Extragalactic globular clusters in the Chandra era

Tom Maccarone (University of Southampton)

Collaborators: Arunav Kundu (MSU)

Steve Zepf (MSU)

Mark Peacock (Southampton)

Kathy Rhode (Indiana);John Salzer (Indiana, Wesleyan)

Chris Waters (MSU);Dan Stern (JPL)

Christian Knigge (Southampton); Dave Zurek (AMNH)

Michiel Smits (Alkmaar)

Introduction

- Globular clusters produce large numbers of X-ray sources, millisecond pulsars, and other forms of exotic stars through stellar interactions
- Understanding these systems is important in its own right, plus for understanding binary evolution processes which can lead to e.g. Type Ia supernovae, gravitational wave sources
- Fundamental to cluster evolution, as a single close binary with massive components can dominate the total binding energy of a cluster

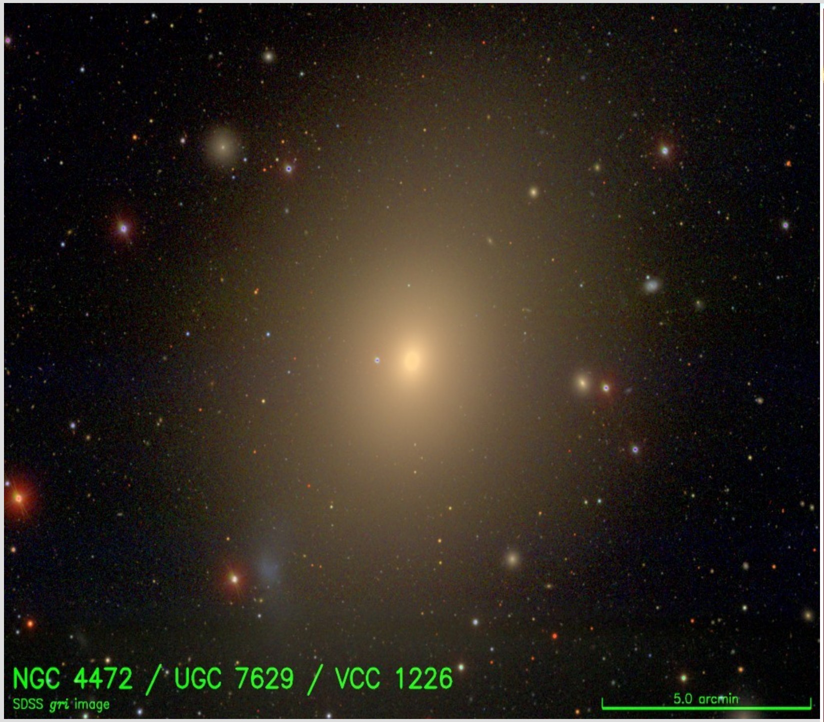
Key questions for globular cluster X-ray source studies

