CHANDRA STUDIES OF OLD STAR CLUSTERS: SIGNATURES OF BINARY FORMATION & DESTRUCTION

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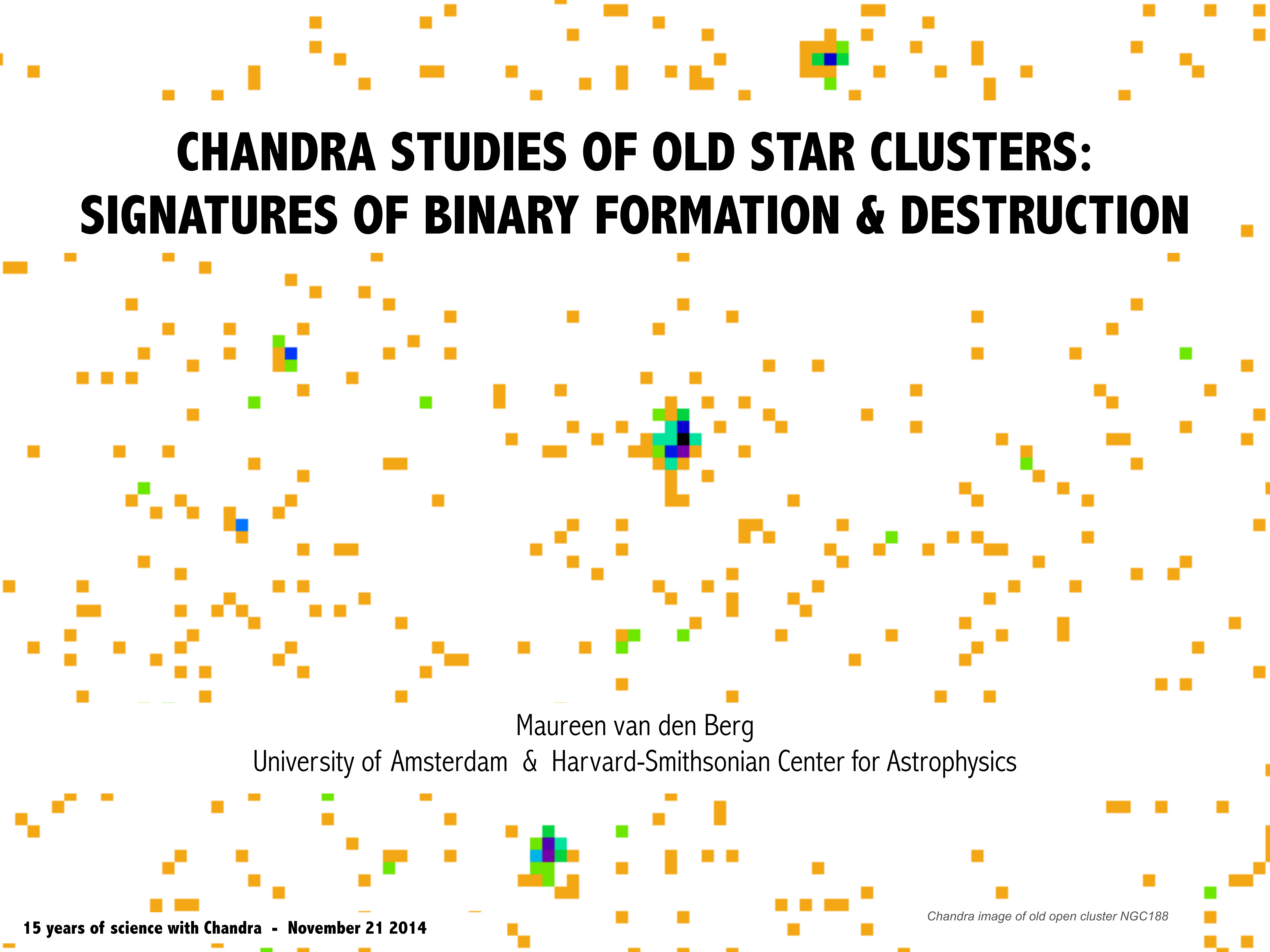
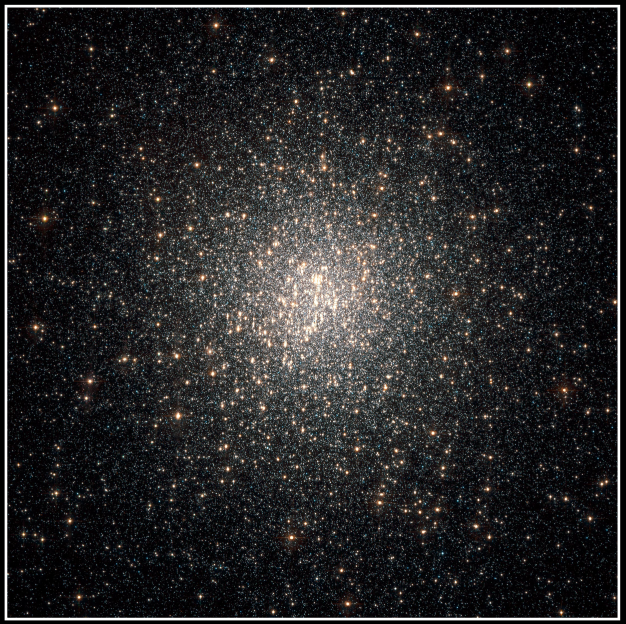


Chandra image of old open cluster NGC188

BINARIES IN STAR CLUSTERS

- binaries probe cluster dynamics
  - close binaries form an energy reservoir that supports the core against collapse
  - energy is released through dynamical encounters: formation, destruction, modification of binaries
  - properties of binary populations are best way to study these dynamical encounters on a stellar scale
- X-ray studies of star clusters
  - globular clusters (10+ Gyr), old open clusters (1-10 Gyr)
  - X-ray observations highlight the close binaries
  - study exotic systems that are rare in the field
  - uniform samples with accurate distance/age/composition



HST image of NGC2808 (credit: STScI)

