



SPECIAL RELATIVITY

A Primer for Spaceflight

And God said...

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\epsilon_0}$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{j} + \mu_0 \epsilon_0 \frac{\partial \mathbf{E}}{\partial t}$$

...and there was light.

Clarendon Press Series

AN
ELEMENTARY TREATISE
ON
ELECTRICITY

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CLASSICAL ELECTRODYNAMICS

- **Faraday's Law:** A moving magnet induces an electric current
- **Luminiferous Ether:** The hypothesized all-pervasive medium that carries EM waves



SEARCHING FOR THE ETHER



- Is the magnet or coil moving? Two answers!
- Michelson and Morley couldn't find the ether
- Newton's worldview could not be reconciled with Maxwell's physics of electromagnetism

EINSTEIN'S RE-FRAMING

- **One phenomenon:** Coil and Magnet approach each other
- One phenomenon demands a **single answer**
- His goal: a single account not requiring the ether

NEWTON, VERZEIH' MIR.

- Three hundred years earlier, Galileo questioned **frames of reference**
- Newton's absolute space and constantly flowing river of time would be abandoned
- At stake: The principle of relativity

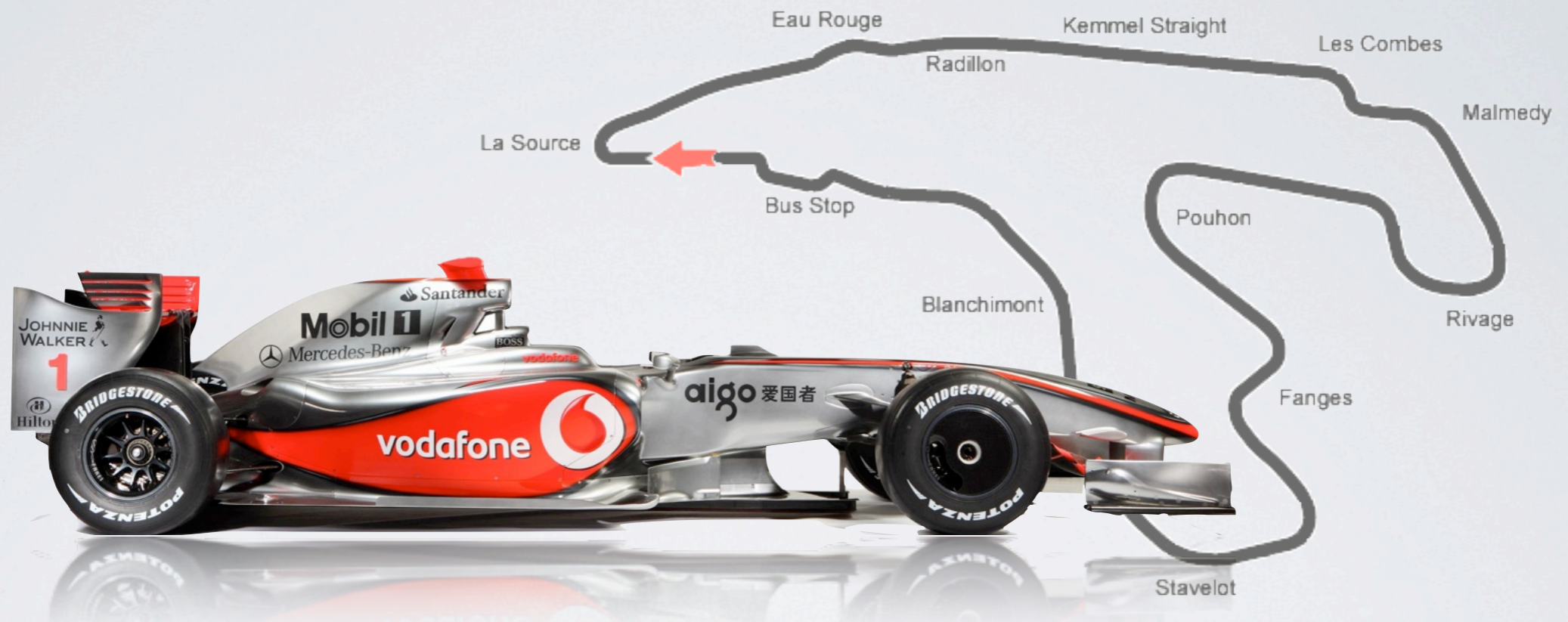
SPECIAL RELATIVITY POSTULATES

- The laws of physics are **the same** in all inertial *frames of reference*
- The speed of light in a vacuum has the **same value** c in all inertial frames of reference

WHAT DOES IT ALL MEAN?

- Einstein believed physicists were simply asking the wrong questions
- Understanding forces was secondary
- Understanding the behavior of clocks and rulers in constant, force-free motion was primary

