Probing the vicinity of the Galactic Center black hole with LISA

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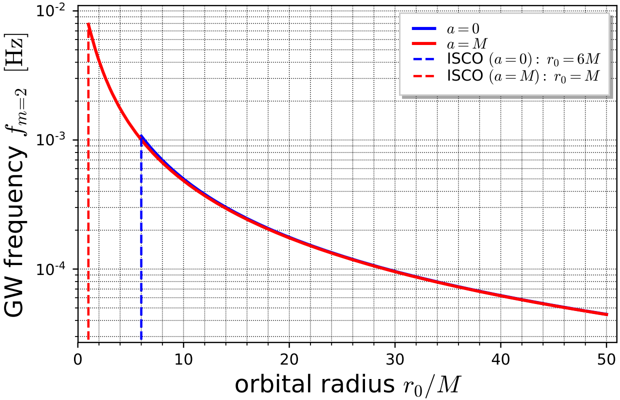
GW frequencies from circular orbits around Sgr A*



Angular velocity of circular equatorial orbits around a Kerr BH

$$\omega_0 = \frac{M^{1/2}}{r_0^{3/2} + aM^{1/2}}$$

Dominant GW frequency

$$f_{m=2} = \frac{\omega_0}{\pi}$$

Sgr A* mass

$$\begin{aligned} M &= 4.10 \times 10^6 \, M_\odot \\ &= 20.2 \text{ s} \end{aligned}$$

[Gravity team, A&A **615**, L15 (2018)]

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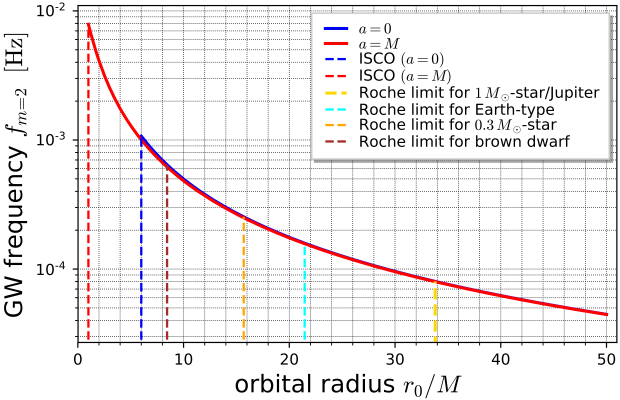

Roche radius: $r_{\rm R} \simeq 1.14 \left(\frac{M}{\rho}\right)^{1/3}$

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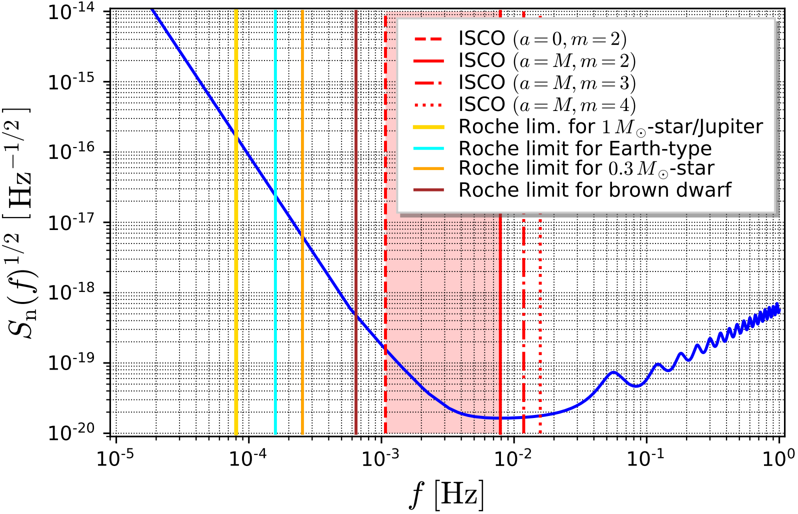
Frequencies of Sgr A* close orbits are in LISA bandwidth



