Accretion evidence for black holes in globular clusters

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Key timescales for star clusters

- Crossing time
  - $t_{cross} = R/v \sim 10^6$ years
- Relaxation time
  - $t_{relax} = (0.1N)/(\ln N) * t_{cross} \sim 10^9$ yrs
- Evaporation time
  - start with Maxwellian distribution of stars
  - $t_{evap}=136\ t_{relax}$
  - Can be faster due to tidal effects – see e.g. Mark Gieles's talk

Black holes: severe mass segregation causes ejection

- Old star clusters – no massive stars left
- Black holes ~5 times heavier than everything else
- Become fully segregated – do not interact with other stars substantially
- Leads to a cluster with only a few hundred stars – very rapid evaporation
- Binary effects can speed this process up
- If there are still some left, GWR rocket effect can “kick in”

Spitzer 1969; Kulkarni et al. 1993; Sigurdsson & Hernquist 1993; Portegies Zwart & McMillan 2000

But, more recent theoretical work argues that these effects do not go to completion in a Hubble time(e.g. Mackey et al. 2007, Melvyn's talk, Moody & Sigurdsson 2008 – see also poster at this meeting)

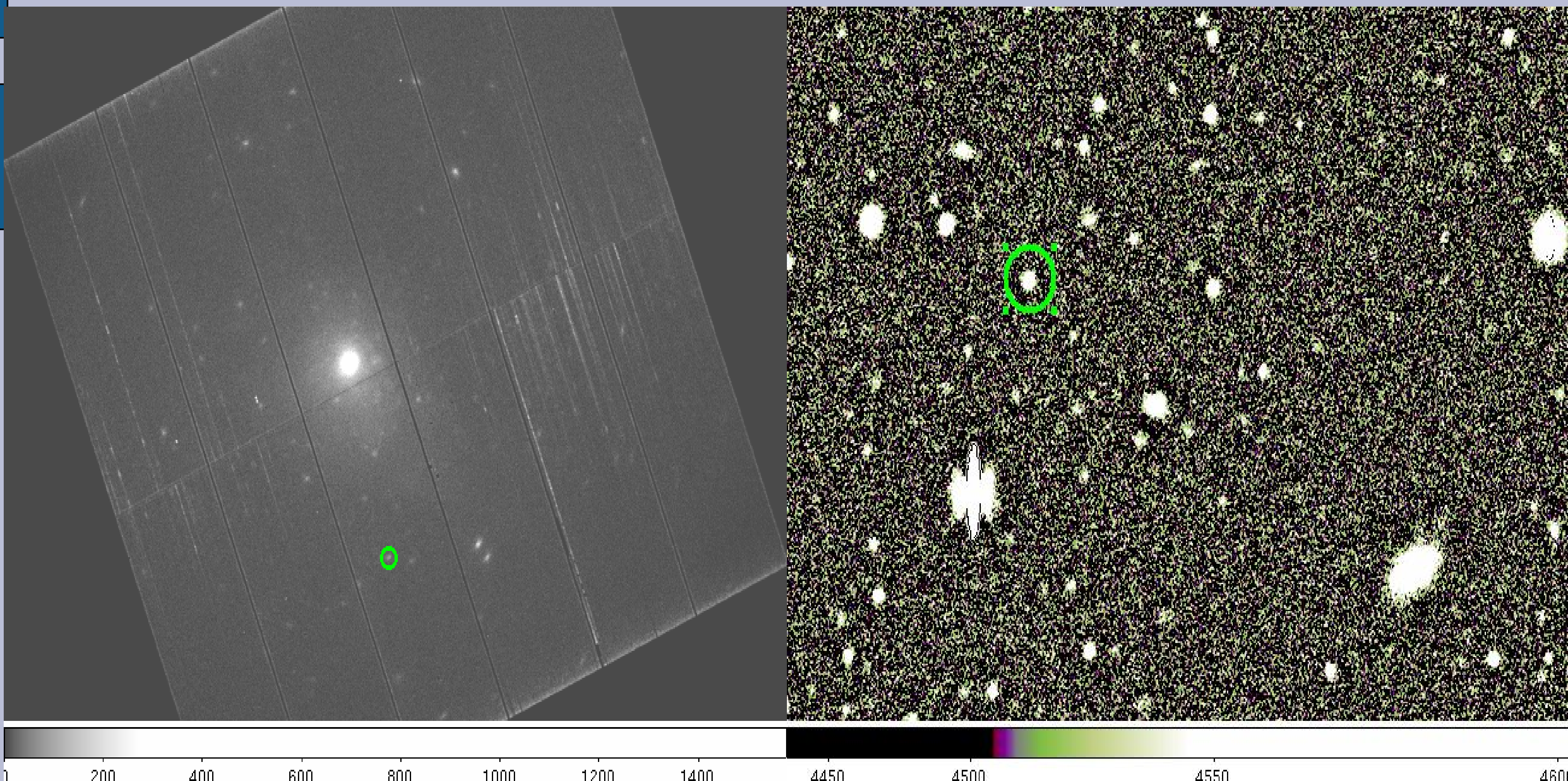
Milky Way Part I

- Milky Way has 13 bright X-ray binaries
- 12 show Type I X-ray bursts, the 13th is edge on and couldn't show them
- Evidence that ejection works, or just small number statistics?

