Pulsars

NRAO Summer Student Lecture

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general

discovered in 1967 -- serendipity and Jocelyn Bell's perseverance
radio astronomer's dream
- rich phenomenology
- interesting physics
  - neutron star interiors
  - coherent emission mechanism
- interesting astronomy
  - neutron star formation scenarios
  - binary system evolution
  - Galactic supernova rate
- useful probes of ISM, Relativity

basic model

rotating neutron star
strong **B** and rotation --> strong surface **E** field
surface effects
primary positrons ($\mathbf{\Omega} * \mathbf{B} < 0$ case)
large Lorentz factors
pair creation cascade --> e^+e^- plasma
plasma instability
- bunching
- coherent radio emission

pulsar phenomena

waveforms (average profiles)
- small duty cycle
- mode switching
- interpulses

single pulses
- pulse energy variations
  - nulling
  - giant pulses
- subpulses
  - drifting
- micropulses

polarization
- waveforms (Radhakrishnan and Cooke)
  - high degree of linear and (sometimes) circular
- single pulses
  - orthogonally polarized radiation
  - depolarization
  - some pulses 100% polarized

pulsars as probes

galactic distribution
- scale height of progenitors

DM (Dispersion Measure) --> n_e

RM (Rotation Measure) and DM --> $\langle B \rangle$

scintillation: n_e variations; clumpiness; turbulence

binary pulsar: General Relativity probe

millisecond pulsars

PSR 1937+214
- discovered November 1982 by Backer, Kulkarni, Heiles, Goss, and Davis -- pure perseverance
- 1.577 millisecond period = 642 Hertz
- pulse and interpulse
- extremely small P-dot (1.0×10^{-19} sec/sec)
- very young or very old?
- pulse emission under extreme conditions
  - low magnetic field
  - proximity of light cylinder

PSR 1953+290

- discovered April 1983 by Boriakoff, Bucheri, and Fauci
- Cos-B error box: gamma-ray source?
  - but P-dot is not very large
- 6.1 millisecond period = 163 Hertz
- 120-day binary orbit
- spin-up scenario
- very large duty cycle

future work

- other searches: are there lots or only a few?
  - difficulty of periodicity searches -- P^{-2} dependence
  - non-pulsed searches
    - high polarization
    - scintillation
    - steep spectra
- comparison of "vanilla" and millisecond pulsar properties
- bank of celestial clocks
  - astronomers could take back time-keeping function

References

historical

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popular level

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Weisberg, J. M. and Taylor, J. H., 1981, "The binary pulsar and general relativity", *Scientific American*, 245, 74.

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Reynolds, S. P. and Stinebring, D. R., editors, 1984, *Millisecond Pulsars*, NRAO Workshop Proceedings (in preparation).

Sieber, W. and Wielebinski, R., editors, 1981, *Pulsars -- Proceedings of I.A.U. Symposium No. 95*, Dordrecht Reidel.

5630 Sawtelle Boulevard
Culver City, California 90230
April 29, 1968

Miss S. Jocelyn Bell
Mullard Radio Astronomy Observatory
Cambridge University, England

Dear Miss Bell:

I am writing to you about the unidentified radio emissions discovered by the astronomers at Cambridge University. These pulses have created great excitement among scientists, and I would like to suggest a new theory about these pulses. Sir Martin Ryle, head of Cambridge University's Radio Astronomy Department, says that the pulses are the most exciting astronomical discovery of all time.

The period of silence between the pulses is exactly the same every time--- 1.3372795 seconds. During my research, I noticed that this figure could be indicated as 13-37-27-95. The next step would be to multiply 13 x 37, with the result of 481. Three sepexrate encyclopedia's list an original height of 481 feet for the Great Pyramid (circa 2600 B. C.).

It is possible that the 1.337 has some special relationship to the engineering design and site of the Great Pyramid. The balance of this 1.337 unit is 2795. To my astonishment, I discovered that these figures appear in order in pi-- the ratio of the diameter of a circle to the circumference.

3.14159265358979323846264338--2--7--9--5....

The Great Pyramid's height (481) and base-side (755) appears to show the approximate proportion: 1: 3.14159 :: 481 : 755 x 2.

I noticed that the units contain the logical pattern of 79-79, 32-32 and 38-38, with the center at 26.

The English alphabet has 26 letters. Therefore, A equals 1, B equals 2, C equals 3, D equals 4--to Z equals the same 26.

A-B-C-D-E-G-G-H-I-J-K-L-M-N-O-P-Q-R-S-T-U-V-W-X-Y-Z (totals) 351. Rechecking, I discovered that 13 x 27 (1.3 37 27 95) equals the same 351.

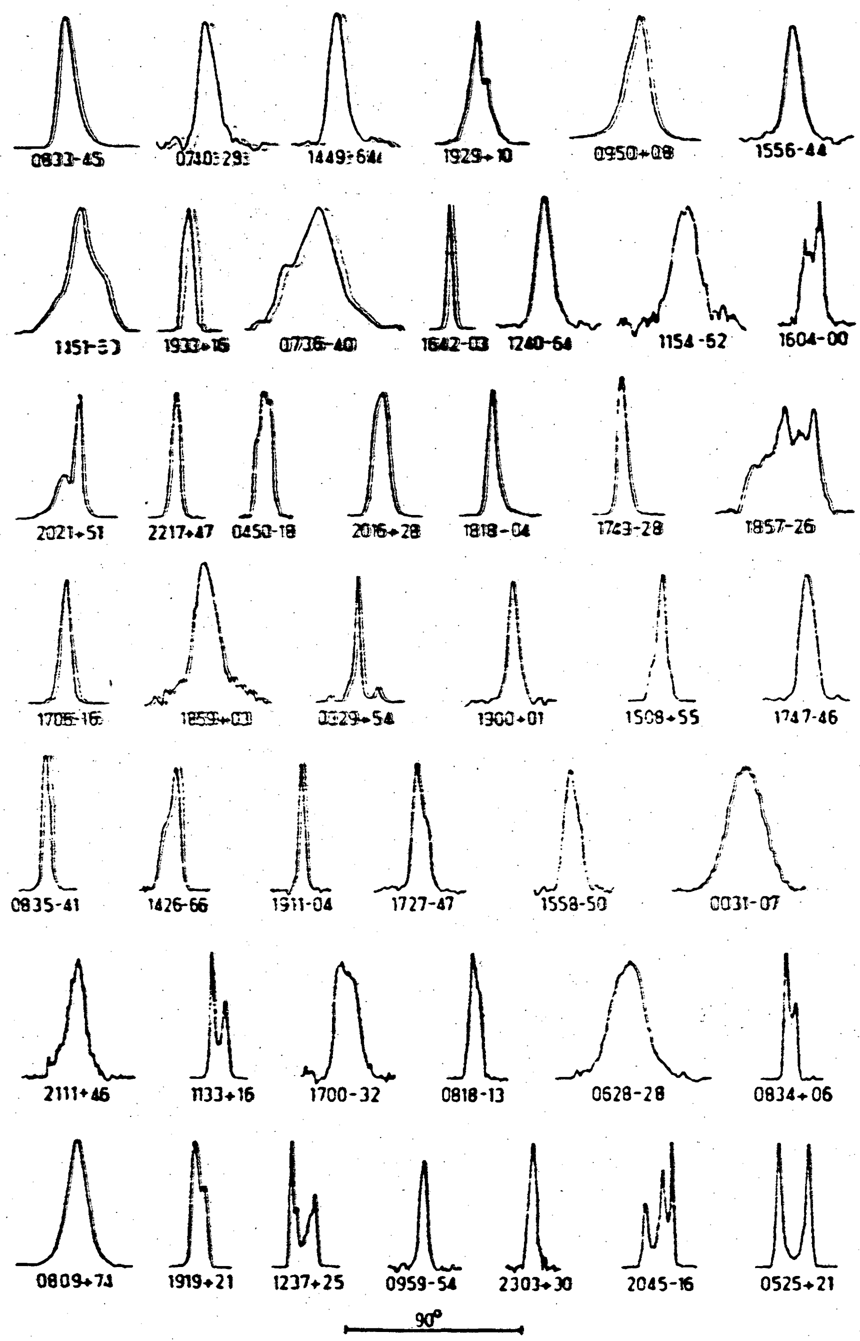
It is my opinion that the radio pulses seem to have some special relationship to pi and to the mathematical design and location of the Great Pyramid. The pulses may be an attempt to direct our attention to the mathematical properties of the Great Pyramid and to the possible mathematical-engineering design of the Earth.

Yours very truly,

Kenneth Larson

Kenneth Larson

VICTORY RESEARCH



2-1 Integrated pulse profiles for 45 pulsars, all plotted on the same longitude scale (a 90° bar is given in the bottom of the figure). These profiles were recorded at frequencies between 400 and 650 MHz, and are arranged in order of increasing pulse period.

