

Title: Phase Shift of Gravitational Waves induced by Aberration

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Series: Strong Gravity

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Abstract: The velocity of a gravitational wave (GW) source provides crucial information about its formation and evolution processes.

Previous studies considered the Doppler effect on the phase of GWs as a potential signature of a time-dependent velocity of the source. However, the Doppler shift only accounts for the time component of the wave vector, and in principle motion also affects the spatial components. In my talk I discuss the latter effect, known as "aberration" for light, for GWs and how it affects the waveform modeling of an accelerating source. I show that the additional aberrational phase shift could be detectable in two astrophysical scenarios, namely, a recoiling binary black hole (BBH) due to GW radiation and a BBH in a triple system.

Further, I discuss how adding the aberrational phase shift in the waveform templates could significantly enhance the detectability of moving sources.

Phase Shift of Gravitational Waves induced by Aberration

Based on: **Phys. Rev. D 101, 083028**

by

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June 18, 2020

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Magnitude of the phase shift and its SNR

Moving sources

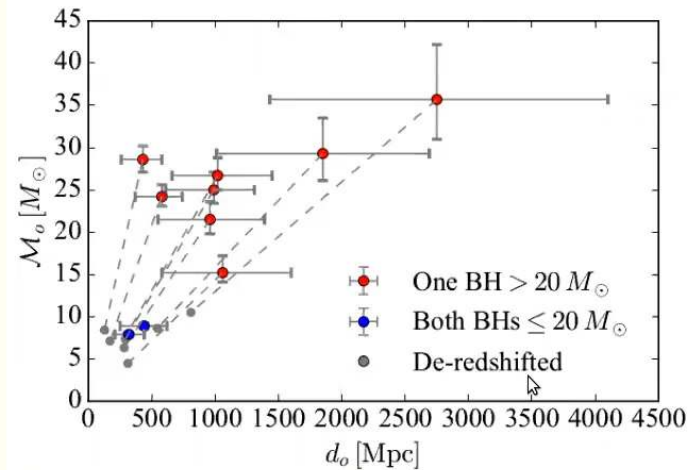
Moving sources

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"... nor are those bodies always truly at rest, which commonly are taken to be so."

- Isaac Newton

The effect of (constant) motion



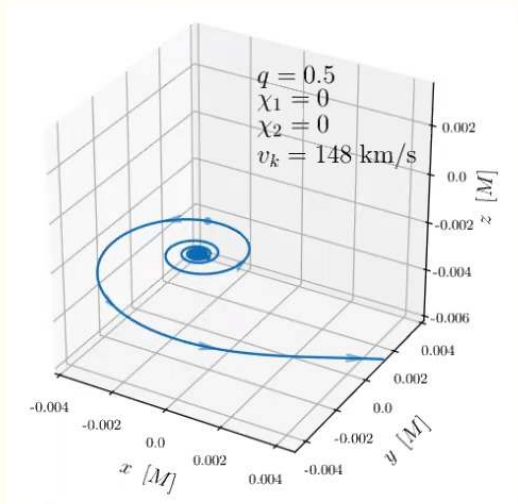
Mass-distance gap in LIGO detections
[Chen+2019]

- velocity affects
observed mass and
distance [Chen+2019]:
$$\mathcal{M}_o = (1 + v)\mathcal{M}$$
$$d_o = (1 + v)d$$
- Is the mass-distance
gap a coincidence?

Kinds of motion

- ❖ GWs sources are not completely isolated → **peculiar velocity** (host galaxy) or **orbital motion** (central potential)
- ❖ GWs carry momentum → emission of GWs can induce a **recoil of the source**
- ❖ these are all **time dependent velocities!**

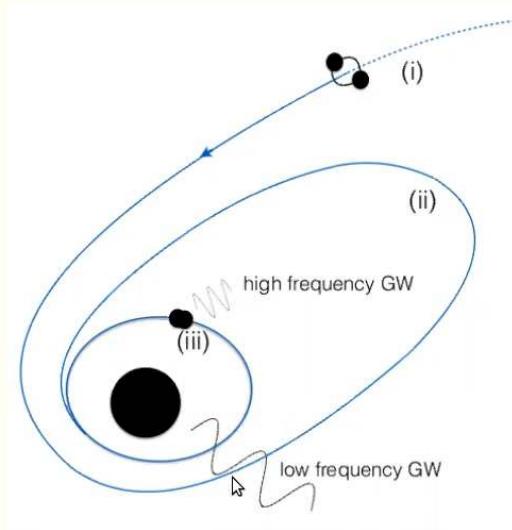
Moving sources I: kicked sources



GW recoil [Gerosa+2018]

