The eastern & western elongations of Venus, 2007–'17

I. The sunlit hemisphere

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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 Venusian 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.[2,3] 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*,[4–19] including the annual Council Reports.

In 2006 the Section was asked by the European Space Agency (ESA) to co-ordinate the initial ground-based support for the *Venus Express (VEX)* mission; there was an excellent response from observers.[20] 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.[21] 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]

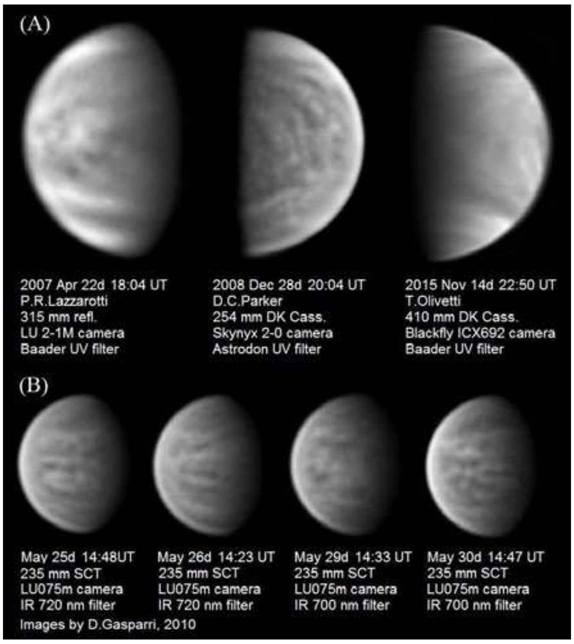

Figure 1. (A) Selected high resolution ultraviolet images. **(B)** Selected high resolution near-infrared images. *Note*: South is uppermost in this and other telescopic figures, unless otherwise stated.

During the 2007 eastern elongation (2007E) it was established how the markings recorded in images varied systematically with wavelength across the visual waveband,[6] 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,[23] while others have described previous improvements in techniques.[9]

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.[2,24]

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,[25] to find matches suitable for obtaining rotation periods. McKim was responsible for the analysis of the bulk of the data, and drafted

Table 1. Observers of Venus, 2007–'17

See continuation on p. 80 for explanatory notes

Name	*Location*	*Instruments*	*Elongations*⁺
P. G. Abel	Leicester, Selsey, W. Sussex, Hampstead Obsy., Ldn.	203mm refl., 381mm refl. & 152mm OG	A–C, E–G, I, K–N
G. & J. Ackermann*	Zaberfeld-Michelbach, Germany	180mm MKT & 317mm DKC	A–E
M. Adachi	Dynic Obsy., Otsu, Japan	600mm refl.	G
G. Adamoli*	Verona, Italy	108mm OG, 125mm MKT & 235mm SCT	*All*
B. S. Adcock*	Victoria, Australia	152mm OG	I
J. Adelaar*	Arnhem, Netherlands	235mm SCT	A
L. Aerts*	Heist-op-den Berg, Belgium	254mm SCT	ACK
T. Akutsu*	Cebu, Phillipines	203mm & 355mm SCT	A–F, IM
J. Albert	Lake Worth, FL, USA	279mm SCT	G
W. Anthony	High Bridge, NJ, USA	152mm refl.	G
M. Araújo*	Évora, Portugal	279mm SCT	M
D. L. Arditti*	Edgware, Middlesex	254mm DKC & 355mm SCT	A–E, GLM
T. Barry*	Broken Hill, Australia	410mm refl.	IJ
D. Basey	Norwich	358mm refl.	N
R. M. Baum (with J. Baum)	Chester	152mm MKT	ABEG
G. Bertrand*	St. Laurent sur Sèvre, France	114mm refl.	AB
G. Boots	Washington, W. Sussex	235mm SCT	G
R. Bosman*	Enschede, Holland	279mm SCT	A–C
J. Boudreau*	Saugus, MA, USA	279mm SCT	G–I, KM
R. Braga*	Milan, Italy	90mm OG & 210mm DKC	G-N
K. Brasch*	Flagstaff, AZ, USA	235mm SCT & 600mm OG	GJ
C. L. Brook	Plymouth	102mm OG	A-C
J. N. Brown	Warmington, Northants.	254mm refl.	C
M. Brown*	York	254mm refl.	G
M. Cardin*	Padua, Italy	300mm refl.	H
E. Chasiotis*	Markopoulo, Greece	279mm SCT	AB
B. Clark*	Melbourne, Australia	710mm refl.	F
A. Clitherow*	Fife, Scotland	254mm refl.	K–M
M. Collins*	Palmerston North, New Zealand	203mm SCT	CD
E. Colombo*	Milan, Italy	80mm OG & 152 mm refl.	AC, E–G, K
J. Cooper*	Wooton, Northants	DSLR camera	G
H. J. Davies	Swansea	203mm SCT	CM
M. Delcroix*	Tournefeuille, France; Pic du Midi Obs., France	254mm SCT; 1.06m Cass.	ACGHN
T. Dobbins	Fort Myers	254mm MKT	G
C. Dole*	Newbury, Berks.	180mm MKT	K–M
A. P. Dowdell	Winchester	Binos.	A
D. Eagle*	Higham Ferrars, Northants.	203mm refl. & 190mm MKN	HK
P. R. Edwards*	Horsham, West Sussex	279mm & 355mm SCT	FGKL
C. Fattinnanzi*	Montecassiano, Italy	Digital camera	K
F. Ferrario	Cajello, Italy	80mm OG	G
A. Finnigan*	Birmingham	203mm SCT	F
D. Fisher	Sittingbourne, Kent	216mm refl.	A
M. Frassati	Crescentino, Italy	203mm SCT	BCEF
A. Friedman*	Buffalo, NY, USA	254mm MKT	BC
M. H. Gaiger	Tolworth, Surrey	254mm refl.	B–E
P. J. Garbett*	Sharnbrook, Beds.	203mm & 305mm SCT; 490mm refl.	A
D. Gasparri*	Perugia, Itay	235mm & 355mm SCT	ACEGIM
M. V. Gavin*	Worcester Park, Surrey	203mm SCT	CD
S. Ghomidazeh*	Tehran, Iran	279mm SCT	F–I, K
J. Gionis*	Breckland AS, Norfolk	203mm SCT	G

(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 Grego, Walter Haas, Willem Kivits, 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, Macsymowicz, McKim, Melillo and Sussenbach. Observational activity was typical, with some western elongations less well covered. Denis Put was awarded the As-

