Solar activity relations in energetic electron events measured by the MESSENGER mission

EGU23-2518 **ECS**

Credit: https://ismaelcaracol.wordpress.com/

Pictures and screenshots are welcome

Link to the article

Rodríguez-García et al. (A&A, forthcoming article)

L. Rodríguez-García, L. A. Balmaceda, R. Gómez-Herrero, A. Kouloumvakos, N. Dresing, D. Lario, I. Zouganelis, A. Fedeli, F. Espinosa Lara, I. Cernuda, G. C. Ho, R. F. Wimmer–Schweingruber, and J. Rodríguez-Pacheco

https://doi.org/10.1051/0004-6361/202245604

Laura Rodríguez-García
Postdoctoral researcher at Universidad de Alcalá (Madrid, Spain)
Solar Orbiter EPD instrument team member
SERPENTINE project member

Financial support by the Spanish Ministerio de Ciencia, Innovación y Universidades FEDER/MCIU/AEI Projects ESP2017-88436-R and PID2019-104863RB I00/AEI/10.13039/501100011033

Motivation

Third science objective of Solar Orbiter:

How do solar eruptions produce energetic particle radiation that fills the heliosphere?

To investigate the acceleration of solar energetic particles sampling events closer to the acceleration site

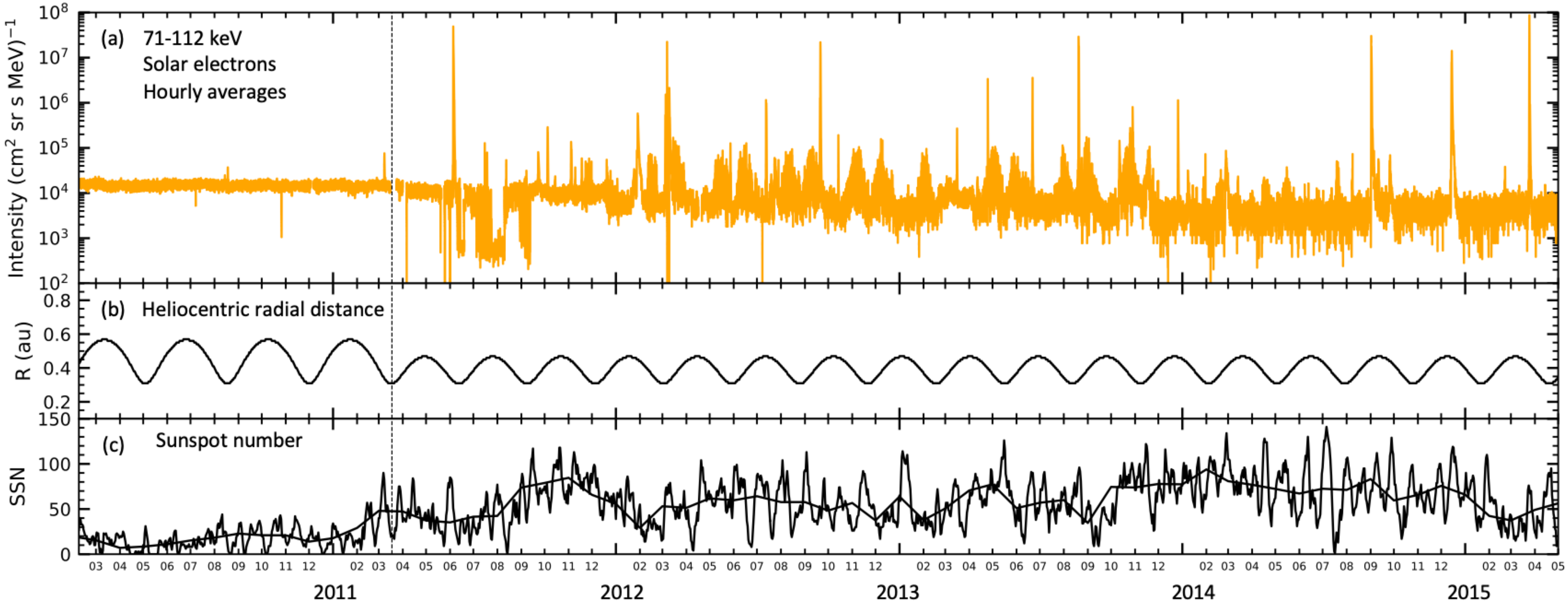
Financial support by the Spanish Ministerio de Ciencia, Innovación y Universidades FEDER/MCIU/AEI Projects ESP2017-88436-R and PID2019-104863RB I00/AEI/10.13039/501100011033

Outline

- ✓ MESSENGER mission: electron events measured close to the acceleration site (near 0.4 au)
- ✓ Relations between solar energetic electron peak intensities and solar source parameters
- ✓ Conclusions

Financial support by the Spanish Ministerio de Ciencia, Innovación y Universidades FEDER/MCIU/AEI Projects ESP2017-88436-R and PID2019-104863RB I00/AEI/10.13039/501100011033

MESSENGER
solar energetic electron observations



Credit: L. Rodríguez-García et al. A&A 670, A51 (2023)

- Most of the rising, maximum, and early decay phase of solar cycle 24
- Heliocentric distance of MESSENGER: 0.31 to 0.47 au
- Solar energetic events observed as vertical spikes in this compressed timescale
- High background of MESSENGER/EPS instrument -> only strong events
- Anti-Sun pointing of MESSENGER-> lower limit of peak electron intensities

Financial support by the Spanish Ministerio de Ciencia, Innovación y Universidades FEDER/MCIU/AEI Projects ESP2017-88436-R and PID2019-104863RB I00/AEI/10.13039/501100011033

Universidad de Alcalá
SPACE RESEARCH GROUP
SRG

MINISTERIO DE CIENCIA E INNOVACIÓN
UNIÓN EUROPEA
FONDO EUROPEO DE DESARROLLO REGIONAL
"Una manera de hacer Europa"
AGENCIA ESTATAL DE INVESTIGACIÓN

MESSENGER list

In **61** solar energetic electron (SEE) events we find that:

- **57** events are **CME** related, **56** of them accompanied by a CME-driven shock
- At least **44** events are **widespread**
- **37** events accompanied by **relativistic electron enhancements**

