Fast and Robust GPS Fix Using One Millisecond of Data

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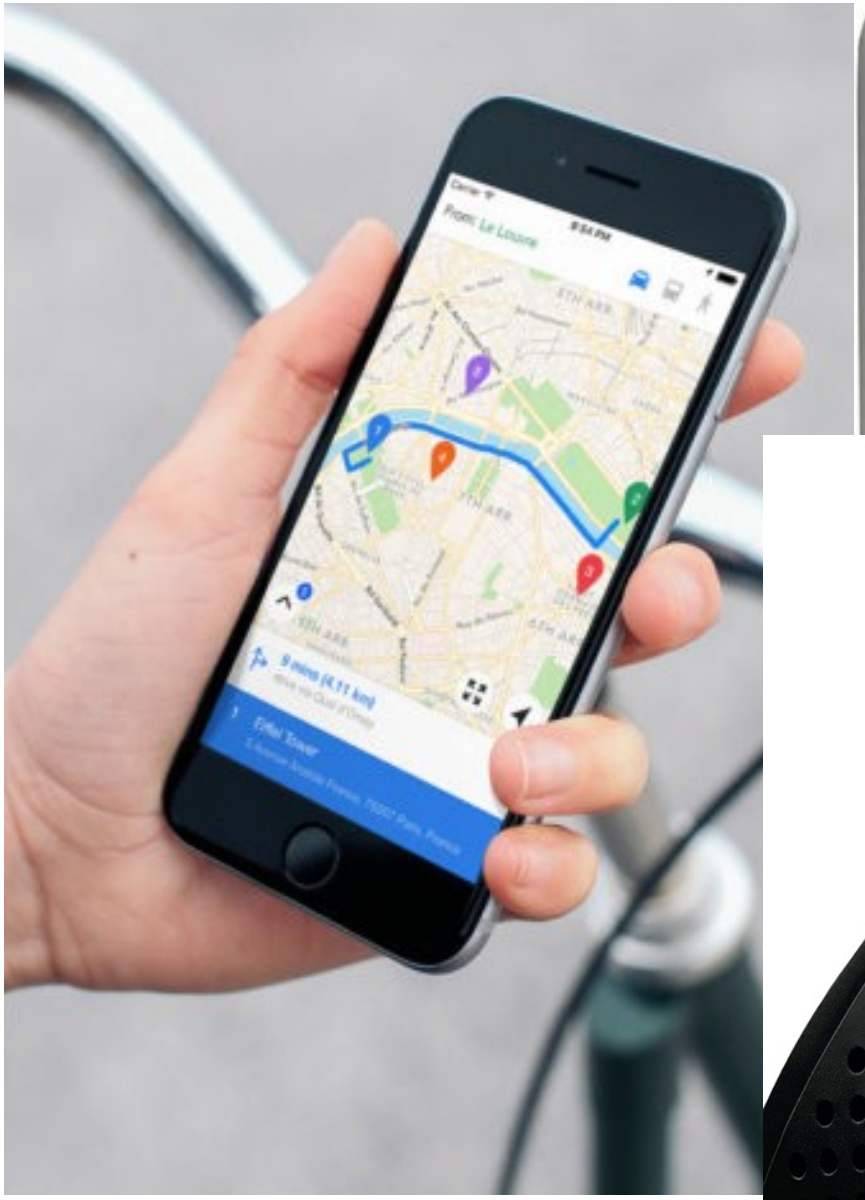
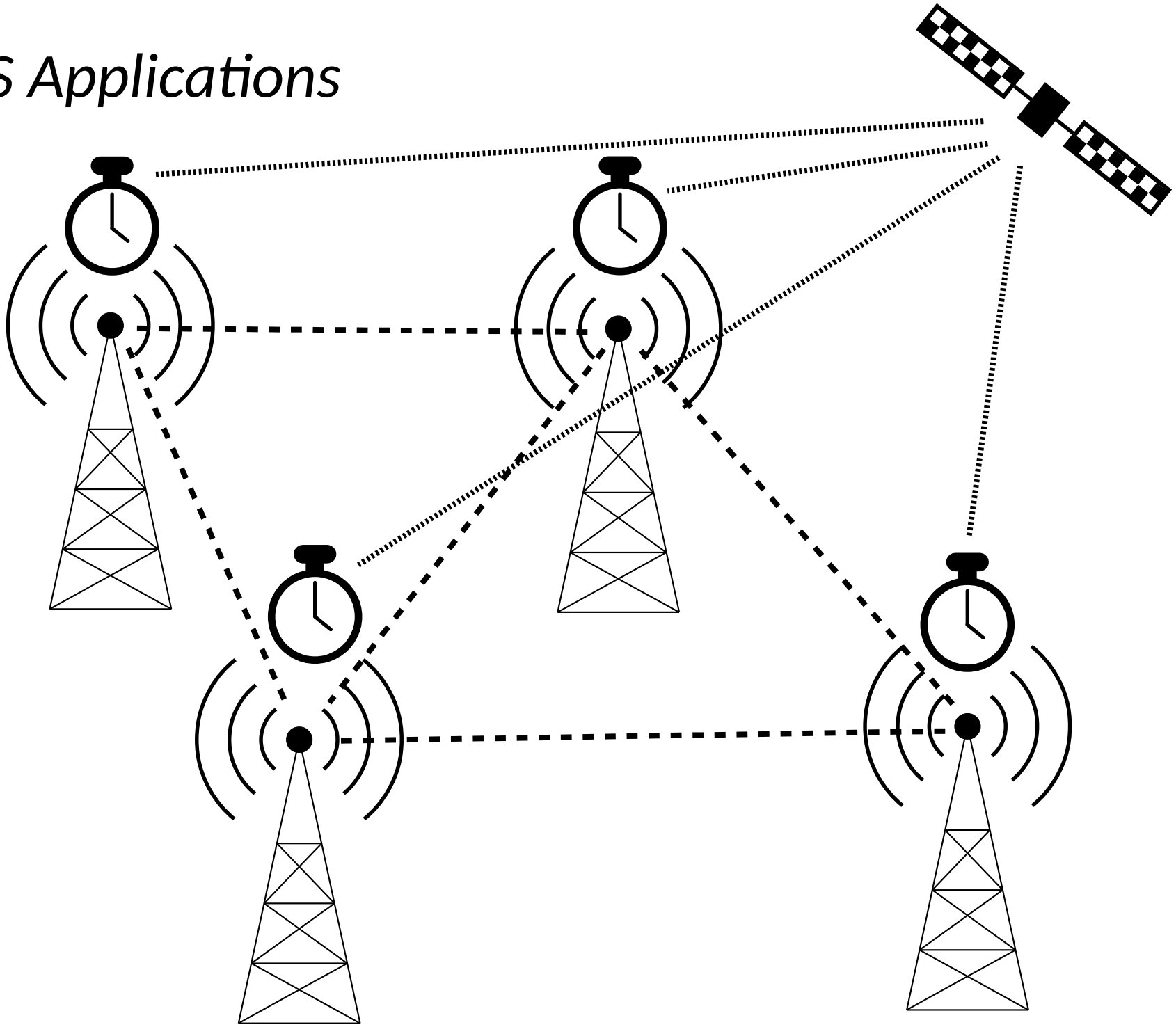
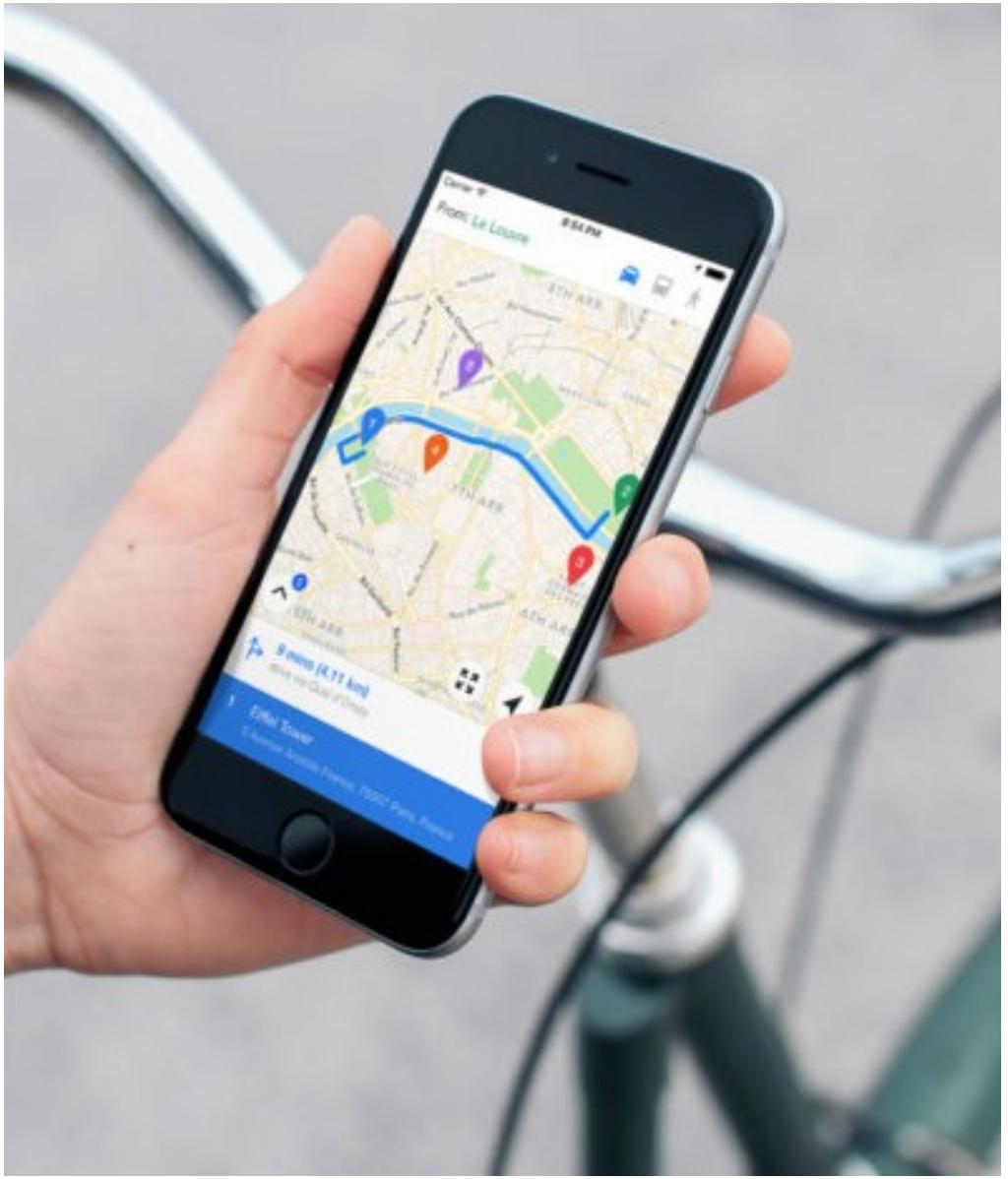
GPS Applications

