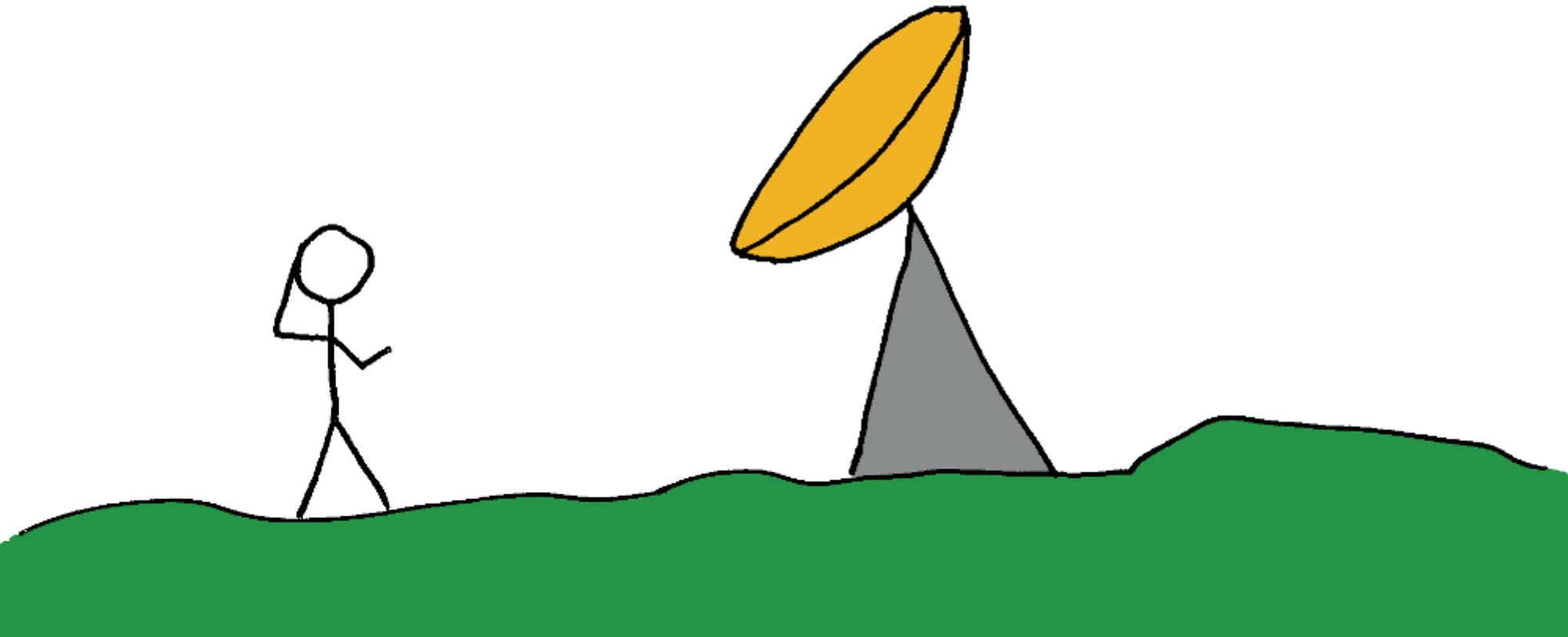
Listening to Quasars and Shooting Satellites with Lasers

Geir Arne Hjelle

Kartverket

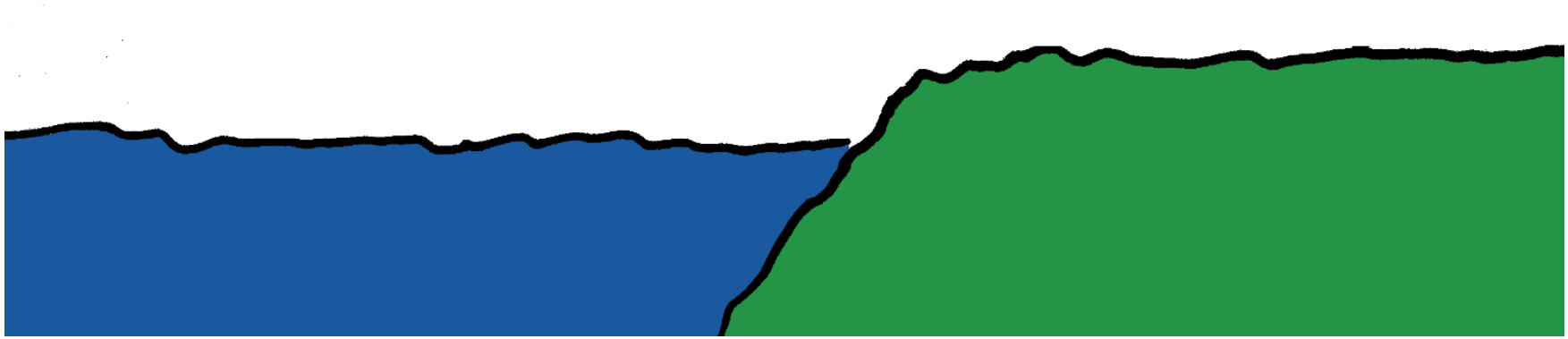
EuroSciPy, August 31st 2018



Part I

Why?

The Problem



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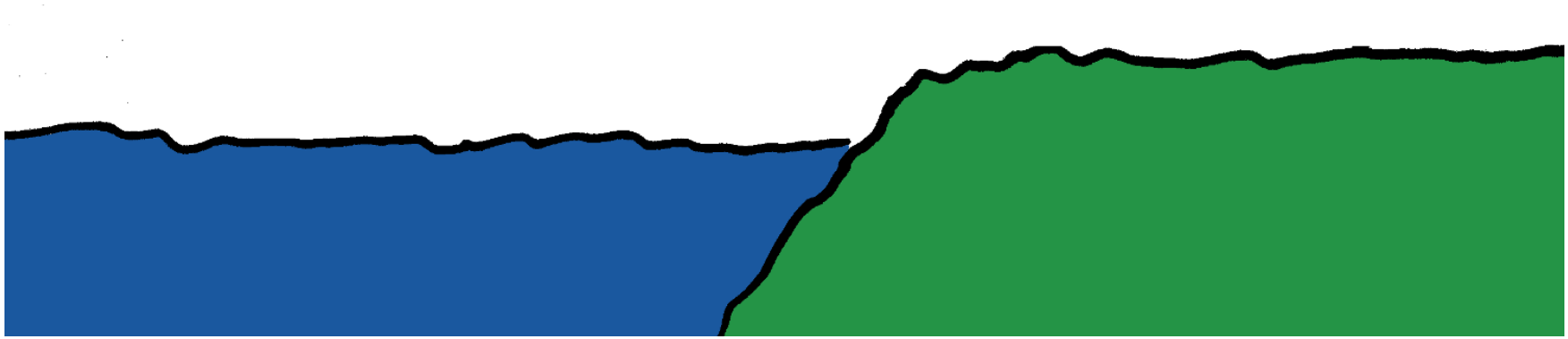

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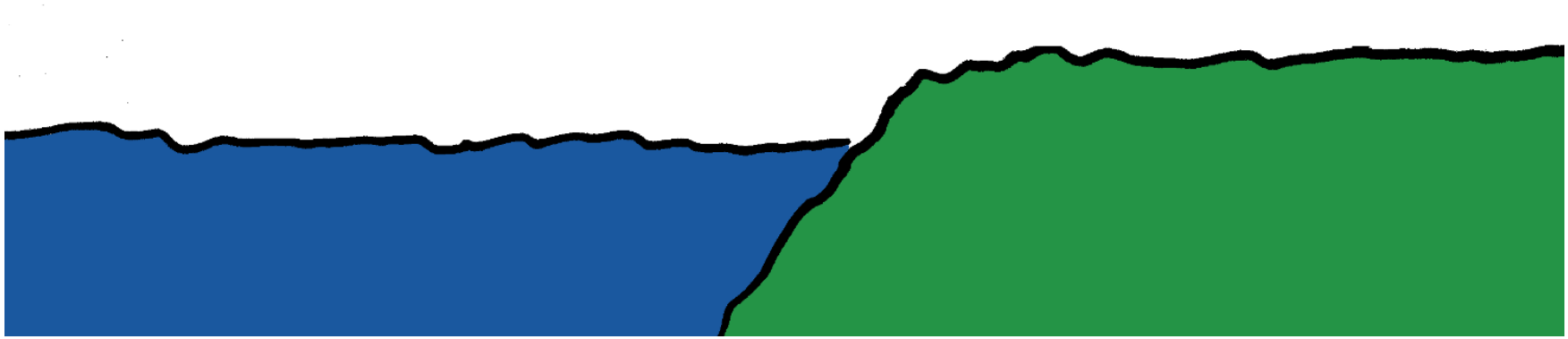

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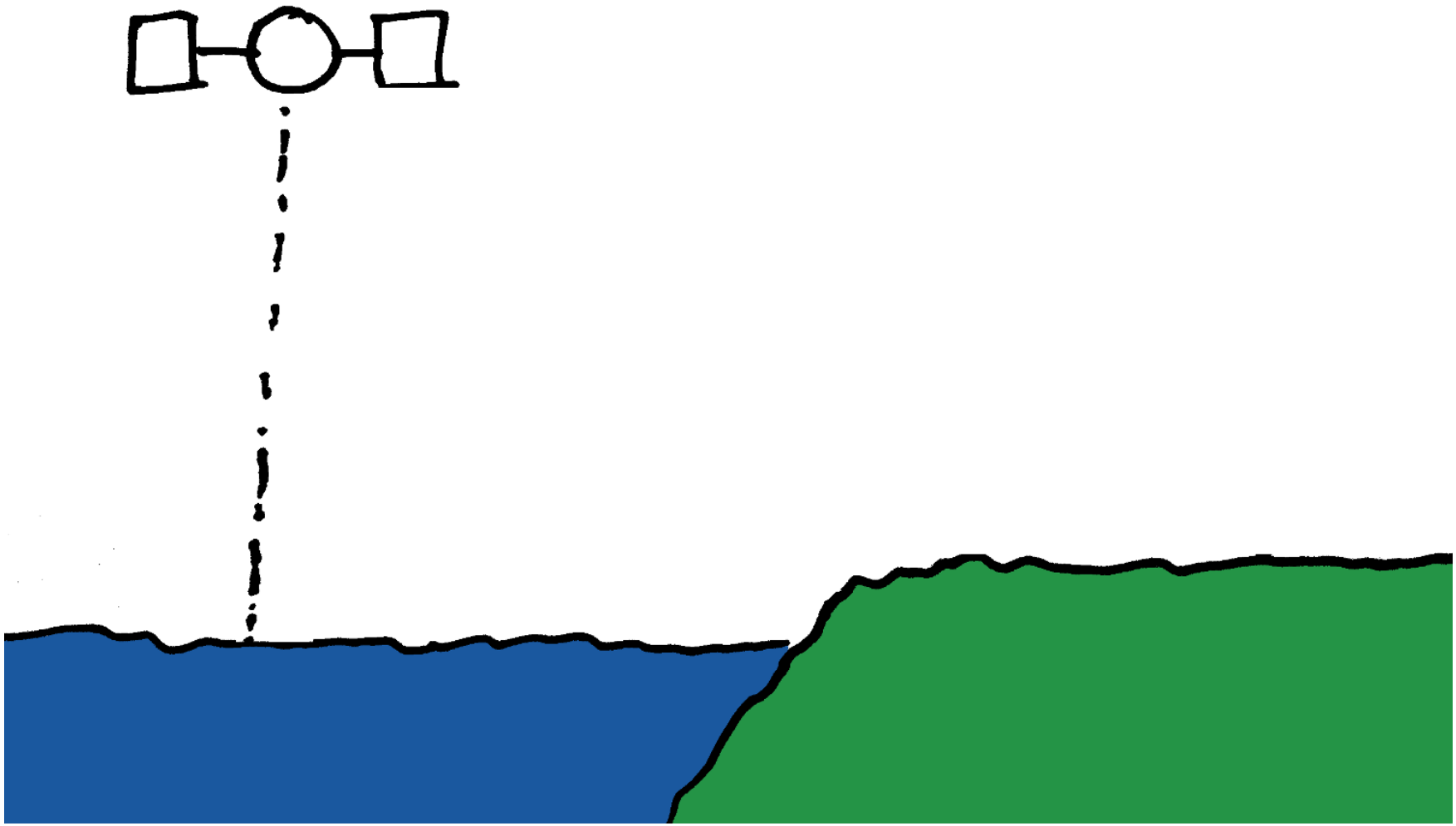

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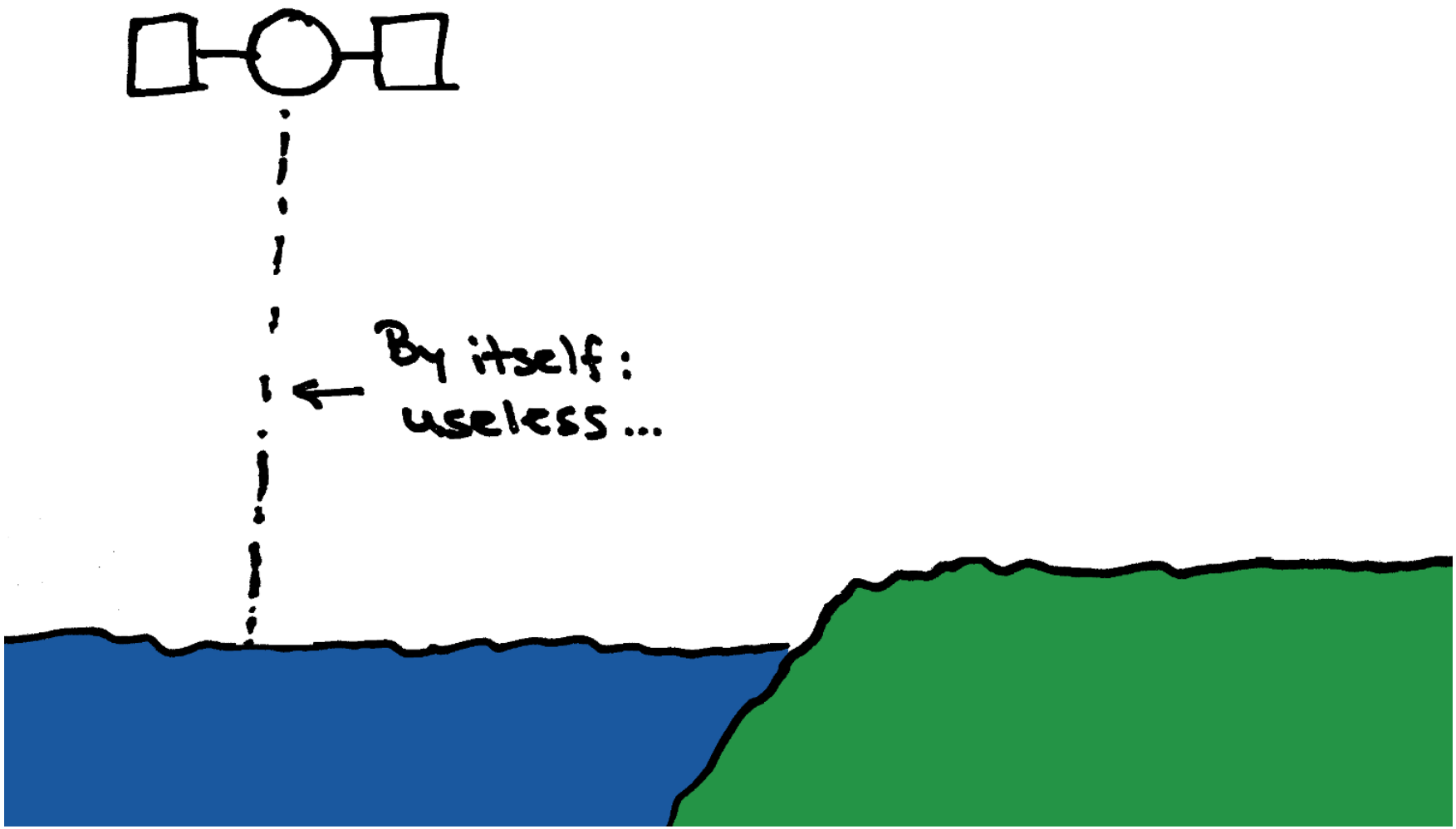