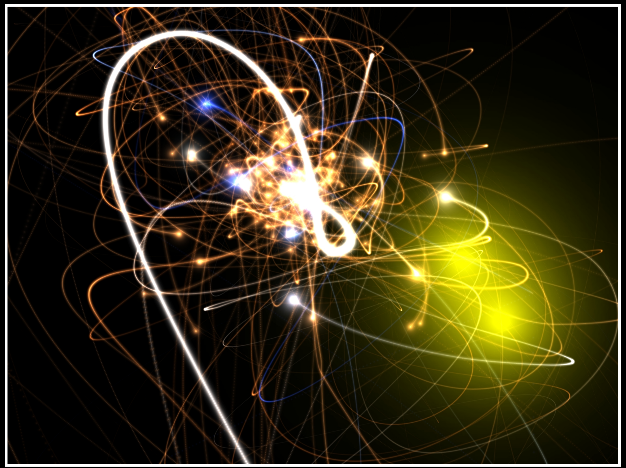
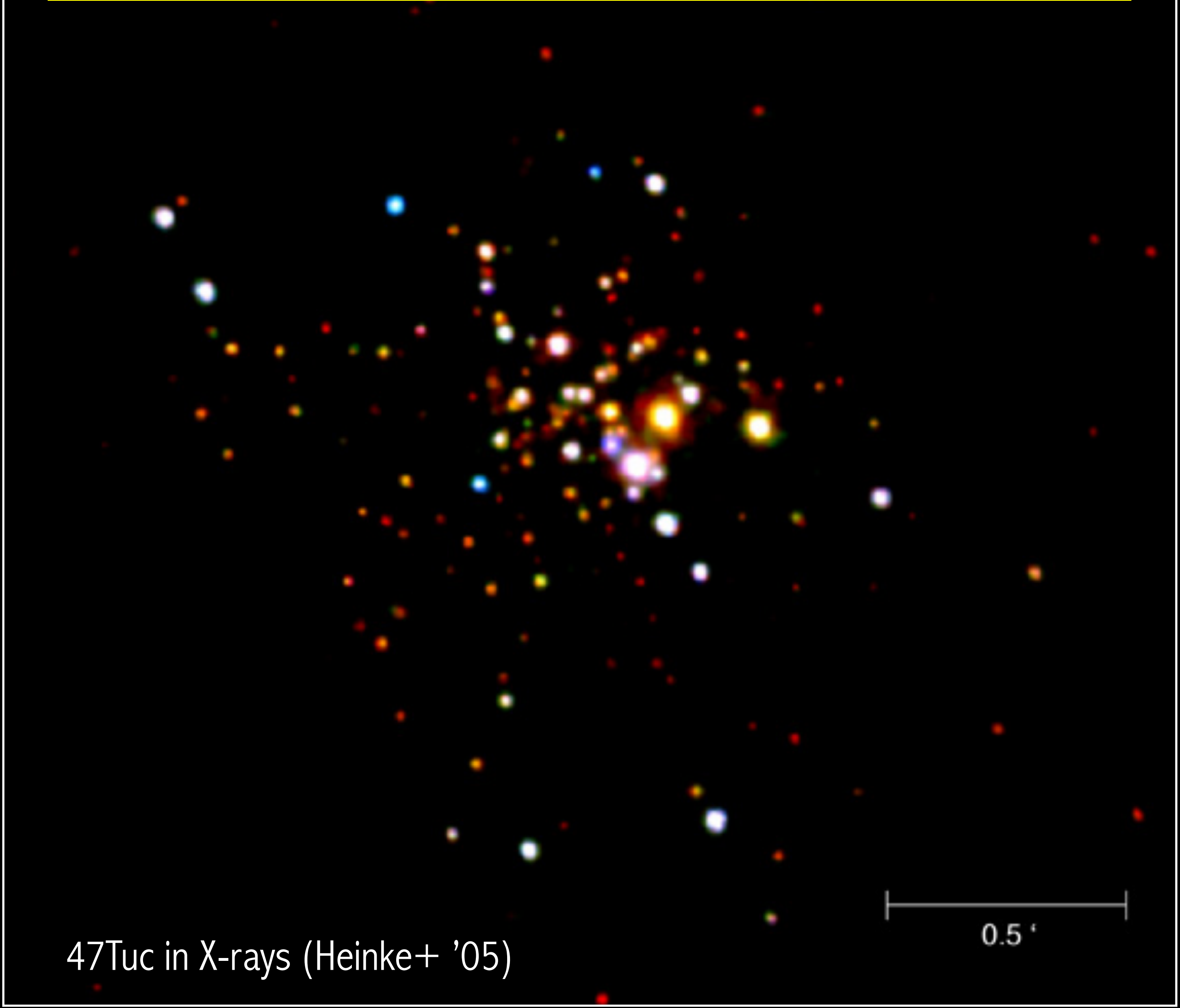


image credit: Aaron Geller

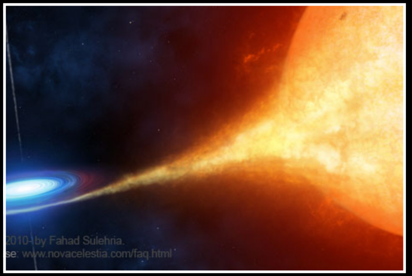
CHANDRA OBSERVATIONS

we need Chandra's sensitivity and spatial resolution to detect the faintest classes of X-ray emitting binaries

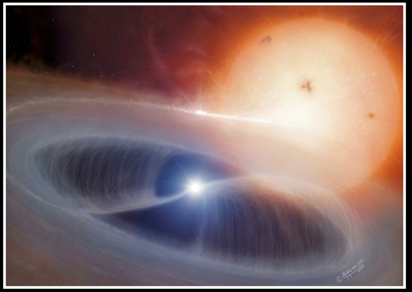


47Tuc in X-rays (Heinke+ '05)

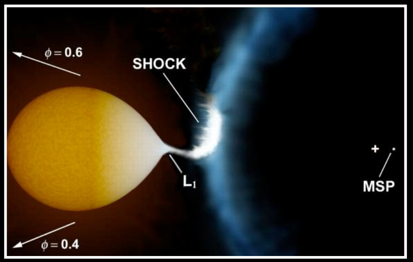
quiescent low-mass X-ray binaries / qLMXBs (neutron stars; black holes?)



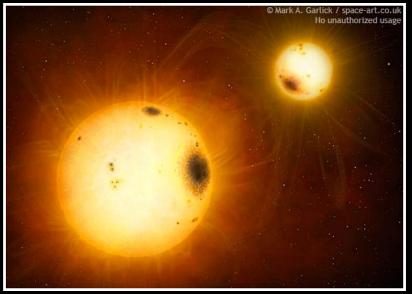
cataclysmic variables / CVs (accreting white dwarfs)



