Probing the vicinity of the Galactic Center black hole with LISA

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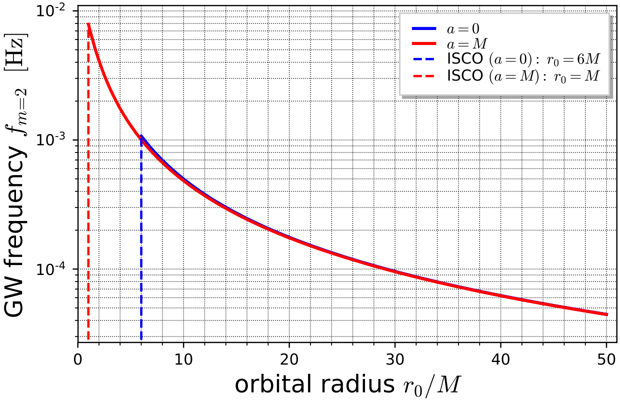
GW frequencies from circular orbits around Sgr A*



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

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

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

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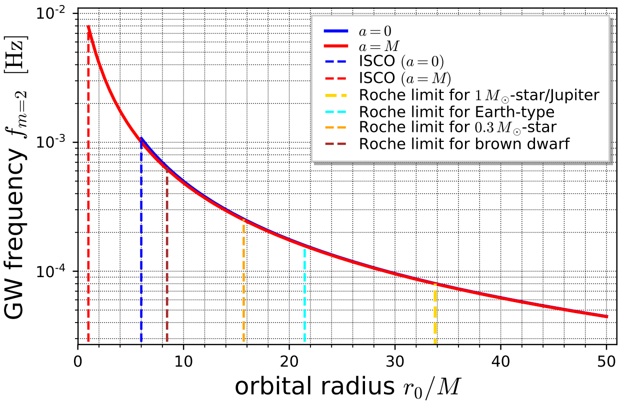

Roche radius: $r_R \simeq 1.14 \left(\frac{M}{\rho}\right)^{1/3}$

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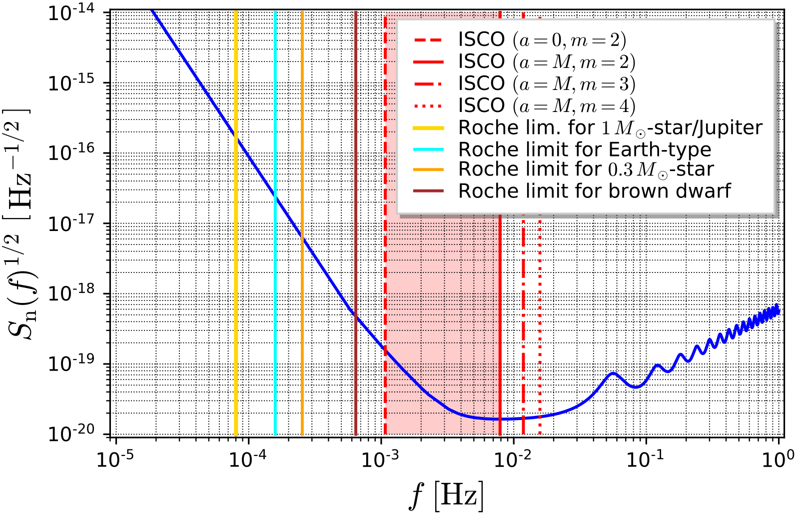
Frequencies of Sgr A* close orbits are in LISA bandwidth



