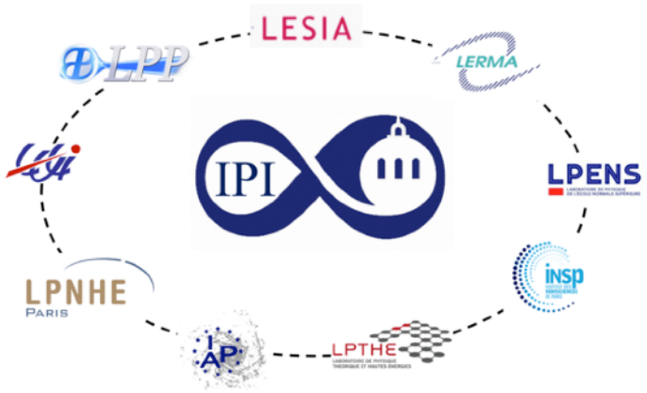
Probing parity violation using astrometry

Angelo Caravano (IPI fellow @ IAP, Paris)



A. Caravano @ “A future space mission with very high precision Astrometry”,Paris, Sept. 11-13 2024

Roadmap

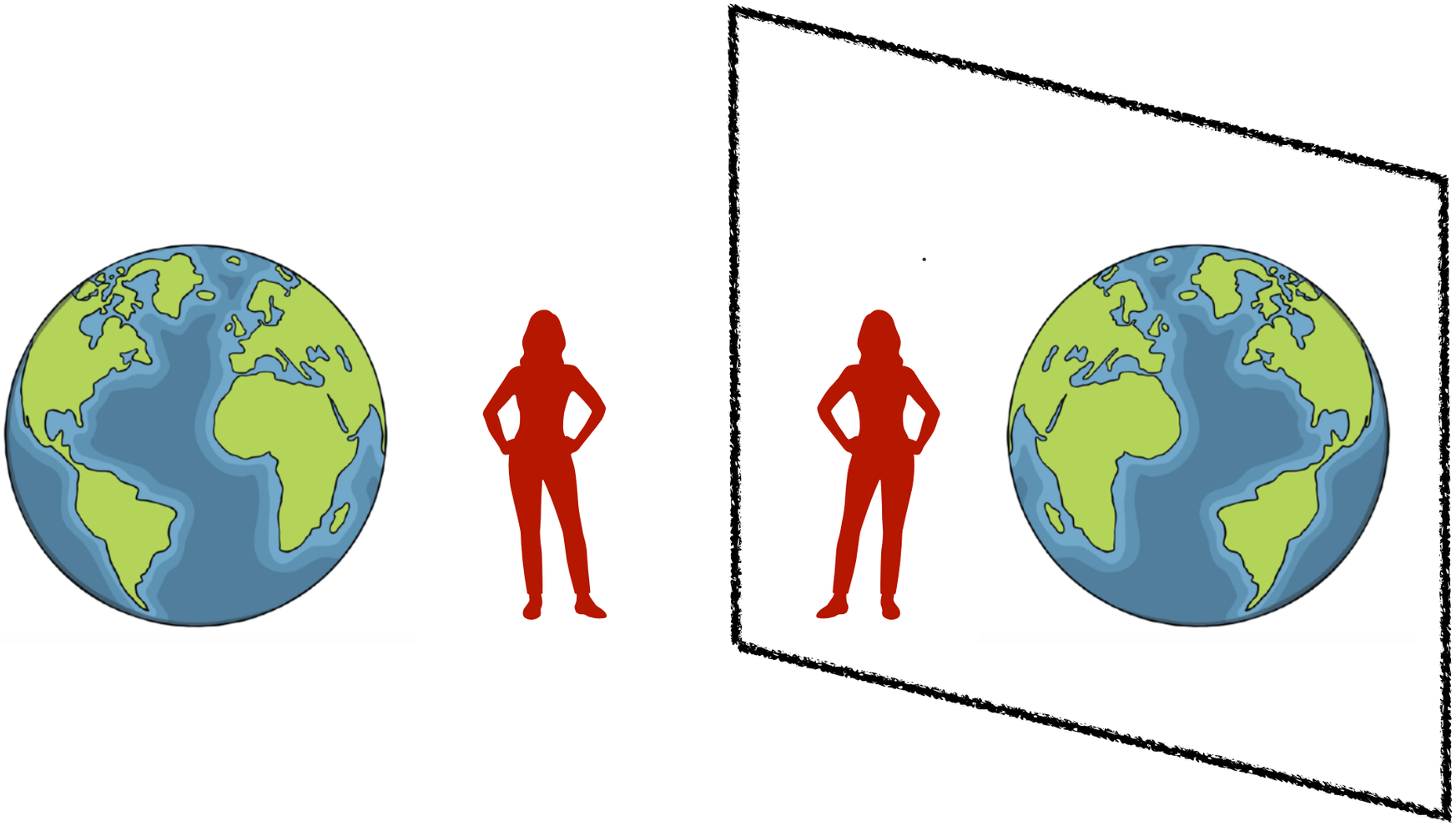
1) What is parity?

2) Cosmological parity violation

3) Astrometry can probe parity

What is parity?

Does nature distinguish between left and right?