millisecond pulsars / MSPs

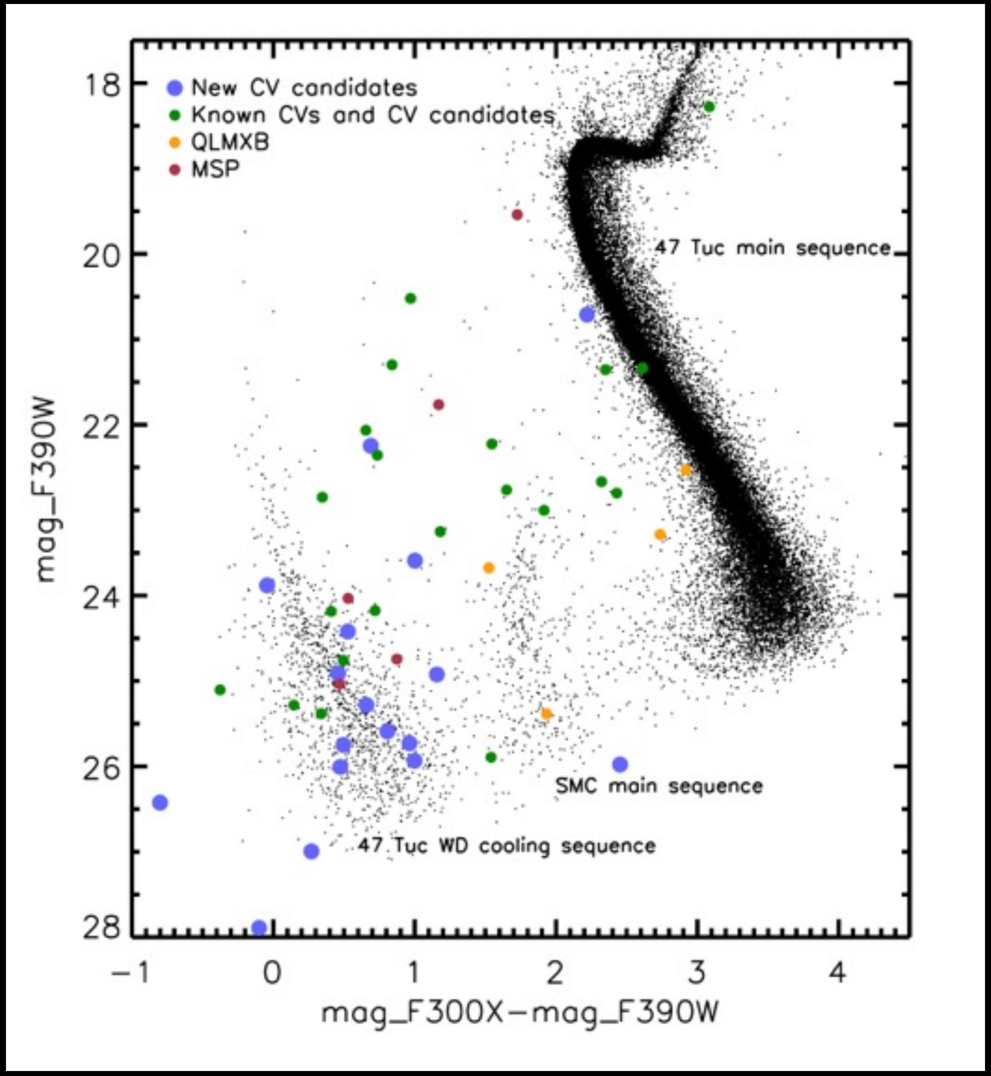


fast-spinning magnetically-active binaries / ABs

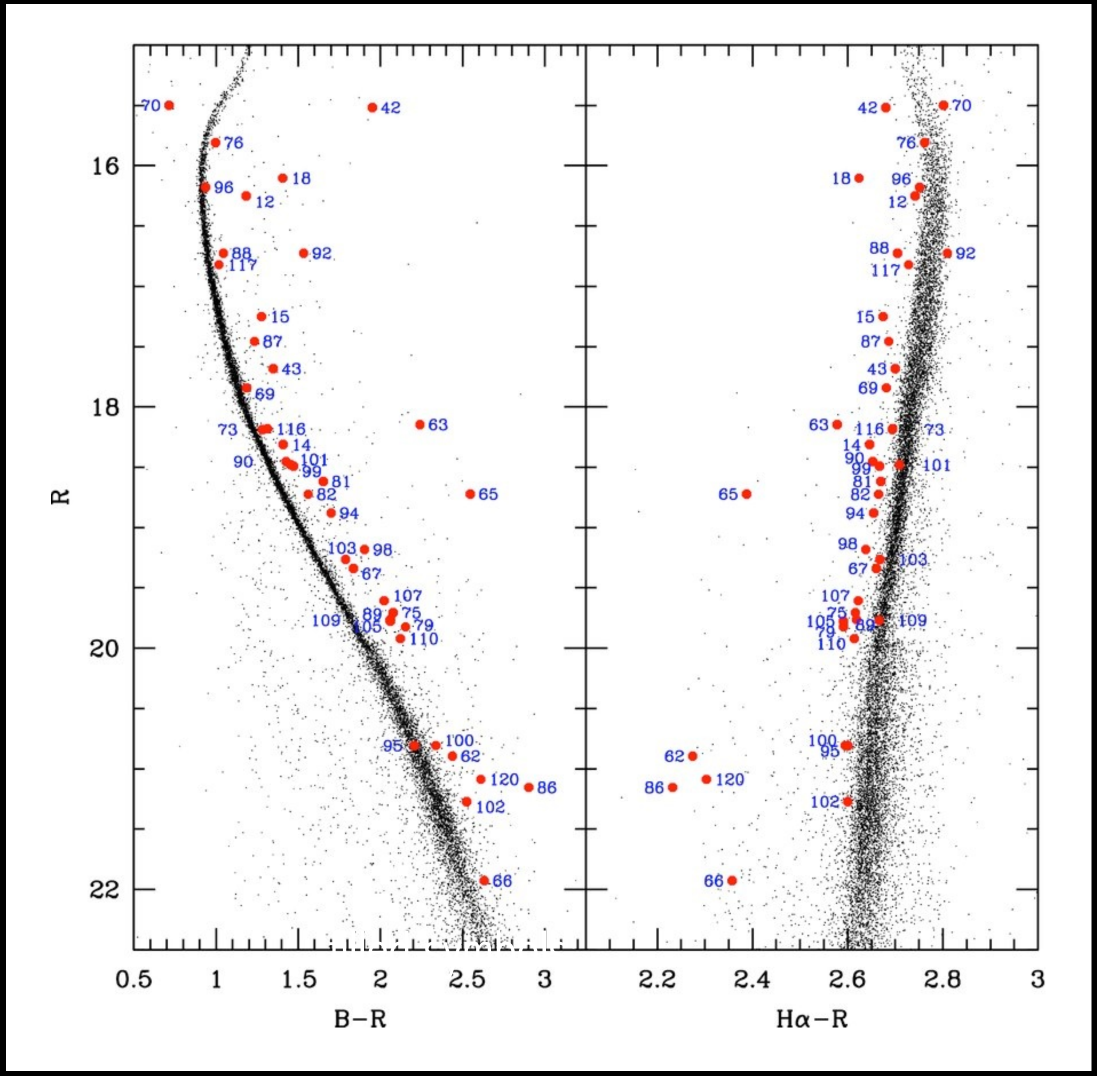


OPTICAL/NEAR-UV IDENTIFICATION OF X-RAY SOURCES

X-ray sources have optical properties that set them apart from the other cluster stars: source classification based on broad- and narrow-band colors, X-ray/optical flux ratios