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

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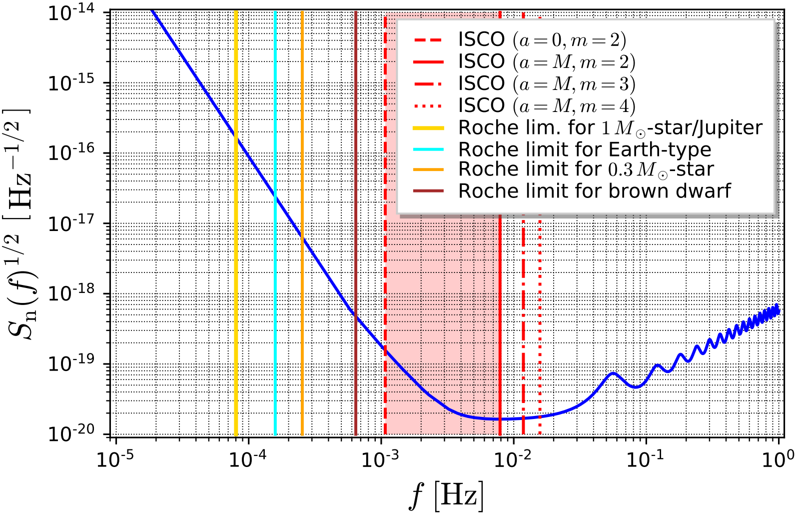
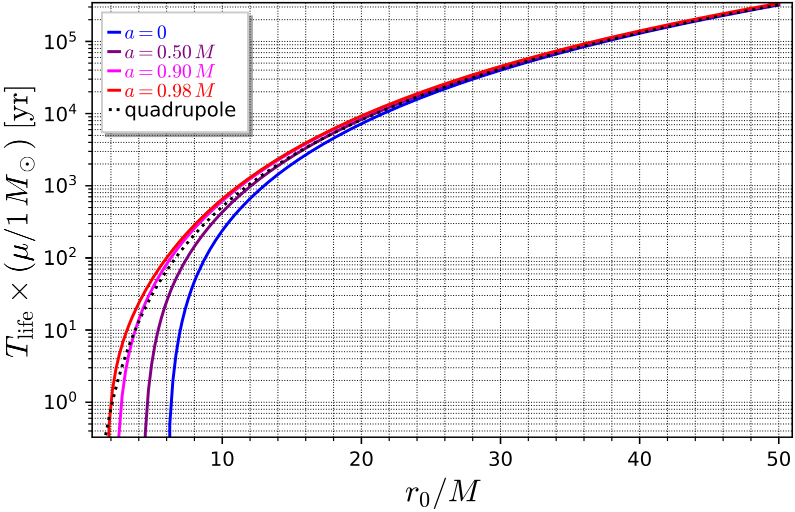


ISCO for $a = M$: $f_{m=2} = 7.9$ mHz $\leftarrow$ coincides with LISA max. sensitivity!

Life time of circular orbits



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

Waveforms from circular orbits

computed as linear perturbations of Kerr metric (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

${}_{-2}S^{am\omega_0}_{\ell m}(\theta,\varphi)$: spheroidal harmonics of spin weight -2

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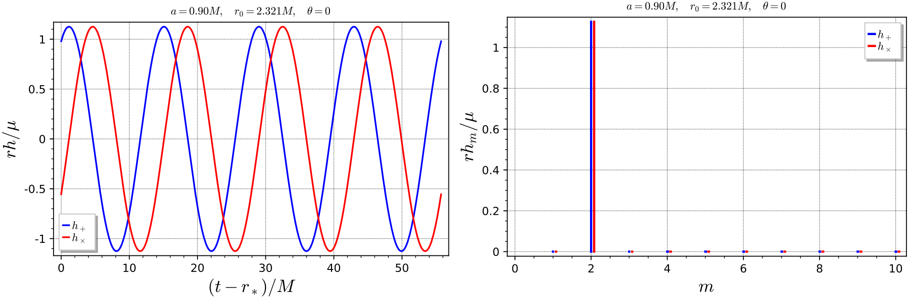
Example for $a = 0.9\,M$, $r_0 = r_{\rm ISCO}(a)$ and viewing angle $\theta = 0$ (face-on)



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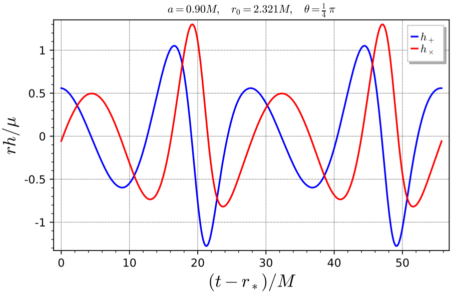
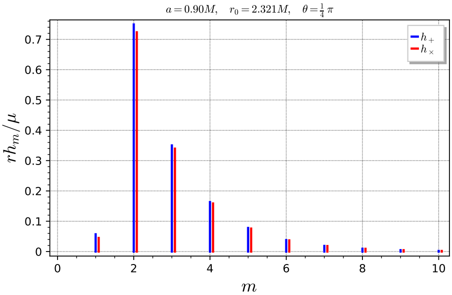
Example for $a = 0.9\,M$, $r_0 = r_{\rm ISCO}(a)$ and viewing angle $\theta = \pi/4$





