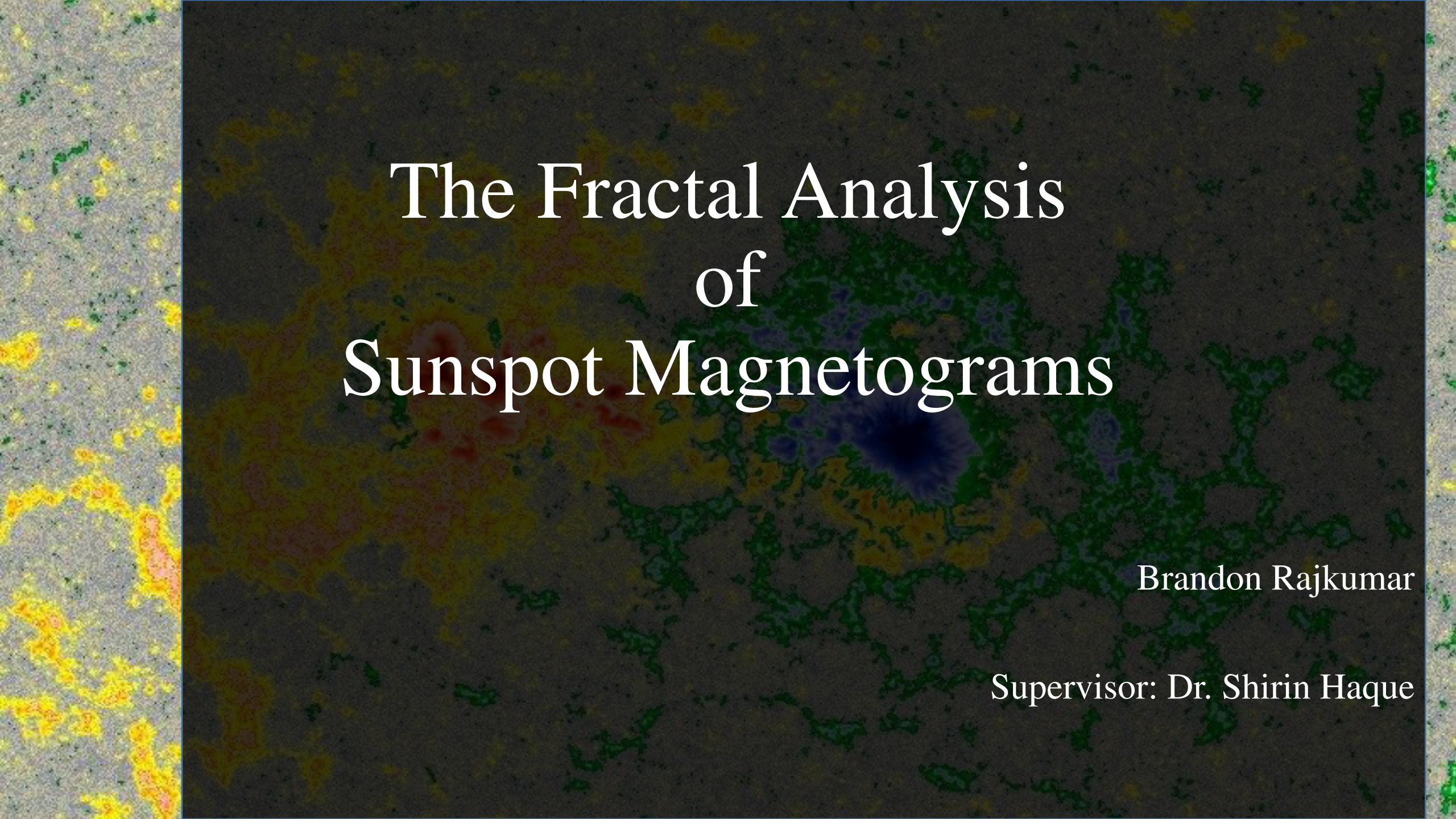


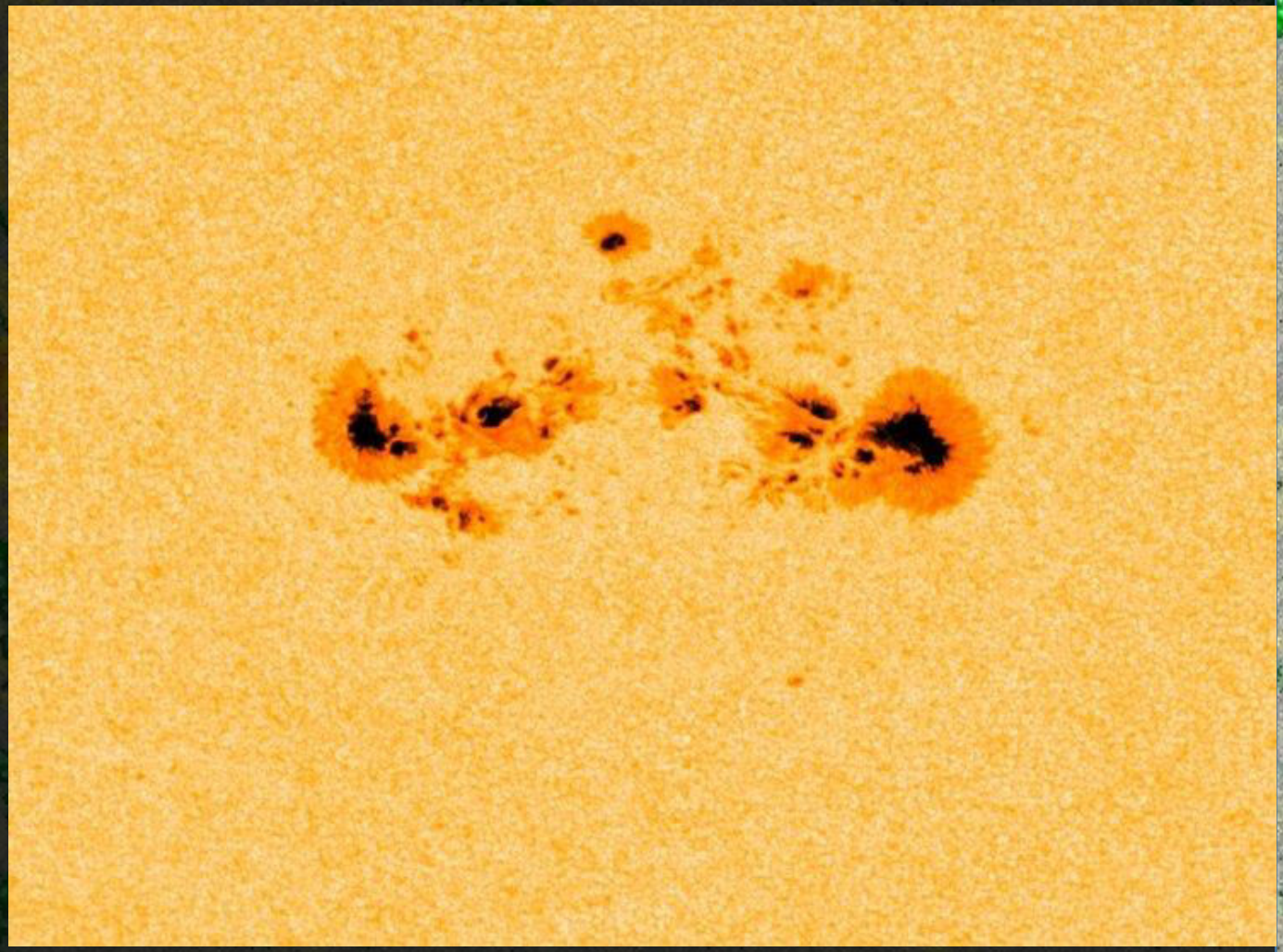
The Fractal Analysis of Sunspot Magnetograms

