Comet Vulcan's Unobserved August 17, 1999 Flyby

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This paper presents a case for a small comet's low-altitude flyby of Earth on August 17, 1999 with a perigee over Nairobi, Kenya that nobody has ever observed at night as far as we know. This flyby maneuver is inferred from one daylight observation of the comet near the Moon on August 11, 1999 (during a solar eclipse) and one nighttime observation in the glare of a bright star on April 6, 2000 by an astronomer attempting to observe an asteroid occultation of that star. That astronomer only reported an unidentified nebulosity surrounding the star. I am the only one who claims that nebulosity was this comet's coma. My claim must be regarded as being speculative unless a subsequent analysis that includes the Moon's gravity can confirm the daylight lunar transit of this comet that I observed on August 14, 1999.

Even if the April 6, 2000 observation were not in doubt, these two observations alone would comprise a very weak case for such a low-altitude flyby of Earth if it were not for the 7.6 magnitude earthquake that occurred in Turkey on August 17, 1999. This paper claims that this comet's tidal forces on the Earth's crust along its ground track during the flyby induced seismic waves that triggered this earthquake several minutes later. An analysis is presented for a mechanism that involves a Doppler frequency shift in the trigger waves due to the radial velocity of the comet's ground track with respect to the earthquake epicenter and also considers the attenuation suffered by the trigger wave in reaching the epicenter from the ground track.

This paper suggests five strategies for a comet to escape observation by comet hunters: (1) be dormant while it is in the night sky, (2) while active, remain near the Sun's line of sight in the daylight sky or in the Earth's shadow or below the horizon at night, (3) hide behind the Moon all night between the eclipse and the lunar transit, (4) hope for cloudy skies during the low-altitude Earth flyby just before sunrise or just after sunset (August is the monsoon season for South Asia), and (5) masquerade as a planetary nebula after the flyby by minimizing its proper motion (with respect to the fixed stars) until its coma has dissipated. This comet has apparently used each strategy at one time or another to escape detection.

1. Introduction

This paper is about a little comet that apparently has had many close encounters with the Earth over the ages but has never been observed in the night sky in modern times, as far as we know. This paper examines the time span from August 11, 1999 to April 6, 2000.

Why should anyone care about this comet? I care because I observed it transit the Moon in my backyard telescope 10 minutes before sunset on August 14, 1999 in Plano, Texas. I was frustrated because my reported observation was never confirmed (Section 4). I found out later that a small comet that looked just like the one I had observed had been seen near the Moon in a webcast of the total solar eclipse in Amasya, Turkey on August 11, 1999 (Figures 1, 2, 4, 5 and Section 3).

I also learned that several unidentified solar transits had been reported in the 19th Century (Section 2) that were thought to have been made by an undiscovered planet inside Mercury's orbit that was dubbed Vulcan by magazine readers. I have good reason to think that those transits were made by this same comet because evidence of parallax indicates that it was as close to Earth as the Moon's orbit. If so, observers saw the opaque silhouette of the comet's nucleus transit the Sun.

In 2009 I learned that an astronomer had reported seeing a nebulosity surrounding the 8th magnitude binary star HIP 66600 on April 6, 2000 while he was attempting to observe an asteroid occultation of that star (Section 5). I believe that nebulosity may have been this comet's coma. The nebulosity was transient. It was not there before the flyby, and it is not there now.

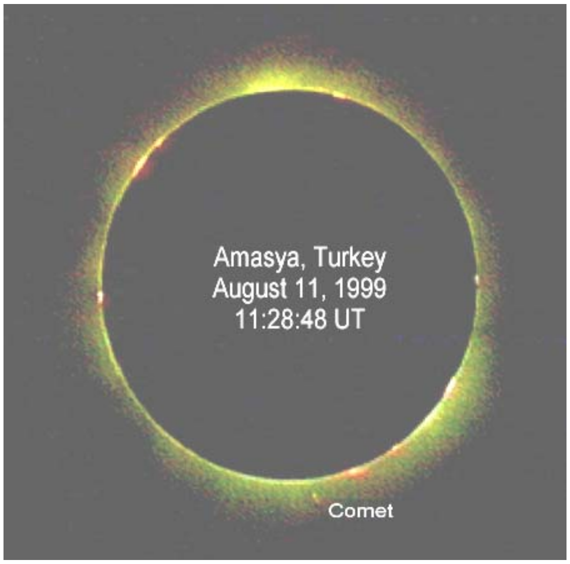


Fig. 1. Comet in August 11, 1999 eclipse field

Finally, in the process of preparing this paper I realized that this comet's close flyby of the Earth could have been the trigger for the 7.6-magnitude Izmit, Turkey earthquake that occurred on August 17, 1999. At first I thought the comet's perigee footprint (intersection of its perigee radius vector with the Earth's surface) had to coincide with the geographical coordinates of the earthquake's epicenter. However, after I found out that these two radius vectors are separated by about 4,800 km on the surface of the Earth (Nairobi, Kenya perigee footprint to the Izmit, Turkey epicenter), I realized that I could not enforce that constraint. The trigger mechanism isn't that simple.

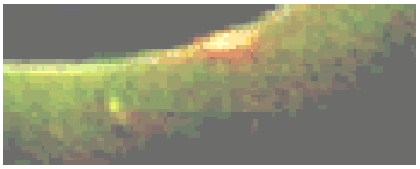


Fig. 2. Enlarged view of 1999 eclipse comet

One theme of this paper is to explain how this comet could have triggered an earthquake that far away from its closest approach to the Earth's surface (Figure 11).

Another theme of this paper is to explain how this comet could possibly have evaded observation in the night sky. The world has many too many competent and diligent comet hunters for any comet, even such a small one, to rely on luck to evade detection.

There are at least five strategies for a comet to evade observation that come to mind: (1) be dormant while it is in the night sky, (2) while active, remain near the Sun's line of sight in the daylight sky or in the Earth's shadow or below the horizon at night, (3) hide behind the Moon all night between the eclipse and the lunar transit, (4) hope for cloudy skies during the low-altitude Earth flyby just before sunrise or just after sunset (August is the monsoon season for South Asia), and (5) masquerade as a planetary nebula after the flyby by minimizing its proper motion (with respect to the fixed stars) until its coma has dissipated (Section 6).

Any hyperbolic flyby orbit will have a small proper motion during its inbound and outbound legs. Borrowing the terminology of meteor showers, I'm calling each asymptote of a geocentric hyperbolic orbit a radiant. There is an inbound radiant and an outbound radiant. The principle is one of perspective. If you see a moving object growing larger but remaining stationary with respect to the background landscape, you know that it is on a collision trajectory with you. Any space body that executes a very close Earth flyby in a hyperbolic geocentric orbit will approach from its inbound radiant and recede towards its outbound radiant. These radiants will have fixed Right Ascensions and Declinations (RA and Dec.) in the celestial sphere.

The strategy of this paper is to adjust the six elements of a Keplerian (2-body) geocentric orbit to satisfy the solar eclipse observation (Section 3) and the HIP 66600 occultation observation (Section 5). Since there are six unknown elements, you need three observations of RA and Dec. to define the orbit. My own observation of the lunar transit on August 14 would be perfect as a third observation if we were including the Moon's gravity in the model. But since this 2-body model is Moonless, we can't use my lunar transit observation.

