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NEW ORBITS FOR COMETS C/1960 M1 (HUMASON), C/1980 E1 (BOWELL), AND MUSINGS ON EXTRASOLAR COMETS

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RESUMEN

Se calculan órbitas nuevas para los cometas Humason (C/1960 M1) y Bowell (C/1980 E1). La órbita de Humason se basa en 34 observaciones hechas durante 348 días y para Bowell en 203 observaciones hechas durante ocho años. Integraciones hacia atrás indican que ambos cometas tenían órbitas originalmente muy elípticas, que fueron cambiadas a hipérbolas por la adición de energía desde el Sistema Solar. Puesto que sus distancias del perihelio son mayores de 3 AU, la posibilidad de fuerzas no gravitatorias es remota. Para el cometa Secchi (C/1853 E1), sin embargo, la órbita es hiperbólica a una distancia de más de 100000 AU del Sol y sin evidencia alguna de fuerzas no gravitatorias. Si la órbita permanece hipérbolica a esa distancia, quizás su origen sea fuera de la nube de Oort.

ABSTRACT

New orbits are calculated for Comets Humason (C/1960 M1) and Bowell (C/1980 E1). Humason's orbit is based on 34 observation made over 348 days and Bowell's on 203 observations made over nearly eight years. Both comets have hyperbolic orbits. Backwards integrations indicate that both comets had originally highly elliptical orbits which changed to hyperbolas by the injection of energy from the Solar System. Given that both of their perihelions are more than 3 AU from the Sun, the possibility of nongravitational forces is remote. For Comet Secchi (C/1853 E1), however, the orbit is hyperbolic at more than 100000 AU from the Sun and with no indication of nongravitational forces. If the orbit is a hyperbola at that distance, could the comet's origin not be from beyond the Oort cloud?

Key Words: comets: individual (Humason, Bowell) — methods: numerical

1. INTRODUCTION

The genesis for this paper arose from my pondering an earlier paper of mine on Comet C/1853 E1 (Secchi), where it is suggested that the comet *may* have an extrasolar origin (Branham 2012). I do not state that the comet *is* of extrasolar origin, but that such an hypothesis remains the simplest one consistent with the observations. One would, nevertheless, like to encounter additional data to bolster, or perhaps not, the hypothesis. Yabushita & Hasegawa (1990) have identified ten comets with hyperbolic orbits, negative values of the reciprocal semi-major axis a^{-1}, that at first glance would suggest an extrasolar origin. Królikowska (2006), however, studied some hyperbolic orbits and found that when nongravitational forces are taken into account, the orbits are transformed into high eccentricity ellipses.

Nongravitational forces, however, seem to be lacking in the behavior of Comet Secchi nor would they be likely for two further comets, C/1960 M1 (Humason) and C/1980 E1 (Bowell), both of which have hyperbolic orbits and perihelion distances so large, greater than 3 AU, that nongravitational forces become most likely inexistent. Can one find any indication that either of these might be of extrasolar origin? The question, however, seems ill-considered because both of these comets have been studied previously, Humason by Van Biesbroek (1970) and Marsden & Sekanina (1973), neither of whom find evidence for an orbit originally hy-

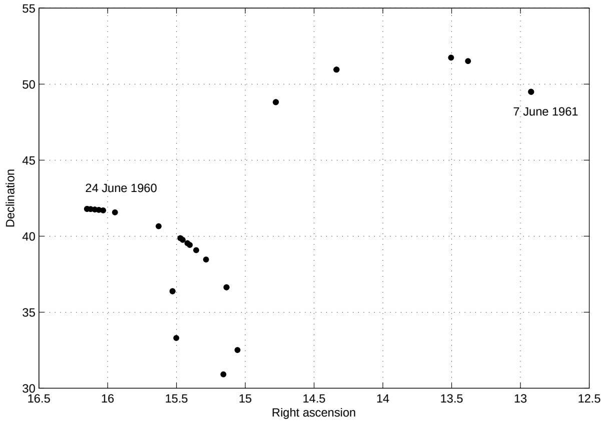

Fig. 1. Observations of Comet Humason.

