PLASMA ASTROPHYSICS AND COSMOLOGY

The Second IEEE International Workshop, Princeton, New Jersey, May 10–12, 1993

Edited by

ANTHONY L. PERATT
Los Alamos National Laboratory, NM, U.S.A.

Reprinted from *Astrophysics and Space Science*
Volume 227, Nos. 1–2, 1995

KLUWER ACADEMIC PUBLISHERS
DORDRECHT / BOSTON / LONDON

INTRODUCTION TO PLASMA ASTROPHYSICS AND COSMOLOGY

Proceedings of the Second IEEE International Workshop on Plasma Astrophysics and Cosmology, held in Princeton, New Jersey, 10–12 May 1993

ANTHONY L. PERATT
Physics Division
Los Alamos National Laboratory
Los Alamos, New Mexico 87545, USA

Abstract. The year 1996 marks the Centennial Celebration of the founding of Plasma Astrophysics and Cosmology; its origins may be traced to the seminal research first published by Kristian Birkeland in 1896. This special workshop issue reports on advances in issues of importance to the plasma universe; topics as timely as when first raised a century ago.

Key words: Radio Astronomy, Plasma Astrophysics, Large Scale Structure, Filaments, Formation of Galaxies, Magnetic Fields, Active Galactic Nuclei, Quasars, Abundance of Light Elements, Redshifts, Microwave Background

1 Introduction

The year 1996 marks the Centennial Celebration of the founding of Plasma Astrophysics and Cosmology; its origins may be traced to the seminal research of Kristian Birkeland published in 1896 that began his life–long study of laboratory produced cathodic rays and corpuscles[1] and their analogies to astrophysical and cosmological phenomena. This work was presented in two papers: "Sur un spectre des rayons catodiques" in *Comptes Rendus*, 28 September 1896, and a paper in *Archives des Sciences Physiques et Naturelles*, Geneva, 4th period, vol. I, 1896, that announced his discovery of magneto–cathode rays. It was in this work that, according to Birkeland (1908):

> ...I expressed for the first time my belief that the northern lights are formed by corpuscular rays drawn in from space, and coming from the sun.

In addition to his solving the mystery of the Aurora with his now–famous terrella experiments; electron beams in vacuum from magnetized copper globe cathodes, Birkeland utilized his data to formulate a theory about a plasma–filled universe populated with *systems* of nebula (galaxies).

We quote from Birkeland (1908, Volume 1, Section 131.):

[1] The term 'plasma' was not to be coined by I. Langmuir until 1923.

Astrophysics and Space Science **227**: 3–11, 1995.

> **The Worlds in the Universe.** From the conceptions to which our experimental analogies lead us, it is possible to form, in a natural manner an interesting theory of the origin of the worlds. This theory differs from all earlier theories in that it assumes the existence of a universal directing force of electro–magnetic origin in addition to the force of gravitation, in order to explain the formation round the sun of planets—which have almost circular orbits and are almost in the same plane—of moons and rings about the planets, and of spiral and annular nebulæ.
>
> ...Poincaré, at the conclusion of the preface to his book, 'Hyptheèses Cosmogoniques', says[2]:
>
> "Un fait qui frappe tout le monde, c'est la forme spirale de certaines nébuleuses; elle se rencontre beaucoup trop souvent pour qu'on puisse penser qu'elle est due au hasard. On comprend combien est incomplète toute théorie cosmogonique qui en fait abstraction. Or aucune d'elles n'en rend compte d'une manière satisfaisante, et l'explication que j'ai donné moi-mème un jour, par mainière de passe–temps, ne vaux pas mieux que les autres. Nous ne pouvons donc terminer que par un point d'interrogation."

