{Report-on-SEBn_2010_to post.doc}

<u>The SEBn in 2010: The dual motion of the chevrons in the rapid jetstream</u>

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[This report was largely written in 2011 April, finalised for posting in 2012 August. Much of it has been incorporated in Ref.2. In this version, based entirely on amateur images, we give more details, and we present the images and charts according to our usual conventions with south up and east to the left.]

Summary

In 2010, the small 'chevrons' in the SEBn jet again returned to the pattern of speeds which the jet had previously shown in the absence of a South Equatorial Disturbance: extended disturbed regions and some individual chevrons moving with the peak jet speed, but other chevrons moving more slowly. Here we analyse these motions in detail, from the uniquely detailed ground-based images of this apparition, to investigate the difference between fast and slow features. Both classes of feature appear to be typical chevrons in almost the same latitude, but the slower-moving features tend to arise in new or newly disturbed clusters, and tend to separate from the SEBn, and are shorter-lived.

Introduction

The SEBn jet is one of the three most rapid jets on the planet, with a peak speed of DL1 ~ -104 (+/-10) deg/mth [u_3 ~ 155 (+/-5) m/s]. This speed is often displayed by the chevron-shaped dark features along the SEBn edge. However, sometimes the chevrons display a wide range of speeds. We have shown that this jet exists in two alternative regimes [ref.1]:
i) When the South Equatorial Disturbance (SED) is conspicuous, the jet speed is reduced east of the SED and sometimes all round the planet (e.g. in 2000).
ii) When the SED is weak or absent, extended disturbed regions as well as some individual chevrons move with the peak jet speed, but other chevrons move more slowly (e.g. in 2005).
For each of these regimes, the physical basis for the variable speeds is unknown.
[All speeds are prograde, eastward, so 'fast' means high negative DL1 (degrees per 30 days) and positive u_3 (m/s).]

The SED had been clearly tracked in 2008, and the chevrons p. it showed the usual gradient of speed with longitude. It was still present though less conspicuous in 2009 [summarised in our interim reports on-line]. In 2010, the SED could probably be identified as a minor feature in May, but there was no trace of it thereafter. Thus it disappeared as the SEB faded *[Ref: Our 2010 Report no.8]*. From June onwards, the alternative regime had taken over the SEBn. As in 2005, there were long-lived bands of disturbance (high density of measured spots), moving with peak jet speed (DL1) ~ -111 deg/mth, and some individual spots moving with the same speed, but many other chevrons were moving more slowly (DL1 ~ -55 to -80 deg/mth, with a few even slower). The disturbed sectors of SEBn were often conspicuous in hi-res images **[Fig.01]**.

With the unprecedented spatial and temporal resolution of this year's observations, we have made progress in elucidating this paradoxical behaviour, by analysing the JUPOS database as a whole, and the origins of 7 individual slow spots or groups in particular. In these 7 case studies we plotted the JUPOS data at higher resolution and also compiled the hi-res images so as to follow individual spots within these complex and rapidly-changing clusters.

Results

This account refers only to dark features on the SEBn, referred to as spots or projections, which are the same as chevrons. These features span ~2.4 degrees in latitude, thus:
8.2 deg.S: SEB(N), small dark condensations, S limb of chevrons;
7.4 deg.S: Centroid of chevrons;
7.0 deg.S: White spots between chevrons;
5.8 to 6.2 deg.S: Dark bluish streaks, N limb of chevrons.

The JUPOS chart **[Fig.02]** shows bands with numerous spots (clusters), spanning tens of degrees longitude, separated by much sparser regions (gaps), all moving with DL1 ~ -111 [+/-4] deg/mth. The clusters are clearly visible in the maps [Fig.01]. Some individual spots travel with the same speed (mean DL1 = -107 [+/-8]), and some of them can be tracked for 1-2 months. The chart suggests that slower-moving spots (slower than DL1 = -90 deg/mth) arise within the clusters, particularly in clusters which have newly formed, and typically last for only a week. On the chart [Fig.02], nine clusters are marked containing slow-moving or decelerating spots.

Because these are rapid and small-scale changes within complex clusters, it is difficult to recognise single spots from day to day in the images, and difficult to be certain about the tracks of some spots on the overall JUPOS chart. Indeed it is remarkable that tracks emerge at all in such disturbed regions. Therefore, we examined 7 examples in detail, where the initial JUPOS chart suggested that individual spots had decelerated within a cluster, to test whether the slow spots formed *de novo* or by deceleration of pre-existing fast spots **[Fig.04]**.

