cluster parameter, important for cluster evolution
  - how does cluster environment affect binary evolution?
  - study exotic binaries that are rare in the field of the Galaxy
  - uniform samples with accurate distances/ages/compositions
- why X-rays?
  - in old populations X-ray sources are efficient tracers of close interacting binaries

OUTLINE

- X-ray sources in globular clusters (GCs) and old open clusters (OCs)
- signatures of binary formation
- signatures of primordial binary destruction

BRIGHT X-RAY SOURCES IN GLOBULAR CLUSTERS

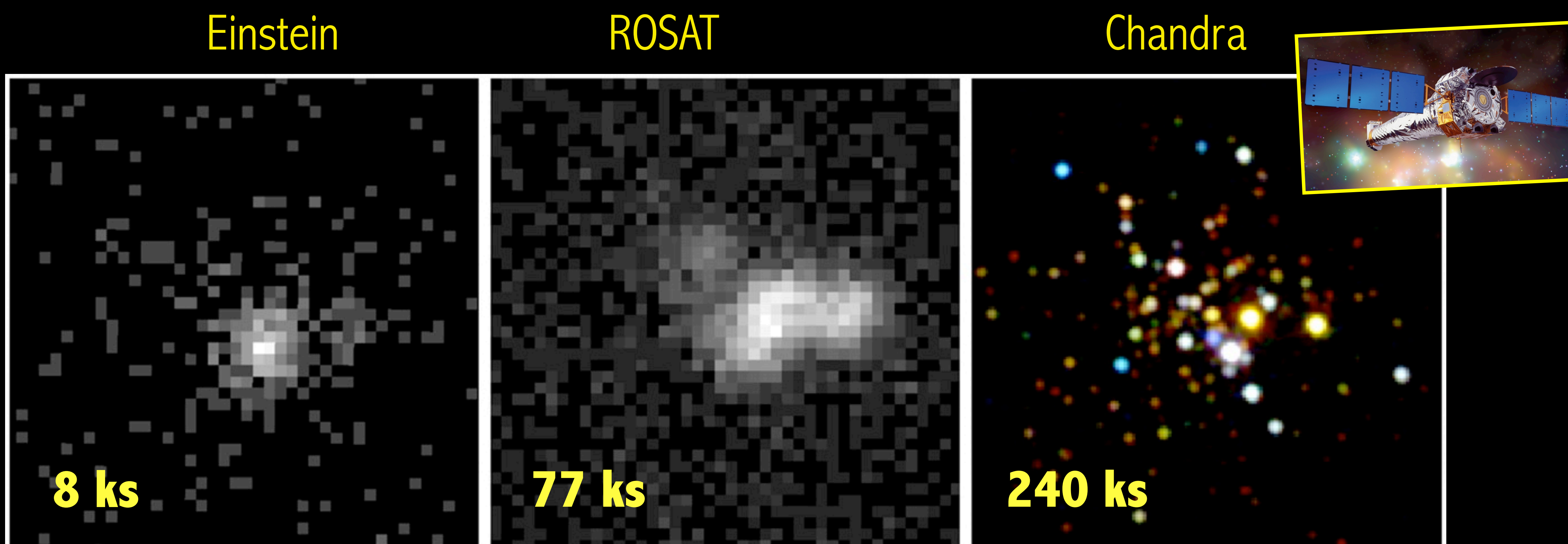
- first GC X-ray sources detected in early 70s:
  - Lx~1e36 erg/s: must be compact objects accreting from companion
  - signature of dynamical formation: high formation rate per unit mass, high incidence of short-period "ultracompact" systems

- even now new bright sources are discovered occasionally;
  - latest: a transient X-ray source in M28 discovered by INTEGRAL in March 2013

- current status: 18 bright sources in Galactic GCs, all neutron-star accretors (thermonuclear bursts on the NS surface, accretion-powered pulsations)

CHANDRA: FAINT X-RAY SOURCES IN CLUSTERS

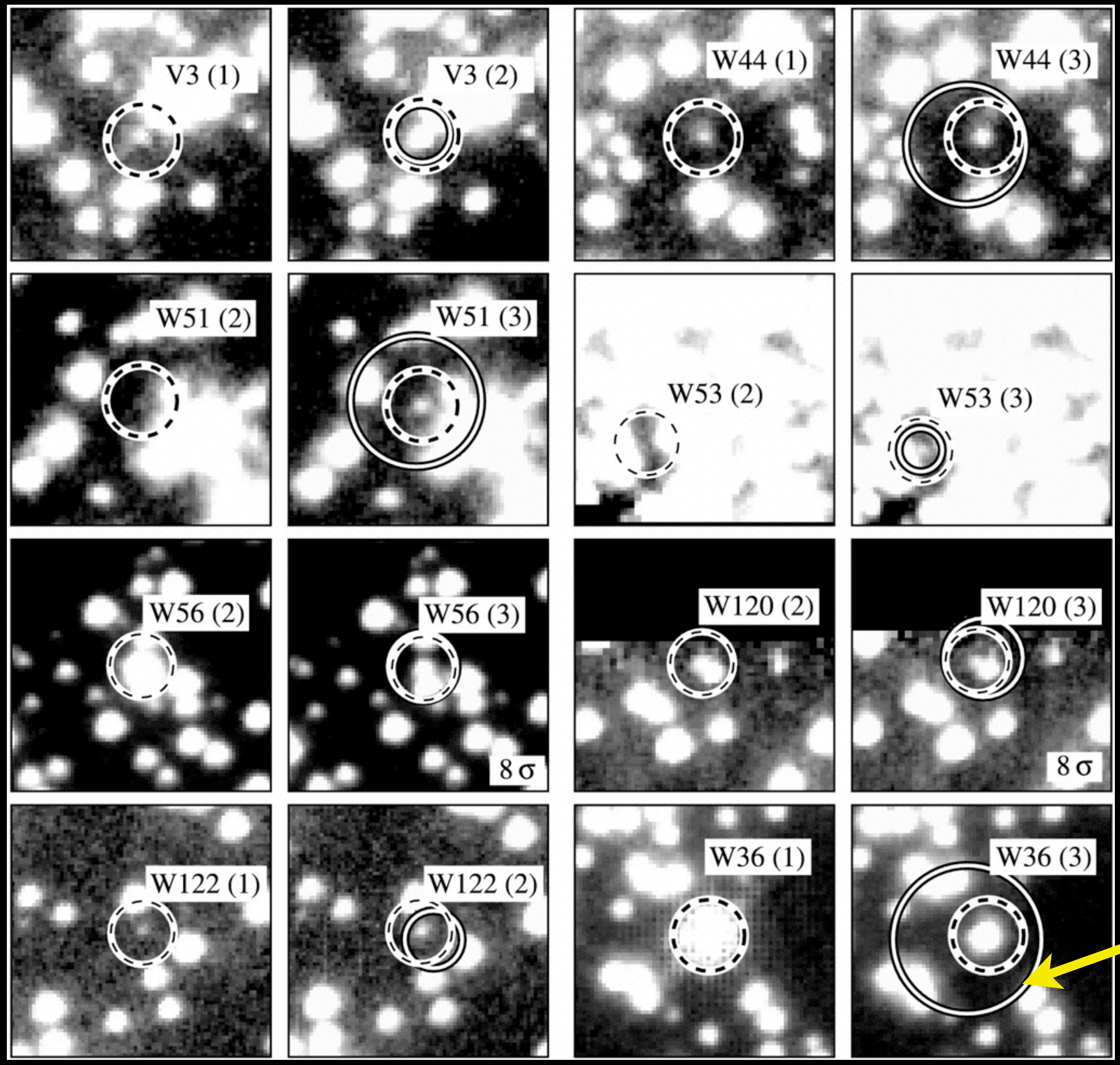
core of 47Tuc as seen by ...



origin: D. Pooley 2010

OPTICAL IDENTIFICATION

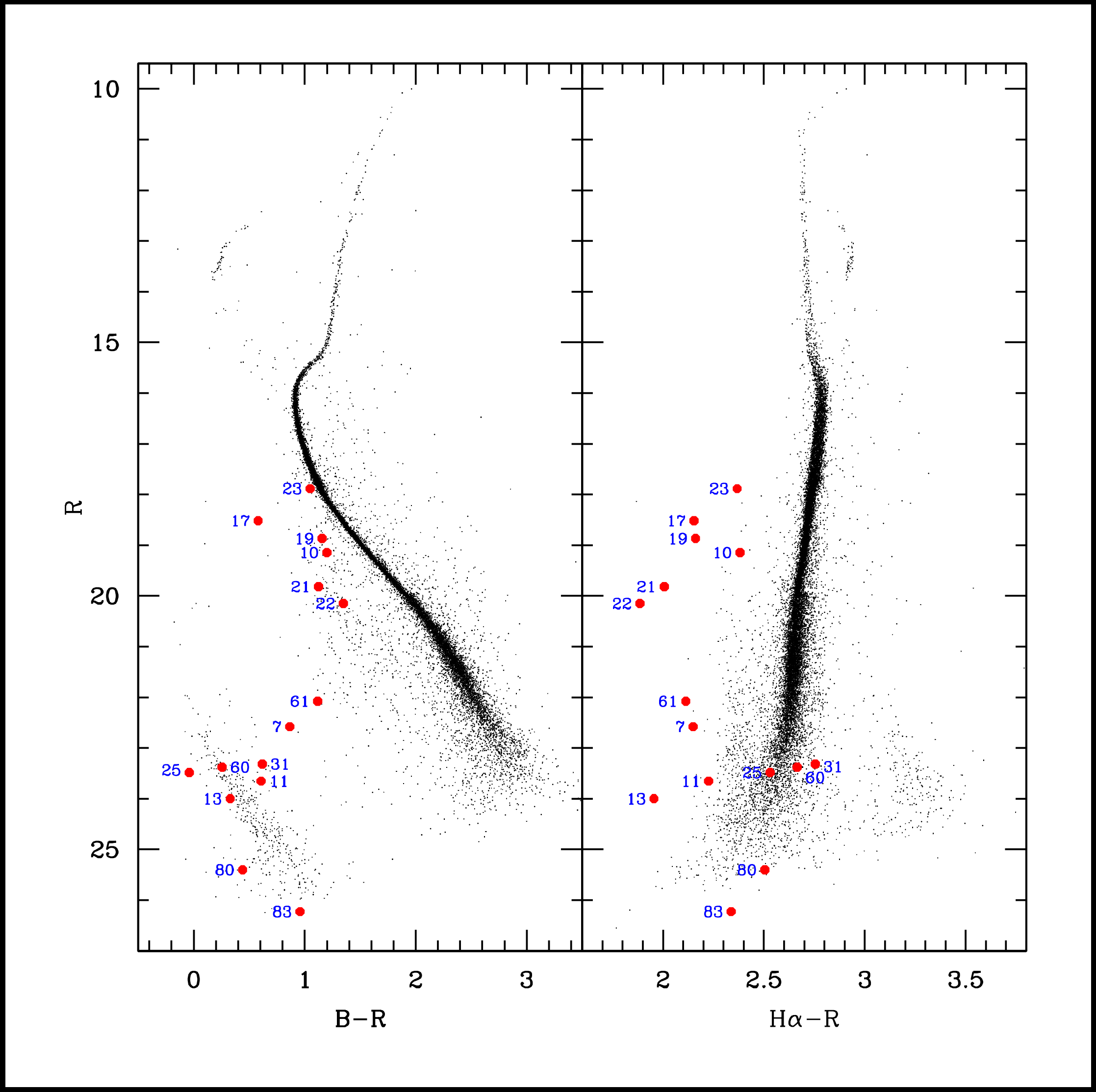
multiple candidate optical counterparts in Chandra error circle, even with HST ....



