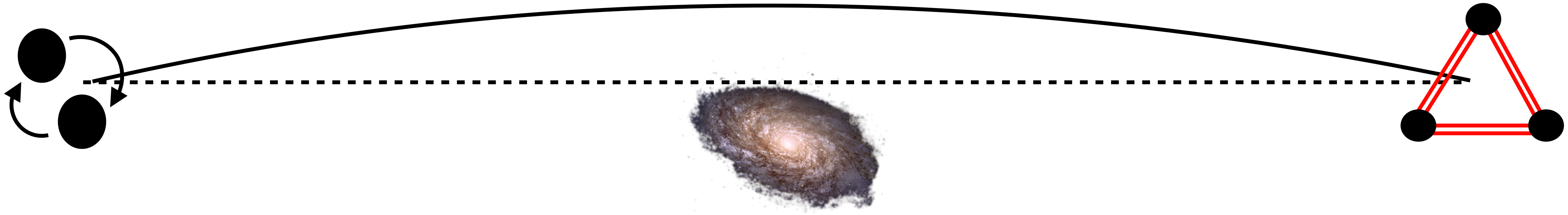
# Polarization distortions of lensed gravitational waves

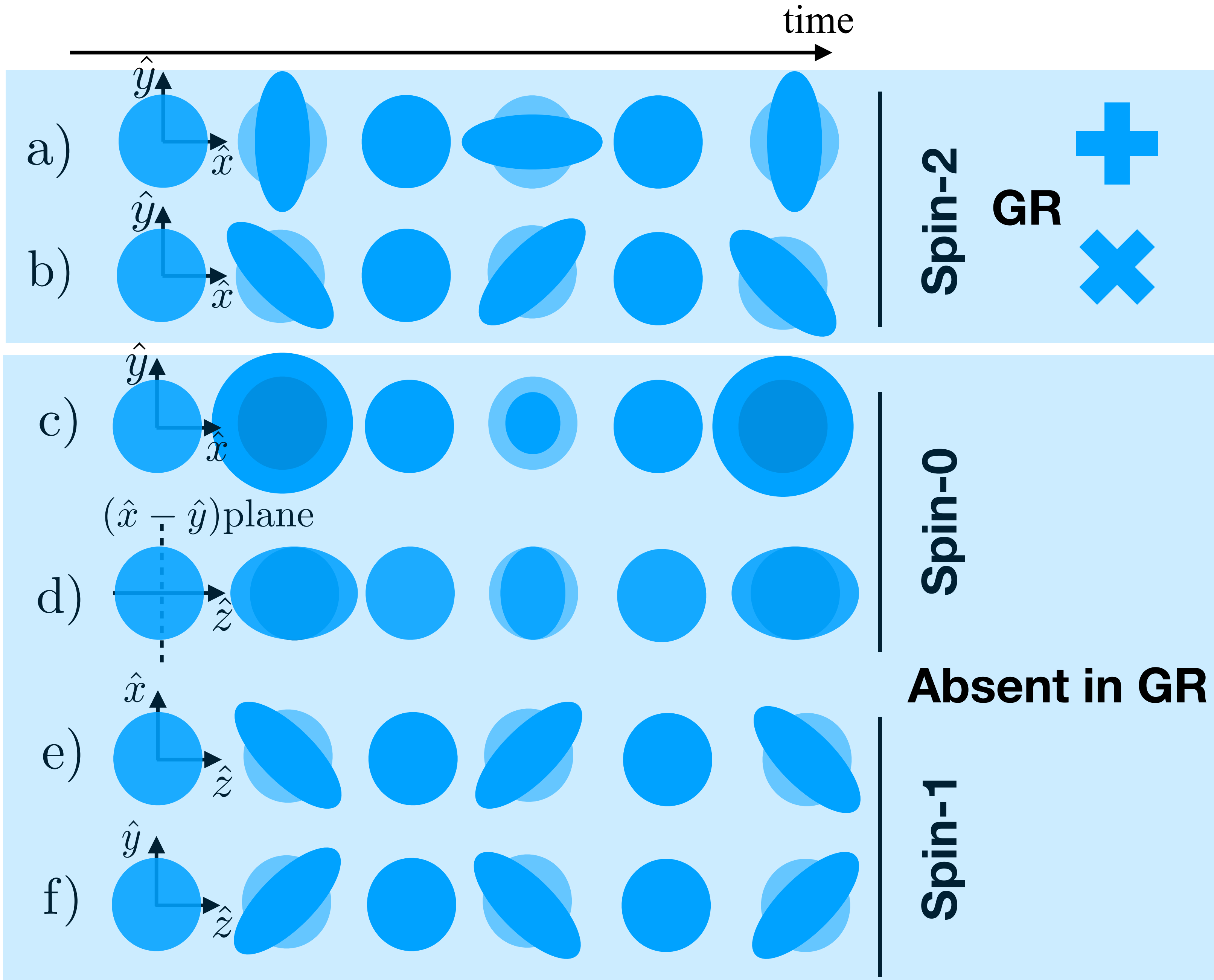
**Charles Dalang**
Département de Physique Théorique
Université de Genève
Swirtzerland



