

Black Hole X-Ray Sources in Extragalactic Globular Clusters

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Accreting stellar mass black holes have been found in globular clusters

- **Evidence for accreting stellar mass BHs in GCs.**
- **What are the donors in these accreting BHs? What are the pathways for formation? Diversity of sources**
- **How are the BHs retained?**
- **IMBHs – present or not? Do accreting stellar mass BHs rule out IMBHs in GCs?**
- **Implications for – 1) making massive BHs in high z star clusters, 2) gravity wave sources**

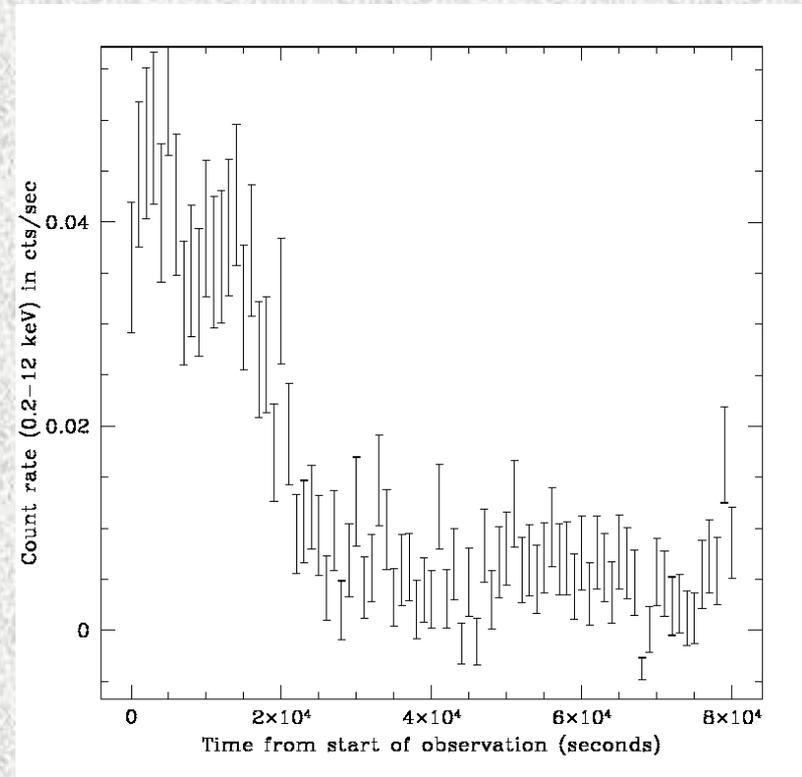
Brief History

- **Spitzer instability (1968) – black holes mass segregate in the center, form separate dynamical system.**
- **Kulkarni, Hut, & McMillan 1983, Sigurdsson & Hernquist 1983 - Dynamical interactions may eject all but one or two BHs from the GC – could account for absence of BH LMXBs in Einstein data on globular clusters.**
- **Formation of accreting BH systems is rare (e.g. Ivanova et al. 2011, Kalogera, King, & Rasio 2004)**
- **Dynamical evidence for central IMBH comes and goes (e.g. M15 in 2002/3).**

Discoveries!

- **First – GC RZ2109 in elliptical NGC 4472 (Maccarone, Kundu, Zepf, & Rhode 2007, Nature) $L_x \approx 4 \times 10^{39}$ ergs/s BH LMXB in a spectroscopically confirmed globular cluster.**

