

Bayesian approach for auroral oval reconstruction from ground-based observations

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Abstract

To understand long term variability of solar activity, homogeneous time series are required. However, proxies like the Zurich sunspot number or cosmogenic isotopes suffer from discontinuities. Naked eye observations of aurorae, however, might be used to bridge discontinuities in solar activity indices in order to approach a homogeneous solar activity record. With information derived from aurora observations like observing site, time of aurora sighting and position on sky we can reconstruct the auroral oval. Since aurorae are correlated with geomagnetic indices like the Kp index, it is possible to obtain information about the terrestrial magnetic field in the form of the position of the magnetic poles as well as the magnetic disturbance level. Here we present a Bayesian approach to reconstruct the auroral oval from ground-based observations by using two different auroral oval models. With this method we can estimate the position of the magnetic poles in corrected geomagnetic coordinates as well as the Kp index. The method is first validated on synthetic observations before it is applied to four modern geomagnetic storms between 2003 and 2017 where ground-based reports and photographs were used to obtain the necessary information. We have shown that we are able to reconstruct the pole location with an accuracy of $\approx 2^\circ$ in latitude and $\approx 11^\circ$ in longitude. The Kp index can be inferred with a precision of one class. The future goal is to employ the method to historical observations.

Table 1: List of the 53 used sightings for the geomagnetic storm between March 27 and 28, 2017. The times given are local time. t_s : start time, t_e : end time, ST: time from Stellarium, az: azimuth, $\overline{az}$: mean azimuth, h : elevation angle, $\overline{h}$: mean elevation angle, r: red, y: yellow, cr: crimson, or: orange, w: white, g: green, go: gold, pi: pink, p: violet, b: blue

nr.	day	t_s [LT]	t_e [LT]	ST [LT]	az [°]	$\overline{az}$ [°]	h [°]	$\overline{h}$ [°]	location	lat. [°]	lon. [°]	colour
1	27	22:00	22:45	-	327 - 33	359.6	3 - 12	7.8	Flensburg (GER)	54.794	9.447	g, p
2	27	20:30	20:30	-	334 - 33	13.3	5 - 30	17.5	Kap Arkona (GER)	54.678	13.427	pi
3	27	-	-	23:15	329 - 52	10.1	12 - 25	18.6	Königsstuhl (GER)	54.757	13.663	g, pi
4	27	22:38	23:10	-	333 - 23	357.9	1 - 8	4.4	Hiddensee (GER)	54.550	13.106	g
5	27	20:19	22:24	23:24	323 - 25	354.2	1 - 9	4.9	Kiel-Bülk (GER)	54.462	10.127	g
6	27	22:50	22:50	-	321 - 32	356.1	0 - 9	4.6	Zingst (GER)	54.436	12.669	g
7	27	20:40	23:30	-	334 - 56	15.4	6 - 9	7.3	Hohenfelde, Plön (GER)	54.374	10.495	g, p
8	27	20:39	20:39	-	314 - 25	349.6	3 - 20	11.5	Graal-Müritz (GER)	54.250	12.246	g, pi
9	27	20:40	20:40	-	328 - 33	0.8	2 - 22	12.4	Börgerende (GER)	54.148	11.898	g, p
10	27	20:30	23:29	-	342 - 55	18.2	7 - 15	10.8	Kühlungsborn (GER)	54.147	11.742	g, p
11	27	20:26	21:07	-	328 - 28	358.3	3 - 10	6.3	Nordermeldorf (GER)	54.113	9.016	g
12	27	20:35	20:35	-	309 - 24	346.7	8 - 27	17.6	Bernitt (GER)	53.903	11.890	g, p
13	27	20:50	22:15	-	328 - 22	355.3	1 - 10	5.4	Feldhorst (GER)	53.861	10.421	g
14	27	20:30	21:00	-	335 - 50	12.4	5 - 21	13.2	Seth (GER)	53.848	10.175	p
15	27	21:00	21:20	-	308 - 29	348.8	3 - 19	11.3	Norderney (GER)	53.707	7.156	pi
16	27	20:40	20:50	-	319 - 27	352.9	2 - 25	13.6	Galenbeck (GER)	53.620	13.706	g, pi, p
17	27	21:08	03:00	22:30	322 - 22	351.7	4 - 12	8.2	Dornsode (GER)	53.566	9.039	pi
18	27	20:45	20:45	-	331 - 31	1.0	11 - 26	18.8	Witzeze (GER)	53.452	10.608	pi
19	27	20:30	23:30	-	329 - 23	355.9	6 - 19	12.5	Oldenburg (GER)	53.148	8.211	g, p
20	27	-	-	22:00	354 - 12	2.7	9	8.6	Oldenburg (GER)	53.148	8.211	g
21	27	20:45	22:35	21:45	337 - 7	351.8	2 - 8	4.9	Lindenberg (GER)	52.599	13.531	g, r
22	27	20:40	21:00	-	331 - 16	353.2	7 - 24	15.1	Wolfsburg (GER)	52.453	10.787	p
23	27	-	-	21:50	324 - 9	346.8	4 - 22	12.9	Fürstenwalde (GER)	52.367	14.067	p
24	27	20:45	20:45	-	322 - 22	351.6	4 - 17	10.5	Wolmirsleben (GER)	51.947	11.487	g, pi
25	27	20:00	20:30	-	344 - 29	6.2	3 - 14	8.9	Hohegeiß (GER)	51.664	10.667	g, p
26	27	20:37	20:37	-	340 - 16	358.2	5 - 13	8.9	Nünchritz (GER)	51.299	13.390	pi
27	27	20:36	20:36	-	311 - 41	356.2	5 - 19	12.2	Herzogswalde (GER)	51.012	13.495	pi

28	27	20:30	22:00	-	335 - 21	357.9	6 - 13	9.1	Halberstadt (GER)	51.895	11.049	pi
29	27	04:00	04:00	-	0 - 360	0.0	90	90.0	Anchorage (AK, USA)	61.218	-149.907	g, p
30	27	04:51	05:21	-	0 - 360	0.0	90	90.0	Shageluk (AK, USA)	62.668	-159.556	g, w
31	27	07:41	07:41	06:30	330 - 119	44.7	5 - 66	35.6	near Coplake (NT, CAN)	60.093	-113.673	g, pi
32	27	21:05	22:50	-	-45 - 45	0.0	5 - 10	7.5	Chapel of Garioch (GBR)	57.305	-2.471	g, p
33	27	20:57	21:12	-	-45 - 45	0.0	5 - 10	7.5	Maryburgh (GBR)	57.574	-4.442	g
34	27	22:10	22:10	-	327 - 74	20.4	2 - 19	10.3	Hornsjo (NOR)	61.247	10.740	g
35	27	21:44	21:44	-	0 - 36	0.0	90	90.0	Doralen (NOR)	61.986	9.951	g
36	27	22:03	22:18	-	-45 - 45	0.0	5 - 10	7.5	Eggmond aan Zee (NLD)	52.624	4.628	g
37	27	21:40	22:10	-	-45 - 45	0.0	5 - 10	7.5	Cregneash (GBR)	54.069	-4.768	g
38	27	21:45	23:00	-	-45 - 45	0.0	5 - 10	7.5	Auchterarder (GBR)	56.290	-3.724	g
39	27	22:27	04:12	-	-45 - 45	0.0	5 - 10	7.5	Moss (NOR)	59.434	10.659	g
40	27	23:03	23:03	-	328 - 49	8.3	5 - 54	29.7	Uppsala (SWE)	59.858	17.639	g, b
41	27	22:41	23:41	-	-45 - 45	0.0	45	45.0	Troon (GBR)	55.542	-4.660	r, g, w, b
42	27	-	-	21:56	345 - 75	30.0	12 - 38	25.0	Duluth (MN, USA)	46.766	-92.118	g, p
43	28	20:34	02:27	22:16	324 - 46	5.4	4 - 24	14.0	Westermarcksdorf (GER)	54.521	11.054	g, pi
44	28	23:30	00:15	-	270 - 90	0.0	5 - 10	7.5	Osterholz-Scharmbeck (GER)	53.227	8.790	g, r
45	28	22:20	23:05	-	0 - 360	0.0	90	90.0	Floi (ISL)	63.989	-21.185	g, w, pi
46	28	01:30	01:30	-	323 - 20	351.4	1 - 25	12.8	Sandviken (NOR)	60.442	5.324	g, p
47	28	22:06	22:06	20:17	330 - 17	353.4	7 - 20	13.6	Mason City (IO, USA)	43.152	-93.198	pi
48	28	22:25	22:55	-	-45 - 45	0.0	5 - 10	7.5	Bemidji (MN, USA)	47.484	-94.907	g
49	28	22:21	01:21	-	-45 - 45	0.0	45	45.0	Tomahawk (AB, CAN)	53.399	-114.627	r, g, w
50	28	21:54	22:24	-	-45 - 45	0.0	45	45.0	Provost (AB, CAN)	52.356	-110.262	g
51	28	22:25	23:25	-	-45 - 45	0.0	45	45.0	Edmonton (AB, CAN)	53.547	-113.500	g
52	28	00:32	00:32	00:30	302 - 20	341.2	9 - 28	20.6	Webster (NY, USA)	43.214	-77.434	pi
53	28	00:01	00:01	03:00	349 - 52	20.8	5 - 10	7.5	Barrows (MN, USA)	46.301	-94.254	g

Table 2: References of the 53 used auroral sightings for the geomagnetic storm in 2017. “aurora archive” refers to the archive from Andreas Möller, which is available from <http://www.polarlicht-archiv.de/>. Aurorasaurus is a citizens science project collecting aurora sightings (<https://www.aurorasaurus.org/>).

nr.	observer	reference
1	Matthias Kirsch	aurora archive
2	Maik Kiehl	aurora archive
3	Melanie Vollbrecht	aurora archive
4	Uta Gau	aurora archive
5	Carsten Jonas	aurora archive
6	Mirko Nettelau	aurora archive
7	Henning Untiedt	aurora archive
8	Dominique Hanke	aurora archive
9	Dan S.	aurora archive
10	Olaf Andrich	aurora archive
11	Jörg Kaufmann	aurora archive
12	Wolfgang Hamburg	aurora archive
13	Thorsten Witt	aurora archive
14	Thomas Rickert	aurora archive
15	Ralf Ulrichs	aurora archive
16	Christian Ollwig	aurora archive
17	Michael Theusner	aurora archive
18	Stefan Gerlach	aurora archive
19	Andreas Abeln	aurora archive
20	Marcus Speckmann	aurora archive
21	Sebastian Baack	aurora archive
22	Alexandra Zimmermann	aurora archive
23	Anke Klemcke	aurora archive
24	Willi Nowak	aurora archive
25	Sibylle Lage	aurora archive
26	Uwe Thieme	aurora archive
27	Heiko Ulbricht	aurora archive
28	Uwe Kohbs	aurora archive
29	Joe Vigil	Aurorasaurus
30	Anonymous	Aurorasaurus
31	Andy Witmann	Aurorasaurus
32	Anonymous	Aurorasaurus
33	I Sinclair	Aurorasaurus
34	One World Institute	Aurorasaurus
35	Christina Pappin	Aurorasaurus
36	Kees Zwaan	Aurorasaurus
37	Anonymous	Aurorasaurus
38	Anonymous	Aurorasaurus
39	Ragnar Rock	Aurorasaurus
40	Scott Davies	Aurorasaurus
41	Milesy303	Aurorasaurus
42	Joe Moore	Aurorasaurus
43	Laura Kranich	aurora archive
44	Kirsten Schmidt	aurora archive
45	Lisi	Aurorasaurus
46	Jeroen vander Sluijs	Aurorasaurus
47	Diana Hayungs	Aurorasaurus
48	Paul Bunyan	Aurorasaurus
49	Anonymous	Aurorasaurus
50	Anonymous	Aurorasaurus

51	Wherezjeff	Aurorasaurus
52	Jerome Davis	Aurorasaurus
53	Preston Hoiseth	Aurorasaurus

Table 3: List of the 15 unused sightings for the geomagnetic storm between March 27 and 28, 2017. The times given are local time. t_s : start time, t_e : end time, ST: time from Stellarium, az: azimuth, $\overline{az}$: mean azimuth, h: elevation angle, $\overline{h}$: mean elevation angle, r: red, y: yellow, cr: crimson, or: orange, w: white, g: green, go: gold, pi: pink, p: violet, b: blue

nr.	day	t_s [LT]	t_e [LT]	ST [LT]	az [°]	$\overline{az}$ [°]	h [°]	$\overline{h}$ [°]	location	lat. [°]	lon. [°]	colour
1	27	-	-	-	-	-	-	-	Flensburg (GER)	54.794	9.447	-
2	27	21:40	21:40	-	-	-	-	-	Kiel-Bülk (GER)	54.462	10.127	-
3	27	21:15	21:15	-	-	-	-	-	Eutin (GER)	54.133	10.610	g, r
4	27	-	-	-	-	-	-	-	Langeln (GER)	53.800	9.856	-
5	27	20:30	20:30	-	-	-	-	-	Oldenburg (GER)	53.148	8.211	g
6	27	-	-	-	-	-	-	-	Pritzerbe (GER)	52.527	12.473	-
7	27	-	-	-	-	-	-	-	Potsdam-Mittelmark (GER)	52.252	12.908	-
8	27	-	-	-	-	-	-	-	Gladbeck (GER)	51.571	6.985	g
9	27	20:40	20:40	-	-	-	-	-	Großer Arber (GER)	49.113	13.136	-
10	27	22:40	22:40	-	-	-	-	-	Miesbach (GER)	47.790	11.833	-
11	27	20:40	20:40	-	-	-	-	-	Funtenseetauern (GER)	47.483	12.983	-
12	27	20:40	20:40	-	-	-	-	-	Großer Asitz (AUT)	47.402	12.702	-
13	27	22:08	22:23	-	-	-	-	-	Bekkjevatnet (NOR)	61.433	5.822	g
14	27	19:32	19:32	-	-	-	-	-	Svartifoss Wasserfall (ISL)	64.014	-16.970	g
15	28	05:34	05:34	-	-	-	-	-	Sandbudir (ISL)	64.932	-17.989	g