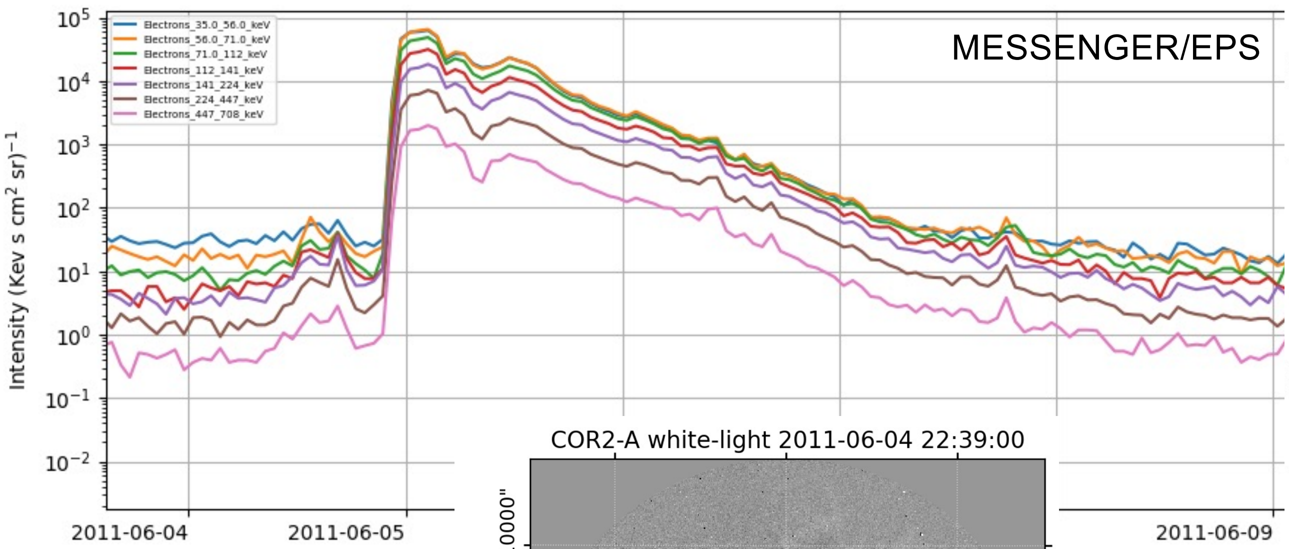
#	Solar event: Date	Solar event: T-III onset (UT ± 5 min)	Flare loc [class] (deg)	CA MESS (deg)	R MESS (au)	SEE event: Imax_MESS (bg) 71 to 112 keV e (cm^2 sr s MeV)$^{-1}$	SEE event: δ MESS (-)
(1)	(2)	(3)	(4)	(8)	(9)	(10)	(11)
*1	2010/08/14	10:00^	N17W052 [C4.4]	-67	0.31	$2.5\times10^{4}\ (1.6\times10^{4})$	-
*2	2010/08/18	05:35	N17W101 [C4.5]	-39	0.31	$3.7\times10^{4}\ (1.5\times10^{4})$	-
*3	2011/03/07	19:55^	N30W048 [M3.7]	168	0.34	$7.5\times10^{4}\ (1.6\times10^{4})$	$-1.78\pm0.13^{\dagger}$
*4	2011/06/04	06:50	N16W144 [-]	-12	0.33	$3.1\times10^{4}\ (9.0\times10^{3})$	-2.26 ± 1.14
*5	2011/06/04	21:50^	N16W153 [-]	-5	0.33	$4.9\times10^{7}\ (2.0\times10^{4})$	$-1.94\pm0.21^{\dagger}$
*6	2011/08/02	06:25^	N15W015 [M1.4]	19	0.46	$1.5\times10^{3}\ (2.5\times10^{2})$	-
*7	2011/08/04	03:50	N19W036 [M9.3]	37	0.46	$1.6\times10^{3}(5.0\times10^{2})$	-
*8	2011/09/22	10:40	N09E089 [X1.4]	90	0.36	$8.1\times10^{4}\ (1.4\times10^{4})$	$-1.97\ \pm0.36^{\dagger}$
*9	2011/10/04	12:30^	N26E153 [-]	-14	0.42	$2.9\times10^{5}\ (1.0\times10^{4})$	$-1.88\pm0.17^{\dagger}$
10	2011/10/14	11:00^	N10E140 [-]	-23	0.47	$2.3\times10^{4}\ (1.2\times10^{4})$	-
*11	2011/11/03	22:15	N09E154 [-]	-74	0.44	$1.4\times10^{5}\ (9.0\times10^{3})$	$-1.69\pm0.10^{\dagger}$
12	2011/11/09	13:10	N24E035 [M1.1]	34	0.42	$3.6\times10^{4}\ (1.0\times10^{4})$	$-1.96\pm0.28^{\dagger}$
*13	2011/11/17	20:15^	N18E120 [-]	-71	0.38	$5.8\times10^{4}\ (7.1\times10^{3})$	$-1.94\pm0.26^{\dagger}$
*14	2012/01/02	14:30	N08W104 [C2.4]	-34	0.43	$2.1\times10^{4}\ (8.1\times10^{3})$	-
*15	2012/01/23	03:40	N28W021 [M8.7]	-157	0.46	$3.4\times10^{4}\ (8.7\times10^{3})$	$-1.78\pm0.36^{\dagger}$
*16	2012/01/27	18:15	N27W078 [X1.7]	-108	0.46	$8.7\times10^{4}\ (8.5\times10^{3})$	$-1.70\pm0.19^{\dagger}$
*17	2012/03/04	11:05	N19E061 [M2.0]	-8	0.31	$8.4\times10^{4}\ (8.9\times10^{3})$	$-2.41\pm1.29^{\dagger}$
*18	2012/03/05	03:35	N17E052 [X1.1]	-2	0.31	$1.5\times10^{6}\ (4.1\times10^{4})$	$-1.98\pm0.20^{\dagger}$
*19	2012/03/07	00:20	N17E027 [X5.4]	13	0.31	$2.2\times10^{7}\ (1.9\times10^{4})$	$-2.02\pm0.26^{\dagger}$
*20	2012/05/17	01:30	N11W076 [M5.1]	-76	0.35	$8.7\times10^{4}\ (2.0\times10^{4})$	-
*21	2012/05/26	20:40	N15W116 [-]	-75	0.31	$1.9\times10^{4}\ (4.0\times10^{3})$	-1.70 ± 0.53
*22	2012/05/27	05:10^	S10E054 [C3.1]	108	0.31	$1.3\times10^{5}\ (2.4\times10^{4})$	$-2.56\pm0.96^{\dagger}$
*23	2012/07/12	15:45^	S15W001 [X1.4]	4	0.46	$1.1\times10^{6}\ (5.5\times10^{3})$	$-1.95\pm0.27^{\dagger}$
24	2012/07/17	14:00^	S20W065 [C9.9]	59	0.46	$1.6\times10^{4}\ (2.8\times10^{3})$	-
25	2012/07/19	05:20	S13W088 [M7.7]	79	0.46	$2.6\times10^{4}\ (7.1\times10^{3})$	-
*26	2012/07/23	02:10^	S17W132 [-]	116	0.45	$5.8\times10^{4}\ (9.5\times10^{3})$	$-1.90\pm0.18^{\dagger}$
27	2012/07/28	21:05	S25E055 [M6.1]	-82	0.44	$5.4\times10^{4}\ (4.7\times10^{3})$	$-2.11\pm0.42^{\dagger}$
*28	2012/09/20	14:55	S15E155 [-]	-29	0.42	$2.0\times10^{6}\ (2.5\times10^{4})$	$-1.91\pm0.21^{\dagger}$
*29	2012/10/14	00:35	N13E137 [-]	-58	0.46	$1.9\times10^{5}\ (4.0\times10^{3})$	$-1.93\pm0.15^{\dagger}$
