Technological Forecasting & Social Change 79 (2012) 963–985

Contents lists available at SciVerse ScienceDirect

Technological Forecasting & Social Change

The struggle for space: Past and future of the space race

Tessaleno Devezas [a,*], Francisco Cristovão L. de Melo [b], Maria Luisa Gregori [b], Maria Cristina V. Salgado [b], Joana R. Ribeiro [b], Christian B.C. Devezas [b]

[a] *University of Beira Interior, Covilhã, Portugal*
[b] *Institute of Aeronautics and Space — IAE-DCTA, São José dos Campos, SP, Brazil*

ARTICLE INFO

Article history:
Received 8 August 2011
Received in revised form 14 November 2011
Accepted 10 December 2011
Available online 5 January 2012

Keywords:
Spaceflight
Future scenarios
Logistic analysis
K-waves
Data mining

ABSTRACT

This article is geared toward shedding some more light on what may be the next space race and its contours.
Space flight is undoubtedly a human achievement of the second half of the 20th century, and probably the most audacious one of the past century. The space race started suddenly in the 1950s and has grown explosively during the following two decades, but decreased steadily after the 1970s. After the 1990s, however, we have seen a shy rebirth of space-related activities, when many other actors (states) entered the stage, adding up to the agonizing role of the two-actor piece that we have witnessed during the so-called Cold War.
The opening years of the 21st century provided a more complex narrative for space exploration. At the start of the new millennium a new technosphere [1] emerged, dominated by what is used to be called as the Information and Communications Technologies (ICT), with the Internet playing the leading role among the bandwagon of technological novelties that appeared during the twilight of space activities. In despite of the fact that artificial satellites represent the very backbone of the global communications system, space activities seem to play a secondary role amidst the apparently accelerated rate of change concerning the technological systems of the present technosphere. But, as it is demonstrated in this paper, things are changing, and very probably a renewed space race will unfold in the coming decades.
A question may be placed: what happened? Why the Earth stood still with regard to the race toward the cosmos? Answer: futurists, even prestigious ones like Herman Kahn and Arthur Clarke, did not consider the existence of socioeconomic long waves (Kondratieff waves, or K-waves for short) with their two decades long economic downturn, which has contributed to the deceleration of space-related activities.
Analyzing the worldwide evolving scenario of space-related activities during the last eighty years under the framework of the succeeding K-waves and applying some technological forecasting tools, namely the logistic analysis, technological surveillance and intensive data mining, scrutinizing more than 7500 events occurred in the period 1930–2010 related with space activities, it is demonstrated that the space race like the one that we have witnessed until now is a natural growth process that has saturated at the dawn of this century. The same analysis demonstrates that a new growth process in this field might be nowadays under way with contours very different from that imagined by futurists and science fiction writers sixty years ago. Also the main trends in the usage of launching vehicles and satellites are framed and discussed in this paper.

* Corresponding author at: University of Beira Interior, Dept. of Electromechanics, Engineering Faculty Bdg 8, Ladeira do Lamego, P-6200-001, Covilhã, Portugal.
E-mail address: tessalen@ubi.pt (T. Devezas).

0040-1625/$ – see front matter © 2011 Elsevier Inc. All rights reserved.
doi:10.1016/j.techfore.2011.12.006

1. Why the Earth stood still?

Space flight is undoubtedly a human achievement of the second half of the 20th century, and probably the most audacious one of the past century. That which is known today as the Space Race began suddenly in the 1950s and has grown explosively during the following two decades, but decreased steadily after the 1970s. After the 1990s, however, we have seen a shy rebirth of space-related activities, when many other actors (states) entered the stage, adding up to the agonizing role of the two-actor piece that we have witnessed during the so-called Cold War.

Very surely most coevals of the baby-boom generation, living as teenagers in the 1960s, have imagined that at the dawn of the 21st century we would be witnessing a very lively space flight era, with manned space stations and human colonies on the Moon and even on Mars. Every teenager at that time has certainly dreamed of this possibility and Kubrik's and Arthur Clarke's 2001—A Space Odyssey (produced in 1968) represented the incarnation of this hopeful future. But later in the 1980s, as mature adults, the idea came to those minds that the Earth seemed to have stood still — at least with regard to space activities.

At the start of the new millennium a new technosphere [1] emerged, dominated by what is used to be called as the Information and Communications Technologies (ICT), with the Internet playing the leading role among the bandwagon of technological novelties that appeared during the twilight of space activities. In despite of the fact that artificial satellites represent the very backbone of the global communications system, the space activities seem to play a secondary role amidst the apparently accelerated rate of change concerning the technological systems of the present technosphere. But, as we intend to demonstrate in this paper, things are changing, and very probably a renewed space race will unfold in the coming decades.

A question may be placed: what happened? Why the Earth stood still with regard to the race toward the cosmos?

Answer: futurists, even prestigious ones like Herman Kahn and Arthur Clarke, did not consider the existence of socioeconomic long waves (Kondratieff waves, or K-waves for short) with their two decades long economic downturn, which has contributed to the deceleration of space-related activities.

2. Failure forecasts

In an article published in 2002 Albright [2] brought some new light on the issue of future forecasts. Reviewing Herman Kahn's and Anthony Wiener's "*One hundred technological innovations very likely in the last third of the 20th century*" published in their 1967 book [3] he relates that a panel of eight experts, people knowledgeable in technology and futures, judged that fewer than 50% of all Kahn's and Wiener's forecasts were good and timely, having occurred in the 20th century. However, narrowing the focus and grouping the forecasts into nine broad technological fields, Albright found that there were wide variations in the judged accuracy of forecasts. Forecasts in Communications and Computers stood out as about 80% correct, while forecasts in all other fields were about or less than 50% correct. In Table 1 below the result for each technological field is presented.

It is important to point out that what is understood in this analysis as "forecast accuracy" refers mainly to the fact that Kahn's and Wiener's forecasts were overoptimistic regarding the technologies that could be available at the dawn of the new century. Specifically within the aerospace sector we do not have supersonic passenger transportation (the Concorde and Tupolev 144 experienced a very brief existence), the on-orbit construction of the International Space Station started only in 1998 and it is only a pale image of what was hoped for a space station in the dreams of space engineers and science fictions writers during the space boom of the 1960s, we do not have human colonies either on the Moon or on Mars, and the space tourism is still a tottering and blossoming space-related activity.

Table 1
Percent of forecasted innovations judged to have occurred by the end of the 20th century [2].

Communications and computers	81
Defense	51
Materials	47
Biotech and agriculture	46
Environment	45
Health and human	39
Infrastructure and transportation	31
Lifestyle	27
Aerospace	**18**

Note that aerospace (bold in the table of our own) appears in the last place, with only 18% accuracy. From this result we can easily infer that the accuracy of forecasts was inversely proportional to the intensity of capital investment necessary to put forth expensive and not priority entangled projects. The reader should keep in mind that many of the technologies implemented in the 1970s and 1980s surfaced in the wake of the Cold War, and that explains why Defense appears in the second place. Albright also points out the existence of two key drivers that were responsible for the great accuracy of forecasts in Communications & Computers (C&C, for short). First, sustained trends in enabling technologies for C&C were apparent in the 1960s and have continued to the present, allowing forecasters to extrapolate capability and cost trends with a high degree of accuracy. Second, the scale of investment required for innovation with technologies of C&C was driven down by the declining costs of the enabling technologies. It is worth to add a third key driver: the defense-related aspect. As Devezas et al. [4] showed, we may assert that just as the electronic digital computer can be attributed to needs and funding in the 1940s arising out of WWII, so the Internet can be attributed to needs and funding in the 1960s arising out of the Cold War (the concept of cooperative network of time-shared computers emerged within ARPA and the first ARPANET plan was proposed in the 1960s). The reduced accuracy in Transportation (31%) and Lifestyle (27%) matches well the feeling in the 1980s referred above of a kind of starvation in technological progress, related with the absence of radical novelties in our daily life.

The main reasons for not achieving the expected spatial aspirations for this new century lie mainly in the ending of the Cold War and in the global economic downturn that started in the mid-1970s. In the following sections of this paper we will analyze in detail the evolutionary trajectory of space-related activities, trying to understand the reasons of its downswing as well as to frame its possible future unfolding.

3. Rhythms in human affairs

K-waves may be defined as a pattern of regularity characteristic of structural change in the modern world economy. Some 50–60 years in length, it consists of an alternation of periods of high sectoral growth with others, start-up periods of slower growth. The study of this pattern helps to trace the evolution of the global economy, and aids in politico-economic prediction [5].

Since the onset of the 20th century, students of the world economy have been drawing attention to this long-term regularity in the behavior of the world economy. The first to make this argument in a sustained manner was Nikolai Kondratieff [6], a Russian economist writing in the 1920s. Statistical work on the behavior of prices, and some output series, for the United States and Britain since the 1790 s, led him to conclude that the existence of long waves was quite probable. In the 1930s, Joseph Schumpeter [7] endorsed this concept, and named the pattern the 'Kondratieff', a name that has since been attached to this phenomenon, even as its existence remained in contention in the years after 1945. Neo-classical economists have remained wary of it, and it was only in the 1970s, as the post-World War II economic expansion slowed down once again that attention was drawn to it, and new research especially on innovation moved the subject forward in an important manner.

Since the 1980s a significant body of scholarship emerged not only discussing its existence, but also trying to present a working theory to explain the possible causes of these long-term oscillations of the global economy. A complete overview of the existing theories on long waves is presented in Devezas and Corredine [8], as well as, for the first time, a possible explanation for their half-century duration based on the human learning capacity and the successions of generations.

The main characteristics of K-waves may be summarized as follows [5]:

1. K-waves are attributes of the world economy and are more visible in international production data than in those of individual national economies. They are processes characteristic first of all of a lead national economy (such as that of the United States in the 20th century, or Britain in the 18-19th centuries) and of world trade in products and services of leading sectors, hence of the global economy.
2. K-waves concern output, rather than prices, and sectoral output surges and infrastructural investment in the world economy rather than the general macroeconomic performance (e.g. GNP growth) of national economies. They should not be sought for in the ups and downs of such indicators as gross domestic product and must be distinguished from shorter-term business cycles and fluctuations in the economic conditions of individual countries. However, high-growth periods for leading sectors tend to translate into general economic expansion and prosperity.
3. K-waves unfold as phased processes that imply S-shaped growth (or learning) curves, including for each particular sector, and over a period of some 50–60 years, a period of slow start-up, followed by fast growth, and ultimate leveling-off. That is why they are waves of economic activity, each wave different in kind from the last one, rather than cycles, seen as mechanical fluctuations in attainment of some uniform quantity. The start-up period of the next leading sector is also the period of flattening growth rates, declining profits, and severe competition for the previous lead industry; this transition between two leading sectors peak may be known as downswing, and takes the form of generalized slow-down.
4. K-waves arise from the bunching of basic innovations that launch technological revolutions that in turn create leading industrial or commercial sectors. In Schumpeter's classic formulation, such innovations concern new products, services, and methods of production, the opening of new markets and sources of raw materials, and the pioneering of new forms of business organization. In that sense, K-waves are caused by the demand for solutions to new problems, and the supply of such solutions by innovative firms. Each such wave therefore has its own individual innovative character, and can be named accordingly, constituting a completely new technosphere. Since the onset of the Industrial Revolution we have had the 'Age of Steam and Railways'(1820), 'Age of Steel, Electricity and Heavy Engineering' (1870), 'Age of Oil, Automobile and Mass Production' (1920), and 'Age of Information and Telecommunications' (1970). The date between brackets means the approximate date of the peak of the corresponding wave, as well as the date corresponding to the full entrenching of the new technosphere (see Table 2).
5. K-waves have their own characteristic location in space (leading country): the two most recent K-waves were leaded by the US that succeeded Britain's leadership of the two previous waves (since the onset of the Industrial Revolution). K-waves also have

Table 2
Secular set of K-waves since the Industrial Revolution.

K-wave	Upswing phase	Downswing phase	Peak	Designation
1st	1790–1820	1820–1840	1815–1820	Age of Steam Engines and Railways
2nd	1840–1870	1870–1895	1865–1870	Age of Steel, Electricity, and Heavy Engineering
3rd	1895–1925	1925–1945	1920–1925	Age of Oil, Automobile, and Mass Production
4th	1945–1970	1970–1995	1970–1975	Age of Information and Telecommunications
5th (?)	1995–2025	202–2045	2020–2025	*Bio*, *AI*, *AL* (?)

a clear location in time, and can be dated. There is no standard listing, but there is some agreement on the four most recent ones, as summarized in Table 2. Historians and world system theorists now extend such dating further into the past [9,10] reaching all the way back to Sung China, and grounded in the argument that the origins of the contemporary global economy might be traced to that source one millennium ago.
6. K-waves each have their own special character and specialization but each in its own way also changes the structure of the world economy; that is why a sequence of K-waves gives rise to structural transformations.

In the 1980s Marchetti [11] pioneered the view of '*society as a learning system*' and the existence of '*fifty year pulsation in human affairs*', perhaps one of the most inspired and insightful view of this challenging phenomenon. His secular curves (logistic Fisher–Pry plots) scanning the technological development since the onset of the Industrial Revolution brought forth robust evidence on the existence of succeeding spurts of inventions and of basic innovations along with the two last centuries, evidencing a pronounced regular half-century beat.

In 2001 Devezas [8] put forth a Generational-Learning Model (GLM) introducing the idea of two biological determinants constraining and imposing the rhythm of collective human behavior and hence the pace of social and technological progress. Later in 2002 [12] the same author developed further this model theoretically, using arguments from nonlinear dynamics and information theory, and more recently Devezas et al. [4]. brought some empirical evidence to this model using as example the entrenching and growth of the Internet and related enabling technologies.

The underlying idea of the GLM is that the observed patterns of regularity in human affairs, manifested as socioeconomic rhythms and recurrent phenomena, are constrained and co-determined by our natural human biological clocks. The proposed model is based on two kinds of biological constraints that impose the rhythm of collective human behavior—generational and cognitive. The generational consists in subsets of the normative life span or human life cycle. The cognitive consists of a limiting learning growth rate. It is proposed that the syncopated beats of succeeding effective generational waves and the dynamics of the learning processes determine the long wave behavior of socioeconomic growth and development. In other words this model proposes that there are indeed limits to the speed of technological progress and these limits are ingrained in our biological nature.