Instead, the third observation in this case is assumed to be a close flyby that triggered the August 17, 1999 Izmit, Turkey earthquake. All we have is the time of the onset of the earthquake and the geographical coordinates of the epicenter. Until the trigger wave propagation timing is considered, this information is enough to define an orbit only if you also assume a perigee distance. This paper assumes perigee distances of 1.01 and 1.1 Earth radii, and it finds that the latter orbit comes very close to satisfying the trigger wave propagation timing constraint, while the former orbit does not.

2. Vulcan's Credited 19th Century Observations

I presume to call this unique comet Vulcan because I assume that it is the same space body that was observed transiting the Sun by the amateur astronomer and physician Edmond Modeste Lescarbault in his home-made telescope at Orgères-en-beauce, France on March 26, 1859 [1]. At that time people thought it was an undiscovered planet inside Mercury's orbit, following the suggestion of the great theoretical astronomer U. J. J. Le Verrier, and magazine readers named it Vulcan, the mythic half-brother of Mercury and a son of Venus.

Le Verrier had hoped that Vulcan would explain the anomalous precession of Mercury's perihelion that he had discovered. As it turned out, Einstein's 1915 General Relativity explanation for this phenomenon became popular, and people stopped looking for Vulcan. I think what Lescarbault observed was not a planet but the opaque nucleus of a small periodic comet that was quite close (about one Moon distance) to the Earth at the time of the solar transit.

Lescarbault's observation was later discredited by sunspot observer Emmanuel Liais in Brazil who had observed the Sun at the same time and never saw any transiting object ([1] page 162). His claim would be valid if the object were inside Mercury's orbit as everyone supposed, but I suggest that it was quite near the Earth. If so, parallax could have moved the transit path outside the Sun's disk for observers in the southern hemisphere. If so, then Liais's criticism of Lescarbault's observation can be ignored.

Other unidentified solar transits had been previously observed by Stark (canon of Augsburg) on October 9, 1819, by Decuppis (Roman College) on October 2, 1839, and by G.D. Lowe and J. Sidebotham on March 12, 1849 ([1] page 159).

These 19th century solar transit observations need to be connected together if possible with more recent observations into a coherent ephemeris before anyone can accept the idea that they all refer to the same comet. However, I don't believe that such connections can be made without resorting to frequent close flybys of Venus and Mercury. Such flybys introduce additional degrees of freedom which could make the connections mathematically possible, yet at the same time they also introduce a considerable amount of skepticism since they require that the comet behave as if it were a spacecraft that was under the influence of an intelligent designer. But we already have that problem with the Earth flyby because it seems highly unlikely that such a precise flyby maneuver that satisfies such unusual constraints could have occurred by accident.

3. August 11, 1999 Solar Eclipse Comet

I suggest that the next known observation of Comet Vulcan (after March 26, 1859) occurred during the total solar eclipse of August 11, 1999 as shown in Figures 1 and 2. The small comet is under the Moon's silhouette [2].

This little 1999 eclipse comet should have made the news, but it was ignored. I suggest that was because people assumed that it must have been near the Sun in space. The SOHO spacecraft has observed many sun-grazing comets. They are quite common. According to my theory, however, this comet was near the Moon in space, not the Sun.

Figure 3 shows a March 12, 2010 SOHO sun-grazing comet falling into the Sun and the differences between it and the eclipse comet are striking. The white circle in Figure 3 is the outline of the solar disk behind the occulting mask. [3, 4] The issue is not about the fact that the 2010 SOHO comet flew into the Sun and the 1999 eclipse comet did not. It's about the fact that the 2010 SOHO comet's tail was about 55 arcminutes long when it was 38 arcminutes away from the solar disk, whereas the 1999 eclipse comet's tail was only about 1 arcminute long when it was 1 arcminute from the solar disk.

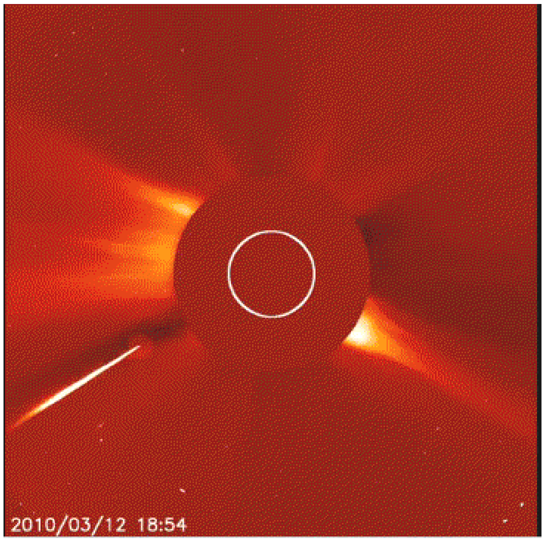


Fig. 3. SOHO comet falling into Sun

Figure 4 illustrates the heliocentric orbits of the Earth and the Moon and their positions with respect to the Sun at the three epochs of interest. For the eclipse epoch (8-11-99) the comet's position is also shown. During the eclipse, the Earth, Moon, and comet are all aligned on the "Ray to Sun" as shown.

