Some Unsung Heroines (and a Few Heroes) of Cosmic Ray Physics

Virginia Trimble

Dept. of Physics & Astronomy, University of California, Irvine CA 92697-4575
and Las Cumbres Observatory Global Telescope Network

Abstract. The women physicists whose work will be featured are Marietta Blau, Madelaine Forro Barnothy, Phyllis Freier, and Connie Dilworth. The "gluons" that connected their lives to each other (and to the author) included Georges Lemaitre, Manuel Sandoval Vallarta, Cecil Powell, Guiseppi Occhialini, Ken Greisen, Beatrice Tinsley, Hannelore Sexl, and perhaps Elizabeth Rona. Most of the stories are not entirely happy ones. For instance it was Sandoval Vallarta who offered Blau (and her mother) refuge in Mexico when they had to leave Vienna. Vallarta was also Lemaitre's collaborator in calculations of how cosmic rays got to us through the earth's magnetic field. The sad part there is that somehow Lemaitre was never disabused of the view that cosmic rays were direct remnants of his primordial atom and not primarily protons. The result was his gradual exile from main-stream scientific communities.

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INTRODUCTION

This presentation had its origins in an invitation from the Victor F. Hess Foundation of Poellau, Austria to speak on some topic in the history of cosmic ray physics at their May, 2012 celebration of the discovery centenary. In due course I decided that a better description than heroines and heroes might be quarks (very important but very hard to observe in isolation) and gluons. This summary makes use of incomplete sentences and references run into the text as space-saving measures.

THE HEROINES

MARIETTA BLAU. Born 1894, Vienna. PhD 1914 Vienna (with Mayer & Exner). Died 1970, Vienna (but remember there were two wars in between). Contributions: development of nuclear emulsions as particle detectors for natural radioactivity, CRs and accelerators (part of the work for which Powell won the 1950 Nobel); later industrial and defense applications.

MADELAINE FORRO BARNOTHY. Born 1904, Zsambok, Hungary. PhD 1928 Budapest (first female physics PhD in Hungary). Died 1993, Evanston, Illinois. Contributions: took Geiger-Muller counters and other detectors down to 1000 m water equivalent in Dorag/Salgorjani coal mine; neutrons among CR secondaries (refuted by Greisen); FIB cosmology in which QSOs all lensed (some actually are); and CRs come from photons that have gone all the way around a closed universe; biological effects of magnetic fields.

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FIGURE 1. (a) At the left is Marietta Blau as a young woman. (b) In the center is Madelaine Forro Barnothy in a picture scanned at the American Institute of Physics. (c) At the right is Phyllis St. Cyr Freier, courtesy of her daughter, Sue Freier.

PHYLLIS ST. CYR FREIER. Born 1921, Robbinsdale, Minnesota. PhD 1950 U. Minnesota (with Ed Ney). Died 1992, Minneapolis. Contributions: use of nuclear emulsions and cloud chambers; discovery of heavies in CRs; abundances of Li, Be, B; solar modulation; Ne, Mg non-standard isotope ratios.

CONSTANCE DILWORTH (later OCCHIALINI). Born 1924, London County. PhD 1948 Bristol (with Powell). Died 2004 Florence. Contributions: improved nuclear emulsions; Auger effect in muon capture (with Schonberg of S-Chandrasekar limit, who later returned to Brazil); K meson decay (with Rossi); spark chambers; 1 of about 10 women at 1953 Bagnères-de-Bigorre conference; later important in establishing X-, γ-ray, and IR astronomy in Europe (the context in which I met her, so that my reaction upon seeing her in the list of BdB participants was, "But Connie does infrared!"

THE GLUONS

This list originally began with Elizabeth Rona (PhD Hungary 1912), but, although she spent time in Vienna and was well-known to Blau, she does not seem to have had any contact with the Barnothys during peri-war period she spent back in Hungary, and so cannot be counted as a gluon.

GEORGES H.J.E. LEMAITRE. Born 1894, Charleroi Belgium. PhD 1920 Louvain (with de la Vallee-Poussin), Died 1966, Louvain. Contributions: one of the "prediscoveries" of Hubble's law; concept of an early, dense universe or primordial atom, of which CRs were the remnants and so not mostly protons (a point of view he defended at least until 1961); penetration of earth's magnetic field by CRs with Sandoval Vallarta; later papers cite only his work and Freier et al. on heavies in CRs.

MANUEL SANDOVAL VALLARTA. Born 1899, Mexico City. PhD 1934 MIT. Died 1977, Mexico City. Contributions: CRs are mostly protons (lots of other folks also claimed/received credit); offered refuge in Mexico to Blau and her mother; first author of first

paper by Richard Feynman (on CRs); some unhappy interactions with my thesis advisor, Guido Munch.

