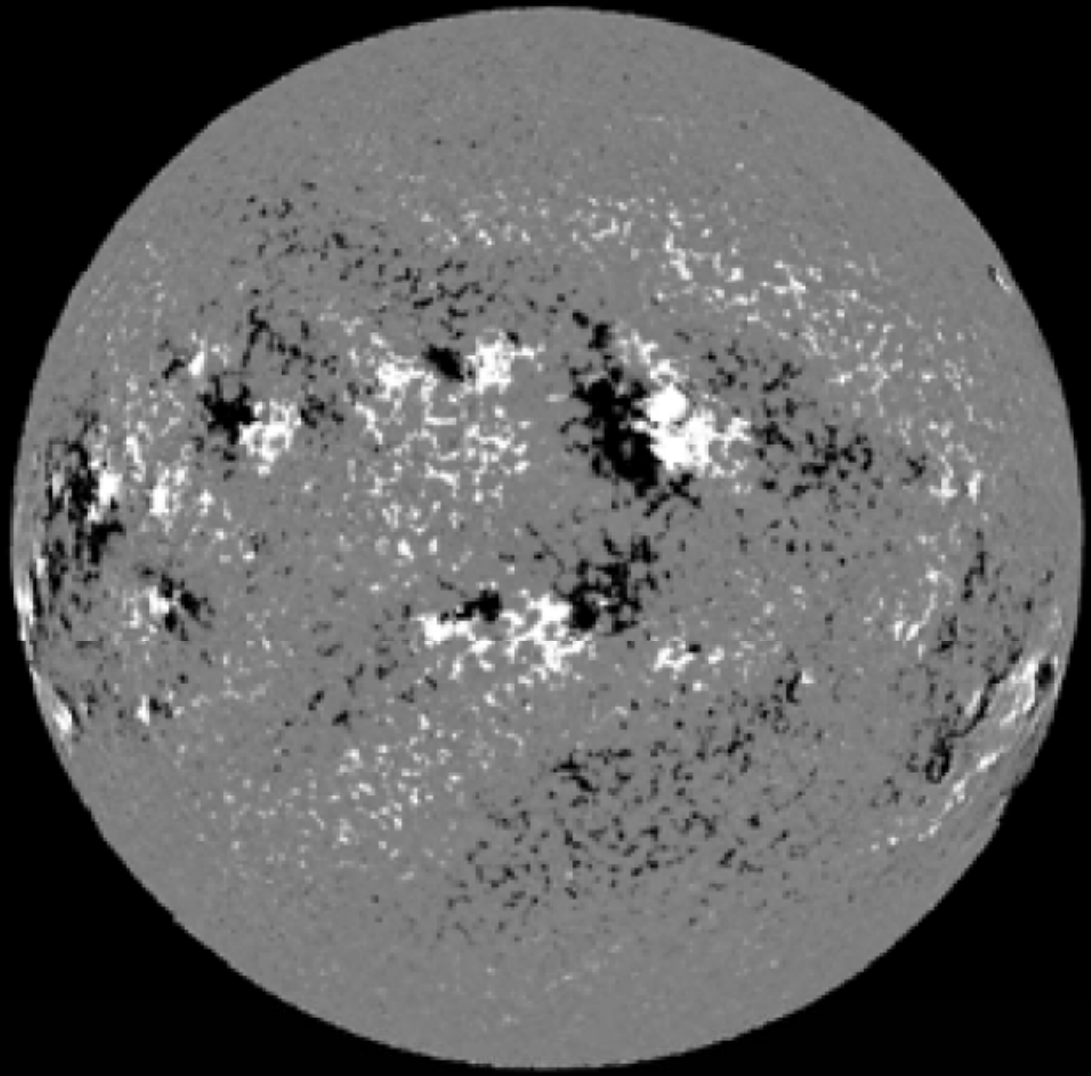
Measuring Coronal Magnetic Fields by Pulsar Faraday Rotation

Yoshiki Sofue

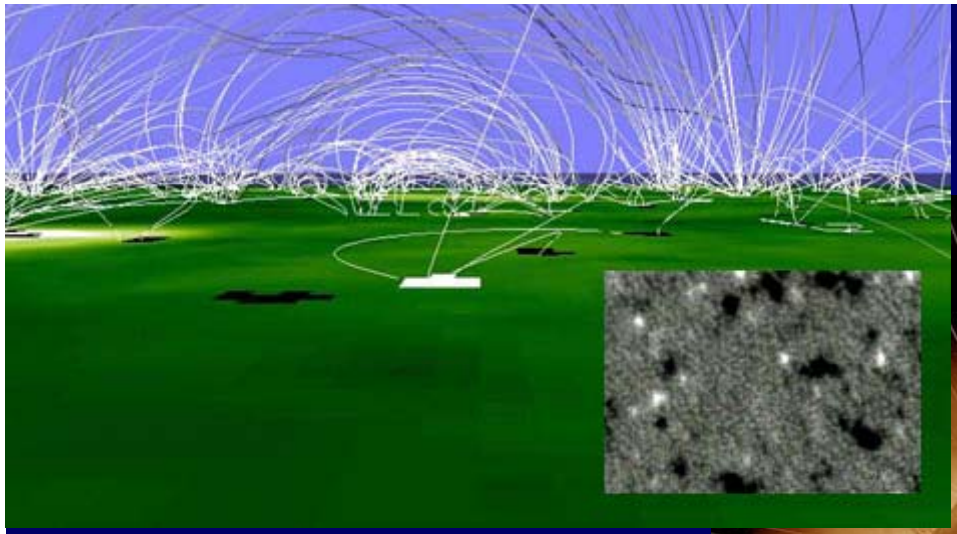
SKA Con. on Cosmic Magnetism
2013 Sep 13-14 @Mizusawa

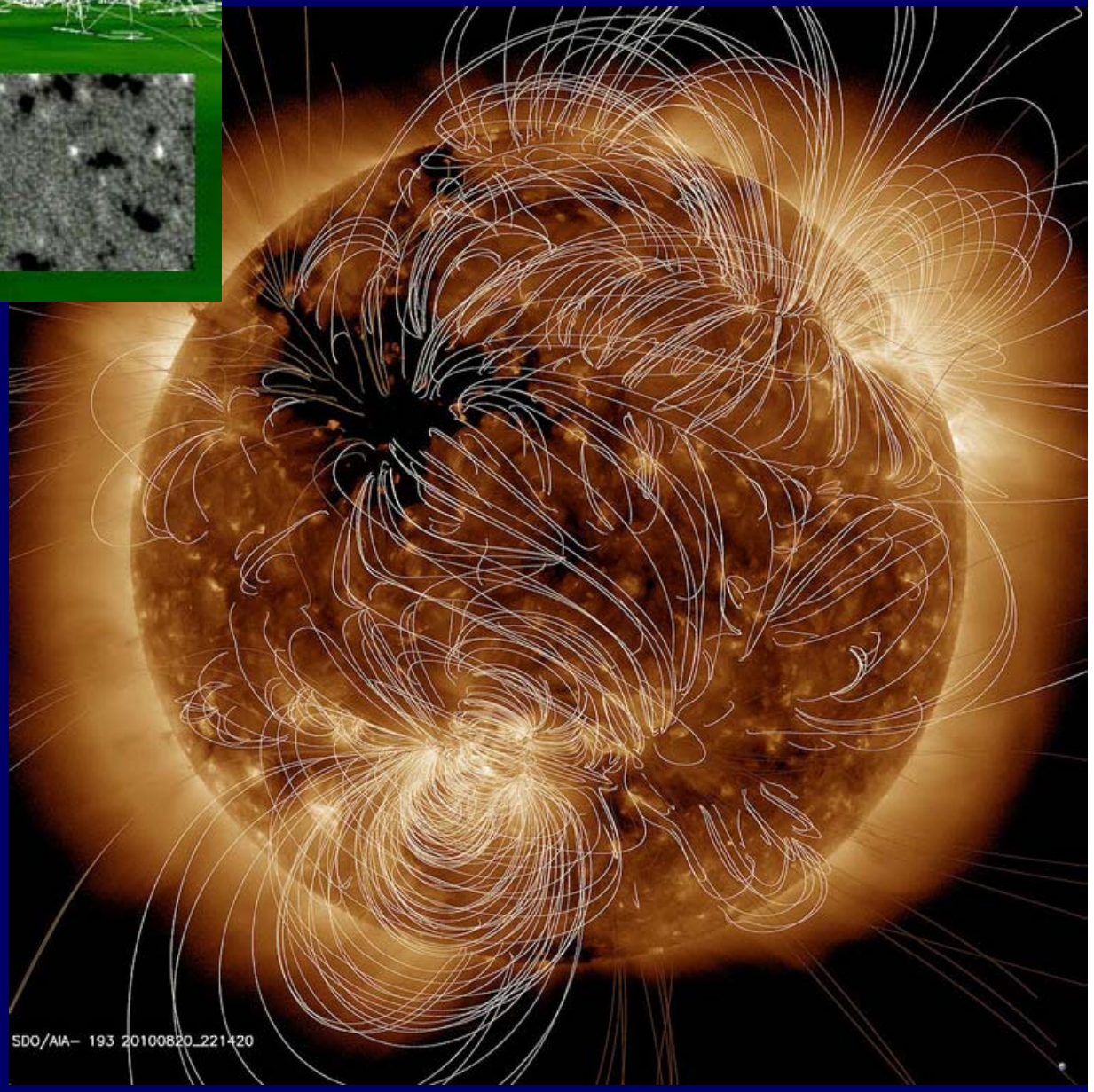
I.
Solar Magnetic Fields

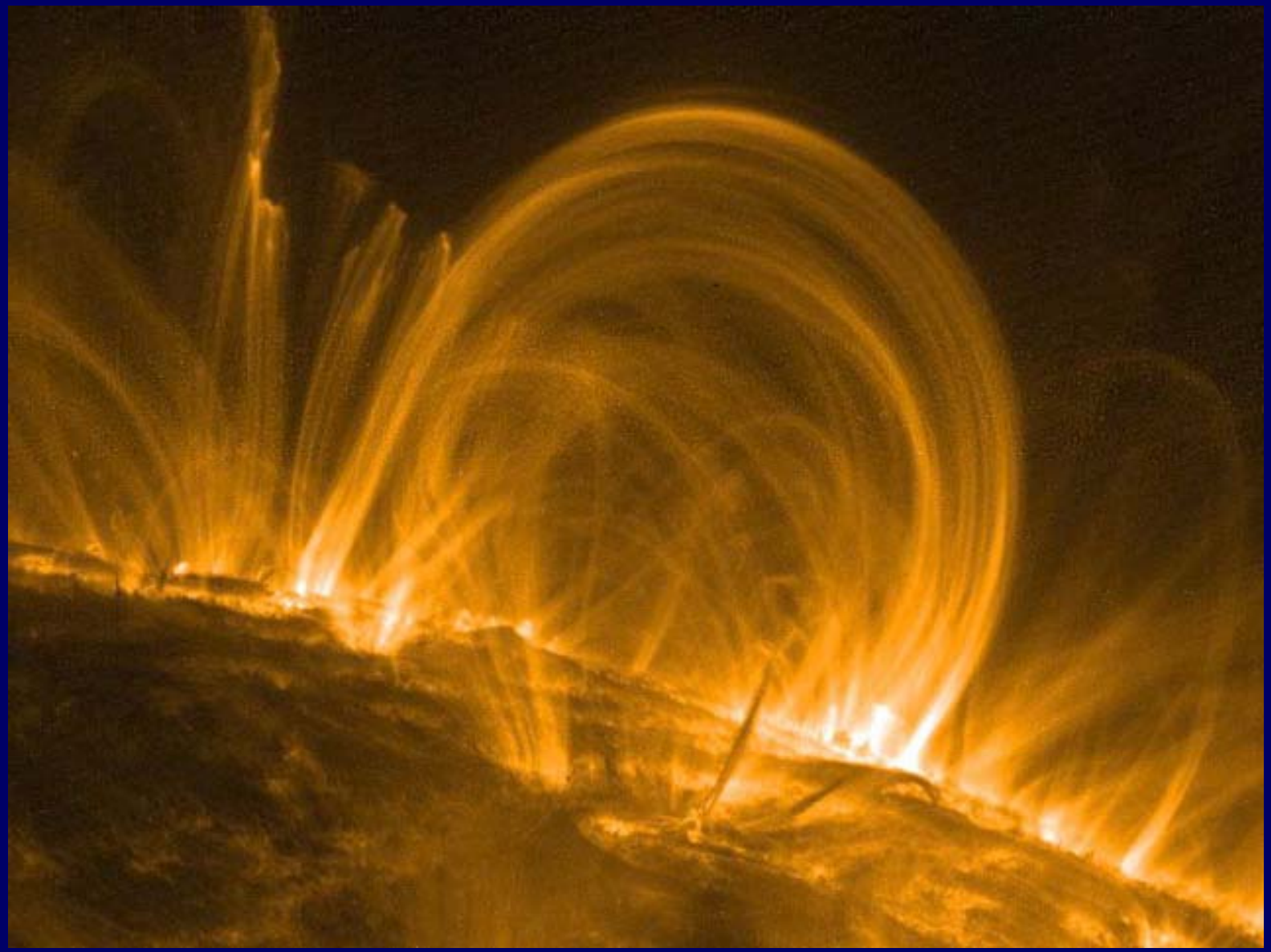
Magnetic map of the Sun
Solar maximum dominated by global dynamo

