SPACE WEATHER, ENVIRONMENT AND SOCIETIES

Jean LILENSTEN

PhD Researcher (CNRS), Planetary Laboratory
of the Grenoble University (Université Joseph Fourier), France,
Chairman of the European Coordination action in Science
and Technology devoted to Space Weather

Jean BORNAREL

Professor at the Grenoble University (Université Joseph Fourier),
Physics Spectrometry Laboratory, France,
Scientific Director of Grenoble Sciences

Springer

2005

Selected and edited by **Grenoble Sciences**, this book is supported by the **European COoperation in the field of Scientific and Technical Research** Network (COST).

Grenoble Sciences

Grenoble Sciences pursues a triple aim :

- to publish works responding to a clearly defined project, with no curriculum or vogue constraints,
- to guarantee the selected titles' scientific and pedagogical qualities,
- to propose books at an affordable price to the widest scope of readers.

Each project is selected with the help of anonymous referees, followed by a one-year (in average) interaction between the authors and a Readership Committee, whose members' names figure in the front pages of the book. Publication is then confided to the most adequate publishing company by Grenoble Sciences.

(Contact : Tél.: (33) (0)4 76 51 46 95 - Fax: (33) (0)4 76 51 45 79
E-mail: Grenoble.Sciences@ujf-grenoble.fr)

Translation: Madeleine POULARD

Grenoble Sciences is supported by the French Ministry of Education and Research
and the "Région Rhône-Alpes".

Front cover photo:
Photograph of the Sun seen by EIT from the SOHO satellite (ESA/NASA)

European ***CO****operation in the field of* ***S****cientific and* ***T****echnical* ***Research***

COST –the acronym for European **CO**operation in the field of **S**cientific and **T**echnical Research– is the oldest and widest European intergovernmental network for cooperation in research. Established by the Ministerial Conference in November 1971, COST is presently used by the scientific communities of 35 European countries to cooperate in common research projects supported by national funds.

The funds provided by COST –less than 1% of the total value of the projects– support the COST cooperation networks (COST Actions) through which, with only around €20 million per year, more than 30,000 European scientists are involved in research having a total value which exceeds €2 billion per year. This is the financial worth of the European added value which COST achieves.

A "bottom up approach" (the initiative of launching a COST Action comes from the European scientists themselves), "à la carte participation" (only countries interested in the Action participate), "equality of access" (participation is open also to the scientific communities of countries not belonging to the European Union) and "flexible structure" (easy implementation and light management of the research initiatives) are the main characteristics of COST.

As precursor of advanced multidisciplinary research COST has a very important role for the realisation of the European Research Area (ERA) anticipating and complementing the activities of the Framework Programmes, constituting a "bridge" towards the scientific communities of emerging countries, increasing the mobility of researchers across Europe and fostering the establishment of "Networks of Excellence" in many key scientific domains such as: Physics, Chemistry, Telecommunications and Information Science, Nanotechnologies, Meteorology, Environment, Medicine and Health, Forests, Agriculture and Social Sciences. It covers basic and more applied research and also addresses issues of pre-normative nature or of societal importance.

EXTRAITS

Table 1.2 - Some distinctive parameters of solar system planets and the Sun

	Diameter at the equator [km]	Mass [kg]	Mass / Mass of the Sun	Density in relation to liquid water	Specific rotation (day)	Gravity** [m s^{-2}]
Sun	1,392,000	2×10^{30}	1	1.4	25.38	275.5
Mercury	4,879	3.302×10^{23}	1.65×10^{-7}	5.43	58.65	2.78
Venus	12,104	4.870×10^{24}	2.44×10^{-6}	5.24	243.01*	8.60
Earth	12,756	5.974×10^{24}	2.99×10^{-6}	5.52	1	9.78
Mars	6,794	6.419×10^{23}	3.21×10^{-7}	3.93	1.026	3.72
Jupiter	142,984	1.900×10^{27}	0.95×10^{-3}	1.33	0.41	22.88
Saturn	120,536	5.685×10^{26}	2.84×10^{-4}	0.69	0.427	9.05
Uranus	51,118	8.683×10^{25}	4.34×10^{-5}	1.27	0.45*	7.77
Neptune	49,528	1.024×10^{26}	0.51×10^{-4}	1.64	0.67	11
Pluto	2,390	1.238×10^{22}	0.65×10^{-8}	1.73	6.39	0.4

