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The Double-Star Experiment:

A Comprehensive Review of de Sitter's 1913 Demonstration

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Abstract:

In this review, the key points of the debate between W. de Sitter and M. la Rosa are discussed; and the main conclusions of de Sitter's 1913 demonstration are re-examined and compared to the theoretical predictions computed on the ballistic assumption, with regard to the velocity of starlight and the orbital velocity of binary stars, in accordance with the kinematic rules of the elastic-impact emission theory.

Keywords:

Binary stars; elastic-impact emission theory; point of maximum brightness; constant speed of light; classical wave theory; ballistic speed of light; new-source emission theory.

Introduction:

The Double-Star Experiment was the primary subject of a long series of exchange between W. de Sitter and M. la Rosa, which started in 1913 and ended, based on the published literature, more than a decade later in 1924.

In spite of the poorly done translations that tend to make the arguments of both sides, and those of la Rosa in particular, appear weaker than they actually are, and contrary to the widely held view that de Sitter won it, the de Sitter-la-Rosa debate ended up in a tie, in which the supposed winner was forced to move from his initial simple position that the prediction of the Ritz theory violates the laws of Kepler [*Ref. 1.a*], and to take the complicated and less clear position that the Ritz theory, according to its Doppler equations, predicts fundamental changes in the spectra of binary stars [*Ref. 1.e*].

Throughout the whole debate, W. de Sitter and, to some extent, M. la Rosa as well, had taken it for granted that starlight retains, based upon the formal Ritz theory, its original velocity resultant for the entire duration of its journey from binary stars to distant observers.

However, recent and more thorough investigations of this subject indicate quite clearly that the formal Ritz theory, based on the published works of W. Ritz himself, is, in fact, a new-source theory, according to which starlight loses its initial velocities upon refraction and reflection by intervening materials.

The distinguishing criterion, here, between a ballistic theory, in which starlight retains its original velocities, and a ballistic theory, in which it does not, is very simple:

Is light, from a stationary source, reflected, according to the ballistic theory in question, from a directly approaching mirror, at the combined velocity of ($\boldsymbol{c + v}$), or at the combined velocity of ($\boldsymbol{c + 2v}$)?

If the combined velocity of reflected light, in the reference frame of the laboratory, is ($c + v$), then the ballistic theory, in question, is a new-source theory, in which starlight loses its initial velocities.

By contrast, if the combined velocity of reflected light, in the reference frame of the laboratory, is ($c + 2v$) instead, then the ballistic theory, in question, is an elastic-impact theory, in which starlight does not lose its initial velocities.

Since the combined velocity of reflected light from an approaching mirror, according to W. Ritz, is ($c + v$) relative to the reference frame of the laboratory, the predictions of his formal theory are very similar to the predictions of the classical wave theory and those of the Lorentz theory and Einstein's theory, with regard to light from binary stars. And so, the entire lengthy debate between de Sitter and la Rosa is irrelevant as far as the theory of W. Ritz is concerned.

Nonetheless, the de Sitter-la Rosa debate is, in itself, interesting and still quite relevant within the framework of the elastic-impact emission theory.

The following is a brief list of the theoretical predictions, based on the assumption of additive velocities of starlight, as discussed in the aforementioned debate between de Sitter and la Rosa, regarding starlight from binary stars:

(1.) If the speed of starlight and the orbital speed of a binary star are additive, then starlight emitted later when the binary star is approaching will get, with distance, increasingly closer to and eventually will overtake starlight emitted earlier when the same binary star was receding, as observed by distant observers. This prediction that de Sitter worked out and mentioned on various occasions is correct, but incomplete; because it applies only to the far-side half of the binary orbit, and only up to a specific distance from the binary star, where the faster starlight emitted at the end of that half will eventually overtake the slower starlight emitted by the same binary star at the start of the same far-side half of the binary orbit. While, by contrast, the opposite effect occurs in the case of the near-side half of the binary orbit, where the faster starlight emitted by the binary star at the start of this half of the binary orbit will get, with distance, farther and farther from the slower starlight emitted by the same binary star at the end of the same near-side half of the binary orbit. And therefore, to distant observers, the orbital time of the far-side half of the binary orbit appears shorter; and the orbital time of the near-side half of the same binary orbit appears longer, both by the same amount of time; but the orbital velocity of the binary star and the orbital period of the total binary orbit remain the same and constant regardless of distance between the binary star and the observer.

(2.) If the apparent orbital time of the far-side half of the binary orbit decreases with distance, as predicted by the elastic-impact emission theory, then the apparent brightness of the binary star, in that half of its orbit, must increase with distance; because distant observers, in this case, will receive, during the shorter apparent orbital time, the same amount of starlight emitted, in their direction, by the binary star, during the longer actual orbital time of the far-side half of the binary orbit.

(3.) If the apparent orbital time of the near-side half of the binary orbit increases with distance, as computed on the basis of the elastic-impact emission theory, then the apparent brightness of the binary star, in that half of the orbit, must decrease with distance; because distant observers, in this case, will receive, during the longer apparent orbital time, the same amount of starlight emitted, in their direction, by the binary star, during the shorter actual orbital time of the near-side half of the binary orbit.

(4.) The increasing apparent brightness of the binary star, in the far-side half of its orbit, with distance, forms a bell curve whose peak point is located at a specific distance, d_F, from the binary star, which can be obtained by using the following equation:

$$d_F = t_F\left(c+v\right) = \frac{1}{4}P\left(\frac{c}{v}-1\right)\left(c+v\right) = \frac{1}{4}Pc\left(\frac{1-v^2/c^2}{v/c}\right)$$

where P is the orbital period; and v is the orbital velocity of the binary star.

(5.) The decreasing apparent brightness of the binary star, in the near-side half of the binary orbit, with distance, takes the form of a sinusoidal function as well, and reaches a minimum value equals to half the actual value of brightness for the binary star, in the near-side half of its orbit; and it's located at the same specific distance, at which the peak point of apparent brightness of the binary star, in the far-side half of its binary orbit, is located; and hence, it can be calculated by using the same equation above.

(6.) If the apparent brightness of the binary star, for both halves of the binary orbit, is symmetrical around the peak point of apparent brightness, as described above, then, when observed from any point along a straight line from the binary star to the peak point, the apparent brightness of the binary star must vary, in a sinusoidal manner, from a minimum value, when the binary star is in the near-side half of its orbit, to a maximum value, when the binary star is in the far-side half of its orbit, during each and every complete orbital period.

