

# Spacecraft clocks and General Relativity

Raymond Angéil  
Prasenjit Saha

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# Clocks in space - nothing new

- ▶ universe's expansion history
- ▶ stellar composition
- ▶ binary neutron star orbit determination
- ▶ galaxy rotation curves
- ▶ exoplanet discovery

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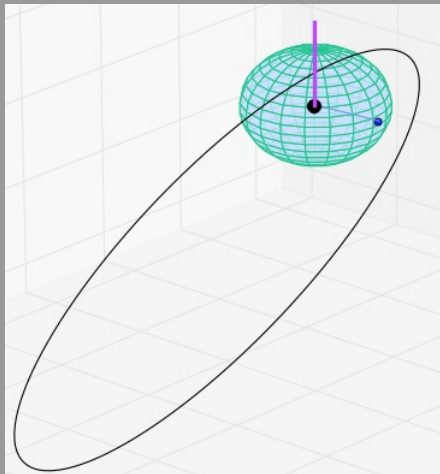
all rely on clocks in space! Natural clocks include

- ▶ Pulsars
- ▶ Stellar spectral lines

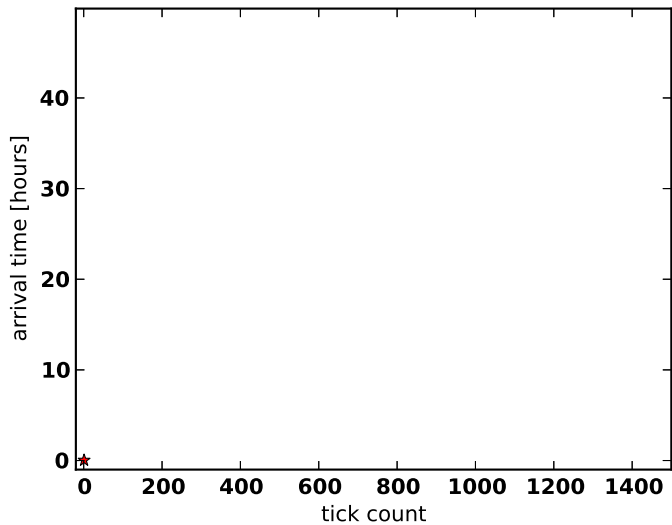
All made possible through frequency shifts due to special relativity.

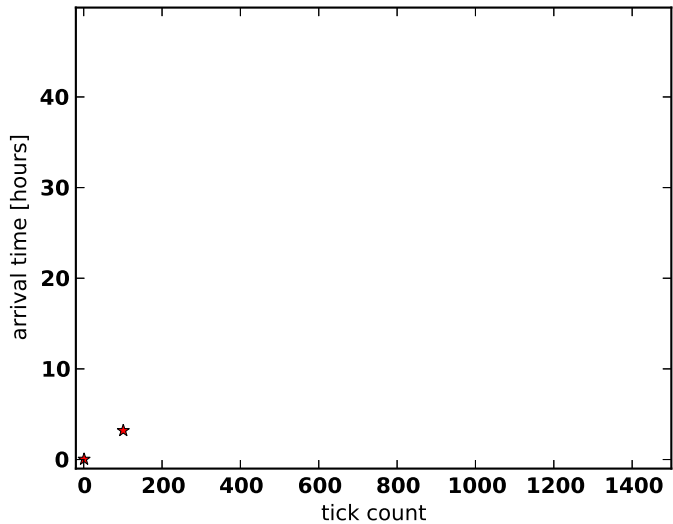
## artificial clock STE-quest

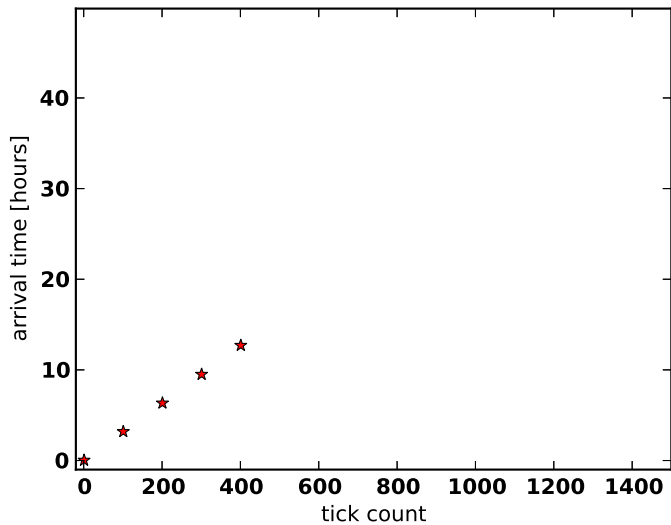
STE-quest falls through space-time, tracing out a 4D world-line