ISCO for $a = M$: $f_{m=2} = 7.9\ \mathrm{mHz}$

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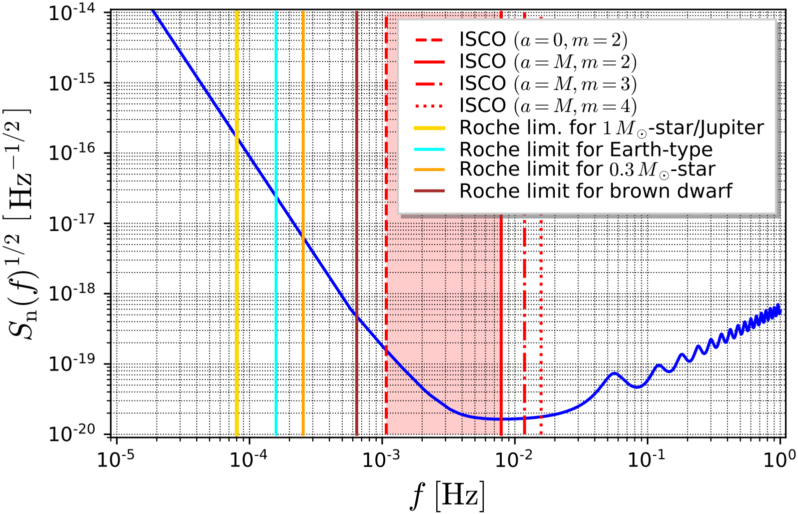
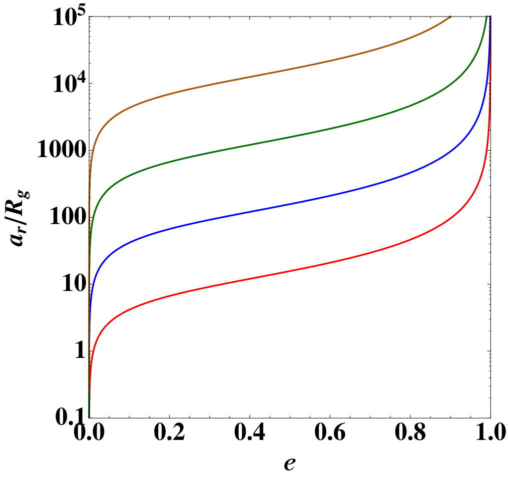


ISCO for $a = M$: $f_{m=2} = 7.9\ \mathrm{mHz}$ ← coincides with LISA max. sensitivity!

Why focusing on circular orbits?



[Dai, Blandford, Eggleton, MNRAS **434**, 2940 (2013)]

Evolution of the eccentricity due to gravitational radiation:

- red: $e_0 = 0.9999$
- blue: $e_0 = 0.999$
- green: $e_0 = 0.99$
- brown: $e_0 = 0.9$

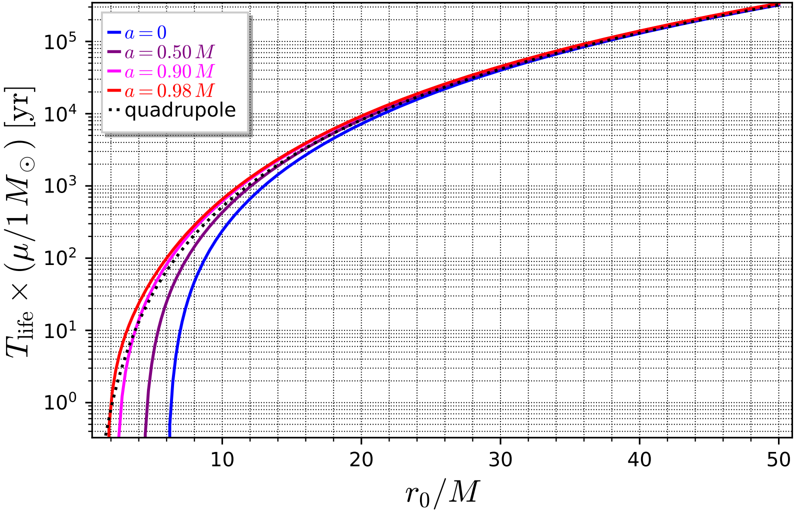
a_r: semi-major axis

$R_g = M$

Rapid decay

$$e_0 \leq 0.99 \Longrightarrow \left| \begin{array}{l} e < 0.01 \\ \text{when } a_r < 100M \end{array} \right.$$

Life time of circular orbits



$T_{\rm life}$: time to reach the ISCO on the slow inspiral induced by gravitational radiation reaction

Waveforms

Teukolsky (1973), Detweiler (1978)

$$h_+ - \mathrm{i} h_\times = \frac{2\mu}{r} \sum_{\ell=2}^{\infty} \sum_{\substack{m=-\ell \\ m\neq 0}}^{\ell} \frac{Z^{\infty}_{\ell m}(r_0)}{(m\omega_0)^2} \, {}_{-2}S^{am\omega_0}_{\ell m}(\theta,\varphi) \, \mathrm{e}^{-\mathrm{i}m(\omega_0(t-r_*)+\varphi_0)}$$

