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EXPERIENCE IN INTEGRATING ROBOTS DESIGNED FOR PLANETARY EXPLORATION AND AN ENVIRONMENT INITIALLY DESIGNED FOR COOPERATING ROBOTS ON PLANET EARTH

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Several functional, mobile platforms of planetary exploration types have been made in the past in our institute, as hands-on opportunities for our students to learn about space technologies. Another line of activities has related to mobile, cooperating robots, in international robotic competition frameworks. Out of necessity however, these initiatives have also triggered original contributions in research domain, as well as brought additional benefits for the industrial context. Now the experience reported in this paper relates to some original cross-feeding. Without waiting for an hypothetic launch to planet Mars, the concept is here to bring closer and integrate solutions both for immediate tests on Earth, and design of later solutions for extraterrestrial contexts, with advantages notably in terms of interest, reactivity and synergies. A 12 motors, rocker-bogie type of platform is controlled with best practice kind of controllers and is given many of the features, perception sensors and cognitive abilities of our proprietary Piaget programming and development environment; due consideration is also given to current standards and technical possibilities for implementation in space environment.

I. INTRODUCTION

Life keeps spreading and mankind has constantly been exploring new territories. It should therefore be no surprise today for us to see humans attempting to extend the reach of our civilization to extra-terrestrial grounds [1].

In this quest, robots can be helpful, not only as scouting elements but also in the next phase where humans join in the journey and may benefit from assistance by machines.

Making experiments along this line is a good way for students to gain the motivation and opportunity to learn more about space matters and to contribute to progress. In this regard, the SpaceBot Cup, a space robotics contest organized by the German Aerospace Center (DLR) and funded by the Federal Ministry of Economics and Technology (BWMi) is an interesting initiative. An example of project in this context is SEAR (Small Exploration Assistant Rover) at Technische Universität Berlin, an attempt to develop an autonomous planetary rover with students [2].

It turns out that our lab did a lot in cognitive aspects (e.g. clip IJCAI 2013 [3]), which has in particular les to smart cooperating robots in domestic and industrial domain. In addition to reporting a purely hands-on project in space matter, it is the purpose of this paper to show how progress made with cooperating robots on Earth can be now also be transposed to the extra-terrestrial world.

The paper is organized as follows: Sections 2 and 3 reviews some of our previous works relating respectively to space hands on projects and cooperating robots engaged in world-level competitions. Section 4 includes new material about OP12-Y, our 12-motor omnidirectional platform. Similarly, Section 5 reports on new elements relating to constraints and opportunities in space context versus the surface of planet Earth.

II. PAST SPACE-RELATED HANDS-ON EXPERIMENTS IN OUR LAB

Our Lab in Robotics and Automation {LaRA) has already led multiple research and hands-on projects in space matters (re. Fig. 1) . Examples include simulated remote control with local obstacle avoidance for a rover on Mars [4], joint control, validation of various architectures for planetary rovers [5], realization of various prototypes such as of Sojourner [6] or FIDO types [7].

More generally, our cooperation with the Swiss Space Association has allowed regular initiatives for spreading knowledge and connecting people in space matters (e.g. [8, 9] and Fig. II.II).

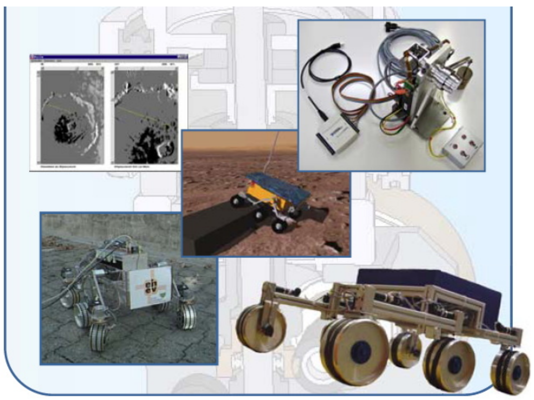

Fig.II.I: Examples of past research and hands-on projects in space matters (re. text)

Fig.II.II: Example of yearly initiative for connecting people in space matters (this year in Yverdon-les-Bains). This page is #1 of 4, the other 3 re. Appendix)

III. HEIG-VD EXPERTISE IN COOPERATING ROBOTS

Progress is obvious in many sectors, including for example microelectronics, communication, materials and energy. Numerous sensors, information processing units, and actuators have been developed and many are available on the market (re. examples of Fig.III.I). Yet their appropriate integration is a particular challenge, for which our Lab has developed the programming and control environment "Piaget" (re. [10]).

