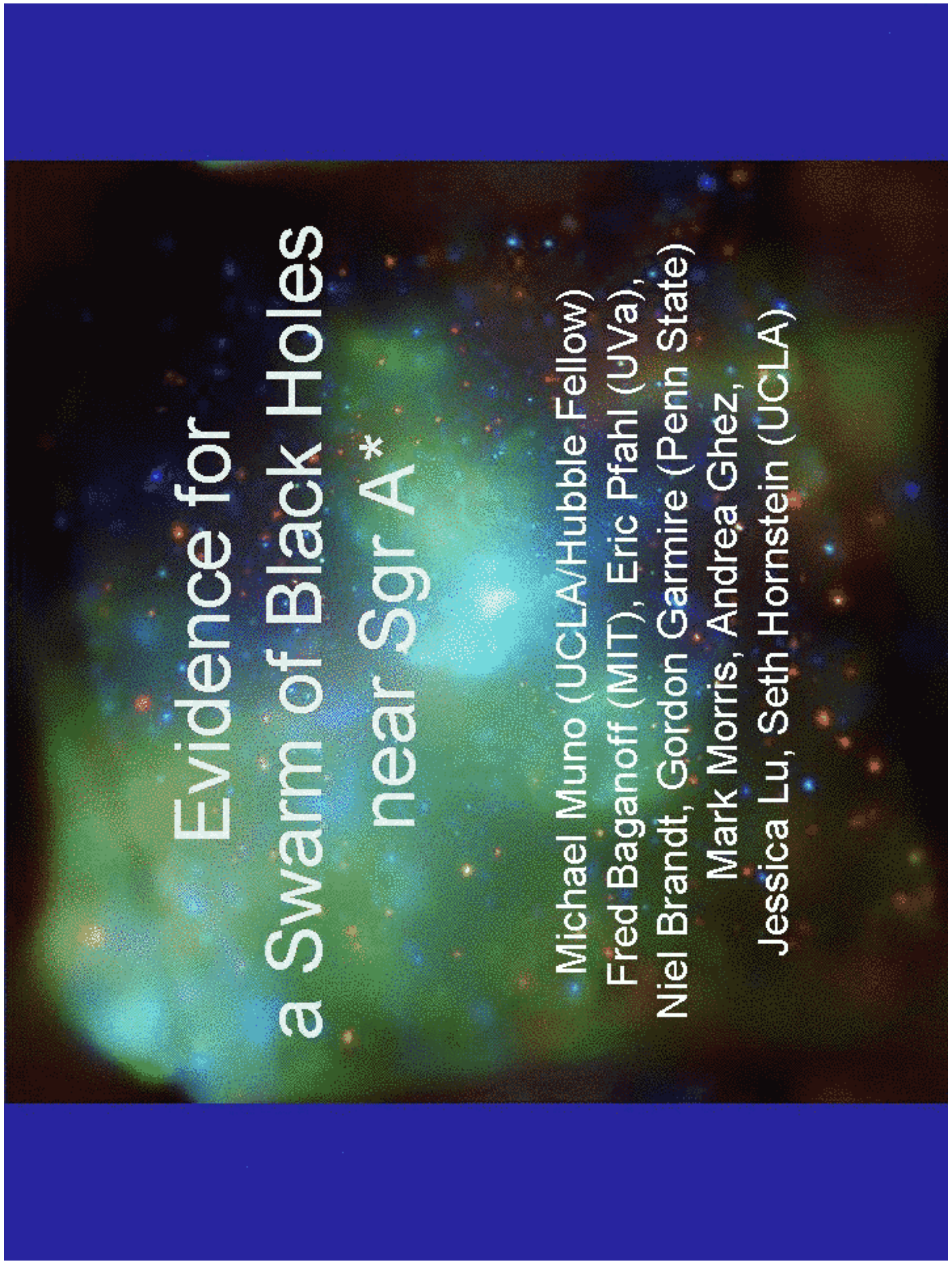
