The speed of light:

299 792 458 m/s

Light travels faster than sound. That's why certain people appear bright until you hear them speak.

Das habe ich nie gesagt.

I never said that.
Albert Einstein.

Derek Muller claims that

"No One Has Measured The Speed Of Light"

(I would have named it: "No one has measured the speed of light.")

(he explains it in https://www.youtube.com/watch?v=pTn6Ewhb27k from his **Veritasium** channel https://www.youtube.com/channel/UCHnyfMqiRRG1u-2MsSQLbXA).

Chris Kennedy came up with:

"Solution to Veritasium Speed of Light test"

(once again too many capitals)

(see https://www.youtube.com/watch?v=O2T2fQZZ0uE).

I think his solution is a bit difficult and far fetched.

Below is my vision.

2023-11-20: see also: http://henk-reints.nl/astro/HR-two-speeds-of-light.pdf

What <u>IS</u> the speed of light?

I see it **not** as the velocity at which light propagates,

but as the ***ratio***

of   that what we perceive as   *distance*

and   that what we perceive as   *time.*

This makes it a very fundamental characteristic of the universe. A beam of light merely gets it pushed down the throat. It just <u>**has**</u> to go exactly that fast.

Measuring the speed of light in different directions at the same point in time cannot ever be done with a single photon.

One might think the same photon can be observed in two directions if it bounces back on a mirror, but then it is not measured at a single point in time.

Observation of a photon passing at a distance is however as good as impossible, *e.g. you cannot see light without it getting into your eye*. It is practically unfeasable to observe a photon without absorbing (i.e. destroying) it.

You MUST measure different photons and then it is irrelevant if it is done at a single location or at the very same single point in time (*apart from the fundamental question if that is possible at all*) or not.

A reliable result will always be the average of a (large) number of measurements. Advantage thereof is that it also yields a standard deviation (something like the average deviation from the overall average), yielding information about the accuracy of the experiment.

Every measurement has some uncertainty.

You can for example never measure
THE temperature in your living room.

You would need to place a thermometer
at each and every thinkable[1] location in it
& if they are accurate enough,
they **will** show different values.

And is it then still your living room or did it
turn into a chock full thermometer room
with no place for anything else?

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[1] I think you can think somethink unthinkable. Wasn't the Thinktanic an unthinkable think?

One way of determining the speed of light is
to measure the time light takes to travel some distance
and then divide this distance by the measured time.

The larger this distance, the more accurate the result will be,
but it always yields the **average** speed of light during its journey.

It might have varied during the measurement,
e.g. it could have been different going back & forth.

You did not measure it at a single point in time,
nor whether it is the same in all directions.

That is what Derek's video is all about.

But I insist you **did** measure the speed of light.

For such a measurement, light is usually sent to some distant mirror which reflects it back to your measuring device.

Another setup could be as follows.

One light source and one detector at some distance.
Both send acknowledgments of emission and reception
via identical cables to some central device that
measures the time between them with one single clock.
If the distance is great, inaccuracies become negligible.

It remains however that it is not at a single point in time,
but during some time span, yielding an average value.

As always, one should not rely on a single measurement.

It should be repeated several times to obtain accurate results.
And both identical cables should be exchanged many times in
order to avoid a bias.

If an experiment is repeated several times a day,
Earth's axial rotation ensures the measurement is
done in various directions in the equatorial plain.

If the setup itself is rotatable,
one can measure in practically any direction.

**If many measurements in many directions
always yield the same result (within a given tolerance),
one CAN say it is the same at any point in time in all directions.**

A totally different way of determining the speed of light is by using stellar aberration. It does not measure any time interval.

The earth orbits the sun at a velocity of about 1/10 000 of the speed of light, definitely yielding measurable effects.

We'll consider it as seen from Earth, and then a star or planet seemingly moves in the opposite direction at the same speed.

We observe it were it was when it emitted the light, but this light took some time to travel towards us, so at the moment of observation it no longer is at that location.

Based on many many many measurements of the motion of celestial bodies, we can accurately calculate were it actually is.

The angle between observed & calculated positions equals the ratio of Earth's orbital velocity & the speed of light. Bingo!

But now I'm using some calculated value, that's not measuring!

Well, wasn't it derived from loads of measured values?

> *We often discussed his notions on objective reality. I recall that during one walk Einstein suddenly stopped, turned to me and asked whether I really believed that the moon exists only when I look at it.*

Einstein's biographer Abraham Pais in Reviews of Modern Physics, 51, 863 (1979): 907.

Stellar aberration yields the speed of light at
one point *(more or less, but more less than more)*
in time in just one direction (i.e. from there to here).

Measuring aberration is one of the many heavenly things
that keep astronomers safely inside their observatories
without causing any harm to the rest of mankind.