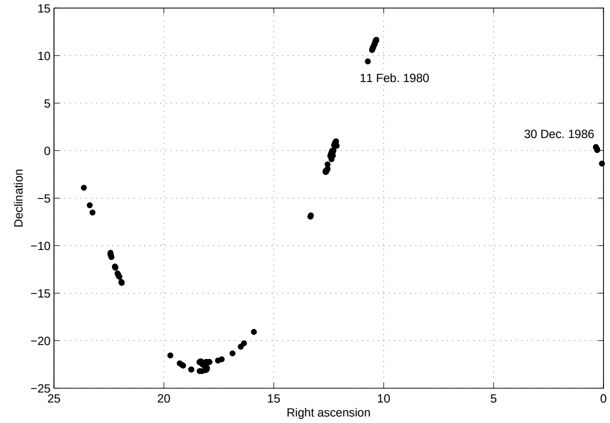

Fig. 2. Observations of Comet Bowell.

perbolic. Marsden (1987) and Hasegawa, Nakano, & Yabushita (1981) have studied Bowell's comet. While Marsden (1987) finds a hyperbolic orbit, the latter authors state that the orbit is not only hyperbolic but that the comet in fact may be interstellar.

2. WHY HUMASON AND BOWELL?

Despite what is written in the preceeding paragraph, reasons remain to re-study both of the orbits. Although only 34 observations are available for Comet Humason, they are of high quality and cover nearly a year. Van Biesbroeck (1970) calculates an orbit, but makes use of normal places, a computational expedient neither necessary nor desired today because they degrade, if only slightly, the solution. Marsden & Sekanina (1973) eschew normal places, but for some reason use only 30 of the 34 observations. Computational technology, moreover, has advanced since 1973 and permits efficient implementation of techniques such as robust estimation. Marsden's orbit for Comet Bowell uses only 100 observations, but 203 are available. Therefore, whether or not one finds evidence for an extrasolar origin for either of these comets, to recalculate their orbits using all of the observations and avoiding computational expedients such as normal places seems neither redundant nor otiose.

3. THE OBSERVATIONS AND THEIR TREATMENT

There are 34 observations of Comet Humason, covering the interval from 24 June 1960 to 7 June 1961, or 348 days; see Van Biesbroeck (1970) for references to the observations, plotted in Figure 1. For Comet Bowell there are 203 observations, made between 11 Feb. 1980 and 30 Dec. 1986, nearly eight years. These observations are found at the Minor Planet Center web site[1] under the heading MPCAT. Figure 2 plots the observations. Notice that the geocentric motion of this comet is complicated. Table 1 gives the orbit for each comet as taken from the Marsden & Williams catalog (2003). This table can be compared after my computation of the orbits with Table 4 and with Table 7. Shown are: T_0, time of periheion passage; a, semi-major axis; e, eccentricity; q, perihelion distance; Ω, node; i, inclination; ω, perihelion.

TABLE 1

INITIAL ORBITAL ELEMENTS

Element	Comet Humason	Comet Bowell
T_0	11.2050 Dec. 1959	12.2930 March 1982
a (AU)	−4826.840	−58.685
e	1.000884	1.057322
q (AU)	4.266927	3.363949
Ω	307.°2619	114.°5563
i	125.°4695	1.°6617
ω	46.°4607	135.°0850

The rectangular coordinates and velocities of the comet and the Earth were calculated by a program, used in numerous investigations previously, that treats the Solar System as an n-body problem and takes the starting coordinates from Table 1. The program is a 12-th order Lagrangian predictor-corrector that incorporates relativity by a Schwarzschild harmonic metric. To obtain coordinates and velocities for the Earth, the Moon is carried as a separate body. This means a small step-size,

[1] `www.minorplanetcenter.net`.

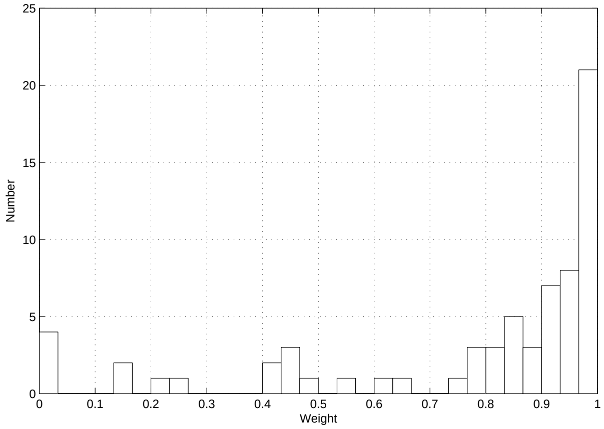

Fig. 3. Weights for Comet Humason.

