BRIGHT X-RAY SOURCES in M31 GLOBULAR CLUSTERS

- observations
- explanations
- implications

...and beyond.
a soft source saga.

R. Di Stefano
KITP
January 2003

6

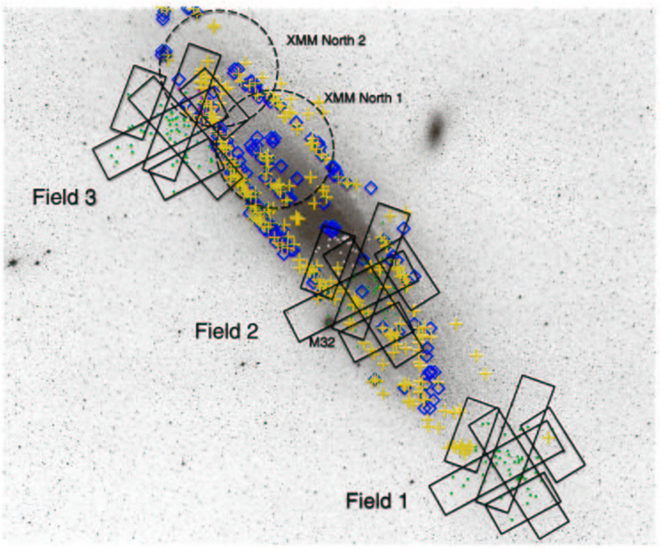
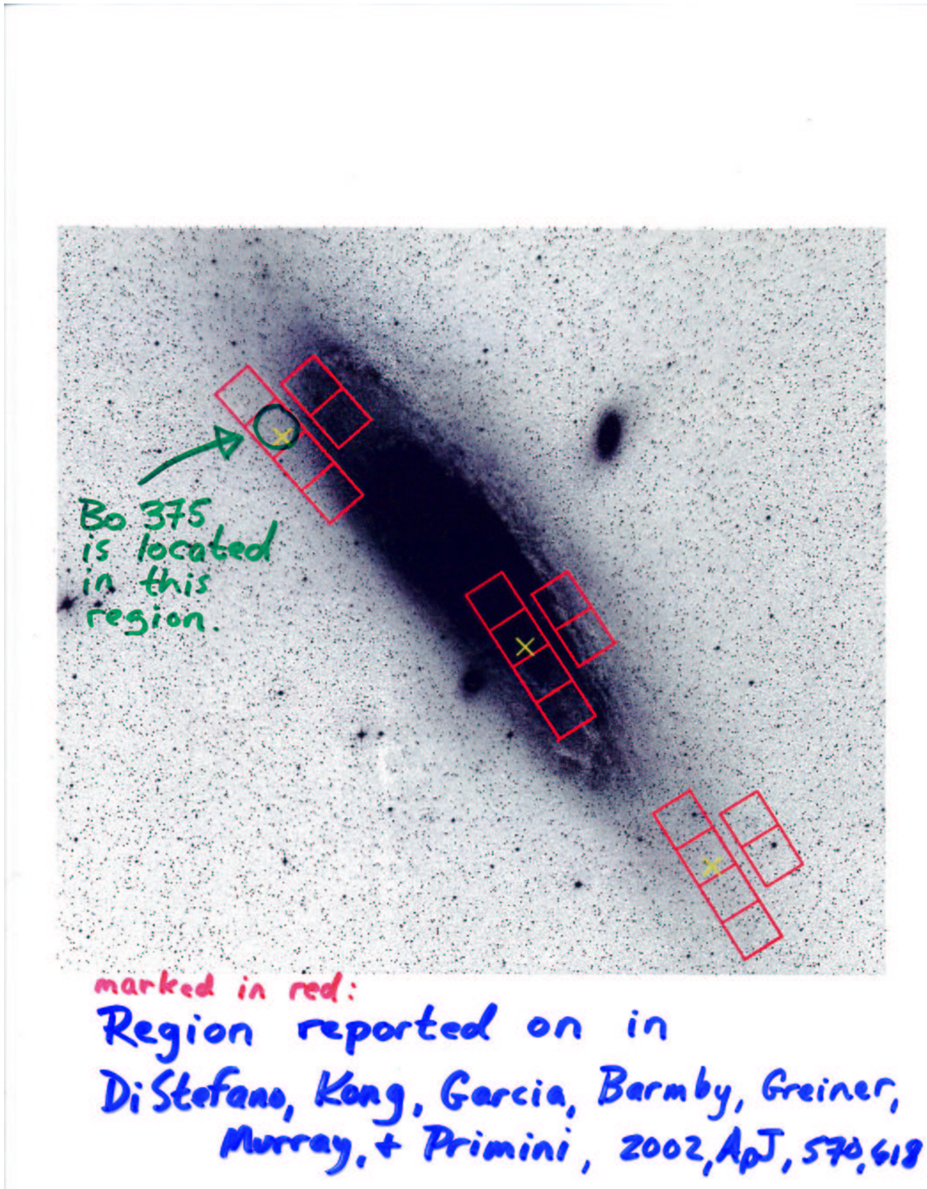
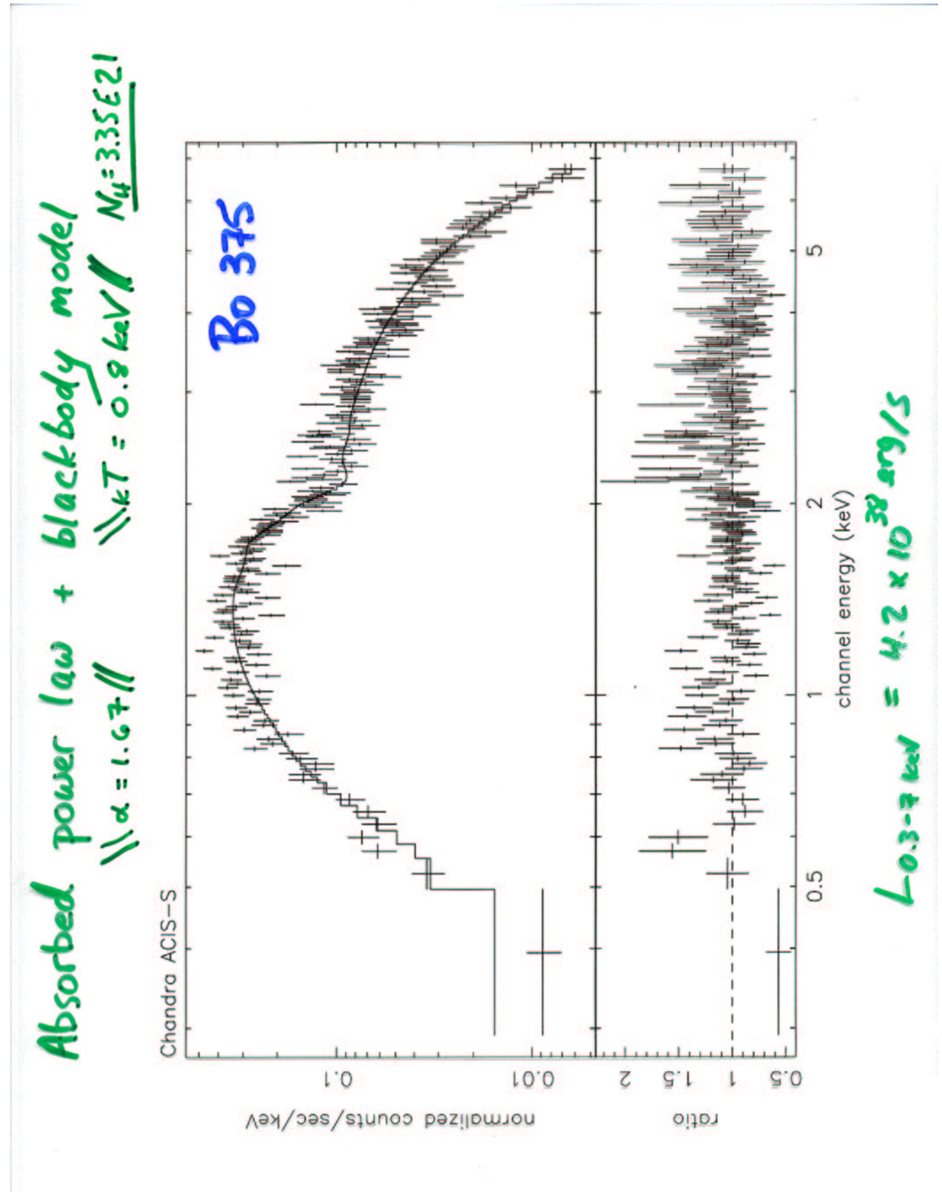


