X-ray Sources and Their Optical Counterparts in Globular Clusters: M12, E3, NGC6144

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TING-NI LU (盧亭霓)
INSTITUTE OF ASTRONOMY,
NATIONAL TSING HUA UNIVERSITY, TAIWAN

ALBERT K. H. KONG (江國興), SHIH-HAO LAN (藍仕豪),
CEES BASSA, FRANK VERBUNT, WALTER H. G. LEWIN,
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2009.03.19
THE 14TH NORTH AMERICAN WORKSHOP
ON CATACLYSMIC VARIABLES AND RELATED OBJECTS

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WILD STARS IN THE OLD WEST II
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Outline

- Scientific Purpose
- Our Targets: M12, E3, NGC6144
- Identification of X-ray Sources
- Discussion

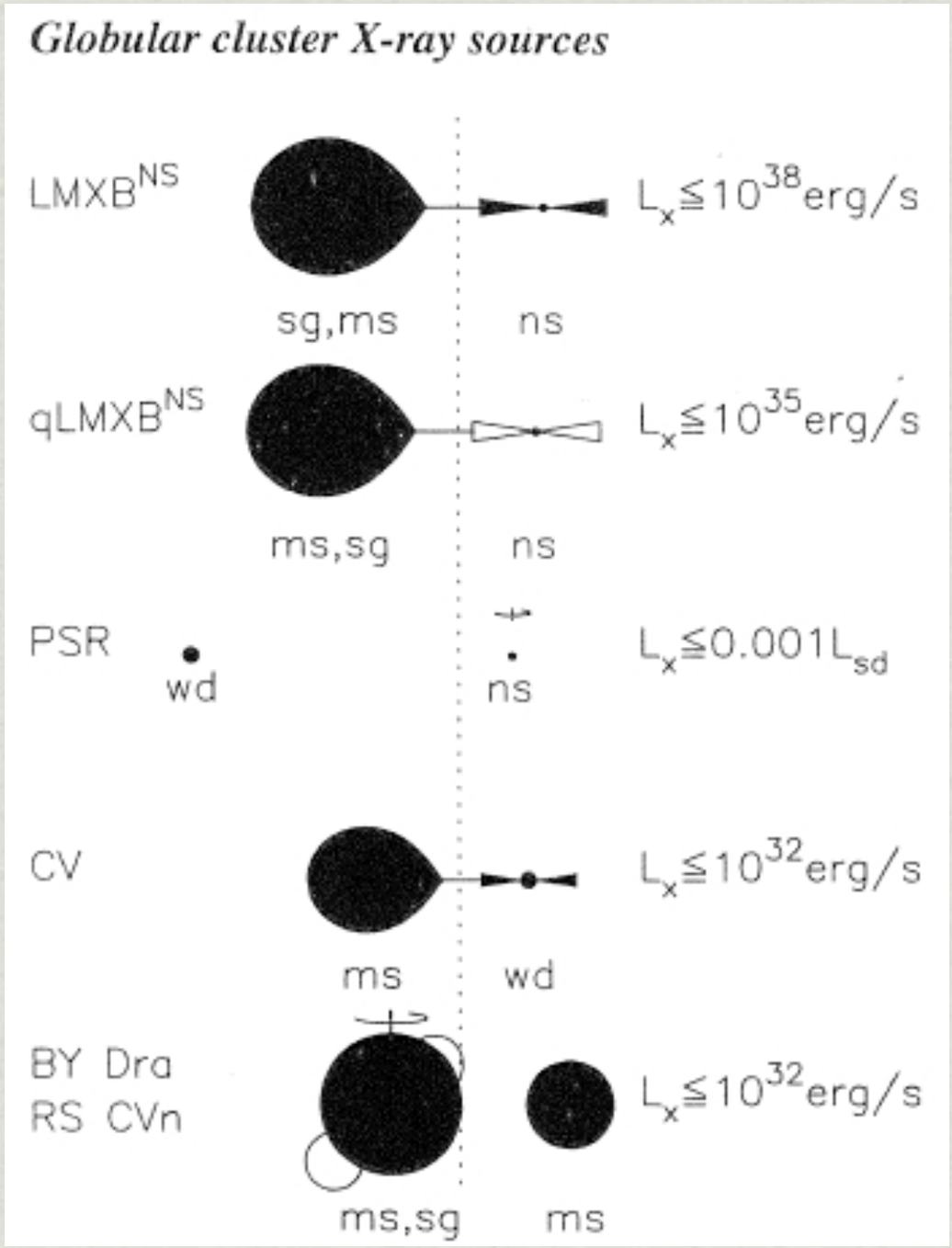
Why Study
X-ray Sources in GCs

- To know the **population** and their **formation mechanism** of X-ray sources in globular clusters.

- To help construct the **dynamical evolution scenarios** for both those X-ray sources and globular clusters.

What
X-ray Sources in GCs

- Low Mass X-ray Binaries (LMXBs)
- quiescent LMXBs
- MilliSecond Pulsars (MSPs)
- Cataclysmic Variables (CVs)
- Active Binaries (ABs)



Verbunt, F., & Lewin, W. H. G. 2006, in Compact Stellar X-Ray Sources, ed. W. H. G. Lewin & M. van der Klis (Cambridge: Cambridge Univ. Press), 341