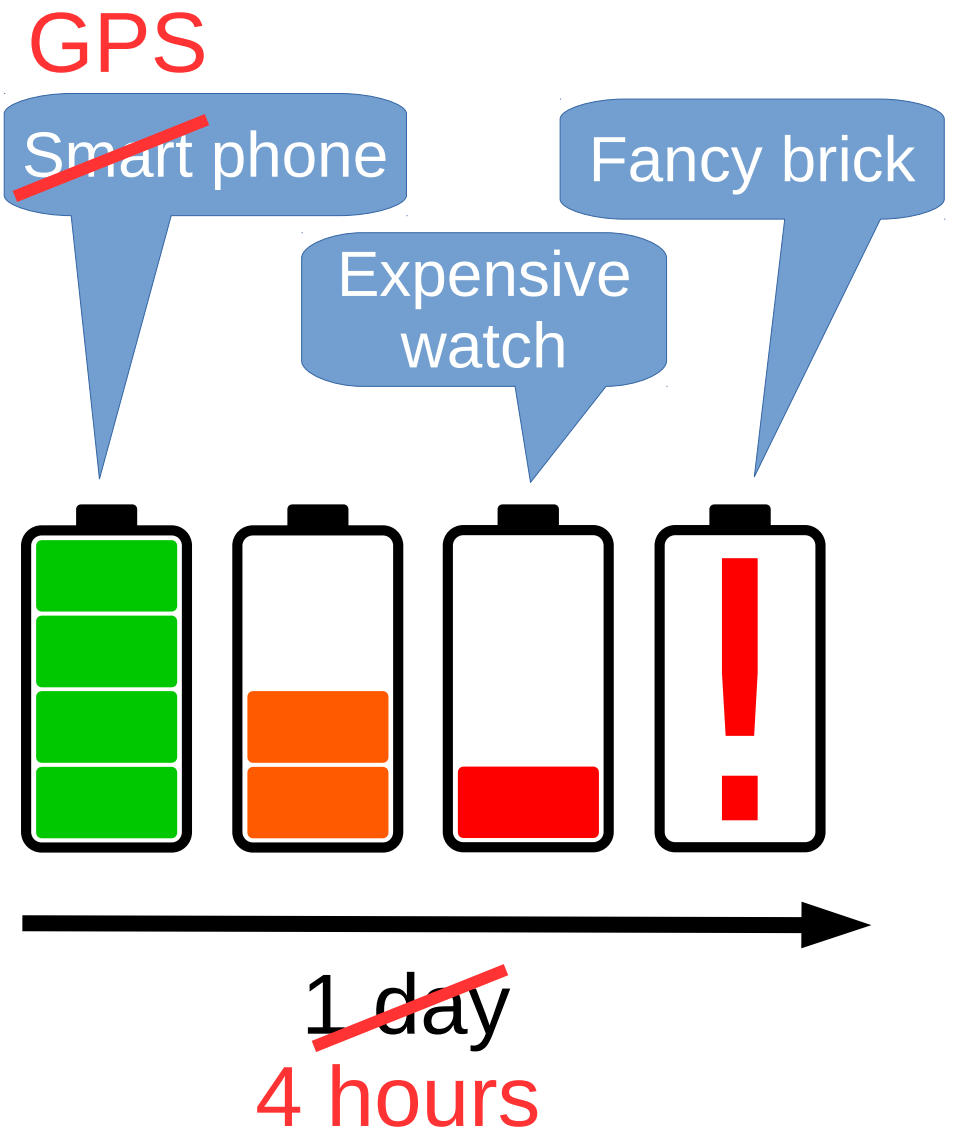


GPS Applications



Problem I





Problem I

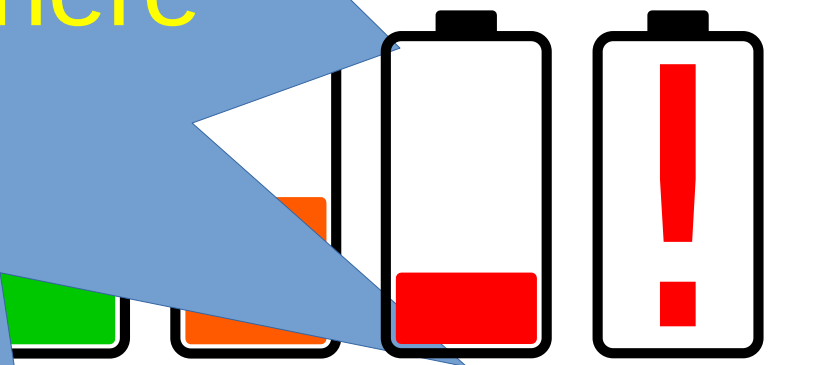
GPS

one

Fancy brick

Expensive watch

Start here



1 ~~day~~

4 hours

Problem II

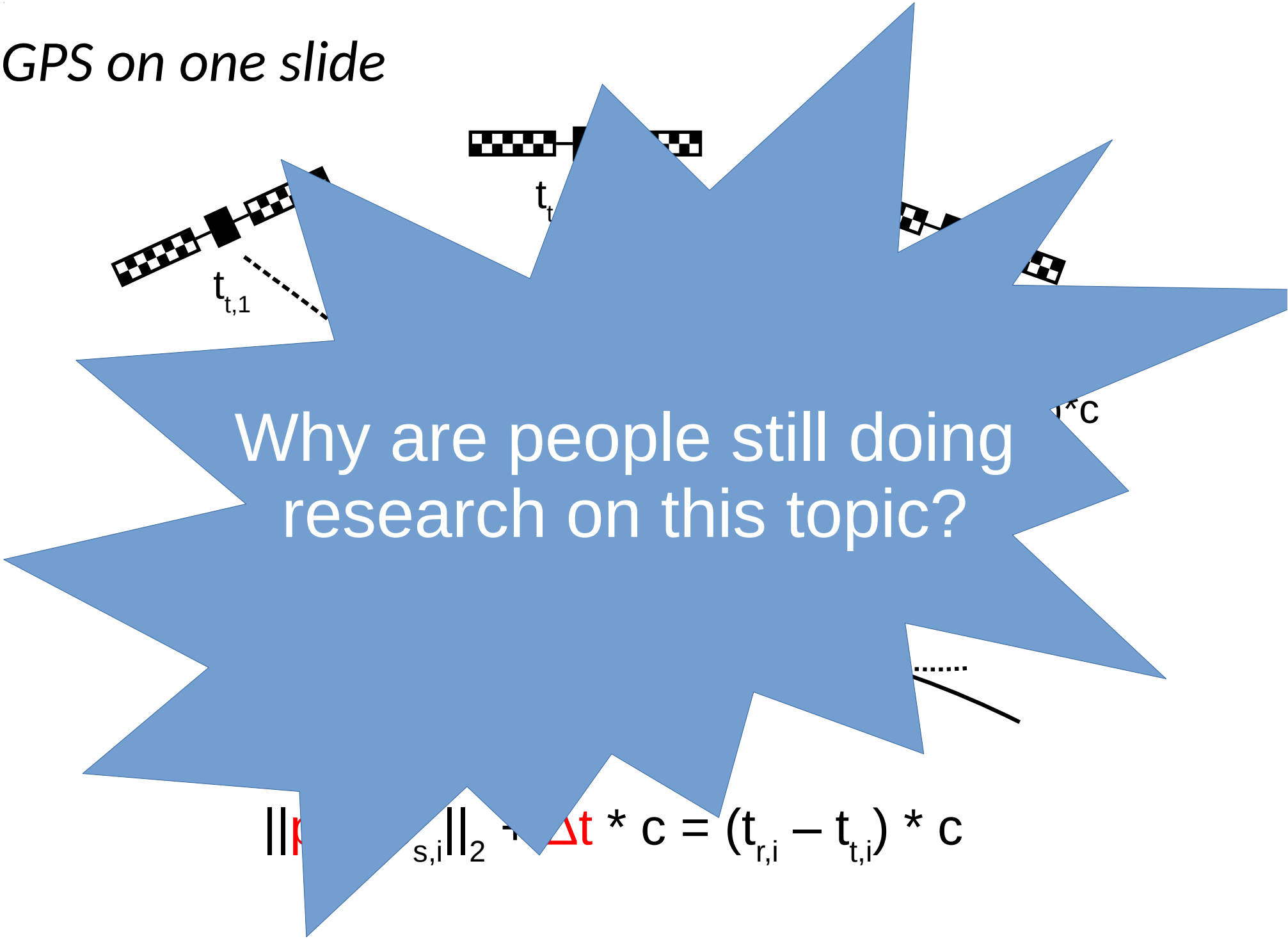
t = 1 ms

time

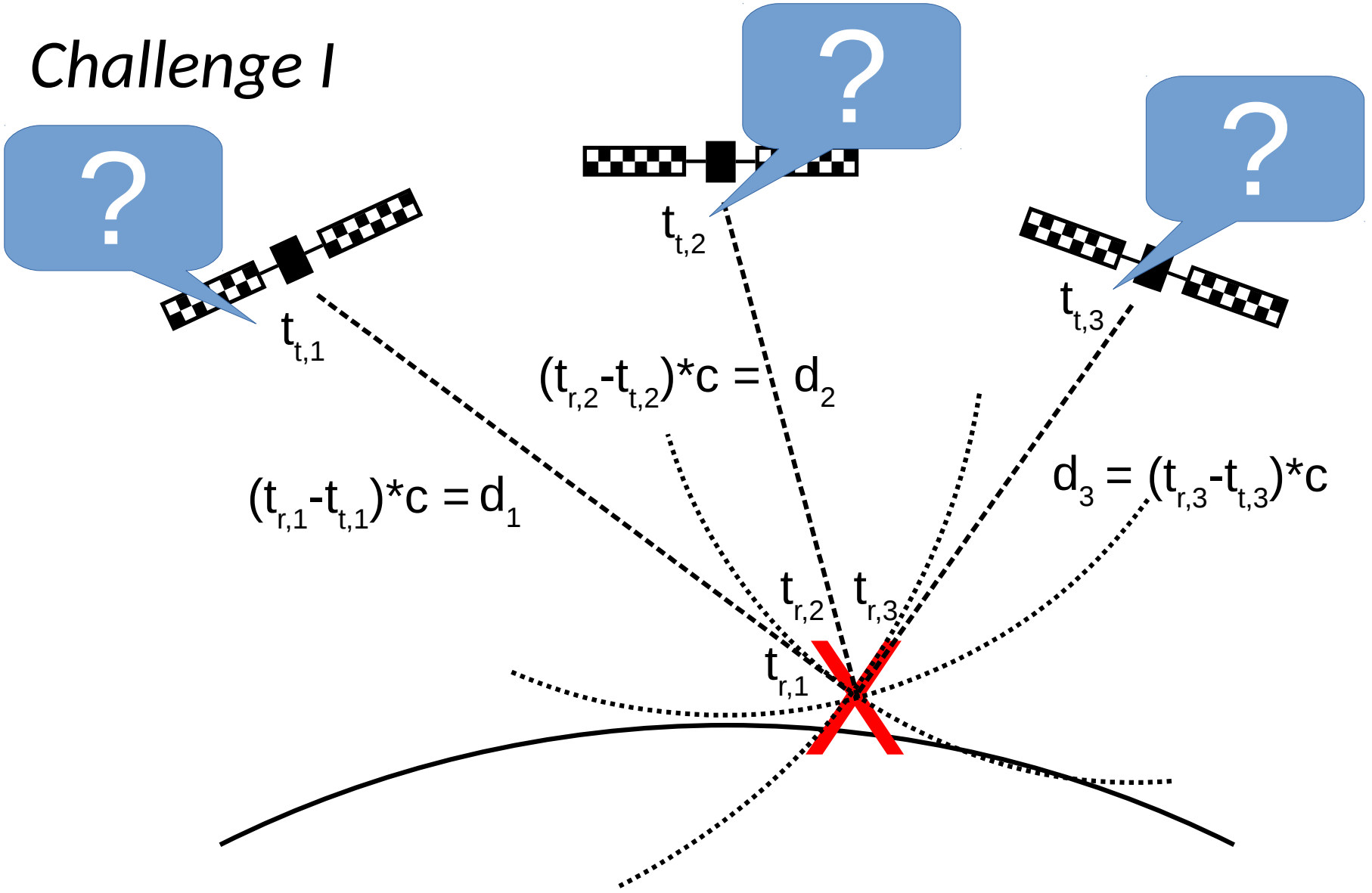
t = 0: trigger ⟶ GPS starts

t = 30 s: position fix

GPS on one slide

