X-ray Binaries in Globular Clusters

Constraints on GC Dynamics and Neutron stars vs. white dwarfs

Josh Grindlay
(Harvard)
and collaborators:
Craig Heinke, Peter Edmonds, Fernando Camillo,
Haldan Cohn and Phyllis Lugger

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Overview of talk

- Review of bright LMXBs and their GCs
- Chandra views of 47Tuc and NGC6397: the compact binary population revealed
- MSPs in 47Tuc & NGC6397: re-recycled?
- Binary ejection & cluster disruption in bulge
- Neutron stars vs. WDs in globulars

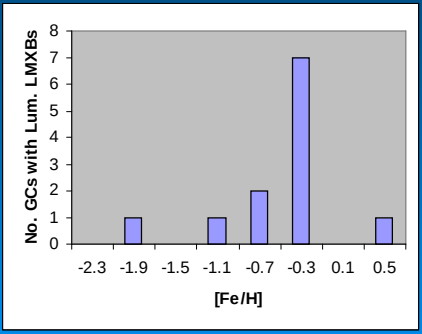
Luminous LMXBs in Globular Clusters

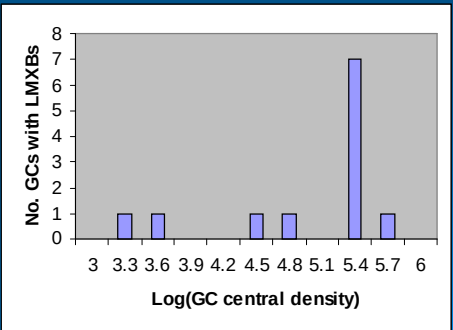
13 LMXBs in 12 globular clusters:

Cluster	LogLx (erg/s)	P_binary	LogRho_c (Msun/pc^3)	[Fe/H]	R_galctr (kpc)	Z_disk (kpc)
N1851	36.2	~82min?	5.3	**-1.2**	16.7	-6.9
N6440	32.5-37		5.3	**-0.3**	1.3	0.6
N6441	36.5	5.5hours	5.2	**-0.5**	3.5	-1
N6652	32.5-36	42min(??)	4.5	**-1**	2.4	-1.9
N6624	37-37.5	11min+~1d*	5.3	**-0.4**	1.2	-1.1
N6712	36	21min	3.1	**-1**	3.5	-0.5
N7078	36.5, 36	17.2d	5.4	**-2.2**	10.4	-4.7
Ter1	32-36		3.5	**-0.3**	1.8	0.1
Ter2	36		4.7	**-0.4**	0.9	0.3
Ter5	32-37		5.5	**-0.3**	0.7	0.2
Ter6	32-36		5.4	**-0.5**	1.6	-0.4
Liller1	32-36		5.4	**0.2**	2.6	0
		*probable triple with ~1d outer binary period				

Primary correlation with [Fe/H], not ρ_c or R_{GC} or Z_{disk} ?

Luminous LMXBs in GCs, cont.





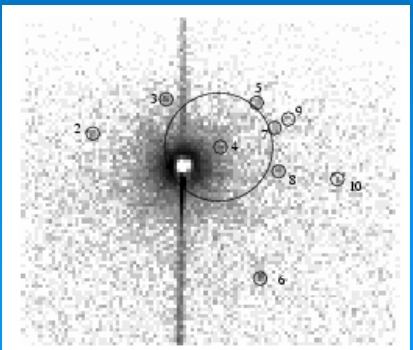
Distribution in [Fe/H] marginally more peaked

Luminous vs. quiescent LMXBs & CVs

Dim sources discovered & suggested to be primarily CVs but also qLMXBs (e.g. transient in N6440)

Hertz and Grindlay (1983)

Chandra can now resolve (just!) both in single GC:



Terzan 5: LMXB in outburst ($L_x \sim 10^{36}$ erg/s) with 9 faint sources at $L_x \sim 10^{32\text{-}33}$ erg/s.

