# Quantum and Atomic Physics

I. Wave/Particle Duality
- quantum energy, Planck's constant
- photons, photoelectric effect
- Bohr model, De Broglie wavelength
- electron diffraction, interference

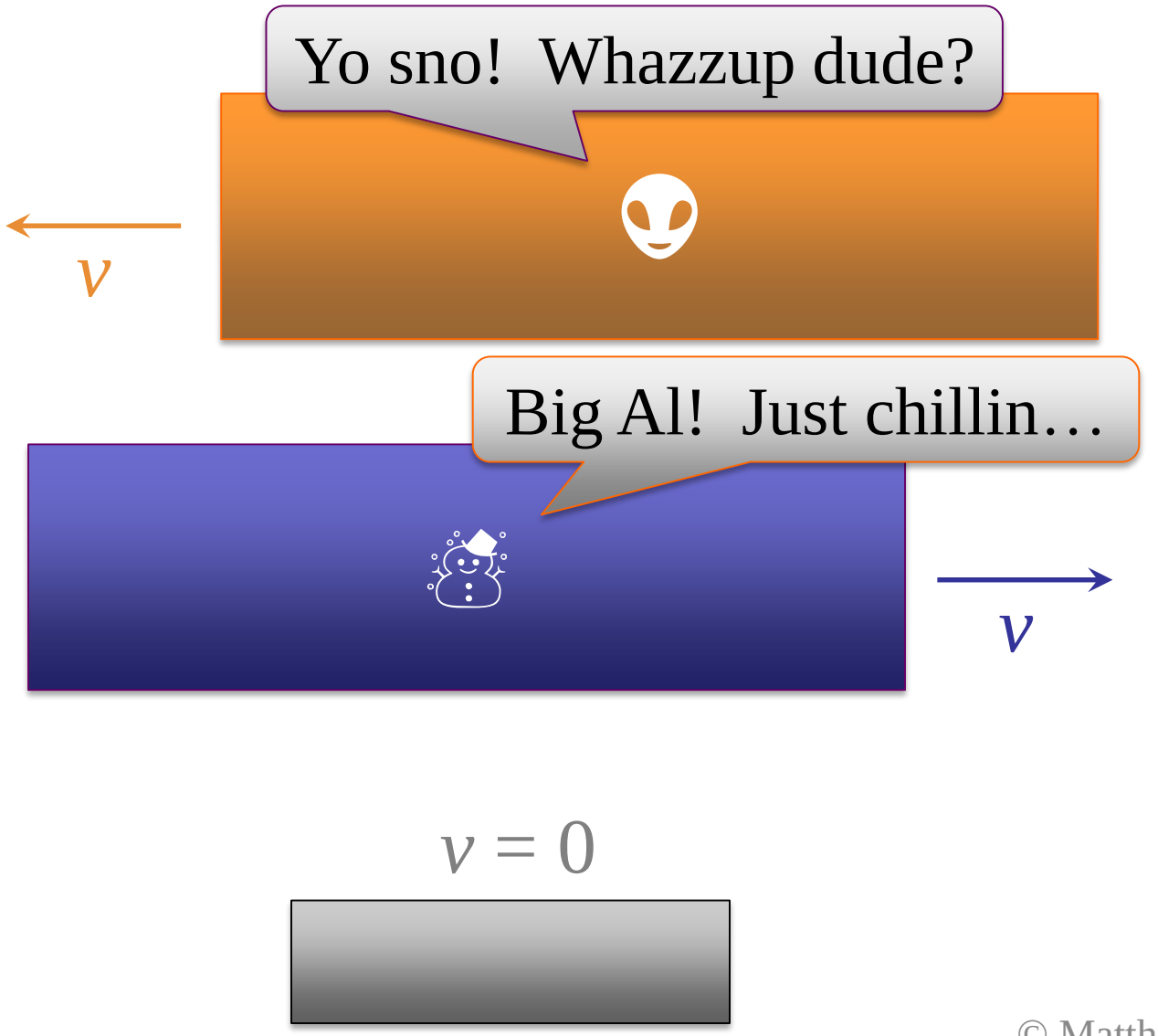
**II. Special Relativity**
**- simultaneity, time dilation**
**- relativistic mass, momentum, and energy**

III. Nuclear Physics
- nucleus structure, energy, strong force
- radiation/nuclear decay, weak force
- nuclear reactions

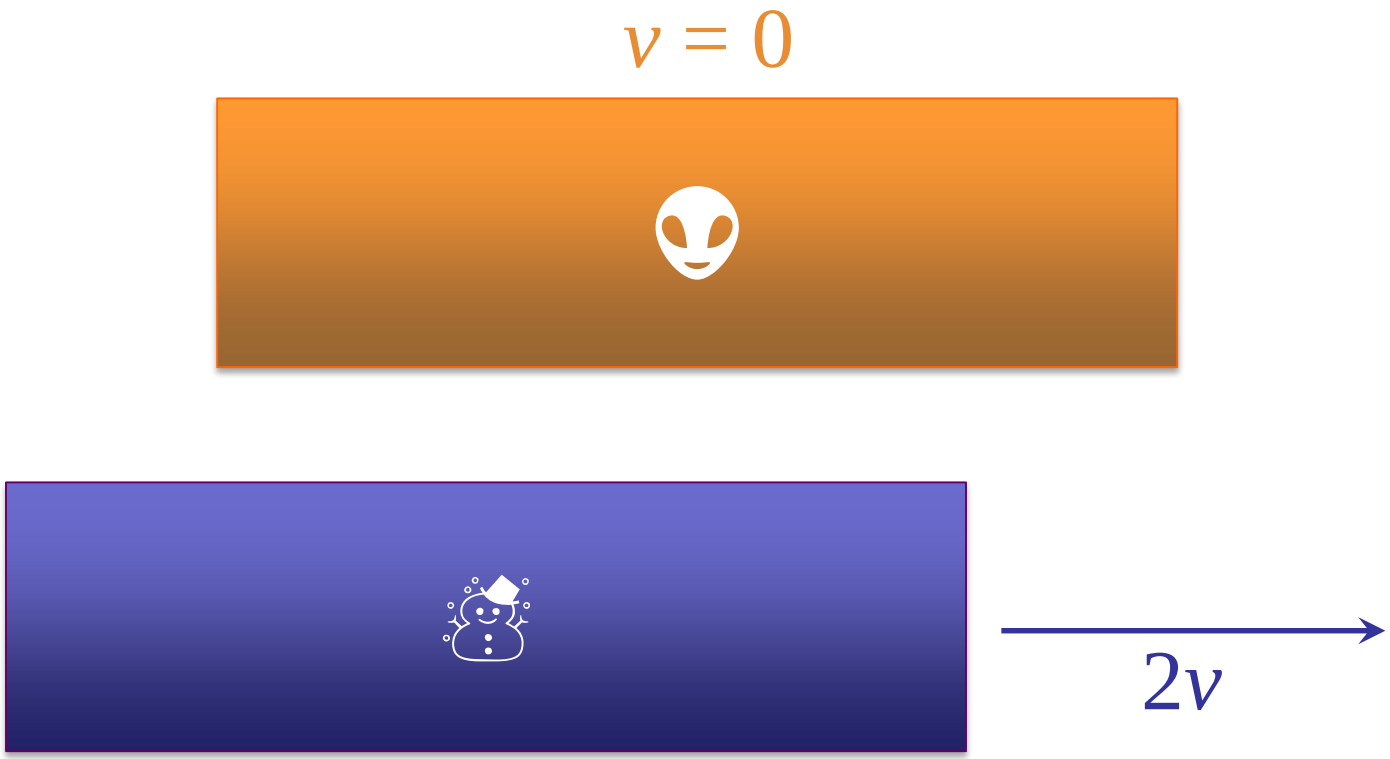
# Special Theory of Relativity

- In 1905 Albert Einstein published his theory of special relativity regarding the effect of reference frame on perception of time and other metrics. (The theory of general relativity came later in 1916.)
- Postulate #1: The laws of physics have the same form in all inertial reference frames.
- Postulate #2: Light propagates through a vacuum with speed *c* (299 792 458 m/s), independent of the speed of the source or observer.