CECIL F, POWELL. Born 1903, Tunbridge UK. PhD 1927 Cambridge (with CTR Wilson & Rutherford). Died 1949, Valsassina, Italy, Contributions: Nobel for discovery of mesons and such with nuclear emulsions; Dilworth's thesis advisor; invited Occhialini to Bristol.

GUISEPPI P.S. OCCHIALINI. Born 1907, Fossombrone, Italy: graduate work at Cambridge with Blackett; died 1993, Paris. Contributions: major portions of Blackett's and of Powell's Nobel work (see R. Giacconi autobiography); Dilworth's husband; commemorated in BeppoSAX X-ray satellite.

The remaining part of the presentation consisted mostly of images of first pages of papers and from Physics Abstracts entries, demonstrating connections, priorities and so forth, plus a few photographs of people abstracted from various sources. Pages from Physics Abstracts will be cited as SAA (Science Abstracts, Part A) Volume #, Page #.

YA GOTTA START SOMEWHERE

Blau's earliest work was on X- and γ- rays. By 1925 (Akad. Wiss. Wien Ber. **134**, 407) she was using photographic film to track "Natural H-rays" (meaning protons kicked off paraffin by alpha rays from polonium decay). Two abstracts away in SAA **30**, 40 is Lisa Meitner (Zs f Ph **37**, 481, *1926*) using a form of cloud chamber to measure ranges of alpha particles from Thorium-C. This is probably not quite the closest they ever got to each other since both were in Vienna (and I think they look rather similar in early photographs, and, for that matter, also rather like the young Rosalind Franklin).

Part II of Photographic Actions of H-rays appeared the next year (SAA **31**, 104), and if you thought it was a safe bet on statistical grounds that the immediately preceding paper would not have a woman author, you would lose (Bertha Swirles, later Jeffreys, on Internal Conversion of γ-Rays, Proc. Roy. Soc. **116**, 491, *1927*). Lady Bertha Jeffreys was the most distinguished fellow of Girton College, Cambridge, during my very undistinguished year there as a postdoc (1970-71). Back up another page-flip in SAA, 30 to find a paper by Miss G. Chamie (Comptes Rendus **185**, 770, *1927*). She also used photographic plates, but as a substrate for depositing thorium.

My connection with Blau is a two-step one. After her post-war return to Vienna, Hannelore Eggstein, later Sexl, was one of the students in her plate group. And Roman Sexl was the first dinner guest Joe Weber and I attempted to entertain in the Chevy Chase house a couple of days after we were married in March, 1972. I didn't yet even know where the knives were kept, and we ever after took visitors out to dinner.

Enter Magdalene Forro, and Some Other Old Friends

Forro's early thesis work (e.g. Zs, f. Ph. **47**, 430, *1928*) was on dielectric constants of gases and their gradients with temperature and pressure. I have not attempted to determine whether the results were roughly correct.

The next year, on two adjacent pages of SAA **33**, 504/5 we find (1) Hess and Matthias (Ph. Zs. **30**, 766, *1929*) not discovering extensive air showers ("two radiation apparatus placed near each other and sheltered from radiation from the earth do not show parallel behavior, but exhibit notable deviations"), (2) Blau and Rona looking at H-particles (Akad. Wiss. Wien Ber. **138**, 717, *1929*) and, (3) R. Peierls (Ann. d Phys. **3**, 1055, *1929*) on heat conductivity in crystals. What is Rudi Peierls doing in here with all the women? Well he once cooked dinner for Joe (Weber) and me when he was visiting UC Irvine not long after his wife died (he knew where the knives were, and produced a magnificent dessert based on vanilla ice cream and raspberry jam).

The years 1932-33 are full of excitement. J. Clay (K. Acad. Amst. Proc. **35**, 1821, *1932*) concludes that "Ultra-Radiation" is corpuscular (from his own latitude measurements). Lemaitre & Vallarta (PhysRev **43**, 87, *1933*) reach the same, charged particle, conclusion, but call the data "Compton's latitude effect of cosmic radiation," and find particle energies near 10^{10} eV. Erich Regener (Zs f Phys **80**, 666, *1933*) estimates the cosmic radiation energy flux hitting the earth and remarks that it is about the same as that in light and heat from the fixed stars (3.53×10^{-3} erg/cm^2-sec). Since both travel close to the speed of light, this is about 1 eV per cubic centimeter, which we now know to be comparable to the galactic energy densities of magnetic field and gas turbulence (and also the CMB, but that is just there to make it more difficult). Regener also notes that both CRs and starlight will influence the temperature of interstellar space. So they do, and in this he was wiser than Gerhard Herzberg in the last few pages of *Spectra of Diatomic Molecules*.