FIG. 1.— The regions observed by *Chandra* and the detected X-ray sources (green dots) overlaid on an optical Digital Sky Survey image of M31. The field-of-views of the two *XMM-Newton* observations are also shown (dashed circles). Also shown in the figures are the optical position of supernova remnants (red crosses) and OB associations (blue diamonds). The location of M32 is marked. North is up, and east is to the left.

2001: A Space Census


Bo 375 is located in this region.
marked in red:
Region reported on in
Di Stefano, Kong, Garcia, Barmby, Greiner, Murray, + Primini, 2002, ApJ, 570, 618


Absorbed power law + blackbody model
α = 1.67
kT = 0.9 keV
N_H = 3.35E21
Bo 375
L_0.3-7 keV = 4.2 x 10^38 erg/s
Chandra ACIS-S
normalized counts/sec/keV
ratio
channel energy (keV)
0.1
0.01
0.5
1
2
5
1.5

20 years of observations by

- Einstein
- ROSAT
- ASCA
- Chandra

agree . . .

$2 \times 10^{38} < L_{Bol\ 375} \lesssim 6 \times 10^{38}$ erg/s

Bol 375 is the brightest GC X-ray source in M31. (at least so far!)

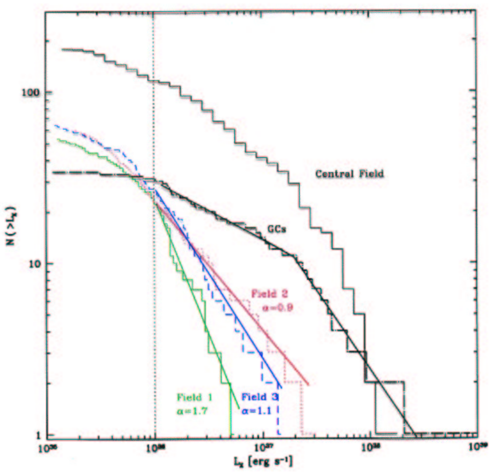
But it is not the only bright GC X-ray source in M31.

Of ~30 GC X-ray sources

~$\frac{1}{10}$ have $L > 10^{38}$ erg/s

~$\frac{1}{3}$ have $L > 10^{37}$ erg/s

In the Milky Way only 1 (of 12) GC X-ray sources considered to be bright ($L_x > 10^{35}$ erg/s) has $L_x > 10^{37}$ erg/s.



M31's GC X-ray sources stand out when compared with other M31 X-ray sources.

FIG. 2.— Cumulative luminosity funstions and their best fit model for Field 1 (green line), 2 (red line), 3 (blue line) and globular clusters (dotted-dash line). The LF of the bulge (solid black line) is shown for reference. The vertical dotted line represents the completeness limit (10^{36} erg s^{-1}) of our data.

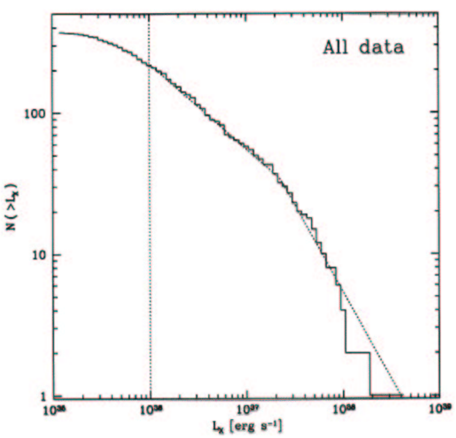
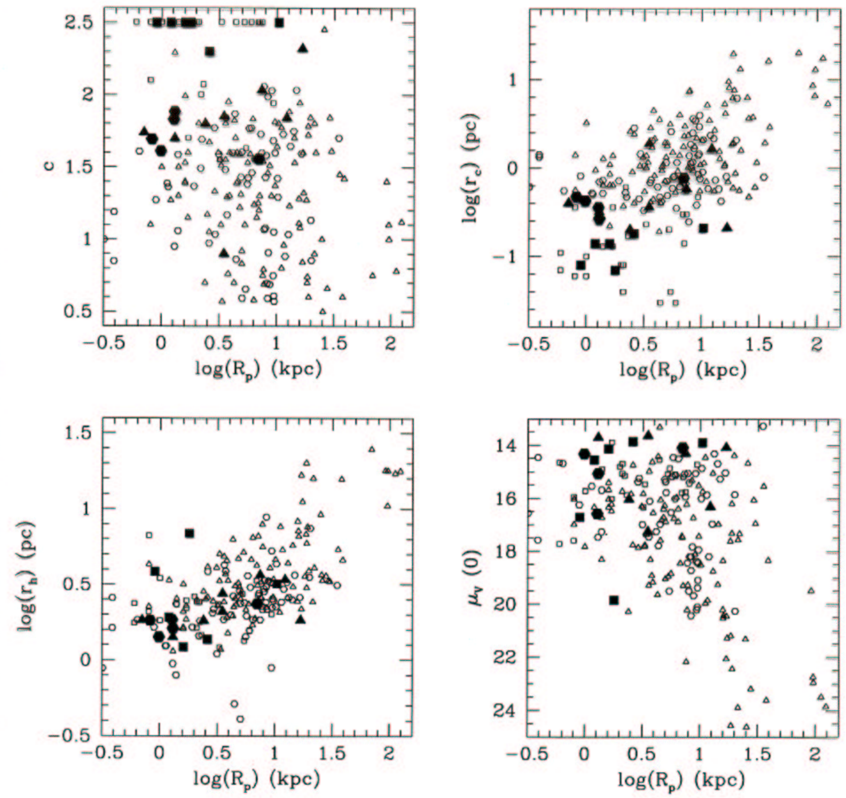
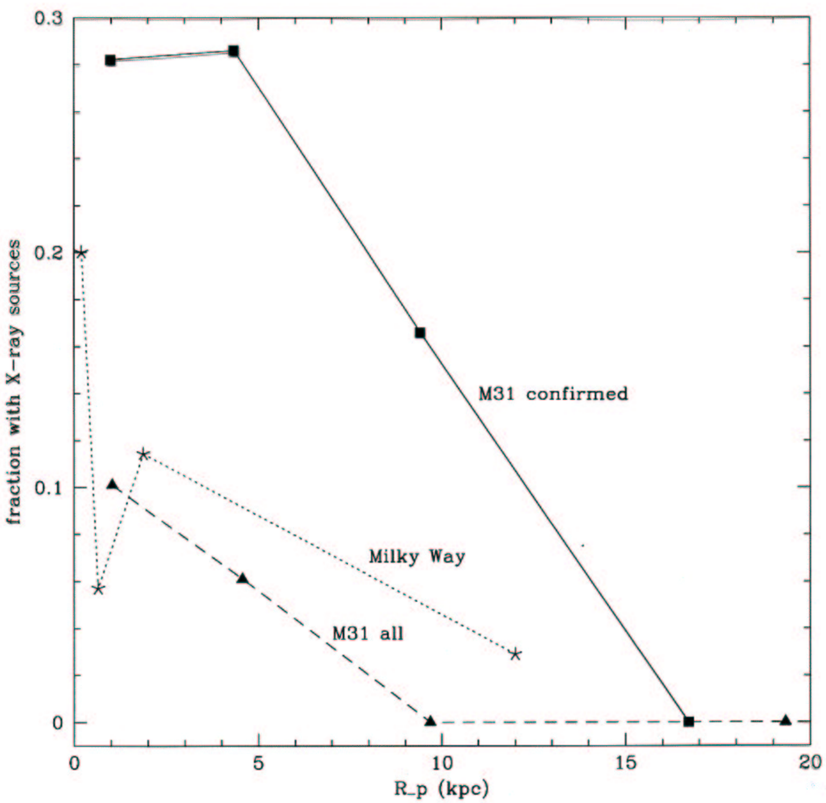