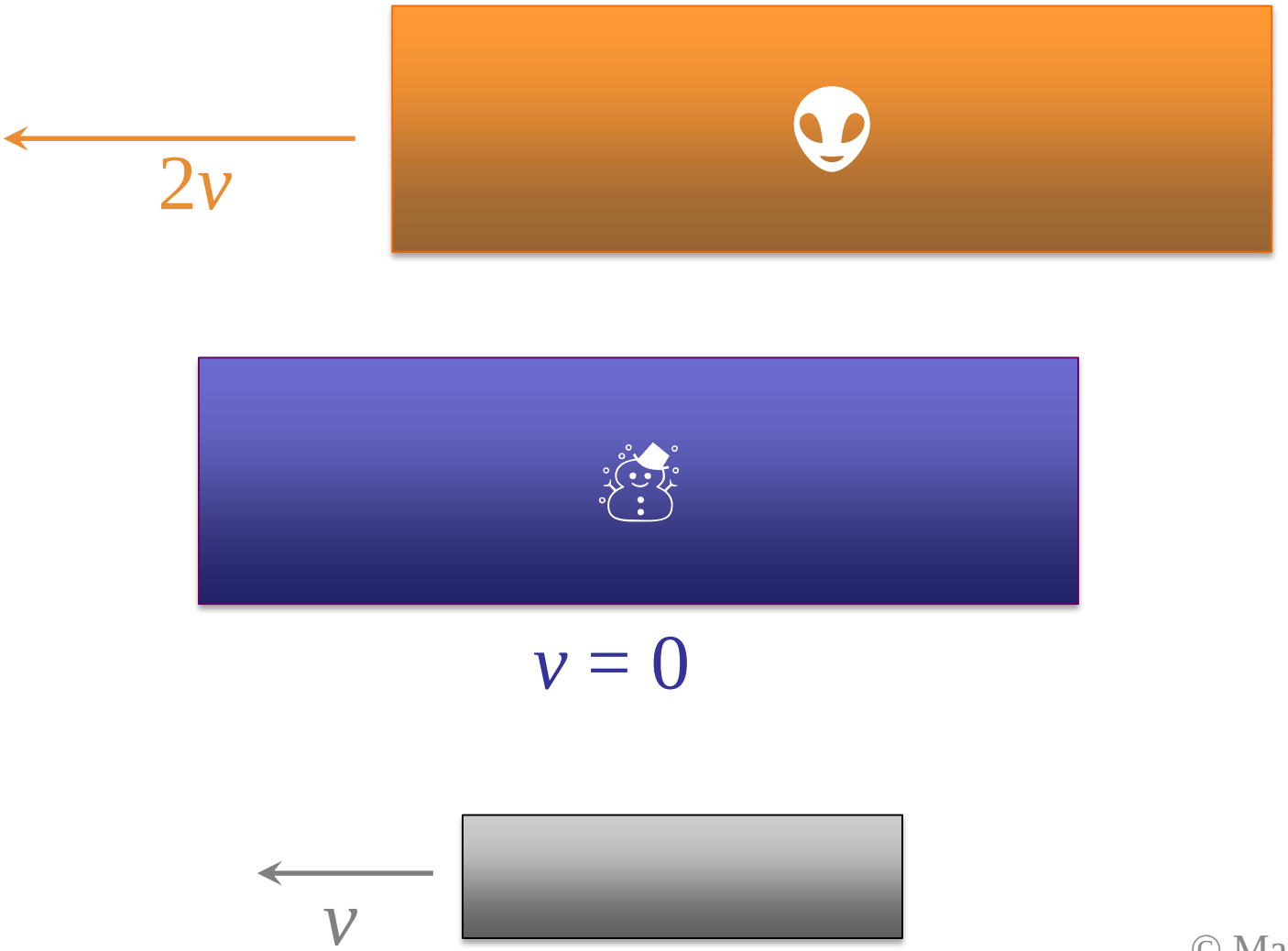
# Earth frame of reference



# Alien's frame of reference



# Snowman's frame of reference



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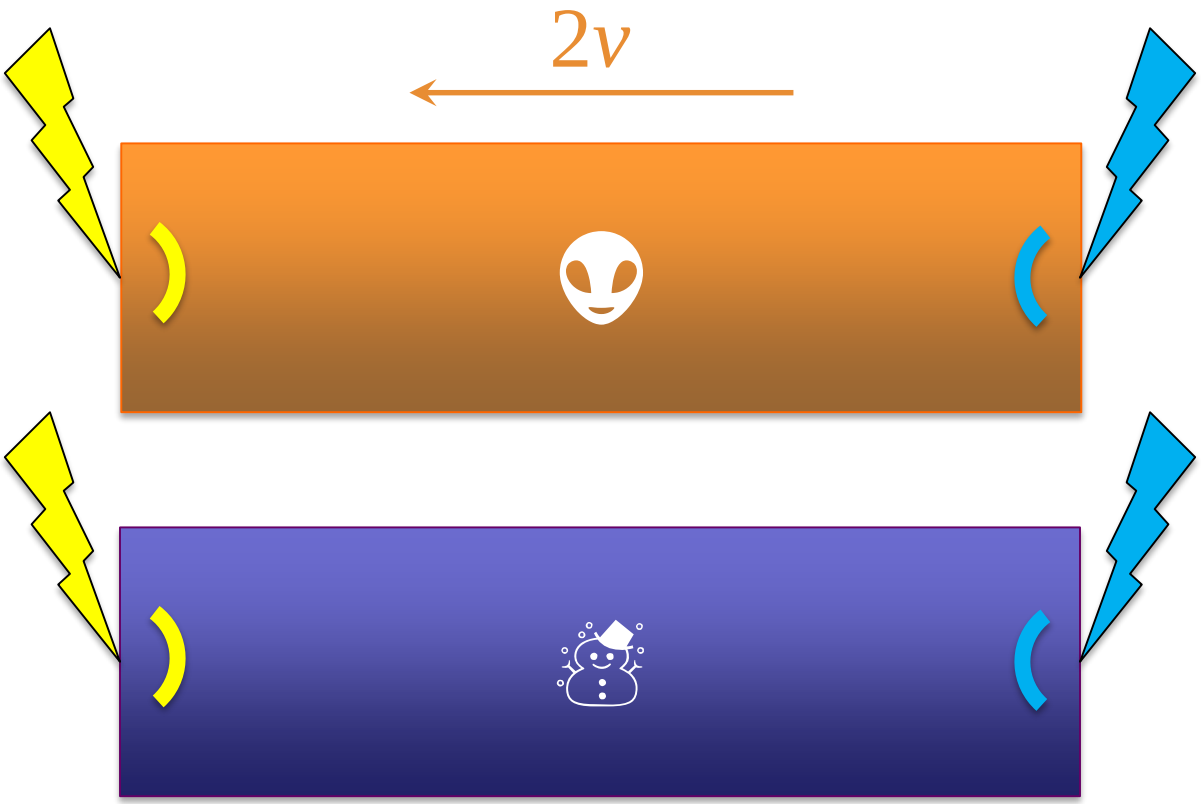


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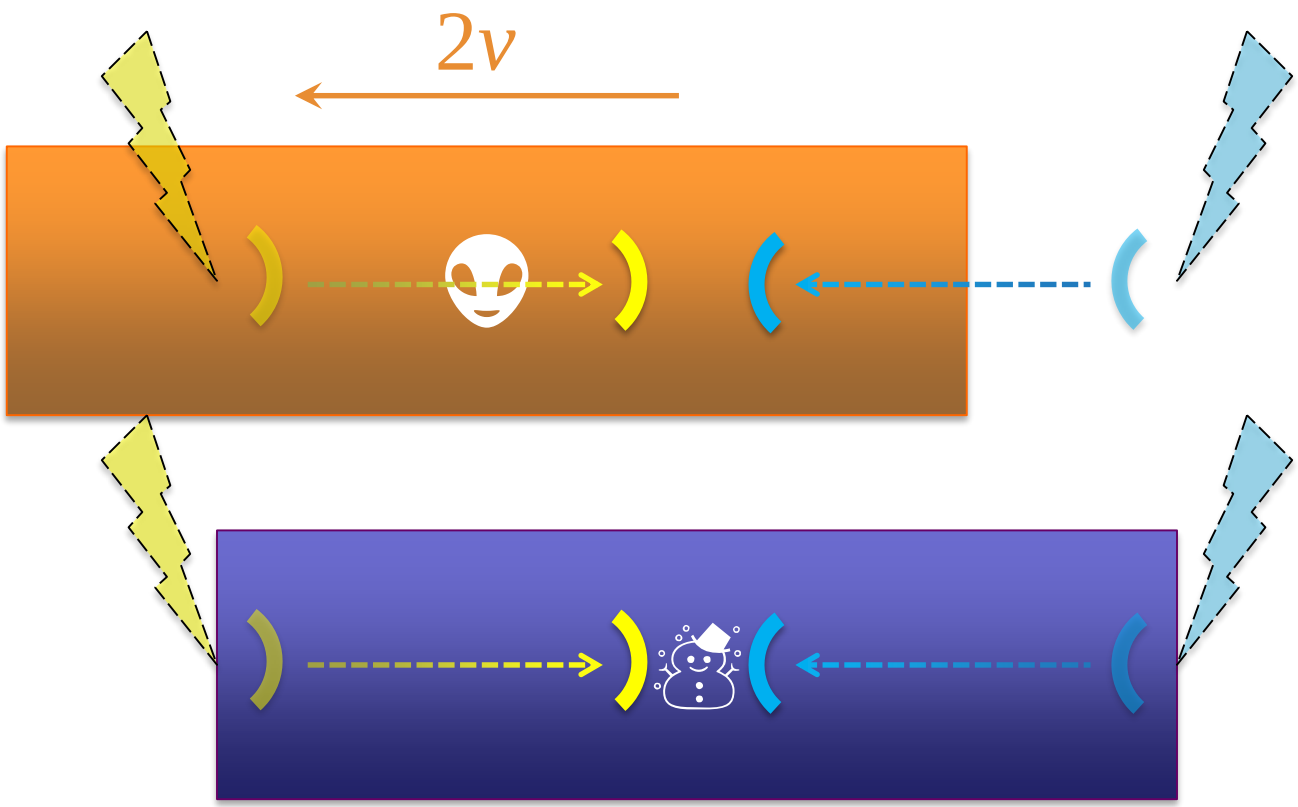


