Compact object populations with Chandra

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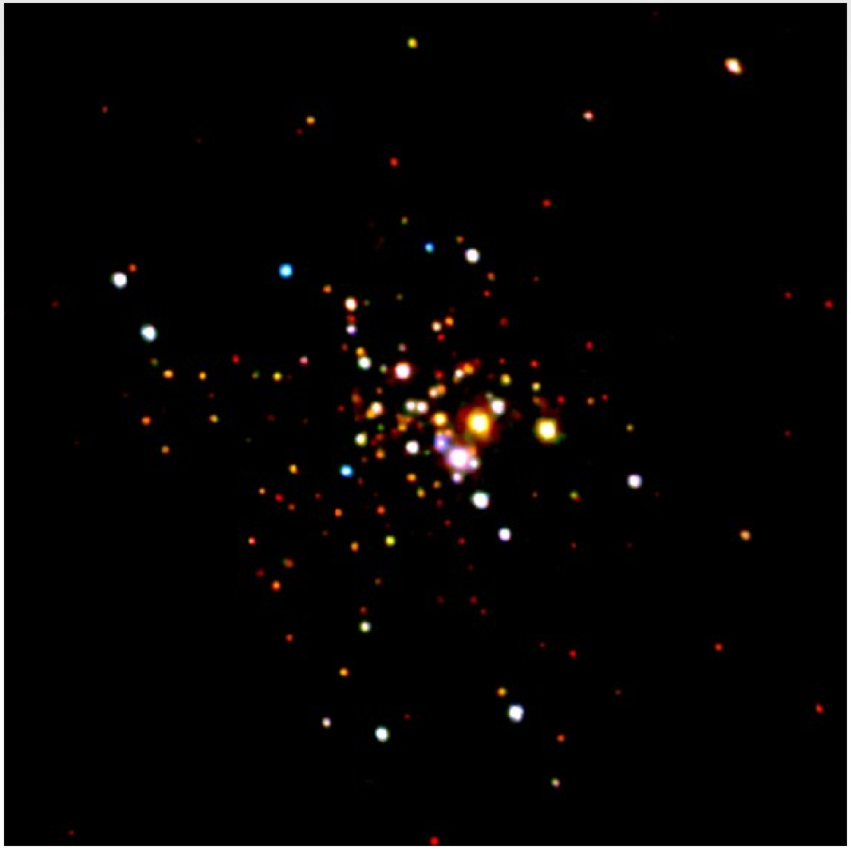
Overview

- Why compact object populations are important
- Chandra's key results
  - The Milky Way
  - Nearby galaxies
  - Galactic and extragalactic globular cluster sources, field sources, black holes, neutron stars, white dwarfs all enhanced with Chandra

Compact object populations

- Compact objects are the fossil remnants of massive stars
- Great probes of binary star evolution – obvious even at large distances
  - Short GRBs
  - Gravitational wave sources
  - The origin of millisecond pulsars
  - Type Ia supernovae, classical novae
  - “Chemical oddities” (RCB, s-stars) result from binary evolution involving WDs
- In globular clusters and a few other locales, good probes of stellar dynamics
- Are there new things out there we weren't (aren't) sure really exist (e.g. IMBHs, globular cluster black holes)?
- I will give a broad, but shallow review of Chandra's biggest achievements in these areas, and try to highlight questions which remain open, representative examples of different science areas

