

# Gyroscopic Gravitational Memory

Blagoje Oblak

LPTHE (Sorbonne) & CPHT (Polytechnique)

arXiv 2112.04535 with A. Seraj



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# Intro

(How a top sees gravitational waves)

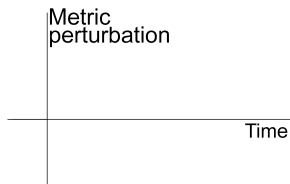
# TWO MOTIVATIONS

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1. Observable **gravitational waves** !

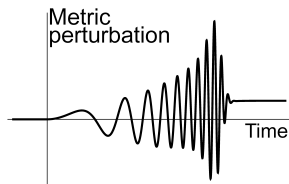
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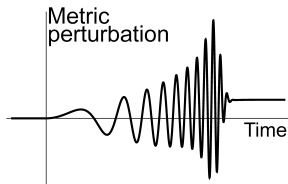
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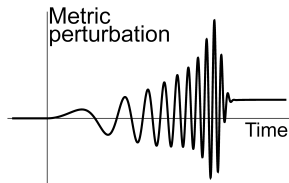
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  - ▶ Measurable implications ?





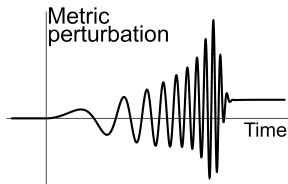
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  - ▶ Measurable implications ?
  - ▶ **Memory effect** :



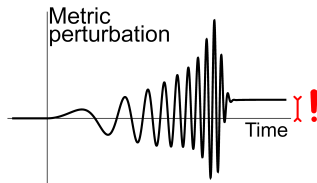
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Metric offset after wave



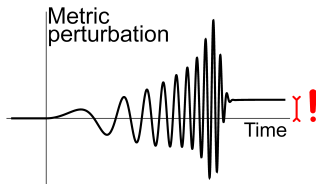
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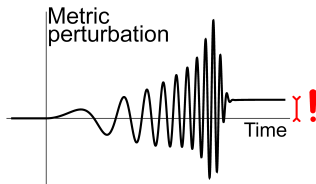


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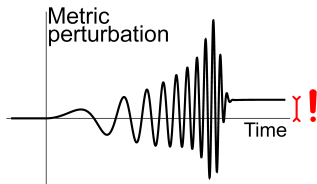
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- ▶ Large distance **asymptotic symmetries**

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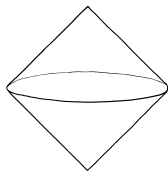
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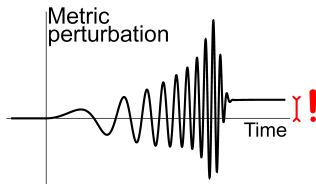
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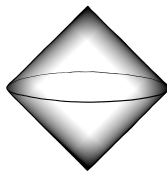
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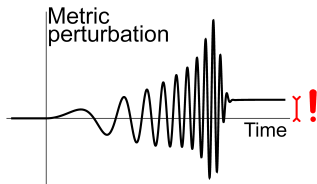
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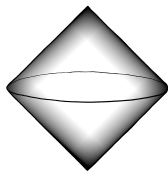
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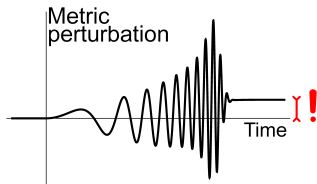




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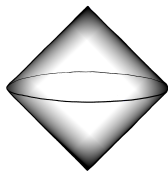
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Memory = **observable** effect of gravitational **symmetries**

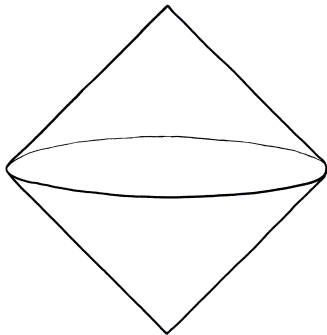
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Gravitational **memory** seen with freely falling **gyroscope**