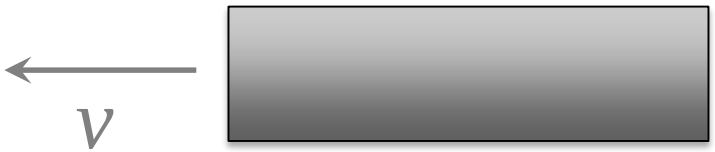

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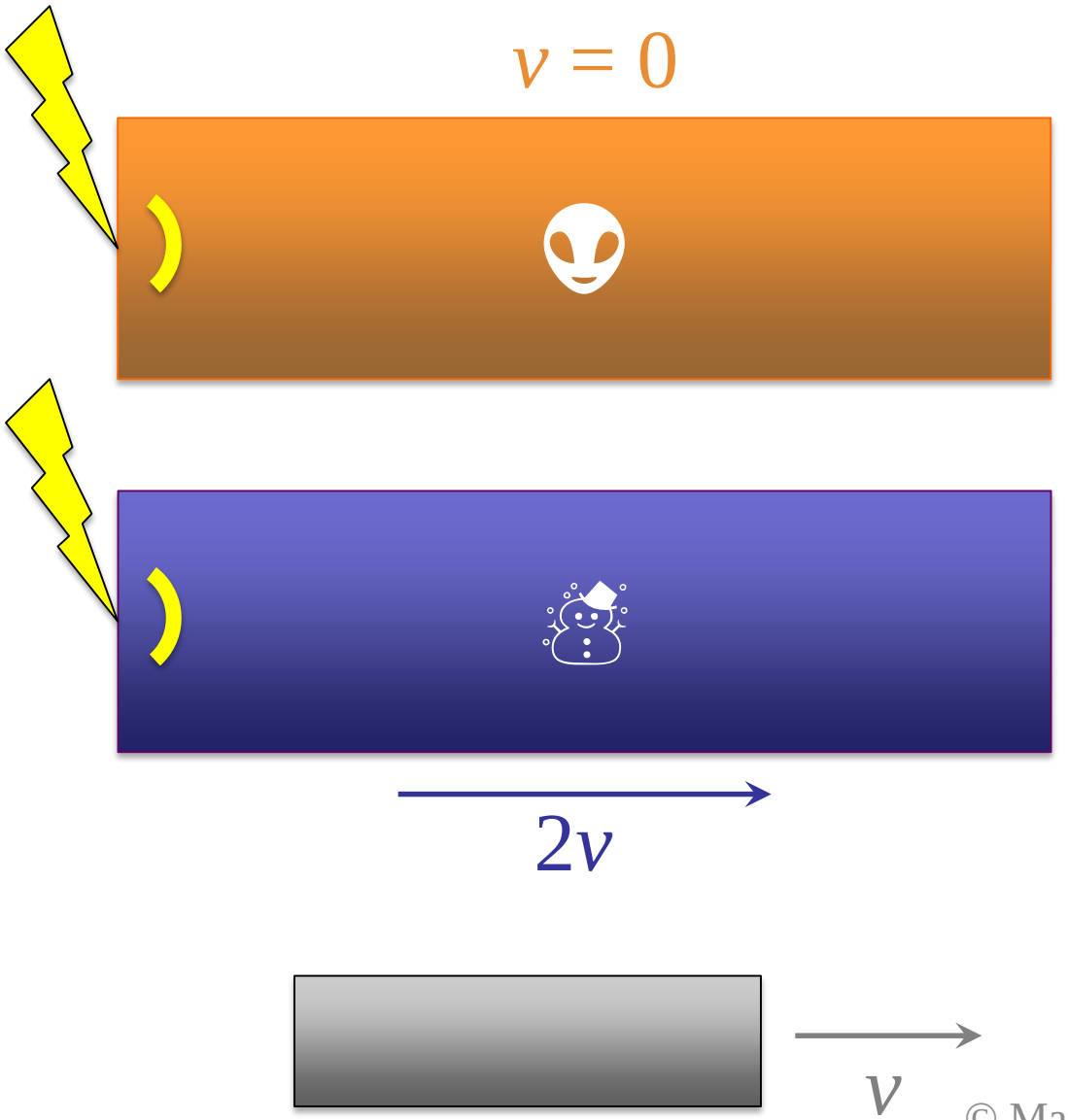

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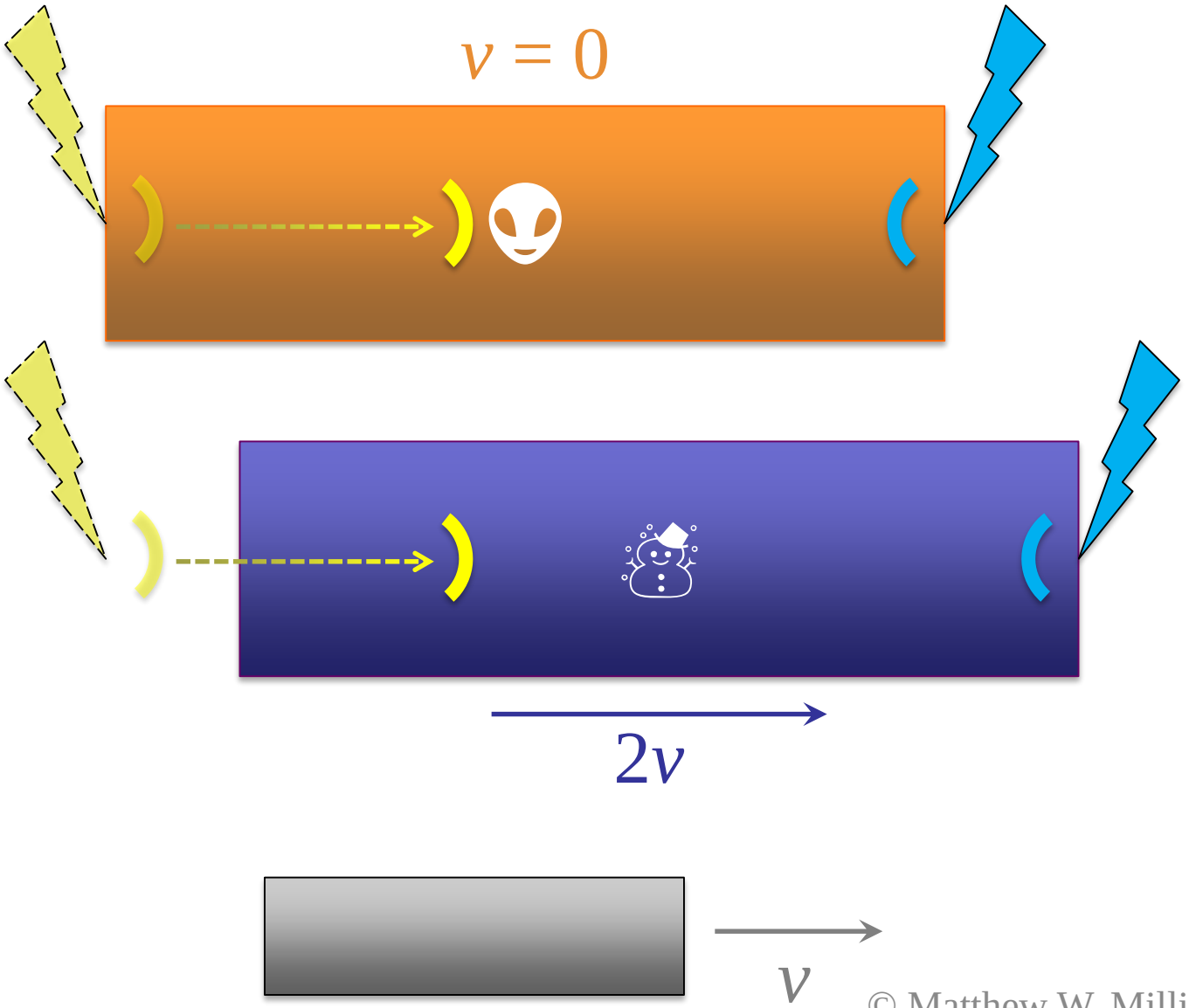

