SEARCH PROGRAMS FOR COMETS

B. G. MARSDEN
Harvard-Smithsonian Center for Astrophysics,
60 Garden Street, Cambridge, MA 02138, U.S.A.
E-mail MARSDEN@CFA.HARVARD.EDU

Abstract. Although there are currently no professional search programs specifically designed for comets, comet discoveries are a significant by-product of the current search programs for near-earth asteroids. With their emphasis on the opposition point and the ecliptic, asteroid patrols are clearly biased toward discovering short-period comets. A comparison of the comet discoveries made at elongations of less than 120° from the sun during the ten-year intervals ending in 1892 and 1992 indicates that the current opposition searches are not able to displace visual searches in the vicinity of the sun. Modification of the near-opposition search region to that proposed for the Spaceguard Project would be helpful, but—as also proposed for Spaceguard—supplementation is still necessary for high-inclination objects. CCD experimentation in the regions traditionally searched visually by amateurs would be useful. Searches for particular types of object like Kreutz sungrazers and comets near Jupiter in space are briefly discussed.

1. Introduction

Ever since it became fashionable, toward the end of the nineteeth century, to draw a distinction between professional and amateur astronomers, to make searches exclusively for comets has been generally regarded as an activity for the latter. Indeed, there must be several hundred amateur astronomers around the world who, on a regular basis, scan the skies visually with small to moderate-sized telescopes in the hope of finding a new comet. The technique, and even the rate of success, has not greatly changed since the 1750s, when Charles Messier attempted to be the first person to reobserve Halley's Comet—and instead effectively inaugurated comet hunting as a serious sport. Until then, the great comet of 1680 was the only one to have been discovered telescopically.

In recent times, the only case where a substantial fraction of the resources of a professional observatory has been expended on comet hunting was the highly successful program conducted using pairs of 25×105 binoculars at the Skalnaté Pleso Observatory in Slovakia during the decade following World War II. About a dozen years ago Ľubor Kresák, one of the best known participants in that program, gave an extensive review of comet discoveries, including a discussion of observational selection (Kresák 1982). In that review he discussed the seminal papers on comet discoveries and observational selection (Everhart 1967a, 1967b) by Edgar Everhart, another successful visual comet hunter who at the time he wrote these papers was in the process of leaving professional physics for professional astronomy.

Even before the time of Messier it was clear that bright comets were most likely to be discovered at relatively small angular distances from the sun. During the preceding century, for example, only four of the 37 comets (or 11 percent) for which orbits have been computed were discovered at elongations $\epsilon > 120°$; these four, all naked-eye objects at discovery, were the comets of 1729 and 1747 (which, with

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perihelion distances q of 4.05 and 2.20 AU, were intrinsically stupendous objects that remained the two comets of largest known q until 1885), the comet of 1744 (which was by far the most spectacular of the eighteenth century as seen from the earth) and the comet of 1678 (which has recently been conclusively demonstrated as an early appearance of periodic comet d'Arrest on a close passage by the earth; Carusi *et al.* 1991). Fully 73 percent of the remainder were discovered west of the sun, in generally the eastern part of the sky before dawn, as the earth's orbital motion allowed them to emerge further from the sun's rays as the days wore on. Most of them were also then well inside the earth's orbit and were brightened significantly by their proximity to the sun. The smaller fraction discovered east of the sun, in the western sky after dusk, were almost exclusively comets in the latter category, frequently much closer to the earth than the sun was, their orbital motions being more important than the earth's in defining their apparent motions.

This morning-evening disparity was less pronounced in the comet searches by Messier and several of the other early comet hunters, perhaps in part for social reasons. More recent data do show a 3-to-2 bias toward the morning sky, however, and the effect is clearly enhanced if one considers only comets in retrograde orbits, i.e., with their own contributions to the prevailing westerly motion. Everhart's (1967a) study of the discovery circumstances of long-period comets since 1840 noted that 53 percent of those in direct orbits and 69 percent of those in retrograde orbits were found in the morning sky. Furthermore, on attempting to adjust the actual discovery dates to those when the comets *ought* to have been discoverable with the available instrumentation, he suggested that these fractions should be increased to 70 percent and 81 percent, respectively. These adjusted numbers are undoubtedly over-optimistic, mainly because many comets do not vary in brightness as the inverse-fourth power of heliocentric distance r—or, indeed, in any uniform manner.

Bright naked-eye comets have, of course, been discovered at very small elongations from the sun. When a telescope has been necessary for discovery, only a few comets have been found at $\epsilon < 30^\circ$. While observers might disagree whether a telescope is actually needed in specific cases, E. E. Barnard's discovery—his first—of comet 1881 VI at $\epsilon = 24^\circ\!.5$ must be a serious contender for the record; he was using a 0.13-m telescope, and the comet was probably of magnitude $m \sim$ 6-7. Perhaps equally noteworthy was Jérôme Coggia's discovery of comet 1890 III at $\epsilon = 26^\circ\!.4$ and $m \sim 8$.