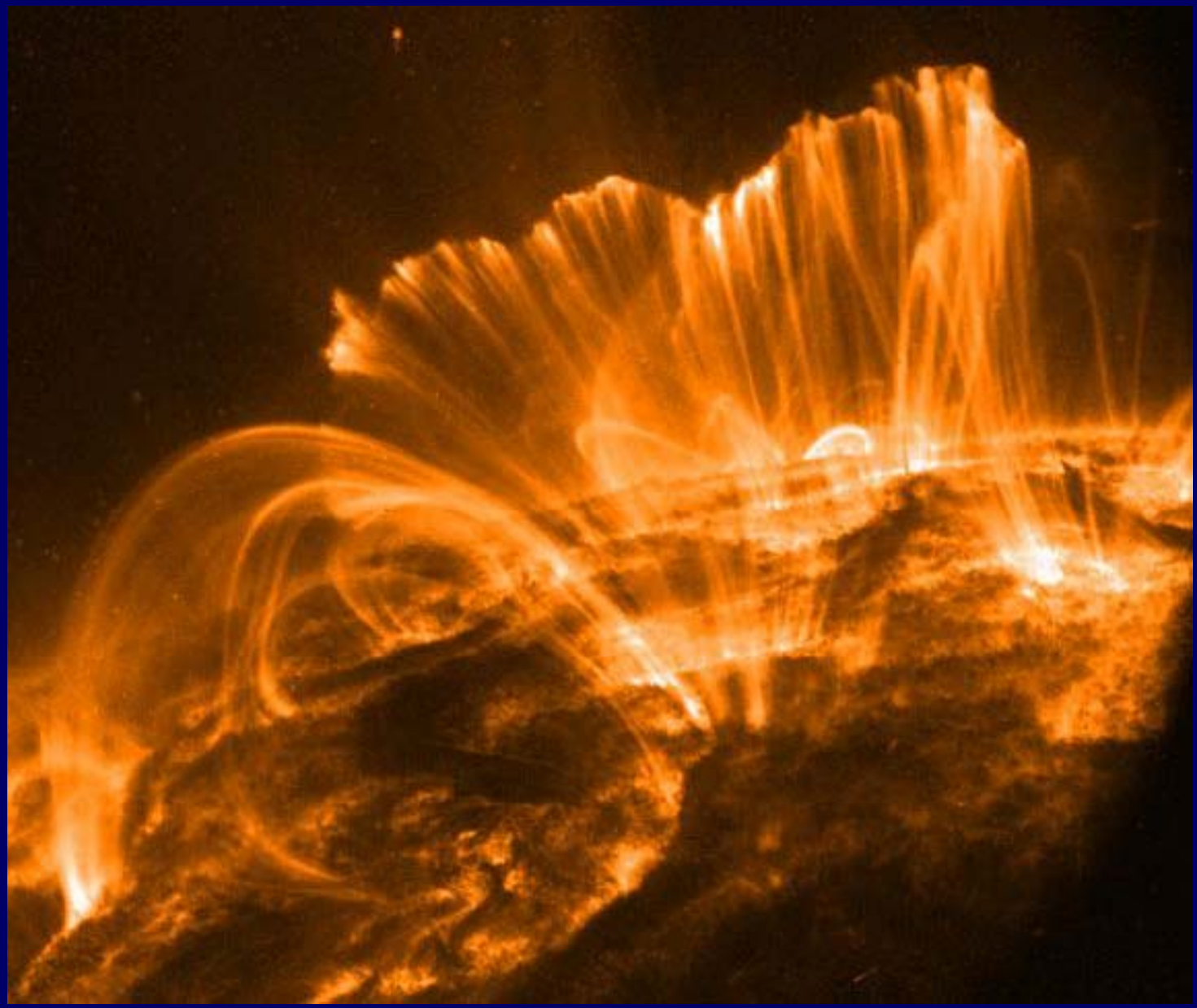


Kitt Peak magnetogram




SDO/AIA- 193 20100820_221420



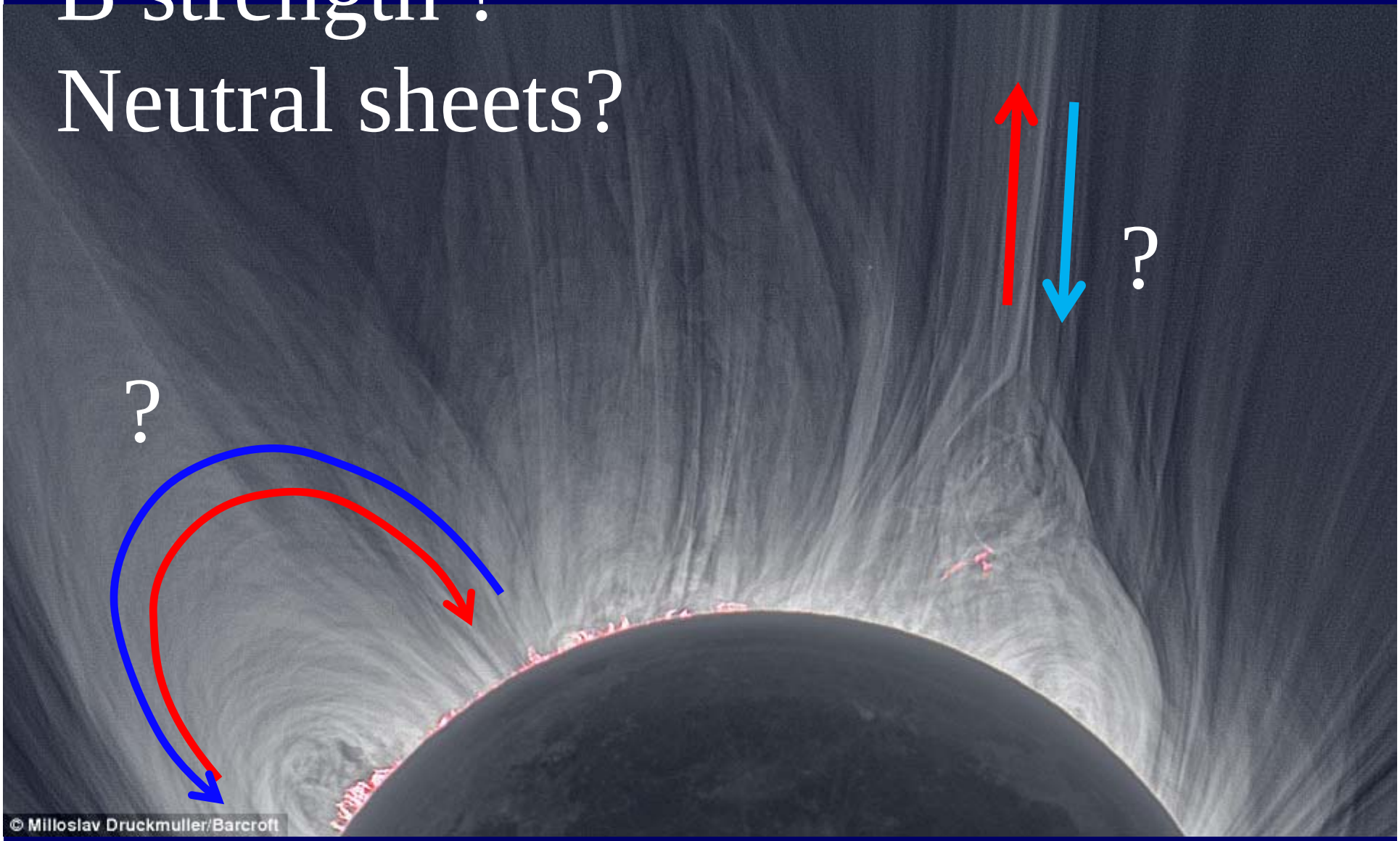


But !

Few direct measurement of magnetic fields.

II.
Coronal Magnetic Fields

B direction ?
B strength ?
Neutral sheets?

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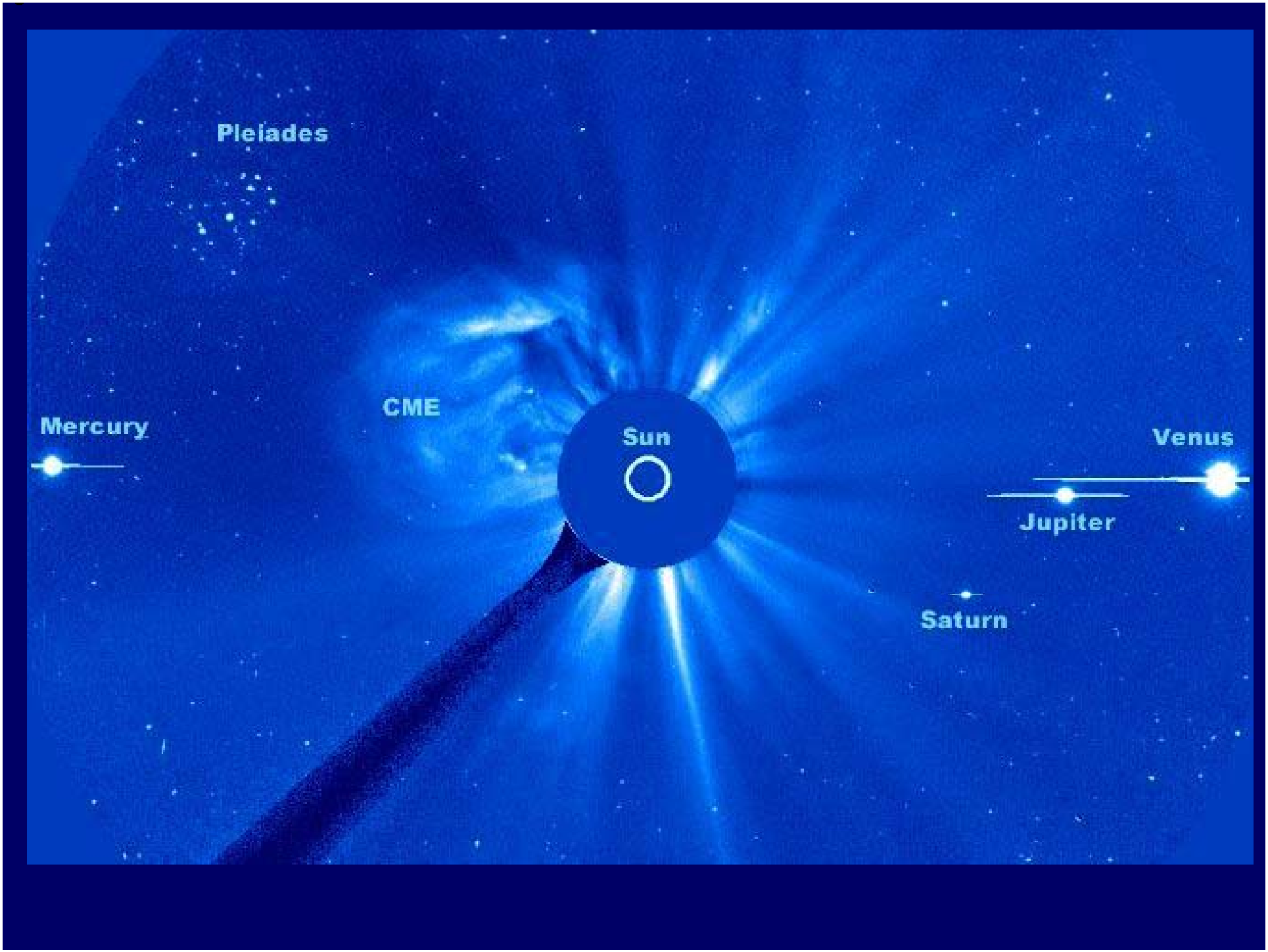
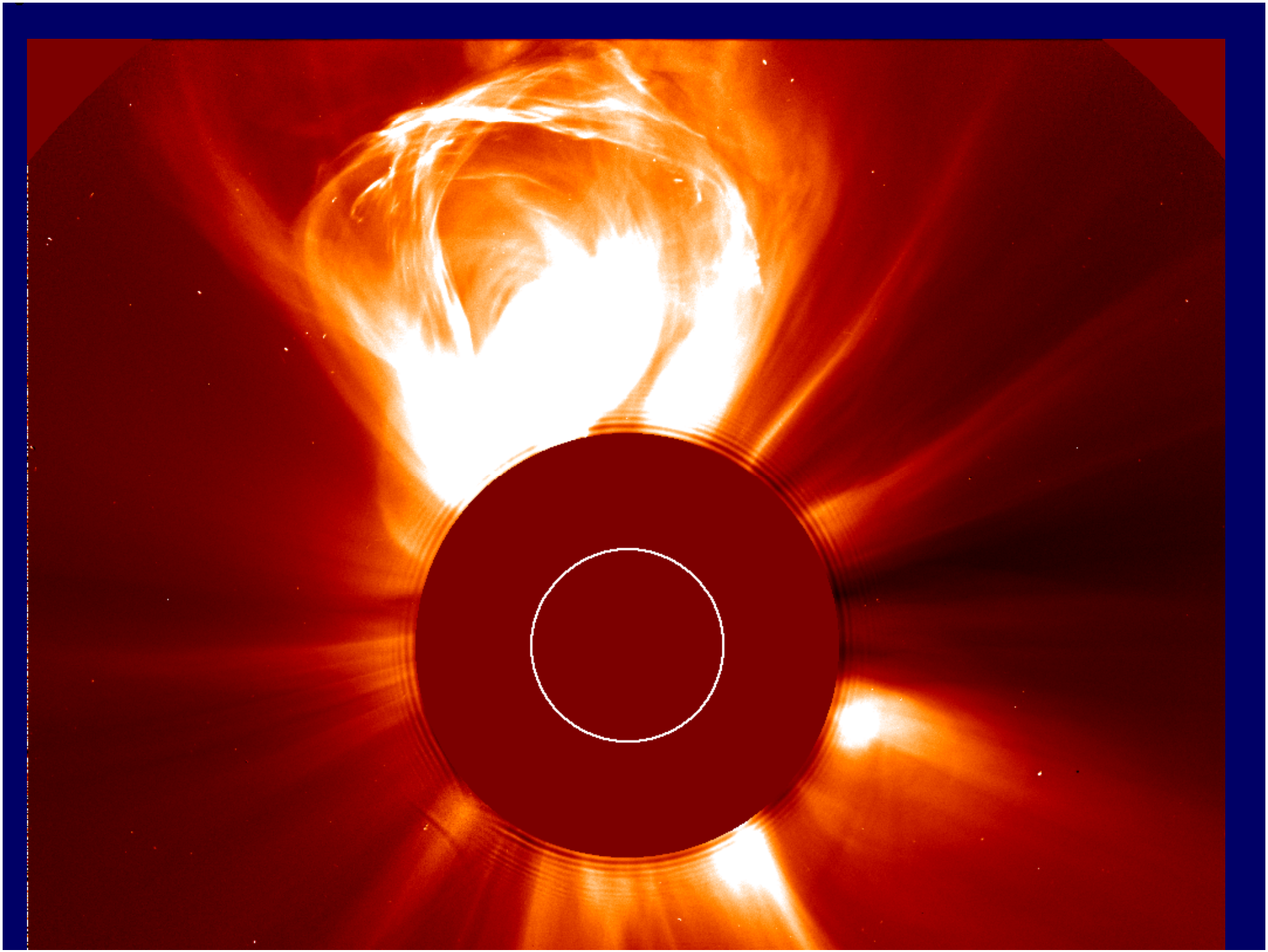
Miloslav Druckmüller
Institute of Mathematics, Faculty of Mechanical Engineering
Brno University of Technology, Czech Republic