** The rotation of Venus and Uranus is retrograde, i.e. in the opposite direction to that of the Earth.*
*** Mean gravity on the surface.*

As the Sun rotates, the matter at the equator drifts towards the poles at a relatively slow speed: about 80 kilometers per hour. The flow of matter back from the poles towards the equator theoretically occurs at a depth of approximately 200,000 kilometers (this has not yet been confirmed) meaning the matter is transported roughly ten times more slowly than on the surface. It would, therefore, take more than twenty years for a particle to complete the full cycle from the surface of the solar equator to a pole and then back through the inside of the Sun; this value can be compared with that of the duration of the cycle of solar activity.

Since the speed of rotation of the Sun varies between the equator and the pole, the latitude[9] must be specified each time a value is given. The usual reference is 16°. At this latitude, as seen from the Earth, the Sun appears to complete a rotation in 27.2753 terrestrial days. If we take a latitudinal average from the equator to the pole, we obtain a value of 27.7 days with extreme values of about 35 days near the poles and 25 on the equator. This is known as *synodic rotation*. However, the Earth rotates on its axis as well as around the Sun. The solar rotation we can observe from

9 The latitude of a site on a rotating sphere is the angle between the zenith of the site and the equatorial plane. This notion will be brought up again in chapter 2 and its appendixes.

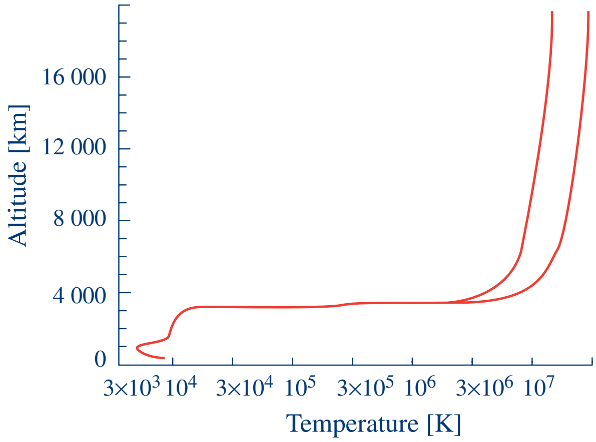


Figure 1.16 - Thermal sections of the solar corona
The two curves correspond to a quiet Sun (lowest temperatures) and to measurements that include emission from the active regions (highest temperatures). Altitude zero corresponds to the top of the convection zone (according to G.W. Simon and co-authors, Solar Physics, volume 39, 1974).

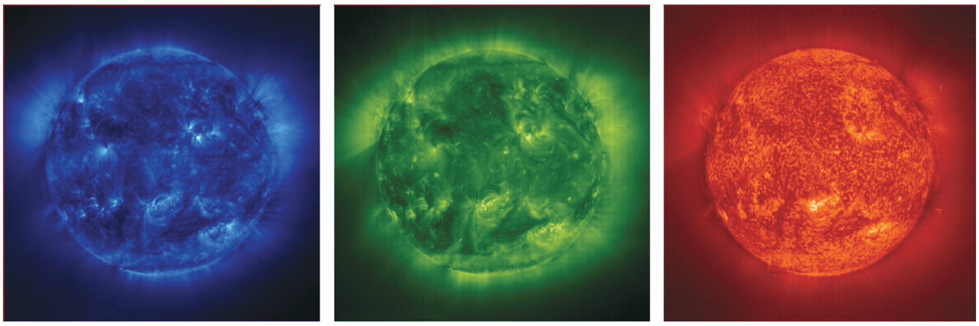


Figure 1.17 - The Sun photographed by EIT on board SOHO
In blue, the picture taken at 17.1 nanometers on August 11th 1999. This radiation is emitted by eight or nine times ionized iron and at a temperature of about 1 million degrees. In green, on the same day, radiation emitted by eleven times ionized iron at 1.5 million degrees, wavelength 19.5 nanometers. Lastly, in brown, radiation of fourteen times ionized iron at 28.4 nanometers. Photograph taken on February 3rd 1996. The temperature is as high as 2 to 2.5 million degrees (credit SOHO/EIT).