Another of Everhart's conclusions (Everhart 1967b) was that more than 80 percent of the long-period comets that should be observable were being missed. This conclusion was based on both observations and observability in the northern hemisphere alone. There is an obvious north-south asymmetry in the distribution of comet observers, and Everhart noted that, in comparison to the inverse, there were six times as many comets discovered in the northern hemisphere that would never have been observable in the southern. The failure of comets to conform to the r^{-4} brightness-variation law again undoubtedly means that the 80-percent discovery failure is far too extreme. It is also unfair to expect a faint comet to be discovered visually in the Coma-Virgo region of galaxies or photographically among the crowded stars close to the Milky Way. Everhart's figure was also disputed by Kresák

(1982), principally on the grounds that many comets have accidental co-discoverers. In my capacity as director of the IAU Central Bureau for Astronomical Telegrams, I am aware of numerous additional cases of independent discoveries that are never published.

Everhart's analysis principally involved visual discoveries of comets, but it did include a number of photographic discoveries. Although there are photographic records of what was evidently a sungrazing comet during the total solar eclipse in 1882, the earliest recognized photographic discovery is that by Barnard of comet 1892 V. Two more photographic discoveries followed in 1898, and by the end of World War I the number of photographic discoveries had risen to a dozen. By the end of World War II photographic discoveries were in the majority. Since most of the photographic discoveries have been by professional astronomers as a by-product of other observations, they have tended to concentrate near opposition. Only 20 percent of them have been made at $\epsilon < 120^\circ$ and less than 7 percent at $\epsilon < 90^\circ$. Except for comets recorded during total solar eclipses, the smallest elongations for photographic discoveries seem to be $\epsilon = 30^\circ\!.8$ and $46^\circ\!.7$ for comets 1911 II and 1945 VII, but both of these objects were bright enough to have been discovered visually. More of a challenge was the rediscovery by Jeff Johnston in 1979 of periodic comet Schwassmann-Wachmann 3 some 25° from its predicted position; at $\epsilon = 49^\circ\!.5$ and $m \sim 13$, such a detection would be borderline for a visual discovery. As for comets that were definitely too faint for visual discovery, mention should be made of Richard West's discovery with the European Southern Observatory's 1.0-m Schmidt of comet 1977 IX at $\epsilon = 71^\circ\!.8$ and $m \sim 17.5$, as well as comet 1955 VI, found during the Palomar Sky Survey at $\epsilon = 73^\circ\!.9$ and $m \sim 15$.

Most of the photographic discoveries during the early years of the twentieth century were made in the course of search programs for asteroids. Although general sky surveys and search programs for extragalactic supernovae have contributed a substantial number of comets, discoveries during patrols for asteroids have continued to dominate, particularly as several such patrols have in recent times concentrated on finding asteroids that come close to the earth. The association with asteroid programs has tended to concentrate photographic comet discoveries near the ecliptic. This in turn has resulted in an excess of discoveries of comets with small orbital inclinations, and the majority of them have therefore been short-period comets of the so-called Jupiter family.

2. Cometary Discoveries, 1818-1992

Fig. 1 shows the number of comets discovered in five-year intervals from 1818 through 1992. During the past ten years the rate of discoveries has been quite extraordinary. The tallies for 1983-1987 and 1988-1992 should be further increased by four and eight, respectively, to include the discoveries of sungrazing comets in coronagraphic observations from the SOLWIND and SMM satellites. The count for 1983 does include the six comets discovered (in two cases involving also ground-based co-discoveries) by IRAS, the American-Dutch-British Infrared Astronomical Satellite. No fewer than 28 comet discoveries—a record for specific discoverers—are named for the observing team led by Carolyn and Eugene Shoemaker in a

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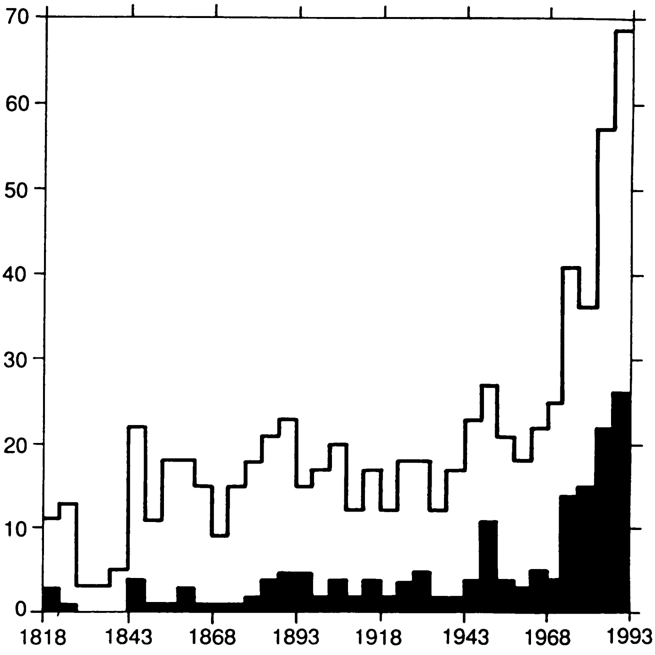

Fig. 1. Comet discoveries in five-year intervals, 1818-1992. The shaded portion refers to short-period comets.

near-earth asteroid search using the 0.46-m Schmidt at Palomar; the team led by Eleanor Helin, in a similar program with the same telescope, produced 11 more comets during the same decade. The years 1991 and 1992 yielded the first CCD discoveries of comets, specifically by using the scanning Spacewatch camera (also designed largely for a near-earth-asteroid search) on a 0.9-m telescope on Kitt Peak; at magnitude 21, the 1991 object is the faintest cometary discovery hitherto made.