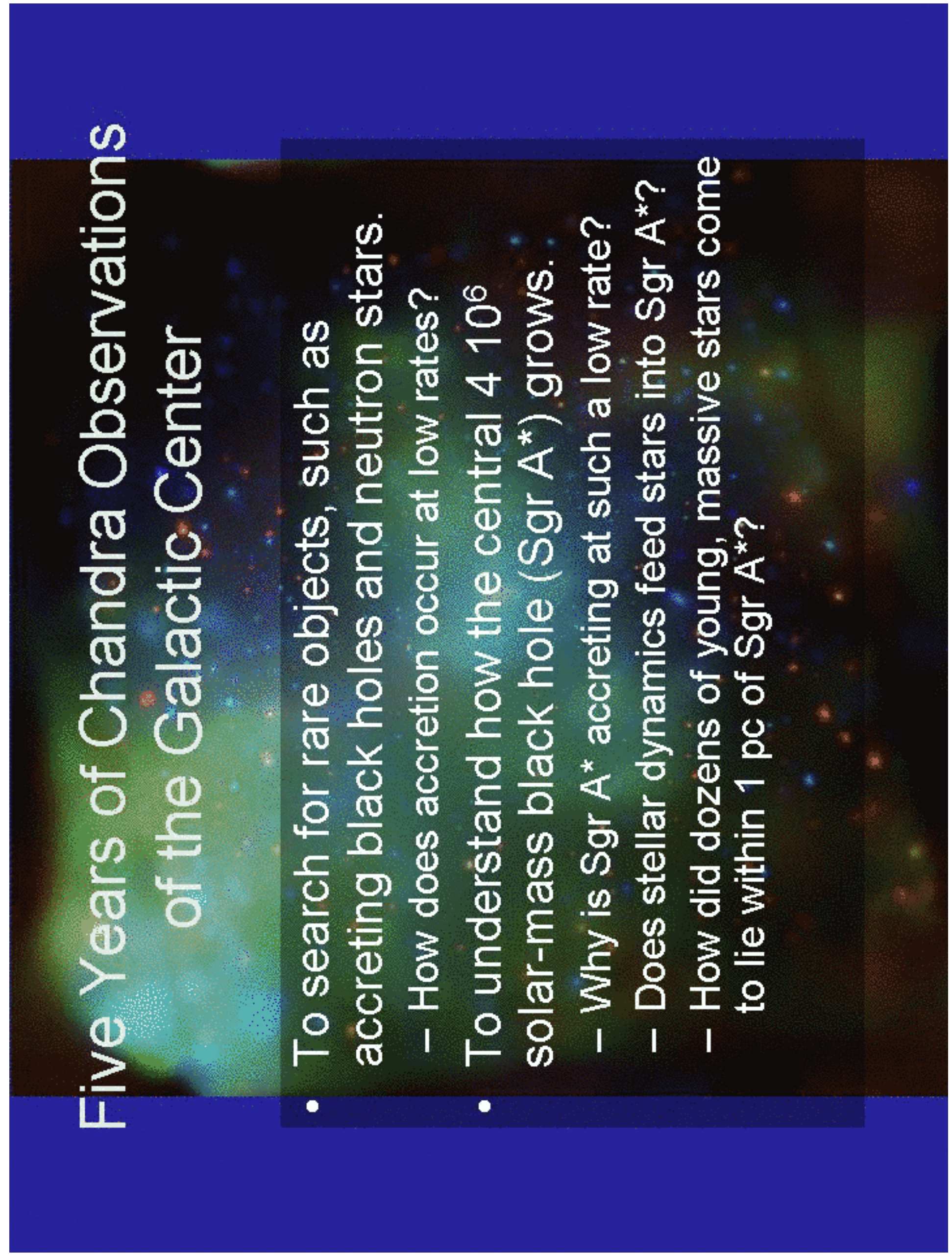
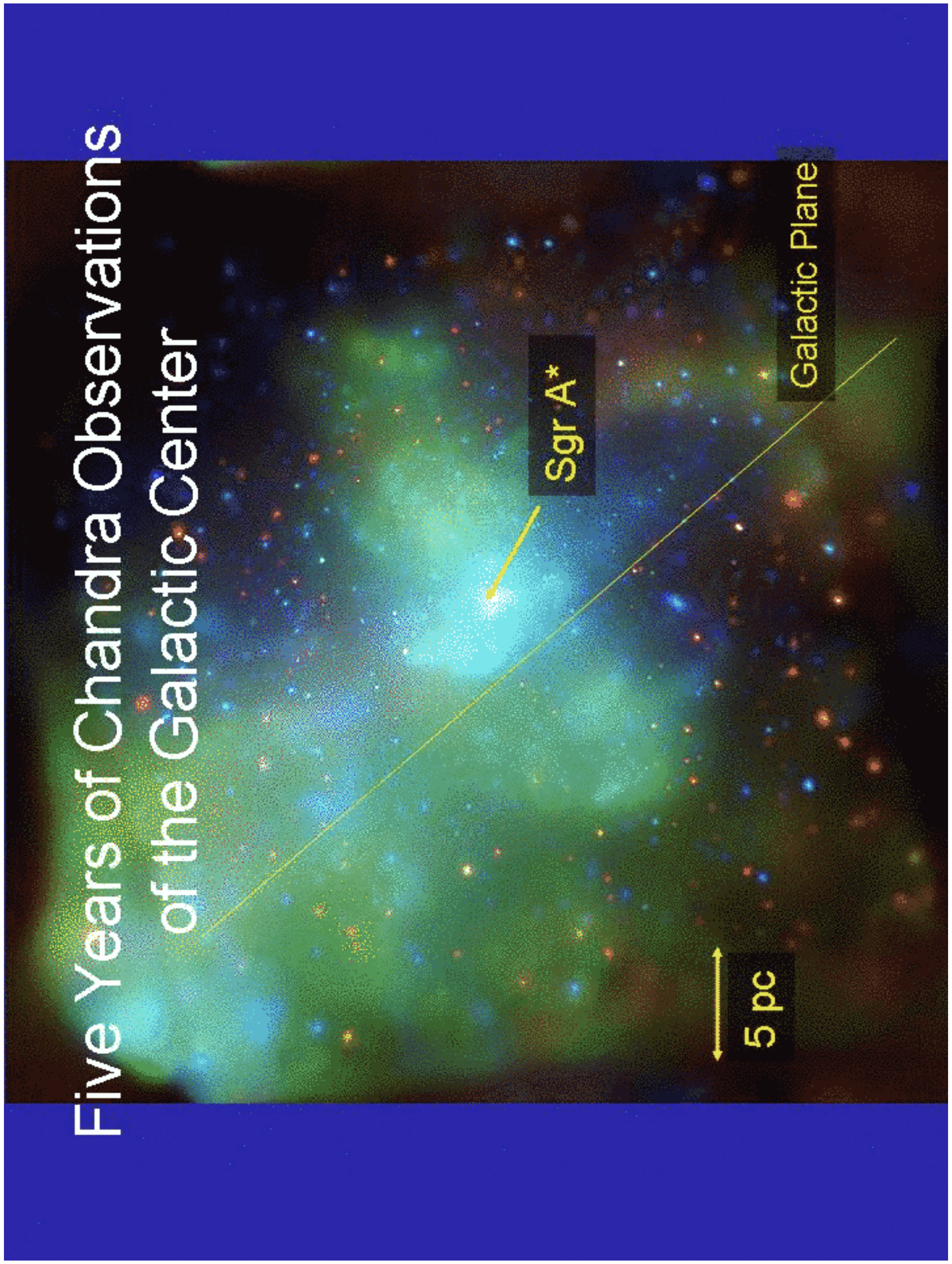