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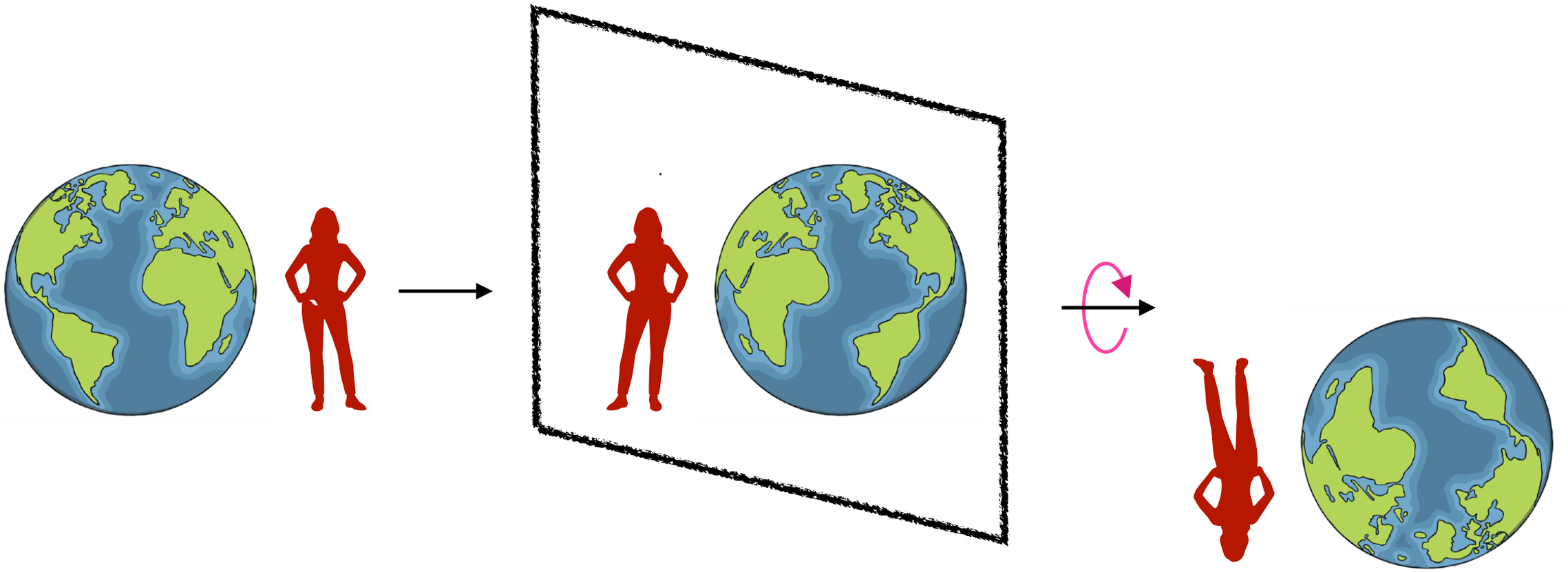
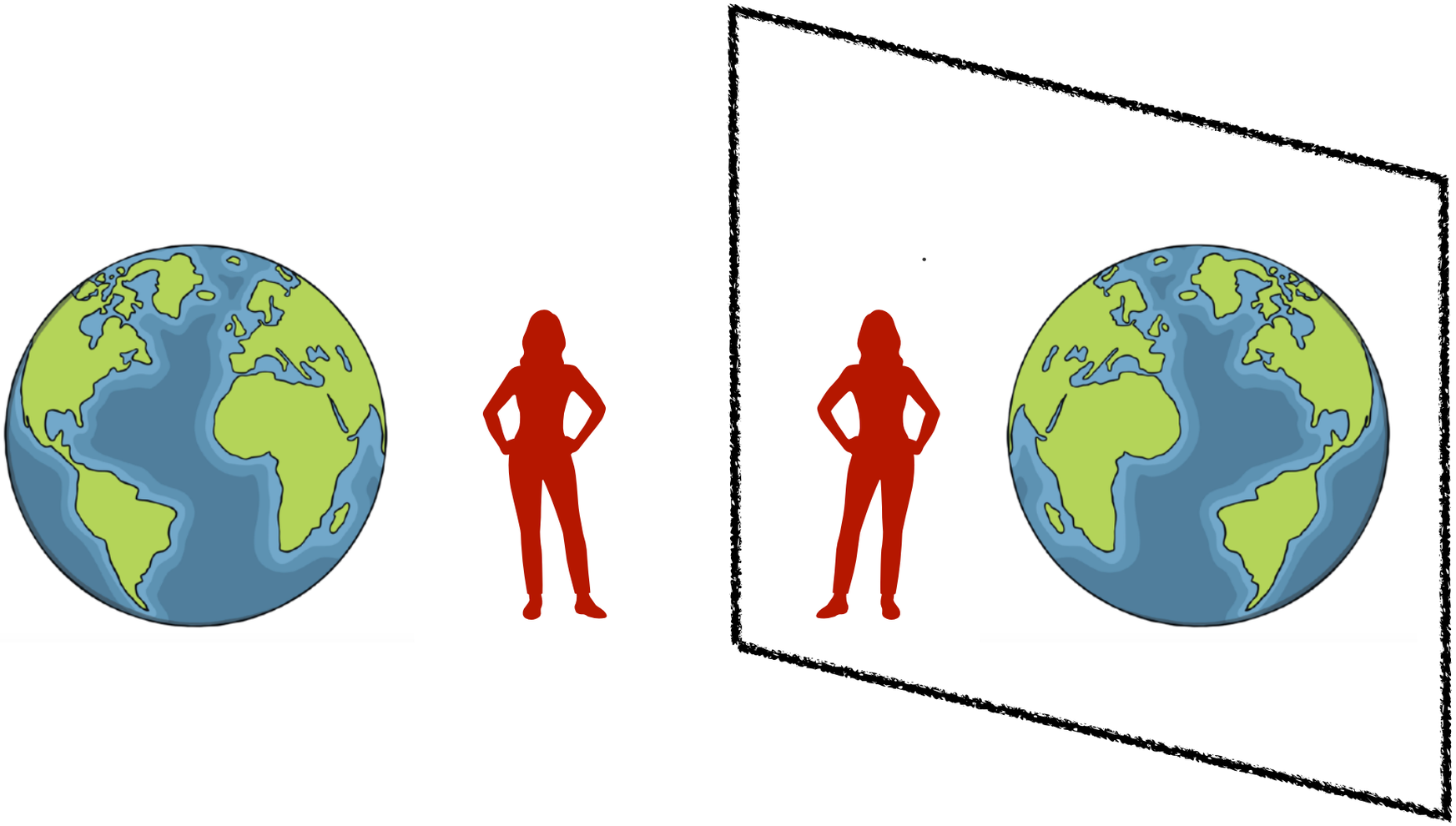


Parity transformation = $\mathbb{P}(\vec{x}) \rightarrow -\vec{x}$ = mirror reflection + rotation

What is parity?