Just above the photosphere, forming a layer of about 1,500 kilometers, is the *chromosphere* [26], where there is an increase in temperature. Over this short distance, the electrons gain 6,000 degrees (the temperature increases from 6,000 to

26 During an eclipse of the Sun, a thin fringe appears; it is red in color, (due primarily to the Hα emission of hydrogen at 656.3 nanometers). This colored appearance explains why it is known as the chromosphere.

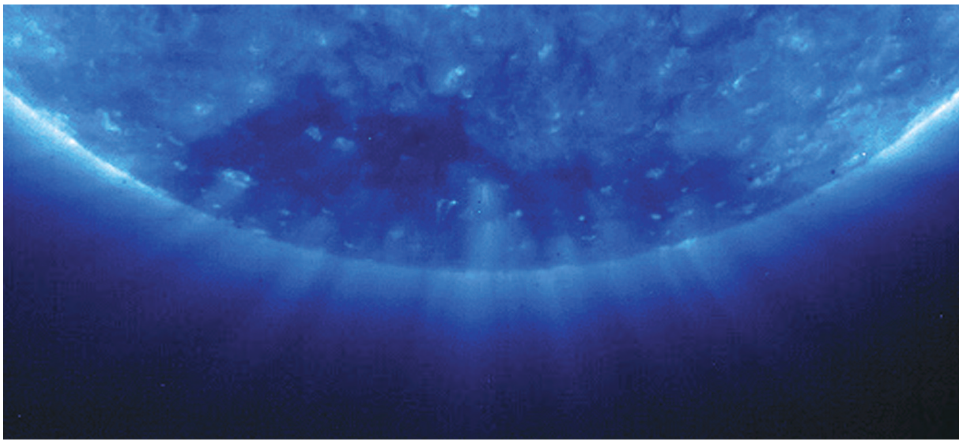


Figure 1.34 - This picture was taken at 17.1 nanometers, with the radiation emitted by eight or nine times ionized iron

At this wavelength we can observe (in processed colors) a darker area at the pole which is a "coronal hole". Plumes are huge strands of matter above this coronal hole (credit EIT on SOHO).

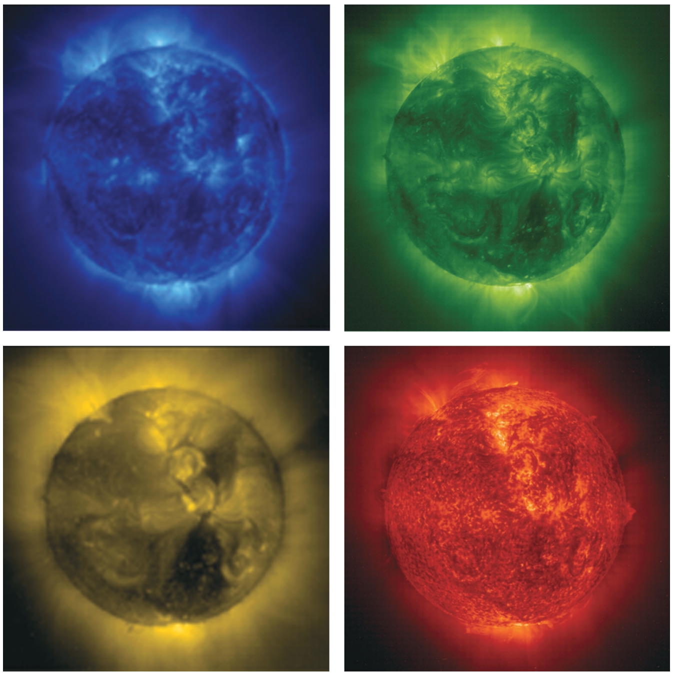


Figure 1.35 - On December 6th 1991, EIT took four photographs of the Sun, at 17.1 nanometers (top left), 19.5 nanometers (top right), 28.4 nanometers (bottom left) and 30.4 nanometers (bottom right)

Coronal loops can be observed on all these pictures, meaning that they occur at various altitudes above the chromosphere. The coronal holes are clearly visible on the picture of the fourteen times ionized iron at 28.4 nanometers.

