History of Planetary Aeronomy

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Some Thoughts on Nomenclature

OUR planet the earth is studied in many ways, some of which correspond roughly to the main divisions of universal science, for example, mechanics, physics and chemistry. Such specialized branches of the universal sciences are appropriately indicated by the prefix 'geo', giving the words 'geomechanics', 'geophysics' and 'geochemistry'. These are modelled on the old word 'geometry', which itself has long since lost its special association with the earth, to become the name of the universal science of the measurement and properties of space. Hence the need for another word ('geodesy') relating to the measurement of the 'figure' of the earth, which must be the basis of geography, the mapping of the earth. The meaning of geography has gradually become elaborated to include much more than graphical representation, and besides physical geography, which shades off into geophysics, covers studies that merge into economics, sociology and general biology.

Another venerable word, 'geology', the significance of which has always been more limited than the word might imply, has nevertheless with time gained a deeper and wider content, so that now it covers many subdivisions which likewise shade off near their boundaries into geophysics, economics and biology (past and present).

I have long thought that a comprehensive word is needed to comprise all these branches of the study of the earth, and the recent growing use of the terms 'the earth sciences' and 'geo-science' in America indicates that others have felt the same need. I wish therefore to propose for this purpose the word 'geonomy', analogous to the ancient word 'astronomy', which has many parallel branches—such as astrophysics, astrometry and astrography, not to speak of the now despised astrology.

The analogy can usefully be carried further. The word 'geonomer', like geonomy, flows smoothly from the tongue, and would comprise not only the geologist and geographer but also such awkwardly named vocations as geophysicist (a too sibilant word), geomagnetician and meteorologist.

The corresponding adjective might be either 'geonomic' or 'geonomical'; 'geonomic' seems preferable for its brevity, and has respectable precedents to justify it, such as 'economic'.

The termination 'nomy' also offers a convenient means of creating a new word to replace 'meteorology', which, especially in its English adjectival form, is excessively polysyllabic; and the association of meteorology with the beautiful word 'meteor' is now irrelevant and misleading. I propose that the word be abandoned in all its many official and unofficial uses, in favour of 'aeronomy' (with the associated words 'aeronomer' and 'aeronomic'): 'aerology' is of course an alternative, but already has a specialized meaning for a part of meteorology.

Possibly the same model might be followed to provide a name for the study of the ionosphere. 'Ionomy', 'ionomer', 'ionomic' might thus replace 'radio-physics' and the associated words, which are certainly less easy to pronounce, and in view of the possible confusion with the physics of radioactivity, somewhat ambiguous: it is to be admitted, however, that ionomy might seem applicable to the study of ions in the laboratory as well as in the ionosphere.

S. CHAPMAN.

Imperial College of Science and Technology,
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If, despite its obvious convenience of brevity in itself and its derivatives, it does not commend itself to aeronomers, I think there is a case for modifying my proposal so that instead of the word being used to signify the study of the atmosphere in general, it should be adopted with the restricted sense of the science of the *upper* atmosphere, for which there is no convenient short word. I would not favour any very exact definition of the level from which the upper atmosphere should be so reckoned in using the suggested term, but it should in my opinion be definitely above the tropopause.

Weather. 1953

- In Ratcliffe's 1960 book "Physics of the Upper Atmosphere" Sydney Chapman states that: ***Aeronomy*** is the science of the upper region of the atmosphere, where dissociation and ionization are important".
- Aeronomy is the scientific discipline devoted to the study of the composition, movement and thermal balance of planetary atmospheres. …… As a field of research, aeronomy demands an understanding of the basic concepts of both chemistry and physics as applied to a highly rarified medium composed of neutral and charged particles. (Banks and Kockarts, 1973)

- A term denoting the physics and chemistry of the upper atmosphere. It is concerned with upper-atmospheric composition (ie, nature of constituents, density, temperature, etc.) and chemical reactions.

- A science that deals with the physics and chemistry of the upper atmosphere of planet.

- The study of the atmosphere of a planet, with particular attention to the composition, properties and motion of atmosphere constituents.

- Aeronomy: aer*on*o*my ¥a(e)r-'an-o-me¥n [fr. Gk aero-] a branch of science that deals with the atmosphere of the Earth and the other planets with reference to their chemical composition, physical properties, relative motion, and responses to radiation from space.