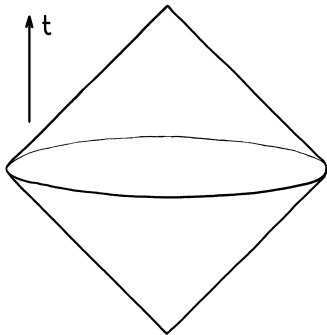
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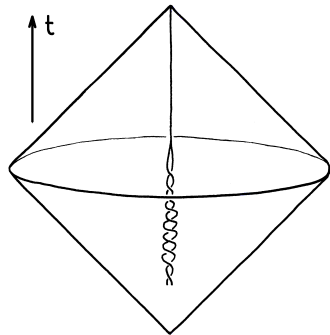
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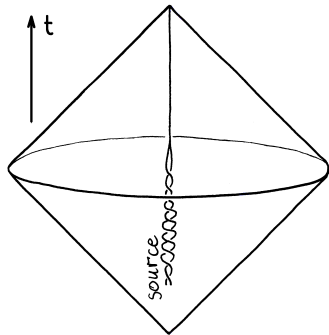
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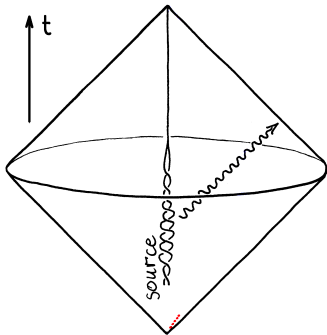






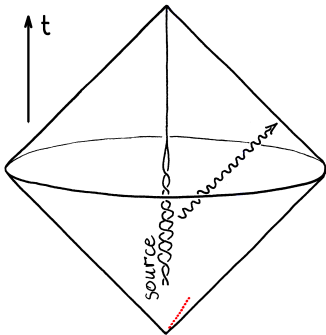
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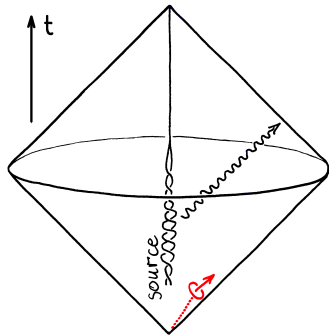
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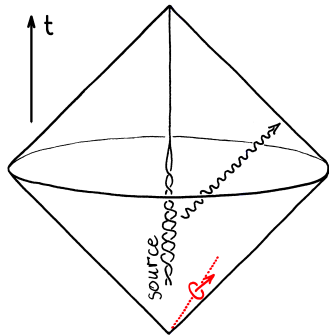
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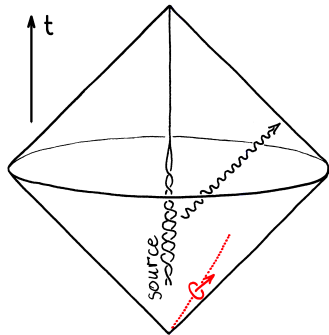
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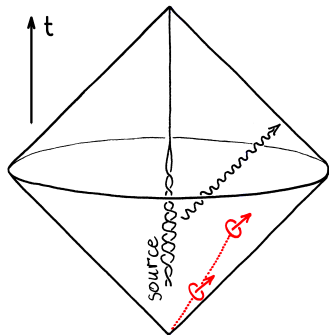
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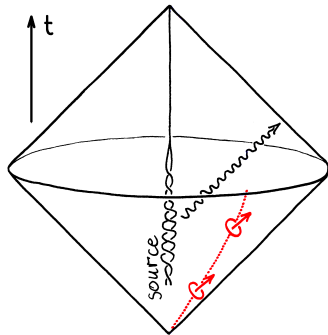
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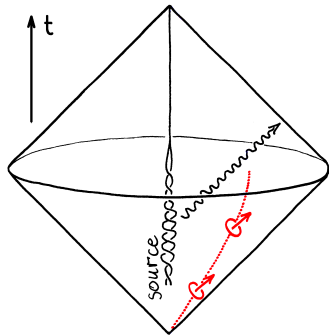
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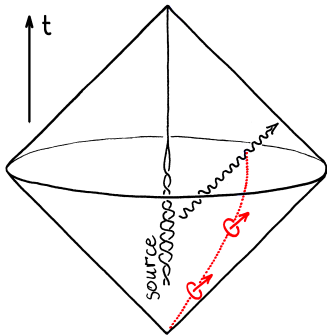
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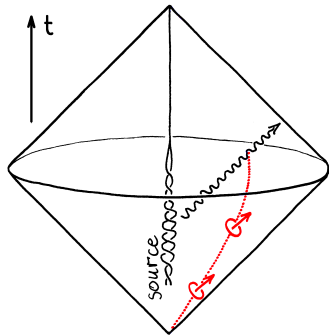
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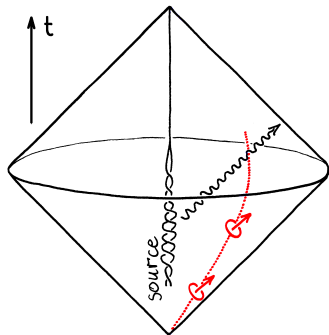
**Waves cause precession**



