Giant Brief X-ray Flares From Extragalactic Globular Clusters

Jimmy Irwin[1], Tyler Speegle[1], Ian Prado[1], David Mildebrath[1], Aaron Romanowsky[1], Jay Strader[2]

[1]University of Alabama

[1] San Jose State University
[2] Michigan State University

Aspen Center for Physics Workshop– January 20, 2015

Black Holes in Globular Clusters?

Do globular clusters harbor black holes (intermediate-mass or otherwise) or not?

Finding X-ray sources that exceed the Eddington luminosity of a neutron star was until recently* a secure way to find black holes.

*M82 X-2!

The Plan

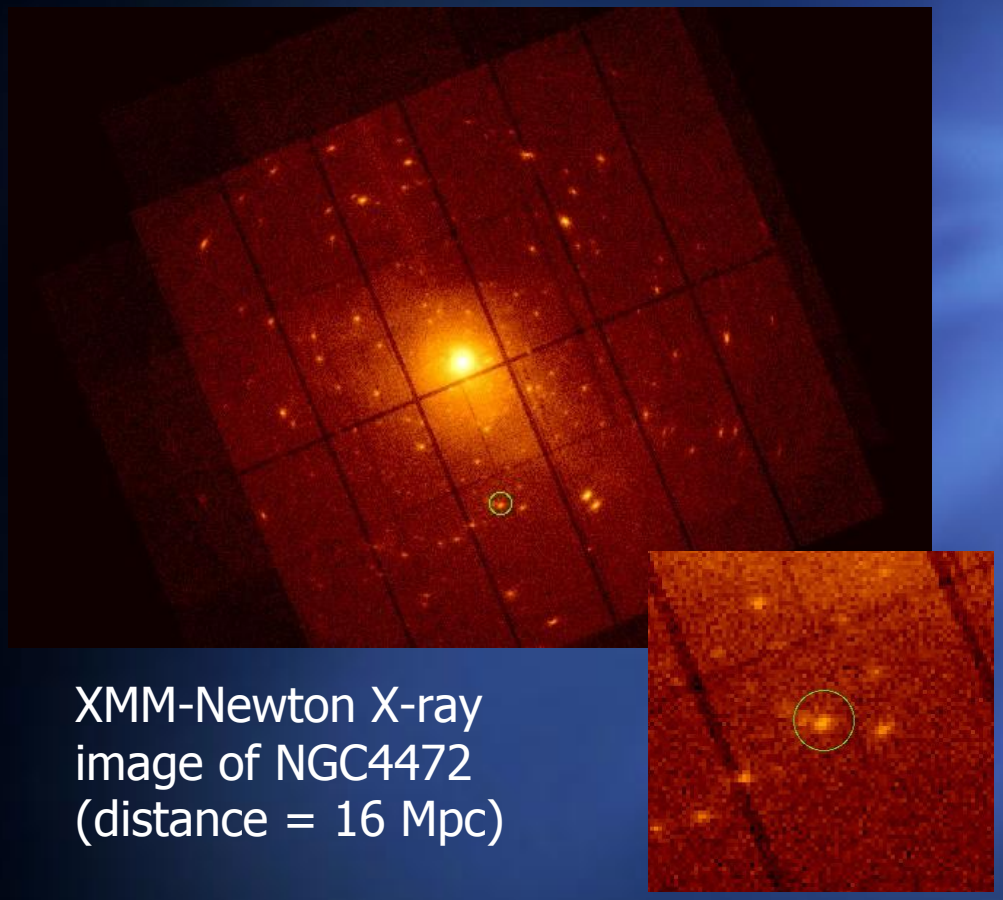
Look for X-ray sources coincident with extragalactic globular clusters that:

1) Exceed the Eddington limit of a neutron star by a factor of several → $> 10^{39}$ ergs s^{-1}