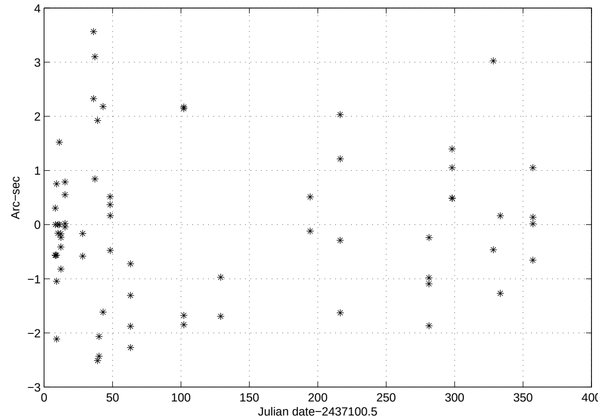

Fig. 4. Residuals for Comet Humason.

$0.^d25$. To correct the comet's orbit partial derivatives are calculated by Moulton's method (Herget 1968), which integrates the partial derivatives to correct for the osculating rectangular coordinates and velocities at the epoch JD2437280.50 for Comet Humason and JD2445000.50 for Comet Bowell. The rectangular coordinates, after interpolation to the moment of observation for the Earth and to the moment of observation antedated by the light time correction to allow for planetary aberration, are then converted to a unit vector that is transformed to a mean or apparent place in α and δ by application of precession, nutation, annual aberration, relativity, and so forth. The final step calculates an observed minus a computed place, (O-C), in α and δ.

Robust weighting schemes recognize that small residuals are more likely than large residuals and assign them higher weight. This differs from a more traditional approach, such as Pierce's criterion (Branham 1990), that uses unit weight out to a cut-off, where the weight becomes zero. Typical of robust weighting is the biweight. To use the biweight, a weighting scheme I have used many times when working with comet orbits, double star orbits, and Galactic kinematics, one scales an individual post-fit residual r_i by the median of the absolute values of the residuals and assigns a weight wt as

$$wt = \begin{cases} \left[1-(r_i/4.685)^2\right]^2 & |r_i| \leq 4.685, \\ 0 & |r_i| > 4.685. \end{cases} \quad (1)$$

Small residuals receive nearly unit weight, which decreases continually until the cutoff of 4.685 is reached, where the weight becomes zero.

Because the starting coordinates for both comets are good, only two differential corrections were required. The first orbit generates weights by use of equation (1), which are used to calculate a second iteration. Figure 3 shows the weights for Comet Humason; notice that four of them are zero. Figure 4 shows the residuals from the final iteration. These residuals indicate 31 runs out of an expected 34 from the nonparametric runs test (Wonnacott & Wonacott 1972), a 46.7% probability, with a two-sided distribution, of the residuals being random. This reinforces the impression that nongravitational forces are absent from this particular comet.

TABLE 2

RECTANGULAR COORDINATES AND VELOCITIES FOR COMET HUMASON AT EPOCH JD2437280.50

Unknown	Value
x_0 (AU)	−2.772282e+000±3.306703e-005
y_0 (AU)	−2.885775e+000±3.511603e-005
z_0 (AU)	3.343295e+000±3.924209e-005
$\dot{x}_0$ (AU day^{-1})	−7.670262e-003±2.071292e-007
$\dot{y}_0$ (AU day^{-1})	5.225179e-003±2.304056e-007
$\dot{z}_0$ (AU day^{-1})	5.231748e-003±2.617125e-007
$\sigma(1)$	$1.''41$

Table 2 shows the recangular coordinates and their mean errors at epoch along with the mean error of unit weight $\sigma(1)$, Table 3 the covariance and correlation matrices for the solution, and Table 4 gives the final orbital elements for Comet Humason. Although some of the correlations are relatively high, 96.3% between x_0 and z_0 for example, the condition number of the data matrix, $1.5 \cdot 10^3$, remains low for the precision of the arithmetic used, machine ϵ of $2.22 \cdot 10^{-16}$, and thus the solution seems stable.