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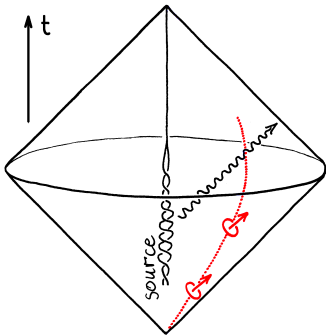
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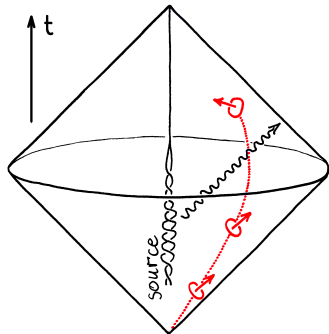
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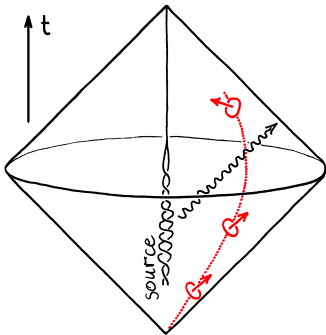
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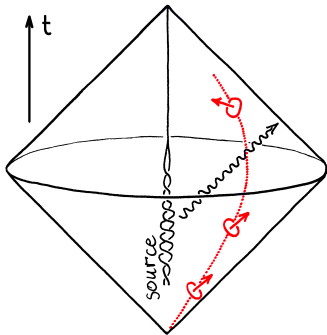
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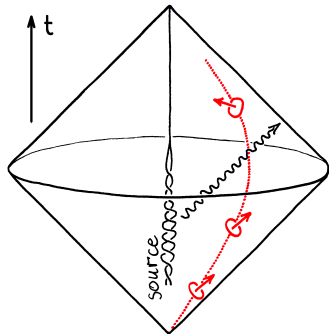
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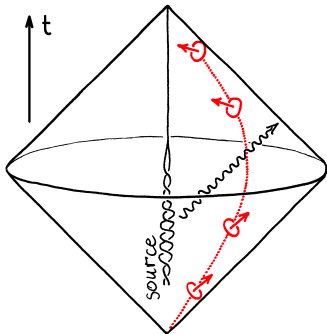




