

# LETTERS

## Hubble trouble

In *Physics Today* for May 1964 (p. 21), Dr. Hong-Yee Chiu has written an admirable account of a symposium on gravitational collapse held in Dallas, Texas, in December 1963. In the course of his exposition, he has occasion to describe and make use of Hubble's law which connects the distance of a galaxy with the red shift in its spectrum. It is stated that the law is expressed by the formula, Distance =  $(1/H)$  (Recession velocity), where  $H$  is the Hubble constant, that  $H^{-1}c$  is a measure of the "dimension" of our universe and that for an object at distance  $H^{-1}c$  "the red shift is total". In this day and age it is surprising to find that these statements are still credited. Since they give rise to much unnecessary confusion it is worth while to state the present-day situation with regard to Hubble's law. To do this, one must look back thirty years and recall what Hubble (1937) did when he established it.

In Hubble's work two points are to be noticed: firstly, the distances he calculated depended on luminosity criteria. Hence he obtained what are nowadays called luminosity-distances,  $D$ . Secondly, the red shifts of the objects he studied were small and did not really exceed  $z = 0.13$ . Hubble multiplied the measured red shift by  $c$  and defined the result,  $V = cz$ , as the velocity of recession, by using the classical Doppler formula. He then showed empirically that for his, cosmologically speaking, nearby objects  $D$  was proportional to  $V$ . The essential feature of this work is that  $D$  is

shown to be proportional to  $z$  so long as objects with red shifts small compared with unity are considered. The constant of proportionality is  $c/H$ , where  $H$  is the Hubble constant, and the fundamental form of Hubble's law is: Luminosity-distance =  $(c/H)$  (Red shift), provided that  $z$  is small compared with unity.

The definition  $V = cz$  is good enough when  $z$  is much less than unity. This is no longer true for most quasars or for 3C295 for example. Exact Doppler formulae should nowadays be used for calculating velocities of recession from red shifts. Each "model of the universe" has its own Doppler formula because the motion of expansion differs from model to model. Unfortunately, this leads to a number of possible definitions of the velocity of recession for an object with a given red shift (McVittie 1961) and it is therefore doubtful if the concept of the velocity of recession is nowadays very useful. This ambiguity is fortunately absent from the notions of luminosity-distance and of red shift. A particularly simple model of the universe is Milne's, which employs special relativity only. In this model it is possible to define a certain velocity of recession,  $U$ , which is connected with  $z$  by the Doppler formula of special relativity,\* namely,

$$1 + z = [(1 + U/c) / (1 - U/c)]^{1/2}.$$

\* On p. 25, the formula is incorrectly quoted by Chiu. The correct treatment may be found, for example, in Møller (1952).

The formula shows, for example, that  $z = 1$  means  $U = 0.6c$ .

In all models of the universe it is possible to define the most distant object as one which, for the observer, has an infinite value of  $z$ . This is presumably what is meant by Chiu's statement that "the red shift is total". But such an object does not have a luminosity-distance equal to  $H^{-1}c$ . In Table 1, five models are listed and the exact formula connecting  $D$  and  $z$  is given for each. The cosmical constant is denoted by  $\Lambda$ . In all five models, the most distant objects lie at infinite luminosity-distances  $D$ . It will be observed that  $D = H^{-1}c$  corresponds to widely differing values of  $z$  in the various models. Equally obviously  $D = H^{-1}c$  fails to give the "dimension" of the universe.

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## References

- Chiu, Hong-Yee, *Physics Today*, May 1964, p. 21.  
Hubble, E. P., 1937. *The Observational Approach to Cosmology*. Oxford: Clarendon Press.  
McVittie, G. C., 1961. *Fact and Theory in Cosmology*. London: Eyre and Spottiswoode, New York: Macmillan. pp. 113-122.  
Møller, C., 1952. *The Theory of Relativity*. Oxford: Clarendon Press. Sections 23 and 25.