Galactic globular clusters

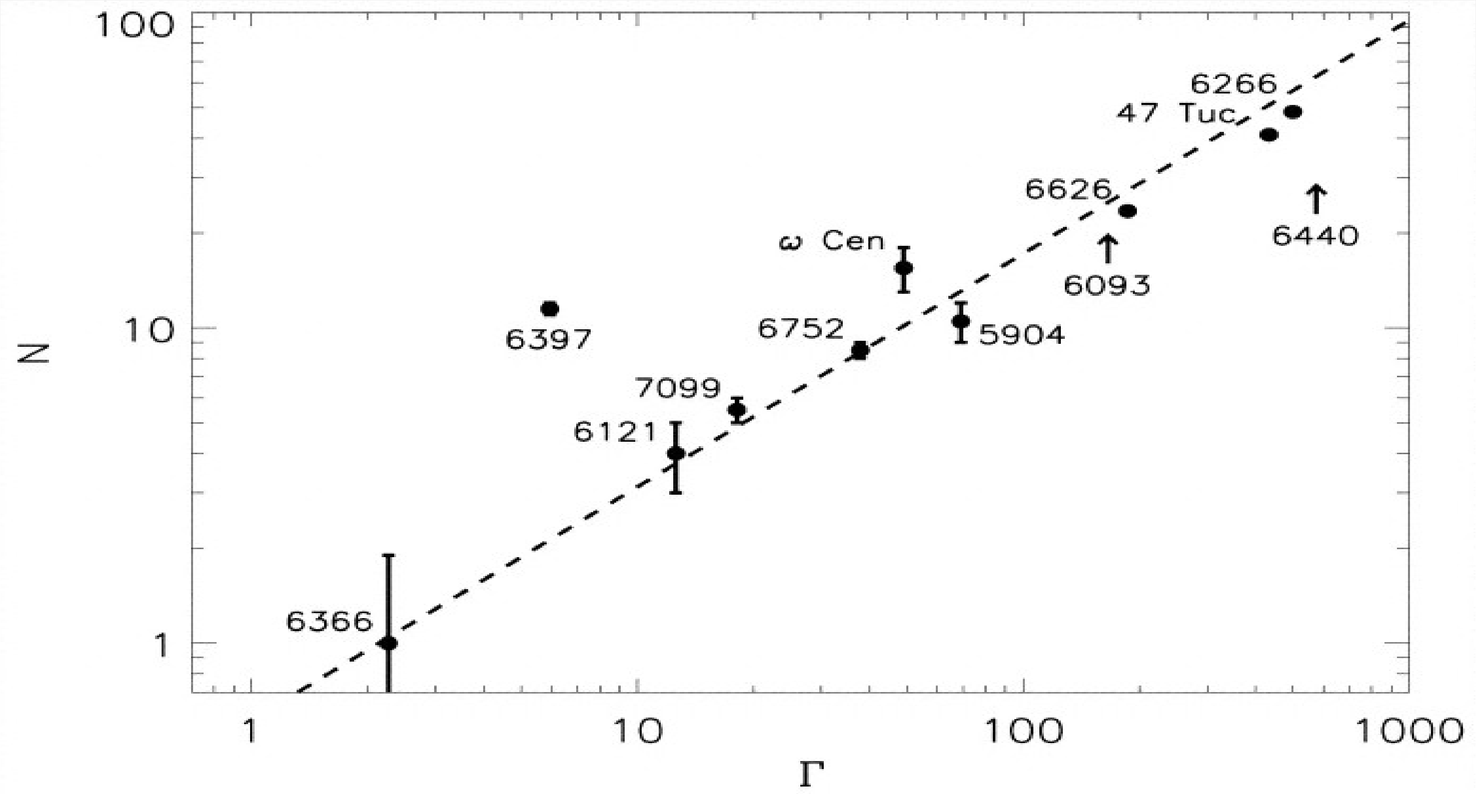


47 Tuc, from Heinke et al. 2005

- Resolved most of the emission from the deepest observed clusters
- qLMXBs, CV populations, millisecond pulsars all found
- Known distances help for some purposes

Galactic globular clusters

Established correlation between collision rate and X-ray source formation – this luminosity range is dominated by CVs