Table 4: References of the 15 used auroral sightings for the geomagnetic storm in 2017. “aurora archive” refers to the archive from Andreas Möller, which is available from <http://www.polarlicht-archiv.de/>. Aurorasaurus is a citizens science project collecting aurora sightings (<https://www.aurorasaurus.org/>).

nr.	observer	reference
1	Thorben Carstensen	aurora archive
2	Patrick Paproth	aurora archive
3	Stefan Heitmann	aurora archive
4	Martin Schwedler-Sommerfeld	aurora archive
5	Carsten Dosche	aurora archive
6	Matthias Krüer	aurora archive
7	Dettlaff Cevin	aurora archive
8	Anke Mo.	aurora archive
9	foto-webcam.eu	aurora archive
10	Thomas Klein	aurora archive
11	foto-webcam.eu	aurora archive
12	foto-webcam.eu	aurora archive
13	Anonymous	Aurorasaurus
14	Extreme Iceland	Aurorasaurus
15	Extreme Iceland	Aurorasaurus

Table 5: List of the 78 used sightings for the geomagnetic storm between May 8 and 9, 2016. The times given are local time. t_s : start time, t_e : end time, ST: time from Stellarium, az: azimuth, $\overline{az}$: mean azimuth, h: elevation angle, $\overline{h}$: mean elevation angle, r: red, y: yellow, cr: crimson, or: orange, w: white, g: green, go: gold, pi: pink, p: violet, b: blue

nr.	day	t_s [LT]	t_e [LT]	ST [LT]	az [°]	$\overline{az}$ [°]	h [°]	$\overline{h}$ [°]	location	lat. [°]	lon. [°]	colour
1	8	22:49	22:31	-	11 - 68	39.5	19 - 34	26.2	Flensburg (GER)	54.794	9.447	p
2	8	-	22:42	-	4 - 28	15.8	8 - 23	15.5	Hiddensee (GER)	54.551	13.106	p
3	8	-	-	22:23	6 - 8	6.8	10 - 17	13.5	Husby (GER)	54.498	9.484	p, g
4	8	23:20	22:47	-	320 - 32	355.1	5 - 18	11.7	Ahrenschoop (GER)	54.379	12.418	p
5	8	-	22:16	-	341 - 11	355.8	4 - 15	9.3	Steinwedel (GER)	54.237	9.669	p
6	8	22:35	22:20	-	348 - 48	17.8	7 - 27	16.6	Helgoland (GER)	54.181	7.889	p
7	8	23:00	22:35	-	333 - 21	356.8	5 - 14	9.9	Meldorfer (GER)	54.151	9.075	p
8	8	23:40	22:50	22:15	320 - 12	346.3	6 - 19	12.0	Nordermeldorf (GER)	54.113	9.016	g, b, p
9	8	23:00	22:38	-	3 - 5	4.3	7 - 21	14.0	Rostock (GER)	54.083	12.100	p
10	8	-	22:35	-	350 - 63	26.4	9 - 31	19.6	Lübeck-Travemünde (GER)	53.960	10.854	pi
11	8	-	21:54	-	349 - 29	8.8	6 - 30	18.1	Kotelow (GER)	53.650	13.656	pi
12	8	-	22:18	-	331 - 18	354.1	6 - 14	10.1	Imsum (GER)	53.612	8.537	pi
13	8	-	22:32	-	26 - 49	37.6	16 - 27	21.5	Bremerhaven (GER)	53.539	8.583	pi
14	8	22:58	22:36	-	343 - 49	16.0	6 - 14	10.0	Witzeze (GER)	53.452	10.608	pi
15	8	-	22:35	-	7 - 37	21.9	9 - 23	15.6	Oldenburg (GER)	53.144	8.211	pi
16	8	-	22:30	-	336 - 23	358.3	6 - 14	9.7	Oldenburg (GER)	53.144	8.211	pi, p
17	8	22:45	22:22	23:00	328 - 29	358.5	5 - 24	14.5	Holdorf, Vechta (GER)	52.575	8.137	pi
18	8	-	22:36	-	346 - 50	17.7	13 - 25	19.1	Itterbeck (GER)	52.505	6.804	p
19	8	-	-	23:19	302 - 3	332.4	8 - 23	15.4	Havelsee (GER)	52.503	12.492	pi
20	8	-	22:30	-	332 - 23	357.3	4 - 9	6.5	Wolfsburg (GER)	52.423	10.787	pi
21	8	-	22:19	-	329 - 32	0.6	5 - 13	8.9	Lübbecke (GER)	52.310	8.622	pi, p
22	8	23:00	22:45	23:30	317 - 11	344.0	6 - 23	14.1	Rheine (GER)	52.282	7.443	pi
23	8	-	-	23:15	309 - 16	342.5	5 - 23	14.2	Georgsmarienhütte (GER)	52.202	8.049	pi
24	8	-	-	23:15	357 - 52	24.5	11 - 52	31.2	Linthe (GER)	52.154	12.786	pi
25	8	22:50	22:25	-	333 - 8	350.7	7 - 20	13.5	Halberstadt (GER)	51.895	11.049	pi, p
26	8	23:30	22:45	-	313 41	357.2	6 - 22	13.9	Elbingerode (GER)	51.747	10.805	g, p
27	8	-	22:43	-	3 - 32	17.0	7 - 16	11.5	Großenhain (GER)	51.291	13.531	pi

28	8	-	22:30	-	310 - 20	344.7	5 - 16	10.5	Bärwalde (GER)	51.202	13.674	p
29	8	22:45	22:36	-	316 - 30	353.2	6 - 19	12.4	Moritzburg (GER)	51.129	13.681	pi
30	8	-	22:47	-	345 - 29	7.3	7 - 20	13.9	Dresden (GER)	51.051	13.737	pi, p
31	8	23:15	22:46	23:17	327 - 7	347.1	4 - 27	15.3	Dresden (GER)	51.051	13.737	pi
32	8	22:40	22:35	-	353 - 12	2.2	4 - 8	6.0	Großer Arber (GER)	49.113	13.136	p
33	8	22:20	22:10	-	324 - 16	350.0	7 - 16	11.4	Bad Schallerbach (AuT)	48.231	13.920	pi
34	8	22:50	22:10	23:20	338 - 359	348.8	3 - 9	5.9	Königssee (GER)	47.554	12.978	p
35	8	01:24	01:54	-	0 - 360	0	90	90	Innisfail (CAN)	52.036	-113.793	r, g, w, pi
36	8	01:23	02:23	-	0 - 360	0	5 - 90	47.5	Carstairs (CAN)	51.562	-114.096	r, g
37	8	22:53	02:23	-	-45 - 45	0	45	45	Calgary (CAN)	51.018	-114.081	g
38	8	00:38	02:08	-	0 - 360	0	5 - 90	47.5	Calgary (CAN)	51.018	-114.081	g
39	8	23:47	01:47	-	-45 - 45	0	5 - 10	7.5	San Juan Islands (WA, uSA)	48.550	-123.075	r, g, w, pi
40	8	00:45	02:30	-	0 - 360	0	5 - 90	47.5	Billings (MT, uSA)	45.783	-108.544	r, g, w
41	8	23:29	03:44	-	-45 - 45	0	5 - 10	7.5	Bedrock (CA, uSA)	38.315	-108.892	w, pi
42	8	02:01	02:31	-	0 - 360	0	90	90	Manvel (ND, uSA)	48.072	-97.178	g, w
43	8	02:02	03:17	-	-45 - 45	0	5 - 10	7.5	Madison (WI, uSA)	43.072	-89.391	g
44	8	22:28	05:28	-	-45 - 45	0	45	45	Butternut (WI, uSA)	46.014	-90.499	g, pi, p
45	8	03:16	04:01	-	-45 - 45	0	45	45	Minneapolis (MN, uSA)	44.969	-93.261	g
46	8	02:08	02:23	-	0 - 360	0	90	90	Calgary (CAN)	51.018	-114.081	r, g, p
47	8	23:42	02:12	-	-45 - 45	0	5 - 10	7.5	Debki (POL)	54.826	18.077	r, g, w
48	8	00:40	00:55	-	-45 - 45	0	5 - 10	7.5	Maardu (EST)	59.457	24.989	g
49	8	01:01	02:01	-	-45 - 45	0	5 - 10	7.5	St. Petersburg (RuS)	59.933	30.364	g
50	8	01:17	02:02	-	-45 - 45	0	45	45	Petrosawodsk (RuS)	61.783	34.358	g
51	8	00:43	01:13	-	0 - 360	0	90	90	Jyväskylä (FIN)	62.236	25.735	g
52	8	01:00	01:15	-	-45 - 45	0	5 - 10	7.5	Tesjoki (FIN)	60.471	26.300	g, w
53	8	21:50	21:50	-	8 - 51	29.8	6 - 19	12.6	Wieringerwerf (NLD)	52.851	5.024	p
54	8	00:52	00:52	23:03	307 - 21	344.0	6 - 20	13.1	Lancashire (GBR)	53.900	-2.700	pi
55	9	02:24	00:19	22:30	322 - 32	357.7	5 - 22	13.3	Kiel-Bülk (GER)	54.456	10.127	p, g
56	9	-	23:00	-	347 - 42	14.8	14 - 27	20.5	Zingst (GER)	54.436	12.689	p
57	9	00:00	23:10	-	358 - 42	20.1	7 - 15	11.3	Winnert (GER)	54.433	9.200	p
58	9	00:45	23:22	-	331 - 45	7.7	6 - 10	7.9	Hubertsberg (GER)	54.479	12.541	p
59	9	-	-	-	18 - 22	20.0	9 - 30	19.4	Hohenstein (GER)	54.288	12.805	p

60	9	23:50	23:02	23:15	323 - 35	359.0	6 - 17	11.4	Travemünde (GER)	53.967	10.867	p, pi
61	9	00:53	23:32	-	338 - 38	7.9	5 - 18	11.3	Schadehorn (GER)	53.845	10.395	pi, p
62	9	00:00	23:00	-	323 - 54	8.3	5 - 15	9.9	Norddeich (GER)	53.617	7.159	pi, p
63	9	02:45	00:22	23:00	320 - 30	355.2	3 - 14	8.7	Langwarden (GER)	53.599	8.238	g, pi
64	9	00:10	23:10	-	332 - 37	4.5	4 - 22	13.1	Wolmirsleben (GER)	51.947	11.487	pi
65	9	-	02:35	-	332 - 11	351.6	4 - 20	12.0	Altena-Hegenscheid (GER)	51.313	7.704	pi, b
66	9	-	23:30	-	327 - 12	349.5	6 - 15	10.4	Frauenstein (GER)	50.801	13.537	pi
67	9	00:57	01:12	-	-45 - 45	0	45	45	Moss (NOR)	59.434	10.659	g
68	9	00:18	00:33	-	-45 - 45	0	5 - 10	7.5	Ovington (GBR)	52.586	0.840	r, g, pi
69	9	00:41	03:36	-	-45 - 45	0	5 - 10	7.5	Troon (GBR)	55.542	-4.660	g
70	9	00:03	00:03	-	336 - 38	7.2	6 - 29	17.6	Dailly (GBR)	55.280	-4.717	pi
71	9	03:07	03:07	-	0 - 360	0	90	90	Frekmyr (NOR)	62.034	9.984	g, b
72	9	03:22	03:37	-	-45 - 45	0	5 - 10	7.5	Starvanger (NOR)	58.969	5.734	g
73	9	02:30	03:45	-	-45 - 45	0	45	45	Ben Macdhu (GBR)	57.071	-3.666	g, pi, p
74	9	-	-	00:00	330 - 37	3.5	9 - 28	18.3	O'Neil Creek (ON, CAN)	49.912	-87.504	g
75	9	23:03	01:03	-	-45 - 45	0	45	45	Bruce Crossing (MI, uSA)	46.529	-89.190	r, g, w
76	9	23:21	01:51	-	-45 - 45	0	5 - 10	7.5	Mackinaw city (MI, uSA)	45.778	-84.749	g, w
77	9	22:48	23:03	-	-45 - 45	0	5 - 10	7.5	Scanterbury (MB, CAN)	50.371	-96.623	g
78	9	00:02	00:02	-	333 - 31	1.8	7 - 23	15.1	Eureka Lake (ON, CAN)	49.834	-85.064	g

Table 6: References of the 78 used auroral sightings for the geomagnetic storm in 2016. “aurora archive” refers to the archive from Andreas Möller, which is available from <http://www.polarlicht-archiv.de/>. Aurorasaurus is a citizens science project collecting aurora sightings (<https://www.aurorasaurus.org/>).

nr.	observer	reference
1	Jannick Bruhns	aurora archive
2	Uta Gau	aurora archive
3	Matthias Kirsch	aurora archive
4	Ekkehard Gnadler	aurora archive
5	Daniel Ricke	aurora archive
6	Brigitte Rauch	aurora archive
7	Alexander Zachen	aurora archive
8	Jörg Kaufmann	aurora archive
9	Olaf Squarra	aurora archive
10	Benjamin Zabel	aurora archive
11	Christian Ollwig	aurora archive
12	Uwe Müller	aurora archive
13	Georg van Druenen	aurora archive
14	Stefan Gerlach	aurora archive
15	Marcus Speckmann	aurora archive
16	Carsten Dosche	aurora archive
17	Ludger Boergerding	aurora archive
18	Kai Dieker	aurora archive
19	Stormchaser Brandenburg	aurora archive
20	Alexandra Zimmermann	aurora archive
21	Uwe Ramsberg	aurora archive
22	Steffen Gude	aurora archive
23	Janina Runschke	aurora archive
24	Egbert von Ehr	aurora archive
25	Uwe Kohbs	aurora archive
26	Sibylle Lage	aurora archive
27	Aris Gutsche	aurora archive
28	Heiko ulbricht	aurora archive
29	Sabine, Frank Wächter	aurora archive
30	Uwe Thieme	aurora archive
31	Rico Hickmann	aurora archive
32	foto-webcam.eu	aurora archive
33	Robert Candrak	aurora archive
34	foto-webcam.eu	aurora archive
35	AAC Shannon	Aurorasaurus
36	Johnfuji	Aurorasaurus
37	Wildrose	Aurorasaurus
38	RobinW	Aurorasaurus
39	ChrisTeren	Aurorasaurus
40	Jules	Aurorasaurus
41	@Theumno	Aurorasaurus
42	Carl Jones	Aurorasaurus
43	ironplatypus	Aurorasaurus
44	Anonymous	Aurorasaurus
45	Sky Love	Aurorasaurus
46	Ulexite	Aurorasaurus
47	Okul	Aurorasaurus
48	MadAstronomer	Aurorasaurus
49	Polkovnik	Aurorasaurus
50	Dimitrii	Aurorasaurus

