The Cygnus Loop—a case study

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The Cygnus Loop is a spectacular supernova remnant (SNR) that has been the subject of numerous theoretical and observational research studies. Published values for its age have included estimates as high as 100,000 years. These very high estimates for its age have proven to be unreliable. Dependable measurements of related observational parameters are now available and show an age that is less than 3,000 years. One of the parameter revisions involved the value of the average density of the interstellar medium (ISM) through which the supernova expands. It was found that the 'local' ISM density associated with the Cygnus Loop is about 10 times less than the 'standard' ISM density value of one atom per cubic centimetre. It has been proposed by some researchers that equally low values for the average ISM density apply to the local environment of many SNRs in the Galaxy. If this proposal is confirmed, then the published ages of SNRs whose ages were calculated using the 'standard' value for the ISM density will also need to be re-evaluated.

The Cygnus Loop is a truly impressive object with a huge angular extent of approximately 230 minutes of arc at its widest span. In comparison, the moon measures only 30 minutes of arc. The Cygnus Loop lies within our own galaxy, in the constellation of Cygnus the Swan, and was first identified as an SNR over 60 years ago. Some astronomers believe that there is a less significant SNR situated in the same direction, but we will be discussing the characteristics of the main SNR traditionally known as the Cygnus Loop.

The importance of the Cygnus Loop

The fact that the Cygnus Loop is relatively near and unusually free from obscuring dust means that it can be observed at a wider range of wavelengths than is usual for galactic SNRs. This permits exceptional observational opportunities that make it one of the best-known and most extensively researched SNRs in the Galaxy. From a creationist standpoint, it is important because it has been quoted as a 'proven' example of an SNR whose published age is greater than 6,000 years.

Some published estimates of the age of the Cygnus Loop

James Kaler, professor of astronomy at the University of Illinois, has a special interest in researching the death of stars. He quotes an age of 100,000 years for the Cygnus Loop in his comprehensive 1994 text on astronomy.[1] Samples of other published high age estimates are 20,000 years;[2] 50,000 years;[3] and 150,000 years.[4] A display in the public galleries of the David Dunlap observatory in Toronto asserts that the Cygnus Loop is several million years old.

All of these high age estimates are wrong. The documentation of the new reality is the subject of this paper.

The parameter errors that have led to the substantial age revisions

One of the ways used to calculate the age of a large SNR like the Cygnus Loop is through the application of the well accepted, and often quoted, Sedov Size-Age relation. This relation can be expressed as $D = 4.3 \times 10^{-11}(E_0/n)^{1/5}\, t^{\,2/5}$.[5]

Here, D is the diameter of the SNR, measured in parsecs (one parsec equals 3.26 light years). E_0 is the initial kinetic energy of the SNR, whose value is well accepted as being around 10^{51} ergs.[6] n is the average density of the ISM that the SNR expands into, and is measured in terms of the number of atoms present in a cubic centimetre. t is the age of the SNR and is measured in years.

The above relation requires the input of three parameters to calculate the age of the Cygnus Loop. Two of these parameters have had incorrect values assigned to them for many years. The account of how long-accepted values were found to be in error, and the implications arising from those errors, reads like a scientific detective story and will be described in this paper.

