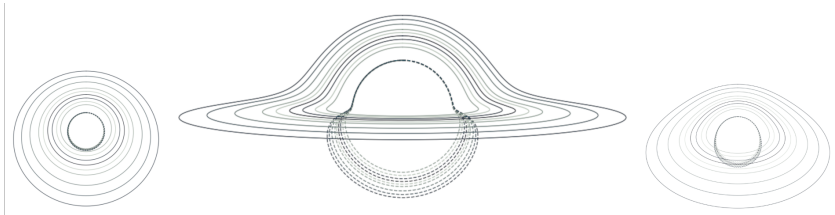


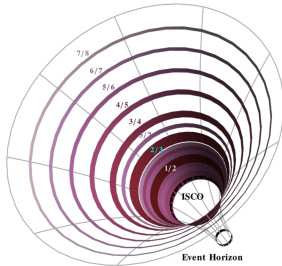
Resonant pacemakers, heartthrob of Sgr A*

Jeandrew Brink, UFS, HEASA 2026



Framework for Theory agnostic tests for GR around black holes

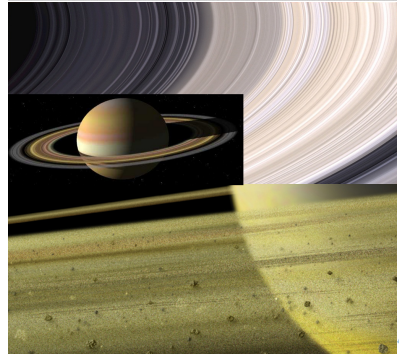
J Brink, M Geyer, T Hinderer (2015)
PRL 114, 081102, PRD 91, 083001
Sgr A* Spin Prediction



Ex. of
resonant effects: Saturn's Rings,
Mean motion resonances in
planetary systems, moons of
Jupiter.

Corlé Visser

Judiet Gerber



General Relativity and Quantum Mechanics
are in conflict at singularities Ex. Sgr A*, Big Bang



The uncertainty principle can't be reconciled with the idea of
squashing matter into a mathematical point

The unlamented death of an army of straw men

Caricature of GR tests around Sgr A*



EM

GW



The unlamented death of an army of straw men

Caricature of GR tests around Sgr A*



EM



GW



Numerical SANE or MAD
possibly windfed accretion disk,
S-stars source of gas
Many model dependent
parameters
Backaction of the disk on
Gravitational field ignored
Flares: magnetic reconnection

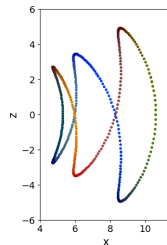
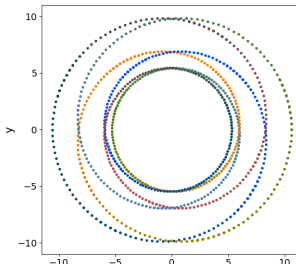
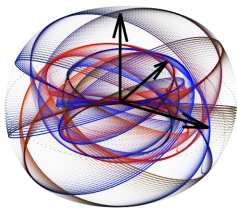
Sgr A* a source of EMRI
inspirals. Two body problem.
Black hole perturbation theory.
Numerical relativity impossible
due to different timescales
Tidal stripping, Roche Rad.
~ 30M for MS stars & Jupiters.
Only compact object spiral in
Flares: tidal disruption of
brown dwarfs

Universal Features
BH Uniqueness Th. Kerr
Departures from Kerr occur
at predictable resonant
locations presented here.
Scale invariance in the
emission spectra.

Integrability of Kerr Geodesics

Brandon Carter - Kerr geodesics are integrable. They admit a full set of isolating integrals. Topology torus

Kepler rotational freq. ω^ϕ
Kerr +libration freqs. ω^r, ω^θ .



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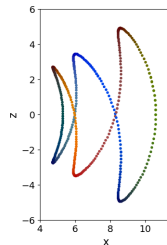
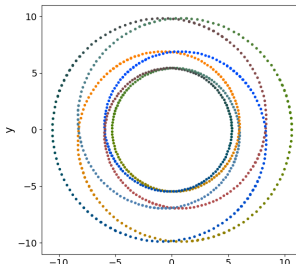
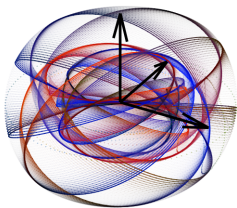
Kepler rotational freq. ω^ϕ

Kerr +libration freqs. ω^r, ω^θ .

