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Gravitational Wave Bursts from Extreme Mass Ratio Encounters

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Why Bursts?

- Stars enter loss cone with $1 - e \ll 1$
 - Either on nearly radial orbits from large radius, or on a nearly radial orbit following a binary tidal disruption at smaller radii
- Periapsis passage may lead to in-band gravitational Brehmsstrahlung event
 - $f_{\text{peri}} \sim \frac{v_{\text{peri}}}{2\pi r_{\text{peri}}}$



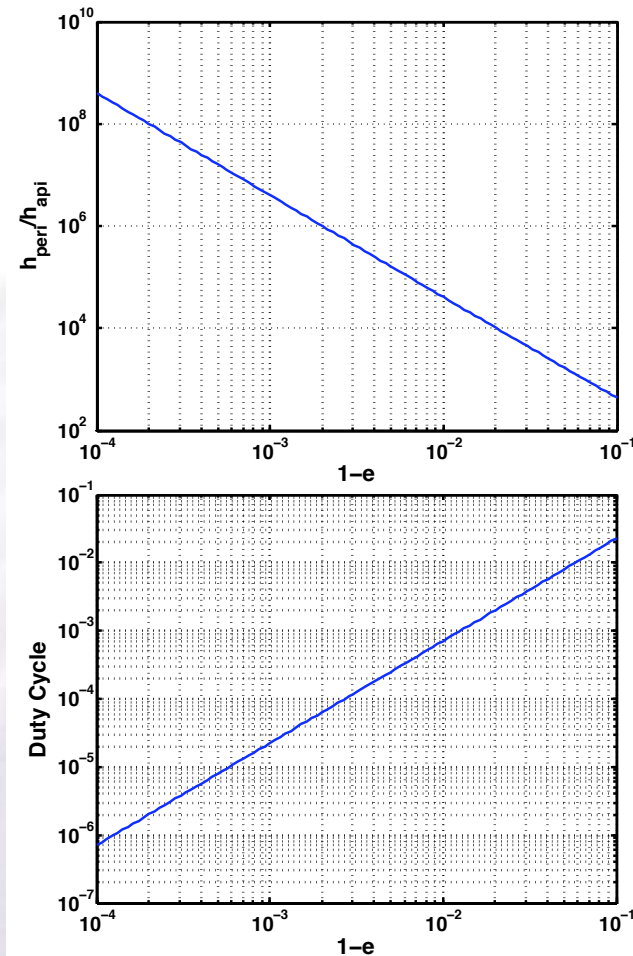
Why Bursts?

- What is the ratio of strain at periaapsis to strain at apoapsis?

$$\begin{aligned} \frac{h_{\text{peri}}}{h_{\text{apo}}} &= \frac{\ddot{I}_{\text{peri}}}{\ddot{I}_{\text{apo}}} \\ &= \frac{Mv_{\text{peri}}^2}{Mv_{\text{apo}}^2} = \left[\frac{1+e}{1-e} \right]^2 \end{aligned}$$

- What is the “duty cycle”: i.e., fraction of orbit where strain is large?

$$\delta = \frac{\Delta t_{\text{peri}}}{P_{\text{orb}}} = \sqrt{\frac{(1-e)^3}{1+e}}$$





Why Bursts?

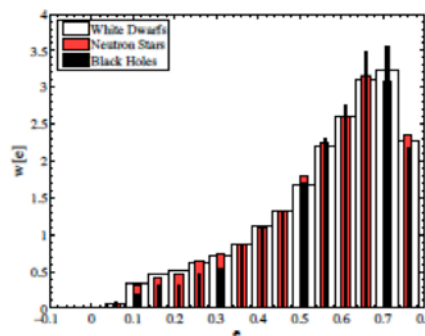
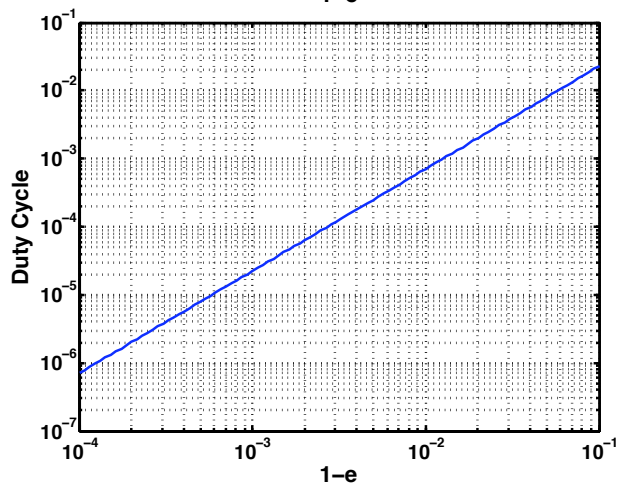
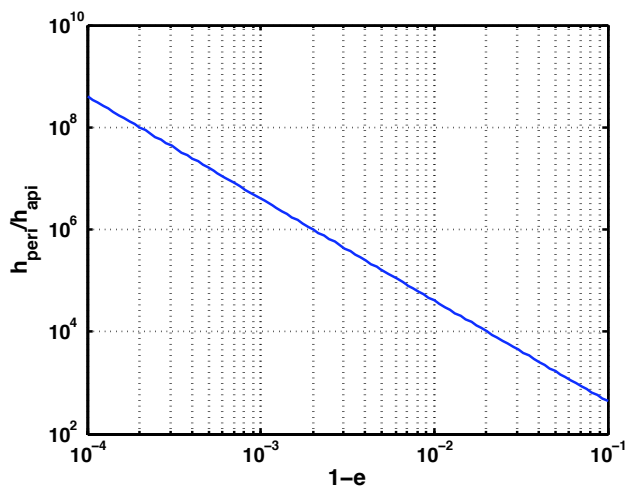


FIG. 4. — The probability DF of a CO entering the *LISA* band with eccentricity e for a MBH of mass $M_* = 3 \times 10^6 M_\odot$. The histograms represent WDs, NSs and BH (from broad to narrow). Note that the maximal possible eccentricity for which $P < P_L$ is $e_{\max} = 0.81$. See table (2) for the cusp parameters.