The following conclusions emerge about the characteristics of the slow spots.
1) Both fast and slow spots had morphologies within the range of typical chevrons.
2) The slow spots tended to occur in dense clusters of spots.
3) Sometimes these clusters were new, and sometimes the spots were decelerating as they appeared (over a few days). In other cases, a long-lived fast spot decelerated, or generated a new slow spot by splitting.
4) The slow spots were shorter-lived: mean duration of track was 8.6 (+/- 4.6) days for slow spots, 17.6 (+/- 13.5) days for fast spots **(Table 1).** (Of course, the actual lifetime of a feature may be longer than the recorded duration of the track.)
5) The slow spots had almost the same latitudes as the fast spots, within the range of the SEBn jet peak, but were often slightly further north. In the examples studied in detail, when a fast spot decelerated or split or was replaced by a slower spot, the slower spot was always further north, by an average of 0.36 (+/- 0.15) deg.
6) Decelerating spots did not move north as a whole, but the chevron centroid often shifted north because the northern limb became darker or detached altogether from SEBn (although in some cases it re-attached to form a typical but slow-moving chevron). Because of the enhanced northward projection, slower spots or clusters were sometimes more conspicuous, both in contrast and in morphology, than longer-lived faster spots.

In the 7 examples studied in detail, we found a variety of behaviours. Some slow spots definitely arose by deceleration of fast ones, whether newly formed or long-lived. (There were only a few examples of possible acceleration, and these could have been due to replacement of a slow spot by a new fast one.) Conversely in Cluster 1, a fast spot persisted through a newly-formed cluster of slower spots, and in another case [PJ-21&22], two fast chevrons each split to produce a short-lived slower spot from their Nf. limbs.

Cluster 1 was particularly informative as it was indeed a new cluster that formed around two pre-existing fast spots. **[Fig.03]** On July 16, there was only a band of rather sparse and irregular spots; around July 23, this transformed into a more regular and conspicuous chain of spots, which comprised Cluster 1. The new spots were decelerating as they formed, from DL1 ~ -80 to -57, although this occurred over just a few days so the speeds are not precise. The chart also suggests that pre-existing fast Spot 1 re-emerged with its speed unchanged, and detailed inspection of images confirms this [Fig.03]: Spot 1 can be seen as a small SEBn projection which interacted with and overtook two successive slower-moving projections in the cluster, which projected further north.

The slight difference in latitude between fast and slow spots is barely significant overall, but appears to be real as it is shown for the overall averages in two separate time intervals, and it is significant in the 7 cases studied in detail. The difference of only 0.1 to 0.4 deg. is much less than the width of the spots or the width of the jet peak **[Fig.05]**. Therefore, this huge range of speeds is all within the jet peak; the slow speeds of some spots are not due to their lower latitude. [We have also tracked a few dark blue streaks further north, at lat.6.0 S, which appear to be detached northern limbs of chevrons, and these show a speed of DL1 ~ -50 deg/mth which does represent the latitudinal gradient on the northern flank of the jet.]

Discussion

We have shown that slower-moving spots tend to arise in new or newly disturbed clusters, and tend to separate from the SEBn, and are shorter-lived. The resulting picture is that the SEBn jet carries disturbed sectors which persist for months, moving at the peak speed of the jet (DL1 ~-111 deg/mth, u_3 ~ 158 m/s) and including many long-lived chevrons with the same speed. But pulses of disturbance arise within these clusters, or create new ones, and generate shorter-lived, slower-moving spots, sometimes by deceleration of fast chevrons, sometimes by splitting of the northerly component of a fast chevron, and sometimes by creation of new, slower-moving chevrons.

What are these clusters? In our previous analysis [ref.1]* we discussed two possible models. In the first, the chevrons are waves, with variable phase speeds that are all less than the true peak jet speed. In the second, the chevrons do indeed trace the physical wind speeds, at different depths: slower-moving chevrons trace the wind speed at cloud-top level, while the faster bands of activity represent disturbances in the faster jet below the cloud tops.

The second model seems to be more consistent with the observed origins of slower-moving spots as whole chevrons which decelerate, or as parts of chevrons which detach from the SEBn. Probably the fast chevrons are rooted more deeply in the fast jet, while the slower ones have no such deep roots and so move with a slower, higher-level wind. Sometimes the disturbance within the full-speed jet generates a whole cluster of weather systems at a higher, slower-moving level. This second model also more naturally explains why the fast-moving chevrons have the same speed as the clusters with which they move: this is the true wind speed of the jet below the cloud tops.

However, the present observations still do not rule out either model, and the origin of the chevron pattern may well be more complex than either. Further discussion in ref.2 suggests that the fast chevrons could be a gravity-inertia wave pattern moving at approximately the true wind speed.