Edmonds et al. 2003

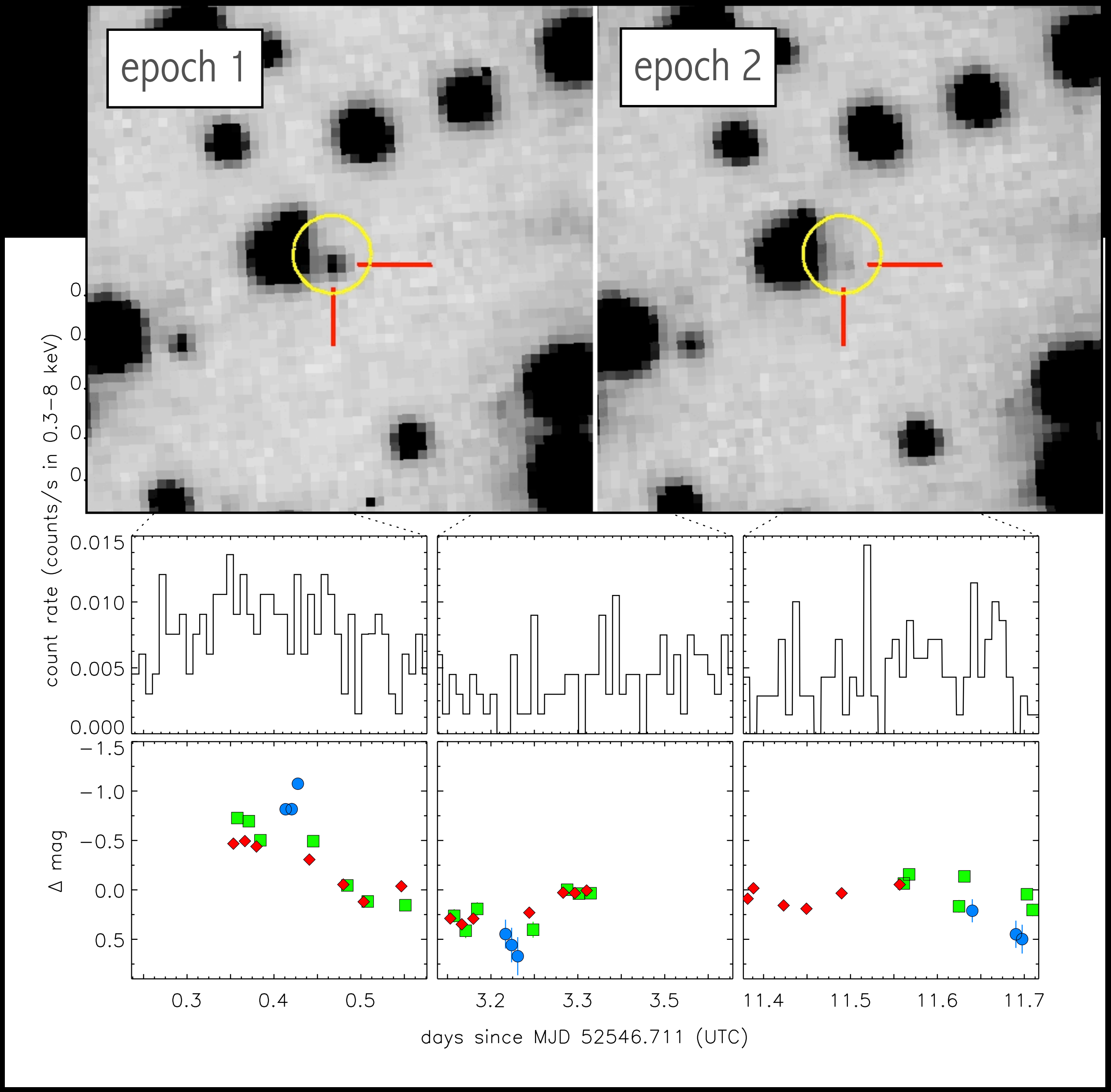
OPTICAL IDENTIFICATION

anomalous colors (blue, Halpha excess, ...):



Cohn et al. 2010

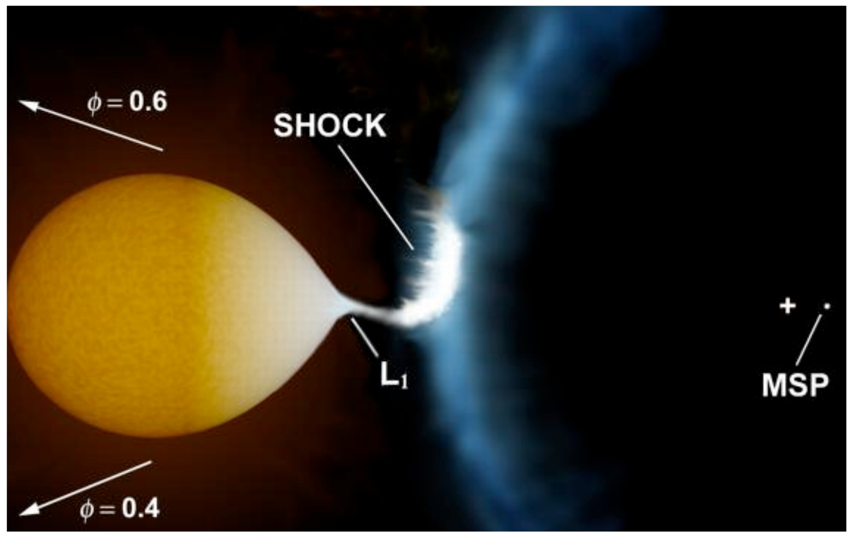
correlated X-ray/optidal variability:



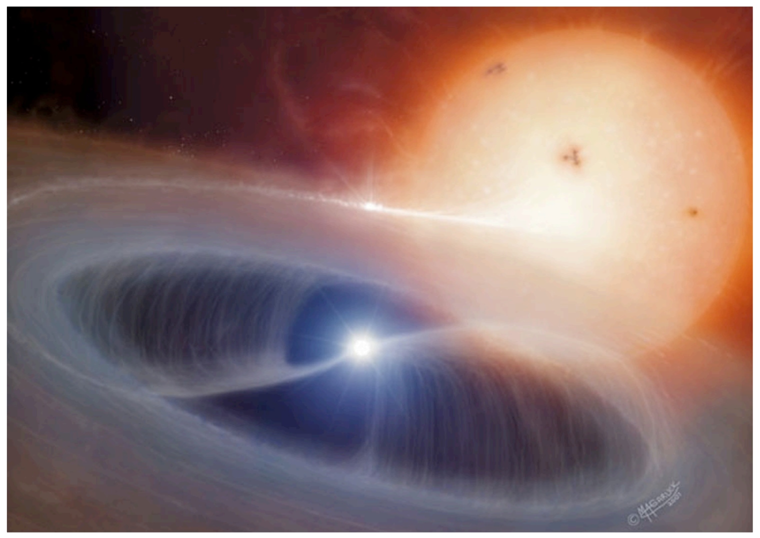
vdBerg ea in prep, see also Beccari ea 2014

X-RAY SOURCES: 4 MAIN SOURCE CLASSES

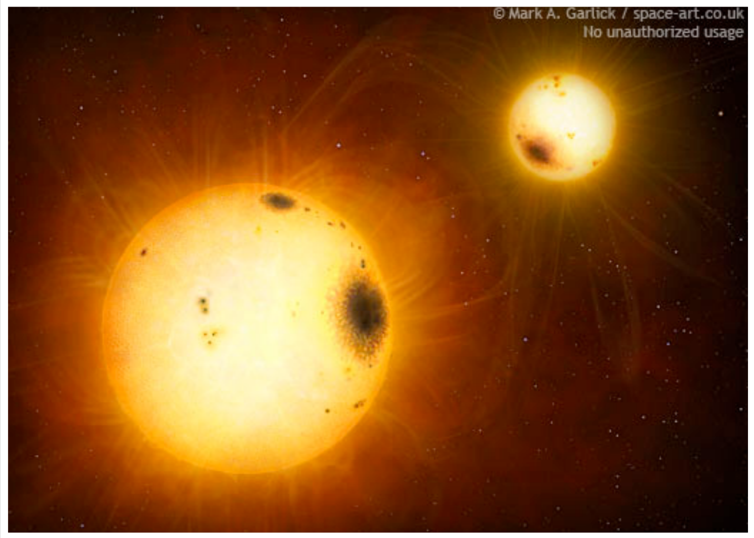
quiescent low-mass X-ray binaries: qLMXBs