Does nature distinguish between left and right?



Parity transformation = mirror reflection

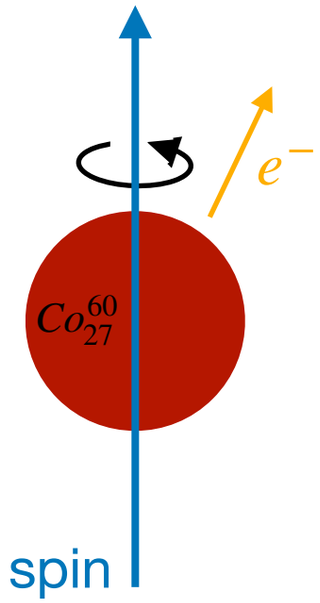
(in cosmology)

What is parity?

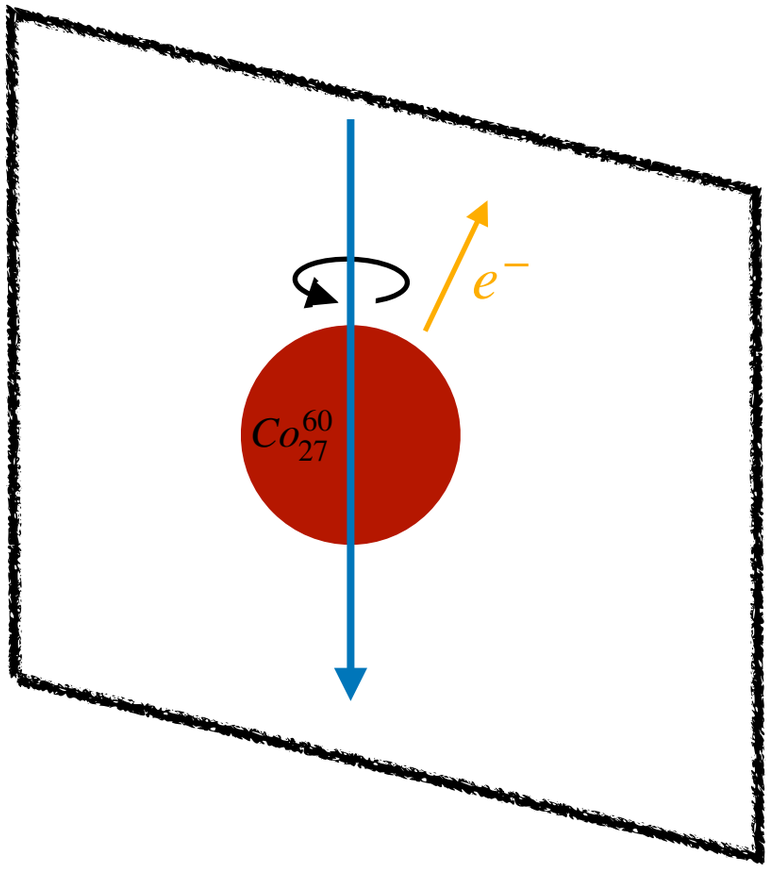
Chien-Shiung Wu

Does nature distinguish between left and right? **YES! Wu (1956)**

$$Co_{27}^{60} \longrightarrow Ni_{28}^{*60} + e^- + \overline{\nu}_e.$$



physical process,
allowed by the standard model



unphysical process,
not allowed by the standard model

Roadmap

1) What is parity?

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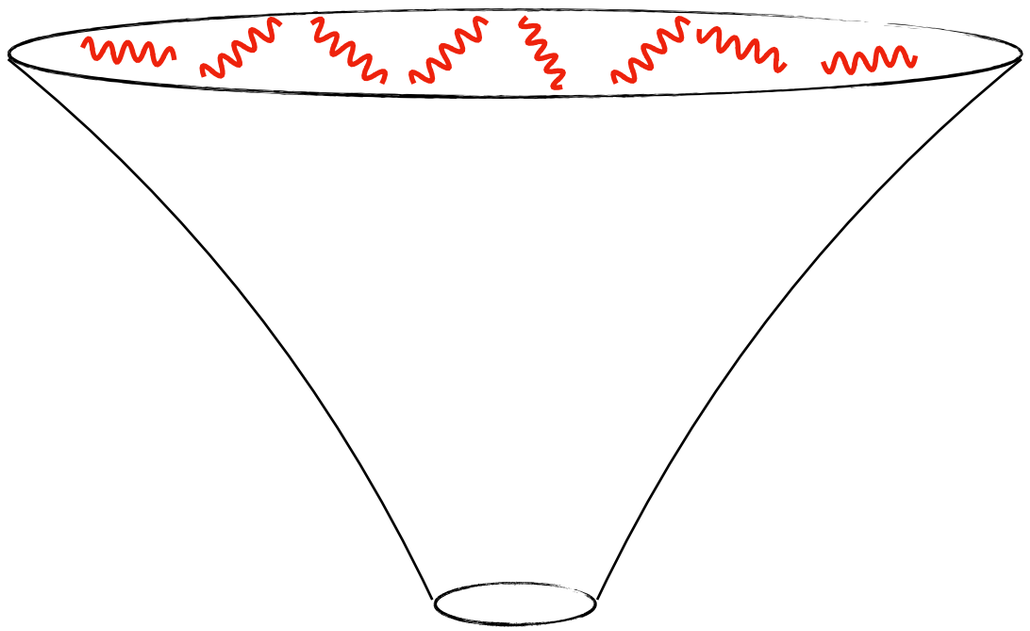
Parity violation in cosmology

[**M. Anber, L. Sorbo** 0908.4089]
[**N. Barnaby, M. Peloso** 1011.1500]

Example: **axion inflation**

Parity violating interaction
$\mathscr{L}_{\rm int} \supset \phi \epsilon^{\mu\nu\rho\sigma} F_{\mu\nu} \tilde{F}_{\rho\sigma}$