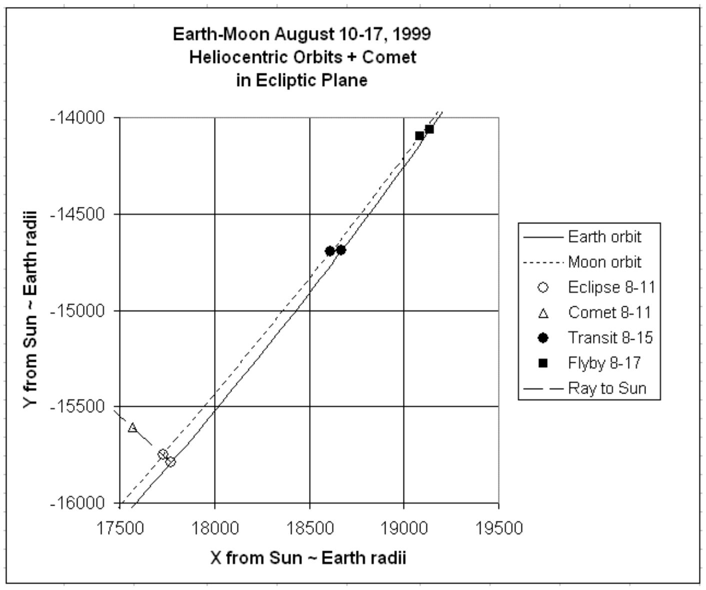


Fig. 4. Earth-Moon heliocentric orbits August 10-17, 1999

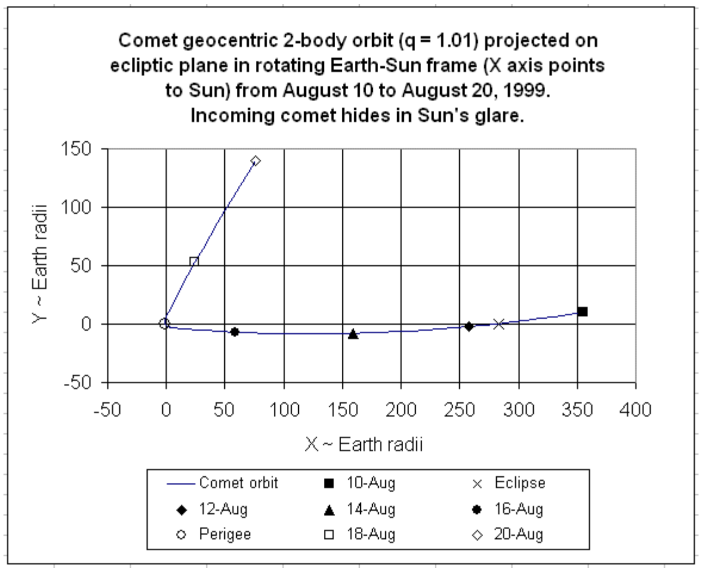


Fig. 5. Comet geocentric orbit August 10-20, 1999

Figure 5 shows the comet's geocentric orbit with respect to the rotating Earth-Sun frame of reference and the comet's position in that frame from August 10 to August 20, 1999. In this rotating frame, the origin is at the Earth (labeled "Perigee" in the figure), and the x axis always points towards the Sun. The comet's orbit crosses the x axis at the eclipse epoch at a distance of about 280 Earth radii. This point is designated by the symbol ×. The comet is hidden from view in the Sun's glare throughout this entire inbound leg.

4. Deen's 1999 Lunar Transit Observation

Although I can't use my lunar transit observation in a Moonless 2-body orbit model, I describe it here to show why I have such a strong interest in this comet.

On August 14, 1999 at 20:02 CDT in Plano, Texas (01:02 UT August 15) I observed a small comet transit the crescent Moon in daylight in my 8-inch Celestron telescope at 100 power. This observation has become the defining event of my life, and it is the reason why I attempt to discover this comet's ephemeris with such enthusiasm. I think it may be the most important comet in human history because it has apparently visited the Earth at very close range frequently, and yet it has managed to escape observation in the night sky for perhaps thousands of years.

I had polar-aligned my telescope the night before the transit on the patio in my backyard, and I had protected the telescope from the Texas daytime heat with a big cardboard box covered with aluminum foil. On Saturday, August 14, 1999, I planned to look for a comet near the Moon in daylight. No astronomer in his right mind would observe the Moon through a telescope in daylight for any reason, much less hoping to see a comet. Obviously I was not in my right mind at the time.

Why would I do such a thing? All I remember is that I had become obsessed with the idea of finding a comet near the Moon in daylight. Furthermore, I had gotten an idea of when to look for it. I had concocted a bogus math model that produced a list of predicted future observation opportunities. If this particular opportunity had failed, I was prepared to keep trying successive epochs in the list. I called this model a "hidden logarithmic periodicity in celestial events." It involved plugging the list of nova and supernova onset epochs going back a thousand years into a logarithmic formula. The free parameter was a convergent epoch in the future that I discovered with a least-squared error analysis. I varied the convergent epoch to minimize the errors between all known novae and supernovae epochs in the past and predictions made by this formula. The optimum convergent date turned out to be November 11, 1999. As the predictions drew closer to that convergent date, the intervals between predictions became shorter, and the time of day for each one became more precise. The point is that I had what I thought was an objective calculation of a list of recommended observation epochs, and I believed in it enough to prepare for the observation and make it.

At 8:00 pm CDT, about 10 minutes before sunset, I took off the protective box, aimed the telescope at the Moon, and I immediately saw the comet in the 8x50 finder scope. The comet was at the center of the lunar crescent and moving rapidly west parallel to the ecliptic plane in the blue sky that filled in the shadowed part of the 3.5-day-old Moon. Its semi-circular coma was about one arcminute in diameter, and it had a very short, stubby fan-shaped tail joined to the coma at its diameter that pointed northward (down in my telescope eyepiece). The coma pointed southward (up in my eyepiece). The comet's height to width ratio was about 3:2. The coma and its stubby tail reminded me of a pack-man ghost or a white ping-pong ball wearing a short white hula skirt that flared out.

The comet moved westward along the bisector of the crescent. Then it emerged into the blue sky heading towards the Sun. During the transit of the crescent the comet was easily visible. The comet was reflecting more sunlight than the lunar surface. The entire transit event took about two minutes. If you didn't look at the right time, you would have missed it. You might say that I was just lucky, but I imagine in retrospect that I was guided by divine providence.

I reported my observation to Brian Marsden at the Central Bureau for Astronomical Telegrams [5] by email, but there was no confirmation. For years afterward, I wondered why nobody else observed this comet. Now I think I know why.

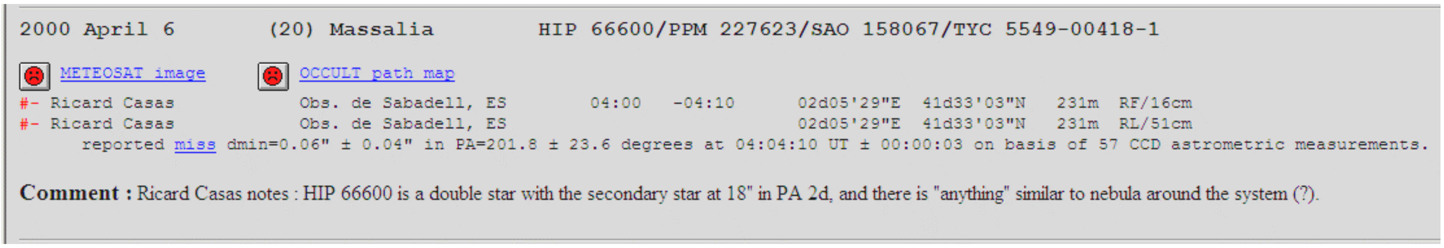
The Moon had already set for European observers when I observed the transit, and it was still in daylight or twilight for U.S. observers. No one could have seen this comet at night between the August 11 eclipse and the August 15 lunar transit observation because it was hiding behind the Moon as it approached the Earth-Moon system, flying in formation with the Moon from Earth's viewpoint. (This hypothesis has not yet been demonstrated. This paper is a Moonless analysis, and the comet was hiding in the glare of sunlight—see Figure 5.) The transit lasted about two minutes, and I was apparently the only person looking at the Moon through a telescope when it happened.

5. April 6, 2000 Occultation of HIP 66600

On April 6, 2000, Spanish astronomer Ricard Casas observed an unexplained nebulosity surrounding the 8th magnitude star HIP 66600 in Virgo as he was attempting to observe an asteroid occultation of this star. His observation was logged on the Internet [6] as shown in Figure 6.

His comment says: "Ricard Casas notes: HIP 66600 is a double star with the secondary star at 18" in PA 2d, and there is "anything" similar to ***nebula*** around the system (?)."[emphasis mine] I recently exchanged emails with him, and he confirmed having "registered a nebulosity around the star", but he didn't still have those 10-year-old images.

I suggest that this nebulosity was the coma of Comet Vulcan. Its tail would have pointed away from the Earth, so it would have been hidden behind the coma for earthbound observers. I suggest that the outbound asymptote of this comet's hyperbolic orbit around the Earth was located precisely at this star.



