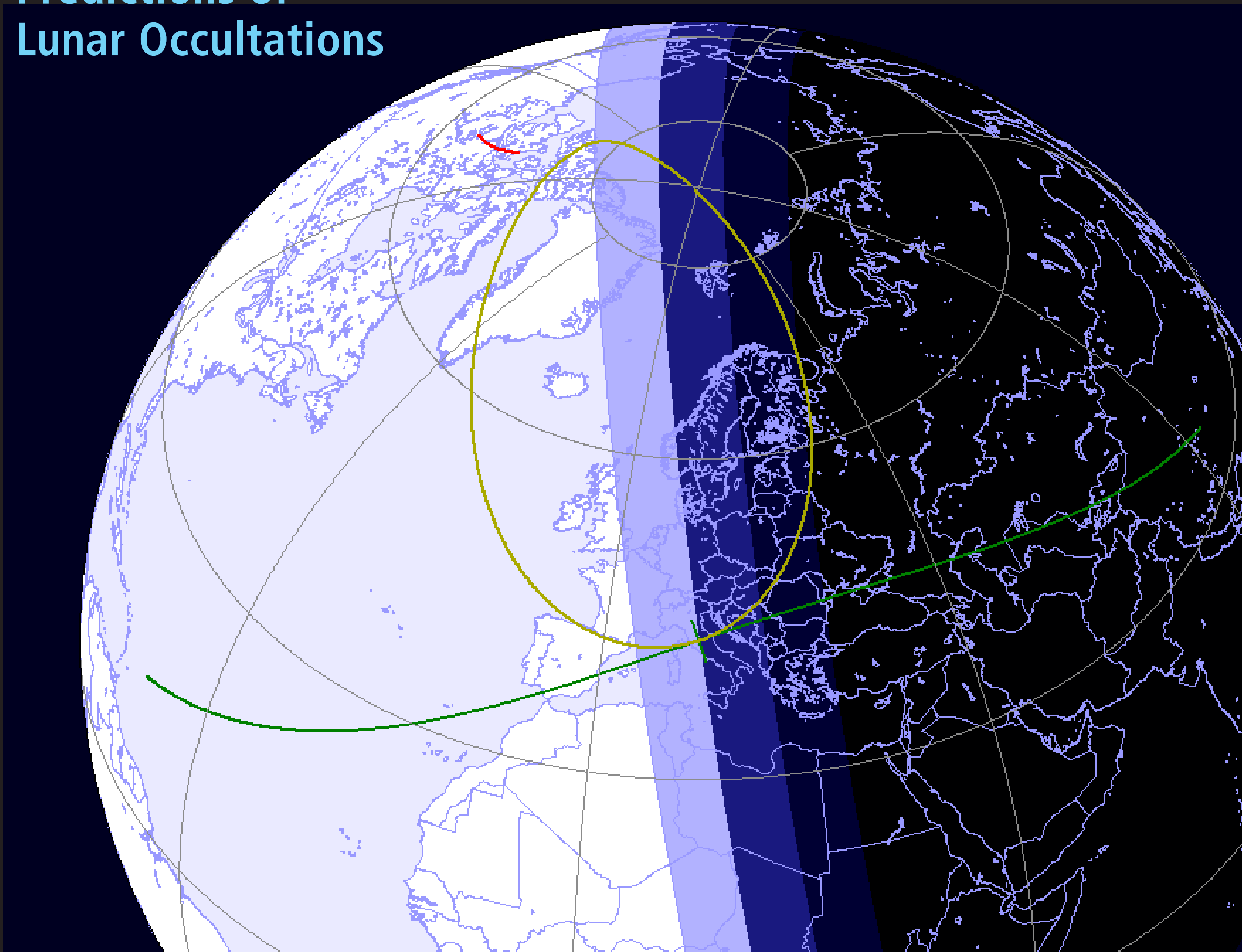
Journal for Occultation Astronomy

Volume 8 · No.1 2018-01

IN THIS ISSUE:



Studying Comets by the Stellar Occultation Method

Richard Miles, British Astronomical Association, Piccadilly, London, UK, rmiles@baa.u-net.com
Mike Kretlow, IOTA/ES, Lauenbrück, Germany, mike@kretlow.de

ABSTRACT: Stellar occultations by comets are generally problematic. The coma is usually too tenuous to be detected by the attenuation effect on stars unless the comet is a very active one and the nucleus passes within a few hundred kilometres of the star as projected on the sky frame. Where an occultation by the solid body of the nucleus occurs, the shadow track will be very narrow: Jupiter-family comets for instance typically measure just 1-5 km across and this small size significantly reduces the probability of a successful occultation for the observer. Another issue concerns the accuracy of cometary orbits, since this tends to be degraded by the presence of light from the inner coma shifting the position of the pseudo-nucleus relative to the true nucleus, and also by the effect of non-gravitational forces.

