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PROGRAMS 'CELESTE' AND 'STELLA' FOR COMPUTATIONS IN SPECIAL RELATIVITY: EVALUATION OF THE CELESTIAL VIEW FROM AN INTERSTELLAR SPACECRAFT

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PROGRAM SUMMARY

Title of programs: CELESTE (batch-processing version); STELLA (time-sharing terminal version)

Catalogue number: AACI

Program obtainable from: CPC Program Library, Queen's University of Belfast, N. Ireland (see application form in this issue)

Computer: CDC Cyber 71/Cyber 170-720; *Installation*: University of Lowell Computer Center

Operating system: FORTRAN-IV EXTENDED (ANSI 1966)

Programming language used: FORTRAN-IV

High speed storage required: 22 Kwords

No. of bits in a word: 60

Peripherals used: terminal (LA36 DECwriter II) for STELLA; card reader (model 405), line printer (model 512) for CELESTE; optional colour display console for direct display of astroscapes

No. of lines in combined program and test deck: program CELESTE has 462 lines, STELLA has 470 lines; star data file NEARDAT has 92 lines, CONDAT has 35 lines, YALSTAR has 520 lines, STARDAT has 2289 lines

Keywords: astroscape, starscape, star plot, celestial view, special relativity, length contraction, time dilation, aberration, parallax, Doppler effect, Doppler shift, brightness, apparent magnitude, stellar temperature, spectral type, colour bolometric correction, spaceflight, interstellar travel, astronavigation

Nature of physical problem
CELESTE and STELLA have been compiled to evaluate the celestial fore and aft views from a spacecraft in relativistic motion, aimed in any specified direction and located at any given distance from the solar system (i.e., Earth). The calculations take account of the special-relativistic effects of space contraction, aberration, parallax, Doppler shift of wavelength (colour) [including shift of infra-red stellar sources into the visible region], and perceived brightness (i.e., apparent visual magnitude). The output may, at option, provide a printed astroscape diagram as well as a tabulation of numerical results. The output data may be fed to a colour display console for a direct visual display.

Method of solution
Using special-relativistic formulae [1,2], the programs convert input data for stars, e.g., visible and infra-red sources (stellar coordinates, distances, spectroscopic class, apparent visual and infra-red magnitudes) into a polar representation of the fore and aft view as a function of craft speed and direction and distance [3,4].

Restrictions on the complexity of the problem
While the programs have been designed to deal with infra-red as well as visible stellar sources, including appropriate bolometric corrections to determine the apparent visual magnitude (perceived brightness), they do not contain similar procedures for ultra-violet sources (since at present only piecemeal data on these are available). The input file for stellar data has been restricted to stars of 4th magnitude or brighter, in order to keep the length of the star catalogue to below 5 500 entries. It could, however, be expanded at will. The programs do not provide side views, but could readily be modified to furnish these if desired.

Typical running time
Less than 1 min in batch mode; 2–3 min in interactive-terminal mode when no plots are generated, 5 min in terminal mode with plots.

[1] R.W. Stimets and E. Sheldon, J. Brit. Interplanetary Soc. - Interstellar Studies 34 (1981) 83.
[2] E. Sheldon and R.W. Stimets, Nukleonika (in press).
[3] R.A. Schorn, Sky and Telescope 62 (1981) 530.
[4] E. Sheldon and R.H. Giles, J. Brit. Interplanetary Soc. - Interstellar Studies 36 (1983) 99.

LONG WRITE-UP

1. Introduction

As an exercise in the application of relativistic physics and a possible anticipation of the future in manned interstellar space travel, undertaken at relativistic speeds in order that time dilation assists in keeping the spacecraft's inherent mission time to within a reasonable portion of the astronaut's lifespan, the evaluation of stellar "astroscapes", or star maps, via the programs "CELESTE" or "STELLA" has attracted widespread interest. This description of the computational procedures and data handling has accordingly been prepared in order to make this resource more generally available. The findings are pedagogically informative, instructive and visually attractive.

Of the eleven stars within 10 light-years (ly) of the Sun, only three (namely, Proxima Centauri, α Centauri A/B) lie at less than 5-ly distance, and the next nearest, Barnard's Star, lies at 6 ly. Barnard's Star has been proposed as the leading candidate for exploration in the Daedalus Project [1] in a 60-year one-way unmanned fly-by mission to be undertaken next century at subrelativistic speed ($\beta \equiv v/c = 0.122$). A further 31 stars lie within 10–15 ly of the solar system; even assuming all technical, physiological, communications and energy problems could be reliably overcome for manned 2-way round-trip missions, these would lie at the limits of accessibility within the astronauts' lifespan unless internal craft time could be "slowed down" through relativistic time dilation. However, relativistic influences affect time and space jointly, causing radical changes in the celestial view from a starship at such speeds. The astroscape at any given flight velocity v is determined by a combination of effects, including contraction of distance, aberration and parallax of apparent angular coordinates, Doppler shift of wavelength (i.e., of perceived colour), and intensity modification of brightness. The present computer programs take the entire totality of effects into consideration for the first time, demonstrating the drastic alteration in the appearance of the firmament at relativistic speeds, when visible sources appear to become extinguished through blue-shift in the forward direction (and red-shift in the rearward view) and hitherto-invisible infra-red sources ahead (or ultra-violet sources astern) are shifted into the visible part of the spectrum, while the entire field of view folds forward, like a closing petal, as a consequence of aberration. The navigational problem would thus take on entirely new aspects in relativistic space-flight, with mission distances seemingly shrinking enormously in the flight direction.

Illustrative examples of such astroscapes based upon conventional and newly-derived relativistic formulae and correction procedures, as cited in the present description of the calculational treatment, have been given for hypothetical flights toward the North Celestial Pole (i.e., to Polaris) by Stimets and Sheldon [2–4]. For this, and other flight directions, e.g., toward the South Celestial Pole and toward nearby stars at sub-relativistic and relativistic speeds, the astroscapes projected onto a colour display console terminal from the computer output were photographed as slides and assembled into an animated sequence on colour movie film, simulating the fore and aft views from a spacecraft in rapid flight. A further set of results has been prepared for publication [5], in which several of these astroscapes, and others indicating the changing appearance of a star during an overtaking fly-by manœuvre, when parallax effects are of significance, are depicted. The programs with display output constitute a particularly interesting and vivid demonstration that illustrates the unique capabilities of computer and graphics systems.

2. Previous studies

It has long been recognised that in lieu of attaining "suspended animation" during spaceflights on interstellar missions, astronauts could make avail of time dilation (see, e.g., refs. [6,7] and papers in refs. [8,9]). In an early study of spaceflight parameters, Sänger [7] pointed out that if a constant acceleration $a' = g = 9.81$ m/s^2 could be maintained to the midpoint of a flight whose second half was undertaken with a constant deceleration $a' = -g = -9.81$ m/s^2, relativistic speeds would be achieved during the first half-year of the mission, and a one-way flight under these conditions to even the farthest bounds of the visible Universe, covering a distance $s = 3 \times 10^9$ ly, could be accomplished within 41.9 astronaut-years (as measured within the craft's frame of reference). Using a hyperbolic representation, Sänger derived the formula for the mission duration (in the spacecraft frame; primes denote variables in the spacecraft system):

$$\tau' = (2c/a') \operatorname{arc\,cosh}\left[1 + \left(a's/2c^2\right)\right], \tag{1}$$

where c is the velocity of light. For large intragalactic and intergalactic distances s, this expression reduces to

$$\tau' = (2c/a') \ln\left(a's/c^2\right). \tag{2}$$

The maximal velocity ratio $\beta_{max} \equiv v_{max}/c$, attained at the midpoint $s/2$, is

$$\beta_{max} = \left\{1 - \left[1 + \left(a's/2c^2\right)\right]^{-2}\right\}^{1/2}. \tag{3}$$

In a revised version of Sänger's graphs, Sagan (ref. [10] reproduced in ref. [9]) has presented plots of distance s and speed ratio β_{max} versus τ' for $a' = g$, $2g$ and $3g$. As fig. 1, we depict the growth of spacecraft-time τ' and Earth-time τ_E with mission distance s, as well as of β_{max} versus s for a one-way boost/deceleration flight with $a' = g$. The data for these plots were obtained from approximation formulae that are in accord with the foregoing [2,3], viz., in the "g-boost mode",

$$s = (2c^2/a')\left[\left(1 - \beta_{max}^2\right)^{-1/2} - 1\right]; \tag{4}$$

$$\tau' = (c/a') \ln\left[(1 + \beta_{max})/(1 - \beta_{max})\right], \tag{5}$$

$$\tau_E = (2c/a')\beta_{max}\left(1 - \beta_{max}^2\right)^{-1/2}. \tag{6}$$

Interstellar trips within an astronaut's lifespan would thus be entirely within the realm of feasibility if the technical means could be attained and other conditions satisfied.