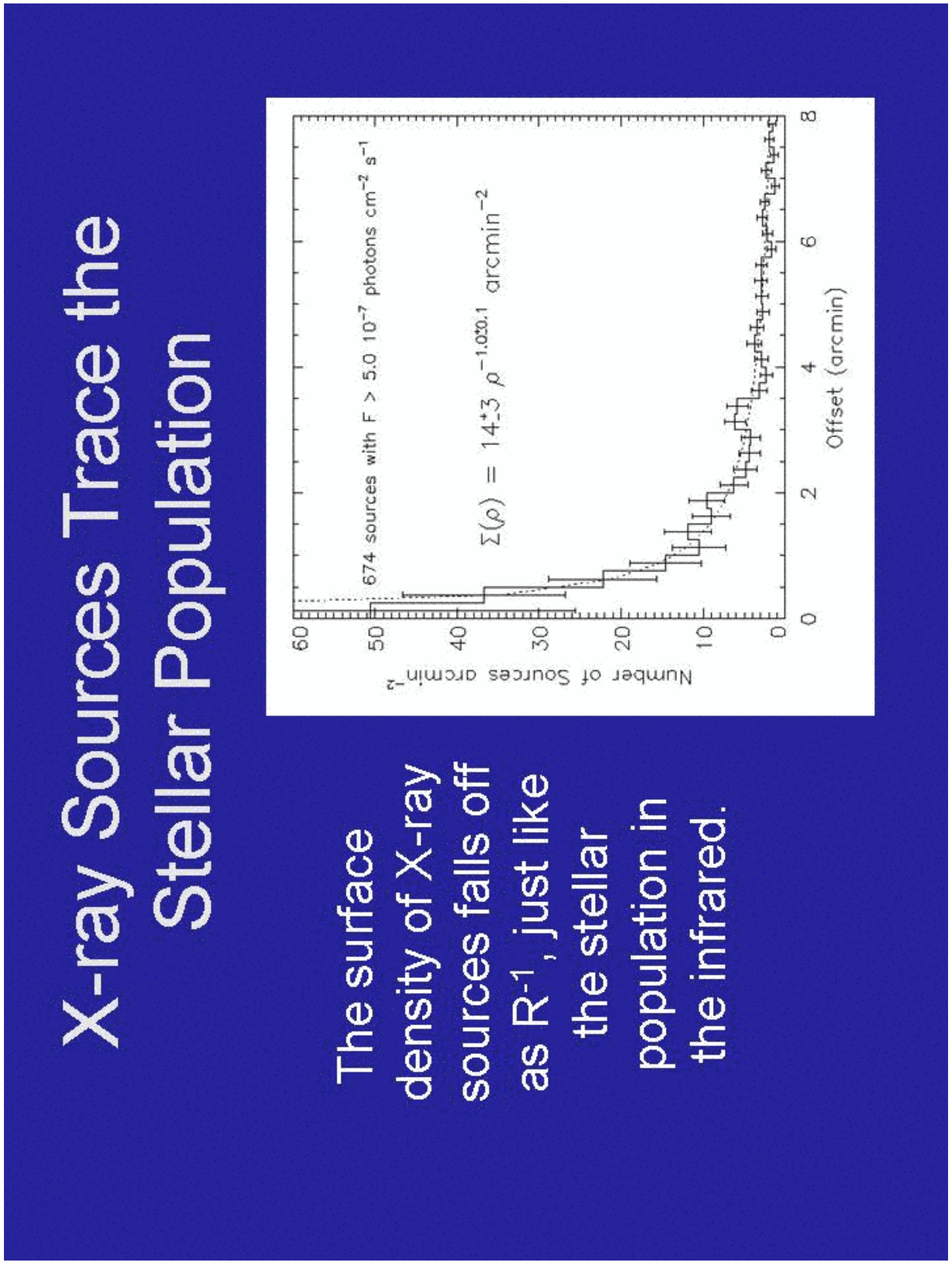

