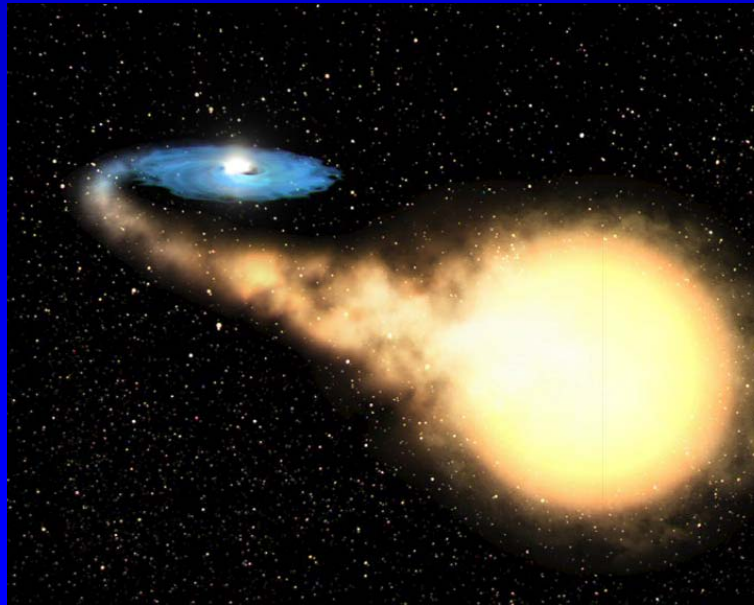


The M_{BH} - σ Relation at Low Masses

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Black Holes and Globular Clusters

- **Utility of high spatial resolution and multi-wavelength science.**
- **Value of expanding discovery space – results new and unanticipated a year ago.**
- **Starting point is our ongoing studies of neutron-star and black-hole X-ray binaries in extragalactic globular clusters (e.g. Kundu, Maccarone, & Zepf 2007).
⇒ enabled by combining Chandra and XMM with HST and ground based optical/near-ir.**
- **Address long-standing questions about NSs and BHs in GCs and beyond (e.g. many NSs but why given natal kicks? X-ray binaries 100x more common in GCs than in the field - - close binary formation in GCs, how? no BH XRBs in Galactic GCs, no clear BHs even, why?)**

So How Did We Get to $M_{\text{BH}} - \sigma$ at Low Masses?

- X-ray/optical studies of large samples of extragalactic GCs reveal a number of GC sources with L_x much higher than Eddington luminosity for a neutron star \rightarrow possible BHs in globular clusters.
- But...extragalactic GCs are not spatially resolved in X-ray data, thus multiple NS sources possible, even likely (KMZ07). This has been known for a long time. So has a solution (e.g. Kalogera, King & Rasio 2004) – Variability is an unambiguous indicator of a BH, since multiple NSs can't conspire to vary together.

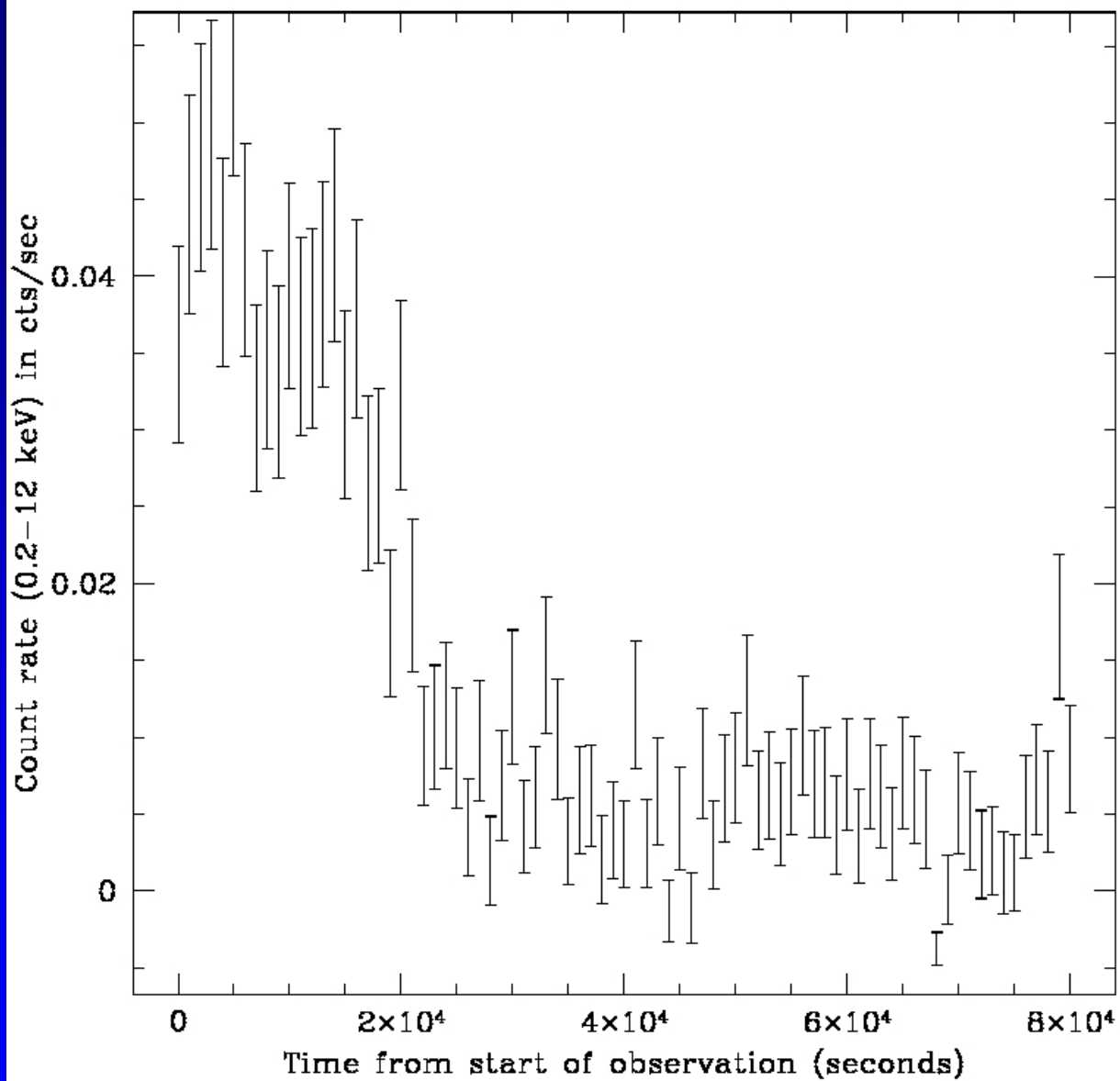
A Black Hole in a Globular Cluster!

