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UV STELLAR DISTRIBUTION MODEL FOR THE DERIVATION OF PAYLOAD DESIGN CONSTRAINTS

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ABSTRACT

We present the results of a model calculation of the stellar distribution in a UV band centered at 2175Å corresponding to the well-known bump in the interstellar extinction curve. The stellar distribution model used here is based on the Bahcall-Soneira galaxy model (1980). The source code for model calculation was designed by Brosch (1991) and modified to investigate various designing factors for UV satellite payload. The model predicts UV stellar densities in different sky directions, and its results are compared with the TD-1 star counts for a number of sky regions. From this study, we can determine the field of view, size of optics, angular resolution, and number of stars in one orbit. These will provide the basic constrains in designing a satellite payload for UV observations.

1. INTRODUCTION

The specific behavior of the wavelength-dependence of the extinction has been modeled as the result of a mixture of large (0.1-0.2 μm) scattering grains, very small scattering grains (tens of Å in size), and some particles whose nature is not clear, but which are absorbing near 2175 Å . Recent attempts to explain the nature of the 2175 Å absorption particles (e.g., Li & Greenberg 1997) invoked some sort of hydrogenated carbon compounds, but this is only one possible explanation out of many. It seems certain that material responsible for the 2175 Å feature contains carbon, because of abundance reasons, but whether this is amorphous carbon, graphite, PAHs (Polycyclic Aromatic Hydrocarbons), or otherwise it is still unknown.

The interstellar dust is very important in the formation of stars and stellar systems. It is the main sink of "metals" in the ISM (Interstellar Medium), and in a proto-planetary environment this dust forms planets, such as the terrestrial planets in the Solar System. In particular, the ISM dust carries the materials which are incorporated in the living beings now on Earth.

A recent study of the interstellar UV extinction, with no specific emphasis on the 2175 Å band, was performed by Megier et al.(1997). They used archival IUE spectra of extinguished stars and compared these to "template" stars observed with the same instrument. Their study emphasizes the large variation in the shapes of the extinction curves and, at the same time, the constancy of the 2175 Å feature.

One of the reasons that the nature of the material has not been understood yet is the scarcity of stars in which it has been observed. Mostly, the study of interstellar extinction relies on UV spectra of extinguished stars, which are compared at each wavelength with spectra of unaffected stars of exactly the same type. This "pair method" requires careful matching of stars and is extremely resource-consuming. A single attempt to deal with large numbers of stars was made by Nandy et al. (1978), using the spectra collected by the TD-1 satellite. They used 3,000 stars brighter than V=7 and earlier than A0. The equivalent width of the 2175 Å feature was measured as EW(2175)=160xE(2190-2500), where E(2190-2500) was the "color excess" of the extinguished star relative to the template star of the same type.

Possible problems with the Nandy et al.(1978) study are the relatively small number of stars and the choice of the normalization for the extinction (2190 and 2500 Å regions). With a modern study it is possible to extend the investigation to fainter objects and to measure the EW(2175) by a two-filter method. The two-filter method uses either two filters with the same central wavelength but with different full-width half-power profile, or two filters of similar profiles but centered on different but nearby wavelengths. The EW is derived by assuming the continuum contribution to be approximately the same in the two filters, with the only difference being the amount of absorption.

In order to understand this extinction bump, one requires large number of observations of stars with two-filter method, because it is more efficient than the pair method. This can be done succesfully by a small size satellite payload. In this study, we calculate the stellar distribution in UV band centered at 2175 Å to derived constraints for a space experiment, and compare the distribution with observed data from the TD-1 satellite. Recently, such calculations were applied to the analysis of the sky at 1600 Å as observed by the Far-Ultraviolet Space Telelcsope (FAUST) by Cohen et al.(1994) and Brosch et al.(1995).

The purpose of the calculation is to set constraints on a possible UV imaging payload designed to study the properties of the 2175 Å extinction feature. Specifically, we need to characterize the stellar distribution with magnitude and projected Galactic location, in order to evaluate the damages of confusion limit at the faint end of detection. This derives the required angular resolution of any payload we might design.