Much of Birkeland's work was rediscovered in the 1980s with renewed interest about the role of large scale magnetic fields and currents in explaining astrophysical, galactic, and cosmological scale phenomena, including the origin and structure or galaxies and the containment of intergalactic gas 'clouds' and filaments, formerly attributed to dark matter gravitational binding energy. While the study of plasma phenomena in astrophysics and cosmology is now a century old, plasma–based theories for the explanations of light element abundances, the cosmic microwave background, and the origin of large–scale structures are relatively recent topics but have rapidly developed since their introduction at the first IEEE International Conference on Plasma Cosmology, La Jolla, California, USA, 20–22 February 1989 (IEEE, 1990).

An important element of the Workshop was the history of the temperature of the universe whose study, incidently, is also at least a century old.

When Birkeland developed his cosmogony and cosmology, it was known that the temperature of space was 5–6K blackbody, the value of which was a topic of considerable interest to both lay– and professional scientists of that era. We quote from his contemporary, Ch.-Ed. Guillaume in the article 'La Température de L'Espace', *La Nature*, vol.24, series 2, pp.210–211, 234

[2] "One fact that strikes everyone is the spiral shape of some nebulae; it is encountered much too often for us to believe that it is due to chance. It is easy to understand how incomplete any theory of cosmogony which ignores this fact must be. None of the theories accounts for it satisfactorily, and the explanation I myself once gave, in a kind of toy theory, is no better than the others. Consequently, we come up against a big question mark."

Fig. 1. Kristian Birkeland.

(1896)[3]:

[3] Captain Abney has recently determined the ratio of the light from the starry sky to that of the full Moon. It turns out to be 1/44, after reductions for the obliqueness of the rays relative to the surface, and for atmospheric absorption. Doubling this for both hemispheres, and adopting 1/600,000 as the ratio of the light intensity of the Moon to that of the Sun (a rough average of the measurements by Wollaston, Douguer and Zöllner), we find that the Sun showers us with 15,200,000 time more vibratory energy than all the stars combined. The increase in temperature of an isolated body in space subject only to the

Le capitaine Abney a determineé récemment le rapport de la lumière du ciel étoilé à celle de la pleine Lune; il le trouve égal à 1/44, toutes réductions faites pour l'obliquitée des rayons par rapport à la plaque; et pour l'absorption atmosphérique. En doublant pour les deux hemisphères, et en adoptant 1/600 000 comme rapport de l'intensité lumineuse de la Lune à celle du Soleil (moyenne grossière des mesures de Wollaston, de Douguer et de Zöllner), on trouvera que le Soleil nous envoie 15 200 000 fois plus d'énergie vibratoire que l'ensemble des étoiles. L'élévation de la température d'un corps isolé dans l'espace, et soumis seulement à l'action des étoiles, sera égale au quotient de l'élévation de température due au Soleil sur l'orbite de la Terre par la racine quatrième de 15 200 000, soit enviorn 60. Ce nombre doit, du reste, être considéré comme un minimum, les mesures du capitaine Abney, faits à South Kensington, ayant pu être faussées par quelque source de lumière étrangère. Nous en conclurons que la radiation des étoiles seule maintiendrait à la termpérature de 338/60 = 5,6 abs = –207°,4 centigrades l'éprouvette que nous avons supposée placée en divers points du ciel.

Il ne faudrait pas en conclure que la radiation des étoiles élève de 5 ou 6 degrés la température des corps célestes. Si l'astre en question possède déjà une température très différente du zéro absolu, sa perte de chaleur est beaucoup plus forte; nous trouverons l'élévation de la température due à la radiation des étoiles en calculant la perie par la loi de Stefan. On trouve ainse que, pour la Terre, l'élvévation de température due à la radiation des étoiles est inférieure à un cent-milliéme de degré. Encore devons–nous considérer ce nombre comme une limite supérieure de l'action nous cherchons à évaluer.

The history of the cosmic background temperature during a crucial period from 1926 to the present is reviewed in this journal by Assis and Neves who show how the tired light models predicted the correct value of 2.7K prior to the epic discovery by Penzias and Wilson in 1965. To this paper we might add the 1953 2.3K Finlay-Freundlich's prediction (*Nachrichten*, N.7,

---

action of the stars will be equal to the quotient of the increase of temperature due to the Sun on the Earth's orbit divided by the fourth root of 15,200,000, or about 60. Moreover, this number should be regarded as a minimum, as the measurements of Captain Abney taken in South Kensington may have been distorted by some foreign sources of light. We conclude that the radiation of the stars alone would maintain the test particle we suppose might have been placed at different points in the sky at a temperature of 338/60 = 5.6 abs. = –207°.4 centigrade.

