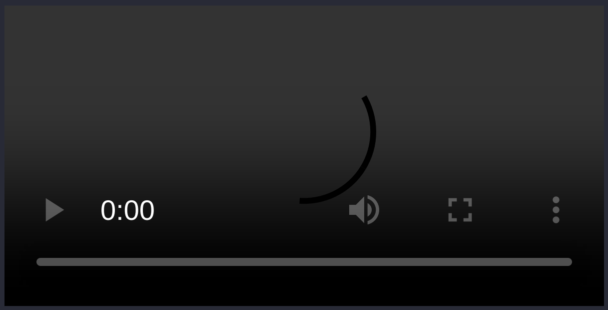
How Math Met Reality



Note:

The purpose of this presentation is to give someone who doesn't know anything about Relativity or Spacetime and give them the foundational building blocks to understanding Einstein's General Theory of Relativity and the observational and experimental evidence that's put forward for the theory.

Note: Well, this is the story all about how, math and reality got turned upside down.

Special Theory:

$$c \pm v = c$$

General Theory:

$$c \pm v \neq c$$

Note: The battle for your mind and control of the sky

- Kinematics
- Dynamics

Note:

To understand the scope and history;

two important concepts:

The Newtonian procedure for predicting the future, given the present, has two parts, *kinematics* and *dynamics*. Kinematics is a complete description of the present. It's a list of what you have to know about a system right now. For example, if you're talking about a piece of chalk, you will want to know where it is and how fast it's moving. Dynamics then tells you why the chalk goes up, why it goes down, and so on. It comes down due to the force of gravity. In kinematics, you don't ask for the reason behind anything. You simply want to describe things the way they are, and then dynamics tells you how and why that description changes with time.

Note:

- Kinematics and Dynamics is a very important concept in physics
- Kinematics - Measurements and predictions of future motion based on the measurements. NO regard for causal mechanism
- Dynamics - Predictions of future motion based on actual forces in a system

https://byjus.com/physics/kinematics-examples-in-real-life/

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1) $v = v_0 + at$

2) $\Delta x = \left(\frac{v+v_0}{2}\right)t$

3) $\Delta x = v_0 t + \frac{1}{2}at^2$

4) $v^2 = v_0^2 + 2a\Delta x$

Note:

Changes in velocity over time

Change in location over time

Acceleration

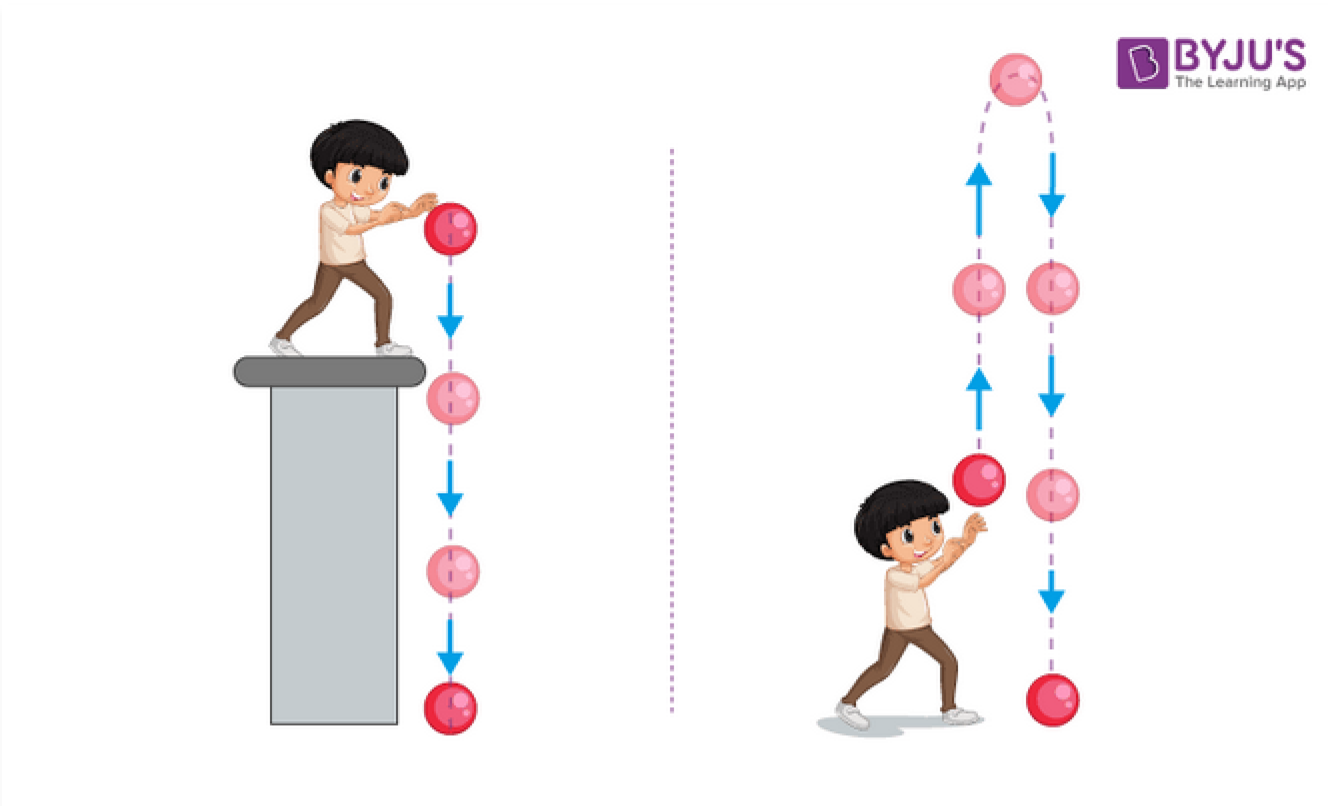
No casual mechanism, just when/where and how fast

https://byjus.com/physics/kinematics-examples-in-real-life/

Vertical Motion:

It is defined as motion in a vertical plane.

The motion of free-falling objects is the best example of vertical motion. Here acceleration is always 9.8 m/s^2.



Note:

> *If a guy jumps off a tall building, we want to know when, and with what speed, he will land. We don't ask why this guy is ending it all today; that is a question for the psych department. So we don't answer everything. We ask very limited questions about inanimate objects, and we*

> *brag about how accurately we can predict the future.*
> **- Shankar, 2019 Fundamentals of Physics,**

We can tell you all about the motion re: from the time of displacement to impact, but not the casual mechanism. Analogous to gravity.

You can take partial derivatives wrt to time to figure out the acceleration at any given moment

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Chapter 1

Introduction: Principles of Dynamics

Principles of Dynamics is a subset of Mechanics that deals with bodies in motion under the action of forces. The subject of Dynamics is completely captured by *Newton's Second Law*, $\sum \vec{F} = m\vec{a}$. To study Dynamics, we must be able to handle correct force analysis. In the book, "*Difficult Engineering Concepts Better Explained: Statics and Applications*,"[1] a vigorous method of force analysis, named the ABCC method for constructing correct free-body diagrams, is presented. We will present the key elements of the ABCC method in Chapter 2.

Notes:

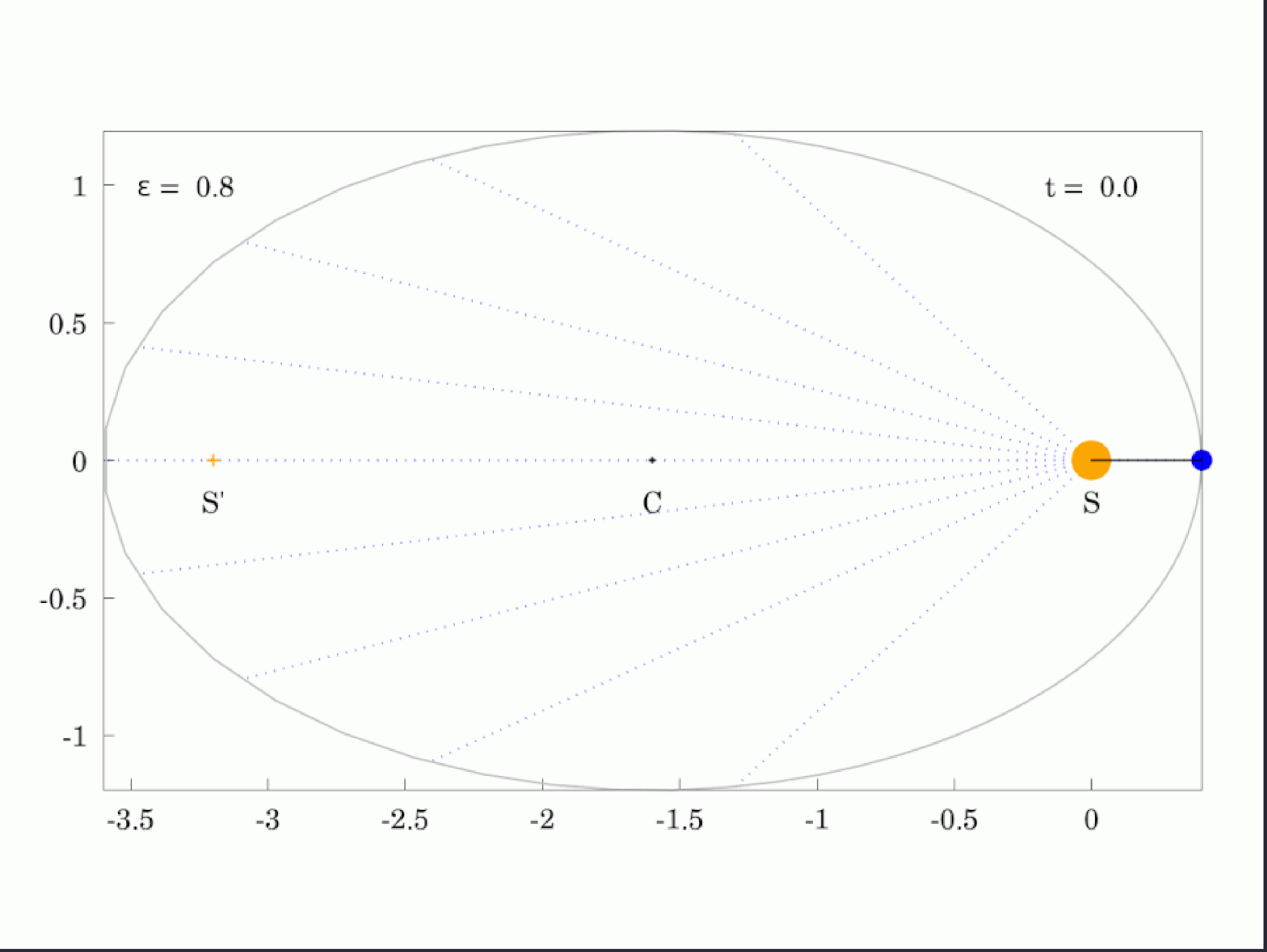
Dynamics; understanding the WHY part of the motion

- Accounting for actual forces

Analogy:

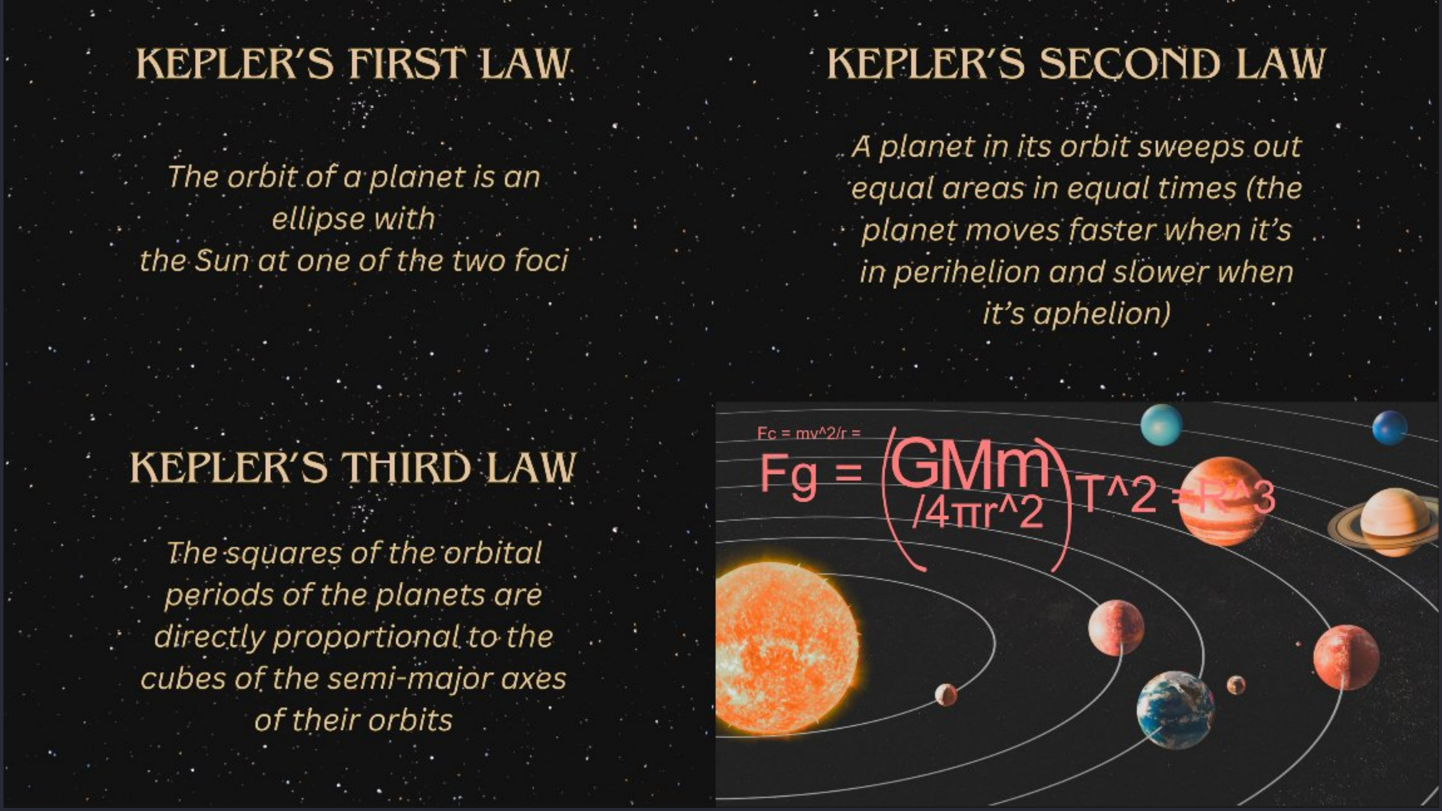
Dynamics - Why the man jumped?

What was the casual force?



Note:

- Foci - S and S'
- ε - eccentricity varies from 0 - 1
- 0 = perfect circle
- 1 = straight line