Maccarone, Kundu, Zepf, & Rhode 2007 Nature

- $L_X \approx 4 \times 10^{39}$ ergs/s LMXB in NGC 4472
- In a spectroscopically confirmed globular cluster
- Metal-poor GC, 6.6' from center (about 4 R_e)

Why Black Hole?

- **Very high X-ray luminosity in GC requires either BH or multiple NSs. XMM observations show decrease in soft X-ray flux by a factor of 7 over 10,000s. Rules out multiple NSs!**



XMM time series of NGC 4472 GC BH source, MKZR07

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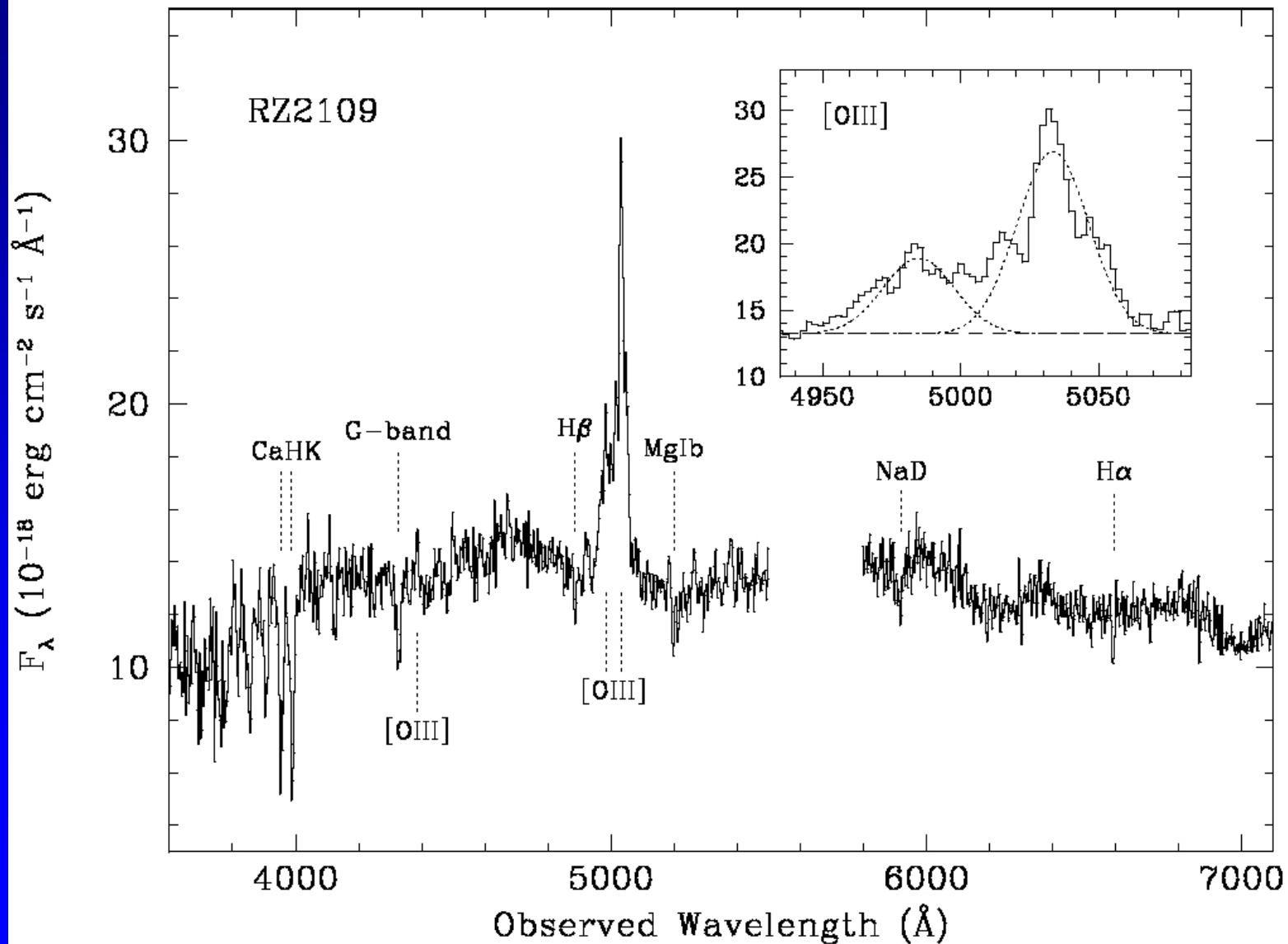
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So we have a Black Hole in a Globular Cluster, what is $M_{\text{BH}} - \sigma$ at Globular Cluster Masses?