References:

(1) Rogers JH & Mettig H-J. (2008 Dec.), 'Influence of Jupiter's South Equatorial Disturbance on jet-stream speed'. JBAA 118 (no.6), 326-334. *[On-line at:]* http://www.britastro.org/jupiter/ JBAA%20118-6%20Rogers_SED-paper.pdf

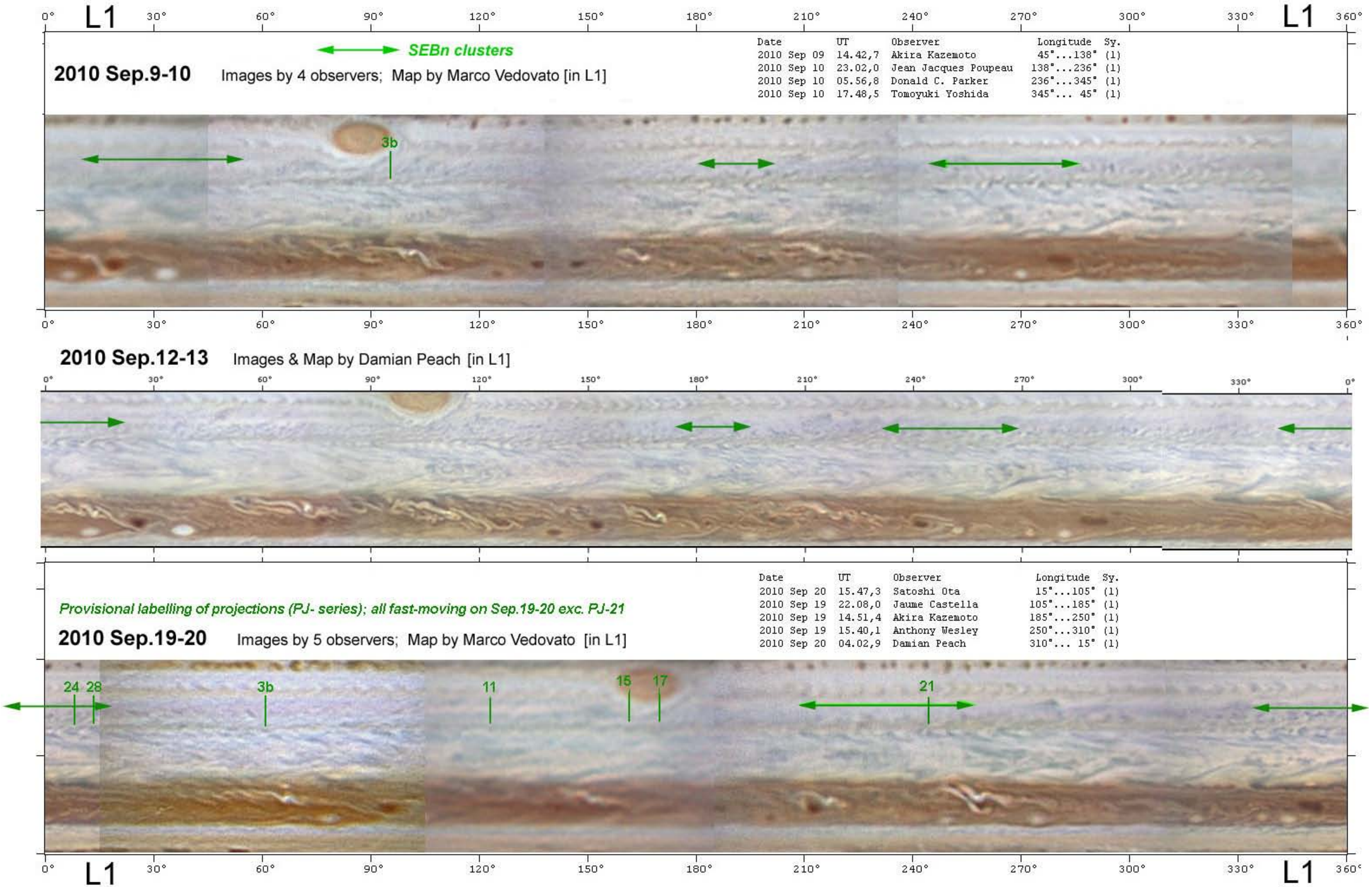
(2) Simon-Miller AA, Rogers JH, Gierasch PJ, Choi D, Allison MD, Adamoli G, Mettig H-J (2012). 'Longitudinal variation and waves in Jupiter's south equatorial wind jet.' Icarus 218, 817–830. [doi:10.1016/j.icarus.2012.01.022]