Brandon Rajkumar

Supervisor: Dr. Shirin Haque

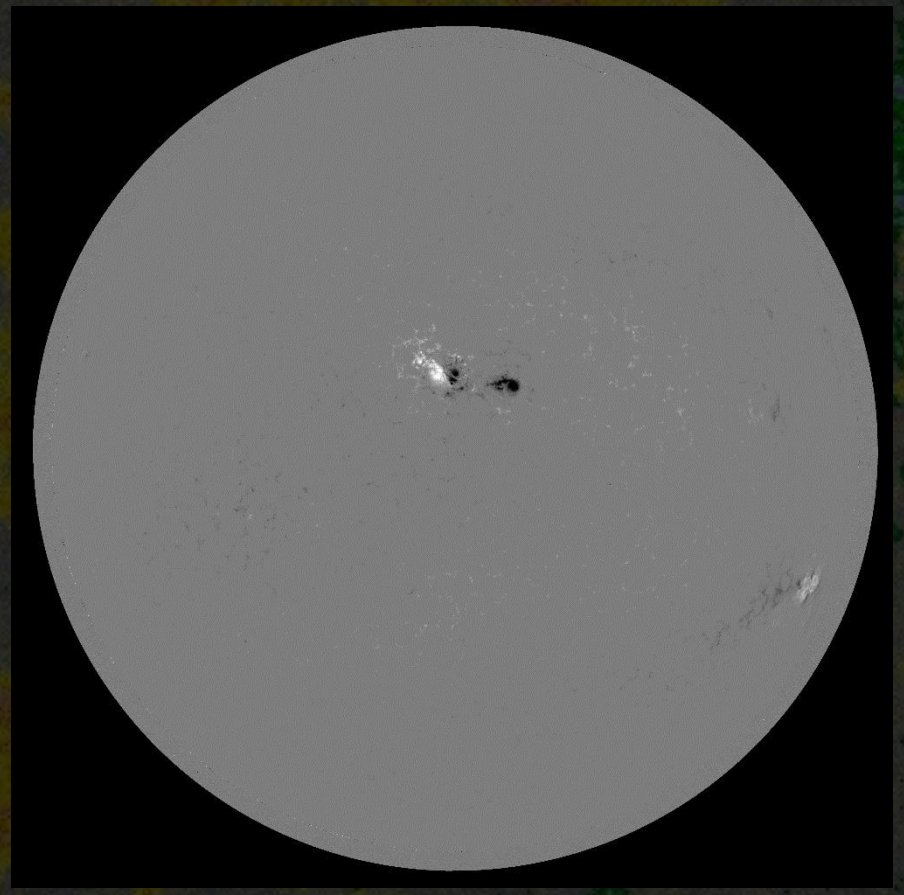
Introduction

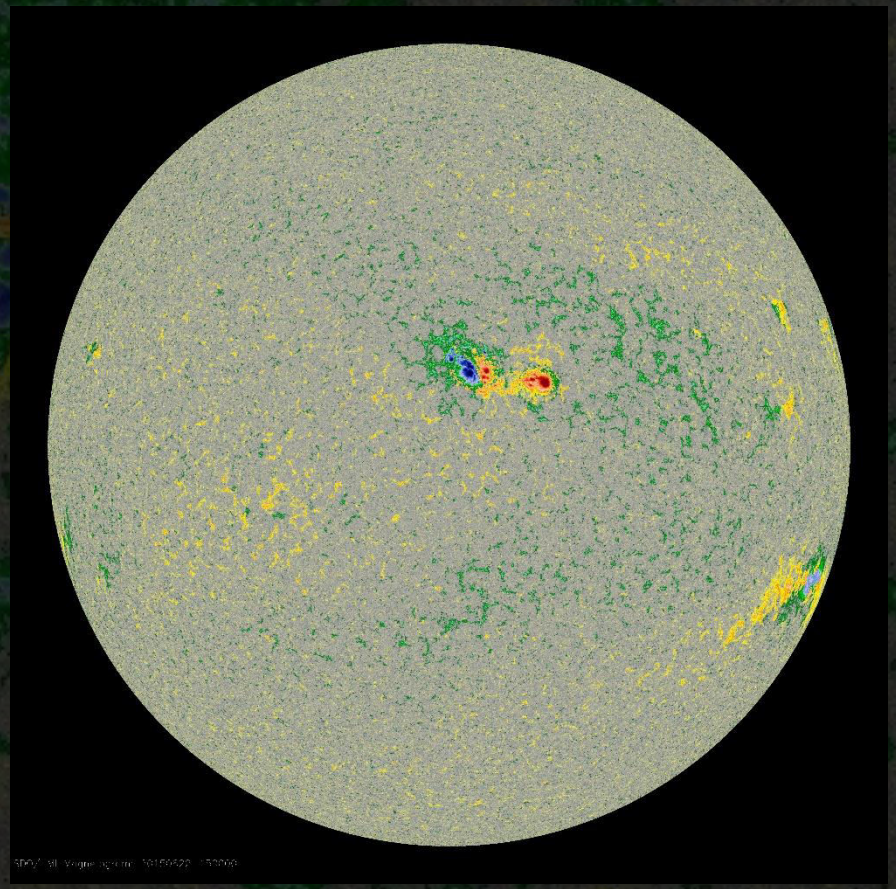
- What are sunspots?
- Why do we study sunspots?



Introduction

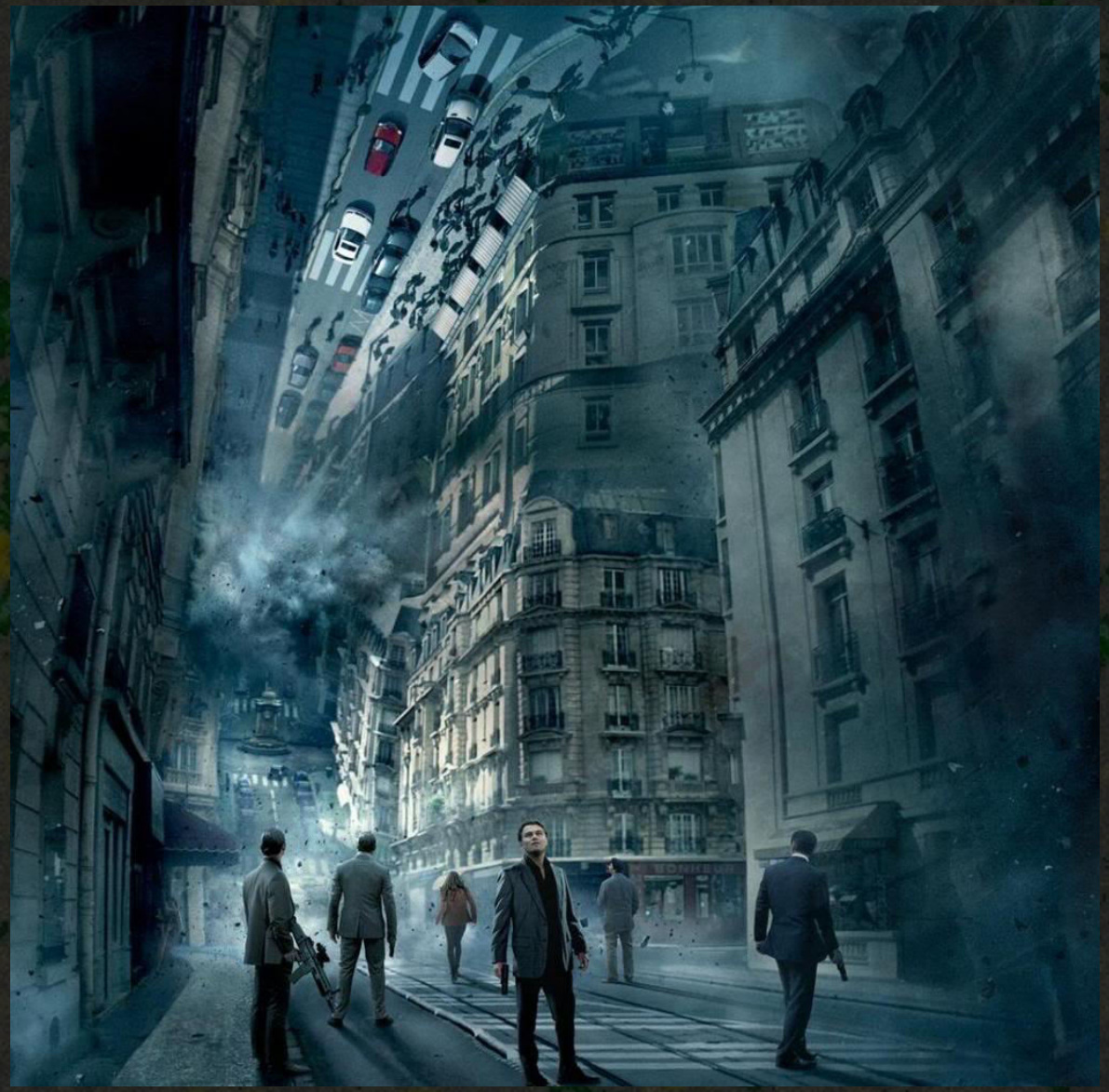
- What are magnetograms?





Introduction

- What are Fractals?
- Why use fractals to analyse sunspots?