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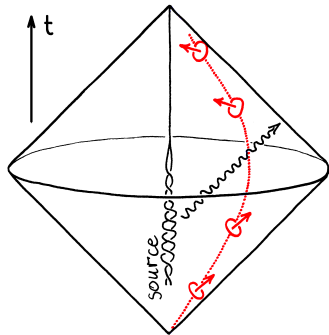
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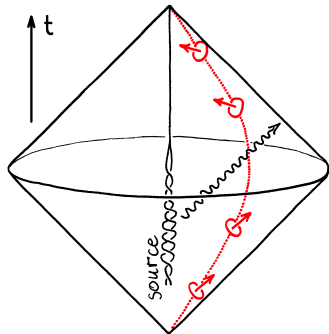
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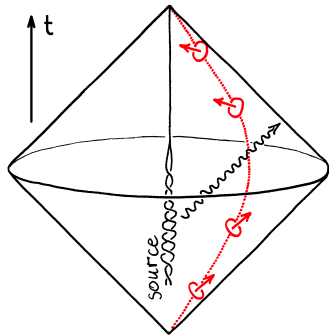


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Gravitational **memory** seen with freely falling **gyroscope** :

**Waves cause precession**

- ▶ Orientation memory !



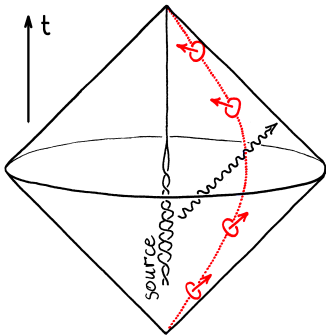
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Gravitational **memory** seen with freely falling **gyroscope** :

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Underlying symmetries :



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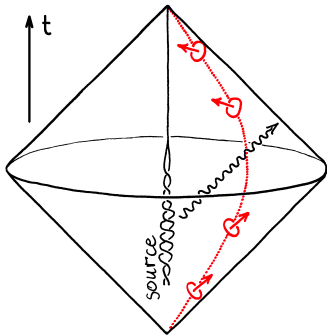
Gravitational **memory** seen with freely falling **gyroscope** :

## Waves cause precession

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Underlying symmetries :

- ▶ Precession rate = current of **dual supertranslations**





# PLAN



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## 1. Method

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**1. Method** : Build a frame tied to distant stars

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**2. Result**

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**1. Method** : Build a frame tied to distant stars

**2. Result** : Gyroscopic precession and memory

# 1. Method

(Stargazing in wobbly space-times)

# SPACE-TIME METRIC

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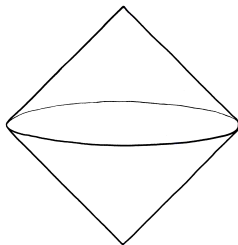
Minkowski in polar coordinates :

$$ds^2 = -dt^2 + dr^2 + r^2 h_{ab} d\theta^a d\theta^b$$

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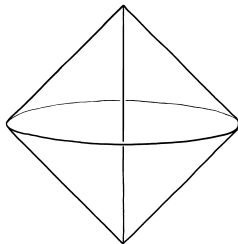




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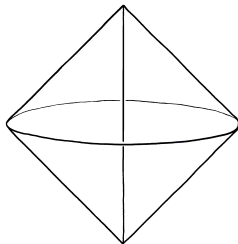
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Minkowski in **Bondi** coordinates :

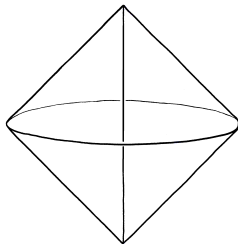
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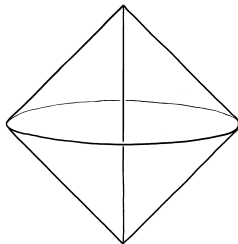
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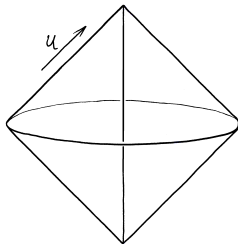
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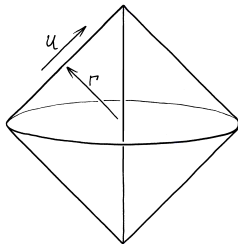
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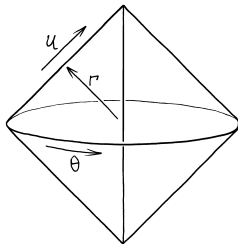
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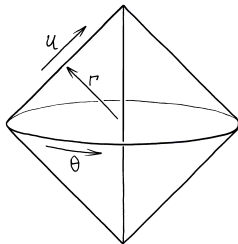