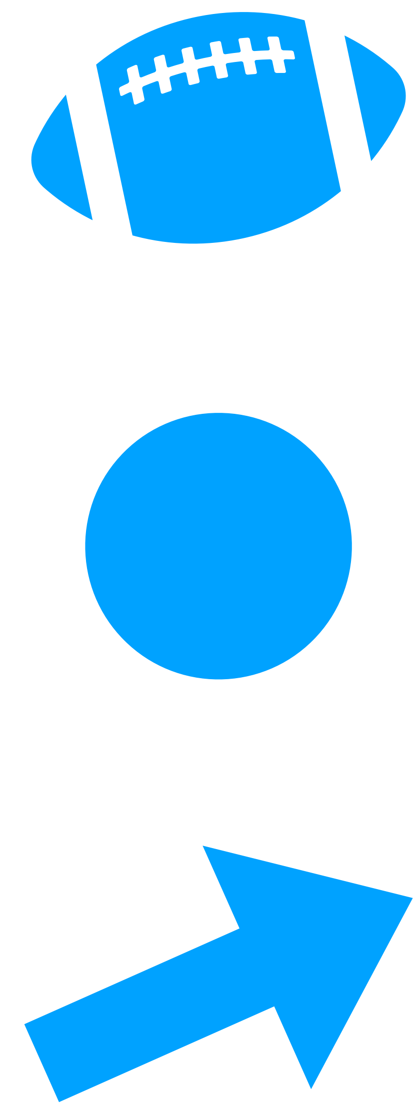
**References**

C.D., Giulia Cusin and Macarena Lagos, [2104.10119]
Giulia Cusin and Macarena Lagos, [1910.13326] Phys. Rev. D.

# GW extra polarization modes are a *smoking gun* signature of beyond GR physics.




Rotation $2\pi/s$



# GW propagation in curved spacetime

Misner, Thorne, Wheeler, 1973
Giulia Cusin, Macarena Lagos, 2020
C.D., Giulia Cusin, Macarena Lagos, 2021

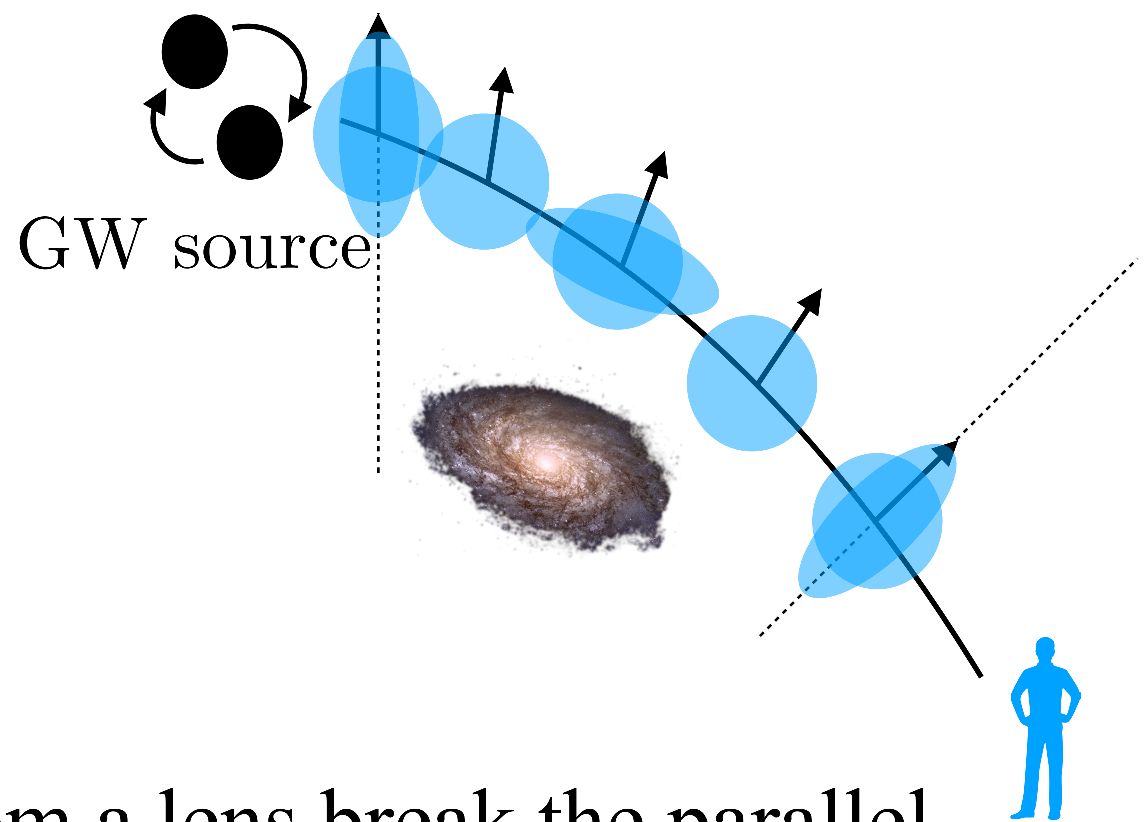
General Relativity curved space GW Eq. of motion