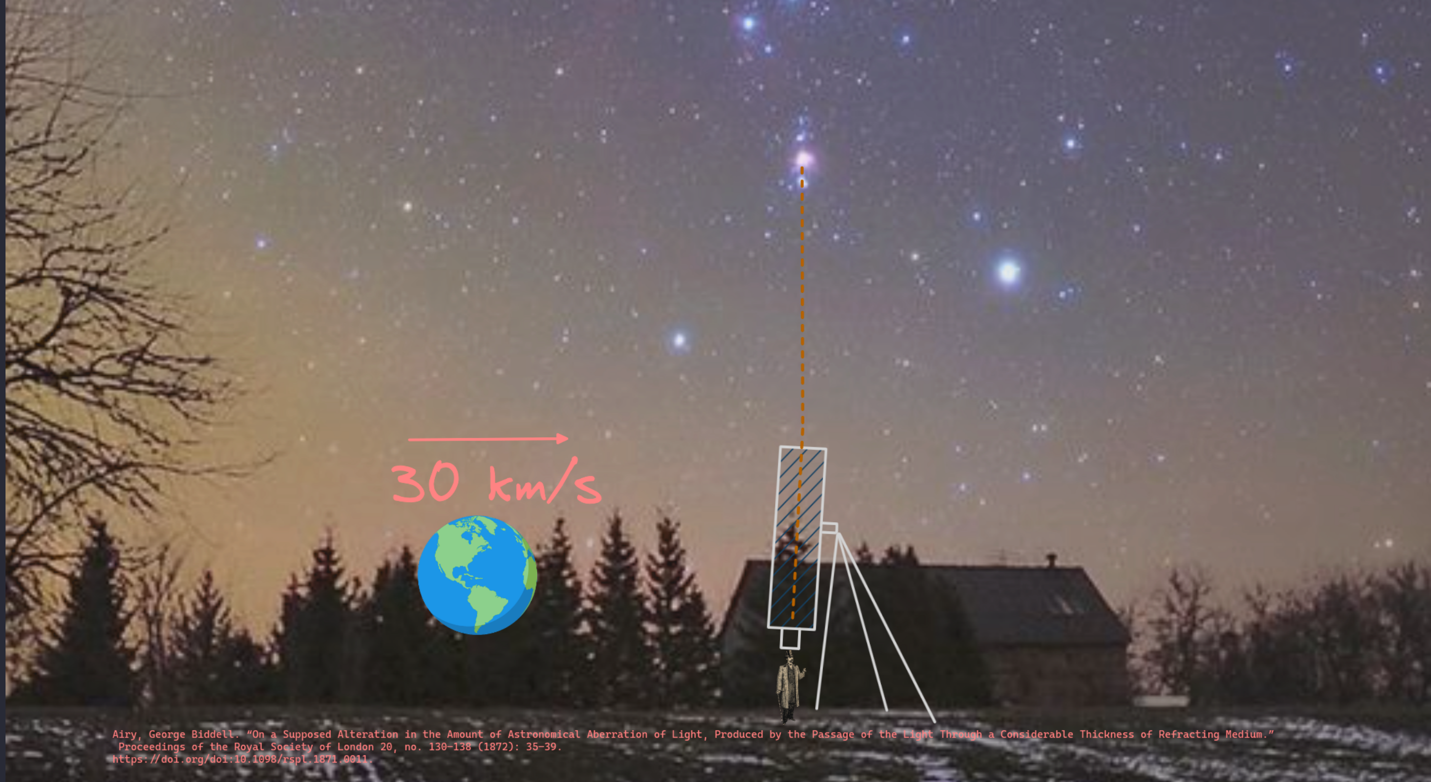


Note: Intro to Kinematics of the sky

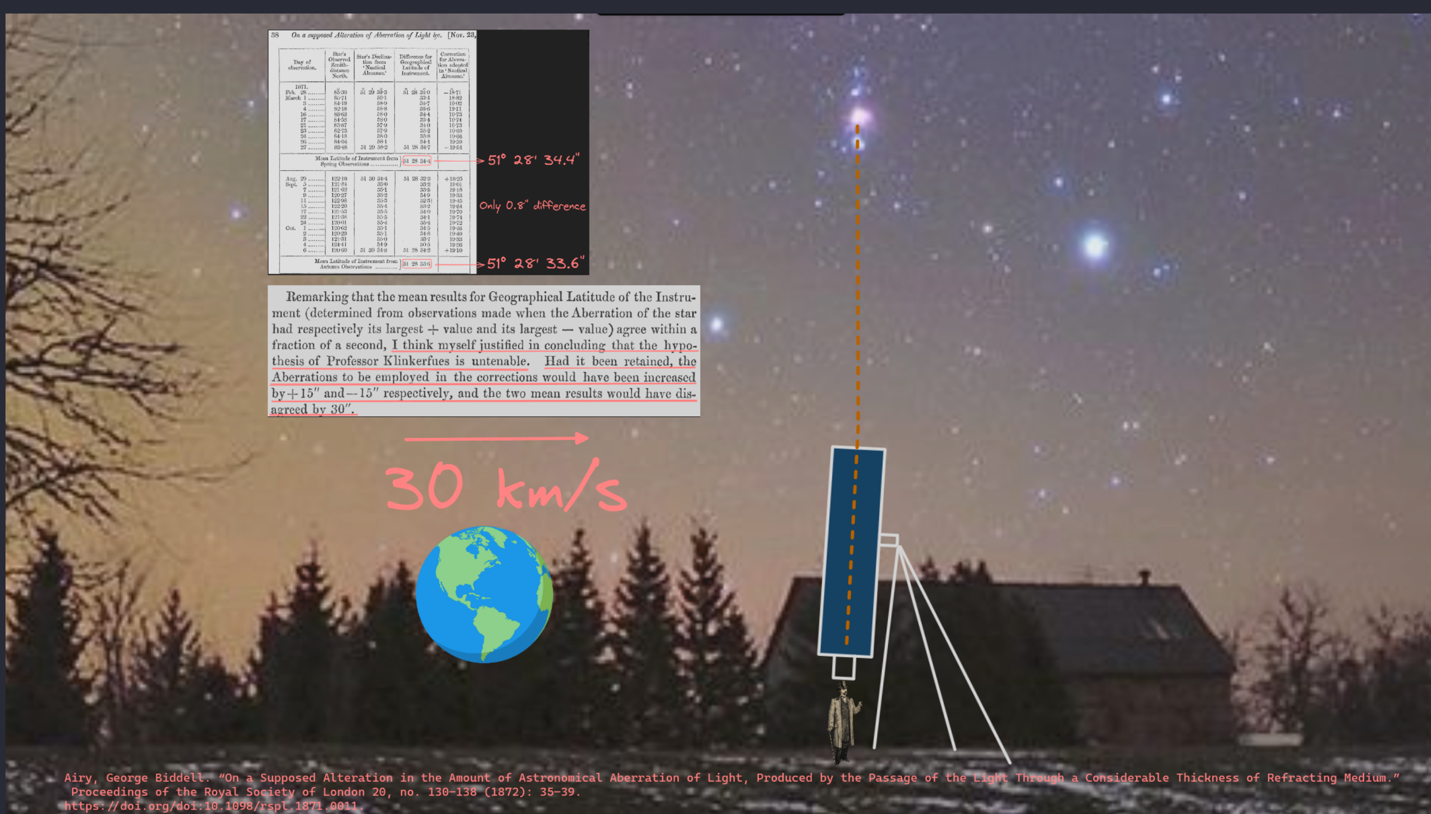
Measurements of how long takes its for a light in the sky for it to return to its original location of the first measurement.

Go to interactive slide - **Kepler's Casual mechanism**

- Kinematic
- Supposed to produce a velocity of 30 km/s
- little m's cancel out
- only constants and proportional ratios to those constants
- Kinematics disguised as dynamics



Note: Attempts to test the dynamics of the Kepler and Newtonian model i.e. Does Earth have a velocity to begin with so we can know our math, when applied to the sky has physical meaning?



38 *On a supposed Alteration of Aberration of Light &c.* [Nov. 23,

Day of observation.	Star's Observed Zenith-distance North.	Star's Declination from 'Nautical Almanac.'	Difference for Geographical Latitude of Instrument.	Correction for Aberration adopted in 'Nautical Almanac.'
1871.				
Feb. 28	85.30	51 29 59.3	51 28 34.0	−18.71
March 1	85.71	59.1	33.4	18.82
3	84.19	58.9	34.7	19.02
4	82.18	58.8	36.6	19.11
16	83.63	58.0	34.4	19.73
17	84.58	58.0	33.4	19.74
21	83.87	57.9	34.0	19.73
23	82.73	57.9	35.2	19.69
24	84.18	58.0	33.8	19.66
26	84.04	58.1	34.1	19.59
27	83.48	51 29 58.2	51 28 34.7	−19.54
Mean Latitude of Instrument from Spring Observations			51 28 34.4	
Aug. 29	122.10	51 30 34.4	51 28 32.3	+18.25
Sept. 5	121.84	35.0	33.2	19.01
7	121.82	35.1	33.5	19.18
9	120.27	35.2	34.9	19.33
11	122.98	35.3	32.3	19.45
15	122.20	35.4	33.2	19.64
17	121.53	35.5	34.0	19.70
22	121.38	35.5	34.1	19.74
24	120.01	35.4	35.4	19.72
Oct. 1	120.62	35.1	34.5	19.46
2	120.29	35.1	34.6	19.40
3	121.31	35.0	33.7	19.33
4	124.41	34.9	30.5	19.26
6	120.60	51 30 34.8	51 28 34.2	+19.10
Mean Latitude of Instrument from Autumn Observations			51 28 33.6	

Remarking that the mean results for Geographical Latitude of the Instrument (determined from observations made when the Aberration of the star had respectively its largest + value and its largest − value) agree within a fraction of a second, I think myself justified in concluding that the hypothesis of Professor Klinkerfues is untenable. Had it been retained, the Aberrations to be employed in the corrections would have been increased by +15″ and −15″ respectively, and the two mean results would have disagreed by 30″.

Note: Attempts to test the dynamics of the sky:

- No correction angle / no velocity
- Particle !=> Must assume light travels faster in the water to make up for the lack of correction angle

- Wave !!=> Must be carried in the opposite direction of motion by aether bouncing around in the telescope.
- => Earth is stationary wrt aether wind (0.8 arcsecond drift)

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tions and distances traversed by the rays will be altered thus:— The ray *sa* is reflected along *ab*, fig. 2; the angle *bab*, being equal to the aberration $=\alpha$, is returned along $ba_{,,}$ ($aba_{,}=2\alpha$), and goes to the focus of the telescope, whose direction is unaltered. The transmitted ray goes along *ac*, is returned along $ca_{,}$, and is reflected at $a_{,,}$ making $ca_{,}e$ equal $90-\alpha$, and therefore still coinciding with the first ray. It may be remarked that the rays $ba_{,}$ and $ca_{,}$, do not now meet exactly in the same point $a_{,,}$ though the difference is of the second order; this does not affect the validity of the reasoning. Let it now be required to find the difference in the two paths $aba_{,}$, and $aca_{,}$.

Let V = velocity of light.
v = velocity of the earth in its orbit.
D = distance *ab* or *ac*, fig. 1.
T = time light occupies to pass from *a* to *c*.
$T_{,}$ = time light occupies to return from *c* to $a_{,}$ (fig. 2.)

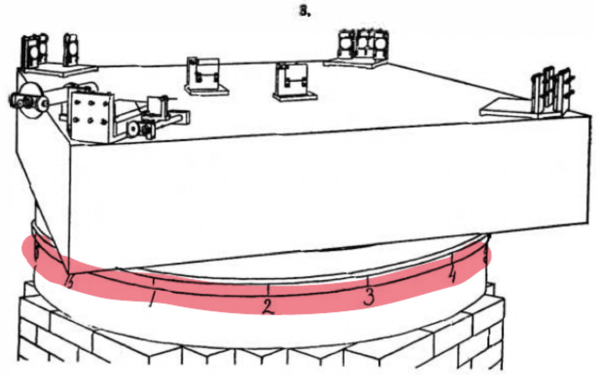
Then $T=\frac{D}{V-v}$, $T_{,}=\frac{D}{V+v}$. The whole time of going and coming is $T+T_{,}=2D\frac{V}{V^2-v^2}$, and the distance traveled in this time is $2D\frac{V^2}{V^2-v^2}=2D\left(1+\frac{v^2}{V^2}\right)$, neglecting terms of the fourth order. The length of the other path is evidently $2D\sqrt{1+\frac{v^2}{V^2}}$, or to the same degree of accuracy, $2D\left(1+\frac{v^2}{2V^2}\right)$. The difference is therefore $D\frac{v^2}{V^2}$. If now the whole apparatus be turned through 90°, the difference will be in the opposite direction, hence the displacement of the interference fringes should be $2D\frac{v^2}{V^2}$. Considering only the velocity of the earth in its orbit, this would be $2D\times10^{-8}$. If, as was the case in the first experiment, $D=2\times10^{6}$ waves of yellow light, the displacement to be expected would be 0·04 of the distance between the interference fringes.

In the first experiment one of the principal difficulties encountered was that of revolving the apparatus without producing distortion; and another was its extreme sensitiveness to vibration. This was so great that it was impossible to see the interference fringes except at brief intervals when working in the city, even at two o'clock in the morning. Finally, as before remarked, the quantity to be observed, namely, a displacement of something less than a twentieth of the distance between the interference fringes may have been too small to be detected when masked by experimental errors.

The first named difficulties were entirely overcome by mounting the apparatus on a massive stone floating on mercury; and the second by increasing, by repeated reflection, the path of the light to about ten times its former value.

The apparatus is represented in perspective in fig. 3, in plan in fig. 4, and in vertical section in fig. 5. The stone *a* (fig. 5) is about 1·5 meter square and 0·3 meter thick. It rests on an annular wooden float *bb*, 1·5 meter outside diameter, 0·7 meter inside diameter, and 0·25 meter thick. The float rests on mercury contained in the cast-iron trough *cc*, 1·5 centimeter thick, and of such dimensions as to leave a clearance of about one centimeter around the float. A pin *d*, guided by arms *gggg*, fits into a socket *e* attached to the float. The pin may be pushed into the socket or be withdrawn, by a lever pivoted at *f*. This pin keeps the float concentric with the trough, but does not bear any part of the weight of the stone. The annular iron trough rests on a bed of cement on a low brick pier built in the form of a hollow octagon.

3.



At each corner of the stone were placed four mirrors *dd ee* fig. 4. Near the center of the stone was a plane-parallel glass *b*. These were so disposed that light from an argand burner *a*, passing through a lens, fell on *b* so as to be in part reflected to $d_{,}$; the two pencils followed the paths indicated in the figure, *bdedbf* and $bd_{,}e_{,}d_{,}bf$ respectively, and were observed by the telescope *f*. Both *f* and *a* revolved with the stone. The mirrors were of speculum metal carefully worked to optically plane surfaces five centimeters in diameter, and the glasses *b* and *c* were plane-parallel and of the same thickness, 1·25 centimeter;

Note: Michelson-Morley (1887)

Testing Newtonian Dynamics of the solar system

The output of Kepler and Newton's equations is that the Earth must be moving at a velocity of 30 km/s

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means 0·02 wave-length. The rotation in the observations at noon was contrary to, and in the evening observations, with, that of the hands of a watch.

NOON OBSERVATIONS.

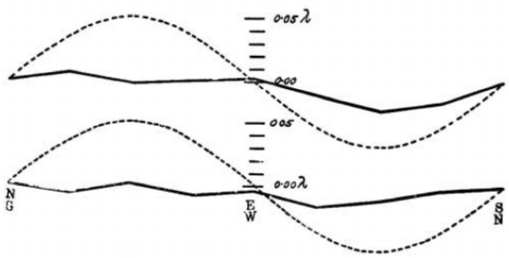
	16.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16
July 8.......	44·7	44·0	43·5	39·7	35·2	34·7	34·3	32·5	28·2	26·2	23·8	23·2	20·3	18·7	17·5	16·8	13·7
July 9.......	57·4	57·3	58·2	59·2	58·7	60·2	60·8	62·0	61·5	63·3	65·8	67·3	69·7	70·7	73·0	70·2	72·2
July 11.. ...	27·3	23·5	22·0	19·3	19·2	19·3	18·7	18·8	16·2	14·3	13·3	12·8	13·3	12·3	10·2	7·3	6·5
Mean........	43·1	41·6	41·2	39·4	37·7	38·1	37·9	37·8	35·3	34·6	34·3	34·4	34·4	33·9	33·6	31·4	30·8
Mean in w. l.	·862	·832	·824	·788	·754	·762	·758	·756	·706	·692	·686	·688	·688	·678	·672	·628	·616
	·706	·692	·686	·688	·688	·678	·672	·628	·616								
Final mean.	·784	·762	·755	·738	·721	·720	·715	·692	·661								

P. M. OBSERVATIONS.

July 8... ...	61·2	63·3	63·3	68·2	67·7	69·3	70·3	69·8	69·0	71·3	71·3	70·5	71·2	71·2	70·5	72·5	75·7
July 9.......	26·0	26·0	28·2	29·2	31·5	32·0	31·3	31·7	33·0	35·8	36·5	37·3	38·8	41·0	42·7	43·7	44·0
July 12......	66·8	66·5	66·0	64·3	62·2	61·0	61·3	59·7	58·2	55·7	53·7	54·7	55·0	58·2	58·5	57·0	56·0
Mean	51·3	51·9	52·5	53·9	53·8	54·1	54·3	53·7	53·4	54·3	53·8	54·2	55·0	56·8	57·2	57·7	58·6
Mean in w. l.	1·026	1·038	1·050	1·078	1·076	1·082	1·086	1·074	1·068	1·086	1·076	1·084	1·100	1·136	1·144	1·154	1·172
	1·068	1·086	1·076	1·084	1·100	1·136	1·144	1·154	1·172								
Final mean.	1·047	1·062	1·063	1·081	1·088	1·109	1·115	1·114	1·120								

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. It seems fair to conclude from the figure that if there is any dis-

6.



placement due to the relative motion of the earth and the luminiferous ether, this cannot be much greater than 0·01 of the distance between the fringes.

Considering the motion of the earth in its orbit only, this

displacement should be $2D\frac{v^2}{V^2}=2D\times10^{-8}$. The distance D was about eleven meters, or 2×10^7 wave-lengths of yellow light; hence the displacement to be expected was 0·4 fringe. The actual displacement was certainly less than the twentieth part of this, and probably less than the fortieth part. But since the displacement is proportional to the square of the velocity, the relative velocity of the earth and the ether is probably less than one sixth the earth's orbital velocity, and certainly less than one-fourth.

In what precedes, only the orbital motion of the earth is considered. If this is combined with the motion of the solar system, concerning which but little is known with certainty, the result would have to be modified; and it is just possible that the resultant velocity at the time of the observations was small though the chances are much against it. The experiment will therefore be repeated at intervals of three months, and thus all uncertainty will be avoided.

It appears, from all that precedes, reasonably certain that if there be any relative motion between the earth and the luminiferous ether, it must be small; quite small enough entirely to refute Fresnel's explanation of aberration. Stokes has given a theory of aberration which assumes the ether at the earth's surface to be at rest with regard to the latter, and only requires in addition that the relative velocity have a potential; but Lorentz shows that these conditions are incompatible. Lorentz then proposes a modification which combines some ideas of Stokes and Fresnel, and assumes the existence of a potential, together with Fresnel's coefficient. If now it were legitimate to conclude from the present work that the ether is at rest with regard to the earth's surface, according to Lorentz there could not be a velocity potential, and his own theory also fails.

Supplement.

It is obvious from what has gone before that it would be hopeless to attempt to solve the question of the motion of the solar system by observations of optical phenomena *at the surface of the earth*. But it is not impossible that at even moderate distances above the level of the sea, at the top of an isolated mountain peak, for instance, the relative motion might be perceptible in an apparatus like that used in these experiments. Perhaps if the experiment should ever be tried in these circumstances, the cover should be of glass, or should be removed.

It may be worth while to notice another method for multiplying the square of the aberration sufficiently to bring it within the range of observation, which has presented itself during the

Note:

Expected: 30 km/s
Measured: 5 - 6 km/s

Michelson's conclusion - more test would needed to be done throughout the year to determine the cause of the 5 - 6 km/s i.e. would the speed increase or decrease wrt the Earth's position in its orbit around the sun.