30	2013/03/16	05:45	S15W045 [C2.8]	-14	0.43	$2.7\times10^{5}\ (5.0\times10^{4})$	$-1.92\pm0.45^{\dagger}$
*31	2013/04/11	07:00	N09E012 [M6.5]	-122	0.46	$2.2\times10^{4}\ (2.7\times10^{3})$	-
32	2013/04/24	21:40	N10W175 [-]	38	0.40	$3.3\times10^{6}\ (7.6\times10^{3})$	$-2.22\pm0.16^{\dagger}$
*33	2013/05/13	15:55	N11E085 [X2.8]	67	0.31	$2.4\times10^{4}\ (6.3\times10^{3})$	-1.80 ± 0.59
*34	2013/06/21	02:50^	S16E073 [M2.9]	-67	0.46	$5.5\times10^{5}\ (4.7\times10^{3})$	$-1.82\pm0.30^{\dagger}$
35	2013/08/19	01:20^	N10W162 [-]	-13	0.32	$4.0\times10^{4}\ (1.5\times10^{4})$	-
*36	2013/08/19	22:30	N08W178 [M3.3§]	-1	0.32	$2.9\times10^{7}\ (1.0\times10^{4})$	$-1.99\pm0.25^{\dagger}$
*37	2013/10/11	07:10	N21E103 [M1.5]	-56	0.43	$1.4\times10^{5}\ (4.6\times10^{3})$	$-1.92\pm0.08^{\dagger}$
*38	2013/10/25	08:00	S10E073 [X1.7]	-62	0.36	$2.2\times10^{5}\ (1.3\times10^{4})$	$-1.85\pm0.16^{\dagger}$
*39	2013/10/25	15:00	S06E069 [X2.1]	-59	0.36	$2.8\times10^{5}\ (5.4\times10^{4})$	$-1.89\pm0.18^{\dagger}$
*40	2013/10/28	15:10	S08E028 [M4.4]	-29	0.34	$8.1\times10^{5}\ (2.1\times10^{4})$	$-1.97\pm0.06^{\dagger}$
*41	2013/11/19	10:25	S15W069 [X1.0]	-41	0.34	$6.2\times10^{4}\ (5.4\times10^{4})$	$-1.93\pm0.31^{\dagger}$
*42	2013/11/30	05:10^	N13W150[-]	2	0.40	$1.5\times10^{4}\ (4.9\times10^{3})$	-
*43	2013/11/30	15:00^	S15E146 [-]	65	0.40	$1.6\times10^{4}\ (8.2\times10^{3})$	-
*44	2013/12/26	03:05	S09E166 [-]	-9	0.46	$1.1\times10^{6}\ (4.2\times10^{3})$	$-2.02\pm0.38^{\dagger}$
*45	2014/01/07	18:05	S15W011 [X1.2]	145	0.43	$3.2\times10^{4}\ (6.1\times10^{3})$	-
*46	2014/01/28	00:30^	S10E081 [C7.6]	-8	0.32	$5.9\times10^{3}\ (8.1\times10^{2})$	-
47	2014/01/28	05:25^	S14E088 [C9.3]	-16	0.32	$2.2\times10^{4}\ (2.7\times10^{3})$	$-2.02\pm1.02^{\dagger}$
48	2014/01/30	16:05	S13E058 [M6.6]	2	0.31	$7.4\times10^{4}\ (7.1\times10^{3})$	$-1.82\pm0.33^{\dagger}$
49	2014/02/20	07:50	S15W073 [M3.0]	34	0.37	$1.3\times10^{4}\ (1.5\times10^{3})$	-
*50	2014/02/25	00:45	S12E082 [X4.9]	-137	0.40	$5.5\times10^{4}\ (1.2\times10^{3})$	$-1.91\pm0.47^{\dagger}$
*51	2014/03/13	21:40^	N15W140 [-]	44	0.46	$2.3\times10^{4}\ (3.8\times10^{3})$	-1.55 ± 0.31
52	2014/08/08	16:15	S10W160 [-]	-41	0.33	$7.3\times10^{4}\ (6.2\times10^{3})$	$-1.82\pm0.21^{\dagger}$
*53	2014/09/01	11:00	N14E127 [-]	-44	0.45	$2.9\times10^{7}\ (3.4\times10^{3})$	$-1.81\pm0.03^{\dagger}$
54	2014/09/05	06:50	S14E069 [C6.8]	6	0.46	$8.6\times10^{4}\ (3.9\times10^{4})$	-2.06 ± 0.65
55	2014/09/08	23:55	N12E029 [M4.5]	39	0.47	$2.6\times10^{4}\ (5.4\times10^{3})$	-
*56	2014/09/10	17:30	N14E002 [X1.6]	64	0.47	$5.6\times10^{4}\ (1.0\times10^{4})$	$-1.77\pm0.16^{\dagger}$
*57	2014/09/24	20:45	N13E179 [-]	-139	0.44	$5.3\times10^{4}\ (4.7\times10^{3})$	$-2.19\pm0.13^{\dagger}$
58	2014/12/13	14:05^	S20W143 [-]	-75	0.46	$7.8\times10^{6}\ (3.4\times10^{3})$	$-1.92\pm0.26^{\dagger}$
59	2015/02/21	09:30^	S40W075 [B4.8]	-19	0.44	$3.8\times10^{4}\ (3.9\times10^{3})$	-
60	2015/03/24	08:30^	S01W121 [-]	-31	0.43	$1.2\times10^{6}\ (1.3\times10^{4})$	$-1.94\pm0.24^{\dagger}$
*61	2015/04/14	09:15^	S15W100 [B9]	-119	0.32	$1.5\times10^{4}\ (4.5\times10^{3})$	-