Resonant orbit if given $k_r, k_\theta, k_\phi \in \mathbb{Z}$

$$\omega^r k_r + \omega^\theta k_\theta + \omega^\phi k_\phi = 0$$

$$\text{Order} = \sum_\alpha |k_\alpha|$$



Integrability of Kerr Geodesics

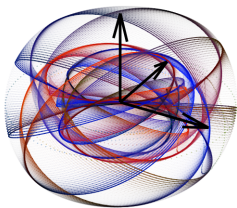
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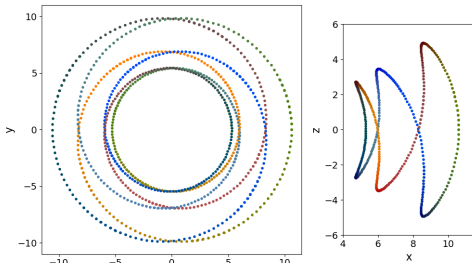
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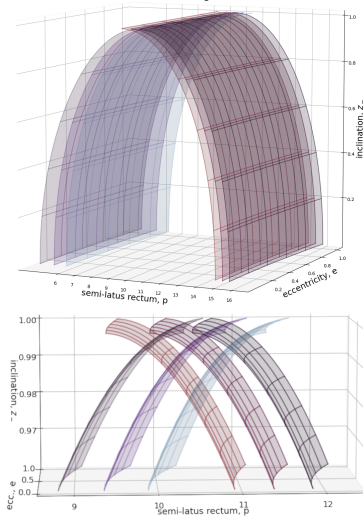
The Kolmogorov-Arnold-Moser (KAM) Theorem

If an integrable system is subject to a weak non-linear perturbation, some of the invariant tori are deformed and survive, while others are destroyed even when arbitrarily small perturbations are applied.

Low order resonant orbits are destroyed.



Resonance Properties



A given resonance surf. is labelled by $k_\alpha \in \mathbb{Z}^3$. Carlsons integrals & params e, z_-, p^* yield rapidly convergent semi analytic results and several simple formula.

For fixed spin (a), the structure shows a weak dependence on eccentricity (e).

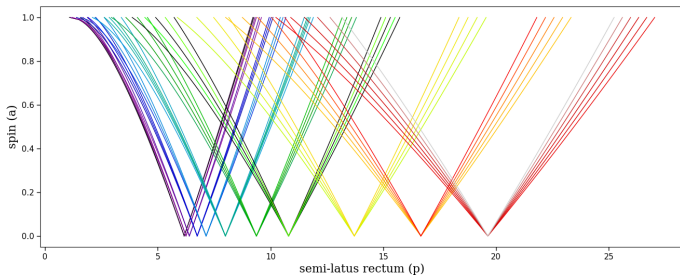
Inclination dependence characterized by an inverted U profile with pro and retrograde branches.

Average location of resonant structures:

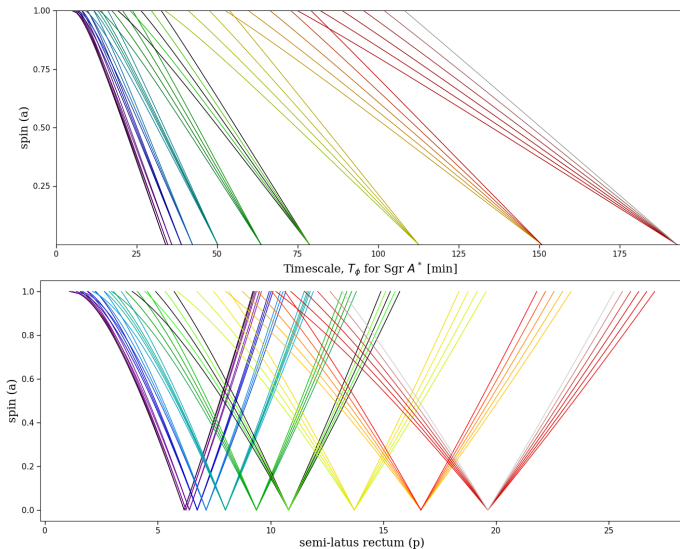
For circular equatorial orbits in the spin zero limit, $p^*(k_\alpha) = \frac{6Mk_r^2}{k_r^2 - (k_\theta \mp k_\phi)^2}$, ($e = z_- = a = 0$)

$$k_r = 3, |k_\theta| + |k_\phi| = 2, a = 0.95$$

Locations of resonant orbits restricted to the equatorial plane



Orbital Timescales $T_\phi = 2\pi/\omega_\phi$ associated with resonant structures

