

SAR, 2. 11. 2019.

**Potruga za najjačim magnetnim poljima
na površini Sunca u posmatranjima
sa HINODE SOT/SP"**

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Super-strong Magnetic Field in Sunspots

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Abstract

Sunspots are the most notable structure on the solar surface with strong magnetic fields. The field is generally strongest in a dark area (umbra), but sometimes stronger fields are found in non-dark regions, such as a penumbra and a light bridge. The formation mechanism of such strong fields outside umbrae is still puzzling. Here we report clear evidence of the magnetic field of 6250 G, which is the strongest field among Stokes I profiles with clear Zeeman splitting ever observed on the Sun. The field was almost parallel to the solar surface and located in a bright region sandwiched by two opposite-polarity umbrae. Using a time series of spectral data sets, we discuss the formation process of the super-strong field and suggest that this strong field region was generated as a result of compression of one umbra pushed by the horizontal flow from the other umbra, such as the subduction of the Earth's crust in plate tectonics.

Key words: Sun: magnetic fields – Sun: photosphere – sunspots

1. Introduction

Sunspots are concentrations of magnetic fields on the solar surface. Their strong magnetic field controls the physical conditions in and around sunspots and produces various kinds of structures. For example, a sunspot usually consists of the umbra with a vertical magnetic field and the penumbra with a

As the strongest magnetic field ever reported, van Noort et al. (2013) showed ~ 7500 G in a sunspot penumbra with the complex inversion technique. Although the proper motion of sunspots or flows in light bridges and penumbrae might contribute to the enhancement of horizontal fields, there is no convincing explanation about the formation mechanism of these strong fields. The origin and behavior of strong fields are

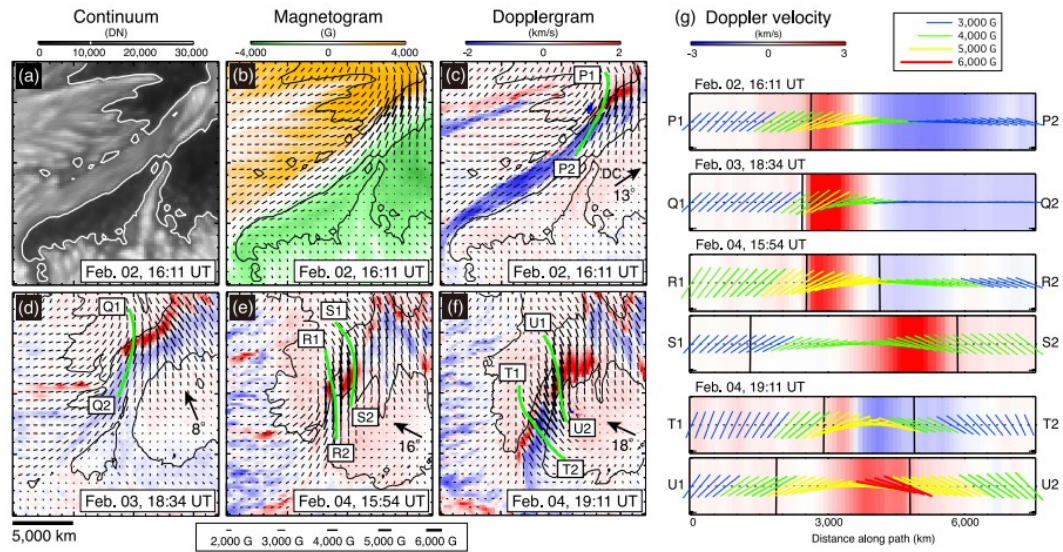
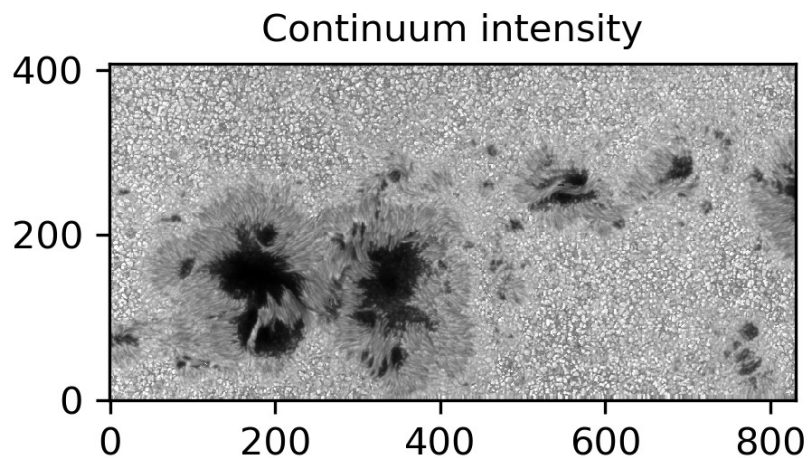


Figure 3. Vector magnetic fields and Doppler velocities in the sunspot region. (a) A continuum map. The white contours indicate the boundary of the umbrae. The same contours are also drawn in black in (b) and (c). (b) A vector magnetogram. The color background (orange for positive and green for negative polarities) and the black bars show the vertical and the horizontal components of the magnetic field in the solar local frame, respectively. (c)–(f) Time series of Doppler (line-of-sight) velocity maps (blue and red mean velocities toward and away from us). Velocities exceeding $\pm 2 \text{ km s}^{-1}$ are saturated. The black bars are the horizontal magnetic fields as in (b). Panels (a)–(c) correspond to frame 3 of Figure 2, while panels (d)–(f) correspond to frames 5, 7, and 8, respectively. Each panel shows the direction of and the angular distance to the disk center at the center of the field of view. (g) Horizontal profiles of vector magnetic fields and Doppler velocities along the green paths shown in (c)–(f). These green paths are drawn along the horizontal magnetic field vectors. The background color (from blue to red) indicates Doppler velocities.

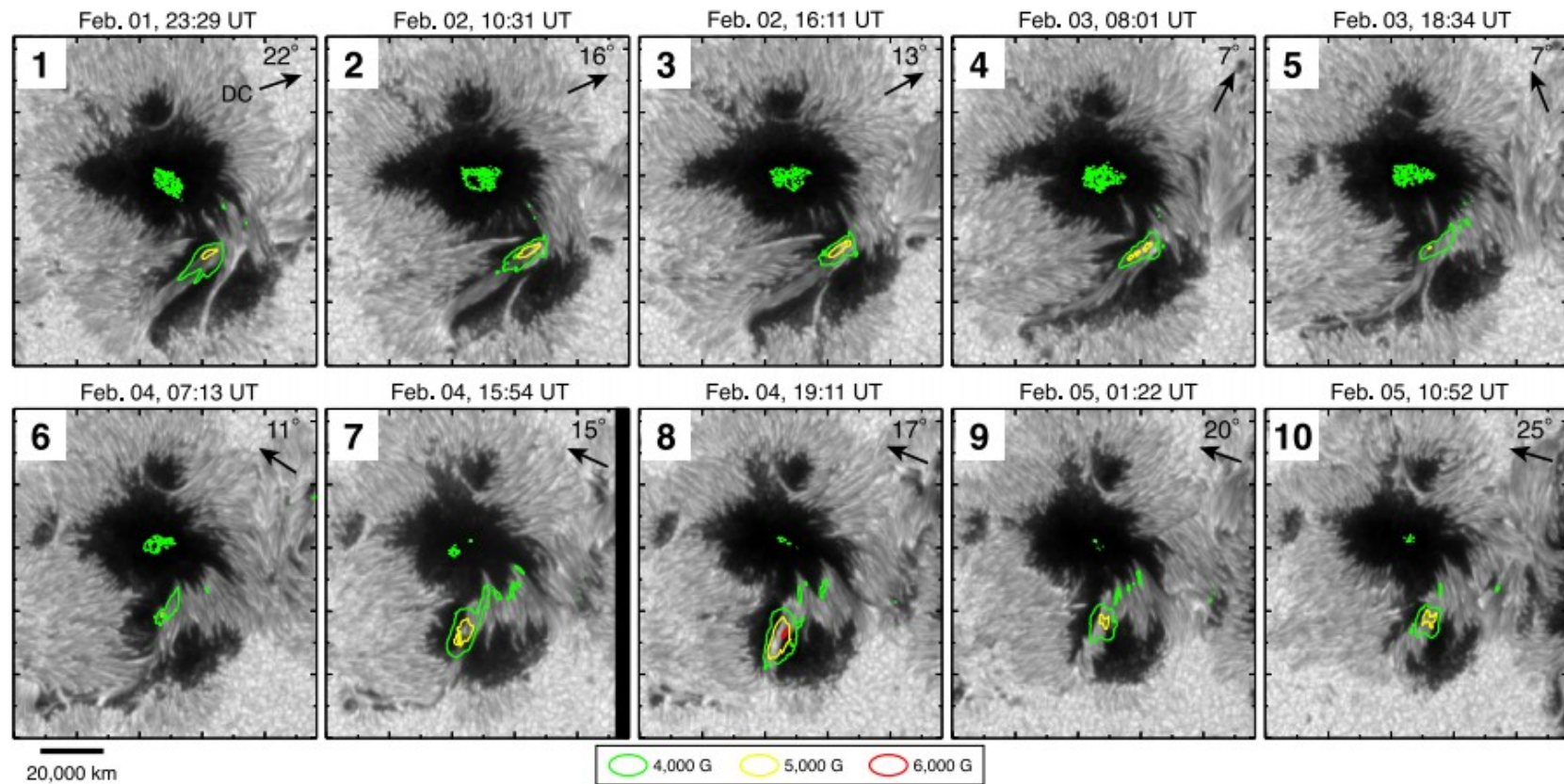


Figure 2. Time series of the continuum images of the sunspot. Contours indicate the magnetic field strength (green, yellow, and red for 4, 5, and 6 kG). Each panel shows the direction of and the angular distance to the disk center at the center of the field of view.