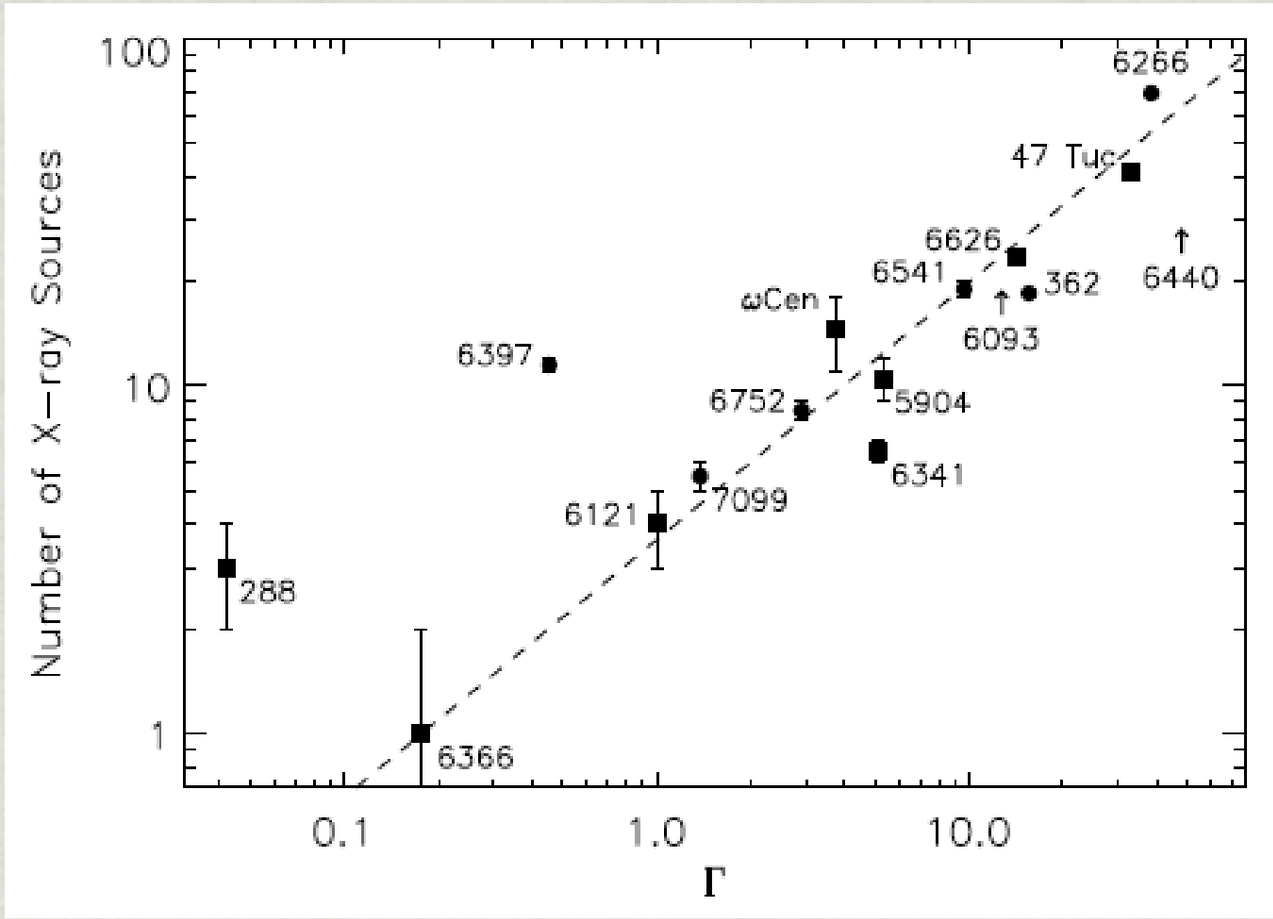
How to form
X-ray Sources in GCs

- Primordial Binaries

- Dynamical Interactions
  - Tidal Capture
  - Close Encounter (exchange companions)

- **$N = a\Gamma + bM_h$**
  The correlation between the number of X-ray sources and the **encounter rate Γ** ($\equiv \rho_0^{1.5} r_c^2$, dynamical origin) and the **mass M_h** of globular clusters (primordial origin)

How to form
X-ray Sources in GCs



- a revised version of Fig. 2 of Pooley et al. 2003

- Previous studies focus on **high core density** GCs and show that the number scales quite well with Γ.

Which GCs are Studied

- Studies on **Low core density GCs**.

- M12

FORS/VLT IMAGE, 3.5’ X 3.5’

ESO R BAND IMAGE, 11.8’ X 11.8’

- E3

SERC I BAND IMAGE, 12.9’ X 12.9’