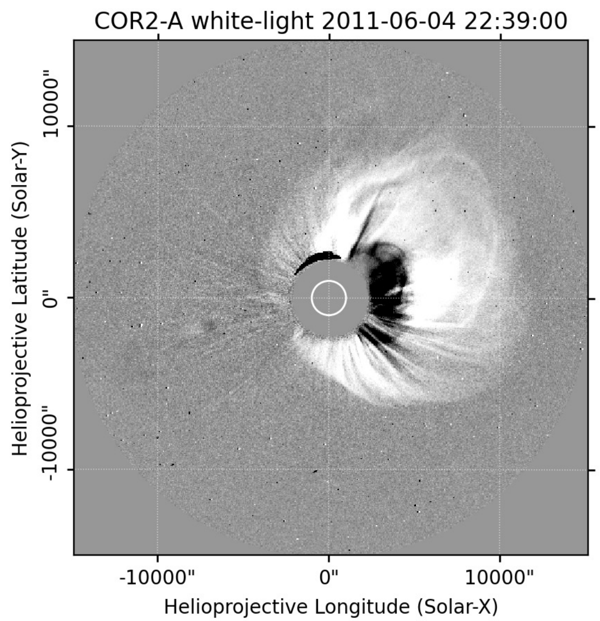
Credit: L. Rodríguez-García et al. A&A 670, A51 (2023)