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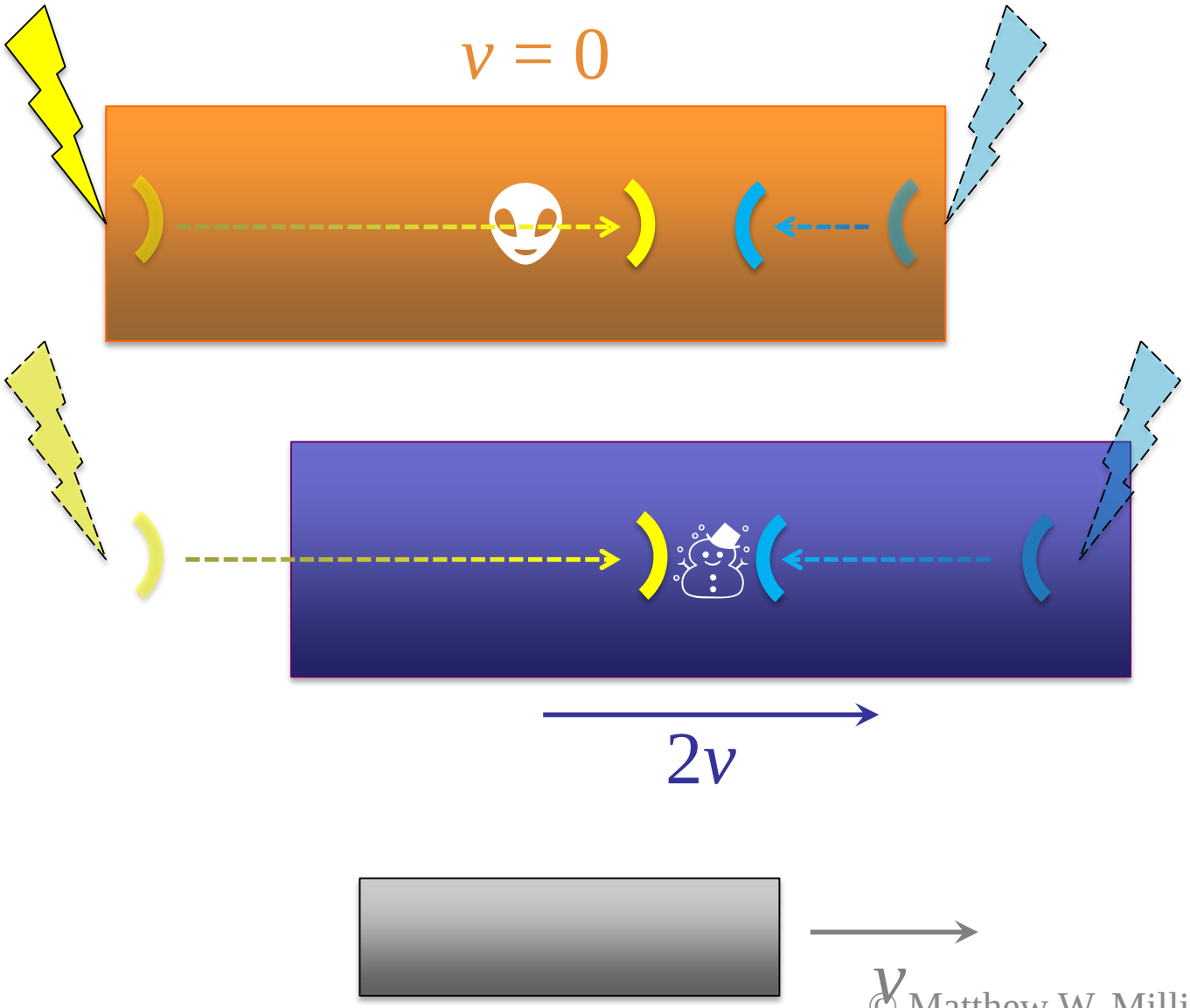

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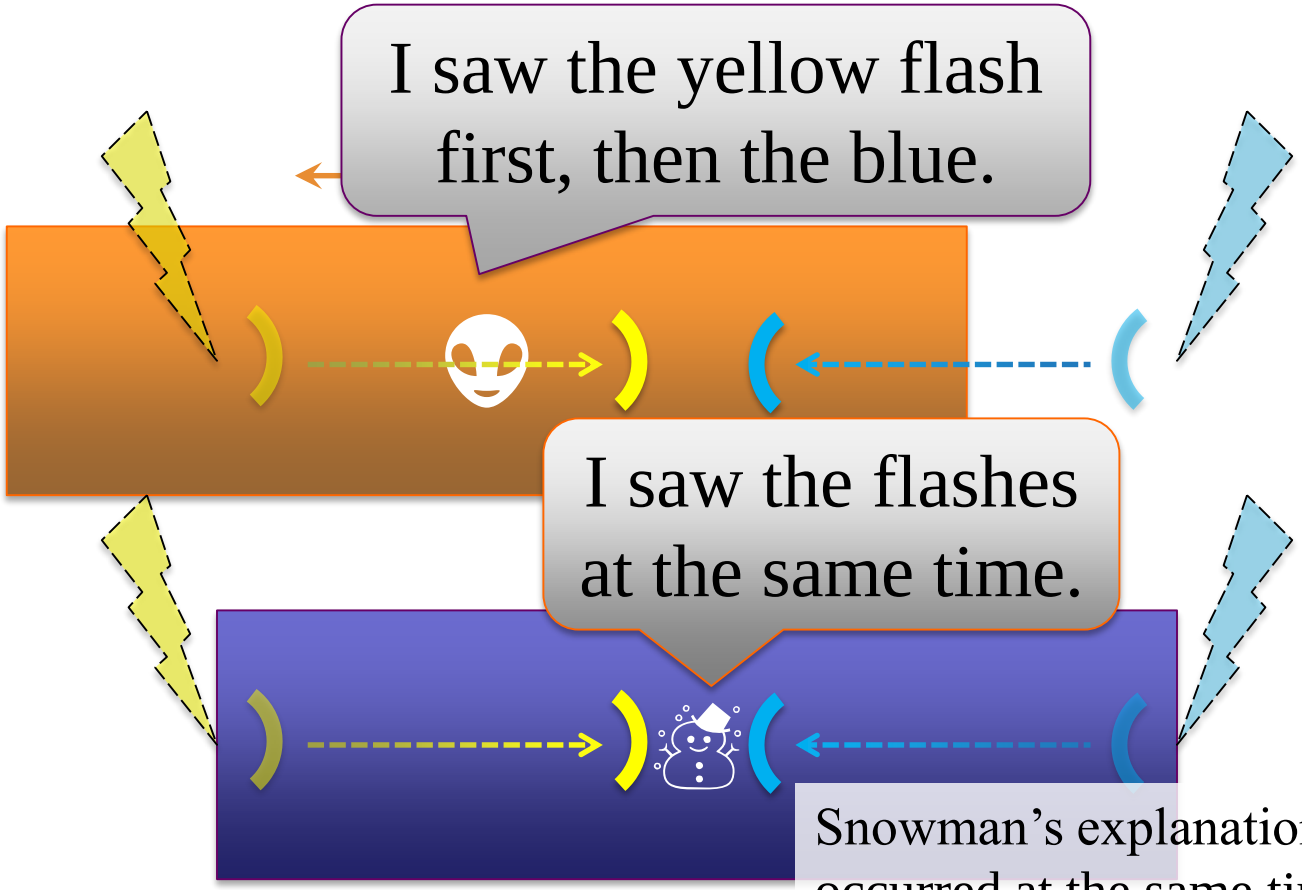
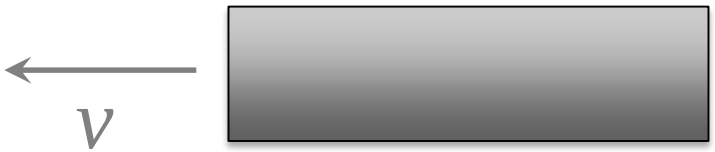



$v = 0$

Snowman's explanation: The two flashes occurred at the same time and travelled equal distance in equal time in my box. But in Alien's box the blue flash had a greater distance to travel and so took more time. That's why he *saw* the blue flash *after* he saw the yellow flash.



