The VLBI contribution to precession (present and future)

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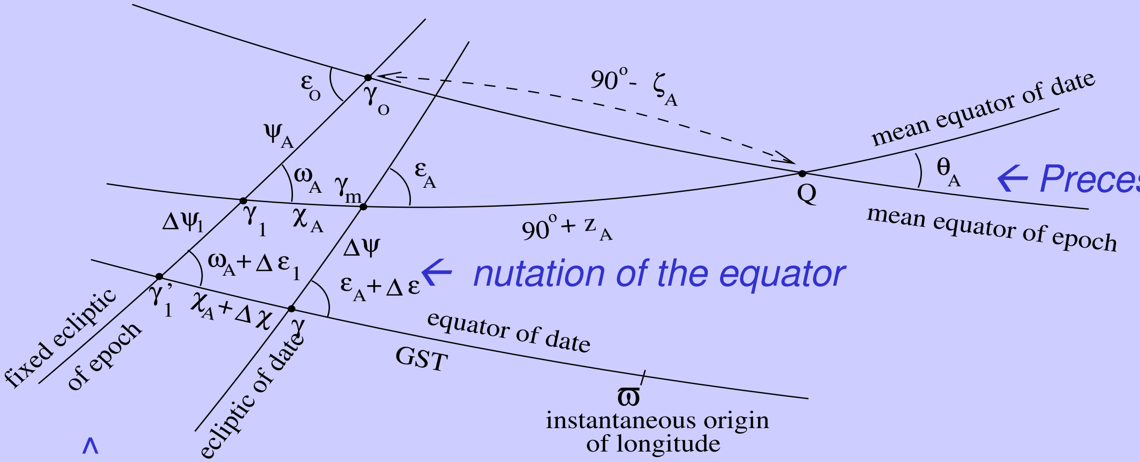
Precession-nutation parameters