P 1.5 msec to 4.2 sec

$\dot{P} \equiv \frac{dP}{dt}$ 2×10^{-19} to 4×10^{-13} $\frac{sec}{sec}$

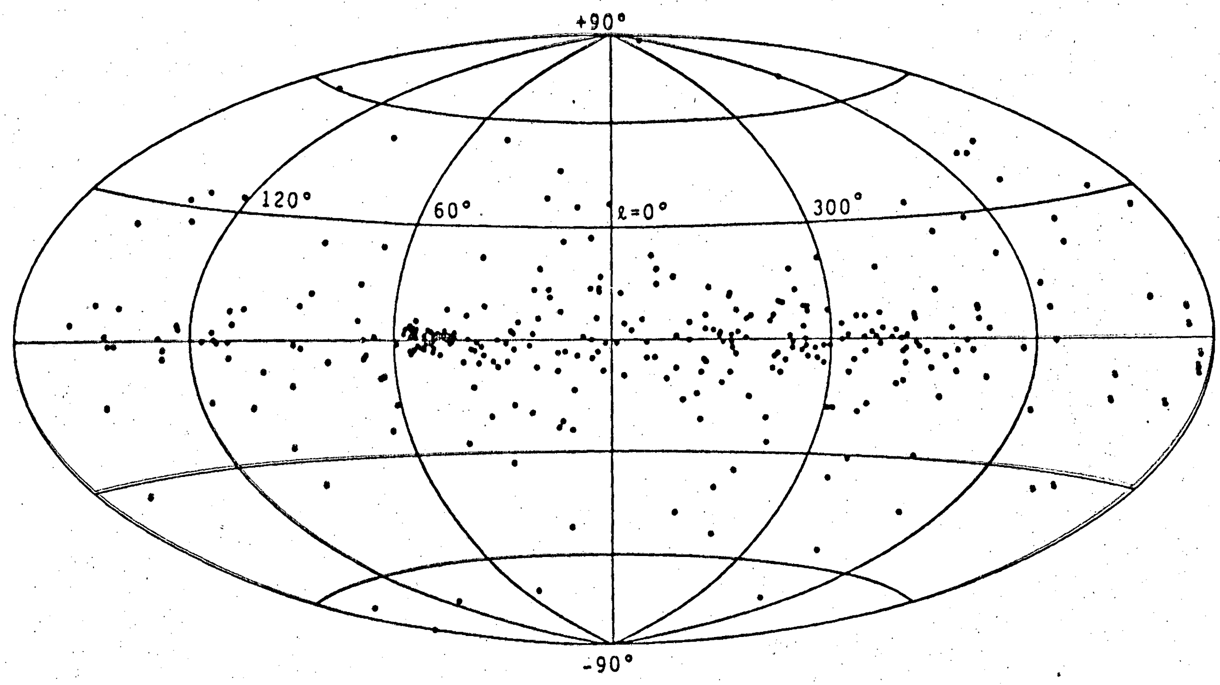
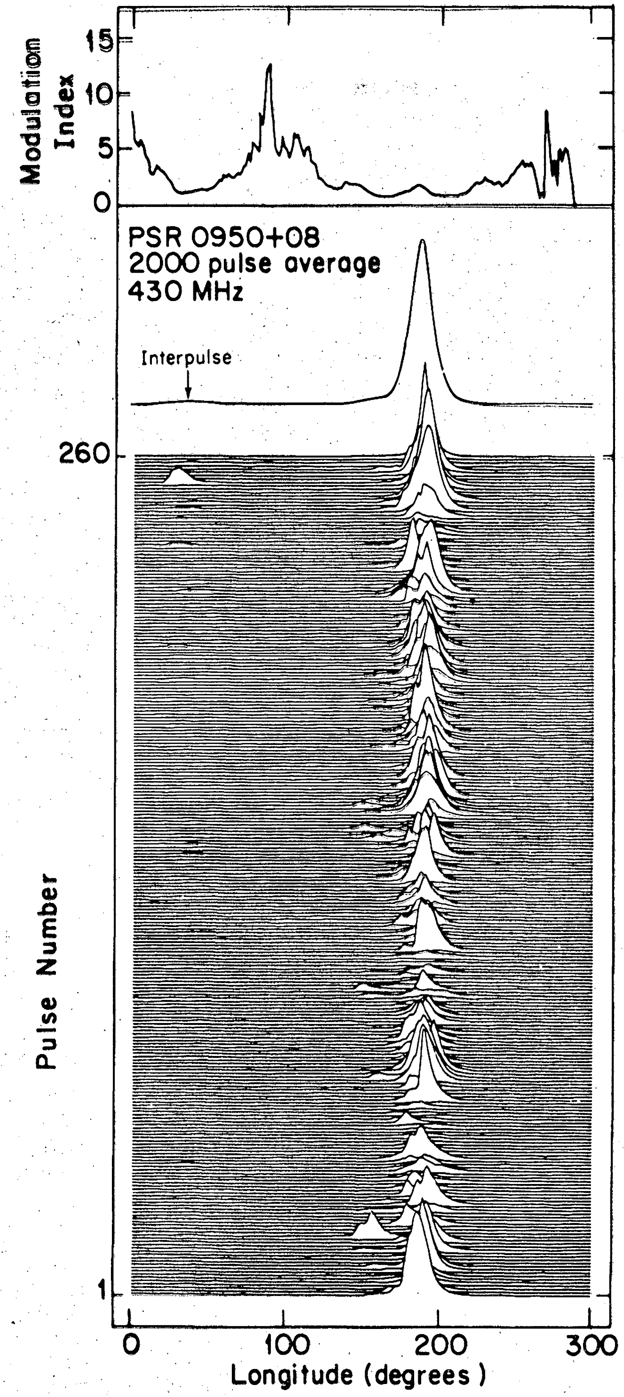
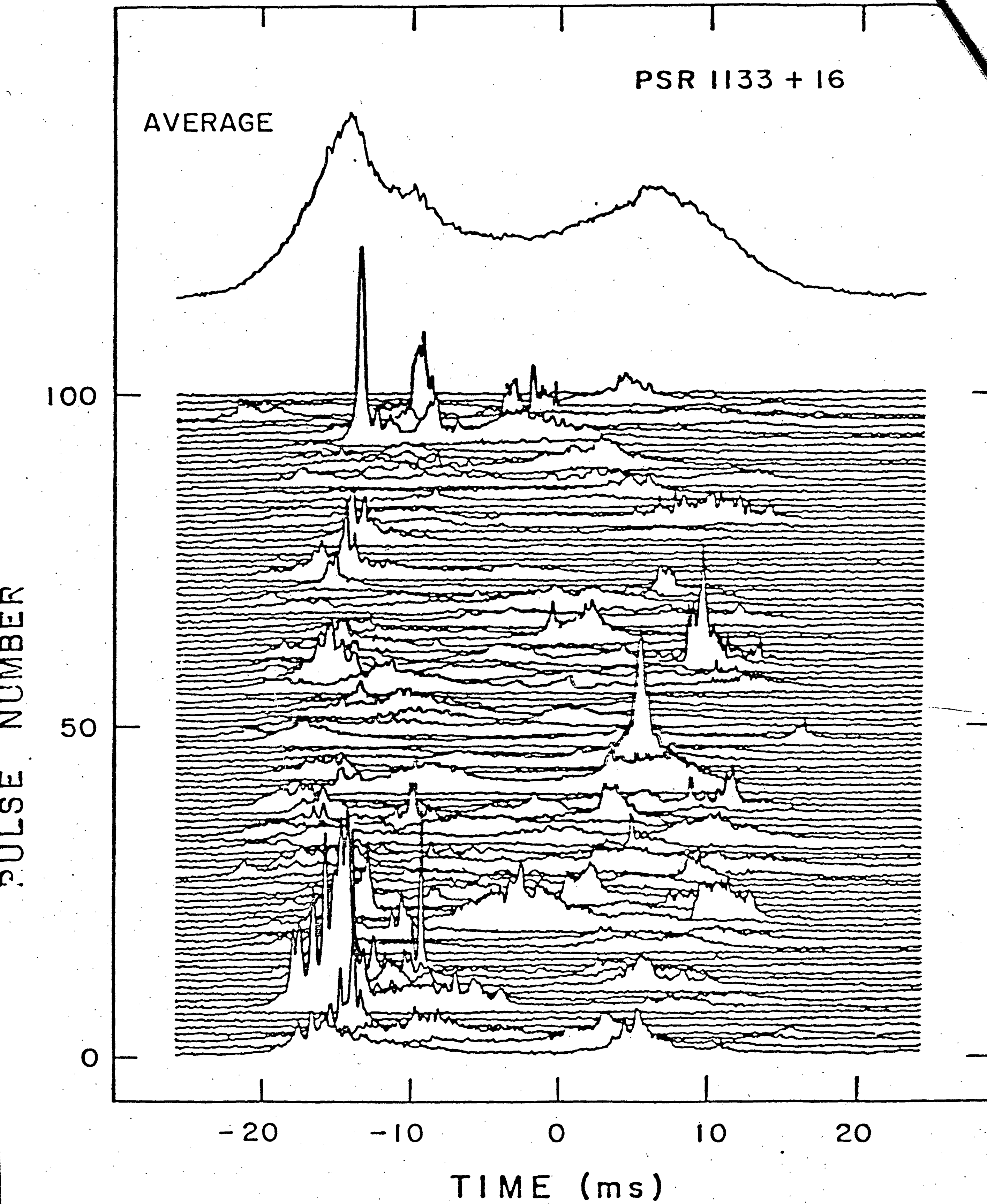


FIG. 1. An equal-area projection of the distribution of the 330 known pulsars in galactic coordinates. The galactic center is in the middle of the figure and longitude increases to the left.

