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Implementation of the new nomenclature in The Astronomical Almanac

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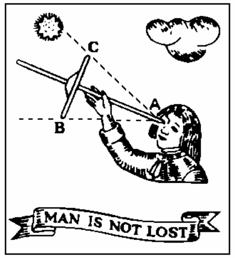
This Talk

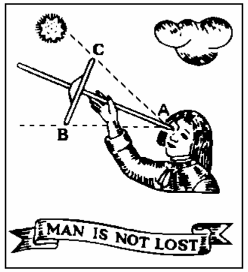
- *The Astronomical Almanac* (AsA)
- Why there are changes to the AsA
- What needed to be done
- Why I've done what I've done
- What the changes actually are



The Astronomical Almanac

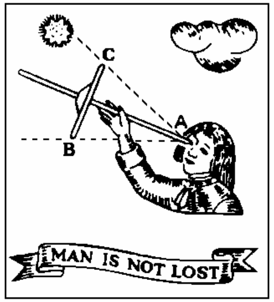
Joint publication with US Naval Observatory

- Reference product for the year
- Useful to the people who need the information
- Must maintain “standards”
  - Up to date & reliable



The Astronomical Almanac

- Not at the leading edge
  - Not yet a standard; changing quickly
  - Users require continuity
- Not an educational product
- Production process
  - Deadlines, funding, and personnel



The AsA & The AsA Online

USNO – sections

- C – Sun
- E – Planets
- F– Satellites*
- H – Stars
- L – Glossary
- M – Notes & References

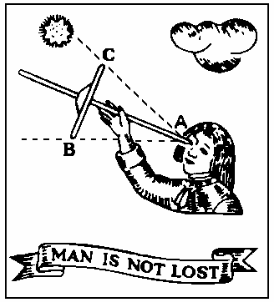
HMNAO – sections

- A – Phenomena
- **B – Times scales & reference systems**
- D – Moon
- G – Minor planets
- K – Reference data

* Some data provided by BdL

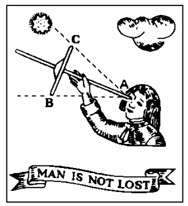
Implications of IAU 2000 Resolutions

- ICRS & Frame Bias
- IAU 2000 Precession-nutation
- Celestial Intermediate Pole & Origin *X, Y, s*
- Earth Rotation Angle
- Explanation & Nomenclature
- Software - IAU SOFA
  - – Comparisons with NOVAS (GK)



Section B: Time Scales and Reference Systems

- Tables
  - Earth rotation angle, (ERA – GAST)
  - Celestial intermediate pole & origin: *X, Y, s*
  - **C** the ICRS to intermediate matrix
- Explanation
  - Celestial Intermediate Reference System
  - Another set of precession angles: χ, ψ, ω, ε_0
  - Use of the CIO Method



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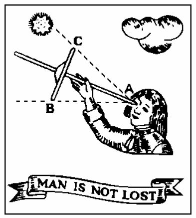
New Table