Long wave theory is not accepted by most orthodox academic economists, but it is one of the bases of innovation-based, development, and evolutionary economics, i.e. the main heterodox stream in economics. Among economists who accept it, there has been no universal agreement about the start and the end years of particular waves. The dates shown in Table 2 express the most agreed values that have been assigned to the upswing and downswing phases of the last four Kondratieff waves, as well as the possible dates assigned to the still unfolding K-wave. Each wave has been characterized by a 'nickname' expressing the leading technologies, as commented on in point 4. Note that a 'nickname' is not yet associated to the still unfolding K-wave. The most people continue to speak that we are still living in the "Information and Telecommunications Era" —; that is true, considering that we are the coevals of the hesitant upswing phase of the 5th K-wave, period during which it is observed the final entrenching and consolidation of the previous leading IT technologies. During the next 20–30 years another name will certainly be assigned to the new wave, very probably related to the new bio-related and artificial life (AL)/artificial intelligence (AI) sciences that are still blowing up.

Reinforcing the points 1 and 2 above Devezas [13] has shown recently that the historical evolution of the global GDP growth rates (using the purchasing power parity – PPP – converters, which eliminates the inter-countries differences, so that the volume of economic activity can be compared across countries) exhibit clear fingerprints of K-waves, and demonstrates that the crisis started in 2007 seems to be a kind of a self-correction mechanism that brought the global output back to its original learning natural growth pattern that started in the 1990s, and that it carries also signals of an imminent transition to a new world economic order. Moreover it is demonstrated that the current decade (2011–2020) will be probably one of the worldwide economic expansion, corresponding to the second half of the expansion phase of the 5th K-wave.

Now that it is celebrated the 50th anniversary of the first human space flight (Yuri Gagarin on April 12th 1961) it is worth to undertake a close examination of the history of space-related activities under the lenses of the K-waves approach.

4. Intensity of activity

In order to characterize the human functioning dynamics in a given sector of human activities we need to choose some counting scheme to quantify it. For this research we have applied the same approach already used some years ago to measure the expansion dynamics of the Portuguese during the so-called 'Age of Discoveries' [10,13,14]. We have already referred in point 5 of the previous section that historians and world system theorists now extend the dating of K-waves further into the past. Devezas and Modelski [10,14] and Nascimento and Devezas [15] have shown that the expansion of the Portuguese maritime Empire during the 15th and 16th centuries has followed the typical unfolding of two entire K-waves, each of which supported by a given set of technological, organizational and political innovations. The quantifying schema used was to establish a count of Portuguese expeditions and campaigns, considered discretely and cumulatively, as a time-series. By expeditions was mean primarily exploratory and preparatory undertakings; campaigns by contrast referred to military, primarily naval, operations that included the capture of cities. This approach was coined as the measure of the '*intensity of activity*' during the overall Portuguese world-wide enterprise.

In this work we have followed a similar approach considering the '*intensity of activity*' of all space-related missions undertaken by several countries, counting discretely and cumulatively the launching of rockets (successful and not successful) with mostly different purposes: exploring the upper atmosphere, placing objects in orbit, training manned space flight, exploring the moon or other solar system bodies, building a space station, or even sending objects outside the solar system. More than 7000 space launches in the last 80 years were considered altogether.

The data for the events used in this research were collected (and cross-compared) from some different websites [16] and books [17-19] and are resumed in the official website of our institutional research project [20]. Our results are presented in the form of several graphs in the following sections, considering separately the most active countries as well as all countries together. Also an overview of the different types of space-related activities is presented and analyzed.

5. Mapping the space race

Space exploration has its origins in the military build up for WW2 and began with the development of rockets by Nazi Germany, which developed the first liquid fuel rocket with the ability to carry missiles. The Nazi defeat resulted in both USSR and the US setting up programs under which intelligence and military services extricated Nazi scientists from Germany, mainly those specialized in aerodynamics and rocketry. The US was the most successful in kidnapping scientists while the USSR succeeded in capturing production plants and missiles.

Already in the middle 1940s the US Army achieved radar contact with the moon, by 1954 the Navy began communication experiments using the moon as a reflector and by 1959 it established an operational communication link between Hawaii and Washington DC. In 1957 the USSR successfully launched Sputnik 1, the first artificial satellite to reach orbit, soon followed by Sputnik 2 that carried into space the first living being, the dog Laika. The United States promptly responded in 1958 with its first satellite, Explorer 1. The attention of both countries then turned to the moon, and already in 1959 the Soviet Union reached the Earth satellite with their Luna probes E1 (which crashed into the lunar soil) and Luna E-2 (which orbited the moon taking photos).

All these Soviet feats caused fear and stirred political debate in the United States — *The Space Race* had begun. In 1958, President Eisenhower signed the National Aeronautics and Space Act establishing the National Aeronautics and Space Administration (NASA). Incidentally Wernher von Braun, who was head of the Nazi rocket program, became NASA's first chief director of the Marshall Space Flight Center and the chief architect of the Saturn V launch vehicle, with which the US reached the Moon in 1969.

The space race reached its peak during the cold war with both the US and USSR competing and establishing various programs to ensure space technology remained balanced toward them. After the cold war space activities have declined significantly, but in the meantime other actors (countries) have been gradually coming into play, especially China which in 2003 became the third nation to put an astronaut into orbit, marking its presence as third space power early this century.

Considering altogether the registers found in the specialized literature [16–19] since the 1930s (Goddard's and Nazi German's rocketry experiments) the worldwide space-related intensity of activity presents the aspect shown in Fig. 1. Note that the resulting graph is a year-after-year representation.

The general wave-like aspect of the resulting graph is striking. In order to understand and interpret the details of this phenomenon it is worth to analyze separately the behavior of the curves for different countries and/or different regions of the world. In the following

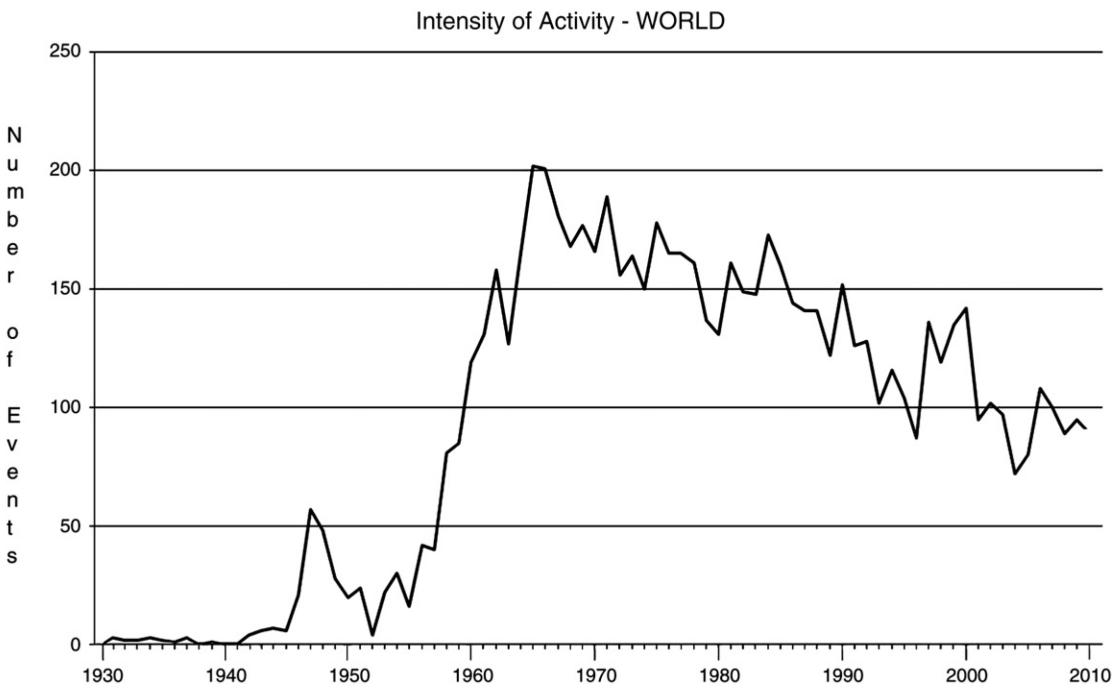

Fig. 1. Worldwide space-related intensity of activity in the time span 1930–2010 considering all the registers found in the specialized literature [16–19]. 7565 entries were considered [20].

series of figures (Fig. 2–4) we can observe the aspect of the curves for the USA plus USSR/Russia, Europe, and Asia respectively. The graphs of Figs. 3 and 4 (Europe and Asia) are presented as histograms instead of straight lines because of the smaller scale of the number of events for these regions of the world.

Considering that in the curve for Asia the share contribution of China and India is the most significant one, graphs for these countries are also presented separately in Figs. 5 and 6 respectively.

Looking at this set of graphs we can infer some important preliminary conclusions:

1 The general appearance of the curve shown in Fig. 1 (World) is quite similar to the general appearance of the curve shown in Fig. 2 (USA plus USSR/Russia), except to the fact that the downward slope from the 1970s onward of the latter is much more pronounced than that of the worldwide curve.
2 The preceding observation implies that the main contributors for the worldwide space activity were obviously the USA and the Soviet Union, but in more recent times the increasing activity of the European and Asian nations has contributed to the observed higher level of intensity of activity in the period 1990–2010 as depicted in Fig. 1.
3 The highest level of space activities of the last 20 years can be divided into 2 parts, with a more expressive contribution from Europe for the first decade (1990–2000, see Fig. 3) and a more significant contribution from Asia (mainly China) for the second decade (2000–2010, compare Figs. 4–6).

At this point it is worth to give a closer look at Fig. 7, which presents the same data of Fig. 2 but now split into two curves, exhibiting separately the unfolding of the space activities for the USA and USSR/Russia respectively.

This figure unveils the fact that the US has applied an enormous amount of effort and resources to the primary objective of "reaching the Moon", what was evidently a genuine geopolitical and ideological target, and after getting this "ideological victory" diminished radically its investment in space activities, but however with a significant recovery in the 1990s. On the other hand the USSR has evidently followed other way around in order to keep its space exploration advantage showed in the 1950s and 1960s, but it is interesting to note that both countries have shown a very similar intensity of activity since the second half of the 1990s.

It is important to observe how the general aspect of the curve of the intensity of activity for the USA matches perfectly the aspect of the curve representing the NASA budget (in 2007 constant dollars and/or as % of US federal spending) that can be seen in Fig. 8. Undoubtedly the US leadership in space exploration was the direct result of the huge amount of the capital invested in the sector, which in the middle 1960s reached the level of 4% of the national public spending, a level never paired by any other nation since then.

From the 1980s onward the US focused its effort in the reusable launcher program (Space Shuttle), decelerating other launcher programs like the Delta and Atlas. But the accident occurred in 1986 with the shuttle Challenger led NASA to reassess its launcher strategy, questioning the reliability of the shuttle system. The result was the acceleration of the development of the launchers of the family Delta IV and Atlas V as well as the more intensive use of the European launcher Ariane to place their satellites into orbit. In Fig. 9 the reader can easily observe that the use of the Shuttle has increased in the period 1981–1986, with a peak in 1985, but

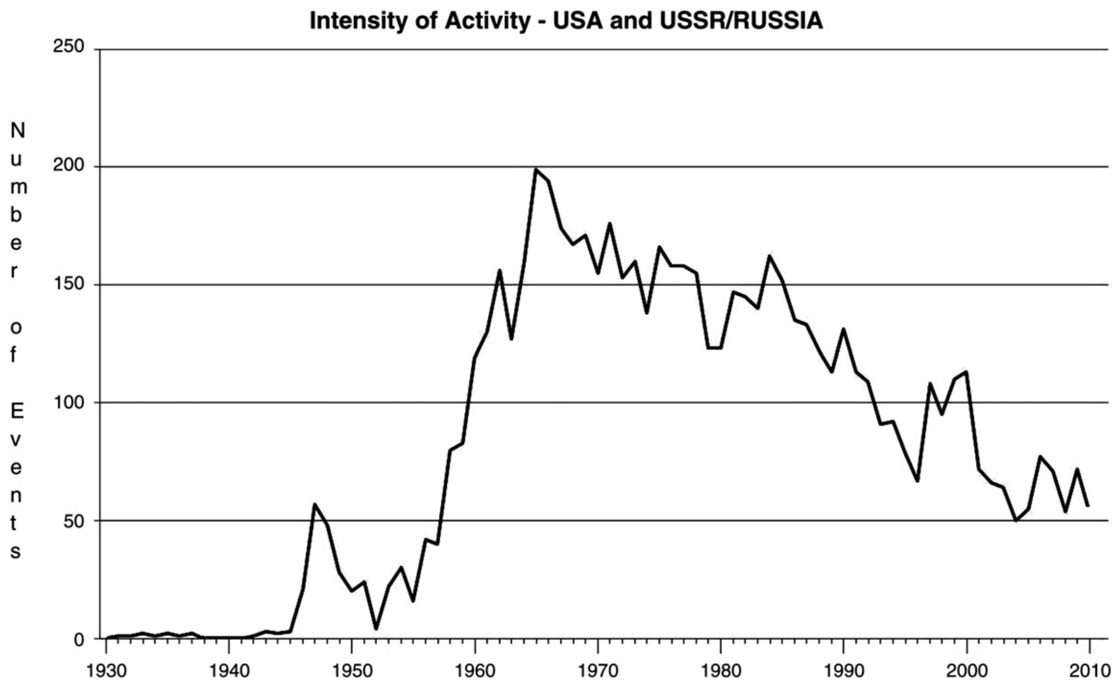

Fig. 2. Space-related intensity of activity for the USA and USSR in the time span 1930–2010. Data until 1991 are for USSR, and for 1992 onwards the data used are for Russia plus the former countries of the Soviet Union.