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2000 April 6        (20) Massalia        HIP 66600/PPM 227623/SAO 158067/TYC 5549-00418-1

METEOSAT image          OCCULT path map
#- Ricard Casas          Obs. de Sabadell, ES        04:00   -04:10      02d05'29"E  41d33'03"N   231m  RF/16cm
#- Ricard Casas          Obs. de Sabadell, ES                            02d05'29"E  41d33'03"N   231m  RL/51cm
     reported miss dmin=0.06" ± 0.04" in PA=201.8 ± 23.6 degrees at 04:04:10 UT ± 00:00:03 on basis of 57 CCD astrometric measurements.
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Comment : Ricard Casas notes : HIP 66600 is a double star with the secondary star at 18" in PA 2d, and there is "anything" similar to nebula around the system (?).

Fig. 6. Observation of unexpected nebulosity surrounding the star HIP 66600

6. Masquerading as a Planetary Nebula

The fifth strategy for evading detection (masquerading as a planetary nebula) would be possible if the comet's tail was hidden behind its coma and the comet's proper motion was so small that it appeared to be stationary. The small proper motion constraint is easily satisfied in the outbound leg following the flyby in a hyperbolic orbit as you can see in Figures 7 and 8. Figure 7 shows that the proper motion drops to one degree per day by 1.6 days after perigee. This is slow enough to escape the notice of visual comet hunters. Figure 8 shows that the proper motion drops to 14.7 arcseconds/day (0.004°/day) by 30 days after perigee. Figure 9 shows that angular distance from the Comet's RA and Dec to the occultation star HIP 66600 drops to 6 arcminutes by 30 days after perigee. This closeness is unremarkable because the orbit was optimized to minimize that arc distance for the observed occultation epoch of April 6, 2000. Figure 9 merely illustrates the asymptotic behavior of a hyperbolic outbound orbit. The orbit was optimized to force the star to become its radiant.

Hiding the comet's tail behind its coma may seem difficult for some readers because the conventional wisdom teaches that comet tails always point away from the Sun due to the solar wind. But we have never observed a comet coming this close to the Earth, so we have no contrary evidence. My theory would be refuted if the Comet Shoemaker-Levy 9 fragments had tails that pointed away from the Sun as they approached Jupiter. It would be confirmed if they pointed away from Jupiter.

I claim that this comet's tail pointed away from Earth during the outbound orbit leg due to an outflowing terrestrial ether wind analogous to the solar wind. If so, the tail would be hidden behind the coma for earthbound observers. The coma would be round, as viewed head-on from Earth, like a planetary nebula.

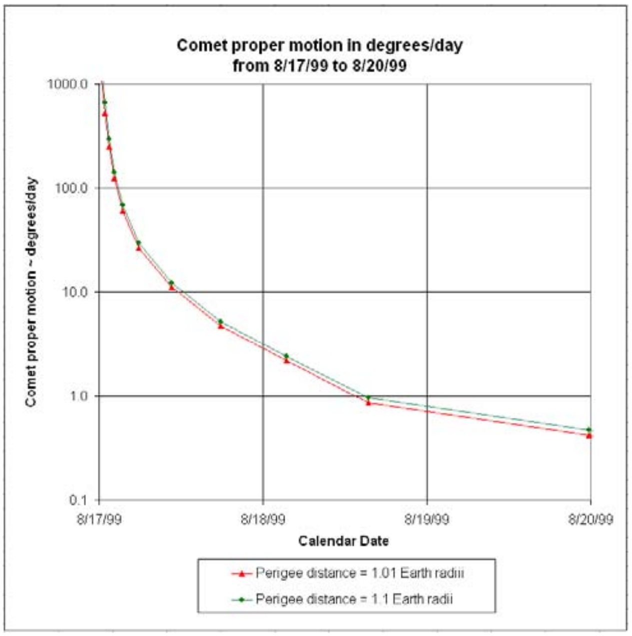

Fig. 7. Comet Proper Motion ~ degrees/day

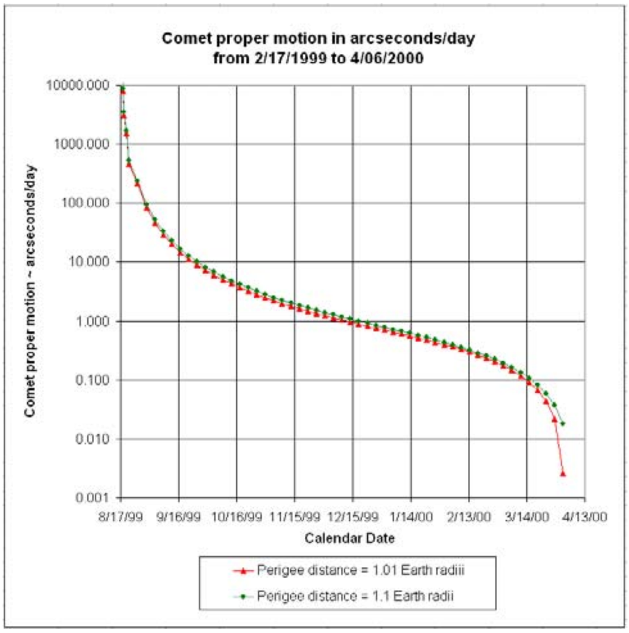

Fig. 8. Comet Proper Motion ~ arcseconds/day

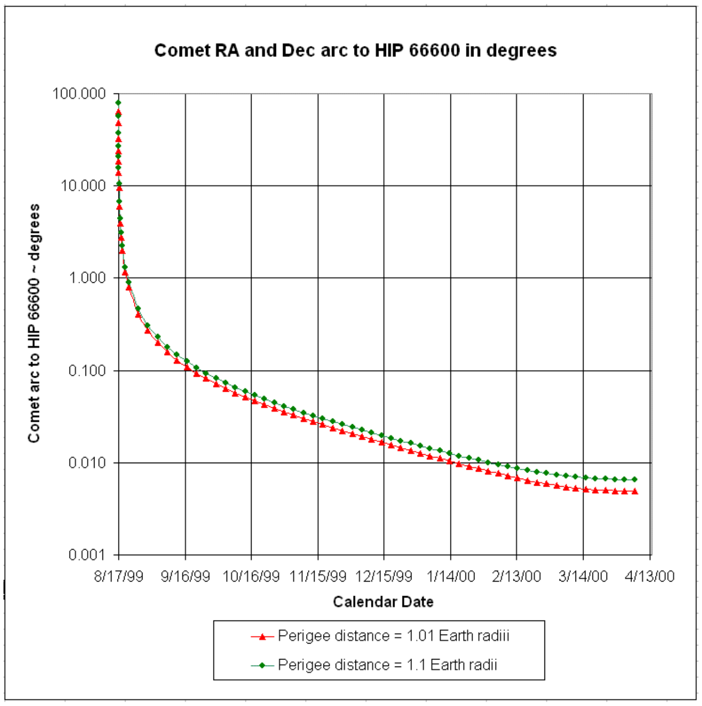

Fig. 9. Comet RA and Dec arc distance to HIP 66600

The comet I observed transiting the Moon on August 14 had a stubby tail (foreshortened by perspective) like the eclipse comet shown in Figures 1 and 2. I suggest that stubby tail was seen during the solar eclipse because it was pointing away from the Moon, which has its own outflowing ether wind. I guess that I saw a stubby tail during the lunar transit because the comet was moving so fast relative to the Earth that its tail had not had time to re-align its direction parallel to Earth's radially outflowing ether wind.