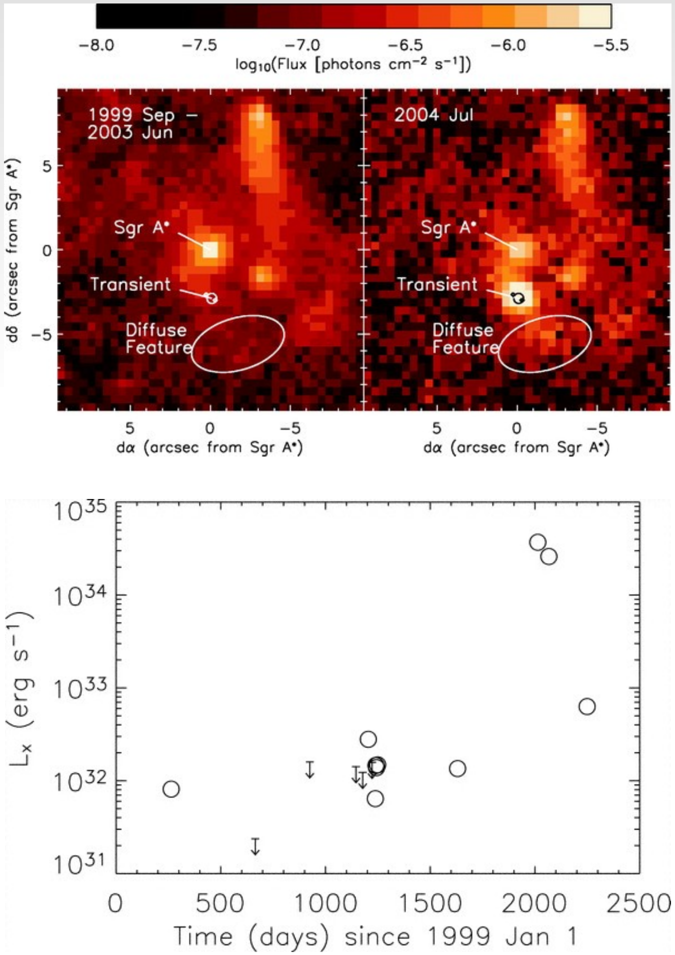


Pooley et al. 2003

Galactic globulars: open questions

- Are there any black holes (intermediate or stellar mass)?
    - X-ray properties similar to quiescent dwarf novae
- Is CV evolution similar in globular clusters to the field?
    - Existing Chandra data are still not deep enough to get period gap CV sources in most clusters
- Are the CV's mostly magnetic? Oft-stated, poorly supported claim.
    - This might change further out in the clusters where optical follow-up is often poor – one possible reason they'd be magnetic would be that they might be more massive, and mass segregation may change the populations.

Very faint X-ray transients



Muno et al. 2005

L_peak of 10^34-35 ergs/sec

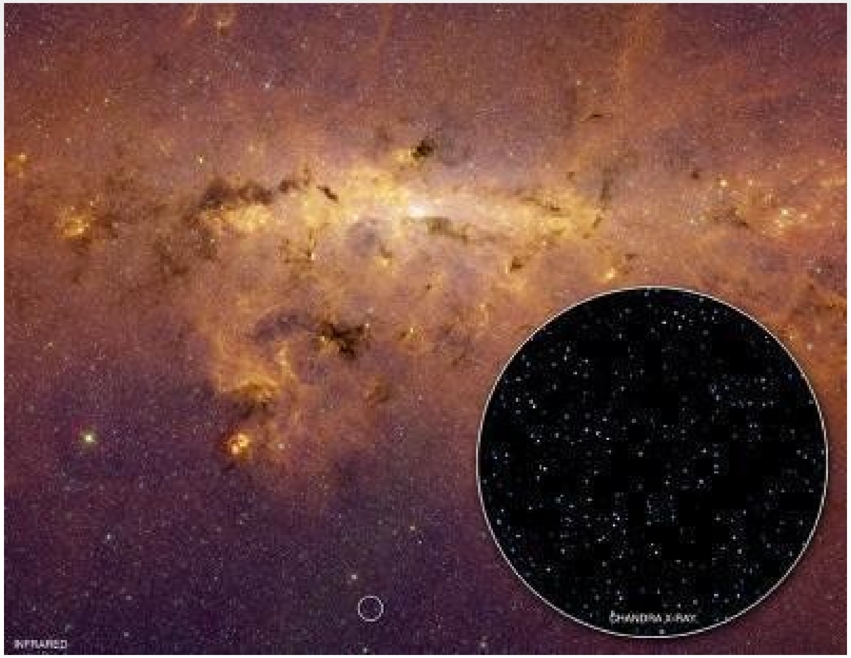
Duty cycle of <10%

Implies mean mdot <10^-13 solar masses/yr or less – problem for normal binary evolution (King & Wijnands 2006)

VFXT questions and speculations

- King & Wijnands showed that most normal solutions don't make sense – the mass transfer rates are so slow that systems couldn't get to this stage in a Hubble time
- A possible solution may be that these are period gap X-ray binaries (TJM, Ale Patruno “in prep”)
    - Accretion would be from winds of M dwarfs