Kepler predictions the Earth slows and speeds up twice a year

Examples of this sort, together with the unsuccessful attempts to discover any motion of the earth relatively to the "light medium," suggest that the phenomena of electrodynamics as well as of mechanics possess no properties corresponding to the idea of absolute rest. They suggest rather that, as has already been shown to the first order of small quantities, the same laws of electrodynamics and optics will be valid for all frames of reference for which the equations of mechanics hold good.[1] We will raise this conjecture (the purport of which will hereafter be called the "Principle of Relativity") to the status of a postulate, and also introduce another postulate, which is only apparently irreconcilable with the former, namely, that light is always propagated in empty space with a definite velocity c which is independent of the state of motion of the emitting body. These two postulates suffice for the attainment of a simple and consistent theory of the electrodynamics of moving bodies based on Maxwell's theory for stationary bodies. The introduction of a "luminiferous ether" will prove to be superfluous inasmuch as the view here to be developed will not require an "absolutely stationary space" provided with special properties, nor

assign a velocity-vector to a point of the empty space in which electromagnetic processes take place.

B by $\frac{1}{2}tv^2/c^2$ (up to magnitudes of fourth and higher order), t being the time occupied in the journey from A to B.

It is at once apparent that this result still holds good if the clock moves from A to B in any polygonal line, and also when the points A and B coincide.

If we assume that the result proved for a polygonal line is also valid for a continuously curved line, we arrive at this result: If one of two synchronous clocks at A is moved in a closed curve with constant velocity until it returns to A, the journey lasting t seconds, then by the clock which has remained at rest the travelled clock on its arrival at A will be $\frac{1}{2}tv^2/c^2$ second slow. Thence we conclude that a balance-clock[7] at the equator must go more slowly, by a very small amount, than a precisely similar clock situated at one of the poles under otherwise identical conditions.

Note: Einstein interpretation of MMX

Claimed Earth's orbital velocity couldn't be measured because linear motion is relative, not absolute.

Absolute space slide:

No absolute space for linear motion

Gamma Factor: Length contraction and time dilation

Note:

Recapping now:

What we're witnessing in history is attempts to measure Earth's velocity around the sun

When experiment doesn't confirm hypothesis, physics is redefined to conform to hypothesis

Special notion for to treat high velocities as "Relativistic velocities" and give them special rules; length contraction and time dilation

Because established theories to keep the concept of Newtonian Dynamics alive, despite overwhelming experimental evidence that the Earth is stationary, everything now has to be canonized through the lens of Relativity

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For further simplification we want to introduce the imaginary time as a fourth variable. The field equations (16a) then take, as a first approximation, the form

$$\frac{1}{2}\sum_{\alpha} \frac{\partial^2 g_{\mu\nu}}{\partial x_{\alpha}^{2}} = \kappa T_{\mu\nu}, \tag{16b}$$

from which one sees immediately that it contains NEWTON's law as an approximation.—

Note:

1915 Proposal for introducing a "General Theory" to include gravitation and acceleration through the equivalence principle.

Eq. Princ. = Mathematically expresses an equivalence between acceleration and gravitation as a warping of Spacetime

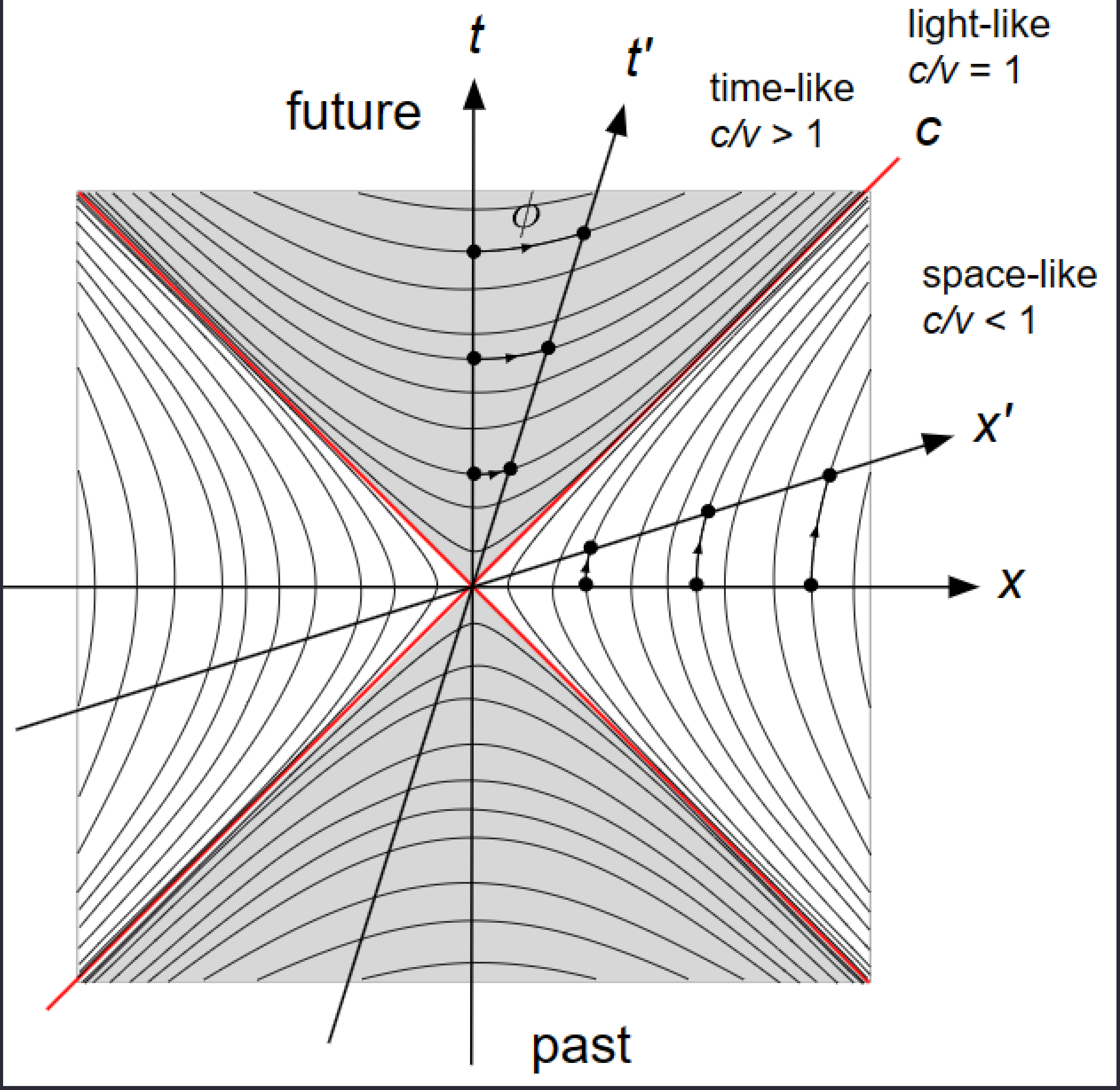
Correspondence principle - If Newton is backwards compatible Kepler, then Einstein must be able to derive Newtonian approximations from Spacetime curvature

By taking a partial derivative from the spacetime metric g_mu_nu, you can reduce the field equations to Newtonian approximations re: objects at low velocity or mass.

This is important because it's the mathematical expression extending Newtonian dynamics of the solar system to giving physical meaning Einstein's geometric expression of spacetime, from which the Newtonian dynamics emerge.

The true test of the equations has not yet been fulfilled, this is just setting the stage for how they would go about testing these equations in a meaningful way.

Let's take a few moments to learn some of the key concepts of the the general theory.



Note: How to conceptualize Spacetime

Reuse length contraction and time dilation as effects of a gravitational field or acceleration.

t = proper time
t' = dilated time wrt to [proper time]

x = [proper distance]
x' = length contracted distance wrt proper distance

In **Relativity theory, there's said to be no absolute ref. frame.** This means the suffix of "proper" given to time and distance when applied to a **coordinate system, is said to be arbitrary.**

For geometric convenience, proper time/distance are always in the rest frame.

In an example of a rotating frame, one might choose the center of the frame to compare velocities radially outward from that stationary fixed point of ref.

UNIFORM VELOCITY TRANSFORMATIONS (for motion along x-axis)

Galilean Transformations

$$x' = x - vt$$
$$y' = y$$
$$z' = z$$
$$t' = t$$

The above transformations cannot be generally valid because they fail to account for the finite speed of light and the effect of velocity on length and time standards.

Lorentz Transformations

$$x' = \frac{x - vt}{\sqrt{1 - v^2/c^2}}$$
$$y' = y$$
$$z' = z$$
$$t' = \frac{t - xv/c^2}{\sqrt{1 - v^2/c^2}}$$

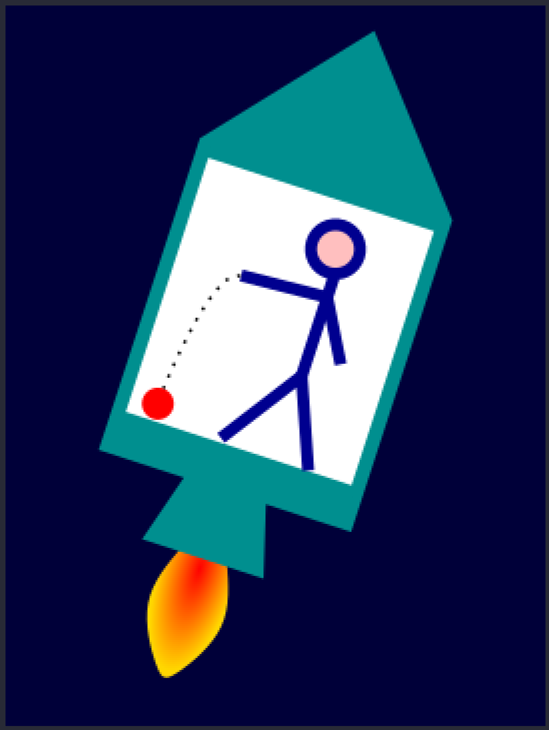
These transformations satisfactorily account for the finite speed of light and they accommodate (predict) length contraction and time dilation. To Lorentz the time *t* represents the "true time" of clocks at rest in the "preferred" ether frame; and *x* represents the corresponding "true" uncontracted lengths. To Einstein, no frame is "truer" than any other.

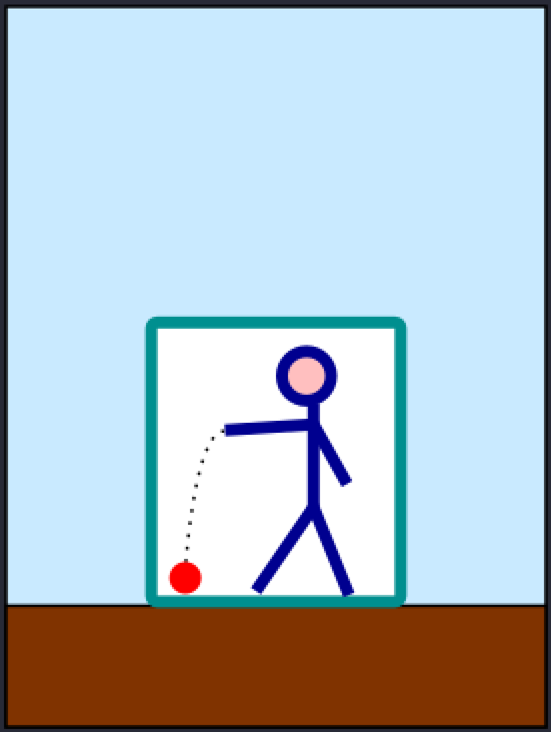
Note: Transformations

What we looked earlier is a more geometrical approach to conceptualizing Relativity theory's emergent second-order effects, i.e. Length contraction and time dilation.

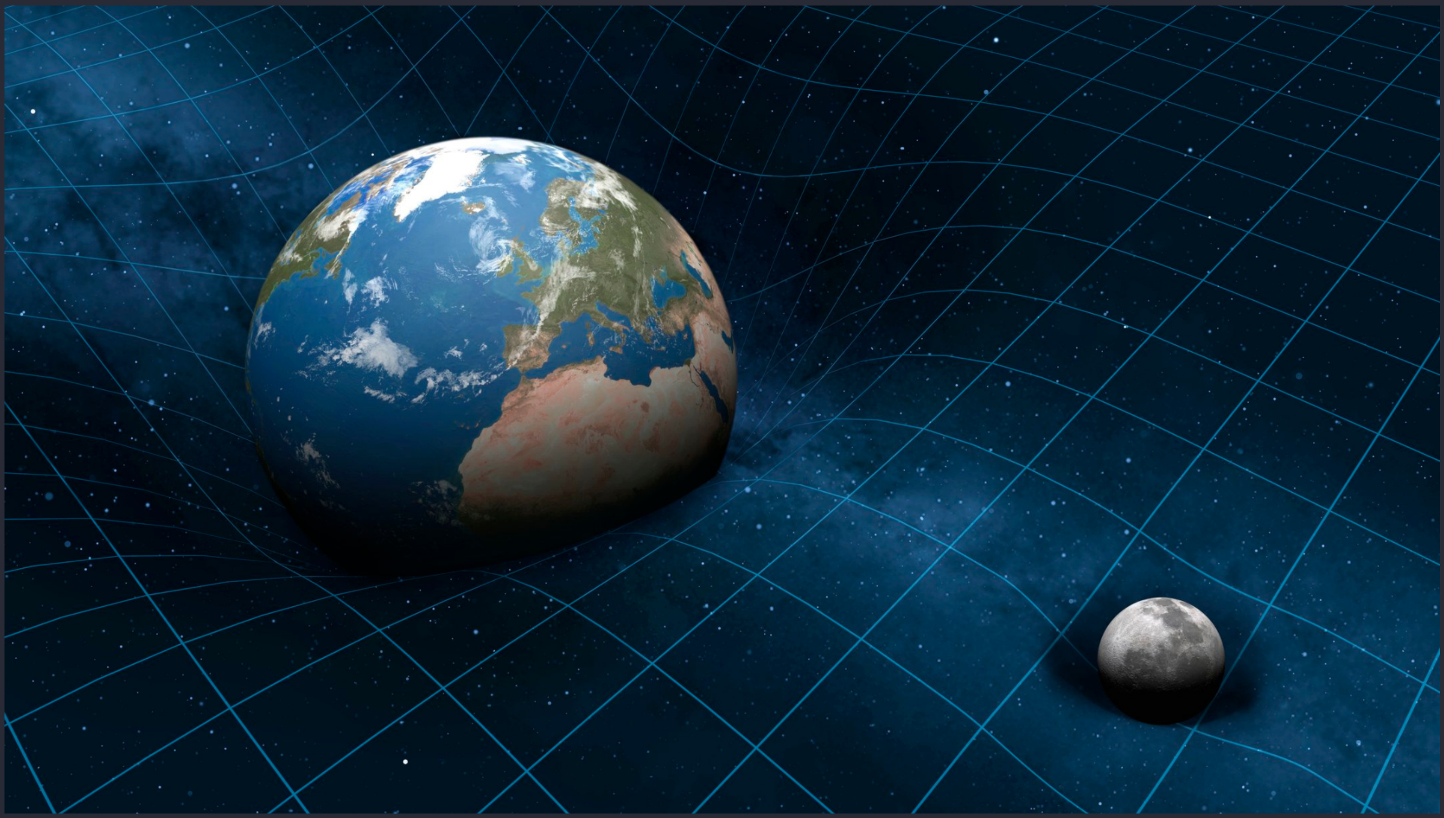
In the Special Theory, these effects are a result of relative velocity.

In the General Theory, the effects are due to be in close proximity to a gravitational field, which distorts spacetime to the same magnitude of velocity in the special theory.





Note: Through a Relativistic Principle called the [Equivalence Principle](), the two theories are linked mathematically. The experience of gravity is equivalent to the experience of acceleration. The Equivalence Principle states that the force experienced by an observer in an accelerated frame is equivalent to the force experienced due to a gravitational field caused by the mass of the body generating the gravitational field.

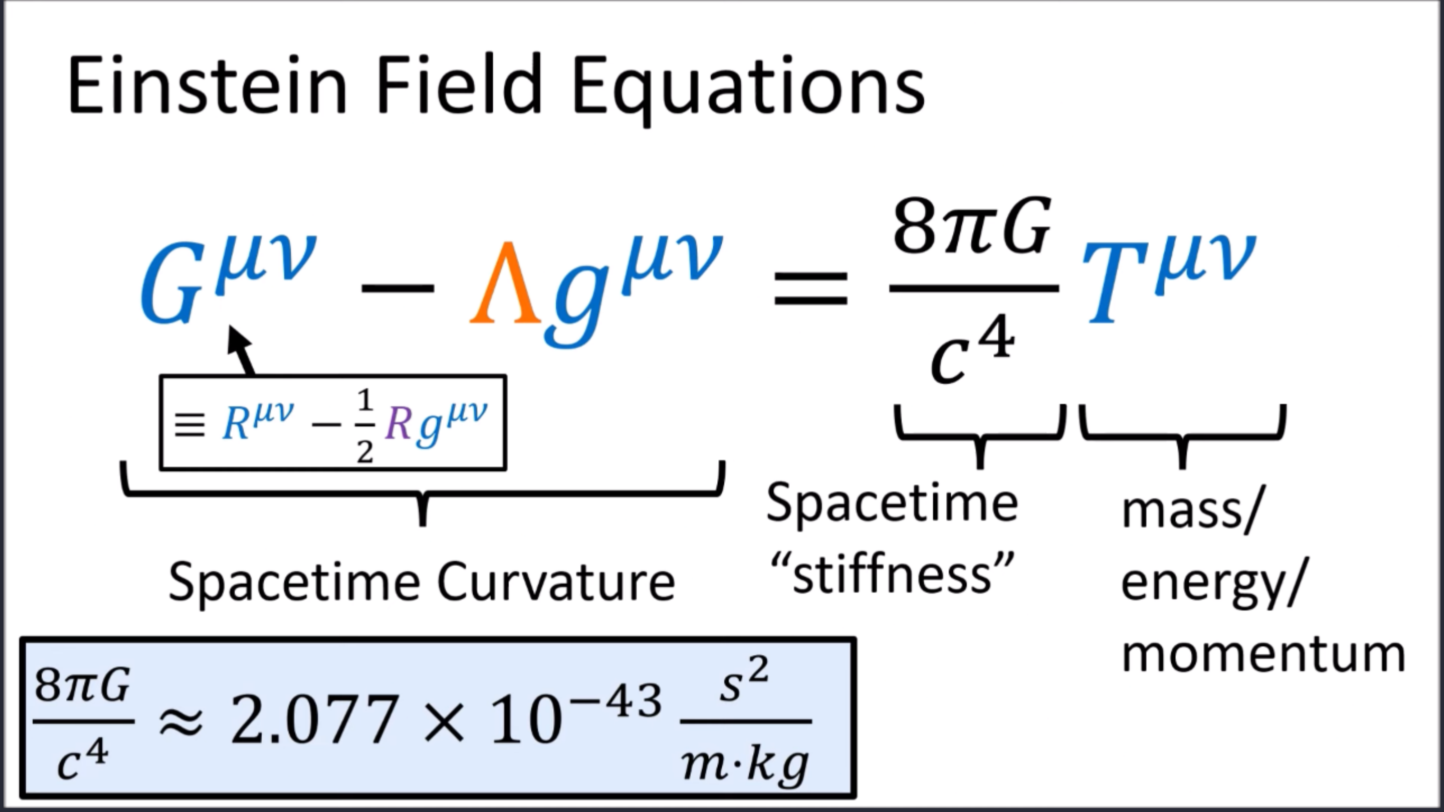


Note:

In General Relativity, gravity is expressed as a field of influence distributed over the entirety of curved Spacetime.