X-ray colors suggest 5 CVs and 4 qLMXBs

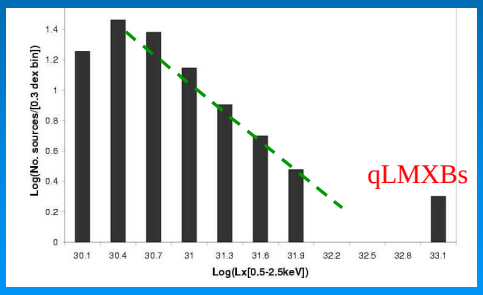
Heinke et al 2003, ApJ, in press

47Tuc, March 16-17, 2000 (Chandra ACIS-I, 70ksec)

47Tuc: Initial Chandra Data Results

(Grindlay et al 2001, Science, 292, 2292)

- 108 sources in central 2 x 2.5arcmin
  - L_x(0.5-2.5 keV) ~ 1 - 1000 x 10^{30} erg/s



  - Power Law X-ray LF: dN/dL ~ $L^{-0.8}$

(MSPs, CVs, and BY Dras) vs. qLMXBs

47Tuc: initial Chandra data, addtl. results

- 108 sources in central 2 x 2.5 arcmin field
  (Grindlay et al 2001, Science)
- 187 sources out to radius 4 arcmin
  (Grindlay et al 2002, ApJ)

X-ray spectral identifications of

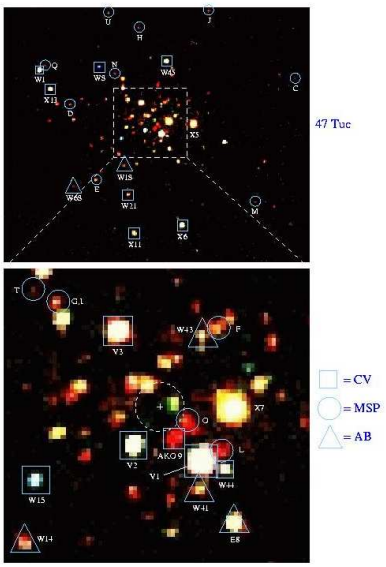
- 2 qLMXBs: kT ~100 eV H-atmos: constrain EOS of NS
  (Heinke et al 2003, ApJ)
- ~30 CVs: kT ~5-20 keV bremstrahlung; magnetic CVs?

HST IDs for >22 CVs, 1 qLMXB, 2 MSPs, 29 ABs
(Edmonds et al 2003, ApJ)

47Tuc: initial Chandra data results, cont.

• BY Draconis stars (chromospherically active m-s binaries; *ABs*) detected in large numbers: 29 HST IDs.
L_x ~1-10 x 10^{30}, kT ≤1keV (usually), P_{binary}~0.5-2d

• Limit on central BH from Bondi accretion & n ~0.1cm^{-3} from variation in DM of MSPs
M_{BH} < 470 M_O, but dependent on uncertain (advection?) $\varepsilon_{accretion}$



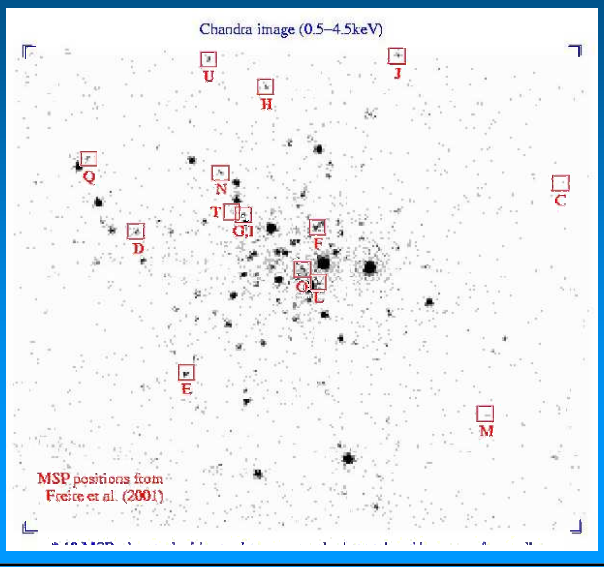
MSPs in 47Tuc: the initial Chandra view

• 9 of the 16 MSPs with precise radio timing positions detected firmly, 5 marginally (2 un-resolved)

• All but 1 (MSP-J) very *soft*: kT~0.2keV emission from polar caps. & L_x ~1-4 x 10^{30}
⇒ departure from L_x - Edot relation

