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Review paper

PRESENT STATUS OF ASTROMETRY*

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SUMMARY: In the history of astronomy the last decade of the 20th century will probably be marked by the end of ground-based classical optical astrometry and the beginning of space and radio astrometry.

The attained precision and accuracy of observations by new methods is 1 millisecond of arc. In some domains this limit is even lower.

The leapwise progress in the observational sense is accompained by the conceptual changes. The traditional concept of realisation of inertial celestial reference system, based on solar system dynamics, has to be abandoned.Its kinematical realisation is more appropriate.

On the level of attained accuracy of time and space positioning,the relativistic corrections are no more negligible. Because of that, the General Relativity corrections are introduced in astrometric observation reductions.

1. INTRODUCTION

The present status of astrometry could be characterized as a leapwise progress in both observational and theoretical sense. In the Positional Astronomy the main events were the successful satellite mission HIPPARCOS (acronym: HIgh Precision PARallax COllecting Satellite) and the apparition of several Very Long Baseline Interferometry (VLBI) catalogues of hundreds of extragalactic radio sources (quasars, radio galaxies), consistent on the level of a few milliseconds of arc (*mas*). After these events it has become clear that the classical concept of the dynamical implementation of an inertial celestial reference system had to be abandoned. This is due to its kinematical implementation, based on the assumption that an ensemble of several hundreds of quasars and other distant radio sources has neither rotation nor non-uniform radial motion, which is more convenient in both observational and conceptual sense.

Since astrometric observations collected during the past decades represent a precious database for the studies of long-period motions of stars and planets, the link between the current international reference frame - FK5 catalogue - and the extragalacic reference frame is the focus of many astrometric activities.

Since January 1, 1988 all ground-based optical instrument observations are no more used for International Earth Rotation Service solutions. Observations with VLBI, Global Positioning System (GPS), Lunar Laser Ranging (LLR) and Satelite Laser Ranging (SLR) represent the current database for the celestial and terrestrial reference frames implementation and maintenance as well as for Earth's Orientation Parameters (EOP - the pôle coordinates, UT1, the nutation in the longitude and the nutation in the obliquity) determination.

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The radioelectric ranging of Mercury, Venus and, particularly, Mars and laser ranging of the Moon provided highly accurate data for the studies of their orbital motions. In this domain the classical astrometry is evidently inferior with respect to the methods of radio ranging.

In the clock technology the progress is also evident. The new cesium clock HP5071A has a stability one order of magnitude better than the old one (HP5061A).With the use of GPS time transfer technique the accuracy of international time scales and the accuracy of clock synchronisation in VLBI networks are noticeably improved.

The discovery of pulsars with an extremly stable millisecond spin period provides an accurate external control of atomic time scales.

The observational progress in Astrometry is followed by the conceptual changes. The definitions of space-time coordinate systems are now given in the framework of General Relativity.

The above mentioned and other events indicate that the era of new astrometry has already begun.

2. GROUND-BASED ASTROMETRY

The number of meridian circles, transit circles, astrolabes and other optical instruments with the classical registration used for star and planetary positions determination has rapidly decreased with time. According to the reports of IAU Commission 8 (Positional Astronomy) Presidents (Requième, 1988; Miyamoto, 1991 ; Morrison, 1994) during the last decade these instruments were operated at: Felix Aguilar Astronomical Observatory, Argentina (Repsold Meridian Circle), Rio Grande and Valinhos, Brasil (astrolabes), Cagliary Astronomical Observatory, Italy (astrolabe), Pulkovo Observatory, Russia (Zverev Photographic Circle), Kislovodsk Mountain Station, Russia (Struve-Ertel Vertical Circle and Struve-Ertel Large Transit Instrument), Sternberg Institute, Russia (Transit Circle and Zenith Telescope), Nikolaev Observatory, Ukraine (Repsold Meridian Circle), Perth Observatory, Australia (Meridian Circle), Yunan Observatory, China (astrolabe), Belgrade Astronomical Observatory, Yugoslavia (Meridian Circle), Bucarest Astronomical Observatory, Rumania (astrolabe).

Modern meridian and transit circles, astrolabes, fully automatic, with CCD micrometers, glass circles and cameras for precise and rapid circle reading (enabling even daily control of graduation errors), the new astrolabes with "cervit angles" (instead of the great prism) are nowadays in expansion.

The Carlsberg Automatic Meridial Circle (CAMC), run jointly by the Copenhagen University Observatory, the Spanish Instituto y Observatorio of Marina and the Royal Greenwich Observatory, is in regular use at the international observatory of the Roque de los Muchachos on the island La Palma (Canaries).

Carlsberg meridian catalogues numbers 1 to 6 contain 28200 of International Reference Stars (IRS) list ($\approx$ 36000 stars north of -45^0).

In October 1991 the divided circle of CAMC is replaced by a glass circle with Diadur lines. The six photoelectric cameras for circle reading are also replaced by CCD cameras.

In France, at Bordeaux Observatory, an Automatic Meridian Circle (BAMC) is regularly operated and is mainly used for the differential position determination of 8000 stars of 11-12th magnitude from the Faint Reference Star programme. The 221 radio stars were also observed and their positions compared by Very Long Area (VLA) positions with the goal to obtain the corrections of extragalactic radio frame orientation in the system FK5.

From the comparison of common star coordinates in CAMC and BAMC catalogues the following values of standard deviations of coordinate differences were obtained: $0''.10$ in RA and $0''.12$ in Dec.

All systematic differences are below $0''.05$.

A new reduction of BAMC positions in the system of FK5 stars in the preliminary HIPPARCOS catalogue (obtained during the first 18 months of mission) results in an important improvement of reference star residuals, but the systematic variation, whose amplitude reaches $0''.04$, remains present.

The planned mounting of CCD micrometers will result in an increased accuracy. It is estimated that errors in position determination for stars of 9-15th magnitude would be in the range of $0''.03$ - $0''.06$, for standard, fourfold observations. Once the final HIPPARCOS positions are available, the accuracy will be even better.

The Tokyo Photoelectric Meridian Circle (TPMC) has produced a series of several catalogues (for example PMC87, PMC88). The second Digital Strip Scaning CCD micrometer (DISCII) was developed for this instrument and that allowed observations of fainter stars (up to 16th magnitude).

The internal error of a single observation by TAMC is close to $0''.06$ for the magnitude about 10 and reaches $0''.15$ with the limiting magnitude.

Fourfold observations with DISCII micrometer allow to deduce the positions of tens of thousands of stars with an internal precision better than $0''.05$.

The US Naval Observatory (USNO) has recently completed the program of absolute observations of FK5, IRS and radio stars from pôle to pôle. This program is observed with the 6-inch Automatic Transit Circle (WATC-6), located at Washington ($\phi = +39^0$) and 7-inch Transit Circle (WATC-7), located at Black Birch ($\phi = -41^0$), New Zealand. The locations of WATC-6 and WATC-7 allow an overlap of 60^0 in the declination zone, which is sufficient to achieve a satisfactory homogenity of the final catalogue.

The USNO program includes a large number of solar system objects. Daytime observations of Mars will provide a good test of systematic differences between daytime observations of Sun, Mercury and Venus and nighttime observations of stars.

The catalogue observed with WATC-6 and WATC-7 is to be derived in 1997.

With the 8-inch Astrometric Scannning Transit Telescope at the USNO Flagstaff Station (FASTT) positions of 210 000 stars of Palomar Sky Survey are determined. The attained mean accuracy is 0″.05, but it varies very much with the magnitude: from 0″.03 (standard deviation), for magnitudes less than 14, up to 0″.25, for the magnitude 17.5.

Currently FASTT observes 200 000 stars of the Sloan Digital Sky Survey. The expected positions will be deduced with an error of about 0″.03. This programme includes 221 radio stars, the FK5 basic stars, outer planets and asteroids. Evidently, one of the goals of this programme is the research of the link between the FK5 and extragalactic reference frame.

The Transit Instrument at Steward Observatory, with CCD registration, produced the differential positions of stars brigther than the 17th magnitude with standard deviation less than 0″.04.

At the Pulkovo Observatory, in Russia, the classical meridian instruments are mainly modernised and are used in several international programs. During the next 10 years all traditional Pulkovo observations will be continued. After this period only the programs which are useful for space astrometry will be supported (Polojentsev, 1995).

The Pulkovo, Nikolaev and Kazan Observatories are cooperating in the joint programme called Meridian Automatic Horisontal Instrument (MAHIS).