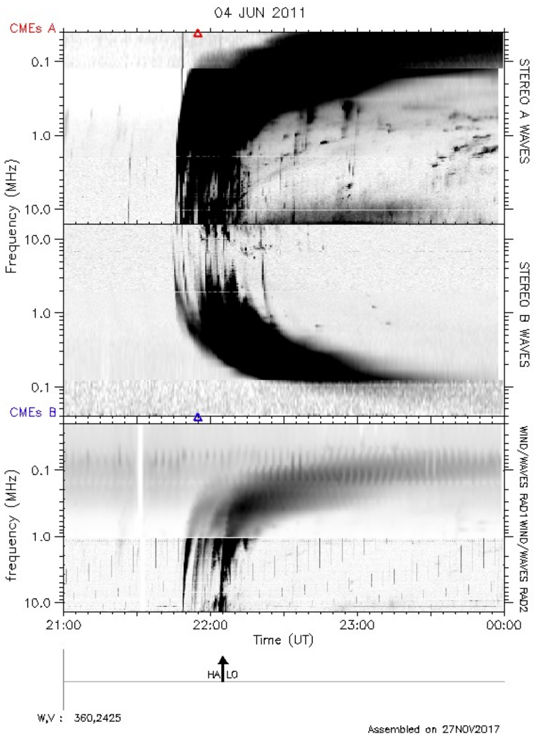
Financial support by the Spanish Ministerio de Ciencia, Innovación y Universidades FEDER/MCIU/AEI Projects ESP2017-88436-R and PID2019-104863RB I00/AEI/10.13039/501100011033

To relate in situ electron enhancements with solar activity

Example: Solar energetic electron event on 2011 June 4





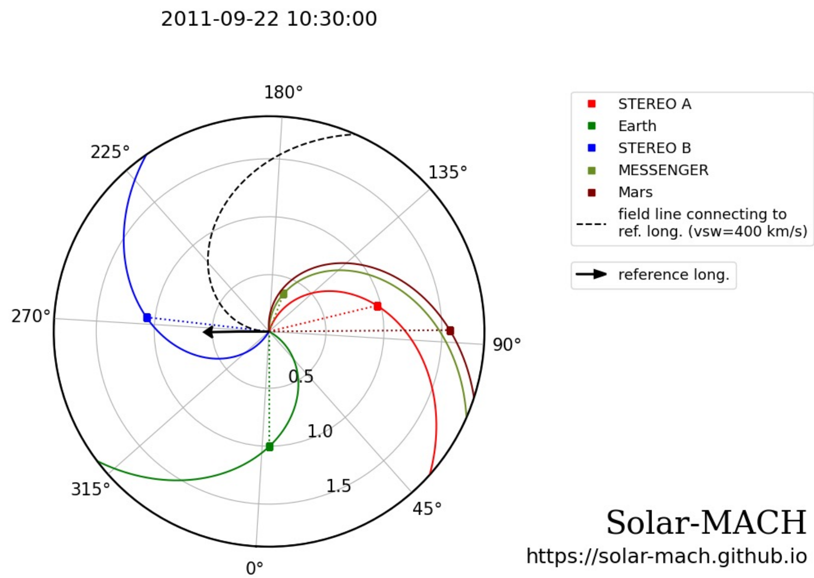


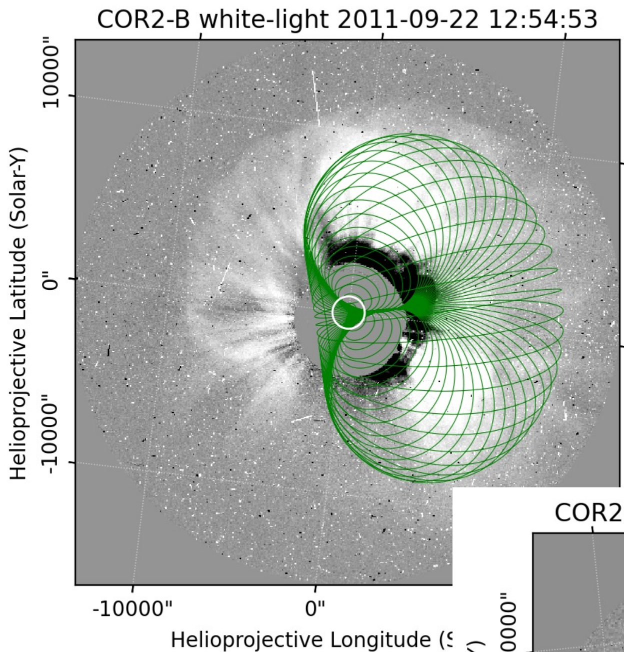
Credit: https://secchirh.obspm.fr/

Financial support by the Spanish Ministerio de Ciencia, Innovación y Universidades FEDER/MCIU/AEI Projects ESP2017-88436-R and PID2019-104863RB I00/AEI/10.13039/501100011033