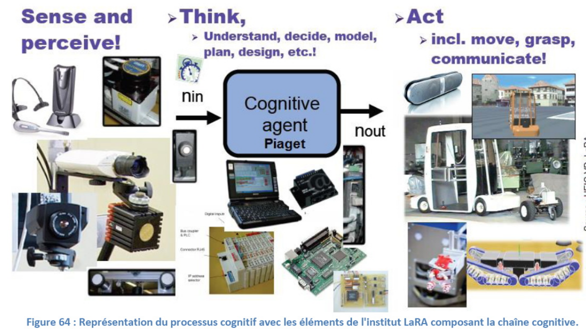

Fig. III.I – Examples of sensors, computing circuits, and actuators, which need be appropriately integrated for the design of smart systems.

More fundamentally, as machines and robots get more smart, and especially as they attempt to cooperate with humans, formal definitions and performance metrics had to be elaborated, for the field of cognition (re. Fig. III.II, and [11]).

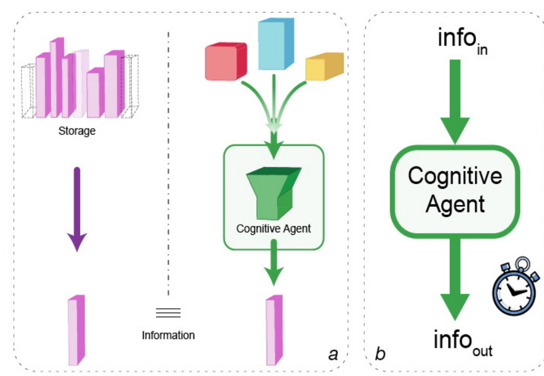

Fig. III.II – Schematic view of cognition. (a) Cognition and, effectively, cognitive systems, generate information. (b) Cognitive properties can be quantitatively estimated on the basis of the input-output information flows, and time.

Validation of our approaches has been made in the framework of the participation of our team to Robocup world – level Congresses and competition, especially in the Robocup-at-Home league (five first editions) (re. e.g. ref. [12, 13] and our video clip publishes at IJCAI 2013 [3]).

Examples of tasks successfully handled in Robocup context include "Copycat", the capacity of a robot to replicate human motions just by watching the tasked first performed by humans; "Fast Follow", the ability for a robot to learn new trajectories and topologies just by following the paces of a human; "Walk and Talk", the ability to easily learn new key locations in space by moving, and entering a vocal dialogue with a human guide.

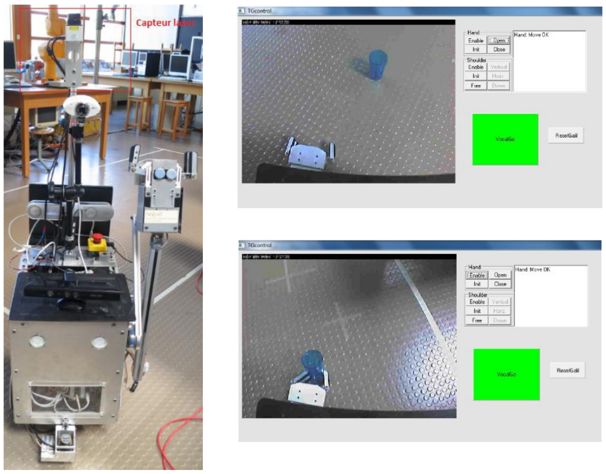

Fig. III.III – Our RH-Y robot, on the left, includes various sensors (rangers, camera, Kinect, microphone, etc.) and actuators (wheel joints, arm, gripper, etc.). On the right, within the « Telegrab » task, the robot can autonomously fetch and carry the blue glass.

