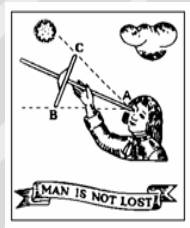
POLISH ACADEMY OF SCIENCES
SPACE RESEARCH CENTRE
l'Observatoire de Paris

Journées 2005
Systèmes de Référence Spatio-Temporels
"Earth dynamics and reference systems:
five years after the adoption
of the IAU 2000 Resolutions"
Warsaw, 19-21 September 2005

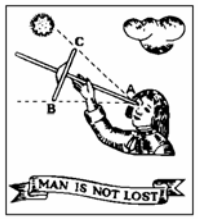
Progress on the Implementation of the New Nomenclature in *The Astronomical Almanac*

Catherine Hohenkerk
HM Nautical Almanac Office

George Kaplan
US Naval Observatory



USNO



The Astronomical Almanac

&

The Astronomical Almanac Online

Joint publication of USNO & HMNAO

- Reference product for the year
- Useful to the people who need the information
- Must maintain international “standards” — up to date & reliable
- 2006 edition available since Jan 2005 — first edition with IAU 2000 & new nomenclature
- 2007 in preparation – to press October 1, 2005

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 – Time scales & reference systems
- D – Moon
- G – Minor planets
- K – Reference data

Section B: Time Scales & Reference Systems

- **Software comparisons**
- **Tables**
- **Explanation**

Software Comparisons

- HMNAO

  IAU-**SOFA**

- USNO

  NOVAS

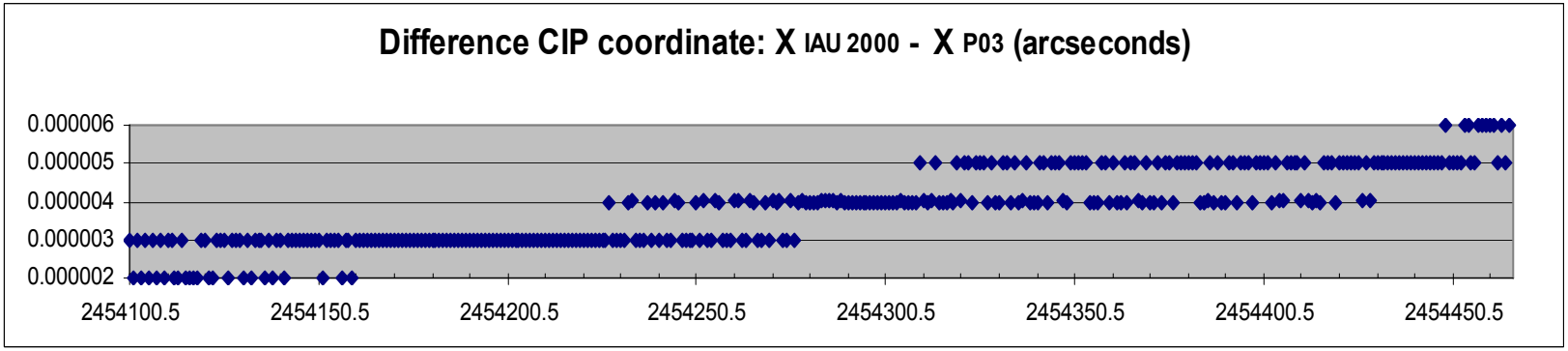
- Recommendations by WG Precession & the Ecliptic (P03)