Another factor may have been a parallax effect due to its nearness to the Earth. The Moon (and comet) had a zenith distance of about 61° as viewed from Plano, Texas when I observed the lunar transit. This would have been enough to produce a parallax effect. The question of tail visibility can be explored in more detail during subsequent investigations that consider the gravitational forces of the Sun and Moon (and the other planets) on this comet. This preliminary investigation studies only a 2-body orbit (Earth and comet) because it is enough to study the earthquake triggering mechanism and because publication deadline constraints on this paper prohibit a rigorous n-body orbit study at this time. A 2-body orbit is much easier to optimize to satisfy observational constraints than an n-body orbit, and it is a good starting place to get into the ball park.

Geocentric Orbital Elements for August 17, 1999 Flyby optimized for August 11 eclipse and April 6 occultation observations						
Perigee distance Earth radii	Eccentricity	Inclination°	Longitude of ascending node°	Argument of perigee°	Time of perigee Julian Day	Time of perigee
1.01	1.20346008188807	179.777089911673	47.7839880053882	54.8642388613333	2451407.49333333	1999 Aug 16 23:50:24
1.1	1.20282950005378	179.777148801097	47.3489995003968	54.3864441351488	2451407.49677083	1999 Aug 16 23:55:21

Table 1. Geocentric Orbital Elements for August 17, 1999 Flyby

7. Earth Flyby Orbital Elements

Table I gives the 2-body Keplerian orbital elements for two geocentric orbits in the standard J2000.0 equinox and ecliptic reference frame having perigee distances of 1.01 and 1.10 Earth radii, respectively. These orbits are hyperbolic because their eccentricities are greater than one, and they are retrograde.

These 2-body orbits are useful in studying the earthquake triggering mechanism because they are quick and easy, but they are only approximations. The true solution requires considering the gravitational forces of the Moon, Sun, and all the planets, but that is beyond the scope of this paper.

Both orbits were optimized to satisfy the observations on August 11, 1999 and April 6, 2000. The RAs and Decs of those observations provide four known variables. We know the time of the earthquake onset, so we can assume that the time of the perigee occurred a few minutes before then. (For 1.01 Earth radii it is 11 min. 15 sec. For 1.1 it is 6 min. 18 sec.) If we also assume the perigee distance, then we only have four unknown orbital elements, and we can solve for them using Microsoft Excel Solver.

We know the geographical coordinates of the epicenter, so we can calculate the trigger wave travel distance from the comet's footprint at the trigger wave launch time to the epicenter. We can estimate the average propagation velocity of the trigger wave from the P-Wave travel times reported by Tokyo, Beijing, Kathmandu, Nairobi, and Lima in the USGS report [7]. These stations are all reasonably near the ground track of this comet.

So we can estimate the trigger wave travel time for any assumed launch time. We can determine the optimum trigger launch time from when the trigger wave amplitude reaches a maximum at the epicenter (Figure 23). We can select the perigee distance that would cause the calculated trigger wave travel time to be closer to the time interval from the launch time to the earthquake time. It turns out that 1.1 Earth radii is a much better perigee distance than 1.01, as we will see in Section 10.

Figure 10 shows the USGS calculated P-Wave travel times at various distances from the epicenter [7]. We will use those travel times to estimate the propagation velocity of the trigger wave as a function of the launch time from the ground track.

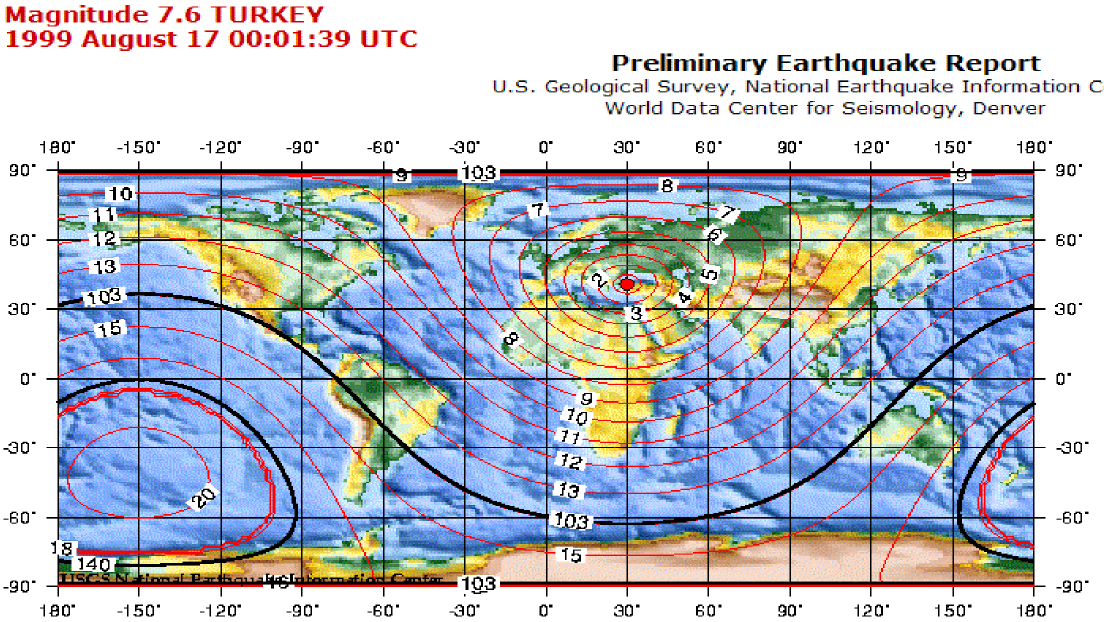

Fig. 10. Earthquake Epicenter and P-Wave Travel Times ~ minutes

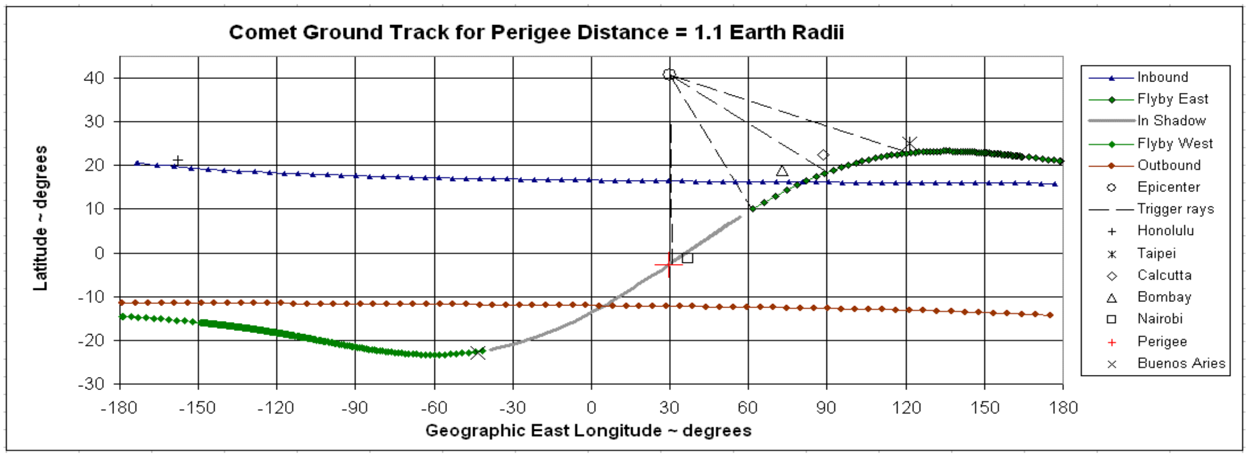

Fig. 11. Comet Ground Track

8. Comet's Ground Track

Figure 11 shows the comet's ground track. The ground track is the locus of points on the surface of the Earth at which an observer would see the comet passing overhead through the zenith if the sky were clear. Each ground track point has a zenith passage time associated with it. We can also say the ground track is the set of geographical coordinates for the comet's footprint on the ground as a function of time. These points are where the radius vector from the center of the Earth to the comet cuts through the surface of the Earth.