At the Kislovodsk Mountain Station (h=2100 m) Pulkovo's Horizontal Meridian Circle (HMS) with CCD cameras is used for star and planetary positioning.

The contribution of astrolabe observations to the common astrometric task – the definition of the celestial reference frame as accurate as possible – is also important. It is widely known that astrolabes are used for the determination of star and planetary positions with a remarkable accuracy in RA. Several astrolabe catalogues are compiled for FK5 positions.

New astrolabes have two important technical improvements: 1.photoelectric or CCD registration, 2. "cervit angles" instead of the great prism. Some of them are fully automatic (at OCA in France). By CCD registration the magnitude limit has moved from about 6 to 16. The "cervit angles"- system of mirrors- allows the observations at different zenith distances and the determination of absolute declinations. By OCA astrolabe, for example, one observes the Sun at 10 zenith distances and tracks it along the whole orbit.

Sun observations with astrolabes are planned at the Paris, San Fernando,Cagliari, Santiago and Sao Paulo observatories.

Besides Sun and planets, the Paris astrolabe is used for observations of the radio star βPersei, a fundamental star important for the link of the optical and radio reference frame (Débarbat, 1991).

In China, visual and automatic astrolabes with photoelectric and CCD registration are operated. Recently, four catalogues, containing from about 600 to 8000 FK5 and GC stars, were published (Tongqi, 1995). Standard deviations of the coordinates are 0″.05 - 0″.06 in RA and 0″.05 - 0″.07 in Dec.

In addition to the modernisation of classical instruments, astronomers have invented completely new ones. At the Pulkovo Observatory the experiments with Meridian Automatic Horizontal Instrument of Suharev, Meridian Reflecting System of Nemiro and Streletzky, Reflector Infrared Meridian Circle, have well advanced. At USNO, Optical Interferometer, a particularly interesting instrument for the ground based astrometry, was developed. The first experimental programme for this instrument contains about 1000 specially selected FK5 stars. It is estimated that after two-year observations with this instrument the star positions will be accurate on the level of 2 - 3 *mas*.

Despite important advances in the instrumental technology, the increase of accuracy of the ground-based optical astrometry has stopped at the limit of several tens of milliseconds of arc. It is well known that the main limiting factors are: 1. unmodellable (anomalous) refraction and 2. uncontrollable instrumental errors (mainly due to thermic deformations).

During the last decades many efforts have been directed towards improving the refraction corrections (see, for example, Teleki, 1987). Using rocket sounding more realistic atmosphere models (density distribution with altitude) were obtained, but the global success in true refraction determination was limited fairly below the current astrometric needs. The room refraction, instrument tube refraction and other anomalous refractions generate errors whose amplitudes may be even by an order of magnitude over instrumental errors. Thus, for example, variable tube refraction detected in meridian circles at USNO, La Palma, Tokyo and vertical circles at Kiev and Golosseevo reach 1"- 2". After installation of the tube ventilation on meridian circle at La Palma, the tube refraction fell to 0″.09.

It is surprising that all previous determinations of the refraction constant were corrupted by the tube refraction (Hog and Miller, 1986). It was also shown that all determinations of the flexure term (k sinz) are more dependent on the tube refraction than on its mechanical deformation (Requième, 1988).

According to Guseva (1994), the quasi-periodical processes (like gravity waves) exist in the mean atmosphere causing large refraction variations. Detection of these processes by the means of meteorology from the ground is impossible.

The contribution of the second source of large errors - vertical circle deformations - is partly eliminated by the application of efficient methods for precise and rapid determination of the graduation corrections. By these means their secular and annual variations were detected on TAMC (Miyamoto and Suzuki, 1991). The amplitude of the latter ones reaches 0″.05 (Fig. 1).

Attempts to control the daily variations of graduation errors (mainly due to thermic effects) are expected.

The results of long-term Positional Astrometry are syntethized in the catalogue FK5. The basic list of FK5 stars contains the positions and proper motions of 1535 stars for the epoch J2000, distribu-

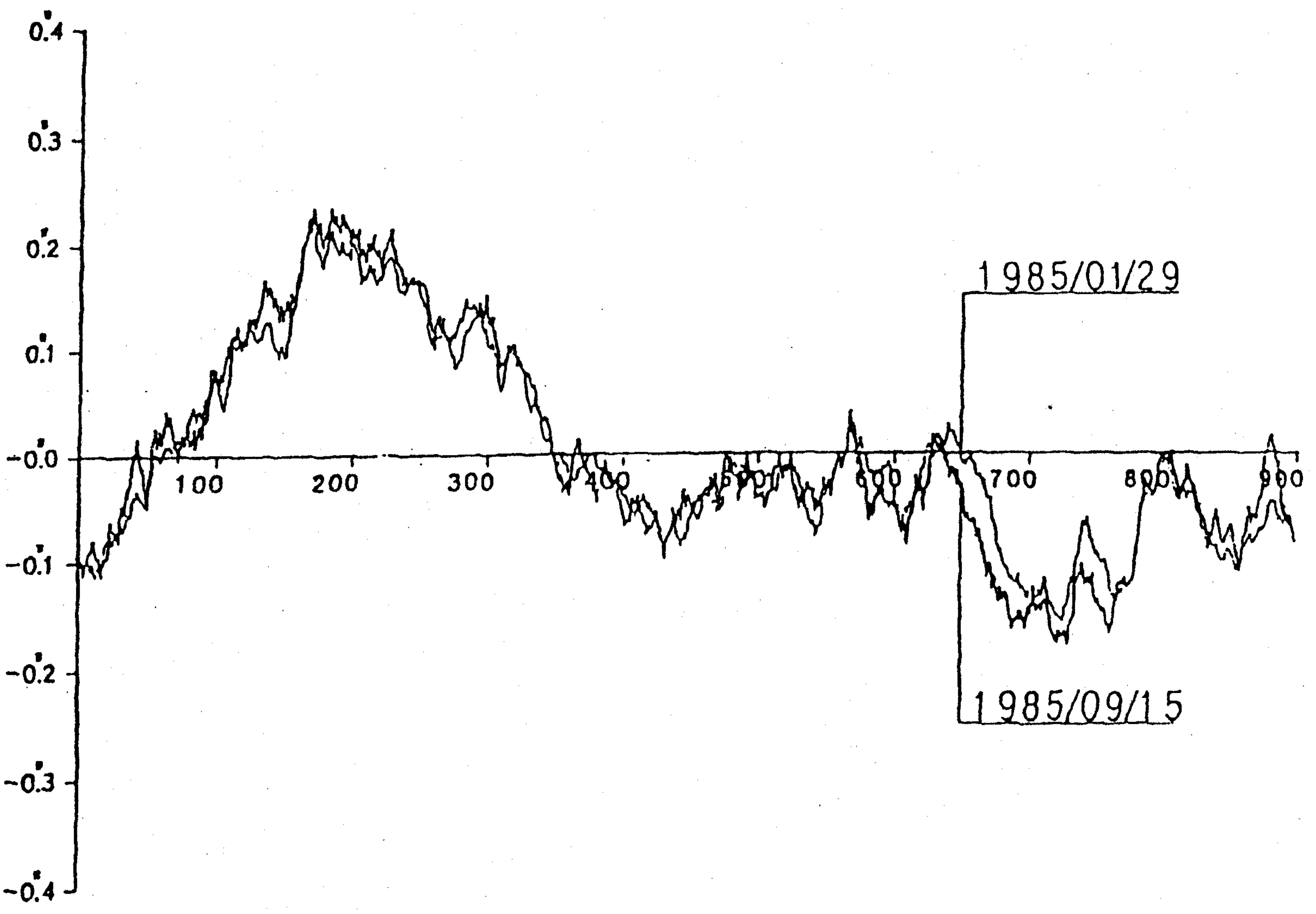

Fig. 1. Seasonal variation of the circle errors
Two sets of circle corrections (with opposite sign to the circle errors) derived from the diameter corrections are illustrated. These corrections to be added to 900 circle readings respectively are given as a function of the numbering (n = 1, 2, 3, ... , 900) of the circle readings. The figure shows the circle errors dependent on the season.