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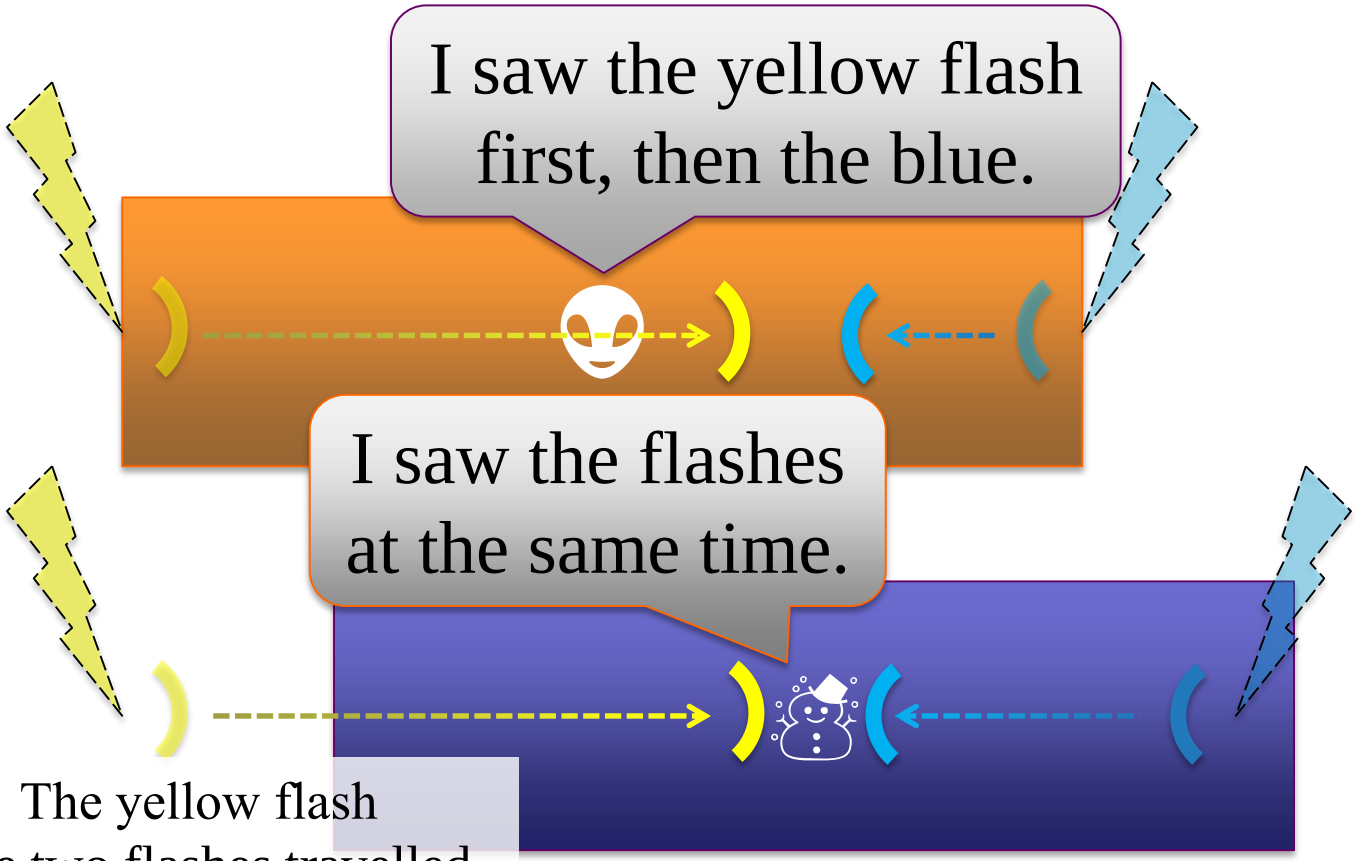
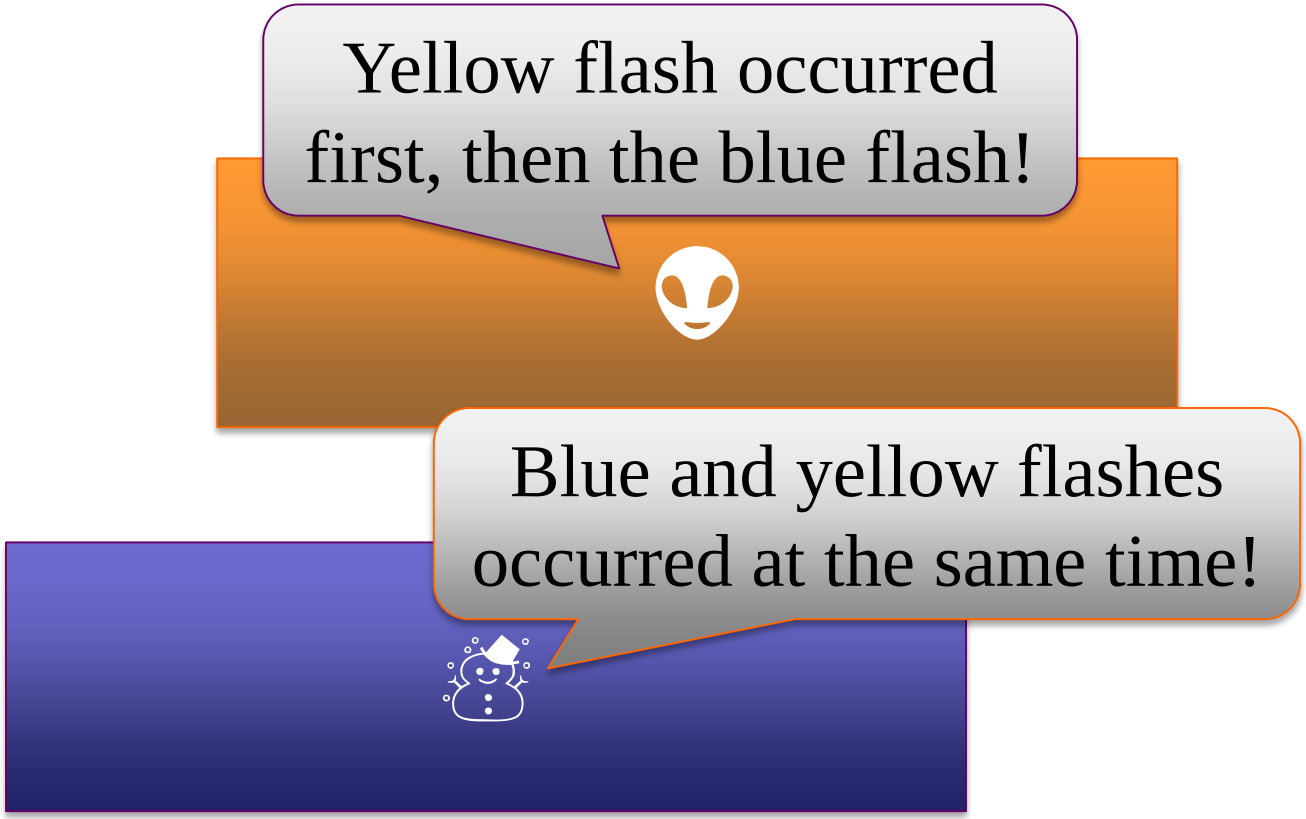



Alien's explanation: The yellow flash occurred first and the two flashes travelled equal distance in equal time in my box. But in Snowman's box the yellow flash had a greater distance to travel and so took more time – that's how he *saw* the flashes at the same time.

