Consequences of Charge Accrual on LISA Test Masses

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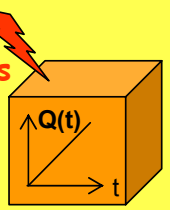
Primary Cosmic Rays & Energetic Solar Flare Particles



$$Q(t) = \dot{\bar{Q}}t + \delta Q(t)$$

Due to the time dependence of the amount of charge accumulated on a test mass, get **unwanted, coherent signals in LISA measurement bandwidth**, due to Lorentz and Coulomb interactions.

Coulomb interactions

$$a_k \approx \frac{1}{2m}\sum_{i=1}^{N-1}\sum_{j=1}^{i-1}\frac{\partial C_{ij}}{\partial k}(V_i - V_j)^2 + \frac{1}{2m}\sum_{l=1}^{N-1}\frac{\partial C_{Nl}}{\partial k}(V_T - V_l)^2 + \frac{\dot{\bar{Q}}^2}{2C_T^2 m}\frac{\partial C_T}{\partial k}t^2 - \frac{\partial V_T}{\partial k}\frac{\dot{\bar{Q}}}{m}t + \frac{1}{m}\left[\frac{\dot{\bar{Q}}t}{C_T^2}\frac{\partial C_T}{\partial k} - \frac{\partial V_T}{\partial k}\right]\delta Q(t)$$

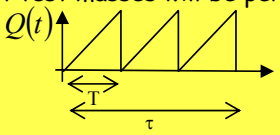
$f(t) = \Xi t^2$ $\quad e(t) = \Theta t$

Lorentz interactions

$$a_L = \frac{\dot{\bar{Q}}}{m}\mathbf{V}\times\mathbf{B}t + \frac{\mathbf{V}\times\mathbf{B}}{m}\delta Q(t)$$

$d(t) = \Phi t$

But test masses will be periodically discharged using UV light, so...



$$f(t) = \Xi(t - nT)^2 \qquad 0 < t < \tau$$

$$g(t) = e(t) + d(t) = \Psi(t - nT)$$

$$f(t) \Leftrightarrow F(f) = \frac{T^2}{3}\Xi\tau\,\mathrm{sinc}\{\tau f\}.e^{-2\pi i f\tau/2} + \sum_{\substack{n=-\infty \\ n\neq 0}}^{\infty}\frac{1}{2}\left(\frac{T}{\pi n}\right)^2(1+i\pi n)\Xi\tau\,\mathrm{sinc}\left\{\tau\left(f-\frac{n}{T}\right)\right\}.e^{-2\pi i\left(f-\frac{n}{T}\right)\tau/2}$$

$$g(t) \Leftrightarrow G(f) = \frac{T}{2}\Psi\tau\,\mathrm{sinc}\{\tau f\}.e^{-2\pi i f\tau/2} + \sum_{\substack{n=-\infty \\ n\neq 0}}^{\infty}\frac{iT}{2\pi n}\Psi\tau\,\mathrm{sinc}\left\{\tau\left(f-\frac{n}{T}\right)\right\}.e^{-2\pi i\left(f-\frac{n}{T}\right)\tau/2}$$

⇒ Series of sinc functions in the acceleration spectrum, each centred on n/T, mainly concentrated in frequencies up to $1/\tau$ on each side of n/T. For T ~ 1 day & τ ~ 1 year, separation 1/T ~10^{-5} Hz, width of primary lobe, $2/\tau$ ~6×10^{-8} Hz (cf f resolution ~3×10^{-8} Hz)

Approaches to eliminate these signals

1.Decrease net charging rate via constant UV illumination

- Require precise balance between rates as need net~0.1 e/s if use this method alone to reduce signals to < accn noise limit!
- Will result in increased accn noise.

2.Choice of charging period, T

- Minimise individual signals & maximise the spacing between the primary spectral peaks by discharging as frequently as is feasible.
- *If* can measure offsets and charging rate, *may* be possible to optimise T, so resultant signal minimised- depends on offsets, so cannot be ensured?

3.Choice of system parameters

- Large electrode-test mass gaps
- Large mass
- Minimise voltages & voltage differences

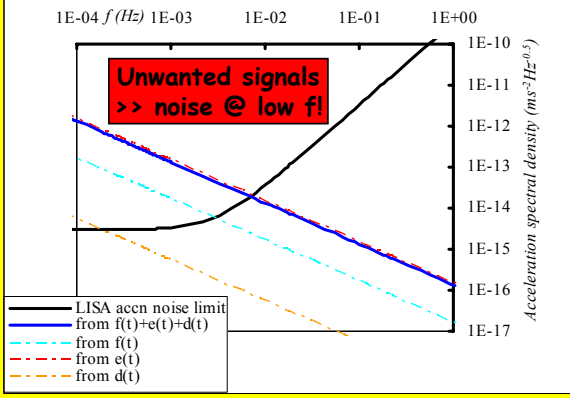
•Choose $\sum_{i=1}^{N-1} C_{i,N}V_i \approx 0$ *(as per Buchman et al, 95)*

4.Minimise offsets

- Level to which geometrical offsets can be reduced is limited by e.g. machining accuracy & test mass positioning accuracy.
- Voltage offsets in the system are unavoidable due to patch effects and work-function variations. The level to which these can be balanced will then determine the residual voltage offsets in the system *(W. Weber et al SPIE, 2002)*

Acceleration spectral density ($ms^{-2}Hz^{-0.5}$) vs f (Hz)

Magnitudes plotted at *primary peaks* of sinc functions



5.Spectral analysis

- Expect, ultimately, signals will be removed via analysis
- Use e.g. pattern matching to extract signal
- Cross-correlate O/P from different test masses ? (limited by differences in mean charging rate)
- Cross-correlate O/P from different DoFs ? (limited by sensitivity)

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