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Cosmic Vision 2015-2025: ESA's long term programme in space sciences

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Abstract. ESA's space science programme is briefly reviewed, with a particular emphasis on its long term plan, "Cosmic Vision 2015-2025". The mission selection process is presented together with the current status of the different projects selected and currently under assessment. The strategy for implementing the plan is outlined, as well as the programmatic and international context.

Key words. Space vehicles: instruments – Telescopes

1. Introduction

The Science Programme is a mandatory programme of the European Space Agency to which all 18 member states must contribute in proportion to their Gross National Product (GNP). Every three years, the Council of Ministers decides by unanimity the Level of Resources (LoR) for the next 5 years. The council of ministers met in November 2008 and allocated a total budget of 2.327 billion Euros for the 5-year period 2009-2013. This corresponds to a LoR of 465 MEuros/year at 2008 Economic Conditions. Since payloads are generally built and funded nationally, to be exhaustive one should add to this figure the space science expenditures of ESA member states. Because of different accountability systems, the latter is not straightforward to establish. Furthermore, it varies substantially from year to year. Nevertheless, a recent study commissioned by the European Science Foundation shows that in recent years European member states globally spend on average 250 to 300 MEuros/year on space science (in addition to their mandatory contribution to ESA). The content of the science programme is defined by the European scientific community through open calls for mission concepts followed by peer review and the eventual selection of future missions to be developed and launched 10 to 15 years later. The cycle is repeated every 10 years or so. Two previous cycles established the Horizon 2000 and Horizon 2000+ science programmes, in 1984 and 1994-1995, respectively. The current cycle, Cosmic Vision 2015-2025 (CV in short) was initiated in 2004.

ESA is currently operating 12 scientific satellites which were selected and developed as part of the Horizon 2000+ programme.

- The X-Ray observatory XMM-Newton, launched in December 1999 continues to collect 0.1-10 keV images and spectra of all kind of celestial sources, from planets to the most distant quasars.

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- The Integral observatory has been gathering hard X-ray and gamma-ray images and spectra from celestial sources since its launch in October 2002. Both XMM-Newton and Integral are observatories opened to the world-wide astronomical community via calls for proposals and the usual peer review selection process.
- In exchange for ESA's contribution to NASA'S Hubble Space Telescope, European astronomers have access to at least 15% of HST observing time.
- Since its launch in December 1995, the ESA-NASA SOHO observatory has been collecting a wealth of data on the Sun, from its deep core interior to the outer corona, the solar wind and its interaction with the interplanetary medium.
- The 4 Cluster spacecrafts have been providing vital 3D in-situ measurements of the earth magnetosphere and its interaction with the solar wind since their launches in July and August 2000.
- Launched in June 2003, Mars Express is in orbit around the red planet and provides a wealth of scientific data, including high resolution stereo images.
- Venus-Express was launched in November 2005. The probe collects data on the Venusian surface and atmosphere from the vantage point of its polar orbit around the planet.
- With its 3.5 m diameter telescope feeding 3 cryogenically cooled instruments, Herschel is the most sensitive far-IR to submillimeter ($100 - 800\mu$m) observatory in operations to date. It will revolutionize our understanding of the interstellar medium and in particular of the early stages of the process by which stars and planetary systems form. Its vastly improved sensitivity will permit deep cosmological surveys and shed light on the formation process of galaxies and large scale structures of the Universe. Launched on May 14, 2009, Herschel is currently en route toward its final Lissajous orbit around the second Sun-Earth Lagrange point L2.
- Launched together with Herschel in a single Ariane-V rocket, Planck is also on its way to L2. Planck is a third generation satellite to map the Cosmic Microwave Background (CMB) radiation temperature and polarisation with μK sensitivity. Compared to WMAP, Planck features a much better angular resolution (up to 5 arcmin), a greater sensitivity and 9 frequency channels which will vastly improve the control of systematics and removal of foreground parasitic emission. Planck will pin down cosmological parameters to a 1 percent accuracy and stands a good chance of detecting inflation directly through the imprint left by gravitational waves on the CMB polarisation signal. Through the Sunyaev-Zeldovich effect, it will discover thousands of distant galaxy clusters and thereby tighten the constraints on the dark energy equation of state.
- Finally, the Rosetta spacecraft, launched in March 2004, is on its way to comet 67P. It will rendezvous the comet in May 2014 and land a probe on its surface in November 2014 for in situ measurements. On September 5, 2008, Rosetta collected spectacular images and a wealth of measurements while it flew-by asteroid 2867 Steins from a distance of 800 km. In July 2010, Rosetta will encounter a second asteroid, 21 Lutetia

