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Some FORTRAN Subprograms Used in Astronomy

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Lincoln Laboratory
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Lexington, Massachusetts

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Group 21

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Abstract

This note is a description of the subprograms DOP, which calculates the Doppler velocity of an earth-bound observer, JULDA which calculates the Julian day-number, MOVE which calculates precession, COORD which performs coordinate transformations, and the GRM series of subprograms which deal with Doppler velocities in terms of a standard galactic rotation model. These subprograms are written in basic FORTRAN and should be useable on a wide variety of computers.

Accepted for the Air Force
Franklin C. Hudson
Chief, Lincoln Laboratory Office

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      SUBROUTINE DOP (RAHRS,RAMIN,RASEC,DDEG,DMIN,DSEC,NYR,NDAY,
     2 NHUT,NMUT,NSUT,ALAT,OLONG,ELEV,   XLST,VSUN,VMON,VOBS,V1)
C
C  DOP CALCULATES THE VELOCITY COMPONENT OF THE OBSERVER WITH RESPECT
C  TO THE LOCAL STANDARD OF REST AS PROJECTED ONTO A LINE SPECIFIED BY THE RIGHT
C  ASCENSION AND DECLINATION (RAHRS, RAMIN, RASEC, DDEG, DMIN, DSEC) EPOCH OF
C  DATE, FOR A TIME SPECIFIED AS FOLLOWS+  NYR = LAST TWO DIGITS OF THE YEAR
C  (FOR 19XX A.D.), NDAY = DAY NUMBER (GMT), NHUT, NMUT, NSUT = HRS, MIN, SEC
C  (GMT).  THE LOCATION OF THE OBSERVER IS SPECIFIED BY THE LATITUDE (ALAT),
C  LONGITUDE (OLONG) (GEODETIC) (IN DEGREES) AND ELEVATION (ELEV) (IN METERS)
C  ABOVE MEAN SEA LEVEL.  THE SUBROUTINE OUTPUTS THE LOCAL MEAN SIDEREAL TIME
C  (XLST IN DAYS), THE COMPONENT OF THE SUN'S MOTION WITH RESPECT TO THE LOCAL
C  STANDARD OF REST AS PROJECTED ONTO THE LINE OF SIGHT TO THE SOURCE (VSUN IN
C  KM/SEC) AS WELL AS THE TOTAL VELOCITY COMPONENT V1 (KM/SEC).  POSITIVE
C  VELOCITY CORRESPONDS TO INCREASING DISTANCE BETWEEN SOURCE AND OBSERVER.
C
C  THIS VERSION OF DOP TAKES INTO ACCOUNT COMPONENTS OF THE OBSERVER'S
C  MOTION DUE TO THE ROTATION OF THE EARTH, THE REVOLUTION OF THE EARTH-MOON
C  BARYCENTER ABOUT THE SUN, AND THE MOTION OF THE EARTH'S CENTER ABOUT THE
C  EARTH-MOON BARYCENTER.  THE PERTURBATIONS OF THE EARTH'S ORBIT DUE TO THE
C  PLANETS ARE NEGLECTED.  THE ABSOLUTE PRECISION OF THIS VERSION OF DOP IS
C  ABOUT 0.004 KM/SEC, BUT SINCE THE DOMINANT ERROR TERM IS SLOWLY VARYING, THE
C  RELATIVE ERROR WILL BE CONSIDERABLY LESS FOR TIMES UP TO A WEEK OR SO.
C
C  REFERENCES+  MCRAE, D. A., WESTERHOUT, G., TABLE FOR THE REDUCTION OF
C                  VELOCITIES TO THE LOCAL STANDARD OF REST, THE OBSERVATORY,
C                  LUND, SWEDEN, 1956.
C               SMART, W. M., TEXT-BOOK ON SPHERICAL ASTRONOMY, CAMBRIDGE
C                  UNIV. PRESS, 1962.
C               THE AMERICAN EPHEMERIS AND NAUTICAL ALMANAC
C               THE SUPPLEMENT TO THE ABOVE
C
C     VERSION OF JUNE 1969
C
C
C
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C
C   THE FOLLOWING CALCULATIONS DEAL WITH THE SUN'S MOTION WITH RESPECT TO THE
C   LOCAL STANDARD OF REST.
C   THE VELOCITY OF THE SUN WITH RESPECT TO THE LOCAL STANDARD OF REST IS THE
C   CONVENTIONAL VALUE OF 20.0 KM/SEC TOWARD RA = 18 HRS, DEC = 30 DEG (1900).
      AAA=18.0*3.1415926535/12.0
      DD=30.0*3.1415926535/180.0
C   MOVE PRECESSES THIS DIRECTION TO DATE
      CALL MOVE (1900,1900+NYR,1,NDAY,AAA,DD,  DELA,DELDD,DC)            MOVE
      AAA=AAA+DELA
      DD=DD+DELDD
C   THIS VELOCITY IS CONVERTED TO CARTESIAN COMPONENTS
      XO=20.0*COSF(AAA)*COSF(DD)
      YO=20.0*SINF(AAA)*COSF(DD)
      ZO=20.0*SINF(DD)
C   RA1 IS THE RIGHT ASCENSION (REVS=DAYS)