Pleiades
CME
Mercury
Sun
Venus
Jupiter
Saturn



But !

Few direct measurement of magnetic field.

III.
Current Measurements

Kim+2012

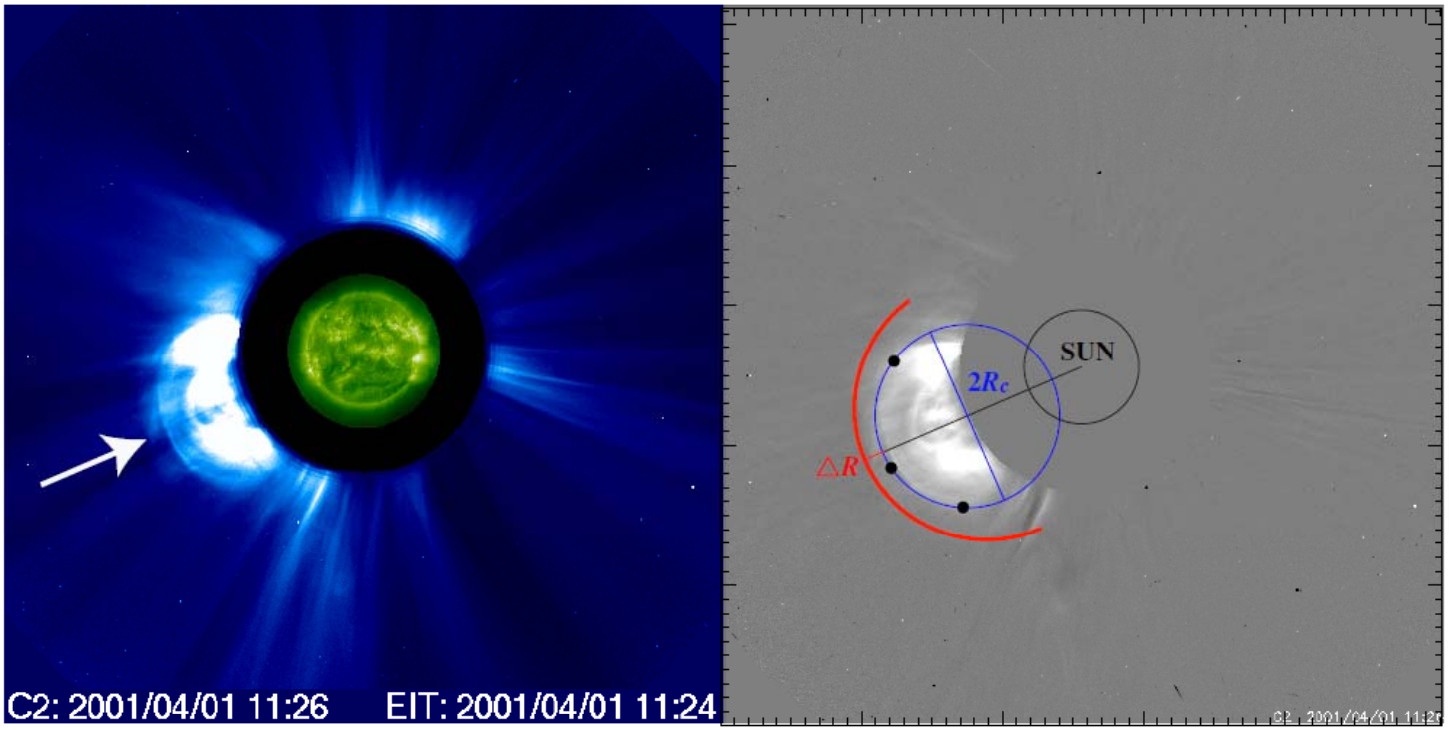


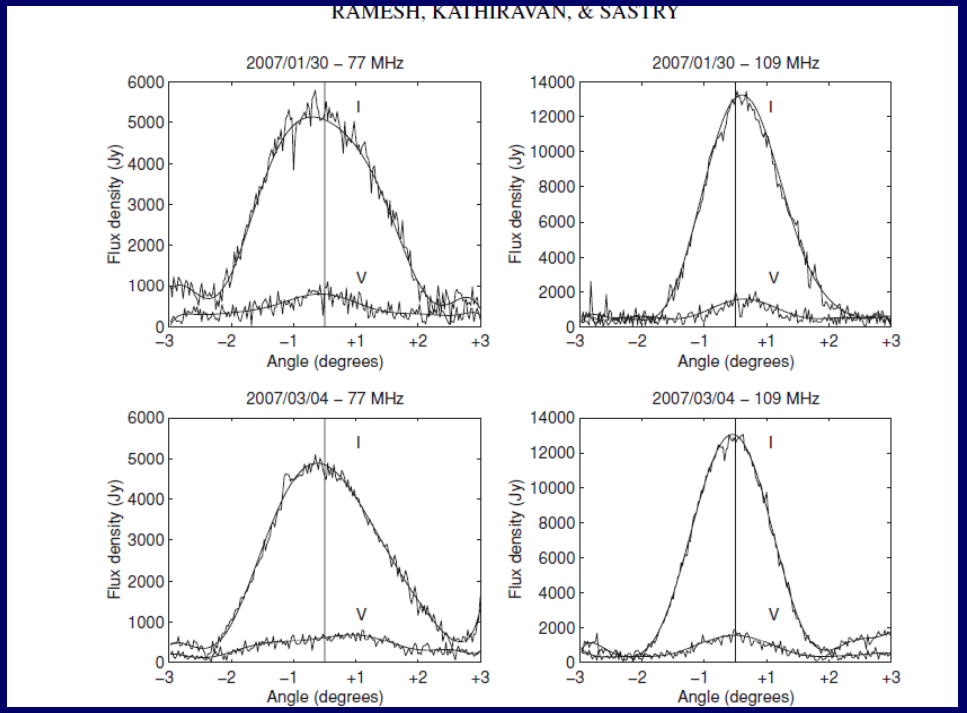
Figure 1. Left panel shows a *SOHO*/LASCO image of the 2001 April 1 CME at 11:26 UT showing the diffuse structure ahead of the CME flux rope (the sharp feature). The arrow indicates the shock nose. The right panel shows the running difference image of the event. The radial black line marks the central P.A. of the shock nose, and the blue circle indicates the CME as an obstacle. The red lines indicate the shock front and standoff distance, ΔR.

Information about Very Fast ($\geqslant$1000 km s^{-1}) Limb CMEs that Show Clear Shock Structures from 1997 to 2003

No.	CME	Type II[a]	Shock Position		Shock Parameter			Mach No.		V_A (km s^{-1})		B(mG)	
	Date/Time	Time	P.A. (°)	Height (R_s)	$\Delta R/R_c$	ρ_d/ρ_u	V_{SH} (km s^{-1})	$M_{\Delta R}$	M_ρ	$V_{A\Delta R}$	$V_{A\rho}$	$B_{\Delta R}$	B_ρ
1	1997 Nov 14 10:14:03	No	70	3.33	0.78	1.35	862	1.49	1.63	580	527	101	92
	1997 Nov 14 10:52:30		67	6.19	0.35	1.12	988	2.09	1.53	471	647	27	37
2	1999 Jul 25 13:31:21	13:21 M	301	3.08	0.27	1.30	1259	2.51	1.61	501	780	105	163
	1999 Jul 25 13:54:05		301	5.55	0.38	1.22	1370	2.00	1.58	684	869	46	58
	1999 Jul 25 14:18:05		301	8.50	0.53	1.08	1546	1.71	1.51	902	1025	34	38
	1999 Jul 25 14:42:05		301	11.7	0.54	1.05	1400	1.70	1.49	825	937	21	24
3	2000 Apr 4 16:43:01	15:31 M	325	11.46	0.55	1.01	1279	1.68	1.48	761	867	20	23
	2000 Apr 4 17:18:06	15:45 D	326	15.33	0.34	1.00	1049	2.12	1.47	494	711	10	14
4	2000 May 4 11:42:05	11:06 M	226	7.92	0.61	1.14	705	1.62	1.53	435	459	18	19
	2000 May 4 12:42:05	11:10 D	226	12.64	0.20	1.07	1142	3.20	1.51	356	758	8	18
5	2000 May 5 16:18:05	16:35 D	213	6.35	0.37	1.17	1308	2.03	1.55	643	843	35	46
	2000 May 5 16:42:06		214	9.06	0.33	1.12	1299	2.16	1.53	601	851	21	29
6	2000 Jun 15 20:26:06	19:43 M	306	6.06	0.31	1.08	761	2.25	1.51	338	504	20	29
	2000 Jun 15 20:42:05	19:52 D	307	7.11	0.33	1.07	1030	2.17	1.51	473	683	22	32
	2000 Jun 15 21:18:05		307	10.31	0.25	1.06	947	2.59	1.50	365	632	11	19
	2000 Jun 15 21:42:05		308	12.27	0.19	1.04	889	3.43	1.49	258	596	6	15
7	2001 Apr 1 11:26:06	No	116	4.21	0.27	1.33	1197	2.45	1.62	488	737	52	79
	2001 Apr 1 11:50:07		117	6.69	0.24	1.12	1318	2.69	1.53	490	861	25	44
8	2001 Dec 28 20:30:05	19:59 M	151	5.98	0.33	1.19	2132	2.17	1.56	981	1366	58	81
	2001 Dec 28 21:18:32	20:35 D	152	14.89	0.25	1.10	2067	2.62	1.52	788	1360	16	27
9	2002 Jan 14 06:05:05	06:08 M	220	4.82	0.25	1.91	1461	2.66	1.90	549	768	46	64
	2002 Jan 14 06:30:05	06:25 D	220	7.78	0.20	1.33	1762	3.19	1.63	551	1083	23	45