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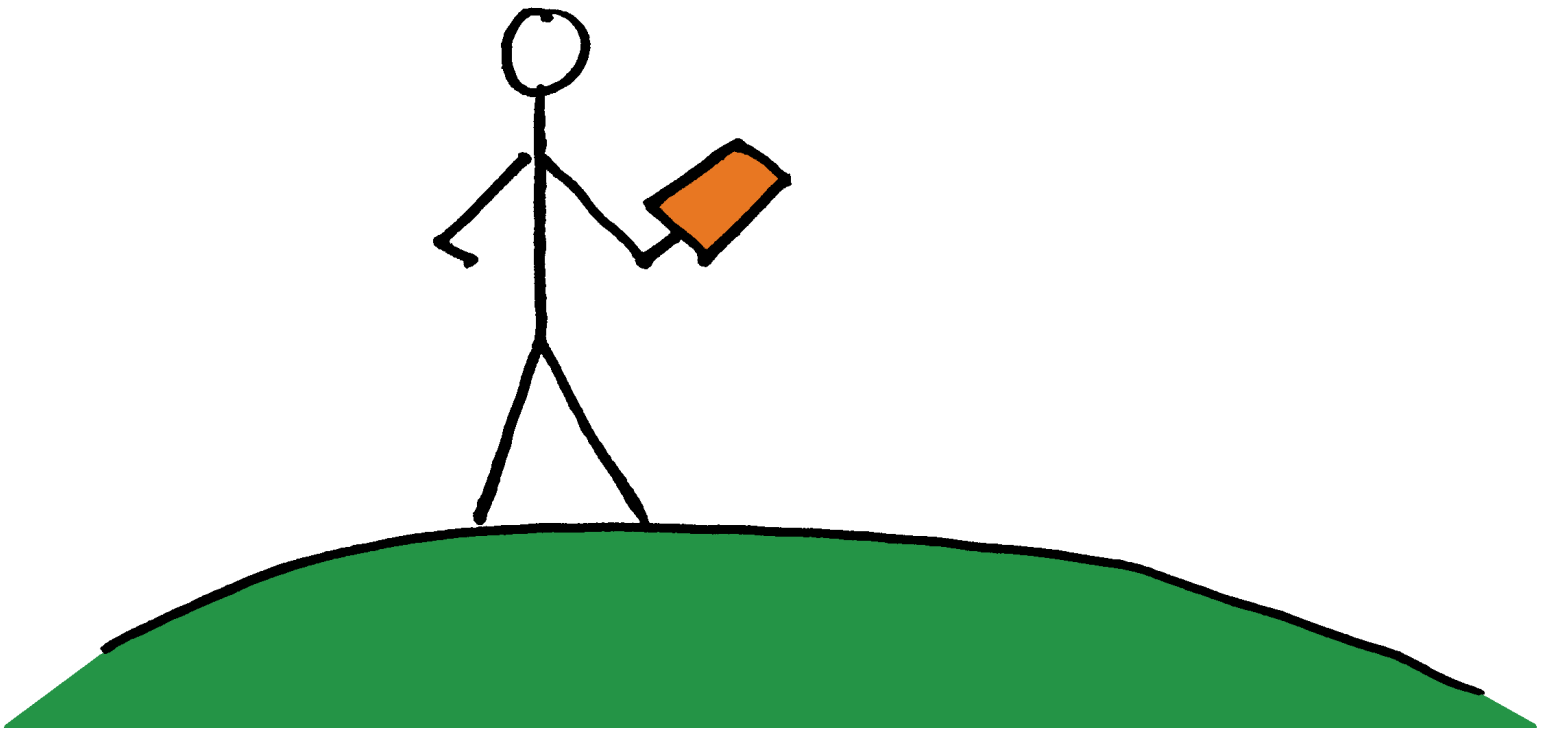

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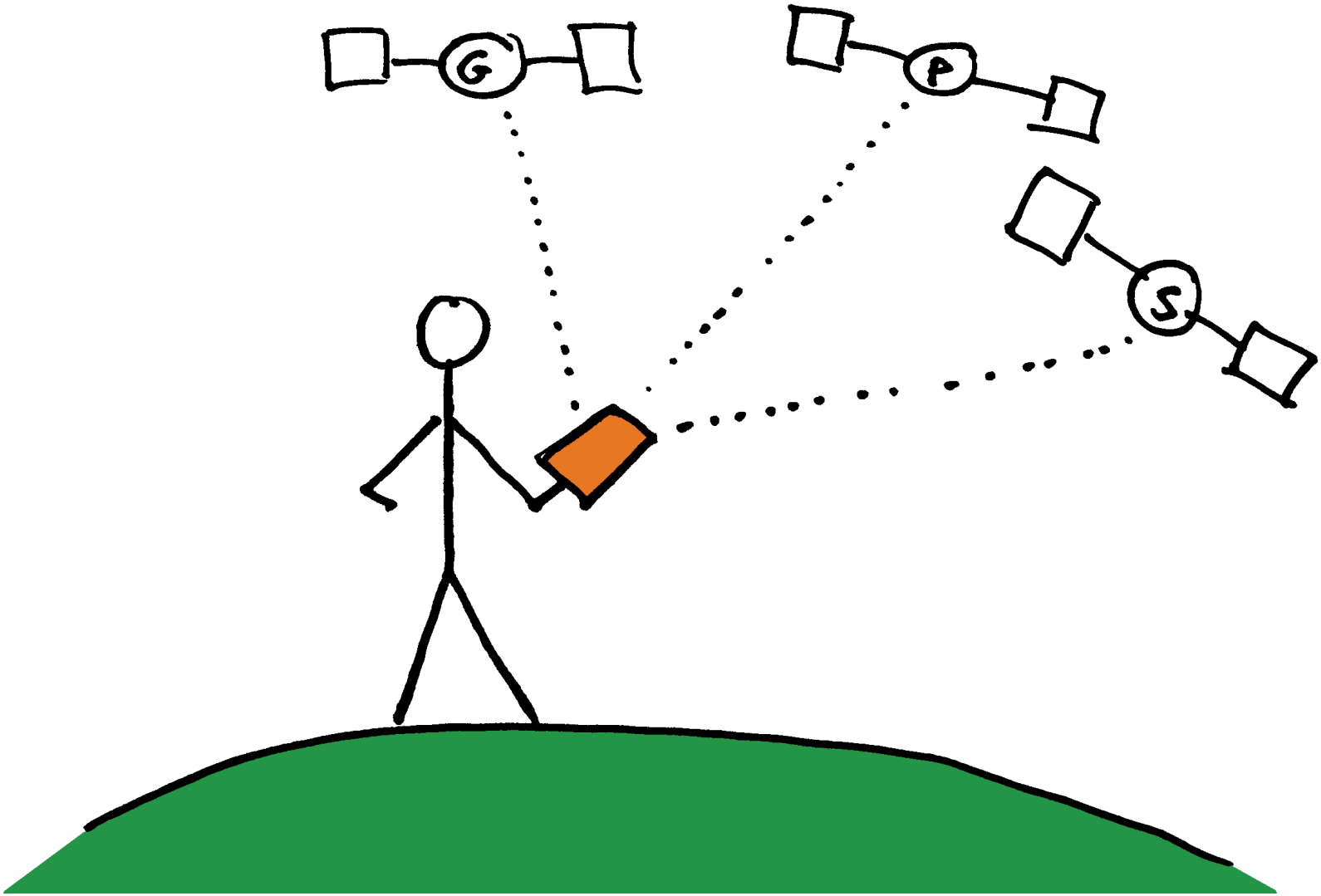

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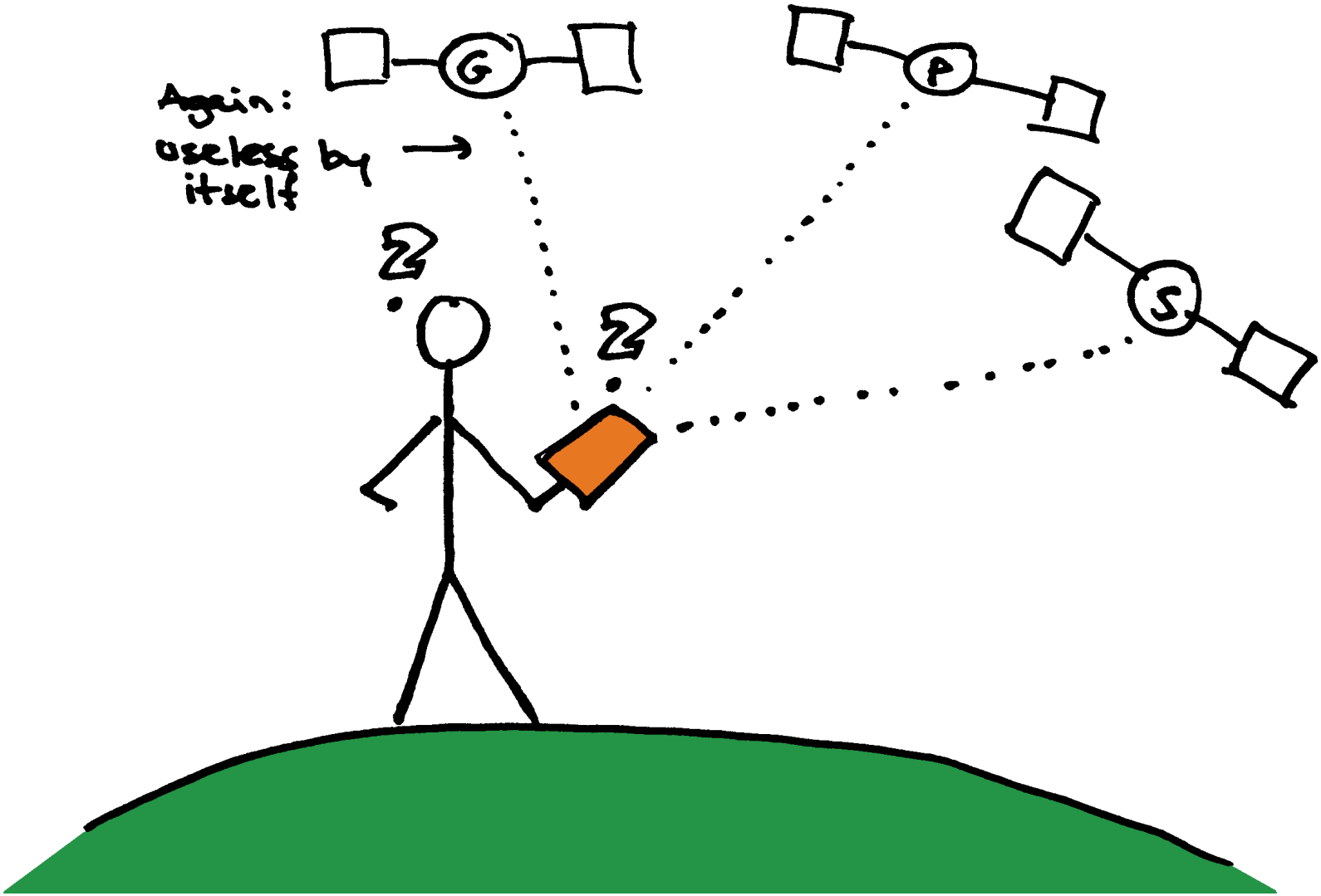
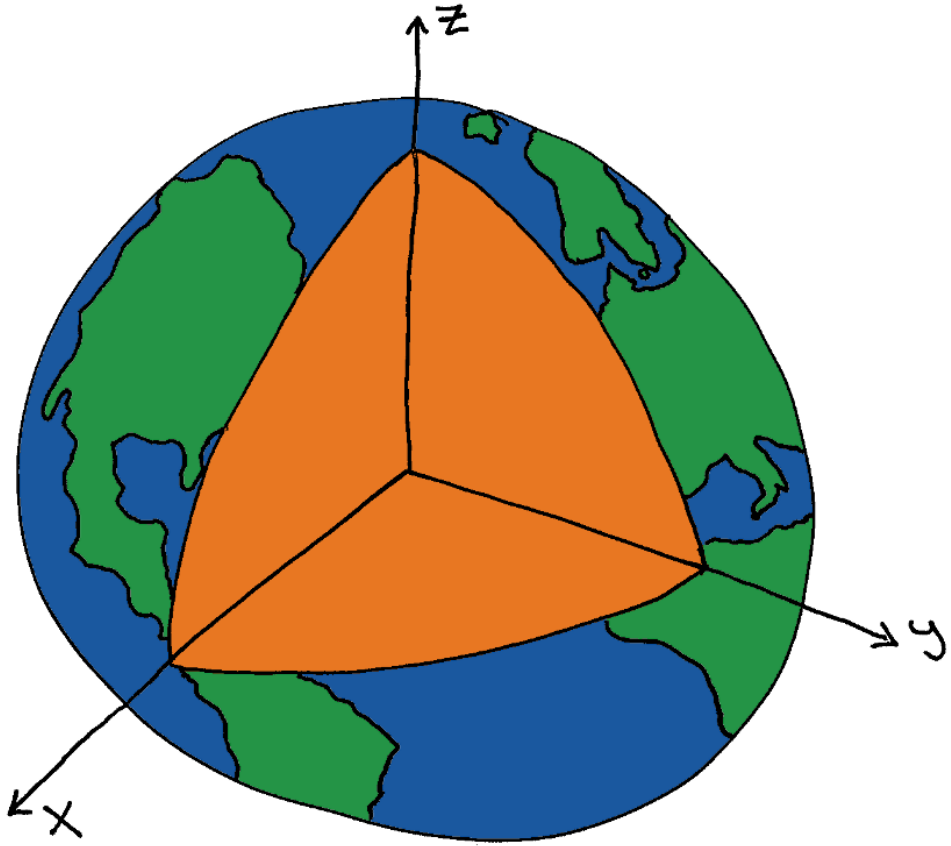


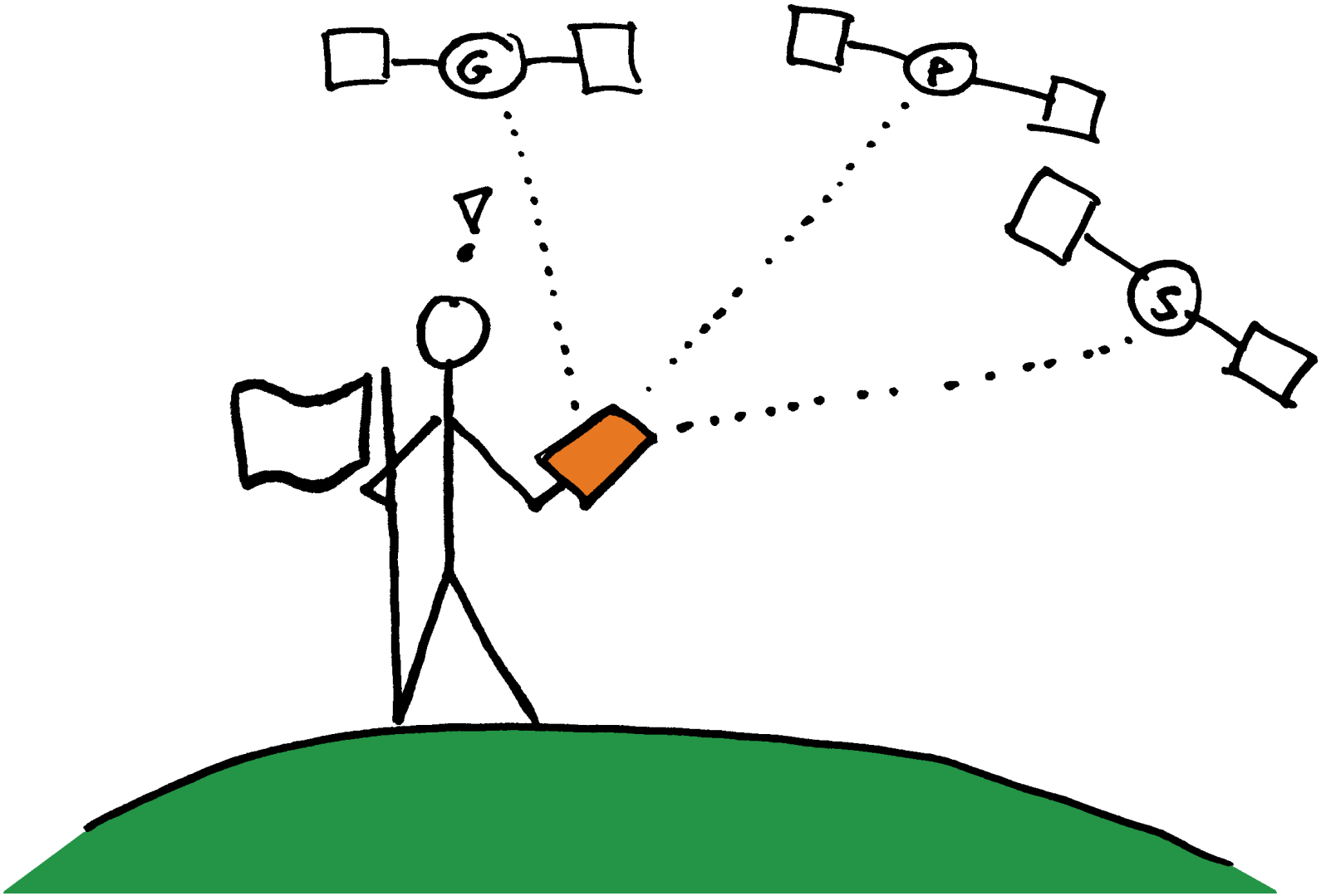
The Solution



A **Reference System**[1]