Table 1. Mean values of drift rates, latitudes, and durations

		ΔL1(°/30d)	U3(m/s)	Lat.	N	Duration (d)
Fast spots (all, DL1 > -90)):						
	Mean:	**-106,6**	**156,4**	**-7,43**	**26**	**17,6**
	SD:	7,6	3,6	0,15		13,5
	Range:	-92 to -121				
Slow spots (all, DL1 -40 to -90):						
	Mean:	**-71,4**	**139,6**	**-7,35**	**34**	**8,6**
	SD:	10,4	5,0	0,24		4,6
	Range:	-51 to -90				
June-July only:						
Fast spots	**Mean:**	**-111,1**	**158,5**	**-7,43**	**7**	**17,4**
	SD:	7,0	3,4	0,22		8,7
Slow, in Cluster 1	**Mean:**	**-68,3**	**138,1**	**-7,14**	**6**	**5,3**
	SD:	9,7	4,1	0,26		3,3
Slow, elsewhere	**Mean:**	**-65,3**	**136,7**	**-7,27**	**3**	**19,7**
	SD:			0,18		6,8
Aug-Nov. only:						
Fast spots	**Mean:**	**-104,9**	**155,6**	**-7,43**	**19**	**18,1**
	SD:	7,3	3,5	0,13		15,0
Slow spots	**Mean:**	**-70,6**	**139,2**	**-7,38**	**24**	**8,0**
	SD:	15,7	7,5	0,23		2,7

FIGURES:

Fig.01 ***[next page]:*** Hi-res maps of the equatorial region in September, showing the 3 clusters of conspicuous chevrons. There were few slow chevrons at the time of the first and second maps.


L1
0° 30° 60° 90° 120° 150° 180° 210° 240° 270° 300° 330° 360°
SEBn clusters
2010 Sep.9-10
Images by 4 observers; Map by Marco Vedovato [in L1]
Date UT Observer Longitude Sy.
2010 Sep 09 14.42,7 Akira Kazemoto 45°...138° (1)
2010 Sep 10 23.02,0 Jean Jacques Poupeau 138°...236° (1)
2010 Sep 10 05.56,8 Donald C. Parker 236°...345° (1)
2010 Sep 10 17.48,5 Tomoyuki Yoshida 345°... 45° (1)
3b
2010 Sep.12-13
Images & Map by Damian Peach [in L1]
Provisional labelling of projections (PJ- series); all fast-moving on Sep.19-20 exc. PJ-21
2010 Sep.19-20
Images by 5 observers; Map by Marco Vedovato [in L1]
Date UT Observer Longitude Sy.
2010 Sep 20 15.47,3 Satoshi Ota 15°...105° (1)
2010 Sep 19 22.08,0 Jaume Castella 105°...185° (1)
2010 Sep 19 14.51,4 Akira Kazemoto 185°...250° (1)
2010 Sep 19 15.40,1 Anthony Wesley 250°...310° (1)
2010 Sep 20 04.02,9 Damian Peach 310°... 15° (1)
24 28
3b
11
15 17
21

