Dynamics of Black Holes and Binaries Near Sgr A*

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with

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Recent Observations (X-ray)

Wang, Gotthelf, & Lang (2002)

280 pc

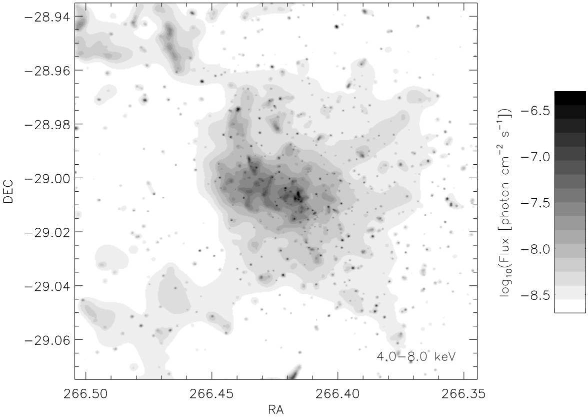
Recent Observations (X-ray)

$\sim$500 hard X-ray sources within 100 pc:

- $L_X \gtrsim 10^{33}\,\mathrm{erg\,s^{-1}}$
- Wind-accreting neutron stars?
  (Pfahl, Rappaport, & Podsiadlowski 2002)

Recent Observations (X-ray)

Muno et al. (2003)



20 pc

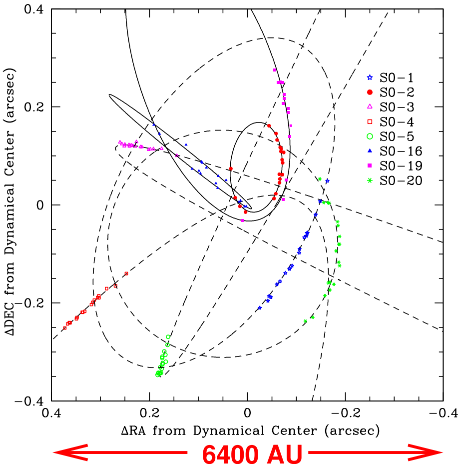
Recent Observations (X-ray)

$\sim$1000 hard X-ray sources within 10 pc:

- $L_{\rm X} \simeq 10^{30}$–$10^{33}\,{\rm erg\,s^{-1}}$
- Accreting compact objects in binaries:
  - Magnetic white dwarfs.
  - Wind-accreting neutron stars.
  - Black hole X-ray binaries.
- Surface density $\propto \theta^{-1}$.
- 7 interesting transients (more later).

Recent Observations (near-IR)

Ghez et al. (2003)



Recent Observations (near-IR)

Dozens of young stars within 4000 AU:

- Spectroscopy indicates stars are massive ($\gtrsim 10\,M_\odot$).
- Don't know how they got there.
- Two stars pass within 100 AU.
    - Sgr A* is a black hole ($[3\text{–}4] \times 10^6\,M_\odot$).
    - Do binaries play a role?
      (Gould & Quillen 2003)
- Hundreds of radio pulsars?
  (Pfahl & Loeb 2004)

The Central Parsec

- Density: $n(r) \simeq 10^5\,\mathrm{pc}^{-3}(r/\mathrm{pc})^{-2}$.
- Velocity dispersion: $\sigma(r) \simeq (GM/3r)^{1/2}$.
- Mixture of young and old stars.
- Are there binaries? (Yes.)
- $\sim 10^4$ black holes?

  (Morris 1993; Miralda-Escudé & Gould 2000)

Dynamical Friction

Energy-Loss Timescale:

$$\tau \sim 10\,\mathrm{Gyr}\left(\frac{m}{M_\odot}\right)^{-1}\left(\frac{r}{\mathrm{pc}}\right)^{1/2}$$

- Only 1 Gyr for $10\,M_\odot$ black holes.
- Steady number of $\gtrsim 10^4$.
- Binaries also migrate faster than average.