Kim+2012

Ramesh+2010



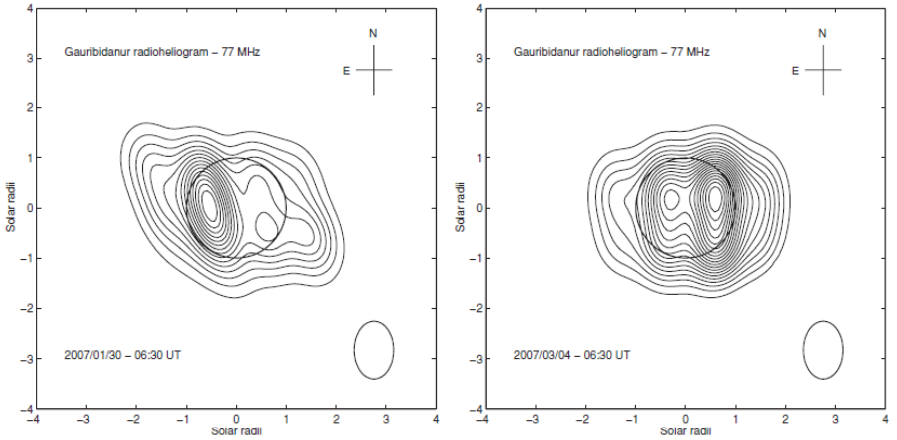


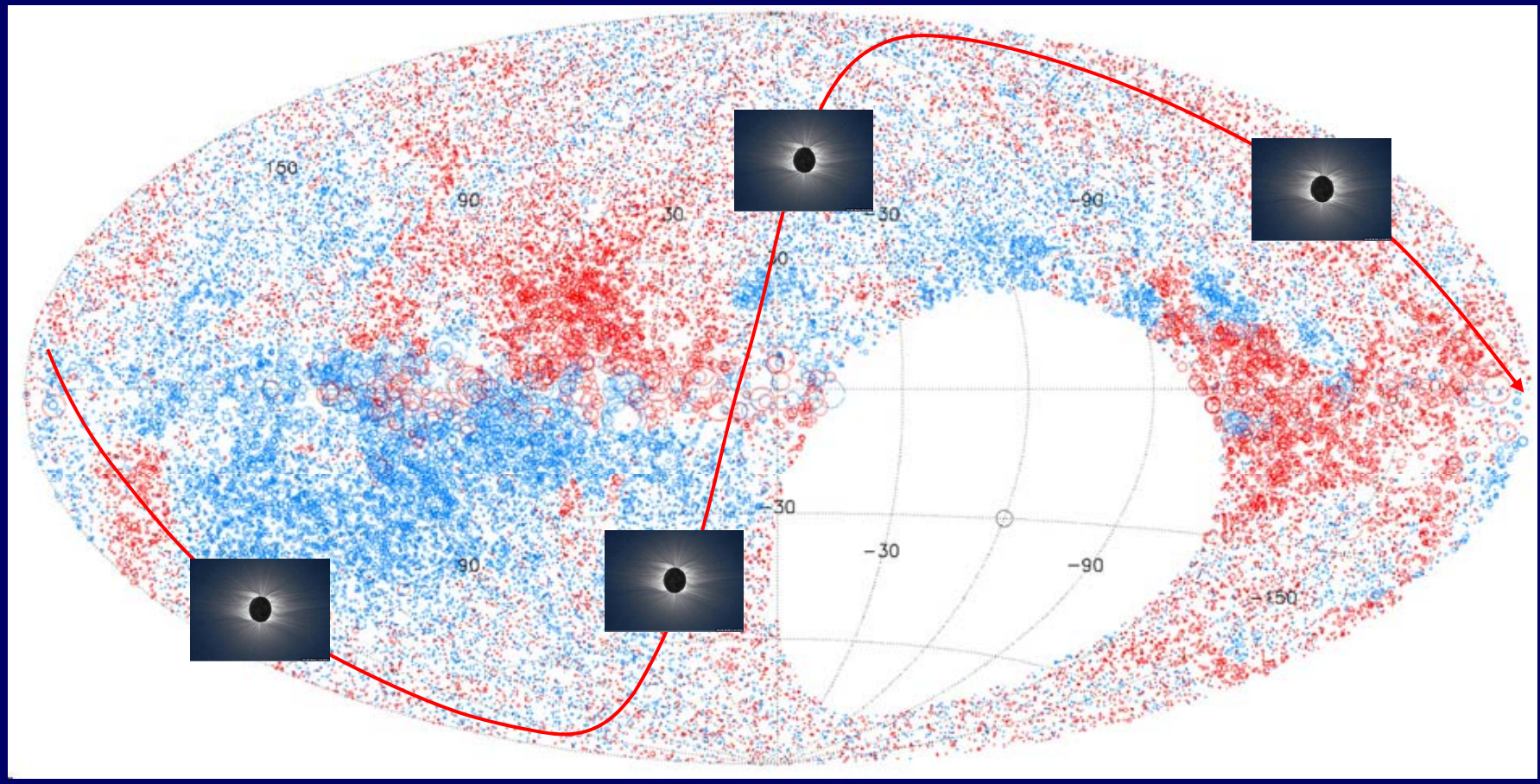
Figure 2. Radioheliograms obtained with the GRH on 2007 January 30 (left panel) and 2007 March 4 (right panel) at 77 MHz. The peak T_b values are $\approx 0.76 \times 10^6$ K and 0.78×10^6 K, respectively, on the above two days. They correspond to the discrete sources near the east limb (2007 January 30) and west limb (2007 March 4). The open circle at the center represents the limb of the solar photosphere, and the ellipse near the bottom right corner indicates the size of the GRH "beam" at 77 MHz in both the images.

Ramesh+2010

Table 1
Details of Gauribidanur Radio Polarimeter and Heliograph Observations

Parameter	2007 January 30	2007 March 4
Polarimeter observations		
109 MHz		
Stokes I flux	$13263 \pm 100\ Jy$	$13052 \pm 100\ Jy$
Stokes V flux	$1421 \pm 100\ Jy$	$1579 \pm 100\ Jy$
dcp	$10\% \pm 2\%$	$12\% \pm 2\%$
77 MHz		
Stokes I flux	$5133 \pm 150\ Jy$	$4875 \pm 150\ Jy$
Stokes V flux	$800 \pm 150\ Jy$	$687 \pm 150\ Jy$
dcp	$15\% \pm 5\%$	$14\% \pm 5\%$
Spectral index (β)–Stokes I	2.7 ± 0.3	2.8 ± 0.5
Spectral index (β)–Stokes V	1.7 ± 0.3	2.4 ± 0.5
GRH observations		
77 MHz		
Integrated flux	$5342 \pm 200\ Jy$	$5643 \pm 200\ Jy$
Peak T_b	0.76×10^6 K	0.78×10^6 K
Magnetic field		
109 MHz ($r \approx 1.5\ R_\odot$)	$6 \pm 2\ G$	$6 \pm 2\ G$
77 MHz ($r \approx 1.7\ R_\odot$)	$5 \pm 1\ G$	$5 \pm 1\ G$

Use SKA for, not only Tau A, but also the Faraday sky

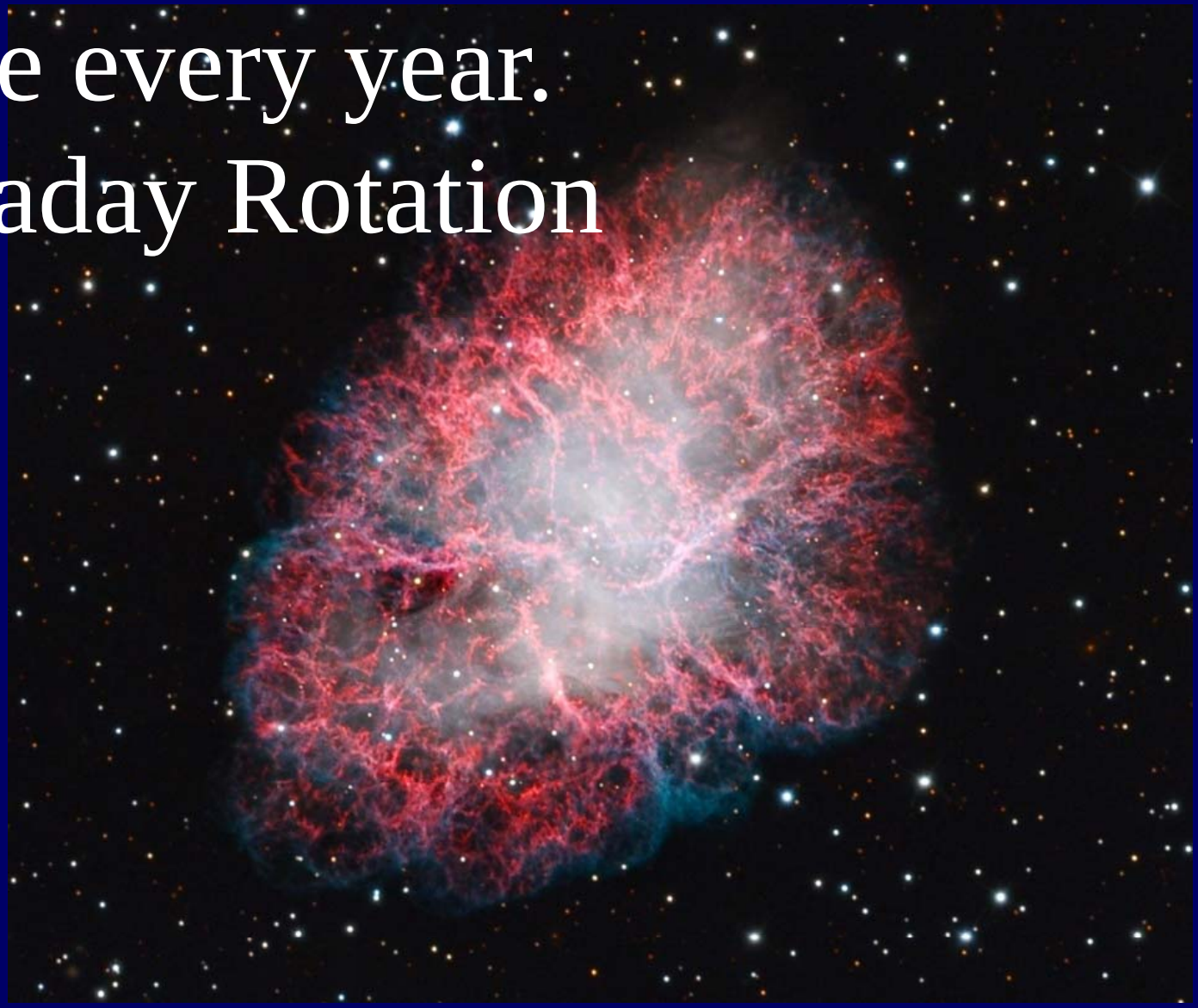


(Taylor 2009)

Coronal Occultation of Tau A

June every year.

Faraday Rotation



Sofue et al 1976 Sol. Phys.

CORONAL FARADAY ROTATION OF THE CRAB NEBULA, 1971–1975

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Department of Physics, Nagoya University, Nagoya, Japan

and

F. TAKAHASHI and N. KAWAJIRI
Kashima Station, Radio Research Laboratories, Kashima, Japan

(Received 17 June; in revised form 13 September, 1976)

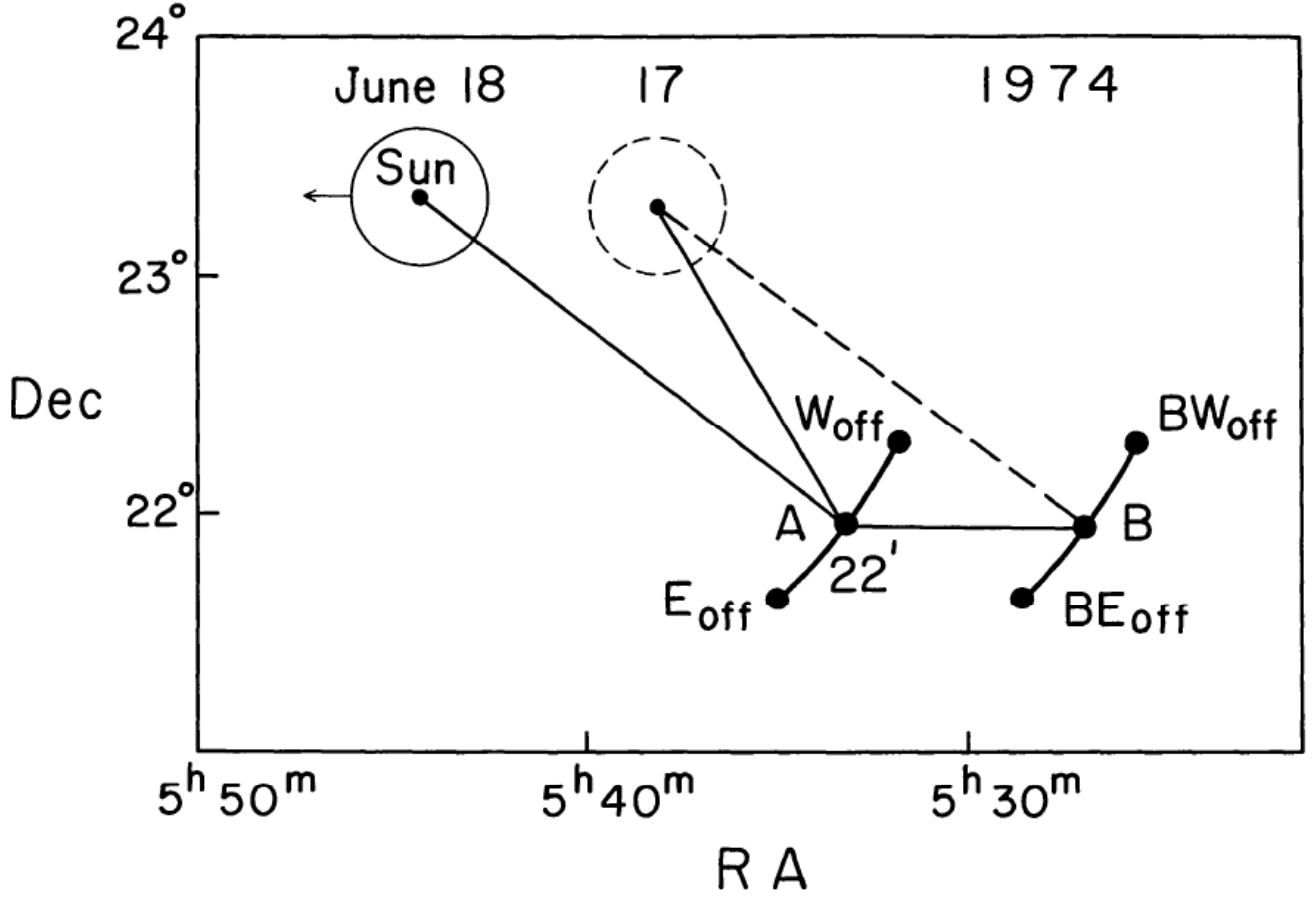


Fig. 1. Relative positions of Tau A (Point A) and the Sun on June 18 and 'off positions' (E_{off} and W_{off}), at