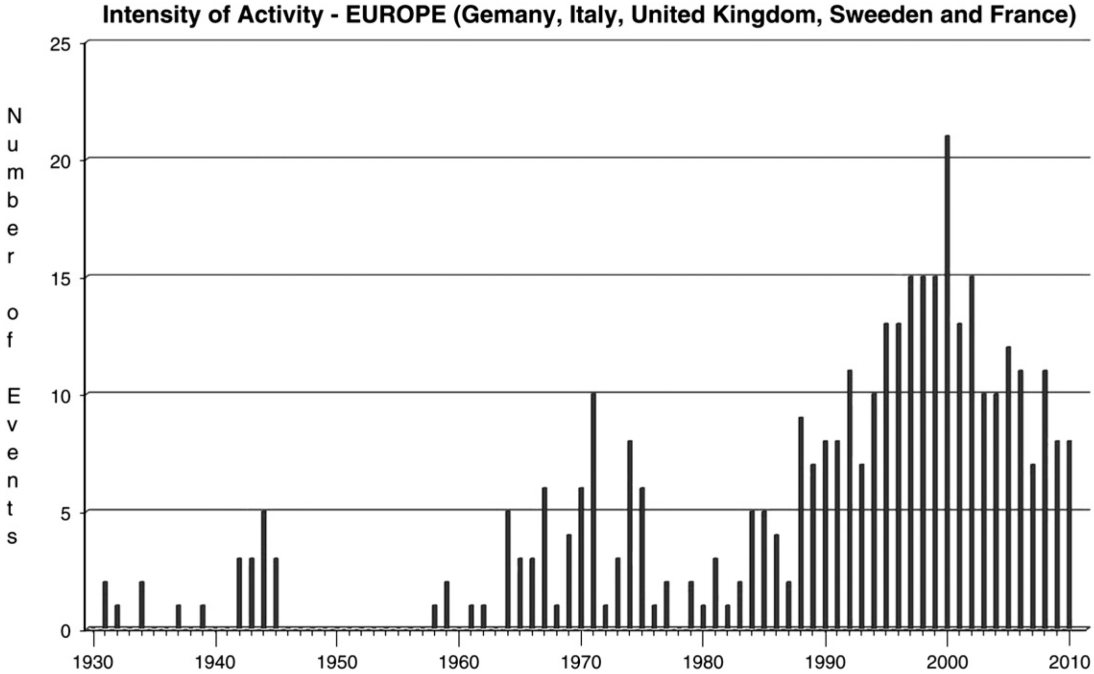

Fig. 3. Space-related intensity of activity for Europe (five countries) in the time span 1930–2010.

declined after this date giving place to a more intensive usage of vehicles of the family Atlas and Delta. In Fig. 10 we can verify that the usage of vehicles of the Ariane family has increased to a considerable extent after 1987, but was reduced slightly after 2002 coinciding with the accident with the Ariane 5 as well as with the date when the US has started using the larger vehicle Delta IV. It is important to note that after 2005 the usage of Ariane launchers has increased again after the development of the most powerful launcher Ariane 5 ECA with a payload capacity of 10 tons.

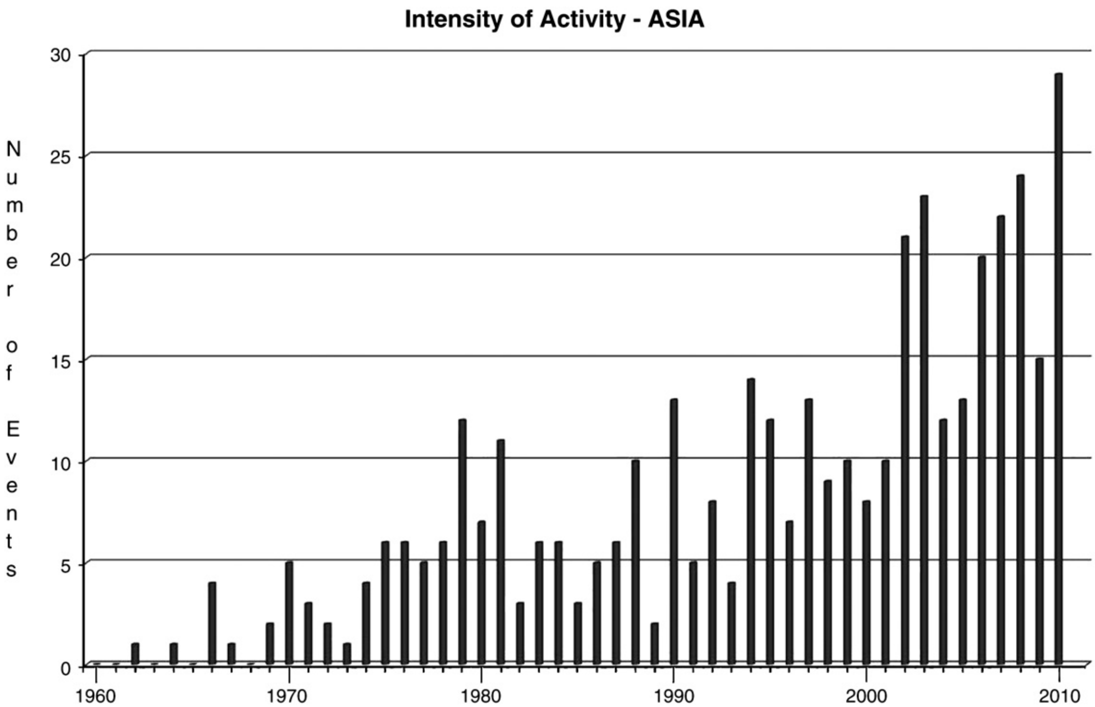

Fig. 4. Space-related intensity of activity for Asia (five countries) in the time span 1930–2010.

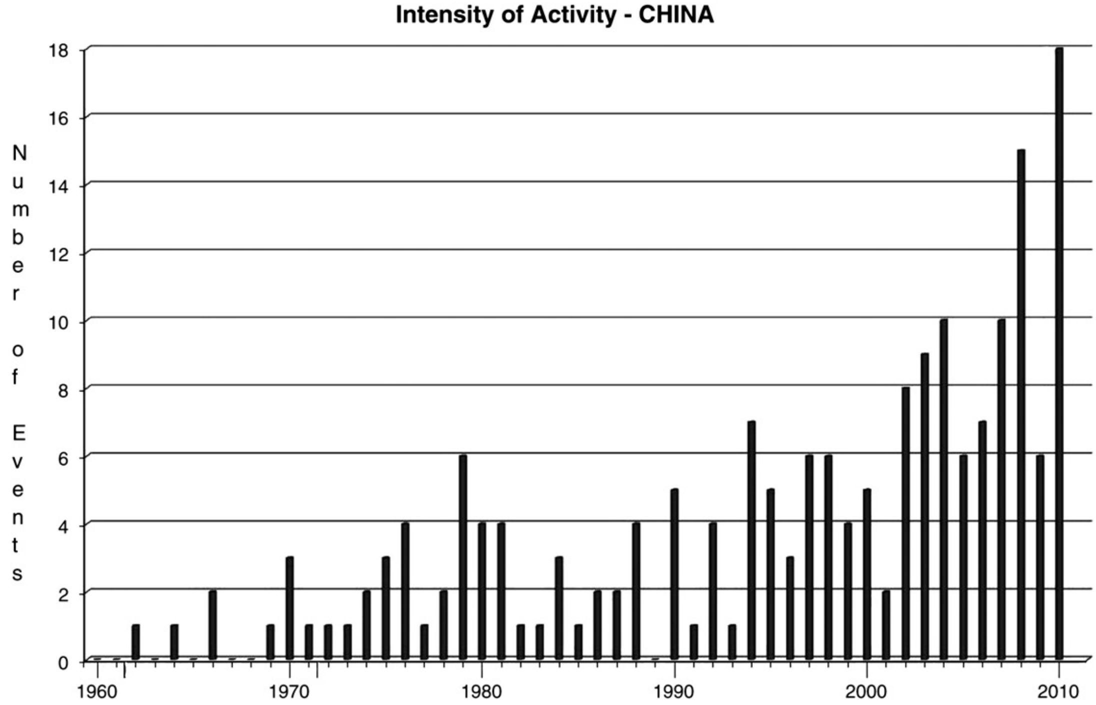

Fig. 5. Space-related intensity of activity for China in the time span 1930–2010.

As can be seen in Fig. 7 the former Soviet Union kept its rate of space activities throughout the Cold War sustained by the state. The factors that fueled this high productivity were the strong support and pressure of the government for development in the area of space, mainly to meet military needs and political projection of the Soviet state, the extremely low cost of skilled labor (estimated as of $ 100 per month [21]) and high investment in production to the detriment of investment in innovation. As a consequence, today Russia uses the same launcher technology already developed in the 1960s. After the disintegration of the Soviet Union, Russia faced a broken country, poor and unstructured. Space activity lost all that thrust, just as the financial conditions of

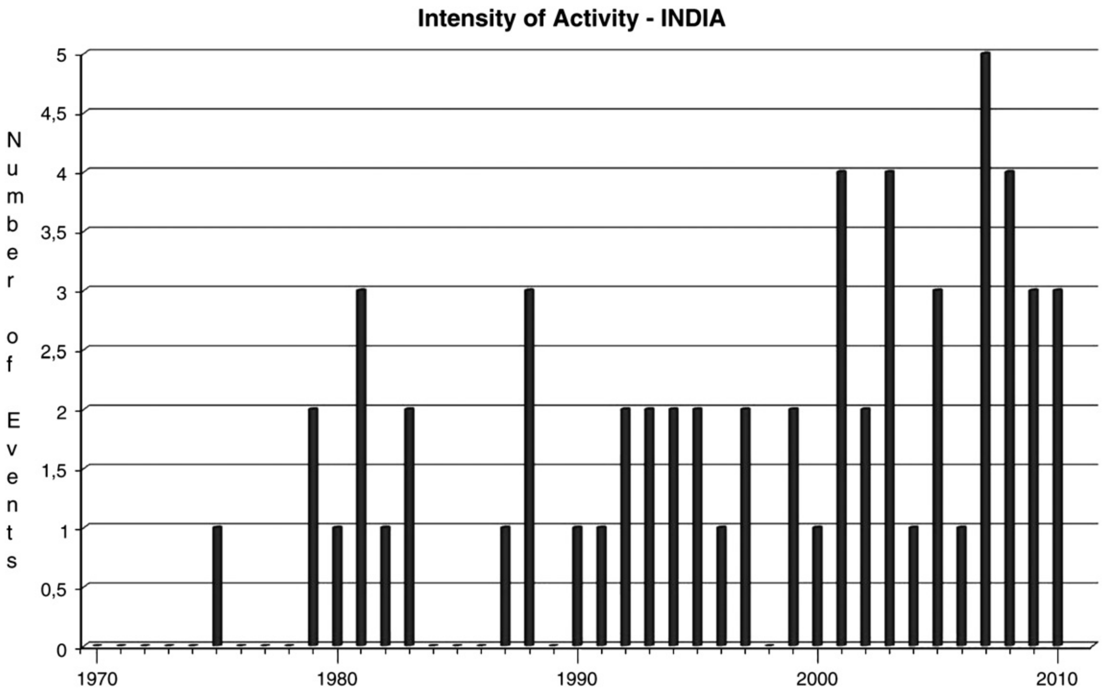

Fig. 6. Space-related intensity of activity for India in the time span 1930–010.

Fig. 7. Space related intensity of activity for the USA and USSR/Russia in the time span 1930–2010.

investment in the sector and the escape of skilled labor to other sectors of the economy that offered better wages, such as electronics and automobiles. Russia's space budget has then shrunk to about 5% of what it was in the 1980s, resulting even in severe difficulties in maintaining its basic supply operations to the International Space Station.

But after years of decline the Russian space industry is getting significant state subsidies once again, with US$ 3.8 billion earmarked for 2011 [22], or four times the financing in 2005 and on par with spending by China and Japan (see Section 7).

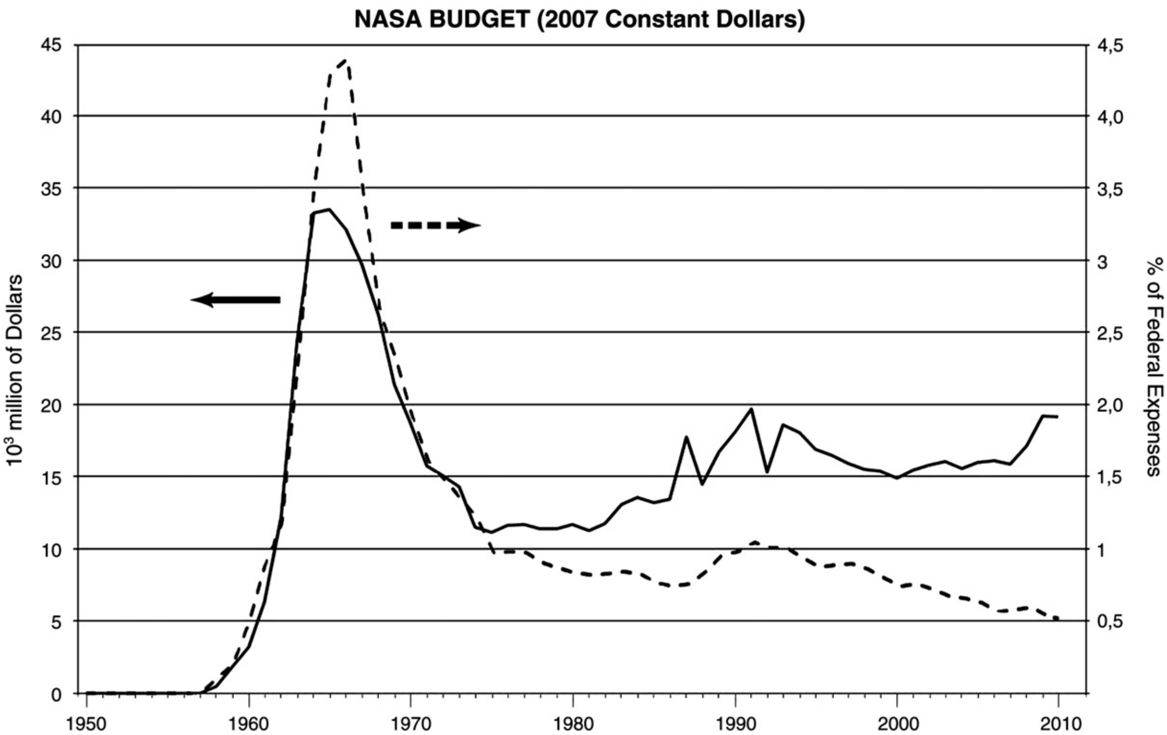

Fig. 8. NASA budget in constant dollars (solid line) and % of US federal spending (dotted line) in the time span 1958–2010.

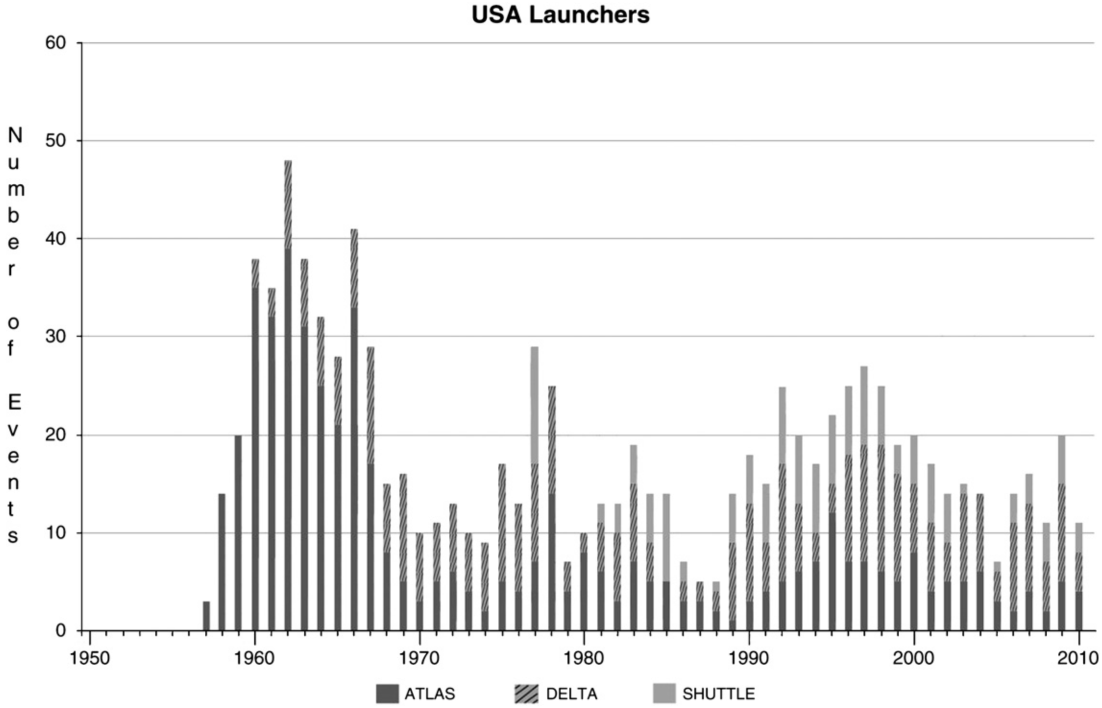

Fig. 9. Historical unfolding of the usage of the launchers Atlas, Delta and Shuttle.