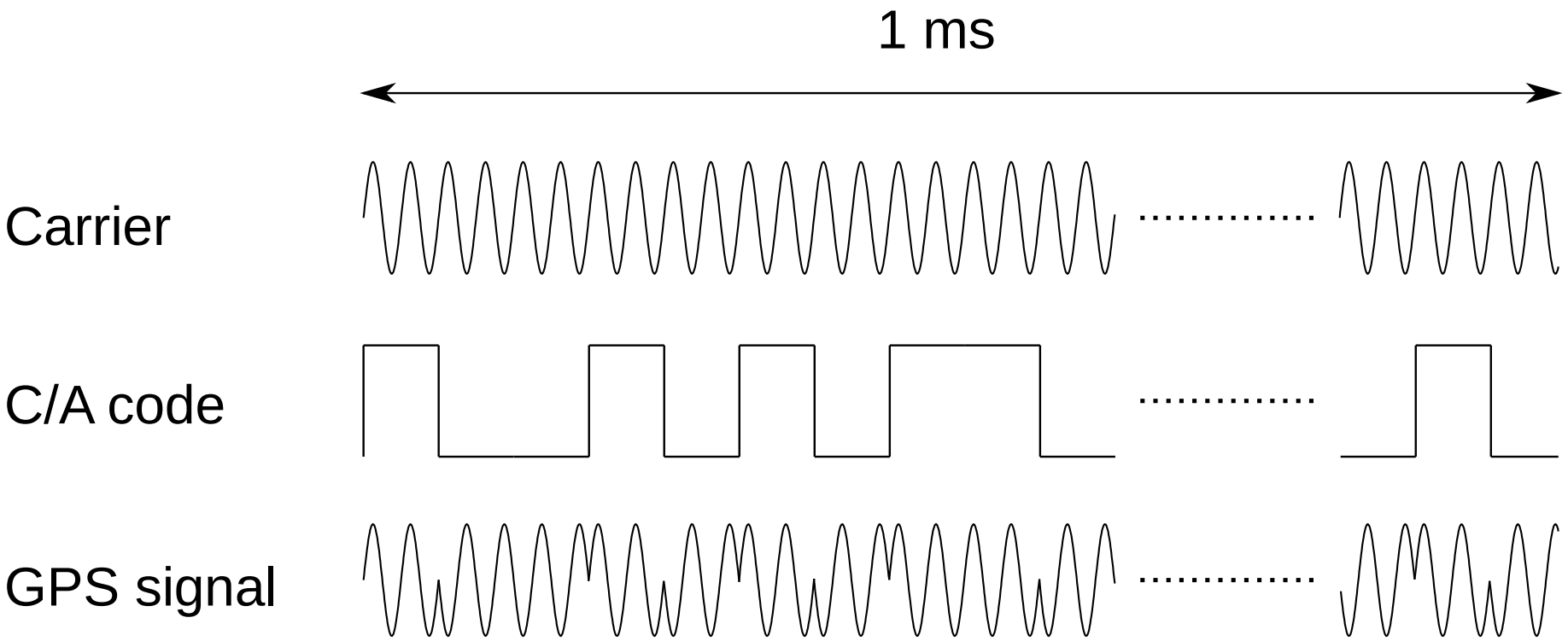


Challenge I

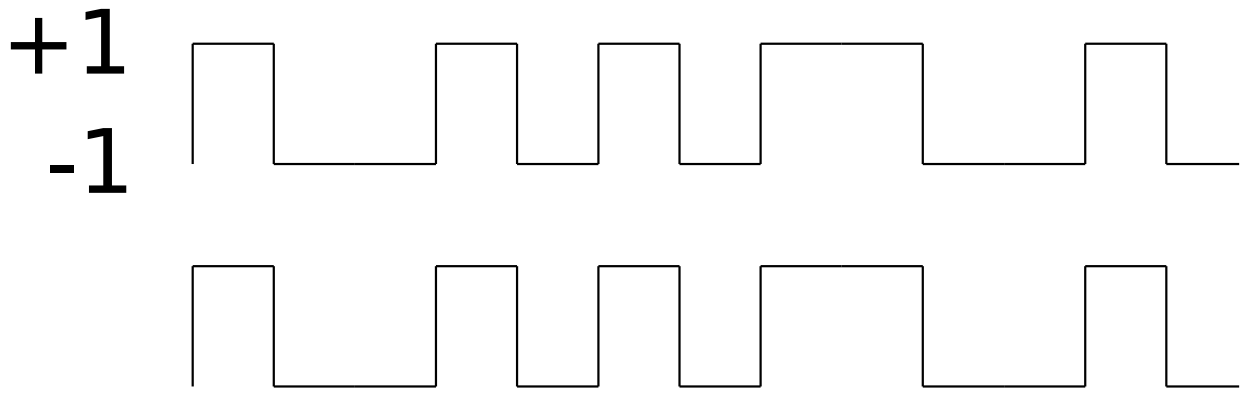


$$\|p_r - p_{s,i}\|_2 + \Delta t * c = (t_{r,i} - t_{t,i}) * c$$

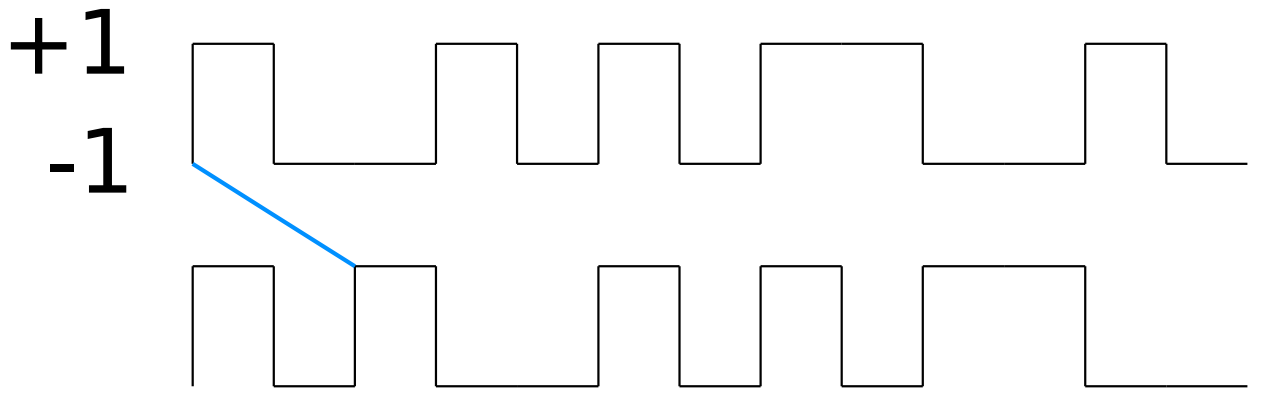
GPS signals



Correlation

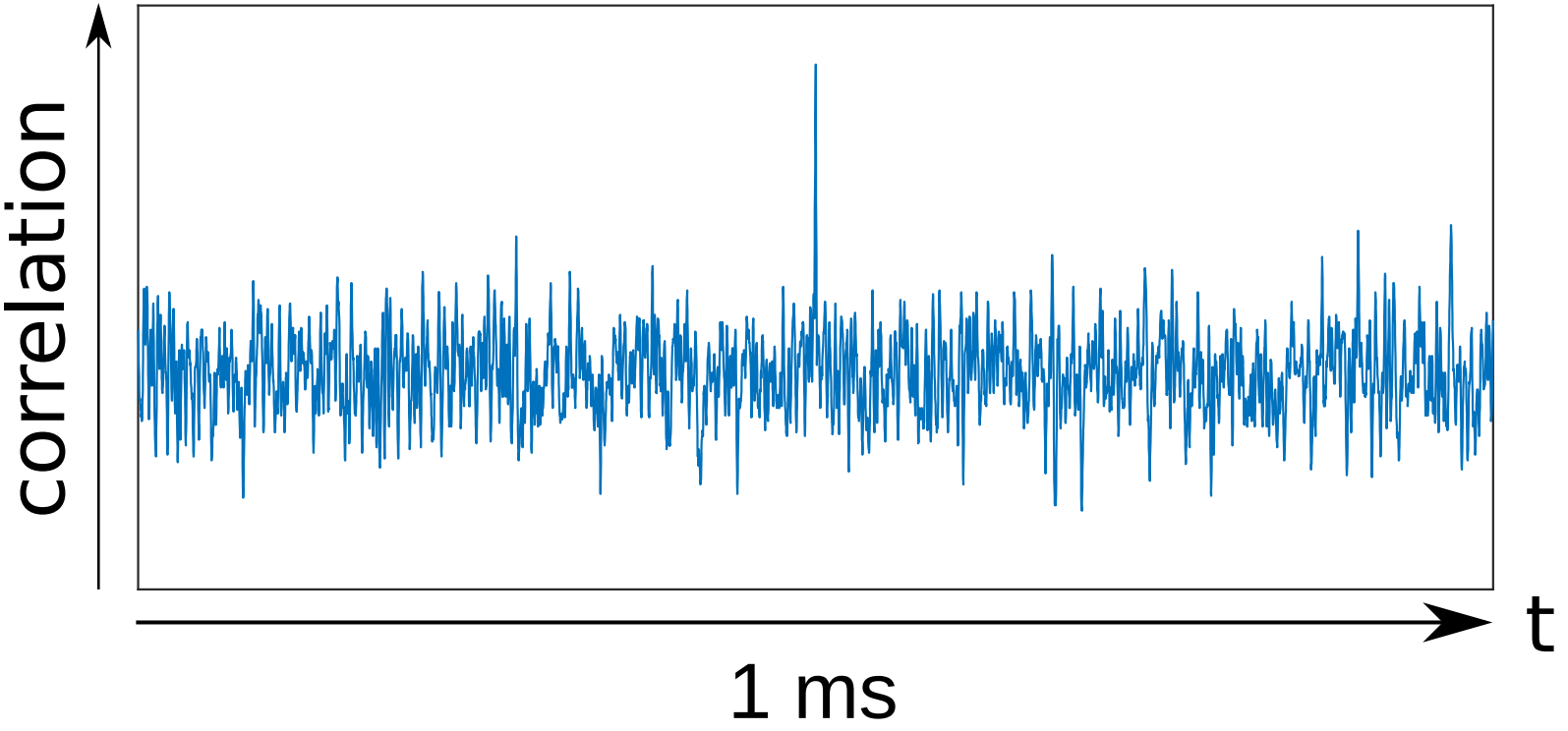


1 1 1 1 1 1 1 1 1 1 1 1 1 = 13



1 1-1-1 1 1 1 1-1-1-1-1 1 1 = 1

Timing & Decoding



