Summer Student Lecture Notes
1 August 1983
Dan Stinebring

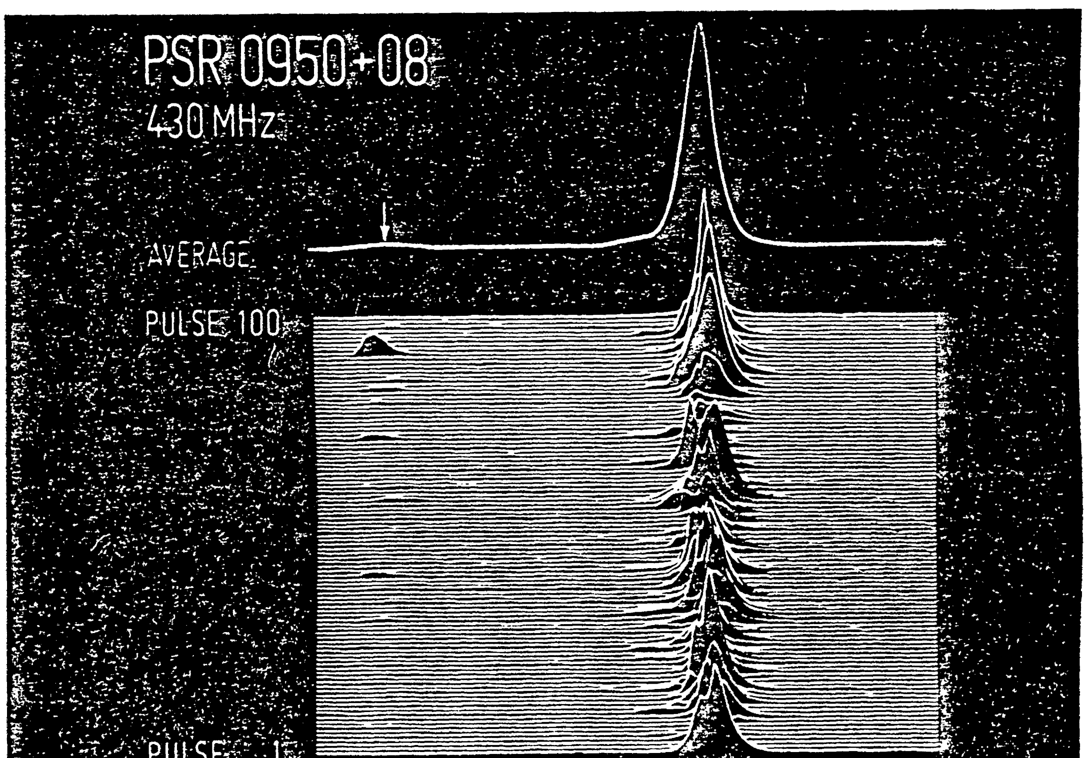
INTERNATIONAL ASTRONOMICAL UNION

SYMPOSIUM No. 95

# PULSARS

## 13 Years of Research on Neutron Stars

Edited by W. SIEBER and R. WIELEBINSKI

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# Pulsars

## Summer Student Lectures

Dan Stinebring
1 Aug 83



### Pulsars in general — | references

discovery – JB's perserverence
uniquely radio objects — {coherent emission $T_B >> 10^{12} K$
time stationary waveforms, (>10 yrs)
but very time variable
highly polarized
accurate clocks: $P, \dot{P}$, phase jitter
(neutron star dynamics)

Basic Pulsar Model → p. 2

### Pulsars as tools

galactic ~~popn~~ distribution
DM ⟶ $n_e$
RM, DM ⟶ $\langle B \rangle$ scintillation ($n_e$ variations: dispersion,
binary pulsar: GR probe

### Pulsar phenomenology

waveforms | mode switching | interpulses
single pulses
pulse energy variations | giant pulses
micropulses
subpulses
drifting subpulses
polarization
waveforms (Rad. & Cooke)
OPR
single pulse transitions

<u>Basic pulsar model</u> (What makes pulsars shine)

strong B + rotation ⟶ strong E
surface effects
priming positrons (e.g.) [$\Omega \cdot B < 0$]
high energy $\gamma$'s
pair creation ~~→~~ cascade → $e^{\pm}$ plasma
plasma instability
plasma fluctuations → coherent radio emission

1 Aug 83

# Pulsar References

## general

~~Pu~~ Manchester, R.N., Taylor J.H., *Pulsars*, Freeman and Combany, 1977.

Smith, F.G., *Pulsars*, Cambridge University Press, 1977.

## historical

*Pulsating Stars I and II*, Nature reprints 1968– MacMillan and Co., Ltd.

## current research

Siebor, W., and Wielebinski, R., eds. Pulsars – Proceedings of IAU Symp #95., D. Reidel, 1981.

F. Curtis Michel, "Theory of pulsar Magnetospheres", Rev. of Mod. Phys. 54, 1, 1982

## popular

Helfand, D.J., *American Scientist*, 66, 332, 1978

Weisberg, J.M., and Taylor, J.H. *Scientific American*, 245, 74, 1981. – "binary pulsar and GR"

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 3--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.

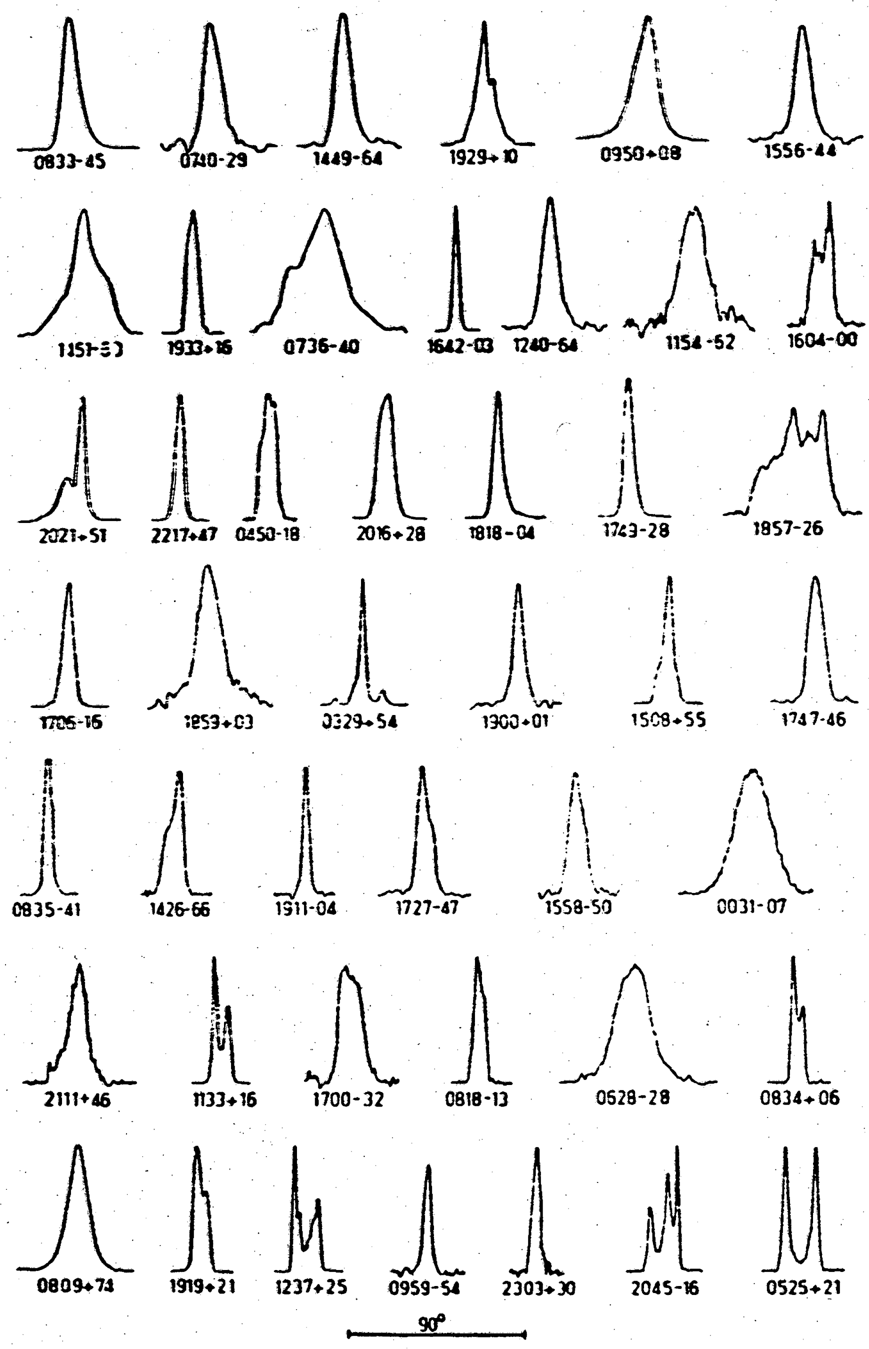
It is my opinion that the radio pulses seem to have some special relationship to pi and to the mathematical design and location of the Great Pyramid. The pulses may be an attempt to direct our attention to the mathematical properties of the Great Pyramid and to the possible mathematical-engineering design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

$$\dot{P} = \frac{dP}{dt} \qquad 2\times10^{-19} \text{ to } 4\times10^{-13} \ \frac{\text{sec}}{\text{sec}}$$

