Evaluating the USNO-Flagstaff DISPIs

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ABSTRACT

Changes since the last version are typeset in boldface. A) I fixed the rms values for the CDC-color regressions, B) Determined A_V from a full regression analysis: about two times better than in version 1.0. To further test this, we need a larger set of observations, with some emphasis on stars with a "large" extinction.

The grating data obtained by Dave Monet on 2003/08/13 with a DIVA-like grating device have been analyzed and interpreted. A simple analysis suggests that the apparent color-temperature of the stars can be determined to **30** mmag, while the interstellar extinction can be determined to **about 75** mmag.

The Gunn-Stryker catalog (1983, or "GS1983") is not very well-suited to establish the viability of a grating device for the AMEX mission. This is so because very few the GS1983 stars can boost of a determination of their physical parameters ($T_{eff}, log(g)$ and $[Fe/H]$, or "TGM").

The catalog by Le Borgne *et al.*(2003, A&A, 402, 433, or "B2003") is much better suited because this catalog contains stars selected from Cayrel de Strobel *et al.*'s TGM catalog (Cayrel *et al.*, 2001, A&A, 373, 159). The B2003 catalog contains *observed* spectra (corrected for instrumental and earth-atmospheric effects), as well as a version corrected for interstellar extinction. The errors in the absolute photometry are of the same order as for the GS1983 catalog: 20 mmag for the broad-band fluxes.

1. Introduction

I worked with the original flat-field corrected data as prepared by Dave Monet. I re-gridded these images such that the 0^{th} order images is centered at pixel #400. The dispersed images are about 100 pixels long and can be found between pixel number 270 and 370, approximately (see Figure 1 for an example). The "flux" values at each pixel of these DISPIs are determined by fitting Gaussian functions (in the cross-dispersion direction). The one-component Gaussian fits are displayed in the bottom panel. A two-component fit characterizes the profile much better, and the fluxes derived from these fits are shown in the top panel.

For the space-born AMEX case, such two-component decomposition might be used to separate the contributions from the overlapping orders. After all, the two (three) wavelengths that contribute to the observed DN number are very different, so that their in-scan (cross-dispersion) PSF widths are very different (factor of two) as well (see Willemsen *et al.*, 2003, A&A, 401, 1203; their Figure 1).

As can be seen from the comparison "red" and "blue" stars [e.g., Z Cyg (M5III) and 9 Sge (O8F)], the red end of the DISPIs lies furthest from the 0^{th} order position. Conversely, the part of the DISPI closest the 0^{th} order is the blue end of the 1^{th} order image. Note that this is reversed from the DIVA-DISPI case, presumably because the USNO grating is operated in transmission while the DIVA grating is reflective.

Based on my analysis of the 0^{th} order profiles displayed in Figure 2, I reject several stars from DGM's selection of GS1983 stars. One stars is clearly saturated (α Ser), while 59 Her (2^{nd} row, 2^{nd} column) is almost double peaked. In fact, 59 Her is listed by GS1983 as a star with large negative interstellar extinction, one that should be used with care in future analyzes[1]. All in all, I exclude α Ser, 59 Her, HR 6169, 78 Her, HD 148513, ϕ Ser, and HD 155675 from my analyzes.

The GS1983 catalog also lists estimated values for interstellar extinction (A_V) as well as several broad-band colors [$(U-B), (B-V), (V-R)$ and $(R-I)$]. Note however that these colors are determined from their *de-reddened* spectra. To derived *observed* colors, one has to perform two transformations: 1) from the scan-based colors to the standard Johnson colors employing the GS1983 equations listed in their section III, 2) from intrinsic colors to observed colors. Note that the first transformations are accurate to about 30 mmag.

2. Results

The simplest test to perform is to correlate various DISPI colors with tabulated observed Johnson colors. I have omitted Z CYG from the analysis because its spectral properties are very far from the other stars, so that it is likely to skew the analysis. This problem should be addressed in the future by observing a more continuous range in stellar characteristics.

I present the results for the $(B-V)$ color in Figure 3, which also comprises two panels [for the one- and two-component flux determination: bottom and top panels, respectively]. Because the two-component flux-determinations are more tightly correlated with $(B-V)$, I will not discuss the one-component results further. The actual DISPI color used for analysis and plotting is defined as

[1] In fact, this star is a double star: the Hipparcos solution is bad, and indicates $\Delta m \sim 3.2$ mag and $\Delta rho \sim 2.9''$, while also the Hipparcos & Tycho-2 proper motions are widely different.

the observed count rate relative to that in pixel 320:

$$D_{\#\#\#} = -2.5\log\left(\frac{F_{\#\#\#}}{F_{320}}\right) \quad (1)$$

where $F_{\#\#\#}$ is the observed DN number at pixel number ### (and with the 0^{th} order at pixel 400).