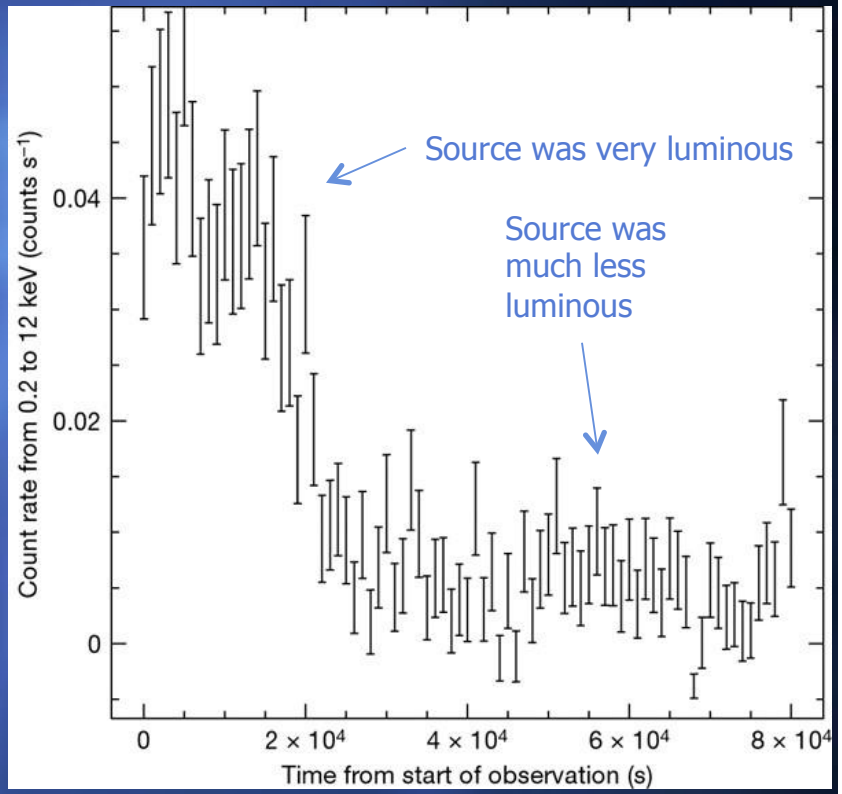
AND

2) Show significant X-ray variability → rules out multiple neutron star binaries

RZ2109: First Black Hole in a Globular Cluster

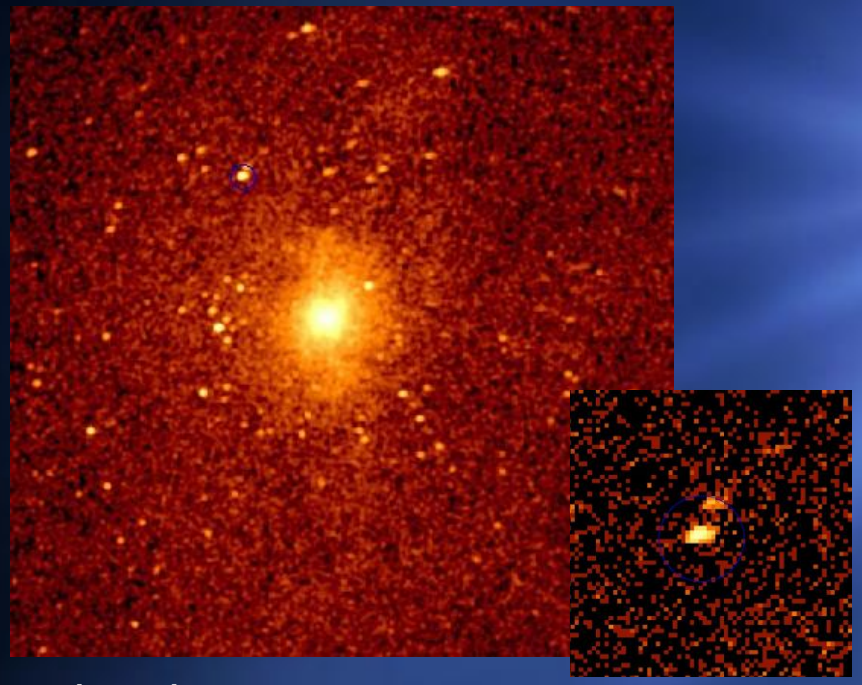


XMM-Newton X-ray image of NGC4472 (distance = 16 Mpc)

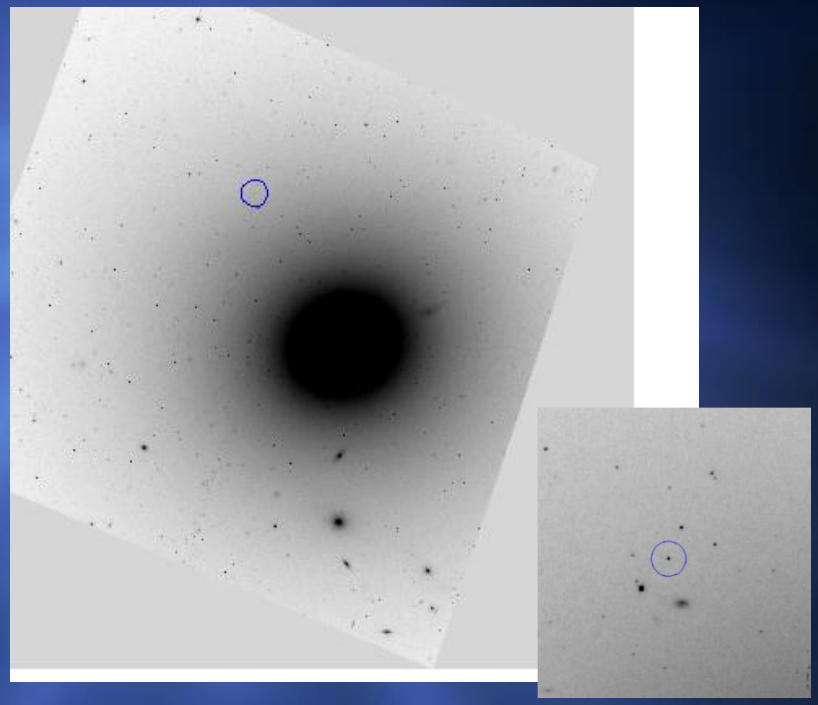


Highly X-ray variable (factor of 7), very luminous (4 x 10^{39} ergs s^{-1}) source in a globular cluster in the Virgo elliptical galaxy NGC4472 (Maccarone et al. 2007).

CXO J033831.8-352604 in NGC1399



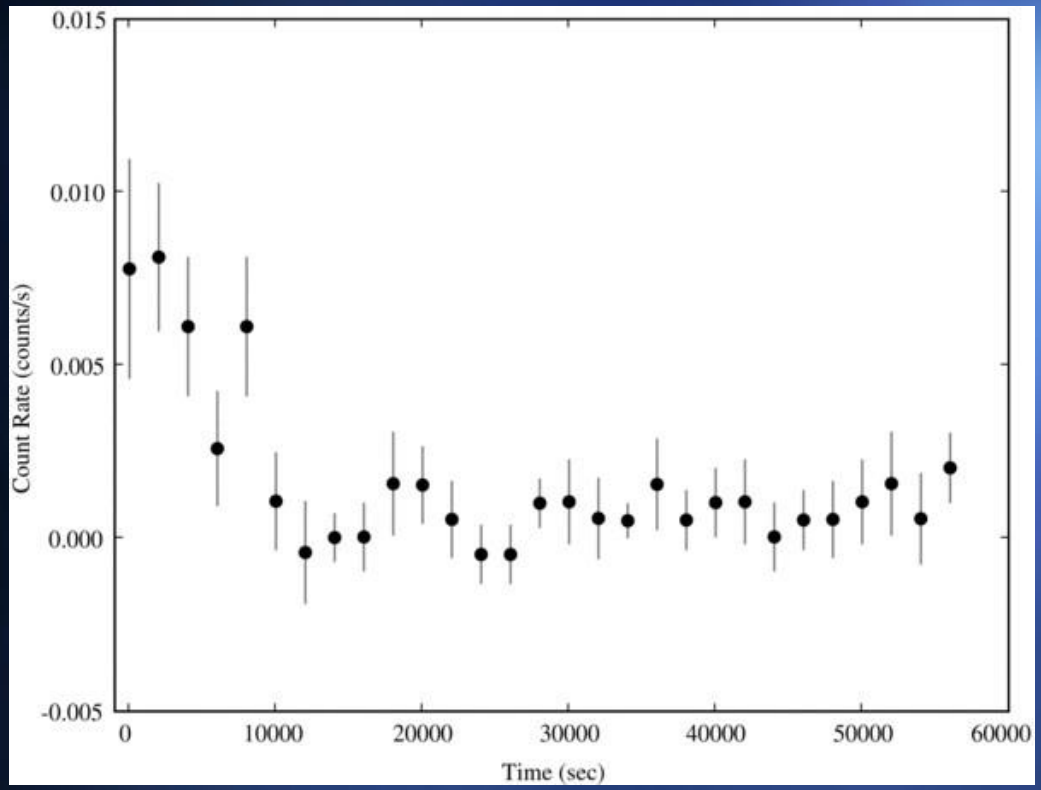
Chandra X-ray image of NGC1399 (distance = 20 Mpc)