 0004-6256/81/121953-21$00.90

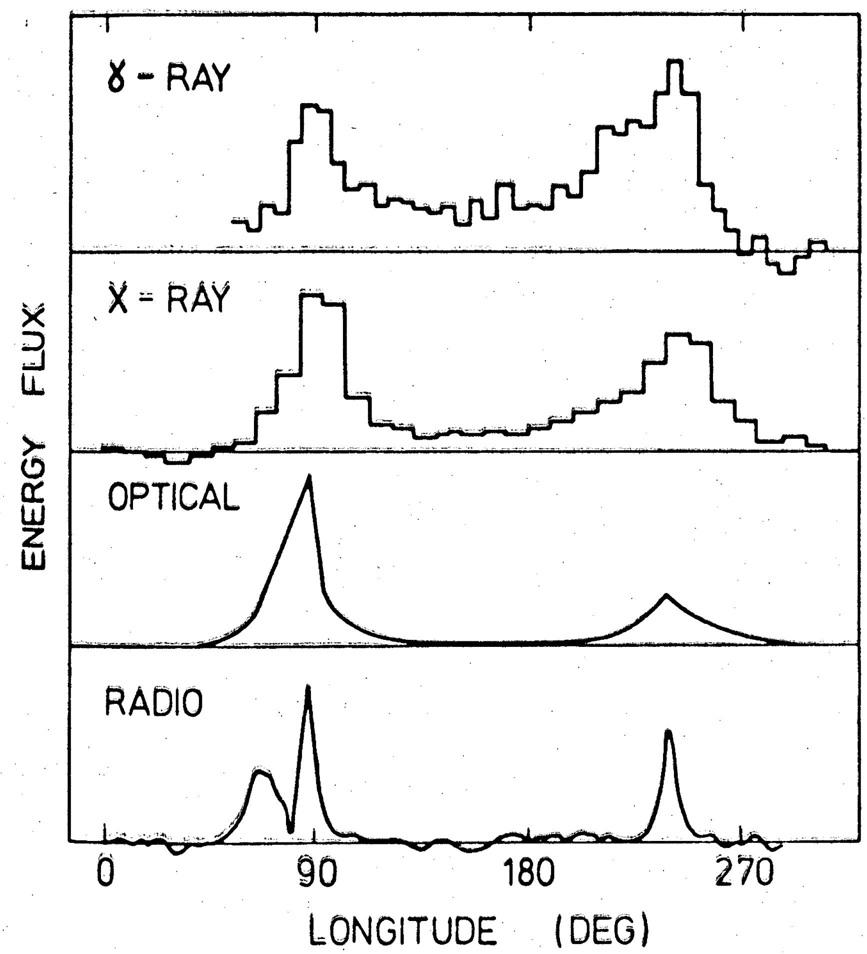


T.H. Hankins and J.M. Cordes, 1981, Ap.J, 249, 241.



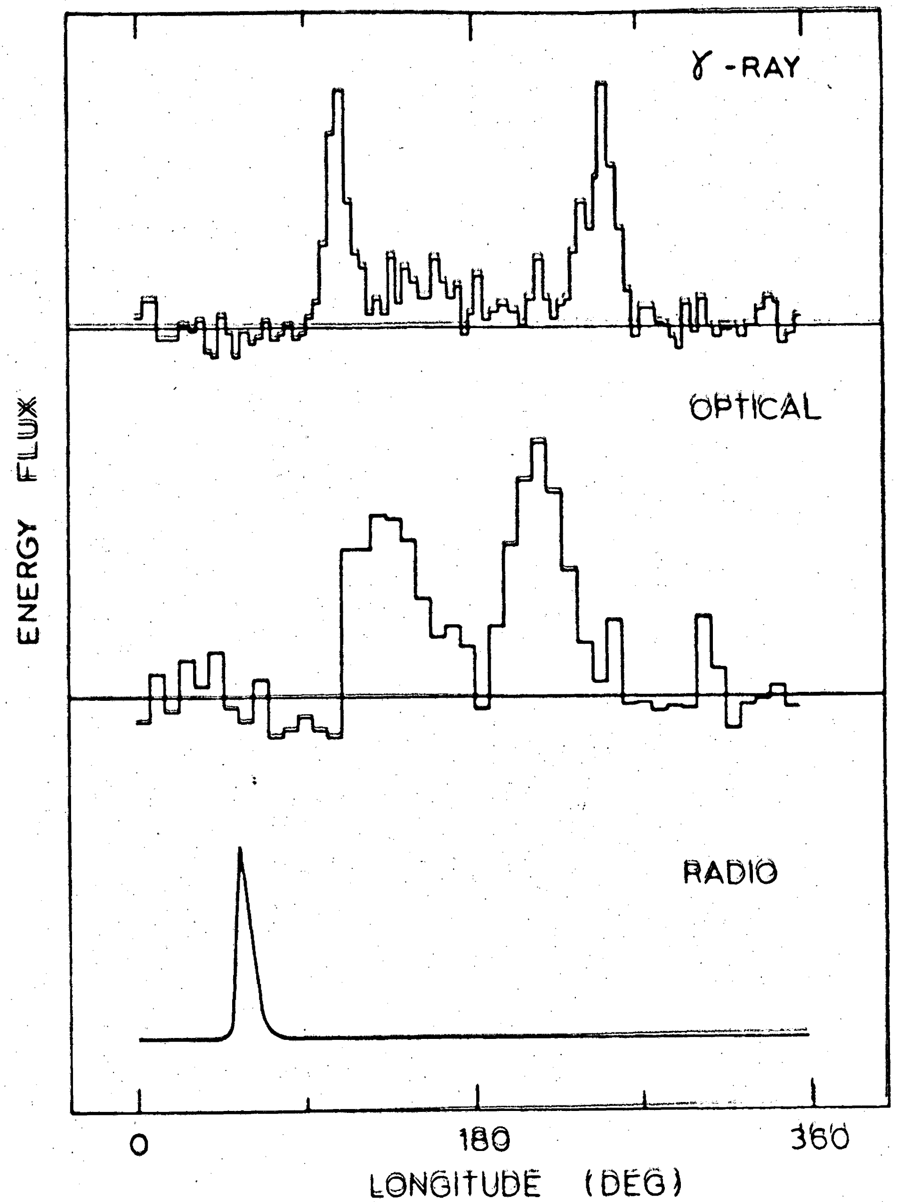
courtesy T. H. Hankins, J. M. Cordes

PSR 0531+21 Crab



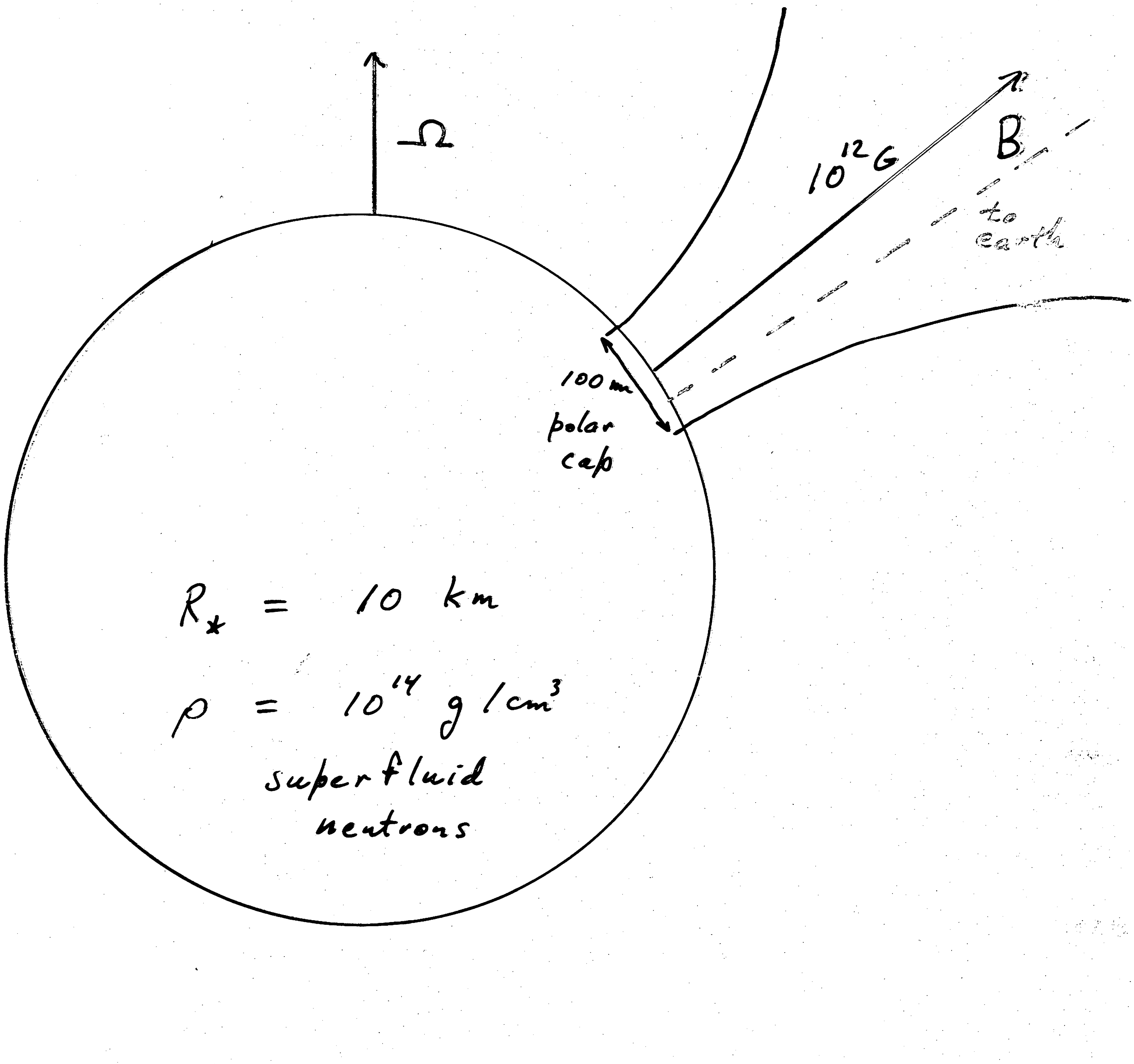
R. N. Manchester, 1978, Proc. ASA 3 (3), 200.