      RA1=(RAHRS+RAMIN/60.0+RASEC/3600.0)/24.0
C   RA IS THE RIGHT ASCENSION (RADIANS)
      RA=2.0*3.1415926535*RA1
C   DEC IS THE DECLINATION (RADIANS)
      DEC=3.1415926535*(DDEG+SIGNF(DMIN/60.0+DSEC/3600.0,DDEG))/180.0
C   CC, CS, AND S ARE THE DIRECTION COSINES CORRESPONDING TO RA AND DEC
      CC=COSF(DEC)*COSF(RA)
      CS=COSF(DEC)*SINF(RA)
      S=SINF(DEC)
C   VSUN IS THE PROJECTION ONTO THE LINE OF SIGHT TO THE STAR OF THE SUN'S
C   MOTION WITH RESPECT TO THE LOCAL STANDARD OF REST (KM/SEC)
      VSUN=-XO*CC-YO*CS-ZO*S
C
C   COORDINATES OF THE OBSERVER, LATITUDE (RADIANS), AND LONGITUDE (REVS=DAYS)
      CAT=ALAT*3.1415926535/180.0
      WLONG=OLONG/360.0
C
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C
C   THE FOLLOWING CALCULATIONS DEAL WITH THE TIME
C   THE EPOCH IS 1900 JANUARY 0.5 UT = JULIAN DAY 2415020.0
C   DU IS THE TIME FROM THE EPOCH TO JAN 0.0 OF THE CURRENT YEAR (DAYS)
        DU=(JULDA(1900+NYR)-2415020)-0.5                                      JULDA
C   TU IS DU CONVERTED TO JULIAN CENTURIES
        TU=DU/36525.0
C   UTDA IS THE GMT FROM JAN 0.0 TO THE PRESENT (DAYS)
        UTDA=NDAY+NHUT/24.0+NMUT/1440.0+NSUT/86400.0
C   SMD (SMALL D) IS THE TIME FROM THE EPOCH TO THE PRESENT (DAYS)
        SMD=DU+UTDA
C   T IS SMD CONVERTED TO JULIAN CENTURIES
        T=SMD/36525.0
C   START IS THE GREENWICH MEAN SIDEREAL TIME ON JAN 0.0 (DAYS)
C   (THE EXTRA 129.1794 SECS CORRESPONDS TO THE 0.7 CENTURY SUBTRACTED FROM TU.
C   THE PRECISION IS THEREBY IMPROVED.)
        START=(6.0+38.0/60.0+(45.836+129.1794+8640184.542*(TU-0.7)+0.0929
      2 *TU**2)/3600.0)/24.0
C   C1 IS THE CONVERSION FACTOR FROM SOLAR TIME TO SIDEREAL TIME
        C1=(23.0+56.0/60.0+4.09054/3600.0)/24.0
C   GST IS THE GREENWICH MEAN SIDEREAL TIME (DAYS)
        GST=START+UTDA/C1
C   XLST IS THE LOCAL MEAN SIDEREAL TIME (FROM JAN 0) (DAYS)
        XLST=GST-WLONG
        XLST=XLST-IFIX(XLST)
C
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```
C
C   THE FOLLOWING CALCULATIONS DEAL WITH THE OBSERVER'S MOTION WITH
C   RESPECT TO THE EARTH'S CENTER.
C   REDUCTION OF GEODETIC LATITUDE TO GEOCENTRIC LATITUDE (ARCSECONDS)
       DLAT=-(11.0*60.0+32.7430)*SINF(2.0*CAT)+1.1633*SINF(4.0*CAT)
     2 -0.0026*SINF(6.0*CAT)
C   CONVERT CAT TO GEOCENTRIC LATITUDE (RADIANS)
       CAT=CAT+DLAT*3.1415926535/3600.0/180.0
C   RHO IS THE RADIUS VECTOR FROM THE EARTH'S CENTER TO THE OBSERVER (METERS)
       RHO=6378160.0*(0.998327073+0.001676438*COSF(2.0*CAT)-0.000003519
     2 *COSF(4.0*CAT)+0.000000008*COSF(6.0*CAT))+ELEV
C   AND VRHO IS THE CORRESPONDING CIRCULAR VELOCITY (METERS/SIDEREAL DAY)
       VRHO=2.0*3.1415926535*RHO
C   CONVERTED TO KILOMETERS/SEC
       VRHO=VRHO/24.0E3/3600.0*C1
C   VOBS IS THE PROJECTION ONTO THE LINE OF SIGHT TO THE STAR OF THE VELOCITY
C   OF THE OBSERVER WITH RESPECT TO THE EARTH'S CENTER (KM/SEC)
       VOBS=VRHO*COSF(CAT)*COSF(DEC)*SINF(2.0*3.1415926535*(XLST-RA1))
C
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C
C   THE FOLLOWING CALCULATIONS DEAL WITH THE EARTH'S ORBIT ABOUT THE SUN
C   AM IS THE MEAN ANOMALY (OF THE EARTH'S ORBIT) (RADIANS)
       AM=(358.47583+0.9856002670*SMD-0.000150*T**2-0.000003*T**3)
      2 *3.1415926535/180.0
C   PI IS THE MEAN LONGITUDE OF PERIHELION (RADIANS)
       PI=(101.22083+0.0000470684*SMD+0.000453*T**2+0.000003*T**3)
      2 *3.1415926535/180.0
C   E IS THE ECCENTRICITY OF THE ORBIT (DIMENSIONLESS)
       E=0.01675104-0.00004180*T-0.000000126*T**2
C   AI IS THE MEAN OBLIQUITY OF THE ECLIPTIC (RADIANS)
       AI=(23.452294-0.0130125*T-0.00000164*T**2+0.000000503*T**3)
      2 *3.1415926535/180.0
C   VS IS THE TRUE ANOMALY (APPROXIMATE FORMULA) (RADIANS)
C   (EQUATION OF THE CENTER)
