Dangerous space activities: Paolo, the USPID and the space debris problem

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At the time of his premature demise Paolo Farinella already was an authoritative senior member of the USPID. The Italian Union of Scientists for Disarmament (USPID) began its activities in 1983, but its founding fathers were already active as a group since a few years. The association was born with the purpose of providing information and analyses on various aspects of arms control and disarmament, and its members believe that this task is part of the social responsibility of scientists. The issues addressed by USPID include: nuclear proliferation, consequences of nuclear explosions, control of fissile material, developments of military technology and environment, satellites, space security and debris, conventional disarmament, chemical and biological disarmament, problems of conflicts and conflict resolution. Members of USPID, both individually and collectively, share their views with Italian policy-makers and opinion-makers. To this end they try to held objective standpoints in order to be trusted by interlocutors and to be able to influence the policymaking process. Their role as scientists is then instrumental and carefully promoted.

The USPID organizes conferences and meetings, including the biennial Castiglioncello (LI) conference (since 1985: now at its 14th edition in 2011) with the financial support of the Municipality of Rosignano Marittimo, courses and seminars in Italian Universities, courses for high-school teachers. To this end USPID has academic collaborations, promotes the establishment of inter-departmental Centers affiliated to Italian Universities, and actively collaborated along the years with several of them: CIRP (Centro Interdipartimentale di Ricerche sulla Pace, Bari University) and CISP (Centro Interdipartimentale Scienza per la Pace, Pisa University). It also collaborates with University teaching programs as: the Corso di Perfezionamento in *Politiche e Tecnologie della Pace e del Disarmo* (Bari University) and the Corso di laurea in *Scienze per la Pace* (Pisa University). USPID also collaborates with international organizations of scientists and other Italian institutions: Archivio Disarmo (Roma), Forum per i Problemi della Pace e della Guerra (Firenze), Pugwash, Isodarco and Landau Network-Centro Volta, Como (Italy).

The USPID was born during the Euro-missiles crisis. The new soviet missiles were perceived to alter the security of Western Europe, and NATO finally agreed to a two pronged strategy: first to pursue arms control negotiations with the Soviet Union to reduce their and the American INF arsenals; second to deploy in Europe from 1983 up to 464 ground-launched cruise missiles (GLCM) and 108 Pershing II ballistic missiles. Until the late 1970s NATO had clear superiority over USSR in INF. So Soviet attempts to close the gap by SS-20 and Tu-22M deployment was met with NATO moves to secure Western alliance nuclear advantage in Europe thanks to GLCM and Pershing II installation. In 1979 NATO decided to deploy US Pershing II and Tomahawk missiles in Western Europe in attempt to counter the RSD-10. Soviet Union agreed to open negotiations and preliminary discussions began in Geneva in 1980. Formal talks began in September 1981 with the US *Zero option* offer but, following disagreement over the exclusion of British and French delivery systems, the talks were suspended by the Soviet delegation in November 1983. In 1984, despite public protest, the US began to deploy INF systems in West Germany, Italy, and the United Kingdom. In

March 1986 negotiations between the US and the Soviet Union resumed, and on January 15, 1986, Gorbachev announced a Soviet proposal for a ban on all nuclear weapons by 2000, which included INF missiles in Europe. A series of meetings in August and September 1986 culminated in the Reykjavík Summit between Reagan and Gorbachev on October 11, 1986. Both agreed in principle to remove INF systems from Europe and to equal global limits of 100 INF missile warheads. The INF treaty text was finally agreed in September 1987. You bet USPID first (1985) Castiglioncello conference was a big success!