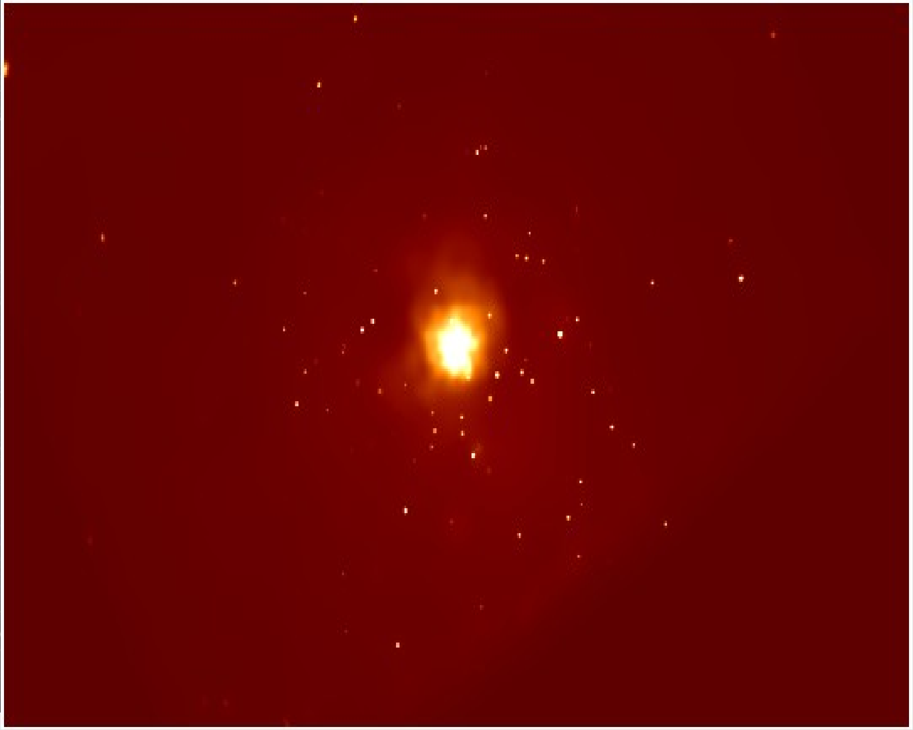
- Galactic
  - What are the X-ray properties of millisecond pulsars and quiescent neutron stars?
  - How common are globular cluster CVs?
  - What are the orbital periods of GC X-ray sources?
  - Is there dynamical evidence for intermediate mass black holes in globular clusters? *(Although G1 in M31 probably the best case right now)*
- Extragalactic
  - What properties of a cluster make it most likely to contain an X-ray binary?
    - More clusters in other galaxies, plus more diverse properties