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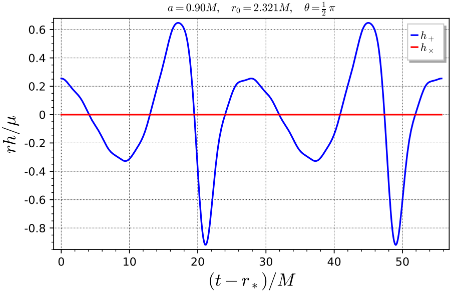
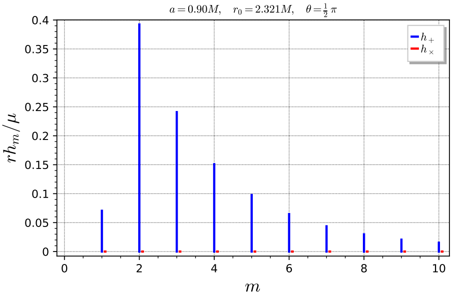
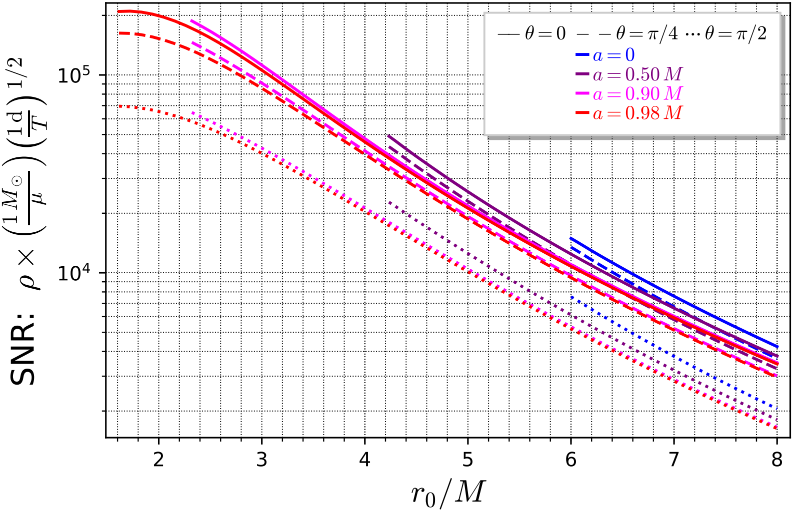
Example for $a = 0.9\,M$, $r_0 = r_{\mathrm{ISCO}}(a)$ and viewing angle $\theta = \pi/2$ (edge-on)





Signal-to-noise ratio in the LISA detector



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

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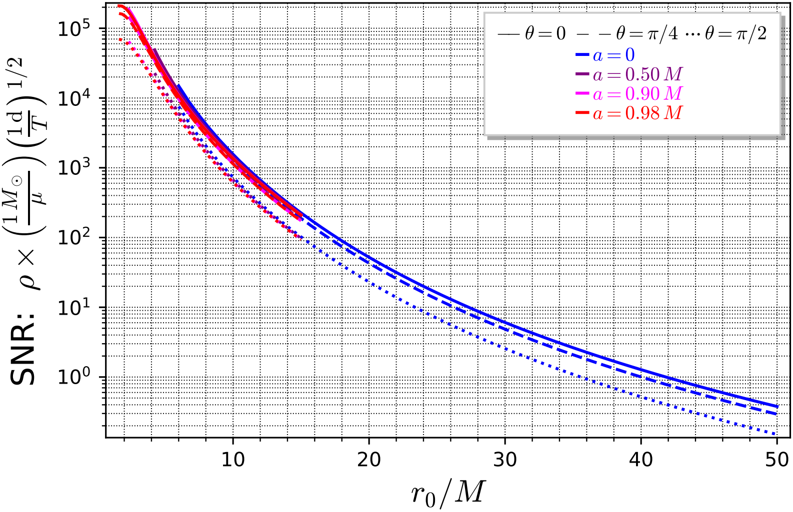