USPID characteristic is to put our competence as scientists to the service of objective assessments about several questions concerning arms, strategies, environment, conflicts, and its activities led to several scholarly publications: since 1984 for a few years the SIPRI Yearbook Italian translation was published, along with several essay collections as *Nuclear weapons in Europe* (Scientia, 1986) and *Tecnologie avanzate, armi e disarmo* (Dedalo, 1988), and the series of the proceedings of Castiglioncello Conference since 1985. One of the more interesting outcomes of these years, however, remains the publication of the *Bollettino USPID* (USPID Bulletin) spanning from January 1984 to Decembre 1992: this invaluable today to track also our personal activity in that decade. The interest in space activities was already present as can be seen from papers, book reviews and seminar announcements. Paolo was (along with Francesco lenci) one of its two editors. Of course the Bollettino USPID has been made obsolete by the web: not surprisingly the Bulletin stopped its publications in 1992, while the *Mosaic* first web browser was introduced in 1993. Finally USPID also produces documents agreed by its Scientific council: notably we had an SDI document (1985), a Patriot document (1992), an Iraq war document (2002), a NATO tactical nuclear forces in Europe and Italy (2008), and a US Missile in Europe (2008).

As tracked on the Bulletin records, the Paolo USPID association began in 1983 when he was deputy secretary of the Pisa section (with Giuliano Colombetti), and his seminars on Space Militarization with Luciano Anselmo are already announced. In the subsequent years he contributed several papers to the Bulletin as those of 1987 on *Space weapons and arms control* with Bruno Bertotti, and on *Alternative defense policies* both prepared for the ISODARCO school. In the same year he was one of the two proponents of a document approved by the Italian Astronomical Society in its Genova meeting: the statement called for limiting the Italian space activities only to the non military sector, for a refusal of the SDI, for not broadening the military sector in the Italian research, and for making clear any possible Italian involvement in the SDI projects. Paolo was a prolific writer, so other Bulletin papers followed: in 1989 on SDI, and in 1990 on *International Surveillance of the Outer Space* (with Anselmo and Bertotti), and in the same year he replaced Francesco Lenci as editor. The following (final) two years of the Bulletin were devoted to a campaign in favor of Mordechai Vanunu, to a discussion on NATO transformations, to a debate on military conscription and conscientious objection, to a paper on *Dangerous space activities* and to the publication of the proceedings of the 1991 4th Castiglioncello conference.

In the march 1990 Bulletin he also opened a discussion on *USPID: what future?* that still periodically surfaces among USPID members: after the end of Cold War he spoke in favor of an association less closed on its technical skills, and more open to social and political problems, more responsive to the demands of pacifist and environmentalist movements. Following a familiar pattern, however, the discussion ended by reaffirming the USPID character of an association of scientists and it is also possible that this 1990 discussion influenced the development of its interest in the space debris problem as an application of his scientific competence to a problem seated at a crossroad of space security, environmental threats, astronautical science and military technology. On the other hand the USPID interest in space debris was due to several factors:

- the relation between military activities (in particular the ASAT, anti-satellite weapons) and debris population;

- the security for observation satellites (needed for treaty verifications and confidence building) and general space activities;
- a general interest for treaties on use and preservation of outer space.

Paolo was in fact a bright example of how USPID works: his expertise as a scientist was considered – and was – instrumental in his social and political engagement. His interest in dangerous space activities was then obvious and in particular he turned his attention to the space debris problem from the beginning of the 90's.

Paolo's bibliography is an extensive one: about 270 scientific articles and conference proceedings, almost 100 popular science publications and more than 40 disarmament and security papers. It is then interesting to remark that, beyond papers on asteroid fragmentation, satellite collisions, and general space activities (published from 1978) we also have numerous papers specifically on space debris all published in the 90's with several collaborators (Anselmo, Bertotti, Cordelli, Pardini, Parrinello and Rossi). In particular we find: 7 full research papers[1] out of a total of 143; 11 conference proceedings[2] out of 120; 2 popular science articles[3] out of 85; 3 papers on disarmament and international security[4] out of 39; and 1 popular science book[5] out of 3. This last book in our opinion deserves a new printing after updating because public awareness about this problem – in particular in Italy – is still largely wanting.

The fact that space debris constitute a new risk factor for the use of the outer space was known from the end of the 70's. Also a new term, *Kessler Syndrome*, was coined from the name of Donald J. Kessler who first discussed[6] the problem of the exponential growth of the debris number due to their mutual collisions, and of a possible kind of chain reaction leading to a situation effectively forbidding usual space activities. However, besides the fact that apparently no cheap disposal of this kind of garbage is still in sight, it is not at all evident that the public opinion is really aware of what is at stake. Take for example a recent event that considerably contributed to anticipate the possible date of the Kessler syndrome onset, and compare that with the public response to see how even now the risk of space debris problem is still understated in the press and in the public opinion.