Classical: equinox-based



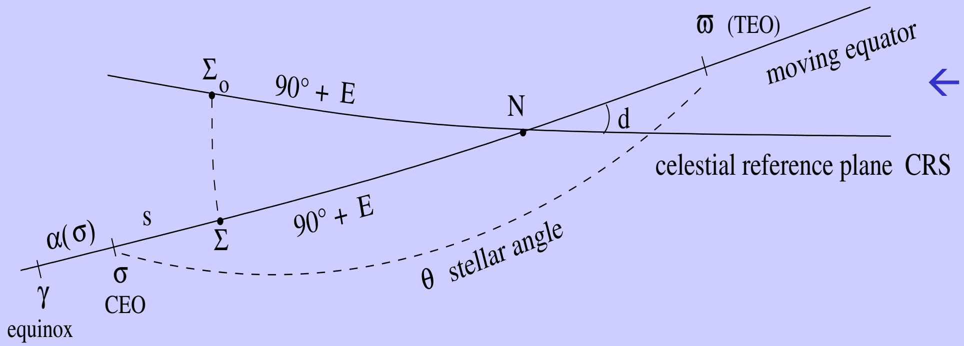
← Precession of the equator

← nutation of the equator

^

Precession
of the
ecliptic

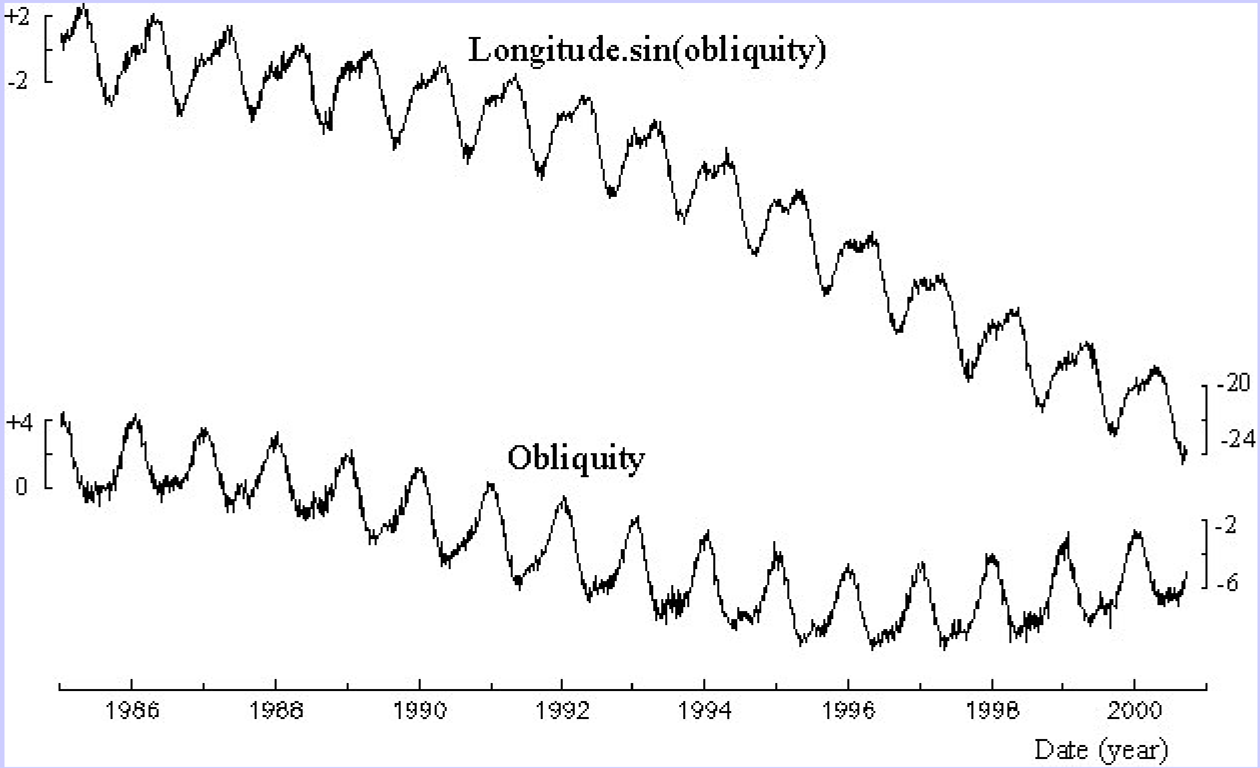
New: CEO based



←Precession-nutation
of the equator

VLBI estimation of celestial pole offsets

w.r.t. 1976/1980 precession-nutation model



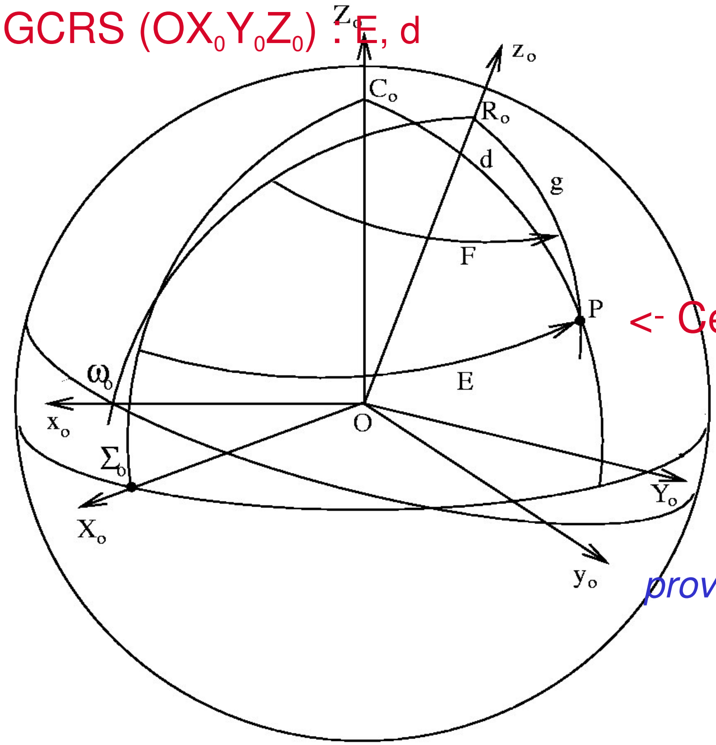
VLBI provides the actual position of the pole in the GCRS

-> *corrections to the model + frame biases*

Position of the CIP in GCRS and ITRS

position of the CIP
in the ITRS ($Ox_0y_0z_0$): F, g

position of the CIP
in the GCRS ($OX_0Y_0Z_0$) : E, d



<- Celestial Intermediate Pole

X=sind cosE, Y=sind sinE

are the x, y-coordinates
of the CIP unit vector
provides directly where the pole is in the sky

IAU 2000 precession-nutation

- *IAU 2000 Nutation (FCN not included)*

  IAU 2000A **:** for high precision level

  luni-solar terms (678) + planetary terms (687) *(Mathews et al. 2002)* based on rigid Earth nutation *(Souchay et al. 1999), MHB transfer function and VLBI data*

  → 7 basic Earth parameters (BEP) including H (dynamical flattening)

  IAU 2000B (its shorter version): for 1 mas level *(McCarthy & Luzum 2002)*

- ***Precession component of the IAU 2000 model***

  Lieske et al. 1977 + improved **rates of precession**

  $\mathrm{d}\psi_A$ (IAU 2000) = (- 0.299 650 +- 0.000 400)" /c

  $\mathrm{d}\omega_A$ (IAU 2000) = (- 0.025 240 +- 0.000 100)"/c

- *Celestial pole offsets* at J2000 in the GCRS (VLBI estimates)

  ξ_0 (IAU 2000) = (- 16.6170 +- 0.0100) mas

  η_0 (IAU 2000) = (- 6.8192 +- 0.0100) mas

IAU 2000 expressions for X and Y

(Capitaine, Chapront, Lambert, Wallace 2003, A&A 400)

$$X = -0.''016617 + 2004.''191743\, t - 0.''4272190\, t^2$$
$$- 0.''1986205\, t^3 - 0.''0000460\, t^4 + 0.''0000060\, t^5$$
$$+ \Sigma_i [(a_{s,0})_i \sin(\text{ARGUMENT}) + (a_{c,0})_i \cos(\text{ARGUMENT})]$$
$$+ \Sigma_i [(a_{s,1})_i\, t \sin(\text{ARGUMENT}) + (a_{c,1})_i\, t \cos(\text{ARGUMENT})]$$
$$+ \Sigma_i [(a_{s,2})_i\, t^2 \sin(\text{ARGUMENT}) + (a_{c,2})_i\, t^2 \cos(\text{ARGUMENT})]$$
$$+ \ldots$$

$$Y = -0.''006951 - 0.''025382\, t - 22.''4072510\, t^2$$
$$+ 0.''0018423\, t^3 + 0.''0011131\, t^4 + 0.''0000099\, t^5$$
$$+ \Sigma_i [(b_{c,0})_i \cos(\text{ARGUMENT}) + (b_{s,0})_i \sin(\text{ARGUMENT})]$$
$$+ \Sigma_i [(b_{c,1})_i\, t \cos(\text{ARGUMENT}) + (b_{s,1})_i\, t \sin(\text{ARGUMENT})]$$
$$+ \Sigma_i [(b_{c,2})_i\, t^2 \cos(\text{ARGUMENT}) + (b_{s,2})_i\, t^2 \sin(\text{ARGUMENT})]$$
$$+ \ldots$$

precession ; bias effect ; nutation ; cross terms precessionxnutation

IAU 2000 expression for GST

(Capitaine, Wallace, McCarthy 2003, A&A 406)

$$\mathrm{GST} = \theta + \int_{t_0}^{t} \overset{\cdot}{\overbrace{(\psi_A + \Delta\psi_1)}} \cos(\omega_A + \Delta\varepsilon_1)\,dt - \chi_A + \Delta\psi \cos\varepsilon_A + \Delta\psi_1 \cos\omega_A$$

$$\mathbf{GMST_{2000}} = \theta\,(\mathrm{UT1}) + 0''.014506$$

$$+\ 4612''.15739966\, t + 1''.39667721\, t^2 - 0''.00009344\, t^3 + 0''.0000188\, t^4$$

accumulated precession in RA (in TT)

$$\mathbf{EE_{2000}} = +\,\Delta\psi \cos\varepsilon_A - \Sigma_k C_k \sin\alpha_k - 0.87\ \mu\mathrm{as}\ t \sin\Omega$$

kinematical equation of equinoxes

Further improvement in Precession

Expressions for the precession of the equator should be (i) solutions of the dynamical equations for the Earth's rotation and (ii) referred to an improved ecliptic precession w.r.t Lieske et al. 1977

