

Gravitational Time Dilation

Physics

Clocks run slower deeper in a gravitational field.

Time passes more slowly where the gravitational potential is lower.

$$\Delta t = \Delta t_0 / \sqrt{1 - 2GM/rc^2}$$

GPS satellites

Weaker field.

Run fast by 45 $\mu\text{s/day}$

Their orbital speed

Special relativity.

Slows them by 7 $\mu\text{s/day}$

Net correction

Both effects.

38 $\mu\text{s/day}$

THE COMMON MISTAKE

✗ **Assuming the two effects cancel**

✓ **They partly oppose but do not cancel**

The gravitational effect is larger for GPS orbits, so satellite clocks run net fast and must be slowed before launch.

Optical clocks now resolve a height difference of a few centimetres.
Relativity has become a surveying tool.