The eastern & western elongations of Venus, 2007–17
I. The sunlit hemisphere

Richard McKim, Paul Abel & Bill Leatherbarrow
A report of the Mercury & Venus Section Director: R J McKim

Fourteen successive morning and evening elongations of Venus from 2007–17 are reviewed. The work of 153 observers covered the time period of ESA's Venus Express and Japan's Akatsuki missions and wavelengths from 335–1750nm. The instantaneous rotation period of the ultraviolet markings was studied as a function of latitude, and the results compared with previous wind profile data. We find that the equatorial markings showed the shortest periods (and fastest velocities) with respect to the surface. A small north–south hemispherical inequality in the latitudinal variation of period and velocity is suggested. Comparison of eastern and western elongation data indicates an acceleration of equatorial markings during the Venustian day from a morning average of -97m/s to -117m/s in the afternoon. Instantaneous measurements of 700–720nm red images yield an average rotation period of 4.72d considerably longer than the ultraviolet 4d period. Transient bright clouds, best observed in blue/violet light or using ultraviolet images, visually exhibited a higher frequency in the S, compared to the N hemisphere, in agreement with findings for 1991–98 & 1999–2006. However, this trend was strikingly reversed at the 2017 eastern elongation, suggesting some change in the planet's atmosphere. We also found that the degree of aerosol scattering—measured by the degree of angular cusp extension towards inferior conjunction—also varied with time, with a considerably reduced extension at inferior conjunction in 2015 & 2017. Part II will discuss phenomena of the nocturnal hemisphere: the infrared thermal emission from the planet's surface, and the Ashen Light.

Introduction

Viewed in certain wavebands, Venus offers much intriguing telescopic detail (Figure 1). After eight terrestrial years, the planet returns to almost exactly the same place in the sky, with the same geocentric phenomena recurring 2.5 days earlier in the next 'cycle'.

We have previously analysed and compared ten successive elongations for 1991–98,1 and ten more for 1999–2006. In order to bring our work up to date, we now analyse 14 elongations (seven eastern and seven western) from 2007E–2017W (2006 Oct 27 till 2018 Jan 9), falling within the directorship of the first author. Numerous observational notes and short reports have already appeared in the Journal, including the annual Council Reports.

In 2006 the Section was asked by the European Space Agency (ESA) to coordinate the initial ground-based support for the Venus Express (VEX) mission; there was an excellent response from observers. The then-Director forwarded batches of Section images to ESA. Later, contributors could upload images directly to the VEX website (as ever, only those contributed directly to the BAA are analysed here). This report covers the whole span of VEX, which proved to be remarkably enduring. The craft's fuel reserves were exhausted by late 2014, and the mission was terminated by the entry of the craft into the planet's scorching atmosphere. For a time, only ground-based observations monitored Venus, until the arrival of JAXA's Akatsuki (also known as Venus Climate Orbiter) in 2015 December.22

During the 2007 eastern elongation (2007E) it was established how the markings recorded in images varied systematically with wavelength across the visual waveband, a phenomenon long known to visual observers. The best drawings through blue or violet filters resemble ultraviolet images. A useful review of UV imaging was written by Sean Walker, while others have described previous improvements in techniques. At inferior conjunction (IC) in 2004 & 2012, Venus was in transit across the Sun. The BAA observations have been previously reviewed in detail, and are not discussed here.24

For Part I, Leatherbarrow analysed the extensive visual data for the 2007 E elongation and deduced the date of apparent dichotomy graphically. Abel plotted phase data for the nine following elongations to determine dichotomy dates, while McKim dealt with the rest. All laboriously searched the Section image database and ALPO Japan online archive to find matches suitable for obtaining rotation periods.

Figure 1. (A) Selected high resolution ultra-violet images. (B) Selected high resolution near-infrared images. Note: South is uppermost in this and other telescopic figures, unless otherwise stated.
Table 1. Observers of Venus, 2007–17

<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
<th>Instruments</th>
<th>Elongations*</th>
</tr>
</thead>
<tbody>
<tr>
<td>P. G. Abel</td>
<td>Leicester</td>
<td>203mm refl.</td>
<td>A–C, E–G, I,</td>
</tr>
<tr>
<td></td>
<td>Selsey, W. Sussex</td>
<td>381mm refl.</td>
<td>K–N</td>
</tr>
<tr>
<td></td>
<td>Hampstead Obsy., Ldn.</td>
<td>&amp; 152mm OG</td>
<td></td>
</tr>
<tr>
<td>G. &amp; J. Zabberfeld-Michelbach</td>
<td>Germany</td>
<td>180mm MKT</td>
<td>A–E</td>
</tr>
<tr>
<td></td>
<td></td>
<td>417mm DKC</td>
<td></td>
</tr>
<tr>
<td>M. Asadchi</td>
<td>Dying Obysy., Otsu, Japan</td>
<td>600mm refl.</td>
<td></td>
</tr>
<tr>
<td>G. Adamoli</td>
<td>Verona, Italy</td>
<td>108mm OG, All</td>
<td>125mm MKT &amp;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>235mm SCT</td>
<td></td>
</tr>
<tr>
<td>B. S. Adcock</td>
<td>Australia</td>
<td>152mm OG</td>
<td>I</td>
</tr>
<tr>
<td>J. Adembra</td>
<td>Arnhem, Netherlands</td>
<td>235mm SCT</td>
<td>A</td>
</tr>
<tr>
<td>L. Aerts</td>
<td>Heist-op-den Berg, Belgium</td>
<td>254mm SCT</td>
<td>ACK</td>
</tr>
<tr>
<td>T. Akutsu</td>
<td>Cebu Philipines</td>
<td>203mm</td>
<td>A–F, IM</td>
</tr>
<tr>
<td>J. Albert</td>
<td>Lake Worth, FL, USA</td>
<td>279mm SCT</td>
<td>G</td>
</tr>
<tr>
<td>W. Anthony</td>
<td>High Bridge NJ, USA</td>
<td>152mm refl.</td>
<td></td>
</tr>
<tr>
<td>M. Araiji</td>
<td>Evora, Portugal</td>
<td>279mm SCT</td>
<td>M</td>
</tr>
<tr>
<td>L. D. Arriendi</td>
<td>Edgewater, Middlesex</td>
<td>254mm DKC</td>
<td>A–E, GLM</td>
</tr>
<tr>
<td>T. Barry</td>
<td>Broken Hill, Australia</td>
<td>410mm refl.</td>
<td>LJ</td>
</tr>
<tr>
<td>D. Basey</td>
<td>Norwich</td>
<td>358mm refl.</td>
<td>N</td>
</tr>
<tr>
<td>R. M. Baum (with J. Baum)</td>
<td>Chester</td>
<td>152mm MKT</td>
<td>ABEG</td>
</tr>
<tr>
<td>G. Bertrand</td>
<td>ST. Laurent sur Sèvre, France</td>
<td>114mm refl.</td>
<td>AB</td>
</tr>
<tr>
<td>G. Boots</td>
<td>Washington, W. Sussex</td>
<td>235mm SCT</td>
<td>G</td>
</tr>
<tr>
<td>R. Bosman</td>
<td>Enschede, Holland</td>
<td>279mm SCT</td>
<td>A–C</td>
</tr>
<tr>
<td>J. Boulreau</td>
<td>Sagus, MA, USA</td>
<td>279mm SCT</td>
<td>G–I, KM</td>
</tr>
<tr>
<td>R. Braga</td>
<td>Milano, Italy</td>
<td>90mm OG</td>
<td></td>
</tr>
<tr>
<td>K. Brash</td>
<td>Flagstaff, AZ, USA</td>
<td>&amp; 210mm DKC</td>
<td></td>
</tr>
<tr>
<td>C. L. Brook</td>
<td>Plymouth</td>
<td>235mm SCT</td>
<td>GJ</td>
</tr>
<tr>
<td>J. N. Brown</td>
<td>Warmington, Northants</td>
<td>&amp; 600mm OG</td>
<td></td>
</tr>
<tr>
<td>M. Brown</td>
<td>York</td>
<td>254mm refl.</td>
<td>C</td>
</tr>
<tr>
<td>M. Cardin</td>
<td>Padua, Italy</td>
<td>254mm refl.</td>
<td>G</td>
</tr>
<tr>
<td>E. Chassiotis</td>
<td>Markopoulo, Greece</td>
<td>300mm refl.</td>
<td>H</td>
</tr>
<tr>
<td>B. Clark</td>
<td>Melbourne, Australia</td>
<td>279mm SCT</td>
<td>AB</td>
</tr>
<tr>
<td>A. Clithrow</td>
<td>Fife, Scotland</td>
<td>710mm refl.</td>
<td>F</td>
</tr>
<tr>
<td>M. Collins</td>
<td>Palmerston North, New Zealand</td>
<td>254mm refl.</td>
<td>K–M</td>
</tr>
<tr>
<td>E. Colombi</td>
<td>Milano, Italy</td>
<td>203mm SCT</td>
<td>CD</td>
</tr>
<tr>
<td>J. Cooper</td>
<td>Woonono, Northants</td>
<td>80mm OG</td>
<td>AC, E–G, K</td>
</tr>
<tr>
<td>H. J. Davies</td>
<td>Swansea</td>
<td>&amp; 152 mm refl.</td>
<td></td>
</tr>
<tr>
<td>M. Delcineix</td>
<td>Tournesuelle, France</td>
<td>203mm SCT</td>
<td>CM</td>
</tr>
<tr>
<td></td>
<td>Pic du Midi Obs., France</td>
<td>254mm SCT</td>
<td>ACGHIN</td>
</tr>
<tr>
<td>T. Dobbs</td>
<td>Fort Myers</td>
<td>1.06m Cاس</td>
<td></td>
</tr>
<tr>
<td>C. Dole</td>
<td>Newbury, Berks.</td>
<td>254mm MKT</td>
<td>G</td>
</tr>
<tr>
<td>A. P. Dowdell</td>
<td>Winchester</td>
<td>180mm MKT</td>
<td>K–M</td>
</tr>
<tr>
<td>D. Eagle</td>
<td>Higham Ferrars</td>
<td>710mm refl.</td>
<td></td>
</tr>
<tr>
<td>P. R. Edwards</td>
<td>Harlow, West Sussex</td>
<td>203mm refl.</td>
<td>HK</td>
</tr>
<tr>
<td></td>
<td>&amp; Northants</td>
<td>279mm</td>
<td></td>
</tr>
<tr>
<td>C. Farrinanzo</td>
<td>Montescassiano, Italy</td>
<td>190mm MKN</td>
<td></td>
</tr>
<tr>
<td>F. Ferrario</td>
<td>Caglioto, Italy</td>
<td>235mm</td>
<td>FGKL</td>
</tr>
<tr>
<td>A. Firmigian</td>
<td>Birmingham</td>
<td>&amp; 355mm SCT</td>
<td></td>
</tr>
<tr>
<td>D. Fisher</td>
<td>Sittingbourne, Kent</td>
<td>Digital camera</td>
<td>K</td>
</tr>
<tr>
<td>M. Frassali</td>
<td>Crescentino, Italy</td>
<td>80mm OG</td>
<td></td>
</tr>
<tr>
<td>A. Friedman</td>
<td>Buffalo, NY, USA</td>
<td>216mm refl.</td>
<td></td>
</tr>
<tr>
<td>M. H. Graiger</td>
<td>Tolworth, Surrey</td>
<td>200mm SCT</td>
<td></td>
</tr>
<tr>
<td>P. J. Garbett</td>
<td>Shambrook, Beds.</td>
<td>203mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&amp; 305mm SCT; 490mm refl.</td>
<td>ACEGIM</td>
</tr>
<tr>
<td>D. Gasparri</td>
<td>Perugia, Italy</td>
<td>255mm</td>
<td></td>
</tr>
<tr>
<td>M. V. Gavin</td>
<td>Worcester Park, Surrey</td>
<td>255mm</td>
<td>CD</td>
</tr>
<tr>
<td>S. Ghomidzadeh</td>
<td>Tehran, Iran</td>
<td>279mm</td>
<td>F–L, K</td>
</tr>
<tr>
<td>J. Gionis</td>
<td>Breckland AS, Norfolk</td>
<td>203mm</td>
<td>G</td>
</tr>
</tbody>
</table>