6. The space race and the 4th K-wave

As already pointed out the most striking aspect of the graph pictured in Fig. 1 is its wave-like aspect, which matches perfectly the very well known and classical pictorial representation of the secular succession of K-waves that we can find in several articles and books since the 1980s [4,8,23,24]. In Fig. 11 it is shown the coordinated unfolding of the 3rd and 4th K-waves with the

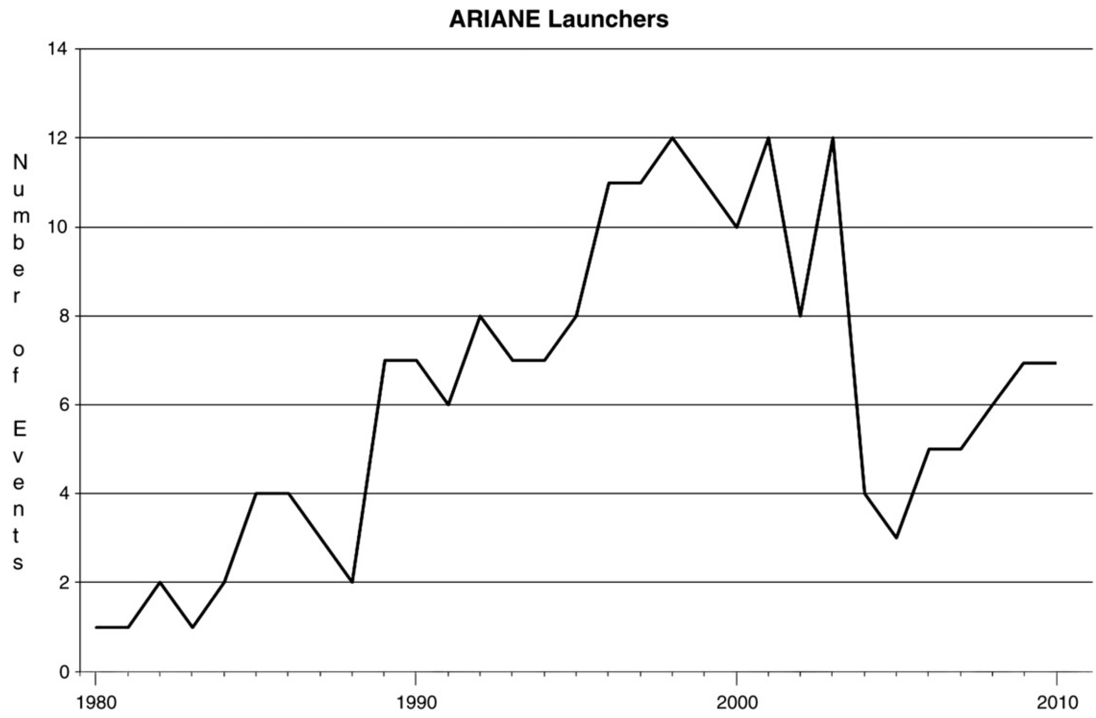

Fig. 10. Historical unfolding of the usage of the European launchers of the Ariane family.

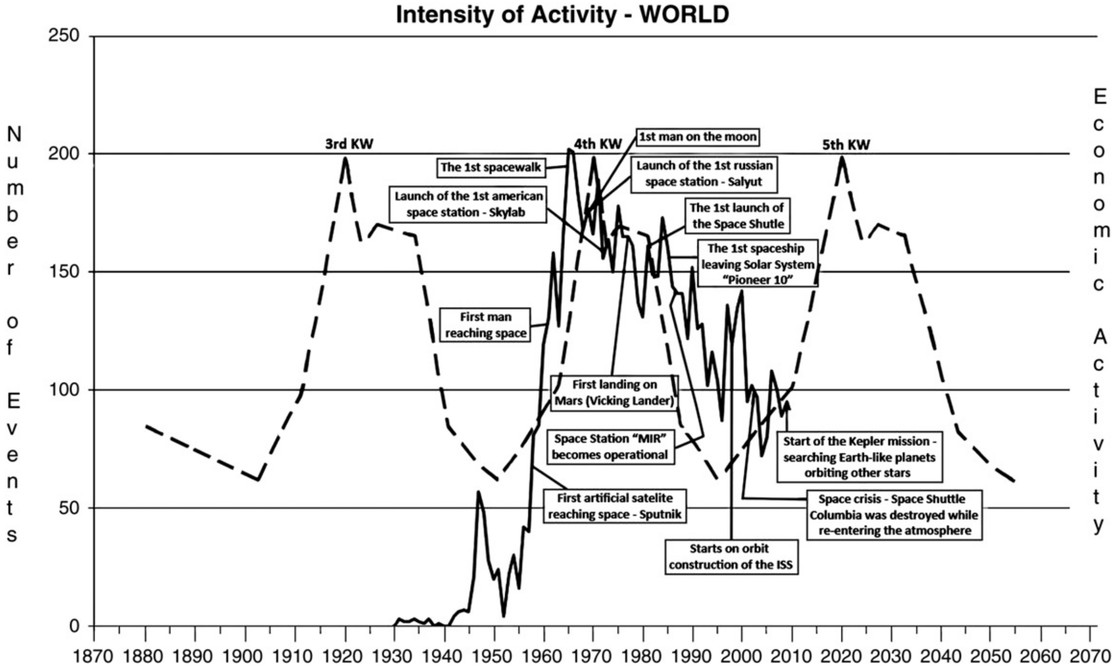

Fig. 11. Coordinated unfolding of the 3rd and 4th K-waves with the historical unfolding of the global space-related intensity of activity as represented in Fig. 1.

unfolding of the global space activities, as well as the main benchmarks in the history of the space endeavor and a projection for the 5th K-wave that will be discussed later in this paper.

This perfect matching between the 4th K-wave and the space activities allows us to draw the first main conclusion of this paper: *the space race was an important outcome of the technosphere consolidated during the fourth Kondratieff wave.*

As we have seen in Table 2 the 4th K-wave has been coined as the Era of Information and Telecommunications, based mainly in the revolutionary advances in electronics and synthetic materials (plastics, fibers, semiconductors). Some new industrial leading sectors emerged with great impetus, as the computers and semiconductors industry, television (TV sets and broadcasters), aeronautics (aircraft manufacturers and airlines), and nuclear (military, energy, and medicine). In a synergistic fashion activities in rocketry, already emerged with WWII as we can see in Figs. 1, 2, and 11, raised spectacularly in the 1950s and 1960s pushed mainly by the military looking for the development of ballistic missiles and observation satellites. But at the same time communication companies began to delve into the still unexplored field of global communications, and again synergistically at least three main sectors of human activities were completely transformed by the advent of rockets and related space activities: military (the menace of global destruction), entertainment (global TV broadcasting) and information exchange (IT technologies).

Undoubtedly the activities of production, launch, and use of satellites represent today the most important share of what is done in space activities, be it for military, meteorological, communications and scientific purposes. Nowadays about 3511 satellites are orbiting the Earth, 1040 of which are still in operation. In Fig. 12 the reader can appreciate the yearly worldwide intensity of activity in the sector of satellites and can still distinguish the total number of satellites launched in a given year from the number of satellites still in orbit (not necessarily operational) as well as from the number of decayed satellites.

There are some aspects worth noting in this figure. First we observe that for almost three decades (1960s until 1980s) there has been an average of 150 satellite launches per year. After 1989 there was a marked decrease in the number of releases, but after 1997 we see a clear recovery in the number of satellites in orbit, which fell sharply once more early in this century. However it is important to note that a recovery can be observed in recent years.

The sharp decrease after 1989 was due to the strong reduction of the space activities of the former Soviet Union after the fall of the Berlin Wall, from an average of 113 satellites per year (from 1970s until 1990s) to about 35 satellites launched per year. The strong peak observed in 1998 was due to the enormous growth in the production of commercial satellites (telecommunications) between 1995 and 2002, from an average of 5 satellites per year to 42, but with a decrease from 2003 to an average of 15 satellites per year.

The general aspect of the upper curve in Fig. 12 does resemble the curve shown in Fig. 1, but however with some minor differences, as for instance regarding the total numbers, which allow us to drawn some important conclusions. In 1965, when both curves reach a peak, the satellites launching activities accounted for about 82% of all space activities, which implies that some other activities were being conducted, especially concerning manned spaceflight.

Comparing, however, the numbers in both curves for 1975 and also for 1985, we found that the quantities involved are equivalent, which allow us to conclude that the activities at this time were focused on actually the launching of satellites. But what about the numbers from the year 1990 onwards, when the number of satellite launches is even higher than the figures for the

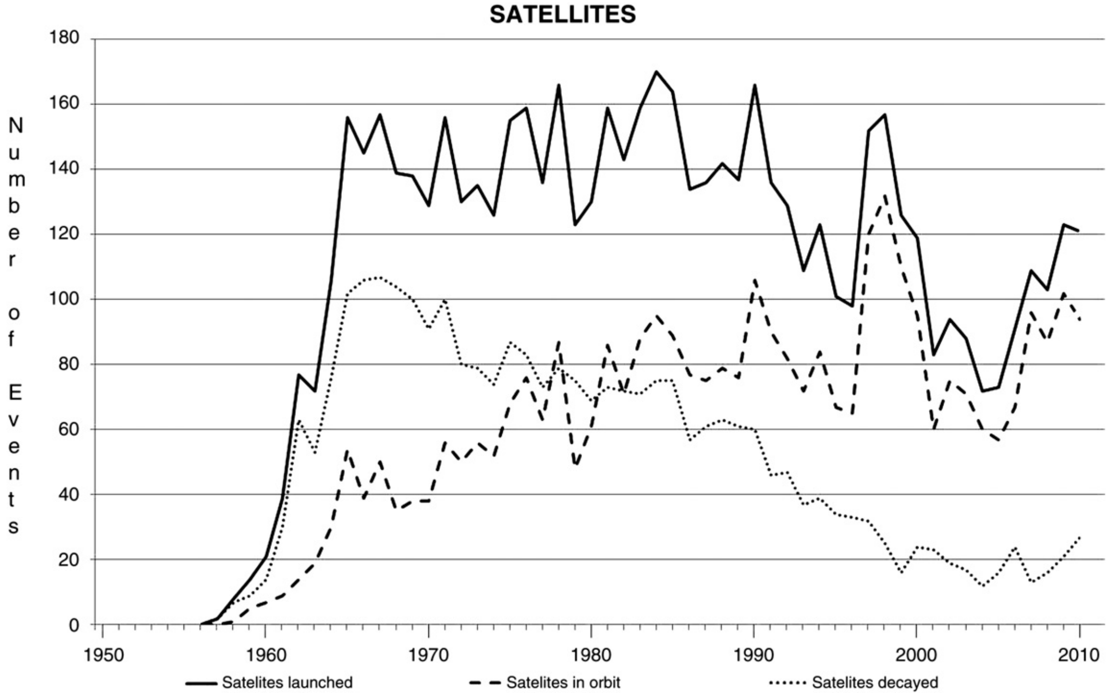

Fig. 12. Worldwide intensity of activity in satellites launches, showing the total number of launches, the number of satellites still in orbit and the number of decayed satellites.

total intensity of activity? Compare for example the peak in 1998 for the number of satellite launches (about 160) with the total intensity of activity in this same year (about 130 events). The same comparison, though involving much smaller numbers, is also valid for more recent years. The answer to this seemingly puzzling question is quite simple: from the 1990s onwards it started the use of multiple releases, in other words, the same launching vehicle putting into orbit two or more satellites.

In fact this event is quite clear in the histogram of Fig. 13 for the satellites still in operation. In this graph the ever increasing use of smaller satellites in the last two decades can be observed. For this reason a classification of satellites by mass category has been developed, most commonly designated as *large* (>1000 kg), *medium* (500 kg to 1000 kg), and *small* (<500 kg); *small* satellites are still further classified as *mini* (100 kg to 500 kg), *micro* (10 kg to 100 kg), *nano* (1 kg to 10 kg), *pico* (0,1 kg to 1 kg), and *femto* (<100 g) [25,26].

Another important aspect to point out is that the satellites average mass launched yearly has remained almost constant as we can infer from the graph in Fig. 14. This curve represents the average of the masses of all satellites launched every year in the last two decades, and despite the large variation of the masses of the satellites currently used, we can observe that the average of these masses remained fairly constant at about 2000–2500 kg. On the other hand, through careful analysis of the available data set, we observe that since 2000 there is a tendency in the use of larger commercial satellites, carrying more fuel and therefore more autonomy, able to keep operating longer, as can be observed in Fig. 15.

As we have seen in the analysis and discussion on the results of Figs. 12 and 13 it is evident that there is a clear transition occurring in the middle 1990s that was mainly a consequence of the leverage provoked by the activities of private enterprises entering strongly in the global play of launching commercial telecommunications satellites. This transition is straightforwardly evident in the graph shown in Fig. 16, in which we can appreciate the substitution process of military missions in space, which were being replaced by a growing number of civil missions.