The shaded area in Fig. 1 shows the comets that are of short period, an upper limit of 20 years (for Jupiter-family membership), rather than the conventional 200 years, being adopted here for this definition. The year 1818 is significant for producing the observations that led to the final recognition of Encke's Comet, and the following year brought P/Blanpain and the first observations of what later became known as P/Pons-Winnecke. Although there was already some suspicion that what came to be known as P/Biela had already been observed in both 1772 and 1805, this was not proven until Biela found the comet in 1826. The discovery of P/Faye in 1843 started the sequence of frequent discoveries of short-period comets that continues to this day. Although the fraction of comets discovered that are of short period remained fairly consistently at one out of four or five until around 1970, this has now increased to more than one out of three, mainly as a result of the near-earth-asteroid search programs mentioned above.

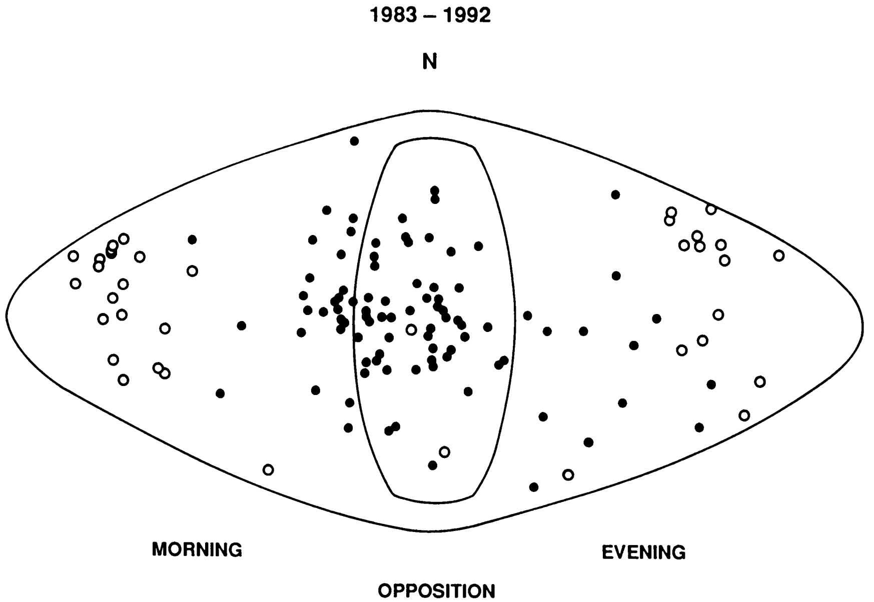

Fig. 2. Equal-area plot of discovery positions of comets during 1983-1992, centered on opposition, around which the prime "Spaceguard" search region is marked. The ecliptic north pole is at the top. Open circles denote visual discoveries, closed circles non-visual discoveries.

Fig. 2 is an all-sky, equal-area plot showing the discovery positions for the comets found during 1983-1992. Ecliptic coordinates are used, and the plot is centered on opposition. The open circles show the visual discoveries (or, at least, cases where the first of independent discoveries were visual). As expected, the non-visual (i.e., essentially photographic) discoveries are concentrated near opposition, while the visual discoveries are generally far from opposition. It is useful to term the region of the sky with $\epsilon > 120^\circ$ the "opposition region", and during the decade in question 63 percent of the comet discoveries were in this region. On the other hand, only eight discoveries, or 6 percent, were made when $90^\circ < \epsilon < 120^\circ$, which I shall term the "transition region". Actually, the transition region is dominated by the six comets (counting independent discoveries) found by IRAS, which was designed to survey the sky near $\epsilon = 90^\circ$; if all the comets of 1983—the year IRAS was operating—are removed from the sample, the fraction in the transition region drops to less than 3 percent. The minimum value of ϵ for the comets during this decade was 29°.1 in the case of comet 1983 V.

The morning-evening asymmetry is evident in Fig. 2, but *only in the opposition region*, where there are precisely *twice* as many on the morning side as on the evening. Given the concentration of professional programs near opposition and the

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fact that, unless they are close to the earth, all comets are moving from morning to evening and are essentially equally bright at the same elongation before and after opposition, this bias is really not at all surprising.

Fig. 2 also shows the north-south bias, with 57 percent of the discoveries at positive ecliptic latitudes β. This separates into 56 percent for the opposition region and 60 percent for the remainder. More significant is the fact that only 24 percent of the discoveries are in the half of the sky with $|\beta| > 30°$, and this fraction drops to 14 percent in the opposition region, where the extreme latitude values are $\beta = +38.^{\circ}4$ and $-42.^{\circ}1$, the maximum possible latitude being 60°. Each hemisphere has five discoveries at higher latitudes outside the opposition region, the extremes being $\beta = +70.^{\circ}2$ and $-62.^{\circ}9$.