Figure 11 plots the ground track as geographic latitude vs. longitude for three orbit segments (inbound, flyby, and outbound) for the orbit in which the perigee distance is 1.1 Earth radii. The segments are arbitrarily divided in time according to when the comet's footprint crosses the International Date Line at 180° East Longitude. The longitude of each segment begins at +180° and ends at -180°, so the curves in the chart run from right to left. The chart is cylindrical, so the path wraps at the International Date Line.

The flyby segment is subdivided into three parts with the middle part being in the Earth's shadow. The time sequence for these parts is east flyby, shadow, west flyby.

The flyby ground track passes within 213 km of Honolulu, 242 km of Taipei, 482 km of Calcutta, 544 km of Bombay, 175 km of Nairobi, and 102 km of Rio De Janeiro (mislabeled Buenos Aries in Figure 11).

Trigger rays are shown as discrete dashed lines. The comet's gravity will pull a wide tidal bulge in the Earth's crust that is centered on the footprint and will follow the footprint as it moves along the ground track continuously in time. All trigger rays originate at their launch time on the ground track and terminate at the epicenter. The comet footprint's radial velocity with respect to the epicenter will produce a Doppler effect in the trigger wave propagation.

9. Plan Views of Earth Flyby Orbit

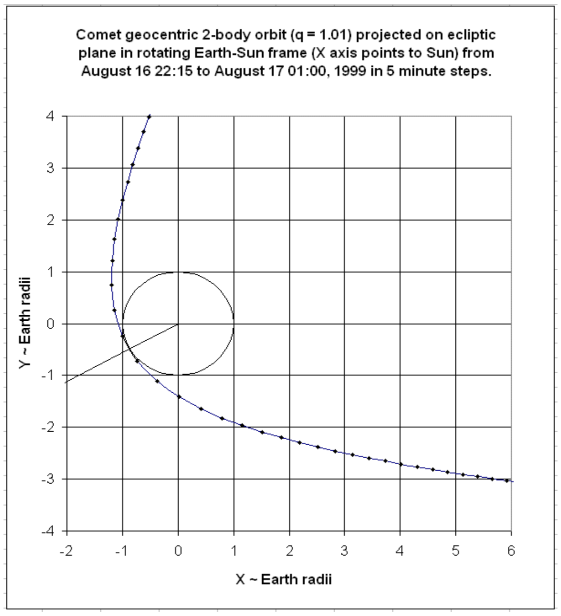

Fig. 12. Flyby Orbit Plan View ~ 5 minute steps

Figures 12 and 13 show two plan views of the Earth flyby orbit at two different scales and time increments. These plots are for the case where the perigee distance is equal to 1.01 Earth radii. But both orbits look the same at this scale. Only the timing is slightly different between them. The line that is drawn from (0.0, 0.0) to (-1.8, -1.0) is the perigee radius vector from the center of the Earth.

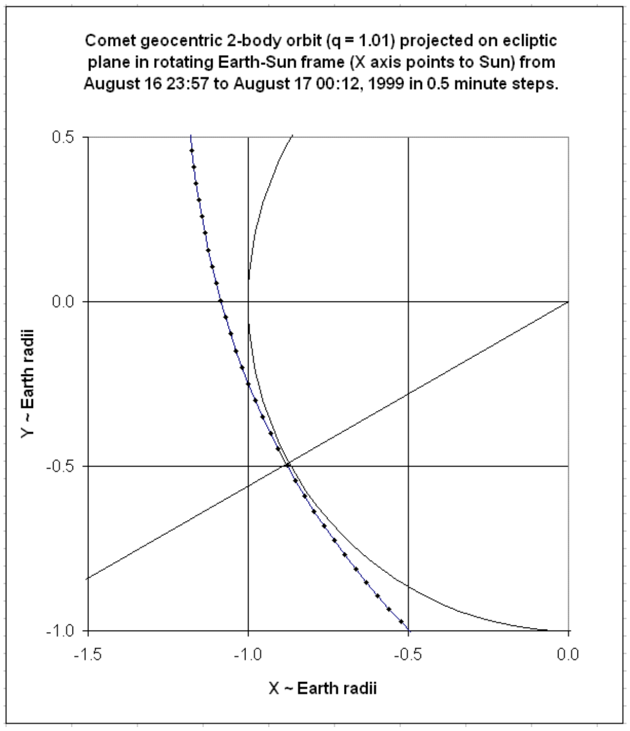

Fig. 13. Flyby Orbit Plan View ~ 0.5 minute steps

These plots are in the rotating Earth-Sun frame so that the x axis always points toward the Sun. This makes the Earth's shadow easy to see. The Earth's shadow is the space to the left of $x = 0$ between $y = -1$ and $+1$.

The magnification of Figure 13 is necessary to see the low-flying altitude of 0.01 Earth radii (64 km) for this orbit. The 1.1 Earth radii orbit's altitude is obviously 10 times higher.

10. Trigger Wave Amplitude and Timing

The amplitude of a seismic P-Wave trigger that propagates in the Earth's crust is given by C.M.R. Fowler [8].

$$A = A_0 \exp\left(-\omega t/2Q\right)$$

where A is the received amplitude of the trigger wave at the epicenter, A_0 is the transmitted amplitude of the trigger wave at the comet footprint at launch time, ω is the angular frequency of the wave, $t = d/v$ is the propagation time (d is the path distance, and v is the propagation velocity), and Q is the quality factor of the propagation medium, which for the lithosphere is given by Fowler as $Q = 200$. [9]

Since we don't know the comet's mass, we can't compute an absolute tidal force as a function of altitude. But we can compute a relative force that uses the inverse square law of gravity. So I define the launch wave amplitude relative to that at 0.25 Earth radii altitude as being:

$$A_0 = (0.25/h)^2$$

where h is the altitude of the comet above the surface of the Earth expressed in Earth radii.

The angular frequency is affected by the Doppler shift.

$$\omega = \omega_0 \left(\frac{v_{wave}}{v_{wave} + v_{source}} \right)$$

where ω is the Doppler-shifted frequency, $\omega_0 = 2\pi f_0$ is the unshifted frequency, v_{wave} is the P-Wave propagation velocity in the lithosphere, and v_{source} is the radial velocity of the comet footprint with respect to the epicenter. The seismic wave frequency can be estimated from seismometer waveforms.