Spacetime is a continuous manifold of Space and Time used make a single fourth dimensional coordinate system of x(space), y, z, t(time) that's expressed by differential calculus and differential geometry.

The benefit of this infinite manifold cordinate system or geometry is that for analytical purposes, any location in manifold can be infinitesimally zoomed in to such that a flat localized portion can be used so only the gravitational influence of the bodies in question is considered.



Note:

Now that a basic rundown has been given, we'll look at a couple of equations to familiarize ourselves with what they are describing so we don't get too lost in the abstraction.

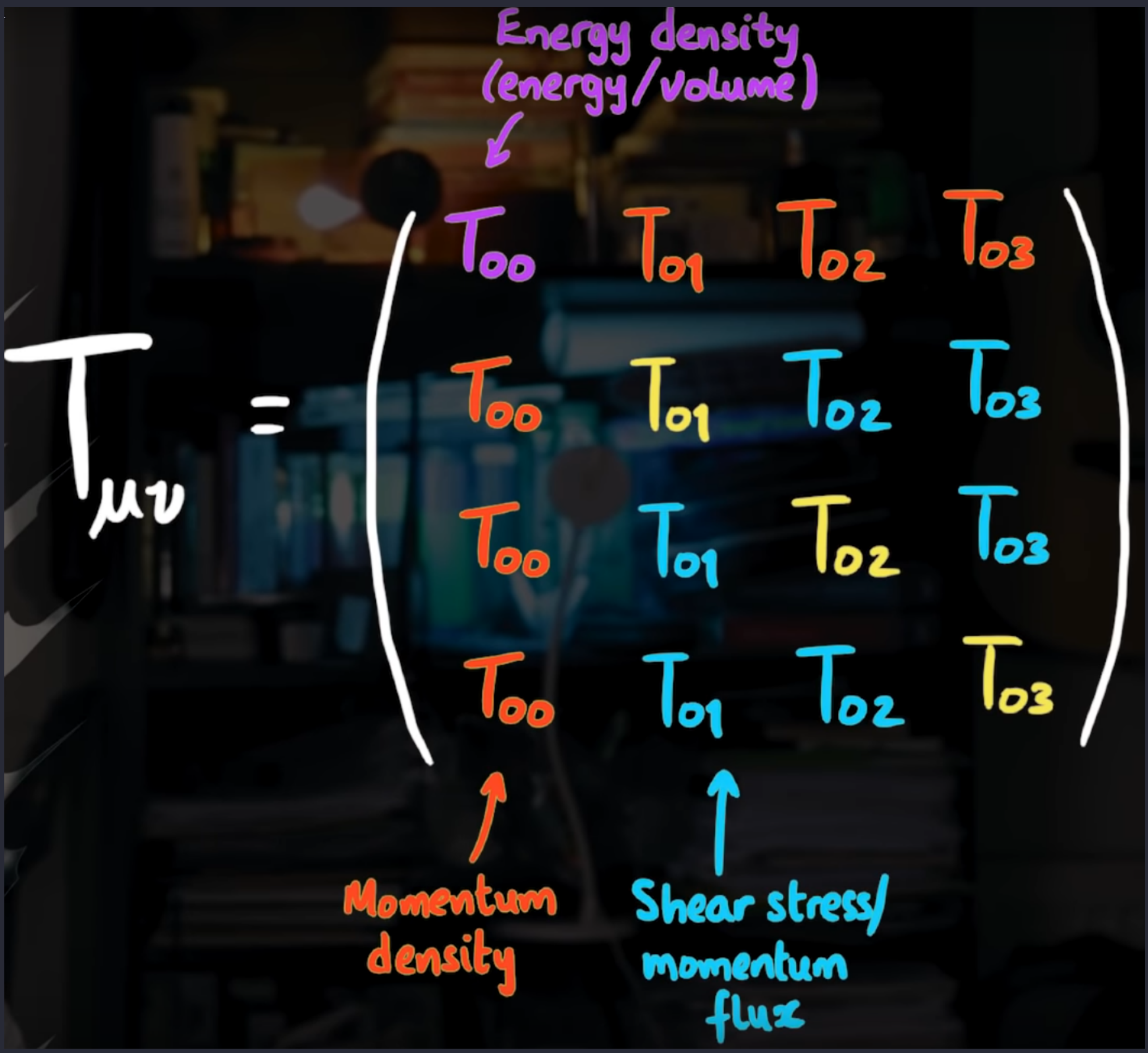
- T^{uv} - Mass, energy and momentum, and the conservation thereof, which cause spacetime curvature. Additionally, the flux and pressure of a body or energy can be accounted for by using the tensor to measuring the amount of conservation in the system.

Additional info: Generalizes the mass density to a 4x4 tensor by multiplying the mass density by the speed of light squared, which equals the energy density.

- $8\pi G/c^4$ - A proportionality constant using Newtonian gravity (G) to describe the distribution of energy and momentum as a function of spacetime curvature. This distribution ratio is what provides the covariant extension of Newtonian gravity to the concept of spacetime curvature. As the mass of a body, in the Einsteinian sense will distort space and time as a unified manifold called "Spacetime" that produces things like the illusion of gravity, reference frame dependent second-order effects of length contraction and time dilation.
- More Notes on G:
- G is more like a volumetric pressure value per cubic centimeter that falls off at /r^2. Especially how it's applied in the abstraction of a gravitational field. It would be like a density gradient in a fluid medium. g would be a localized effect of that gradient.

- G^{uv} - The Einstein tensor, derived from the combination of the Ricci tensor, the Ricci scalar, and the metric tensor (g_uv). It characterizes the curvature of spacetime induced by the distribution of mass-energy, including both mass and velocity, which are treated as energy in general relativity. This tensor determines the gravitational field and how it distorts spacetime.

- λg^{uv} - The term λ represents the cosmological constant, now interpreted as dark energy, driving the accelerated expansion of the universe. When combined with the metric tensor g^{uv}, it contributes to the overall curvature of spacetime. This term represents the energy density of empty space and; used for large-scale structure and dynamics of the universe.



Note: Rows and Columns

The indices are matrixes

0 = time
1 = x
2 = y
3 = z


21

Note: Recap: What did we just learn?

In Newtonian dynamics re: the solar system the causal mechanism for bodies in motion is gravity, which is equivalent to a centripetal force, at least mathematically. This in Newtonian gravity, this centripetal force can be thought of as "mass attracting mass".

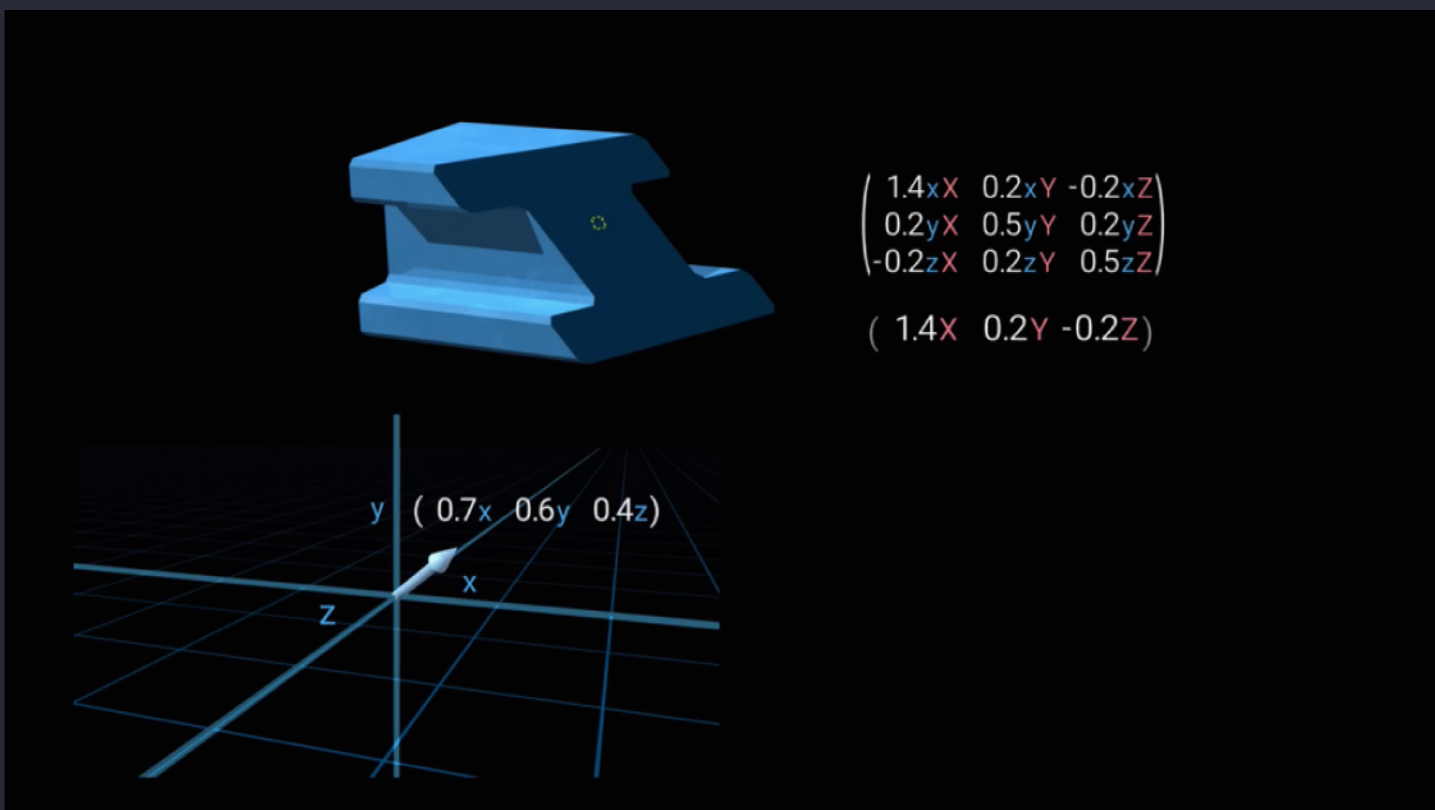
However, these dynamics, were starting to fail to explain certain celestial phenomena, i.e. the perihelion precession of Mercury for example.

To give a more accurate approximation of gravity, a new system of mathematics was proposed to explain things on a "Relativistic scale" where higher-order approximation using a ratio of the speed of light squared can be used to explain these phenomena that appear to be anomalous on the Newtonian scale.

Using this method of general approximations, Spacetime curvature and geodesics along said curvature become dominate explanation of solar system and cosmological dynamics.

Instead of mass attracting mass producing a velocity to describe an circular or elliptical orbit, a velocity can be produced by a body traveling along a curved geodesic. The free-fall speed aka orbital velocity will be determined by spacetime curvature.

Conceptually, you can think of it like this; the steeper the curvature, the fast the velocity of the body moving along that geodesic.



Note: a few more things of note;

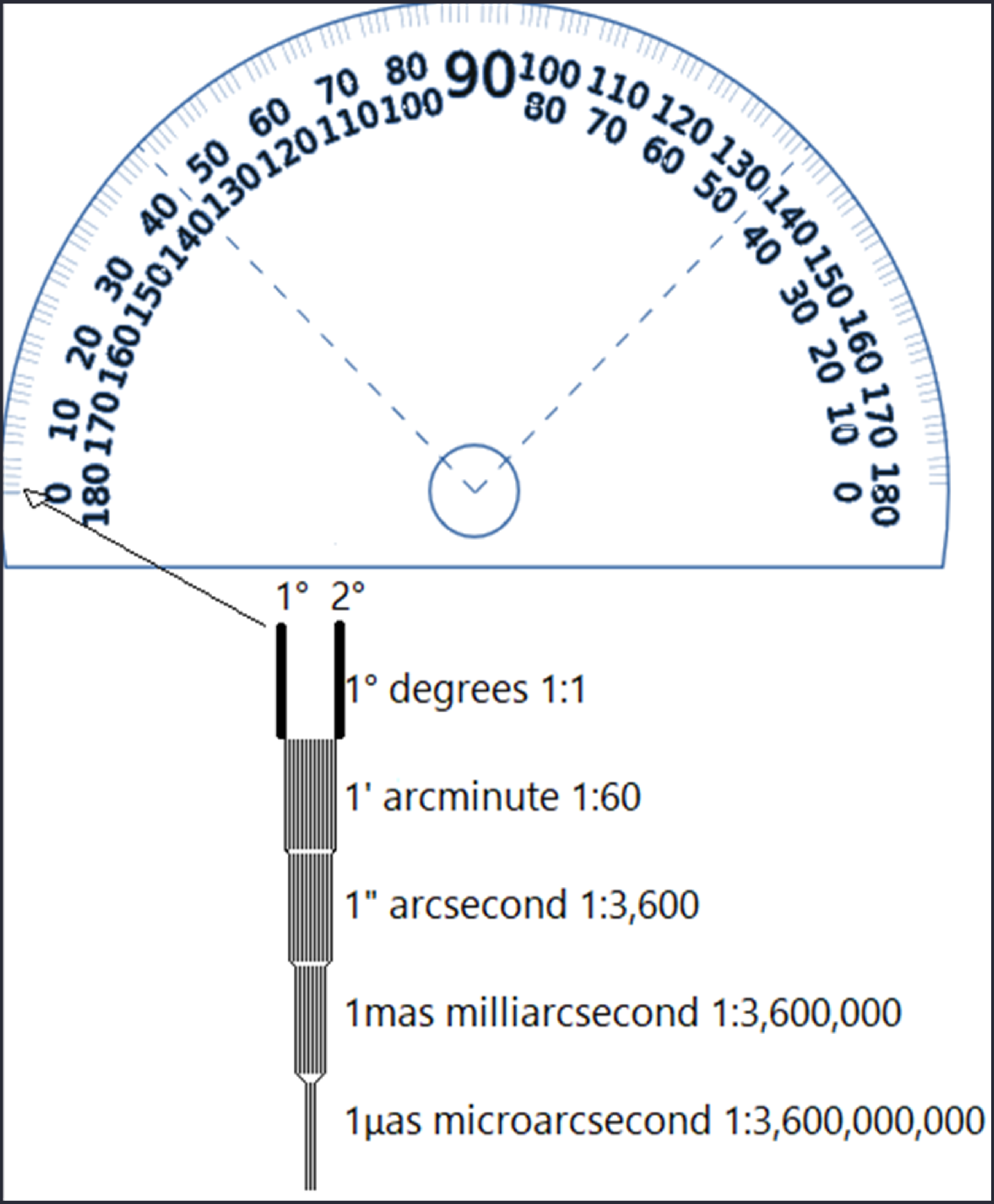
Now that we know how gravity and spacetime curvature work conceptually, let's discuss a few more things of note

Relativity is mathematically structured in absolute differential calculus. This means that metrics in the field equations can be swapped out. Example: The metrics that measure spacetime curvature can be swapped for flat or curved metrics, depending on what conditions you need to satisfy. You can also change the conservation tensors.

Now that's not to say differential calculus can't be useful. I-Beam analogy

Tensors are supposed to represent physical quantities, such as mass or energy, at points in the spacetime coordinate system. They describe how these quantities vary from point to point and are used to establish relationships, including angles, between objects, reflecting the gravitational influence or spacetime curvature caused by the distribution of mass and energy within spacetime.

There's a variety of metrics to choose from, we'll go over the more relevant ones now.



Note:

One of the units of measurement that will be discussed

A degree (1°) is a unit of angle measurement, equal to 1/360th of a full rotation.

•60’ arcminutes in a degree.

•3,600” arcseconds in a degree

•3,600,000mas milliarcseconds in a degree.