Currently only a handful of nations, individually or in consortia, have the rocket technology to launch satellites into orbit, and there has not been a significant entry of new players in this dispute in the past two decades; however, it is expected that this picture will change dramatically in coming years as will be seen in the next section. Table 3 summarizes a list of major launch vehicles currently in use and/or ready for use, capable of launching satellites in GEO and/or GTO orbits [27]. As can be seen it is a mixture of old and new vehicles, some still from the 1960s (like the Russians Soyuz U, Kosmos 3M, Proton K, Molniya), letting the idea of little progress in the field of rocket propulsion technology. We have eliminated from our original listing the presence of the most robust and heavy launch vehicle, the US' Space Shuttle (24 tons GEO capacity, 3.8 tons LEO capacity, over 2000 tons total mass), for as it is known the thirty-year old Space Shuttle Program (reusable vehicles) that has been disabled in July 2011 with the last flight of the shuttle Atlantis, due to its high operating cost (more than US$ 600 million each launch operation). The continuity of operations of the International Space Station will now be dependent on the use of non-reusable vehicles until it is made possible some of the projects for reusable vehicles currently under way.

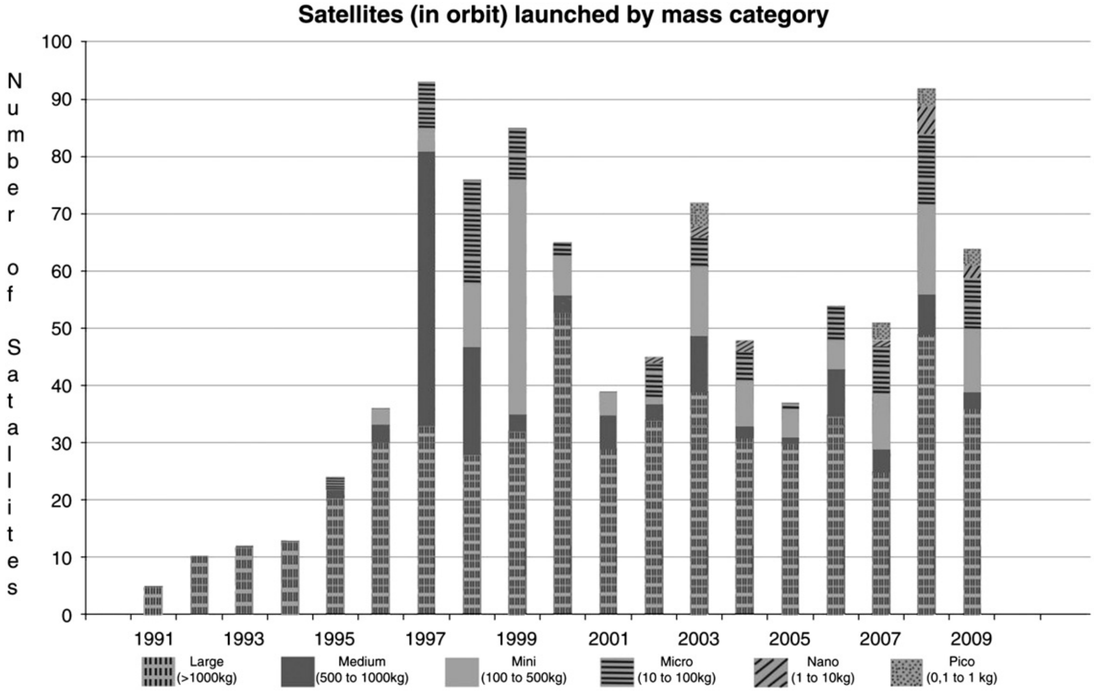

Fig. 13. Histogram of the number of satellites in orbit by mass category (worldwide).

In December 2008, NASA announced the selection of SpaceX's Falcon 9 launch vehicle and Dragon spacecraft to resupply the International Space Station (ISS) when the Space Shuttle retires. Dragon is a free-flying, reusable spacecraft being developed by SpaceX under NASA's Commercial Orbital Transportation Services (COTS) program. A project initiated internally by SpaceX in 2005, the Dragon spacecraft is made up of a pressurized capsule and unpressurized trunk used for Earth to LEO (6 tons payload) transport of pressurized cargo, unpressurized cargo, and/or 4 to 7 crew members. Dragon is designed for water landing under parachute for ocean recovery and is planned to be fully operational in 2012.

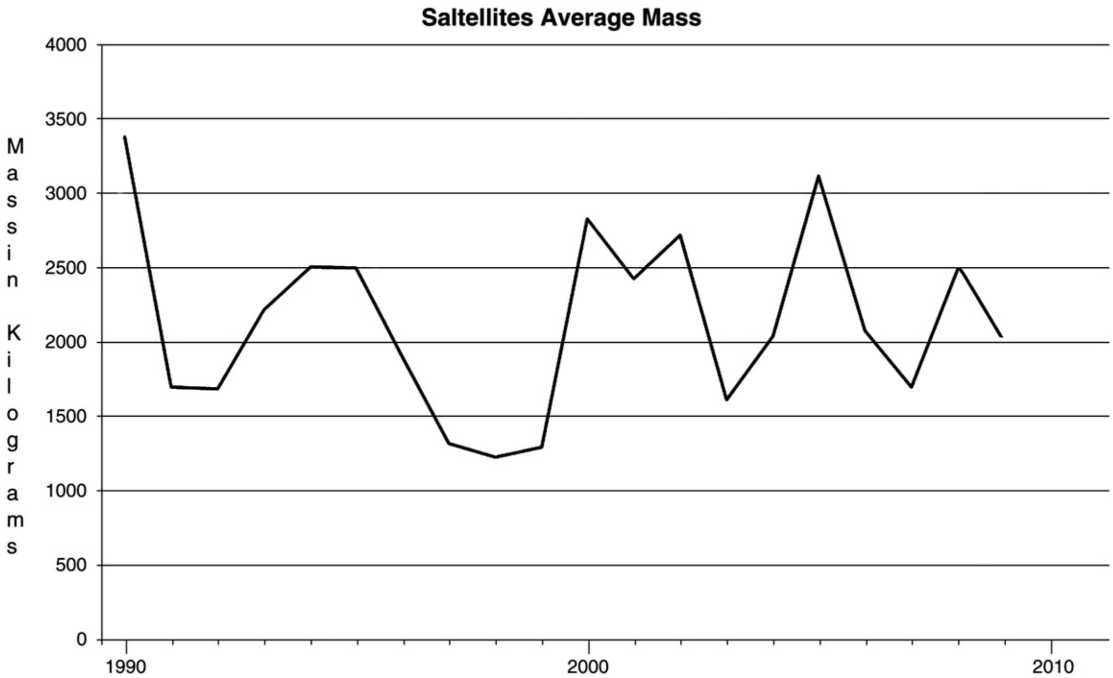

Fig. 14. Average of the masses of all satellites launched every year in the last two decades.

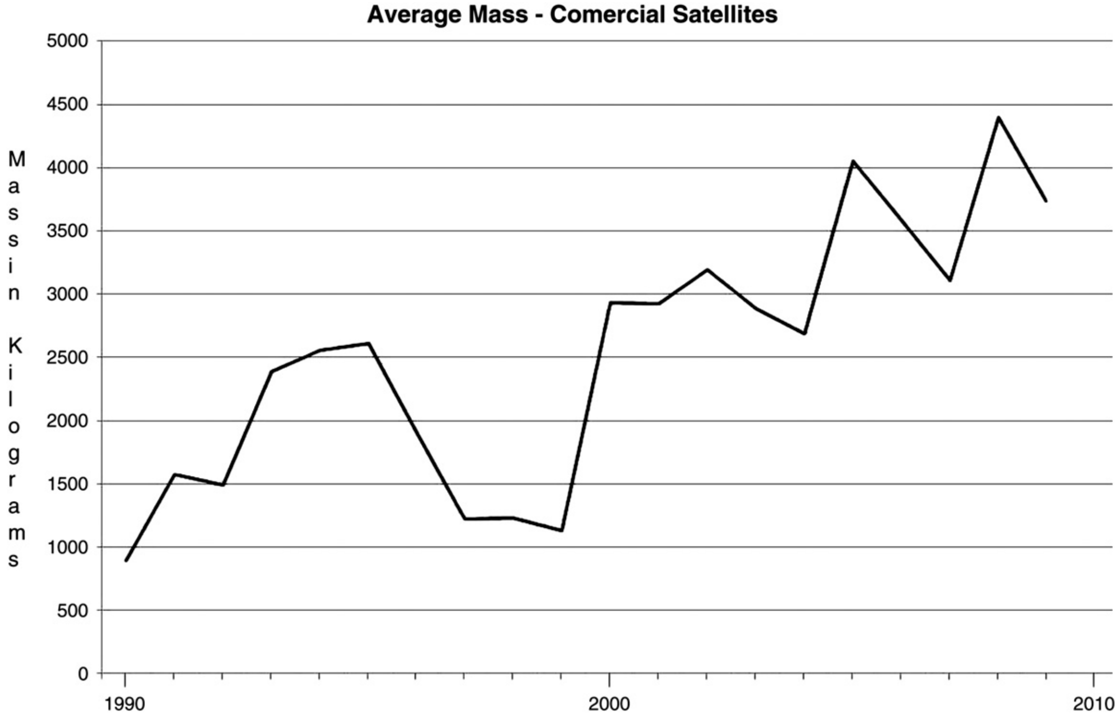

Fig. 15. Average of the masses of commercial satellites launched every year in the last two decades.

It is worth to point out that the use of this type of recoverable capsule-like spacecraft means a slight decline from what was imagined in the early 1980s as reusable spacecraft like the Space Shuttle, a spacecraft with flight autonomy to return to Earth like a manned airplane. We have here again a kind of backlash in the human adventure into space as a result of budget cuts, looking for cheaper ways to perform in-orbit operations and obviously also lack of progress in means of propulsion.

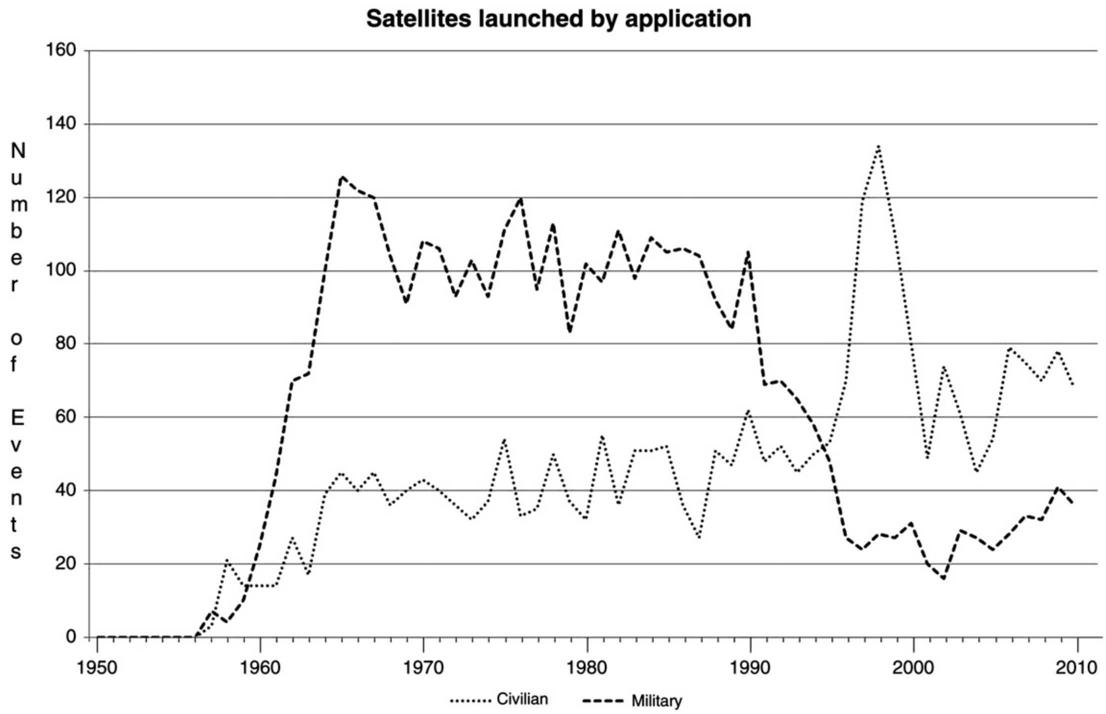

Fig. 16. Substitution process of military missions in space replaced by a growing number of civil missions, evidencing a crystal clear transition in the middle 1990s.

Table 3
List of the main launch vehicles currently in use [27].

Country	Launch vehicle (category)*	Capacity LEO (Kg)	Capacity GTO (Kg)	First flight	Success rate	Stages	Mass (kg)	Cost per launch (million)
China	Long March 2 (medium)	3850–8400	1400	1975	100%	2–3	233,000–464,000	$30
China	Long March 3 (medium to mid-heavy)	6000–11,200	2600–5100	1994	93%	3	241,000–425,800	$47.5–$60
China	Long March-4B (medium)	4200	1500	1999	100%	3	249,200	$30
USA	Delta II (medium)	2700–6100	900–2170 kg	1989	98%	3	151,700–231,870	$45
USA	Delta IV (medium to heavy)	8600–22,560	3900–12,980	2002	94%	2	249,500–733,400	$70
USA	Atlas V (medium to heavy)	9750–29,420	4750–13,000	2002	96%	2	431,870	$90
USA	Pegasus XL (small)	443	–	1994	88%	4	23,130	$20
USA	Falcon 1e (small)	1010	–	–	0%	2	35,180	$11
USA	Taurus XL (small)	1458	–	1994	67%	4	77,000	
USA	Minotaur (small)	310–1730	–	2000	100%	4	86,300	$50
Europe	Ariane 5ES (heavy)	21,000	7575	2008	100%	2	760,000	$120
Europe	Ariane 5ECA (heavy)	20,000	10,000	2002	93%	2	780,000	$120
India	PSLV (medium)	3250	1050	1993	88%	4	294,000	$16
Israel	Shavit (small)	350	–	1995	50%	4	50,000	$15
Israel	Shavit 2 (small)	800	–	2007	100%	4	70,000	$15
Russia	Soyuz U (medium)	7000	–	1963	97%	2	313,000	$35
Russia	Soyuz FG (medium)	7100	–	2001	100%	3	308,000	$40
Russia	Soyuz 2 (medium)	7900	–	–	78%	3	305,000	$40
Russia	Kosmos 3M (small)	1500	–	1967	95%	2	109,000	$12
Russia	Proton K (med-heavy)	19,760	1880	1967	92%	4	687,530	$105
Russia	Proton M (heavy)	21,000	2920	1999	94%	4	712,800	$105
Russia	Molniya M (small)	1800	1600	1964	94%	3	305,000	$35
Russia	Angara	1650–40,500	7300	2005	?	3	149,000–478,000	$40
Russia	Rockot (small)	1850	–	1994	94%	3	107,000	$14
Russia/ Ukraine	Dnepr (medium)	2650	500	1999	94%	3	211,000	$11
Ukraine / Russia	Zenit 2 (mid-heavy)	13,740	–	1985	84%	3	458,900	$60
Ukraine	Zenit 3SL (mid-heavy)	–	5250	1999	87%	3	471,000	$85
Ukraine	Cyclone 4 (medium)	5860	1560	–	0%	3	198,000	$40
Japan	H-IIA (medium)	9940	5800	2001	100%	2	348,250	$75
Japan	H-IIB (mid-heavy)	19,000	8000	2009	100%	2	531,000	–
Brazil	VLS-1 (small)	250	–	1997	0%	4	50,000	$8
Brazil	VLSM (small)	67	–	–	0%	4	16,000	$4

(*)Launch vehicle by category

Category	Payload lift capacity to LEO
Small	<2000 kg
Medium	≥2000 kg <10,000 kg
Mid-heavy	≥10,000 kg <20,000 kg
Heavy	>=20.000 kg

GT0 — Geostationary transfer orbit; LEO — Low Earth orbit

7. The new space race: the 5th K-wave

The early years of space exploration provided the world with a simple narrative: a life-and-death struggle between the Soviet Union and the United States — one that climaxed on the Moon in July 1969. Barely noticed, other countries had already begun to build their space programs. Japan launched its first satellite in February 1970, followed by China (April 1970) and then India (1980). Israel followed in 1988. Earlier (1965), France inaugurated what evolved into Europe's extensive space program.