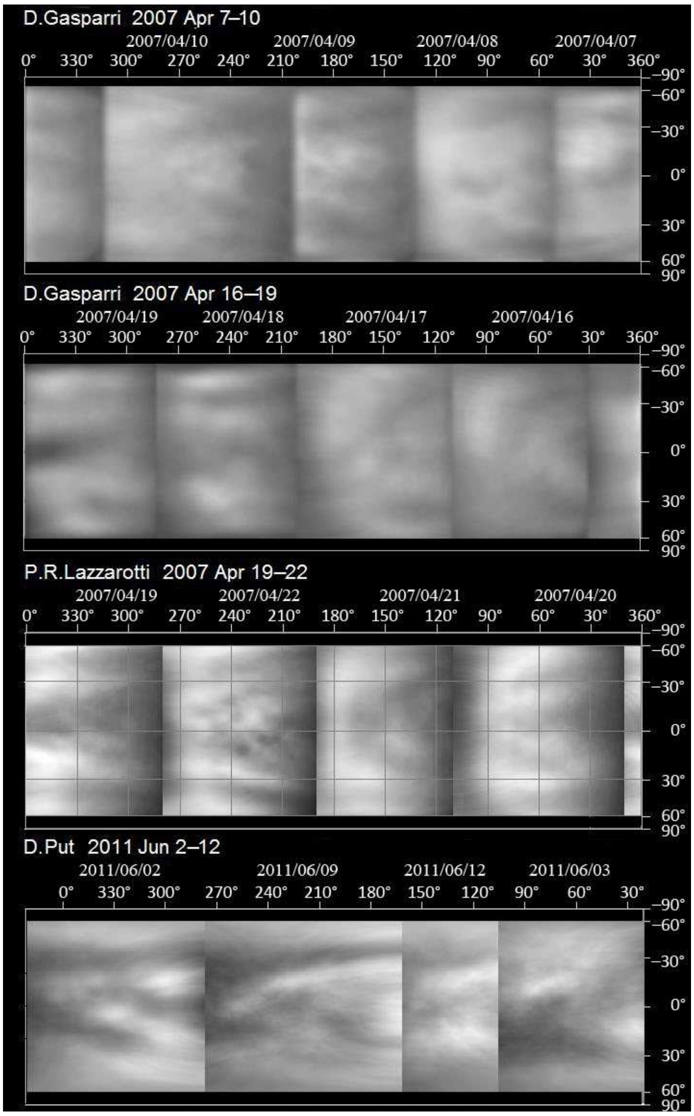

Figure 2. Four-day UV maps with planetocentric latitudes and System II *WinJUPOS* longitudes,[27] during 2007E by D. Gasparri (235mm SCT & ST7-XME camera with Baader UV & Schott BG48 filters) and P. R. Lazzarotti (315mm refl. with LU2-1M camera & Baader UV filter); during 2011W by D.Put (235mm SCT with DMK21AU camera & Astrodon UV filter). The System II ephemeris is slightly imperfect, as explained in the text.

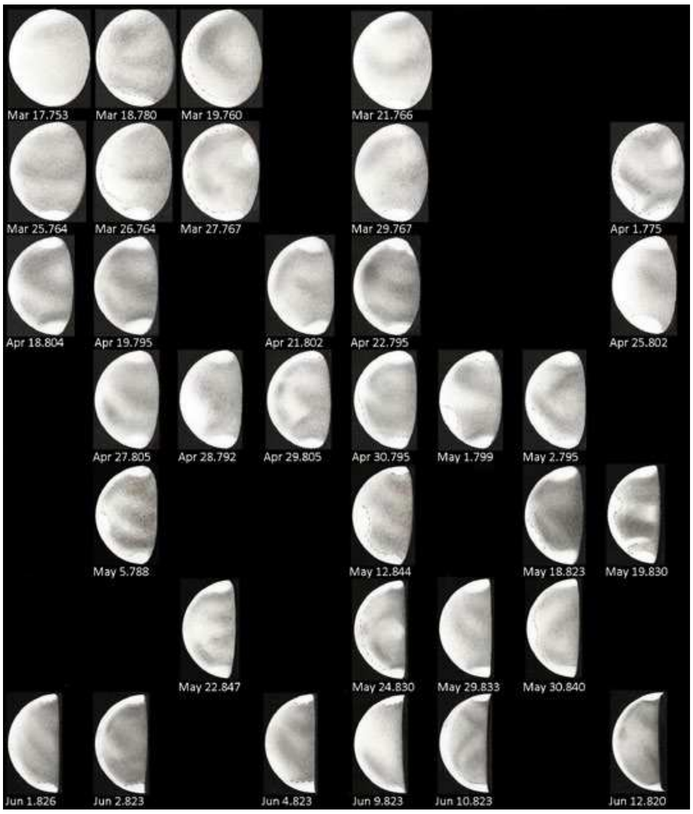

Figure 3. Systematic white light drawings 2007 Mar–Jun, 76mm OG; ×120 (but 410mm DK Cass., ×265 for Apr 29 and 102mm OG, ×120, ×160 for May 24–29 & Jun 1–12). The observer was away from home Apr 3–17. Drawings show decimal date, arranged in four-day sequences. *R. J. McKim*

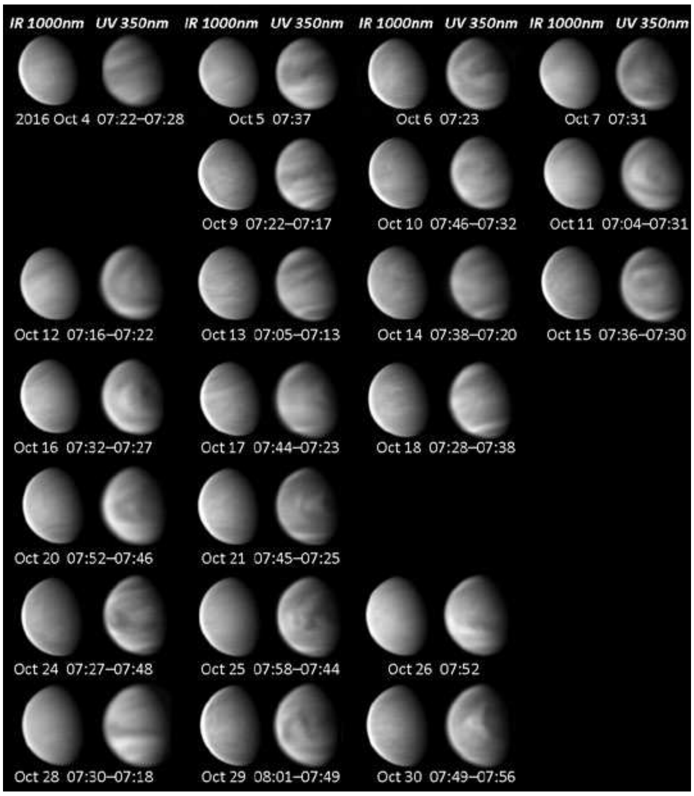

Figure 4. Image pairs taken with Astrodon UV (350nm) & Thorlabs IR (1000nm) filters, 2017 Oct 4–30. 406mm refl. & Point Grey BFLY-PGE-31S4M-C camera. Times in UT. *A. Wesley*

sociation'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.[1–3] 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,[10] and one of his maps is included in Figure 2. We also published series by Lindberg for 2013E,[15] and Miles for 2017E.[18] 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 243.018d, accurately giving the surface longitude. Unfortunately, System II is based upon an

Table 2. Venus elongation data, 2007–'17

*SC**	*GEE**	*IC**	*GEW**	*SC**
2006 Oct 27	2007 Jun 9	2007 Aug 18	2007 Oct 28	2008 Jun 9
2008 Jun 9	2009 Jan 14	2009 Mar 27	2009 Jun 5	2010 Jan 11
2010 Jan 11	2010 Aug 20	2010 Oct 29	2011 Jan 8	2011 Aug 16
2011 Aug 16	2012 Mar 27	2012 Jun 6	2012 Aug 15	2013 Mar 28
2013 Mar 28	2013 Nov 1	2014 Jan 11	2014 Mar 22	2014 Oct 25
2014 Oct 25	2015 Jun 6	2015 Aug 15	2015 Oct 26	2016 Jun 6
2016 Jun 6	2017 Jan 12	2017 Mar 25	2017 Jun 3	2018 Jan 9

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

Table 3. Venus inferior conjunctions, 2007–'17

Inferior conjunction	*Angular separation from the Sun (deg, arcmin)*
2007 Aug 18	–7° 59′
2009 Mar 27	+8° 10′
2010 Oct 29	–5° 59′
2012 Jun 6	+0° 09′ (transit)
2014 Jan 11	+5° 11′
2015 Aug 15	–7° 51′
2017 Mar 25	+8° 18′