51	DarthBrandt	Aurorasaurus
52	AuroraFinland	Aurorasaurus
53	Jan Ruers	Aurorasaurus
54	Geraint Johnes	Aurorasaurus
55	Laura Kranich	aurora archive
56	Jürgen Vogel	aurora archive
57	Mario Losereit	aurora archive
58	Henning untiedt	aurora archive
59	Wim de Vries	aurora archive
60	Thomas Schwarzbach	aurora archive
61	Thorsten Witt	aurora archive
62	Sabine Löbbe	aurora archive
63	Michael Theusner	aurora archive
64	Willi	aurora archive
65	Björn	aurora archive
66	Mathias Fleischer	aurora archive
67	Ragnar Rock	Aurorasaurus
68	Chunder10	Aurorasaurus
69	Milesy303	Aurorasaurus
70	Jonathan Cooper	Aurorasaurus
71	Lars Mathisen	Aurorasaurus
72	nicobty	Aurorasaurus
73	Anonymous	Aurorasaurus
74	Jake Avery	Aurorasaurus
75	Anonymous	Aurorasaurus
76	Mia	Aurorasaurus
77	davem	Aurorasaurus
78	Melinda Zosh	Aurorasaurus

Table 7: List of the 26 unused sightings for the geomagnetic storm between May 8 and 9, 2016. The times given are local time. t_s : start time, t_e : end time, ST: time from Stellarium, az: azimuth, $\overline{az}$: mean azimuth, h : elevation angle, $\overline{h}$: mean elevation angle, r: red, y: yellow, cr: crimson, or: orange, w: white, g: green, go: gold, pi: pink, p: violet, b: blue

nr.	day	t_s [LT]	t_e [LT]	ST [LT]	az [°]	$\overline{az}$ [°]	h [°]	$\overline{h}$ [°]	location	lat. [°]	lon. [°]	colour
1	8	-	22:00	-	-	-	-	-	Süderlügum (GER)	54.873	8.898	-
2	8	-	-	-	-	-	-	-	Kiel (GER)	54.323	10.123	p
3	8	-	-	-	-	-	-	-	Büdelsdorf (GER)	54.318	9.680	-
4	8	-	-	-	-	-	-	-	Schellhorn (GER)	54.228	10.298	p
5	8	21:42	21:38	-	-	-	-	-	Warnemünde (GER)	54.167	12.083	-
6	8	-	21:47	-	-	-	-	-	Husby (GER)	54.147	11.742	-
7	8	23:00	22:30	-	-	-	-	-	Henstedt-Ulzburg (GER)	53.790	9.980	p
8	8	-	-	-	-	-	-	-	Klein Trebbow (GER)	53.711	11.372	p
9	8	22:54	22:29	-	-	-	-	-	Oldenburg (GER)	53.144	8.211	-
10	8	-	22:16	-	-	-	-	-	Schüttorf (GER)	52.323	7.225	p
11	8	23:00	22:55	-	-	-	-	-	Gütersloh (GER)	51.902	8.383	g
12	8	23:00	22:30	-	-	-	-	-	Marienmünster (GER)	51.819	9.231	-
13	8	-	-	-	-	-	-	-	Gladbeck (GER)	51.571	6.985	-
14	8	-	21:39	-	-	-	-	-	Collm (GER)	51.301	13.017	-
15	8	-	-	-	-	-	-	-	Fulda (GER)	50.556	9.668	-
16	8	-	-	-	-	-	-	-	Bad Neustadt (GER)	50.323	10.203	-
17	8	-	22:17	-	-	-	-	-	Premenreuth (GER)	49.844	12.140	-
18	8	-	-	-	-	-	-	-	Schlägl (AUT)	48.637	13.967	-
19	8	-	-	-	-	-	-	-	-	-	-	-
20	8	22:00	21:30	-	-	-	-	-	-	-	-	-
21	8	03:30	03:30	-	-	-	-	-	Anchorage (AK, USA)	61.218	-149.907	-
22	8	22:38	22:38	-	-	-	-	-	Lofoten (NOR)	68.300	14.300	g
23	9	23:45	23:22	-	-	-	-	-	Sylt (GER)	54.900	8.300	-
24	9	23:40	23:04	-	-	-	-	-	Bernitt (GER)	53.903	11.890	-
25	9	03:00	00:37	-	-	-	-	-	Hooksiel (GER)	53.631	8.026	-
26	9	00:30	23:15	-	-	-	-	-	Harpstedt (GER)	52.909	8.587	-

Table 8: References of the 26 unused auroral sightings for the geomagnetic storm in 2016. “aurora archive” refers to the archive from Andreas Möller, which is available from <http://www.polarlicht-archiv.de/>. Aurorasaurus is a citizens science project collecting aurora sightings (<https://www.aurorasaurus.org/>).

nr.	observer	reference
1	Thomas Pest	aurora archive
2	Carsten Jonas	aurora archive
3	Michael Green	aurora archive
4	Tim Peukert	aurora archive
5	Leibniz-Institut für Atmosphärenphysik (IAP)	aurora archive
6	Leibniz-Institut für Atmosphärenphysik (IAP)	aurora archive
7	Martin Schwedler-Sommerfeld	aurora archive
8	Torsten Menz	aurora archive
9	Andreas Abeln	aurora archive
10	Marc Sluiter	aurora archive
11	Gudrun Vornholt	aurora archive
12	Marion Struck	aurora archive
13	Anke Mo.	aurora archive
14	Leibniz-Institut für Atmosphärenphysik (IAP)	aurora archive
15	Florian	aurora archive
16	Jan Gensler	aurora archive
17	Werner Moller	aurora archive
18	Karl Kaiser	aurora archive
19	Wilfried Fritz	aurora archive
20	Robin Bogaletzki	aurora archive
21	aikosque	Aurorasaurus
22	EmmaB	Aurorasaurus
23	Klaus Czerwi	aurora archive
24	Wolfgang Hamburg	aurora archive
25	O. Janssen	aurora archive
26	Thomas Lindemann	aurora archive

Table 9: List of the 186 used sightings for the St. Patrick's Day storm between March 17 and 18, 2015. The times given are local time. t_s : start time, t_e : end time, ST: time from Stellarium, az: azimuth, $\overline{az}$: mean azimuth, h: elevation angle, $\overline{h}$: mean elevation angle, r: red, y: yellow, cr: crimson, or: orange, w: white, g: green, go: gold, pi: pink, p: violet, b: blue

nr.	day	t_s [LT]	t_e [LT]	ST [LT]	az [°]	$\overline{az}$ [°]	h [°]	$\overline{h}$ [°]	location	lat. [°]	lon. [°]	colour
1	17	-	-	23:30	289 - 46	347.5	9 - 59	34.5	Ellund (GER)	54.770	9.308	g, cr, bl
2	17	19:56	03:56	-	311 - 22	346.5	16 - 44	30	Juliusruh (GER)	54.621	13.372	g, r
3	17	21:00	3:30	-	339 - 58	18.5	6 - 42	24	Stohl, Dänischenhagen (GER)	54.471	10.147	g, y, r, cr
4	17	-	-	00:20	317 - 35	356	7 - 46	26.5	Leuchtturm Bülk (GER)	54.455	10.197	r, g, w
5	17	-	-	00:20	359 - 37	19	9 - 33	21.5	Laboe (GER)	54.402	10.224	r, g, cr
6	17	20:45	23:10	-	303 - 8	335.5	6 - 27	16.5	Kembs (GER)	54.348	10.917	g, cr
7	17	22:00	-	-	282 - 349	315.5	16 - 43	29.5	Hohwacht (GER)	54.324	10.668	g, cr
8	17	00:06	-	-	335 - 29	352	6 - 35	20.5	Stralsund (GER)	54.309	13.088	g, bl, cr
9	17	-	-	20:30	336 - 67	23	4 - 44	24	Nordvorpommern (GER)	54.22	12.83	g, r, cr
10	17	21:16	21:46	-	278 - 354	316	16 - 53	34.5	Helgoland (GER)	54.181	7.889	g, r, cr
11	17	21:00	23:00	-	265 - 80	352.5	10 - 54	32	Malente (GER)	54.173	10.559	g, r
12	17	20:00	01:20	-	0 - 360	0	90 - 90	90	Loissin (GER)	54.112	13.528	g, w, r
13	17	21:15	-	-	312 - 26	349	17 - 38	27.5	Friedrichskoog (GER)	54.014	8.898	r, cr
14	17	22:00	-	-	342 - 32	7.5	5 - 31	18	Pariner Berg (GER)	53.947	10.679	y, g, r
15	17	23:45	00:02	-	285 - 67	356	15 - 61	38	GroßParin (GER)	53.939	10.697	g, r
16	17	-	-	23:30	281 - 75	357.5	0 - 52	26	Hartenholm (GER)	53.900	10.060	g, w, r
17	17	21:00	23:00	-	331 - 80	25.5	8 - 54	31	Seth (GER)	53.847	10.145	g, r, cr
18	17	21:00	-	-	253 - 27	320	4 - 49	26.5	Klein Trebbow (GER)	53.711	11.372	g, r, cr
19	17	23:55	00:20	23:45	349 - 43	16	9 - 29	19	Mölln (GER)	53.620	10.689	g, r
20	17	19:45	00:00	-	318 - 69	13.5	9 - 44	26.5	Imsum (GER)	53.612	8.537	g, pi
21	17	21:00	-	-	340 - 52	17	9 - 37	23	Hamburg (GER)	53.551	9.994	g, r, cr
22	17	20:59	00:51	-	305 - 61	1.5	7 - 49	28	Buchholz, Nordheide (GER)	53.317	9.867	g, y, r
23	17	19:53	00:45	-	301 - 15	338	10 - 42	21.5	Oldenburg (GER)	53.144	8.211	g, pi
24	17	-	-	21:00	330 - 40	5	8 - 43	25.5	Krelingen (GER)	52.803	9.659	y, r, pi
25	17	-	-	21:30	327 - 37	2	16 - 41	28.5	Sulingen (GER)	52.683	8.811	pi
26	17	-	-	20:15	300 - 39	349.5	8 - 30	19	Berlin (GER)	52.519	13.405	g, pi
27	17	23:45	-	21:15	316 - 54	5	5 - 42	23.5	Arpke (GER)	52.388	10.097	g, r, pi

28	17	20:00	21:30	21:00	297 - 11	334	7 - 33	20	Fürstenwalde (GER)	52.369	14.067	g, r, pi
29	17	-	-	21:30	318 - 41	359.5	10 - 36	23	Rheine (GER)	52.282	7.443	r, cr
30	17	-	-	21:00	290 - 359	324.5	11 - 37	24	Osnabrück (GER)	52.280	8.047	g, r
31	17	21:01	-	21:00	309 - 21	345	15 - 31	23	Osnabrück (GER)	52.280	8.047	pi
32	17	23:50	00:20	23:00	327 - 40	3.5	10 - 41	25.5	Bünde (GER)	52.198	8.583	g, r
33	17	20:00	01:55	00:00	309 - 56	2.5	6 - 53	29.5	Köbelitz (GER)	52.180	11.782	g, r
34	17	20:30	23:00	20:15	296 - 21	338.5	0 - 33	16.5	Kalme, Wolfsbüttel (GER)	52.058	10.646	y, g, r, cr
35	17	21:00	21:30	20:15	301 - 33	347	9 - 41	25	Versmold (GER)	52.042	8.148	y, cr
36	17	19:00	01:30	23:45	310 - 37	353.5	5 - 43	24	Coesfeld (GER)	51.936	7.168	y, r
37	17	21:45	01:00	23:30	340 - 46	13	4 - 34	19	Merfeld (GER)	51.848	7.283	r, g
38	17	20:53	21:09	21:00	21 - 61	41	7 - 28	17.5	Dessau (GER)	51.831	12.242	r
39	17	20:00	01:30	-	342 - 62	22	4 - 40	22	Sankt Andreasberg (GER)	51.712	10.523	g, r, cr
40	17	19:40	-	23:15	329 - 34	1.5	3 - 37	20	Cottbus (GER)	51.757	14.333	g, r
41	17	-	-	21:30	337 - 42	9.5	7 - 27	17	Nordkirchen (GER)	51.738	7.522	g, r, pi
42	17	-	-	00:00	316 - 29	352.5	12 - 39	25.5	Gladbeck (GER)	51.571	6.985	r
43	17	21:00	-	22:00	344 - 16	0	11 - 24	17.5	Dortmund (GER)	51.514	7.465	cr
44	17	-	-	22:30	331 - 40	5.5	2 - 41	21.5	Riesa (GER)	51.317	13.268	g, w, r
45	17	19:40	00:12	23:30	325 - 39	2	5 - 39	22	Lampertswalde (GER)	51.310	13.676	g, r, cr
46	17	20:33	23:05	21:15	323 - 59	11	0 - 37	18.5	Collm (GER)	51.301	13.017	g, r, cr, pi
47	17	20:50	00:04	00:00	322 - 10	346	7 - 39	23	Bad Sooden Allendorf (GER)	51.269	9.980	g, r
48	17	21:00	-	21:30	326 - 16	351	0 - 30	15	Mönchengladbach (GER)	51.179	6.443	g, b
49	17	21:04	00:27	00:00	301 - 19	340	5 - 30	17.5	Reichenberg, Moritzburg (GER)	51.129	13.681	g, w, pi
50	17	21:10	-	22:10	25 - 49	37	9 - 24	16.5	Heinsberg (GER)	51.059	6.118	r
51	17	20:59	-	21:00	319 - 31	10	6 - 32	19	Kretzschau (GER)	51.054	12.077	g, r, cr
52	17	-	-	23:45	347 - 52	19.5	5 - 39	22	Dresden (GER)	51.051	13.737	y, g, r
53	17	23:55	00:20	00:15	331 - 19	355	5 - 29	17	Tautenhain (GER)	50.922	11.905	g, r
54	17	19:40	21:30	21:00	311 - 58	4.5	6 - 42	24	Jena (GER)	50.927	11.589	g, r, cr
55	17	21:15	-	20:45	315 - 21	348	4 - 26	15	Jena (GER)	50.927	11.589	g, r, cr
56	17	21:45	00:20	22:45	330 - 27	358.5	6 - 30	18	Brand-Erbisdorf (GER)	50.867	13.324	r, g
57	17	21:30	-	21:07	316 - 39	357.5	0 - 30	15	Neunkirchen-Seelscheid (GER)	50.855	7.332	g, cr
58	17	21:10	-	21:45	311 - 37	354	0 - 29	14.5	Hennef (GER)	50.760	7.283	g, cr
59	17	22:15	-	23:08	318 - 43	0.5	3 - 52	27.5	Hohensolms (GER)	50.652	8.516	g, r