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[1] *Proliferation of orbiting fragments: a simple mathematical model*, Science and Global security (1991). *Future collisional evolution of earth orbitino debris*, Advances in Space Res. (1993). *Collisional evolution of Earth's orbital debris cloud*, J. Geophysical Res. (1994). *Long term evolution of space debris population*, Advances in Space Res. (1997). *A new model to simulate impact breakup*, Planetary and Space Science (1997). *The influence of fragmentation threshold on the long term evolution of the orbital debris environment*, Planetary and space science (1998). *Modelling the evolution of the space debris population*, Planetary and space science (1998).

[2] *Approaching the exponential growth: parameter sensitivity of the debris evolution*, First Eur Conf on Space Debris (Darmstadt 1993). *Long term evolution of debris clouds generated by explosions in Earth orbits*, Spacefl. Mech Meeting (Florida 1994). *Modelling the space debris evolution: two new computer codes*, AAS/AIAA Meeting (New Mexico, 1995). *Long term evolution of Earth orbitino objects*, Int Astronautical Congr (Oslo, 1995). *Artificial satellites and space debris: current stocks, orbital distribution and current activities*, UNIDIR (Dartmouth 1996). *Modelling the evolution of the space debris population: recent work in Pisa*, Second Eur Conf on Space Debris (Darmstadt 1997). *Numerical simulations of fragmentation processes*, Second Eur Conf on Space Debris (Darmstadt 1997). *Effects of the RORSAT NaK drops on the long term evolution of the space debris population*, Intern Astronautical Congr (Torino, 1997). *The 1997.0 CNUCE orbital debris reference model*, Space Flight Mech Meeting (Monterey, 1998). *Earth orbiting debris cloud and its collisional evolution*, in Lect Notes in Phys 505 (1998). *Interaction of the satellite constellations with the low Earth orbit debris environment*, Int Astronautical Fed (1998).

[3] *Spazzatura cosmica*, Sapere (1995). *Uno spazio affollato di detriti*, Le Scienze (1998).

[4] *Proliferation of orbiting fragments: a simple mathematical model*, Science and Global security (1991). *Monitoring and regulating dangerous space activities*, Space and nuclear weaponry, ISODARCO 1990 (MacMillan 1992). *Artificial satellites and space debris: current stocks, orbital distribution and current activities*, UNIDIR (1996).

[5] L. Anselmo, B. Bertotti and P. Farinella *Detriti Spaziali* (CUEN, Napoli 1999)

[6] D.J. Kessler and B.G. Cour-Palais, *J. Geophys. Res.* 83 (1978) 2637. See also Kessler more recent (2009) opinion about the syndrome in http://webpages.charter.net/dkessler/

On January 11, 2007 China conducted a successful anti-satellite missile test. A Chinese weather satellite (the FY-1C polar orbit satellite of the Fengyun series, at an altitude of 865 Km, with a mass of 750 Kg) was destroyed by a kinetic kill vehicle traveling with a speed of 8 Km/s in the opposite direction. It was the first known successful satellite intercept test since 1985, when the United States conducted a similar anti-satellite missile test using a ASM-135 ASAT to destroy the P78-1 satellite. Several nations responded negatively to the test and highlighted the serious consequences of engaging in the militarization of space. Chinese Foreign Ministry spokesman Liu Jianchao on the other hand stated that "There's no need to feel threatened about this" and argued that "China will not participate in any kind of arms race in outer space." Anti-satellite missile tests, however, especially ones involving kinetic kill vehicles as in this case, contribute to the formation of orbital space debris which can remain in orbit for many years and could severely interfere with future space activity. The test is the largest recorded creation of space debris in history – according to Wikipedia[7] – with at least 2,317 pieces of traceable size (golf ball size and larger), thereby increasing the total number of currently tracked objects in earth orbit by about 12%. That notwithstanding the focus of public opinion interest was almost entirely concentrated on the space militarization issue rather than on the debris creation.