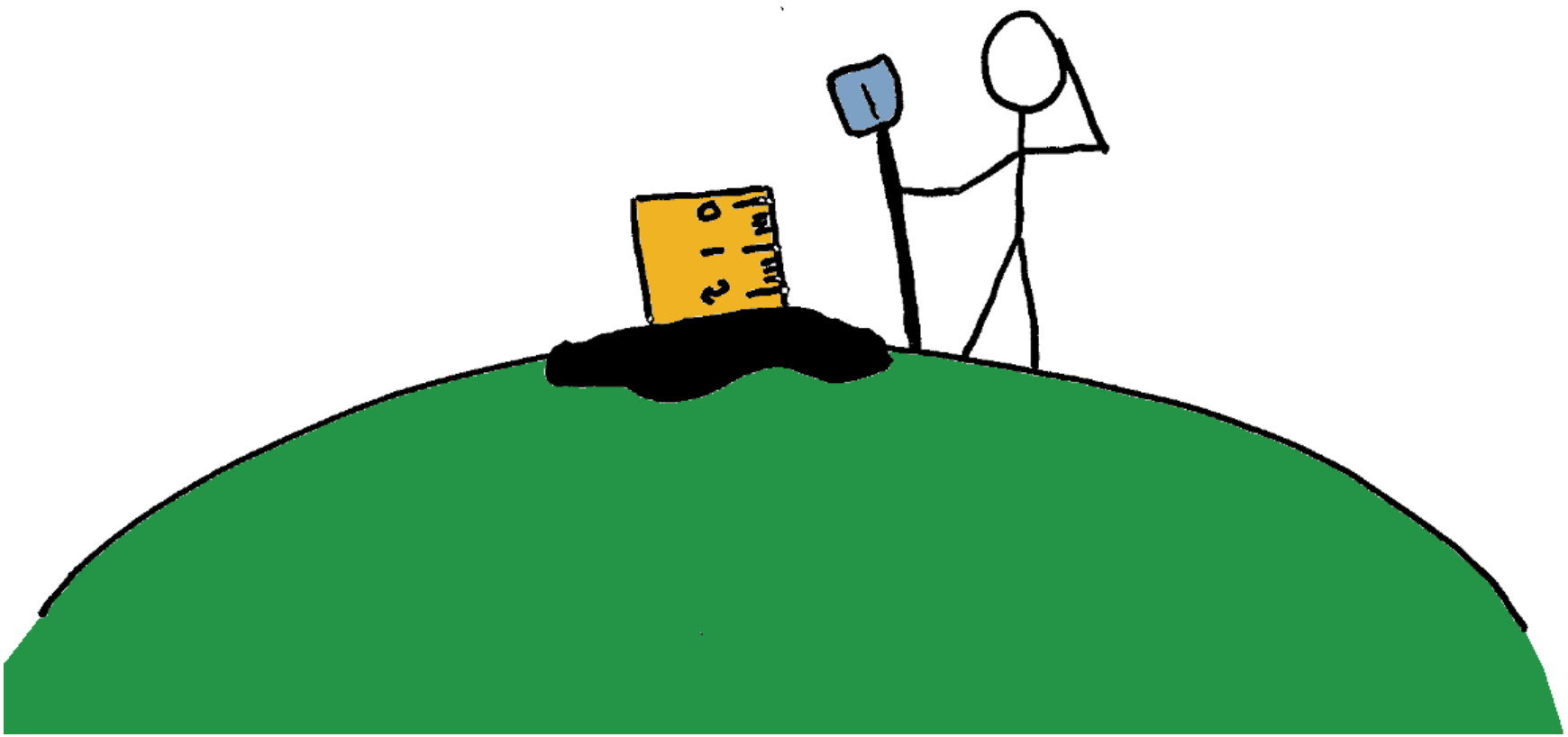
[1] Really just a coordinate system based on reference points

The Solution



The Solution

But it's not trivial to define such a Reference System ...



The Solution

Want a **Reference System** that is:

The Solution

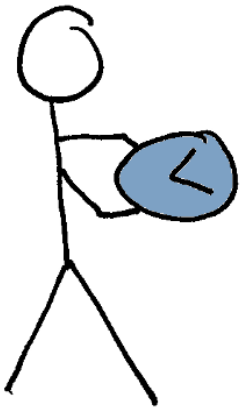
Want a **Reference System** that is:

- precise

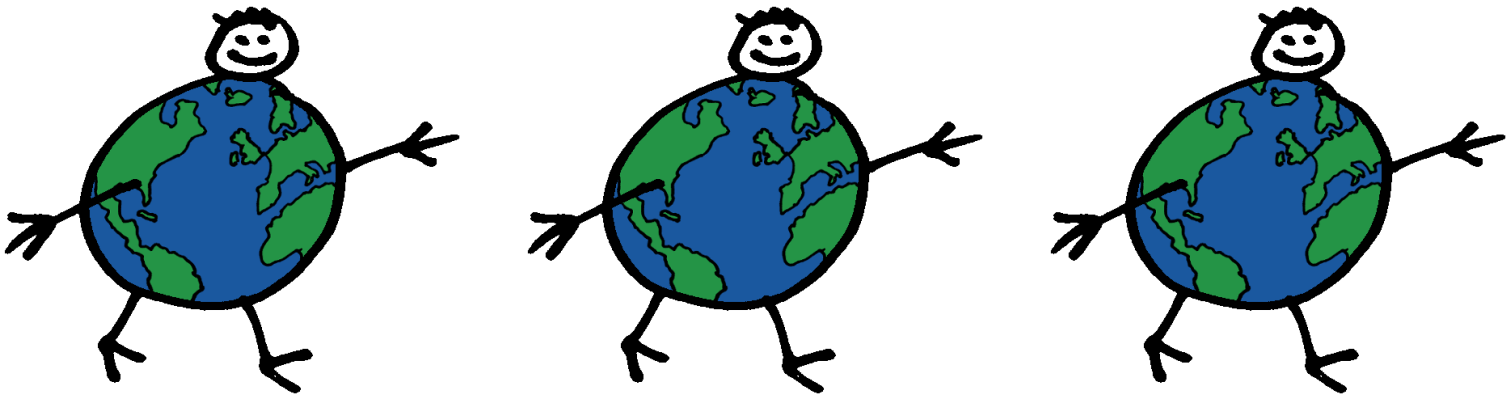
The Solution

Want a **Reference System** that is:

- precise
- stable over time

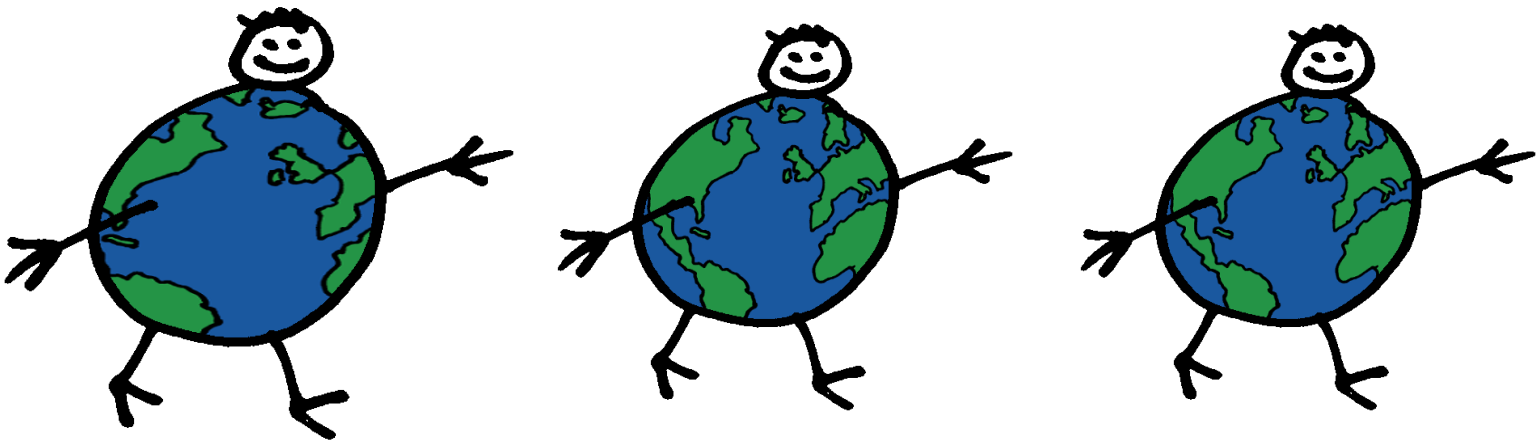


Challenges



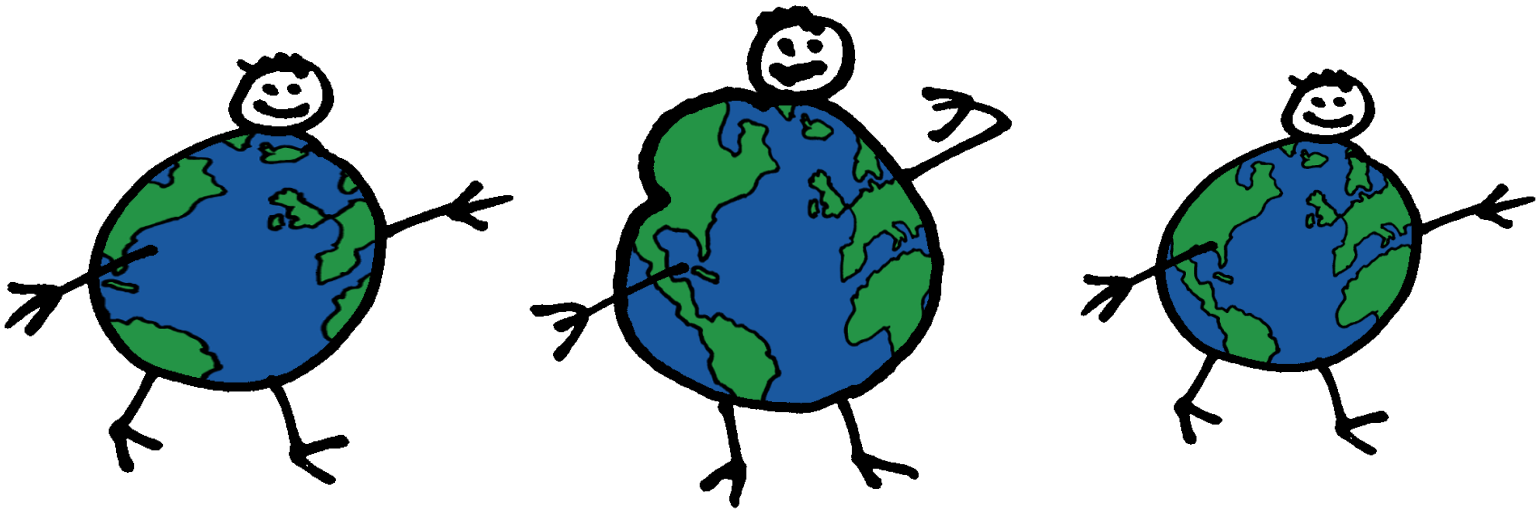
Challenges

- Tectonic plates drifting



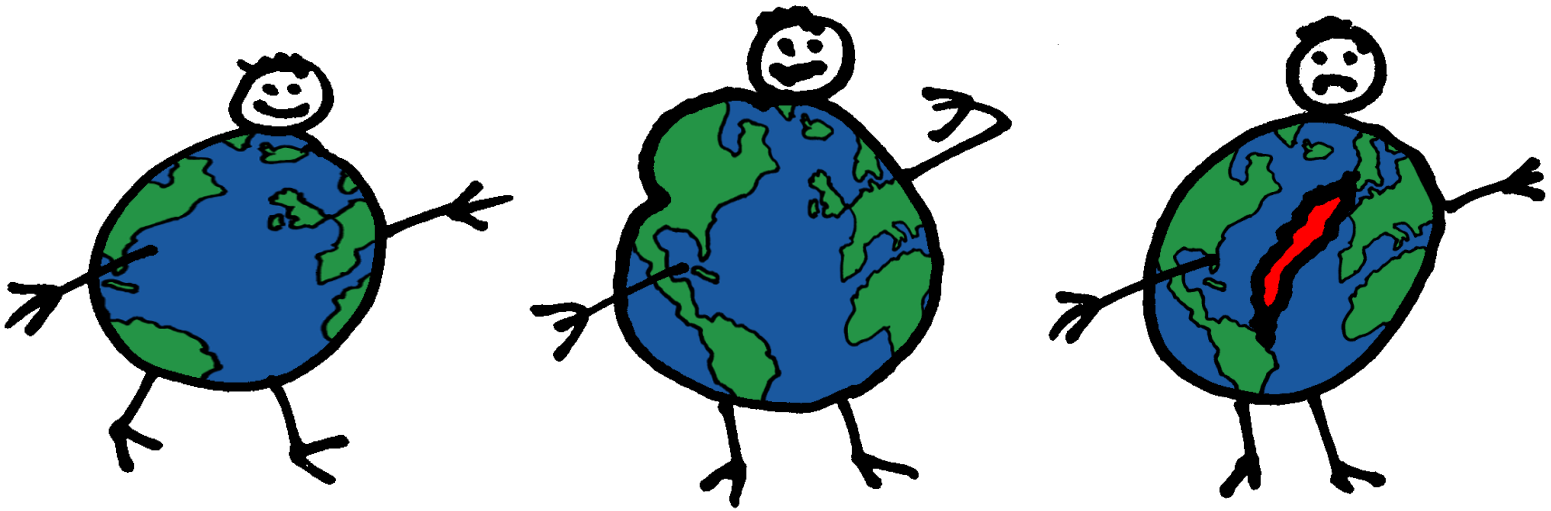
Challenges

- Tectonic plates drifting
- Land rise and sea level rise



Challenges

- Tectonic plates drifting
- Land rise and sea level rise
- Earthquakes



Solutions

- Local Systems

Solutions

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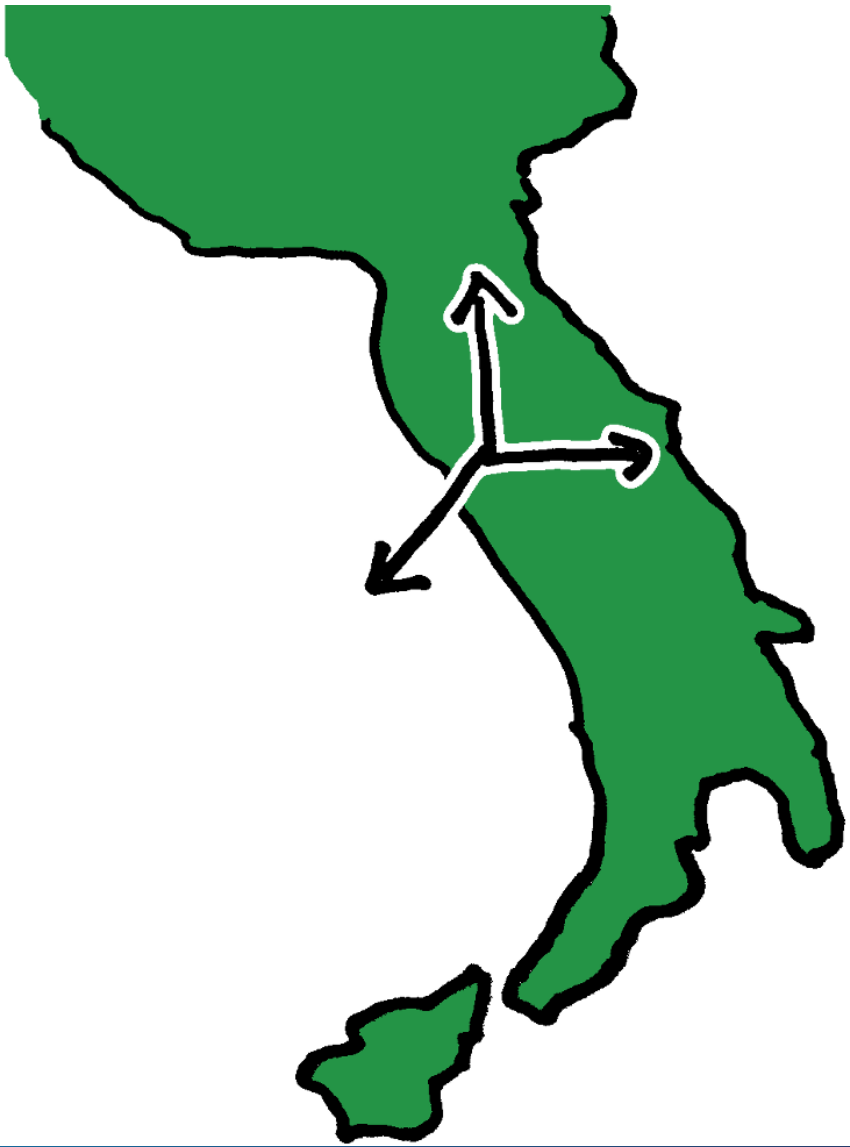
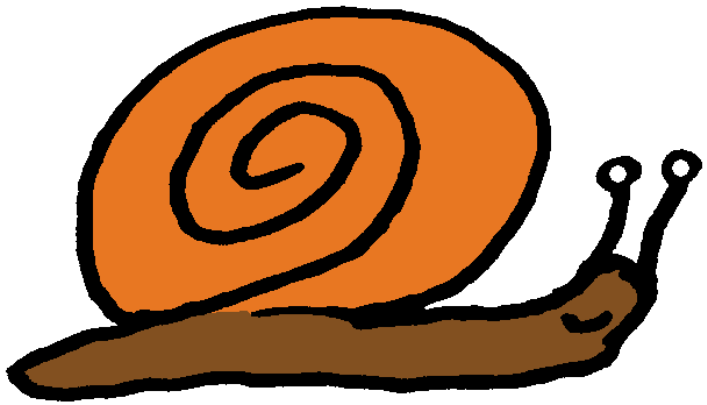