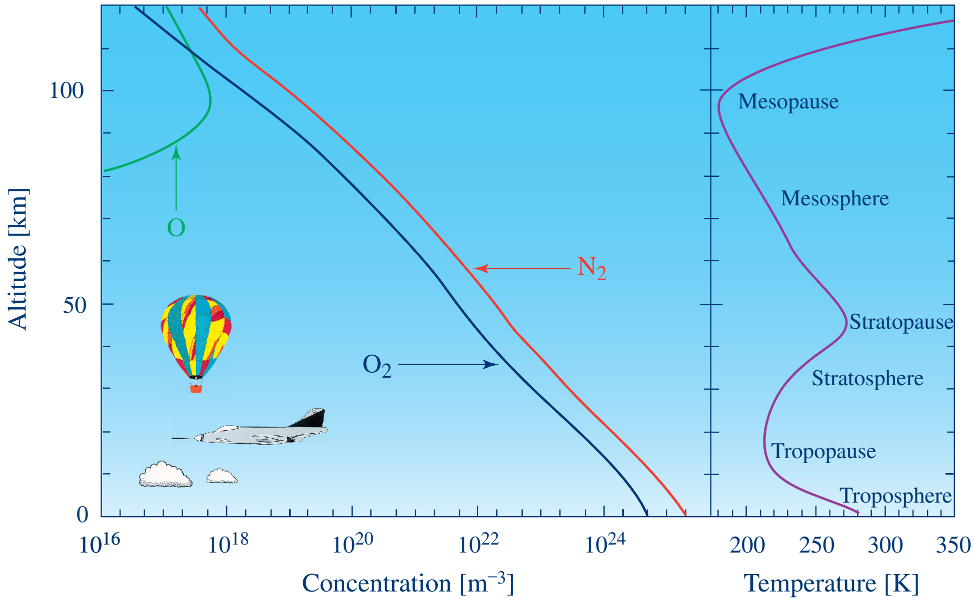


Figure 2.10 - The vertical structure of the homosphere obtained using model MSIS 95

The beginning of April, on a calm day, toward noon, at a latitude of 45° North. To the left, we see the concentration lines ([m^{-3}]) of the principal components from ground level up to 120 kilometers (N_2 in red, O_2 in dark blue, O in green); on the right, the vertical temperature line ([K]) in function of altitude.

3.2. THE HETEROSPHERE, THE THERMOSPHERE, THE IONOSPHERE

The *heterosphere* begins above the homosphere. It only became possible to explore the properties of this part of the atmosphere with the advent of radio communications in the twentieth century. Subsequently, sophisticated radar techniques and measurements by satellite revealed a complex, dynamic medium, a gas consisting of a mixture of electrically-charged particles and neutral particles. This sheath still raises a great many questions about the part it plays in the eco-system of the Earth and in the emergence of life on Earth.

Space begins in the heterosphere, the lower legal limit of which is 80 kilometers. This is also where space weather really starts.

In the heterosphere, the concentration of molecules and atoms becomes very low and each component behaves as if it were alone. Here, the perfect gas behavior of the whole of the homosphere now applies separately to nitrogen, oxygen, and hydrogen, with a fundamental difference: each has its own scale height. The immediate result is a variation in their exponential concentration but with different magnetosphere. It is because of these entrances that the magnetospheric cavity contains a (low) number of the ions and electrons that, a few hours to a few days earlier, were being blasted off the Sun.