1-1000 x few % Jy

20,000 Jy

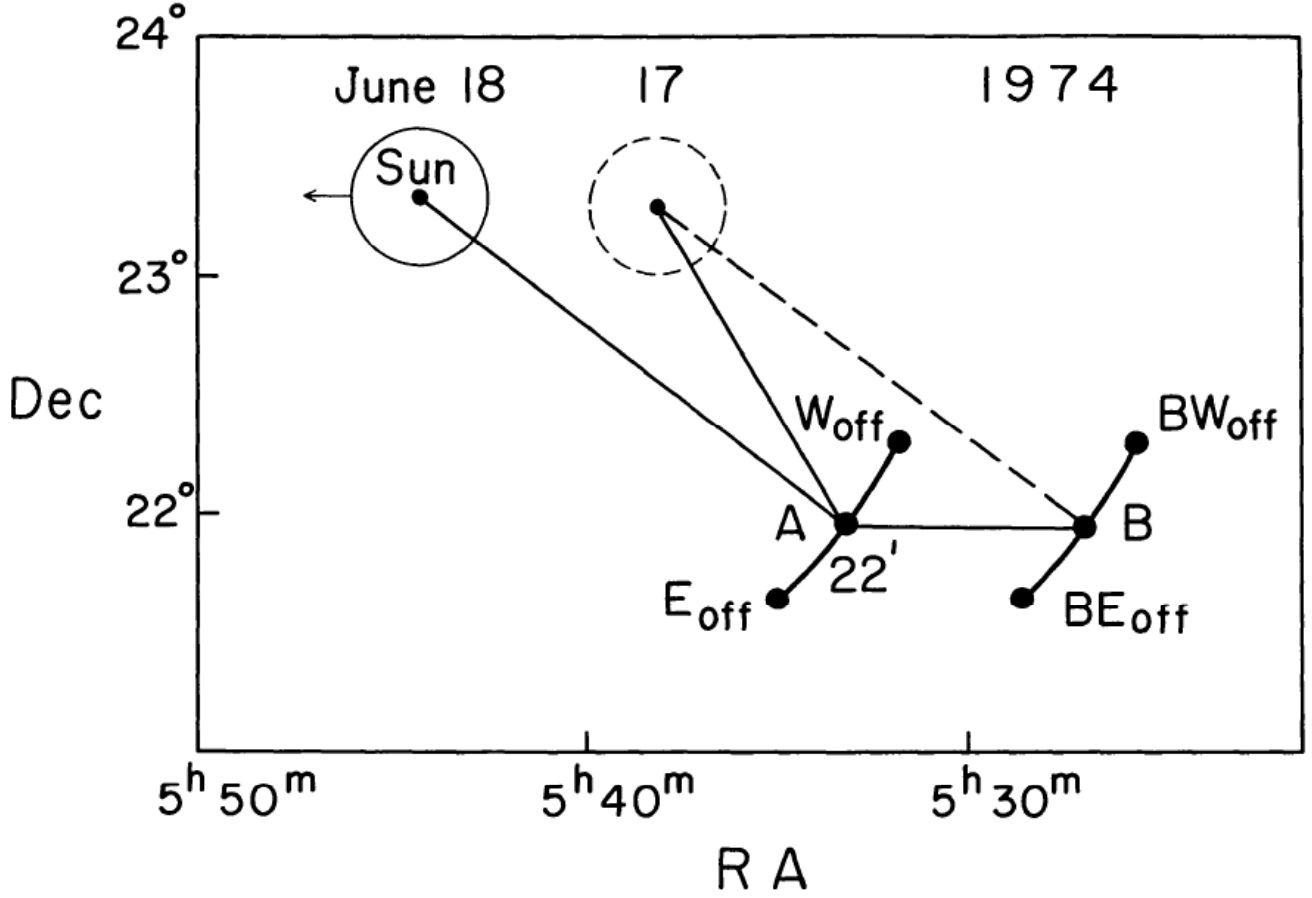
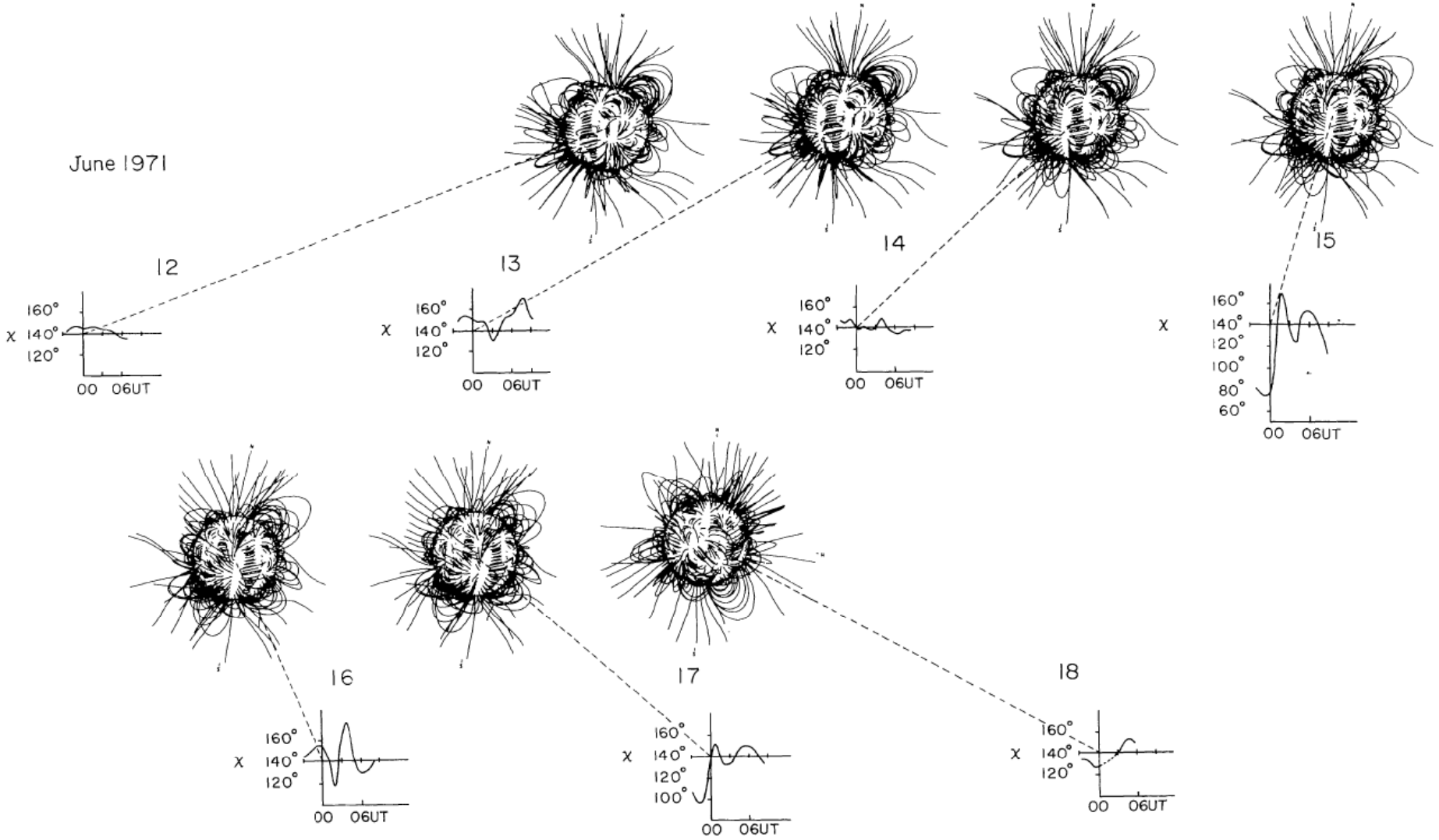
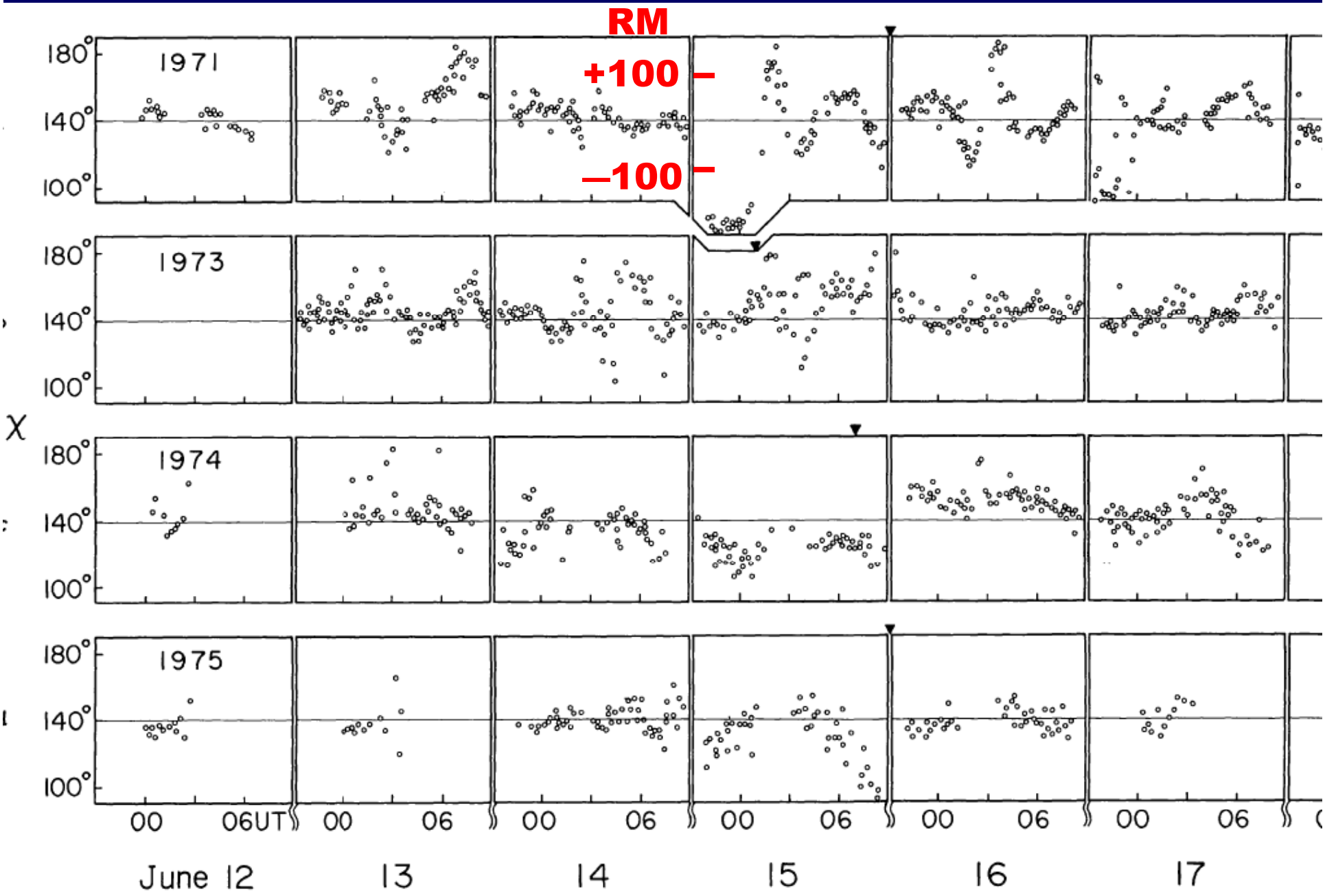


Fig. 1. Relative positions of Tau A (Point A) and the Sun on June 18 and 'off positions' (E_{off} and W_{off}), at