Larger, more distant periodic comets, such as active Centaurs, are more attractive occultation targets, and of these one of particular interest appears to be comet 29P/Schwassmann-Wachmann 1. Measuring about 60 km across, it is famous for its cometary outbursts, which number about 10 per year. The hypothesis is put forward here that the nucleus of 29P/S-W1 is surrounded by a debris belt of the order of 1000 km across, and that this could be detected by the stellar occultation technique. However, astrometry of its orbit is generally of poor accuracy owing to its outbursts, which tend to shift the photocentre of the nucleus away from its true position - especially when observed in small telescopes or where the aperture used for astrometry is too large. The case is put forward that astrometry of 29P should be carried out using a new measurement methodology with images taken by 1.0-m and 2.0-m telescopes, so as to refine the orbital elements and achieve more accurate occultation predictions.

Some Reports from the Literature

Comets generally develop a coma or dust tail as they approach perihelion, seen by reflected sunlight. The coma exhibits a variety of forms but is usually very tenuous even in very active comets such that stars passing behind the extended coma will show no significant decrease in brightness as the filling factor of the dust (fraction projected on the sky occupied by dust) is very small, i.e. <0.001. Most observations actually record an appulse rather than a physical occultation, an early example being an event seen by Friedrich Archenhold whilst observing 1P/Halley on 1909 December 5, when the 12th magnitude nucleus was seen to merge with a 12th magnitude star as seen under high magnification in the 0.65-m refractor of Treptow Observatory, Berlin [1]. Attenuation of starlight can occur very close to a very active comet such as Hale-Bopp (C/1995 O1) or 17P/Holmes soon after its mega-outburst of 2007. In the case of Hale-Bopp, a drop of 0.06 mag was registered some 43000 km from the nucleus and interpreted as enhanced absorption due to a local jet [2].

Probably the most successful occultation record for Hale-Bopp was achieved when it occulted a mag 9.1V star (PPM 200723) on 1996 October 05 whilst 2.8 AU from the Sun [3]. For one station using a photomultiplier detector, a positive event was recorded lasting about 30 seconds although sky conditions were affected by thin cloud at the time and so were non-photometric.

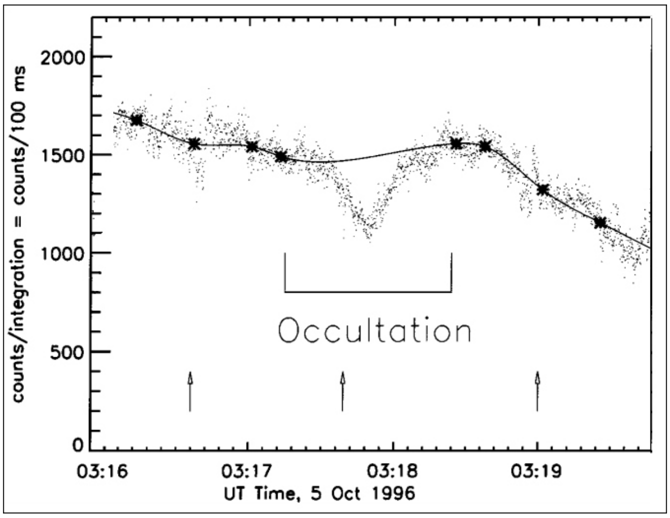


Figure 1: Positive event recorded by Yanga Fernández and Dennis Wellnitz in 1996 showing the occultation by the nucleus or near-nucleus region of comet Hale-Bopp (adapted from [3]).

At mid-event, the light from the star had effectively been extinguished showing that the coma was optically thick within 100 km of the nucleus, the radius of which was estimated to be 30-48 km.