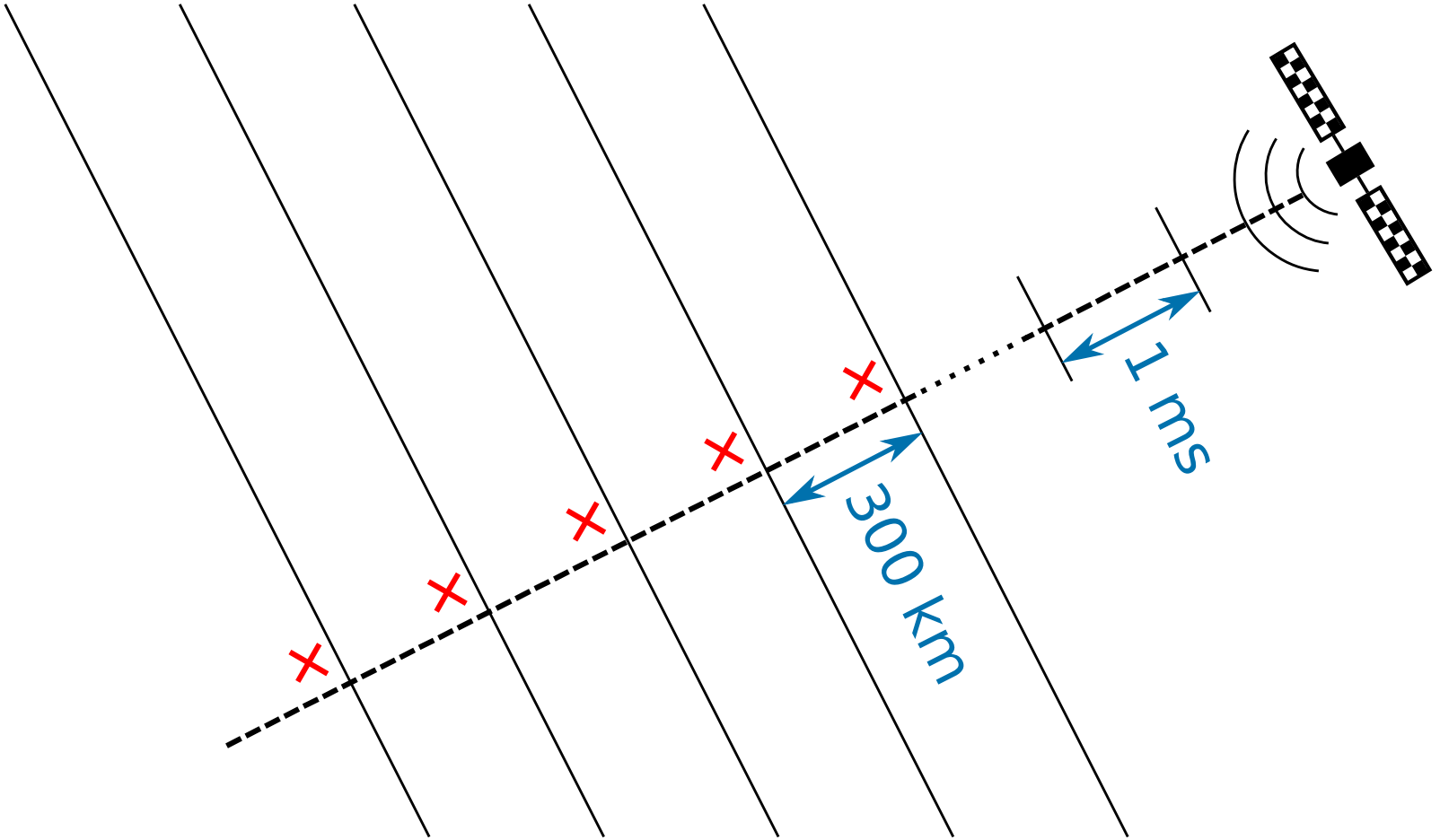
- 50 bps
- Time stamp sent every 6 seconds

Sub-ms time sync

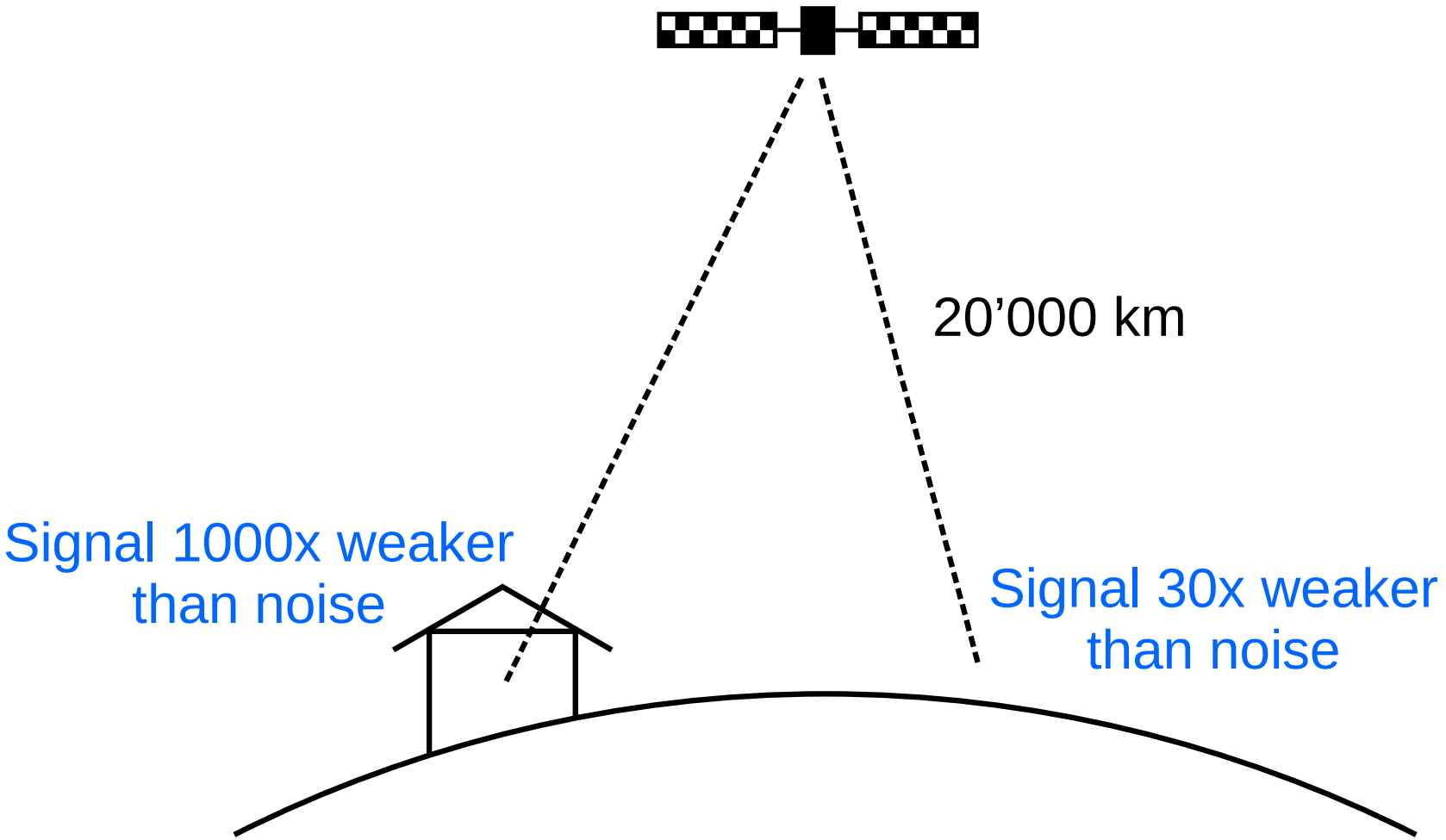
- We already have some time information
- C/A codes start at whole milliseconds
- $t_{transmit} = k * 1\ ms$

Coarse-Time Navigation (CTN)

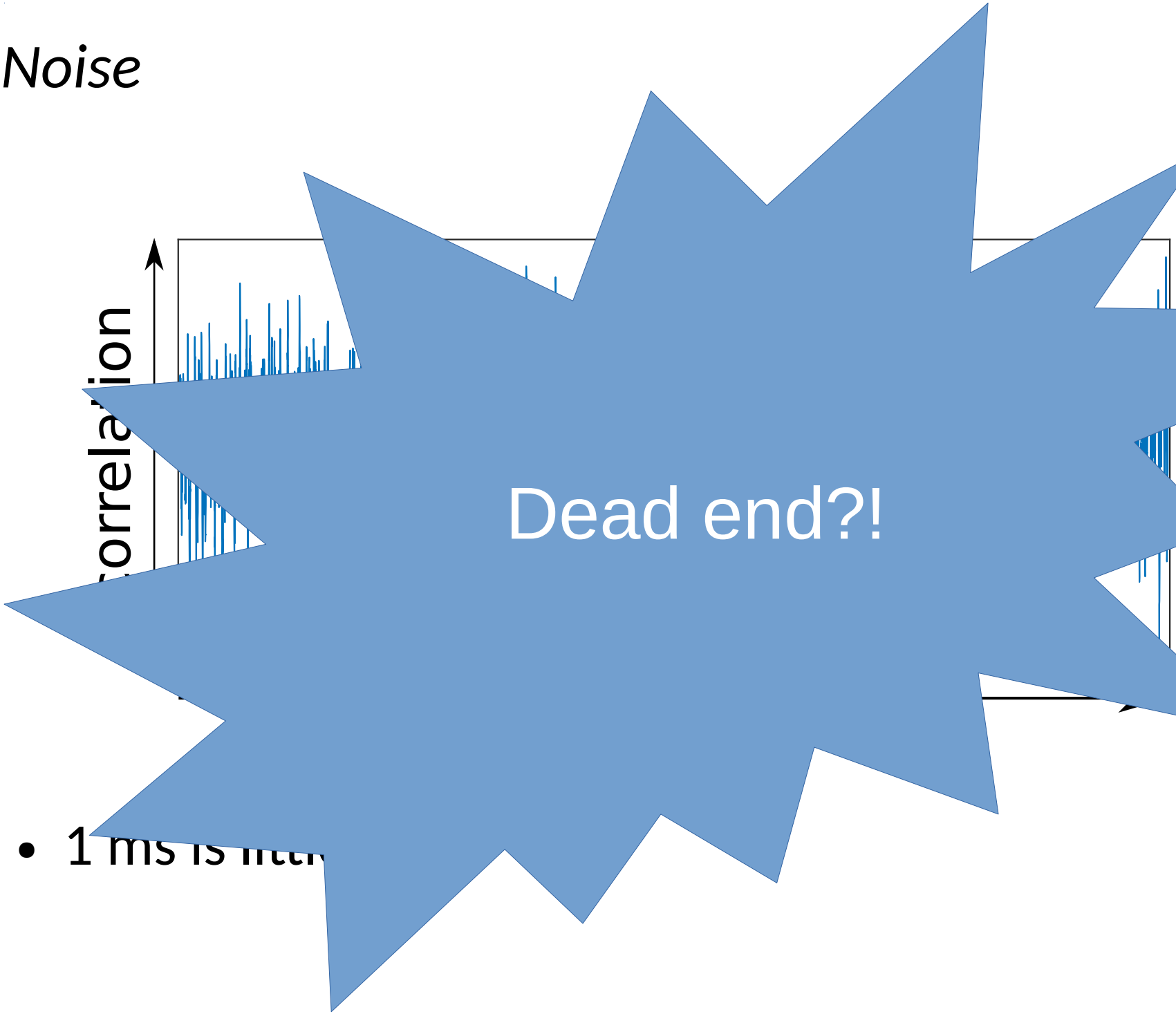
- 1 ms ↔ 300 km
- Known approximate position → whole ms time sync