Hubble optical image of NGC1399

Moderately variable (40%), very luminous (2 x 10^{39} ergs s^{-1}) source in a globular cluster in the Fornax elliptical galaxy NGC1399 (Irwin et al. 2010; Clausen et al. 2012).

CXOKMZJ033831.7−353058 in NGC1399



Average luminosity for the entire 58,000 second Chandra exposure is below 10^{39} ergs s^{-1}.....but the 10,000 second flare was above 10^{39} ergs s^{-1}.

Another highly variable (~10x), very luminous (2×10^{39} ergs s^{-1}) source in a globular cluster also in the Fornax elliptical galaxy NGC1399 (Shih et al. 2010).

Other Black Hole-Globular Cluster Candidates

CXOU 1229410+075744 in NGC4472 (Maccarone et al. 2011)

CXOU J124346.9+113234 in NGC4649 (Roberts et al. 2012)

Source A8 in NGC3379 (Brassington et al. 2012)

All show variability with peaks around $2 – 4 \times 10^{39}$ ergs s^{-1}.

So black holes in globular clusters seem to be out there…..can we find more with a concerted effort?

A New Search for X-ray Variability

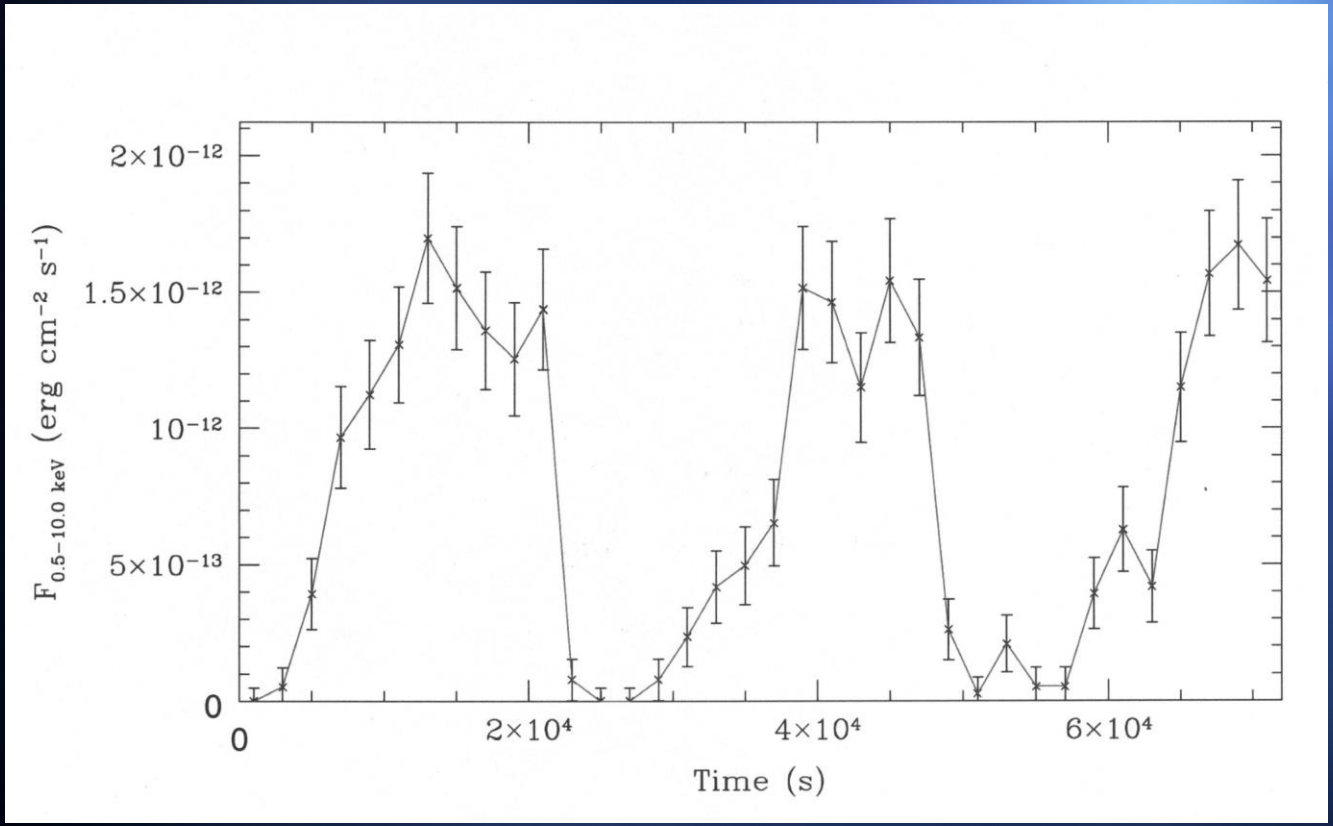
We want to be sensitive to all types of intra-observation variability, especially very short intense bursts that might not be identified in some automated searches.

We need a different way to look at light curves when we have so few X-ray photons to work with.

Our timing analysis searches for statistically significant photon bursts above the average count rate of the entire observation for each source, including “look elsewhere” effects.