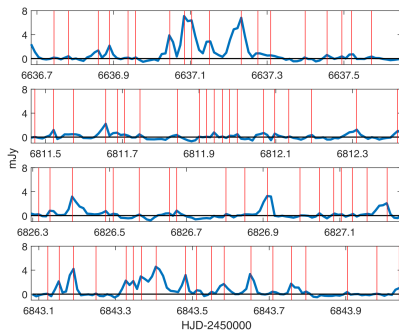


Observed Sgr A* Timescales

- Leibowitz Frequencies

2020 ApJ 896:75, 2021 ApJ 915:2

Statistical Periodicities in X-Ray and IR flares. Suggested the existence of a periodic **pacemaker** that triggered flares.



NIR Light curve for Sgr A* by Spitzer 2013-2017. Witzel et al. 2018

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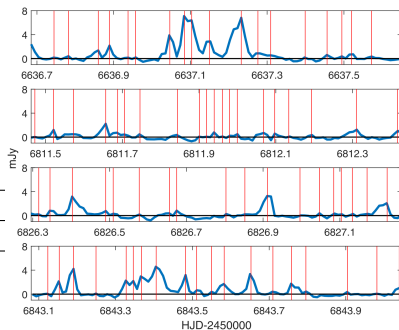
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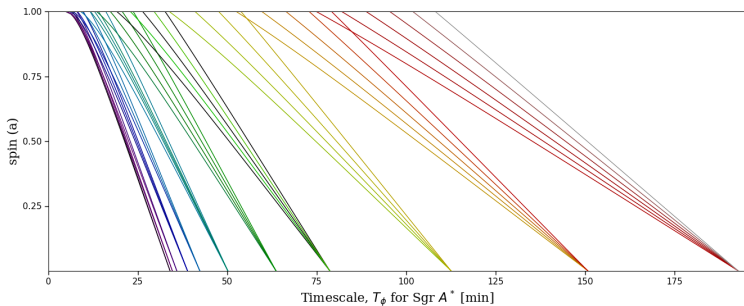
Period	Frequency	Res.	Structure
[min]	[day ⁻¹]	k_r	$ k_\theta + k_\phi $
$P_X = 149$	$F_X = 9.69$	6	5
$P_{IR} = 40.7$	$F_{IR} = 35.4$	5	3
$P_{IRM} = 56.1$	$F_{IRM} = 25.7$	3	2
$P_I = 80.9$	$F_I = 17.8$	4	3

Res. struct assumes Sgr A* has $a \sim 0.5$.

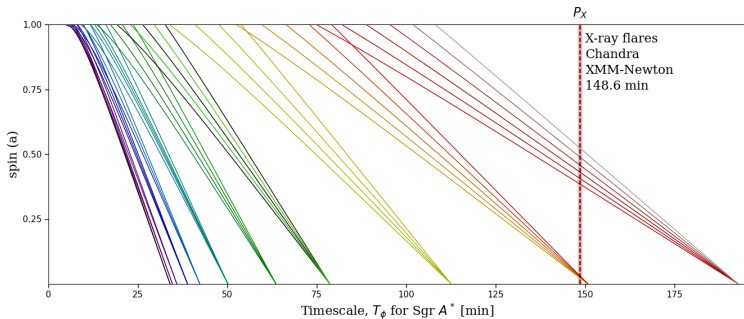


NIR Light curve for Sgr A* by Spitzer 2013-2017. Witzel et al. 2018

Orbital Timescales $T_\phi = 2\pi/\omega_\phi$ associated with resonant structures

