HIPPARCHOS

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Contents

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Hipparchos is the official newsletter of the Hellenic Astronomical Society. It publishes review papers, news and comments on topics of interest to astronomers, including matters concerning members of the Hellenic Astronomical Society.

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Cover Image: Celebrating Hubble's 25-year anniversary: the prolific stellar breeding area Gum 29 in the constellation Carina, some 20000 light years away. The area includes the young-star cluster Westerlund 2.

(Image courtesy: NASA, ESA, the Hubble Heritage Team (STScI/AURA), A. Nota (ESA/STScI) and the Westerlund 2 Science Team)

Message from the President

May 21, 2015

Dear Colleagues,

On May 1995 the first issue of Hipparchos was published. Reading the issues of Hipparchos over the last twenty years one is able to trace the growth and evolution of our academic institutions and the research activities of the members of our Society. In this 20^{th} anniversary issue, three young astronomers and space physicists have been invited to contribute the main review articles.

Andreas Zezas analyses the remarkable ways of using the extragalactic X-ray binaries as a tool for understanding the physical processes enabling the formation of accreting binaries. With the methods presented in this review we can follow the pathways to the formation of these binary stars, the relation of extreme sources to these pathways and the cosmological evolution of accreting binaries.

Theodoros Sarris worked with a team of student engineers from the Democritus University of Thrace to build a Greek nano-satellite for the upper terrestrial atmosphere. This remarkable new concept of building and launching a CubeSat (a modular satellite of standardized dimensions, assembled using primary commercial, off-the shelf components) provides an excellent opportunity for Greek students to be engaged on the construction of a Greek miniaturized satellite. The internationally booming CubeSat trend paves new ways for research and it is a highly innovative educational tool.

Markos Trichas presents a proposal for a space weather monitoring mission (Carrington-L5). This UK/US collaboration investigates the user requirements for an operational mission/spacecraft concept. The review introduces the reader to the basic steps a new mission follows from concept level to payload selection and finally the construction of the spacecraft. The analysis pertains to a mission at Lagrange 5 (L5) libration point (Earth trailing) since this point offers the greatest benefit for the earliest possible warning on hazardous Space Weather events.

We are proud to report that in 2015 a large number of competitive national and international research projects are implemented in various Greek institutions (see details on the list and short presentation of projects presented in this issue). The total budget of the active proposals increased drastically over the last five years. A large number of young researchers are currently employed by these projects. The two prevailing international sources of funding in Greece come from the European Commission (the latest Horizon 2020 Framework Programme is one of them, as detailed in the article by Haris Kontoes) and the European Space Agency (see the opinion article by Manolis Georgoulis).

Vassilis Charmandaris collected data for Astronomy PhDs in Greece. In his report, Vassilis touched some very sensitive issues related to human recourses, which play a crucial role for the future of our Society. The comments made by Vassilis in his report and the opinion statements by Manolis Georgoulis showcase some of the main problems and difficulties that are ahead of us and will continue to hamper further progress unless action steps are taken.

Closing this editorial, I would like to outline some more general thoughts:

- The seamless participation of Greece in the European Union is the key factor behind the remarkable success of Astronomy and Space Physics in the country.
- The re-orientation of our activities toward space-related projects is connected with the Greek participation in ESA. This technologically oriented research activity is still in its infancy in our country, with many important steps yet to be taken.
- The research in Astrophysics and Space Physics in Greece has achieved a state of maturity as we demonstrated here. We would like to stress that to sustain and enhance this growth we need a well-documented strategic plan from our government and the meaningful revision of many traditional approaches to our research policies.

Many of the topics discussed in this issue of Hipparchos are laid out in the agenda of our 12^{th} conference in Thessaloniki. As the previous Hel.A.S. President, Nikos Kylafis, stressed in his editorial of a previous issue of Hipparchos, 'we do (as members of Hel.A.S.) and should continue doing what we can do best, namely research and teaching in Astronomy'. We readily second this statement. However, as argued above, the coupling between scientific and technological progress relies on (but needs more than) basic research and teaching. Hel.A.S. supports our government's effort to maintain an active membership in the European Union and the European Space Agency. We therefore envision that, in coming years, a strong collaboration that we will strive to forge between Academia and Industry on astrophysics and space physics projects will be empowered by innovative, in-house space technologies and will play a, literally, instrumental role in our country's economic revival.

Loukas Vlahos
President of Hel.A.S.

Greece and ESA: a membership and relation that is imperative to maintain, in spite of problems[1]

Figure: An ESA member state since 2005, Greece has yet to unfold its full potential in participating in the core ESA activity, the Science Programme.

by Manolis K. Georgoulis
National Delegate in ESA's
Science Programme Committee (ESA/SPC)

It will become obvious to the readers of this issue of Hipparchos (see the list of research projects currently implemented by Greek Universities and Research Centers) that Greek astronomers, astrophysicists, and space / solar physicists rely heavily on the European Space Agency (ESA) for support of their research ideas and, in particular, for bringing the most practical facets of these ideas to fruition for the benefit of the Agency and the international scientific community at large.[1]

In addition to the predominantly scientific projects mentioned here, ESA is a major technology procurement organization, awarding contracts that support its Cosmic Vision[2] through the ESA/EMITS online service[3]. These contracts refer to both the mandatory ESA program, the Science Programme[4], and to specific Optional Programmes that help the Agency achieve specific goals. Both the Science Programme and Optional Programmes are subscription-based: member states must contribute roughly according to their GDP (or at a pre-negotiated rate) for Science, and invest – if they so wish – in Optional Programmes that serve their scientific and technological needs.

The ratio of the funds gained by contractors of a member state in science and technology over the state's contribution to each ESA Programme reflects the *return* the member-state enjoys. This ratio can be equal to one (*balanced return*), smaller than one (*under-return*), or larger than one (*over-return*). An over- (under-) return implies a net gain (net loss) of funds for the member state while a balanced return means that the entire contribution of a member-state returns in the form of competitive ESA contracts. The benefit of an ESA contract is that beneficiaries (universities / research centers / companies or corporations) gain in technological know-how and forge collaborations throughout Europe that help them solidify and expand their business portfolios. At the same time, ESA has established a set of Industrial Policy rules aiming at a fair geographical return of national contributions[5].

Greece became an ESA member state in January 2005. Since then, it contributes to the mandatory Science Programme. The country also used to contribute with smaller amounts to an array of Optional Programmes until March 2013, when it completely retracted citing adverse economic conditions due to the looming financial crisis. Following a line of negotiations, Greece also managed to lower its mandatory contribution to the Science Programme for years 2013 and 2014. As of this writing, delays in the payment of the Greek contribution for 2014 and earlier have resulted in the enforcement of Article XI.6(b) of the ESA Convention[6], depriving Greece from the right to vote in ESA Committee meetings. But even before this unwanted development, Greece's geographical return ratio was persistently smaller than one, resulting in annual net losses. A set of special measures put forth by ESA, in collaboration with GSRT, has managed to reverse this situation in 2014, with support actions "Restricted to Greece"[7]. However, such actions will not repeat from ESA's side for more than a decade, implying that under-return may be back for years to come. This overall uncertainty has resulted in criticism that Greece should withdraw from its ESA membership to discontinue an otherwise non-profitable partnership.

ESA currently encompasses 22 member states (the entire western and

1. Views expressed in this article reflect solely the opinion of the author and not necessarily those of the Greek General Secretariat for Research and Technology (GSRT).
2. More information about ESA's Cosmic Vision at http://sci.esa.int/cosmic-vision/
3. Accessible via registration at http://emits.sso.esa.int
4. More information about ESA's Science Programme at http://sci.esa.int/
5. For more information, visit http://www.esa.int/About_Us/Business_with_ESA/How_to_do/Industrial_policy_and_geographical_distribution
6. Available online at http://esamultimedia.esa.int/multimedia/publications/SP-1317-EN/pageflip.html
7. See the pertinent GSRT press release at http://www.gsrt.gr/central.aspx?sId=110I458I1163I323I453938&olID=777&neID=589&neTa=2_1014&ncID=0&neHC=0&tbid=0&lrID=2&oldUIID=aI777I0I119I428I1089I0I3&actionID=load&JScript=1

central Europe, Switzerland, the Scandinavian countries, UK and Ireland) with the latest entries, Estonia and Hungary, signing the ESA Convention in February 2015. At the same time, ESA maintains cooperation agreements with Bulgaria, Cyprus, Lithuania, Malta, and Canada, while Latvia, Slovenia and Slovakia participate in the Plan for European Cooperating States (PECS)[8]. One clearly sees that countries with less vigorous astronomy and astrophysics communities than Greece are long-standing ESA members or strive to join in. An ESA "GRexit" (to use a painfully familiar, contemporary term) is therefore not an option: if it happens, it will plunge the country deep into past decades and will deprive several developing state-owned and private vendors from their lifeblood funding for development and innovation[9].

To this author's view, the following issues are detrimental to Greece's continuing inability to fully realize its capabilities and potential within ESA:

- **Lack of technological involvement in space missions of the mandatory Science Programme.** This lack is conspicuous, with few, glaring but insufficient, exceptions. It is beyond our scope to delve into the debate of why this is the case, but let us safely admit that this is the case and that the situation must be reversed.
- **Lack of involvement in Optional ESA Programmes.** This deprives Greek technology vendors from the flexible powerhouse conditions they need in order to achieve sustainability. Even when Greece participated in some ESA Optional Programmes the funds invested were insufficient, unable to create the stimulating conditions that the country so badly needs. In addition, lack of Optional-Programme contracts sharply limits the odds of Greek technology vendors to become "ESA trusted partners", through partnership with key European Contractors (Airbus/Astrium, Thales Alenia, DLR, Arianne). Such alliances would set the stage for a continuous, routine Greek involvement into large, prestigious Science-Programme Contracts.

The central question is how can this adverse situation be rectified. What measures should be implemented for Greece to achieve a "trusted ESA partner" status? To this author's view, such measures should include:

- **Substantial revisions of the country's space strategy to better align with the ESA *modus operandi*.** Successful member states typically implement a "pyramid strategy" with one or two big Contractors (state-owned or private) establishing contact directly with ESA and the major European Contractors mentioned above. These entities consistently attract large contracts, part of which is diverted to numerous small and medium enterprises (SMEs) within the country. A major Greek stakeholder for this role could be the Hellenic Aerospace Industry (HAI[10]) that has existing ties with ESA and key partners around Europe and the globe.
- **Establishment of an "Office of Space Research" and a "Virtual Institute of Space Research"** staffed by representatives from technology, industry, and academia. Such a practice, endorsed by several ESA member states (see, for example, the brilliant example of the Space Agency of Poland[11], a recent member state) acts as the "brains" of the country in its ESA partnership: a Space Office draws the national strategy in transparency, and this strategy is then implemented by an interfacing Virtual Institute. In Greece there are existing proposals to the GSRT in this direction. Moreover, GSRT recently established the Corallia Innovation Cluster[12] with which a Virtual Institute of Space Research could interface optimally.
- **Major reallocation of Greece's investment in ESA.** A more balanced distribution between Greece's subscription to the Science Programme and contributions to Optional Programmes can instantly create powerhouse conditions within the country. Obviously Greece should return to strategically selected Optional Programmes with institutions such as a Virtual Institute helping in this selection. A third funding element should be disbursed to competitive native institutions and SMEs for support that includes, but is not limited to, in-house spacecraft payload development[13]. Such an action is essential and will prepare the country for direct collaboration with major European stakeholders.
- **Continuous, uninterrupted participation of national delegates to all key ESA Committee meetings.** A team of at least two delegates is needed for optimal participation and redundancy. Participation at the moment is intermittent, at best, and is almost invariably achieved by a single delegate. Hence, results are far from optimal. An insightful choice of competent delegates can only act to protect and secure Greece's strategic investment in its ESA membership.

Greece enjoys a sizable, well-organized astronomical community. At these turbulent times, it also needs technological innovation more than any time in the past. For these two reasons, independently or in conjunction, Greece cannot afford not to be an ESA member state. At the same time, it cannot afford to remain in a disadvantageous membership position. Conditions are ripe and ample expertise exists – we only need the decisive leap that will help this and future generations of Greek space professionals to remain in the country and thrive.

The author gratefully acknowledges numerous enlightening discussions with GSRT and ESA policy officers, as well as colleagues and collaborators who have provided insight and feedback that have helped shape the views presented in this article.

8. See http://www.esa.int/About_Us/Welcome_to_ESA/New_Member_States
9. The reader is encouraged to read the lecture of the 2006 Nobel Laureate in Chemistry, Prof. Roger Kornberg (Zappeion, 3 July 2014, available at the GSRT web site), for an insight of his views about innovation and how diligently should Greece pursue it.
10. Visit http://www.haicorp.com
11. Online information at http://www.polska.pl/en/business-science/investments-projects/polish-space-agency/
12. Information at http://www.corallia.org/en/
13. Traditionally, spacecraft payload in ESA missions is covered by national contributions. Greece cannot support such efforts, even the most promising ones, since budget for this activity is currently non-existent.

A database of Greek Astronomy PhDs

Vassilis Charmandaris
Univ. of Crete & National Obs. of Athens

As it has already been mentioned in the e-newsletters of the Society, we have recently compiled a database of all doctoral dissertations (PhDs) completed in Greek academic institutions in the general area of "Astronomy". The meaning of the term "Astronomy" here is rather broad, since we include not only the fields of classical observational astronomy, astrophysics, and dynamical astronomy, but also the areas of modern space physics and ionospheric physics. The period we cover starts in 1886, when Prof. Demetrios Eginitis obtained his PhD degree from the University of Athens and it ends in 2014.

To collect the data we relied on a number of sources including the records of Greek Universities, previous reports with biographies of Greek astronomers (Laskarides "Yearbook of Greek Astronomers" 1992, 2009), feedback from senior colleagues, as well as

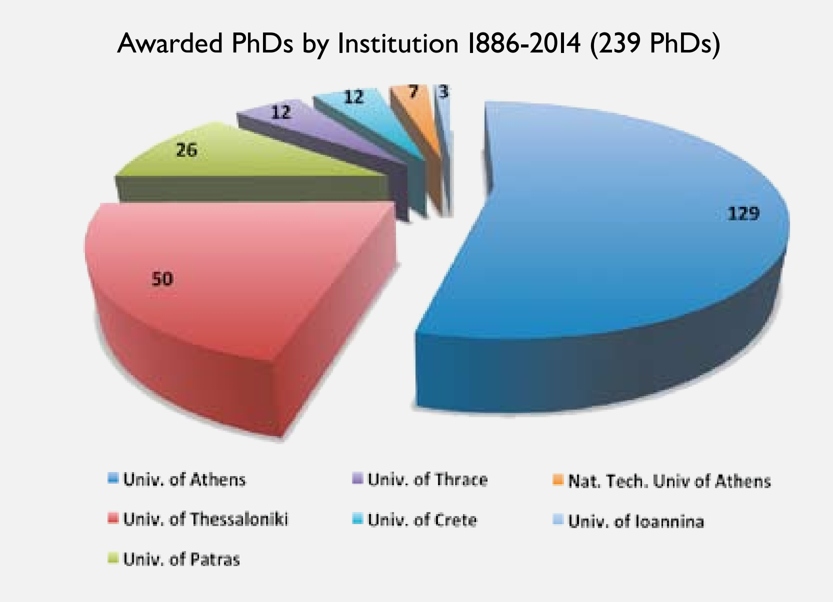


Figure 1: A pie chart of the 239 dissertations performed at the 7 major Universities in Greece, from 1886 through 2014.

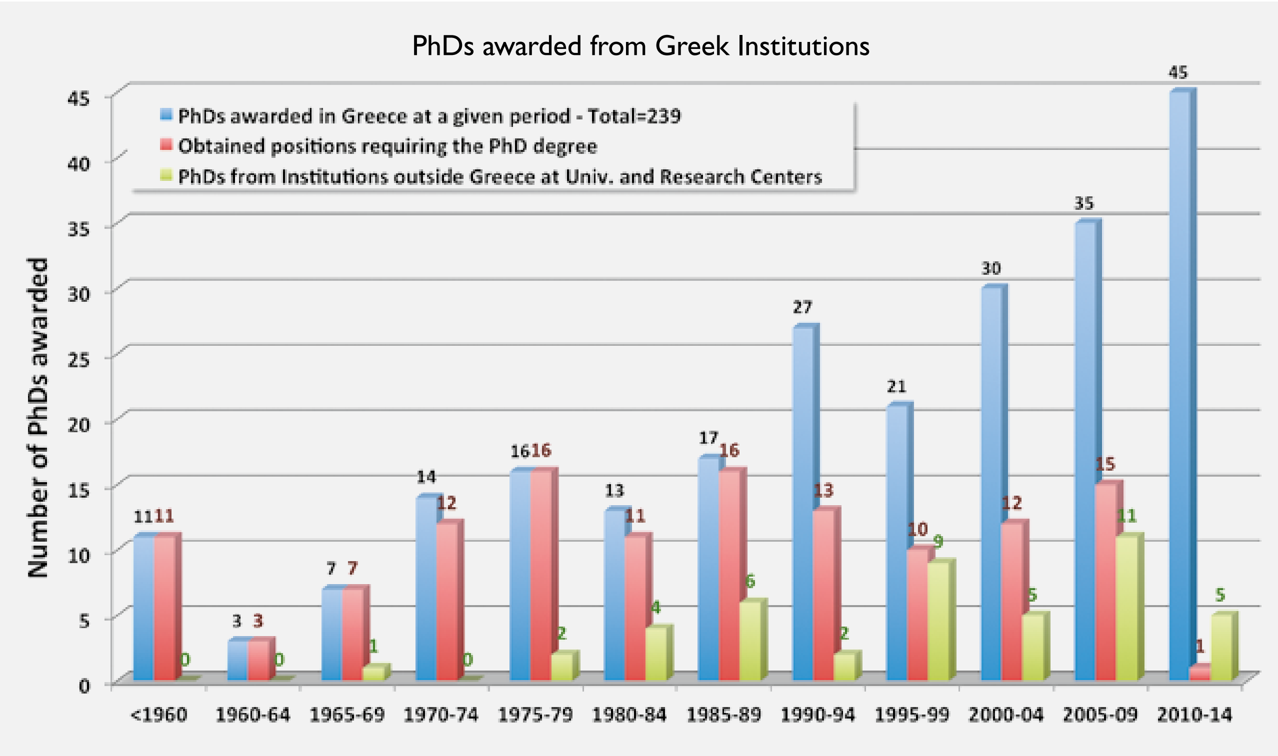


Figure 2: Histogram of the "Astronomy" PhDs awarded in Greece binned in 5-year periods. The degrees awarded prior to 1960 are grouped together.

the dissertation archive of the National Documentation Center. The final output was 239 PhDs from 7 academic institutions and it is available online in the web server of the Society (Figure 1)[1]. With the exception of three nationals from Egypt, Poland, and Bulgaria, all PhD recipients were Greek. All individuals of the database have also been included in the PhDTree[2].

In Figure 2 we present in blue the number of degrees awarded, binned in 5-year periods. In red we indicate whether the individuals who obtained their degree within the given timespan eventually obtained a permanent position that required a PhD, whether in Greece or abroad. This effectively means that the individual obtained a job either as a faculty member at a University/TEI, or that she/he found a tenure track (or is currently in a long term) position as a researcher or research support personnel at a Research Institute. Note that it is not implied that this permanent position was obtained within the 5-year period the PhD degree was awarded.

In the same histogram we indicate in green the number of tenure track positions in Greece, which were filled by scientists who obtained their PhD outside Greece. One should note that in these we include truly "outsiders", that is individuals who had no prior employment connection with Universities in Greece.

It is instructive to briefly discuss a few conclusions one may draw from Figure 2:

- It is obvious that up until the end of the 1980s, nearly every one of the 81 PhDs recipients eventually obtained a permanent position in academia. This was probably due to the expansion of the academic system, the small number of PhD students, and limited competition from abroad.
- Past 2010, with one exception (a foreigner who obtained a tenure track position in her country), no one has a permanent position yet. This is expected though since the current stiff competition typically requires at least two postdocs (5-6 years research experience past the PhD) before someone is sufficiently competitive to obtain a tenure track position.
- After the 1980s the number of PhDs from abroad who obtained a permanent position in Greece steadily increases. In fact, if one focuses only on the 67 faculty and researchers currently in tenure track positions, 49% of them are Greeks who have obtained their PhD outside Greece. The fraction is even higher (63%) if we restrict ourselves on the hires over the past 10 years.

A more detailed report based on this data has been prepared; it is available at the historic document section of the web server of Hel.A.S.[3] and it will be presented during the 12th Conference of the Society in June 2015.

1. The database with all ancillary information is available at http://www.helas.gr/documents.php
2. PhDTree is a Wiki project to document the academic family tree of PhDs worldwide, both past and present (see http://phdtree.org).

3. See "Greek Astronomy PhDs: The last 200 years…", V. Charmandaris (2015)

Greece's participation in the 1st H2020 space call (2014)

Participation Review & Results

Space research is supported in Horizon 2020 under the priority "Industrial Leadership", in line with the main objectives and challenges towards fostering a cost-effective competitive and innovative space industry, SMEs, and research community to develop and exploit space infrastructure, data, and science, to meet current and future European Union policy and societal needs. Building on the successes of the Seventh Framework Programme, Horizon 2020 foresees to enable the European space research community to develop innovative space technologies and operational concepts, and to use the space data for scientific, public, or commercial purposes. The H2020 work programme has been structured to address the following thematic calls:

1. Applications in Satellite Navigation – Galileo, which in the 1st round of calls, included topics as: a) GALILEO-1–2014: New innovative EGNSS applications with future commercial impact, b) GALILEO-2–2014: Small and Medium Enterprise (SME) based EGNSS applications, exploring new EGNSS niche market sectors and business models, c) GALILEO-3–2014: Releasing the potential of EGNSS applications through international cooperation, and d) GALILEO-4–2014: EGNSS awareness raising, capacity building and/or promotion activities, inside or outside of the European Union.

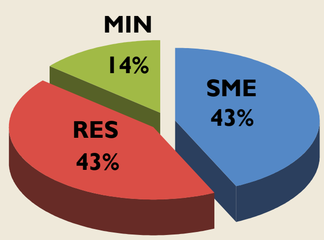
2. Earth Observation, including the topics of: a) EO-1–2014: New ideas for Earth-relevant space applications, b) EO-2–2014: Climate Change relevant space-based Data reprocessing and calibration, and c) EO-3–2014: Observation capacity mapping in the context of Atmospheric and Climate change monitoring.

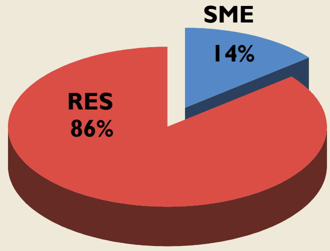
3. Protection of European assets in and from space, addressing the topics of: PROTEC-1–2014: Space Weather, and b) PROTEC-2–2014: Access technologies and characterisation for Near Earth Objects (NEOs).

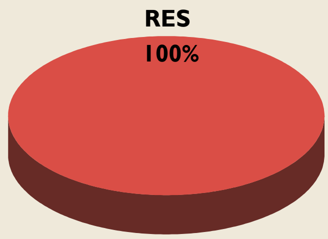
4. Competitiveness of the European Space Sector: Technology and Science, a call to strengthen the competitiveness, non-dependence and innovation of the European space sector through topics as: a) U1–Space qualification of low shock non-explosive actuators, U2–Advanced thermal control systems, U5–Alternative to Hydrazine in Europe, U11–Application Specific Integrated Circuits (ASICS) for Mixed Signal Processing, U17–High density (up to 1000 pins and beyond) assemblies on PCB, b) Independent access to space tackling all possible technologies and launching systems, including partly reusable systems and subsystems, c) In-Space electrical propulsion and station keeping, d) Space Robotics Technologies, e) In-Orbit demonstration/Validation (IOD/IOV), f) Bottom-up space technologies at low TRL, g) Space exploration ñ Life support, h) Science in context: sample curation facility and scientific exploitation of data from Mars missions, i) Technology 'demonstrator projects' for exploration, k) Outreach through education, l) Transnational and international cooperation among NCPs.

The results from the participation of the Greek scientific (RES), governmental (MIN), and industrial (SME) technological communities in the above mentioned call are summarized in the following:

GALILEO 2014

Number of Greek entities involved in proposals	Number of Greek entities assuming the role of coordinator	Number of Greek entities in winning consortia	Number of Greek entities assuming the role of coordinator in successful proposals	EC Funding awarded to Greek entities / vs / requested funding (in M€)	Winning Greek Entities per sector (Research (RES), Industry (SME), and Governmental (MIN))
16	2	5	1	**605 / 3.348** (success rate 18%)	**SME:** TELETEL SA, EXODUS SA, ARATOS SA, GLOBAL AVIATION SA, TERRASPATIUM SA, KNOWLEDGE & INNOVATION CONSULTANT LTD **RES:** AUTH, NKUA, DEMOKRITOS, KEMEA, I-BEC **MIN:** MIN OF NATIONAL DEFENCE, MIN OF CIVIL PROTECTION
Statistics of winning entities per sector (Research (RES), Industry (SME), and Governmental (MIN))					

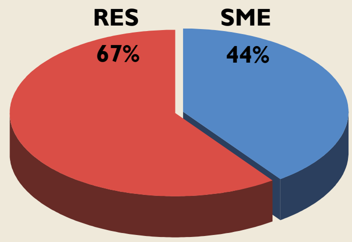
EO 2014					
Number of Greek entities involved in proposals	Number of Greek entities assuming the role of coordinator	Number of Greek entities in winning consortia	Number of Greek entities assuming the role of coordinator in successful proposals	EC Funding awarded to Greek entities / vs / requested funding (in M€)	Winning Greek Entities per sector (Research (RES), Industry (SME), and Governmental (MIN))
4	1	1	1	499.3 / 3980 (success rate 12%)	**SME:** DIADYMA SA **RES:** NAT OBSERVATORY ATHENS (NOA), NAT. KAPODISTRIAN UNIV ATHENS (NKUA) **MIN:**
Statistics of winning entities per sector (Research (RES), Industry (SME), and Governmental (MIN))					

PROTEC 2014					
Number of Greek entities involved in proposals	Number of Greek entities assuming the role of coordinator	Number of Greek entities in winning consortia	Number of Greek entities assuming the role of coordinator in successful proposals	EC Funding awarded to Greek entities / vs / requested funding (in M€)	Winning Greek Entities per sector (Research (RES), Industry (SME), and Governmental (MIN))
9	2	2	2	586.7 / 3.166 (success rate 18,5%)	**SME:** DIADYMA SA **RES:** NOA, NKUA, ACADEMY of ATHENS (AOA) **MIN:**
Statistics of winning entities per sector (Research (RES), Industry (SME), and Governmental (MIN))					

COMPET 2014					
Number of Greek entities involved in proposals	Number of Greek entities assuming the role of coordinator	Number of Greek entities in winning consortia	Number of Greek entities assuming the role of coordinator in successful proposals	EC Funding awarded to Greek entities / vs / requested funding (in M€)	Winning Greek Entities per sector (Research (RES), Industry (SME), and Governmental (MIN))
18	3	5	1	900 / 4.377 (success rate 20.6%)	**SME:** EUROPEAN SENSOR SYSTEMS SA, TELETEL SA, INTEGRATED SYSTEMS DEVELOPMENT, TELECOM SYSTEMS INSTITUTE, SPACE ASICS OLOKLIROMENA DIASTIMIKA MICROSISTIMATA, AEROTRON RESEARCH ASTIKI ETAIRIA, INDUSTRY DISRUPTORS GANE CHANGERS **RES:** FORTH, DUTH, ATHENA RESEARCH CENTER, Un. of PELOPONNESE, ELLINOGERMANIKI AGOGI, NOA, KENTRO DIADOSIS EPISTIMON KAI MOUSEIO TECHNOLOGIAS, DEMOCRITOS RESEARCH CENTER **MIN:**

COMPET 2014

Statistics of winning entities per sector (Research (RES), Industry (SME), and Governmental (MIN))



Conclusions

Five high ranked proposals coordinated by Greek entities have successfully passed to the contract award phase. These are:

a) **GHOST** – Galileo EnHancement as BoOster of the Smart CiTies, coordinated by the TELETEL S.A. – TELECOMMUNICATIONS AND INFORMATION TECHNOLOGY company in the GALILEO-2–2014 call (8th ranked proposal).

b) **URBANFLUXES** – URBan ANthrpogenic heat FLUX from Earth observation Satellites, coordinated by the FOUNDATION FOR RESEARCH AND TECHNOLOGY HELLAS in the EO-1–2014 call (1st ranked proposal).