Challenge II



Noise

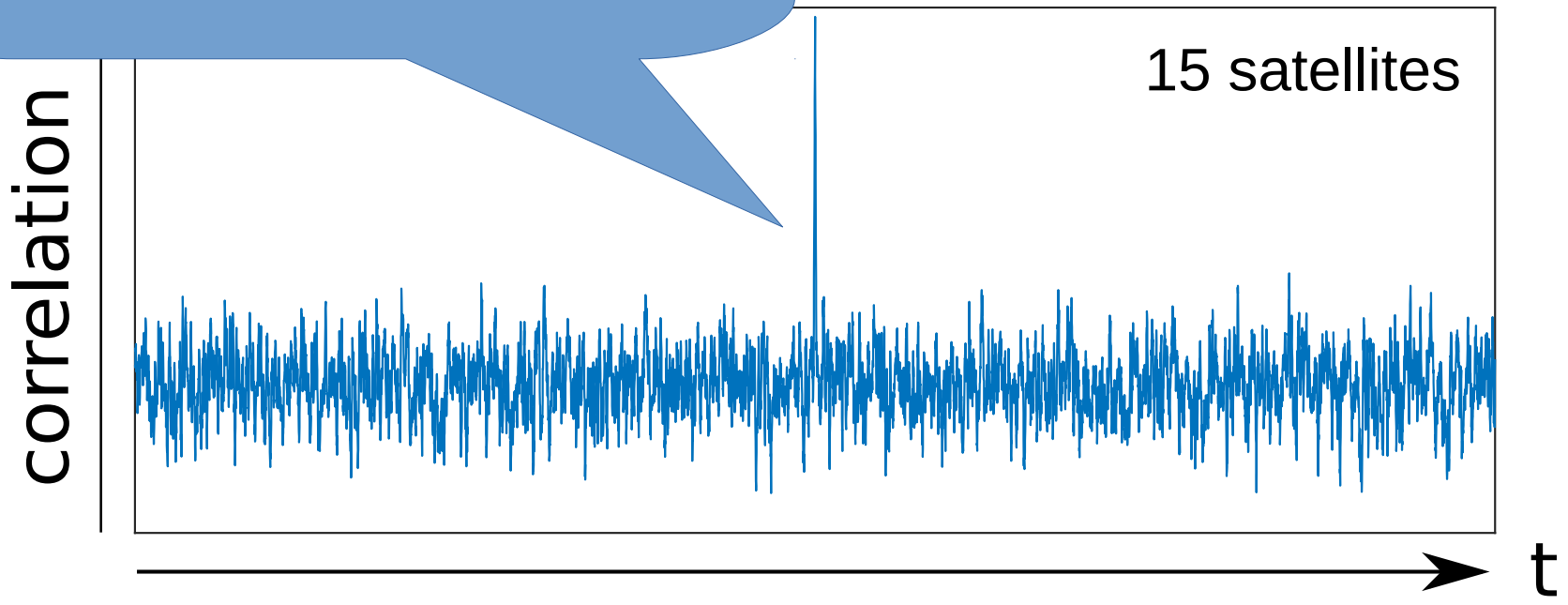


- 1 ms is littl

Sum over satellites

Signals from all satellites have to be aligned!

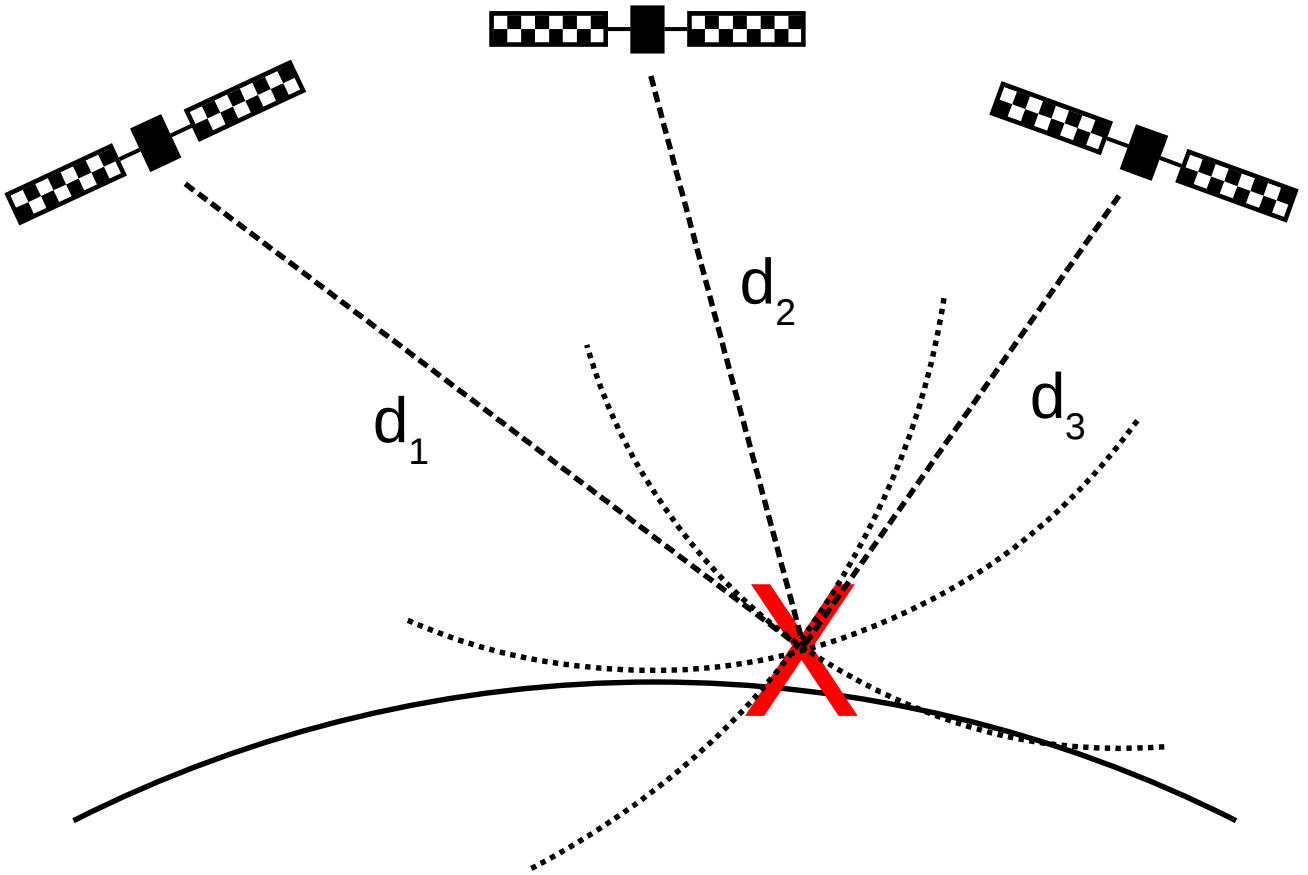
ble, not only over time



- Increased SNR

Hypotheses

- Assumed receiver state: (x,y,z,t)
- Satellite ranges known → signal alignment known



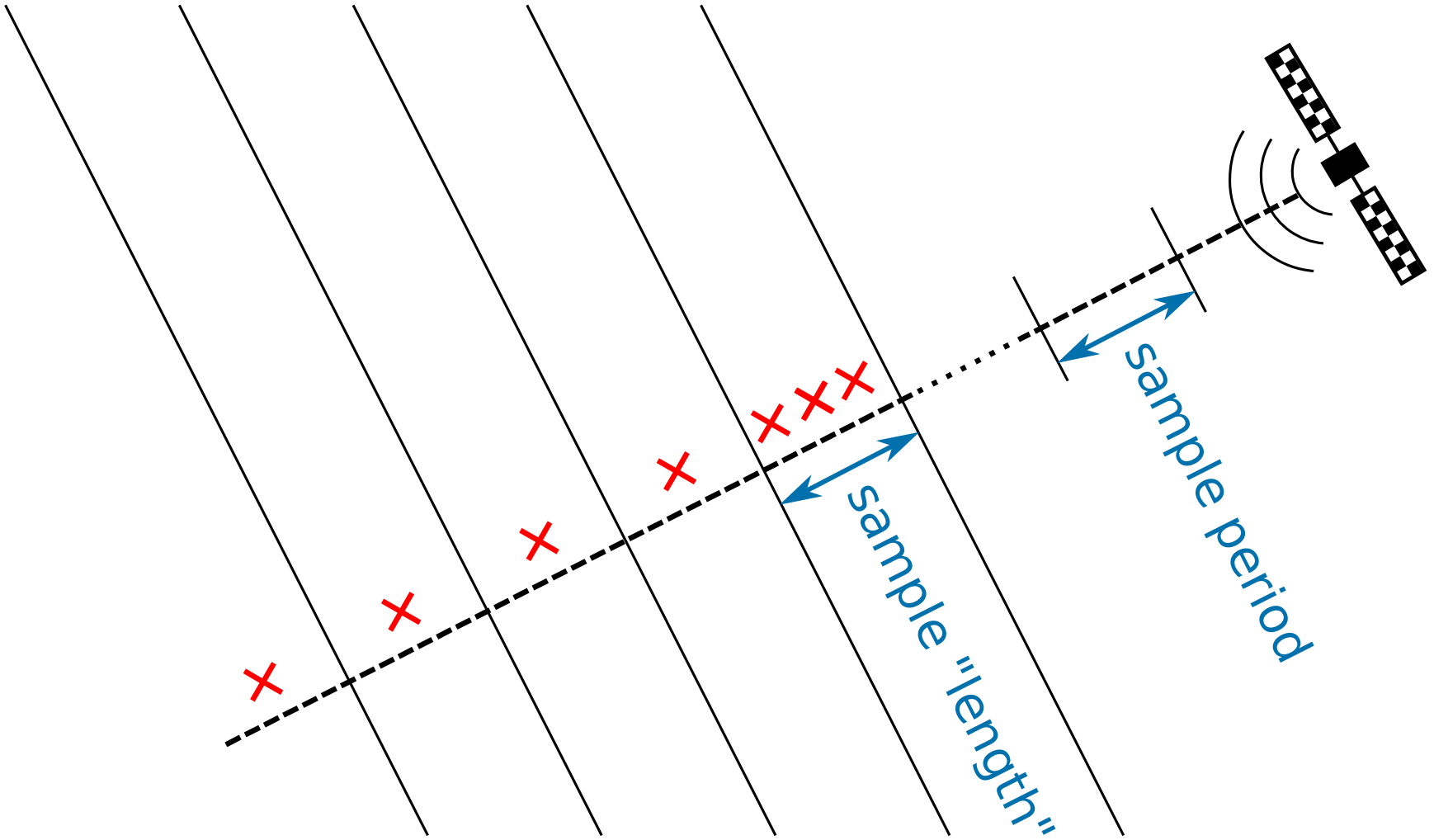
Best hypothesis?