milli-second pulsars: MSPs

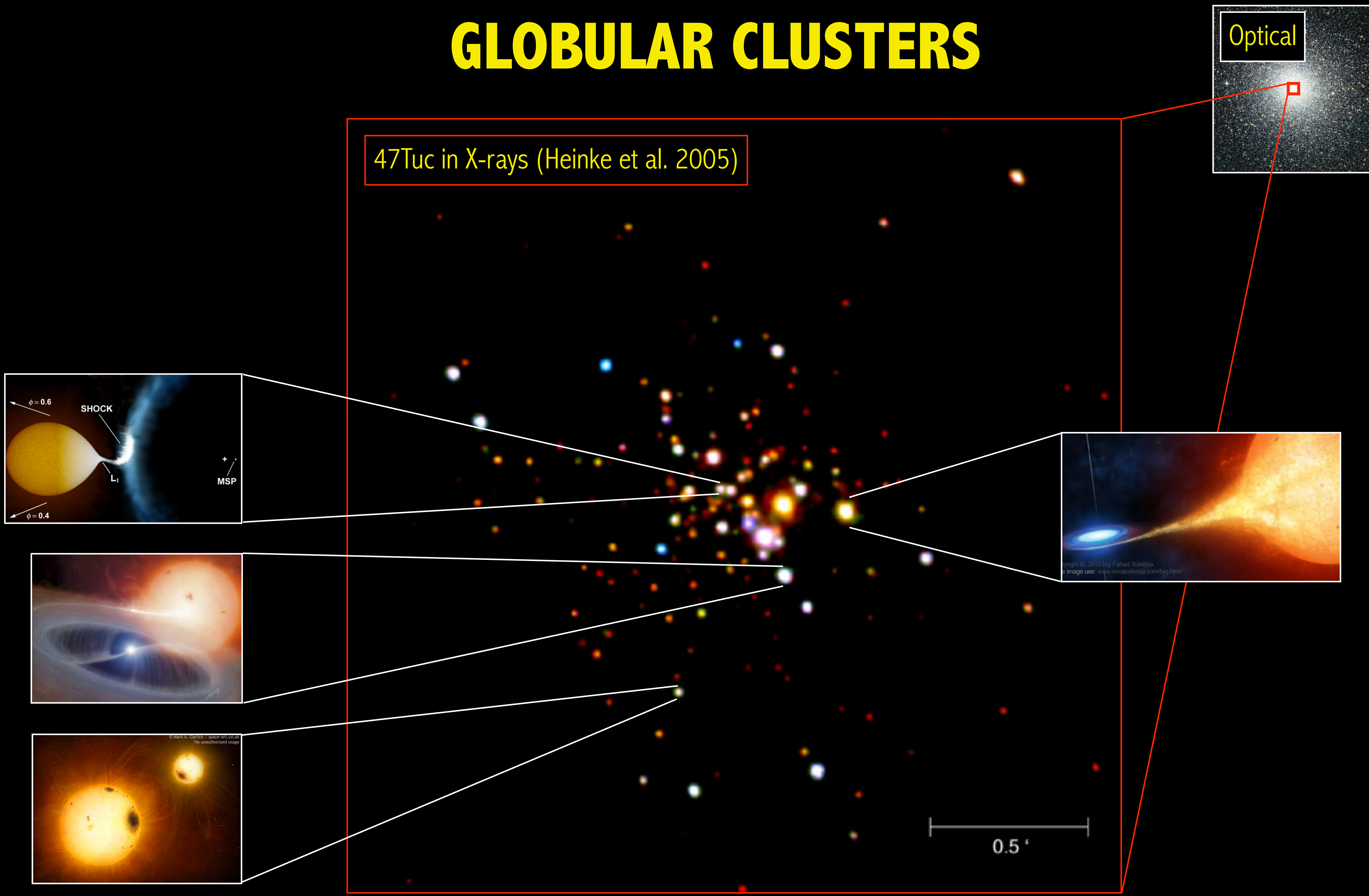


cataclysmic variables: CVs

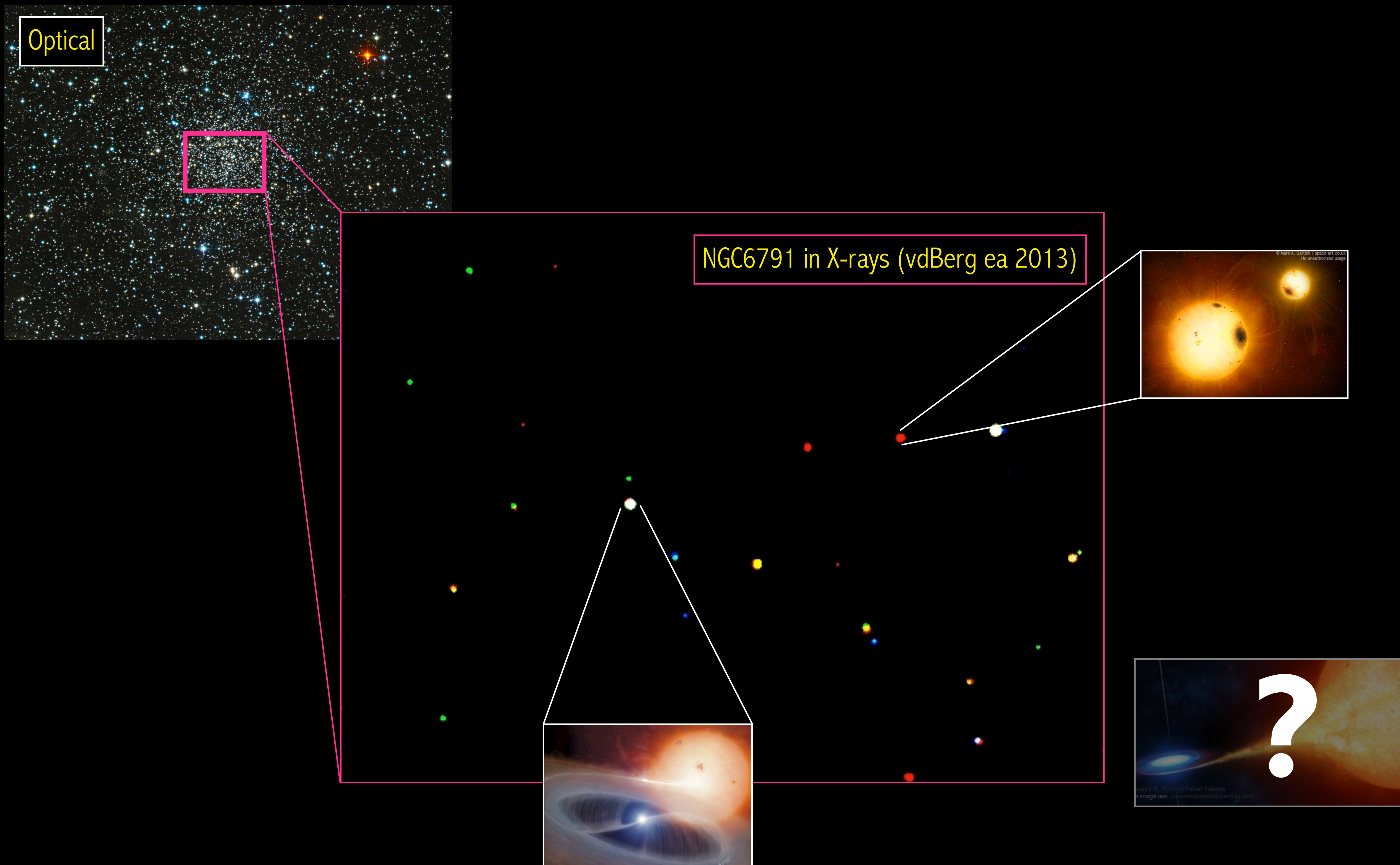


magnetically-active binaries: ABs

GLOBULAR CLUSTERS



OLD OPEN CLUSTERS

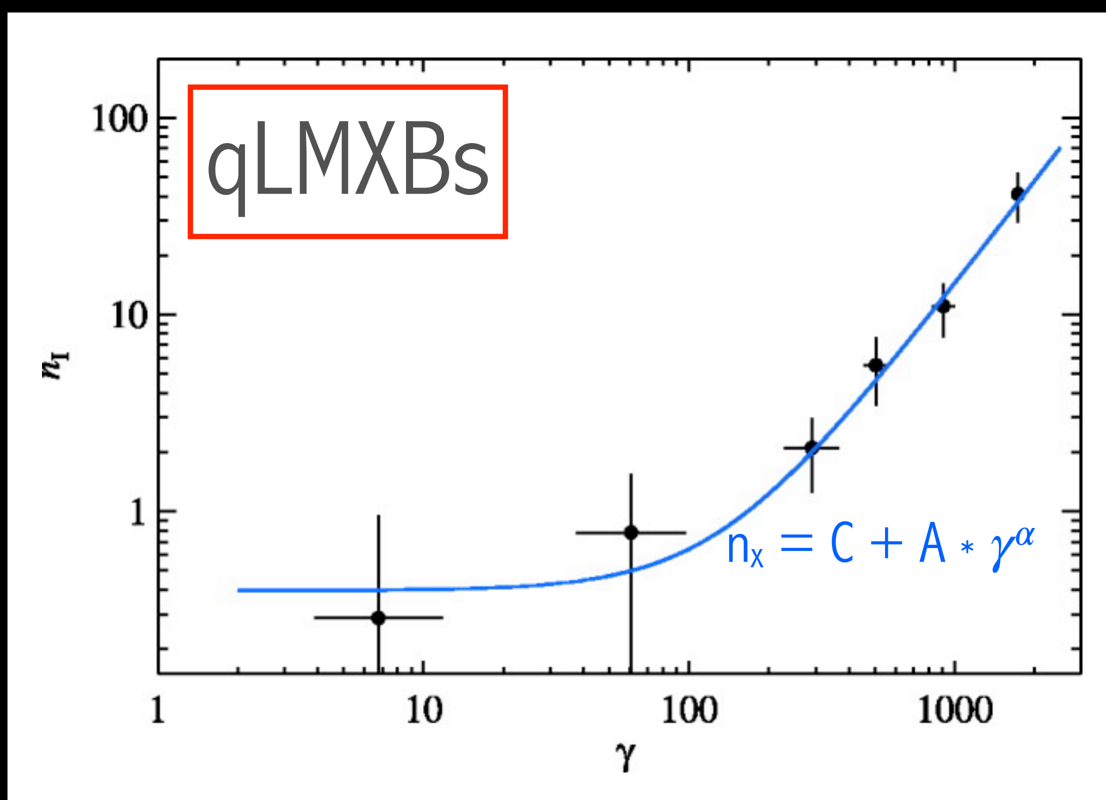


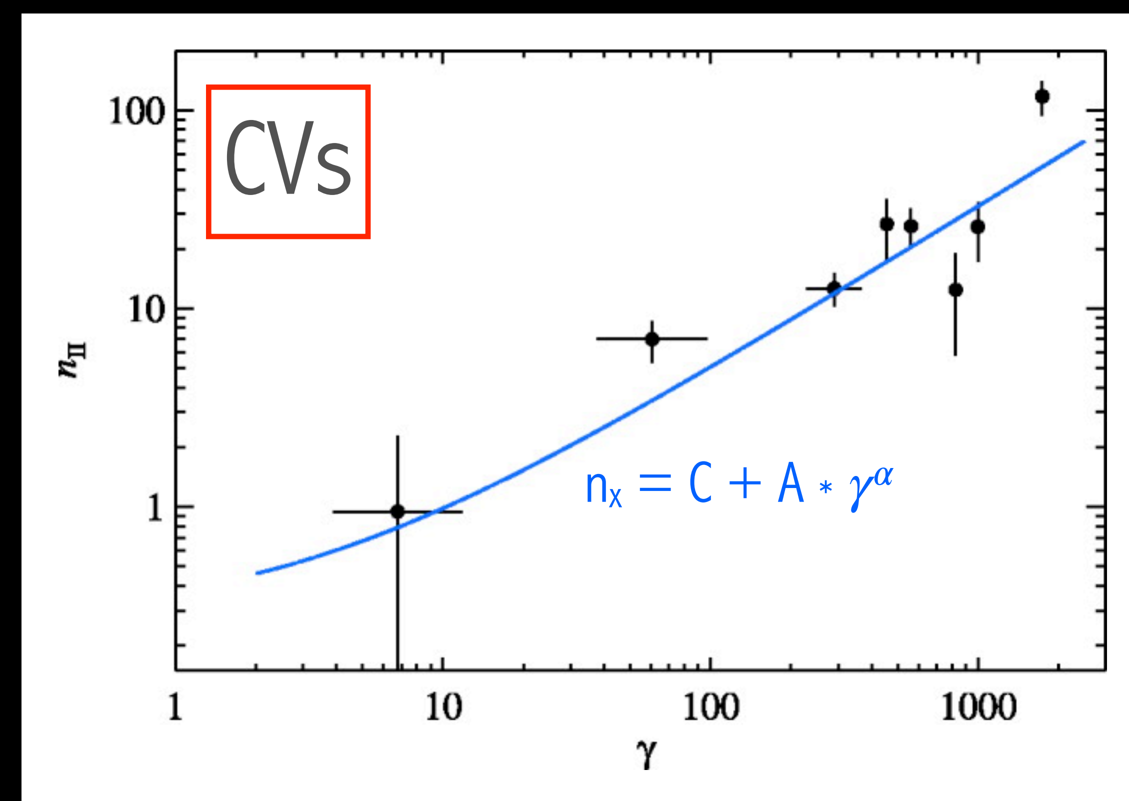
SIGNATURES OF BINARY FORMATION - I

number of X-ray sources per unit mass ($n_x = N_x/M$) can be described as a primordial (C) + dynamically-formed component ($\gamma = \Gamma/M$, with Γ = encounter rate):