Table 1. Observers of Venus, 2007–'17 *(Cont'd)*

See continuation on p. 80 for explanatory notes

Name	*Location*	*Instruments*	*Elongations+*
M. Giuntoli	Montecatini Terme, Italy	80mm OG, 127mm MKT & 203mm SCT	A–B, E–N
D. L. Graham	Richmond, N. Yorks.	152mm OG & 230mm MKT	ABGMN
D. Gray	Kirk Merrington, Co. Durham	415mm DKC	A–C, FHJKM
P. T. Grego	St. Dennis, Cornwall	203mm SCT & 305mm refl.	EG
M. Griffiths*	Bridgend, Mid Glam.	100mm OG	C
W. H. Haas	Las Cruces, NM, USA	203mm refl.	AC
B. Halls*	Lancing, West Sussex	152mm OG	GI
I. Hancock*	Canterbury, Kent	222mm refl. & 254mm SCT	A–C
A. W. Heath	Long Eaton, Notts.	76mm OG, 203mm MKT & 254mm refl.	A–E, G–I, KM
M. Hezzlewood	Burnley, Lancs.	100mm OG	M
R. Hill*	Tucson, AZ, USA	203MKT & 355mm SCT	EGIKM
D. A. Holt	Buntingford, Herts.	350mm refl.	BC
C. J. Hooker	Didcot, Oxon.	203mm MKT	AB
R. Humphrey	Bristol	90mm MKT	AB
T. Ikemura*	Nagoya, Japan	310mm & 380mm refls.	ACE, G–J
W. Jaeschke*	West Chester, PA, USA	256mm SCT	EGK
N. D. James*	Chelmsford, Essex	279mm SCT	AM
S. Johnson	Plymouth, Devon	66mm OG & 254mm refl.	A–C, E–G
R. W. Johnson*	Ewell, Surrey	279mm & 305mm SCT	EGLM
G. F. Johnstone*	Birdingbury, Warwicks.	90mm MKT & 203mm SCT	A–C, GHKM
M. Kardasis*	Athens, Greece	279mm & 355mm SCT	G–I, KM
A. S. Kidd*	Cottered, Herts.	355mm SCT	KN
M. Kilner*	Broadstairs, Kent	102mm OG	A
B. A. Kingsley	Maidenhead, Berks.	100mm OG & 279mm SCT	A–C
W. Kivits*	Siebengewald, Holland	355mm SCT	A–H
S. Kowollik*	Ludwigsburg, Germany Zollern-Alb Obsy., Germany	203mm refl. & 800mm refl.	AC
G. Lampert	Dornbirn, Austria	110mm Schiefspiegler	G
P. R. Lawrence	Selsey, W. Sussex	355mm SCT & 102mm OG	BGKL
P. R. Lazzarotti* (with P. Orecchiella)	Massa, Italy	315mm refl.	ABD
W. J. Leatherbarrow*	Sheffield	80mm & 127mm OGs; 235mm SCT & 305mm MKT	A–D, G, K–N
M. R. Lewis*	St. Albans	222mm & 444mm refls.	GKM
H-G. Lindberg*	Skultana, Sweden	254mm SNT & 180mm MKT	A, G–K
E. Lomeli*	Sacramento, CA, USA	235mm SCT	AB
N. Longshaw	Oldham, Lancs.	78mm OG, 90mm & 125mm MKT	A–C
P. Lyon	Birmingham	203mm SCT	A
L. T. Macdonald	Newbury, Berks.	222mm refl.	
D. McCracken*	Skellingthorpe, Lincs.	Digital camera	K
R. J. McKim	Oundle and Upper Benefield, Northants. Mnichovo Haradiste, Czech Republic	76 & 102mm OGs; 410mm DKC 70mm OG	A–C, E–G, I–K, M
S. Maksymowicz	Ecquevilly, France	100mm OG & 254mm Cass.	C–N

(Continued)

arbitrary period of 4.2d rather than the well-established long-term UV synodic period of almost exactly 4d. This leads to a large error of 17° with respect to the 4-day ephemeris, after even 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)d – in perfect accord with the classic work of Boyer (1975): 3.99525 (±0.00001)d.[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 ±6%. 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 3–5h apart, with 3h 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 6,052km, and the circumference at any latitude θ is 2πr cos θ. Account was taken of the latitude of the sub-Earth point, D_e (which, according to *WinJUPOS*, 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.

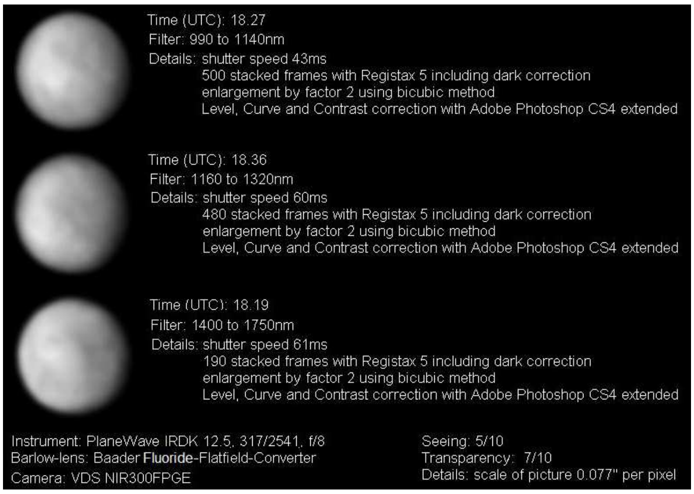

Figure 5. The variation in markings is shown at different wavelengths within the IR region, 2010 Apr 1. *G. & J. Ackermann*

Date (2007)	Latitude (°)	Angular motion (°)	Period (h)	Velocity (m/s)
Mar 11	–1	21.5	90.9	–116 ±11
Apr 14	–11	33.5	87.6	–118 ± 7
May 5	–16	7.8	126.0	–81 ±21
May 5	–12	8.9	125.4	–82 ±18
May 5	–12	24.2	86.7	–119 ±10
May 5	–1	11.7	84.0	–126 ±21
May 5	+10	23.7	88.6	–117 ±10
Jun 11	–2	18.3	99.8	–106 ±12
Jun 16	–2	20.2	88.2	–120 ±12

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.

Date (2009)	Latitude (°)	Angular motion (°)	Period (h)	Velocity (m/s)
Jul 23	–34	8.8	96.1	–91 ± 21
Jul 23	–15	10.6	79.8	–128 ± 24
Jul 23	–3	8.4	100.7	–105 ± 25
Jul 23	+6	8.2	103.2	–102 ± 25
Jul 23	+25	7.8	108.5	–88 ± 23

2010 E. Elongation

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

Date (2010)	Latitude (°)	Angular motion (°)	Period (h)	Velocity (m/s)
May 23	–43	14.2	91.7	–84 ± 12
May 23	–23	14.2	91.7	–106 ± 15
May 23	–12	17.3	75.3	–137 ± 16
May 23	+5	12.1	107.6	–98 ± 16
May 23	+5	16.7	78.0	–135 ± 16
May 25	+1	16.9	73.5	–144 ± 17
May 26	–46	12.8	97.5	–75 ± 12
May 26	–31	16.0	78.0	–116 ± 15
May 26	–26	14.8	84.3	–112 ± 15
May 26	–11	10.8	115.6	–90 ± 17
May 26	0	10.6	117.7	–90 ± 17
May 26	+11	10.8	115.6	–90 ± 17

2012 E. Elongation

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

Date (2012)	Latitude (°)	Angular motion (°)	Period (h)	Velocity (m/s)
Mar 11	–1	23.1	87.0	–121 ± 10

2012 W. Elongation

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

Date (2012)	Latitude (°)	Angular motion (°)	Period (h)	Velocity (m/s)
Sep 16	+17	20.9	114.8	–88 ± 8

