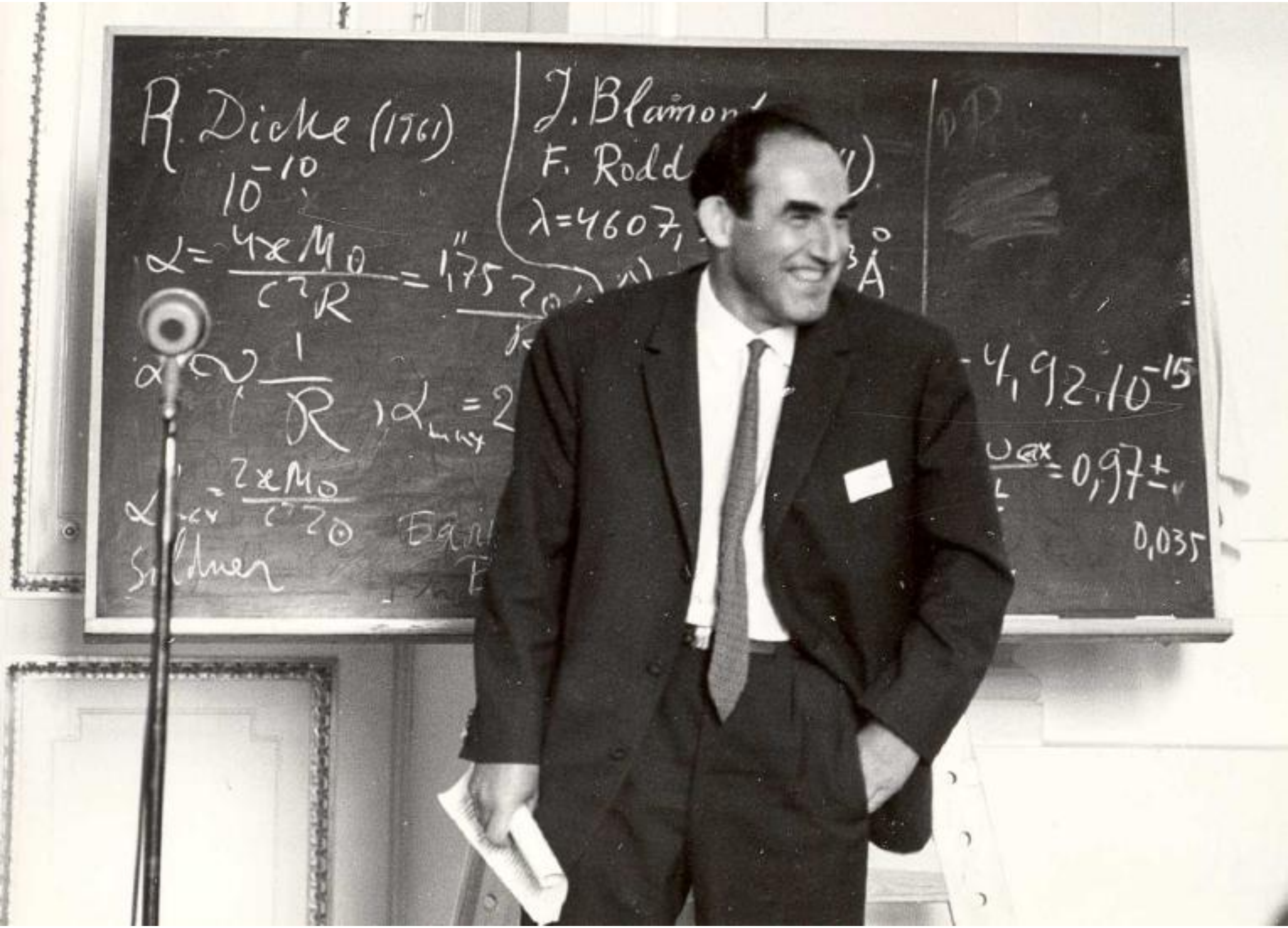
Gwiazdy neutronowe z perspektywy Jabłonnej

Marek Demiański

Wydział Fizyki UW


POLSKA
AKADEMIA
NAUK

Na konferencji w Jabłonnie (1962); z lewej P.A.M. Dirac, z prawej Leopold Infeld (fot. Marek Holzman)


R. Dicke (1961)
J. Blamont
F. Rodd
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EXPERIMENTAL VERIFICATION OF GENERAL RELATIVITY THEORY

V. L. GINZBURG

The Academy of Sciences, Moscow

THE aim of this article is to present the progress made in the experimental verification of General Relativity Theory (G.R.T.). Of course, in the first place all the facts available should be reported. But perhaps since the facts in this field are very poor, experimental verification of G.R.T. has shown itself to be particularly connected with various, so to say, collateral features. Here we mean above all a discussion of non-Einsteinian gravitational theories and also the significance of various experiments from the point of view of testing with their help the various aspects of G.R.T. In order to avoid any misunderstanding it should be stressed that in discussing these problems below, the present author will not strive either for any detailed analysis or comparison of various views found in the literature but he will only present his own views.

TETRADS AND CONSERVATION LAWS

J. PLEBAŃSKI

The University of Warsaw, Warsaw
and
The Institute of Physics of the Polish Academy of Sciences

LET V_4 be a hyperbolic normal Riemann space. Let C_∞ be the group of arbitrary coordinate transformations. From the assumed signature $(+,-,-,-)$ there follows the existence at any point of the space, x^α, of four orthonormal vectors $g^{\hat{a}}_{\alpha}(x)$ (greek indices are vectorial indices; "roofed" indices, which run through $\hat{a}=\hat{0},\ \hat{1},\ \hat{2},\ \hat{3}$ do not refer to C_∞, but just label the tetrad vectors). Their orthonormality properties may be expressed as:

$$g^{\alpha\beta}(x)g^{\hat{a}}_{\alpha}(x)g^{\hat{\beta}}_{\beta}(x)=g^{\hat{a}\hat{\beta}} \quad \text{where} \quad \|g^{\hat{a}\hat{\beta}}\|=\|\operatorname{Diag}(1,-1,-1,-1,)\|=\|g_{\hat{a}\hat{\beta}}\|. \tag{1}$$

By a simple algebraical argument, it follows that

$$g_{\alpha\beta}(x)=g_{\hat{a}\hat{\beta}}g^{\hat{a}}_{\alpha}(x)g^{\hat{\beta}}_{\beta}(x). \tag{2}$$

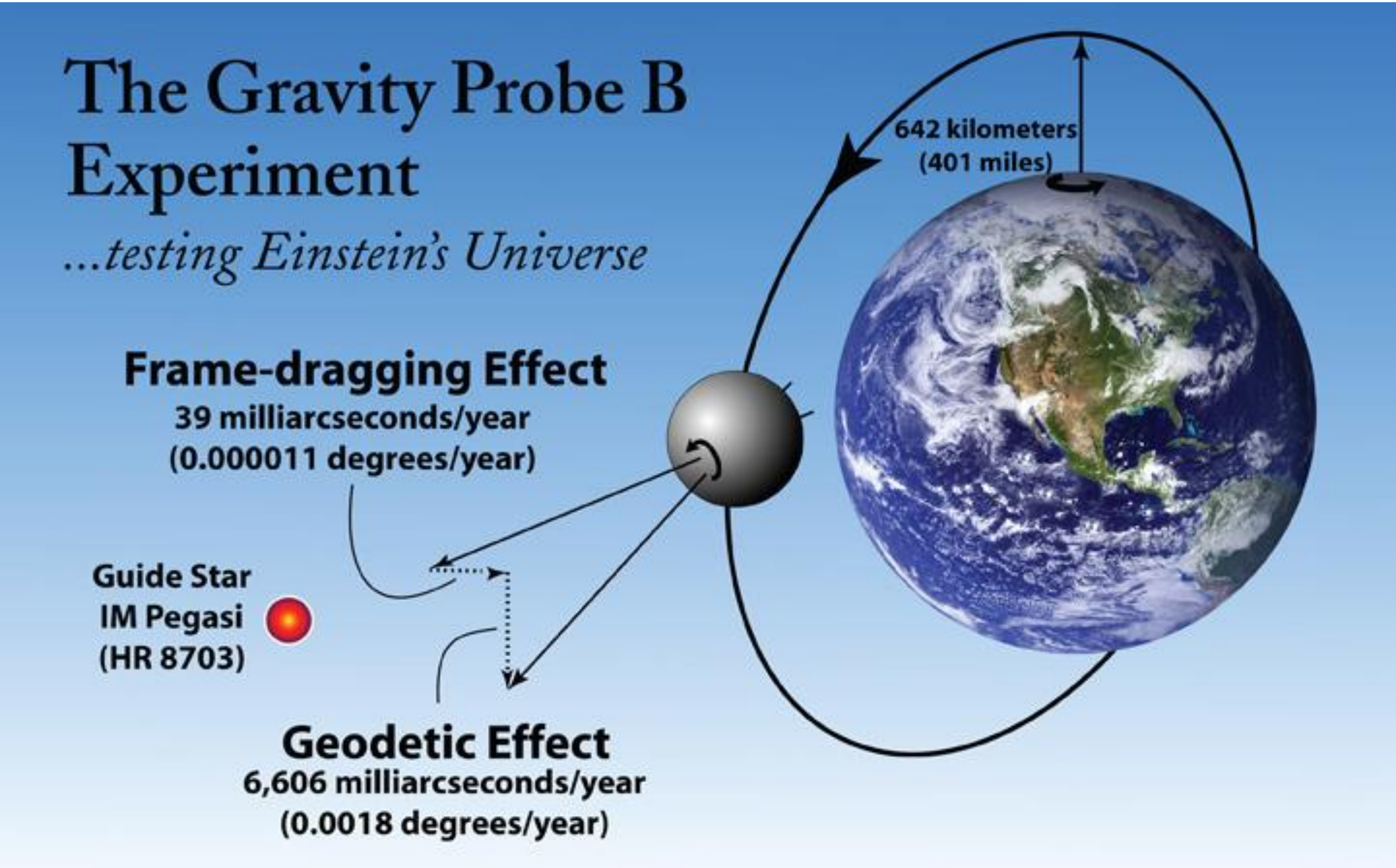
If $g^{\hat{a}}_{\alpha}(x)$ as functions of x are assumed to be of class C^3, one may speak of a normal hyperbolical V_4 with a built-in regular tetrad lattice. Observe that if $g=\operatorname{Det}\|g_{\alpha\beta}\|$ and $\hat{g:}=\operatorname{Det}\|g^{\hat{a}}_{\alpha}\|$ then (2) yields: $-g=(\hat{g:})^2$. Note also that the assumption that $g_{\alpha\beta}$ may be algebraically expressed by the right hand member of (2) is equivalent to Hilbert's conditions which assure the correct signature of the metric.

PROPOSED GYROSCOPE EXPERIMENT TO TEST GENERAL RELATIVITY THEORY*

L. I. SCHIFF

Institute of Theoretical Physics, Department of Physics, Stanford University, California

THERE is a striking difference between the experimental bases of the special and general theories of relativity. Special relativity has been amply verified in several aspects: for example, the dynamics of electrons and protons moving with speeds close to that of light, the time dilation of the decay of rapidly moving π mesons, the classical radiation from fast electrons in magnetic fields, and the predictions of relativistic quantum electrodynamics with respect to bremsstrahlung and more subtle radiative processes. In each of these categories, so many experiments have been found to yield results in agreement with theoretical expectation (and none in disagreement) that there can be no reasonable doubt as to the correctness of special relativity as a description of natural phenomena within its domain of validity. The situation is completely different with general relativity. Here, there are thus far only the three so-called "crucial tests": the gravitational red shift, the deflection of starlight passing close to the sun, and the precession of the perihelia of the orbits of the inner planets, especially Mercury. And of these the first, which was recently established in terrestrial experiments, [1], [2] was shown by Einstein [3] to follow directly from the equivalence principle, already established experimentally by Eötvös,(1) without employing the formalism of general relativity.


The Gravity Probe B Experiment
...testing Einstein's Universe
642 kilometers
(401 miles)
Frame-dragging Effect
39 milliarcseconds/year
(0.000011 degrees/year)
Guide Star
IM Pegasi
(HR 8703)
Geodetic Effect
6,606 milliarcseconds/year
(0.0018 degrees/year)

GENERAL DISCUSSION

J. WEBER:

Measurement of the Riemann Tensor. At the University of Maryland, we have constructed apparatus for detection of gravitational waves. This is a device to measure the Fourier transform of the Riemann tensor component R_{0101}.

The theory of this method[1] is that relative displacements occur in an elastic body in a curved space. A time dependent curvature, therefore, interacts with the normal modes of an elastic body. For one-dimensional acoustic waves set up in this body in the x' direction, we may choose coordinates such that the strain θ is given by the differential equation[2]

$$y \frac{\partial^2 \theta}{\partial x'^2} - \varrho \frac{\partial^2 \theta}{\partial t^2} - b \frac{\partial \theta}{\partial t} = c^2 \varrho R_{0101},$$

here y is the elastic modulus, ϱ is the density.