       VS=AM+(2.0*E-0.25*E**3)*SINF(AM)+1.25*E**2*SINF(2.0*AM)+
      2 13.0/12.0*E**3*SINF(3.0*AM)                                     +...
C   XLAM IS THE TRUE LONGITUDE OF THE EARTH AS SEEN FROM THE SUN (RADIANS)
       XLAM=PI+VS
C   ALAM IS THE TRUE LONGITUDE OF THE SUN AS SEEN FROM THE EARTH (RADIANS)
       ALAM=XLAM+3.1415926535
C   BETA IS THE LATITUDE OF THE STAR (RADIANS)
C   ALONG IS THE LONGITUDE OF THE STAR (RADIANS)
       CALL COORD (0.0,0.0,-3.1415926535/2.0,3.1415926535/2.0-AI,
      2 RA,DEC, ALONG,BETA)                                              COORD
C   AA IS THE SEMI-MAJOR AXIS OF THE EARTH'S ORBIT (KM)
       AA=149598500.0
C   AN IS THE MEAN ANGULAR RATE OF THE EARTH ABOUT THE SUN (RADIANS/DAY)
       AN=2.0*3.1415926535/365.2564
C   HOP IS H/P FROM SMART = THE COMPONENT OF THE EARTH'S VELOCITY PERPENDICULAR
C   TO THE RADIUS VECTOR (KM/DAY)
       HOP=AN*AA/SQRTF(1.0-E**2)
C   CONVERTED TO KM/SEC
       HOP=HOP/86400.0
C   V IS THE PROJECTION ONTO THE LINE OF SIGHT TO THE STAR OF THE VELOCITY
C   OF THE EARTH-MOON BARYCENTER WITH RESPECT TO THE SUN (KM/SEC)
       V=-HOP*COSF(BETA)*(SINF(ALAM-ALONG)-E*SINF(PI-ALONG))
C
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C
C   THE FOLLOWING CALCULATIONS DEAL WITH THE MOON'S ORBIT AROUND THE
C   EARTH-MOON BARYCENTER
C   OMGA (OMEGA) IS THE LONGITUDE OF THE MEAN ASCENDING NODE OF THE LUNAR ORBIT
C   (DEGREES)
      OMGA =259.183275-0.0529539222*SMD+0.002078*T**2+0.000002*T**3
C   OMGAR IS OMGA IN RADIANS
      OMGAR=OMGA*3.1415926535/180.0
C   AMON IS OMGA PLUS THE MEAN LUNAR LONGITUDE OF THE MOON (DEGREES)
C   (SHOULD BE 13.1763965268)
      AMON=270.434164+13.176396527 *SMD-0.001133*T**2+0.0000019*T**3
C   GAMP (GAMMA-PRIME) IS OMGA PLUS THE LUNAR LONGITUDE OF LUNAR PERIGEE (DEGREES
      GAMP=334.329556+0.1114040803*SMD-0.010325*T**2-0.000012*T**3
C   PIM IS THE MEAN LUNAR LONGITUDE OF LUNAR PERIGEE (TO RADIANS)
      PIM=(GAMP-OMGA)*3.1415926535/180.0
C   EM IS THE ECCENTRICITY OF THE LUNAR ORBIT
      EM=0.054900489
C   OLAMM IS THE MEAN LUNAR LONGITUDE OF THE MOON (TO RADIANS)
      OLAMM=(AMON-OMGA)*3.1415926535/180.0
C   AIM IS THE INCLINATION OF THE LUNAR ORBIT TO THE ECLIPTIC (RADIANS)
      AIM=5.1453964*3.1415926535/180.0
C   AMM IS THE APPROXIMATE MEAN ANOMALY (RADIANS)
C   (IT IS APPROXIMATE BECAUSE PIM SHOULD BE THE TRUE RATHER THAN THE MEAN LUNAR
C   LONGITUDE OF LUNAR PERIGEE)
      AMM=OLAMM-PIM
C   VSM IS THE TRUE ANOMALY (APPROXIMATE FORMULA) (RADIANS)
C   (EQUATION OF THE CENTER)
      VSM=AMM+(2.0*EM-0.25*EM**3)*SINF(AMM)+1.25*EM**2*SINF(2.0*AMM)
     2 +13.0/12.0*EM**3*SINF(3.0*AMM)                                   +...
C   ALAMM IS THE TRUE LUNAR LONGITUDE OF THE MOON (RADIANS)
      ALAMM=PIM+VSM
C   ANM IS THE MEAN ANGULAR RATE OF THE LUNAR ROTATION (RADIANS/DAY)
      ANM=2.0*3.1415926535/27.321661
C   AAM IS THE SEMI-MAJOR AXIS OF THE LUNAR OBRIT (KILOMETERS)
      AAM=60.2665*6378.388
C   BETAM IS THE LUNAR LATITUDE OF THE STAR (RADIANS)
C   ALGM IS THE LUNAR LONGITUDE OF THE STAR (RADIANS)
      CALL COORD (OMGAR,0.0,OMGAR-3.1415926535/2.0,3.1415926535/2.0-AIM,
     2 ALONG,BETA, ALGM,BETAM)                                          COORD
C   HOPM IS H/P FROM SMART = THE COMPONENT OF THE LUNAR VELOCITY PERPENDICULAR
C   TO THE RADIUS VECTOR (KM/DAY)
      HOPM=ANM*AAM/SQRTF(1.0-EM**2)
C   CONVERTED TO KM/SEC
      HOPM=HOPM/86400.0
C   VMON IS THE PROJECTION ONTO THE LINE OF SIGHT TO THE STAR OF THE VELOCITY
C   OF THE EARTH'S CENTER WITH RESPECT TO THE EARTH-MOON BARYCENTER (KM/SEC)
C   (THE 81.30 IS THE RATIO OF THE EARTH'S MASS TO THE MOON'S MASS)
      VMON=-HOPM/81.30*COSF(BETAM)*(SINF(ALAMM-ALGM)-EM*SINF(PIM-ALGM))
C
```