In "optical relativity" the formulae have also long been available, except for the brightening, which has not been subjected to quantitative investigation. With the recognition of the Penrose–Terrell effect [11,12], the re-examination of visual relativistic phenomena received renewed impetus. Computer programs were compiled to evaluate the instantaneous appearance of transversely-moving rods and rectangular grids [13], cubes and other shapes [14]. Although this effect has, as it turns out, no bearing upon our present spaceflight considerations, its relationship to aberration, which does of course affect the views crucially, provides a connection with the approach that we pursue in this project. While examining the appearance of a self-luminous sphere when viewed in approach, recession and transverse passage, Scott and Van Driel [15] extended their computations to depict the views, fore, aft and athwart, from a relativistic spacecraft bound for Polaris in the direction of the North Celestial Pole. They also illustrated the appearance of a train of box-cars in transverse motion. The consequences of aberration in distorting the spatial geometry were particularly evident in these displays. For illustrative purposes, the astroscape results were taken over by Kaufmann [16]; a similar depiction of astroscapes in the course of an imaginary flight toward 45 Eridani, including a quantitative treatment of aberration and a qualitative treatment of the Doppler shift, was presented by Moskowitz [17], who also mentioned the occurrence of appreciable relativistic brightening and pointed out selective features of this. Among other writers who have given representations of star maps in which aberration was allowed for, Schroeder [18] showed fore and aft astroscapes as would be seen in the course of a flight toward the South Celestial Pole. In none of these, however, was parallax explicitly taken into consideration, nor was intensity enhancement incorporated into the calculations. Moskowitz [17] mentioned that stars whose radiation peaks in the infra-red (IR) part of the spectrum would appear bluer and brighter on approach, but failed to allow for IR sources to intrude into the forward astroscape (as ultra-violet [UV] sources enter into visibility in the rearward astroscape) when craft speeds proceed into the relativistic region.

These shortcomings are avoided in our programs, which take aberration, parallax, Doppler shift and intensity modification into account quantitatively for actual stellar sources as viewed in conjectured relativistic flight at any given speed in any specified direction. The underlying formulation upon which these programs are based is described in the next section, and a review of the programs themselves is presented in section 4.

3. Relativistic formulation and correction procedures

The treatment follows that given by Stimets and Sheldon [2,3], allowing for acceleration within the framework of special relativistic theory. The spacecraft thus passes through a succession of inertial reference frames, while the galactic system (i.e., the Earth) is taken as the rest frame. All quantities expressed in the spacecraft system are characterised by a prime; variables in the galactic system are unprimed. The proper acceleration a' of the spacecraft as determined in its own momentary inertial frame is related to the acceleration a as measured by Earth-based observers through the familiar expression

$$a' = \gamma^3 a \equiv \gamma^3 \mathrm{d}v/\mathrm{d}t = \gamma^3 c(\mathrm{d}\beta/\mathrm{d}t), \qquad (7)$$

in terms of the Einstein factor $\gamma \equiv (1-\beta^2)^{-1/2}$. On substituting the time-dilation relation for $\mathrm{d}t$, namely

$$\mathrm{d}t = \gamma \mathrm{d}t' \qquad (8)$$

and integrating,

$$\int a'\mathrm{d}t' = \int \gamma^2 c \mathrm{d}\beta = c\int (1-\beta^2)^{-1} \mathrm{d}\beta, \qquad (9)$$

one readily obtains the result (4) used to generate data for fig. 1.

After converting stellar coordinates (r, δ, α) in the galactic frame, where r is the distance, δ the declination (in degrees/arc-minutes) and α the right ascension (in h/min/s), to polar coordinates (r, θ, ϕ) and allowing for spacecraft flight in the angular direction $\hat{\beta} \equiv (\theta_s, \phi_s)$ which is taken to define the new z-axis, one obtains the new spherical polar coordinates of the star referred to this new direction as (r, Θ, Φ), where

$$\Theta = \arccos[\sin\theta \sin\theta_s \cos(\phi - \phi_s) + \cos\theta \cos\theta_s], \qquad (10)$$

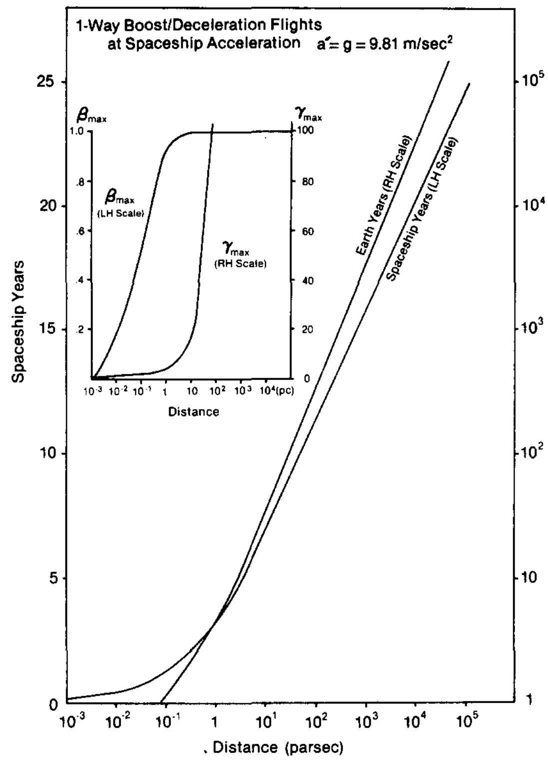

Fig. 1. Comparison of time-duration in the spaceship frame of reference (left-hand scale) with that in the galactic (i.e., Earth) system for one-way boost/deceleration flights over a distance s. In the first half of the flight, to $\frac{1}{2}s$, a constant proper acceleration (as measured in the spacecraft system) $a' = g = 9.81$ m/s^2 is maintained, to reach a maximum speed $\beta_{max} \equiv v_{max}/c$, where c is the velocity of light. Thereafter, a constant deceleration at the rate $a' = -g = -9.81$ m/s^2 is maintained. Plots of β_{max} and the corresponding Einstein factor $\gamma_{max} \equiv (1-\beta_{max}^2)^{-1/2}$ versus distance s are shown inset.

$$\Phi = \arctan[\sin\theta \sin(\phi - \phi_s) / (\sin\theta \cos\theta_s \cos(\phi - \phi_s) - \cos\theta \sin\theta_s)]. \qquad (11)$$