FIG. 3.— Integrated (combining the central 17′ × 17′ region, Field 1, 2 and 3) cumulative luminosity funstion of M31. The vertical dotted line represents the completeness limit (10^{36} erg s^{-1}) of our data. The dotted line show the broken power law fit for the data.



In M31, GCs with X-ray sources are on average brighter (~1.7 in flux)



In the MW and in M31,
GCs with X-ray sources are
more centrally concentrated.

Is Bo 375

- multiple ?
- a BH ?
- beamed ?
- → a thermal-time scale mass transfer binary?

evidence from
- structure of image
- variability

$$\dot{m} = \frac{\mathcal{N}}{\mathcal{D}}$$

$$\mathcal{N} = \mathcal{N}_{gr} + \mathcal{N}_{mb} + \mathcal{N}_{nuc} + \mathcal{N}_{th}$$

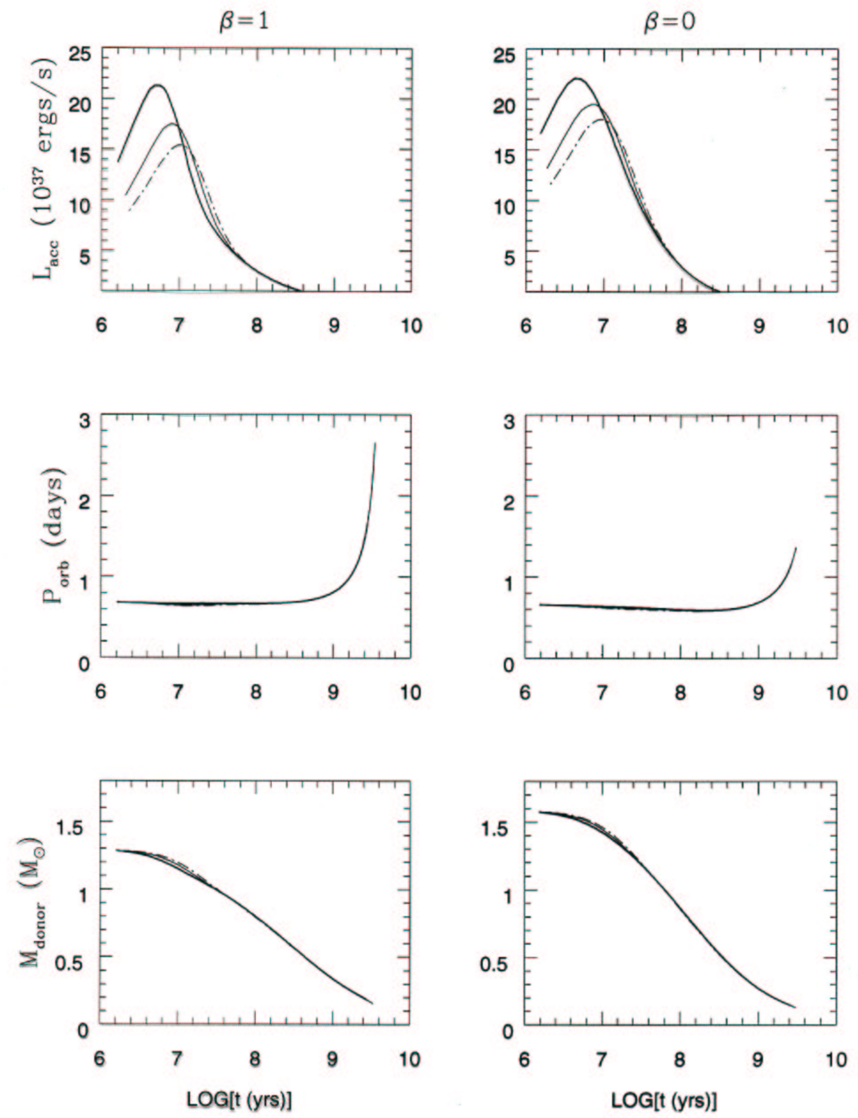
$$\frac{\mathcal{N}_{th}}{\mathcal{D}} \sim \frac{R_{eq} - R_L}{R_{eq}} \left(\frac{1}{\tau_{kh}}\right)$$