We must not conclude that the radiation of the stars raises the temperature of the celestial bodies to 5 or 6 degrees. If the star in question already has a temperature that is very different from absolute zero, its loss of heat is much greater. We will find the increase of temperature due to the radiation of the stars by calculating the loss using Stefan's law. In this way, we find that for the Earth, the temperature increase due to the radiation of the stars is less than one hundred-thousandth of a degree. Furthermore, this figure should be regarded as an upper limit on the effect we seek to evaluate.

pp. 95–102, 1953):

Auf die hier für die B-Sterne benutzten Einheiten umgerechnet resultiert die Gleichung:

$$T_R^4 \cdot l_R = T_*^4 \cdot l_*$$

wo T_R = Temperatur des Weltraumes, $l_R = 6 \cdot 10^{22}$ cm, entspr. d. beob. Exp. $T_* = 20000°$ für B-Sterne, $l_* \approx 10^7$ cm. Das Ergebnis ist:

$$T_R = +2°, 3\text{K},$$

ein durchaus plausibler Wert.

The Workshop benefited from the attendance of Emil Wolf, the person responsible for bringing Finlay-Freundlich's work[4] to the attention of his teacher, Max Born.[5]

Max Born (*Nachrichten*, N.7, pp.102–108, 1953) realized the seriousness of Finlay–Freundlich's few–degree temperature prediction and suggested radio astronomy as an arbitrator between expanding and infinite cosmologies as they differed orders of magnitude in energy density. It is noteworthy that Born's manuscript was printed 12 years before the Penzias–Wilson measurement. We quote from the opening of Born's paper:

> Freundlich glaubt zeigen zu können, daß die übliche relativistische Deutung der R.-V. durch die Beobachtungen nicht bestätigt wird, wogegen die Formel [$\Delta\nu/\nu = -AlT^4$, $A = 2 \cdot 10^{-29}\ cm^{-1} grad^{-4}$] mit allen bekannten Tatsachen in Einklang ist, einschließlich der Nebelflucht (Hubble-Effekt), sofern man dem Weltenraum eine Temperatur von wenigen Graden beilegt. Ein solcher Widerspruch gegen die auf einfachsten Überlegungen beruhende relativistische Erklärung ist natürlich eine sehr bedenkliche Sache. Trotzdem schien es mir angebracht, die Freundlichsche Formel ein wenig zu analysieren; dabei bin ich zu dem Schluß gelangt, daß die Formel eine einfache wenn auch seltsame Deutung erlaubt, bei der überdies Zusammenhänge mit einer anderen Gruppe von Erscheinungen, nämlich der Radioastronomie, nahegelegt werden.

Today, plasma cosmology is a vigourous field of study supported by new observations such as filamentation, large–scale structure, the 2.7K blackbody background, non-Doppler redshifts, the existance of charged particle beam

[4] E. Finlay–Freundlich befriended the younger Wolf, both post–war refugees, during their stay at the University Observatory of St. Andrews. Finlay–Freundlich, long noted for his careful observations, was unable to accept the recessional velocity interpretation as the source of galaxy redshifts. He often paced the Observatory's halls pondering the nature of redshifts.

[5] Born at first refused, viewing cosmology as a form of philosophy or art, or something less respectable.

