Event Rates of Extreme Mass Ratio Inspirals (EMRIs) in Milky Way Galaxy

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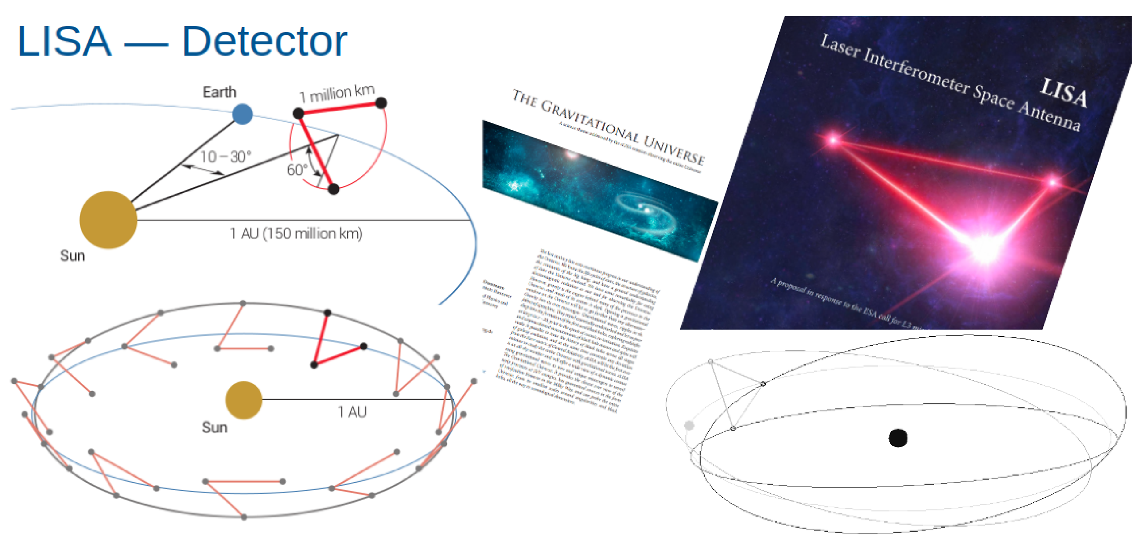
Introduction

Numerous galaxies hosts a Super Massive Black hole (SMBH) in the galactic centers (GCs) enclosed by stellar clusters with large verity of dense stellar population. **Extreme mass ratio inspirals (EMRIs)** and **Intermediate mass ratio inspirals (IMRIs)** are the most compelling sources of gravitational radiation detectable by **Laser Interferometer Space Antenna (LISA)** that will have competence to observe the entire sky probing for the gravitational universe . Sensitivity band of LISA lies in frequency range of about 10^{-4} to 10^{-1}Hz with mass range $\sim 10^4 - 10^7 M_\odot$. EMRIs and IMRIs are the prime source for LISA encompasses the whirling of compact objects (COs), typically **stellar mass black holes (BHs)**, **neutron stars (NS)**, **white dwarfs (WD)** and **intermediate mass blackholes (IMBH)** with mass ratio $q \ll 1$ and prolonged cycles $\sim 10^4 - 10^5$, emitting gravitational radiations lasting for several years [6].



17 physical parameters fully elucidates complicated waveform emitted by CO–SMBH system categorized by intrinsic–extrinsic characteristics [1]. Excluding the spinning effects of CO, 14 plausible parameters shown in Illustration 1 contribute to the evolution of waveform. We further reduce the parameter space by constraining the mass of the SMBH, distance and sky location angles for **Sgr A***, in which case the parameter space further reduces to 10 dimensions.