• Journées 2004

B20 UNIVERSAL TIME AND EARTH ROTATION ANGLE, 2006

Date 0^h UT1	Julian Date 245	Earth Rotation Angle ° ′ ″	Equation of the Origins ′ ″	Date 0^h UT1	Julian Date 245	Earth Rotation Angle ° ′ ″	Equation of the Origins ′ ″
Jan. 0	3735·5	99 26 39·6076	− 4 34·6091	Feb. 15	3781·5	144 46 57·0025	− 4 41·9679
1	3736·5	100 25 47·8118	− 4 34·9270	16	3782·5	145 46 05·2067	− 4 41·9872
2	3737·5	101 24 56·0160	− 4 35·2004	17	3783·5	146 45 13·4109	− 4 42·0010
3	3738·5	102 24 04·2203	− 4 35·4072	18	3784·5	147 44 21·6152	− 4 42·0258
4	3739·5	103 23 12·4245	− 4 35·5460	19	3785·5	148 43 29·8194	− 4 42·0771
5	3740·5	104 22 20·6287	− 4 35·6349	20	3786·5	149 42 38·0236	− 4 42·1679
6	3741·5	105 21 28·8330	− 4 35·7030	21	3787·5	150 41 46·2279	− 4 42·3065
7	3742·5	106 20 37·0372	− 4 35·7807	22	3788·5	151 40 54·4321	− 4 42·4937
8	3743·5	107 19 45·2414	− 4 35·8911	23	3789·5	152 40 02·6364	− 4 42·7206
9	3744·5	108 18 53·4457	− 4 36·0466	24	3790·5	153 39 10·8406	− 4 42·9676
10	3745·5	109 18 01·6499	− 4 36·2482	25	3791·5	154 38 19·0448	− 4 43·2059
11	3746·5	110 17 09·8542	− 4 36·4870	26	3792·5	155 37 27·2491	− 4 43·4034
12	3747·5	111 16 18·0584	− 4 36·7477	27	3793·5	156 36 35·4533	− 4 43·5359
13	3748·5	112 15 26·2626	− 4 37·0119	28	3794·5	157 35 43·6575	− 4 43·5984
14	3749·5	113 14 34·4669	− 4 37·2617	Mar. 1	3795·5	158 34 51·8618	− 4 43·6093



GHA = Earth rotation angle $- \alpha_i$, $\alpha_i = \alpha_e +$ equation of the origins

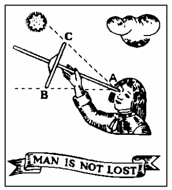
α_i, α_e are the right ascensions with respect to the CIO and the true equinox of date, respectively.

Modified Table

B32 NUTATION, OBLIQUITY & INTERMEDIATE SYSTEM, 2006

FOR 0^h TERRESTRIAL TIME

Date 0^h TT		NUTATION in Long. $\Delta\psi$	NUTATION in Obl. $\Delta\epsilon$	True Obl. of Ecliptic ϵ 23° 26′	Julian Date 0^h TT	CELESTIAL INTERMEDIATE SYSTEM Pole $\mathcal{X}$	Pole $\mathcal{Y}$	Origin s
		″	″	″		″	″	″
Jan.	0	− 2·1954	+ 8·3424	26·9813	3735·5	+ 119·3163	+ 8·2546	− 0·0025
	1	− 1·9865	+ 8·3810	27·0186	3736·5	+ 119·4543	+ 8·2931	− 0·0025
	2	− 1·8262	+ 8·4452	27·0815	3737·5	+ 119·5731	+ 8·3570	− 0·0025
	3	− 1·7383	+ 8·5198	27·1548	3738·5	+ 119·6630	+ 8·4316	− 0·0026
	4	− 1·7246	+ 8·5872	27·2209	3739·5	+ 119·7234	+ 8·4989	− 0·0026
	5	− 1·7653	+ 8·6328	27·2653	3740·5	+ 119·7621	+ 8·5445	− 0·0026
	6	− 1·8287	+ 8·6496	27·2808	3741·5	+ 119·7918	+ 8·5612	− 0·0026
	7	− 1·8817	+ 8·6388	27·2687	3742·5	+ 119·8256	+ 8·5503	− 0·0026
	8	− 1·8990	+ 8·6079	27·2365	3743·5	+ 119·8736	+ 8·5193	− 0·0026
	9	− 1·8672	+ 8·5679	27·1952	3744·5	+ 119·9410	+ 8·4793	− 0·0026
	10	− 1·7852	+ 8·5304	27·1564	3745·5	+ 120·0285	+ 8·4417	− 0·0025
	11	− 1·6625	+ 8·5053	27·1300	3746·5	+ 120·1321	+ 8·4164	− 0·0025
	12	− 1·5160	+ 8·4991	27·1226	3747·5	+ 120·2453	+ 8·4101	− 0·0025
	13	− 1·3657	+ 8·5146	27·1368	3748·5	+ 120·3600	+ 8·4254	− 0·0025
	14	− 1·2311	+ 8·5505	27·1714	3749·5	+ 120·4684	+ 8·4612	− 0·0025