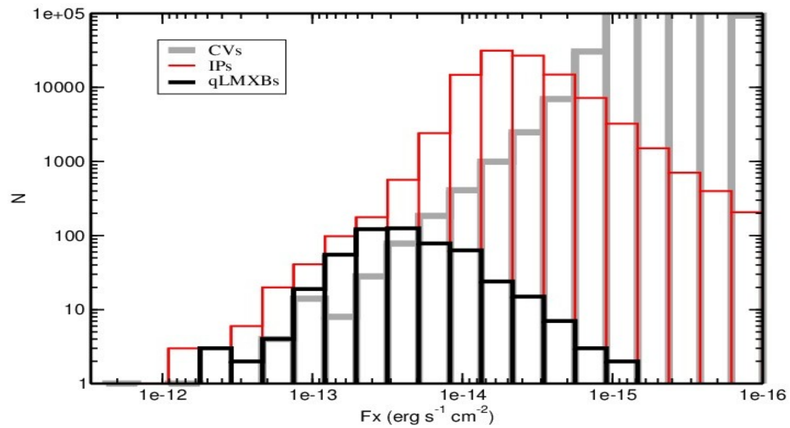
Galactic surveys

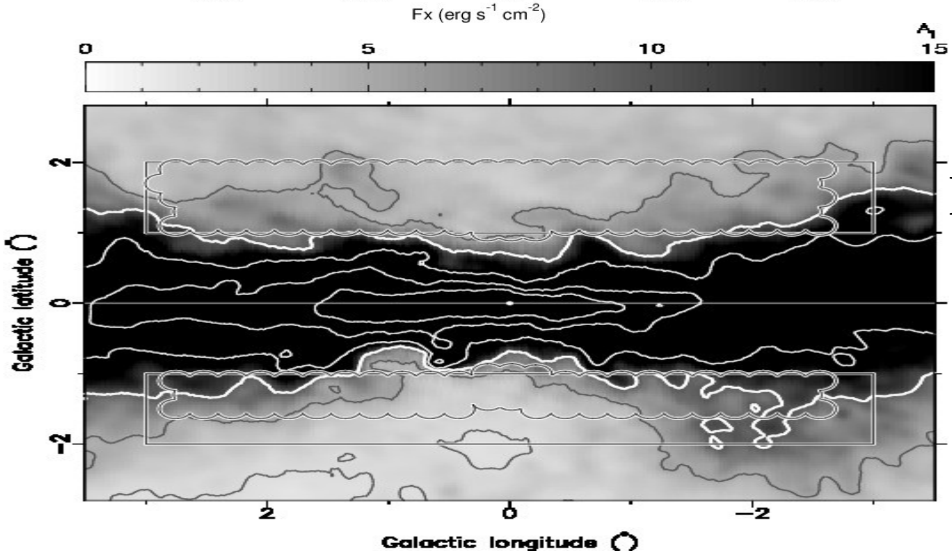


From Revnivtsev et al. 2009

- Resolved the Galactic ridge emission
- Previously suggested to be diffuse hot gas in Galactic Plane
- Shown to be predominantly point sources, probably CV and AB

The Galactic Bulge Survey





2 ksec depth is actually optimal

Need Chandra's angular resolution, not its sensitivty to chase quiescent X-ray binaries

Deeper just gets CV, AB, AGN populations, or sources too far away to follow up optically

Must combine with deep enough optical and infrared coverage – dedicated Blanco surveys in optical, and VVV in IR

Jonker et al. 2011

Galactic surveys: open questions

- Can we find eclipsing black holes?
- Can we find some wide separation black hole systems, since
    - “Binaries are the best single stars” – Selma De Mink
- Can we find neutron stars that can be used for excellent constraints on equation of state?
- Can we get a sample with a well-enough understood star formation history to provide real tests on binary evolution