RELATIVITY AT SPA



Time to 125 mph: 3.4 s

Kemmel Straight: 214 mph

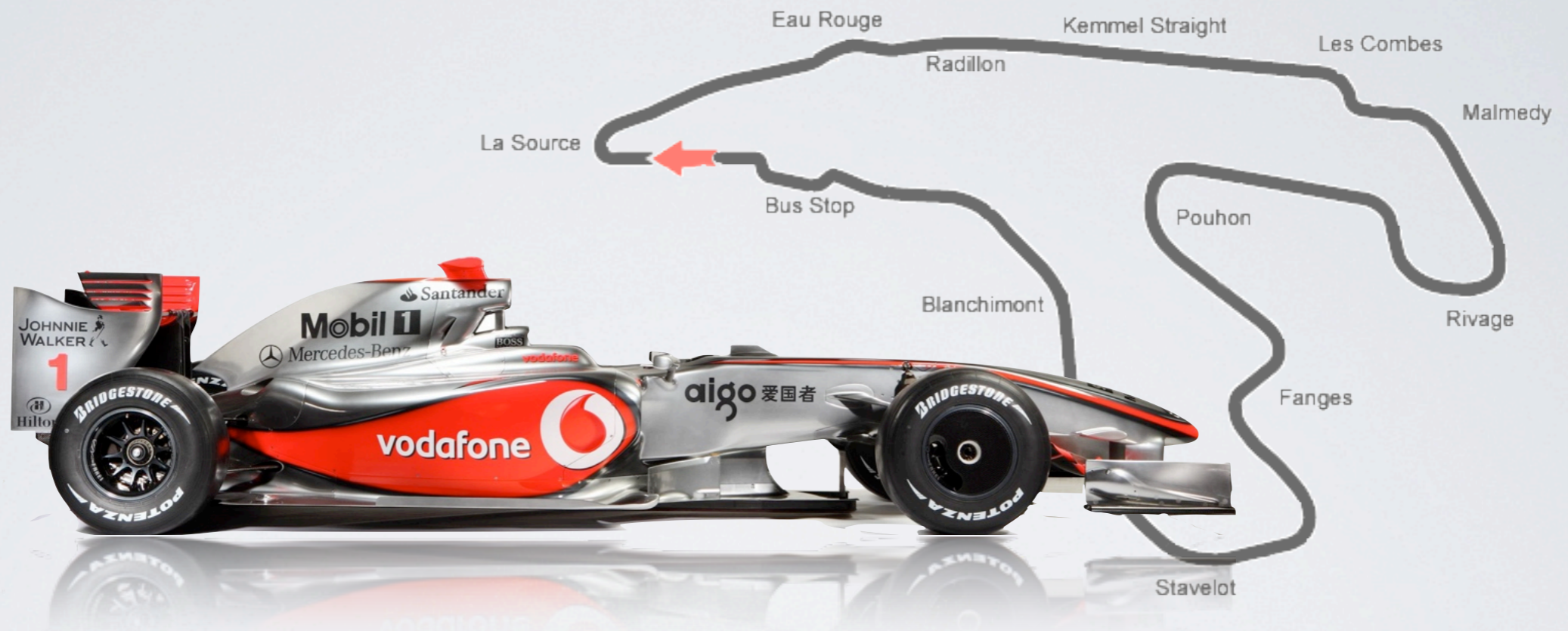
Driver: Marianne

Mass: 600 kg

Length: 14.8 ft

Crew chief: Ginger

GINGER'S FRAME OF REFERENCE

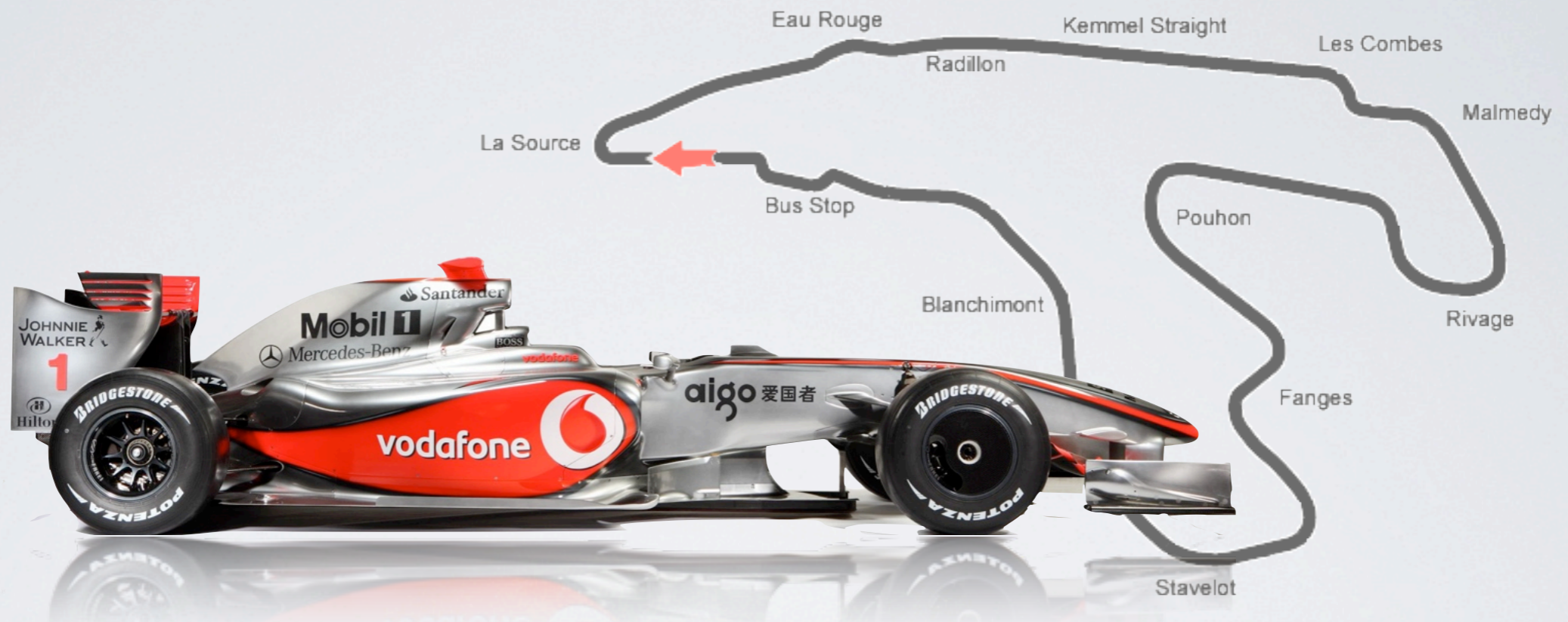