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- ▶ Null infity at  $r \rightarrow \infty$



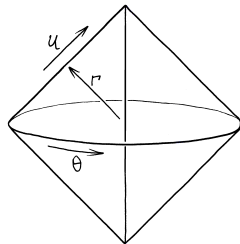


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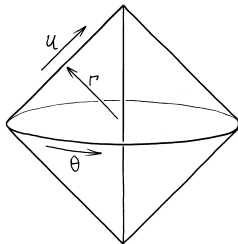
Observer sees **asymptotically flat** metric :

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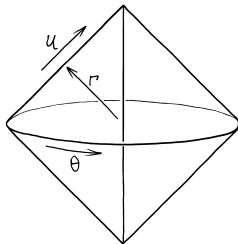
$$ds^2 \sim -(1 + \dots) du^2$$

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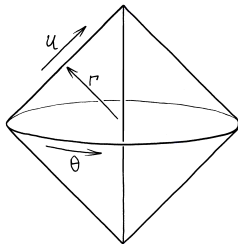
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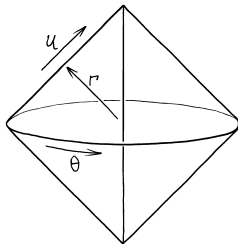
$$ds^2 \sim -\left(1 + \dots^{\text{mass}}\right) du^2 - \left(2 + \dots\right) du dr$$

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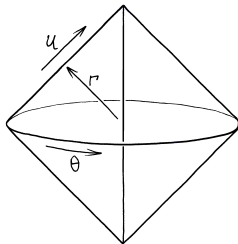
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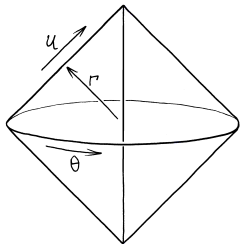
mass
angular mom

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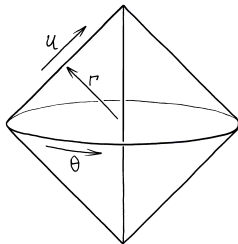
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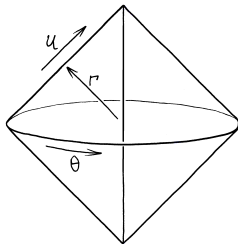


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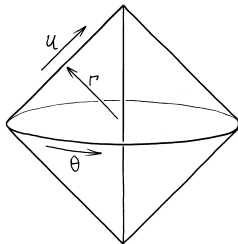
- $C_{ab}(u, \theta)$

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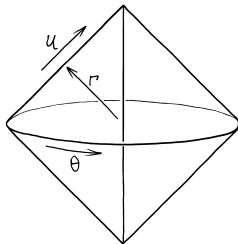
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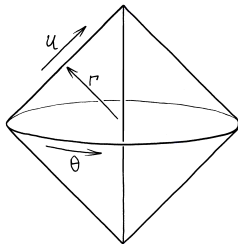
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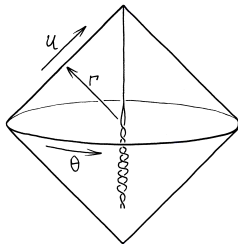
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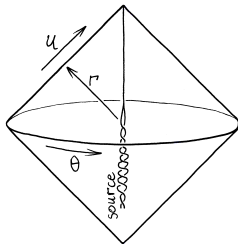
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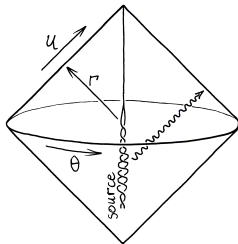
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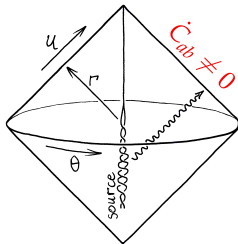
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Freely falling observer

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# LOCAL FRAME

Freely falling observer



# LOCAL FRAME

Freely falling observer with gyroscope



# LOCAL FRAME

Freely falling observer with gyroscope



# LOCAL FRAME

Freely falling observer with gyroscope

Measure orientation ?