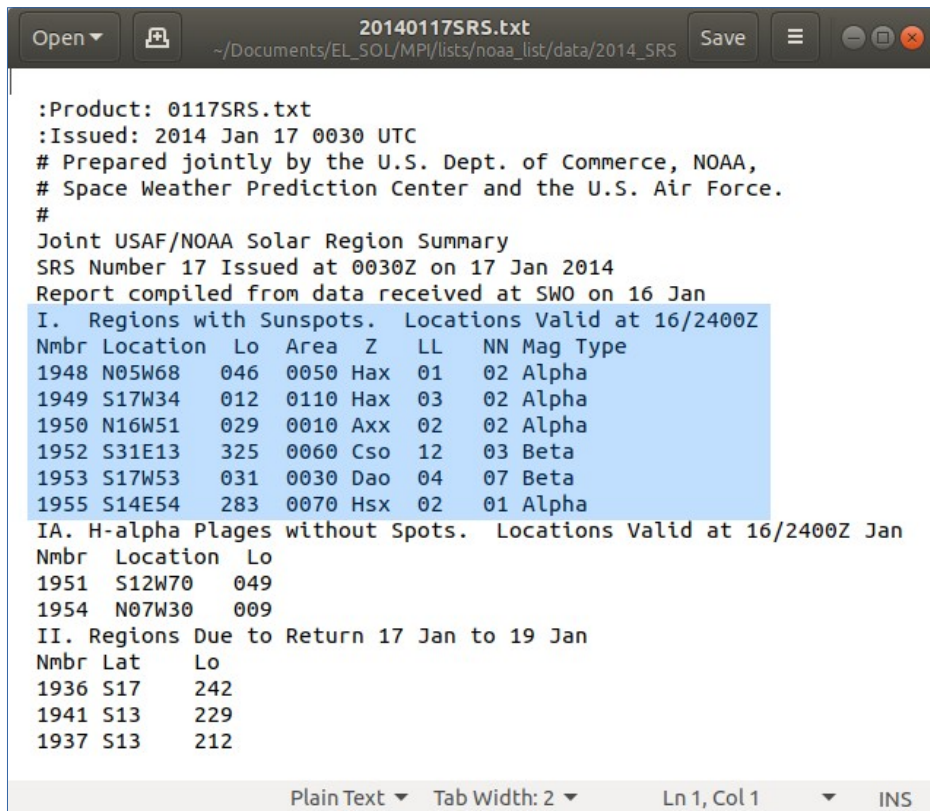
Šta zapravo tražimo?

- Verovatno velike kompleksne aktivne regione (AR) sa pegama
- Verovatno δ -tip pega
- Verovatno AR koji imaju “light bridge”
- Verovatno AR koji imaju jake ponore materije (“downflow”)

- Trebaju nam posmatranja sa Hinode
 - Hinode: rezolucija 0.16" ili 0.32", ali ciljana posmatranja
- Prolazni fenomen, najbolje ako je praćena evolucija

Pa, gde početi?