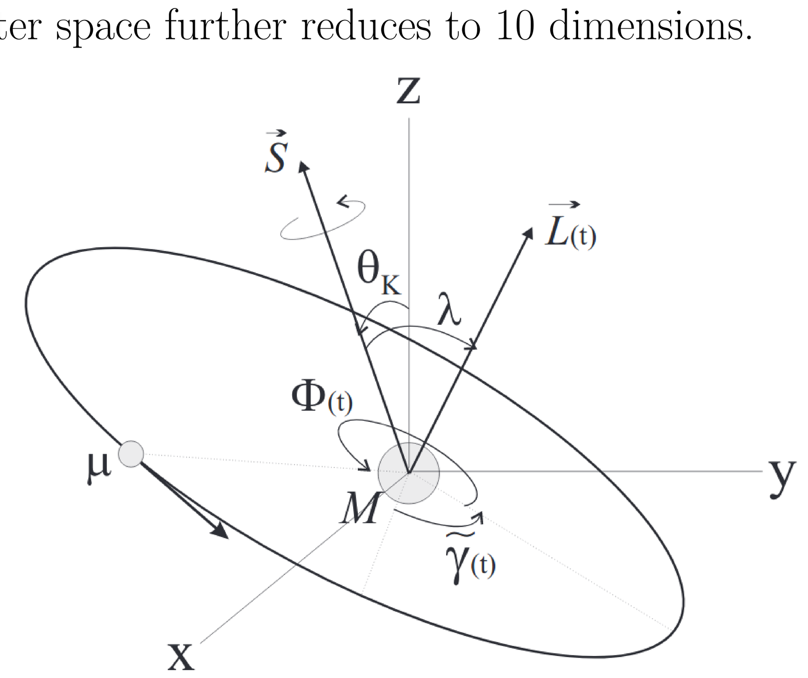


Figure 1:Characteristic evolution of EMRI system, defined by above mentioned parameter–space (in Cartesian based ecliptic coordinates) attributed to their physical significance. In ecliptic based coordinate system spin vector $\vec{\mathbf{S}}$ of SMBH is projected away from z^{th} by measure of radians θ_k. Angular momentum vector $\vec{\mathbf{L}}$ of SMBH is parameterized by angle ι relative to $\vec{\mathbf{S}}$ and varies by azimuthal angle $\alpha(t)$ in time t. $\tilde{\gamma}$ gives the measure of directional precession of pericenter w.r.t $\vec{\mathbf{L}} \times \vec{\mathbf{S}}$. Φ represents orbital phase variation from pericenter. The symbolic representation of inclination angle ι [1].