```
C
      V1=V+VSUN+VMON+VOBS
      RETURN
C
C   THIS PROGRAM OMITS THE PLANETARY PERTURBATIONS ON THE EARTH'S ORBIT.  THESE
C   AMOUNT TO ABOUT 0.003 KM/SEC AND ARE THOUGHT TO BE THE LARGEST CONTRIBUTION
C   TO THE ERROR IN THE VELOCITY.
C
      END
```

```
      FUNCTION JULDA(NYR)
C   THIS FUNCTION COMPUTES THE JULIAN DAY NUMBER AT 12 HRS UT ON JANUARY 0
C   OF THE YEAR NYR (GREGORIAN CALENDAR).  JULDA IS AN INTEGER BECAUSE OF THIS
C   DEFINITION.  FOR EXAMPLE, JULDA = 2439856 FOR NYR = 1968.
C
      NYRM1=NYR-1
      IC=NYRM1/100
      JULDA=1721425+365*NYRM1+NYRM1/4-IC+IC/4
      RETURN
      END
```

```
      SUBROUTINE COORD (AO,BO,AP,BP,A1,B1,  A2,B2)
C
C   THIS SUBROUTINE CONVERTS THE LONGITUDE-LIKE (A1) AND LATITUDE-LIKE (B1)
C   COORDINATES OF A POINT ON A SPHERE INTO THE CORRESPONDING COORDINATES (A2,
C   B2) IN A DIFFERENT COORDINATE SYSTEM THAT IS SPECIFIED BY THE COORDINATES
C   OF ITS ORIGIN (AO, BO) AND ITS NORTH POLE (AP, BP) IN THE ORIGINAL COORDINATE
C   SYSTEM.  THE RANGE OF A2 WILL BE FROM -PI TO PI.
C
C   ALL ARGUMENTS ARE IN RADIANS.
C
C   EXAMPLES OF USE
C      PI = 3.1415926535
C      PIO2 = PI/2.0
C
C   EXAMPLE I--TO CALCULATE AZIMUTH AND ELEVATION FROM HOUR ANGLE AND DECLINATION
C      CALL COORD (PI,PIO2-LATITUDE,0.0,LATITUDE,HOUR ANGLE,DECLINATION,
C     2 AZIMUTH,ELEVATION)
C   THEN IF AZIMUTH IS DESIRED IN THE RANGE 0 TO PI SET
C      AZIMUTH = AZIMUTH + (PI - SIGNF(PI,AZIMUTH))
C
C   EXAMPLE II--TO CALCULATE HOUR ANGLE AND DECLINATION FROM AZIMUTH AND
C   ELEVATION
C      CALL COORD (PI,PIO2-LATITUDE,0.0,LATITUDE,AZIMUTH,ELEVATION,
C     2 HOUR ANGLE,DECLINATION)
C
C   EXAMPLE III--TO CALCULATE LI AND BI FROM RIGHT ASCENSION AND DECLINATION
C   (EPOCH 1900.0)
C      AP = (12.0+40.0/60.0)*PI/12.0
C   (I.E. 12 HOURS 40 MINUTES CONVERTED TO RADIANS)
C      BP = 28.0*PI/180.0
C      AO = (18.0+40.0/60.0)*PI/12.0
C      BO = 0.0
C   (REFER TO KRAUS, P., RADIO ASTRONOMY, MCGRAW HILL, NEW YORK, 1966.  BUT FOR
C   FURTHER REFINEMENTS, SEE ALSO ALLEN, C. W., ASTROPHYSICAL QUANTITIES,
C   ATHLONE PRESS, LONDON, 1963.)
C      CALL COORD (AO,BO,AP,BP,RIGHT ASCENSION,DECLINATION,LI,BI)
C
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```
C
C   EXAMPLE IV--TO CALCULATE RIGHT ASCENSION AND DECLINATION (EPOCH 1900.0) FROM
C   LI AND BI
C   IN GENERAL, WHENEVER WE KNOW THE FORWARD TRANSFORMATION (EXAMPLE III ABOVE)
C   WE MAY DO THE REVERSE TRANSFORMATION WITH AT MOST TWO EXTRA PRELIMINARY CALLS
C   TO COORD TO CALCULATE THE COORDINATES IN SYSTEM 2 OF THE POLE AND ORIGIN IN
C   SYSTEM 1.  BUT OFTEN IT IS POSSIBLE TO GET THESE NEEDED COORDINATES BY
C   INSPECTION.  FOR EXAMPLE, BP WILL REMAIN THE SAME FOR THE FORWARD AND REVERSE
C   TRANSFORMATIONS.  FOR THIS EXAMPLE WE SEE BY INSPECTION THAT
C      APP = 6.0*PI/12.0
C      BPP = 28.0*PI/180.0
C   (THE SECOND P REPRESENTS PRIME.)  AND WE MAY CALCULATE AOP AND BOP FROM
C      CALL COORD (AO,BO,AP,BP,0.0,0.0,AOP,BOP)
C   WHERE THE AO, ETC. ARE FROM EXAMPLE III.  THEN THE ACTUAL CONVERSION IS
C      CALL COORD (AOP,BOP,APP,BPP,LI,BI,RIGHT ASCENSION,DECLINATION)
C
C   EXAMPLE V--TO CALCULATE LII AND BII FROM RIGHT ASCENSION AND DECLINATION
C   (EPOCH 1950.0)
C      AP = (12.0+49.0/60.0)*PI/12.0
C      BP = 27.4*PI/180.0
C      AO = (17.0+42.4/60.0)*PI/12.0
C      BO = -(28.0+55.0/60.0)*PI/180.0
C      CALL COORD (AO,BO,AP,BP,RIGHT ASCENSION,DECLINATION,LII,BII)
C
C   EXAMPLE VI--TO CALCULATE RIGHT ASCENSION AND DECLINATION (EPOCH 1950.0) FROM
C   LII AND BII
C   FIRST CALCULATE APP AND BPP FROM
C      CALL COORD (AO,BO,AP,BP,0.0,PIO2,APP,BPP)
C   THEN CALCULATE AOP AND BOP FROM
C      CALL COORD (AO,BO,AP,BP,0.0,0.0,AOP,BOP)
C   WHERE THE AO, ETC. ARE FROM EXAMPLE V.  THEN THE ACTUAL CONVERSION IS
C      CALL COORD (AOP,BOP,APP,BPP,LII,BII,RIGHT ASCENSION,DECLINATION)
C
```