Nekakva baza pega?



```
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~/Documents/EL_SOL/MPI/lists/noaa_list/data/2014_SRS
Save

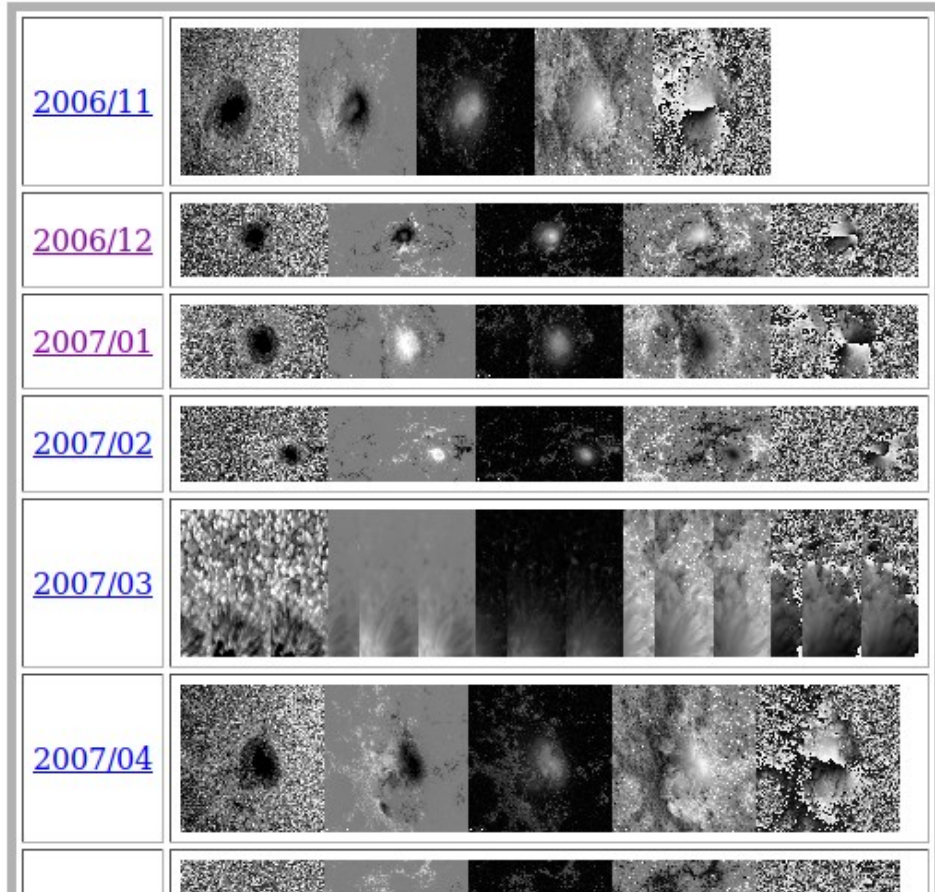
:Product: 0117SRS.txt
:Issued: 2014 Jan 17 0030 UTC
# Prepared jointly by the U.S. Dept. of Commerce, NOAA,
# Space Weather Prediction Center and the U.S. Air Force.
#
Joint USAF/NOAA Solar Region Summary
SRS Number 17 Issued at 0030Z on 17 Jan 2014
Report compiled from data received at SWO on 16 Jan
I. Regions with Sunspots. Locations Valid at 16/2400Z
Nbr Location Lo Area Z LL NN Mag Type
1948 N05W68 046 0050 Hax 01 02 Alpha
1949 S17W34 012 0110 Hax 03 02 Alpha
1950 N16W51 029 0010 Axx 02 02 Alpha
1952 S31E13 325 0060 Cso 12 03 Beta
1953 S17W53 031 0030 Dao 04 07 Beta
1955 S14E54 283 0070 Hsx 02 01 Alpha
IA. H-alpha Plages without Spots. Locations Valid at 16/2400Z Jan
Nbr Location Lo
1951 S12W70 049
1954 N07W30 009
II. Regions Due to Return 17 Jan to 19 Jan
Nbr Lat Lo
1936 S17 242
1941 S13 229
1937 S13 212

Plain Text Tab Width: 2 Ln 1, Col 1 INS
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- NOAA¹ daily reports:
<ftp://ftp.swpc.noaa.gov/pub/warehouse>
 - ▶ Lista svih AR of all ARs with sunspots from 2006 to 2019
- Sortiranje + Helioviewer + strpljenje...
- Koji od tih regiona su zapravo posmatrani sa Hinode?

¹Nacionalna okeanska i atmosferska administracija

Promena plana

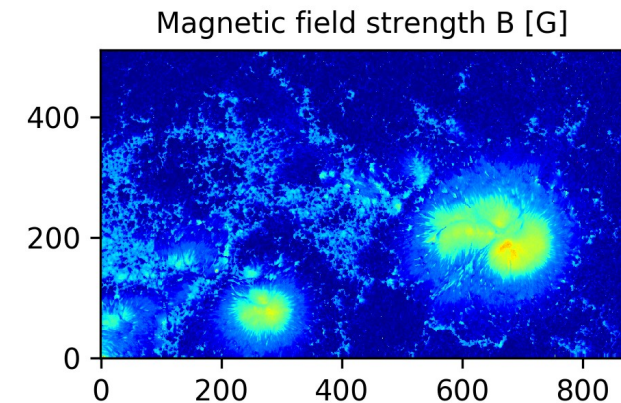
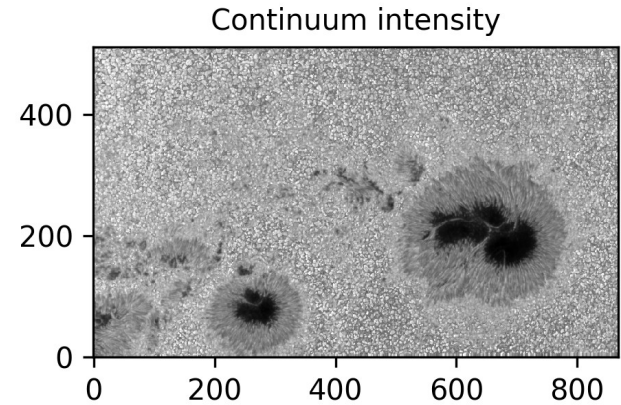
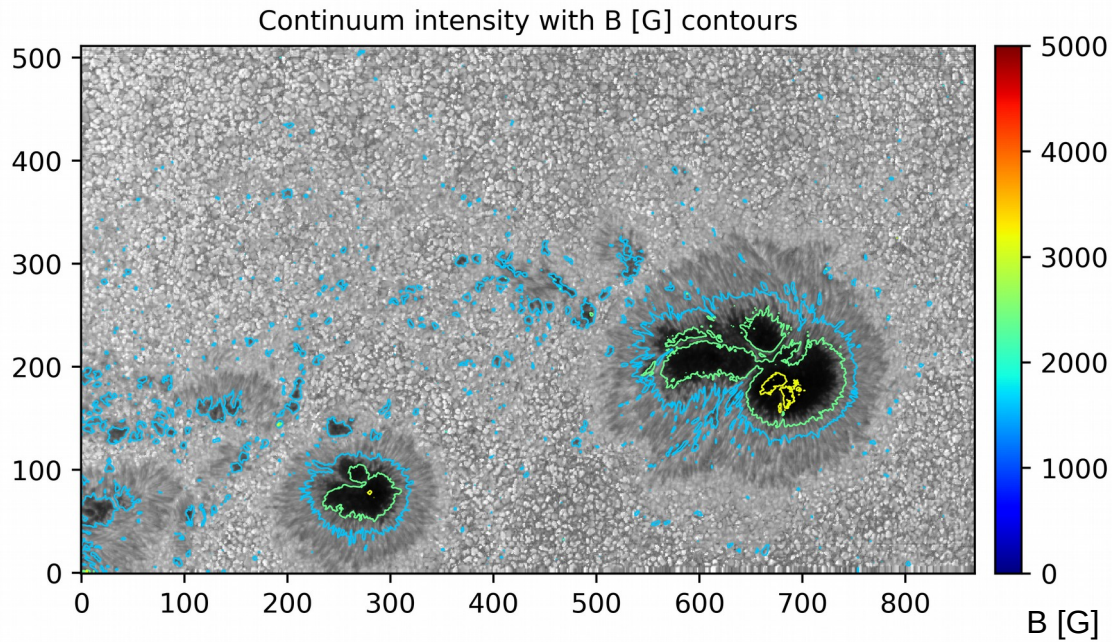


- LMSAL lvl2 podaci:
<http://sot.lmsal.com/data/sot/level2d/>
 - ▶ Lista od oko 22000 posmatranja (yyyymmdd_hhmmss)
- B, intenzitet u kontinuumu, v u pravcu vizure, inklinacija **B**
- Pege, mirno Sunce, rub, sit-and-stare posmatranja