2. Galaxy Model

The structure of the stellar component of the Galaxy is inferred from star counts and from comparisons with other spiral galaxies. The galaxies are modeled in terms of the surface brightness distribution and analytic descriptions are obtained. For the Galaxy, these are compared with distributions of stars obtained from deep surveys of specific sky areas. Examples of such modelling of the Galaxy may be found in the reviews of Bahcall (1986) and of Gilmore, Wyse & Kuijken (1989). The modeling is done mainly in the visible domain, where data are readily available. A Galaxy model in Ultraviolet was presented by Gondhalekar & Wilson (1975) and Gondhalekar (1990), with the aim of understanding the diffuse UV light from TD-1 all-sky survey.

Cohen (1994) extended to the far-ultraviolet the basic model orginally created for the point source infrared sky by Wainscoat et al.(1992). This model contains a Galactic geometry comprising a disk, halo, bulge, spiral arms, Gould's Belt and two local spurs in which the stellar populations can be augmented by those associated with local molecular clouds, and a molecular ring.

Brosch (1991) adopted the Bahcall & Soneira (1980) galaxy model, which consists of an exponential disc and a spheroidal component, each characterized by a luminosity function and a color-magnitude diagram, including only main-sequence and giant stars. Adding white dwarfs and including Gould's Belt as an extra ultraviolet-specific geometrical component, he adaped the model to the 1500 Å 2000 Å and 2500 Å sky for the first Israeli scientific satellite and 1600 Å for FAUST (Brosch et al. 1994). In this study, we calculate projected stellar densities based on this model in the visible and transform these to the UV, using known color-color relations between $(B - V)$ and any $(UV - V)$ color.

3. Optical-to-UV Transformation

The conversion of the galaxy model from optical to the UV is basically accomplished by introducing a transformation from $(B - V)$ colors to $(UV - V)$ and by adopting an extinction ratio $A_\lambda/E(B - V)$ appropriate to the spectral band of interest. The extinction in the UV band is taken from Savage & Mathis (1979).

In order to derive the tranformation from optical to UV, one needs to link empirically the derived $(UV - V)$ colors to standard UBV data from observed spectrophotometric data such as the IUE archive. Several plots show these relations between $(UV - V)$ colors and $(B - V)$ color in Carnochan(1982), Fanelli, O'Connell & Thuan (1987), Guideroni & Rocca-Volmerange (1987) and Brosch (1991). However, the problem with the 2175Å region is that it is strongly affected by extinction, and in this part of the spectrum the IUE LW Camera is rather inefficient. We can avoid this problem using stellar atmosphere models for the early-type stars. >From Kurucz (1993) models we adopted $log\ g = 4.0$ and $log\ g = 1.0$ for main-sequence and giants stars respectively and assumed solar abundances. We essentially followed Carnochan (1982) in setting the "zero point" of color index so that an A0 V star (T_{eff} = 10,000 K, log gravity of 4.0) has $(2175 - V) = -0.36$ by linear interpolation in wavelength between his values of instrinsic $(2365 - V)$ and $(2740 - V)$.

Figure 1 shows the relations of $(UV - V)$ and $(B - V)$ for main-sequence and giant stars, derived from the Kurucz models and the relation derived from 41 IUE normal stars used for studying the stellar color-temperature relation in the UV region (Choi et al., 1998). For $(1500 - V)$, $(2000 - V)$ and $(2500 - V)$ colors, the relations from model atmospheres are compared with the empirical relations formed by Brosch (1991). The relations between the $(UV - V)$ and $(B - V)$ color indices may be approximated as linear relations of the form $(UV - V) = a + b * (B - V)$.

The relations are shown in Table 1. Figure 1(a) shows significant difference for $(B - V) > 0.2$. Figures 1(b) and 1(c) show similar trends between model atmospheres and the observed stars and little difference between main-sequence and giant stars except for the cool stars. Figure 1(d) shows us difference between model atmosphere results and observed stars, but a small difference between main-sequence and giant stars. Therefore we adopted the relation between $(2175 - V)$ and $(B - V)$ from model atmospheres for main-seqence and giant stars separately. For the white dwarfs,

Table 1. The relations between $(UV - V)$ and $(B - V)$.

UV index	a	b
(1500-V)ms	0.83±0.18	18.46±0.34
(1500-V)gi	5.04±1.03	16.94±1.09
(2000-V)ms	-0.30±0.09	10.48±0.18
(2000-V)gi	0.17±0.54	11.48±0.57
(2500-V)ms	-0.71±0.09	6.95±0.17
(2500-V)gi	0.15±0.42	7.28±0.44
(2175-V)ms	-0.61±0.12	8.89±0.23
(2175-V)gi	-0.06±0.62	9.87±0.62

we approximated the spectral energy distribution as black bodies and calculated the tranformation using this relation.

