Jupiter in 2010/11: Report no.24 (2011 Sep.17)

The SEB Revival: final interim report

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Our previous reports in this series have covered the SEB Revival up to mid-January, 2011, all summarised in report no.21:
<http://www.britastro.org/jupiter/2010report20.htm>
Here we continue the story and analysis up to the end of hi-res imaging, in mid-Feb., and on to the end of the apparition in March.

The previously reported types of activity in the source, central branch, and southern branch, are confirmed extended. It is especially notable that the SEB(S) became repopulated by slowly-retrograding chains of white ovals even as dark spots were still retrograding much faster. The origin of the northern branch, and interactions of all three branches with the GRS, are also described. The main parameters of this SEB Revival as a whole are summarised in Table 2.

For the most complete sets of images, from 2010 Nov. 7 to 2011 Mar. 9, scaled and aligned, see the compilations by Yuichi Iga ['The SEB Revival in 2010-2011']:
http://alpo-j.asahikawa-med.ac.jp/kk11/Jupiter_SEB-Revival/index.htm
For a set of maps up to early Feb., see Fig.1 (compiled by Marco Vedovato). Compilations of the higher-resolution images of certain regions are also included as figures in this report.

We are very grateful to all the observers, whose details will all be listed in Report no.25.

I. The source and central branch, mid-Jan. to mid-Feb.

The overall structure of the Revival continued as before (Fig.2), with new bright spots appearing in the source region near L2 ~300; and very complex disturbance p. this comprising the central branch (which was now too complex to track individual spots, and showed extensive reddish-brown colour); and an oblique leading edge of the central branch, prograding towards the GRS.

At the source, further small brilliant white spots appeared on:
Jan.3/4 (L2 = 293; WS13; methane-bright on Jan.9);
Jan.14 (L2 = 307; but failed to grow, and was not visible after Jan.15);
Feb.5 (L2 = 305, lat.15.5 S; also very methane-bright [M.Delcroix]; disappeared by Feb.8 & 9 [Parker, Akutsu]).
This list may be incomplete because obs'ns were sparser at this late stage of the apparition; however, the plumes were certainly less frequent and less persistent than before.

The leading edge prograded with average speed DL2 ~ -32 deg/month (Nov.21-Feb.18), but it was of course irregular in shape (often being disrupted by the bright spots which we have described in earlier reports) and in motion. It was roughly stationary in L2 in early Dec. and mid-late Jan., but had DL2 ~ -42 deg/mth at other times.

The leading edge reached the Red Spot Hollow (RSH) about Feb.20 (Fig.3). It was not obvious whether this caused any change, as the RSH was already much darkened by material from the northern branch, and it was too late for hi-res imaging. However, it may have contributed to the emergence of a S. Tropical Band soon after (see below).

II. The northern branch: SEB(N), mid-Jan. to mid-Feb.

In Report no.21, we described the limited amount of disturbance on SEB(N) in the early stages of the Revival. Now we can add a preliminary summary of JUPOS data, and an account of the more substantial northern branch that developed from Jan.5 onwards. (See Appendix 1 for further details.)

The northern branch really began on Jan.5, as described in Report no.21, when the narrow SEB(N) p. the central branch suddenly broke up into an impressive series of 9 dark spots (Fig.4). They had a range of speeds from DL2 ~ -150 (near the p. end of the series, over just a few days) to DL2 ~ -90 (at the f. end of the series, later) (Fig.5). Thus the separation of the spots increased from 6 deg.(Jan.5) to 9 deg.(Jan.12), as they approached the GRS.

As they prograded past the GRS, successive spots formed a large, extremely dark, bluish-black spot on its N edge (just as in the 1990 SEB Revival). This spot appeared to be roughly fixed there, but this was an illusion due to successive spots becoming very dark as they passed through this position. The tracks of these spots were often disturbed as they passed the GRS, but did not show systematic change of speed.

After passing the GRS, in Jan.-Feb., the spots had DL2 ~-125, spacing 9 deg. They were tracked until ~Feb.10 when the leading edge of the series was near L2 ~40.