- Cilj: Naći „interesantna” posmatranja bez pregledanja svakog pojedinačno

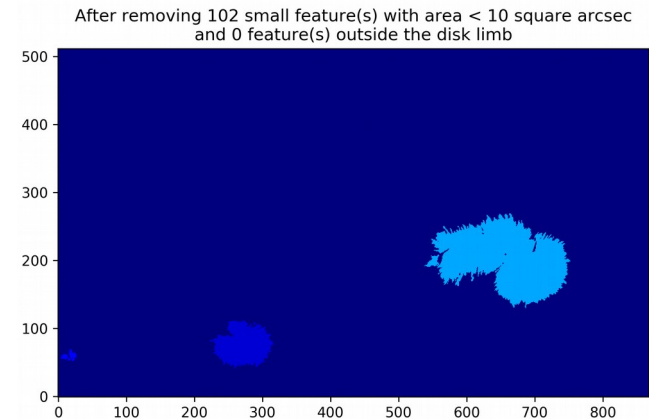
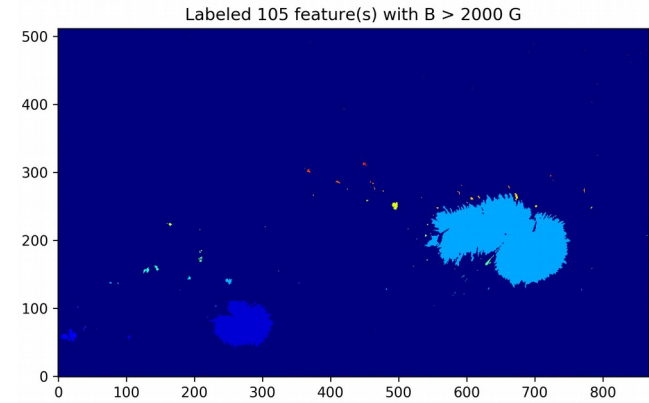
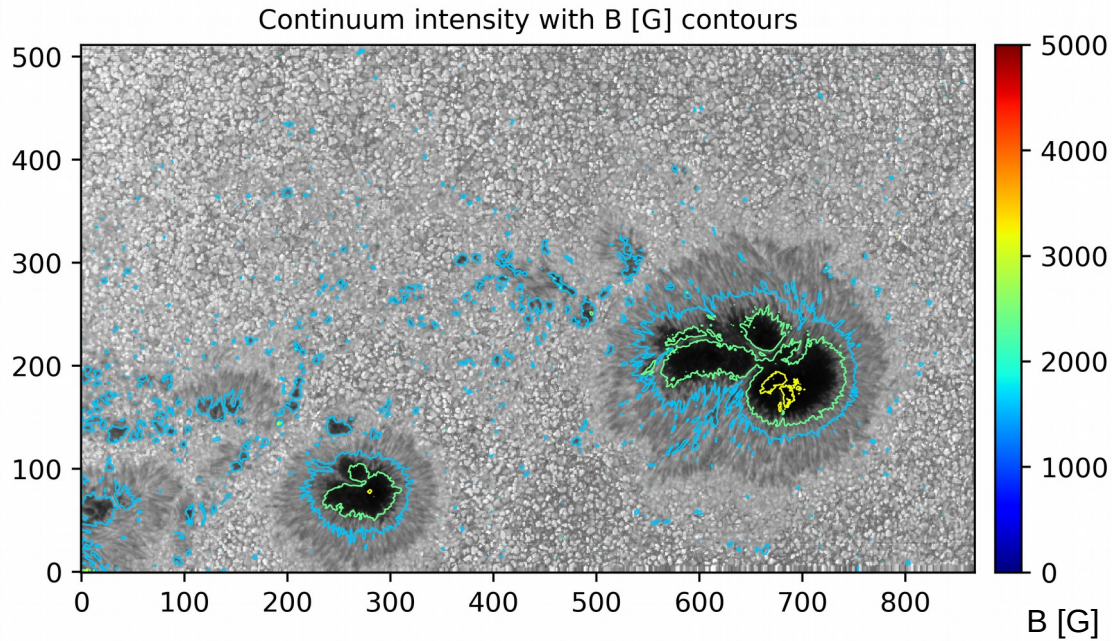
Pisanje Python skipte koja...

- Preskače posmatranja ruba (na osnovu koordinata vidnog polja)
- Preskače posmatranja mirnog Sunca (na osnovu traženja povezanih regiona u kojima je $B > 2000$ G)
- Nalazi posmatranja AR sa pegama
 - Na osnovu NOAA izveštaja nalazi koji je region u pitanju
 - Računa nekoliko potencijalno korisnih stvari za dalju selekciju i pravi nekoliko grafika/slika
- Naravno da ovo ne radi sjajno (dosta posmatranja ruba se provuklo)

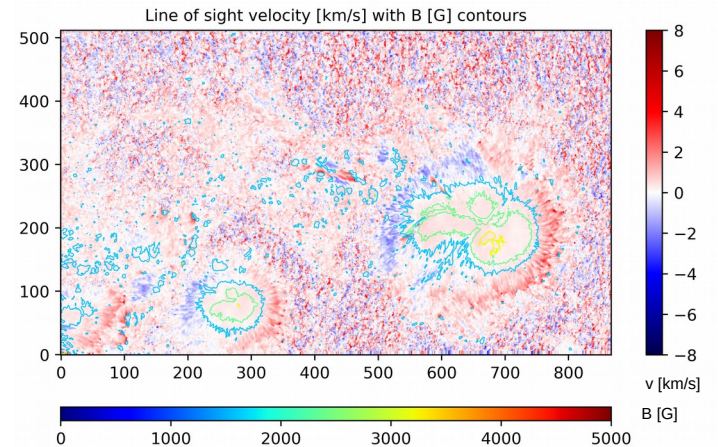
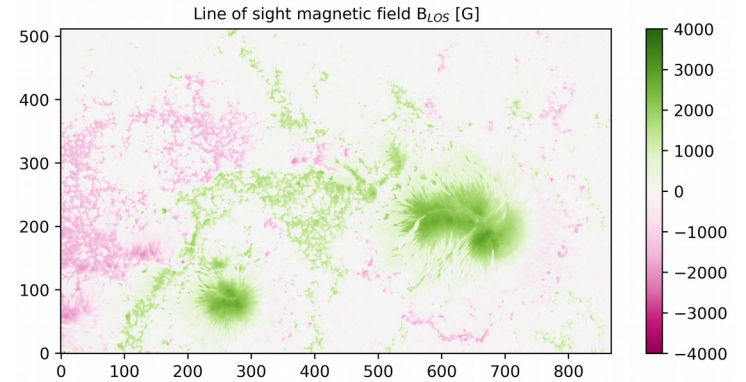
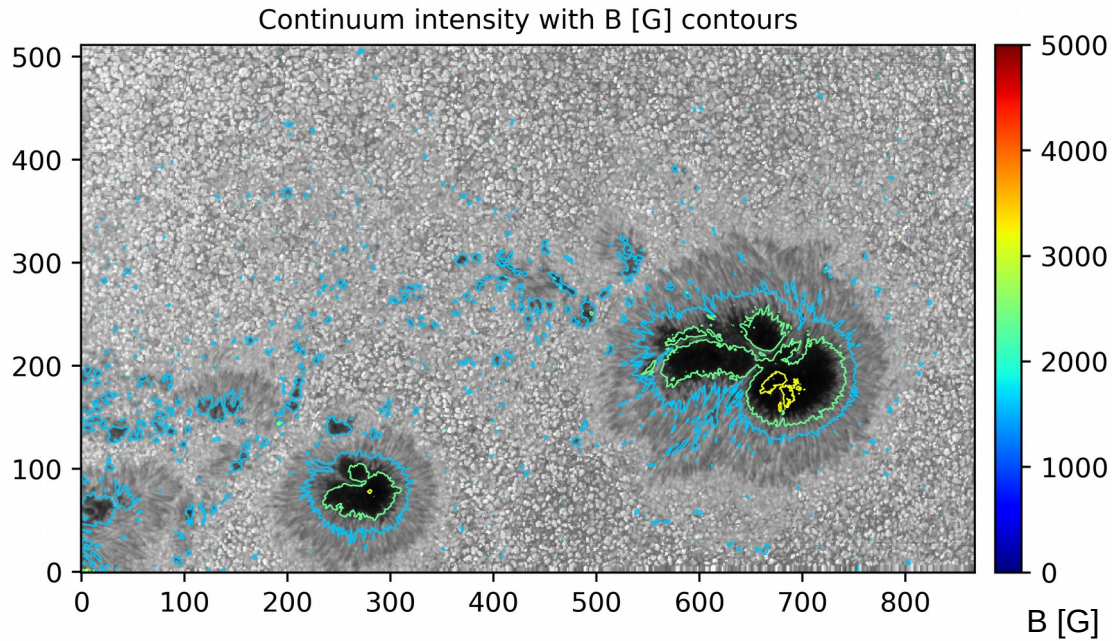
Primer: Posmatranje jednog AR sa pegama



Primer: Posmatranje jednog AR sa pegama

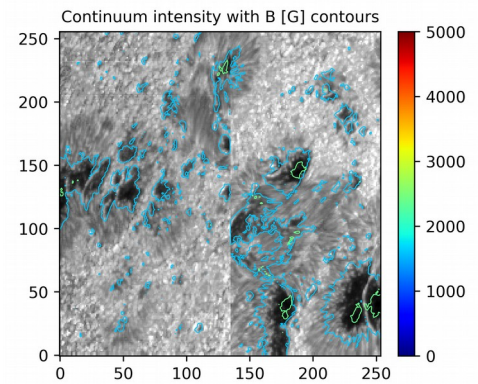
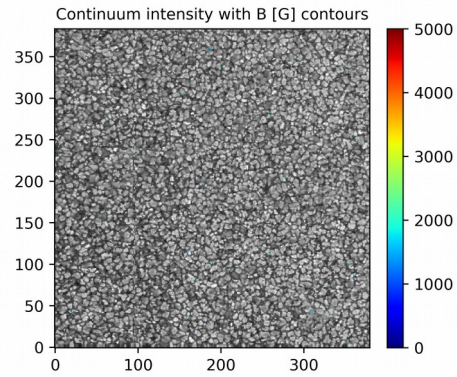
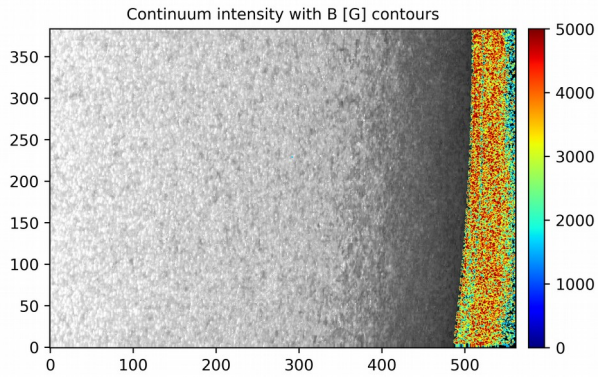


Primer: Posmatranje jednog AR sa pegama

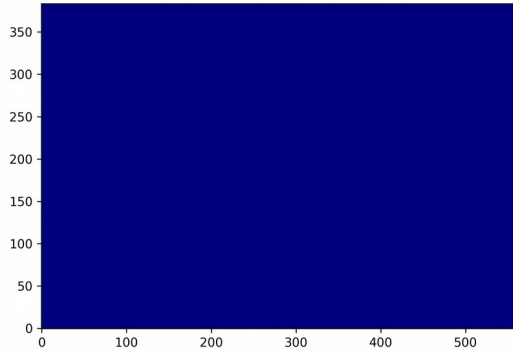


Primer:

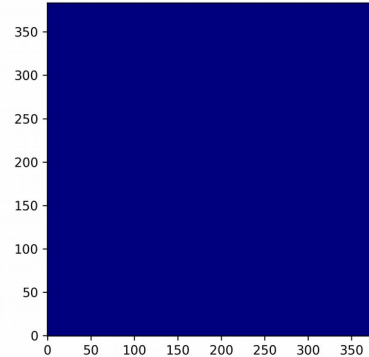
Razne stvari koje nam ne trebaju



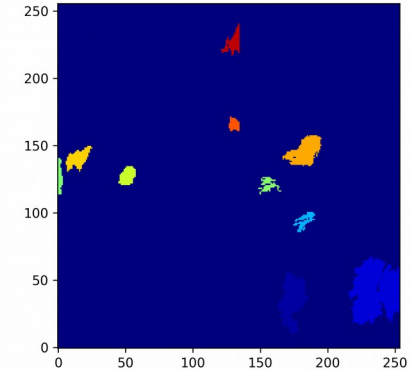
After removing 248 small feature(s) with area < 10 square arcsec and 1 feature(s) outside the disk limb



After removing 26 small feature(s) with area < 10 square arcsec and 0 feature(s) outside the disk limb



After removing 78 small feature(s) with area < 10 square arcsec and 0 feature(s) outside the disk limb



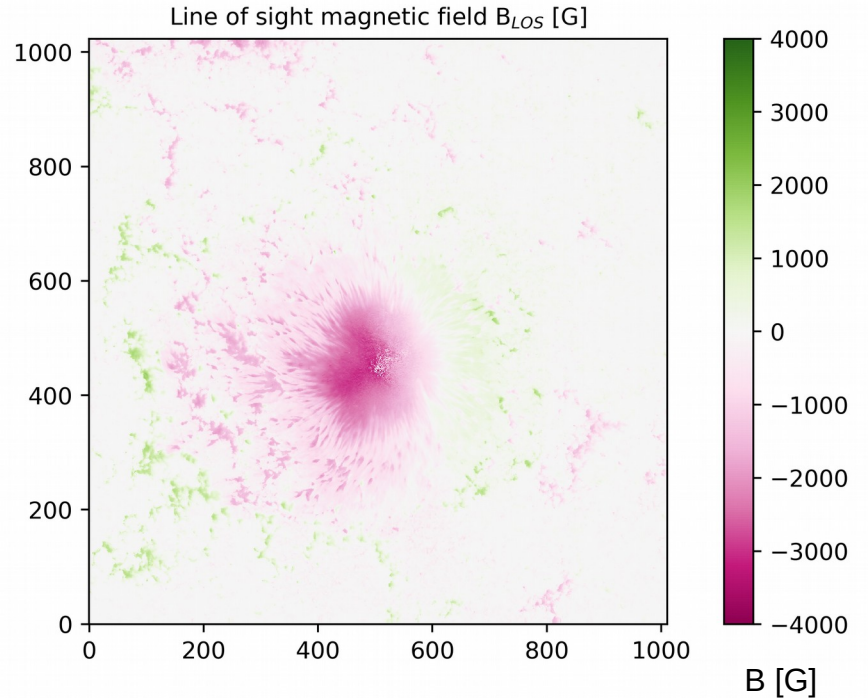
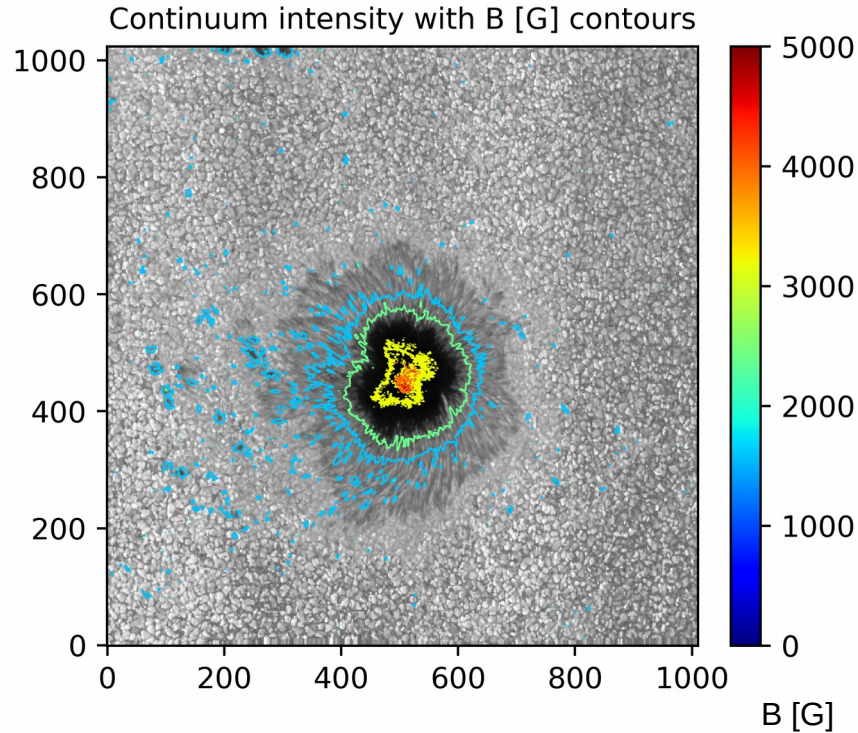
Primer: Deo tabele sa rezultatima

22000 lvl2 posmatranja → preklapanje sa NOAA listom pega → 8000 lvl2 posmatranja