Let us look for instance to the news and comments published on the *International Herald Tribune* in those days: on January 19, 2007 the new was related only in the 4th page in a small article emphasizing the strategic implications of the test and only quoting in passing the debris problem as a “key concern”. On January 20 the news analysis by J. Kahn was entirely devoted to the new “military space race”: China “contests American military supremacy in space” by means of a “most provocative military action”. Even Chinese reassurance was that “China will not participate in any kind of arms race in outer space”. The problem then was the danger to US satellites from China military capabilities, not from debris proliferation. In fact debris were not even quoted. Finally on January 22 a front page article by D. Sanger and J. Kahn was mainly concerned with the mysterious Chinese leaders silence and with the danger that “China could destroy American spy satellites”, and only at the end (page 4) it is said that the experiment “also left debris in space that could damage satellites from other nations”. On the same date the title of an editorial is “China’s muscle flex in space” and it also states that the event produced “pieces large enough to pose a danger … for a decade or more”, while on the same page a comment by Ph. Bowring (“Beijing satellite blast reverberate in Washington”) only quotes the “informal international understanding .. to avoiding filling space with debris of exploded satellites that could put other satellites out of action.” These seem rather nice exercises in understatement.

If I may add a personal recollection, at the epoch of the Chinese test I discussed of the possible implications with Beppe Nardulli, still another senior figure of USPID and Pugwash who unfortunately soon after left us for good in June 2008. I remember that we disagreed about the strategic relevance of the event: for my part I had the inclination to not emphasize the danger posed to Americans by the Chinese missiles. After all the US was always conducting ill fated anti-missile tests. Beppe on the other hand correctly underlined the strategic danger posed by anti-satellite weapons. However it is remarkable that even to us it did not occur that the main concern was the debris production: I do not remember in our discussion to have spoken of space debris. We too in 2007 were deeply influenced by the public opinion trend.

A different awareness was displayed in more recent accidents which were also not clouded by strategic confrontation concerns. On February 10, 2009 the Iridium/Kosmos accident was the first hypervelocity collision between two intact artificial satellites in Earth orbit. The collision occurred

[7] http://en.wikipedia.org/wiki/2007_Chinese_anti-satellite_missile_test

at 789 kilometres above the Taymyr Peninsula in Siberia, when Iridium 33 (a US, operational communication satellite) and Kosmos-2251 (a Russian out of service satellite) collided. The satellites collided at a speed of 11.7 kilometres per second, or approximately 42,120 kilometres per hour. As of March 2010 the U.S. Space Surveillance Network has cataloged 1740 pieces of debris from the collision, with about 400 additional pieces awaiting cataloging[8]. NASA says the risk to the International Space Station, which orbits about 430 kilometres (270 mi) below the collision course, is low. However, Chinese scientists (!) have said that the debris does pose a threat to Chinese satellites in Sun-synchronous orbits.

This time however the public opinion concern about orbiting debris was sensible: on February 13 the *International Herald Tribune* titled "Satellites collide leaving a trail of menacing debris", albeit in a small article at page 2. Then on February 17 an editorial entirely dedicated to space debris problem was particularly worried by the fact that "Iridium company apparently had no clue of the upcoming collision." And finally on February 20 a comment by James C. Moltz (associate professor at the Naval Postgraduate School) was totally devoted to orbiting debris and their danger.

Data and ideas about space debris and their growth contained in the Anselmo-Bertotti-Farinella (ABF) booklet quoted above are still up-to-date and can be fairly used. The principal numbers about orbital velocities and heights around the Earth following the classical calculations can be resumed as follows:

- 6.378 Km earth radius
- 200 Km (just out of atmosphere), velocity 7,8 Km/s = 28.000 Km/h, period 1h 30'
- 2.000 Km, velocity 6,9 Km/s = 24.800 Km/h, period 2h
- 35.800 Km (*geosynchronous*), velocity 3,0 Km/s = 11.000 Km/h, period 24h

The atmospheric drag – the most important perturbation – is relevant at different degrees depending on the orbit height: under 150 Km it is so important that no stable orbit is possible. Beyond this limit and under 1.000 Km it still important, while beyond 2.000 Km it can be considered no longer relevant. The fall time (and hence the life time spent in orbit) of orbiting objects depends on height, mass, area and form, but we can roughly say that larger objects tend to stay longer in orbit. Most of satellites are divided between low orbits (under 2.000 Km) and geosynchronous orbits (at 36.000 Km), while a lesser number populates intermediate or highly elliptical orbits.