  - Do stellar mass black holes exist in globular clusters, or are they all ejected dynamically? *(Although the Milky Way may contain quiescent black hole XRBs in clusters)*

Elliptical galaxies

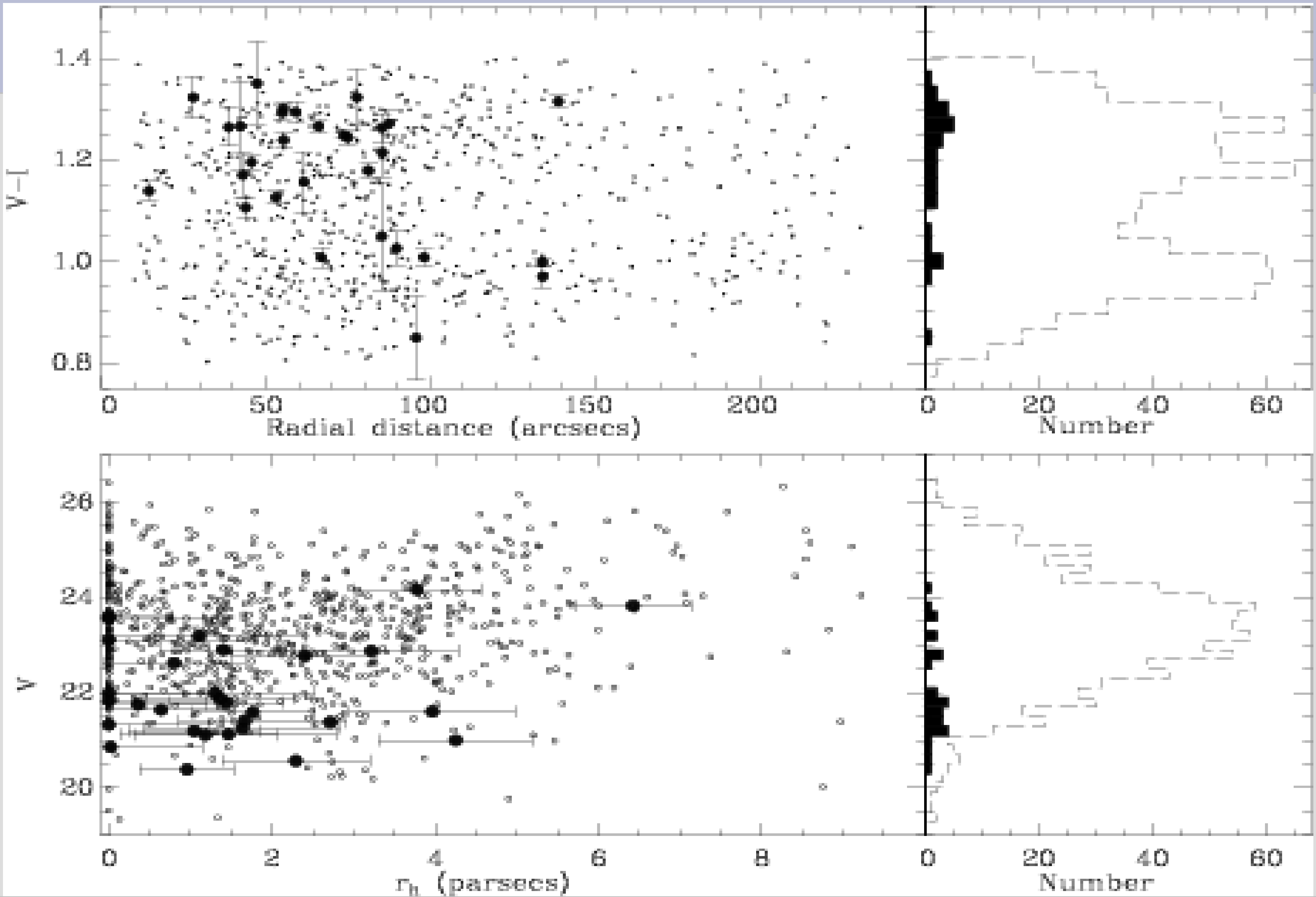
- Smooth light profile
  - Easy to see the clusters
- Delicate balance between getting a bright galaxy with a lot of stars and GCs and getting too much diffuse emission
- Large numbers of clusters
  - Up to 10 times as much of stellar mass is in clusters
- Larger populations of metal rich clusters than Milky Way, plus maybe more young clusters
- Spirals (esp. M31) still have some value