$$n_x = C + A * \gamma^{\alpha}$$

number of X-ray src per unit mass





mass-specific encounter rate γ

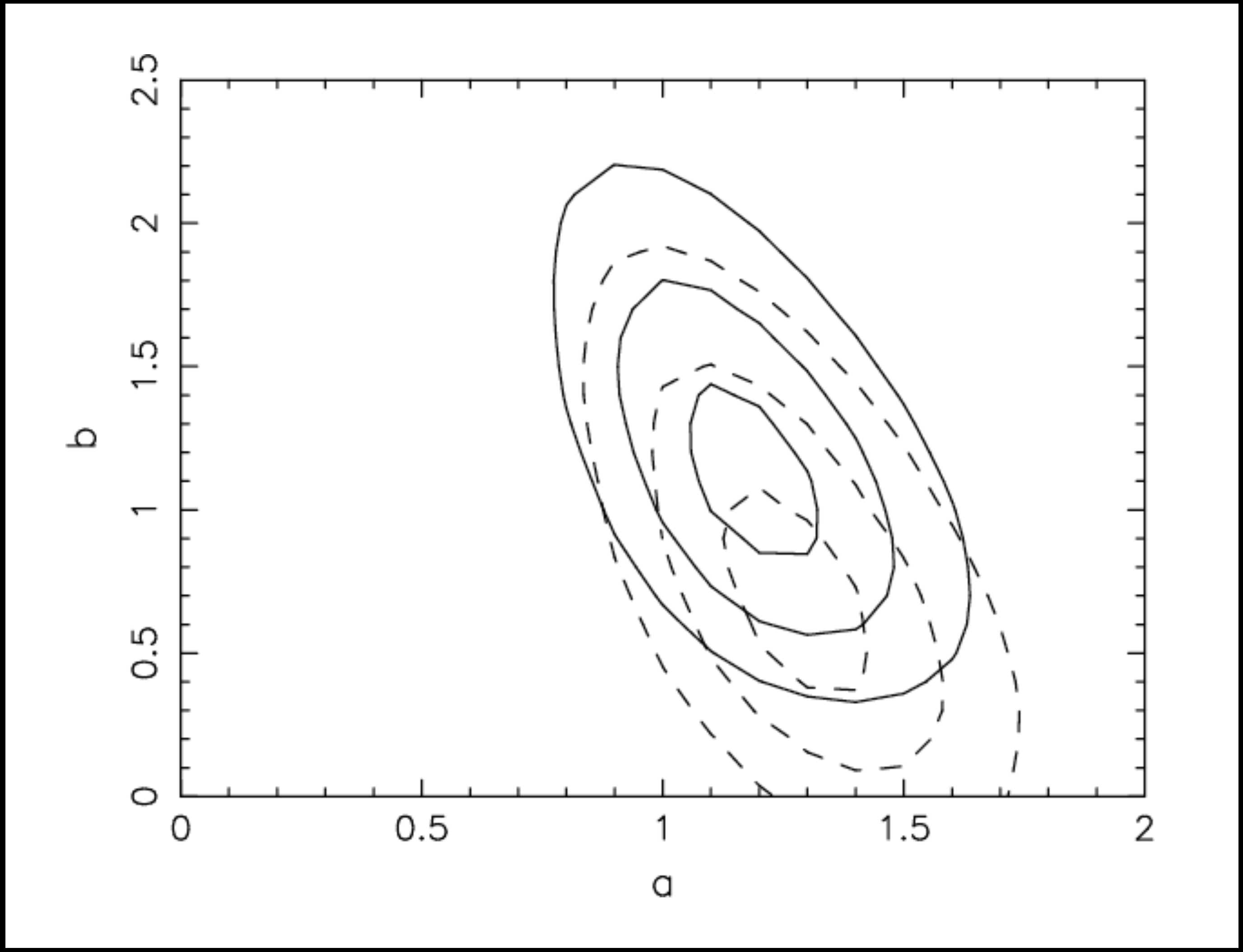
Pooley & Hut 2006

source classification based on X-ray properties alone (Lx>4e30 erg/s)

SIGNATURES OF BINARY FORMATION - II

same conclusion when all source classes are grouped together:

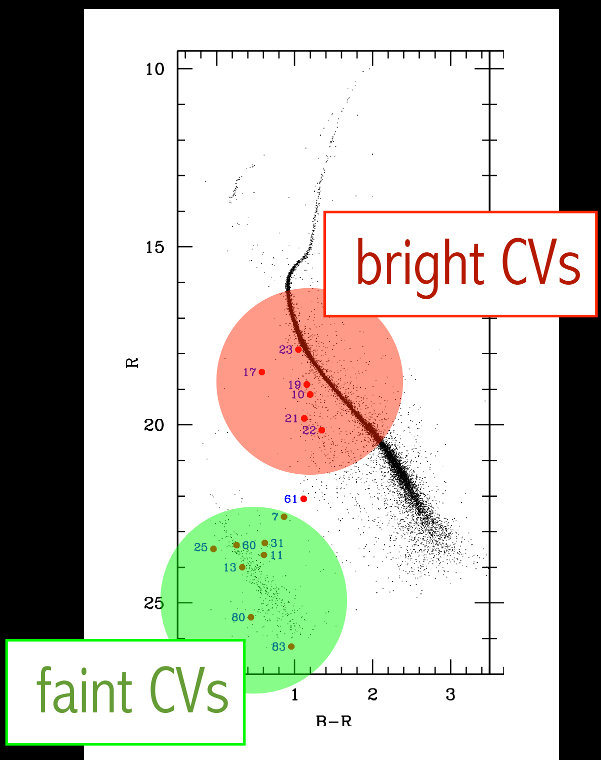
$N_x = a_*\Gamma + b_*M$, and a and b significantly >0