Evidence for
a Swarm of Black Holes
near Sgr A*
Michael Muno (UCLA/Hubble Fellow)
Fred Baganoff (MIT), Eric Pfahl (UVa),
Niel Brandt, Gordon Garmire (Penn State)
Mark Morris, Andrea Ghez,
Jessica Lu, Seth Hornstein (UCLA)


Five Years of Chandra Observations
of the Galactic Center
• To search for rare objects, such as accreting black holes and neutron stars.
– How does accretion occur at low rates?
• To understand how the central 4 10^6 solar-mass black hole (Sgr A*) grows.
– Why is Sgr A* accreting at such a low rate?
– Does stellar dynamics feed stars into Sgr A*?
– How did dozens of young, massive stars come to lie within 1 pc of Sgr A*?


Five Years of Chandra Observations of the Galactic Center
Sgr A*
Galactic Plane
5 pc


X-ray Sources Trace the Stellar Population
674 sources with F > 5.0 10^{-7} photons cm^{-2} s^{-1}
$\Sigma(\rho) = 14 \pm 3\ \rho^{-1.0 \pm 0.1}$ arcmin^{-2}
Number of Sources arcmin^{-2}
Offset (arcmin)
The surface density of X-ray sources falls off as R^{-1}, just like the stellar population in the infrared.

