N71-19233

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Report 32-1523

UBV: Subroutine to Compute Photometric Magnitudes of the Planets and Their Satellites

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Prepared Under Contract No. NAS 7-100
National Aeronautics and Space Administration

Preface

The work described in this report was performed by the Guidance and Control Division of the Jet Propulsion Laboratory.

Acknowledgment

Thanks go to Janis Beltz for coding and checking out the subroutine.

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Abstract

This computer subroutine computes the visual, blue and ultraviolet photometric magnitudes of the planets, their natural satellites, and the sun at varying observation distances and phase angles. Currently available observational magnitude and phase function data are stored in the program and used in the computation.

UBV: Subroutine to Compute Photometric Magnitudes of the Planets and Their Satellites

I. Introduction

Design and performance evaluation of optical sensors and instruments for planetary missions requires the knowledge of planet and moon brightness. A computer subroutine has been written to calculate the Johnson and Morgan (Ref. 1) visual (V), blue (B), and ultraviolet (U) photometric magnitudes of the planets, all their known natural satellites, and the sun.

II. Computation of Visual Magnitude

The visual magnitude of a planet or satellite is given by:

$$V = V(1,0) + 5 \log r_s r_o - 2.5 \log \Phi_v(\phi) \tag{1}$$

where $V(1,0)$ is the visual magnitude at one astronomical unit (1 AU = 149, 597, 893 km) from the sun and observer and 0 deg phase angle, r_s is the sun-body distance in AU, r_o is the observer-body distance in AU, and Φ_v is the visual phase function dependent on the phase angle ϕ where $0 \leq \phi \leq 180$ deg. The phase angle is the sun-body-observer angle. All logs are to the base 10. Figure 1 illustrates the observational geometry.

For the sun the visual magnitude is given by:

$$V = V_s + 5 \log r_o \tag{2}$$

where $V(1,0)$ is replaced by V_s the visual magnitude of the sun at one AU and r_o is the sun-observer distance in AU.

The above equations are valid only for large planet-observer distances, typically greater than twenty planet radii. For distances closer than this, the phase angle varies over the surface of the planet and an integration technique is required.

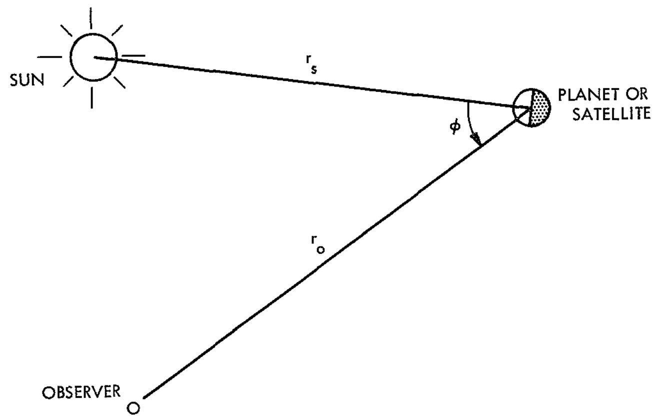

Fig. 1. Observational geometry

III. Stored Data

Data stored in the program are listed in Tables 1 and 2. The data were obtained from various references and these are indicated by the numbers in parentheses in Table 1 and in the column headings of Table 2.

Table 1 lists the object, its body number as assigned in the program, $V(1,0)$, the B-V and U-B color indexes, and Φ_v the visual phase function assumed as identified by Table 2. The values for $V(1,0)$ are average values since actual magnitude can vary with the variation in the sun's magnitude or with changing features due to planet or moon rotation, seasonal variations, atmospheric conditions, or other surface changes. This variation can be as large as two magnitudes as is the case with Iapetus (Ref. 2). The value for Saturn is for "no-rings" as the actual magnitude varies with the changing aspect of the rings. An empirical formula (Ref. 2) for the change in magnitude due to the rings is

$$\Delta V = -2.60 \sin B + 1.25 \sin^2 B \; (0^\circ \leq B < 27^\circ) \qquad (3)$$

where B is the saturnicentric latitude of the observer.

Additional variations in the values for $V(1,0)$ are possible due to observational uncertainties. Since not all the planets can be observed at exactly 0 deg phase angle, some uncertainty is possible when extrapolating to 0 deg. Some of the dimmer moons have only been observed photographically, and errors may be introduced when converting to photometric magnitudes.

Note that constant values of the color indexes B-V and U-B are stored in the program and that no computation is done. Although the indexes do vary with phase, there are only limited data available, and thus it is not modeled in the program at this time. Where no color information was available, a reasonable value has been stored in the program. These assumed values are noted by parentheses in Table 1. Uncertainties in the color indexes are due to the same factors that affect $V(1,0)$.

