The effect of a constant velocity of the source on gravitational waves

Alejandro Torres-Orjuela • TianQin Center @ KIW9 , June 7, 2022

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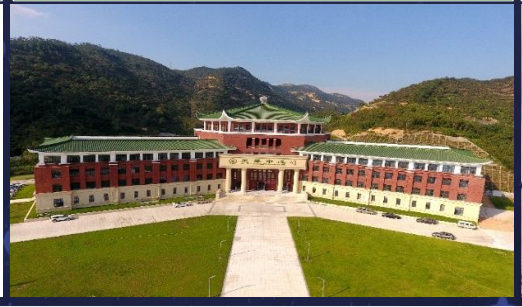
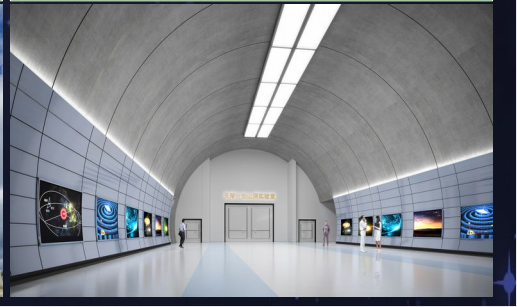
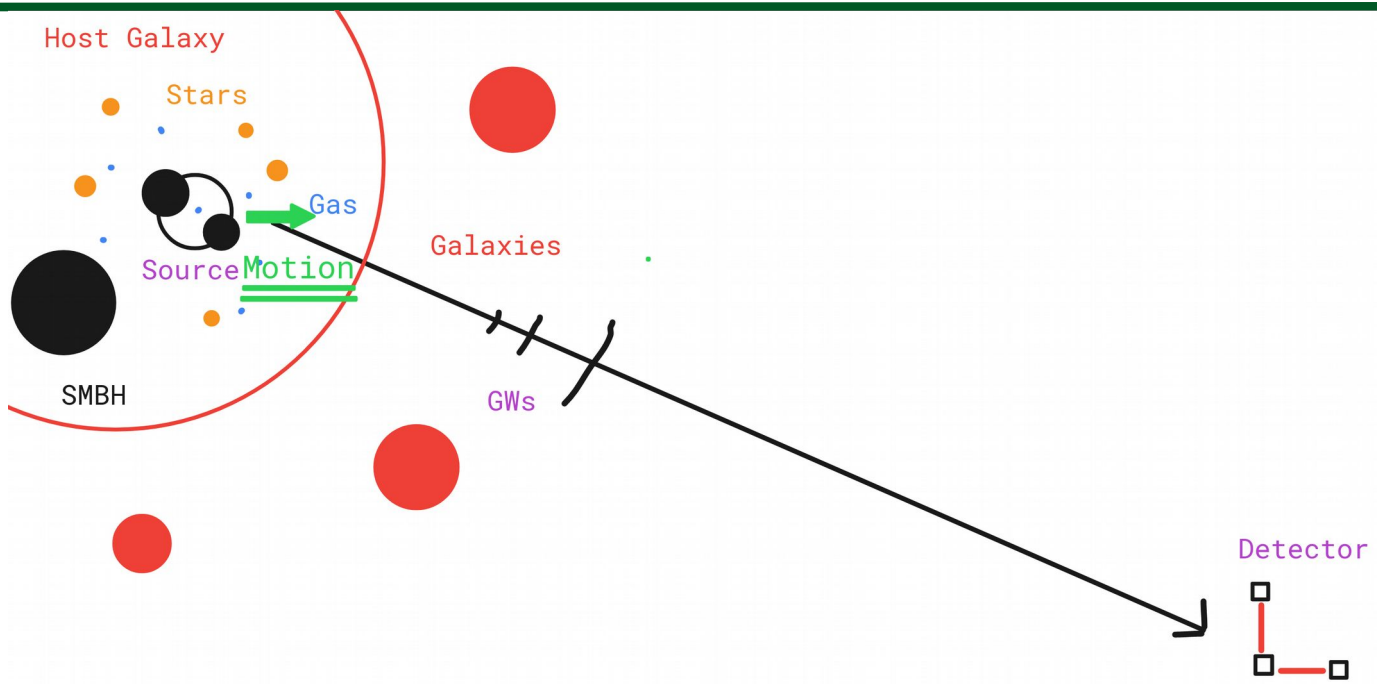
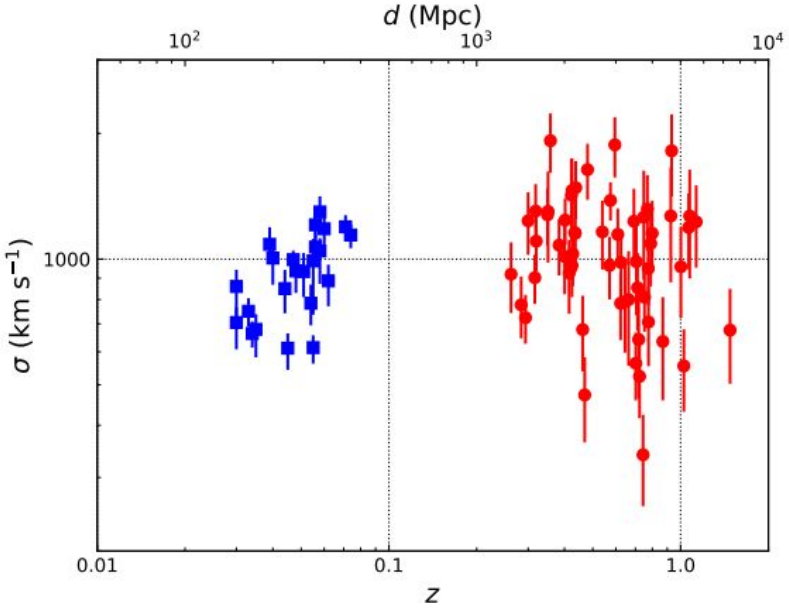
			