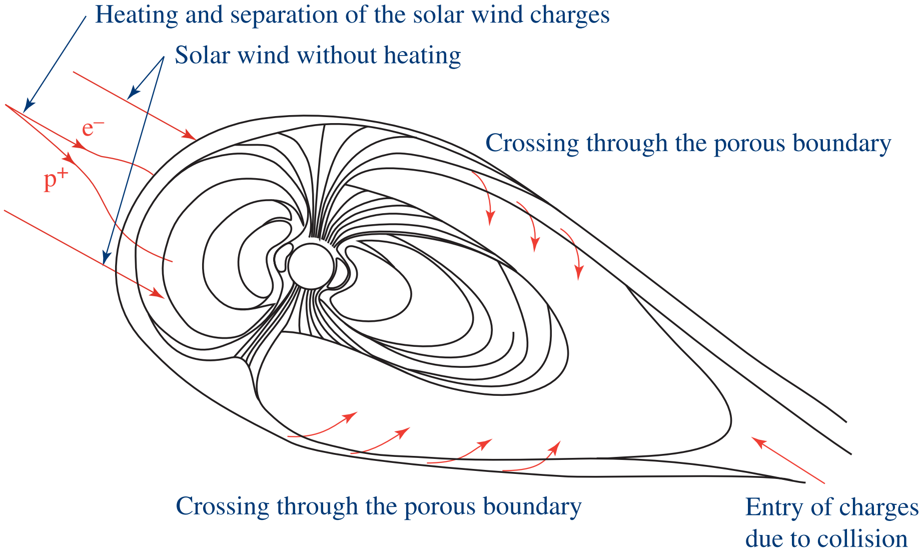


Figure 2.18 - Solar wind particles enter the magnetosphere

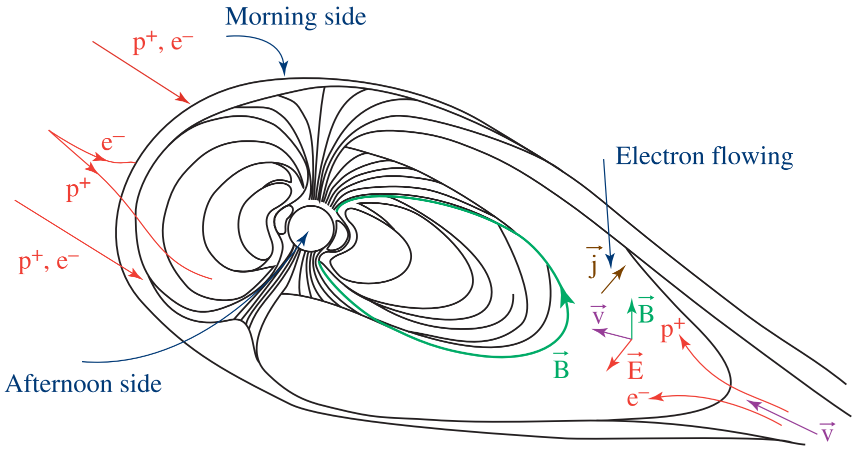


Figure 2.19 - The creation of the electric field $\vec{E}$ and of a current $\vec{j}$ crossing the magnetosphere

The particles of the solar wind that have reached the front of the magnetosphere have undergone a separation of charge (p^+ means protons and e^- electrons). Inside the magnetosphere, ions are attracted to the morning side and ions to the evening side but they all undergo a force under the combined influences of the magnetic field and the geomagnetic field $\vec{B}$. They are compelled to move toward the Earth (velocity $\vec{v}$).

Chapter 3

TOWARD A SPACE WEATHER

Figure 3.1 - Sunrise seen from space
(credit J.P. Haigneré, CNES, Perseus mission)

Various attempts to explain the Aurora Borealis are at the origin of the discoveries concerning the ionized environment of our planet. The first magnetic measurements were taken by VON HUMBOLDT in 1805. It was he who first used the term "magnetic storm" to explain the perturbations of his measurements. Together with GAUSS, he was able to put forward an explanation for the terrestrial magnetic field. The first observation of a solar eruption was in 1859. R. CARRINGTON, a British astronomer, noted a magnetic storm followed about 18 hours later by auroras at a medium latitude. However, at the time it was impossible to say whether this was a coincidence or if there was a correlation.