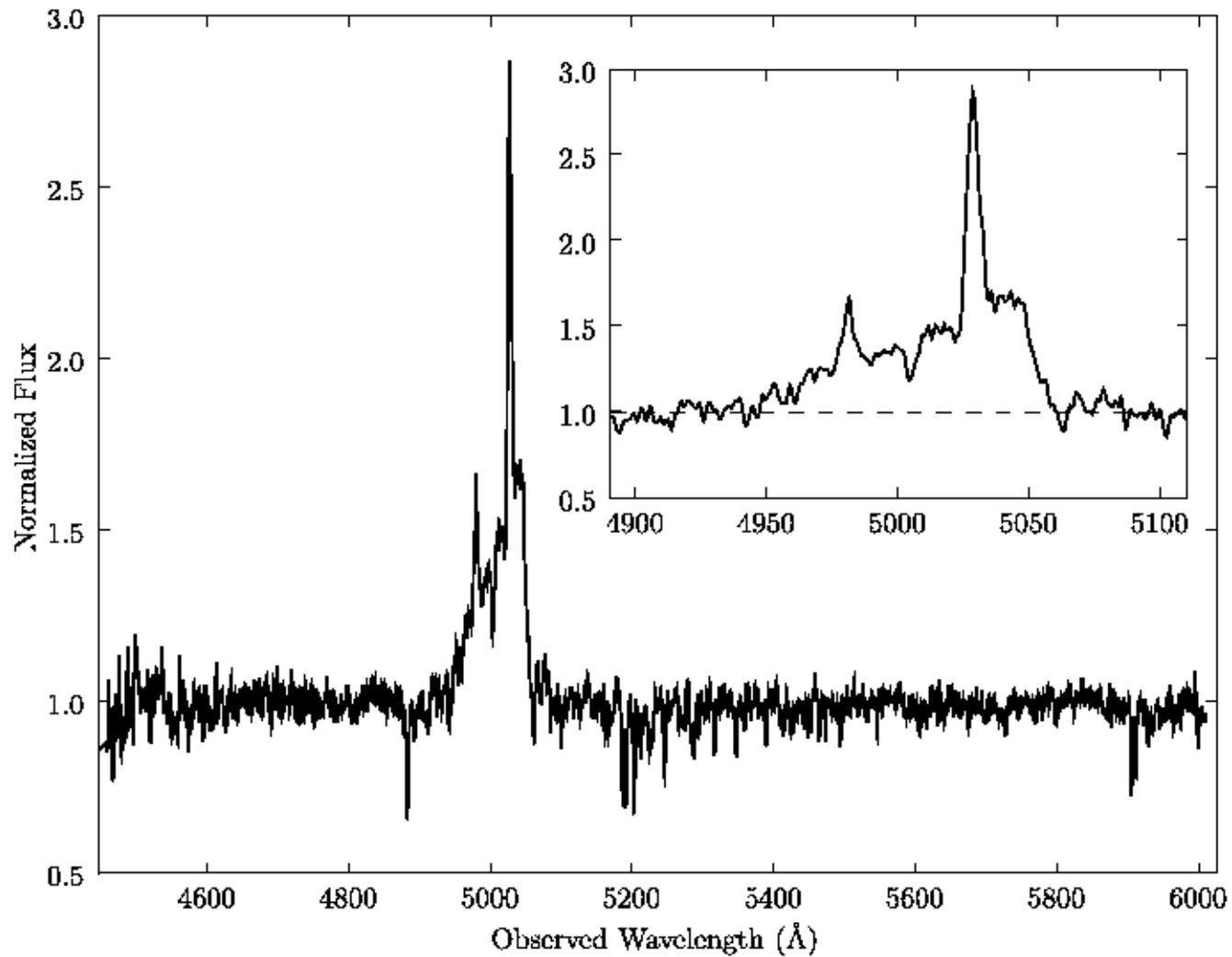
→ XMM observations show decrease in soft X-ray flux by a factor of 7 over 10,000s. Rules out multiple NSs, must be a BH.



RZ2109

- **Follow up work reveals remarkably broad, strong [OIII]5007 emission (Zepf et al. 07, 08, Steele et al. 2011).**
- **Complete absence of optical emission lines other than [OIII]4959, 5007, e.g. $5007/H\beta > \sim 100$ - requires O rich and very H poor system, CO white dwarf donor most likely (Steele et al. 2014).**
- **HST STIS spectra resolves emission line region to be ~ 5 pc (Peacock et al. 2012a). Low critical density of [OIII] requires 5007 emitting region to be at least ~ 0.1 pc.**
- **Absence of similar [OIII] emission in other GCs rules out strong beaming (Peacock et al. 2012b).**
- **L_X over time – RZ2109 seen by ROSAT through 2014. Variability on both short and long timescales. Also spectral changes with flux changes (also Tom's talk).**