Table 2 indicates how the visual magnitude varies with phase angle. The quantity $-2.5 \log \Phi_v (\phi)$ is also given by Δm, and it is this quantity that is stored in the program. The phase function data have been determined empirically from observational data or from theoretical considerations. For planets and moons outside the earth's orbit, observations can only be made over a limited range in phase angle. Mars can only be observed from the earth up to about 48 deg phase angle, and the value of Δm must be extrapolated as indicated by the parentheses in Table 2. Since the phase angle of the outer planets and their moons never exceed more than a few degrees as seen from the earth, a theoretical phase function must be assumed. The same phase function has been assumed (Ref. 2) for the larger planets with optically thick atmospheres; Jupiter, Saturn, Uranus and Neptune. Since the size of Pluto is closer to the size of Mars, the Mars phase function has been assumed for Pluto. Since the phase function of the earth's moon is the only one that has been accurately observed over all phase angles, it has been assumed as the phase function for all the moons at this time.

Extrapolated values of Δm at 180 deg phase, in Table 2, are given to allow interpolation in the program. The actual magnitude of a planet or moon at 180 deg phase would be a function of the observer-body distance, the sun-body distance, the planet or moon radius and the atmospheric properties of the planet or moon. These factors would determine if a halo were visible or not. Thus, care should be used when interpreting the program output when the phase angle is within a few degrees of 180 deg.

As a matter of interest Δm is plotted for all the planets and moons in Fig. 2.

IV. Program Usage and Logic

The subroutine is coded in Fortran V for use on the JPL Scientific Computing Facility Univac 1108

Table 1. Planet and satellite body numbers and photometry data

Object	Body number	Visual magnitude V(1,0)	Color indexes		Φ_v
			B-V	U-B	
0. Sun	0.00	−26.74 (6)[a]	0.63	0.14 (2)	N/A
1. Mercury	−1.00	− 0.42 (3)	0.97	(0.4) (3)	1
2. Venus	−2.00	− 4.41 (3)	0.82	0.50 (2)	2
3. Earth	−3.00	− 3.87 (2)	0.2	(0.0) (4)	3
I. Moon	−3.01	+ 0.21 (2)	0.92	0.46 (2)	6
4. Mars	−4.00	− 1.73 (5)	1.33	0.63 (3)	4
I. Phobos	−4.01	+12.1 (2)	0.6	(0.3) (2)	6
II. Deimos	−4.02	+13.3 (2)	0.6	(0.3) (2)	6
5. Jupiter	−5.00	− 9.25 (2)	0.83	0.48 (2)	5
I. Io	−5.01	− 1.90 (2)	1.17	1.30 (2)	6
II. Europa	−5.02	− 1.53 (2)	0.87	0.52 (2)	6
III. Ganymede	−5.03	− 2.16 (2)	0.83	0.50 (2)	6
IV. Callisto	−5.04	− 1.20 (2)	0.86	0.55 (2)	6
V. Almalthea	−5.05	+ 6.3 (2)	(0.8)	(0.4)	6
VI. Hestia	−5.06	+ 7.0 (2)	(0.8)	(0.4)	6
VII. Hera	−5.07	+ 9.3 (2)	(0.8)	(0.4)	6
VIII. Poseidon	−5.08	+12.1 (2)	(0.8)	(0.4)	6
IX. Hades	−5.09	+11.6 (2)	(0.8)	(0.4)	6
X. Demeter	−5.10	+11.9 (2)	(0.8)	(0.4)	6
XI. Pan	−5.11	+11.4 (2)	(0.8)	(0.4)	6
XII. Andrastea	−5.12	+12.1 (2)	(0.8)	(0.4)	6
6. Saturn	−6.00	− 8.88 (2)	1.04	0.58 (2)	5
I. Mimas	−6.01	+ 2.6 (2)	(0.6)	(0.3)	6
II. Enceladus	−6.02	+ 2.22 (2)	0.62	(0.3) (2)	6
III. Tethys	−6.03	+ 0.72 (2)	0.73	0.34 (2)	6
IV. Dione	−6.04	+ 0.89 (2)	0.71	0.30 (2)	6
V. Rhea	−6.05	+ 0.21 (2)	0.76	0.35 (2)	6
VI. Titan	−6.06	− 1.16 (2)	1.30	0.75 (2)	6
VII. Hyperion	−6.07	+ 4.61 (2)	0.69	0.42 (2)	6
VIII. Iapetus	−6.08	+ 1.48 (2)	0.71	0.28 (2)	6
IX. Phoebe	−6.09	+ 4.45 (4)	(0.8)	(0.4)	6
X. Janus	−6.10	+ 4.45 (7)	(0.8)	(0.4)	6
7. Uranus	−7.00	− 7.19 (2)	0.56	0.28 (2)	5
I. Ariel	−7.01	+ 1.7 (2)	(0.8)	(0.4)	6
II. Umbriel	−7.02	+ 2.6 (2)	(0.8)	(0.4)	6

[a]The numbers in parentheses indicate the various references from which the data were obtained.