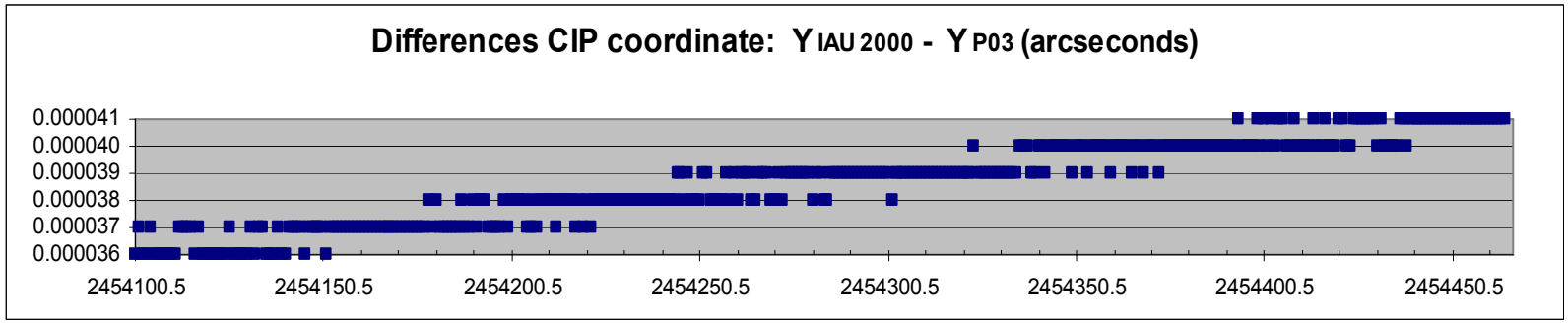
Software: P03
Recommended by IAU WG on Precession & the Ecliptic

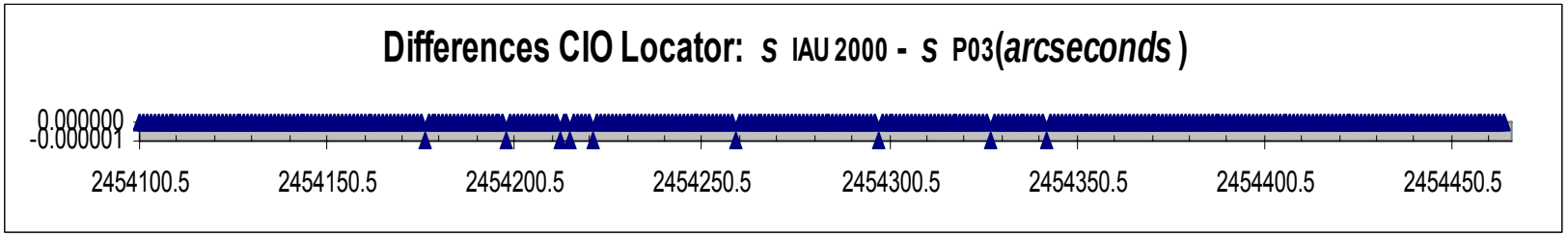
- AsA 2007 (& 2006) do **not** use P03
  - Not yet an IAU standard
  - Not yet incorporated into SOFA
  - NOVAS (v 3) code is **already** written
  - Differences **hardly** affect the printed precision of AsA 2007.
- AsA 2008 will use P03 from SOFA & NOVAS 3