Thirty years earlier, Hans Christian ØRSTED of Denmark, had noticed that electric wires deflected the needles of magnets. In 1831, the Englishman, Michael FARADAY, proved that inversely a magnet is capable of generating a current. The laws on electromagnetism that followed, standardized by the Scot James Clerk MAXWELL in

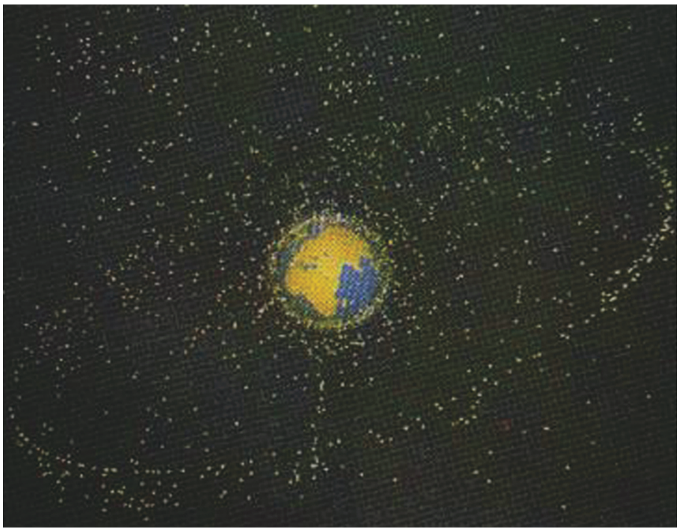


Figure 3.17 - Each point of this picture represents a space debris (in 1993)
The ring of debris of satellites in geostationary orbit, 36,000 kilometers from the Earth, can be seen quite clearly (credit ESOC).

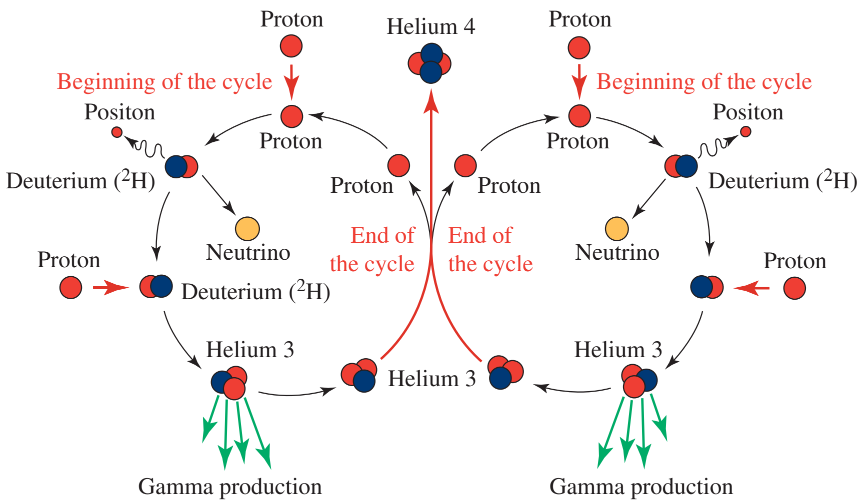
stabilizing arm of which was sectioned in July 1996 when it collided with a debris from the explosion of a stage of an Ariane rocket. This rocket had sent the satellite SPOT-1 into orbit in February 1986. The stage exploded 9 months later, scattering more than 700 fragments bigger than a fist. Since then, Arianespace have opted for "passivation" of the stages after the satellites are in orbit. This essentially means emptying the tanks completely to avoid explosions. Furthermore, space agencies have agreed that retired geostationary satellites be shifted about 200 kilometers above their orbit so as to draw them slowly away from the attraction of the Earth. However, no solution has been found as yet to make low orbit satellites harmless.

So a close watch most be kept on this debris. This is possible for fragments that are bigger than 10 centimeters across and of which there are (only) about 8,500. "Only" is in regard to the 110,000 fragments which vary in size from 1 to 10 centimeters, and which are about 300 times less numerous than the smallest scraps that are impossible to localize. Altogether, more than 2 million kilograms of debris are in orbit above our heads. The risk of losing a satellite through a collision with one of these fragments is, at the moment, 10,000 to 1, but increases exponentially with time. It is already quite an undertaking to keep track of the largest pieces: atmospheric tides can displace them over hundreds of meters in a few minutes. For example, during a violent solar event, the monitoring center (NORAD) lost track of 1,300 of them!