The year continues with J.A Wheeler (whom you all knew) writing (PhysRev **43**, 258, *1933*) on dispersion and absorption of helium. He begins by citing Karl Herzfeld, who was a late student of Boltzmann, taught Joe quantum mechanics in Catholic University in the late 1940s, and whom I had the pleasure of meeting briefly at a Symposium held by Johns Hopkins University to honor the work of Rowland and Wood.

In 1933, Lemaitre is a cosmologist (Comptes Rendus **196**, 903 & 1085) as well as a cosmic ray physicist, discussing the formation of nebulae in an expanding universe. He is a firm supporter of general relativity, whose universe will ever after include a cosmological constant. In contract, Erwin Freundlich (Zs f Ap **6**, 218, *1933*) firmly asserts that the deflection of light by the sun (at the 1929, not 1919 eclipse) is 2.2 arcsec, significantly larger than the GR value. The abstract was translated by G.C. McVittie, whom the oldest of us knew as the long-time secretary of the American Astronomical Society. Van der Waerden and Veblen also appear on SAA **36**, 686, but with connections too remote to fit into a single sentence.

It is 1935, and Forro is back, now second author to Jeno Barnothy, her former student and future husband, concluding (Zs f Ph **94**, 77) that Nova Herculis was not, despite a claim from Kohlhörster, a source of cosmic rays. J. Clay and H.R. Woltjer also said no, a month later (Physica 2, 582). The distinction between supernovae and common novae was only a couple of years old (though you might want to credit H.D. Curtis and K. Lundmark ahead of Baade and Zwicky), and we are left wondering about the relatives of H.R. Woltjer, a surname so rare that the senior astrophysical holder of it, Lodewijk, says he never heard of one who wasn't a traceable relative. Less fortunately, Barnothy & Forro (Nature **138**, 325, *1936*) thought they had

found neutrons among the CR secondaries arriving underground. After several false starts, this was eventually refuted by K.I. Greisen et al. (PhysRev **80**, 535, 1950).

The Era of Priorities

Blau is back, looking (with H. Wambacher, Nature **140**, 585, *1937*) at tracks from plates exposed at Hafelkar near Innsbruck. The tracks made some of the famous stars, attributable to disintegration of an atom in the emulsion (a Blau discovery). She "hopes to give further details before long in the Wiener Akademie-Bericht." There are more plates (now from Jungfraujoch) and, of course, more tracks and stars, but now measured in Oslo and submitted from there (Nature **142**, 613, *1938*) with thanks to Prof. Ellen Gleditsch for "her kind hospitality, which has made it possible for me to continue my investigations." Not until well after WWII does Blau again publish in German.

Extensive CR showers were established as a recognizable phenomenon even as Austria fell that same year, and I mention Janossy & Lovell (Nature **142**, 716, *1938*) because (1) Janossy is widely thought in his home country to have been the first Hungarian cosmic ray physicist and (2) Lovell goes on to become Sir Bernard, the leader of radio astronomy at the University of Manchester (where that paper originated). He set out to look for radar reflections from CR trails in the atmosphere, found meteor trail reflections, and it was a lifetime before the trails from CRs were actually found. Lovell hosted the 1970 IAU Symposium on the Crab Nebula there at Jodrell Bank, where I gave my first long, invited international talk. He died in August, 2012 at 98. That 1938 paper reported data from a cloud chamber detector.

Onward to War and Beyond

Barnothy and Forro continued their investigations, taking a triple-coincidence experiment ever deeper (to 2,500 mwe) in a coal mine near Budapest and concluding that the primary particles, whose secondaries they saw, must have energies near 10^{12} eV, "using the formula of Bethe." (Yes, of course we all knew him.). Subsequent papers (PR **55**, 870, *1939*; PR **58**, 849, *1940*) reported both diurnal and sidereal variations of intensity, attributing them to air temperature changes (widely agreed upon) and galactic rotation (not so clear). Another expedition in Dorog mine classified the radiation at 980 mwe as consisting of "a non-ionizing component (neutrinos or neutrettos) and an ionizing component (mesotrons or protons)" and we must soon part company with them.

The same double page of abstracts (SAA **42**, 676-77, *1939*) has Compton endorsing positive particles, the charge-neutralizing negative ones rotating with the Milky Way and generating a galactic magnetic field of about 0.1 Gauss. If this were right, you would know about it! Clay (Physica **6**, 497, *1939*) has also gone mining; Auger's showers (CR **208**, 1641, *1939*) have become still more extensive; and GR Miczaika (Zs f Ap **18**, 146, *1939*) has found some anti-correlations with sunspots and faculae in a year of data, some his own and some from his mentor, Kohlhörster. (I knew Miczaika and only now realize this gives me Kohlhörster in one!)