Solutions

- Coordinates that move



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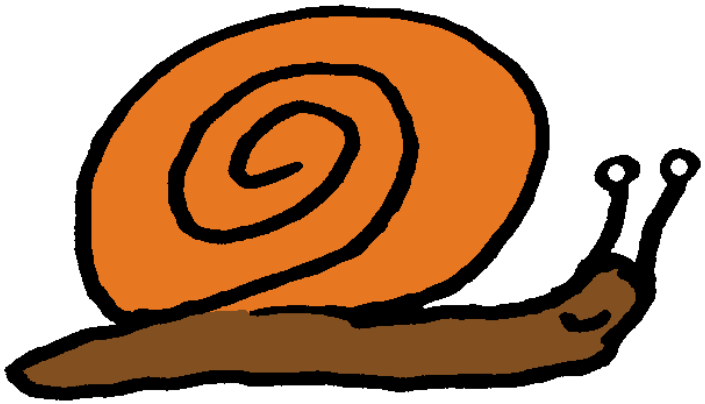

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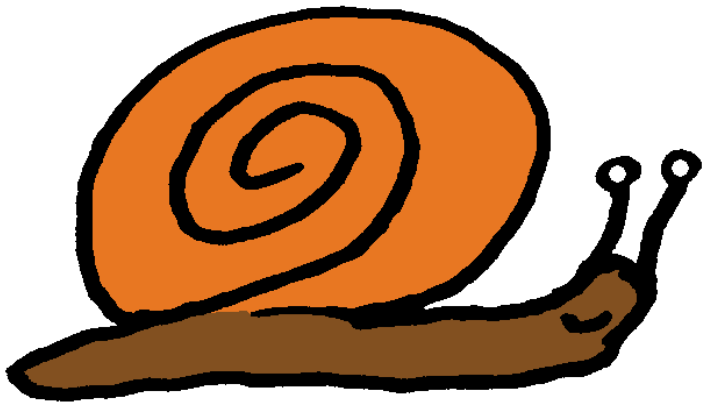

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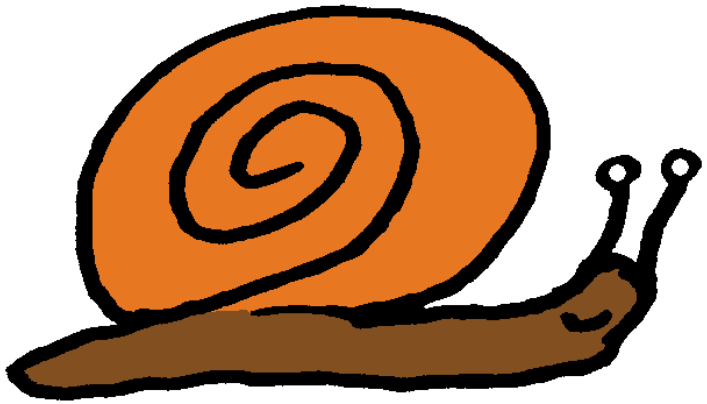

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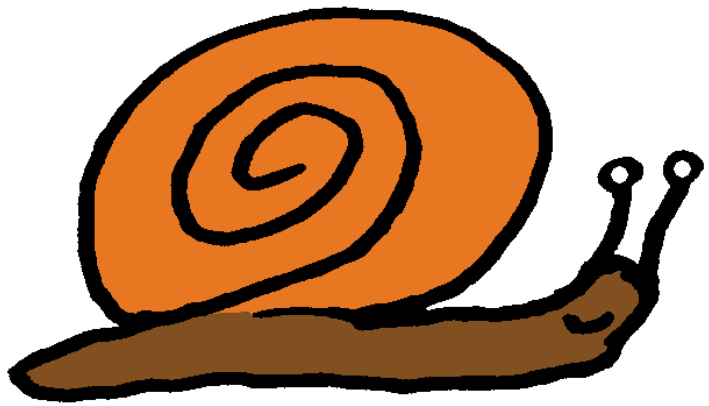
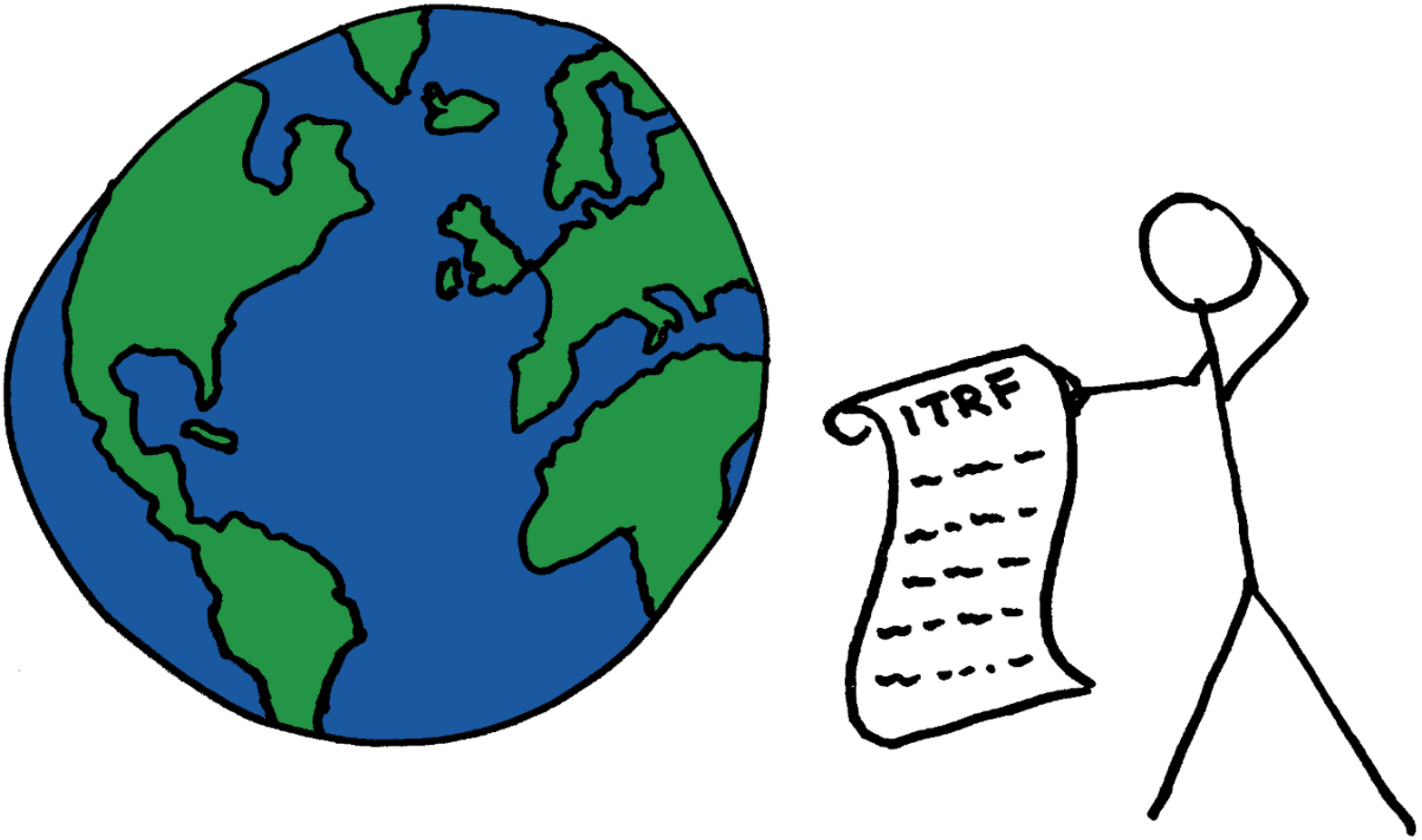


Part II

What?

ITRF

- The International Terrestrial Reference Frame



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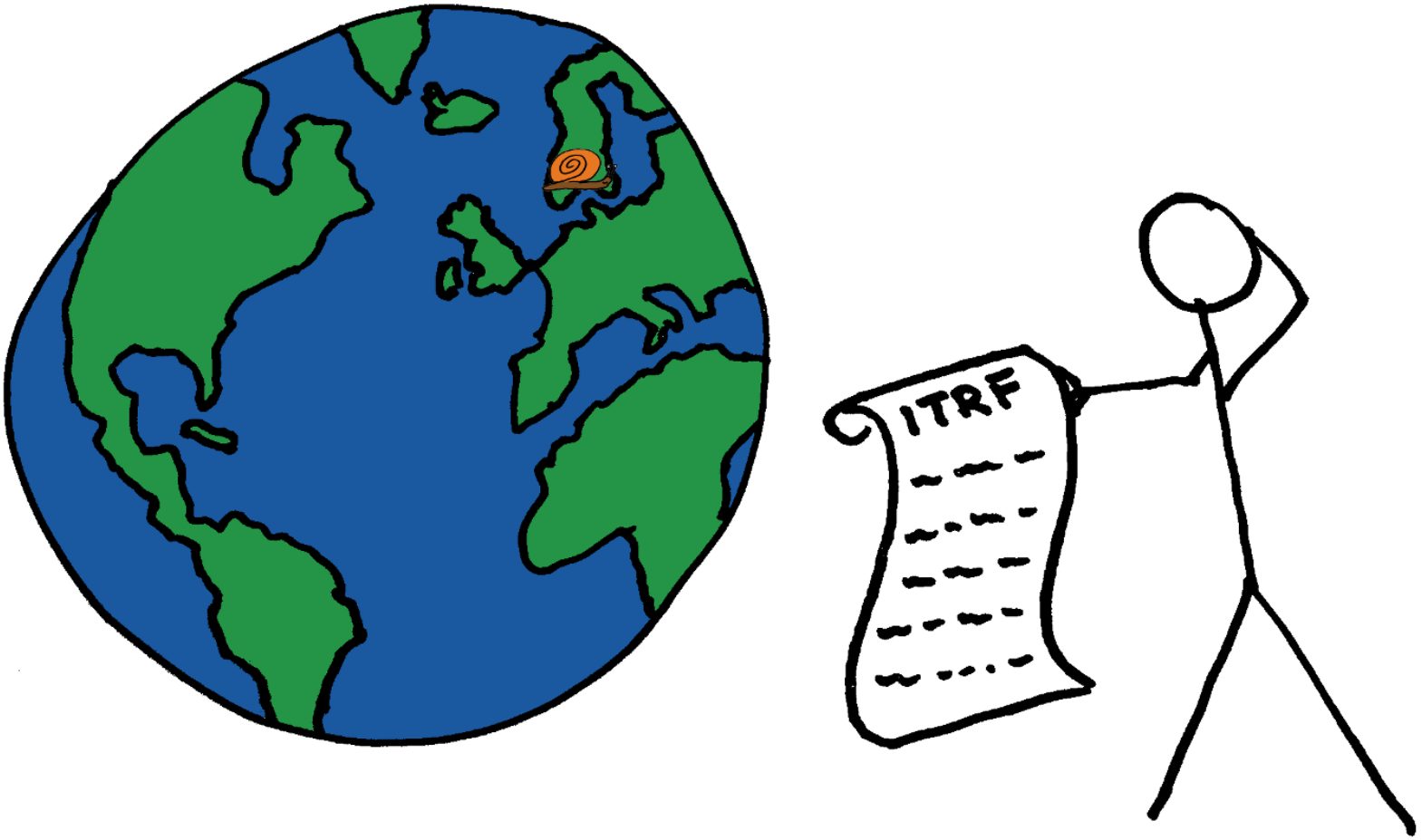

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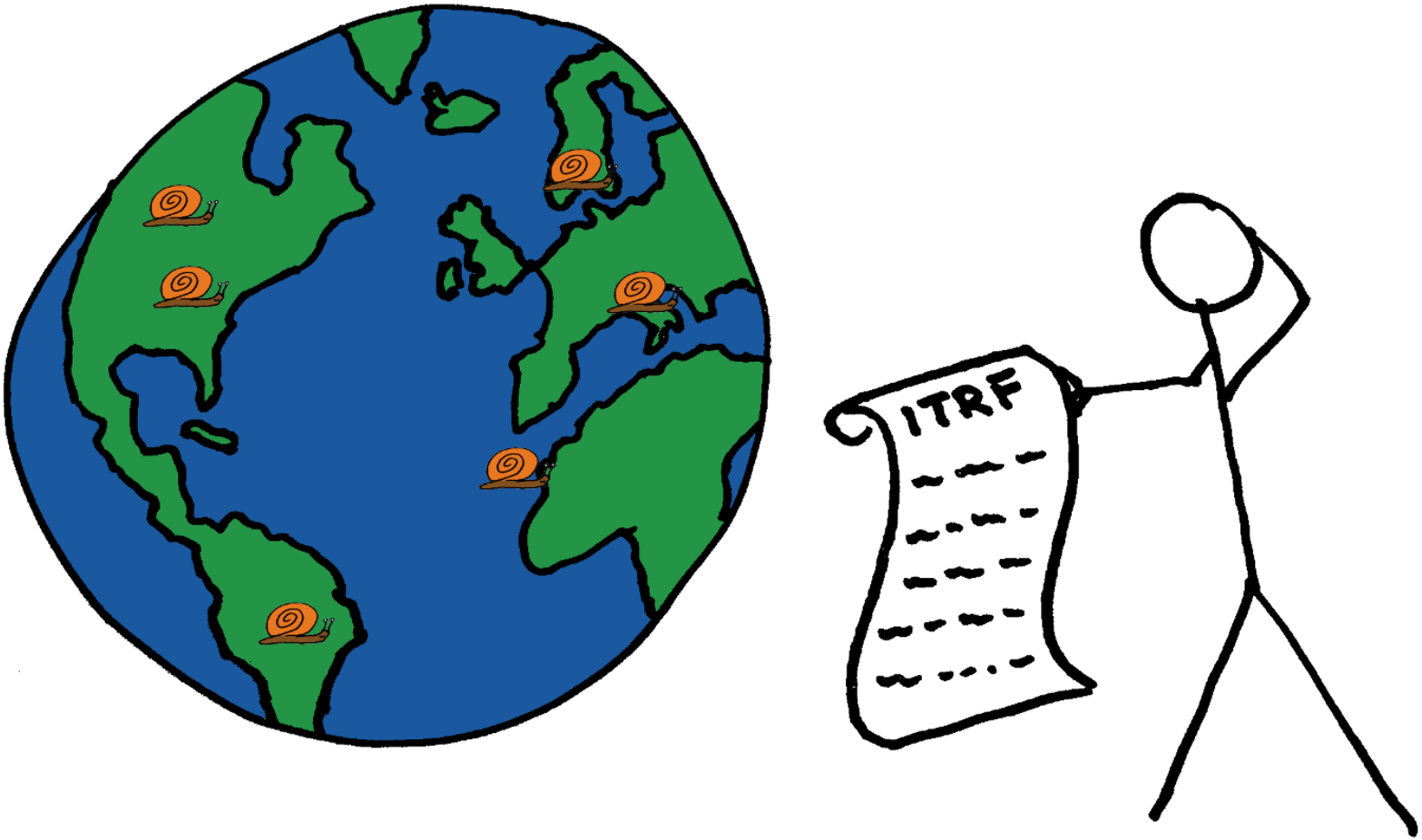


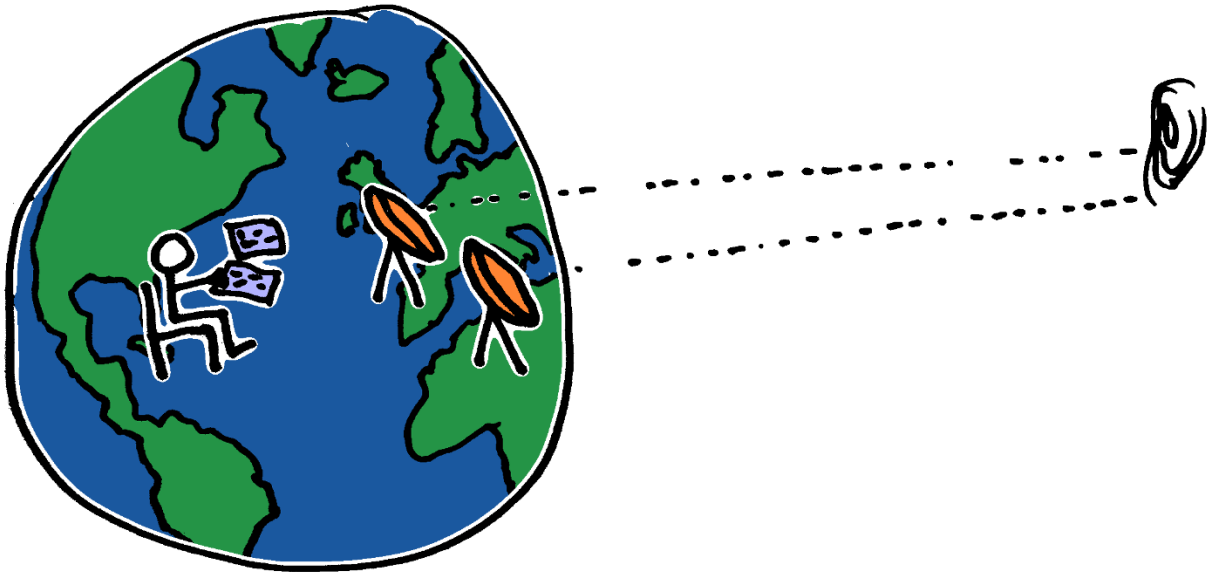
Part III

How?