PSR 0833-45 Vela

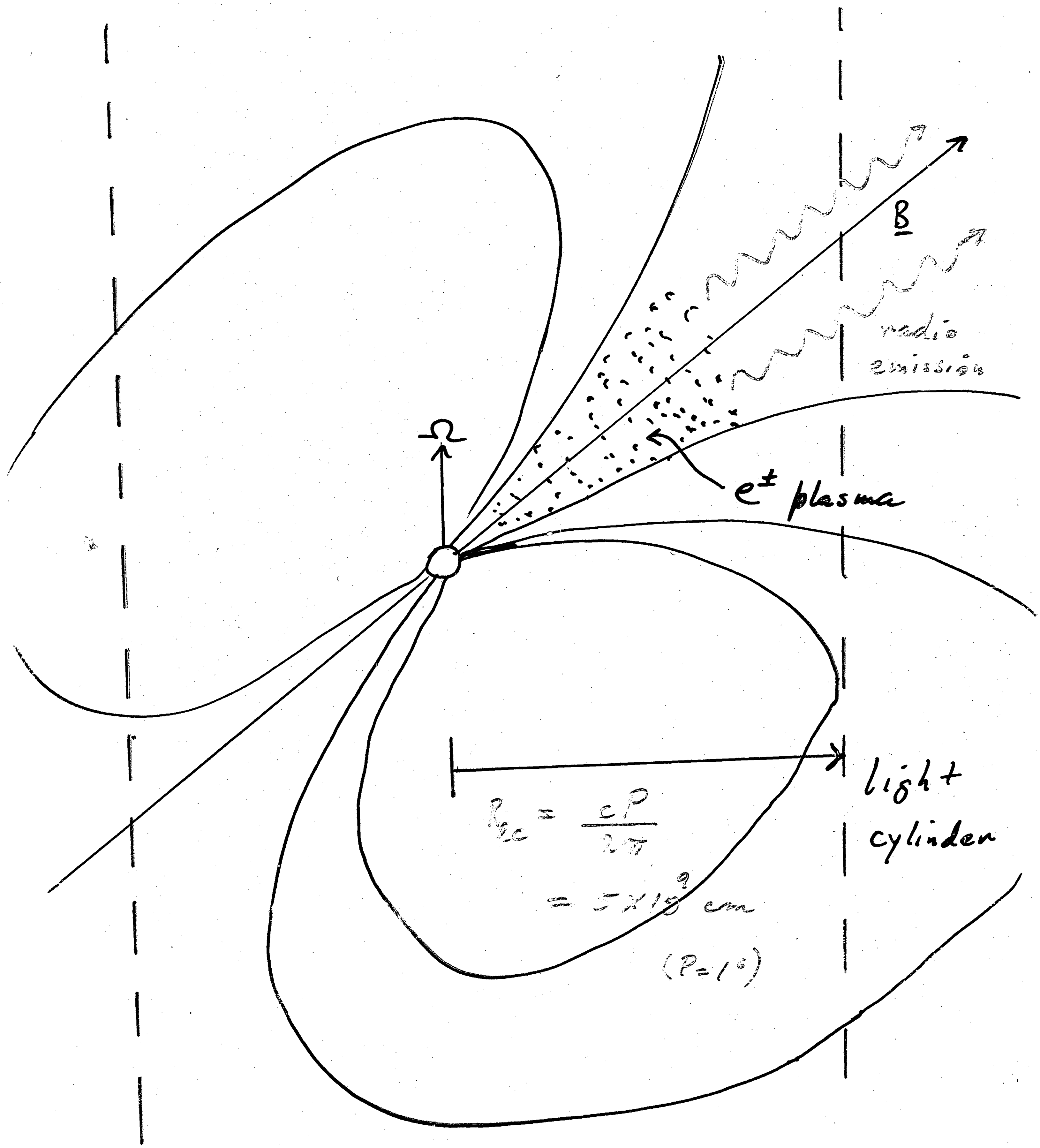


R.N. Manchester
1978, Proc. ASA,
3 (3), 200.

Pulsar = Rotating Neutron Star



Pulsar environment



Dispersion Measure

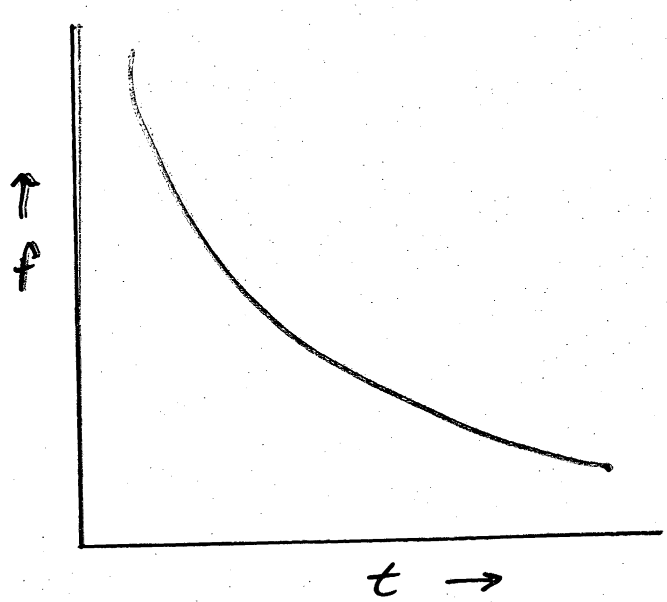
$$v_g = c\,(1 - \omega_p^2/\omega^2)^{1/2}$$

with $\omega_p^2 = \dfrac{4\pi n_e e^2}{m}$

[$\omega_p \sim 10\,kHz$ for ISM]

time delay between f_1 and f_2 :

$$\Delta t = K\left[\frac{1}{f_1^2} - \frac{1}{f_2^2}\right] \int n_e\, ds$$



f (GHz)	t (sec)
2.0	0.10
1.0	0.41
0.5	1.66
0.2	10.4

Electron density

$$DM \equiv \int n_e \, ds \qquad [\mathrm{cm^{-3}\ pc}]$$

$$3 \leq DM \leq 450$$

$$\langle n_e \rangle = \frac{DM}{d}$$

approaches:

1) measure DM for a sample of pulsars (≈ 30) whose distances are known by other means

$$\langle n_e \rangle \sim 0.03 \ \mathrm{cm^{-3}}$$

2) assume $\langle n_e \rangle$ known
use DM to derive distances to all known pulsars

⟹ pulsar scale height ~ 230 pc

Faraday rotation

$$v_{g1} \neq v_{g2}$$

$$\Delta \chi = \frac{K'}{f^2} \int n_e B \cos\theta \, ds$$

$$\Delta \chi = RM \, \lambda^2$$

where $RM \equiv K' \int n_e B \cos\theta \, ds$

[rad m^{-2}]

$$-500 \lesssim RM \lesssim +500$$

field away from us — field toward us

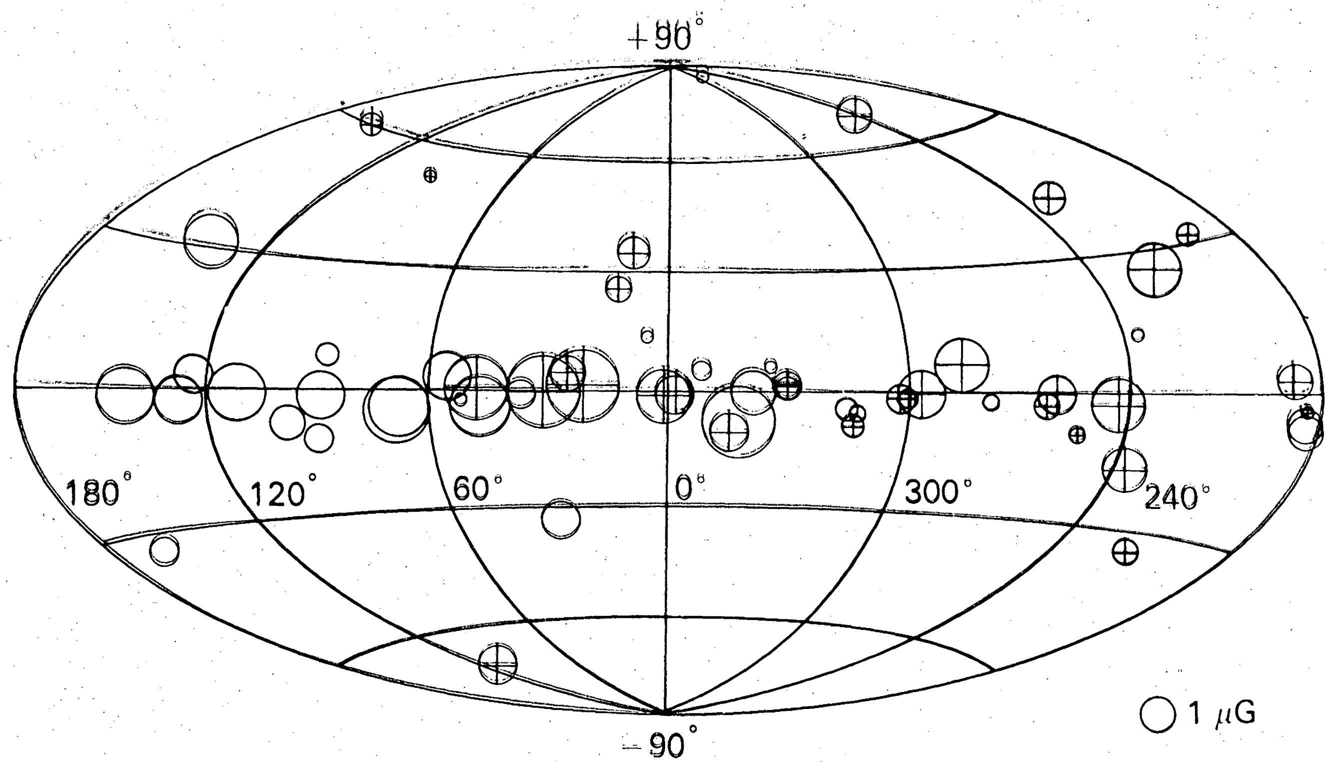
Galactic magnetic field

$$\langle B \cos\theta \rangle = \frac{\int n_e B \cos\theta \, ds}{\int n_e \, ds}$$

$$= 1.23 \frac{RM}{DM} \qquad [\mu G]$$

pulsars are ideal:

1) direct measure of field strength
2) highly polarized
3) all RM is due to the ISM
4) pulsar distances known fairly well



7-5 Mean line-of-sight magnetic field components in the paths to pulsars. For fields greater than 0.1 μG the area of the circle is proportional to the field strength (a circle representing a 1 μG field is shown in the lower right corner). A cross within a circle means the rotation measure is positive (field directed toward the observer). [From Manchester *et al.*, 1977.]