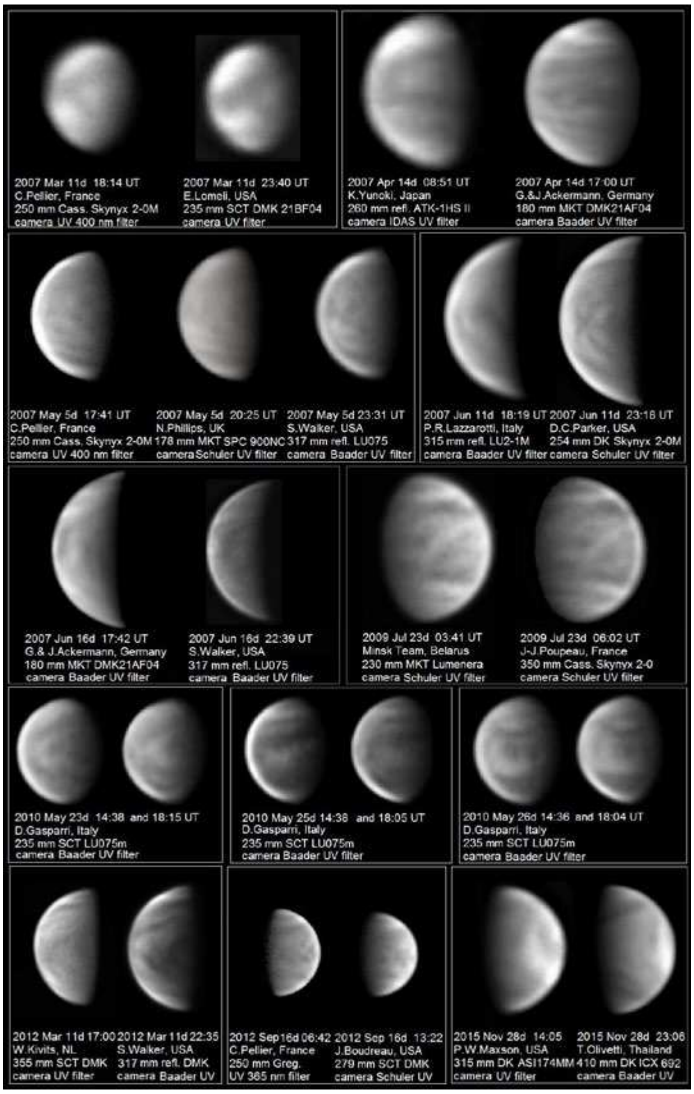

Figure 6. Image pairs for atmospheric velocity determinations, at 2007E, 2009W & 2015W. Filter maximum transmissions and bandwidth half-maximum (BWHM): Baader UV, 350nm & 60nm, Schuler/Astrodon, 365nm & 60nm and IDAS/Hutech, 335nm & 70nm.

2015 W. Elongation

One match, with an unusually long time interval (9h) was found (Figure 6).

Date (2015)	Latitude (°)	Angular motion (°)	Period (h)	Velocity (m/s)
Nov 28	–31	31.5	103.0	–88 ± 6
Nov 28	–10	27.2	119.3	–87 ± 6
Nov 28	–1	29.0	111.9	–94 ± 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.[28] The near-equatorial markings exhibit av-

Table 1. Observers of Venus, 2007–'17 *(Cont'd)*

See continuation on p. 80 for explanatory notes

Name	*Location*	*Instruments*	*Elongations*⁺
S. S. Massey*	Hervey Bay, Queensland, Australia	254mm & 305mm refl.	DI
M. Mattei*	Littleton, MA, USA	355mm SCT	H
P. W. Maxson*	Surprise, AZ, USA	254mm & 355mm SCT	A–E, KLM
F. J. Melillo*	Holtsville, New York, USA	203mm & 254mm SCT	A–E, G–N
C. Meredith*	Prestwich, Manchester	203mm SCT & 216mm refl.	AE
P. Miles*	Rubyvale, Queensland, Australia	508mm refl.	MN
M. P. Mobberley*	Bury St. Edmonds, Suffolk	245mm refl.	A
D. M. Moore*	Phoenix, Arizona, USA	362mm Cass.	A
E. Morales Rivera*	Aguadilla, Puerto Rico	310mm SCT	G
M. Morini*	Milan, Italy	279mm SCT	H
L. Morrone*	Agerola, Italy	279mm SCT	M
M. Nicholls*	Sheffield	180mm MKT	M
D. Niechoy	Göttingen, Germany	203mm SCT	*All*
T. Olivetti*	Bangkok, Thailand & Soiano del Lago, Italy	410mm DKC	ABEJKLM
R. Palgrave*	Newcastle upon Tyne	355mm SCT	M
R. W. Panther	Walgrave, Northants.	80mm & 90 mm OGs	CD, F–H, J
D. C. Parker*	Miami, FL, USA	254mm DKC	ACDG
P. W. Parish	Rainham, Kent	10×50 binos.	H
A. J. Paterson*	Fareham, Hants.	203mm SCT	A
D. A. Peach*	Selsey, W. Sussex	235mm & 355mm SCT	ACEGHKN
	Pic du Midi Obsy., France	1.06m Cass.	
C. Pellier*	Bruz & Paris, France	254mm Cass. & 250mm Gregorian	AC, G–I, KM
	Astroqueryas Obs., France	620mm Cass.	
I. S. Phelps	Warrington, Cheshire	216mm refl.	AC
N. Phillips*	Crayford, Kent	178mm MKT	A
M. Porter*	Petts Wood, Kent	178mm MKN	A
J-J. Poupeau*	Pecqueuse, France	355mm Cass.	C–H, LM
R. J. Prettyman*	Oadby, Leics.	235mm SCT	A
J-P. Prost*	Valbonne, France	212mm Cass.	A
D. Put*	Brielle, Netherlands	203mm refl. & 235mm SCT	AEF
M. Radice*	Salisbury, Wilts.	279mm SCT	M
A. Robertson	Broome, Norfolk	203mm MKN	F
A. H. Robinson*	Dawlish, Devon	279mm SCT	C
M. Salway*	Central Coast, NSW, Australia	305 mm refl.	A–D
D. Scanlan*	Romsey, Hants.	203mm SCT	K
G. J. Scheffer*	Malden, Netherlands	200mm MKT	C
R. W. Schmude	Barnesville GA, USA	130mm OG	AG
R. Schulz*	Vienna, Austria Namibia, Africa	320mm refl. & 505mm RCT	AM
R. Sedrani*	Pordenone, Italy	355mm SCT	M
I. D. Sharp*	Ham, Sussex	279mm SCT	C
W. P. Sheehan*	Flagstaff, AZ, USA	600mm OG	G
M. Smrekar (w. J. Atanackov & R. Pucer)	Swan Astron. Socy., Slovenia	254mm refl.	G
A. Snook	Dover	500mm refl.	M
J. Sussenbach*	Houten, Holland	235mm & 279mm SCT	A–I, KMN
A. Tasselli*	Lincoln	254mm refl.	ABG
C. Taylor	Hanwell	102mm OG	K
M. M. Taylor*	Leicester	203mm SCT	A
A. Tough*	Elgin, Moray, Scotland	235mm SCT	G
D. B. V. Tyler*	Flackwell Heath, Bucks.	355mm SCT	AG
Unione Astrofili Italiani (UAI)	*Various*	*Various*	GH
R. Vandebergh*	Wittem, Netherlands	254mm refl.	AB
A.van Kranenberg*	Vlaardingen, Netherlands	235mm SCT & 315mm Cass.	A–C

(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).

Latitude range (°)	*No. of features*	*Mean period (h)*	*Mean velocity (m/s)*
–41 to –50	2	95	–80
–31 to –40	3	92	–98
–21 to –30	2	88	–109
–11 to –20	7	100	–108
0 to –10	9	100	–107
0 to +10	6	95	–114
+11 to +20	2	115	–89
+21 to +30	1	108	–88

Boyer (1975) observed a wider range than us in instantaneous velocities.[28] The regular Y and ψ equatorial features seemed to accelerate during the morning, reaching a maximum velocity after subsolar 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).[29] However, both results showed a hemispherical inequality, with the longest periods found in the north. Limaye has reviewed later data up to 2007.[30] Sanchez-Lavega *et al.* (2016) report recent ground-based results including those from the *Galileo* and *VEX* instruments, up to the *Akatsuki* mission.[27] 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 VIRTIS instruments) were in general accord.[31,32] 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 2015W showed considerably less turbulence than the afternoon markings during 2015E.[27] 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 disk 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.[2] Faint, near-horizontal banding characterises 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.