(Continued)

The text of the report. All the authors reviewed and revised it. Part II will discuss observations of the nocturnal hemisphere.

Observers and elongations

Table 1 (p. 75) lists 153 contributors, with key dates given in Table 2. Jean Meeus published the angular separation between the centres of Venus and the Sun at IC (Table 3). 26

We much regret the passing of Richard Baum, Peter Gregor, Walter Haas, Willem Kiwiet, Roy Panther and Don Parker. Baum joined the Section in 1950 (under its first Director, Henry McEwen) and was later to lead it with distinction. Haas first contributed to the Section in 1936 and had been its longest-standing member.

Credit must go to Gianluigi Adamoli and Detlev Niechoy for covering all 14 elongations, while the following observed ten or more: Abel Giuntoli, Heath, Masymowicz, McKim, Mellillo and Sussenbach. Observational activity was typical, with some western elongations less well covered. Denis Put was awarded the As-

---

Figure 2. Four-day UV maps with planetocentric latitudes and System II WinUPOS longitudes27 during 2007E by D. Gasparri (235mm SCT & STT-XME camera with Baader UV & Schott BGR8 filters) and P. R. Lazzarotti (315mm refl. with LUV2+1M camera & Baader UV filter); during 2011 W by D. Put (225mm SCT with DMR21AU camera & Astroboton UV filter). The System II ephemeris is slightly imperfect as explained in the text.
society’s 2013 Patrick Moore prize for his excellent Venus work as a young astronomer. This included the demanding task of map-making from ultraviolet imaging (Figure 2).

Eastern (evening) elongations show the sunset terminator, and western (morning) ones the sunrise terminator.

The observations 2007–17

The appearance of Venus in visual and ultraviolet wavebands is well known. Here we focus only upon two themes. Firstly, the instantaneous rotation rate of the various markings as a function of latitude, and secondly, the variation in their appearance across the visible waveband.

UV markings: charts and four-day sequences

UV images can be highly complex; examples feature in Figure 1(A). Some observers made their own atmospheric charts from their images (Figure 2) and one could construct many more from our records, particularly 2007E.

Of the visual observers, during 2007E, 2012E & 2017E McKim made long series of drawings every clear evening for months. See Figure 3 for his 2007E results, which faintly depict the UV markings. Figure 4 shows paired UV and IR images of the gibbous disk during an unusually complete run of clear evenings for 2017E, by Wesley. A collage of the work of Put for 2011W has already been published, and one of his maps is included in Figure 2. We also published series by Lindberg for 2013E and Miles for 2017E. The collages and charts show the usual variations from one rotation to the next, though the characteristic Y and ψ equatorial “wave” markings are quasi-permanent. Specific phenomena are illustrated later.

Many observers quoted WinJUPOS longitudes (for example, in Figure 2). System I has a period of 243.0184d, accurately giving the surface longitude. Unfortunately, System II is based upon an

Table 2. Venus elongation data, 2007–17

<table>
<thead>
<tr>
<th>SC*</th>
<th>GEE*</th>
<th>IC*</th>
<th>GEW*</th>
<th>SC*</th>
</tr>
</thead>
</table>

*SC= Superior conjunction; GEE= Greatest elongation east; IC= Inferior conjunction; GEW= Greatest elongation west.

Table 3. Venus inferior conjunctions, 2007–17

<table>
<thead>
<tr>
<th>Inferior conjunction</th>
<th>Angular separation from the Sun (deg. arcmin)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007 Aug 18</td>
<td>−7° 59′</td>
</tr>
<tr>
<td>2009 Mar 27</td>
<td>+8° 10′</td>
</tr>
<tr>
<td>2010 Oct 29</td>
<td>−5° 59′</td>
</tr>
<tr>
<td>2012 Jun 6</td>
<td>+0° 09′ (transit)</td>
</tr>
<tr>
<td>2014 Jan 11</td>
<td>+5° 11′</td>
</tr>
<tr>
<td>2015 Aug 15</td>
<td>−7° 51′</td>
</tr>
<tr>
<td>2017 Mar 25</td>
<td>+8° 18′</td>
</tr>
</tbody>
</table>
Table 1. Observers of Venus, 2007–17 (Cont’d)

<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
<th>Instruments</th>
<th>Elongations*</th>
</tr>
</thead>
<tbody>
<tr>
<td>M. Giurongi</td>
<td>Montecatini Terme, Italy</td>
<td>80mm OG, 127mm MKT</td>
<td>A-B, E-N</td>
</tr>
<tr>
<td>D. C. Graham</td>
<td>Richmond, N. Yorks</td>
<td>152mm OG, 230mm MKT</td>
<td>ABGMN</td>
</tr>
<tr>
<td>D. Gray</td>
<td>Kirk Merrington, Co. Durham</td>
<td>415mm DKE</td>
<td>A-C, FJHKM</td>
</tr>
<tr>
<td>P. E. Grego</td>
<td>St. Dennis, Cornwall</td>
<td>203mm SCT, 306mm refl.</td>
<td>EG</td>
</tr>
<tr>
<td>M. Griffiths†</td>
<td>Bridgend, Mid Glam.</td>
<td>125mm OG</td>
<td>C</td>
</tr>
<tr>
<td>W. H. Haas*</td>
<td>Las Cruces, NM USA</td>
<td>206mm refl</td>
<td>A-C</td>
</tr>
<tr>
<td>B. Halls*</td>
<td>Lancing, West Sussex</td>
<td>125mm OG</td>
<td>G-I</td>
</tr>
<tr>
<td>L Hancock*</td>
<td>Camberley, Kent</td>
<td>222mm refl</td>
<td>A-C</td>
</tr>
<tr>
<td>A. W. Heath</td>
<td>Long Eaton, Notts</td>
<td>60mm OG, 203mm MKT, 254mm refl</td>
<td>A-E, G-I, KM</td>
</tr>
<tr>
<td>M. Hezlerwood</td>
<td>Burely, Lancs</td>
<td>100mm OG</td>
<td>M</td>
</tr>
<tr>
<td>R. Hill†</td>
<td>Tucson, AZ USA</td>
<td>200MKT</td>
<td>EGIKM</td>
</tr>
<tr>
<td>D. A. Holt</td>
<td>Buntingford, Herts.</td>
<td>&amp; 35mm SCT</td>
<td>BC</td>
</tr>
<tr>
<td>C. J. Hooker</td>
<td>Didcot, Oxon.</td>
<td>203mm MKT</td>
<td>AB</td>
</tr>
<tr>
<td>R. Humphrey</td>
<td>Bristol</td>
<td>90mm MKT</td>
<td>AB</td>
</tr>
<tr>
<td>T. Hmeina*</td>
<td>Nagoia, Japan</td>
<td>310mm &amp; 380mm refl.</td>
<td>ACE, G-I</td>
</tr>
<tr>
<td>W. Janson†</td>
<td>West Chester, PA, USA</td>
<td>256mm SCT</td>
<td>EGK</td>
</tr>
<tr>
<td>S. Johnson</td>
<td>Plymouth, Devon, Plymouth</td>
<td>66mm OG</td>
<td>A-C</td>
</tr>
<tr>
<td>R. W. Johnson*</td>
<td>Ewell, Surrey</td>
<td>279mm SCT, 254mm refl</td>
<td>A-G</td>
</tr>
<tr>
<td>G. F. Johnstone*</td>
<td>Birdingoir, Warwicks</td>
<td>90mm MKT, 203mm MKT</td>
<td>A-C, GHKM</td>
</tr>
<tr>
<td>M. Kardasis*</td>
<td>Athens, Greece</td>
<td>29mm MKT, 35mm SCT</td>
<td>G-I, KM</td>
</tr>
<tr>
<td>A. S. Kidd*</td>
<td>Cottered, Herts</td>
<td>35mm SCT</td>
<td>KN</td>
</tr>
<tr>
<td>M. Kainer*</td>
<td>Broadstairs, Kent</td>
<td>102mm OG</td>
<td>A</td>
</tr>
<tr>
<td>B. A. Kingsley*</td>
<td>Maidenhed, Berks</td>
<td>100OG</td>
<td>A-C</td>
</tr>
<tr>
<td>W. Kivits*</td>
<td>Siebergewald, Holland</td>
<td>35mm SCT</td>
<td>A-I</td>
</tr>
<tr>
<td>S. Kowolik*</td>
<td>Ludwigsburg, Germany</td>
<td>203mm refl</td>
<td>AC</td>
</tr>
<tr>
<td>G. Lampert</td>
<td>Dornbirn, Austria</td>
<td>110mm</td>
<td>G</td>
</tr>
<tr>
<td>P. R. Lawrence*</td>
<td>Selsey, W. Sussex</td>
<td>35mm SCT &amp; 102mm OG</td>
<td>BGKL</td>
</tr>
<tr>
<td>P. R. Lazzoroti*</td>
<td>Massa, Italy (with P. Grecchieti)</td>
<td>315mm refl</td>
<td>ABD</td>
</tr>
<tr>
<td>W. J. Leatherbar*</td>
<td>Sheffield</td>
<td>80mm</td>
<td>A-D, G-K-N</td>
</tr>
<tr>
<td>M. R. Lewis*</td>
<td>St. Albans</td>
<td>127mm OGs, 235mm SCT &amp; 305mm MKT</td>
<td>GKM</td>
</tr>
<tr>
<td>H-G. Lindberg*</td>
<td>Skalina, Sweden</td>
<td>222mm &amp; 444mm refl.</td>
<td>A-G-K</td>
</tr>
<tr>
<td>E. Lomeg*</td>
<td>Sacremento, CA, USA</td>
<td>254mm SNT, 180mm SNT</td>
<td>A-G-K</td>
</tr>
<tr>
<td>N. Longshaw</td>
<td>Oldham, Lancs</td>
<td>235mm SCT &amp; 78mm OG</td>
<td>AB</td>
</tr>
<tr>
<td>P. Lyon</td>
<td>Birmingham</td>
<td>90mm &amp; 125mm MKT</td>
<td>A</td>
</tr>
<tr>
<td>L. T. Macdonald*</td>
<td>Newbury, Berks</td>
<td>222mm refl</td>
<td>A</td>
</tr>
<tr>
<td>D. McCracken*</td>
<td>Skellingthorp, Lincs.</td>
<td>Digital camera</td>
<td>K</td>
</tr>
<tr>
<td>D. M. McKim</td>
<td>Oundle and Uper</td>
<td>76 &amp; 102mm OGs, A-C, E-G, G</td>
<td>K-K, M</td>
</tr>
<tr>
<td>M. Makoszynowicz</td>
<td>Ecuquyville, France</td>
<td>70mm OG</td>
<td>C-N</td>
</tr>
<tr>
<td>M. Maksymowicz</td>
<td></td>
<td>100mm OG, 254mm refl.</td>
<td>C-N</td>
</tr>
</tbody>
</table>