Encouraged by the low rms uncertainties of these fits (∼20 mmag), I went ahead and determined the interstellar extinction (A_V) as well. A simple-minded way to do this is to combine all the DISPI colors to predict observed as well as the *intrinsic* colors. The latter is possible because each DISPI color is correlated differently to extinction and stellar color.

I construct two independent subsets of DISPI colors [(305, 330, & 345), and (295, 310, 335, & 355)] and determine –via linear regression– the observed and intrinsic colors. The results are displayed in Figure 4. The top panel displays the relation between the "Combined DISPI color" (CDC) and the observed $(B-V)$ as (black) crosses, and the intrinsic color $[(B-V)_0]$. In the middle panel, I present the differences between the so-fitted observed and intrinsic colors as a function of CDC. Note that $(B-V)$ and $(B-V)_0$ have different, independent CDCs[2]. The difference between these two fitted relation is the color excess: $E_{B-V} = (B-V)-(B-V)_0$. The interstellar extinction is then given by:

$$A_V = R_V \times E_{B-V} \quad (2)$$

where we follow GS1983 and use $R_V = 3$. We have also performed this analysis for other Johnson colors: the results are best for $(B-V)$ and $(B-R)$, and worst for $(U-B)$. The results (**green squares in the** bottom panel of Figure 4) indicate that the extinction can be determined to ±172 mmag, independent of the absolute value of the extinction. A similar behavior was found for the 7-band system proposed for the FAME Classic mission.

Based on the rms values in the intrinsic and observed colors, we would expect an error in A_V of $3 \times \sqrt{68^2+29^2} = 74$ mmag. Since the observed rms error equals 174 mmag, it seems that the methods of color excess is not optimal.

Alternatively, one can determine A_V directly from a linear regression between all CDCs and the tabulated extinction A_V values. The difference between this linear-regression fit and the observed values has an rms of 74 mmag (blue triangles in the bottom panel of Figure 4).

If this result holds up in future experiments, even ground-based DISPI observations might be worth their while.

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[2] $CDC(B-V) = \sum_{i=(305,330,345)} D_i$, while $CDC(B-V)_0 = \sum_{i=(295,310,335,355)} D_i$.

3. Discussion

A 20 mmag photometric error is typical for good ground-based photometry. However, for AMEX we need to do better than that. In a forthcoming memo, I find that classification accuracy is a strong function of the total number of photons detected[3], while the number, width and location of the bands are second order. To reasonable approximation, I find that the error in $log(g)$ scales as:

$$\Delta log(g) \approx 0.0367 \times \left(\sqrt{1 + 15.5\Delta V_7} - 1\right)\ [dex] \tag{3}$$

where ΔV_7 is the photometric error (in mmag) in each band, for a 7-band system. Thus, 5, 10 & 20 mmag errors correspond to error in $log(g)$ of 0.28, 0.42, and 0.61 dex. For constant stellar mass, a 0.61 dex $log(g)$ error corresponds to a factor of four in stellar radius. Thus, (our) ground-based tests can be expected to tell dwarfs from giant stars, but not dwarfs from sub-giants.

Another thing to keep in mind is that the AMEX photometric system only needs to have an *internal* accuracy of several mmag. *External* accuracy at that level is hard to obtain since very few ground based data sets with this *accuracy* exist. The link with physical parameters of stars is then made via observations of stars with known physical parameters (e.g., from the Cayrel catalog), where we can only include calibration stars whose parameters are determined with the same observational & theoretical methods. The corresponding model spectra then allow for the calculation of "absolute photometry" of the AMEX stars. We thus ensure the transformability of our observations to other model atmospheres and arbitrary photometric systems.

It may be so that other physical parameters may be derived from USNO-grating observations. In order to do so, the GS1983 catalog should be abandoned in favor of the B2003 catalog. For example, specific tests may be performed that sample the extremes of parameter space. Such test include: A) dwarf-giant separation in the K-type regime [$log(g)$ sensitivity], B) dwarf-subdwarf separation ($[Fe/H]$ sensitivity), and so forth. For any such test, it is imperative to sample the parameter space well.