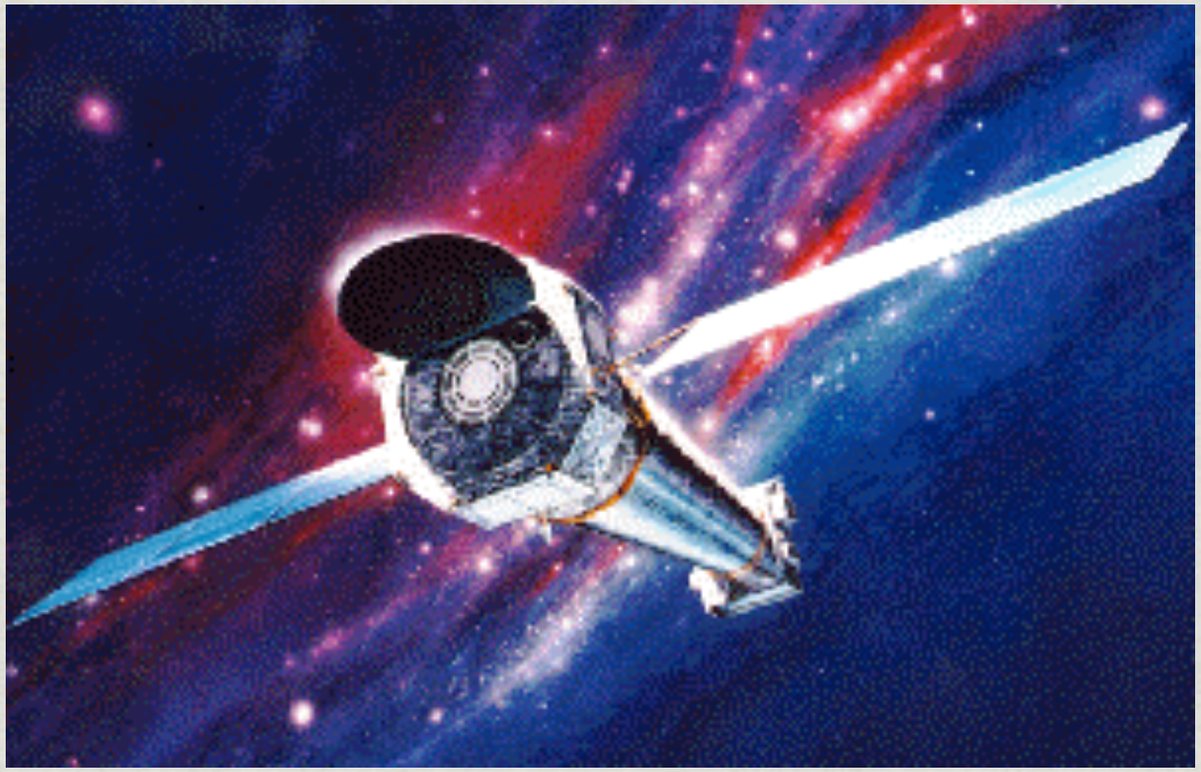
- NGC6144

Which GCs are Studied

Cluster	log ρ_0 ($L_\odot$ pc^{-3})	r_c (“)	d (kpc)	M_V	Γ	M_h
M4	4.01	49.8	1.7	-6.90	1.00	1.00
M12	3.23	43.2	4.9	-7.32	0.41	1.47
NGC6144	2.23	56.4	8.5	-6.75	0.065	0.87
E3	1.11	112.2	4.3	-2.77	0.001	0.02

How to “See”
X-ray Sources in GCs

- High **spatial resolution** and high **sensitivity**
- Chandra X-ray Observatory (ACIS-S)
- Hubble Space Telescope (HST)



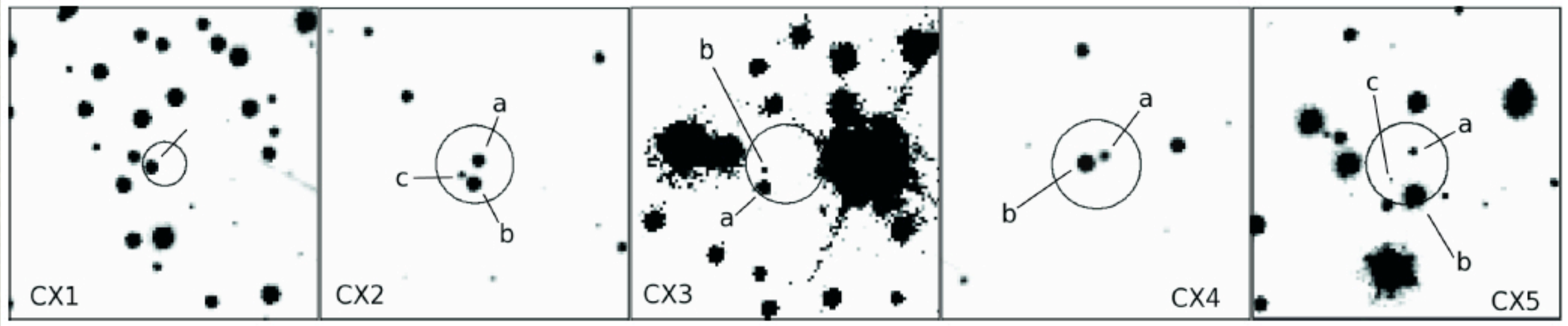
How to Identify
X-ray Sources in GCs

- We identified the optical counterparts to the Chandra X-ray sources inside the FOV of HST ACS based on:

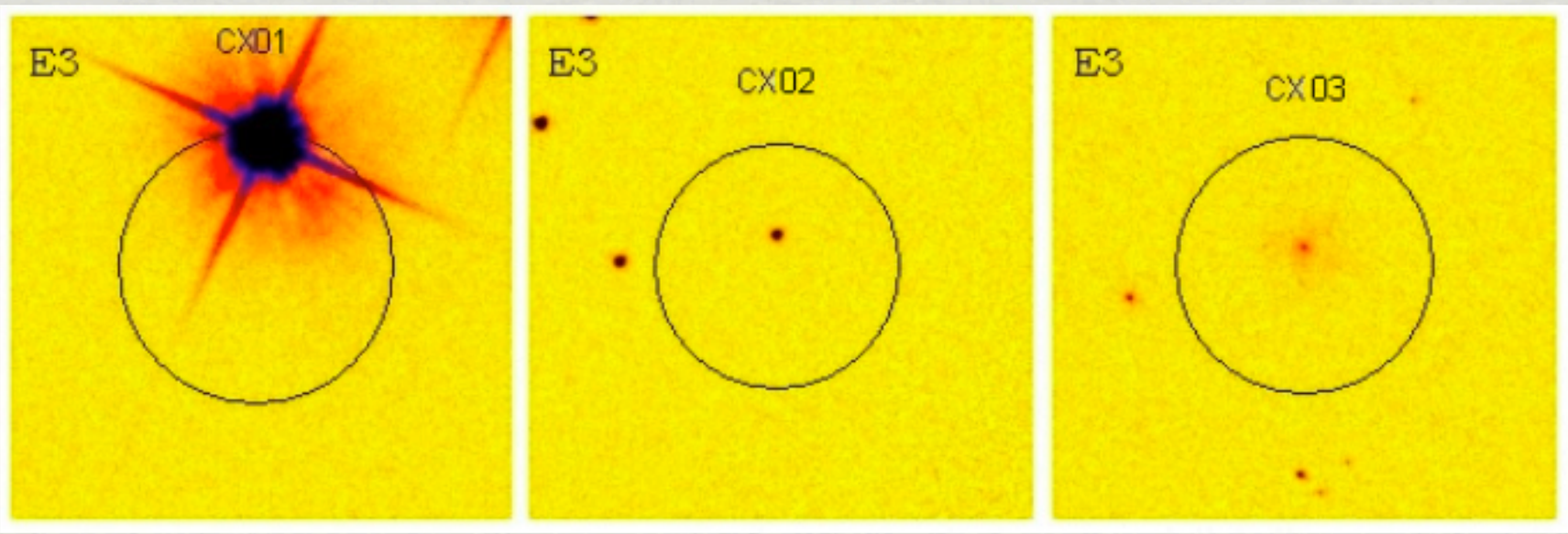
1) X-ray luminosity
2) X-ray spectrum/spectral feature
3) optical spectrum (CMD)
4) X-ray to optical flux ratio: f_X / f_{opt}
5) log L_X to M_V diagram