60	17	20:38	21:28	21:00	302 - 20	341	6 - 47	26.5	Simmerath (GER)	50.607	6.299	b, cr
61	17	21:07	21:55	20:30	286 - 64	355	6 - 35	20.5	Schwarzenberg (GER)	50.543	12.779	g, cr, pi
62	17	19:50	-	-	271 - 340	305.5	- - 40	40	Hinternah (GER)	50.518	10.794	cr
63	17	23:58	00:14	23:30	317 - 45	1.5	4 - 38	21	Großer Feldberg (GER)	50.234	8.459	g, pi
64	17	-	-	21:00	320 - 26	353.5	5 - 31	18	Würzburg (GER)	49.791	9.954	r, cr
65	17	20:50	22:15	21:00	300 - 60	45	10 - 15	12.5	Niederstetten (GER)	49.399	9.919	g, r
66	17	23:50	-	23:50	321 - 29	355	9 - 46	27.5	Waghäusel (GER)	49.250	8.515	r
67	17	21:24	-	21:24	313 - 27	350	5 - 35	20	Hermersbergerhof-Pfälzerwald (GER)	49.247	7.836	cr, pi
68	17	-	-	23:50	339 - 53	16	0 - 28	14	Regensburg (GER)	49.015	12.101	g, w, r
69	17	-	-	00:00	343 - 17	0	10 - 24	17	Erdweg-Walkertshofen (GER)	48.324	11.293	r, cr
70	17	02:08	-	23:45	327 - 38	2.5	5 - 26	15.5	Hohenzell (GER)	48.350	11.186	g, r, pi
71	17	21:00	00:30	22:00	308 - 354	331	14 - 28	21	Bad Endorf (GER)	47.907	12.301	cr
72	17	22:30	-	22:30	295 - 116	25.5	0 - 81	40.5	Lindenberg, Allgäu (GER)	47.604	9.888	g, r
73	17	-	-	23:30	318 - 44	1	7 - 23	15	Schöckl, Graz (AuT)	47.183	15.482	y, r
74	17	20:59	21:14	-	5 - 22	13.5	14 - 40	27.5	Hohen Sonnblick (AuT)	47.054	12.957	r, cr
75	17	21:00	-	21:00	10 - 38	24	4 - 9	6.5	Mölltaler Gletscher (AuT)	46.980	13.006	r
76	17	00:59	-	-	0 - 360	0	90 - 90	90	Espoo (FIN)	60.207	24.652	g, r
77	17	00:48	-	-	35 - 35	350	13 - 60	36.5	Tampere (FIN)	61.496	23.756	g, cr
78	17	06:30	-	-	0 - 360	0	90 - 90	90	Donelly Creek (AK, uSA)	63.676	-145.883	g, r
79	17	22:56	-	-	0 - 0	0	7 - 15	11	Moskow (RuS)	55.750	37.599	g
80	17	20:50	-	-	0 - 0	0	5 - 34	19.5	Feldberg (GER)	47.875	8.006	g, r
81	17	23,1	-	-	0 - 360	0	90 - 90	90	Northumberland (GBR)	55.229	-2.185	g, r, pi
82	17	21:28	-	-	0 - 360	0	90 - 90	90	Isle of Mull (GBR)	56.436	-6.004	g, r
83	17	20:00	-	-	287 - 354	320.5	8 - 40	24	Northumberland (GBR)	55.229	-2.185	g, r, pi
84	17	04:00	-	-	355 - 39	17	0 - 22	11	Paradox Valley (CO, uSA)	38.325	-108.865	g, r
85	17	00:26	-	-	0 - 360	0	90 - 90	90	Kiruna (SWE)	67.856	20.226	g
86	17	22:36	-	-	0 - 360	0	90 - 90	90	Sodankylä (FIN)	67.416	26.588	-
87	17	22:30	-	-	5 - 22	13.5	14 - 40	27	Sonnblick (AuT)	47.054	12.957	r, cr
88	17	03:00	-	-	338 - 23	0.5	11 - 23	17	Hokkaido (JPN)	43.33	142.58	r
89	17	00:15	-	-	272 - 54	343	5 - 36	20.5	Jena (GER)	50.927	11.589	g, r
90	17	23:30	-	-	323 - 31	357	20 - 66	43	Northumberland (GBR)	55.229	-2.185	g, r, pi
91	17	20:59	-	-	340 - 54	2	9 - 18	13.5	Jance (SVN)	46.064	14.696	or, r

92	17	21:00	-	-	287 - 48	347.5	10 - 24	17	Riesa (GER)	51.317	13.268	y, r, pi
93	17	03:30	-	-	0 - 98	49	19 - 66	42.5	Barriere (CAN)	51.182	-120.123	g, bl, w, r
94	17	21:20	-	-	0 - 360	0	90 - 90	90	Narsarsuaq (GRL)	61.157	-45.425	-
95	17	03:10	-	-	0 - 360	0	90 - 90	90	Athabasca (ON, CAN)	54.722	-113.286	-
96	17	03:20	-	-	0 - 360	0	90 - 90	90	Calgary (AB, CAN)	51.044	-114.073	-
97	17	05:30	-	-	0 - 360	0	90 - 90	90	Goose Bay (NL, CAN)	53.299	-60.335	-
98	17	03:45	-	-	0 - 360	0	90 - 90	90	Fort Simpson (NT, CAN)	61.863	-121.358	-
99	17	04:30	-	-	0 - 360	0	90 - 90	90	Fort Smith (NT, CAN)	60.005	-111.899	-
100	17	01:30	-	-	0 - 360	0	90 - 90	90	McGrath (Ak, uSA)	62.954	-155.593	-
101	17	05:00	-	-	0 - 360	0	90 - 90	90	Pinawa (MB, CAN)	50.151	-95.879	-
102	17	01:50	-	-	0 - 360	0	90 - 90	90	Rabbit Lake (SK, CAN)	53.142	-107.767	-
103	17	01:20	-	-	0 - 360	0	90 - 90	90	Kuuujuaq (QC, CAN)	58.104	-68.419	-
104	17	19:26	03:26	-	0 - 360	0	90 - 90	90	Oblast Nischni Nowgorod (RuS)	56.322	43.924	pi, g, r
105	17	19:44	20:14	-	330 - 30	0	5 - 10	7.5	Covasna (ROu)	45.846	26.177	r
106	17	-	02:14	-	330 - 30	0	45 - 45	45	Danzig (POL)	54.353	18.639	g, w
107	17	17:56	-	23:40	359 - 121	60	5 - 68	36.5	Salte (NOR)	58.708	5.592	g, w, r
108	17	19:59	01:59	-	330 - 30	0	45 - 45	45	Valga (EST)	57.781	26.053	g, w
109	17	20:03	01:03	-	0 - 360	0	5 - 90	90	Pieksämäki (FIN)	62.294	27.132	pi, g, r
110	17	20:42	21:12	-	0 - 360	0	5 - 90	90	Stockholm (SWE)	59.327	18.069	g
111	17	20:30	03:30	-	0 - 360	0	90 - 90	90	Saare maakond (EST)	58.265	22.478	pi, g, w, r
112	17	20:39	01:09	-	0 - 360	0	5 - 90	90	Helsinki (FIN)	60.167	24.963	g, r
113	17	21:08	-	-	0 - 360	0	90 - 90	90	Lahti (FIN)	60.979	25.657	-
114	17	20:32	-	-	0 - 360	0	5 - 90	90	Luosto (FIN)	67.133	26.899	-
115	17	22:44	22:59	-	0 - 360	0	5 - 90	90	Mala (SWE)	65.185	18.749	g, w
116	17	21:18	00:03	-	330 - 30	0	5 - 10	7.5	Alkmaar (NED)	52.632	4.755	w
117	17	20:01	-	20:15	289 - 17	333	5 - 53	29	Trefelwys (GBR)	52.502	-3.519	p, w, bl
118	17	21:20	21:05	-	0 - 360	0	90 - 90	90	Isle of Skye (GBR)	57.272	-6.235	p, pi
119	17	22:39	23:24	-	0 - 360	0	90 - 90	90	Karlstad (SWE)	59.401	13.510	w, r
120	17	23:00	02:30	-	0 - 360	0	5 - 90	90	Grisslehamn (SWE)	60.096	18.806	g, w
121	17	00:09	02:54	-	0 - 360	0	5 - 90	90	Tallinn (EST)	59.441	24.757	pi, g, w
122	17	23:04	00:19	-	0 - 360	0	5 - 90	90	Groa (NOR)	62.644	8.729	g
123	17	21:33	01:33	-	0 - 360	0	5 - 90	90	Lewis and Harris (GBR)	58.249	-6.666	g, w, r, p

124	17	20:17	20:32	-	0 - 360	0	90 - 90	90	Reykjavik (ISL)	64.146	-21.946	g
125	17	19:56	-	22:00	31 - 106	68.5	11 - 50	30.5	Kirkjufell (ISL)	64.942	-23.307	g
126	17	00:09	00:24	-	330 - 30	0	5 - 10	7.5	Göttingen (GER)	51.542	9.914	r
127	17	23:56	01:23	-	330 - 30	0	5 - 10	7.5	Fürstenwalde (GER)	52.369	14.067	pi, g, w, r
128	17	00:37	01:37	-	330 - 30	0	5 - 10	7.5	Posen (POL)	52.408	16.915	pi, g
129	17	22:48	23:18	-	330 - 30	0	5 - 10	7.5	Bailrigg (GBR)	54.011	-2.787	-
130	17	23:59	01:14	-	330 - 30	0	5 - 10	7.5	Puisieux-et-Clanlieu (FRA)	49.853	3.677	w
131	17	23:28	-	20:30	321 - 16	348.5	11 - 43	27	Cassel (FRA)	50.799	2.486	p
132	18	00:19	00:34	-	330 - 30	0	5 - 10	7.5	Claughton (GBR)	54.093	-2.669	g
133	18	23:46	02:16	-	0 - 360	0	90 - 90	90	Dalvik (ISL)	65.971	-18.533	pi, g, w, p
134	18	20:04	20:19	-	330 - 30	0	5 - 10	7.5	New York (NY, uSA)	40.715	-73.994	g
135	18	20:03	20:18	-	330 - 30	0	45 - 45	45	Paterson (NJ, uSA)	40.917	-74.174	w
136	18	20:18	21:03	-	330 - 30	0	5 - 10	7.5	Hustontown (PA, uSA)	40.049	-78.027	pi, g, r
137	18	20:04	23:49	-	330 - 30	0	45 - 45	45	Rochester (NY, uSA)	43.157	-77.612	g, r, p
138	18	20:21	22:51	-	330 - 30	0	5 - 10	7.5	Newark (OH, uSA)	40.065	-82.416	g
139	18	20:51	20:33	-	330 - 30	0	5 - 10	7.5	St. Johns (MI, uSA)	43.000	-84.559	g
140	18	20:33	20:48	-	330 - 30	0	5 - 10	7.5	Rodney (MI, uSA)	43.673	-85.329	g
141	18	22:29	23:44	-	330 - 30	0	5 - 10	7.5	Quebec (QC, CAN)	46.809	-71.204	g
142	18	21:49	21:49	-	330 - 30	0	45 - 45	45	Saratoga Springs (NY, uSA)	43.086	-73.786	g
143	18	21:52	22:07	-	330 - 30	0	5 - 10	7.5	Cascade Falls (VA, uSA)	37.354	-80.599	g, r
144	18	22:12	22:42	-	330 - 30	0	5 - 10	7.5	Newmarket (ON, CAN)	44.059	-79.459	g
145	18	21:34	01:04	-	330 - 30	0	5 - 10	7.5	Southampton (ON, CAN)	44.495	-81.369	pi, g
146	18	21:35	21:50	-	330 - 30	0	5 - 10	7.5	Grabill (IN, uSA)	41.211	-84.967	g
147	18	21:17	21:32	-	330 - 30	0	5 - 10	7.5	Traverse City (MI, uSA)	44.763	-85.621	g, w, bl
148	18	20:33	20:48	-	330 - 30	0	5 - 10	7.5	Beaver Island (MI, uSA)	45.645	-85.555	g
149	18	21:09	02:39	-	330 - 30	0	5 - 10	7.5	Marinette (WI, uSA)	45.099	-87.632	g, r
150	18	20:45	21:30	-	330 - 30	0	5 - 10	7.5	Zimmerman (MN, uSA)	45.443	-93.591	g, or
151	18	21:15	21:15	-	330 - 30	0	5 - 10	7.5	Milaca (MN, uSA)	45.756	-93.655	pi, g
152	18	21:07	21:22	-	330 - 30	0	45 - 45	45	Ely (MN, uSA)	47.903	-91.848	g
153	18	20:34	21:49	-	0 - 360	0	90 - 90	90	Zhoda (MB, CAN)	49.284	-96.510	pi, g, p
154	18	19:58	19:58	-	0 - 360	0	5 - 90	90	Elke island national park (AB, CAN)	53.608	-112.862	pi, g, w, p, bl
155	18	19:34	20:49	-	0 - 360	0	5 - 90	90	Fort McMurray (AB, CAN)	56.724	-111.381	pi, g, r