Table 1 (contd)

Object	Body number	Visual magnitude V(1,0)	Color indexes		Φ_v
			B-V	U-B	
III. Titania	−7.03	+ 1.30 (2)	0.62	0.25 (2)	6
IV. Oberon	−7.04	+ 1.49 (2)	0.65	0.24 (2)	6
V. Miranda	−7.05	+ 3.8 (2)	(0.8)	(0.4)	6
8. Neptune	−8.00	− 6.87 (2)	0.41	0.21 (2)	5
I. Triton	−8.01	− 1.16 (2)	0.77	0.40 (2)	6
II. Nereid	−8.02	+ 4.0 (2)	(0.8)	(0.4)	6
9. Pluto	−9.00	− 1.01 (2)	0.80	0.27 (2)	4

Table 2. Values for $\Delta m = -2.5 \log \Phi_v(\phi)$

Phase angle, deg	Phase functions[a]					
	1 (Ref. 3)	2 (Ref. 3)	3 (Ref. 3)	4 (Ref. 5)	5 (Ref. 2)	6 (Ref. 3)
0	0.000	0.000	0.000	0.000	0.000	0.000
10	.355	.139	.133	.340	(.016)	.280
20	.667	.291	.271	.510	(.056)	.564
30	.950	.451	.420	.659	(.127)	.845
40	1.210	.630	.580	.811	(.215)	1.131
50	1.471	.820	.759	(1.000)	(.327)	1.406
60	1.726	1.031	.952	(1.200)	(.468)	1.690
70	2.010	1.251	1.165	(1.410)	(.649)	2.003
80	2.320	1.479	1.406	(1.639)	(.843)	2.348
90	2.666	1.721	1.674	(1.911)	(1.079)	2.742
100	3.069	1.970	1.970	(2.224)	(1.344)	3.110
110	3.511	2.224	2.302	(2.556)	(1.644)	3.522
120	4.086	2.478	2.664	(2.903)	(1.990)	3.984
130	4.724	2.770	3.073	(3.297)	(2.45)	4.524
140	5.458	3.055	3.495	(3.760)	(3.019)	5.114
150	6.307	3.391	4.005	(4.260)	(3.820)	5.891
160	(7.275)	3.720	4.560	(4.770)	(4.802)	(7.160)
170	(8.391)	4.120	5.114	(5.30)	(6.06)	(8.807)
180	(10.500)	4.490	(6.000)	(6.200)	(8.500)	(12.000)

[a]The column-head numbers refer to the planets and their moons, as follows:

1 Mercury	4 Mars and Pluto
2 Venus	5 Jupiter, Saturn, Uranus, and Neptune
3 Earth	6 Moons

Computer. The subroutine is called by: CALL UBV (BN, PHA, RS, RO, V, BV, UB) where the input is:

BN = body number as given in Table 1

PHA = ϕ phase angle of body in degrees, where $0 \leq \phi \leq 180$ deg

RS = r_s sun-body distance in AU

RO = r_o observer-body distance in AU

and the output is:

V = the visual magnitude as given by equation 1 or 2

BV = B-V color index

UB = U-B color index.

The subroutine first checks the body number to see if it is acceptable. When an incorrect body number is input, the message "ILLEGAL BODY NUMBER" is printed, and the following values are output:

$V = 99.0$

BV = 0.0

UB = 0.0

When a correct body number is input, the program extracts the correct values of $V(1, 0)$, B-V and U-B as shown in Table 1. V is computed using equations 1 or 2. The function Δm is determined by linear interpolation between the values given in Table 2.

