ASTROPHYSICS IN A NUTSHELL
FROM THE TELESCOPE TO THE SPUTNIK

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Abstract

Progress in astrophysics - as well as in many other sciences - is not only due to new ideas but also to the introduction of new methods of observation. The "Copernican revolution" was more due to the introduction of the telescope than to the heliocentric model which had been invented 2000 years earlier. Further, the decisive importance of electromagnetic effects in astrophysics originated from Langmuir's invention of the plasma probe and from Birkeland's terrella experiment and his observations of plasmas in space (aurora). A similar revolution has now been introduced by space research which has made possible in situ measurements in cosmic plasmas and has opened the X-ray and γ-ray regions to observation. The result is a drastic revision of essential parts of astrophysics (including cosmology) leading to the "Plasma Universe" model.
1. Introduction of the Telescope

300 years ago what is usually called the "Copernican revolution" caused the transition from the geocentric to the heliocentric cosmology. This revolution was in reality caused by the introduction of the telescope. Aristarchus had presented the heliocentric cosmology 2000 years earlier, but as he lived in what Kopal (1970) calls the pre-telescopic era, his model could not be proved.

During the following 300 years increasingly sophisticated telescopes have explored a rapidly increasing region of our cosmic environment. Newtonian theory dominated the mechanics during the 18th and 19th centuries. In the beginning of the 20th century its limitations in three respects became obvious:

(1) Quantum mechanics showed that it was not valid for atom-size phenomena.
(2) The theory of relativity showed that it did not hold for velocities approaching the velocity of light.
(3) During the 19th century, studies of electric currents in gases showed that electromagnetic phenomena often produced forces which were more important than mechanical forces.

2. Auroral Research, Terrella and the Plasma

Whereas the consequences of (1) and (2) have been generally recognized, this is not the case for (3).

A systematic combination of mechanical and electromagnetic effects led to the discovery of the magneto-hydrodynamic waves (Alfvén, 1942). It also led to a theory of the origin of the solar system, including a mechanism for transfer of angular momentum from a rotating magnetized central body to a surrounding plasma, and further to the discovery of the critical velocity and the 2:3 contraction of a partially co-rotating medium at the transition from an ionized state to neutrality (Alfvén,
1942). The latter effect explains the structure of the massive Saturnian rings and the asteroid belt.

One reason why (3) has drastic consequences is that, in ionized matter - plasma - which dominates the universe, electromagnetic forces cause the constituent particles to exhibit an exceedingly complicated collective behavior. Although each individual particle obeys well-known laws, the complexities of their interactions defy purely theoretical deductions and can be understood only if theory is closely guided by empirical knowledge, as the history of space science has shown.

Thus, the importance of electromagnetic forces was convincingly demonstrated already by Birkeland's auroral investigations and terrella experiments. Furthermore, Langmuir achieved fundamental insights into the behavior of plasmas - a word coined by him - on the basis of experimental studies using the probes he developed for this purpose. Unfortunately, these results were not fully appreciated until much later.

The dramatic development in space science has been excellently described by Dessler (1983). Broad reviews of the consequences for astrophysics and cosmogony have been given by Alfvén (1981) and Fälthammar (1986).

3. The Radio Telescope

The next step in the development of astronomical instruments was the introduction of the radio telescope. It was found that much of what was observed by this could be attributed to synchrotron radiation from magnetized plasmas (Alfvén and Herlofson, 1950; Kiepenheuer, 1950; Shklovsky, 1960). This gave us a possibility to detect plasmas in the universe and one got an increasing understanding that the universe to a large part consists of magnetized plasma.

However, this possibility to investigate cosmic plasmas has still not been used to a full extent. The reason seems to be
that theoretical astronomers have been deprived of a proper education in cosmical plasma physics. As we have seen, this new field was opened by pioneers like Birkeland with his terrella experiments (Fig. 1) and Langmuir with his introduction of plasma research firmly based on experiments. However, most astronomers have had almost no contact with plasma experiments in the laboratory or with investigations of cosmical plasmas in the ionosphere and magnetosphere.

Even today, the transfer of knowledge to astrophysics is not taking place. This is evident from Table 1, which shows to what extent some basic concepts in cosmic plasma physics are mentioned in the most used books in astrophysics. Therefore, although astronomers know that most of the matter in the Universe is in the plasma state, the far-reaching and exciting consequences of this are hidden to them by the inadequate background given to them in the field of plasma physics. Only when this shortcoming is eliminated can the astrophysics of our Plasma Universe come into full bloom.