International Cooperation

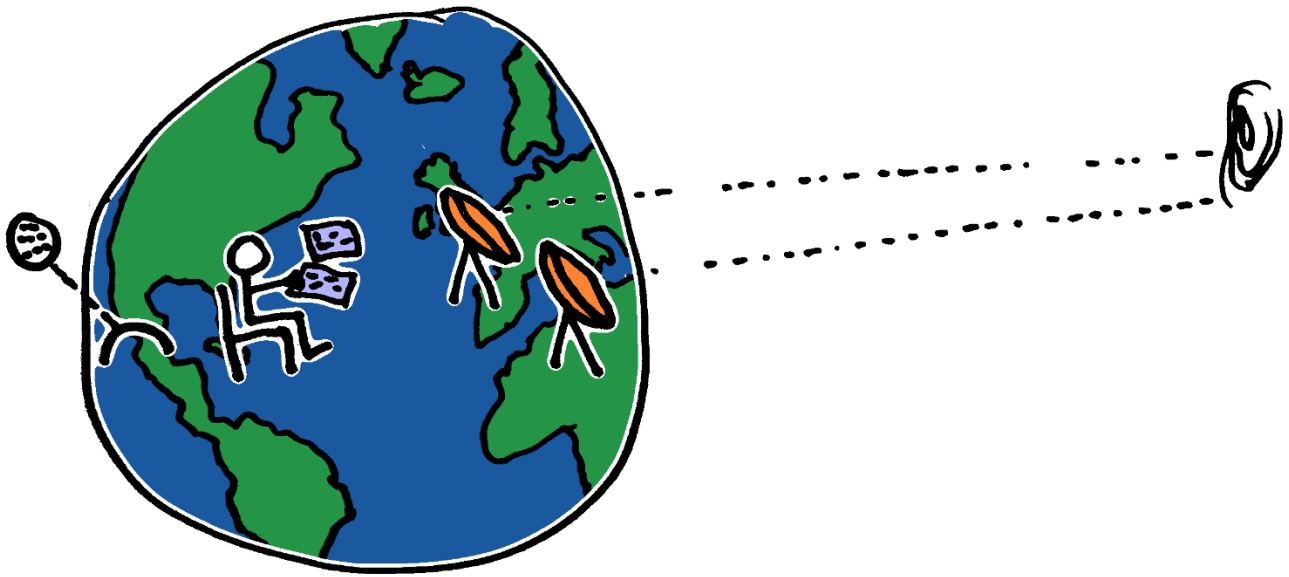
- The ITRF is created based on observations from four different space geodetic techniques

International Cooperation



- The ITRF is created based on observations from four different space geodetic techniques
  - VLBI – Very Long Baseline Interferometry

International Cooperation



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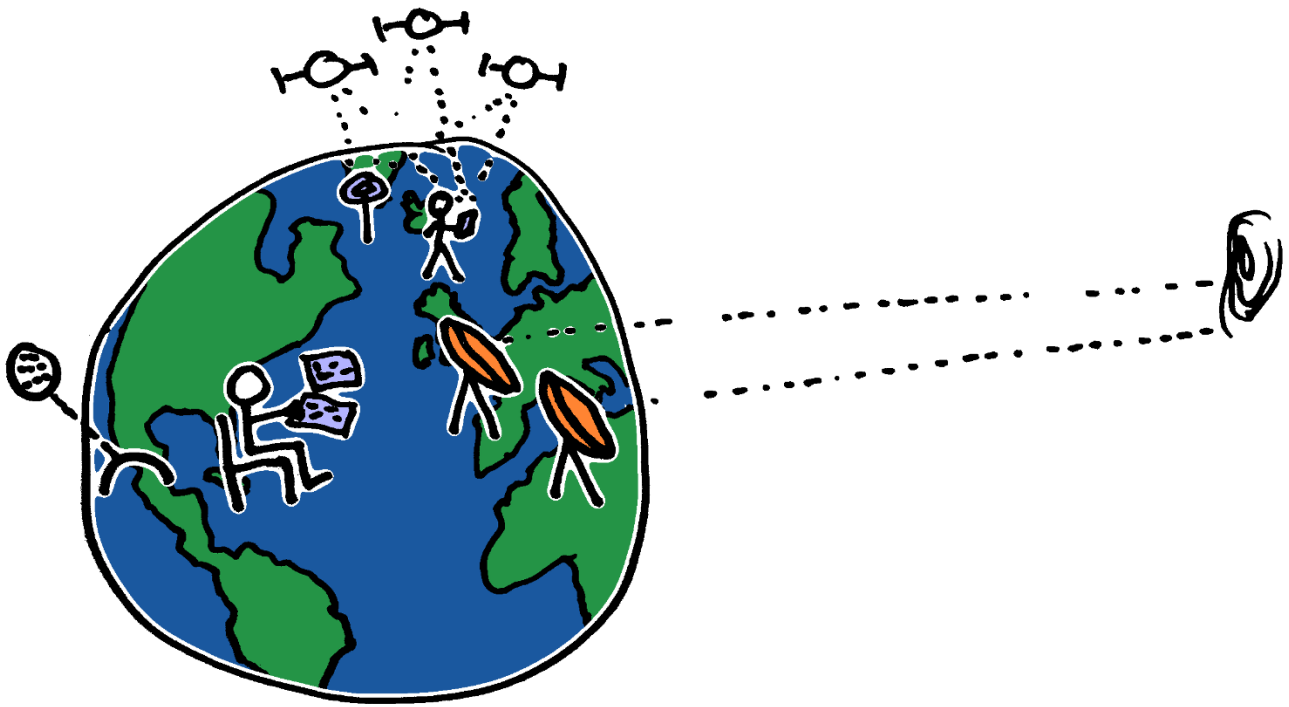

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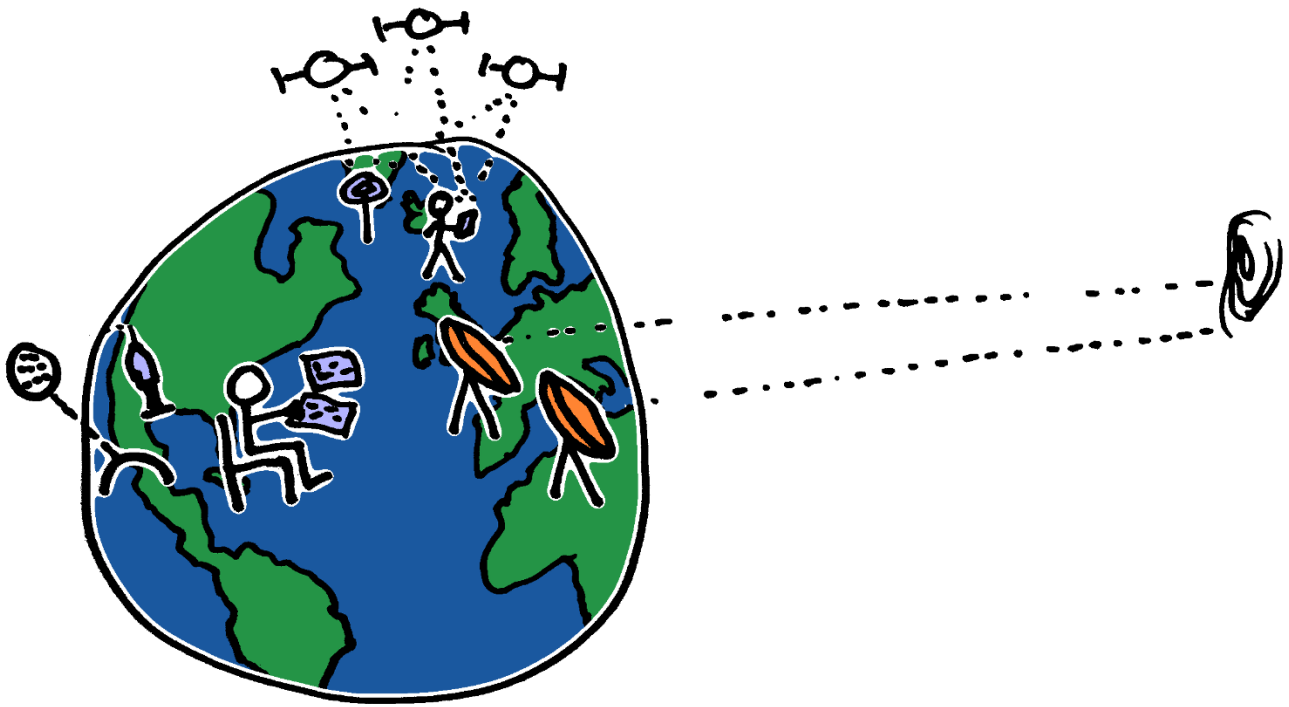

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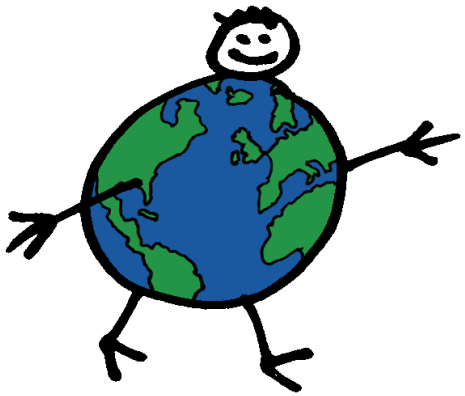
  - VLBI – Very Long Baseline Interferometry
  - SLR – Satellite Laser Ranging
  - GNSS – Global Navigation Satellite Systems (e.g. GPS)
  - DORIS – Doppler Orbitography and Radiopositioning

Still Some Challenges

- The Earth rotates



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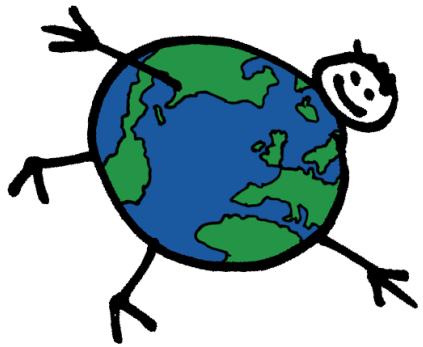

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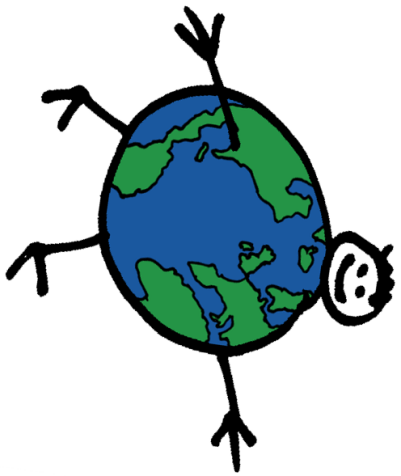

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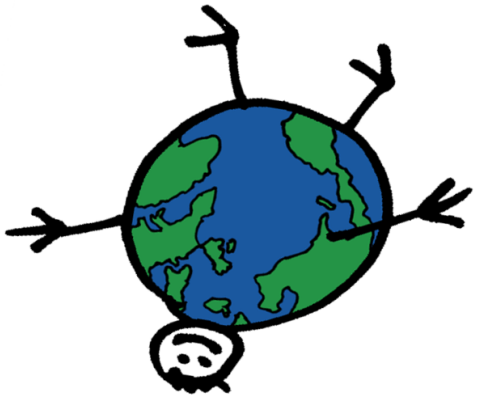

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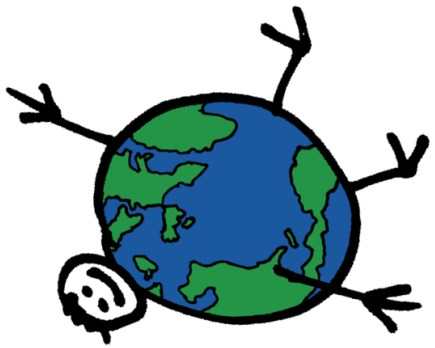

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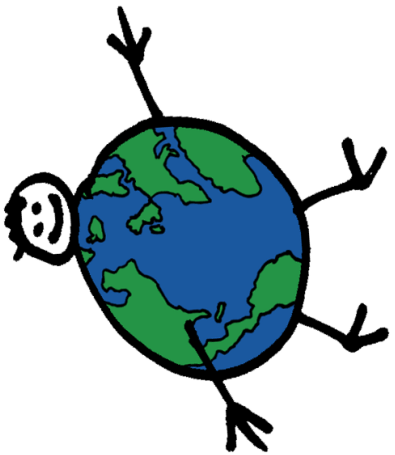

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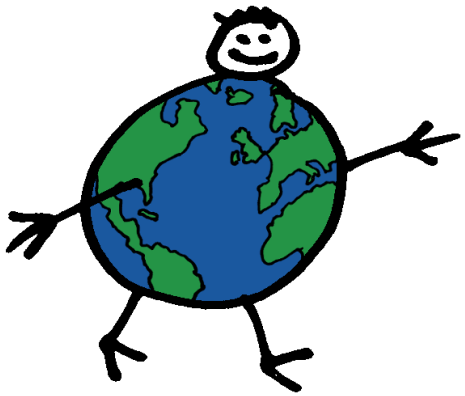

- Fix the Reference System to the Earth with z as the rotation axis

Still Some Challenges

- The Earth wobbles

Still Some Challenges

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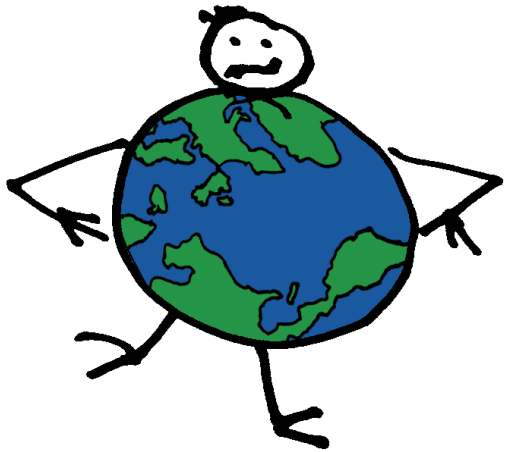

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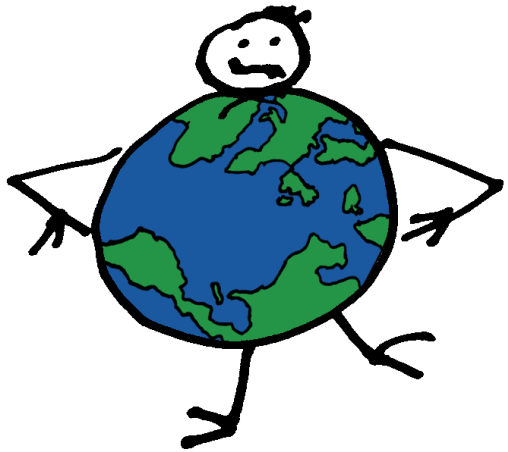

