SUPERLUMINAL MOTION IN QUASARS

25/12/2012 17:42

We are going to begin with a problem that is not really very easy and the answer touches on relativity physics and astrophysics, yet the mathematics to explain it is not too hard if you hang in there.

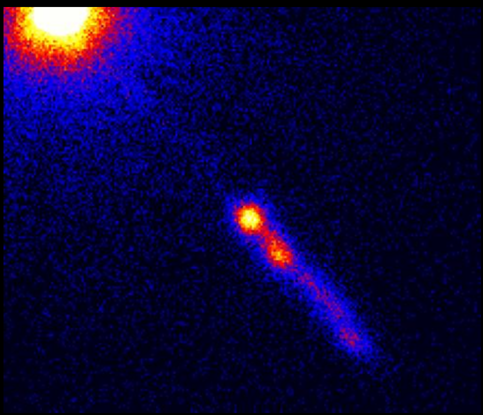
Physical objects do not go faster than the speed of light, right? Then, what is happening with this observation from astronomy.

Quasars, quasi-stellar objects, are star-like sources of light located billions of light years away. They are far smaller than any galaxy but typically put out more than 100 times the energy of the entire Milky Way, our home galaxy.

Despite many interesting things about quasars the observation that is of interest here is that many quasars have a jet of plasma (extremely hot ionized particles that form the fourth state of matter: solid, liquid, gas, plasma) streaming away from them at extremely high velocities.

How high?

In the case of the first quasar ever to be identified, known as 3C273, located in the constellation of Virgo, at a speed of about 9 times the speed of light, what physicists call “superluminal” speed because it is faster than the speed of light!



Quasar 3C 273, with its jet
(Image by Chandra X-ray Observatory)

The observation of the travel of the jet is made very easy by the bright knots in it so that the speed of separation can be measured relatively easily, even though this quasar is some 2.6 billion (2,600,000,000 light years from Earth or in scientific notation 2.6 x 10^9 light years).

Interestingly, with an apparent magnitude of 12.9 it is probably the furthest object from the Earth that is visible in a small telescope.

We will do the measurements and make the calculation for the jet speed later as there are detailed maps showing the movement of the jet since its identification as a quasar in 1962.

We will return to this problem later and explain in detail what is happening but we will look at an easier problem first to understand the underlying problem.

FASTER THAN THE SPEED OF LIGHT

26/12/2012 19:03

Let us understand right now that no physical particle has ever been measured to move faster than the speed of light. This includes the infamous neutrinos in the 2011 CERN experiment which were claimed to be moving faster than the speed of light by a team of Italian researchers (it was subsequently discovered that the superluminal speed of these neutrons was due to procedural errors in the experiment) and also the postulated, but never observed tachyons.

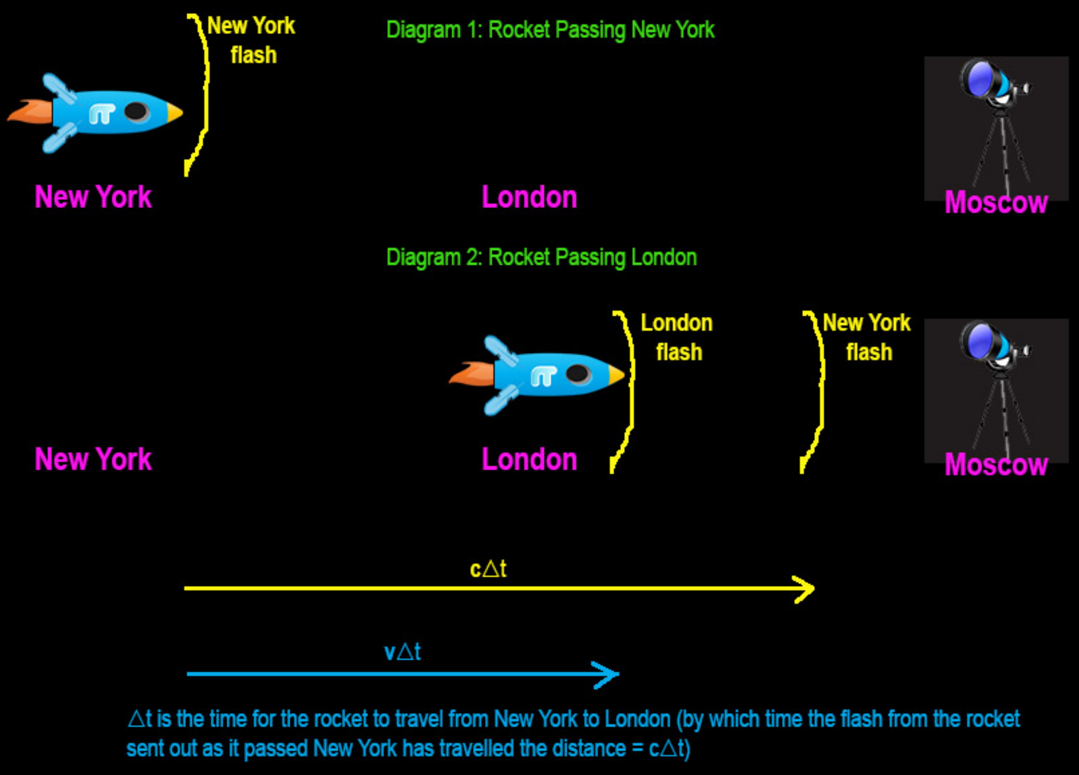
To many physicists this is a relief because if superluminal speeds were possible for physical particles, causality, that certainty that something is born before it dies, cannot be maintained for all observers.