4. The Sputnik

The real break-through of instruments to investigate the universe came 30 years ago with the launch of the first satellite, Sputnik. Among the first to use this new possibility was van Allen, who together with his many competent students developed sophisticated instruments to investigate plasmas by in situ measurements in those regions of space which could be reached by spacecraft. Such measurements led to the understanding that cosmic plasmas and laboratory plasmas have the same basic properties. Now we have an increased understanding how to "translate" from one plasma region to another, plasma physics from laboratory dimensions out to the reach of spacecraft, merges into one field of science which is open to investigations by in situ measurements (Alfvén, 1981, 1986).
5. New Spectral Regions

The artificial satellites did not only mean that new regions of space were opened to scientific investigation, but also that new spectral regions were opened.

For centuries or millennia our knowledge of the universe has been based on information received in the visual octave 0.4-0.8μ (see Fig. 1). During the last half-century the visual light astronomy has been supplemented by infrared and radio astronomy. During the last decade space research has opened the whole electromagnetic spectrum. This means that we now also receive information in the whole infrared region and the ultra-violet-X-ray-γ-ray regions.

We shall here concentrate our attention on the X-ray and γ-ray regions. Most of the emissions in these wavelengths are likely to be produced by electrons with energies in excess of some hundred eV. We know that processes in magnetized plasmas, especially in connection with double layers or other magnetic field aligned electric fields, accelerate auroral electrons to some 10^3 eV (Fälthammar, 1983, 1985; Block, 1987). Furthermore, in solar flares basically similar plasma processes produce energies of 10^3 to 10^10 eV. Carlqvist's theory of relativistic double layers demonstrates that under cosmic conditions even much higher energies may be generated in magnetized cosmic plasmas (Carlqvist, 1982).

Hence with some confidence, we can assume that the X-γ-rays we observe derive mainly from magnetized plasmas with electron energies in excess of some hundred eV. This means that it seems legitimate to call the picture we get from these wavelengths "the high energy plasma universe".

As we shall see this picture is often drastically different from the traditional picture of the visual universe which is based on observations in visual light. This light derives from
solid bodies (e.g., planets) but to a much larger extent from stellar photospheres which usually are in a state of low energy plasmas (≤10 eV). Hence "visual universe" is not far from a synonym to low energy plasma universe, but for the sake of convenience we shall use the term visual universe or perhaps better - in analogy with Kopal's term "pre-telescope era" - the pre-Sputnik universe. We shall compare this with the high energy plasma universe, a term which we shall shorten to plasma universe (Alfvén, 1986a).

High energy magnetized plasmas do not only emit X-ray-γ-rays, but also synchrotron radiation which often falls in the radio bands. Hence, radio astronomy also gives us information about the plasma universe, as mentioned earlier.

6. Difference Between the Plasma Universe and the Pre-Sputnik Universe*

The following figures show a few typical differences. Figure 2 shows that the sun seen in X-ray is shockingly different from our visual picture. This has been discussed in Physics Today, September, 1986.

The general time scales of the visual, and the plasma universe are also often different. Whereas our night sky gives an impression of calm (the moon moves with a time period of one month, planets with periods of years or centuries) γ-ray bursts which are the most energetic events in the γ-ray region (Fig. 3) change their output by orders of magnitude in seconds or milliseconds, i.e. ten orders of magnitude more rapidly.

Also, those radio waves which derive from synchrotron radiation in a plasma give us a picture of the plasma universe which does

*) In English "artificial satellite" is usually shortened to "satellite". This is inconvenient in cosmogonic discussions because, for example, "pre-satellite era" means the period when the planets but not yet the satellites were formed.
not resemble the pre-satellite universe or the visual night sky very much (Fig.4).

7. Relations Between the Visual (Pre-Sputnik) and the Plasma Universe

The relation between the pre-Sputnik and the plasma universe is somewhat analogous to the relation between a visual and an X-ray picture of a man. The visual picture is - literally - superficial; you see his skin and not very much more. The X-ray picture reveals the structure of his whole body, it shows the skeleton and intestines, and gives us a better understanding of how his body works (Fig.5).

Similarly, the visual picture of our solar system gives us information about thin surface layers of the celestial bodies, whereas plasma investigations tell us the structure of the interplanetary space, and - by extrapolation - how once the solar system was formed out of a dusty plasma. Similarly, as most of the universe is likely to be in a state of dusty plasma, the plasma universe is more basic than the visual universe. Further, the X-ray - γ-ray regions cover 10 times more octaves and \( \gg 1000 \) times more band width than the visual light, and when receivers in these wavelength regions have been adequately developed we can expect to obtain more observational data from them than from the single visual light octave.

There is still another good reason for concentrating our attention on the plasma universe; our views of the universe are traditionally based on visual observation and in order to compensate for the "generally accepted" but distorted views of the structure of the universe and how it has developed it is healthy to put much emphasis on the plasma universe.