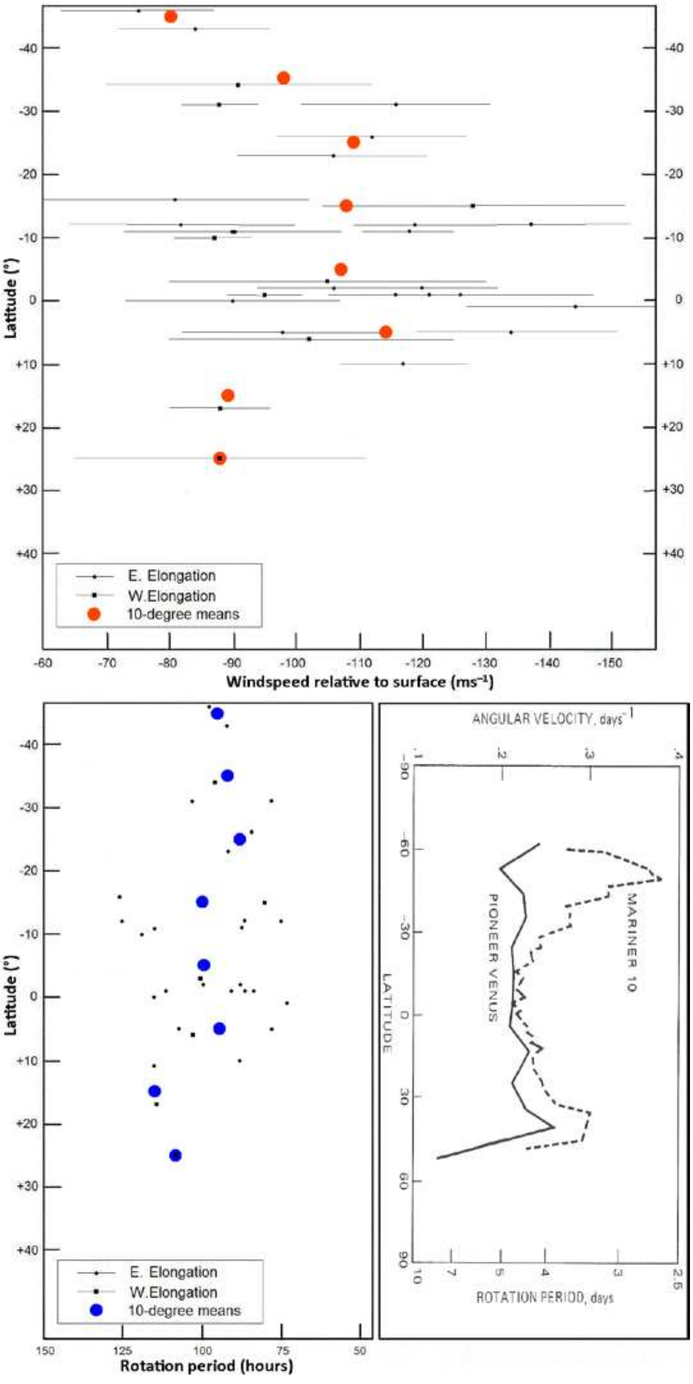

Figure 7. Atmospheric wind profile (*Top:* latitude *vs.* wind velocity relative to the surface; *bottom:* latitude *vs.* rotation period), determined from BAA observations. Means in 10° of latitude have been added. *Lower right:* rotation period data, at a different scale, from *Mariner 10* and *Pioneer Venus.*[29]

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

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.[6] BAA colour filter visual work dates back to 1956 – Hedley Robinson and Alan Heath, two early visual filter pioneers, recount the story elsewhere.[33–35]

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

Table 4. Venus phase anomaly date, 2007–'14

Elongation	*Date of dichotomy*		*Anomaly**	
	Predicted	*Observed**		
2007E	Jun 8.65	Jun 5.3	3.4d	early
2007W	Oct 27.64	Oct 31	4d	late
2009E	Jan 17.02	Jan 13	4d	early
2009W	Jun 6.61	Jun 10	4d	late
2010E	Aug 17.64	Aug 12	5d	early
2011W	Jan 8.28	Jan 12	4d	late
2012E	Mar 29.34	Mar 22	7d	early
2012W	Aug 15.18	Aug 21	6d	late
2013E	Oct 31.14	Oct 25	6d	early
2014W	Mar 23.73	Mar 29	6d	late
2015E	Jun 6.38	Jun 1	5d	early
2015W	Oct 25.27	Oct 29	4d	late
2017E	Jan 14.56	Jan 9	5d	early
2017W	Jun 4.26	Jun 8	4d	late

* 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)*

Name	*Location*	*Instruments*	*Elongations*+
C. van Ruissen	Netherlands	305mm refl.	A
J. Vetterlein*	Rousay, Orkney	175mm MKT & 100mm OG	A–C, FG
A. Vincent*	Worthing, Sussex	Digital camera	E
S. Walker*	Chester, NH, USA	254mm & 317mm refl.	ABDG
A. Wesley*	Murrambateman & Rubyvale, Australia	406mm refl.	IKMN
P. Welters*	Deventer, Netherlands	210mm DKC	C
W. J. Wilson	Chester	203mm SCT	ACD
P. B. Withers*	Romsey, Hants.	355mm SCT	G
K. Yunoki*	Sakai City, Japan	260mm refl.	A–H

+A= 2007E; B= 2007W; C= 2009E; D= 2009W; E= 2010E; F= 2011W; G= 2012E; H= 2012W; I= 2013E; J= 2014W; K= 2015E; L= 2015W; M= 2017E; N= 2017W. We exclude those observers who reported only the 2012 transit.

* 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, Morrone & Sedrani were sent by R. Braga, UAI Venus Coordinator. Observations by Lampert were sent by Niechoy, those of Finnigan by Robertson and those of Scheffer, van Ruissen and Welters by Adelaar. An observation by Ferrario was forwarded by Giuntoli. Niechoy's records for elongaions 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:

Cass.= Cassegrain; DK= Dall-Kirkham, DKC= Dall-Kirkham Cassegrain, MKT= Maksutov-Cassegrain (Telescope), MKN= Maksutov-Newtonian, RCT= Ritchey-Chrétien, SCT= Schmidt-Cassegrain and SNT= Schmidt-Newtonian.

(2000).[36] 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 Astrofili Italiani* (UAI) data for 2012E & 2012W,[37] and of his personal work for 2015W, concluded:

2012E	4.6d early
2012W	4.7d late
2015W	9d late

The terminator

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

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.

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 8, 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

McKim 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); Abel also saw the N. horn sharper than the S. on Mar 24. Heath saw the terminator straight on Mar 24–26, as did Leatherbarrow on Mar 24–25. In good seeing on May 12, Heath reported irregularities along the terminator.