X-rays from Accreting Compact Objects

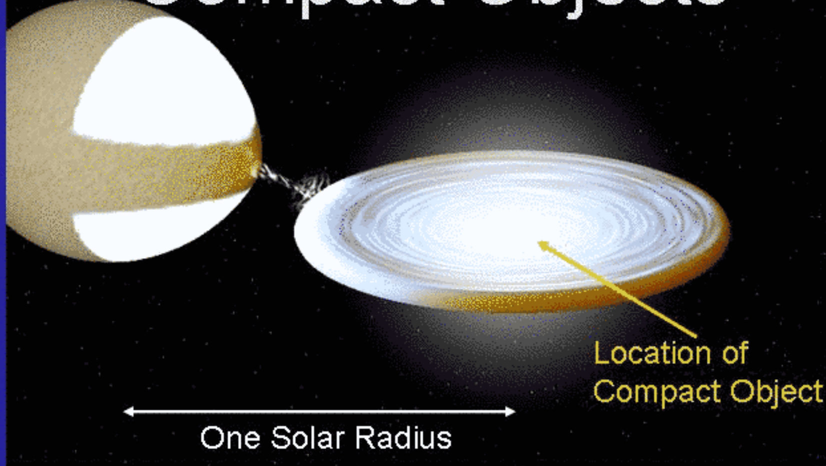
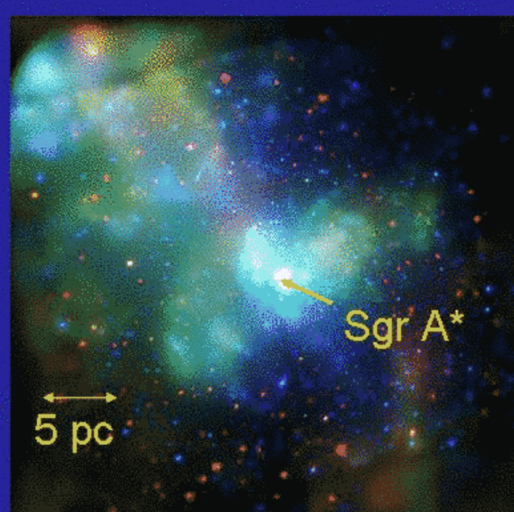


Image creates with binsim, by Rob Hynes

- Most of the X-ray sources are accreting white dwarfs, the brightest 10% of which are detectable.
- Accreting neutron stars and black holes are 100 times rarer, and most are accreting at low rates.

Searching for Accreting Compact Objects

- Sources that produce sudden outbursts with $L_X > 10^{34}$ erg s^{-1} are likely to be accreting black holes and neutron stars.
- We found 7 such transients within 25 pc of the Galactic center.