- ❖ BBHs with asymmetries → **recoil velocities** $\sim (100-1000) \text{ km/s}$ independent of the mass [Gerosa+2018]
- ❖ can **exceed escape velocities** of most massive galaxies [Merritt+2004]

Moving sources II: triples



BBH orbiting SMBH
[Chen+2018]

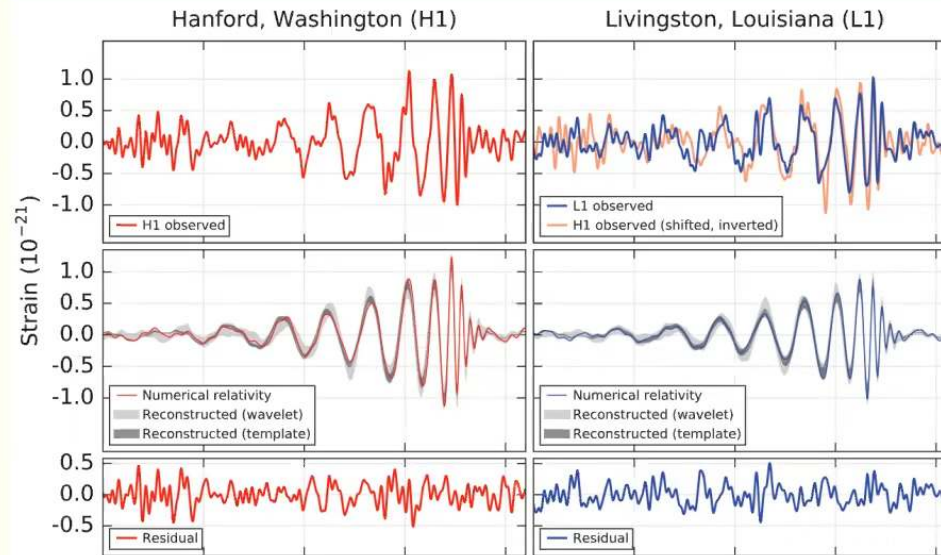
- ❖ BBHs interact with third body
→ **CoM velocity**
 $\sim (100-1000) \text{ km/s}$ [Chen+2018, ArcaSedda2020, Tagawa+2019]
- ❖ GWs of different frequencies →
test alternative theories
[Han+2019]

Templates & motion

Templates & motion

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GWs templates



First GW detection [LIGO2016]

- ❖ templates are essential for the **detection and interpretation** of GWs sources

Formalisms & motion

Formalism	NR (Sur)	Post-Newtonian	EOB	Phenom
CoM motion	yes, but restricted	usually not	restricted through PN & NR	restricted through PN & NR

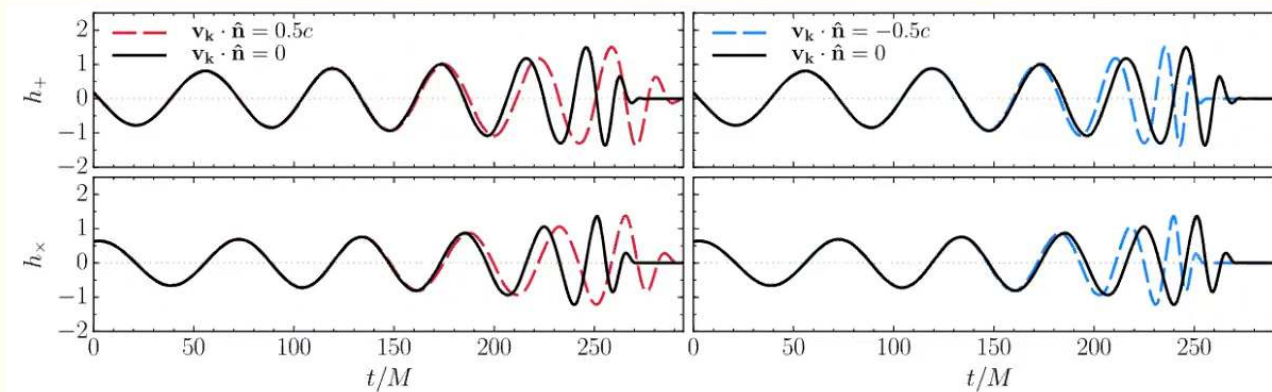
- ❖ **no formalism** describes **general motion** of center-of-mass (CoM) [SXS2019, Varma+2019, Blanchet2006, Buonanno+1999, Santamaria+2010]