It would appear that analysis of cometary discoveries can benefit by separating the discoveries into those that were made in the opposition region and those that were not. The opposition region has discoveries that are mainly photographic and nowadays faint and frequently short-period comets. The non-opposition region has mainly visual discoveries of bright, long-period comets. The boundary point in ϵ is not particularly critical, and the outcome would not be greatly different if the transition region were included with the opposition region.

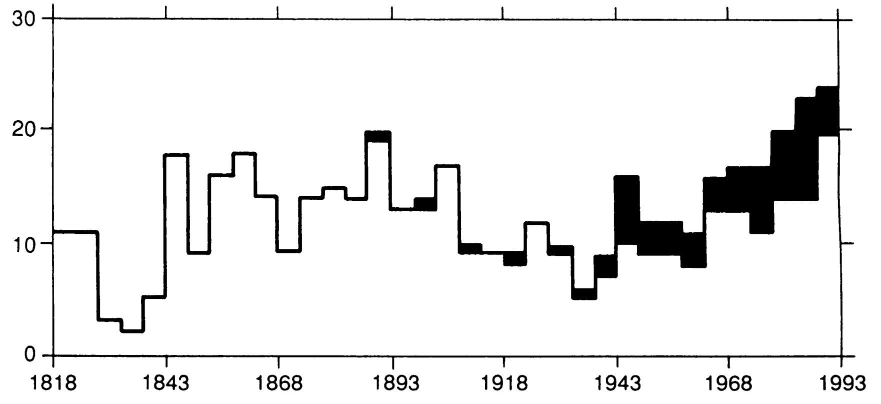

Fig. 3. Non-opposition comet discoveries in five-year intervals, 1818-1992. The shaded portion refers to non-visual discoveries.

Fig. 3 is the subset of Fig. 1 that contains the comets discovered in the non-opposition region. Short-period comets are not distinguished, the shaded area this time showing comets not discovered visually. For the entries before 1982 this plot utilized Rudenko's (1986) convenient compilation of cometary discovery data. The distribution with time in Fig. 3 is, understandably, much more uniform than in Fig. 1. After photography came widely into use the number of comet discoveries at small elongations diminished, and it is only recently that the level of non-opposition discoveries has returned to that of the late-nineteenth century.

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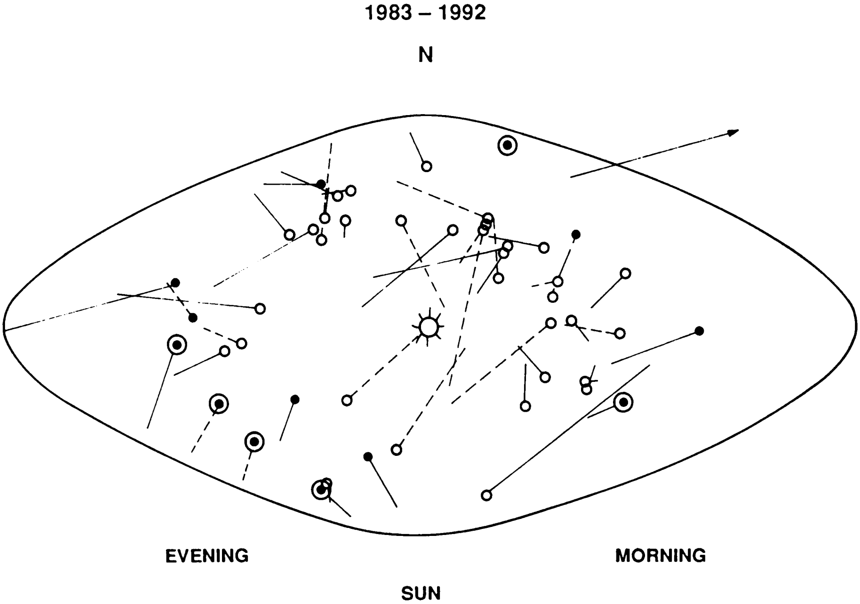

Fig. 4. Equal-area plot of discovery positions of comets during 1983-1992, centered on the sun. See also the caption to Fig. 2 and the text.

3. Comparison of Discoveries during 1883-1892 and 1983-1992

The near equality of the numbers suggests that it might be useful to compare the non-opposition discoveries during 1983-1992 with those during 1883-1892, the end of which decade saw the first photographic discovery of a comet.

Fig. 4 is a plot of the 47 non-opposition 1983-1992 discoveries, much in the form of Fig. 2 and as already discussed, except that the center is now the sun, rather than the opposition point. An outer open circle identifies each IRAS discovery (or co-discovery), the aforementioned extreme case of $\beta = +70^{\circ}.2$ being comet 1983 VII (IRAS-Araki-Alcock). The straight lines attached to the comet points are drawn from the positions (again with respect to the sun) the comets would have occupied 30 days earlier. A solid line indicates that, according to an r^{-4} law, the comet should have been brightening during that month, a broken line that it should have been fading. One comet, 1989 IX, passed through opposition during that month, so the line, extending outside the diagram, is a particularly bad representation of the comet's motion in this instance. The comets should have been brightening in 70 percent and by more than three magnitudes in 11 percent of the cases. In six cases, or 43 percent of the comets that were fading, the elongation the previous month would clearly have been too small to permit discovery; all of them would in