Realistic GW sources



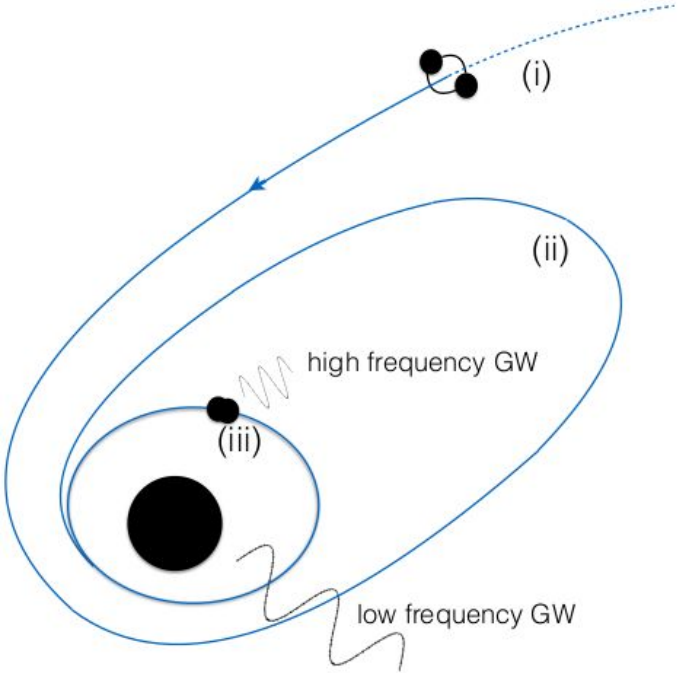
Peculiar velocity of galaxies



Velocity dispersion in Galaxy clusters [ATO+2021]

- Galaxies form galaxy clusters
- Gravitational interaction induces motion
- Galaxy and GW source moves with ≈ 1000 km/s relative to us