And then there was a war, during which Blau, settled in Mexico, did a great deal of teaching. She seems to have been the only woman among a teaching staff of 50+ at the mechanical and electrical engineering part of the polytecnique institute in Mexico City. She also used radiation

detection techniques in geophysical investigations of interest to the host country. Blau's 1940 paper, "El Helio. Su Origen y su Localizacion" (Ciencia **1**, 265) indicates that she has somehow quickly mastered another language and that she had not yet heard about the 1937-39 papers by Bethe and by von Weizsäcker on hydrogen fusion in the sun.

I do not know what the Barnothys did during the war (having foolishly never asked). But afterwards, their efforts to re-establish cosmic ray physics in Hungary failed, leaving problems such that they crossed the border in the trunk of a car and lived for a week on a sack of potatoes. The Barnothys arrived in the United States in 1948 and were not active in CR physics thereafter, though their so-called FIB cosmology (Zeitschrift fur Physik A, Hadrons and Nuclei **176**, 435, *1963*) said that the high-energy entities were photons that had traveled all the way around a closed universe. I had the pleasure of knowing them moderately well from about 1980 onward.

The Last Hurrah of Nuclear Emulsions and Cosmic Ray Particle Physics

Phyllis Freier and Constance Dilworth both first appear in the CR literature in 1948. Freier processed the nuclear emulsion stack data from an April balloon flight and recognized tracks of what could only be nuclei significantly heavier than helium (PhysRev **74**, 213; the authors are in alphabetical order). Dilworth, Occhilalini & Payne (Nature **163**, 102, *1948*, authors again alphabetical) was submitted on May 20th and dealt with processing techniques for thick emulsions. They thank C.F. Powell and G.W.W. Stevens of Kodak, Ltd. for preparing the emulsions. Cosyns, Dilworth (a Miss among the Drs. and Profs.), Occhialini & Schoenberg (Nature **164**, 129, *1964*) was another emulsion paper, and I mention it mostly in case you were wondering what Mario Schoenbrg did after the Schoenberg-Chandrasekhar limit (he was by then Professor in Sao Paulo in any case). Freier again appears as first author (PR **113**, 921, *1959*) of the paper reporting discovery of Li, Be, and B in the primary CRs, where their greatly enhanced abundances reflect spallation by interstellar protons of what started out as CNO nuclei and so tell us that the CR path length is 3-10 g/cm^2, and of a paper (ApJ **240**, L53, *1980*) reporting excesses of the neutron-rich isotopes of Ne and Mg among the CRs.

Meanwhile, the era of cosmic ray women as unique and isolated was coming to an end. The 1939 Chicago conference (picture shown by G. Yodh) had none. At the 1953 Bagnères de Bigorre conference (which also marked the hand-over of particle physics from cosmic rays to accelerators) there were at least 11, most from France and Italy, and including Occhialini-Dilworth and Milla Baldo Ceolin (known primarily in particle physics) according to the participant list.

All three processes – replacement of nuclear emulsions, triumph of accelerators, and incorporation of women - took time. The 97 founding members of the High Energy Astrophysics Division of the American Astronomical Society (1968-69) included one woman – Phyllis St. Cyr Freier. Having been in England when the division was established, I was among the handful of women added in the next few years. In case you might suppose this was the US lagging Europe, there were no women among the 57 founding members of the Commission on High Energy Astrophysics of the International Astronomical Union in 1970. It included many radio and X-ray astronomers and theorists as well as CR practitioners. Because the IAU required a minimum of 3 years of research beyond the PhD and elected members only at its triennial General Assembly

(both still roughly true), I was elected to the IAU only in 1973, into Commission 48 in 1976, and on to its organizing committee for the 1985-94 terms. In 1994 the Commission declared itself to be indistinguishable from Commission 44 (Astrophysics from Space) and voted itself out of existence. The merged entity then stabilized for a decade or so at about 8% women (67 out of 780 by 2003), only slightly smaller than the Union as a whole. Cosmic ray and high-energy astrophysics are not, of course, unique in this respect. An article (Eur. Phys. J. – H37, 237-309) shows that the teams at Darmstadt who discovered elements 107 and 110-111 in 1981 and 1995 were all men.

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First thanks go to the late Maurice Shapiro, from whom I heard my first lectures on cosmic rays at conferences in Cambridge in 1968 and 1974 (La plus **ç**a change…), next to Kenneth Ingvard Greisen, because preparing an NAS Memoire about him updated that knowledge, and then Gaurang Yodh, who kindly provided a number of corrections to the Greisen manuscript. Jim Cronin guided me to the 1953 proceedings (the website in his article doesn't quite get you there, but from amongst the polytechniciens-illustres, click on Leprince-Ringuet). And among the many other kindnesses in the too-short life of Beatrice Muriel Hill Tinsley was her connecting me to the Barnothys.

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