What We Can Do When We Have Lots of X-ray Photons

http://science.psu.edu/alert/images/Circinus_graph300.jpg



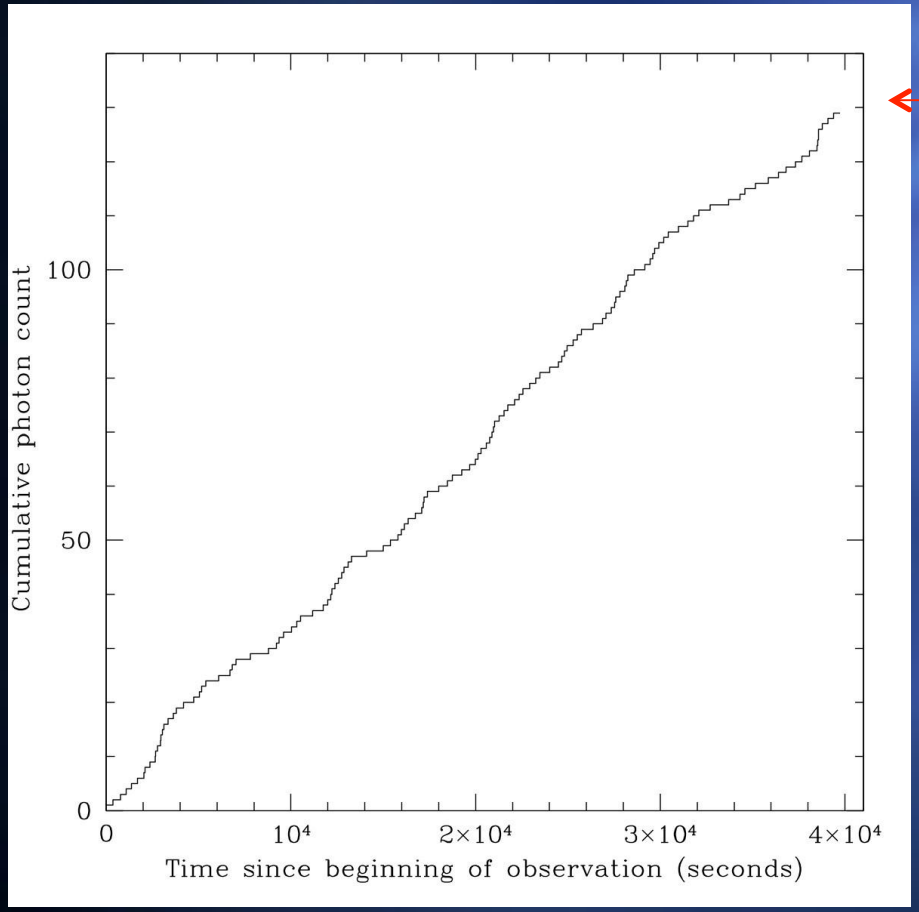
This is a traditional light curve.

We can bin the photons into independent time groups, with each time group having an associated count rate uncertainty.

What We Have To Do When We Do Not Have Lots of

X-ray Photons

Photon Arrival Plot for a Very Interesting Source!



130 photons detected total

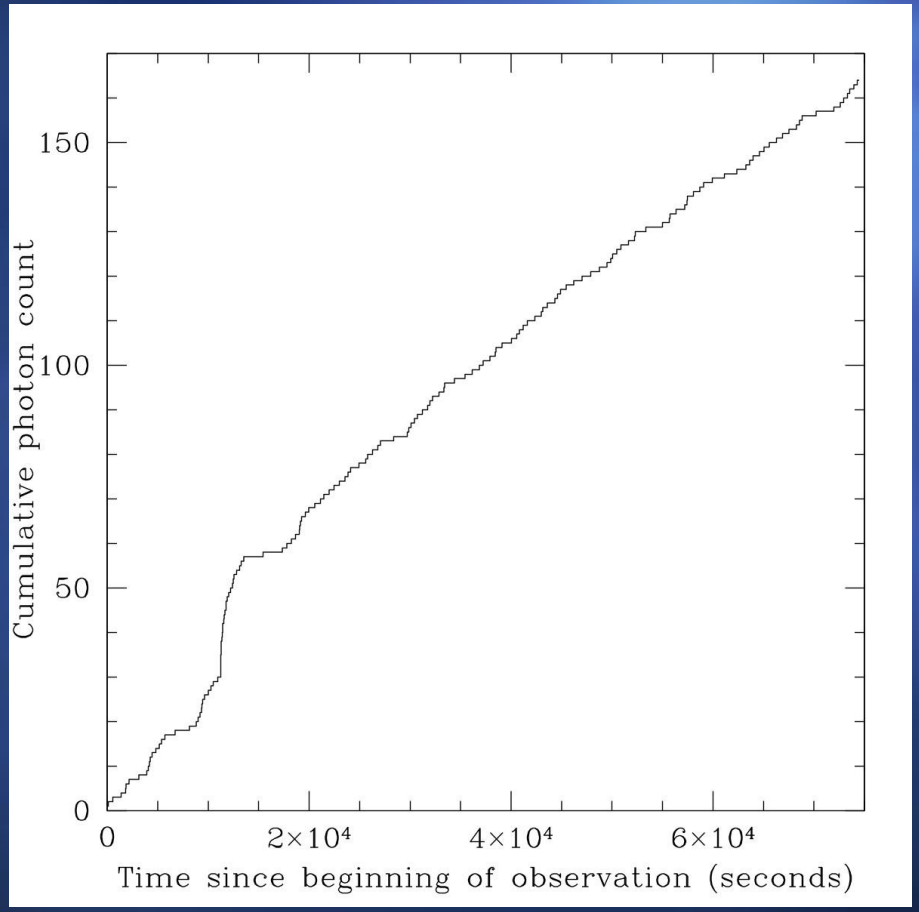
CUMULATIVE photon number count plotted as a function of arrival time.

Allows us to see very short-term flaring.

Arrival time (starting at t = 0 seconds) of each photon versus total cumulative photons. This is an uninteresting source (no significant variation).

Photon Arrival Plot for a Very Interesting Source!

X-ray source in Virgo elliptical galaxy NGC4636 at d = 15 Mpc.