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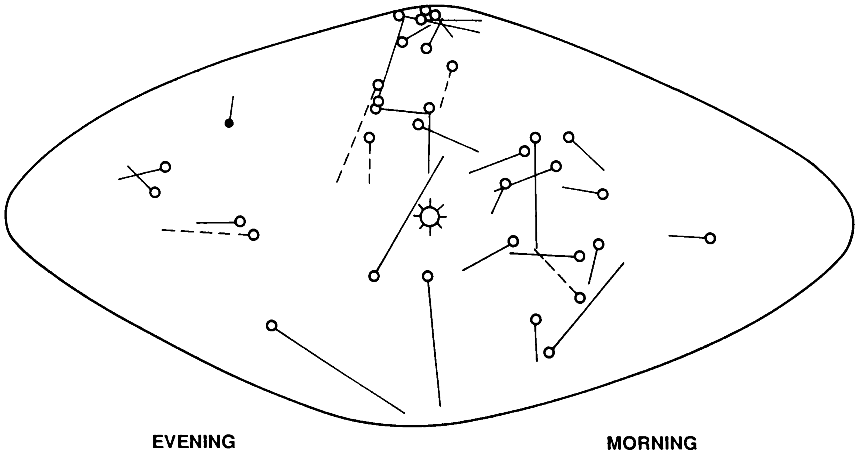

Fig. 5. Equal-area plot of discovery positions of comets during 1883-1892, centered on the sun. See also the caption to Fig. 2 and the text.

fact have had $\epsilon < 24^\circ\!.5$, the value for the record case of comet 1881 V. In no case was it particularly surprising that the discovery was not made one month earlier.

Fig. 5 is the corresponding plot for the 34 comets discovered in the non-opposition region during 1883-1892, only one of them, of course, being not a visual discovery. As for the 1983-1992 non-opposition discoveries, there is *no excess* on the morning side; in fact, as long as one includes the transition region, which accounts for 15 percent of the discoveries, there is a 19-to-15 bias in favor of *evening* discoveries. Almost 65 percent of the values of β are positive, which is not unreasonable, considering that 85 percent of the comets were discovered from sites at north-temperate latitudes; the maximum southern value was $\beta = -48^\circ\!.2$ for comet 1891 IV, which was actually discovered by Barnard from northern California. The β distribution north of the ecliptic shows a sharp difference from 1983-1992, 65 percent of the latitudes being north of $+30°$; four comets were found further north than any of those of the past decade, the maximum latitude being $+84^\circ\!.7$ for comet 1887 II. Comparison with the situation 30 days before discovery shows that brightening should have occurred for 85 percent of the comets, by more than three magnitudes in the case of the sungrazing comet 1887 I, which was of first magnitude and only $16^\circ\!.2$ from the sun at discovery. At least seven of the brighteners and one of the faders would have been too close to the sun for discovery a month earlier.

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In terms of searches with modern professional instrumentation, however, the real test for possible earlier discovery involves examination of the circumstances when a comet was previously near opposition. The proposed "Spaceguard Project" (Morrison *et al.* 1992) for searching for near-earth objects—principally asteroids—specified the need for wide-field CCD instrumentation with a limiting magnitude of 22 and concentration on the "standard Spaceguard region" (SSR) extending $\pm 30^{\circ}$ in ecliptic longitude and $\pm 60^{\circ}$ in ecliptic latitude about the opposition point. The SSR is delineated in Fig. 2. At least for objects near the ecliptic, the peak longitude for the discovery of comets in the opposition region during the past decade, $\sim 20^{\circ}$ on the morning side of opposition, is included in the SSR. The discovery statistics for 1983-1992 suggest that these searches have fallen far short of the SSR limit in latitude. In any case, Marsden and Steel (1993) have shown that strict adherence to the SSR, particularly in latitude, would result in the failure to detect some 25 percent of the long-period comets that may be on collision courses with the earth, and the same logic applies to the discovery of all long-period comets with perihelia near and inside the earth's orbit.

TABLE I
1983-1992 comets at previous opposition.

Comet	β (deg)	t (day)	r (AU)	m	
1983 I	+25.4	263	2.47	17*	
1983 XII	+37.2	237	3.99	13	MW
1984 XXIII	−25.6	89	2.12	12	
1986 XVIII	+36.2	352	4.77	18*	
1987 III	+15.2	47	1.93	10	MW
1987 XXIX	−31.4	88	2.83	13	
1987 XXX	−34.4	421	4.18	15	MW
1988 III	−27.0	480	4.95	17*	MW
1988 XV	− 7.1	324	5.47	18*	
1990 III	− 6.1	189	2.95	14	
1991 I	+16.6	141	2.12	10	SP
1991 XI	−23.9	391	5.01	17*	MW
1992 XIV	−22.4	423	3.57	13	SP