Optical Counterparts to X-ray Sources in GCs

- M12

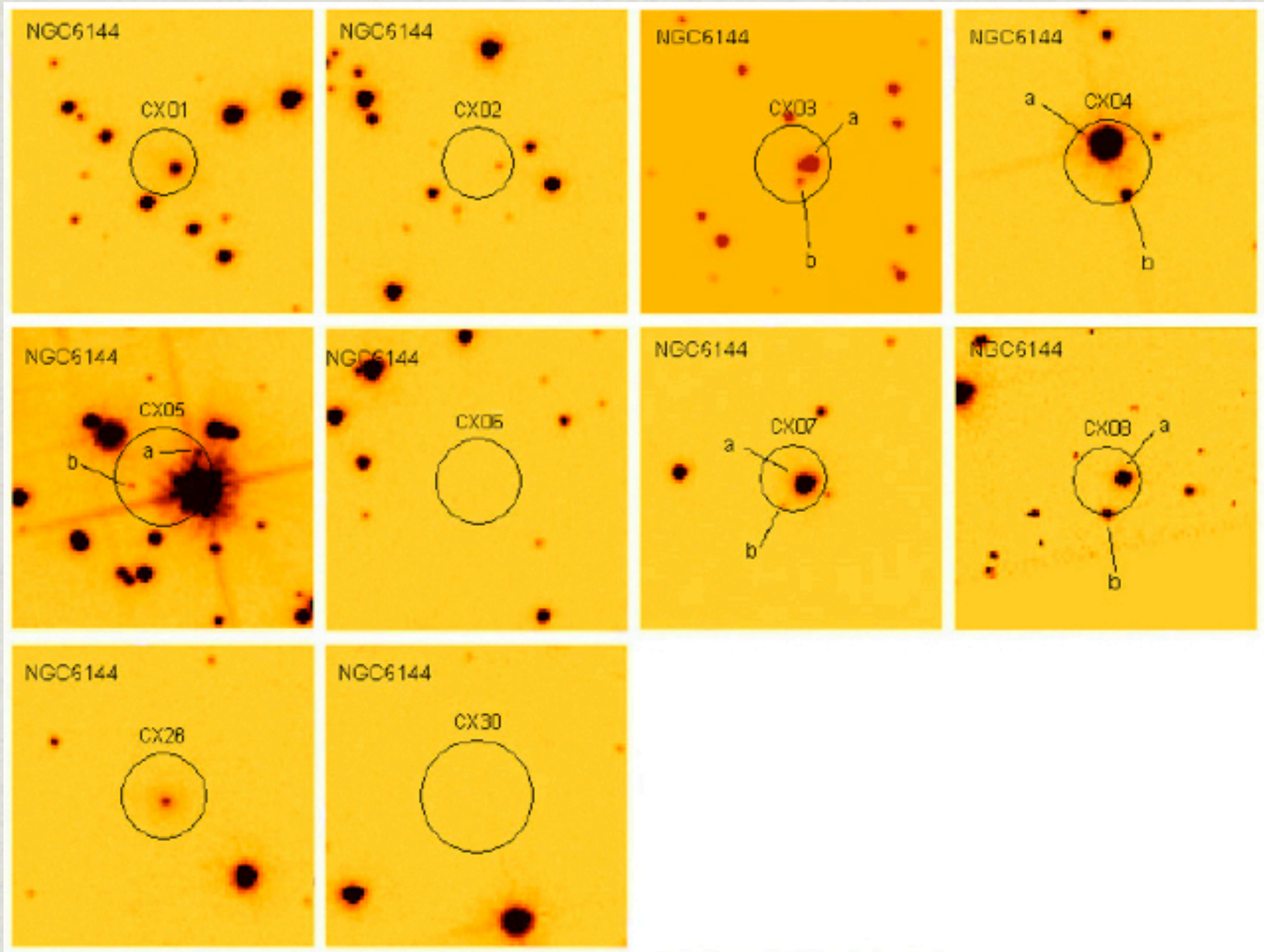


- E3



Optical Counterparts to X-ray Sources in GCs

- NGC6144



Identified X-ray Sources in GCs

❋ Sources in **M12**

CX Source	L_X ergs s^{-1}	Spectral Feature	Optical Counterpart	CMD	f_X/f_{opt}	log L_X to Mv diagram	Identification
CX1	10^32	hard	1	MS, Hα	3.151	CV like	CV
CX2	10^31	hard	2a	MS	0.032	AB like	?
			2b	red	0.021	AB like	AB
			2c	blue, Hα	0.149	CV like	CV
CX3	10^30	hard	3a	blue, Hα abs.	1.375	CV like	AGN
			3b	MS (faint)	12.703	AGN like	?
CX4	10^30	soft	4a	MS	0.205	AB/CV	?
			4b	red	0.026	AB like	?
CX5	10^30	hard	5a	MS	0.573	AB/CV	?
			5b	red, Hα	0.018	AB like	AB
			5c	MS	2.298	AB/AGN	?

Identified X-ray Sources in GCs

- Number of the X-ray Sources

Cluster	log ρ_0 ($L_\odot$ pc^{-3})	N_h	N_c secured member	Bkg	Γ	M_h
M4	4.01	6	--	2	1.00	1.00
M12	3.23	6	3 (2CVs; 1AB)	4	0.41	1.47
NGC6144	2.23	6	3 (1CV; 2ABs)	4.5	0.065	0.87
E3	1.11	3	1 (CV)	1.5	0.001	0.02

Discussion on
X-ray Sources in GCs

- **Maximum Likelihood Fitting**

$$P(N,\mu) = \frac{\mu^N}{N!}e^{-\mu} \qquad P = \prod_j [P(N_c,\mu_c)P(N_b,\mu_b)]_j$$