They **do** measure the same speed of light
every time & in all directions.

A speed radar measures the Doppler effect
of a radar signal reflecting back from your car.

This Doppler effect depends on the ratio of
your car's velocity and the speed of light.

If you know one of them, you measure the other.

Reading your car's velocity on the dashboard
enables determination of the speed of light.

Let's do some maths.

Suppose the speed of light towards your car is c_0,
that of the reflection is c_1, and the car's velocity
equals v, positive if away from the measuring device.

Even *your* car is very slow: $v \ll c_0$ & $v \ll c_1$, so we'll use the classical
Doppler effect, i.e. without taking Einstein's relativity into account.
We also presume $\{v, c_0, c_1\}$ are all w.r.t. the stationary radar gun.

If the radar gun (at rest) emits a frequency f_0 at c_0,

the (moving) car receives: $f_1 = \dfrac{c_0 - v}{c_0} f_0$, which is reflected at c_1.

The radar gun (at rest) then receives: $f_2 = \dfrac{c_1}{c_1 + v} f_1 = \dfrac{c_1}{c_1 + v} \cdot \dfrac{c_0 - v}{c_0} f_0$

so the total Doppler effect is: $\dfrac{f_2}{f_0} = \dfrac{c_1 (c_0 - v)}{c_0 (c_1 + v)} = \dfrac{c_1}{c_0} \cdot \dfrac{\frac{c_0}{c_0} - \frac{v}{c_0}}{\frac{c_1}{c_0} + \frac{v}{c_0}}$.

With: ξ (Greek letter xi) $:= \dfrac{c_1}{c_0}$ & $\beta := \dfrac{v}{c_0}$ this becomes: $\dfrac{f_2}{f_0} = \xi \dfrac{1 - \beta}{\xi + \beta}$.

For: $0 \leq \beta \ll 1$, we obtain next graph:
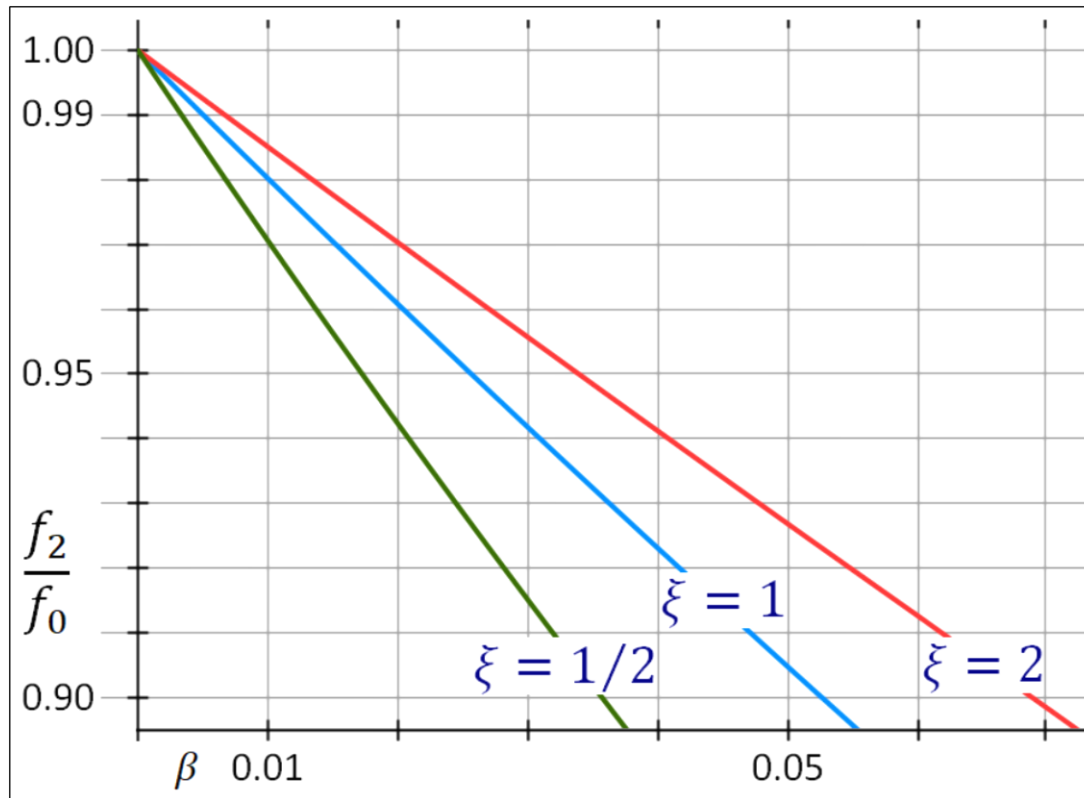
The magnitude of the Doppler effect clearly depends on the ratio of the speed of light in both directions, even at a small velocity.