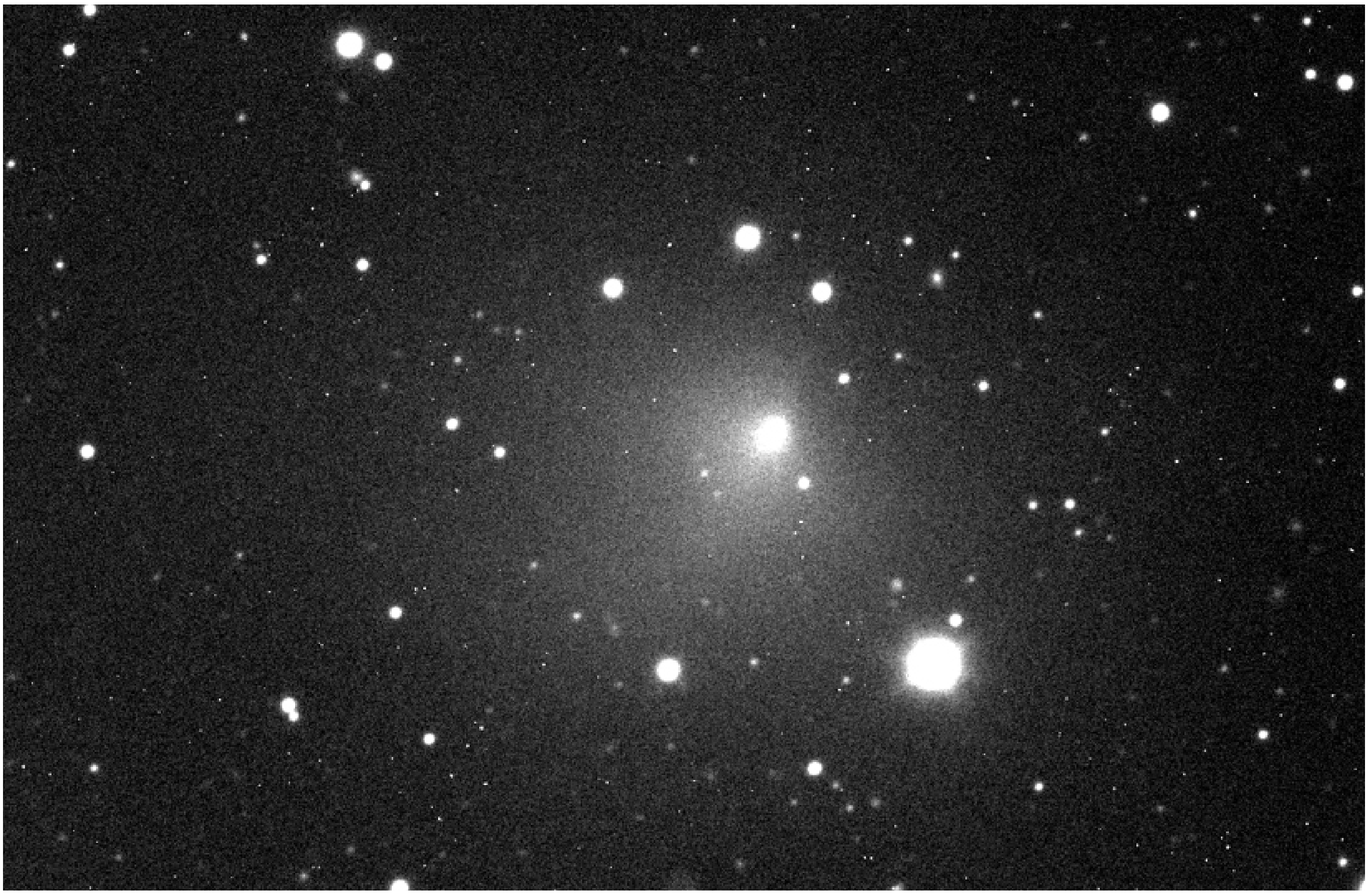


Figure 2: Deep image of 29P/S-W1 on 2017 October 12.42 (Las Cumbres Observatory). 2.0-m f/10 Faulkes Telescope South, Siding Spring (SDSS-r' filter, 8 frames stacked) Integration time = 1440 sec, Field of view = 5.0' x 6.5', linear stretch, motion 0.02"/min

On 2007 October 29, some 5 days after the intense outburst of comet 17P/Holmes, the nucleus passed within 0.8 arcsec of a magnitude 11.1R star and measurements using a narrow-band filter on a 2.2-m telescope indicated an optical depth of just 0.04 some 1.5 arcsec from the nucleus [4]. The authors concluded that the coma was optically thick only within about 0.01" (12 km) of the nucleus.