It is therefore necessary to quantify in real time any modification of the thermosphere over the whole of the globe, so that spatial operators can keep track of debris. Forecasts on a scale of a few hours are also necessary to have time to prepare avoidance procedures for satellites or the International Space Station. This was the

In most cases, this lithium then fuses with a proton, producing helium 4 atoms:

$$^{7}Li + {}^{1}H \rightarrow {}^{4}He + {}^{4}He \quad (7)$$



The second cycle, suggested by Bethe and Weizsäcker, is also known as the *carbon-nitrogen cycle* since it is implemented by the production of these heavy elements. It can only occur when the temperature exceeds 9 million degrees and is responsible for only a minor part of solar energy. However, it becomes primordial above 16 million degrees, making it the principal source of energy of some stars. It starts with the action of carbon, the residue of the explosion of a supernova, on a proton:

$$^{1}H + {}^{12}C \rightarrow {}^{13}N + \gamma \quad (8)$$

Nitrogen ^{13}N is unstable and transforms into carbon ^{13}C by losing a positron and a neutrino:

$$^{13}N \rightarrow {}^{13}C + e^{+} + \upsilon \quad (9)$$

Successive proton captures produce oxygen ^{15}O:

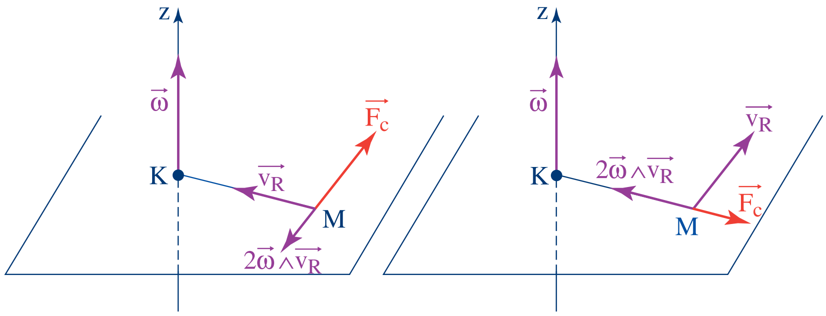
$$^{13}C + {}^{1}H \rightarrow {}^{14}N + \gamma$$
$$^{14}N + {}^{1}H \rightarrow {}^{15}O + \gamma \quad (10)$$

This unstable oxygen ^{15}O dissociates spontaneously into nitrogen ^{15}N, that fuses with a proton, finally resulting in helium and carbon:

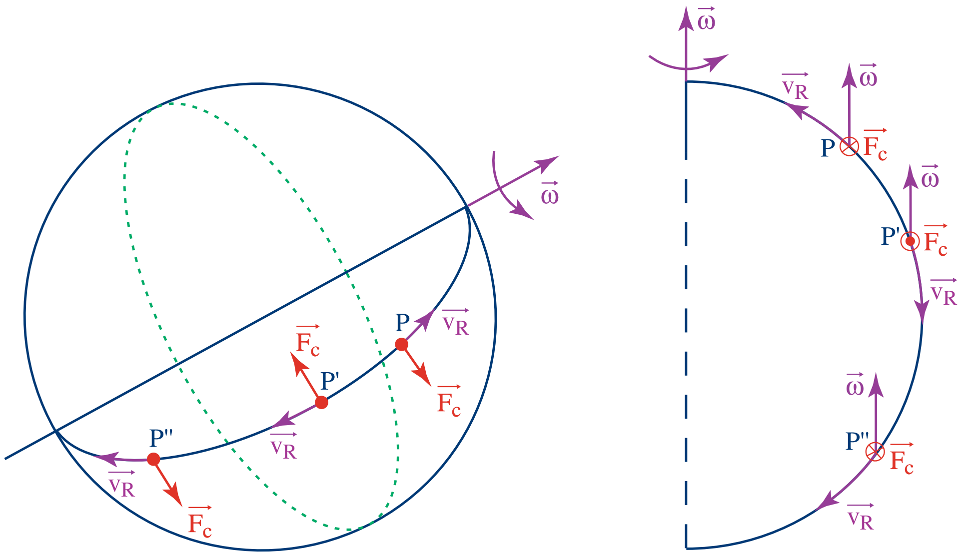
$$^{15}O \rightarrow {}^{15}N + e^{+} + \upsilon$$
$$^{15}N + {}^{1}H \rightarrow {}^{12}C + {}^{4}He \quad (11)$$