Note: Averaging each set of two readings of 3600 divisions separated by 180°, we have 1800 diameter readings. Averaging again each set of four readings of 3600 divisions separated by 90°, we have 900 circle readings. In routine observations, only these 900 circle readings are used, which are distinguished by the numbering n = 1, 2, 3, ... , 900. Thus, we need 900 circle corrections at any observational instant (J.D.).

ted from pôle to pôle. These positions and proper motions with adopted values of precession and aberration constants, nutation tables, etc. define international *conventional celestial reference frame.*

The density of stars per square degree in the so-called basic FK5 does not satisfy the needs in many astronomical works, particularly in Photographic Astrometry. This was the reason to extend the FK5 list in both bright and faint magnitude range. Thus, the Bright Extension consists in about 1000 stars from FK4 Supplement whose magnitudes lie in the range 5 - 7, the Faint Extension - in 2000 stars from IRS list with magnitudes between 6.5 and 9.5.

The average mean errors of positions and proper motions for the above three lists are given in Table 1, taken from Commission 8 President's report at XXIth IAU General Assembly (Miyamoto, 1991).

The comparison of FK5 star positions with their positions in modern meridian catalogues (CAMC, BAMC, TAMC) reveals the presence of systematic errors whose amplitude reaches 0″.05 (see, for example, Fig. 2 taken from Yoshizawa et. al. 1991). Besides, the systematic regional distortions of FK5 frame reach even 0″.1 (Morrison *et al.* 1991).

The above examples, and many others which are not mentioned, explain why optical astrometry on the ground passes today through the phase of stagnancy.

Table 1.

Catalogue	*epoch*(α)	*epoch*(δ)	α	δ	μ_α	μ_δ
*BasicFK*5	1955	1944	0^s001	0"02	0^s005	0".07
BrightExtension	1956	1949	0.002	0.04	0.010	0.18
FaintExtension	1942	1939	0.004	0.07	0.019	0.30

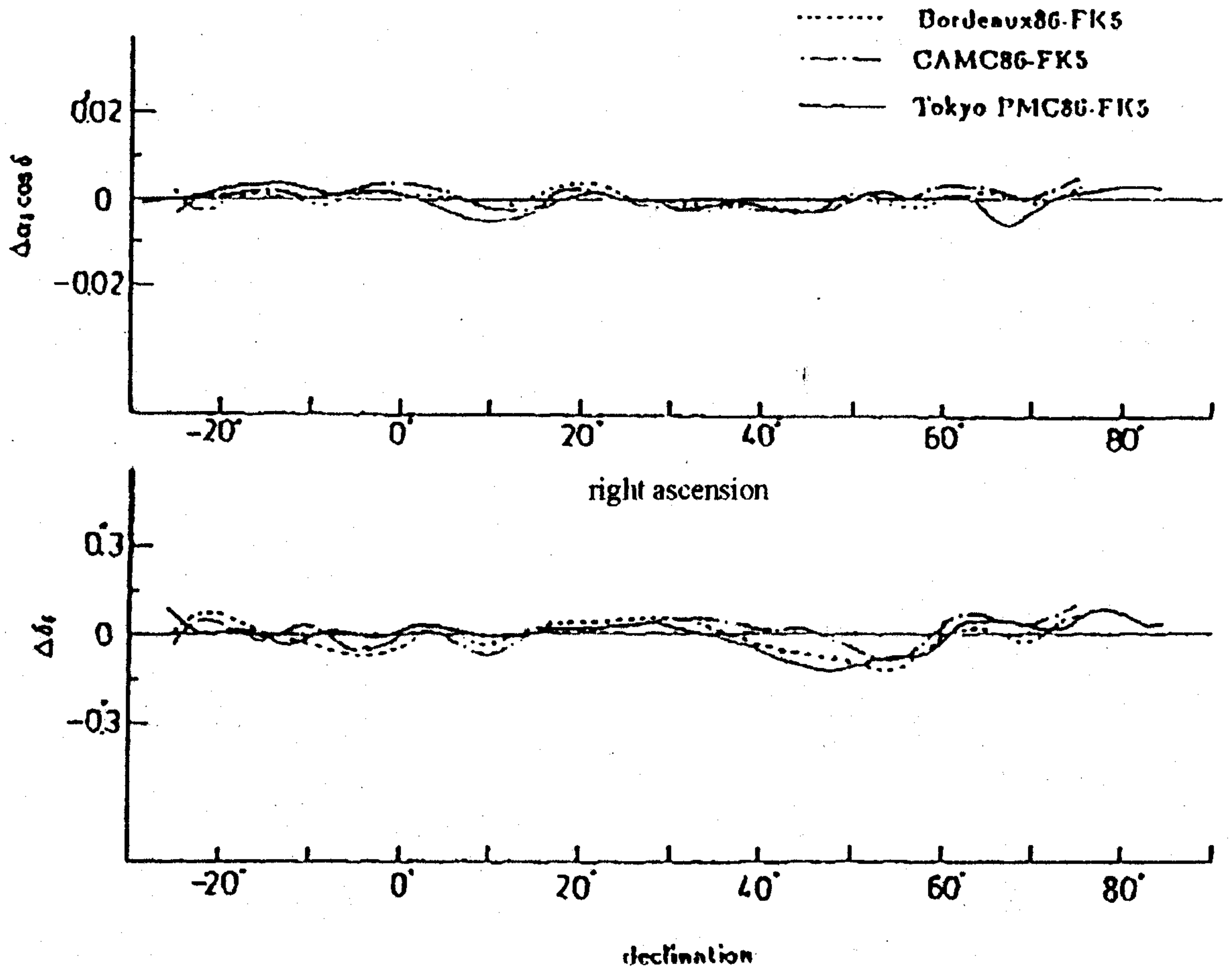

Fig. 2. The systematic differences $\Delta\alpha_i \cos\delta$ (upper panel) and $\Delta\delta_i$ (lower panel) for the FK5 basic stars observed in 1986.

3. RADIO ASTROMETRY

The idea to abandon the traditional implementation of the inertial reference frame (dynamical implementation), based on ephemerides of Sun and solar system bodies, and to define the frame of fixed points on the sky is not new. It was even considered by Laplace and Hershel (Ma, 1989), some two hundred years ago, even though the distant objects (like quasars and galaxies) at that time have not been known.

Two main reasons to abandon the dynamical implementation of inertial reference frame lie in: 1. the difficulties related to the link between apparent positions of the Sun and planets and apparent star positions (observational errors, errors in precession and nutations, initial positions and velocities of planets, etc), 2. the errors in star proper motions which destroy the frame homogenity in time.

Thanks to Jansky's discovery of extraterrestrial radio signals in 1931, the new branch of astronomy - radioastronomy - was born. The first extragalactic radio emission was detected by Hey 1946. The intensive search for distant radio sources began about 1960. The focus of astronomers' interest were the galaxies 3C295, with red shift RS=0.46, 3C48, with RS=0.37 and 3C273, with RS=0.16. The "3C" designates Third Cambridge Survey which contains 471 radio sources.

The radio sources of quasi-stellar form, like 3C48, whose radio size is below 1", are named *quasars*.

First astrometric positions of quasars were determined by Connected Element Radio Interferometer (CERI) in 1970. Uncertainties of these positions were within ±1". Only six years thereafter, these limits were ±0".02.

First VLBI positions have had a similar accuracy as the first CERI positions. However, since about 1975 the errors of VLBI positions have fallen to the level of a few *mas*; (Robertson *et al.* 1976; Ma, 1988; Sovers *et al.* 1988, etc).

Main activities in the implementation of the international VLBI reference frame today are going on in United States of America, Russia, China and International Earth Rotation Service. These activities are now coordinated by the International Astronomical Union (IAU). The IAU Working Group on the Radio/Optical Reference Frame was formed in 1978 by the Commission 24 (Photographic Astrometry). A program to establish a radio/optical reference frame was undertaken in 1987. The goal of this program was the determination of radio and optical positions for 400 radio sources, uniformly distributed over the whole sky. If the radio source, whose position in the extragalactic reference frame is known, can be observed in optical wavelengths, it is possible to determine the link between the optical and extragalactic radio frame with an accuracy of the optical position. Of course, that implies the hypothesis of coincident radio and optical emission of extragalactic objects.

The following information, related to above mentioned program, is based on the report of Johnston *et al.* (1991).

The extragalactic radio sources, included in the above programme, are selected according to the following criteria: they are compact in both radio and optical emissions, their total flux density at 5 GHz is over 1 Jy and the apparent magnitude is less than 19.

The radio positions are determined using the observations by Mark III recording system at two frequencies.