Relativistic aberration is expressed through the relation between these and the angular coordinates (Θ', Φ') in the spacecraft frame:

$$\Theta' = \arccos\left[\frac{\beta + \cos\theta}{1 + \beta\cos\theta}\right], \qquad (12)$$

$$\Phi' = \Phi. \qquad (13)$$

The azimuthal coordinates are thus unchanged;

the shape of constellations is thereby simply scaled down or up (in the forward or rearward direction of observation) and the Penrose–Terrell effect is non-evident. Allowance for parallax after the spacecraft has moved a distance z along the z-axis from the origin results in a change in the sagittal angle at which a star at a distance r from the origin now has to be viewed; the new angle Θ_z is related to Θ through the simple trigonometric formula

$$\tan \Theta_z = \frac{\tan \Theta}{1 - (z/r) \sec \Theta} = \frac{\tan \Theta}{1 - K} = \frac{(r^2K^2 - z^2)^{1/2}}{z(1-K)}, \tag{14}$$

where K has been introduced as an abbreviation for $(z/r)\sec \Theta$, and use has been made of the identity $\tan^2 \Theta \equiv \sec^2 \Theta - 1$. The radial distance to the star (in the galactic frame) is

$$d = (r^2 - 2rz \cos \Theta + z^2)^{1/2}. \tag{15}$$

It is straightforward to combine the aberration result (12) analytically with the parallax result (14), but in practice the computation is best performed sequentially, first calculating Θ_z from Θ and then substituting Θ_z throughout the right-hand side of formula (12) for numerical evaluation of Θ'. For the analytic combination, it is easier to use the first of two equivalent expressions in place of (12), namely

$$\sin \Theta' = \frac{\sin \Theta}{\gamma(1 + \beta \cos \Theta)}, \tag{16}$$

from which, with eq. (12), one may deduce that

$$\tan(\Theta'/2) = [(1-\beta)/(1+\beta)]^{1/2} \tan(\Theta/2). \tag{17}$$

For computational purposes, the conversion formula (16) suffers from the dichotomy of the arc sin function: for a given positive value of the expression on the right-hand side, two values of Θ' satisfy the relation, e.g., an angle in the first quadrant and its supplement in the second quadrant. In the computation, the former would automatically be adopted, even though the latter would be dictated by the problem. No such ambiguity arises with the transformation formulae (12) or (17). However, using (16) and (14), one obtains the aberration/parallax formula

$$\sin \Theta' = \frac{\tan \Theta}{\gamma(1 + \beta \cos \Theta)\left[(1-K)^2 + \tan^2 \Theta\right]^{1/2}}. \tag{18}$$

This is an amended form of the expression cited in ref. [3].

The general Doppler formula for the shift in wavelength, relating the received wavelength λ' (in the spacecraft system) to the emitted wavelength λ (in the galactic system) for a craft viewing starlight at an angle Θ_z, is

$$\lambda' = [\gamma(1 + \beta \cos \Theta_z)]^{-1}\lambda. \tag{19}$$

Since the effective Planck temperature $T \equiv hc/k\lambda$ (where h is Planck's constant and k is Boltzmann's constant) is inversely proportional to the wavelength, it follows from eq. (19) that the apparent stellar temperature T' may be calculated from the actual temperature T with the aid of the relation

$$T' = \gamma(1 + \beta \cos \Theta_z)T. \tag{20}$$

In this approach, starlight is considered to have a black-body spectrum: the observed radiation accordingly also has a black-body spectrum corresponding to the transformed temperature T'. The power flux per unit solid angle is proportional to T^4 (according to Stefan's law), and the solid angle transformation ensues from eqs. (12) and (17) as

$$d\Omega' = [\gamma(1 + \beta \cos \Theta)]^{-2} d\Omega, \tag{21}$$

where

$$d\Omega' = \sin \Theta' d\Theta' d\Phi' \text{ and } d\Omega = \sin \Theta d\Theta d\Phi. \tag{22}$$

Using the concept of apparent visual magnitude m_v as a measure of the perceived brightness for radiation at the wavelength $\lambda = 0.5556$ μm, one obtains the observed brightness in the spacecraft system as the apparent magnitude

$$m'_v = m_v - 2.5 \log[\gamma(1 + \beta \cos \Theta_z)]^2 + \text{B.C.} - \text{B.C.}', \tag{23}$$

where B.C. denotes the bolometric correction, defined as the difference between the apparent bolometric magnitude m and the apparent visual magnitude:

$$\text{B.C.} = m - m_v \quad \text{and} \quad \text{B.C.}' = m' - m'_v. \tag{24}$$

In the classification of brightness of stellar sources that emit mainly in the IR region, the apparent magnitudes m_I and m_K are used as a measure of luminosity at $\lambda = 0.84$ μm and $\lambda = 2.20$ μm, respectively. These magnitudes have been listed in the Two-Micron Sky Survey catalogue compiled by Neugebauer and Leighton [19]; the authors also describe how to correct the m_I values to be in accord with those tabulated by Johnson [20] for the nearby wavelength $\lambda = 0.90$ μm. For our calculations, we assembled an IR data file from the Neugebauer–Leighton catalogue, including all sources with $m_K \leq 2$.

In our programs, the bolometric correction procedure is varied according to the category of the star under consideration. We distinguish between three categories:

(a) For visible stars in the spectral classes O, B, A, F, or G (for all subclasses 0–9) the black-body temperature T is taken to be the typical effective stellar temperature appropriate to the respective spectral type in accord with Allen's classification [21], and the corresponding bolometric correction (B.C.) is taken from Johnson's tabulation [20]. The transformed bolometric correction (B.C.′) is either extracted by interpolation within Johnson's tabulation [20] for T' or, if the apparent temperature T' exceeds 12 500 K, from the extrapolated approximation formula

$$\text{B.C.}' = -5.468 \log T' + 21.939. \tag{25}$$

(b) For visible stars in the spectral classes K, M, N, S or C (for all subclasses 0–9), the temperature assignment T is made on the basis of Johnson's tabulation [20] for *giant* stars. However, to correct for the diminution of visual brightness due to possible molecular blanketing effects, a modified procedure has been adopted as a means of obtaining more realistic bolometric corrections. For any given effective temperature T the bolometric correction (B.C.) is deduced by interpolation in data listed by Johnson [20,22] and Allen [21], and plotted as a calibration curve in fig. 2. These data are built into the programs as data file blocks. To arrive at the value of B.C.′ the same procedure as in (a) is followed, and thence the observed apparent visual magnitude m'_v is determined from the input m_v in accordance with eq. (23).

(c) For IR sources, the magnitude difference $m_I - m_K$ is used to arrive at the appropriate temperature T, as indicated on the calibration curve, fig. 2. Thence T' is calculated with the transformation formula (20), and the bolometric corrections B.C. and B.C.′ are deduced as above. This enables m'_v to be computed from eq. (23).

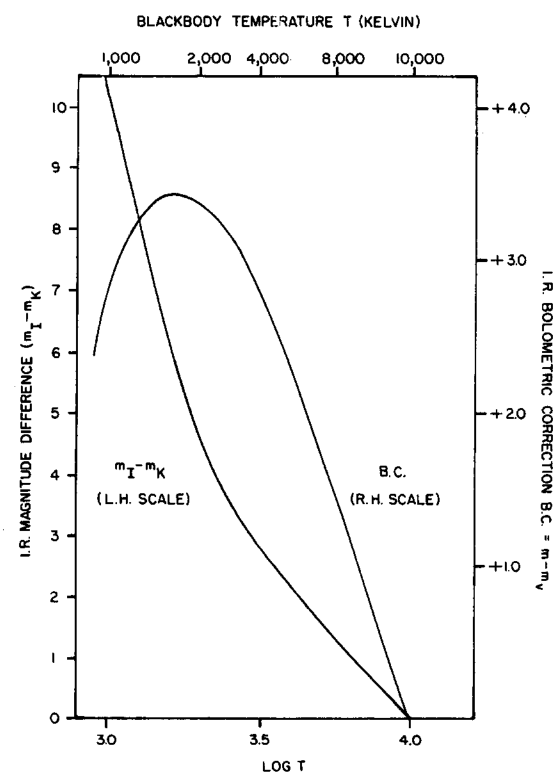

Fig. 2. Plot of infra-red (IR) apparent magnitude differences $(m_I - m_K)$ and bolometric corrections $(m - m_v)$ versus blackbody Planck temperature T and $\log_{10} T$, as used for the calculation of perceived apparent magnitude m'_v with the aid of the data block INFR1. m is the bolometric magnitude, m_v is the visual magnitude (at $\lambda = 0.5556$ μm), m_I is the shortwave IR magnitude (at $\lambda = 0.84$ μm), and m_K is the longwave IR magnitude (at $\lambda = 2.20$ μm).