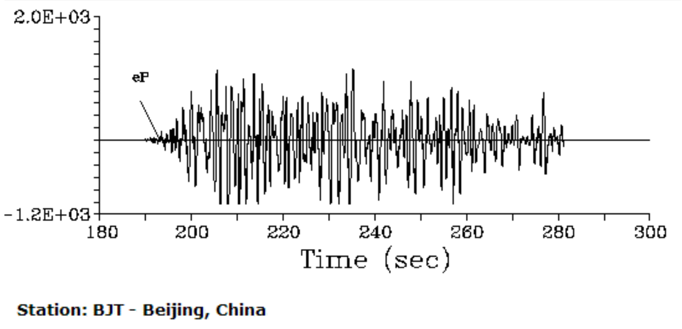

Fig. 14. Beijing Waveform

The unshifted frequency of the trigger wave is assumed to be the same as that of the earthquake P-Wave. The value used in this paper, $f_0 = 42.667$ cycles per minute, was scaled from the Beijing waveform trace in Figure 14.

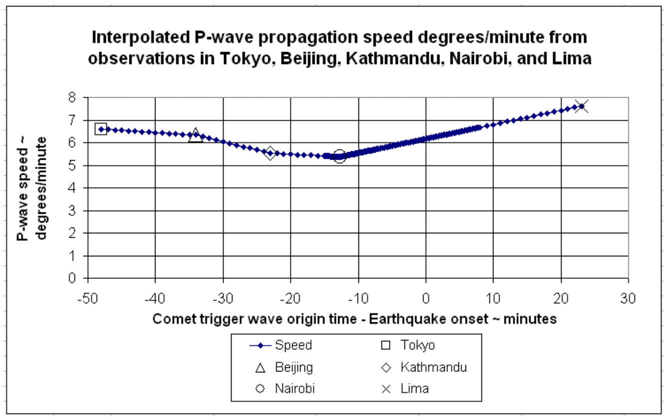

Fig. 15. P-Wave Propagation Speed

The USGS report [7] tabulates the angular distances and the travel times from the epicenter to 34 cities around the world. Five of these cities happen to be near this comet's ground track. The average P-Wave propagation speed along each of these five paths is computed by dividing the angular distance by the travel time and plotting the data as discrete points in Figure 15. The abscissa for each point is the time when the comet's ground track is nearest to each city. By using linear interpolation we obtain a continuous function of average P-Wave propagation speed as a function of the trigger wave launch time.

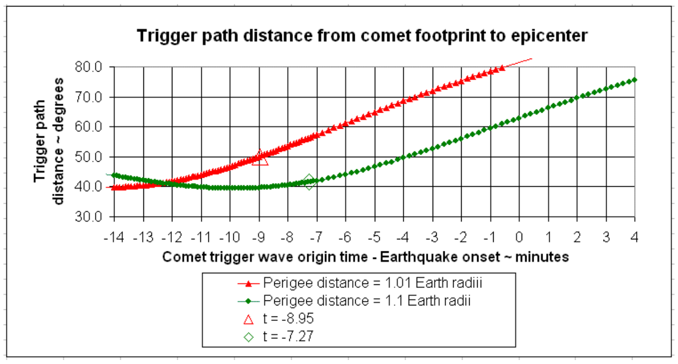

Fig. 16. Trigger Path Distance

The trigger path distance in degrees as a function of launch time in Figure 16 is computed using spherical trigonometry.

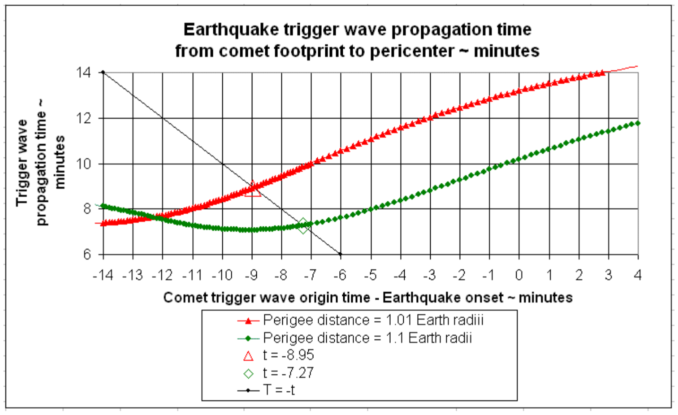

Fig. 17. Trigger Wave Propagation Time

The trigger wave propagation time in Figure 17 is computed by dividing the path distance in Figure 16 by the average P-Wave propagation speed in Figure 15. This propagation time for each path length should be the same as the time delay from launch to the earthquake onset. This propagation time constraint is satisfied where the solid black line in Figure 17 crosses each orbit curve.

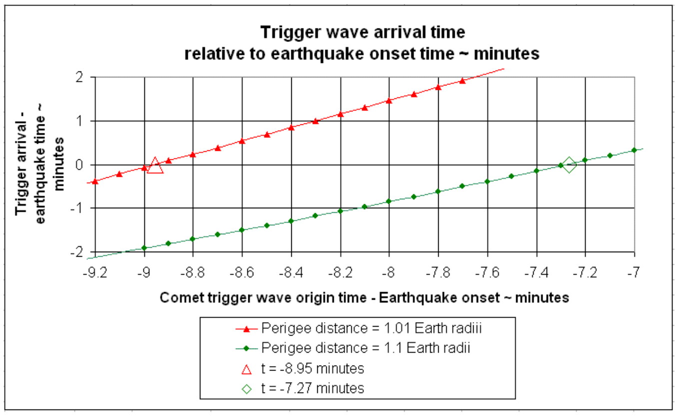

Fig. 18. Trigger Wave Arrival Time

The data in Figure 17 are replotted in Figure 18 where the arrival time relative to the earthquake onset time is plotted for each orbit as a function of the launch time. The zeros of these functions are 8.95 minutes for the 1.01 Earth radii perigee and 7.27 minutes for the 1.10 perigee.

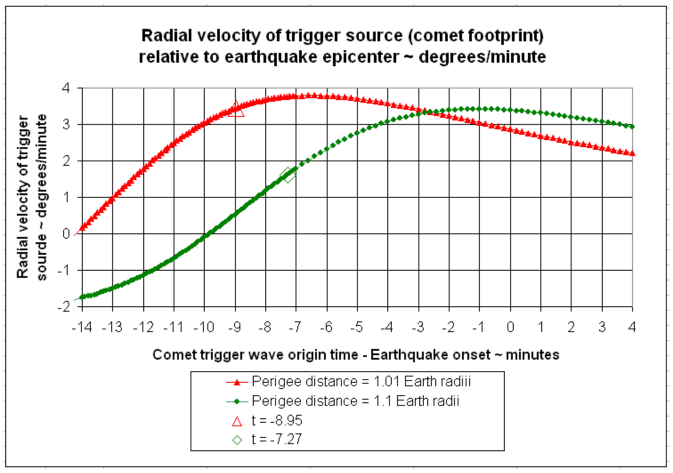

Fig. 19. Radial Velocity of Trigger Source

The radial velocity of the trigger wave source in Figure 19 is the time derivative of the path distance in Figure 16.