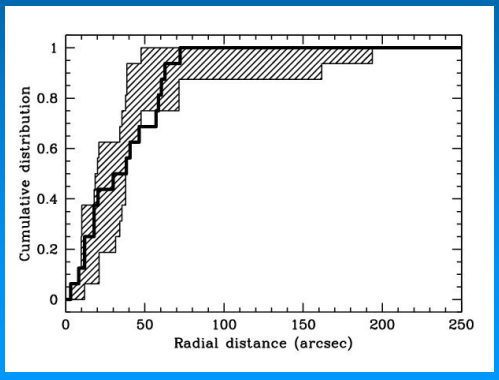
• Significant underlying "red" source pop. and incompleteness: ***~35-90 MSPs, total***

47Tuc, March 16-17, 2000 (Chandra ACIS-I, 70ksec)

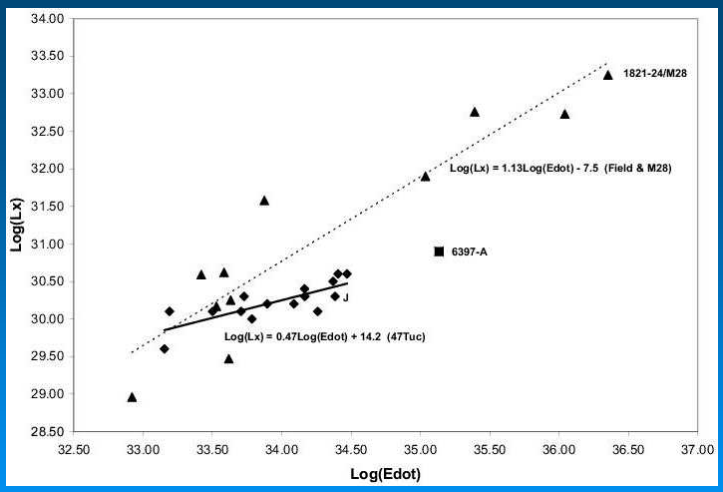


Radial Distribution of MSPs in 47Tuc

Radio positions (16) all within ~3.5r_c but Chandra soft sources follow King profile: $n_x(r_x) \sim n_*(r_*)^q$, with q ~1.5-1.7 & r_x ~15±3”



Monte-Carlo sampling of 16 soft sources (shaded band) vs. MSPs



L_x vs. Edot for MSPs in 47Tuc & NG6397 vs. Field

⇨ *NS surface B-field altered (multipole?) by renewed accretion in additional encounters?*

(Grindlay et al 2002, ApJ)

47Tuc: first looks at NEW Chandra data

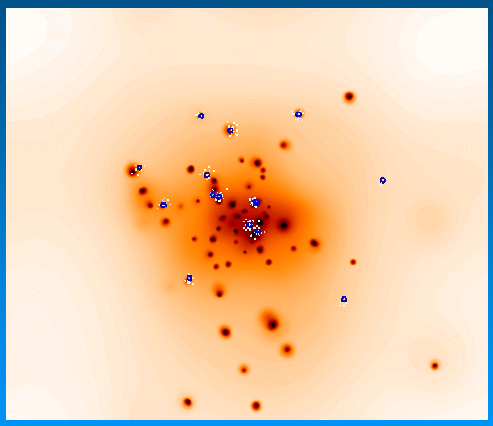
4 x 65 ksec exposures with ACIS-S (better soft response) with ~1, 3, 10d separations (Sept. 30 - Oct. 10, 2002)

and

HST-ACS imaging (V, R, Hα), for 3 (of Chandra's 4) visits at 3 orbits each

Scroll through smoothed (minimally) Chandra images...

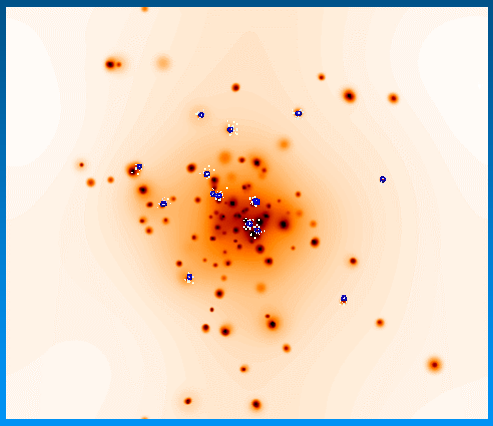
47Tuc, March 16-17, 2000
(Chandra ACIS-I, 70ksec)