In the Northern Hemisphere (NH) this program is carried out at the Green Bank and Maryland Point on the East coast of USA,Hat Creek on the West coast of USA, Fairbanks, Alaska for a northern site and Hawaii for a far western site. In the Southern Hemisphere (SH), the stations are Tidbinbilla, Australia, Hobart, Tasmania and Hartebeesthoek, South Africa. The southern sky radio sources are observed less than the northern ones (due to technical problems). Because of that the attained precision is different: 1 *mas* in NH and 2 - 10 *mas* in SH.

The optical determination of extragalactic sources' positions is based on a minimum of two long focus plates. For fainter objects observations (visual magnitude over 18), the 4 meter focus telescopes are used. Brighter objects are even observed with the smaller focus telescopes. The prime plate served for the determination of the source position relative to the field stars within one degree of the object ("local" field). The plates with a field of about five degrees on the side allow the determination of "local" field star positions in the FK5 system via IRS stars.

The prime focus telescopes used in the above program are the Kitt Peak 4m, the AAT 3.9m and ESO 3.6m ones. The astrographs are: the Hambourg Observatory's one, the USNO astrograph at Black Birch and Lick Observatory astrograph.

Uncertainties of reference star positions determined by 4 plates are about 60 *mas*. It is clear that this level of accuracy requires use of some hundreds of positions to obtain the radio/optical frames link at satisfactory level of accuracy.

Radio positions of extragalctic objects are determined with an average precision better than 1 *mas*. As it will be shown later, the uncertainties, estimated from the analysis of differences between the independent VLBI catalogues (accuracy), are of the same order of magnitude.

In the definition of the international reference frame the contribution of US programs was dominant. At USNO, the Navnet program in VLBI is designed to monitor the space orientation of the Earth (Ma and Shaffer, 1991). Navnet program complements the program coordinated by the National Geodetic Survey (NGS) as a part of the International Radio Interferometric Survey (IRIS). The Naval Research Laboratory (NRL) and the Crustal Dynamics Project (CDP) at NASA and the Goddard Space Flight Center (GSPFC) have also participated in the development of USNO/NGS program. The observation stations were: Gilmore Creek (Alaska), Kokee Park (Hawaii), Richmond (Florida), Green Bank (Virginia), Maryland Point (Maryland). Some other stations have also participated but their contribution has not been important.

Since the basic task of Navnet program was the determination of polar coordinates, UT1 and nutation, as a part of International Earth Rotation Service (IERS), the Navnet reference frame was aligned with both the terrestrial and celestial IERS frames.

Using 461 000 Mark III dual frequency observations, divided into 4 subsets (206 000 from CDP, 210 000 from IRIS, 29 000 from the Navnet program and 16 000 from NRL, CDP and IRIS) Ma and Shaffer (1991) have derived the catalogues from subsets and from all data. From the comparison of subset catalogues with all data catalogue it follows that the relative rotations of the coordinate axes are under 0.5 *mas*.

From this comparison one can also conclude that catalogues of separate networks, for different years and seasons keep their orientation with respect to all data catalogue within 1 *mas*.

The IERS Celestial Reference Frame (ICRF), defined by the positions of 422 compact extragalactic radio sources, has the origin at the barycentre of the solar system, polar axis and right ascension origin coincide with those of FK5 system at J2000.0. The accuracy of the link is better than 10 *mas*. The stability of reference axes is mantained within 0.1 *mas* (Lestrade, 1994).

New implementations of the ICRF are adjusted whenever justified by the newly collected data or by the progress in the theoretical sense. From the source positions in successive implementations it follows that the coordinates of 51 primary sources have changed less than 0.7 *mas* (Arias and Feissel, 1991).

The demonstrated capabilities of VLBI technology for different scientific applications (inertial reference frame, Earth's Rotation, tectonic plate motion, nutations and related geophysical models, space navigation,...) let me believe that VLBI is the technology of the astrometric future. The number of VLBI stations and networks is rapidly growing. As reported by W.E.Carter (Carter, 1994) the VLBI operations are runing: at Matera (Italy), a Japan facility at Syowa (Antarctica), at Santiago (Chile), at O'Higgins station (Chilean Antarctica) of Institute of Applied Geodesy, Germany (IFAG), at Algonquin Park (Canada), at Fortaleza (Brasil), at US stations Kokee Park (Hawaii), Green Bank (West Virginia) and Richmond (Florida). The US 10-station Very Long Baseline Area (VLBA) network spans North America, from Virgin Islands to Hawaii. The Russian network Qusar is also operating.

New observatory is under construction at Ny Alesund, Spizbergen, by Norwegian Mapping Authority.

Haystack Observatory, with the joint support of NASA, NOAA, IFAG and USNO, is developing the generation Marc IV system with twice higher sensitivity, increasing the maximum data rate to 1024 Mbits/sec.

The Chineese VLBI Network (CVN) consists of five stations and a data analysis center (Ye Shuhua and Qian Zhihan 1991).

Today many existing VLBI reference frames are constructed for different purposes. Recognizing that differences between them may be the source of confusing research results, IAU at the XXIInd General Assembly in Hague (1994) adopted Resolution B5 (*Information Bulletin*, IAU, 74,1995) part of which is the list of 443 radio sources which have to define the new international conventional reference frame together with 166 candidate sources. At some future date the candidate sources may be included in the definition of the frame.

The IAU requests that the Working Group on Reference Frames continues activities with the purpose to:

1. define the positions of the radio sources on the list,
2. determine the relationship of this frame to an optical frame defined by stars,
3. recommend to the XXIIIrd General Assembly (1997) a way to organise the work for the maintenance and evolution of this frame and its extension to other frames at other wavelengths.

The capabilities of VLBI are also limited by instrumental and refraction errors and effects of non-point-like structure of radio sources.

In the class of instrumental errors dominate those of clock synchronisation and receiver-recorder equipment chain. These errors are on the sub-centimeter level, which is demonstrated by the observations of short baseline Haystack - Westford (1.2 km) in Massachusetts (Robertson, 1986). The short baseline ensures that the effects of the propagation medium are being canceled.

By the convenient selection of radio sources, the effects of the source structure can also be reduced to sub-centimeter level. However, the main limiting factor are the errors due to the atmospheric propagation. In practice, one distingishes two basic components: a dispersive ("ionosphere") and non-dispersive ("troposphere") components. The dispersive component has an amplitude of 15-30 cm in the zenith at 8 GHz with an order of magnitude variation between day and night. By dual frequency observations it is eliminated with a centimetric accuracy. The non-dispersive component, whose magnitude (in zenith) is about 1.5 meters, can be modelled and eliminated 90 percent. The residual tropospheric propagation errors remain relatively large and variable. They are considered as the major hindrance to an improvement of the VLBI accuracy.

The definition of a quasi-inertial reference frame by the positions of an ensemble of quasars and other distant radio sources (most of them are farther away than 1000 Mpc) is quite convenient because their proper motions are negligeable at the current level of accuracy. The link to this frame is accessible by the VLBI technology, but for the application in the range of optical wavelengths it should be extended to the stars, too. This complementary task is performed by the space astrometry.

4. SPACE ASTROMETRY

First astrometric satellite HIPPARCOS has been launched in August 1989 by ESA. The expected uncertainties of final positions, paralaxes and annual proper motions for $\approx$ 120000 stars were estimated to be below 2 *mas*. However, results obtained from data reduction for the first 18 months of the mission exceed all expectations. Results of the photoelectric photometry for these 120 000 and one million Tycho Catalogue objects were also outstanding. Besides, several thousand of double star systems were detected.

For the data reduction and analysis four consortia are organized: INCA (Input Catalogue), FAST (Fundamental Astronomy by Space Techniques), NDAC (Northern Data Analysis Consortium) and TDAC (Tycho Data Analysis Consortium).

The final HIPPARCOS catalogue is planned for 1996.

The FAST data-reduction consortium solutions for 6, 12 and 18-month mission show a steady and rapid increase of the precision. To illustrate this, the mean precision of ecliptic coordinates, proper motion and paralax for the stars of magnitude 9, deduced from 18 and 31- month solutions respectively are: 1.4 and 1.3 *mas* in longitude, 1.2 and 1.1 *mas* in latitude, 3.3 and 1.7 *mas/yr* in proper motion in longitude, 2.7 and 1.5 in proper motion in latitude, 1.6 and 1.5 in parallax.

The precision of double stars separation is better than 12 *mas*.

Reduction of the first year observations from the Ticho catalogue shows that 3-year HIPPARCOS mission would give the positions, annual proper motions and paralaxes of one million stars with an accuracy of 30 *mas* (rms) at the 11th magnitude increasing to 6 *mas* for stars below the 9th magnitude.