Infinitely many hypotheses?

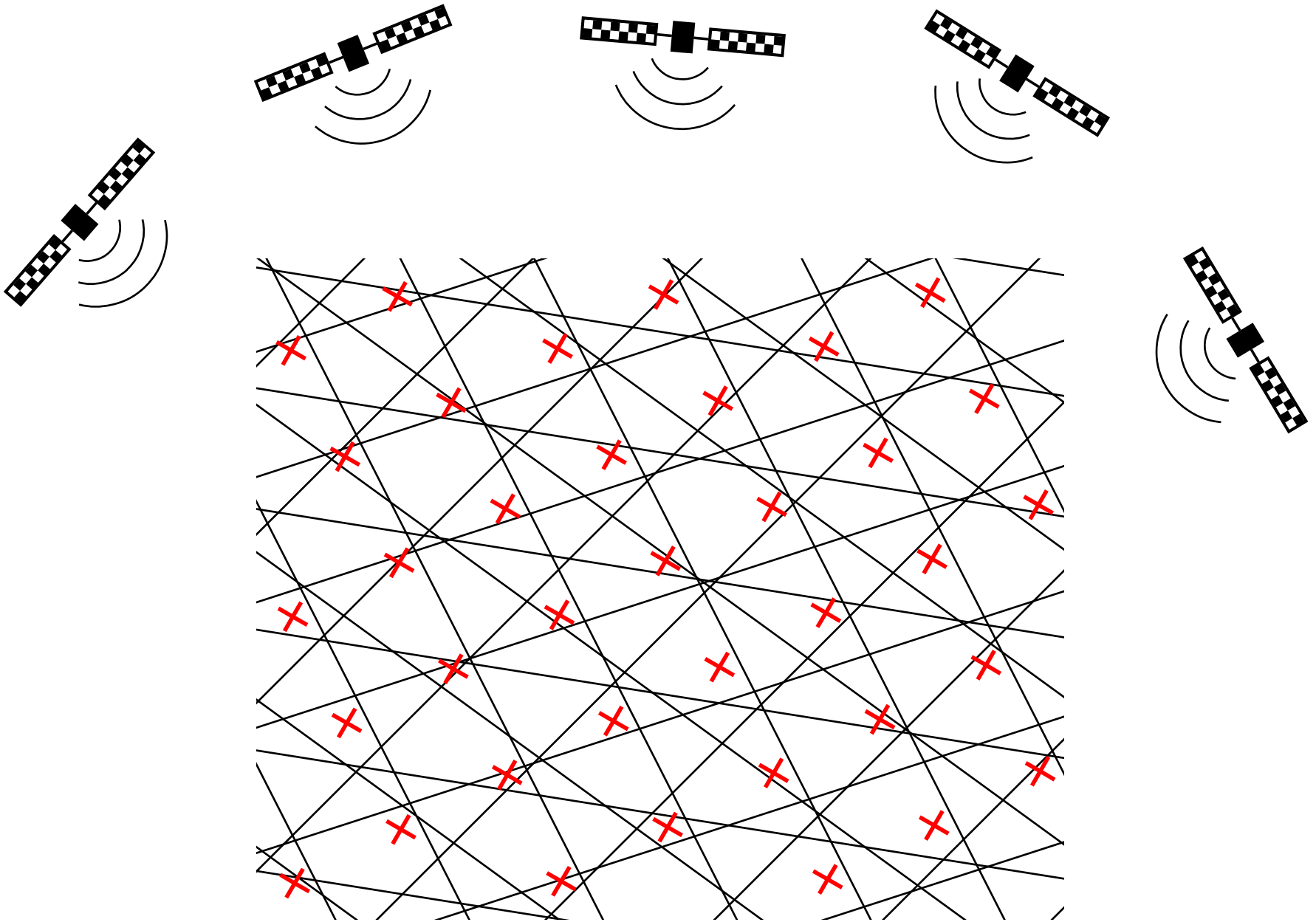
- M
- Number of hypotheses proportional to size of search spac

Discretization of search space: 1D

- Discrete samples → discrete positioning resolution

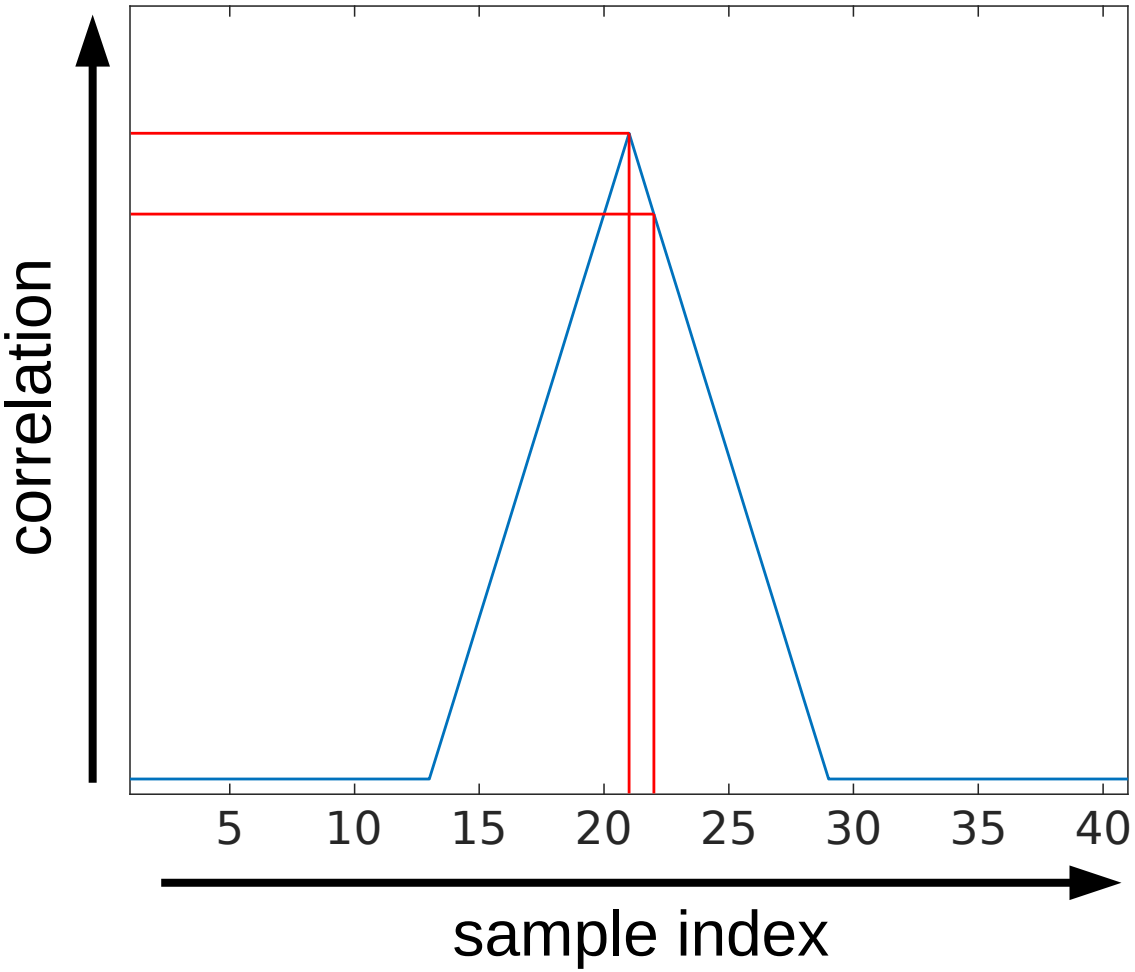


Discretization of search space: 2D



Off-by-one error

- Oversampling: triangular peak
- 8 Msps → ~1/8 lower → - 0.6 dB
- Loss incurred only for some satellites

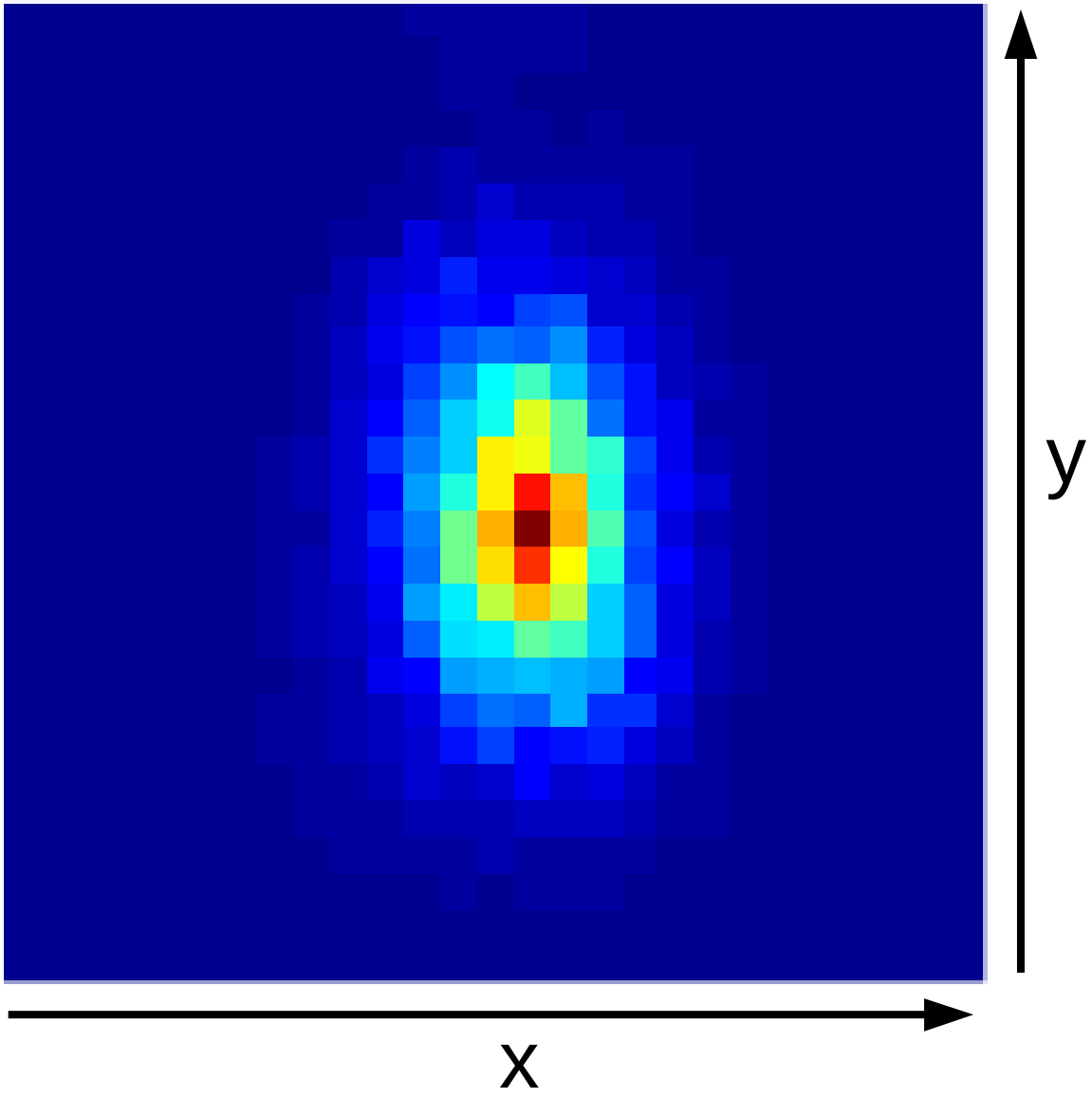


Challenge III

- We do not only have to search in the position domain…
- Time offset → Satellite position error
- 10 km * 10 km * 1 km * 1 min, 8 Msps → 2.8 billion hypotheses