O = MSP positions

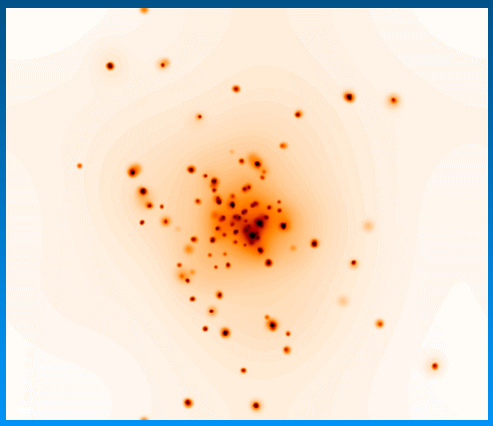
Same minimal smoothing for original ACIS-I image, above, as for new ACIS-S images to follow

47Tuc, Sept. 30, 2002
(Chandra ACIS-S, 65ksec)

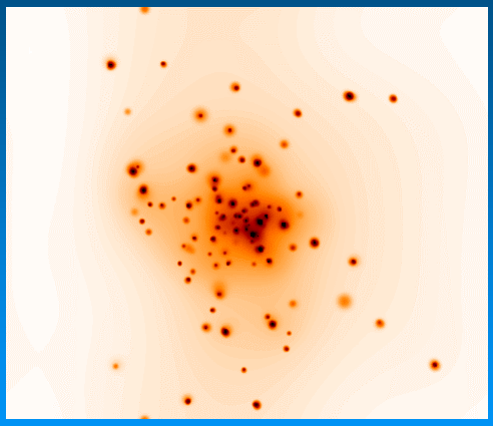


O = MSP positions

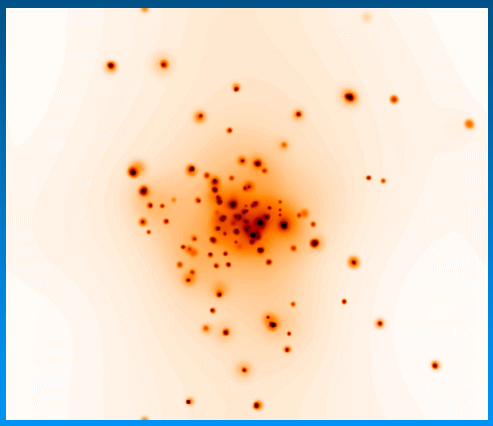
47Tuc, Oct. 1, 2002
(Chandra ACIS-S, 65 ksec)



47Tuc, Oct. 3, 2002
(Chandra ACIS-S, 65 ksec)



47Tuc, Oct. 10, 2002
(Chandra ACIS-S, 65ksec)



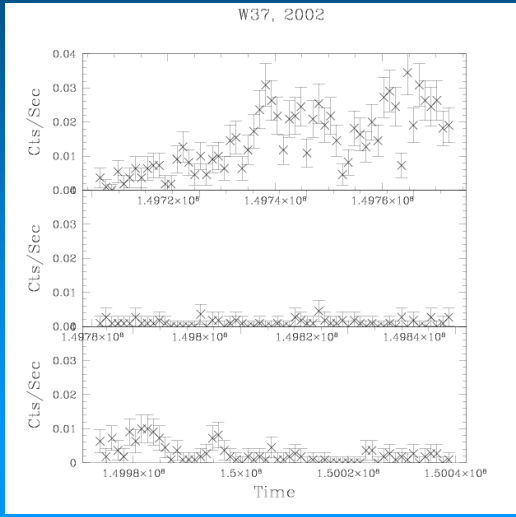
Initial results from new 47Tuc Chandra data

- *All resolved MSPs (15/17) detected; spectra will be possible on summed images (>100cts)*
- *At least 150 sources detected significantly by WAVDETECT in same 2 x 2.5 arcmin central box; many more if crowding considered*
- *New flaring (mostly ABs, but also CVs?) and steady (MSPs, CVs?) sources detected*

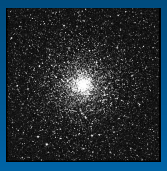
Example light curve from new Chandra images

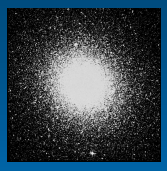
W37: source closest to cluster center, ~1" offset, and limiting L_x for any central black hole (IMBH)

Soft (kT < 1keV) emission: possible magnetic CV (polar) or accreting NS?