All above Horizon 2000+ missions are in good health and their operations are funded through 31 December 2012. For completeness, ESA is also partner on 4 nationally-led projects currently in operation:

- CoRoT, a CNES mission to detect exoplanets via the transit method and perform astro-seismologic measurements of several tens of thousands of stars. CoRoT was launched in December 2006.
- Chandrayan, a lunar Orbiter developed by the Indian space agency, ISRO and to which Europe through ESA contributes several instruments. Chandrayan was launched in October 2008.
- Double Star, a collaborative project with the Chinese National Space Administration, consists of 2 satellites in earth orbit that study the earth magnetosphere. Launched in December 2003

and July 2004, the two spacecrafts nicely complement the Cluster flotilla.
- Cassini-Huygens, is a collaborative mission with NASA and the Italian space agency ASI to study the Saturnian system and in particular its Titan moon. Launched in October 1997, the mission consisted of a Saturn orbiter developed and operated by NASA plus the ESA probe Huygens, which successfully landed on Titan surface on January 14, 2005. After obtaining the first in-situ measurements and images of Titan, Huygens ceased functioning. Cassini continues to orbit Saturn and collect data on the planet and its many satellites.

Several other H2000+ missions are still under development:

- LISA Pathfinder is a technology demonstrator for the ambitious LISA mission. When launched in mid-2011, it will demonstrate the feasibility of putting two free-floating test masses in purely geodesic motion, free from electromagnetic, solar wind or any other perturbations. LISA Pathfinder will also validate the technology required to measure the relative positions of the two test masses to picometer accuracy.
- Gaia is the successor of the successful Hipparcos Astrometric mission. When launched in December 2011, it will measure the parallax and proper motions of a billion stars down to micro-arcsec accuracy as well as their radial velocity and energy distributions over the 320-1000 nm range. This will allow the reconstruction of the formation and accretion history of the milky-way. Among other things, Gaia will also detect tens of thousand of Jupiter-size exo-planets as well as comets, asteroids and trans-neptunian objects in our own solar system.
- Through ESA, Europe is also collaborating with NASA on the James Web Space Telescope (JWST). Europe is currently developing the near IR spectrograph NIRSpec as well as half of the Mid-IR Instrument MIRI. On behalf of NASA, ESA will also launch the JWST spacecraft on an Ariane V rocket in 2014.
- Bepi-Colombo is a collaborative venture with the Japanese Space Agency JAXA whereby ESA provides the Mercury Planetary Orbiter (MPO) and JAXA develops the Mercury Magnetospheric Orbiter (MMO). Thanks to its sophisticated payload and relatively low orbit, Bepi-Colombo will provide high resolution images of Mercury and in situ measurements that will vastly improve our knowledge of the mysterious planet. The two Bepi-Colombo probes will be launched together by a single Ariane-V rocket in August 2014 and arrive at Mercury in 2020.
- ESA is also collaborating with the French space agency CNES to develop Microscope, a mission that will provide a stringent test of the Equivalence Principle, one of the founding pillars of General Relativity. Specifically, ESA is developing the Field Emission Electric Propulsion (FEEP) technology, a low thrust low-noise propulsion system that has 0.1 micro-Newton accuracy. Microscope is currently slated for launch in 2012.