Most interesting cases include the capacity of a robot group to interact with humans in order to assist them at home (re. bringing at will drink and snacks; or assisting humans to remotely grasp objects – Fig. III.III). A particular role of humanoids may be to mediate humans and machines (re. Fig. III.IV)

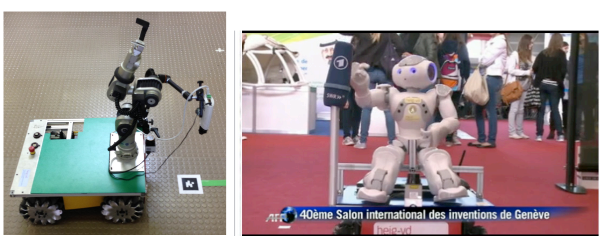

Fig. III.IV – OP-Y, left (photo HEIG-VD - Emilien Kobi) is ready to address tasks of the Robocup@Work league . On the right, the NAO-typed humanoid Nono-Y has been integrated to our Piaget environment and is useful as a mediator between humans and other robots and machines.

IV. OP12-Y, A VERSATILE, PIAGET-DRIVEN PLATFORM AND ROBOT

Our OP12-Y platform has been functional already in the past, but with the changes reported below, a new potential appears for robot cooperation with humans. The first section briefly reminds the past architecture for joint control; the second one describes the new architecture; section 3 illustrates the integration of the OP12-Y to the Piaget environment, thereby in particular supporting group behaviour and cooperation with humans; Section 4 refers to the locomotion capabilities of the new system.

IV.I Six wheels and 12 motors platform with control via parallel port

OP12-Y is the second platform with rocker-bogie design that was developed by the "LaRA". This one was first realised in 2002 (lower right of Fig. II.I) and has been recently improved in many respects, in the scope of the reported project (re. Fig. IV.V).

OP12-Y has essentially six wheels and six joints to independently re-orient each wheel. So there are twelve motors and encoders for this design.

The control of motors was initially based on the architecture illustrated in Fig. IV.I, essentially relying on CPU computation and very agile communication via parallel port.

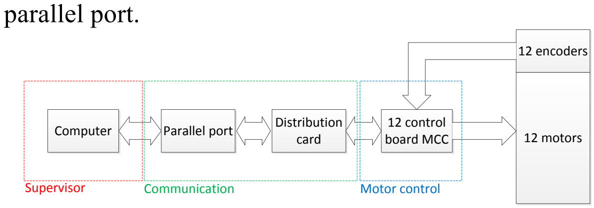

Fig. IV.I: Architecture initially adopted to implement a fully computer-based motor control.

IV.II New architecture

The evolution in digital resources calls now for a distributed approach, whereby only the strategic aspects remain to be managed at the supervisory level, while joint coordination and individual servoing are "outsourced" and rely on specialized peripheral circuits (re. § IV.II).

The new architecture implies a TCP/IP integration of external resources, in particular here of Galil joint servocontrollers.

So, below the new architecture is described:

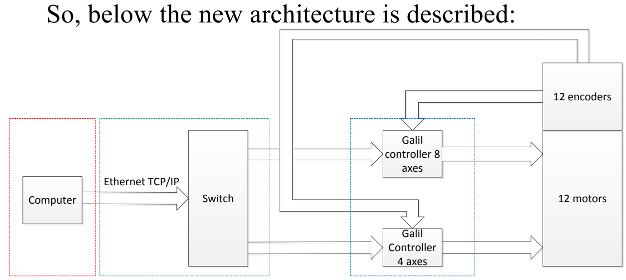

Fig. IV.III: New architecture for joint control

IV.III Integration with "Piaget"

The figure IV.IV shows the integration of OP12-Y in "Piaget".

The integration of OP12-Y in "Piaget" is a good advantage because it's possible to imagine interactions with other robots or for example to have the arm Katana on OP12-Y. Similarly all our integrated sensors (e.g. Mesa-imaging time of flight camera, or Microsoft Kinect), cognitive processes and communication channels are thus de facto inherited.

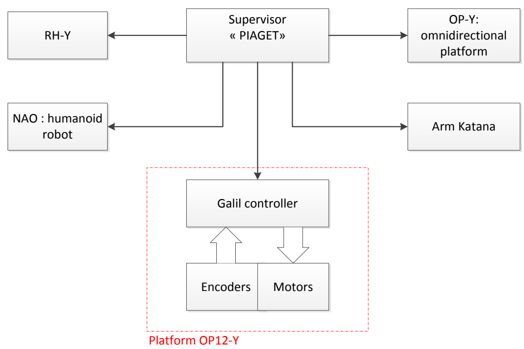

Fig. IV.IV: Integration in "Piaget"