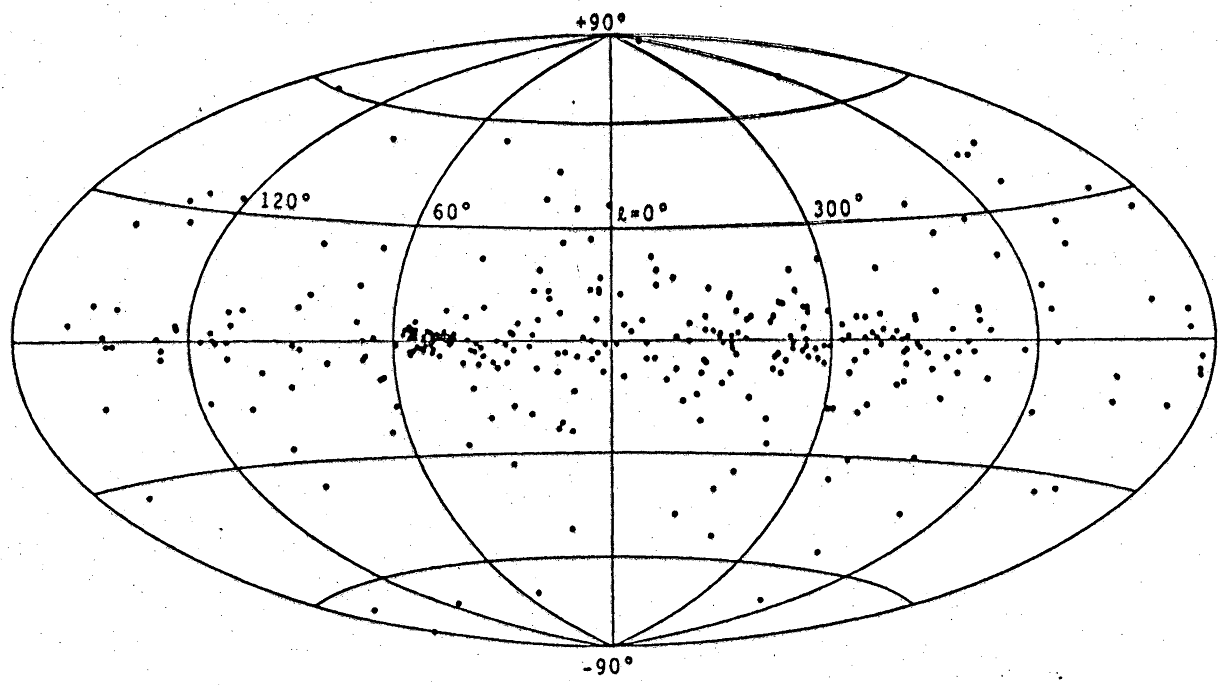



FIG. 1. An equal-area projection of the distribution of the 330 known pulsars in galactic coordinates. The galactic center is in the middle of the figure and longitude increases to the left.