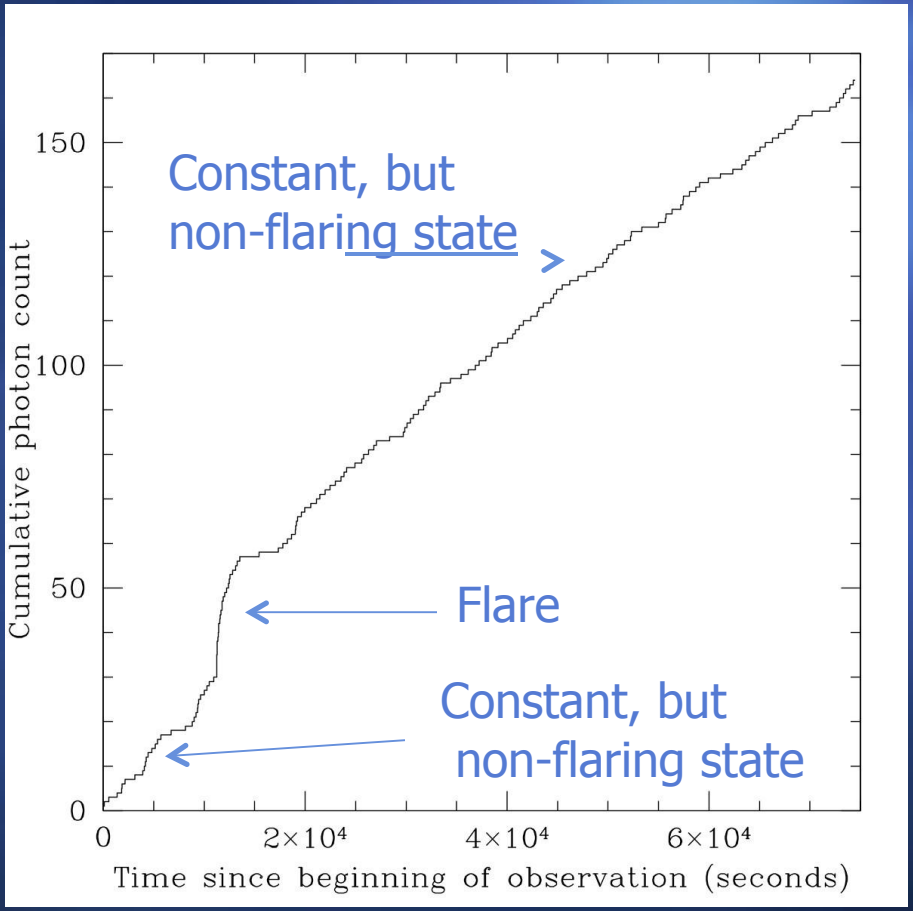


Resides within a suspected globular cluster of NGC4636.

162 photons received in 75,000 seconds → or about 1 photon every 500 seconds → L_X = 6 x 10^{38} ergs s^{-1} (nice, but nothing spectacular).

Photon Arrival Plot for a Very Interesting Source!

X-ray source in Virgo elliptical galaxy NGC4636 at d = 15 Mpc.

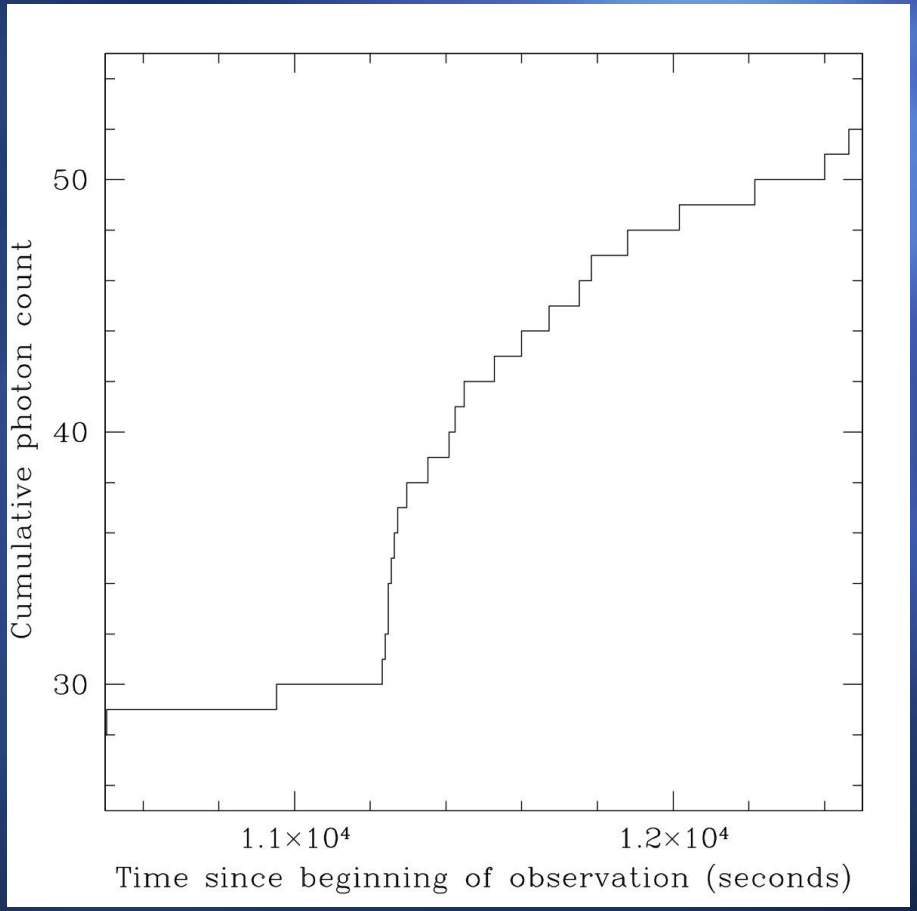


Resides within a suspected globular cluster of NGC4636.

162 photons received in 75,000 seconds → or about 1 photon every 500 seconds → L_X = 6 x 10^{38} ergs s^{-1} (nice, but nothing spectacular). But a flare!

Photon Arrival Plot for a Very Interesting Source!

X-ray source in Virgo elliptical galaxy NGC4636 at d = 15 Mpc.



Resides within a suspected globular cluster of NGC4636.

6 photons detected within 22 seconds → 7.5 x 10^{40} ergs s^{-1} → Eddington luminosity of a 600 $M_\odot$ black hole in a globular cluster, or unusual very super-Eddington accretion event?

