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BRIDGING THE UV GAP BETWEEN HST AND HWO IN FRANCE: THE INTEREST OF SUBORBITAL/CUBESATS PROJECTS

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Abstract. Over the past 30 years, the Hubble Space Telescope has significantly advanced our understanding of galaxy formation and evolution. Its future decommissioning will end the last high-resolution UV spectroscopy capability in astronomy. Recognizing the need for a successor, the Astro2020 decadal survey has advocated for a new multi-wavelength flagship mission with UV spectroscopic capabilities: the Habitable Worlds Observatory (HWO). To prevent repeating the challenges encountered with JWST, NASA plans to invest $1 billion in a great observatory maturation program. In accordance, the upcoming years will be used to define long-term scientific objectives, identify candidate science instrument designs and performance, establish enabling precursor science investigations, etc. This innovation initiative also explores new ways to leverage small missions (CubeSats, suborbital rockets, and balloons) to develop HWO-enabling technologies, guide science trades, and train future scientists. As a historic leader in UV research, France has a significant opportunity to contribute to this ambitious project. With no complete consensus yet on scientific priorities, the best approach to reach it, or what constitutes a balanced UV instrumental portfolio, there are significant opportunities to take part in future HWO decisions if convincing arguments are presented. In this general presentation, based on a brief overview of suborbital interest and use, France's historical leadership in UV science and instrumentation, and the American infrastructure set up to prepare HWO development, I will try to provide some perspectives on how suborbital and CubeSat projects can help consolidate France's UV expertise and position it for active participation in HWO.

Keywords: Ultraviolet, Spectroscopy, Suborbital projects, Habitable World Observatory, Science history

1 Introduction and context

The James Webb Space Telescope (JWST), the most recent astrophysical flagship mission, encountered significant challenges due to its high complexity, human errors, and the need for ongoing technological advancement throughout its implementation. Originally budgeted at $1 billion, the final cost of JWST escalated to $9.66 billion, accompanied by nearly 15 years of delays. Given the initial HWO cost estimate of 11B$, it is clear that NASA cannot risk a cost overruns ratio similar to JWST's, which would equate to the cost of 90 Hubble Space Telescopes or 220 servicing missions. To avoid repeating JWST's challenges, the 2020 decadal survey recommended a $1.2B great observatory maturation program which NASA has begun to follow. The survey noted: *"GOMAP evolves NASA's project management strategies by applying decades of research-based consensus of past lessons learned to reduce technical/cost/schedule risk & develop large, complex astrophysics space observatories with predictable costs and schedules."* The National Academies of Sciences (2021).

This next great observatory, HWO, a combination of the proposed LUVOIR and HABEX, will have about four instruments. While three of them derive from the LUVOIR proposal and are progressively being constrained (a coronograph, a high-resolution imager, and a UV spectrograph), the fourth one remains open to suggestions, with France eager to contribute. To guide the development of HWO, NASA has established two community-driven working groups: the START (Science, Technology, Architecture Review Team) and the TAG (Technical Assessment Group). START focuses on defining scientific objectives, identifying precursor investigations tailored to HWO, and evaluating candidate instruments, while TAG evaluates architectural options, assesses necessary technologies, and analyzes associated risks.

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With the last UV spectrograph (COS) installed on the HST 15 years ago, an interesting aspect about the UV scientific community is the lack of clear consensus on the scientific priorities of HWO's UV instrument, the optimal approach to achieve these scientific priorities, the instrument's performance requirements or even what constitutes a balanced UV instrument portfolio in the meanwhile. This open landscape provides some opportunity for influencing trade-offs and architectures if convincing scientific arguments are made. GOMAP, as an innovation initiative, also aims to explore novel approaches. One of them is to continue and improve the way NASA *"leverages small missions like CubeSats, suborbital rockets, and balloons to advance technologies and inform strategic science decisions"* Armus et al. (2023).