4. Program review

The FORTRAN-IV programs "CELESTE" and "STELLA" are identical in structure and composition, with the same variables, functions, procedures and subroutines. The only distinction between them is the fact that "CELESTE" is designed for batch-mode operation (with a non-interactive input data package), while "STELLA" has been compiled for running from an interactive time-sharing terminal (such as the model LA36 DECwriter II with 300 BAUD that we have used principally).

4.1. Data files used in input

Various catalogue files have been prepared for input purposes, listing various categories of stars and their characteristic data. The most comprehensive of these, STARDAT, comprises 2288 entries, made up of the 519 brightest visible stars (with $m_v \leq 4$) from the Yale Catalogue of Bright Stars [23] together with 1313 northern-hemisphere and 456 southern-hemisphere Neugebauer–Leighton IR sources [19] with $m_K \leq 2$. The 519 brightest visible stars alone are listed, with their characteristic data, in the input file YALSTAR. Considerably less voluminous than these are such alternative specific files as CONDAT, which lists 34 of the brightest ($m_V \leq 4$) of the visible stars to be found in the principal northern and southern-hemisphere constellations (Aps, Boo, CaM, Car, Cas, Cen, Cru, Hyi, Per, Sco, UMa and UMi), and NEARDAT, which lists a selection of 91 near and prominent stars (essentially, the 66 nearest with $r \leq 6.1$ pc down to 14th magnitude, and the 25 brightest, with $m_v \leq 1.65$ and $r < 490$ pc). For each of these input files for stellar data, the following characteristics are specified in the following sequence and format:

Identification, Location (right ascension α in a h/min/s and declination δ in deg/arc-min), Brightness (as apparent magnitudes m_K, m_I, m_v), Spectral class and Distance (r in pc), viz.

ID1, ID2, IHOUR, MIN, ISEC, IDEG, SMIN, AMK, AMI, AMV, A, B, C, R [FORMAT (A1, A6, I2, X, I2, X, I2, 2X, I3, F5.1, 3F5.2, 3X, 3A1, 8X, F6.1)].

These data are as follows:

Identification

ID1 = B (for a visible bright star, or I for an IR source, or U for a UV source, or any other characteristic designation) [FORMAT A1]

ID2 = Alphanumeric sequential designation [FORMAT A6], (e.g., Y00001 for 1st star from Yale catalog, or N00003 for 3rd-nearest star, etc.);

Location

IHOUR, MIN, ISEC = Right ascension α in h/min/s [FORMAT (I2, X, I2, X, I2, 2X)]

IDEG, SMIN = Declination δ in deg/arc-min [FORMAT (I3, F5.1)];

Brightness

AMK, AMI, AMV = Apparent K-magnitude, I-magnitude and visual magnitude (m_K, m_I, m_v) [FORMAT (3F5.2, 3X)];

Spectral class

A = O, B, A, F, G, K, M, N, S or C, according to the stellar spectroscopic classification scheme [FORMAT A1],

B = 0, 1, 2, 3, 4, 5, 6, 7, 8 or 9, according to the spectral subclass [FORMAT A1],

C = E (for emission spectrum) or P (for peculiar spectrum) or other identifying spectral specification [FORMAT A1];

Distance

R = r, the distance from Earth in parsec [FORMAT F6.1]

NOTE A gap [FORMAT 8X] has been left prior to the F6.1 format for entry of other stellar information that might be desired in the future (i.e., UV data).

Space on the stellar data file entries has also been left for, e.g., star names as designated by constellation and brightness (for example, Polaris = αUMi) or by catalogue (such as the BD = Bonner Durchmusterung, or HD = Henry Draper, etc.). The respective stellar data input file (file-name = STARDAT, YALSTAR, CONDAT or NEARDAT, etc.) is called by the command GET, STAR = file-name.

The only other file that has to be called prior to running the programs is VIDEO, used as the repository for output data in the tabulation that is employed for generating a display in video-recording mode. The file VIDEO itself, as called by the command GET, VIDEO prior to running the programs, comprises two blank lines in its original form; as the output data are generated, they are entered into this file, displacing the blank lines. As each new batch of output data from a series of computational runs is created, each batch is stacked behind the other, sequentially expanding the output tabulation.

Thus, the instructions to start the calculations are as follows:

OLD, CELESTE (or STELLA, as the case may be)
GET, STAR = file-name (e.g., GET, STAR = CONDAT)
GET, VIDEO
RUN

Then follow the running specifications, as described in section 4.2, input either from the interactive terminal or from IBM punched cards.

To initiate a further run (the output from which would be appended to the end of the file VIDEO), one repeats the command
RUN
and continues with a fresh set of running specifications, etc.

When the sequence of one or more runs has been completed, the tabulated output data are listed by giving the command
EDIT, VIDEO
(In terminal operating mode, the message "BEGIN TEXT EDITING" signals that the system is ready)
LIST; * (implying "List to the end-of-file")

When the entire table of output is printed, one leaves the Text Editor mode through the command END (and then either LOG-OFF or begin a new cycle of computations).

4.2. Running specifications

The specifications that determine the computer run are input either on IBM cards or as an 8-line data batch from the terminal in the case of the batch program "CELESTE", or in interactive conversational mode from the terminal in the case of the terminal program "STELLA". The running responses are entered in free-field format, numerical data entries being separated by commas. To illustrate this part of the input, the data statements are underlined below; the non-underlined statements in curly brackets {· · ·} indicate the conversational prompts from the terminal in the program "STELLA", describing the next line of data to be entered (line numbers refer to "STELLA" input, card numbers to "CELESTE" input):

Statement 1: {DESCRIPTIVE TITLE (A96)}
Line 1 or Card 1: TITLE HEADER (96 alphanumeric characters, FORMAT 12A8)
Statement 2: {WOULD YOU PREFER A FORE OR AFT VIEW?}
Line 2 or Card 2: Enter either FORE or AFT [FORMAT A4]
Statement 3: {PLEASE SPECIFY APEX SEMIANGLE (IN DEGREES):}
Line 3 or Card 2: Enter $\underline{\alpha}$ [FORMAT F5.1]
Note: If $\alpha \leqslant 0°$ or $> 90°$, set to $\alpha = 60°$.
Statement 4: {WHAT IS YOUR DIRECTION OF FLIGHT?}
Line 4 or Card 3: Enter $\underline{\theta_s, \phi_s}$ (the flight angles THETAS, PHIS in degrees)
Statement 5: {WHAT IS YOUR DISTANCE FROM EARTH (IN PARSEC)?}
Line 5 or Card 3: Enter $\underline{z}$ (the variable Z in parsec; 1 pc = 3.26 ly = 3.086 $\times 10^{16}$ m)
Statement 6: {ENTER CUTOFF MAGNITUDE, BETA, VISUAL OPTION:}
Line 6 or Card 3: Specify $\underline{(m'_v)_{max}}$, $\underline{\beta}$, IOPT [FORMAT F5.1, F7.6, I1]

Note: (i) The specification of $(m'_v)_{max}$ = CMAG serves as a curb upon the extensiveness of the output data by limiting the number of stars featured in the output plot and tabulation.
(ii) The speed ratio $\beta = \text{BETA} \equiv v/c$ is dimensionless; v is the speed of the

spacecraft and c is the speed of light (2.998×10^8 m/s).

(iii) The "visual option" IOPT excludes IR and UV data from the output when it is set to zero, i.e., when IOPT = 0 only stars in the visible region of the spectrum are output; when IOPT = 1 all stars, e.g., IR, visible and UV are included in the output.