Two projects that were initially envisaged in the framework of the H2000+ programme but never formally approved have been put back into competition with the new Cosmic Vision missions. These are:

- LISA, a very ambitious collaborative mission with NASA the purpose of which is to detect and measure gravitational waves in the astrophysically interesting $0.1 - 10^{-4}$ Hz frequency range, inaccessible from the ground. LISA features a constellation of 3 identical spacecrafts in a 1 AU orbit around the sun. Separated by 5 million kilometres, the 3 S/C form an equilateral triangle that is inclined by 60 degrees with respect to the ecliptic plane and trails the earth by 50 millions kilometres. The passage of gravitational waves through the solar system distorts space-time and therefore the 3 sides of the triangle by a minute amount which depends on the strength of the GW source, its distance and its direction. This is precisely this minuscule deformation which LISA will measure via

laser interferometry with picometer accuracy. Through phase and amplitude modulation, LISA will provide an angular resolution of up to 1 arcmin for the strongest sources and an estimate of the mass and (luminosity-) distances accurate to better than 1 %. In 2011, the LISA Pathfinder will hopefully demonstrate most - but not all - the technologies required for LISA.
– Solar Orbiter is the next generation Solar Observatory to be put into a 0.3 AU orbit around the Sun and up to 27 degree above the ecliptic.

2. The Cosmic Vision process

2.1. Selection of scientific themes

In April 2004, ESA issued a Call for Cosmic Vision science themes, i.e. for important scientific questions that are likely to remain unresolved at the horizon 2015-2025 and concepts of space missions to answer them. The European (and beyond) community responded massively and submitted 151 novel ideas, more than twice as many as for H2000.

The Space Science Advisory Committee (SSAC) of ESA, assisted by its three thematic working groups, the Astronomy Working Groups (AWG), the Solar System Working Group (SSWG) and the Fundamental Physics Advisory Group (FPAG), analysed the responses from the community and pre-selected a few themes. These themes were presented and discussed at a workshop in Paris in September 2004 which more than 400 scientists attended. The SSAC and the three WGs are teams of scientists chosen for their scientific standing and who are expected to represent the views of the European scientific community as a whole rather than any particular national interest. The SSAC prepared a first version of the Cosmic Vision plan which was presented to the scientific community during a workshop in Noordwijk, Holland in May 2005. The plan was further elaborated during the summer and eventually issued in October 2005 as ESA-BR 247[1]. The plan identifies four main scientific themes as follows:

[1] http://www.esa.int/esapub/br/br247/br247.pdf

– What are the conditions for planet formation and the emergence of life?
– How does the Solar System work?
– What are the fundamental physical laws of the Universe?
– How did the Universe originate and what is it made of?

The plan also identifies specific aspects of each general theme that are judged to be ripe for investigation with new space missions in the period 2015-2025. It proposes a strategy for implementing these missions and identifies the new technologies that must be developed to enable such projects.

2.2. Cosmic Vision implementation strategy

Based on the Cosmic Vision (CV) plan, ESA elaborated a strategy for its implementation that is compatible with the financial constraints imposed by the LoR and missions currently under development or in operations. The plan was eventually endorsed by the Science Programme Committee (SPC), the most senior body that governs ESA Science programme and where each member states is represented by one national delegate.

The CV2015 implementation strategy foresees:

– 3 Call for mission proposals, with roughly one call being issued every $\sim$ 3.5 years over the period 2007 to 2015.
– Each Call has a financial envelope of 950 MEuros, to be spent into one Large (L) and one Medium (M) size mission.
– The cost to ESA of an L mission is capped to 650 MEuros at 2006 economic conditions (EC).
– The cost to ESA of an M mission is capped to 300 MEuros (2006 EC)
– As a rule, M missions must have their technology ready at the time of their selection, whereas some technology development is acceptable for the more complex and ambitions L missions. Specifically, M missions must achieve Technology Readiness Level (TRL) 5 before development, which

means that a breadboard has been developed, tested and qualified in representative conditions.
- As a baseline, payloads continue to be developed and financed by national member states outside of the ESA science programme LoR.
- As explained above, LISA will compete with new CV projects for selection as an L class mission and Solar Orbiter as an M class mission.