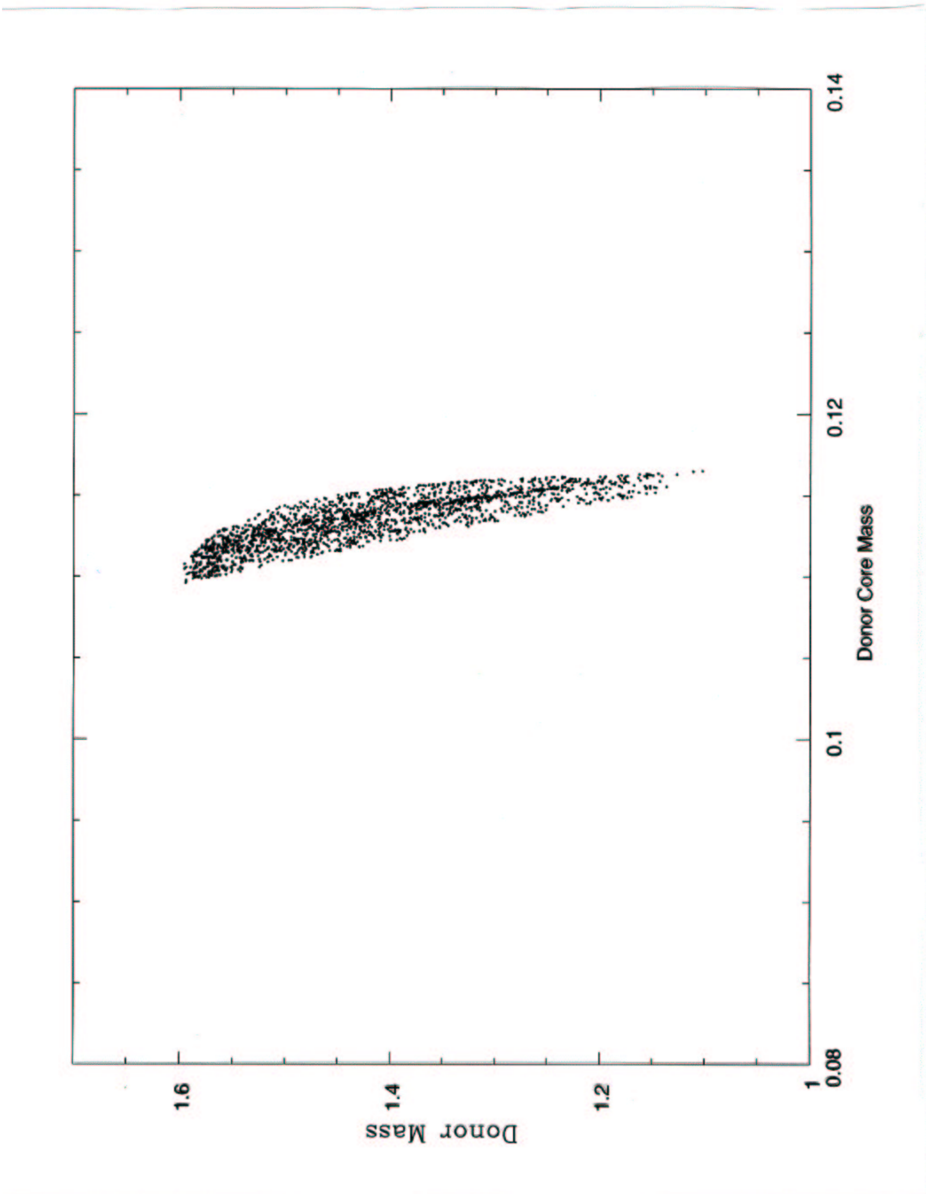
↓

Can dominate when the star "wants" to expand faster than the Roche lobe can.

↓

$P_{orb} \sim 1$ day { Donor is typically more massive + somewhat evolved..





Conjecture: Thermal time scale mass transfer occurs in present-day GCs.

Tests:

- In M31 we may measure ~1-day time scale variability in bright GC X-ray sources.
- $M_d > 0.8\ M_\odot$ ⇒ tests based on cluster properties, statistics.

Conjecture: Thermal time scale mass transfer occurs in present-day GCs.

Tests:

- In M31 we may measure ~1-day time scale variability in bright GC X-ray sources.
- $M_d > 0.8\,M_\odot$ ⇒ tests based on cluster properties, statistics.

Is the turn-off mass $> 0.8\,M_\odot$?

⇓

Bright X-ray sources in young GCs

We test these conjectures by studying an ensemble of GC systems.

... but first let's visit the halo of M31.