On computing the previous-opposition circumstances for the 47 comets discovered outside the opposition region during the last decade, we find that 26 percent of them would escape Spaceguard detection because $|\beta| > 60^{\circ}$. As noted, however, the latitude range actually scanned is much smaller, and 57 percent of the comets would have escaped prior opposition detection because $|\beta| > 40^{\circ}$. Some 30 percent of the comets would have escaped detection because the r^{-4} law predicts them to have been fainter than magnitude 19. Combination of the faintness and SSR limit would prevent the detection of 53 percent of the comets, rising to 72 percent for the 40° latitude limit. The 13 comets that ought to have been detectable near their previous opposition are shown in Table I. In terms of the opposition-region comets that *were* discovered, this represents a failure of 16 percent—considerably less than Everhart's 80 percent. The 16 percent is also an overestimate, in the sense that comet 1987 III, for example, expected at $m = 10$ at opposition $t = 47$ days before its actual discovery, would probably not have been recorded at opposition because it was then near the Milky Way; it is one of five comets probably rendered undiscoverable for this reason and noted by "MW" in the table). Comets 1991 I and 1992 XIV, which are of short period ("SP" in the table), must surely have brightened more rapidly than by an r^{-4} law; the former, an accidental rediscovery of P/Metcalf, previously observed only in 1906, undoubtedly experienced an anomalous brightening before discovery. Comets 1987 XXX and 1988 III are known to have separated from each other at their previous perihelion passage and may also therefore have brightened more rapidly than indicated. Actually, the r^{-4} law is always suspect when one tries to relate the total visual magnitude of a bright, nearby comet and the magnitude that would be recorded with a large telescope when the comet is much farther away. The comets computed here to be no brighter than magnitude 17 (shown with asterisks) would undoubtedly have been undetected in normal photographic searches. Perhaps the most surprising prior failure is 1984 XXIII, predicted to be at $m = 12$ and at opposition $t = 89$ days before discovery (but at a declination of $-37°$), and one wonders to some extent about the failure to record 1987 XXIX and 1990 III.

By way of stressing the problem of cometary brightness variability, it should be noted that two of the comets shown in Fig. 2 in the opposition region were discovered visually at $m = 9$ or 10 but that they clearly experienced significant brightness variations. Comet 1984 VII, a new short-period comet, had in fact been noticed by a photographic observer some three weeks earlier, when it was much fainter than would have been expected from geometry alone, and this observer had not reported the discovery because he could not confirm the object on an exposure two days before that; he did subsequently find the comet on that exposure, when it was four magnitudes fainter still. Comet 1988 I, only 0.4 AU from the earth at discovery, was expected to brighten further as it approached the earth and the sun, but instead, it quickly fizzled out.

Although photographic opposition searches were essentially unknown for most of 1883-1892—they came into play for asteroid work at the end of 1891—it is instructive to carry out the same exercise on the comets discovered in the non-opposition region during that decade. Of these comets the fraction that would have escaped opposition detection is similar to that during the latest decade—24 percent because $|\beta| > 60°$ and 56 percent because $|\beta| > 40°$. I adopt a limiting magnitude of 12.0, thereby clearly favoring our nineteenth-century predecessors, but this is a good practical bound for visual discoveries. More than 82 percent would therefore have escaped opposition detection on faintness grounds alone, increasing to 85 percent because of both faintness and high latitude. Only five comets would therefore have been potentially observable, and these are listed in Table II. The brightest one predicted, 1886 IV, was a short-period comet that has not been subsequently

TABLE II
1883-1892 comets at previous opposition.

Comet	β (deg)	t (day)	r (AU)	m	
1886 IV	+27.9	76	1.65	10	SP
1889 I	−14.6	227	4.61	12*	
1889 II	− 2.8	67	2.74	12*	
1889 VI	+ 3.3	77	1.73	12*	SP
1890 II	−23.5	209	3.76	10	

observed; it was probably therefore erratic in brightness, and in any case, it was located in the Coma-Virgo region, a booby-trap that visual comet hunters usually avoid. Comet 1889 VI was also of short period (SP) and undoubtedly too faint, and the other magnitude 12 entries (shown with asterisks) would be very borderline. The principal failure was comet 1890 II, although even in this case, extrapolation of the magnitude formula to the distance involved is probably questionable. One is tempted to claim that the comet searches actually made during the decade were almost completely successful.

4. The Comets of W. A. Bradfield

The champion visual discoverer of the twentieth century is William Bradfield, of Dernancourt, South Australia. He has found 16 comets since 1972, generally using a 0.15-m refractor at 26×, and it is quite remarkable that in no case has he had to share a comet with a co-discoverer. This is probably indicative of an absence of competition in the southern hemisphere, but it is also the case that, after Bradfield's first half-dozen or so discoveries, the Central Bureau made a point of announcing his comets very quickly—often before they had been confirmed by other observers, although that confirmation has always been forthcoming. Only two individuals, Jean-Louis Pons and William R. Brooks, have made more visual discoveries of comets than he has, but their actual totals are unclear, because the published records do contain objects that were not confirmed by others.

Bradfield's comets therefore make a convenient set for our continuing discussion, although it should be noted that 11 of the 16 were discovered during the three-month summer season beginning in mid-December. The relevant discovery information is listed in Table III; not surprisingly, all the comets were south of the ecliptic, and the fact that 10 of the 16 were in the morning sky (an "M" in the ϵ column, as opposed to "E" for evening sky) is surely the discoverer's personal preference. Two of the comets were particularly bright and at significantly less than 30° from the sun. The remainder were in the magnitude range 8-12 (all but three of them magnitude 9-10), and ten were confined to the surprisingly narrow range of $30° < \epsilon < 48°$ and $-38° < \beta < -16°$. The comets of $m = 11$ or 12 had $\epsilon > 40°$.