The universe gets filled with “chiral photons”



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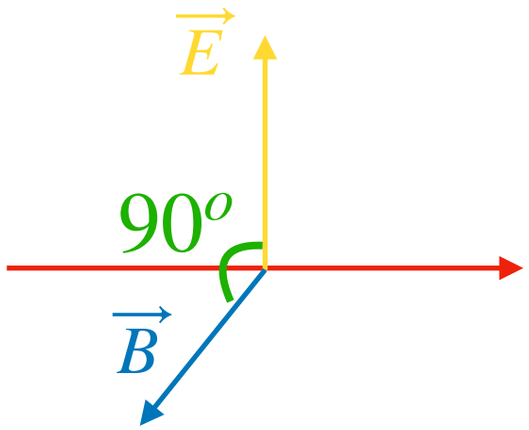
Normal photon recap:



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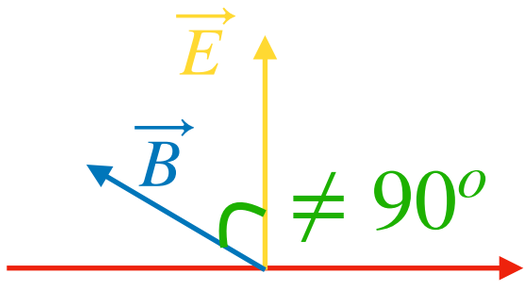

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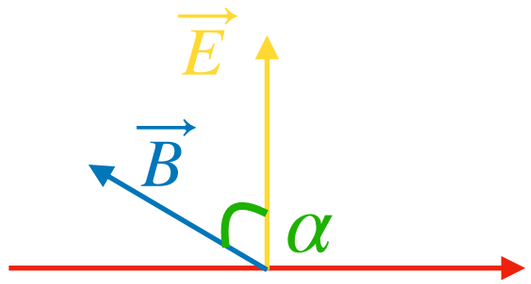

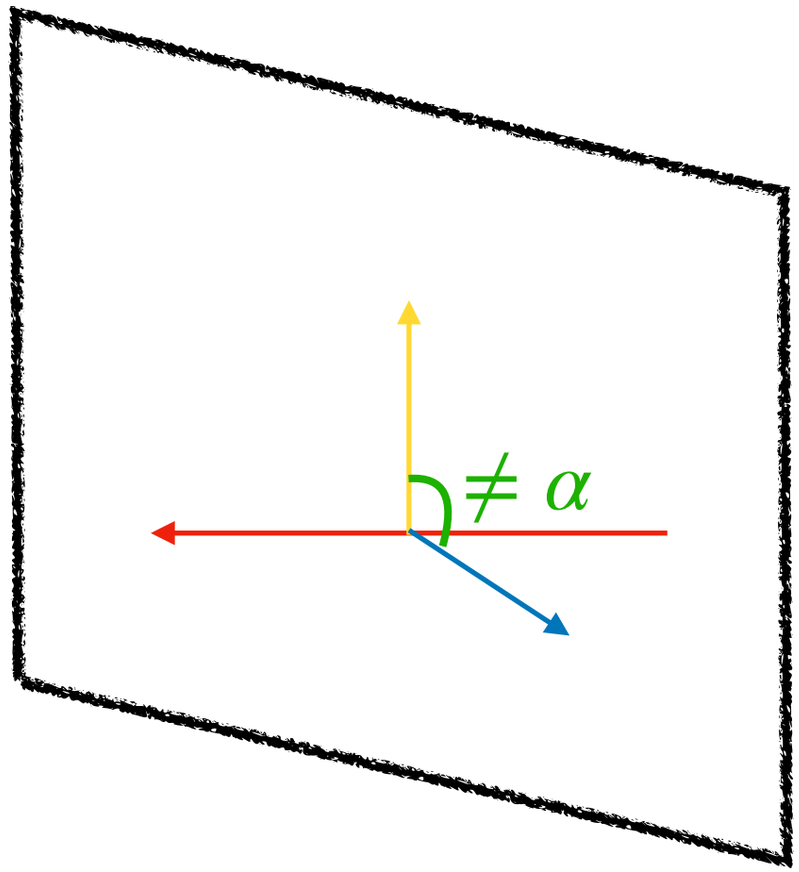

$\vec{E} \cdot \vec{B} > 0$ $\qquad$ $\vec{E} \cdot \vec{B} < 0$

Parity violating Universe

Parity violation in cosmology

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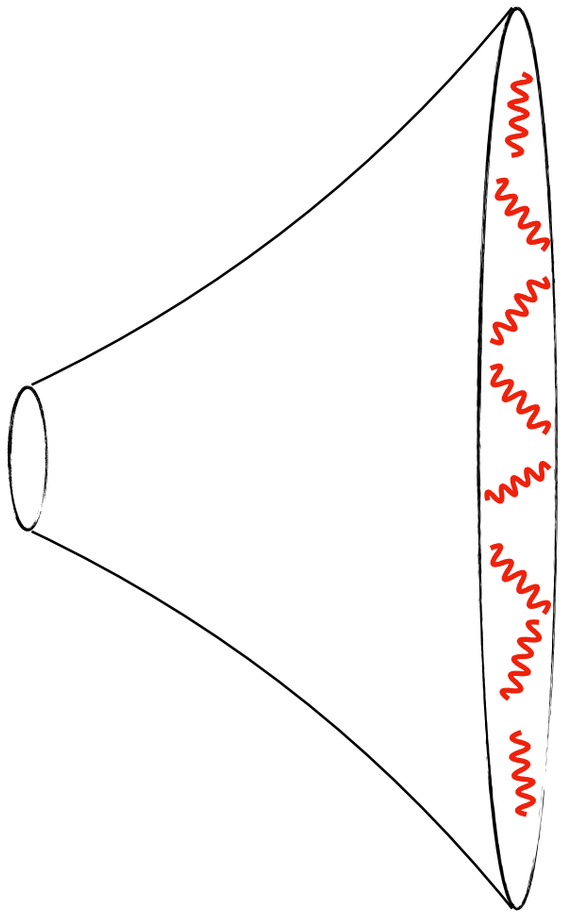
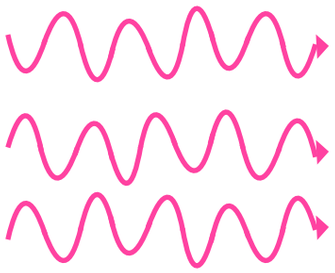
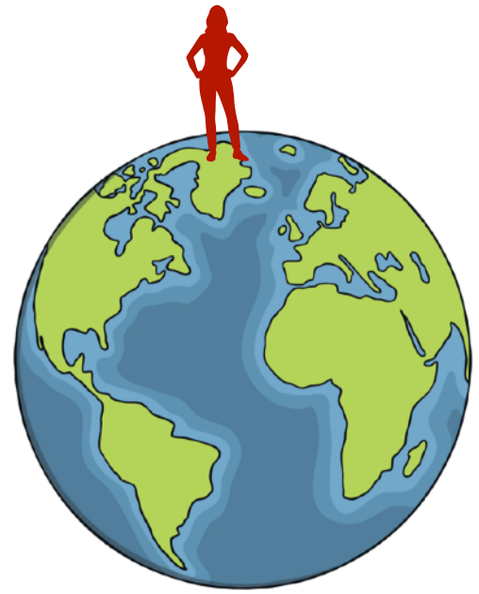
Example: **axion inflation**

