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JOHN MICHELL, THE PLEIADES, AND ODDS OF 496,000 TO 1

David W. Hughes and Susan Cartwright
Department of Physics and Astronomy, The University of Sheffield, Sheffield S3 7RH, UK.
E-mail: d.hughes@sheffield.ac.uk

Abstract: John Michell, M.A., B.D., F.R.S. (1724–1793), was the first scientist to apply statistics to the spatial distribution of the stars on the celestial sphere. He was the first to realise that certain groupings, like the Pleiades cluster in Taurus, were non-random, thus indicating that these stars were a physical group in space, held together by gravity.

This paper presents a step-by-step exposition of Michell's rather convoluted mathematical approach, and discusses the implication of his findings when it came to the acceptance of Newtonian gravitation, the search for stellar parallax and the investigation of binary stars.

Key words: John Michell, stars, statistics, clusters, binaries, gravity

1 INTRODUCTION

Unfortunately Geikie (1918: 3), Davison (1927), Kopal (1986: 398) and Sheynin (1995) were unable to establish the date, or place of the birth, of the somewhat obscure Reverend John Michell, M.A., B.D., F.R.S. Davison hinted that Michell was probably born in Nottingham in either 1724 or 1725. However, extensive recent research by Crossley (2003) has established that Mitchell was actually born in the tiny village of Eakring in north Nottinghamshire (see Figure 1). Eakring is three and a half miles to the south of Ollerton and two and a half miles south east of Rufford Abbey, which, at the time of his birth, was the home of the Savile family, of Oxford University Savilian Chair fame. Considering Michell's prowess in the field of geology it is interesting to note that Eakring is now the site of England's first productive oil well.

Michell was born on Christmas day, 1724. His father, Gilbert, was appointed rector of Eakring in 1722, the advowson belonging to Sir George Savile.

John Michell went up to Queen's College, Cambridge as a Pensioner on 17 June 1742, and took his Bachelor's degree in 1748, appearing as Fourth Wrangler. In 1749 he became a Fellow of Queen's and stayed at that College for the next fifteen years, taking an M.A. in 1752 and a B.D. in 1761. He was elected a Fellow of the Royal Society on 12 July 1760, and was appointed to the Woodwardian Chair of Geology at Queen's, in preference to his friend Neville Maskelyne (1732–1811), the fifth Astronomer Royal (see Howse, 1989: 43), at the end of 1762. Career highlights during that time were Michell's epoch-making dissertation on earthquakes and seismicity (Michell, 1760); his membership of the six-man committee that, in 1765, started to investigate John Harrison's chronometrical solution, using the H-4, for the determination of longitude at sea; his invention and manufacture of the mass balance that was eventually used by Henry Cavendish in 1798 to measure Newton's constant of gravity (see McCormack, 1968); and his pioneering investigations of black holes (Michell, 1784; see also Schaffer, 1979) and artificial magnets (Michell, 1750; see also Hardin, 1966); and his detection of radiation pressure.

In 1763 Michell left Cambridge and became Rector of Compton near Winchester. In the following year he resigned from his Cambridge chair, and forsook the celibacy required by that institution. On 23 August 1764 he married Sarah Williamson, who, according to the *Cambridge Chronicle* of 8 September 1764, was "… a young lady of considerable fortune". A year later their daughter Mary was born. Seven weeks after this happy event disaster struck and his wife died.[1]

In 1767 Michell moved up the church hierarchy to become the Rector of St Michael's Thornhill, near Dewsbury and Leeds, the patron of this benefice being the afore-mentioned Sir George Savile. Thornhill parish was not only well endowed, but was also in the heart of the geologically-interesting great Yorkshire Coalfield and close to the home of Michell's friend, Joseph Priestley.

In this paper we would like to stress the fact that Michell was the first *statistical* astronomer, and that he pioneered the application of probability theory to stellar distributions. We investigate his approach to stellar statistics, and specifically his estimations of the probability of stars being separated by specific distances on the celestial sphere.