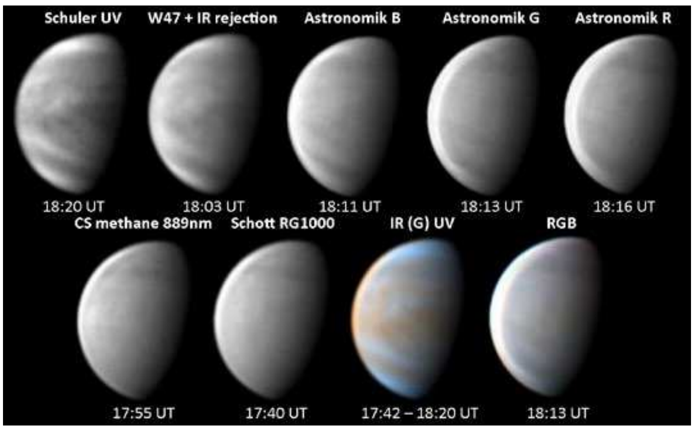

Figure 8. Filter images with 235mm SCT and Lumenera Skynyx camera, 2007 Apr 2. Note the gradual variation in the markings across the visible spectrum. In particular, note how the high latitude northern dark belt is best seen at short wavelength and the one at high S. latitude at long wavelength. The 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*

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

Niechoy 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.

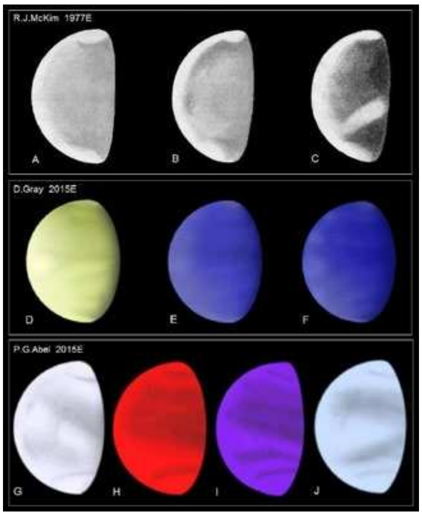

Figure 9. Visual filter drawing sequences. *Top row*: 1976 Dec 28d; **(A)** W25 15:58 UT, **(B)** W15 16:06 UT & **(C)** W44A 16:14 UT; 216mm refl., ×232, *R. J. McKim*. *Second row*: 2015 Apr 4d 14:50–15:55 UT; **(D)** W15 + W58, **(E)** W47B, & **(F)** W47B + W38A; 415mm DK Cass., ×365, *D.Gray*. *Bottom row*: 2015 Apr 14d; **(G)** No filter 19:22 UT, **(H)** W25 19:40 UT, **(I)** W47 19:51 UT & **(J)** W82A 20:01 UT, 152mm OG, ×176, *P. G. Abel*.

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 Macsymowicz on Jun 13 & 17 saw any unusual appearance.

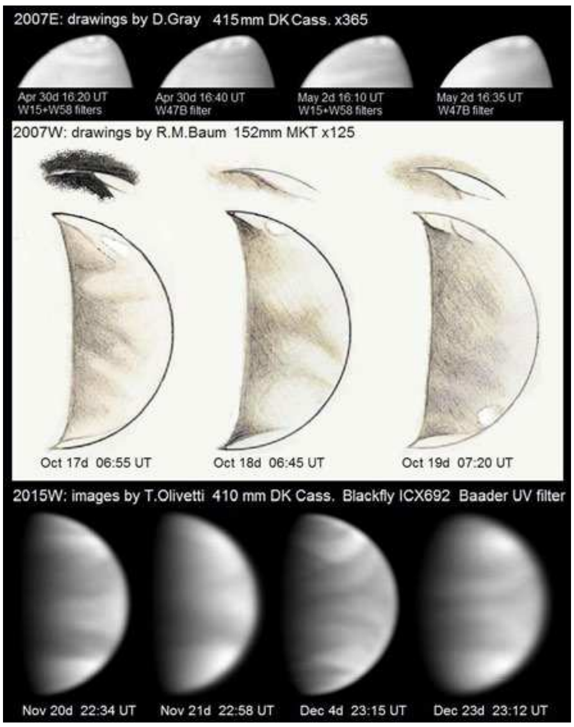

Figure 10. Illustrating aspects of the cusps, 1975–2015. The insets above Baum's drawing show additional details suspected to be extending from the S. cusp.

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 small 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 (Arditti) 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 knotted 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 NCC and SCC 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.

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 no 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 rarely 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 July 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.[10]

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.[12]

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.[15] 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 cusp-caps were equal during June. During Jul–Sep the cusp-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 light 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 unremarkable 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 ψ 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.

2007E

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

From the UV images: Apr 2 (S*p.*, Pellier), 9 (S. of disk centre, Lazzarotti), 14 (S*p.*, several observers), 18 (N*p.*, Pellier), 22 (*p.* side near equator, Lazzarotti (Figure 1(A))) & 23 (near disk centre, Gasparri); May 2 (S*p.*, Ackermanns), 3 (S*p.*, Pellier), 29 (S*p.*, Peach) & 30 (*p.*, Peach); Jun 10 (S*p.*, 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 (N*f.*, Baum), 20 (S*f.*, Niechoy) & 23 (N*f.*, Leatherbarrow); Nov 15 (N. hemisphere streak, Baum); Dec 13 (S*f.*, Adamoli & Baum) and 2008 Mar 19 (S*f.*, Niechoy).

Of the UV data, Oct 23 (S*f.*, Sussenbach & Tasselli) should be cited.

2009E

Visual work: 2008 Dec 7 (S*p.*, Adamoli) & 14 (S*p.*, Niechoy); 2009 Jan 3 (N. hemisphere streak, McKim), 21 (*p.*, S*p.* & S. disk, Gray), 22 & 24 (S*p.*, Gray); Jan 31 & Feb 7 (S*p.*, McKim), Feb 3 (*p.* & S*p.*, Gray), 6 (S*p.*, *p.* & N*p.*, Gray), 10 (S*p.* Leatherbarrow & Phelps; N*p.*, Phelps), 11 (S*p.*, Leatherbarrow), 13 & 19 (*p.* & N*p.*, McKim); and lastly Mar 1 (N*p.*, Davies & McKim).

From the UV image archive, we cite the Ackermanns, Dec 30 & Jan 1 (N*p.*).

2009W

Visual work: May 21, 23 (*f.*, Macsymowicz), Jun 22 (*f.*, Niechoy), Jul 20 (S*f.*, Adamoli) & Aug 23 (S*f.*, Niechoy).

In the UV images, an extremely bright spot upon the S*f.* limb was recorded by Kivits (10:57 UT) and Mellilo (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 7h. It was located just N. of the edge of the existing light S. cuspidal area, 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.[8] 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 Maxson 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 ALPO 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 (S*f.* & N*f.*), one being at the same latitude as the July clouds.

None of these features showed up upon any IR image.

2010E

Visual work: May 17 (S*p.*, Adamoli) & 22 (S*p.*, Niechoy); Jun 3 (N. terminator, Niechoy), 11 (S*p.*, Macsymowicz), 24 (N*p.*, Niechoy), 25 (*p.*, Macsymowicz) & 29 (*p.*, Adamoli); Jul 2 (N*p.*, Niechoy), 30 (*p.*, Macsymowicz) & Aug 14 (*p.*, and N*p.*, Niechoy).

Yunoki's UV image of May 16 has a bright area at the S*p.* limb.

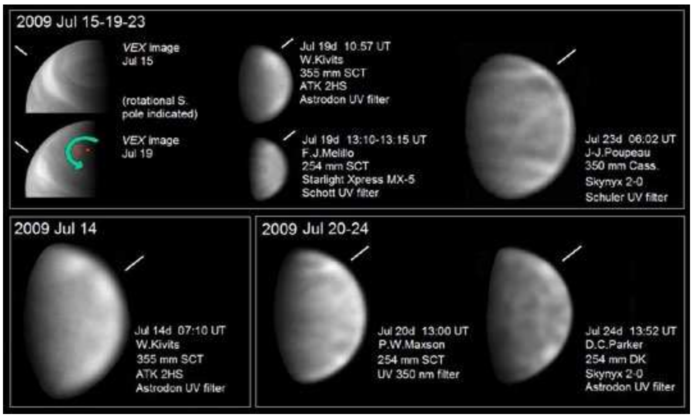

Figure 11. Illustrating the large, brilliant cloud outbreaks near latitude –50° at the 2009 western elongation.