•3,600,000,000uas microarcseconds in a degree

> *"Viewed at high power from the bottom of our ocean of air, a star is a living thing. It jumps, quivers, and ripples tirelessly, or swells into a ball of steady fuzz. Rare is the night (at most sites) when any telescope, no matter how large its aperture or perfect its optics, can resolve details finer than 1 arc second. More typical at ordinary locations is the 2-or-3-arc-second seeing, or worse."*

- MacRobert, (1995) Sky & Telescope, 89, 40

Note:

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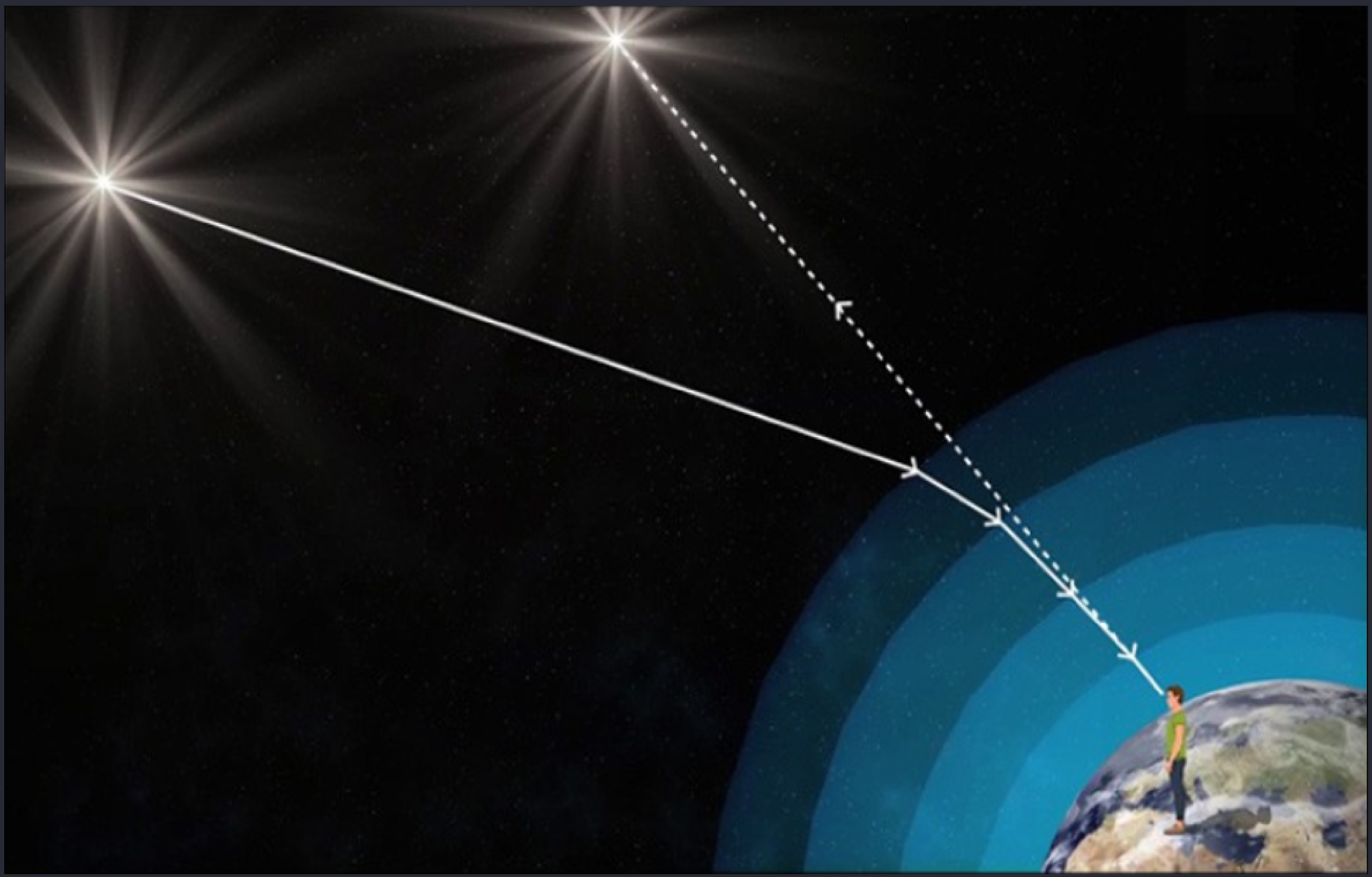
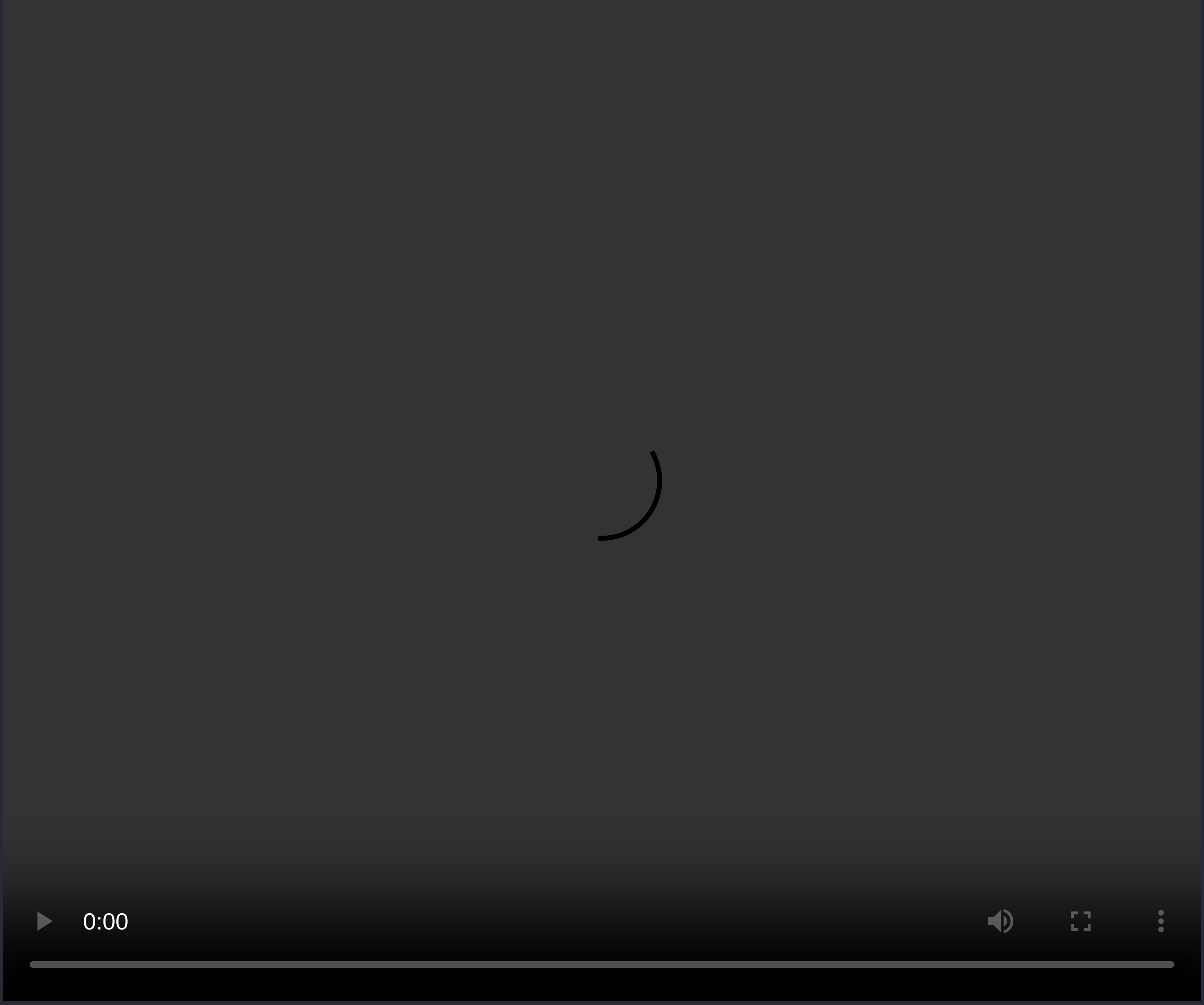
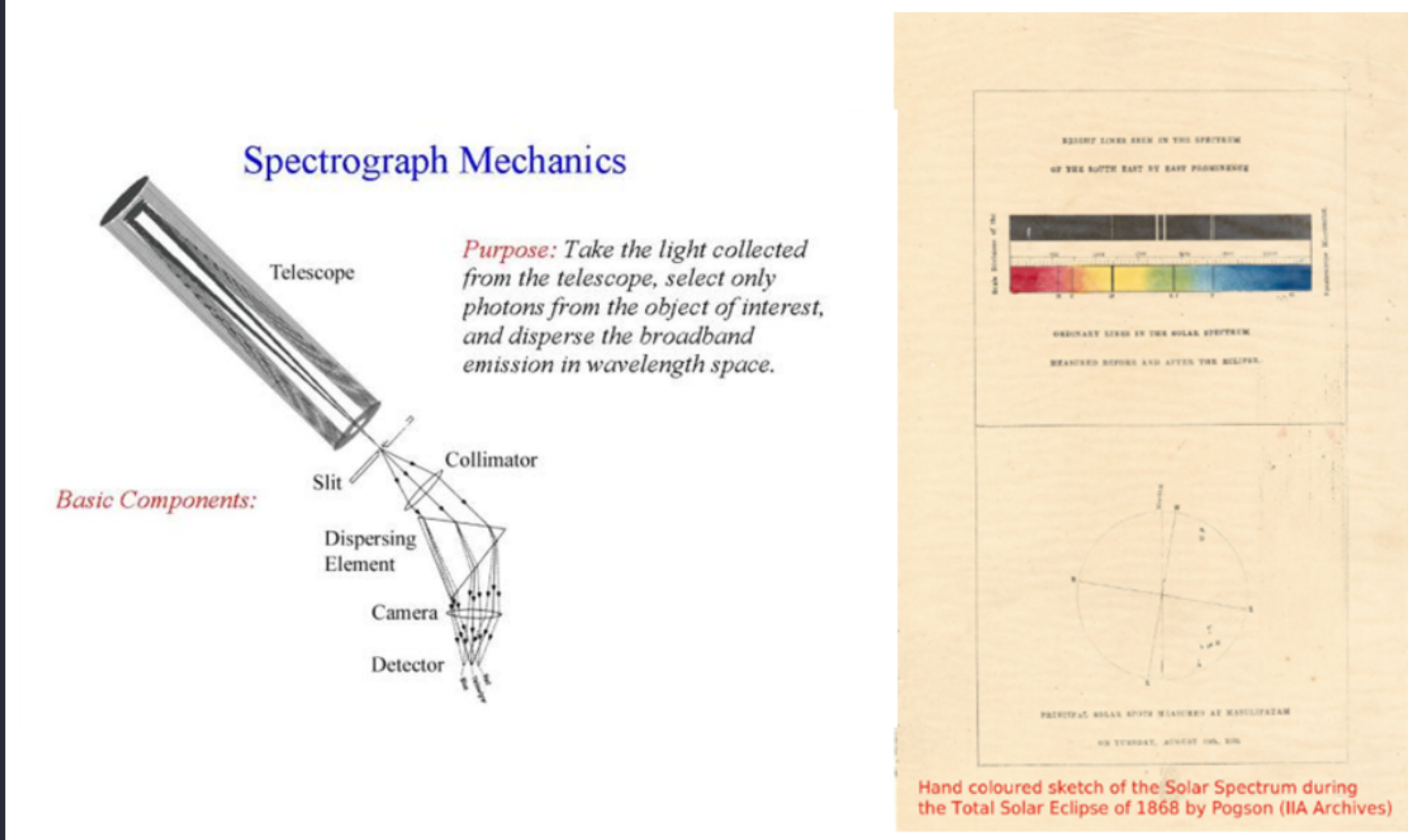


Note: Standard viewing conditions. +2 to 3 arcseconds



Note: Last section re: Doppler shift and how it relates to redshift.



Note: How the spectral shift in light is measured.

Telescope -> Prism -> Rainbow -> Analyze

APS News

May 2016 (Volume 25, Number 5)

This Month in Physics History

May 29, 1919: Eddington Observes Solar Eclipse to Test General Relativity

When Albert Einstein published his general theory of relativity (GR) in 1915, he proposed three critical tests, insisting in a letter to *The Times* of London that if any one of these three proved to be wrong, the whole theory would collapse.

- Advance of the perihelion of Mercury
- Deflection of light by a gravitational field
- Gravitational red shift

Once he had completed his theory, Einstein immediately calculated the advance of the perihelion of Mercury, and he could hardly contain himself when GR produced the correct result. The next classical test was the deflection of light by a gravitational field, first performed by Sir Arthur Eddington in 1919.

Photo: Royal Society of London

One of Eddington's photographs of the May 29, 1919, solar eclipse. The photo was presented in his 1920 paper announcing the successful test of general relativity.

Born to Quaker parents in December 1882, Arthur was just two years old when he lost his father to a typhoid epidemic that ravaged England. As a child, Eddington was enamored of the night sky and often tried to count the number of stars he could see. Initially Eddington was schooled at home, but when he did start attending school, he excelled so much in mathematics that he won a scholarship to Owens College in Manchester at age 16. He graduated with first class honors in physics, and promptly won another scholarship to attend Trinity College at Cambridge University.

Eddington completed his M.A. in 1905. First he worked on thermionic emission at the Cavendish Laboratory, and then tried his hand at mathematics research, but neither project

Note:

What did we just learn?

the abstract mathematics is redefining gravity as gravitation, which is a distribution of energy over a coordinate system which manifest as temporal pockets of curvature in the coordinate system to explain celestial motion.

There were three proofs given by Einstein himself to give validity to his abstractions. The terms and conditions are as follows:

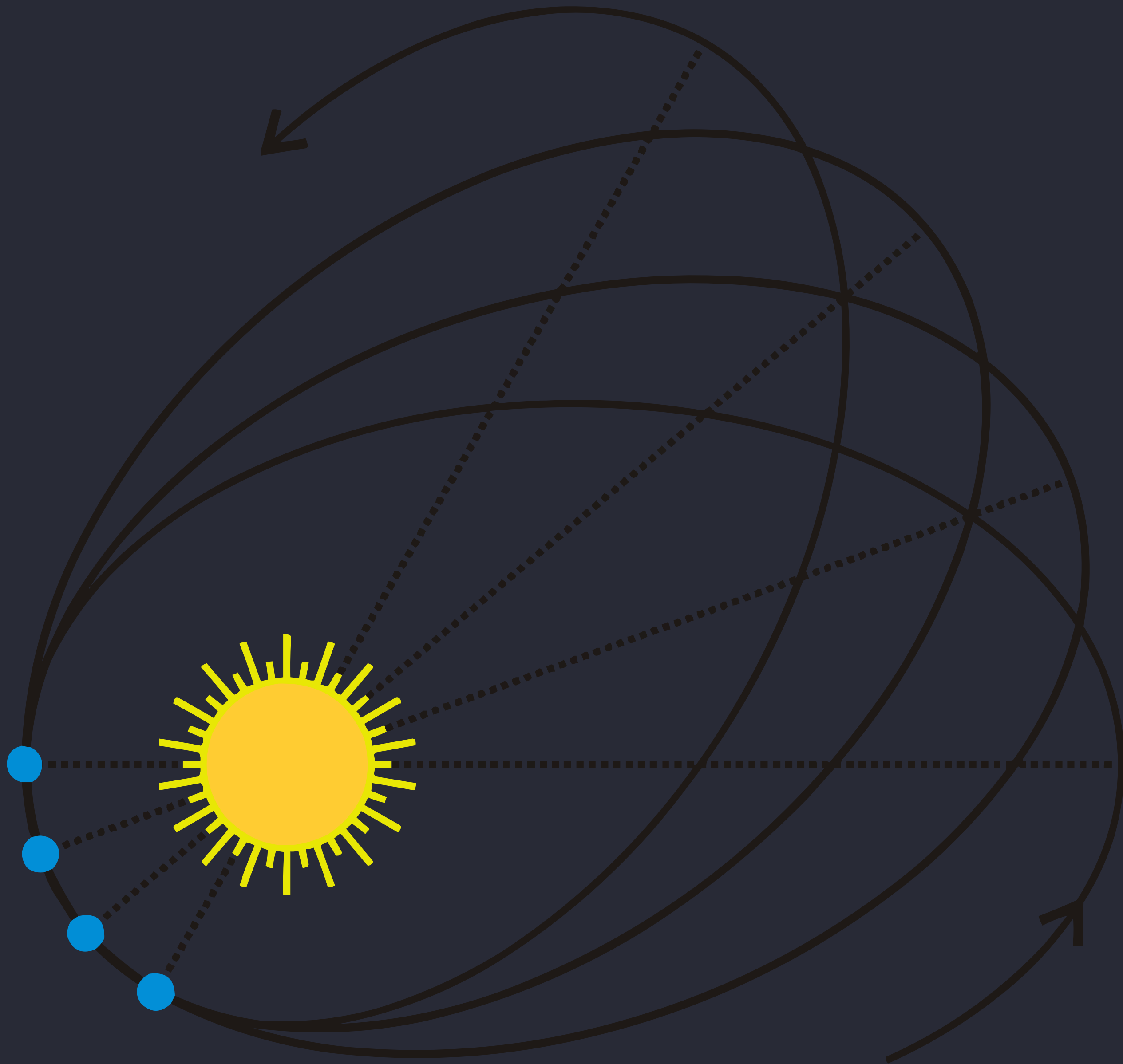
- perihelion
- light ray deflection
- gravitational redshift

I) Perihelion Precession of Mercury

II) Deflection of Light Rays (Gravitational Lensing)

III) Gravitational Redshift of Light

Note: Starting with perihelion precession of Mercury



Note:

In 1846, Urbain Le Verrier, observed and recorded a perihelion precession of Mercury as it orbits the sun. He calculated a perihelion precession to be 5600 or 1.25° arcseconds per century.

- Actual observed value: 5600 arcseconds per century
- Newtonian gravity post-diction: 5557 arcseconds per century
- Relativity theory post-diction: 5600 arcseconds per century

Newton with mass-attracting mass on light as a corpuscle prediction was off by 43 arcseconds

Relativity Theory was able to derive the full 1.25 degree as an effect of spacetime curvature due to the Sun's gravitational field based on the conditions from the Schwarzschild metric.

At least, that's the story we're told. We'll circle back to the metric in a bit, before we do that though, let's look at Einstein's first attempt to solve precession using his General Theory.