(7.) If the velocity of starlight and the orbital velocity of the binary star are additive, then the apparent spectrum of the binary star must vary with the orbital phase and with distance between the binary star and faraway observers; because the velocities of emitting atoms, in this case, at the start and at the end of every wave period are different. This prediction of the elastic-impact emission theory was the last major challenge by W. de Sitter to M. la Rosa at the end of their long debate. It's true, as de Sitter pointed out, that his final challenge is an immediate consequence of additive speeds of starlight; but the total correlation, he wanted to establish theoretically between varying apparent spectra and varying intensities of apparent brightness, with distance between binary stars and distant observers, does not exist at all. And that is because, even though the latter effect can vary significantly on the galactic scale as well as on the cosmological scale, the former predicted effect requires vast cosmological distances to be equally significant. However, if different layers of the stellar atmosphere rotate at different speeds around the geometrical axis of the binary star, then apparent changes in brightness can cause apparent changes in its temperature and spectrum by making some layers appear brighter or dimmer than their actual and relative brightness within the stellar atmosphere.

The de Sitter's Binary-Star Demonstration:

W. de Sitter states, at the start of his demonstration, that, according to the Ritz theory, when a source of light has a speed of u, the speed of light emitted in the same direction is c + u [*Ref. 1.a*]. And accordingly, he works out the details of the following calculations:

Assume that the distance between a binary star and an observer is Δ; the half orbital period of the star, in each half of its circular orbit, is T; and the maximum velocity of approach is at A; and the maximum velocity of recession is at B.

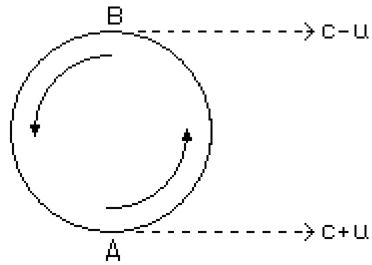

Figure #I

According to the Ritz theory, light, emitted by the star from points near A, travels towards the observer at the speed resultant of c + u. And light emitted by the star from points near B, travels towards the observer at the speed resultant of c – u.

And therefore, light emitted from A is observed after the time:

$$\Delta / c + u$$

and light emitted from B is observed after the time:

$$\Delta / c - u$$

in accordance with the Ritz theory.

Let's call T the half orbit time of the star whose orbit is a circle.

And so, from A to B:

$$T + \frac{\Delta}{c-u} - \frac{\Delta}{c+u}$$

$$T + \frac{\Delta(c+u) - \Delta(c-u)}{(c-u)(c+u)}$$

$$T + \frac{\Delta c + \Delta u - \Delta c + \Delta u}{c^2 - u^2}$$

$$T+\frac{2\Delta u}{c^2-u^2}$$

and so, for u << c:

$$T+\frac{2\Delta u}{c^2}$$

according to the Ritz theory.

And from B to A:

$$T+\frac{\Delta}{c+u}-\frac{\Delta}{c-u}$$

$$T+\frac{\Delta(c-u)-\Delta(c+u)}{(c+u)(c-u)}$$

$$T+\frac{\Delta c-\Delta u-\Delta c-\Delta u}{c^2-u^2}$$

$$T-\frac{2\Delta u}{c^2-u^2}$$

and so, for u << c:

$$T-\frac{2\Delta u}{c^2}$$

according to the Ritz theory.

And so, when the star goes in the first half of its period from A to B, the time interval between the two observations is:

$$T+2u\Delta/c^2$$

And when the star goes in the second half of its period from B to A, the observed time interval is:

$$T - 2u\Delta / c^2$$

according to the Ritz theory.

In the customary theory of celestial mechanics, both intervals from A to B, and from B to A are equal to T.

But if:

$$2u\Delta / c^2$$

is on the same order of magnitude as T, then if the Ritz theory were true, it would be impossible to bring the observations into agreement with Kepler's laws.

And that is because, according to W. de Sitter, in all spectroscopic binary stars:

$$2u\Delta / c^2$$

is not only of the same order of magnitude as T, but probably in most cases even much larger.

For example, if one takes u = 100 km/sec, T = 8 days, Δ/c = 33 years, then one has:

$$T - 2u\Delta / c^2 \approx 0$$

which is in accordance with the best known spectroscopic binary stars.

And subsequently, W. de Sitter concludes that the existence of spectroscopic binary stars and the fact that in most cases the observed radial velocity is completely represented by Kepler's laws of motion, is a strong proof for the constancy of the speed of light. And that, in many cases, the radial velocities of derived orbits are corroborated by visual observations as in the cases of δ Equulei and ζ Herculis, or by the observation of the darkening of one component of a binary system by the other as with Algol-variables.

Remarks on de Sitter's Double-Star Demonstration:

The following remarks can be put forward with regard to de Sitter's Double-Star Demonstration:

- W. de Sitter, in his above demonstration, fails to distinguish between the two main ballistic theories classified by A. Michelson as the 'new-source' theory and the 'elastic-impact' theory. And as a result, he mistakes the former theory, which is labeled by him as the Ritz theory, for the latter theory, which he does not mention at all.

- According to the new-source theory, or the Ritz theory as de Sitter prefers to call it, light, emitted by a binary star, loses its initial speed upon transmission by intervening materials, in the immediate vicinity of the star or across the vast distances between that star and the observer. And since, there is plenty of such intervening materials in most astronomical settings, the de Sitter's astronomical test doesn't really apply to this theory whose predictions, in this particular case, are practically indistinguishable from those of the classical wave theory and the Lorentz-Einstein theory.

- However, the above de Sitter's astrophysical test does apply in its entirety to the elastic-impact emission theory, in which the conservation laws of energy and momentum clearly guarantee that light emitted by moving sources always travels towards distant observers at the same combined speed.

- W. de Sitter, in the above calculations, does not investigate the immediate consequences and the far-reaching implications of the observed fact that the orbital velocity of a binary star, with respect to a stationary observer located anywhere along the plane of the binary orbit, forms necessarily a sinusoidal function that varies in a continuous manner from the velocity of +v, through the velocity of 0 midway, to the velocity of -v, through the velocity of 0, and to the velocity of +v once again.

- Also, W. de Sitter, in this demonstration under discussion, does not take into consideration the crucial characteristics of radiation emitted by a binary star, during successive orbital periods, which necessarily fills the entire space between a binary star and a distant observer.