The preliminary results of the HIPPARCOS mission let me believe that the mission might end (after approximately 37 months) with fairly better results.

The most of the above information about the HIPPARCOS program was taken from Morrison (1994).

In addition to the high precision of differential positions, the HIPPARCOS method of observations provides the frame free of regional distortions. Since this frame includes all 1535 FK5 stars, the systematic errors of the current international reference frame will be accurately determined.

The radio stars of our Galaxy, included in HIPPARCOS program, are simultaneously observed by VLBI networks. Two sets of their positions provide the link between the HIPPARCOS and extragalactic reference frames.

Huble Space Telescope (HST),launched April 24, 1990, among six scientific instruments is carrying The Fine Guidance Sensors (FGSs) - an instrument for astrometric measurements: positions,proper motions and paralaxes. The FGSs are designed for milliarc second astromerty (2 *mas* rms).Its prime astrometric task is to determine the rotation of HIPPARCOS reference frame with respect to extragalactic frame by the relative positioning of extragalactic objects (till the 17th magnitude) in HIPPARCOS system.

After the elimination of first drawbacks due to spherical abberation of the primary mirror and initial tracking jitter from solar panel oscillations, HST operates giving the results better than expected.

The first satellite mission has encouraged astrometric community to prepare the programs for future space missions. Thus, Europeen astronomers have proposed to ESA the ROEMER mission for accurate astrometric and photometric observations of hundred million stars up to 18th magnitude. The expectations based on experience gained in HIPPARCOS mission and involving the CCD detection system, more sensible than photoelectric one, are 0.1 - 1.5 *mas* uncertainty in positions,paralaxes and annual proper motions (depending on magnitude) and multi-colour photometry to 0.001 - 0.02 magnitude.

The programme will contain a complete survey of the 50 million stars brighter 15.5 magnitude.

The project named Astrometric Integrating Space Telescope (AIST) was proposed at Pulkovo. Its aim would be the survey of positions, proper motions and paralaxes of 10 - 15 million stars.

5. LINK BETWEEN FK5 AND EXTRAGALACTIC REFERENCE FRAME. PROBLEM OF PRECESSION AND NUTATIONS

Astrometry is the oldest branch of astronomy. Since the first astronomical documents, concerning the predictions of eclipces of the Sun and the Moon, in ancient China, till nowadays have passed about 70 centuries. During this long time period many pieces of information about the universe geometry and dynamics have been accumulated. This database allows different studies of long-term evolution of star positions, planetary orbits and Earth's rotation parameters. The accurate link beween the current celestial reference frame (FK5) and recently adopted IAU extragalactic frame, defined by the positions of selected extragalactic radio sources, is necessary to follow the mentioned evolution in the future. For this purpose several methods are proposed. The best expectatios are related to simultaneous determinations of radio star positions in both frames of optical sources, by satellites like HIPPARCOS and HST, and frame of extragalactic radio sources,determined by VLBI.

As already emphasized, the accuracy attained by these methods is, at least, one order of magnitude better than the one of the older, classical methods. Besides these methods, the problem of mentioned link mobilizes today classical astrometric techniques: astrographs, meridian circles, astrolabes, etc. The wide-angle astrographs are quite appropriate for the determination of quasar positions in the stellar frame. The large field astrographs allow to have more reference stars on the plate and to determine better relative position of quasars. The CCD micrometer on positional instruments has made possible the access to fainter stars and some quasars. Accordingly, the establishment of the mentioned link is yet entering in the programs of ground - based optical Astrometry.

The link between FK5 and the extragalactic frames involves the knowledge of exact position of the mean equator and equinox point at the standard epoch J2000.0. To reduce the quasar positions observed today, for example, to FK5 reference system we use the nutation tables and precession constant which are conventionally adopted by the IAU. However,as many people reported (Sovers, 1991; Williams *et al.* 1991; Herring, 1991; Dehant, 1996; etc), these constants contain errors which exceed several *mas*.

The state-of the art of the nutation problem and considerations for the future of non-rigid Earth nutation theory is completly expounded in the study of Dehant *et al.* (1996).In this study the main impediments to obtain the Earth nutation theory which will provide the set of real nutations at the accuracy level necessary for current and future astronomic, geodetic and space navigation applications are enlightened.

The comparisons of the last nutation series adopted by the IAU (IAU 1980) with the observation results show that (Dehant *et al.* 1996):

1. in the time domain, the differences, apart from the trend wich is due to the prcession, reach 10 *mas*;
2. in the frequency domain, the differences in the in-phase and out-of-phase amplitudes for particular frequencies are several tenths of *mas*, plus differences at the level of *mas* at some frequencies (nutations with maximum amplitudes);
3. there is an observed obliquity rate of about -0.3 *mas*/year ;
4. there is a difference in the precession rate of about -3 *mas*/year.