NGC 4472

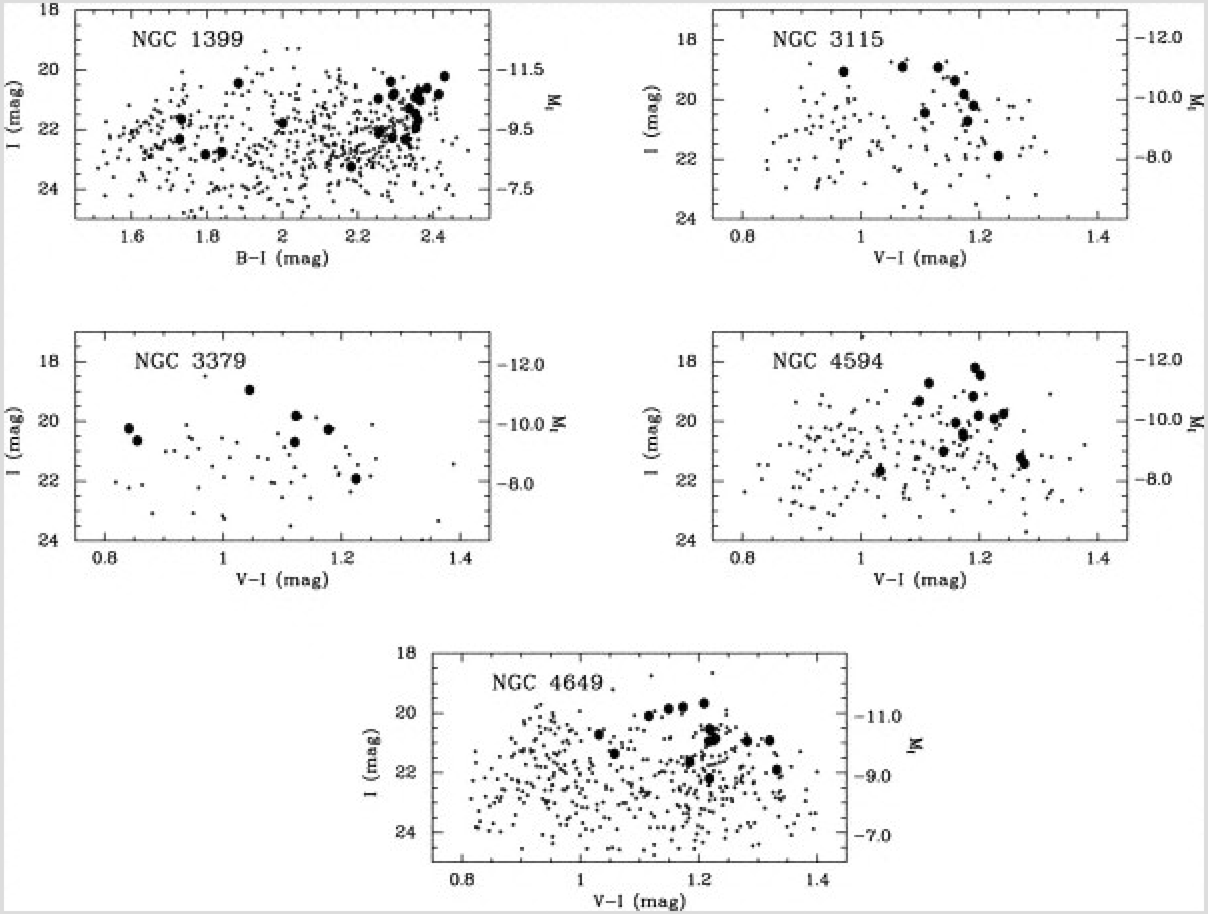




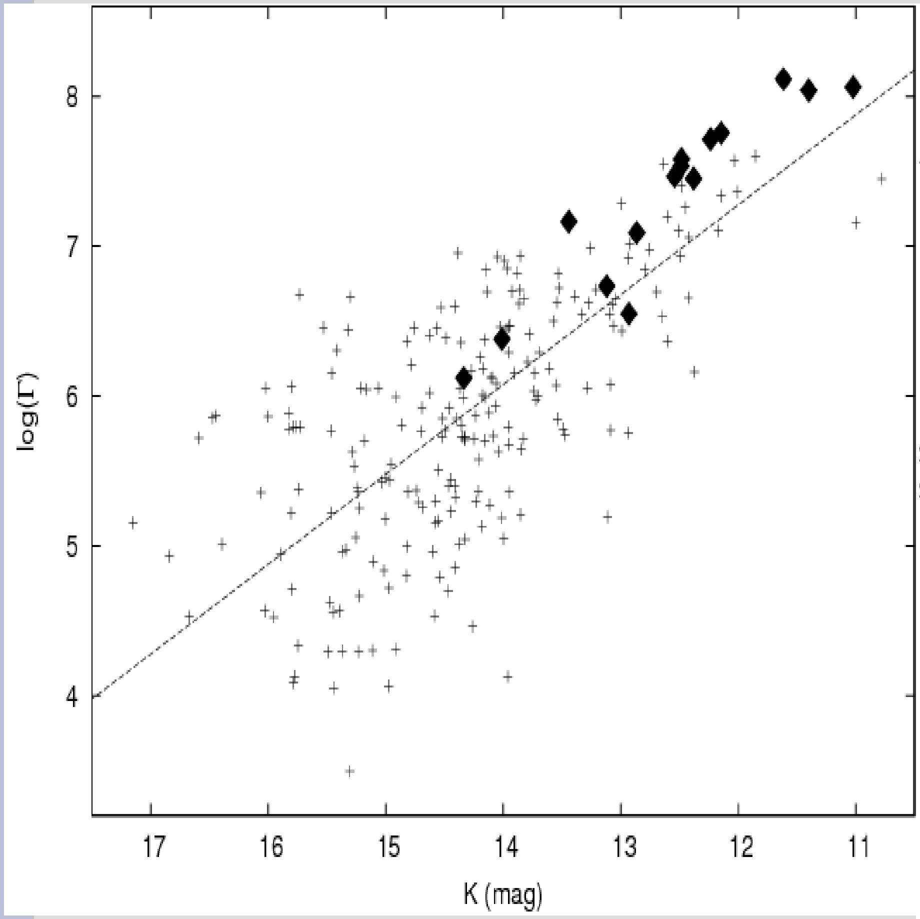
Metallicity and luminosity matter!