- **1951** - At the Brussels IUGG General Assembly upper atmosphere scientists pressed to have their interests recognised within the International Association of Terrestrial Magnetism and Electricity (IATME). (The alternatives were the International Union of Radio Science and the International Association of Meteorology.)
- **1954** - The International Association of Terrestrial Magnetism and Electricity was renamed the International Association of Geomagnetism and Aeronomy at the General Assembly in Rome. Aeronomy was defined as "the science of the upper atmospheric regions where dissociation and ionization are important".

Solar System "Aeronomy" Space Missions

- Pioneer Venus (1978-1992) (neutral mass spect., ion mass spect., magnetometer, LP probe, RPA, plasma analyzer, electric field inst, UV spectrometer, radio science.)
- Viking lander (1976) (neutral mass spect., RPA)
- Giotto (1986) (neutral and ion mass spectrometers, plasma analyzers, energetic particle detector, magnetometer)
- VEGA 1&2 (1986) (neutral mass spect., plasma analyzer, energetic particle analyzer, magnetometer, wave and plasma analyzer)
- Phobos 2 (1989) (magnetometers, plasma wave, ASPERA, energy-mass charge spect, proton & a spect, ion & electron spect, energetic charged particle spect.)
- Mars Express (2003-present) (ASPERA, SPICAM, MaRS)
- Venus Express (2006-2015) (ASPERA, Mag, SPICAV, VeRa)
- Cassini Orbiter (2004-2017) (UVIS, INMS, CAPS, MAG, MIMI, RPWS,RSS)
- Rosetta (2004, 2013-2017) (UV, Plasma package, dust analysis, ion/neutral spect., microwave, visible and infrared inst., radio sci.)
- New Horizon (2006, 2015-present) (UV, plasma instr., radio sci., dust)
- Juno (2013, 2016-present) magnetometer, UV, plasma, wave,radio sci.
- MAVEN (2114-present) well known to this group
- Many other space missions carried magnetometers, UV spectrometers, plasma instruments and radio occultation systems; e. g. Mariners, Mars, Veneras, Vikings, Pioneers, Voyagers

The Beginning of Planetary Aeronomy Studies. Mars (1).

- In the first half of the 60's ground-based spectral observations showed the presence of water and CO_2 in the atmosphere of Mars The latter was thought to be a minor constituent at that time and the estimate for the surface pressure was ~ 25 mbar.
- There were many attempts to send spacecraft to Mars in the 60's by both the US and USSR. The first successful mission to reach, flyby and make measurements at Mars was Mariner 4 in 1965. Arv Kliore and colleagues, using radio occultation observations, set the likely surface pressure at 4-5 mbar, suggested that CO_2 is the major species, the surface density is around 2×10^{17} cm $^{-3}$ and the temperature is between about 170-180^{o}K.

The Beginning of Planetary Aeronomy Studies. Mars. (2)

- Furthermore they established the presence of a daytime ionosphere with a peak density of around $1x10^5$ cm $^{-3}$ at an altitude of 125 km and a scale height of 20-25 km above the peak (twice the estimated neutral scale height as appropriate in a chemical equilibrium situation!). Finally they estimated the electron density to have dropped by about a factor of 20 at a solar zenith angle of 106^o. Amazing results published a month after the flyby and now 50 years later still “true”.

The Beginning of Planetary Aeronomy Studies. Mars. (3)

- Most of the aeronomic information about Mars came from radio occultation and UV observations.
- Radio occultation provided many electron density profiles, but in the early years there were many questions of what the major topside ion is. Some assumed it to be CO_2^+ (based on the major neutral constituents) and that assumption led to a plasma (thermospheric) temperature estimates of ~700° K, using measured electron scale heights, an overestimate of nearly a factor of two. At the same time there were a number of papers also published, which considered reasonably complex ion chemistry, involving among other species neutral O atoms, coming close to the correct answer (e. g. model calculations for Venus and Mars by McElroy and McConnell, 1971, which had O_2^+ as the major ion). The paper by Kumar and Hunten in 1974 discussing Venus is often considered "the" landmark publication (?) spelling out the correct basic ion chemistry, which holds for both Mars and Venus and to a large degree still stands today. A few percent of neutral O changes the ion chemistry drastically, making the major ion to be O_2^+. This was confirmed by the RPA results from Viking.