There you are, and therefore, my dear dareful Derek, I dare to say they're there to use their radar not to see if your car there dares to go faster than the wind right there, they're there to use their radar to confirm they're right with their suspicion there is just one single speed of light in all directions they're observing there and their daring dairyman dares to ask if you dare say they're wrong with their conclusion made there.

The police in many countries confirm there is just one speed of light.

Or would they have some top secret correction built into their radar guns?

And then we have the Global Positioning System.

Those satellites know their own position with an accuracy of *well* below 25 cm and they have an on-board atomic clock. They constantly "shout" their time and position to us.

Based on the differences in signal travel time, your smartphone can calculate its own position here on earth within 8 metres (in 95% of open-field measurements).

We can never exactly calculate gravitational movement over a long period, so they are tracked using reflected laser beams. They receive daily updates to maintain their accuracy. Their clocks have — by design — been corrected for relativistic effects and of course they are recalibrated whenever necessary.

In fact, GPS implicitly *does* continuously measure the one-way speed of light in all directions and its worldwide $52 \times 7 \times 24$ accuracy tells it has the same value at all times in all directions.

But any measurement is done on or near Earth.

Do we actually *know* the speed of light at a (very) great distance?

Communication with devices on the moon and especially those on mars appears to be consistent with a constant speed of light, thus extending this measurement domain.

And what about the good old Voyagers 1 & 2? Both are considered to have left the solar system and they still are communicating with us. To my knowledge their timing is in agreement with a constant speed of light.

Astronomers observe similar phenomena practically everywhere they look. This suggests that the laws of nature, including the speed of light, are the same throughout the cosmos.

What if we could derive fully consistent equations
from many verifiable experimental results,
never ever yielding any significant error?

What if those equations would then predict
the speed of light as a true constant of nature?

Do we then still <u>need</u> to measure it?

Or are we just looking for confirmation of the obvious?

As far as electricity & magnetism are concerned,
such equations actually **<u>do</u>** exist
& they never miss the point
& they never missed a point.

James Clerck Maxwell, 1864:

VIII. *A Dynamical Theory of the Electromagnetic Field.* By J. CLERK MAXWELL, F.R.S.

Received October 27,—Read December 8, 1864.

Philosophical Transactions of the Royal Society of London, 155: 459–512.

Found small set of equations for ALL of electricity & magnetism.

Everything electric/magnetic works according to it.

Microwave ovens, smartphones, radios, TVs, electric motors, oldfangled bicycle dynamos, lightning, radar, maglev trains, computers, radio telescopes, transformers, you name it.

ALL were designed [lightning?] using Maxwell's equations
(or derivations thereof).

You don't need to understand

Maxwell's equations:

$$\nabla \cdot \vec{E} = \frac{\rho}{\varepsilon_0} \qquad \nabla \times \vec{E} = \qquad \frac{\partial \vec{B}}{\partial t}$$

$$\nabla \cdot \vec{B} = 0 \qquad \nabla \times \vec{B} = \mu_0 \vec{J} + \varepsilon_0 \mu_0 \frac{\partial \vec{E}}{\partial t}$$

but you should notice $\boldsymbol{\varepsilon_0}$ (epsilon-nought) & $\boldsymbol{\mu_0}$ (mu-nought).

They are velocity independent constants of nature,

indicating how easy an electric or magnetic force
can pierce through the (empty) space between
two electrically charged things or two magnets.

They are considered properties of empty space.

Maxwell found:

possibility of electromagnetic waves

(first conclusive experimental proof was given by Heinrich Hertz)

propagating at a speed of

$$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$$

Example:
two magnets exert a force at a distance on one another;
moving one of them changes the force felt by the other;
it is this change that propagates at the speed found by Maxwell.

Maxwell wrote:

By the electromagnetic experiments of MM. WEBER and KOHLRAUSCH *,

$$v = 310,740,000 \text{ metres per second}$$

is the number of electrostatic units in one electromagnetic unit of electricity, and this, according to our result, should be equal to the velocity of light in air or vacuum.

The velocity of light in air, by M. FIZEAU's † experiments, is

$$V = 314,858,000:$$

according to the more accurate experiments of M. FOUCAULT ‡,

$$V = 298,000,000.$$

The velocity of light in the space surrounding the earth, deduced from the coefficient of aberration and the received value of the radius of the earth's orbit, is

$$V = 308,000,000.$$

(he used v & V instead of c)

Maxwell continues:

(97) Hence the velocity of light deduced from experiment agrees sufficiently well with the value of v deduced from the only set of experiments we as yet possess. The value of v was determined by measuring the electromotive force with which a condenser of known capacity was charged, and then discharging the condenser through a galvanometer, so as to measure the quantity of electricity in it in electromagnetic measure. The only use made of light in the experiment was to see the instruments. The value of V found by M. FOUCAULT was obtained by determining the angle through which a revolving mirror turned, while the light reflected from it went and returned along a measured course. No use whatever was made of electricity or magnetism.