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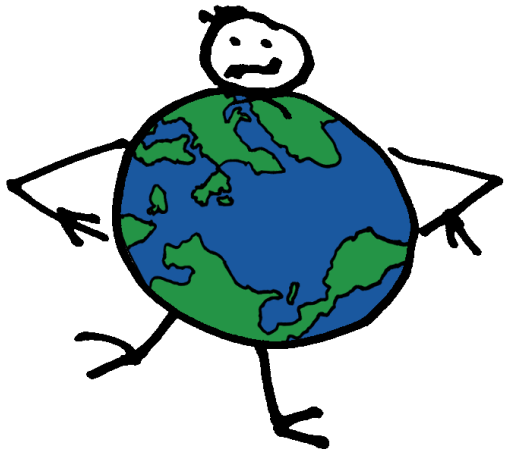

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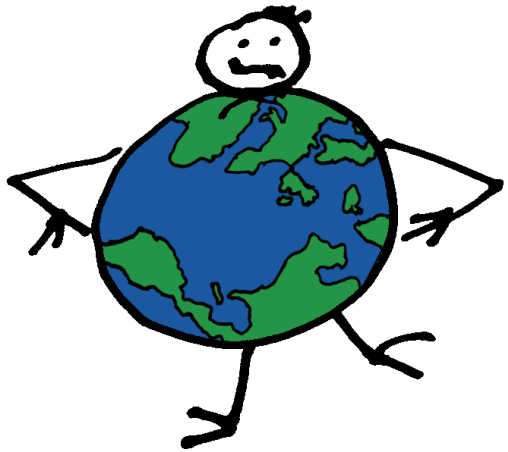
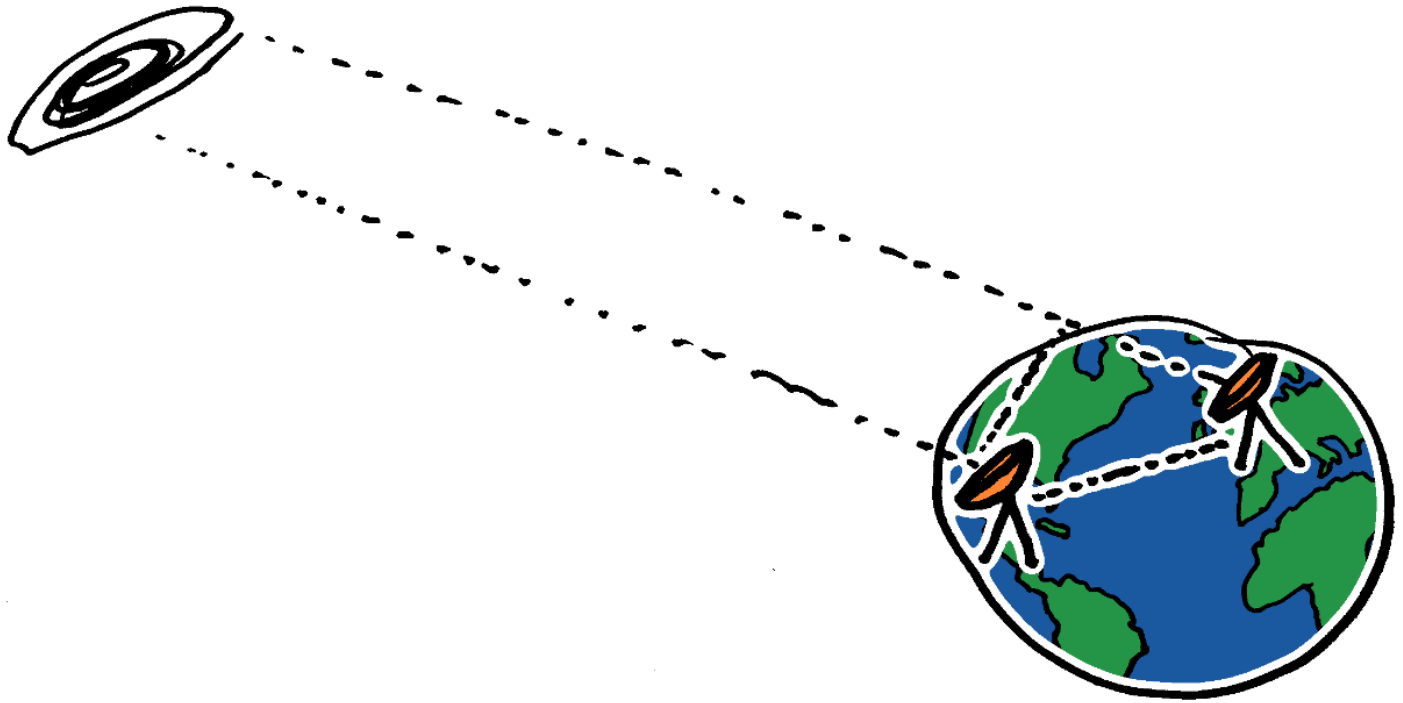


- Continuously update the Earth Orientation Parameters

VLBI



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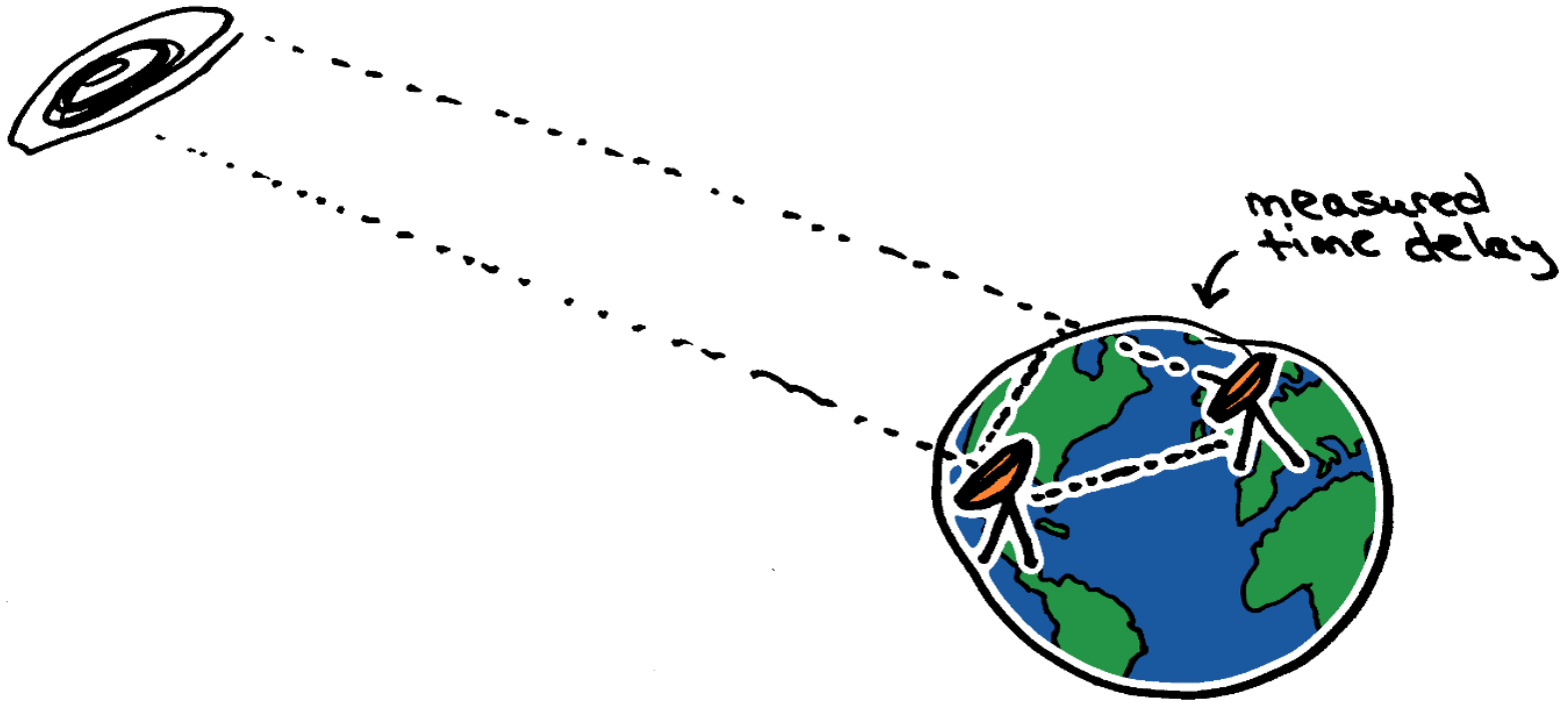

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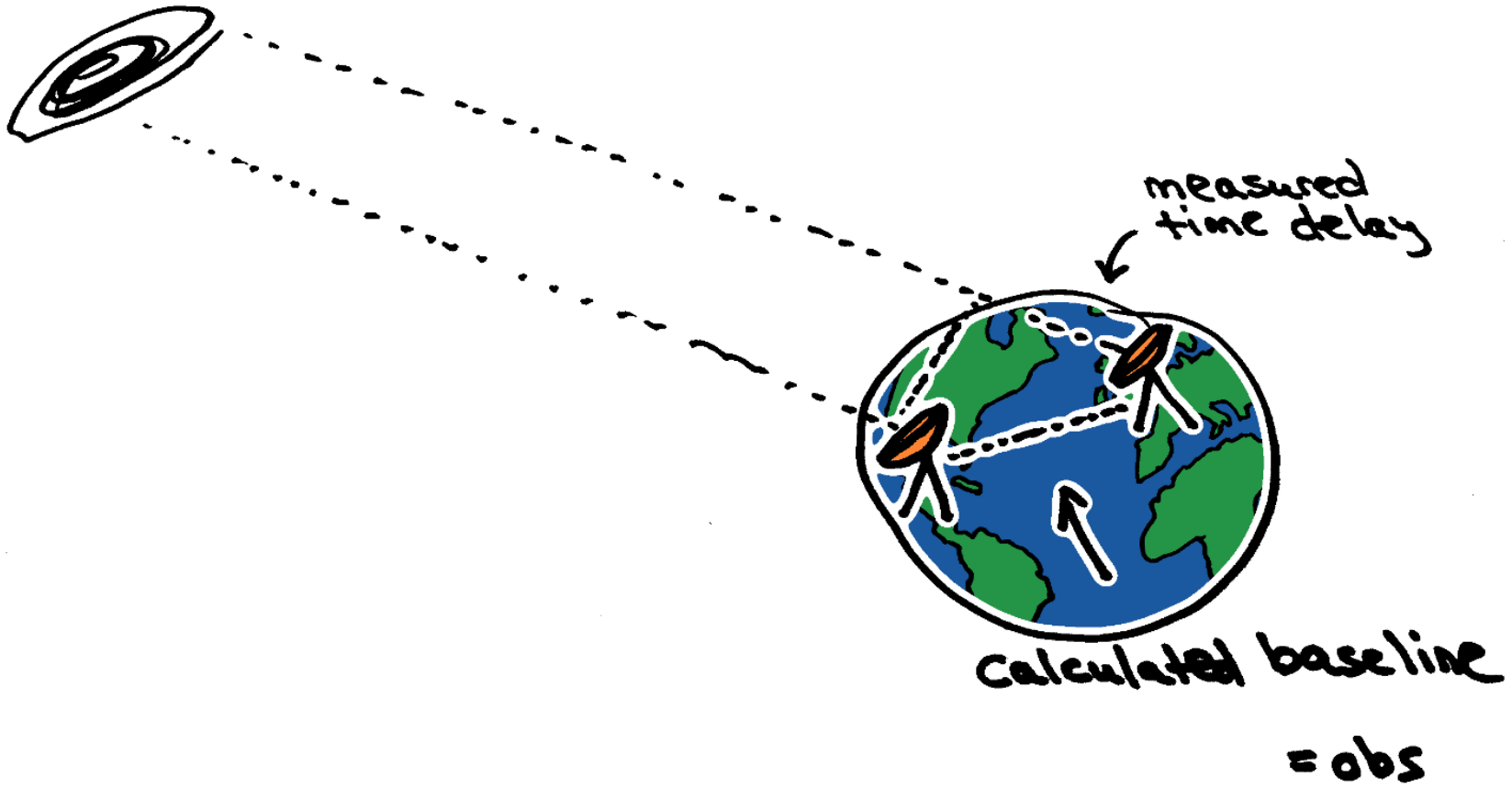
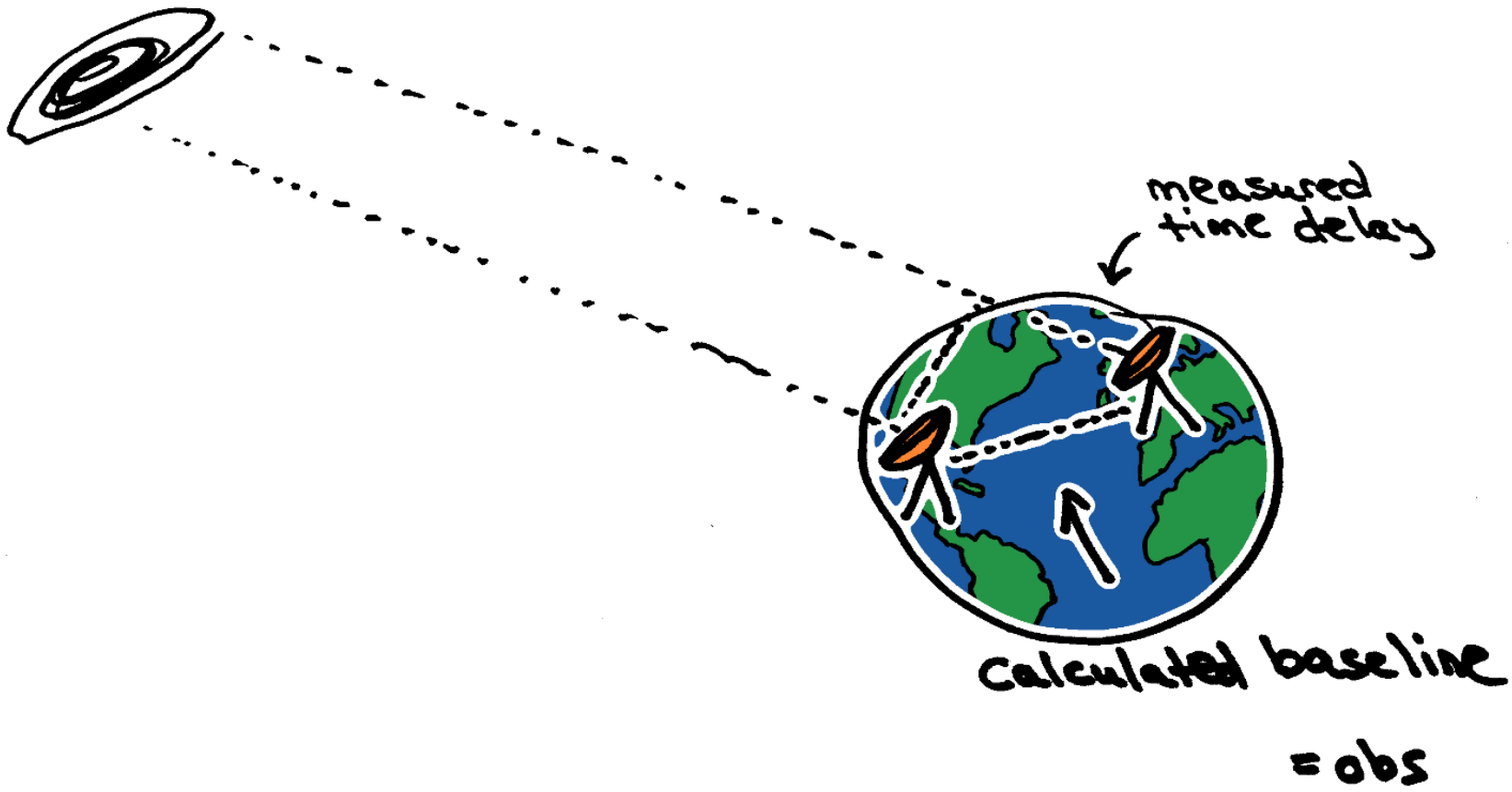


VLBI



Calculate **model** where:

- position of stations is assumed known (ITRF)
- a priori estimate of wobble is included

VLBI

The residual

obs - model

can be used to estimate the true wobble.