June 1971
12
13
14
15
16
17
18
160°
140°
120°
100°
80°
60°
X
00 06UT


RM
+100
–100
1971
1973
1974
1975
180°
140°
100°
χ
00
06UT
06
June 12
13
14
15
16
17

$$RM = 0.81 \int N_e[\mathrm{cm}^{-3}] B_{//}[\mu\mathrm{G}] ds[\mathrm{pc}]$$

$$= 1.82 \times 10^{-2} \int N_e[\mathrm{cm}^{-3}] B_{//}[\mathrm{G}] ds/R_\odot \quad [\mathrm{rad\ m}^{-2}]$$

$$N_\mathrm{e} \simeq 1.5 \times 10^6 \left(\frac{R}{R_\odot} \right)^{-2.5} \quad [\mathrm{cm}^{-3}]$$

$$B \simeq 1 \left(\frac{R}{R_\odot} \right)^{-2} \quad [\mathrm{G}]$$

At $R = 1R_\odot$, $s = 1R_\odot$,

$$N_\mathrm{e} \simeq 1.5 \times 10^6 \quad [\mathrm{cm}^{-3}]$$

$$B \simeq 1 \quad [\mathrm{G}]$$

$$RM = 1.82 \times 10^{-2} \times 1.5 \times 10^6 \times 1$$

$$\sim 3 \times 10^4 \quad [\mathrm{rad\ m}^{-2}]$$

Quiet corona model

At 7 Ro

BNe=400 G cm^{-3}

Across streamer 1971-1973

RM=100-150 rad m^{-2}

BNe=5000-8000 G cm^{-3}

Across streamer 1974-1975

RM=120-150 rad m^{-2}

BNe=2000-3500 G cm^{-3}

IV.
Pulsar Faraday Rotation

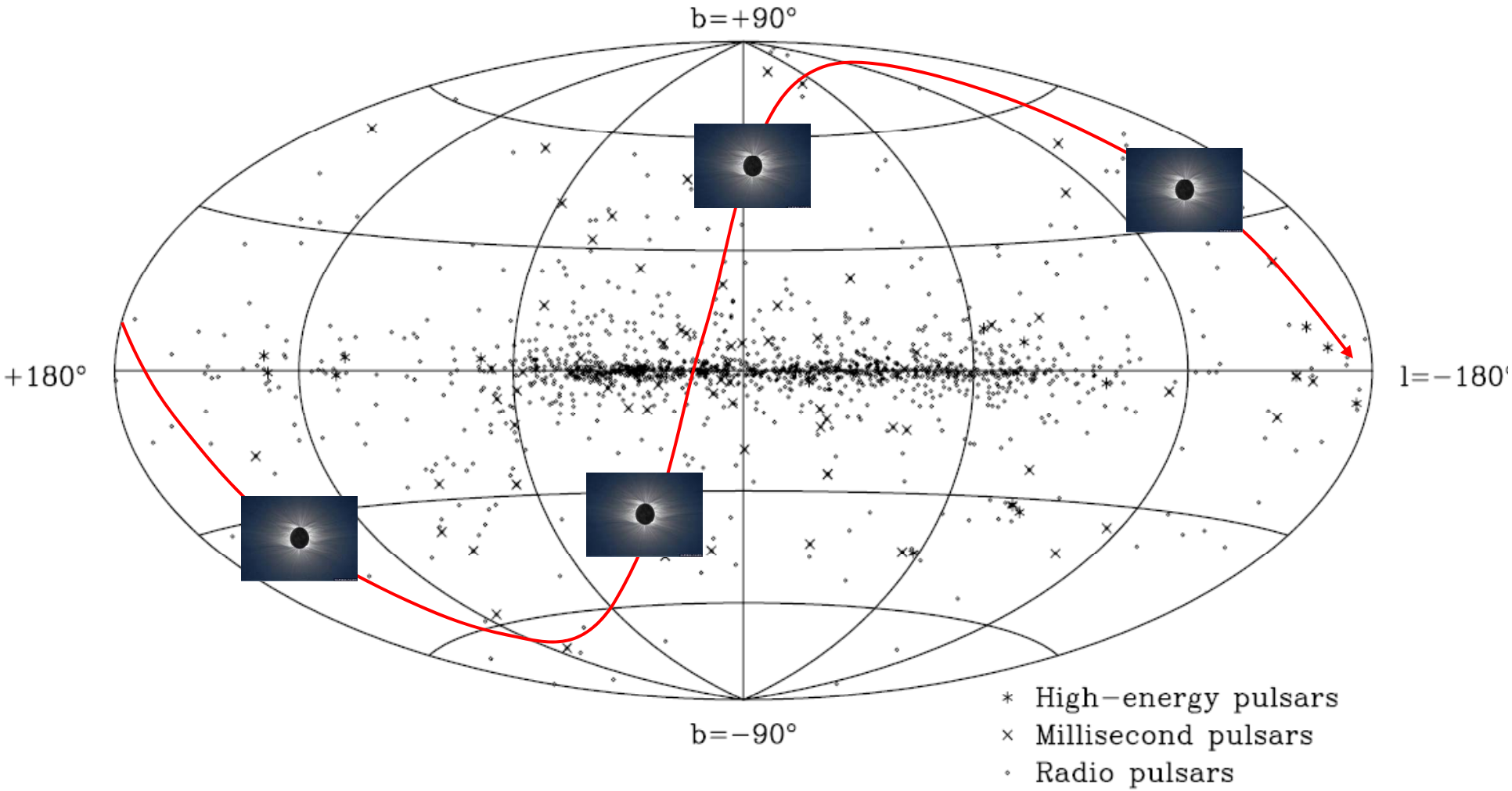


FIG. 3.—Distribution of pulsars on a Hammer-Aitoff equal-area projection in Galactic coordinates with the Galactic center at the center of the plot.

Manchester+ 2005

Pulsar RM Coronal Mag. Fields.

Strongly polarised & "Pulsating" = FM

(Freq. modulation)

1-1000 x few % Jy

20,000-20,000 Jy

Ord+2007

The Magnetic Field of the Solar Corona from Pulsar Observations

ORD, JOHNSTON AND SARKISSIAN

Table I. Possible Targets

Pulsar Name	Ecliptic Longitude : Latitude	Flux (mJy) at 1400 MHz
J1652-2404	254.73 : -1.50	1.1[a]
J1721-2457	261.18 : -1.81	unknown
J1730-2304	263.19 : 0.19	4[b]
J1733-2228	263.86 : 0.821	2.3[d]
J1753-2501	268.52 : -1.576	2.3[d]
J1756-2251	269.26 : 0.57	0.6[e]
J1756-2435	269.30 : -1.1554	2.0[d]
J1757-2421	269.42 : -0.9307	3.9[d]
J1757-2223	269.50 : 1.04	1.1[c]
J1759-2205	269.86 : 1.3467	1.3[d]
J1759-2302	269.96 : 0.40	1.3[c]
J1801-2304	270.31 : 0.36	2.2[d]
J1803-2137	270.89 : 1.8282	7.6[d]
J1807-2459A	271.66 : -1.57	1.1[d]
J1817-2311	273.91 : 0.20	unknown
J1822-2256	275.28 : 0.392	2.4[d]
J2048-1616	310.12 : 1.49	13[a]

$$n(r,\theta,\phi) = n_{CH}(r) + [n_{CS}(r) - n_{CH}(r)] \times \exp[-\theta^2/w^2(r,\phi)]. \quad (10)$$

Where,

$$n_{CH}(r) = \left[16.15\left(\frac{r}{R_\odot}\right)^{-4.39} + 9.975\left(\frac{r}{R_\odot}\right)^{-4.09} + 1.099\left(\frac{r}{R_\odot}\right)^{-2}\right] \times 10^5. \quad (11)$$

and the streamer (n_{CS}) is given by:

$$n_{CS}(r) = \left[365\left(\frac{r}{R_\odot}\right)^{-4.31} + 3.6\left(\frac{r}{R_\odot}\right)^{-2}\right] \times 10^5, \quad (12)$$

$$B_r = \sum_{lm} P_l^m(\cos\theta)\,(g_{lm}\cos m\theta + h_{lm}\sin m\theta) \times \left((l+1)\left(\frac{R_\odot}{r}\right)^{l+2} - l\left(\frac{r}{R_s}\right)^{l-1} c_l\right) \quad (6)$$

$$B_\theta = -1 \times \sum_{lm}\left(\left(\frac{R_\odot}{r}\right)^{l+2} + \left(\frac{r}{R_s}\right)^{l-1} c_l\right) \times (g_{lm}\cos m\theta + h_{lm}\sin m\theta)\,\frac{\delta P_l^m(\cos\theta)}{\delta\theta} \quad (7)$$

$$B_\phi = \sum_{lm}\left(\left(\frac{R_\odot}{r}\right)^{l+2} + \left(\frac{r}{R_s}\right)^{l-1} c_l\right)\frac{m}{\sin\theta} \times (\cos\theta)\,(g_{lm}\sin m\theta - h_{lm}\cos m\theta)\,P_l^m(\cos\theta) \quad (8)$$

$$c_l = -\frac{R_\odot}{R_s}, \quad (9)$$

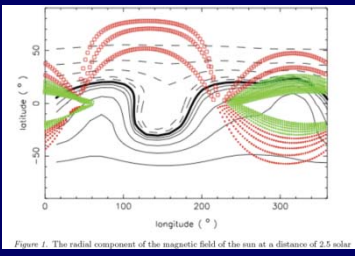


Figure 1. The radial component of the magnetic field of the sun at a distance of 2.5 solar

Ord+2007

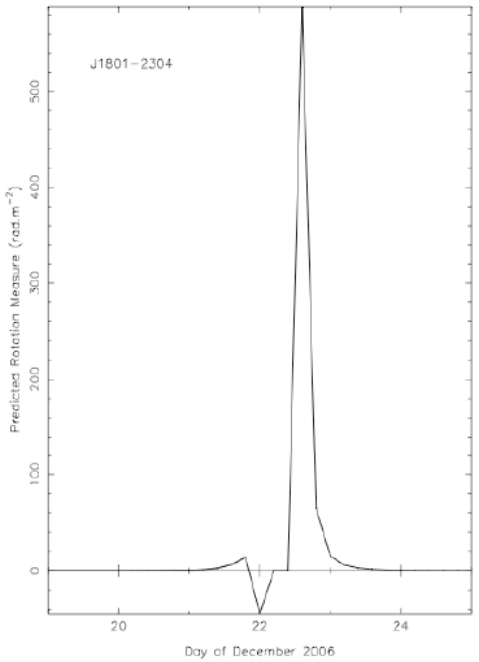


Figure 2. The predicted excess Faraday rotation for J1801−2304. The pulsar was observed throughout this period, unfortunately the observation at the height of the predicted Faraday rotation has insufficient signal to noise ratio to allow a confirmation

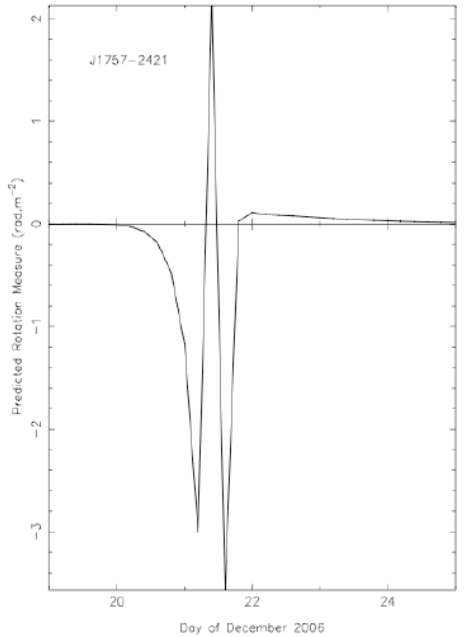


Figure 3. The predicted excess Faraday rotation for J1757−2421. The line of sight to this pulsar traverses regions of the corona that are symmetric in their magnetic field and electron properties, therefore it displays little net Faraday rotation.