Why is this minuscule amount of deviation important?

The a body's perihelion remains fixed wrt pure gravitational forces, which are bound to the inverse square of the gravitational potential between the bodies.

i.e. the precession indicates a casual mechanism outside of "gravity" where only gravity is supposed to be acting.

After accounting for planetary perturbation i.e. gravitational tug-of-war between the planets, an unaccounted amount of 43 arcseconds remained

Postdiction vs prediction, no real value here in terms of proving the relationship that this truly meaningful and covariant with Newtonian dynamics of the solar system.

Gerber:

$$\varPsi = 24\pi^3 a^2 / (\tau^2 c^2 (1 - \varepsilon^2))$$

Einstein:

$$\varepsilon = 24\pi^3 a^2 / (T^2 c^2 (1 - e^2))$$

Note:

```
a = semi-major  axis
e = eccentricity of the orbit
T = orbital period (periodicity)
```

24pi^3 is a constant multiplier; gives the geometry of the orbit from which the eccentricity output will be the deviation from a perfect circle

Gerber, 1898
Einstein, 1915

Gerber: Gravitation propagates @ c

Einstein: Spacetime curvature due to the gravitational field of the sun is causing the precession

Who's right? Mathematically they give the same prediction, only different mechanisms

A familiar notion; Einstein's math and theory differ from Lorentz's aether theory only in the theoretical explanation. The math is identical.

In Schwarzschild coordinates (t, r, θ, ϕ) the Schwarzschild metric (or equivalently, the line element for proper time) has the form

$$ds^2 = -c^2\, d\tau^2 = -\left(1 - \frac{r_s}{r}\right) c^2\, dt^2 + \left(1 - \frac{r_s}{r}\right)^{-1} dr^2 + r^2\, d\Omega^2,$$

where $d\Omega^2$ is the metric on the two sphere, i.e. $d\Omega^2 = \left(d\theta^2 + \sin^2\theta\, d\phi^2\right)$. Furthermore,

- $d\tau^2$ is positive for timelike curves, in which case τ is the proper time (time measured by a clock moving along the same world line with a test particle),
- c is the speed of light,
- t is, for $r > r_s$, the time coordinate (measured by a clock located infinitely far from the massive body and stationary with respect to it),
- r is, for $r > r_s$, the radial coordinate (measured as the circumference, divided by 2π, of a sphere centered around the massive body),
- Ω is a point on the two sphere S^2,
- θ is the colatitude of Ω (angle from north, in units of radians) defined after arbitrarily choosing a *z*-axis,
- ϕ is the longitude of Ω (also in radians) around the chosen *z*-axis, and
- r_s is the Schwarzschild radius of the massive body, a scale factor which is related to its mass M by $r_s = 2GM/c^2$, where G is the gravitational constant.[5]

Note: More aptly accepted canonized version:

Imposing conditions on the calculations to give the observed amount:

Solution Conditions:

- Spherically symmetric
- No charge potential
- Stationary, non-rotating
- Static spacetime metric, not dependent on time
- Treats orbital body as a photon (massless)

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By using a spherical symmetrical coordinate system, Schwarzschild was able to establish points in based based on center of mass and polar angle to describe the spacetime distortion around the sun due to its gravitational field.

By using these mathematically imposed ideal conditions to give higher order approximations based on the second-order Relativistic effects of length contraction and time dilation, something like gravitational lensing or orbital precessions can be described with a higher degree of precession.

$$ds^2 = -c^2 \cdot d\tau = -(1 - r_s/r)c^2 \cdot dt^2 + (1 - r_s/r)^-1 \cdot dr^2 +$$

Note:

Does any of that have any physical meaning? So far in the kinematic stage and we're dealing with a theory that's said to be the causal mechanism of another theory that couldn't explain the phenomena either.

Let's continue and see if can find sum substantiation of the concepts put forward to explain the sky observations as we continue

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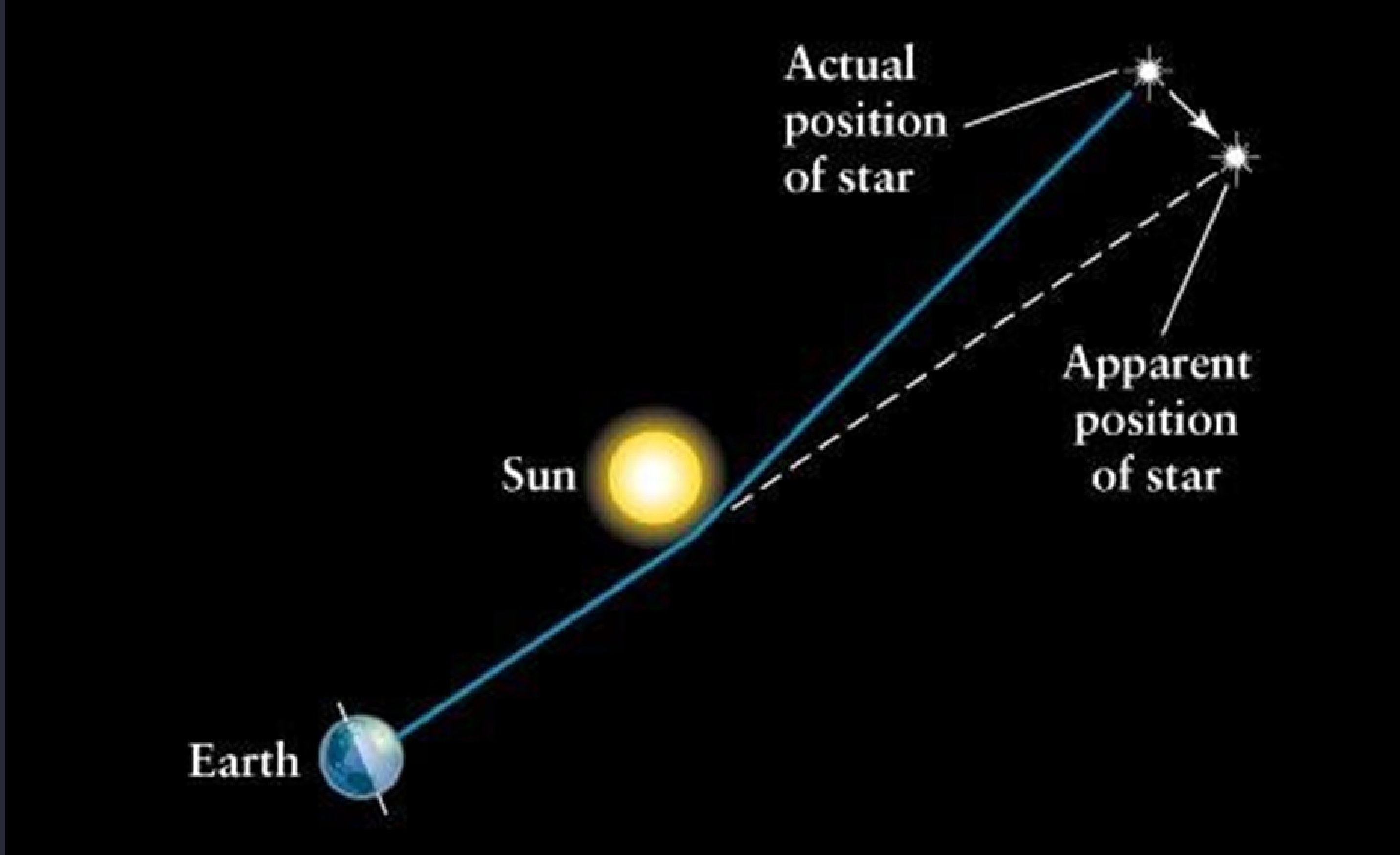
I) Perihelion Precession of Mercury

II) Deflection of Light Rays (Gravitational Lensing)

III) Gravitational Redshift of Light

Note: Starting with perihelion precession of Mercury



Note:

General Relativity predicts a spatial displacement, i.e. spacetime curvature around the gravitational field of a body. In the case of the sun, its gravitational field should displace light by 1.75 arcseconds whereas the Newtonian prediction was .87 seconds of arc.

Additionally, without getting into the quantization of light; the two theories have different conceptualizations of what light is.

For simplicity, let's look at it in terms of "mass attracting mass" theory makes a different prediction than the spacetime curvature theory.

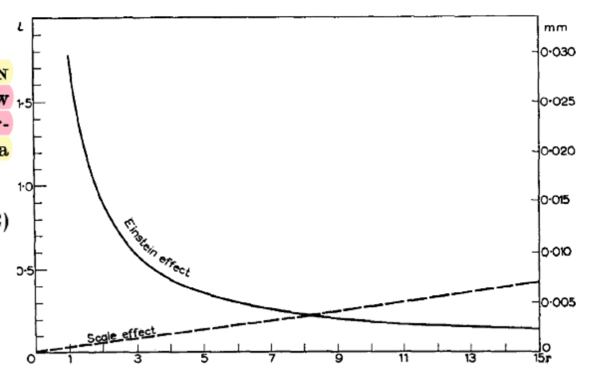
---

because of the outbreak of war; (FREUNDLICH, 1930). Shortly afterwards EINSTEIN (1916) published his famous General Theory of Relativity, in which he used his new law of gravitation, differing from NEWTON's classical law by small terms; it nevertheless become appreciable for the light-deflection close to the Sun. His formula reads

$$\alpha = \frac{4kM}{c^2r} \quad \ldots . (2)$$

and with the modern values

$$k = 6{\cdot}67 \,.\, 10^{-8}\ \mathrm{cm^3g^{-1}sec^{-2}}$$
$$M = \text{mass of the Sun} = 1{\cdot}991 \,.\, 10^{33}\mathrm{g}$$
$$c = 2{\cdot}998 \,.\, 10^{10}\ \mathrm{cm\ sec^{-1}}$$
$$r = \text{radius of the Sun} = 6{\cdot}956 \,.\, 10^{10}\ \mathrm{cm},$$

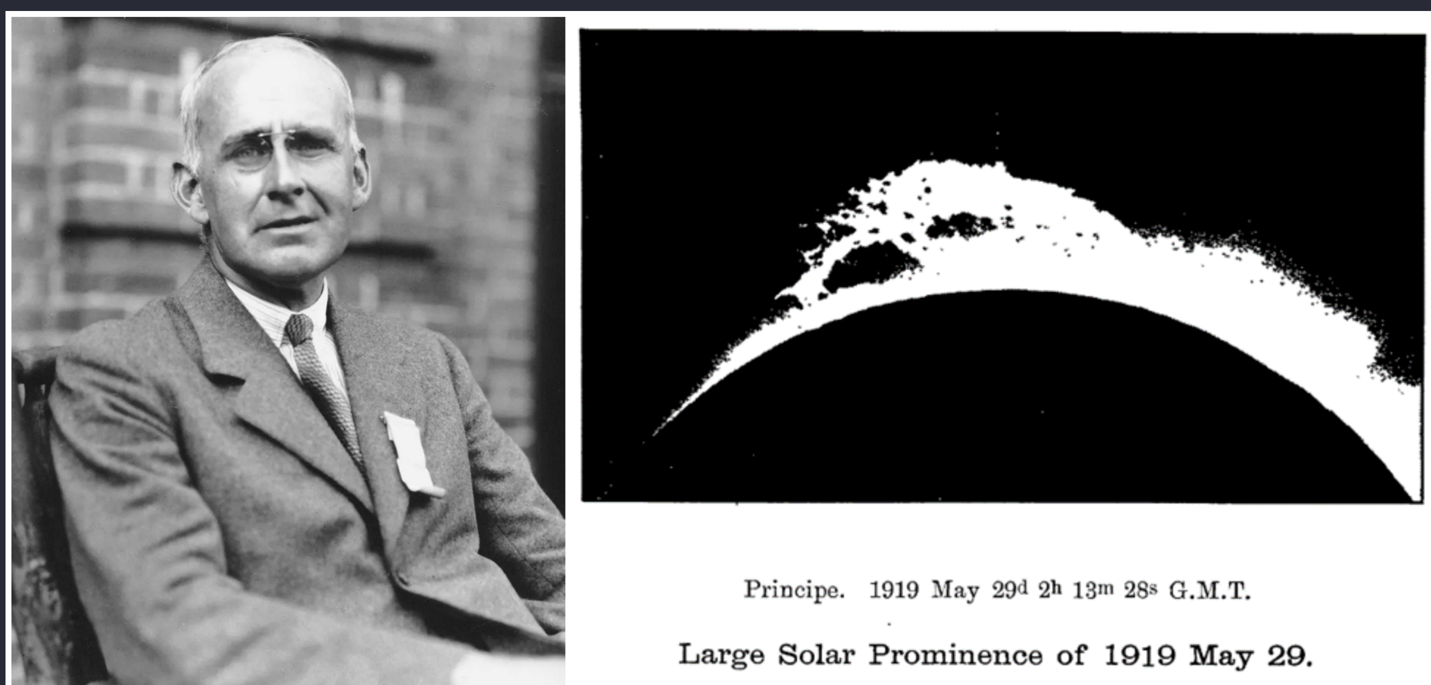


ɜ. 2. This graph, a hyperbola, shows the behaviour of the predicted light-deflection, plotted as a ıction of the distance r from the centre of the Sun. The broken straight line indicates the "Scale ·ect" (see p. 53), produced by an alteration of 0·1 mm in the focal setting of a "Normal Astrograph" (f = 343 cm).

Abscissae: distances from the centre of the Sun, expressed in units of the solar radius.
Left-hand ordinate: light-deflections in seconds of arc, as predicted by EINSTEIN (1916). See eq. (2).
Right-hand ordinate: the same, but expressed in millimetres on the photophraphic plate, assuming the focal length of the telescope to be 343 cm.

Note:

- Einstein's proposed derivation for the deflection angle
- k = Big G
- M = Mass of the sun
- c = SoL
- r = radius of the sun



Note:

- Solar eclipse in 1919 May 29
- Crommelin, Sobral Brazil
- Eddington, Island of Principe off the west coast of Africa
- Crommelin's data: unusable due the thermal expansion and contraction due to the temperature differential during the eclipse.
- Two Eddington plates with poor star distribution
- Only observed in the solar limb or one solar radii
- Already assumed to a medium there of gas and plasma, electric field and magnetic, unknown pressure, etc

- Subsequent observations yielded similar results,
- NEVER OBSERVE OUTSIDE OF THE SOLAR LIMB <- CORRECTION
- Discussed at the Nov 6. 1919 R.A.S. & R.S. Eclipse meeting

Eddington and Crommelin set out with 16 photograph plates and 16 ref. plates to the Principe off the west coast of Africa, and Sobral, Brazil, respectively.

All of Crommelin's photographs and ref. plates are said to be unusable due the thermal expansion and contraction due to the temperature differential during the eclipse.

2 of 16 plates were said to be usable by Eddington. Zero of his ref. Plates were usable. Ref. plates taken a year prior and with different material from that which was used by Eddington in 1919.

Due to the the clouds, and weather, the visibility factor really effected Eddington's observations.

Dr. Silberstein. In the first place, I should like also to congratulate the astronomers upon their observational results. But, in spite of what the President said, I believe this result to be essentially an *isolated* fact. There is a deflection of the light rays, but it does not prove Einstein's theory; it cannot be logically deduced from his theory as a gravitational effect in the absence of the spectroscopic result. And, as far as we know from St. John's and Evershed's observations, the predicted shift of the spectrum lines, of an amount exceeding almost 100 times the probable error of the modern spectroscope (as Prof. Fowler has just told us), is not obtained. Prof. Lindemann's attempt to explain the obstinate nullity of this effect by the motion of the luminous gases in the line of vision is not satisfactory; for St. John was well aware of such complicating circumstances, and therefore purposely observed as many as 43 lines at the Sun's centre and almost as many (35) at the limb. Now, we cannot well assume that the gases move everywhere towards or away from us only to suit Einstein's theory, *i.e.* just to compensate his theoretical shift effect. As I have already pointed out on another occasion, if there is no spectral shift, Einstein's coefficient g_{44}, which is entirely responsible for it, must be unity, and if we go back to the differential equations (Einstein's field-equations) we shall see at once that the other coefficient in his well-known approximate solution becomes unity at the same time (the one being $1-\frac{2M}{c^2r}$, the other $1+\frac{2M}{c^2r}$), so that the world element reduces simply to $ds^2=c^2dt^2-(dx^2+dy^2+dz^2)$. And since the equations of motion are always given by $\delta\int ds=0$, we see ultimately that, the spectral shift being absent, Einstein's theory not only does not give such refinements of the planetary motion as is a secular motion of the perihelion, but not even the ordinary Newtonian or Keplerian motion. In short, the orbits of the planets would be straight lines and the planets would move along them uniformly in spite of the Sun's presence. The theory stands or falls on the correctness of the results of Evershed and St. John. It is unscientific to assert for the moment that the deflection, the reality of which I admit is due to gravitation. It

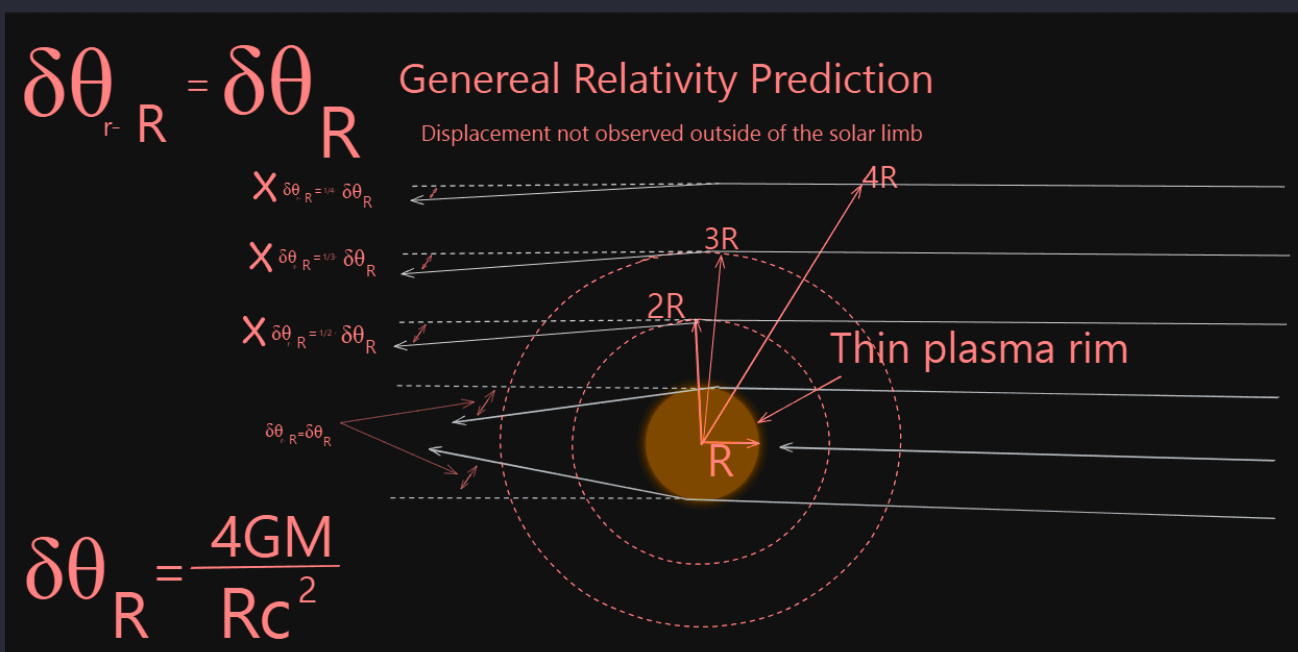
deflection, the reality of which I admit is due to gravitation. It is in this sense that I declared it a moment ago to be an isolated fact. The discovery made at the eclipse expedition, beautiful though it is, does not, in these circumstances, prove Einstein's theory. We owe it to that great man [pointing to Newton's portrait] to proceed very carefully in modifying or retouching his Law of Gravitation; this is by no means defending blind conservatism. The spectral shift required is perhaps 100 times, but certainly not less than 40 or 50 times, the error of modern measurement. The solar spectrum can, even in this country, be observed many times a year, and the matter can thus be decided without our having to wait years or centuries for another equally advantageous eclipse. If the shift remains unproved as at present the whole theory collapses, and the phenomenon just observed by the astronomers remains a fact awaiting to be accounted for in a different way.