2 THE STATISTICS OF THE DISTRIBUTION OF STARS ON THE CELESTIAL SPHERE

Throughout the history of pre-Michellian astronomy it was assumed that the bright stars were scattered at random on the celestial sphere. It is this very randomness that produces the differing shapes of the constellation groupings. One of the breakthroughs of late eighteenth and nineteenth century astronomy was the extension of the easily-mapped two-dimensional distribution of stars on the celestial sphere to a gradual understanding of their three-dimensional distribution in space. The term 'double star' had been in use for millennia, Ptolemy, for example, using it to describe Nu Sagittarii, two fifth-magnitude stars about 14 minutes of arc apart. The numbers of know double stars increased considerably with the introduction of the telescope. Until the work of John Michell, they had all been thought of as optical pairs, their close proximity on the sky being simply a matter of chance. Michell changed this with his pioneering introduction of statistics to the field of astronomy, and specifically to star groupings. He presented his findings to the Royal Society on 7 and 14 May 1767. In the published paper, Michell (1767: 243) wrote:

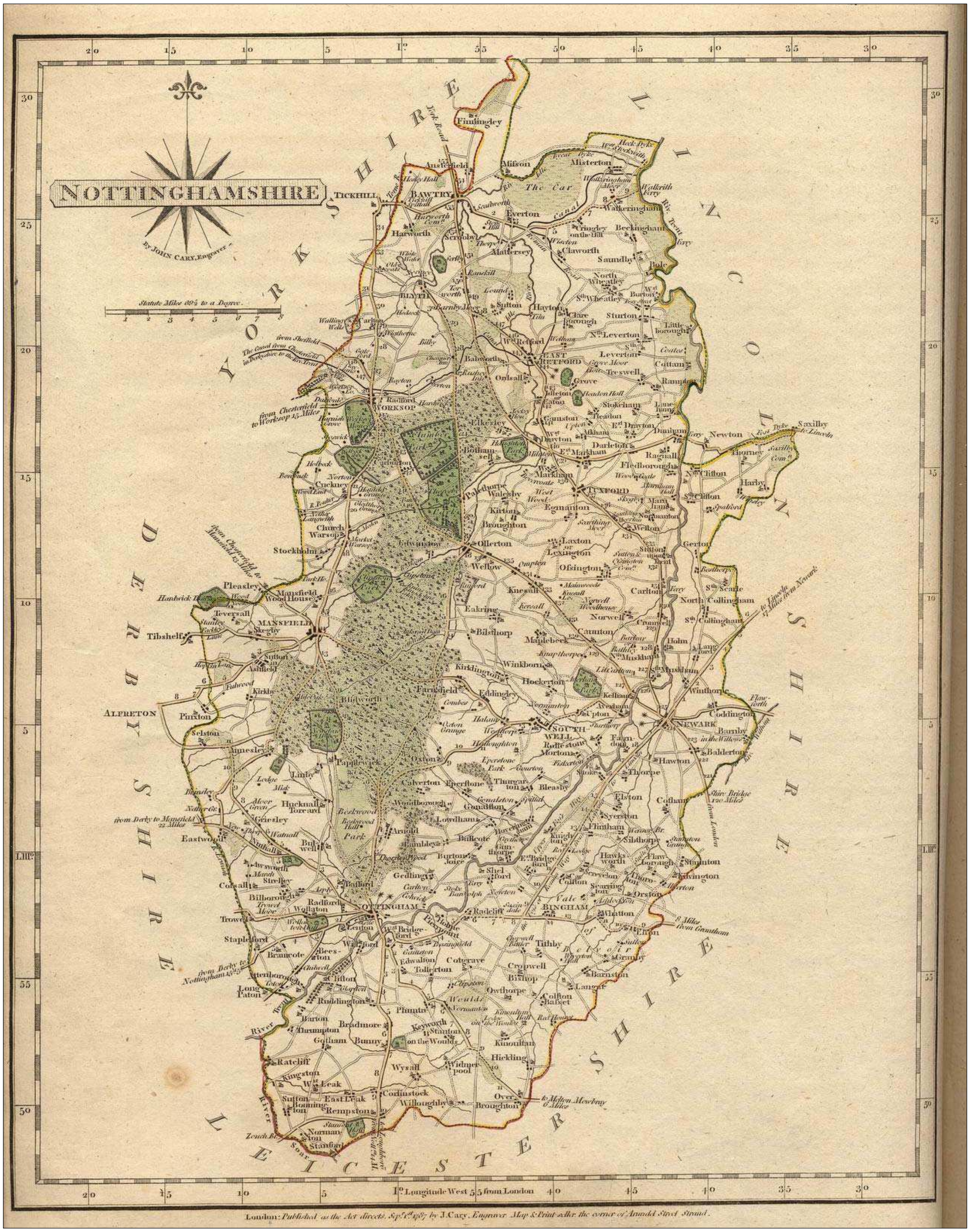

Figure 1: The village of Eakring, the birth place of John Michell, can be seen in the centre of Nottinghamshire on this contemporary map (Cary, 1787). The area is known as the Dukeries. The main thoroughfare is the Great North Road, this passing though Newark, East Retford and Bawtry.