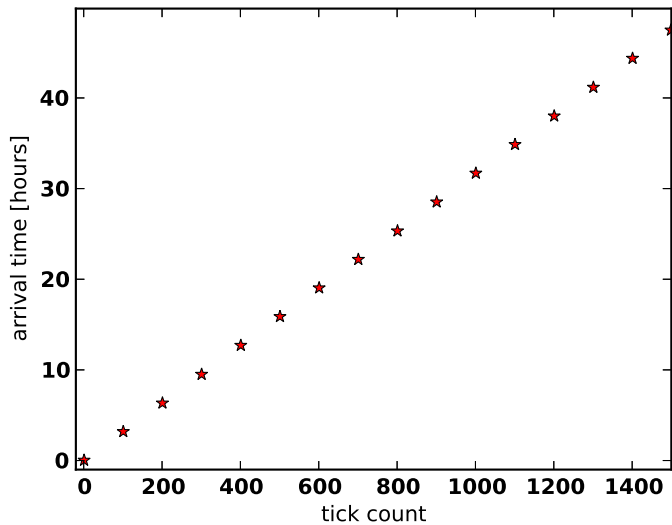
'ticks' emitted at equal proper time intervals; received by observer

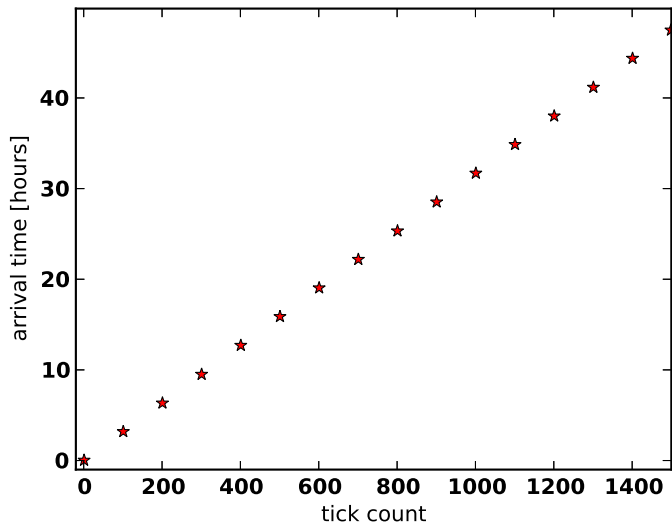


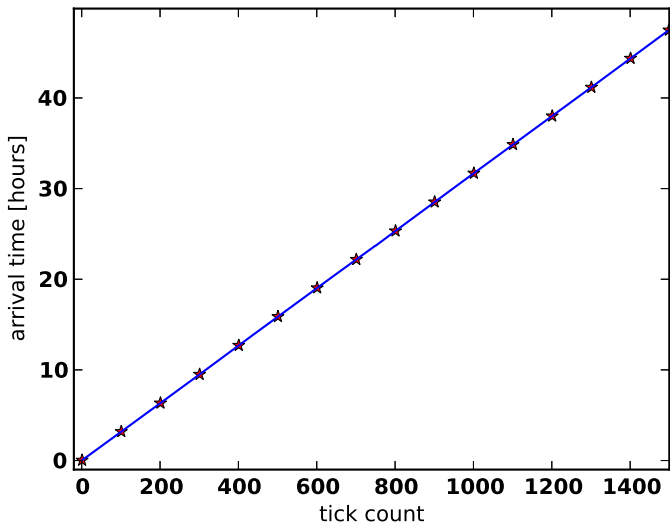


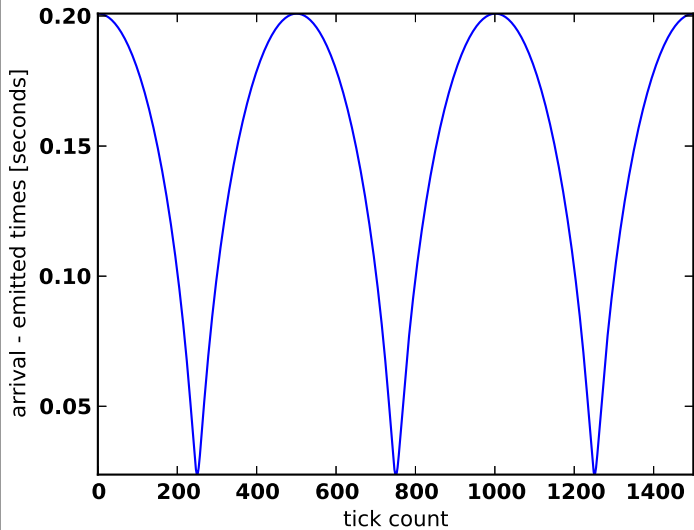












redshift

$$\frac{dt_a}{dt_e}$$

redshift