```
C
C  EXAMPLE VII--TO CALCULATE (ECLIPTIC) LATITUDE AND LONGITUDE FROM RIGHT
C  ASCENSION AND DECLINATION
C  EPS IS THE OBLIQUITY OF THE ECLIPTIC WHICH IS ABOUT 23.443 DEGREES, BUT IT
C  DEPENDS ON THE EPOCH.  SEE THE AMERICAN EPHEMERIS AND NAUTICAL ALMANAC.
C      EPS=23.443*PI/180.0
C      CALL COORD (0.0,0.0,-PIO2,PIO2-EPS,RIGHT ASCENSION,DECLINATION,
C     2 LATITUDE,LONGITUDE)
C
C
C  THE NOTATION USES S OR C FOR SINE OR COSINE OF THE CORRESPONDING VARIABLE,
C  FOR EXAMPLE, SBO = SINF(BO), ETC.
C
C  NOTE THAT THE INPUT PARAMETERS ARE PARTIALLY REDUNDANT.  FOR EXAMPLE, IF
C  AP, BP, AND AO ARE SPECIFIED, THEN THERE ARE ONLY TWO DISCRETE VALUES
C  POSSIBLE FOR BO (EXCEPT FOR A FEW DEGENERATE SPECIAL CASES).  SEE BELOW FOR
C  WHAT TO DO IF IT IS NECESSARY TO PRECALCULATE AO AND BO.
C
C  IF, INSTEAD OF AO AND BO, THE LONGITUDE OF THE ASCENDING NODE IS KNOWN IN
C  BOTH THE OLD (AN1) AND NEW (AN2) COORDINATE SYSTEMS, THEN AO AND BO MAY BE
C  CALCULATED BY A PRELIMINARY CALL TO COORD
C      CALL COORD (0.0,0.0,AN1-AP,BP,-AN2,0.0,AO,BO)
C  THEN THIS AO AND BO MAY BE USED FOR A SERIES OF ORDINARY CALLS TO COORD AS
C  DESCRIBED ABOVE.
C
C  IF AP, BP, AND AO ARE KNOWN, THEN THE TWO POSSIBLE VALUES OF BO MAY BE
C  CALCULATED FROM
C      SBO=(SBP $ 2.0*CBP**2*CAPAO*SGRTF(I.0+CAPAO**2))/
C     2 (SBP**2+(CBP*CAPAO)**2)
C  WHERE CAPAO = COSF(AP-AO) AND THE OTHER NOTATION IS EXPLAINED ABOVE, AND
C  WHERE THE $ IS TO BE REPLACED BY + AND -.
C
C  IF AP, BP, AND BO ARE KNOWN, THEN THE TWO POSSIBLE VALUES OF AO MAY BE
C  CALCULATED FROM
C      CAPAO=(1.0-SBO*SBP)/(CBO*CBP)
C  BOTH ANGLES WITH THIS COSINE ARE POSSIBLE.
C
```

```
C
      SB0=SINF(B0)
      CB0=COSF(B0)
      SBP=SINF(BP)
      CBP=COSF(BP)
      SB1=SINF(B1)
      CB1=COSF(B1)
C
      SB2=SBP*SB1+CBP*CB1*COSF(AP-A1)
      B2=ASINF(SB2)
C  (NOTE B0 IS NOT NEEDED TO CALCULATE B2)
      CB2=COSF(B2)
C
      SAA=SINF(AP-A1)*CB1/CB2
      CAA=(SB1-SB2*SBP)/(CB2*CBP)
C
      CBB=SB0/CBP
      SBB=SINF(AP-A0)*CB0
C
      TA202=(1.0-CAA*CBB-SAA*SBB)/(SAA*CBB-CAA*SBB)
      A2=2.0*ATANF(TA202)
C
      RETURN
      END
```