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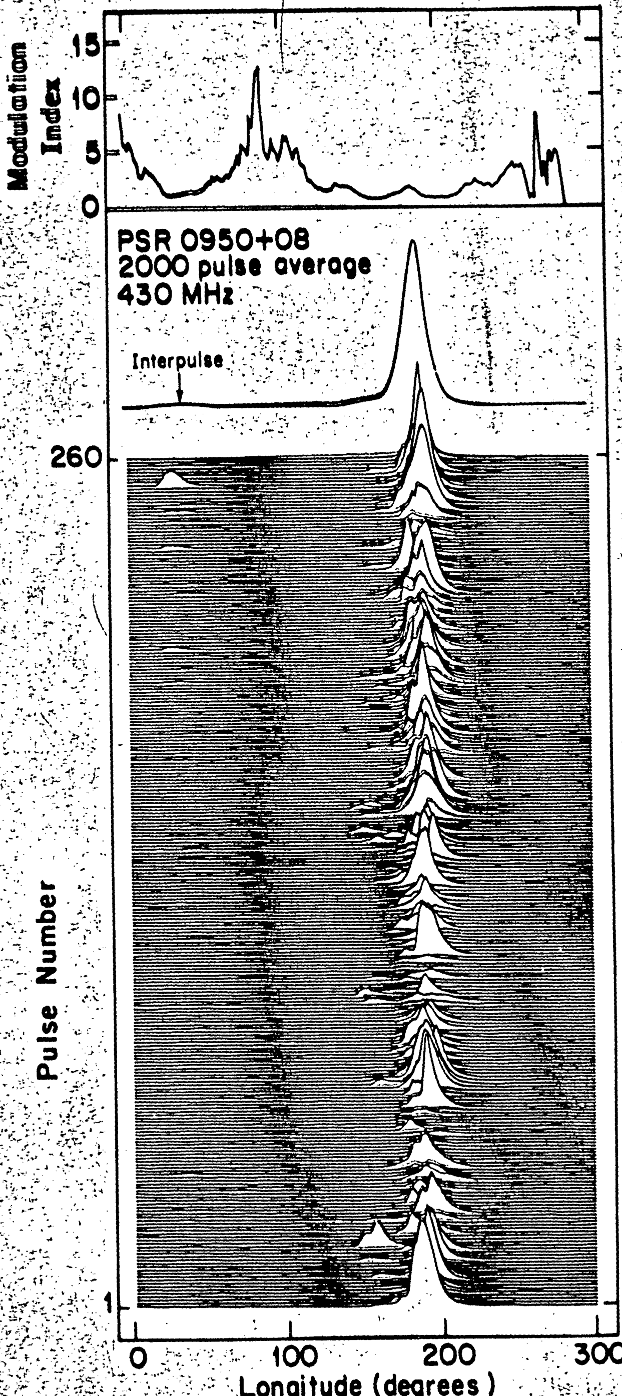
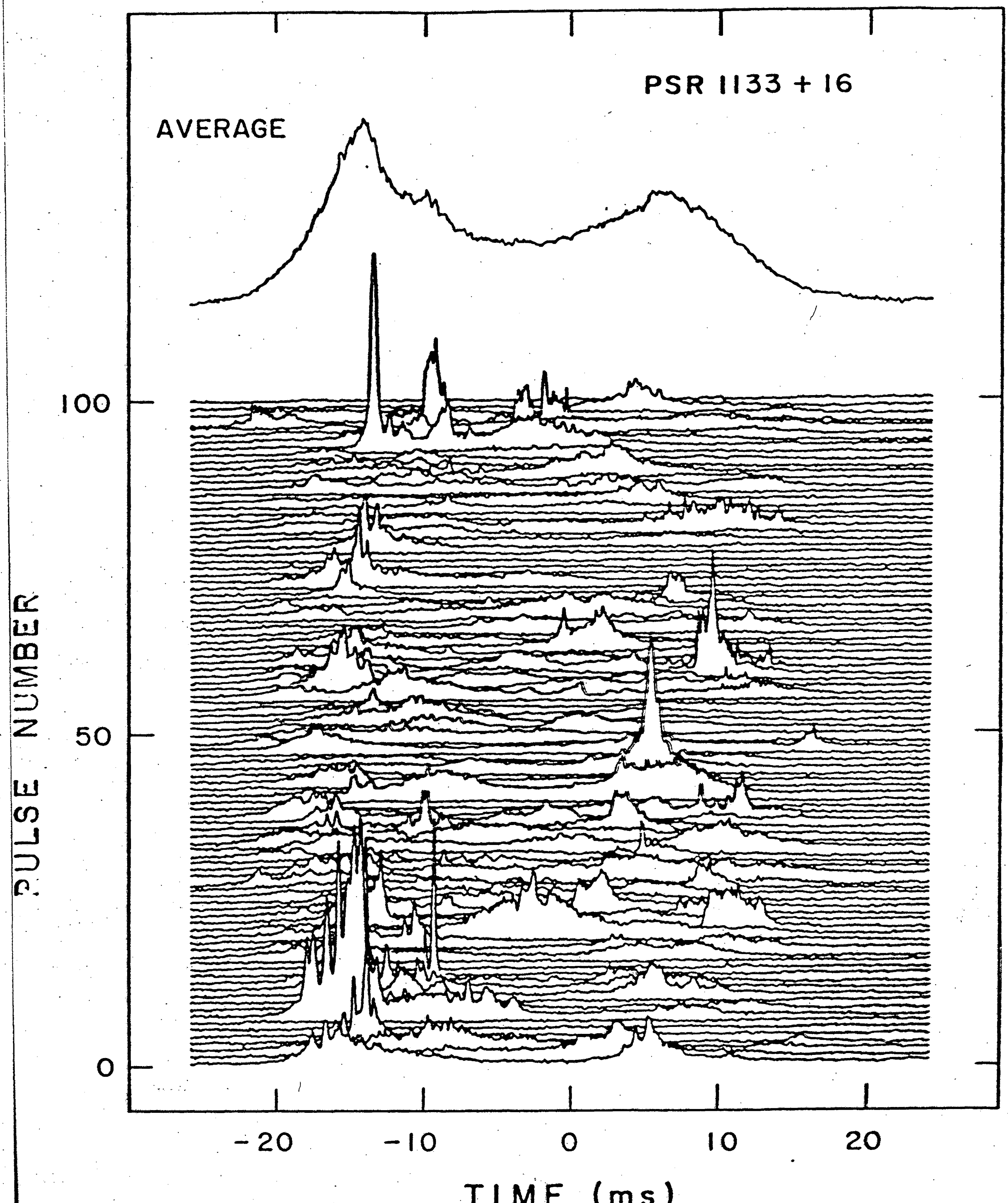
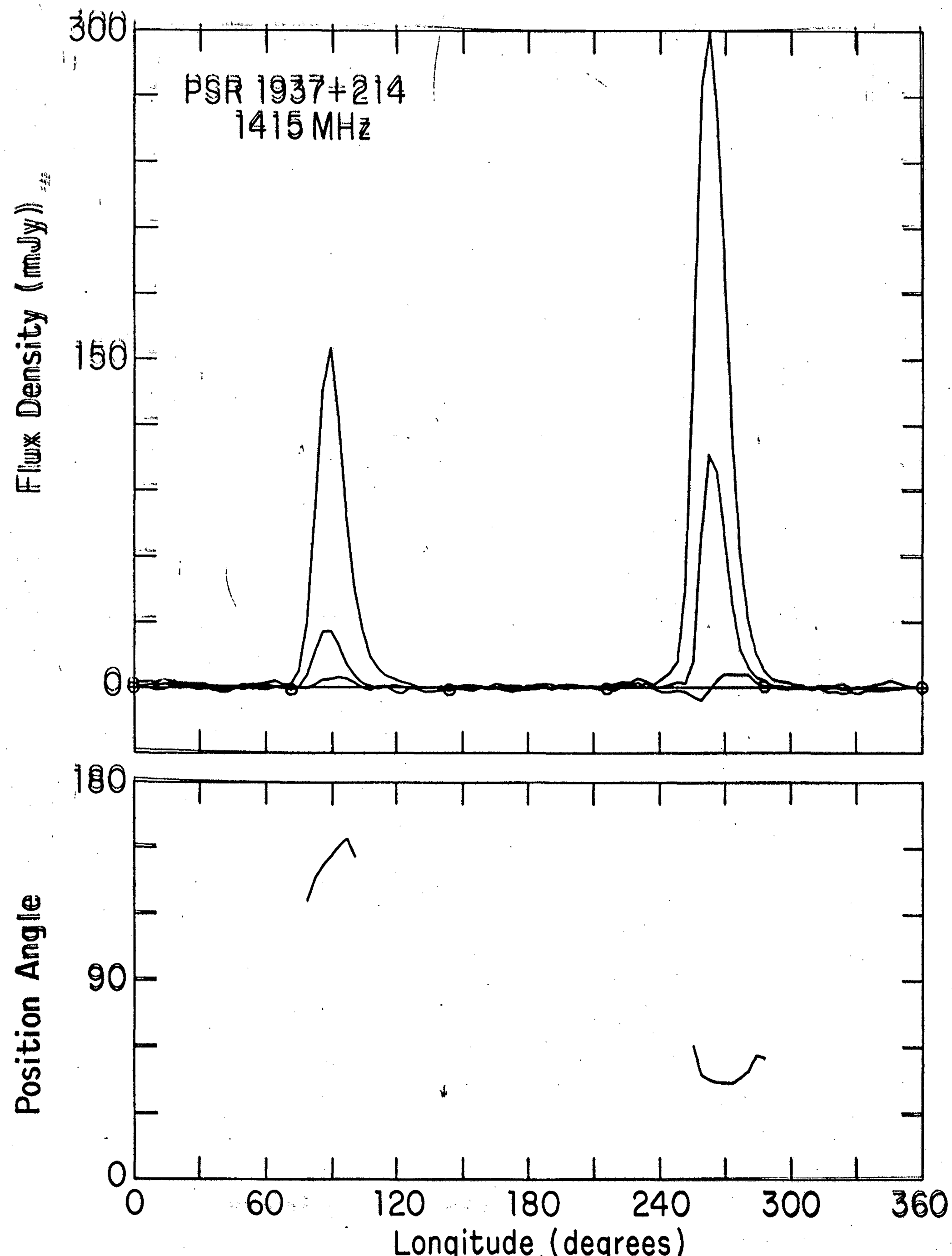



T.H. Hankins and J.M. Cordes, 1981, Ap. J, 249, 241.