-> New models compatible with IAU 2000 with improved dynamical consistency

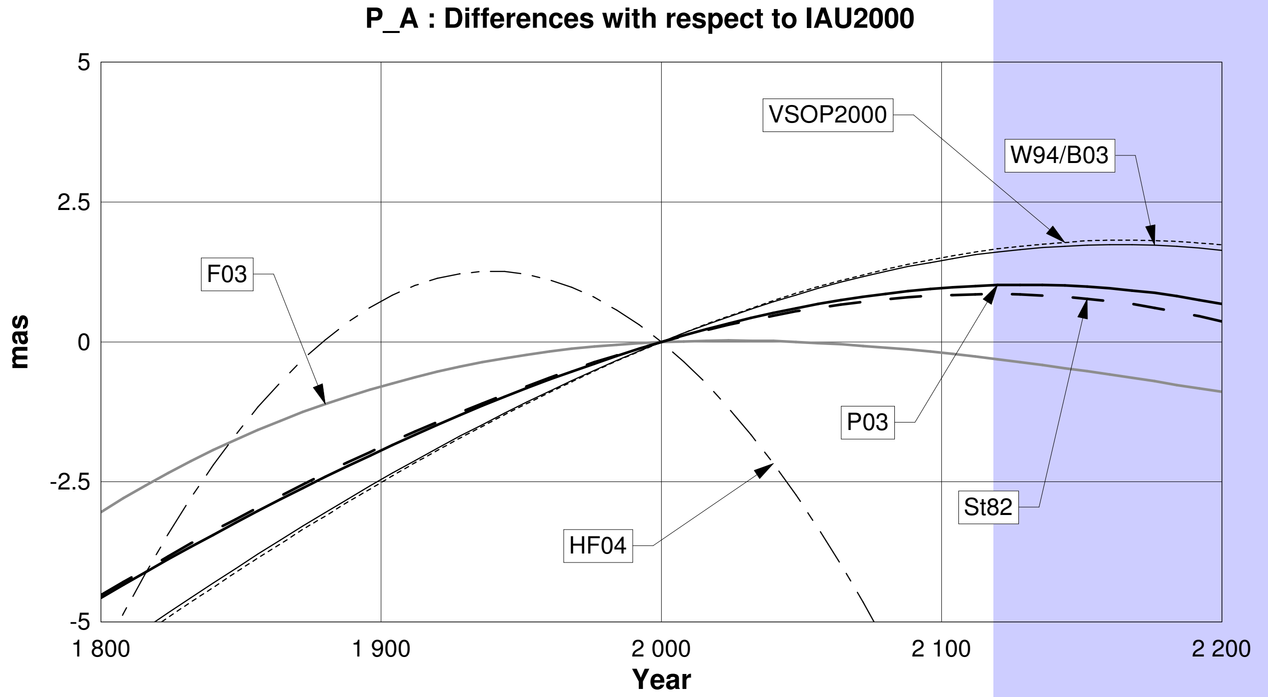
- Bretagnon P., Fienga A., Simon J.L. (2003, *A&A* 400): BO3
VSOP87 ecliptic + SMART 97 nutation + MHB precession rate in longitude

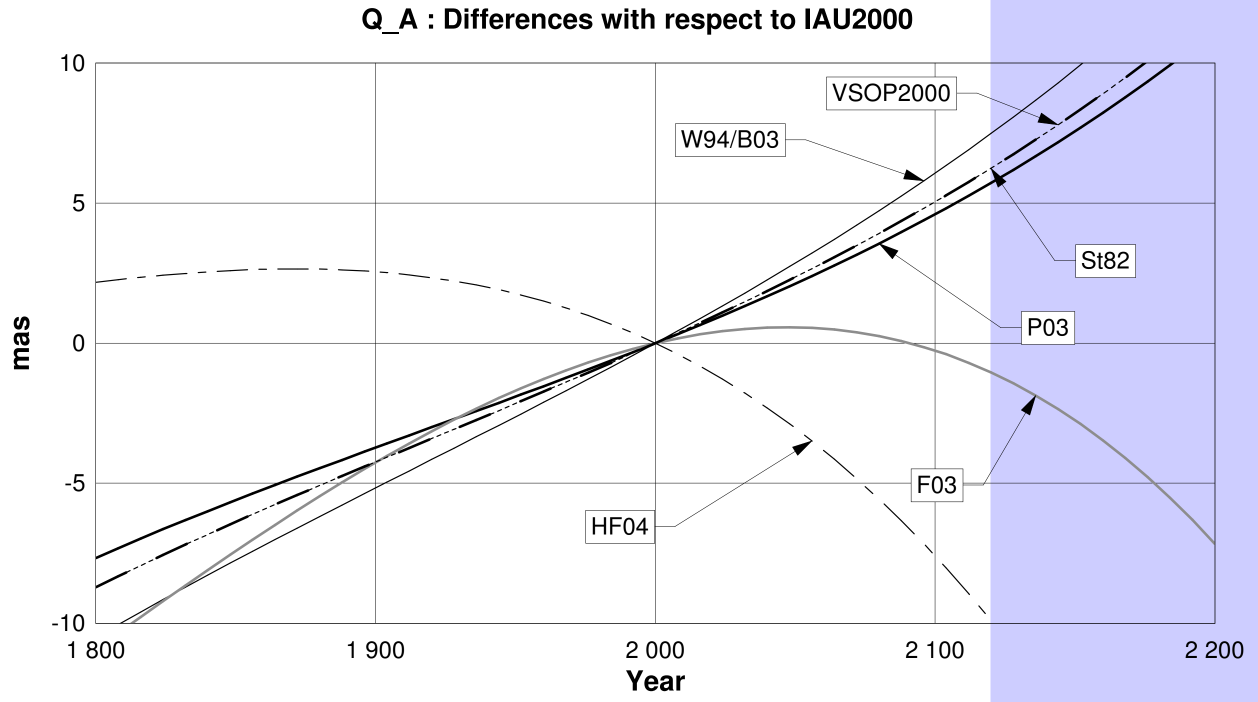
- Fukushima (2003, *A.J.* 126): F03
ecliptic fitted to DE405 (1600-2200) + SF01 nutation + quadratic fit to VLBI
+ Harada & Fukushima (2004, *A.J.* 127): HF04 ecliptic