III. The southern branch: SEB(S), mid-Jan. to mid-Feb.

Since dark material on SEB(S) first reached the RSH in mid-Jan. [see Report no.20], the SEB(S) was fully revived from the source (L2 ~ 300) to the Red Spot Hollow (RSH: L2 ~ 160). The SEBZ alongside it was still bright white, unaffected by the Revival. Within the revived SEB(S) [hereinafter, "the belt"], and along its S edge, there were many dark spots (Figs.6-8): large and conspicuous near the source, but decreasingly so at higher longitudes, where the belt was instead perforated by a chain of small white ovals (visible only in hi-res images). The dark spots tended to fade away as they retrograded to high longitudes, and the chain of white ovals was reappearing, to dominate the structure of the belt. In fact, only one substantial dark spot (DS3=A) got as far as the RSH.

Dark spots:
Details of these dark spots are in Appendix 2. This analysis shows that, during this period, the faster-retrograding spots disappeared, while slower-retrograding speeds developed, so drifts (DL2) varied from +70 deg/mth to ~0, in a very complex pattern (Fig.9). (NB: In this section on SEB(S), 'fast' and 'slow' refer to speeds in the retrograding direction.)

After DS3 had disappeared into the RSH, other leading spots (P1, DS1, etc.) had faded away and/or moved south and decelerated. A cluster of conspicuous dark spots (initially labelled E to K) had formed a very dark complex on the S edge. It was reduced to just one conspicuous dark streak (F) in mid-Jan., then in Feb. there were 4 short dark streaks on the S edge in this sector (J1-J4). Behind them (further p.) came the two most conspicuous and southerly dark spots, P and T, which had decelerating retrograding speeds and remained quite close to the source. Spot P was initially a very dark oval, later a ring with light (reddish?) interior, and was the only dark spot which looked like a vortex.

The chain of white ovals in the revived SEB(S):
We earlier reported speeds for the pre-existing chain of ovals in Nov. at longitudes not yet affected by the Revival: mean DL2 = +71 (Nov.1-25). This speed was maintained in Dec. for the same sector ('Sector 0'), which was initially ahead of the Revival, but was overtaken by dark spot P1 in its final days.

The reviving SEB(S) is here divided into two sectors (Figs.1 & 9). Sector 1 extended from DS3(A) to the main dark complex (G,F etc.), in Jan., where other substantial dark spots faded away and the chain of white ovals appeared to be re-establishing itself. The mean speed was DL2 = +51, both for small dark spots between the ovals (a,b,c), and for the white ovals themselves (lat.20.5 S), confirming that the revived chain of ovals had the original slowly-retrograding speed – half the speed of the normal jetstream and the early dark spots of the Revival, even though they were in the same latitude!

Sector 2 was alongside or within the major dark features (M, G-F, J1-J4, etc.). Here too, white ovals were reappearing, and showed essentially the same speed and latitude as in Sector 1 (DL2 = +44 to +55; lat.20.3 S). Note that the chain of ovals generally had higher retrograding speed at higher longitudes.

Conclusions (Summary):
There were only a few well-defined rapidly-retrograding dark spots in the southern branch of this Revival (P1, DS1-DS6; DL2 ~ +108 to +134 deg/month) and these were not vortices and were not stable. Only DS3 persisted as far as the GRS. The others faded away and/or moved to the south edge of the SEB(S) (lat.22 S), and decelerated to DL2 ~ +34 to +60. Other dark spots within the SEB(S) may have had rapid retrograding speeds but were transient, and were progressively replaced by a re-forming chain of white ovals within the broad dark revived SEB(S), with slow retrograding speeds. The speed of this chain of white ovals was the same as before at high longitudes (DL2 ~ +70), and even slower towards lower longitudes (DL2 +57 to +43).

The drift rates and latitudes for the southern-branch spots, over the whole Revival, are summarised in Table 1 and Fig.10. (These confirm, supplement, and supercede the equivalent displays in Report no.22.)