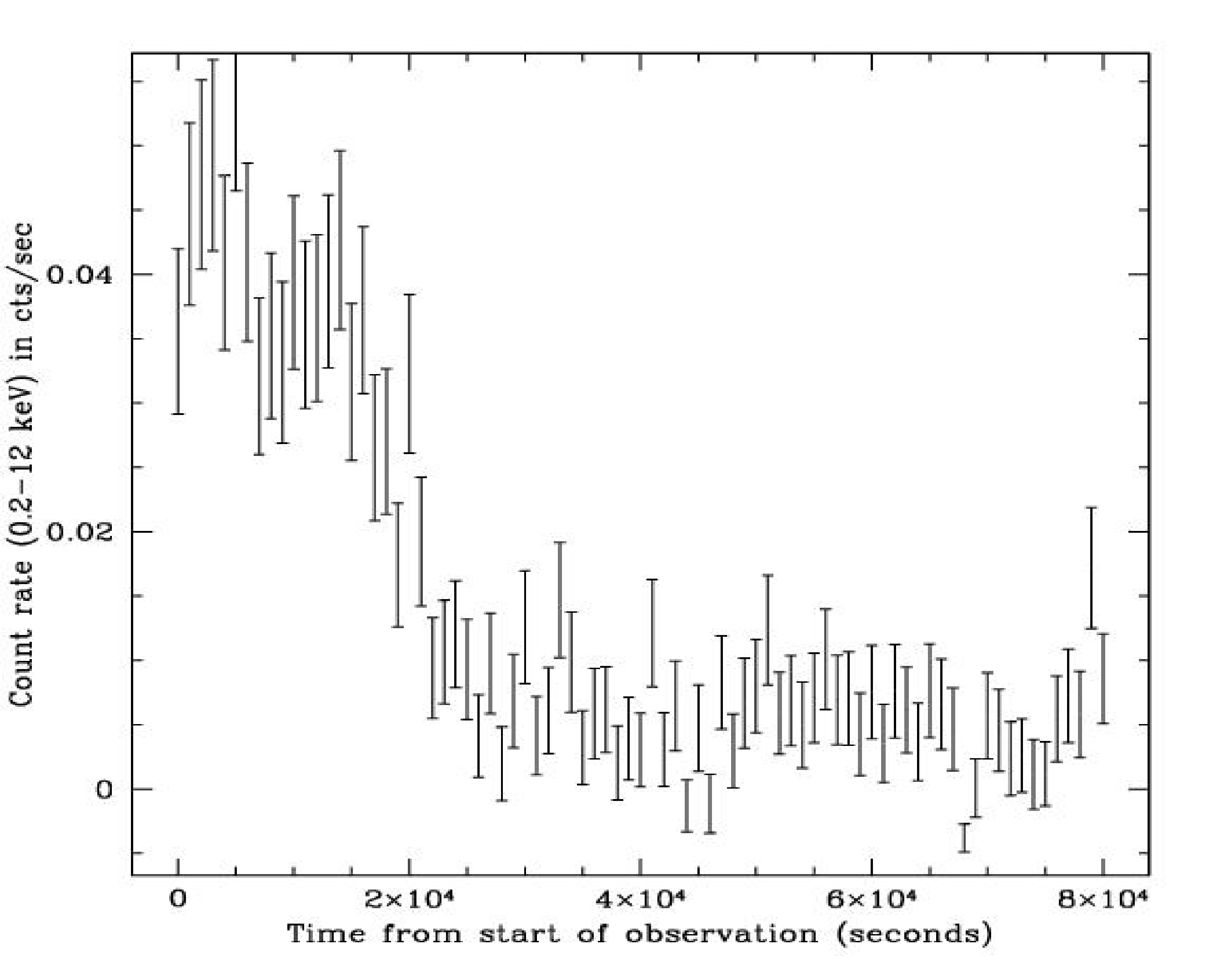
Early evidence for GC black holes

- Some X-ray sources brighter than L_{EDD} for a neutron star in extragalactic globular clusters
  - Known since first Chandra observations of nearby ellipticals
- Never show variability? (Irwin 2006)