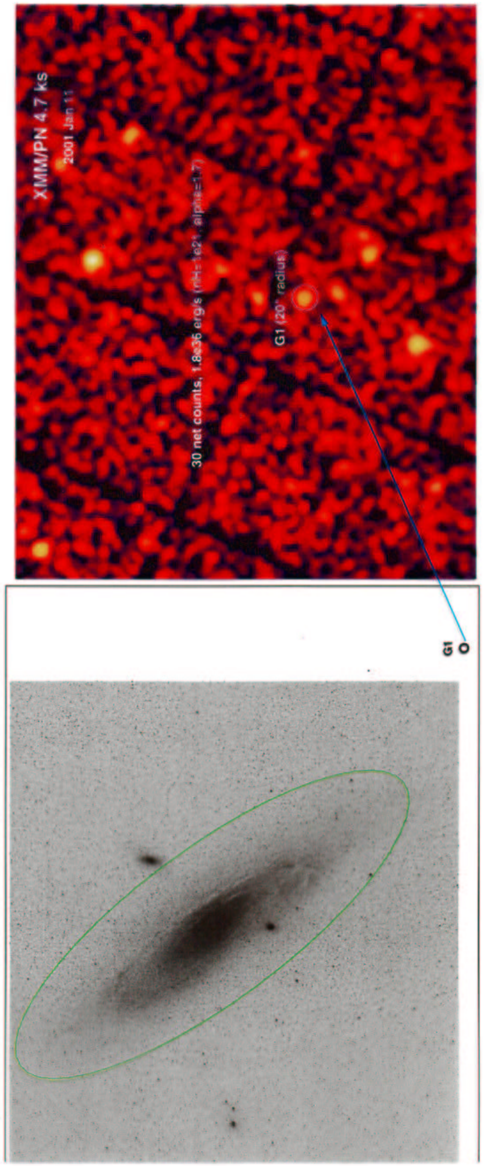
Is the system a BS-NS binary?

⇓

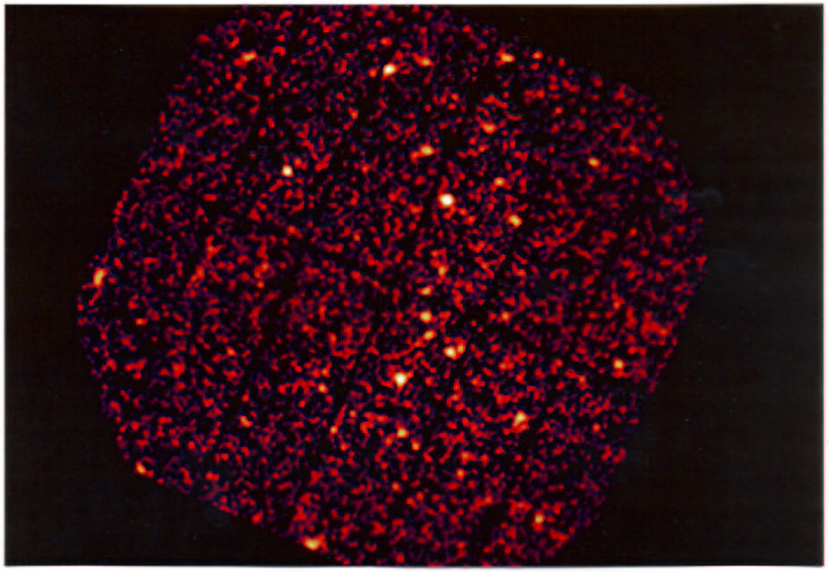
Requires a high rate of interactions.

Bright X-ray sources in massive +/or centrally-concentrated GCs.

X–ray source in G1?



Zooming out ...



linear dimensions are ~ 30′

Could some X-ray sources outside G1 have been ejected from it?

$(100\,km/s)(10^7\,yr) \gtrsim 1\,kpc \sim 4'$ at M31

We will test whether GCs send out X-ray binaries like fireworks.

... which brings us to elliptical galaxies, about which it has been conjectured that