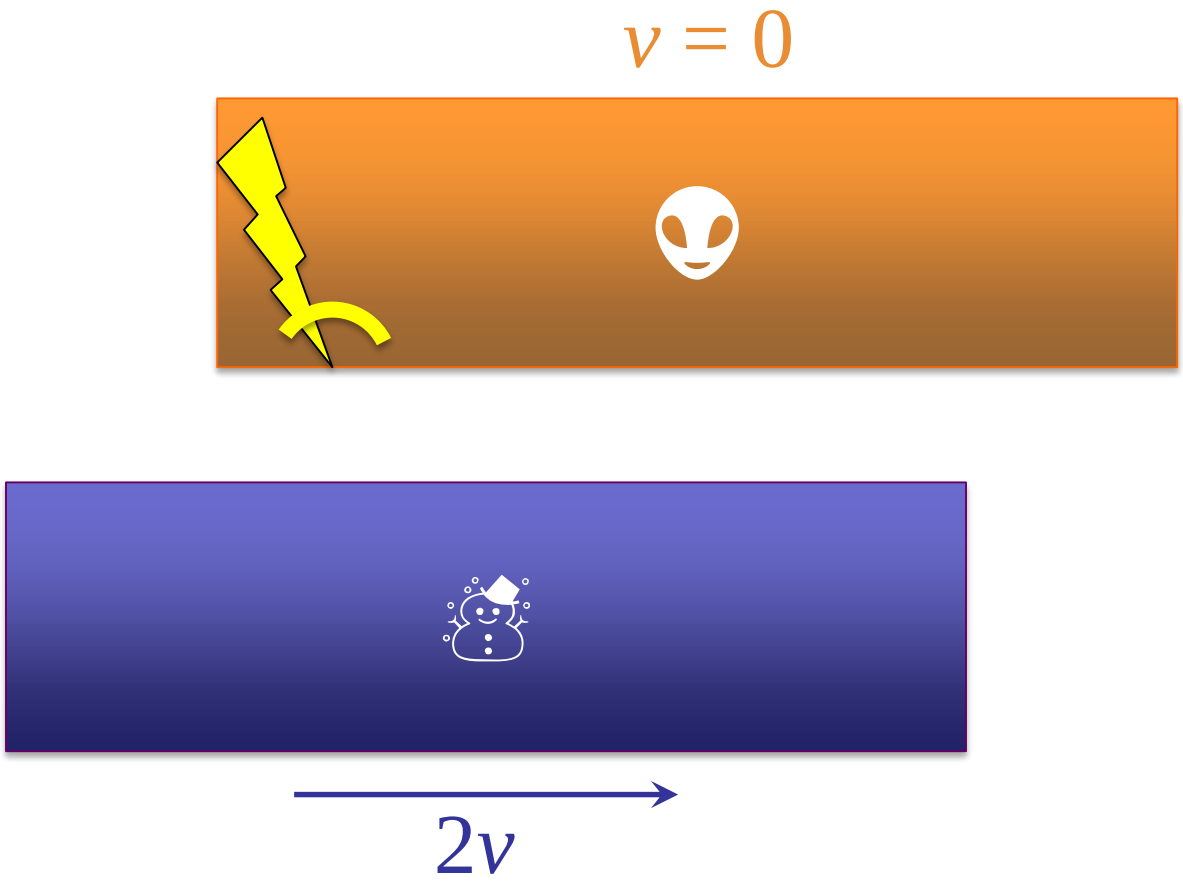
disagreement – simultaneity of events (which first)




agreement – speed of light

# Earth frame of reference

# Alien's frame of reference



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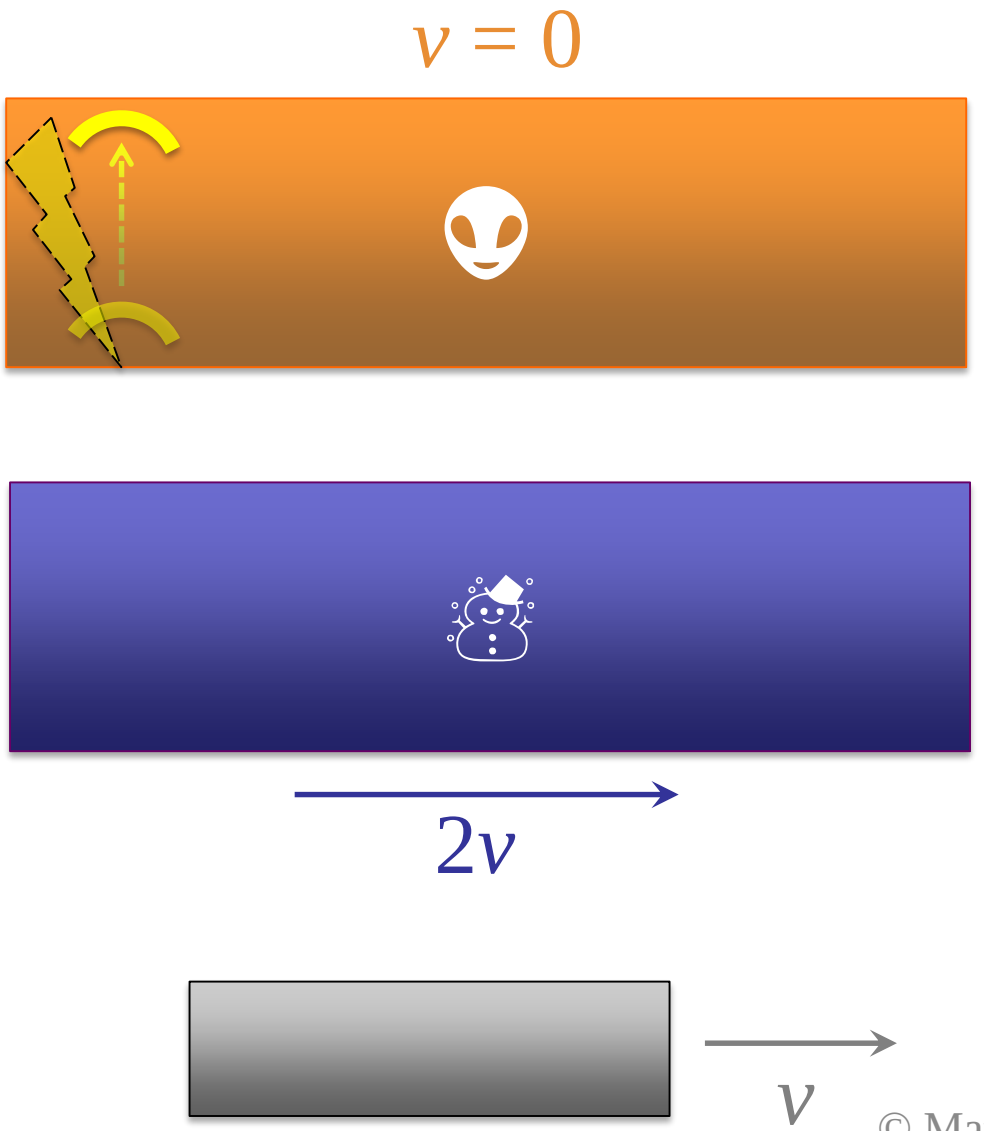