- Variability is the key to proof (Kalogera, King & Rasio 2004) – otherwise, may be a superposition of many sources

XMM observations of NGC 4472



Highly variable

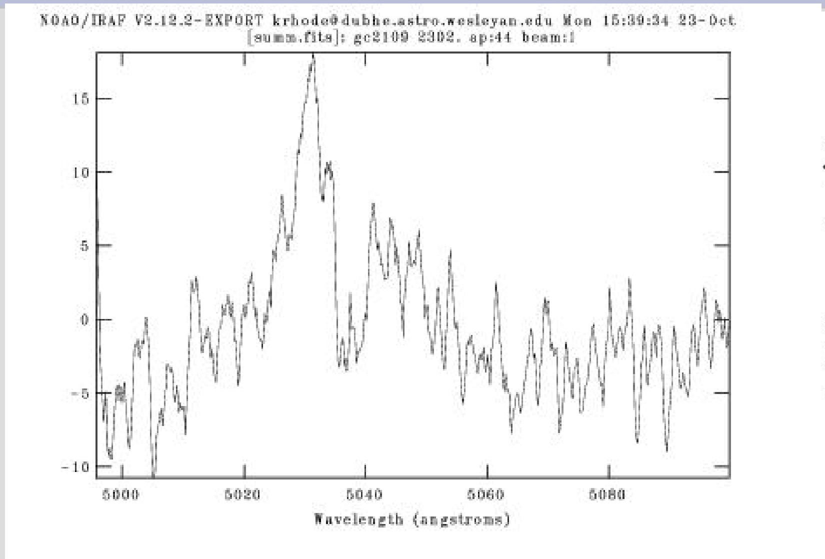


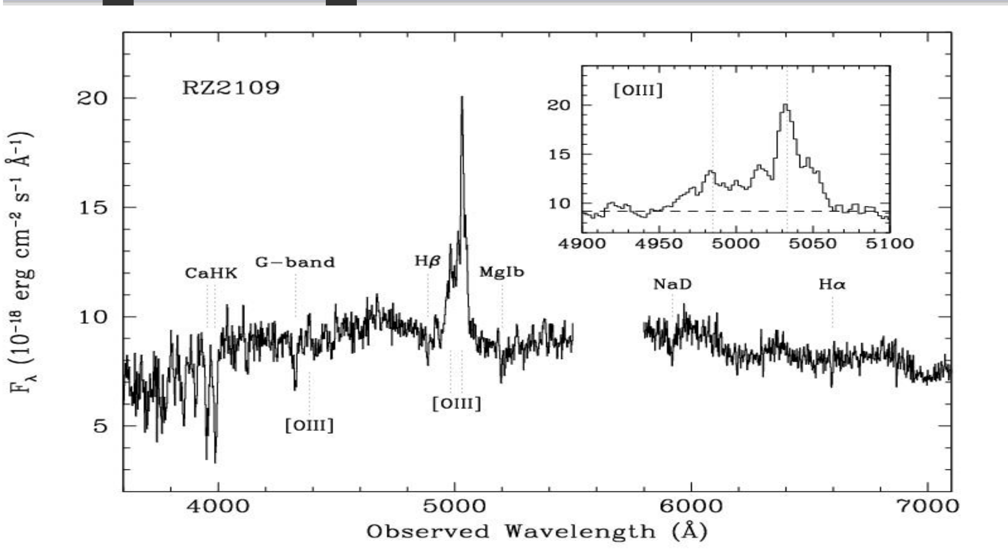
What is this object?