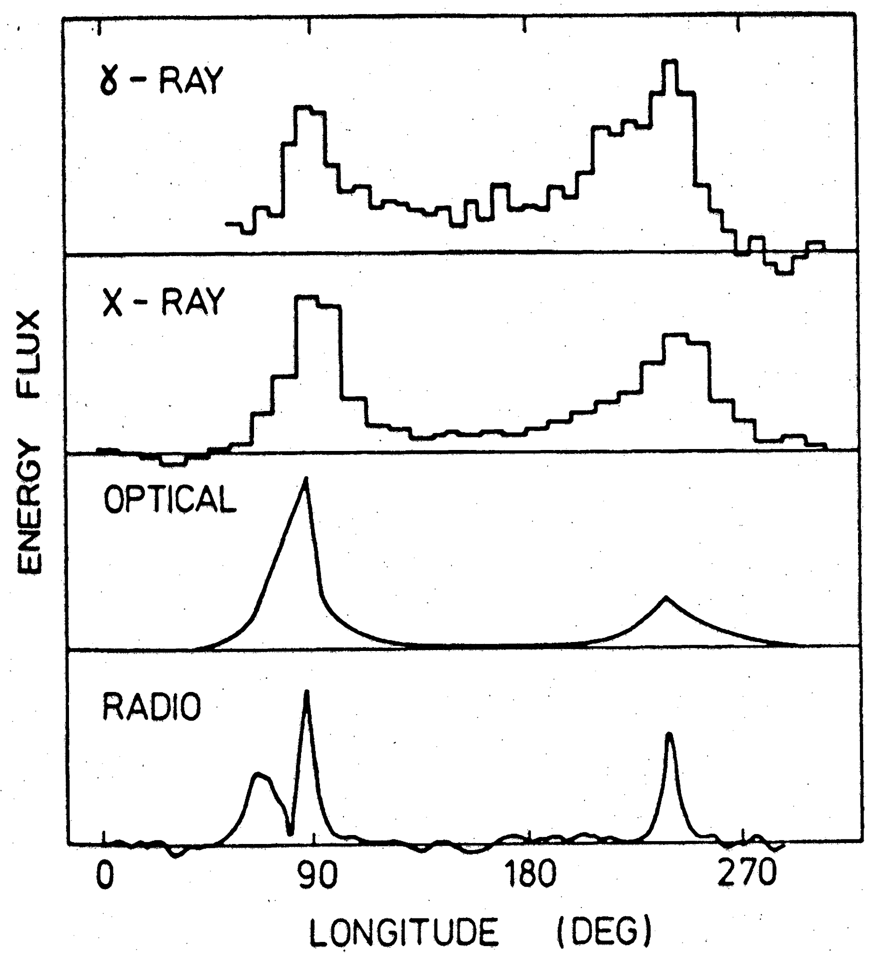



courtesy T. H. Hankins, J. M. Cordes



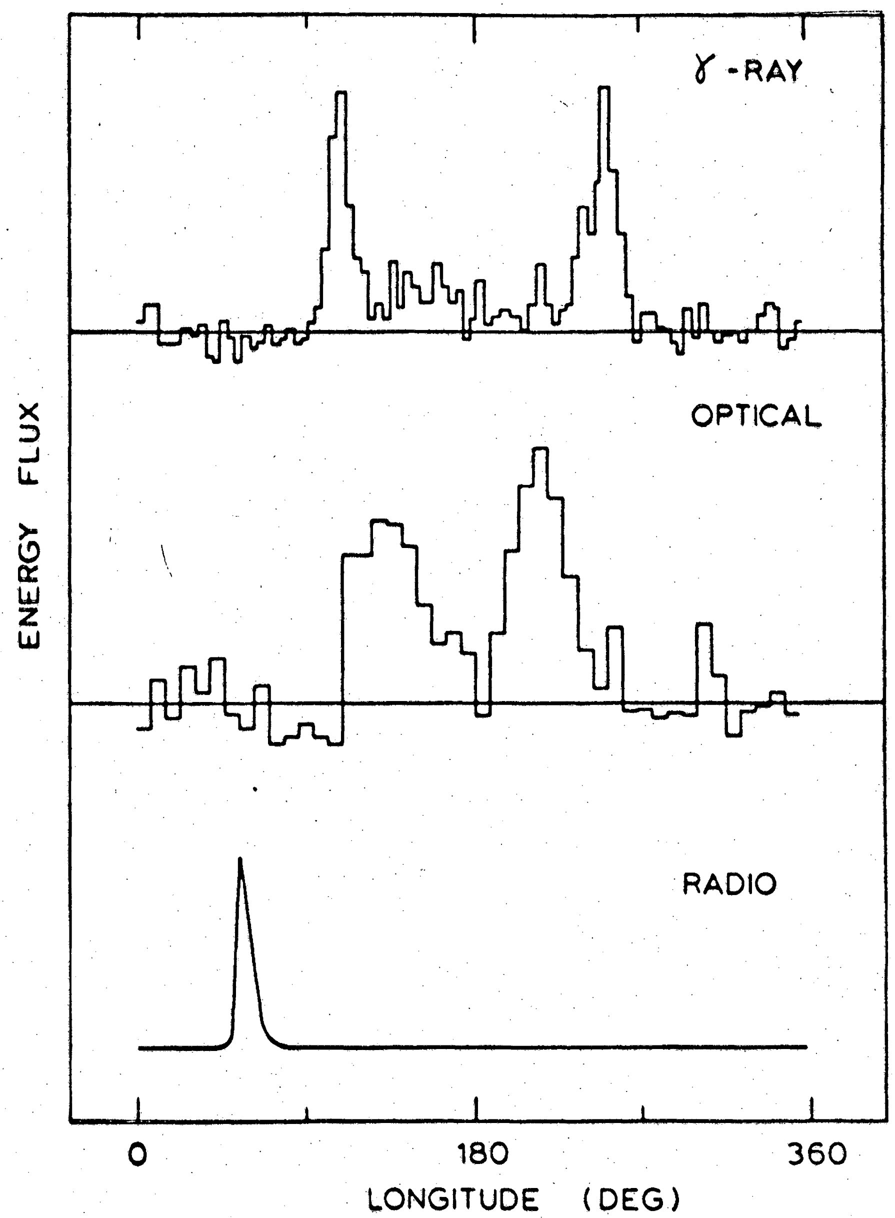

D.R. Stinebring
1983, Nature,
302, 698.