Differences: 2007, CIP & CIO Locator

IAU 2000 – P03







Differences: XY of CIP, CIO Locator & Obliquity

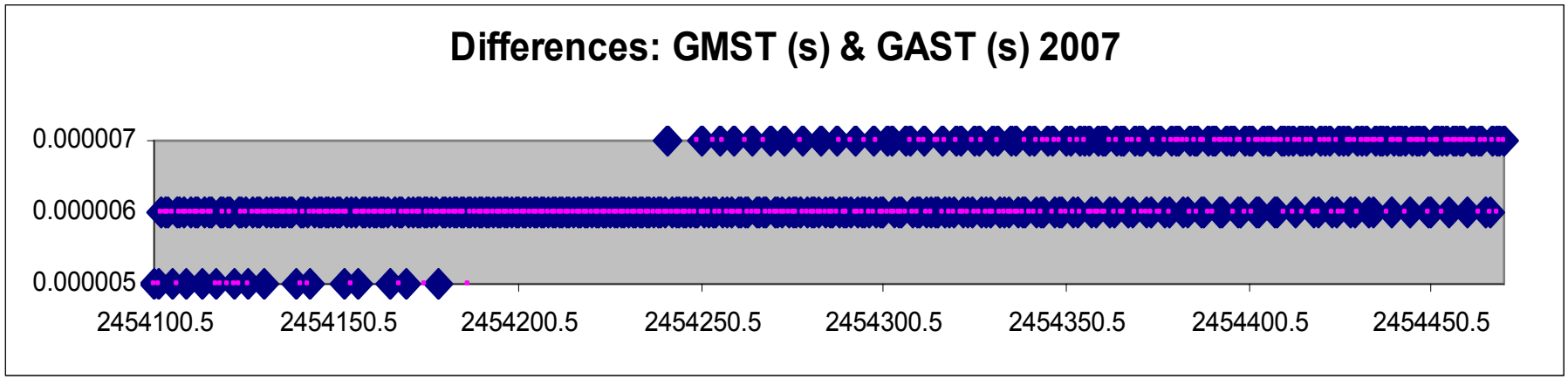
IAU 2000 – P03

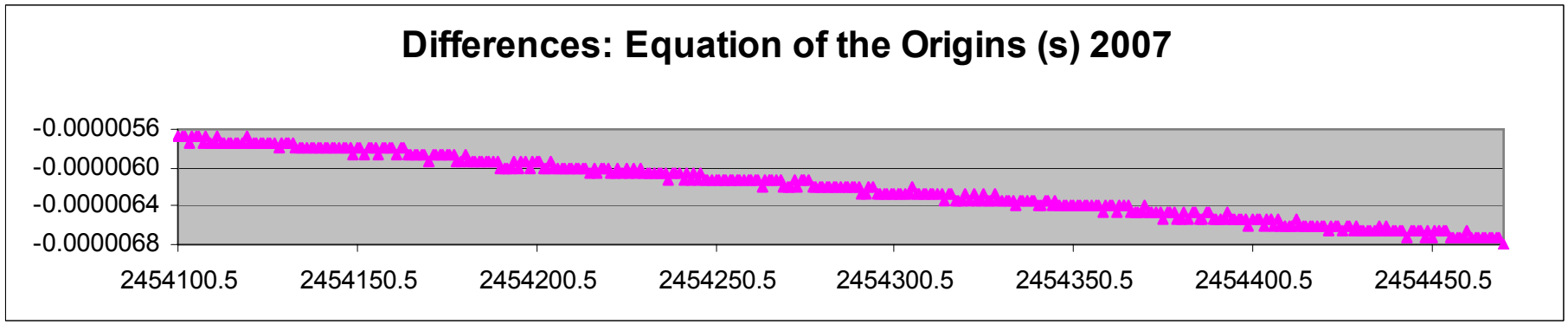
In units of printed precision 0.1 mas (0″.0001)

Quantity	2007	2006-2008
	mas	mas
X	[0.00,+0.01]	[0.00, +0.01]
Y	[+0.04]	[+0.03, +0.05]
s	[0.00]	[0.00]
ε	[+41.7, +41.8]	[+41.7, +41.8]

Differences: 2007, GMST/GAST & E_O

IAU 2000 – P03





Differences: Greenwich Mean & Apparent Sidereal Time, Equation of the Origins

IAU 2000 – P03

In units of the printed precision 0.1 ms ($0^s.0001$)

Quantity	2007	2006-2008
	ms	ms
GMST/GAST	[+0.005, +0.007]	[+0.004, +0.008]
E_o	[-0.007, -0.006]	[-0.008, -0.005]
	mas	mas
GMST/GAST	[+0.1]	[+0.1]
E_o	[-0.1]	[-0.1]

HMNAO(SOFA) v NOVAS: 2005 – 2007

1101 dates

Quantity Daily 0^h UT1	Unit	Decimal Places Printed	Decimal Places Checked	Number of Values 1 Different
GMST	s	4	6	0
GAST	s	4	6	1
E_E	s	4	6	0
ERA	″	4	6	0
E_O	″	4	6	224

HMNAO(SOFA) v NOVAS: 2005 – 2007

(1101 dates)

Quantity Daily 0^h TT	Unit	Decimal Places Printed	Decimal Places Checked	Number of Values 1 Different
$\Delta\psi$	″	4	6	3
$\Delta\varepsilon$	″	4	6	0
ε	″	4	6	0
X	″	4	6	160
Y	″	4	6	0
s*	″	4	10	see below