47Tuc vs. NGC6397: Chandra Results



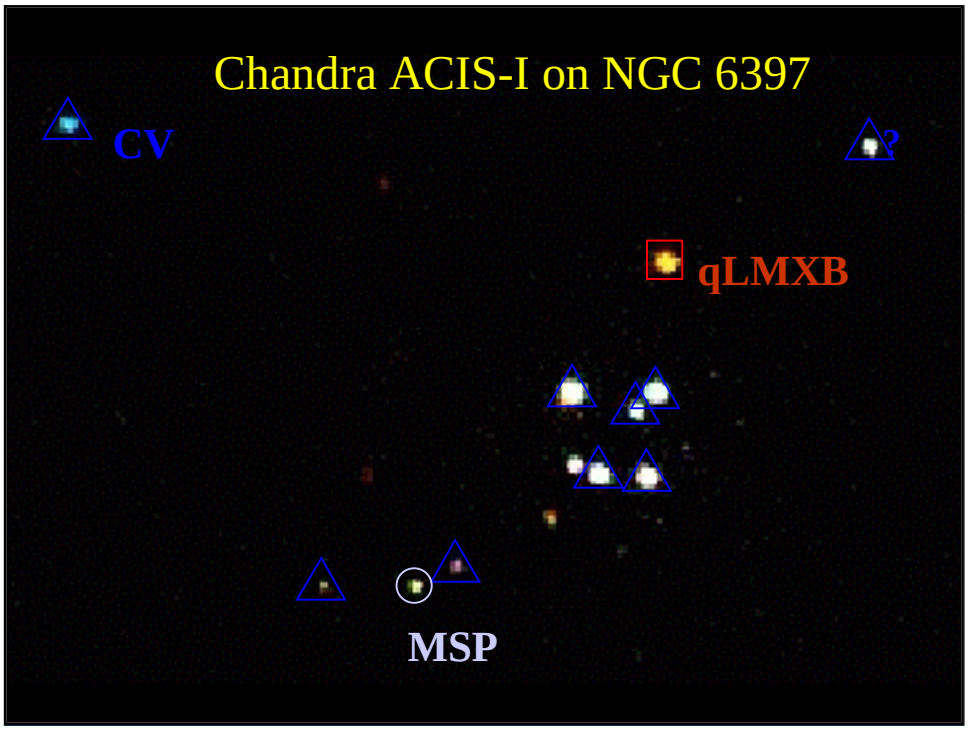


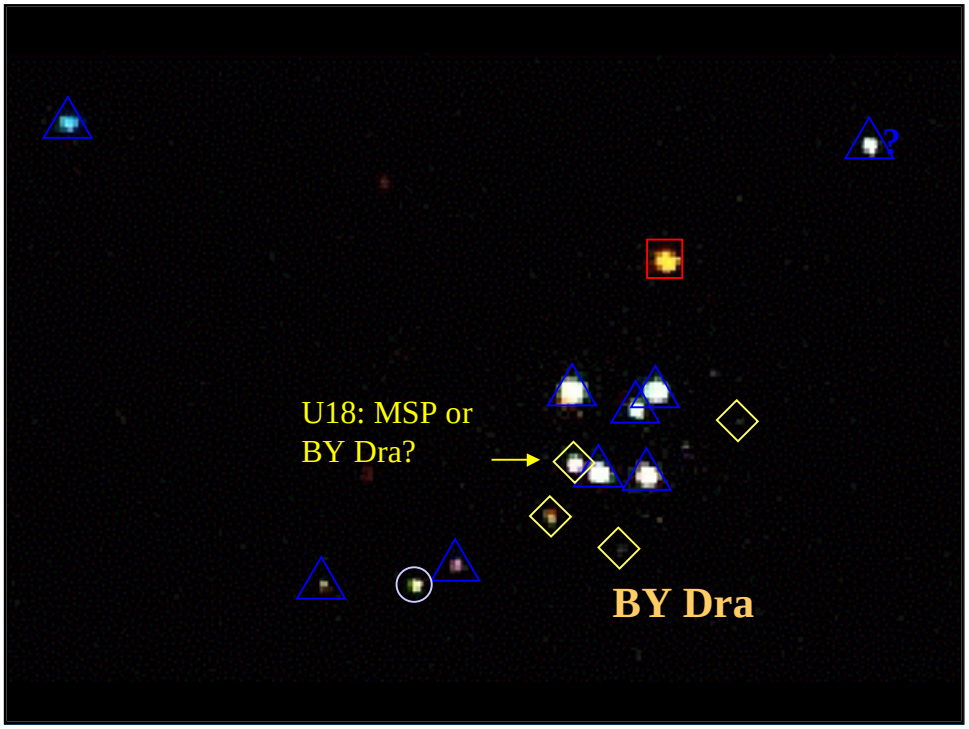
	NGC 6397	47Tuc
distance (kpc)	~ 2.5	~ 4.6
mass (M_{sun})	~ 2 x 10^5	~ 10^6
core radius (arcsec)	~ 5	~ 23
core radius (pc)	~ 0.06	~ 0.5
central density (M_{sun}/pc^3)	~ 2 x 10^5	~10^5
central velocity dispersion (km/s)	~ 5	~ 12
relative collision rate	1	~ 30