Statement 7: {WOULD YOU LIKE A STAR PLOT? (ENTER "YES" OR "NO"):}

Line 7 or Card 4: Specify YES or NO [FORMAT A3]

Note: If "NO" is specified, the input concludes at this point; if "YES", then one more statement and specification follows.

Statement 8: {A COLOUR PLOT? (ENTER "YES" OR "NO"):}

Line 8 or Card 5: Specify YES or NO [FORMAT A3]

Note: Having specified "YES" to the plot option (APLOT) in line 7 or card 4, one has the choice of representation of stars, either through letters (U, B, G, W, Y, R, I) denoting the star colour if this option (BPLOT) is set to "YES", or through asterisks (*) if this option (BPLOT) is set to "NO". The star plot in either case depicts the FORE or AFT view from the spacecraft headed in the direction (θ_s, ϕ_s) at the speed β; the view is a cone of semi-angle α.

To summarize, the running data specifications for "CELESTE" are the following:

(1) DESCRIPTIVE TITLE
(2) FORE or AFT, α
(3) θ_s, ϕ_s, z, $(m'_v)_{max}$, β, IOPT
(4) YES or NO
(5) YES or NO (only if the preceding specification was YES).

The running data specifications for "STELLA" are the same, except that the data in (2) and (3) are divided up:

(1) DESCRIPTIVE TITLE
(2) FORE or AFT
(3) α
(4) θ_s, ϕ_s
(5) z
(6) $(m'_v)_{max}$, β, IOPT
(7) YES or NO
(8) YES or NO (only if the preceding specification was YES).

Sample inputs are given in section 5 for various test runs.

4.3. Description of program procedure and subroutines

Both programs operate identically once the stellar data files and running specifications have been established. They both use the same variables and subroutines, as identified in table 1. For clarity in the description below, variables will be designated with capital letters in square brackets, e.g., as [VARIAB].

The programs each commence by preparing VIDEO to act as the repository for output data and use the data block INFR1 (containing data tabulations that have been plotted as fig. 2) to associate a temperature T [= antilog TEMP(J) ≡ BOL(1, J)] with each of the 33 categories [J] of stellar spectral classes [SP1(1, J) = SPCL(J)] and subclasses [SP1(2, J) = SPCN(J)]. Then, for these temperatures T, the programs assign appropriate magnitude differences [$m_I - m_K$ = DIFIK(J) = BOL(2, J)] and IR bolometric corrections [$m - m_K$ = DIFBK(J) = BOL(3, J)].

The programs then read in the running specifications (interspersing the specifications with interactive printed-out statements in the case of "STELLA") and proceed with calculations as follows:

(a) The programs compute the Einstein speed factor $\gamma \equiv (1-\beta^2)^{-1/2}$ [= GAMMA] and enter the main program loop in which the various relativistic transformations are carried out.

(i) The right ascension α [= IHOUR/MIN/ISEC] and declination δ [= IDEG/SMIN] are converted to ϕ [= PHI] and θ [= THETA], expressed in radians, and

(ii) taking account of the flight direction (θ_s,

Table 1
Glossary of principal symbols, variables, subroutines and data blocks

Symbol	Variable	Sub routine	Data block	(eq.) no.	First mention in CELESTE line	First mention in STELLA line	Definition
A	APEX				37	41	Apex semiangle of viewing cone
a				(7)			Spacecraft acceleration in galactic system
a'				(1)			Proper acceleration of spacecraft (in own frame)
	ABMP				142	156	m', apparent bolometric magnitude
	AMI				59	72	m_I, IR apparent magnitude at $\lambda = 0.84$ μm
	AMK				59	72	m_K, IR apparent magnitude at $\lambda = 2.20$ μm
	AMV				59	72	m_v, apparent visual magnitude
	AMVP				143	157	m'_v, perceived apparent visual magnitude
	APLOT				50	61	Plot option
β	BETA			(12)	40	52	Speed ratio $\beta \equiv v/c$ (v = spacecraft speed)
β_{max}				(3)			Maximal speed ratio in g-boost flight
B.C.				(23)			Bolometric correction
B.C.′				(23)			Apparent bolometric correction
			BC1		139/429	152/444	Tabulated bolometric correction
			BCOR		176/408	191/423	Visible star data tabulation
			BCOR1		408	423	Visible star data tabulation (first part)
			BCOR2		427	442	Visible star data tabulation (second part)
	BCP				139	145	Bolometric correction (B.C. or B.C.′)
	BPLOT				51	64	Colour option in plot
		BRSTR			91/278	104/293	Bright visible star assignment subroutine
c				(1)			Velocity of light
	CMAG				40	52	$(m'_v)_{max}$, the cutoff apparent visual magnitude
		CONV			120/257	133/272	Polar to rectangular coordinate conversion routine
δ							Declination, read as IDEG, SMIN
	DIFBK				30/401	30/416	$m - m_K$, IR magnitude difference
	DIFIK				29/398	29/413	$m_I - m_K$, IR magnitude difference
d	DIST			(15)	110	158	Radial distance to star from spacecraft
$d\Omega$				(21)			Solid angle in galactic frame
$d\Omega'$				(21)			Solid angle in spacecraft system
dt				(8)			Time interval in galactic frame
dt'				(8)			Time interval in spacecraft frame
dv/dt				(7)			Acceleration a in galactic frame
γ	GAMMA			(7)	55	68	Einstein factor, $\gamma \equiv (1 - \beta^2)^{-1/2}$
η	ETA				93/118	106/131	Speed-direction parameter, $\eta \equiv \gamma(1 + \beta \cos \Theta_z)$
	IDEG				59	72	Declination component in degrees
	IHOUR				59	72	Righ ascension component, in h

		IMAG			221/226	236/241	Subroutine, called by SPEC, to assign temperature and bolometric magnitude for IR stellar sources and/or K, M, S, C class stars
			INFR1		385	400	Tabulated data block for IR stars
	IOPT				40	52	Visual option (provision for star plot)
	ISEC				59	72	Right ascension component, in s
K				(14)			$K=(z/r)\sec\Theta$, parallax formula variable
λ				(19)	.		Star principal wavelength in galactic system
λ'				(19)			Star principal perceived wavelength, $\lambda' \equiv hc/kT'$
m				(24)			Bolometric magnitude
m_I	AMI				59	72	IR apparent magnitude at $\lambda = 0.84$ μm
	MIN				59	72	Right ascension component, in min
m_K	AMK				59	72	IR apparent magnitude at $\lambda = 2.20$ μm
m_v	AMV				59	72	Apparent visual magnitude at $\lambda = 0.5556$ μm
m'_v	AMVP			(23)	143	157	Perceived apparent visual magnitude
ϕ	PHI			(10)	70	83	Azimuthal angular coordinate of star (polar)
Φ				(11)			Azimuthal angle of star in flight direction
Φ'	PHIP			(13)	83	96	Transformed azimuthal angle of star (perceived)
ϕ_s	PHIS			(10)	40	46	Azimuthal angle of flight direction
	PI				32	32	$\pi = 3.141592654$
		PLOT			155/336	169/351	Plot subroutine, to provide astroscape
r	R			(14)	60	73	Distance to star from origin of solar system
s				(1)			Distance covered in flight
	SMIN				59	72	Declination component, in min of arc
	SPCL				26/388	26/403	Spectral class designation (O, B, A, F, G, K, M, S, C)
	SPCN				27/391	27/406	Spectral subclass designation (0–9)
		SPEC			90/173	103/188	IR data assignment subroutine
T	TEMP			(20)	28/394	28/409	Planck temperature of star
T'	TEMPP			(20)	122	135	Apparent Planck temperature of star
τ_E				(6)			Time duration of flight in Earth frame
τ'				(1)			Time duration of flight in spacecraft frame
θ	THETA			(10)	74	87	Sagittal polar coordinate of star
Θ	THETA			(10)	86	99	Transformed polar coordinate of star referred to flight direction as z-axis
Θ'	THETAP			(12)	119	132	Apparent sagittal coordinate of star
θ_s	THETAS			(10)	40	46	Sagittal polar flight angle
Θ_z	THETAZ			(14)	97	110	Polar coordinate of star, corrected for parallax
			TMP1		134/438	147/453	Data listing of temperature in block BCOR2
v				(7)			Velocity of spacecraft
			VI1		214/410	229/425	Data listing of m_I apparent magnitudes
	VIEW				37	39	Astroscape view option ("FORE" or "AFT")
			VK1		302/418	230/433	Data listing of m_K apparent magnitudes
		WAVE			123/240	136/255	Subroutine associating colour with temperature
z	Z			(14)	40	48	Distance travelled by spacecraft along z-axis

ϕ_s) [= THETAS, PHIS] cited in the running specifications, the stellar coordinates are converted to new coordinates (Θ, Φ) [= THETA, PHIP] referred to the flight direction as the z-axis.