*s, 2 daily, 12^hTDB, differences between $\pm$ 1″ x 10^{-6}

HMNAO(SOFA) v NOVAS: 2005 – 2007

(1101 dates x 9 elements)

Quantity Daily 0^h TT	Decimal Places Printed	Decimal Places Checked	Number of Values 1 Different
NPB	10	12	15%
C* (ignoring elements C_{21} & C_{12})	10	12	15%

C_{21} & C_{12} 15% were different; maximum $\pm$ 5 in the 12^{th} place

Apparent Places, Sun, Moon, Planets: HMNAO v NOVAS

0″.001 printed precision

- Method in Section **B** ≠ **NOVAS** (2.9 Beta)
  - NOVAS modern implementation & includes light deflection from planets
- **2005-2015**, daily at 0^h TT, agreement better than $9'' \times 10^{-6}$, except
  - Moon; 0″.0003; limitations of double precision on the light-time iteration
  - Uranus & Neptune; close to Jupiter: 0″.0002

Tables in Section B

- Universal & Sidereal Times
- UT, Earth rotation angle, equation of the origins

- Nutations Long., & Obl., ε, and *X, Y, s*
- **NPB:** the GCRS to equator and equinox matrix
- **C:** the GCRS to intermediate matrix
- Position and velocity of the Earth

B20 UNIVERSAL TIME AND EARTH ROTATION ANGLE, 2007

Date 0^h UT1		Julian Date	Earth Rotation Angle θ	Equation of Origins E_o	Date 0^h UT1		Julian Date	Earth Rotation Angle θ	Equation of Origins E_o
		245	° ′ ″	′ ″			245	° ′ ″	′ ″
Jan.	0	4100·5	99 11 34·1541	− 5 25·6403	Feb.	15	4146·5	144 31 51·5490	− 5 33·2447
	1	4101·5	100 10 42·3583	− 5 25·8980		16	4147·5	145 30 59·7532	− 5 33·4479
	2	4102·5	101 09 50·5626	− 5 26·1914		17	4148·5	146 30 07·9575	− 5 33·5985
	3	4103·5	102 08 58·7668	− 5 26·4943		18	4149·5	147 29 16·1617	− 5 33·6866
	4	4104·5	103 08 06·9710	− 5 26·7799		19	4150·5	148 28 24·3660	− 5 33·7209
	5	4105·5	104 07 15·1753	− 5 27·0274		20	4151·5	149 27 32·5702	− 5 33·7279
	6	4106·5	105 06 23·3795	− 5 27·2259		21	4152·5	150 26 40·7744	− 5 33·7432
	7	4107·5	106 05 31·5838	− 5 27·3749		22	4153·5	151 25 48·9787	− 5 33·7980
	8	4108·5	107 04 39·7880	− 5 27·4825		23	4154·5	152 24 57·1829	− 5 33·9090
	9	4109·5	108 03 47·9922	− 5 27·5620		24	4155·5	153 24 05·3871	− 5 34·0758
	10	4110·5	109 02 56·1965	− 5 27·6293		25	4156·5	154 23 13·5914	− 5 34·2833
	11	4111·5	110 02 04·4007	− 5 27·7006		26	4157·5	155 22 21·7956	− 5 34·5090
	12	4112·5	111 01 12·6049	− 5 27·7908		27	4158·5	156 21 29·9999	− 5 34·7286
	13	4113·5	112 00 20·8092	− 5 27·9126		28	4159·5	157 20 38·2041	− 5 34·9211