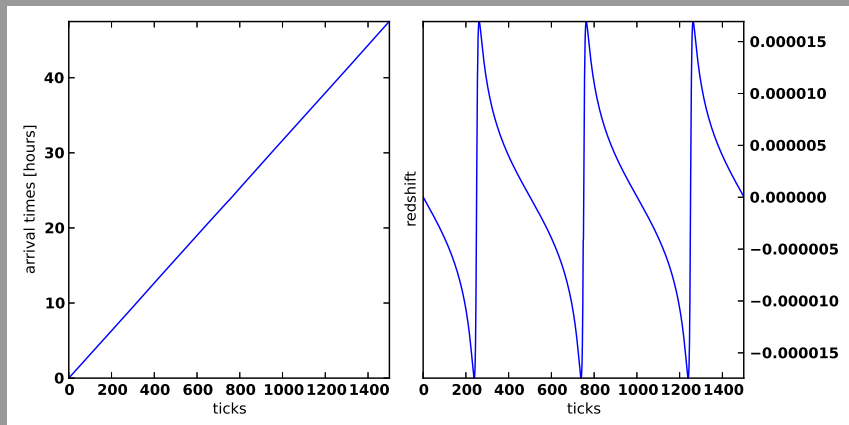
$$\frac{dt_a}{dt_e} = 1$$

redshift

$$\frac{dt_a}{dt_e} - 1 \equiv \text{redshift}$$

# redshift

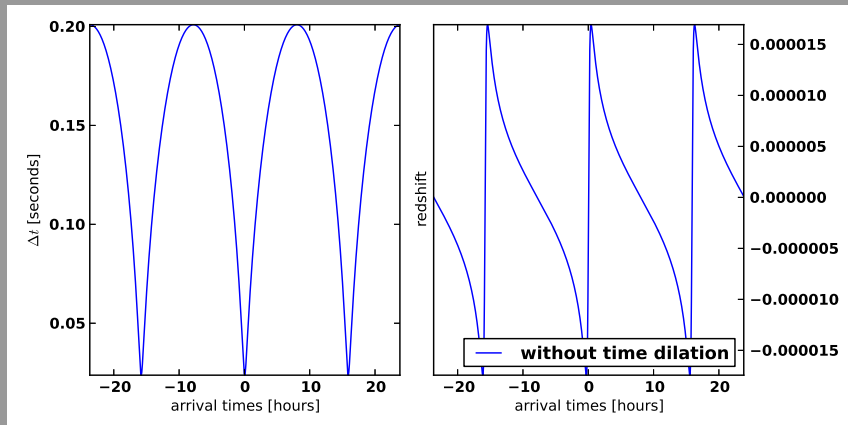
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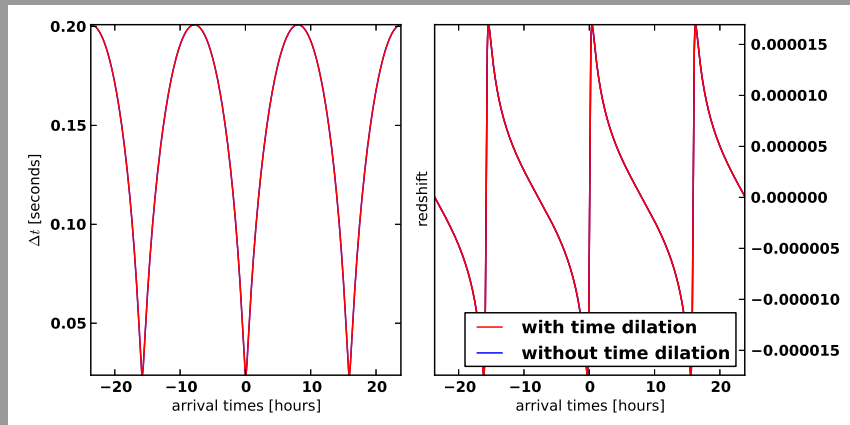
# gravitational time dilation