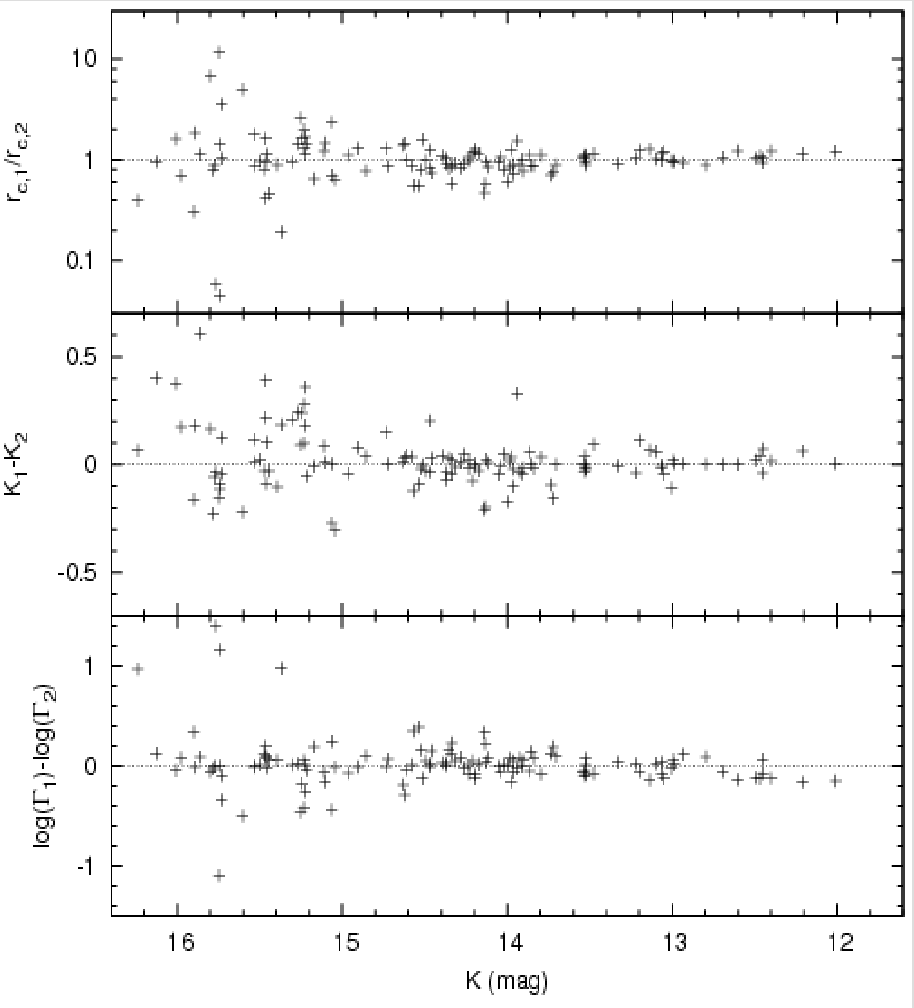


Seen in all galaxies...