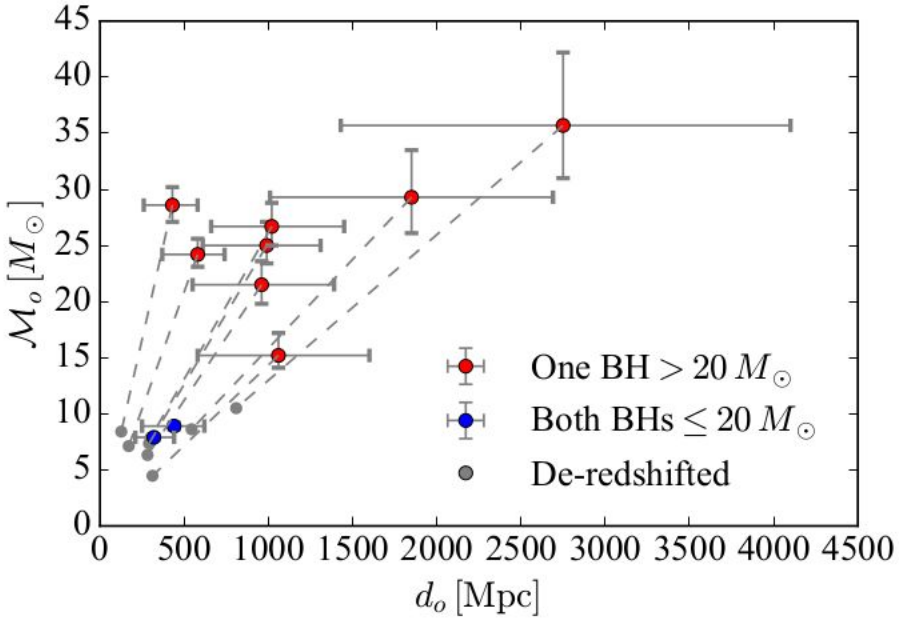
Triple systems



Triple system: BBH and SMBH [Chen+2018]

- In dense systems triples can form: in particular center of galaxies
- Third body induces orbital velocities from 100s km/s to highly relativistic

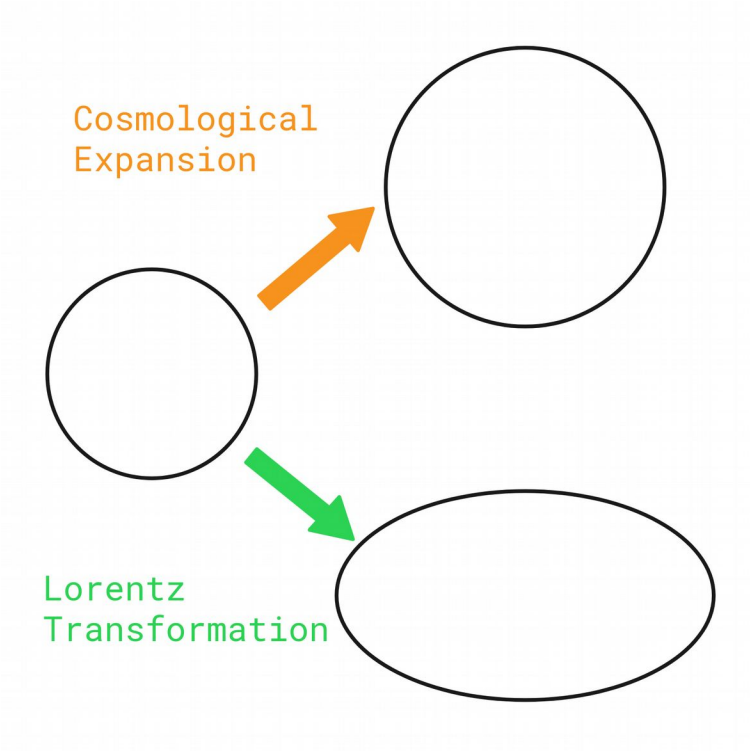
Mass-redshift degeneracy



Redshifted GW sources [Chen+2019]

- Simplistic picture:
  consatnt velocity → redshift → GW sources appear more massive and distant

Redshift ≠ redshift



- *Global rescaling* → Mass-redshift degeneracy
- Velocity changes the scale in preferred direction → no (simple) mass-redshift degeneracy