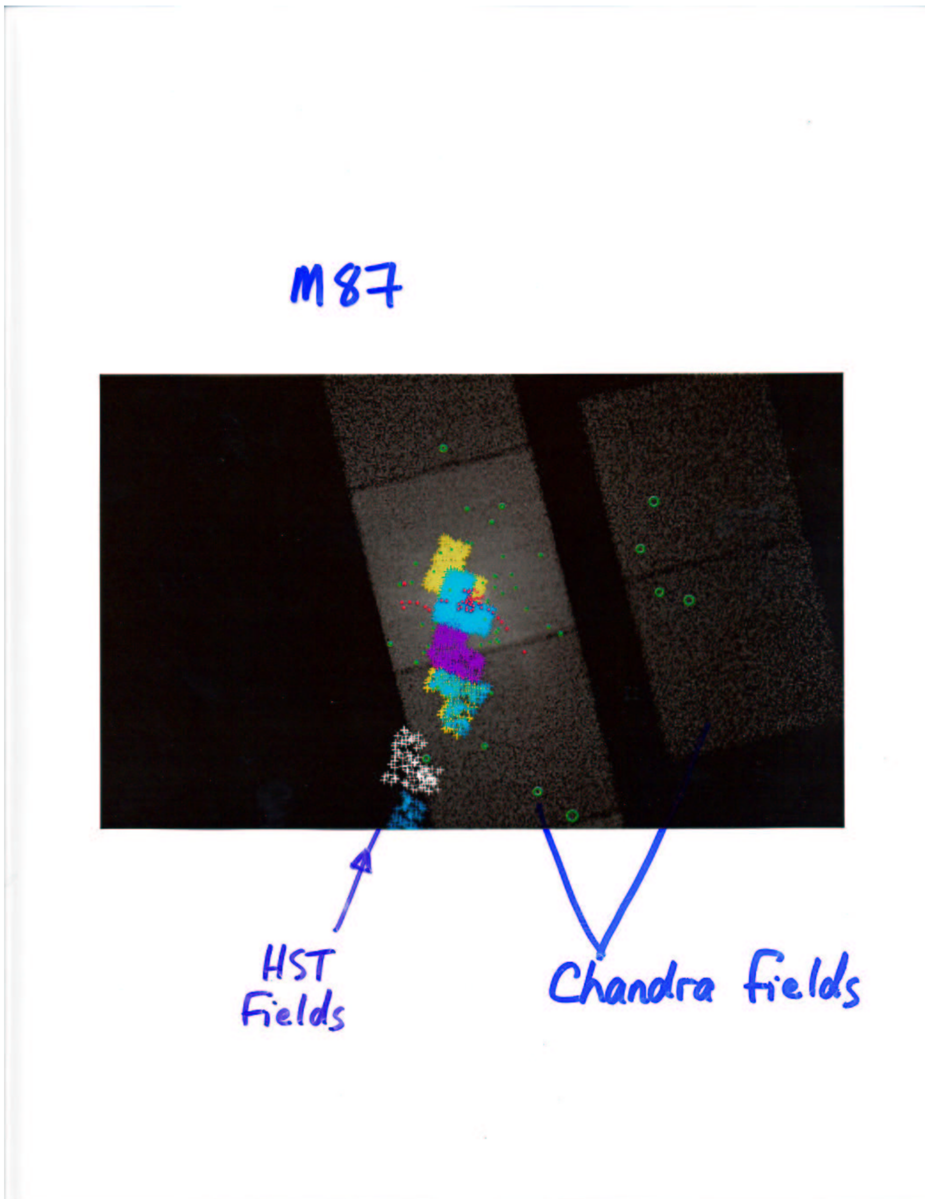
Most X-ray sources form in GCs.

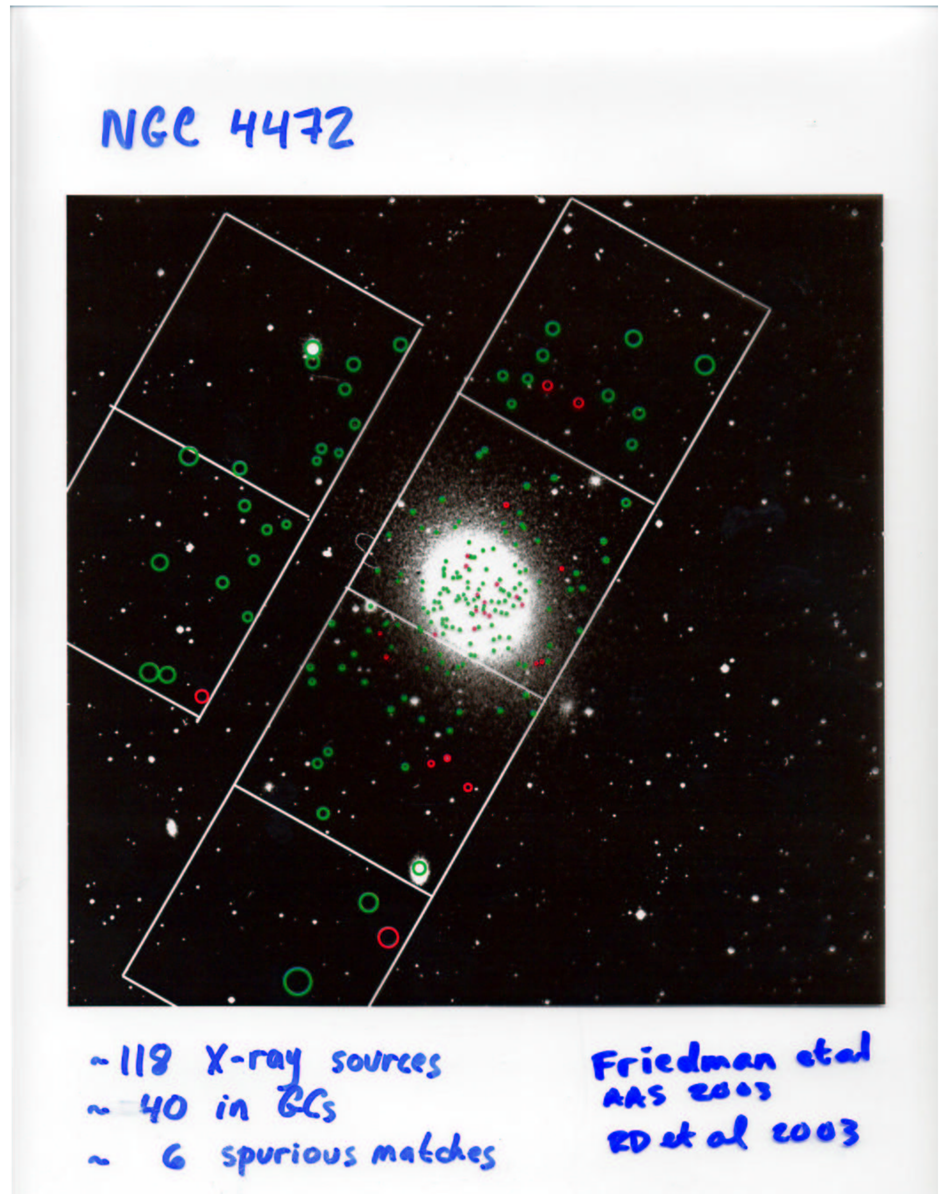
... another conjecture to test!