The agreement of the results seems to show that light and magnetism are affections of the same substance, and that light is an electromagnetic disturbance propagated through the field according to electromagnetic laws.

Entirely different experiments yielding the same value!
He did not believe this was a fluke (neither does any modern physicist).

Both Fizeau and Foucault actually measured

average speed of light during its entire journey

to a distant mirror (Foucault: ~8 km) and back.

It might have varied while it was on its way,

e.g. unequal when leaving and returning.
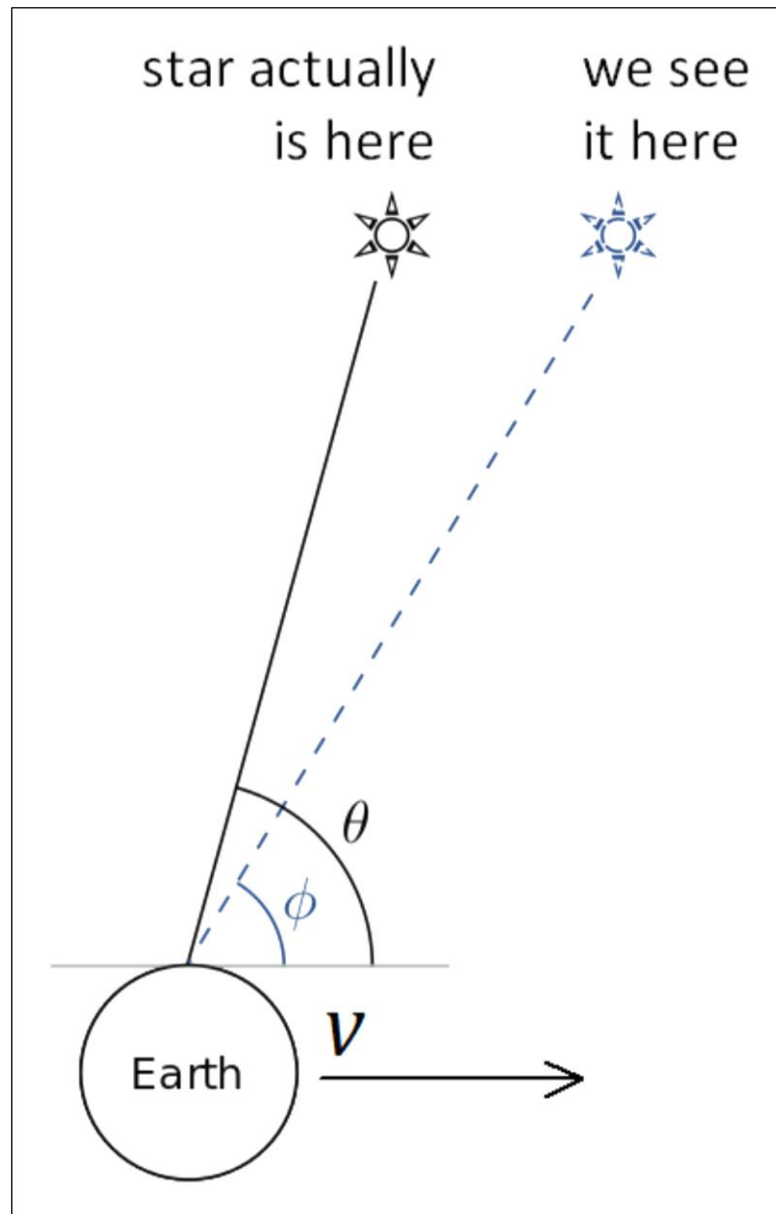
The last value Maxwell gives is based on stellar abberration.

Due to Earth's velocity in combination with the finite speed of light, we see a star at another position than where it actually is,

from which we can derive the speed of light w/o reflection on a mirror.