EXACT DEGENERATE SOLUTIONS OF EINSTEIN'S EQUATIONS*

I. Robinson

Laboratory of Nuclear Studies, Cornell University, Ithaca, N. Y.
Department of Physics, Syracuse University, Syracuse, N. Y.

and

A. Trautman

Institute of Theoretical Physics, Warsaw University

1. INTRODUCTION

In this lecture we wish to review recent works on gravitational fields that admit a congruence of null geodesics without shear.

Most of our present ideas on waves in general relativity are based on analogies between electromagnetism and gravitation. From the point of view of physics, among the most important features of electromagnetic waves is their ability to transport energy and to carry information. Accordingly, physicists are inclined to consider as gravitational waves those solutions of Einstein's equations *in vacuo* which correspond to a mass changing in time, or contain an arbitrary, information carrying, function. Unfortunately these properties are of such a kind that they do not seem to suggest a method for constructing such solutions. Among electromagnetic waves, there are particularly simple ones, corresponding to a null electromagnetic tensor. With null electromagnetic waves there is associated a remarkably simple and beautiful geometrical structure. Its properties can be stated independently of the electromagnetic field. Thus, one can single out the class of gravitational fields that admit a similar structure and look for waves among them. Gravitational fields belonging to this class are nowadays referred to as 'algebraically special' or 'degenerate'. Before we proceed to review these fields, we wish to describe two typical electromagnetic null fields which have close analogues among our gravitational waves.

THE QUANTIZATION OF GEOMETRY

B. S. DEWITT

Department of Physics, University of North Carolina, Chapel Hill

RELATIVITY and quantum theory have both demanded a fundamental revision in our ways of thinking about Nature. Relativity has forced us to revise our concepts of space and time. Quantum theory has forced us to change our attitude toward determinism and measurability. Both have led us to rethink, at a basic level, the problem of *what constitutes an observation.*

I should like to indicate briefly today some of the new problems to which one is led in the course of attempting to bring about a fundamental union of the two theories. The union which is envisaged goes beyond the familiar superposition of special relativity on a quantum framework and, although informally referred to as *quantum gravidynamics*, has implications by no means limited to gravitation theory.

The problem of what constitutes an observation continues to be a basic one in the quantum theory of geometry. In order that my subsequent remark be understood in proper perspective, let us, therefore, first review the elements of measurement theory in quantum mechanics and its relation to the Uncertainty Principle.

THE MOTION OF AN EXTENDED PARTICLE IN THE GRAVITATIONAL FIELD

P. A. M. Dirac

St. John's College, Cambridge

THE MODEL

With the Einstein theory of gravitation there is a minimum size for a particle of given mass m, namely the radius $\varrho = 2m$ in the Schwarzschild system of coordinates. The gravitational field can be extended to smaller radii consistent with Einstein's field equations for empty space, but the region $r < 2m$ is then physically inaccessible (it would need an infinite time to send in a signal and get it out again), so it cannot be allowed in a physical theory.

Thus, to get a precise theory of the motion of a particle in the gravitational field, one cannot take the particle to be a point singularity. One must take it to have a finite size ϱ, such that Einstein's equations for empty space hold only for $r > \varrho$ and ϱ must be $\geqslant 2m$. It is awkward to work with the case $\varrho = 2m$, because of the singular character of space-time at this radius. We shall here consider the case of $\varrho > 2m$.

QUANTIZATION OF THE GRAVITATIONAL FIELD*

S. MANDELSTAM

Department of Mathematical Physics, University of Birmingham

PRESENT quantum theories of the gravitational field generally work in "flat space". The original attempt at quantization was made by Gupta (1952) and carried out by him to first order. He started with the Lagrangian of the classical theory and applied the normal methods of quantization to it, treating the $g_{\mu\nu}$ as ordinary variables which have no connection with the metric. Owing to the ambiguities in the ordering of the factors, such a programme cannot be carried through exactly. However, it may be that one can write down a Lagrangian to any order in the gravitational constant and obtain consistent equations of motion up to that order.

Quantization in flat space can only be regarded as a provisional solution of the problem for several reasons. One would like to be able to formulate the equations of a theory exactly, even though approximations have to be made in their solution. This cannot be done or, at any rate, has not yet been done, in the flat space gravitation theory. Also, one has to introduce an indefinite metric and unphysical states, just as in quantizing electrodynamics with the Lorentz gauge. Both these disadvantages would be overcome if Arnowitt, Deser and Misner (1960) succeed in their programme of finding canonical variables for the quantum theory. At the moment a solution does not appear to be in sight, and in any case it would yield a theory which completely lacked manifest Lorentz covariance.

THE QUANTUM THEORY OF GRAVITATION*

R. P. FEYNMAN

Norman Bridge Laboratory, Pasadena

THE quantum theory of gravitation is studied by seeing what difficulties arise if one actually tries to solve specific problems in perturbation theory to increasing orders of accuracy. We specifically keep all energies involved below some upper limit (e.g. 10^3 GeV), and do not analyze the philosophical consequences of a quantized metric, etc. Instead, we begin by writing the classical Lagrangian for a matter field (most calculations were made for spin zero particles) in interaction with a gravitational field represented by a metric $g_{\mu\nu}$. By writing $g_{\mu\nu} = \delta_{\mu\nu} + h_{\mu\nu}$ and expanding in terms of $h_{\mu\nu}$, which we consider as the potential of the spin-two gravitational field, we find a Lagrangian involving h in second order (which we call the free Lagrangian) plus third, forth etc. orders in h. These latter terms can be considered as interaction terms where three, four, etc. gravitations interact at a point.

Because of the invariance of the complete Lagrangian under coordinate transformations, the free wave equation is singular, and can only be solved if some gauge condition is chosen, analogous to the choice of the Lorentz gauge condition in electrodynamics. Then diagrams can be made for each process in any order and the results calculated in the usual way.

THE LIGHT CONE AT INFINITY

R. Penrose

King's College, London

Abstract—From the point of view of the conformal structure of space-time, "points at infinity" can be treated on the same basis as finite points. Minkowski space can be completed to a highly symmetrical conformal manifold by the addition of a null cone at infinity—the "absolute cone". Owing to their conformal invariance, zero rest-mass fields can be studied on the whole of this conformal manifold. The behaviour of the fields on the absolute cone can be used to define the radiation fields. General relativity can be treated from this point of view if the gravitational field is represented by an expression originally equal to the Weyl tensor but which transforms slightly differently under conformal transformation.

Questions concerning radiation, or asymptotic flatness of space-time, involve statements about events in the "neighbourhood of infinity". It would appear, therefore, that some deeper understanding of the mathematical nature of this "infinity" might be of great conceptual value to physics. I wish to describe here an idea which seems to have been partially suggested by a number of people, and to me particularly by E. Schücking. The essential construction can apparently be traced back to Möbius [1].(1)

Then infinity is represented by the sides of the square and to complete the picture, opposite sides must be identified preserving sense. The resultant compact manifold is topologically a torus. Next, consider the three-dimen-

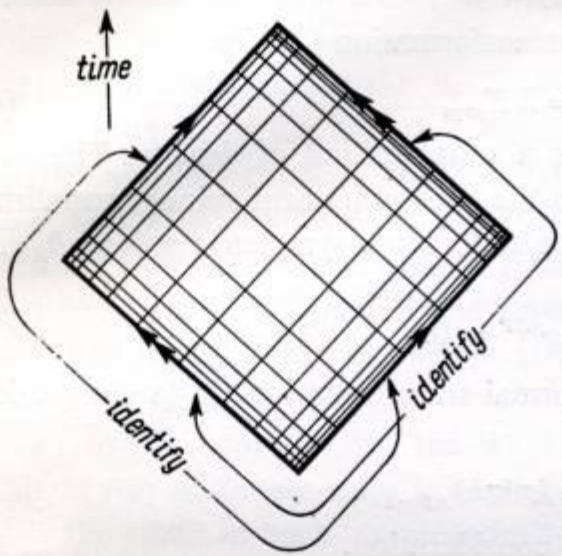


FIG. 1.

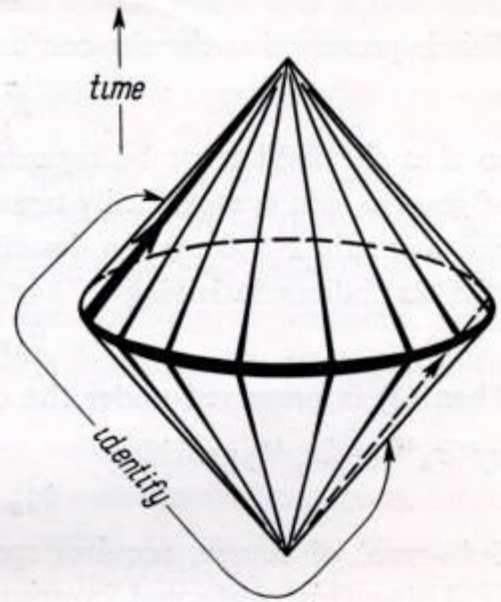
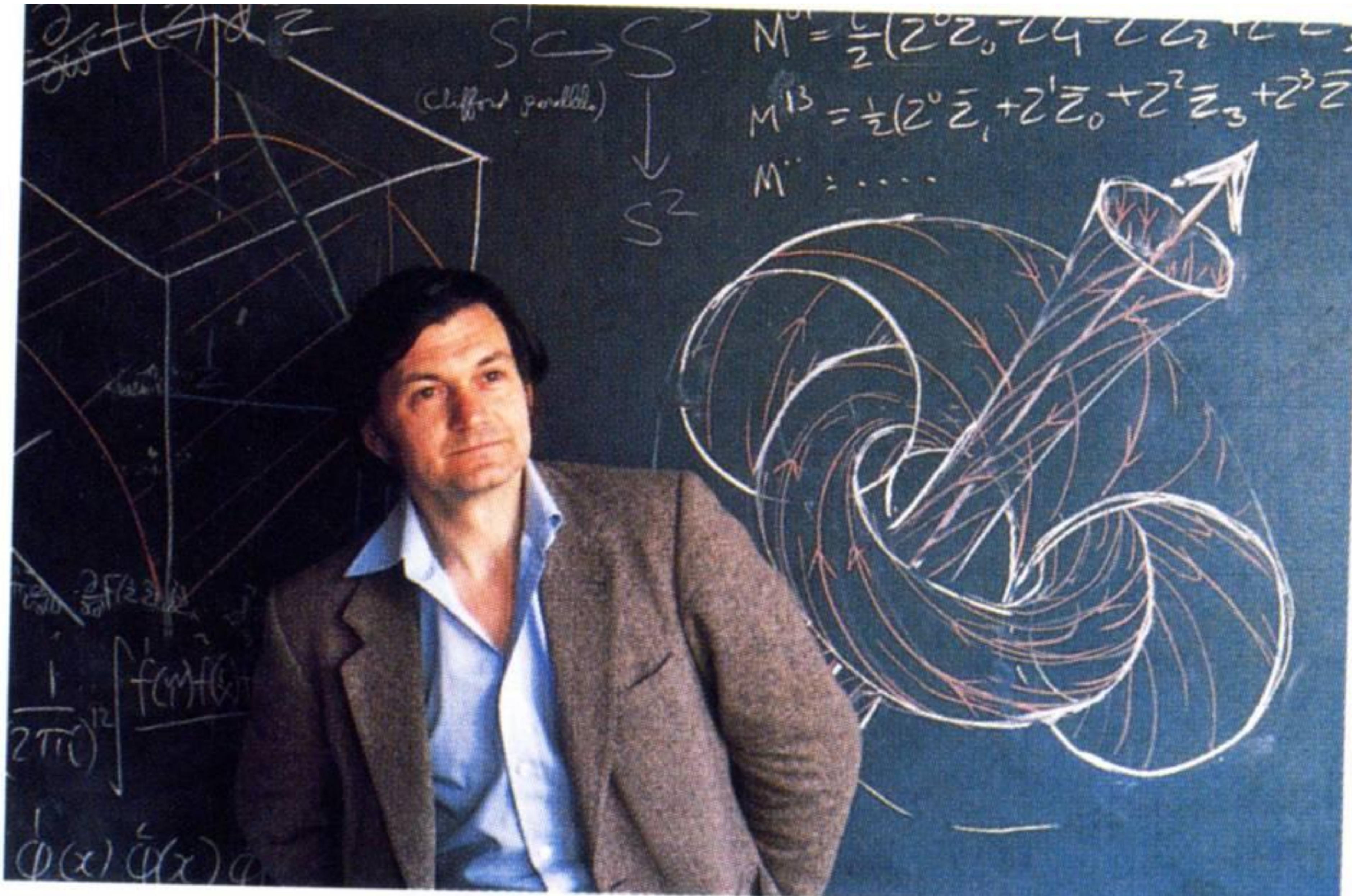


FIG. 2.

sional case (two space and one time dimension). This time we map the space-time continuously onto the interior of a region bounded by two portions of cones joined base to base (see Fig. 2). Each generator of the top cone is to be identified with the opposite generator of the bottom cone, preserving future sense. It follows that both the top vertex and the bottom vertex must be identified with the whole of the "equator"—which must therefore be considered as a point. The resultant compact manifold is non-orientable and has the topology of a three-dimensional analogue of Klein's bottle. The four-dimensional case is very similar, except that in this case the manifold turns out to be orientable again and has the topology $S^1 \times S^3$.