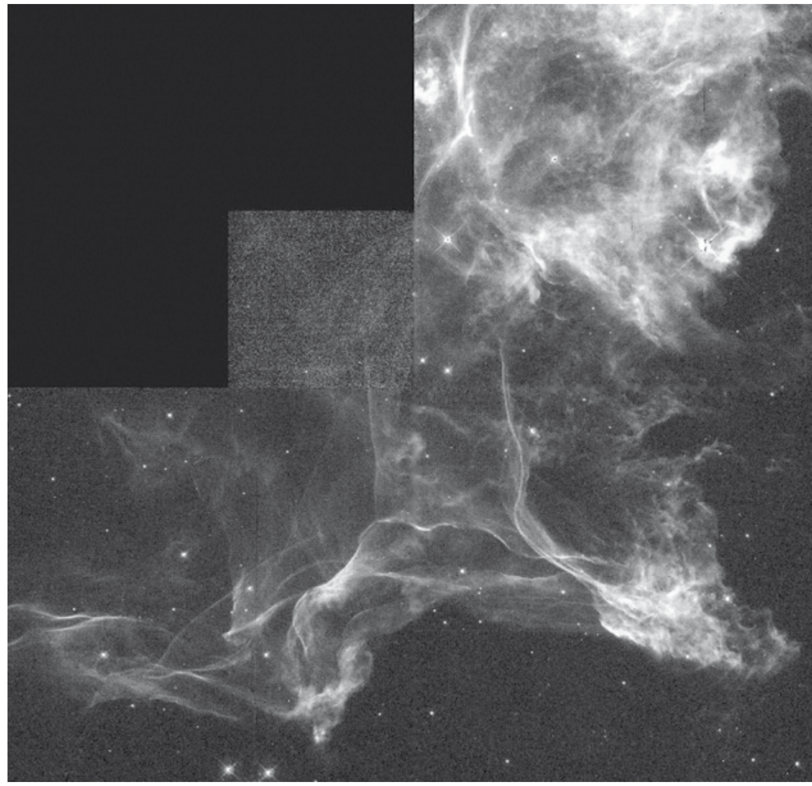
The story of the first major change in the age estimate of the Cygnus Loop—the error in the density parameter (*n*)

One of the first research papers to demonstrate a problem with the published estimates of the density parameter was written more than thirty years ago by Sergio Ilovaisky and James Lequeux.[7]

The authors performed a fascinating statistical analysis involving the frequency of occurrence of supernovae in the Galaxy. They considered whether the published high ages for the Cygnus Loop were compatible with their statistical analyses.

The results were a surprise. If the Cygnus Loop was an old classic remnant with the characteristics they initially considered, then the rate of production of supernovae in the Galaxy would have to be about one every 315 years. Something was very wrong. This value was far too high when compared with other independent estimates. They concluded that the problem lay in the assumed age of the Cygnus Loop. It must be considerably younger than was previously thought. They state, in their paper, that an explanation for the discrepancy they found was that the age of the Cygnus Loop had been 'grossly overestimated'. They suggested, at that time, that the Cygnus Loop needed to be reassessed as being around 14,000 years, which is nearly five times smaller than a previous estimate of around 67,000 years that they reference in their paper.

But how could the previous estimates for the age of the Cygnus Loop have been so wrong? What error in the data could have resulted in the requirement that its age estimate needed to be reduced by so much?



The filamentary structure of the Cygnus Loop. (Photo by Jeff Hester [Arizona State University] and NASA).

The error in the value used for the density of the interstellar medium

Astronomers have a rather unusual way of measuring the near-vacuum densities found in space. Density is expressed as the number of particles (usually hydrogen atoms) in a defined volume. They typically use a value of n equal to one particle per *cubic centimetre* as a standard for the density of space between stars and an even smaller value of n equal to one particle per *cubic metre* for the space between galaxies.[7]

Ilovaisky and Lequeux pointed out in their paper that the Cygnus Loop is located in a rather tenuous medium, where $n \approx 0.1$. The more tenuous the medium the more rapidly the SNR will expand—and this will have a large effect on any age estimate that is made.

It was this error in the density (of a factor of 10) that was partly the culprit for the age of the Cygnus Loop being so grossly overestimated in prior publications.

Confirmation of the new lower value for the ambient ISM density

The lower value for the ambient ISM density which the Cygnus Loop SNR moves through has since been confirmed several times. For example, one study showed that the periphery of the Cygnus Loop encounters regions where n = 0.2, while in the original interior region of the huge remnant n = 0.08.[8] These more accurate estimates confirm and are in reasonable accord with the early value of Ilovaisky and Lequeux that was referenced above. The ISM density of 0.08 will be used later in this paper to make a current 'best estimate' value for the age of the Cygnus Loop.