2 Suborbitals and CubeSats in France and in the US

Suborbital platforms, such as stratospheric balloons and sounding rockets, as well as CubeSats, offer significant opportunities for scientific exploration due to their cost-effectiveness and flexibility. In addition to serving as valuable science pathfinders, they serve as platforms for technology advancement and offer unique opportunities to train future instrument scientists and PIs. These benefits are crucial to prepare the development of large instruments for flagships. The characteristics of balloons, sounding rockets, and CubeSats vary significantly (Picouet et al. 2022). This field is rapidly evolving, driven by the substantial development of CubeSats and the introduction of ultra-long-duration balloons. The main interest of the balloon capability is the ability to accommodate explorer-sized payloads, facilitating significant advancements in scientific capabilities through more sophisticated and complex instruments.

In the United States, suborbital platforms are heavily utilized for scientific research, technological development, and training purposes. They enable young scientists to participate fully in all phases of payload development–from initial scientific concept formulation to mission design, construction, integration, testing, flight operations, and data analysis. This hands-on experience provides them essential skills and perspectives to lead larger-scale projects. Notably, the Principal Investigators (PIs) of all astrophysics explorers since 2000 (including UVEX, COSI, SPHEREX, IXPE, TESS, NuSTAR, WISE, Swift, and GALEX) have had heritage in suborbital instruments (*Miles et al. in prep*). A significant part of space technology maturation is conducted through suborbital and CubeSats projects. Indeed, based on the same astrophysics explorers since 2000, the vast majority of astrophysics explorer missions have benefited from instrumental heritage originating in suborbital projects (*Miles et al. in prep*). In France, almost only the scientific case is considered for suborbital projects - technology advancement and training being only seen as byproducts behind the scientific driver.

In the case of UV instrumentation (see Figure 1) for astrophysics, NASA has been able to fund all the CubeSats and suborbital projects with only a couple percents of the budget that will be allocated to HWO (between \$5M to \$20M for each suborbital/cubesat project, with an addition of ∼\$1M for launches).

In the specific case of ultraviolet spectroscopy, Figure 1 illustrates the landscape of UV spectrographs in space since 2000. It immediately highlights the American leadership in UV astronomy instrumentation, with ULTRASAT being the notable exception as a non-US instrument, while also demonstrating significant French involvement in these missions (see Section 1). The graph underscores the substantial disparity in the utilization of small-scale projects between the US and France.

3 The historic leadership of France in UV astronomy & instrumentation

In this context, what justifies France's significant involvement in the potential ultraviolet instruments of the upcoming HWO? One of the reasons for France's ambition to contribute to HWO UV instrument(s), must come from its historic legacy of leadership in UV instrumentation. This leadership, established over decades of incremental advancements through suborbital projects, has positioned France to play a pivotal role in UV space projects. This historical perspective is mostly drawn from Lequeux (2021); Courtès (2001) and outlined in Figure 2. Post-World War II, France leveraged available rocketry technology, initially derived from German V2 rockets, to propel its space program. The Véronique rockets were essential to the first UV observations (Courtès 2001). For cost considerations, France transitioned to high-altitude balloons (with significant development of UV telescopes and spectrographs) a decade later. Continuous enhancements in pointing systems and grating technology by companies like HORIBA in France enabled increasingly precise UV observations, contributing to major milestones across various fields such as the interstellar medium, photometry, stellar populations, galaxy evolution (Deharveng et al. 1980; Milliard et al. 1992; Treyer et al. 1998; Buat et al. 2002; Boissier et al. 2004). Moreover, beyond their scientific contributions, these suborbital projects have been essential in preparing