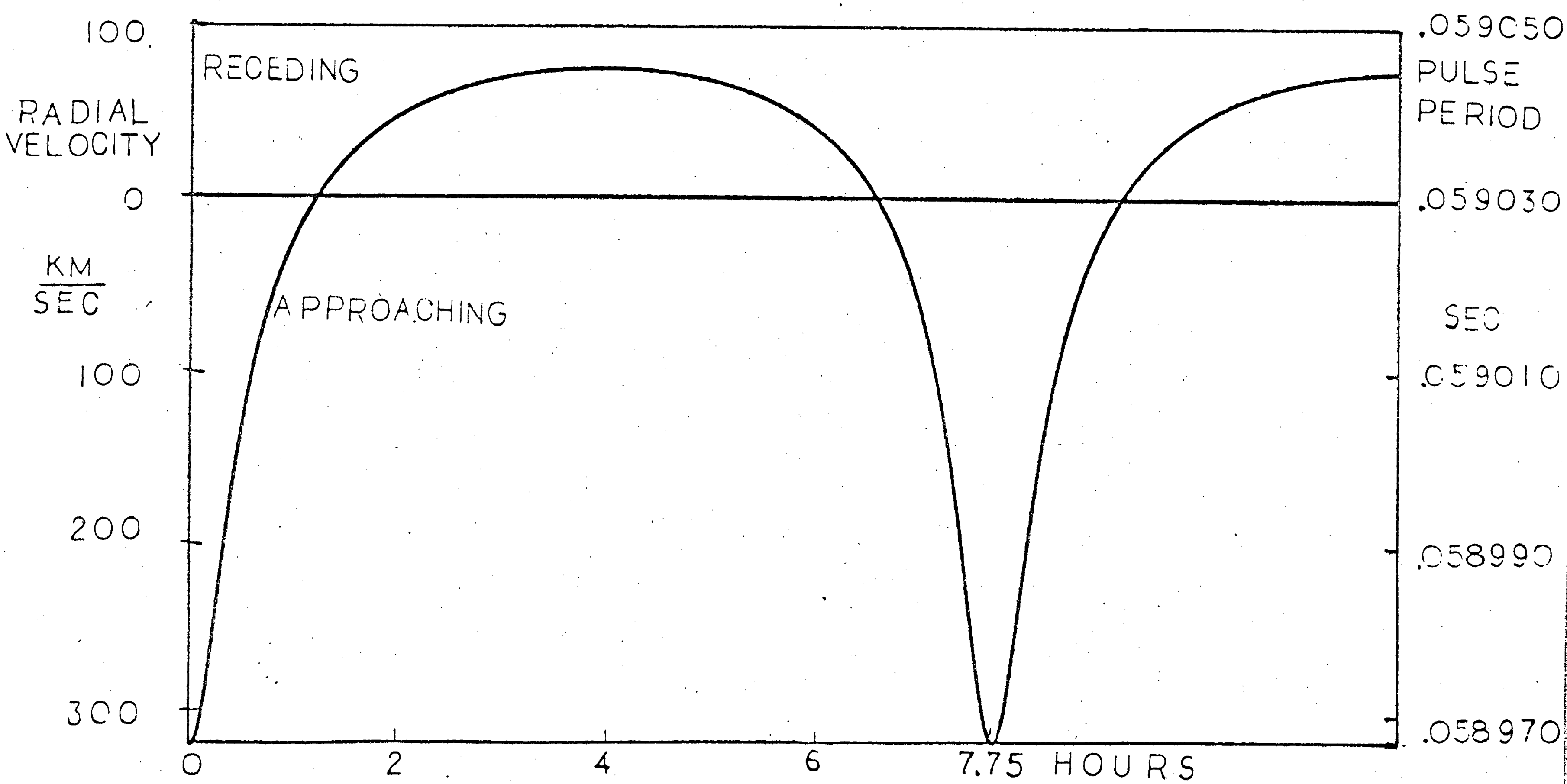
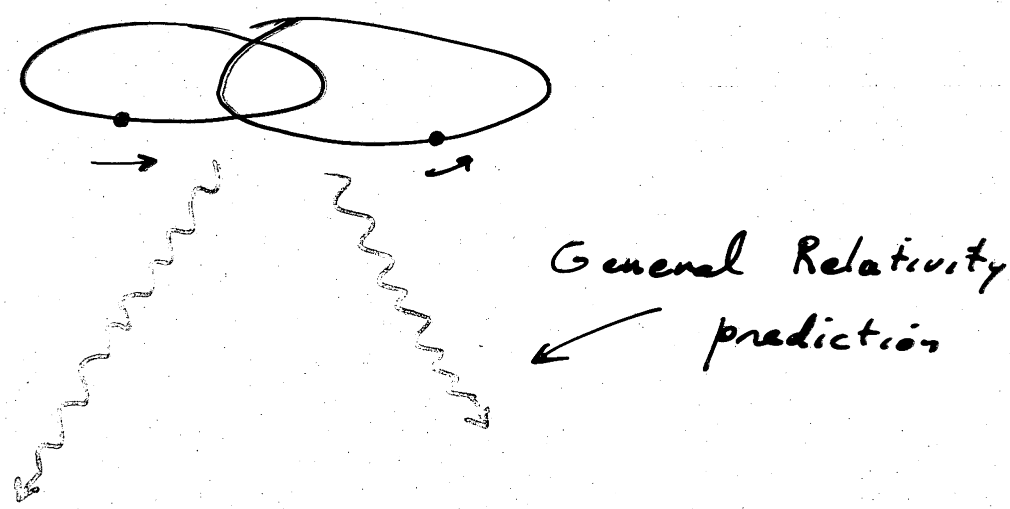


FIGURE 1a. RADIAL VELOCITY CURVE.

Gravitational radiation



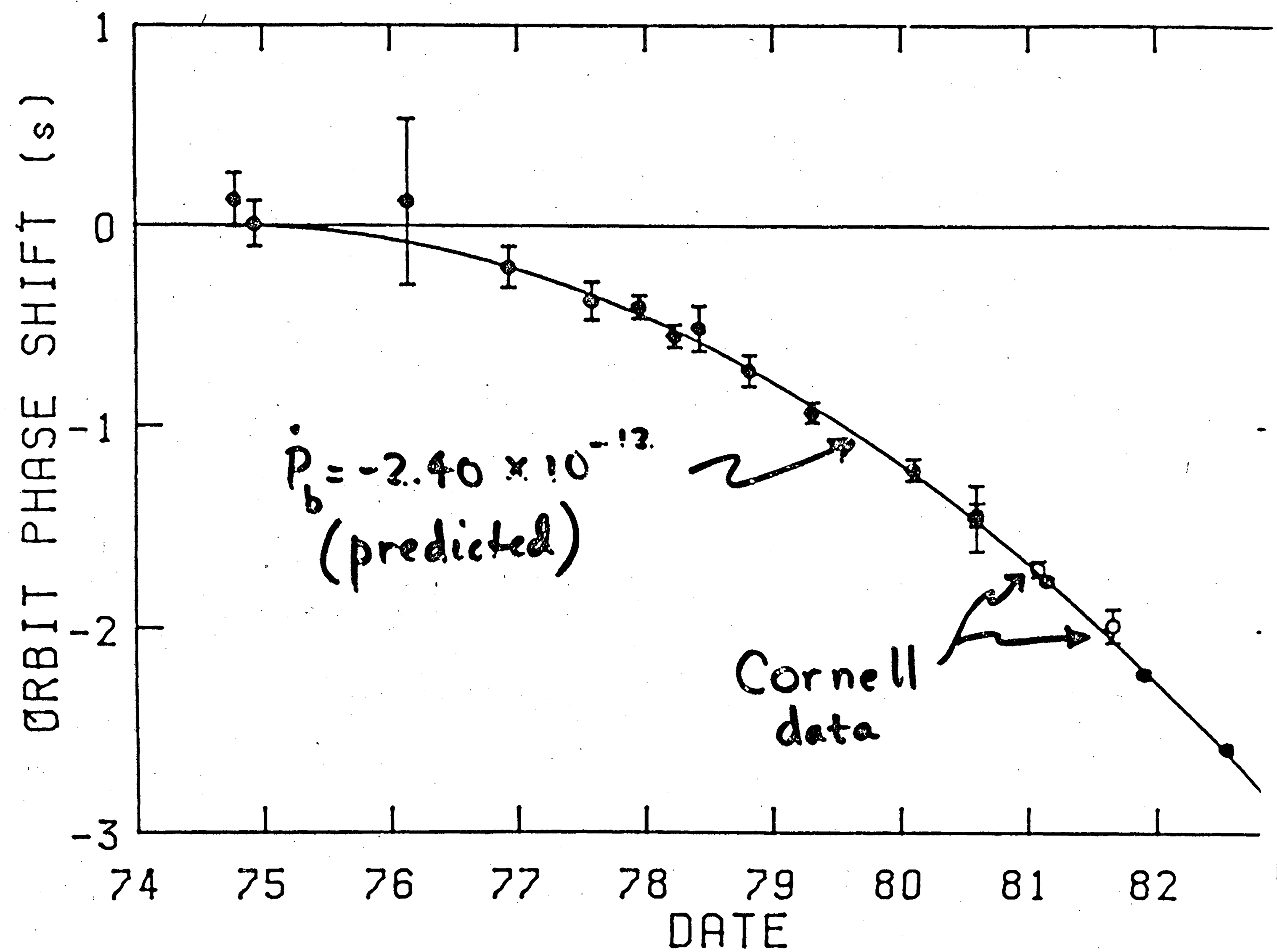
now know <u>all</u> orbital parameters

predicted orbit shrinkage 3.5 m/yr

orbital period shortens

1 year	0.04 s
6 years	1.00 s

(quadratic)