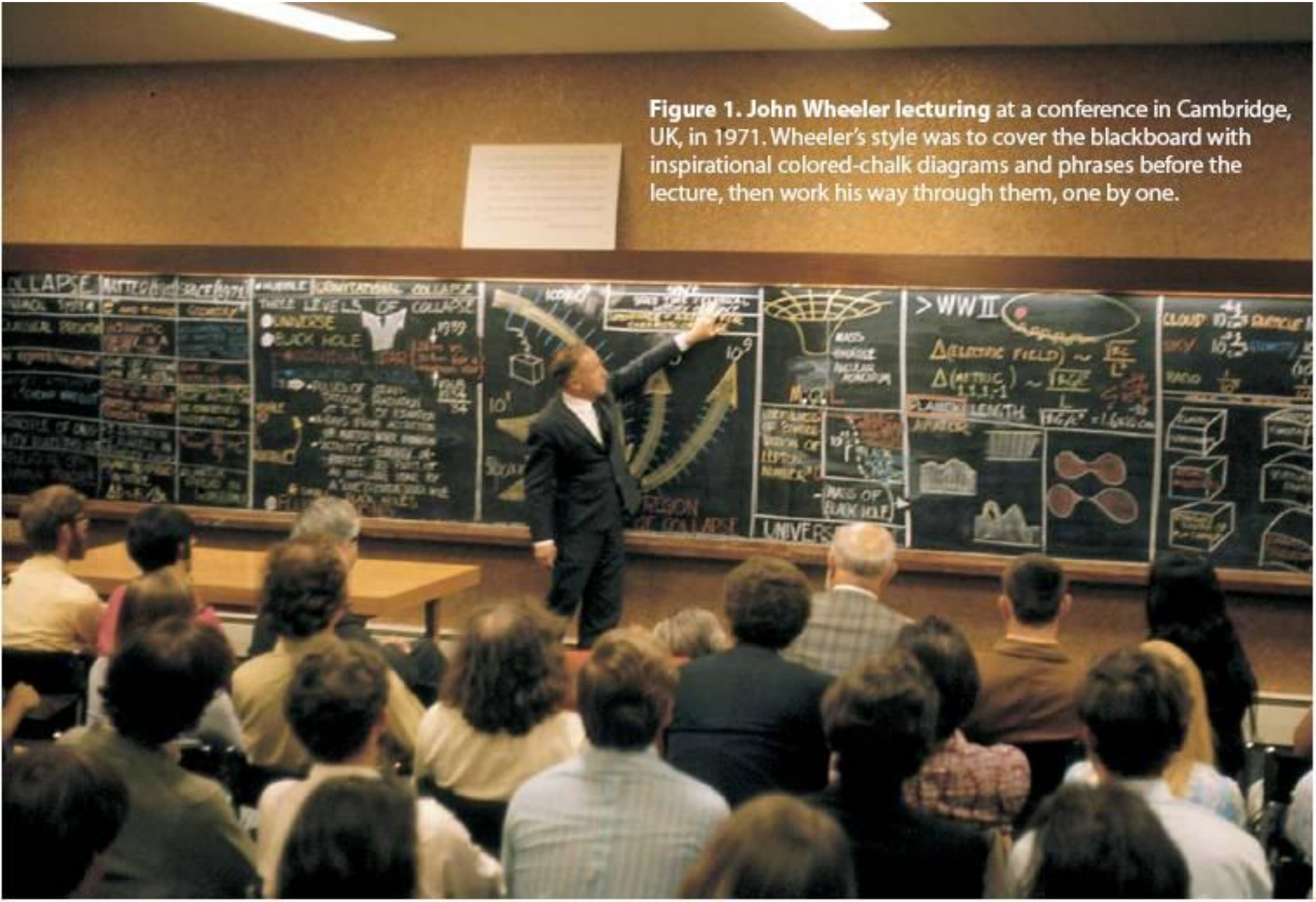


Figure 1. John Wheeler lecturing at a conference in Cambridge, UK, in 1971. Wheeler's style was to cover the blackboard with inspirational colored-chalk diagrams and phrases before the lecture, then work his way through them, one by one.

GOŚCIE INSTYTUTU FIZYKI TEORETYCZNEJ

Ważnym wskaźnikiem rozwoju IFT były i są stale rozwijające się kontakty zagraniczne. Oto kilka zdjęć z różnych spotkań.

A brief history...

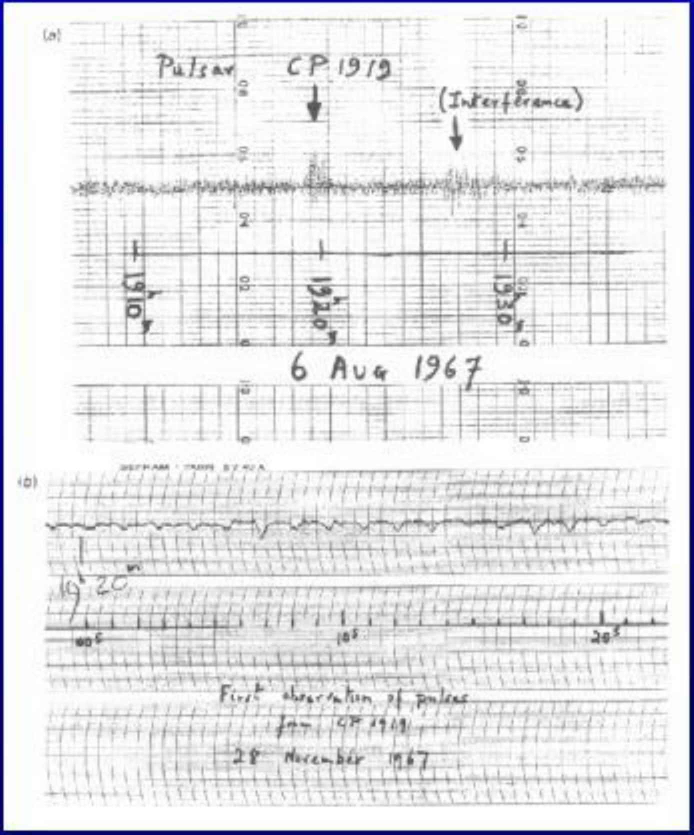
- In 1932 Chadwick discovers the neutron
- In 1934 Baade & Zwicky propose that "stars" mostly consisting of neutrons will be created in Supernova explosions
- In 1939 Oppenheimer & Volkov calculate size and mass of these "neutronstars" to be ~20 km and $\sim 1.4 M_{\odot}$
- In 1967 a young research student was working with A.Hewish on her PhD on planetary scintillation…

The discovery...

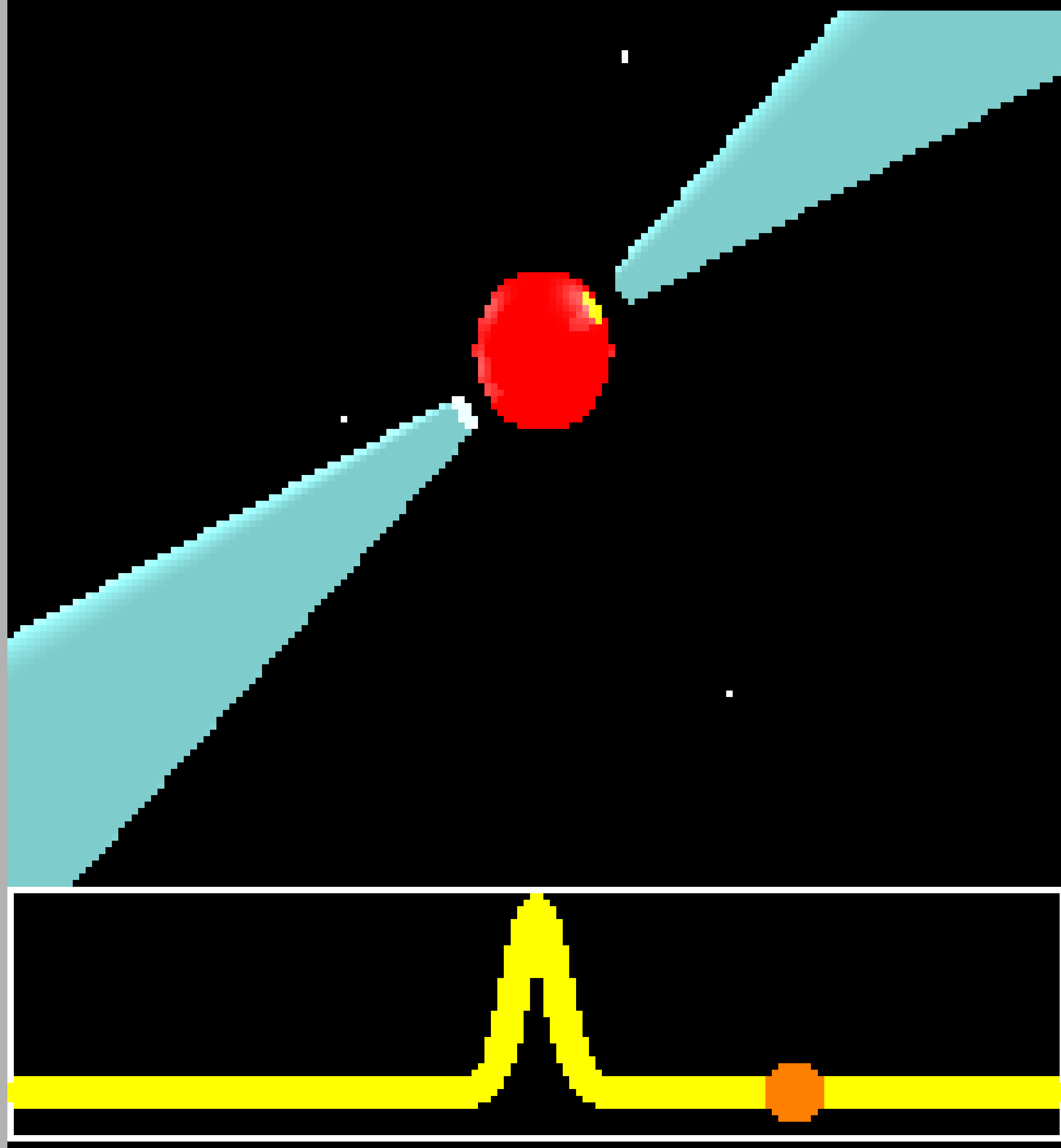
- Jocelyn Bell discovers a periodic extra-terrestrial signal of 1.337 s at position:

  RA 19:19:36

  DEC +21:47:16



MPIfR-Bonn Pulsar Group



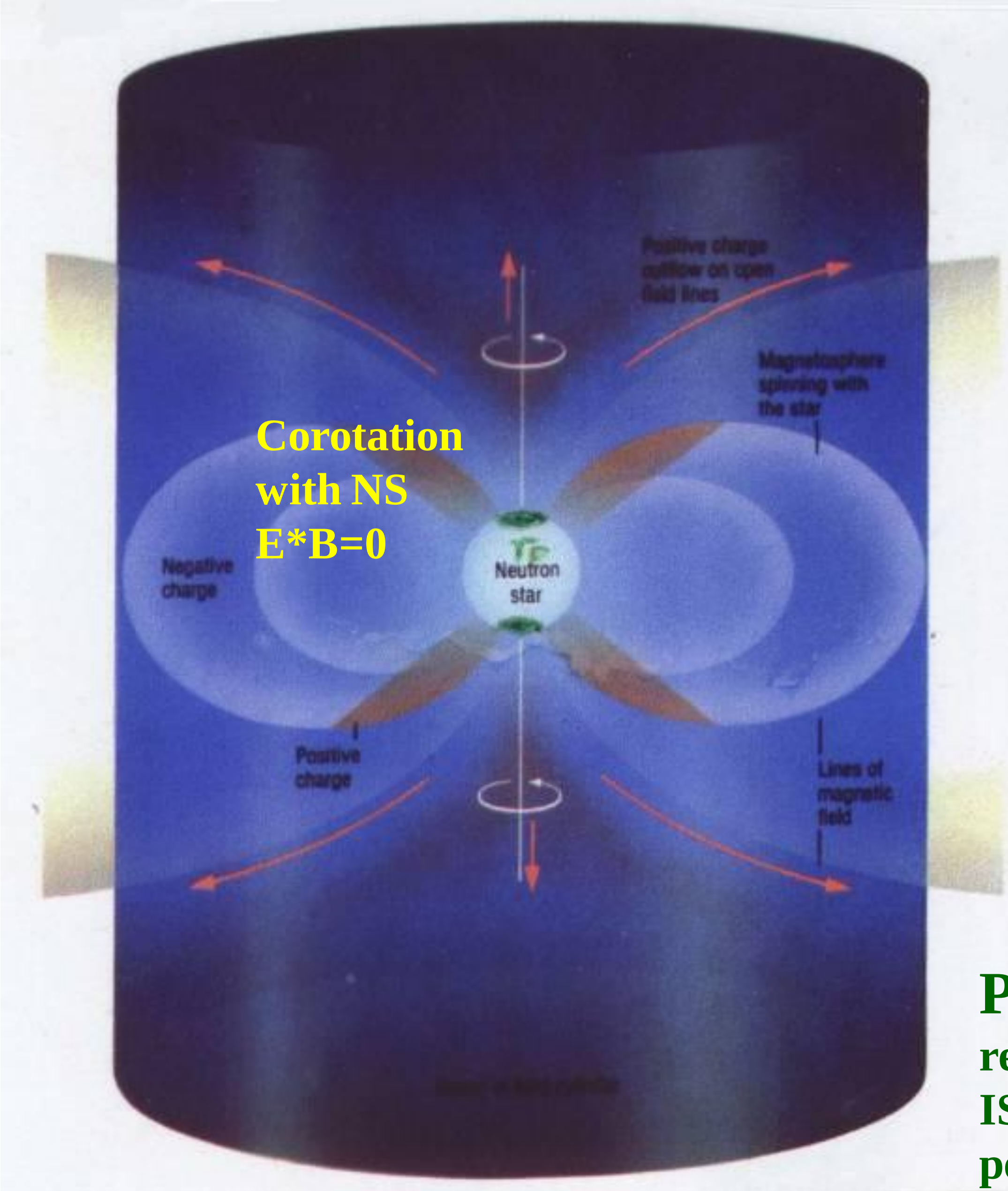
The Crab Pulsar

- A period of P=33 ms rules out white dwarfs:
  - radial oscillation only fo P>1sec
  - Estimate max radius for rotating object:

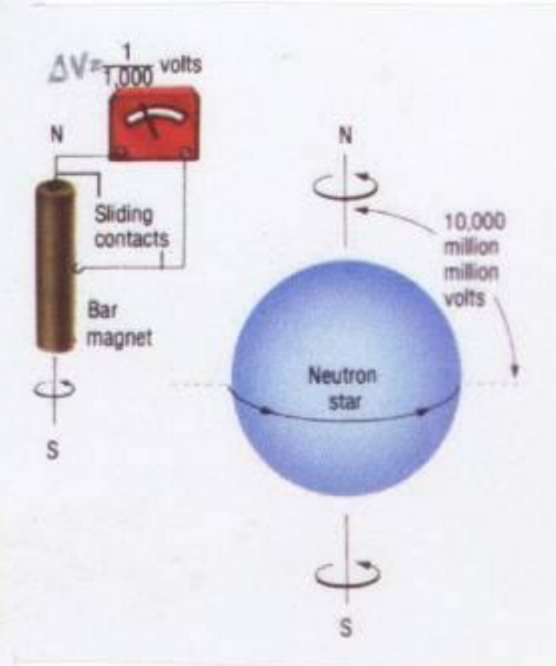
$$F_{centrifugal} = R \cdot M_1 \cdot \omega^2 = G \cdot M_1 \cdot \frac{M_2}{R^2} = F_{grav}$$

  - For M_2=1.4 $M_\odot$ and period of Crab pulsar

    $R_{max} = 1.7 \cdot 10^5$ m
  - Typical radius of WD is 10^7 m
- Crab-Pulsar period increases by 36 ns a day!



Pulsars are fast rotating and strongly magnetized Neutron Stars (NS)



Polar Cap (PC)

region of NS surface connected to ISM via open magnetic field lines penetrating the Light Cylinder

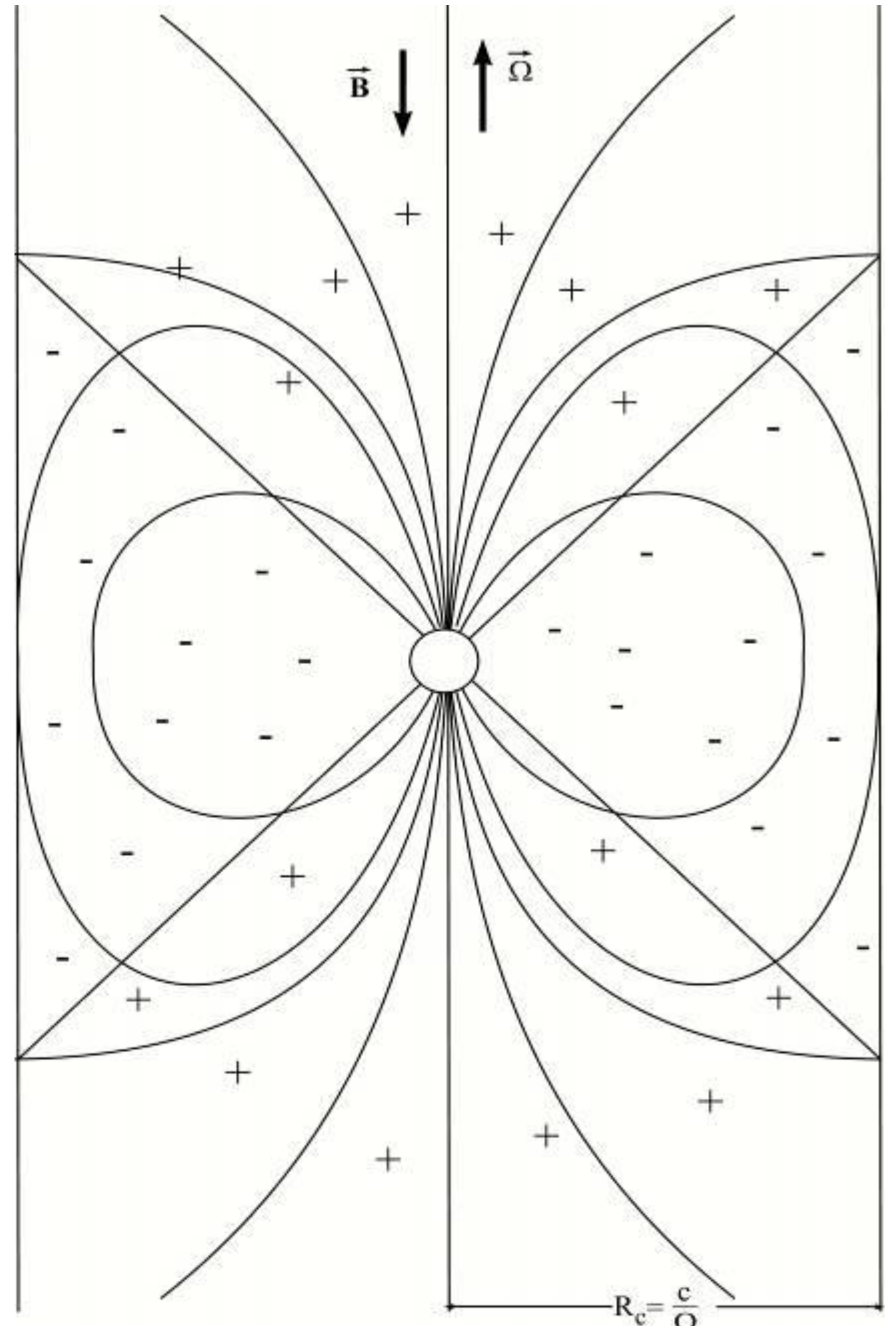
Charged particles will leave through LC due to inertia and create charge depletion just above the PC. If this charge cannot be re-supplied by the PC surface (strong binding) then huge accelerating potential drop V~10^{12} V will occur along the open magnetic field lines close to the PC surface.

The charge distribution in the magnetosphere of the rotating neutron star

$$E_{||} \approx 0$$

$$\vec{E} + \left(\vec{\Omega} \times \vec{r} \right) \times \vec{B} / c = 0$$

Charge density $\rho_{\mathrm{GJ}} = -\dfrac{\vec{\Omega} \cdot \vec{B}}{2\pi c}$



Magnetic Fields

- Assuming magnetic dipole, $B=|m|/r^3$

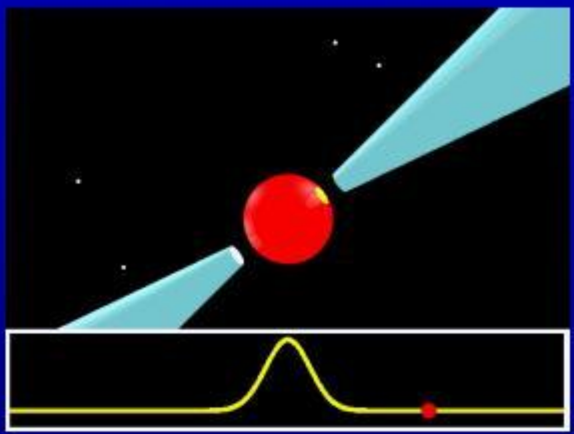
$$B = \sqrt{\frac{3c^3}{8\pi^2}\frac{I}{R^6 \sin^2 \alpha} P \dot{P}} = 3.2 \cdot 10^{19} \sqrt{P \dot{P}} \text{ Gauss}$$

Surface field

- Here we have assumed:
  - $R = 10$ km
  - $I = 2/5\, M R^2 = 10^{45}$ g cm^2
  - $\alpha = 90$ deg ($\angle$rotation,magnetic axis)
- Typical values: 10^{12} Gauss (Earth: 1 Gauss!)

Spin-down

Increase in P results from loss of rotational energy



Radiating mostly magnetic dipole radiation:

$$\dot{E} = \frac{d}{dt}\left(\frac{1}{2} I\Omega^2\right) = I \cdot \Omega \cdot \dot{\Omega}$$

$$= \frac{2}{3c^3} |m|^2 \Omega^4 \sin^2 \alpha$$

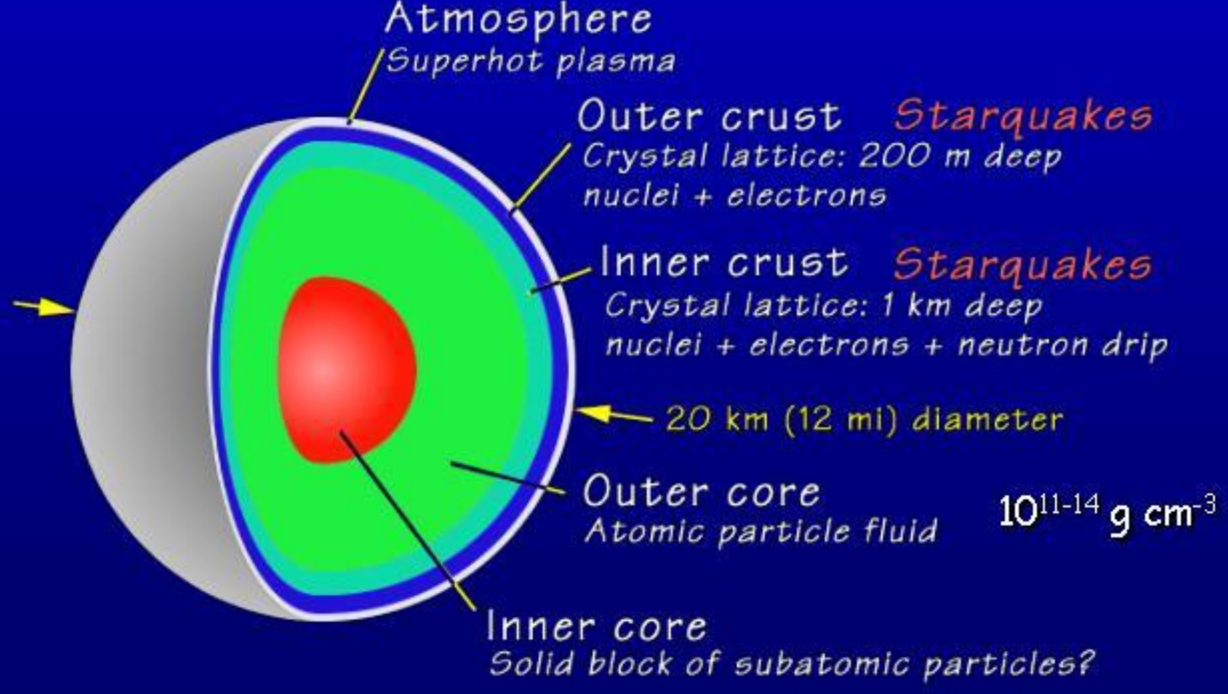
Evolution of spin-frequency:

$$\dot{\Omega} = -\left(\frac{2m^2 \sin^2 \alpha}{3c^3 I}\right)\Omega^3 \propto -\Omega^n$$

n=breaking index

Size and Structure

- Very dependent on Equation-of-State (EOS)!
- Current research suggests:



Podstawowe własności gwiazd neutronowych

Masa – bezpośredni pomiar $(1 - 2)M_\odot$

Promień – tylko oszacowania (10 – 20) km

$<\rho> \sim (10^{14} - 10^{15})\ \mathrm{g/cm^3}$

Czarne dziury $R_{\mathrm{BH}} = R_S = \frac{2GM}{c^2} = 3.0 \frac{M}{M_\odot}\ \mathrm{km}$

$$\overline{\rho}_{\mathrm{BH}} = \frac{M}{\frac{4}{3}\pi R_S^3} = 1.95 \times 10^{15}\ \mathrm{g\ cm^{-3}} \times \left(\frac{M}{3M_\odot}\right)^{-2}$$

EOS - matter in nuclear equilibrium (minimum of E at $T=0$)

$\rho(P=0) = 7.86\ \ \mathrm{g\ cm^{-3}}$

$T=0$ Regions of increasing density

outer crust $[(A,Z),e]$

inner crust $[(A,Z),n,e]$

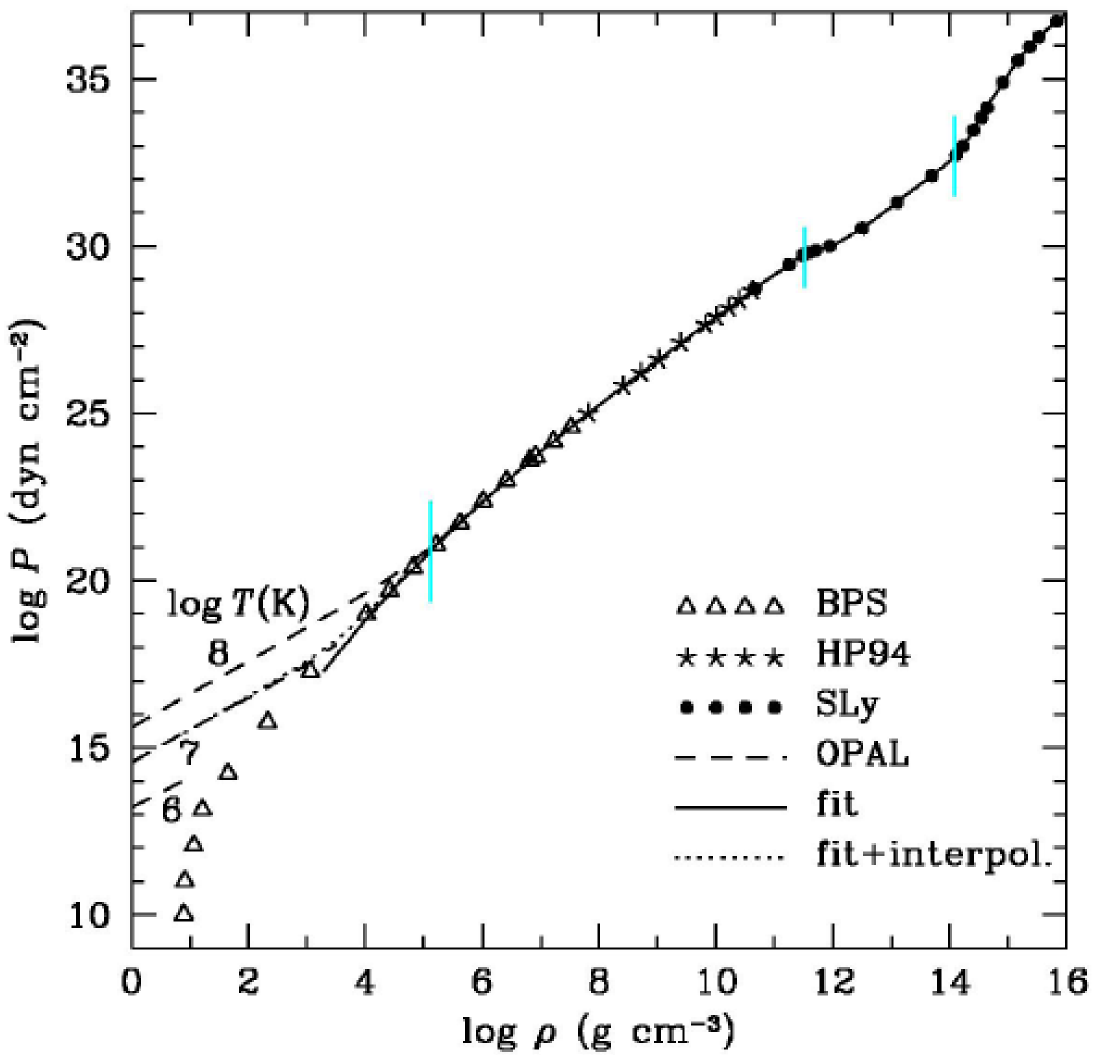
outer core $[n,p,e,\mu]$

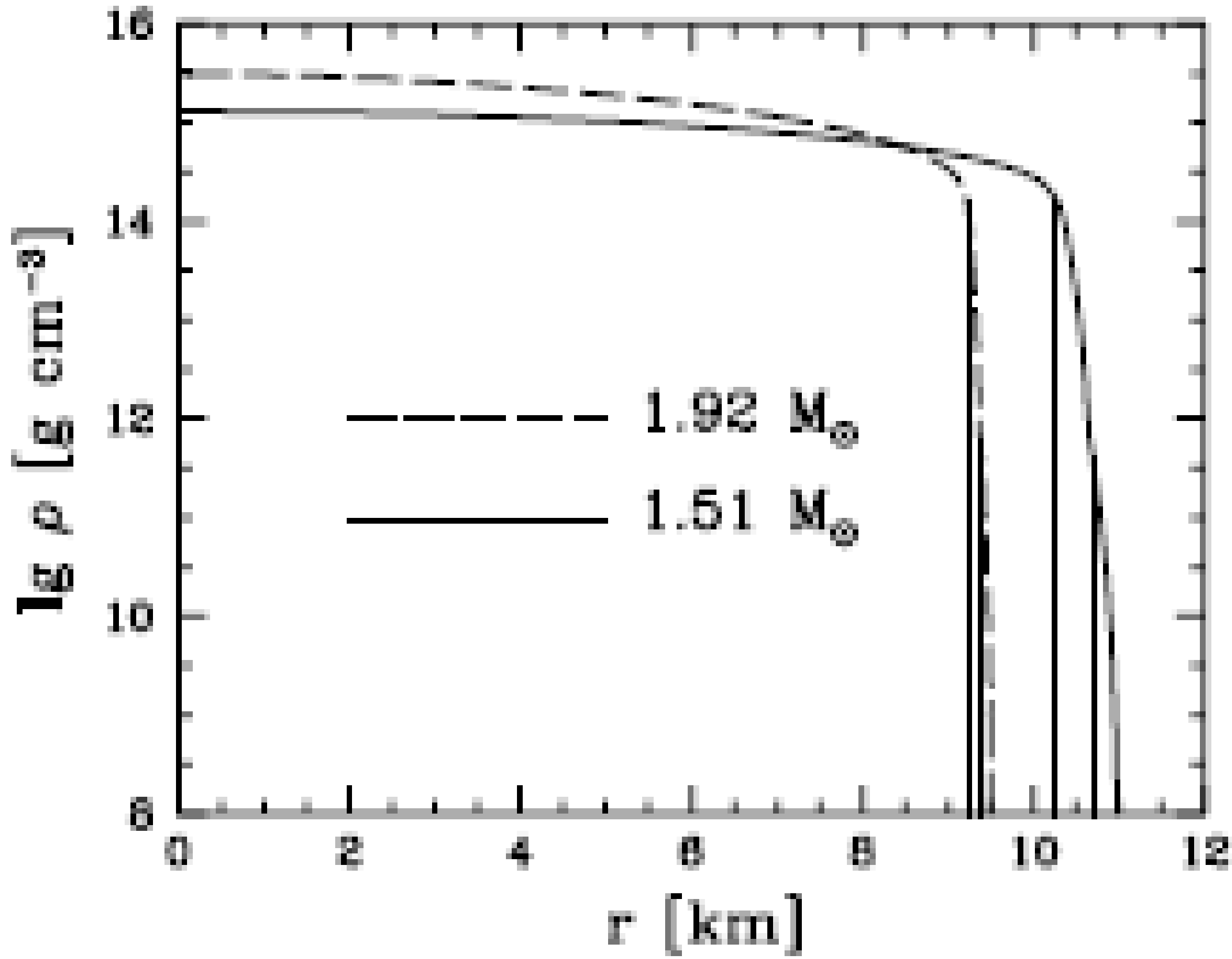
inner core $[n,p,e,\mu,\ hyperons\ ?,\ boson\ condensates??,\ quarks\ ??]$

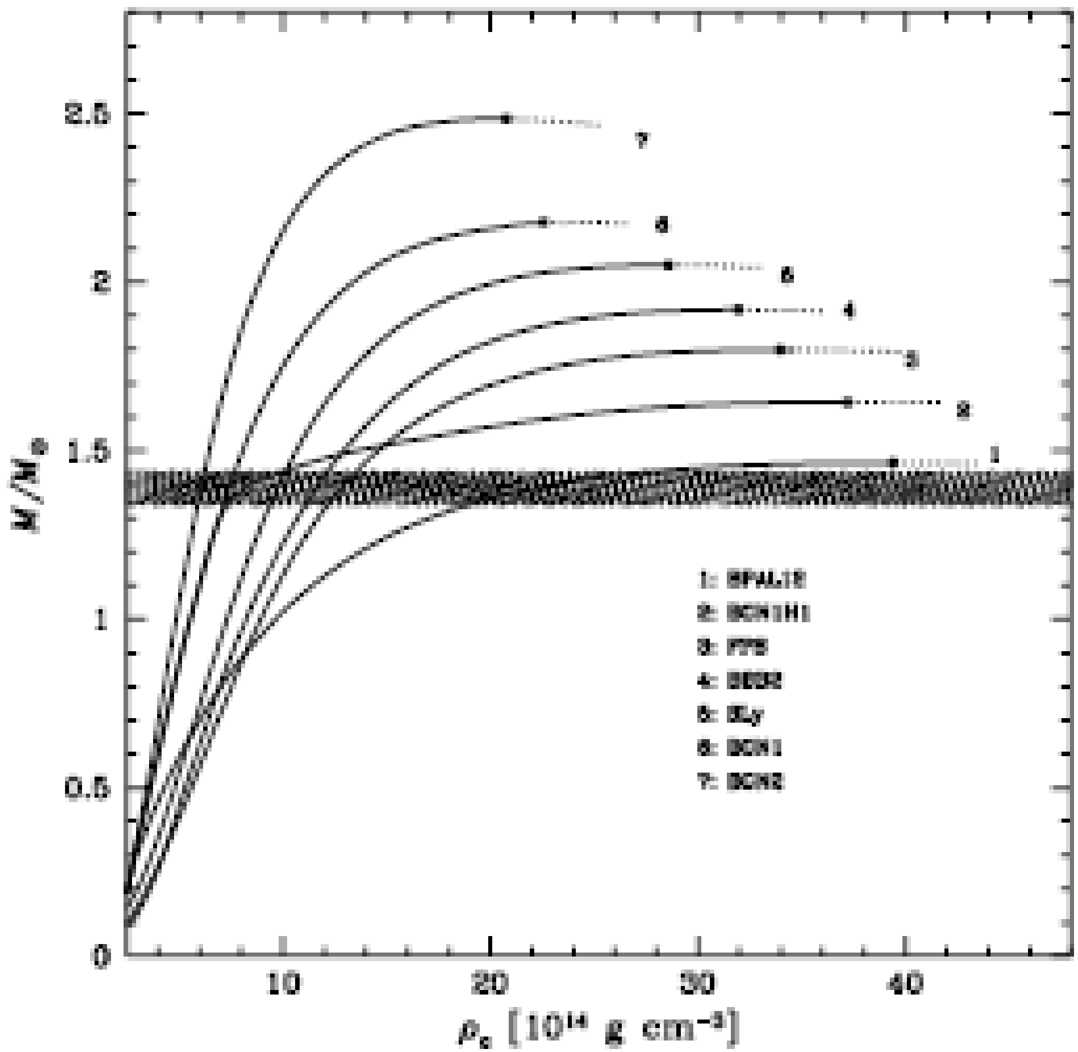
Typical for NS: $T \lesssim 10^8$ K, matter with $\rho > 10^6\ \ \mathrm{g\ cm^{-3}}$ **strongly degenerate**

Outer layers of increasing density: [atmosphere][ocean][outer crust][...][...]...