Hopefully, you see that Maxwell's equations

(to be considered true, since <u>everything</u> electric/magnetic

flawlessly works according to them)

leave room for just one speed of light:

$$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$$

Modern value: 299 792 458 m/s

(which today is an exact value since it has been defined as such;
the metre is defined as the distance light travels in 1/299 792 458 seconds).
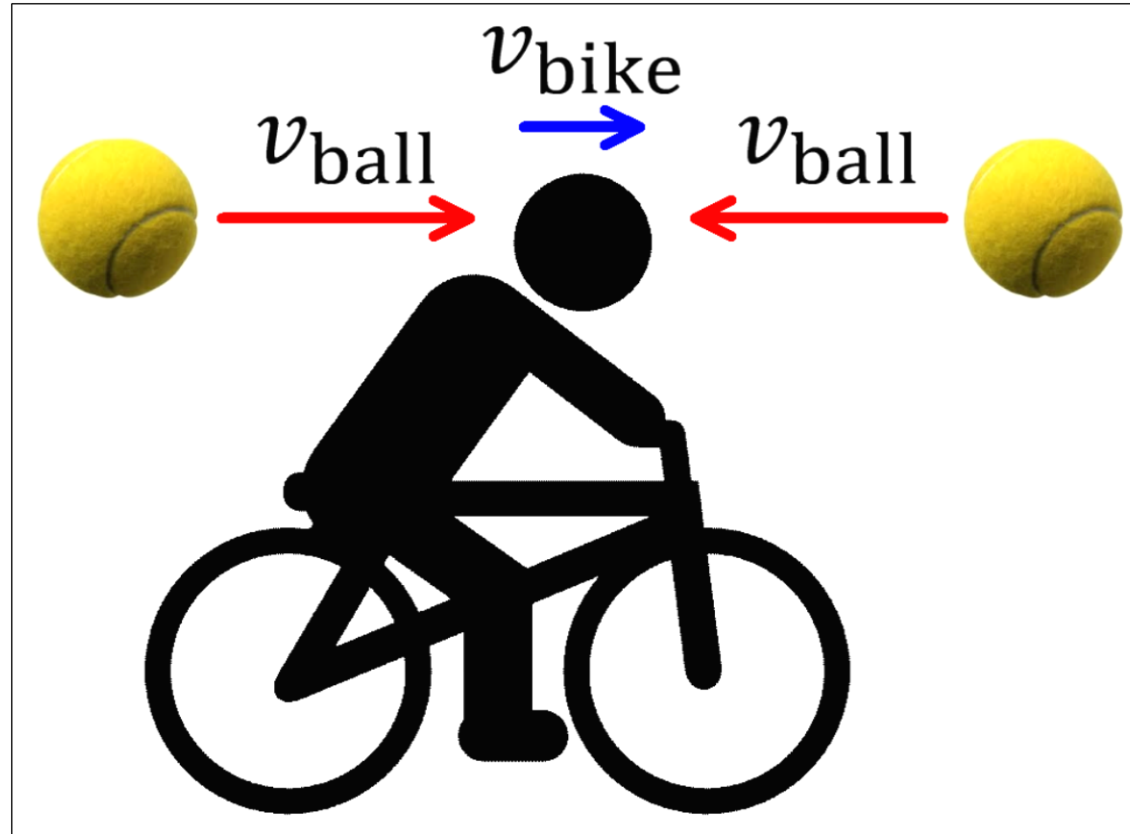
But with respect to what?

Speed always is w.r.t. some reference point, which ultimately must be a 𝔱𝔥𝔦𝔫𝔤.

You cannot have any velocity with respect to vacuum.

Speed w.r.t. nothing is meaningless
and has no value at all, **not even zero**.

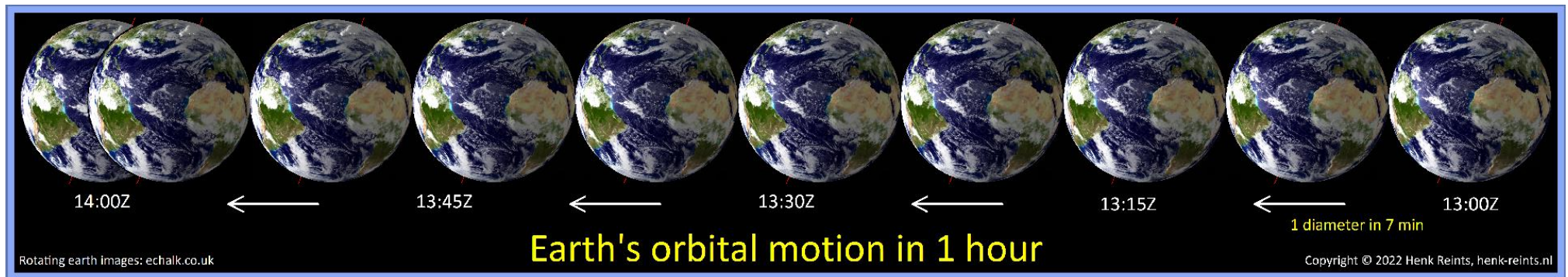Thought since Aristotle: light propagates through a medium called the luminiferous aether.

$$v_{\mathrm{hit}} = v_{\mathrm{ball}} - v_{\mathrm{bike}} \qquad\qquad v_{\mathrm{hit}} = v_{\mathrm{ball}} + v_{\mathrm{bike}}$$

forehead receives a harder hit than occiput;
the head "measures" two different ball velocities.