IV.IV Locomotion

Some movements were programmed and integrated in "Piaget":

- Moving rectilinearly
- Moving crabwise
- Rotation of the platform
- Moving by segments

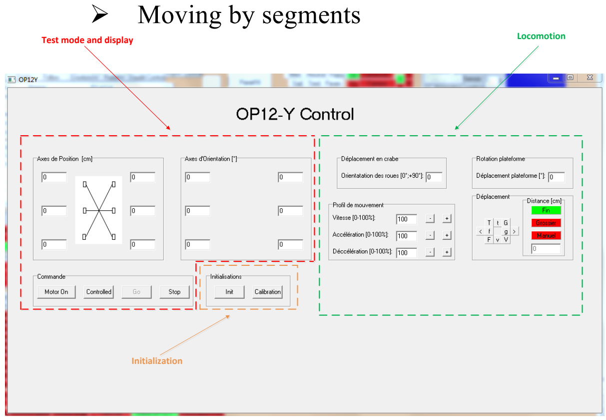

Fig. IV.IV: Form in "Piaget" for OP12-Y

To have all comportments on the same page, the form of Fig.IV.IV was designed.

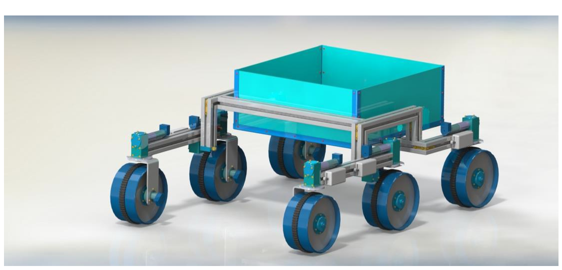

Fig. IV.V: The new version of OP12-Y has various improvements in mechanical terms as well. It is shown here in a configuration for straight motions.

So with this interface, it's possible to control each axis separately to test the performance. In another way, there are displays to show orders for each wheel. Finally, there are buttons for the previously described motions.

V. SPACE CONSTRAINTS AND OPPORTUNITIES

In Space missions, the local environment becomes the key factor to the spacecraft design. Due to the fact that it will pass through many different environments, a various type of constraints need to be taken care of by specific parts. On earth, the weather and conditions are well-known and can be predicted. It is therefore an interesting test ground for upcoming missions, but not every orbital and environmental parameters have been measured for every planet of the solar system, so that the space exploration is not on the same level for each of them. The current ones of interest are the Moon, Mars and Titan.

Being the closest to us, the Moon is the only planet to have ever had manned missions landings. Even though scientists started to lose interest in it, the fact that there is an enormous amounts of Helium under its surface and Earth starting to be short on supply of it, new missions are starting to be planned. Recently, the mission Mars Science Laboratory sent an Orbiter and the Curiosity Rover on the surface of Mars to learn more about the past of this planet. Presence of iced water lately discovered and the local relief suggest that Mars used to have an Earth-like environment [14]. Mars will subsequently be the next planet to have manned missions. Finally, Titan one of the moons of Saturn. In 2005 the mission Cassini-Huygens provided in-situ information on Titan. Titan had been considered for a long time bigger than Ganymede (one of the moons of Jupiter and the biggest in the solar system), but the atmosphere of Titan is 100 km wide and therefore makes it smaller. Titan is the only planet in the solar system of have such a dense atmosphere which makes it interesting for missions.

	Earth	Moon	Mars	Titan
M/M_E	1	0.012	0.11	0.023
G (m/s^2)	9.81	1.622	3.71	1.352
v_e (km/s)	11.19	2.38	5.03	2.639
R (AU)	0	0,00257	1.52	9.54
T_{mean} (K)	288.15	196	210	93.7

Table 1: Different parameters of the Moon, Mars and Titan, compared to Earth's. Data from [15].

During the mission's flight, the most present environment is the vacuum. Different deepness of vacuums will be present during most of the trip and need to be thoroughly tested on Earth. Thermal Vacuum Chambers (TVC) are used by most agencies to duplicate the sunrise-sunset cycle in vacuum conditions. The spacecraft is required to be gaz-tight, radiations-proof and for planetary exploration dust-proof. The two first constraints can be tested in a TVC, as the last one can be tested via probing here on Earth.