(Continued)

arbitrary period of 4.2 days rather than the well-established long-term UV synodic period of almost exactly 4 days. This leads to a large error of 17° with respect to the 4-day ephemeris, even after a single atmospheric rotation.27

Instantaneous UV atmospheric rotational rates

In a previous paper,10 it was shown that the equatorial features (specifically, the fork of the long-enduring ‘Y’ marking) still maintained a constant average period over many months and years, determined by us to be 3.99515 (±0.0004) days – in perfect accord with the classic work of Boyer (1975): 3.99525 (±0.00001) days.28

Here we derive instantaneous rates during a single rotation. This avoids the uncertainty in identity after one or more rotations, but has its price in high percentage errors. The difficulty is in finding similar processing techniques, adequate resolution and a sufficient time interval for image pairs. The near-full Venus offers a wide range in longitude but a tiny disk, whereas dichotomy offers a large disk but nearly inadequate longitude span. Measurement of two images 10h apart to a precision of ±1° each would correspond to a percentage error in period of ±4%. We will assume this precision in the following velocity determinations, though the overall error is likely to be higher due to the diffuse nature of most markings. In reality most matches were 3–5i apart, with 5i regarded as the minimum acceptable.

The derived periods at different latitudes were converted to retrograde velocities with respect to the surface. For this, the equatorial radius (r) of Venus is 6052km, and the circumference at any latitude θ is 2πr cos θ. Accurate was taken of the period of the sub-Earth point, D (which, according to WinJUPUS, varied from 3.1 to +1.4 for the data in question). Latitudes are given to the nearest degree.

Kardasis, Kidd, Pellier, Sussenbach and Wesley also made impressive GIF files from some of their own UV or IR work, but the timescales were too short for useful measurement.

2007 E. Elongation

There were many contributors, leading to several matches (Figure 6), though higher resolution was more generally achieved in later elongations. We quote the lower limit for the probable error in velocity; the probable fractional error in period is the same.

Figure 5. The variation in markings is shown at different wavelengths within the IR region, 2010 Apr 1, G. & J. Ackermann
2009 W. Elongation

Paired images for Jul 23, together with 11 others, were found by Kivits from online searches and made into animated GIF files by him. However, only one pair (Figure 6) was suitable for measurement.

2010 E. Elongation

Gasparri succeeded in taking several excellent image pairs more than 3h apart (Figure 6). We measured the best.

2012 E. Elongation

Only one match was secured, but with a long interval of 5.6h (Figure 6).

2012 W. Elongation

Again, one match, but with a long interval of 6.7h (Figure 6).

Discussion

Our data are plotted by latitude in Figure 7. Up to the latitudes explored, the period did not vary a great deal (from 88±115h), but a tendency for it to lengthen above +10°, and a slight asymmetry between the hemispheres is suggested. The paucity of N. hemisphere features for tracking is notable.

The equatorial 4-day retrograde rotation period corresponds to ~112m/s at the equator.29 The near-equatorial markings exhibit av-
Table 1. Observers of Venus, 2007–17 (Cont’d)

See continuation on p. 80 for explanatory notes

<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
<th>Instruments</th>
<th>Elongations</th>
</tr>
</thead>
<tbody>
<tr>
<td>S. S. Massey*</td>
<td>Hervey Bay, Queensland, Australia</td>
<td>254mm DI</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&amp; 305mm refl.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M. Mage*</td>
<td>Littleton, MA, USA</td>
<td>355mm SCT</td>
<td>H</td>
</tr>
<tr>
<td>P. W. Maxson*</td>
<td>Surprise, AZ, USA</td>
<td>254mm</td>
<td>A–E, KLM</td>
</tr>
<tr>
<td></td>
<td>&amp; 355mm SCT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F. J. Mullik*</td>
<td>Hollsview, New York, USA</td>
<td>203mm</td>
<td>A–E, G–N</td>
</tr>
<tr>
<td>C. Meredith*</td>
<td>Prestwick, Manchester</td>
<td>203mm SCT</td>
<td>AE</td>
</tr>
<tr>
<td></td>
<td>&amp; 216mm refl.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P. Miles*</td>
<td>Rubyvale, Queensland, Australia</td>
<td>508mm refl.</td>
<td>MN</td>
</tr>
<tr>
<td>M. P. Mobberley*</td>
<td>Bury St. Edmonds, Suffolk</td>
<td>245mm refl.</td>
<td>A</td>
</tr>
<tr>
<td>D. M. Moore*</td>
<td>Phoenix, Arizona, USA</td>
<td>362mm Cass.</td>
<td></td>
</tr>
<tr>
<td>E. Morales-Rivera*</td>
<td>Miami, Italy</td>
<td>279mm SCT</td>
<td></td>
</tr>
<tr>
<td>M. Nicholls*</td>
<td>Agegola, Italy</td>
<td>279mm SCT</td>
<td>M</td>
</tr>
<tr>
<td>D. N. Neuho*</td>
<td>Göttingen, Germany</td>
<td>203mm SCT</td>
<td>All</td>
</tr>
<tr>
<td>F. Giviero*</td>
<td>Bangkok, Thailand</td>
<td>410mm DFC</td>
<td>ABEKLM</td>
</tr>
<tr>
<td>R. Palgrave*</td>
<td>Newcastle upon Tyne</td>
<td>355mm SCT</td>
<td></td>
</tr>
<tr>
<td>R. W. Panther*</td>
<td>Walgrave, Northants.</td>
<td>80mm CD, F–H, J</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&amp; 90 mm OGS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D. C. Parker*</td>
<td>Miami, FL</td>
<td>254mm DFC</td>
<td>ACDDG</td>
</tr>
<tr>
<td>P. W. Parish*</td>
<td>Raisham, Kent</td>
<td>10–50 binox. H</td>
<td></td>
</tr>
<tr>
<td>A. J. Paterson*</td>
<td>Fareham, Hants.</td>
<td>203mm SCT</td>
<td>A</td>
</tr>
<tr>
<td>D. A. Peach*</td>
<td>Selsey, W. Sussex</td>
<td>235mm</td>
<td>ACEGHKN</td>
</tr>
<tr>
<td></td>
<td>&amp; 355mm SCT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. Pellier*</td>
<td>Brux &amp; Paris, France</td>
<td>254mm Cass.</td>
<td>AG, G–I, KM</td>
</tr>
<tr>
<td></td>
<td>&amp; 250mm Gregorlan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I. S. Phelps*</td>
<td>Astroquays Obs., France</td>
<td>620mm Cass.</td>
<td></td>
</tr>
<tr>
<td>N. Phillips*</td>
<td>Warrington, Cheshire</td>
<td>216mm refl.</td>
<td></td>
</tr>
<tr>
<td>M. Porter*</td>
<td>Crayford, Kent</td>
<td>178mm MKT</td>
<td>A</td>
</tr>
<tr>
<td>J.-J. Poupart*</td>
<td>Pets Wood, Kent</td>
<td>178mm MKN</td>
<td></td>
</tr>
<tr>
<td>A. J. Treby*</td>
<td>Pequeque, France</td>
<td>255mm Cass.</td>
<td>C–H, LM</td>
</tr>
<tr>
<td>J. P. Post*</td>
<td>Aigad, Liege</td>
<td>235mm</td>
<td>G</td>
</tr>
<tr>
<td>D. Put*</td>
<td>Vailonne, France</td>
<td>212mm Cass.</td>
<td></td>
</tr>
<tr>
<td>M. Radice*</td>
<td>Briele, Netherlands</td>
<td>203mm refl.</td>
<td>AEF</td>
</tr>
<tr>
<td>A. Robertson*</td>
<td>Salisbury, Wilts.</td>
<td>279mm</td>
<td>M</td>
</tr>
<tr>
<td>A. H. Robinson*</td>
<td>Boving, Norfolk</td>
<td>203mm refl.</td>
<td>F</td>
</tr>
<tr>
<td>M. Salway*</td>
<td>Dawlish, Devon</td>
<td>279mm</td>
<td>C</td>
</tr>
<tr>
<td>D. Scanlan*</td>
<td>Central Coast, NSW, Australia</td>
<td>305 mm refl.</td>
<td>A–D</td>
</tr>
<tr>
<td>G. J. Scheffer*</td>
<td>Romney, Hants</td>
<td>203mm SCT</td>
<td>K</td>
</tr>
<tr>
<td>R. W. Schmuda*</td>
<td>Malden, Netherlands</td>
<td>200mm MKT</td>
<td></td>
</tr>
<tr>
<td>R. Schulz*</td>
<td>Barnesville GA, USA</td>
<td>130mm OAG</td>
<td></td>
</tr>
<tr>
<td>R. Sedrani*</td>
<td>Vienna, Austria</td>
<td>320mm refl.</td>
<td>AM</td>
</tr>
<tr>
<td>I. D. Sharp*</td>
<td>Namibia, Africa</td>
<td>&amp; 305mm RCT</td>
<td></td>
</tr>
<tr>
<td>W. B. Sheehan*</td>
<td>Pordenone, Italy</td>
<td>355mm SCT</td>
<td>M</td>
</tr>
<tr>
<td>M. Smiekar*</td>
<td>Ham, Saxon</td>
<td>297mm SCT</td>
<td>C</td>
</tr>
<tr>
<td>(w. J. Astrovsky &amp; R. Paz*</td>
<td>Flagstaff, AZ, USA</td>
<td>600mm OAG</td>
<td></td>
</tr>
<tr>
<td>A. Snoek</td>
<td>Swan Astron. Soc., Slovenia</td>
<td>254mm refl.</td>
<td>G</td>
</tr>
<tr>
<td>J. Susenbach*</td>
<td>Dover</td>
<td>500mm refl.</td>
<td>M</td>
</tr>
<tr>
<td>A. Tasselli*</td>
<td>Houten, Holland</td>
<td>235mm</td>
<td>A–I, KMN</td>
</tr>
<tr>
<td></td>
<td>&amp; 279mm SCT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. Taylor*</td>
<td>Lincoln</td>
<td>254mm refl.</td>
<td>ABG</td>
</tr>
<tr>
<td>M. M. Taylor*</td>
<td>Harvard</td>
<td>102mm OAG</td>
<td></td>
</tr>
<tr>
<td>A. Tous*</td>
<td>Leicester</td>
<td>203mm SCT</td>
<td>A</td>
</tr>
<tr>
<td>D. B. V. Tyler*</td>
<td>Eglinton, Moray, Scotland</td>
<td>235mm SCT</td>
<td>G</td>
</tr>
<tr>
<td>Uniono Astrofili*</td>
<td>Blackwell Heath, Bucks</td>
<td>355mm SCT</td>
<td>AG</td>
</tr>
<tr>
<td>Italiani (UAI)</td>
<td>Various</td>
<td>Various</td>
<td>GH</td>
</tr>
<tr>
<td>R. Vandenbergh*</td>
<td>Wittem, Netherlands</td>
<td>254mm refl.</td>
<td>AB</td>
</tr>
<tr>
<td>A. van Kransenberg*</td>
<td>Vaardeningen</td>
<td>235mm SCT</td>
<td>A–C</td>
</tr>
<tr>
<td></td>
<td>&amp; 313mm Cass.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Continued)