To thoroughly check the accuracy of the A_V determination process, we need a larger dataset that can be split up in two groups. We should "train" the linear regression on a subset of the data, and estimate A_V of the other stars employing this linear regression. It is imperative to have a bunch of stars with large A_V values.

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[3]Much like in astrometry.

4. Recommendations

Finally, to go much beyond the results presented in this memo, it is absolutely necessary that any future observations are better calibrated:

- by selecting stars from the B2003 catalog
- by observing a designated calibration star repeatedly during the observing run(s)
- by better sampling the physical parameter space
- by avoiding known binaries
- more???

Fig. 1.— The Observed DISPIs from DGM's 2003/08/13 observing run. All observed stars are plotted. The DN counts are normalized to unity at pixel # 320. The top panel displays the result for a two-component flux fit, the bottom panel for a one-component flux determination.

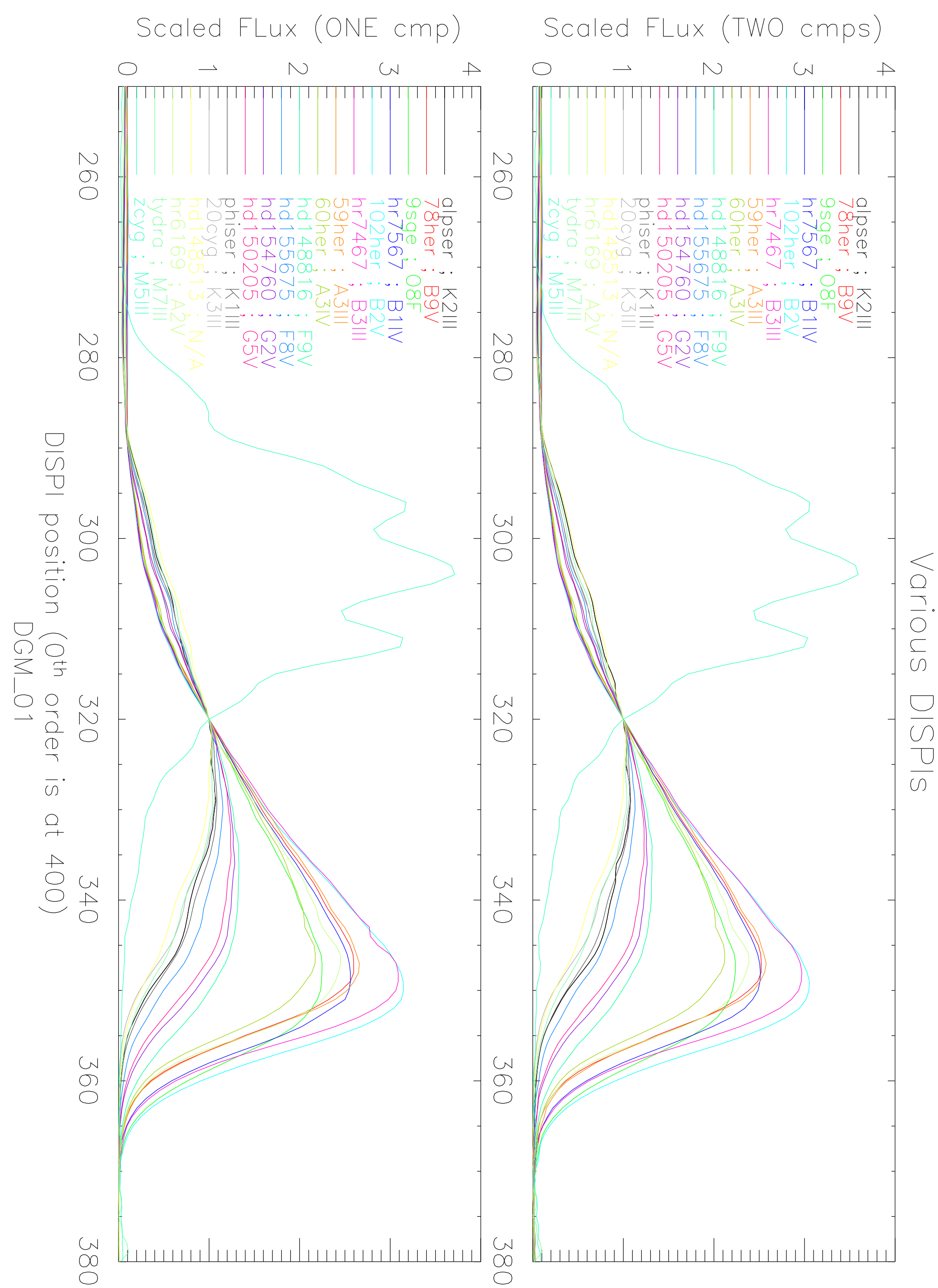


Fig. 2.— The profiles of the 0^{th} order image (in the dispersion image). All profiles are centered on pixel #400. The name of the star and it's spectral type are listed in the top-left corner of each plot. The dispersion of the width of the PSFs is also listed. the histogram-style plot is the profile for the star, while the thick, drawn line is the average of all profiles. α Ser (lower-left corner) is clearly saturated, and 59 Her (2^{nd} row, 2^{nd} column) appears to be double peaked.