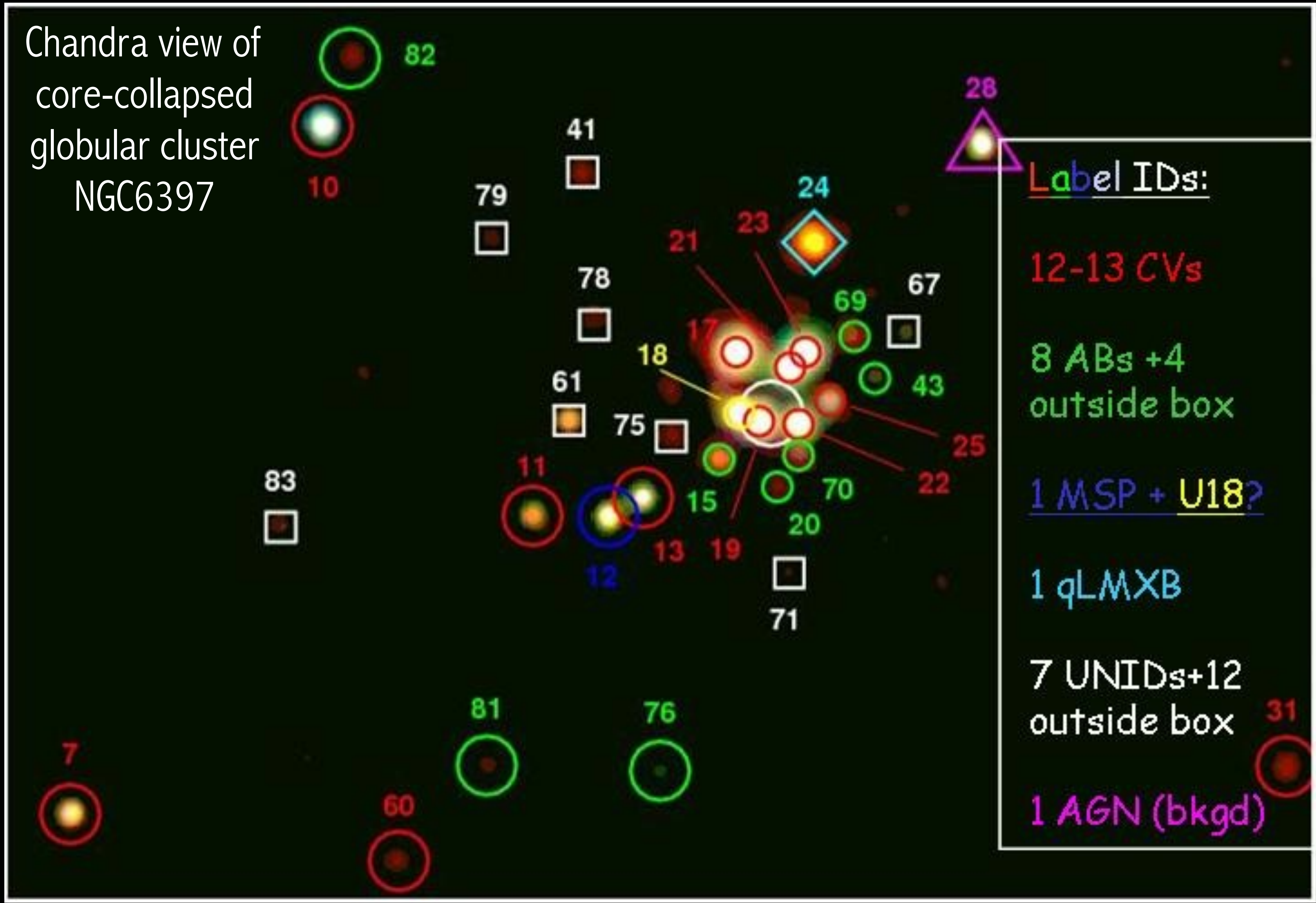


47Tuc, Rivera+ in prep.



NGC6397, Cohn+ '10

SOURCE CLASSIFICATION



3.3 x 2 arcmin2

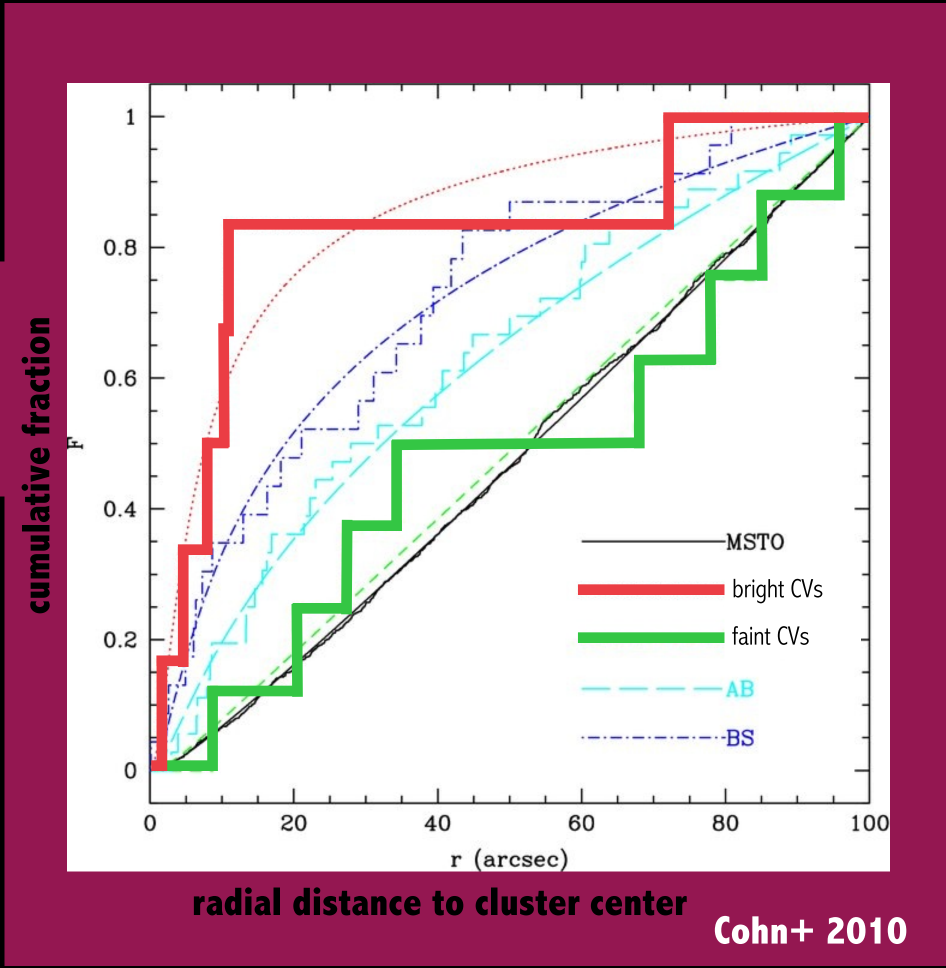
adapted from Grindlay '06

SIGNATURES OF BINARY FORMATION

- bright LMXBs (Lx~1e36 erg/s or higher): ~100x overabundant in globular clusters compared to Galactic field when scaled by mass (Clark '75)

- Chandra results on faint sources:
  - spatial distribution of CVs in core-collapsed cluster NGC6397: optically bright/young CVs more centrally concentrated than optically faint/primordial CVs (Cohn+ '10)
  - number of qLMXBs or CVs per unit mass scales with encounter frequency
    Pooley & Hut '06, Verbunt '07, Bassa+ '08