8. The Role of Laboratory and Space Experiments

There is a very important complementary approach to the study of the plasma universe. The basic properties of plasmas are
presumably the same everywhere. Hence, plasma experiments in
the laboratory are relevant also for the understanding of
distant astrophysical regions. Similarly, passive in situ mea-
surements, as well as active experiments in accessible space
plasma regions give us important information about galactic,
cosmogonic, and cosmological conditions (Fälthammar et al.,
1978; Alfvén, 1986; Fälthammar, 1988). This is particularly
true for the Earth's magnetosphere which allows very compre-
hensive investigations, but also for other magnetospheres,
(including solar magnetosphere = heliosphere = solar wind
region).

9. Survey of the Development of Astrophysics

1. The introduction of the telescope caused the transition from
geocentric cosmology to the heliocentric cosmology
("Copernican Revolution").

2. The Newtonian Universe dominated astrophysics until around
1900 when three limitations to it appeared. One of them was
due to the introduction of electromagnetic force by

3. The beginning of space research made it possible to explore
our cosmic surrounding through in situ measurements and to
discover the universe as seen in X-ray - γ-rays ("Plasma
Universe"). These increases in our ability to observe is now
causing a new revolution, "The Sputnik Revolution",
analogous to the telescope revolution (see Fig.6).
10. References


Figure Captions

Fig. 1  Atmospheric absorption of electromagnetic waves given in height to which the radiation penetrates. Practically all our information about the universe used to be derived from the visual octave up to the introduction of radio astronomy. Space observations have now opened the whole spectrum. The enormous increase in information makes most of the pre-sputnik astrophysics obsolete.

Fig. 2  The Sun as seen in X-rays. As the photosphere emits very little X-rays it is dark. The light regions in the figure derives from the plasma in the chromosphere and corona.

Fig. 3  Visual observations of the sky are characterized by time constants of months, years or centuries (periods of the Moon and the planets) whereas X-ray and γ-ray observations often have time constants millions or billions times shorter.

Fig. 4  Double radio stars often consist of two giant plasma clouds which are energized by a visual galaxy located half way between the clouds.

Fig. 5  X-ray photographs of hand and of stomach. The difference between the universe as seen in visual light and in X-rays is analogous to the human body as seen in visual light and in X-rays.

Fig. 6  Three epochs in the evolution of astrophysics.
1. Introduction of the telescope
2. Introduction of scale model experiments (Birkeland's terrella) and Langmuir's discovery that the properties of plasma are drastically different from what the Chapman-Cowling theory predicted.
3. Space research has demonstrated that the universe, when studied with access to the whole electromagnetic spectrum is drastically different from that of the present conventional astrophysics. The latter is essentially based on the visual octave and gives a highly misleading picture of real universe (Plasma Universe).
Figure 1
X-RAY & $\gamma$-RAY OBSERVATIONS GIVE US A DRASTICALLY DIFFERENT VIEW OF THE UNIVERSE

$\gamma$-RAY BURST

MORE THAN 99% OF THE UNIVERSE (at least by volume) CONSISTS OF PLASMA

Figure 3
DIFFERENCE BETWEEN THE VISUAL AND THE PLASMA UNIVERSE

INTENSITY CONTOURS OF DOUBLE RADIO SOURCE SHOWING TWO GIANT PLASMA CLOUDS

IN VISUAL LIGHT ONLY A GALAXY BETWEEN THEM IS SEEN

Figure 4
ASTROPHYSICS IN A NUTSHELL

TELESCOPE

SPUTNIK

PRE-TELESCOPIC ERA

CURRENTS IN GASES

PLASMA

IN SITU MEASUREMENTS

NEWTONIAN UNIVERSE

PRE-SPUTNIK ASTROPHYSICS

X-RAYS

γ-RAYS

CHAPMAN

MAXWELL

1900

RELATIVITY QUANTUM

HELIOCENTRIC COSMOLOGY

GEOCENTRIC COSMOLOGY

CRYSTAL SPHERES

Figure 6
Progress in astrophysics - as well as in many other sciences - is not only due to new ideas but also to the introduction of new methods of observation. The "Copernican revolution" was more due to the introduction of the telescope than to the heliocentric model which had been invented 2000 years earlier. Further, the decisive importance of electromagnetic effects in astrophysics originated from Langmuir's invention of the plasma probe and from Birkeland's terrella experiment and his observations of plasmas in space (aurora). A similar revolution has now been introduced by space research which has made possible in situ measurements in cosmic plasmas and has opened the X-ray and γ-ray regions to observation. The result is a drastic revision of essential parts of astrophysics (including cosmology) leading to the "Plasma Universe" model.

Key words: Plasma Universe, Astrophysics, Plasma physics, Space research