> … from the apparent situation of the stars in the heavens, there is the highest probability, that, either by the original act of the Creator, or in consequence of some general law (such perhaps as gravity) they are collected together in great numbers in some parts of space, whilest in others there are either few or none.

John Michell's probability arguments rested on the following contentions:

(1) The surface area of the three-dimensional celestial sphere, assuming that this sphere has a diameter D, is equal to πD^2. A sufficiently small circle, of radius r (and $r << D$), drawn on the surface of the celestial sphere will be approximately plane, and will therefore have an area of πr^2. Thus the ratio of the area of the small circle to the total area of the sphere is $(r/D)^2$. In the case of the sky, r and D are measured in angular

units. So consider a small circle of radius 1^o, i.e. 60 minutes of arc. The area of this circle is $\pi 60^2$ square minutes of arc, whereas the area of the surface of the whole celestial sphere is 4π square radians = 4π $(57.29578)^2$ = 41252.96 square degrees = 1.485×10^8 square minutes of arc = $\pi(6875.5)^2$ square minutes of arc.

(2) If stars are randomly distributed on the celestial sphere, the supposition, as Michell (1767: 243) puts it, being "… that they had been scattered by mere chance …", then the probability that a particular star is located in a particular circle of radius r, this circle being centred on the specified star, is simply the afore-mentioned ratio of areas, $(r/D)^2$. And the probability that it is *not* so located is the complement, $1 - (r/D)^2$, or equivalently $(D^2 - r^2)/D^2$. So the probability, C, of a specified star being in a specified area, 60 arc min in radius, is given by

$$C = \left(\frac{60}{6875.5}\right)^2 = 0.00076154. \qquad (1)$$

Taking the reciprocal of the number given in equation (1) indicates that the chance is 1 in 13,131.

(3) The probability of two independent events both occurring is the product of their individual probabilities.

John Michell then argues that if there be n stars visible on the celestial sphere, brighter than a given limiting magnitude, the probability, P, that none of them should lie within a distance r of a given reference star is given by

$$P = ((D^2 - r^2)/D^2)^n. \qquad (2)$$

As, however, he is interested in the probability that *no* star lies within distance r of *any* other star, he writes (1767:244) that "… we must again repeat the last found chance n times …", leading to the probability

$$P_n = ((D^2 - r^2)/D^2)^{n\times n}. \qquad (3)$$

The first stellar example that Michell chose to illustrate his argument was the visual double star β Capricorni (R.A. (2000.0) $20^h\ 21^m\ 00.5^s$, Declination (2000.0) $-14^o\ 46'\ 53''$). In order to calculate the probability that this was a chance pairing he needed to know

(i) the separation of the two stars, which Michell (1767: 246) took to be "… something less than 3⅓ …" arc minutes (in good agreement with the modern value of 205 arc seconds); and
(ii) the number of stars at least as bright as either of the components of β Cap, which he took to be "… about 230".[2]

Using the logarithmic tables of the day, and equations (1) and (2) above, Michell calculated that $6{,}875.5^2$ divided by $(3⅓)^2$ equals 4,254,603.[3] He then logarithmically calculated the value of the fraction 4,254,602/4,254,603 and (by multiplication) raised this fraction to the power of 230 × 230, obtaining a final answer of 0.987653. As 1/(1 – 0.987653) is very close to 81, Michell concluded that the probability of the two stars being that close by chance was about 80 to 1 against. The inference is that their close proximity is not produced by a chance alignment and that the system is a double star, in which both members are orbiting a common centre of mass.