Introduction (Summary of Previous Work – Fractal Dimensions of Umbral and Penumbral Regions of Sunspots – Rajkumar, Haque, Hrudey 2017)

- Using images of 16 AR taken at the Dr. Wm. Hrudey Observatory, an analysis was done to determine the fractal dimensions of sunspot umbra and penumbra.
- The results gave
  - Umbra fractal dimension = 2.09 ± 0.42
  - Penumbra fractal dimension = 1.72 ± 0.40

Introduction (Summary of Previous Work)

- Comparison to "Limits of the Fractal Dimension for Irreversible Kinetic Aggregation of Gold Colloids" – (Weitz et al. 1985) formed a good analogy since
  - The larger clusters formed by diffusion limited kinetics gave a fractal dimension of 1.77 ± 0.05 for $E << kT$ similar to the larger penumbra region which had fractal dimensions of 1.72 ± 0.40
  - While reaction limited kinetics produced smaller clusters with a fractal dimension of 2.01 ± 0.05 for $E \geq kT$ analogous to the smaller umbra region which had a fractal dimension of 2.09 ± 0.42

Introduction (Summary of Previous Work)

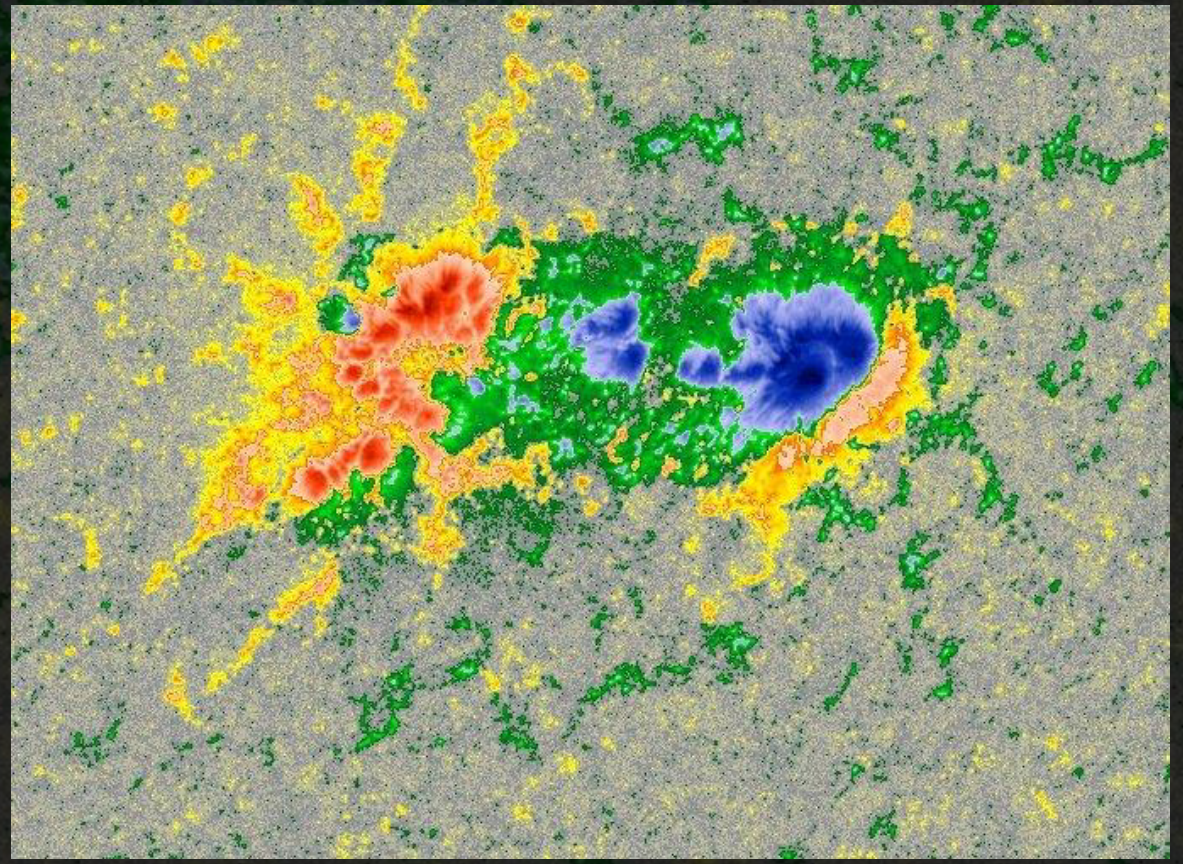
- Together with a recent model of sunspot formation by Jaeggli, Lin, and Uitenbroek 2012 which suggests that ionised hydrogen becomes molecular hydrogen due to the reduced temperature in sunspots.
- It is proposed that the kinetic dynamics in a gold colloid system may be used to model the similar process of compressible flow in sunspots because of their similar geometrical structures.

Aims

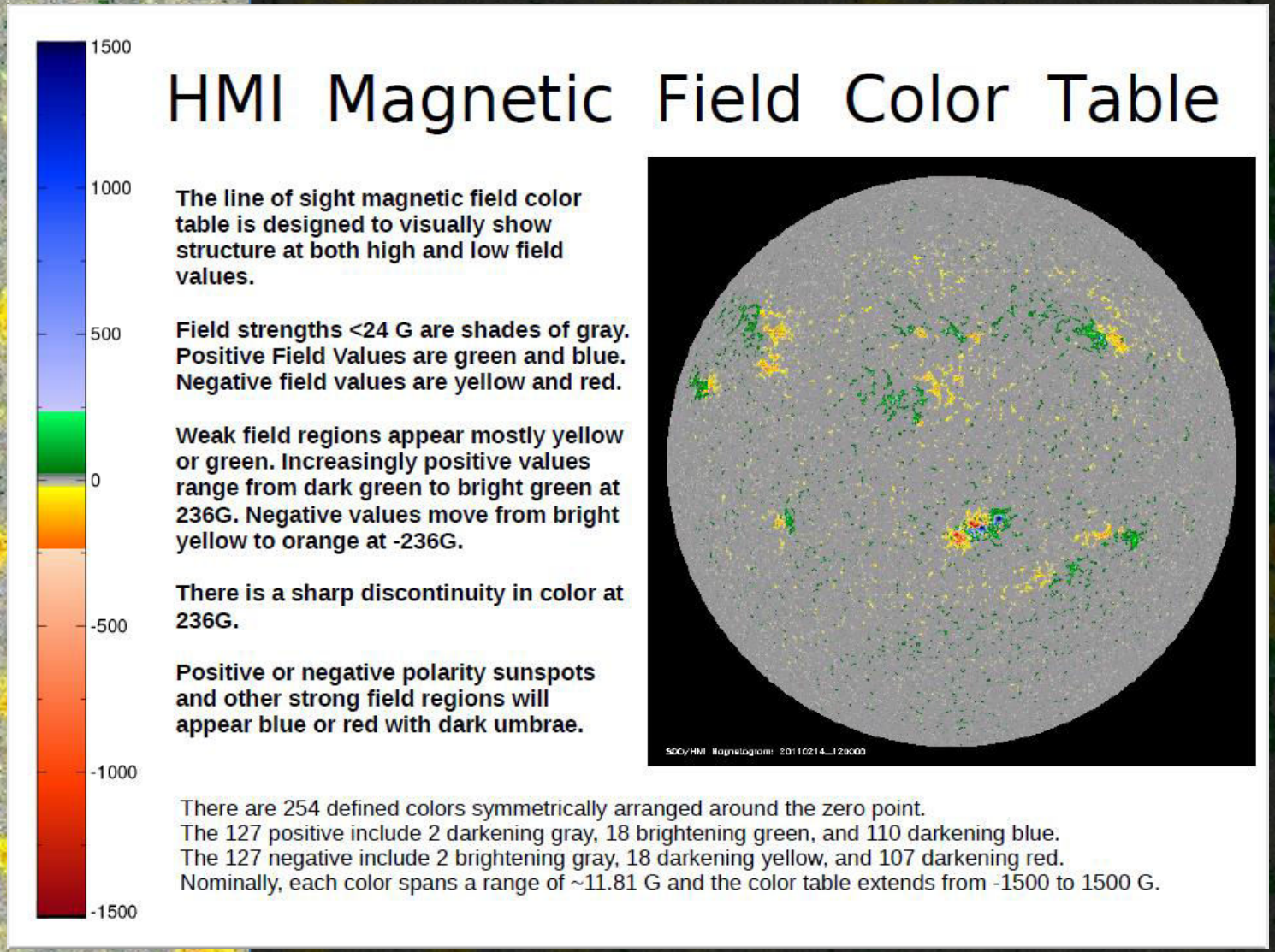
- This study seeks to determine the fractal dimensions of the magnetic structure in active regions using the area-perimeter method and to determine the magnetic structure distribution within an active region.

Method

- 16 colour magnetograms and flattened intensity images containing the AR's used by Rajkumar, Haque and Hrudey(2017) were obtained from the Joint Science Operations Centre (JSOC).
- The images were then overlaid and the 16 AR were isolated and cropped.



Method



Using the HMI Magnetic Field Colour Table, the magnetic fields in each AR were separated into 4 magnetic groups :-

- Weak positive fields (24 to 236 G) – green
- Weak negative fields (-24 to -236 G) – yellow/orange
- Strong positive fields (237 to 1500 G) – blue
- Strong negative fields (-237 to -1500 G) – red

Method

- The area and perimeter of each threshold group was then measured using the ImageJ software and the fractal dimension determined using the analysis below.

Note: The magnetic structure was also separated, measured and analysed for strong and weak fields.

- To quantify the distribution of the magnetic field contained within the umbra and penumbra, each active region was overlaid with the magnetogram and the umbra/penumbra area percentages calculated.