The UCS (Union of Concerned Scientists) Satellite Database[9] for 2010 lists 928 operational satellites (they were about 600 in 1999 when ABF was published): 449 in low, 98 in medium and elliptical, and 381 in geosynchronous orbits. However according to US Strategic Command the orbiting detectable objects – with a cross section of about 10 cm – now near 19.000 (they were 8.500 in 1999), while the majority of debris objects remain unobserved: there are more than 600.000 objects larger than 1 cm in orbit according to the ESA Meteoroid and Space Debris Terrestrial Environment Reference (MASTER)[10]. The number of debris larger than 1 mm is finally estimated in the order of 10^7 objects. The maximum debris concentrations can be noted at altitudes of 800 to 1000 km, and near 1400 km. Spatial densities in geosynchronous and near the orbits are smaller by two to three orders of magnitude.

These numbers roughly agree with that published on ABF booklet ten years ago, but we are also witnessing growing space activities, mostly for commercial purposes: out of 425 US satellites (in 2010) 8 are for civilian use, 193 commercial (about 50%), 120 governmental and 104 military. On

[8] http://en.wikipedia.org/wiki/2009_satellite_collision
[9] http://www.ucsusa.org/nuclear_weapons_and_global_security/space_weapons/technical_issues/
[10] http://www.esa.int/esaMI/Space_Debris/SEMXP0WPXPF_0.html
http://en.wikipedia.org/wiki/Space_debris

the other hand accidents and explosions are responsible for other large fragments (detectable and catalogued): most notably the 1996 the French satellite Cerise accident (severely damaged by a fragment of the size of a suitcase), the 2007 Chinese ASAT test and the 2009 Iridium/Kosmos collision. Centimetric (0,5-4,0 cm) debris come from dumped old satellite reactors, spent stages or operational waste; millimetric and submillimetric would come instead from erosion, degradation, exhausted combustible. At the low altitudes at which the International Space Station (ISS, in orbit since 1998) orbits there is a variety of objects, consisting of everything from entire spent rocket stages and defunct satellites, to explosion fragments, paint flakes, slag from solid rocket motors, small needles and NaK drops of coolant released by RORSAT nuclear powered satellites: Paolo and his collaborators gave on this last kind of junk a contribution that is still quoted in the literature[2]. The microscopic debris can be slowly swept away naturally, but they are also continuously produced. Larger and more dangerous debris on the contrary are more difficult to eliminate.

Orbital collisions happen at typical relative velocities of around 3-10 Km/s = 10.800-36.000 Km/h: remember indeed that low orbits are trodden at about 8 Km/s = 28.800 Km/h, and geosynchronous orbits at 3 Km/s = 10.800 Km/h. This means that the impact velocity typically exceeds the velocity of sound in solids (3-5 Km/s) and hence that orbital impacts happen in a regime of *hypervelocity* with extreme pressures and temperatures and production of jets of dust and fragments. Under these conditions also small (millimetric) debris can create holes and craters, but when the mass ratio projectile/target exceeds 10^{-3} a catastrophic fragmentation takes rise with production of a large number of new debris. Even when the impact is not catastrophic, however, the debris could perforate walls and are deemed more dangerous than micro-meteoroids. It is then necessary to protect large space ships with prolonged exposure – the 11.000 m^2 of the ISS launched in 1998 will be in orbit until 2015/20 – by means of shields and, whenever possible, with DAM's (Debris Avoidance Manoeuvre).