The story of the second major change in the age estimate of the Cygnus Loop—the error in the size parameter (*d*)

The second parameter we will consider in this account of falling age estimates is the linear size of the Cygnus Loop. We can measure the angular size of this huge object directly. It is known to be 230 ×160 minutes of arc,[9] giving a mean value of 195 minutes, but in order to find its actual diameter; we need to know how far it is away from us. The standard value for the distance to the Cygnus Loop has, for many years, been 770 parsecs.[10] We now know that this value is substantially in error. The revised distance is only 440 parsecs.[9] This new value was originally based upon observations made with the Hubble telescope, but such a large revision did not find immediate acceptance. There was an understandable reluctance to accept that such a large error could previously have been made in the measurement of the distance to such a well known and well observed object. However, the new Hubble measurement was soon confirmed by the fortuitous discovery of a star, of known distance, that was found to be behind the Cygnus Loop.[11] The new measurement of the distance to the Cygnus Loop means that its diameter must be now revised to 25 parsecs[12] instead of the older value of 56 parsecs. This new, smaller, size of the Cygnus Loop means that once again its age has to be recalculated. Using the diameter $D \approx 25$ parsecs, the average ambient ISM density $n \approx 0.08$ and the initial kinetic energy $\approx 10^{51}$ ergs, we obtain an age that is considerably less than previously published ages. The age obtained by applying the above revised values to the Sedov relation is around *2,400 years*. However, the story of the continuing fall in the calculated theoretical age of the Cygnus Loop is still not over. The Cygnus Loop continues to surprise researchers.

One final surprise

In 2002 a team of researchers announced that a 'bulge' observed in one section of the periphery of the Cygnus Loop might be a second SNR that is smaller and younger than the primary SNR. If this is confirmed then it would mean that the angular dimension of the primary SNR is even smaller than before, making the Cygnus Loop even younger than 2,400 years! If we apply the revised angular measurements for the primary SNR of 180 by 156 arc minutes[13] to the Sedov relation as before, and using the same values for the other parameters, then the calculated age of the primary SNR falls to 1,700 years, while the smaller SNR would be less than 1,000 years old.

Application to other SNRs

The question must now be asked, from a creationist standpoint, whether the errors in observational measurements that have resulted in such a dramatic revision in the age of the Cygnus Loop would apply more generally to other SNRs. Of particular interest is the question of the average value of the ISM density that needs to be used when determining the age of individual SNRs.

The case study of the Cygnus Loop showed that the 'standard' density value of n equal to one particle per cubic centimetre was far too high and that the actual value was about ten times smaller.

One text on galactic astronomy now states that 90% of the volume of interstellar space in the Galaxy is probably associated with $n < 0.5$.[14] Other published estimates have indicated that as much as 70% of the volume of interstellar space could be associated with a value as low as 0.001![6] If these values are confirmed, then substantial age reassessments would need to be made for those galactic SNRs whose ages have previously been calculated by the use of the old standard of $n = 1$ for the ISM density.

Conclusion

The results are clear. Most of the age estimates for the Cygnus Loop published over the years are wrong. This 'classic' example of a supernova remnant is not an 'ancient' object at all. It is less than a few thousand years old. This case study, if nothing else, illustrates the care that needs to be taken before accepting the published age estimates of SNRs at face value.

It is of considerable interest to creationists that the 'local' ISM density associated with the Cygnus Loop is about 10 times less than the 'standard' ISM density value of one atom per cubic centimetre. It has been proposed by some researchers that equally low values for the average ISM density could apply to the local environment of many SNRs in the Galaxy. If this proposal is confirmed, then the published ages of SNRs whose ages were calculated using the 'standard' value for the ISM density will also need to be re-evaluated.

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