Carbon is, therefore, neither consumed nor produced. In a way, it serves as a catalyst during the Bethe cycle, since it is restored at the end and can be used again. The Bethe cycle can, therefore, be of considerable importance in a star that has very little carbon.

point M, it will undergo a fictitions force $-m\left(2\vec{\omega} \wedge \vec{v_R}\right)$ which will deflect the path of object M toward the right (from our position of observation). This fictitions force is the **Coriolis' force** $\vec{F_c}$.



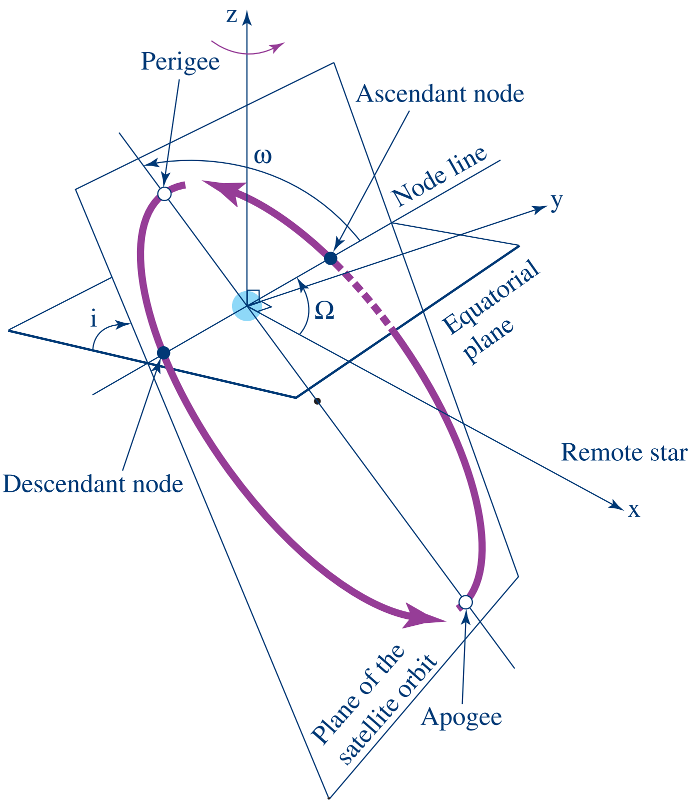
Let us consider an object that moves, along a meridian, in the rotating terrestrial reference frame whose influence it undergoes. We have represented this object on the globe below. At a point P of the northern hemisphere, a particle of relative velocity $\vec{v_R}$ directed northward, undergoes a Coriolis force perpendicular to both $\vec{\omega}$ and to $\vec{v_R}$, directed eastward, that deflects its path. At point P', a particle with a relative velocity directed southward is deflected westward. In the southern hemisphere (point P''), the vectorial product indicates that a particle with a relative velocity $\vec{v_R}$, directed southward, is deflected eastward (figure in perspective on the left and meridian cross-section, on the right).



ascendant node, the node line forms an angle Ω with axis Ox. This is called the right ascension and can vary in time.

The plane containing the orbit forms an angle i, called the inclination, with the equatorial plane. This is 0 in the case of a satellite in equatorial orbit and 90° if the orbit is polar. Since it is calculated in the northern hemisphere, it can be positive or negative (see figure).

Finally, the argument of the perigee ω is the angle formed by the straight line of the semi-major axis (on the perigee side) and the node line.



In order to define the *shape of the orbit*, one can use one of these couples:
– semi-major axis, eccentricity
– perigee radius / apogee radius

One can be deduced from the knowledge of the other. In orbital mecanics, the first one is more commonly used.

In order to define the *position of the orbit*, three parameters are needed:
– inclination
– right ascension of the ascending node
– argument of perigee