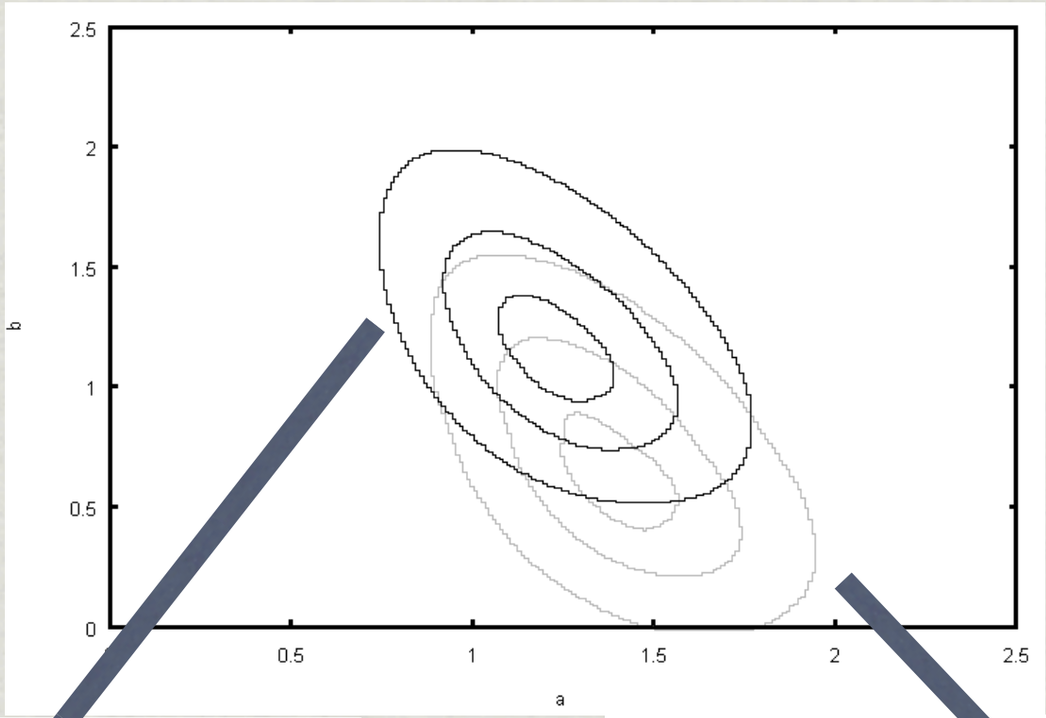
(Verbunt et al. 2007)

N = aΓ + bM$_h$

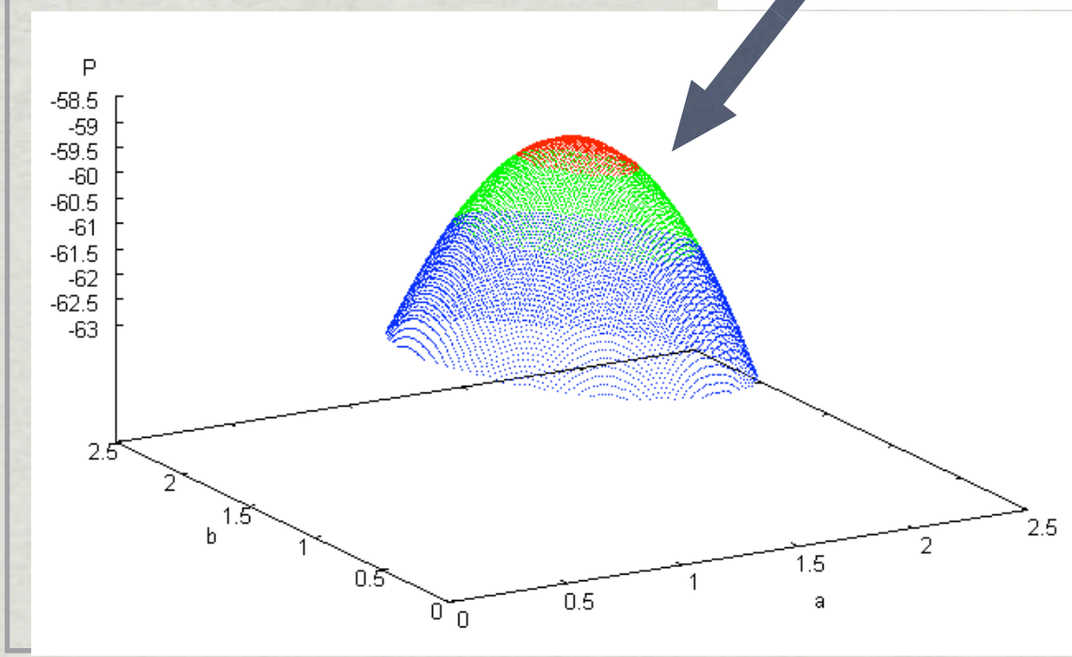
- **N = 1.4Γ + 0.6M$_h$**
  (free fitting)