It is very difficult to estimate the evolution of the debris population in a 50-100 years scale. There are two dangerously populated shells: between 900-1.000 Km, and between 1.400-1.700 Km. There the atmospheric drag is not able to clean over-centimetric debris quickly enough and then a possible positive exponential feedback is in order. This could produce a chain reaction (the Kessler syndrome) such that the space activities can become impossible at these altitudes. It is important then to estimate when this could happen, and to this end we should know when the catastrophic impacts will become dominant with respect to the local damage impacts. This depends on the projectile number, but also on the value of the ratio between projectile energy and target mass. A critical value for orbiting objects seems to be 40-60.000 Joules/Kg. If this is true a chain reaction could take place in 300 years (see the Paolo 1998 papers[1]); however if the critical value is 3.000 J/Kg (as happens for usual rocks) a chain reaction could take place sooner within 100 years. If we think that an acceptable disposal of the nuclear waste is supposed to keep them safely for about 10.000 years we can also understand the relevance of the problem.

What could then be done? Given the number of the debris, cleaning the space would be very difficult and astronomically expensive. Think simply to the fact that most of these orbiting objects will not fall on earth by themselves, and that there is no way of simply and cheaply *catching* them. One point will then be to stop the debris production, namely to avoid:

- explosions of stages with dangerous materials
- production of operational debris: components, combustible, various objects
- accidental collisions

But it would also be very important to design every future space activity in such a way that it would be possible to remove spent stages and non operational satellites. In particular for geosynchronous orbit it is possible – at a reasonable cost – to bring the satellites 50-300 Km higher into what are called *graveyard orbits*. No graveyards are however available for orbits under 2.000 Km. In this case, since to bring the satellites on earth would be very expensive, they could at least be moved to lower orbits (5-700 Km) waiting for air friction (about 25 years) to finish the job.

All that would require international treaties and binding agreements. Beginning in 1957, nations began discussing systems to ensure the peaceful use of outer space. In 1959 the UN created the Committee on the Peaceful Uses of Outer Space (COPUOS): its Legal Subcommittee has been a primary forum for discussion and negotiation of international agreements relating to outer space. Five international treaties have been negotiated and drafted in the COPUOS:

- The 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies (the *Outer Space Treaty*).
- The 1968 Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space (the *Rescue Agreement*).
- The 1972 Convention on International Liability for Damage Caused by Space Objects (the *Liability Convention*).
- The 1975 Convention on Registration of Objects Launched Into Outer Space (the *Registration Convention*).
- The 1979 Agreement Governing the Activities of States on the Moon and Other Celestial Bodies (the *Moon Treaty*).

In addition, the 1963 Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space, and Under Water (*Partial Test Ban Treaty*) banned the testing of nuclear weapons in outer space. Finally in addition to the international treaties that have been negotiated at the United Nations, the nations participating in the International Space Station have entered into the 1998 Agreement among the governments of Canada, Member States of the European Space Agency, Japan, Russian Federation, and the United States of America concerning cooperation on the Civil International Space Station (*Space Station Agreement*).

There is however still no international treaty mandating behavior to minimize space debris, but the COPUOS did publish voluntary guidelines in 2007, while in 2008 NASA has implemented its own procedures[11] for limiting debris production as have some other space agencies, such as the European Space Agency. The vast majority of space debris, especially smaller debris, cannot be removed under its own power. A variety of proposals have been made to directly remove such material from orbit. In any event – today as ten years ago – none of the existing solutions are currently cost-effective. The advent of commercial space activities beyond the scope of the satellite communications industry, and the development of many commercial spaceports, is leading many countries to consider how to regulate private space activities. This lends the hope of future agreements, and the challenge is to regulate these activities in a manner that does not hinder or preclude investment, while still ensuring that commercial activities comply with international law. Arguably the resources of space are infinite, and limited only by our ability to use them in a manner that is fair and equitable to all nations and which is environmentally ethical. If commercial space transportation becomes widely available, with substantially lower launch costs, then all countries will be able to directly reap the benefits of space resources. In that situation, it seems likely that consensus will be much easier to achieve with respect to commercial development and human settlement of outer space. A topic still of interest for USPID as was for our friend Paolo.

[11] http://orbitaldebris.jsc.nasa.gov/index.html