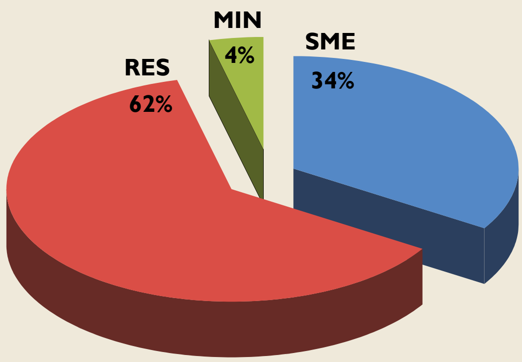
c) **FLARECAST** – Flare Likelihood and Region Eruption Forecasting, coordinated by the ACADEMY OF ATHENS, in the PROTEC-1–2014 call (1st ranked proposal).

d) **HESPERIA** – High Energy Solar Particle Events foRecastIng and Analysis, coordinated by the NATIONAL OBSERVATORY OF ATHENS, in the PROTEC-1–2014 call (4th ranked proposal).

e) **PHySIS** – Sparse Signal Processing Technologies for HyperSpectral Imaging Systems, coordinated by the FOUNDATION FOR RESEARCH AND TECHNOLOGY HELLAS, in the COMPET-06–2014 call (1st ranked proposal).

The Overall EU budget awarded to winning Greek entities was of the order of 2.6-3 M€. This corresponds to 2.5% of the total budget allocated to the first H2020 Space Call (2014). The budget allocation per call area, as well as the extremes reported in some countries, indicating the emphasis placed by countries to the different research topics compared to Greece, are given in the following. In the GALILEO call area, the geo-return to Greece was of the order of 1.6 %, while the reported geo-return extremes referred mainly to Italy (23%), and Germany (12%). in the EO call area, Greek entities have awarded a total 2.4% of the available budget; the extremes here were referred to Germany (31%), and UK (32%). In the PROTEC call area, the 4.7% of the available budget returned to Greece; the extremes in this call area were 24% for France, and 21% for Germany. Finally in the COMPET call area, Greece's geo-return was of the order of 1.9 %, vs 19% for France, 15% for Germany, 14% for Italy, and 13% for Spain.

Finally, as it regards the participation of the three sectors (Research (RES), Industry (SME), Government (MIN)) to the 1st H2020 Space call, it should be noted that out of the 53 Greek participations in all areas of the call, 18 came from the SME sector, 33 from the Research/Academic sector, and 2 were from the Government sector. The following diagram is indicative to the participation per sector.



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REVIEWS

DUTHSat: A Greek QB50 nano-satellite for Upper Atmosphere Studies

by Theodoros E. Sarris, Thanasis Mpalafoutis, Georgios Kottaras, Athanasios Psomoulis, Ilias Vasileiou, Aggelos Papathanasiou, Dimitrios Mpaloukidis, Ioannis Nissopoulos, Panagiotis Pirnaris, Aggelis Aggelis, Konstantinos Margaronis

Abstract

The Laboratory of Electromagnetism and Space Research of the Democritus University of Thrace (DUTH/SRL) has been selected to join the QB50 European initiative for the launch of 50 nano-satellites in the upper atmosphere by January 2016. The aim is to investigate with multi-point measurements the transition region between the atmosphere and space. The 50 nano-satellites follow the CubeSat standard, where a CubeSat is a modular satellite of standardized dimensions, assembled using primarily commercial, off-the shelf components. This provides an excellent opportunity for the launch of a Greek miniaturized satellite that is entirely built by University students and engineers. Through the QB50 program a launch opportunity and part of the science payload are provided whereas the development of each CubeSat and the ground station for communications and operations are built by the host institution. In this paper we present the objectives of the QB50 mission and the status of development of the Greek QB50 CubeSat.

1. Introduction: *Towards Satellite Miniaturization*

Following the general trend in technology for "smaller, faster, cheaper" designs, there is a continuing interest in exploring the lower limit of the size of a spacecraft capable of achieving a significant mission objective. The increasingly diminutive "small" satellites range from the micro-satellites (10-100 kg) of the 1980's and '90's, to the nano-satellites (1-10 kg) of recent years, and the pico-satellites (0.1-1 kg) of the near future. This trend for miniaturization is driven in part by the large launch costs of satellites of larger mass, but also by the development time and associated costs required for developing larger and more complex satellites, with customized components and interfaces of the satellite bus.

A key development in the process of satellite miniaturization has been the "CubeSat" concept: A CubeSat is a cube-shaped spacecraft, measuring 10 cm per side with a mass of ~1kg, which offers all the standard functionality of a normal satellite, such as on-board data handling and storage by an On Board Computer (OBC), an Electric Power Subsystem (EPS) including a battery and body-mounted solar panels, uplink and downlink telecommunications (COMMS) and Attitude Determination and Control Subsystem (ADCS). Several CubeSats can be attached to form a larger nano-satellite that can carry a technology package such as an instrument or sensor, with typically 2 cubes forming what is termed a 2-Unit or 2U CubeSat, of size $10\times10\times20$ cm and with a mass of ~2 kg and 3 cubes forming a 3U CubeSat. Started in 1999, the CubeSat Project began as a collaborative effort between California Polytechnic State University and Stanford University to develop common standards and procedures for building, testing and qualifying these CubeSats. Through this standardization, the project has enabled a design of nano-satellites that reduces cost and development time, while providing increased accessibility to space through sustaining frequent and inexpensive launches. All standards, assembly procedures, integration procedures, and testing procedures have been distributed to many developers worldwide, who develop multiple Commercial-Off-The-Shelf (COTS) as well as custom-made components for a number of applications. Presently, the CubeSat Initiative is an international collaboration of dozens of universities, institutes and private firms developing nano-satellites that contain scientific, private, and government payloads. CubeSats have also become very useful as research and educational tools: Their relatively low cost means that they become affordable within the context of laboratory equipment, and their relative simplicity means that systems and engineering principles can be taught in a clear fashion with direct relevance to systems engineering, as applied to bigger aerospace projects.

Another feature of CubeSats is that they are accompanied by a standard set of launch interface specifications, which have led to the development of P-POD, the Poly Pico-Satellite Orbital Deployer, a common interface between a launch vehicle and CubeSats. A common P-POD is capable of containing and deploying three individual 1U CubeSats, or a single 3U CubeSat, providing all essential interfaces and a spring-based CubeSat release mechanism. The P-POD has lead to a simplified integration with almost any launch vehicle and its standardization greatly reduces the possibility of interference with the primary payloads of a launch, ensuring that the CubeSats will deploy reliably; this, together with its small and modular design that allows it to fit in under-utilized spaces inside a launch vehicle has greatly enhanced CubeSat launch opportunities in recent years.

2. The QB50 CubeSat Initiative

QB50 is an innovative concept that is based entirely on CubeSats: It is a project funded by the European Commission through an FP7 grant, targeting to launch a network of 50 CubeSats in Low Earth Orbit (LEO), in order to study the Earth's Lower Thermosphere. Through QB50, universities worldwide were invited to submit proposals for their Cube-

Sat design and implementation in a highly competitive call. Out of the numerous submitted proposals, 50 universities were invited to join the project and send a satellite to space. All 50 CubeSats will be launched together on a single launch vehicle, with launch currently planned for 1/2/2016. Each team is responsible to build their own spacecraft, securing their own funds, and is also expected to downlink its satellite's data and uplink commands with its own ground station, while networks of ground stations are also envisioned and encouraged, in order to enhance coverage, satellite tracking and data volumes. By the time of launch it is expected that many of the QB50 ground stations in different parts of the world will be collaborating, linking their ground stations and providing nearly continuous uplink and downlink capability for all QB50 CubeSats, but also for other future missions.

The target of all satellites will be to study in-situ the temporal and spatial variability of a number of key constituents and upper atmosphere environmental parameters. The CubeSats will be launched from the same launch vehicle at an initial altitude of ~400 km with an inclination of 98 deg. Due to atmospheric drag, the satellites will gradually decelerate, spiraling down to the lower layers of the upper atmosphere. This will enable obtaining measurements throughout the entire Mesosphere – Lower Thermosphere and Ionosphere (MLTI) region, which, as described below, is a great step forward in MLTI research. When the satellites reach the lower and denser layers, the large temperatures that will develop due to enhanced friction will eventually lead to loss of satellite functionality and subsequently to melting and the loss of surface material from the spacecraft by evaporation. This is expected to occur in the Mesosphere, at altitudes between 80 and 100 km, where all meteorites ablate due to friction with the atmosphere.

3. DUTHSat: *A Greek participation in the QB50 initiative*

The Department of Electrical and Computer Engineering of the Democritus University of Thrace has a long-term involvement in space science and technology. It submitted a proposal to join the QB50 team in 2012, and currently DUTH is officially listed as one of the participating universities (https://www.qb50.eu/index.php/community). Participation in the QB50 consortium provides the science sensors and coordination of the project, whereas each participant of QB50 needs to design and develop their own CubeSat, securing funding through institutional or national funds. In addition, each team needs to contribute towards launch costs. For DUTHSat funding for the development of the satellite was secured through a competitive proposal to the "ARISTEIA" program, which is part of the Operational Program: Education and Lifelong Learning, a research grant that is co-funded by the European Social Fund (ESF) and National Resources and managed by the General Secretariat for Research and Technology (GSRT). Furthermore, the contribution towards launch costs was sponsored by Raycap S.A., a Greek company that manufactures and supports advanced solutions for telecommunications, renewable energy, transportation and other applications worldwide.

4. DUTHSat Components and Subsystems

Owing to its multi-national nature, a key aspect of the CubeSat initiative is that all critical components of the CubeSat are available as Commercial-off-the-shelf (COTS) components without export restrictions, contrary to most aerospace-qualified components. This significantly reduces costs, while the standardization of all subsystems has lead to greatly minimized integration efforts. However some COTS components that are commonly used by CubeSats in space have limited capabilities, such as low bit-resolution, high power consumption, and also are not radiation hardened: Space systems operate in conditions that involve plasmas and high-energy electrons, protons and heavier ions that are hazardous to the electronics of common technological systems, which are vulnerable to Single-Event Upsets (SEU), Single-Event Latchups (SEL) and Total Ionizing Doze (TID). The Space Research Laboratory of the Democritus University of Thrace (DUTH/SRL), with a long-term experience in the development of space ASICs components that are miniaturized, ultra-low-power, high-resolution and also radiation hardened, is demonstrating through DUTHSat solutions that can be used in any future CubeSat-based missions in more harsh environments than QB50, enhancing their capabilities and reliability, and also expanding the region in space where they can safely operate.

In the schematic of **Figure 1** we present an overview of the CubeSat design, including the power and data connections between different sub-systems. An overview of the design of the DUTHSat Subsystems and their relative positioning is shown in **Figure 2**. In further detail, the main DUTHSat subsystems include the following:

4.1 On-board Computer (OBC): The On Board Computer (OBC), the "brains" of DUTHSat, is responsible for all functions of the spacecraft, including deploying the antennas and mNLP booms, spacecraft telemetry data collection, attitude determination and control execution, constructing or deconstructing a file in order to upload or download it to the Ground Station, controlling the power in every subsystem, receiving and executing commands from the Ground Station, automated failure recovery, high-level system and payload control, etc. The OBC also monitors spacecraft temperature and housekeeping parameters, and plays a supervisor role for the power subsystem by interfacing with battery monitors and recording voltage and current levels of the batteries, automatically switching off non-critical subsystems in case of low levels of power. The OBC is interfaced with the Communications subsystem through which it receives ground station commands and transmits data and satellite status information. DUTHSat uses a CubeComputer OBC designed by Stellenbosch University, which is based on a high performance, low power 32-bit ARM Cortex-M3 based processor. Other features of the OBC include: PC104 bus connector, Flash Memory Data Storage, MicroSD card support, Power monitor/power-on reset, CAN bus interface, UART interface, SPI interface, GPIO pins, ADC interface and I^2C interface. Single Event Upset protection is implemented by means of an FPGA based flow-through EDAC, and Single Event Latchup protection is implemented by detecting and isolating latchup currents. For robustness, no operating system is used in the DUTHSat design. This decision creates several dif-

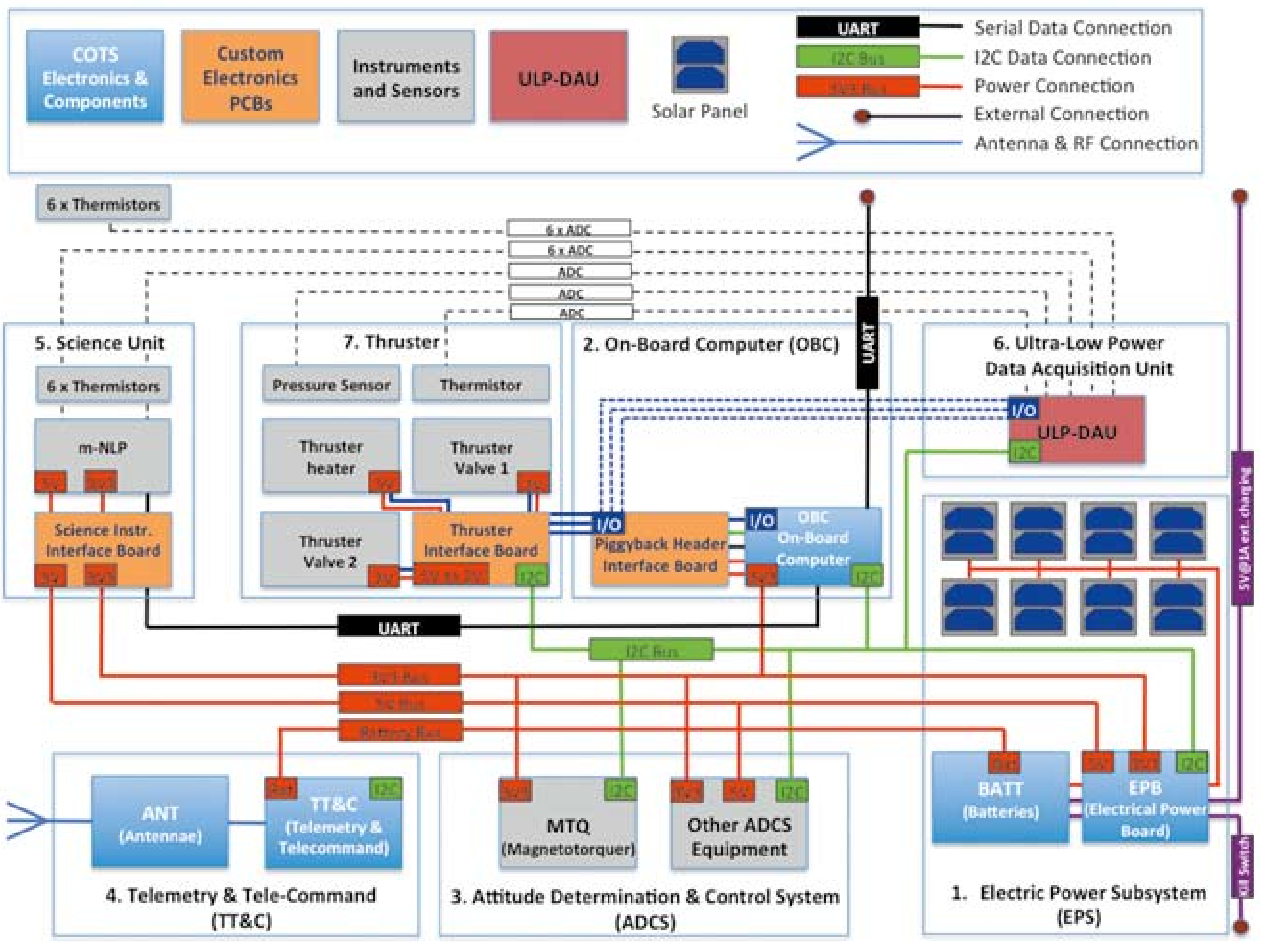


Figure 1: Overview of the DUTHSat subsystems, including power and data connections between different sub-systems.

ficulties in the design process, as all low level drivers (e.g. CAN,UART,SPI, GPIO, ADC,I2C) are created from scratch. Also, if an operating system is not used, techniques such as threading and schedulers that are used by default in every operating system cannot be used in the satellite. The advantages are that the code can be much more time and energy efficient, and that system engineering has much larger flexibility in the design of satellite operations.

4.2 Electrical Power Subsystem (EPS): The Electric Power Subsystem (EPS) includes high-efficiency solar panels placed at the sides of the CubeSat, a Power Distribution Module and Battery. Power is expected to be 4.6W at ambient temperature with a supply voltage of 3V3 and 5V. A Li-Ion battery of 2600mAh has been selected after extensive orbital and subsystem simulations. The power is supplied to all subsystems through the NanoPower P31U power supply designed by GOMSpace. The power capabilities of this power supply are for missions with power demands of up to 30W. The power coming from the solar panels and/or from the battery is used to feed the output power buses of 3.3V@5A and 5V@4A. Each of these buses has three individual output switches with over-current shutdown and latch-up protection. Finally, a heater is automatically switched on to protect the batteries from very low temperature and increase battery life.

4.3 Communications Subsystem: The Space Segment of the Communications Subsystem is formed from the antennas and the TRXVU VHF/UHF Transceiver, which enables the system to have full duplex capabilities with telemetry, telecommand and beacon capabilities on a single board. The peak power consumption of the transceiver is < 1.7W while it only uses <0.2W on receive only mode with an average transmit power of 22dBm. The transmitter frequency is controlled from the installed crystal and ranges between 400-450 MHz while the receiving frequency ranges between 130-160 MHz. DUTHSat's communication frequencies are 436.420 for downlink and 145.810 for uplink. The modulation scheme for downlink is RRC-BPSK (Root-Raised Cosine Binary Phase-Shift Keying). For uplink it will use the AFSK scheme on FM with 1200 b/s bit rate. The supported data rates from TRXVU are 1200 to 9600 bits per second with the protocol AX.25 for the communication channel. The antennas have a crossed UHF/VHF dipole configuration and deploy from inside an enclosure through a command from the OBC that is issued upon ejection of the satellite from its P-POD.

4.4 Attitude Determination and Control Subsystem (ADCS) and GPS: An Attitude Determination and Control Subsystem is used by DUTHSat, in order to achieve the following: a) Alignment of the long axis of the satellite with the velocity vector so that the

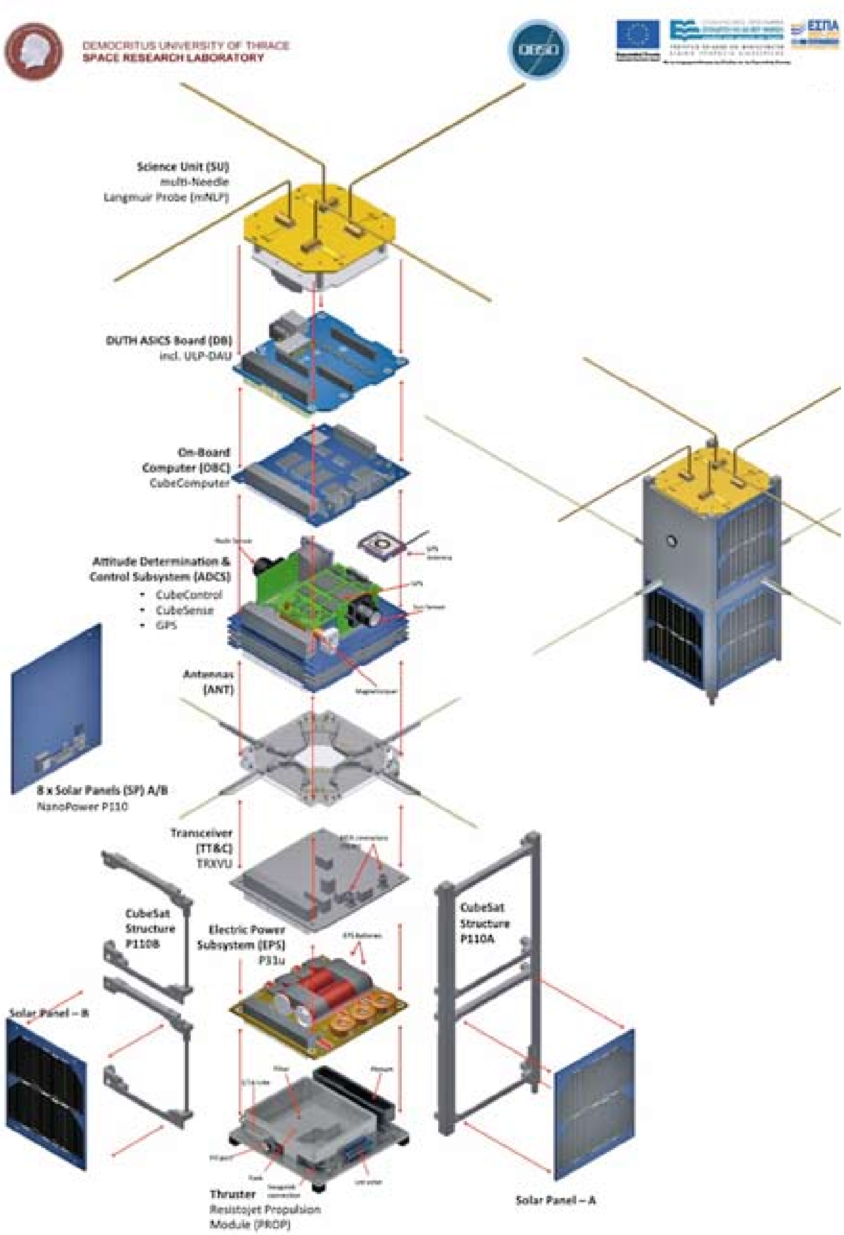


Figure 2: *CAD drawings of the subsystems of DUTHSat (left) and a drawing of the final, assembled satellite (right) with deployed antennas and Langmuir Probe booms.*

experiment package is pointed in the direction of motion (velocity-vector stabilization). b) Control of the attitude so that there is less than 5° between the long axis of the satellite and the velocity vector, down to 250 km altitude (velocity-vector pointing accuracy). c) Measurement of the satellite velocity-vector attitude to within ±1° at the time of receiving data from the payload (velocity-vector attitude knowledge). d) De-tumbling and stabilization during commissioning phase within 2 days. e) Recovery from tip-off rates of up to 100°/sec (tip-off rate recovery). An ADCS that is tailored to the above needs has been developed at the University of Surrey together with Stellenbosch University. This ADCS is modular and in its full configuration it can achieve 3-axis stabilized attitude control, accurate position, velocity & time from a GPS, <1° roll, pitch, yaw stability. The sensors that are used in the various modes of operation of the ADCS include a Y-axis aligned rate sensor, Magnetometer, Coarse Sun Sensors, Sun Sensor, Nadir Sensor. This configuration has relatively low power consumption (2W for 3-axis mode), compact size (0.4U), and low cost. DUTHSat will also feature a GPS receiver for timing and position determination purposes. The Novatel OEM615 GPS receiver module with special Space Firmware is used. The GPS receiver will also interface to the ADCS to assist the attitude determination process as well as in obtaining a timing stamp for the CubeSat.

4.5 Ground Station at DUTH: The Ground Station of DUTHSat is located at the laboratories of the Department of Electrical and Computer Engineering of the Democritus University of Thrace, at address: Vasilisis Sofias 1, 67100, Xanthi, at a Latitude of 41° 08'32.81" and a Longitude of 24° 53'24.83"**.** The equipment used in the ground station together with the setup and interconnections are given in the schematic of **Figure 3a**. The antennas and the indoor equipment of the ground station are shown in **Figure 3b** and **3c**.

4.6 Satellite bus, Structure and Thermal Subsystem: For the QB50 project a 2U CubeSat structure is baselined, which has an aluminum chassis with an outside envelope of 100×100×227.0 mm. The QB50 Science Unit will be accommodated at one end of the CubeSat structure, in the spacecraft ram velocity direction. The thermal control subsystem is particularly important in the QB50 mission: During the gradual re-entry large temperatures will develop, and eventually the CubeSat will ablate due to friction with the upper atmosphere. The operational range of the primary Science Unit is –20° to +40°, and, in order to extend measurements at as low altitudes as possible within the largely unknown lower layers of the Thermosphere, thermally conducting plates will be used in the design to serve as a passive heat dissipation and thermal control system: this will be done by attaching struts, plates and heat conducting wires, which in turn will be attached to a heat dissipation plate, at the lower end of the CubeSat (anti-ram direction).