l	date+time	x [°]	y [°]	r [°]	mu	x_sc [°]	y_sc [°]	N_tot [px]	N_lim [px]	N_2k [px]	N_3k [px]	N_4k [px]	N_5k [px]	mean_max_B [G]	std_max_B [G]	mean_reg_B [G]	mean_reg_vel [km/s]	NOAA	area	z_type	mag_type
4322	20160213 101204	267.871	299.523	971.329	0.91	0.297	0.32	443392	96	2803	241	10	1	3288	332	5000	9.1	12497	250	Eac	Beta-Gamma-Delta
4323	20070604 125036	-625.441	-89.444	945.311	0.74	0.297	0.32	512000	78	2531	25	2	2	2731	288	5000	9.5	10960	540	Fkc	Beta-Gamma-Delta
4324	20100209 224006	369.604	460.761	971.845	0.79	0.297	0.32	519680	84	1685	80	17	2	2921	503	5000	9.1	11045	420	Fkc	Beta-Gamma-Delta
4325	20110215 204005	346.674	-228.561	970.866	0.9	0.297	0.32	263040	95	6486	54	4	2	2922	309	5000	0.9	11158	450	Ekc	Beta-Gamma
4326	20110925 012335	-699.888	118.388	955.994	0.67	0.297	0.32	381952	70	14465	960	21	2	3472	314	5000	10	11302	1300	Fkc	Beta-Gamma-Delta
4327	20110926 065034	-547.829	97.874	956.322	0.81	0.297	0.32	172032	86	4600	428	60	2	3620	424	5000	10	11302	980	Ekc	Beta-Gamma-Delta
4328	20110929 004505	82.824	83.292	957.068	0.99	0.297	0.32	384000	104	11697	442	12	2	3313	304	5000	9.1	11302	1070	Fkc	Beta-Gamma-Delta
4329	20110929 041004	106.539	83.664	957.107	0.99	0.297	0.32	380928	104	11633	436	12	2	3305	323	5000	6.2	11302	1070	Fkc	Beta-Gamma-Delta
4330	20111106 120041	-398.031	259.235	967.398	0.87	0.297	0.32	262272	92	10710	366	4	2	3251	227	5000	10	11339	1250	Ekc	Beta-Gamma-Delta
4331	20120307 080005	-399.184	384.336	966.293	0.82	0.297	0.32	258048	86	10074	65	9	2	3020	340	5000	9.3	11429	1120	Dkc	Beta-Gamma-Delta
4332	20120509 190005	-400.764	-222.735	949.757	0.88	0.297	0.32	260096	92	6704	497	19	2	3489	321	5000	7.9	11476	940	Fkc	Beta-Gamma-Delta
4333	20131026 223109	-763.635	-205.838	964.84	0.57	0.297	0.32	261632	60	3252	89	11	2	2997	419	5000	10	11882	280	Dkc	Beta-Gamma-Delta
