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Short Papers

The discovery of Charon: Happy accident or timely find?

Robert L. Marcialis

It is argued that the discovery of Pluto's only known satellite was not serendipitous, but rather an event whose time had come. The 1960s through 1980s represented an era when both geometry was favourable and technology available to allow the find to occur. The 1978 discovery happened nearly at the midpoint of the interval when discovery probability was at its highest.

Introduction

I have often heard it said, both at professional meetings and informal gatherings, that the discovery of Pluto's satellite Charon (1978P1) was one of the luckier findings of the past few decades for planetary astronomy. The discovery, by James Christy and Robert Harrington of the United States Naval Observatory (1978), came a scant ten years before the 1988 passage of the Earth through the orbital plane of the satellite.[5] This passage has resulted, since 1985, in the ongoing season of eclipses, transits, and occultations (hereafter, mutual events). These mutual events have yielded more concrete results about the Pluto-Charon system in the past three years than was learned about the ninth planet since its discovery by Clyde Tombaugh in 1930. It is the intention of this paper to try to demonstrate that the discovery time, coming only 3% of an orbit before the mutual event season, was *not* fortuitous. Rather, it was the natural result of the concurrent ripening of technology and Pluto's favourable viewing geometry as seen by earthbound observers. In this paper are recounted the advances in instrumentation and observing technique (which impose an early bound to the discovery), and the several characteristics of both Charon's orbit about Pluto, and their mutual heliocentric orbit, which place a latter bound on the most likely time of discovery. It was almost exactly at the middle of the twenty-odd year period that James Christy noticed a bump circulating around Pluto's image.

Technological advances (a pre-1965 limit)

There were three major advances in the science of astrometry which had to occur before Charon could have been detected. These three are all intertwined, coming about as a result of each other. Two concern the hardware used in obtaining astrometric data; the third was a result of the increased sensitivity afforded by the equipment introduced in the mid-1960s.

The 1964 completion of the USNO 155-cm reflector in Flagstaff, Arizona marked the beginning of a new era for astrometry.[1] It was significant in that it hailed the introduction of large reflecting telescopes to astrometrical problems, a field previously the domain of the classical long-focus refractor. The greater light-gathering ability of a large mirror allowed plates to be exposed for shorter times with the same results. These shorter exposures resulted in narrower point-spread functions for stellar images, *i.e.*, turbulence in the atmosphere had less time to statistically 'smear out' the image of a star. Although the existence of this telescope was, in and of itself, not a requirement for the discovery of Charon, it *did* cause astrometrists to rethink their procedures as to plate reductions.

A simultaneous advance in the field of astrometry was the introduction of automated measuring engines. Milestones in this area were the SAMM and GALAXY machines.[2,3,4] The additional speed afforded by automating the previously tedious process of plate mensuration allowed a marked increase in the productivity of a given facility: the locations of many more objects could be monitored without producing a backlog of unreduced plates. In addition to being faster at measuring plate positions, these machines afforded greater positional accuracy than was possible previously. Profiles of stellar images could be determined analytically, and centroids of individual point-spread functions determined to better than a micrometer – a distance much smaller than the actual image size recorded on the photographic emulsion.

Increased accuracy of measurement induced the third – and probably most significant – modification to observing techniques (Christy, 1987, personal communication). When manual determination of the centre of a stellar image was the norm, plates traditionally were overexosed. Although this saturated the cores of the stellar images, it tended to 'smear out' the wings, providing large, round images whose centers the human eye could then determine. When measuring engines had advanced to the point of fitting image profiles, say, as the sum of gaussians, it was found that such fits became more accurate if the cores of the images were not saturated, but rather more properly exposed in the linear regime of the photographic emulsion. Once exposure times were cut down, it was then possible to resolve many binaries – both for stars, and in the case of Pluto, for a planet – that had previously been 'burnt in' to the emulsion as a single source. This explains the failure of Humason's 1950 Plutonian satellite search using the 200-in Palomar telescope.[6] With the shorter exposures, I have seen the asymmetry which is Charon on images taken with as small a telescope as the 61-cm Seyfert reflector of the A. J. Dyer Observatory.[7]

The combined effects of the above three innovations were such that the technology required to discover a faint, close-in ($m_V \simeq +16$, separation $\leqslant 0.9''$) satellite such as Charon simply did not exist prior to about 1965, which may be taken as an approximate earliest bound to the possibility of discovery.