# LOCAL FRAME

Freely falling observer with gyroscope

Measure orientation :

- ▶ Build **source-oriented frame**

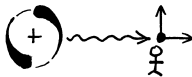


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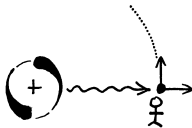


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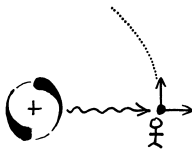


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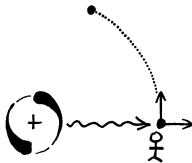


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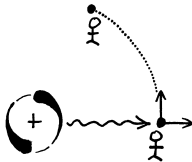


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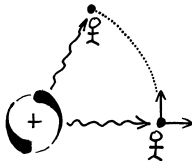


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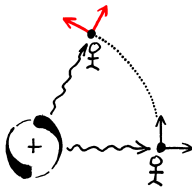


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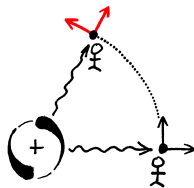


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Measure orientation :

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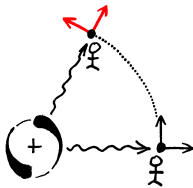
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Choose **distant stars** instead



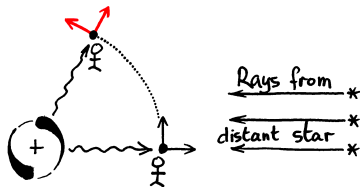
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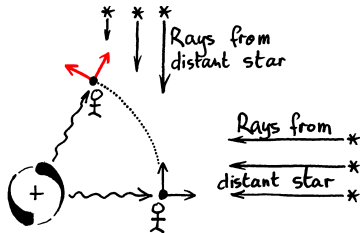
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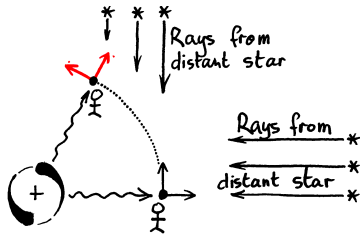
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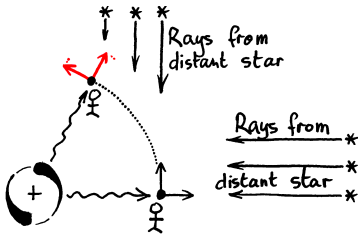
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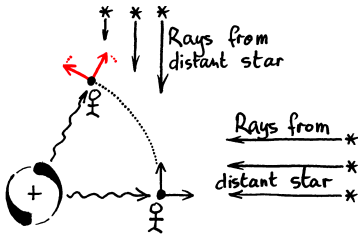
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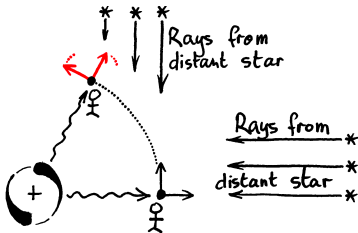
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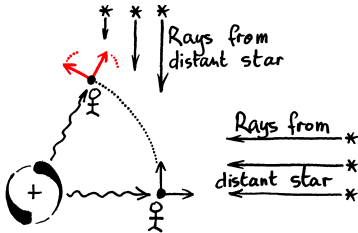
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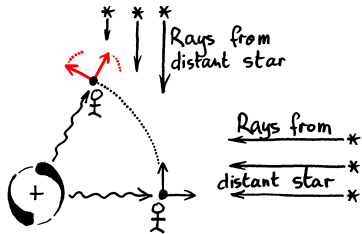
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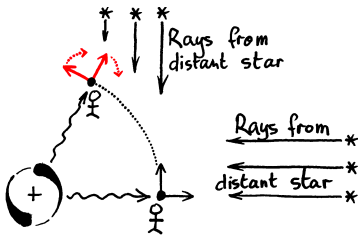
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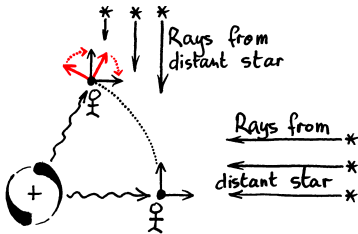
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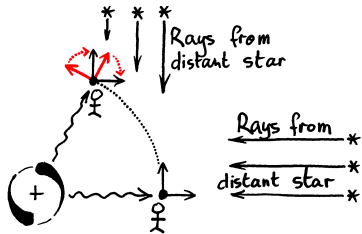
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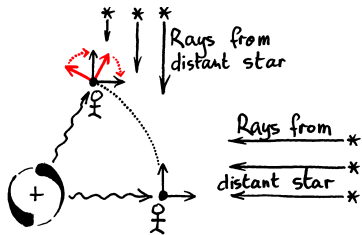
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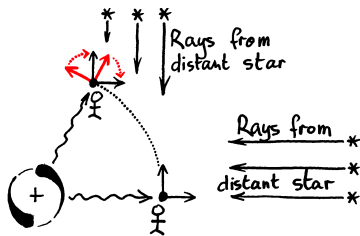
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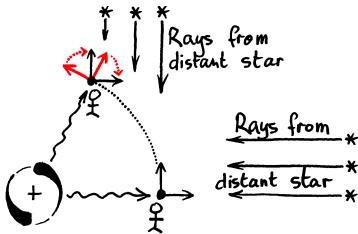
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- ▶ Frame  $e_1, e_2, e_3$
- ▶ Gyroscope's spin  $\mathbf{S} = S^i e_i$