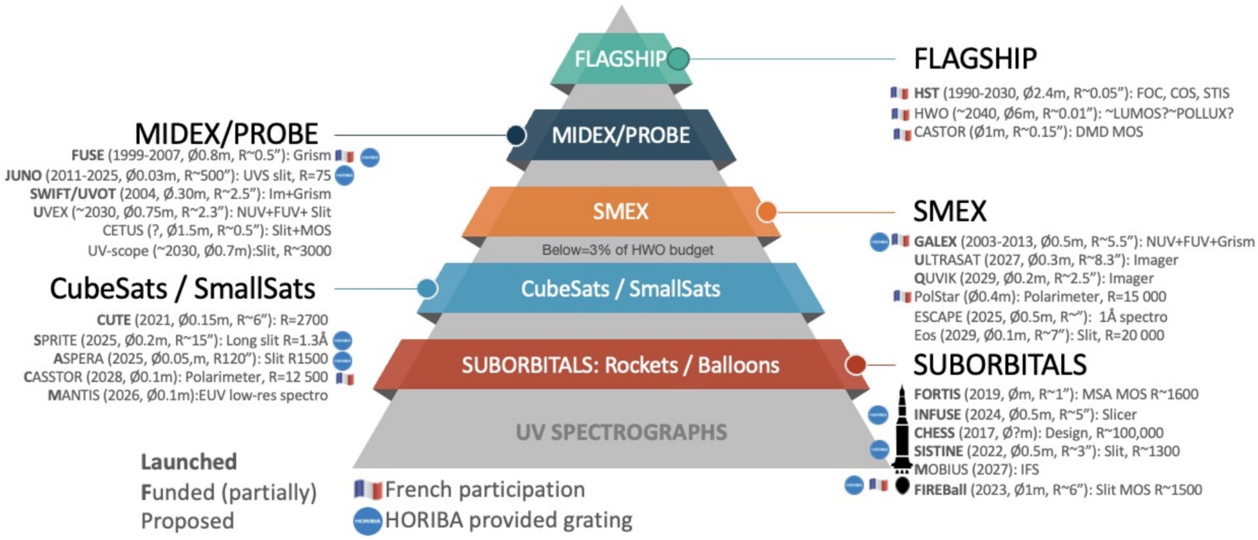

Fig. 1. UV spectrographs in space since 2000

France's involvement in more ambitious space-based instruments. From the 1980s onward, France has actively contributed UV telescopes and spectrographs to space missions, such as D2B AURA (1975), the UV telescope on Astron (1983), VWFC (1985), HST-FOC (1990), and the FUSE and GALEX gratings in 1999 and 2003, respectively. Figure 2 recap the significant steps of UV instrumentation and science advancement since WWII.

FOCA (Milliard et al. 1992) and GALEX (Martin et al. 2005) illustrate perfectly how continuity and incremental improvement has been a remarkably successful approach. Most of the scientific cases explored by GALEX were already initiated by FOCA: Galaxy clusters studies (Boissier et al. 2004), first galaxy UV number counts (Milliard et al. 1992), UV based SFR estimation (Buat et al. 2002) and SFR history (Gavazzi et al. 2002; Treyer et al. 1998). Even more Specifically, GALEX instrument parameters were informed and constrained using important lessons learned from FOCA (two large bandpasses around the FOCA bandpass, similar aperture, FOCA's resistive-anode was a precursor of GALEX's MCP, a better spatial resolution driven by FOCA's results, etc.). UV space astronomy in France also benefited from strong industrial leaders in space grating manufacturing (e.g. HORIBA), low light imaging systems (e.g. Photonis - Exosens), optical systems (e.g. Bertin Winlight) or space instrumentation (e.g. Thales). In particular, Figure 1 emphasizes the widespread use of HORIBA UV gratings in the UV space spectrographs, playing a pivotal role in advancing UV astronomy. The evolution of UV astronomy in France demonstrates the significant impact of sustained investment in suborbital projects. By continuously developing and improving UV instrumentation through rockets and balloons, France has maintained a leadership position in this domain. This historical context can provide valuable lessons for current and future projects, such as HWO, where France's expertise can continue to play a crucial role. A fortuitous conjunction of circumstances and opportunities allowed France to pioneer UV space instrumentation with the US. The unique access to rockets with the USA and URSS, at the very beginning of UV astronomy (when the field was less competitive and more exploratory), fostered pioneering discoveries. Accompanied by significant strategic investments in space research infrastructure (CNES creation in 1961, the LAS in 1965 which merged with Marseille Observatory in 2000 to create the LAM with bigger space infrastructure) and in suborbital programs allowed France to become a pioneer in this domain. This success was further amplified by the support of visionary scientists at the frontier between science and instrumentation (e.g. Jacques Blamont and Georges Courtès, Academy of Science), and a very successful continuity for more than 40 years.