TABLE III
The comets of Bradfield.

Comet	β (deg)	ϵ (deg)	Δ (AU)	r (AU)	m	β (deg)	ϵ (deg)	m
1972 III	−23.1	M 30.7	1.67	0.96	10	− 9.0	E 9.6**	12*
1974 III	−28.5	E 32.9	1.57	0.92	9	−26.1	E 39.1	12*
1975 V	−26.7	E 30.4	2.02	1.27	9	−18.0	E 28.2*	10
1975 XI	−40.3	M 57.5	1.25	1.10	10	−32.2	M 60.2	13**
1976 IV	−41.6	E 56.2	0.78	0.85	9	−39.0	E 56.8	11
1976 V	−30.4	M 44.4	0.64	0.70	9	+ 1.9	M 25.8*	12*
1978 VII	−26.5	M 47.8	1.41	1.04	8	−35.6	M 53.7	11
1978 XVIII	−23.3	M 31.8	0.83	0.53	9	+ 2.0	E 6.6**	11
1979 VII	−19.2	E 43.9	1.16	0.82	10	−65.5	E 88.5	12*
1979 X	−13.7	M 26.5	1.21	0.55	5	− 1.9	E 15.5**	7
1980 XV	−14.6	M 21.7	1.19	0.45	6	−17.8	E 18.6**	11
1983 XIX	−25.9	M 46.4	1.84	1.37	11	−12.2	M 39.3	11
1987 XXIX	− 9.6	E 80.7	1.56	1.72	10	−19.5	E106.7	11
1988 XXIII	−37.9	E 40.5	1.35	0.88	12	− 8.2	M 14.4**	9
1992 VII	−20.2	M 65.2	1.14	1.16	10	−19.2	M 69.0	13**
1992 XIII	−16.6	M 47.2	0.87	0.76	10	− 6.3	M 34.0	14**

The last three columns of Table III also show β, ϵ and m 30 days before discovery. All of the comets should then have been fainter, except for comet 1988 XXIII, predicted at $m = 9$ but at an impossibly small elongation from the sun. Predicted magnitudes of 12 are asterisked, and fainter objects are double-asterisked. Elongations less than 30° are asterisked, and those less than 20° are double-asterisked. Obviously, the nine comets with a total of two or more asterisks could not then have been discovered. The three with single asterisks would have been very borderline for a visual discovery, and although comet 1979 VII was almost in the transition region, its high southern ecliptic latitude would count against discovery (particularly by Bradfield, for this was a discovery in June, not his favored time of the year). This leaves the four cases of 1976 IV, 1978 VII, 1983 XIX and 1987 XXIX, all calculated at $m = 11$. Since 1983 XIX was the first comet as faint as magnitude 11 that Bradfield has discovered, the 1976 and 1978 cases should probably also be classified as borderline. Perhaps he could have found 1983 XIX a month earlier. As for 1987 XXIX, the time of year (August) was again not favored, and it is not obvious that Bradfield's searches extend into the transition region anyway; but this comet might have been found then by some other observer.

Table IV shows the situation with regard to the Bradfield comets at their preceding opposition. Four of the comets (with double-asterisked magnitudes) would obviously then have been impossibly faint—two of them were also in the Milky Way—and another faint case (single asterisks denoting m = 17 or 18) was also in the Milky Way. Two more cases (with β double asterisked) were outside the SSR, and the five comets with a single asterisk had $|\beta| > 40°$. Six comets (1974 III, 1975 V, 1976 IV, 1979 X, 1980 XV and 1987 XXIX) would have been viable candidates for a prior discovery at opposition, and one of them (1980 XV) was in fact subsequently identified on a U.K. Schmidt plate taken about a month after opposition. The brightest comet, 1979 X, should have been a straightforward opposition discovery in the northern hemisphere, as should 1975 V, and the failure to detect 1987 XXIX has already been noted.

TABLE IV
Bradfield comets at previous opposition.

Comet	β (deg)	t (day)	r (AU)	m	
1972 III	+40.5*	171	2.93	15	
1974 III	−22.7	171	3.39	16	
1975 V	+24.9	207	3.34	14	
1975 XI	−24.6	317	5.32	20**	MW
1976 IV	−25.4	153	2.62	16	
1976 V	+45.6*	193	3.04	18*	
1978 VII	−59.4*	345	5.43	18*	MW
1978 XVIII	+59.5*	141	2.45	17*	
1979 VII	−78.6**	45	1.62	13	
1979 X	+36.8	130	2.33	12	
1980 XV	−27.4	179	3.40	16	
1983 XIX	+60.8**	363	4.39	18*	
1987 XXIX	−31.4	88	2.83	13	
1988 XXIII	+52.7*	436	5.42	23**	MW
1992 VII	−18.7	353	5.52	20**	
1992 XIII	+ 7.0	231	3.90	20**	

5. Concluding Remarks

Photographic searches for comets near opposition will continue to be effective, particularly for discovering short-period comets, but it would clearly be useful to extend the latitude range to $|\beta| = 60°$, as recommended in the Spaceguard Survey, even if this is accomplished at the expense of the present more extended range in longitude. Progressive replacement of photography by wide-field CCD operation would be effective in increasing the magnitude limit, and at some point in the not-too-distant future a CCD survey will become more efficient than a photographic survey in terms of sky coverage.