- Capitaine N., Wallace P., Chapront J. (2003, *A&A* 412): P03
ecliptic based on both VSOP87 and fit to DE406 (2000-yr interval) + integration of dynamical equations for precession + MHB precession rates in longitude and obliquity

-> *IAU Division I WG on « Precession and ecliptic » established at the 2003 GA (Chair: J. Hilton) to recommend a new model*

- Capitaine N., Wallace P.W., Chapront J. (2004, *A&A*)
Comparison between precession models


P_A : Differences with respect to IAU2000
5
2.5
0
-2.5
-5
mas
1 800
1 900
2 000
2 100
2 200
Year
VSOP2000
W94/B03
F03
P03
St82
HF04


Q_A : Differences with respect to IAU2000
10
5
0
-5
-10
mas
1 800
1 900
2 000
2 100
2 200
Year
VSOP2000
W94/B03
St82
P03
F03
HF04

P03 precession

Capitaine, Wallace, Chapront, 2003, A&A 412

- Improvement of the ecliptic precession
  (based on VSOP/DE406)

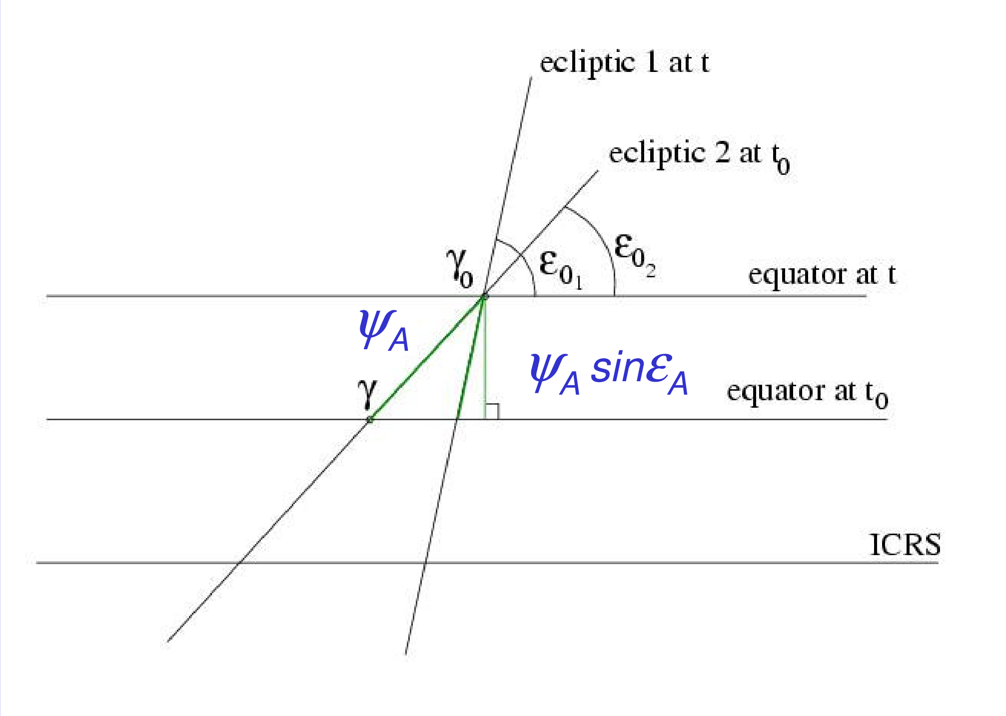
- Choice of the integration constants
  (non-rigid Earth model based on MHB2000, Williams 1994 and corrections for perturbing effects on the observed quantities)

- Improvement of the precession of the equator
  (based on: dynamical precession equations, improved ecliptic, updated MHB integration constants)

- Discussion on the precession parameters
  (rotation vector approach, X, Y approach)