Haensel & Potekhin (2004)⟶



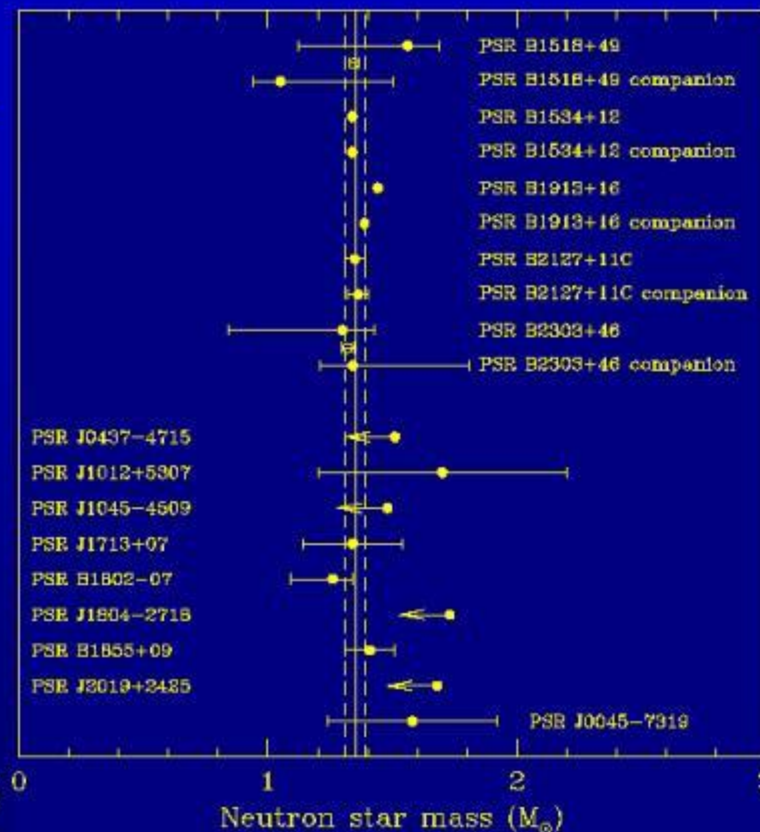

16
14
12
10
8
0
2
4
6
8
10
12
lg ρ [g cm⁻³]
r [km]
1.92 M⊙
1.51 M⊙



M/M⊙
0
0.5
1
1.5
2
2.5
10
20
30
40
ρc [10^14 g cm^-3]

Masses

- QM predicts 1.4 $M_\odot$
- Depends on Equation-of-State (EOS)
- Accretion can increase mass
- Observations show mean values ~1.35$M_\odot$



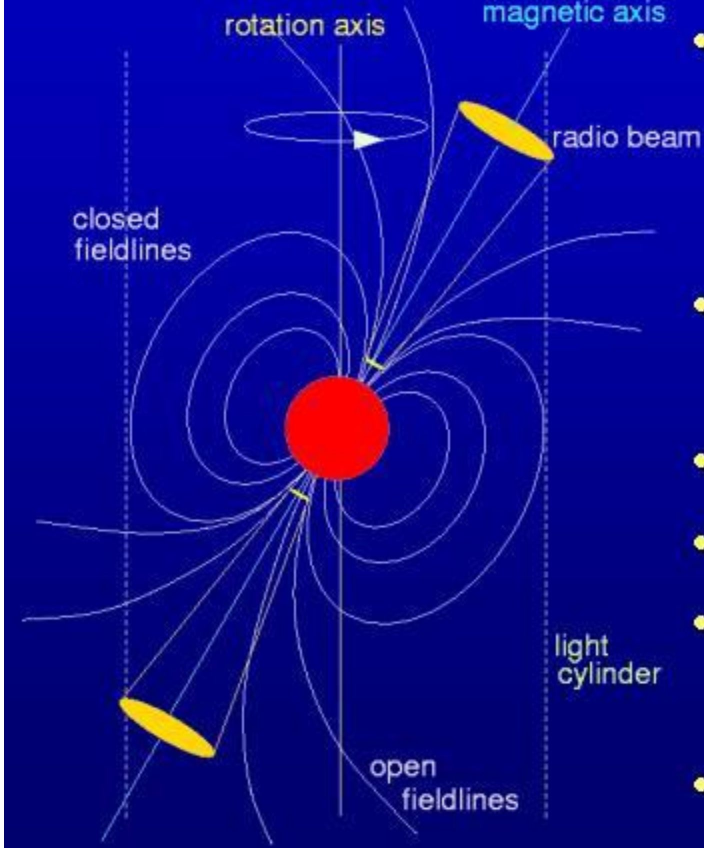
Thorsett & Chakrabarty '99

2 - Pulsars as Radio Sources

In this section, we look at:

- Magnetosphere
- Emission properties
- Average & single pulses
- Geometry
- Emission heights
- The European-Pulsar-Network

Pulsar - Magnetosphere



- rotation induces electric quadrupole field

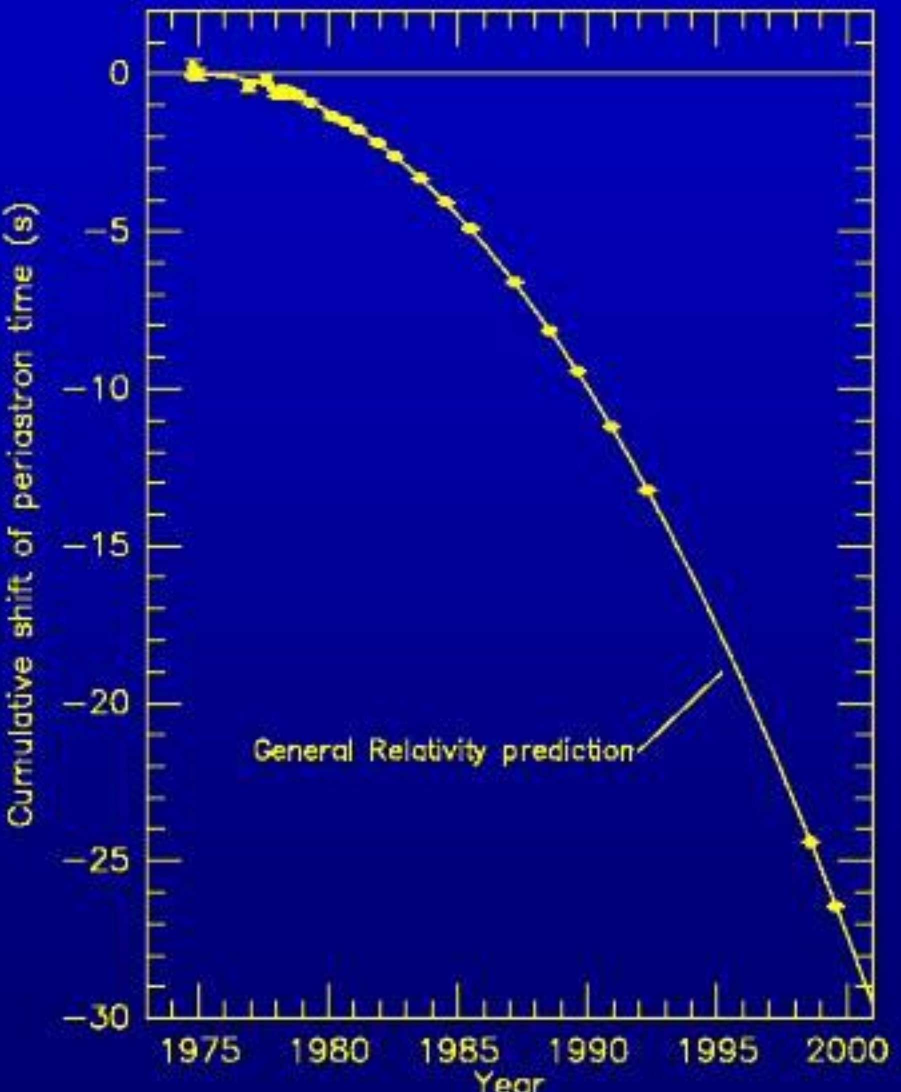
$$F_{el} / F_{grav} = 10^{12}$$

- charges pulled out of surface, shielding force
- plasma fills surrounding
- co-rotation with pulsar
- light cylinder:

$$v = R_L \Omega = c$$

- open and closed fieldlines

Theories of Gravity: Gravitational Waves



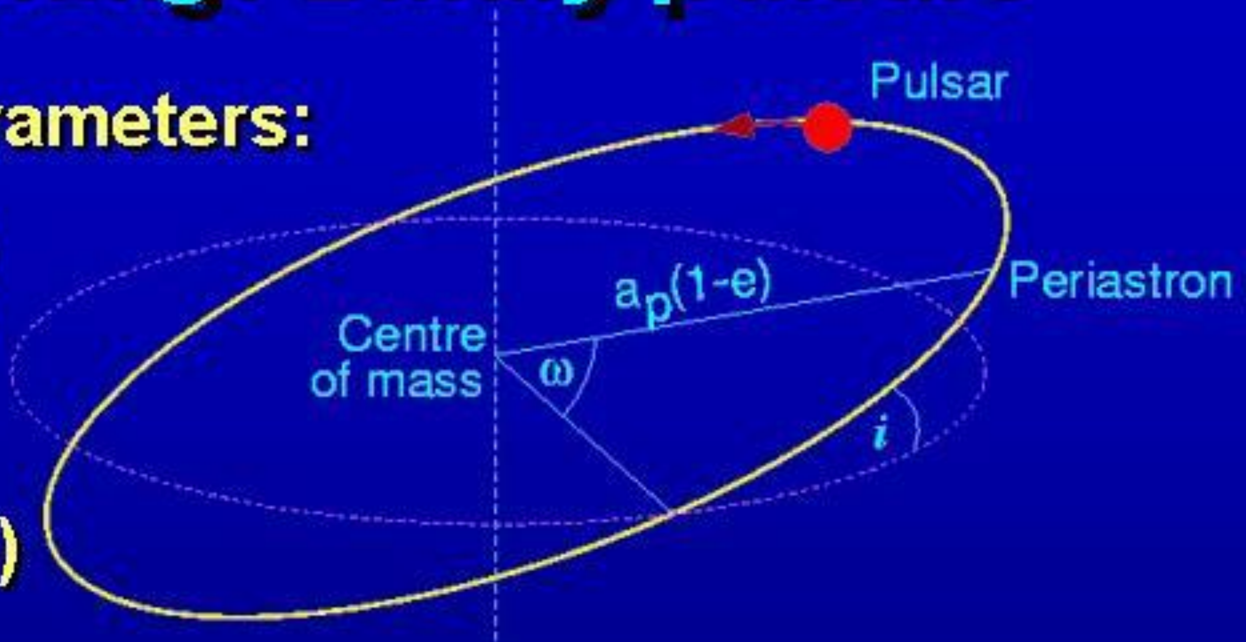
- **Orbit shrinks every day by 1cm!**

Pulsar Timing: Binary pulsars

- 5 Keplerian-parameters:

  P_{orb}, a_p, e, ω, T_0

- Post-Keplerian parameters (rel.corrections)



- Mass function:

$$f(m_p, m_c) = \frac{4\pi^2}{G}\frac{(a_p \sin i)^3}{P_{orb}^2} = \frac{(m_c \sin i)^3}{(m_p + m_c)^2}$$

- Estimate of companion mass if inclination known
- Minimum mass for i=90 deg

letters

Does PSR0329+54 have companions?

M. Demiański & M. Prószyński

Institute of Theoretical Physics, Warsaw University, 00-681 Warsaw, Hoża 69, Poland

An extensive pulse timing programme has been carried out over the past 10 years for several pulsars[1–5]. The timing observations revealed a wide range of different effects such as glitches, noise in the pulsar rotation and unexpectedly large second time derivatives of the rotation frequency. We suggest here that these unexpectedly large values of $\ddot{\nu}$ may be caused by a binary motion with an orbital period, P_b, longer than the span of timing observations. Even a distant planet of a relatively low mass ($100\,M_\oplus$ for $P_b = 50$ yr) would influence $\ddot{\nu}$. In the case of PSR0329+54, besides a large $\ddot{\nu}$ term, a quasi-sinusoidal modulation shows up in timing residuals. This 3-yr periodicity may be caused by: (1) a change in pulse shape, (2) precession of a magnetic dipole axis, or (3) a small planet ($m = 0.06 - 0.57\,M_\oplus$) orbiting the pulsar.

All known pulsars are slowing down at a rate conveniently

pulsars. It also includes the Crab pulsar, PSR0531+21, for which $\ddot{\nu}$ is large because of its very rapid slowdown (large $\dot{\nu}$).

Here we discuss some features of the timing data for PSR0329+54. The barycentric arrival times covering 8 yr of pulsar observations[5] at National Radio Astronomy Observatory and Five College Radio Astronomy Observatory were kindly supplied by Dr D. J. Helfand.