$L_{radio} = 5 \times 10^{28}$
$L_{grav} = 7.5 \times 10^{31}$
Spindown 1.7×10^{33}
3×10^{-5}
.04

Observed $\dot{P}_b = -2.41 \pm 0.13$

Radius to Frequency Mapping

Assume:

1) emission at local plasma frequency

$$\nu \propto n^{1/2}$$

2) dipolar divergence of particle density

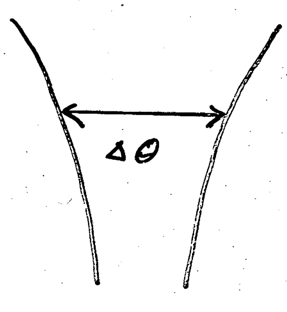
$$n \propto r^{-3}$$

Implies:

$$r_{em} \propto \nu^{-2/3}$$

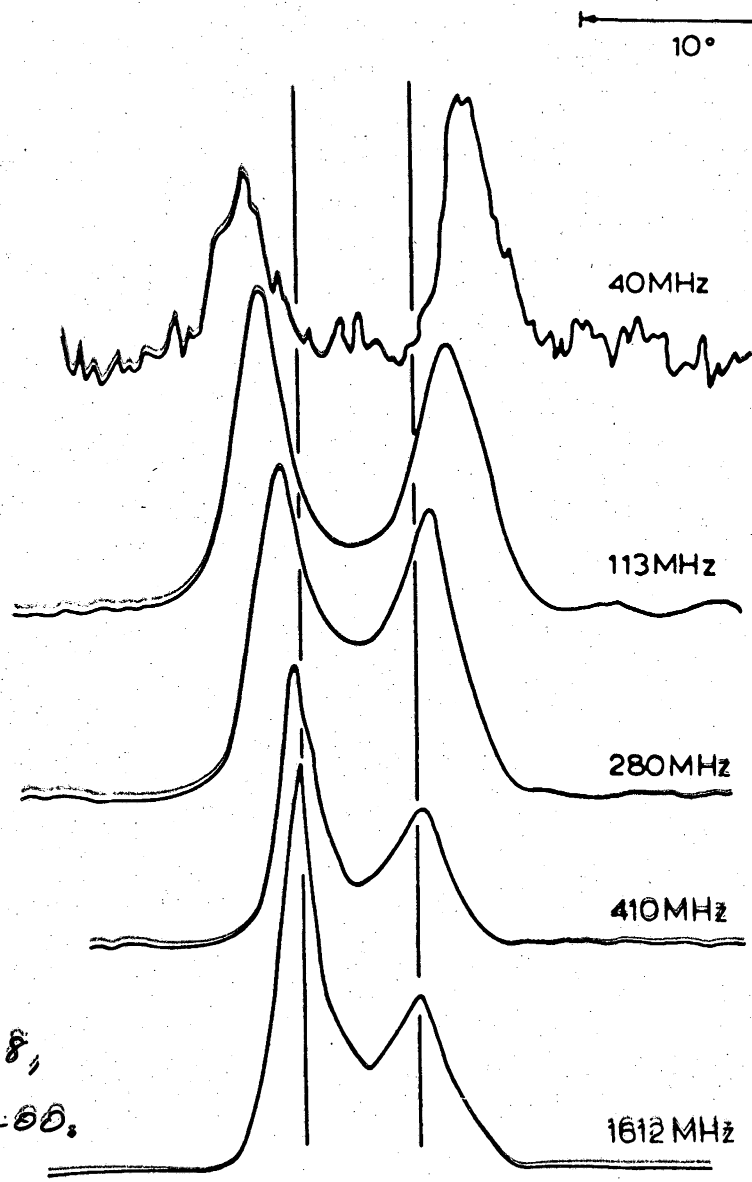
If profile features are generated along the same field line at all frequencies:

dipolar: $$\frac{\sin^2\theta}{r} = \text{const.}$$

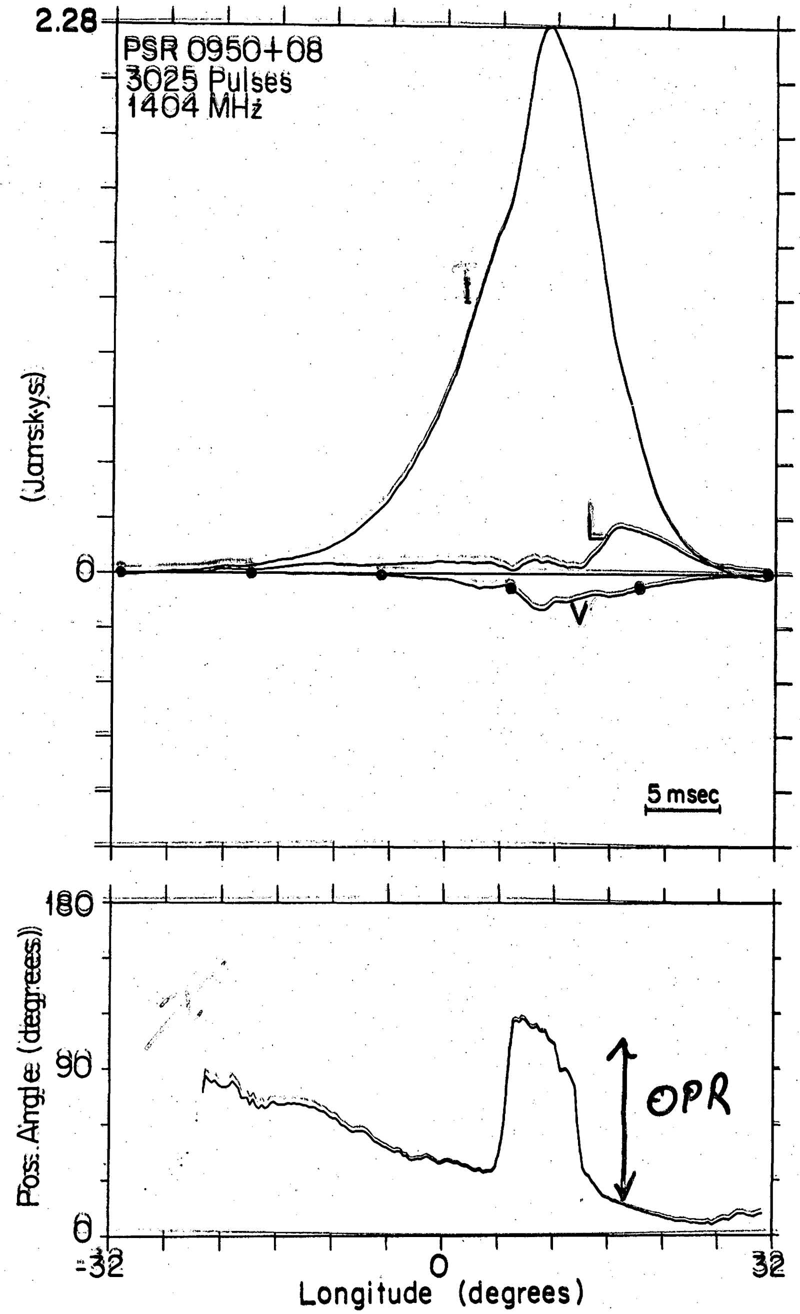


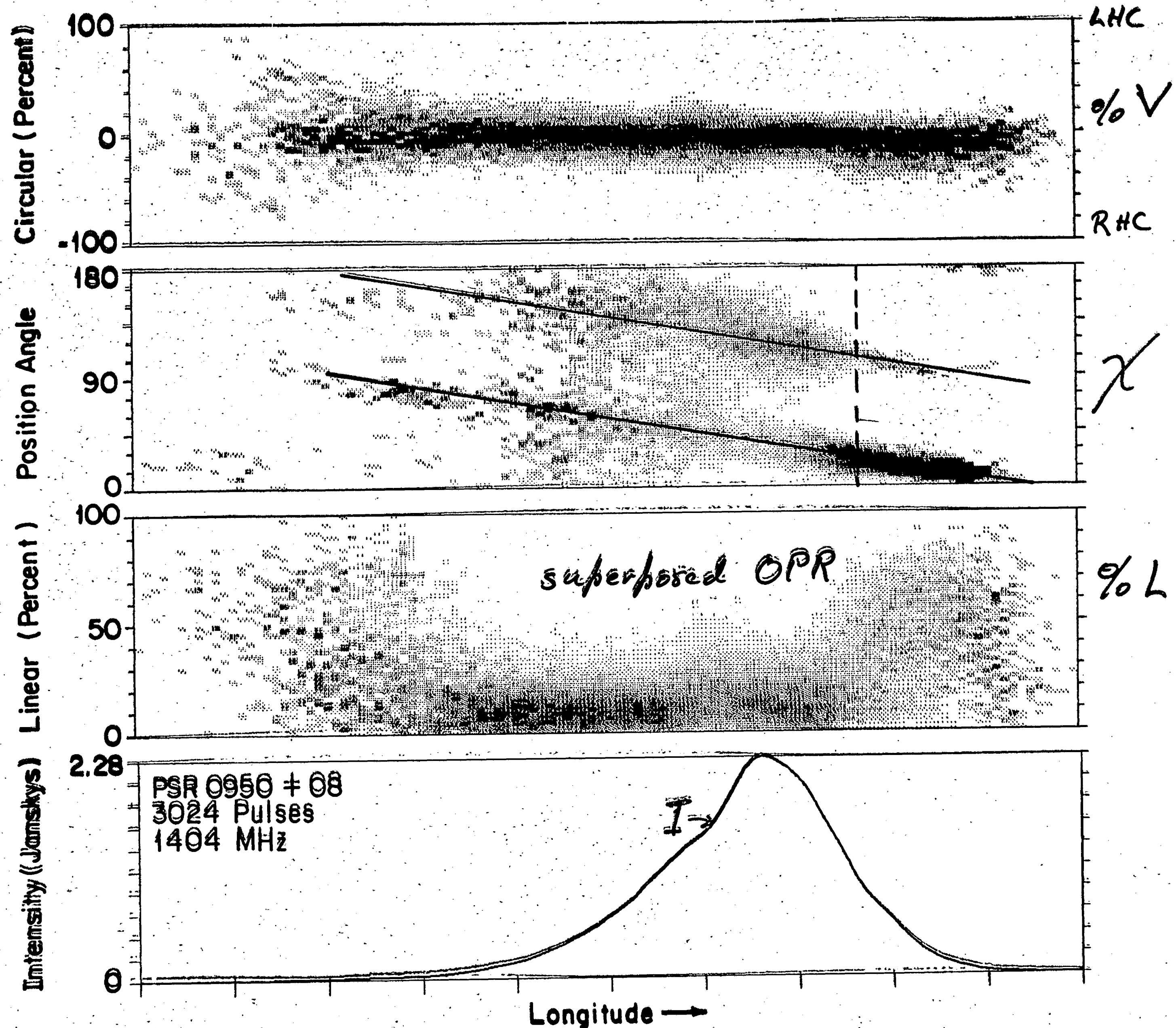
$$\Delta\theta \propto \nu^{-1/3}$$

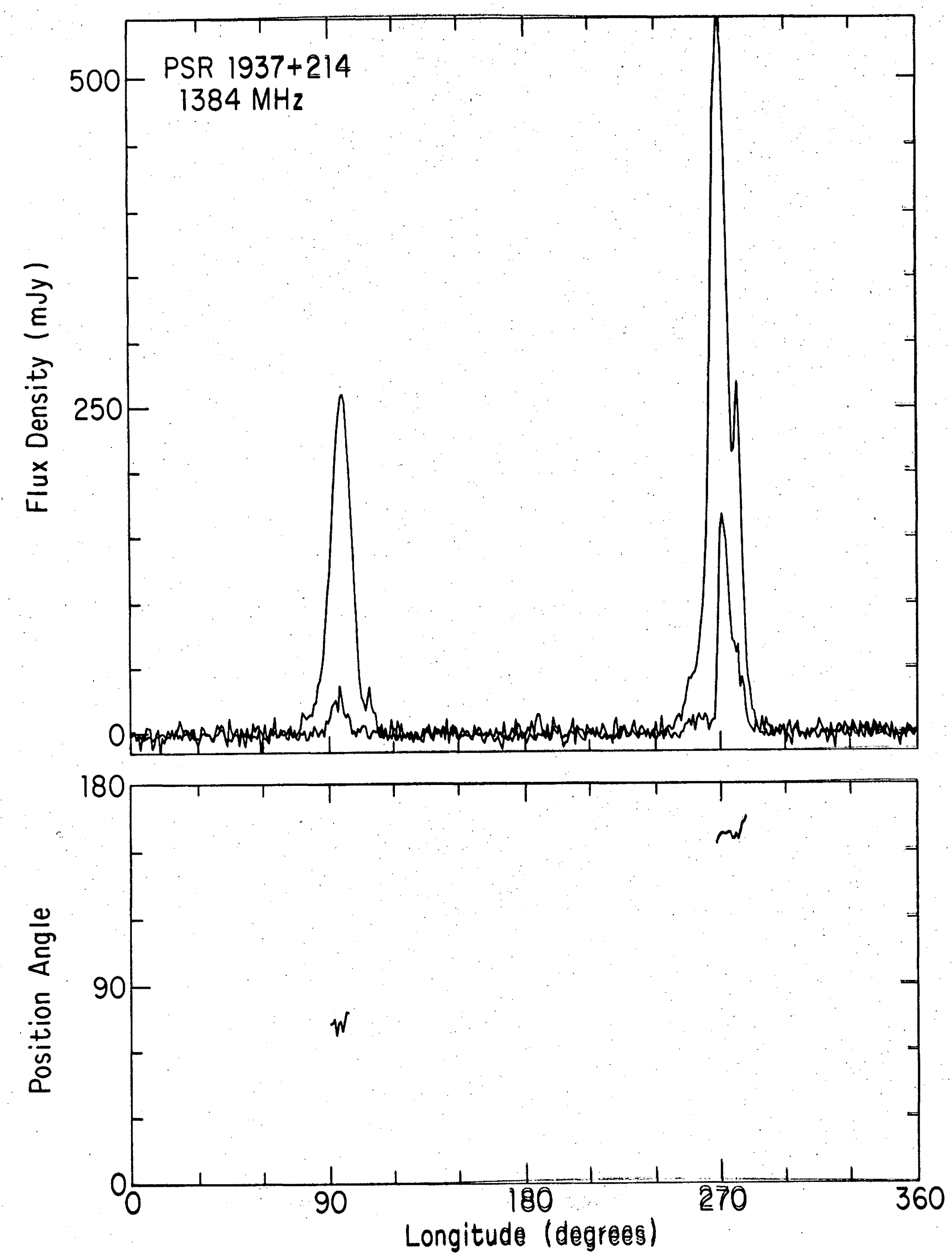
PSR 1133+16



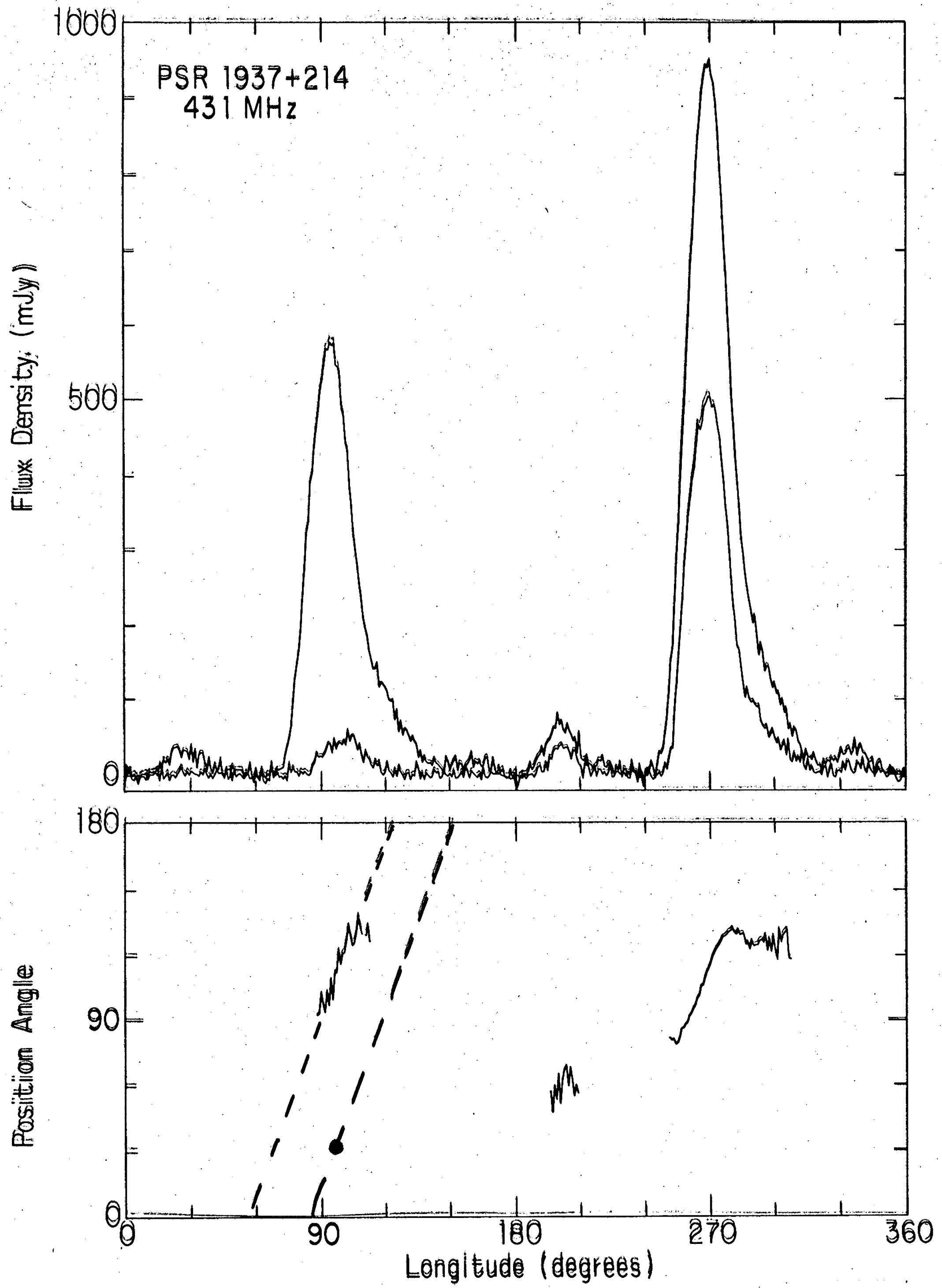
R.N. Manchester 1978,
Proc. ASA. 3 (3), 200.