eraged periods close to 4d, while those further from the equator obviously have lower velocities (due to the smaller circumference at higher latitude). Averaging velocities in small latitude bands shows the general trend, as well as suggesting that latitudes −11 to −30° (mean −108m/s) show a faster current than their N equivalent (mean, −89m/s).

Boyter (1975) observed a wider range than us in instantaneous velocities. The regular Y and ψ equatorial features seemed to accelerate during the morning, reaching a maximum velocity after sub-solar meridian passage. Our data (latitudes 0 to ±10°) for the W. elongations (Venusian morning) averaged −97m/s, whereas those for the E. elongations (Venusian afternoon) averaged −117m/s, strongly supporting this daily acceleration.

Spacecraft data show a lengthening in period with increasing northern or southern latitude. Surprisingly, there were considerable differences in the time interval between Mariner 10 and Pioneer Venus; in particular, a high latitude fast current was seen by Mariner 10 (see Figure 7). However, both results showed a hemispherical inequality, with the longest periods found in the north. Limaye has reviewed later data up to 2007. Sanchez-Lavega et al. (2016) report recent ground-based results including those from the Galileo and VEX instruments. Up to the Akatsuki mission, Figure 7 may be compared with these. Sanchez-Lavega et al. obtained similar results to us in showing (again, despite large scatter) a reduction in wind velocity away from the equator. VEX data (acquired from its VMC and VIRIS instruments) were in general accord. In our own study, we unfortunately could not follow any features of very high latitude.

Sanchez-Lavega et al. commented that the morning clouds seen during 2015 showed considerably less turbulence than the afternoon markings during 2015E. Indeed, this is generally the case in comparing E. and W. elongations.

Infrared and near-infrared observations of the sunlit disk

Most infrared observations were in the 1-micron (μm) window. In the IR, the cusps are generally dull and never brighter than the disc centre; specific bright features are rare. A fine, reticular pattern sometimes appears at very high resolution, not conducive to measuring the rotation rate. Nonetheless, for 2004W we deduced a tentative period of just under five days for equatorial bright patches. Faint, near-horizontal banding characters many IR and near-IR images; quite different from the chevron-shaped dark areas imaged in the UV. Some of the higher resolution red images are shown in Figure 1(B).
Figure 4 presents Wesley’s comprehensive results for 2017E, with paired UV (350nm) and IR (1000nm) images. These serve to illustrate the difference in character of the patterns between UV and IR, and highlight the difficulty involved with ground-based measurements of IR rotation rates. Several of the IR images show a certain resemblance after five days (never after four), but no unambiguous matches were possible.

It was possible to make short-term investigations of the period from several excellent pairs of near-infrared (700–720nm) images, taken 3–4h apart by Gasparri during 2010 May 23–26: some images feature in Figure 1(B). Here, we quote average results.

The overall average period was 113.2h (4.72d). Given the scatter and small number of measurements it is unwise to draw conclusions, other than that the average period was considerably longer than the 4-day UV one. Some markings showed considerable variation in 3–4 hours.

At 2009W & 2010E, G. & J. Ackermann took a series of long-wavelength IR images up to 1750nm, with a number of specialist filters. The IR markings showed considerable variation with wavelength: Figure 5 shows their best results.

**Variation in atmospheric markings across the visual waveband**

Improved imaging work at 2007E, particularly by Pellier and Peach, demonstrated the reality of the variation in appearance of markings across the visible waveband, as previously reported by visual observers. BAA colour filter visual work dates back to 1956 – Hedley Robinson and Alan Heath, two early visual filter pioneers, recount the story elsewhere.31-33

A comprehensive filter sequence imaged by Damian Peach features in Figure 8. We illustrate various visual series in Figure 9. In all these, the pattern of bright and dark markings changes from red through to blue. The diminution of the phase, accentuation of terminator shading and increase in limb brightening with decreasing wavelength shown here were established through photography by our members in the 1960s.

**Apparent dichotomy in the visible waveband**

Visual apparent dichotomy data deduced from plotting the observed phase are given in Table 4. Predicted dates are from Meeus

![Image](image-url)

**Figure 7. Atmospheric wind profile (Top: latitude vs. wind velocity relative to the surface; bottom: latitude vs. rotation period), determined from BAA observations. Means in 10° of latitude have been added. Lower right: rotation period data, at a different scale, from Mariner 10 and Pioneer Venus.**

<table>
<thead>
<tr>
<th>Latitude range (°)</th>
<th>No. of features</th>
<th>Mean period (h)</th>
<th>Mean velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-41 to -50</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>-31 to -40</td>
<td>1</td>
<td>110</td>
<td>-80</td>
</tr>
<tr>
<td>-21 to -30</td>
<td>1</td>
<td>99</td>
<td>-100</td>
</tr>
<tr>
<td>-11 to -20</td>
<td>5</td>
<td>116</td>
<td>-89</td>
</tr>
<tr>
<td>0 to +10</td>
<td>2</td>
<td>122</td>
<td>-87</td>
</tr>
<tr>
<td>0 to +10</td>
<td>2</td>
<td>121</td>
<td>-87</td>
</tr>
<tr>
<td>+11 to +20</td>
<td>1</td>
<td>109</td>
<td>-93</td>
</tr>
<tr>
<td>+21 to +30</td>
<td>2</td>
<td>102</td>
<td>-96</td>
</tr>
</tbody>
</table>

*The 2007E data were voluminous with an uncertainty of not more than ±0.5d. The other data have an uncertainty of ±0.5–1.0d.*
Table 1. Observers of Venus, 2007–17 (Cont’d)

<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
<th>Instruments</th>
<th>Elongations</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. van Ruisen</td>
<td>Netherlands</td>
<td>305mm refl.</td>
<td>A</td>
</tr>
<tr>
<td>J. Veverie*</td>
<td>Romsey, Orkney</td>
<td>175mm MCT &amp; 100mm OG</td>
<td>A–C, FG</td>
</tr>
<tr>
<td>A. Vincent*</td>
<td>Worthing, Sussex</td>
<td>Digital camera E</td>
<td></td>
</tr>
<tr>
<td>S. Walker*</td>
<td>Chester, NH, USA</td>
<td>254mm</td>
<td>ABDG</td>
</tr>
<tr>
<td>A. Wesley*</td>
<td>Murramateman &amp; Rubyvale, Australia</td>
<td>400mm refl.</td>
<td>IKMN</td>
</tr>
<tr>
<td>P. Welters*</td>
<td>Deventer, Netherlands</td>
<td>210mm DKC</td>
<td>C</td>
</tr>
<tr>
<td>W. J. Wilson</td>
<td>Chester</td>
<td>200mm SCT</td>
<td>ACD</td>
</tr>
<tr>
<td>P. B. Withers*</td>
<td>Romney, Hunts</td>
<td>355mm SCT</td>
<td>G</td>
</tr>
<tr>
<td>K. Yutoki*</td>
<td>Sakai City, Japan</td>
<td>260mm SCT</td>
<td></td>
</tr>
</tbody>
</table>


* denotes images contributed. The other observers submitted visual data: Adamoli, Adcock, Braga Colombo, Hancock, Johnstone, Leatherbarrow and Meredith made both images and drawings.

Summary reports of the UAI observers and observations from Cardin, Morini, Moronne & Sodini were sent by R. Braga, UAI Venus Coordinator; Observations by Lampert were sent by Niechoy, those of Finnigan by Robertson and those of Schefter, van Ruisen and Welters by Adelaar. An observation by Ferrario was forwarded by Giuntoli. Niechoy’s records for elongations L-N were received after submission of this paper and it has only been possible to include his notes on cusp extensions in (Part I) and the Ashen Light (in Part II).

Abbreviations:

Case= Cassegrain; DK= Dall-Kirkham; DKE= Dall-Kirkham Cassegrain, MCT= Makoslov-Cassegrain (Telescope); MK= Makoslov-Newtonian; RCT= Richey-Chretien; SCT= Schmidt-Cassegrain and SNT= Schmidt-Newtonian.

(2000).26 The phase anomaly showed no particular trend as usual, though there were significant differences between similar elongations: 2007E & 2015E were both well observed, and the anomaly was greater for the latter. The following estimations refer to white light or yellow filter (W15) data. The discrepancy in phase was greater at shorter wavelengths.

