INTRODUCTORY REMARKS FOR SESSION 2

G. H. KAPLAN
President, IAU Commission 4 (Ephemerides)
e-mail: gk@gkaplan.us

ABSTRACT. Three institutions are now providing high-quality fundamental solar system ephemerides to the astronomical community. This session presents some important new information on how the ephemerides from all three groups are constructed, and how they compare with each other. These kinds of comparisons are essential in improving solar system ephemerides generally and understanding their limitations.

Since the 1960s, there has been a continuing need to develop ever more accurate representations of the motions of the planets, their satellites, and the Moon, due to the requirements of spacecraft navigation and the continued development of high-precision observational techniques like radar ranging, LLR, pulsar timing, and VLBI. Indeed, the accuracy of the best observations currently exceeds our modeling capabilities — we simply don't have good mass estimates for the huge number of small bodies in the solar system — so that new ephemerides must be constantly recomputed to meet the latest requirements.

We have come a long way just over the course of my career. When I started at the U.S. Nautical Almanac Office 39 years ago, we were still using Newcomb's developments extensively, and progress seemed to be defined by ever more complicated general planetary theories similar to Newcomb's, that is, analytical developments for a planet's position based on a series expansion of the disturbing function. The most sophisticated theories at that time were probably Clemence's Theory of Mars, published in 1961, and Eckert's Improved Lunar Ephemeris, published in 1954, the latter based on Brown's 1919 theory. The group of planetary and lunar theories developed by Bretagnon, Chapront, Deprit, Krasinski, and collaborators in the last few decades of the 20th century are part of this important branch of celestial mechanics.

Fundamental Solar System Ephemerides
Used in *The Astronomical Almanac*
(and predecessor publications)
Over the Past 50 Years

1960 to 1983

Mercury – Earth: Newcomb (1895) theories
Mars: Newcomb (1898) theory with Ross (1917) corrections
Jupiter – Pluto: *Coordinates of the Five Outer Planets, 1653-2060* (Eckert, Brouwer & Clemence 1951) *
Moon: Improved Lunar Ephemeris (Eckert 1954)

1984 to 2002

JPL DE200/LE200 (Standish 1982, 1990) *

2003 to present

JPL DE405/LE405 (Standish 1998) *

* N-body numerical integrations
(others are analytical theories)

N-body numerical integrations become practical after World War II due to the commercialization of electronic computers and their steady increase in speed, especially after the introduction of solid-state circuitry. In fact, some of the first applications of automated computing technology to scientific problems involved the calculation of ephemerides. A landmark in this field was the completion of the *Coordinates of the Five Outer Planets, 1653–2060*, by Eckert, Brouwer, and Clemence, published in 1951, which were calculated on one of the first stored-program electronic computers, IBM's SSEC, with 12,500 electron tubes. In the introduction to this ephemeris, it was noted that each integration step took "less than two minutes." Its descendents included, in the U.S., integration programs developed in Fortran at MIT and JPL in the 1960s, and similar integrators written elsewhere, for example, at the Institute of Theoretical Astronomy in Leningrad.

Figure 1: IBM's SSEC computer in its New York City location. IBM photo from *Columbia University Computing History* at http://www.columbia.edu/acis/history/ (used with permission).

The JPL planetary and lunar ephemerides have been the recognized state of the art for three decades (and counting). These ephemerides have been developed under the leadership of Myles Standish and now Bill Folkner, with significant contributions from Jim Williams, Skip Newhall, and others. The quality of the product is due not only to the increasing sophistication of the perturbation model, but also to the inclusion of spacecraft and other high-precision observations in increasing numbers and kinds, along with careful post-solution analysis. This work requires meticulous attention to detail, and the need to continually incorporate new types of observations undoubtedly discouraged other groups with fewer resources from trying to compete. Even Bretagnon's analytical theories were fit to JPL's DE200/LE200 ephemeris rather than to individual observations.

So it is very exciting that now we have two other institutions, the Institute for Applied Astronomy in St. Petersburg, and the Institut de Mécanique Céleste et de Calcul des Ephémérides here in Paris, that have produced independent ephemerides for general use, fit to a large number and variety of observations, that are comparable in quality to those produced by JPL. This session provides some important new information on how the ephemerides from all three institutions are constructed, and how they compare with each other. These kinds of comparisons are essential in improving solar system ephemerides generally and understanding their limitations.

One last note: IAU Commission 4 has established a Working Group on Standardizing Access to Ephemerides, to suggest standard software or data formats that would allow users to easily obtain ephemeris data and to switch seamlessly (if possible) among the available sources. James Hilton (jms.l.hilton@gmail.com or james.hilton@usno.navy.mil) is the working group's chair, and he welcomes input from everyone.