This result is clearly critically dependent on the estimate of there being 230 stars in the sky as bright as the components of β Cap. In contrast to his very careful explanation of the mathematical foundations of his probability calculations, Michell offers us no justification for this number. In fact, the two components of β Cap are very different in brightness. β Cap is a 'telescope' double, the primary having apparent visual magnitude 3.08 and the secondary only 6.10. A magnitude distribution fit to a modern whole-sky catalogue of stars brighter than fifth magnitude (see, for example Ochsenbein and Halbwachs, 1987) indicates that the number of stars, N_m, brighter than apparent visual magnitude m_V, where $2 < m_V < 5$, is given by

$$\log_{10} N_m = (0.494 \pm 0.004)\, m_V + (0.735 \pm 0.015). \qquad (4)$$

This equation indicates that there are 180 stars in the sky brighter than β_1 Cap, but (extrapolating to magnitude 6.1) fully 5,570 brighter than β_2 Cap. Using these numbers in the calculation gives a chance probability of 21% (i.e. 1/4.8) rather than Michell's 1/81.

Michell did not have access to a good star catalogue, but he comments that

> … it seems to be an object worth the attention of Astronomers, to enquire into the exact quantity of light, which each star affords us separately, when compared with the Sun; that, instead of distributing them, as has hitherto been done, into a few ill defined classes, they may be ranked with precision both according to their respective brightness, and the exact degree of it. (Michell, 1767: 241).

So it is surely inconceivable that he had failed to observe the difference between the third and sixth magnitudes of the two components of β Cap. Given, however, that he does not make any further use of the result that he obtained, one may charitably assume that he intended the calculation for β Cap to stand as a simple example before tackling the more complicated arithmetic needed for the Pleiades.

It is, however, ironic that he chose β Cap for this demonstration, since it is in fact a far more convincing exemplar than he could have known. Both components are spectroscopic and occultation binaries; in addition, there is a magnitude 9 visual companion which was discovered by William Herschel. So the total number of known components of this complex system is eight (see Hoffleit and Warren, 1991).

3 THE STATISTICS OF THE PLEIADES

Michell then turns his attention to one of the most obvious groupings of stars in the sky, this being the Pleiades galactic cluster in Taurus (see Jones, 1991: 168 and 394). The Pleiades (or Messier 45) has the honour of being mentioned three times in the Bible (Job 9:9, Job 38: 31 and Amos 5:31). Also the observation of the heliacal rising of the Pleiades in the month of May was regarded by the calendrically-minded Julius Caesar as indicating the start of summer. Six of the Pleiades stars are clearly visible to the naked eye, these being Alcyone, or η Tau (apparent visual magnitude, m_V = 2.96); Atlas, or 27 Tau (m_V = 3.8); Electra, or 17 Tau (m_V = 3.81); Maia, or 20 Tau (m_V = 4.02); Merope, or 23 Tau (m_V = 4.25); and Taygeta, or 19 Tau (m_V = 4.37); all of the afore-mentioned apparent magnitudes being taken from Hoffleit and

Warren, 1991. These stars occupy a region of the sky that is about 60 minutes of arc across, the actual interstellar separations quoted by Michell being shown in Figure 2. Michell concluded that the odds against this celestial grouping occurring randomly were about 496,000 to 1, and he went on to suggest that the Pleiades were an actual physical group in space, held together by the influence of Newtonian gravitation.

His methodology was as follows. Michell estimated that there were 1,500 stars visible in the sky brighter than Taygeta (19 Tau, m_V = 4.37). Our modern estimate, based on data in Ochsenbein and Halbwachs (1987) and Hoffleit and Warren (1991), would be about half this number, namely 722. This discrepancy indicates the parlous state of astronomical photometry and magnitude estimation in the later half of the eighteenth century. Michell should have at least realised that each magnitude class contains about three times as many stars as the one preceding (see von Humboldt, 1851: 275), and that most contemporary star catalogues showed that there were about 20 first magnitude stars, 65 second, 190 third, 425 fourth, 1100 fifth, and so on.