IV. GRS & S.Tropical Band, 2011 March

In 2011 Jan., we noted dark material streaming around the GRS; Each SEB(N) dark spot in turn became very dark when due N of the GRS, and dark material streaming Sf. from these dark spots was probably the main cause of the darkening of the RSH. From Jan.15-22, substantial darkening of the Nf. and Sf. quadrants resulted from dark material from spots on three converging jets: STBn (small jetstream spot, prograding*), SEBn (very dark north-branch spots, as described above), and SEBs (large dark spot DS3, retrograding).

> [*Similar motions of spots around the GRS, from the point due N of it and from the STBn jet, were shown even before the SEB Revival: see our Reports no.6 & 12.
> The phenomena in Jan. were illustrated with images up to Jan.31 in Report no.20.]

In late Jan., the collar around the GRS was further reinforced by a very dark grey streak emitted from the dark spots to the N, which extended anticlockwise around the GRS. Its leading part emerged at the p. end of the GRS as a little dark streak (Jan.29), which then expanded into a large, light brown loop (like the LRS in 2008) – a bizarre sight in Don Parker's multispectral images on Jan.31.

Subsequent developments are shown in Fig.3. Similar activity continued with greater intensity. In Feb., more prograding dark spots on SEB(N) (e.g. one cluster marked by a green arrow), were piling into the bluish-black spot on the N edge of the GRS; from there, dark material was streaming Sf. around the rim to another very dark patch at the f. end of the GRS; and from there, streaks and spots were running p. around the S. edge.
One very dark blob followed this course, anticlockwise around the GRS to its p. side, from Feb.9 onwards (red arrow in Fig.3). It was probably this which emerged on the p. side as a large brown streak in the first week of March (red arrowhead) – although the arrival of the central branch at the RSH around Feb.22 may also have contributed more dark material.
This brown streak was only seen in the last, lo-res images of the apparition, which we did not examine closely until the next apparition. Then, images by T. Akutsu in 2011 April-May revealed a long, dark grey S. Tropical Band which was a prominent feature in the following months. The brown streak in early March was probably the begining of this S. Tropical Band. It was similar to one seen in 1991 after the 1990 Revival, and is an example of those diverse dark formations which sometimes develop in the STropZ, prograding, from the p.(E) end of the GRS, usually at the end of an SEB Revival or (in more normal times) after a series of SEBs jetstream spots has disappeared into the GRS rim. (See 'The Giant Planet Jupiter' pp.203-214.)
So, congratulations to those who imaged up to the end of the 2010/11 apparition, and to T. Akutsu for imaging 3 weeks after solar conjunction at 8 deg. altitude, without whose work this phenomenon would have been missed.

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APPENDIX 1: Details of motions on SEB(N) (northern branch).

The JUPOS charts for the northern half of the SEB show the following tracks for dark spots:
[preliminary estimates of drifts and latitudes from inspection of the charts]:

Before the SEB Revival:

1) In July-Nov., lat.~12-13 S, DL2 = -77 to -92 (mean ~-85): mostly f. GRS, up to L2 ~ 0. Rather faint bluish-grey spots, with long tracks; this was during the SEB Fade, in the faint residual SEB.
2) With the same parameters, several shorter-lived spots p. the GRS, esp. from late July to early Aug., and in Oct.: these were just the times when the bright plume N of the GRS was active, and these were no doubt disturbances prograding from it.

During the SEB Revival:

3) In Dec., lat.~11 S, DL2 = -110; [approx. from L2~270 (Nov.28) to ~190 (Dec.18)]. This was the first d.s. on SEB(N) from the outbreak: it appeared at the p. end of the expanding WS-N and thus of the whole disturbance, and prograded until it disappeared at the RSH.
4) In Dec., lat.~12 S, DL2 ~ -86 (imprecise): 3-4 short variable tracks, starting at the leading edge of the disturbance, ~25-30 deg. p. the source.
5) On Jan. 5-20, lat.~10-11 S, DL2 ~ -120 *[with additional measurements and analysis by Gianluigi Adamoli]:* The main N. branch began on Jan.5 when the SEB(N), from the GRS to the leading edge of the central branch, broke up into a series of 9 dark spots (Fig.4). They had a range of speeds from DL2 ~ -150 (near the p. end of the series, over just a few days) to DL2 ~ -90 (at the f. end of the series, after Jan.10) (Fig.5). Thus the separation of the spots increased from 6 deg.(Jan.5) to 9 deg.(Jan.12), as they approached the GRS.
The first substantial and well-tracked spot in the series formed a big dark projection at the GRS on Jan.5, and emerged from this on a track with DL2 ~-130. (There may have been one or two minor dark spots ~10-20 deg. ahead of it.)
The tracks of these spots were often disturbed as they passed the GRS, but did not show systematic change of speed. After passing GRS, in Jan.-Feb., they had lat. ~10 S, DL2 ~-125, spacing 9 deg.