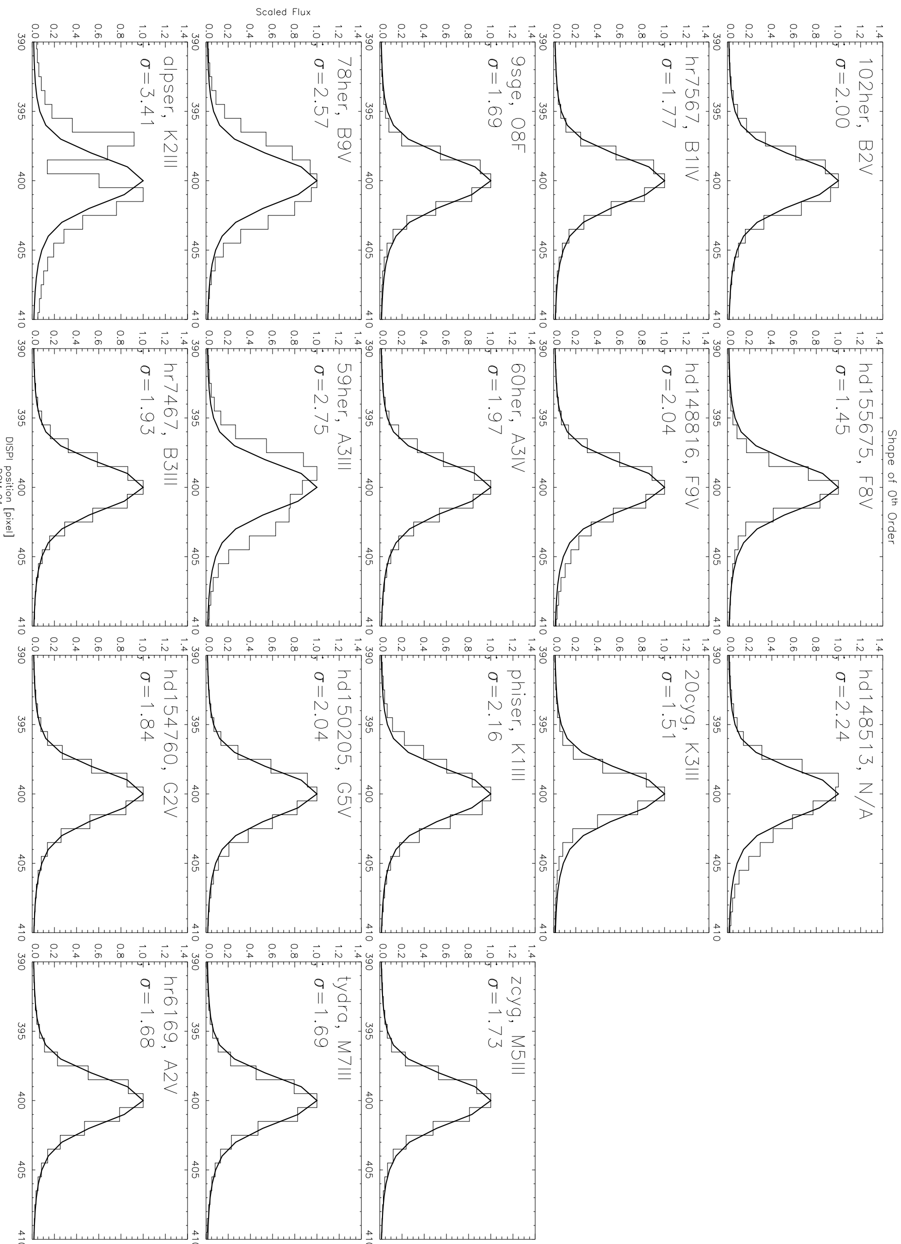
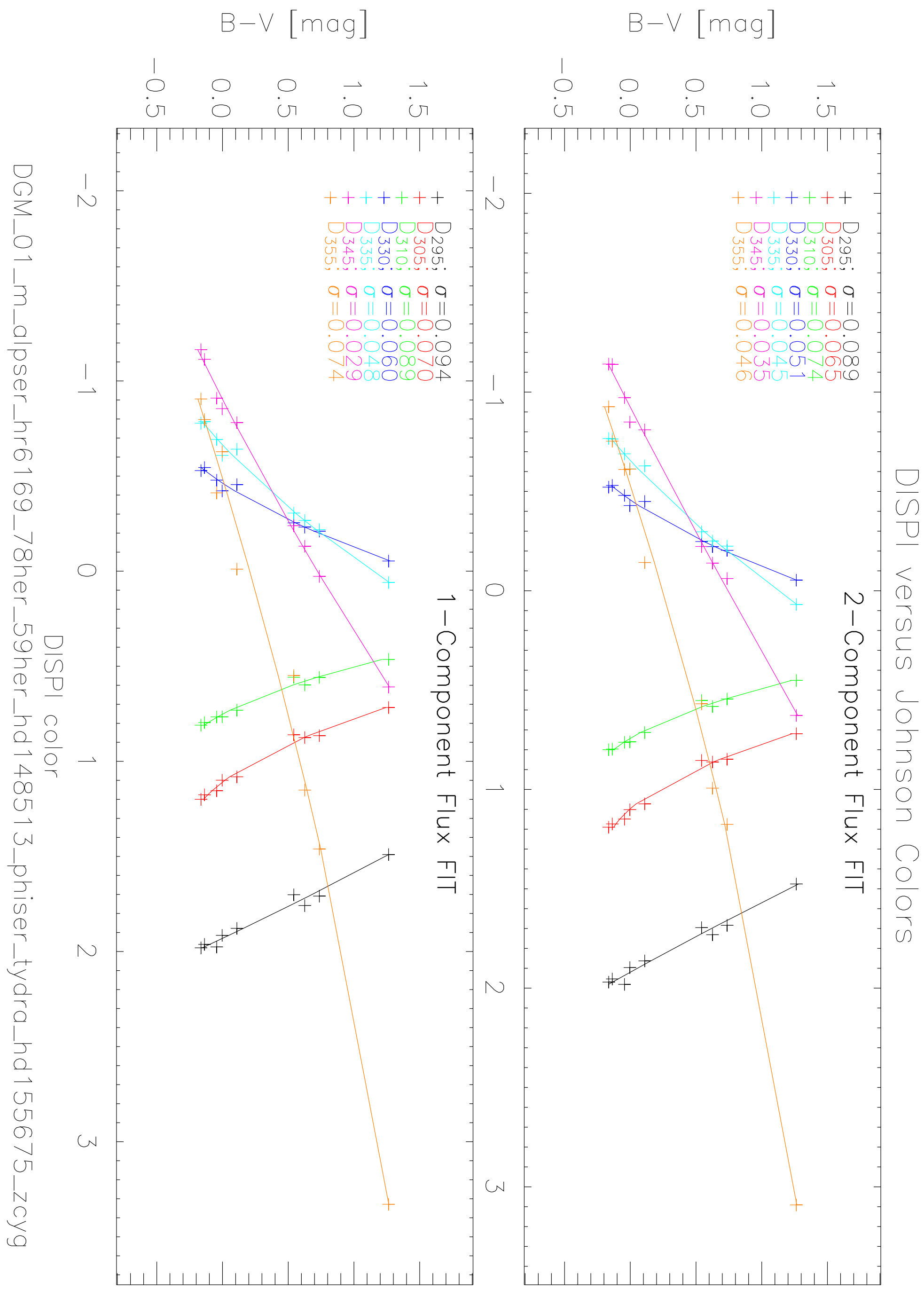


Fig. 3.— Various "DISPI-colors" versus the observed Johnson $(B-V)$ color for two- and one component cross-dispersion fits (top and bottom panel, respectively). The DISPI colors are extracted at pixel locations 295, 305, 310, 330, 335, 345 and 355. Each DISPI-color correlates fairly well with the observable $(B-V)$ color (**correct**) standard deviations of the fit are also listed).



caption Observed and intrinsic colors as a function of Composite DISPI Color (pluses & stars in the top panel). The middle panel displays the residuals between the fitted and true colors. The residuals in extinction are presented in the bottom panel, **where the green squares (blue triangles) correspond to the extinction determined from the "color-excess" ("linear regression") methods.**