The universe gets filled with “chiral photons”



Chiral GWs





Parity violation in cosmology

Chiral gravitational waves

t

h_+ polarisation $\mathbb{P}(h_+)=+h_+$

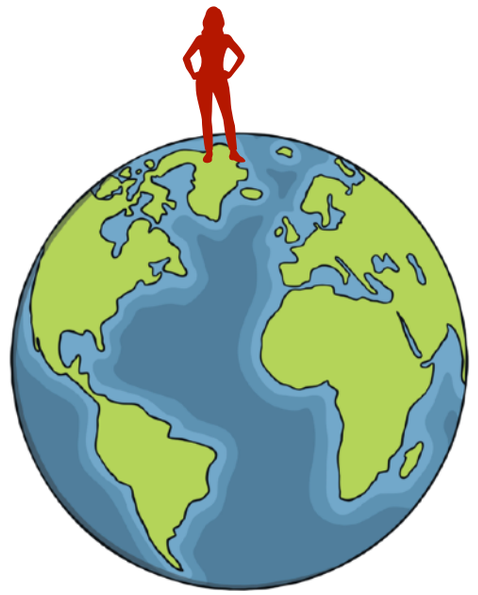
$h_\times$ polarisation $\mathbb{P}(h_\times)=-h_\times$

$\langle h_\times h_+ \rangle \neq 0$ is a parity violating observable

Parity violation in cosmology

Chirality of GWs can tell us a lot about the Universe

- PV due to propagation
  e.g.: PV medium, PV modified gravity
- PV during inflation or reheating
  e.g.: axion inflation
- PV in the “late” universe
  Due to axion physics
- ???



Parity violation in cosmology

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Chiral GWs

Chien-Shiung Wu

More importantly:

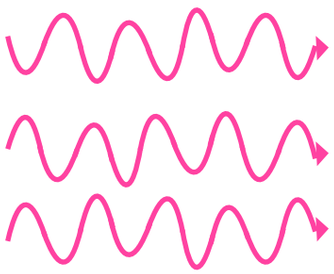
It is a fundamental symmetry that no one has ever tested!

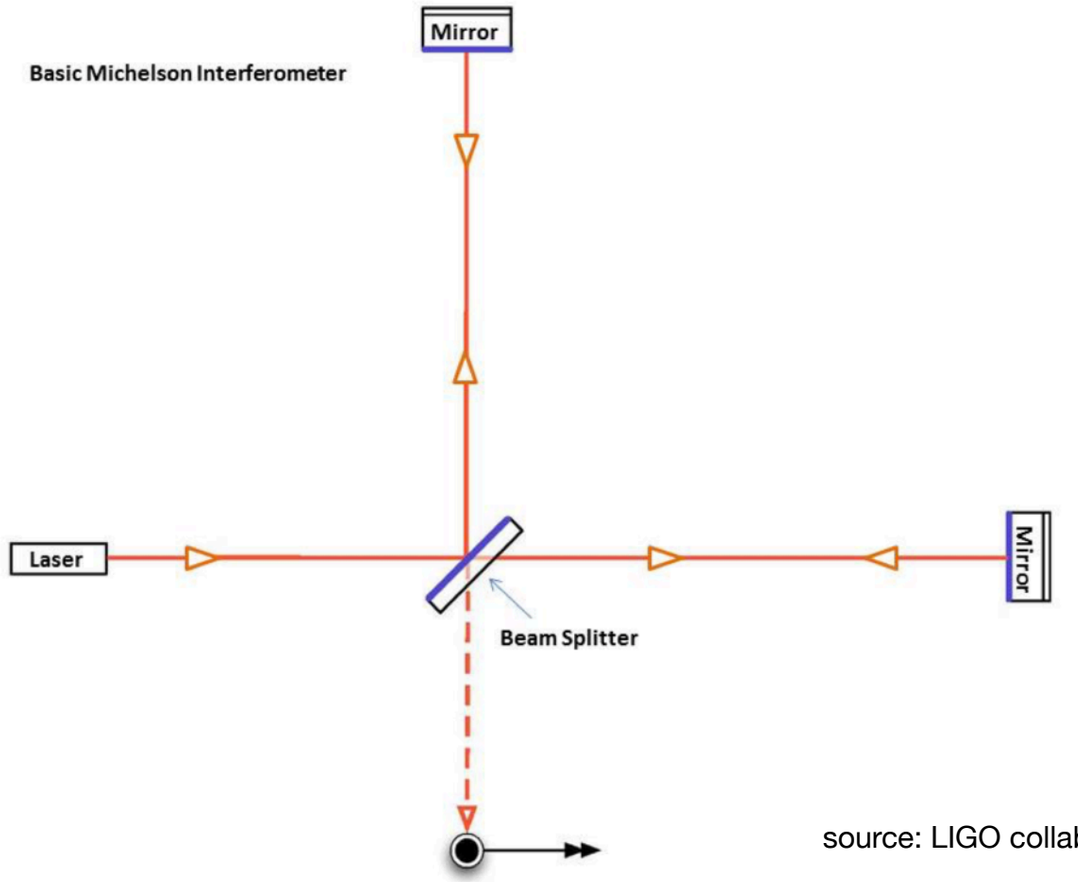
Astrometry and parity violation

How to detect chirality of GWs?