156	18	21:29	23:14	-	330 - 30	0	45 - 45	45	Drumheller (AB, CAN)	51.459	-112.718	g
157	18	20:23	20:38	-	330 - 30	0	5 - 10	7.5	Olds (AB, CAN)	51.795	-114.120	g, r
158	18	21:16	23:46	-	0 - 360	0	5 - 90	90	Hay River (NT, CAN)	60.816	-115.788	pi, g, w
159	18	00:47	01:02	-	0 - 360	0	5 - 90	90	Orange (VA, uSA)	38.245	-78.112	pi, g, r, or
160	18	00:01	00:46	-	330 - 30	0	5 - 10	7.5	Winnipeg (MB, CAN)	49.895	-97.139	g, w
161	18	20:28	20:43	-	0 - 360	0	90 - 90	90	McCarthy (AK, uSA)	61.433	-142.938	g
162	18	21:12	22:27	-	330 - 30	0	45 - 45	45	Dawson (YK, CAN)	64.044	-139.429	pi, w
163	18	21:30	21:45	-	0 - 360	0	90 - 90	90	Anchorage (AK, uSA)	61.221	-149.919	w
164	18	20:54	23:09	-	0 - 360	0	90 - 90	90	Fairbanks (AK, uSA)	64.839	-147.723	pi, g, w, r, bl
165	18	00:47	01:47	-	330 - 30	0	5 - 10	7.5	Vancouver (BC, CAN)	49.282	-123.123	g
166	18	01:15	02:00	-	0 - 360	0	90 - 90	90	Lake Louise (AB, CAN)	51.425	-116.178	w
167	18	01:57	02:57	-	0 - 360	0	90 - 90	90	Alix (AB, CAN)	52.399	-113.194	pi, g, w, r
168	18	22:00	-	20:00	4 - 81	42.5	5 - 45	25	Rjasan (RuS)	54.610	39.706	g, r, p, y
169	18	22:45	23:00	-	0 - 360	0	90 - 90	90	Mala (SWE)	65.185	18.749	g
170	18	00:06	-	00:06	342 - 66	24	5 - 52	28.5	Kiel Bülk (GER)	54.456	10.127	r, w, pi
171	18	00:15	01:30	-	342 - 33	7.5	10 - 31	20.5	Büdelndorf (GER)	54.319	9.680	-
172	18	00:13	-	20:45	312 - 35	353.5	4 - 45	24.5	Stavenhagen (GER)	53.699	12.909	g, r, cr
173	18	00:10	-	-	345 - 19	25.5	7 - 21	14	Bremerhaven (GER)	53.539	8.583	g, r
174	18	00:18	00:30	-	305 - 56	0.5	19 - 58	38.5	Sandplacken (GER)	50.245	8.430	r
175	18	00:58	-	-	360 - 51	25.5	7 - 43	25	Sittensen (GER)	53.281	9.512	g, pi
176	18	00:30	-	00:30	330 - 49	9.5	8 - 45	26.5	Gudensberg (GER)	51.177	9.369	g, r
177	18	00:22	00:25	01:30	306 - 45	355.5	2 - 47	24.5	Nassau (GER)	50.766	13.544	g, pi
178	18	00:21	-	00:21	357 - 71	34	7 - 48	27.5	Mömbris (GER)	50.169	9.157	y, r
179	18	00:14	-	00:14	309 - 70	9.5	6 - 34	20	Fornach (AuT)	48.023	13.428	r
180	18	00:58	01:07	01:06	353 - 51	22	9 - 34	21.5	Schörfling (AuT)	47.936	13.605	r
181	18	01:14	-	01:14	288 - 21	334.5	0 - 30	15	Gahberg (AuT)	47.914	13.606	r
182	18	00:10	-	00:10	18 - 30	24	8 - 11	9.5	Achensee (AuT)	47.462	11.709	cr
183	18	00:25	-	00:25	308 - 358	333	6 - 15	10.5	Gais (CHE)	47.362	9.453	g, pi
184	18	00:10	00:20	00:15	321 - 41	1	6 - 25	15.5	Wiliberg (CHE)	47.269	8.022	cr, pi
185	18	22:00	-	-	353 - 14	3.5	3 - 15	9	New York (NY, uSA)	40.715	-73.994	y, b
186	18	00:30	-	-	0 - 360	0	5 - 90	90	Hankasalim (FIN)	62.389	26.436	r, g

Table 10: References of the 186 used auroral sightings for the St. Patrick’s Day storm in 2015. “aurora archive” refers to the archive from Andreas Möller, which is available from <http://www.polarlicht-archiv.de/>. Aurorasaurus is a citizens science project collecting aurora sightings (<https://www.aurorasaurus.org/>).

nr.	observer	reference
1	Philip Schulze	aurora archive
2	Leibniz-Institut/ Atmo-sphärenphysik	aurora archive
3	Laura Kranich	aurora archive
4	Carsten Jonas	aurora archive
5	Tim Peukert	aurora archive
6	Thorsten Witt	aurora archive
7	Sören Petersen	aurora archive
8	Bernd Pfeifer	aurora archive
9	Nadja Giesau	aurora archive
10	Brigitte Rauch	aurora archive
11	Stefan Heitmann	aurora archive
12	Michael Heiß	aurora archive
13	Andreas Kluck	aurora archive
14	Denis Hessberger	aurora archive
15	Uwe Freitag	aurora archive
16	Hartwig Luethen	aurora archive
17	Thomas Rickert	aurora archive
18	Torsten M.	aurora archive
19	Joachim Ostendorf	aurora archive
20	Uwe Müller	aurora archive
21	Joh	aurora archive
22	ulrich Rieth	aurora archive
23	Andreas Abeln	aurora archive
24	Sven Beermann	aurora archive
25	Gaby Klüber	aurora archive
26	Andreas Möller	aurora archive
27	Daniel Ricke	aurora archive
28	Anke Klemcke	aurora archive
29	Jörg Ö.	aurora archive
30	Sven Lüke	aurora archive
31	Stefan Fockenberg	aurora archive
32	Ole Wortmann	aurora archive
33	Astrid Beyer	aurora archive
34	Michael Müller	aurora archive
35	Mathias H.	aurora archive
36	Andre P.	aurora archive
37	Sven Wienstein	aurora archive
38	Thomas Nemet	aurora archive
39	Sibylle Lage	aurora archive
40	Chris Sommer	aurora archive
41	Ben Mestermann	aurora archive
42	Anke Mo.	aurora archive
43	Jonas Bartscher	aurora archive
44	Sabrina Hofmann	aurora archive
45	Uwe Thieme	aurora archive
46	Tilo Schroth	aurora archive
47	Timo Lohrberg	aurora archive
48	Sebastian Alberts	aurora archive
49	Maik Simon	aurora archive

50	Bernd Tillmanns	aurora archive
51	Karsten Hansky	aurora archive
52	Norbert Bläsner	aurora archive
53	Michael Pflügner	aurora archive
54	Mandy Skibba	aurora archive
55	Jan Schulhauser	aurora archive
56	Heiko ulbricht	aurora archive
57	Anja Hoff	aurora archive
58	Markus Retzlaff	aurora archive
59	HR Maurer	aurora archive
60	Rene Pelzer	aurora archive
61	Claudia Hinz	aurora archive
62	Fabian Wimmer	aurora archive
63	Michael Theusner	aurora archive
64	Georg Keller	aurora archive
65	Andy Neumaier	aurora archive
66	Oswald Dörwang	aurora archive
67	Raik Krotofil	aurora archive
68	Wolf-Peter Hartmann	aurora archive
69	Roman Breisch	aurora archive
70	Alois Doblinger	aurora archive
71	Thomas Klein	aurora archive
72	Michael Johler	aurora archive
73	Roswitha Karpf	aurora archive
74	Hermann Scheer	aurora archive
75	foto-webcam.eu	aurora archive
76	-	http://www.metsahovi.fi/allsky-gallery
77	Patrick Ford	https://www.flickr.com/photos/djseventen/16847227882/in/photostream/
78	Sebastian Saarloos	https://www.huffingtonpost.com/2015/03/18/st-patricks-day-aurora-northern-lights_n_6896118.html?guccounter=1
79	Dimitry Matsnev	http://www.skyandtelescope.com/online-gallery/aurora-over-moscow-on-march-17-2015-2256-ut/
80	Michael Theusner	aurora archive
81	Steve Clasper	https://www.flickr.com/photos/sclasper
82	John	https://twitter.com/GM7PBB/status/577967626871291905/photo/1?ref_src=twsrc%5Etfw&ref_url=http%3A%2F%2Fmetro.co.uk%2F2015%2F03%2F18%2Fnorthern-lights-did-you-see-aurora-borealis-last-night-5108614%2F
83	Steve Clasper	https://www.flickr.com/photos/sclasper
84	Derick Wilson	https://earthobservatory.nasa.gov/IOTD/view.php?id=85556
85	-	http://www2.irf.se/allsky/
86	-	http://sgo.fi/Data/AllSky/allskyData.php
87	Hermann Scheer	aurora archive
88	-	https://www.japantimes.co.jp/news/2015/03/19/national/science-health/hokkaido-sighting-first-aurora-observation/-in-japan-since-2004/
89	Alu	http://www.astro.uni-jena.de/index.php/gsh-home.html
90	Steve Clasper	https://www.flickr.com/photos/sclasper
91	Javor Kac	http://www.orion-drustvo.si/MBKTeam/sunrora/20150317.htm

92	-	http://www.sternenfreunde-riesa.de/bildergalerie/atmosphaerische-phaenomene/aurora-borealis-nordlichter/polarlichter-maerz-2015/
93	Lisa-Marie Morgan	https://twitter.com/tenacrewood/status/577798412323663872/photo/1
94	AGO Keograms	https://data-portal.phys.ucalgary.ca/ago/keograms/
95	AGO Keograms	https://data-portal.phys.ucalgary.ca/ago/keograms/
96	AGO Keograms	https://data-portal.phys.ucalgary.ca/ago/keograms/
97	AGO Keograms	https://data-portal.phys.ucalgary.ca/ago/keograms/
98	AGO Keograms	https://data-portal.phys.ucalgary.ca/ago/keograms/
99	AGO Keograms	https://data-portal.phys.ucalgary.ca/ago/keograms/
100	AGO Keograms	https://data-portal.phys.ucalgary.ca/ago/keograms/
101	AGO Keograms	https://data-portal.phys.ucalgary.ca/ago/keograms/
102	AGO Keograms	https://data-portal.phys.ucalgary.ca/ago/keograms/
103	AGO Keograms	https://data-portal.phys.ucalgary.ca/ago/keograms/
104	-	Aurorasaurus
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169	-	Aurorasaurus
170	Achim Hellmann	aurora archive
171	Michael Green	aurora archive
172	Wolfgang Hamburg	aurora archive
173	Georg van Druenen	aurora archive
174	Hennig Wrage	aurora archive
175	Nils N.	aurora archive
176	Lutz Schenk	aurora archive
177	Mathias Fleischer	aurora archive
178	Markus Pfarr	aurora archive
179	Hermann Koberger	aurora archive
180	Wolfgang Gebetsroither	aurora archive
181	Erwin Filimon	aurora archive
182	addicted-sports.com	aurora archive
183	Mark Vornhusen	aurora archive
184	Heiko Rodde	aurora archive
185	Melanie Kern-Favilla	https://twitter.com/mkfphotos/status/578024691471773696
186	-	https://www.youtube.com/watch?v=cTzAL1f_kyE

Table 11: List of the 49 unused sightings for the St. Patrick's Day storm between March 17 and 18, 2015. The times given are local time. t_s : start time, t_e : end time, ST: time from Stellarium, az: azimuth, $\overline{az}$: mean azimuth, h: elevation angle, $\overline{h}$: mean elevation angle, r: red, y: yellow, cr: crimson, or: orange, w: white, g: green, go: gold, pi: pink, p: violet, b: blue

nr.	day	t_s [LT]	t_e [LT]	ST [LT]	az [°]	$\overline{az}$ [°]	h [°]	$\overline{h}$ [°]	location	lat. [°]	lon. [°]	colour
1	17	-	-	-	-	-	-	-	Amrum (GER)	54.663	8.339	-
2	17	-	-	-	-	-	-	-	Bredstedt (GER)	54.619	8.966	-
3	17	-	-	-	-	-	-	-	Bülker Leuchtturm (GER)	54.455	10.197	-
4	17	22:00	00:45	-	-	-	-	-	Hessenstein (GER)	54.329	10.547	-
5	17	19:40	-	-	300 - 330	315.5	-	-	Klausdorf, Kiel (GER)	54.306	10.212	-
6	17	20:30	-	-	-	-	-	-	Wankendorf (GER)	54.112	10.204	-
7	17	-	-	-	-	-	-	-	Pariner Berg (GER)	53.947	10.679	-
8	17	-	-	-	-	-	-	-	Pariner Berg (GER)	53.947	10.679	g, w, r
9	17	21:00	00:30	-	-	-	-	-	Funtensee (GER)	47.493	12.939	-
10	17	00:36	-	-	-	-	-	-	Dunedin (NZL)	-45.880	170.501	g, r
11	17	19:17	-	-	-	-	-	-	Kouvola (FIN)	60.865	26.683	-
12	17	19:13	-	-	-	-	-	-	Miiluranta (FIN)	63.962	26.015	g
13	17	18:38	-	-	-	-	-	-	Harstad (NOR)	68.798	16.54	g
14	17	19:30	-	-	-	-	-	-	Skierniewice (POL)	51.955	20.157	-
15	17	20:20	-	-	-	-	-	-	Rondane (NOR)	61.932	9.789	g, r
16	17	22:30	22:30	-	-	-	-	-	Lossiemouth (GBR)	57.722	-3.28	-
17	17	22:36	-	-	-	-	-	-	Medvednica (CRO)	45.918	15.966	-
18	17	23:24	-	-	-	-	-	-	Kocser (HuN)	47.001	19.917	-
19	17	-	-	-	-	-	-	-	Oldenburg (GER)	53.144	8.214	-
20	17	23:00	23:30	-	-	-	-	-	Oldenburg (GER)	53.144	8.214	-
21	17	23:45	-	-	-	-	-	-	Bremen Blockland (GER)	53.142	8.845	r, g
22	17	21:25	21:45	-	-	-	-	-	Biesenthal (GER)	52.765	13.644	-
23	17	-	-	-	-	-	-	-	Linum (GER)	52.759	12.876	r, cr, g
24	17	22:00	22:00	-	270 - 90	0	-	-	Liepnitzsee (GER)	52.748	13.507	-
25	17	21:14	-	-	-	-	-	-	Gifhorn (GER)	52.482	10.551	-
26	17	20:00	22:00	-	-	-	-	-	Marienmünster (GER)	51.819	9.231	-
27	17	-	-	-	-	-	-	-	Bad Lippspring (GER)	51.784	8.816	-

