Electromagnetic interactions with matter mediated by Gravitational Waves

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➧ Conventional approach: search for wave-like solutions to Einstein eqs. in a space-time with very modest curvature and with a metric line element which is that of flat space-time but for small derivations on nonzero curvature (linearized Einstein eqs.)

source:

- GW can put energy into things they pass through (detector)
- carry energy away from their sources
- effects of the loss of energy by GW can be observed although the GW itself not

Summary

- GW are fluctuations in curvature that propagate through the universe at speed of light.
  They are a natural consequence of Einstein's theory of relativity.
- GW are transverse and traceless in nature and are produced by **changes** in the quadrupole moment of a mass distribution.
- Mass and momentum conservation ensure **no** monopole or dipole GWs.

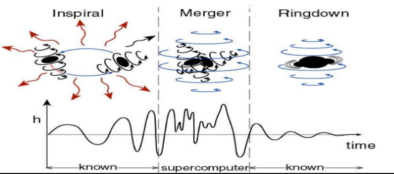
- GW carry energy and momentum, which create background curvature. This is equal to the energy and momentum lost by radiation reaction at the source.
- GW can be lensed and redshifted in the same way as electromagnetic waves, but not readily absorbed or dispersed ...

Accretion Disk

source: AEI - LSU

- merger of a pair of gas-rich galaxies with SMBHs in gral, channels large quantities of gas to the ctral region ➠ gaseous envelope around the SMBH binary
- presence of gas and stars ➨ catalyze the emission of GW
- the high infall rate ➠ formation of a geometrically-thin accretion disk
- nearly equal mass binary, tidal field ➠ open a ctral cavity in the disk
- GW dissipation, punctured disk ➠ EM transient ➠ traditional observation!!!

- GW interact weakly, that are expected to escape from the densest environments
- in the vicinity of coalescing SMBBH, a minuscule coupling with matter could lead to a bright EM signal
- viscous dissipation of GWs in the surroundings of SMBBH might be detectable



EM counterparts to SMBH mergers

- periodic variation of the grav.pot. – early stage of the inspiral
- shocks ➠ mass loss of the binary due to GW burst ($t \sim$ days-weeks)
- shocks ➠ gravitational recoil kick ($t \sim$ months-yrs)
- infall of gas onto the SMBH remnant ($t \sim$ years)

- viscous dissipation (heating) of GWs dominates, during the late inspiral at larger distances... prompt EM counterpart

GW from Black Hole mergers

GWs produced BBH merger

energy flux at large distances, $e_{GW}(t,r,\theta,\phi) = Y(\theta)\frac{L_{GW}(t_{ret})}{4\pi c r^2}$ $L_{GW}(t_{ret})$ GW luminosity at the retarded time $t_{ret} = t - r/c$

GW dissipation in a viscous medium

GWs induced shear in the fluid, $\sigma_{\mu\nu} = \frac{1}{2}\dot{h}_{\mu\nu}$ ∴ energy density is dissipated at the rate,
$\dot{e}_{heat} \equiv \dot{e}_{GW} = \frac{16\pi G\eta}{C^2} e_{gw}$
➠ energy density dissipates exp. with a time constant $t_d = (16\pi G\eta/c^2)^{-1}$

heating a thin accretion disk

α-model: gas orbiting around the ctral SMBH within a thin coplanar disk ($H(r) \ll r$ & low temp. $T \lesssim 10^6$K)

- mass accretion rate $\dot{M}$ → Eddington luminosity $L_E(M)$
- GW energy absorbed puA, $H\dot{e}_{heat}$ ➠ rate of GW dissipation puA is indep. of the disk viscosity or opacity, $= \frac{16\pi G}{c^2}\eta H e_{GW} = \frac{8}{3}\frac{G}{c^3}\dot{M}Y(\theta)\frac{L_{GW}(t_{ret})}{4\pi r^2}$
- comparing heating & std dissipation rates, $\frac{\dot{e}_{heat}(t_{ret},r)}{\dot{e}_{disk}(r)} = \frac{32}{9}Y(\theta)r_3 L^{GW}_{-3}(t_{ret})$
- result universal: indep. M or acc.disk parameters.

Cooling & Brightening of the disk

- excess of heat deposited by GWs will be re-radiated away EM:

the EM light curve depends on the uncertain details of the turbulent accretion disk and the vertical transport of heat.

➡ opt. thick disk, $\tau \gg 1$ ➡ $t_{diff} \sim \tau H/c$

➡ time scale by turbulent heat transport, $t_{therm} \sim H/c_S/\alpha$

➡ time scale, $t_c = \min(t_{diff}, t_{therm})$

- 3 regions: inner (rad.pres.), middle (gas pres. and electron scat.), outer (gas pres. and ff transitions).

Brightening of the disk

➡ «stationary disks» no radial heat transport.

➡ the flux is determined by an 1st order ODE, $t_c \Delta\dot{F} + \delta F = H\dot{e}_{heat}$

➡ $\frac{\Delta F(t_{ret},r)}{F_{disk}(r)} \approx$

$$\begin{cases} \frac{32}{9} Y(\theta) r_3 L^{GW}_{-3}(t_{ret}) & \Delta t_{GW} \gg t_c \\ \frac{16}{9} \kappa Y(\theta) r/(c t_c) & \Delta t_{GW} \ll t_c \end{cases}$$

- net excess apparent luminosity disk,

$$\Delta L(t) = \frac{\cos\theta_{obs}}{4\pi d_L^2} \int_{r_{min}}^{r_{max}} \int_0^{2\pi} \Delta F(t'_{ret}, r) r d\phi_{disk} dr$$

$$t'_{ret} = t - \frac{r}{c}(1 - \sin\theta_{obs} \cos\phi_{disk})$$

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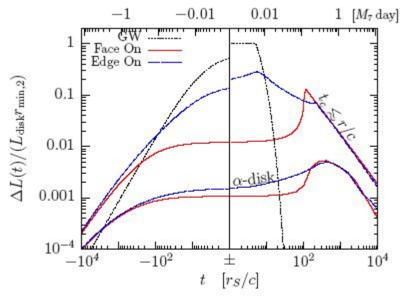
➡ "excess luminosity curve" – [Kocsis, Loeb. PRL 101 (2008)]



➡ during the t^{-1} decline of the EM transient, the characteristic emission wavelength (surf.temp. of the disk) ➡ IR-band and increases $\propto t^{3/4}$ as the GW propagates outwards.

➡ In radiatively inefficient (geometrically-thick) accretion flows, the resulting light curve is fainter and difficult to observe.

➡ the light curve is highly sensitive to θ_{obs} due to the geometric (GW travel-time) delay;

➡ the excess luminosity of a thin circumbinary disk peaks with a delay $\sim 10 M_7$ hours relative to the peak of the GW burst;

➡ Measurement of the GW heating effect would provide an indirect detection of GWs with traditional EM observatories, and test GR for the interaction of GWs with matter.

summary & discussion

- “Set-up” for ONE potential scenario for EM-counterpart from GW

➡ Important spatial information regarding positioning and location of GW sources

- Measuring the GW-“heating”,

➡ indirect detection of GW with traditional EM observatories,

➡ test of GR theory for interaction of GW with matter.

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- "Set-up" for ONE potential scenario for EM-counterpart from GW

➡ Important spatial information regarding positioning and location of GW sources

- Measuring the GW-"heating",

➡ indirect detection of GW with traditional EM observatories,
➡ test of GR theory for interaction of GW with matter.

References

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