4334	20141219 100006	200.909	-295.578	974.604	0.93	0.297	0.32	354552	98	7994	12	5	2	2703	313	5000	10	12242	970	Ekc	Beta-Gamma-Delta
4335	20141119 164505	-143.76	-306.483	970.327	0.94	0.297	0.32	352920	99	13822	548	8	2	3286	245	5000	8.5	12209	1100	Fkc	Beta-Gamma-Delta
4336	20141119 100005	-203.086	-306.894	970.27	0.93	0.297	0.32	351288	97	13648	485	17	2	3301	310	5000	10	12209	1100	Fkc	Beta-Gamma-Delta
4337	20170907 100004	688.119	-225.95	951.694	0.65	0.297	0.32	260096	68	9653	579	9	2	3514	246	5000	2.9	12673	960	Ekc	Beta-Gamma-Delta
4338	20170907 050218	631.773	-230.105	951.645	0.71	0.297	0.32	85248	74	9818	1248	192	2	4164	272	5000	6.9	12673	960	Ekc	Beta-Gamma-Delta
4339	20170404 000104	391.605	-94.637	958.884	0.91	0.297	0.32	442368	95	4206	43	5	2	2966	358	5000	10	12645	700	Ekc	Beta-Gamma-Delta
4340	20160522 101920	366.717	-142.726	947.22	0.91	0.149	0.16	607488	383	38665	6873	217	2	4135	196	5000	1.6	12546	550	Cho	Beta
4341	20130817 201708	468.307	-202.105	947.35	0.84	0.297	0.32	147072	89	4046	47	3	2	2917	245	5000	10	11819	10	Bxo	Beta
4342	20130516 104806	-696.127	188.228	948.391	0.65	0.297	0.32	243072	68	1137	2	2	2	2428	279	5000	1.2	11748	260	Dki	Beta-Gamma-Delta
4343	20090707 140306	468.031	-489.252	943.262	0.7	0.297	0.32	261888	73	1210	114	3	2	3065	452	5000	10	11024	160	Dsi	Beta
4344	20130423 173805	655.869	243.284	953.621	0.68	0.297	0.32	432996	71	8278	363	91	3	3714	497	5000	9	11726	550	Ekc	Beta-Gamma-Delta
4345	20140214 063104	417.289	-111.803	971.094	0.9	0.297	0.32	333696	94	7626	526	51	3	3778	308	5000	8	11974	780	Fkc	Beta-Gamma-Delta
4346	20170905 033607	145.56	40.797	951.158	0.99	0.149	0.16	859776	415	445172	72377	43	3	3874	175	5000	5.7	12674	740	Fhi	Beta
4347	20160522 002927	284.044	-140.952	947.293	0.94	0.149	0.16	604416	396	36091	7805	304	3	4180	174	5000	0.9	12546	550	Cho	Beta