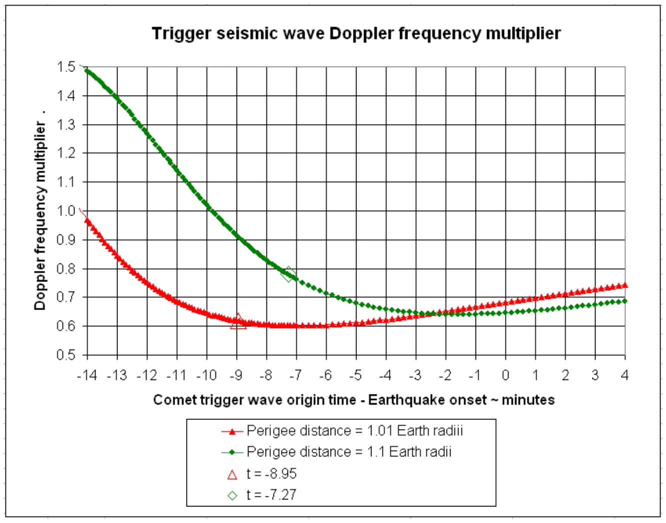

Fig. 20. Doppler Frequency Multiplier

The Doppler frequency multiplier in Figure 20 is obtained from the Doppler formula, using the P-Wave speed (Fig. 15) and the radial velocity (Fig. 19).

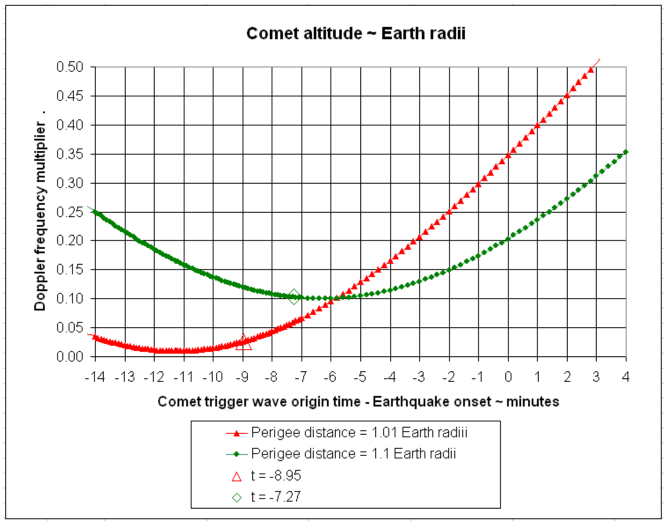

Fig. 21. Comet Altitude

The comet altitude curves in Figure 21 show that the perigee (minimum altitude) for the 1.01 Earth radii orbit occurs at 11.25 minutes before the earthquake, and the perigee for the 1.10 Earth radii orbit occurs at 6.30 minutes before the earthquake. This is confirmed by comparing the perigee times in Table I with the earthquake time in Figure 10.

23:61:39 – 23:50:24 = 11:15.

23:61:39 – 23:55:21 = 6:18.

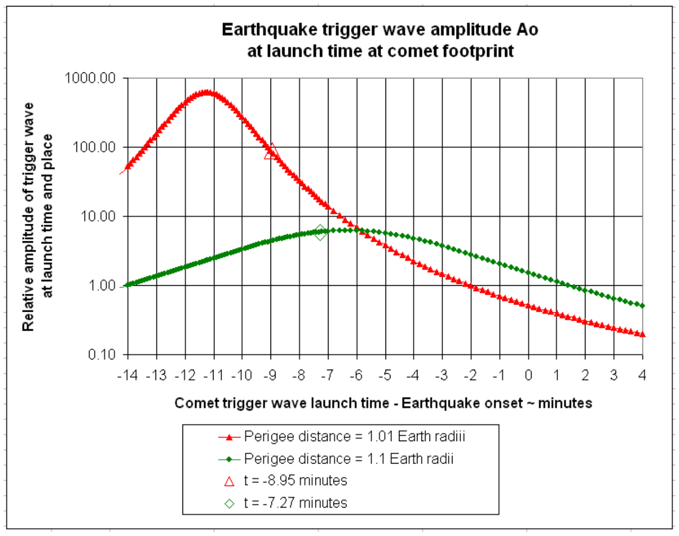

Fig. 22. Trigger Wave Amplitude Ao at Launch

Figure 22 shows the relative amplitude of the trigger wave when it is launched from the comet footprint. This amplitude is inversely proportional to the square of the altitude (Fig. 21).

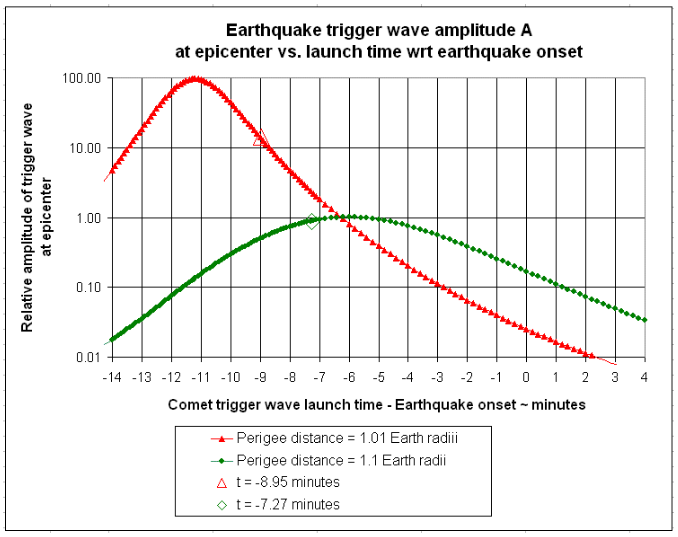

Fig. 23. Trigger Wave Amplitude A at Epicenter

Figure 23 shows the relative amplitude of the trigger wave at the epicenter after having experienced the attenuation of propagation through the Earth's crust. This attenuation is a function of the path length and the Doppler frequency shift (Figure 20) caused by the radial velocity of the source (comet footprint) relative to the epicenter (Figure 18).

The maximum epicenter amplitude in Figure 23 occurs 11.2 minutes before the earthquake for the 1.01 perigee orbit and 6.0 minutes before the earthquake for the 1.1 perigee orbit. The propagation timing constraints occur at 2.25 minutes after the trigger peak for the 1.01 perigee orbit and 1.27 minutes before the trigger peak for the 1.1 perigee orbit. This means that the 1.1 orbit is preferred over the 1.01 orbit because the propagation timing constraint needs to be satisfied before the trigger peak occurs.

11. Conclusion

This paper does not prove that this comet executed an Earth flyby that triggered the August 17, 1999 earthquake in Turkey. It merely gives some circumstantial evidence in support of that hypothesis. To become more convincing, this research needs to consider the gravity of the Moon, Sun, and all the planets and show that an n-body orbit is possible that satisfies my observation of a lunar transit on August 14, (15 UT) 1999 that this paper ignored as well as the eclipse observation of August 11, 1999 and the stellar occultation observation of April 6, 2000 that were satisfied in this paper.

A comet that followed the 2-body orbits in this paper would have been observed in Rio de Janeiro in the early evening following the earthquake unless the sky was completely overcast. It would also have been observed in southern India in the pre-dawn sky before the earthquake. But India is unlikely to have observed it because August is in the middle of their monsoon season.

To become convincing, the perigee would need to occur sooner in the n-body model than it does in the 2-body model and therefore be moved eastward such that every major city would have a good excuse for not having observed this comet. For example, it would be good if the comet could pass by unseen below Japan's southern horizon because so many good comet hunters live in Japan.

References

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[8] C.M.R. Fowler, **The Solid Earth: An Introduction to Global Geophysics**, p. 112 (Cambridge University Press, 1990).

[9] *ibid*, p. 113