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Energy-Loss Timescale:

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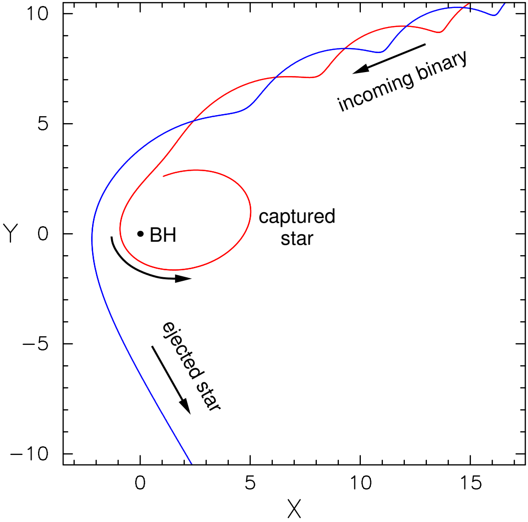
- Only 1 Gyr for 10 $M_\odot$ black holes.
- Steady number of $\gtrsim 10^4$.
- Binaries also migrate faster than average.

Exchange encounters between binaries and black holes!

Exchange Interaction



Exchange Rate

1. Proportions:
   - Binaries $\sim$10% of the stars.
   - Black holes $\sim$1% of the stars.

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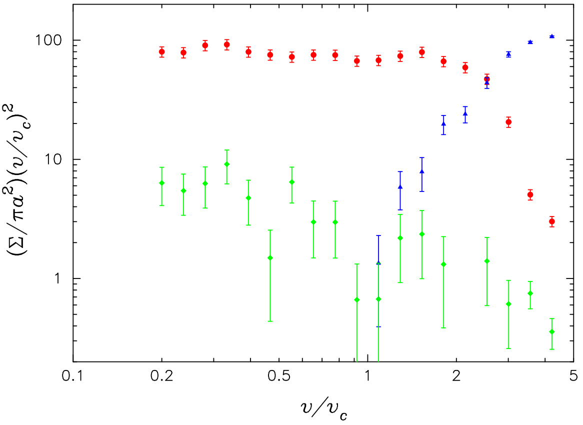
Exchange cross section: $\Sigma \simeq 4\pi \langle a \rangle G(\langle M_b \rangle + M_{BH})\sigma^{-2}$.

Cross Sections

$(1+1)+10$

Exchange—Ionization—Collision



Exchange Rate

Rate per black hole:

$$\Gamma(r) \sim n_{\rm bin}\,\Sigma\,\sigma$$
$$\sim \text{few} \times 10^{-11}\,\text{yr}^{-1}\left(\frac{r}{\rm pc}\right)^{-3/2} \quad .$$

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Total rate in the central parsec:

$$\Gamma_{\rm tot} = 4\pi\int_{0.1\,\text{pc}}^{1\,\text{pc}} dr\, r^2\, n_{\rm BH}(r)\,\Gamma(r)$$
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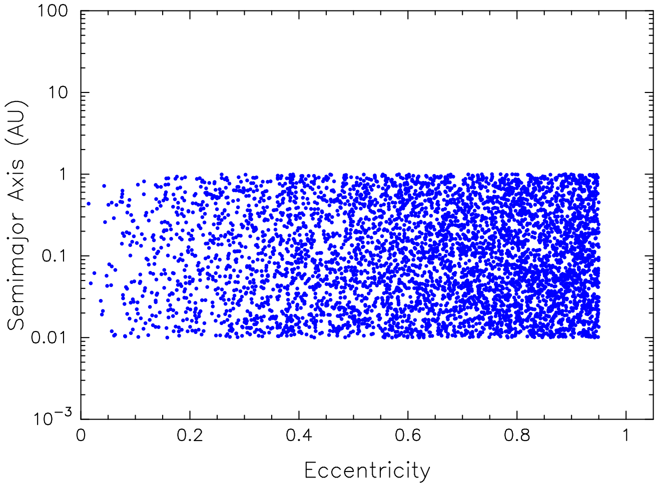
Lifetime: $\lesssim 10^9$ yr for dynamical friction.