NGC6397: Initial Chandra imaging results

- *49 ksec observation with Chandra ACIS-I*
- *~ 25 X-ray sources within < 2' (~ 24 core radii)*
- *~ 20 cluster members*
- *L_x ~ 3 x 10^{29} – 2 x 10^{32} erg/s*
- *9 CVs (hard spectra: kT > 5keV); 8 with HST IDs*
- *1 qLMXB (kT ~0.2 keV)*
- *1 MSP (soft+hard spectrum)*
- *4 ABs with HST Ids; no He-WDs (NFs)*

(Grindlay et al 2001, ApJ)



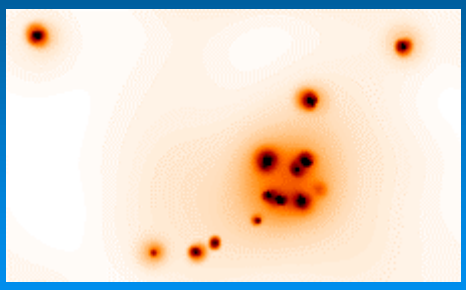


NGC 6397: NEW Chandra data

2 x 28 ksec exposures with ACIS-S with 2d separation (May 13, 15, 2002)

Scroll through smoothed (minimally) Chandra images...

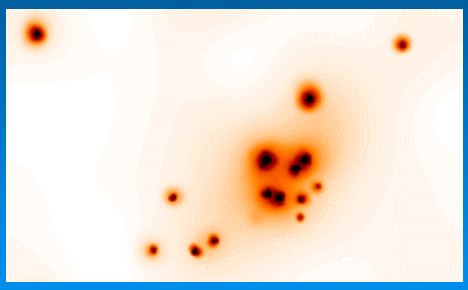
NGC 6397, July 31, 2000
(Chandra ACIS-I, 49ksec)



~2arcmin x 1.5arcmin

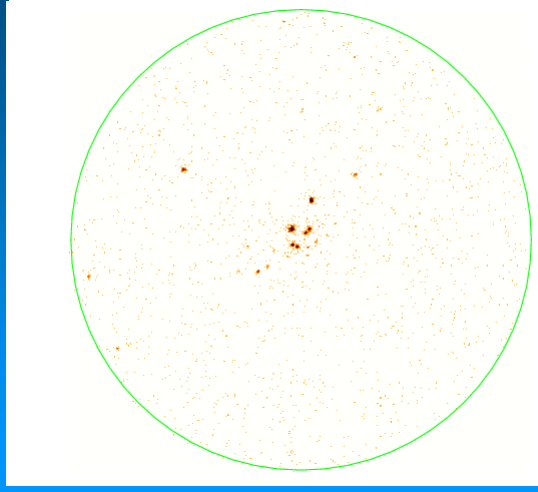
Same minimal smoothing for original ACIS-I image, above, as for new ACIS-S images to follow

NGC 6397, May 13 ***and*** 15, 2002
(Chandra ACIS-S, 28ksec *each*)