Braga’s analyses of the (largely independent) Unione Astrofilì Italiani (UAI) data for 2012E & 2012W,37 and of his personal work for 2015W, concluded:

<table>
<thead>
<tr>
<th>Year</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012E</td>
<td>46d early</td>
</tr>
<tr>
<td>2012W</td>
<td>47d late</td>
</tr>
<tr>
<td>2015W</td>
<td>9d late</td>
</tr>
</tbody>
</table>

The terminator

We exclude apparent deformities due to dark markings crossing the terminator. However, the uneven rounding of the cusps near dichotomy was sometimes well observed. The following are mostly visual impressions, since images show this effect much less clearly than the true terminator being lost in processing. See also Figure 10.

2007W

Leatherbarrow was able to make a direct estimate of apparent dichotomy on Oct 30–31.

2009E

On Jan 6 with the terminator convex, Leatherbarrow (16:12 UT) saw the SC rounded and the NC pointed. The same day, McKim saw bright cusps in twilight and, as the sky darkened, the tip of the S. cusp appeared to contain a brilliant point made to seem extended by irradiation; a typical illusion. On Jan 6, Baum also saw an apparently projecting S. cusp while Leatherbarrow saw the SC rounded and the NC pointed. Heath was able to make a direct estimate of apparent dichotomy on Jan 13–14.

2009W

With the terminator slightly convex on Jun 12, Adamoli saw the brighter SC pointed in full daylight with a W15 filter; in W25, no such impression was found. Panther observed at dawn and saw both horns pointed.

2010E

On Aug 1, Giuntoli saw the SC pointed and apparently projecting beyond the still convex terminator – probably an illusion, as Adamoli recorded a small bright S. cusp-cap (SCC) the next day. Heath saw the terminator dead straight on Aug 12.

2011W

On Jan 9, the terminator was nearly straight to McKim and in an image by Edwards. Giuntoli saw the planet exactly dichotomised on Jan 12.

2012E

McKiam found the N. horn more pointed than the S. on Mar 18–24. Leatherbarrow saw the S. horn blunted and the N. projecting on Mar 20, 22 & 25 (possibly due to superior brightness); Adamoli also saw the N. horn sharper than the S. on Mar 24. Heath saw the terminator straight on Mar 24–25. In good seeing on May 12, Heath reported irregularities along the terminator.

Figure 8. Filter images with 235mm SCT and Lunemena Sky fox camera, 2007 Apr 2. Note the gradual variation in the markings across the visible spectrum. In particular, note how the high latitude northern dark belt is best seen at short wavelength and the one at high S. latitude at long wavelength. The UV markings are best contrasted with the Schuler UV filter, but are nearly as well seen with W47 blue-violet in conjunction with an IR-blocking filter. The dark UV markings are weakly visible in blue light, although the bright areas upon mid-disk are invisible. D. A. Peach

2007E

Jun 2: McKim saw the terminator convex, but with the N. horn slightly pointed – similarly to Baum and Johnstone, during May 29–Jun 2. Jun 4: McKim recorded 50% phase, but the terminator was convex in the south and concave in the north, with the N. horn pointed (Figure 3). Jun 6: Baum saw the terminator concave, the SC blunted and NC pointed. Jun 7: Adamoli showed an S-shaped terminator. Jun 8–9: Baum and McKim recorded the terminator concave with both horns pointed.
2012W

Adamoli found the terminator straight on Aug 18, as did Heath; Aug 21–22, Cardin’s Aug 22 image shows a slightly convex terminator, but the presence of polar collars caused apparent indentations near the cusps, making them appear to project.

2013E

Niezchow found an irregularity upon the N terminator on Sep 5 & 6. Adcock found it straight on Oct 24, as did Adamoli on Oct 26 and Giuntoli on Oct 25–26.

2014W

Giuntoli saw the phase exactly 50% on Mar 29.

2015E

McKim found the SC slightly rounded until May 26, but by then the NC was no longer rounded. A few days before dichotomy he saw the NC to project slightly as the sky darkened, due to the irradiation of the small NCC.

2015W

Coverage of this elongation was thin.

2017E

On Jan 2–5, McKim found the SC more rounded than the N; on Jan 11 he saw the SC blunted and the NC pointed. Graham saw the cusps projecting on Jan 2, the SC more rounded than the N on Jan 8, and a projection of the SC on Jan 14.

2017W

Although dichotomy had already occurred, on Jun 17 (and less strongly on Jun 18) Graham showed the SC apparently projecting and the NC rounded. Likewise, Basey on Jun 13–14 drew a convex terminator but with projecting cusps. However, neither Abel on Jun 14 & 18 nor Maćsymowicz on Jun 13 & 17 saw any unusual appearance.

Cusp-caps and collars

We consider here the north and south cuspidal areas, or ‘cusp-caps’ (NCC and SCC), usually bounded by darker polar collars visually and in UV images. Cusp-caps are rarely prominent upon the ‘full’ Venus, and are best seen from gibbous to thick crescent phase. Here, we particularly note the NCC, SCC or collars if unusually large or prominent. Aspects of the terminator and cusps are illustrated in Figure 10.

2007E

During Mar–Jun (Figure 3), visual work showed little difference in the NCC and SCC. To Baum, the NCC was often extended southwards along the limb. From Apr 11 onwards: On Apr 22, to McKim the SCC was extended north along the terminator (see Figure 3). The cusp collars were particularly dark (intensity 4) to Adamoli on 2006 Dec 15 & 21 (N), on 2007 Feb 15 (N), 19 (both) & 26 (N); and on Mar 10 (both), 13 & 22 (N) & 29 (both). Fisher found the S collar dark on Mar 2 & Apr 8, with both collars appearing dark on Mar 11.

Gray resolved some very bright spots preceding the SCC on Apr 30, as well as on May 2, 3 & 21: see Figure 10. The generally low-resolution UV images available for these dates do not confirm them. Hancock on May 24 shows a bright spot at the N edge of the SCC, with a bright spot within it on Jun 1 & 2.

In UV light, Parker found the caps prominent and bounded by strong collars on Jan 13. In the later UV images, the NCC, SCC and collars are mostly similar and unremarkable, but on Feb 6 (Arditii) the SCC appeared particularly large.

2007W

Neither cap was ever large visually; the NCC and SCC were similar over the period 2007 Oct – 2008 Feb, with some exceptions. Leatherbarrow found the SCC significantly more prominent from Nov 6–12 (with the S collar dark) and to Adamoli, Dec 13–20, and McKim. Dec 11, the SCC was clearly the brighter. During 2008 Mar–Apr the NCC and SCC (with collars) could be recognised, but they were generally dull. Adamoli recorded intensity 4 collars on Feb 19 (N), Apr 4 (N) and May 2 (S).

During Oct 17–19, Baum saw areas of differing brightness in the SCC (Figure 10) as well as very slight extensions (suspected to be extended and longer on Oct 17). Extremely well-defined and equally bright caps were imaged in the UV by the Ackermanns, Dec 21.

2009E

Inconspicuous to Adamoli in his visual work during 2008 Aug–Oct, during November the SCC appeared considerably brighter than the NCC, with dark collars (intensity 4) on Aug 10 & 14 (both), 19 (N), 23 (S) & 29 (N); Sep 2 & 5 (both), 8 (N), 24 (both) & 29 (N); Oct 9 (both), 15 (S) & 20 (both) and on Nov 14 (S) & 16 (both). During 2008 Dec – 2009 Mar, all observers found the SCC and SSC similar. To McKim, the SCC contained a brilliant, irradiating point near the horn on Jan 6. Wilson found the S collar especially prominent on Jan 22.

Figure 10. Illustrating aspects of the cusps, 1975–2015. The insets above Baum’s drawing show additional details suspected to be extending from the S cusp.
2009W

During May–Oct the NCC and SCC were visually normal, with the SCC slightly more conspicuous in Jul–Oct. Adamoli found both collars particularly well-marked on Aug 1, 12 & 22. During Nov–Dec the caps were identifiable but not brighter than the central disk; to Adamoli the N. collar reached intensity 4 on Dec 16.

The Jul–Oct UV images also show the SCC larger and brighter.

2010E

In visual work, the caps were visible but barely bright during Feb–May. Collars were seen. On Mar 6 & 12; Apr 7, 12, 19 & 25; and May 12, Adamoli saw a dark S. collar (intensity 4–4.5) and a fainter N. collar; both collars attained intensity 4 on Mar 15. Apr 5 & May 31. McKim found the SCC more prominent than the NCC on Apr 17. Abel agreed on Apr 20 but found the NCC the more prominent on Apr 27. The SCC became brighter from late June and, during Jul–Aug, to Adamoli and McKim it was generally large and brighter than the NCC. Adamoli again recorded particularly dark collars on Jun 4 (S.), 14 (N.), 22 (S.). 24 & 29; and on Jul 5, 8 & 18 (both). To McKim on Aug 19 the SCC was particularly large, shrinking the next day. Adamoli also saw it large on Aug 17.

Gasparri's Mar–Apr UV images show well-bounded and roughly equal bright cusps; Arditti's of Jul 9 shows the SCC especially large.

2011W

During 2010 Dec – 2011 Feb, visually either the caps were equal, or the SCC appeared brighter (particularly to McKim on Jan 9 & 16, when the SCC was larger). Panther saw the NCC, but not the SCC, on Feb 14 & 16. From Mar–Apr the caps were discernible to Adamoli, but no brighter than the central disk. In May–Jun he found the SCC discernible but dull, and the N. limb shaded. During Jul he more usually found both poles shaded, attaining intensity 4 on Jul 11.

In UV light, the SCC was appreciably more noticeable throughout May–Jul.

2012E

In visual work. Adamoli saw the cusps dull and sometimes shaded during 2011 Sep–Dec, with intensity 4 collars in December. During 2011 Dec 31 – 2012 Jan 16, McKim found the SCC light but offset from the S. pole and with no NCC. Colombo saw the SCC well on Jan 22. Adamoli and Braga saw the S. collar at intensity 4 on some dates from Jan 21 – Mar 16. From late January till late April, the NCC and SCC were roughly equal; however McKim on Mar 3–7, Baum on Mar 6 and Leatherbarrow on Mar 11 found the SCC particularly large and brighter. Abel saw the SCC larger on several dates and Braga saw only the SCC on Mar 2, 10 & 20.

There were numerous UV images confirming visual impressions, but in extra detail. In particular, we note the unusually large SCC recorded by Poupeau on Feb 11 & 29.

2012W

Visually, the caps were never large. In July, the NCC and SCC seemed equal. In Aug–Oct the SCC was often more prominent, but they were similar during Oct–Nov, after which they were not reported. The S. collar was generally darkest. Sep–Oct: The poles were often dusky to Adamoli, 2012 Dec – 2013 Mar.