$\Longrightarrow$ dynamical formation of qLMXBs and CVs

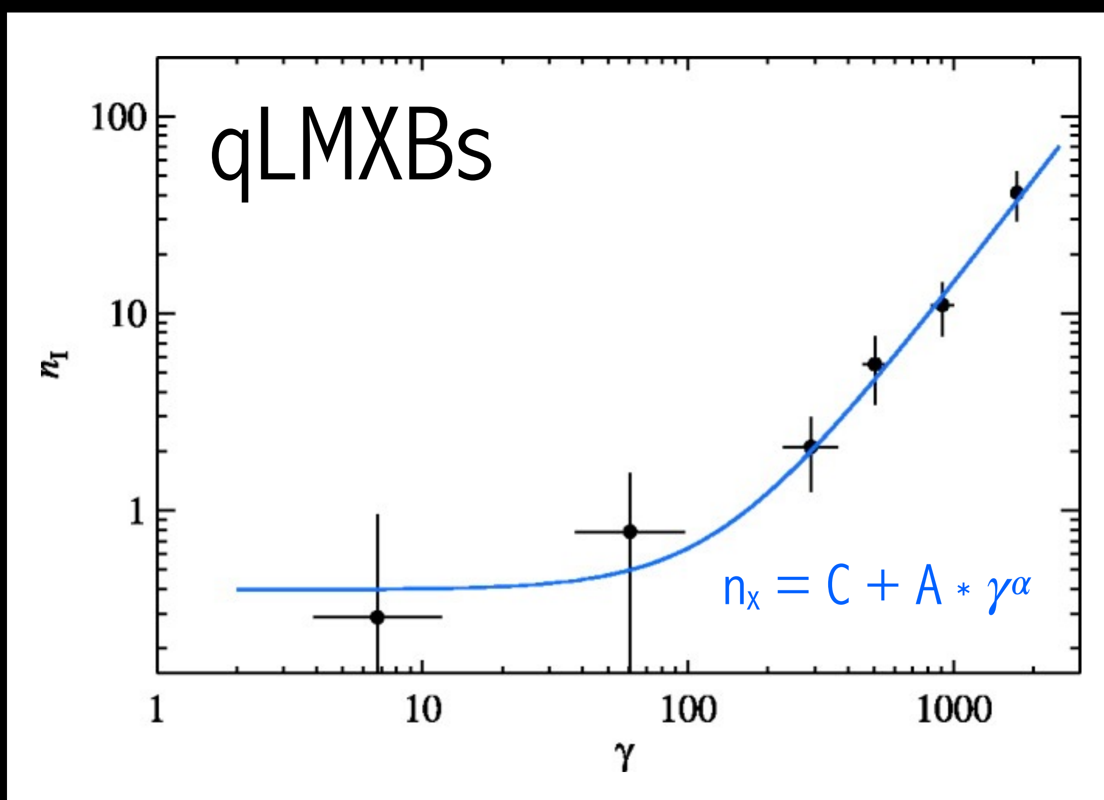


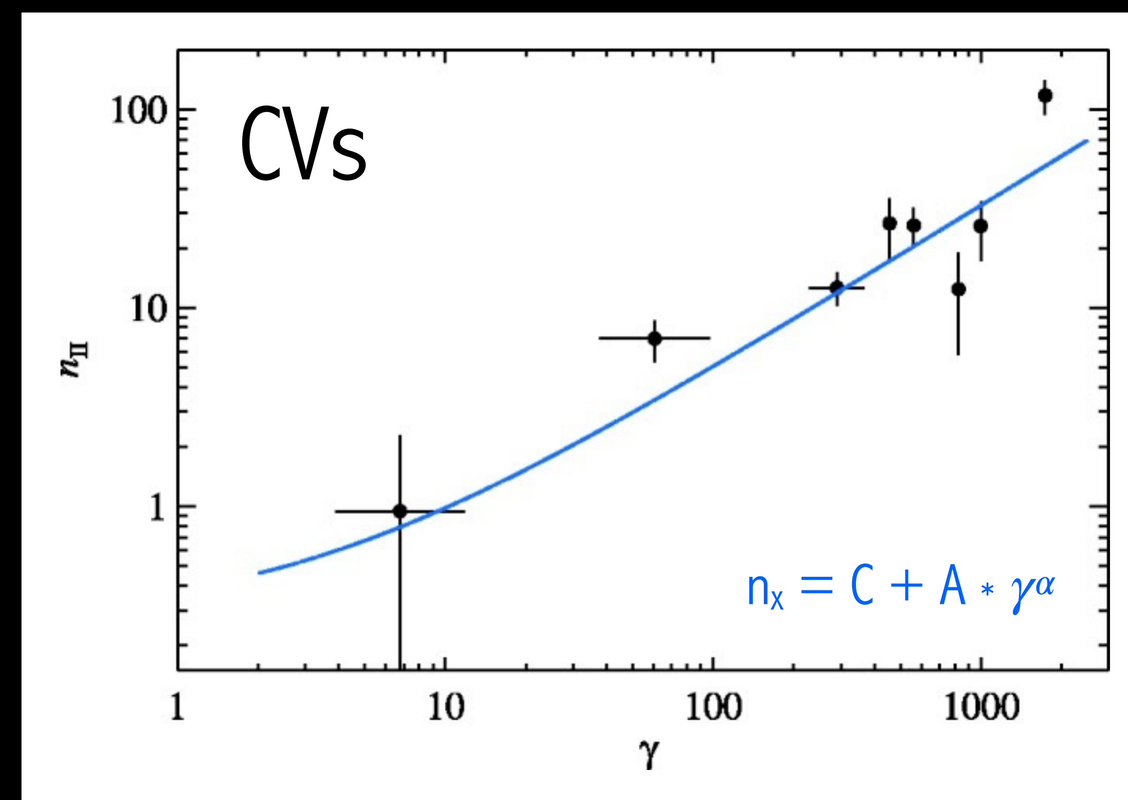
Cohn+ 2010

SIGNATURES OF BINARY FORMATION

number of Chandra qLMXBs and CVs per unit of cluster mass ($n_x=N_x/M$) can be modeled by a primordial (C) + dynamically-formed component ($\gamma=\Gamma/M$, with Γ= encounter rate):