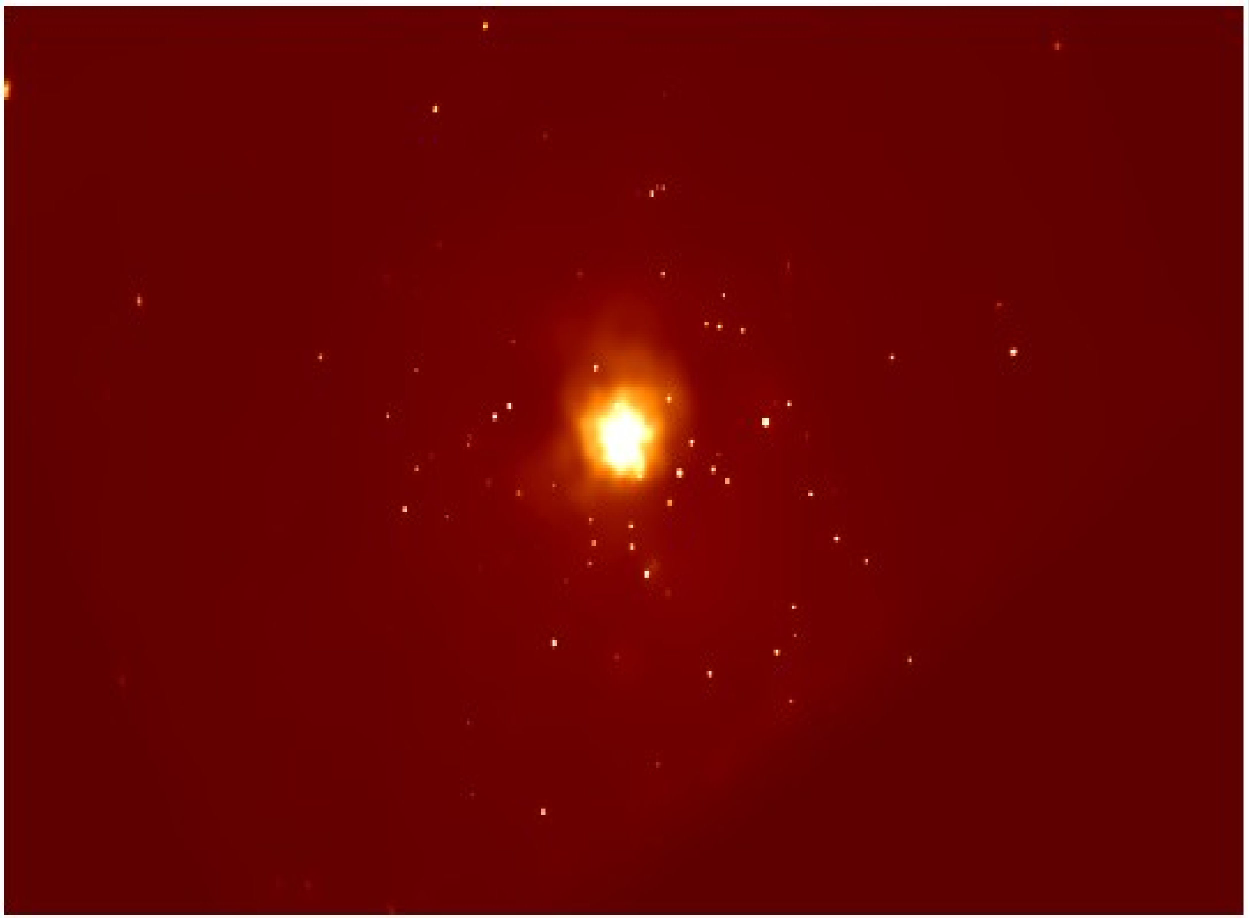
I think many of these goals can be answered with existing X-ray data, but with much effort and telescope time needed