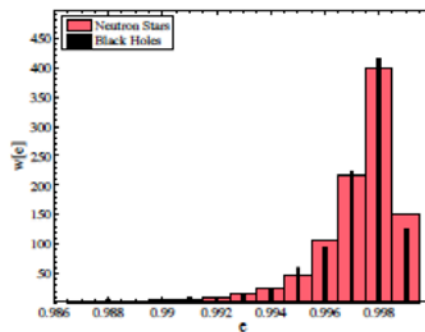


FIG. 5. — The probability DF of a compact remnant entering the *LISA* band with eccentricity e for an IBH of mass $M_* = 10^3 M_\odot$. Only NSs (broad) and BHs (narrow) are considered; WDs are probably disrupted by the tidal field. For an IBH, the maximal possible eccentricity for which $P < P_L$ is nearly unity, $e_{\max} = 0.998$, all inspiraling stars are likely to have eccentricities close to the maximum value. See table (2) for the cusp parameters.

- EMRI sources

- $h_{\text{peri}}/h_{\text{apo}} \sim 30$
- $\delta \sim 12\%$

- IMRI sources

- $h_{\text{peri}}/h_{\text{apo}} \sim 10^6$
- $\delta \sim 3 \times 10^{-5}$

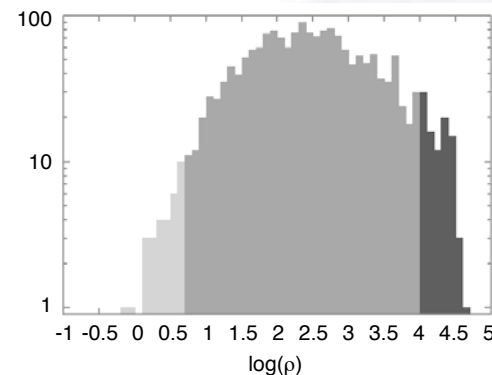
- Caveats

- Kepler wrong for $v \sim c$
- More relevant is e when $\Delta t_{\text{peri}} \sim 3 \times 10^4$ s (cf. $P_{\text{orb}} \sim 3 \times 10^4$ s)

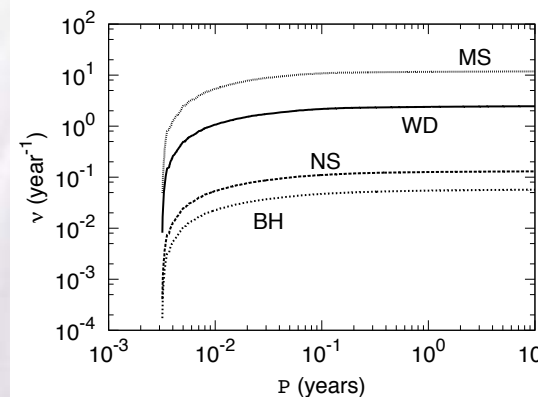
Galactic and Galactic Neighborhood Bursts

Rubbo, Holley-Bockelmann
& Finn 2006 ApJL

- Bulge
 - η - model density profile
 - Embedded black hole
 - Kroupa IMF
- Find phase space fraction leading to in-band burst
 - Exclude plunges
- Select bursts with $\rho > 5$
 - Galactic Center: $> 12 \text{ y}^{-1}$ (mostly LMMS stars)
 - Virgo Cluster: $> 3 \text{ y}^{-1}$ (all $10 M_{\odot}$ BHs)



Number vs. snr for BH binaries



Contribution to rate from sources of different period



Discussion

- Spherical bulge?
 - Triaxial w/bar: centrophillic orbits can *increase* rate two orders of magnitude
 - Median P_{orb} larger than spherical case
- Mass segregation?
 - Ignored here; can *decrease* rate of bursts from LMMS stars by two orders of magnitude
- Quadrupole approximation radiation?
 - $v_{\text{peri}} \approx c$: higher moments, beaming



Discussion

- Most S/N deposited in peri-passage bursts
 - Except at very end do we need waveforms outside of peri-passage? Need to “match-up” (nearly) periodic bursts
- Self-force driven orbital evolution greatest at peri-passage, where S/N is deposited
 - Matched filtering requires getting orbital evolution right in this sector
 - Successive bursts will be different



Conclusions

- Gravitational wave bursts with significant S/N are generated by extreme mass ratio encounters in galactic center, Virgo cluster
 - EMRI progenitors *plus* white dwarfs, LMMS stars
 - Initial estimates suggest ~ 10 's yr^{-1} in LISA
 - Diagnostic of triaxiality, mass segregation?
- $h_{\text{peri}}/h_{\text{apo}}$ large, duty cycle small for small $|1-e|$
 - Data analysis, self-force calculation implications