(b) Various subroutines are then called in to correlate temperatures and brightnesses (i.e., apparent magnitudes) with the individual stars as the stellar input file is scanned. For bright visible stars, characterized as such by the identifying letter B [as ID1], the subroutine BRSTR is called; for all other spectral sources, such as IR stars (for which the identification ID1 is not "B"), the subroutine SPEC is called instead.

In BRSTR, the following is effected;

(i) For visible stars in the spectral class O, B, A, F or G the appropriate temperature T [= TEMP], and magnitudes m_I, m_K and m [= AMI, AMK, AMB] are determined, according to class [= SPCL] and subclass [= SPCN].

(ii) For stars in the spectral category C or N, the bolometric correction B.C. [= BC] appropriate to high temperature $T >$ antilog 4.1 is calculated according to the formula (25), which corresponds to the Johnson tabulation [20] for main-sequence stars or, if $T <$ antilog 4.1, corrected values of the magnitudes m_I, m_K and m [= AMI, AMK, ABM] are calculated in accord with Johnson's tabulation as encapsulated within the data listings of VI1, VK1, BC1 and TMP1 in the block data BCOR (subdivided into BCOR1 and BCOR2).

In SPEC, essentially the same treatment is applied to dwarf visible stars and IR stellar sources, namely,

(i) For stars in the spectral class K, M, S or C the subroutine IMAG is called, which builds the magnitude difference $m_I - m_K$ [= DIFIK], using data table INFR1, and thence obtains the respective temperature [= T = TEMP] and bolometric magnitude m [= ABM].

(ii) For stars in classes C or N, or for stars in the input file that have no specification of the m_I-magnitude, corrected apparent magnitudes m_I and m [= AMI, ABM] are determined from the specified m_K [= AMK], and thence the temperature T [= TEMP] is established.

(iii) For IR stars, the m_K-specification is used as a means to assign a temperature T [= TEMP] corresponding to the appropriate tabulated value of BOL(1, J) and thence, if m_I has not also been specified in the input file, its value [= AMI] is determined. From these, the requisite bolometric magnitude m [= ABM] is obtained.

(c) Having assigned temperatures and apparent (visual and/or bolometric) magnitudes to each star in the input file, the programs then evaluate the parallax formulae (14) and (15) to obtain Θ_z [= THETAZ] and d [= DIST]. To take due account of aberration, the programs first calculate the speed-direction parameter $\eta \equiv \gamma(1 + \beta \cos \Theta_z)$ [= ETA] and then perform the relativistic transformation to Θ. Since $\Phi' = \Phi$ [= PHIP], the polar coordinates (Θ', Φ') are thereby established [as THETAP, PHIP], corrected for parallax and aberration. As a means of specifying the star's location on the (rectangular) display grid in the depiction of an astroscape (plotted as print-out, or displayed on a colour console), it is convenient to convert these polar coordinates to rectangular Cartesian coordinates (x, y) [= X, Y], which are stored and may be conveyed directly to a colour display unit. In the output, the apparent polar coordinates are listed under "THETA", "PHI", and the rectangular coordinates under "HORIZ", "VERTICAL".

(d) The programs then use η [= ETA] to calculate the apparent temperature T' [= TEMPP] via eq. (20), and thence, using the subroutine WAVE, assign the requisite colour (i.e., wavelength) to each star as perceived ("U", "B", "G", "W", "Y", "R", "I" = ultra-violet, blue, green, white, yellow, red, infra-red).

(e) At this point, the programs establish whether the apparent temperature T' conforms to wavelengths in the visible region of the spectrum and, if the specification option IOPT (= "visual option") has been set to zero, retains only the visible stars for further handling (i.e., rejects all entries Doppler-shifted into the UV or IR regions). If IOPT = 1, all stars (UV, visible and IR) are included in the output. For these stars, the apparent bolometric correction B.C.′ [= BCP] is determined along similar lines to those used previously for B.C. [= BC], and thence the magnitudes m' and m'_v [= ABMP, AMVP] are calculated, using eq. (23).

(f) Having obtained the entire batch of results for each member of the set of stars contained in the input file (and, at option, having rejected those which underwent a Doppler shift into the UV or IR regions), the programs then, if so directed in the running specifications, provide a printed plot of the astroscape with the aid of the PLOT subroutine, and append the output tabulation to the contents of the file VIDEO (and/or feed them directly to a display unit).

4.4. Output

As each run is completed, a new run with fresh specifications may be initiated through the command

RUN (or CELESTE in batch mode)

wherein the stellar input data will continue to be taken from the file STAR = file-name (file-name = STARDAT, YALSTAR, CONDAT or NEARDAT, etc., as the case may be). If a new star-file is desired, this is called and used via the directive

GET, STAR = new-filename
RUN (or CELESTE in batch mode)

The new run specifications again have provision for directing that a star chart in the form of an astroscape is printed out (or suppressed) at will. The numerical results are sequentially appended to the output file VIDEO. At any stage, the contents of this output file may be stored in the user's catalogue for future reference, e.g., either by directing

RENAME, ASTRODAT = VIDEO
SAVE, ASTRODAT

thus storing the output in a saved file ASTRODAT or, at the cost of losing the original file VIDEO with its two empty lines as lodged in the catalogue, simply storing the new VIDEO, filled with output data, via the command

REPLACE, VIDEO = VIDEO

Alternatively, if a print-out of the numerical data in VIDEO is desired at any time, this may most simply be accomplished through the employment of the "TEXT EDITOR" mode, which leaves STELLA (or CELESTE) as the primary working file. The commands entered from the terminal, or from cards, would then be as underlined below (with interactive terminal statements illustrated within curly brackets {· · ·} as before, in the case of "STELLA"):

Command:	<u>EDIT, VIDEO</u>
Statement:	{BEGIN TEXT EDITING.}
Optional command to enumerate the number of lines in VIDEO:	<u>NUMBER</u>
Responsive statement:	{xxx LINES TO EOF.} (EOF = end of file)
	<u>L;*</u> (list to end)
	{Tabulated output data follows here}
Statement:	{-END OF FILE-}
Command:	<u>END</u> (to leave the "TEXT EDITOR" mode).

From this point, one may start afresh with a new cycle of operations, destroying the filled VIDEO file with its old output data and recalling the original VIDEO file with its two blank lines from the catalogue, ready to receive new data:

GET, VIDEO, STAR = file name
RUN (or CELESTE, in batch mode)

As indicated in the program summary, the only restriction on the extent of the program has been in the feasible length of the stellar input data files and in the omission of a treatment to evaluate the bolometric correction for UV sources. The latter would be needed only in the consideration of Doppler red-shifts that affect stars in the rearward view, causing UV sources to become shifted into the visible range of wavelengths. As UV star catalogues are still incomplete, this provision has been left to await future refinement. It has not been felt necessary, either, to allow for views in other directions than fore or aft (though the changes needed for the admission of sideways views would be slight). The program deals only with point sources, and is not therefore designed to accommodate extended emitters such as nebulae, etc. Indeed, the ultimate in aberration and Doppler-shift would be experienced at the speed $\beta = 1 - 10^{-8}$, when the entire firmament of 3 K cosmic background radiation would be shifted into the visible range and perceived as an intense ($m'_v \approx -24.5$) point of light spanning less than 1 min of arc in diameter, in an otherwise totally black environment.