to be invested in follow-up.

Extragalactic work

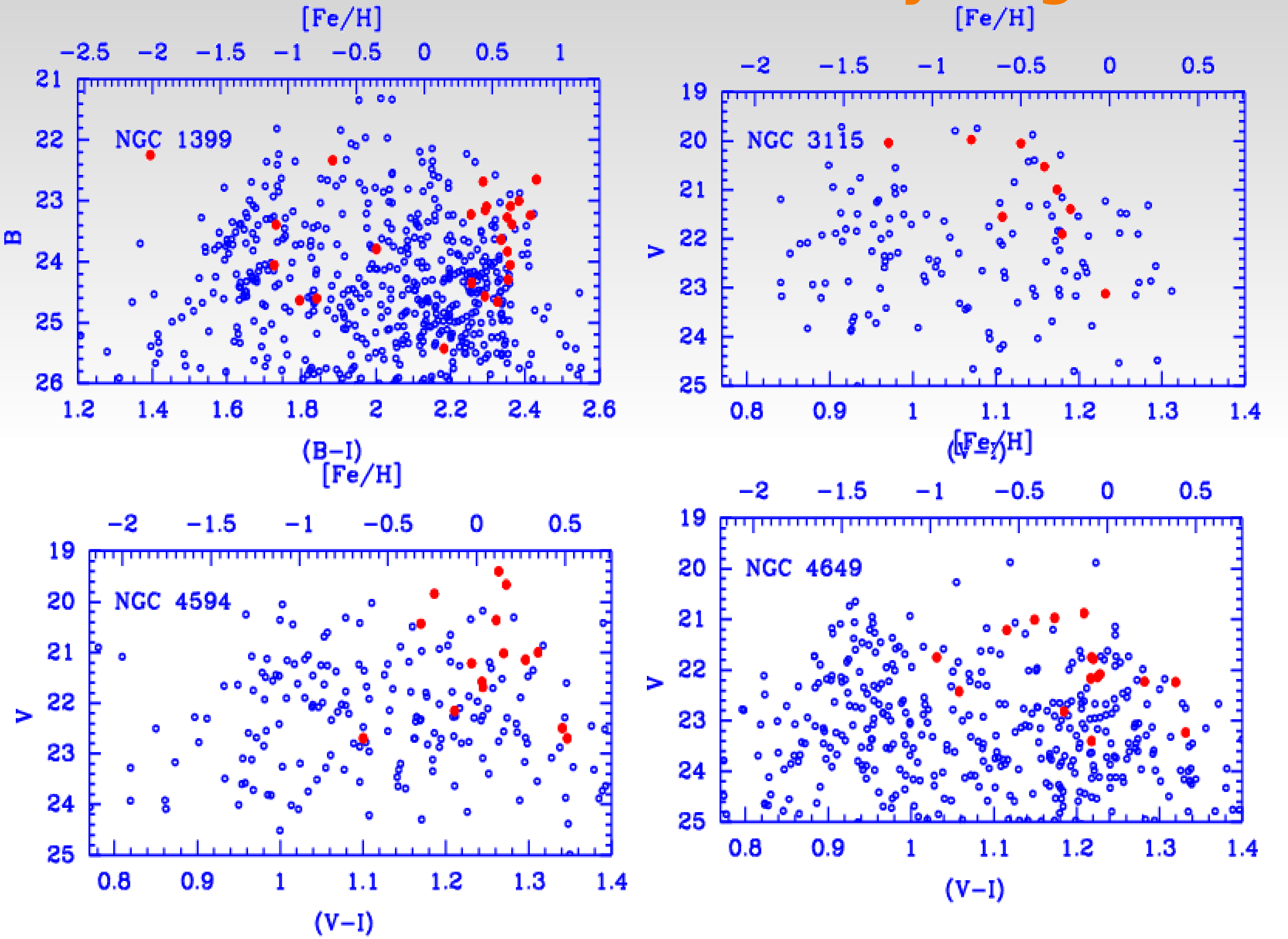
Motivation must to be do things that cannot be done in the Galaxy