4.7 Primary Payload: multi-Needle Langmuir Probe, Thermistors, Magnetometer. The main payload of DUTHSat is a multi-needle Langmuir probe system. Langmuir probes have been widely used to determine plasma electron density and temperature in space. The Langmuir probe works by placing an exposed conductor in a plasma, biasing it relative to a reference potential and measuring the collected current. A swept bias probe sweeps the bias voltage from a negative to a positive value, and the collected probe characteristic makes it possible to determine

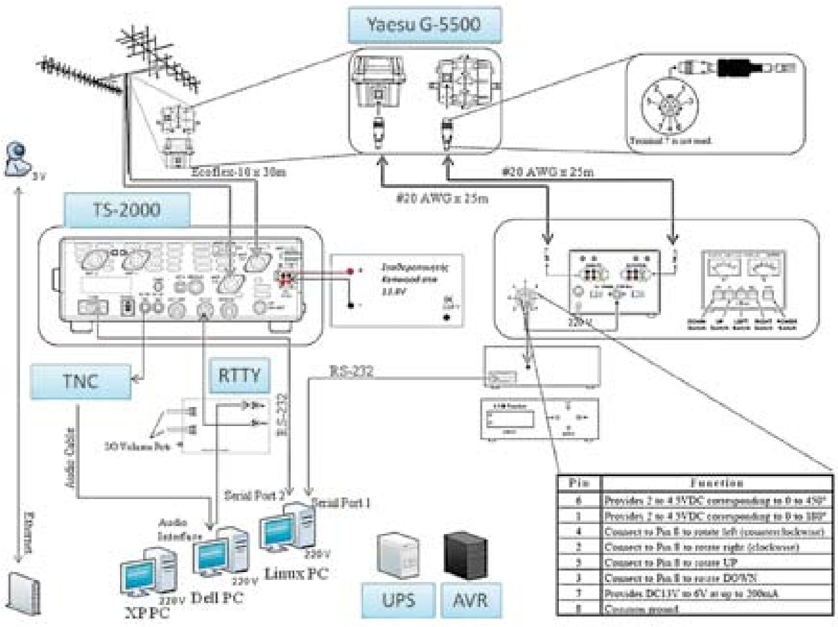


Figure 3: *a) Layout of the Ground Station equipment at DUTH; b) Antennas of the Ground Station and c) the indoor equipment at DUTH.*

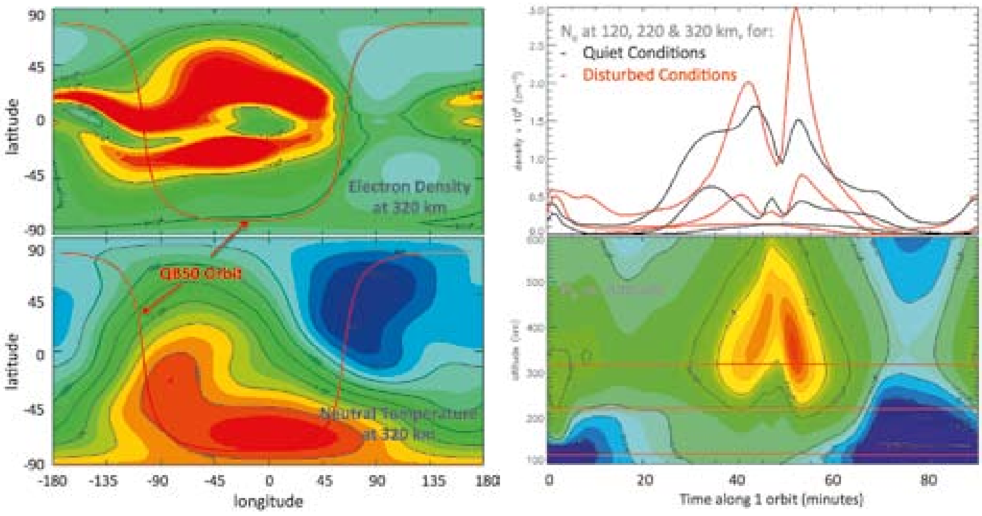
electron density n_e, electron temperature T_e and the spacecraft potential. In addition, Thermistors will be monitoring the Temperature at various locations on the spacecraft and a magnetometer will provide magnetic field measurements along the orbit.

4.8 Secondary Payload: DUTH ASICs Board and ULPDAQ chip. In addition to the mNLP Science Unit, DUTHSat will house an Ultra-Low Power Data Acquisition Unit, ULP-DAU, which is designed as a prototype smart-sensor data acquisition system-on-a-chip for use particularly in micro/nano/pico-satellite missions, but with features that will also be attractive to larger missions. This prototype will be flown in the DUTH/SRL developed nano-satellites of the CubeSat standard so as to demonstrate that the boards used currently by CubeSats can be replaced with ASICs, drastically reducing the size, weight and power requirements of the CubeSat avionics and I/O units. Thus, this mission also provides an opportunity to flight-test ASICs microchips developed at DUTH, which would accelerate their acceptance as standard and flight-proof components for other larger space missions; it is expected that the DUTH ASICs microchips will prove to be an invaluable asset in micro/nano/pico-satellite missions, where space, power and reliability are critical.

5. Science Questions and Educational Aspects of QB50

5.1 Motivation – Why Study the Upper Atmosphere? The Earth's upper atmosphere, which includes the Mesosphere and Lower Thermosphere, together with the Ionosphere (MLTI) is a complex dynamical system, sensitive to effects both from above and bellow. From above, the sun produces dramatic effects and significantly alters its energetics, dynamics and chemistry in a way that is not entirely understood; and from below, atmospheric motions are dominated by poorly understood gravity waves and tides that both propagate through and dissipate in this region. The response of the upper atmosphere to global warming in the lower atmosphere is also not well known: whereas the increase in CO_2 is expected to result in a global rise in temperature, model simulations predict that the thermosphere might actually show a cooling trend and a thermal shrinking of the upper atmosphere, and might play a role in energy balance processes. However, despite its significance, the MLTI region is the least measured and least understood of all atmospheric regions: Situated at altitudes from 50 to ~300 km the MLTI region is too high for balloon experiments and too low for orbital vehicles, due to significant atmospheric drag. Even with the new advances from remote-sensing measurements from missions at higher altitudes, this remains an under-sampled region with many remaining open questions. Thus it is not surprising that among scientists the MLTI region is often called (quite appropriately) the "Agnostosphere". The continuous and ever-increasing presence of mankind in space, and the importance of the behavior of this region to multiple issues related to aerospace technology, such as orbital calculations, vehicle re-entry, space debris lifetime etc., make its extensive study a pressing need. The QB50 mission targets to perform measurements in exactly this region, and, though instrumentation will be limited due to spacecraft size and power, the combination of the large number of in-situ measurements from all 50 CubeSats will be able to provide answers to some of the questions on the sequence of events that lead to MLTI heating and expansion, as well as its composition.

5.2 Upper Atmosphere Electrodynamics Modeling: DUTH/SRL has ex-



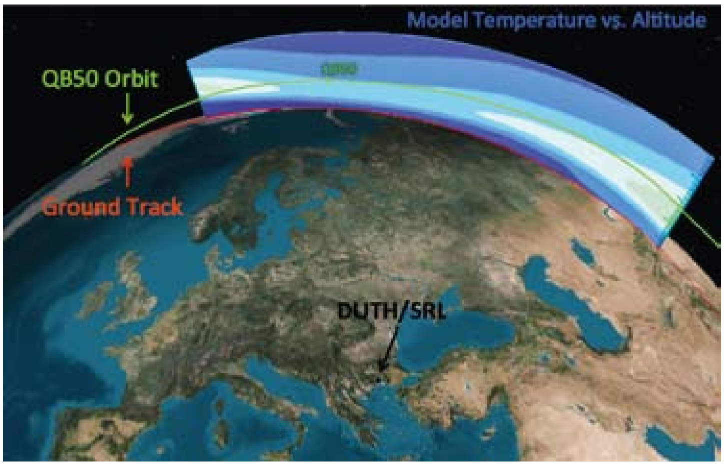


***Figure 4:** DUTHSat measurement simulations: a) Electron density (Ne) over one orbit at three altitudes, for quiet and disturbed conditions; b) Electron Density and Neutral Temperature vs. latitude and longitude and DUTHSat ground track; c) Model temperature vs. altitude at high latitudes together with a sample QB50 orbit. The location of the ground station at the Democritus University of Thrace is also shown.*

tensive expertise in modeling and data analysis in the Mesosphere-Lower Thermosphere-Ionosphere (MLTI); DUTH/SRL has undertaken and has recently successfully completed an ESA project titled "Electrodynamics Simulations in support to Future MLTI Missions", aiming to investigate the range of variability of key variables in the MLTI. Through this project a number of key MLTI models were run for a range of input conditions (solar, geomagnetic, seasonal) and the results from the models were intercompared and also compared against measurements. The models and corresponding variables investigated are listed below:

- **TIE-GCM**(**T_n**,T_i,T_e,U,W,**O**,**O_2**,NO, N(^{4}S),N(^{2}D),O^+,O_2^+,N_2^+,NO^+,N^+,N_e,G-Potential,E-Pot)
- **GUMICS-4** (N,P,U,T,MF,EF,$\Sigma_{Pedersen}$, Σ_{Hall}, E-Potential, PP power, Joule heating, FAC)
- **IRI-07** (**N_e**,T_e,T_i, **H^+**, **He^+**, NO^+, O^+, O_2^+, ion drifts, TEC, F1 and spread-F probability)
- **NRLMSISE-00** (T_n, He, **O**, **O_2**, **N_2**, Ar, H, N, Density, collision frequency)
- **CHAMP Currents Model** (Horizontal and Field Aligned Currents)
- **Alpha parameter Model** (Pedersen/Hall conductivity ratio)
- **HWM-07** (Zonal and Meridional winds)

In the list above we mark in **red** the MLTI variables that will be sampled by the QB50 CubeSats. The analysis performed at DUTH/SRL will allow for the optimal calibration of the QB50 Science Units and will play a key role in the data analysis, through comparisons of the measurements of all 50 QB50 sensors with current state-of-the-art models. Some examples of running QB50 orbits through the above models and sampling electron density and neutral temperature through the models are presented in **Figures 4a** and **4b**, as described. An overview of the DUTHSat orbit together with a cut-out of modeled temperatures as a function of Latitude, Longitude and Altitude is shown in **Figure 4c**.

5.3 Educational Aspects of the QB50 CubeSat Initiative: Together with its scientific impact, the QB50 initiative has an important educational aspect: the QB50 CubeSats are being designed and built by a large number of young engineers, supervised by experienced university staff and guided by the QB50 project through formal reviews and feedback. At the same time, space mission analysis and design procedures and standards are followed, introducing in the optimal way young engineers in a broad variety of aspects of space projects. These engineers will not only learn about space engineering in theory but will leave their universities with hands-on experience. At the Democritus University of Thrace, the design and construction of the satellite is accompanied by a series of classes on Space Systems, Space Applications and Space Electrodynamics; furthermore, multiple undergraduate and graduate diploma theses are focused on Satellite Subsystems. The students that participate in this project have a unique opportunity to follow all phases of a space mission, from design to spacecraft development, integration with instruments, testing, launch, tracking and finally to receiving and analyzing valuable scientific data.

Figure 4: Graduate students of the Department of Electrical and Computer Engineering of the Democritus University of Thrace are working on the assembly of DUTHSat in a Controlled Environment area of the Laboratory of Electromagnetism and Space Research.

6. Status, Schedule and Satellite Operations

Currently, DUTHSat is undergoing its "flat-sat" tests, which involves interconnecting all subsystems of the satellite "flat" on the laboratory bench, so that all functional tests can be conducted, before assembling and integrating the Flight Model with the CubeSat structure (**Figure 5**). After integration, the Flight Model will undergo a rigorous set of tests (functional, electrical, thermal, vacuum and vibration), to ensure that the satellite will be able to withstand the harsh space environment, including the intense vibrations during launch. These tests will be followed by pre-launch operations and final checkout tests, which will include a flight-like full-satellite testing; this will include testing satellite operations on internal batteries and solar arrays, with all beacons and devices on, testing communications with the Ground Station, telemetry and payload data collections, etc. After testing phase is completed, DUTHSat will be shipped to the QB50 coordinators and participating entities for integration with the CubeSat deployer that will release each satellite individually. The CubeSat deployer with all 50 satellites will then be shipped to the launch site for integration with the launcher. The early in-orbit operations and commissioning activities will include an Initialization Phase, in which the DUTHSat antenna is deployed, radio communication with the Ground Station at DUTH are established and the initialization commands are issued. Subsequently, during the Characterization and Commissioning Phase, DUTHSat functions and overall health will be monitored. This phase also includes achieving attitude stabilization and testing DUTHSat instruments. After achieving attitude stabilization, DUTHSat will move on to the Mission Phase, switching on the instruments in the appropriate mode and gradually maximizing the amount of science data downloaded and reducing the amount of housekeeping parameters.

Acknowledgements

Together with the core team of professionals and graduate students listed above, a number of undergraduate students have contributed to various phases of the development, testing and assembly of DUTHSat; these include: Stergios Fraggos, Vassilios Stathopoulos, Spyridon Galanoulis, Dimitrios Moutzikis, Dimitrios Siafarikas, Theodoros Kalogiannis, Eleni Tsani, Evaggelia Afendra, Konstantinos Katsinos, Anastasios Lazaridis. We are also very thankful to the Radio Amateur Club of Xanthi, SZ7XTH, and in particular to Giorgos Tsataltzinos, Akis Pantazidis, Kostas Kalaitzidis. The project is co-funded by the European Social Fund (ESF) and National Resources under the Operational Programme "Education and Lifelong Learning", program "ARISTEIA" of the General Secretariat for Research and Development. Finally, we are grateful to Raycap, S.A., a Greek company in Drama, for sponsoring the launch costs of DUTHSat.

Extragalactic X-ray binaries: a tool for understanding accreting binary formation and evolution

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Introduction: lessons from our Galaxy

Accreting binaries are systems consisting of a compact object (black hole, neutron star, or white dwarf) that is accreting material from a companion (donor) star. They are an invaluable tool for Astrophysics, since they provide insights into fields such as the formation and demographics of compact objects and the evolution of binary stellar systems. In addition since they are the progenitors of short γ-ray bursts, and gravitational waves from in-spiraling binary stellar systems, their study is important for understanding and modeling these types of sources.

Depending on the nature of the donor star they are classified into: (a) High Mass X-ray binaries (HMXBs) if the donor is an early-type star (typically a main sequence O,B star or a supergiant), and (b) Low Mass X-ray binaries (LMXBs) if the donor is a low-mass star (typically ~1M⊙ or less). A third less populous category are the Intermediate Mass X-ray binaries with donor stars of masses between 1 and ~3 M⊙.

The accretor in these binary systems, can be any type of compact objects: white dwarfs, neutron stars, or black holes. The compact objects in HMXBs are predominantly pulsars, although there are a few well know black hole X-ray binaries (e.g. Cyg X-1, LMC X-1, LMC X-3; McClintock & Remillard 2006). On the other hand the compact objects in LMXBs are either neutron stars or black holes, or for low-luminosity systems, they can be white dwarfs.

Detailed studies of the X-ray binary populations in our Galaxy with the Rossi X-ray Timing Explorer (RXTE), as well as other observatories operating at harder X-ray bands (e.g. INTEGRAL, *Swift* BAT), have led to the identification of ~115 HMXBs and ~185 LMXBs so far (e.g. Liu et al. 2006, 2007). These studies also showed that the HMXBs are associated with the Galactic disk, while the LMXBs are preferentially located at the Galactic bulge and globular clusters (e.g. Grimm et al. 2002). This directly links these binary populations with early-type and late-type stars, respectively. In fact HMXBs are associated with young stellar populations (<100 Myr), while LMXBs are associated with older ones (>1 Gyr old).

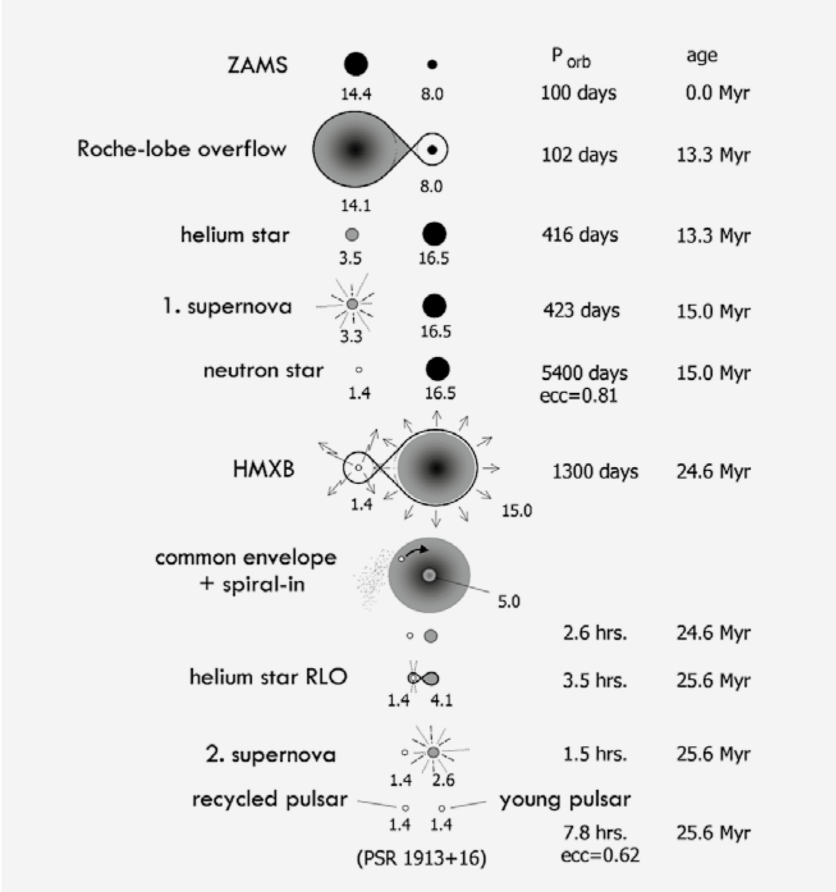


Figure 1: A schematic diagram showing the different stages in the evolution of a HMXB (*left*) and a LMXB (*right*) X-ray binary (adopted from Tauris & van den Heuvel, 2006).

Systematic observations since the dawn of X-ray Astronomy also showed that the accreting binaries can have either persistent or transient activity. A source is characterized as persistent if it has been active since its discovery, while transient sources exhibit long periods of inactivity interupted by shorter outbursts (e.g. Psaltis 2005, for a review). In addition, even when X-ray binaries are active, they go through different accretion states which affect their X-ray luminosity, broad-band spectra, and jet launching (e.g. Done et al. 2007; Remillard & McClintock 2006; for extensive reviews).

The wealth of data for Galactic accreting binaries that can be obtained from their detailed observations (e.g.

donor and compact object types and mass, orbital separations and eccentricities, evolutionary state of the donor star), in combination with advances in our understanding of single and binary stellar evolution, led to the development of a general framework for their formation and evolution (e.g. Tauris & van den Heuvel, 2006). In the standard picture a binary stellar system consistinng of a star and a compact object, will enter an accretion phase only if the orbital separation of the two objects is small enough to initiate mass transfer either through a stellar wind or Roche-lobe overflow (RLOF). Mass transfer in HMXBs can be achieved by either mechanism (with wind accretion being more common), while in LMXBs Roche-lobe overflow is the only option. Given the small mass of the stars in LMXBs, in order to enter a RLOF phase the orbit of the binary system needs to shrink dramatically. This can be achieved, by several different mechanisms such as common envelope, magnetic breaking, and tidal evolution (e.g. Tauris & van den Heuvel, 2006). The most efficient mechanism is common envelope, during which the compact object (or the less massive star if a compact object has not formed yet) is engulfed by the tenuous envelope of the other object which has evolved off the main sequence. If the energy released during the orbital decay of the engulfed object is larger than the binding energy of the envelope, then the envelope can be ejected and the system survives, but with a much smaller orbital separation. Otherwise the two objects merge and the binary system is destroyed (e.g. Taam & Sandquist 2000). This is a critical phase in the evolution of a binary system since it determines which systems will survive and what will be the orbital parameters of the surviving system.

Once the mass transfer between the star and the compact object is initiated, we have the X-ray emitting phase. This phase lasts up to several Myr for HMXBs (owing to their high mass loss rates and fast nuclear evolution timescale) and up to several Gyr for LMXBs. Fig. 1 shows the general evolutionary paths for a HMXB and a LMXB, indicating the different stages in their evolution. However, the exact evolutionary path of an accreting binary depends critically on the metallicity and inital mass of its stellar components, and the initial orbital parameters of the system which ultimately determine its evolution.

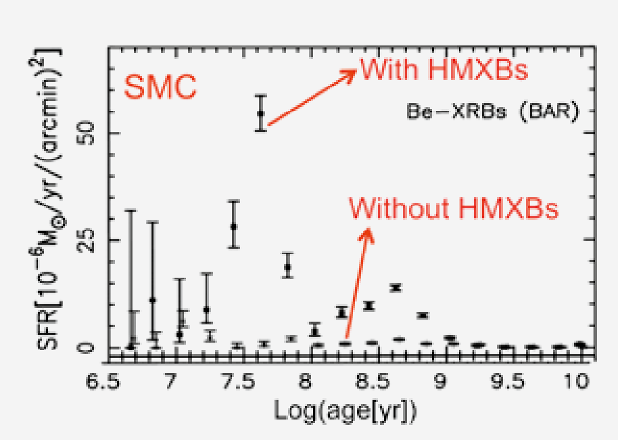


Figure 2: Comparison of the star-formation rate per unit area as a function of time in regions of the SMC with and without HMXBs. The regions which contain HMXBs show a burst of star formation ~30-60 Myr ago (Antoniou et al. 2010).

Therefore, studies of Galactic accreting binaries and their properties (e.g. populations of compact objects, donor stars, orbital separations, eccentricities) have led to major advances in our understanding and the development of a general framework for their evolution, mass transfer mechanisms, and accretion processes. However, difficulties in measuring their distances, and the obscuration of a significant fraction of the Galaxy's volume due to the interstellar material, hampers their study as a population. Furthermore, our Galaxy offers a limited range of stellar populations and as a result it gives us only a partial picture of the different types of accreting binaries. The only way to remedy these limitations is to study accreting binaries in nearby galaxies.

Studies of extragalactic binaries

The first imaging X-ray observations with the *Einstein* and subsequent X-ray Observatories (ROSAT, ASCA, BeppoSAX) showed that the Local Group galaxies also host a large number of discrete sources with X-ray properties similar to those of Galactic accreting binaries (e.g. Fabbiano 1989). Observations of more distant galaxies were limited to measurements of their integrated X-ray emission (e.g. Fabbiano 1989; Read & Ponman 2001; O'Sullivan et al. 2001; Ranalli et al. 2003), and their most luminous X-ray sources (e.g. Roberts & Warwick 2000).

A major revolution in the study of accreting binary populations came with the launch of the *Chandra* X-ray Observatory in August 1999 (Weisskopff et al. 2000). Its sub-arcsecond resolution (0.5″ FWHM for an on-axis source) enabled the detection of discrete X-ray binaries in nearby galaxies down to luminosities of 10^{36}-10^{37} erg/s, similar to those of active binaries in our Galaxy. We can reach these limits out to distances of ~25 Mpc (or higher for more luminous objects). This is an increase of the available cosmic volume for studies of resolved binaries by more than two orders of magnitude compared to previous X-ray observatories. Therefore, for the first time we are able to study and compare the populations of accreting binaries in environments different than our Galaxy. Furthermore, its sub-arcsecond resolution allows the association of the X-ray sources with sources in other wavelengths, which is crucial for their classification.

Next we will discuss some indicative results from recent studies of accreting binary populations in nearby galaxies.

a. A deep census of the X-ray binaries in the Small Magellanic Cloud

The Small Magellanic Cloud (SMC) is a trove of HMXBs. Systematic observations with the RXTE, ROSAT and ASCA observatories identified more than 50 X-ray pulsars in the SMC. Subsequent observations with the *Chandra*, XMM-*Newton*, and INTEGRAL observatories raised this census to ~70 X-ray pulsars (see e.g. Sturm et al. 2013), rivalling the population of X-ray pulsars in binary systems in our Galaxy.

Spectroscopic follow-up of the optical counteparts of the X-ray sources in the SMC showed that its HMXB population is dominated by Be X-ray binaries (e.g. Maravelias et al. 2014; Antoni-

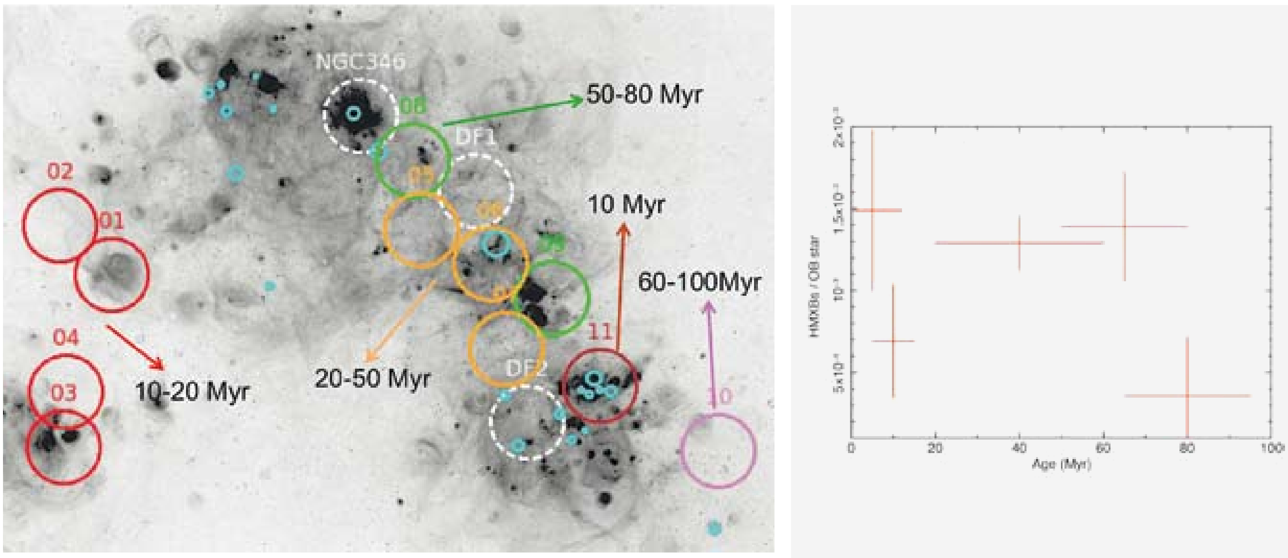


Figure 3: (Left) The fields comprising the Deep *Chandra* Survey of the SMC overplotted on an Hα map from the MCELS survey (Smith et al. 1999, http://astro.wsu.edu/worthey/html/mcsurvey.html). Circles of different colours indicate fields containing stellar populations of different ages. The small cyan circles show the location of Supernova Remnants (SNRs) in the SMC (from the catalogue of Badenes et al. 2010).