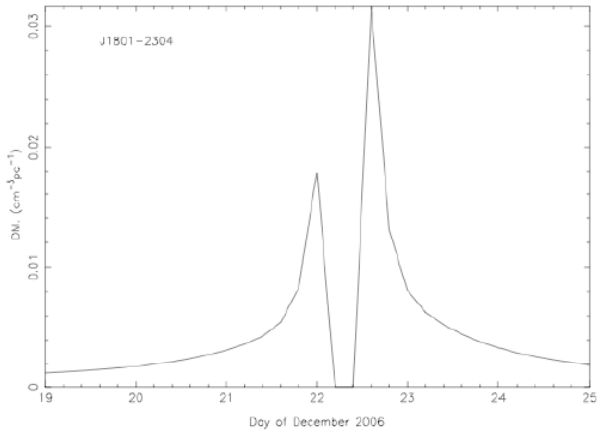
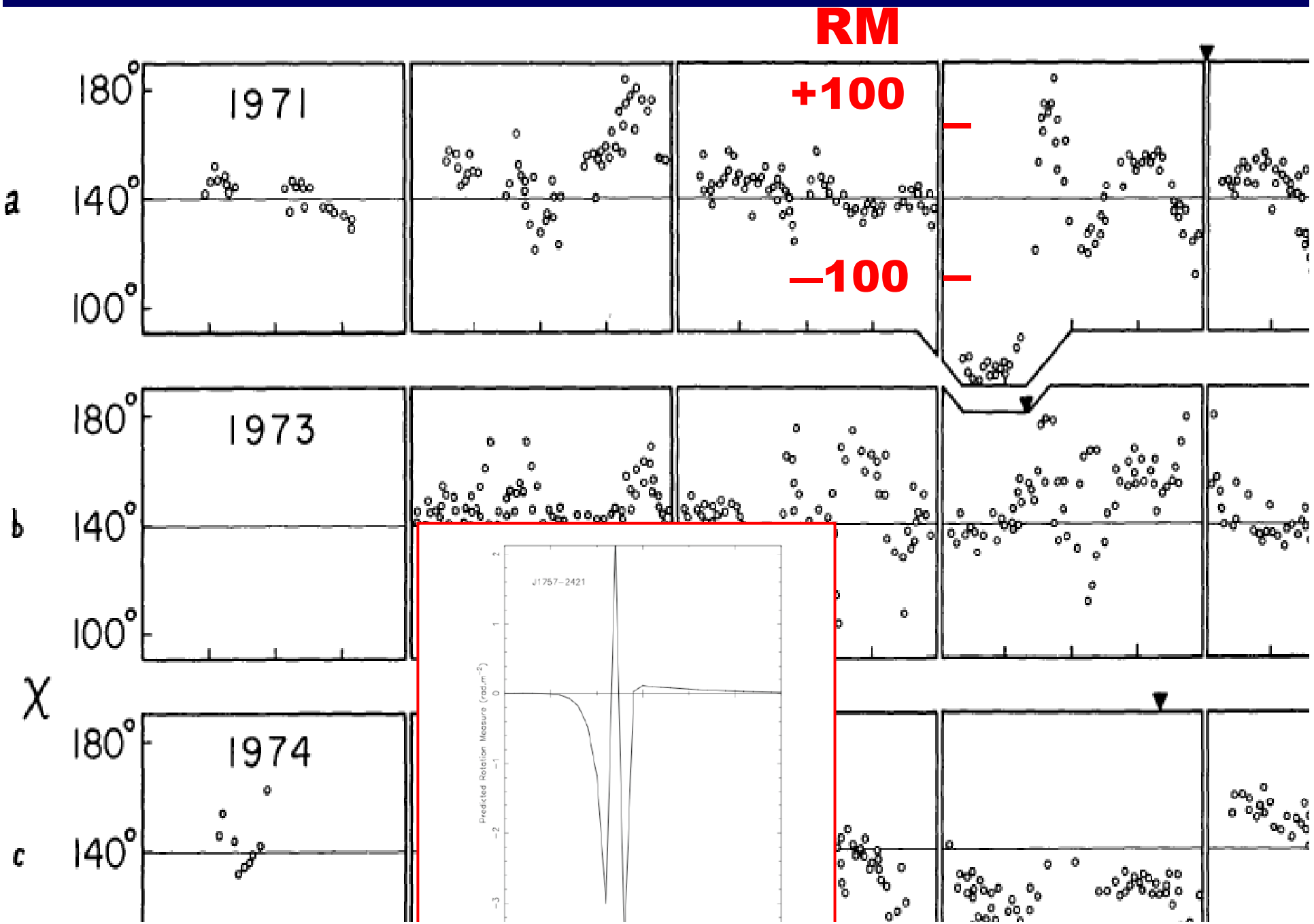


Figure 4. The expected DM variations for J1801−2304.

Ord+2007


RM
+100
–100
1971
1973
1974
180°
140°
100°
a
b
c
X
J1757–2421
Predicted Rotation Measure (rad.m⁻²)

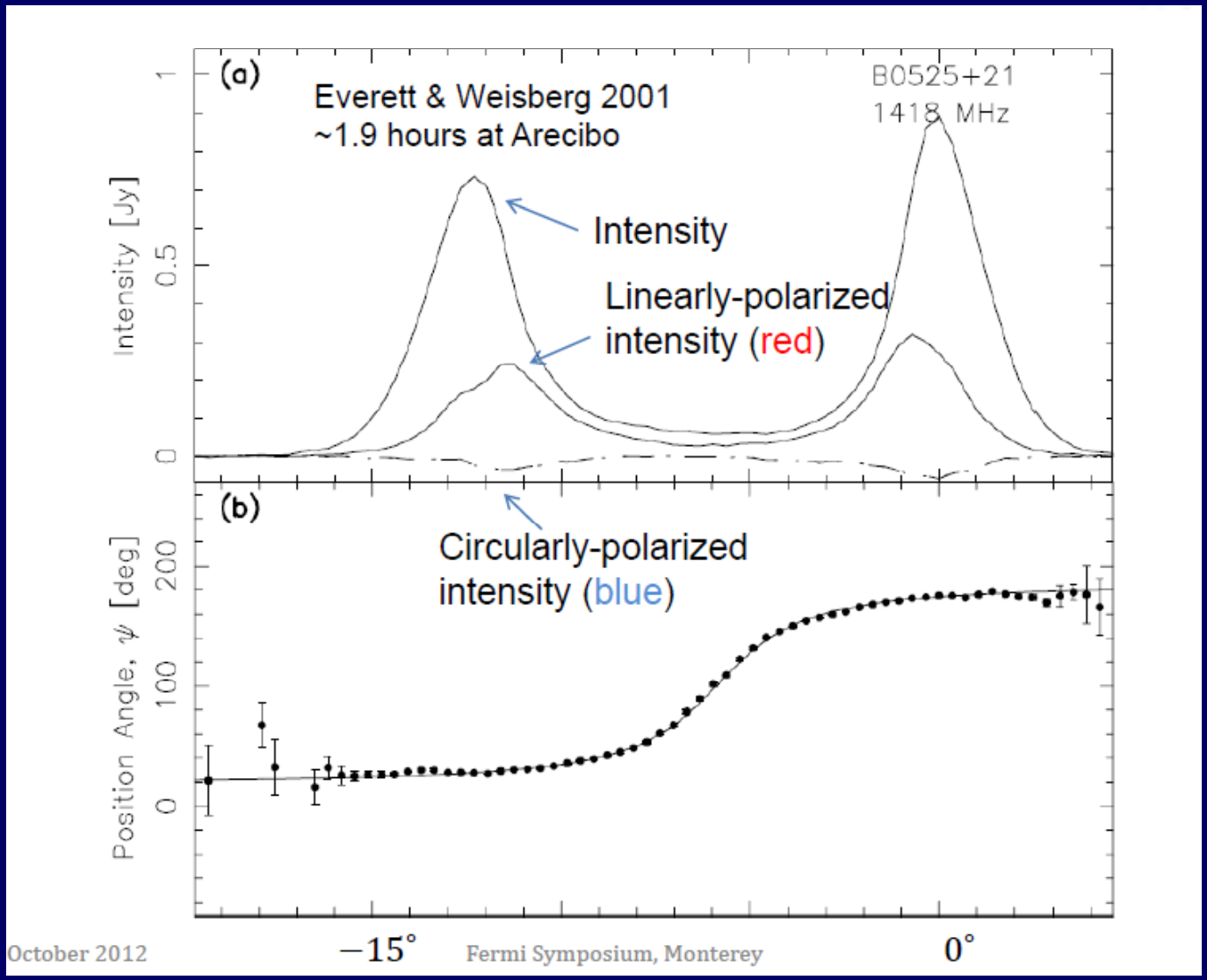
Catalogue version: 1.47

TABLE PLOT

Clear Parameters Clear Conditions
Clear All

Display parameters **Predefined Variables**

☐ Name	☐ JName	☑ RaJ	☑ DecJ	☐ PMRA	☐ PMDec
☐ PX	☐ PosEpoch	☐ ELong	☐ ELat	☐ PMELong	☐ PMELat
☐ GL	☐ GB	☐ RaJD	☐ DecJD		


(a)
Everett & Weisberg 2001
~1.9 hours at Arecibo
B0525+21
1418 MHz
Intensity
Linearly-polarized
intensity (red)
Intensity [Jy]
0
0.5
1
(b)
Circularly-polarized
intensity (blue)
Position Angle, ψ [deg]
0
100
200
−15°
0°
October 2012
Fermi Symposium, Monterey

