ALMAGESTO - Technical Manual

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Contents

List of Abbreviations

DST Daylight Saving Time. 3, *see* Daylight Saving Time

ERA Earth Rotation Angle. 23

IAU International Astronomical Union. 1

ICRF International Celestial Reference Frame. 23

IERS International Earth Rotation and Reference Systems Service. 1, 3, 4, 21, 22

TAI International Atomic Time. 4, 21, 22, *see* International Atomic Time

TCG Geocentric Coordinate Time. 4

TDB Barycentric Dynamical Time. 3

TT Terrestrial Time. 4, 22

TZ Time Zone. 3, *see* Time Zone

UT Universal Time. 23, *see* Universal Time

UTC Coordinated Universal Time. 3, 4, 21–23, *see* Coordinated Universal Time

Chapter 1

Introduction

Almagesto is a free source-code library in pascal that provides common astronomical and astrometric quantities and coordinate systems transformations.

The algorithms used in Almagesto are based on a vector and matrix formulation that is rigorous and consistent with the recommendations by the International Astronomical Union (IAU) and with the conventions of the International Earth Rotation and Reference Systems Service (IERS).

The following sections describe the calculation methods that implement the models used in fundamental astronomy.

Chapter 2

Coordinate Systems

Chapter 3

Date and Time

The astronomical computations use two main time scales, UT1 and Barycentric Dynamical Time (TDB). Both can be derived from Coordinated Universal Time (UTC).

3.1 Coordinated Universal Time (UTC)

UTC is the primary time standard by which the world regulates clocks and time and can be obtained from Standard Time, Time Zone (TZ) and Daylight Saving Time (DST).

$$UTC = StandardTime - TZ - DST \tag{3.1}$$

3.2 Universal Time (UT1)

The difference between UT1 and UTC is derived from observation and the uniform time scale UTC.

Forecast values are published at IERS Bulletin A and daily final values at 0:00 UT of ΔUT1 can obtained from IERS Bulletin B with the following time span: one month with final values and one month with preliminary values.

Weekly updated values of DUT1 with 0.1 s precision are announced at IERS Bulletin D. The latest IERS Bulletins can be accessed at `https://www.iers.org/IERS/EN/Publications/Bulletins/bulletins.html`.

$$UT1 = UTC + \Delta UT1 \tag{3.2}$$

$$UT1 = UTC + DUT1 \tag{3.3}$$

3.3 International Atomic Time (TAI)

UTC is based on International Atomic Time (TAI), with leap seconds (ΔAT) added to keep it within 0.9 second of UT1.

IERS publishes announcements every six months, whether leap seconds are to occur or not, in its IERS Bulletin C.

All leap seconds can be obtained from `https://hpiers.obspm.fr/eoppc/bul/bulc/UTC-TAI.history`[1].

$$TAI = UTC + \Delta AT \tag{3.4}$$

UT1R and UT2 can be obtained from UT1:

$$TerrestrialTime(TT) = TAI + 32.184\,\mathrm{s} \tag{3.5}$$

$$GeocentricCoordinateTime(TCG) - TT = (\frac{L_G}{1 - L_G}) \cdot (TT - T_0) \cdot 86\,400\,\mathrm{s} \quad \text{where} \tag{3.6}$$

$$T_0 = \mathrm{JD}2\,443\,144.500\,372\,5 \tag{3.7}$$

$$L_G = 6.969\,290\,134 \times 10^{-10} \tag{3.8}$$

[1] As of January 2021, there have been 27 leap seconds in total, all positive, putting UTC 37 seconds behind TAI.

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Chapter 5

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Chapter 6

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Glossary

Coordinated Universal Time UTC is the primary time standard by which the world regulates clocks and time. It is within about 1 second of mean solar time at 0° longitude, and is not adjusted for Daylight Saving Time. It is effectively a successor to Greenwich Mean Time (GMT). The current version of UTC is defined by International Telecommunication Union Recommendation (ITU-R TF.460-6), Standard-frequency and time-signal emissions, and is based on TAI with leap seconds added at irregular intervals to compensate for the slowing of the Earth's rotation. Leap seconds are inserted as necessary to keep UTC within 0.9 second of the UT1 variant of universal time [1]. iii, 3

Daylight Saving Time The practice of advancing clocks during warmer months so that darkness falls later each day according to the clock. The typical implementation of Daylight Saving Time is to set clocks forward by one hour in the spring ("spring forward") and set clocks back by one hour in autumn ("fall back", from the North American English word "fall" for autumn) to return to Standard Time. As a result, there is one 23-hour day in late winter or early spring and one 25-hour day in the autumn [2]. iii, 3, 21, 23

ΔAT It's the current difference between UTC and TAI (accumulated leap seconds). 4

ΔUT1 It's the difference between the UT1 parameter derived from observation and the uniform time scale UTC always less than 0.9 second. 3