Earth orbits the sun at greatest possible speed that could be used in 19th century experiments:

14:00Z ← 13:45Z ← 13:30Z ← 13:15Z ← 13:00Z

1 diameter in 7 min

Earth's orbital motion in 1 hour

Rotating earth images: echalk.co.uk

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29.78 km/s ≈ 107 200 km/h ≈ 8.4 × Earth's diameter in 1 hour
(yes, that is how fast we orbit the sun)

Should feel an "aetherwind"

that differs in forward & backward directions.
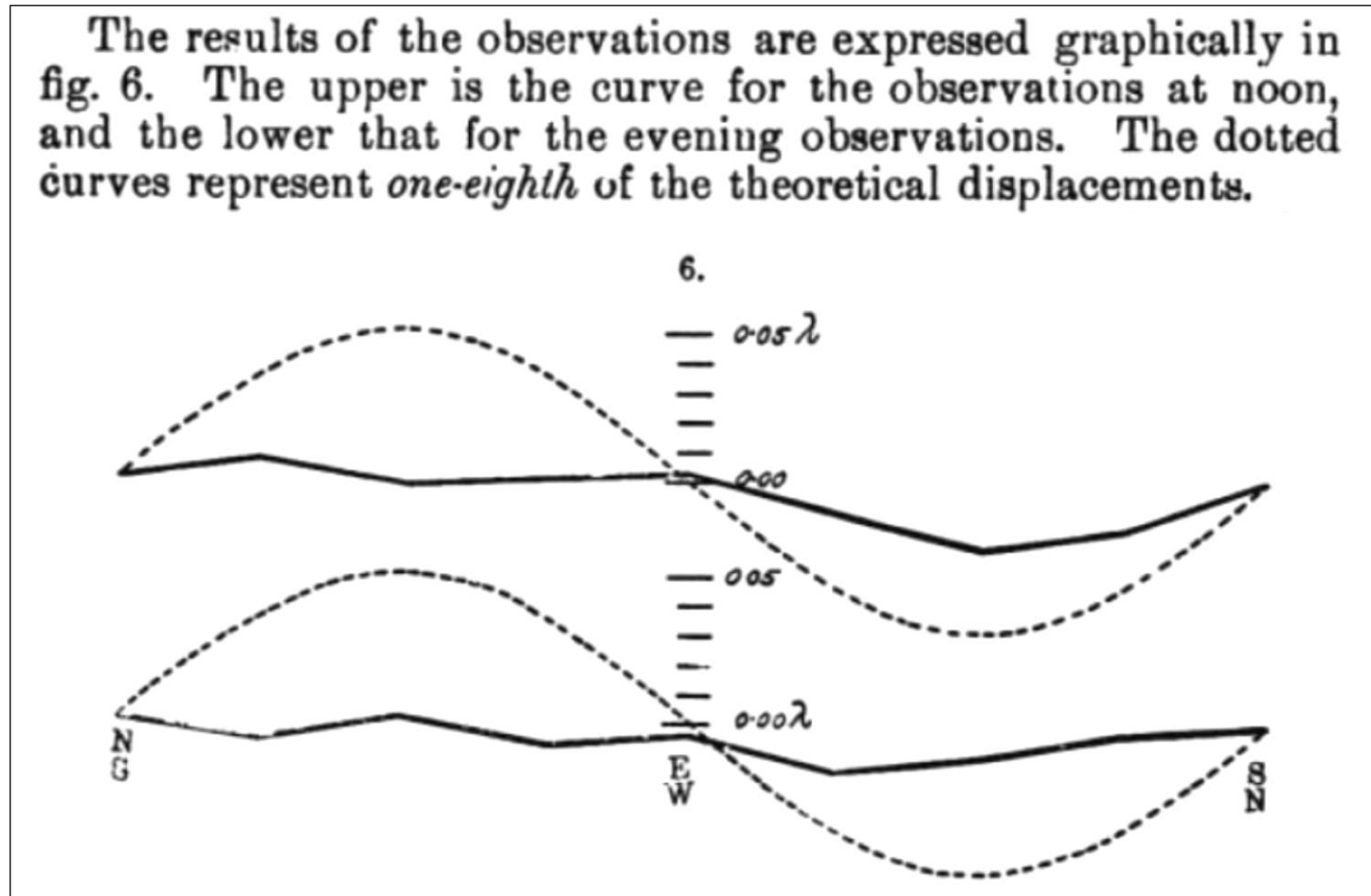
Michelson & Morley (1887):

essentially measured differences in speed of light
in Earth's orbital direction and perpendicular to it,
assuming equality w.r.t. the aether in all directions;

used very accurate interferometer;

could rotate it in any (horizontal) direction;

used fact that noon & evening measurements
are perpendicular to one another
due to Earth's axial rotation.