To determine $\ddot{\nu}$ we take

$$N(t) = N_0 + \nu t + \tfrac{1}{2}\dot{\nu}t^2 + \tfrac{1}{6}\ddot{\nu}t^3 \qquad (2)$$

The values of $\ddot{\nu}$ calculated from data covering the first 5, 6, 7 and whole 8 yr of observations are respectively $\ddot{\nu} \times 10^{25} = 0.66, 0.64, 0.48$ and $0.55\ \mathrm{s}^{-3}$. For the last 5 and 6 yr one gets $\ddot{\nu} \times 10^{25} = 0.94$ and $0.51\ \mathrm{s}^{-3}$. The value of $\ddot{\nu}$ does not depend strongly on the set of data. As our sets of data overlap, this cannot be treated as proof that the effect is a real one. In fact, it has been suggested[5,7,8] that the observed values of $\ddot{\nu}$ can result from a noise-type variation in the pulsar rotation. A random-walk type phenomenon in the phase, frequency and/or frequency derivative may lead to large values of $\ddot{\nu}$ when the span of timing data has a finite length.

To check the value of $\ddot{\nu}$ and to find whether it is a real effect, it sh be derived from independent sets of data; noise processes should

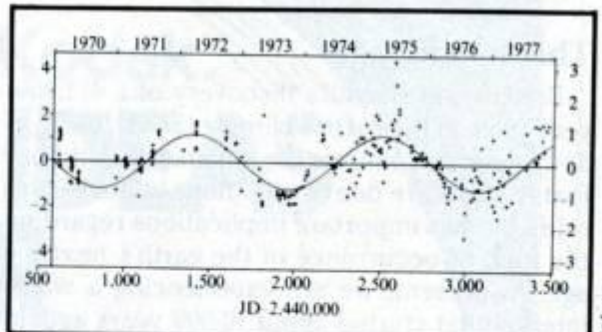
SCIENCE NEWS OF THE WEEK

The Plausibility of Pulsar Planets

A number of astronomers have been seeking evidence that stars other than the sun have planets orbiting them. No telescope on earth could resolve the image of a planet belonging to even the nearest star, so the search has concentrated on looking for changes in the motion (or the spectrum) of the star caused by reaction to the orbiting planet. A few claims of such evidence have been made, but they are stridently debated.

Now comes a suggestion that pulsars may have planetary companions, especially the pulsar PSRO329+54. These pulsars have been monitored in a program for the precise timing of pulsar pulses that has been going on for the past ten years. From such information a great deal can be calculated about the dynamics of the pulsar. In one recent case it led to a determination that a binary pulsar is radiating gravitational radiation in the amount predicted by Einstein (SN: 2/24/79, p. 116).

In this case the suggestion about planetary companions is made by M. Demiański and M. Prószyński of the Institute of Physics of Warsaw University. They worked from eight years of data taken at the U.S. National Radio Astronomy Observatory and the Five College Radio Observatory, which were supplied to them by D. J. Helfand.



Nature

Cyclic variation in PSRO329+54's pulse count may be due to an orbting planet.

At the basis of the analysis is the now generally accepted model of a pulsar as a compact body (most likely a neutron star) that possesses some kind of radio emitting region in its atmosphere. The rotation of the neutron star carries this region around, and the pulses come every time it crosses our line of sight.

Years of observation show that the pulse rates of pulsars are generally slowing down. To describe this, a "braking index" can be defined as a ratio involving the frequency, the rate of change of the frequency and the rate of change of the rate of change. (The more precise names for these last two terms are the first and second time derivatives of the frequency.)

An expected figure for the braking index can be calculated from the rate at which theoretical astrophysics says a pulsar should lose energy. This number — it equals 3 — requires a very small value for the second time derivative of the frequency. In the Nov. 22 NATURE Demiański and Prószyński point out that, on the contrary, a number of pulsars in the survey show high values of the second derivative. This needs a theoretical explanation. The possibility they want to stress here is the effect of a distant planet with a very long orbital period on the pulsar's rotation. Such a planet might have 100 times the earth's mass and a period of 50 years or so. There are 11 pulsars with anomalously large braking indices for which this could be an explanation.

More curious and perhaps more specific is that in the data for PSRO329+54 a cyclic change with a period of three years appears. This could result from some kind of periodic displacement of the emitting region in the pulsar's atmosphere, but probably the more exciting suggestion is that it is the effect of a small planet, one between 0.06 and 0.57 times the earth's mass orbiting the pulsar every three years. □

Science News of the Year

This is a review of important science news stories of 1979 as reported in the pages of Science News. *The references after each item refer to the volume and page number in which the main article on the subject appeared in* Science News *(Vol. 115 is Jan.-June; Vol 116 is July-Dec.). Where several references exist, the news developed and was reported in more than one issue. Back issues or, when out of stock, copies of articles are available for 50 cents each by writing to* Science News, *1719 N Street, N.W., Washington, D.C. 20036*

Space Technology

• A new record for human beings in orbit was set by Soviet cosmonauts Vladimir Lyakhov and Valery Ryumin, who boarded the Salyut 6 space station on Feb. 26 (115: 135), eclipsed the old 139-day mark on July 14 (116: 39) and finally returned to earth on Aug. 19 after 175 days aloft (116: 132).

• The U.S. space shuttle experienced a variety of developmental and managerial problems that delayed its first orbital flight from 1979 at least until late 1980. 115: 132; 116: 5, 212

• The huge Skylab space station created considerable furor before finally reentering the earth's atmosphere on July 11 (116: 39), leaving a trail of debris across Australia to the Pacific. 115: 71, 85, 309, 387, 422

• Major satellite launches during the year included Magsat (116: 327), for measuring

Astronomy

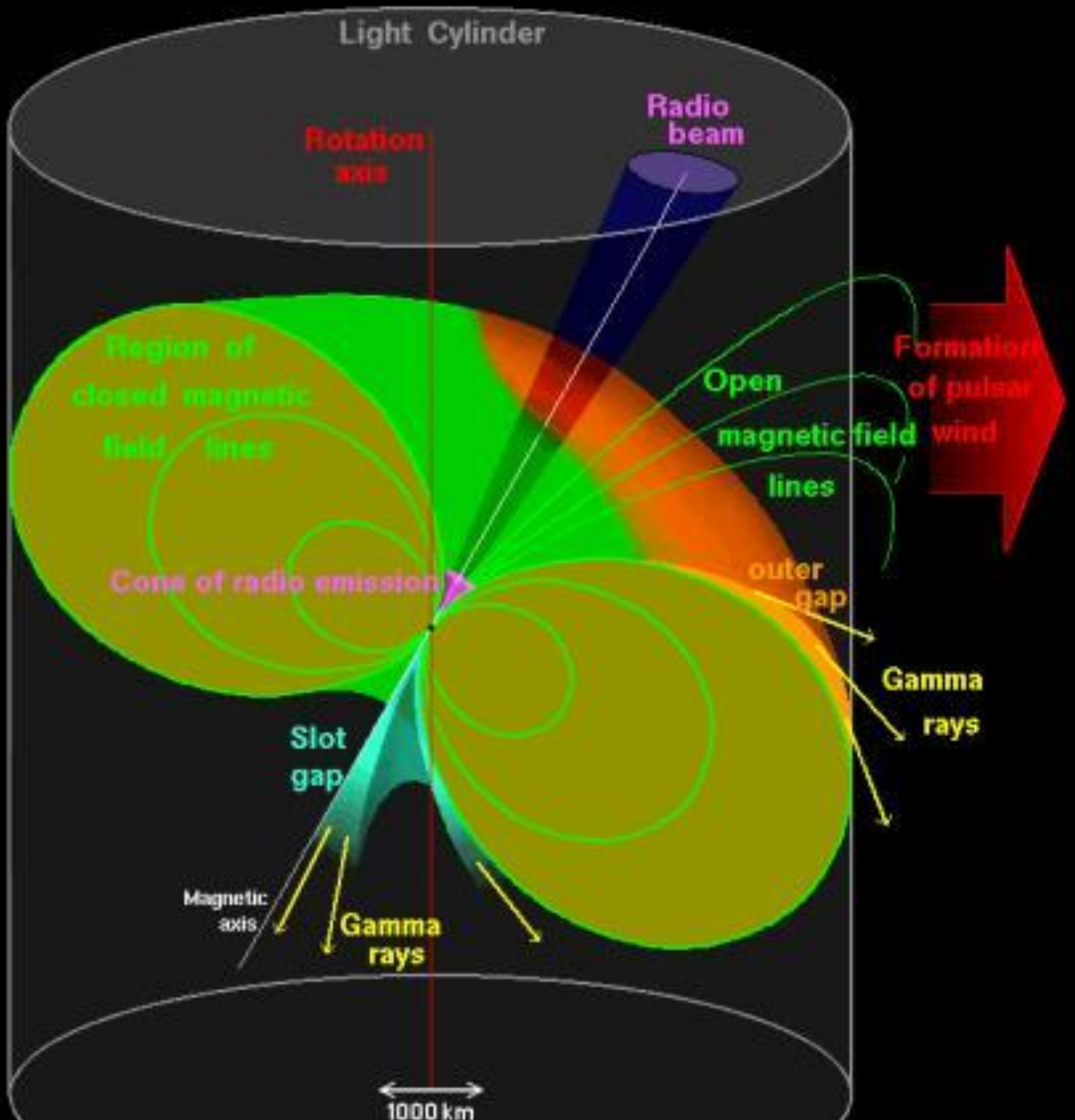
• There is no polarization evident in the cosmic microwave background radiation, but some anomalies have been found even as its blackbody character was demonstrated to improved levels of accuracy. 115: 37, 260; 116: 4, 229

• A definite number for the flux of neutrinos from the sun was reported, and, being far smaller than theoretical prediction, prompted plans for new experiments to find out what is wrong. 115: 103

