REFERENCE COORDINATE SYSTEM REQUIREMENTS FOR SPACE PHYSICS AND ASTRONOMY

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ABSTRACT

Changes in reference coordinate systems have major implications well beyond the realm of Earth dynamics. Definitions that serve geodynamic convenience may cause considerable effects for other disciplines. After presenting some typical areas in which coordinate frame definitions are important, recommendations are given for criteria to be considered as boundary conditions in discussing changes. These cover such qualities as observability, complexity, stability, internal coherence and uniqueness.

The very existence of this 2nd International Colloquium on Reference Coordinate Systems for Earth Dynamics — your very presence here — is an evidence that high-precision observing techniques no longer permit the various aspects of dynamical astronomy and solar system physics to be treated as isolated phenomena. Viewed in the context of the continual forcing action between theory and observation, we are currently in a phase where measurement capability has far outdistanced the capacity for theoretical interpretation. Simply to provide descriptive models, we are driven to computational complexity undreamed of two decades ago. The primary explanation of this state of affairs is that the physical interdependences between effects previously treated separately produce observable motions at a level that cannot be ignored if the data are to be correctly interpreted. Even the identification of appropriate coordinate systems now plays a critical role. It is my purpose here to remind you that, despite its title, this colloquium has responsibilities and influences well beyond the restricted realm of Earth dynamics.

In fact, if one considers the program and the list of participants objectively, it is evident that the word "Earth" in the colloquium title is more for administrative convenience than for scientific description. Our number includes many who are far less interested in the Earth as a subject of study than in the Moon, planets, asteroids, stars, and even extra-galactic objects. They (we!) are not here just

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to give a neighborly helping hand to the geoscientists. Surely, both observations and theoretical descriptions of extraterrestrial objects are required to establish an adequate set of coordinate systems for Earth dynamics. But as a practical matter, there will not be — there must not be — different "fundamental" reference systems for different applications. Even if the primary motivation for defining new fundamental systems comes from terrestrial concerns, these systems should be designed for universal applicability. Directly or indirectly, most observations of extraterrestrial objects will be related to terrestrial frames for the indefinite future.

COORDINATE SYSTEMS IN ASTRONOMY AND SPACE PHYSICS

It is both impractical and unnecessary to compile an exhaustive survey of the aspects of astronomy and space physics in which coordinate system definitions can play a significant role. It may be useful here, however, to give a few examples, just to emphasize the point.

— In the study of pulsars, the physical mechanism for pulsation depends on the time derivatives of the pulsation period evaluated in an inertial coordinate frame. Thus, the observations are normally reduced to the solar system barycenter. The topocentric position and motion of the barycenter are affected by the assumed planetary masses and orbits, by the station motion, and thus by coordinate system definitions, including the transformation between proper time and coordinate time.

— The dynamical and statistical properties of our galaxy, as well as its dimensions, are based on observed values of both systematic and random components of the proper motions of stars. The precession of the Earth's equatorial plane and the rate of change of obliquity are perfectly correlated with systematic proper motions.

— Dynamical and geometric determinations of solar oblateness depend on coordinate system definitions in different ways. Thus, reference frame inconsistencies may introduce noise into even otherwise perfect observational comparisons.

— Inadequate coordinate systems can introduce inconsistencies in planetary orbits through the interaction of mass, heliocentric distance and mean angular speed (Kepler's third law).

— Unmodelled coordinate system motions can introduce errors into estimates of the anomalous accelerations of the Moon and artificial satellites, thus biasing discussions of lunar evolution and terrestrial dissipation processes.

In terminating this list, I remind you that it is far from complete, only a small sample to illustrate the scope of subjects that may be influenced by what we do here.

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REQUIREMENTS AND RECOMMENDATIONS

I will not dwell long nor in detail on questions of desired or necessary precision and accuracy. The reason is simple. From an astronomical point of view, Earth is the most closely, intensively and accurately observed of all celestial bodies. In addition to purely terrestrial measures, every Earth-based observation of an exterior body is also an observation of Earth. It is indeed from this point that geophysics was born nearly a century ago: I remind you that Chandler was an editor of the Astronomical Journal and that Love's historic work "On Some Problems in Geodynamics" was a John Couch Adams prize essay of Cambridge University. This pre-eminence of Earth as a planet means that a set of coordinate systems that provides the necessary precision and accuracy for attaching terrestrial dynamics to an internal frame will also satisfy the accuracy requirement of non-terrestrial applications. But accuracy is not the only problem. There are significant qualitative aspects which must also be addressed in any redefinition of fundamental systems, as well as the realization and use of multi-application intermediate references.