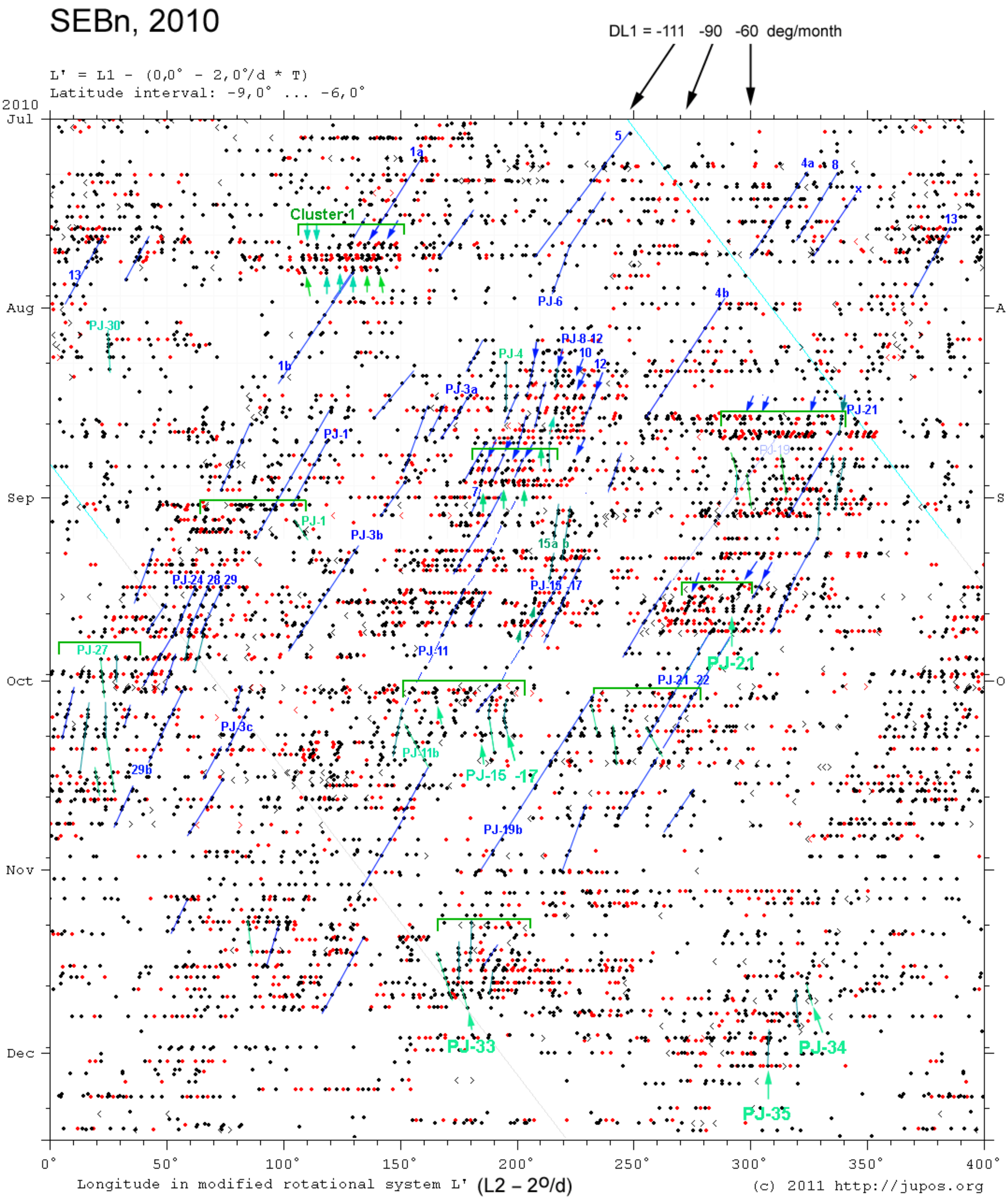


Fig.02: JUPOS chart of longitude vs time, for dark spots (black points) and bright spots (red points) in the latitude range 9.0 to 6.0 deg.S, in a longitude system moving at -2.0 deg/day relative to System I (-9.633 deg/day relative to System III). The reliable tracks are marked, with different colours for different speed ranges, and some are identified as numbered projections (PJ...).

The chart suggests that, within the long-lived bands of activity, clusters of distinct spots appear rather suddenly (nine examples are marked by a green line above), initially moving with full jet speed (dark blue arrows or tracks on the chart) but decelerating within a few days to the slower speeds (cyan and green arrows). In some cases the appearance of a new cluster on the JUPOS chart may represent only the fortuitous arrival of high-quality images; however, cluster 1 was genuinely forming at this time.