- Compare X-ray binary properties with star formation histories (i.e. ages, metallicities, etc.)
- Get substantial globular cluster populations
- Look for the rarest objects, which might not be present right now in the Milky Way

Chandra image of NGC 4472



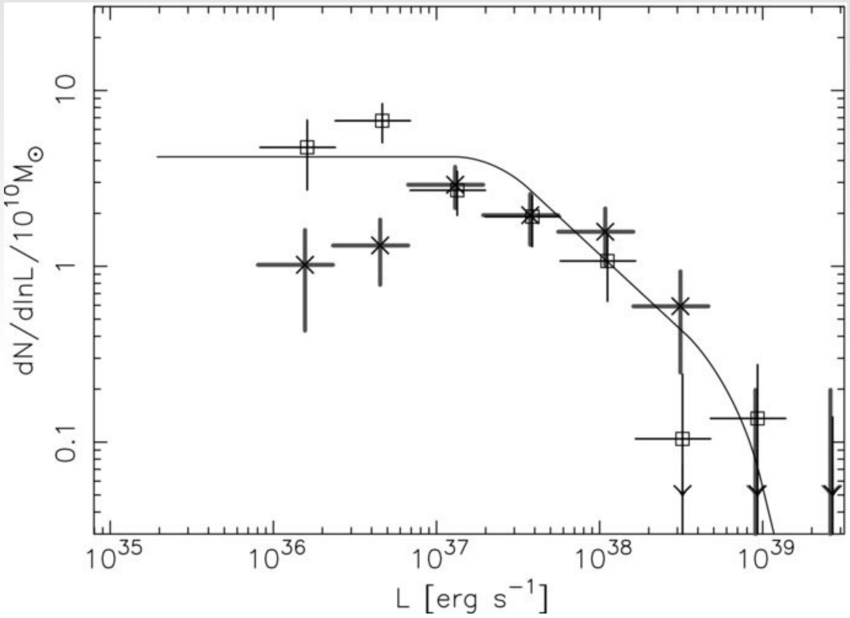
What makes a cluster X-ray bright



From Kundu et al. 2007

Field/cluster luminosity function differences

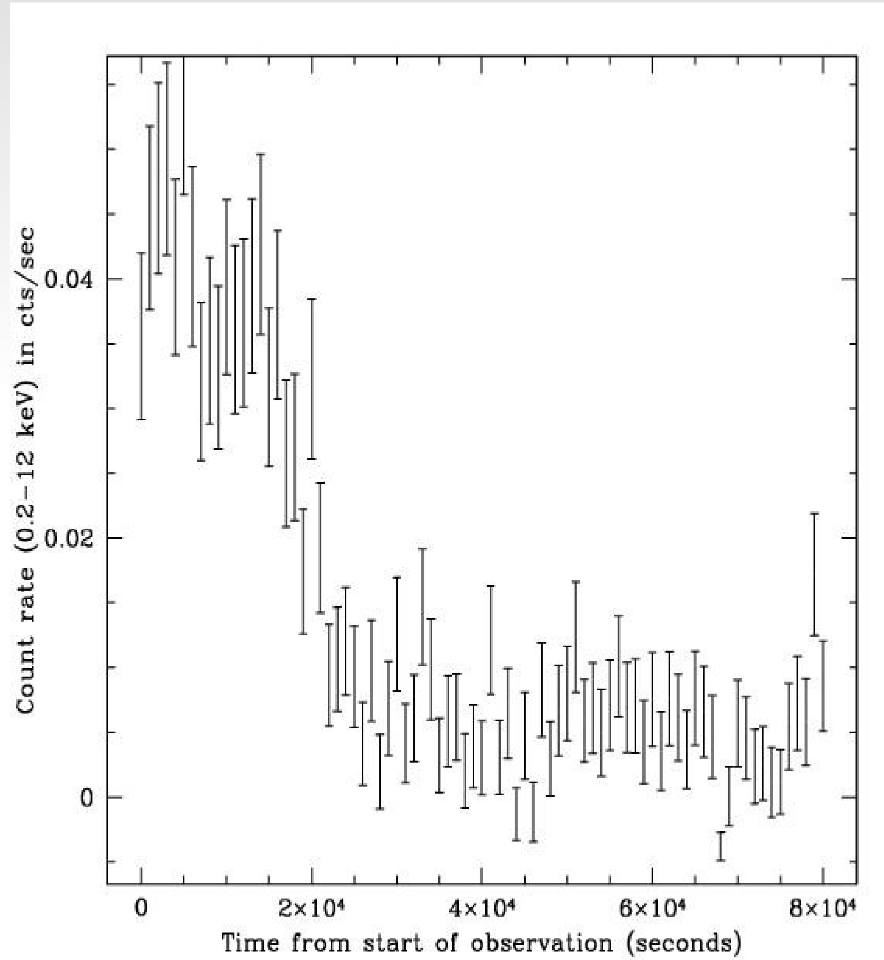
- Early work showed similar luminosity functions for cluster and field sources
- Marked divergence below about 10^{37} ergs/sec – the depth of typical early Chandra observations