APPENDIX 2: Details of motions on SEB(S) (southern branch), mid-Jan. to mid-Feb.

This follows on from our Report no.22. (In this section on SEB(S), 'fast' and 'slow' refer to speeds in the retrograding direction.)

Because of the complexity and rapid variability of these spots, they could not be tracked by the routine JUPOS analysis. Therefore they have again been tracked by JHR, by identifying the more persistent spots visually on hi-res images and measuring their longitudes manually (+/-1 deg.) (Figs.6-9). JUPOS measurements were added where available to provide more precise longitudes and latitudes.

In general, dark spots within the belt were too short-lived to be tracked during this period, although there were suggestions of rapid retrograding speeds. Dark spots/streaks on the S edge were more persistent, although their appearance was very variable due to changing dark or bright structures alongside them. The JUPOS measurements of their latitudes had averages between 21-22 S, but were bimodal for most of the spots: values between 22-23 S probably represent the true persistent dark streak on SEB(S)s. while lower latitudes represent the streak when there was extra dark material adjacent to it.

Notes on individual dark spots:

A(DS3): This arrived at the RSH on Jan.17 (Report no.20) – the only one ever to do so!

B(DS1): It had become a small faint dark spot on the S edge. Decelerated to DL2=+32 (Jan.8-16; lat. 22.7 S) then disappeared.

E,F,G (DS5, etc.): A very dark complex on the S edge. (Faster-retrograding dark spots (H,J,K) had disappeared into it in early Jan.) It was reduced to just one conspicuous dark streak (F) in mid-Jan., approx. stationary at L2 ~ 34 (lat.22.2 S). In late Jan., a similar dark streak was present at L2 ~ 55, and in Feb. there were 4 short dark streaks spanning L2 ~ 40-90, all with DL2 = +43 (J1-J4: nominal lats.21.6 S +/-0.75 [n=15], but if the higher latitudes representing the dark streaks along are selected, 22.3 S +/-0.28).

M: Dark spot on S edge, steady DL2 = +70 to Jan.17 (lat.-21.9) but not identifiable thereafter (tho J1 appeared close to its track, DL2 = +43). Several very dark spots within the belt in this sector failed to give consistent tracks; they were app. short-lived features, possibly rapidly retrograding, between more stable white ovals of Sector 2 with DL2 = +44.

P,T: The two most conspicuous and southerly dark spots, remaining quite close to the source. Spot P was initially an oval very dark spot, later a ring with light interior (interior reddish in Peach's images on Feb.8). It was the only dark spot which looked like a vortex.
Spot T was initially complex, and swelled up in late Jan. to become a huge dark mass spanning the STropZ (never imaged at hi-res).
Both P & T began with moderate retrograding speeds but then decelerated and moved further S.
Spot P then maintained steady drift, DL2 = +34, for a month (lat. 22.3 S).
Spot T successively had DL2 ~ +56, 0, +44, 0, -16 (or even more negative), as this dark mass in STropZ drifted back towards the source in Feb.