Analysis

The area, S, is related to the perimeter, L, as shown:

$$S \sim L^q --Eqn\ 1$$

From Eqn 1, we see:

$$q = \frac{Log\ S}{Log\ L} --Eqn\ 2$$

Therefore, q can be determined via linear regression analysis of Log S and Log L. q is related to the fractal dimension, d, by:

$$d = \frac{2}{q} --Eqn\ 3$$

Analysis

Umbra area percentage,

$$UArea\% = \frac{Mag\ Area}{Umbra\ Area} --Eqn4$$

Penumbra area percentage,

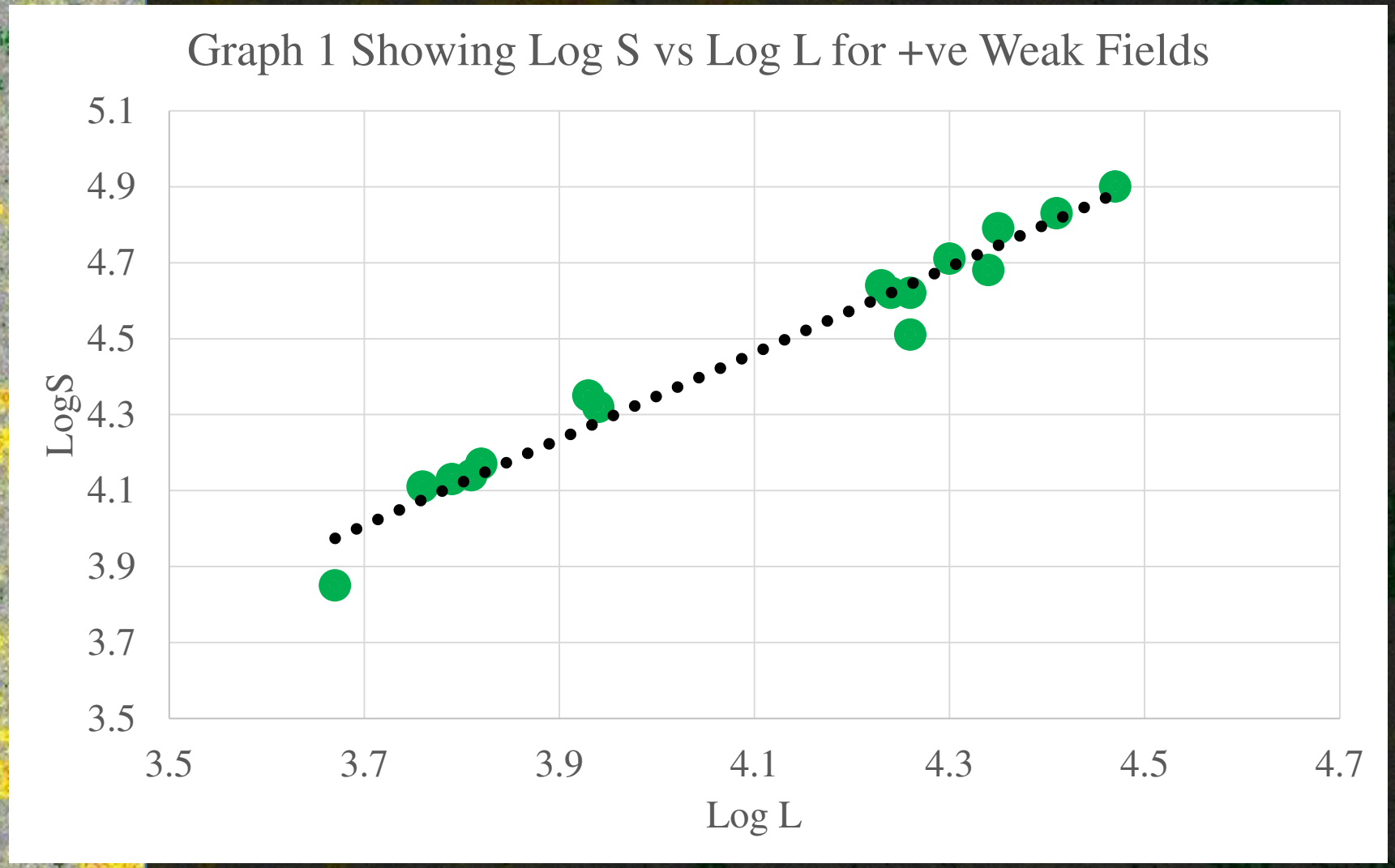
$$PArea\% = \frac{Mag\ Area}{Penumbra\ Area} --Eqn5$$

Where “Mag Area” = the area of any magnetic region.

Results

AR #	Date	Time (UTC)	Heliographic Latitude	+ve Weak Fields (green)			
				Area-S (pixels)	Perimeter-L (pixels)	log S	log L
12367	16/06/2015	18:00:00	-20.15	51823	20158.06	4.71	4.30
12371	22/06/2015	15:00:00	12.16	67046	25681.37	4.83	4.41
12373	03/07/2015	17:15:00	16.30	7109	4716.84	3.85	3.67
12381	10/07/2015	15:00:00	13.51	42131	18404.34	4.62	4.26
12384	14/07/2015	15:30:00	-18.38	22348	8428.13	4.35	3.93
12386	20/07/2015	14:45:00	12.09	14733	6567.12	4.17	3.82
12387	20/07/2015	14:45:00	16.48	20989	8734.82	4.32	3.94
12394	06/08/2015	14:00:00	12.38	13501	6186.00	4.13	3.79
12396	10/08/2015	13:30:00	-17.67	41732	17202.73	4.62	4.24
12400	14/08/2015	14:15:00	17.21	12858	5754.15	4.11	3.76
12401	18/08/2015	13:30:00	-10.67	13696	6387.01	4.14	3.81
12403	22/08/2015	13:15:00	-15.34	32371	18401.13	4.51	4.26
12418	20/09/2015	15:30:00	-15.54	47869	21828.56	4.68	4.34
12434	18/10/2015	15:15:00	-9.87	43556	17015.51	4.64	4.23
12436	23/10/2015	15:30:00	8.74	61579	22245.91	4.79	4.35
12443	03/11/2015	15:00:00	6.60	78911	29495.76	4.90	4.47