While it will continue to be the case that some comets, subsequently observable far from opposition, are always too faint for prior opposition detection, the Spaceguard search region has the principal disadvantage that some of the comets of high orbital inclination will be missed. The loss is not so great for comets of large q, but it increases to $\sim$ 25 percent for $q \lesssim 1$ AU. If one wishes to accommodate this problem by increasing the latitude coverage still further, it does become necessary to extend the longitude coverage—into the transition region and perhaps even beyond.

Extension of "professional" comet searches into the realm of the amateur is probably inevitable. It is rather curious, however, that photographic forays into this field have not been particularly productive. Non-apocryphal information on negative searches is difficult to assimilate, but it is not impossible that intrinsically faint long-period comets simply do not exist. Drummond *et al.* (1993) have recently mentioned a promising but unproductive survey covering $28° < \epsilon < 40°$ in 1989 by Martin Hoffmann and Edward Geyer with the 1.0-m Schmidt near Mérida, Venezuela. Of course, plate fogging in a twilit sky at the solar elongations favored by the most successful amateurs has obviously been a problem, there is magnitude loss at the inevitable low altitudes concerned, and many professional telescopes are not designed to operate at the extreme hour angles that would be necessary. As already remarked, the principal professional accomplishment at a moderately small ϵ was the discovery of comet 1977 IX. From the point of view of a discovery that could not otherwise be made, however, this was a wasted effort, for this particular comet has $q = 5.6$ AU and was later found on plates taken almost two years earlier! CCD searches at small elongations from the sun will have several advantages over photographic searches, and the experience of the visual searches suggests that it will be essential to experiment at small elongations before simply expanding the SSR about opposition.

Some will read these comments with sadness. The point about Spaceguard is that it is to be an *automated* survey. For more than two centuries comet hunting has been a sport, often highly competitive, and this competition has also been clear in many of the professional discoveries : this is one of the reasons that the professional discoveries encroach more on the morning side of opposition. Perhaps the time has already come for competition to be replaced by cooperation. The aim should not simply be to beat one's competition by a matter of a day or two, or even hours, but to ensure that, at a given time, the appropriate parts of the sky are properly covered to a useful magnitude limit. Automation implies that each comet found would be confirmed on a second night, with the necessary astrometry provided as a matter of course. Cooperation would undoubtedly also mean a departure from the custom of naming comets for their discoverers. I know of at least one successful comet hunter who would give up searching if this were done. To some extent this attitude is understandable, but it is rather pathetic that someone would hunt for comets *solely* because discoveries would be named for him. This is not science!

The emphasis of this paper has been on the general discovery of comets in the course of observing programs—professional or amateur—that may or may not have comet hunting as their principal aim. There are also searches for a specific comet or type of comet. These generally involve a one-dimensional sky search using a particular cometary orbit, generally treating the perihelion time as the only variable. Such a search led to the recovery of P/Swift-Tuttle in 1992, and the technique has also been used to search for members of the Kreutz sungrazing group. Kreutz searches were undertaken by a few observers in 1988, following the SMM discovery of 1987 XXII and XXV, only 12 days apart in the same orbit. It is evidently the case that the Kreutz sungrazers found near the sun by SMM later in 1988 and 1989 were all too faint for earlier detection in a dark sky. To the best of my knowledge, the only object actually discovered on the basis of the Kreutz ephemeris was the great comet 1970 II (Bennett), which was not a sungrazer at all! Bradfield's comet 1975 XI was found on the Kreutz track, as the discoverer quickly realized, but he does not specifically isolate this track in his comet hunting.

Another type of specific comet-search program is for comets near Jupiter in space, and thus within a few degrees of Jupiter in the sky. Such a search was discussed by Tancredi and Lindgren (1992), and these authors obtained the plates appropriate for their first search with the 1.0-m Schmidt at the European Southern Observatory around Jupiter's opposition in 1992. No cometary candidate was then found to a limiting magnitude—for a stationary object—of $B = 22.1$ (Tancredi and Lindgren 1993). As is now well known, such a comet, 1993e, was found a few days before Jupiter's opposition in 1993, but it was as bright as $m = 12$-13. First reported near opposition by the Shoemakers' near-earth-asteroid program, comet 1993e was independently discovered by at least three other groups, including Tancredi and Lindgren in their 1993 search. This is encouraging from the point of view of the completeness of general searches for comets near opposition. The discouraging part is that the comet must already have substantially brightened more than eight months earlier, around the time it passed inside Jupiter's Roche limit and broke up into at least eleven components. Jupiter was approaching conjunction at that time, and comet 1993e was evidently not bright enough for visual comet searches then or during the months following conjunction. Nevertheless, this is one case where the professional opposition-region searches might have been usefully extended into the morning sky!

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