Table 1.	**Latitudes and speeds of retrograding dark spots on SEBs.**								
							& White spots:		
	L2	*Dates*	***DL2***	*Lat. (DS)*	*(Lat) SD*	*(Lat) n*	*Lat. (WS)*	*(Lat) SD*	*(Lat) n*
Pre-existing sawtooth projections:									
	fast sector (av.)	July-Aug.	**75**	-20,84	0,46	628	-20,88	0,48	295
	slow sector (av.)	Aug.-Sep.	**57**	-20,84	0,48	280	-20,98	0,5	183
	fast sector (range)	July-Aug.	+70 to +82						
	slow sector (range)	Aug.-Sep.	+51 to +66						
(Speeds & latitudes have not been accurately analysed for Sep-Oct. yet; they were much the same as July and Nov.)									
in Nov:	20-140	Nov.1 - Dec.3	**74**	-20,65	0,37	321			
	230-380	Nov.1-8	**72**	-20,49	0,43	73	-20,38	0,46	65
	320-380	Nov.9-29	**72**	-20,51	0,40	83			
	290-330	Nov.10-15	**70**	-20,08	0,53	53	-20,16	0,33	16
	310-360	Nov.16-25	**70**	-20,48	0,53	24	-20,54	0,40	38
mean of these 4:	230-380 (undist.)	Nov.1-25	**71**	**-20,39**	**0,47**	233	-20,36	0,40	119
including the actual projs. w became P1-P3:									
	260-300	Nov.1-9	**70**	-20,20	0,31		-20,32	0,29	
The first 2-3 dark spots in S. branch (sawtooth projections):									
	P1-P3	Nov.16-25	**132**	-20,74	0,60	41			
	P1-P3	Nov.27-Dec.4	**117**	-20,75	0,40	11			
	P1	Dec.3-23	110	-20,76	0,32	7			
Larger dark spots in main S. branch (revised from orig. report):							*Notes*		
	DS1	Nov.24-Dec.6	**118**	-21,23	0,24	13			
	DS3	Nov.28-Dec.6	**120**	-20,01	0,45	9			
	DS3	Dec.3-31	114	-20,23	0,50	4			
	DS4	Dec.3-7	114	-20,10	0,30	3			
	DS5	Nov.27-Dec.6	**108**	-20,63	0,40	9			
	DS5	Dec.7-26	45	-21,93	0,55	4			
	DS6-7	Dec.5-19	116	-20,03	0,59	3			
	A (DS3)	Dec.31-Jan.18	108	-21,3	0,20	3	very large: entered RSH		
	B (DS1)	Dec.19-Jan.16	57	-22,1	0,69	4	*Oscillating between these 2 extremes:*		
	B (DS1)	Dec.31-Jan.6	80	-21,8	0,7	2			
	B (DS1)	Jan.8-16	35	-22,4	0,3	2	(last seen Jan.16)		
Notes:	B	Remnant of DS1 after passing DS3. DL2 oscillates +35 to +80.							
	z1,z2	Dec.4-13	40	-19,6	0,30	11	(JUPOS tracks)		
	a,b,c	Jan.0-8	51	-20,0	0,33	8	see Sector 1 below		
	E,F,G	Jan.0-12	44	-21,8	0,54	13	(complex after Jan.11)		
	F	Jan.11-17	~0	-22,2	0,43	7			
	K	Jan.4-8	134	-21,0		1			
	M	Jan.2-17	70	-21,9	0,47	9			
	P	Jan.2-9	72	-21,1	0,17	3			
	P	Jan.10-Feb.8	34	-22,3	0,83	6*			
	T	Jan.4-12	56	-21,9	0,50	4			
	T	Jan.13-Feb.7	~+44 to -16 (sic)				very large		
				-22,8	(Jan.18)	1			
	J1	Jan.23-Feb.13	43	-21,7	0,74	7*			
	J4	Feb.6-13	43	-21,4	0,77	7*			
	*Latitude measurements for these slowly-retrograding spots/streaks were bimodal								
	(see text footnote):			-22,2	0,35	8			
	J1 & J4			-20,8	0,23	6			
CHAINS OF WHITE OVALS IN BELT:			***DL2***	*Lat. (WS)*	*(Lat) SD*	*(Lat) n*			
Sector 0	(7 dark projs.	Dec.11-Jan.2	69,9				(Ahead of DS3/A.)		
	between 8 ovals)		(+/-4,3: N=7)						
	[Individual speeds: DL2 = +65 to +75.]								
Sector 1	(7 ovals tracked	Jan.11-Feb.1	50,6	-20,49	0,36	17	(Ahead of d.s. F)		
	out of 8 present)		(+/-4,5: N=7)						
	[Individual speeds: DL2 = +43,47,53,50,51,53,57. Same as for intervening d.ss. a,b,c, above.]								
Sector 2	(3 ovals tracked	Jan.9-Feb.8	47,7	-20,29	0,39	11	(Alongside major d.ss.)		
	out of 5-7 present)		(+/-6,4: N=3)						
	[Individual speeds: DL2 = +44,44,55.]								