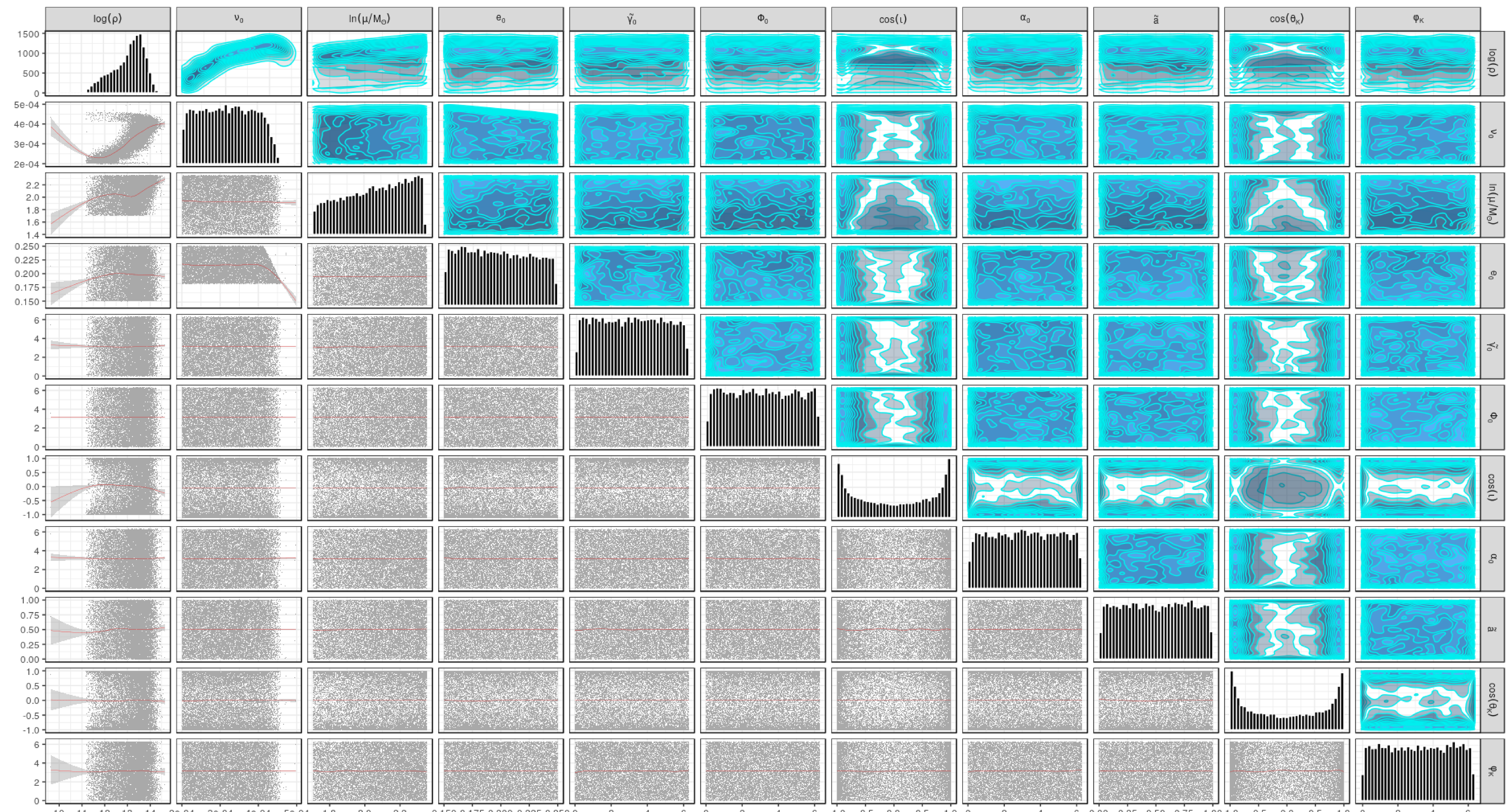


Figure 2:Correlogram: Upper panels reads statistical density contour variation, diagonal represents two dimensional posterior distributions. Lower panels illustrates scatter plots and regression lines.

Methodology

We have used **classic Analytical Kludge (AK) waveform model** [1] that is based Peters and Mathews (1963) sum modes [2], using frequency approximation [4, 5].
We further computed event rates for detectable EMRIs using mission life time of **LISA** $t_{life} = 2$ **years**, we have used the number density of comoving SMBHs and intrinsic rate of probable EMRIs, ignoring the red-shifted component of comoving volume. SMBH's spins remains highly uncertain parameter, hence, we took a uniform range of spins ranging from 0 to 1, considering the **prograde spin orbits**.

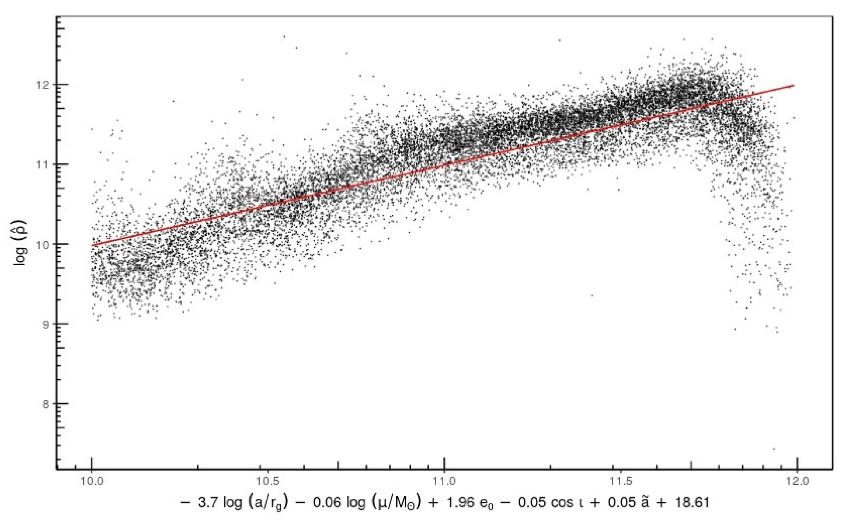


Figure 3:Scatter plot of estimated mass–normalized SNR as a function of orbital parameters i.e. a, μ, e_0, $cos\ \iota$ and $\tilde{a}$. Red line corresponds to the best–fit estimates $\log(\hat{\rho}) = -3.70\log(\frac{a}{r_g}) - 0.06\log(\frac{\mu}{M_\odot}) + 1.96\ e_0 - 0.05\ cos\ \iota + 0.05\ \tilde{a} + 18.61$ of SNR meanwhile the radial parameter sweeps between $6.09r_g \leqslant a \leqslant 11.18r_g$. $\log(\hat{\rho})$ gives good fit for logarithmic $a > 7r_g$ and drops steeply for lower semi–major axis with reduced chi–square value of $\chi^2/\nu = 0.015$.