Geometry (a post-1990 limit)

Several aspects of the geometry of the Pluto-Charon system as seen from our nearly heliocentric (dis)advantage point simultaneously conspire to make the discovery of Charon more likely in the two or three decades prior to the 1990s. We first consider those factors due to the specifics of Pluto's own orbit which have optimized the potential for the discovery of Charon.

As is well-known, Pluto's orbit about the Sun is both highly eccentric ($e = 0.246$) and highly inclined with respect to the ecliptic ($i = 17°.1$). Pluto takes 248 years to complete one circuit about the Sun. The orientation of this ellipse is such that at perihelion Pluto is some 9.2 astronomical units above (to the north of) the ecliptic, and only 29.7 AU from the Sun. (Compare this to its mean distance of 39.5 AU and aphelion distance of 49.3 AU.) The planet actually is closer to the Sun than Neptune for the years 1979–1999, with the first perihelion passage since its discovery to occur in June 1989. There is no known dynamical reason why Charon's orbital plane should point toward the Sun almost exactly at perihelion. Currently, this alignment must be regarded as purely due to chance, although I find such a configuration to be a bit *too* coincidental, nonetheless.

It is immediately apparent that at perihelion, the Pluto–Charon separation of 19,640 km subtends its largest angular distance, by virtue of its proximity to the Earth. Additionally, one would naïvely expect Pluto to be at its brightest near perihelion, due to the inverse-square law. (Due to the actual distribution of albedo features on the surface of Pluto, we now know this not to be the case, hence the use of the word 'naïvely'.[8,9]

A third point of consideration is that, due to the relative orientation of Pluto's orbital ellipse and the Earth's axial obliquity, Pluto reaches its greatest northern declination during the inbound quarter of its 248-year orbit. If one were to make a plot of Pluto's declination at opposition *versus* time, it can be seen that the declination has increased since the discovery in 1930 (when it was in Gemini), culminating at its northernmost value about the year 1946, and has been moving southward ever since. (For simplicity, one may ignore the parallactic effect of the Earth's motion about the Sun, as it amounts to less than 2° yr^{-1}, and is of only minor consequence to the argument.) Since most of the Earth's major observatories reside in the northern hemisphere (for this century, at least), then studies of Pluto are best conducted when it is at positive declinations. This manifests itself in two different ways. First, the 'observing window' (defined here as the amount of time per night that Pluto is high enough in the sky so as to be below 1.5 airmasses) is a strong function of the declination.

Second, for large declinations (up to the colatitude of the observing site, anyway) the altitude of an object above the horizon at meridian passage increases. Thus, one need look through less of the Earth's atmosphere at transit, resulting in greater image stability and therefore plates of superior quality. Taking a concrete example, for an observatory located at 40° North latitude, the maximum observing window in 1946 was ∼7h 18m, while in 1990 it will be only ∼ 3h 49m. When one folds in the seasonal variation of evening twilight, then the actual usable window in 1990 is further compromised, while the effect in the 1940s is of only slight consequence. This serves only to strengthen the preceding argument.

We now consider the actual orbit of Charon about Pluto, enumerating the various factors which also favour the discovery of Charon prior to the 1990s. Charon orbits Pluto in a circle which is highly inclined to both the ecliptic and Pluto's path about the Sun. In fact, the orbit is oriented such that Charon's motion is almost entirely in the N/S direction.