Mitchell (1767) proceeded by considering the six brightest Pleiades as five pairs. Here he related Taygeta, Electra, Merope, Alcyone and Atlas to the star Maia, the later presumably being selected as it is the closest to the centre of the visible grouping (see Figure 2). Using the β Capricorni approach for the Maia-Taygeta pair (but now assuming a separation of 11 mins arc and a value of n = 1,500) Michell calculated P (see equation 2) to be 0.996173. Similar calculations for Maia-Electra, Maia-Merope, Maia-Alcyone and Maia-Atlas yielded P values of 0.988018, 0.982506, 0.977148 and 0.926766 respectively. The number n has not been modified to take account of the differing magnitudes. Wanting to calculate the chance that the grouping *will* occur, as opposed to *will not*, Michell then calculated the complements of these quantities to unity, i.e. 0.003827, 0.011982, 0.017494. 0.022852 and 0.073234. As all these pairings occur simultaneously in the Pleiades, these numbers must be multiplied together, giving 1.3424987×10^{-9}. The reciprocal of this number, i.e. 744,880,000, then represents the odds of this grouping occurring at random. Michell then took his readers step by step through a calculation similar to the β Capricorni calculation discussed above. The combined probability is

$$[(744{,}880{,}000 - 1)/744{,}880{,}000]^{1500} = 0.99997984.$$

And $1/(1 - 0.99997984) = 496{,}000$.

Repeating this calculation on a modern pocket calculator gave 1 in 458,000; the difference can be ascribed to rounding errors in taking the logarithms of numbers that are very close to 1. Using the more realistic estimate that there are 720 stars at least as bright as the star Taygeta, this calculation would give even more impressive odds of 1 in 36 million.

Michell (1767: 249) contends that the value 496,000

> … is smaller than it ought to be upon two accounts; for, in the first place, this method of computation gives only the probability, that no five stars would be within the distances above specified from a sixth, if they occupied the largest space, they possibly could do, under that limitation; and secondly, we have made no allowance upon account of the different magnitudes, which, if it had been attended to, would have given a somewhat greater result. These considerations, however would have made the reasoning a good deal more intricate; and we have no need to descend to minutiae, a difference in the pro-portion of 10 to 1 not at all affecting the general conclusion.

Michell, our pioneer astronomical statistician, quite rightly points out that his conclusion—that the Pleiades group cannot possibly be a chance near-alignment—would have been the same even if the number that he calculated turned out to be ten times larger or ten times small that the figure 496,000.

This approach is most refreshing considering that Michell was working in the days when most astronomers quoted numbers to as many places of decimals as were given by their logarithmic calculation or there was room for on the piece of paper that they were using. Michell's astronomical breakthrough was in recognising the fact that some of the stars in the heavens were not like the Sun, i.e. both single, and hundreds of thousands of astronomical units distant from their nearest neighbours. Michell showed that some stars were in gravitationally-controlled groups, and his work pioneered and encouraged the search for stellar binaries by William Herschel, whose first and second catalogues of double stars were published in the *Philosophical Transactions of the Royal Society* in 1782 and 1785.

Historians of statistics such as Boole (1854: 364-367) and Hald (1998: 70-74) have investigated the statistical contributions of Michell, but they mainly concentrated on determining whether he was a Bayesian or not, or whether his work was an example of direct or inverse probability theory. Here we concentrate on Michell's Pleiades investigation, and why he was specifically interested in whether this grouping was a chance association of unrelated stars (at a range of distances from Earth, but all in a similar direction), or whether they were a cluster of stars kept together by gravitational forces

A modern statistical astronomer would use the Poisson distribution to calculate the probability of a chance celestial assemblage similar to the Pleiades. Taking the diameter of the Pleiades cluster to be 60′ (the distance from Taygeta to Atlas in Figure 2), we may calculate that there are 52,524 'pixels' of this size on the celestial sphere. The average number of stars brighter than Taygeta per pixel is thus 0.0286, assuming we use Michell's figure of 1500 such brighter stars on the celestial sphere, or 0.0137 using the more realistic estimate of 720. The Poissonian probability of actually observing r objects in a specific region when the expected number is μ is

$$P\,(r;\mu) = (e^{-\mu}\,\mu^{r})/r! \qquad (4)$$

yielding a probability of 7.3×10^{-13} for 1,500 stars, and 9.1×10^{-15} for 720. Since we do not care which particular pixel contains the assemblage in question, we must multiply these numbers by 52,524, thus obtaining overall odds of 1 in 26 million for 1,500 stars, and 1 in 2.1 billion for 720 stars.