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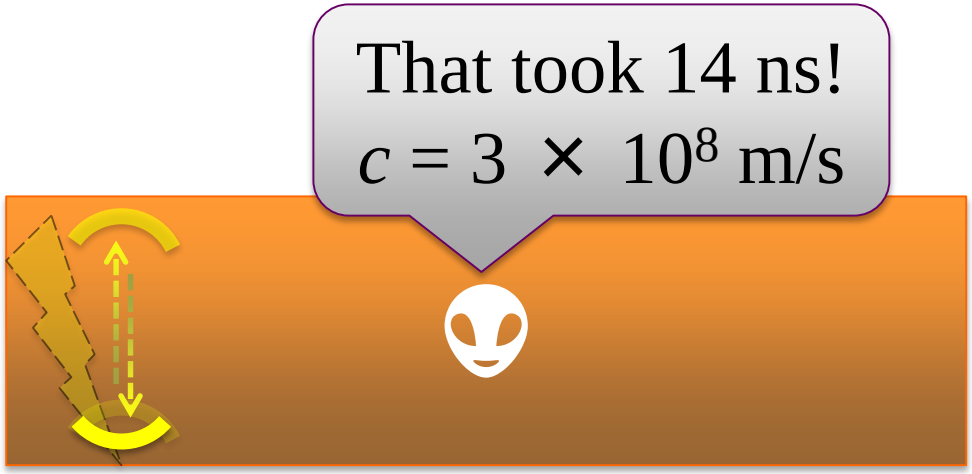
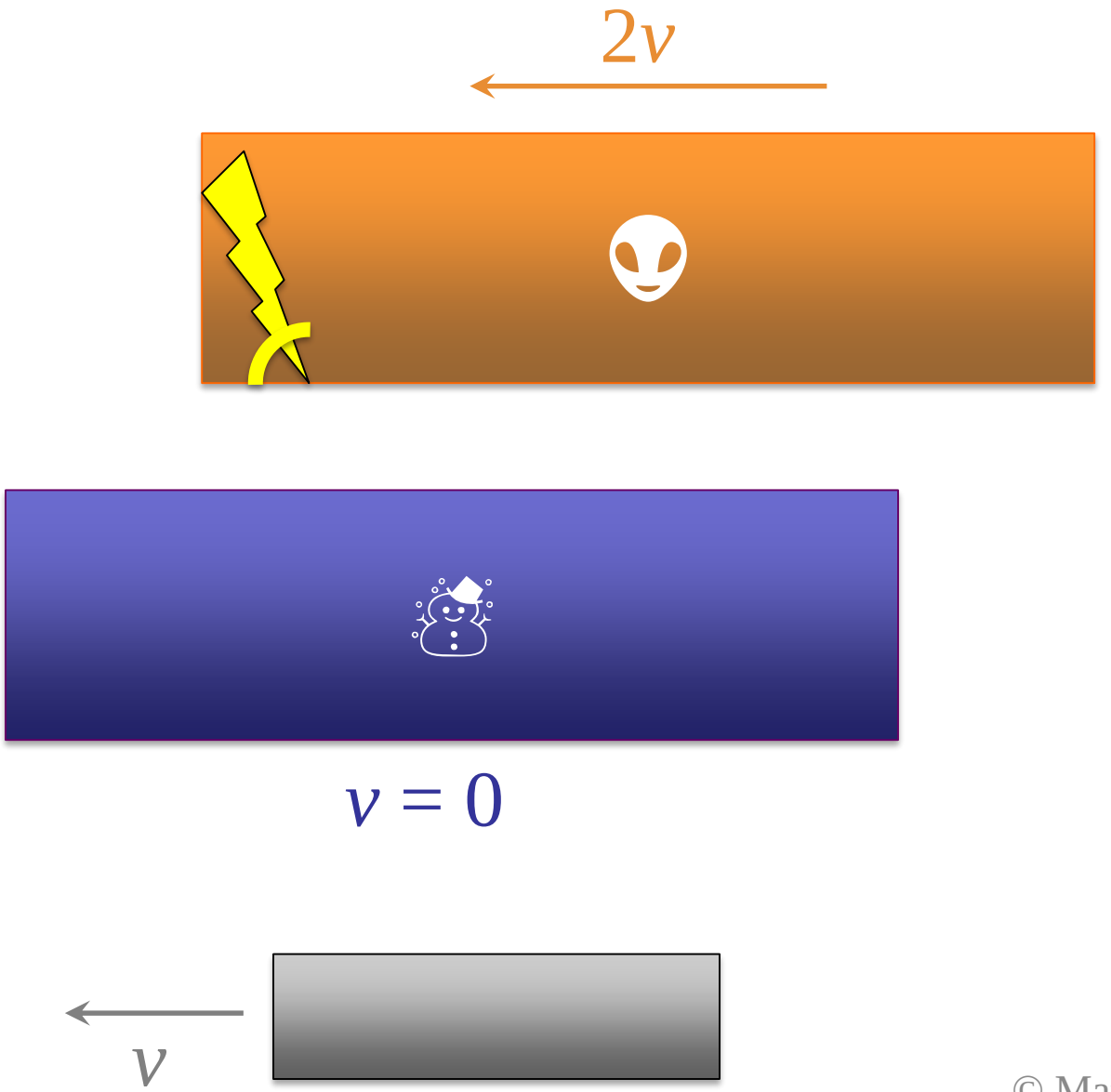



Alien's explanation: The yellow flash travelled a distance twice the width of the car and returned to its starting position.

# Earth frame of reference

# Snowman's frame of reference



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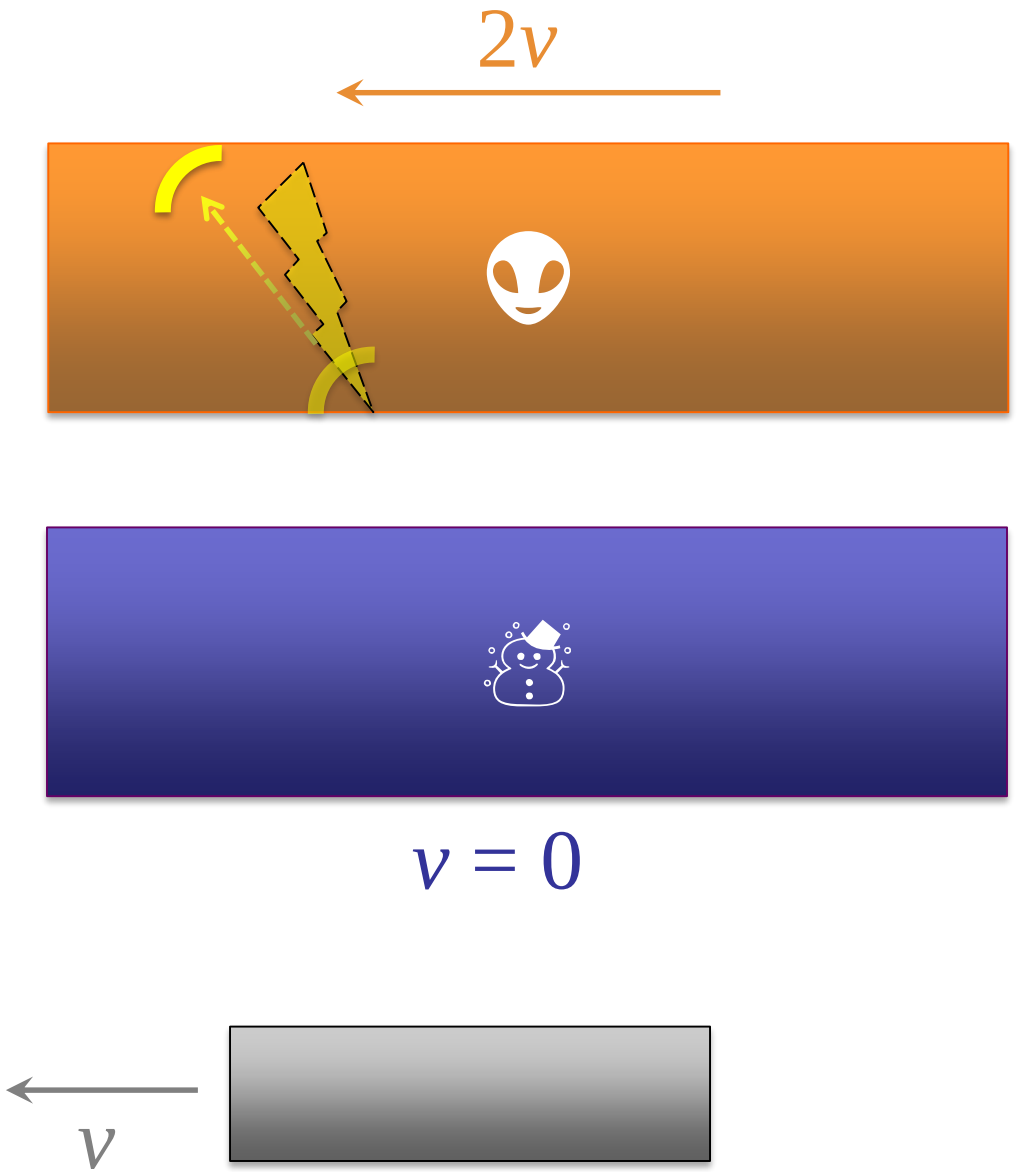