DUT1 It's the value of UT1-UTC transmitted with time signals with a precision of +/-0.1s and by the IERS Bulletin D. 3

IERS Bulletin A IERS "Bulletin A" [3] contains Earth orientation parameters x/y pole, UT1-UTC and their errors at daily intervals and predictions for 1 year into the future. Contents are divided into four sections:

1. General information including key definitions and the most recently adopted values of DUT1 and TAI-UTC.

2. Quick-look daily estimates of the EOPs determined by smoothing the observed data. This involves the application of systematic corrections and statistical weighting. The results are published with a delay of about one to three days between the date of publication and the last available date with estimated EOP.
3. Predictions of x, y, and UT1-UTC, up to 365 days following the last day of data. The predictions use similar algorithms based on seasonal filtering and autoregressive processing for x, y, and UT1.
4. The combination series for the celestial pole offsets. Bulletin A contains celestial pole offsets with respect to the IAU1980 Nutation theory (dpsi and deps) and the IAU 2000 Resolutions (dX and dY), beginning on 1 January 2003

3

IERS Bulletin B IERS "Bulletin B" [4] provides current information on the Earth's orientation in the IERS Reference System, including Universal Time, coordinates of the terrestrial pole, and celestial pole offsets. Contents are divided into five sections:

1. Daily final values at 0:00 UT of x, y, UT1-UTC, dX, dY, and their uncertainties. Time span: one month with final values, one month with preliminary values.
2. Daily final values at 0:00 UT of celestial pole offsets dPsi and dEps in the IAU 1980 system and their uncertainties.
3. Earth angular velocity (daily estimates of LOD and OMEGA with their uncertainties).
4. Information on the time scales and announcement of occurring leap seconds.
5. Average formal precision of the individual and combined series contributing or not to the combination and their agreement with the combination.

3

IERS Bulletin C IERS "Bulletin C' [5] provides announcement of leap seconds in UTC and information on UTC-TAI. 4

IERS Bulletin D IERS "Bulletin D" [6] provides announcements of the value of DUT1 to be transmitted with time signals with a precision of +/-0.1s. 3, 21

International Atomic Time TAI is a high-precision atomic coordinate time standard based on the notional passage of proper time on Earth's geoid. It is the principal realisation of TT (with a fixed offset of epoch). It is also the basis for UTC [7]. iii, 4

leap second It's a one-second adjustment that is occasionally applied to UTC, to accommodate the difference between precise time (as measured by atomic clocks) and imprecise observed solar time (known as UT1 and which varies due to irregularities and long-term slowdown in the Earth's rotation) [8]. 4, 21

Standard Time The synchronization of clocks within a geographical area or region to a single time standard, rather than using solar time or a locally chosen meridian (longitude) to establish a local mean time standard. Generally, standard time agrees with the local mean time at some meridian that passes through the region, often near the center of the region. Historically, the concept was established during the 19th century to aid weather forecasting and train travel. Applied globally in the 20th century, the geographical areas became extended around evenly spaced meridians into time zones which (usually) centered on them. The standard time set in each time zone has come to be defined in terms of offsets from UTC. In regions where Daylight Saving Time is used, that time is defined by another offset, from the standard time in its applicable Time Zone [9]. 3, 21, 23

Time Zone A designated area of the globe that observes a uniform Standard Time for legal, commercial and social purposes. Time zones tend to follow the boundaries of countries and their subdivisions instead of strictly following longitude because it is convenient for areas in close commercial or other communication to keep the same time [10]. iii, 3, 23

Universal Time UT is a time standard based on Earth's rotation. There are several versions of Universal Time, which differ by up to a few seconds. The most commonly used are UTC and UT1. All of these versions of Universal Time, except for UTC, are based on Earth's rotation relative to distant celestial objects (stars and quasars), but with a scaling factor and other adjustments to make them closer to solar time [11]. iii, 23

UT1 The principal form of Universal Time. While conceptually it is mean solar time at 0° longitude, precise measurements of the Sun are difficult. Hence, it is computed from determining the positions of distant quasars using long baseline interferometry, laser ranging of the Moon and artificial satellites, as well as the determination of GPS satellite orbits. UT1 is the same everywhere on Earth, and is proportional to the rotation angle of the Earth with respect to distant quasars, specifically, the International Celestial Reference Frame (ICRF), neglecting some small adjustments. The observations allow the determination of a measure of the Earth's angle with respect to the ICRF, called the Earth Rotation Angle (ERA) [11]. 3, 4, 21, 23, 24

UT1R A smoothed version of UT1, filtering out periodic variations due to tides. It includes 62 smoothing terms, with periods ranging from 5.6 days to 18.6 years [11]. 4

UT2 A smoothed version of UT1, filtering out periodic seasonal variations. It is mostly of historic interest and rarely used anymore [11]. 4