number of X-ray sources per unit mass





mass-specific encounter rate γ

Pooley & Hut ‘06

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

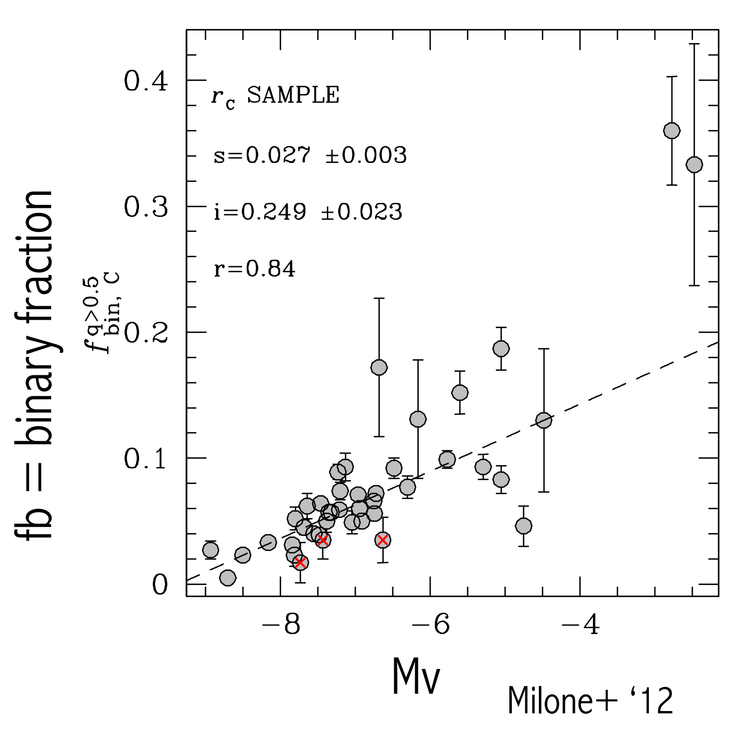
SIGNATURES OF BINARY DESTRUCTION

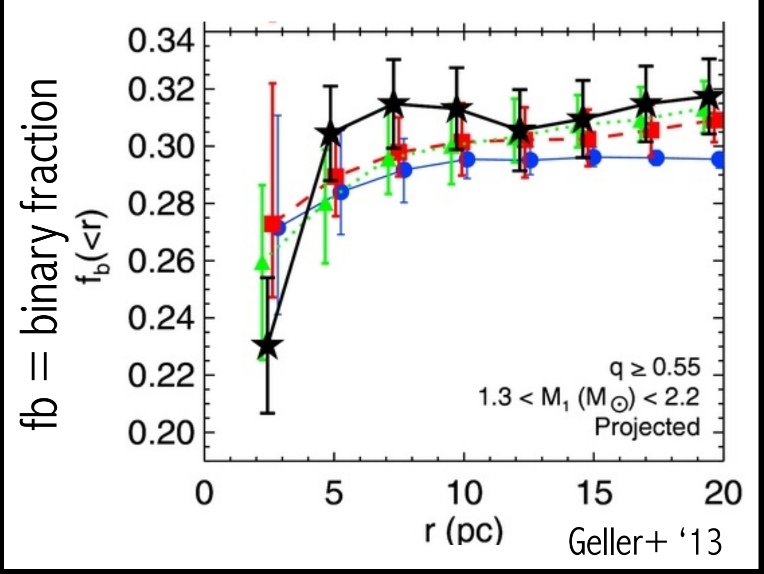
- soft/hard binaries: weakly/strongly bound compared to kinetic energy of typical cluster star
  soft binaries are "easy" to destroy by dynamical encounters

- optical studies point at an overall low binary fraction for (massive) globular clusters
  e.g. Milone+ '12, massive clusters are brighter (lower Mv)

- in the young (15-30 Myr) LMC cluster NGC1818 the binary frequency drops towards the core
  soft binaries are destroyed in the core, and mass segregation has not had time yet to bring (massive) binaries to the core (Li+ '12, de Grijs+ '13, Geller+ '13)

- these studies provide no direct information on the orbital-period distribution, but we can use Chandra to study the hard binaries





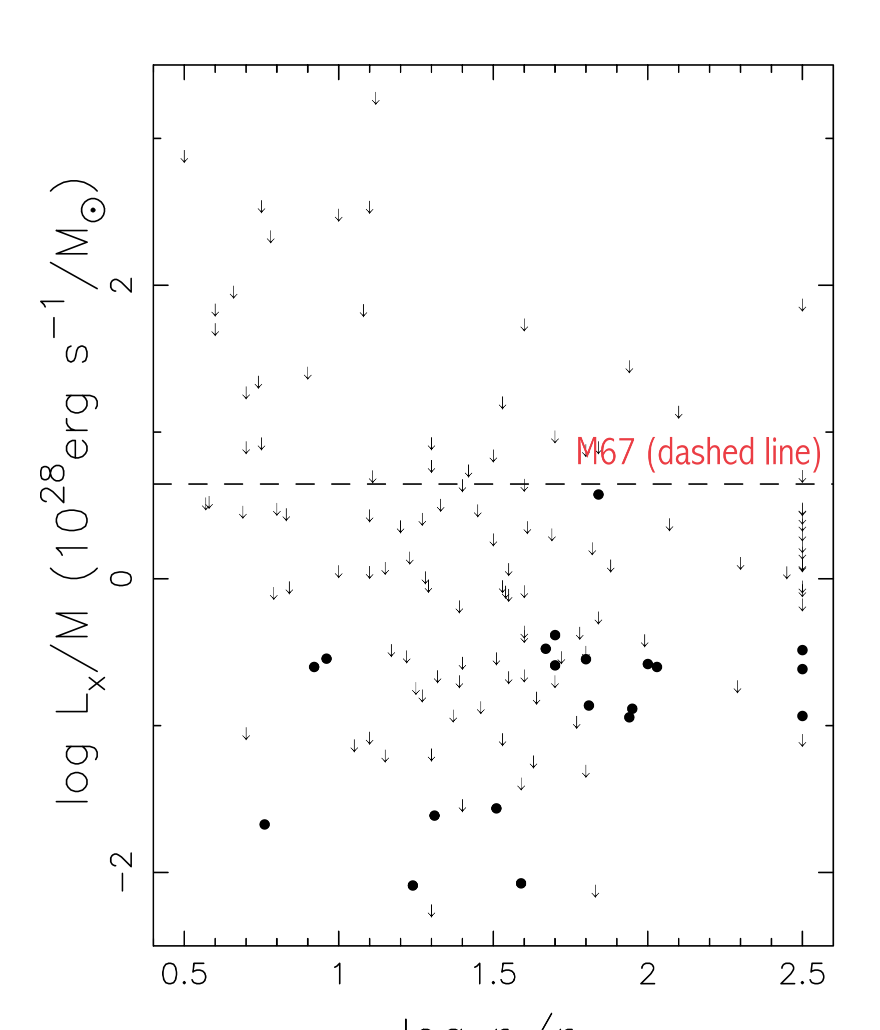
SIGNATURES OF BINARY DESTRUCTION

- ROSAT: ratio of total X-ray luminosity Lx and cluster mass M (Lx/M) in most globular clusters is lower than in old open cluster M67 (bright LMXBs not included)

  ⟹ close/hard binaries relatively under-abundant in globulars?

- what is the composition of these X-ray populations?

- need Chandra to probe deeper and classify individual sources, which could not be resolved by ROSAT



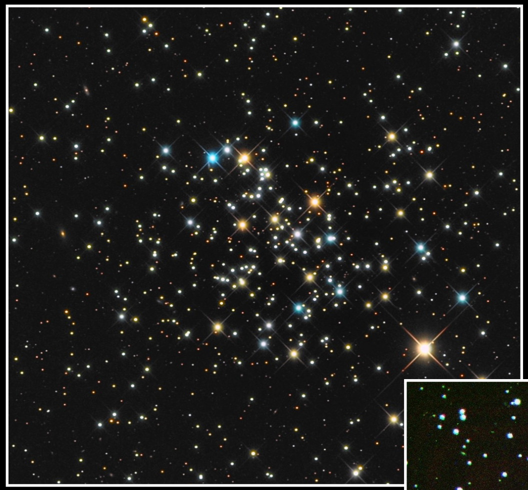
Verbunt '01

CHANDRA SURVEY OF OLD OPEN CLUSTERS

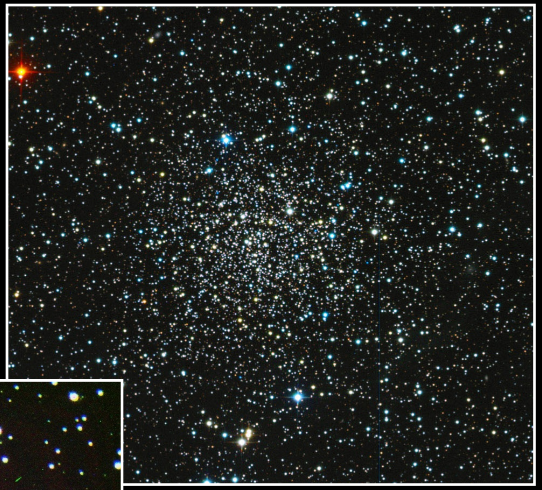
- survey of old open clusters, down to at least Lx~1e30 erg/s
- old open clusters allow detailed comparisons of CV and AB populations in lower-density environments than globular clusters