2011W

Visual work: 2010 Dec 9 (*f.*, Gray), 2011 Jan 3 (S*f.*, Niechoy) & 18 (S*f.* quadrant, two small areas, Gray); May 22 (N*f.*, Niechoy, confirmed on Put's UV image two rotations later on Jun 3) & Jun 2 (N*f.*, Macsymowiz, 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.

Figure 12. Venus nearing inferior conjunction, 2015 Jul 25–Aug 8. 355mm SCT, 742mm IR pass filter and ASI174MM camera. North is uppermost. *P. R. Lawrence*

2012E

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

Gasparri's and Sussenbach's Jan 16 images show a number of UV-bright clouds upon the central disk.

2012W

Visual work: Jul 24 (*f.*, Niechoy), & Oct 19 (N*f.*, Gray).
UV work: Jul 22 & 25 (N*f.*, Lindberg).

2013E

As illustrated in the *Journal*,[16] a particularly bright area was seen in visual work at the S*p.* limb by Heath, on 2013 Dec 31. Other bright areas were: 2013 Aug 19 (S*p.*, Macsymowicz) & 27 (S. disk, Niechoy); Sep 5 (S*p.*, Niechoy); Dec 1 (N*p.*, McKim), 10 (*p.*, Niechoy), 13 (*p.*, Braga), 26 (*p.*, McKim); & 2014 Jan 2 (S*p.*, fainter than Dec 31, Heath).
UV images by Lindberg show the expansion of a bright area along the S*p.* limb,[15] confluent with the SCC, after Jul 12 (this was noted earlier,[15] where we referred to the N*f.* 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 (S*f.*, Gray).

Lindberg's UV images show a large bright area at the N*f.* limb on May 25.

2015E

Visual work: Feb 22 (*f.*, Niechoy) & 24 (*p.*, Macsymowicz); Apr 5 (S*f.*, *f.* & N*f.*, Gray (Figure 9)), 12 (S*f.*, Colombo), 17 (S*f.* near the SCC, Gray & Niechoy, both with W25) & 21 (S*f.*, Niechoy, W25); May 7 (*f.*, Macsymowicz and N*f.*, Niechoy), 11 (near disk centre, Abel), 23 (*f.*, McKim), 25 (*p.*, Macsymowicz) & 29 (S*f.* & *f.*, Braga & McKim); Jun 3 (S*f.*, Braga (confirmed by several UV images)), 4 (*f.*, Niechoy – confirmed by Sussenbach's UV image), 5–7 (N*f.*, McKim), 10 (S*f.*, McKim), 15 (N*f.*, McKim), 20 (*f.*, Colombo), 21 (S*p.*, Giuntoli), 23 & 28 (N*f.*, 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 (N*f.*, Olivetti) & 27 (N*f.*, Maxon); Nov 6 (S*f.*, Maxson), 9 (S*f.*, *f.* & N*f.*, Maxson), 14 (S*f.*, Maxson), 18 (*f.*, Maxson), 23 (N*f.*, Maxson), 27 (S*f.*, Melilo) & 28 (N*f.*, *f.*, Maxson & Olivetti); Dec 4 & 11 (S. & N. hemispheres, Olivetti (Figure 10)), 6 (S*f.*, Melillo) & 23 (S*f.*, N. hemisphere, Olivetti (Figure 10)).

2017E

Visual work: 2017 Jan 5 (S*p.*, Abel & N*f.*, McKim),[18] 11 (*p.*, McKim – confirmed in UV image by Miles), 14 (S*p.*, two small patches, McKim),[18] & 17 (*p.*, Macsymowicz); & Feb 4 (S*p.* & N*p.*, Gray (W47B)) & 18 (N*p*, McKim).

UV work (Figure 4): 2016 Oct 5, 7, 9, 12–15, 17–18, 25, 26, 28 (N*p.*, Wesley), 11, 15, 16, 21, 30 (central disk, Wesley), 13, 14, 17, 18, 21, 24–28 (N. hemisphere, Miles), 15 (S. hemisphere, Wesley) & 30 (central disk, Miles); Nov 6, 7, 11 (N*p.*, Miles), 8, 14, 23, 27 (near disk centre, Miles), 20 & 30 (N. hemisphere, Miles); Dec 2, 5 (N*p.*, Miles), 4 (near equator, Miles, and N*p.*, Melillo), 6 (*p.* & N*p.*, Miles) & 29 (N*p.*, Pellier); 2017 Jan 2 (*p.*, Lewis), 8 (N*p.*, Miles), 11 (*p.*, Miles), 12 (N*p.*, Maxson), 13 (N*p.*, Miles, Olivetti), 16 (S. hemisphere, Miles), 17, 19 & 21 (N*p.*, 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 (N*f.*, Melillo) & 25 (N. hemisphere, *f.*, Melillo); Jul 3, 8, 10 (N*f.*, Melillo) & 18 (N*f.*, Braga); Aug 24 (N*f.*, Melillo), 25 (*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–'98,[1] 1999–2006,[3] & 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 too 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.[38] Prof F. W. Taylor has commented:[39] '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 overlain 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_e= –4.3°) – showing small and well-defined bright spots upon the mid-disk – must have represented some extraordinary activity to have been visible in white light.[40,41] 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 be linked to ongoing surface volcanism.[42]

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 'cusps') 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,[3] 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:

Date(s)	*Observer*	*Angular extension (°)*
Jul 21	Hancock	Small, equal extensions
Jul 27	Adamoli	220°
Jul 27	Hancock	Longer extension to N. than S; S. extension fragmented
Jul 28	McKim	Small, equal extensions
Jul 31	Adamoli	245°; S. longer
Aug 5	McKim	225°, S. longer
Aug 9	McKim	270°; S. longer
Aug 11	McKim	300°; S. longer
Aug 12	Adamoli	S. extension longer than N.
Aug 13	McKim	Extensions obvious to 270°; moments when complete 360° circle glimpsed (Figure 13(A))
Aug 15	Wilson	Usually only 160° arc seen, but at times, hair-like extensions continued to nearly 360°
	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.

Date(s)	*Observer*	*Angular extension (°)*
Mar 10	Baum & McKim	Small extensions
Mar 14	McKim	190°
Mar 15	Baum	195°; NC (regular) 5°, SC (broken) 10°
Mar 16	Baum	200°
Mar 17	Haas	205°; S. longer
Mar 18	Baum & Phelps	200°
Mar 18	McKim	225°
Mar 19	Baum	260°
Mar 20	Baum	270°
Mar 21	Adamoli	260°; NC 60°, SC 20°
Mar 21	Baum	310°
Mar 22	Adamoli	280°; NC 60°, SC 40°
Mar 22	Baum	310°
Mar 23	Longshaw	275°
Mar 24	Adamoli	320°; NC 80°, SC 60°
Mar 26	Adamoli	360° (Figure 13(B))
Mar 26	Baum	360°
	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).

Date(s)	*Observer*	*Angular extension (°)*
Oct 19	Adamoli	200°; NC 20°, SC 0°
Oct 21	Adamoli	225°; NC 20°, SC 25°
Oct 27	Adamoli	Extensions obvious to 300°; NC 60°, SC 60°; full circle suspected
Oct 29	Adamoli	Extensions obvious to 305°; NC 45°, SC 80°; full circle suspected
	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.