$$\text{GHA} = \theta - \alpha_i, \qquad \alpha_i = \alpha_e + E_o$$

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

B34 NUTATION, OBLIQUITY & INTERMEDIATE SYSTEM, 2007

FOR 0^h TERRESTRIAL TIME

Date 0^h TT		NUTATION in Long. $\Delta\psi$	NUTATION in Obl. $\Delta\epsilon$	True Obl. of Ecliptic ϵ $23^\circ\ 26'$	Julian Date 0^h TT	CELESTIAL INTERMEDIATE Pole $\mathcal{X}$	Pole $\mathcal{Y}$	Origin s
		″	″	″		″	″	″
Jan.	0	+ 3·1893	+ 8·3914	26·5622	4100·5	+ 141·4879	+ 8·2711	− 0·0020
	1	+ 3·3325	+ 8·3471	26·5166	4101·5	+ 141·5996	+ 8·2267	− 0·0020
	2	+ 3·5146	+ 8·3248	26·4930	4102·5	+ 141·7269	+ 8·2041	− 0·0020
	3	+ 3·7071	+ 8·3297	26·4966	4103·5	+ 141·8584	+ 8·2088	− 0·0020
	4	+ 3·8808	+ 8·3605	26·5261	4104·5	+ 141·9824	+ 8·2394	− 0·0020
	5	+ 4·0129	+ 8·4103	26·5747	4105·5	+ 142·0899	+ 8·2891	− 0·0020
	6	+ 4·0917	+ 8·4693	26·6324	4106·5	+ 142·1762	+ 8·3479	− 0·0020
	7	+ 4·1165	+ 8·5272	26·6890	4107·5	+ 142·2411	+ 8·4057	− 0·0020
	8	+ 4·0962	+ 8·5755	26·7360	4108·5	+ 142·2880	+ 8·4539	− 0·0021
	9	+ 4·0453	+ 8·6083	26·7676	4109·5	+ 142·3226	+ 8·4867	− 0·0021

GCRS to Equator of Date Matrices

B42 FRAME BIAS, PRECESSION AND NUTATION, 2007

MATRIX ELEMENTS FOR CONVERSION FROM
GCRS TO TRUE EQUATOR AND EQUINOX OF DATE
FOR 0^h TERRESTRIAL TIME

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	−14815	−1578 7515	− 685 8885	+1578 7236	−12470	−41 1824	+ 685 9526	+40 0995	−2361
	1	−14838	−1580 0005	− 686 4306	+1579 9728	−12490	−40 9686	+ 686 4945	+39 8840	−2364
	2	−14865	−1581 4229	− 687 0478	+1581 3952	−12512	−40 8613	+ 687 1116	+39 7747	−2369
	3	−14892	−1582 8915	− 687 6851	+1582 8638	−12536	−40 8860	+ 687 7490	+39 7975	−2373
	4	−14918	−1584 2762	− 688 2860	+1584 2483	−12558	−41 0363	+ 688 3502	+39 9458	−2377

FRAME BIAS, PRECESSION AND NUTATION, 2007 B43

MATRIX ELEMENTS FOR CONVERSION FROM
GCRS TO CELESTIAL INTERMEDIATE ORIGIN & TRUE EQUATOR OF DATE
FOR 0^h TERRESTRIAL TIME

Julian Date	$C_{11}-1$	C_{12}	C_{13}	C_{21}	$C_{22}-1$	C_{23}	C_{31}	C_{32}	$C_{33}-1$
245									
4100·5	− 2353	− 40	− 685 9526	−235	− 8	−40 0995	+ 685 9526	+40 0995	− 2361
4101·5	− 2356	− 40	− 686 4945	−233	− 8	−39 8840	+ 686 4945	+39 8840	− 2364
4102·5	− 2361	− 41	− 687 1116	−233	− 8	−39 7747	+ 687 1116	+39 7747	− 2369
4103·5	− 2365	− 41	− 687 7490	−233	− 8	−39 7975	+ 687 7490	+39 7975	− 2373
4104·5	− 2369	− 41	− 688 3502	−234	− 8	−39 9458	+ 688 3502	+39 9458	− 2377

Explanation

- Corrected some mistakes
- Improved explanation
- ICRS/BCRS/GCRS
- Date – JD_{TT}, JD_{UT}
- Nomenclature, in line with WG recommendations
- Included the precession matrix using χ, ψ, ω, ε_0
- Made the pages less full – a few more pages

Approximate GCRS to CIO & Equator of Date, Valid for a Year (0″.3) : 2007

$$X = 140''.20 + 0.0549\,d - 6.8 \sin\Omega - 0.5 \sin 2L$$

$$Y = -0''.12 + 9.2 \cos\Omega + 0.6 \cos 2L$$

$$\mathbf{C} = \begin{pmatrix} 1 - X^2/2 & 0 & -X \\ 0 & 1 & -Y \\ X & Y & 1 - X^2/2 \end{pmatrix}$$