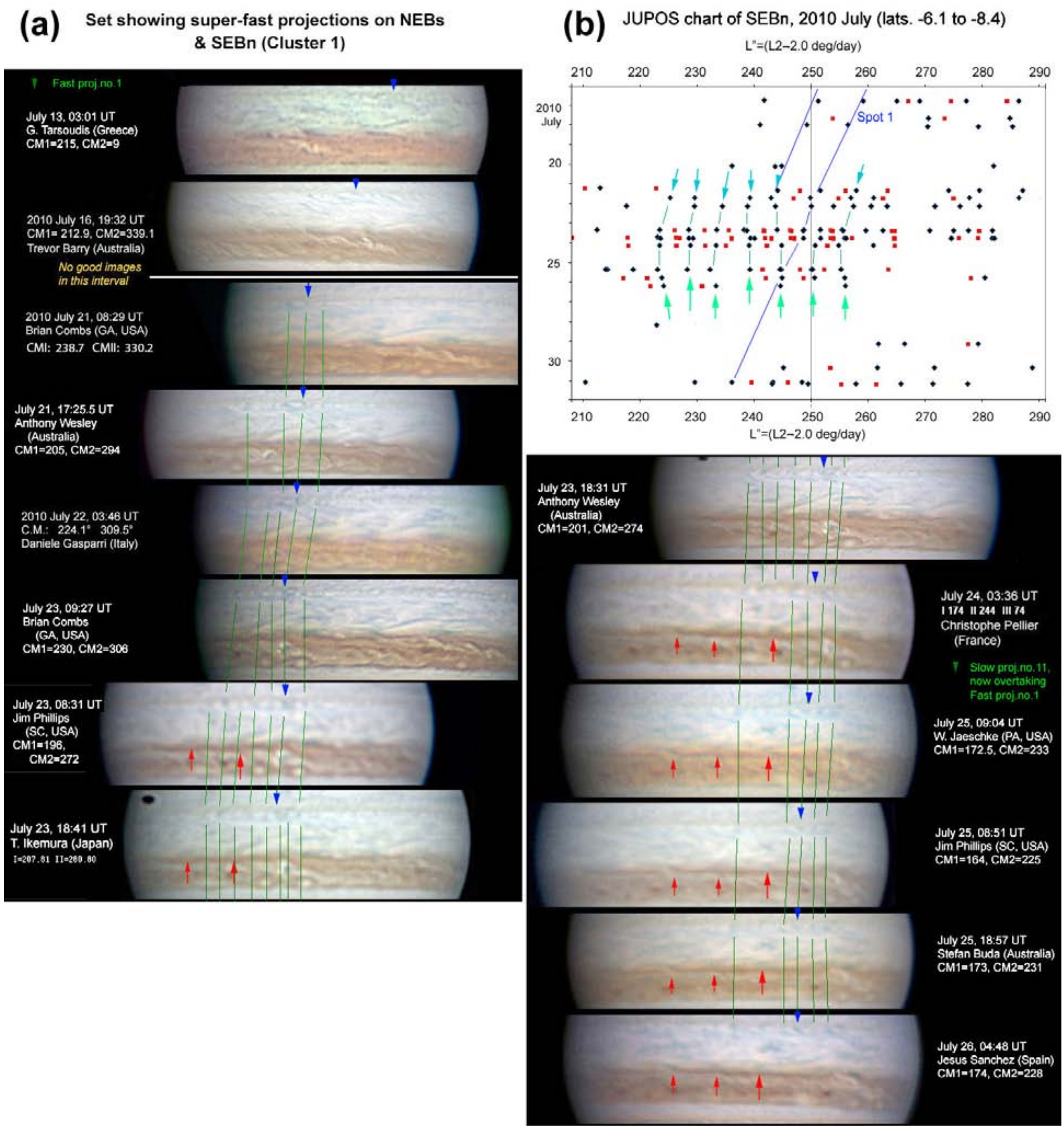


Fig.03: Case study: Cluster 1.
(a) Set of hi-res images tracking Cluster 1. Also note fast-moving projections on NEBs (red arrows). (b) Enlarged JUPOS chart of Cluster 1, as in Fig.1, L1 – 2.0 deg/day.