4. COMPARISON WITH THE TD-1 STAR COUNTS

The validity of the stellar density calculated using the model can be tested by comparing with the number density observed by TD-1 satellite. The TD-*Catalogue of Stellar Ultraviolet Fluxes* contains 31,215 stars measured with S/N > 10 with apparent monocromatic magnitudes in all four TD-1 bands: 2585-2895 Å (λ_c = 2740 Å), 2200-2530 Å (λ_c = 2365 Å), 1800-2130 Å (λ_c = 1965 Å), and 1400-1730 Å (λ_c = 1565 Å). An unpublished version, with lower S/N restrictions, lists 58,012 objects(Landsman 1984).

Figure 2 shows comparisons between the predictions of model for one square degree areas at the selected regions listed in Table 2, and the actual star counts scaled to a one square degree areas. The sky field was enlarged at high galactic latitudes, to maximize the number of sampled stars and thus minimize the influence of counting errors. The model predictions are shown with error bars which represent upper and lower limits to the prediction, assuming Poissonian detection probability for any star. To compare with the predicted stellar density calculated at 2175 Å we averaged the TD-1 stellar densities between the 1965 Å and 2365 Å bands. Gondhalekhar (1990) noted the nonlinearity of TD-1's faint-end calibration so we excluded sources fainter than 8 magitude from consideration in matching star counts. The values for the reduced χ^2 are given in Table 2 to test the goodness-of-fit with the standard χ^2 test, by comparing predicted and observed star numbers per magnitude interval.

The plots for the Galactic pole (Figures 2(a),(b)) indicate that the predicted number of stars is higher than the number actually measured at all magnitudes. If the extinction was not properly accounted for, the ISM dust would mask off some stars and shift them to fainter magnitude bins in 2175 Å as expected. Additionally, the star counts from the unpublished TD-1 data are higher than those from the published version. We can see the well-fitted plots at the ecliptic poles (Figures 2(c),(d)) which were explored the longest by TD-1. However the Galactic center (Figure 2(e)) are fit badly, while the Galactic anticenter (Figure 2(f)) and low intermediate latitude (Figure 2(g)) are fit

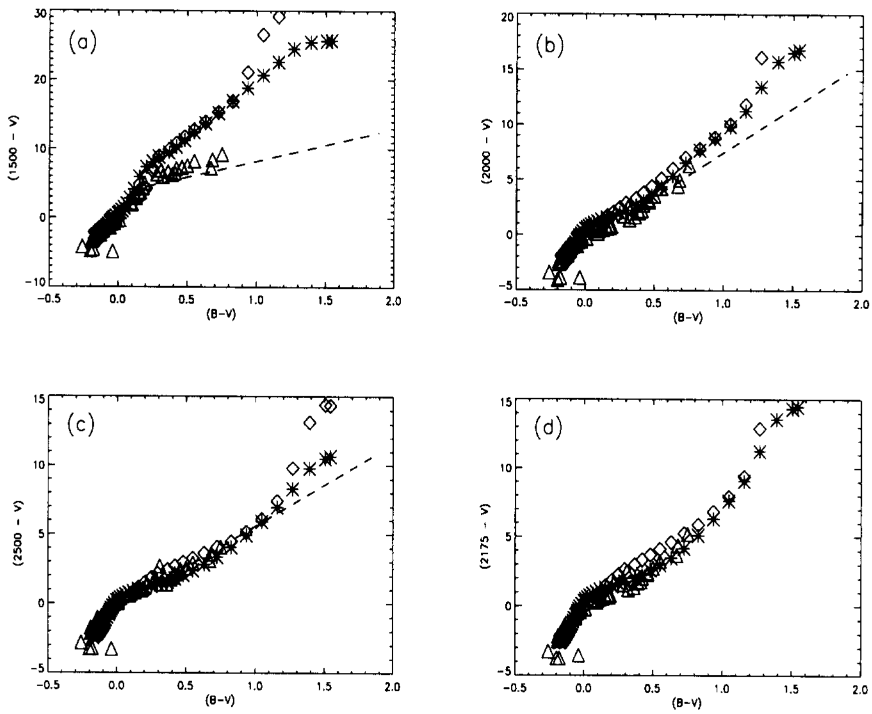

Figure 1. $(B-V)$ versus (a)$(1500-V)$, (b)$(2000-V)$, (c)$(2500-V)$ and (d)$(2175-V)$ relation. Asterisks and diamonds represent main-sequence and giant stars of Kurucz model respectively, triangles represent 41 IUE normal stars in Choi et al. (1998) and the dashed lines show the relations from Brosch (1991).

quite well. This indicates the model fits reasonaly well at low latitudes, except toward the Galactic center due to unresolved stars and dust. This was already noted by Brosch (1991) and is surprising, given the simple description of the dust in the Bahcall-Soneira model.