$$\bar{\nabla}^\alpha \bar{\nabla}_\alpha h_{\mu\nu} - 2\bar{R}_{\alpha\mu\nu\beta} h^{\alpha\beta} = 0$$

Effective mass-like term

Short wavelength approximation

→ Parallel transport of + and × modes in curved space




Does the presence of curvature from a lens break the parallel transport of GW polarizations?

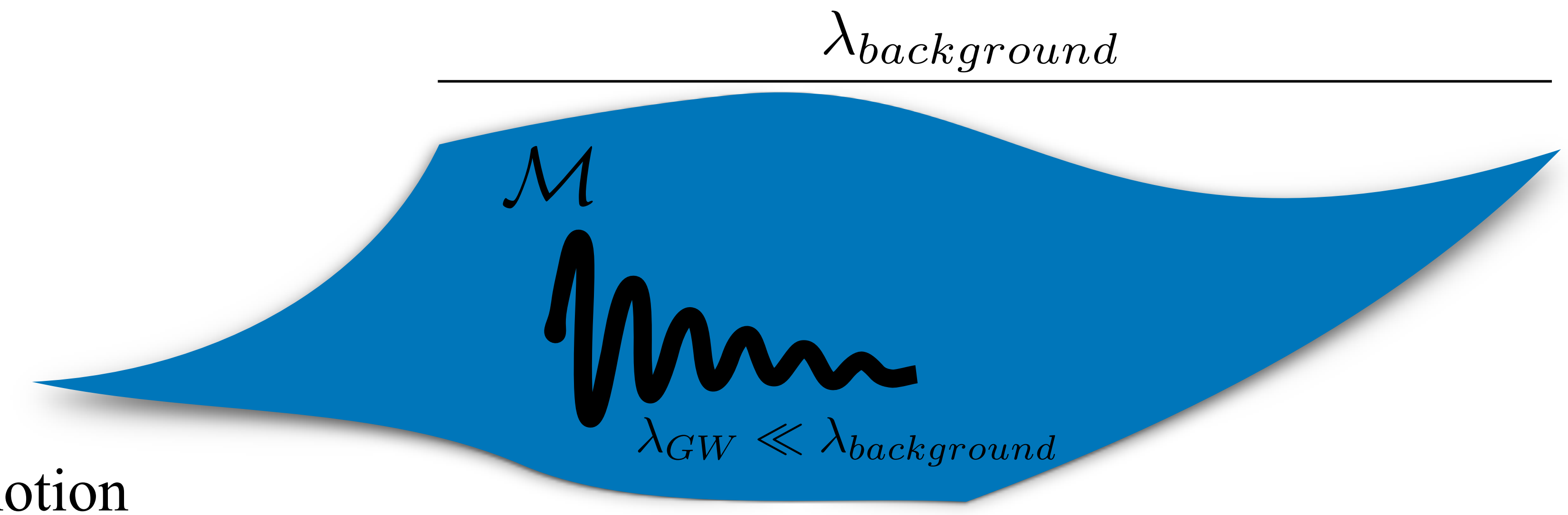
# Geometric optics and beyond

Giulia Cusin, Macarena Lagos, 2020

Wave ansatz

$$h_{\mu\nu} = \Re\left(\left(\underbrace{\varepsilon^{(0)}_{\mu\nu}}_{\substack{\text{amplitude}\\ \text{polarization tensor}}} + \omega^{-1}\underbrace{\varepsilon^{(1)}_{\mu\nu}}_{\substack{\text{amplitude}\\ \text{correction}}} + \dots\right) \underset{\text{phase}}{e^{i\omega\Phi}}\right) \qquad \underset{\text{wavevector}}{k_\mu \equiv \Phi_{,\mu}}$$