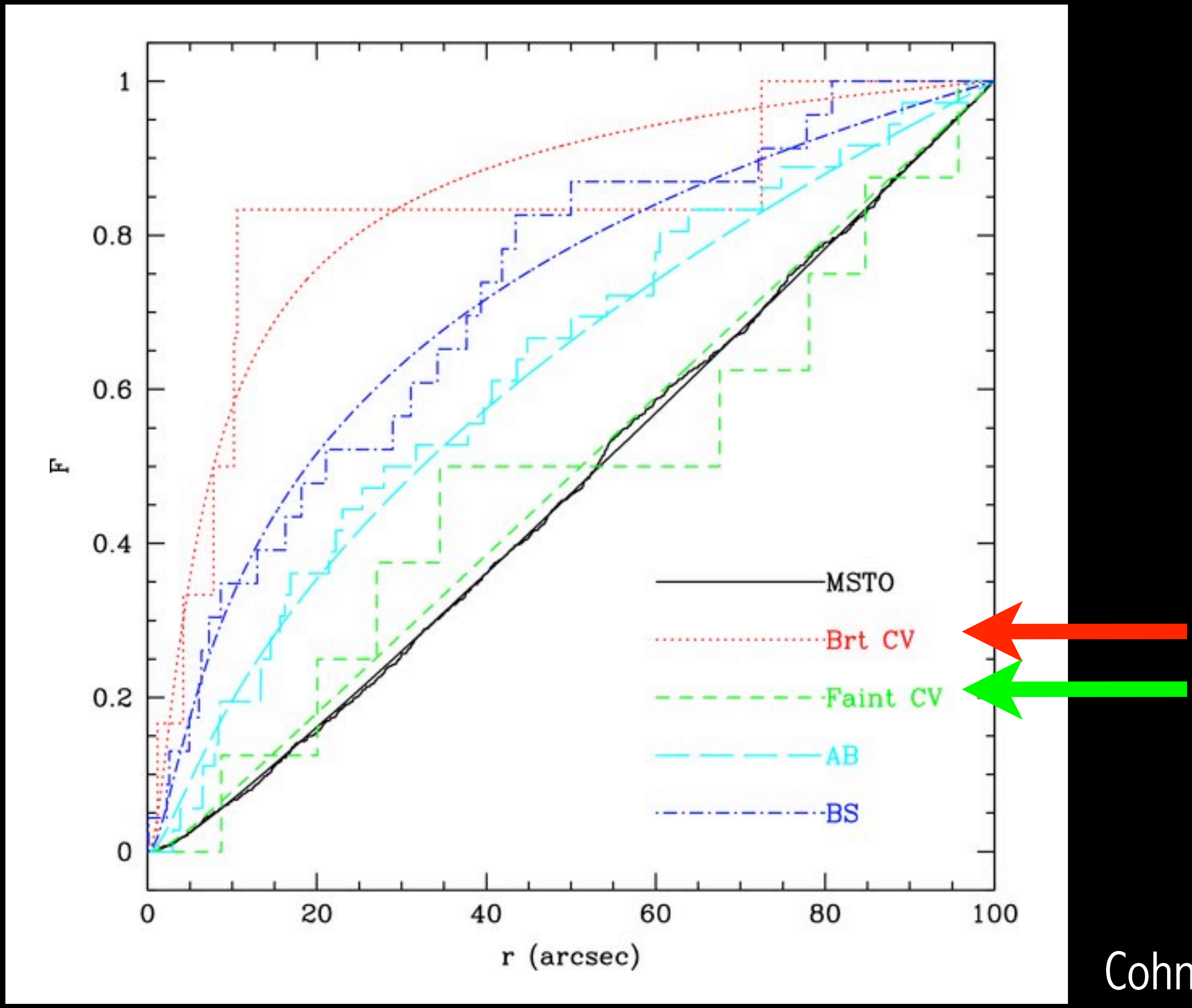


Verbunt et al. 2007
Bassa et al. 2008

SIGNATURES OF BINARY FORMATION - III

bimodal populaton of CVs in NGC6397 core collapsed: bright (young) CVs more centrally concentrated than faint (primordial?) CVs





see also poster by Liliana Rivera

Cohn et al. 2010

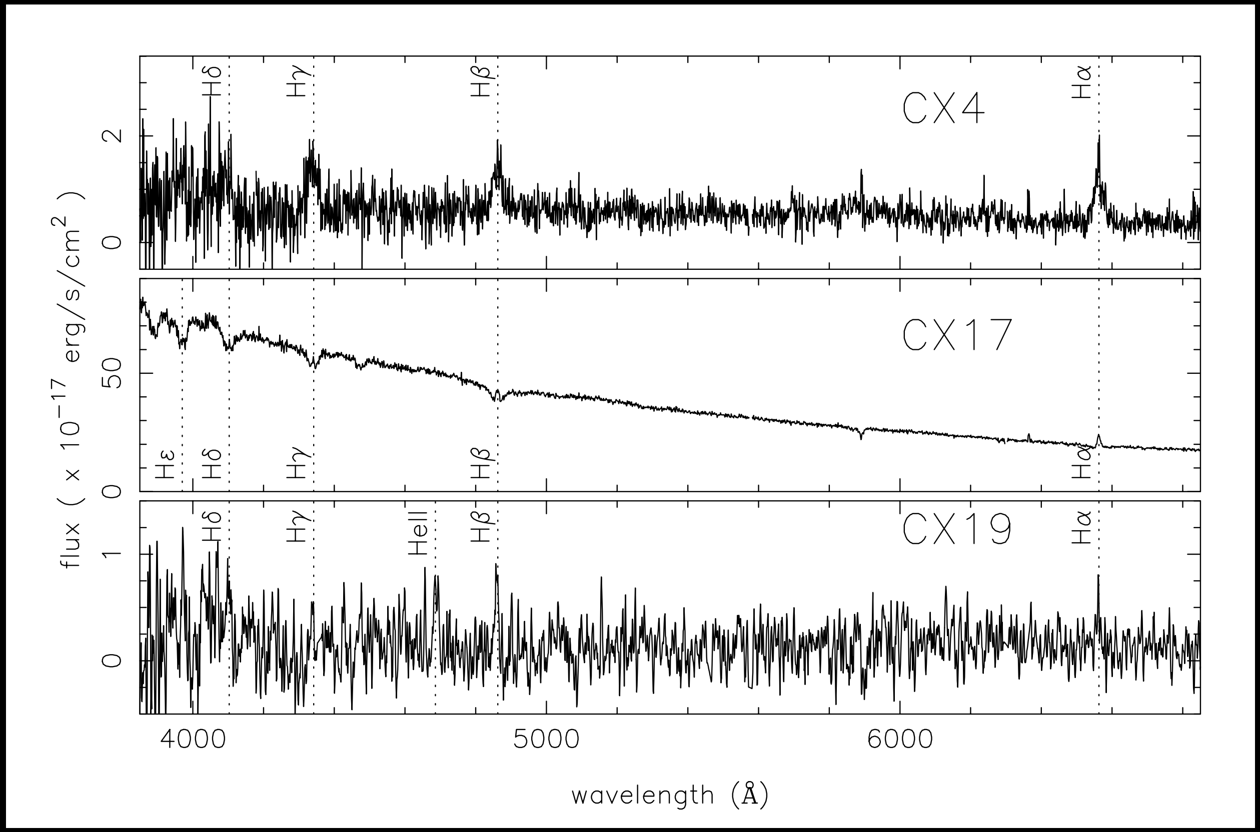
ABSOLUTE NUMBERS? NEED REFERENCE POPULATION

- clear signs of dynamical formation, but are these binaries also overabundant in an absolute sense?
- need a reference population
- use old open clusters, with ages >1 Gyr where single sources are very X-ray dim
- can be done for CVs and ABs, not MSPs or qLMXBs (not found in OCs)

CATACLYSMIC VARIABLES - I

- 4-5 spectroscopically-confirmed CVs in OCs: 1 in M67, 3-4 in NGC6791
- CV density per unit mass approx. the same as in field: ~10^{-5} pc^{-3})
- approx. scaling of N_{CV} with mass: M67~1000Msun, NGC6791~5000Msun

CVs in NGC6791

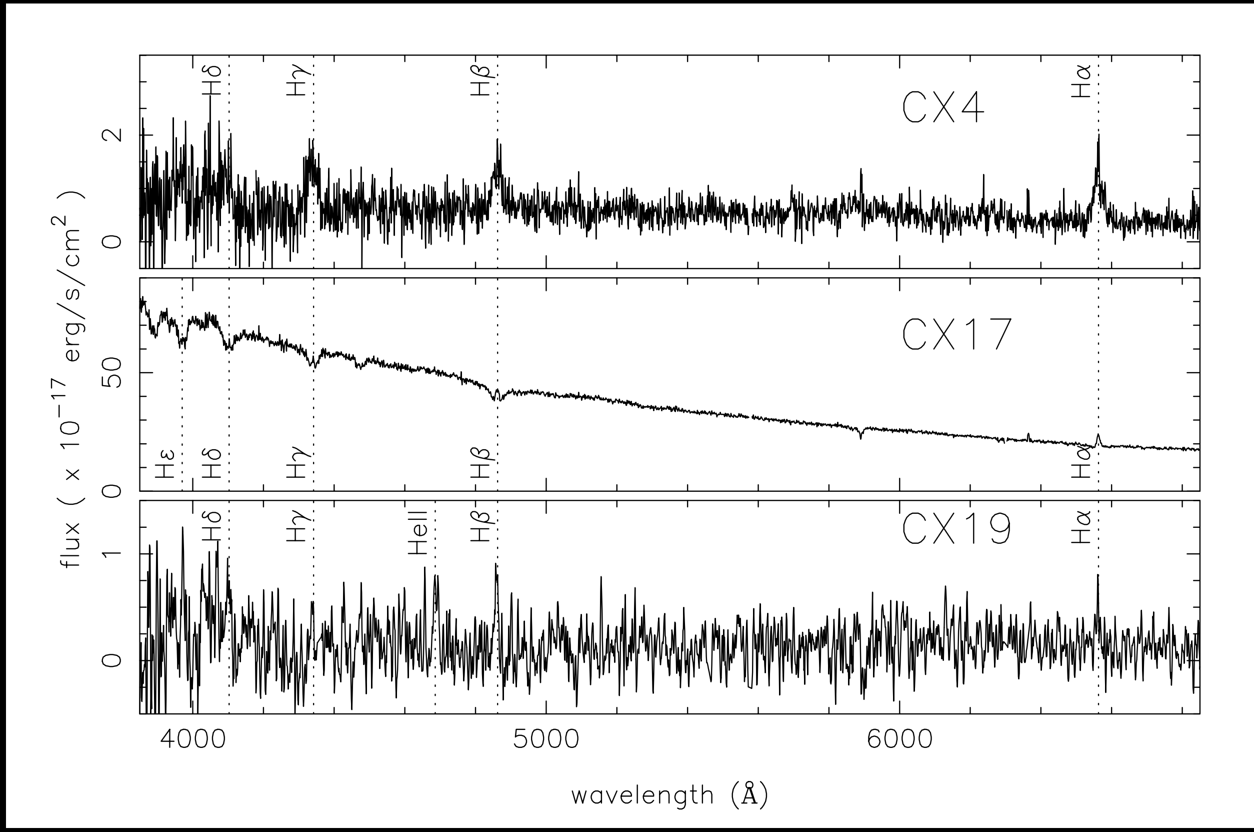


vdBerg ea 2013

CATACLYSMIC VARIABLES - II

- CVs with Lx=1e30 erg/s or more
- CVs in GCs are underabundant:
  - 47Tuc is ~250x more massive than NGC6791, but has at most 30x more CVs
  - NGC6397 is ~50x more massive than NGC6791, has ~3x more CVs
- suggests CV progenitors are destroyed in GCs before they reach CV stage (Davies 1997, Ivanova ea 2006)