- How $M_{\text{BH}} - \sigma$ does or doesn't extend to globular cluster masses valuable for growth of black hole masses and physical origin of $M_{\text{BH}} - \sigma$.
- X-ray observations show BH in NGC 4472 GC, but could be from stellar ($10 M_{\odot}$) to intermediate mass ($1000 M_{\odot}$).
⇒ Visible light spectroscopy may distinguish these.
- Fiber spectra we had for other reasons shows strong, broad [OIII] 5007 emission at radial velocity of GC (Zepf, Maccarone, Bergond, Kundu, Rhode, & Salzer 2007, ApJ, 669, L69).
⇒ Get high S/N full optical spectrum of BH-GC source...

- Keck LRIS spectrum of RZ2109, BH hosting GC (Zepf et al. 2008/arXiv.org:0805.2952)
- [OIII]5007 remarkably broad - fwhm $\sim 2,000$ km/s, corresponding [OIII]4959 now seen
 - Broad [OIII] and high 5007/H β suggest photoionized wind from stellar mass BH



How to get M_{BH} from Observations

- The high [OIII] 5007 luminosity at large line width requires that it originate from material driven at high velocity from the BH.

The volume near the BH is orders of magnitudes too small to produce the observed [OIII] 5007.

- Only known way to drive such a strong wind is high L/L_{Edd}

High L/L_{Edd} and observed $L_{\text{X}} \Rightarrow$ stellar mass BH

- stellar dynamics - stellar mass BH X-ray binary formation infeasible in a GC with an IMBH \Rightarrow No IMBH in this luminous GC.

Thus likely $M_{\text{BH}} \sim 10M_{\odot}$, $M_{\text{BH}} - \sigma$ prediction about $1000M_{\odot}$.

What's next?

Future Work and role(s) of GSMT

- In favored model, strong wind extends across most of the GC, tens of pc, at distance of Virgo cluster, several-tenths of an arcsecond. HST-STIS time allocated.

1. Nice to know σ , current work uses stellar mass or analogy with Galactic GCs. Need $R \sim 50,000$ at $V = 21$,

⇒ HROS/QSPEC- like instrument (S/N=30 in ~ 6 hours).

2. Many questions about physical structure of emission. Is picture above correct? How is feedback working? Requires high spatial resolution ($< \sim 0.1''$), moderate spectral resolution ($R \sim 1-3,000$)

⇒ IRIS – IFU at high spatial resolution to map out velocities and luminosities of near-IR lines.

Predicted lines S/N ~ 10 over ~ 100 pixels in 10 hrs

understand how accretion and feedback in this BH-GC system works, study future discoveries of new BH/NS emission line sources in GCs.

Conclusions

- 1. Emission lines from X-ray sources in extragalactic globular clusters provide new probe of $M_{\text{BH}} - \sigma$ at low masses.**
- 2. Current evidence for the NGC 4472 globular cluster RZ2109 indicates a likely stellar mass BH system, suggesting no IMBH in this luminous globular cluster.**
- 3. Much follow-up to confirm (or not) this conclusion, understand the accretion and feedback processes in this system, and to find and study new such systems.**
- 4. Role in particular for high spatial resolution, moderate spectral resolution spectroscopy, also use for very high resolution spectrometer.**