TABLE 3

COVARIANCE (DIAGONAL, UPPER TRIANGLE) AND CORRELATION MATRICES (LOWER TRIANGLE) FOR COMET HUMASON

23.2454	22.4027	26.5535	−0.0079	−0.0723	−0.0092
0.9075	26.2154	25.8395	−0.0526	−0.1091	−0.0627
0.9626	0.8820	32.7379	−0.0010	−0.0743	0.0094
−0.0542	−0.3400	−0.0056	0.0009	0.0009	0.0011
−0.4467	−0.6344	−0.3865	0.8469	0.0011	0.0011
−0.0500	−0.3207	0.0430	0.9554	0.8376	0.0015

TABLE 4

ORBITAL ELEMENTS FOR COMET HUMASON

Orbital element	Value
T_0	JD2436913.35215$\pm$0.^{d}016
	10.85215Dec.1959
a (AU)	−0.285013e+005$\pm$0.106366e+005
e	0.100015e+001$\pm$0.558963e-004
q (AU)	0.426743e+001$\pm$0.247956e+000
Ω	0.$^\circ$288884e+003$\pm$0.$^\circ$150547e+000
i	0.$^\circ$136774e+003$\pm$0.$^\circ$420072e-001
ω	0.$^\circ$189700e+002$\pm$0.$^\circ$131965e+000

The calculation of the mean errors of the orbital elements proceeds via a modernized version of Rice's procedure (1902). Let $\mathbf{C}$ be the covariance matrix for the least squares solution for the rectangular coordinates and velocities. Identify the errors in a quantity such as the node Ω with the differential of the quantity, $d\Omega$. Let $\mathbf{V}$ be the vector of the partial derivatives $(\partial\Omega/\partial x_0 \quad \partial\Omega/\partial y_0 \quad \cdots \quad \partial\Omega/\partial \dot{z}_0)$. Then the error can be found from

$$(d\Omega)^2 = \sigma^2(1)\mathbf{V}\cdot\mathbf{C}\cdot\mathbf{V}^T. \qquad (2)$$

The partial derivatives in equation (2) are calculated from the well known expressions linking orbital elements, whether elliptical or hyperbolic, with their rectangular counterparts. The orbit represents a hyperbola and differs, in some instances significantly, from the orbit in Table 1.

For Comet Bowell, Figure 5 shows the weights used for the final solution, of which eight are zero (lower than the machine ϵ), and Figure 6 exhibits the residuals. A runs test indicates 196 runs out of an expected 203, or a 48.7% probability of random residuals with a two-sided distribution. Once again, there seems little evidence for nongravitational forces.

Table 5 gives the osculating rectangular coordinates and velocities for Comet Bowell as well as $\sigma(1)$, Table 6 the covariance and correlation matrices, and Table 7 the orbital elements. The elements differ somewhat from those of Table 1, although the orbits remains highly hyperbolic.

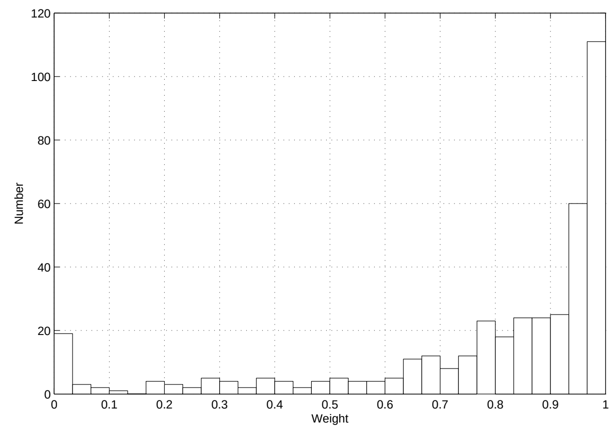

Fig. 5. Weights for Comet Bowell.

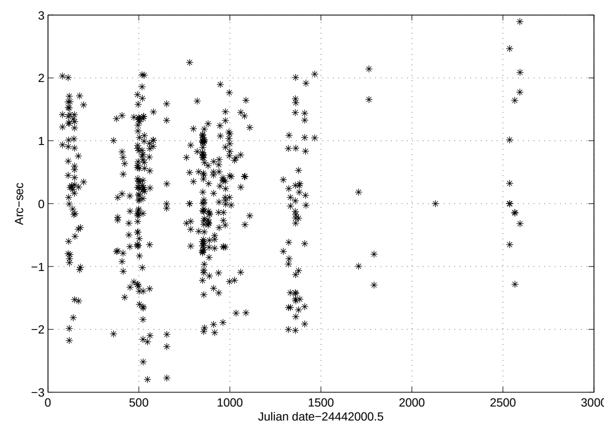

Fig. 6. Residuals for Comet Bowell.