5. Description of test runs

For each program, four sample runs have been undertaken, and are presented with specimen input and output. These are as follows:

(a) The fore view from the midpoint ($z = 100$ pc) of a flight to Polaris (αUMi) in the direction of the north celestial pole (NCP), with the coordinates $(\alpha, \delta) = (1^h31^m13^s, 89°15.0') \to (\theta, \phi) = (\theta_s, \phi_s) = (\Theta, \Phi) = (0°, 0°)$ at the extreme relativistic speed $\beta = 0.999$ (at which Polaris, identified as star BY011 in the STARDAT, CONDAT and YALSTAR catalogues, is blue-shifted into the UV range, with $T' = 268\ 215$ K), excluding UV output (IOPT = 0) from the starfile CONDAT;

(b) The same as (a), but including UV output through setting OPT = 1;

(c) The fore view from the midpoint ($z = 0.92$ pc) of a flight to Barnard's Star (identification number BN004 in NEARDAT; not included in the CONDAT stellar data file used in the test runs) at the coordinates $(\alpha, \delta) = (17^h56^m0^s, 4°36.0')$, i.e., $(\theta,\phi) = (\theta_s, \phi_s) = (85.4°, 269.0°)$ at the non-relativistic speed $\beta = 0.122$ proposed for the Daedalus mission, excluding UV output from the starfile CONDAT;

(d) The same as (c), but with the file NEARDAT (containing nearby and bright stars) used for the stellar input data file (this contains Barnard's Star as BN004), excluding UV output.

Only the last few pages of printout are reproduced in this paper.

Acknowledgements

These programs have been developed from a project commenced by graduate students participating in an advanced course on relativity and cosmology conducted by the first author (E.S.). To these students and to the Director and staff of the University Computation Center, as also to Dr. Chuck E. Wegrzyn, who made his own colour display console available and programmed the requisite display instructions for the imaging of astroscapes, we express our appreciation for continued interest, enthusiasm, assistance and encouragement. But above all we are indebted to Dr. Richard W. Stimets for having introduced us to these considerations and for evaluating the basic approach used in the present work. His continued involvement and advice, enabling this project to go forward, are here acknowledged with sincere gratitude.

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TEST RUN OUTPUT

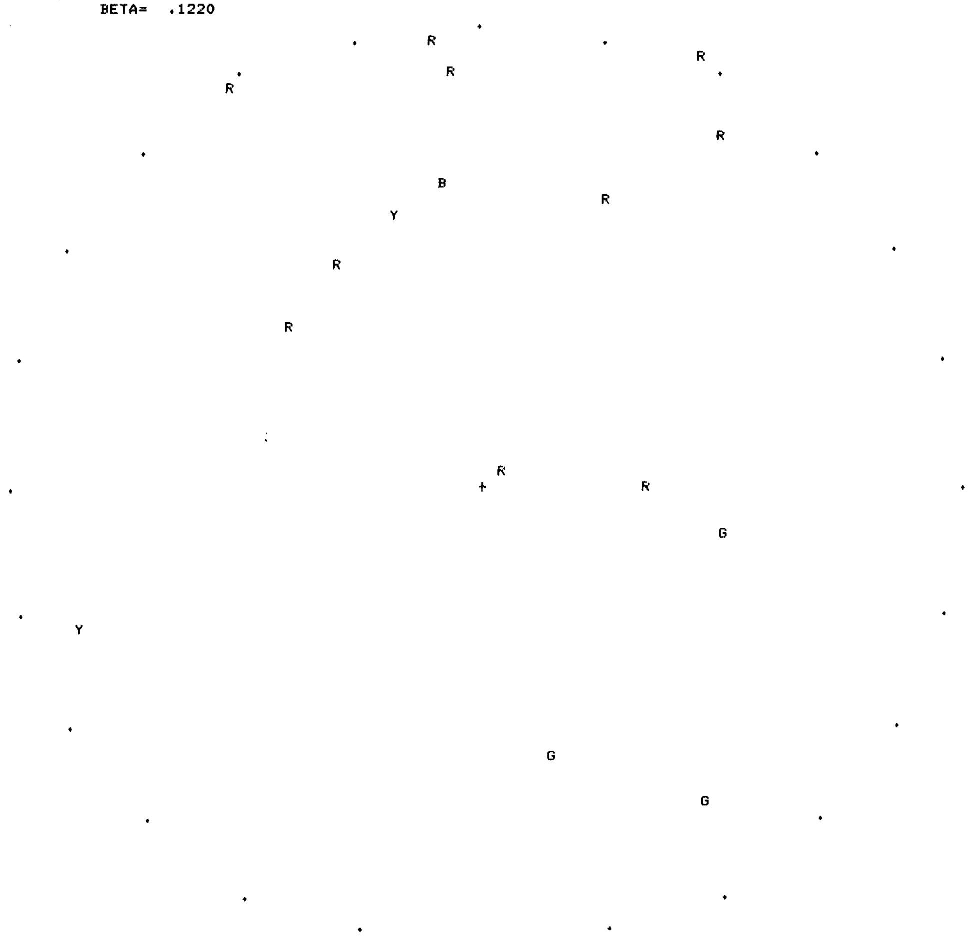
```
 READY.
GET,STAR=NEARDAT


 READY.
RUN

 82/11/29. 16.47.24.
PROGRAM   STELLA

 DESCRIPTIVE TITLE (A80)
? STELLA-NEARDAT FORE MIDWAY (Z=0.92PC) VIEW TO BARNARD'S STAR AT .122C WITH MV'.LE.14
 WOULD YOU PREFER A 'FORE' OR 'AFT' VIEW?
? FORE
 PLEASE SPECIFY APEX SEMIANGLE (IN DEGREES):
? 60.0
 WHAT IS YOUR DIRECTION OF FLIGHT?
? 85.4,269.0
 WHAT IS YOUR DISTANCE FROM EARTH (IN PARSEC) ?
? 0.92
 ENTER CUTOFF MAGNITUDE,BETA,VISUAL OPTION:
? 14.0,0.122,0
 WOULD YOU LIKE A STAR PLOT? (ENTER #YES# OR #NO#):
? YES
 A COLOUR PLOT? (ENTER #YES# OR #NO#):
? YES

STELLA-NEARDAT FORE MIDWAY (Z=0.92PC) VIEW TO BARNARD'S STAR AT .122C WITH MV'.LE.14
          BETA=  .1220
```



```
          CMAG=  14.00

SRU      11.217 UNTS.

 RUN COMPLETE.
EDIT,VIDEO
```

BEGIN TEXT EDITING.
? L;*
STELLA-CONDAT FORE NCP VIEW FROM Z=100PC AT BETA=0.999 WITH MV'.LE.4 (EXCL. UV)
THE CUTOFF MAGNITUDE = 4.0 AND BETA = .9990000 WITH FORE SEMIAPEX = 60.0 IN DIRECTION (0.0, 0.0) AT DISTANCE Z = 100.00 PC.