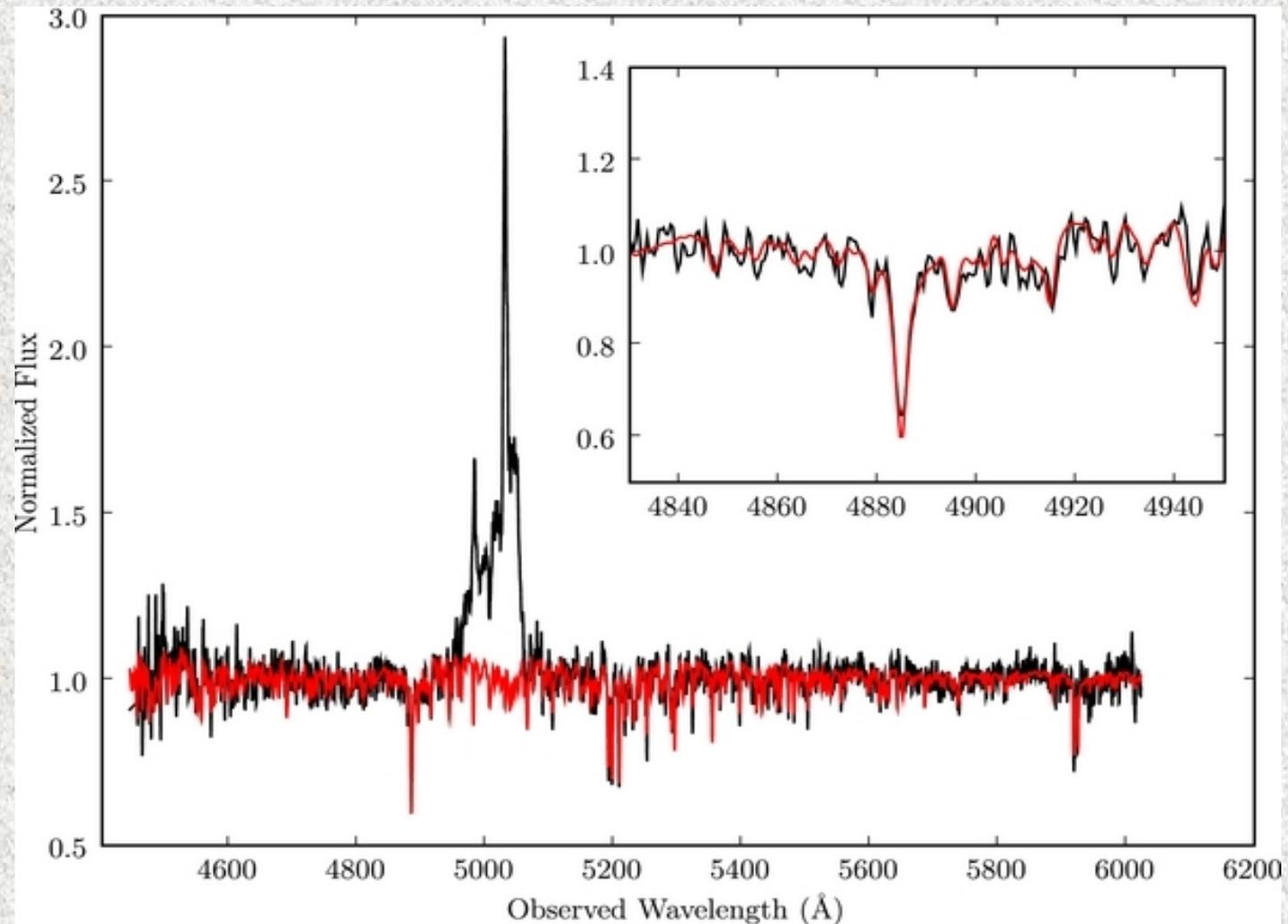
GMOS spectrum of RZ2109 (Steele et al. 2011)



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Absence of H β in RZ2109 (Steele et al. 2014)