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The residual

obs - model

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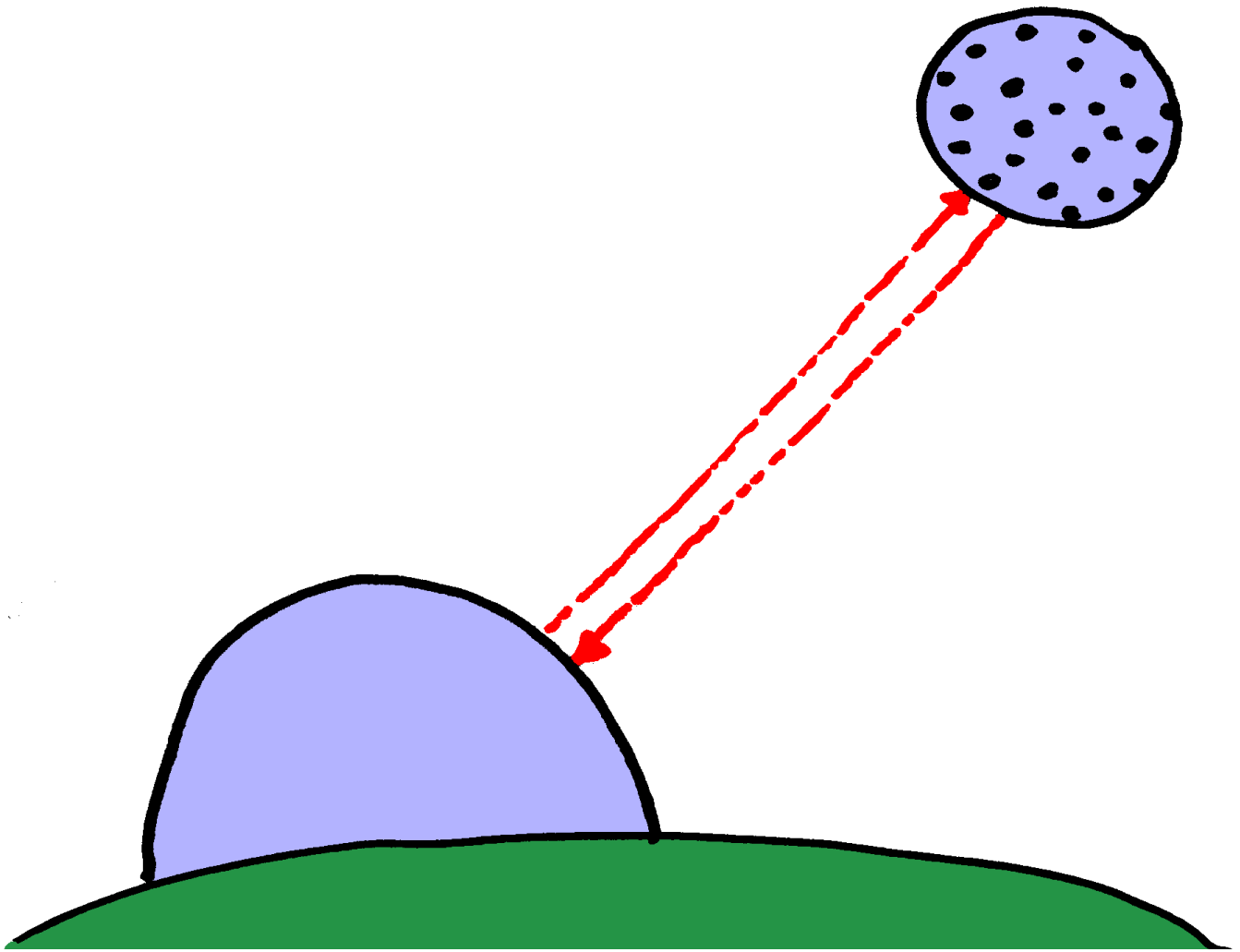
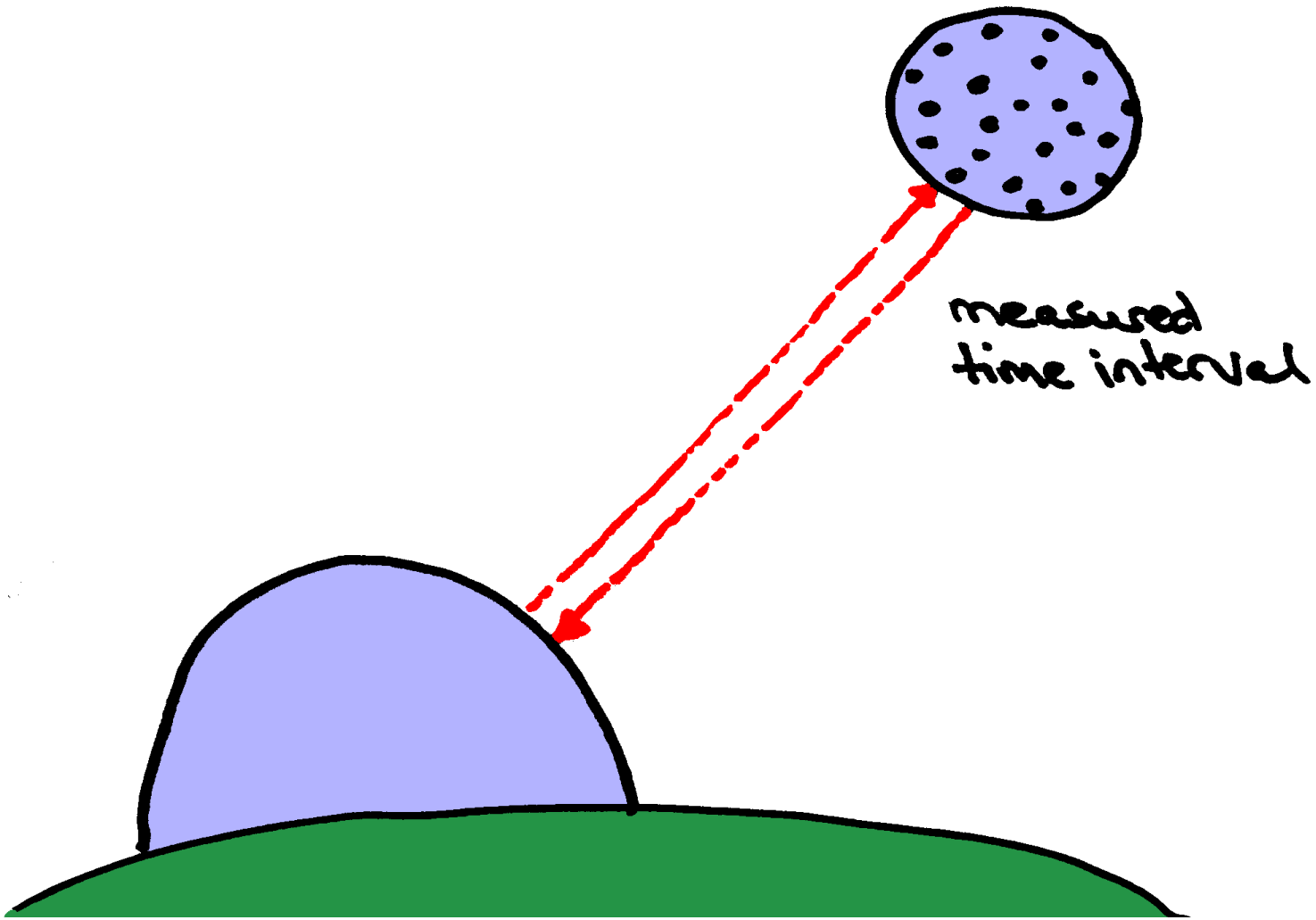
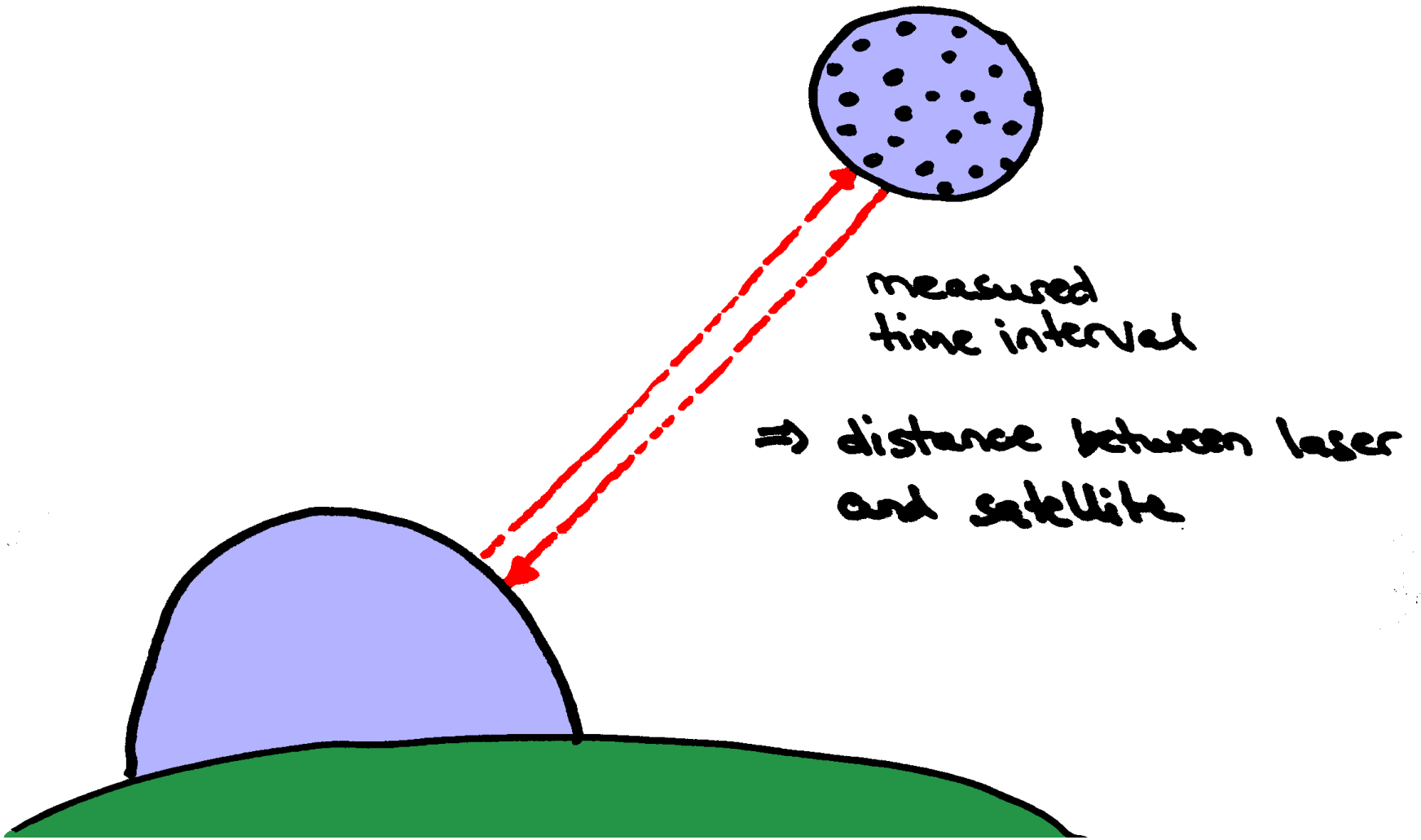
SLR



SLR

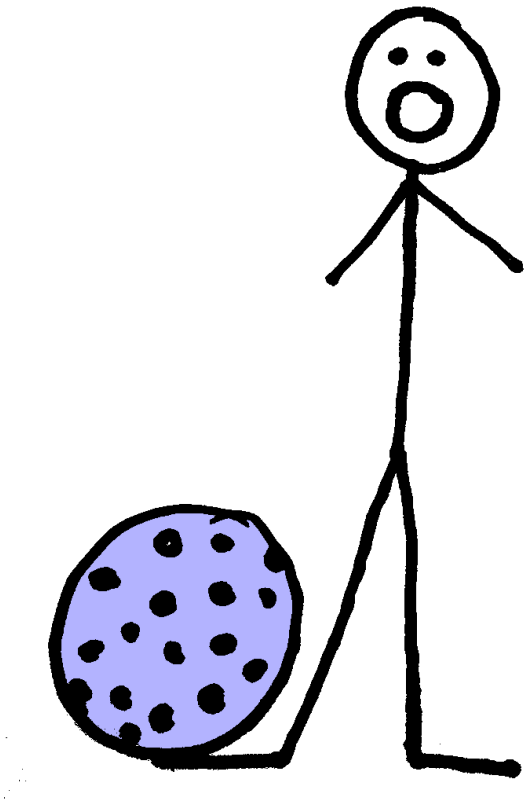


SLR


measured
time interval
⇒ distance between laser
and satellite

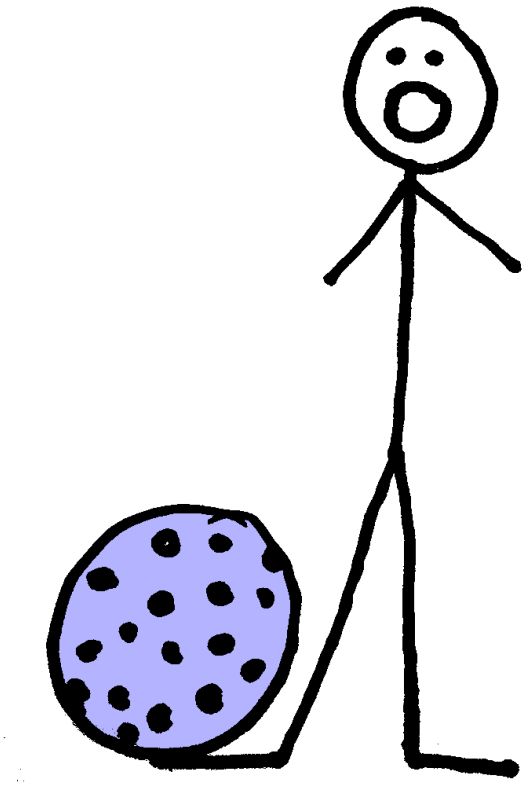
SLR

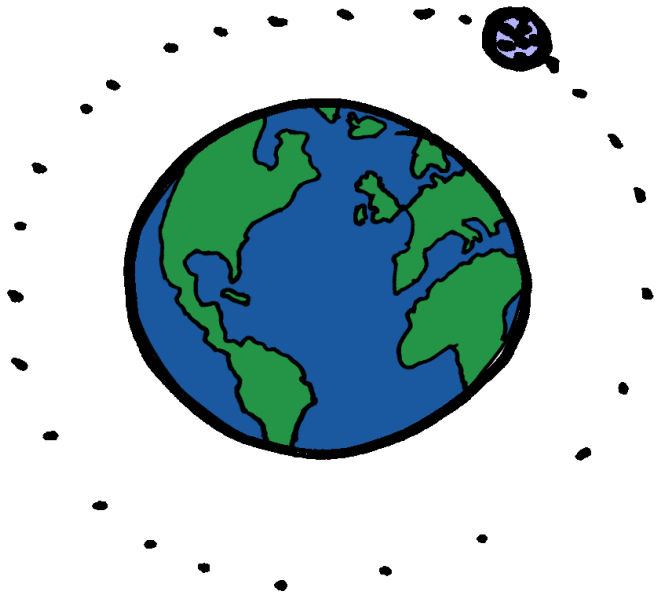
Two applications:



SLR

Two applications:

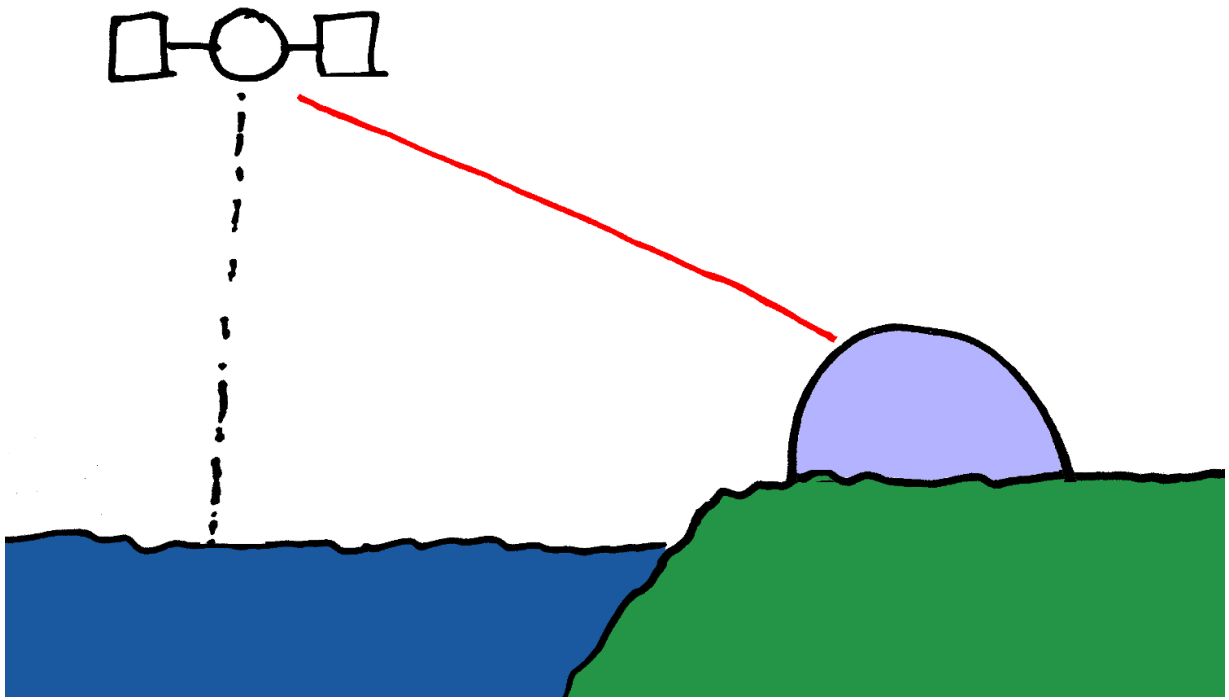




- Stable satellite orbit
  $\Rightarrow$ Can calculate the position of the station (ITRF)