large $\omega$




Equation of motion

$$0 = -\omega^2 k_\beta k^\beta \varepsilon^{(0)}_{\mu\nu} + i\omega^1[2k^\beta \varepsilon^{(0)}_{\mu\nu;\beta} + k^\beta{}_{;\beta}\varepsilon^{(0)}_{\mu\nu}]$$

$$+\omega^0\left[i[2k^\beta \varepsilon^{(1)}_{\mu\nu;\beta} + k^\beta{}_{;\beta}\varepsilon^{(1)}_{\mu\nu}] + \bar{\Box}\varepsilon^{(0)}_{\mu\nu} - 2\varepsilon^{\alpha\beta}_{(0)}\bar{R}_{\alpha\mu\nu\beta}\right]$$

# Solve order by order

Giulia Cusin, Macarena Lagos, 2020

$\mathcal{O}(\omega^2)$ $$k_\beta k^\beta = 0$$ GWs follow nul geodesics!

$\mathcal{O}(\omega^1)$ $$[2k^\beta \varepsilon^{(0)}_{\mu\nu;\beta} + k^\beta{}_{;\beta}\varepsilon^{(0)}_{\mu\nu}] = 0$$ The polarization is parallel transported along $k^\mu$

$\mathcal{O}(\omega^0)$ $$2k^\beta \varepsilon^{(1)}_{\mu\nu;\beta} + k^\beta{}_{;\beta}\varepsilon^{(1)}_{\mu\nu} = -i\left[2\varepsilon^{\alpha\beta}_{(0)}\bar{R}_{\alpha\mu\nu\beta} - \bar{\Box}\varepsilon^{(0)}_{\mu\nu}\right]$$

The background gravitational field sources amplitude corrections of the GW!

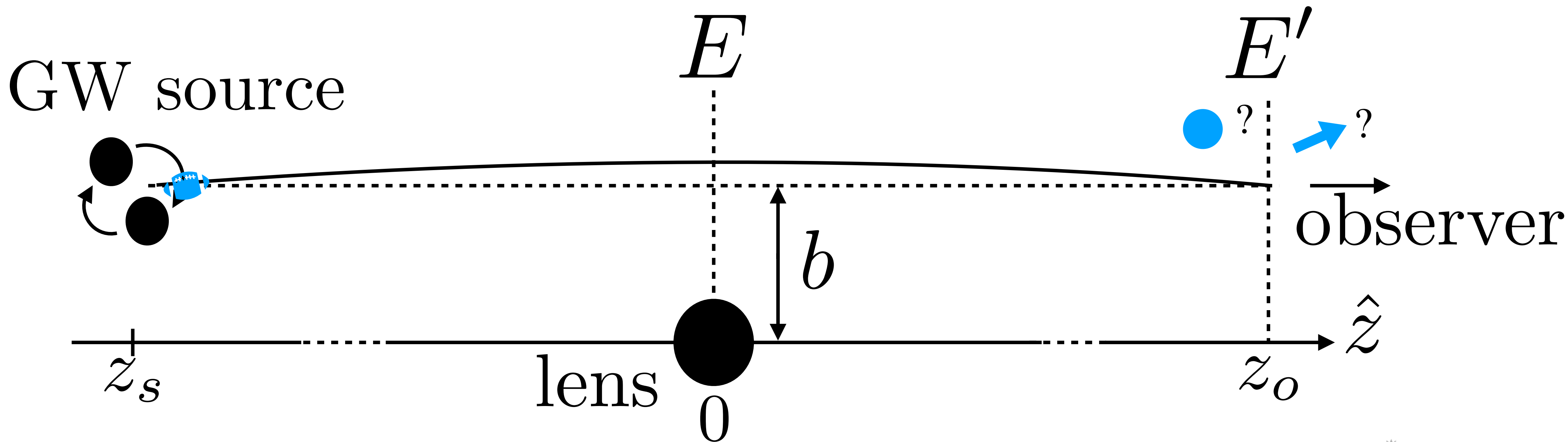
# Point-like lens

C.D., Giulia Cusin, Macarena Lagos, 2021

Schematically,

$$\varepsilon^{(1)}_{\mu\nu}(\lambda) = \underbrace{\frac{\varepsilon^{(1)}_{\mu\nu}(\lambda_s)D(\lambda_s)}{D(\lambda)}}_{=0} - \frac{i}{D(\lambda)}\int_{\lambda_s}^{\lambda} \mathrm{d}\lambda' D\left(\varepsilon^{\alpha\beta}_{(0)}\bar{R}_{\alpha\mu\nu\beta} - \frac{1}{2}\bar{\Box}\varepsilon^{(0)}_{\mu\nu}\right)$$