PLUS ... the search for SSSs!

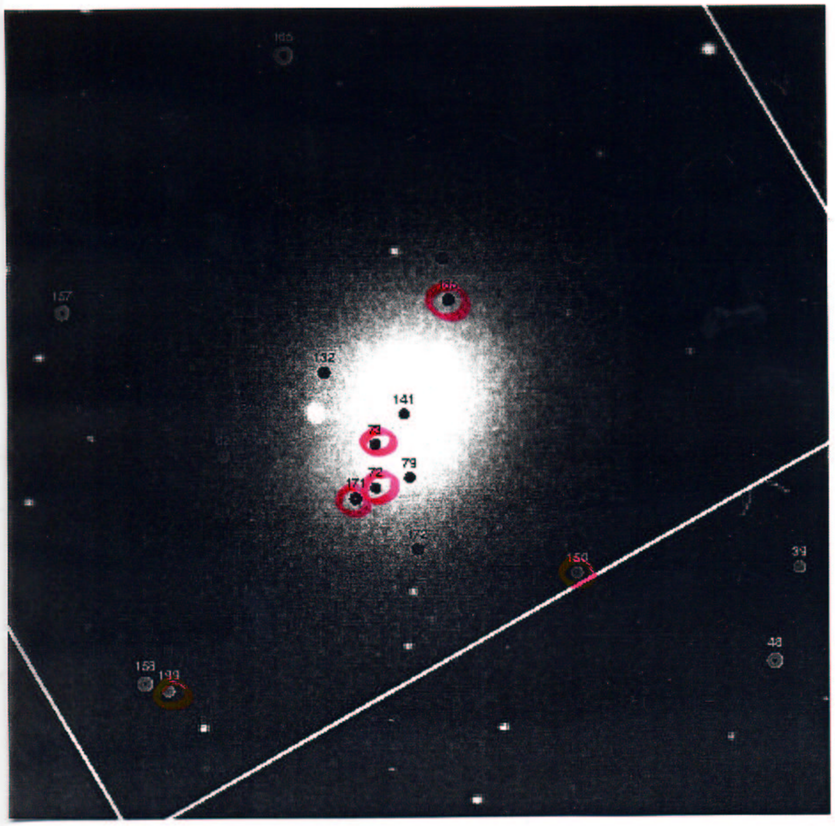
A Note of Caution about this last conjecture:

- Today's LMXBs can be descendants of an early primordial population.
- Were M31 in Virgo, ~½ of the detected X-ray sources would be in GCs.
- In some galaxies, matches can best be made near the center, where f_{GC-X} is highest.
- The specific ellipticals we are studying may have experienced multiple epochs of star formation.


M87
HST Fields
Chandra fields


NGC 4472
~118 X-ray sources
~ 40 in GCs
~ 6 spurious matches
Friedman et al
AAS 2003
RD et al 2003

6 very soft sources



are in GCs.

Source 185:

$125 eV < kT < 175 eV$

5×10^{37} erg/s

N_H: 4×10^{20} cm^{-2}

Could possibly be a nuclear-burning WD.
[in a GC?] (RD + Davies 1996)

The other 5 sources:

$200 eV < kT < 250 eV$

$\sim 10^{38}$ erg/s

$N_H < 2 \times 10^{21}$ cm^{-2}

Too hot to be a NBWD.

Thin disk

$$M = 10^3 M_\odot \left[\frac{49\,\mathrm{eV}}{kT}\right]^2 \left[\frac{L}{3\times 10^{37}\,\mathrm{erg/s}}\,\frac{0.1}{\eta}\right]^{1/2} g(n)$$

$$g(n) = \left[\frac{\frac{1}{n^3}\left(1-\frac{1}{n^{1/2}}\right)}{\frac{1}{3^3}\left(1-\frac{1}{3^{1/2}}\right)}\right]^{1/4}$$

Masses of the 5 sources:

$$50 M_\odot < M < 100 M_\odot$$

Color T vs Effective T
BH spin
Underestimate of L
→ true value of M may be higher

But is L/L_{Edd} too low?

We may have evidence of 50-100 $M_\odot$ BHs in the GCs of NGC 4472.

Whatever these sources are, they are (so far) unique.

The study of X-ray sources
in the GC systems of
other galaxies will provide
us with remarkable
opportunities!