2013E

Adamoli visually recorded dull caps during Apr–May, reaching intensity 4 on May 19 & 26. Abel saw the N. collar dark on May 25. The SCC was the brighter to Abel on Jun 4, and to Adamoli on Jul 8; while the NCC was brighter to Abel on May 25, to McKim on Aug 3, and Braga on Aug 4. Otherwise, in Jun–Aug the NCC and SCC were neither very large nor bright. Adamoli saw the collars especially dark on several dates, Jul 2 – Aug 21.

UV images during 2013 Jun–Jul mostly showed a bright NCC and/or SCC: the NCC more frequently. In August, UV images showed the NCC and SCC to be substantial and similar in size.

During Sep–Nov the SCC was slightly brighter to the visual observers (with the S. collar more apparent) and on Oct 31 it looked bifurcated to Adamoli. Adamoli saw both collars thin but dark on Sep 1 & 11.

2014W

In visual work Adamoli found the caps inconspicuous. Feb–Mar Barry's Mar 24 UV image shows the SCC brighter. The caps were brighter in Apr–May, Adamoli often seeing the NCC smaller but better defined; with a darker collar. McKim on Apr 5 saw a large NCC, but no SCC. The cup-caps were equal during June. During Jul–Sep the cup-caps were dull to Adamoli, but some UV images in Jul–Aug showed the SCC vaguely lighter.

2015E

Adamoli visually observed dull cusps in Jan–Feb. The NCC and SCC were roughly equal in Mar–Apr, though McKim saw the SCC considerably larger on Mar 28. The SCC was occasionally the larger in May–Jun. On May 21 at 21:00 UT, Taylor reported 'a very conspicuous, bright, white and very concentrated spot exactly at the S. cusp', which lay within a slight SCC.

In the UV, the NCC and SCC were generally more prominent than in the visual work, and the SCC was sometimes the larger or brighter in 2015 Mar–Jun. The SCC was especially large to Hill and Lindberg, Mar 9–17.

2015W

There were few visual observations. The NCC and SCC were hardly seen before 2015 Nov, and were remarkable 2015 Dec – 2016 Feb. In March Adamoli could see only the SCC, occasionally.

In the UV images, the cusps were also not obvious prior to 2015 Nov. The caps alternated in prominence in the Nov–Dec UV images. The NCC appears very large in Olivetti's Nov 20 & 21 images, while both NCC and SCC look remarkably large in Olivetti's Dec 23 image. Olivetti had also imaged wide bands of white cloud in mid-latitudes on Dec 4. Some Nov–Dec images feature in Figure 10.

2017E

In 2016 Aug, Adamoli found the cusps dull; in Sep–Nov he resolved them but did not find them bright. During 2016 Dec – 2017 Mar, bright caps were widely observed. The NCC was sometimes more prominent in Dec, but in Jan–Mar the SCC was more generally the larger or brighter. Davies on Jan 28 drew attention to the brilliant SCC.

The caps were not prominent in the October UV images (Figure 4): the SCC was sometimes bright but small. The SCC was sometimes well seen in the November images, but never large. In Dec–Jan the cusps were bright in the UV data, with the SCC sometimes more prominent; in Feb–Mar they were not well-defined.

2017W

Abel, Adamoli and Basey saw both caps repeatedly during 2017 May–Aug: the SCC was somewhat more often (but not exclusively) larger. By September they were less prominent, and during Oct–Nov none were recorded.
In the UV images, the cusps were similar during Jun–Jul, but Melillo found the NCC especially large on Jul 16 & 30. The SCC was significantly the larger in Aug–Sep.

**Discussion**

The bright belts of cloud that make small angles with parallels of latitude (Figures 1, 2 & 4) may form (as we shall see later in discussing the temporary bright spot outbreaks of 2009W when such features spread out in longitude. As these bright belts trend towards the poles, they merge with any existing NCC or SCC and so enlarge them, especially if viewed at low resolution. See the remarks for 2015W, above, for more details.

**Other bright areas**

In the 1960s the occasional absence of either the south or north branch of the Y or y marking was noted by Dollfus & Guerin, who inferred veiling by higher cloud. This effect can frustrate short-term measurements of the UV rotation period. However, there is the bonus of much minute detail in modern UV images as Figure 1(A) shows. Notable outbreaks of bright clouds were recorded by VEX and by ground-based observers, the best example being a large, bright UV cloud observed during 2009W.

First we list those bright spots seen visually, which were mostly located at the limb. In UV, bright limb clouds often continue into light belts inclined at small angles to the equator. For historical continuity and statistical purposes we continue to report the visual aspect, but include confirmatory and selected UV work.

In the following, bright areas were located near the equator unless stated otherwise. By ‘p. limb’, we simply mean the ‘preceding’ limb of the planet upon the sky (on the left in the inverted telescopic image): ‘f’ refers to the ‘following’ limb.

**2009E**

Visual work: 2009 Aug 20 (Sp.时, Adamoli) & 22 (Sp.时, Niechoy); Jun 3 (N. hemisphere streak, McKeown); 23 (Sp.时, Adamoli) & 24 (Sp.时, Niechoy); Jul 19 (Sp.时, Niechoy); Aug 18 (Sp.时, Adamoli) & 20 (Sp.时, Niechoy.)

Yunoki’s UV image of May 16 has a bright area at the Sp. limb.

**2009W**


In the UV images, an extremely bright spot upon the Sp. limb was recorded by Kivits (10:57 UT) and Melillo (13:10 UT) on Jul 19. Melillo announced the discovery, informing the VEX team, and had preceded the spacecraft’s imaging of the feature on that date by 7 h. It was located just N. of the edge of the existing light S. cuspal ridge, at latitude ca. -50°. It subsequently transpired that a much less bright area had been seen by VEX to be forming at the same longitude, one rotation earlier on Jul 15. Some of these observations were reported at the time. On Jul 23, Poupeau as well as Y. Goryachko & colleagues (Minsk, Belarus) recorded it much diminished. On Jul 27, neither Poupeau nor Kivits recorded any trace of the Jul 19 cloud, two rotations later. Figure 11 illustrates this large, striking feature.

This was not the only outburst in 2009. Kivits shows another only slightly less conspicuous limb feature at the same latitude on Jul 14 at 07:10 UT. Another bright spot was caught at the same latitude on the limb by Masson on Jul 20 (13:00 UT). Parker imaged it again on Jul 24 (13:52 UT) but found it less conspicuous (see also Figure 11). Images posted by Goryachko on the ALOP Japan website reveal that his group had discovered it on Jul 16.

Further significant bright areas are shown in the UV image by Lazzarotti on Aug 14 (Sp. & Nf.), one being at the same latitude as the July clouds.

None of these features showed up upon any IR image.

**2010E**


**2007E**

Visual work: 2007 Mar 2 (N. central disk, Fisher), 6 (p., Longshaw), 9 (Np., Schmidt), 11 (Np., Fisher), 25 (near S. cusp, Baum) & 28 (Sp., Niechoy); Apr 1 (p., Baum; and Np., McKeown), 8 (disk centre, Fisher), 10 (Sp., Adamoli), 11 (disk centre, Baum), 14 (Sp., Adamoli), 15 (Np., Fisher), 18 (Sp. & Np., Gray) & 28 (p., McKeown); May 1, 2, 5, 11, 15 (Sp., McKeown), 2 (Sp., Baum & Gray (confirmed by UV images)), 10 (Sp., Adamoli), 12 (p., McKeown), 18 (Sp., McKeown), 19 (p., Baum, Longshaw & McKeown; Np., Hancock & McKeown) & 30 (p., McKeown (resolved into several small clouds in an UV image by Peach)); and Jun 18 (p., McKeown). Many of McKeown’s drawings are shown in Figure 3.

From the UV images: Apr 2 (Sp., Pellier), 9 (S. of disk centre, Lazzarotti), 14 (Sp., several observers), 18 (Np., Pellier), 22 (p. side near equator, Lazzarotti (Figure 1(A)) & 23 (near disk centre, Gasparri); May 2 (Sp., Ackermanns), 3 (Sp., Pellier), 29 (Sp. Peach) & 30 (p., Peach), Jun 10 (Sp., Walker) & 11 (near equator, Lazzarotti & Parker).

**2007W**

Visual work: 2007 Aug 30 (f., Niechoy), Sep 16 & 24 (S. hemisphere, Niechoy), 26 (f., two areas, Gray); Oct 19 (Nf., Baum), 20 (Sp., Niechoy) & 25 (Nf., Leatherbarrow); Nov 15 (N hemisphere streak, Baum); Dec 13 (Sp., Adamoli & Baum) and 2008 Mar 19 (Sp., Niechoy).

Of the UV data: Oct 23 (Sp., Susenbach & Tasselli) should be cited.

Figure 11. Illustrating the large, brilliant cloud outbreaks near latitude -50° at the 2009 western elongation.
Visual work: 2010 Dec 9 (f., Gray), 2011 Jan 3 (f., Niechoy) & 18 (f., quadrant, two small areas; Gray); May 22 (Nf., Niechoy, confirmed on Put’s UV image two rotations later on Jun 3) & Jun 2 (Nf., Macsymowicz, confirmed in Put’s UV image).

Put’s UV images of 2011 May 25 & Jun 20 also show several large, bright spots near the disk centre, and one was shown by Kivits on May 23.

**2012E**

Visual work: Jan 6 (Sp., Adamoli) & 14 (central terminator, Abel); Feb 24 (light area at central terminator; Abel, Heath & McKim); Mar 1 (Sp., Abel), 3 (Sp., Adachi), 11 (p., McKim), 14 (Sp., Leatherbarrow, confirmed by Iekumura’s UV image), 20 (p., Niechoy) & 27 (Np., McKim); Apr 8 (Np., McKim), 12 (N. hemisphere streak, McKim), 17, 21 (p., McKim) & 25 (Np., limb, McKim).

Gasparrini’s and Sussentbacher’s Jan 16 images show a number of UV-bright clouds upon the central disk.

**2012W**


UV work: Jul 22 & 25 (Nf./, Lindberg).

**2013E**

As illustrated in the Journal, a particularly bright area was seen in visual work at the Sp. limb by Heath, on 2013 Dec 31. Other bright areas were: 2013 Aug 19 (Sp., Macsymowicz) & 27 (S. disk, Niechoy); Sep 5 (Sp., Niechoy); Dec 1 (Np., McKim), 10 (p., Niechoy), 13 (p., Braga), 26 (p., McKim); & 2014 Jan 2 (Sp., fainter than Dec 31, Heath).