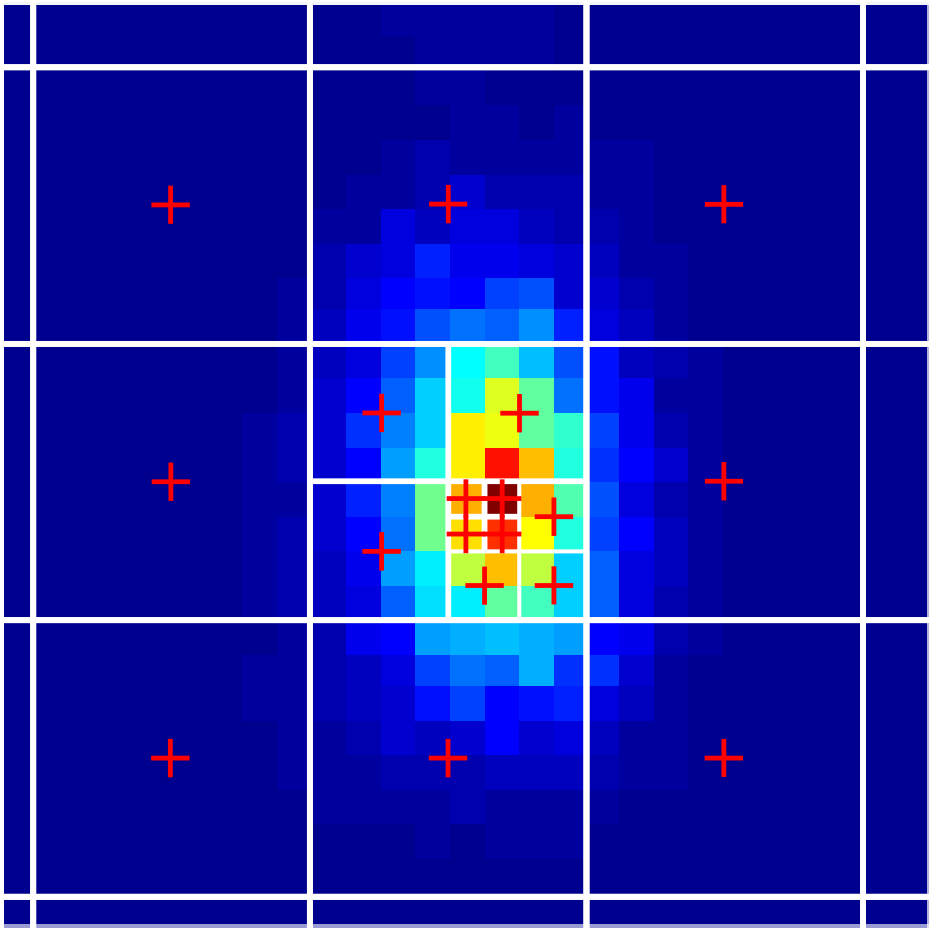
Exhaustive search

- Brute force
- Possible, but slow
- ~ 20 k evaluations / s
- Parallelizable



Branch and bound

- Explore promising regions first
- Discard “bad” regions
- Runtime: a few seconds (single thread, good SNR)

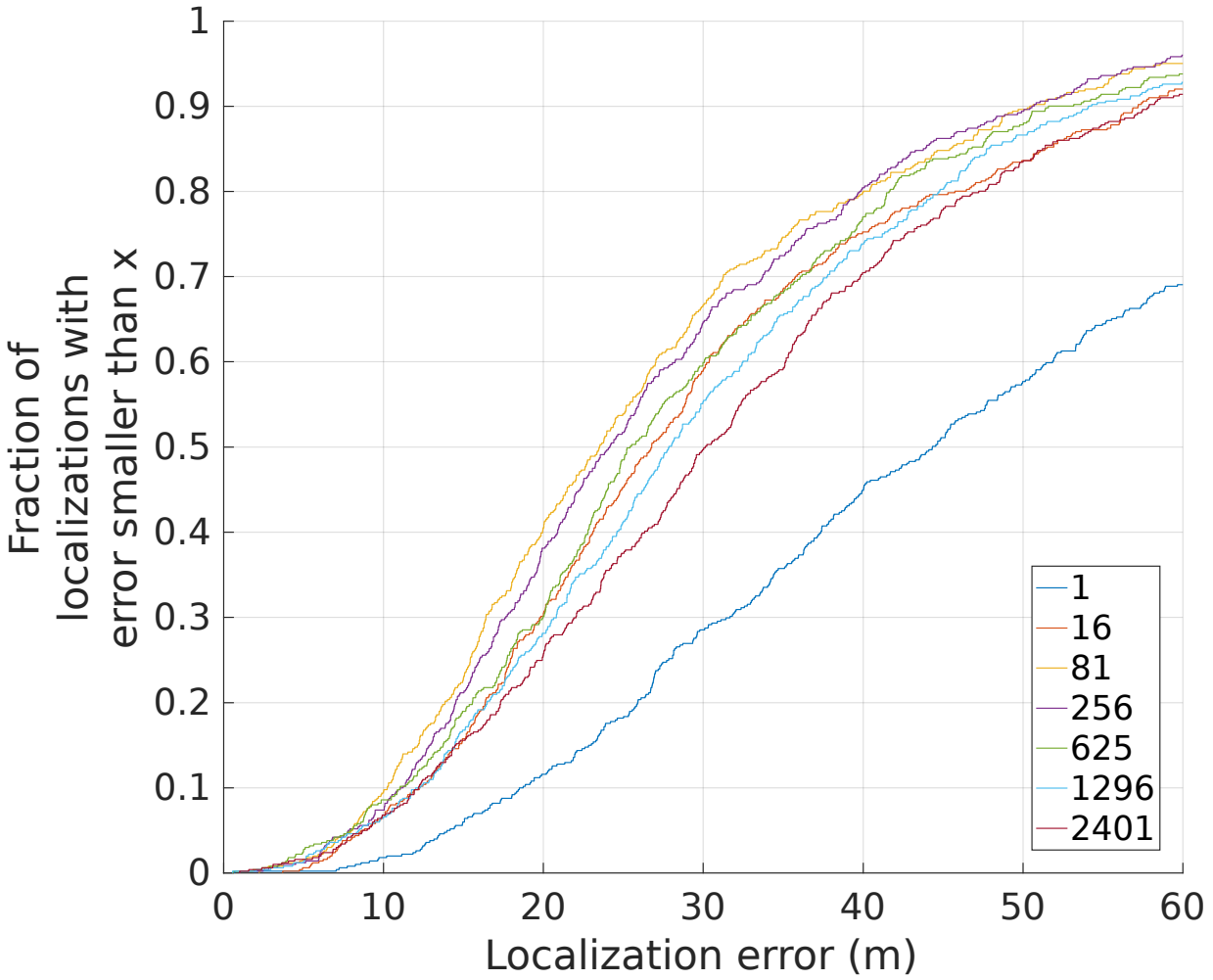


Related Work

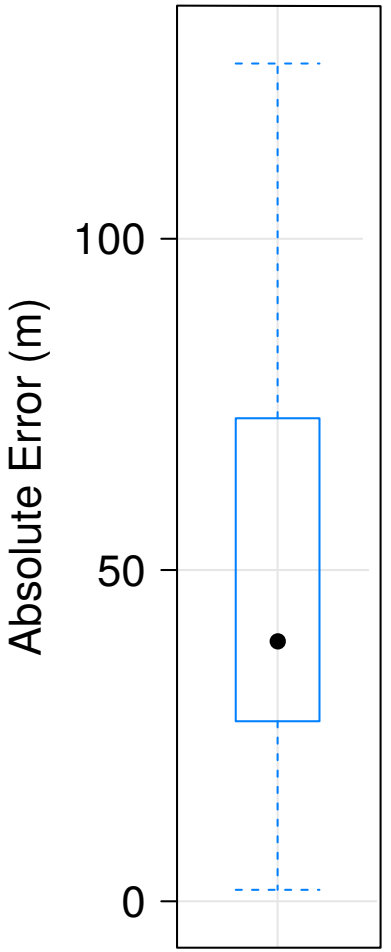
- Liu et al. “Energy Efficient GPS Sensing with Cloud Offloading” (SenSys‘12, Best Paper)
  - CTN, suffer from noise
- Collective Detection
  - Various papers: 1) slow or 2) not optimal
  - Closas et al. “Maximum likelihood estimation of position in GNSS” (IEEE Signal Processing Letters, 2007)
    - Mathematical analysis of the superior robustness of “direct positioning”

Accuracy: Average of the k best hypotheses

Our method (3D, 1ms)

