Probing the Spacetime Around Sgr A* with Radio Pulsars

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*Massive Stars Orbiting Sgr A**

- Near-IR observations have revealed roughly two dozen stars within $\simeq 0\overset{\prime\prime}{.}5$ of Sgr A*.

- Dynamics $\Rightarrow$ black hole of mass $(3\text{–}4) \times 10^6\, M_\odot$.

- Spectral evidence suggests that many of the stars have masses of 10–20 $M_\odot$.

Massive stars leave neutron-star remnants . . .

Radio pulsars!

Number of Pulsars

- Steady-state population of $\sim$10–100 massive stars with orbital periods of $\lesssim 100\,\mathrm{yr}$.

- Stellar lifetimes of $\sim 10^7$ yr $\Rightarrow$ NS birthrate of 10^{-6}–$10^{-5}\,\mathrm{yr}^{-1}$.

- Characteristic pulsar lifetime of $(1\text{–}5) \times 10^8$ yr $\Rightarrow$ $\sim$100–5000 active radio pulsars.

What is the detectable fraction?

Pulsar Statistics

Take the steady-state assumption further, and use the statistics of the Galactic pulsar population:

- 400-MHz luminosity function: $p(L_{400}) \propto L_{400}^{-2}$.
- Luminosity to flux: $L_\nu \simeq D^2 S_\nu$.
- Spectrum: $S_\nu \propto \nu^{-\alpha}$.
- Spectral slopes: $p(\alpha) \propto \begin{cases} \exp[-(\alpha - \langle\alpha\rangle)^2/2\sigma_\alpha] & \alpha > 0 \\ 0 & \alpha < 0 \end{cases}$

  ($\langle\alpha\rangle \simeq 1.7$, $\sigma_\alpha \simeq 0.8$)

Pulsar Detection: High-Frequency Surveys

Extreme radio-wave scattering:

- Angular broadening of $\simeq 1''(\nu/\mathrm{GHz})^{-2}$ for Sgr A*.
- Temporal smearing of $\sim 300\ \mathrm{s}\,(\nu/\mathrm{GHz})^{-4}$ vs pulse period of $P_p \sim 1$ s.
- Optimum observing frequency: $\nu' \simeq 7\,\mathrm{GHz}\,(\alpha^{1/2}P_p)^{-1/4}$ (Cordes & Lazio 1997).
- Pulsed flux sensitivity (e.g., GBT):

$$S_{\mathrm{min}} \simeq 20\text{–}40\,\mu\mathrm{Jy}\left[\frac{\epsilon}{0.05}\cdot\frac{1\,\mathrm{GHz}}{\Delta\nu}\cdot\frac{1\,\mathrm{hr}}{t_{\mathrm{int}}}\right]^{1/2}$$

Detectable Fraction

$S_{\rm min}$ (μJy)	ν (GHz)	$F_{\rm det}$ (%)
25	10	2.4
25	15	2.0
25	20	1.8
50	10	1.2
50	15	1.0
50	20	0.9

- Detectable fraction $\sim$1%.
- Not much variation with ν.

Several tens of pulsars may orbit Sgr A* with $P_{\rm orb} \lesssim 100$ yr and $S > S_{\rm min}$. The beaming fraction is $\simeq$0.2, and so perhaps a few pulsars will be detectable with current telescopes.

Pulsar Timing

Analysis of pulse arrival times reveals the dynamics of a pulsar orbiting Sgr A*.

- Arrival-time precisions are $\delta t \sim (10^{-3}$–$10^{-2})P_p$, or $\sim$1–10 ms.
- The RMS timing precision is then $\sim\delta t/\sqrt{N}$, which is $\lesssim$1 ms for $N \sim 100$.
- Pulsar spin-down model: $\phi = \nu_p T + \dot{\nu}_p T^2/2 + \ldots$
- Time delays: $t - t_0 = T + \sum_i \Delta_i$.

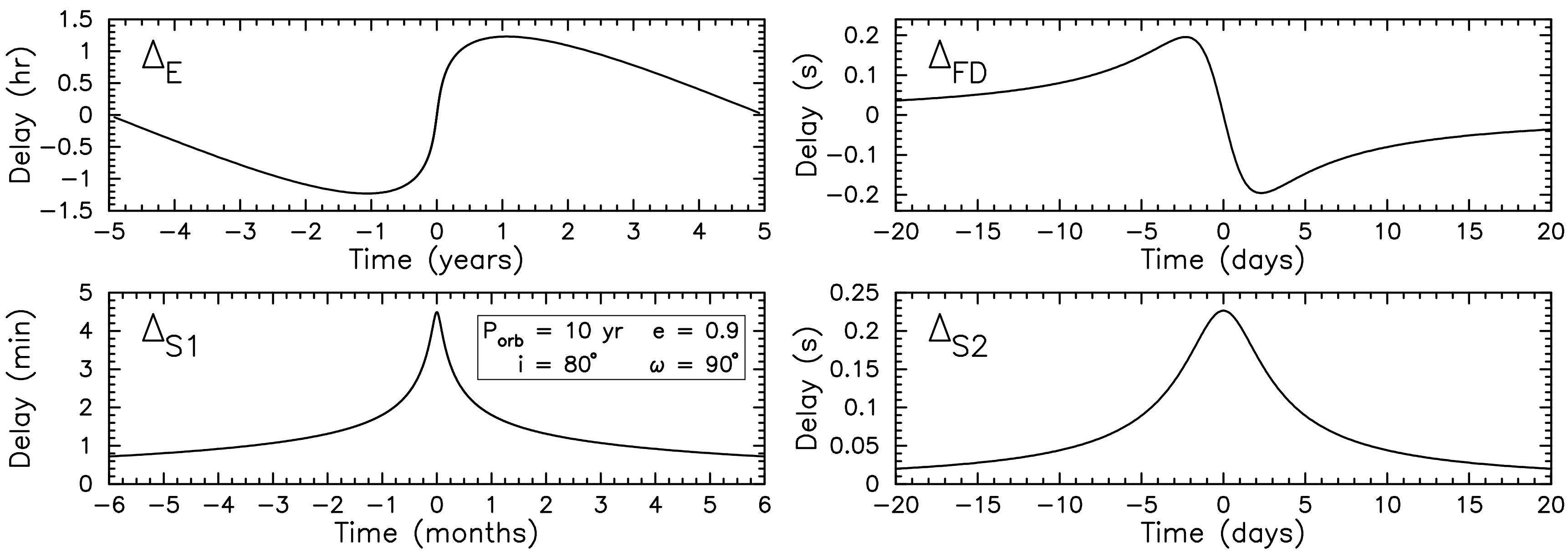
Largest post-Keplerian timing residuals:

(1) Einstein

(2) First-order Shapiro

(3) Frame-Dragging

(4) Second-order Shapiro



Other Issues

- Probe the accretion flow onto the black hole via dispersion-measure variations.
- Dynamics of the Sgr A^* cluster. Gravitational perturbations may be evident in the timing residuals.
- Radio imaging and astrometry. It may be possible to measure the precession of the orbit and determine the spin of the black hole in 3-D.