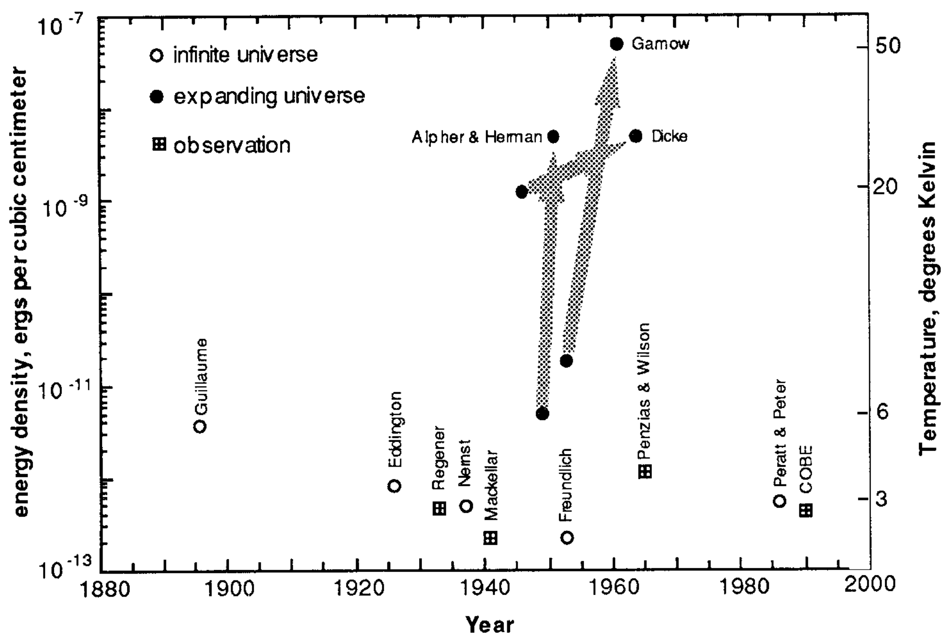

Fig. 2. History of the blackblody cosmic background radiation over 100 years. Note that energy density, *i.e.*, relating to a *physical mechanism*, is a better cosmological indicator than is the relatively insensitive (fourth-root of energy) temperature. (Adapted from Assis & Neves, 1995).

phenomena in cosmic objects, and the morphological observations of the Hubble Space Telescope. This chain of success really started in 1974 when a rocket–launched satellite verified the existence of Birkeland Currents in the earth's magnetosphere/ionosphere (IEEE, 1986, 1989, 1992; Peratt, 1988).

The workshop topics were organized in a size hierarchy, starting from what is now well–documented space and laboratory phenomena and ending with speculative issues in cosmology. T. Chang (MIT) reported on charged particle energization in space physics and astrophysics. K. Nishikawa (University of Iowa) presented three–dimensional, fully electromagnetic particle–in–cell simulations of Birkeland's orginal hypothesis: the interaction of the solar wind with the earth's magnetosphere to drive magnetic–field–aligned currents into the lower atmosphere.

In order, the following topics were discussed: galaxy formation and structure, origin of the light elements, and large scale structure, ending with a presentation by P. Kronberg (University of Toronto) on magnetic field estimates in distant galaxy systems. Active galactic nuclei, cosmic rays, and dark matter were next on the agenda, followed by the two largest sessions, "theoretical explanation of the Hubble relation" and " 'anomalous' redshifts and periodicities". J. Vigier (Université Pierre et Marie Curie) opened the former session while E. Wolf and D. James (University of Rochester) substantiated the latter session with a presentation on spectral invariance from light scattering on anisotropic media (James & Wolf, 1994), outlining quite possibly the non–recessional redshift mechanism sought by E. Finlay–Freundlich.

Table I delineates the topics covered over three days of sessions.

Periodically throughout the Workshop, issues now a hundred years old were debated including plasma cosmology's traditional refusal to claim any knowledge about an 'origin' of the universe (*e.g.,* Alfvén, 1988). Addressing this lively issue, the noted plasma theoretician and cosmologist David Bohm (Buckley & Peat, 1979) was quoted[6]:

> ...the universe is an unending transformation in flux whose previous states we are not privileged to know...

with plasma physicists generally agreeing that their work would simply lead to more questions about the nature of the universe. The Workshop ended with a lively debate "Is the Big Bang Theory Supported by Observation?" between E. Lerner (Lawrenceville Plasma Physics) and D. Spergel (Princeton University), both laudable in their respective cosmologies presentations.