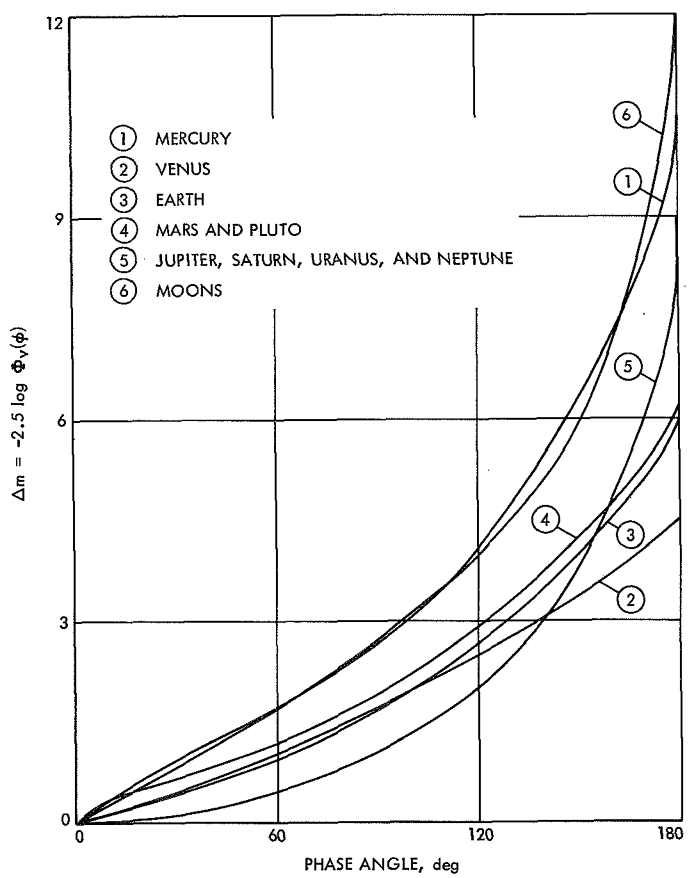

Fig. 2. Variation of magnitude with phase angle for the planets and their moons

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5. O'Leary, B. T., *Mars: Visible and Near Infrared Studies and Composition of the Surface*, University Microfilms, Ann Arbor, Mich., 1967.

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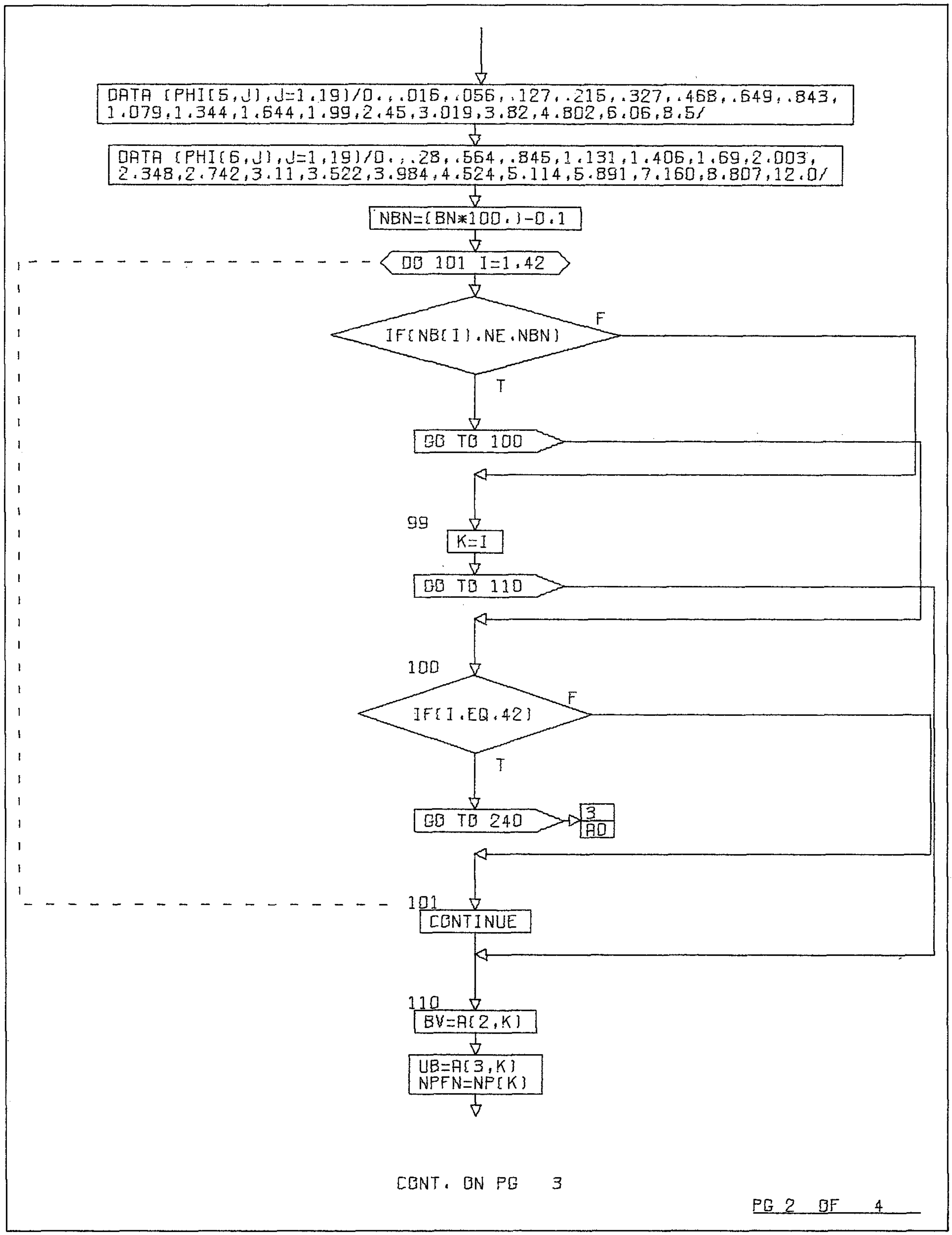
7. *British Astronomical Association Handbook*, Brit. Astron. Soc., Great Britain, 1968.

