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Session 1. Orbital Parameters

THE TOOLS TO DETERMINE ORBITAL PARAMETERS

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How can an apparently cut-and-dried textbook matter such as orbits become the topic for an international conference? The answer is found in statements from the reports of presidents of Commission 26 which criticize the existing state of affairs and is further elaborated upon by van den Bos (1962) in his well-known query "Is this orbit really necessary?" The objections refer to useless repetitions or multiple solutions and results that are distinctly inferior to observational accuracy. Unanimous agreement on what constitutes a useful orbit, or revision, is unlikely to be achieved, but considerable published work which is based more on computer experience than on double-star knowledge is clearly of inferior quality. To some extent, errors of observation (including poor distribution of data, etc.) are unavoidable, but published material contains errors due to the method of analysis which could have been avoided.

If it is the accumulation of observations which triggers excessive orbit computations then I am "glad" to say that this incentive is dying out. Seen from today, the nineteen-fifties were still a golden age of binary observation. By 1961, at the first double-star conference held in Berkeley, voices of concern arose on the lack of observers and a resolution was submitted by Hertzsprung, yet the situation worsened steadily. Most of the highly productive observers of fifteen years ago have terminated or reduced their output. Combined with the dropout of some other contributors, the loss of observers is a full dozen and the three or four younger additions to the trade cannot make up for this loss. The particularly desperate situation in the southern sky is well known.

The main purpose of orbital analyses is the determination of masses through the quantity a^3/P^2 which also is proportional to $c^2/p \cos^2 i$ if expressed in terms of the apparent areal constant c. In close, short-period pairs, the semi-axis a is the vulnerable quantity and is frequently affected by systematic errors. In wider pairs, generally with longer periods and shorter observed arcs, c is usually well known, and the accuracy of the inclination i is crucial for the reliability of the masses. Radial-velocity observations are a powerful tool for parallax determinations as well as for investigations of irregularities which may indicate the presence of third bodies. The radial velocities should be compared with good orbit ephemerides which closely match the observed positions.

My opinion on the subject of methods of calculation may not be generally shared but it is offered as a contribution to the discussion. It can be summarized in four statements:

(1) The quality of an orbit depends not only on the observations but also very much on the calculator. From the same material, sloppy as well as careful solutions can be obtained. There are many, too many, examples.

(2) The high information content of measurements should be fully exploited and not thrown away. I consider that 90 or 95 per cent of the observations contain more-or-less-useful information. Consequently, the adoption of a few "standard" observations is not favoured since the influence of random and systematic errors, and the risk of overlooking runs in the residuals, would then be too high.

(3) First-orbit methods cannot exhaust the information and corrections will almost always be necessary. What matters, therefore, is not the initial method employed but the final result which must give a good representation of all usable measurements.

(4) If the criterion for the quality of a method is that it should lead closest to the truth in the first application then there is no best or "standard" method for all purposes. Mathematically, all methods should yield identical results. But each method emphasizes different data, the reliability of which may vary greatly from one orbit to another, and, in practice, this affects the results. For instance, the application of Lagrange (differential) and Gauss (integral) type methods is quite different.

Ideally, the least-squares fit should be the best solution, *if* freedom from systematic errors and an optimum distribution of weights could be achieved. The solution may be very sensitive to these factors because, in most cases, some elements or combinations thereof remain weakly determined.

Some comments on the practical application of various methods are indi-

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cated: geometrical methods (of the well-known Russell and Kovalsky type) which do not incorporate the law of areas probably cannot be recommended in any case. The Thiele-van den Bos method is widely used, with good reason, but it is certainly not an all-purpose procedure. It is elegant and fully analytical which creates a temptation to overuse it. Moreover, the method relies strongly on measured separations and it is very sensitive to small errors of measurement in cases of incomplete arcs. Any long-period orbit derived in this manner in which the product $e \sin i \sin \omega$ is near unity should be regarded with deep suspicion.