ICRS to Equator of Date Matrices

B40 ICRS FRAME BIAS, PRECESSION AND NUTATION, 2006

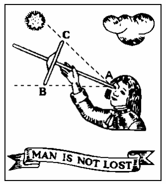
MATRIX ELEMENTS FOR CONVERSION FROM
ICRS TO TRUE EQUATOR AND EQUINOX OF DATE

Date 0^h TT		$NPB_{11}-1$	NPB_{12}	NPB_{13}	NPB_{21}	$NPB_{22}-1$	NPB_{23}	NPB_{31}	NPB_{32}	$NPB_{33}-1$
Jan.	**0**	−105	−133 134	− 57 841	+133 132	− 89	−4079	+ 57 846	+4002	− 17
	1	−106	−133 288	− 57 908	+133 286	− 89	−4098	+ 57 913	+4021	− 17
	2	−106	−133 421	− 57 965	+133 418	− 89	−4129	+ 57 971	+4052	− 17
	3	−106	−133 521	− 58						
	4	−106	−133 588	− 58						
	5	−106	−133 631	− 58						
	6	−106	−133 664	− 58						
	7	−106	−133 702	− 58						
	8	−106	−133 756	− 58						
	9	−106	−133 831	− 58						

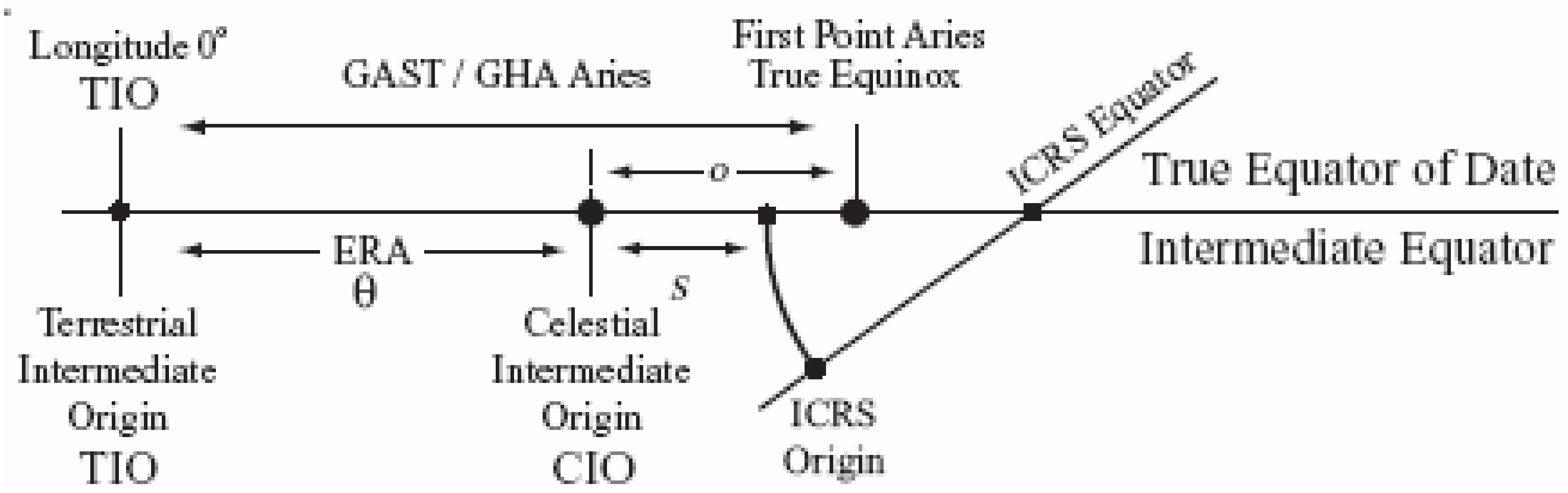
ICRS TO CELESTIAL INTERMEDIATE SYSTEM, 2006 B41