Because of planar geometry, interferometers (LIGO, VIRGO, LISA…) can not probe the chirality

Chiral GWs



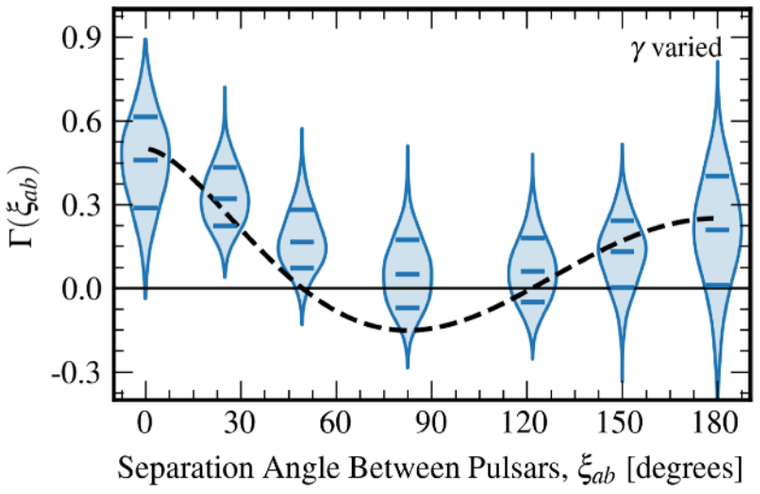


source: LIGO collaboration

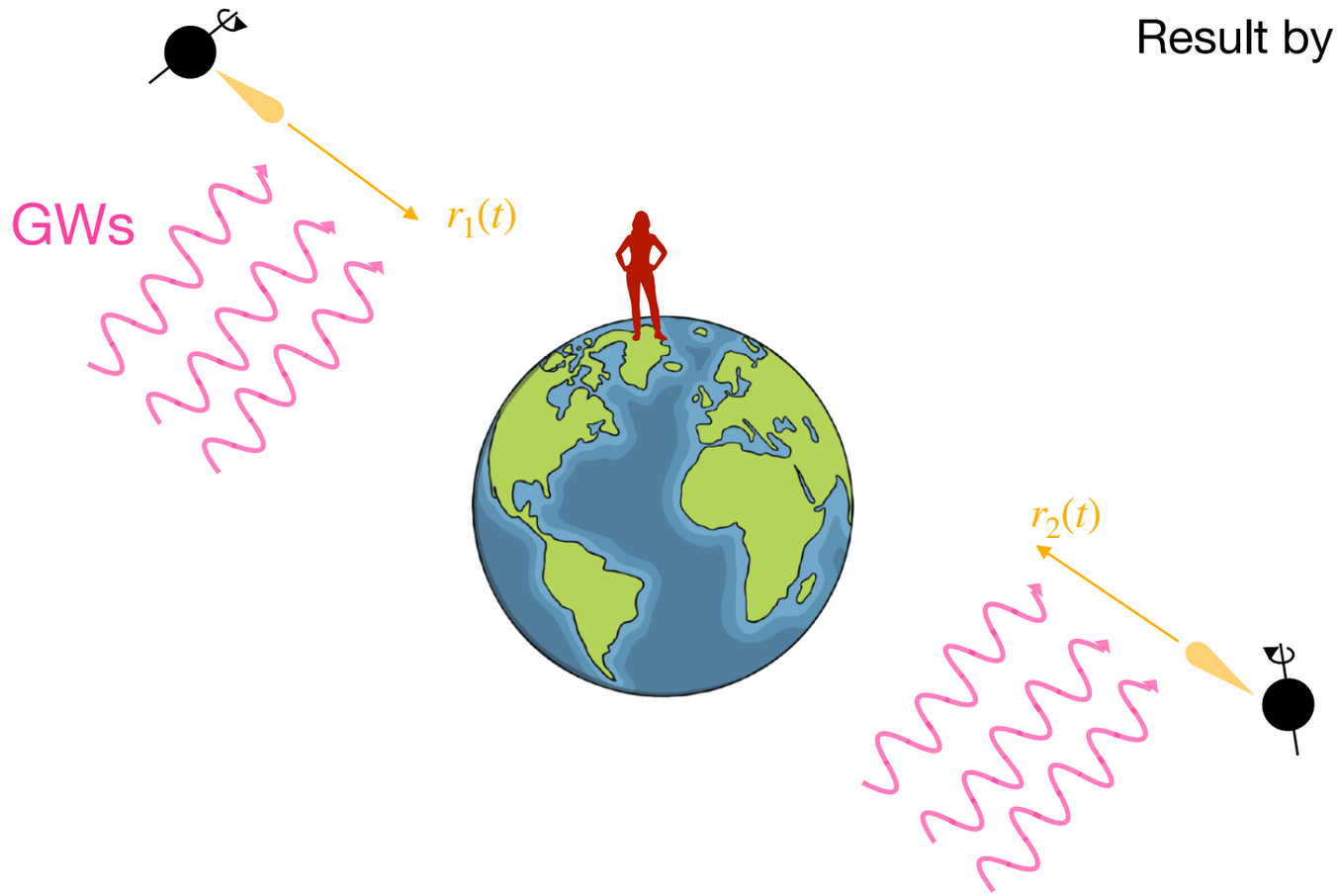
Astrometry and parity violation

PTA is another probe of GWs