- On the basis of the elastic-impact emission theory, light, emitted at the same point of the binary orbit, travels towards a distant observer at the same velocity resultant and has the same spatial and temporal densities in all orbital periods, regardless of distance between the binary star and the observer.

- According to the elastic-impact emission theory, light, emitted in multiple orbital cycles at Point A in de Sitter's illustration above, travels at the speed resultant of (c + v), arrives at each point of its path with the same temporal frequency as the orbital period of the binary star, and has a spatial frequency equals to its speed resultant (c + v) times the orbital period of the binary star.

- According to the elastic-impact emission theory as well, light, emitted in multiple orbital cycles at Point B in the above de Sitter's illustration, travels at the speed resultant of (c - v), arrives at each point of its path with the same temporal frequency as the orbital period of the emitting star, and has a spatial frequency equals to its speed resultant of (c - v) times the orbital period of the binary star.

- And according to the elastic-impact emission theory, light, emitted in multiple orbital periods at a point located midway between Point A and Point B in the de Sitter's illustration, travels at the speed c, arrives at each point of its path with the same temporal frequency as the orbital period of the emitting star, and has a spatial frequency equals to its speed of c times the orbital period of the binary star.

- And so, it's this constancy of the binary orbital period for light emitted in all orbital periods and for all velocity values from (c - v) through c to (c + v) that determines the parameter values of the binary orbit, as measured by a distant observer, and guarantees their consistency with Kepler’s laws for binary orbits as observed from anywhere and regardless of distance.

- It follows, therefore, that de Sitter's conclusion that the existence of spectroscopic binary stars is a strong proof for the constancy of the speed of light is unwarranted and incorrect; because it's based entirely on the treatment of two instants of light traveling at (c + v) and two instants of light traveling at (c – v), emitted by the binary star in one single orbital period, and neglecting everything else emitted by the same binary star before or between or after these four special instants.

The Effects of Ballistic Speed of Starlight from Binary Stars:

The predictions of the elastic-impact emission theory, in the fields of astronomy and astrophysics, are numerous, highly unusual, and interesting to investigate regardless of whether its basic assumption about the speed of light in vacuum may well turn out, in the end, to be correct or otherwise.

In the demonstration under discussion, W. de Sitter assumes that one of the binary star is invisible; and that the rotational period of the visible binary star around its geometrical axis is equal to its orbital period; and that the center of the binary system is at rest with respect to the observer. And furthermore, the binary orbit is circular. And hence, this de Sitter's orbital configuration for his hypothetical binary stellar system is simple and more convenient for calculating theoretical predictions and for classifying primary effects, in any treatment, based upon the ballistic assumption, according to which the velocity of light is dependent upon the velocity of the light source.

Beside replacing the new-source emission theory, or the theory of Ritz as W. de Sitter calls it, with the elastic-impact emission theory, no other changes in this de Sitter's arrangement are necessary to be made, within the context of the current discussion, throughout the following treatment.

For light emitted by a binary star towards a distant observer, there are three distinct parts of its path with three different sets of calculated predictions, which should be made clear and treated separately in any computations based on the elastic-impact emission theory. The first part starts from the location of the binary star, and ends at the point along the light path, where faster light emitted at the end of the first half of the orbital period catches up with slower light emitted at the beginning of the same first half of the orbital period. The second part starts from the catching-up point and ends with the point of restoration, at which the orbital time for the near-side half and the far-side half of the circular orbit of the binary star become equal once again.   And the third part of the light path starts from the latter point and extends to infinity.

In the de Sitter's arrangement, the orbital velocity vector of the binary star makes with the line of sight an angle θ that varies from 0^o to 360^o during each orbital period. And subsequently, the radial velocity $v\cos\theta$ of the binary star varies from $+v$, through 0, to $-v$ to 0, and to $+v$ once again, during each orbital period. And since the line of sight, within the framework of the elastic-impact emission theory, is the direction of the velocity resultant of emitted light as measured by a distant observer, the magnitude of the velocity resultant of light must vary with the values of θ, in accordance with this equation:

$$c' = c\sqrt{1-\frac{v^2}{c^2}\sin^2\theta} + v\cos\theta$$

where c' is the combined speed of light as measured by a stationary observer.

With the exception of (c + v) and (c – v), for each velocity value, computed for any point on the far side of the binary orbit, there is an equal velocity value, computed for a corresponding point on the near side of the same binary orbit, according to the elastic-impact emission theory. Equal velocities imply equal displacements in equal times. And hence, the differences in arrival times between light emitted at points of equal velocity values remain constant and the same regardless of the distance between the binary star and the observer.

Moreover, according to the elastic-impact emission theory, light, emitted in multiple orbital periods at the same point, travels at the same speed and arrives at each point of its path with the same temporal frequency as the orbital period of the emitting star. For instance, light emitted at Point A, in the de Sitter's arrangement, during all orbital periods, travels at the same velocity resultant of (c + v), and arrives at every point of its path at an interval of time equals to the orbital period of the binary star.

The following is a detailed treatment of the main observable effects of variable speed of starlight from binary stars, as predicted, in advance, on the basis of the elastic-impact emission theory.

1. The First Part of Starlight Path from a Binary Star to a Distant Observer:

For the binary orbit, illustrated in Figure I, P is the orbital period of the binary star; v is the orbital velocity of the binary star; the maximum velocity of approach is at Point A; the maximum velocity of recession is at Point B; AB is the near-side half of the binary orbit; and BA is the far-side half of the binary orbit.

According to the elastic-impact emission theory, light, emitted by the star at Point A, travels towards the observer at the speed resultant of (c + v). And light emitted by the star at Point B, travels towards the observer at the speed resultant of (c – v).

Since light emitted at Point B, during all orbital periods, travels at the same speed resultant of (c – v), this light is necessarily distributed, throughout the space between the binary star and the observer, at regular distances of $P(c - v)$, and with regular differences in arrival time of exactly one orbital period P at every point along its path.

And likewise, since light emitted at Point A, during all orbital periods, travels at the same speed resultant of $(c + v)$, this light is necessarily distributed, across the expanse of space between the binary star and the observer, at regular distances of $P(c + v)$, and with regular differences in arrival time of exactly one orbital period P at every point along its path.