28	17	20:50	21:20	-	270 - 10	320	-	-	Riesa (GER)	51.317	13.268	w
29	17	21:03	-	-	330 - 30	0	-	-	Niederkrüchten (GER)	51.199	6.219	cr
30	17	-	-	-	-	-	-	-	Dresden (GER)	51.051	13.737	g, cr
31	17	-	-	-	-	-	-	-	Bonn (GER)	50.739	7.098	g, cr
32	17	-	-	-	-	-	-	-	Bad Lobenstein (GER)	50.453	11.639	r, cr
33	17	21:00	-	-	-	-	-	-	Großer Feldberg (GER)	50.234	8.459	cr
34	17	23:55	00:35	-	330 - 30	0	-	-	Wackernheim (GER)	49.978	8.118	-
35	17	-	-	-	-	-	-	-	Trier (GER)	49.749	6.637	-
36	17	21:02	-	-	-	-	5	5	Kämpfelbach (GER)	48.949	8.624	-
37	17	21:00	00:30	-	-	-	-	-	Funtensee (GER)	47.493	12.939	-
38	17	22:01	-	-	-	-	-	-	Turku (FIN)	60.451	22.268	g, y
39	17	19:30	19:45	-	300 - 330	315	-	-	Berlin (GER)	52.519	13.405	w, pi
40	18	00:00	00:15	-	-	-	-	-	Isle of Man (GBR)	54.321	-4.531	-
41	18	01:45	02:00	-	-	-	-	-	Ballyshannon (IRL)	54.503	-8.192	-
42	18	01:45	-	-	-	-	-	-	Bulyea (SK, CAN)	50.985	-104.865	g, r
43	18	00:00	00:15	-	-	-	-	-	Isle of Man (GBR)	54.321	-4.531	-
44	18	01:45	02:00	-	-	-	-	-	Ballyshannon (IRL)	54.503	-8.192	-
45	18	06:45	07:15	-	-	-	-	-	Palmer (AK, uSA)	61.599	-149.116	g, r
46	18	00:06	-	-	330 - 30	0	-	-	Dresden (GER)	51.051	13.737	g
47	18	00:10	00:25	-	-	-	-	-	Pohlheim-Hausen (GER)	50.541	8.741	-
48	18	00:10	00:30	-	-	-	-	-	Klingebrunn-Bahnhof (GER)	48.922	13.336	r
49	18	03:42	-	-	-	-	-	-	Dalton (GA, USA)	34.771	-84.971	g, w, pi

Table 12: References of the 49 unused auroral sightings for the St. Patrick's Day storm in 2015. "aurora archive" refers to the archive from Andreas Möller, which is available from <http://www.polarlicht-archiv.de/>. Aurorasaurus is a citizens science project collecting aurora sightings (<https://www.aurorasaurus.org/>).

nr.	observer	reference
1	Jost Jahn	aurora archive
2	Alex Schweigert	aurora archive
3	Patrick Paproth	aurora archive
4	Henning untiedt	aurora archive
5	Claudia Beer	aurora archive
6	Markus Bruhn	aurora archive
7	Manuela Westphal	aurora archive
8	Torsten Lohf	aurora archive
9	foto-webcam.eu	aurora archive
10	Paul le Comte	https://twitter.com/five15design/status/577894908188471296/photo/1?tfw_site=rnz_news&ref_src=twsrc%5Etfw&ref_url=https%3A%2F%2Fwww.radionz.co.nz%2Fnews%2Fregional%2F268996%2Fgreen-sky-at-night%2C-nz%27s-delight
11	-	Aurorasaurus
12	-	Aurorasaurus
13	-	Aurorasaurus
14	-	Aurorasaurus
15	-	Aurorasaurus
16	-	Aurorasaurus
17	-	Aurorasaurus
18	-	Aurorasaurus
19	Marcus Speckmann	aurora archive
20	Carsten Dosche	aurora archive
21	Frank Maier	aurora archive
22	Falk Becker	aurora archive
23	Christina Meier	aurora archive
24	Dennis Hennig	aurora archive
25	Karsten Radwan	aurora archive
26	Marion	aurora archive
27	Wolfgang Dzieran	aurora archive
28	Christian Bartzsch	aurora archive
29	Hans Schremmer	aurora archive
30	Steffen Hildebrandt	aurora archive
31	Stefan Krause	aurora archive
32	Jens Schikowski	aurora archive
33	Steffi Kister	aurora archive
34	Anna Zerneck	aurora archive
35	Sven Aulenberg	aurora archive
36	Michael Großmann	aurora archive
37	foto-webcam.eu	aurora archive
38	Marko Wallius	https://www.flickr.com/photos/mvallius/16822288936/in/photolist
39	-	Aurorasaurus
40	-	Aurorasaurus
41	-	Aurorasaurus
42	-	Aurorasaurus
43	-	Aurorasaurus
44	-	Aurorasaurus
45	-	Aurorasaurus

46	Marcus Degenkolbe	aurora archive
47	Marcus Dobler	aurora archive
48	Tanja Beutel	aurora archive
49	-	http://spaceweathergallery.com/indiv_upload.php?upload_id=109913&PHPSESSID=vabta06kevqtmpuc7gg5r0d8e3

Table 13: List of the 128 used sightings for the Halloween storm between October 29 and 31, 2003. The times given are local time. t_s : start time, t_e : end time, ST: time from Stellarium, az: azimuth, $\overline{az}$: mean azimuth, h : elevation angle, $\overline{h}$: mean elevation angle, r: red, y: yellow, cr: crimson, or: orange, w: white, g: green, go: gold, pi: pink, p: violet, b: blue

nr.	day	t_s [LT]	t_e [LT]	ST [LT]	az [°]	$\overline{az}$ [°]	h [°]	$\overline{h}$ [°]	location	lat. [°]	lon. [°]	colour
1	29	01:00	02:30	-	330 - 30	0	90	90	Heide (GER)	54.194	9.102	g
2	29	-	-	21:15	345 - 35	10	11 - 26	18.5	Greifswald (GER)	54.087	13.389	g
3	29	20:00	02:00	23:00	300 - 78	9	0 - 85	42.5	Bendorf (GER)	54.087	9.382	g, w, r
4	29	18:40	21:30	21:05	312 - 8	340	11 - 38	19.5	Diedrichshagen (GER)	54.169	12.029	g, w
5	29	21:30	23:00	21:45	334 - 29	1	9 - 33	21	usedom (GER)	53.934	14.098	g, r
6	29	22:11	01:32	22:11	318 - 69	13.5	6 - 45	25.5	Bensersiel (GER)	53.676	7.577	g, r, cr
7	29	18:56	01:01	20:15	284 - 73	358.5	8 - 73	41	Westerstede (GER)	53.256	7.926	g, r, cr
8	29	-	-	20:00	291 - 345	318	9 - 31	20	Leer (GER)	53.235	7.466	g, r, cr
9	29	18:15	00:00	22:15	345 - 42	13.5	5 - 41	23	Wüste Kunersdorf (GER)	52.405	14.513	g, w, r, cr
10	29	-	-	19:45	332 - 26	359	5 - 36	20.5	Horstmar (GER)	52.081	7.306	g, r, cr
11	29	23:30	23:40	-	330 - 30	0	90	90	ubbedissen (GER)	51.988	8.635	g, w
12	29	23:30	00:00	23:45	33 - 108	70.5	24 - 70	47	Münster (GER)	51.959	7.623	g, w, r
13	29	22:16	23:08	22:15	330 - 15	352.5	13 - 43	28	Bergkamen (GER)	51.616	7.624	g, cr
14	29	18:20	23:30	19:30	296 - 48	352	0 - 38	19	Görlitz (GER)	51.149	14.968	g, r, cr
15	29	18:26	21:05	19:00	330 - 2	346	8 - 41	24.5	Radebeul (GER)	51.111	13.650	g, r, cr
16	29	-	-	19:45	303 - 56	359.5	15 - 52	33.5	Radebeul (GER)	51.111	13.650	g, r
17	29	19:30	23:00	20:00	321 - 60	10.5	5 - 64	34.5	Kleefeld (GER)	52.369	9.796	g, r
18	29	23:45	00:15	00:00	331 - 40	34.5	13 - 42	32.5	Witthoh (GER)	47.936	8.827	g, r
19	29	00:47	01:10	01:10	6 - 42	24	6 - 24	15	Gais AR (CHE)	47.362	9.453	r
20	29	22:00	-	22:00	269 - 66	1	8 - 79	43.5	Vorarlberg (AuT)	47.226	9.873	g, r
21	29	19:07	23:55	01:00	306 - 8	337	0 - 42	21	Dissen (GER)	52.112	8.198	g, r
22	29	02:30	-	-	0 - 0	0	90 - 90	90	Orlando (FL, uSA)	28.532	-81.381	r, y
23	29	18:45	-	-	29 - 86	57.5	5 - 44	24.5	Albany (MO, uSA)	40.249	-94.331	r, y
24	29	-	-	20:45	23 - 95	59	5 - 42	23.5	Big Bay (ON, CAN)	44.791	-80.948	g, w, r
25	30	-	-	19:45	26 - 84	55	10 - 48	29	Elphin (ON, CAN)	44.923	-76.617	g, r
26	29	01:00	-	-	333 - 15	354	5 - 25	15	Salt Lake City (uT, uSA)	40.759	-111.903	g, r
27	29	-	-	02:15	358 - 32	15	5 - 19	12	Houston (TX, uSA)	29.756	-95.377	r

28	29	-	-	02:20	39 - 95	67	5 - 38	21.5	Iowa (IA, uSA)	41.6	-93.7	r, w
29	29	03:15	-	-	330 - 34	2	9 - 25	17.5	Dahlonaga (GA, uSA)	34.526	-83.985	r
30	29	-	-	02:45	26 - 46	36	5 - 34	19.5	St. Jacob (IL, uSA)	38.720	-89.769	g, r
31	29	-	-	05:00	338 - 25	1.5	5 - 26	15.5	Wichita (KS, uSA)	37.687	-97.320	g, r
32	29	-	-	02:30	29 - 88	58.8	8 - 46	27	Divide (CO, uSA)	38.942	-105.158	g, r
33	29	03:10	-	-	29 - 52	40.5	10 - 27	18.5	southeast Missouri (MO, uSA)	37.1	-90.2	r
34	29	00:00	-	-	292 - 347	319.5	5 - 36	20.5	Spokane Valley (WA, uSA)	47.673	-117.129	g, r
35	29	-	-	02:00	332 - 11	351.5	5 - 22	13.5	Yampa (CO, uSA)	40.152	-106.909	g, r
36	29	04:00	-	02:45	358 - 62	30	5 - 38	21.5	Midland (TX, uSA)	31.997	-102.078	r
37	29	-	-	20:30	72 - 109	90.5	6 - 42	24	Lake Wateree (SC, uSA)	34.414	-80.828	r
38	29	-	-	18:00	187 - 276	231.5	24 - 57	40.5	Tromso (NOR)	69.648	18.956	cr
39	29	-	-	23:00	285 - 335	310	10 - 28	19	Caledon (ON, CAN)	43.835	-79.879	g
40	29	-	-	02:00	327 - 42	4.5	5 - 44	24.5	LaOtto (IN, uSA)	41.300	-85.801	g, w, r
41	30	00:00	01:11	-	0 - 360	0	0 - 90	90	Hamerstorf (GER)	52.917	10.459	g, r
42	30	-	-	00:57	289 - 103	16	14 - 68	41	Soltau (GER)	52.984	9.841	w, r
43	30	-	-	00:30	289 - 25	337	13 - 54	33.5	Bassum (GER)	52.850	8.726	g, r
44	30	21:30	03:00	-	0 - 360	0	0 - 90	90	Wedemark (GER)	52.546	9.731	-
45	30	01:11	02:30	02:14	337 - 48	35.5	6 - 32	19	Potsdam (GER)	52.389	13.060	g, w, y, r
46	30	21:00	01:30	20:30	313 - 17	345	0 - 43	21.5	Lehrte (GER)	52.376	9.975	g, r
47	30	21:50	02:45	23:30	290 - 7	328.5	11 - 41	26	Münster (GER)	51.959	7.623	w, r, cr
48	30	23:35	02:13	01:00	110 - 212	161	23 - 67	45	Oerlinghausen (GER)	51.951	8.661	g, r
49	30	23:30	01:45	23:45	338 - 24	1	12 - 39	25.5	Gütersloh (GER)	51.902	8.383	g, r
50	30	-	-	22:00	309 - 27	348	10 - 39	24.5	Merfeld (GER)	51.848	7.200	g, r, cr
51	30	-	-	23:00	315 - 7	341	7 - 36	21.5	Merfeld (GER)	51.848	7.200	g, w, r, cr, pi
52	30	-	-	23:00	315 - 7	341	7 - 36	21.5	Merfeld (GER)	51.848	7.200	g, w, r, cr, pi
53	30	21:30	22:00	22:09	12 - 68	40	9 - 51	30	Lippetal (GER)	51.662	8.142	g, r
54	30	22:00	01:30	22:00	271 - 321	296	0 - 30	15	Dortmund (GER)	51.514	7.465	g, r
55	30	-	-	23:30	2 - 79	40.5	5 - 54	29.5	Hagen (GER)	51.365	7.462	g, r, y
56	30	-	-	00:30	25 - 66	45.5	5 - 26	15.5	Burghasungen (GER)	51.323	9.277	g, r
57	30	00:15	01:20	23:30	254 - 313	283.5	23 - 43	33	Riesa (GER)	51.317	13.268	g, r
58	30	-	-	22:00	2 - 78	42.5	5 - 47	26	Kürten (GER)	51.051	7.263	g, r, w
59	30	01:00	02:00	23:30	352 - 50	20	0 - 39	19.5	Erfurt (GER)	50.986	11.029	g, r, cr

