COMETARY EPHEMERIDES - NEEDS AND CONCERNS

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I. Astrometry and Ephemeris Improvement

With the use of narrow field-of-view instrumentation on faint comets, the accuracy requirements upon computed ephemerides are increasing. Today, it is not uncommon for instruments with a one arc minute field-of-view to be tracking a faint comet that is not visible without a substantial integration time. As with all ephemerides of solar system objects, the computed motion of a comet is based upon past observations. As well as being corrupted by errors in the taking and reduction of these observations, the computed motion of a comet is further dependent upon effects related to the comet's activity. Thus, the ephemeris of an active comet is corrupted by both observational errors and errors due to the comet's activity.

A. Errors in Observations

The ideal cometary position observation is generally the shortest exposure possible that still shows a (nearly stellar) cometary image. Generally the telescope is guided on the comet's predicted motion so that the surrounding star images are trailed. The accuracy of the comet's reduced position depends upon the accuracy of the trailed star positions that are used in the reduction procedure. Often the only suitable star catalog is the Astrographic Catalog which has only rectangular star coordinates for most zones. These coordinates can be reduced to right ascension and declination using the given plate constants but these constants are often out-of-date or inaccurate. While new constants are being determined for the northern hemisphere zones, the plate constants of the southern hemisphere zones are not being updated as yet. Because of these plate constant problems and also because the stars of the Astrographic Catalog do not have proper motion corrections, the star positions can have errors of up to 1-2" (Roemer, 1976). Personal mistakes in observation reductions sometimes yield errors of 1-4" and while an occasional error of 4" can easily be detected and the observation rejected, a run of observations biased by 4" can skew the computed orbit away from the actual orbit.

The cometary orbit determination process, and the ephemeris computations that are based upon this process, assume that published positions of comets refer to the comet's actual center-of-mass. However, it is the comet's "center-of-light" that is actually measured. Any center-of-light/center-of-mass offsets would be particularly damaging to ephemeris accuracy if they were systematically located on one side of the center of mass. Since the photometric center-of-light is likely to be the area of highest dust density in the cometary neighborhood, there is some reason to believe that the center-of-light is systematically offset toward the sun for a dusty comet like Halley.

B. Errors Due to the Comet's Activity

Unlike other solar system bodies, the motions of comets are usually affected by substantial nongravitational perturbations. These effects are thought to be due to the rocket effect of the outgassing cometary nucleus (Whipple, 1950). For comet Halley, nongravitational effects cause the comet's period to increase by ~ 4 days per period (Yeomans, 1977). For most comets of the Jupiter class (Period ~ 5-6 years), the existing model for these nongravitational effects seems to succeed rather well (Marsden, Sekanina and Yeomans, 1973). However, the nongravitational force model does not succeed for some comets of intermediate period (Period ~ 70 years). For comet Halley, the

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model succeeds better than for most intermediate comets but even so there are systematic residual trends in the observed minus computed observation residuals. For an extreme example, an orbit solution based upon observations over the 1759-1835-1910 interval yielded systematic residual trends to 20" in May 1910 when the comet passed within 0.18 AU of the Earth. This would correspond to an absolute comet position error of ~ 2600 km. Since observation errors probably do not account for more than say 4" of this 20" residual trend, one must assume that the model for the comet's equations of motion is deficient. It may be that the nongravitational acceleration model is not symmetric with respect to perihelion as is now assumed. There may be significant (but unmodeled) stochastic nongravitational accelerations acting upon the comet's nucleus.

C. Techniques for Ephemeris Improvement

To reduce the observational errors, the observer should guide on the comet's motion to obtain faint and nearly stellar images, hence minimizing center-of-light/center-of-mass offsets. Each observer should take at least two plates per evening to identify weak images and properly identify the comet by comparing the observed and computed motion of the image. To facilitate plate reductions, each observer should be equipped with the appropriate star catalogs for each section of the comet's path through the constellations. At least 5 reference stars should be used in the reduction procedure.

Errors due to the comet's activity are dependent upon the model used in describing the comet's motion. One might try to model the center-of-light/center-of-mass offset or try a nongravitational acceleration model that was asymmetric with respect to perihelion. However the solution for extra parameters in the least squares orbit determination process is dangerous; while the solution may be improved, the predictive power of the solution can be destroyed.

Cometary orbit determination and subsequent ephemeris computations can be improved by using observations over as long a data arc as possible with the observations concentrated when the comet's apparent motion on the sky is largest. Cometary position measurements made at close geocentric distances, when the comet's apparent motion is large, are the most powerful observations for ephemeris improvement.