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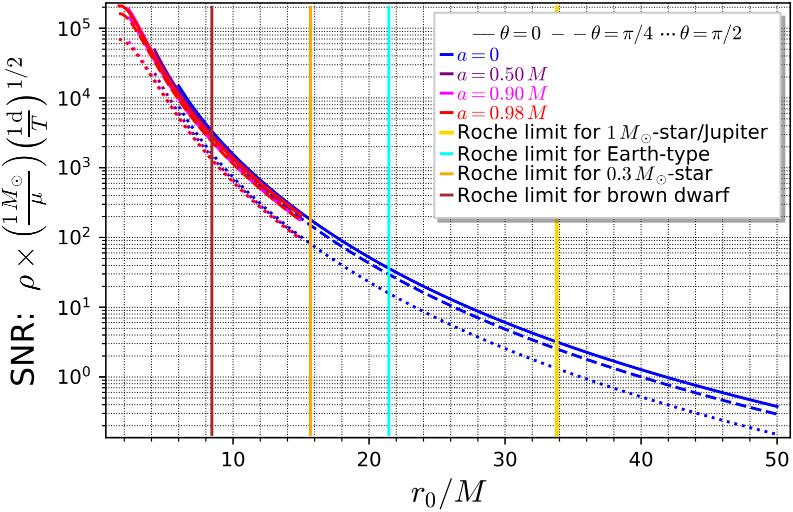

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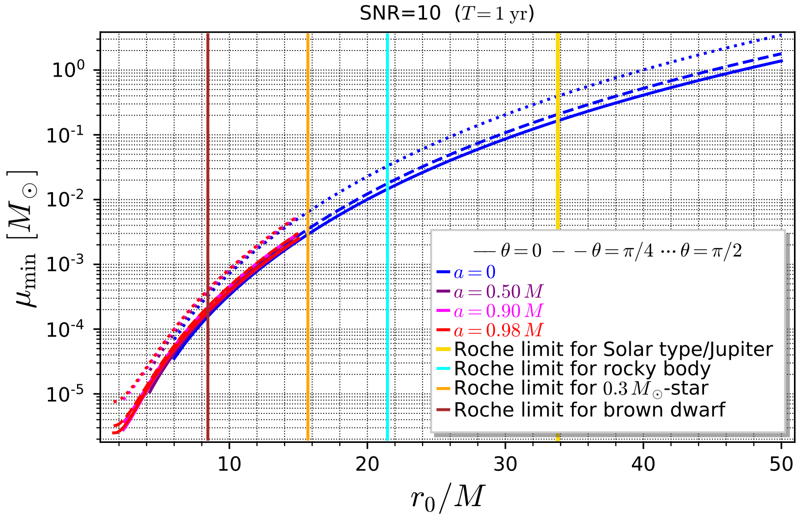
Signal-to-noise ratio in the LISA detector

object	r_0/M	SNR$\times \frac{1\,M_\odot}{\mu}$ (1 day)	SNR$\times \frac{1\,M_\odot}{\mu}$ (1 year)
Solar-type star / Jupyter	34.5	3.2	61
rocky body	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

Minimal detectable mass by LISA

Detection criteria: SNR $\geq$ 10
Observation time: 1 yr



Potential sources

- Zero-eccentricity EMRIs from binaries tidally split by Sgr A* [Miller et al., ApJ **631**, L117 (2005)]

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

A candidate?

MNRAS **474,** 3380–3390 (2018)
Advance Access publication 2017 November 15
doi:10.1093/mnras/stx2939

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

Elia Leibowitz★
School of Physics & Astronomy and Wise Observatory, Sachler Faculty of Exact Sciences, Tel Aviv University

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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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star $\mu = 0.18\, M_\odot$, $r_0 = 13.2 M \Longrightarrow$ 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), any orbital motion 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 a long lasting Jupiter-mass orbiter, left as a "messenger" by an advanced civilization, which possibly disappeared billions of years ago.

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

Conclusions

- We have computed gravitational emission for close circular orbits around Sgr A* in full general relativity (previous studies [Freitag, ApJ **583**, L21 (2003)], [Linial & Rabi, MNRAS **469**, 2441 (2017)], [Kuhnel et al., arXiv:1811.06387] were limited to quadrupole formula (Newtonian orbits))
- SNR has been evaluated by means of the latest LISA sensitivity curve
- Beside compact objects, small mass stars and brown dwarfs have Roche radii sufficiently close to Sgr A* to be good candidates
- LISA has the capability to detect orbiting masses close to the ISCO as small as $\sim 10 M_{\rm Earth}$ or even $\sim 1 M_{\rm Earth}$ if Sgr A* is a fast rotator ($a \geq 0.9M$); this could involve primordial BH or very dense artificial objects