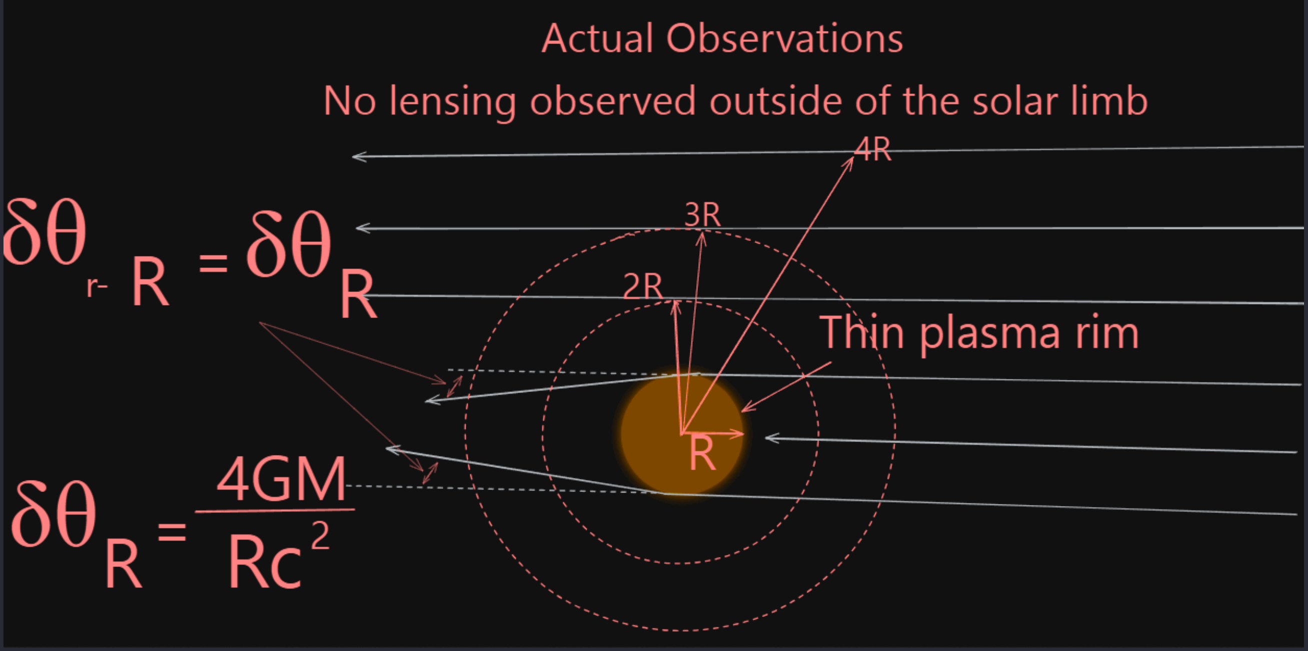
Note: Silberstein @ the R.A.S/R.S. meeting states:

- If there is starlight displacement there must also be redshift observed in accordance with the magnitude of the gravitational field that caused the displacement.
- to establish cause and effect with deflection and redshift, renowned spectroheliograph operators, Chares St. John and John Evershed were tasked with making the observations
- Over a year of observations various celestial transits to find redshift that gives an agreement with Einstein's equations.

- Never found any redshift that agreed with Einstein
- Silberstein points out that the lensing effect is contingent on a gravitational field altering spacetime to change the geodesic path of light
- This interaction has to produce a frequency shift proportional to the magnitude of the of the gravity field.
- Without spacetime gravitational fields, there can be no spacetime curvature and the theory would lack the ability to explain orbits in the Newtonian or Keplerian
- No redshift = no gravitational field => no curvature
- Geodesics = straight = no & no curve = orbit

Without a redshift detection to accompany the starlight displacement, it cannot be stated as scientific fact that spacetime curvature caused by the gravitational field of the sun altered the geodesic path of light unless it can be successfully shown that the frequency shift is accompanied.





Note:

Look into guy who derived it first

Kinematics, no casual mechanism implied only a proportional ratio

- LEAST ACTION PRINCIPLE
- R = Gaussian sphere; allows the electric field of a body with radius R to be calculated by assuming proportionality with the electric flux through a closed sphere and the surface charge.
- Changing G from a mass gravitational field to an electric field gradient
- Replacing G as the mechanism entirely.
- Why it was so important for the redshift to accompany the lensing
- With no established cause and effect someone can come along and derive the same thing with different dynamics and you can't refute it

Edward Dowdye Jr.

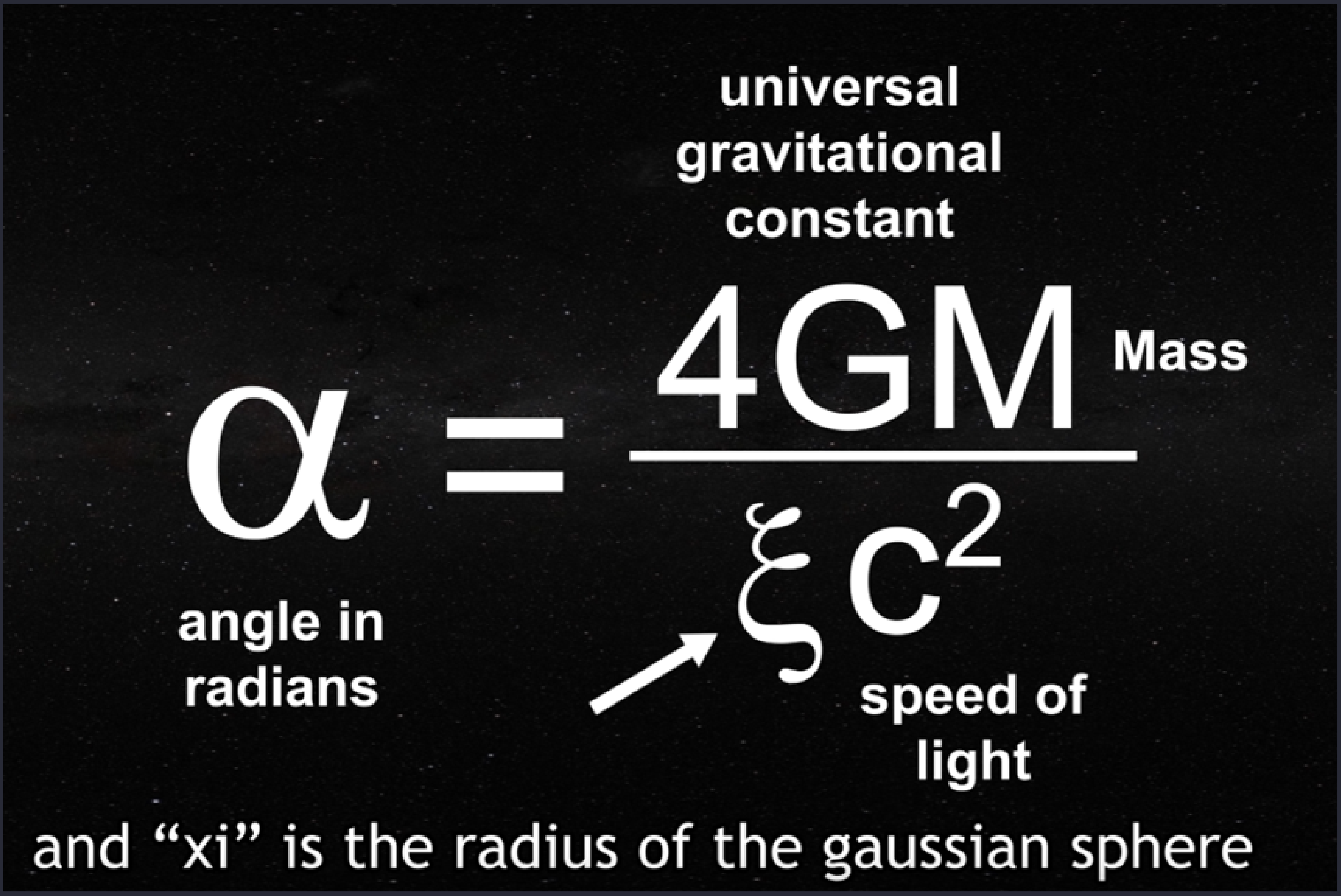
- `The equation was derived from the assumptions of a minimum energy path of light in a plasma atmosphere exposed to the gravitational gradient field of the sun.`
- Made his own derivation based off plasma and classical mechanics instead of spacetime curvature
- Least Action
- DeltaTheta: Change in angle in radians
- G: Gravitational Constant
- M: Mass of the sun

- Modern radio interfomertry confirms the same, only at the solar limb

Gauss's law states that the electric flux through a closed surface (such as a Gaussian sphere) is proportional to the electric charge enclosed by that surface.

By using a Gaussian sphere as the closed surface, the symmetry of the problem can often be exploited to simplify the calculation of the electric flux and thus find the electric field produced by a given charge distribution.

Dowdye Jr, EH. “Gauss’s Law for Gravity and Observational Evidence Reveal No Solar Lensing in Empty Vacuum Space,” 8121:62–71. SPIE, 2011.



Note:

- Non-mutually exclusive proof of GR has been put forward as mutually exclusive proof
- Works off proportional ratios relative to the the size of the assumed radius.

I) Perihelion Precession of Mercury

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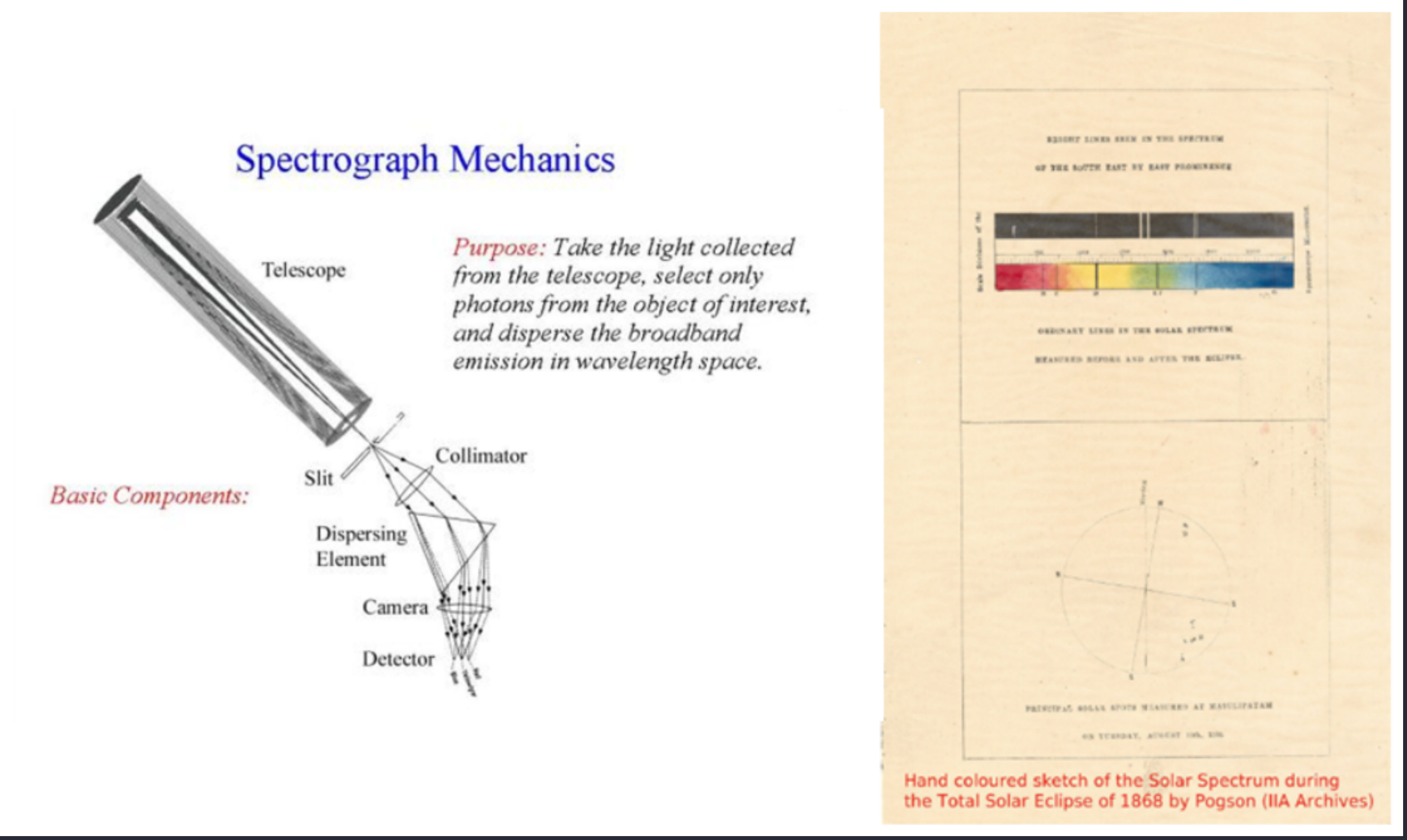
III) Gravitational Redshift of Light



Hand coloured sketch of the Solar Spectrum during the Total Solar Eclipse of 1868 by Pogson (IIA Archives)

Note:

Astronomical Obs HOWTO:

- Split starlight into a rainbow
- Spectrum study; assertions based on frequency shift predictions, which would result in color changes
- Freq change = color change
- Successful color predictions = the more likely people will believe your story about what happened to the light before it got to your measuring device

For example, light traveling against a gravitational field will be red shifted, as it loses energy to pass through the field. The wavelength increases inversely proportional to the frequency decrease. This is what is said to maintain the constancy of c, even when it loses energy.

JOHN EARMAN* and CLARK GLYMOUR†

THE GRAVITATIONAL RED SHIFT AS A TEST OF GENERAL RELATIVITY: HISTORY AND ANALYSIS

CHARLES St. John, who was in 1921 the most widely respected student of the Fraunhofer lines in the solar spectra, began his contribution to a symposium in *Nature* on Einstein's theories of relativity with the following statement:

> The agreement of the observed advance of Mercury's perihelion and of the eclipse results of the British expeditions of 1919 with the deductions from the Einstein law of gravitation gives an increased importance to the observations on the displacements of the absorption lines in the solar spectrum relative to terrestrial sources, as the evidence on this deduction from the Einstein theory is at present contradictory. Particular interest, moreover, attaches to such observations, inasmuch as the mathematical physicists are not in agreement as to the validity of this deduction, and solar observations must eventually furnish the criterion.'

Note:

- Disaster, straight to the lab
- Charles St. John, John Evershed
- No spectrum shift matching GR predictions for other obs prior to 1919 eclipse
- 1919 eclipse, no spectrum shift in agreement with GR
- Eddington was even attempting to jump shit, in 1918 Dec. he wrote to Weyl asking if his gravitational theory could explain why there is no redshift

The astronomical observations re: gravitational redshift during the 1918s to ~1940s can be summed as: trial and error with no real meaningful results.

With that said, we'll skip right into the laboratory experiments of gravitational red shift.

