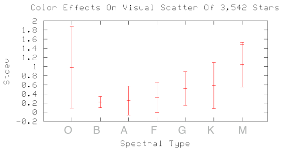
The Precision of Visual Estimates of Variable Stars

A. Price (AAVSO), G. Foster (AAVSO), B. Skiff (Lowell Observatory)

Existing records of visual observations of variable stars date back centuries. The largest database of visual variable star observations is the AAVSO International Database with over 11 million visual observations, which for some stars dates back to 1845. The AAVSO receives thousands of requests for this data from the astronomical community per year. We show early results of a project to assign a precision to variable star estimates based on properties such as the star's color index, time resolution, lunar phase, etc.

Spectral Effects



Any observer will tell you "red stars are hard to estimate!" This is largely due to the Perkinje Effect, which cause red stars to seem brighter the longer they are observed (Graham & Hartline 1935). There are observing techniques to minimize the effect (observing out of focus, quickly glancing between the variable and the comparison stars, etc.) but they require skill, thus datasets for red stars are a heterogenous mix of quality.

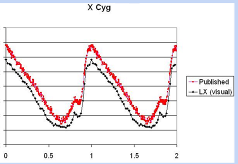
We took the data from 3,542 stars for which we had over 1,000 observations each (below) and subtracted a 10th degree polynomial (to remove periodic variation). We then averaged the data from each star into bins equivalent in size to their period as listed in the General Catalogue of Variable Stars (GCVS; Kholopov 1989), leaving out bins with <10 observations. We averaged the standard deviation of the bins and then categorized them based on their GCVS spectral type (above). **Results show that scatter does increase with spectral type**. Our next step will be to plot the standard deviation as a function of B-V instead of spectral type.

GCVS Spectral Type	Number of Stars
O	11
B	111
A	142
F	379
G	442
K	130
M	2327

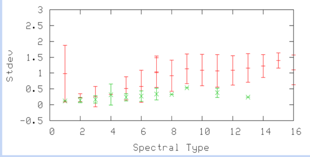
A Truly Remarkable Observer

Wayne Lowder (AAVSO observer ID "LX"), was a remarkable observer of variable stars. He made over 209,000 variable star estimates from1949 until his passing in 2005. He was known as having "photometric eyes".

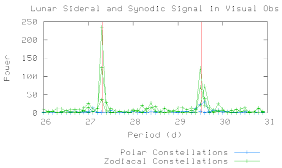
Below is a plot of the cepheid variable X Cyg, with Lowder's visual data plotted over data from published photometry (Szabados 1981; Moffet & Barnes 1984; Berdnikov 1986, 1992b,c,d,1993; Berdnikov & Voziakova 1995; Barnes et al. 1997; Kiss 1998).



And below is a version of our scatter vs. spectral type plot (top), with Lowder's data in green, showing much more precision than the general data as a whole.



Lunar Effects



We searched for lunar effects in the visual data and found mixed results. On the assumption that lunar interference depends on proximity to the Moon, we ran a fourier analysis on 327,132 observations of stars in three zodiacal constellations (Aqr, Vir and Leo) and also on 383,344 observations from stars in polar constellations (UMi, Cep and Oct). The results find very strong lunar sidereal and synodic signals in the zodiacal constellations (above). As expected, there is no sidereal signal in the polar constellations and the synodic signal is very weak. **Thus we conclude that the Moon's proximity has a higher amplitude, but more localized effect on visual observations while the Moon's phase has a lower amplitude effect, but reaches further across the sky.**

To determine how this interference manifests itself, we tested for increased scatter and a magnitude offset. For scatter, we analyzed ~53,000 observations of Omi Cet and ~35,000 observations of R Cyg. We removed 10 degree polynomials and then averaged the data into 14.765 days (1/2 synodic cycle) bins centered on full Moon and new Moon dates going back to 1900. We then compared the standard deviation of all the full Moon averages with the new Moon averages (ignoring bins with <5 observations) and found **no increase in scatter caused by the full Moon** (below).

Star	Phase	StDev	Bins
Omi Cet	Full	0.3554	1,168
Omi Cet	New	0.3654	977
R Cyg	Full	0.4240	771
R Cyg	New	0.4745	968

To look for a magnitude offset, we averaged the magnitufes of all AAVSO program stars in the six aforementioned zodiacal and polar constellations in the same bins centered on the full and new Moon dates (below). **We found a small brightening (~0.2 mag) when the Moon was full vs. new. However, the brightening is consistent across all constellations thus cannot be the cause of the signal in the fourier analysis.** (Note the scatter increases during new Moon.)

Constellation	Phase	Average Magnitude	StDev	Mag Diff	StDev Diff
Aqr	Full	9.5467	2.0167		
Aqr	New	9.6934	1.7520	-.1724	0.2647
Leo	Full	9.0444	1.4142		
Leo	New	9.2804	1.3956	-.1959	0.0186
Vir	Full	9.0725	2.0271		
Vir	New	9.4612	1.5297	-0.3887	0.0186
Cep	Full	7.2083	1.3896		
Cep	New	7.3726	1.3757	-.1719	0.0139
Oct	Full	10.0126	1.4694		
Oct	New	10.1789	1.4244	-.1875	0.045
UMi	Full	9.35	1.9753		
UMi	New	9.4839	1.8739	-0.1339	0.1014

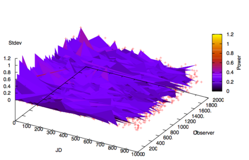
One or Two Decimal Places?

The effect of scatter can be modelled as a Gaussian function centered on the true magnitude, μ, with inherent scatter σ.

$$f(m) = \frac{e^{-(m-\mu)^2/(2\sigma^2)}}{\sigma\sqrt{2\pi}}$$

Visual observers typically report observations to tenths of a magnitude, while CCD and PEP report to hundredths. This 0.1 mag finite resolution has no significant effect on averages for resolution as high as 2σ and no significant effect on observed vs. inherent scatter up to 1σ.