Implications for Stellar Occultations by Comets

From the above, it can be seen that for an average comet, we can only expect the nucleus itself to occult the star and that the detection of any true dimming prior to ingress, or after egress will be very challenging to measure. Thus the shadow projected on the Earth will be very comparable to the size of the comet nucleus, and since the vast majority of comets measure <100 km across, the shadow tracks will generally be very narrow. Short-period Jupiter-family comets (JFCs) represent especially difficult targets, typically measuring just 1-5 km across [5].

With the Gaia mission well underway, we can expect highly-accurate astrometric positions and proper motions for almost a billion stars in the next few years, as well as much more accurate orbital elements and mass estimates of the larger asteroids. For comets, however, a key factor in predicting stellar occultations is the precise position of the occulting body, i.e. the nucleus. This can be problematic for several reasons:

One issue is the measured position of the so-called 'pseudo-nucleus', which is generally displaced relative to the position of the actual nucleus owing to reflected light from the inner coma. Astrometric software determines the position of the peak in brightness within the inner coma and so if the comet is particularly active or has exhibited an outburst such that the coma is markedly asymmetric, this peak intensity is displaced. This is particularly the case under conditions of poor seeing, or when the instrument is a small telescope, since then the stellar FWHM is broadened and more of the inner coma contaminates the pseudo-nucleus lowering the peak intensity and shifting it further from the position of the true nucleus (see Figure 2). Whether Gaia 'exo-atmosphere' astrometry of comets will improve our knowledge of cometary orbits is yet to be seen.

The other main issue for comets is that being generally small, they are of low mass and so non-gravitational forces arising from exposure to solar radiation and internally generated jets can perturb their motion thereby complicating the task of predicting future occultations. There is a case for deriving a methodology aimed at enhancing the precision and accuracy of comet astrometry.

The Attraction of Stellar Occultations by Centaurs and TNOs

From the foregoing it is clear that successful occultation results on comets that approach the Sun closer than the orbit of Jupiter are expected to be few and far between in the near future. In contrast, more distant objects are generally larger and hence their shadow tracks wider mak-

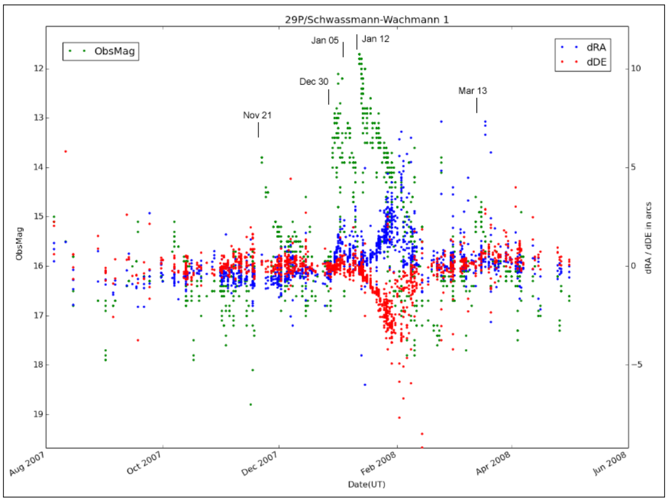


Figure 3: An illustration showing how cometary outbursts of comet 29P/S-W1 degrade astrometric accuracy. Data taken from the Minor Planet Center (MPC) and analysed to show residuals (O-C) from the predicted aastrometric position, RA and Dec (blue and red points) alongside the reported m2 magnitude of the pseudo-nucleus (green points). The times of five outbursts are shown.

ing them more favourable targets. Although they may be cometary in nature, they do not suffer from the presence of a persistent coma, except in one notable case, namely comet 29P/Schwassmann-Wachmann 1. So most Centaurs represent attractive targets for study by the occultation method and indeed, Project Lucky Star led by Bruno Sicardy [6] is specifically designed to study Centaurs and Trans-Neptunian Objects since 2015 using this technique. Many positive occultations have already been recorded – take for example the recent announcement of the discovery of a dense ring around the trans-Neptunian dwarf planet, Haumea [7]. Some Centaurs have been found to be cometary in nature including (60558) Echeclus (also known as periodic comet 174P/Echeclus) and an article written by Oliver Klös describing this object and making predictions for future occultations appeared in Journal for Occultation Astronomy Vol. 7 No. 4. However, of all the Centaurs known, the most enigmatic is without any doubt 29P/S-W1.