## Chiu's views

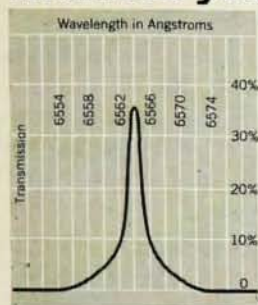
I think Professor McVittie has misunderstood the points that I made in my paper. My paper was already fairly long and it did not seem necessary to confuse readers further with the fine points of cosmological theories (for which reasons I shall discuss below). I carefully inserted an " $\approx$ " sign when I said "at a distance  $\approx H^{-1}c$  the red shift is total". I meant an event horizon exists at roughly this distance. I never said that  $H^{-1}c$  was the distance. Professor McVittie is correct in his letter in pointing out that at large distances all the fine

Table 1. Luminosity-distance and red shift

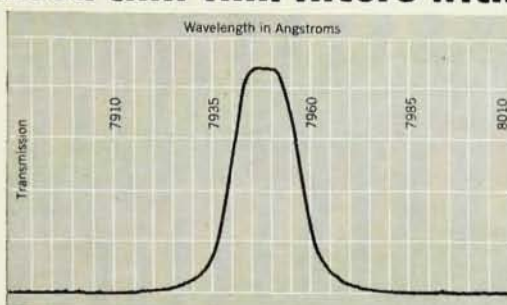
| Model                                          | $D/cH^{-1} =$                                          | Value of $z$ for<br>$D = cH^{-1}$  |
|------------------------------------------------|--------------------------------------------------------|------------------------------------|
| Milne's                                        | $z(1 + \frac{1}{2}z)$                                  | $\sqrt{3} - 1 = 0.73$              |
| Einstein-de Sitter<br>$q_0 = 1, \Lambda = 0$ . | $2 \left\{ 1 + z - (1 + z)^{1/2} \right\}$             | $\sqrt{3}/2 = 0.87$ .              |
| $q_0 = 2, \Lambda = 0$ .                       | $\frac{1}{4} \left\{ 2z - 1 + (1 + 4z)^{1/2} \right\}$ | $3 - \sqrt{3} = 1.27$              |
| Steady-state, de Sitter.                       | $z(1 + z)$                                             | $\frac{1}{2}(\sqrt{5} - 1) = 0.62$ |

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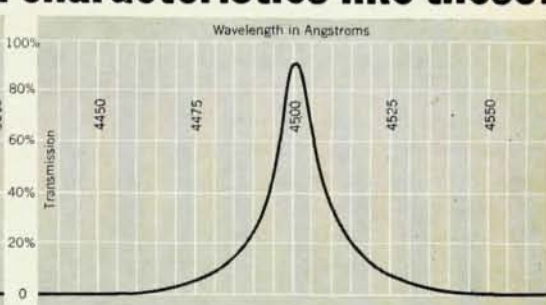
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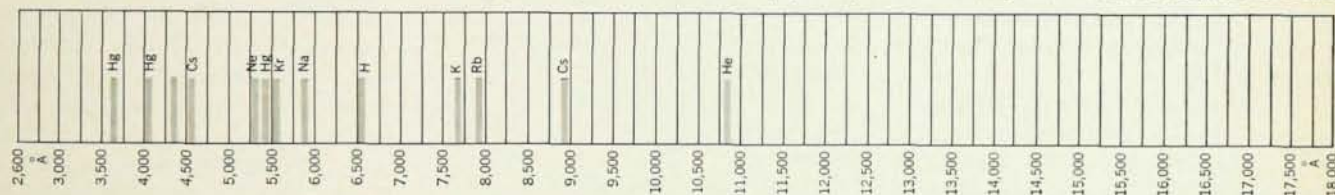


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points that he described in his letter must appear, and I thank him for using the words "luminosity-distance" which is what the distance actually is, and also the mistake that he pointed out in a formula on page 25.