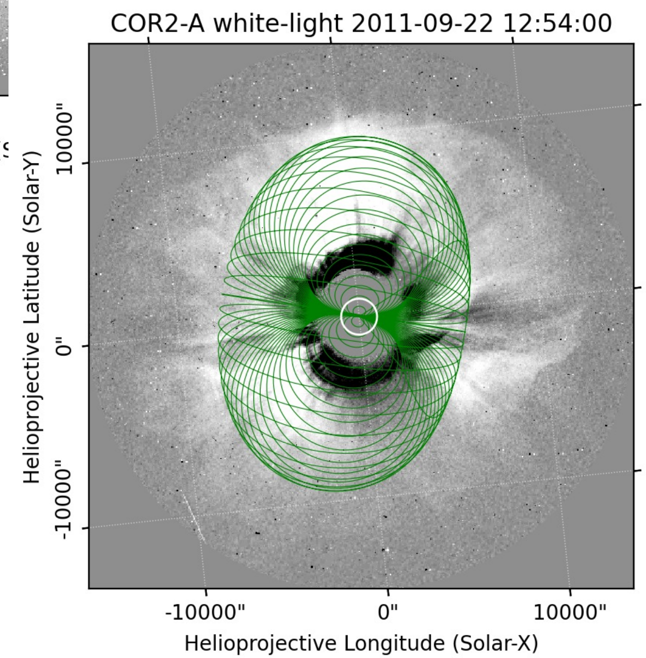
Parker spiral/3D CME & CME-driven shock reconstruction

Example: Solar energetic electron event on 2011 September 22





Reconstruct the 3D structure of CMEs and shock waves



Nominal connection angle (CA) using 400 km/s solar wind speed

3D CME/CME-driven shock geometry and kinematics

https://serpentine-h2020.eu/

Financial support by the Spanish Ministerio de Ciencia, Innovación y Universidades FEDER/MCIU/AEI Projects ESP2017-88436-R and PID2019-104863RB I00/AEI/10.13039/501100011033

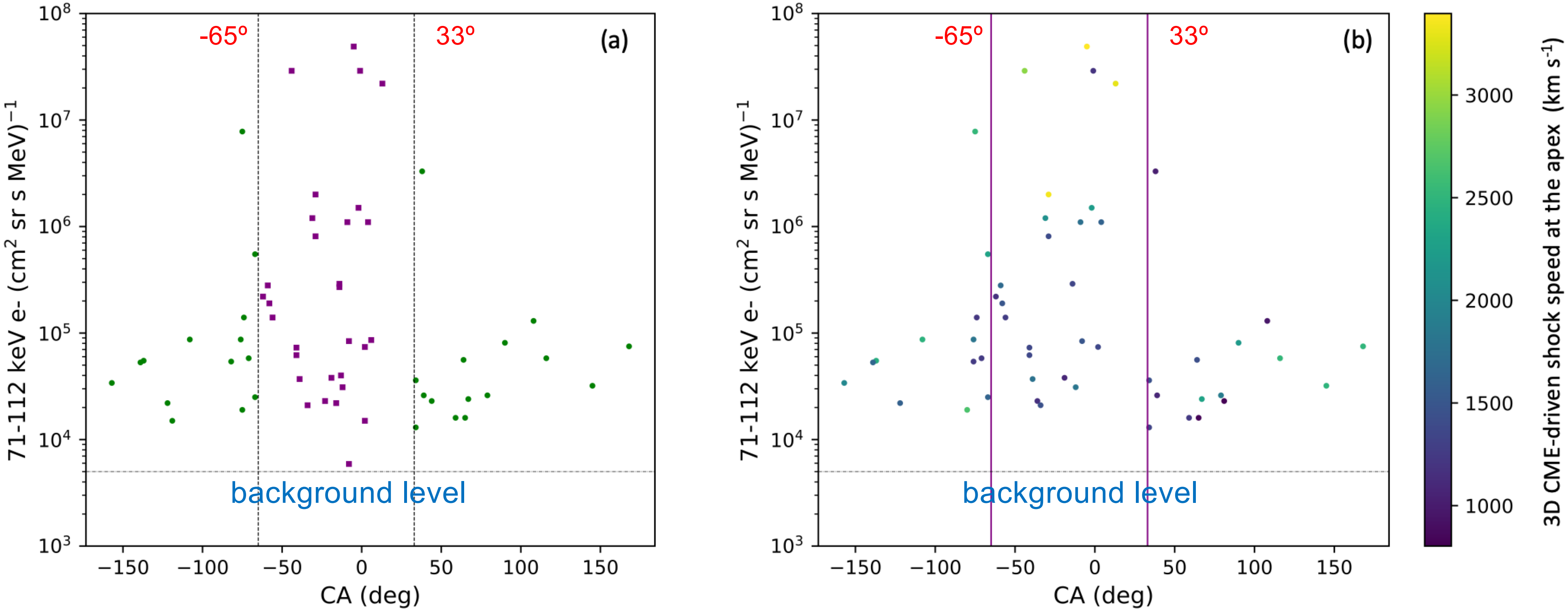
MESSENGER list completed with the 3D reconstruction of CMEs and CME-driven shocks

Table A.1. Solar energetic electron events measured by MESSENGER.