The opening years of the 21st century provided a more complex narrative for space exploration. China joined the space superpowers of Russia and the United States in achieving manned spaceflight (2003). Not long after, China, India, and Japan launched moon probes (2007–2008). New countries began to invest substantial resources and energy in space development: Brazil developed its own launcher, as well as an Earth resources observation program with China; at a time of some political and military tension, Iran put its first satellite in orbit (February 2009); Israel developed its space program principally to fulfill intelligence purposes; North Korea, whose path to space has been idiosyncratic and difficult to interpret; and South Korea, a recent but enthusiastic user of space technologies for economic development.

The statement in the previous paragraph is better translated through the graph of Fig. 17 where it is shown the development in founding space agencies all over the world (yearly and accumulated). Today we have about 60 nations with their own space agencies, 30 of which were created in the last two decades (1991–2010). About 20% of these space agencies have a military-inspired origin, as can be inferred from the list available at our institutional website [20]. The creation of space agencies grew at a rate of 0.88 per year between 1955 and 1990, while between 1991 and 2002 was recorded an increase of 2.8 per year.

As we have seen in the two previous sections there are strong signals of changes in space-related activities that point not only to the important role to be played by the new actors (countries) entering the stage, but also to new characteristics of these activities that will define the future scenario of a renewed space race.

In despite of the worldwide financial crisis that started in 2008 the budgets of the main actors on the stage of space activities still present very significant figures. The USA still leads the investment in space exploration — the NASA budget earmarked for 2011 is about US$ 19 billion, to which we should add the DoD space budget. However, tracking the DoD space budget is extremely difficult, but figures released for the last few years allow to estimate an yearly space budget of about US$ 20 billion [28]. More conservative numbers for DoD space budged (FY 2012) were recently announced, about US$ 10 billion [29], looking for maintaining US supremacy in space.

Although very difficult to estimate, China's space budget for 2011 may be as high as US$ 6 billion [30], with some media estimating a lower figure of about US$ 3 billion [31]. More reliable figures we can get for ESA in 2011 (US$ 5.43 bi) [32] and India (US$ 1.5 bi) [33].

The space race that unfolded during the 4th K-wave was a natural growth process whose main aspects we have already discussed on in the preceding sections. In order to speculate about what will come next in space-related activities let's apply the logistic approach on the complete data set for the worldwide intensity of activity.

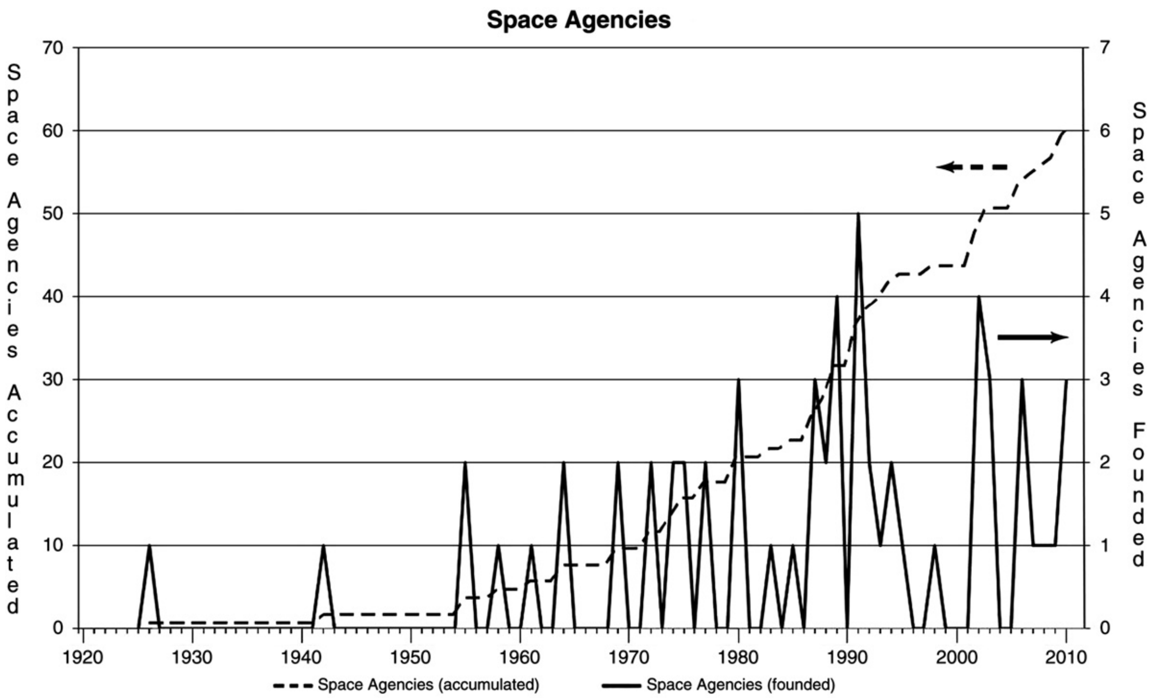

Fig. 17. Yearly and accumulated founding of space agencies all over the world in the time span 1930–2010.

Fig. 18 presents the cumulative counting of the worldwide intensity of activity: the solid line for the complete set of events presented discretely (yearly) in Fig. 1 and the dashed line for the complete set of events regarding the launching of all satellites already presented discretely (yearly) in Fig. 12.

As can be seen both curves present the typical S-shaped pattern of logistic growth processes, displaced by just a couple of years, typically 5 to 8 years in the 1960s and 1980s respectively, and 10 years after the 1990s, but in average we can state that both have followed the same growth pattern.

The solid line shows some evidence of a bi-logistic growth pattern, being possible to fit a first logistic curve to the early years of the space endeavor (before the 1960s). But ignoring this first push in rocketry activities the general aspect of both curves is one of an already completed growth process that has saturated and being replaced by a new growth process. This conclusion is unequivocally demonstrated in the logistic fits presented in the next set of figures, Figs. 19 and 20 for the complete set of space-related events and Figs. 21 and 22 for the launching of satellites. Figs. 20 and 22 are the same as Figs. 19 and 21, but plotted linearly using the Fisher–Pry logit transform [8].

Both fittings show very similar results, evidencing natural growth processes with almost the same characteristic time Δt (time to grow from 10% until 90% of the complete growth — 43 years for the total activity and 40 years for satellites) and almost the same growth rate (10%/year for the total and 11%/year for satellites). The T_0 (year when 50% of the complete growth was reached) happened as of 1980 (1979 for the total and 1982 for satellites).

Thus, both the overall growth curve as the curve for the launch of satellites point to processes that saturated (90%) around the beginning of this century (between 2002 and 2003). In all graphs the outline of the beginning of a new process of growth is quite evident, particularly in the graphs of Figs. 20 and 22 (Fisher–Pry plots), in which there is most clearly demonstrated the deviation of the points up to the straight line. Coincidently 2003 is a benchmark year of the new space race, when on 15th October China became only the third country in the world to put its own astronaut into orbit, circa 40 years after the predecessors Russia (1961) and USA (1962). The reader should keep in mind that 40 years is exactly the characteristic time found in our logistic fits, and also matches satisfactorily the typical duration of a K-wave.

All in a nutshell, *there are signals that a new space race has already started*.

At this point we can pose the questions: what shall be this next space race? Who shall be the main actors? What is the most likely scenario for space activities that will unfold over the next two or three decades? As demonstrated earlier in this article, space activities are strongly dependent on a very heavy capital investment, and the global economic system is undergoing a very critical and turbulent period of transition, as were the periods of transition from previous K waves. The answers to these questions are not trivial because they still depend on the further unfolding of the complex global economic system and the further conduct of the geopolitical changes in motion.

The above questions are intimately related to another set of questions regarding K-waves: what is coming with the already started fifth K-wave? Which are the leading sectors? Which country will lead it economically? Devezas [34] has recently performed an in deep analysis of these questions and has demonstrated that we are witnessing the entrenching of a new Era, a

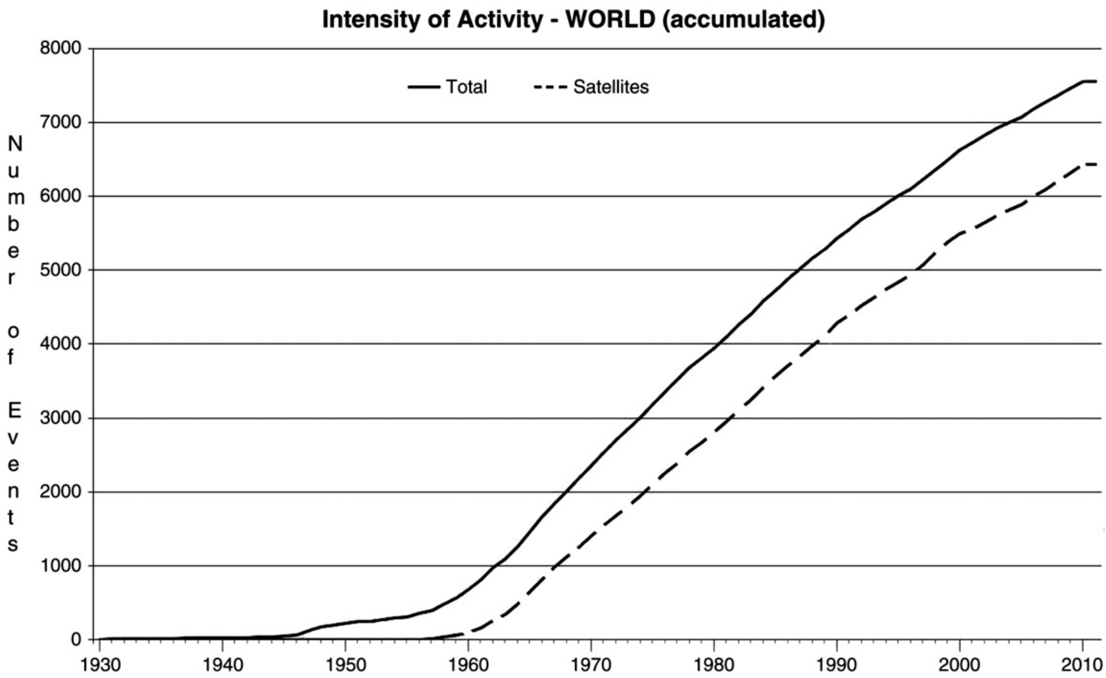

Fig. 18. Accumulated worldwide space-related intensity of activity in the time span 1930–2010 for all events (total) and satellites.

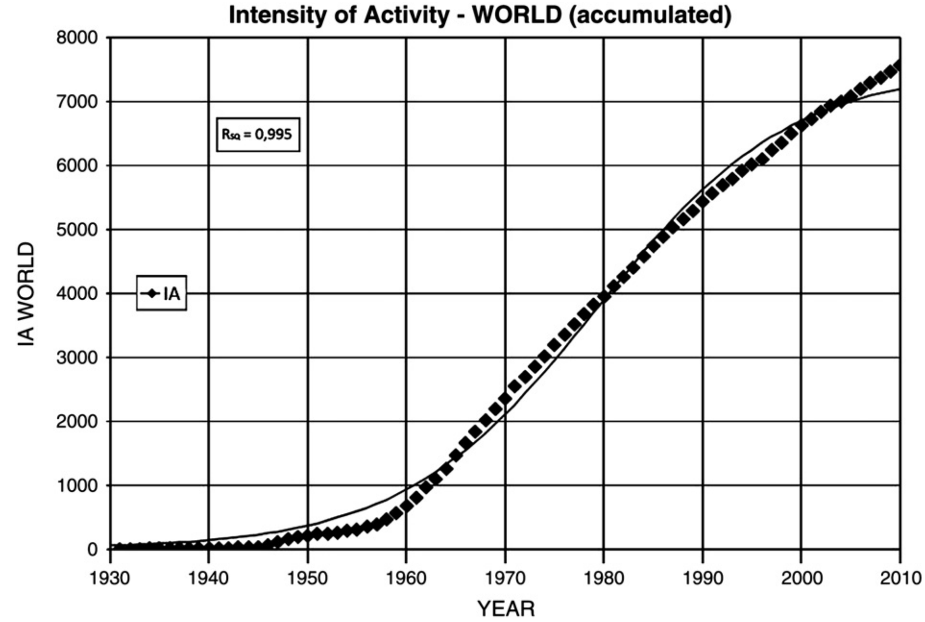

Fig. 19. Logistic fit for the accumulated worldwide space-related intensity of activity in the time span 1930–2010 ($R_{sq}=0.995$).

true Age of Transition, with the superposition of the transition phase of some different co-evolutionary processes of the World System. This overlapping will result in a completely new socioeconomic and geopolitical scenario whose contours are difficult to predict. It does not belong to the scope of this paper to speculate on the details of this complex transition, but the current world economic and political landscape allow us to envision that a great global transformation is underway, multipolar in character, evidencing a clear tendency for an eastwards displacement of power [34].

Such multipolarity as well as the eastwards displacement of power is also very clear from our analysis in Section 5 (Mapping the space race). In despite of the complexity of the present K-wave transition phase our common sense still allows perhaps that some reasonable speculations about future space-related activities can be made.