LINE	ID	SC	COLOUR	HORIZ	VERTICAL	THETA'(DEG)	PHI(DEG)	ETA	TEMP'(KELVIN)	AVM'	DISTANCE (PC)
1	BY023	F5	Y	13.394	10.814	17.2145	51.0833	.9772	6254.	3.59	76.92
2	BY057	A0	B	.294	-10.902	10.9064	178.4542	2.3477	23125.	3.12	66.64
3	BY215	F0	R	21.836	-2.290	21.9556	95.9875	.6087	4279.	3.28	148.10
4	BY321	B2	B	-.787	-11.894	11.9205	183.7875	1.9833	35700.	3.49	421.69
5	BY325	B1	B	-2.237	-19.189	19.3193	186.6500	.7809	16790.	2.91	218.91
6	BY326	B3	G	-2.239	-19.189	19.3193	186.6542	.7809	12104.	3.32	218.91
7	BY329	M3	G	-1.293	-9.450	9.5379	187.7917	3.0189	9997.	-2.44	1085.24
8	BY354	B1	G	-13.080	-21.805	25.4268	210.9583	.4573	9832.	2.71	157.39
9	BY405	M1	Y	-12.769	-5.327	13.8361	247.3542	1.4910	5413.	.89	132.10
10	BY436	F2	G	-13.439	-.729	13.4591	266.8958	1.5723	10534.	3.83	160.70

STELLA-CONDAT FORE NCP VIEW FROM Z=100PC AT BETA=0.999 WITH MV'.LE.4 (INCL. UV)
THE CUTOFF MAGNITUDE = 4.0 AND BETA = .9990000 WITH FORE SEMIAPEX = 60.0 IN DIRECTION (0.0, 0.0) AT DISTANCE Z = 100.00 PC.

LINE	ID	SC	COLOUR	HORIZ	VERTICAL	THETA'(DEG)	PHI(DEG)	ETA	TEMP'(KELVIN)	AVM'	DISTANCE (PC)
1	BY005	K0	U	.508	2.846	2.8910	10.1292	19.6835	92067.	-.64	61.66
2	BY011	F8	U	.013	.031	.0335	22.8042	44.7025	268215.	.53	100.02
3	BY023	F5	Y	13.394	10.814	17.2145	51.0833	.9772	6254.	3.59	76.92
4	BY057	A0	B	.294	-10.902	10.9064	178.4542	2.3477	23125.	3.12	66.64
5	BY060	A0P	U	-.569	-2.368	2.4353	193.5083	23.5041	231515.	1.03	70.08
6	BY063	B3	U	-.685	-1.352	1.5158	206.8833	33.1294	513506.	1.90	185.97
7	BY069	A3	U	-.615	-.513	.8009	230.1833	40.7346	358465.	2.25	109.52
8	BY215	F0	R	21.836	-2.290	21.9556	95.9875	.6087	4279.	3.28	148.10
9	BY321	B2	B	-.787	-11.894	11.9205	183.7875	1.9833	35700.	3.49	421.69
10	BY325	B1	B	-2.237	-19.189	19.3193	186.6500	.7809	16790.	2.91	218.91
11	BY326	B3	G	-2.239	-19.189	19.3193	186.6542	.7809	12104.	3.32	218.91
12	BY329	M3	G	-1.293	-9.450	9.5379	187.7917	3.0189	9997.	-2.44	1085.24
13	BY337	B0	U	-2.148	-10.166	10.3901	191.9333	2.5724	68168.	1.59	1087.41
14	BY354	B1	G	-13.080	-21.805	25.4268	210.9583	.4573	9832.	2.71	157.39
15	BY397	B0	U	-4.623	-2.525	5.2672	241.3583	8.5678	227047.	3.43	299.06
16	BY405	M1	Y	-12.769	-5.327	13.8361	247.3542	1.4910	5413.	.89	132.10
17	BY426	B3	U	-5.651	-.725	5.6968	262.6917	7.5346	116786.	3.22	1063.48
18	BY428	B1	U	-5.634	-.652	5.6720	263.4000	7.5894	163171.	2.33	1063.22
19	BY432	B2	U	-5.902	-.452	5.9193	265.6208	7.0671	127207.	2.96	1065.71
20	BY436	F2	G	-13.439	-.729	13.4591	266.8958	1.5723	10534.	3.83	160.70

STELLA-CONDAT FORE MIDWAY (Z=.92PC) VIEW TO BARNARD'S STAR AT .122C WITH MV'.LE.4
THE CUTOFF MAGNITUDE = 4.0 AND BETA = .1220000 WITH FORE SEMIAPEX = 60.0 IN DIRECTION (85.4, 269.0) AT DISTANCE Z = .92 PC.

LINE	ID	SC	COLOUR	HORIZ	VERTICAL	THETA'(DEG)	PHI(DEG)	ETA	TEMP'(KELVIN)	AVM'	DISTANCE (PC)
1	BY397	B0	B	-23.953	22.196	32.6563	312.8196	1.1061	29313.	2.62	249.26
2	BY405	M1	R	-18.437	28.494	33.9389	327.0949	1.1043	4009.	.27	51.87
3	BY412	K2	Y	-13.683	36.554	39.0314	339.4777	1.0964	4898.	1.69	19.72
4	BY415	K5	R	-11.586	43.142	44.6708	344.9671	1.0868	4132.	3.09	47.00
5	BY419	F0	W	-8.494	45.374	46.1618	349.3971	1.0841	7622.	3.06	15.31
6	BY426	B3	B	-4.912	37.506	37.8265	352.5393	1.0984	17025.	2.69	999.22
7	BY428	B1	B	-4.368	37.313	37.5674	353.3238	1.0988	23624.	1.80	999.22
8	BY432	B2	B	-2.591	39.049	39.1349	356.2032	1.0963	19733.	2.45	999.24
9	BY436	F2	W	-1.614	40.439	40.4715	357.7146	1.0941	7330.	2.75	76.25

STELLA-NEARDAT FORE MIDWAY (Z=0.92PC) VIEW TO BARNARD'S STAR AT .122C WITH MV'.LE.14
THE CUTOFF MAGNITUDE = 14.0 AND BETA = .1220000 WITH FORE SEMIAPEX = 60.0 IN DIRECTION (85.4, 269.0) AT DISTANCE Z = .92 PC.

LINE	ID	SC	COLOUR	HORIZ	VERTICAL	THETA'(DEG)	PHI(DEG)	ETA	TEMP'(KELVIN)	AVM'	DISTANCE (PC)
1	BN004	M5	R	0.000	.000	.0000	0.0000	1.1304	3336.	6.75	.91
2	BN008	M5E	R	15.930	36.030	39.3942	23.8521	1.0958	3234.	9.11	2.15
3	BN025	M5	R	-24.177	19.620	31.1367	309.0602	1.1083	3271.	8.33	3.23
4	BN030	M4	R	-5.925	55.626	55.9409	353.9201	1.0653	3292.	8.38	4.13
5	BN032	M5	R	-4.152	52.751	52.9139	355.4996	1.0713	3162.	10.13	4.15
6	BN041	K1	Y	1.885	2.244	2.9302	40.0339	1.1302	5166.	3.24	4.21
7	BN042	K6	R	1.885	2.244	2.9302	40.0339	1.1302	4199.	4.95	4.21
8	BN047	K0V	Y	-10.936	33.038	34.8011	341.6844	1.1030	5159.	4.33	4.69
9	BN048	K3V	R	30.100	44.084	53.3800	34.3243	1.0704	4462.	5.84	5.12
10	BN060	M4	R	-31.611	49.336	58.5946	327.3508	1.0599	3275.	9.17	5.47
11	BN065	M4	R	20.243	-.810	20.2590	92.2922	1.1208	3464.	7.78	5.16
12	BN066	M0	R	27.336	53.229	59.8378	27.1831	1.0573	3839.	7.28	5.67
13	BP003	K2	Y	-50.726	-18.700	54.0633	249.7634	1.0691	4775.	-.51	10.51
14	BP005	A0	G	8.286	-34.260	35.2483	166.4033	1.1024	10858.	-.25	7.37
15	BP012	A7	G	30.169	-5.325	30.6354	100.0108	1.1089	8738.	.21	4.31
16	BP015	M1	R	-18.495	28.144	33.6774	326.6897	1.1047	4011.	.13	158.27
17	BP018	A2	G	27.899	-39.978	48.7506	145.0902	1.0794	9844.	1.18	489.46
18	BP023	B1	B	-4.660	37.609	37.8963	352.9373	1.0983	23613.	1.76	94.32

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