Accelerated motion & the phase

Accelerated motion & the phase

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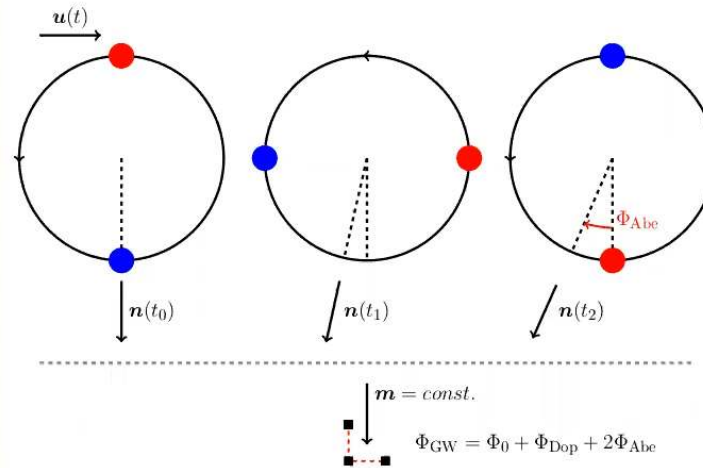
Doppler shifted gravitational waves



Dephasing due to a kick [Gerosa+2016]

- changing **velocities along the line-of-sight(!)**
can be detected for kicks and triples
[Gerosa+2016, Inayoshi+2017, Meiron+2017]

Aberration induced phase shift



Phase shift due to the aberration effect [Torres-Orjuela+2020]

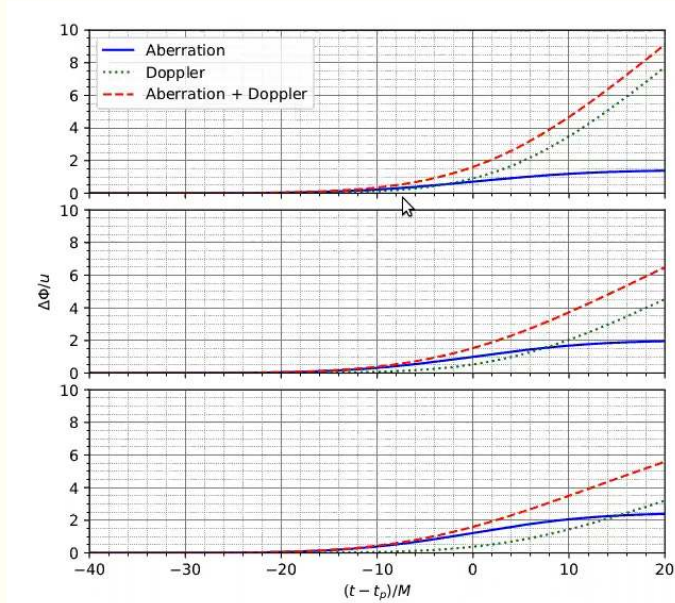
- ❖ **line-of-sight** (LoS) constant in observer's frame but **time dependent in source's frame** → **aberration induced phase shift**