TABLE 5

RECTANGULAR COORDINATES AND VELOCITIES FOR COMET BOWELL AT EPOCH JD2445000.5

Unknown	Value
x_0 (AU)	−1.669049e+000$\pm$2.04337e-006
y_0 (AU)	−2.733928e+000$\pm$1.724129e-006
z_0 (AU)	−1.098591e+000$\pm$1.881796e-006
$\dot{x}_0$ (AU day^{-1})	1.216754e-002$\pm$1.069496e-008
$\dot{y}_0$ (AU day^{-1})	−5.066559e-003$\pm$5.818456e-009
$\dot{z}_0$ (AU day^{-1})	−2.472574e-003$\pm$6.916898e-009
$\sigma(1)$	1.$''$07

TABLE 6

COVARIANCE (DIAGONAL, UPPER TRIANGLE) AND CORRELATION MATRICES (LOWER TRIANGLE) FOR COMET BOWELL

0.1542	−0.0584	−0.0298	−0.0003	0.0002	0.0001
−0.4491	0.1098	−0.0045	0.0002	−0.0001	−0.0000
−0.2096	−0.0377	0.1308	0.0001	−0.0000	−0.0001
−0.3269	0.3000	0.1758	0.0000	−0.0000	−0.0000
0.3730	−0.2463	−0.1095	−0.4262	0.0000	−0.0000
0.1896	−0.0824	−0.1584	−0.2541	−0.0513	0.0000

TABLE 7

ORBITAL ELEMENTS FOR COMET BOWELL

Orbital element	Value
T_0	JD2444960.20996±0.^{d}00032
	21.70996Dec.1981
a (AU)	−0.584547e+002±0.336783e-002
e	0.105755e+001±0.373909e-005
q (AU)	0.336395e+001±0.545905e-004
Ω	0.°390372e+001±0.°434463e-002
i	0.°227960e+002±0.°180380e-002
ω	0.°227667e+003±0.°419219e-002

The correlations are lower than those for Comet Humason, the highest being −44.9% between x_0 and y_0, and the condition number of the data matrix, $5.0 \cdot 10^2$, is also lower, undoubtedly a consequence of the greater length of the observed arc of the orbit.

4. DISCUSSION

Now that one has calculated new orbits for both of these comets, is there any evidence that either may be of extrasolar origin? Consider first Comet Humason. Although Van Biesbroeck found no reason to suspect anything other than an elliptical orbit, the orbit of Table 4 nevertheless differs in many ways from his. To address the issue I integrated the orbit represented by Table 4 out to JD −9044849.5 (12 Dec. −29477), where the comet is 5333.7 AU from the Sun. The integration was done using barycentric coordinates and with the planets Mercury-Pluto as perturbing planets. For details of how to perform the integration see Branham (2012). At this distance the barycentric eccentricity of 0.99965 corresponds to a semi-major axis of 12197.4 AU, a highly eccentric ellipse. The orbit does not become hyperbolic until JD 2431060.5 (2 Dec.1943) when the comet finds itself 32.03 AU from the Solar System barycenter. This is a clear instance of a comet receiving sufficient energy from the Solar System to change an elliptical orbit to a hyperbolic one as can be seen by looking at Figure 7, which graphs the energy integral versus Julian date. The integral E is defined as

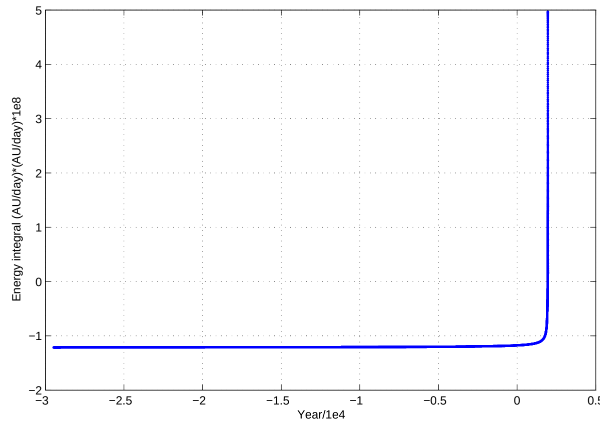

Fig. 7. Energy integral versus year for Comet Humason.