PSR 0531+21 Crab



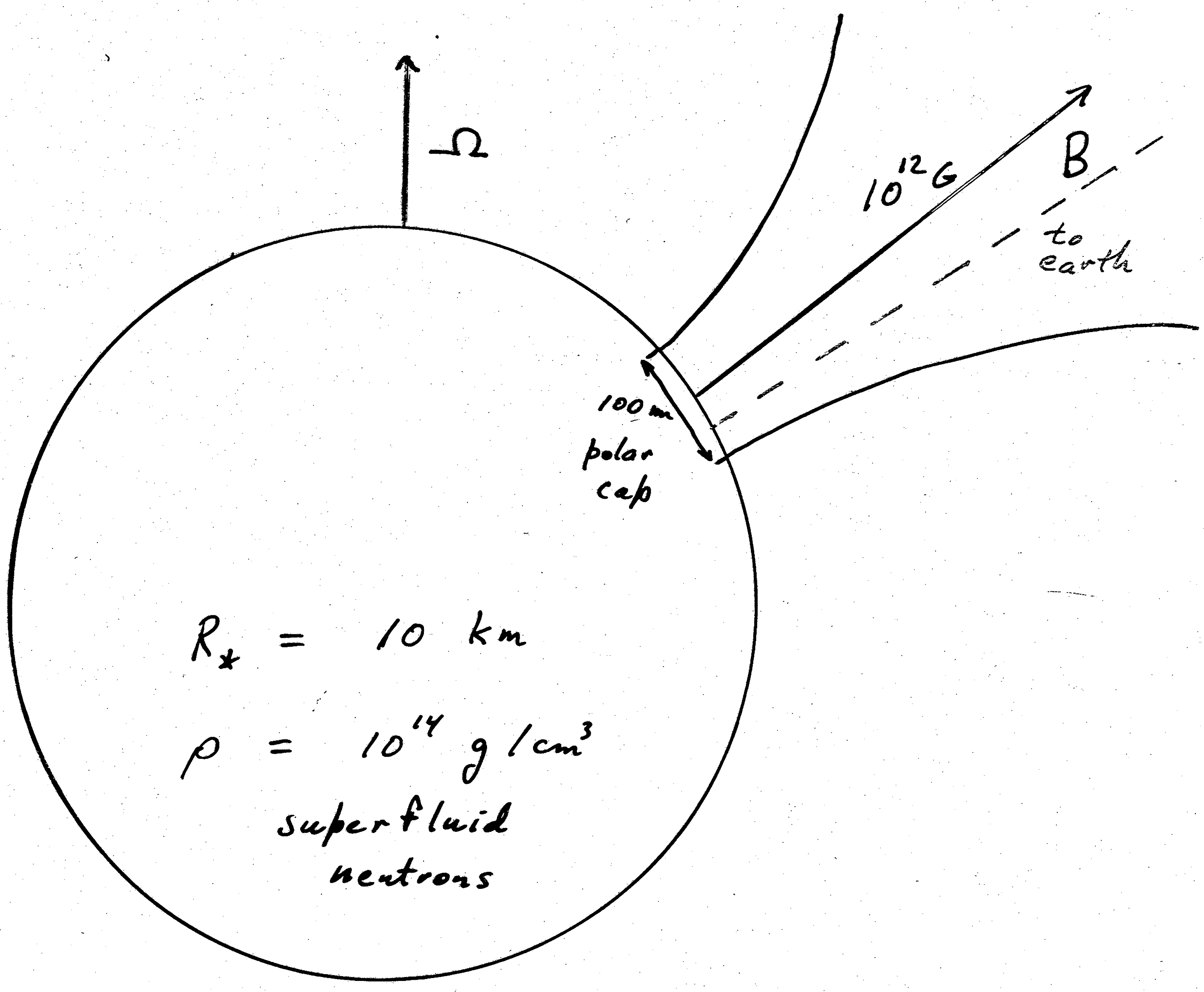

R. N. Manchester, 1978, Proc. ASA 3 (3), 200.

PSR 0833-45 Vela

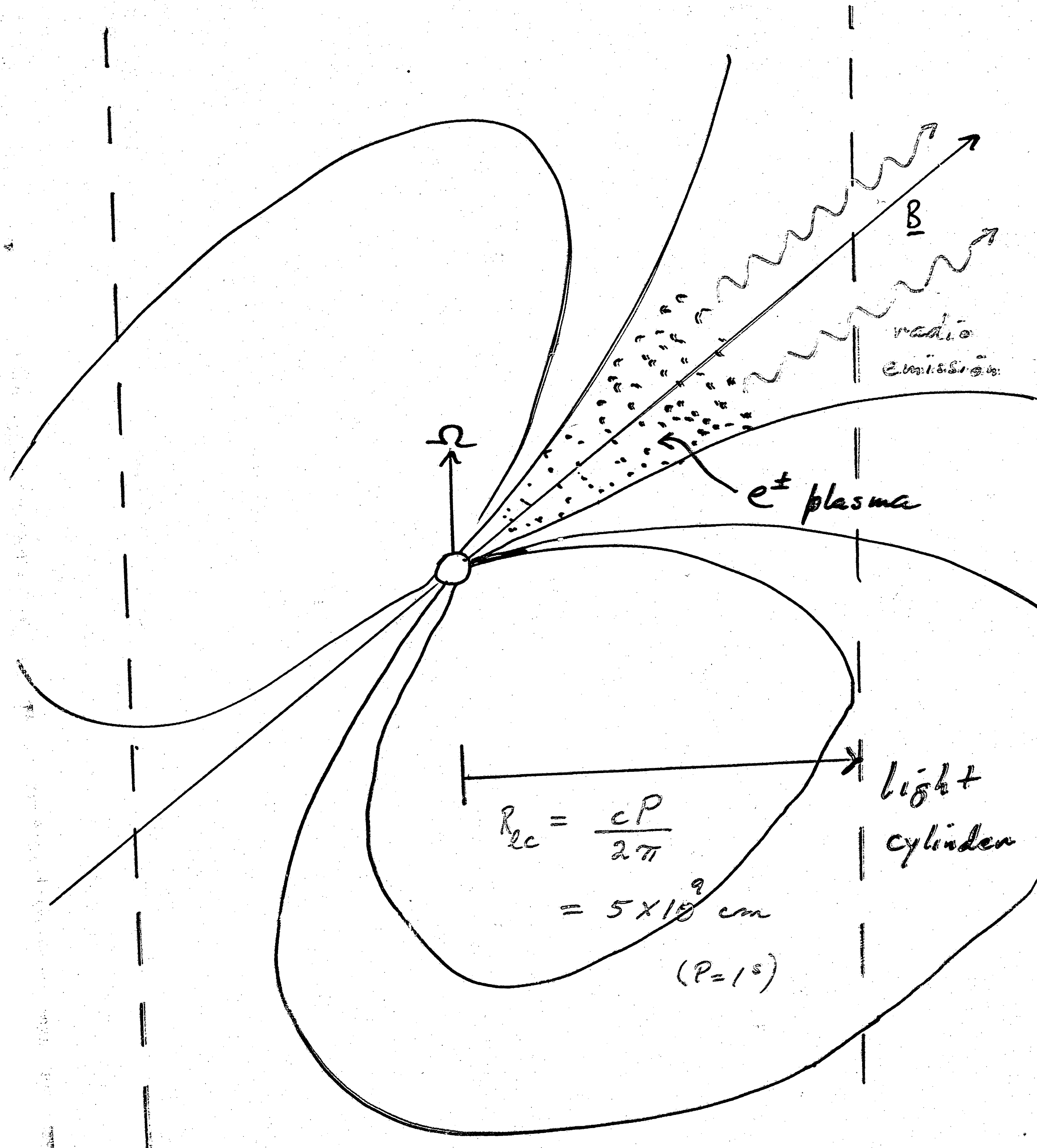



R.N. Manchester
1978, Proc. ASA,
3 (3), 200.

# Pulsar = Rotating Neutron Star



# Pulsar environment



# Dispersion Measure

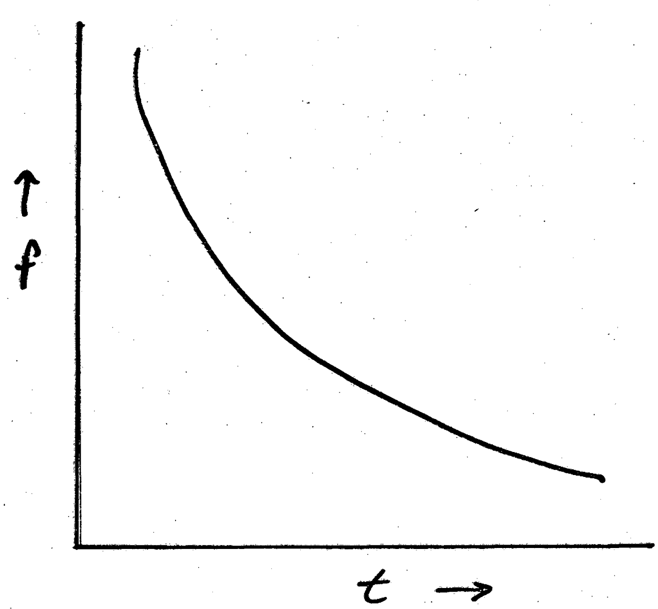
$$v_g = c\left(1 - \omega_p^2/\omega^2\right)^{1/2}$$

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

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

$$3 \leq DM \leq 450$$

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

approaches:

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

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

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

$\Longrightarrow$ pulsar scale height $\sim 230$ pc

# Faraday rotation

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

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

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

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

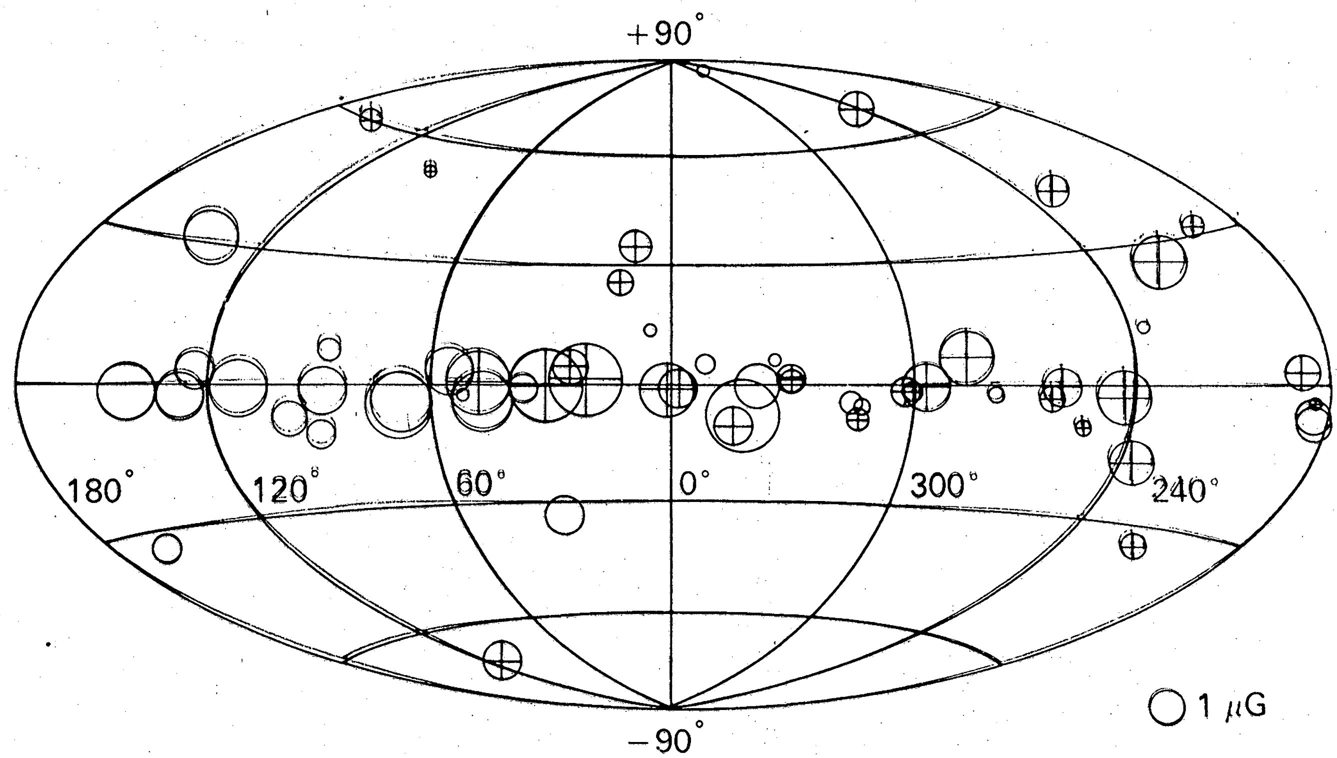
# Galactic magnetic field

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

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

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 $\mu$G the area of the circle is proportional to the field strength (a circle representing a 1 $\mu$G 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.]