P03 solution

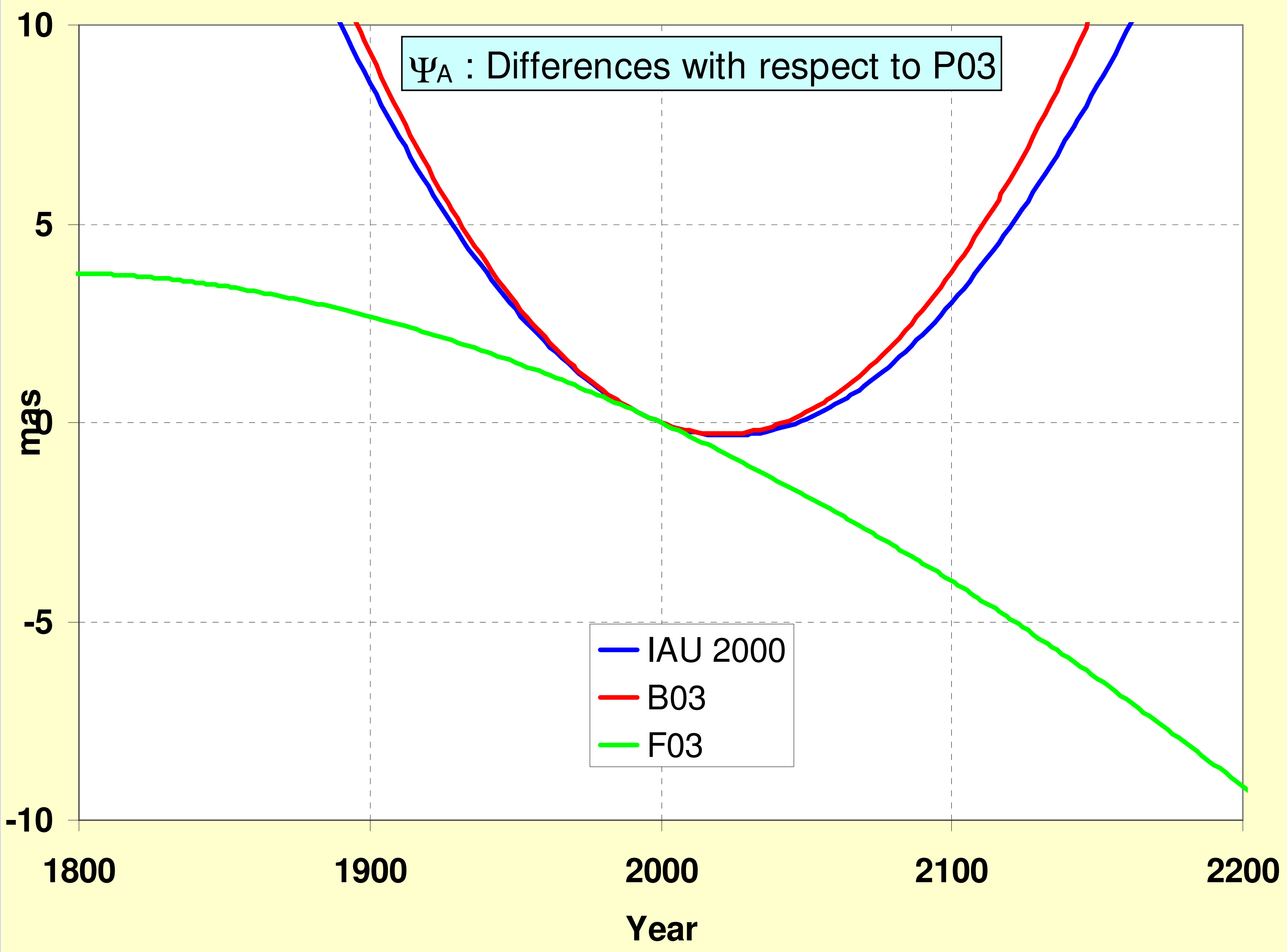
The derived precession in longitude is in fact the projection of the observed quantity on the conventional ecliptic with a conventional obliquity used in the current VLBI software

