A LIVELY ELECTRONIC COMPENDIUM OF RESEARCH, NEWS, RESOURCES, AND OPINION

Astronomy Education Review

Volume 2, Sep 2003 - Jan 2004
Issue 2

What Should Students Learn? Stellar Magnitudes?

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Posted: 09/30/03

The Astronomy Education Review, Issue 2, Volume 2:162-165, 2004

One of the perennial questions for teachers of astronomy survey courses is whether to use the magnitude system in general use by amateur and professional astronomers, or whether to give all star brightnesses in powers-of-ten notation. The problem goes to the goals of the course and to the philosophy of history, liaison with others, and course content held by the professor. It also leads to discussions of the mathematical and conceptual levels intended.

1. The Magnitude Scale

The magnitude scale is thought to have come from the work of Hipparchus in about 150 B.C., though the original references are lost. It was used by Ptolemy in his Almagest in about A.D. 150 in the form of a six-point scale. The history of the magnitude scale was discussed, for example, by Mayer (1986) and Hearnshaw (1992, 1996), and sources referenced therein.

Basically, the brightest stars in the sky were said to be "of the first magnitude." The next brightest group were "of the second magnitude," and so on, until the faintest stars that could be seen (with the naked eye, of course, at that time) were "of the sixth magnitude." As telescopes were invented and extended the need for magnitudes to fainter stars, and the equivalent of fractional magnitudes was worked out by W. Herschel and others, the six-point magnitude scale was extended to brightnesses and precisions not originally foreseen. Nineteenth-century star tables had wide variations in the magnitudes assigned to the same stars through visual observing.

The mathematical form of the magnitude scale came from Norman Pogson at Oxford, who in 1854 suggested that the brightness ratios then measured were, to available accuracy, close to a factor of 100 for the difference between first and sixth magnitude. We, and generations of college students, have Pogson to thank for the notion that the ratio of brightness that corresponds to a difference of one magnitude is the fifth root of 100, or 2.512.... Mayer describes how the scale was standardized by E. C. Pickering at the Harvard College Observatory, with the zero-point fixed by setting Polaris at magnitude 2.1. Various discrepancies of stellar observations persisted for decades, as can be found by looking at "magnitude scale" references available at the Astrophysical Data System (adswww.harvard.edu), but a detailed discussion is beyond the scope of this paper.

2. Re-evaluating the Magnitude Scale

Pogson's magnitude scale is logarithmic. As Young (1990) and Hearnshaw (1992, 1996) describe, the eye's sensitivity was long thought to be largely logarithmic, based on 19th-century work by Gustav Fechner in 1858 and 1860, but Ernst Zinner in 1926, Knut Lundmark in 1932, and Andrew T. Young in 1984 differed. The psychologist S. S. Stevens concluded in the 1940s (and reviewed in 1961) that the eye's sensitivity is a power law rather than a logarithmic law, going back to John Herschel's suggestion from 1849.

Hearnshaw (private communication 2003) writes, "In a paper analysing the Almagest scale and comparing with modern photoelectric magnitudes, I came to the conclusion that the earlier critics of Pogson and Fechner, who claimed the scale was not really logarithmic, were in fact erroneous. You can find this analysis in a paper by D. Khan and me in *Southern Stars* 36, 169 (1995). The reason for the conclusions of a non-logarithmic scale relate to huge selection effects in the plot of Almagest magnitude vs. modern photoelectric mag, in that Ptolemy included stars really brighter than sixth mag which he listed as being mag 6, but not fainter than sixth mag and listed as brighter. In other words the distribution of errors is severely skewed, because of the eye's limiting magnitude."

Schulman & Cox (1997) reviewed the use of the magnitude scale, showing a graph comparing the logarithmic and power-law relations over a factor of 10,000 in intensity, corresponding roughly from magnitudes –1 to 9. They present an exercise in the use of magnitudes to derive "a cosmologically interesting quantity (the mass-to-light ratio for spiral galaxies)." They suggest that "only those non-science majors who are going to make a serious foray into the world of amateur astronomy really need to understand how magnitudes work."

3. Goals for Student Learning

The idea of the magnitude scale, and teaching it, can be divided into several subsections:

Apparent vs. absolute magnitudes. The apparent magnitude scale is relatively easy to describe and to comprehend. The brightest things are of the first magnitude, fainter ones are of the second magnitude, and so on. The numbers are much easier to comprehend than SI units, which have powers of 10 that usually wash over the heads of students. The step to absolute magnitudes, involving considering the apparent magnitudes of stars if they were moved to a standard distance (10 parsecs, itself an unusual unit), is a step toward increasing abstractness. But some professors may choose to use this comparison to teach the abstract thought, bringing students to apply the inverse-square law in their heads. Doing so requires changing from ratios of brightnesses to logarithmic magnitudes. Showing students that 1 mag + 1 mag corresponds to approximately $2.512 \times 2.512 = 6.3$ times can be something professors choose to do.

General idea of relative brightness vs. mathematical calculation. A phrase I hate to hear from students is "plug in," as in "you plug in the value in this formula." In my course, I don't even supply the logarithmic magnitude formula. Still, I think it is easier for students to realize that something of fifth magnitude is relatively bright for a professional astronomer (and something of 25th magnitude is very faint) than it is for them to understand exponents in brightness comparisons.

Logical reasoning vs. use of a formula. I prefer to use magnitudes, aside from the general notion of whether things are bright or faint, to bring students to consider stellar brightness logically. In particular, in one of my textbooks (Pasachoff 2002), I have them reason, using the inverse-square law, rather than use a formula:

> ***Question:*** A star is 20 parsecs away from us, and its apparent magnitude is +4. What is its absolute magnitude?
> ***Answer:*** If the star were moved to the standard distance of 10 parsecs away, it would be twice as close as it was at 20 parsecs and, therefore, by the inverse-square law, would appear four times brighter. Because 2.5 times is one magnitude, and $(2.5)^2 = 6.25$ is two magnitudes, it would be approximately 1½ magnitudes brighter. Because its actual apparent magnitude is 4, its absolute magnitude would be 4 – 1 ½ = 2 ½, equivalent to the apparent magnitude it would have if it were 10 parsecs from us. (We see that we must subtract the magnitude difference, because the star would be closer and therefore brighter at 10 parsecs.)

In Pasachoff & Filippenko (2004), we do not do these mathematical examples at all, though we do discuss the inverse-square law with an equation.

Usefulness of liaison with the general public and amateur astronomers. A subsidiary goal of my course is that a student, if asked a question by a random amateur astronomer, be able to respond sensibly. Magnitudes, however historically out of date in an age of CCDs (Brecher 2002), are so widely used that it seems reasonable that a graduate of an astronomy survey course should know about them. As Filippenko and I wrote, "The magnitude scale is intuitive but from another era; still, astronomers often use it, and it appears in amateur astronomy magazines. It has the advantage of using small numbers that are relatively easy to remember."

4. Conclusion

Although the magnitude scale can be treated at various levels of complexity, I think its link with history and with the general community of professional and amateur astronomers is so great that it should be taught in survey astronomy courses. It should be taught in terms of comprehension of the concepts; any choice to plunge into the mathematical formula is at the discretion of the teacher.

Note: Jay M. Pasachoff wrote this piece while at the Harvard-Smithsonian Center for Astrophysics.

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