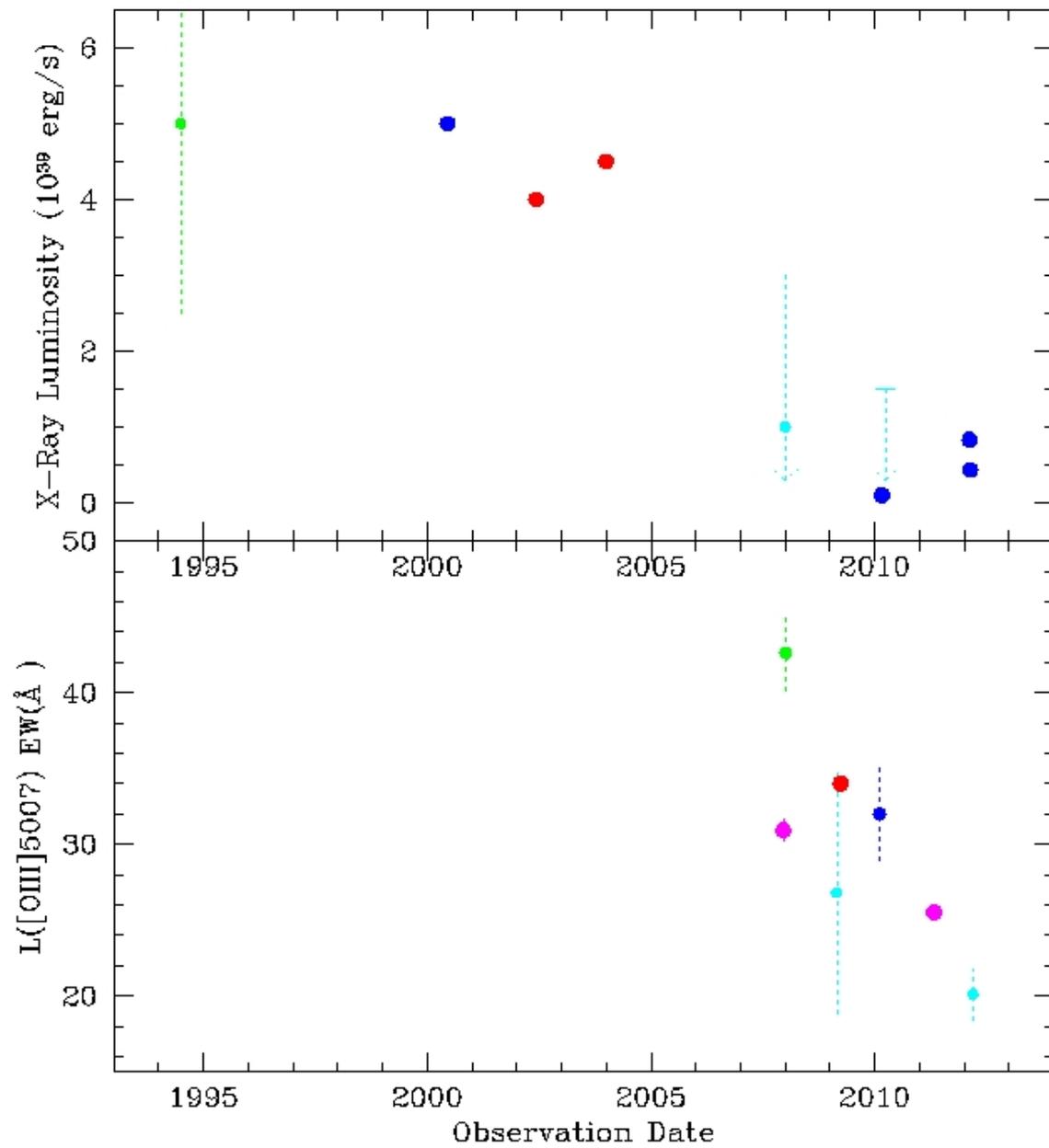


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Other BH X-ray sources in extragalactic GCs

- 1. High L_x system in metal rich NGC 1399 GC found to vary within an old Chandra observation. Long-term decline in more recent X-ray data (Shih et al. 10).**
- 2. Another metal rich NGC 1399 GC with high L_x . Weak narrow [NII] and [OIII] optical emission (Irwin et al. 10), $\sim 50 M_{\text{sun}}$ BH tidally disrupting red clump HB star (Clausen et al. 12), or photoionizing a R Cor Bor star (MacCarone & Warner 11), or...**
- 3. Metal-rich NGC 4472 GC, formerly fainter LMXB up to few $\times 10^{39}$ (MacCarone et al. 11).**
- 4. Metal-rich NGC 4649 GC with variable, several 10^{39} X-ray source (Roberts et al. 12) – no optical emission.**
- 5. Metal-rich NGC 3379 GC with variable X-ray source somewhat brighter than L_{Edd} , (Brassington et al. 10).**

Diversity of sources

Galactic BH LMXBs in GCs

- No bright BH in a Galactic GC – just numbers of GCs extragalactic >> galactic.
- Quiescent stellar mass BHs hide in pool of faint XRBs.
- Use VLA+Chandra – Strader et al. 12 (M22) and Chomiuk et al. 13 (M62) find strong candidates, more coming?...

Question 1 – What are the donors? What are the formation pathways for these systems? Upcoming COS UV spectrum for RZ2109.

Question 2 – What about BHs ejecting themselves?

Much recent work showing retention stellar mass BHs (e.g. Heggie & Giersz 14, Morscher et al. 13, 14, Sippel & Hurley 13, Moody & Sigurdsson 09, Mackey et al. 08).

Question 3 – Does presence of accreting stellar mass BHs in GCs rule out IMBHs? Zepf et al 08 say yes. Leigh et al. 15 find this is the case in simulations. Would be evidence of absence for IMBHs in GCs.

Note 1: Same radio searches that find stellar mass BHs set limits on IMBHs (Strader et al. 12b, Chomiuk talk).

Note 2: Ongoing dynamical work on IMBHs, nearly all (all?) upper limits, e.g. talks by Lanzoni, Lutzgendorf

Implications – 1) no growth to IMBHs in star clusters, 2) stellar mass BHs and gravity

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RZ2109 flux and spectrum same in 2000 as in 2004 and probably back through ROSAT, but significant change by 2008-2010