Results

Parameters	*R–squared*	*p–value*
ν_0	0.55	0
$\ln \mu$	0.054	4.2×10^{-181}
e_0	0.00027	0.048
$\tilde{\gamma}_0$	3.4×10^{-5}	0.48
Φ_0	1.5×10^{-6}	0.88
$\cos \iota$	0.0028	1.9×10^{-10}
α_0	3.5×10^{-5}	0.47
S/M^2	0.0067	0.0016
$\mu_k \equiv \cos \theta_k$	1×10^{-4}	0.22
ϕ_k	6.9×10^{-5}	0.32

Table 1:The SNR correlate strongly with ν_0 and weakly with $\ln \mu$ with statistically significant p–*values* of 0 and 4.2×10^{-181}.

We investigate the dependency of signal–to–noise ratios (SNRs) to parameters and make inferences regarding the properties of **Galactic EMRIs**. Constraining the intrinsic parameters of **Analytical Kludge (AK) waveform model** we employ the well calibrated stellar properties of the SMBH to extrapolate the scaling relation that contemplates **fiducial fit for back–of–envelop computations of SNRs**. Also, we enumerate the averaged probability of **1.43** EMRI events to occur in **Milky Way (MW)** hosting SMBH, by employing the known astrophysical stellar dynamics of stellar population near the SMBH and considering the detector's sensitivity.

Discussion

Scrutinizing SMBHs, inhabited at the galactic centers, is one of the key objectives of the LISA mission. Precision measurements of gravitational wave strain amplitude and phase modulations lead to the mapping of space-time around the central BH. In General Relativity, stationary and axisymmetric solutions of BHs can be described in terms of its infinite number of multipolar moments. LISA will unveil the assembly of SMBHs up to redshifts $z \sim 20$ that will investigate the underlying understanding of the origin and growth of SMBHs [6].

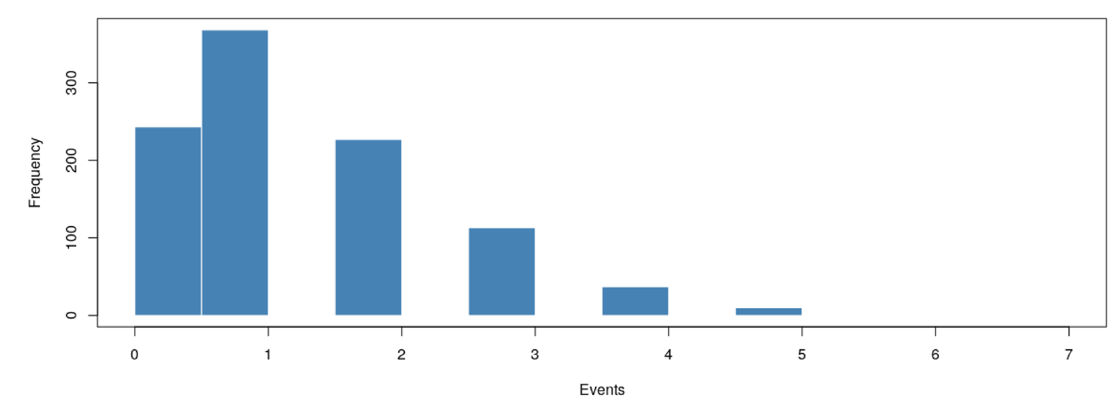


Figure 4:Poisson probability distribution averaged over 10^4 realizations for enumerated number of EMRI events $N_{EMRI} = 1.43$ per year be detectable in LISA frequency band form GC over mission duration of 2 years.

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