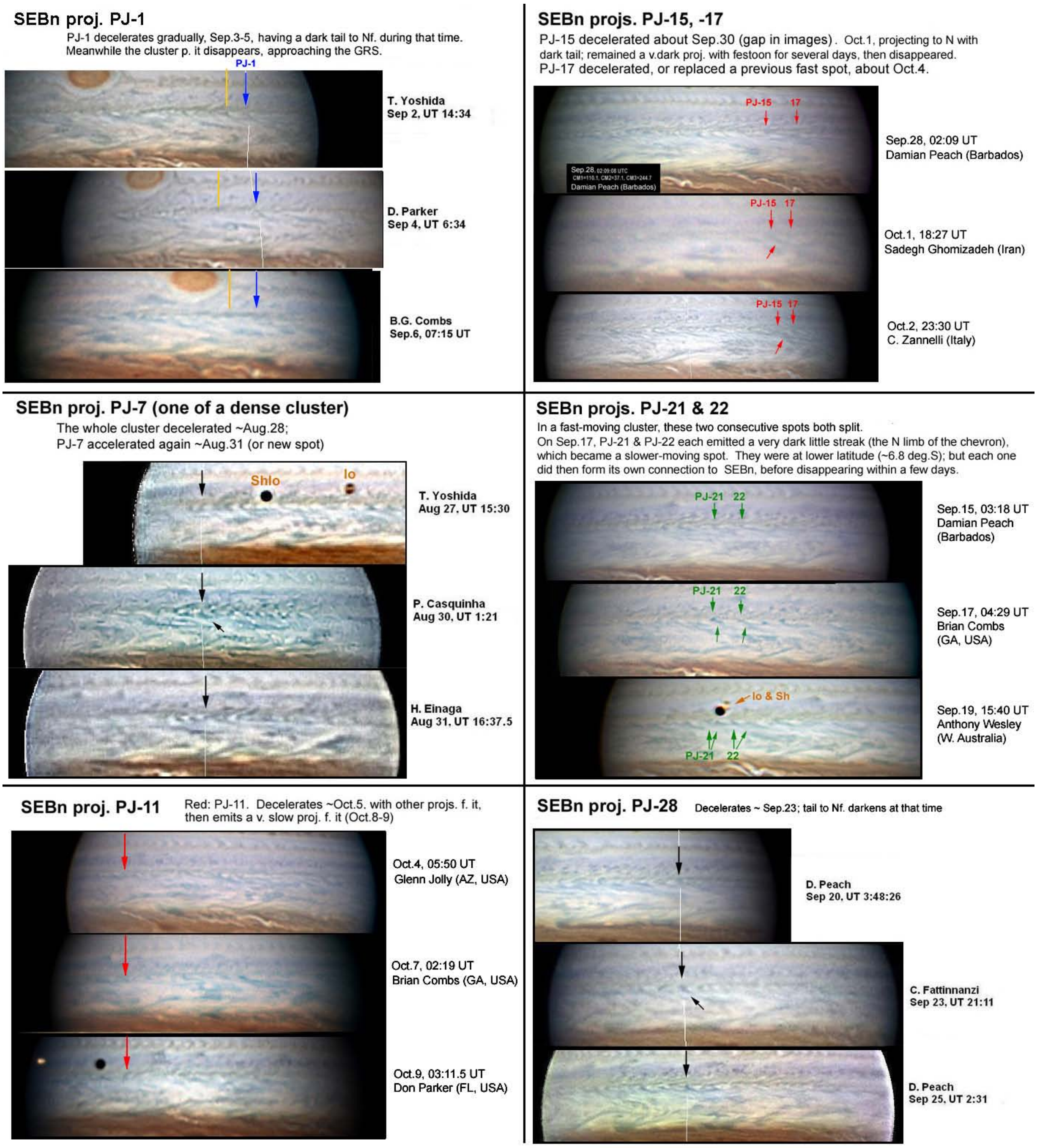


Fig.04: Examples of hi-res images from the other 6 case studies.
These are some of the best images around the time of apparent deceleration in each case, excerpted from much larger sets of images. The numbered SEBn spots are marked by arrows. Images are aligned approximately by eye on the SEBn projections. (In some cases, NEBs projections are also moving at ~ -2 deg/day in L1.)