4348	20170825 070534	-163.36	-34.261	948.723	0.98	0.297	0.32	216576	104	556	10	3	3	2548	517	5000	-5.4	12672	240	Esi	Beta-Gamma
4349	20150317 082405	741.419	-217.974	963.835	0.6	0.297	0.32	261120	63	3796	28	3	3	2887	299	5000	8.8	12297	380	Ekc	Beta-Gamma-Delta
4350	20110925 031505	-693.439	116.476	956.015	0.68	0.297	0.32	352768	71	13319	913	42	4	3754	502	5000	8.7	11302	1300	Fkc	Beta-Gamma-Delta
4351	20130423 143005	635.128	245.129	953.654	0.7	0.297	0.32	447488	74	8829	401	102	4	3835	444	5000	7.6	11726	550	Ekc	Beta-Gamma-Delta
4352	20141205 133005	570.576	-344.055	973.133	0.73	0.297	0.32	192768	77	2172	36	4	4	2916	293	5000	-2.2	12222	770	Ekc	Beta-Gamma
4353	20170907 112906	704.413	-250.374	951.709	0.62	0.149	0.16	1026048	260	36419	2571	31	4	3858	213	5000	10	12673	960	Ekc	Beta-Gamma-Delta
4354	20111016 213655	243.683	351.47	962.03	0.9	0.297	0.32	479232	94	55764	47	5	4	2940	595	5000	0.4	11314	330	Cho	Beta
4355	20061208 121357	-621.922	-95.518	973.565	0.76	0.297	0.32	480256	80	8404	2095	240	5	4210	231	5000	10	10930	430	Dki	Beta-Gamma-Delta
4356	20061208 145005	-593.615	-95.346	973.578	0.79	0.297	0.32	498176	83	8334	2154	273	5	4249	228	5000	10	10930	430	Dki	Beta-Gamma-Delta
4357	20061208 180506	-570.016	-95.152	973.595	0.8	0.297	0.32	512000	85	8499	2295	306	5	4269	202	5000	10	10930	430	Dki	Beta-Gamma-Delta
4358	20061214 112602	630.214	-85.725	974.213	0.76	0.149	0.16	1048576	319	31440	6922	190	5	4143	245	5000	0.2	10930	670	Dki	Beta-Gamma-Delta
4359	20120706 190513	643.261	-359.05	943.248	0.62	0.297	0.32	346112	66	7795	400	17	5	3355	367	5000	10	11515	670	Ekc	Beta-Gamma-Delta
4360	20140203 182306	64.787	-110.598	972.829	0.99	0.297	0.32	183192	104	27409	5293	411	5	4333	237	5000	8.2	11967	1510	Fkc	Beta-Gamma-Delta