UV images by Lindberg show the expansion of a bright area along the Sp. limb, confluent with the SCC, after Jul 12 (this was noted earlier, where we referred to the Nf. limb in error). The bright area was often present until Aug 4, when Lindberg’s series ended.

**2014W**

Visual work: Mar 16 (f. disk, Panther), 29 (f. limb, Giuntoli) & Jun 12 (Sf./, Gray).

Lindberg’s UV images show a large bright area at the Nf. limb on May 25.

**2015E**

Visual work: Feb 22 (f., Niechoy) & 24 (p., Macsymowicz); Apr 5 (Sf./, f. & Nf./, Gray (Figure 9)), 12 (Sf., Colombo), 17 (Sf. near the SCC, Gray & Niechoy, both with W25) & 21 (Sf., Niechoy, W25); May 7 (f., Macsymowicz and Nf., Niechoy), 11 (near disk centre, Abel), 23 (f., McKim), 25 (p., Macsymowicz) & 29 (Sf./ & f., Braga & McKim); Jun 3 (Sf./, Braga (confirmed by several UV images)), 4 (f., Niechoy – confirmed by Sussenbach’s UV image), 5–7 (Nf./, McKim), 10 (Sf./, McKim), 15 (Nf./, McKim), 20 (f., Colombo), 21 (Sp., Giuntoli), 23 & 28 (Nf./, McKim).

UV work: Apr 18 (f., Lewis) & 19 (f., Olivetti).

**2015W**

The few visual observations do not record any significant bright areas.

UV work: Oct 24 (Nf., Olivetti) & 27 (Nf., Maxson); Nov 6 (Sf., Maxson), 9 (Sf./, f. & Nf./, Maxson), 14 (Sf./, Maxson), 18 (f., Maxson), 23 (Nf./, Maxson), 27 (Sf./, Melillo) & 28 (Nf./, f., Maxson & Olivetti); Dec 4 & 11 (S. & N. hemispheres, Olivetti (Figure 10)), 6 (Sf./, Melillo) & 23 (Sf./, N. hemisphere, Olivetti (Figure 10)).

**2017E**


UV work (Figure 4). 2016 Oct 5, 7, 9, 12–15, 17–18, 25, 26, 28 (Np./, Wesley), 11, 15, 16, 21, 30 (central disk, Wesley), 13, 14, 17, 18, 21, 24–28 (N. hemisphere, Miles), 15 (N. hemisphere, Wesley) & 30 (central disk, Miles); Nov 6, 7, 11 (Np./, Miles), 8, 14, 23, 27 (near disk centre, Miles), 20 & 30 (N. hemisphere, Miles); Dec 2, 5 (Np./, Miles) 4 (near equator, Miles and Np., Melillo), 6 (p. & Np., Miles) & 29 (Np./, Pellerit); 2017 Jan 2 (p., Lewis), 8 (Np./, Miles), 11 (p., Miles), 12 (Np./, Maxson), 13 (Np., Miles, Olivetti), 16 (S. hemisphere, Miles), 17, 19 & 21 (Np., several observers).

**2017W**

Visual work: Jun 4 (S. hemisphere, Abel – confirmed by Melillo’s UV image) & 18 (central disk, Abel).

UV work (few images): Jun 4 (Nf./, Melillo) & 25 (N. hemisphere f./, Melillo); Jul 3 & 10 (Nf./, Melillo) & 18 (f./, Braga); Aug 24 (Nf./, Melillo), 23 (f./, Melillo) & Sep 9 (f./, Melillo).

**Discussion**

To enable comparisons with our past 8-year reports, we counted only the bright areas recorded visually during the ten elongations from 2007E–2014W. Each period from 1991–1998, 1999–2006, & 2007–2014 showed significantly more bright areas in the S. hemisphere than in the N. With 244 visual sightings in total over the entire 1991–2014 period, 113 (46%) were in the S. hemisphere, 54 (22%) at or close to the equator, and 77 (32%) in the north. Even the smaller number of UV data quoted here for 2007E–2014W showed the same clear preference for the S. hemisphere. We noticed that the ultraviolet bright belts of cloud at small angles with parallels of latitude (Figures 1, 2 & 4) were more common in the south than in the north.

The only striking exception to the above is the lack of bright UV cloud sightings in the S. hemisphere for 2017E (and possibly 2017W).

There is some evidence from VEX of ongoing volcanic activity. Prof F. W. Taylor has commented: The glow from eruptions...
would not be visible on the day side, of course, but the particles in the plumes could form clouds that are more reflective than the background cloud and therefore appear as bright spots. It is hard to imagine why the dark ultraviolet markings would otherwise be interrupted or over lain only at certain times and latitudes, given the extreme stability of the four-day atmospheric patterns. Of past Earth-based observations, an observation of McEwen’s on 1940 Apr 17 (CM (System I) = 186.3°; D = -4.3°) — showing small and well-defined bright spots upon the mid-disc — must have represented some extraordinary activity to have been visible in white light. It is tempting to suggest that the change in distribution of bright areas seen at 2017E could be related to the appearance of the unusually bright (and therefore warmer) features seen in the infrared thermal emission (IRTE) images in the same year. This will be described in Part II.

Taylor remarks that the Galileo 1990 February flyby data showed a north-south asymmetry in cloud type, probably due to different particle sizes. This might in turn lead to ongoing surface volcanism.

### Cusp extensions

As Venus approaches the Sun, its phase and angular diameter change in the opposite sense; see Figure 12. When very close to the Sun the horns (or ‘cusp’) gradually extend, sometimes to a complete 360° ring; this is illustrated in Figure 13.

Reports quoted are visual unless stated. ‘Extensions to 220°’ (for example) means a 40° continuation beyond the normal 180° arc of the crescent, and hence by 20° at each cusp unless stated otherwise.

### 2007E & 2007W

Venus was nearly 8° from the Sun at IC, so only small cusp extensions were anticipated. Contrarily, on a few occasions they appeared extensive. At the 1999 IC, we noted ‘...under transparent New Mexico skies (and much to his own surprise). Haas was able to see the complete ring from August 16–20 (the latter the day of IC).’ This observation was repeated by Wilson and McKim at the corresponding elongation in 2007:

<table>
<thead>
<tr>
<th>Date(s)</th>
<th>Observer</th>
<th>Angular extension (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jul 21</td>
<td>Hancock</td>
<td>Small, equal extensions</td>
</tr>
<tr>
<td>Jul 27</td>
<td>Adamoli</td>
<td>22°</td>
</tr>
<tr>
<td>Jul 27</td>
<td>Hancock</td>
<td>Longer extension to N, than S; S. extension fragmented</td>
</tr>
<tr>
<td>Jul 28</td>
<td>McKim</td>
<td>Small, equal extensions</td>
</tr>
<tr>
<td>Jul 31</td>
<td>Adamoli</td>
<td>245°; S. longer</td>
</tr>
<tr>
<td>Aug 5</td>
<td>McKim</td>
<td>225°; S. longer</td>
</tr>
<tr>
<td>Aug 9</td>
<td>McKim</td>
<td>270°; S. longer</td>
</tr>
<tr>
<td>Aug 11</td>
<td>McKim</td>
<td>300°; S. longer</td>
</tr>
<tr>
<td>Aug 12</td>
<td>Adamoli</td>
<td>S. extension longer than N.</td>
</tr>
<tr>
<td>Aug 13</td>
<td>McKim</td>
<td>Extensions obvious to 270°; moments when complete 360° circle glimpsed (Figure 13(A))</td>
</tr>
<tr>
<td>Aug 15</td>
<td>Wilson</td>
<td>Usually only 160° arc seen, but at times, ha’-like extensions continued to nearly 360°</td>
</tr>
</tbody>
</table>

**After IC, few reports:**

| Aug 23  | Frassati | Small, equal extensions |
| Oct 17–19 | Baum | Oct 17: knotted and extended S. cusp suspected; short extension seen the next two days (Figure 10) |

### 2009E & 2009W

Adamoli, Baum & Wilson succeeded in seeing the complete ring near IC, when Venus was again some 8° from the Sun. Prior to IC, the cusp extensions were again unequal.

<table>
<thead>
<tr>
<th>Date(s)</th>
<th>Observer</th>
<th>Angular extension (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mar 10</td>
<td>Baum &amp; McKim</td>
<td>Small extensions</td>
</tr>
<tr>
<td>Mar 14</td>
<td>McKim</td>
<td>190°</td>
</tr>
<tr>
<td>Mar 15</td>
<td>Baum</td>
<td>195°; NC (regular) 5°</td>
</tr>
<tr>
<td>Mar 17</td>
<td>Haas</td>
<td>205°; S. longer</td>
</tr>
<tr>
<td>Mar 18</td>
<td>Baum &amp; Phelps</td>
<td>200°</td>
</tr>
<tr>
<td>Mar 18</td>
<td>McKim</td>
<td>225°</td>
</tr>
<tr>
<td>Mar 19</td>
<td>Baum</td>
<td>300°</td>
</tr>
<tr>
<td>Mar 20</td>
<td>Baum</td>
<td>270°</td>
</tr>
<tr>
<td>Mar 21</td>
<td>Adamoli</td>
<td>260°; NC 60°, SC 20°</td>
</tr>
<tr>
<td>Mar 21</td>
<td>Baum</td>
<td>310°</td>
</tr>
<tr>
<td>Mar 22</td>
<td>Adamoli</td>
<td>280°; NC 60°, SC 40°</td>
</tr>
<tr>
<td>Mar 22</td>
<td>Baum</td>
<td>310°</td>
</tr>
<tr>
<td>Mar 23</td>
<td>Longshaw</td>
<td>275°</td>
</tr>
<tr>
<td>Mar 24</td>
<td>Adamoli</td>
<td>320°; NC 80°, SC 60°</td>
</tr>
<tr>
<td>Mar 26</td>
<td>Adamoli</td>
<td>360° (Figure 13(B))</td>
</tr>
<tr>
<td>Mar 26</td>
<td>Baum</td>
<td>360°</td>
</tr>
</tbody>
</table>

**After IC:**

| Mar 29  | Wilson   | ‘In the best moments, the cusp extensions, though discontinuous, met...’ |

### 2010E & 2011W

Again the full circle was recorded by Adamoli close to IC; the planet was closer to the Sun than at IC in 2007 or 2009 (see Table 3).

