Superluminary Haloes?

by Bill Smith

Einstein said that nothing can travel faster than light because it is a law of the universe. When it comes to supernovas however, it seems that this law can be broken. Surrounding the recent supernova, 2014J in M82, there is an expanding halo of light, a so-called "light echo". A simple calculation of the rate of expansion of this halo returns a surprise: the halo is apparently expanding faster than the speed of light! *Superluminary haloes!* what's going on? We have too much confidence in Einstein's theories to believe this outcome is true, so what is the explanation? Intrigued by this question I started thinking about plausible models for the phenomenon and eventually came up with one that demonstrates the effect clearly.

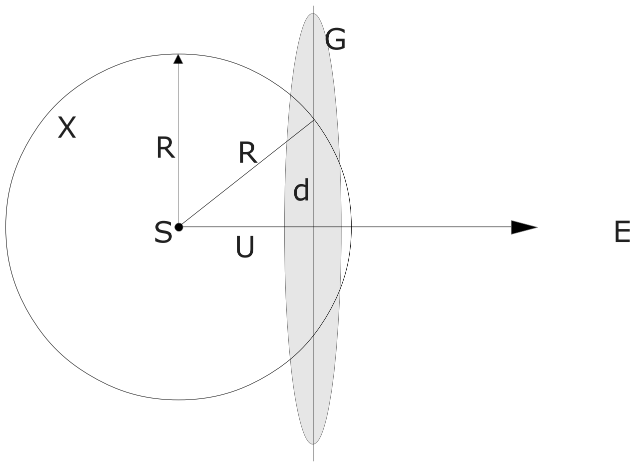

Figure 1

In Figure 1, S represents the progenitor star of the supernova. Far away, possibly in another galaxy is the Earth, E. Somewhere between S and E is a cloud of dust and gas, G, at a distance U from the star. (Perhaps the star itself ejected this cloud, but it is not necessary to assume this.) Just to keep things simple, this model assumes that the cloud is narrow and conveniently oriented in a perpendicular direction to the S-E line.

When the supernova explosion occurs it send a bright sphere of light (X) out from the star, the radius of which (R) is given by

$$R = c\,t, \tag{1}$$

where c is the velocity of light and t is the time from the instant of explosion. As time increases, the sphere of light crosses the distance U and starts to illuminate the cloud. The effect eventually seen from Earth (when the light scattered by the dust cloud has travelled the immense distance in between) is a disc of illuminated gas expanding with time as the light sphere sweeps through the cloud. This is the light halo.

According to this model, the radius of the halo at time t is given by the distance d in the figure. It is easy to see from Pythagoras' theorem that this distance is given by

$$d = \sqrt{(R^2 - U^2)}. \tag{2}$$

Inserting into this the formula (1) for the light sphere radius R gives

$$d = \sqrt{(c^2 t^2 - U^2)}. \quad (3)$$

This formula has no real solution when ct is less than U (which is the case immediately after the explosion) as it requires taking the square root of a negative number. But this simply means there is no halo before the light sphere reaches the cloud! Only when ct is larger than U can a halo develop.

From equation (3) we can determine the rate of expansion of the halo using high school calculus. Differentiating (3) with respect to t gives

$$v = c^2 t / \sqrt{(c^2 t^2 - U^2)}. \quad (4)$$

We can put this into a more convenient form by taking $c^2 t^2$ outside the square root and cancelling terms common to the numerator and denominator, giving the result

$$v = c / \sqrt{(1 - U^2 / c^2 t^2)} . \quad (5)$$

This simple equation has an amazing property: at the instant ct equals U (i.e. at the time t= U/c) the denominator becomes zero. So at this precise moment the rate of expansion of the halo is infinite! Later, as ct increases (i.e. as the light sphere expands) the denominator gradually approaches the value 1, which means the velocity v eventually falls to the speed of light. However, it requires ct to be very much larger than U for this to happen.

From Earth an observer would measure the angular diameter of the halo and, provided the distance to the supernova is known, determine the halo's radius d. Dividing d by the difference in time between when the angular measurement was taken and when the supernova first appeared, provides an estimate of the halo's expansion rate. Based on the above argument, the likelihood of this exceeding the speed of light is high!

One other interesting thing to note about equation (5), is that whenever U is zero, then v equals c. In other words, if the star is actually *embedded* in the cloud, no superluminary effects will be seen.

Admittedly this is only one possible model for the generation of a halo around a supernova. But, I think, it is a plausible one that easily demonstrates superliminary halo expansion. It seems likely to me that other models could do the same. The real lesson here is that the halo is not a physical object. Rather like a rainbow it is an optical effect without physical substance and as such it is not subject to the physical laws devised by Einstein.