2.3. Selection of mission concepts

Based on the Cosmic Vision Plan elaborated by the SSAC and WG and on the strategy proposed by ESA executive and approved by the SPC, ESA issued the first of the 3 Cosmic Vision Calls for mission proposals in March 2007. The Call foresees the selection of one M mission for launch in 2017 and one L mission for a launch in 2018.

Again, the scientific community responded massively to the Call, submitting a total of 50 proposals by the 29 June 2007 deadline, more than twice as many as for H2000+. Over the summer, the SSAC and the WGs evaluated the proposals and eventually selected 4 M and 3 L mission concepts for assessment, plus one "mission of opportunity", i.e. a mission whose cost to ESA is $\leq$ 100 MEuros. The selection was announced in October 2007.

2.4. Cosmic Vision M-class missions currently under assessment

The M-class missions selected for assessment studies are EUCLID, PLATO, MARCO-POLO, and CROSS-SCALE, plus the SPICA mission of opportunity.

EUCLID aims at constraining the equation of state of Dark Energy (DE) and its evolution as a function of cosmic time. It is a survey mission which combines two proposals from the community, DUNE & SPACE. The DUNE concept proposed an imaging and photometric survey in the visible to near IR in order to map the total amount of matter (luminous and dark) and therefore the growth of structure as a function of redshift. The amount of matter along the line-of-sight is inferred through the Weak gravitational Lensing (WL) distortion of galaxy shapes and orientations it induces. Because it is a statistical method, WL requires a very large sample of galaxy shapes to be measured over the entire extra-galactic sky. The overall distortion is small and requires sub-arcsec angular resolution to be measured to the required level of accuracy. The second proposal, SPACE, aims at constraining the DE equation of state through its effect on the growth of cosmic structures as a function of time. More specifically, it measures Baryonic Acoustic Oscillations (BAO) as a function of look-back time. BAO are small amplitude modulations (5-10%) in the distribution of matter imprinted at early stages of the universe when radiation and matter decoupled shortly after the big-bang ($z \sim 1000$). This initial imprint seeded the subsequent growth of structures in the Universe. The later evolution of BAO depends on the competing effects of gravity, which accelerates the formation of galaxies and clusters of galaxies and DE which tends to rip them apart. This is precisely the effect which SPACE aims at measuring by correlating the redshifts of half a billion galaxies up to $z \sim 2$. On the advice of a specially appointed ad-hoc scientific committee and of the AWG, the DUNE and SPACE proposals were merged into one single mission concept baptised EUCLID. EUCLID aims at constraining the DE equation of state to 1% accuracy, sufficient to distinguish between competing models of its origin. Since the systematic errors which limit the power of the WL and BAO methods are "orthogonal", EUCLID is more powerful that the sum of DUNE & SPACE. Furthermore, it is theoretically possible that BAO and WL yield conflicting results. This would be a strong indication of a break-down of General Relativity, a result which cannot be achieved through DUNE or SPACE alone. In its current design, EUCLID features a 1.2 m diameter telescope feeding an optical imaging channel ($\sim$ 0.2" resolution), a NIR (Y, J, H) photometric channel and a 0.8-1.7 μm spectrometric channel with a resolution $\lambda/\Delta\Lambda$= 400. During 4 years, EUCLID will survey 20,000 square-degrees down to 24.5 magnitudes in the visible and measure the photometric redshift of half a billion galaxies as well as the spectroscopic redshift of a subsample of 10^8 galaxies brighter than AB = 22. Preliminary discussions with NASA for an eventual merging of EUCLID with its US equivalent JDEM into a single joint dark energy mission have been put on hold because of schedule incompatibilities between Cosmic Vision and the US decadal ASTRO2010 survey.

The goal of PLATO is to discover a large number of close-by earth-size exoplanets and characterise their mass and radius with 1% accuracy. PLATO features between 12 and 54 small telescopes, providing a total collecting area of 0.3 m^2 and a $>$ 600 deg^2 FOV. Two fields will be observed for 2.5 years each in order to collect the light-curves of 20,000 F, G & K stars to a relative photometric accuracy of 10^{-6}/month, and 500,000 stars to somewhat less precision. The light-curves will be searched for the small dimming produced by a planet as it transits in front of its parent star. The light-curves will also be subjected to astroseismologic analysis in order to precisely determine the age, mass and size of the stars. PLATO will improve upon the NASA Kepler mission by detecting a larger number of earth-size planets and characterising their mass and radius. PLATO will be put into a large amplitude orbit around the Sun-Earth L2 point by a Soyuz-Fregat launcher.