cluster	age (Gyr)
NGC 6253	3.5
M67	4
Cr 261	7
NGC 188	7
NGC 6791	8
Berkeley 17	9

vdBerg+ '04, vdBerg+ '13, Vats+'14, Vats+ in prep



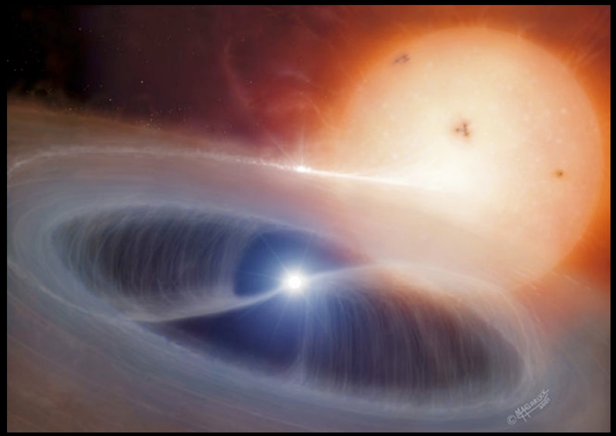
M67



NGC6791

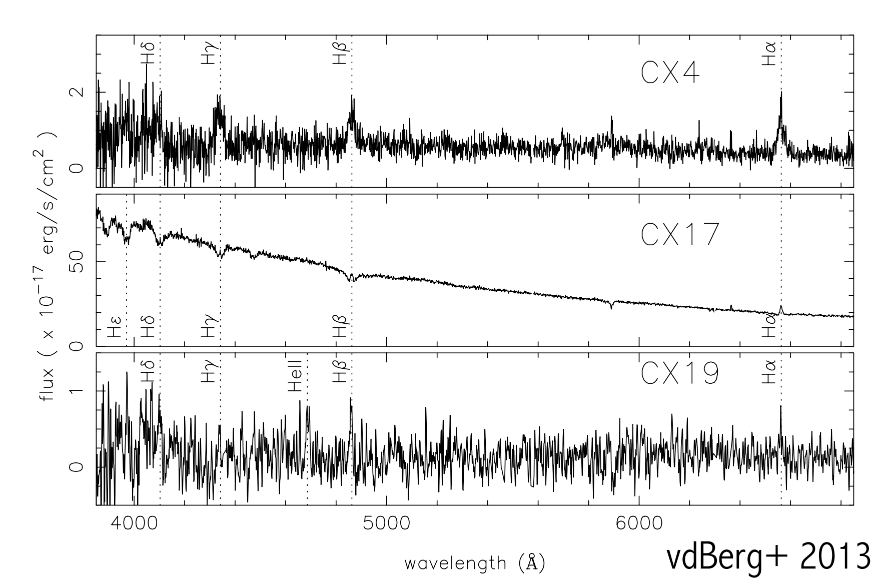
NGC188

CATACLYSMIC VARIABLES



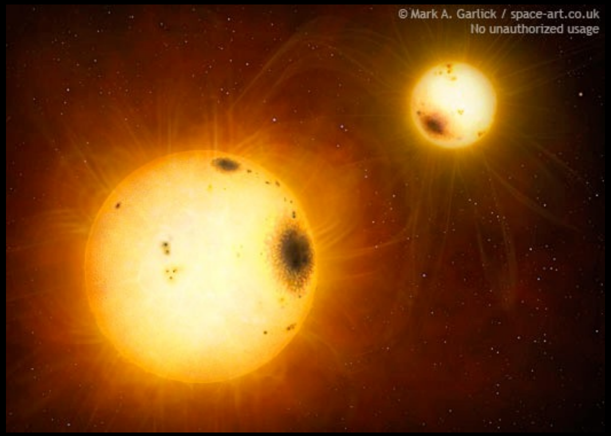
- CVs in old open clusters likely primordial
  - small sample: 5 spectroscopically confirmed CVs, more candidates
  - CV density in open clusters similar to field density: ~10^{-5} pc^{-3} $\Longrightarrow$ primordial population
- CVs in globular clusters are under-abundant despite scaling of their numbers with encounter frequency:
  - 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
  - CV progenitors are destroyed? (Davies ’97, Ivanova+ ’06)