- Variability indicates that it is clearly a single object, and at this luminosity ($4.5*10^{39}$ ergs/sec), it must be a black hole
  - Variability predominantly below 0.7 keV
  - Probably change in absorption
- X-ray spectrum dominated by a kT=0.22 keV disk blackbody component with ~4000 km inner radius
- Black hole mass
  - luminosity and temperature hint at something much larger than 10 solar masses
  - character of the variability suggests, though, that this may be super-Eddington accretion

Maccarone, Kundu, Zepf & Rhode 2007

Optical spectra – strong broad [OIII]





Keck & WHT spectra show ~1500 km/sec component to the line
(see also poster by Matt Steele), but also a narrower (~200 km/sec) core

This line requires an outflow, because it is not possible to fit enough oxygen close enough to an IMBH to produce the
line luminosity

No H-alpha emission?

Little or no line variability over 5 years baseline, argues against supernova idea suggested by Jimmy Irwin

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
- Blows out a bubble in the intracluster medium
- Puffs up accretion disk, drives irradiative warping, leads to precessing self-obscurration
- Question: very tight ultracompact X-ray binary (period of ~5 minutes) or peak of outburst of a stellar mass black hole? Zepf et al. 2007, Shih et al. 2007

Are there more: extragalactic?

- Many of the L_X>10^{38} ergs/sec sources probably are black holes
- Use “spectral states” + luminosities or use detailed spectral characteristics (e.g. Barnard et al. 2008; talk by Natalie Webb)
  - But must be careful about superpositions of sources, and spectral state hysteresis effects for former, absorption for latter
- A few more high L_x, highly variable sources are being found – Fabbiano/Brassington/Blake et al in prep, Shih et al in prep.

Are there any in the Milky Way Part II

- Want some hope of getting a mass function, to meet the highest standard of proof for black holes
- Within our Galaxy?
  - quiescent black hole XRBs are very hard to tell apart from CVs
  - Radio emission would be strong evidence
    - $L_R \alpha L_X^{0.7}$ for BHs (Gallo, Fender & Pooley 2003)
    - Should be feasible with EVLA, E-Merlin, maybe SKA pathfinders
  - L_opt/L_X too high for orbital period is suggestive
    - 47 Tuc W21? (Maccarone & Knigge 2007)