Table 2: Summary of key features of SEB Revival									
				DL2 (deg/mth)		u_3 (m/s)	Lat. (zenographic)		No.of spots
			Dates	Mean	SD or [Range]	Mean	Mean	SD or [Range]	tracked
Start	(w.s.at L2=288)		Nov.9				-17,1		1
Central branch:									
	Source (locus of new plumes)	WS1-3:	Nov.9-17				-17,3	0,2	3
		WS3-12:	Nov.17-Dec.20	5,3		-6,2	-16,1	0,2	4
	White spots (plumes,	Hi-lat:	Nov.9-Jan.5	-3,0	6,2	-2,3	-16,9	0,7	7
	arising at source or leading edge)	Lo-lat:	Nov.12-Jan.5	-33,3	15,9	11,8	-14,0	1,1	8
	Leading edge		Nov.21-Feb.18	-32	[~-42 to 0]	11,2	(-14)		
S. branch:									
	Pre-existing chain	D.ss:	Nov.1-Jan.2	72	[+66 to +78]	-36,3	-20,5	0,5	many
		W.ss:	(ditto)				-20,4	0,4	many
	Fast dark spots in S.branch:		Nov.16-Jan.18	117,4	8,7	-56,9	-20,6	0,5	11
					[+108 to 134]			[-20.0 to -21.3]	
	Slower dark spots in S.branch,		Dec.7-Feb.13	49,9	11,9	-26,0	-22,0	0,2	10
	on S edge of SEB(S) [omitting extremes]				[~0 to +70]			[-21.9 to-22.3]	
	Renewed chain of w.ovals		Jan.9-Feb.8	49,7	5	-26,2	-20,4	0,4	10
	in revived SEB(S)				[+43 to +57]				
N.branch:									
	First major d.s.		Jan.4-Feb.3	-130		57,7	-11,0	0,5	1
	All dark spots		Jan.5-Feb.9	-120	[~-150 to -90]	53,0	-10,7	0,9	12

Figures *[see separate files]*

Fig.1. Development of the SEB Revival, 2010 Dec.- 2011 Feb.: Maps made by Marco Vedovato.

Fig.2. Images of the source regions and central branch, 2011 Jan.12-23.

Fig.3. Events at the GRS, 2011 Feb.-March, with dark streaks extending around it, and probable origin of S.Trop.Band at its p. edge around March 2. See text for description of indicated features.

Fig.4. Onset of the northern branch of the SEB Revival: Images from 2011 Jan.5-9, showing the SEB(N) f. the GRS breaking up into very dark 'waves'.

Fig.5. Onset of the northern branch of the SEB Revival: Chart of longitude vs time.
Longitude is in a system moving at 4.0 deg/day relative to System II.

Fig.6. Images of the southern branch, 2011 Jan.11-22. This was a working chart with identifiable dark spots in SEB(S) marked. Small white ovals developing in SEB(S) are marked with red circles below. These were the spots measured for the chart in Fig.9. (Labels were provisional and may differ from final designations in Fig.9 and Table 1).

Figs.7 & 8. Images of the southern branch, 2011 Jan.22-31 and 2011 Feb. As in Fig.6.

Fig.9. Southern branch of the SEB Revival: Chart of longitude (L2) vs time, for identified dark spots and for white ovals within SEB(S).

Fig.10. Southern branch of the SEB Revival: Chart of speed vs latitude, for identified dark spots and for white ovals within SEB(S). Blue line is the zonal wind profile from Cassini in 2000 [Porco et al., 2003]. Note that the dark spots in the Revival are systematically to the right of the line from 20.5-21.5 deg.S, whereas the bright ovals and associated dark projections, both before and after the Revival, are systematically to the left of the line from 19.5-20.8 deg.S.