To get some insight into the problem of the faster than light jet from quasar 3C273, let us look at a somewhat simpler problem:

In a joint effort between the USA, UK and Russia a new rocket has been developed that will carry passengers at speeds close to the speed of light. Its first test run is from Los Angeles pat New York and London non-stop to Moscow. By the time the rocket passes New York it is travelling at close to the speed of light and observers in Moscow watch events unfold through a telescope.

As the rocket passes New York and London it illuminates itself with an extremely powerful flash of laser light so observers on the ground can easily see it as it passes overhead.

What do the observers in Moscow actually see? The details are summarized in this diagram, where the velocity of the rocket is designated as "v" and "Δt" is the time it takes the rocket to travel from New York to London and "c" is the speed of light:



In the time the rocket takes to travel from New York to London (a total distance of $v\Delta t$), the light wave sent out by the rocket as it passed New York has travelled a distance $c\Delta t$.

Therefore the distance separating the two light waves as they streak toward Moscow at the speed of light is:

$$c\Delta t - v\Delta t = (c - v)\Delta t$$

The time that light takes to travel this distance is just:

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

$$\text{time for light from London to enter telescope after light from New York} = \frac{(c - v)\Delta t}{c}$$

Taking c = 1, these equations become very simple:

$$\text{time for light from London to enter telescope after light from New York} = (1 - v)\Delta t$$

To an observer in Moscow, the rocket takes $(1 - v)\Delta t$ to travel from New York to London, a distance which is known to equal:

$v\Delta t$ = speed of rocket x time of travel from New York to London

The speed of the rocket to an observer in Moscow therefore appears to be:

$$V_{apparent} = \frac{\text{distance}}{\text{time}} = \frac{v\Delta t}{(1-v)\Delta t} = \frac{v}{1-v}$$

and the Δt, the time for the rocket to travel from New York to London, which we did not know disappears from the calculation.

Let's plug some numbers in to see what this means:

speed of rocket = v	**1 - v**	**$V_{apparent} = \frac{v}{1-v}$**
0.1 = 0.1 the speed of light	0.9	0.1 (x the speed of light)
0.5	0.5	1 (x the speed of light)
0.6	0.4	1.5 (x the speed of light)
0.8	0.2	4 (x the speed of light)
0.99	0.01	99 (x the speed of light)
1.0	0	∞

As can be seen here the apparent speed of the rocket can go all the way to infinity (∞) even though the speed of the rocket is below the speed of light, for example at a casual 0.8xthe speed of light, to the observers in Moscow, it appears to be moving at 4xthe speed of light.

This is the OBSERVED (apparent) speed – it is not the speed the rocket is actually moving with and causality is safe, and superluminal speeds remain a dream.