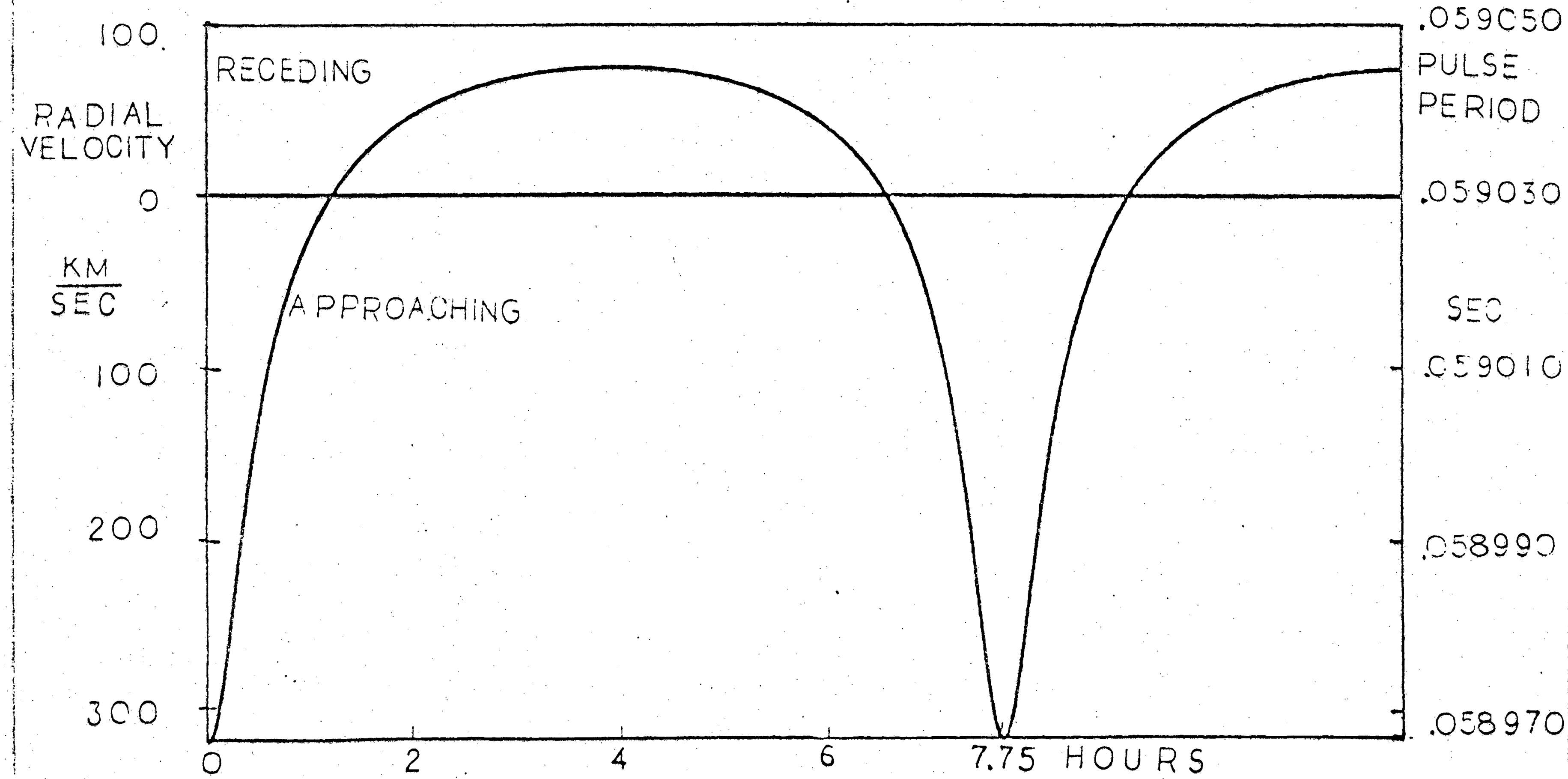
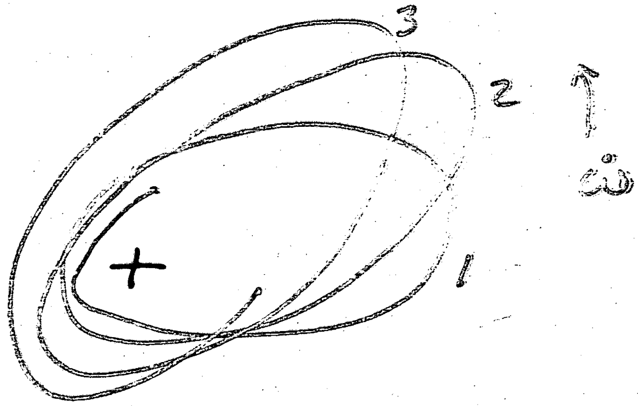



FIGURE 1a. RADIAL VELOCITY CURVE.

# Periastron advance

radial velocity curve ⟶ 5 of 7 orbital elements

assume GR (use it as a tool)




Mercury around the sun  43″/century

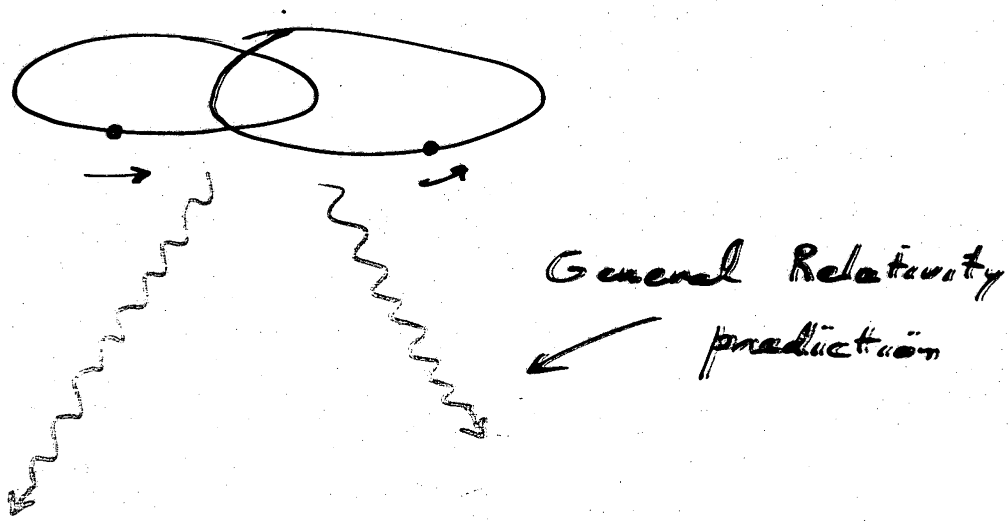
binary pulsar:  $\dot{\omega} = 2.11\,(M_1 + M_2)^{2/3}$

measured:  4.2°/year

(35 000 times Mercury's advance)

$\Longrightarrow M_1 + M_2 = 2.83\, M_\odot$

# 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)

# Radius to Frequency Mapping

Assume:

1) emission at local plasma frequency

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

2) dipolar divergence of particle density

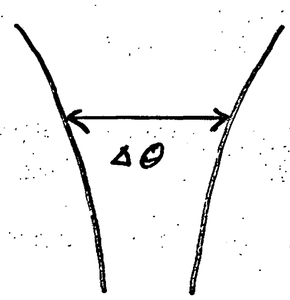
$$n \propto r^{-3}$$

Implies:

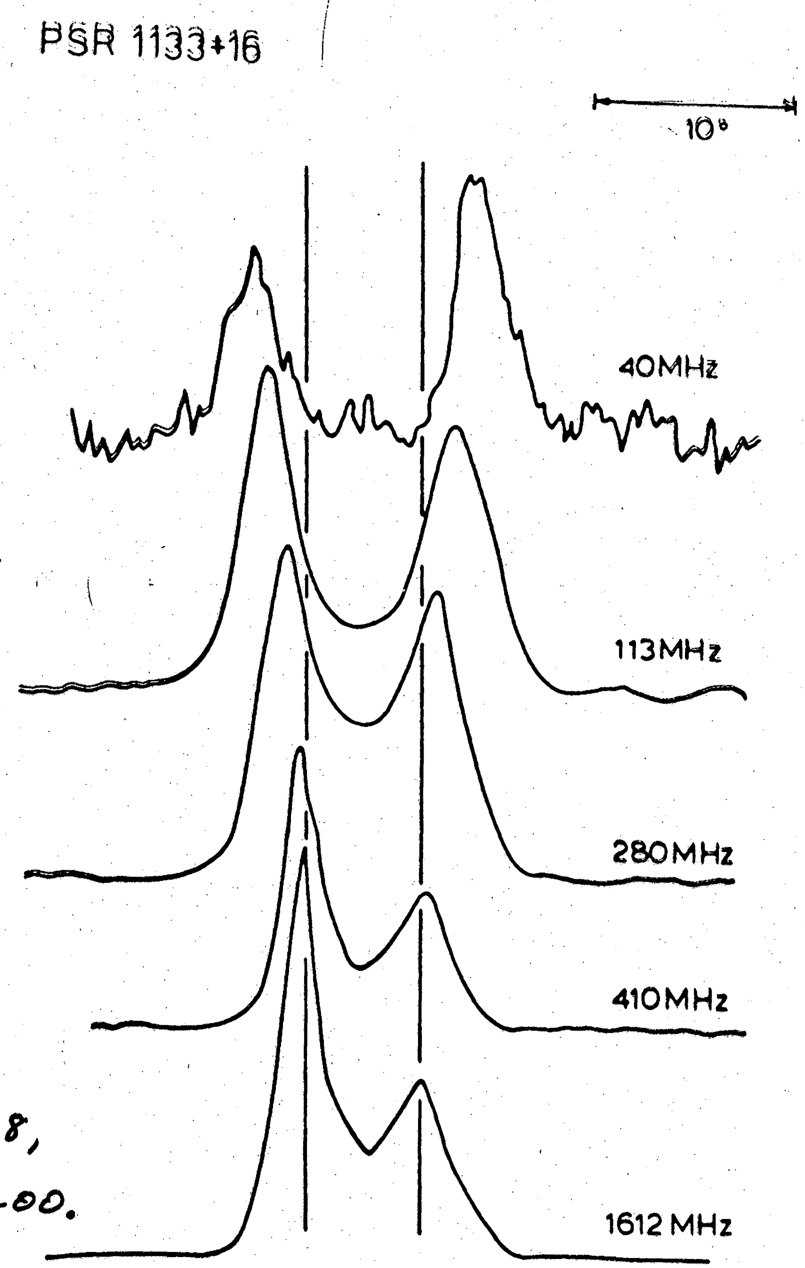
$$r_{em} \propto \nu^{-2/3}$$

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

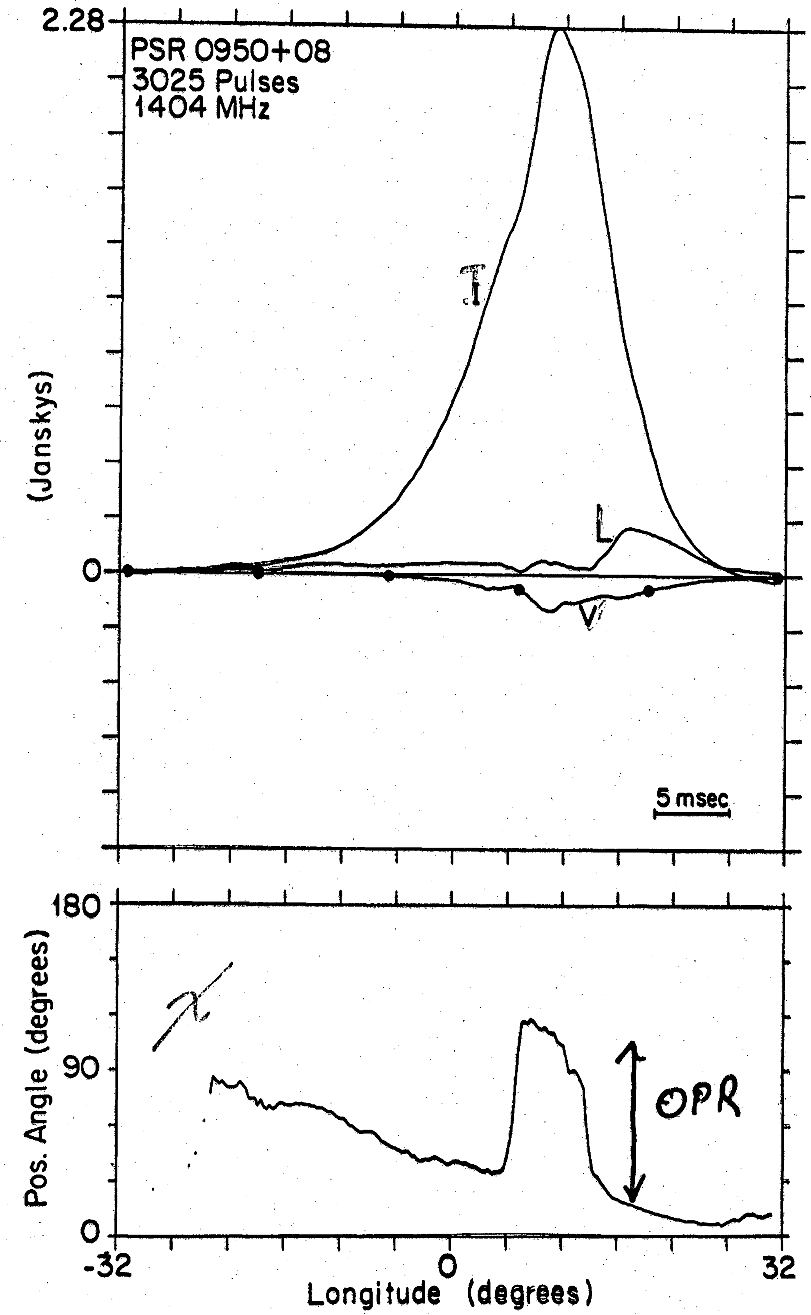
dipolar: $$\frac{\sin^2\theta}{r} = \text{const.}$$