4 Summary and conclusion

The United States holds several strategic advantages and assets that naturally position them to lead astronomy advances. This remains true for developing the next generation of UV instruments on HWO. Institutionally, the U.S. benefits from a large community and a competitive framework in UV instrumentation supported by institutions such as Caltech, JPL, Boulder/LASP, Goddard, Johns Hopkins, UC Berkeley, and and others that

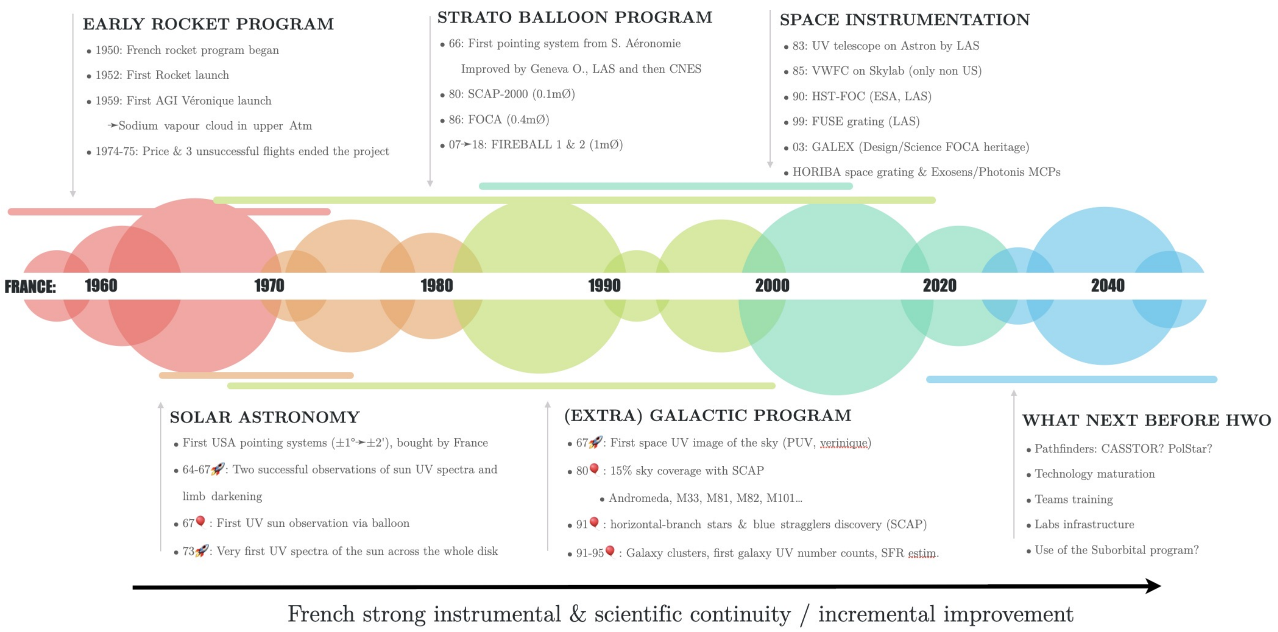

Fig. 2. Evolution of UV french astronomy instrumentation and scientific advances.

contributes significantly to advancing UV science and technology. They knowingly and effectively leverage their suborbital and CubeSat program to prepare HWO science, instruments, and scientists. They also maintain a robust instrument scientist and PI training based on strong involvement in suborbital projects, a model which is less considered and valued in France. The long-term roadmaps and rigorous identification of technology gaps further enhance their preparedness. As it proved to not be enough, they now set up a $1B great observatory maturation program.

In contrast, and despite a successful historical trajectory that positioned the French community as a leader in this field, France faces challenges in maintaining its hard-earned expertise in UV science and instrumentation. These challenges stem from factors such as a shift towards ground-based instrumentation and diminishing support for suborbital projects which are also underutilized for training and technology advancement. As the HWO project progresses, France has the opportunity to capitalize on its historic expertise in UV instrumentation. Suborbital projects like CASSTOR and PolStar might serve as scientific pathfinders, allowing technology maturation and training new scientists. By continuing to engage with suborbital programs, France can maintain its leadership and contribute valuable insights and technologies to the HWO initiative.

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