Exclude X^2 term: 2014 error in Dec increased to +/-0″.4

2025 error in Dec increased to +/-0″.7

Summary: Calculate GHA & δ

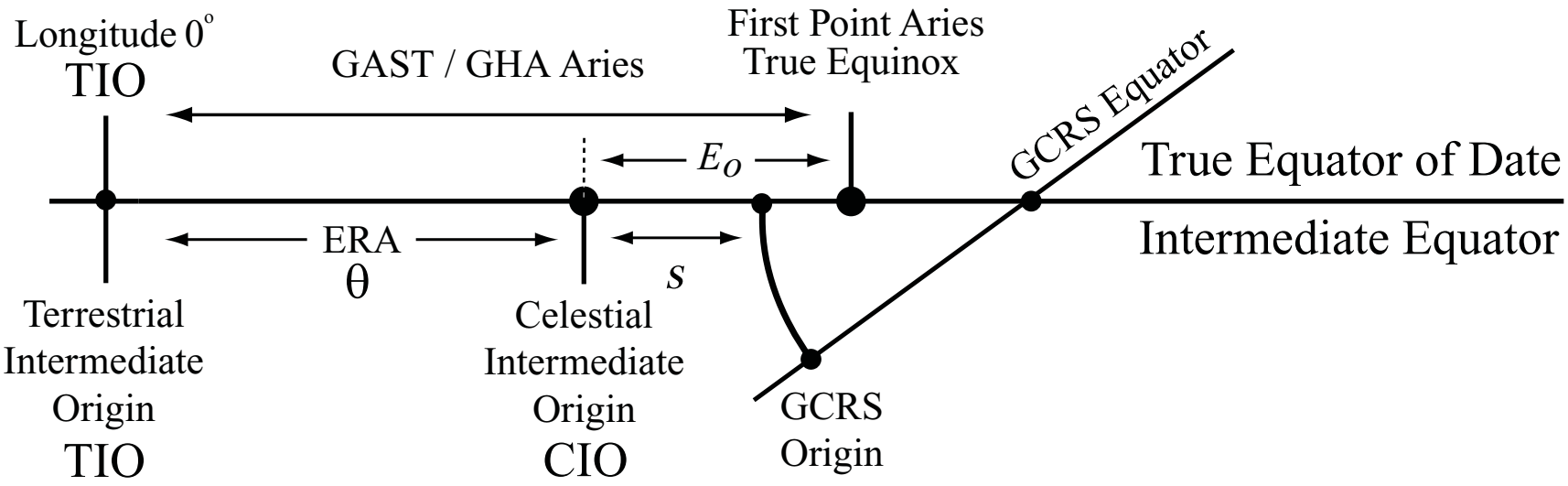
1. **GCRS**: calculate geocentric vector, apply corrections for light-time, light deflection, aberration as appropriate;

2. **Rotations**: transform **GCRS** to required "of date" system;

Equinox-based	OR	CIO-based
A. Apply **NPB** to give the true equinox and equator of date,		A. Apply **C**(*X*,*Y*,*s*) to give Celestial Intermediate Reference System,
B. Apply GAST.		B. Apply ERA.

3. **Calculate** hour angle (GHA) and declination (δ).

Summary
Relationship between GAST & ERA



Schematic Diagram

Summary of Nomenclature

Equinox Based

- True Equator & Equinox of date
  - CIP (*X*, *Y*)
  - True equator of date
  - True equinox of date
  - Apparent place
  - Apparent RA
  - Declination
- GAST
- Hour angle

CIO Based

- Celestial Intermediate Reference System
  - CIP (*X*, *Y*)
  - Celestial Intermediate Equator
  - CIO – located using *s*
  - Intermediate place
  - Intermediate RA
  - Declination
- ERA
- Hour angle

IAU 2000 (2006) Resolutions Explained

- USNO Circular 179 by George Kaplan

  http://aa.usno.navy.mil/kaplan/Circular.html

- Printed version available in December 2005