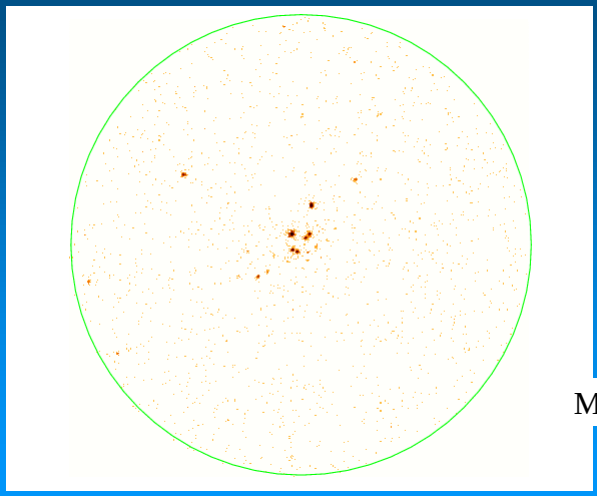
~2arcmin x 1.5arcmin

NGC 6397, May 27 vs. 30, 2002
(Chandra ACIS-S, 30ksec *each*)



May 30

2arcmin *radius* field



May 30

Initial results from new NGC6397 Chandra data

- *CV2 highly variable; others relatively constant. No new obvious CVs (N ~9-10 total in cluster)*
- *U18 relatively constant: consistent with being like known MSP: a doubly-exchanged sysem with "red straggler" secondary since optical IDs same…*
- *MSP PSR1740-5340 shows marginal variability consistent with radio eclipse (but not required by data)*
- *Relatively small number ABs (only ~2 new variables?)*

Comparison *Chandra* Source Counts: 47Tuc vs. NGC 6397 (initial data)

Source	*47Tuc*	*NGC6397*
qLMXB (NSs)	*2*	*1*
MSPs (NSs)	*~90*	*1*
CVs (WDs)	*~30*	*~10*
ABs (m-s stars)	*>30*	*~4*
Γ_c (rel. coll. rate)	**~3**	**~0.3**
M_{GC} (rel. mass)	**5**	**1**
⇨ **(NS/WD)/(Γ_c /M_{GC})**	**~5**	**~0.6**

NSs ~10X overabundant vs. WDs in 47Tuc ([Fe/H]?)
OR CVs produced vs. MSPs scattered in N6397 core collapse?

Compact Binary Ejection?

- *MSP in NGC6397 well out in cusp: ejected in same encounter that swapped in RS secondary*
- *qLMXBs in NGC6652 out at >8 r_c (Heinke et al 2001); ~0.6 r_h in NGC 6293 (Jonker et al 2003)*
- *LMXB/MSP XTEJ0929-31 and othrs in halo*
- *Best evidence from external galaxies GC sources*

Sco X-1 Ejected from a Globular? (even?!)

Posting of Jan. 29, 2003, on astro-ph:
astro-ph/0301580 [abs, ps, pdf, other] :

Title: The origin of Scorpius X-1
Authors: I. Felix Mirabel, Irapuan Rodrigues
Comments: 4 pages, 1 figure. Animation and high resolution figures can be retrived from the NRAO press release: this http URL
Journal-ref: Astronomy & Astrophysics, 398, L25--L28 (2003)

We have used multi-wavelength observations of high precision to derive the space velocity and compute the orbit around the Galactic Centre of the prototype X-ray binary Scorpius X-1. An origin in the local spiral arm of the Milky Way is ruled out. The galactocentric kinematics of Scorpius X-1 is similar to that of the most ancient stars and globular clusters of the inner Galactic halo. Most probably, this low-mass X-ray binary was formed by a close encounter in a globular cluster. However, it cannot be ruled out that a natal supernova explosion launched Scorpius X-1 into an orbit like this from a birth place in the galactic bulge. In any case, the Galactocentric orbit indicates that Scorpius X-1 was formed more than 30 Myrs ago.

Conclusions

- *CVs are indeed over-produced in globulars*
  (& confirms HG83 that CVs dominate qLMXBs)
- *MSPs vs. CVs may probe IMFs or GC initial conditions*
- *Active binaries are bright x-ray markers of binary formation/destruction (destroyed relative to CVs in NGC6397?)*
- *Compact binaries from GCs may populate galactic bulge*