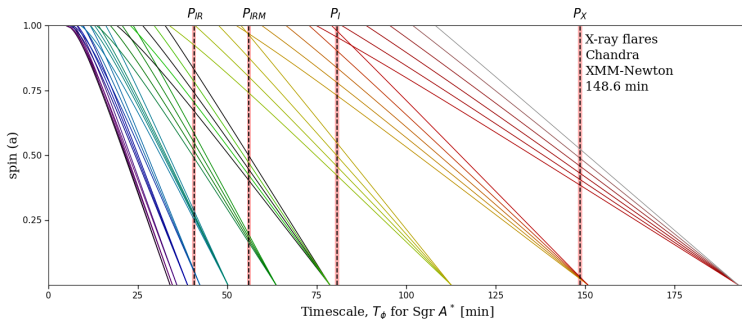


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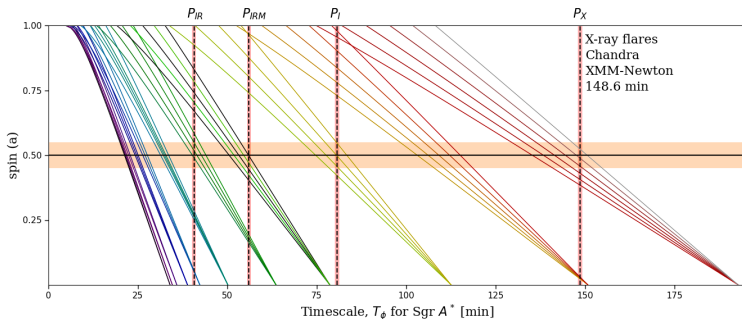
Leibowitz Pacemakers.
MNRAS 474, 3380 (2017),

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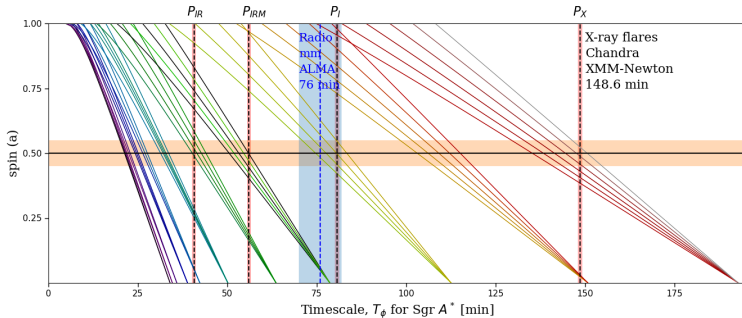
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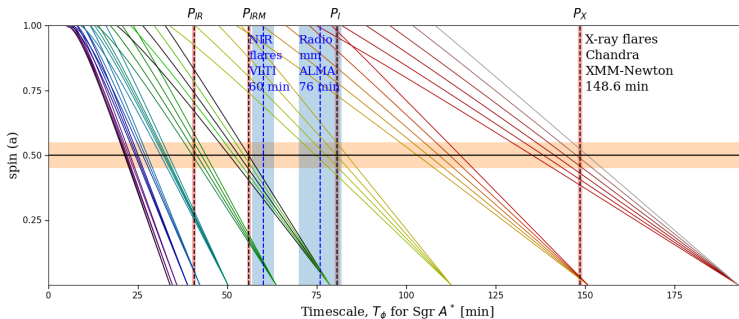
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Wielgus et al. mm emission

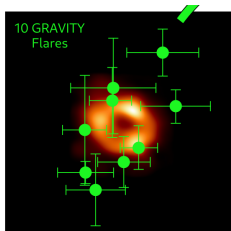
A&A 665, L6 (2022).