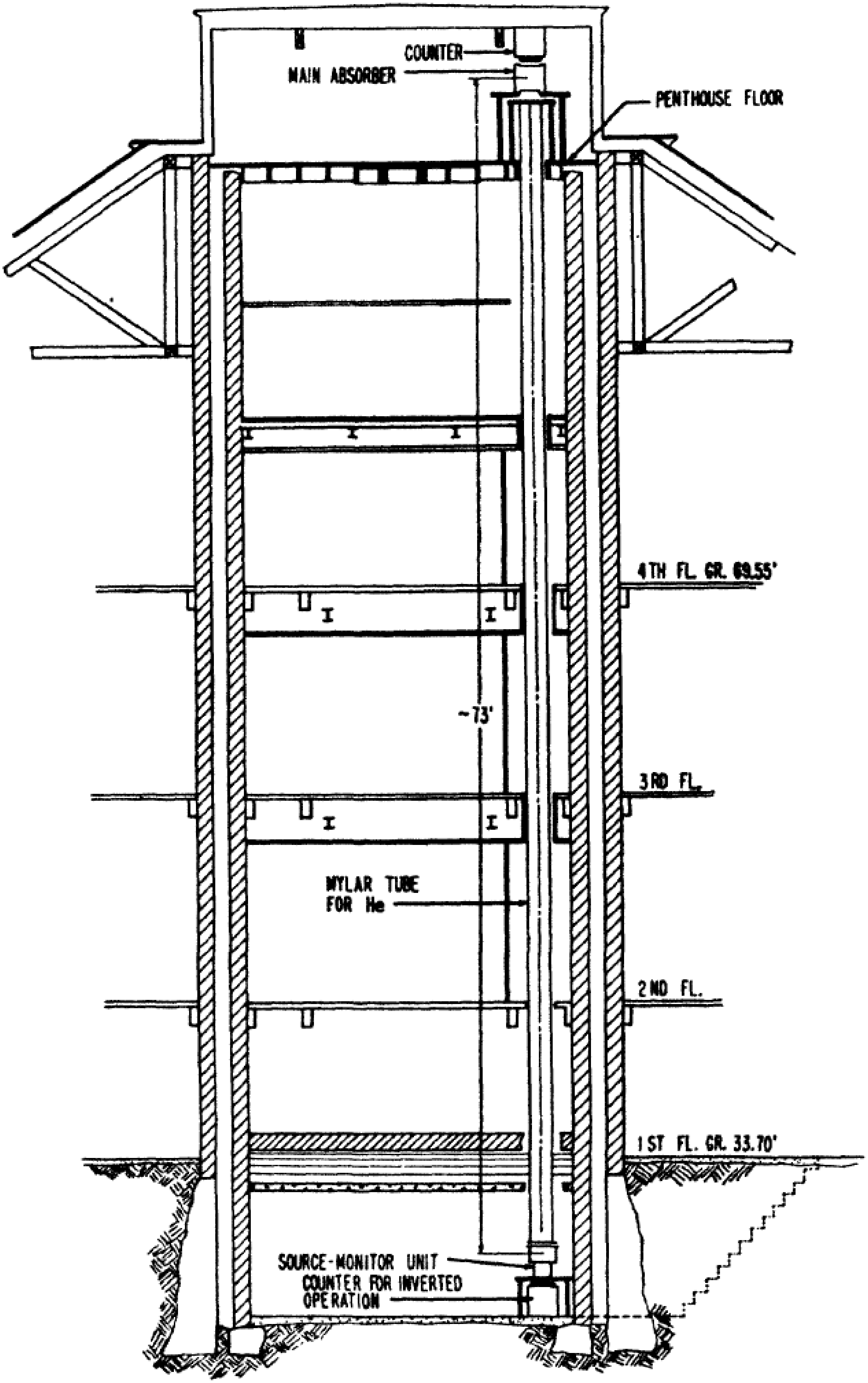


FIG. 2. An architectural sketch of the arrangement of the

FIG. 2. An architectural sketch of the arrangement of the system in the enclosed "isolated" tower in the Jefferson Physical Laboratory.

Note:

- 1960, 65, Pound-Rebka-Snider
- Emitted energy from top at specific freq
- Expected gravitational freq shift from 75ft to 0
- Mössbauer detector set to only accept a freq of the expect shift from 75ft
- Successful detection

In 1960 and 1965, Pound-Rebka-Snider (PRS) conducted a series of experiments where electromagnetic radiation of a specific frequency was emitted from the top of a 75ft tower with a detector at the bottom that would only accept energy of certain frequency.

The detector's only accepts energy at a certain frequency. The frequency it was set to, was the frequency that the energy would be shifted to assuming Earth's gravitational potential from Big G.

PHYSICAL REVIEW VOLUME 140, NUMBER 3B 8 NOVEMBER 1965

Effect of Gravity on Gamma Radiation*

R. V. Pound and J. L. Snider
Laboratory of Physics, Harvard University, Cambridge, Massachusetts
(Received 26 May 1965)

It is not our purpose here to enter into the many-sided discussion of the relationship between the effect under study and general relativity or energy conservation. It is to be noted that no strictly relativistic concepts are involved and the description of the effect as an "apparent weight" of photons is suggestive. The velocity difference predicted is identical to that which a material object would acquire in free fall for a time equal to the time of flight.

for confirmation. The present experiment is unable to distinguish between frequency changes and velocity changes, for example. It appears as if an experimental

comparison of clocks at different potentials would make a useful complementary contribution to the over-all status of confirmation of theory.

Note:

- The experiment provides no distinction from Relativistic physics and classical physics
- First paper titled "Apparent Weight of a Photon"
- Second paper: "The present experiment is unable to distinguish between frequency and velocity shift"
- Classical prediction c +-v != c
- Relativity prediction c = c, with a freq change and wavelength change
- The tubes were filled with helium

The detector received energy matching the prediction and Pound-Rebka-Snider were given the Nobel prize for confirming GR and gravitational redshift.

However, their test also provided evidence that the speed of light going up and down the tower was different by an amount that would correspond to a material object falling at 9.8 m/s^2

Note:

Atomic clock shuffle;

All suffer from the thing;

Can't distinguish between Relativistic effects and velocity shift;

Converts energy through ionization

Need to measure wavelengths

Note: The problem here is the experiment can't determine if c +- v = c or of it's != c by virtue of the detector only differentiating between frequencies.

PRS suggest doing another test with atomics clocks at the top and bottom of the tower to time when the signal is sent and received to verify the correctness in their measurements.

Next slide ->

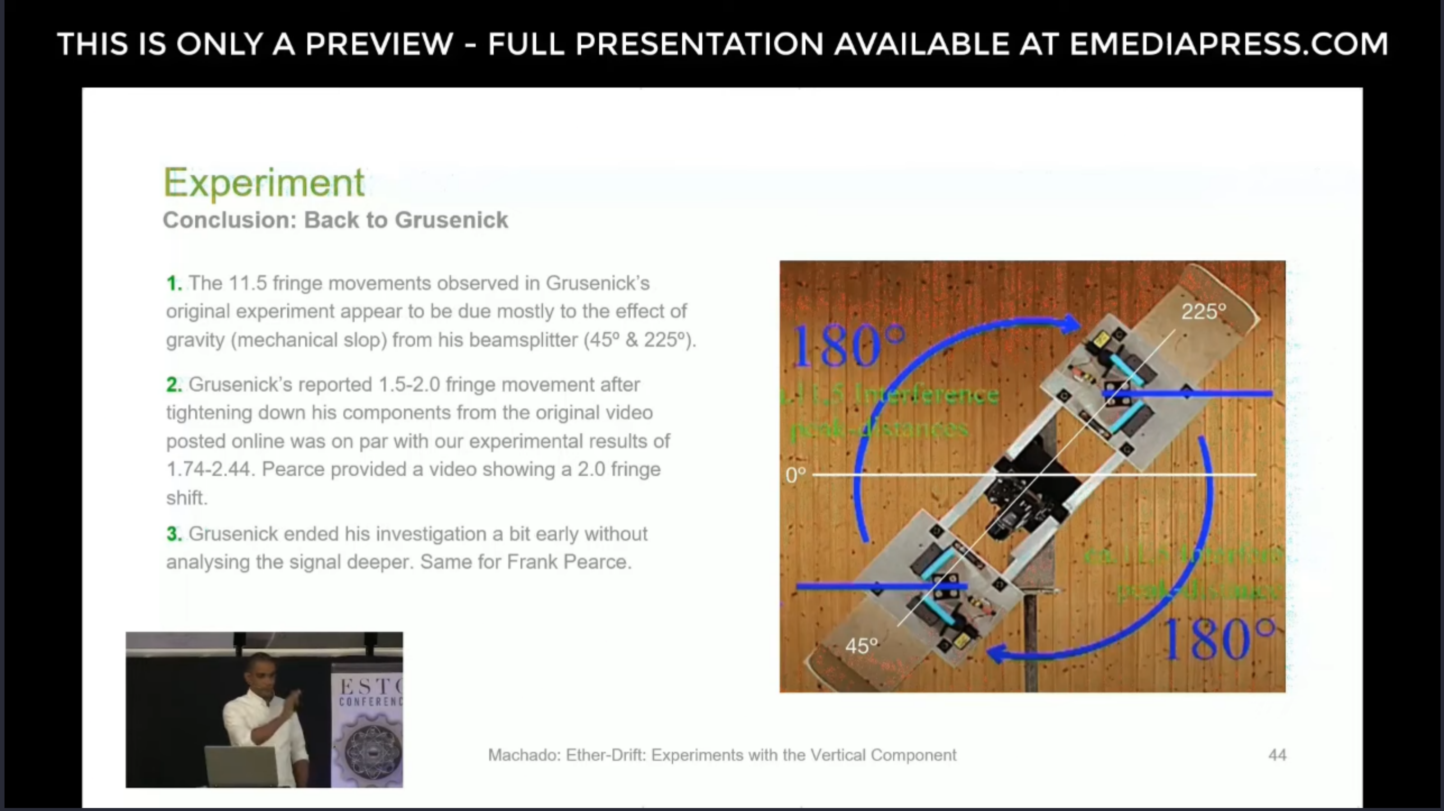
Note: No experiment like that has been done.

However, using a vertically orientated interferometer, the downward variance in c can be measured via fringe displacement.

Relativity predicts c is isotropic in all directions, including up and down.

Vertical interferometry should yield no fringe.

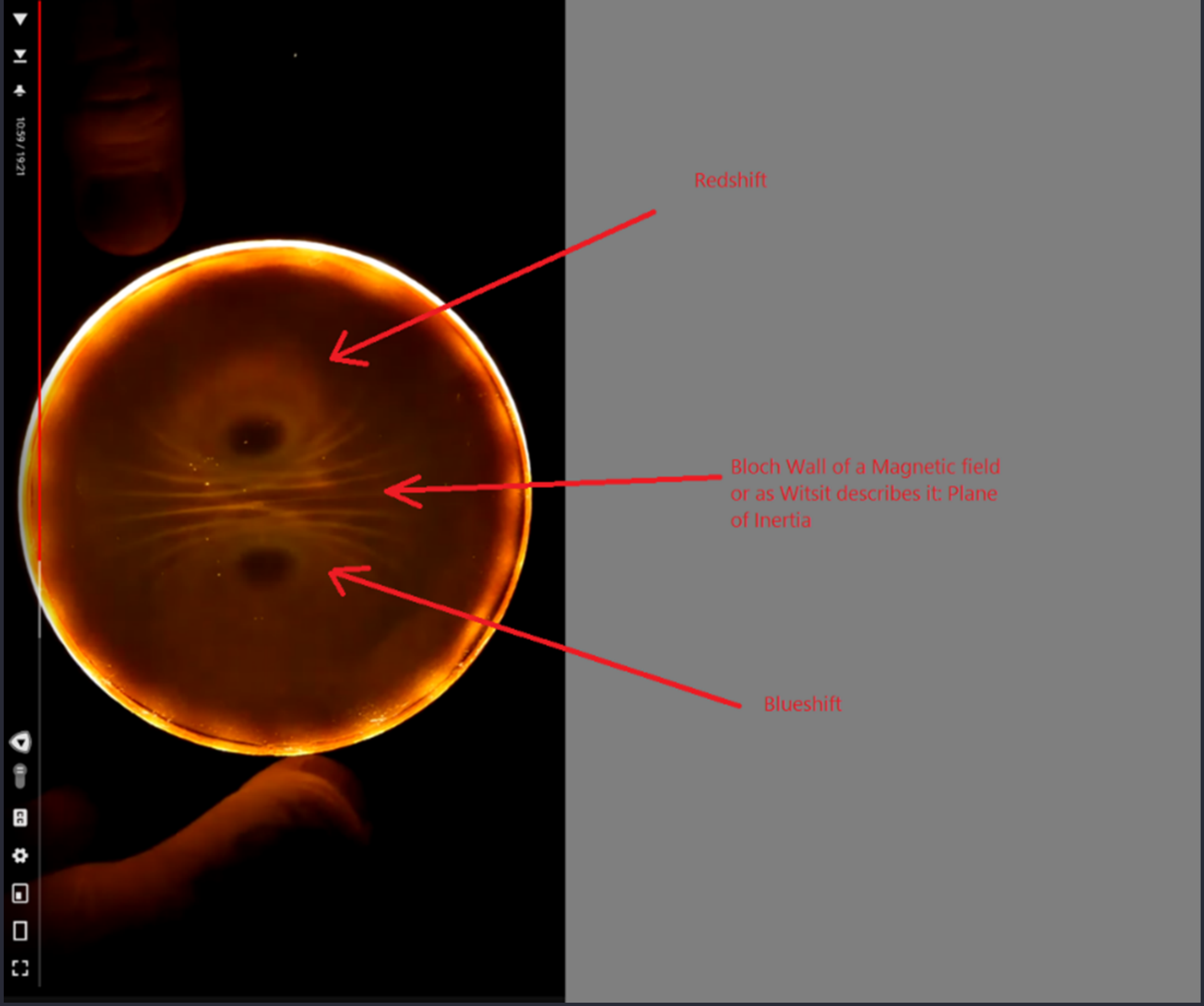
Both these YTers measured 2 fringes.



Note:

Chris Machado, repeats Grusenick's and Powerrak results by measuring 2.0 fringes with their vertical setup.

Conclusion: c is anisotropic and the theory of Relativity offers no new insights into the motion of celestial bodies or the behavior of light.



Note:

Relative motion through an electric or magnetic field produces electromagnetic retardation or acceleration.

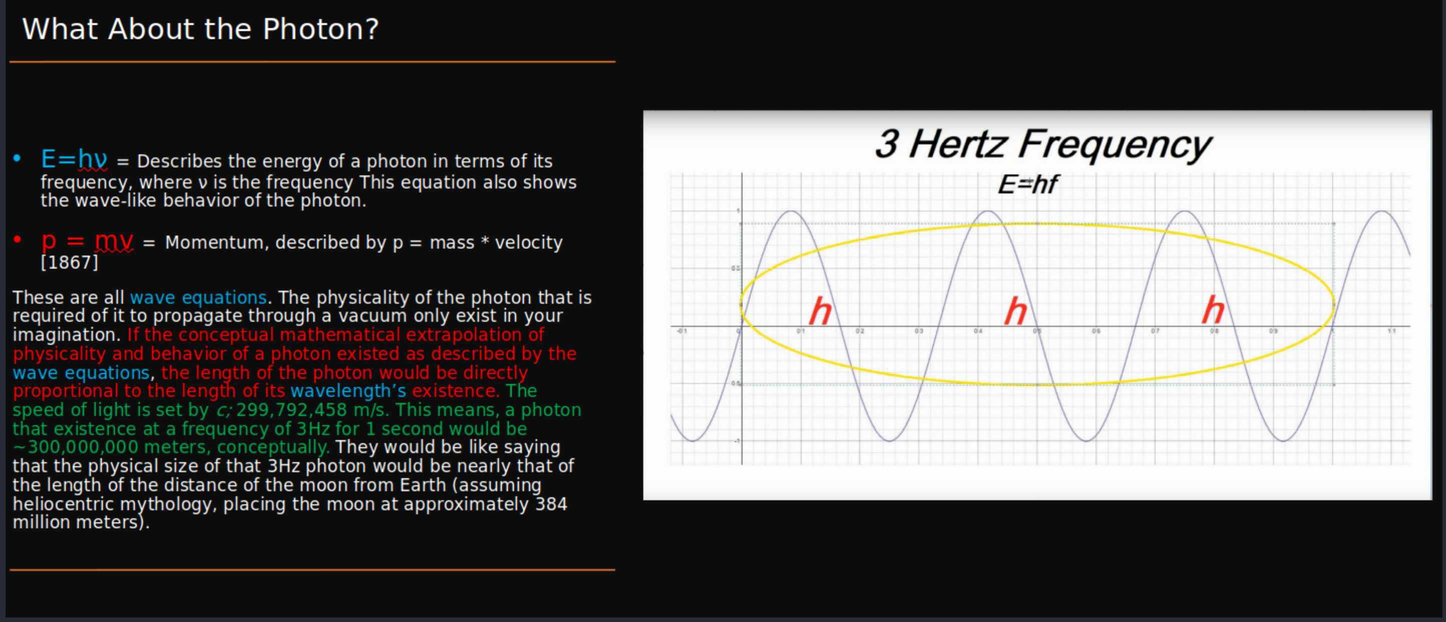
This is known as the Stark and Zeeman effects.

https://youtu.be/47T1_5P8jtg @ 6:18 – 8:35

I) Perihelion Precession of Mercury

II) Deflection of Light Rays (Gravitational Lensing)

III) Gravitational Redshift of Light



Note: Quantization of Light / Quantum Flaw

The physicality of the photon would be 300,000,000 m long.

Conclusion

Note:

The theories of Relativity offer no insights into the casual mechanism of the motion of the bodies in the sky.

It's purely a reification of the original kinematic mathematics that were to firstly attributed and imposed as dynamics of the motion of the celestial bodies

Space and time are absolute;

SoL like any other wave, varies relative to the observer's velocity with a 1:1 ratio in v/c.