Figure 3 shows the reduced χ^2 values with respect to the Galactic longitude and latitude for the entire sky, assuming a field of 400 square degree. We can see the dependance on galactic latitude and longitude, which means the Galactic center region is fit badly. The lower reduced χ^2 values for the unpublished version indicate that if deeper sky survey data would be available, the model prediction will be close to observed data.

The payload design contraints, in order to survey the sky to deeper limits in 2175 Å band, can be determined by this calculation. The minimum angular resolution should be 18 arcsec to observe stars as faint as $UV \sim 16$ magnitude with 1024×1024 detector, because the stars are very crowded

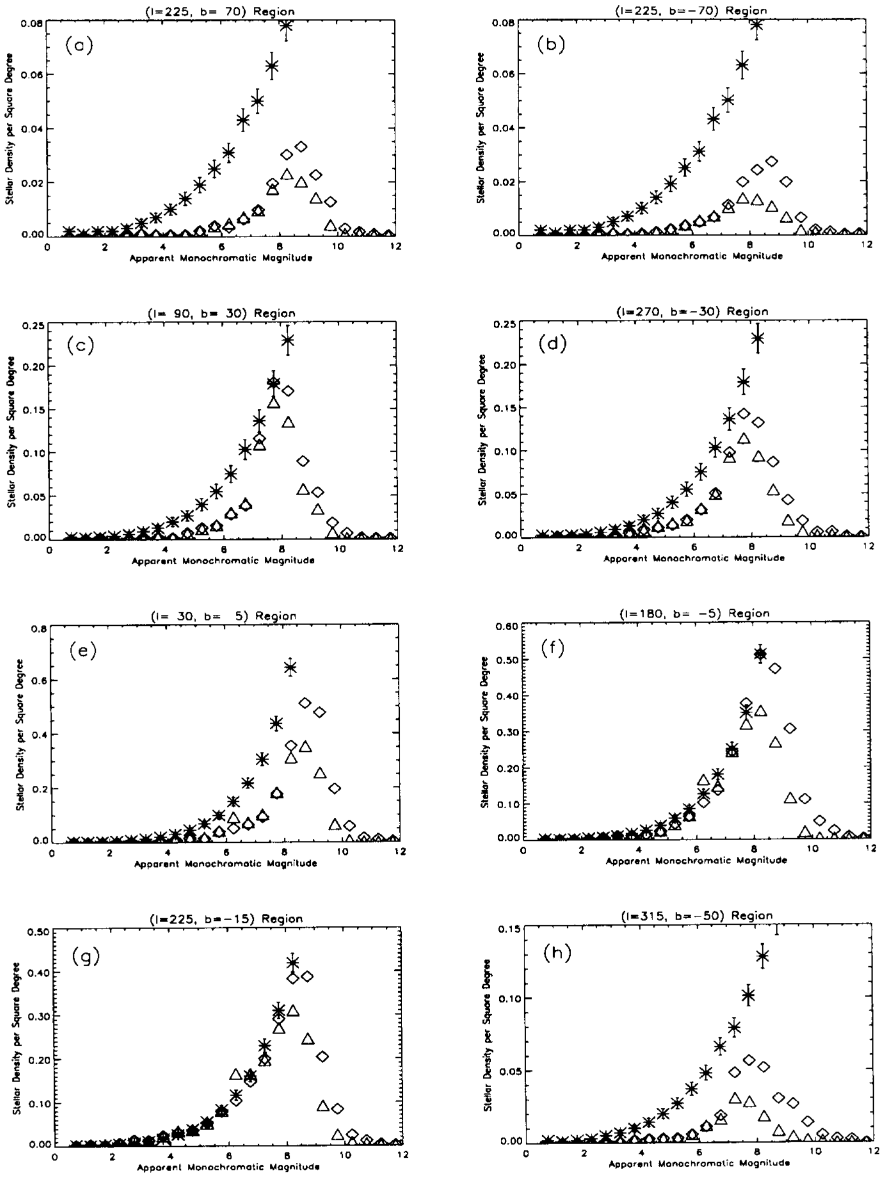

Figure 2. Model predictions compared with TD-1 at 2175 Å(a) North Galactic pole; (b) South Galactic pole; (c) North Ecliptic pole; (d) South Ecliptic pole; (e) Galactic center; (f) Galactic anticenter; (g) Low intermediate latitude; (h) Intermediate latitude regions.