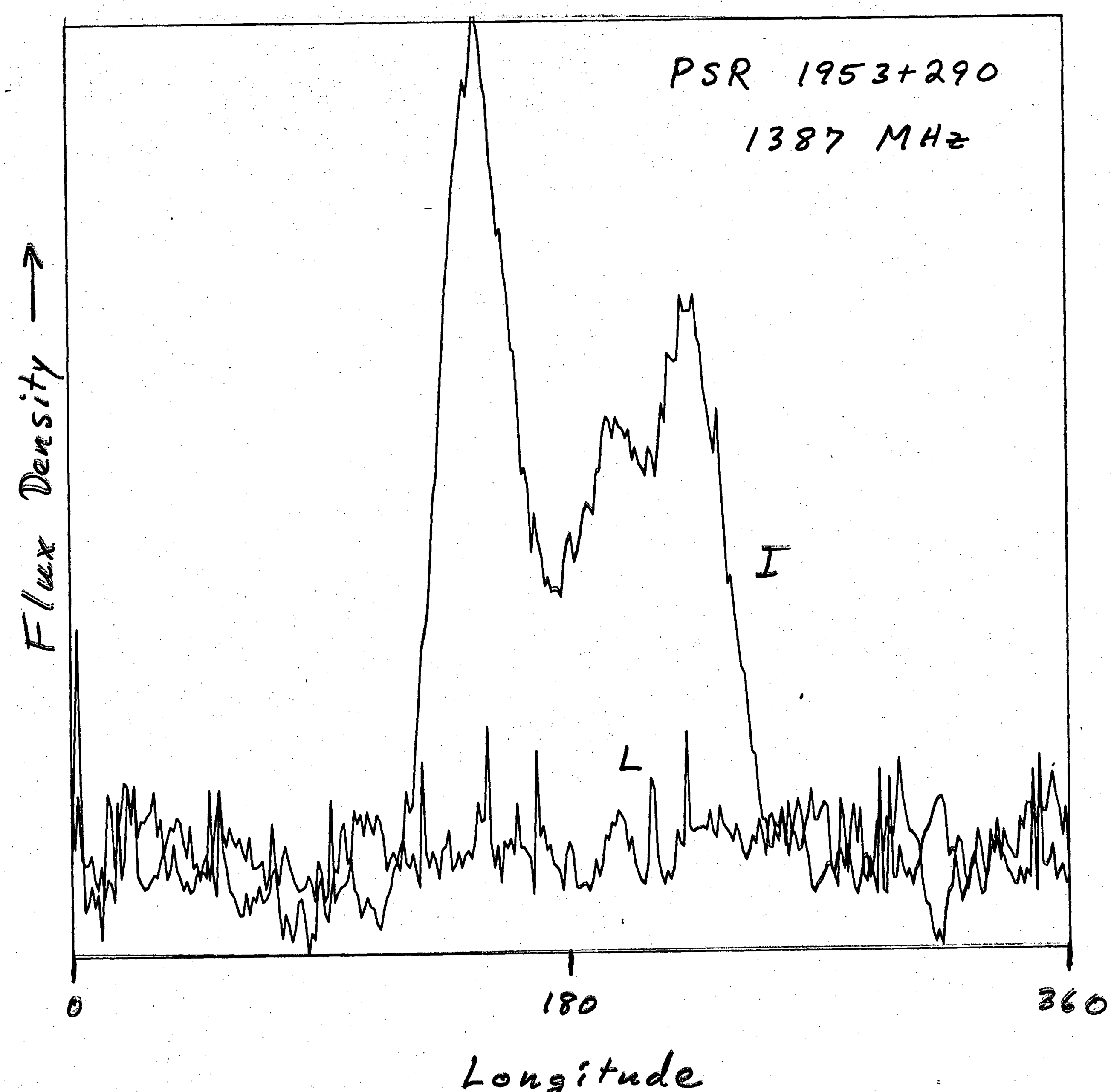

PSR 0950+08
3025 Pulses
1404 MHz
2.28
(Janskys)
0
I
L
V
5 msec
180
90
0
Pos. Angle (degrees)
OPR
-32
0
32
Longitude (degrees)

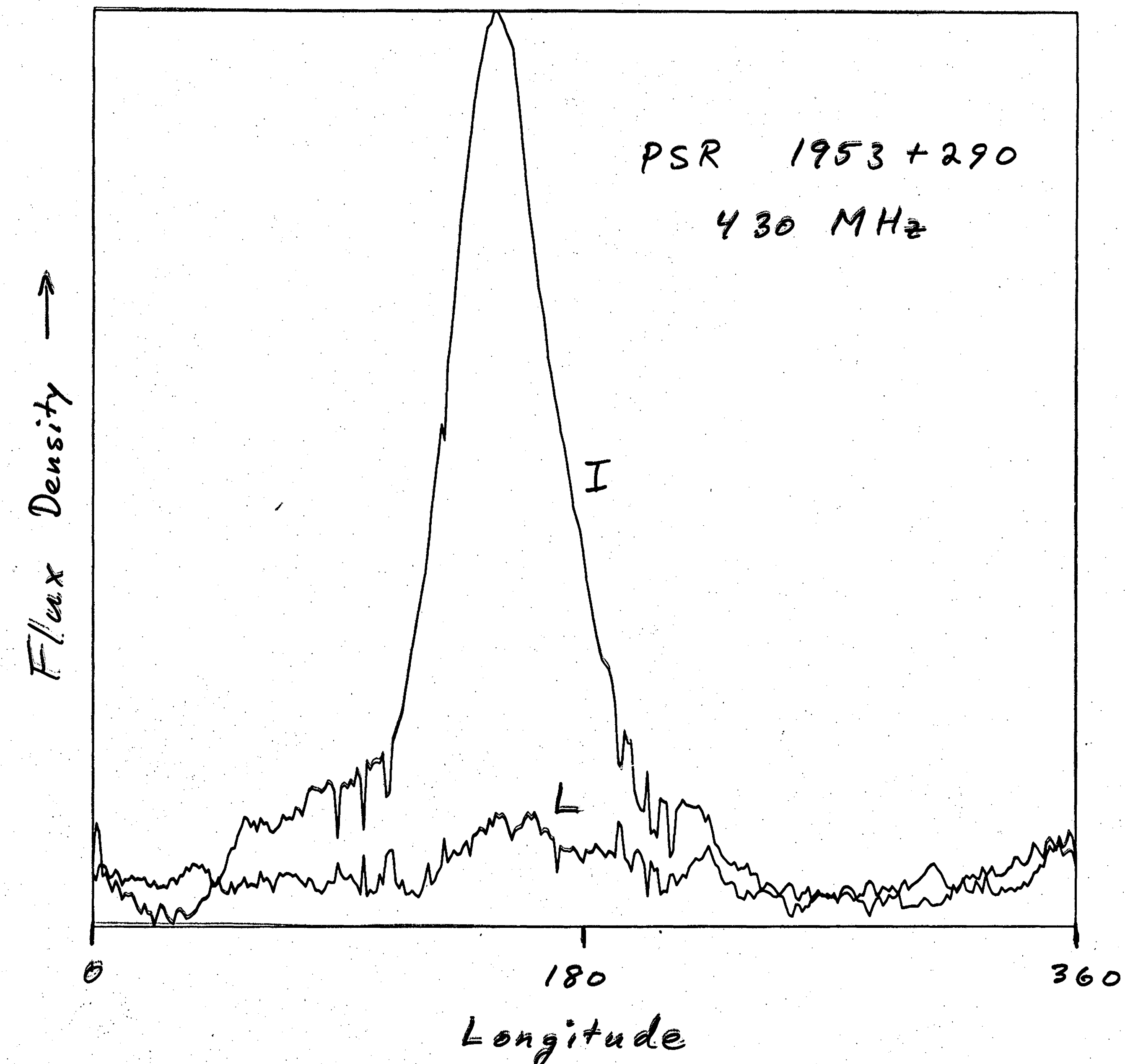

100
0
-100
Circular (Percent)
LHC
%V
RHC
180
90
0
Position Angle
χ
100
50
0
Linear (Percent)
superposed OPR
%L
2.28
0
Intensity (Jansky)
PSR 0950 + 08
3024 Pulses
1404 MHz
I
Longitude



Stinebring
Cordes
Wolszczan
Deich


PSR 1937+214
431 MHz
Flux Density (mJy)
1000
500
0
Position Angle
180
90
0
0
90
180
270
360
Longitude (degrees)


PSR 1953+290
1387 MHz
Flux Density →
I
L
0
180
360
Longitude


PSR 1953+290
430 MHz
I
L
Flux Density →
0
180
360
Longitude