Electromagnetic flares in the jet spectrum as beacons for gravitational waves from supermassive black hole mergers

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Outline

- Supermassive black holes
- Spin-flip phenomena
- Electromagnetic flares in jet spectrum
- Predicting the arrival time of gravitational waves

Supermassive Black Holes (SMBH)

- Typical mass: 10^6 $M_\odot$ 10^{10} $M_\odot$
- At the center of our galaxy: 10^6 $M_\odot$
- Accretion -> high spin -> particles ejected at the poles (jet)
- Galaxies merge -> the SMBH-s inside them merge
- Typical mass ratio ($\nu = m_2/m_1$), derived from mass distribution: 1/3 to 1/30

Gergely, L. Á., Biermann, P. L.: 2009, Astrophys. J. 697, 1621

Spin-flip

- For the typical mass ratios
- At the beginning of the inspiral -> orbital angular momentum $L>S_1$ dominant spin
- At the end of the inspiral $S_1>L$
- During the inspiral a spin-flip happens
- The spin direction changes -> direction of the jet changes.
- The spin precesses about the total angular momentum J

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Electromagnetic Flare in the Jet

- We consider the jet observable while the angle between J and S_1 (β) changes 1º -> an observable period
- While this change occurs, the jet precesses around J. -> second observable period
- From this we can give some predictions of when we can see gravitational waves from the direction of the jet.

Timescales

- Parameters: t_p, t_j, β, $\kappa=\alpha+\beta$, m, ε, ν, $\Delta\beta=1°$
- Analytical expression between α, κ, ν and ε

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$$\frac{\sin 2\alpha}{1+\cos 2\alpha} \approx \frac{\sin(\alpha+\beta)}{\varepsilon^{-1/2}\nu + \cos(\alpha+\beta)}$$

$$f_{GW} = \frac{c^3}{\pi G m}\varepsilon^{3/2}$$

- Expressions of t_p/t_j and t_p

$$\frac{T_J}{T_p}(\nu,\varepsilon,\beta;\Delta\beta) = \frac{5\Delta\beta}{32\pi}\frac{\nu\sin^2\kappa}{\varepsilon^2\sin^3\beta}$$

$$T_p(f_{GW},\nu,\varepsilon,\beta) = \frac{(1+\nu)^2}{\varepsilon\nu}\frac{\sin\beta}{\sin\kappa}f_{GW}^{-1}$$

- For a given ν, and β and observed t_p and t_j we can calculate ε_J, m (thus f_{gw}) (and κ)
- Thus we have the starting conditions for gravitational waveform

Detecting gravitational waves

- Gravitational waves from SMBH binaries will be detected by LISA
- Here we give estimates for the time when the gravitational waves from the inspiraling SMBH-s we see from the jet can be detected.
- We use leading order frequency domain waveforms for these estimates

Arun, K. G.: 2006 Phys. Rev. D74 024025

$$\tilde{h}_\alpha(f) = \frac{\sqrt{3}}{2} A f^{-7/6} e^{i\psi(f)}, \ \alpha = I, II,$$

$$A = \frac{1}{\sqrt{30}\pi^{2/3}} \frac{m_{chirp}^{5/6}}{D_L},$$

$$\psi(f) = 2\pi f t_c - \phi_c - \frac{\pi}{4} + \frac{3}{4}\left(\frac{8\pi G m_{chirp} f}{c^3}\right)^{-5/3}$$

$$m_{chirp} = \eta^{3/5} m$$

Signal to noise ratio (SNR)

- The spectral density of the noise for the LISA detector (instrument noise and confusion noise):

$$S_{h,inst}(f) = 5.049 \times 10^5 \left[a^2(f) + b^2(f) + c^2\right]$$
$$a(f) = 10^{-22.79}\left(f/10^{-3}\right)^{-7/3}$$
$$b(f) = 10^{-24.54}\left(f/10^{-3}\right)$$
$$c = 10^{-23.04}$$

$$S_{h,conf}(f) = \begin{cases} 10^{-42.685} f^{-1.9} & f \leq 10^{-3.15} \\ 10^{-60.325} f^{-7.5} & 10^{-3.15} < f \leq 10^{-2.75} \\ 10^{-46.85} f^{-2.6} & 10^{-2.75} < f \end{cases}$$

Cutler, C.: 1998 Phys.Rev. D57 7089

- The SNR

$$SNR = \sqrt{4 \int_{f_{in}}^{f_{end}} \frac{\left|\tilde{h}(f)\right|^2}{S_h(f)} df}$$

Signal to noise ratio (SNR) 2

- We consider detection, when the SNR reaches 10.
  Finn, L. S., Thorne, K. S.: 2000 Phys. Rev. D62 124021
- We calculate the time from the start of the transient jet flare ups (ε_J) to when the SNR reaches 10. (ε_1)
- And we give an estimation for when from that time the end of the inspiral (ε_2=0.1) will happen

$$\Delta t = 5 \frac{Gm}{2^8 c^3} \frac{(1+\nu)^2}{\nu} \left(\varepsilon_J^{-4} - \varepsilon_1^{-4}\right)$$

Example

- Observed: t_p=126 days, t_j=656 days
- Assumed: β=30º, ν=1/10
- Calculated: m= 10^6 $M_\odot$, ε_J=0.0100 κ=60º
- SNR reaches 10 at: ε_1=0.0117
  the time it takes for this: 647 days
- From this point the time until the end of the inspiral (ε_2=0.1) is: 708 days

Summary

- Based on the spin-flip phenomena, we derived a possible electromagnetic beacon that can predict when an SMBH binary reaches the end of the inspiral, and when we can expect to detect the gravitational waves from a certain direction by the LISA detector

Thank you for your attention!