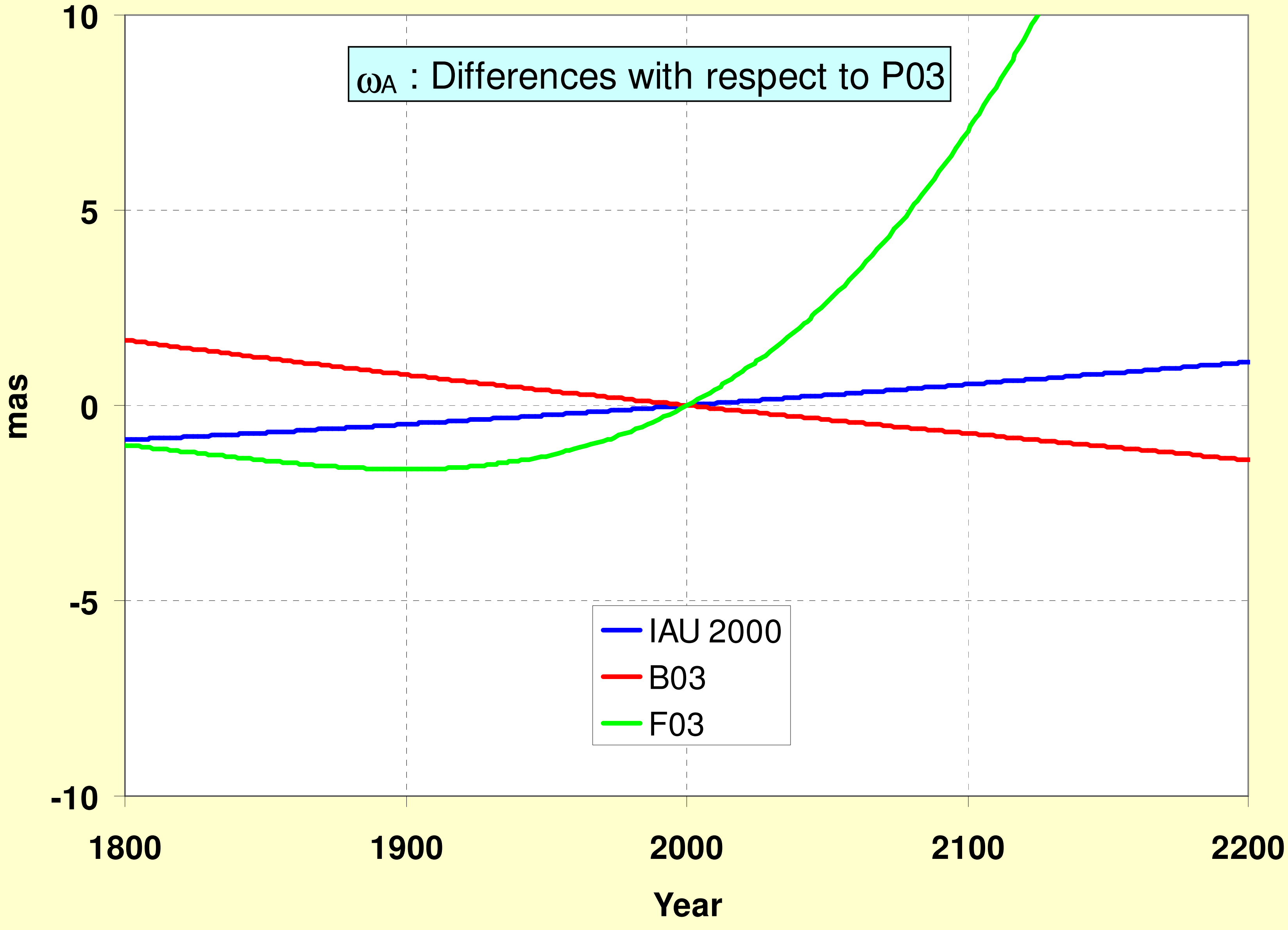


Comparison: equator precession solutions

unit: mas

Source		t	t^2	t^3	t^4	t^5
IAU1976 (L77)		5038778.4	-1072.59	-1.147		
IAU2000		5038478.750	-1072.59	-1.147		
W94		5038456.501	-1078.977	-1.141	0.133	
B03		5038478.750	-1071.9530	-1.14366	0.132832	-0.0000940
F03	ψ_A	5038478.143	-1079.1653	-1.10654	0.129144	
$P03_{prel}$		5038478.750	-1079.0091	-1.14044	0.132851	-0.0000951
P03		5038481.507	-1079.0069	-1.14045	0.132851	-0.0000951
IAU1976 (L77)		0.0	51.27	-7.726		
IAU2000		-25.240	51.27	-7.726		
W94		-24.4	51.268	-7.727	0.000000	
B03		-26.501	51.2769	-7.72723	-0.000492	0.0003329
F03	$\omega_A - \epsilon_0$	-21.951	53.9411	-7.19621	$+0.001907$	
$P03_{prel}$		-25.240	51.2623	-7.72502	-0.000467	0.0003337
P03		-25.754	51.2623	-7.72503	-0.000467	0.0003337


Ψ_A : Differences with respect to P03
10
5
0
-5
-10
mas
1800
1900
2000
2100
2200
Year
IAU 2000
B03
F03

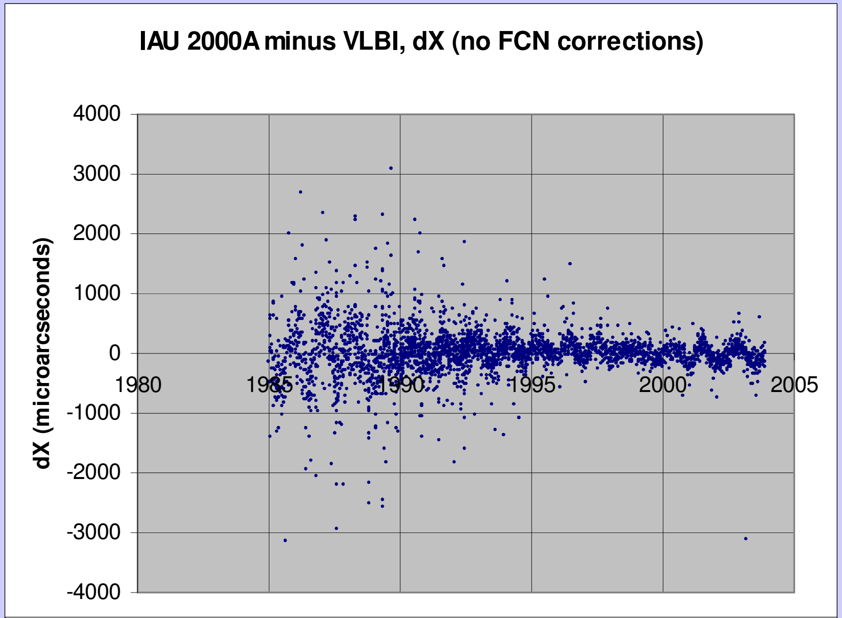

ωA : Differences with respect to P03
10
5
0
-5
-10
mas
1800
1900
2000
2100
2200
Year
IAU 2000
B03
F03

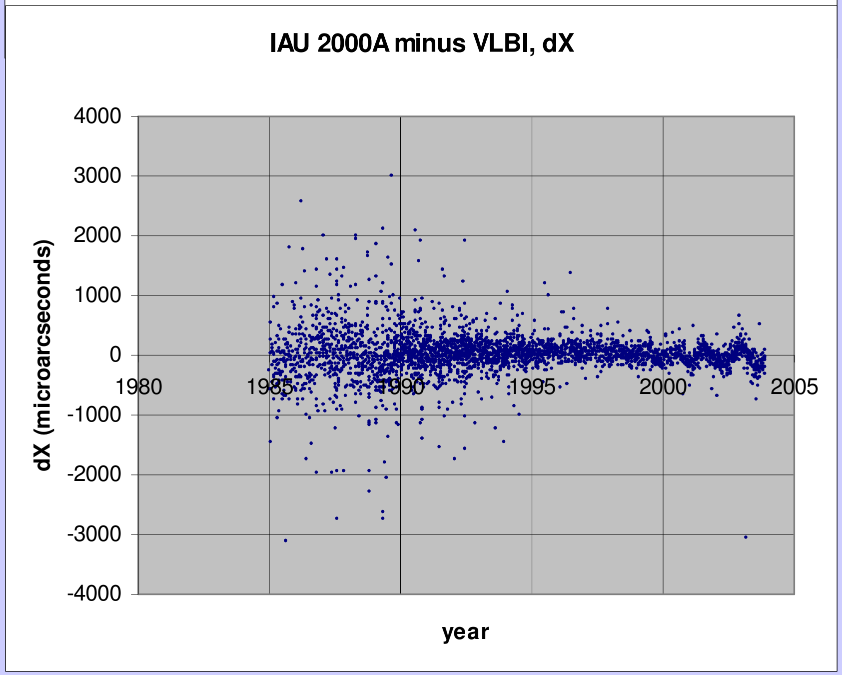
P03 expressions for X and Y

(Capitaine, Wallace, Chapront 2003, A&A 412)