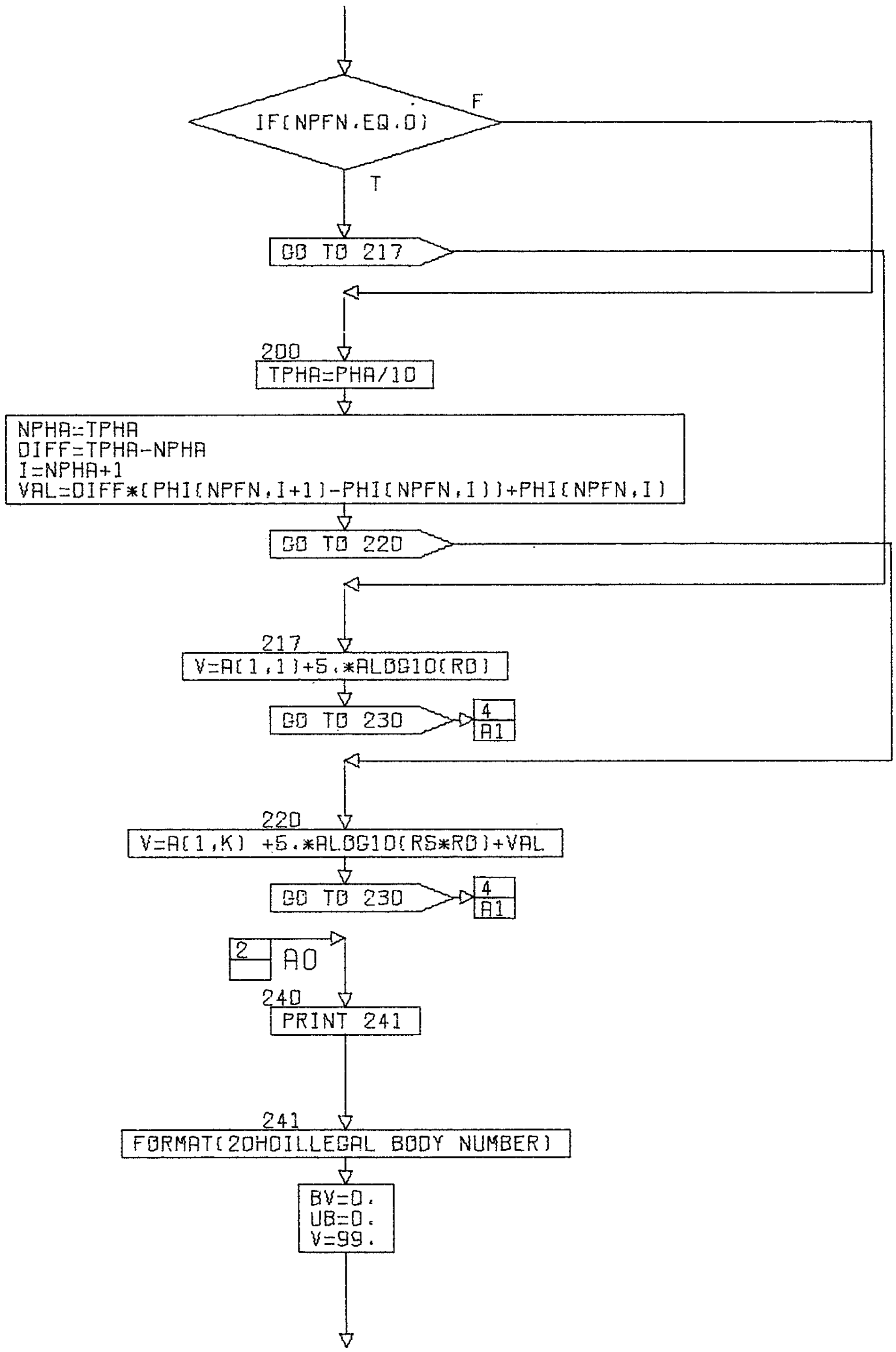
Appendix

Subroutine UBV Flow Diagram and Listing

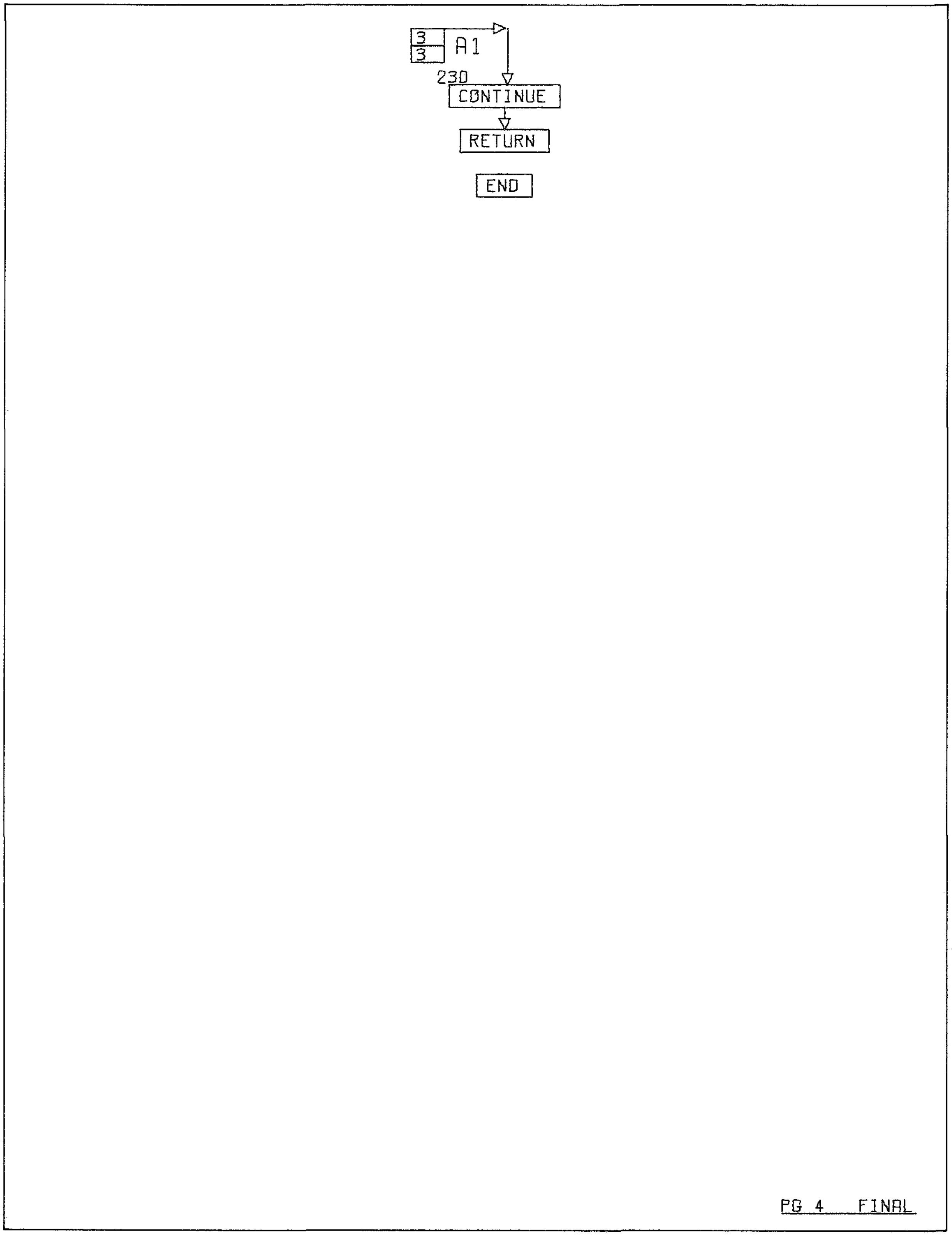
```
SUBROUTINE UBV(BN,PHA,RS,RO,V,BV,UB)
C      VERSION OF 11/12/70
DIMENSION NB(42),A(3,42),PHI(6,19),NP(42)
C      A(1,J)'S ARE V(1,0)'S
DATA (A(1,J),J=1,42)/-26.74,-.42,-4.41,-3.87,.21,-1.73,12.1,13.3,
-9.25,-1.90,-1.53,-2.16,-1.20,6.30,7.00,9.30,12.1,11.6,11.9,11.4,
12.1,-8.88,2.60,2.22,.72,.89,.21,-1.16,4.61,1.48,4.45,4.45,-7.19,
1.70,2.60,1.3C,1.49,3.80,-6.87,-1.16,4.00,-1.01/
C      A(2,J)'S ARE B-V'S
DATA (A(2,J),J=1,42)/.63,.97,.82,.20,.92,1.33,.60,.60,.83,1.17,
.87,.83,.86,.80,.80,.80,.80,.80,.80,.80,.80,1.04,.60,.62,.73,.71,
.76,1.30,.69,.71,.80,.80,.55,.80,.80,.62,.65,.80,.41,.77,.80,.80/
C      A(3,J)'S ARE U-B'S
DATA (A(3,J),J=1,42)/.14,.40,.50,.00,.46,.63,.30,.30,.48,1.30,.52,
.50,.55,.40,.40,.40,.40,.40,.40,.40,.40,.58,.30,.30,.34,.30,.35,
.75,.42,.28,.40,.40,.28,.40,.40,.25,.24,.40,.21,.40,.40,.27/