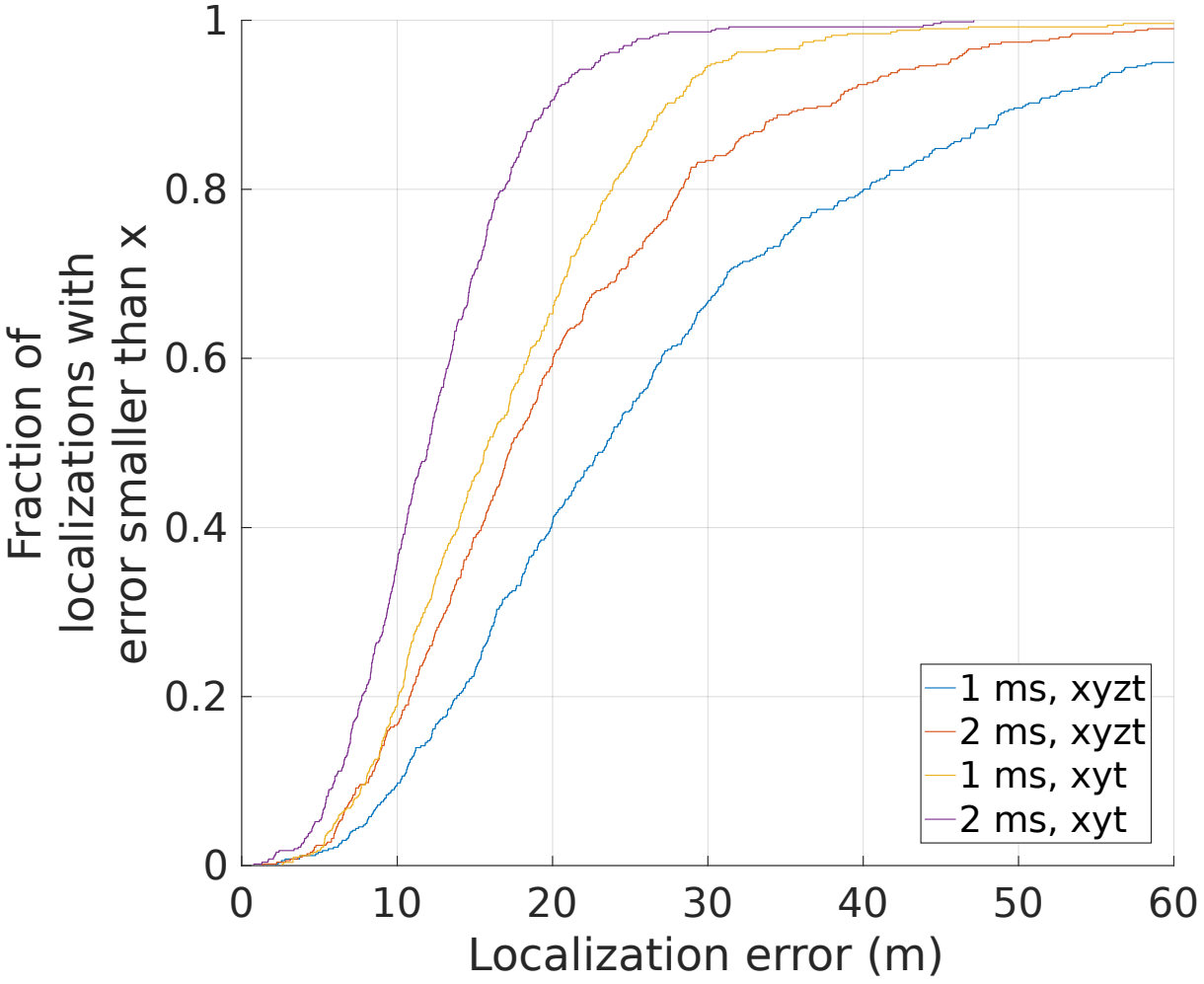


Liu et al. (2D, 2ms)



Accuracy: 3D vs. 2D

Our method



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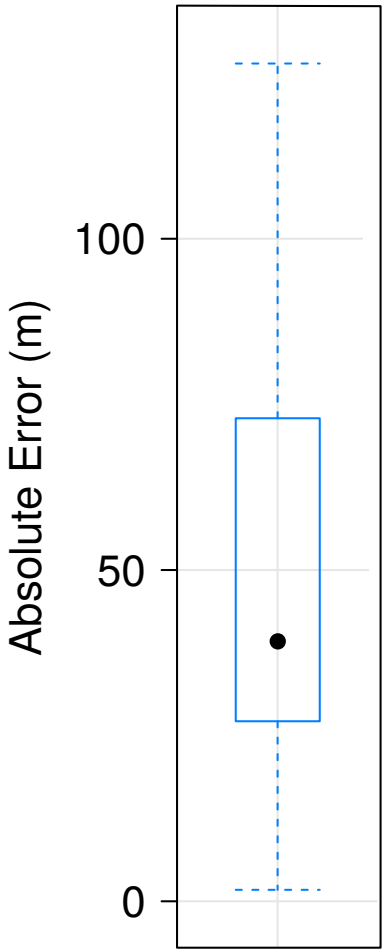
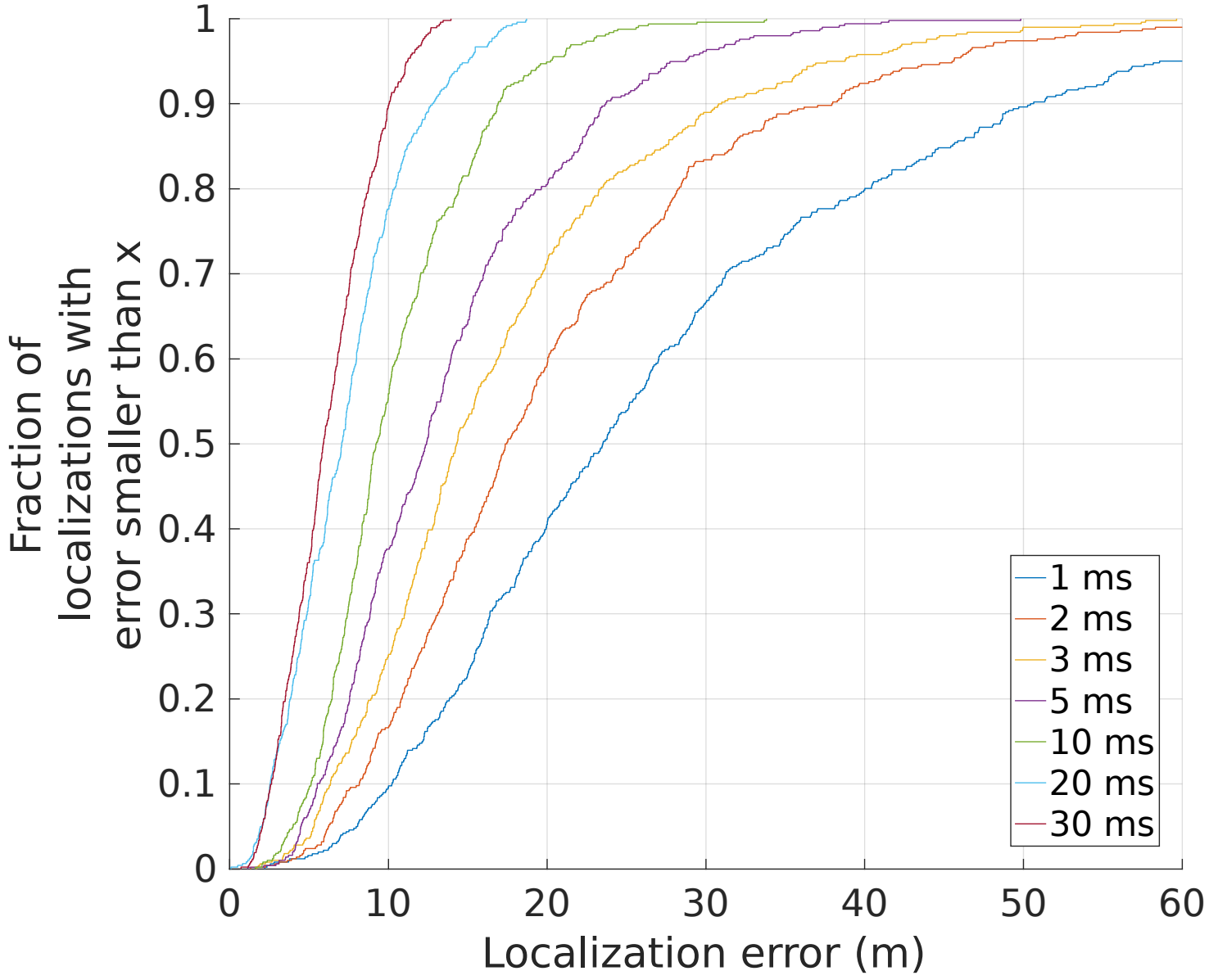


Accuracy: Average of k fixes



Tracking

- Branch-and-bound for initial fix
- First fix results in small search space
- Brute force subsequently

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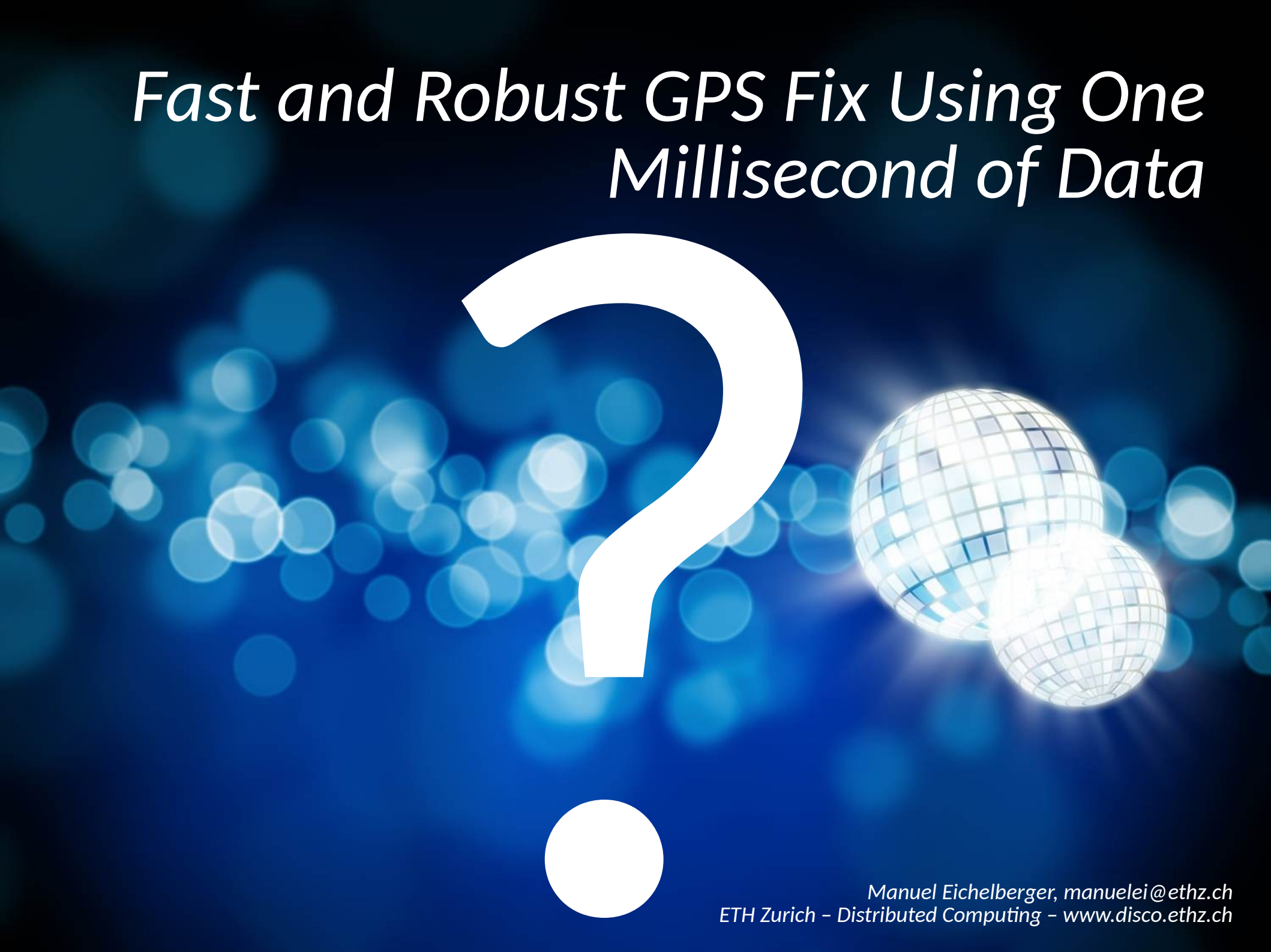

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