Time to 125 mph: 3.4 s

Mass: 600.0000000000000027 kg

Length: 14.77777777777773 ft

MARIANNE'S FRAME



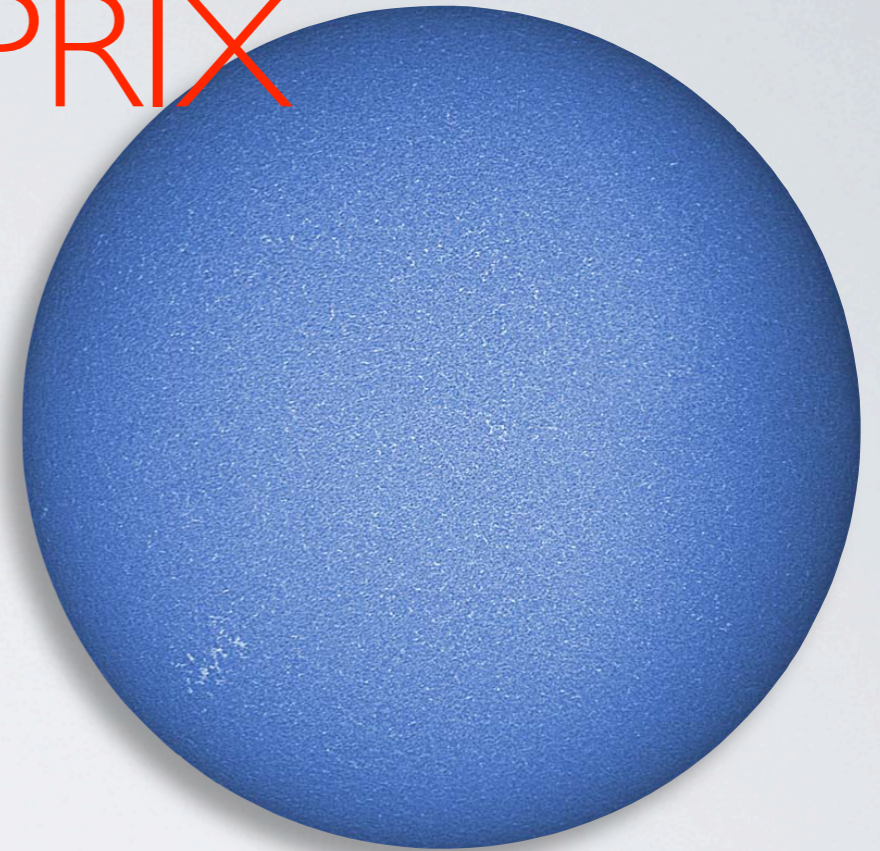
Time to 125 mph: 3.333333333333335 | s

Mass: 600 kg

Length: 14.8 ft

THE SOLAR GRAND PRIX

Ginger's Frame of Reference



Speed:	0.87c (580 million mph)
Time to 1 AU:	9 min 47 s
Mass:	1,217 kg
Length:	7.4 ft

THE SOLAR GRAND PRIX

Marianne's Frame of Reference



Speed: 0.87c (580 million mph)