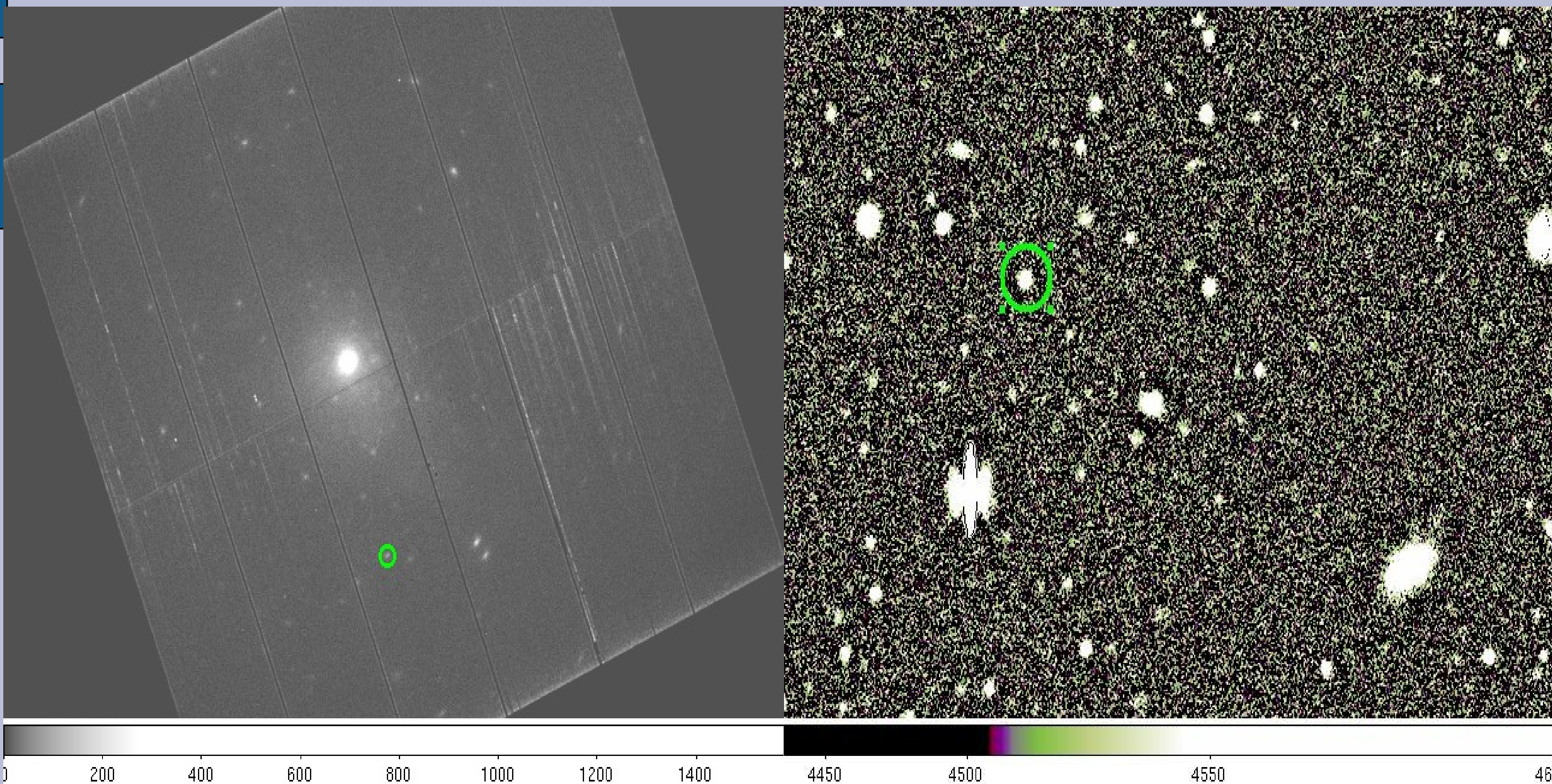
M31: Best place to look at collision rates