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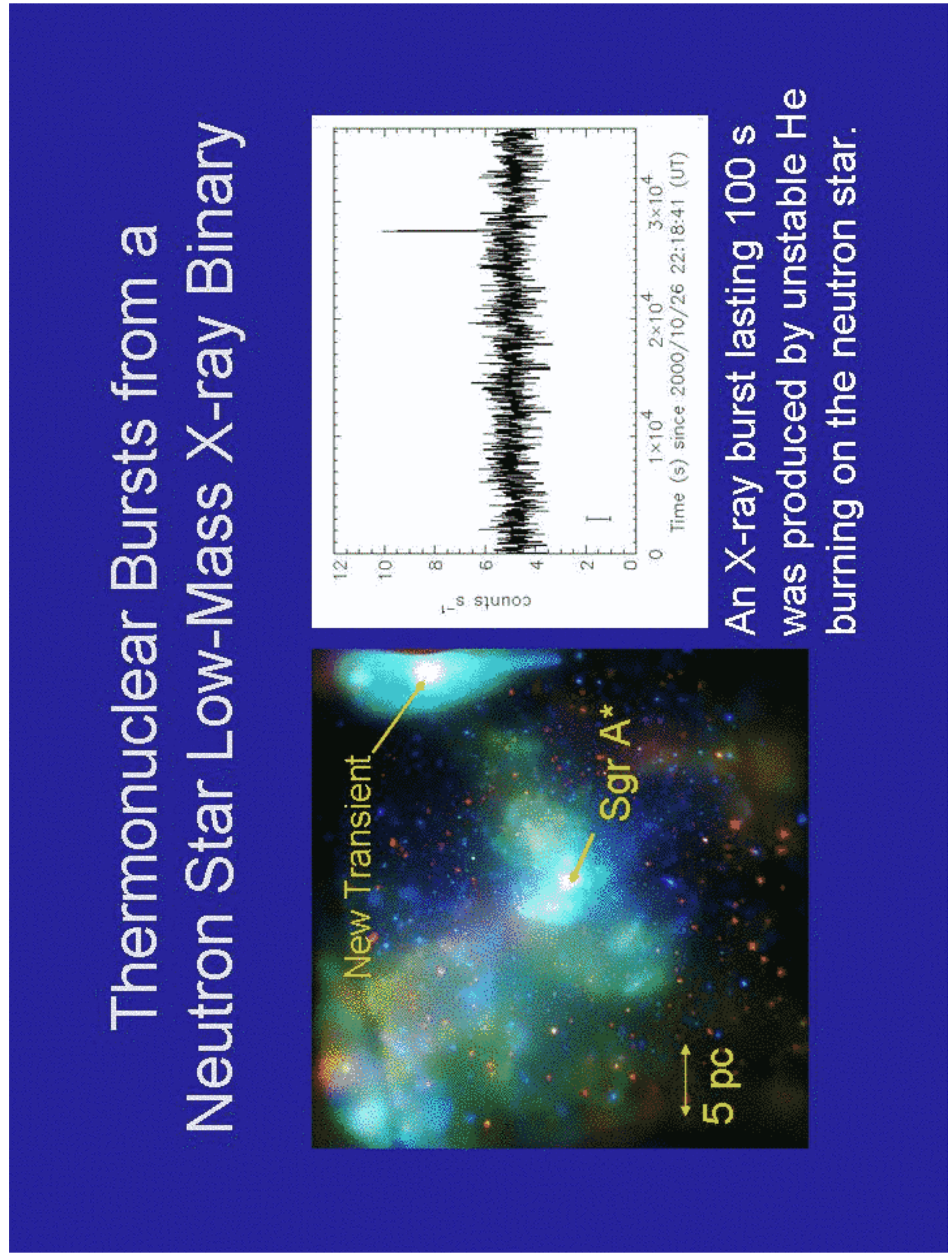
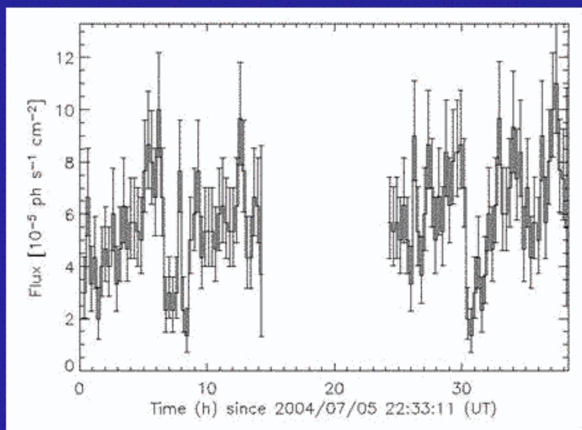
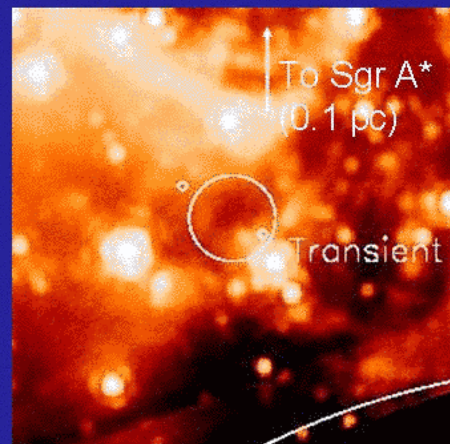
New Transient
Sgr A*
5 pc


Thermonuclear Bursts from a Neutron Star Low-Mass X-ray Binary
New Transient
Sgr A*
5 pc
counts s^{-1}
Time (s) since 2000/10/26 22:18:41 (UT)
An X-ray burst lasting 100 s was produced by unstable He burning on the neutron star.

Another LMXB (0.1 pc from Sgr A*) with Periodic Eclipses



The X-ray light curve displays partial eclipses at the 8 hour orbital period.