$$\mathrm{d}s^2 = -(1+2\Psi)\mathrm{d}t^2 + (1-2\Psi)\mathrm{d}\boldsymbol{x}^2 \qquad \Psi = \frac{R_s}{2||\boldsymbol{x}||}$$

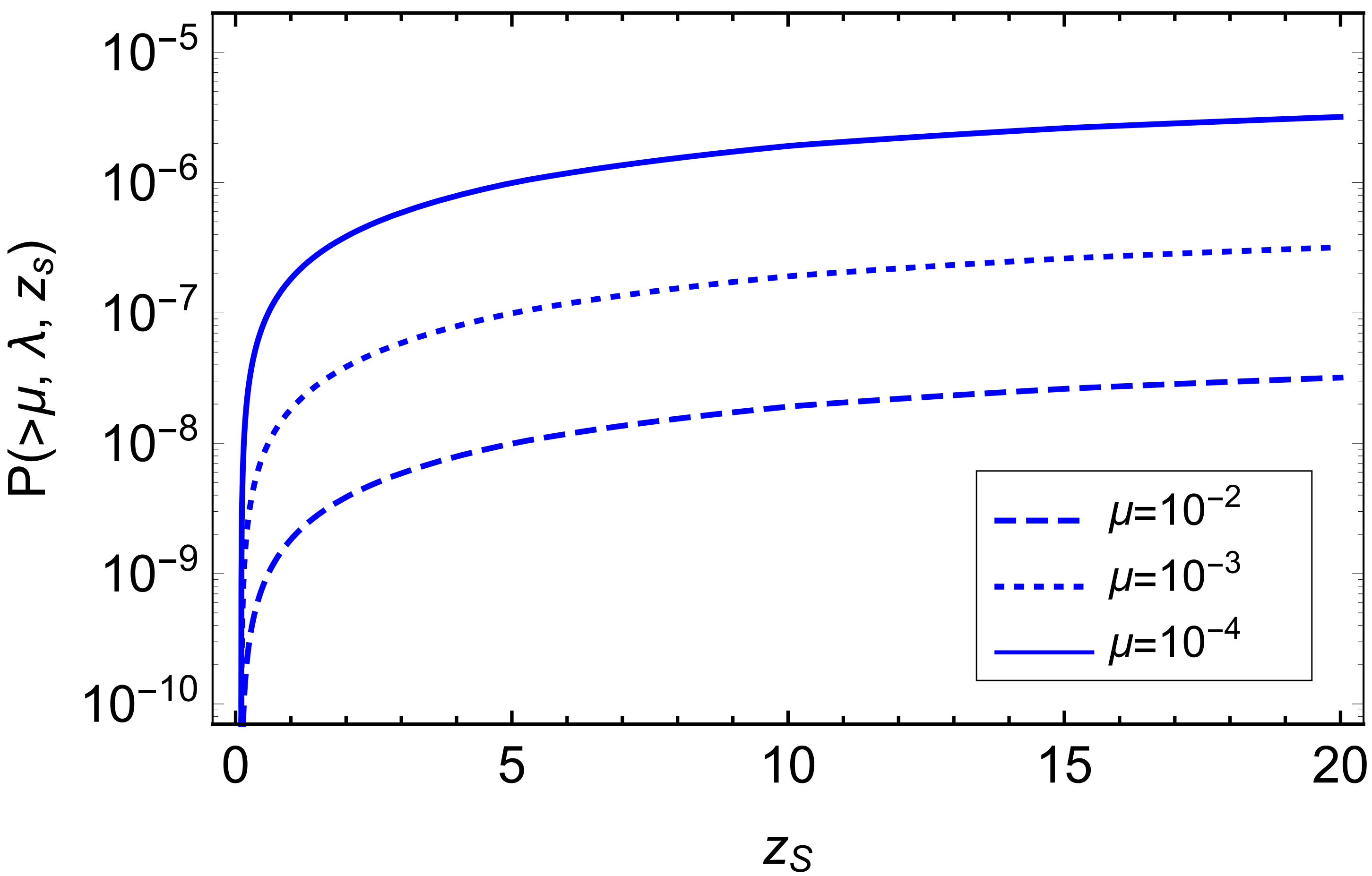