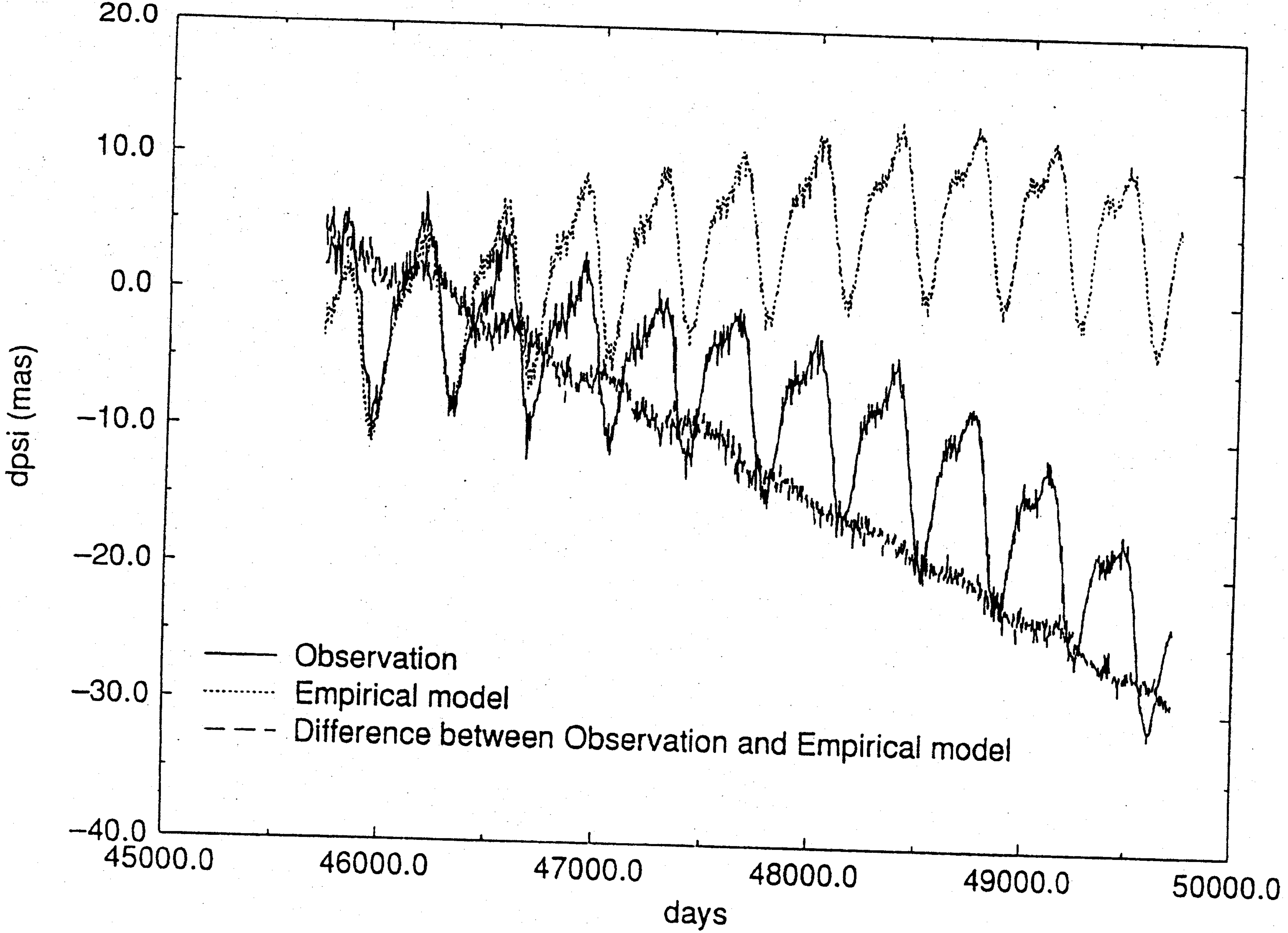

Fig.3 Nutation in longitude - IAU80 adopted nutation

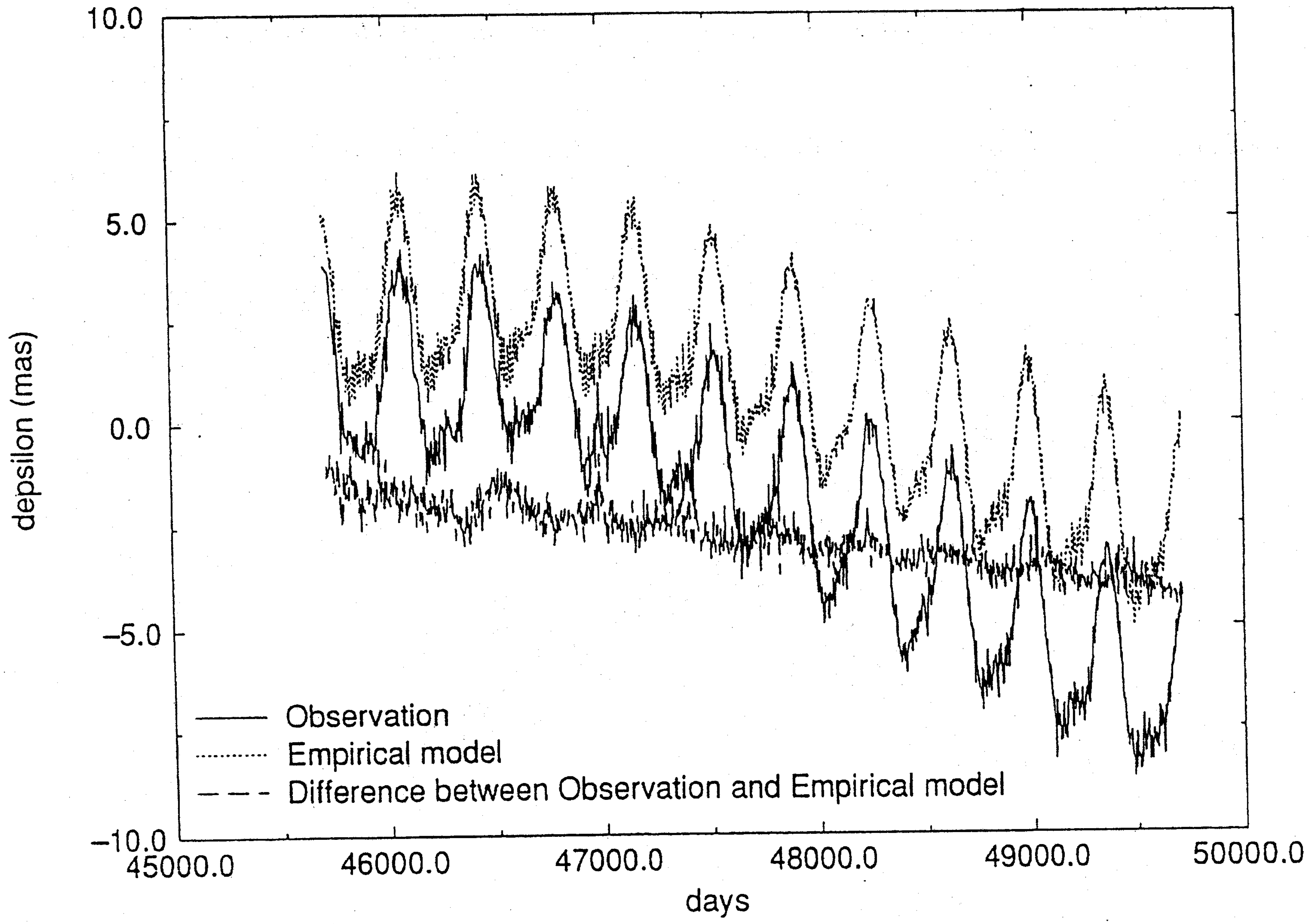

Fig. 4 Nutation in obliquity - IAU80 adopted nutation

The lack of the satisfying geophysical theory is temporarily overcome by the so-called empirical nutation model. It concerns the fitting of observed nutations and application of fitted values to the data reduction. However,the differences between observed and empirical nutations retain a systematic character. As an illustration of the above discrepancies, the Figures 3 and 4, kindly provided by V. Dehant, are presented.

The long-term variations of the above differences are due to the precession error.

Besides the systematical differences,the empirical model involves the ambiguities in the geophysical interpretation of observation results, as well as in our understanding to which system of reference our observations are reduced.

6. EARTH'S ROTATION MONITORING AND RELATED ACTIVITIES

As a body in a physical sense, the Earth has a non-homogeneous structure: the crust, mantle, outer core, inner core,atmosphere and oceans, each of constituents having different mechanical properties. The actions of variable internal and external forces perturb its rotation parameters (pôle coordinates and spin period) and orientation in space (nutations). The interference of reactions between different Earth's constituents makes the studies of its rotation very complex. On the other hand, these studies make possible the insights into the Earth's interior, the global atmosphere, ocean and 'solid' Earth interactions, the interactions between Earth, Moon and Sun.

The new observational techniques provide the data necessary for the realisation of the terrestrial reference frame whose space orientation (with respect to the extragalactic reference frame) is currently known with an accuracy better than 1 *mas*. Accordingly, the Wegener's dream to prove the relative displacements of continents by the observations has become reality. As we know today, tectonic plates move with respect to each other by up to 4 *mas*/yr (Minster and Jordan, 1978).

The variations of the Earth's spin period are usually classified as secular, long-period (decadal), mean-period (interannual), seasonal (annual and semi-annual) and short-period (intraannual) variations.

Secular deceletation of the Earth's rotation is mainly caused by the tidal dissipation both in the oceans (greater part) and the atmosphere. Tidal buldge, due to the Moon's attraction, generates the torque whose consequences are the expansion of the Moon's orbit and Earth rotation deceleration. The second cause lies in some (unknown) process (es) in the Earth's interior (Mignard, 1983).

In the recent study of Stephenson and Morrison (1995), based on the analysis of records of solar and lunar eclipces in the period 700 BC to AD 1600 from the ancient and medieval civilisations of Babylon, China, Europe and Arabia, observations of lunar occultations in the period AD 1600-1955.5 and the data of atomic epoch 1955.5-1990., it is found that the secular deceleration increases the length of mean solar day by $0.00170s \pm 0.00005s$ per century. Estimations based on modern tidal measurements give the value of $0.0023s \pm 0.0001s$/century (Dickey, 1995). The difference represents the estimation of non-tidal term, equal to 0.0006 s (acceleration). This value is consistent with the modern measurements of the variation of the Earth's oblateness (Cheng *et al.* 1989).

In the range of decadal fluctuations our understanding has not substaintially progressed. In principle,they might be generated by the torques produced at outer core-mantle boundary by the topographic, viscous, gravitational and electromagnetic torques.

Concerning interannual variations of the LOD, the Quasi-Biennial Oscillation (QBO) has first been detected by Iijima and Okazaki (1966; 1972). Despite the proven existence of the quasi-biennial zonal winds alternation in the equatorial stratosphere, any relation between stratospheric and Earth's rotation QBO is not yet known (Djurović and Pâquet, 1993).

Second interannual LOD variation, recently detected by Djurović and Pâquet (1990, 1993) and later confirmed by Dickey (1994), Abarca and Cazenave (1994) and Djurović and Pâquet (1996), has a variable period of 4-6 years. It is not yet clear what is its origin, even two ways are proposed to search for the mechanism generating this variation. One way is related to atmospheric anomalies manifested as El Niño/Southern Oscillation (Dickey, 1995), the second one - to the solar activity effects in the atmosphere and geomagnetic field (Djurović and Pâquet, 1996).

In seasonal domain, there are no spectacular new discoveries. The main characteristic of annual and semi-annual oscillations and their physical causes are well described in many studies (Munk and MacDonald, 1960; Lambeck, 1980; Barnes *et al.* 1983, etc).

Short-period fluctuations are mainly due to atmospheric excitation (see, for example, Barnes *et al.* 1983; Dickey, 1995 and references therein).