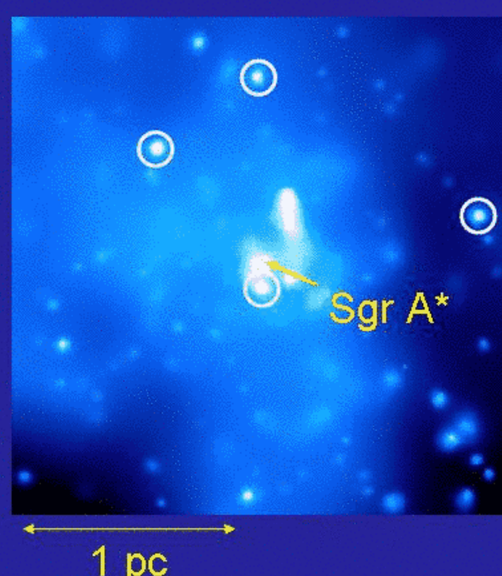


Infrared images reveal no infrared companion with K<15, ruling out a high-mass star.

Muno et al. (2005b)

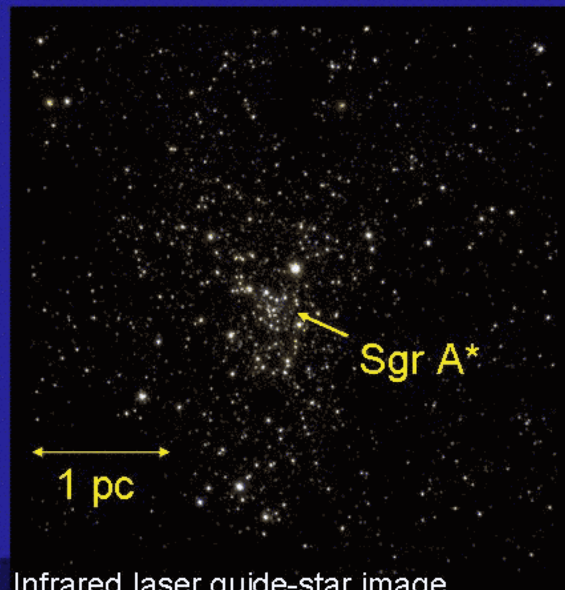
An Overabundance of X-ray Binaries in the Central Parsec

- 4 of 7 transients are within 1 pc of the Galactic Center.
- The chance of this happening randomly is $<2\times10^{-4}$.
- Transients are 20 times more abundant per unit stellar mass within 1 pc than within1--25 pc.



Young High-Mass X-ray Binaries

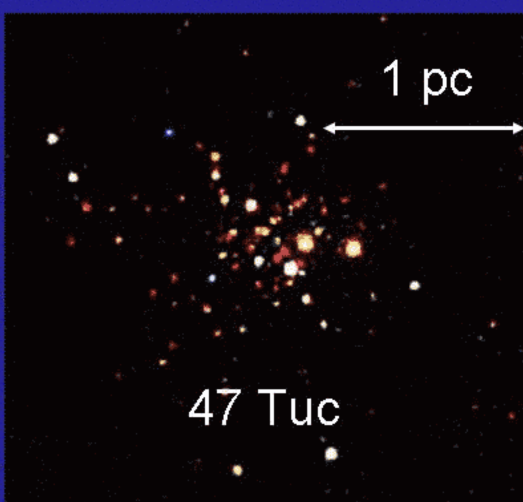
- Seven Myr ago, several dozen massive stars formed among on order 10^4 stars.
- Up to 300 black holes may have already descended from these stars.
- Up to 10% of these could be in HMXBs, or on order 30 systems.



Infrared laser guide-star image courtesy W.M. Keck Observatory.

Muno et al. (2005a)