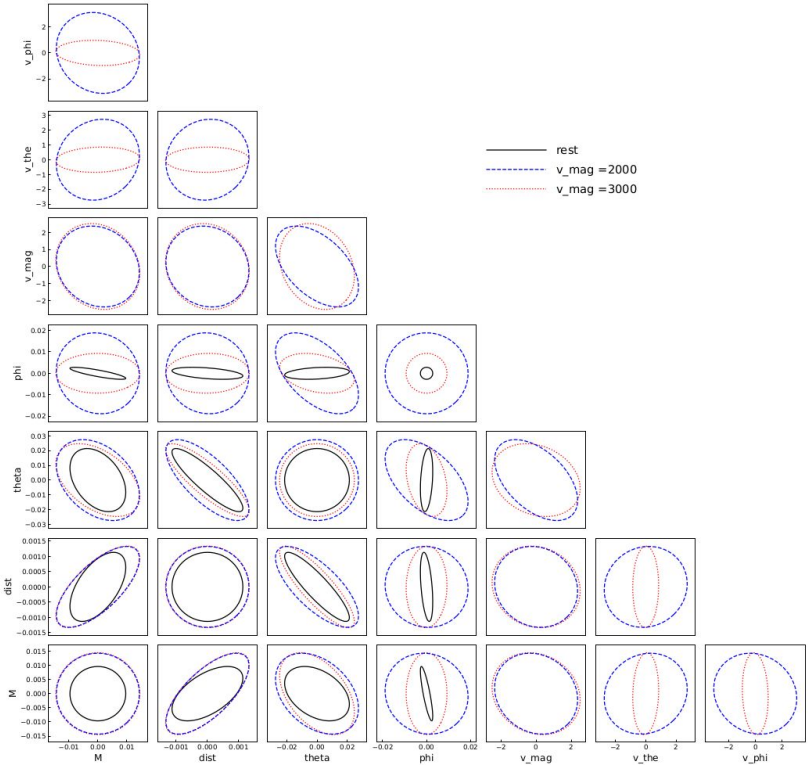
The effect on the wave

- The transformed complex amplitude of the wave takes the form:

$$H = e^{-2i\alpha}\frac{1}{D}H'(D\,\omega')$$

  - mixing of +- and x-polarisation
  - redshifted sources appear closer (not further away!)
  - ‚fundamental frequencies‘ are direction-dependent

Detectability



- Credits: Chanqing Ye
- Standard EMRI at 0.1 Gpc (SNR ≈ 200)
- Vel. magnitude ~ 2 km/s & direction ~ 1 rad
- Other parameters affected

Summary

- Source environment → CoM velocity (peculiar velocity of galaxies & triples)
- Velocity → direction-dependent transformation of the field → detectable velocity of the source
  → velocity magnitude ~ 2 km/s
  → velocity direction ~ 1 rad
  → parameter bias significant

Thanks for your attention ！

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	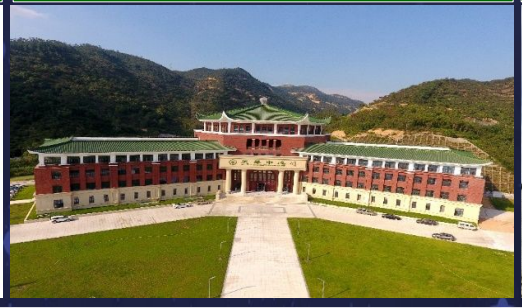		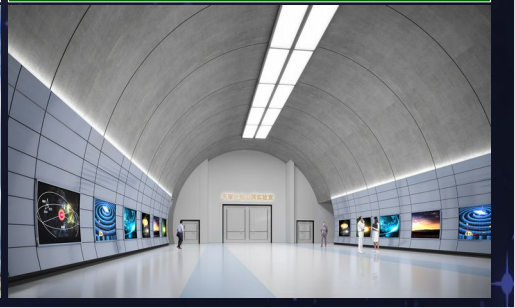

Possible degeneracies

- Shift chirp mass M = (1+ΔM)M‘, luminosity distance R = (1+ΔR)R‘, and orientation sin(θ‘) = (1+Δθ)sin(θ)
- to linear order:
  - $\Delta R = +v\cos(\theta)$: redshifted source appears closer
  - $\omega \propto M^{v\cos(\theta)/\Delta M}$: frequency needs to be monomial of chirp mass
  - $\sin(\theta') = \sin(\theta) - \frac{v}{2}\sin(2\theta)$: asymmetric change of the orientation