```
      SUBROUTINE MOVE (NYRI,NYRF,MO,NDA,RA,D,  DELR,DELD,DC)
C
C  MOVE CALCULATES THE CORRECTION (DELR) IN RIGHT ASCENSION (RA) AND THE
C  CORRECTION (DELD) IN DECLINATION (D) (ALL IN RADIANS) TO BE ADDED TO THE
C  MEAN COORDINATES FOR EPOCH NYRI (E.G. 1950) TO GIVE THE APPARENT POSITIONS
C  OF A DATE SPECIFIED BY THE YEAR (NYRF, E.G. 1968), MONTH (MO, 1 TO 12), AND
C  DAY (NDA).  IF THE DAY-NUMBER IS KNOWN, USE IT FOR NDA AND SET MO = 1.
C  MOVE ALSO CALCULATES THE EQUATION OF THE EQUINOXES (DC, IN MINUTES OF TIME)
C  WHICH MAY BE ADDED TO THE MEAN SIDEREAL TIME TO GIVE THE APPARENT SIDEREAL
C  TIME (AENA-469).  DELR AND DELD CONTAIN CORRECTIONS FOR PRECESSION, ANNUAL
C  ABERRATION, AND SOME TERMS OF NUTATION.  IF RA AND D ARE FOR THE MEAN EPOCH
C  (I.E. HALFWAY BETWEEN NYRI AND NYRF) THEN THE PRECISION OF DELR AND DELD IS
C  ABOUT 2 ARCSECONDS (SEE NEGLECTED TERMS IN ESE-44).  IF RA AND D ARE EITHER
C  OF THE END POINTS OF THE INTERVAL, THEN THE PRECISION MAY BE SOMEWHAT WORSE.
C  AENA = THE AMERICAN EPHEMERIS AND NAUTICAL ALMANAC (THE BLUE BOOK).
C  ESE = THE EXPLANATORY SUPPLEMENT TO ABOVE (THE GREEN BOOK).
C
      SND=SINF(D)
      CSD=COSF(D)
      TND=SND/CSD
C
      CSR=COSF(RA)
      SNR=SINF(RA)
C
C  AL IS AN APPROXIMATE DAY NUMBER (I.E. THE NUMBER OF DAYS SINCE JANUARY 0
C  OF THE YEAR NYRF).
      AL=30*(MO-1)+NDA
C
C  TO IS THE TIME FROM 1900 TO NYRI (CENTURIES)
      TO=FLOATF(NYRI-1900)/100.0
C  T IS THE TIME FROM NYRI TO DATE (NYRF, MO, NDA) (CENTURIES)
C  (365.2421988 IS THE NUMBER OF EPHEMERIS DAYS IN A TROPICAL YEAR)
      T=(FLOATF(NYRF-NYRI)+AL/365.2421988)/100.0
C  ZETAO IS A PRECESSIONAL ANGLE FROM ESE-29 (ARCSECONDS)
      ZETAO=(2304.250+1.396*TO)*T+0.302*T**2+0.018*T**3
C  DITTO FOR Z
      Z=ZETAO+0.791*T**2
C  AND THETA
      THETA=(2004.682-0.853*TO)*T-0.426*T**2-0.042*T**3
C  AM AND AN ARE THE M AND N PRECESSIONAL NUMBERS (SEE AENA-50, 474) (RADIANS)
      AM=(ZETAO+Z)*4.848136811E-6
      AN=THETA*4.848136811E-6
C
```

```
C
C   ALAM IS AN APPROXIMATE MEAN LONGITUDE FOR THE SUN (AENA-50) (RADIANS)
      ALAM=(0.985647*AL+278.5)*0.0174532925
      SNL=SINF(ALAM)
      CSL=COSF(ALAM)
C   DELR IS THE ANNUAL ABERRATION TERM IN RA (RADIANS) (ESE-47,48)
C   (0.91745051 = COS(OBLIGUITY OF ECLIPTIC))
C   (-9.92413605E-5 = K = 20.47 ARCSECONDS = CONSTANT OF ABERRATION (ESE-48))
      DELR=-9.92413605E-5*(SNL*SNR+0.91745051*CSL*CSR)/CSD
C   PLUS PRECESSION TERMS (SEE AENA-50 AND ESE-38)
     2 +AM+AN*SNR*TND
C   DELD IS DITTO ABOVE IN DECLINATION
      DELD=-9.92413605E-5*(SNL*CSR*SND-0.91745051*CSL*SNR*SND
C   (0.39784993 = SIN(OBLIQUITY OF ECLIPTIC))
     2 +0.39784993*CSL*CSD) +AN*CSR
C
C   THE FOLLOWING CALCULATES THE NUTATION (APPROXIMATELY) (ESE-41,45)
C   OMEGA IS THE ANGLE OF THE FIRST TERM OF NUTATION (ESE-44) (APPROXIMATE
C   FORMULA) (DEGREES)
      OMEGA=259.183275-1934.142*(TO+T)
C   ARG IS OMEGA CONVERTED TO RADIANS
      ARG=OMEGA*0.0174532925
C   DLONG IS THE NUTATION IN LONGITUDE (DELTA-PSI) (RADIANS)
      DLONG=-8.3597E-5*SINF(ARG)
C   DOBLQ IS THE NUTATION IN OBLIQUITY (DELTA-EPSILON) (RADIANS)
      DOBLQ= 4.4678E-5*COSF(ARG)
C
C   ADD NUTATION IN RA INTO DELR (ESE-43)
      DELR=DELR+DLONG*(0.91745051 +0.39784993 *SNR*TND)-CSR*TND*DOBLQ
C   AND DEC.
      DELD=DELD+0.39784993 *CSR*DLONG+SNR*DOBLQ
C   DC IS THE EQUATION OF THE EQUINOXES (MINUTES OF TIME) (ESE-43)
      DC=DLONG*210.264169
      RETURN
      END
```