60	30	01:00	02:00	23:30	352 - 50	20	0 - 39	19.5	Erfurt (GER)	50.986	11.029	g, r, cr
61	30	-	-	21:15	291 - 346	318.5	3 - 28	15.5	Rodenkirchen (GER)	50.893	6.963	g, y, r
62	30	00:25	01:10	-	0 - 360	0	0 - 90	90	Chemnitz (GER)	50.827	12.919	g, r
63	30	-	-	20:45	337 - 11	354	13 - 30	21.5	Aachen (GER)	50.8774	6.083	g, r
64	30	18:00	01:00	20:45	325 - 9	347	9 - 27	18	Aachen (GER)	50.8774	6.083	g, r
65	30	-	-	22:00	18 - 66	42	7 - 30	18.5	Sankt Augustin-Niederpleis (GER)	50.771	7.211	g, r
66	30	-	-	00:30	40 - 84	62	0 - 38	19	Gebhardshain (GER)	50.746	7.820	g, r
67	30	-	-	00:45	265 - 322	293.5	0 - 39	19.5	Stollberg (GER)	50.709	12.774	g, r, y
68	30	21:57	01:46	22:11	342 - 46	14	14 - 41	27.5	Schwalbach (GER)	50.148	8.536	g, r
69	30	22:30	00:15	-	330 - 30	0	70	70	Eschborn (GER)	50.147	8.561	g, r
70	30	-	-	22:30	273 - 352	312.5	5 - 45	25	Aschaffenburg (GER)	49.981	9.135	g, r, cr
71	30	23:30	-	23:30	16 - 70	43	5 - 37	21	Aschaffenburg (GER)	49.981	9.135	g, r, cr
72	30	21:00	01:00	00:00	14 - 79	46.5	4 - 43	23.5	Wertheim Main (GER)	49.757	9.513	g, y, r
73	30	-	-	22:30	13 - 71	42	9 - 40	24.5	Mainz-Ebersheim (GER)	49.959	8.266	g, b, r, cr
74	30	20:30	23:45	-	270 - 45	337.5	15 - 22	18.5	Darmstadt (GER)	49.872	8.648	g, w, r
75	30	20:51	01:39	22:30	298 - 83	10.5	10 - 62	36	Wolfsheim (GER)	49.874	8.039	g, r
76	30	-	-	21:00	327 - 23	355	0 - 31	15.5	Wolfsheim (GER)	49.874	8.039	g, r
77	30	20:54	00:20	-	0 - 360	0	90 - 90	90	Ober-Ramstadt (GER)	49.8331	8.743	g, r
78	30	21:00	23:30	22:00	66 - 238	152	52 - 70	61	Kleefeld (CAN)	49.502	-96.873	r
79	30	-	-	21:15	323 - 14	348.5	4 - 32	18	Wendelstein (GER)	49.351	11.155	g, r
80	30	22:00	22:30	22:30	349 - 36	12.5	0 - 30	15	Möckmühl-Züttlingen (GER)	49.296	9.331	g, r
81	30	-	-	20:45	332 - 19	355.5	0 - 21	10.5	Waghäusel (GER)	49.249	8.515	g, r
82	30	22:00	23:15	-	270 - 90	0	0 - 90	90	Sinsheim (GER)	49.249	8.888	g, r
83	30	22:00	22:15	20:45	328 - 22	355	7 - 30	18.5	Hohenfels (GER)	49.203	11.849	g, r
84	30	-	-	22:45	317 - 15	346	5 - 39	22	Rottal (GER)	49.002	15.023	g, b, r
85	30	-	-	23:15	277 - 23	330	8 - 37	22.5	Schlierbach (GER)	48.674	9.518	g, r
86	30	20:00	20:20	22:00	286 - 58	352	6 - 41	23.5	Gerstetten (GER)	48.623	10.019	g, r
87	30	21:13	22:30	22:00	311 - 10	340.5	0 - 40	20	Tübingen(GER)	48.522	9.056	g, r
88	30	21:37	01:38	22:18	333 - 22	8.5	0 - 29	14.5	Haimhausen (GER)	48.315	11.554	g, r
89	30	-	-	23:00	350 - 78	34	5 - 49	27	Meggenhofen (GER)	48.180	13.796	g, r
90	30	00:10	22:35	00:12	10 - 68	39	0 - 54	27	Fürstenfeldbruck (GER)	48.174	11.243	g, r
91	30	20:20	00:30	-	315 - 45	0	0 - 80	40	Puchheim (GER)	48.150	11.350	g, r, w

92	30	01:00	02:00	01:00	280 - 341	310.5	6 - 44	25	Steyr (AuT)	48.050	14.418	g, r
93	30	01:27	02:42	01:27	353 - 56	24.5	7 - 45	26	Seewalchen am Attersee (AuT)	47.952	13.584	g, r
94	30	23:00	23:30	22:00	10 - 66	38	5 - 42	23.5	Fellach (GER)	47.903	11.733	g, r, cr
95	30	21:15	22:30	-	315 - 45	0	60 - 60	60	Sonnenreuth (GER)	47.775	11.915	g, w, cr, r
96	30	-	-	23:00	354 - 48	21	12 - 35	23.5	Gais AR (CHE)	47.362	9.453	r
97	30	-	-	22:00	319 - 21	350	7 - 34	20.5	Mäder, Vorarlberg (AuT)	47.349	9.619	r
98	30	-	-	22:00	269 - 109	9	0 - 48	24	Vorarlberg (AuT)	47.249	9.979	r
99	30	-	-	19:30	326 - 1	343.5	3 - 25	14	Zermatt (CHE)	46.021	7.748	g, w, r
100	30	-	-	20:00	331 - 23	357	5 - 51	28	Maine (NY, uSA)	42.193	-76.061	g, y, r
101	30	-	-	19:15	325 - 346	335.5	5 - 35	20	Franklin (TN, uSA)	35.924	-86.869	r
102	30	-	-	03:00	346 - 64	25	5 - 43	24	Dover (OK, uSA)	35.981	-97.911	g, r
103	30	-	-	02:00	343 - 44	13.5	5 - 39	22	Craig (CO, uSA)	40.514	-107.548	g, r
104	30	-	-	20:15	335 - 8	351.5	5 - 44	24.5	Posen (POL)	52.408	16.922	g, r
105	30	-	-	19:30	283 - 325	304	5 - 37	21	Catonsville (MD, uSA)	39.271	-76.734	r
106	30	19:30	-	18:30	320 - 52	62	8 - 58	33	Warrensburg (MO, uSA)	38.761	-93.737	g, r
107	30	-	-	23:00	308 - 358	333	5 - 31	18	Lyndeborough (NH, uSA)	42.909	-71.769	g, r
108	30	-	-	23:00	224 - 268	246	5 - 35	20	Scotland (GBR)	56.2	-4.0	g, r
109	30	19:00	-	-	350 - 61	25.5	10 - 39	24.5	Shelby (NC, uSA)	35.291	-81.539	g, r
110	30	17:12	18:34	-	270 - 90	0	5 - 45	25	Rikubetsu (JPN)	43.467	143.748	-
111	31	23:30	02:00	01:23	0 - 360	0	0 - 90	90	Hannover (GER)	52.376	9.732	g, r
112	31	-	-	02:30	154 - 252	203	24 - 68	46	Hannover (GER)	52.376	9.732	g, w, r
113	31	-	-	02:00	283 - 347	315	2 - 41	21.5	Vöcklamarkt (AuT)	48.002	13.483	g, r
114	31	-	-	23:50	285 - 324	304.5	10 - 41	25.5	Wien (AuT)	48.208	16.376	r
115	31	19:30	-	-	27 - 38	32.5	12 - 40	26	Buchannon (WV, uSA)	38.997	-80.232	g, r, y
116	31	-	-	18:30	32 - 81	56.5	5 - 30	17.5	Orchard Park (NY, uSA)42.767	42.767	-78.745	g, r
117	31	-	-	21:15	271 - 338	304.5	14 - 41	27.5	Hamme-Mille (BEL)	50.779	4.717	r
118	31	19:00	-	-	358 - 50	24	5 - 46	25.5	Hughesville (MD, uSA)	38.532	-76.785	g, r
119	31	-	-	19:15	29 - 76	52.5	5 - 35	20	Kingsport (TN, uSA)	36.549	-82.564	r
120	31	-	-	22:30	317 - 358	337.5	5 - 25	15	Mount Airy (MD, uSA)	39.376	-77.154	r
121	31	-	-	18:30	57 - 119	88	5 - 59	32	Galway (NY, uSA)	43.019	-74.032	g, r
122	31	-	-	19:15	309 - 351	330	5 - 26	15.5	Pittsburgh (PA, uSA)	40.441	-79.999	r, cr
123	31	20:00	07:00	20:00	0 - 360	0	90 - 90	90	Anchorage (AK, uSA)	61.221	-149.919	b, r

124	31	-	-	18:30	329 - 15	352	5 - 30	17.5	Farmington (NY, uSA)	42.987	-77.327	g, r
125	31	-	-	00:00	292 - 41	346.5	23 - 50	36.5	Normandy (FRA)	49.0	0.3	w, r
126	31	-	-	19:00	303 - 358	330.5	5 - 39	22	Clarence (NY, uSA)	42.983	-78.577	g, w, r
127	31	-	-	19:00	56 - 97	76.5	5 - 32	18.5	Sherbrooke (QC, CAN)	45.397	-71.896	g, r
128	31	-	-	21:00	46 - 93	69.5	5 - 47	26	Prince Edward Island (NB, CAN)	46.344	-63.434	g, r

Table 14: References of the 128 used auroral sightings for the Halloween storm in 2003. “aurora archive” refers to the archive from Andreas Möller, which is available from <http://www.polarlicht-archiv.de/>. Auro-rasaurus is a citizens science project collecting aurora sightings (<https://www.aurorasaurus.org/>).

nr.	observer	reference
1	Gerd Neumann	aurora archive
2	Mario Berger	aurora archive
3	Jost Jahn	aurora archive
4	Olaf Squarra	aurora archive
5	Wolfgang Dzieran	aurora archive
6	Michael Theusner	aurora archive
7	Wolfgang Hamburg	aurora archive
8	Torsten Kallweit	aurora archive
9	Uwe Müller	aurora archive
10	Sven Wienstein	aurora archive
11	Peter Buschkamp	aurora archive
12	Winfried Backhaus	aurora archive
13	Joachim uhlig	aurora archive
14	Alexander Wünsche	aurora archive
15	Thomas Böhme	aurora archive
16	Martin Fiedler	aurora archive
17	Rainer Bölts	aurora archive
18	Harald Wochner	aurora archive
19	Mark Vornhusen	aurora archive
20	Philipp Salzgeber	aurora archive
21	Lutz Schenk	aurora archive
22	-	http://www.astronomyufo.com/Astronomy/Astronomy.htm
23	Bush	https://www.spaceweather.com/
24	Irvine	https://www.spaceweather.com/
25	Brooks	https://www.spaceweather.com/
26	Bourne	https://www.spaceweather.com/
27	Ponder	https://www.spaceweather.com/
28	Richard	https://www.spaceweather.com/
29	Cason	https://www.spaceweather.com/
30	Brown	https://www.spaceweather.com/
31	Davies	https://www.spaceweather.com/
32	Mayfield	https://www.spaceweather.com/
33	Thomas	https://www.spaceweather.com/
34	Nam	https://www.spaceweather.com/
35	Westlake	https://www.spaceweather.com/
36	Lindley	https://www.spaceweather.com/
37	Reed	https://www.spaceweather.com/
38	Bernardi	https://www.spaceweather.com/
39	Kangas	https://www.spaceweather.com/
40	Slobins	https://www.spaceweather.com/
41	Jost Jahn	aurora archive
42	Hartwig Luethen	aurora archive
43	Wolfgang Hamburg	aurora archive
44	Frank Jungclaus	aurora archive
45	Matthias Juchert	aurora archive
46	Daniel Rieke	aurora archive
47	Winfried Backhaus	aurora archive
48	Wolfgang Steinhoefer	aurora archive
49	Jan Neuhaus	aurora archive

50	Sven Wienstein	aurora archive
51	Christian Brinkmüller	aurora archive
52	Andr��f Walczak	aurora archive
53	Oliver Gottlob	aurora archive
54	Heinz Hovel	aurora archive
55	Alexander Cremer	aurora archive
56	Rainer Kaufhold	aurora archive
57	Maik Palmer	aurora archive
58	Peter Broich	aurora archive
59	Christian Harder	aurora archive
60	Andre Wulff	aurora archive
61	Bj��rn Wargenau	aurora archive
62	Claudia Hinz	aurora archive
63	Achim Christoph	aurora archive
64	Andr��f M��ller	aurora archive
65	Torsten Kallweit	aurora archive
66	Andreas Weller	aurora archive
67	Thomas B��hme	aurora archive
68	Martin Ergh	aurora archive
69	Norman	aurora archive
70	udo Langenohl	aurora archive
71	Markus Pfarr	aurora archive
72	Josef Sch��fer	aurora archive
73	Stefan Stumpf	aurora archive
74	Hans & Stanislava Zekl	aurora archive
75	ulrich Rieth	aurora archive
76	Michael Schmidt	aurora archive
77	Eric von der Heyden	aurora archive
78	Rainer B��lts	aurora archive
79	Christoph Ries	aurora archive
80	Peter Hofmann	aurora archive
81	Oswald D��rwang	aurora archive
82	Uwe Gr��n	aurora archive
83	Harald Wochner	aurora archive
84	Rudolf Prinz	aurora archive
85	Bernhard Hubl	aurora archive
86	Thomas G��tzfried	aurora archive
87	Till Credner	aurora archive
88	Robert Wagner	aurora archive
89	Stefan Felber	aurora archive
90	Thorsten B��ckel	aurora archive
91	Gernot Osterloh	aurora archive
92	Feli	aurora archive
93	Erwin Filimon	aurora archive
94	Wilfried Wiehler	aurora archive
95	Rudolf Reiser	aurora archive
96	Mark Vornhusen	aurora archive
97	Alois Ortner	aurora archive
98	Philipp Salzgeber	aurora archive
99	Max Funk	aurora archive
100	Edwards	https://www.spaceweather.com/
101	Murdic	https://www.spaceweather.com/
102	Ewoldt	https://www.spaceweather.com/
103	Cunningham	https://www.spaceweather.com/
104	Gola	https://www.spaceweather.com/