Luminosities and Fluences

Pre-flare: 29 counts in 10,683 seconds: 7.5e38 ergs s^{-1}

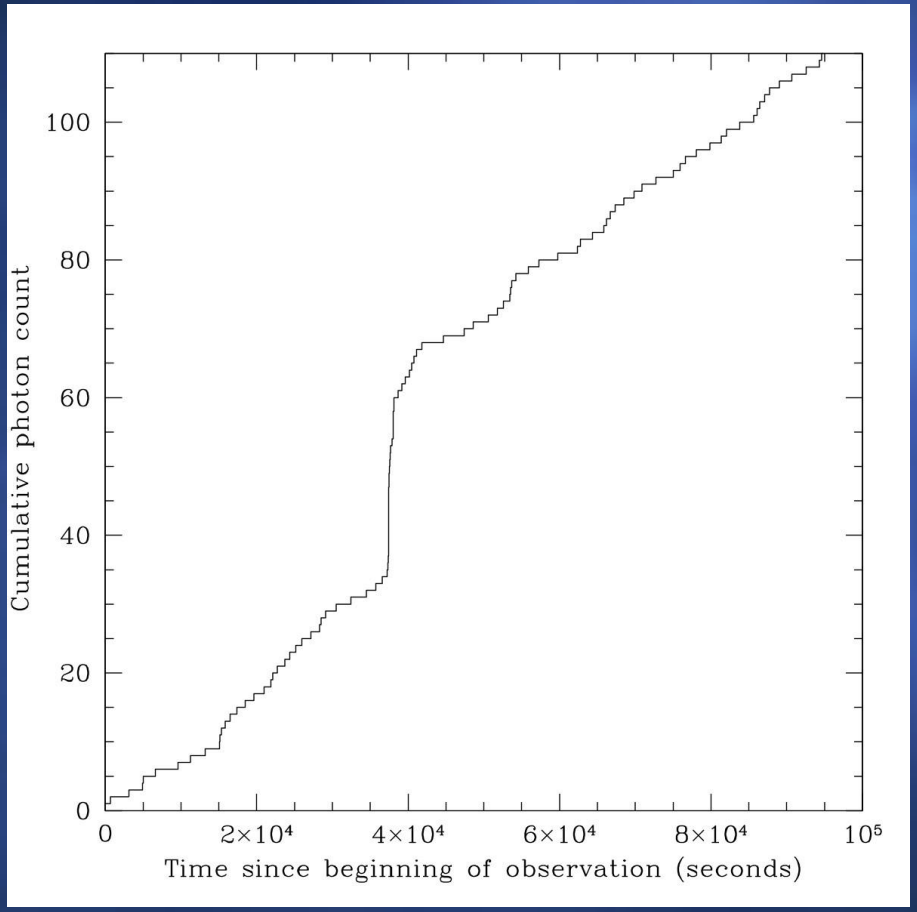
Flare	Fluence
6 photons in 22 seconds: 7.5e40 ergs s^{-1}	1.7e42 ergs
12 photons in 198 seconds: 1.7e40 ergs s^{-1}	3.4e42 ergs
18 photons in 565 seconds: 8.8e39 ergs s^{-1}	5.0e42 ergs
24 photons in 1363 seconds: 4.8e39 ergs s^{-1}	6.5e42 ergs

Next 6 photons in 5358 seconds: 3.0e38 ergs s^{-1}

Post-flare: 109 photons in 61,300 seconds: 4.9e38 erg s^{-1}

Another Very Interesting Source

X-ray source in a confirmed massive globular cluster (or ultra-compact dwarf) of NGC5128 at d = 3.8 Mpc.



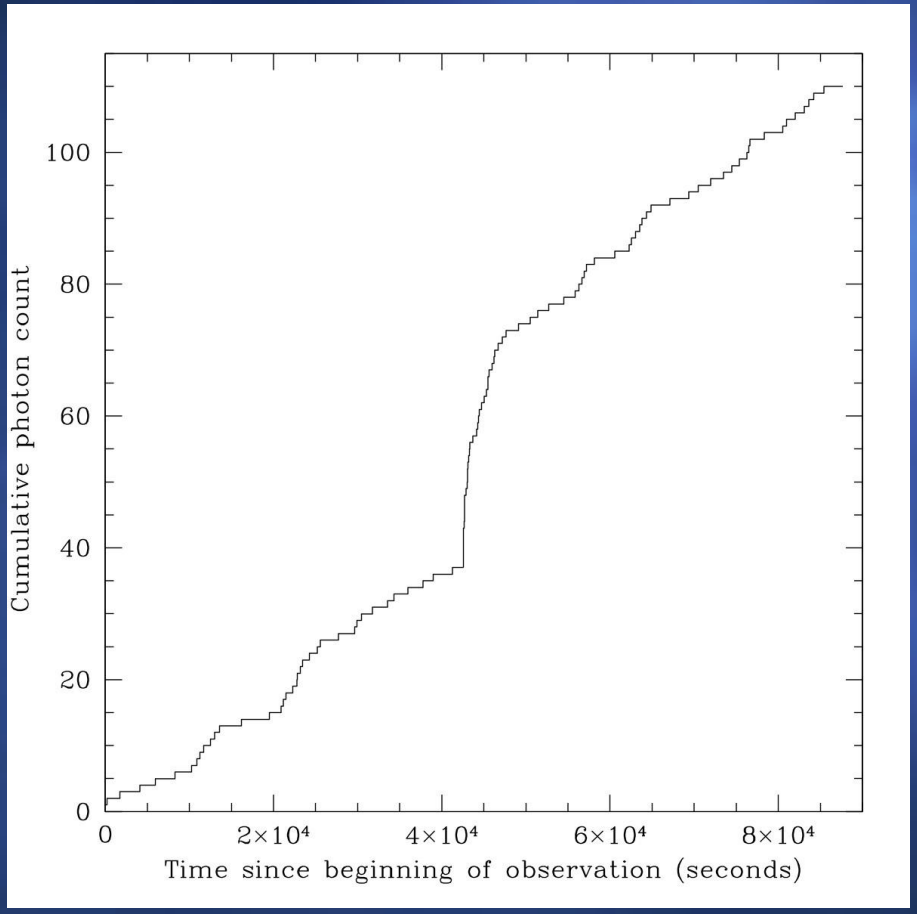
Epoch 1 –

March 30, 2007

Non-flare: 2 x 10^{37} ergs s^{-1} (83 photons in 95,000 sec)
Flare (peak): 5 x 10^{39} ergs s^{-1} (10 photons in 51 sec)
Flare (total): 8 x 10^{38} ergs s^{-1} (25 photons in 757 sec)

It Flared Again!