Maybe 100-1000 black holes with $\sim 1\,M_\odot$ companions.

Simulations

Blue = $1 + 1$; Red = $1 + 10$; $N = 5000$



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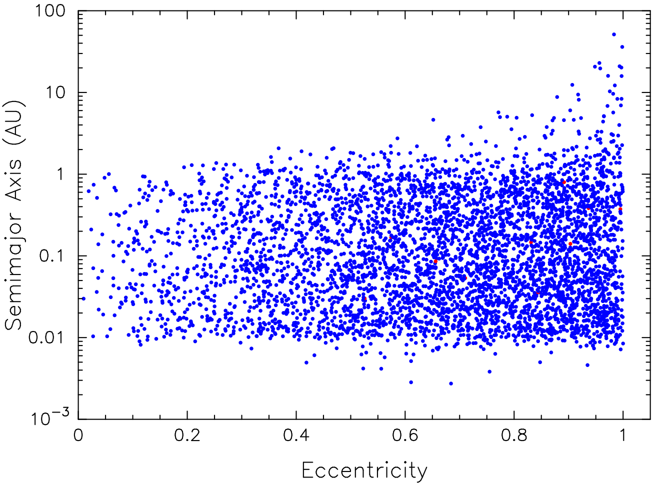
Blue = $1 + 1$; Red = $1 + 10$; $N = 4725$



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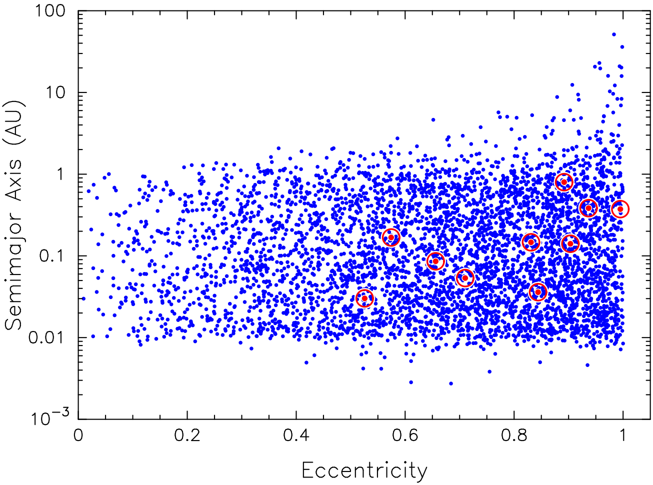

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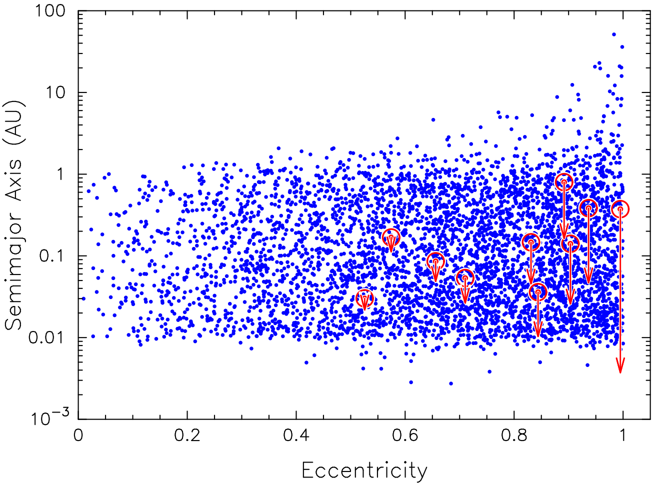
Blue = 1 + 1; Red = 1 + 10; $N = 4725$ $a \rightarrow a(1 - e^2)$