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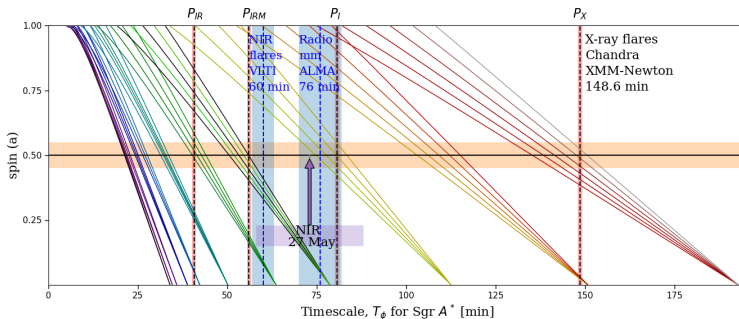
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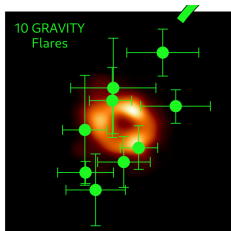
GRAVITY et al. VLT
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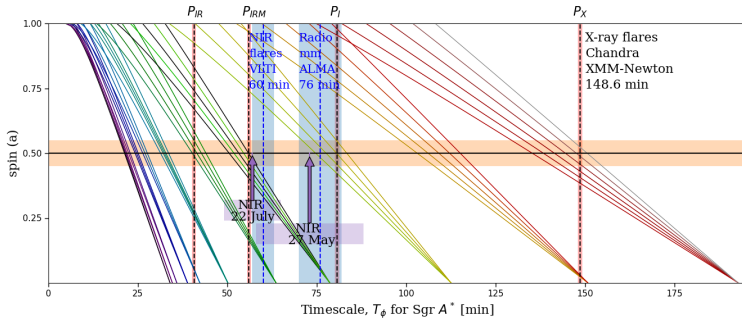
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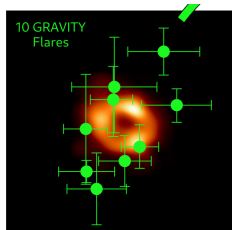
GRAVITY et al. VLT
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Seperate analysis
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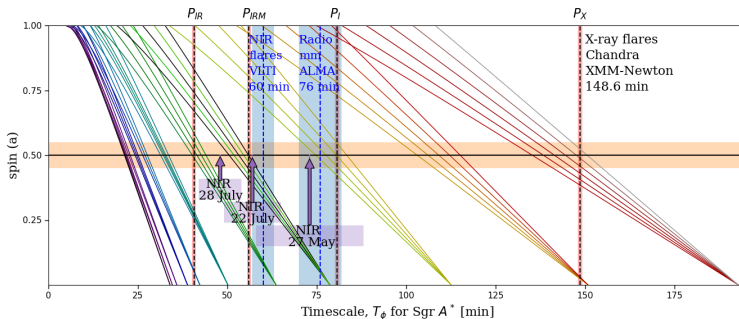
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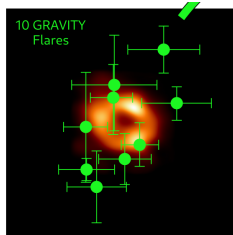


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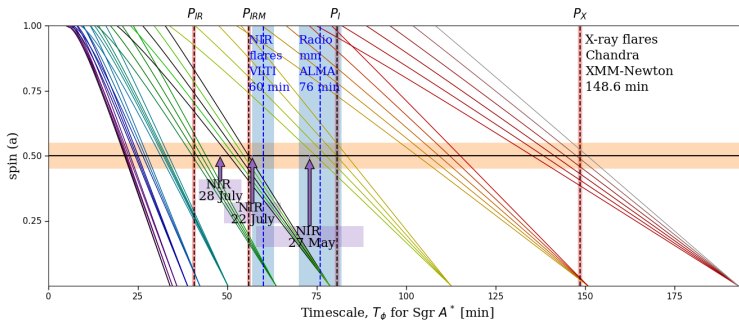


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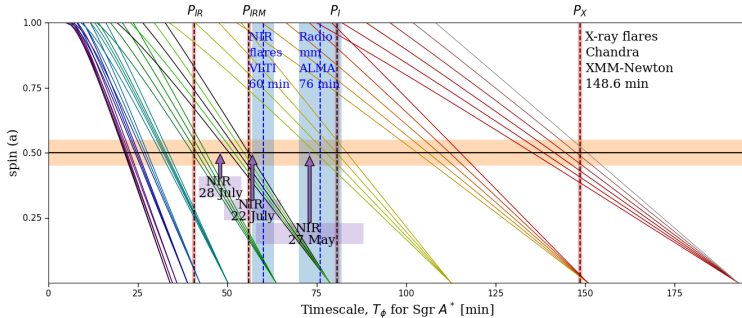


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Inspiral-Disk-Resonance (IDR) Galactic Flare models: Speedtrap