Mechanical constraints are the second most crucial aspect to consider. In Space Engineering "Every gram counts", so in order to accomplish a mission's goal state of the art methods are deployed. Vibration, thermal, voluminous and energetic constraints will define the mechanical structure of the spacecraft. It has already been stated above that "The light the better", but Material Engineering is all about compromises. Every part needs to be developed bearing in mind those parameters, but for each of them a critical point will be reached on different key-points of the journey. For example, the maximal thermal constraint will be present during the atmosphere entry and will be solved via a Thermal Shield. All of the other pieces need to be able to withstand and work under the local temperature conditions, but only the shield needs to work under the maximal temperature, etc. The mission's lifespan will define what type of energetic solutions to embark, and the irradiance from the sun diminishing with the squared value of the distance, solar-panels stop being useful after Mars. Batteries (rechargeable or not), fuel cells and even Radioisotope Thermoelectric Generators are the standard.

Finally, the local gravity is the last key-factor. Every current mission is leaving from Earth and need to overcome the escape velocity, stated in the Table 1. A mission leaving from the Moon, Mars or even Titan would make it way easier to take off with much less fuel and deployed energy. Even though the gravity, in this case is a problem, it is a crucial parameter. Without gravity there wouldn't be Orbiter possibilities, or even a Rover wouldn't be able to explore the surface of a planet. As declared above, new type of missions are being developed as the ones on the Moon to harvest Helium. Some asteroids passing close to earth are composed mainly of rare materials which would be interesting to be harvested. But here, there is no local gravity which makes it impossible for a Rover to move on the surface of it. Only Landers, more precisely Impactors, have been successfully sent on asteroids, but a new type of Rover for Low or No-gravity exploration needs to be developed.

Thus experience brings several contrasting conclusions in the integration of robots designed for planetary exploration with our environment initially designed for cooperating robots on planet Earth. The aspects relating to concretization on Earth are relatively easy to handle. On the contrary, the space part is very open, and as just shown, even the principles are still sometimes very fuzzy e.g. for the design of novel rovers for the recent case of asteroid exploration. Nevertheless the meta-goal of offering an attractive possibility for students to be exposed to space issues and to progress is well attained.

VI. CONCLUSION

Several functional, mobile platforms of planetary exploration types have been made in the past in our institute, as hands-on opportunities for our students to learn about space technologies. Another line of activities has related to mobile, cooperating robots, in international robotic competition frameworks. Out of necessity however, these initiatives have also triggered original contributions in research domain, as well as brought additional benefits for the industrial context. Now the experience reported in this paper relates to some original crossfeeding. Without waiting for an hypothetic launch to planet Mars, the concept is here to bring closer and integrate solutions both for immediate tests on Earth, and design of later solutions for extraterrestrial contexts, with advantages notably in terms of interest, reactivity and synergies. A 12 motors, rocker-bogie type of platform is controlled with best practice kind of controllers and is given many of the features, perception sensors and cognitive abilities of our proprietary Piaget programming and development environment; due consideration is also given to current standards and technical possibilities for implementation in space environment.

ACKNOWLEDGEMENTS

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APPENDIX – SWISS SPACE DAYS P2 TO P4

The flyer of the Swiss Space Days 2013 consists in 4 pages. P1 can be found above in Fig. II.II .

Vendredi 4 octobre 2013

Matin, écoles primaires et secondaires — pour les écoles

10h *Visite de Claude Nicollier* *
avec éventuelle présentation de travaux et/ou réponses aux questions

Après-midi, HEIG-VD — pour l'économie, les écoles et le public

13h Ouverture de l'exposition

13h30 Accueil et bienvenue
Roland Prélaz-Droux, directeur adjoint HEIG-VD / Daniel von Siebenthal, syndic Yverdon-les-Bains / Jean-Daniel Dessimoz, prof. HEIG-VD et président Swiss Space Association

13h50 *"La Suisse - une nation active dans l'espace aujourd'hui et demain„*
Johann Richard, Secrétariat d'Etat à la formation, à la recherche et à l'innovation, Division Affaires spatiales

14h15 *"CubeSat et Science„*
Federico Belloni, Swiss Space Center

14h35 *"Un cluster aérospatial pour l'économie et la société suisse„*
Alain Geiger, Prof. ETHZ et vice-président du Swiss Aerospace Cluster

15h00 Pause café et visite de l'exposition

15h20 *"Rexus - des étudiants suisses réussissent leur lancement dans l'espace„*
Roberto Putzu, prof. HESSO-HEPIA

15h40 *"Contrôles non-destructifs au service de l'industrie spatiale„*
Jean-Pascal Reymondin, prof. HEIG-VD.