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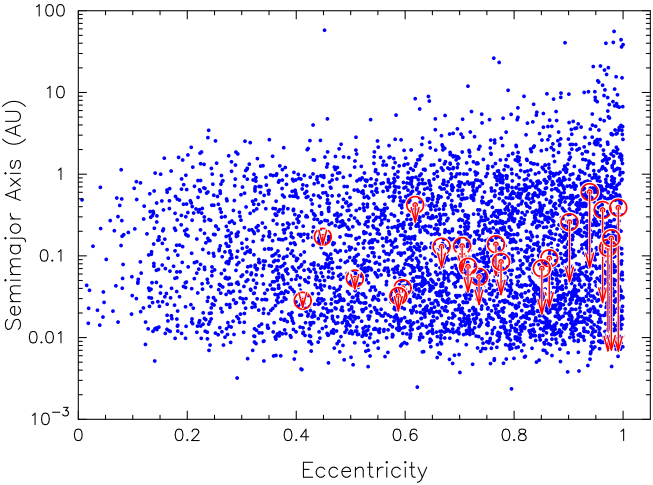
Blue = $1 + 1$; Red = $1 + 10$; $N = 4489$



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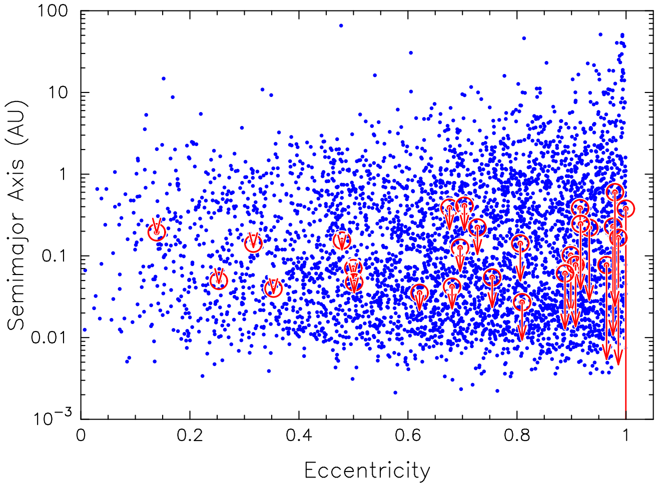
Blue = 1 + 1; Red = 1 + 10; $N = 4264$



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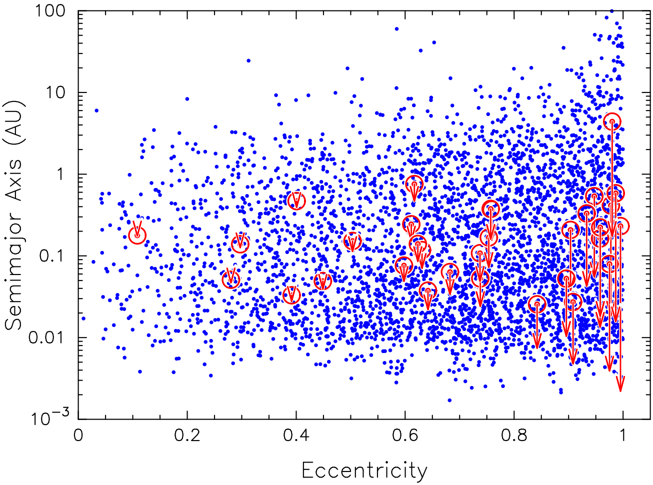
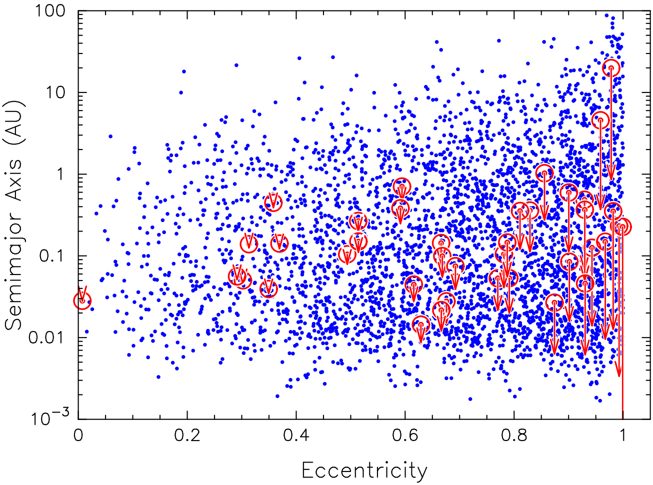
Blue = $1 + 1$; Red = $1 + 10$; $N = 4070$