(Right) The number of HMXBs per OB star in regions of the SMC with stellar populations of different ages (Antoniou et al. in prep). We see an increase in the fraction of HMXBs (i.e. their formation efficency) between ~30-70 Myr (the excess of sources in the first bin is due to a population of colliding-wind binary stars).

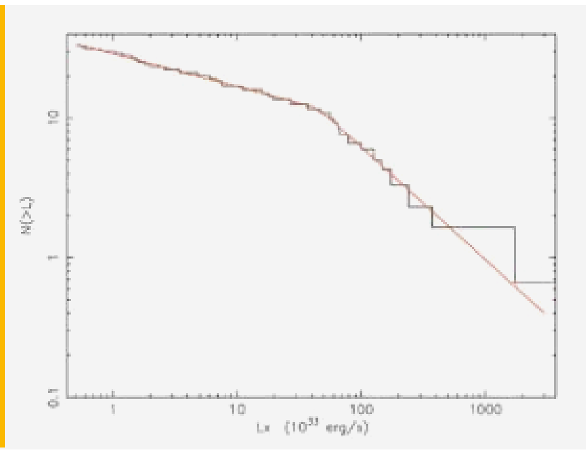
ou et al. 2009a; Mc Bride et al. 2008). These systems consist of a pulsar and a Be star (i.e. Main sequence stars of B spectral type, which exhibit a transient equatorial decretion disk responsible for the production of Balmer emission lines), and they are the dominant population of HMXBs in our Galaxy (see Reig 2013 for a review). During the periastron passage, the pulsar plunges through the decretion disk and accretes material, resulting in outbursts with typical luminosities of $\sim 10^{35} - 10^{37}$ erg/s.

The identification of the optical counteparts of these X-ray sources has also enabled their association with a particular star-formation episode in the SMC that took place ~25-60 Myr ago (Fig. 2; Antoniou et al. 2009b; 2010). By comparing the star-formation rate during this episode with the number of X-ray binaries observed today, we find that the formation efficiency of overall HMXB populaion in a 25-60Myr old stellar populations is 3×10^{-3} systems $M_\odot^{1}$ Myr^{-1} (Antoniou et al. 2010).

A new more systematic study of the SMC performed with *Chandra*, extends the previous investigations in depth (reaching luminosities of $\sim 10^{33}$ erg/s) while probing a wider range of stellar populations with ages between 10 and 100 Myr (Fig.3). The goal of this study is to extend the first observational constraints on the formation efficiency of HMXBs, and measure for the first time their formation efficiency as a function of time (Antoniou et al. 2015, in prep): Figure 3, shows the number of X-ray binaries per OB star as a function of the stellar-population age in the regions they are found. We clearly see an increase in the formation efficiency of HMXBs in regions with stellar populations of ages 30-70 Myr, in agreement with expectations from theoretical models for the formation and evolution of HMXBs (e.g. Fragos et al 2013a; Linden et al. 2009; Dray 2006).

These observations also allowed us to probe the faint-end of the luminosity distribution of X-ray binaries down to unprecedented depth, covering the entire population of active sources and reaching the luminosity levels of those in quiescence. The X-ray luminosity function (XLF) of HMXBs in the SMC (Fig. 4) shows a clear break at luminosities around $\sim 4\times10^{34}$ erg/s. This break confirms previous results from shallower surveys, mainly with XMM-*Newton* (Shtykovskiy & Gilfanov 2005; Sturm et al. 2013), which have been interpreted as evidence for the onset of the propeller effect (i.e. the centrifugal inhibition of accretion due to the interaction of the pulsar magnetic field with the accretion flow; Illarionov & Sunyaev 1975).

Figure 4: The cummulative XLF of HMXBs in the SMC from the Deep *Chandra* Survey of the SMC (see Fig. 3). We see a clear break at an X-ray luminisity of $\sim 4\times10^{34}$ erg/s, which has been interpreted as evidence for the onset of the propeller effect (Antoniou et al. in prep).



b. Studies of accreting binaries in other galaxies

Star-forming galaxies

Extension of these systematic studies to other galaxies gives us the opportunity to broaden our census of accreting binary populations to a wider range of galactic environments. The first investigations of X-ray binary populations in nearby starburst galaxies showed that their cummulative XLFs can be decsribed by a power law ($N(>L) = AL^{-\alpha}$) with an index α~0.5 and normalization proportional to the star-formation rate (e.g. Mineo et al. 2012; Zezas et al. 2007; Fabbiano 2006; Ott et al. 2005).

Similar studies in spiral galaxies showed that the XLF of their X-ray source populations changes between the disk and the bulge regions. The cummulative XLF of X-ray sources associated with the disk is well described by a power law similar to that of starburst galaxies (although often with a steeper index; e.g. Mineo et al. 2012; Fabbiano 2006). Furthemore, there is evidence for systematic changes of the index between the arm and the interarm regions, with the latter showing steeper XLFs (e.g. Sell et al. 2011; Kong et al. 2003; Soria et al. 2003). These results strongly suggest a dependence of the XLF of the accreting binaries on the stellar population age.

In the case of sources associated with the bulge (which are predominantly LMXBs), their XLF is described by a broken power law similar to those observed in elliptical galaxies (e.g. Fabbiano 2006, and references therein)

$$N(>L) = \begin{cases} AL^{-\alpha_1} & (L \geq L_b) \\ AL_b^{\alpha_2-\alpha_1}L^{-\alpha_2} & (L < L_b) \end{cases},$$

where $L_b \cong 5\times10^{38}$ erg/s, is the energy of the break-point. In this case the normalization *A* depends on the stellar mass, which is dominated by the older stellar populations. These results will be discussed in more detail in the section on elliptical galaxies.

The comparison of the XLFs obtained from a sequence of observations of the Antennae and M81 galaxies, showed that despite the variability of the individual sources, the shape of their XLF does not show significant variations. This result is particularly important since it demonstrates that a single observation of a galaxy gives us a representative picture of its X-ray binary populations (Sell et al. 2011; Zezas et al. 2007).

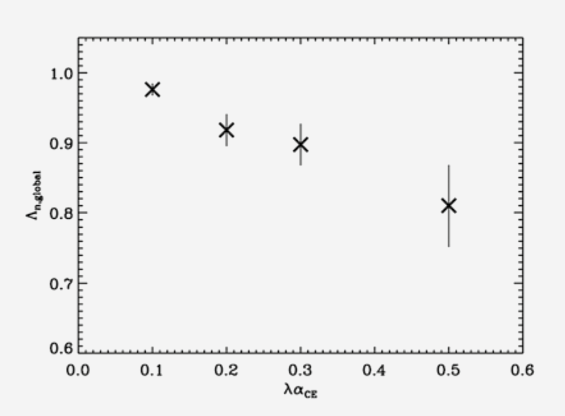


Figure 5: The combined likelihood from fits of the XLFs of 12 nearby galaxies with synthetic XLFs from population synthesis models, as a function of the common envelope ejection efficiency $\lambda\alpha_{CE}$, one of the free parameters in these models. We see that very low values of $\lambda\alpha_{CE}$ are required to fit the data (figure from Tzanavaris et al. 2013).

The development of state-of-the-art accreting binary population synthesis models (e.g. Hurley et al. 2002; Belczynski et al. 2008) allows us to use the observations of populations of X-ray binaries in nearby galaxies in order to constrain their formation and evolution pathways (e.g. Fragos et al. 2008; Linden et al. 2010). These tools can model the populations of accreting binaries for a given star-formation scenario, while accounting for the different physical processes during their evolution (e.g. conservative and non-conservative mass transfer, angular momentul loss via stellar winds, effects of magnetic breaking and tidal circularization; see e.g. Fragos et al. 2009; Belczynski et al. 2008; Tauris & van den Heuvel 2006;).

We can constrain the physical parameters that influence these physical processes (and hence determine the formation and evolution pathways of accreting binaries) by comparing the observed XLFs with those of the modeled populations for different values of these parameters. Such parameters include the shape of the stellar Initial Mass Function (IMF), the distribution of the initial mass ratio of the binary system components ($q \equiv M_{donor}/M_{CO}$), the stellar wind strength, the magnitude of supernova kicks, or the efficiency of the common-envelope ejection (which is parameterized by the product $\lambda\alpha_{CE}$ of a parameter λ describing the density profile of the stellar envelope, and the fraction α_{CE} of the released orbital energy that is used to eject the envelope; e.g. Ivanova et al. 2013). The latter is a notoriously difficult to constrain parameter.

The first such systematic effort was based on the comparison of the XLFs for a sample of 12 nearby galaxies with well determined star-formation histories, and deep *Chandra* observations which reach luminosities as low as 10^{37} erg/s (Tzanavaris et al. 2013). At this luminosity limit we observe the vast majority of outbursting X-ray sources, which allows for meaningful comparisons with population synthesis models. Despite the significant number of X-ray binary formation and evolution parameters (>10) and the complexity of the physical processes involved, previous studies showed that population synthesis models are sensitive only on a small number of parameters. Therefore, these comparisons can be used to reject binary evolution parameters which are inconsistent with the observed populations (e.g. Fragos et al. 2008; Tremmel et al. 2013; Fragos et al. 2013a) and thence constrain accreting binary formation and evolution channels.

In fact, our analysis of the sample of nearby galaxies showed that the same X-ray binary formation and evolution parameters fit almost unanimously the XLFs of accreting binaries in all galaxies in this sample, which sets self-consistent constraints on these parameters. For example this process showed that a common envelope ejection efficiency of $\lambda\alpha_{CE} = 0.1$ (Fig 5), and an IMF with an exponent of –2.7 best describe the observations (Tzanavaris et al. 2013).

Elliptical galaxies

Elliptical galaxies are a prime target to study clean populations of LMXBs. The first such studies showed that their LMXBs are associated either with globular clusters (GCs) or with field stars (e.g. Fabbiano 2006; Kundu 2002). This result revived a long-standing debate between two competing models for the origin of field LMXBs: (a) evolution of binary stellar systems in situ, or (b) formation of LMXBs by dynamical interactions between stars in dense GCs which are later deposited in the field either through ejection, or by disruption of the GCs (e.g. Grindlay 1984). Support for the latter model comes from studies of X-ray sources in GCs in our Galaxy, M31, and elliptical galaxies (e.g. Sivakoff et al. 2007; Peacock et al. 2010), which showed a preference for X-ray sources to be associated with more compact and massive GCs. These studies also showed that accreting binaries are more likely to be associated with the red sub-populations of GCs, which is interpreted as the result of the dependence of the numbers and mass of red giants on metallicity (e.g. Ivanova et al. 2013) .

The correlation between the number of LMXBs and the specific frequency S_N of GCs in elliptical galaxies[1], or the radial distribution of LMXBs, GCs, and star-light, have been used to address the origin of the field LMXB populations in elliptical galaxies[2] with either contradicting or inconlussive results so far (e.g Kim et al. 2009; Fabbiano 2006; Irwin, 2005).

As described earlier, the LMXB XLFs above $\sim 10^{37}$ erg/s are represented by a broken power law with two break points (Fig. 6). A high-luminosity break at $\sim 5\times 10^{38}$ erg/s (e.g. Gilfanov 2004; Kim & Fabbiano 2004), has been interpreted as the transition from neutron star to black-hole LMXBs, or the result of a cutoff in the high-luminosity end of the XLF. A lower-luminosity break at $\sim 5\times 10^{37}$ erg/s has been interpreted, on the basis of population synthesis models, as the signature of a population of neutron-star LMXBs with red-giant donors (Kim et al. 2009). Recent work on the XLFs of elliptical galaxies with stellar population of different ages, showed that younger elliptical galaxies have an excess of LMXBs per unit K-band luminosity (a stellar mass proxy), and subsequently higher integrated X-ray luminosities than older elliptical galaxies (Fig. 6; Lehmer et al. 2014; Kim & Fabbiano 2010; see also Zhang et al. 2012, who report the opposite behaviour).

1. The specific frequency S_N is defined as $S_N \equiv N_{GC} 10^{0.4(MV+15)}$, i.e. the number of GCs normalized to a fiducial galaxy with MV = –15mag
2. The S_N in late-type galaxies is too low to explain the observed numbers of LMXBs.

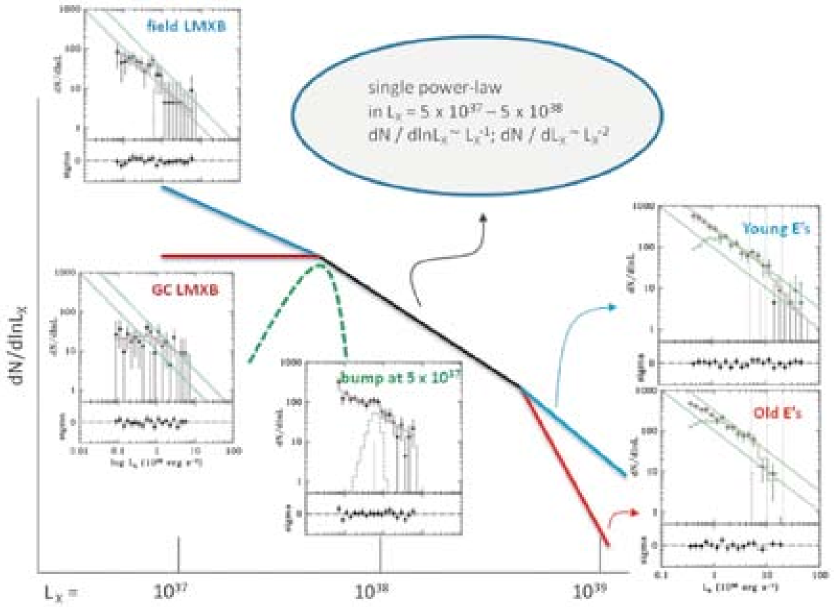


Figure 6: A schematic view of the XLFs of field and GC LMXB populations in elliptical galaxies, indicating a deficit of low-luminosity LMXBs in GCs, and a comparison between the XLFs of old (~10 Gyr) and young (<5 Gyr) elliptical galaxies, showing the larger numbers of LMXBs in the latter (adopted from Kim & Fabbiano 2010).

c. Extreme sources

The large number of extragalactic accreting sources, and the wide variety of environments in which they form gives us the opportunity to detect and study rare types of objects which are not present in our Galaxy. One such example are the Ultra-luminous X-ray sources (ULXs), which are defined as sources with X-ray luminosities in excess of 10^{39} erg/s. X-ray observations showed that star-forming galaxies often host X-ray sources with luminosities in excess of 10^{40} erg/s, and some times up to 10^{41} erg/s (e.g. Swartz et al. 2011). These large luminosities have been attributed either to super-Eddington accretion onto a typical stellar black-hole (which may be combined with mild beaming of the emitted radiation; e.g. King et al. 2001), or accretion onto intermediate-mass black holes (e.g. Miller et al. 2004; 2013), i.e. black holes with mass above ~100M⊙, well in excess of the maximum expected from stellar evolution (e.g. Miller & Colbert, 2004). More recently, the discovery of a ULX with a neutron-star accretor in the M82 galaxy (Bachetti et al. 2014) complicated the picture even more, and posed new challenges in our understanding of these systems (e.g. Fragos et al. 2015)

This conundrum will only be resolved conclusively with the measurement of the dynamical masses of the compact objects in these systems. However, recent systematic analysis of the X-ray spectra of ULXs in the 0.5-10.0 kev band with XMM-*Newton* (and more recently up to ~20keV with NuSTAR) suggests that their X-ray spectra, which exhibit a turnover above ~7keV, are in agreement with an accretion disk in a super-critical regime (e.g. Sutton et al. 2013, Walton et al. 2014; Rana et al. 2015), favoring the super-Eddington accretion scenario.

On the other hand, measurement of the dynamical masses in extragalactic accreting binaries which exhbit deep eclipses in their X-ray lightcurves, has led to the discovery of black-holes with masses in the range between ~10 – ~30M⊙, much higher than the black-hole masses of X-ray binaries in our Galaxy (e.g. Ozel et al. 2010; Farr et al. 2011 for a summary). Even though these masses are well below those of intermediate-mass black holes, the formation of these systems, which involve a massive donor star and a very massive compact object, is a challenge for theoretical models (e.g Valsecchi et al. 2010). Since these systems are prime candidates for progenitors of gravitational wave sources, their study gives new insights in the formation pathways and rates of gravitational wave sources (e.g. Maccarone et al. 2014).

NuSTAR: a new window on studies of X-ray emission from galaxies

The launch of NuSTAR in June 2012 has revolutionized the studies of accreting binaries in other galaxies by providing for the first time measurements of their integrated hard X-ray emission, and detections of individual sources above 10keV (e.g. Wik et al. 2014).

The hard X-ray emission of accreting binaries is an important diagnostic of their accretion state. Observations of Galactic black-hole binaries in the 4 – 100 keV band (mainly with RXTE) have shown that during an outburst they follow a «q» shaped pattern in a luminosity-spectral hardness diagram, which resembles a hysterisis loop (e.g. Maccarone et al. 2003; Remillard & McClintock 2006). This pattern has been interpreted in terms of changes in the structure of the accretion flow and the ejection of material in the form of a jet (e.g. Done et al. 2007, Fender et al. 2004). The limited energy coverage of the *Chandra* and XMM-*Newton* observatories (~0.5 -10.0 keV) did not allow the unambiguous determination of the accretion state of extragalactic binaries. However, this has changed with NuSTAR which allows us to measure their intensity above 10 keV. Fig 7 presents a NuSTAR accretion-state diagnostic based on RXTE observations of Galactic black-hole binaries which clearly shows the characteristic hysterisis pattern. The black points correspond to individual sources detected in NuSTAR observations of the nearby star-forming galaxy NGC253, clearly showing that the majority of the accreting binaries in NGC253 are in the «intermediate state» which is characterized by strong thermal emission from the accretion disk, as well as a strong non-thermal component.

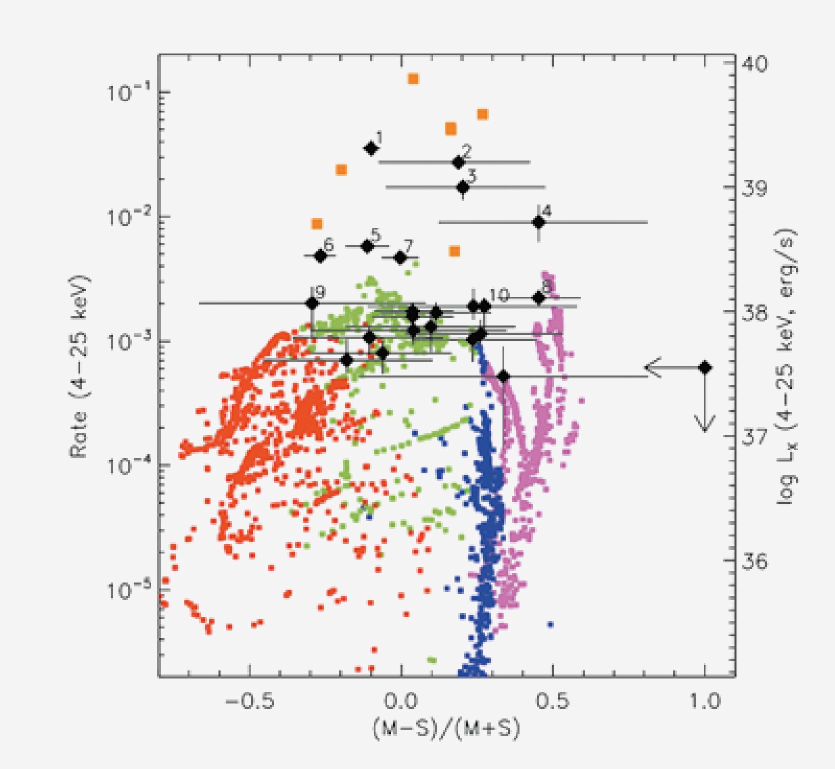


Figure 7: An intensity – hardness ratio diagram for NuSTAR observations of extragalactic X-ray binaries. This diagram is based on the translation of RXTE spectra of Galactic black-hole X-ray binaries (blue, green, red points) and accreting pulsars (purple points) to the NuSTAR spectral bands (Zezas et al. in prep). The blue, green, and red points correspond to the locus of the hard, intermediate, and soft black-hole accretion states respectively. The orange squares show NuSTAR observations of ULXs, while the black points are X-ray sources observed with NuSTAR in NGC253 (figure from Wik et al. 2014).

Summary

The study of accreting binaries is a very rich field with great potential in terms of new observational constraints and theoretical advances. Particularly the combination of deep *Chandra* observations with multi-wavelength data and hard X-ray NuSTAR observations is becoming a powerful tool for fully characterizing accreting binaries on the basis of their donor stars, compact objects, and accretion states.

This enables detailed studies, similar to those perfomed in our Galaxy since the beginning of X-ray Astronomy, but in a much wider range of accreting binary populations than available in our neighbourhood. As demonstrated by the first studies that combine these observational results with state-of-the-art accreting binary population synthesis theoretical models, this synergy is very powerful for understanding the types of accreting binaries present in other galactic environments and constraining their formation and evolution channels .

This way we can tackle long-standing problems such as: accreting binary formation pathways and their universality, the relation of extreme sources with these general pathways, the cosmological evolution of accreting binaries and their importance for feedback (e.g. Fragos et al. 2013b).

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References

Antoniou, V., Zezas, A., Hatzidimitriou, D., & Kalogera, V. 2010, ApJL, 716, L140

Antoniou, V., Zezas, A., Hatzidimitriou, D., & McDowell, J. C. 2009a, ApJ, 697, 1695

Antoniou, V., Hatzidimitriou, D., Zezas, A., & Reig, P. 2009b, ApJ , 707, 1080

Badenes, C. Maoz, D., Draine, B. T., 2010, MNRAS, 407, 1301

Bachetti, M., Harrison, F.A., Walton, D.J., et al. 2015, Nature, 514, 202

Belczynski, K., Kalogera, V., Rasio, F. A., et al. 2008, ApJS, 174, 223

Done, C., Gierliński, M., Kubota, A. 2007, A&ARv, 15, 1

Dray, L. M. 2006, MNRAS, 370, 2079

Fabbiano, G. 2006, ARA&A, 44, 323

Fabbiano, G. 1989, ARA&A, 27, 87

Farr, W. M., Sravan, N., Cantrell, A., et al. 2011, ApJ, 741, 103

Fender, R. P., Belloni, T. M., Gallo E. 2004, MNRAS, 355, 1150

Fragos, T., Linden, T., Kalogera, V., & Sklias, P. 2015, ApJL, 802, 5

Fragos, T., Lehmer, B., Tremmel, M., et al. 2013a, ApJ, 764, 41

Fragos, T., Lehmer, B. D., Naoz, S., Zezas, A., & Basu-Zych, A. 2013b, ApJL, 776, L31

Fragos, T., Kalogera, V., Willems, B., et al. 2009, ApJL, 702, 143

Fragos, T., Kalogera, V., Belczynski, K., et al. 2008, ApJ, 683, 346

Gilfanov, M. 2004, MNRAS, 349, 146

Grimm, H.-J., Gilfanov, M., Sunyaev, R., 2002, A&A, 391, 923

Grindlay, J. E. 1984, AdSpR, 3, 19

Hurley, J.R., Tout, C.A., & Pols, O.R. 2002, MNRAS 329, 897

Illarionov, A. F., Sunyaev, R. A., 1975, A&A, 39, 185

Irwin, J. A. 2005, ApJ., 631, 511

Ivanova, N., et al. 2013, A&ARv., 21, 59

Kim, D.-W., Fabbiano, G., Kalogera, V., et al. 2006, ApJ, 652, 1090

Kim, D.-W., Fabbiano, G., Brassington, N. J., et al., 2009, ApJ., 703, 829

Kim, D. W., & Fabbiano, G., 2010, ApJ, 721, 1523

King, A. R., Davies, M. B., Ward, M. J., Fabbiano, G., & Elvis, M. 2001, ApJ l, 552, L109

Kong, A. K. H., DiStefano, R., Garcia, M. R., & Greiner, J. 2003, Ap.J. , 585, 298

Kundu, A., Maccarone, T. J., & Zepf, S. E. 2002, ApJ l, 574, L5

Lehmer, B. D., Berkeley, M., Zezas, A., et al. 2014, ApJ, 789, 52

Linden, T., Kalogera, V., Sepinsky, J. F., et al. 2010, ApJ, 725, 1984

Linden, T. Sepinsky, J. F., Kalogera, V., Belczynski, K. 2009, ApJ, 699, 1573

Liu Q. Z., van Paradijs J., & van den Heuvel E. P. J., 2006, A&A, 455, 1165

Liu Q. Z., van Paradijs J., & van den Heuvel E. P. J., 2007, A&A, 469, 807

Maccarone, T. J., Lehmer, B. D., Leyder, J. C., et al. 2014, MNRAS, 439, 3064

Maccarone, T. J., & Coppi, P. S. 2003, MNRAS, 338, 189

Maravelias, G., Zezas, A., Antoniou, V., & Hatzidimitriou, D. 2014, MNRAS, 438, 2005

Mc Bride, V., A., et al. 2008, MNRAS, 388, 1198

McClintock, J. E., & Remillard, R. A. 2006, in Compact stellar X-ray sources, 157, Cambridge Univ. Press

Miller, J. M., Fabian, A. C., & Miller, M. C. 2004, ApJL. 614, 117

Miller J. M., Walton, D. J., King, A. L., et al. 2013, ApJ, 776, 36

Miller, M. C., & Colbert, E. J. M. 2004, Int. J. Mod. Phys. D, 13, 1

Mineo, S., Gilfanov, M., Sunyaev, R, 2012, MNRAS, 419, 2095

O'Sullivan, E., Forbes, D. A., & Ponman, T.J. 2001, MNRAS, 328, 461

Ott, J., Walter, F., Brinks, E., 2005, MNRAS, 358, 1423

Özel, F., Psaltis, D., Narayan, R., & McClintock, J. E. 2010, ApJ , 725, 1918

Peacock, M. B., Maccarone, T. J., Kundu, A., & Zepf, S. E. 2010, MNRAS, 407, 2611

Psaltis, D. 2006, in Compact stellar X-ray sources, 1, Cambridge Univ. Press

Rana, V., Harrison, F. A., Bachetti, M., et al. 2015, ApJ , 799, 121

Ranalli, P., Comastri, A., & Setti, G. 2003, A&A, 399, 39

Read, A. M., & Ponman, T. J. 2001, MNRAS, 328, 127

Reig, P., 2011, Ap&SS, 332, 1

Remillard, R. A., & McClintock, J. E., 2006, ARA&A, 44, 49

Sell, P. H., Pooley, D., Zezas, A., et al. 2011, ApJ, 735, 26

Shtykovskiy, P. & Gilfanov, M. 2005, MNRAS, 362, 879

Sivakoff G. R., et al. 2007, ApJ, 660, 1246

Smith et al 1999, IAU Symp. 190

Soria, R., & Wu, K. 2003, A&A, 410, 53

Sturm, R., Haberl, F., Pietsch, W., et al. 2013, A&A, 558, A3

Sutton A. D., Roberts, T. P., Middleton M. J., 2013, MNRAS, 435, 1785

Swartz, D. A., Ghosh, K.K., Tennant, A. F., & Wu, K. 2004, ApJS, 154, 519

Taam, R. E., & Sandquist, E. L. 2000, ARA&A 38, 113

Tauris, T. M., & van den Heuvel, E.P.J. 2006, in Compact stellar X-ray sources, 623, Cambridge Univ. Press

Tremmel, M., Fragos, T., Lehmer, B.D., et al. 2013, ApJ, 766, 19

Tzanavaris, P., Fragos, T., Tremmel, M., et al. 2013, ApJ, 774, 136

Valsecchi, F., Glebbeek, E., Farr, W. M., et al. 2010, Nature, 468, 77

Walton, D. J., Harrison, F.A., Grefenstette, B. W., et al. 2014, ApJ , 793, 21

Weisskopf, M. C., Tananbaum, H. D., Van Speybroeck, L. P., & O'Dell, S. L. 2000, SPIE, 4012, 2

Wik, D. R., Lehmer, B. D., Hornschemeier, A. E., et al. 2014, ApJ, 797, 79

Zezas, A., Fabbiano, G., Baldi, A., et al. 2007, ApJ, 661, 135

Zhang, Z., Gilfanov, M., & Bogdán, Á. 2012, A&A, 546, 36

Carrington-L5: The UK/US Operational Space Weather Monitoring Mission

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Abstract

Airbus Defence and Space (UK) has carried out a study to investigate the possibilities for an operational space weather mission, in collaboration with the Met Office, RAL, MSSL and Imperial College London. The study looked at the user requirements for an operational mission, a model instrument payload, and a mission/spacecraft concept. A particular focus is cost effectiveness and timelineness of the data, suitable for 24/7 operational forecasting needs. We have focussed on a mission at L5 assuming that a mission to L1 will already occur, on the basis that L5 (Earth trailing) offers the greatest benefit for the earliest possible warning on hazardous SWE events and the most accurate SWE predictions. The baseline payload has been selected to cover all UK Met Office/NOAA's users priorities for L5 using instruments with extensive UK/US heritage, consisting of: heliospheric imager, coronograph, magnetograph, magnetometer, solar wind analyser and radiation monitor. The platform and subsystems are based on extensive re-use from past Airbus Defence and Space spacecraft to minimize the development cost and a Falcon-9 launcher has been selected on the same basis. A schedule analysis shows that the earliest launch could be achieved by 2020, assuming Phase A kick-off in 2015-2016. The study team have selected the name "Carrington" for the mission, reflecting the UK's proud history in this domain.