MARCO-POLO is a mission to perform in-situ analysis of a primitive Near-Earth Object (NEO) - Comet or Asteroid - and return a sample to earth for laboratory analysis. This will shed light on the initial conditions and evolution of the solar nebula, the properties of the building blocks of terrestrial planets and the formation history of planetesimals. The spacecraft consists of an orbiter with 7 instruments on-board and a lander featuring 5 instruments for a 3 months in-situ analysis of surface and sub-surface NEO materials. MARCO-POLO is a collaborative mission with the Japanese space agency JAXA.

CROSS-SCALE aims at quantifying the coupling between different scales in the plasma that surrounds the earth. It will seek an answer to questions such as: how do shocks accelerates particles? How does reconnection convert magnetic energy? How does turbulence control transport in plasmas? The mission will comprise up to 7 identical spin-stabilised spacecrafts, separated by distances varying between 1.4 and 25 earth-radii so as to investigate plasma phenomena on a range of spatial and temporal scales. CROSS-SCALE will work in partnership with its JAXA sister mission SCOPE, thereby adding 2 spacecrafts to the constellation. Each spacecraft will include a different but complementary suite of instruments for in situ plasma measurements. The constellation will be put into orbit by a single Soyuz-Fregat launch.

SPICA is a very ambitious JAXA mission for medium to far IR (5-210 μm) astronomy to which ESA would contribute a 3.5 m diameter actively cooled (to $<$ 5K) telescope, a ground-station and the nationally funded SAFARI far-IR instrument. The other two JAXA-provided instruments are a Mid-IR coronagraph and a Mid-IR Camera & Spectrometer. Conceived as a general purpose observatory, SPICA represents the next logical step beyond Spitzer and Herschel, improving upon their sensitivities and resolutions thanks to its larger and actively cooled mirror. Among other things, its coronagraph will collect the first uncontaminated mid-IR spectra of young massive planets. SPICA will be injected toward an L2 orbit by a JAXA H2A launcher. In July 2008, JAXA officially approved the selection of SPICA for a 2-years pre-project phase, akin to a phase-A study.

During the first half of 2008, all 5 M mission concepts went through a 3-months ESA internal study aimed at propagating the scientific requirements into a baseline design and identifying the technologies which must be developed to enable the missions. No show stoppers were indentified but these quick studies already showed that, with the exception of SPICA, none of the M mission fits into its 300 MEuros financial envelope. The results of these studies served to prepare the Invitation-to-Tender (ITT) to industry for a follow-on in-depth technical assessment of the mission concepts. The ITT were issued during the summer 2008 to which European space industries responded with technical and financial proposals for a detailed study and design of the missions. For each of the 5 missions, two industries were eventually selected to perform two competitive assessment studies in parallel. The industrial studies lasted from September 2008 to August 2009. Following a Call for Declaration of Interest issued in June 2008, instrument consortia have been selected who are responsible for the nationally funded assessment studies of the mission payloads. These payload studies will run in member states in parallel to ESA funded system studies in order to define the baseline instrumentation of each mission. The results of the system and payload studies will be combined and presented to the scientific community and the ESA advisory structure in December 2009. Two important outputs of the assessment studies are a cost estimate and an evaluation of the technological maturity of each mission. Where necessary, technology development plans have been prepared and are being implemented.

2.5. Cosmic Vision L-class missions currently under assessment

The two L-class missions selected by the SSAC for an assessment phase are IXO (formerly XEUS) and LAPLACE/EJSM.