#	Solar event: Date	Solar event: T-III onset (UT ± 5 min)	Flare loc [class] (deg)	CME parameters: speed (GCS) ($km\ s^{-1}$)	CME parameters: width (GCS) (deg)	Shock speed (3D) ($km\ s^{-1}$)	CA MESS (deg)	R MESS (au)	SEE event: Imax_MESS (bg) 71 to 112 keV e (cm^2 sr s MeV)$^{-1}$	SEE event: δ MESS (-)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
*1	2010/08/14	10:00^	N17W052 [C4.4]	960	64	1631	-67	0.31	2.5×10^{4} (1.6×10^{4})	-
*2	2010/08/18	05:35	N17W101 [C4.5]	1634	57	1781	-39	0.31	3.7×10^{4} (1.5×10^{4})	-
*3	2011/03/07	19:55^	N30W048 [M3.7]	2250	51	2505	168	0.34	7.5×10^{4} (1.6×10^{4})	$-1.78\pm0.13^{\dagger}$
*4	2011/06/04	06:50	N16W144 [-]	1086	106	1826	-12	0.33	3.1×10^{4} (9.0×10^{3})	-2.26 ± 1.14
*5	2011/06/04	21:50^	N16W153 [-]	2200	126	3397	-5	0.33	4.9×10^{7} (2.0×10^{4})	$-1.94\pm0.21^{\dagger}$
*6	2011/08/02	06:25^	N15W015 [M1.4]	807	90	1114	19	0.46	1.5×10^{3} (2.5×10^{2})	-
*7	2011/08/04	03:50	N19W036 [M9.3]	1125	88	2572	37	0.46	1.6×10^{3}(5.0×10^{2})	-
*8	2011/09/22	10:40	N09E089 [X1.4]	1300	81	2206	90	0.36	8.1×10^{4} (1.4×10^{4})	$-1.97\pm0.36^{\dagger}$
*9	2011/10/04	12:30^	N26E153 [-]	1358	77	1341	-14	0.42	2.9×10^{5} (1.0×10^{4})	$-1.88\pm0.17^{\dagger}$
10	2011/10/14	11:00^	N10E140 [-]	889	74	1166	-23	0.47	2.3×10^{4} (1.2×10^{4})	-
*11	2011/11/03	22:15	N09E154 [-]	890	76	1210	-74	0.44	1.4×10^{5} (9.0×10^{3})	$-1.69\pm0.10^{\dagger}$
12	2011/11/09	13:10	N24E035 [M1.1]	1133	45	1446	34	0.42	3.6×10^{4} (1.0×10^{4})	$-1.96\pm0.28^{\dagger}$
*13	2011/11/17	20:15^	N18E120 [-]	948	106	1254	-71	0.38	5.8×10^{4} (7.1×10^{3})	$-1.94\pm0.26^{\dagger}$
*14	2012/01/02	14:30	N08W104 [C2.4]	1125	83	1443	-34	0.43	2.1×10^{4} (8.1×10^{3})	-
*15	2012/01/23	03:40	N28W021 [M8.7]	1775	91	2014	-157	0.46	3.4×10^{4} (8.7×10^{3})	$-1.78\pm0.36^{\dagger}$
*16	2012/01/27	18:15	N27W078 [X1.7]	1750	70	2468	-108	0.46	8.7×10^{4} (8.5×10^{3})	$-1.70\pm0.19^{\dagger}$
*17	2012/03/04	11:05	N19E061 [M2.0]	1588	46	1497	-8	0.31	8.4×10^{4} (8.9×10^{3})	$-2.41\pm1.29^{\dagger}$
*18	2012/03/05	03:35	N17E052 [X1.1]	850	72	2231	-2	0.31	1.5×10^{6} (4.1×10^{4})	$-1.98\pm0.20^{\dagger}$
*19	2012/03/07	00:20	N17E027 [X5.4]	2700	71	3303	13	0.31	2.2×10^{7} (1.9×10^{4})	$-2.02\pm0.26^{\dagger}$
*20	2012/05/17	01:30	N11W076 [M5.1]	1458	75	1807	-76	0.35	8.7×10^{4} (2.0×10^{4})	-
*21	2012/05/26	20:40	N15W116 [-]	1850	55	2665	-75	0.31	1.9×10^{4} (4.0×10^{3})	-1.70 ± 0.53
*22	2012/05/27	05:10^	S10E054 [C3.1]	1052	78	958	108	0.31	1.3×10^{5} (2.4×10^{4})	$-2.56\pm0.96^{\dagger}$
*23	2012/07/12	15:45^	S15W001 [X1.4]	1393	75	1617	4	0.46	1.1×10^{6} (5.5×10^{3})	$-1.95\pm0.27^{\dagger}$
24	2012/07/17	14:00^	S20W065 [C9.9]	821	50	1245	59	0.46	1.6×10^{4} (2.8×10^{3})	-
25	2012/07/19	05:20	S13W088 [M7.7]	1500	71	1897	79	0.46	2.6×10^{4} (7.1×10^{3})	-
*26	2012/07/23	02:10^	S17W132 [-]	1900	116	2520	116	0.45	5.8×10^{4} (9.5×10^{3})	$-1.90\pm0.18^{\dagger}$
27	2012/07/28	21:05	S25E055 [M6.1]	792	68	1255	-82	0.44	5.4×10^{4} (4.7×10^{3})	$-2.11\pm0.42^{\dagger}$
*28	2012/09/20	14:55	S15E155 [-]	2600	54	3353	-29	0.42	2.0×10^{6} (2.5×10^{4})	$-1.91\pm0.21^{\dagger}$
*29	2012/10/14	00:35	N13E137 [-]	1200	61	1502	-58	0.46	1.9×10^{5} (4.0×10^{3})	$-1.93\pm0.15^{\dagger}$
30	2013/03/16	05:45	S15W045 [C2.8]	260	61	-	-14	0.43	2.7×10^{5} (5.0×10^{4})	$-1.92\pm0.45^{\dagger}$
*31	2013/04/11	07:00	N09E012 [M6.5]	1350	130	1602	-122	0.46	2.2×10^{4} (2.7×10^{3})	-
32	2013/04/24	21:40	N10W175 [-]	560	73	1017	38	0.40	3.3×10^{6} (7.6×10^{3})	$-2.22\pm0.16^{\dagger}$
*33	2013/05/13	15:55	N11E085 [X2.8]	2000	84	2308	67	0.31	2.4×10^{4} (6.3×10^{3})	-1.80 ± 0.59
*34	2013/06/21	02:50^	S16E073 [M2.9]	1428	60	2303	-67	0.46	5.5×10^{5} (4.7×10^{3})	$-1.82\pm0.30^{\dagger}$
35	2013/08/19	01:20^	N10W162 [-]	-	-	-	-13	0.32	4.0×10^{4} (1.5×10^{4})	-
*36	2013/08/19	22:30	N08W178 [M3.3§	1149	118	1192	-1	0.32	2.9×10^{7} (1.0×10^{4})	$-1.99\pm0.25^{\dagger}$
*37	2013/10/11	07:10	N21E103 [M1.5]	875	160	1267	-56	0.43	1.4×10^{5} (4.6×10^{3})	$-1.92\pm0.08^{\dagger}$
*38	2013/10/25	08:00	S10E073 [X1.7]	500	65	1188	-62	0.36	2.2×10^{5} (1.3×10^{4})	$-1.85\pm0.16^{\dagger}$
*39	2013/10/25	15:00	S06E069 [X2.1]	1225	69	1686	-59	0.36	2.8×10^{5} (5.4×10^{4})	$-1.89\pm0.18^{\dagger}$
*40	2013/10/28	15:10	S08E028 [M4.4]	1400	56	1393	-29	0.34	8.1×10^{5} (2.1×10^{4})	$-1.97\pm0.06^{\dagger}$
*41	2013/11/19	10:25	S15W069 [X1.0]	1138	52	1361	-41	0.34	6.2×10^{4} (5.4×10^{4})	$-1.93\pm0.31^{\dagger}$
*42	2013/11/30	05:10^	N13W150[-]	-	-	-	2	0.40	1.5×10^{4} (4.9×10^{3})	-
*43	2013/11/30	15:00^	S15E146 [-]	830	48	830	65	0.40	1.6×10^{4} (8.2×10^{3})	-
*44	2013/12/26	03:05	S09E166 [-]	1738	47	1753	-9	0.46	1.1×10^{6} (4.2×10^{3})	$-2.02\pm0.38^{\dagger}$
*45	2014/01/07	18:05	S15W011 [X1.2]	2190	61	2486	145	0.43	3.2×10^{4} (6.1×10^{3})	-
*46	2014/01/28	00:30^	S10E081 [C7.6]	-	-	-	-8	0.32	5.9×10^{3} (8.1×10^{2})	-
47	2014/01/28	05:25^	S14E088 [C9.3]	-	-	-	-16	0.32	2.2×10^{4} (2.7×10^{3})	$-2.02\pm1.02^{\dagger}$
48	2014/01/30	16:05	S13E058 [M6.6]	1450	66	1367	2	0.31	7.4×10^{4} (7.1×10^{3})	$-1.82\pm0.33^{\dagger}$
49	2014/02/20	07:50	S15W073 [M3.0]	1103	70	1328	34	0.37	1.3×10^{4} (1.5×10^{3})	-
*50	2014/02/25	00:45	S12E082 [X4.9]	2350	69	2431	-137	0.40	5.5×10^{4} (1.2×10^{3})	$-1.91\pm0.47^{\dagger}$
*51	2014/03/13	21:40^	N15W140 [-]	498	23	803	44	0.46	2.3×10^{4} (3.8×10^{3})	-1.55 ± 0.31
52	2014/08/08	16:15	S10W160 [-]	1035	57	1352	-41	0.33	7.3×10^{4} (6.2×10^{3})	$-1.82\pm0.21^{\dagger}$
*53	2014/09/01	11:00	N14E127 [-]	1842	77	2947	-44	0.45	2.9×10^{7} (3.4×10^{3})	$-1.81\pm0.03^{\dagger}$
54	2014/09/05	06:50	S14E069 [C6.8]	565$^{!}$	56$^{!}$	NP	6	0.46	8.6×10^{4} (3.9×10^{4})	-2.06 ± 0.65
55	2014/09/08	23:55	N12E029 [M4.5]	1120	36	1077	39	0.47	2.6×10^{4} (5.4×10^{3})	-
*56	2014/09/10	17:30	N14E002 [X1.6]	1580	74	1427	64	0.47	5.6×10^{4} (1.0×10^{4})	$-1.77\pm0.16^{\dagger}$
*57	2014/09/24	20:45	N13E179 [-]	1516	76	1651	-139	0.44	5.3×10^{4} (4.7×10^{3})	$-2.19\pm0.13^{\dagger}$
58	2014/12/13	14:05^	S20W143 [-]	2036$^{!}$	92$^{!}$	2519$^{!}$	-75	0.46	7.8×10^{6} (3.4×10^{3})	$-1.92\pm0.26^{\dagger}$
59	2015/02/21	09:30^	S40W075 [B4.8]	884$^{!}$	65$^{!}$	1088$^{!}$	-19	0.44	3.8×10^{4} (3.9×10^{3})	-
60	2015/03/24	08:30^	S01W121 [-]	1371$^{!}$	106$^{!}$	2102$^{!}$	-31	0.43	1.2×10^{6} (1.3×10^{4})	$-1.94\pm0.24^{\dagger}$
*61	2015/04/14	09:15^	S15W100 [B9]	484$^{!}$	31$^{!}$	NP	-119	0.32	1.5×10^{4} (4.5×10^{3})	-