SLR

Two applications:

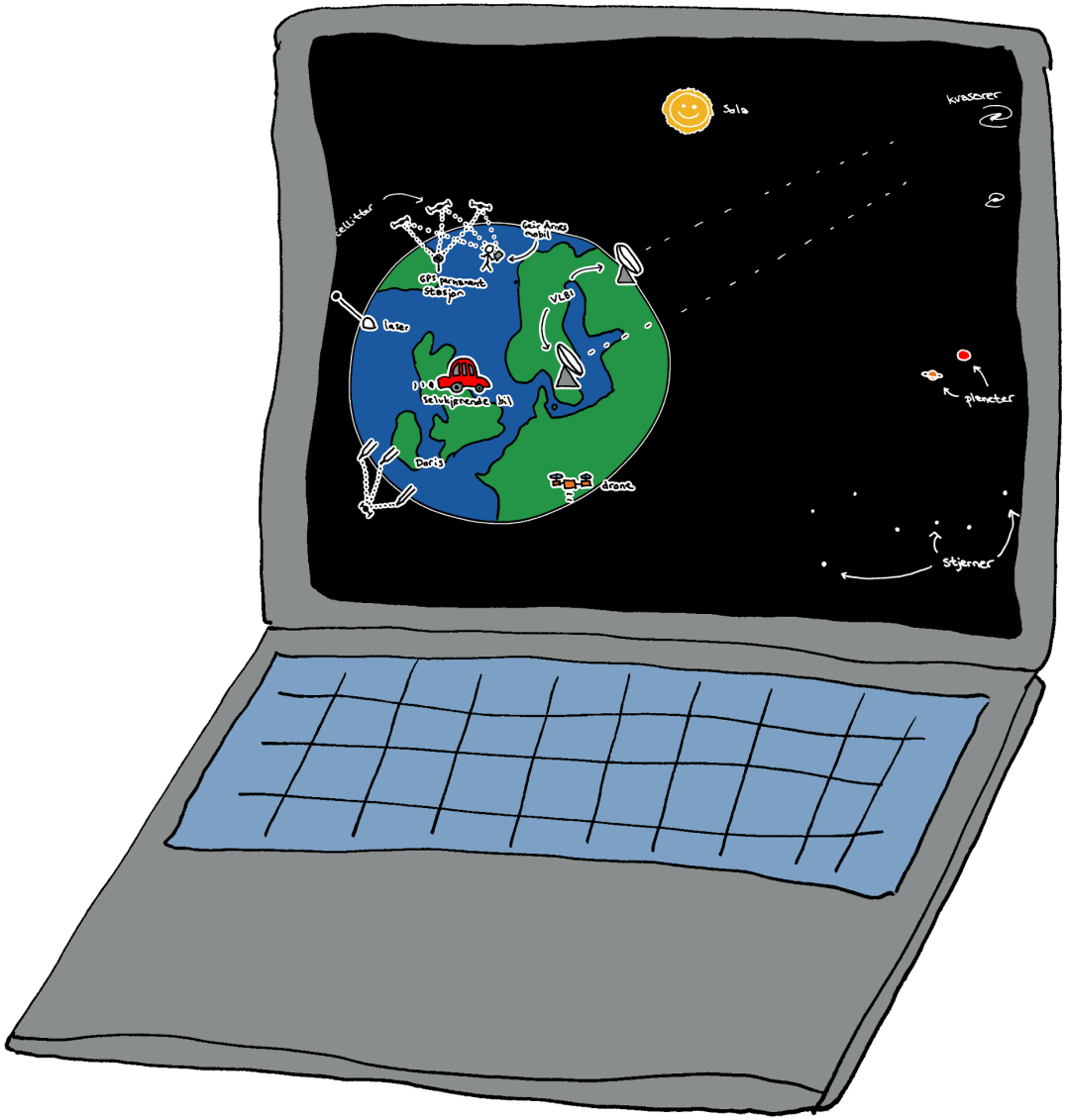


- Known station position
  $\Rightarrow$ Can calculate satellite orbits (remote sensing)

Part IV

Python

Where?


Sola
kvasarer
satellitter
GPS
VLBI
laser
Doris
drone
planeter
stjerner

Where?

Where is software that can analyse VLBI, SLR, and GNSS data, and contribute to the ITRF

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- Python (mostly NumPy with a bit of Cython and F2Py)

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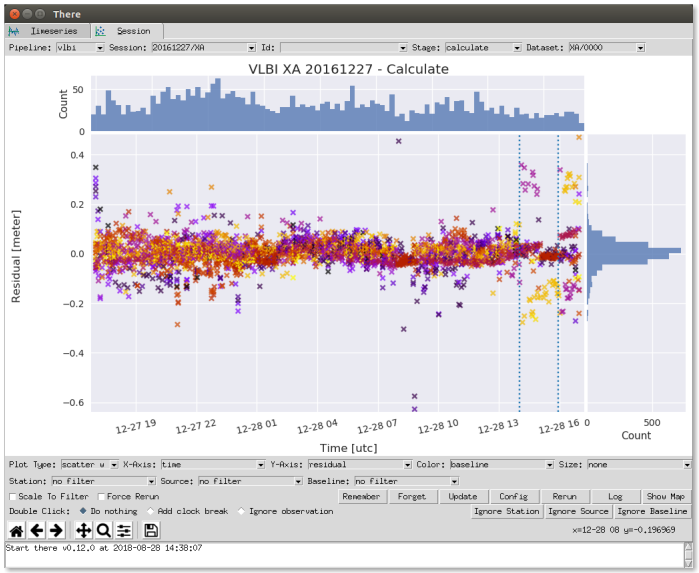
- Open Source (`https://kartverket.github.io/where/`)

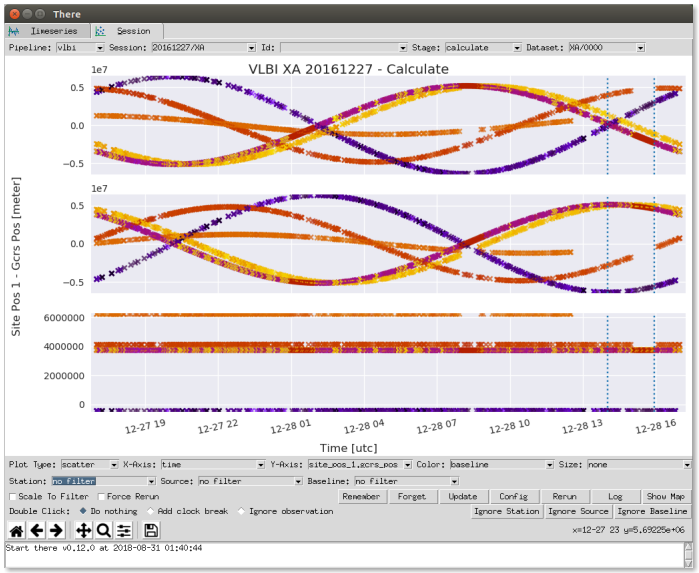
Where?

Where is software that can analyse VLBI, SLR, and GNSS data, and contribute to the ITRF

- Python (mostly NumPy with a bit of Cython and F2Py)
- Open Source (`https://kartverket.github.io/where/`)
- Fairly niche user base though

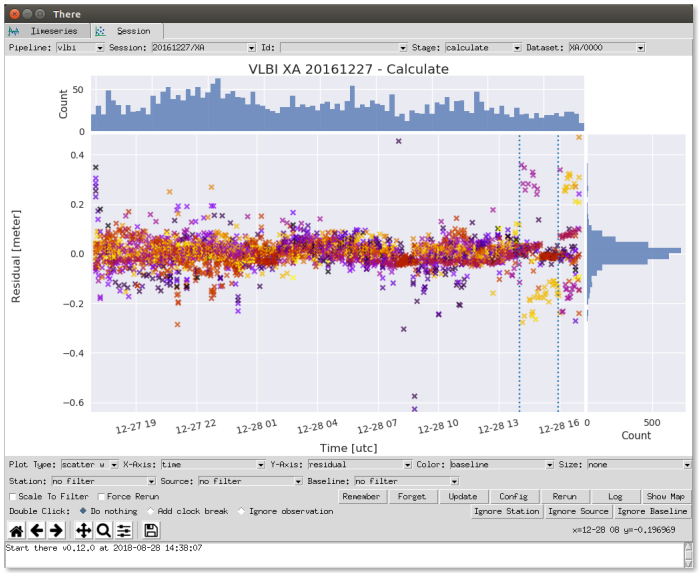
There!

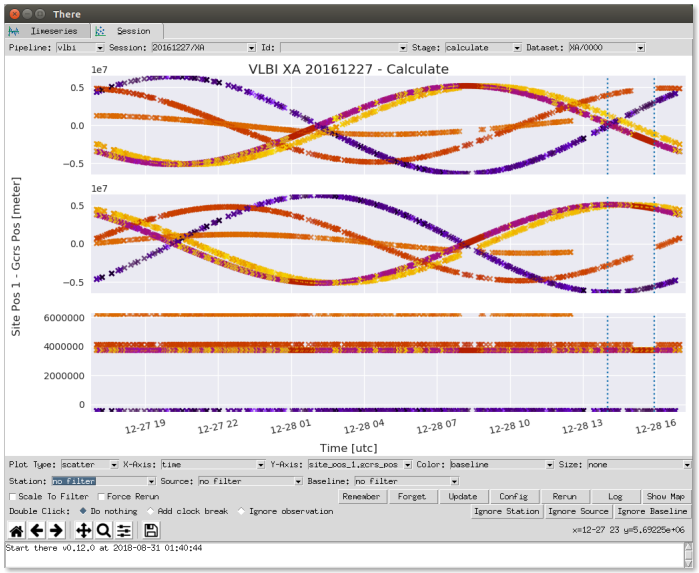




Experiences:

There!

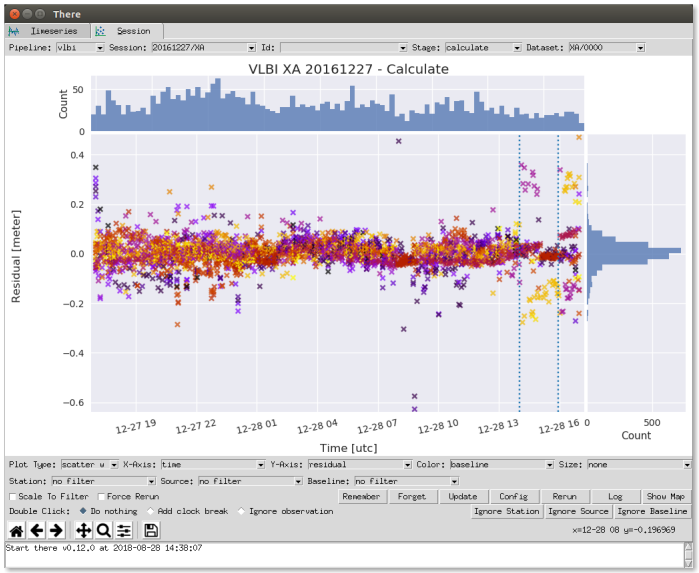


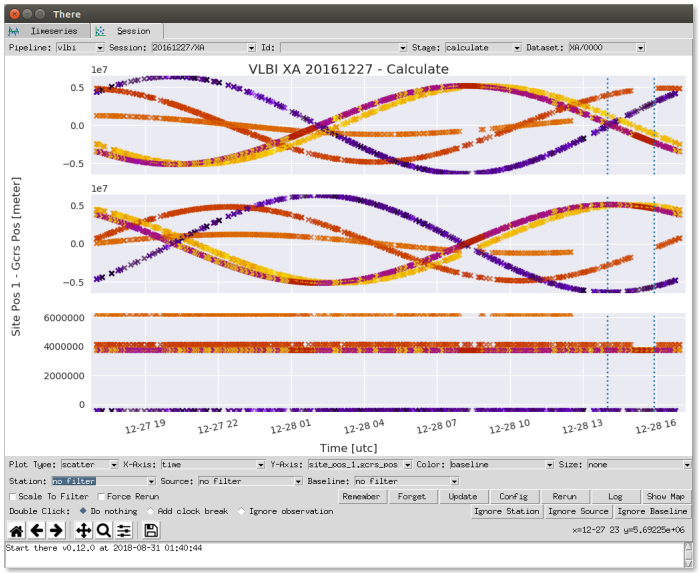


Experiences:

- Thank you to everybody that contribute to the Python data science stack!!

There!

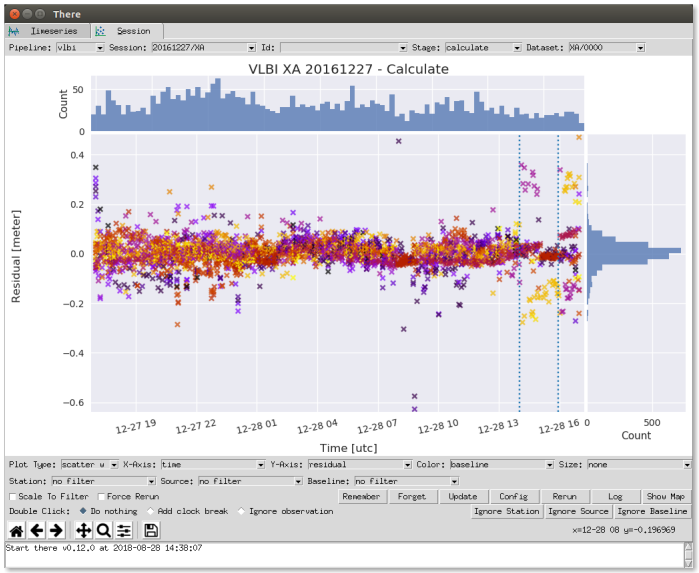


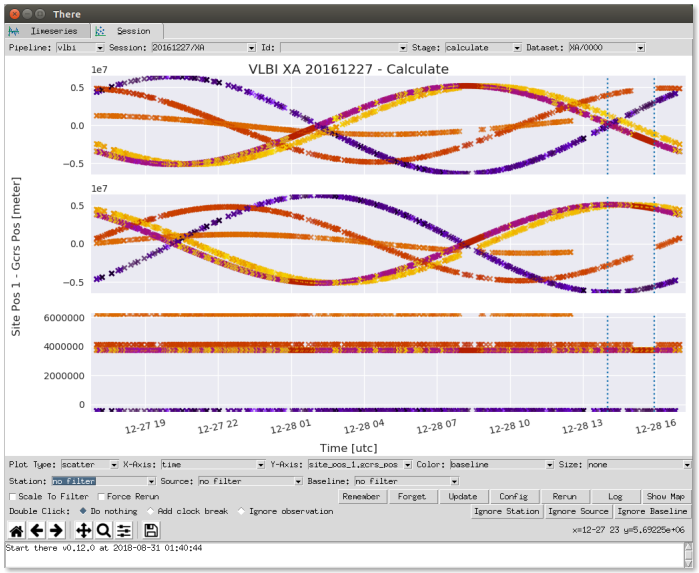


Experiences:

- Thank you to everybody that contribute to the Python data science stack!!
- Performance: Decent Python is faster than non-optimal Fortran code :)

There!





Experiences:

- Thank you to everybody that contribute to the Python data science stack!!
- Performance: Decent Python is faster than non-optimal Fortran code :)
- Cython can help a lot in the right circumstances

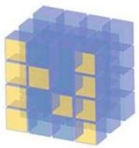
Midgard

Reusable components of Where are being separated out into its own library: **Midgard**

- ‘pip install midgard‘
- Containers for coordinates that move over time
- Readers and parsers for geodetic file formats

Thank you

kartverket.github.io/where/



NumPy

pandas

$y_{it} = \beta' x_{it} + \mu_i + \epsilon_{it}$

F2PY