- **N = 1.2Γ + 1.1M$_h$**
  consider secured cluster members in low core GCs;
  fitting with lower limit on the number of X-ray sources
  (consistent with Bassa et al. 2008)

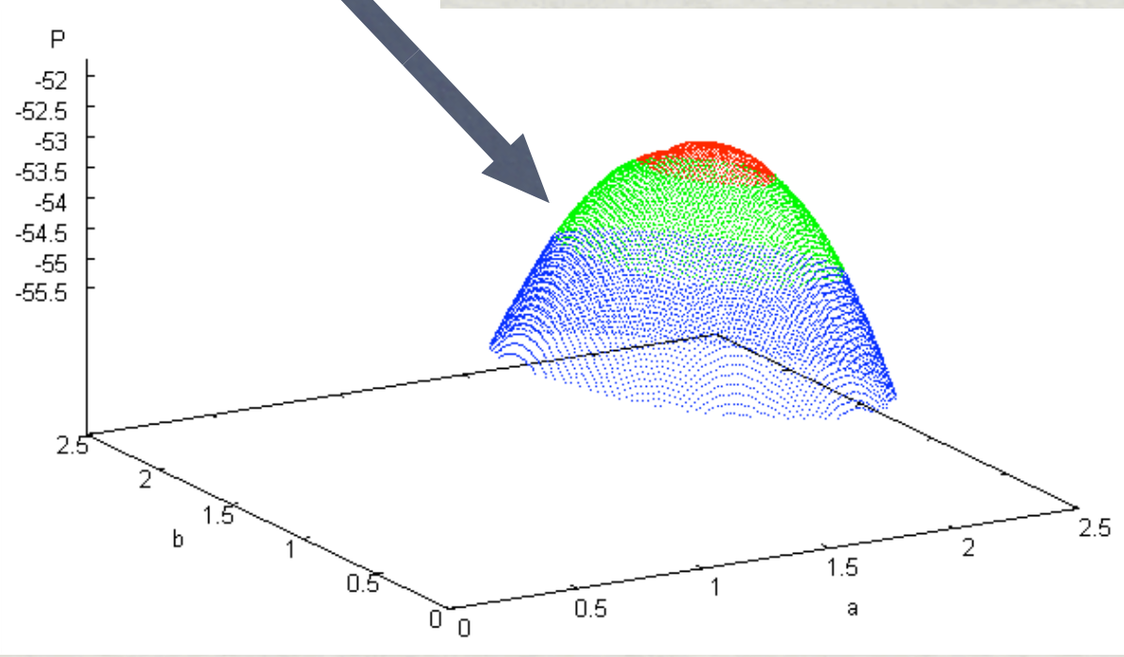
Discussion on
X-ray Sources in GCs



❋ $N = 1.2\Gamma + 1.1M_h$



❋ $N = 1.4\Gamma + 0.6M_h$



Discussion on
X-ray Sources in GCs

- Increased ratio of b/a indicates the increased importance of the primordial formation channel for X-ray sources in low core density GCs.

- Evidences of **primordial binaries** (CVs and ABs) in **low core density GCs**.

THANK YOU very much!!