Known from GPS. STE-quest aims for  $10^{-7}$  redshift determination.



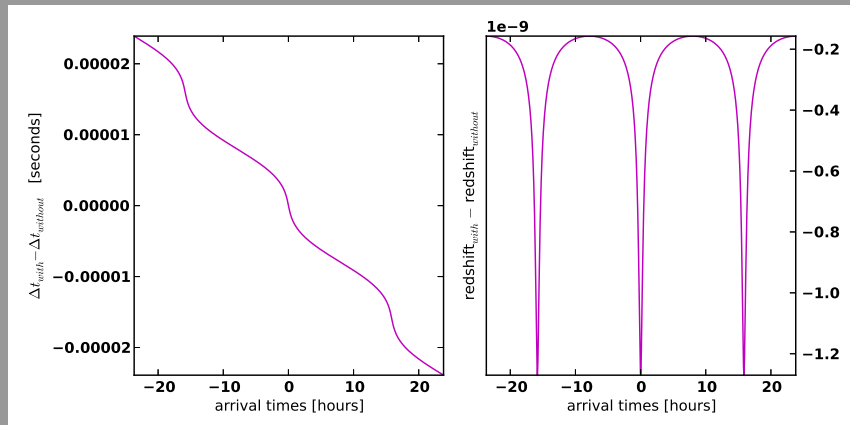
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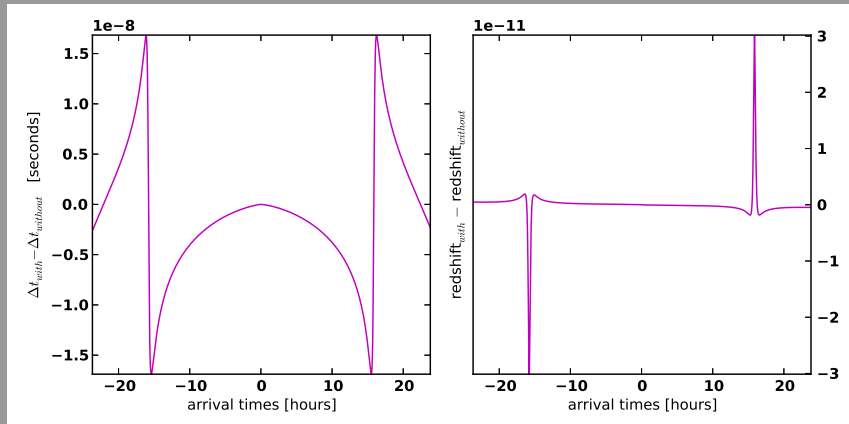
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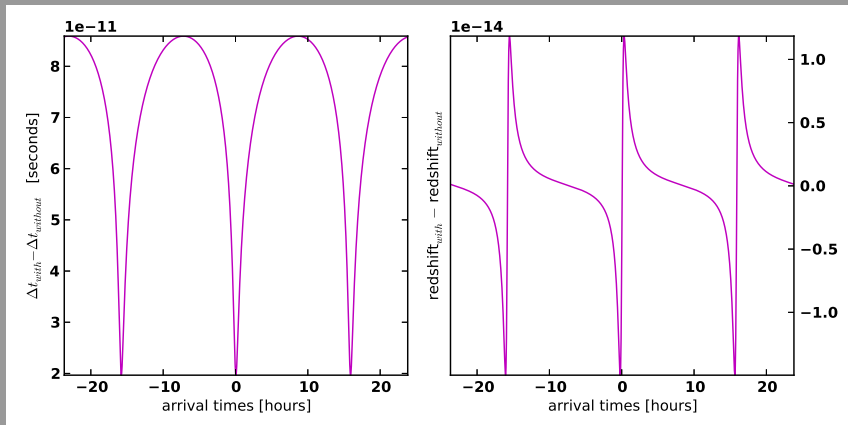
# space-curvature on orbit