Table 2. The selected TD-1 areas compared with model predictions.

Longitude(°)	Latitude(°)	Area (Square Degree)	Reduced χ^2 TD-1	Reduced χ^2 TD-1 unpub	Predicted no. of stars ($UV < 16$, per square degree)
195∼255	50∼90	2400	23.44	21.53	15.8
195∼255	-90∼-50	2400	26.95	22.43	15.8
70∼110	20∼40	800	15.27	10.76	34.6
250∼290	-40∼-20	800	25.32	15.55	34.6
0∼60	0∼10	600	148.33	141.96	197.4
140∼220	-10∼0	800	23.26	3.48	115.1
180∼270	-20∼-10	900	15.50	2.76	61.7
270∼360	-60∼-40	1800	46.23	26.05	24.4

near the Galactic center direction as shown in the last column of Table 2. The maximum field of view can be 5.12 degree, in this case, with 24 μm per detector pixel, and at least 80 stars can be observed per field, even in the Galactic pole region.

5. SUMMARY

The model prediction of the stellar distribution based on Bahcall-Soneira galaxy model, was calculated in 2175 Å band and compared with thd TD-1 star counts. The Kurucz model atmospheres were used for the transformation from the optical to 2175 Å. The prediction showed somewhat more star counts at all magnitudes and at high latitudes, and fitted well the measured star counts at low latitudes except for the Galactic center. This calculation is useful for the determination of payload design constraints, such as field of view, angular resolution, number of stars detected in one orbit.

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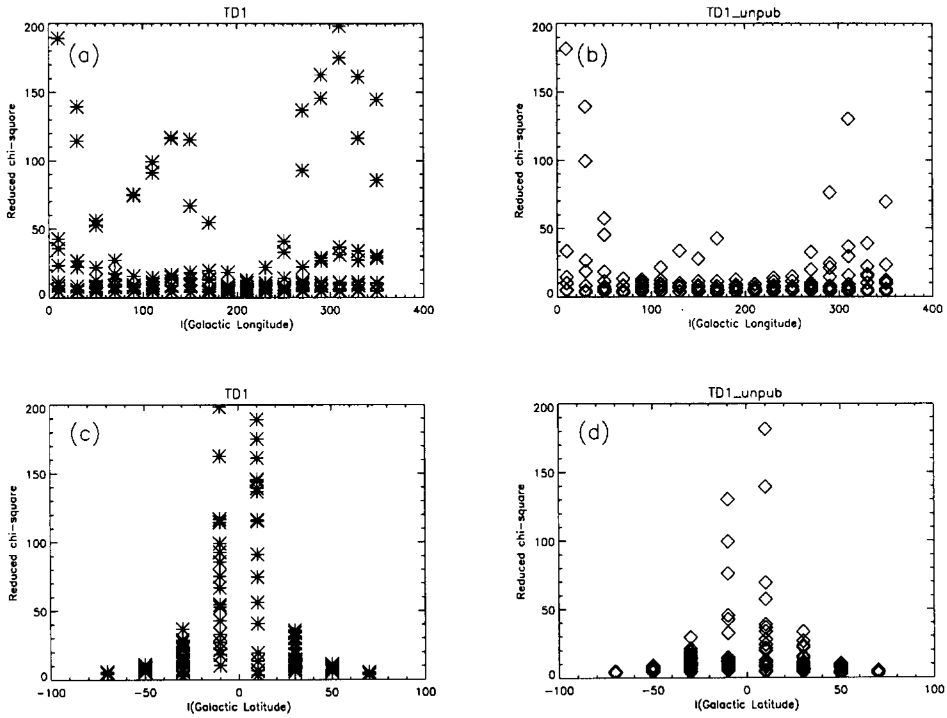

Figure 3. The reduced χ^2 values with respect to the Galactic longitude and latitude for the entire sky and for a sky field of 400 square degrees.

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