In other words, it is not just light emitted once at Point A moving relative to light emitted once at Point B; but a whole carpet of a long series of light emitted many times at Point A is moving at a relative speed of *2v* with respect to a whole a carpet of a long series of light emitted many times at Point B.

And because, each light A is emitted exactly at ½P between the previous light B_1 and the next light B_2, by moving away at a relative speed of *2v* from the latter, it must get closer at a relative speed of 2v to the former:

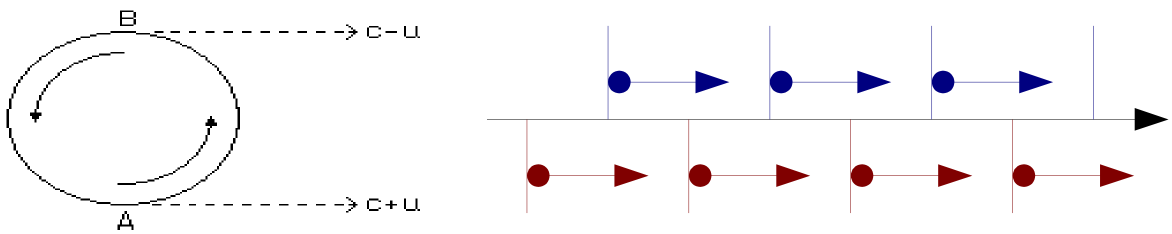

Figure #II

A. The Point of Maximum Apparent Brightness of Light Emitted by a Binary Star:

Since the relative velocity between light traveling at the velocity resultant of $(c + v)$ and light traveling at the velocity resultant of $(c - v)$ is 2v, the instantaneous displacement D_1 between light A and light B_1 after any interval of time t since emission of light A, can be obtained from this equation:

$$D_1 = \frac{1}{2}P(c - v) - 2vt$$

and the instantaneous displacement D_2 between light A and the light B_2 after any interval of time t since emission of light A, can be obtained from this equation:

$$D_2 = \frac{1}{2}P(c-v) + 2vt$$

Let F denote the point of maximum apparent brightness on the light path, at which:

$$D_1 = 0$$

and

$$D_2 = P(c-v)$$

and hence, the interval of time t_F, since the emission of light A, is:

$$t_F = \frac{\frac{1}{2}P(c-v)}{2v} = \frac{1}{4}P\left(\frac{c}{v} - 1\right)$$

and therefore, the distance d_F between the binary star and the point of maximum apparent brightness F is:

$$d_F = t_F(c+v) = \frac{1}{4}P\left(\frac{c}{v} - 1\right)(c+v) = \frac{1}{4}Pc\left(\frac{1 - v^2/c^2}{v/c}\right)$$

from which it can be obtained that, for v of 100 km/sec and P of 16 days in the de Sitter's example, the computed distance of the point of maximum apparent brightness F from the binary star is about 32.88 light-years away.

B. The Binary Star as Observed from any Location Closer than Point F:

The Near-Side Half of the Binary Orbit, AB:

Because in this part of the binary orbit, light A is emitted ½P earlier before light B, the instantaneous displacement increases with distance, along the light path from the binary star to the point of maximum brightness F, as the observer moves from the center of the binary system towards the point of maximum brightness F. And hence, the time T_{near} for traversing the near-side half of the orbit (from Point A to Point B) by the binary star, increases with distance, in accordance with this equation:

$$T_{near} = \frac{1}{2}P\left(\frac{D_2}{\frac{1}{2}P(c-v)}\right) = \frac{1}{2}P\left(\frac{\frac{1}{2}P(c-v)+2vt}{\frac{1}{2}P(c-v)}\right) = \frac{1}{2}P\left[1+t\frac{4v/c}{P(1-v/c)}\right]$$

Also, along the light path from the binary star to the point of maximum apparent brightness F, as the observer moves from the center of the binary system towards the point of maximum apparent brightness F, the brightness b_{near} of the binary star during traversing the near-side half of its orbit (from Point A to Point B), changes in accordance with this equation:

$$b_{near} = \frac{L}{4\pi d^2}\left(\frac{\frac{1}{2}P(c-v)}{D_2 - r_{near}}\right) = \frac{L}{4\pi d^2}\left(\frac{\frac{1}{2}P(c-v)}{\frac{1}{2}P(c-v)+2vt-r_{near}}\right) = \frac{L}{4\pi d^2}\left[1-t\frac{4v/c}{P(1-v/c)+4t\,v/c-\tau_{near}}\right]$$

where L is the intrinsic luminosity of the binary star; and d is the distance between the binary star and the observer, as defined by this equation:

$$d = t(c+v)$$

r_{nearr} is the radius of the near-side half of the binary orbit; τ_{near} is the light travel time across the radius of the near-side half of the binary orbit; and t is the interval of time since the emission of light A.

The elastic-impact emission theory, therefore, predicts that the time, for traversing the near-side half of the binary orbit (from Point A to Point B) by the binary star, varies from ½P to P with increasing distance from the center of the binary system to the point of maximum apparent brightness F. And that, as the observer approaches the point of maximum apparent brightness F, the brightness of the binary star, in the near-side half of its orbit, approaches one half of its computed value on the basis of the inverse square law.

The Far-Side Half of the Binary Orbit, BA:

Since in this part of the binary orbit, light B is emitted ½P earlier before light A, the instantaneous displacement decreases with increasing distance, along the light path from the binary star to the point of maximum apparent brightness F, as the observer moves from the center of the binary system towards the point of maximum apparent brightness F. And hence, the time T_{far} for traversing the far-side half of the orbit (from Point B to Point A) by the binary star, decreases with increasing distance, in accordance with this equation:

$$T_{far} = \frac{1}{2}P\left(\frac{D_1}{\frac{1}{2}P(c-v)}\right) = \frac{1}{2}P\left(\frac{\frac{1}{2}P(c-v)-2vt}{\frac{1}{2}P(c-v)}\right) = \frac{1}{2}P\left[1-t\frac{4v/c}{P(1-v/c)}\right]$$

Also, along the light path from the binary star to the point of maximum apparent brightness F, as the observer moves from the center of the binary system towards the point of maximum apparent brightness F, the apparent brightness b_{far} of the binary star during traversing the far-side half of its orbit (from Point B to Point A), increases in accordance with this equation:

$$b_{far} = \frac{L}{4\pi d^2}\left(\frac{\frac{1}{2}P(c-v)}{D_1+r_{far}}\right) = \frac{L}{4\pi d^2}\left(\frac{\frac{1}{2}P(c-v)}{\frac{1}{2}P(c-v)-2vt+r_{far}}\right) = \frac{L}{4\pi d^2}\left[1+t\frac{4v/c}{P(1-v/c)-4t\,v/c+\tau_{far}}\right]$$

where L is the intrinsic luminosity of the binary star; and d is the distance between the binary star and the observer, as defined by the following equation:

$$d = t(c+v)$$

and r_{far} is the radius of the far-side of the binary orbit; τ_{far} is the light travel time across the radius of the far-side half of the binary orbit; and t is the interval of time since the emission of light A.