From Voss et al. 2009

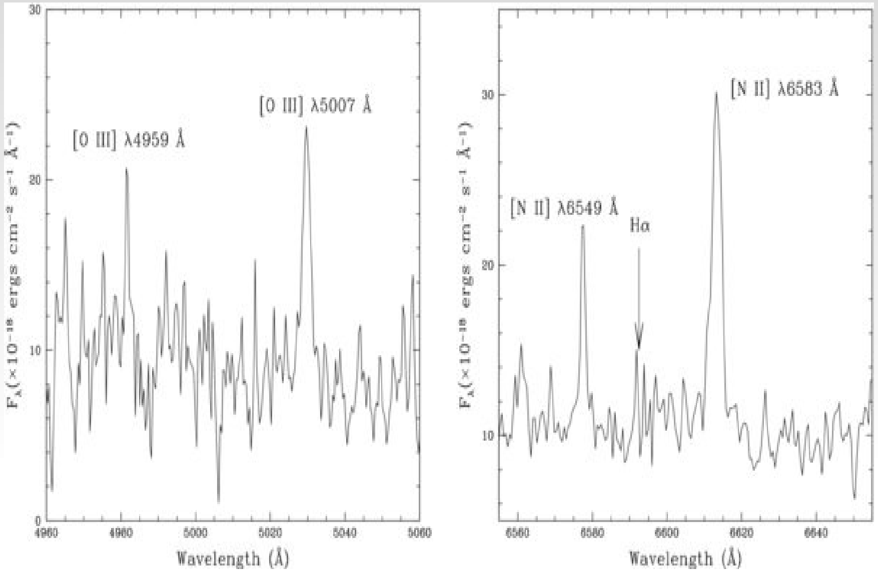
Black holes in GCs

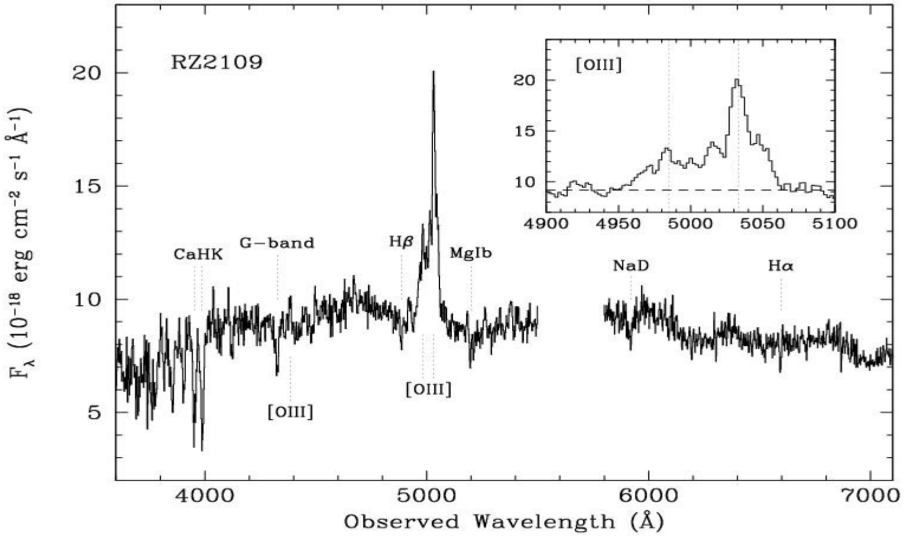
- No clear examples in MW
- Spitzer instability says BH's should be ejected
- Hard to tell from multiple neutron stars
- Variability sorts it out
- Several have been seen since the first NGC 4472 source



From Maccarone et al. 2007

Emission line sources





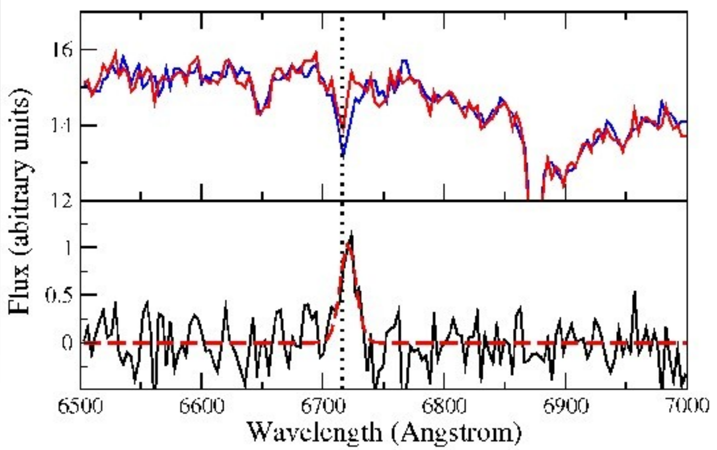
- NGC 1399 source (Irwin et al. 2010)
  - Narrow [OIII],[NII] lines
  - [NII] stronger than [OIII]
  - RCB star wind photoionized by X-rays (Maccarone & Warner 2011)
- NGC 4472 source
  - Very broad lines
  - [OIII] strong
  - White dwarf donor, super-Eddington accretion

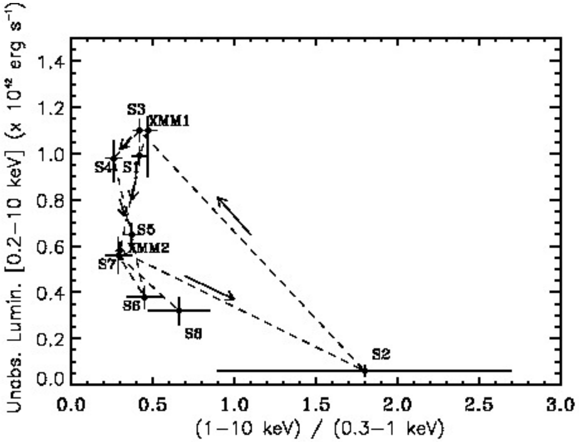
Intermediate mass black holes?

- Missing links between AGN and stellar mass black holes
- Mergers in LISA frequency range
- Maybe Pop III remnants?
- Formed in star clusters?
- Dwarf galaxy nuclei?

HLX-1

- About 10^42 ergs/sec (Farrell et al. 2009)
- Makes spectral state transitions (Godet et al 2009)
- Optical counterpart may be consistent with dwarf galaxy or cluster host, but not yet clear





Open questions for nearby galaxies

- Lower mass galaxies' halos
    - No real data on the intermediate mass elliptical galaxies, despite high profile claims of unusual IMFs in massive ellipticals
    - Does the metallicity affect field star X-ray binary properties?
- Collisional formation outside clusters?
- Deviations from linear N-Gamma relation?
- What effect does age of star cluster have on LMXB hosting probability?
- How common are IMBHs, and are they preferentially in clusters, dwarf galaxies, or elsewhere?

Conclusions

- Chandra has revolutionized studies of compact binary populations
- Even in some cases where the initial discoveries have been made with XMM (e.g. HLX-1, the NGC 4472 black hole), Chandra positioning has been required to make real statements about the sources
- There is another dozen years' worth of stuff to do!