X-ray source in a confirmed massive globular cluster (or ultra-compact dwarf) of NGC5128 at d = 3.8 Mpc.



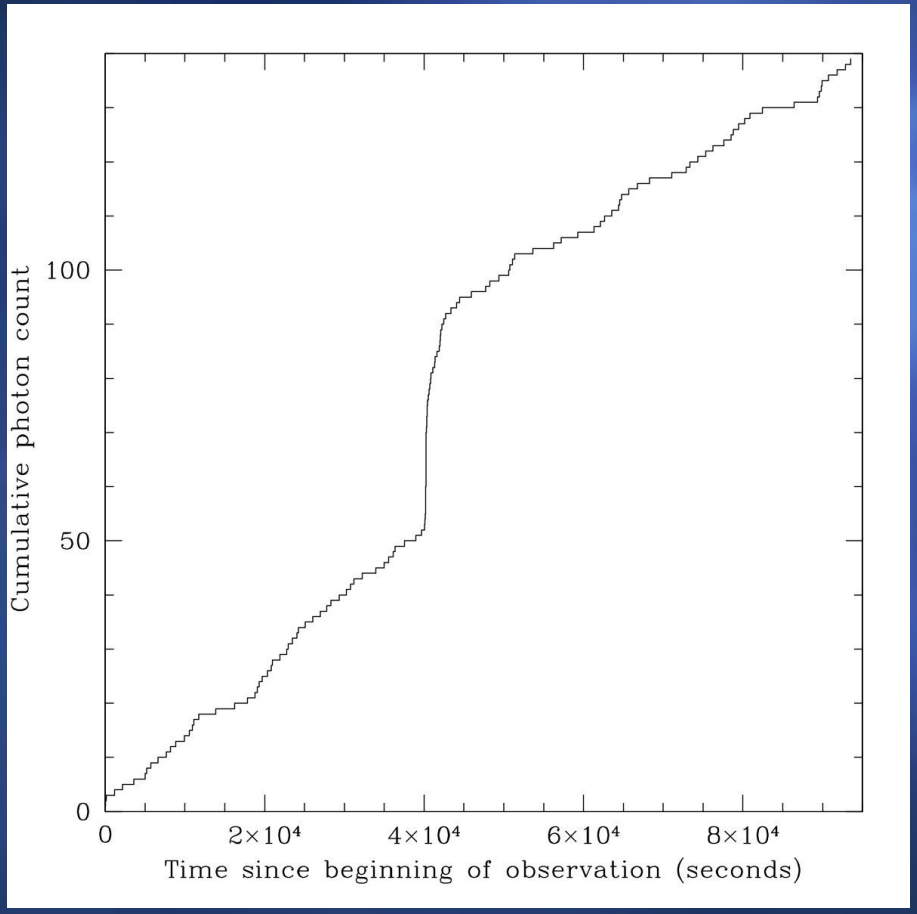
Epoch 2 –

April 17, 2007

Flare (peak): 7 x 10^{39} ergs s^{-1} (6 photons in 22 sec)
Flare (total): 7 x 10^{38} ergs s^{-1} (20 photons in 766 sec)

And Again!

X-ray source in a confirmed massive globular cluster (or ultra-compact dwarf) of NGC5128 at d = 3.8 Mpc.



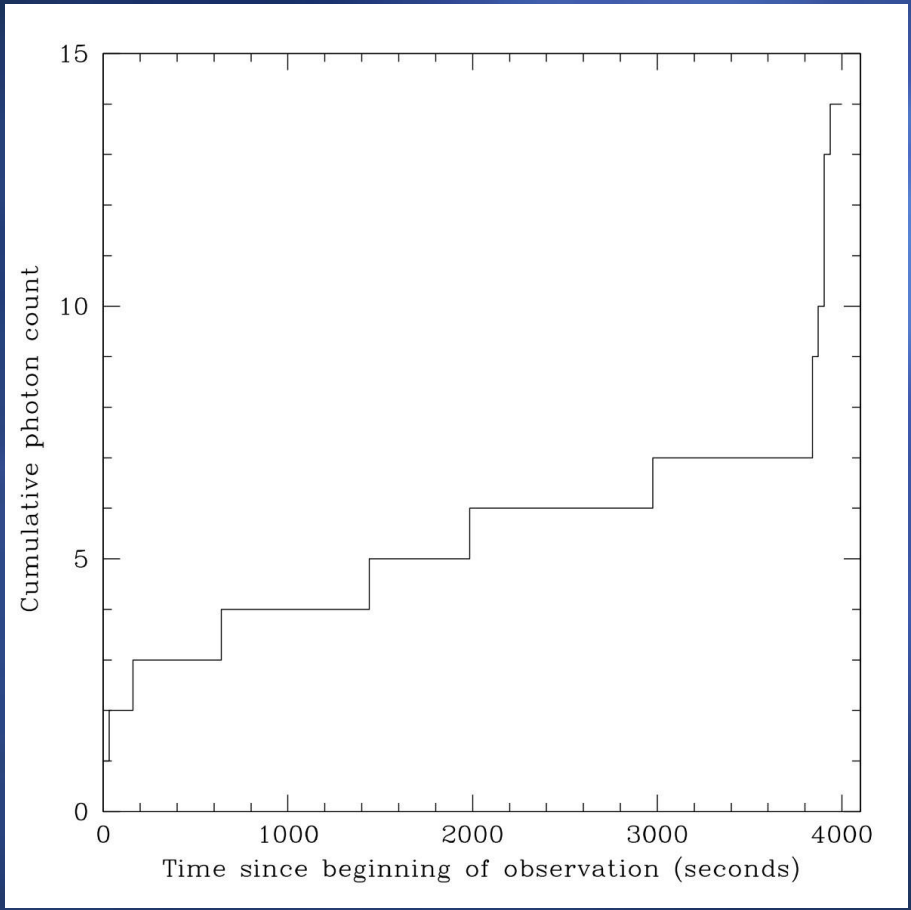
Epoch 3 –

May 30, 2007

Flare (peak): 1 x 10^{40} ergs s^{-1} (8 photons in 26 sec)
Flare (total): 2 x 10^{39} ergs s^{-1} (24 photons in 305 sec)

And Yet Again!