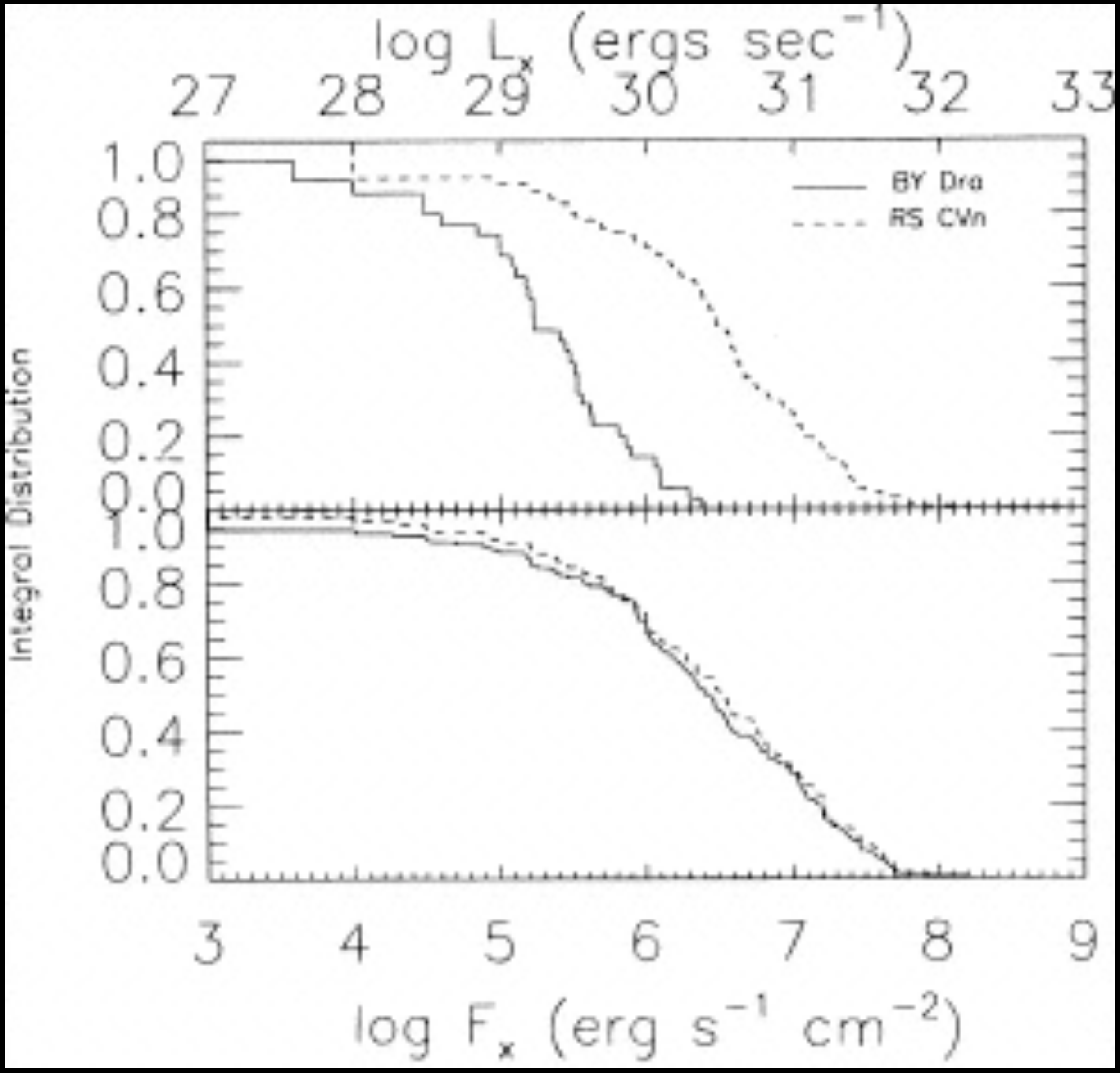
CVs in NGC6791



vdBerg ea 2013

ACTIVE BINARIES - I

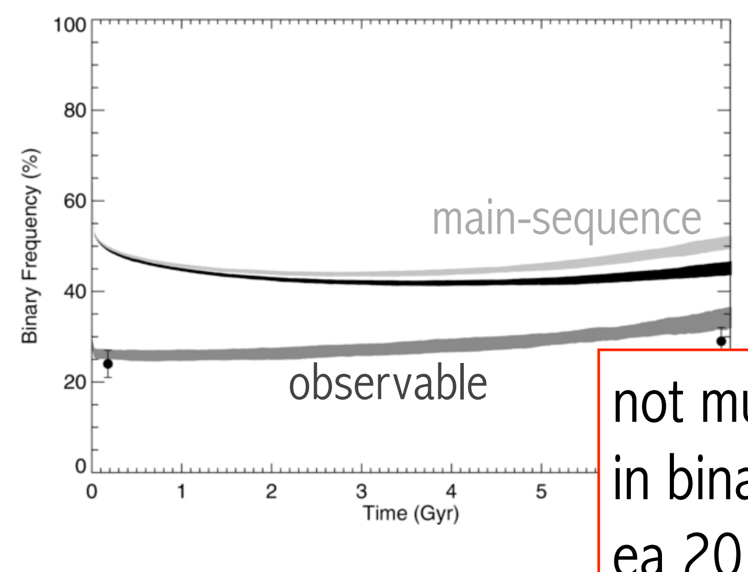
- faintest of the 4 main source classes
- 80+ GCs have been studied by Chandra, but for only ~5 GCs the sensitivity reached is Lx~1e30 erg/s or better



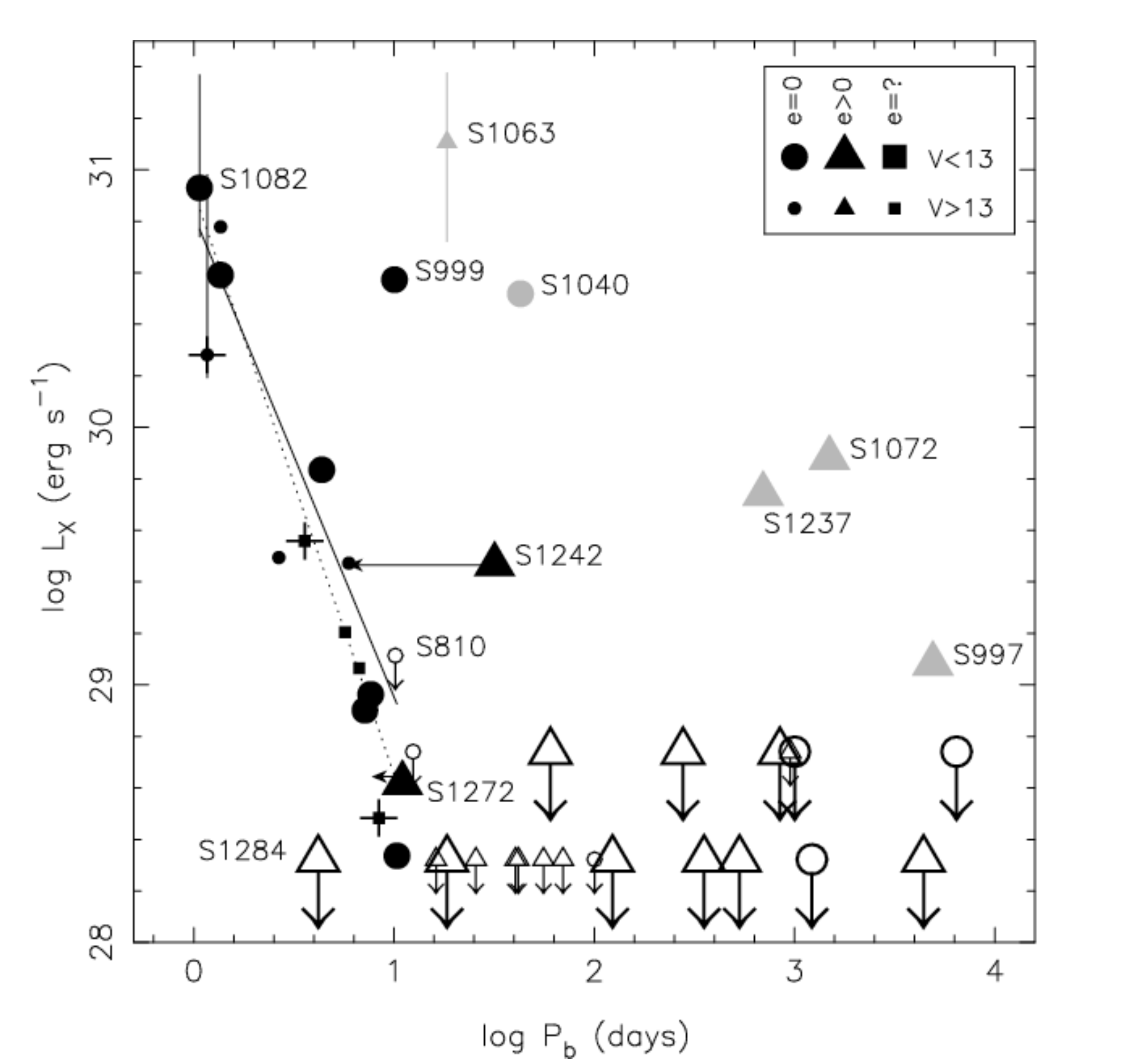
Dempsey et al. 1997

ACTIVE BINARIES - II

- dominant source class in OCs
- many ABs in M67, down to Lx~2e28 erg/s
  - anomalous sources with long periods (up to 14 yrs ...)
- are ABs really primordial?



not much change expected in binary frequency (Geller ea 2013)



vdBerg ea 2004

filled symbols: detections
open symbols: upper limits

ACTIVE BINARIES - III

	age (Gyr)	mass ($M_\odot$)	N_{AB} Lx>1e30 erg/s	refs
NGC6819	~2.4	2600	<4	Gosnell ea '12
M67	4	1100	8	vdBerg ea '13
NGC188	6.5	2300	>5	Gondoin '05
NGC6791	8	5000-7000	8	vdBerg ea '04

no clear trend between N_{AB} and cluster mass!