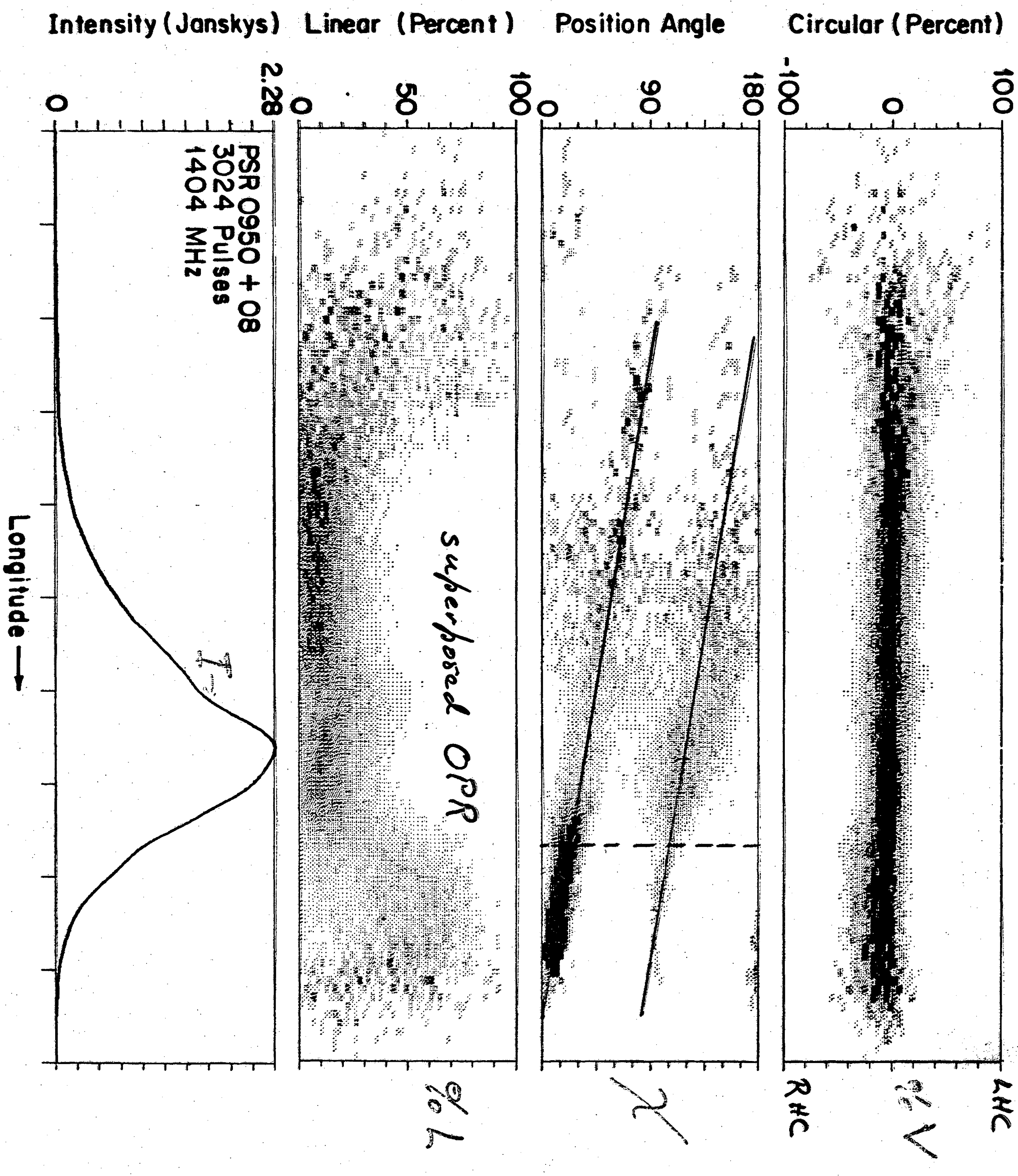

$$\Delta\theta \propto \nu^{-1/3}$$



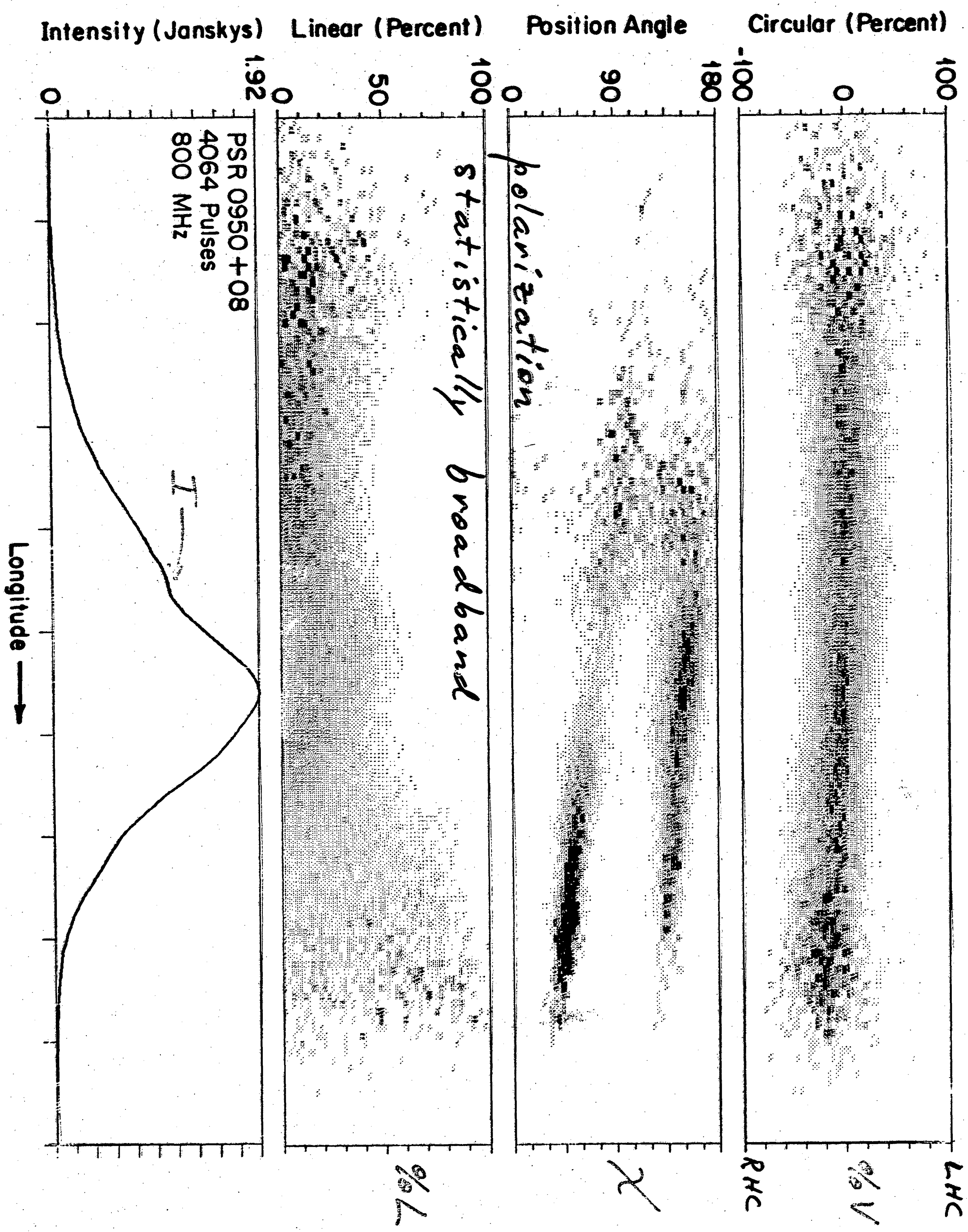

R.N. Manchester 1978,
Proc. ASA. 3 (3), 200.

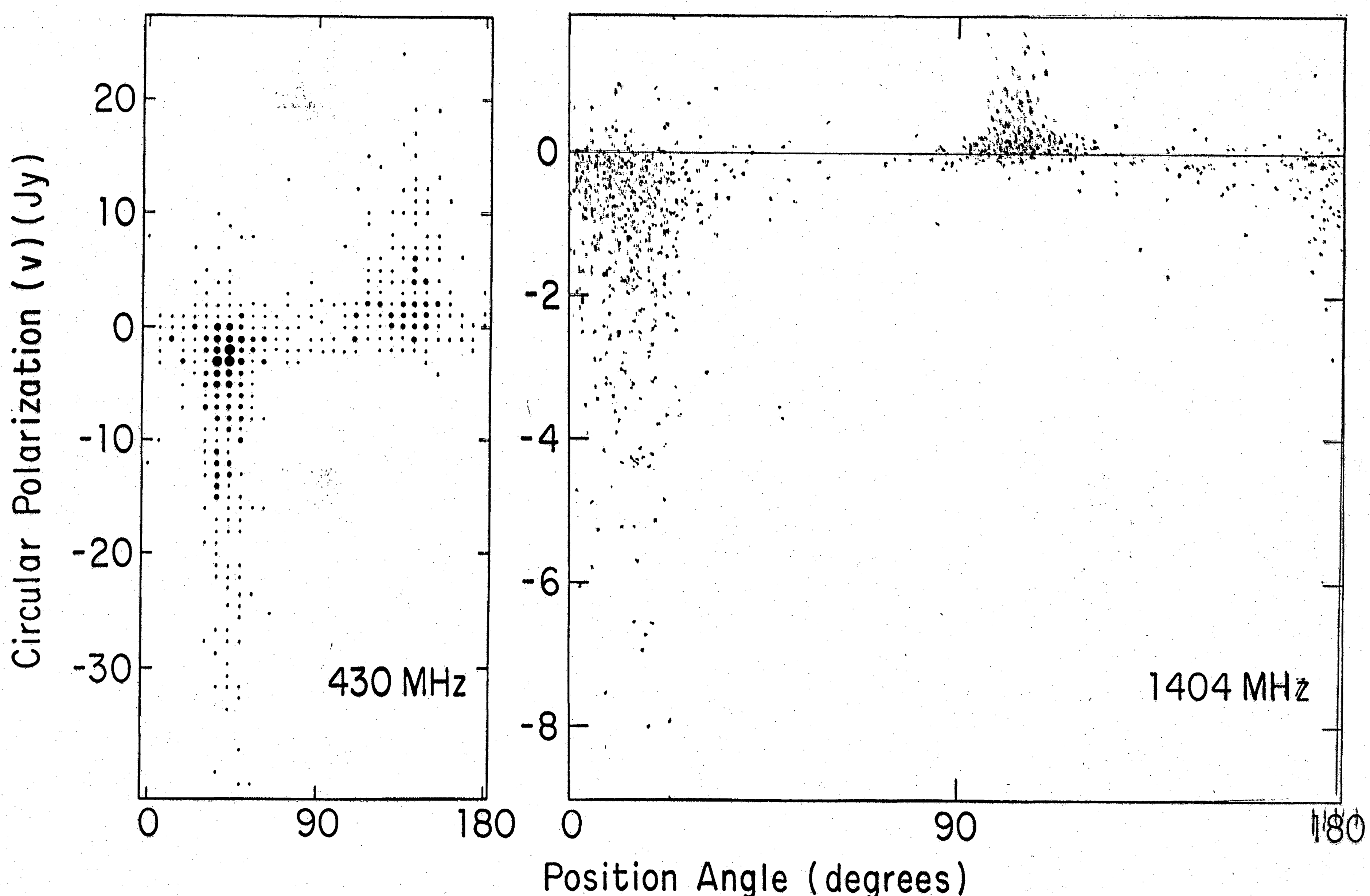


PSR 0950+08
3025 Pulses
1404 MHz
2.28
0
(Janskys)
I
L
V
5 msec
180
90
0
Pos. Angle (degrees)
χ
OPR
-32
0
32
Longitude (degrees)



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


Circular (Percent)
Position Angle
Linear (Percent)
Intensity (Janskys)
-100
0
100
180
90
0
100
50
0
1.92
0
PSR 0950+08
4064 Pulses
800 MHz
Longitude
polarization
statistically broadband
LHC
%V
RHC
χ
%L
I


Circular Polarization (v) (Jy)
20
10
0
-10
-20
-30
430 MHz
0
90
180
0
-2
-4
-6
-8
1404 MHz
0
90
180
Position Angle (degrees)