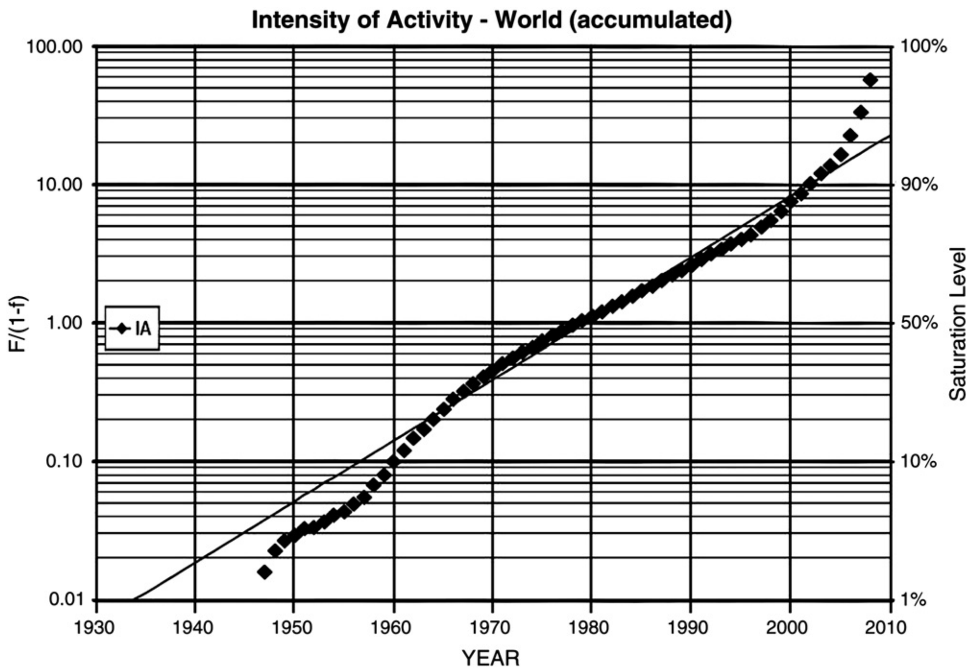

Fig. 20. Fisher–Pry plot for the accumulated worldwide space-related intensity of activity in the time span 1930 – 2010.

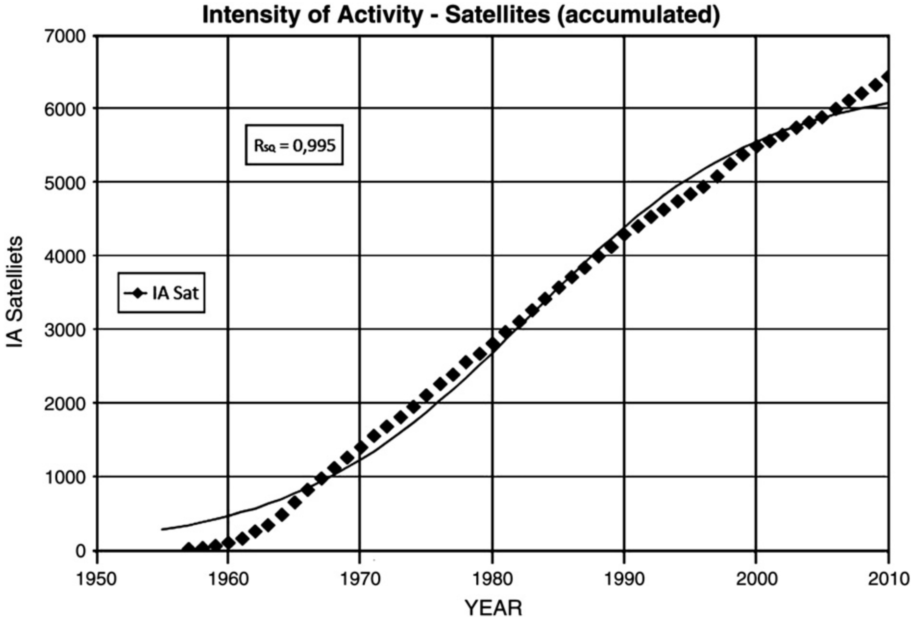

Fig. 21. Logistic fit for the accumulated worldwide satellites launching intensity of activity in the time span 1930–2010 ($R_{sq} = 0.995$).

If the K-wave pattern is to be maintained we might still have ahead at least one decade, or perhaps two, of rampant worldwide economic growth, as Devezas [13] has recently suggested. If this comes to be true the realization of most of the ambitious planned tasks of the nations nowadays involved in space activities will be possible. Within this scenario we will have the return of manned flights to the Moon and very probably humans will walk on Mars until 2020.

If, on the other hand, the K-wave pattern is to be destroyed or profoundly affected as a consequence of the complex transition phase already commented on above, resulting in a deepening and/or severe worsening of the international financial crisis as has been widely speculated in the media, these ambitious Moon–Mars tasks should be postponed for some decades ahead.

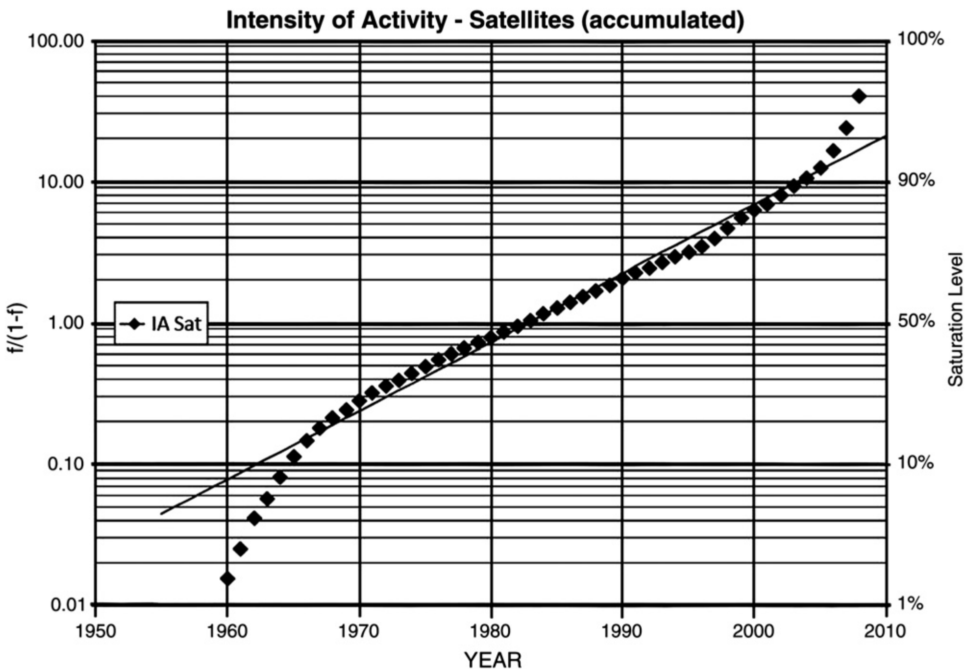

Fig. 22. Fisher–Pry plot for the accumulated worldwide satellites launching intensity of activity in the time span 1930–2010.

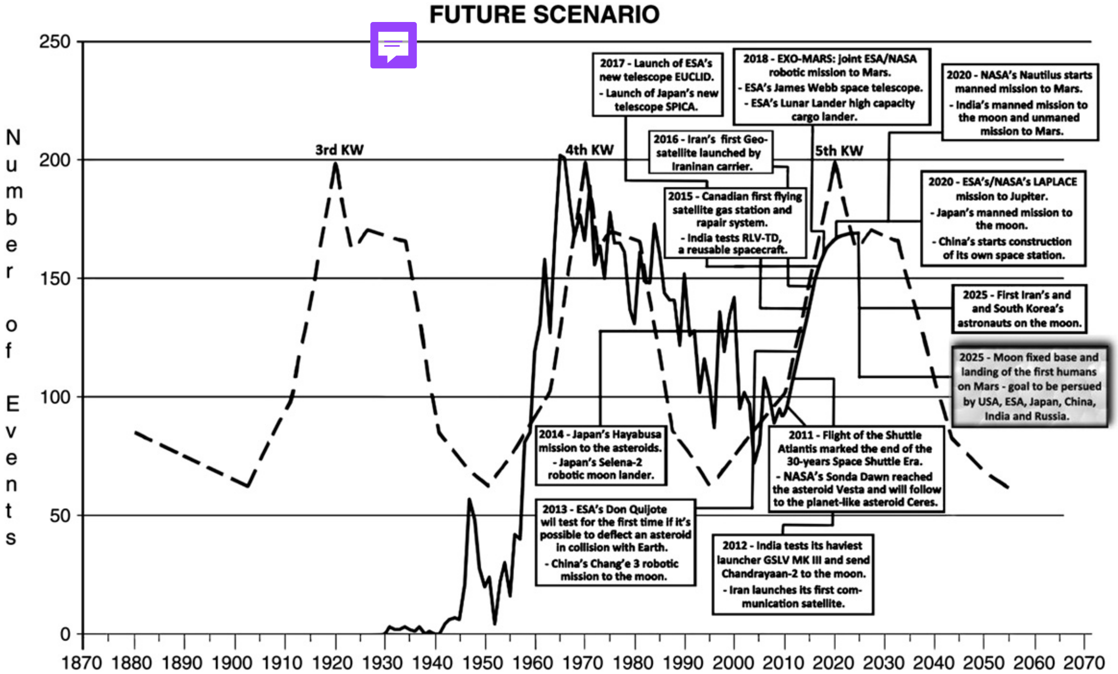

Fig. 23. Future scenario for space activities based on ongoing activities and/or planned activities for the next two decades.

8. Scrutinizing the near future

But let's navigate through a 'muddling through' or middle course scenario, not so optimistic or pessimistic, based simply in the analysis of the current trends. We can take some few points as sure:

1 Whatever the economic scenario to unfold in the coming years human space aspirations were substantially amended in relation to the dreaming scenarios a la 'Space Odyssey' that developed in the years 1950–1960, to which we referred earlier in this paper. Such scenarios were the result of simple linear extrapolations to the future, which, as we have seen, do not work. This is not to say that such kind of space endeavors is completely out of perspective. We are speaking here of our immediate future ahead (let's say a time horizon of about 30 years) and not about a distant future when Star Trek-like adventures can become a reality (as alias was imagined in 1966 by its creator, the screenwriter Gene Goldenberry, a story from the 23th century).
2 Political aspirations are still the main driving force to go to space, as it was in the past, but perhaps slightly different. Of course, during the Cold War both defiant countries have had reasons related to defense issues (launching rockets as a means of mastering the technology of ballistic missiles for instance), but in general it was quite evident the ideological-driven need to show what political system was the most correct, fair and efficient. This latter motivation has lost its meaning in today's world, but the former motivations related to defense have gained a new dimension and is in the process of spreading around the world.
3 The new outer limit of planet Earth, the geostationary orbit, is already tamed by a couple of few countries, and within it the buzz of space activities will continue to grow and fill the national priority list of the countries already present in this part of space as well as of several other new entrants in the space race. Owning a satellite into orbit today is synonymous with national sovereignty and for this reason there is today an international race in this direction, with many nations chasing a place in this privileged zone of space.
4 If on the one hand the rocket launching technology has not progressed significantly, satellite technology (regarding operation systems, capability, supply, maintenance and durability) has evolved a lot, mainly as a consequence of the huge advances in computational capability.

All in one, the above referred new outer limit of planet Earth represents the 4th frontier after land, sea and air and epitomizes today an important arena for dominance and superiority. Like the sea and air before it, this new frontier has become a critical enabling domain for global security-related operations, and undoubtedly most of the near-future space-related activities will concentrate in disputing the dominance (from the part of the leading powers) or at least a place of honor in this arena (from the part of the followers).

The usage of satellites has today a very wide range of purposes, civil and military. Among the civil or non-military purposes we find navigation and communications, Earth observation, weather, help in search and rescue, and science and technology development. And among the military missions we find secure communications, Earth observation, weather, reconnaissance and surveillance, guiding weapons systems, and support for military operations. As we can see there is some overlapping in applications, but the civil/commercial applications are gaining strong relevance, as for instance in the launch of satellites, space tourism, the help in potential natural disaster detection and activities aiming to mitigate the danger of space debris. But we can observe also an increasing trend in the 'dual-use' of satellites, artifacts compliant for both military and civil purposes. Certainly much of financial effort in the forthcoming years will be directed in fine-tuning the efficiency and capability of satellites in this wide range of applications, aiming the dominance of the above mentioned 4th frontier of the planet.

In Fig. 16 we have seen a clear change in the motivation for space missions from military to commercial. This does not mean necessarily a decrease in military missions but instead an important transition in the players in the space race from governments to private companies, which can operate more efficiently and innovate more quickly than government agencies.

In a recent article published in the June 30th issue of the British periodical The Economist [35] it is presented the idea that humanity's dreams of a future beyond this final 4th frontier have largely faded and that the Space Age is coming to the end. The title is meaningful: "Inner space is useful. Outer space is history". The authors were certainly motivated by the recent deactivation of the US' Space Shuttle Program and the diminishing NASA's budget for the incoming years as well as by the turbulence in the global financial system. This article epitomizes the typical pessimistic view so common in times of crisis and transition. The authors underestimate the potential of projects already in development by new entrants in the space race, as China, India and Japan as well as the large number of projects that are still being conducted by NASA and ESA, which can be fully implemented even with the reduced budget planned for the coming years. It is also underestimated the potential use of the inner and outer space for commercial applications, a target that is being pursued by a large number of old and new enterprises and vision-rich entrepreneurs [36].

Space technology is still, as it was, at the higher end of the technology ladder and has a huge effect to other technological developments. Nations and entrepreneurs are today keenly aware of the advantages arising from space activities and are setting ways to exploit these advantages for themselves. It is very well known that with the right mindset budget challenges are the spark for creativity and innovation — this fact is historical and very easy to infer from previous periods of crises and transition that have characterized the historical unfolding of K-waves.

Again, all in a nutshell: the space age is not coming to an end, but instead is prone to a rebirth.

Our results depicted in a series of graphs present a robust evidence of change in the path of development of space-related activities that happened at the dawn of this new century (and is still happening), signaling a new space race, thus opening an important window of opportunity for new entrants in the space race, whether nations or commercial companies.

The strongest feature of this new space race will be a multipolar struggle for dominance in the new external border of the planet Earth, the 4th frontier, whether for political, military or commercial purposes. But the scientific objectives should also continue on the agenda, for we should not forget that the scientific–technological leadership is also a guarantee of political hegemony.

The robotic exploration of the solar system and even of our stellar neighborhood will certainly continue. Numerous projects to launch new astronomical observatories are running, and not just by Americans or Russians. Europe, China, Japan and India have well defined plans for scientific exploration of space and also to put foot on the moon and even on Mars [28]. In despite of serious budget constraints NASA continues his intense scientific exploration of the near space, as is the case of the Juno spacecraft that is heading to Jupiter powered by solar energy, and the Dawn spacecraft, the first one ever planned to orbit two different bodies after leaving Earth, and powered by ionic propulsion, which reached in July 2011 the asteroid Vesta and will follow to the planet-like asteroid Ceres.