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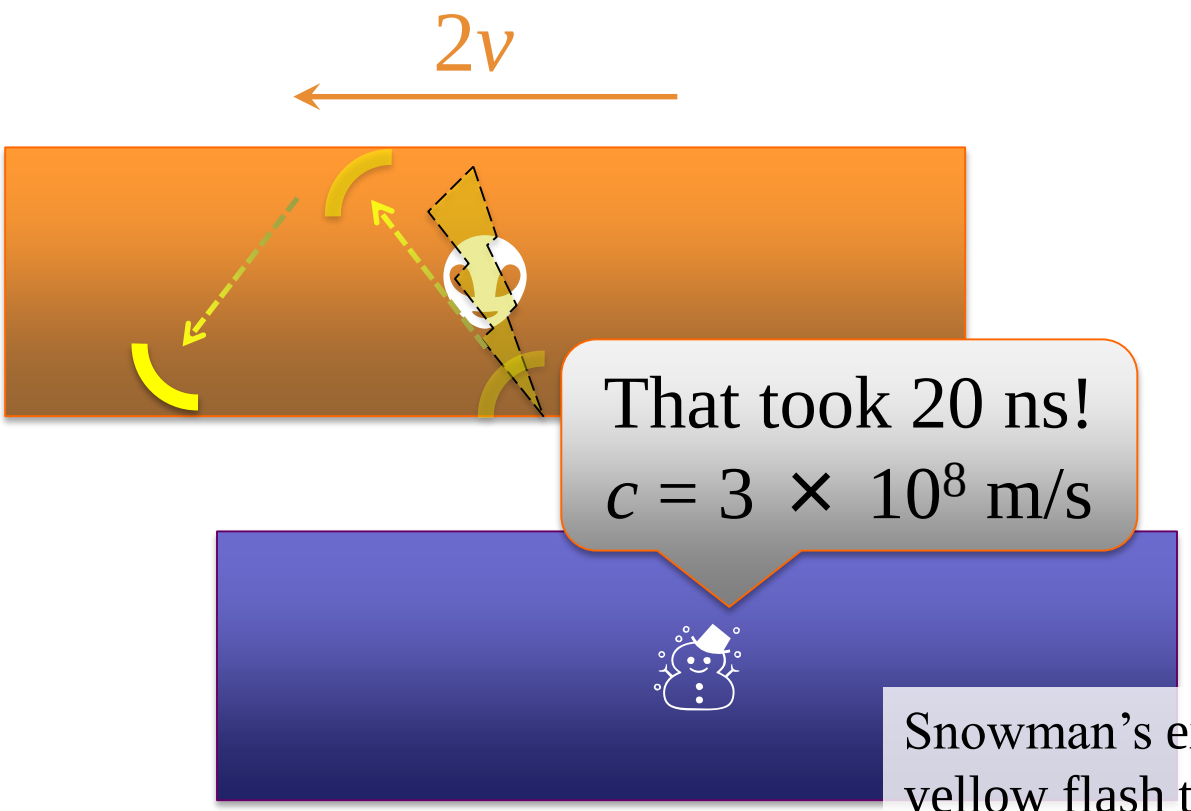
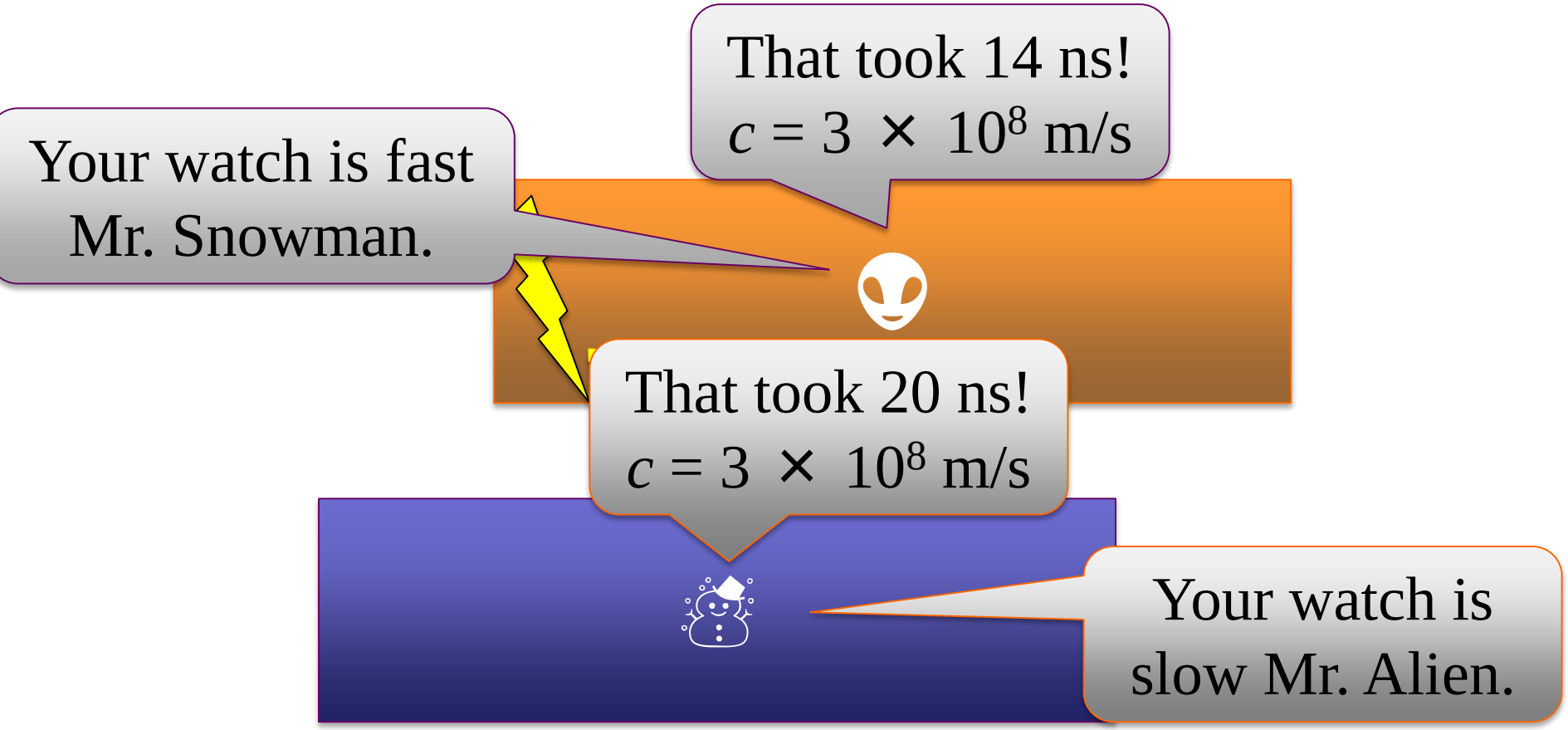



Snowman's explanation: The yellow flash travelled a distance more than twice the width of the car and returned to the bottom side of the car – a different position in space in my frame of reference.

disagreement – amount of time for the light to travel




disagreement – distance that the light travelled

agreement – speed of light

# Relativity of Time

- Counter to our intuition the passage of time is not an absolute phenomenon that proceeds independent of observers.
- The time interval between two events is smallest in a frame in which the events happened at the same position. In other frames the same interval is measured to be a greater value and hence it is dilated. This is called **time dilation**.
- The time interval between events that occur *at the same position* is called the **proper time**.

# Relativity of Other Quantities

- Building on the conclusion that time is relative, Einstein found that other quantities such as distance, mass, momentum, and energy are also dependent upon the observer's frame of reference.
- The distance between two objects in a frame in which *the objects are at rest* is the **proper length**. In other frames it is observed to be less and hence it is contracted. This is called length contraction.
- The mass of an object is least in a frame at which is at rest – this is called the **rest mass**. The mass of a moving object is observed to be greater.

Quantities observed in a "rest frame" in terms of the same quantities observed in a frame moving at speed $v$:

$$\Delta t = \frac{\Delta t_0}{\sqrt{1 - v^2/c^2}}$$

$$L = L_0 \sqrt{1 - v^2/c^2}$$

$$m = \frac{m_0}{\sqrt{1 - v^2/c^2}}$$

# Relativistic Energy

Using the work-energy theorem, Einstein showed that the observed kinetic energy of an object relates to its relativistic mass and its rest mass by:

$$K = mc^2 - m_0c^2$$

$$K + m_0c^2 = mc^2$$

$$\boxed{E = mc^2}$$

where: $K$ = kinetic energy
$c$ = speed of light
$m_0$ = rest mass
$m$ = relativistic mass
$E$ = total energy (disregarding potential energy)