Time to 1 AU: 4 min 38.5 s

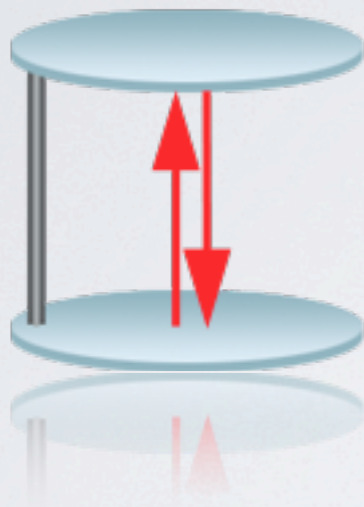
Mass: 600 kg

Length: 14.8 ft

THE LIGHT CLOCK

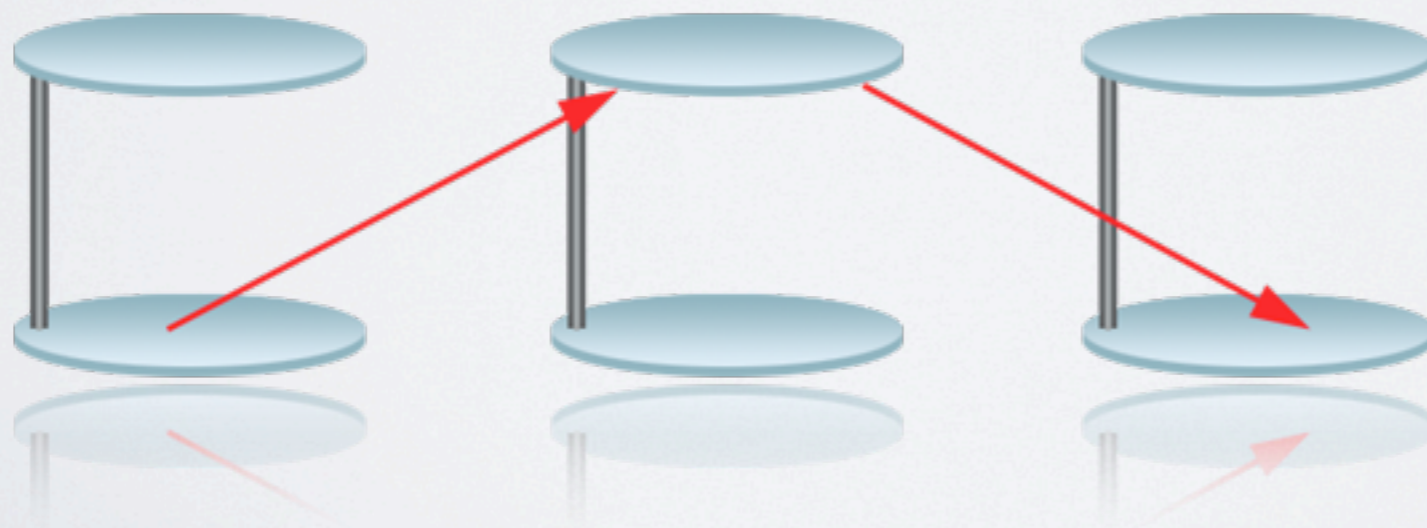
Stationary clock

$t = l \text{ cycle (tick)}$



Clock moving at velocity v

$t_o > t$



SPECIAL RELATIVITY EQUATIONS

$$m = \frac{m_0}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} \quad L = L_0 \sqrt{1 - \left(\frac{v}{c}\right)^2}$$

$$t_0 = \frac{t}{\sqrt{1 - \left(\frac{v}{c}\right)^2}}$$

THESE ARE THE VOYAGES...



Velocity	Mass (tons)	Length (ft)	Length of Mission (Years from Earth)	Length of Mission (On ship)
100,000 mph	150,000	947 ft	167,000 yrs	167,000 yrs
0.25c	154,900	907	100	97 yrs
0.50c	173,000	811	50	43 yrs
0.90c	344,000	408	27.8	12 yrs, 2 months
0.98c	754,000	186	25.5	5 yrs, 2 weeks
0.999c	3,350,000	41.9	25.0	1 yrs, 2 months
0.9999c	10,700,000	13.2	25.0	4 months, 1 week

Calculations based on round-trip mission to the spectral class M5 red dwarf star Luyten 725-32 (distance 12.5 l-yrs).

THE FUNDAMENTAL UNIT OF MEASURE IN
THE UNIVERSE IS THE SPEED OF LIGHT—
MEASUREMENTS OF LENGTH AND MASS ARE
RELATIVE.

SPACE AND TIME ARE INTERWOVEN IN A
“FABRIC” OF SPACETIME.

EVERYTHING TRAVELS THROUGH SPACETIME
AT THE VELOCITY OF LIGHT.

THE SLOWER ONE MOVES THROUGH SPACE,
THE FASTER ONE MOVES THROUGH TIME.

THE FASTER ONE MOVES THROUGH SPACE,
THE SLOWER ONE MOVES THROUGH TIME.