Michelson & Morley's result:

The results of the observations are expressed graphically in fig. 6. The upper is the curve for the observations at noon, and the lower that for the evening observations. The dotted curves represent *one-eighth* of the theoretical displacements.

American Journal of Science 203 (Nov. 1887): 332-345.

Sweet Fanny Adams, diddly squat, zilch.

The sinusoidial curves (showing expected values)

should actually swing eight times

more than drawn, so measured

difference equals zero in all directions.

Nobody understood it,

but conclusion must be:

same speed of light measured in all directions,

independent of Earth's motion around the sun.

Albert Einstein's cleverness was to
not try to explain it, but draw a conclusion from it:

Wir setzen noch der Erfahrung gemäß fest, daß die Größe

$$\frac{2\,\overline{A\,B}}{t'_A - t_A} = V$$

eine universelle Konstante (die Lichtgeschwindigkeit im leeren Raume) sei.

Annalen der Physik 17 (1905): 891-921.

We further establish in agreement with experience that the quantity V be a universal constant (the speed of light in empty space).

Please note: he defined V as a back & forth velocity.

Fact of your own experience:

in any type of vehicle (car, train, whatever),
everything works the very same way as when standing still,
independent of the vehicle's speed or direction,
as long as it is moving smoothly with no sudden changes.

Einstein expressed this in his *relativity principle* (1st postulate):

> 1. Die Gesetze, nach denen sich die Zustände der physikalischen Systeme ändern, sind unabhängig davon, auf welches von zwei relativ zueinander in gleichförmiger Translationsbewegung befindlichen Koordinatensystemen diese Zustandsänderungen bezogen werden.

The laws by which the states of physical systems undergo changes are independent of which one of two coordinate systems, in uniform translational motion relative to each other, these state changes are referred to.

It says that *all laws of nature*

appear identical to you and me

as perceived from our own perspective,

no matter how fast we move

with respect to one another,

as long as that motion does not change.

The laws of nature travel with you & they travel with me.

The *speed of sound* under water is about four times greater than in air, so it is not a property of the *sound itself*, but of the *medium* through which it propagates.

It also is not a property of the sound *source,* which can cause only a single point of the medium to oscillate and it is the medium itself that transports this oscillation.

Similarly, the **speed of light** is **not a property of light**, nor of the light source.

Not any **wave velocity depends on the source's speed.**

It implies the motion of a sound or light ***source*** does not affect the speed of the sound or light ***itself***.

Speed (not pitch) of sound independent of velocity of sound source:

So pocht das Schicksal

an die Pforte
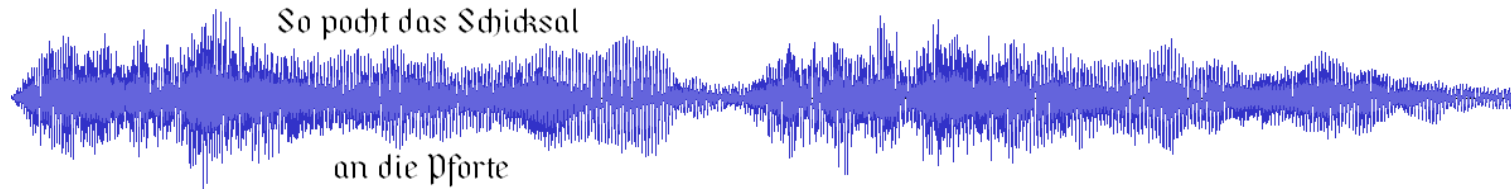
100 km/h
(in a car)

same speed of sound to each observer who does not move
w.r.t. the medium through which the sound propagates.

Speed (not color) of light independent of velocity of light source:

1090 km/s
z = 0.003642
(redshift)
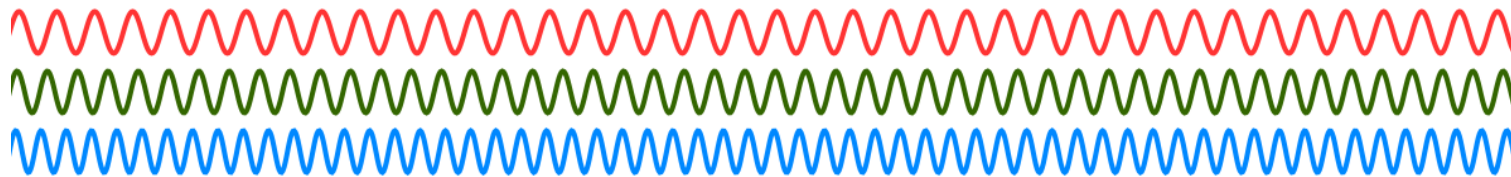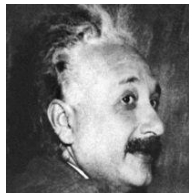
same speed of light to each observer who does not move
w.r.t. the vacuum through which the light propagates.