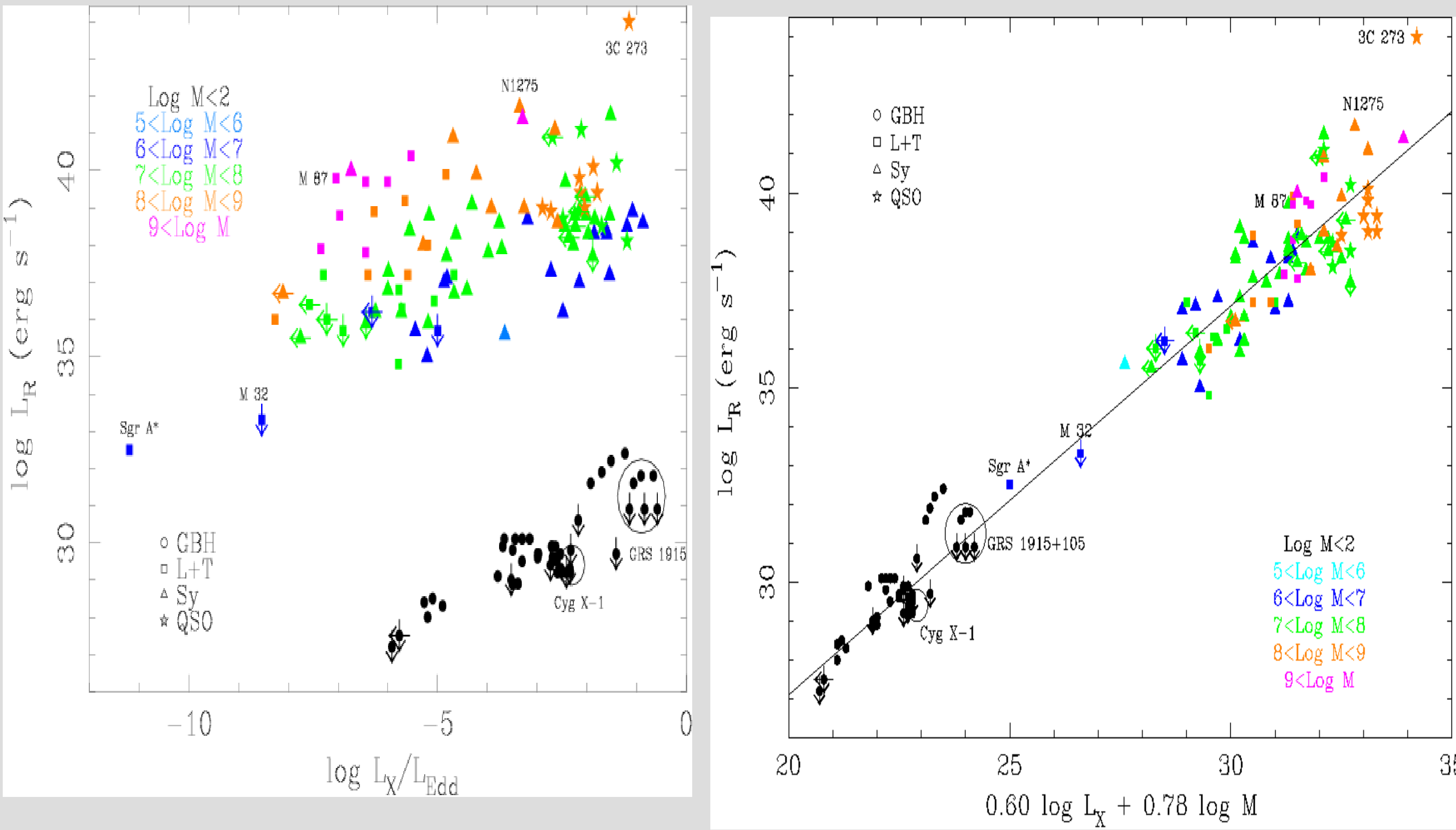
Intermediate mass black holes

- Several methods of searching
  - Dynamics
    - See most of the rest of the talks in this session
    - Controversial about whether it works
  - Accretion from ISM
    - Will not give precise mass estimates when it works, but gives a much clearer yes/no signature

Accretion measures

- X-ray and radio or just radio flux
- Assumptions needed
  - Gas density (typically about 0.1 cm^{-3}, as found in 47 Tuc from pulsars – Freire et al. 2001)
  - Alternatively, can take ISM from free expansion of stellar winds (Pfahl & Rappaport 2001)
  - Accretion rate is fraction of Bondi rate (we typically take 10^{-2-3}) – based on AGN results – Pellegrini 2005
  - Radiatively inefficient accretion
    - ($L_x \alpha$ $mdot^2$)
  - Fundamental plane of black hole activity to go between radio and X-ray (Gallo et al. 2003 for binaries; extended to AGN, refined in Merloni et al. 2003; Falcke et al. 2004; Koerding et al. 2006)

Fundamental plane



From Merloni, Heinz & Di Matteo (2003)

Results

- None of the Galactic globular clusters we've looked at has the right kind of radio source (Maccarone, Fender & Tzioumis 2005; tabulation of many groups' work in Maccarone & Servillat 2008)
  - A few give clear limits that the M-sigma relation is not being satisfied in some clusters- Omega Cen, NGC 6266, NGC 6440
  - Argues against heavy black holes being too common
- However, good evidence in G1 for a ~10000 solar mass black hole (Trudolyubov & Priedhorsky 2004;Pooley & Rappaport 2006; Maccarone & Koerding 2006; Ulvestad, Greene & Ho 2007)
  - L_x = 2*10^36 ergs/sec, F_radio = 30 μJy

Conclusions

- There are accreting black holes in globular clusters
- Our object is most likely to be a stellar mass black hole at L>L_EDD
- There is reasonable hope to find quiescent BHXBs in the Milky Way
- Evidence for IMBHs in globular clusters is starting to amass (at least in G1), although there is still the question of what defines a cluster