```
      SUBROUTINE GRM1 (ELII,VR,  RS,RC,PSI)
      DIMENSION RS(2),PSI(2)
C   SUBROUTINE GRM1 (GALACTIC ROTATION MODEL - 1) ACCEPTS THE GALACTIC LONGITUDE
C   (ELII IN DEGREES) AND THE DOPPLER VELOCITY WITH RESPECT TO THE LOCAL STANDARD
C   OF REST (VR IN KM/SEC) AND RETURNS THE DISTANCE FROM THE SUN (RS), THE
C   DISTANCE FROM THE GALACTIC CENTER (RC) (BOTH IN KPC), AND THE GALACTOCENTRIC
C   LONGITUDE (PSI IN DEGREES).  THE RANGE OF PSI WILL BE -180 TO +180 DEGREES.
C   FOR MANY VALUES OF ELII AND VR, THERE WILL BE A DISTANCE AMBIGUITY AND THE
C   TWO POSSIBLE DISTANCES WILL BE RETURNED IN RS(1) AND RS(2) AND THE ASSOCIATED
C   ANGLES IN PSI(1) AND PSI(2).  IF RS(1) IS NEGATIVE OR ZERO, THEN THERE IS
C   ONLY ONE SOLUTION AND IT IS IN RS(2) AND PSI(2).  IF BOTH RS(1) AND RS(2)
C   ARE NEGATIVE OR ZERO, THEN THERE ARE NO SOLUTIONS TO THE EQUATIONS, I.E. THE
C   GIVEN VR IS IMPOSSIBLE FOR THIS ELII.
C   SEE SUBROUTINE GRM3 FOR FURTHER DETAILS.
C
      PI=3.1415926535
      TPI=2.0*PI
C   ELIIR IS ELII CONVERTED TO RADIANS
      ELIIR=ELII*PI/180.0
C   SLII IS SIN(ELII)
      SLII=SINF(ELIIR)
C   RO IS THE SUN'S DISTANCE FROM THE GALACTIC CENTER (KPC)
      RO=10.0
C   OMGAO IS THE ANGULAR ROTATION VELOCITY AT THE SUN (KM/SEC/KPC)
      OMGAO=25.0
C   OMGA IS THE ANGULAR ROTATION VELOCITY AT THE SOURCE (KM/SEC/KPC)
      OMGA=VR/(RO*SLII)+OMGAO
C   GRM3 CALCULATES RC (KPC)
      CALL GRM3 (OMGA,  RC)                                            GRM3
C   H IS THE LENGTH OF THE PERPENDICULAR DROPPED FROM THE GALACTIC CENTER TO THE
C   LINE OF SIGHT (KPC)
      H=RO*SLII
C   GO TO 50 IF THERE IS NO SOLUTION
      IF (ABSF(H)-RC) 20,20,50
C   DELT IS THE ANGLE BETWEEN THE SUN AND THE GALACTIC CENTER AS SEEN FROM THE
C   SOURCE (RADIANS)
   20 DELT=ASINF(H/RC)
C   PSI1 AND PSI2 ARE THE TWO SOLUTIONS FOR PSI (RADIANS)
      PSI1=ELIIR-DELT
      PSI2=ELIIR+DELT+PI
C   CONVERT THESE TO DEGREES, SET THE RANGE TO -180 TO 180, AND PUT IN PSI
      PSI(1)=PSI1*180.0/PI-360.0*IFIX(PSI1/TPI+SIGNF(0.5,PSI1))
      PSI(2)=PSI2*180.0/PI-360.0*IFIX(PSI2/TPI+SIGNF(0.5,PSI2))
C   THEN SET RS(1) AND RS(2) (KPC)
      RS(1)=-RC*SINF(PSI1)/SLII
      RS(2)=-RC*SINF(PSI2)/SLII
      RETURN
C
C   GO TO 50 FOR NO SOLUTIONS TO THE EQUATIONS (ABSF(H/RC) .GT. 1)
   50 RS(1)=0.0
      RS(2)=0.0
      PSI(1)=0.0
      PSI(2)=0.0
      RETURN
      END
```