Therefore, the elastic-impact emission theory predicts that the time, for traversing the far-side half of the orbit (from Point B to Point A) by the binary star, varies from ½P to τ_{far} with increasing distance from the center of the binary system to the point of maximum apparent brightness F. And that, as the observer approaches the point of maximum apparent brightness F the apparent brightness of the binary star approaches the sum of its values, as computed on the basis of the inverse square law, for the binary star in the entire far-side half of its orbit.

Consequently, the radiant flux from the binary star as observed at point F, can be tremendous, because the total output of radiant flux during ½P is received in just a tiny fraction of the orbital period.

Nonetheless, this tiny fraction of the orbital period cannot be reduced to zero, because light is emitted, necessarily, at various parts of half of the circular orbit; and hence, at various distances from the observer. And therefore, the maximum radiant flux at the point of maximum apparent brightness F, b_F is:

$$b_F = \frac{L}{4\pi d^2}\left(\frac{\frac{1}{2}P}{\tau_{far}}\right)$$

So, an observer at the point of maximum apparent brightness F, in accordance with the prediction computed above, observes that, each time, light A and light B arrive nearly at the same time; and the interval of time between each two instants of their nearly simultaneous arrival is equal to the orbital period P. And also, during the nearly simultaneous arrival of light A and light B, the binary star is much brighter and bigger; and that, during the rest of its orbital period, the same star is much dimmer and smaller.

In a nutshell, from the viewpoint of an observer located at the point of maximum apparent brightness F, the binary star appears to be a cataclysmic variable star, similar to the well-known star U Geminorum, with an orbital period of one P, and a sinusoidal orbital speed of one v.

The de Sitter's conclusion that it would be absolutely impossible to bring these observations into agreement with Kepler's laws, therefore, is demonstrably incorrect.

2. The Second Part of Starlight Path from a Binary Star to a Distant Observer:

As pointed out earlier in this discussion, the second part of the starlight path starts from the point of maximum apparent brightness *F* and extends to the point *2F,* which is at twice the distance of the point of maximum apparent brightness *F* from the binary star.

When the fastest starlight A arrives at the point *2F,* the time for traversing the near side of the circular orbit and the time for traversing the far side of the same orbit by the binary star become equal once again; because the fastest light A, in this case, is located exactly midway along the constant displacement of P(c – v) between the leading slowest light B_0 and the trailing slowest light B_1.

Immediately after passing through the point of maximum apparent brightness *F*, the faster starlight starts to move away from the slower light B_1, and towards the previously emitted slower light B_0. And as a result, the two sides of the binary orbit are reversed: The far side of the binary orbit BA, in de Sitter's arrangement, is, now, the near side of the binary orbit AB_1. And the near side of the binary orbit AB is, now, the far side of the binary orbit B_0A.

And because the relative velocity between starlight traveling at the velocity resultant of (c + v) and starlight traveling at the velocity resultant of (c – v) is 2v, the instantaneous displacement D_1 between the faster starlight A and the slower starlight B_0 after any interval of time *t* since emission of starlight A, can be obtained from this equation:

$$D_1 = P(c-v) - 2v(t - t_F)$$

and the instantaneous displacement D_2 between light A and the starlight B_1 after any interval of time *t* since emission of starlight A, can be obtained from this equation:

$$D_2 = 2v(t - t_F)$$

where t_F is defined by this equation:

$$t_F = \frac{\frac{1}{2}P(c-v)}{2v} = \frac{1}{4}P\left(\frac{c}{v} - 1\right)$$

The Far Side of the Binary Orbit B_0A:

Along the light path from the binary star, as the observer moves beyond the point of maximum apparent brightness *F* and towards the point *2F*, the time T_{far} for traversing the far-side half of the binary orbit (from Point B_0 to Point A) by the binary star, changes in accordance with this equation:

$$T_{far} = P\left[1 - \frac{D_1}{P(c-v)}\right] = P\left[1 - \frac{2v(t-t_F)}{P(c-v)}\right]$$

And also, the apparent brightness b_{far} of the binary star, during traversing the far-side half of its orbit (from Point B_0 to Point A), changes in accordance with the following equation:

$$b_{far} = \frac{L}{4\pi d_2}\left(\frac{\frac{1}{2}P}{P+t-t_F}\right)$$

where L is the intrinsic luminosity of the binary star; and d is the distance between the binary star and the observer and defined by this equation:

$$d = t(c+v)$$

and where t_F is:

$$t_F = \frac{\frac{1}{2}P(c-v)}{2v} = \frac{1}{4}P\left(\frac{c}{v}-1\right)$$

The Near Side of the Binary Orbit AB_1:

Along the starlight path from the binary star, as the observer moves beyond the point of maximum apparent brightness F and towards the point $2F$, the time T_{near} for traversing the near-side half of the orbit (from Point A to Point B_1) by the binary star, changes in accordance with this equation:

$$T_{near} = P - T_{far}$$

and furthermore, along the starlight path beyond the point of maximum apparent brightness F, as the observer moves outward from the point of maximum apparent brightness F and towards the point $2F$, the apparent brightness b_{near} of the binary star during traversing the near-side half of its orbit (from Point A to Point B_1), changes in accordance with this equation:

$$b_{near} = \frac{L}{4\pi d_2}\left(\frac{\frac{1}{2}P}{t - t_F + \tau_F}\right) + b_{far}\left(\frac{T_{near}}{T_{far}}\right)$$

where b_{far} is defined by this equation:

$$b_{far} = \frac{L}{4\pi d_2}\left(\frac{\frac{1}{2}P}{P + t - t_F}\right)$$

T_{near} is defined by this equation:

$$T_{near} = P - T_{far}$$

and T_{far} is defined by the following equation:

$$T_{far} = P\left[1 - \frac{D_1}{P(c - v)}\right] = P\left[1 - \frac{2v(t - t_F)}{P(c - v)}\right]$$

and t is the interval of time since the emission of light A.