<table>
<thead>
<tr>
<th>Date(s)</th>
<th>Observer</th>
<th>Angular extension (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oct 19</td>
<td>Adamoli</td>
<td>200°; NC 20°, SC 0°</td>
</tr>
<tr>
<td>Oct 21</td>
<td>Adamoli</td>
<td>225°; NC 20°, SC 25°</td>
</tr>
<tr>
<td>Oct 27</td>
<td>Adamoli</td>
<td>Extensions obvious to 300°; NC 60°, SC 60°; full circle glimpsed</td>
</tr>
<tr>
<td>Oct 29</td>
<td>Adamoli</td>
<td>Extensions obvious to 355°; NC 45°, SC 80°; full circle suspected</td>
</tr>
</tbody>
</table>

**After IC:**

| Nov 3   | Adamoli  | Extensions obvious to 240°; full circle glimpsed |
| Nov 10, 11 | Adamoli | 245°; NC 20°, SC 45° |

### 2012E & 2012W

This time, several observers were able to see or image the complete ring of light. The phenomenon was caught not only as Venus was entering onto or leaving the Sun’s disk at the Jun 6 transit, but also a few days either side of IC.

<table>
<thead>
<tr>
<th>Date(s)</th>
<th>Observer</th>
<th>Angular extension (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>May 21</td>
<td>McKim</td>
<td>190°</td>
</tr>
<tr>
<td>May 22</td>
<td>Adamoli</td>
<td>200°; NC &amp; SC, 10° each</td>
</tr>
<tr>
<td>May 22, 25</td>
<td>Adamoli</td>
<td>200°; NC &amp; SC, 10° each</td>
</tr>
<tr>
<td>May 24</td>
<td>Niechay</td>
<td>245°; SC brighter</td>
</tr>
<tr>
<td>May 26</td>
<td>Adamoli</td>
<td>220°; NC &amp; SC, 20° each</td>
</tr>
<tr>
<td>May 27</td>
<td>Adamoli</td>
<td>240°; NC &amp; SC, 30° each (S. brighter)</td>
</tr>
<tr>
<td>May 29</td>
<td>Adamoli</td>
<td>275°; NC 35°, SC 60° (S. brighter); glimpses of full circle</td>
</tr>
<tr>
<td>Jun 3</td>
<td>Peach</td>
<td>270°</td>
</tr>
<tr>
<td>Jun 4</td>
<td>Kardasheva</td>
<td>Complete circle clearly imaged</td>
</tr>
<tr>
<td></td>
<td>Lawrence &amp; Stassenbach</td>
<td>Cont’d overleaf</td>
</tr>
</tbody>
</table>
### 2012E & 2012W (cont’d)

<table>
<thead>
<tr>
<th>Date(s)</th>
<th>Observer</th>
<th>Angular extension (°)</th>
<th>After IC:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jun 5</td>
<td>Secker et al.</td>
<td>Complete circle clearly imaged (Figure 13(C))</td>
<td></td>
</tr>
<tr>
<td>Jun 8</td>
<td>Kivits</td>
<td>Complete circle clearly imaged (Figure 13(D))</td>
<td></td>
</tr>
<tr>
<td>Jun 9</td>
<td>Adamoli</td>
<td>260°; NC 20°, SC 60°</td>
<td></td>
</tr>
<tr>
<td>Jun 9</td>
<td>Johnstone</td>
<td>Extensions to ca. 240° imaged</td>
<td></td>
</tr>
<tr>
<td>Jun 13, 16</td>
<td>Macysmowicz</td>
<td>Complete circle faintly observed</td>
<td></td>
</tr>
<tr>
<td>Jun 16</td>
<td>Giuntoli</td>
<td>Complete, very faint circle suspected (203mm SCT)</td>
<td></td>
</tr>
</tbody>
</table>

### 2013E & 2014W

Adamoli alone suspected the full circle close to IC.

<table>
<thead>
<tr>
<th>Date(s)</th>
<th>Observer</th>
<th>Angular extension (°)</th>
<th>After IC:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec 26</td>
<td>McKim</td>
<td>Slight extensions at NC &amp; SC 5° each</td>
<td></td>
</tr>
<tr>
<td>Dec 27, 29</td>
<td>Adamoli</td>
<td>SC extension 15°</td>
<td></td>
</tr>
<tr>
<td>Dec 31</td>
<td>Adamoli</td>
<td>SC extension 25°</td>
<td></td>
</tr>
<tr>
<td>Dec 31, Jan 6</td>
<td>Giuntoli</td>
<td>Slight extensions at NC &amp; SC</td>
<td></td>
</tr>
<tr>
<td>Jan 6</td>
<td>Adamoli</td>
<td>280°; certain; NC 40°, SC 60°; complete circle suspected</td>
<td></td>
</tr>
</tbody>
</table>

### 2015E & 2015W

At IC in 2007, McKim & Wilson had seen the full circle, but at this comparable elongation only relatively small extensions were seen.

<table>
<thead>
<tr>
<th>Date(s)</th>
<th>Observer</th>
<th>Angular extension (°)</th>
<th>After IC:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jul 27–Aug 9</td>
<td>Niechoy</td>
<td>Small extensions seen</td>
<td></td>
</tr>
<tr>
<td>Aug 8</td>
<td>Peach</td>
<td>Crescent extends to 190° (IR image)</td>
<td></td>
</tr>
<tr>
<td>Aug 9</td>
<td>Abel &amp; Braga</td>
<td>Slight extensions</td>
<td></td>
</tr>
<tr>
<td>Aug 15</td>
<td>Lawrence</td>
<td>Crescent extends to 206° (IR image)</td>
<td></td>
</tr>
<tr>
<td>Aug 18</td>
<td>Braga</td>
<td>Both cusps extended</td>
<td></td>
</tr>
</tbody>
</table>

**Discussion**

Even when the planet does not approach the Sun closer than 8°, extension of the cusps to a full circle can sometimes be observed. McKim, using a 102mm OGI, was able to see the complete circle at IC in 2007 at -7° 59′ separation (as others had been able to record in 2009 at +8° 10′), but when he used the same instrument at IC at the comparable elongation in 2017 (+8° 18′) under equally fine conditions, only short extensions could be made out. The 2015 IC also yielded only short extensions; yet the writer and others had seen long extensions at the comparable 1975E.\(^4\) It seems reasonable that the degree of atmospheric scattering varies. The degree of extension of the northern and southern cusps was sometimes quite different, an effect occasionally seen at ingress or egress in solar transits.\(^4\)

Observers who preferred imaging over visual work sometimes used an infrared filter to improve daytime seeing, but the scattering effect that gives rise to the extensions is reduced at these longer wavelengths.

Haas published a thoughtful analysis of his personal data over six decades.\(^4\) G. D. Roth quotes the formula of E. Schoenberg.\(^4\) This relates the angular extension of one cusp (and the angular elongation from the Sun) to the ratio of the height of the scattering/refracting layer of atmosphere and the radius of Venus.

### Conjunctions and lunar occultations

Several observers watched the occultation by the Moon on 2007 Jun 18.\(^5\) Images were supplied by Dowdell, Kilner, Niechoy, Patterson, Porter and Vetterlein, while Kowol-
lik obtained an excellent video (from which we captured some frames for Figure 14). Heath and McKim were clouded out. On 2007 Aug 19, Vetterlein photographed the close conjunction of Venus with Mercury.

Another occultation by the Moon occurred on 2008 Dec 1. Reports were received from R. M. & J. Baum, Collins, Griffiths, Kingsley, Robinson and Sharp. Kingsley’s view from Stonehenge is reproduced in Figure 15. The occultation of 2010 May 16 was imaged by Akutsu: see Figure 16.

2012 March saw a close conjunction between Venus and Jupiter.14 Vincent photographed the conjunction between Venus and Mercury in 2010 April. A conjunction of Venus with the Pleiades took place in 2012 April,46 which was recorded by Cooper, Halls and Tough (Figure 17). The conjunction between Mercury and Venus on 2012 Jun 1 was photographed by Vetterlein.14 We previously published an image taken on 2014 Aug 18 by K. Brasch, showing the close approach of Venus to Jupiter.17 In 2015 June–July, members watched another close encounter between Venus and Jupiter, as previously reported and illustrated here in Figure 18.17 On 2016 Jan 9, Arditi was able to image Venus and Saturn in the same telescopic field.

Meeus & Rao (2011) list nocturnal occultations of Venus by the Moon.47

Unusual observations

An earthquake

On 2012 Jan 27, at 14:35 UT, Adamoli was observing Venus from his balcony when the image began to shake wildly, due to an earthquake in northern Italy.

References & notes

2 McKim R. J., Blasch K. W. & Heath A. W., “Venus 2004: east and west elongations and solar transit”, ibid., 117(2) 65–76 (2007) [Erratum: Figure 9 – in which north is uppermost – should have been labelled May 21]
16 McKim R. J., ‘The crescent Venus and bright spots on the limb’, *ibid.*, 124(2) 65 (2014)
25 The ALPO JAPAN Venus archive: [http://alpo-j.asahikawa-med.ac.jp/Latest/Venus.htm](http://alpo-j.asahikawa-med.ac.jp/Latest/Venus.htm)
34 Hedley Robinson J., *ibid.*, 42(2) 64–65 (1990)
37 Braga R., *Astronomia* (UAL) 2014, No. 5, 18–23
38 Shalayin E. V., et al., ‘Active volcanism on Venus in the Ganiki Chasma rift zone’, *Geophys. Research Letters*, 42(12) 4762–4769 (2015). The authors used VEX 1.10um data to show that hot spots estimated to range from 800–1100K in temperature and 1–200km2 in area could be the result of ongoing volcanic activity.
43 Hedley Robinson J., J. Brit. Astron. Assoc., 86(2) 155–161 (1976). At IC on Aug 27, the elongation was 8° 26’. The writer (using a 216mm refl.) saw cusp extensions to 270° with certainty on Aug 25, while several observers reported the complete circle.
45 Roth G. D., *Handbook for Planet Observers*, Faber & Faber, 1970, 114–116; Roth G. D. (ed.), *Compendium of Practical Astronomy*, vol. 2, Springer-Verlag, 1994, 212–213. F. Schoenberg’s formula (in his ‘Refraktion und Dämmerungs- bogen des Planeten Venus’, F. d. Sternwarte München, 3(11) 123–128 (1949)) relating the angular extension at each cusp m and the angular elongation V, to the ratio of the height of the scattering/refracting layer of atmosphere h to the planet’s radius R (0.0525km) is: h/R = ½ tan² m / sin² m. For the full circle, m = 90°, hence sin² m = 1. If the minimum angular extension V needed to see the full circle is 8°, then h/R = 0.0198, yielding the not reasonable result of h = 120km.
46 Moore S. in BAA e-Bulletin No. 662 notes Venus reached the cluster’s edge on Apr 2, and on Apr 3 lay well within it.
49 McGee H., BAA e-Bulletin No. 485

Submitted 2018 March 1; accepted 2018 May 30