Since NOTHING & NOBODY can move w.r.t. vacuum,
the speed of light is identical to each & every observer.

It essentially is the *vacuum* (Latin for *emptyness*) itself
that manifests identically to each & every observer.

It contains nothing by which it could reveal any difference.

It does not have any reference points,
so it cannot **have** any velocity (not even zero!),
but it cannot **manifest** something else
than zero w.r.t. each & every observer.

This simply implies the
same speed of light to all <u>observers</u>.

1) ***Any*** wave velocity is always with respect to medium, independent of any movement of source or observer.

2) If observers do not move w.r.t. medium, wave velocity is obviously same w.r.t. all observers.

3) Light has ability to propagate through vacuum, i.e. use empty space as a medium, ***no matter how and why it is able to do so.***

4) Not any observer can move w.r.t. vacuum, so all measure same *speed of light* in empty space.

5) The above suffices to explain M&M's result without ***any*** length contraction. As explanation of M&M, the latter is even inconsistent with a constant *speed of light*.

Einstein expressed this in the *principle of the constancy of the speed of light* (2nd postulate):

> 2. Jeder Lichtstrahl bewegt sich im „ruhenden" Koordinatensystem mit der bestimmten Geschwindigkeit V, unabhängig davon, ob dieser Lichtstrahl von einem ruhenden oder bewegten Körper emittiert ist.

Annalen der Physik 17 (1905): 891-921.

Each ray of light moves in the "stationary" system of coordinates with the determined velocity V, independent of whether this ray is emitted by a body at rest or in motion.

It essentially says that each and every observer perceives identically the same speed of light, from his own perspective, independent of any motion of the light source.

From his two _fact based_ postulates,
Einstein derived his so called

special theory of relativity

by _deduction_ only, _without_ any _assumptions_.

In his very next writing, he refers to his former paper and repeats his 1st postulate, the _relativity principle_, but not his 2nd, the _principle of the constancy of the speed of light_. Instead, he writes a footnote:

> 2) Das dort benutzte Prinzip der Konstanz der Lichtgeschwindigkeit ist natürlich in den Maxwellschen Gleichungen enthalten.

Annalen der Physik 18 (1905): 639-641.

The there used principle of the constancy of the speed of light is of course contained in Maxwell's equations.

Einstein had seen the light.

He did not need to *postulate* the
principle of the constancy of the speed of light,
since it follows from Maxwell's equations.

As said, these allow for just one speed of light:

$$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$$

which is independent of <u>any</u> velocity,
since both ε_0 & μ_0 are fully speed independent.

Einstein's postulates together say that you & I always perceive the same speed of light, independent of our mutual velocity, even if we measure the very same ray of light.

If we now use this constant speed of light as a starting point, it appears that we will have a different perception of *time* when we are in (fast) motion w.r.t. to one another.

Effectively, we both have our own time frame and each of us measures the speed of light in 𝔥𝔦𝔯[2] own frame.

For both of us, everything is completely normal, except the other one, whom we consider 𝖓𝖔𝖓 𝖈𝖔𝖒𝖕𝖔𝖘 𝖒𝖊𝖓𝖙𝖎𝖘.

The difference in our time frames is such that we both measure the same speed of light.

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[2] In order to also phonetically make it gender neutral it should be pronounced with the **i** as in 𝔱𝔥𝔦𝔠𝔨.

This difference in time frames also makes that if for example a WITCH is passing you at a great velocity, her broom appears shortened in the direction of motion.

The faster it goes, the shorter it becomes, but only for you, the stationary observer, not for that WITCH.

From your own perspective you are always stationary and the *street* is passing *you*. The faster you go, i.e. the faster the street is passing you, the shorter it will become for you, but not for itself! Since it cannot become shorter than zero, **you cannot go faster than light.**

Moreover, wouldn't it be senseless to try going faster if the street already has a zero length?

Finally:

if Maxwell's equations, based on many

measurements of electricity & magnetism,

and which are fully consistent with the working

of all electric/magnetic devices or phenomena,

allow for just one speed of light,

then we must presume it is correct

& need only to *check* its *value* by measurement.

So why consider the impossibility of two

different speeds of light going back & forth?

Because physicist are curious and want to be certain,
so they do their utmost to confirm everything by measurements.