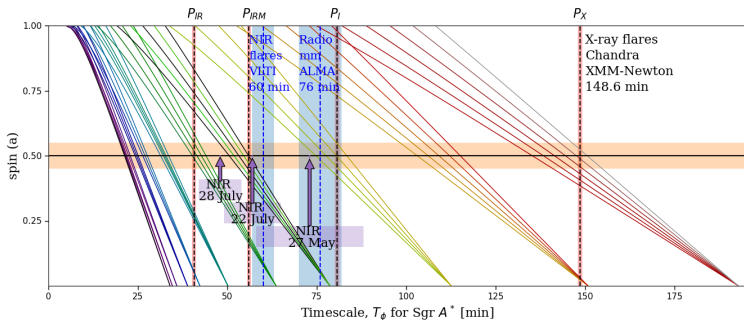


Inspirational-Disk-Resonance (IDR) Galactic Flare models: Speedtrap



Tidal stripping for solar type main sequence stars begins at $34R_M$
 MNRS 434,2948 (2013) **Gas**
populates resonance structures.
 Inspiralling object sets off flares
 as it traverses structures with
 timestamps d_i

Inspiral-Disk-Resonance (IDR) Galactic Flare models: Speedtrap



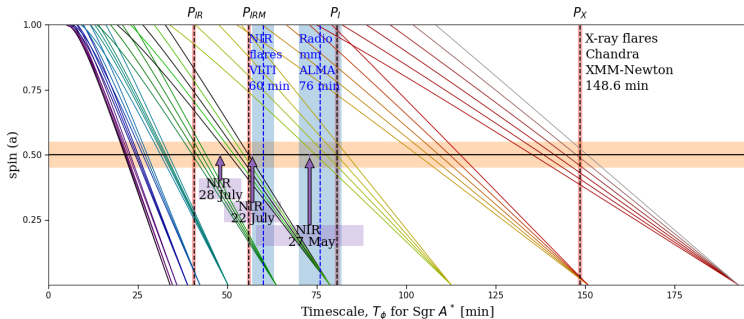
Tidal stripping for solar type main sequence stars begins at $34R_M$ MNRS 434,2948 (2013) **Gas populates resonance structures.** Inspiralling object sets off flares as it traverses structures with timestamps d_i

Inspiral time (A&A 627, A92 (2019)).

$$T_{in}(p_a, p_b) = \frac{5R_M}{64c\eta} \int_{p_b/R_M}^{p_a/R_M} x^3 \frac{1 - \frac{6}{x} + \frac{8a}{x^{3/2}} - \frac{3a^2}{x^2}}{(1 - \frac{3}{x} + \frac{2a}{x^{3/2}})^{3/2}} dx.$$

scales linearly with mass ratio η

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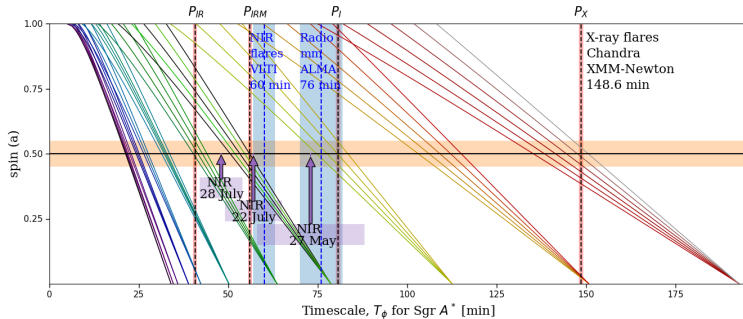
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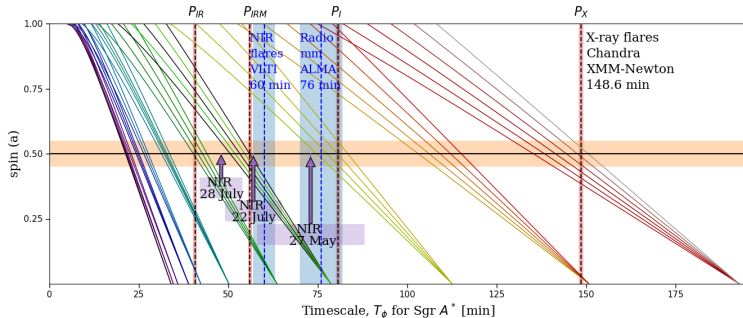
If flares were caused by single inspiral $\frac{d_2 - d_1}{d_3 - d_2} = \frac{T_{in}(p_1, p_2)}{T_{in}(p_2, p_3)}$, the latter depends only on the resonance locations.

Inspiral-Disk-Resonance (IDR) Galactic Flare models: Fish and Release



SpeedTrap only works for objects heavy enough to pass unhindered through the resonances. Lighter compact objects temporarily retained by the resonances could accrete gas resulting in novae.