Dynamically Forming LMXBs

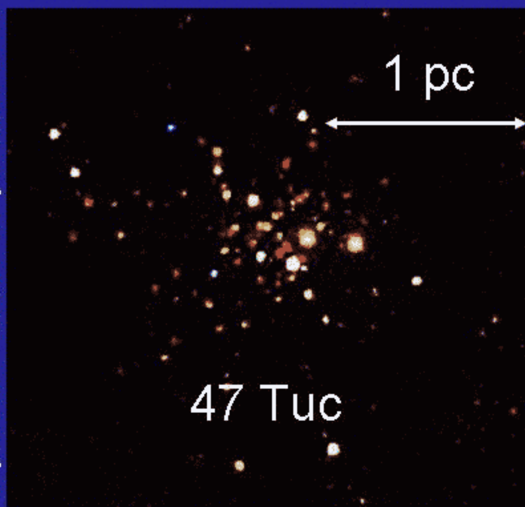


Grindlay et al. 2001; Pooley et al. 2003

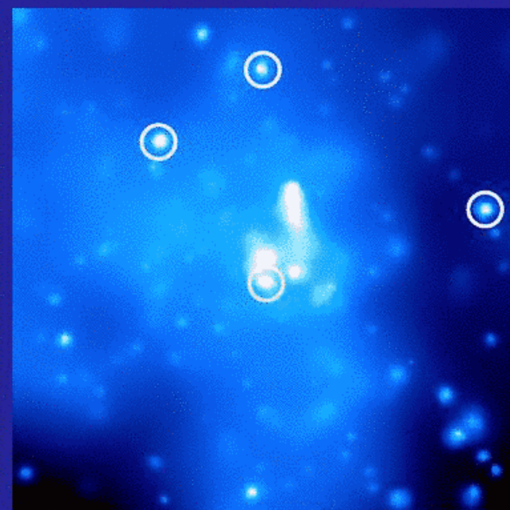
In globular clusters, LMXBs are over-abundant by a factor of 100 per unit stellar mass, because neutron stars dynamically settle into the cores and form LMXBs through single-binary exchanges.

Dynamically Forming LMXBs

Grindlay et al. 2001; Pooley et al. 2003



- $\rho_c = 6\ 10^4\ M_o\ pc^{-3}$
- $\sigma = 12\ km\ s^{-1}$

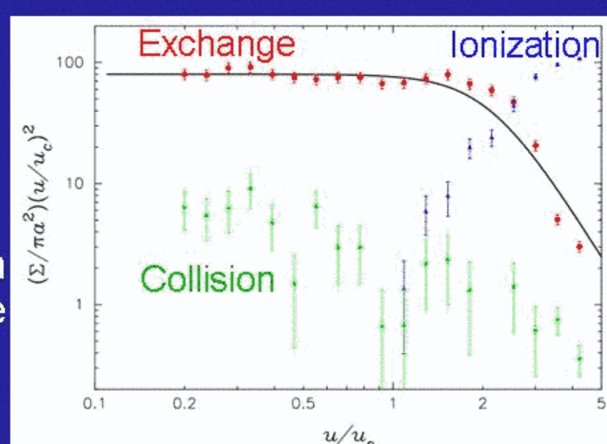


- $\rho_c = 7\ 10^6\ M_o\ pc^{-3}$
- $\sigma = 70\ km\ s^{-1}$

Interaction rate: $\Gamma \sim \int \rho^2/\ \sigma\ dr$

LMXBs Form When Black Holes Capture Stars

- 10^4 black holes have dynamically settled into the central pc (Morris 1993, Miralda-Escudé & Gould 2000).
- Pfahl & Loeb (in prep.) estimate that these form LMXBs via binary-single interactions at a rate of $10^{-6}\ yr^{-1}$.
- Over the dynamical time scale of 10 Gyr, 10^3 LMXBs could form.



simulation by E. Pfahl

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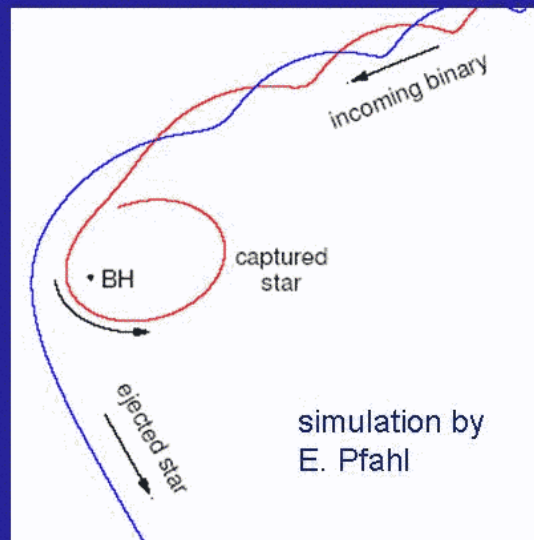

Summary and Implications

- Transient X-ray binaries are over-abundant within 1 pc of Sgr A*.
- The best explanation is that a cusp of compact objects surrounds Sgr A*.
  - This could prevent low-mass stars from remaining in the region.
  - This could allow high-mass stars to be captured onto tight orbits around Sgr A* (Alexander & Livio 2004).
  - This could result in detectable gravitational wave (LISA) events from galactic nuclei in the Local Group (talk to Eric Pfahl!).