Results



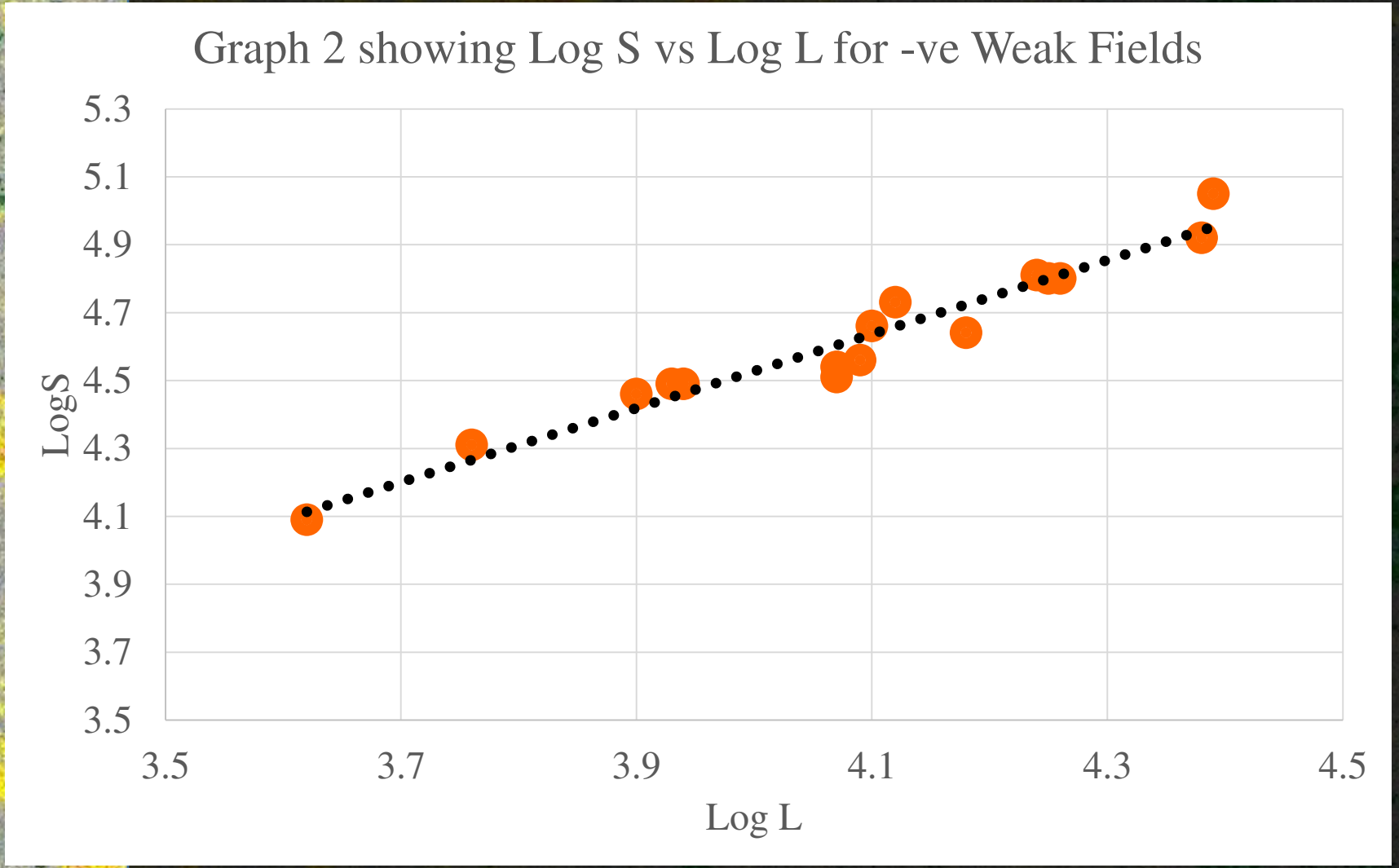
$q = 1.13 \pm 0.13$

$d = 1.77 \pm 0.20$

Results

AR #	Date	Time (UTC)	Heliographic Latitude	- ve Weak Fields (orange/yellow)			
				Area-S (pixels)	Perimeter-L (pixels)	log S	log L
12367	16/06/2015	18:00:00	-20.15	65110	17270.78	4.81	4.24
12371	22/06/2015	15:00:00	12.16	43974	15289.03	4.64	4.18
12373	03/07/2015	17:15:00	16.30	112287	24551.53	5.05	4.39
12381	10/07/2015	15:00:00	13.51	32090	11779.77	4.51	4.07
12384	14/07/2015	15:30:00	-18.38	12203	4137.06	4.09	3.62
12386	20/07/2015	14:45:00	12.09	28888	7875.55	4.46	3.90
12387	20/07/2015	14:45:00	16.48	53098	13332.76	4.73	4.12
12394	06/08/2015	14:00:00	12.38	20575	5771.12	4.31	3.76
12396	10/08/2015	13:30:00	-17.67	34709	11655.08	4.54	4.07
12400	14/08/2015	14:15:00	17.21	30674	8548.47	4.49	3.93
12401	18/08/2015	13:30:00	-10.67	30929	8715.56	4.49	3.94
12403	22/08/2015	13:15:00	-15.34	83362	23908.05	4.92	4.38
12418	20/09/2015	15:30:00	-15.54	45530	12733.99	4.66	4.10
12434	18/10/2015	15:15:00	-9.87	36185	12198.12	4.56	4.09
12436	23/10/2015	15:30:00	8.74	63691	17658.91	4.80	4.25
12443	03/11/2015	15:00:00	6.60	62544	18051.08	4.80	4.26

Results



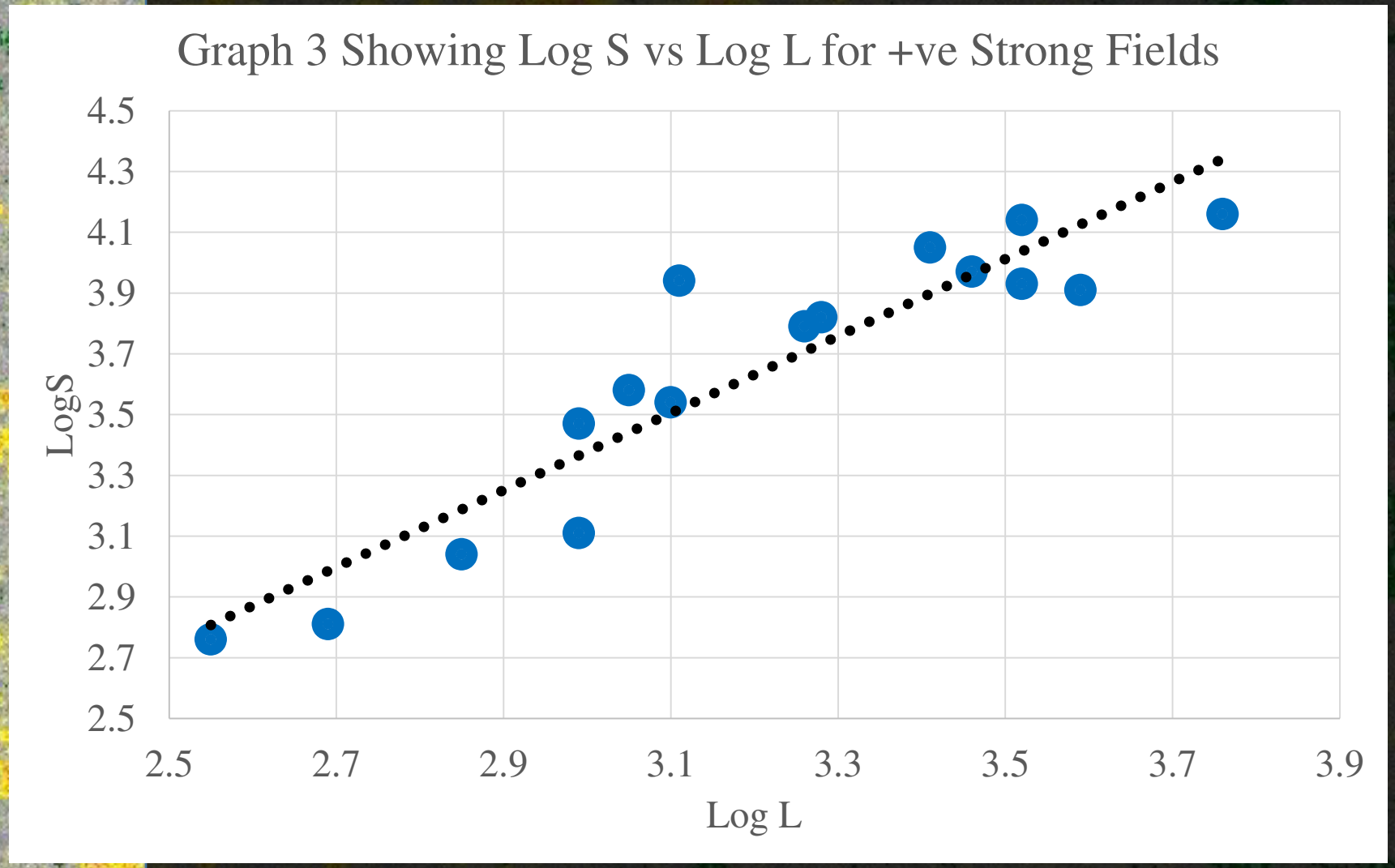
$q = 1.09 \pm 0.15$

$d = 1.83 \pm 0.25$

Results

AR #	Date	Time (UTC)	Heliographic Latitude	+ve Strong Fields (blue)			
				Area-S (pixels)	Perimeter-L (pixels)	log S	log L
12367	16/06/2015	18:00:00	-20.15	9387	2914.67	3.97	3.46
12371	22/06/2015	15:00:00	12.16	13775	3324.23	4.14	3.52
12373	03/07/2015	17:15:00	16.30	574	352.20	2.76	2.55
12381	10/07/2015	15:00:00	13.51	6591	1916.59	3.82	3.28
12384	14/07/2015	15:30:00	-18.38	3452	1245.06	3.54	3.10
12386	20/07/2015	14:45:00	12.09	3840	1113.70	3.58	3.05
12387	20/07/2015	14:45:00	16.48	1289	980.25	3.11	2.99
12394	06/08/2015	14:00:00	12.38	643	491.75	2.81	2.69
12396	10/08/2015	13:30:00	-17.67	8712	1291.35	3.94	3.11
12400	14/08/2015	14:15:00	17.21	1094	703.92	3.04	2.85
12401	18/08/2015	13:30:00	-10.67	2953	986.94	3.47	2.99
12403	22/08/2015	13:15:00	-15.34	11335	2543.56	4.05	3.41
12418	20/09/2015	15:30:00	-15.54	6097	1807.02	3.79	3.26
12434	18/10/2015	15:15:00	-9.87	8596	3279.80	3.93	3.52
12436	23/10/2015	15:30:00	8.74	8072	3899.07	3.91	3.59
12443	03/11/2015	15:00:00	6.60	14407	5717.53	4.16	3.76