Since the famous French mathematical physicist Siméon-Denis Poisson (1781–1840) was twelve years old when John Michell died, Michell can be forgiven for not using Poissonian probabilities. However, we might reasonably ask why these probabilities are so much smaller than those calculated using Michell's method. The reason is simple. Michell made a mistake. In a Poissonian distribution the probability of observing two objects is not, as Michell assumed, the square of the probability of observing one object. Michell's algebra corresponds to assuming that $P(1; \mu) = \mu$; and since μ is so much less than unity, this is not a bad approximation. Unfortunately he also assumed that $P(n;\mu)/P(1;\mu) = \mu^{n-1}$, whereas in a true Poissonian distribution $P(n;\mu)/P(1;\mu) = \mu^{n-1}/n!$. The latter is this factor of 6! = 720 less than the former, this explaining the difference between the two calculations.

Conceptually, this can be understood by recognising that the five binary pairs considered by Michell (Alcyone-Maia, Atlas-Maia, Electra-Maia, Merope-Maia and Taygeta-Maia) are only a subset of the fifteen possible binary pairings of a set of six stars. So requiring that Taygeta be 11′ from Maia and that Atlas be 49′ from Maia *also* constrains the distance between Atlas and Taygeta, and this is not taken into account in Michell's calculation. There may be a hint of recognition of this problem in Michell's statement (1767: 249) that

> … this method of computation gives only the probability, that no five stars would be within the distance above specified from a sixth, if they occupied the largest space, they possibly could do, under that limitation.

4 DISCUSSION

Briefly returning to his county of birth (a county much loved by one of the authors (DWH), who was born in East Retford), we would like to tentatively suggest that Michell deserves the title of Nottinghamshire's greatest astronomer. He was the pioneering astronomical statistician, using statistics to show that nearly all double stars were actually gravitationally-bound systems, and not merely chance couplings of two stars close to the same line of sight. This proved that the attractive force of gravity was also a stellar phenomenon and not just a property of our Solar System. Michell was also the first astronomer to discuss black holes and the effect of gravity on light. His estimates of the expected interstellar distances were reasonable in that he intimated (Michell, 1767: 237) that stellar parallaxes were definitely less than 2 arcsec and probably less than 1 arcsec. He suggested that stellar twinkling was due to turbulence in the atmosphere and not eye motion, and his attempts to actually measure radiation pressure were commendable. His construction of the first 'Cavendish torsion balance' led eventually to the measurement of the constant of gravitation, G, and thus the mass of astronomical bodies. His role as a telescope-maker is also worthy of mention. To construct a 10-foot focal length, 30-inch diameter speculum mirror reflector that was so good that William Herschel was willing to pay 30 pounds sterling for it surely underlines Michell's skill.

In ranking Michell as Nottinghamshire's first astronomer, we should briefly mention the 'runners up'. Another prominent Nottinghamshire astronomer was John Russell Hind, FRS (1823–1895), Royal Astronomical Society President and Gold Medallist, Superintendent of the Nautical Almanac (1853-1891), discoverer of ten asteroids, cometary astronomer and celestial mechanician. Maybe Hind deserves second place. Third place might go to Norman Robert Pogson (1829–1891), photometrist, meteorologist, definer of the stellar magnitude scale, discoverer of six asteroids, superintendent of the Madras Observatory (1861-1891) and discoverer (in 1881) of a relationship between sunspot numbers and the price of Indian cereals!