The Case for 29P/Schwassmann-Wachmann 1

Although space precludes any detailed account of this object here, readers may wish to consult a series of papers published in the journal, Icarus [8–10] to understand the very special nature of this body, which is worthy of study by a variety of techniques including the occultation method. Figure 2 illustrates the quiescent appearance of 29P/S-W1 as seen 40 days after its last strong outburst.

29P/S-W1 is moving northwards, crossing the celestial equator next June, and will be well placed for northern hemisphere observers in the next 8-10 years. Astrometry appears to be seriously biased by the many outbursts of the comet (typically 10 per year). After an outburst, the asymmetric coma shifts the position of the photocentre / pseudo-nucleus relative to the true nucleus and this shift can persist for several weeks as shown in Figure 3. The apparent deviation from the expected position can exceed 5" in both R.A. and Dec. at times. It is our view that to be able to make accurate predictions of stellar occultations by 29P/S-W1, it will be necessary to refine the current orbital elements.

Since the apparent photocentre shifts as the measuring aperture size is changed, it may be worthwhile making measurements with astrometric apertures of several sizes and then extrapolating the position as a function of size to a value close to, or equal to the FWHM or 'seeing' at the epoch of the observation. An on-going 29P monitoring project is being conducted using the Las Cumbres Observatory global network of telescopes and we have already built up several years of frequent imaging of the comet using 1.0-m and 2.0-m telescopes. It will be interesting to compare the astrometric precision achievable using such large telescopes and an improved method of astrometric measurement, relative to the current astrometry reported to the MPC.

One possible approach for minimising astrometric bias arising from the displacement of the photocentre would be to apply an appropriate weighting scheme during orbit computations to those astrometric observations made around the times of outburst.

One other reason why 29P is a worthy target for occultation studies is that it is likely to possess some form of temporary debris/dust belt that fluctuates in size and density (and tilt relative to the Earth) but which is likely to be of the order of 1000 km across. The latest estimate of the size of the nucleus is in the range 55-68 km across [11].

References

[1] Archenhold, F.S. "The occultation of a star by the nucleus of Halley's Comet". Das Weltall 10, 108 (1910)

[2] Betzler, A.S. & Betzler, L.B.S. "Observations of Three Stellar Occultations by Comet Hale–Bopp". Earth, Moon, and Planets 120(1), 1 (2017)

[3] Fernández, Y.R. et al. "The Inner Coma and Nucleus of Comet Hale–Bopp: Results from a Stellar Occultation". Icarus 140(1), 205 (1999)

[4] Lacerda, P., & Jewitt, D. "Extinction in the Coma of Comet 17P/Holmes". Astrophys. J. Lett. 760(1) L2 (2012)

[5] Snodgrass, C., Fitzsimmons, A., Lowry, S.C., Weissman, P. "The size distribution of Jupiter Family comet nuclei". MNRAS 414(1), 458 (2011)

[6] European Research Council Project Lucky Star, see website at: http://lesia.obspm.fr/lucky-star/predictions/

[7] Ortiz, J.L. et al. "The size, shape, density and ring of the dwarf planet Haumea from a stellar occultation". Nature 550, 219 (12 October 2017)

[8] Miles, R., Faillace, G.A., Mottola, S., Raab, H., Roche, P., Soulier, J.-F., Watkins, A., "Anatomy of outbursts and quiescent activity of comet 29P/Schwassmann-Wachmann". Icarus 272, 327 (2016)

[9] Miles, R. "Discrete sources of cryovolcanism on the nucleus of Comet 29P/Schwassmann–Wachmann and their origin". Icarus 272, 387 (2016)

[10] Miles, R. "Heat of solution: A new source of thermal energy in the subsurface of cometary nuclei and the gas-exsolution mechanism driving outbursts of Comet 29P/Schwassmann–Wachmann and other comets". Icarus 272, 356 (2016)

[11] Schambeau, C.A. et al. "A new analysis of Spitzer observations of Comet 29P/Schwassmann–Wachmann 1". Icarus 260, 60 (2015)