One of the anonymous reviewers of this paper drew attention to the fact that the bold statement above about "*the strongest feature of the new space race will be a multipolar struggle for dominance in the new external border of the planet Earth*" is not really well supported, but it is a proposition about world politics (and not K-waves), and forecasts a struggle for "political hegemony" over this new outer limit. He remembers that there is "The Outer Space Treaty" (1967), with over 100 signatories, which prohibits the national appropriation of outer space (including the Moon and other celestial bodies). The reviewer still points out that such "struggle for dominance" and even "space wars", are of course conceivable but, given the high costs involved, and the meagerness of likely rewards, so are cooperative outcomes, as exemplified by the International Space Station (ISS), or plans for "planetary defense".

On the (very welcome) points above raised by the reviewer we would like to place the following observations:

1 When we speak about a "struggle for dominance of the new external border" (the 4th frontier) we are not speaking necessarily of belligerent-like or hostile-like actions, but about actions of peaceful nature as for instance that of positioning in orbit as many satellites as possible, fine-tuning their efficiency and capability in a wide range of applications, that may include surveillance, guiding weapons systems, and supporting military operations.
2 The above referred kind of "dominance" is not prohibited and/or inhibited by any kind of treaty already negotiated between nations because we are dealing neither with 'appropriation' nor with claims for sovereignty; it is just a new kind of space race involving new actors, be them nations aiming a place in this region of the space or enterprises disputing for leadership in communications businesses.
3 The 1967 "Outer Space Treaty" does refer ONLY to placing in orbit nuclear weapons or other weapons of mass destruction, and does NOT refer to conventional weapons; attempts were made in 2001 (Space Preservation Act) and in 2005 (Space Preservation Treaty) to expand the ban of weapons to all kind of weapons (and not only to nuclear and WMDs), but both so far have minimal success [37].
4 International cooperation is indeed a reality, but for the time being it seems restricted only to the construction and use of the ISS and plans for "planetary defense" in case of some kind of menace coming from the outer space (as for instance the impact of asteroids). It has been widely publicized the independent plans from USA, Russia, China, India, Japan, and even Iran and South Korea, to reach the Moon and /or Mars before 2025, and very probably the return to the Moon or the first steps of humans on Mars will be a *political feat* of some of these countries in the near future. At the time we were writing these lines Russia failed to repair its spacecraft Phobos-Grunt launched on November 9th aiming to reach Mars' moon Phobos in early 2013 (they have had

troubles in controlling the spacecraft soon after the launching, it remained in Earth's orbit instead to take its way to Mars, and will fall on Earth in early 2012). With this note we intend just only to show that attempts to reach other bodies of the solar system are still a goal being pursued by independent countries. Few cooperative outcomes are expected for the next few years and may be considered as exceptions, as is the case of the ESA/NASA's joint missions EXO-MARS and Viking (to Jupiter).

Closing this article it is presented in Fig. 23 a picture of a possible future scenario for space activities during the unfolding of the 5th K-wave, covering only the next two decades. Trying to foresee beyond this time horizon is certainly a useless activity, with very little chance of success.

9. Conclusions

Analyzing the worldwide evolving scenario of space-related activities during the last eighty years under the framework of the succeeding K-waves and applying some technological forecasting tools, namely the logistic analysis, technological surveillance and intensive data mining we can conclude that *we are presently witnessing the birth of a new space race*, multipolar in character, and very different from the dreaming-like scenarios imagined by most futurists and science fiction writers of the 1960s.

Our main conclusions and characteristics of this renewed space race are listed below:

1 The first space race (1950s until 1990s) was an important outcome of the technosphere consolidated during the fourth Kondratieff wave, in the same vein as aeronautical activities were an important outcome of the technosphere consolidated during the 3rd K-wave. The matching between the 4th K-wave and the wave-like behavior of the worldwide space-related intensity of activity in the same time span is perfect.
2 Neither aeronautics (in the 3rd-K) nor space activities (in the 4th-K) constituted the leading sectors of these preceding K-waves, but were undoubtedly very important synergistic effects of enabling technologies emerged during each of these preceding socioeconomic long waves.
3 Space technology constitutes a very intensive capital consuming activity and the synergistic effects of the technological developments necessary for its full deployment 'hits and heats' in almost all other sectors of human socioeconomic development. For this reason, futurists in the 1960s and 1970s failed by large in constructing reliable space flight scenarios for the dawn of the 21st century.
4 The space race that has characterized the 4th K-wave was a natural growth and learning process that saturated around the beginning of this century (between 2002 and 2003). Our logistic trend analysis reveals that a new natural growth process is probably under way, or in another words, there are signals that a new space race has already started.
5 As a rule that we can learn from the past, this transition to a new natural growth process constitutes an excellent window of opportunity to new entrants in the space race. This renewed space race, still motivated by the same geopolitical reasons as the previous one, but in no way of ideological character, will be concentrated in the hegemonic dispute for the new outer limit of planet Earth, the geostationary orbit, which is already tamed by a couple of few countries.
6 Within this new 4th frontier of planet Earth the buzz of space activities will continue to grow and fill the national priority list of the countries already present in this part of space as well as of several other new entrants in the space race.
7 Owning a satellite into orbit today is synonymous with national sovereignty and for this reason there is today an international race in this direction, with many nations chasing a place in this privileged zone of space.
8 This new space race is providing a more complex narrative for space exploration. China joined the space super-powers of Russia and the United States in achieving manned spaceflight (2003). Not long after, China, India, and Japan launched moon probes (2007–2008). New countries began to invest substantial resources and energy in space development.
9 The above mentioned window of opportunity is presently being explored not only by nations as new entrants, but also by private enterprises and vision-rich entrepreneurs and we can state that in the not very distant future space activities will be also under control of private enterprises, just as aviation activities are no longer an activity under the exclusive control of the state and now constitute an important and giant segment of business.
10 Whatever the economic scenario to unfold in the coming years robotic exploration of the solar system and outer space will continue, and this time pursued also by a couple of the new actors in the space race, and the return of humans to the lunar surface around 2020 is perfectly predictable and achievable.

Acknowledgments

Funding from the National Council for Scientific and Technological Development (CNPq — Brazil, research grant no. 55998/2010-7, Project Prospecta) is gratefully acknowledged. Author Tessaleno Devezas wishes to thank Dr. Carlos Alves Cairo, Head of the Materials Division (AMR–IAE–DCTA, São José dos Campos, SP, Brazil) and Dr. Francisco Cristovão Lourenço de Melo, Supervisor of the Project Prospecta, for the kind invitation and opportunity to stay with the AMR staff during his sabbatical absence from the University of Beira Interior, the period during which this paper was written. Tessaleno Devezas is also indebted to his students Alexandra Couto and Radu Godina, from the University of Beira Interior (Portugal), for collecting the first data sets that enabled the start of this research.

References

[1] A concept originally proposed by Devezas in: T.C. Devezas, The impact of major innovations: guesswork or forecasting, J. Futures Stud. 1 (2) (1997) 33–50.
[2] R.E. Albright, What can past technology forecasts tell us about the future, Technol. Forecast. Soc. Change 69 (2002) 443–464.

[3] H. Kahn, A. Wiener, The Year 2000, A Framework for Speculation in the Next Thirty-Three Years, MacMillan, New York, 1967.
[4] T. Devezas, H. Linstone, H. Santos, The growth dynamics of the internet and the long wave theory, Technol. Forecast. Soc. Change 72 (2005) 913–935.
[5] G. Modelski, http://faculty.washington.edu/modelski/IPEKWAVE.html.
[6] N.D. Kondratieff, Die LangenWellen der Konjuntur, Arch. Sozialwiss. Sozialpolitik 56 (3) (1926) 573–609 (and N.D. Kondratieff, The World Economy and its Conjunctures During and After the War, International Kondratieff Foundation, Moscow, 2004 (!rst English translation of the original from 1922)).
[7] J.A. Schumpeter, Business Cycles: A Theoretical, Historical, and Statistical Analysis of the Capitalist Process, McGraw-Hill, London, 1939 (2 vols.).
[8] T. Devezas, J. Corredine, The biological determinants of long wave behavior in socioeconomic growth and development, Technol. Forecast. Soc. Change 68 (2001) 1–57.
[9] G. Modelski, W. Thompson, Leading Sectors and World Powers: The Coevolution of Global Economics and Politics, University of South Carolina Press, Columbia, 1996.
[10] T. Devezas, G. Modelski, Power law behavior and world system evolution: a millennial learning process, Technol. Forecasting Soc. Change 70 (2003) 819–859.
[11] C. Marchetti, Fifty-year pulsation in human affairs, futures 17 (1986) 376–388, and society as a learning system — discovery and innovation cycles revisited, Technol. Forecast. Soc. Change 18 (1980) 267–282.
[12] T. Devezas, J. Corredine, The nonlinear dynamics of technoeconomic systems: an informational interpretation, Technol. Forecast. Soc. Change 69 (2002) 1–57.
[13] T. Devezas, Crisis, depressions, and expansions: global analysis and secular trends, Technol. Forecast. Soc. Change 77 (2010) 739–761.
[14] T. Devezas, G. Modelski, The Portuguese as system builders in the XVth–XVIth centuries: a case study on the role of technology in the evolution of the world system, Globalizations 3 (4) (2006) 503–519.
[15] J.N. Rodrigues, T. Devezas, *Pioneers of Globalization, Why Portugal Surprised the World*, Centro Atlântico, V.N. Famalicão, November 2007 (1st ed.), December 2009 (2nd ed.).
[16] Researched websites: http://claudelafleur.qc.ca/Spacecrafts-index.html; http://www.satbeams.com/; http://www.n2yo.com/; http://space.skyrocket.de/doc_sdat/; http://celestrak.com/satcat/boxscore.asp; http://www.planet4589.org/space/jsr/jsr.html; http://www.russianspaceweb.com/; http://www.spacehorizons.com/; http://www.astronautix.com; http://www.spaceline.org/history/3.html; http://www.geocities.com/CapeCanaveral/launchpad/1921; http://www.satsig.net/sslist.htm; http://www.china.org.cn/english/features/cslc/139839.htm; http://www.aerospaceguide.net/space/2011.html; http://www.spaceandtech.com/spacedata/elvs/zenit_specs.shtml; http://www.satelliteonthenet.co.uk/index.php/launch-schedule.
[17] B. Harvey, China's Space Program, Springer/Praxis Pub, Chichester, UK, 2004.
[18] B. Harvey, H.H.F. Smid, T. Pirard, Emerging Space Powers, Springer/Praxis Pub, Chichester, UK, 2010.
[19] E. Seedhouse, The New Space Race — China vs. the United States, Springer/Praxis Pub., Chichester, UK, 2010.
[20] http://www.iae.cta.br/prospecta.
[21] An assessment of the International Science and Technology Center: Redirecting Expertise in Weapons of Mass Destruction in the Former Soviet Union, Office of International Affairs (OIA), The National Academies Press, Washington D.C, 1996.
[22] http://www.federalspace.ru/main.php?lang=en&id=2&nid11156(retrieved June 13th 2011).
[23] E. Mandel, Long Waves of Capitalist Development: The Marxist Interpretation, Cambridge Univ, Press, London, 1980.
[24] N.H. Mager, The Kondratieff Waves, Praeger Pub, New York, 1987.
[25] http://www.isprs.org/proceedings/XXXV/congress/comm4/papers/428.pdf.
[26] G. Konecny, Small Satellites — A Tool for Earth Observation?, XXth ISPRS Congress, 12–13 July 2004, Instambul, Turkey.
[27] S.J. Isakowitz, J.B. Hopkins, J.P. Hopkins Jr., International Reference Guide to Space Launch Systems, American Institute of Aeronautics and Astronautics, Reston, Va., 2004
[28] http://www.fas.org/sgp/crs/space/RL33601.pdf.
[29] http://comptroller.defense.gov/defbudget/fy2012/FY2012_Budget_Request_Overview_Book.pdf.
[30] http://www.oecd-ilibrary.org/economics/the-space-economy-at-a-glance-011_9789264111790-en.
[31] http://www.spacefoundation.org/research/TSR07.php?id=419.
[32] http://www.spacenews.com/civil/110121-esa-budget-rises.html.
[33] http://www.spacenews.com/civil/110301-indian-space-budget-boost.html.
[34] T. Devezas, The evolutionary trajectory of the world system toward an age of transition, in: W.R. Thompson (Ed.), Systemic Transitions, Chapter 11, pp, Palgrave MacMillan, New York, January 2009, pp. 223–240.
[35] The end of the Space Age — Inner space is useful. Outer space is history, The Economist, June 30th 2011.
[36] http://www.iae.cta.br/prospecta/future.html.
[37] http://www.sourcewatch.org/index.php?title=Space_Preservation_Act.

Tessaleno Devezas: Physicist and systems scientist, PhD in Materials Engineering at the University Erlangen-Nürnberg. Currently, Associate Professor with Habilitation at the Department of Electromechanics of the University of Beira Interior, Covilhã, Portugal, where teaches and researches in the field of Materials Science and Technological Forecasting and leads the Working Group in Technological Forecasting and Innovation Theory. Foreign advisor of the *Prospecta* project at IAE.

Francisco Cristovão Lourenço de Melo: Graduate in Materials Engineering at Universidade Federal de São Carlos (UFSCar), Brazil, Ph.D. in Nuclear Engineering at Universidade de São Paulo (USP), Brazil. Currently, Senior Researcher at the Institute of Aeronautics and Space (IAE), Brazil, and manager of the *Prospecta* project at IAE.

Maria Luisa Gregori: Graduate in Chemical Engineering at Federal University of Rio de Janeiro, Brazil and PhD degree in Materials Engineering at Sheffield University, UK. Currently, scholarship holder DTI of CNPq (The National Council for Scientific and Technological Development), Brazil, and member of the *Prospecta* project at IAE.

Maria Cristina Vilela Salgado: Graduate in Mechanical Engineering, Master degree in Production Engineering and PhD student in Production Engineering at Aeronautics Technological Institute. Currently, manager of financial resources invested by the Brazilian Space Agency (AEB) in projects and technologies associated with satellite launch vehicles and sounding rockets in development at the Institute of Aeronautics and Space (IAE), Brazil, and member of the *Prospecta* project at IAE.

Joana Ramos Ribeiro: Graduate in Management Science, Master degree in Production Engineering and PhD student in Production Engineering at Aeronautics Technological Institute. Currently, scholarship holder DTI of CNPq (The *National Council* for *Scientific* and *Technological Development*), Brazil, and member of the *Prospecta* project at IAE.

Christian Biscchi Coelho Devezas: Graduate in Computer Science at Universidade Paulista (UNIP), Brazil. Currently, scholarship holder DTI of CNPq (The *National Council* for *Scientific* and *Technological Development*), Brazil, and member of the *Prospecta* project at IAE.