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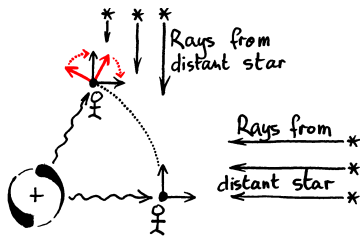
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Parallel transport  $\leftrightarrow$  **precession**  $\dot{\mathbf{S}} = \boldsymbol{\Omega} \times \mathbf{S}$

- ▶ **Find  $\boldsymbol{\Omega}$  !**

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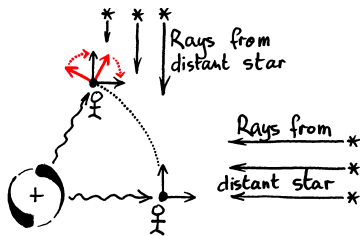
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## 2. Results

Precession and orientation memory

# RADIATION CAUSES PRECESSION

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- ▶ Precession along ray axis
- ▶ Linear term has dual shear  $\tilde{C}_{ab} \equiv \epsilon_{ca} C_b^c$

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$$DD\tilde{C} - \frac{1}{2}\dot{C}\tilde{C} = \text{dual mass aspect} \quad [\text{Porrati+, Godazgar+, Freidel+,...}]$$

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$\swarrow$                        $\downarrow$   
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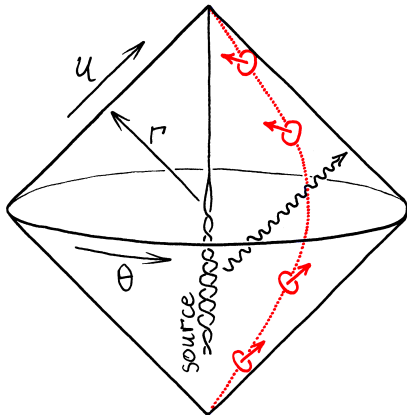
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Flux

**Duality generator** on radiative phase space



# Thanks !