μ: mass of orbiting object; (t, r, θ, φ): Boyer-Lindquist coordinates of the observer

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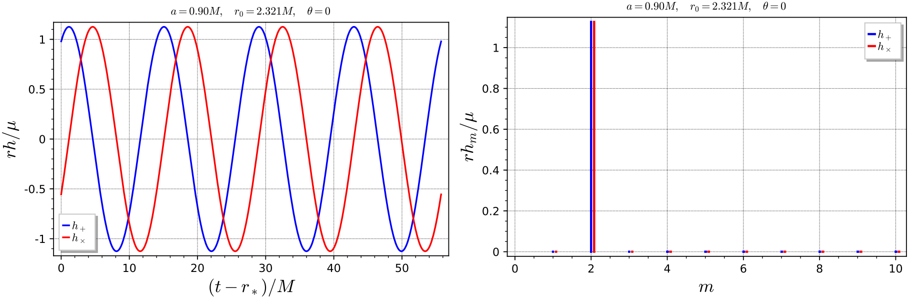
Example for $a = 0.9\,M$, $r_0 = r_{\mathrm{ISCO}}(a)$:

Viewing angle $\theta = 0$ (face-on)



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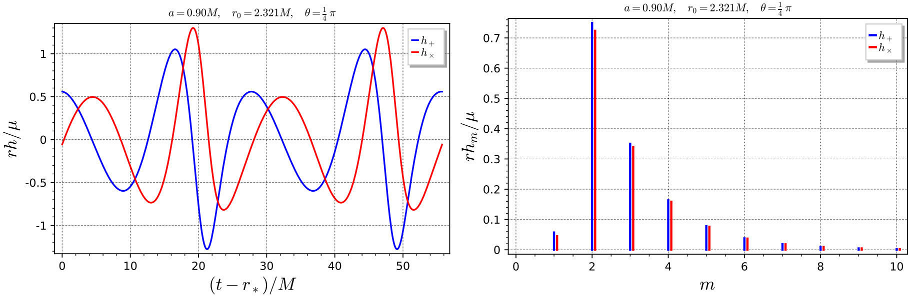
Example for $a = 0.9\,M$, $r_0 = r_{\rm ISCO}(a)$:

Viewing angle $\theta = \pi/4$



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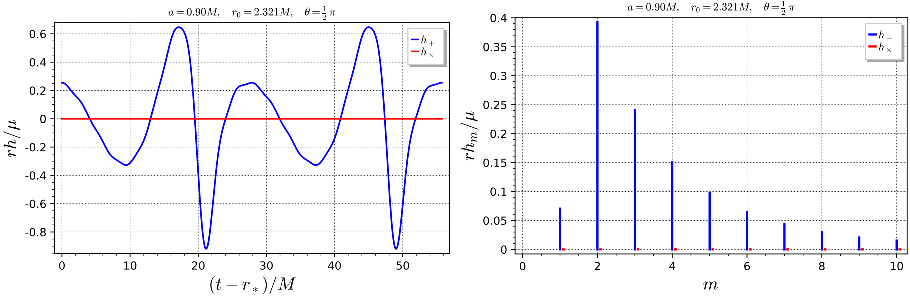
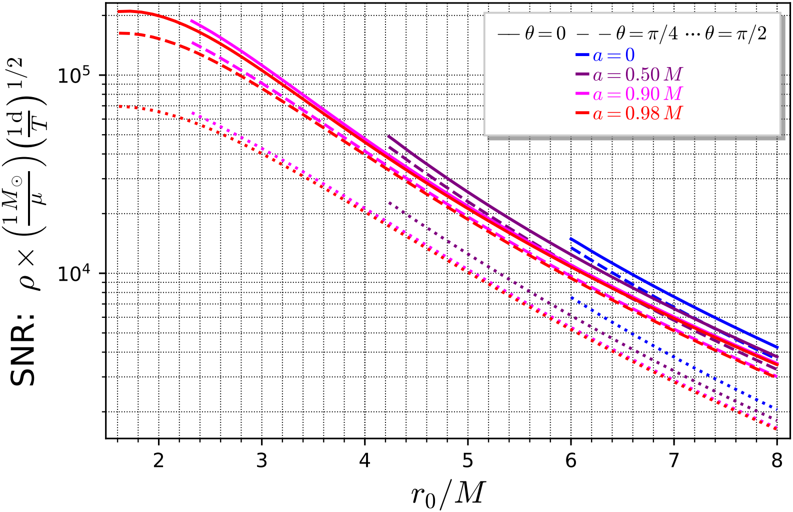
Example for $a = 0.9\,M$, $r_0 = r_{\mathrm{ISCO}}(a)$:

Viewing angle $\theta = \pi/2$ (edge-on)



Signal-to-noise ratio in the LISA detector



[Gourgoulhon, Le Tiec, Vincent & Warburton, in preparation]

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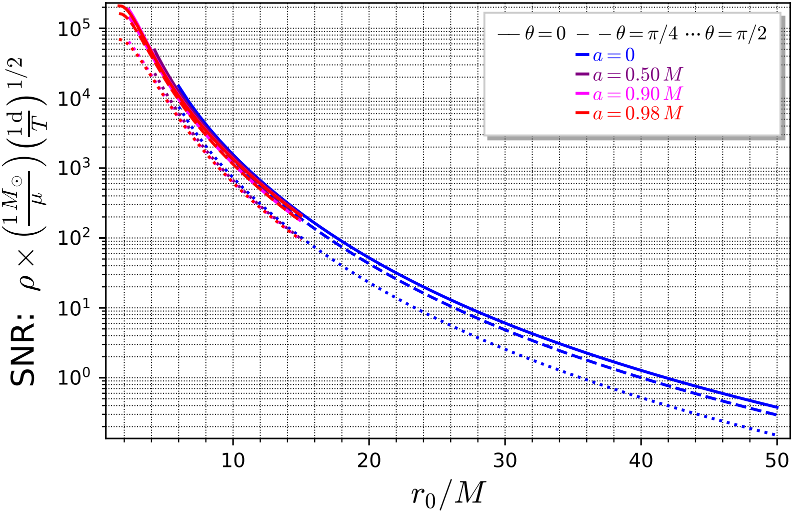

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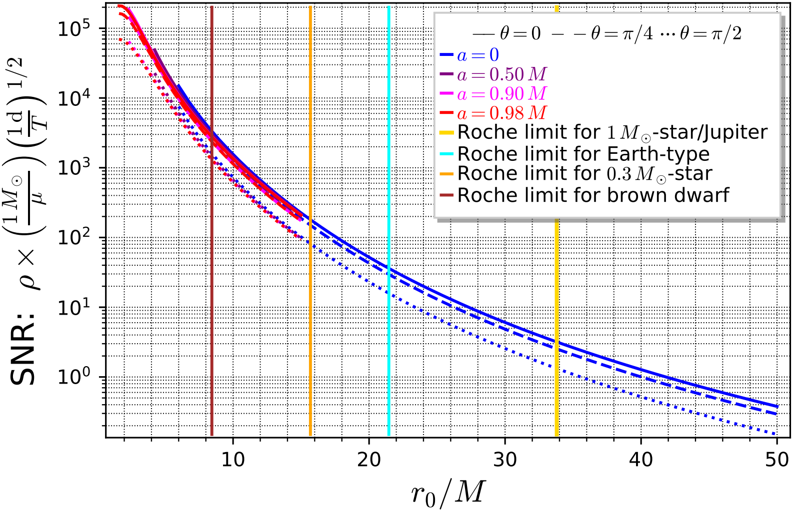

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Signal-to-noise ratio in the LISA detector

object	r_0/M	SNR$\times\dfrac{1\,M_\odot}{\mu}$ (1 day)	SNR$\times\dfrac{1\,M_\odot}{\mu}$ (1 year)
$1M_\odot$-MS star / Jupyter	34.5	3.2	61
rocky	21.5	36	690
$0.3M_\odot$-MS star	15.7	180	3.4×10^3
$0.05M_\odot$-brown dwarf	8.4	3.3×10^3	6.4×10^4
compact object $(a=0)$	6	1.5×10^4	2.8×10^5
compact obj. $(a=0.5M)$	4.23	4.9×10^4	9.4×10^5
compact obj. $(a=0.98M)$	1.61	2.1×10^5	4.0×10^6

MS: main sequence
compact object: white dwarf, neutron star, stellar-mass black hole

Potential sources

- Formation of stars close to Sgr A* during a past AGN phase [Collin & Zahn, A&A **477**, 419 (2008)]
  detailed studies of star evolution driven by gravitational radiation + Roche lobe overflow: [Dai & Blandford, MNRAS **434**, 2948 (2013)], [Linial & Sari, MNRAS **469**, 2441 (2017)] $\Longrightarrow$ inverse chirp