Detecting the aberrational phase shift

Detecting the aberrational phase shift

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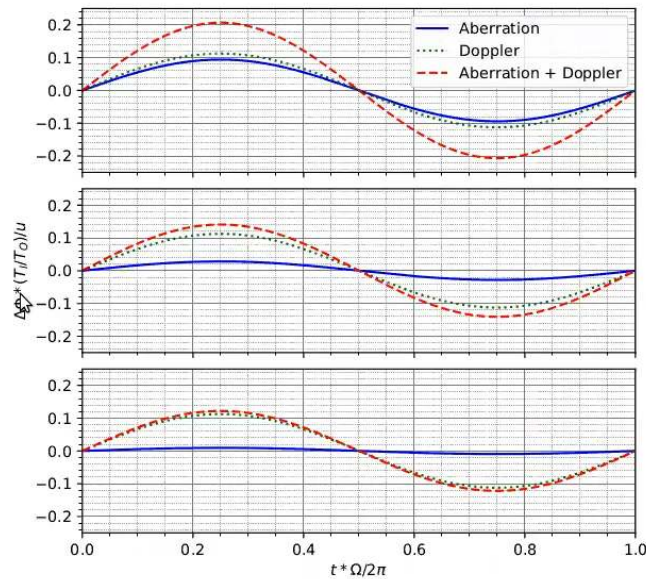
Aberrational vs. Doppler shift: kick



Aberrational+Doppler shift for kicked sources [Torres-Orjuela+2020]

- ❑ Aberrational and Doppler shift of **same order**
- ❑ Aberrational shift sensitive to **velocity perpendicular to LoS**
- ❑ **total phase shift significantly enhanced**

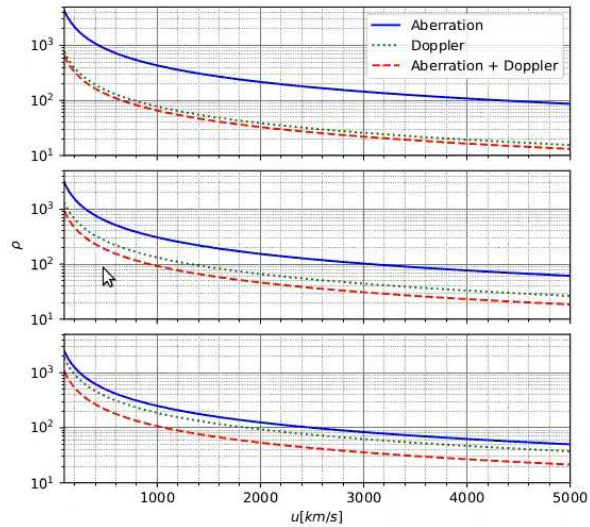
Aberrational vs. Doppler shift: triple



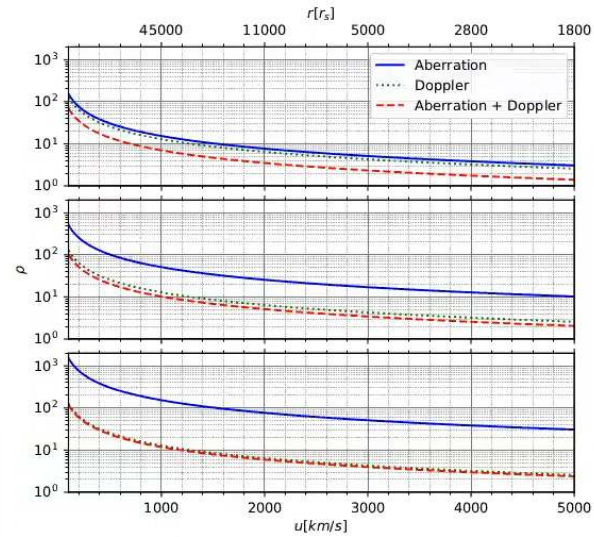
Aberrational+Doppler shift for triples
[Torres-Orjuela+2020]

- ❖ Aberrational shift's magnitude depends on time scale
- ❖ frequency and acceleration's time scale similar → Aberrational and Doppler shift have similar magnitude

The effect on the SNR



SNR to detect phase shift (kicks)



SNR to detect phase shift (triples)

- ❖ **Detectability enhanced** by factor up to 1.8 \rightarrow approx. **6 \times** **more sources** detectable [Torres-Orjuela+2020]

To cut a long story short

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Remember...

- ❖ most GWs sources are NOT at rest (e.g., orbital motion or kicks)
- ❖ general CoM motion cannot be described by any kind of template
- ❖ time dependent velocity → detectable aberrational and Doppler phase shift
- ❖ NEW! Aberrational phase shift enhances detectability of moving sources significantly

To cut a long story short

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