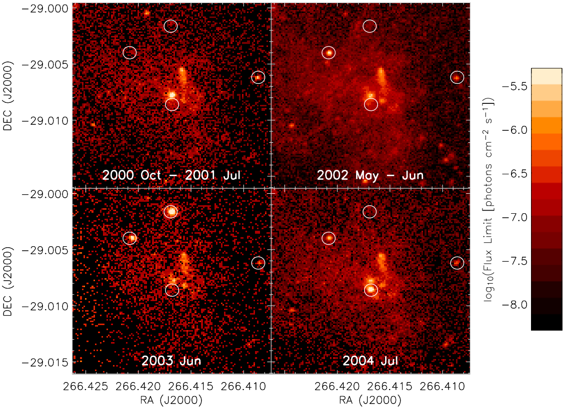
Simulations

Blue = $1 + 1$; Red = $1 + 10$; $N = 3870$



X-ray Transients

Muno, Pfahl et al. (2004)



←2.5 pc→

X-ray Transients

Source (CXOGC J)	Offset (arcmin)	Min L_X 2–8 keV	Max L_X 2–8 keV
174502.3–285450	9.98	$< 7 \times 10^{31}$	1.5×10^{36}
174554.3–285454	6.38	$< 2 \times 10^{31}$	6.2×10^{34}
174535.5–290124	1.35	$< 9 \times 10^{30}$	3.3×10^{35}
174538.0–290022	0.44	1.2×10^{33}	2.6×10^{34}
174540.0–290005	0.37	$< 4 \times 10^{31}$	3.4×10^{34}
174541.0–290014	0.31	$< 8 \times 10^{31}$	4.8×10^{33}
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- 4 transients inside $0.5'$ (1 pc); 3 within 1–$10'$ (2.5–25 pc).
- Mass within 1 pc is $\sim 2 \times 10^6\, M_\odot$.
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- Mass within 1 pc is $\sim 2 \times 10^6 M_\odot$.
- Mass in 2.5–25 pc is $\sim 5 \times 10^7 M_\odot$.
- $(N/M)_1 \sim 2 \times 10^{-6}$; $(N/M)_{2.5-25} \sim 6 \times 10^{-8}$
- Overabundance per unit mass of $\sim$30 in the central parsec.

Double Black Holes

- $(1 + 10) + 10 \rightarrow (10 + 10) + 1$
- Cross section similar to $(1 + 1) + 10$.
- Proportion of single black holes same.
- Pool of $(1 + 10)$ binaries only 0.1-1% of the total.

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Important gravity-wave sources?

$$\tau_{\rm GW} \simeq 1.6 \times 10^{10}\,{\rm yr}\,\left(\frac{a}{0.1\,{\rm AU}}\right)^4 \left(\frac{M}{10\,M_\odot}\right)^{-3} (1-e^2)^{7/2}$$

Outlook

Next Steps:

1. Full spectrum of stellar masses and evolutionary states.
2. All varieties of compact objects.
3. Proper rate estimates and more realistic simulations.

Specific Problems:

1. Sources of X-rays and gravitational radiation.
2. Double compact-object binaries.
3. Collisions in general.
4. Collisions between black holes and stars.
5. Generalize to other galactic nuclei.