C      NP'S ARE MODEL NUMBERS
DATA (NP(J),J=1,42)/0,1,2,3,6,4,6,6,5,6,6,6,6,6,6,6,6,6,6,6,6,5,6,
6,6,6,6,6,6,6,6,6,5,6,6,6,6,6,5,6,6,4/
C      NB'S CORRESPOND TO PLANET NUMBERS
DATA NB/0,-100,-200,-300,-301,-400,-401,-402,-500,-501,-502,-503,
-504,-505,-506,-507,-508,-509,-510,-511,-512,-600,-601,-602,-603,
-604,-605,-606,-607,-608,-609,-610,-700,-701,-702,-703,-704,-705,
-800,-801,-802,-900/
C      PHI'S ARE -2.5*LOG10(PHI)'S
DATA (PHI(1,J),J=1,19)/0.,.355,.667,.95,1.21,1.471,1.726,2.01,2.32
,2.666,3.069,3.511,4.086,4.724,5.458,6.307,7.275,8.391,10.5/
DATA (PHI(2,J),J=1,19)/0.,.139,.291,.451,.63,.82,1.031,1.251,1.479
,1.721,1.97,2.224,2.478,2.77,3.055,3.391,3.72,4.12,4.49/
DATA (PHI(3,J),J=1,19)/0.,.133,.271,.42,.58,.759,.952,1.165,1.406,
1.674,1.97,2.302,2.664,3.073,3.495,4.005.4.56,5.114,6./
DATA (PHI(4,J),J=1,19)/0.,.34,.51,.659,.811,1.,1.2,1.41,1.639,1.91
1,2.224,2.556,2.903,3.297,3.760,4.26,4.77,5.3,6.2/
```