• The existence of planets orbiting several pulsars was suggested. 116: 388

• Antiprotons were found in the cosmic rays for the first time. 116: 277

Pulsar Model: Radio & High Energy



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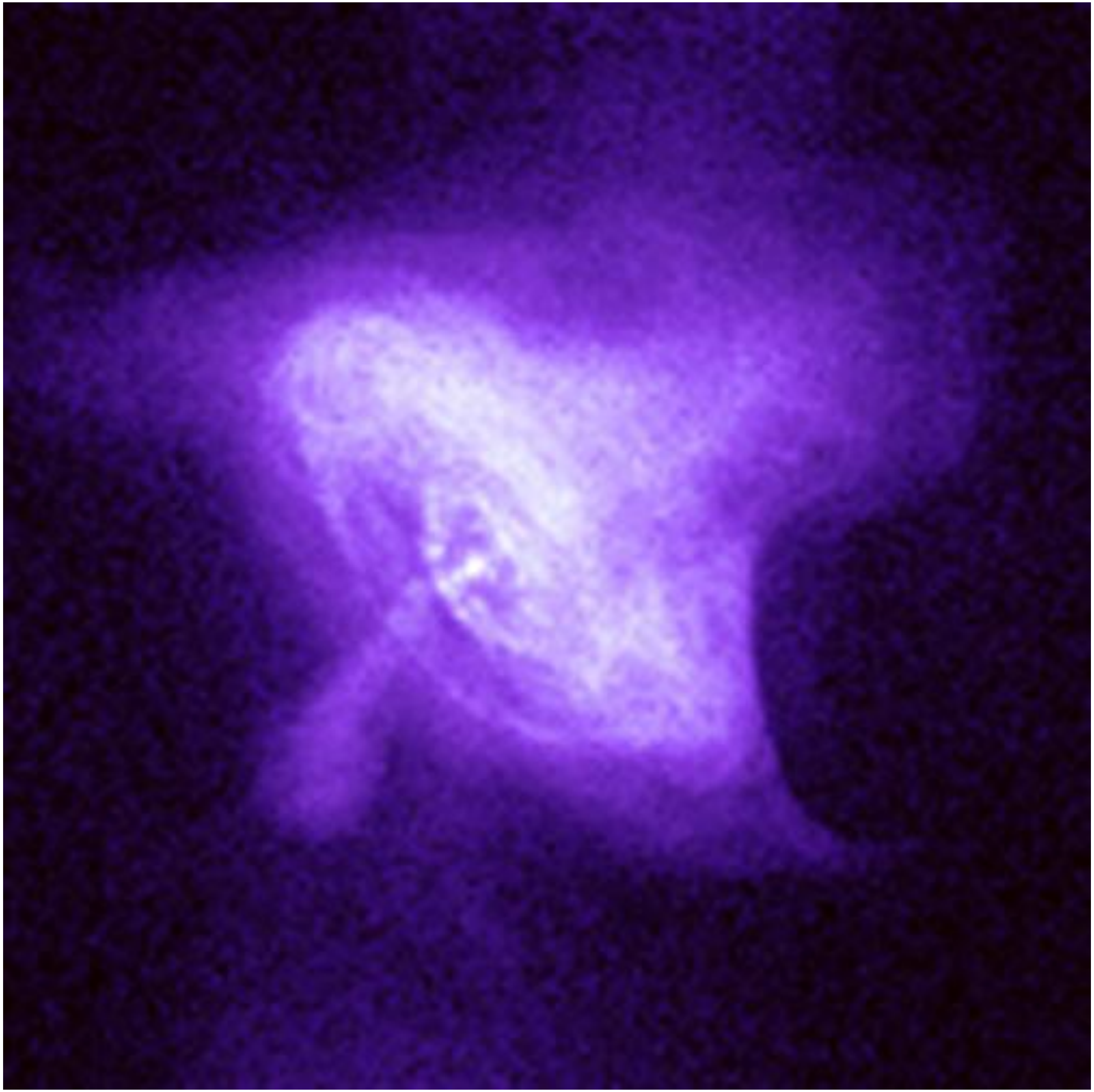
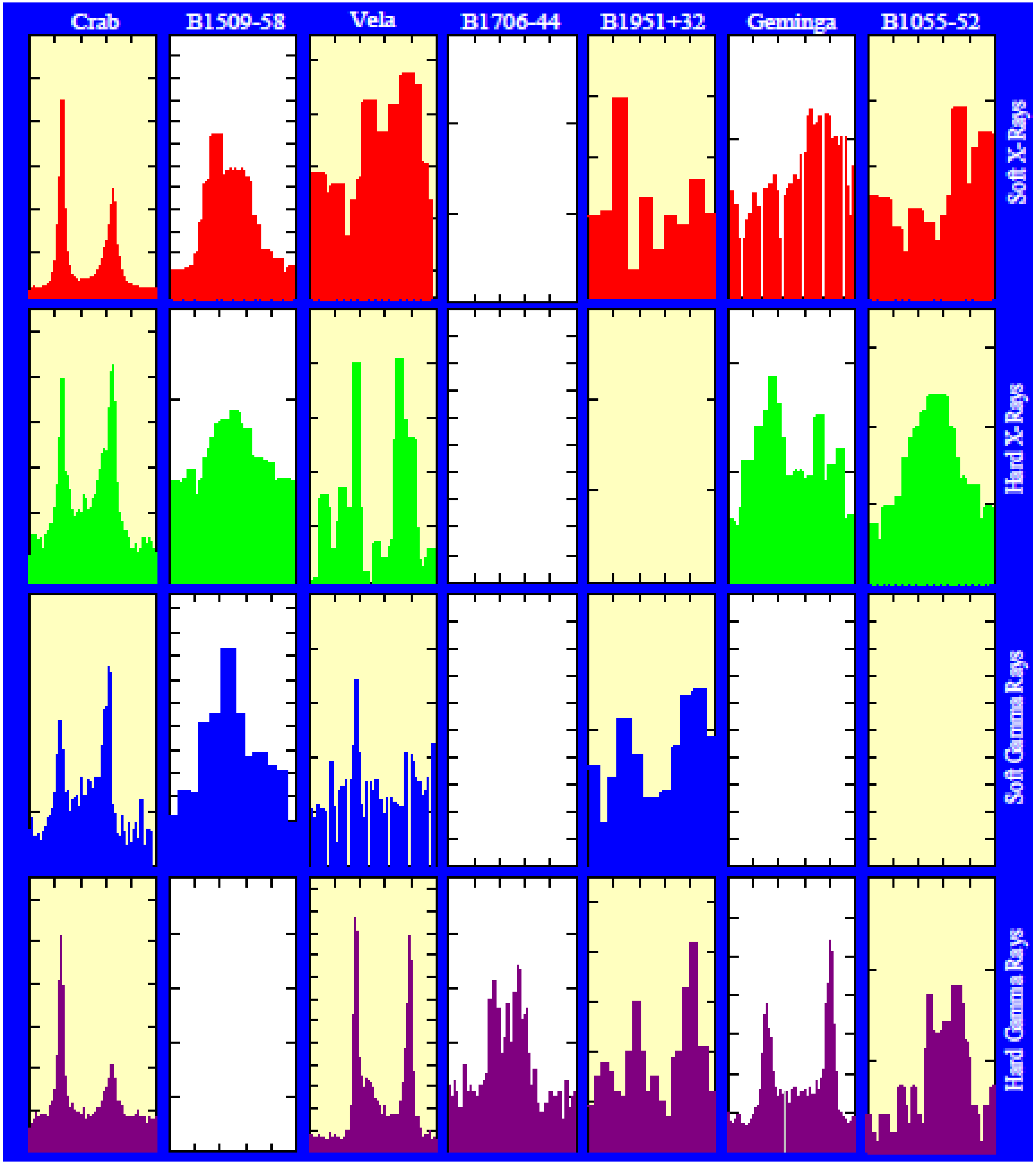
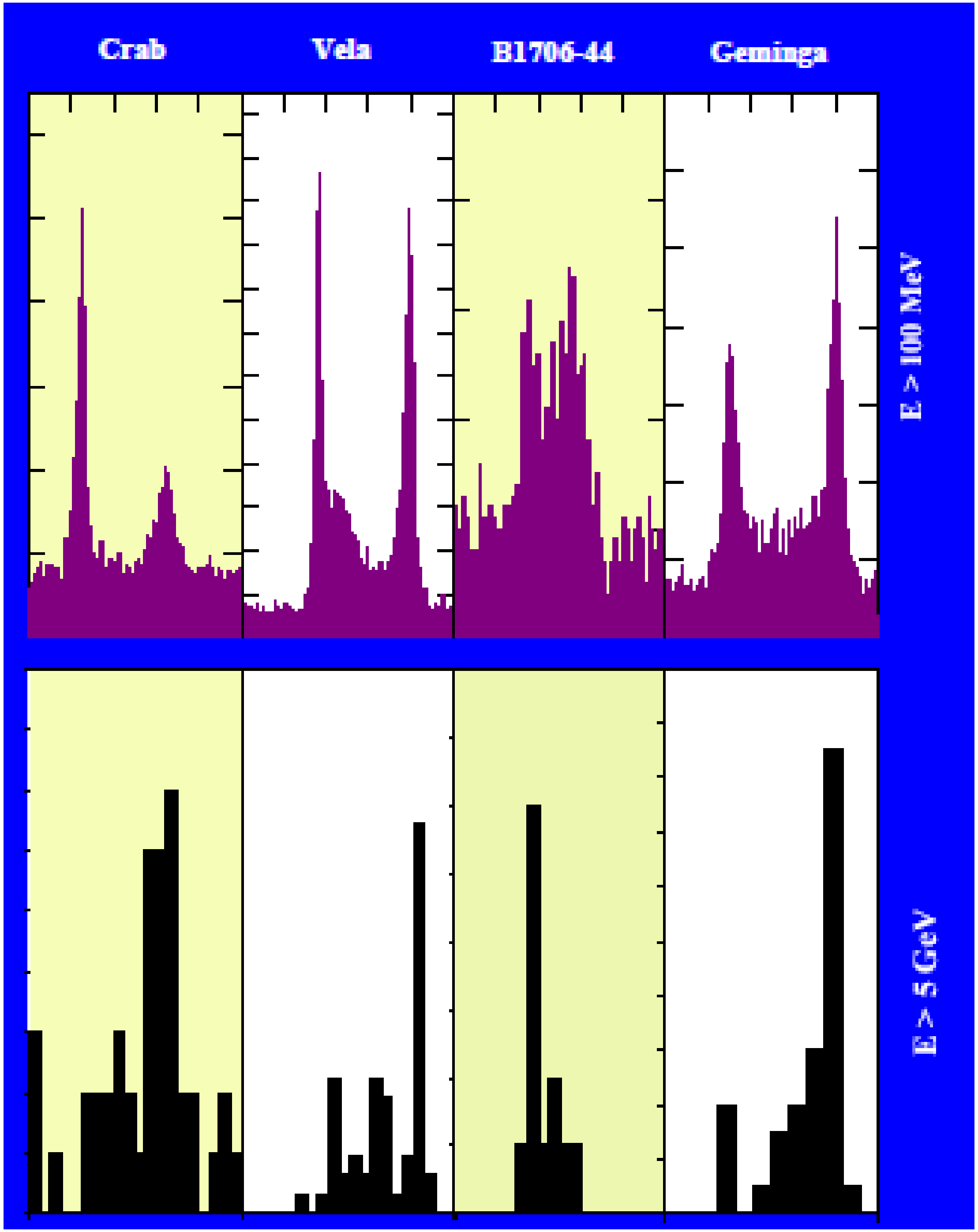



Crab
B1509-58
Vela
B1706-44
B1951+32
Geminga
B1055-52
Soft X-Rays
Hard X-Rays
Soft Gamma Rays
Hard Gamma Rays


Crab
Vela
B1706-44
Geminga
E > 100 MeV
E > 5 GeV

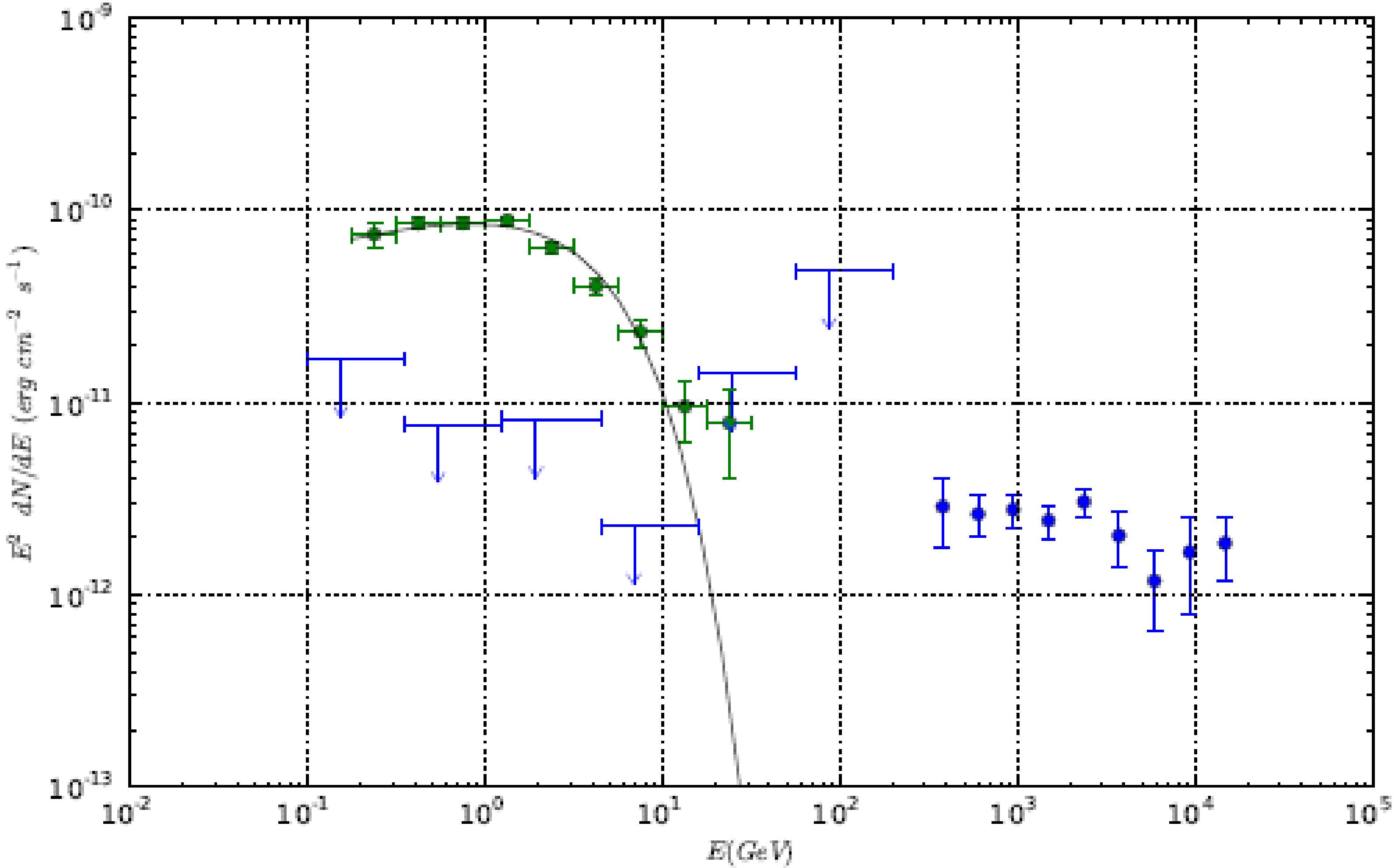


Fig. 4.— Phase-averaged spectral energy distribution for PSR J1907+0602 (green circles). Blue circles are data from HESS for HESS J1908+063 TeV source. 2 σ upper limits from Fermi for emission from this TeV source are shown in blue. The black line shows the spectral model for the pulsar (equation 1). The upper limits suggest that the spectrum of HESS J1908+063 has a low energy turnover between 20 GeV and 300 GeV.