It follows, therefore, that at the point $2F$:

The time T_{far} for traversing the far-side half of the orbit (from Point B_0 to Point A), by the binary star, is:

$$T_{far} = \frac{1}{2} P$$

the time T_{near} for traversing the near-side half of the orbit (from Point A to Point B_1), by the binary star, is:

$$T_{near} = \frac{1}{2} P$$

and the apparent brightness b_{far} of the binary star, during traversing the far-side half of its orbit (from Point B_0 to Point A), is:

$$b_{far} = \frac{L}{4\pi d^2}\left(\frac{\frac{1}{2}P}{P+\frac{1}{2}P}\right) = \frac{L}{4\pi d^2}\left(\frac{1}{3}\right)$$

and the apparent brightness b_{near} of the binary star, during traversing the near-side half of its orbit (from Point A to Point B_1), is:

$$b_{near} = \frac{L}{4\pi d^2}\left(\frac{4}{3}+\frac{1}{3}\right) = \frac{L}{4\pi d^2}\left(\frac{5}{3}\right)$$

And therefore, an observer at the point *2F*, observes that the binary star goes from Point B_0 to Point A during an interval of time equal to ½P; and from Point A to Point B_1 during an interval of time equal to ½P. And that the apparent brightness of the binary star, during the latter interval is 5 times its apparent brightness during the former interval.

3. The Third Part of Starlight Path from a Binary Star to a Distant Observer:

As stated earlier, the third part of the starlight path starts from the point *2F* and extends to infinity.

In the current calculations, it's convenient to divide this third part of the starlight path to equal segments, each of which equals to the distance of the peak point of apparent brightness from the binary star. And hence, the entire starlight path, from the binary star to infinity, takes the form of the following numerical series: *F, 2F, 3F, 4F, 5F, 6F, 7F, ..., nF, ...*; where the first term, *F*, in this series, is the location of the peak point of apparent brightness; and *n* is 1, 2, 3, ….

In the above series, the odd numbers: *3F, 5F, 7F, 9F, ...,* n_oF ... denote the locations along the starlight path from the binary star, where the faster starlight of later orbital cycles continue to overtake slower starlight of previous orbital cycles. While the even numbers: *2F, 4F, 6F, 8F, ...,* n_eF ... denote the locations along the starlight path from the binary star, where the orbital time for traversing the near side of the circular orbit and the orbital time for traversing the far side of the same orbit by the binary star become equal.

The faster starlight overtakes the slower starlight only at the odd-number locations of *3F, 5F, 7F, 9F, ...,* n_oF ..., because, even though the faster starlight, at the relative speed of *2v*, covers only the displacement:

$$D = \frac{1}{2}P(c-v)$$

in order to catch up with the slower starlight, from the same orbital period, at the point of maximum apparent brightness F; the faster starlight must cover, in all other cases, at the same relative speed of *2v*, the displacement:

$$D = P(c-v)$$

in order to overtake slower starlight, from previous orbital periods, at the locations of *3F, 5F, 7F, 9F, ...,* n_oF ….

As in the case of the point *2F*, each time, the faster starlight arrives at the points *4F*, *6F*, *8F*, *10F* … etc., the orbital time for traversing the near side of the circular orbit and the orbital time for traversing the far side of the same orbit by the binary star become equal.

The radiant flux of faster starlight A, f_A, at the points *4F*, *6F*, *8F*, *10F*, … n_eF, ..., continues to decrease in accordance with this equation:

$$f_A = \frac{L}{4\pi d^2}\left(\frac{1}{n_e - 1}\right)$$

And the radiant flux of slower starlight B, f_B, continues to decrease in accordance with this equation:

$$f_B = \frac{L}{4\pi d^2}\left(\frac{1}{n_e + 1}\right)$$

where d is defined by this equation:

$$d = n_e d_F = \frac{1}{4} n_e P c\left(\frac{1 - v^2/c^2}{v/c}\right)$$

and n_e is 4, 6, 8, 10, … etc.

The Apparent Brightness of the Binary Star in the Near Side of its Orbit:

At the same time, in the near-side half of the binary orbit, the number of superimposed faster starlight A from multiple orbital periods, N_A continues to increase as:

$$N_A = \frac{n_e}{2}$$

Likewise, in the near-side half of the binary orbit, the number of superimposed slower starlight B from multiple orbital periods, N_B, continues to increase as:

$$N_B = \frac{n_e}{2} + 1$$

where n_e, is 4, 6, 8, … etc..

Therefore, in the near-side half of the binary orbit, the total radiant flux of faster starlight A, f_{nA}, at each one of these points *4F*, *6F*, *8F*, … n_eF, can be obtained by using the following equation:

$$f_{nA} = f_A\left(N_A\right) = \frac{L}{4\pi d^2}\left(\frac{0.5n_e}{n_e - 1}\right)$$

And the total radiant flux of slower starlight B, f_{nB}, at the points *4F*, *6F*, *8F*, … n_eF, can be obtained by using this equation:

$$f_{nB} = f_B\left(N_B\right) = \frac{L}{4\pi d^2}\left(\frac{0.5n_e + 1}{n_e + 1}\right)$$

And accordingly, the apparent brightness of the binary star, in the near-side half of its orbit, b_{near} varies with distance in accordance with this equation:

$$b_{near} = f_{nA} + f_{nB} = \frac{L}{4\pi d^2}\left(\frac{n_e^{\,2} + n_e - 1}{n_e^{\,2} - 1}\right) = \frac{L}{4\pi d^2}\left(1 + \frac{1}{n_e - 1/n_e}\right)$$

where d is defined by this equation:

$$d = n_e d_F = \frac{1}{4} n_e P c\left(\frac{1 - v^2/c^2}{v/c}\right)$$

and n_e, is 4, 6, 8, … etc..

It follows, therefore, that, as the value of n_e approaches infinity, the apparent brightness of the binary star, in the near-side half of its orbit, approaches the value deduced from the inverse square law:

$$\frac{L}{4\pi d^2}$$

The Apparent Brightness of the Binary Star in the Far Side of its Orbit:

As in the case of the near-side half above, in the far-side half of the binary orbit, the number of superimposed faster starlight A from multiple orbital periods, N_A continues to increase as:

$$N_A = \frac{n_e}{2} - 1$$

At the same time, in the far-side half of the binary orbit, the number of superimposed slower starlight B from multiple orbital periods, N_B, continues to increase as:

$$N_B = \frac{n_e}{2}$$

where n_e, is 4, 6, 8, … etc..