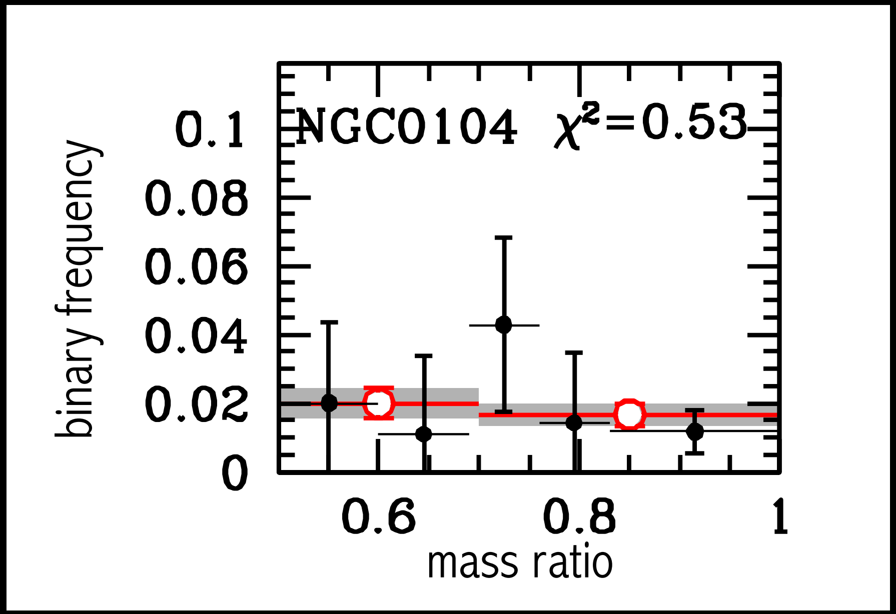
ACTIVE BINARIES - IV

		age (Gyr)	mass ($M_\odot$)	N_{AB} Lx>1e30 erg/s	refs
open cl.	NGC6819	~2.4	2600	<4	Gosnell ea '12
	M67	4	1100	8	vdBerg ea '13
	NGC188	6.5	2300	>5	Gondoin '05
	NGC6791	8	5000-7000	8	vdBerg ea '04
globular cl.	47 Tuc	11	1.30E+06	40 ... 130	Heinke et al. 2005
	NGC6397	14	2.50E+05	0-2	Cohn et al. 2010

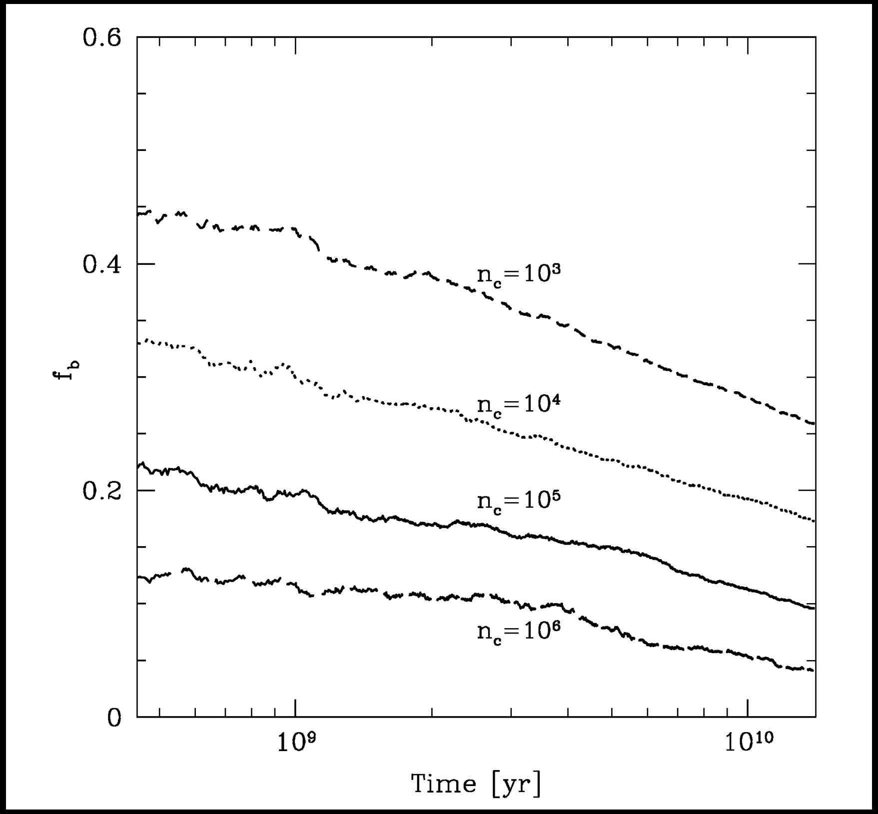
ABs clearly underabundant in GCs:
e.g. 47Tuc is ~250x more massive than NGC6791, but has at most ~16x more ABs

BINARY FREQUENCY

- Result from Chandra ABs is consistent with estimates of GC binary frequency from radial-velocity studies, optical variability studies, and photometric studies.
- GC binary frequency is much lower than in field, OCs
- theory: stellar evolution and dynamics lower the frequency of hard binaries (e.g. Ivanova ea 2005)
- ABs constrain the period range to a few days for Lx,lim~1e30 erg/s



Milone ea 2011



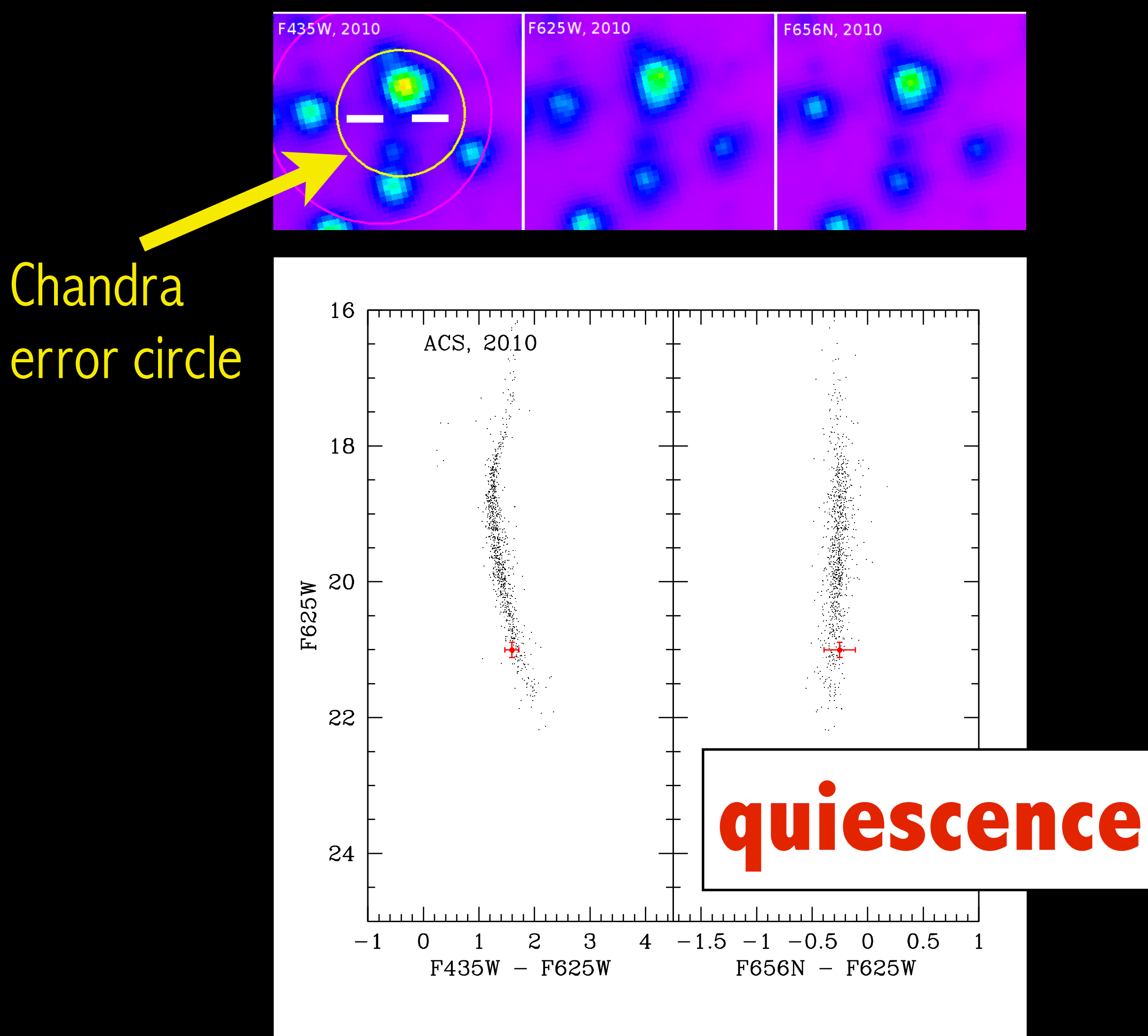
Ivanova ea 2005

UPCOMING WORK

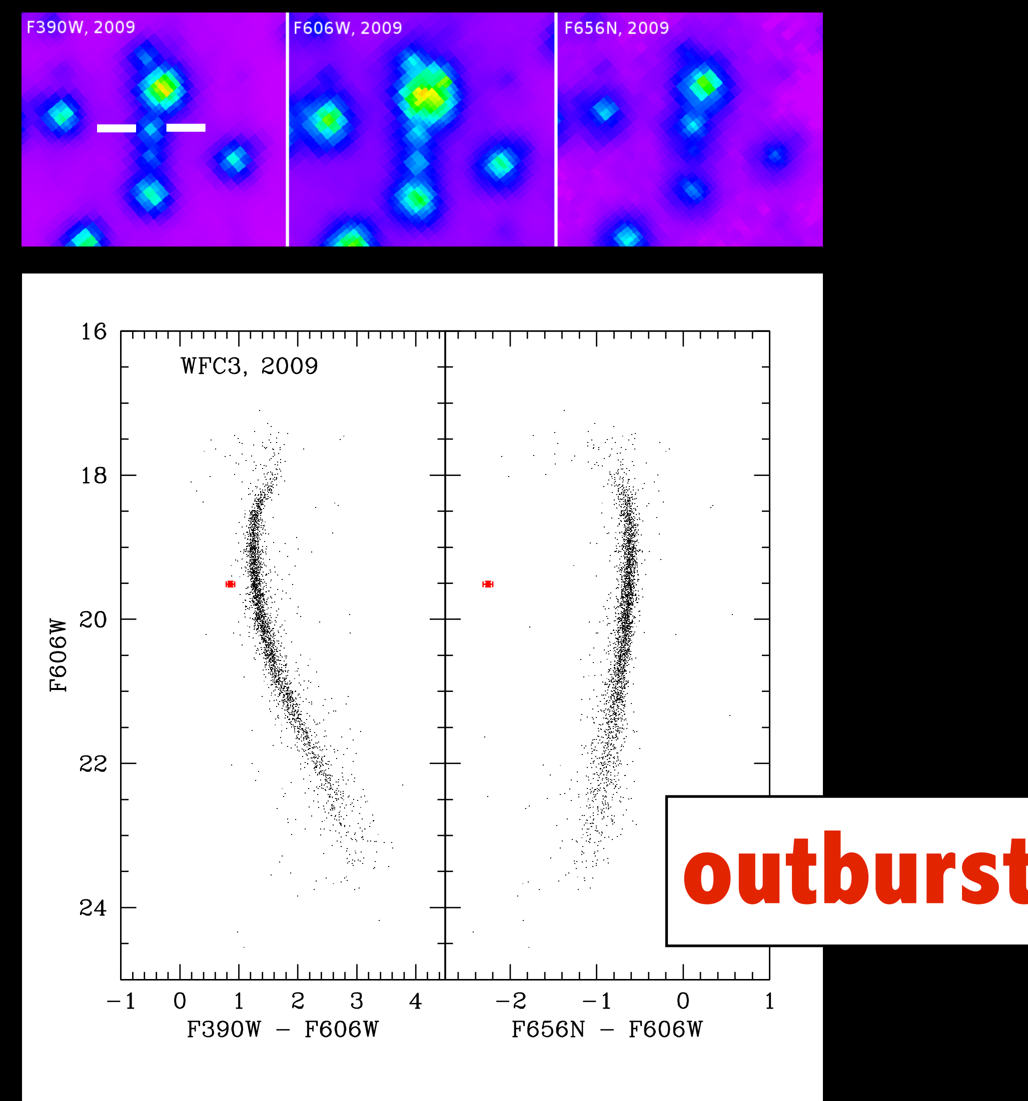
- Improve trends: need more optical identifications & classifications of more faint Chandra sources in more clusters ...
- Study more OCs (see poster by Smriti Vats): we have new Chandra data on 4 more old open clusters with sensitivity of $L_x \sim 1e30$ erg/s or better: NGC6253, Cr261 NGC188, Be17; 3-9 Gyr
- Optical/nUV identification of X-ray sources in the deepest ($L_x \sim 1e30$ erg/s or better) Chandra datasets for GCs: 47Tuc, M28, M4, NGC6397 (see poster by Liliana Rivera).
- What is the effect of age difference between OCs and GCs? Role of stellar evolution.