CONT. ON PG 2


DATA (PHI(5,J),J=1,19)/0.,.016,.056,.127,.215,.327,.468,.649,.843,
1.079,1.344,1.644,1.99,2.45,3.019,3.82,4.802,6.06,8.5/
DATA (PHI(6,J),J=1,19)/0.,.28,.564,.845,1.131,1.406,1.69,2.003,
2.348,2.742,3.11,3.522,3.984,4.524,5.114,5.891,7.160,8.807,12.0/
NBN=(BN*100.)-0.1
DO 101 I=1,42
IF(NB(I).NE.NBN)
F
T
GO TO 100
99
K=I
GO TO 110
100
IF(I.EQ.42)
F
T
GO TO 240
3
AO
101
CONTINUE
110
BV=A(2,K)
UB=A(3,K)
NPFN=NP(K)
CONT. ON PG 3
PG 2 OF 4


IF(NPFN.EQ.0)
F
T
GO TO 217
200
TPHA=PHA/10
NPHA=TPHA
DIFF=TPHA-NPHA
I=NPHA+1
VAL=DIFF*(PHI(NPFN,I+1)-PHI(NPFN,I))+PHI(NPFN,I)
GO TO 220
217
V=A(1,1)+5.*ALOG10(RO)
GO TO 230
4
A1
220
V=A(1,K) +5.*ALOG10(RS*RO)+VAL
GO TO 230
4
A1
2
A0
240
PRINT 241
241
FORMAT(20H0ILLEGAL BODY NUMBER)
BV=0.
UB=0.
V=99.