```
      SUBROUTINE GRM2 (ELII,RS,  VR,RC,PSI)
C   SUBROUTINE GRM2 (GALACTIC ROTATION MODEL - 2) ACCEPTS THE GALACTIC LONGITUDE
C   (ELII IN DEGREES) AND THE DISTANCE FROM THE SUN (RS IN KPC) AND RETURNS THE
C   DOPPLER VELOCITY WITH RESPECT TO THE LOCAL STANDARD OF REST (VR IN KM/SEC),
C   THE DISTANCE FROM THE GALACTIC CENTER (RC IN KPC), AND THE GALACTOCENTRIC
C   LONGITUDE (PSI IN DEGREES).
C   SEE SUBROUTINE GRM4 FOR FURTHER DETAILS.
C
      PI=3.1415926535
C   ELIIR IS ELII CONVERTED TO RADIANS
      ELIIR=ELII*PI/180.0
C   RO IS THE SUN'S DISTANCE FROM THE GALACTIC CENTER (KPC)
      RO=10.0
C   THEN RC IS JUST
      RC=SQRTF(RS**2+RO**2-2.0*RS*RO*COSF(ELIIR))
C   OMGA (FROM GRM4) IS THE ANGULAR ROTATION VELOCITY AT THE SOURCE (KM/SEC/KPC)
      CALL GRM4 (RC,  OMGA)                                                 GRM4
C   OMGAO IS THE ANGULAR ROTATION VELOCITY AT THE SUN (KM/SEC/KPC)
      OMGAO=25.0
C   AND THEN VR IS JUST
      VR=(OMGA-OMGAO)*RO*SINF(ELIIR)
C   A IS THE ANGLE BETWEEN THE SUN AND THE SOURCE AS SEEN FROM THE GALACTIC
C   CENTER (RADIANS)
C   SNA IS SIN(A) (DIMENSIONLESS)
      SNA=RS*SINF(ELIIR)/RC
C   CSA IS COS(A) (DIMENSIONLESS)
      CSA=(RO**2+RC**2-RS**2)/(2.0*RO*RC)
C   THEN A IS JUST
      A=2.0*ATANF(SNA/(1.0+CSA))
C   AND PSI (CONVERTED TO DEGREES) IS JUST
      PSI=-A*180.0/PI
      RETURN
      END
```

```
      SUBROUTINE GRM3 (OMGA,  RC)
C     SUBROUTINE GRM3 (GALACTIC ROTATION MODEL - 3) ACCEPTS THE ANGULAR ROTATION
C     VELOCITY (OMGA IN KM/SEC/KPC) AND RETURNS THE DISTANCE FROM THE GALACTIC
C     CENTER (RC IN KPC), BASED ON THE MODEL OF THE GALAXY SUGGESTED BY SCHMIDT
C     (1965).  SEE SUBROUTINE GRM4 FOR FURTHER DETAILS.
C
C     IF OMGA .LE. 0 THEN RC = 0
      IF (OMGA) 10,10,20
   10 RC=0.0
      RETURN
C
C     UNFORTUNATELY THERE IS NO WAY TO INVERT SCHMIDT'S EQUATIONS TO OBTAIN RC
C     DIRECTLY FROM OMGA.  THE FOLLOWING ITERATION PROCEDURE SEEMS TO WORK AS WELL
C     AS ANY.  IT IS BASED ON THE APPROXIMATION THAT THE CIRCULAR VELOCITY
C     (=OMGA*RC) IS A SLOWLY VARYING FUNCTION OF RC.  THE NUMBER 200 IS A FIRST
C     GUESS AT THIS VELOCITY.
   20 RC=200.0/OMGA
      DO 30 I=1,5                                                       I
      CALL GRM4 (RC,  OMGAT)                                         GRM4
C     (NOTE THAT B GOES TO 1 FOR RC MUCH LESS THAN 10, AND TO 2/3 FOR LARGE RC)
      B=(2.0+10.0/(10.0+RC))/3.0
      RC=RC+RC*B*(OMGAT-OMGA)/OMGA
   30 CONTINUE                                                          I
      RETURN
      END
```

```
      SUBROUTINE GRM4 (RC,  OMGA)
C   SUBROUTINE GRM4 (GALACTIC ROTATION MODEL - 4) ACCEPTS THE DISTANCE FROM THE
C   GALACTIC CENTER (RC IN KPC) AND RETURNS THE ANGULAR ROTATION VELOCITY (OMGA
C   IN KM/SEC/KPC).  BASED ON THE MODEL OF THE GALAXY SUGGESTED BY MAARTEN
C   SCHMIDT, CHAP. 22 IN GALACTIC STRUCTURE, ED. BY A. BLAAUW AND M. SCHMIDT,
C   UNIV. OF CHICAGO PRESS, 1965.
C
C   IF RC .LE. 0 THEN OMGA = 0
      IF (RC) 10,10,20
   10 OMGA=0.0
      RETURN
C
   20 IF (RC-10.0) 40,30,50
   30 OMGA=25.0
      RETURN
C
C   THE FOLLOWING CALCULATIONS ARE FOR RC .LT. 10 KPC
C   VC IS THE CIRCULAR VELOCITY (KM/SEC)
   40 VC=SQRTF(30000.0/RC+10120.2*RC-41.722*RC**3)
C   THEN OMGA IS JUST
      OMGA=VC/RC
      RETURN
C
C   THE FOLLOWING CALCULATIONS ARE FOR RC .GT. 10 KPC
   50 VC=SQRTF(851611.6/RC-2148585.1/RC**2)
      OMGA=VC/RC
      RETURN
      END
```

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13. ABSTRACT

This note is a description of the subprograms DOP, which calculates the Doppler velocity of an earth-bound observer, JULDA which calculates the Julian day-number, MOVE which calculates precession, COORD which performs coordinate transformations, and the GRM series of subprograms which deal with Doppler velocities in terms of a standard galactic rotation model. These subprograms are written in basic FORTRAN and should be useable on a wide variety of computers.

14. KEY WORDS

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computer programming