105	Belas	https://www.spaceweather.com/
106	Winter	https://www.spaceweather.com/
107	Kierstein	https://www.spaceweather.com/
108	Cockman	https://www.spaceweather.com/
109	Clapper	https://www.spaceweather.com/
110	Nam	https://www.spaceweather.com/
111	Andreas Schulze	aurora archive
112	Michael Theusner	aurora archive
113	Hermann Koberger	aurora archive
114	Seidner	https://www.spaceweather.com/
115	Reyes	https://www.spaceweather.com/
116	Goller	https://www.spaceweather.com/
117	Coeckelberghs	https://www.spaceweather.com/
118	Cahn	https://www.spaceweather.com/
119	Felknor	https://www.spaceweather.com/
120	Varros	https://www.spaceweather.com/
121	Curtis	https://www.spaceweather.com/
122	Zhu	https://www.spaceweather.com/
123	Hall	https://www.spaceweather.com/
124	Atkins	https://www.spaceweather.com/
125	Trophardy	https://www.spaceweather.com/
126	Buyers	https://www.spaceweather.com/
127	Boucher	https://www.spaceweather.com/
128	Arsenault	https://www.spaceweather.com/

Table 15: List of the 79 unused sightings for the Halloween storm between October 29 and 31, 2003. The times given are local time. t_s : start time, t_e : end time, ST: time from Stellarium, az: azimuth, $\overline{az}$: mean azimuth, h: elevation angle, $\overline{h}$: mean elevation angle, r: red, y: yellow, cr: crimson, or: orange, w: white, g: green, go: gold, pi: pink, p: violet, b: blue

nr.	day	t_s [LT]	t_e [LT]	ST [LT]	az [°]	$\overline{az}$ [°]	h [°]	$\overline{h}$ [°]	location	lat. [°]	lon. [°]	colour
1	29	-	-	-	-	-	-	-	Kiel (GER)	54.323	10.123	g, cr
2	29	-	-	-	-	-	-	-	Hohn (GER)	54.299	9.503	-
3	29	-	-	-	-	-	-	-	Rostock (GER)	54.083	12.100	-
4	29	-	-	-	-	-	-	-	Elmshorn (GER)	53.751	9.663	-
5	29	-	-	-	-	-	-	-	Norderney (GER)	53.707	7.156	-
6	29	-	-	-	-	-	-	-	Schwerin (GER)	53.632	11.413	-
7	29	19:00	20:00	-	330 - 30	0	-	-	Potsdam (GER)	52.389	13.060	g
8	29	-	-	-	-	-	-	-	Steinfurt (GER)	52.148	7.344	-
9	29	-	-	-	330 - 30	0	90	90	Kürten (GER)	51.053	7.263	-
10	29	-	-	-	-	-	-	-	Kürten (GER)	51.053	7.263	-
11	29	21:00	21:45	-	-	-	-	-	Köln (GER)	50.938	6.960	-
12	29	-	-	-	-	-	-	-	Westerwald (GER)	50.667	7.917	-
13	29	-	-	-	-	-	-	-	Bad Honnef (GER)	50.643	7.226	-
14	29	-	-	-	-	-	-	-	Montabaur (GER)	50.436	7.826	-
15	29	01:00	01:10	-	0 - 45	22.5	-	-	Isny (GER)	47.695	10.042	-
16	29	-	-	-	-	-	-	-	Zürich (CHE)	47.369	8.539	-
17	29	-	-	-	0 - 360	0	5 - 90	47.5	Metchosin (BC, CAN)	48.382	-123.538	g, r
18	29	-	-	-	-	-	-	-	Wasilla (AK, uSA)	61.579	-149.441	g, r
19	30	-	-	-	-	-	-	-	Greifswald (GER)	54.087	13.389	-
20	30	-	-	-	-	-	-	-	Elmshorn (GER)	53.751	9.663	-
21	30	-	-	-	-	-	-	-	Osnabrück (GER)	52.279	8.047	-
22	30	00:15	01:30	-	-	-	-	-	Bielefeld (GER)	52.021	8.530	-
23	30	22:10	22:22	-	-	-	-	-	Bitterfeld (GER)	51.626	12.328	-
24	30	-	-	-	-	-	-	-	Warstein-Belecke (GER)	51.485	8.339	-
25	30	-	-	-	-	-	-	-	Essen (GER)	51.456	7.012	-
26	30	-	-	-	-	-	-	-	Leipzig (GER)	51.339	12.373	-
27	30	-	-	-	-	-	-	-	Altenstädt (GER)	51.275	9.194	-

28	30	-	-	-	-	-	-	-	Altenstädt (GER)	51.275	9.194	-
29	30	-	-	-	-	-	-	-	Wuppertal (GER)	51.256	7.151	-
30	30	22:30	22:45	-	300 - 330	315	-	-	Wuppertal (GER)	51.256	7.151	r
31	30	01:25	-	-	-	-	-	-	Erkrath (GER)	51.221	6.907	-
32	30	-	-	-	-	-	-	-	Wipperfürth (GER)	51.118	7.396	-
33	30	01:00	01:30	-	-	-	-	-	Gotha (GER)	50.947	10.709	-
34	30	20:00	00:00	-	-	-	-	-	Köln (GER)	50.938	6.960	-
35	30	00:40	01:00	-	-	-	-	-	Jena (GER)	50.927	11.589	y, r
36	30	21:30	-	-	-	-	-	-	Bad Salzungen (GER)	50.808	10.235	r
37	30	-	-	-	-	-	-	-	Niederkassel-Rheidt (GER)	50.789	7.049	-
38	30	-	-	-	-	-	-	-	Stollberg (GER)	50.709	12.774	-
39	30	-	-	-	0 - 360	0	5 - 90	47.5	Stollberg (GER)	50.709	12.774	g, r
40	30	22:00	22:40	-	-	-	-	-	Westerwald (GER)	50.667	7.917	-
41	30	-	-	-	0 - 60	30	-	-	Bad Nauheim (GER)	50.367	8.739	r
42	30	-	-	-	-	-	-	-	udenhain (GER)	50.316	9.333	r
43	30	-	-	-	-	-	-	-	Hanau (GER)	50.126	8.931	-
44	30	23:34	00:19	-	-	-	-	-	Frankfurt am Main (GER)	50.111	8.682	-
45	30	21:45	00:30	-	-	-	-	-	Frankfurt am Main (GER)	50.111	8.682	-
46	30	-	-	-	-	-	-	-	Fichtelgebirge (GER)	50.000	12.000	r
47	30	-	-	-	-	-	-	-	Würzburg (GER)	49.791	9.954	-
48	30	-	-	-	-	-	-	-	Bensheim (GER)	49.686	8.619	-
49	30	-	-	-	-	-	-	-	Erlangen (GER)	49.591	11.014	-
50	30	-	-	-	-	-	-	-	Peterberg (GER)	49.538	6.977	g, r
51	30	21:30	00:25	-	-	-	-	-	Bad Mergentheim (GER)	49.489	9.770	g, r
52	30	22:20	22:40	-	-	-	-	-	Runding (GER)	49.216	12.762	-
53	30	-	-	-	-	-	-	-	Karlsruhe (GER)	49.009	8.379	-
54	30	-	-	-	-	-	-	-	Welzheim (GER)	48.874	9.632	g, r
55	30	-	-	-	-	-	-	-	Korntal (GER)	48.846	9.107	-
56	30	-	-	-	-	-	-	-	Stuttgart (GER)	48.775	9.182	-
57	30	22:15	21:30	-	-	-	-	-	Baden-Baden (GER)	48.766	8.229	r
58	30	-	-	-	-	-	-	-	Donzdorf (GER)	48.685	9.807	-
59	30	20:00	22:30	-	-	-	-	-	Moosburg (GER)	48.470	11.936	g, w, r

60	30	22:09	22:40	-	-	-	-	-	Schwäbische Alb (GER)	48.385	9.453	-
61	30	22:40	-	-	-	-	-	-	Augsburg (GER)	48.371	10.898	r
62	30	-	-	-	-	-	-	-	Traun (AuT)	48.221	14.237	-
63	30	-	-	-	-	-	-	-	Ried (GER)	48.213	13.493	-
64	30	-	-	-	-	-	-	-	Wien (AuT)	48.208	16.376	-
65	30	00:00	-	-	-	-	-	-	Wien (AuT)	48.208	16.376	-
66	30	20:30	23:30	-	240 - 300	270	-	-	Inning (GER)	48.076	11.150	-
67	30	-	-	-	-	-	60	60	Weigelsdorf (AuT)	47.943	16.408	-
68	30	-	-	-	-	-	-	-	Dettendorf (GER)	47.824	11.968	g, r, cr
69	30	-	-	-	-	-	-	-	Ebensee (AuT)	47.807	13.779	-
70	30	-	-	-	-	-	-	-	Isny (GER)	47.695	10.042	g, r
71	30	-	-	-	-	-	-	-	Rorschacherberg (CHE)	47.464	9.494	-
72	30	-	-	-	-	-	-	-	Zürich (CHE)	47.369	8.539	-
73	30	-	-	-	0 - 360	0	90	90	Cap-Rouge (QC, CAN)	46.766	-71.357	r
74	30	-	-	-	-	-	-	-	West Babylon (NY, uSA)	40.718	-73.356	g, r
75	31	-	-	-	-	-	-	-	Dortmund (GER)	51.571	6.985	g, r
76	31	-	-	-	-	-	-	-	Wageningen (GER)	51.514	7.465	g, r
77	31	-	-	-	-	-	-	-	Steinhuder Meer (GER)	52.473	9.338	-
78	31	-	-	-	-	-	-	-	Waremmе (BEL)	50.697	5.253	g, r
79	31	-	-	-	0 - 0	0	90	90	Aberdeen (GBR)	57.149	-2.091	g,r

Table 16: References of the 79 unused auroral sightings for the Halloween storm in 2003. “aurora archive” refers to the archive from Andreas Möller, which is available from <http://www.polarlicht-archiv.de/>. Auro-rasaurus is a citizens science project collecting aurora sightings (<https://www.aurorasaurus.org/>).

nr.	observer	reference
1	Peter Haubold	aurora archive
2	Michael Green	aurora archive
3	Jörg Fenner	aurora archive
4	Rainer Kracht	aurora archive
5	Oliver Kürten	aurora archive
6	Torsten Menz	aurora archive
7	Matthias Juchert	aurora archive
8	Herman Harperink	aurora archive
9	Bernd Pröschold	aurora archive
10	Peter Broich	aurora archive
11	Benjamin Kühne	aurora archive
12	Björn Goldhausen	aurora archive
13	Christoph Prall	aurora archive
14	Eric von der Heyden	aurora archive
15	Wolfgang van Oorschot	aurora archive
16	Heiko Rodde	aurora archive
17	Buttnor	http://www.spacew.com/gallery/image002152.html
18	Gillan	https://www.spaceweather.com
19	Michael HeiB	aurora archive
20	Rainer Kracht	aurora archive
21	Sven Lüke	aurora archive
22	Martin Liebermann	aurora archive
23	Manuel Schäfer	aurora archive
24	Michael Koers	aurora archive
25	Thomas Payer	aurora archive
26	Anita Raute	aurora archive
27	Eyk Neidert	aurora archive
28	Jens Wolf	aurora archive
29	Wojtek Welnowski	aurora archive
30	Peter Gaydos	aurora archive
31	Andreas Otte	aurora archive
32	Thomas Schoenstein	aurora archive
33	Rene Winter	aurora archive
34	Benjamin Kühne	aurora archive
35	Michael Bechmann	aurora archive
36	Gerhard Lampert	aurora archive
37	Sascha	aurora archive
38	Michael Stammeler	aurora archive
39	Martin Fiedler	aurora archive
40	Björn Goldhausen	aurora archive
41	Thomas Sävert	aurora archive
42	Dietmar Bähr	aurora archive
43	Frank Bork	aurora archive
44	Frank M. Berger	aurora archive
45	Peter Kuklok	aurora archive
46	Andreas Reinl	aurora archive
47	Albert Engert	aurora archive
48	Ralf	aurora archive
49	Frank Gieseler	aurora archive
50	Philippe Grand-Montagne	aurora archive

51	Jens Hackmann	aurora archive
52	Stefan Engl	aurora archive
53	Georg Müller	aurora archive
54	Steffen Brückner	aurora archive
55	Gerald Dietze	aurora archive
56	Stefan Seip	aurora archive
57	Nathalie Dautel	aurora archive
58	Jürgen Biedermann	aurora archive
59	Thomas Rattei	aurora archive
60	Martin Wagner	aurora archive
61	Bernd Wißner	aurora archive
62	Florian Kollmann	aurora archive
63	Anton Kellner	aurora archive
64	Herfried Eisler	aurora archive
65	Wolfgang Zima	aurora archive
66	Rainer Timm	aurora archive
67	Johannes Pichler	aurora archive
68	Thomas Klein	aurora archive
69	Stefan S.	aurora archive
70	Wolfgang van Oorschot	aurora archive
71	Andreas Walker	aurora archive
72	Heiko Rodde	aurora archive
73	Mousette	https://www.spaceweather.com
74	Gross	https://www.spaceweather.com
75	Ruesing	https://www.spaceweather.com
76	Luijting	https://www.spaceweather.com
77	Achim Kämper	aurora archive
78	Maillard	https://www.spaceweather.com
79	Henderson	https://www.spaceweather.com