1. INTRODUCTION

Hazardous Space Weather events (SWE) have been responsible for devastating effects throughout the globe[1]. Two recent reports in UK[2] and USA[3] estimated the cost of a severe SWE to £10 billion and $2 trillion respectively. Following these studies, the UK Cabinet Office performed an extensive risk analysis of SWE, concluding that indeed Carrington-like events[4] are one of the highest UK national risks[5,6]. In order to address the SWE threat, both USA and UK governments, in very close collaboration, established operational services with the sole goal of providing timely and accurate forecasts of SWE to both commercial and governmental users. In 2014, the UK/USA bilateral effort in tackling the effects of SWE, culminated with the opening of MOSWOC, the UK Met Office Space Weather Operations Centre, the partner organization to USA's Space Weather Prediction Centre (SWPC). Both MOSWOC and SWPC use the same software and spaceborne data to produce accurate and timely forecasts of SWE. The key spaceborne facilities used for MOSWOC/SWPC data generation are:

1) NASA's Solar Dynamics Observatory (SDO), a science mission in a geosynchronous orbit (36,000 Km from Earth), launched in 2010 and designed for an operational lifetime of 10 years.
2) NASA's Advanced Composition Explorer (ACE), a science mission in L1 (1,500,000 Km from Earth), launched in 1997 and planned to be decommissioned by 2002
3) ESA's Solar and Heliospheric Observatory (SOHO), a science mission in L1 (1,500,000 Km from Earth), launched in 1995 and planned to be decommissioned by 2005 the latest
4) NASA's STEREO (Solar TErrestrial RElations Observatory), a science mission consisted of two identical spacecraft in heliocentric orbit. STEREOs were launched in 2006 planned to be decommissioned by 2010. Currently both spacecraft have moved behind the Sun rendering them inoperable.

Both MOSWOC and SWPC have identified as their key priorities for producing accurate and timely forecasts a system consisting of L1 and L5 operational sentinel spacecraft. L1 provides a couple of hours warning with very low probability of false prediction while L5 provides 2-5 days of early detection and warning. The latter capability has been identified as crucial from both MOSWOC and SWPC.

At the moment, none of the available spaceborne facilities are operational (no

1. http://www.lloyds.com/~/media/Lloyds/Reports/360/360%20Space%20Weather/7311_Lloyds_360_Space%20Weather_03.pdf
2. http://www.raeng.org.uk/publications/reports/space-weather-full-report
3. http://science1.nasa.gov/science-news/science-at-nasa/2009/21jan_severespaceweather/
4. http://www.nature.com/nature/journal/v484/n7394/full/484311a.html
5. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/211867/NationalRiskRegister2013_amended.pdf
6. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/307648/National_Space_Security_Policy.pdf

Payload	*Comment*
Coronagraph	*To identify Earth-directed Coronal Mass Ejections (CMEs)*
Heliospheric Imager	*To identify and track CMEs through the heliosphere, including arrival at Earth. Also, able to image CIRs approaching near-Earth space.*
Particles/fields	*To sample CIR plasmas rotating towards Earth*
EUV Imager	*To image solar active centres, in particular to assess the potential for eruptions/flare at sites as the approach locations well connected to Earth*
Magnetograph	*To image the magnetic structure of the photosphere at sites approaching locations well connected to Earth*

Table 1: MOSWOC payload requirements for an L5 operational mission.

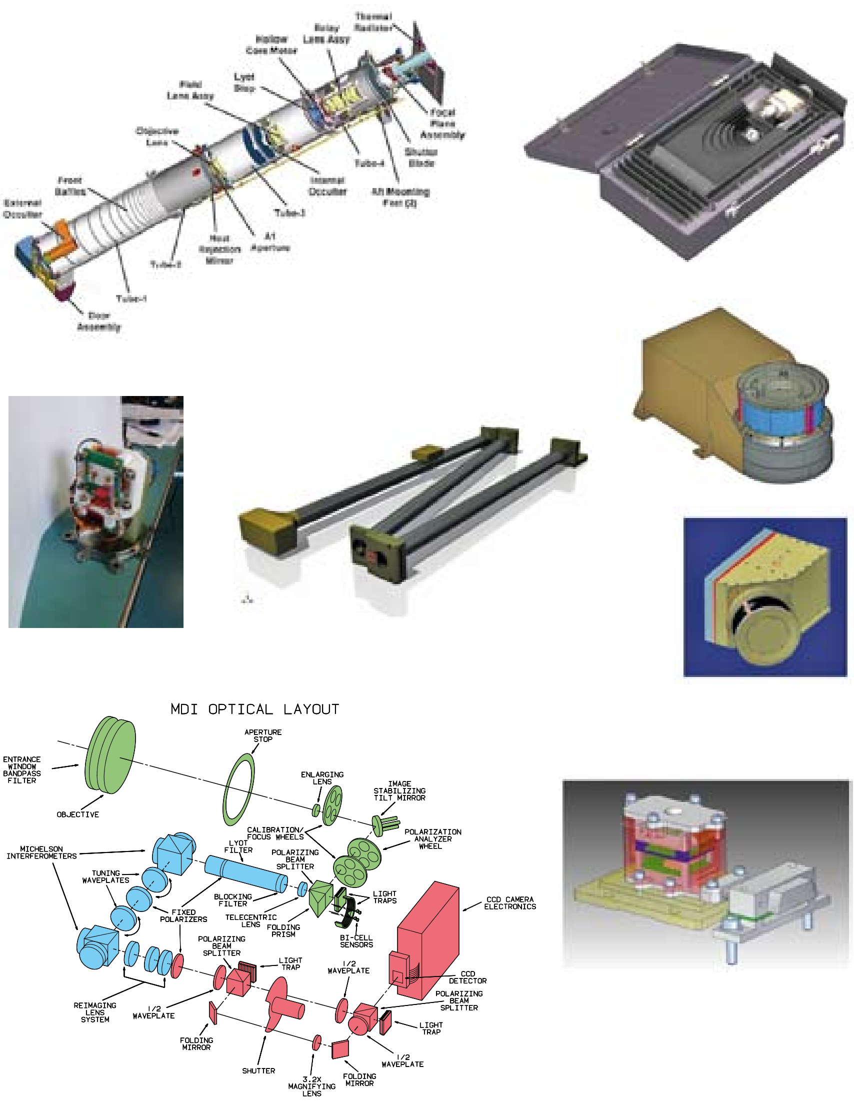


Figure 1: Schematic showing all proposed operational payloads on Carrington L5. Top left shows the operational Coronagraph that RAL Space has been studying for the ESA SSA programme. Top right shows the Heliospheric Imager that RAL Space developed for the STEREO mission. Middle left shows the magnetometer that Imperial College London has been developing for the Solar Orbiter mission. The boom shown is based to the one developed for the Solar Orbiter mission but with an extra elbow mechanism as Carrington platform will be smaller to that of the Solar Orbiter mission. Middle right shows the Solar Wind Ion and Solar Wind Electron that MSSL are working on for the Solar Orbiter mission. Bottom left shows a schematic of the MDI magnetograph while bottom right shows the Radiation Monitor developed by RAL and Imperial College London.

24/7 data back to Earth) but rather science missions with no operational capabilities. The twin STEREO spacecraft, due to their mission profile, trailing heliocentric orbits, at the moment are inoperable with no guarantee of becoming operational again. SOHO and ACE have severely exceeded their mission lifetime with the coronagraph on SOHO been currently non-functional. US government has identified the problem and is planning to replace the two facilities in L1. DSCOVR was launched in 2015 as a replacement to ACE and NOAA is working on a subsequent launch in 2020 to replace the SOHO coronagraph in L1. In addition, USA is actively looking for international partners investing on the development of an L5 operational sentinel mission to support their planned L1 spacecraft. Airbus Defence and Space UK in close collaboration with the UK Met Office, RAL, MSSL and Imperial College London have come up with the Carrington-L5 mission concept, a design that fully addresses all MOSWOC and SWPC requirements for an operational L5 mission. The spacecraft concept in based on a consolidated design derived from previous Airbus Defence and Space led missions. The approach focuses on two main aspects: reuse of technologies that have already flown or developed for planned missions (e.g. Solar Orbiter, Sentinel-5P, Venus/Mars-Express) in order to reduce both the expected cost and development time, and exploit the extensive UK heritage on payload technologies.

II. PAYLOADS

Table 1 summarizes the operational payloads that MOSWOC have identified as critical for an L5 mission. As Carrington-L5 is an operational mission, it is expected that the payload requirements, especially for the imagers will be lower in comparison to their science equivalents. However, the key requirement is the continuous monitoring and downlink of all collected data back to Earth. Figure 1 shows a schematic of all payloads that will fly on Carrington L5.

Coronagraph

Currently, we rely on coronagraph data to run our principal space weather models – yet humanity is dependent on one aging science instrument (LASCO aboard SOHO; in its 20th year of op-

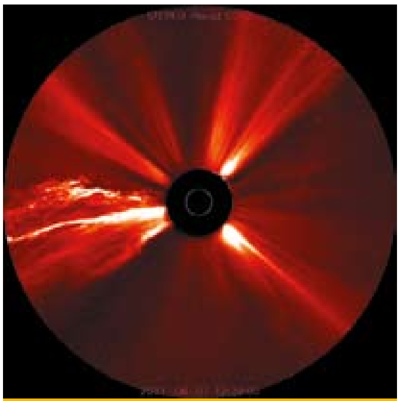


Figure 2: Left image shows STEREO-B (L5-proxy) coronagraph imaging from a CME eruption in 2011.

eration) to provide that information. A dedicated coronagraph, suited to operational space weather needs is required urgently. A coronagraph is a device that occults the solar disk, in order to image outward propagating solar ejecta – the billion tonne CMEs. An example of L5-proxy coronagraph imaging from STEREO-B is shown in Figure 2. An operational space weather coronagraph does not need the same flexibility and performance as a science-grade coronagraph – we require 'sit and stare' synoptic operations from a small, robust instrument. Our basic strategy is the following:

- Based on the STEREO/COR2 (basic white-light instrument)
- Employ smaller pixels (possibly APS detector), a larger occulter, higher resolution (arcsec), modest pixel arrays, no polarisers and minimise mechanisms
- These reduce the baffling and stability demands, and reduce the instrument size/mass

Heliospheric Imager

The only device that can image solar transients passing through the heliosphere and engulfing the Earth is a Heliospheric Imager (HI) stationed outside the Sun-Earth line. The Heliospheric Imaging instruments aboard NASA's STEREO Mission are the only instruments to have made such observations (Figure 3). STEREO/HI has demonstrated the technique for a science mission, and has been exploited to develop tools for the rapid analysis of such data for space weather application. Thus, a HI instrument is a critical tool for space weather applications. Our strategy is to utilise the STEREO HI concept, employing a wide-angle telescope system with occultation and an extensive baffle system achieving light rejection (from the Sun) of ~10^{-13} of the solar brightness. Modifications could include:

- One telescope system
- Upgraded detector system
- Robust mounting
- Modification to structure and baffles resulting in a smaller, robust, operational instrument.

Magnetograph

This instrument will provide full Sun line-of-sight magnetograms which allows to obtain:

- Earlier knowledge of new Active Regions as they rotate around from the far side of the Sun. Active Regions are regions of high magnetic complexity and are potential sources of solar flares and coronal mass ejections.
- Earlier knowledge of likely flare and coronal mass ejection activity of Active Regions.
- Earlier knowledge (through input to modelling) of the magnetic configuration of coronal mass ejections when they reach 1AU

Earlier knowledge of the magnetic field is essential for predicting flare & CME activity and the level of coupling of the CME with the magnetosphere. Example is shown in Figure 4. Our strategy for the specific payload will be based on the SOHO Michelson Doppler Imager instrument that should be modified to discard oscillation measurement capability. In the Carrington-L5 case the measurement characteristics will be designed to requirements while cadence could be altered significantly for space weather objectives (e.g. >1 image every hour).

EUV Imager

The instrument will provide full Sun images in the 195Å wavelength which allows to obtain:

- Earlier knowledge of new Active Regions and near-equatorial coronal holes as they rotate around from the far side of the Sun. Equatorial coronal holes are sources of fast solar wind.
- Earlier knowledge of evolution of Active Regions and near-equatorial coronal holes as they rotate around the far side of the Sun. Example is shown in Figure 5.

Figure 3: A 20° × 20° field of view with the Sun 4° off the left hand side; a large CME is shown in the heliosphere; the planet Saturn is visible to the right (Courtesy: STEREO/HI RAL team).

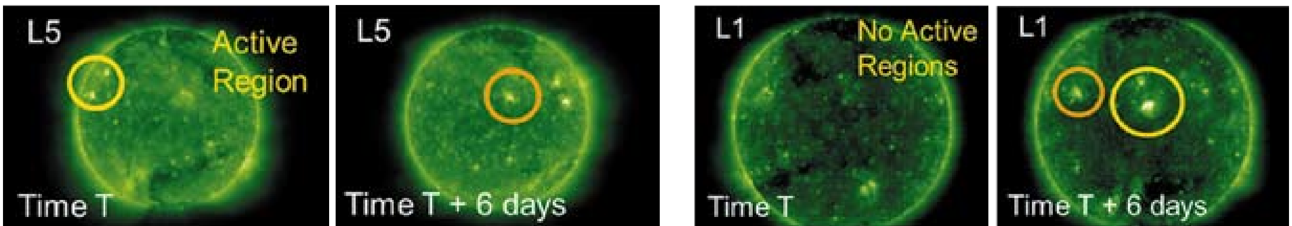


Figure 4: Six days earlier visibility of approaching Active Regions. Data from STEREO-B at L5 and SOHO at L1 (60° apart). Figures adapted from STEREO mission website.

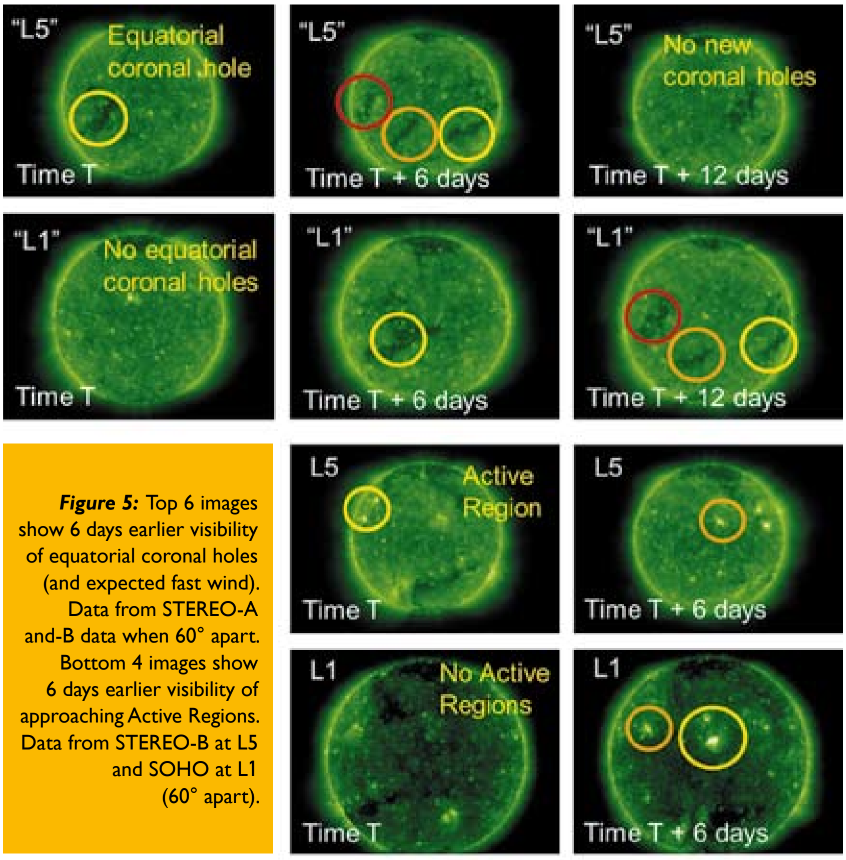


Figure 5: Top 6 images show 6 days earlier visibility of equatorial coronal holes (and expected fast wind). Data from STEREO-A and-B data when 60° apart. Bottom 4 images show 6 days earlier visibility of approaching Active Regions. Data from STEREO-B at L5 and SOHO at L1 (60° apart).

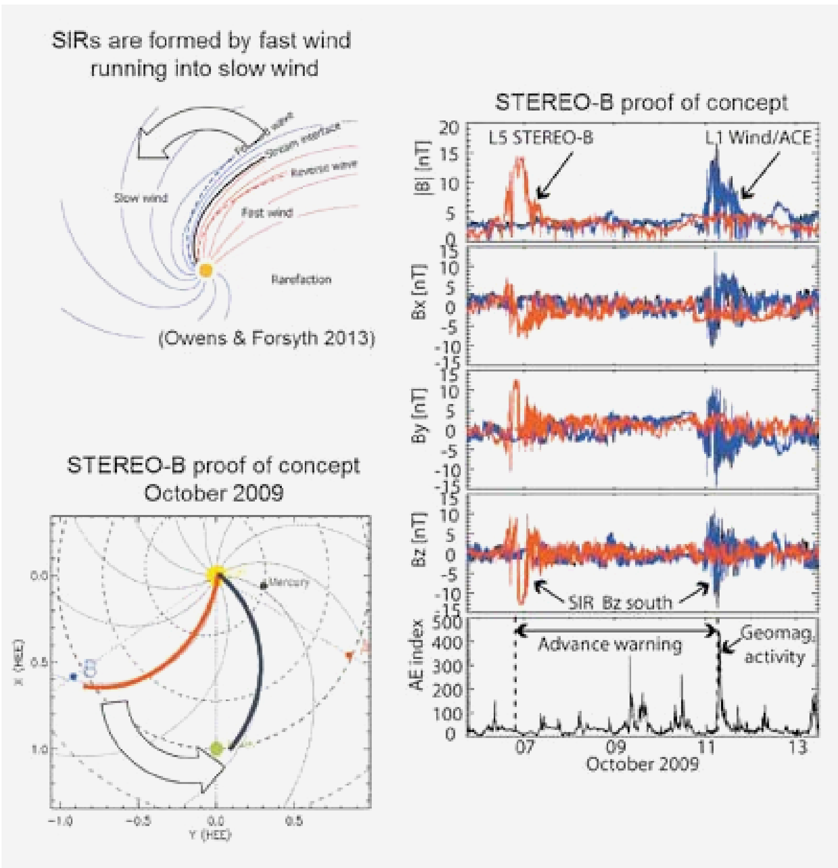


Figure 6: Bottom panel shows the AE index (auroral electrojet) of the Geomagnetic activity on 11 October. Similar solar wind observed on 6 October by STEREO-B at L5 suggesting that a magnetometer in L5 could provide more than four days warning.

Our strategy for the EUVI is based on a Solar Orbiter EUI-Full Sun Imager derivative, modified to discard other EUI telescopes with some design changes as this EUVI will not be going close to the Sun.

Magnetometer

Stream interaction regions (SIRs) co-rotate with the Sun and are able to cause geomagnetic activity (storms and substorms) depending on their magnetic field structure. SIRs are stronger at solar minimum, hence indicating that an operational space weather mission is needed throughout the solar cycle. Magnetic field observations at L5 not only will provide a 4-5 day warning of geoeffective SIRs but will also allow us to constrain solar wind models and forecasts. In Figure 6 we provide a proof of concept for this scenario based on October 2009, STEREO-B magnetic measurements at L5.

On Carrington-L5 we will be using a derivative of the Solar Orbiter magnetometer that will be operational, i.e. continuous data flow 24/7 for more than 10 years. This consists of a fully redundant dual sensor fluxgate that utilises the same sensor and drive electronics as Solar Orbiter.

Radiation Monitor

We are planning to employ two such instruments that will be looking in the ecliptic plane along the Parker spiral magnetic field both towards and away from the Sun, in the following energy ranges:

- Electron Energy Range: 35 keV – 6 MeV
- Proton Energy Range: 600 keV – 500 MeV

These two payloads will be ideal for monitoring and alerting about energetic particles within solar energetic particle (SEP) events. SEP events affect radio transmission and the chemistry of the upper atmosphere, and are extremely damaging to satellite electronics and human health. Such measurements will be used for: monitoring of real-time radiation environment, health of spacecraft and instruments, SEP effects at Earth (~30 mins warning), validation of space weather models, studying underlying physics of the SEP sources.

Solar Wind Ions

This instrument will measure solar wind

proton density, velocity, temperature. The large scale structure of the radially outflowing solar wind rotates with the Sun. The large scale pattern seen at L5 is repeated ~5 days later at Earth with the speed at L5 been very similar to that of L1. Density and hence dynamic pressure are quite similar, but not so much as speed. Coronal mass ejections are exceptions; proton data are used to recognise and measure them. Speed predictions are vital as the energy transfer from the solar wind to the magnetosphere depends on the solar wind speed given by the equation below:

$$P = V_{sw}\, B_{IMF}^2\, \mu_0 \sin^4(\theta /2)$$

High speed solar wind events are associated with radiation belt flux enhancements of "killer electrons" (> MeV energy). Example of the speed correlation between L5 and L1 is shown in Figure 7. Carrington-L5 will be using a derivative of the Solar Orbiter SWA-EAS.

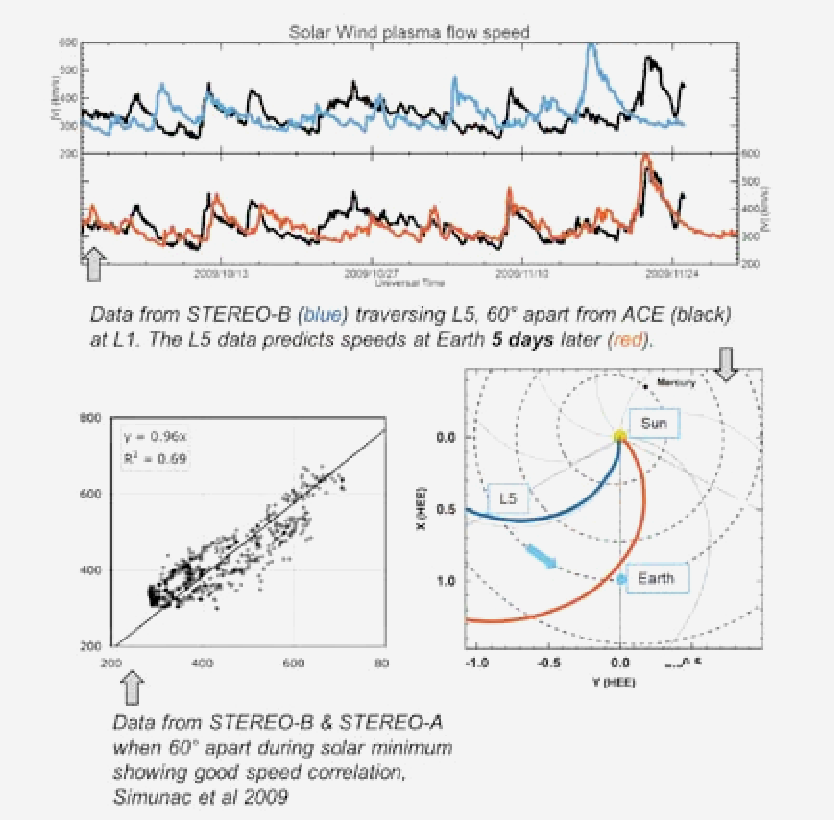


Figure 7: Speed correlation between L1 and L5.

