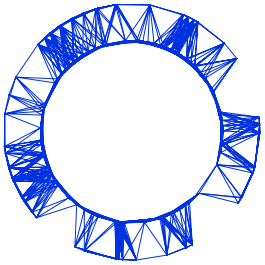

IPhO 2018
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Detailed Marking Scheme Theory Problem 1

LIGO-GW150914

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v6.0

GW150914 (10 points)

Part A. Newtonian (conservative) orbits (3.0 points)

A.1

Apply Newton's law to body 1	0.3
Relate the particle positions	0.3
Final expression (identification of n and α)	0.4
Total	1.0

[Give full points to final answer without derivation]

A.2

The total energy of the system	0.5
Obtain $M_1 r_1^2 + M_2 r_2^2 = \mu L^2$	0.2
Final expression for the energy (identification of $A(\mu, \Omega, L)$	0.3
Total	1.0

[Give full points to final answer without derivation]

A.3

Equate the gravitational acceleration to the centripetal acceleration	0.5
Obtain E (identification of β)	0.5
Total	1.0

[Give full points to final answer without derivation; it is accepted to use virial theorem]

Part B - Introducing relativistic dissipation (7.0 points)

B.1

Cartesian components for $\vec{r}_1$ and $\vec{r}_2$	0.2
Expression for Q_{ij}	0.5
Simplified expression for Q_{ij} (identification of k, a_i, b_i, c_{ij})	0.3
Total	1.0

B.2

Third order derivative	0.5
Summation to obtain $\mathrm{d}E/\mathrm{d}t$ (identification of ξ)	0.5
Total	1.0

B.3

Obtain $\mathrm{d}E/\mathrm{d}t$	0.2
Identify the power loss with the luminosity of GWs	0.2
Write expressions for L and $\mathrm{d}L/\mathrm{d}t$	0.2
Find the expression for $(\mathrm{d}\Omega/\mathrm{d}t)^3$	0.2
Expression for M_c	0.2
Total	1.0

B.4

Relate the frequency of the GWs with the orbital frequency	0.5
Write eq. (10) in question sheet as $\mathrm{d}\Omega/\mathrm{d}t = \chi\Omega^{11/3}$	0.5
Usage of (11) in the question sheet	0.5
Expression for the GW frequency (identification of p)	0.5
Total	2.0

[dimensional analysis to determine p is OK]

B.5

Estimate frequencies and time averages	0.3
Obtain t_0 and A	0.3
Value for the chirp mass	0.3
Total mass	0.1
Total	1.0

B.6

Angular orbital velocity	0.3
Obtain L and R_max	0.3
Value for the collision velocity	0.4
Total	1.0