MATRIX ELEMENTS FOR CONVERSION FROM
ICRS TO CELESTIAL INTERMEDIATE ORIGIN AND TRUE EQUATOR OF DATE

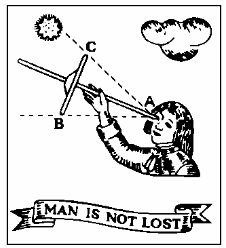
Julian Date	$C_{11}-1$	C_{12}	C_{13}	C_{21}	$C_{22}-1$	C_{23}	C_{31}	C_{32}	$C_{33}-1$
245									
3735·5	− 1673	+ 6	− 578 4616	−237	− 8	−40 0195	+ 578 4616	+40 0195	− 1681
3736·5	− 1677	+ 6	− 579 1308	−238	− 8	−40 2059	+ 579 1308	+40 2060	− 1685
3737·5	− 1680	+ 5	− 579 7065	−240	− 8	−40 5160	+ 579 7065	+40 5161	− 1689
3738·5	− 1683	+ 5	− 580 1425	−242	− 8	−40 8775	+ 580 1425	+40 8775	− 1691
3739·5	− 1685	+ 5	− 580 4354	−244	− 8	−41 2038	+ 580 4354	+41 2038	− 1693
3740·5	− 1686	+ 5	− 580 6232	−245	− 9	−41 4247	+ 580 6232	+41 4247	− 1694
3741·5	− 1686	+ 5	− 580 7672	−246	− 9	−41 5060	+ 580 7672	+41 5060	− 1695
3742·5	− 1687	+ 5	− 580 9309	−246	− 9	−41 4531	+ 580 9309	+41 4531	− 1696
3743·5	− 1689	+ 5	− 581 1634	−245	− 9	−41 3029	+ 581 1634	+41 3029	− 1697
3744·5	− 1691	+ 5	− 581 4906	−244	− 8	−41 1086	+ 581 4906	+41 1086	− 1699



Relationship between GAST & ERA



Schematic Diagram



Apparent Place Example

1. **ICRS**: Form geocentric vector, apply corrections for light-time, light deflection, aberration as appropriate;

2. **Rotations: from ICRS** to required equator of date & origin;

Equinox-based

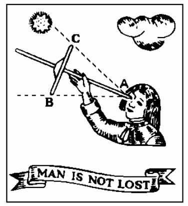
1. Apply **NPB** to give the true equinox and equator of date,
2. Apply GAST.

OR

CIO-based

1. Apply **C**(X,Y,s) to give the Celestial Intermediate System,
2. Apply ERA.

3. **Calculate** hour angle and declination.



How to Calculate an Apparent Place

Planetary reduction

Data and formulae are provided for the precise computation ... solar system, of its apparent geocentric right ascension, its gec... ascension, declination, and the hour angle, ignoring polar mot... instant of time, from a barycentric ephemeris in rectangular ... coordinate time referred to the International Celestial Refere... J2000·0).

1. Given an instant for which the position of the planet is re... time (TDB) to use with the ephemeris. If the position is ... Time (UT1), or the hour angle is required, then obtain ... have to be predicted.
2. Calculate the geocentric rectangular coordinates of ... ephemerides of the planet and the Earth for the IC... ordinate time argument TDB, allowing for light tir... coordinates.
3. Calculate the direction of the planet relative to the ... inertial frame that is instantaneously stationary in th... the solar system), allowing for light deflection due ...
4. Calculate the direction of the planet relative to ... applying the correction for the Earth's orbital ... annual aberration). The resulting direction is for th...

Equinox Method

5. Apply frame bias, precession and nutation to convert from the ICRF to the true equator and equinox of date frame.
6. Convert to spherical coordinates, giving the geocentric apparent right ascension and declination with respect to the true equinox and equator of date.
7. Calculate Greenwich apparent sidereal time and form the hour angle for the given UT1.

IAU 2000 Method

5. Rotate the ICRS frame to the celestial intermediate frame using $\mathcal{X}, \mathcal{Y}$ and s to apply frame bias, precession & nutation.
6. Convert to spherical coordinates, giving the geocentric intermediate right ascension and declination with respect to the CIO and the true equator of date.
7. Calculate the Earth Rotation Angle and form the hour angle for the given UT1.

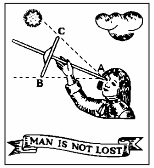
Alternatively, if right ascension is not required, combine Steps 5 and 7

*5. Apply frame bias, precession and nutation, and Greenwich apparent sidereal time to convert from the ICRS to the terrestrial frame; origin the TIO and the true equator of date frame.