16h00 *"Apports de l'industrie suisse au spatial„*
Frédéric Boden, APCO-Technologies, Vice-président du Swiss Space Industry Group

16h20 *"Navette suisse pour petits satellites et l'aviation du futur„*
Pascal Jaussi, Swiss Space Systems

16h40 *"Questions-réponses en matière spatiale„*
avec l'astronaute Claude Nicollier

17h00 *"Concours des gymnasiens„*
Grégoire Bourban, Swiss Space Center

Soirée, Maison d'Ailleurs — pour le public

19h30 Bienvenue des autorités et des organisateurs

19h45 *"Quelques aspects de la science perçus par un artiste„*
Claude Ecken, écrivain de science-fiction et critique littéraire

19h55 *"Quelques commentaires d'un scientifique face à certaines conjectures artistiques en matière spatiale„* **
Claude Nicollier, astronaute

20h05 *"Science et Fiction„*
Débat avec l'astronaute Claude Nicollier et l'écrivain Claude Ecken, modération Marc Atallah, directeur Maison d'Ailleurs

21h00 Apéro et discussions en groupes

* matin ou après-midi; sous réserve, notamment selon contraintes de vols Hunter
** à confirmer

P2

The last 2 elements of the event flyer, P3 and P4, can be found next page.

SWISS SPACE days 2013

Samedi 5 octobre 2013

Journée principalement en allemand / Tagung vor allem deutsche

VORMITTAGSPROGRAMM, HEIG-VD, E03 — für SRV-SSA-Mitglieder / membres

9h45	Empfang der Teilnehmer (Kaffee & Gipfeli) / accueil (Café-croissants)
10h15	SRV, Generalversammlung / assemblée générale
12h30	Lunch für Mitglieder / repas pour les membres

NACHMITTAGSPROGRAMM, HEIG-VD, F01 — Öffentlicher Anlass / public

14h00	Accueil et bienvenue Roland Prélaz-Droux, directeur adjoint HEIG-VD / Daniel von Siebenthal, syndic Yverdon-les-Bains / Jean-Daniel Dessimoz, prof. HEIG-VD et président Swiss Space Association
14h15	***"Die Schweiz - eine aktive Nation im Weltraum, heute und morgen„*** Oliver Botta, Staatssekretariat für Bildung, Forschung und Innovation, Abteilung Raumfahrt
14h30	***"CubeSat et Science„*** Federico Belloni, Swiss Space Center
14h45	***"Raumfahrt, neue Resultate, neue Projekte„*** Claude Nicollier
15h15	Fragen und Atworten - Réponse aux questions mit Claude Nicollier
15h25	Kaffeepause und Ausstellungsbesuch - pause café et visite de l'exposition
15h40	***"Rexus - des étudiants suisses réussissent leur lancement dans l'espace„*** Roberto Putzu, prof. HESSO-HEPIA
15h55	***"Die Zerstörungsfreie Prüfungen in der Raumfahrtindustrie„*** Jean-Pascal Reymondin, prof. HEIG-VD
16h10	***"Beiträge der Schweizer Industrie in den Weltraum„*** Frédéric Boden, APCO-Technologies, Vice-président du Swiss Space Industry Group
16h25	***"Schweizerisches Pendelflugzeug für Satelliten und die Luftfahrt der Zukunft„*** Pascal Jaussi, Swiss Space Systems
16h45	***"Futures activités relatives au spatial chez Swiss-Engineering„*** Josef Horvath, président STV Space Group
17h	Apero und Ende der Swiss Space Days - Apéritif et fin des Swiss Space Days

Les 2 jours, exposition dans le Hall de la HEIG-VD

P3

partenaires et exposants

Samedi, bus gratuit "Swiss Space Days" de la gare d'Yverdon-les-Bains à la HEIG-VD.
Départ : 10h

Am Samstag kostenloser Shuttle-Bus "Swiss Space Days" vom Bahnhof zur HEIG-VD.
Abfahrt: 10h

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P4