CONT. ON PG 4


3
3
A1
230
CØNTINUE
RETURN
END
PG 4 FINAL

SUBROUTINE UBV(BN,PHA,RS,RO,V,BV,UB)

```
      SUBROUTINE UBV(BN,PHA,RS,RO,V,BV,UB)
C     VERSION OF 11/12/70
      DIMENSION NB(42),A(3,42),PHI(6,19),NP(42)
C     A(1,J)'S ARE V(1,0)'S
      DATA (A(1,J),J=1,42)/-26.74,-.42,-4.41,-3.87,.21,-1.73,12.1,13.3,
     1-9.25,-1.90,-1.53,-2.16,-1.20,6.30,7.00,9.30,12.1,11.6,11.9,11.4,
     212.1,-8.88,2.60,2.22,.72,.89,.21,-1.16,4.61,1.48,4.45,4.45,-7.19,
     31.70,2.60,1.30,1.49,3.80,-6.87,-1.16,4.00,-1.01/
C     A(2,J)'S ARE B-V'S
      DATA (A(2,J),J=1,42)/.63,.57,.82,.20,.92,1.33,.60,.60,.83,1.17,
     1.87,.83,.86,.80,.80,.80,.80,.80,.80,.80,.80,1.04,.60,.62,.73,.71,
     2.76,1.30,.69,.71,.80,.80,.56,.80,.80,.62,.65,.80,.41,.77,.80,.80/
C     A(3,J)'S ARE U-B'S
      DATA (A(3,J),J=1,42)/.14,.40,.50,.00,.46,.63,.30,.30,.48,1.30,.52,
     1.50,.55,.40,.40,.40,.40,.40,.40,.40,.40,.58,.30,.30,.34,.30,.35,
     2.75,.42,.28,.40,.40,.28,.40,.40,.25,.24,.40,.21,.40,.40,.27/
C     NP'S ARE MODEL NUMBERS
      DATA (NP(J),J=1,42)/0,1,2,3,6,4,6,6,5,6,6,6,6,6,6,6,6,6,6,6,6,5,6,
     *6,6,6,6,6,6,6,6,6,5,6,6,6,6,6,5,6,6,4/
C     NB'S CORRESPOND TO PLANET NUMBERS
      DATA NB/0,-100,-200,-300,-301,-400,-401,-402,-500,-501,-502,-503,
     *-504,-505,-506,-507,-508,-509,-510,-511,-512,-600,-601,-602,-603,
     *-604,-605,-606,-607,-608,-609,-610,-700,-701,-702,-703,-704,-705,
     *-800,-801,-802,-900/
C     PHI'S ARE -2.5*LOG10(PHI)'S
      DATA (PHI(1,J),J=1,19)/0.,.355,.667,.95,1.21,1.471,1.726,2.01,2.32
     *,2.666,3.069,3.511,4.086,4.724,5.458,6.307,7.275,8.391,10.5/
      DATA (PHI(2,J),J=1,19)/0.,.139,.291,.451,.63,.82,1.031,1.251,1.479
     *,1.721,1.97,2.224,2.478,2.77,3.055,3.391,3.72,4.12,4.49/
      DATA (PHI(3,J),J=1,19)/0.,.133,.271,.42,.58,.759,.952,1.165,1.406,
     *1.674,1.97,2.302,2.664,3.073,3.495,4.005,4.56,5.114,6./
      DATA (PHI(4,J),J=1,19)/0.,.34,.51,.659,.811,1.,1.2,1.41,1.639,1.91
     *1,2.224,2.556,2.903,3.297,3.760,4.26,4.77,5.3,6.2/
      DATA (PHI(5,J),J=1,19)/0.,.016,.056,.127,.215,.327,.468,.649,.843,
     *1.079,1.344,1.644,1.99,2.45,3.019,3.82,4.802,6.06,8.5/
      DATA (PHI(6,J),J=1,19)/0.,.28,.564,.845,1.131,1.406,1.69,2.003,
     *2.348,2.742,3.11,3.522,3.984,4.524,5.114,5.891,7.160,8.807,12.0/
      NBN=(BN*100.)-0.1
      DO 101 I=1,42
      IF(NB(I).NE.NBN) GO TO 100
   99 K=I
      GO TO 110
  100 IF(I.EQ.42) GO TO 240
  101 CONTINUE
  110 BV=A(2,K)
      UB=A(3,K)
      NPFN=NP(K)
      IF(NPFN.EQ.0) GO TO 217
  200 TPHA=PHA/10
      NPHA=TPHA
```

```
                    SUBROUTINE UBV(BN,PHA,RS,RO,V,BV,UB)
      DIFF=TPHA-NPHA
      I=NPHA+1
      VAL=DIFF*(PHI(NPFN,I+1)-PHI(NPFN,I))+PHI(NPFN,I)
      GO TO 220
  217 V=A(1,1)+5.*ALOG10(RO)
      GO TO 230
  220 V=A(1,K) +5.*ALOG10(RS*RO)+VAL
      GO TO 230
  240 PRINT 241
  241 FORMAT(20H0ILLEGAL BODY NUMBER)
      BV=0.
      UB=0.
      V=99.
  230 CONTINUE
      RETURN
      END
```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N71-19233

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. 32-1523	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle UBV: SUBROUTINE TO COMPUTE PHOTOMETRIC MAGNITUDES OF THE PLANETS AND THEIR SATELLITES		5. Report Date February 15, 1971
		6. Performing Organization Code
7. Author(s) G. Pace		8. Performing Organization Report No.
9. Performing Organization Name and Address JET PROPULSION LABORATORY California Institute of Technology 4800 Oak Grove Drive Pasadena, California 91103		10. Work Unit No.
		11. Contract or Grant No. NAS 7-100
		13. Type of Report and Period Covered Technical Report
12. Sponsoring Agency Name and Address NATIONAL AERONAUTICS AND SPACE ADMINISTRATION Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This computer subroutine computes the visual, blue and ultraviolet photometric magnitudes of the planets, their natural satellites, and the sun at varying observation distances and phase angles. Currently available observational magnitude and phase function data are stored in the program and used in the computation.

17. Key Words (Selected by Author(s))	18. Distribution Statement
Planetary Surfaces Optical Sensors and Instruments	Unclassified -- Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
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