Results



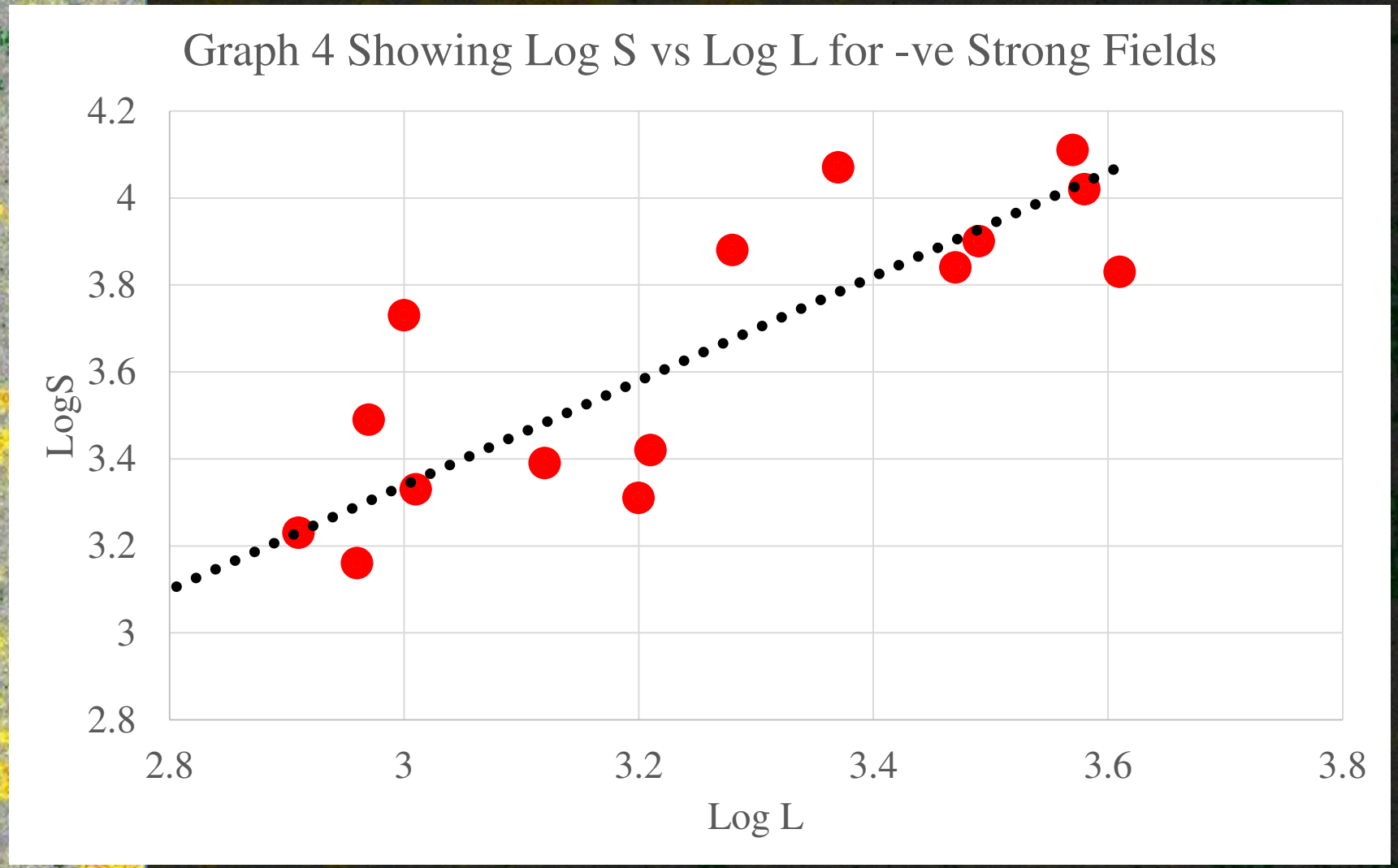
$q = 1.27 \pm 0.30$

$d = 1.57 \pm 0.37$

Results

AR #	Date	Time (UTC)	Heliographic Latitude	-ve Strong Fields (red)			
				Area-S (pixels)	Perimeter-L (pixels)	log S	log L
12367	16/06/2015	18:00:00	-20.15	6891	2944.64	3.84	3.47
12371	22/06/2015	15:00:00	12.16	11827	2366.80	4.07	3.37
12373	03/07/2015	17:15:00	16.30	6797	4054.84	3.83	3.61
12381	10/07/2015	15:00:00	13.51	5400	999.25	3.73	3.00
12384	14/07/2015	15:30:00	-18.38	203	172.55	2.31	2.24
12386	20/07/2015	14:45:00	12.09	1695	820.60	3.23	2.91
12387	20/07/2015	14:45:00	16.48	2648	1624.98	3.42	3.21
12394	06/08/2015	14:00:00	12.38	3075	941.63	3.49	2.97
12396	10/08/2015	13:30:00	-17.67	7657	1926.85	3.88	3.28
12400	14/08/2015	14:15:00	17.21	2126	1017.67	3.33	3.01
12401	18/08/2015	13:30:00	-10.67	1459	907.10	3.16	2.96
12403	22/08/2015	13:15:00	-15.34	10559	3770.22	4.02	3.58
12418	20/09/2015	15:30:00	-15.54	2064	1585.32	3.31	3.20
12434	18/10/2015	15:15:00	-9.87	2472	1307.86	3.39	3.12
12436	23/10/2015	15:30:00	8.74	7858	3117.61	3.90	3.49
12443	03/11/2015	15:00:00	6.60	12783	3753.78	4.11	3.57

Results



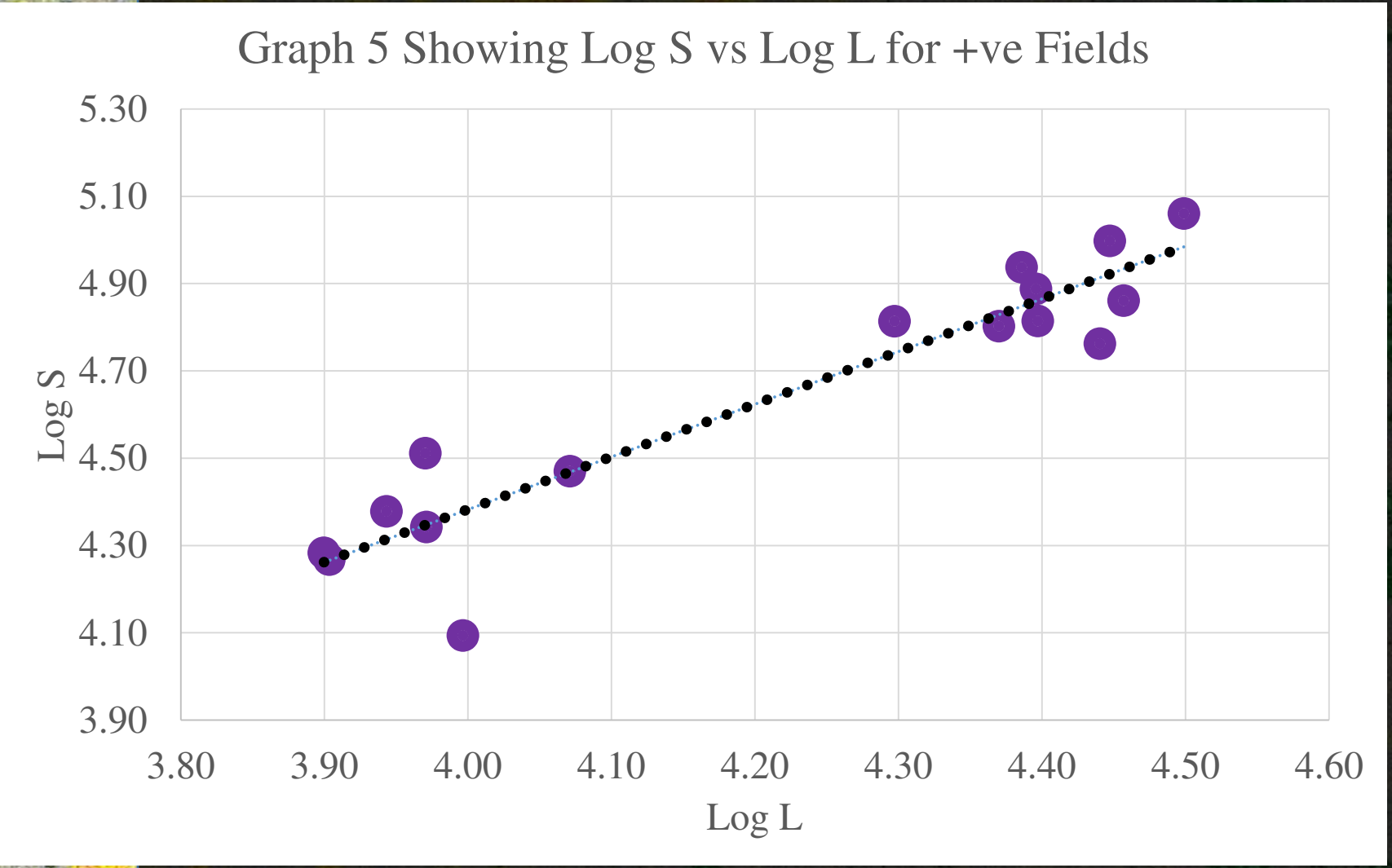
$q = 1.20 \pm 0.30$

$d = 1.67 \pm 0.42$

Results

AR #	Date	Time (UTC)	Heliographic Latitude	+ve Fields (blue + green)			
				Area-S (pixels)	Perimeter-L (pixels)	log S	log L
12367	16/06/2015	18:00:00	-20.15	61210	23072.72	4.89	4.40
12371	22/06/2015	15:00:00	12.16	80821	29005.61	5.00	4.45
12373	03/07/2015	17:15:00	16.30	7683	5069.04	4.09	4.00
12381	10/07/2015	15:00:00	13.51	48722	20320.93	4.80	4.37
12384	14/07/2015	15:30:00	-18.38	25800	9673.18	4.51	3.97
12386	20/07/2015	14:45:00	12.09	18573	7680.83	4.38	3.94
12387	20/07/2015	14:45:00	16.48	22278	9715.07	4.47	4.07
12394	06/08/2015	14:00:00	12.38	14144	6677.75	4.28	3.90
12396	10/08/2015	13:30:00	-17.67	50444	18494.08	4.81	4.40
12400	14/08/2015	14:15:00	17.21	13952	6458.07	4.27	3.90
12401	18/08/2015	13:30:00	-10.67	16649	7373.95	4.34	3.97
12403	22/08/2015	13:15:00	-15.34	43706	20944.69	4.76	4.44
12418	20/09/2015	15:30:00	-15.54	53966	23635.58	4.86	4.46
12434	18/10/2015	15:15:00	-9.87	52152	20295.31	4.81	4.30
12436	23/10/2015	15:30:00	8.74	69651	26144.98	4.94	4.39
12443	03/11/2015	15:00:00	6.60	93318	35213.29	5.06	4.50