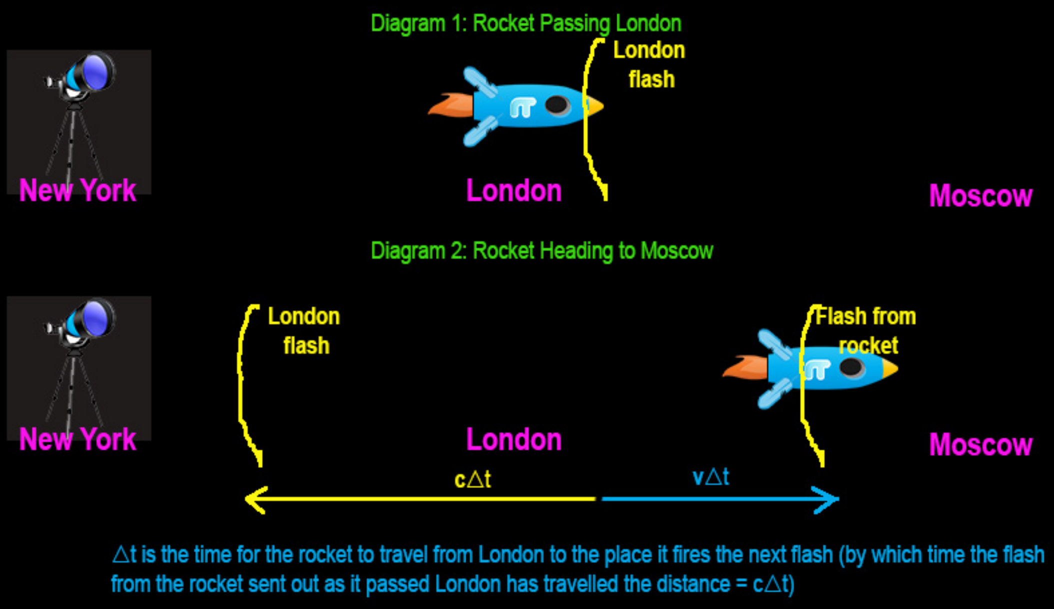
We get the idea from basic physics that nothing that has ever had a speed less than the speed of light can ever move faster than it, so when we are confronted with speeds that look superluminal we are oft confounded and look for very complex explanation to what might be a very simple cause.

This indeed happened when scientists tried to explain the superluminal jets from quasars. A topic we will return to shortly, but I think you can see the writing on the wall, these jet velocities are not real, like the rocket travelling to Moscow they are APPARENT speeds not real ones.

HIGH SPEEDS MOVING AWAY FROM THE OBSERVER
29/12/2012 00:11

We might ask an equally interesting question although one with a less dramatic answer: how does the rocket look to an observer watching from New York?

The analysis is very similar to the previous case and is summarized in this diagram:



By the time the rocket has travelled for a time Δt, it will have travelled a distance of:

$$\text{Speed} = \frac{\text{distance}}{\text{time}}$$

$$\text{distance} = \text{speed x time}$$

For the light flash travelling from London toward New York, this will be: $c\,\Delta t$

In this same time the rocket moves a distance $v\Delta t$ before sending out the next flash. Therefore the total distance between these two flashes is just:

$$c\Delta t + v\,\Delta t = (c + v)\Delta t$$

i.e. taking $c \equiv 1$, and using

$$\text{time} = \frac{\text{distance}}{\text{speed}}$$

We therefore find that the time between these two flashes is:

$$\text{time} = \frac{\text{distance}}{\text{speed}} = \frac{(1+v)\Delta t}{c} = (1 + v)\Delta t$$

The extra distance the rocket flash must cover compared to the London flash is:

$$\text{distance}_{\text{(London flash – rocket flash)}} = v\Delta t$$

The observer in New York sees the flash from London a time Δt after it was emitted, in which time the rocket has travelled a further $v\Delta t$ before emitting the next flash

The observer in New York sees the flash from London and a time $(1 + v)\Delta t$ later sees the flash emitted by the rocket as it approaches Moscow and therefore calculates the rocket speed to be given by the distance the rocket travelled between the two flashes divided by the time taken between them:

$$v_{\text{apparent measured in New York}} = \frac{\text{distance}}{\text{time taken}} = \frac{v\Delta t}{(1+v)\Delta t} = \frac{v}{1+v}$$

Let us plug some numbers into this to see what is happening:

Speed of rocket x (times the speed of light)	1 + v	$v_{\text{apparent}} = \frac{v}{1+v}$
0.1	1.1	0.09
0.5	1.5	0.33
0.6	1.6	0.375
0.8	1.8	0.44
0.99	1.99	0.497
1	2	0.5

Remember that because we have taken c = 1, these fractional speeds are actually times the speed of light.

The observer in New York is not going to be very impressed with what she sees. The highest speed she will EVER see is if the rocket is getting very close to the speed of light when the New York observer will see the rocket move at almost half the speed of light.

We didn't need this result to answer the question about the jet from the quasar which look like it is travelling faster than the speed of light, although it does tell us what to expect if we observe a jet that is moving away from the Earth, instead of one moving towards it.