It is important to stress that we are concerned here with <u>both</u> fundamental and secondary reference frames. It is frequently impossible to use fundamental frames directly. Good examples of this are the use of lunar and planetary ephemerides or the analysis of range and doppler observations of artificial satellites. Thus, it is reasonable to discuss qualitative desiderata for fundamental systems while ignoring the comparable aspects of secondary systems. In my opinion, the following considerations are to be taken into account:

I. Observability — Standard coordinate systems, both fundamental and derivative, should be as close as possible to the observations. Secondary systems should be directly observable. Definitions of fundamental frames should avoid conceptual bases that are inherently inaccessible to observation. As an example, despite its advantages to theorists, a terrestrial reference frame based on the total angular momentum vector must be rejected.

II. Complexity — Fundamental coordinate systems should be conceptually as simple as the demands upon them permit. In Earth dynamics, it is evident that observing stations must be permitted to move relative to any reference frame. For many non-terrestrial applications, however, the station motions will remain trivial for the foreseeable future. For these uses, a fundamental terrestrial system with time variant "mean positions" of surface points will be an unnecessary and expensive complication.

III. Stability — In general, astronomy and astrophysics are concerned as much with phenomena over periods of eons as well as nanoseconds. Changes of fundamental systems, even when obviously required, represent a serious material nuisance and a potential source of

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calculational error. Such changes must be held to a minimum. Proposed changes must be subjected to the most minute inspection and criticism, so that formal adoptions may have the longest useful life span possible. A painful example at present is the astronomical nutation series. Two aspects of this controversy should be distinguished: a) the numerical adequacy of the adopted IAU model, and b) the manner of its adoption.

There is some opinion that the numerical coefficients adopted at Montreal in 1979 were then already inadequate to represent the observations. If this be true, then it is best to change the nutation series now, before it is used. In that case, we simply admit to a stupidity which we quickly erase. This should not be done carelessly, however; reversal of an official adoption should not be permitted to become a light matter. If the objection is not based on a currently observable astronomical error, then the IAU decision should stand.

IV. Departures from conventional models — Two decades ago, the reality of space exploration introduced astronomy to the world of "crisis science". Since then, a *modus operandi* has evolved that one must recognize not only as realistic but as valid. Except for periods of scientific stagnation, or immediately after new conventions are adopted, conventional systems designed for multi-disciplinary use cannot serve satisfactorily for all applications at a rapidly-evolving frontier of physical knowledge. A conventional model should represent as well as possible the needs and capacities of its epoch of adoption, without being expected to anticipate the future in any detail. As the scientific frontier is pushed outward, certain high precision applications *must* eventually abandon the adopted system to realize maximum value from the observations. In such cases, the departures from conventionality must be as explicit and as well-defined as possible.

V. Internal Coherence — Adopted *sets* of reference systems, whether fundamental or derivative, should be internally coherent. A near-trivial example is the use of planetary ephemerides as a connecting link between terrestrial and celestial reference frames. For proper use, the ephemeris must be used together with a set of constants (e.g. astronomical constants, station coordinates) appropriate to that ephemeris. Station coordinates obtained by comparing observations with an orbital ephemeris are *ephemeris-dependent*, not absolute.

VI. Form of Presentation — Definition of reference frames should include not only the conception, but also the method of realization and application. Definitions should be realizable avoiding the sort of impossible situation that surrounded the use of Ephemeris Time.

VII. Uniqueness — Elements of a chain of coordinate systems should be uniquely identified. Non-uniqueness offers the opportunity for ambiguity and miscomprehension. A classical pre-space-age example is the difference in numerical results obtained by use of Newcomb's theory of the Sun and Newcomb's Tables of the Sun, which were constructed from

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that theory. There is in fact a current analogue to that situation. Machine-readable planetary and lunar ephemerides for space research are now distributed as polynomial series fitted to numerical integrations. A single integration can be reduced to multiple versions by choosing different parameters for constructing the series. Such multiple versions can give different numerical results. We have already experienced one case of two different ephemerides with the same identification. Great care should be exercised to avoid such ambiguities.

CONCLUSION

Happily, the Program Committee did not ask me to provide solutions to the problems that the needs of astronomy and space physics pose for the definition of new reference coordinate systems. I have tried simply to pose boundary conditions that I think should be taken into consideration during our discussions and deliberations, to try to minimize the RMS chaos in future influences of our actions here.

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