The dominant contribution of atmospheric disturbances to the Earth's rotation spin in short-period range was the reason for the organisation of the International Earth Rotation Service (IERS) Sub-bureau for Atmospheric Angular Momentum (in October 1989) which routinely computes the atmospheric excitation functions. These functions are used for the predictions of the Earth's space orientation as well as for the studies of different perturbing factors.

Data back to 1976 are available at daily or semi-daily resolution.

In the polar motion domain, it is proven that the phase of the free nutation during the period 1920-1940 changed by about 180^0, outside of this interval it remains constant. Controversies related to the double frequency of Chandlerian nutation (Okubo, 1982 and references therein), to the systematic variation of this frequency as function of the total polar motion amplitude (Carter, 1981; Vondrak, 1988; Pejović, 1990) remain yet unexplained.

Instrumental base for the Earth's rotation monitoring is modern and powerful. The number and the structure of instruments providing the database for the realisation and maintaining of the IERS Terrestrial Reference Frame ITRF93 are given in Table 2 (data taken from Feissel's 1994 report).

Table 2.

Observing technique:	VLBI	LLR	GPS	SLR
Number of sites	101	3	48	71
Position accuracy (in cm)	0.5	3.0	0.8	1.1

As a consequence of the involving of new technology and the new IERS organisation, this international service is able to furnish the data of fascinating precision and accuracy. Thus, for example, in the period 1992 onwards the precision of instantaneous pôle coordinates, celestial pôle coordinates ($d\psi \sin\epsilon, d\epsilon$) and universal time was: $0\overset{''}{.}0002$, $0\overset{''}{.}0005$ and $0\overset{s}{.}00005$ respectively. Some thirty years ago, when the solutions were based only on classical astrometry observations, the precision was $0\overset{''}{.}01$, for instantaneous pôle coordinates, and $0\overset{s}{.}001$, for universal time (Feissel, 1994).

7. TIME SCALES

A short historical overview of time reference evolution might be expressed by a few sentences. Before 1950 Earth's rotation has been considered as the best reference for the realisation of uniform time scale (Universal Time), mean solar day being the basic time unit. After two centuries (1750 - 1950) this reference has been replaced by apparent orbital motion of the Sun (1950-1955). New unit and new time scale (Ephemeris Second and Ephemeris Time) were internationally adopted. That was a consequence of the discovery of the Earth's rotation irregularities. However, soon thereafter the atomic clocks have replaced the previous dynamical scales (since 1955 onward). The main reason to abandon Ephemeris Time was the problem of rapid and precise accessibility (reading) of the scale.

International time scale TAI (Temps Atomic International) and deduced UTC (Universal Time Coordinated) result from individual scales of about 200 atomic clocks at 60 laboratories worldwide. The present stability and accuracy of TAI are: 5.10^{-15} and 2.10^{-14} respectively (Kovalevsky, 1995). The new stability improvement (up to 10^{-15} is expected in the next few years. At the level 10^{-16}, which is not so far from the one of today, the present relativistic terms,introduced in time scales comparisons, must be corrected.

The important increment of accuracy and precision of TAI realisation result mainly from the extensive use of GPS for the time transfer betwen individual laboratories and the corresponding centers and from the clock technology advance. The new model of Hewlett-Packard clock HP5071A has a stability by an order of magnitude higher than the previous model HP5061A.

Besides the cesium clocks, for the time keeping are used the Hidrogen-Masers, as well as quartz and rubidium clocks. H-masers are improved by autotuning the long-term drift (10^{-16}/day). The involving of such masers in the realisation of atomic time scales results in the improvement of their quality.

At several laboratories, as well as at Bureau International des Poids et Mésures (BIPM), the control of long-term atomic time scales stability is performed by Millisecond Pulsar (MSP) emission.

First MSP (PSR 1937+21) was discovered in October, 1982.As known, pulsars are galactic objects with radio jet-like emission and very stable spining period. Thus, for example, PSR 1855+09 has the spin rate whose stability is better than 1.10^{-14}). Accordingly, the radio observations of pulsars are used to realise the reference to the so-called pulsar time. The number of MSP with high timing stability observed today is about 30. These observations provide the possibility to deduce an average time scale, independent of TAI, and improve the control of long-term TAI stability.

New possibilities for the control of the long-term TAI stability lie in the timing of orbital motion of pulsars in binary systems. In BIPM and CNES (Centre National des Recherches Spaciales), France, has already developed technique to determine the time of arrival of pulsar signals at a radiotelescope (Petit, 1995).

The outstanding long-term stability of MSP spining has motivated Guinot, using the clocks contributing in TAI definition, to construct one after-the-fact very stable terrestrial time scale.

The step-wise progress in the realisation of space and time references was the reason for the IAU, at its XXIst General Assemblee, Buenos Aires, Argentina, 1991, to adopt the recommendations I to IX, relative to the definitions of space-time coordinates within the framework of General Theory of Relativity (*Information Bulletin*, IAU, 67, 1992).

Recomendation I

The four space-time coordinates ($x^0 = ct, x^1$, x^2, x^3) be selected in such a way that in each coordinate system centered at the barycentre of any ensemble of masses,the squared interval ds^2 be expressed with minimum degree of approximation in the form:

$$ds^2 = -cd\tau^2 = -(1 - \frac{2U}{c^2})(dx^0)^2 +$$
$$+ (1 + \frac{2U}{c^2})[(dx^1)^2 + (dx^2)^2(dx^3)^2].$$

where c is the light velocity, τ is proper time and U is the sum of the gravitational potentials of the above mentioned ensemble of masses and of a tidal potential,generated by bodies external to the ensemble, the later potential vanishing at the barycentre.

The algebraic sign of U is to be taken as positive.

The above definition of ds^2 includes only those terms required at the present level of observation accuracy.Higher order terms may be added, as deemed necessary.

Recommendation II

1. The space coordinate girds with origins at the solar system barycentre and at the centre of mass of the Earth show no global rotation with respect to a set of distant extragalactic objects.

2. The time coordinates be derived from a time scale realized by atomic clocks operating on the Earth.

3. The basic physical units of space-time in all coordinate systems be the second of the International System of Units (SI) for proper time and SI meter for proper length, connected to the SI second by the value of the velocity of light $c = 299792458 ms^{-1}$.

It is assumed that the average rotation of a large number of extragalctic objects can be considered to represent the rotation of the universe which is assumed to be zero.

If the barycentric reference system as defined above is used for the studies of dynamics within the solar system,the kinematic effects of the galactic geodesic precession may have to be taken into account. In addition, the kinematic constraint for the state of rotation of the geocentric reference system implies that when the system is used for dynamics (e.g. motions of the Moon and Earth satellites), the time dependent geodesic precession of the geocentric frame must be taken into account by introducing inertial terms in the equations of motion.

Recommendation III

1. The units of measurement of the coordinate times of all coordinate systems centred at the barycentre of ensembles of masses be chosen so that they are consistent with proper unit of time, the SI second.

2. The reading of these coordinate times be 1977 January 1. $0^h0^m32.184^s$ exactly, on 1977 January 1.$0^h0^m0^s$ TAI exactly (JD = 2443144.5), at geocentre.

3. Coordinate times in coordinate systems having their spacial origins respectively at the centre of mass of the Earth and at the solar system barycentre, and established in conformity with the above sections (1) and (2) be designated as Geocentric Coordinate Time (TCG) and Barycentric Coordinate Time (TCB).

The relationship between the above two time scales in seconds is:

$$TCB - TCG = c^{-2}[\int_{t_0}^{t}(v_e^2/2 + U_{ext}x_e)dt + v_e(x - x_e)].$$

x_e, v_e denote barycentric position and velocity of the Earth's centre of mass and x - the barycentric position of the observer. The external potential U_{ext} is the Newtonian potential of all solar system bodies apart from the Earth. It must be evaluated at the geocentre. In the integral t=TCB and t_0 is chosen to agree with the epoch of Note given below.

As an approximation to TCB-TCG in seconds one might use:

$$TCB - TCG = L_C(JD - 2443144.5)86400 +$$
$$+ c^{-2}v_e(x - x_e) + P$$

The present estimate of L_c is $1.480813 \pm 1..10^{-14}$ (Fukushima *et al.* 1986).

NOTE: The origins of coordinate times have been arbitrarily set so that these times all coincide with Terrestrial Time (TT) of Recommandation IV at the geocentre on 1977 January 1 $0^h0^m0^s$ TAI.