$\langle r_1(t) r_2(t) \rangle$ correlated residuals



Result by NANOGrav collaboration



Astrometry and parity violation

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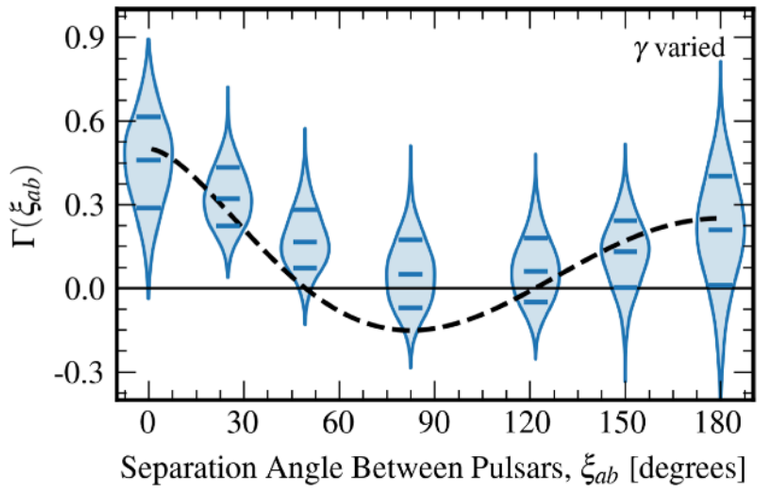

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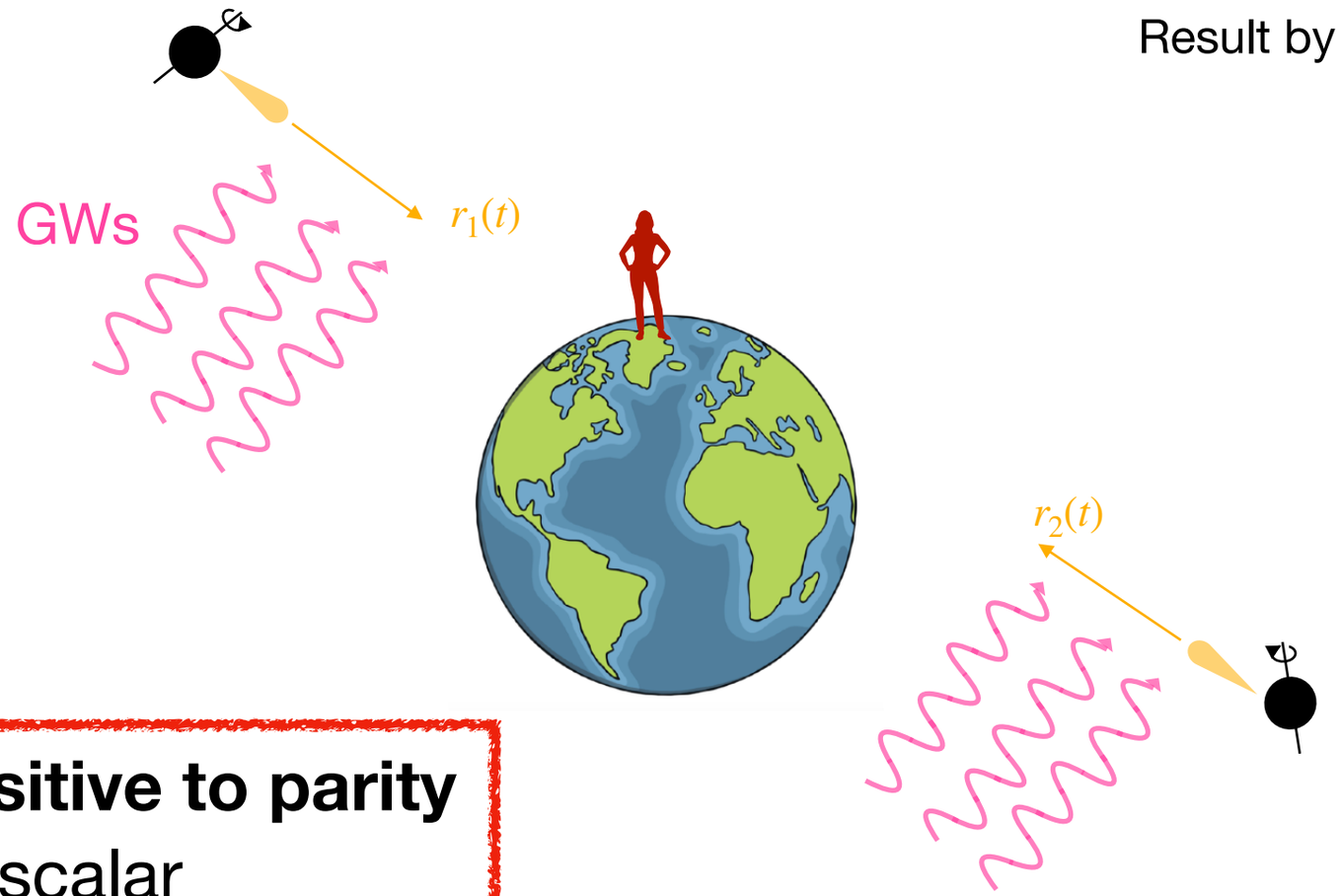