Date(s)	*Observer*	*Angular extension (°)*
May 21	McKim	190°
May 22	Adamoli	200°; NC & SC, 10° each
May 22, 25	McKim	200°; NC & SC, 10° each
May 24	Niechoy	245°; SC brighter
May 26	Adamoli	220°; NC & SC, 20° each
May 27	Adamoli	240°; NC & SC, 30° each (S. brighter)
May 29	Adamoli	275°; NC 35°, SC 60° (S. brighter); glimpses of full circle
Jun 3	Peach	270°
Jun 4	Kardasis, Lawrence & Sussenbach	Complete circle clearly imaged

Cont'd overleaf

2012E & 2012W (cont'd)

Date(s)	*Observer*	*Angular extension (°)*
Jun 5	Srekar *et al.*	Complete circle clearly imaged (Figure 13(C))
	After IC:	
Jun 8	Kivits	Complete circle clearly imaged (Figure 13(D))
Jun 9	Adamoli	260°; NC 20°, SC 60°
Jun 9	Johnstone	Extensions to *ca.* 240° imaged
Jun 9	Macsymowicz	Complete circle faintly observed
Jun 13, 16	Adamoli	210°; NC & SC 15° each (125mm MKT)
Jun 16	Giuntoli	Complete, very faint circle suspected (203mm SCT)

2013E & 2014W

Adamoli alone suspected the full circle close to IC.

Date(s)	*Observer*	*Angular extension (°)*
Dec 26	McKim	Slight extensions at NC & SC, 5° each
Dec 27, 29	Adamoli	SC extension 15°
Dec 31	Adamoli	SC extension 25°
Dec 31, Jan 6	Giuntoli	Slight extensions at NC & SC
Jan 6	Adamoli	280° certain; NC 40°, SC 60°; complete circle suspected
	After IC:	
Jan 22	Adamoli	SC extension 15°

2015E & 2015W

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

Date(s)	*Observer*	*Angular extension (°)*
Jul 27–Aug 9	Niechoy	Small extensions seen
Aug 8	Peach	Crescent extends to 190° (IR image)
Aug 9	Abel & Braga	Slight extensions
Aug 15	Lawrence	Crescent extends to 206° (IR image)
Aug 18	Braga	Both cusps extended
	After IC:	
Aug 18	Adamoli	SC extends 30° (extension only suspected in N.)
Aug 18	Braga	Both cusps slightly extended
Aug 20	Adamoli	Crescent extends to *ca.* 220°
Aug 21	Niechoy	Small extensions seen

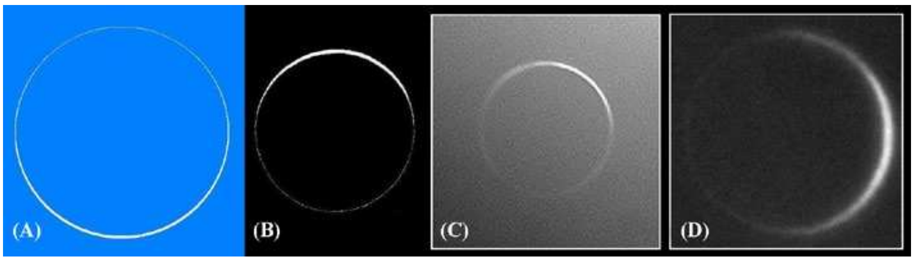

Figure 13. Showing the horns extended to the complete circle near inferior conjunction. **(A)** 2007 Aug 13d 15:00 UT, 102mm OG ×40, white light drawing by *R. J. McKim*. **(B)** 2009 Mar 26d 12:10 UT, 125mm MKT ×150, white light drawing by *G. Adamoli*. **(C)** 2012 Jun 5d 20:45 UT, 254mm refl., image 100mm off-axis mask, Astrodon UV filter and Basler Ace ac640-100gm camera, *M. Srekar*. **(D)** 2012 Jun 8d 06:13 UT, 355mm SCT, image with DMK camera and 990nm filter (long-wavelength), *W. Kivits*.

2017E & 2017W

At IC in 2009 the full circle had been seen by Adamoli, Baum & Wilson, whereas at this comparable elongation in 2017, extensions never reached three-quarters of a circle. Adamoli did consider that a faint line of light extended all round the dark limb on Mar 25, but had dismissed earlier sightings of this effect as illusory.

Date(s)	*Observer*	*Angular extension (°)*
Mar 11–24	Niechoy	Slight extensions seen
Mar 14	McKim	Extensions to 200°
Mar 15, 20	McKim	Extensions to 210°
Mar 15	Lewis	Slight extensions (IR image)
Mar 17	Adamoli	Extensions to *ca.* 250°
March 19, 25	Graham	Extensions to 210°
Mar 22–25	Sussenbach	Extensions to *ca.* 200°
Mar 23	Abel	Extensions to 215°
Mar 25	Abel	Extensions to 200°
Mar 25	McKim	Extensions to 210°
Mar 25	Macsymowicz	Extensions to *ca.* 240°
Mar 25	Akutsu	Extensions to *ca.* 205°
	After IC:	
Mar 26–28	Niechoy	Slight extensions seen
Mar 27	Macsymowicz	Extensions to *ca.* 230°
Apr 9	Adamoli	Very faint extension of S. cusp, only by *ca.* 35°

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 OG, 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.[43] 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.[24]

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.[44] G. D. Roth quotes the formula of E. Schoenberg.[45] 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 occcultation by the Moon on 2007 Jun 18.[5] Images were supplied by Dowdell, Kilner, Niechoy, Patterson, Porter and Vetterlein, while Kowollik 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, Griffths, 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.

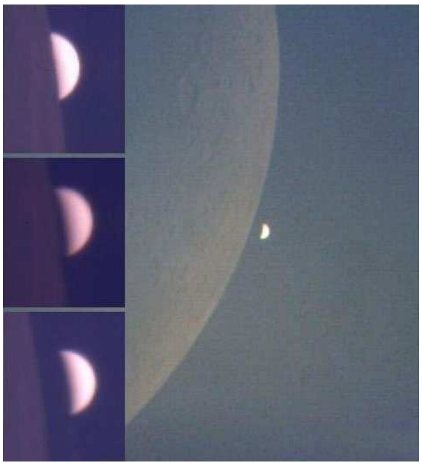

Figure 14. The lunar occultation, 2007 Jun 18. *Left panel:* 800mm refl., reappearance frames from webcam video, *S. Kowollik*. *Right:* reappearance image taken with digital camera and 203mm SCT, *D. Niechoy*. North is uppermost in all these images.

Figure 15. The lunar occultation of 2008 Dec 1, taken from Stonehenge with a digital camera. Venus is at the lunar limb, with Jupiter above and to the right. *B. A. Kingsley*

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 Jun–Jul, members watched another close encounter between Venus and Jupiter, as previously reported and illustrated here in Figure 18.[17] On 2016 Jan 9, Arditti 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.

A Venusian green flash

This is a rare phenomenon and a recent report by David Gray, on 2016 Nov 2, has already appeared.[48]

It is appropriate to close this report with another green flash observation from the late Richard Baum. On 2010 Mar 1 he saw Venus low in the WSW, 18:14–18:43 UT. '*A sparkling gem deepening to a shade of amber-yellow, approaching a gap between trees and houses and a clear bit of the skyline formed by the Clwyd hills. I watched through 15×70 binoculars… Now dimmer and of a deeper shade of orange-yellow, I followed it down to the edge of the skyline where it hovered for a fraction of a second on the verge of extinction so it seemed, before breaking up into glittering star-like fragments. To my utter astonishment, the last fragment stood on the edge of the hill, a gorgeous sapphire with green facets, and as if in salute twinkled and vanished.*'[49,50]

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Figure 16. The lunar occultation of 2010 May 16. From left to right: 10:53, 11:15, 11:46 & 11:53 UT. 60mm OG and DSLR. *T. Akutsu*

Figure 17. The 2012 Apr 5 conjunction of Venus with the Pleiades, taken with a wide angle lens and digital camera. *J. Cooper*

Figure 18. The close conjunction of Venus and Jupiter in the evening sky on 2015 Jun 30, photographed from Montecassiano, Italy. *C. Fattinnanzi*

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Submitted 2018 March 1; accepted 2018 May 30