Results



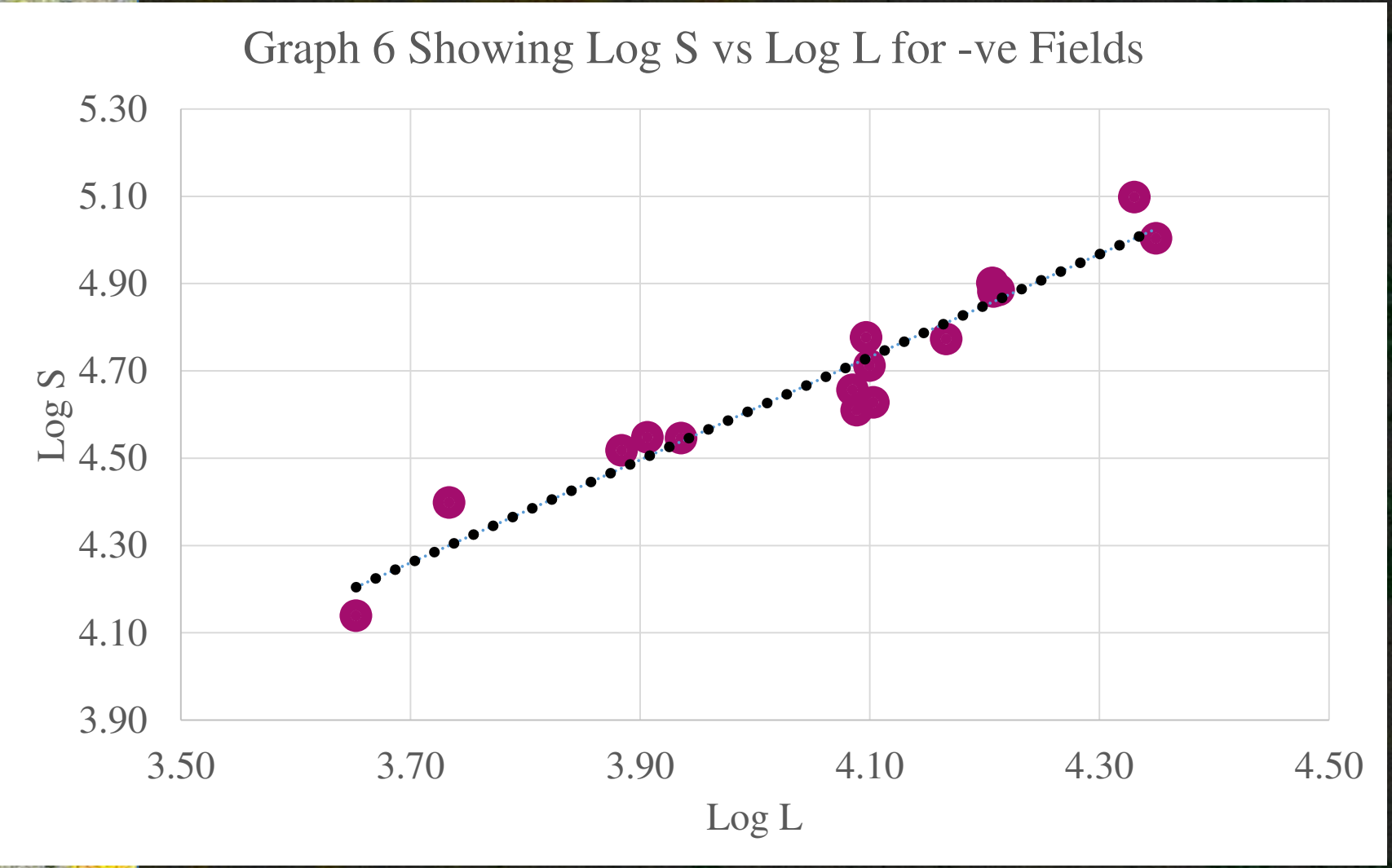
$q = 1.21 \pm 0.26$

$d = 1.65 \pm 0.36$

Results

AR #	Date	Time (UTC)	Heliographic Latitude	-ve Fields (red + orange/yellow)			
				Area-S (pixels)	Perimeter-L (pixels)	log S	log L
12367	16/06/2015	18:00:00	-20.15	72001	20215.42	4.88	4.21
12371	22/06/2015	15:00:00	12.16	55801	17655.83	4.77	4.17
12373	03/07/2015	17:15:00	16.30	119084	28606.36	5.10	4.33
12381	10/07/2015	15:00:00	13.51	37490	12779.02	4.61	4.09
12384	14/07/2015	15:30:00	-18.38	12406	4309.61	4.14	3.65
12386	20/07/2015	14:45:00	12.09	30583	8696.16	4.52	3.88
12387	20/07/2015	14:45:00	16.48	55746	14957.74	4.78	4.10
12394	06/08/2015	14:00:00	12.38	23650	6712.74	4.40	3.73
12396	10/08/2015	13:30:00	-17.67	42366	13581.93	4.66	4.09
12400	14/08/2015	14:15:00	17.21	32800	9566.14	4.55	3.91
12401	18/08/2015	13:30:00	-10.67	32388	9622.67	4.55	3.94
12403	22/08/2015	13:15:00	-15.34	93921	27678.27	5.00	4.35
12418	20/09/2015	15:30:00	-15.54	47594	14319.31	4.71	4.10
12434	18/10/2015	15:15:00	-9.87	38657	13505.98	4.63	4.10
12436	23/10/2015	15:30:00	8.74	71549	20776.52	4.88	4.21
12443	03/11/2015	15:00:00	6.60	75327	21804.86	4.90	4.21

Results



$q = 1.18 \pm 0.19$

$d = 1.69 \pm 0.27$

Results

- Summary of Results

Magnetic field	Fractal dimension
Strong +ve	1.57 ± 0.30
Weak +ve	1.77 ± 0.20
+ve	1.65 ± 0.36
Strong –ve	1.67 ± 0.42
Weak –ve	1.83 ± 0.25
-ve	1.69 ± 0.27