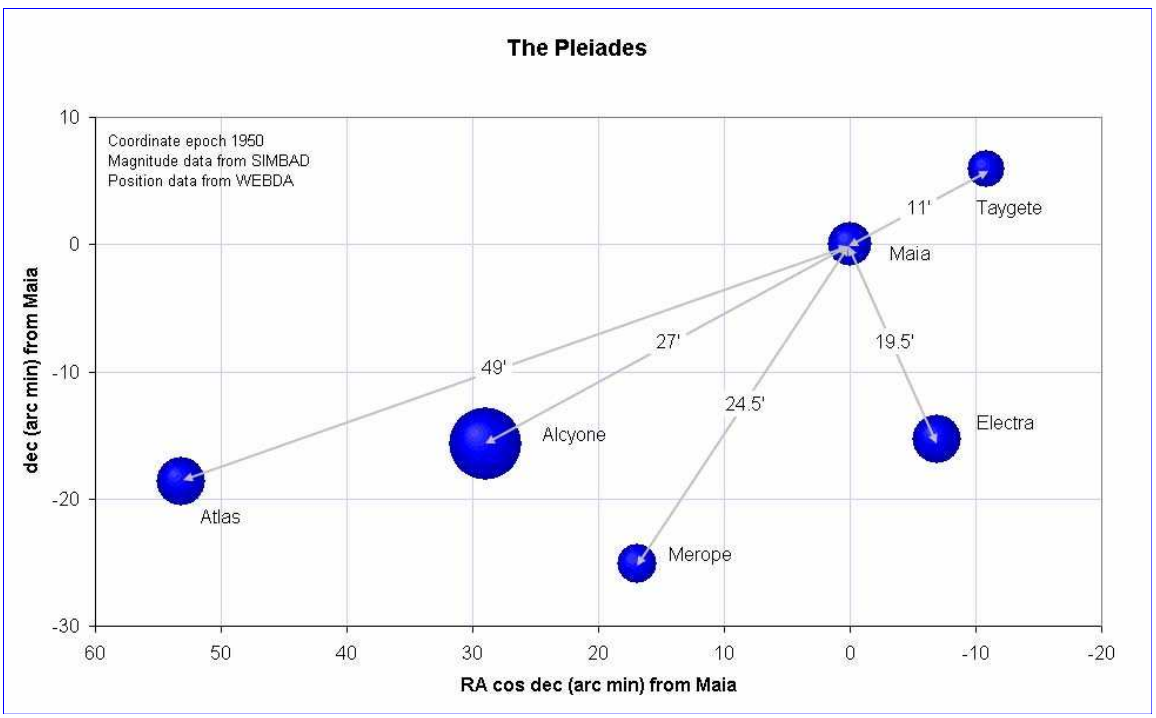

Figure 2: The positions of the six brightest stars of the Pleiades, showing the separations assumed by Michell. The sizes of the points represent the brightnesses of the stars, according to the apparent visual magnitudes taken from the astronomical online database SIMBAD (http://simbad,u-strasbg.fr/Simbad, maintained at the Centre de Données Astronomiques de Strasbourg); the positions are based on epoch 1950.0 coordinates taken from the open cluster database WEBDA (see Jean-Claude Mermilliod, http://obswww.unige.ch/webda/).

5 CONCLUSIONS

Apart from heralding the usefulness of statistics in the study of astronomy, Michell's work on the Pleiades and β Capricorni were important steps in the expansion of the realm of Newtonian gravitation, and in the search for stellar parallax (see, for example, Hoskin, 2003: 68; Hirshfeld, 2001: 186-188). Newton had claimed that his law of gravitational attraction applied throughout the *whole* universe, and to all the individual bodies within it. Evidence for this universality had at the time been only gleaned from the nearby Solar System. The predicted 1758/1759 return of Comet 1P/Halley (see Hughes, 1987), occurring as it did eight years before Michell wrote his statistical astronomy paper, had extended the known 'Newtonian' region well beyond the orbit of Saturn, to a distance of around 35 AU from the Sun. The possibility that the distant stars were influenced by gravity was still, however, a matter of supposition. Michell's insistence that the two components of β Capricorni were actually mutually interacting companions, strengthened the resolve of people investigating double stars. William Herschel started to hunt for them in earnest, presenting a catalogue of 269 doubles to the Royal Society in 1782, and an additional list of 434 three years later (see Herschel, 1782a; 1785). Similar searches were also carried out on the Continent by, for example, the German astronomer Father Christian Mayer. In 1784, Michell (page 56) noted:

> … it is not improbable, that a few years may inform us, that some of the great number of double, triple stars, &c. which have been observed by Mr HERSCHEL, are systems of bodies revolving about each other.

Nearly two decades later Herschel (1803 and 1804) had the proof that many of his double stars were actually binary companions "… intimately held together by the bond of mutual attraction." As the nineteenth century progressed the orbits of these stars about their common centres of mass were carefully plotted (see, for example, Herschel, 1833) and soon, to quote Agnes Clerke (1885: 24), "… the fundamental quality of attractive power was proved to be common to matter so far as the telescope was capable of exploring."

At the time of Michell's work double stars were also playing a part in the hunt for stellar parallax (see Herschel 1782b). Galileo Galilei (1632) had suggested that double stars would be useful in this endeavour. For this to be the case, however, the double had to be a chance alignment, with one of the stars close to the Sun, and the other extremely distant. As the Earth orbited the Sun the movement of the close star measured accurately with respect to the more constant position of the distant star should lead to an estimation of the parallactic distance of the nearer of the double. Michell's statistical analysis led him to conclude that the majority of observed double stars were actually binary stars. The fact that the two stars, in this case, were gravitationally attached companions, made their observation from any position useless when it came to measuring stellar distance with the imperfectly-mounted instruments of the day.