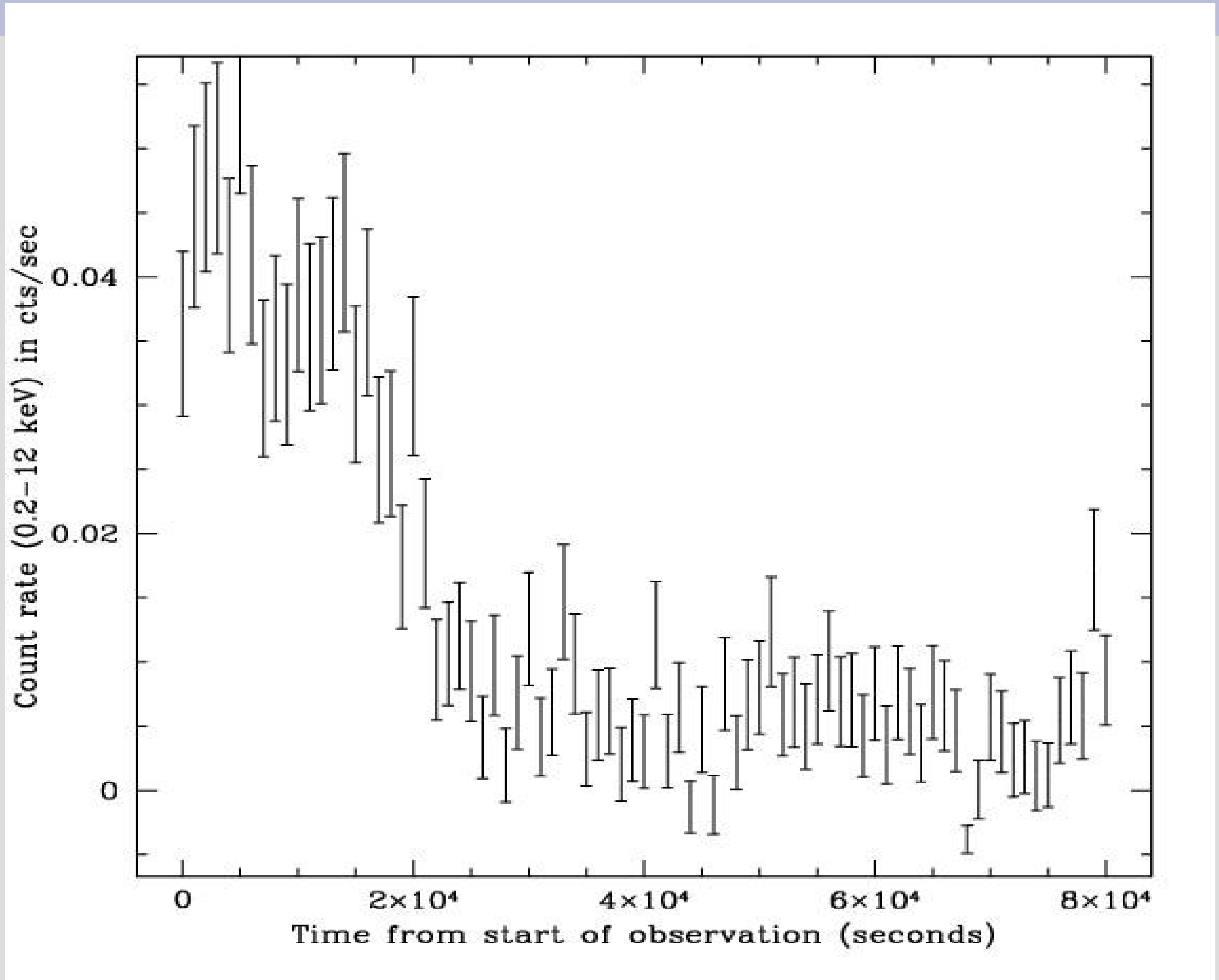


From Peacock et al. (2009)