I did not use the concepts of cosmological models and I did not intend to use them for good physical reasons. In his letter Professor McVittie failed to inform us of one important fact about the present status of cosmological theories; perhaps he is more enthusiastic about this present status than I am. *There does not yet exist any data to reveal to us that even a curvature exists in the structure of our universe.* From all galaxies observed, the most one can say is that there exists a linear relation such as I gave in my paper. Hence all familiar noncosmological concepts of distance, etc., may be used. Cosmological effects become noticeable when the red shift is large. For 3C273, the red shift is 0.16 and the relativistic correction in converting it to velocity, using a linear relation, is around 0.01, hardly significant. For 3C48, the red shift is 0.37 and the relativistic correction is 0.07, around 25 percent. These corrections are not significant, since Hubble's constant has fluctuated by more than a few decibels in the past few years. The same, however, cannot be said for quasars with a larger red shift.

I am not pessimistic about cosmological theories. It is well known that the ability of the 200" telescope to resolve world models by using galaxies is limited to a distance of around 2 billion light years, where a poor physicist's concept of space and time (which he is used to) is still valid. With the high luminosity of quasars (100 times that of galaxies), the range of the 200" telescope is extended roughly ten fold (the exact number depends on what cosmology one believes in). If good statistics and a knowledge about the structure of quasars can be obtained, there is a good hope that even the modest 200" telescope we now have on earth may give cosmological theories an experimental boost, which they badly need.

After my article on gravitational collapse was published, I received a letter commenting on W. H. Jefferys'

measurements on the motion of 3C273 (which were discussed on page 26 of the May issue). Dr. W. J. Luyten of the University of Minnesota, an expert in the measurement of proper motions of stars, remarked that the measurement that Jefferys made on old plates may contain larger errors than that quoted in his work. The Harvard plates have a scale of 180 seconds of arc to one millimeter, and to achieve the accuracy quoted by Jefferys one needs to measure the position of a star to an accuracy of 1/35 micron. During these years of storage, the Harvard plates may have suffered shrinkage, rendering such accuracy impossible.

Dr. Luyten has measured the proper motion of four quasars (3C48, 3C196, 3C273, 3C286) using different techniques. He found that their proper motions are not larger than their mean errors of measurement. His result was published in *Publ. of the Astron. Obs. of the Univ. of Minn.*, Vol. III, #13, July, 1963.

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### Teacher exchange

The COPFIC Report (*Physics Today*, May 1964, p. 36) was both gloomy and stimulating. In general, it should have a beneficial effect. It might be especially effective if reprints were put into the hands of administrators in the same way as the "Five Colleges" Report.

I wish to make two comments about recommendation (e) in the COPFIC report.

1. I have seen only two requests associated with the summer job Placement Service of AIP but both of these were requests for PhD's with considerable experience. If this is generally true, the service is of little help to the beginning teacher with the PhD or to any teacher with the master's degree only.

2. In a letter to Dr. Brode, Chairman of the Committee, dated October 9, 1963, I made a suggestion which I still believe would be useful. With very moderate NSF support, the summer job Placement Service could extend its service to the deliberate exchange of beginning teachers between

colleges for the summer session. The only cost involved would be transportation and, perhaps, a small removal sum. The advantage to the teacher of limited experience would be the association with experienced teachers other than those of his home institution. Although it is recognized that there are other problems involved, it would still seem a relatively inexpensive method for a fairly rapid diffusion of innovations in teaching, student evaluation, demonstration techniques, etc., through the college physics community.

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### General exam

With the increased interest in graduate study, it is surprising that the general examination (sometimes called the preliminary or qualifying examination) for the doctorate has received so little attention. The general examination may be described as ranging from superficial to sadistic. It appears that many graduate students are so exhausted when they pass the examination that they never regain their drive to do really creative work.

The writer has taken four such examinations, failing twice (University of Chicago) and passing twice (Northwestern University and Western Reserve University). In my opinion, there is an urgent need for reform with respect to the general examination. I should like to correspond with anyone who has specific criticisms of the examination or suggestions for its improvement.

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### Underdeveloped countries

Two articles in recent months have discussed research in underdeveloped countries. In the first (*Physics Today*, August 1963) David Tabor criticizes the efforts of some underdeveloped countries to undertake fundamental research on the grounds that such activities are not in line with the state of technological development in these countries and that the primary purpose of such research is national