X-ray source in a confirmed massive globular cluster (or ultra-compact dwarf) of NGC5128 at d = 3.8 Mpc.



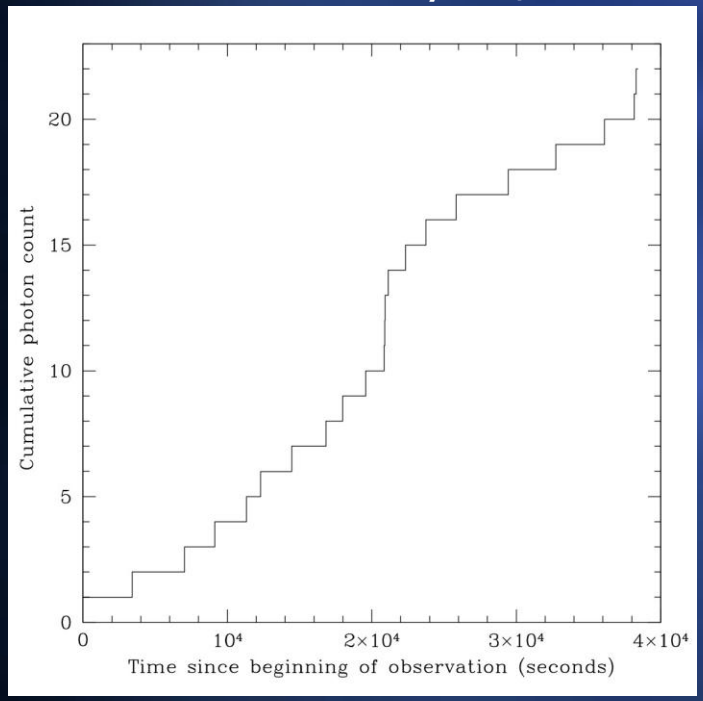
Epoch 4 –

January 4, 2009

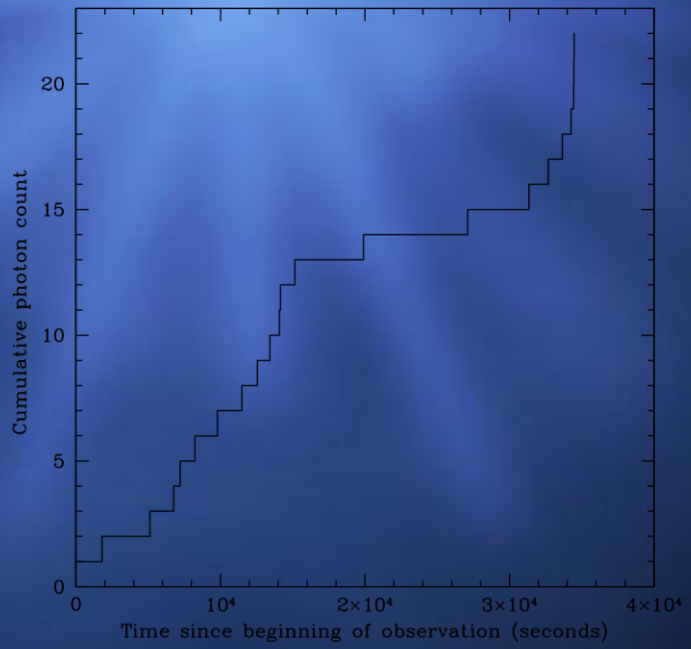
Flare: 4 x 10^{39} ergs s^{-1} (5 photons in 35 sec)

NGC4697 - CXOU J124839.0-054750

January 15, 2000



December 26, 2003



4 photons in 65 seconds 4 photons in 47 seconds Sivakoff et al. (2005) found evidence for a brief flare in two different

Chandra epochs of an NGC4697 source, although the source had no optical counterpart.

Recurrence Rate and Duty Cycle

NGC 4636: single ~20 minute flare in 212 ksec of Chandra data and 164 ksec of XMM-Newton data

Source is flaring every ~4 days for 0.3% of the time

NGC 5128: 4 flares for a total of ~30 minutes in 860 ksec of Chandra data and 39 ksec of XMM-Newton data

Source is flaring every ~2.5 days for 0.1% of the time

So What Have We Found Here?

Good question!

Very few energetic ($L > L_{Edd}$ for a $10\ M_\odot$ black hole) types of objects in the Universe vary by more than a factor of >100 on time scales of < 1 minute:

1) Gamma-ray bursts – one time event
2) Soft gamma repeaters/AXPs – young NS, lowish soft L_X
3) Type II bursts (Bursting Pulsar – GRO 1744-28) – fluence too low, many bursts per day for weeks
4) XRT000519 discussed by Thomas Wevers – distance?

So What Have We Found Here?

If a black hole, we have three choices:

1) The black holes have masses of hundreds of solar masses.
– unlikely if field NGC4697 source is at distance of NGC4697

2) Beaming scenario: small opening cone angle gives enhancement of 100-300x every 0.1%–0.3% of orbit – although most flares are consistent with fast rise/ exponential decay

3) These black holes are somehow beating their Eddington limit by large amounts for very short periods of time by some unknown mechanism.

Summary

1) Giant X-ray flares discovered in a suspected and confirmed globular cluster (or UCD) of NGC4636 and NGC5128, respectively (and potentially a previouslydiscovered field source of NGC4697)

2) Sources vary by factors of 100-300x on time scales of ~20 seconds, and last ~10-20 minutes before the source returns almost precisely to its pre-flare state. 3) Unlikely to be SGRs/AXPs/Type II bursts

4) IMBH, beaming, or other?