And therefore, in the far-side half of the binary orbit, the total radiant flux of faster starlight A, f_{nA}, at any of these points *4F*, *6F*, *8F*, … n_eF, …, can be computed by using the following equation:

$$f_{nA} = f_A\left(N_A\right) = \frac{L}{4\pi d^2}\left(\frac{0.5n_e - 1}{n_e - 1}\right)$$

And the total radiant flux of slower starlight B, f_{nB}, at the points *4F*, *6F*, *8F*, … n_eF, can be obtained by using this equation:

$$f_{nB} = f_B\left(N_B\right) = \frac{L}{4\pi d^2}\left(\frac{0.5n_e}{n_e+1}\right)$$

And therefore, the apparent brightness of the binary star, in the far-side half of its orbit, b_{far} varies with distance in accordance with this equation:

$$b_{far} = f_{nA} + f_{nB} = \frac{L}{4\pi d^2}\left(\frac{n_e^2 - n_e - 1}{n_e^2 - 1}\right) = \frac{L}{4\pi d^2}\left(1 - \frac{1}{n_e - 1/n_e}\right)$$

where d is defined by this equation:

$$d = n_e d_F = \frac{1}{4} n_e Pc\left(\frac{1 - v^2/c^2}{v/c}\right)$$

and n_e, is 4, 6, 8, … etc..

It follows, therefore, that, as the value of n_e approaches infinity, the apparent brightness of the binary star, in the far-side half of its orbit, approaches the value deduced from the inverse square law:

$$\frac{L}{4\pi d^2}$$

And so, for large values of n_e, numerical predictions based upon the assumption of variable speed of starlight, with regard to stellar binaries, become, from practical standpoint, very close to numerical predictions based on the assumption of constant speed of starlight.

The de Sitter's Chosen Examples of Binary Stars:

W. de Sitter gave four examples of binary stellar systems that, in his view, support the main conclusions of his demonstration:

1. ***The Binary System of δ Equulei:***

Distance:	60.3 light-years
Orbital period:	5.7 years
Orbital velocity:	22.5 km/s

And, therefore, the distance d_F between this binary system and the point of maximum brightness F can be computed by using the following equation:

$$d_F = t_F\left(c+v\right) = \frac{1}{4}P\left(\frac{c}{v}-1\right)\left(c+v\right) = \frac{1}{4}Pc\left(\frac{1-v^2/c^2}{v/c}\right)$$

from which the computed distance of the point of maximum apparent brightness F from the binary star is about 19000 light-years. And since δ Equulei is only about 60.3 light-years from the solar system, effects on apparent brightness and orbital time for both sides of its binary orbit cannot exceed 0.0032, according to the elastic-impact emission theory.

2. ***The Binary System of ζ Herculis:***

Distance:	35 light-years
Orbital period :	34.45 years
Orbital velocity:	13 km/s

And, accordingly, the distance d_F between this binary star and the point of maximum apparent brightness F can be calculated by using the following equation:

$$d_F = t_F\left(c+v\right) = \frac{1}{4}P\left(\frac{c}{v}-1\right)\left(c+v\right) = \frac{1}{4}Pc\left(\frac{1-v^2/c^2}{v/c}\right)$$

and hence, the computed distance of the point of maximum apparent brightness F from the binary star is about 198750 light-years. And because ζ Herculis is only about 35 light-years from the solar system, effects on brightness and orbital time for both sides of its binary orbit cannot exceed 0.0002, according to the elastic-impact emission theory.

3. *The Binary System of β Aurigae:*

Distance:	81.1 light-years
Orbital period:	3.96004 days
Orbital velocity (primary):	108 km/s
Orbital velocity (secondary):	110 km/s

It follows, therefore, that the distance d_F between this binary system and the point of maximum apparent brightness F_P for the primary star and F_S for the secondary star can be computed by using this equation:

$$d_F = t_F\left(c+v\right) = \frac{1}{4}P\left(\frac{c}{v}-1\right)\left(c+v\right) = \frac{1}{4}Pc\left(\frac{1-v^2/c^2}{v/c}\right)$$

from this equation, the computed distances of the points of maximum apparent brightness F_P and F_S from the binary system are about 7.534 light-years and 7.397 light-years respectively. Since β Aurigae is about 81.1 light-years from the solar system, the point of maximum apparent brightness for its primary component F_P and the point of maximum apparent brightness for its secondary component F_S are about 10.76 times and 10.96 times closer to the binary stellar system than to the solar system. And hence, as seen from Earth, the starlight, from the primary star, traveling at the speed resultant of (c + v) is at 76% of the *11F* segment of its path. And the light, from the secondary star, traveling at the speed resultant of (c + v) is at 96% of the *11F* segment of its path. And therefore, according to the elastic-impact emission theory, β Aurigae appears, as seen from Earth, to belong to the class of eclipsing binary stars, and to have a binary orbit very close to being circular.

4. *The Binary System of Algol (β Persei):*

Distance:	93 light-years
Orbital period:	2.86736 days
Orbital velocity (Primary):	55.12 km/s
Orbital velocity (Secondary):	248 km/s

For the Primary Component:

The distance d_F between this binary star and the point of maximum apparent brightness F_P can be computed by using this equation:

$$d_F = t_F\left(c+v\right) = \frac{1}{4}P\left(\frac{c}{v}-1\right)\left(c+v\right) = \frac{1}{4}Pc\left(\frac{1-v^2/c^2}{v/c}\right)$$

from which the computed distance of the point of maximum apparent brightness F_P from the binary system is about 10.7 light-years. And since β Persei is about 93 light-years from the solar system, the point of maximum apparent brightness F_P is about 8.7 times closer to the binary system than to the solar system. It follows that the fastest light from this component, therefore, is at 70% of the *9F* segment of its path.

And for the Secondary Component:

The computed distance of the point of maximum apparent brightness F_S from the binary system is about 2.4 light-years. And since β Persei is about 93 light-years from the solar system, the point of maximum apparent brightness F_S is about 38.75 times closer to the binary system than to the solar system. And hence, the fastest light, from this component, is at 75% of the *39F* segment of its path.