In closing the Workshop, it is worthwhile to repeat Birkeland again:

> *According to our manner of looking at the matter, every star in the universe would be the seat and field of activity of electric forces of a strength that no one could imagine.*
>
> *We have no certain opinion as to how the assumed enormous electric currents with enormous tension are produced, but it is certainly not in accordance with the principles we employ in technics on the earth at the present time. One may well believe, however, that a knowledge in the future of the electrotechnics of the heavens would be of great practical value to our electrical engineers.*
>
> *It seems to be a natural consequence of our points of view to assume that the whole of space is filled with electrons and flying electric ions of all kinds. We have assumed that each stellar system in evolutions throws off electric corpuscles into space. It does not seem unreasonble therefore to think that the greater part of the material masses in the universe is found, not in the solar systems or nebulæ, but in "empty" space.*

It is to this point of view that the Second IEEE International Workshop on Plasma Astrophysics and Cosmology was devoted.

[6] According to Bohm: "It means a lot to these people [big bang advocates] that they are explaining their own origin with the origin of the universe. That gives them tremendous impetus to do the work."

TABLE I
Plasma Astrophysics & Cosmology Workshop Paper Topics.

author	size					phenomena							
	inter-planetary	inter-stellar	quasars/ galaxies	clusters	cosmological	B field	E field	Bennett Pinch	filaments	cmb	red-shifts	dark matter	relativity
Assis & Neves					X					X	X		
Tifft					X						X		
Ghosh				X							X	X	
Miller & Miller			X		X						X		X
Lerner				X	X	X	X	X	X	X			
Healy					X								
Reber			X										
Peratt			X	X	X	X	X	X	X	X			
Kanipe			X	X	X	X	X	X	X	X			
Roscoe													X
Brandenburg					X	X	X			X			
Lerner					X					X			
Wszolek			X									X	
Venturi & Giovanni				X		X							
Snell & Peratt			X			X	X	X	X				
Whitney			X			X	X						X
Verschuur		X				X	X	X	X				
Chargeishvili & Sakai		X				X			X				
Goldstein	X	X				X			X				
Healy & Peratt			X			X	X	X	X				
Wells	X					X	X						
Nishikawa et al.	X					X	X						

2 Documentation

Updates and further information related to the plasma universe and plasma cosmology will be posted on the Plasma Science & Technology homepage on the World Wide Web (http:\\www-plasma.umd.edu).

References

Alfvén, H.: 1988, *Has the Universe an Origin?*, unpublished

Assis, A. K. T., Neves, M. C. D.: 1995, "The Redshift Revisited", *Astrophys. & Space Sci. this edition*

Birkeland, Kr. : 1908, 1913 *The Norwegian Aurora Polaris Expedition 1902–1903*, Christiana, Norway, Aschehoug, Secs. 1 and 2

Buckley, P., Peat, F. D.: 1979, "David Joseph Bohm" in *A Question of Physics: Conversations in Physics and Biology*, University of Toronto Press, Toronto, p.124

IEEE: 1986, *Transactions on Plasma Science* **Vol. 14**, Special Issue on Space and Cosmic Plasma

IEEE: 1989, *Transactions on Plasma Science* **Vol. 17**, Special Issue on Space and Cosmic Plasma

IEEE: 1990, *Transactions on Plasma Science* **Vol. 18**, Special Issue on Plasma Cosmology

IEEE: 1992, *Transactions on Plasma Science* **Vol. 20**, Special Issue on Space and Cosmic Plasma

James, D. F. V., Wolf, E.: 1994, "Doppler-Like Frequency Shifts Generated by Dynamic Scattering", *Physics Lett. A* **Vol. 146**, pp. 167–171

Peratt, A. L.: 1988, *Laser and Particle Beams* **Vol. 6**, part. 3, Special Issue on Particle Beams and Basic Phenomena in the Plasma Universe