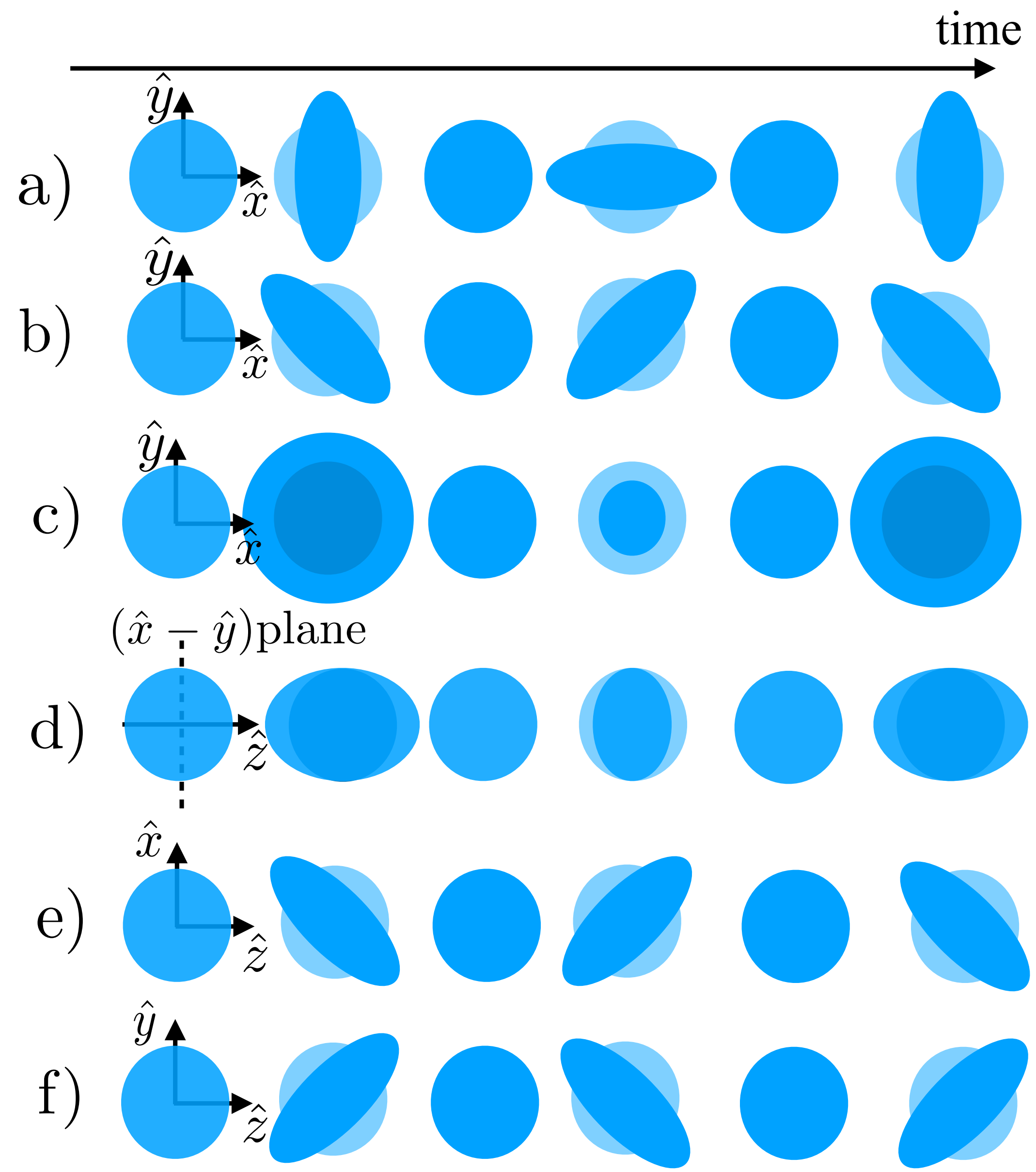
# Some + and × leak into scalar polarizations (c), (d) due to the presence of the lens!