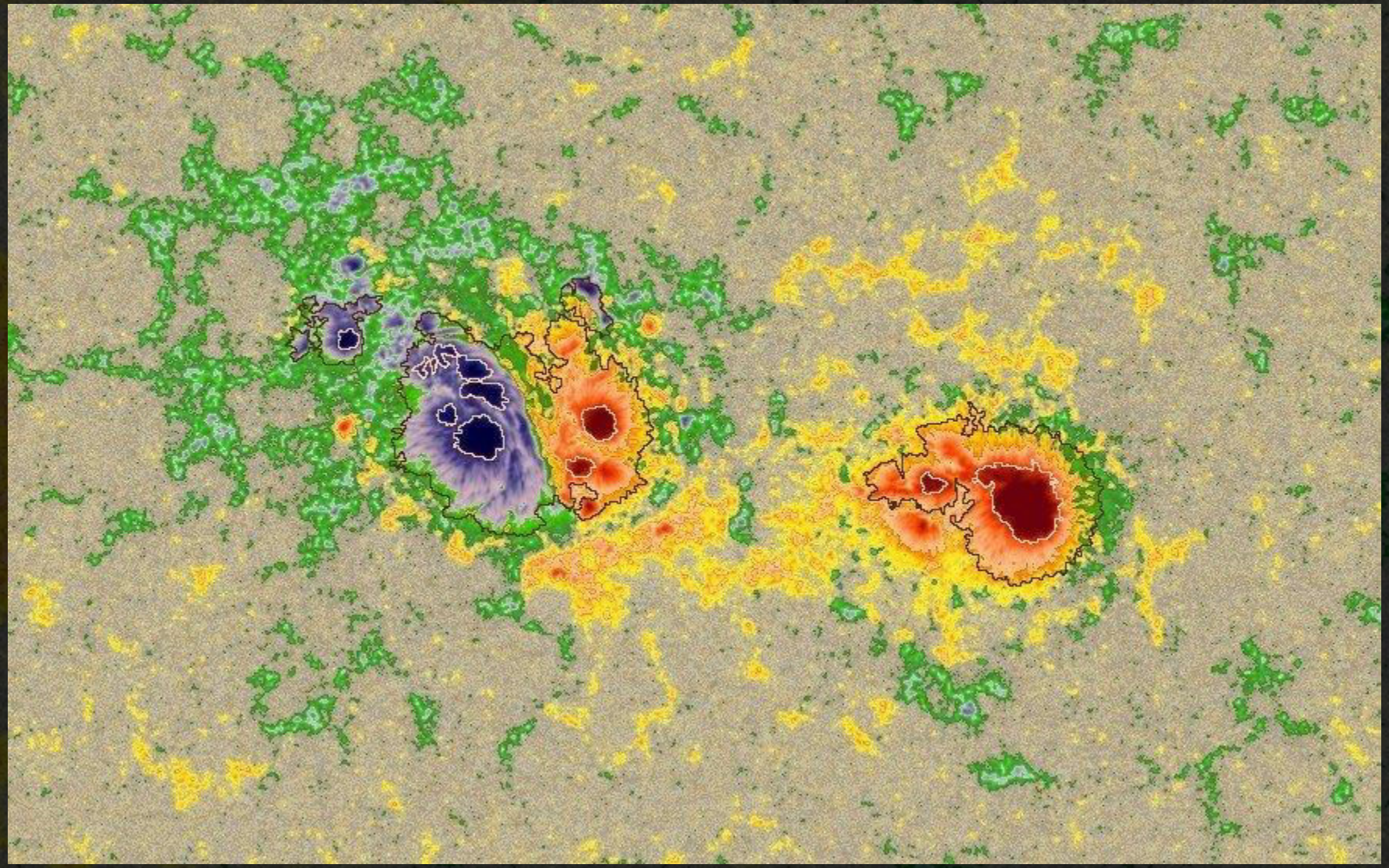
Results

AR #	Umbra Area	Area %			
		+ve Weak Fields (green)	-ve Weak Fields (orange/yellow)	+ve Strong Fields (blue)	-ve Strong Fields (red)
12367	1221	0.0%	0.0%	68.9%	31.0%
12371	4153	0.0%	0.0%	39.8%	60.7%
12373	520	0.0%	0.0%	0.0%	100.2%
12381	1925	0.0%	0.0%	26.8%	74.1%
12384	383	0.0%	0.0%	100.0%	0.0%
12386	250	0.0%	0.0%	0.0%	100.0%
12387	404	0.0%	0.0%	33.9%	66.1%
12394	525	0.0%	0.0%	0.0%	99.6%
12396	1815	0.0%	0.0%	75.0%	26.1%
12400	134	0.0%	0.0%	0.0%	100.7%
12401	37	0.0%	0.0%	100.0%	0.0%
12403	2351	0.0%	0.0%	59.3%	41.2%
12418	1060	0.0%	0.0%	100.2%	0.0%
12434	775	0.0%	0.0%	100.0%	0.0%
12436	764	0.0%	0.0%	0.0%	100.3%
12443	1954	0.0%	0.0%	5.9%	95.5%

Results

AR #	Umbra Area	Area %			
		+ve Weak Fields (green)	-ve Weak Fields (orange/yellow)	+ve Strong Fields (blue)	-ve Strong Fields (red)
12367	8907	14.9%	13.8%	42.0%	25.8%
12371	27887	12.7%	19.3%	32.6%	33.4%
12373	3111	1.1%	32.3%	0.0%	64.1%
12381	10413	15.8%	13.9%	25.8%	41.5%
12384	2140	25.5%	6.8%	64.4%	0.0%
12386	1256	6.9%	24.7%	0.0%	63.1%
12387	1288	5.4%	6.9%	47.7%	35.5%
12394	3864	9.5%	30.2%	0.0%	57.5%
12396	13700	12.3%	11.3%	45.3%	26.9%
12400	672	0.0%	2.4%	0.0%	97.5%
12401	881	0.0%	0.0%	99.2%	0.0%
12403	27506	17.4%	22.0%	30.1%	25.4%
12418	5752	19.5%	15.7%	67.4%	0.0%
12434	5847	19.7%	12.4%	53.7%	10.2%
12436	5647	0.7%	33.6%	0.0%	63.0%
12443	14598	5.2%	27.2%	7.7%	54.2%

Results



Results

Discussion – What does this mean?

- Umbral regions are dominated by strong magnetic fields with low fractal dimensions. These describe low complexity and high stability.

- Weak magnetic fields which occur in the penumbral regions are associated with increased complexity and lower stability which is reflected by higher fractal dimensions.

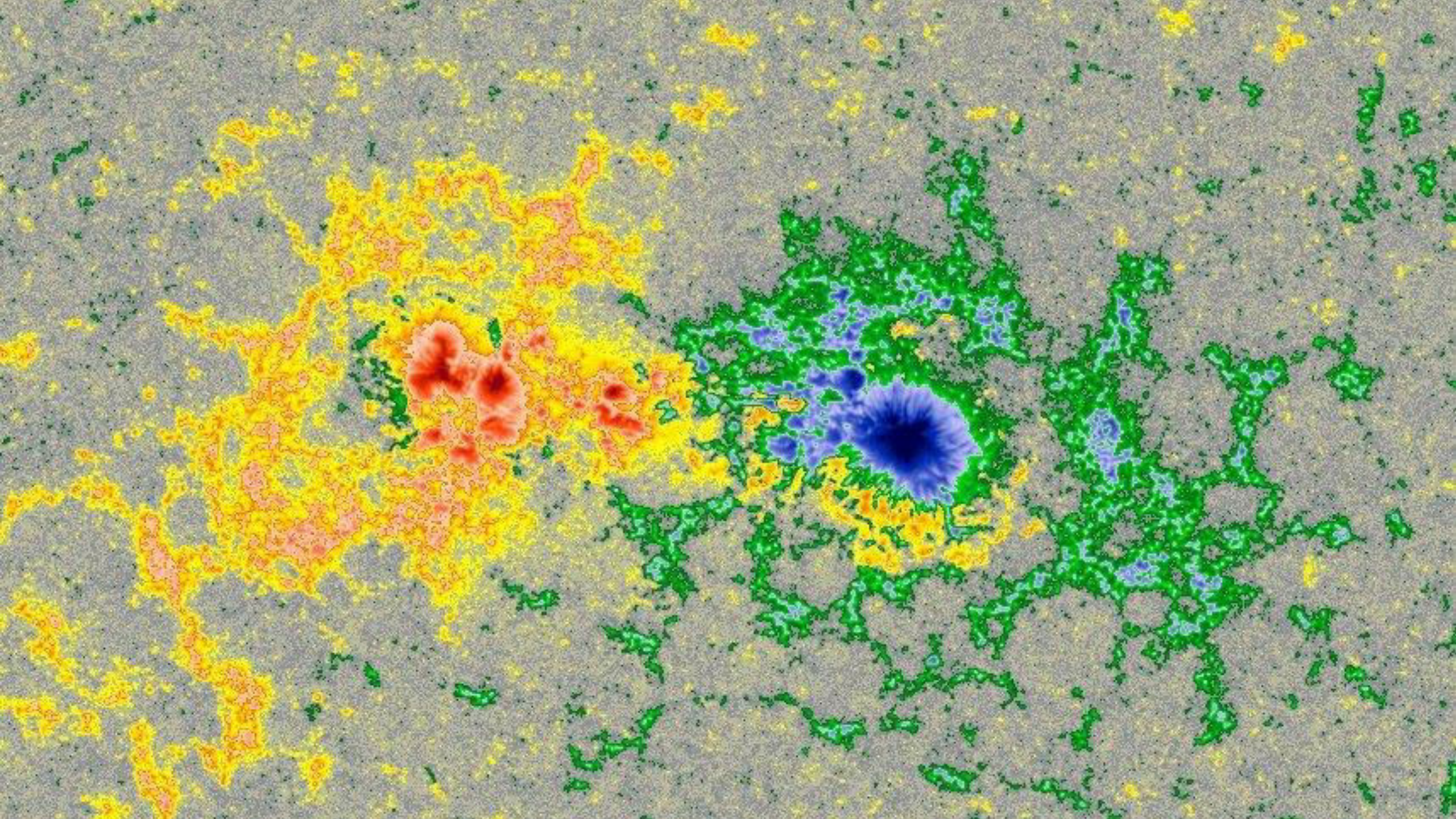
Discussion

- Compared to the fractal dimensions for the penumbra (1.72) and umbra (2.09) measured by Rajkumar, Haque and Hrudey (2017), it is found that while the magnetic structure within the umbra exhibits lower complexity than the penumbra, the umbra itself has a higher fractal dimension than the penumbra.
- This indicates that more complex magnetic fields produce active regions with greater stability.

Conclusion

- Sunspot's umbrae are dominated by strong magnetic fields with fractal dimensions of 1.57 ±0.37 for +ve fields and 1.67 ±0.42 for –ve fields which indicate the presence of more stable structures.
- •Penumbral regions of sunspots, while dominated by strong magnetic fields, contain weak magnetic fields which contribute to more unstable structures indicated by higher fractal dimensions of 1.77 ±0.20 for +ve fields and 1.83 ±0.25 for –ve fields.
- •Comparing to Rajkumar, Haque and Hrudey(2017), it is suggested that an increase in complexity of magnetic structures can lead to an increase in stability of active regions.

Questions?



Comparison

Magnetic field	Fractal dimension
Strong +ve	1.57 ± 0.30
Weak +ve	1.77 ± 0.20
+ve	1.65 ± 0.36
Strong –ve	1.67 ± 0.42
Weak –ve	1.83 ± 0.25
-ve	1.69 ± 0.27
Umbra	2.09
Penumbra	1.72