Observing Experience

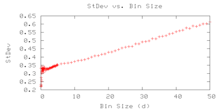


We also wanted to see if an observer's experience affected the precision of their observation. We took 144,482 observations of SS Cyg in quiescence (v=<10.5) and sorted by observer (for a total of 1,815 observers). We set the date of the first observation of each observer at 0 and then averaged their data into 100 day bins, following that start date. We searched for a trend in the standard deviation of the bins and found nothing statistically significant. However, a visual inspection of a plot (above) shows that some observers did obviously improve while others remained consistent. **We conclude that experience does not have an impact on observational precision for most observers, however the few exceptions improve quickly (within 300 days) and then plateau.**

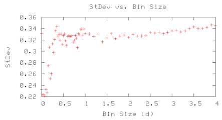
Conventional wisdom says that experience should have a bigger impact in accuracy than precision (due to the ability to pick better comparison stars). That will be a subject of a follow up study and experiment in 2007.

Wholesale Scatter

We took 53, 041 observations of Omi Cet and subtracted a 10th degree polynomical. We then averaged the data into whole day bins between 1 and 50 days and plotted the standard deviation (below).



As expected, the standard deviation dropped with bin size. We then averaged bins between 0.1 and 5 days at a resolution of 0.1 days. Finally, we averaged data in bins between 0.025 and 1 days at a resolution of 0.25 days (below).



The linear decay breaks around 0.33 (at 0.5 day bins) but scatter never drops below 0.22, even with bins as small as 0.025 days. **Therefore, we conclude that the average observer-induced scatter in the data set is between 0.22-0.33 magnitudes.**

Effect of Brightness

We tested the data set of Omi Cet and R Cyg (35,227 observations) for increased scatter during the faint ends of their cycles. Omi Cet has a range of 2-10.1 magnitudes and R Cyg's range is 6.1-14.4 according to the GCVS. We divided this range in half and averages all observations into one bin each for the bright and the faint end (below).

Star	Phase	Average Magnitude	StDev
Omi Cet	Bright	4.5386	1.1305
Omi Cet	Faint	8.3049	0.6695
R Cyg	Bright	8.7953	1.1952
R Cyg	Faint	12.4403	0.8799

Surprisingly, the **results do not show an increase in scatter at the faint end**. In fact, scatter was higher in the bright end of the observation!

Why Do This?

The AAVSO International Database has a mixture of visual, PEP and CCD observations. Visual observations historically have dominated the database, but recently CCD observations have begun to outnumber new visual observations. The high precision of these new CCD datasets have raised questions about the precision in the corresponding visual datasets.

CCD and PEP observers submit uncertainty estimates with their observations. However, that is not possible with visual observations due to their qualitative nature. Yet we need to associate some type of uncertainty with visual observations.

The goal of this project is to assign a "HQ Uncertainty Estimate" to each visual observation in our database such that when someone downloads the data from our web site, they can get a first order approximation of the uncertainty in the data regardless of whether it is CCD, PEP, visual or some other type of observation.

The first stage of the project is to identify factors that affect visual precision. That is the goal of this poster. The second stage will be to quantitatively illustrate those factors in magnitude space.

Conclusion

The precision of visual observations are affected by the spectral type of the star. The redder the star, the greater the scatter. Also, the proximity of the Moon to the field being observed has a significant impact on visual data sets for stars that are near the ecliptic but it has no effect on stars near the poles. The phase of the Moon has a slightly less significant effect for stars near the ecliptic, and it also has an effect on stars near the poles, but far less so. Finally, the experience of the observer does not have a significant impact on visual data sets. However, there are a few exceptions and for these exceptions, the extra scatter caused by inexperience is usually limited to their first year of observing.

The poster describes large visual data sets analyzed en masse. Individual visual observers can achieve much better precision. Visual observations by a single observer (Wayne Lowder-LX) have been shown to reach a level of 0.02 magnitudes of precision.

The white elephant in this discussion is the quality and consistency of charts and comparison star sequences. We hope that by using such large datasets we have relegated that to a second order effect.

The tentative conclusion of this poster is that large variable star visual data sets typically have a precision of around 0.2-0.3 magnitudes. Individual observers can sometimes reach 0.02 magnitudes. An experiment is being designed to test this conclusion with AAVSO observers and standard fields in 2007. It will also address the thornier issue of visual accuracy.

References

Barnes, T.G., Fernley, J.A., Frueh, M.L., Navas, J.G., Moffett, T.J., & Skillen, I. 1997, PASP, 109, 645
Moffett, T.J., & Skillen, I. 1997, PASP, 109, 645
Berdnikov, L.N. 1986, Variable Stars 22, 369
Berdnikov, L.N. 1992b, A&AT, 2, 107
Berdnikov, L.N. 1992c, A&AT, 2, 157
Berdnikov, L.N. 1992d, Pis'ma Astron. J. 18 325
Berdnikov, L.N. 1993, Pis'ma Astron. J. 19, 210
Berdnikov L.N., & Voziakova O.V. 1995, Pis'ma Astron. J. 21
Graham, C. H. and Hartline, H. K. 1935. The Jour. of Gen. Physiology,18, 917-931
Kholopov, P. N., et al., 1985, General Catalog of Variable Stars, 4th edition, Moscow
Kiss, L.L. 1998, MNRAS, 297, 825
Moffett, T.J., & Barnes, T.G. 1984, ApJS, 55, 389
Szabados, L. 1981, Mitt. Sterw. ungar Akad. Wiss.

Download AAVSO Data: http://www.aavso.org