IXO represents the next-generation general purpose X-ray observatory. With ≥ 3 m^2 effective area at 1 keV and advanced focal plane detectors, its sensitivity will improve by one to two orders of magnitude upon the highly successful XMM-Newton ESA and Chandra NASA missions. IXO main scientific objectives are to investigate how super-massive black-holes formed and grew in the early universe, how this influenced the formation of galaxies, how large scale structures evolved and how they became chemically enriched. IXO was initially proposed as XEUS, an ESA-JAXA collaborative missions consisting of a mirror spacecraft and a detector spacecraft in formation-flying. An internal study rapidly confirmed that such an ambitious concept was well beyond the financial envelope of an L-class mission. In July 2008, ESA and NASA therefore agreed to merge the assessment studies of XEUS and its American equivalent Constellation-X. The combined ESA-NASA-JAXA mission was re-baptised International X-ray Observatory (IXO). Instead of 2 spacecrafts in formation flying, the baseline mission now consists of one single satellite with a ≥ 20 m deployable optical bench to provide the required focal length and high energy sensitivity. The diameter of the mirror is 3.3 m. The model payload consists of several focal plane instruments, including a Wide-Field Imager, a Narrow-Field Imager and a high-resolution grating spectrometer. IXO will be put into a halo orbit around L2 by an Ariane-V or an Atlas V launcher. The IXO concept went through internal assessments both at ESA and at NASA, with JAXA participation. A baseline design was selected jointly by the three agencies in early 2009. This forms the basis of the two competitive industrial studies which will be initiated July 2009 and last 18 months. Though no “show stoppers” have been identified so far, it is nevertheless clear that IXO will require several years of technological development, in particular in the area of light-weight X-ray mirrors and advanced Transition Edge Sensors micro-calorimeters.

The SSAC retained one mission to the outer solar system for assessment studies, to be selected from the two original LAPLACE and TANDEM proposals submitted by the community. In February 2009, ESA and NASA jointly down-selected LAPLACE for further assessment. LAPLACE is a 3-agencies joint mission to the Jovian system consisting of a NASA provided Europa Orbiter (EO), a JAXA-provided Jupiter Magnetospheric Orbiter (JMO) and an ESA-provided Jupiter Planetary Orbiter (JPO). JPO is a three-axis stabilized platform optimized for remote sensing observations and in situ measurements optimized for Jupiter System Science complementing EO and JMO. Its trajectory around Jupiter includes flybys of the four Galilean moons (Io, Europa, Callisto, Ganymede). Among LAPLACE many scientific goals, one should underline the study of Europa’s capability to sustain life. LAPLACE underwent two parallel internal phase-0 assessments, both at ESA and at NASA. No “show stoppers” have been identified such that the two competitive industrial studies will start in July 2009. They are expected to last 18 months and be completed toward the end of 2010. LAPLACE will require several years of technological development. Most critical is the protection against the harsh particle radiation environment characteristic of the Jovian system.

3. The future

LISA must await the in-orbit validation of its technologies by LISA Pathfinder in late 2011. Both IXO and LAPLACE require technological development that will extend beyond 2011. It is therefore clear that none of the 3 L missions currently under assessment can be ready for implementation in 2011. The original plan, which was to select 1 L and 1 M mission for implementation in 2011, is therefore no longer feasible. Furthermore, the assessment studies have already demonstrated that, with the exception of SPICA, none of the M mission candidates fits into the 300 MEuro envelope originally envisaged. It was therefore decided to modify the plan in such a way that 2 M missions will be selected in 2011 for development at a total cost to ESA of 950 MEuro, the budget of one Cosmic Vision "slice".

3.1. Timeline for the M-class missions

To retain a healthy competition up to the end, at least three M missions will be selected for a definition phase in early 2010. The 3 missions will be selected among the 5 CV candidates plus Solar-Orbiter. Beyond scientific excellence, one important selection criterion is technological maturity. As previously mentioned, an M mission must demonstrate that it can reach Technology Readiness Level (TRL) 5 by the time it starts implementation in 2011. Though the assessment studies are not yet completed, it seems that this will be the case for at least 3 M missions.