It should be noted that a low-inclination orbit *i.e.*, one that is nearly face-on to the observer, is much more conducive to the discovery of a satellite. The face-on geometry ensures that at all times the photocenter of the combined image differs most from its barycenter. Charon's orbit was oriented nearly face-on (much like the Uranian satellite orbits are now positioned) in the 1940s. Unfortunately, the planet was only rarely observed then, due to, among other things, the Second World War. Since then the apparent orbit, when projected on the sky plane, has been 'closing up', *i.e.*, becoming more elongate with time. At minimum elongations it becomes progressively more difficult to resolve the pair, whose seeing disks overlap even under the best of photographic conditions. During 1988, when the Earth passes through the orbit plane, the bump of Charon may be seen for only two nights per orbit (1 orbit = 6.387230 days), that is, for one night at northern elongation and one at southern – less than one-third of all orbital phases. Even this estimate is optimistic in that it presumes that Pluto be visible from a given observatory near the times such elongations occur, and that the atmosphere then be sufficiently stable so as to permit quality imaging. Rather than a detection rate of 30%, a more likely figure is ∼ 10% or less.

So we see that, in order to obtain a reasonable sampling of position angles of Charon with respect to Pluto (a require-

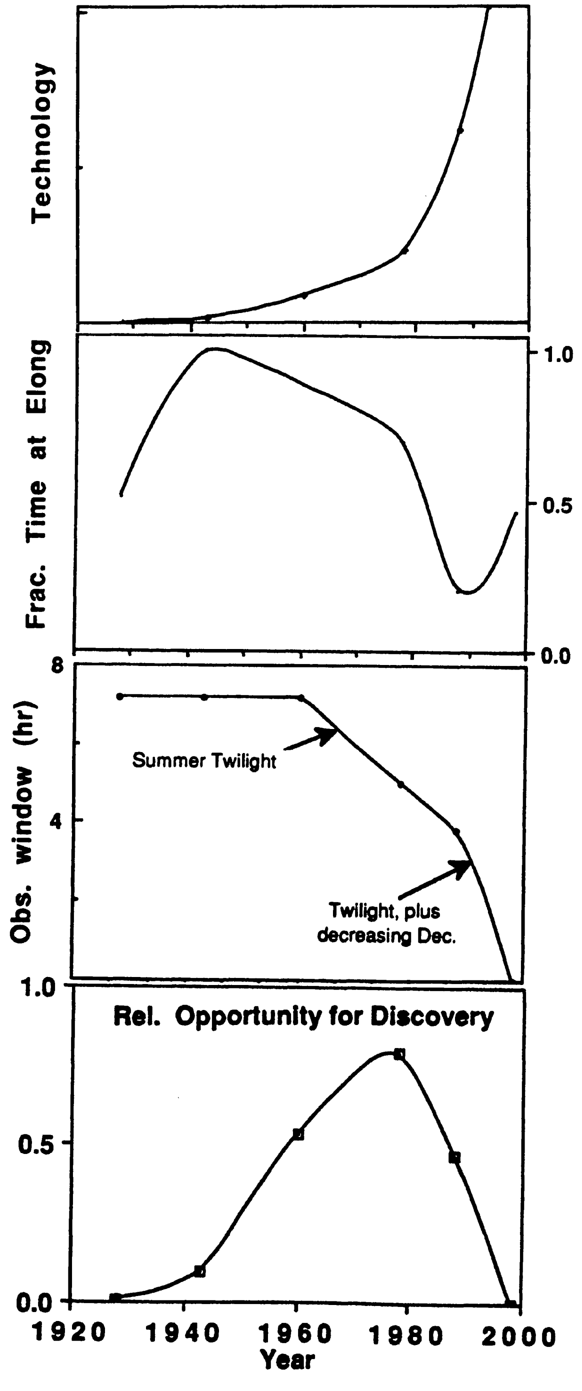

Figure 1. *(top to bottom) a.* Technology increases roughly exponentially with time. This result is simply a consequence of inverting the 'learning curve', a common systems engineering concept. *b.* As Charon's orbital plane becomes aligned with our line of sight, the satellite spends less time at elongation, the time when its light is most readily separated from Pluto's. *c.* Hours per day when Pluto may be observed from an Earthbound observatory at latitude 40°N. *d.* Renormalized product of these four functions yields the relative discovery probability for Charon. The actual discovery year was 1978.