Back to NGC 4472



Highly variable GC ULX

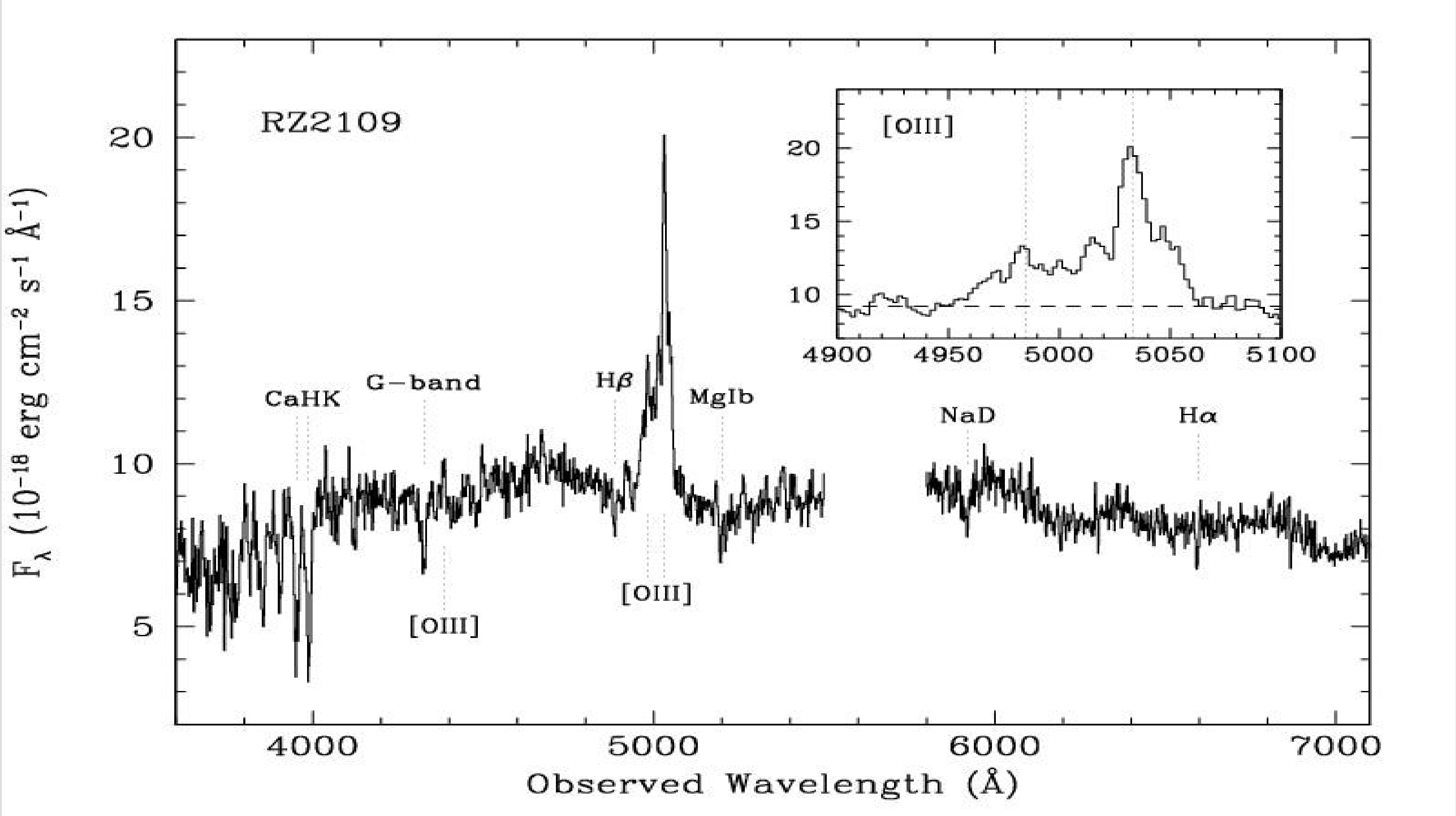


What is this object?

- Only because there existed archival Chandra data could we safely associate this source with its host cluster
- Variability indicates that it is clearly a single object, and at this luminosity, it must be a black hole
- X-ray spectrum dominated by a kT=0.22 keV blackbody component
- X-ray properties alone consistent with either ~400 solar mass BH, or ~10 solar mass black hole in a mildly super-Eddington state

Maccarone, Kundu, Zepf & Rhode 2007

Keck spectrum



Note: no species but [O III]

Super-eddington accretion

- Accretion at local Eddington rate in annuli
  - gives R_in α mdot R_SCH
  - L α (ln mdot) L_EDD
  - strong disk winds (e.g. King & Pounds 03)
- Blows out a bubble in the intracluster medium
- Self-obscurration by the disk wind leads to change in foreground absorption
  - Similar effects seen in high luminosity observations of V404 Cyg by Oosterbroek et al. (1997)

Zepf et al. 2007, Shih et al. 2007

Are there more?

- Many of the other bright extragalactic sources may be black holes
  - Some unpublished results of variability
  - Also, another [O III] source – Irwin et al. (2009)
- Within our Galaxy?
  - Our object is probably a WD-BH system
  - Evolve quickly to longer periods, with very low mdot
  - quiescent black hole XRBs are very hard to tell apart from CVs
  - Radio emission would be the clincher, but L_opt/L_X high for orbital period is suggestive
  - 47 Tuc W21?
- More recent theory work suggests BH retention is not as hard as thought before (Mackey et al. 2007; Moody & Sigurdsson 2008)

Conclusions

- Globular clusters have a wide range of exotic stellar objects
- These include X-ray sources, and even X-ray sources *with black holes as the accretors*
- Properties of cluster which predict formation rate include metallicity and collision rate
- Most of this work could be done only with Chandra, because angular resolution is so important to matching X-ray with clusters!