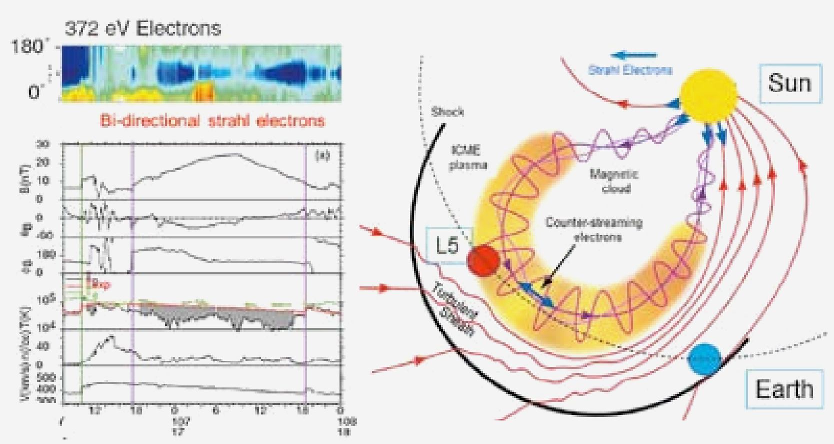


Figure 8: Left image presents the ICMEs that seem halo like at L5. Figure adapted from Gosling. Right image shows a classic ICME with magnetic cloud, and associated bi-directional strahl and depressed proton temperature signatures (Zurbuchen and Richardson, 2005).

Solar Wind Electrons

The instrument will measure solar wind electrons, in particular the "strahl" population to provide advance warning for Earth of ICMEs that seem halo-like at L5 (Figure 8). Bi-directional (counter-streaming along the magnetic field) electrons are one of the signatures of ICMEs while Bi-directional electrons signatures are also a signature of Stream Interaction Regions, associated with local magnetic compression. Carrington-L5 will utilise a derivative of the Solar-Orbiter SWA-EAS.

III. MISSION DESCRIPTION

The MOSWOC/SWPC requirements for early warning of hazardous SWE can be efficiently addressed by an L5 sentinel spacecraft equipped with a suite of remote sensing and in situ instruments as the ones summarised in Table 1.

The key mission drivers for Carrington are:

i. Address all MOSWOC/SWPC L5 operational requirements.

ii. Be able to downlink all data back to Earth 24/7 to ground stations with 15m dishes to keep the cost down and maximise coverage.

iii. Have an operational lifetime of 10 years with a maximum transfer time to L5 of <2 years.

iv. To keep the cost down a cheap launcher has to be used. To achieve that, the payload mass has to be less than 100 Kg with total mass on station less than 700 Kg.

v. To keep the overall cost down, it has to be a high TRL mission with all components either in development or flown before. In addition, all components should have high UK heritage to minimise the cost of procurement and increasing the benefits to UK economy.

To address all the above requirements, a detailed trade-off analysis has been performed for the mission transfer to L5, launcher selection and all major subsystems. Below we summarize our analysis and engineering study.

Mission Analysis

In order to achieve a low energy Earth escape to L5 there are two ways, either a direct injection to L5 using the launch vehicle or via an initial injection to an Earth orbit (e.g. GTO) followed by an escape manoeuvre. In the latter case, the escape manoeuvre is performed by the spacecraft. In this case a separate propulsion module needs to be used, similar to the LISA Pathfinder Mission. The complexity of implementing a separate propulsion module (cost, mass, implementation, launch vehicle) makes the direct injection the preferred choice for launching Carrington to L5. In order to achieve this, a range of cheap launchers has been considered: Falcon 9, Soyuz-Fregat, Delta 2 and a shared launch on an Ariane-5. The shared launch option would require the use of a dedicated propulsion module and for this reason was disregarded. Delta-2 was not considered because of the expected high procurement cost. Falcon-9 and Soyuz-Fregat resulted to be the most viable options as shown in Figure 9, providing enough margin for the launch requirements. Falcon-9 was selected as the baseline purely on a cost basis, and Soyuz-Fregat as the first backup option.

Platform Selection

The main requirements for selecting the platform were: low cost, mass at station ~700 Kg, matching the DV and propellant requirements needed for performing the stopping manoeuvre (i.e. ~550 Kg). To keep the cost down, we considered only platforms that Airbus Defence and Space have built and flown in the past. Options considered were the Solar Orbiter, Sentinel-5P, Venus/Mars-Express and E3000/EP platforms. E3000 and Solar Orbiter platforms were not selected as they could not fit to our mass budget. Sentinel-5P uses a platform designed for Earth Observation (Low Earth Orbit) and therefore its compatibility with the expected deep space environment has not been demonstrated yet. Moreover, it does not satisfy the DV and propellant mass requirements for the proposed mission. The VEX/MEX platform is a much more suitable platform because has flown twice in the past in deep space and provides enough margin to address the propellant and DV requirements for the mission. In addition, the propulsion system of the VEX/MEX platform is ideally suited to our mission profile.

AOCS

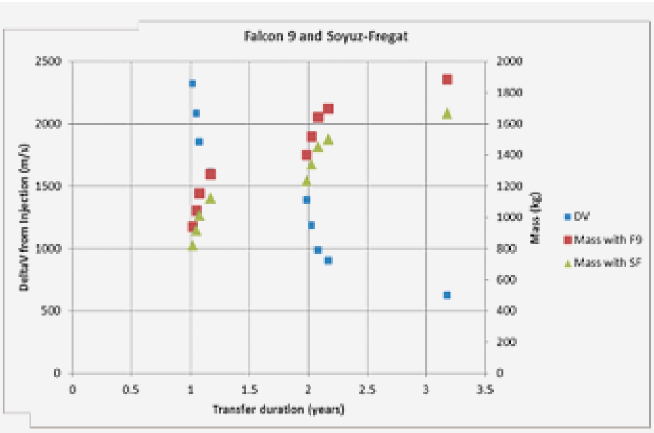
The main drivers for Carrington, in terms of AOCS (Attitude and Orbit Control Systems), are the imager requirements i.e. Absolute Pointing Error of 0.06 degrees and Relative Pointing Error of 3 arcsec over 10 seconds at 1σ level. To address these requirements two options were selected for Carrington: Either re-use of the MEX/VEX system or re-use of the Sentinel-5P system. As the Sentinel-5P AOCS components are more recent with lower procurement cost we have used them as our baseline. Detailed simulations shown that the following performance could be achieved:

- APE with Star Trackers only at AOCS level: X=0.6485 arcsec, Y=0.4901 arcsec, Z=0.7095 arcsec, 1-sigma. To guarantee the required performances, the Star Trackers are mounted very close to the Imagers to use them for accurate calibration
- RPE with Star Trackers: X=0.5480 arcsec, Y=0.4418 arcsec, Z=0.4191 arcsec, 1-sigma (arcsec). The use of an IMU was considered as backup solution.

The predicted performance appears to be fully compliant with the payload requirements.

Communications, DHS & Power Subsystems

In order to guarantee a 24/7 operations, continuous transfer of data back to Earth is required. For a mission in L5, data could be transferred continuously to Earth only if at least four Ground Stations equally distributed over the globe are available. To increase the number of suitable Ground Stations and to minimise the cost to operate them, it was decided to consider antenna dishes not larger than 15m and X-Band communication. With a required continuous telemetry data rate in the order of 50 Kbits/s, the RF power that is needed to transfer the data back to the ground is ~90W at 58.4dBW. Figure 9 shows that this could be achieved only with an antenna of 1.6m located in L5. The Communications System selected for Carrington that satisfies these criteria was largely based on the one implemented on Mars-Express, which allowed a further reduction to the mission cost. Although Carrington is an operational mission, it will be able to transmit more than 4Gb of data that scientists could use for science. It is worth noting that STEREO-B, a science mission, produces ~5Gb of data daily, very similar to what Carrington could achieve



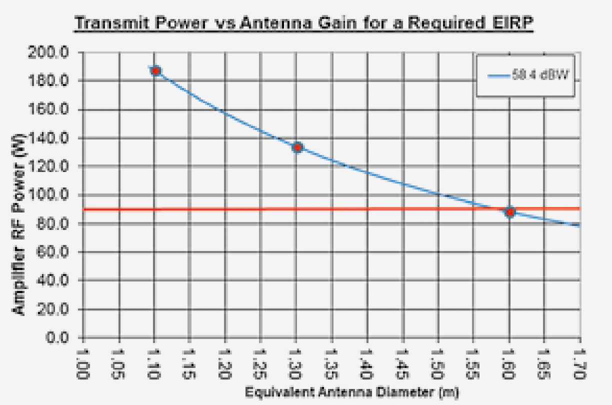


Figure 9. Left: Comparison of Falcon-9 versus Fregat capabilities for different transfer times 1, 2 and 3 years and different launch masses. Blue dots represent the DV requirements to achieve specific transfer times to L5. Green triangles and red squares represent the Fregat and Falcon-9 capabilities at each different scenario. ***Right:*** Figure showing the size of a spacecraft antenna as a function of the RF power. The red line indicates the Carrington requirement for communicating 50 Kbits/s to a 15 m ground dish continuously. The Blue-red dots indicate the available antennas that Airbus Defence and Space produces for science missions. The 1.6 m antenna is the one used for the Mars-Express mission.

with the current design. Carrington besides the High-gain Antenna, it will also use two LGAs during LEOP, early operations and commissioning while still close to Earth and an MGA during cruise and Safe Mode. For data management, Carrington will be using the same data handling system as that of Solar Orbiter. The OBC and RIU from the Solar Orbiter mission represent the state of the art currently available for science missions and were selected because of the payload and data similarities between Solar Orbiter and Carrington-L5. In terms of power, Carrington-L5 power generation system relies on Sentinel-5P solar panels. In particular, Carrington needs only 2 of the 3 solar wings, thus reducing the cost further. Figures 10-13 show schematics of Carrington-L5 in both stowed and deployed configurations.

IV. SUMMARY

Carrington-L5, a collaborative effort between Airbus, the UK Met Office, RAL, UCL and Imperial College London, aims at providing the first ever operational Sentinel spacecraft for monitoring SWE. It addresses all MOSWOC and SWPC L5 operational requirements for providing data essential for timely and accurate forecasts of hazardous SWE when it works in combination with L1 in-situ and coronagraphic missions. It has been designed as a low-cost, low-risk, high TRL mission which is able to be developed in less than 5 years. Upon launch, it will be able to perform a fast transfer (between 1 and 2 years) to L5 and remain operational for at least 10 years. It is designed to perform 24/7/365 operations and transfer all data continuously back to Earth. The amount of data that it will produce is comparable to STEREO-B, hence providing a key science facility. It represents an excellent opportunity for a UK/US bilateral mission while it presents a unique opportunity for UK to take the lead in a field where UK has extensive heritage. It is predicted that Carrington-L5 will be for SWE monitoring what TIROS-1 was for terrestrial weather monitoring.

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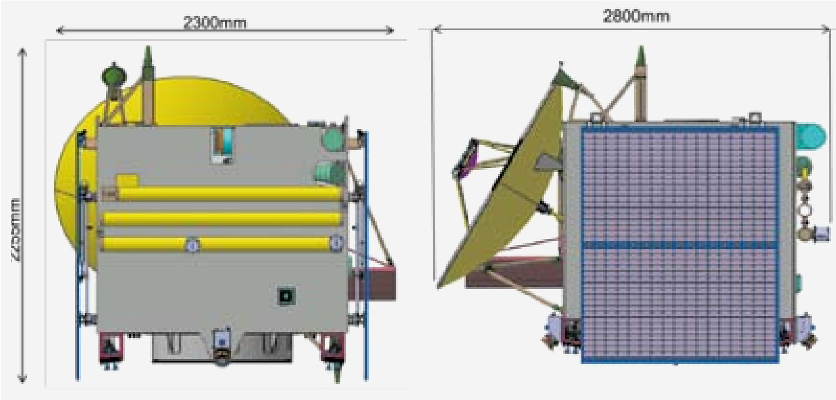


Figure 10: Carrington-L5 main dimensions in stowed configuration.

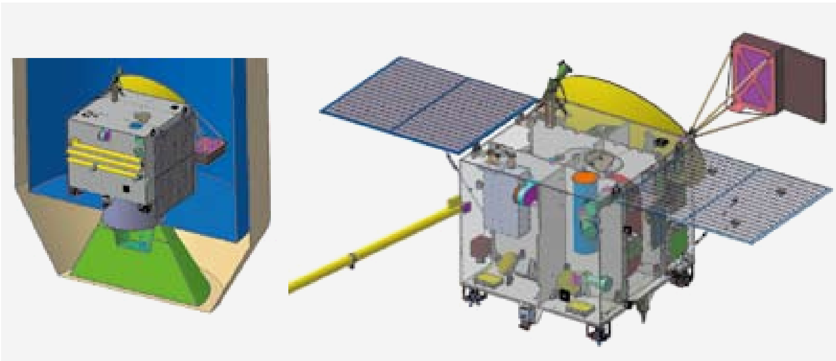


Figure 11: Carrington-L5 within the Falcon 9 fairing (left) and internal structural configuration (right).

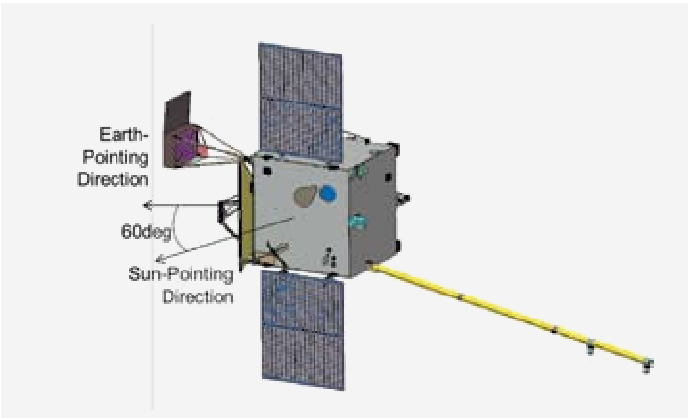


Figure 12: Carrington-L5 on station deployment.

Figure 13: Graphic showing Carrington-L5 on station deployment during a CME eruption.

A Snapshot of Competitive, Sponsored Astronomy and Astrophysics Research Implemented in Greek Institutes

Amidst challenging funding conditions, research in Astronomy and Astrophysics in Greece is thriving. This is manifested by a large array of competitive research projects implemented in Greek universities and institutes that have been awarded either via the nominal course of proposal writing and robust, expert evaluation or via invitation by the European Space Agency (ESA), acknowledging leading expertise in a given topic. In this Hipparchos issue we attempt a snapshot, representative cross-section of such projects, by including brief descriptions of each, hopefully providing Hel.A.S. members with succinct information that can be further enriched by contacting the Lead Investigator.

In summary, the known projects, Lead Investigators, host institutes, and sponsors are provided in the table below in alphabetical order of the projects' short names.

In what follows, a brief description of each project is provided.

Project Short Name	Project Title	Lead Investigator[1]	Host Institute	Sponsor
	Accreting Binary Populations in Nearby Galaxies	A. Zezas (azezas@phys.uoc.gr)	FORTH – University of Crete	EC / ERC[2]
A-EFFort	Athens Effective Solar Flare Forecasting	M. K. Georgoulis (manolis.georgoulis@academyofathens.gr)	Academy of Athens	ESA[3]
AWFC	Aristarchos Wide Field Camera	P. Boumis (ptb@astro.noa.gr)	National Observatory of Athens	GSRT[4]
DustPedia	A Definitive Study of Cosmic Dust in the Local Universe	M. Xilouris (xilouris@astro.noa.gr)	National Observatory of Athens	EC / FP7[5]
EPN2020-RI	Europlanet 2020 Research Infrastructure	I. A. Daglis (iadaglis@phys.uoa.gr)	University of Athens	EC / H2020[6]
FLARECAST	Flare Likelihood and Region Eruption Forecasting	M. K. Georgoulis (manolis.georgoulis@academyofathens.gr)	Academy of Athens	EC / H2020
FORSPEF	Forecasting Solar Particle Events and Flares	A. Anastasiadis (anastasi@noa.gr)	National Observatory of Athens	ESA
HCV	Hubble Catalogue of Variables	K. Tsinganos (tsingan@phys.uoa.gr)	National Observatory of Athens	ESA

1. Either project-wide, or of the local, Greek team in case of international collaboration.
2. European Commission / European Research Council
3. European Space Agency
4. Hellenic General Secretariat of Research and Technology
5. European Commission / 7th Framework Programme
6. European Commission / Horizon 2020

Project Short Name	Project Title	Lead Investigator[1]	Host Institute	Sponsor
HERMES	Hellenic Evolution of Radiation Data Processing and Modelling of the Environment in Space	I.A. Daglis (iadaglis@phys.uoa.gr)	University of Athens	ESA
HESPERIA	High Energy Solar Particle Event Forecasting and Analysis	O. Malandraki (omaland@astro.noa.gr)	National Observatory of Athens	EC / H2020
HNSWR	Hellenic National Space Weather Research Network	L.Vlahos (vlahos@astro.auth.gr)	University of Thessaloniki	GSRT
MAARBLE	Monitoring, Analyzing, and Assessing Radiation Belt Loss and Energization	I.A. Daglis (iadaglis@phys.uoa.gr)	University of Athens	EC / FP7
MAWFC	The Manchester-Athens Wide Field Camera	P. Boumis (ptb@astro.noa.gr)	National Observatory of Athens	GSRT
NELIOTA	New Lunar Monitoring Project	A. Bonanos (bonanos@astro.noa.gr)	National Observatory of Athens	ESA
	Origin of Astrophysical Magnetic Fields	I. Contopoulos (icontop@academyofathens.gr)	Academy of Athens	GSRT
SAPS	ESA Science Archives Publication System	I.A. Daglis (iadaglis@phys.uoa.gr)	University of Athens	ESA
SEP	Solar Eruptive Phenomena	S. Patsourakos (spatsour@cc.uoi.gr)	University of Ioannina	EC/FP7
SEPCalib	Recalibration and Validation of SEPEM Dataset	I.A. Daglis (iadaglis@phys.uoa.gr)	University of Athens	ESA
SFOnset	Onset of Star Formation: Connecting Theory and Observations	Konstantinos Tassis (tassis@physics.uoc.gr)	University of Crete	EC/FP7
SOLAR	Solar Small-Scale Events and their Role in the Heating of the Solar Atmosphere	G.Tsiropoula (georgia@noa.gr)	National Observatory of Athens	GSRT
SoME-UFo	Solar Magnetic Eruptions: Understanding and Forecasting	M. K. Georgoulis (manolis.georgoulis@academyofathens.gr)	Academy of Athens	EC / FP7
SREM_DC	SREM and REM Data Consolidation	I.A. Daglis (iadaglis@phys.uoa.gr)	University of Athens	ESA
SRREMs	Slot Region Radiation Environment Models	I.A. Daglis (iadaglis@phys.uoa.gr)	University of Athens	ESA

Accreting Binary populations in Nearby Galaxies: Observations and Simulations

Lead Investigator: *Andreas Zezas, FORTH – University of Crete* | ***Funding Agency:*** *EC / ERC*

X-ray binaries are stellar systems consisting of compact object that is accreting material from a donor star. They are a unique tool for the study of the populations of compact objects, as well as, binary stellar evolution. In addition since they are progenitors of gravitational-wave sources and short γ-ray bursts, their study is key for modeling and understanding these types of sources.

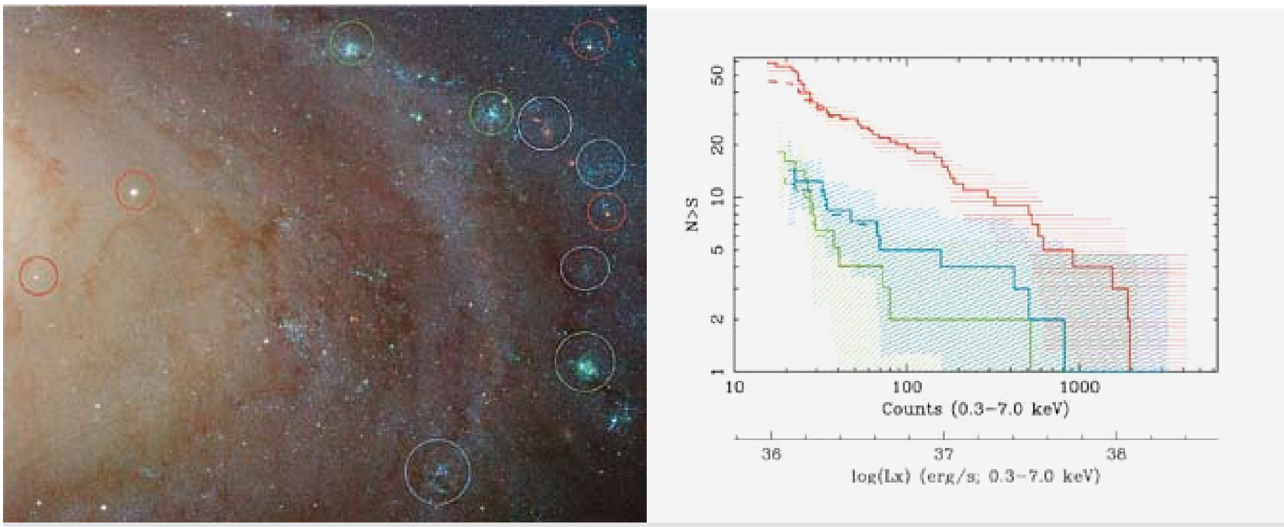
The availability of high-sensitivity, high-resolution X-ray observations of nearby galaxies with *Chandra* led to the development of detailed phenomenological picture of the populations of X-ray binaries in elliptical, spiral, and starburst galaxies. These observations in combination with advances in X-ray binary population models allowed us to set the first general constraints on key parameters related to their formation and evolution, and to model their cosmological evolution.

However, these studies are now limited by two factors: mixing of different types of accreting binaries (which generally follow different evolutionary channels), and uncertainties in the properties of their parent stellar populations. Therefore, the next major step forward in these investigations requires a closer look at the X-ray binaries and the stellar populations they are associated with.

The goal of this project is to overcome these limitations by identifying the different types of X-ray binaries present in a representative sample of nearby galaxies, and investigating separately their characteristics, and in particular their X-ray luminosity functions (XLF) in a variety of stellar environments. Key in this effort is the use of high spatial resolution *Chandra* data in tandem with deep *Hubble* Space Telescope observations. The former give us a deep census of the active X-ray binary populations, while the latter can detect individual early-type stars, star-clusters, and star-forming regions, and associate them with the *Chandra* X-ray sources (Figure). This way we can characterize the X-ray sources into High-Mass X-ray Binaries and Low-Mass X-ray Binaries, measure their XLFs, identify their parent stellar populations, and, in combination with supporting data in the UV, near, and far IR wavebands, obtain a complete picture of their star-formation histories.

Comparison of the X-ray binary subpopulation XLFs with predictions from X-ray binary population synthesis models will set direct constraints on parameters that control their formation and evolution (e.g. initial mass ratio, stellar-wind, supernova-kick strength, common-envelope ejection efficiency). In this effort we will also employ the vast database of observations of X-ray binaries in our Galaxy to derive diagnostics for the nature of compact objects and accretion state of the X-ray binaries, as well as, prescriptions that are used in the X-ray binary population synthesis models.

The end-result of this project will be: (a) direct measurements of the formation efficiency of accreting binaries in different environments; (b) constraints on their evolutionary paths, and (c) a heritage multi-wavelength dataset of galaxy observations, and a library of X-ray binary population synthesis models for future studies of galaxies and accreting binaries.



Left: A «true-colour» image of the inner disk of M81 composed of deep B, V, and I-band HST-ACS observations. Red, blue, green, and white circles, indicate globular clusters, OB associations, HII-regions, and background galaxies respectively, associated with X-ray sources [http://hubblesite.org/newscenter/archive/releases/2007/ Image credit: NASA, ESA, A. Zezas and J. Huchra (Harvard-Smithsonian Center for Astrophysics)].
Right: The cumulative X-ray luminosity function (XLF) of X-ray sources associated with OB stars (green), globular clusters (GC; blue), and late-type field stars (red) based on deep *Chandra* observations of M81 (Sell et al. 2014). The X-ray sources associated with OB stars have a very similar XLF to that of HMXBs in the Small Magellanic Cloud or the Milky Way, while their relatively low luminosities indicate that the mass transfer takes place through a stellar wind rather than Roche-lobe overflow; The X-ray sources associated with GCs or field early-type stars show the same XLF as observed in LMXBs in our Galaxy, or in elliptical galaxies (Zezas et al. in prep).

The ESA/SSA Athens Effective Solar Flare Forecasting (A-EFFort) Project

Lead Investigator: *Manolis K. Georgoulis, RCAAM of the Academy of Athens* | ***Funding Agency:*** *ESA*

ESA's Space Situational Awareness (SSA) Programme represents Europe's efforts "to autonomously detect, predict, and assess the risk of life and property" due to adverse space weather (SWE segment), near-Earth objects (NEO segments) and space debris (SST segment). Following a successful RFQ, the A-EFFort project entered negotiation phase in April 2014, kicked off in June 2014 and officially started in October 2014, with a 12-month period of performance (i.e., until September 2015). The project's aim is to enhance the SSA/SWE user services beyond the initial precursor services by establishing an online solar-flare forecasting service that monitors, evaluates, and provides advance warning of major, potentially disruptive or catastrophic, solar flares. The A-EFFort service is fully automated and committed to work until at least September 2018. It is physically based at its host institution (RCAAM of the Academy of Athens) but is accessed through the SWE Expert Service Center via a single sign-on registration process (http://ssa.swe.esa.int). Team Members include Drs. K. Tziotziou, K. Themelis, and M. Magiati. The service provides forecasting of major flares (GOES flare classes M1, M5, X1, and X5) with zero latency (i.e., effective immediately) and a 24-hour forecast window refreshed every three (3) hours.

The header of the online A-EFFort service including the content sections and the countdown to the next update of results (http://a-effort.acacemyofathens.gr)

The A-EFFort analysis combines at least three (3) standalone computer codes in an Interactive Data Language (IDL) "wrapper" fashion: a pattern-recognition automatic active region identification algorithm (ARIA), that identifies candidate flaring active-region targets on the solar disk, a code calculating the flare-prediction parameter, named the "effective connected magnetic field strength" (B_{eff}), and a code utilizing an existing archive of SOHO/MDI data from solar cycle 23 to translate B_{eff}-values into flare-forecast probabilities. B_{eff} quantifies a long-known property of flaring solar active regions, namely to organize their photospheric magnetic field in tight opposite-polarity patches interfacing via strong magnetic polarity inversion lines (PILs). Major flares are almost exclusively triggered above unstable photospheric PILs.

The A-EFFort data source is the HMI instrument onboard NASA's Solar Dynamics Observatory (SDO) mission, the current flagship of solar observation. We download and perform our analysis on the latest SDO/HMI full-disk line-of-sight solar magnetograms posting the results online in near-real time.