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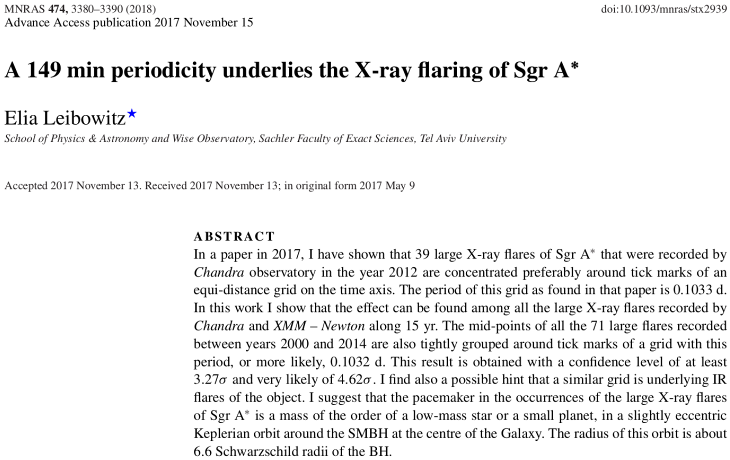
- Clumps in some dark matter spike [Le Tiec et al., in preparation]

A candidate?



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doi:10.1093/mnras/stx2939

A 149 min periodicity underlies the X-ray flaring of Sgr A*

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ABSTRACT

In a paper in 2017, I have shown that 39 large X-ray flares of Sgr A* that were recorded by *Chandra* observatory in the year 2012 are concentrated preferably around tick marks of an equi-distance grid on the time axis. The period of this grid as found in that paper is 0.1033 d. In this work I show that the effect can be found among all the large X-ray flares recorded by *Chandra* and *XMM – Newton* along 15 yr. The mid-points of all the 71 large flares recorded between years 2000 and 2014 are also tightly grouped around tick marks of a grid with this period, or more likely, 0.1032 d. This result is obtained with a confidence level of at least 3.27σ and very likely of 4.62σ. I find also a possible hint that a similar grid is underlying IR flares of the object. I suggest that the pacemaker in the occurrences of the large X-ray flares of Sgr A* is a mass of the order of a low-mass star or a small planet, in a slightly eccentric Keplerian orbit around the SMBH at the centre of the Galaxy. The radius of this orbit is about 6.6 Schwarzschild radii of the BH.

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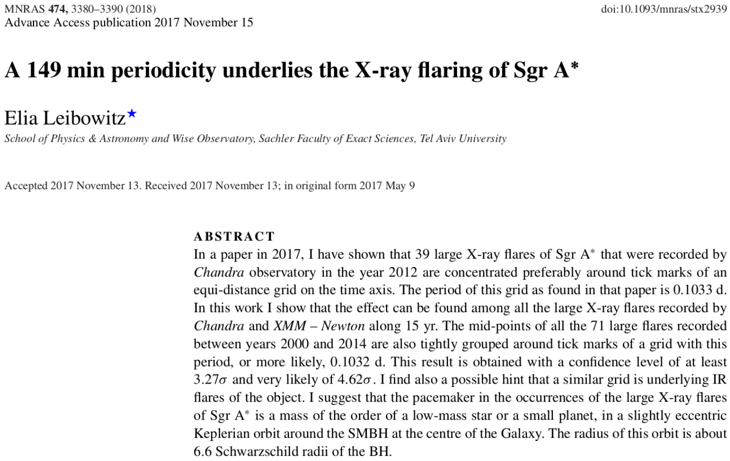

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star $\mu = 0.18\, M_\odot$, $r_0 = 13.2M$ $\Longrightarrow$ SNR = 76 in 1 day of LISA data!

Artificial sources?

The massive BH Sgr A* is a unique object in our Galaxy.
If[1] an advanced civilization exists, or has existed, in the Galaxy, it would seem unlikely that it has not shown any interest in Sgr A*...

It would indeed seem natural that an advanced civilization has put some material in close orbit around Sgr A*, for instance to extract energy from Sgr A* via the Penrose process.

Whatever the reason for which the advanced civilization acted so (it could be for purposes that we humans simply cannot imagine), the orbital motion of this material necessarily emit gravitational waves and if the mass is large enough, these waves could be detected by LISA.

This potentiality is discussed further in [Abramowicz, Bejger, Gourgoulhon & Straub, in preparation], in the form of on a long lasting Jupiter-mass orbiter, left as a "messenger" by an advanced civilization, which possibly disappeared billions of years ago.

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[1] Granted, this is a big *if*...