Financial support by the Spanish Ministerio de Ciencia, Innovación y Universidades FEDER/MCIU/AEI Projects ESP2017-88436-R and PID2019-104863RB I00/AEI/10.13039/501100011033

e- peak intensity versus flare location

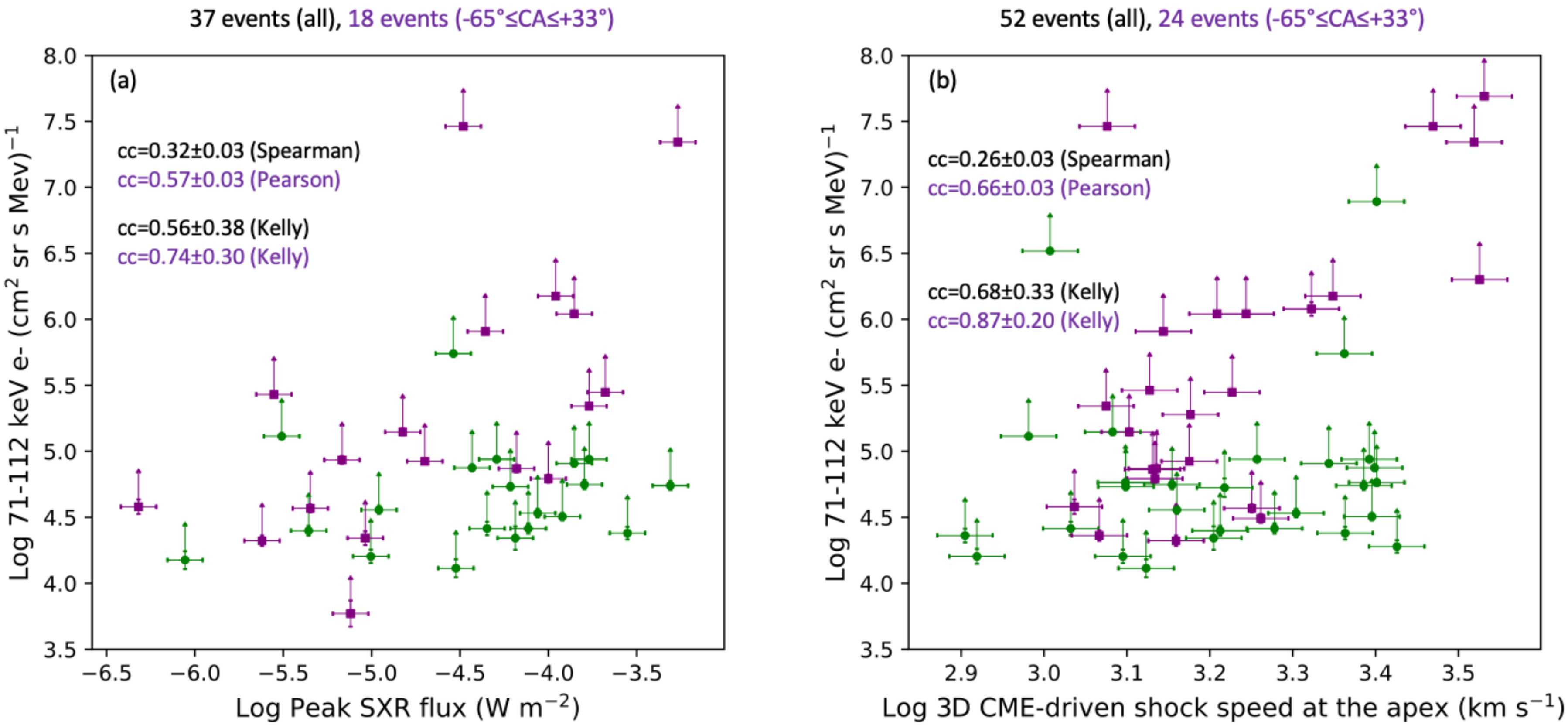


- The sample is truncated (high background level of the MESSENGER/EPS instrument)

Asymmetry in the SEE events showing the largest intensities->
Centroid and sigma by Lario et al. 2013 are used for defining well-connected events->
-65º<CA< 33º

Financial support by the Spanish Ministerio de Ciencia, Innovación y Universidades FEDER/MCIU/AEI Projects ESP2017-88436-R and PID2019-104863RB I00/AEI/10.13039/501100011033

Relations between e^- peak intensity and solar source parameters

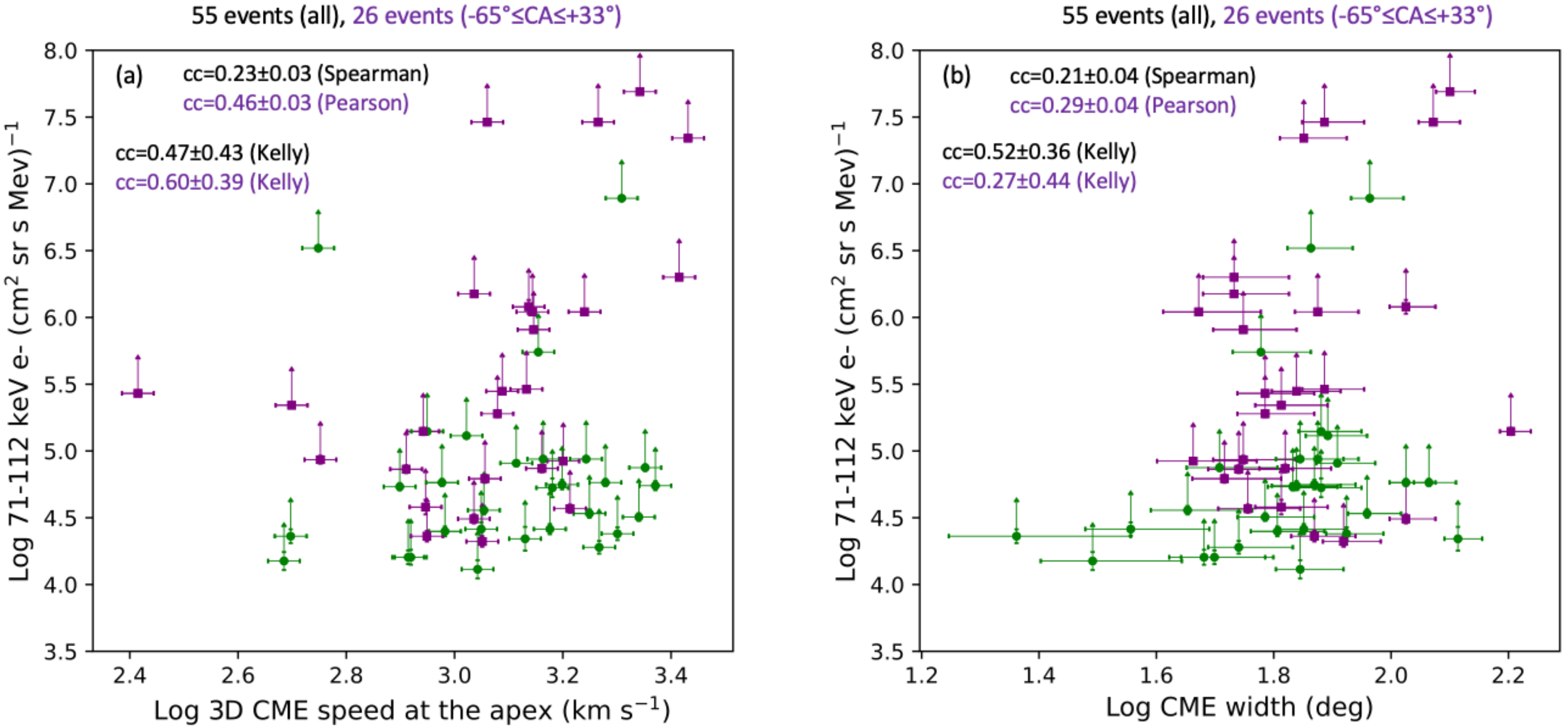


- Spearman, Pearson, and Kelly correlation methods used
- Corrected for the lower limit of peak intensity values measured by MESSENGER

Similar correlations (within uncertainties) between the SEE peak intensities and the flare or shock parameters

Financial support by the Spanish Ministerio de Ciencia, Innovación y Universidades FEDER/MCIU/AEI Projects ESP2017-88436-R and PID2019-104863RB I00/AEI/10.13039/501100011033

Relations between e⁻ peak intensity and solar source parameters



The correlation of the peak electron intensity with the maximum speed of the 3D CME-driven shock at the apex is stronger and also more significant than that with the CME speed at the apex

The 3D CME geometry plays a moderate role in the acceleration of particles

Financial support by the Spanish Ministerio de Ciencia, Innovación y Universidades FEDER/MCIU/AEI Projects ESP2017-88436-R and PID2019-104863RB I00/AEI/10.13039/501100011033

Conclusions

✓ **Both flare and shock-related processes may contribute to the acceleration of near relativistic electrons in large SEE events, in agreement with previous studies based on near 1 au data**

✓ **The maximum speed of the CME-driven shock is a better parameter to investigate particle-acceleration-related mechanisms than the average CME speed, as suggested by the stronger correlation with the SEE peak intensities**

Contact: l.rodriguezgarcia@uah.es

Link to the article

Financial support by the Spanish Ministerio de Ciencia, Innovación y Universidades FEDER/MCIU/AEI Projects ESP2017-88436-R and PID2019-104863RB I00/AEI/10.13039/501100011033