The Beginning of Planetary Aeronomy Studies. Mars. (4)

- Ian Stewart, using airglow data in the wavelength region of 1900-4000 A arrived at a thermospheric temperature of about 350^o K back in 1972.
- A low neutral gas temperature (~200^oK) was also confirmed by the neutral mass spectrometer results from the Viking landers.
- The Viking RPA's also provided information on the ionospheric ion temperatures and later the electron temperatures. These measured values were too high to explain in terms of EUV heating and/or classical thermal conductivities. Models (e. g. Chen et al. 1978; Johnson, 1978) were constructed and in order to reproduce the measured temperatures either an ad hoc topside heat inflow and/or reduced conductivity was needed. Once ionospheric plasma temperatures were obtained for Venus, models (e. g. Cravens et al., 1980) the same difficulties were encountered.

The Beginning of Planetary Aeronomy Studies. Mars. (5)

- Mariner 4 also had a magnetometer (Ed Smith), which detected the presence of a bow shock relatively close to the planet indicating clearly that if there is an intrinsic magnetic field it is very small. The discussions on whether Mars has an intrinsic magnetic field continued with arguments on both side of this issue, until the observations by Acuna et al. with the magnetometer on Mars Global Surveyor, which answered this question clearly. No intrinsic field, but significant remnant crustal fields. The Soviet Mars missions provided a good data base to arrive at an early “model” of the bow shock configuration by Slavin and colleagues, which is still quite reasonable today.

The Beginning of Planetary Aeronomy Studies. Venus. (1)

- Mariner 2 flew by Venus on December 1962, at a closest approach of 6.6R_v, but not much relevant aeronomic data was obtained.
- The magnetometer of Ness at al., detected no evidence of a planetary disturbance in the solar wind.
- The next flyby was by Mariner 5 in October 1967, one day after the arrival of Venera 4. The Mariner 5 trajectory approached to within 1.7 R_v of the center of the planet and Venera 4 was a lander. The observed bow shock crossings implied a very weak or non existent intrinsic magnetic field. This “argument” was not settled until the Pioneer Venus observations.
- Pre Pioneer Venus the most commonly used model to describe the interaction of the solar wind with Venus was the hydrodynamic model of Spreiter and colleagues (although there was significant work by Michael and Cloutier).

The Beginning of Planetary Aeronomy Studies. Venus. (2)

- The Mariner 5 flyby of Venus in 1967, provided the first electron density profiles of Venus using radio occultation. The dayside showed a main peak of 5×10^5 cm^{-3} at an altitude of ~140 km and a sharp decline in density above 500 km, the significance of which was not recognized at that time. (the first indication of an ionopause, which was an important clue to the nature of the solar wind interaction with Venus). The nightside ionosphere also exhibited a peak density of ~ 1×10^4 cm^{-3} at 140m km. The existence of such a dense nightside ionosphere was quite a surprise given the long Venus night. This led to long lasting “arguments” on whether electron impact ionization or day-to-night transport is responsible for maintaining this nightside ionosphere. (later it was shown that transport is the dominant source most of the time). Mariner 5 was followed by other missions (e. g. Mariner 10, Venera 9 and 10) providing further electron density profiles by radio occultation.

The Beginning of Planetary Aeronomy Studies. Venus. (3)

- The Mariner 5 Lyman alpha observations showed a “two slope” behavior. This behavior led to extended discussions (e.g. H and H_2 [CAB] or deuterium [MBMcE]) and some caused wrong estimates on the thermospheric temperature. It was Ian Stewart who eventually came up with the correct answer: he estimated that ratio of the slopes is aboi=ut 3:1 and proposed that it is caused by the presence of hot and cold hydrogen. He presented this at an Arizona Meeting in 1972. A detailed analysis by D. Anderson in 1976 demonstrated that the dayside profile is best fitted with a cold component of 275 ^{o}K and a hot component with 1020 ^{o}K. The nightside results were fitted with 150 ^{o}K and 1500 ^{o}K , respectively. Kumar and Hunten 1974 paper mentioned earlier reconfirmed the temperature is low (their estimate was ~ 350 ^{o}K.)
- In 1975 Veneras 9 and 10 observed four O_2 band emissions and put a very low upper limit on the 5577 emission in the nightglow.
- The real breakthrough on our understanding of the aeronomy of Venus had its beginning with the launch of the Pioneer Venus Orbiter in 1978.