*5. Rotate, using $\mathcal{X}, \mathcal{Y}$, s and θ to apply frame bias, precession, nutation and Earth rotation, from the ICRS to the terrestrial frame; origin the TIO and the true equator of date frame.

*6. Convert to spherical coordinates, giving the (apparent) hour angle and declination with respect to the TIO and the true equator of date.

Note: In *Step 7* and *Step 5** the tiny difference between the ITRF zero meridian and the terrestrial intermediate origin and the effects of polar motion (see page B74) have been ignored.



Approximate (~1″) Star Altitude & Azimuth

Step B. Apply aberration (from $\dot{e}$) and precession-nutation (using $\mathcal{X}$, $\mathcal{Y}$) to form

$$
\begin{aligned}
x_i &= (1 - \mathcal{X}^2/2)\, p_x - \mathcal{X}\, p_z + \dot{e}_x/c &&= -0{\cdot}373\,494 \\
y_i &= p_y - \mathcal{Y}\, p_z + \dot{e}_y/c &&= -0{\cdot}312\,495 \\
z_i &= \mathcal{X}\, p_x + \mathcal{Y}\, p_y + (1 - \mathcal{X}^2/2)\, p_z + \dot{e}_z/c &&= -0{\cdot}873\,355
\end{aligned}
$$

where (x_i, y_i, z_i) is the position with respect to the intermediate system. $c = 173{\cdot}14$ au/d,

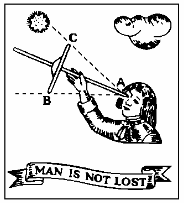
$$\dot{e} = (0{\cdot}0172 \sin\lambda, -0{\cdot}0158\cos\lambda, -0{\cdot}0068\cos\lambda) = (-0{\cdot}016\,89, -0{\cdot}002\,98, -0{\cdot}001\,28)$$

and $\mathcal{X} = +0{\cdot}000\,579$, $\mathcal{Y} = +0{\cdot}000\,041$, the position of the CIP, are evaluated using the approximate formulae on page B56, with arguments $\Omega = 8^{\circ}\!.9$, $2L = 201^{\circ}\!.7$, and the longitude of the Earth, $\lambda = (2L + 360^{\circ})/2 = 280^{\circ}\!.9$. Converting to spherical coordinates gives $\alpha_i = 14^{\mathrm{h}}\ 39^{\mathrm{m}}\ 40^{\mathrm{s}}\!.5$ and $\delta = -60^{\circ}\ 51'\ 22''$ (see page B61).

Step C. Transform from the celestial intermediate origin and equator of date to the observer's meridian (longitude $\lambda = -60^{\circ}\!.0$, west longitudes are $-$ve)

$$
\begin{aligned}
x_g &= +x_i \cos(\theta + \lambda) + y_i \sin(\theta + \lambda) &&= +0{\cdot}286\,584 \\
y_g &= -x_i \sin(\theta + \lambda) + y_i \cos(\theta + \lambda) &&= +0{\cdot}393\,727 \\
z_g &= +z_i &&= -0{\cdot}873\,355
\end{aligned}
$$

where $\theta = 99^{\circ}\!.444\,335 + 0^{\circ}\!.985\,6123 \times$ day of year $+ 15^{\circ}\!.041\,07 \times \mathrm{UT1} = 225^{\circ}\!.968\,542$ is the Earth rotation angle (see B9). Thus $LHA = \tan^{-1} - y_g/x_g = 306^{\circ}\ 03'\ 00''$, measured clockwise from south is the local hour angle, and $\delta = -60^{\circ}\ 51'\ 22''$ is unchanged (Step B).



Summary of Nomenclature

Equinox Based

- True Eq & Eq of Date
  - CIP (*X*, *Y*)
  - True equator of date
  - True equinox of date
  - Apparent place
  - Apparent RA
  - Declination
- GAST

CIO Based

- CIRS
  - CIP (*X*, *Y*)
  - Celestial Intermediate Equator
  - CIO (*s*)
  - Intermediate place
  - Intermediate RA
  - Declination
- ERA

Quantities in the same colour are **identical**