Aristarchos Wide Field Camera (AWFC)

Lead Investigator: *Panagiotis Boumis, National Observatory of Athens* | ***Funding Agency:*** *GSRT*

This project concerns the optical and mechanical design, construction, setup and installation of a new wide field camera on the 2.3m Aristarchos telescope. The detector will be the *Vernikos-Eugenidis optical CCD imaging camera* (Liquid nitrogen cooling, Back illuminated, 4096×4096 total pixels with a size of 15μm; see Fig. 1), while for accurate guiding of the telescope the *Apogee Aspen CG47* will be used. The instrument attached on the telescope will provide a Field-of-View of app. 26×26 arcmin^2 and is intended to be used for observations of extended faint objects using a variety of narrow and broad band filters. It is part of the funded PROTEAS/KRIPIS project (WP1), and the responsible person for this camera is the Senior Researcher of the IAASARS/NOA Dr. P. Boumis. Team members include Dr. Alexios Liakos, PostDoctoral Researcher at IAASARS/NOA. The design and the setup are anticipated to be completed in the summer of 2015, while the installation on the telescope and the first tests will probably occur in mid-2016.

DustPedia: A Definitive Study of Cosmic Dust in the Local Universe

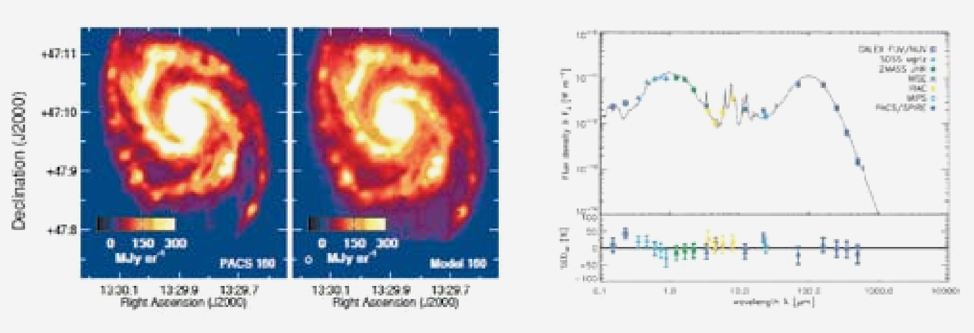
Lead Investigator: *Manolis Xilouris, National Observatory of Athens* | ***Funding Agency:*** *EC / FP7*

The European Space Agency has invested heavily in two cornerstone missions: Herschel and Planck. These space observatories provided us with an unprecedented opportunity to study, at far infrared wavelengths, the cold Universe beyond our Galaxy. These missions have produced a huge legacy data set that we intend to exploit. To maximise our spatial resolution and sensitivity to cosmic dust we will analyze in detail 3045 local galaxies (v<3000 km/s) selected via their near infrared luminosity (stellar mass). This data provides us with an opportunity to study cosmic dust in galaxies to answer fundamental questions about: the origin of the chemical elements, physical processes in the interstellar medium (ISM), its effects on the emitted stellar radiation, its relation to star formation and the cosmic far infrared background. In the course of our work we will develop tools and computer models that will help us relate observed cosmic dust emission to the physical properties of the dust (chemical composition, size distribution, temperature), the origins of dust (evolved stars, super novae, growth in the ISM) and the processes that destroy it (high energy collisions and shock heated gas). To help us interpret the data we will use our own, world leading, Monte Carlo photon tracing radiative transfer model of galaxies (see the Figure below) and our state-of-the-art model of dust physical properties. To carry out this research we will need to combine the Herschel/Planck data with that from many other recently compiled databases that contain observations of our sample galaxies at other wavelengths, thus creating the definitive legacy database – "DustPedia".

"DustPedia" is an FP7-SPACE-2013-1 funded program utilizing the complimentary expert skills of researchers at six sites across Europe [Cardiff University (UK), INAF-Osservatorio Astrofisico di Arcetri (Italy), University of Ghent (Belgium), Service d'Astrophysique, CEA (France), Université Paris-Sud (France), and the National Observatory of Athens (Greece)]. The "DustPedia" team at the National Observatory of Athens consists of Manolis Xilouris and Letizia Pasqua Cassarà. More information about the project can be found at:

http://dustpedia.com

3D radiative transfer modeling of the grand-design spiral galaxy M51 (de Looze, et al. 2014, A&A, 571, 69). The observed Herschel/PACS 160 μm image and the corresponding model are shown on the left while the multi-wavelength spectral energy distribution and the modeled emission (solid line) is on the right.



EPN2020-RI ("Europlanet 2020 Research Infrastructure")

Lead Investigator: *Ioannis A. Daglis, University of Athens* | ***Funding Agency:*** *EC / Horizon 2020*

EPN2020-RI addresses key scientific and technological challenges facing modern planetary science by providing access to state-of-the-art research facilities across the European Research Area and providing a mechanism to coordinate the European planetary science community. EPN2020-RI addresses major questions related to planetary and exoplanetary science, such as the conditions for planetary formation and the emergence of life, the formation of the solar system and its early evolution, the formation of the terrestrial planets, the nature and origin of organic materials in primitive asteroids, etc.

The project is coordinated by the Open University (United Kingdom) and includes 33 Partners from 17 European countries. In Greece, EPN2020-RI is being implemented at the University of Athens, by a team including Ioannis A. Daglis, Kosmas Gazeas, Eleni Chatzichristou and Marina Georgiou.

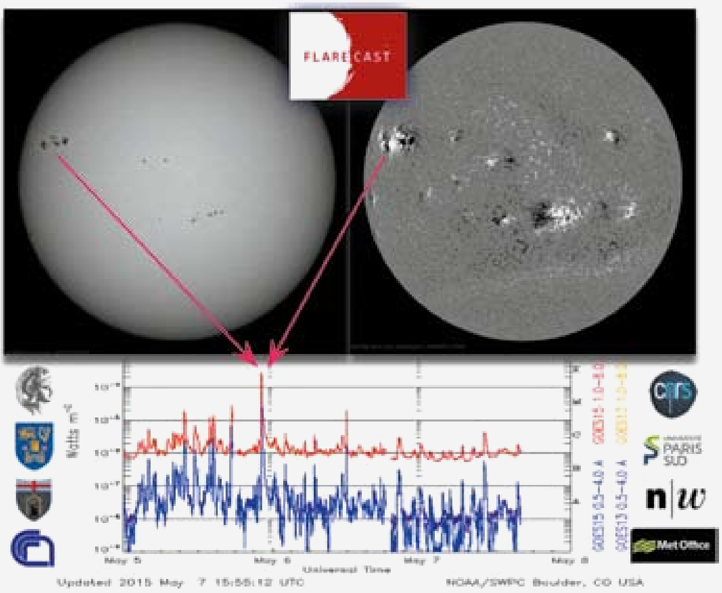
EPN2020-RI is funded by the European Commission through Horizon 2020.

Flare Likelihood and Region Eruption Forecasting (FLARECAST)

Lead Investigator: *Manolis K. Georgoulis, RCAAM of the Academy of Athens* | ***Funding Agency:*** *EC / Horizon 2020*

A key element of the PROTEC component of the European Commission (EC) Horizon 2020 Framework Programme refers to the prediction of adverse space weather, which is mostly inflicted by eruptive solar activity. Solar flares and coronal mass ejections (CMEs) are the main agents of this activity. FLARECAST was the first PROTEC project to be approved by the EC (PROTEC-1-2014). The 2.4 MEUR project kicked-in in January 2015 and has a 36-month nominal period of performance, until the end of December 2017. It comprises a consortium of eight institutes within Europe, based in Greece, Ireland, Italy, France, Switzerland, and the United Kingdom. Project Coordinator is Dr. Manolis K. Georgoulis of the RCAAM of the Academy of Athens, with Dr. Constantinos Gontikakis and two postdoctoral research associates, to be selected, comprising the local RCAAM team.

The primary objectives of the FLARECAST project (http://flarecast.eu) are to (1) understand the drivers of solar flare activity and improve flare prediction, (2) provide a globally accessible flare prediction service that facilitates expansion, and (3) engage with space-weather end users and inform policy makers and the public. FLARECAST is designed to reshape the state of the art in flare prediction and will develop a quantitative, physically motivated and autonomous solar active-region monitoring and flare-forecasting system that will be of use to space-weather researchers and forecasters in Europe and around the globe. The forecasting power of FLARECAST will rely on automatically extracted physical properties of solar active regions coupled with advanced prediction methods and validated using the most appropriate performance verification techniques. Keys to the success of FLARECAST are the breadth of diverse expertise within the consortium, with artificial-intelligence (neural networks and machine-learning) experts striving to identify the best flare predictors, and the project's explorative research component that will strive to identify new, promising flare predictors and improve the understanding and prediction of CMEs.

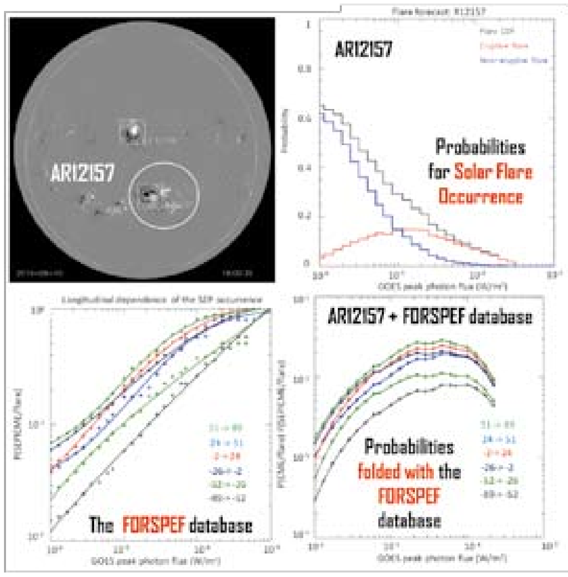


The objective and consortium of the FLARECAST project, aiming to advance solar flare prediction beyond the present state of the art. Multiple flare prediction parameters will be revisited and tested on common grounds via statistical and machine-learning prediction algorithms, while the project will create its own comprehensive database of solar observations, accessed via advanced data-mining techniques.

FORSPEF: An Operational Service for the prediction of Solar Particle Events and Flares

Lead Investigator: *Anastasios Anastasiadis, National Observatory of Athens* | ***Funding Agency:*** *ESA*

Solar Energetic Particle (SEP) events related to intense eruptive events on the Sun such as solar flares and coronal mass ejections (CMEs), pose a significant threat for both personnel and infrastructure in stormy space-weather conditions. FORSPEF (Forecasting Solar Particle Events and Flares), a new web-based service for the prediction of energetic-particle events (http://tromos.space.noa.gr/forspef), was designed and implemented by IAASARS/NOA, to perform forecasts and nowcasts of the occurrence and the characteristics of solar flares and SEP events. The prediction of solar flares relies on a morphological method based on the effective connected magnetic field strength (Beff) of potentially flaring active-region (AR) magnetic configurations and utilizes analysis of a large number of AR magnetograms. For the prediction of SEP events a new reductive statistical method has been implemented based on a newly constructed database of solar flares, CMEs and SEP events that covers a long time span from 1984-2013. The method is based on flare location (longitude), flare size (maximum soft X-ray intensity), and the occurrence (or not) of a CME. Warnings are issued for all > C1.0 soft X-ray flares. The warning time in the forecasting scheme is 24 hours with a refresh rate of 3 hours while the respective warning time for the nowcasting scheme depends on the availability of the near real-time data and ranges between 15-20 minutes. The system is capable of predicting the likelihood of SEP event occurrence, as well as the timing of the peak, duration of the event, and peak flux and fluence at a range of energies. The dual FORPSEF approach (i.e. forecasting and nowcasting scheme) allows refinement of predictions upon the availability of new data that characterize changes on the Sun and the interplanetary space, while the combined usage of solar flare and SEP forecasting methods upgrades FORSPEF to an integrated forecasting solution. The FORSPEF service was developed in the framework of the ESA Contract No. 4000109641/13/NL/AK, "Improvement of Solar Particle Events and Flare Prediction".

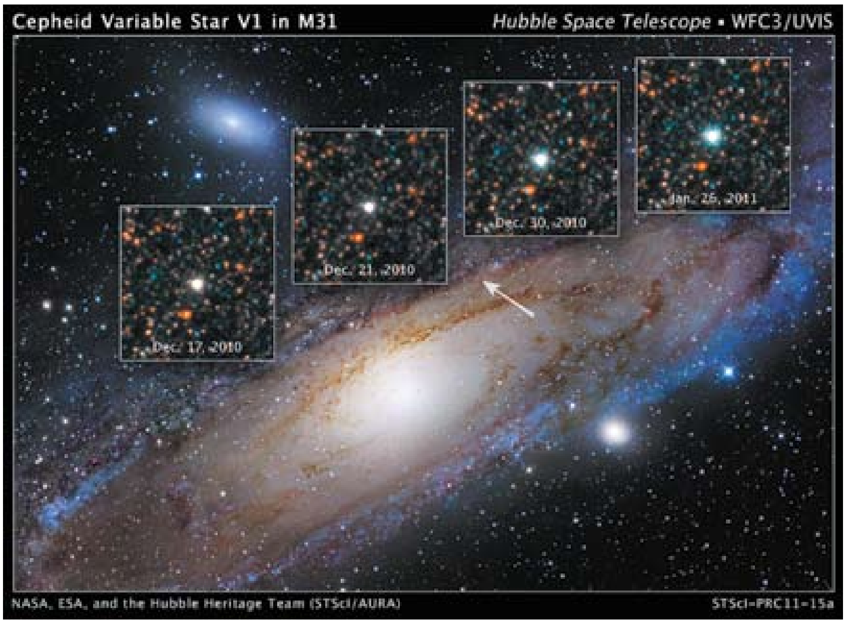


FORSPEF's forecasting work scheme: for a given AR (i.e. AR12157), the probabilities of flare and CME occurrence are first derived, (right top panel). Results stemming from the FORSPEF database are presented in the bottom left panel. The abscissa corresponds to the flare peak photon flux and the ordinate corresponds to the derived probabilities of SEP occurrence The probabilities derived by the SF prediction are folded with the probabilities derived by the FORSPEF database. This is illustrated at the bottom right panel.

Hubble Catalogue of Variables

Lead Investigator: *Kanaris Tsinganos, National Observatory of Athens* | ***Funding Agency:*** *ESA*

The "Hubble Catalogue of Variables" or HCV is a new activity of the European Space Agency (ESA) launched at the National Observatory of Athens (NOA). The program, which was kicked-off in April 2015, aims to identify all the variable and transient sources in the Hubble Source Catalog (HSC; http://archive.stsci.edu/hst/hsc/), which has combined the tens of thousands of visit-based source lists in the Hubble Legacy Archive (HLA; http://hla.stsci.edu/) into a single master catalog. The HSC was designed to optimize science from the *Hubble Space Telescope* (HST) and the HCV will take this a step further, by extending the original HSC services and implementing added-value functionality. The HCV system will consist of three modules or elements. One module is a highly-automated data-processing pipeline for querying the HSC, detecting and validating the variable sources, and populating the catalogue of variables. The second element is the HCV itself. The third module is a web-based, user-friendly interface that will make the HCV accessible to the public.



The novelty of this activity is expected to be the improved efficiency in identifying variables and its enormous coverage due to HST's archive of imagery from the 25 years of HST observations. HST's extremely long baseline of observations is totally unprecedented for any space mission. Given the combination of high angular resolution and depth of the HST data, the HCV has the potential to produce groundbreaking science despite the non-uniformity of the data and the limitations of the HSC. The time domain and variability properties of astronomical sources provide a wealth of information that can be very useful for characterizing e.g. the fundamental properties of stars, or for identifying particular types of sources from a large dataset. Objects showing variations in flux may be associated with variable stars in our own Galaxy, stars in nearby galaxies, or distant Active Galactic Nuclei (AGN), or possibly transient events such as novae and supernovae. Variable stars are fundamental to our understanding of the Universe, as they play a critical role in setting the first rung of the extragalactic distance scale, the discovery of the expansion of the Universe via studies of distant Type Ia supernovae and the determination of the parameters of extrasolar planets.

This 3-year activity is being undertaken by a team led by Prof. Kanaris Tsinganos (PI) and Dr. Alceste Bonanos (Project Scientist) at the Institute for Astronomy, Astrophysics, Space Applications & Remote Sensing at the National Observatory of Athens, Greece, with the participation of the Athena Research Center as a subcontractor. NOA team members include Ioannis Bellas-Velidis (Technical Manager), Ioannis Georgantopoulos, Vassilis Charmandaris, Despina Hatzidimitriou, Stavroula Papatheochari and postdoctoral researchers Panagiotis Gavras, Kirill Sokolovsky, Ming Yang and Maria Ida Moretti.

HERMES ("Hellenic Evolution of Radiation data processing and Modelling of the Environment in Space")

Lead Investigator: *Ioannis A. Daglis, University of Athens* | ***Funding Agency:*** *ESA*

The goal of this project is to improve and combine radiation data processing routines and environment modelling results to enable more accurate evaluation of the radiation environment in space.

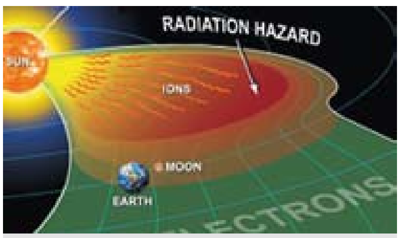
HERMES is being implemented at the University of Athens, by a team including Ioannis A. Daglis, Ingmar Sandberg, Constantinos Papadimitriou, Christos Katsavrias, Omiros Giannakis, Antonios Tsinganos, Sigiava Giamini, Georgios Provatas, Marina Georgiou, and with two external partners (DH Consultancy, Belgium; Paul Scherrer Institute, Switzerland).

HERMES is funded by the European Space Agency (ESA).

'HESPERIA: High Energy Solar Particle Event Forecasting and Analysis'

Lead Investigator: *Olga Malandraki, National Observatory of Athens* | ***Funding Agency:*** *EC / Horizon 2020*

High-energy particles emitted from the Sun are of utmost interest both for astrophysics and for space weather applications. From the astrophysical viewpoint the Sun is the unique object where in situ measurements of the particles and remote sensing observations of their radiation can be combined. Both can be carried out with a time resolution that is relevant to the fundamental processes of particle acceleration and transport. From the space weather perspective high-energy particles from the Sun have well-known effects in the Earth's space environment. Extreme solar particle events are even known to affect atmospheric chemistry through the production of molecules that interact with ozone. Engineering measures have been fruitful in mitigating space weather hazards, but large and extreme events need prediction. These events may be an excessive radiation threat for human beings aboard transpolar aircraft, and constitute such a threat for sure for spacecraft crews of future planned manned missions to Mars and asteroids.



HESPERIA focuses on the high-energy SEP events which constitute a major space weather radiation hazard (Courtesy: B. Heber, CAU, Kiel, Germany)

After completion of the successful FP7 projects 'SEPServer' and 'COMESEP', with Dr. Malandraki as PI for the National Observatory of Athens (NOA), a new project 'HESPERIA' has been selected for implementation under HORIZON 2020 'Space Weather' of the European Union. Dr. Malandraki is the Project Coordinator of 'HESPERIA' and PI for NOA. She is member of staff at NOA, and is, besides all other, expert in the National Delegation team to ESA/SPC, National Coordinator of the 'International Space Weather Initiative' (ISWI) of the United Nations and Deputy President of the Solar-Terrestrial Division of the European Geosciences Union.

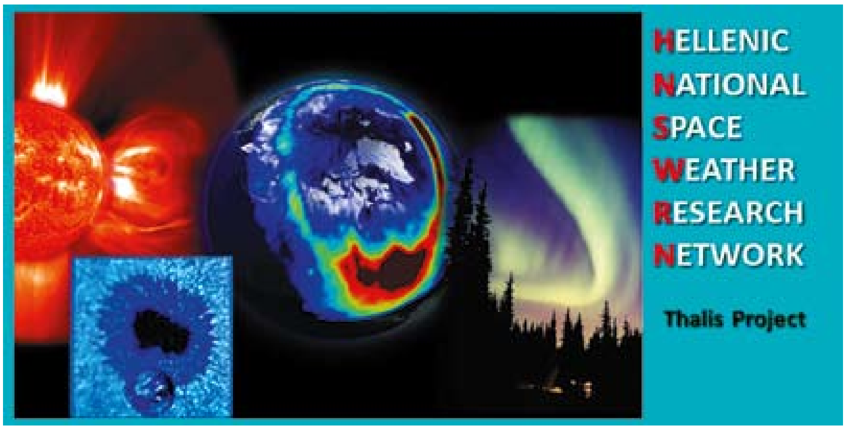
HESPERIA will provide new insight into the physics of Solar Energetic Particle (SEP) events and develop improved and novel tools for SEP analysis and forecasting. The project will for the first time conduct systematic research on *protons* from the Sun to 1 AU, through a systematic exploitation of the new high-energy gamma-ray observations of the FERMI mission together with in situ SEP measurements near 1 AU. This will put an end to the decade-long bias of remote sensing observations towards electrons, which emit the vast majority of the electromagnetic emissions analysed so far. The project will lead to a better understanding of forecasting schemes and to policy recommendations for future space weather services. For the first time publicly available software to invert neutron monitor observations of relativistic SEPs to physical parameters that can be compared with the space-borne measurements at lower energies will be provided. These are important results in view of the future mission 'Solar Orbiter' of ESA, in which Dr. Malandraki participates as a Co-I. HESPERIA, coordinated by NOA, comprises 8 European Collaborating partner Universities/Research Institutes and a SME. The Consortium is enhanced through the involvement in the project of 4 external experts, e.g. from NASA. The project has a 2-year duration.

HESPERIA focuses on the high-energy SEP events. We aim at unfolding both the physical processes that result into these events but at the same time we aim at building novel forecasting operational services. The scientific community has addressed the problem of the origin, acceleration and propagation of high-energy SEPs in a fragmented approach, so far. The HESPERIA consortium will utilize novel datasets, employing detailed modelling and data driven analysis to identify the underlying physical processes. Proven operational forecasting tools with a very successful tradition will be further improved either by adapting new datasets as seeders of the algorithms or by expanding their capabilities.

Hellenic National Space Weather Research (HNSWR) Network

Lead Investigator: *Loukas Vlahos, University of Thessaloniki* | ***Funding Agency:*** *GSRT*

A team named the *Hellenic National Space Weather Research Network* (HNSWR, http://proteus.space.noa.gr/~hnswrn/) including the majority of space physicists working in six different Greek universities and research institutes and abroad on topics related to space weather. We aim to understand, and ultimately help predict, adverse space weather conditions by combining cutting-edge observations, data analysis, theory, modeling, and space instrumentation. This task constitutes a research effort to which Greek space physicists have played – and strive to continue playing – a very significant role.



Advancing the current understanding of the Sun-Earth connection is a central challenge of contemporary space physics. The Sun incessantly and intermittently forces the terrestrial and other planetary magnetospheres both with its far-reaching magnetic fields and continuous plasma flows, known as the *solar wind*, and via sudden explosions (*solar flares*) related to expulsions of magnetic flux and plasma in the heliosphere, known as *coronal mass ejections* (CMEs). This variable solar forcing is termed *Space Weather*, in analogy to terrestrial weather. Inclement (i.e., powered by solar eruptions) space weather poses a serious safety threat to our space assets (e.g., satellites, astronauts) and to sensitive ground-based activities and infrastructure (e.g., power grids, polar flights, GPS-reliant tasks). We have proposed to address and work on alleviating this threat by placing a highly experienced team of researchers to implement a focused, thorough, and well-targeted research plan.

Almost two years completed since the funding of the program started and a number of achievements can be listed already. More than twenty articles have been published in refereed journals and or are close on the final stages of their completion. A few of them are listed below:

1. A large collaborative study on Sun-to-Earth analysis of the geoeffective solar eruptions of 7 March 2012. We try to draw quantitative and qualitative links between solar and interplanetary activities and conditions.
2. Detailed investigation of a theoretical idea for solar eruption initiation, relying on the progressive formation of highly twisted magnetic flux ropes above intense photospheric magnetic-polarity inversion lines.
3. Particle acceleration in regions of magnetic flux emergence
4. Multi-viewpoint observations of a ma-

jor Solar energetic Particles event.

5. Open issues in Modeling the interaction of the Earth's magnetospheric current system with effects emerging from solar activity
6. Intensity periodicities of energetic particles during storms
7. Tsalis q-Triplet and Solar Wind dynamics
8. Use of the ULF observation by the IMAGE ground magnetometer array to assess their dependence on geomagnetic activity and to calculate the radial diffusion in the radiation belts.

A series of schools, workshops and collaboration teams in different parts of Greece have been completed. In the program are currently active 17 faculty members and researches have been involved and 15 young scientists (postdocs, graduate students and students) have been trained. Overall this project has giving us hopes that this multi-discipline national collaborative effort will continue its existence by submitting new national and international projects.

MAARBLE ("Monitoring, Analyzing and Assessing Radiation Belt Loss and Energization")

Lead Investigator: *Ioannis A. Daglis, University of Athens* | ***Funding Agency:*** *EC / FP7*

The MAARBLE project, which was recently completed successfully, had two focused and synergistic aims:
i. to advance scientific research on radiation belt dynamics, in particular during periods of enhanced geomagnetic activity when the most dramatic changes occur;
ii. to enhance data exploitation of European space missions through the combined use of European and United States spacecraft measurements and ground-based observations.

MAARBLE employed multi-spacecraft monitoring of the geospace environment, complemented by ground-based monitoring, in order to analyse and assess the physical mechanisms leading to radiation belt particle energization and loss. These processes are of great importance, because radiation enhancements due to radiation belt energization can adversely impact satellites that modern society increasingly depends on. MAARBLE paid particular attention to the properties of ultra-low frequency (ULF) and very low frequency (VLF) waves and their critical role in radiation belt dynamics. As a central deliverable, a database containing characteristic properties of ULF and VLF waves was created and is now publicly available to the scientific community through the Cluster Science Archive (CSA) website:

http://www.cosmos.esa.int/web/csa

Based on the wave database, statistical models of wave activity for different types of waves were created. These models – or maps – provide statistical distribution of amplitudes and, moreover, wave normal angles and other polarization and propagation characteristics, which determine how the waves interact with particles.

Another central task of MAARBLE was to use data assimilation techniques to guide 'the best' estimate of the state of a complex system such as the electron radiation belt. Multi-spacecraft particle measurements were incorporated into the ONERA data assimilation tool, which is in essence an ensemble Kalman filter. Next, the performance and capabilities of the data assimilation tool were enhanced. One of the major improvements regarding data assimilation itself has been to implement the capability of ingesting count rates data. The validation of the improved data assimilation tool was satisfactory and showed that with its capabilities extended and its performance significantly improved, this ensemble Kalman filter could serve as the essential means to balance model predictions with data.