On 15 November 2009, the M-mission assessment study reports, traditionally known as the "Yellow Books", will be published on the web site of the ESA Scientific & Robotic Exploration Directorate. The reports will also be presented to the scientific community on December 1st in Paris. The M Mission candidates will be evaluated by the AWG and SSWG during the period mid-November 2009 to mid-January 2010. On January 13, 2010, both WG will rank the missions in their respective discipline and issue their recommendations to the SSAC. Based on these recommendations, the SSAC will on January 14, select ≥ M Missions for a definition phase. The selection will be formally approved by the SPC will occur on February 18, 2010.

The Mission Definition Phase will last for 2 years during which the mission candidates will be designed to the level of individual subsystems and components. Each mission will be subjected to two parallel mission definitions by two independent industries competitively selected via an ITT. The industrial competition maximises the chance of later selecting the best possible and most competitive design for implementation at the end of 2011. The payloads of these missions will be subjected to parallel definition studies conducted under the responsibility of nationally funded scientific consortia. At the end of this phase, the overall cost of the mission - to both ESA and member states - will be consolidated to a $\tilde{2}0\%$ accuracy. During the Definition phase, the relevant technologies will continue to be developed as required to reach TRL 5 in 2011.

In late 2011 or early 2012, the advisory structure and SSAC will select two of the M mission candidates and recommend their implementation to the SPC. For each of the 2 M missions, an ITT will be prepared for competitive selection of the industrial consortium that will be responsible for the development of the spacecraft. Similarly, scientific consortia and Principal Investigators will be selected via an open Call for the construction of the instruments. In September 2012, the two M missions will then be ready to enter into implementation - akin to phase B2/C. Nominally, the development of the spacecraft and payload will last 5 to 6 years such that one M mission can be launched in September 2017 and a second one in the second half of 2018.

3.2. Timeline for the L-class missions

As already mentioned, none of the 3 L missions currently under assessment can reach TRL 5 by 2011. Furthermore, all 3 missions require international collaboration with partner agencies and the collaboration schemes are not precisely defined yet. The selection of an L mission will thus be deferred to whenever more than one mission is technologically and programmatically ready for implementation.

Upon completion of the assessment studies in late 2010, IXO and LAPLACE will compete with LISA for entering Definition phase. The selection will be performed by the WG and SSAC in early 2011. The two surviving L missions will then undergo a 2-years detailed definition by industry. When completed, the WG and SSAC will down-select one of the two L missions for implementation. The exact date is TBD and depends on the time it takes for the L missions to reach TRL 5. It seems likely however that this could happen in 2013 or 2014 such that the first Cosmic Vision L mission can be launched in 2020.

3.3. Future calls for & selection of Cosmic Vision Mission proposals

As previously explained, the Cosmic Vision implementation strategy foresees 3 Call for Mission proposals to be issued at a 3.5 years interval. The cycle described above will thus be repeated in 2011 and again in 2014-2015.

For cycle 2, a Call for Mission proposals will be issued in 2011. L missions from previous cycles that were not selected will automatically be carried-over into the following cycle. M missions however, do not carry-over and fresh proposals must be submitted anew. In 2012, 3 M and 3 L missions will be selected for a 1 year Assessment study. Nominally, 2M and 2 L missions will survive selection in 2012 and enter into a 2-years Definition phase. Eventually, one M and one L missions will be selected for implementation and launch after 2020.

4. DISCUSSION

WOLFGANG KUNDT: To your list of possible explanations of "Dark Energy", please add the one by David Wiltshire whereby DE is an artefact introduced by a careless evaluation of the past light-cones in an inhomogeneous Universe (with voids and walls, as observed, Shapiro effect).

JEAN CLAVEL: I am not a DE specialist, but it seems unlikely to me that such an error could reproduce the magnitude of the observed effect.

WOLFGANG KUNDT: Should massive Black-Holes never have formed in the local Universe, is there an expected source in the 10^{-1} – 10^{-4} Hz window such as a very compact binary systems?

JEAN CLAVEL: As a matter of fact, there is a dozen of compact X-ray binaries in our galaxies which are "guaranteed sources" of gravitational waves for LISA. Because their physical parameters are well determined, they will be used to calibrate the LISA GW observatory.