Ker, M. 2012

GMRT – Parkes, Pulsar Polarization survey:243, 325, 660, 1400, 3100 MHz

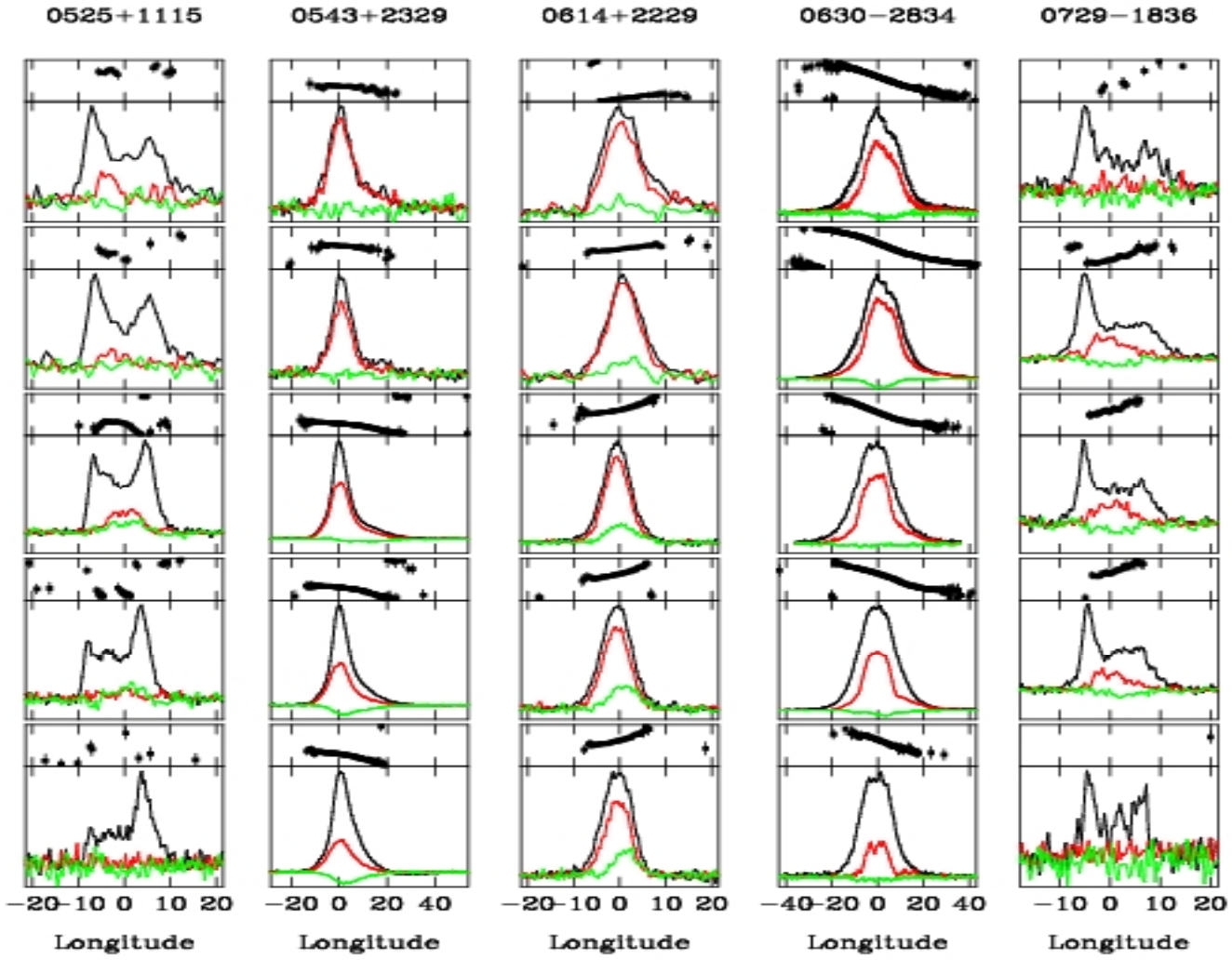
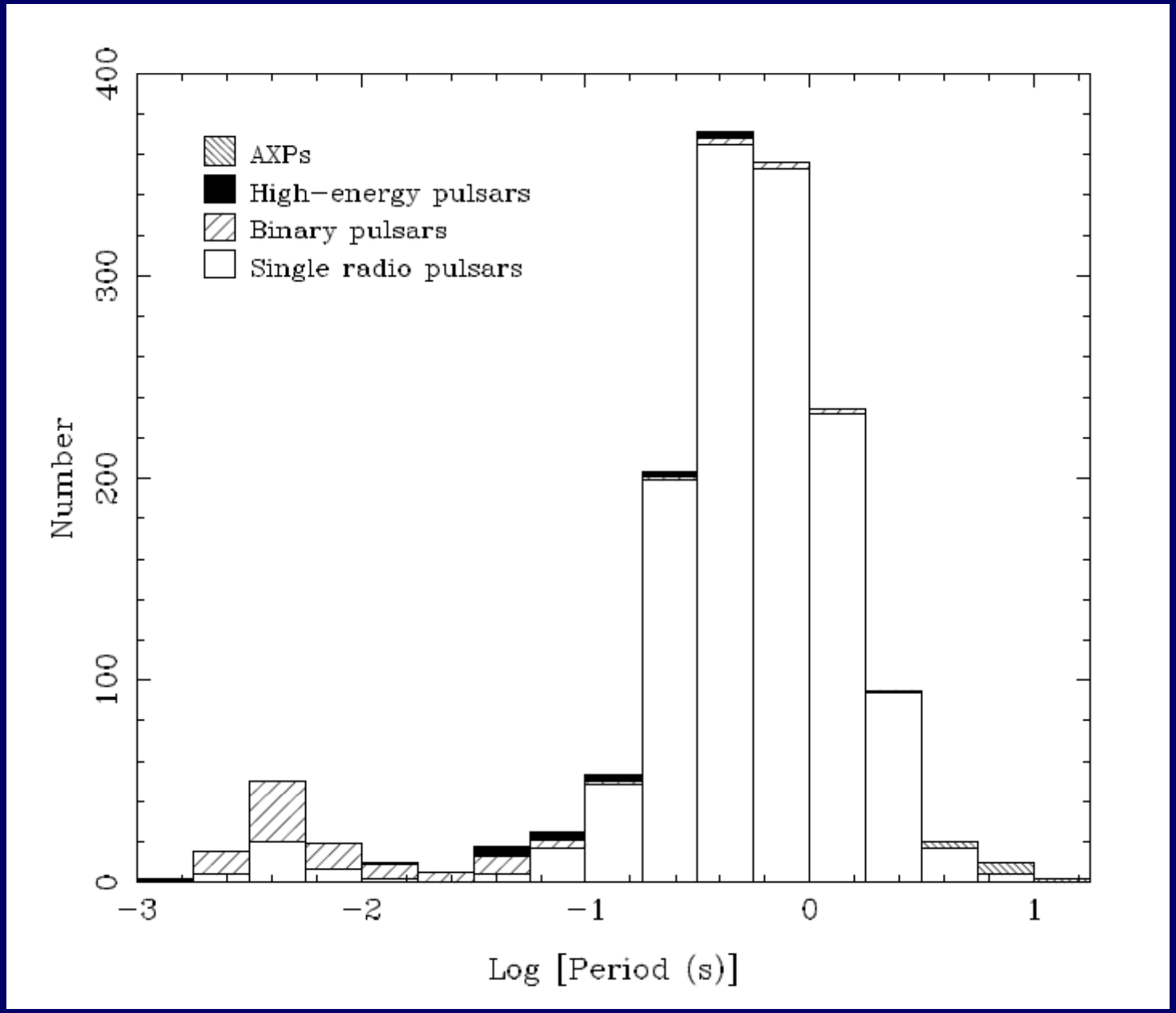
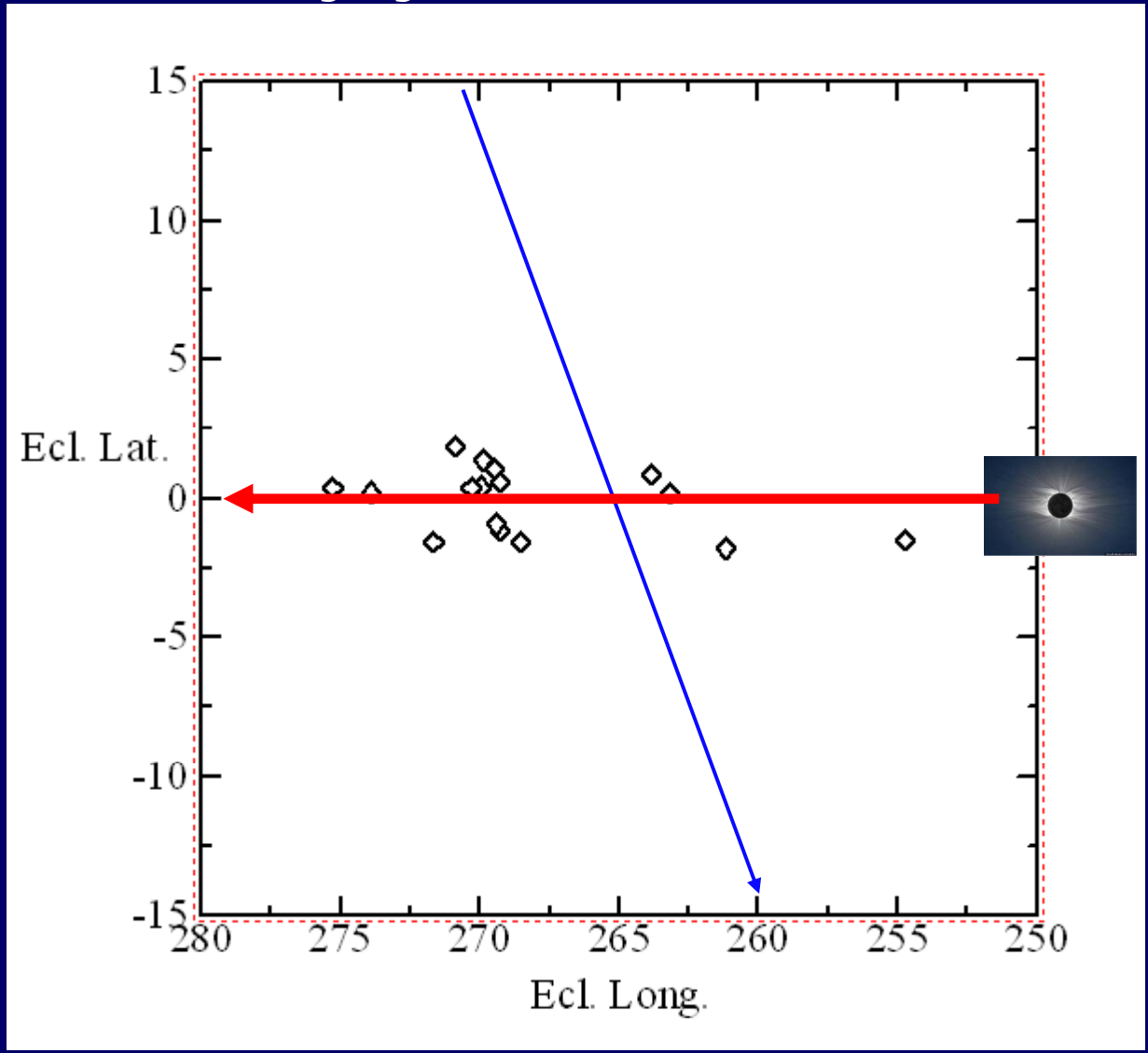


Figure 2. Multifrequency plot 2

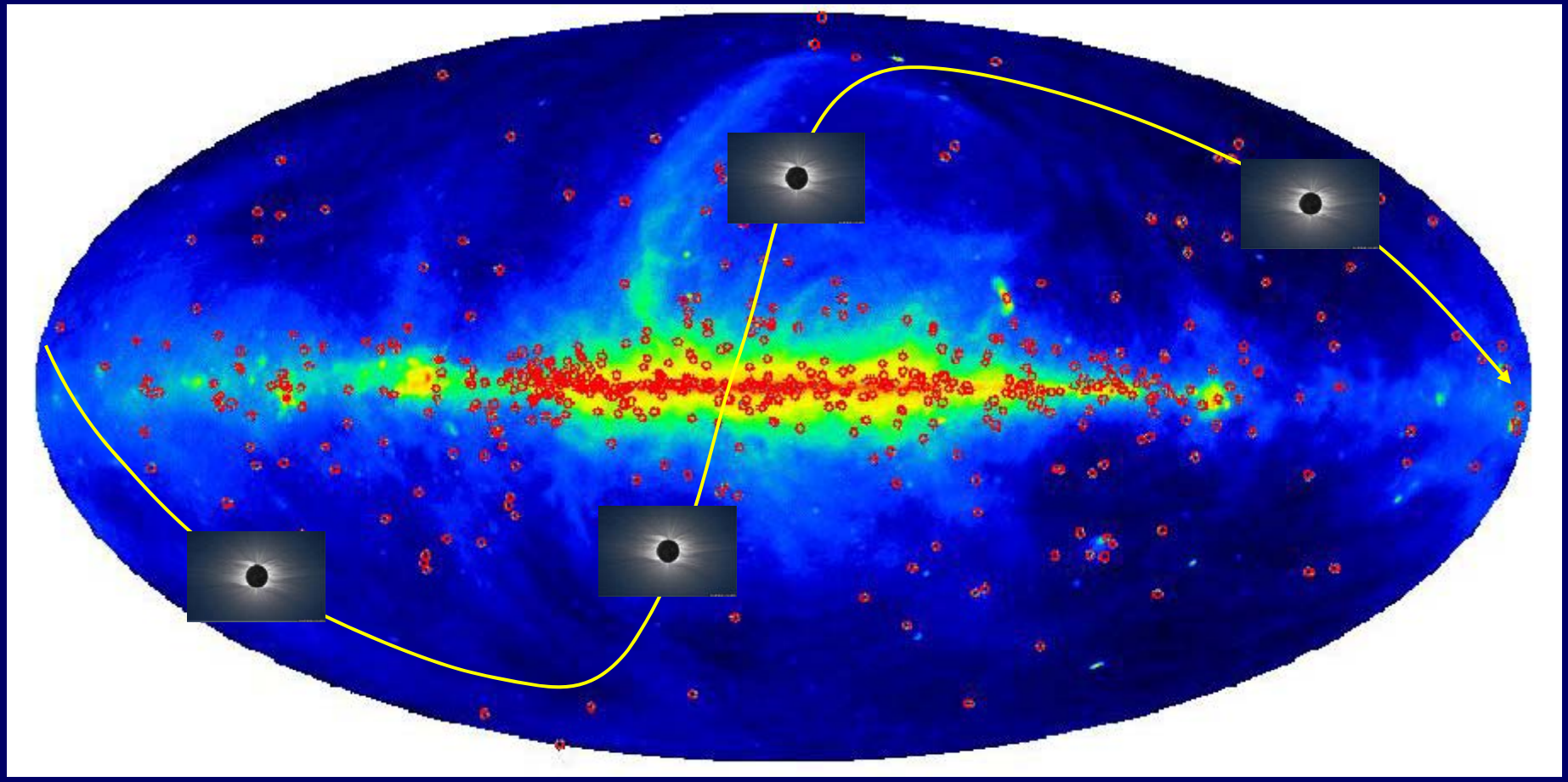
Johnston, Karasterigiou, Mitra, Gupta (2008)


AXPs
High−energy pulsars
Binary pulsars
Single radio pulsars
Number
0
100
200
300
400
−3
−2
−1
0
1
Log [Period (s)]

Ecliptic plane & Pulsars
December every year



Ecliptic plane & Pulsars



Toward SKA

ABOUT LOFAR

* General information
* System
* News Archive
* Informatie over LOFAR (in Dutch!)

Image Gallery

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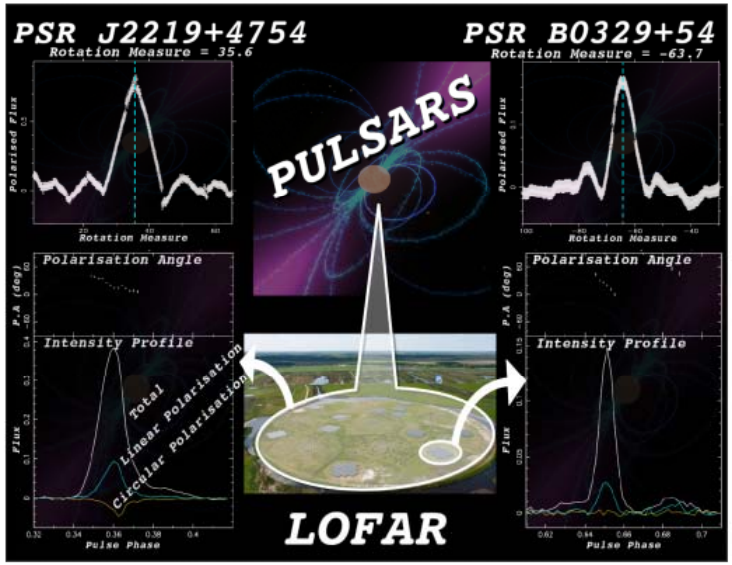
This project was co-financed by the EU, the European Fund for Regional Development and the Northern Netherlands Provinces (SNN), and EZ/KOMPAS.

* About LOFAR * News Archive

First Pulsar Polarisation Profiles with LOFAR

* 12 May 2012: Open Day at LOFAR telescope

Wed, 16/02/2011 - 00:00



Copyright: ASTRON

The image shows two of the very first polarisation profiles of pulsars observed with the LOFAR HBAs, those of PSR B0329+54 and PSR J2219+4754 (lower panels). It is the first time that such high-quality polarisation information is recorded at these frequencies by coherently combining the complex voltages from several LOFAR sub-stations. Although the polarisation profiles are not yet calibrated, work is being done in order to correct for the geometric and instrumental effects that affect the polarisation measurements during observation.

Observing pulsar polarisation at low frequencies can give insight into the magnetospheric physics of pulsars. The properties of polarised pulsar emission can be combined with those

search

Informatie over LOFAR in het Nederlands

ASTRON initiated LOFAR as a new and innovative effort to force a breakthrough in sensitivity for astronomical observations at radio-frequencies below 250 MHz.