4361	20140204 070214	225.367	-112.253	972.752	0.97	0.297	0.32	356592	102	31265	5205	285	5	4189	189	5000	3.6	11967	1490	Fkc	Beta-Gamma-Delta
4362	20061213 125104	455.479	-85.972	974.122	0.88	0.149	0.16	1046528	370	44714	10119	565	6	4287	174	5000	5.2	10930	680	Dki	Beta-Gamma-Delta
4363	20110925 043921	-679.88	115.803	956.03	0.69	0.297	0.32	380416	73	14709	927	72	6	3693	448	5000	9.3	11302	1300	Fkc	Beta-Gamma-Delta
4364	20111002 113449	737.42	129.196	958.026	0.62	0.297	0.32	379392	66	4591	118	32	6	3220	591	5000	9.4	11302	700	Fkc	Beta-Gamma-Delta
4365	20140203 013005	-46.39	-130.875	972.929	0.99	0.297	0.32	356184	104	31452	5979	538	6	4450	256	5000	3	11967	1510	Fkc	Beta-Gamma-Delta

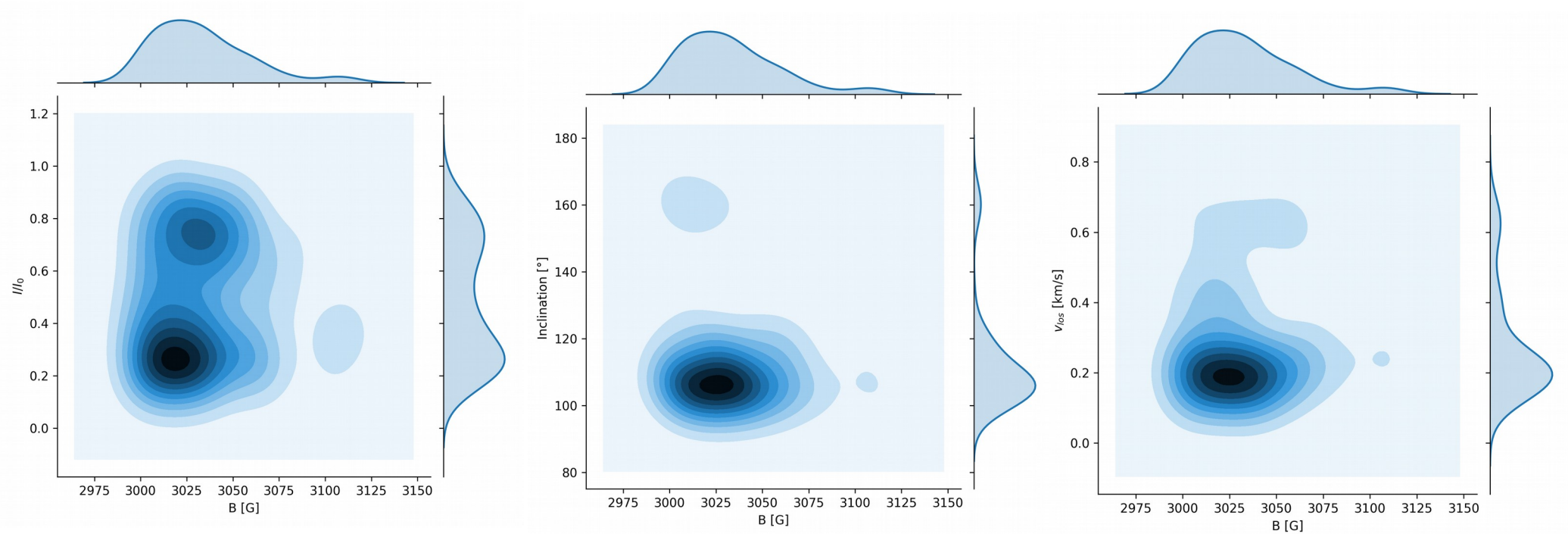
Primer: AR 11899

Neinteresantan region, iako „postoji” jako polje



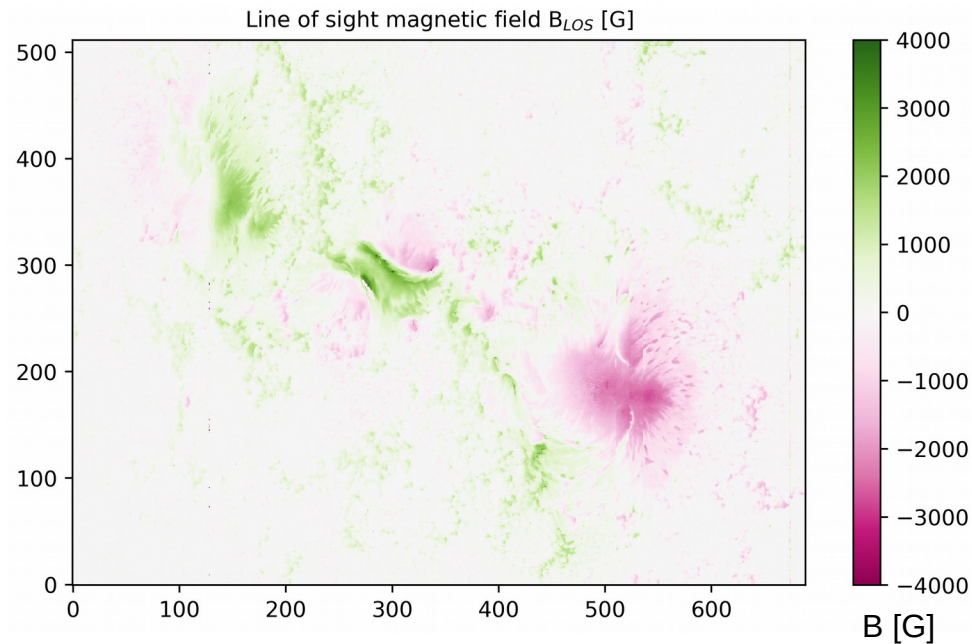
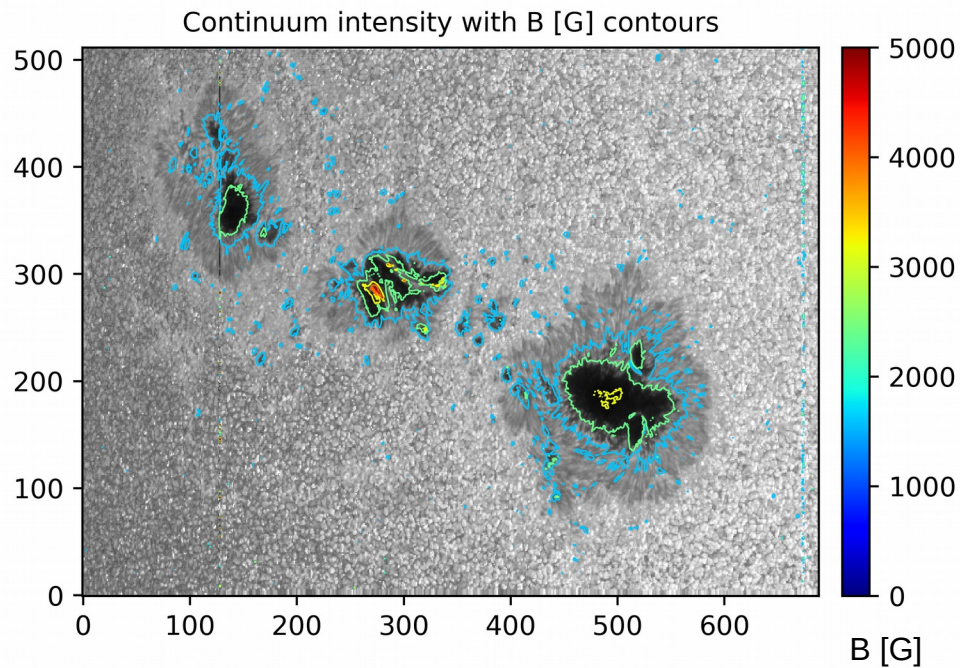
Primer: AR 11899

Pixeli sa $B > 3000$ G i $0.2 < I/I_0 < 0.9$



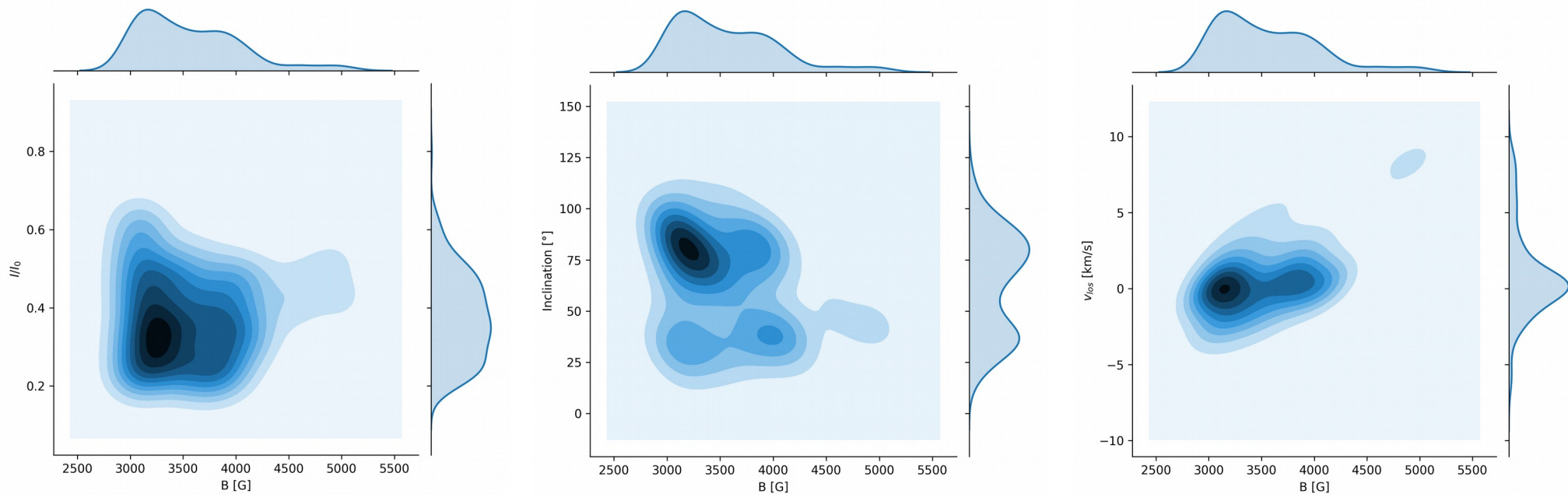
Sa druge strane: AR 11302

Interesantan region

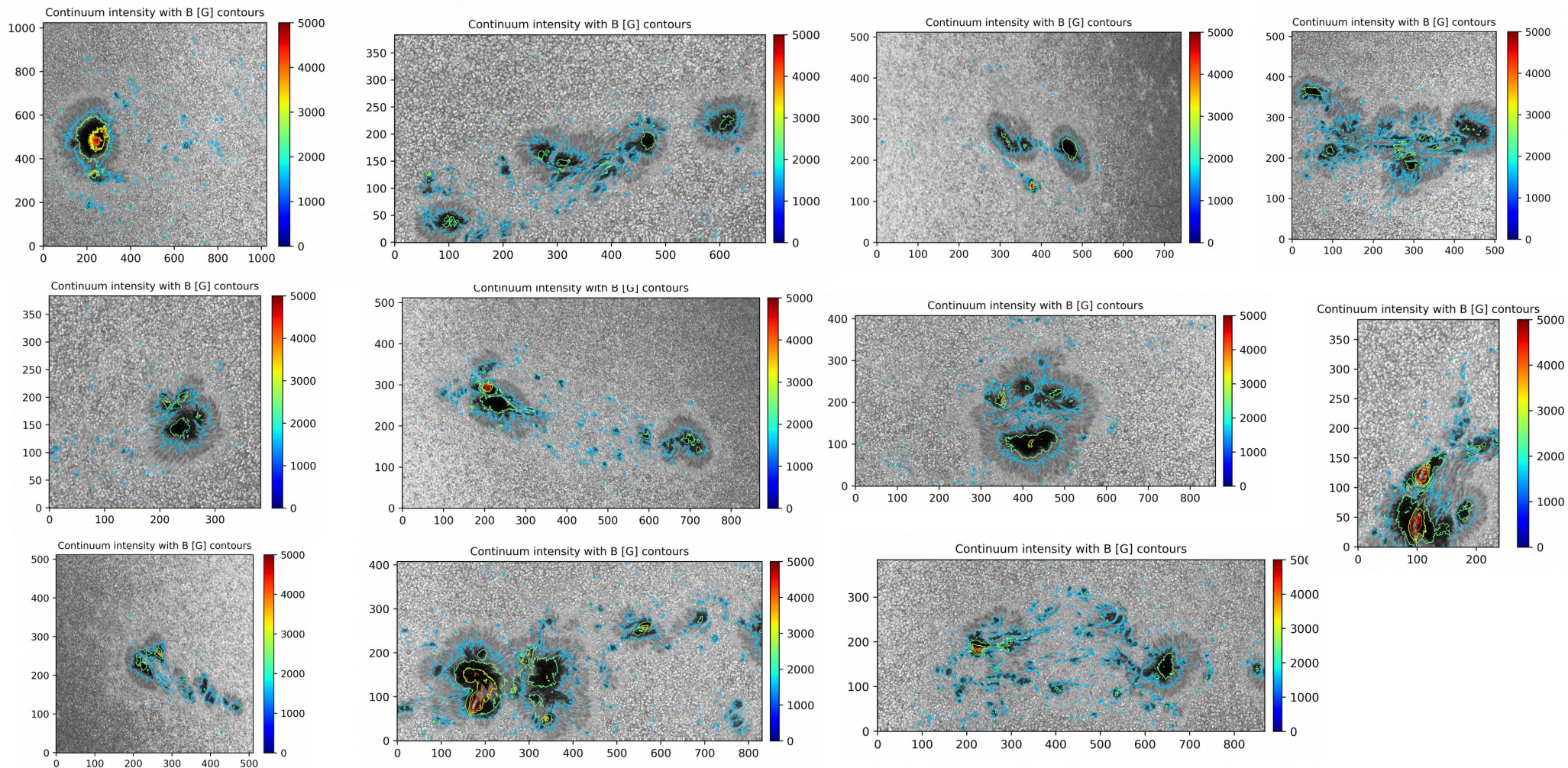


Sa druge strane: AR 11302

Pixeli sa $B > 3000$ G i $0.2 < I/I_0 < 0.9$

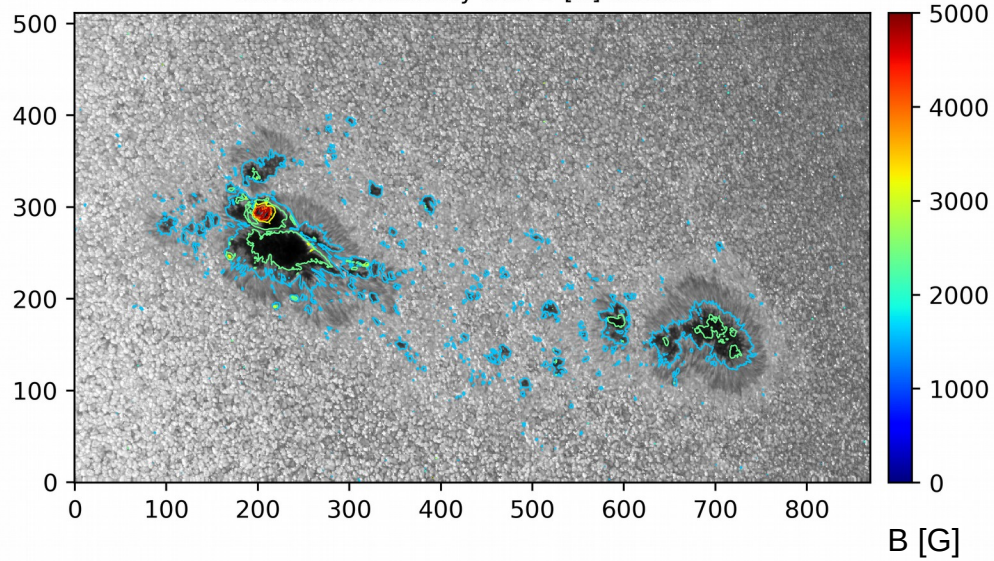


Još pronađenih regiona sa jakim poljima

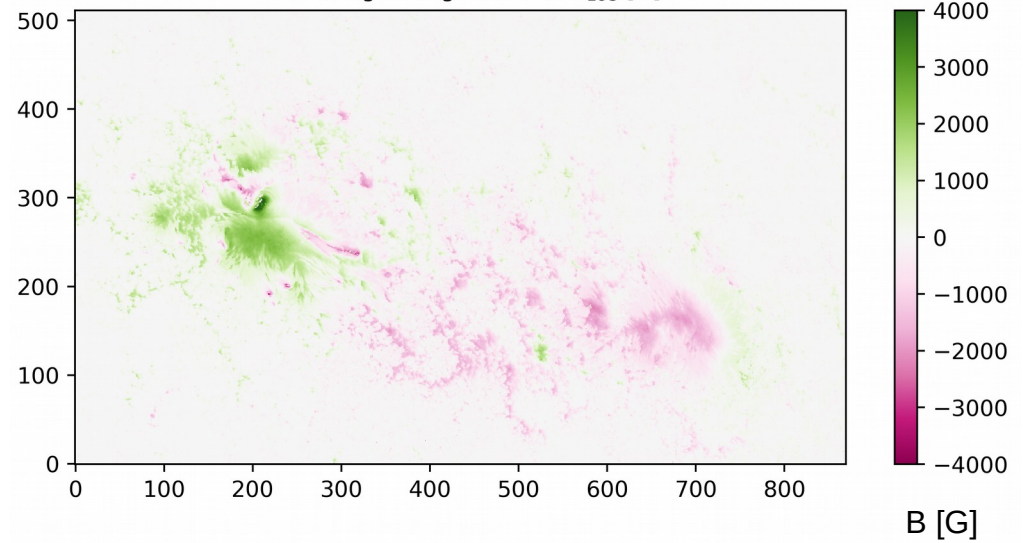


Izbliza: AR 11726

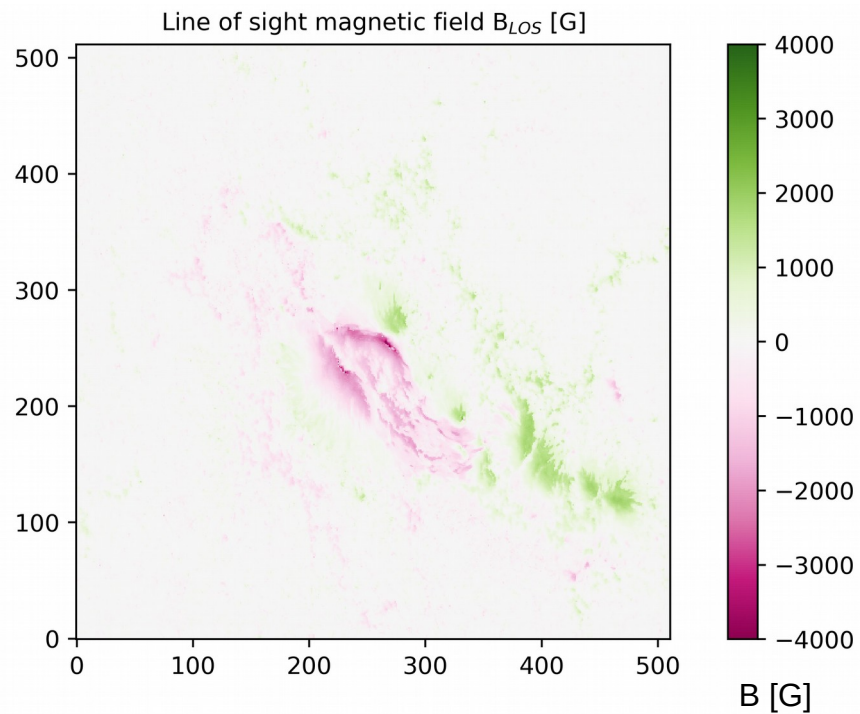
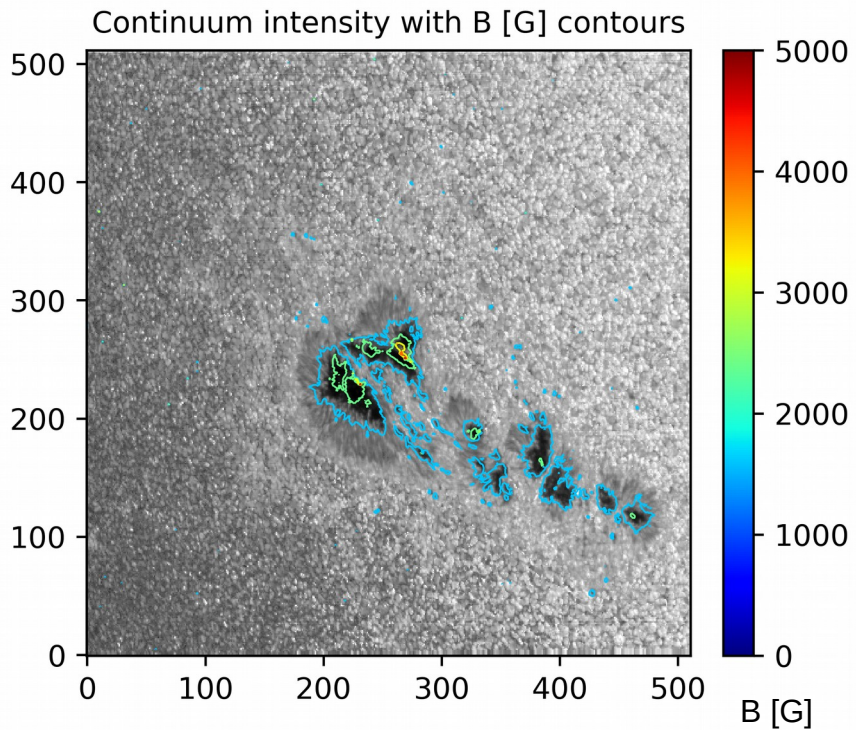
Continuum intensity with B [G] contours



Line of sight magnetic field B_{LOS} [G]



Izbliza: AR 11882



MPI za istraživanje Sunčevog sistema



- **O institutu:**
 - Sun and Heliosphere
 - Solar and Stellar Interiors
 - Planets and Comets

→ *Mogućnosti za praksu, MSc i PhD (IMPRS)*
- **O životu na institutu:**
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Hvala na pažnji!