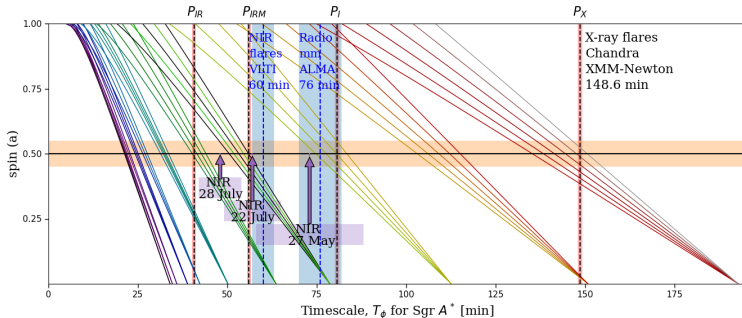
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Fish and Release: 3 body interaction where Sgr A* reels in gas from main sequence stars to temporarily relinquish it to compact objects before they too plunge into the black hole

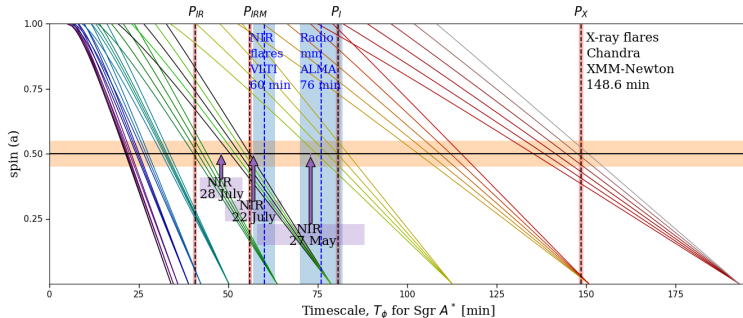
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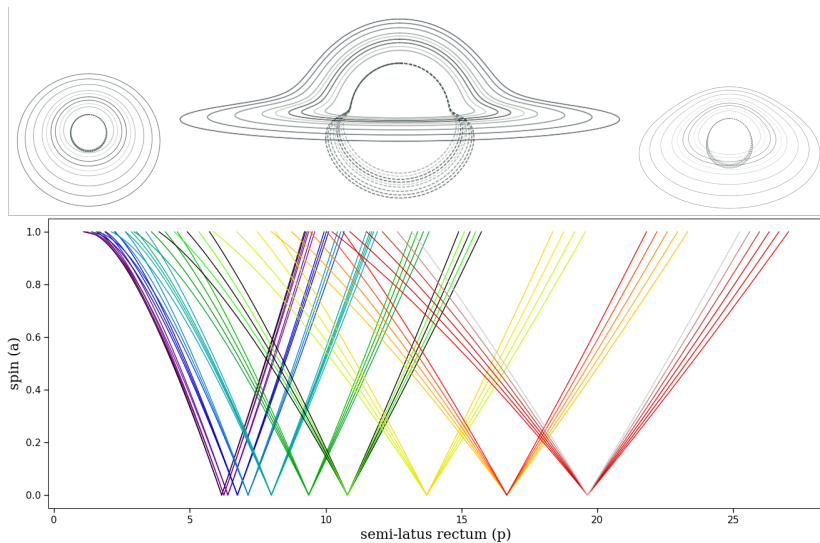
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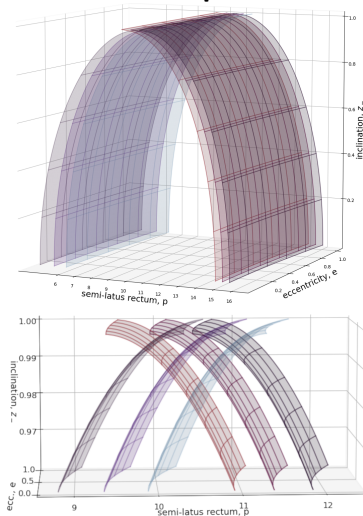


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Resonance Properties



A given resonance surf. is labelled by $k_\alpha \in \mathbb{Z}^3$. Carlsons integrals & params e, z_-, p^* yield rapidly convergent semi analytic results and several simple formula.

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Inclination dependence characterized by an inverted U profile with pro and retrograde branches.

Average location of resonant structures:

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