THE EPHEMERIS REFERENCE FRAME FOR ASTROMETRY

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ABSTRACT. The basic problem of fundamental astrometry is to relate the instrumental reference frame of an observer to the frame defined by ephemerides of stars and objects in the Solar System. It is shown that in principle the choice of definition of the Ephemeris Reference Frame (ERF) can be quite arbitrary. For convenience, it is argued that the ERF should be defined by the rotation of an axi-symmetric rigid model Earth, the celestial pole being the direction of the axis of figure. This definition has practical and theoretical advantages over a model-dependent definition which attempts to take account of non-rigidity of the actual Earth.

The instantaneous ephemeris reference frame (ERF) is defined by the directions of the angular momentum vector of the Earth's orbital motion, and the celestial pole. This definition is embodied in the adopted numerical expressions for these two directions, relative to a supposedly inertial frame, and the ERF is rendered accessible to observation through ephemerides of stars and members of the solar system.

In order to compare observation with theory, the astrometrist needs to know, at any instant, the transformation between his own instrumental frame and the ERF. In the conventional language of meridian astronomy, he specifies the direction of the pole by the azimuth error of his instrumental collimation plane and the colatitude of his local vertical, and the direction of the equinox by his longitude or clock error relative to the ephemeris sidereal time.

The direction of the pole is determined by combining observations made at upper and lower culmination, either (a) of the same star or stars over an extended time interval, or (b) of different stars whose right ascensions differ by about 12 hours. A fuller discussion of the principles involved is given elsewhere (Murray 1978 b). These two procedures are superficially rather different. In case (a) the extended time interval must be at least 12 hours, for azimuth determination, and can extend to several years for colatitude. Any variation

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of longitude, latitude and azimuth, due for example to thermal or geophysical causes, should be known, and interpolated to each instant of observation. In case (b) on the other hand, observations can be made virtually simultaneously and only the differences of tabular right ascension and declination, relative to ERF, have to be assumed.

Case (a) is best illustrated by considering colatitude. Variation of latitude can be measured locally with a zenith instrument adjacent to the meridian instrument, or obtained from the results published by the BIH or IPMS. But observed variation of latitude itself depends on differences of declination between stars, for example, in a zenith zone, which have been determined by the chain or a similar method. An exactly analogous procedure can be applied to variation of longitude, but variation of azimuth is usually monitored by means of terrestrial marks.

We therefore see that in principle, all fundamental meridian observations are initially referred differentially to certain standard stars, whose differences in right ascension and declination relative to the ERF, are assumed known. Subsequently, the zero points in each coordinate are determined from extended series of observations, including those of the Sun, Moon and planets.

Taking this procedure to its logical limit, we could take as standards, stars in a zone very close to the pole, whose relative positions could be mapped very accurately by photographic techniques, thus avoiding problems of seasonal perturbations and closing errors which are inherent in the chain method. The absolute scale of the map must be derived from meridian observations, and is exactly analogous to the determination of the zero point of the declination system. The ephemerides of these stars, relative to the ERF, would give their offset from the celestial pole, which would therefore be almost directly observable at any instant.

It is important to note that at no point in this discussion has it been necessary to appeal to any particular physical definition of the celestial pole. Historically, this has been taken to be the direction of the angular velocity vector of a model Earth with rotational symmetry, whose dynamical behaviour approximates closely to that of the actual Earth. However, as Atkinson (1973, 1975) has pointed out, this vector is essentially unobservable by the meridian astronomer, and its use introduces small but troublesome short period variations in the rotation of the ERF relative even to a rigid model Earth. Within the framework of rigid dynamics, there is no doubt that the adoption of the axis of figure as the definition of the celestial pole is best for the observers.

However, now that the effects of departure from rigidity are observable and can be modelled, there is a temptation to redefine the ERF in terms of a more realistic model Earth. In the view of the present author this would be a mistake. The dynamics of a rigid Earth are well understood and the numerical representation of the rotation of such a rigid model is unlikely to require significant modification. On the other hand, an ERF which is severely model-dependent is liable to be changed as models improve. Deviations of the Earth from a rigid dynamical behaviour are, for the observer, compounded with purely local variations which must be observed directly anyway.

It is therefore proposed that the ERF should be defined by the instantaneous ecliptic and the axis of figure of an "Ephemeris Earth" which is a rotationally symmetrical rigid body with zero Eulerian motion; we may refer to the celestial pole of this reference frame as the "Ephemeris Pole". It has been shown elsewhere (Murray 1978 a) that the coefficients of the Oppolzer terms, representing the forced motion of the axis of figure relative to the angular momentum vector, which are given by Kinoshita (1977), should be used in preference to those listed by Woolard (1953).

The best available values of the displacement of the Ephemeris Pole from the direction of the axis of a more realistic model Earth should be made readily available; these should be regarded as estimates of corrections to be applied to observations in order to reduce them to the ERF. An observer would then have the option of either accepting these corrections or, alternatively, of deducing the direction of the Ephemeris Pole directly from his own observations. In this way the continuity of the ERF as the reference frame for astrometry can logically be preserved.

A further advantage of defining the ERF in this way, as has been pointed out elsewhere (Murray 1978 b), is that the component of angular velocity of the Ephemeris Earth about its axis of figure is rigorously constant, whereas the total angular velocity (about the axis of rotation) is not. We are thus led to a physically simple and rigorously self-consistent model for constructing not only the Ephemeris Reference Frame but also for defining a uniform standard for rotational time.

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DISCUSSION

F.P. Fedorov: I agree with Mr Murray in all points except one, which is one of terminology. It seems to me that the term "axis of figure" could cause confusion. That is why I used another term for the same axis; the "Jeffreys-Atkinson" axis.

C.A. Murray: I would not insist on the term "axis of figure", although it is exactly that axis of what I have called the Ephemeris Earth (to distinguish it from the real Earth) which is proposed as the definition of the celestial pole.

It should be pointed out that the pole which is currently used in the ephemerides is as logically distinct from the axis of rotation of the real Earth as the Jeffreys-Atkinson axis is from its axis of figure.

J.D. Mulholland: Is the avoidance of the rotational pole consistent with your concern for observational convenience?

C.A. Murray: Yes, certainly as far as classical methods are concerned. Indeed I believe that the only techniques for which the instantaneous axis of rotation has any relevance are those involving direct observation of velocity, such as Doppler measurements.

J. Kovalevsky: The reference frame proposed by Mr Murray is a fine example of what I called an intermediary system, since it is derived from the inertial frame by an unambigous mathematical formula independent of any possible modification introduced by a better understanding of the Earth's structure.

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