One of the most significant outcomes from the MAARBLE project was scientific discoveries and new knowledge about the conditions under which different and competing wave-particle interactions control the dynamics of the electron radiation belts – as well as new understanding of when and where specific mechanisms dominate the delicate balance between competing acceleration and loss. Using a new and unique approach to data-driven specification of radial diffusion, we discovered fundamental new impacts of inward and outwards transport, controlled by the availability of plasma-sheet source populations and/or the occurrence of magnetopause shadowing. We furthermore determined when a wide range of plasma wave-particle interactions contribute to loss or acceleration, and for the first time proved EMIC waves can cause the Van Allen belt electron loss by scattering into the atmosphere.

Overall, the MAARBLE project generated extensive new knowledge in a very large number of scientific publications in leading international scientific journals (38 papers, listed here:

http://www.maarble.eu/project/index.php/publications)

with many exciting and high-impact scientific publications expected to provide guidance and new research directions for the international radiation belt community for many years to come.

The project was implemented at the National Observatory of Athens, by a team including Ioannis A. Daglis (Project Coordinator), Georgios Balasis, Anastasios Anastasiadis, Omiros Giannakis, Ingmar Sandberg, Constantinos Papadimitriou, Marina Georgiou, Christos Katsavrias, Sigiava Giamini, Eleni Chatzichristou, Fiori-Anastasia Metallinou, Georgios Ropokis, Ioannis Panagopoulos, and with six external partners (ONERA, France; IRF, Sweden; IAP, Czech Republic; BAS, United Kingdom; Univ. of Alberta, Canada; UCLA, USA)

MAARBLE was funded by the European Commission through FP7-Space.

The Manchester-Athens Wide Field Camera (MAWFC)

Lead Investigator: *Panagiotis Boumis, National Observatory of Athens* | ***Funding Agency:*** *GSRT*

MAWFC is a joint project between the National Observatory of Athens and the Jodrell Bank Centre for Astrophysics of the Manchester University (UK). It is co-funded (budget: 312.000 €) by the European Union (European Social Fund) and the Greek State under the "ARISTEIA II" action of the operational programme "Education and Lifelong Learning". The project, led by the Senior Researcher Dr. Panos Boumis (P.I.) and Prof. John Meaburn, aims to conduct a large-area sky survey with the aid of a customized camera properly designed for a deep and rapid coverage of the northern hemisphere in the optical emission lines of Hα, [O III], and Hβ. Team members include Post-Doctoral researchers Drs. Nikolaos Nanouris, Alexios Liakos, and Alexandros Chiotellis. The instrument has been already constructed and set up – in its final form – since the end of March 2015, while the first light tests took place in Penteli on 1st of April. The first scientific observations are anticipated to be conducted during the spring/early summer of 2015 at the Kryoneri Observatory site.

The instrument consists of a multi-lens optical system and a filter box inside an aluminum tube, equipped with the CCD camera *Andor iKON-L* (back illuminated, low read out noise, thermo-electrical cooling to –100°C, 2048×2048 pixels array, 13.5 μm pixel size). The optical tube is mounted on a *Paramount MEII* german equatorial mount, while a small refractor telescope with the *Starlight-Xpress* auto-guiding CCD has been installed off-axis for guiding. Among its innovations, the wide field of view (~30 deg diameter, ~1 arcmin angular resolution) offers a unique opportunity for studying (and discovering) extended interstellar medium structures with an only small number of individual pointings. The narrow-band filters (~15-40 Å bandwidth) will also allow a composition of the Hα to Hβ flux ratio maps for estimating the dust extinction at Hα, which may be further contributed as an improved template for the calibration and interpretation of the cosmic microwave background (CMB).

MAWFC equipment during the first light tests.

A pipeline for the automated image processing has been also developed in the IDL programming environment addressing the particular specifications and goals of the project. In its current form, it is able to perform (i) the standard bias, dark, and flat-fielding calibration, (ii) identification of stars (found with a Gaussian point spread function) in the continuum broad-band images, (iii) alignment of multiple narrow- and broad-band images, (iv) accurate point spread estimation ("radius" in pixels) relied on the local sky background (intending to efficiently remove the stellar contamination from the narrow-band images), (v) robust smoothing techniques based on the nearest pixel neighbors, (vi) precise astrometry, (vii) mosaic composition, and (viii) output files suitable for a 3D image reconstruction.

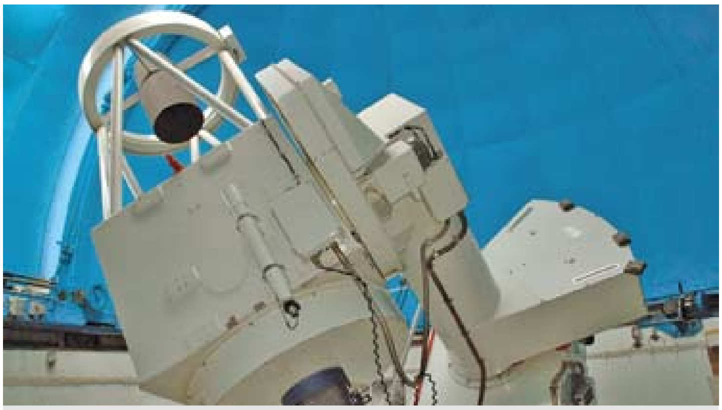
NELIOTA: ESA's new lunar monitoring project in collaboration with the National Observatory of Athens

Lead Investigator: *Alceste Bonanos, National Observatory of Athens* | ***Funding Agency:*** *ESA*

NELIOTA is an activity initiated by the European Space Agency (ESA), which was launched in February 2015 at the National Observatory of Athens (NOA). The project aims to determine the frequency and distribution of near-earth objects (NEOs) by monitoring the non-illuminated side of the Moon for flashes caused by NEO impacts, which result in the formation of a crater on the surface of the Moon. NELIOTA will help assess the threat of small NEO collisions to orbiting spacecraft and to future ESA Moon missions.

The NELIOTA project will use existing facilities at the National Observatory of Athens to establish an operational system that will monitor the Moon, looking for faint NEO impacts. The project involves upgrading the 1.2m Kryoneri telescope, located in the Northern Peloponnese, in Greece, as well as procuring two specialised fast-frame cameras. Specialised software will be developed to control the telescope and cameras, as well as process the resulting images to detect the impacts automatically. The NELIOTA system will then publish the data on the web so it can be made available to the scientific community and the general public.

The objective of this 45 month activity is to design, develop and implement a highly automated lunar monitoring system. The system will conduct an observing campaign for 2 years searching for NEO impact flashes on the Moon. The impact events will be verified, charac-



NOA's 1.2 m Kryoneri telescope to be upgraded for the NELIOTA project at ~10 MK (~1 MK). From Patsourakos, Vourlidas, Stenborg, 2013, ApJ, 764, 125.

Artist rendering of a lunar impact (Credit: NASA/MSFC) at ~ 10 MK (~1 MK). From Patsourakos, Vourlidas, Stenborg, 2013, ApJ, 764,125

terised and recorded. The 1.2m Kryoneri telescope will be capable of detecting flashes far fainter than telescopes currently monitoring the Moon. It is expected that NELIOTA will be able to record NEOs weighing just a few grams.

This activity is being undertaken by a team led by Alceste Bonanos at IAASARS, National Observatory of Athens, Greece, including Manolis Xilouris (Technical Manager), Panos Boumis (Instrumentation Manager), Athanassios Maroussis (IT Manager), Anastasios Dapergolas (Telescope Operations Manager), Stavroula Papatheochari (Assistant Project Manager), project members Ioannis Bellas-Velidis and Anastasios Fytsilis, and advisory board members Kleomenis Tsiganis, Vassilis Charmandaris, Kanaris Tsinganos. The upgrade of the 1.2m Kryoneri telescope will be undertaken by DFM Engineering, Inc. The project website can be found here:

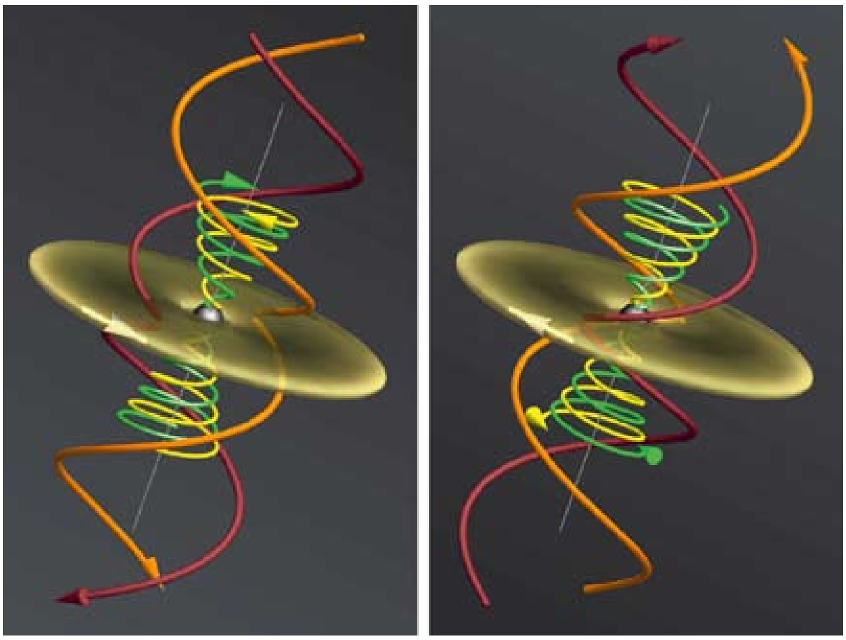
neliota.astro.noa.gr

Program "Excellence": The Origin of Astrophysical Magnetic Fields

Lead Investigator: *Ioannis Contopoulos, RCAAM of the Academy of Athens* | ***Funding Agency:*** *GSRT*

In the past three years, we have been investigating the origin of the magnetic field in the central engines of the most energetic astrophysical systems observed in the Universe. Their source of energy is the black hole spin, and the magnetic field is the "shaft" that transports this energy from the vicinity of the black hole horizon to large astrophysical distances. In particular, we are studying the implications of the Cosmic Battery (Contopoulos & Kazanas 1998) according to which, radiation from the accretion disk around the central black hole scatters on the plasma electrons of the inner disk, decelerates them, and induces a ring current which is the source of the magnetic field. We investigated several aspects of this problem:

1. **Electromagnetic extraction of black hole spin-energy.** We obtained new solutions of the generalized pulsar equation, and emphasized the role of the two light cylinders and the wind generation zone. We discovered that current sheets are a



generic feature of black hole magnetospheres.

2. **Radiation dynamics in General Relativity.** The source of the CB radiation is the surface of the accretion disk itself. We generated sky maps from photon trajectories that originate on the surface of the disk as seen from its inner edge.
3. **Numerical simulations of the Cosmic Battery.** We confirmed the original prediction that astrophysically significant magnetic fields grow naturally on astrophysically relevant timescales.
4. **Helical magnetic field topology in extragalactic jets.** We obtain a definite prediction of the global topology of the magnetic field generated by the CB with very significant observational consequences (see figure below).
5. **Observations of the Blandford-Znajek process in GRBs.** We discovered exponential decay in the prompt emission of XRT light curves, which we believe is an indirect observation of the Blandford-Znajek process in action.

SAPS (“ESA Science Archives Publications System”)

Lead Investigator: *Ioannis A. Daglis, University of Athens* | ***Funding Agency:*** *ESA*

The goal of this project is to develop a system that will provide information on the scientific performance of ESA’s operating missions by linking and examining the publications and the observational data used to produce them.

SAPS is being implemented at the National Observatory of Athens, by a team including Ioannis A. Daglis, Ioannis Georgantopoulos, Omiros Giannakis, Athanasios Akylas, Anastasios Anastasiadis, and Olga Sykioti. The project is coordinated by Planetek Hellas.

SAPS is funded by the European Space Agency (ESA).

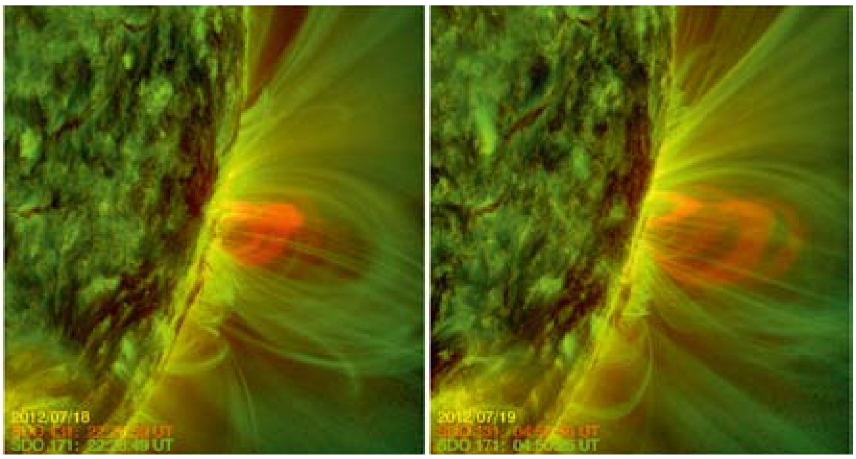
Solar Eruptive Phenomena (SEP)

Lead Investigator: *Spiros Patsourakos, University of Ioannina* | ***Funding Agency:*** *EC / FP7*

The Solar Eruptive Phenomena (SEP) project was carried out at the Department of Physics of the University of Ioannina during the period 2010-2014 under the aegis of an EU reintegration grant. SEP aimed to enhance our understanding of the initial stages and the Sun-to-Earth propagation of Coronal Mass Ejections (CMEs). CMEs represent gigantic transient expulsions of magnetic fields and frozen-in plasmas from the solar corona into the interplanetary (IP) medium and are main space weather drivers. We hereby supply several highlights of this research.

A major obstacle in our understanding of CMEs is the determination of their pre-eruptive magnetic structure. While it is now widely accepted that most CMEs, once in the outer corona and when they reach 1 AU, have a flux rope topology, i.e., coiled magnetic fields around a major axis, it is a matter of strong debate whether a flux-rope topology exists before a CME is born. Answering to this question has important implications for CME initiation models and theories. Using imaging observations of hot (~ 10 MK) plasmas in the corona taken by the Atmospheric Imaging Assem-

AIA observations of the formation of a flux rope during a confined flare (left panel) and its eruption as a CME (right panel). Red (green) correspond to plasmas at ~ 10 MK (~1 MK). From Patsourakos, Vourlidas, Stenborg, 2013, ApJ, 764,125



bly (AIA) suite of telescopes on-board the Solar Dynamics Observatory mission it was found that flux ropes are a *common* occurrence before and during CME onsets. The first observations of a truly pre-existing flux rope were presented. This structure was formed during a confined (i.e., non-eruptive) solar flare (left panel of Figure). Several hours after its formation, the flux rope erupted and led to a CME (right panel of Figure) . It was therefore conjectured that confined flares of all magnitudes could lead to the formation of flux ropes.

Frequently, and in tandem with eruptive flares, global propagating disturbances named EUV waves are observed. The nature of EUV waves is a matter of intense debate with both wave (MHD fast-mode) and non-wave (disk projection of expanding CME) interpretations being proposed. The exact nature of EUV waves was addressed with a synthesis of the current observational and modeling knowledge of this phenomenon. A *hybrid* picture, invoking both wave and non-wave components, was found to best reproduce the bulk of the observations recorded by instrumentation onboard various satellites (STEREO, SOHO, HINODE, SDO) and largely settled the debate.

Finally, it was found that shocks formed around fast CMEs represent a crucial parameter in the description and modeling of their IP propagation. Inclusion of *shocked* solar wind conditions *upstream* the propagating CMEs into the corresponding equation of motion leads to significant improvements in the prediction of their *arrival times* and *speeds* at Earth.

The SEP project was carried out in the frame of the FP7-PEOPLE-2010-RG/268288 grant. More information on the SEP project may be found at:

http://users.uoi.gr/spatsour/sep/sep.html

SEPCalib (“Recalibration and Validation of SEPEM Dataset”)

Lead Investigator: *Ioannis A. Daglis, University of Athens* | **Funding Agency:** *ESA*

The goal of the SEPCalib project is to define new calibration routines for the GOES/SEM data of the SEPEM Dataset. Furthermore it will produce new scaling factors and perform suitable error estimation on the data for propagation in statistical tools to give a contribution to the uncertainty of the model outputs. This work will also allow the updating of the present ECSS (European Cooperation for Space Standardization) standard. SEPCalib is being implemented at the University of Athens, by a team including Ioannis A. Daglis and Ingmar Sandberg.

SEPCalib is funded by the European Space Agency (ESA).

Onset of Star Formation (SFOnset): Connecting Theory and Observations

Lead Investigator: *Kostantinos Tassis, University of Crete* | **Funding Agency:** *EC / FP7*

Interstellar chemistry is one of the most important tools available for probing the physical conditions in molecular clouds and thus understanding the processes that regulate star formation. The temperature, kinematics, irradiation history, and magnetic field strength are just typical examples of physical properties derived from molecular observations. To date, nearly 400 molecules have been identified in the interstellar medium. The production and destruction of these molecules are governed by vast chemical networks with the parameters entering the equations depending on the physical conditions which in turn change with time. Therefore, numerical simulations of the physical and chemical processes become a necessity. By comparing numerical results with observations, the initial conditions for star formation can be deduced. Such a combination of theory and observations can lead to a leap forward in our understanding of star formation.

The SFOnset project aims to facilitate this comparison. We develop self-consistent, non-equilibrium simulations following simultaneously the dynamical evolution of star-forming clouds and the chemical evolution of over 300 molecules, forming a network of over 15,000 reactions. We run suites of massively parallel simulations varying free parameters over the entire range allowed by observations, and we seek observables that can help us make progress in answering the critical open questions in the field: how do molecular clouds fragment to form cores? are filaments or cores the primary substructures of molecular clouds? which physical properties of the starforming cloud determine the distribution of masses of the newborn stars? what are the relative roles of magnetic fields and turbulence in regulating the rate for conversion of interstellar gas to stars?

The project is funded through the Marie Curie CIG programme, MC-CIG-2011, grant SFOnset.

Solar small-scale events and their role in the heating of the solar atmosphere – SOLAR

Lead Investigator: *Georgia Tsiropoula, National Observatory of Athens* | ***Funding Agency:*** *GSRT*

The aim of the funded research under the ARISTEIA II Action is the detailed study of solar fine-scale structures. The interest in getting better insight on these structures is due to the recognition that magnetic flux tubes, which constitute them, provide, through their field lines, direct links between the photosphere and the chromosphere to the corona. Along these tubes energy can be transported from the solar interior into the outer atmosphere, where it can be dissipated immediately or stored and released later. Quite generally, rapid footpoint motions of flux tubes emerging from the solar interior generate photospheric perturbations which can either propagate in the form of various MHD tube waves, the dissipation of which can provide the energy necessary to heat the upper solar layers or built up magnetic stresses which gradually create highly localised current sheets. These current sheets become unstable to resistive instabilities resulting in a very rapid release of energy through field line reconnection. Contrary to its vital role in magnetic free energy release, magnetic reconnection cannot efficiently remove helicity. Relative magnetic helicity quantifies the stress and distortion of the magnetic field lines compared to their potential energy state and builds up either by emergence from the solar interior via helical magnetic flux tubes or by solar differential rotation and photospheric motions (shuffling).

Here, we report some important results we obtained in the context of the project. We derived, statistically, the free magnetic energy and relative magnetic helicity injection rates by using a large set of quiet-Sun observations, and associated them with the energetics and dynamics of fine-scale quiet-Sun structures. We found that there is no dominant sense of helicity injection in quiet-Sun regions and that both helicity and energy injection are mostly due to surface shuffling motions that dominate the respective emergence by a factor slightly larger than two. We, furthermore, estimated the helicity and energy rates per network unit area, as well as the respective budgets over a complete solar cycle. We found that free-energy budgets are high enough to power the dynamics of fine-scale structures residing at the network boundaries, while corresponding estimates of helicity budgets are also provided, pending future verification with high-resolution MHD simulations and/or observations.

Among the objectives of the project is the understanding of the role of fine-scale structures in the propagation of waves. In quiet Sun regions magnetic flux tubes outlining the boundaries of supergranules expand with height and form the so-called magnetic canopy. This critical layer marks the transition between the gas-pressure-dominated and the magnetically dominated atmosphere and plays an important role in the energy transfer. From our work it has been made clear that the many processes that take place on the magnetic canopy by the upwardly propagating waves, i.e. fast/slow, transmission/conversion, and their dependence on the acoustic cut-off frequency and the inclination of the magnetic field complicate the problem of energy transport. Some remarks can be made, however, about the efficiency of the two modes, i.e. fast and slow, to carry energy in the overlying solar layers. Slow waves are guided along the magnetic field lines up to the chromosphere and can escape upward or be reflected downward or even steepen into shocks releasing energy. Fast waves, on the other hand, are refracted or reflected above the magnetic canopy at the so-called turning height. There the fast mode converts partly to an Alfvén wave before totally reflecting. This is an essential process, since Alfvén waves carry energy that may dissipate in the corona.

Team members: Dr G. Tsiropoula, Dr K. Tziotziou, Dr. Sung-Hong Park and Dr. I. Kontogiannis (National Observatory of Athens), Dr. M. Georgoulis and Dr. K. Gontikakis (Academy of Athens), Prof. G. Doyle and Dr M. Madjarska (Armagh Observatory, N. Ireland), Dr V. Archontis (St Andrews Univ., UK)

Solar Magnetic Eruptions: Understanding and Forecasting (SoME-UFo)

Lead Investigator: *Manolis K. Georgoulis, RCAAM of the Academy of Athens* | ***Funding Agency:*** *EC / FP7*

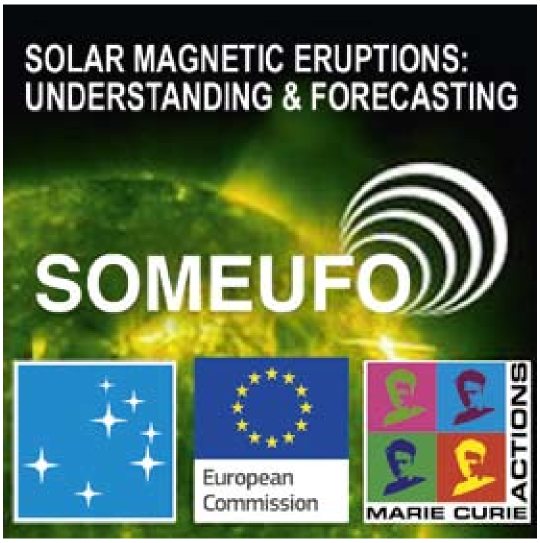
The exponential increase of high-quality observational data in the space age has established that the observed solar eruptions are of magnetic origin. Remarkable progress has followed this realization, but knowledge of the actual relaxation mechanisms of the magnetic lines of force giving rise to the explosive release of energy that powers solar flares and coronal mass ejections (CMEs) is still plagued by several gaps in understanding. Perhaps more importantly, the elusive initiation mechanism(s) of solar flares and CMEs hamper efforts to actually predict these events, thus blocking meaningful advances in space weather forecasting.

The SoME-UFo project was awarded by the Marie Curie International Reintegration Grant (IRG) Programme of the European Commission's FP7 in November 2010, with a four-year period of performance. The project's dual objective was to (1) understand solar eruptions and (2) help build a future capacity to predict them. It was also meant to support the

Principal Investigator to smoothly reintegrate into the European research landscape after a near-decadal tenure in the US. The scientific supervisor of the project was Academician Prof. George Contopoulos and the postdoctoral research associate employed for most of the project's duration was Dr. Konstantinos Tzotziou.

The project underwent its final evaluation in April 2015. The evaluation declared the project a remarkable success congratulating the supervisor and the researchers involved for their performance and efforts in the scientific and public dissemination, and the PI for developing a European network of collaborators, at the same time maintaining his US connections and forging new connections in Russia and China.

In brief, the project resulted in eighteen (18) published refereed works (12 project-supported; 6 project-contributing) with multiple ones in preparation, 24 conference presentations, many of them invited, and in many public seminars and popular articles. The project enabled a valuable new insight into the physics of solar eruption initiation, allowing for a causal sequence of mechanisms that invariably lead to eruptions in case the magnetic energy and helicity budgets of the pre-eruption structure cross some thresholds that came to be understood during the project. In addition, it expanded previous work of the PI on solar flare prediction that has resulted in his leadership of two new projects (ESA / A-EF-Fort and H2020 / FLARECAST, also described in this issue). Last but not least, the project laid the foundations for a novel nonlinear force-free field extrapolation method to assess the unknown magnetic field of the solar corona.



The SoME-UFo project has resulted in a deeper understanding of solar eruptions and enabled an enhanced predictive capability of solar flares. It also gave rise to multiple dissemination works, both scientific and popular, and public seminars that helped increase public awareness in solar activity and solar-terrestrial relations. For more information and dissemination material, visit http://astro.academyofathens.gr/people/georgoulis/SOME_UFO/

SREM_DC
("SREM and REM data consolidation")

Lead Investigator: *Ioannis A. Daglis, University of Athens* | ***Funding Agency:*** *ESA*

The goal of this project is to consolidate the SREM dataset processing chains, cross-calibrate the SREM flux data by comparison with other radiation measuring instruments, e.g. RBSP/MagEIS and RBSP/REPT, and provide a review of the SREM radiation monitoring activity from instrument design to production of flux data and provision to the general public.

SREM_DC is being implemented at the University of Athens, by a team including Ioannis A. Daglis, Ingmar Sandberg, Omiros Giannakis, and an external partner (Paul Bühler, Austria).

SREM_DC is funded by the European Space Agency (ESA).

SRREMs
("Slot Region Radiation Environment Models")

Lead Investigator: *Ioannis A. Daglis, University of Athens* | ***Funding Agency:*** *ESA*

The goal of the SRREMs project is to produce models of the Earth's inner and outer radiation belts with an emphasis on the slot region, for which models are currently poor. SRREMs will provide the mean energetic particle fluxes for a given mission duration as determined by confidence level and date and duration of the mission. The new models reflect the long-term temporal, spatial and spectral variations in electron and proton flux as well as the short-term enhancement events at altitudes and inclinations relevant for satellites in the slot region.

SRREMs is being implemented at the National Observatory of Athens, by a team including Ioannis A. Daglis, Ingmar Sandberg, Anastasios Anastasiadis, Georgios Ropokis, and with two external partners (DH Consultancy, Belgium and Kallisto Consultancy, United Kingdom).

SRREMs is funded by the European Space Agency (ESA).

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