By carefully observing and reducing their data, and by judiciously choosing their observing times, observers of cometary positions can provide the accurate observations required for precision ephemerides. However, if the past is any indication of the future, the precision of computed ephemerides is not so large a problem as is the confusion over the published ephemerides themselves.

II. Confusion Over the Use of Published Ephemerides

Along with the increased accuracy requirements that are being placed upon recent ephemeris computations, the ephemeris users now have the responsibility of understanding what type of ephemeris they are using. Effects that were once negligible for locating an object in wide field instruments become important for locating the object in narrow field instruments.

Some confusion has been evident in the generation and use of precision ephemerides because some of the labels used to describe a celestial position have been used erroneously and/or interchangeably. Prior to an International Astronomical Union (I.A.U.) Commission 20 recommendation in the Fall of 1979, most comet and minor planet ephemerides were geometric. Today they are either astrographic or apparent. Geocentric ephemerides for the planet Pluto and various minor planets published in the American Ephemeris and the Nautical Almanac (A.E.N.A.) are astrometric. Table I presents the various effects that are included in these four types of ephemerides. In general, photographic observations using stellar offsets should be made employing astrographic or astrometric ephemerides. Usually visual observations, radio observations and radar observations will require apparent ephemeris positions. In practice, many radio antennas or telescopes used for visual observations input astrographic or astrometric ephemerides and make the necessary corrections to apparent positions within the computer drive system.

An object's astrometric position is directly comparable with cataloged star positions provided: 1. the stellar positions have been corrected for proper motion and annual parallax, 2. the catalog's reference equinox is 1950.0, and 3. the object's observed positions have been corrected for the effects that depend upon an observer's topocentric location. It should be noted

Table I.

Effects Upon Observed Positions of Solar System Objects

Effects	Approximate Magnitude	Dependent Upon Observer's Location	Are These Effects Included in the Following Ephemeris Types: Geometric	Astrographic	Astrometric	Apparent	Notes
I. PLANETARY ABERRATION							
A. Stellar Aberration							
1. Annual							
a. Circular	< 20"	No	No	No	No	Yes	
b. Elliptic	< 0.3"	No	No	No	Yes	Yes	
2. Diurnal	< 0.3"	Yes	No	No	No	No	
B. Light Time	(Appn.motion)Δ/C	No	No	Yes	Yes	Yes	1
II. NUTATION	< 18"	No	No	No	No	Yes	
III. PRECESSION	< 1/yr in α < 20"/yr in δ	No	eq. 1950.0	eq. 1950.0	eq. 1950.0	eq. of Date	2
IV. GEOCENTRIC PARALLAX	8.8"/Δ	Yes	No	No	No	No	
V. REFRACTION	Δz ~ 60" tan z	Yes	No	No	No	No	3
Types of Published Ephemerides			Comets and Minor Planets in I.A.U. Circ. and MPC before 10/79	Comets and Minor Planets in I.A.U. Circ. and MPC after 10/79	Pluto and Minor Planets in A.E.N.A.	Sun, Moon, and Planets (except Pluto) in A.E.N.A.	

Notes:

1. The light time correction is directly proportional to both the comet's apparent motion on the sky and the earth–comet distance (Δ). C is the velocity of light.
2. The geometric, astrographic and astrometric ephemerides are referred to the 1950.0 equinox while the equinox for an apparent position is the particular ephemeris date.
3. Δz is the approximate correction required in the zenith distance (z).

that the future FK5 standard star catalog and star catalogs that will be tied to it will not include the elliptic portion of annual aberration. Hence these new catalogs will be astrographic.* Most star catalogs now in use (including the Astrographic catalog) are astrometric. Details for freeing an object's position from the various effects listed in Table I can be found in the Explanatory Supplement (1961).

Pitfalls to Avoid

A. Unless otherwise stated, it should be assumed that each of the four ephemeris types in Table I use ephemeris (not universal) time. In 1980, ephemeris time is 51 seconds ahead of universal time.

B. Occasionally someone will try to convert a geometric ephemeris to an astrographic ephemeris by modifying the printed ephemeris time entries by one light travel time. This procedure is incorrect because it effectively backs up the object and the earth instead of just the object.

C. Many observers now generate their own ephemerides using a two body (sun-object) formulation initialized by orbital elements. This is quite acceptable providing that the input elements were generated with a two body orbit determination technique. If the input elements were generated using planetary perturbations in the orbit determination process, care must be taken to use these (osculating) orbital elements only if the given epoch is sufficiently close to the desired ephemeris interval. Osculating orbital elements will be strictly correct only for the instant of the given epoch and it is dangerous to use them as input to a two body ephemeris if the epoch is several weeks from the desired ephemeris interval.

*They will also have a new reference equinox of 2000.0.

References

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