## mercury-like precession



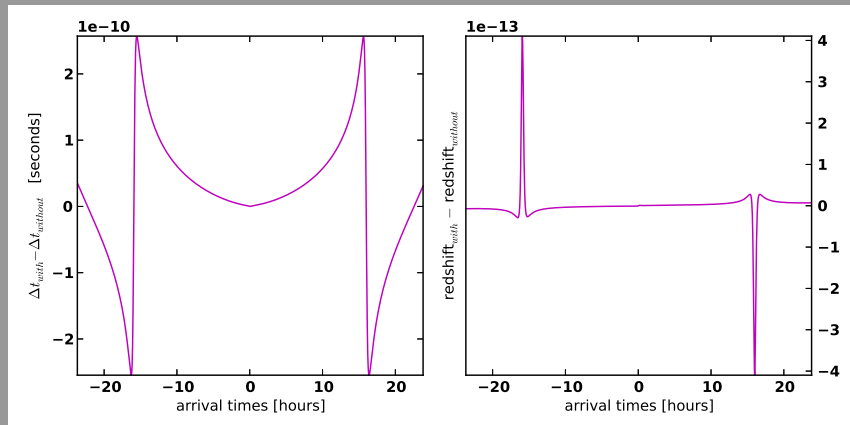
# space-curvature on signals

## shapiro delay



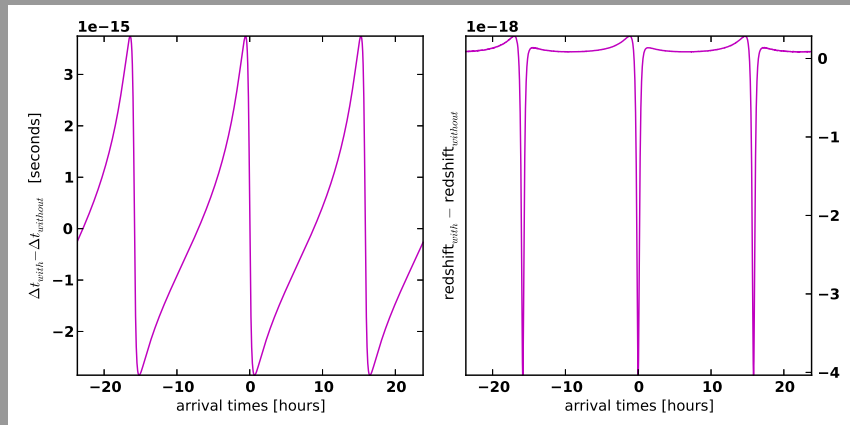
# frame-dragging on orbit

measured by gravity-probe B



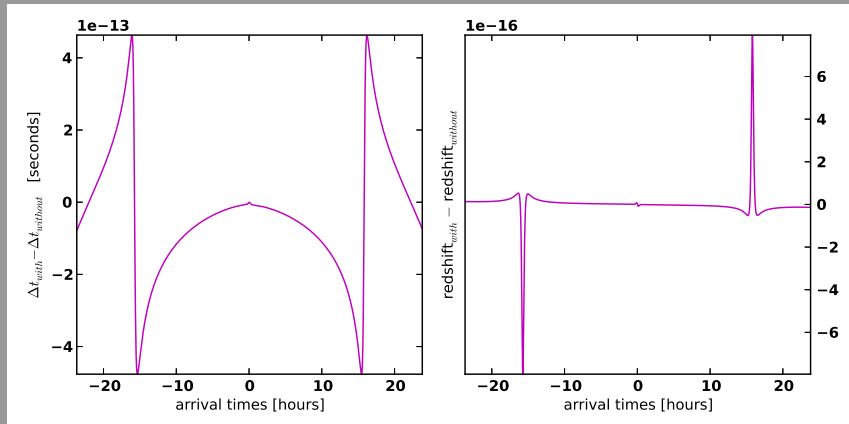
# frame-dragging on signals

never measured before



# spin<sup>2</sup>-effects on orbit

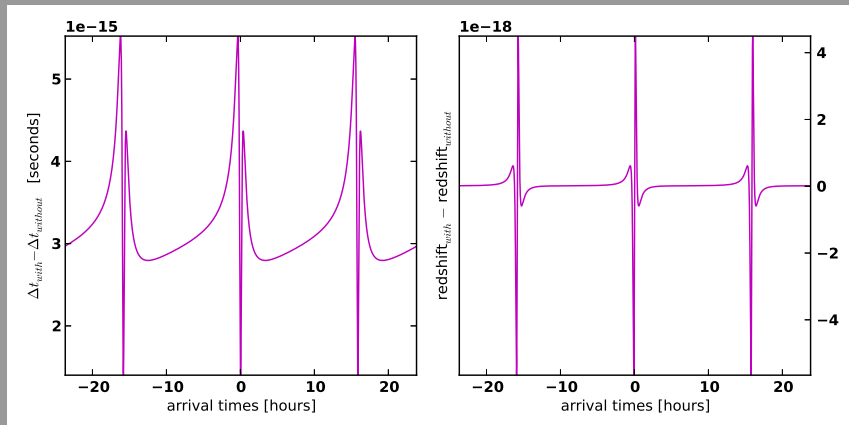
never measured before





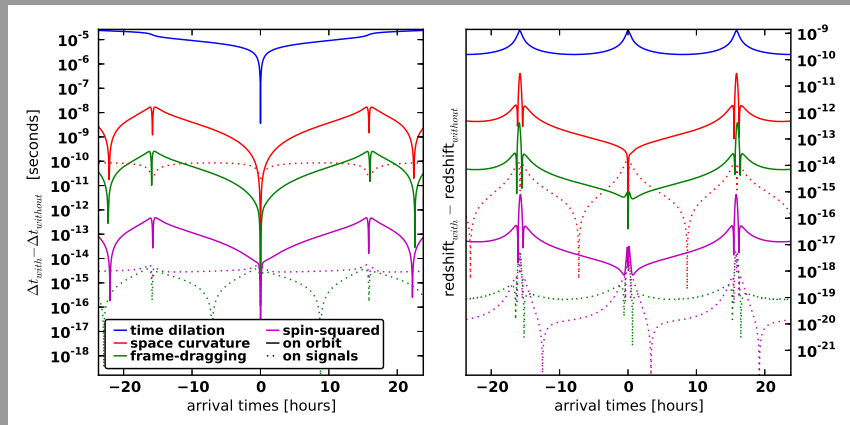
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never measured before