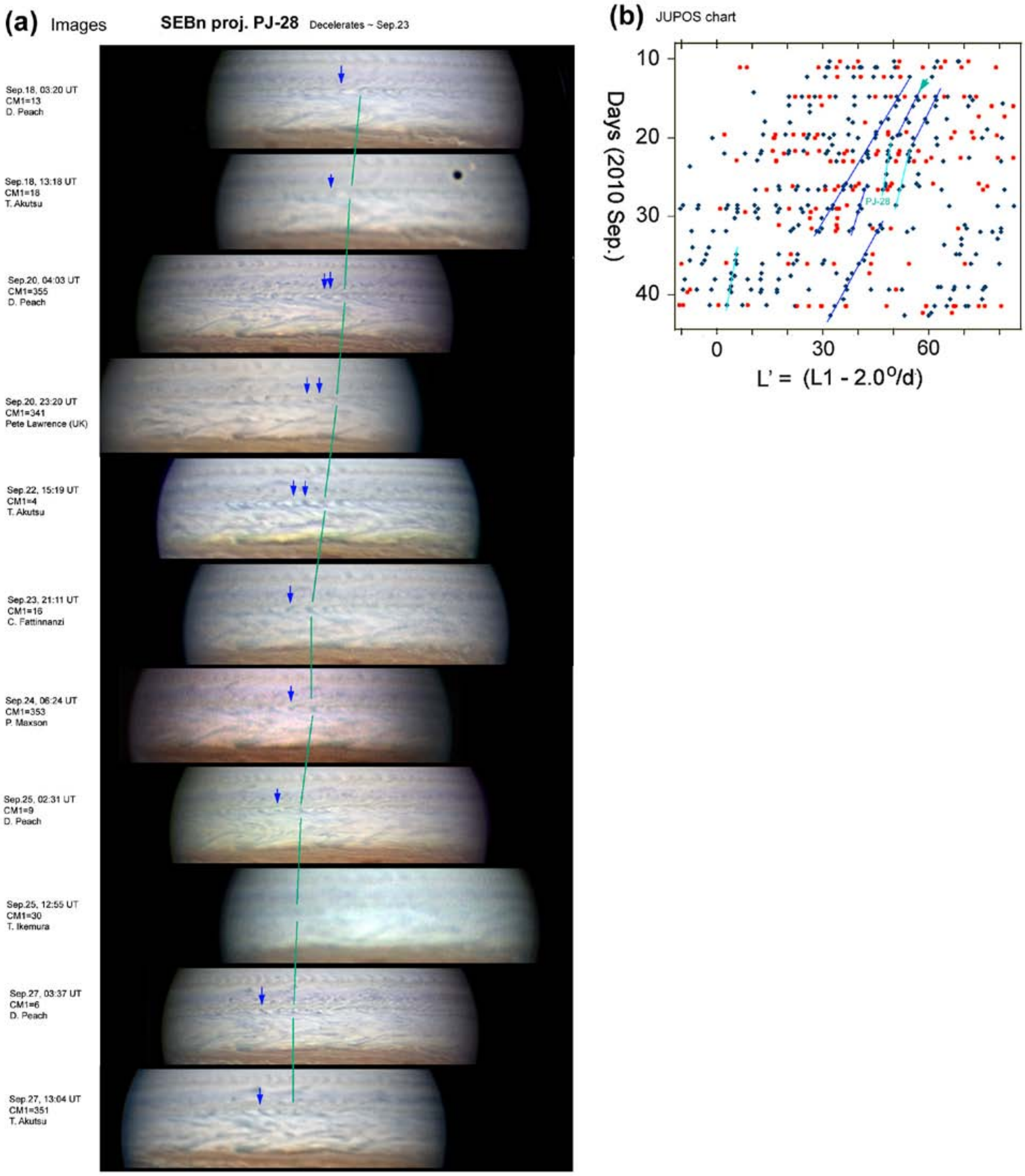


Fig.05: Another case study: PJ-28, a chevron within a fast-moving cluster which suddenly decelerated on Sep.21.

(a) Images, aligned on fast-moving dark projections on NEBs. Chevron PJ-28 is indicated by a bluish-green line. It grows darker and more extended to Nf. as it decelerates, Sep.21-23 (similar to PJ-21 in Fig.04). Blue arrows indicate the chevron p. it, which continued moving fast according to the JUPOS chart, although it seems to have split once or twice. The projection f. it (not marked) was PJ-29 which also seems to have decelerated at the same time although it was not so well tracked.

(b) Enlarged excerpt from the JUPOS chart, showing this cluster. Symbols and scales as in Fig.03.

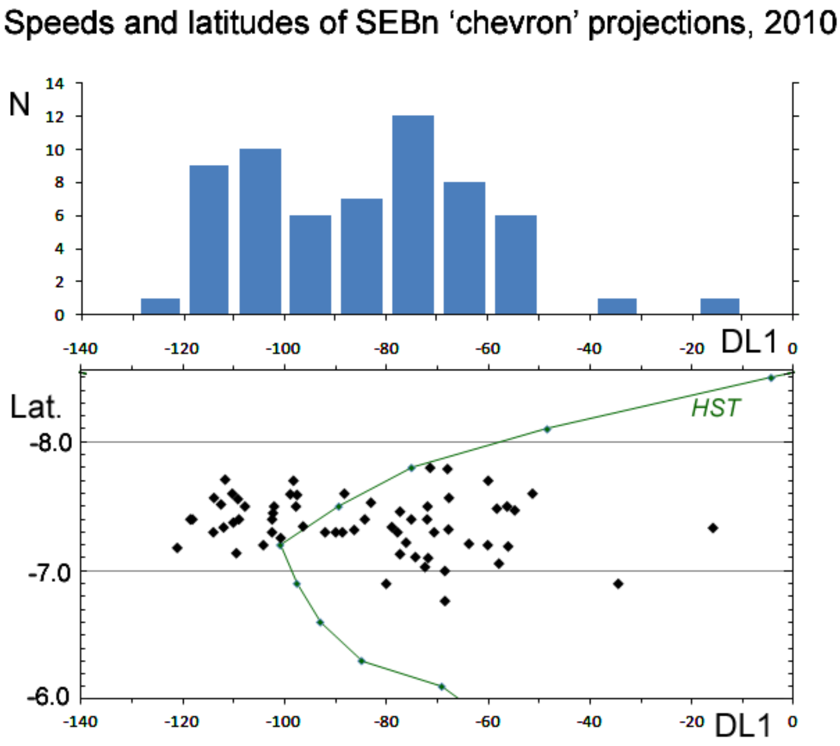


Fig.06:
Top: Histogram of speeds for all the SEBn spots measured.
Bottom: Chart of speed vs latitude for all SEBn spots measured, compared with the zonal wind profile from the Hubble Space Telescope in the 1990s [Garcia-Melendo E & Sanchez-Lavega A, Icarus 152, 316 (2001)]. Slow spots have a slightly lower mean latitude than fast spots, but the latitude difference is much too small to account for the speed difference.