However, **not sensitive to parity** because $r(t)$ is a scalar

Roadmap

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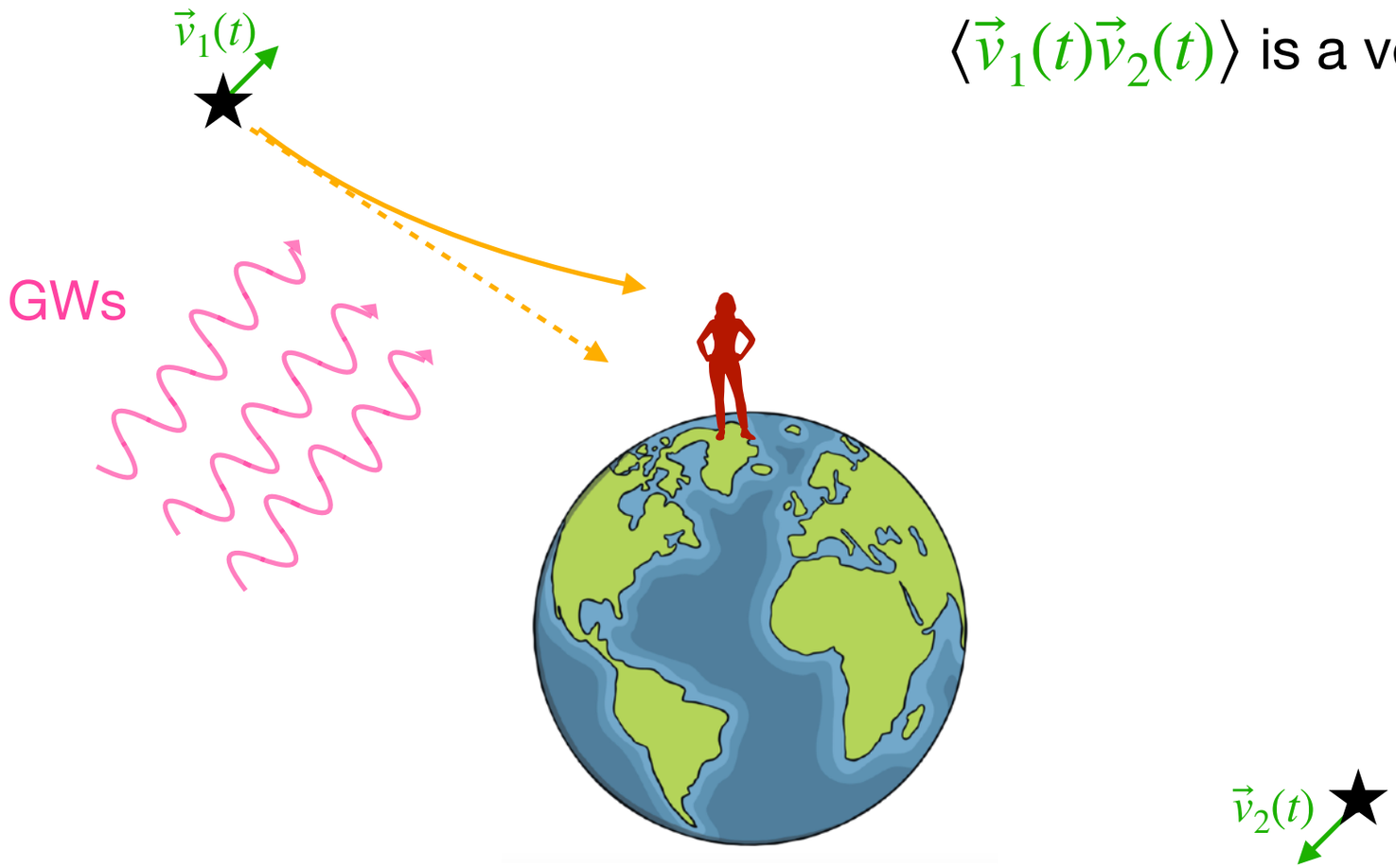
Astrometry and parity violation

Astrometry can probe the chirality of GWs!

See, e.g.:
[**Q. Liang, M. Lin, M. Trodden, S. Wong** 2309.16666]



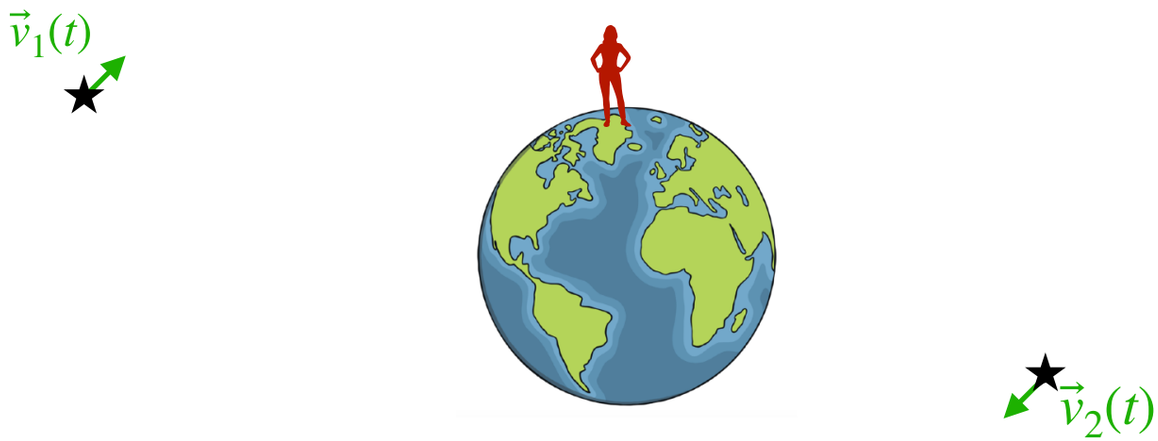
$\langle \vec{v}_1(t)\vec{v}_2(t) \rangle$ is a vector quantity

Astrometry and parity violation

Astrometry can probe the chirality of GWs!

$\vec{v} = \vec{\epsilon}_+ v_+ + \vec{\epsilon}_\times v_\times + \vec{\nabla}\psi$ $\quad\quad$ $\vec{\epsilon}_{+,\times}$ polarisation vectors

$\langle v_{1,\times}\, v_{2,+} \rangle$ is a parity-violating observable! $\quad\quad$ $\propto \langle h_\times\, h_+ \rangle \propto \langle \vec{E} \cdot \vec{B} \rangle$



Astrometry and parity violation

Main message:

- Astrometry can detect GWs (see talks after lunch)
- **Astrometry can probe parity properties of the GWs**
  (and is the only way in the near future)