CVs in open cluster NGC6791



vdBerg+ 2013

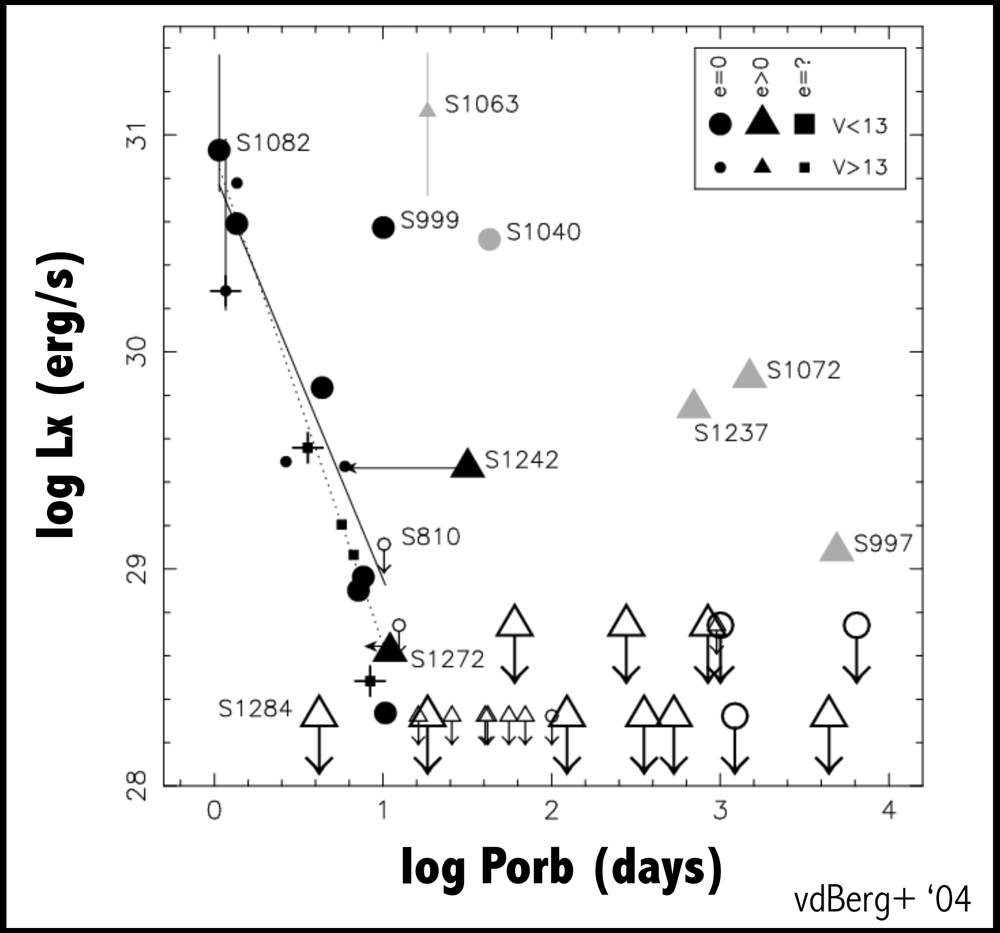
ACTIVE BINARIES



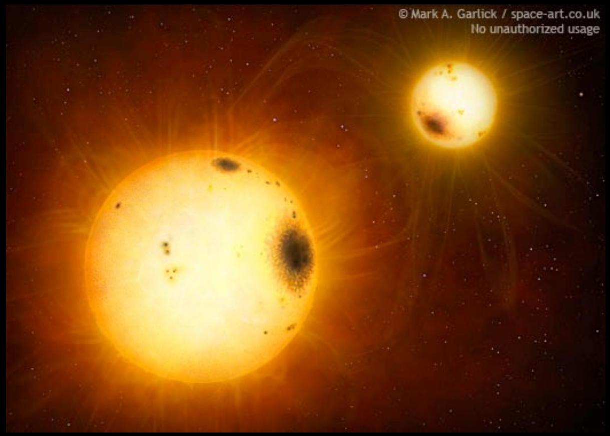
- faintest of the 4 main X-ray source classes
    - X-rays are the result of rotationally powered magnetic activity, which requires tidal coupling $\Longrightarrow$ ABs have orbital periods up to the tidal synchronization time scale (~10-15 days for main-sequence stars, depends on cluster age)

- ABs in old open clusters:
    - dominate integrated X-ray luminosity
    - Lx scales with orbital period Porb, as expected
    - "anomalous" ABs: wide periods (up to 5 yrs), at least one star in the binary is not on the main sequence or giant branch
    - their numbers do not show a clear correlation with current cluster mass

ABs in M67



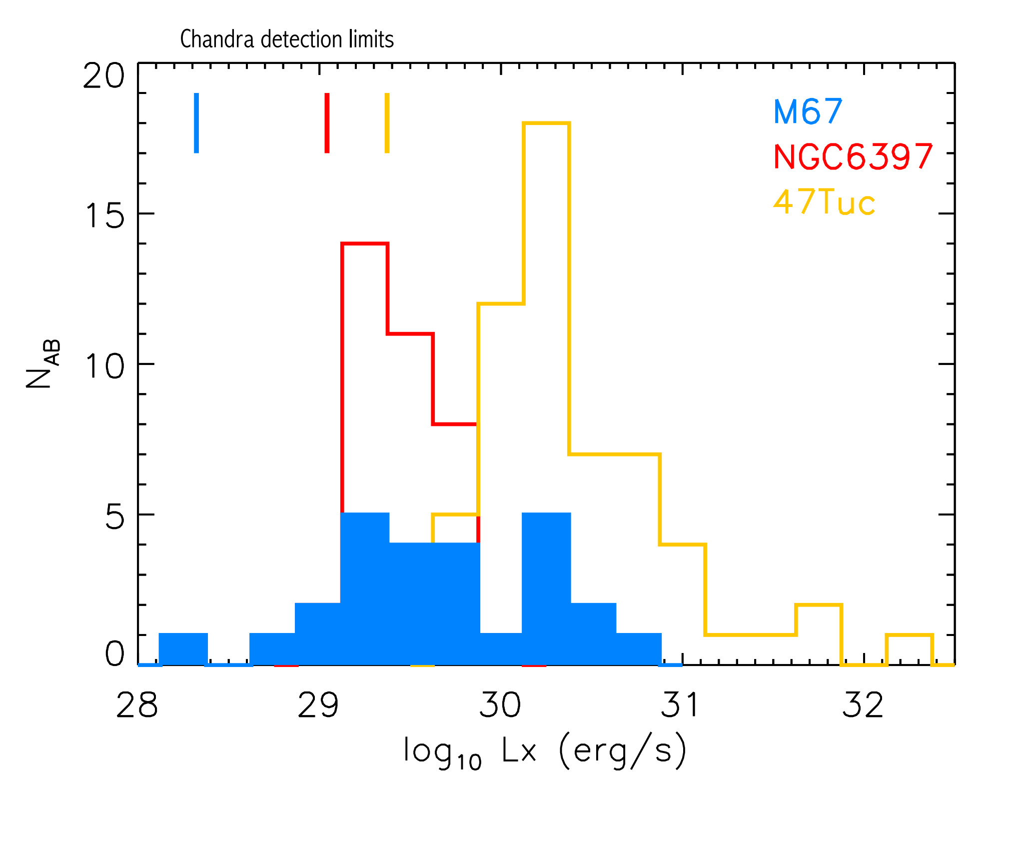
filled symbols: detections
open symbols: upper limits



ACTIVE BINARIES

- ABs (with Lx~1e30erg/s or higher) in globular clusters are under-abundant
  - 80+ globular clusters have been studied by Chandra, but for only ~5 the sensitivity is Lx~1e30 erg/s or better
  - 47Tuc is ~1000x more massive than M67, but has at most ~15x more ABs
  - NGC6397 is ~250x more massive than M67, has ~4x more ABs
- overabundance of qLMXBs and MSPS does not make up for lack of ABs and CVs:
  - Lx/M about ~10x smaller for globular clusters 47Tuc, NGC6397 compared to open clusters M67, NGC6791

Lx histogram of ABs



HOW TO INTERPRET THE LACK OF ABS AND CVS?

- Several factors
  - old open clusters have lost more mass relatively ("evaporation")
    - cluster relaxation time scale scales with cluster mass
    - effect likely not enough to explain the factor of $\sim$100 difference in number of ABs
  - destruction of hard binaries through various channels
    - collisions that break up the binary
    - collision-induced binary mergers
  - metallicity effect on Lx: Lx goes down with metallicity, not well studied (Ottman+ '97)
    - globular clusters more metal-poor than open clusters
- CVs not as under-abundant as ABs, perhaps due to dynamical formation channel for CVs
  - see results by Pooley & Hut '06)

CONCLUSIONS

- Chandra sees individual faint X-ray sources in the cores of the densest clusters
  - binary source classes span a range in orbital periods, but all hard binaries
  - signatures of binary formation in globular clusters for qLMXBs and CVs
  - signatures of binary destruction in globular clusters for CVs and ABs
  - Chandra observations can constrain the period distribution of cluster binary populations

- Excluding bright LMXBs, globular clusters are under-luminous in X-rays (lower Lx/M) compared to old open clusters

- Upcoming work:
  - more Chandra observations of old open clusters (Vats, vdB+, in prep)
  - HST Large Program on nearest globular cluster M4 (PI: Bedin) to study period distribution of binaries:
    - look for wobbles of binaries with compact companions with periods 1 month - 10 years (Bedin+ 2013)
    - deep Chandra data of M4 (PI: Pooley) constrain the population of hardest binaries
  - comparison of observations with models to better understand the formation versus destruction channels