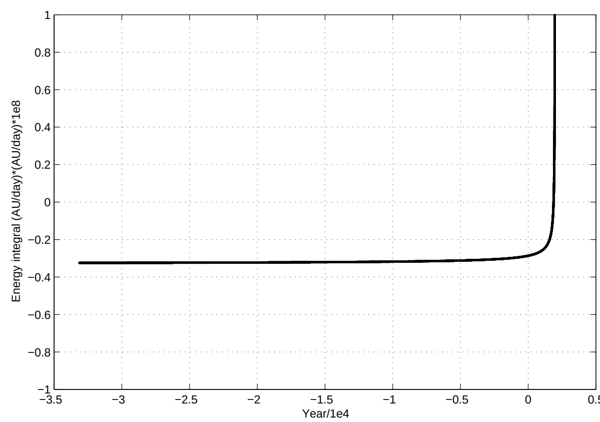

Fig. 8. Energy integral versus year for Comet Bowell.

$$E = v^2/2 - k^2(1+m)/r, \tag{3}$$

where v is the velocity in AU day^{-1}, k the Gaussian gravitational constant, m the object's mass, zero for a comet, in units of the solar mass, and r the heliocentic or barycentric distance.

Turning our attention to Comet Bowell and integrating backwards to JD −10378040.5 (16 Oct. −33127), the comet finds itself at a distance of 5945 AU from the Solar System barycenter with a barycentric eccentricity of 0.99993 and semi-major axis of 45550 AU, an extremely eccentric ellipse, but not a hyperbola. The orbit does not become hyperbolic until JD 2407710.5 (27 Dec. 1879) at a distance of 120 AU from the barycenter; then the hyperbolic

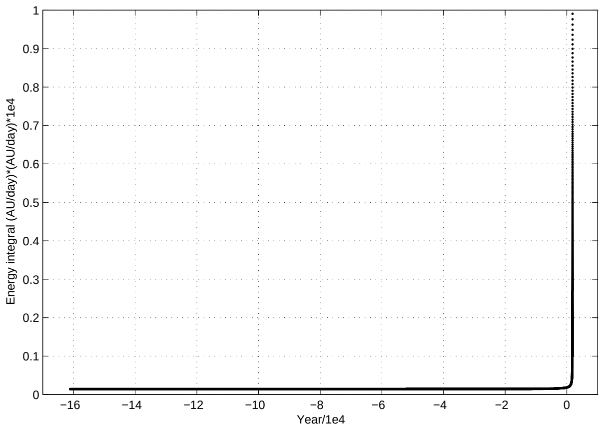

Fig. 9. Energy integral versus year for Comet Secchi.

eccentricity continually increases until reaching the value (heliocentric) in Table 7. Buffoni, Scardia, & Manara (1982) provide a thorough analysis of how this occurs. This is another clear instance of a comet receiving sufficient energy from the Solar System to change an elliptical orbit to a hyperbolic one as can be seen by looking at Figure 8, which again plots the energy integral versus Julian date.

5. WHAT ABOUT COMET SECCHI?

Both Comets Humason and Bowell provide clear evidence of an initial high eccentricity orbit being turned into a hyperbolic orbit by the Solar System pumping energy into an elliptical orbit. Comet Secchi also shows clearly that this mechanism does not work for this particular comet. Look at Figure 9 of the energy integral versus Julian date. The orbit is hyperbolic out to the edge of the Oort cloud at over 100000 AU. In my 2012 paper I examine various proposals, such as Galactic tides and the inclusion of trans-Neptunian objects and the more massive minor planets into the integration, but nothing works. Unless one can find a mechanism to turn a graph like Figure 9 into one like Figure 7 or Figure 8, the suspicious remains that Comet Secchi did indeed originate from beyond the Oort cloud.

6. CONCLUSIONS

Both Comets Huamsen and Bowell have hyperbolic orbits. Upon backwards integration it becomes manifest that the orbits were originally high eccentricity ellipses. The Solar System pumped energy into the orbits to convert the ellipses to hyperbolas. The same cannot be said for Comet Secchi, which has a hyperbolic orbit even at 100000 AU from the Sun. If one does not wish to assert that the comet originated from beyond the Oort cloud, and thus that its orbit was also originally a high eccentricity ellipse, then what converted the ellipse to a hyperbola at such an extreme distance from the Solar System barycenter?

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