CAVEAT: CONFUSION OF SOURCE CLASSES

candidate counterpart to Chandra source looks like main-sequence star of AB ....



... but turns out to be the donor star in a neutron-star low-mass X-ray binary

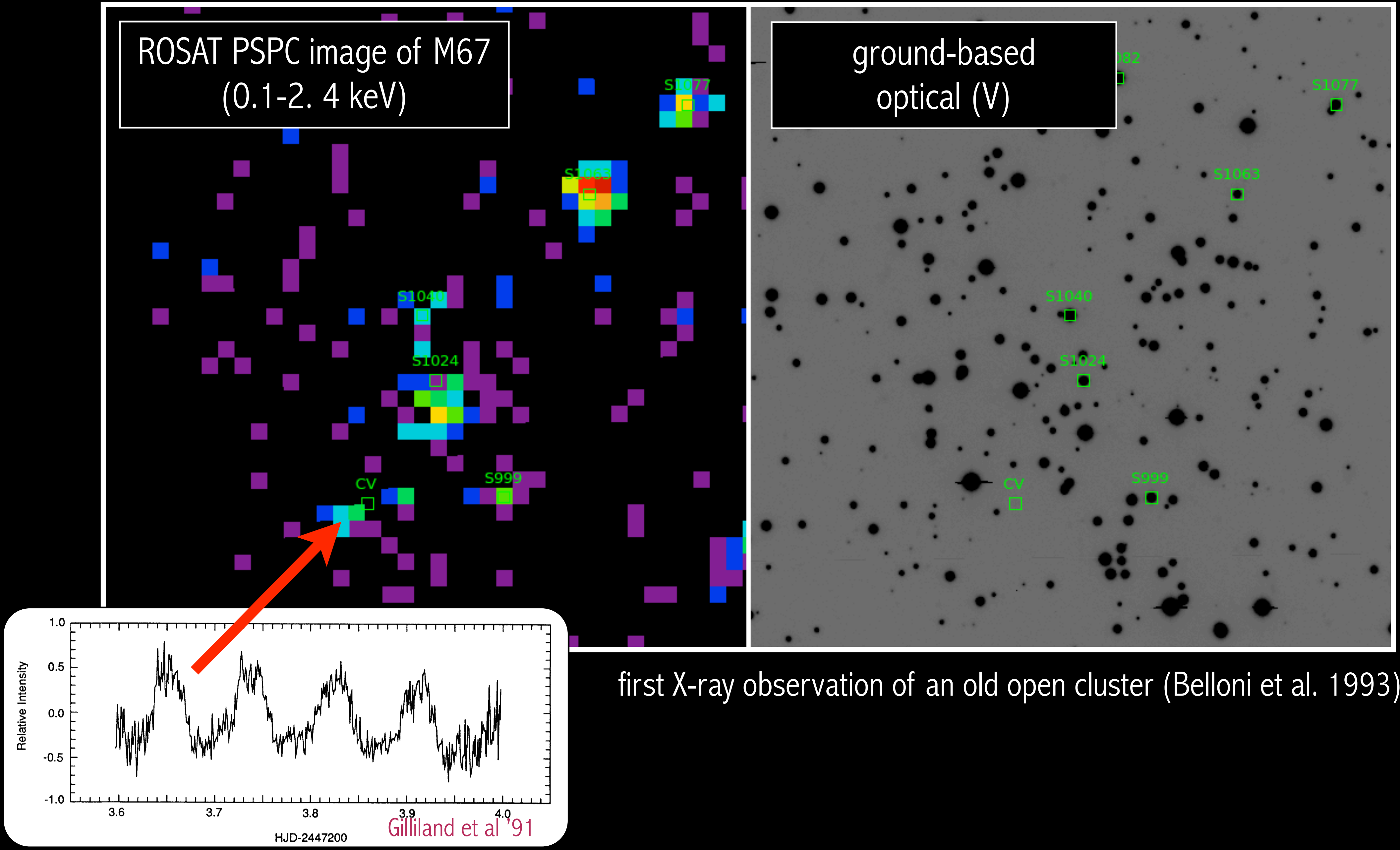


images and CMDs from Cohn et al. 2013, opt.ID first made by Pallanca ea 2013

SUMMARY

- Faint X-ray source populations (Lx ~ 1e33 erg/s or less) show the effects of both binary production and destruction.
- Old OCs: CVs scale with cluster mass, ABs do not.
- GCs: CVs and ABs are underabundant per unit mass compared to old OCs, explains the low Lx/M values ... CVs are also dynamically formed.
- Need larger sample of faintest sources of OCs and GCs to study these trends.

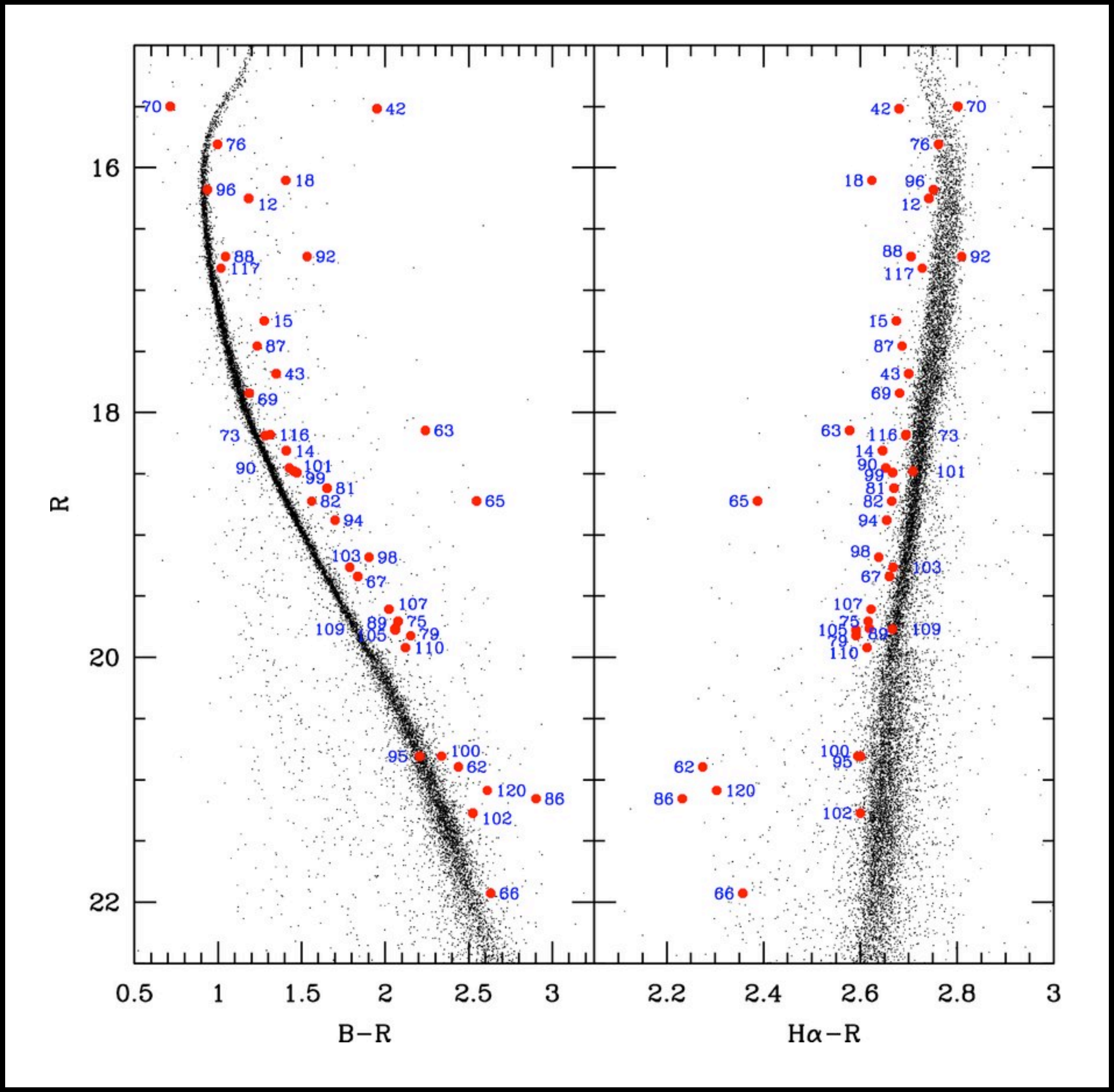
X-RAY IMAGES SELECT THE CLOSE BINARIES



first X-ray observation of an old open cluster (Belloni et al. 1993)

ACTIVE BINARIES - II

- difficult to identify: no or small deviations from the main sequence



Cohn et al. 2010