To turn briefly to some results of recent orbit work: the new Finsen-Worley (1970) catalogue raised the number of entries from the 540 of its predecessor to 700. Part of the increase came from the deliberate inclusion, for the sake of completeness, of some dozens of wholly meaningless orbits, and from the inclusion of 30 astrometric orbits of visually single stars. Many of the newly added orbital binaries have periods in the range from 100 to 200 years and are about ninth magnitude (β, Hu, and A pairs), that is, mostly F and G-type stars at distances of roughly 100 parsecs. The pairs are too faint to have radial-velocity coverage, so the data on the random orientation of orbital planes (Heintz 1969) as derived from some 70 pairs plus 20 edge-on orbits still hold. Another 100 or 200 visual orbits could have their orientations determined from repeated or differential radial-velocity measurements. The growing number of orbits confirms the absence of a period-eccentricity relationship, and also the general distribution of eccentricities according to Couteau's (1960) formula, perhaps with a slight asymmetry toward $e < 0.5$. The count of four quadruple and nearly 30 triple systems with known elements is unchanged. About 40 objects now possess sufficiently accurate orbits, mass ratios and parallaxes (almost all trigonometric) that they can be used to study the mass-luminosity relation.

The subject of "dynamical parallaxes" may be introduced in this connection. It is recommended that this name be given to results based on an orbit and on a mass-luminosity array, and to no others. The formula for the total mass **M** is, following the notation of Baize:

$$\log \mathbf{M} = -\frac{6}{5(3\kappa - 2)}\left(m_t + C + D + \frac{5}{3}\log a^3/P^2\right)$$

whence the dynamical parallax π follows from

$$\log \pi = \tfrac{1}{3}\left(\log a^3/P^2 - \log \mathbf{M}\right).$$

κ is the exponent of the adopted relationship, the quantity M_o (the absolute magnitude of a star of mass 1 $M_\odot$ on the specified relationship) as well as Δm and the bolometric correction being contained in the terms C and D. The combined apparent magnitude m_t has to be known fairly well since it enters more critically than Δm.

Let us comment finally on the combination of radial-velocity and visual data. A very good spectroscopic coverage would permit a combined solution for the elements. Although the period will be taken from the visual data, there are still three elements (T, e and ω) common to both sets and they will be strengthened by the combination. Use of the Thiele-Innes constants has the drawback of an implicit double determination of ω.

This case, however, is quite rare. More often, the radial velocities are too scanty to contribute to the elements yet they may suffice to determine the amplitude K_1, since the spectra are usually single-lined. Then an equation between the parallax and the mass ratio f is still available:

$$f/\pi = 12.086\, K_1(1 - e^2)^{1/2}/na \sin i$$

with the mean motion n, the semi-major axis a, and the inclination i determined by the visual orbit. If, finally, the spectra fail to determine K_1, they may still suffice to indicate the position of the ascending node.

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Discussion

Heintz mentioned that van den Bos' modesty in not attaching his name to the Thiele-van den Bos method should not lead to the use of other names such as Thiele-Innes or Gauss for the method. Couteau suggested that differences between observers, possibly due to different equipment, can lead to noticeably different orbits, yet Worley stated that a study of systematic differences at the U.S.N.O. did not show significant discrepancies among 8 or 10 major observers.

Franz and Hardie recommended more photometry of the combined light of binaries for problems such as parallax determination. Δm can be estimated by eye or with the Muller polarizing photometer. Strand believed photometrists may formerly have avoided stars known to be binaries. The Finsen-Worley orbit catalog can serve to a large extent as a priority list for future measurements but Heintz stated that photometrists should include an infrared colour to help the search for faint companions.

The session closed by noting the critical situation in the southern hemisphere with neither Johannesburg nor Bloemfontein active. It is urgent to stimulate double-star research at other places. The 15″ refractor at Rio de Janeiro does not allow many observations at its present site according to Freitas Mourao, while Worley made 700 measurements in three weeks at Cerro Tololo.