Recommendation IV

1. The time reference for apparent geocentric ephemerides be Terrestrial Time TT.

2. TT be a time scale differing from TCG of Recommendation III by a constant rate,the unit of measurement of TT chosen so that agrees with the SI second on the geoid.

3. At instant 1977 January 1. $0^h0^m0^s$ TAI exactly, TT have the reading 1977 January 1. $0^h0^m32.184^s$ exactly.

The basis of the measurement of time on the Earth is TAI which is made available by the dissemination of corrections to be added to the readings of national time scales and clocks. As the errors of TAI are not negligeable, it is considered necessary to define an idealized form of TAI, apart from the 32.184s offset, now designated Terrestrial Time TT.

In order to define TT it is necessary to define the coordinate system precisely. The relativistic metric from the Recommendation I is consistent with frequency uncertainties of the best clocks today.

The continuity with the previous time argument of ephemerides (Ephemeris Time) is ensured by the including of time offset $TT - TAI = 32.184s$, exactly at 1977 January 1. 0^h TAI.

The divergence between TAI and TT is due to the physical defects of atomic time standards. In interval 1977-1990.,in addition to the constant offset of 32.184^s the deviation probably remained within the approximate limits of $\pm 10\mu s$.

TT differs from TCG of Recommendation III by a scaling factor in seconds:

$$TCG - TT = L_G(JD - 2443144.5)86400$$

where present estimate of L_G ($L_G = 6.96929110^{-10} \pm 3.10^{-16}$) is derived from the estimate of gravitational potential on the geoid $W = 62636860 \pm 30m^2/s^2$.

8. THE CURRENT ACCURACY OF EPHEMERIDES

The ephemerides of the four inner planets and the Moon are today based on higly accurate ranging observations: radar echos from planetary surfaces, radio ranging to spacecraft transponders and laser ranging to the lunar reflectors. The progress in this

Table 3

Data types to which modern ephemerides are adjusted. The (post-fit) rms residuals indicate the accuracy of the data. The values listed without brackets are the units of the original observations; those within brackets give the comparable values for comparison purposes.

Type of observation	time span	post-fit rms residuals		number of observations
		km	″	
Radar ranging				
Mercury	1966-	1.5	[0.″002]	500
Venus	1965-	1.5	[0.″002]	1000
Mars	1967-	2.2	[0.″003]	40000
Mars Closure	1969-1982	0.15	[0.″0002]	200
Spacecraft Ranging				
Ma9 Orbtr (Mars)	1972-1973	0.040	[0.″0002]	600
Vkng Lndr (Mars)	1976-1980	0.007	[0.″000003]	900
	1980-1982	0.012	[0.″000006]	400
Spacecraft Tracking (range,Doppler)				
Pio&Voy (Jup,Sat)	1973-1980	[200,400]	[0.″05]	20000
Lunar laser ranging	1969-1970	0.00100	[0.″0005]	10
	1970-1975	0.00030	[0.″00016]	1700
	1976-1985	0.00015	[0.″00008]	3000
	1985-	0.00006	[0.″00003]	600
Radio astrometry				
Jup,...,Nep	1983-	[100,...,600]	0.″03	10
Ring Occultation				
Uranus	1978-	[1500]	0.″1	14
Optical transits (manual)				
Sun,Mer,Ven	1911-	[700]	1.″0	37000
Mars,...,Nep	1911-	[150,...,10000]	0.″5	18000
Optical transits (photoelectric)				
Mars,...Nep	1982-	[100,...,6000]	0.″3	1000
Astrolabe				
Mars,...,Ura	1961-	[100,...,4000]	0.″3	1500
Astrometry				
Pluto	1914-	[15000]	0.″5	1600

domain is well illustred by the data presented in the Table 3, taken from Williams and Standish (1989). However, the orientation of these ephemerides onto the dynamical reference frame was possible by optical observations. Since optical observations are two order of magnitude less accurate than the ranging data, the global sucess was below the attained relative positioning.

As reported by Standish (1995), the VLBI observations in 1989 from the Phobos Spacecraft aproaching Mars and in 1992-1994 from the Magellan Spacecraft orbiting Venus may be used to determine an offset between ephemeris and extragalactic frames. The comparison DE200 and IERS frame has shown that the difference between them is $0''.01$.

Future JPL ephemerides will be based upon extragalactic reference frame.

9. REFERENCE SYSTEMS AND REFERENCE FRAMES – TERMINOLOGY

The terminology used for references in geophysical and astro-geodetic practice is sometimes confusing. For a clear mutual understanding of specialists, the basic terminology,at least, must be fully determinate. Reckognizig this, astronomers have widely discussed this question at the international level (see, for example, *Astrometric Techniques*, Proc. of IAU Symp. No 109, 1986., *Reference Systems*, Proc. 127th IAU Colloq., 1991., Reference Frames in Astronomy and Geophysics, eds. J. Kovalevsky, I. Muller and B. Kolaczek, 1989, Kluwer Academic Publishers, etc).

According to the report of the IAU subgroup on coordinate frames and origins, presented by J. Kovalevsky (1991) at 127th IAU Colloq., the following terminology will be used:

"I) **Ideal reference system:** Theoretical principle on which the final reference frame is based.

Example 1: the equations of motion of a set of celestial bodies should have no Coriolis or linear acceleration terms when written in the ideal reference system.

Example 2: the ensemble of very distant bodies has no global rotation in the ideal reference system.

II) **Reference system:** It identifies the physical system on which the ideal reference system definition is applied. The solar system together with the physical laws governing it (general relativity or Newtonian mechanics) corresponds to the first example above. For the second example,a certain number of quasars form the system with a recipe on how the "non-rotation" is obtained.

III) **Conventional reference system:** In addition to the statements 1 and 2, parameters describing the physical system are assigned (and therefore conventional).

Example: masses and initial conditions of motions in the first case;they are given in the system of fundamental constants. In the case of extragalactic objects, a list of such objects will be given. The definition of the coordinate axes must also be given.

IV) **Conventional reference frame or, symply, reference frame:** It is a set of fiducial points with their coordinates that materialize the conventional reference system. The origin and axes of coordinates may either be materialized by, or simply inferred from the coordinates of the fiducial points. The coordinates of a point are obtained by interpolating the coordinates of fiducial points."

For better understanding of the above definitions let's remember that apparent positions of the reference stars, say the FK5 stars, represent the reference frame which enables the determination of the unknown coordinates of the observed source,by the reading of relative coordinates (on photographic plate) or by the determination of the instrumental orientation with respect to this frame. On the other hand, the apparent coordinates of FK5 stars at any epoch t are computed from their values given with respect to the mean equator and equinox at standard epoch J2000.0. This computation involves the set of constants as: proper motions,precession, nutations,paralaxes,aberrations, light deflections, etc. Therefore, the frame consisting of apparent star positions is realy conventional.

Besides the nutations,the observed declination include the motion of the instantaneous pole of the Earth's rotation with respect to the pole which the nutation theory is related to.

The positions of mean equator and equinox at the standard epoch $t_0 = J2000.0$ are determined via apparent positions of solar system bodies. The apparent coordinates of Sun,planets, asteroids and satellites are given in conventional reference system. They are computed by using the corresponding theory of motion, initial positions initial velocities, and set of constants. Accordingly, the access to the conventional reference system is possible by simultaneous observations of stars and solar system bodies. In the current astrometric practice, solar system bodies are observed to determine the so-called "correction to equator" and "correction to equinox" - the corrections to all preliminary deduced star coordinates (preliminary catalogue). As Kovalevsky said in the above mentioned report, "at this point, the user forgets completely the definition of the dynamical system, and only uses the frame represented by the catalogue".

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САДАШЊЕ СТАЊЕ АСТРОМЕТРИЈЕ

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Прегледни чланак

У историји астрономије последња деценија 20-ог века ће вероватно бити обележена крајем оптичке астрометрије на Земљи и почетком космичке и радиоастрометрије.

Постигнута тачност и прецизност посматрања са новим методама је на нивоу од 1 лучне милисекунде. У неким сегментима ова граница је осетно нижа.

Скоковити напредак у посматрачком домену праћен је и концептуалним променама. Традиционални концепт реализације инерцијалног небеског система референције, на бази динамике Сунчевог система, ће бити напуштен, јер његова кинематичка реализација је знатно погоднија.

На нивоу постигнуте тачности временског и просторног позиционирања, релативистичке поправке нису више занемарљиве. Због тога су корекције из Опште теорије релативности укључене у редукције астрометријских посматрања.