$$X = -0.''016617 + 2004.''191898\,t - 0.''4297829\,t^2 - 0.''19861834\,t^3 + 0.''000007578\,t^4 + 0.''0000059285\,t^5$$
$$+ \Sigma_i\,[(a_{s,0})_i \sin(\text{ARGUMENT}) + (a_{c,0})_i \cos(\text{ARGUMENT})]$$
$$+ \Sigma_i\,[(a_{s,1})_i\, t \sin(\text{ARGUMENT}) + (a_{c,1})_i\, t \cos(\text{ARGUMENT})]$$
$$+ \Sigma_i\,[(a_{s,2})_i\, t^2 \sin(\text{ARGUMENT}) + (a_{c,2})_i\, t^2 \cos(\text{ARGUMENT})]$$
$$+ \ldots$$

$$Y = -0.''006951 - 0.''025896\,t - 22.''4072747\,t^2 + 0.''00190059\,t^3 + 0.''001112526\,t^4 + 0.''0000001358\,t^5$$
$$+ \Sigma_i\,[(b_{c,0})_i \cos(\text{ARGUMENT}) + (b_{s,0})_i \sin(\text{ARGUMENT})]$$
$$+ \Sigma_i\,[(b_{c,1})_i\, t \cos(\text{ARGUMENT}) + (b_{s,1})_i\, t \sin(\text{ARGUMENT})]$$
$$+ \Sigma_i\,[(b_{c,2})_i\, t^2 \cos(\text{ARGUMENT}) + (b_{s,2})_i\, t^2 \sin(\text{ARGUMENT})]$$
$$+ \ldots$$