C.D., Giulia Cusin, Macarena Lagos, 2021

Probability to create scalar modes $\mu^{-1}$ smaller than the tensor modes

$$\frac{A_s}{A_t} = \frac{R_s \lambda}{b^2} = \mu \ll 1$$



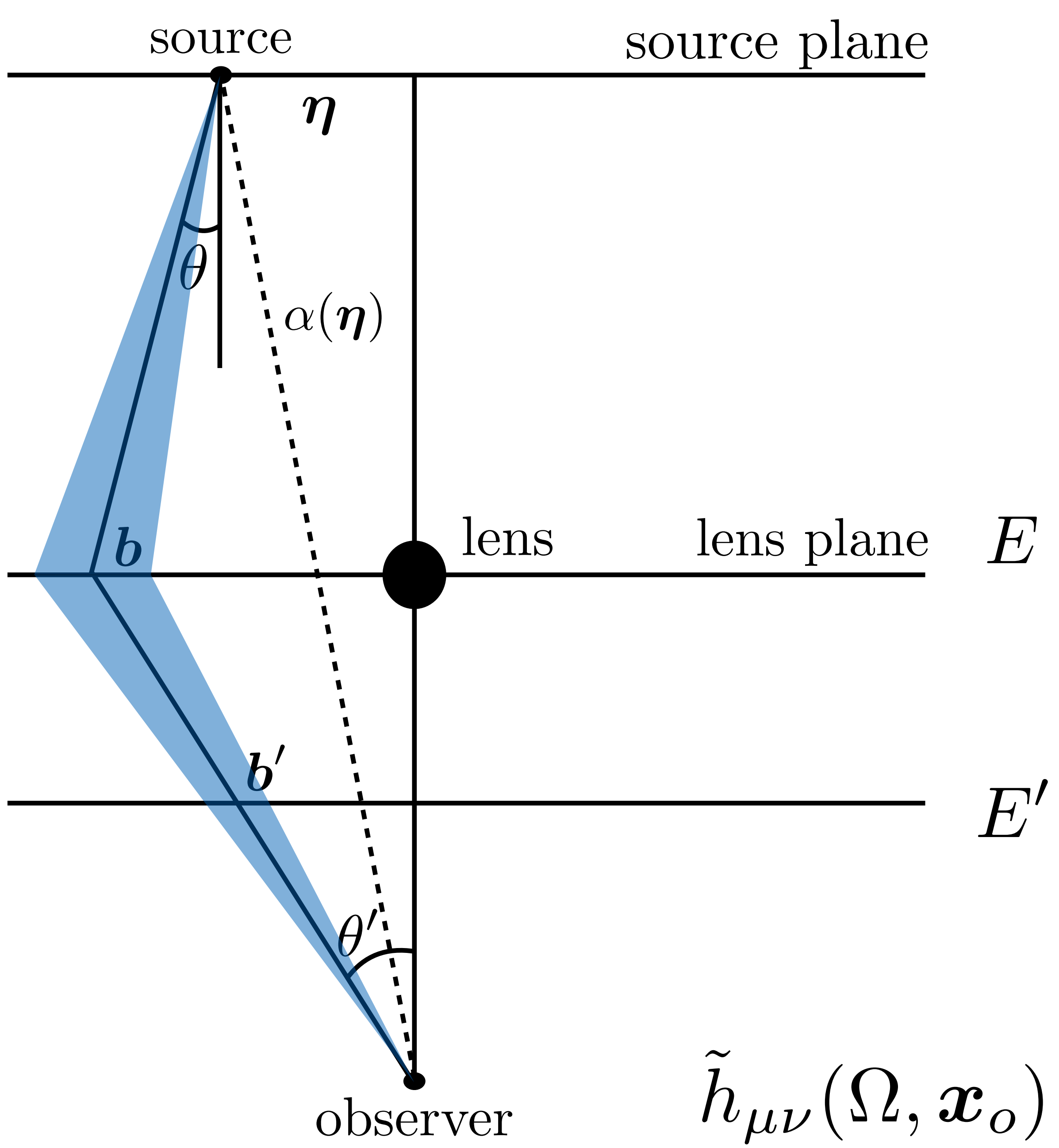

Charles Dalang



UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

# Several paths interacting destructively?

C.D., Giulia Cusin, Macarena Lagos, 2021




Two effects compete:

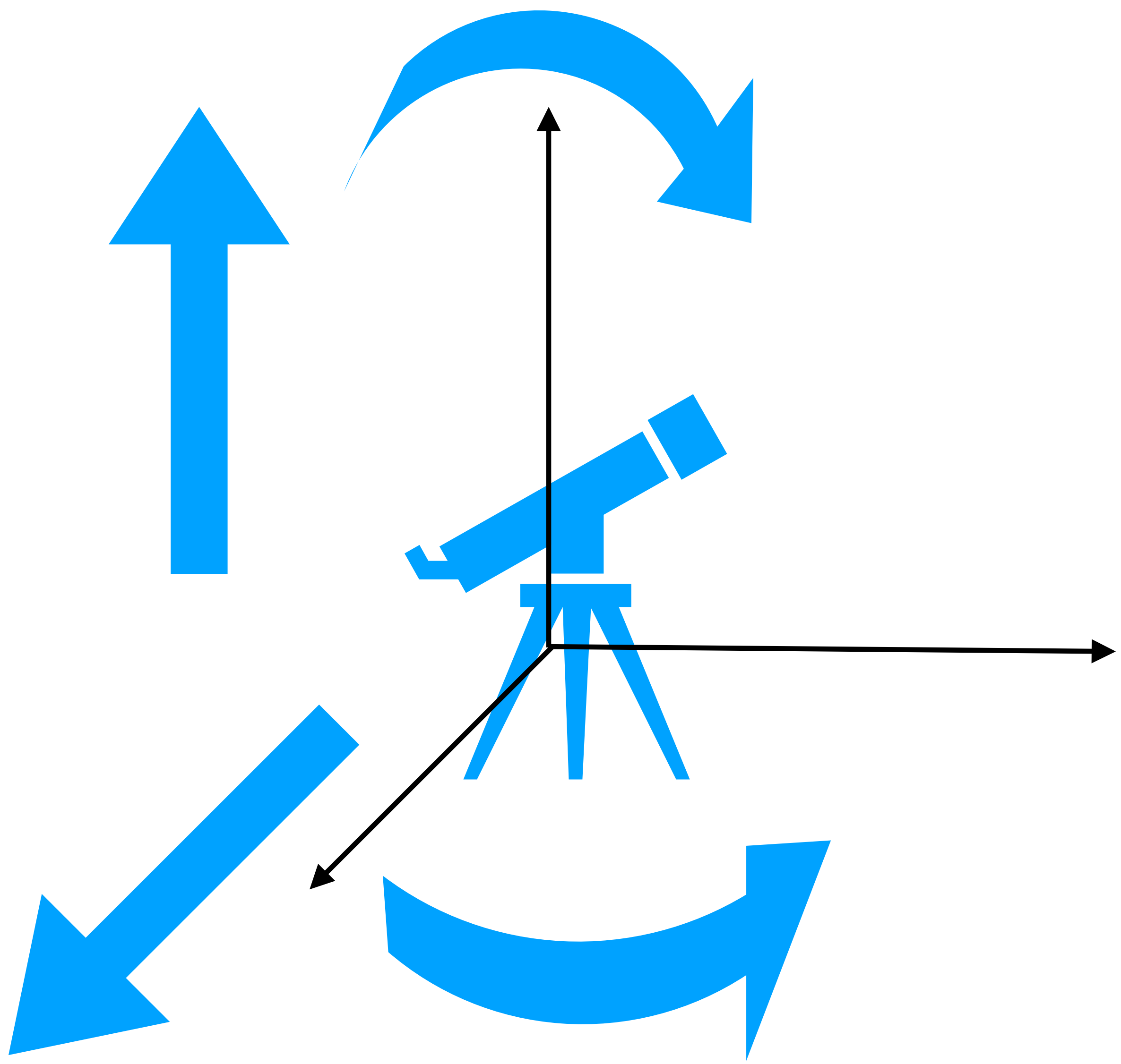
- Geometric time delay
- Shapiro time delay

$$\tilde{h}_{\mu\nu}(\Omega, \boldsymbol{x}_o) = \underbrace{F_s}_{\text{Standard amplification factor}} \cdot \underbrace{F_{\mu\nu\alpha\beta}}_{\text{polarization distortions}} \tilde{h}^{\alpha\beta}_{\text{nolens}}(\Omega, \boldsymbol{x}_o)$$

# Observer dependence?

C.D., Giulia Cusin, Macarena Lagos, 2021

What about observers related by Lorentz transformations?



- 3 boosts
- 3 rotations

- Polarization content is observer dependent but there does not exist any observer who feels only the plus and cross polarizations.

# Conclusion

-Parallel transport of the GW polarization is mostly a good approximation but it is not exact.
-Additional apparent polarization may appear in lensing scenarios, even in GR.

# Thank you!

I am happy to answer any questions you may have :)