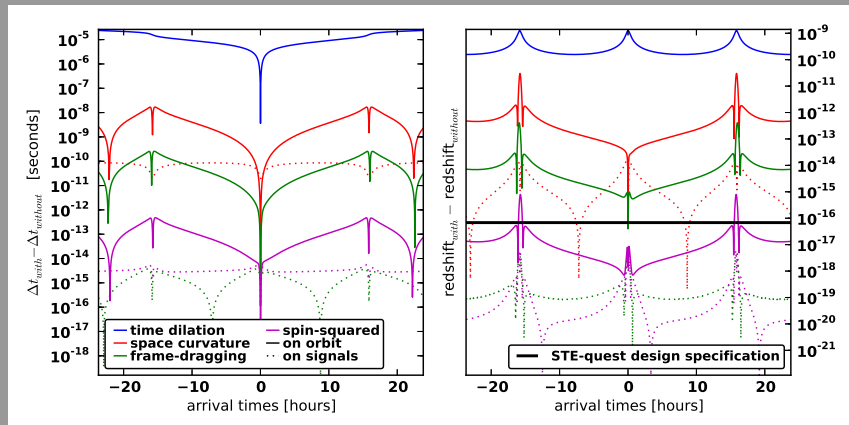
all signals

all signals together



# all signals

STE-quest aims for  $\sim 10^{-7}$  time-dilation measurement



# STE-quest is super

- ▶ STE-quest will simultaneously test all geodesic tests of relativity ever carried out
- ▶ could even resolve  $\text{spin}^2$ -effects
- ▶ prospects improve if more orbits are considered
- ▶ performance depends on handling of the systematics

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