One may also ask if Michell understood the significance of his findings. To this the answer is an unqualified 'yes'. In the footnote on page 238 in his 1767 paper (when he was discussing the question of whether the colour of the light from a star is correlated with its brightness—itself a fascinating anticipation of Wien and Stefan), Michell argues:

> If however it should hereafter be found, that any of the stars have others revolving about them (for no satellites shining by a borrowed light could possibly be visible), we should then have the means of discovering the proportion between the light of the Sun, and the light of those stars, relatively to their respective quantities of matter; for in this case, the times of the revolutions, and the greatest apparent elongations of those stars, that revolved about the others as satellites, being known, the relation between the apparent diameters and the densities of the central stars would be given, whatever was their distance from us: and the actual quantity of matter which they contained would be known, whenever their distance was known, being greater or less in proportion to the cube of that distance.

In other words, Michell foresaw one of the vital attributes of binary stellar systems, this being the way their orbits can be used to determine stellar masses. This led to one of the early twentieth century's foundation stones of modern astrophysics, the relationship between stellar luminosity and stellar mass.

6 NOTES

1. I would like to thank Eric Hutton for informing me (private correspondence, 2006) that Michell's daughter, Mary, married Sir Thomas Turton in 1786, and that they had a daughter, Anna, in 1787. Around 1810 Anna married Henry Peterson, and one of their six children was the famous Yorkshire eccentric and concrete pioneer, Judge Andrew Thomas Turton Peterson, who used to publish under the nom-de-plume *Khoda Bux*.
2. Associate Professor Graeme L. White from James Cook University interestingly points out (private correspondence, 2006) that a more obvious choice for a suitable naked eye double star would have been the nearby Alpha Capricorni. This beautiful naked eye optical double consists of star α^1 of visual magnitude 4.24 and star α^2 of magnitude 3.57, separated by 378 sec. arc. Beta Capricorni, on the other hand is a true visual double but the two stars are more disparate in brightness, being of magnitude 3.4 and 6.2. The possibility of Michell having made a mistake is, however, discounted by the fact that the separation of the components of Beta Capricorni is 205 sec arc, i.e. 3.42′ (see Kaler, 2006a) as opposed to the 378 sec arc, 6.3′ separation of the Alpha Capricorni components (Kaler, 2006b).

   Perhaps Beta Capricorni was selected because of the greater contrast in the brightness of its two components. Michell might have been considering the possibility of using a binary like Beta Capricorni in order to investigate the prospect of using such a pair as a (nearby) target and (more distant) reference for a measurement of trigonometric parallax, as first suggested in 1632 by Galileo in the *Dialogue Concerning the Two World Systems* (see the Stillman Drake translation on pp. 383-384). If this was indeed the initial source of his interest in visual doubles, the choice of a strongly-contrasting pair is eminently sensible, since it suggests (if we assume that all stars are similar to the Sun) a substantial difference in distance.
3. There are rounding errors in his calculation: Michell quoted 2 × log 6,875.5 as being equal to 7.6746086,

whereas today even a simple electronic calculator would give 7.674608572.

7 ACKNOWLEDGEMENTS

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David Hughes is Professor of Astronomy at the University of Sheffield (U.K.) and enjoys researching the minor bodies of the Solar System with particular emphasis on cometary decay and orbital evolution, asteroidal evolution and the relationship between comets a meteoroid streams. He is also interested in the history of astronomy, and is the author of many research papers and the book *The Star of Bethlehem: An Astronomer's Confirmation* (1979). David is a Committee member of the IAU Working Group on Transits of Venus and the Royal Astronomical Society's Astronomical Heritage Committee.

Susan Cartwright is a Senior Lecturer in the Department of Physics and Astronomy at the University of Sheffield (U.K.). She obtained her B.Sc. in Astronomy and Natural Philosophy and her Ph.D. in High Energy Physics from the University of Glasgow. Her research interests are experimental neutrino physics and particle astrophysics. She has wide experience of teaching undergraduate astronomy and a lifelong interest in the minutiae of this subject.