According to the elastic-impact emission theory, therefore, β Persei appears, as seen from Earth, to be an eclipsing binary system with an orbit close to being circular.

Conclusion:

As demonstrated in this discussion, the point of maximum apparent brightness of any binary star, in the farthest parts of its orbit, is the most important marker along the starlight path from the binary system to infinity.

Given the orbital period and orbital velocity of any binary star, the shortest distance possible between the binary star and the point of maximum apparent brightness, is defined by the following equation:

$$d_F = t_F\left(c+v\right) = \frac{1}{4}P\left(\frac{c}{v}-1\right)\left(c+v\right) = \frac{1}{4}Pc\left(\frac{1-v^2/c^2}{v/c}\right)$$

where *P* is the orbital period of the binary star; and *v* is its orbital velocity.

The minimum distance, as defined above, can be made longer and longer and extended to infinity by gradually reducing the inclination angle (*i*) between the observer's line of sight and the polar axis of the binary orbit from the value of 90° towards the value of 0°; and inserting *vsin(i)* in the place of *v* into the aforementioned equation.

The point of maximum apparent brightness is an indispensable tool for classifying the primary effects and pinning down the exact nature of the various optical transformations of the binary star, and their locations along the starlight path on its way towards distant observers.

By definition, the point of maximum apparent brightness lies precisely halfway between the location of the binary star and the location of the point *2F*, at which the orbital time for both sides of the binary orbit is restored to its original value through the continuous movement of faster starlight away from the initial slower starlight and towards the next slower starlight in the slower-light series, from the same binary star, which extends and goes on and on all the way to infinity.

Since the location of the binary star and the location of the point of maximum apparent brightness are at 00% and 100% of the distance computed from the above equation; given x% of that distance as the location of any point at the starlight path, the apparent orbital time of the far-side half, t_f, and the apparent orbital time of the near-side half, t_n, as observed from any point x, are respectively:

$$t_f = t_a\left(100\% - x\%\right)$$

and

$$t_n = t_a\left(100\% + x\%\right)$$

where t_a is the actual orbital time, for each half of the binary orbit.

By dividing the true brightness, B_a, as deduced from the inverse-square law, by (100% - x%) and by (100% + x%) respectively, the apparent brightness of the binary star, in the far-side half of its orbit, B_f, and in the near-side half of its orbit, B_n, as observed at any point x, can be readily obtained from these equations:

$$B_f = \frac{B_a}{100\% - x\%}$$

and

$$B_n = \frac{B_a}{100\% + x\%}$$

for both sides of the binary orbit respectively.

And therefore,

$$\frac{B_f}{B_n} = \frac{100\% + x\%}{100\% - x\%}$$

independent of the given value of $\boldsymbol{B_a}$.

As seen from a point located at 10% of the calculated distance, for example, the binary star appears brighter by a factor of 1.111, in the far-side half; and dimmer by a factor of 0.909, in the near side half of its orbit.

At 50% of the distance, the binary star appears brighter by a factor of 2, and dimmer by a factor of 0.667, in the far side and the near side of its orbit respectively.

And at 90% of the same distance, the same binary star appears, in the same order as well, brighter by a factor of 10, and dimmer by a factor of 0.526 than the calculated apparent brightness on the assumption of constant speed of starlight.

Based on the values of apparent brightness, as given by the above equations, the following conclusions can be made with regard to the general outline for the main optical transformations of the same binary star, as seen by observers at different distances along the starlight path:

I. As observed from any point at less than 50% of the distance between the binary star and the peak point of apparent brightness, the binary star exhibits a low level of variability in apparent brightness; but it remains within the class of binary stars: Visual, astrometric, spectroscopic, . . . etc..

II. As observed from any point between 50% and 90% of the distance between the binary star and the peak point of apparent brightness, the binary star shows an increasing level of high variability in apparent brightness, and no longer appears as a binary star; but as one within the class of pulsating variable stars: Cepheid, RR Lyrae, Delta Scuti, . . . etc..

III. As observed from any point between 90% and 100% of the distance between the binary star and the peak point of apparent brightness, the binary star appears to belong to the class of cataclysmic variable stars: Dwarf nova, nova, Z Andromedae, . . . etc..

IV. Also as observed from any point between 100% and 110% of the distance between the binary star and the peak point of apparent brightness, the binary star appears to belong to the class of cataclysmic variable stars: Dwarf nova, nova, Z Andromedae, . . . etc..

V. And once again, as observed from any point between 110% and 150% of the distance between the binary star and the peak point of apparent brightness, the binary star shows a decreasing level of high variability in apparent brightness, and no longer appears as a cataclysmic variable star; but as a member of the class of pulsating variable stars: Cepheid, RR Lyrae, SX Phoenicis, . . . etc..

VI. And as observed at any point from 150% through 200% and up to 300% of the distance between the binary star and the peak point of apparent brightness, the binary star exhibits a low level of variability in apparent brightness; but appears, once again, as a member of the class of binary stars: Visual, eclipsing, spectroscopic, . . . etc..

VII. And finally, as observed from any point between 300% of the distance between the binary star and the peak point of apparent brightness and infinity, each and every time, the same fastest starlight overtakes one of the slowest phases of starlight, emitted earlier by the same binary star, all of the optical transformations, *#IV*, *#V*, and *#VI* as explained above, are repeated all over again, in the same order; but at a decreasing level of apparent brightness that approaches the values computed on the assumption of constant speed of starlight, as the distance from the same binary star approaches infinity.

VIII. All optical transformations of the binary star, before the peak point of apparent brightness, are composed of starlight emitted in one single orbital period. As a result, the binary star, throughout its orbit, can appear to vary in brightness and size only in one uniform sinusoidal mode.

IX. All of the optical transformations of the binary star, after the peak point of apparent brightness, are composed of starlight emitted in multiple orbital periods whose number increases by two more orbital periods, whenever the fastest starlight overtakes the slowest starlight of the same binary star. Subsequently, the binary star, throughout its orbit, can appear, spectroscopically as well as interferometrically, to vary in brightness and size in multiple modes.

All in all, in conclusion, therefore, it is not the assumption of additive speed of starlight that might be in danger of being falsified by binary stars. Contrary to the aforementioned de Sitter's demonstration, it is the current astronomy that may well be compelled, in the foreseeable future, to relabel half of its inventory of real objects as mere optical manifestations of the other half.

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