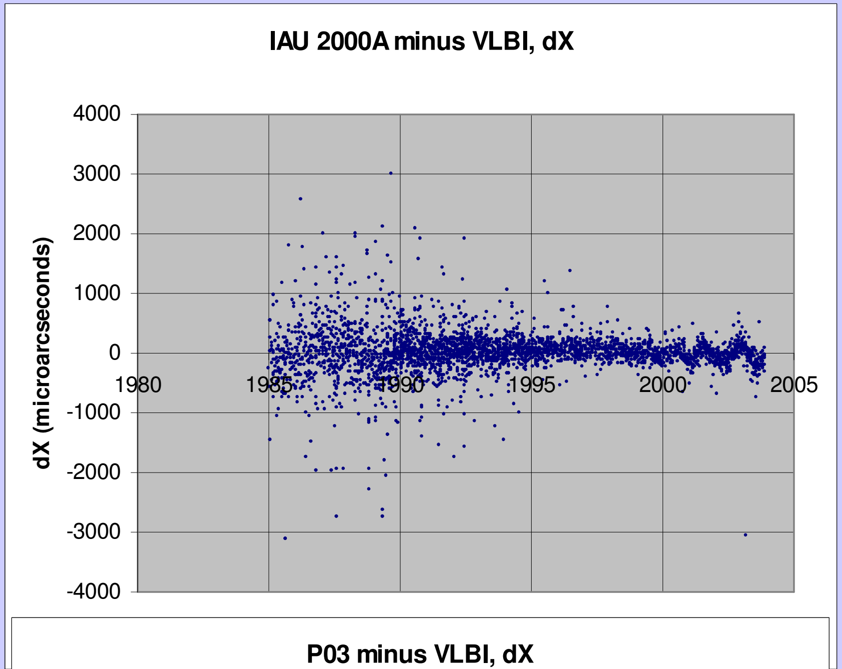


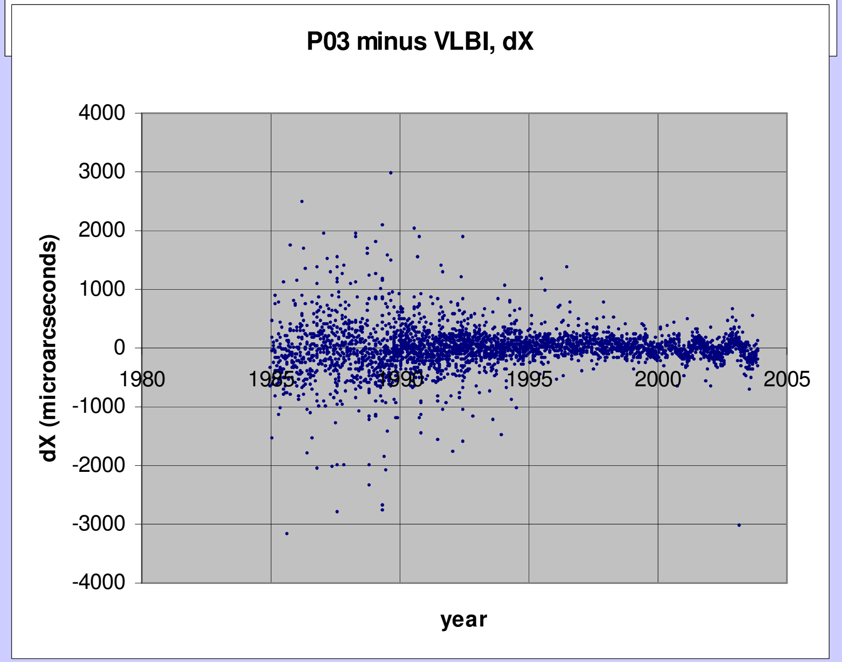


(i) the IAU 2000 model gives a considerably better fit to the data

(ii) the data before 1990 are very noisy

(iii) The FCN must be corrected

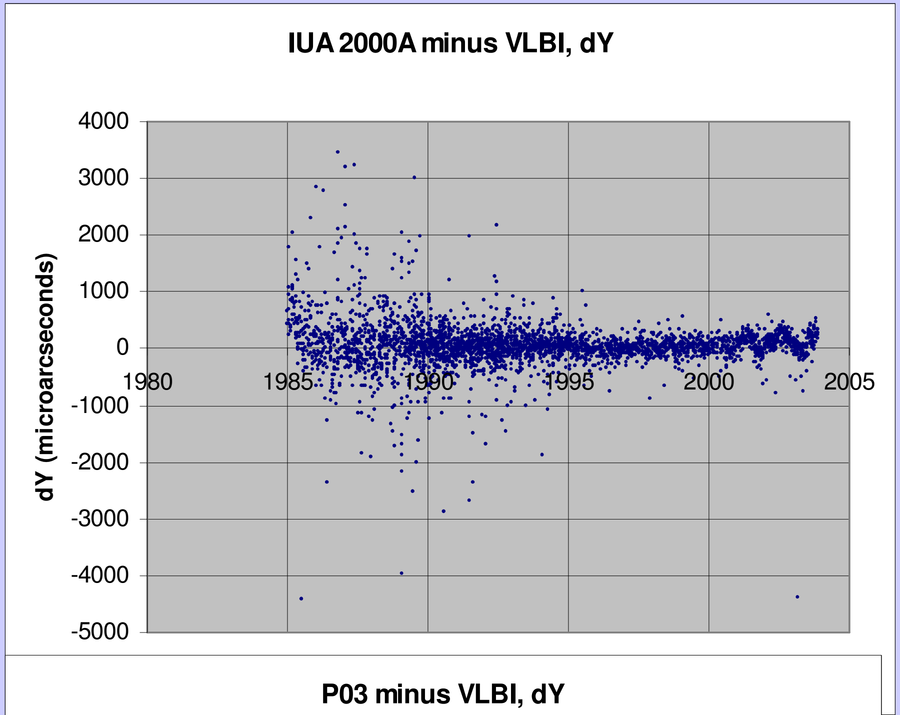


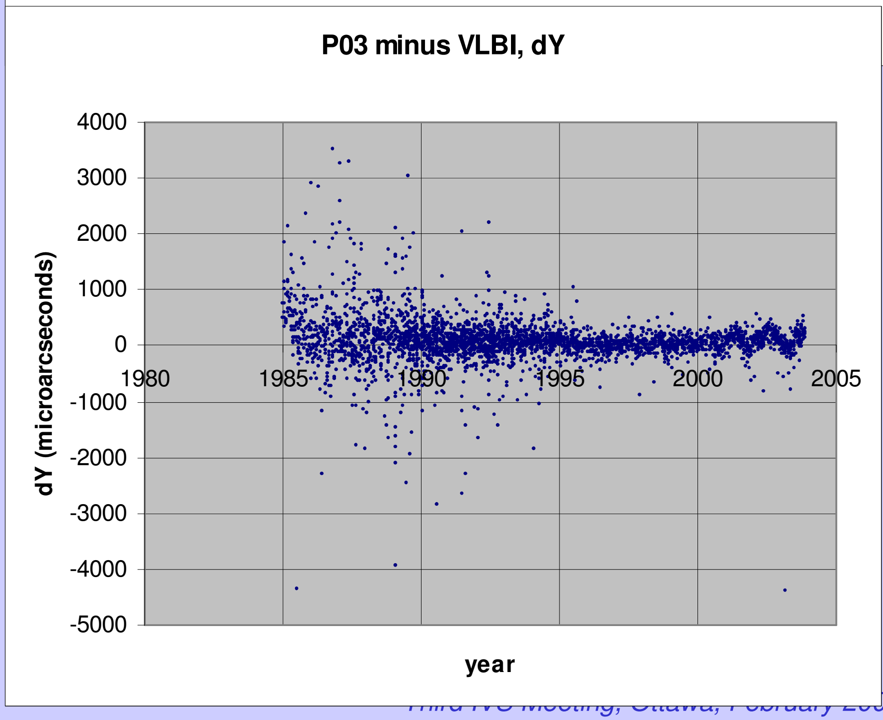


$C_0 + C_1 t + C_2 t^2$

RMS= 374 μas
C_0=(1 +- 10) μas
C_1= (-1368 +- 304) μas
C_2=(-11414 +-2579) μas
Corr(C_1 C_2)=0.9

RMS= 374 μas
C_0=(2 +- 10) μas
C_1= (-1119 +- 304) μas
C_2=(-13296 +-2580) μas
Corr(C_1 C_2)=0.9





$C_0 + C_1 t + C_2 t^2$

RMS= 416 μas
C_0=(33 +- 11) μas
C_1= (2134 +- 338) μas
C_2=(24024 +- 2870) μas
Corr(C_1 C_2)=0.9

RMS= 416 μas
C_0=(33 +- 11) μas
C_1= (1620 +- 338) μas
C_2=(23991 +- 2870) μas
Corr(C_1 C_2)=0.9

Summary

- VLBI is potentially the most powerful technique to estimate the motion of the celestial equator w.r.t. GCRS (and consequently the precession of the equator) but not the ecliptic precession

- The IAU 2000A precession-nutation which consists only on corrections to the precession rates in longitude and obliquity of the IAU 1976 precession is not 'dynamically consistent' but gives a very good fit to VLBI

- Improvement in the precession model for the ecliptic is necessary (few mas in the t term): the resulting effect on the precession of the equator is at a level of 100 μ as for one century (on the t^2 term in ψ_A)

- Improvement in the precession model for the equator is necessary. However, the possible improvement in the model is dependent on the model for some parameters of the non-rigid Earth as the J2 rate

- Observations covering a longer period of time are necessary to separate
  - the precession rates and amplitudes of long-period nutations
  - the precession rates and the t^2 terms in the developments (indirect access to the motion of the ecliptic).

Conclusion

- *What is required from VLBI in the future in order it can be powerful at the present level of accuracy for discriminating between various precession models:*
  - *Refined ICRF (without any global rotation + the largest number of sources)*
  - *longest interval of celestial pole offsets with low noise level and no systematic error (FCN)*
  - *Adopt IAU 2000 precession-nutation model in order than the celestial pole offsets can be considered as being first order quantities*
  - *Adopt the X, Y representation that is close to the parameters to which VLBI is sensitive*
  - *Adopt the CEO instead of the equinox to avoid possible risks of inconsistencies in the terrestrial to celestial transformation (for microarcsecond accuracy)*

- *In parallel:*

  Models for contribution (t term and t^2 term) to precession of a non-rigid Earth have to be improved ('improved' MHB)