REPORT

of the

HUBBLE SPACE TELESCOPE ULTRAVIOLET LEGACY SCIENCE DEFINITION WORKING GROUP

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EXECUTIVE SUMMARY

Star formation is the basis for understanding cosmic origins from the largest scales to the smallest. High-mass stars are the tracers of star formation on extragalactic and galactic scales, and are the powerhouses of radiative, mechanical, and nucleosynthetic feedback, thus playing an essential role in galaxy evolution across cosmic time. Low-mass stars are the vast majority of stellar mass in the universe and are home to planetary systems, including the only one we know in detail: our own. At ages < 10 Myr, both high-mass and low-mass stars generate complex UV emission processes that are difficult to model, and these are central to a wide range of vital astrophysical problems, ranging from cosmic reionization to the origin of our Earth.

Therefore, in response to the STScI Director's charge to identify a large, legacy UV program focused on star formation and related stellar physics, the HST UV Legacy Science Definition Working Group recommends that the HST UV Initiative be devoted to obtaining a **Hubble UV Legacy Library of Young Stars as Essential Standards (ULLYSES)** to serve as a UV spectroscopic reference sample of high-mass and low-mass, young stars. The recommended library will provide observations that uniformly sample the fundamental astrophysical parameter space for each class of stars, i.e., spectral type, luminosity class, and metallicity for massive stars; and spectral type, age, and disk accretion rate in low-mass stars. Key elements of this program include extending template spectra of massive stars to low-metallicity regimes for studies of the high-redshift universe; and extending those for young, low-mass stars and brown dwarfs to masses below 0.5 M_sun. By combining high-mass and low-mass stars, this program will produce a definitive UV dataset on the first 10 Myr of stellar evolution. The legacy value will be enhanced by enabling additional studies of the ISM, CGM, jets, and exoplanet science.

We recommend that the ULLYSES library be generated in 1000 orbits of HST time, divided equally between high-mass and low-mass stars. For the massive stars, the grid of observations should sample the parameter space of spectral type, luminosity class, and metallicity. We estimate this will require observing about 70 OB stars each, in the lower metallicity, Large and Small Magellanic Clouds, prioritizing the SMC; plus 5 - 10 additional stars that are accessible in even lower metallicity, Local Group galaxies. These observations should correspond to about 200, 250, and 50 orbits, respectively, with COS/G130M+G160M or STIS/E140M, plus STIS/E230M for the Magellanic Clouds targets; and COS/G140L for the few, more distant targets. For the low-mass stars, the grid should sample spectral type, age, and accretion rate, obtaining observations of about 40 K and M-type, T Tauri stars and brown dwarfs. These should correspond to about 400 orbits using COS/G130M+G160M, together with shorter, coeval exposures using STIS/G750L+G430L+G230L. Since these are variable objects, we also recommend time-series monitoring of 4 prototypical targets with COS/G160M+230L, totaling about 100 orbits.

The impact of the ULLYSES library will be greatly enhanced by community engagement during the planning process, both in partnering to develop the final program and target samples, and organizing campaigns for coordinated observations. The latter is especially important for the low-mass component, since the variability of the target objects makes ancillary coeval data especially valuable. It will also be

essential to construct a user-friendly archive, with relevant metadata and tools. Including existing archive data in a uniform manner to complete the grids will be also be critical to the library's integrity, and it would be helpful to provide convenient links to external, relevant databases of ancillary and coordinated observations. The sum of these efforts will generate a unique UV legacy data set of great impact and lasting value.

1. Background and Charge

Since the release of the first Hubble Deep Field in 1995, the Directors of the Space Telescope Science Institute (STScI) have allocated Director's Discretionary (DD) time on the *Hubble Space Telescope* (HST) to sponsor a series of community initiatives dedicated to deep imaging of the farthest reaches of the cosmos. These campaigns, the Hubble Deep Field North (HDF-N), Hubble Deep Field South (HDF-S), Hubble Ultra-Deep Field (HUDF), HUDF Infrared follow-up, and finally, the HST Frontier Fields (HFF), have transformed humanity's understanding of the first galaxies and the early evolution of the universe. But HST's contributions to science are not limited to galaxies at cosmological distances. Indeed, roughly two thirds of all HST time in recent years goes toward observing phenomena in the local universe, including sources within the Milky Way galaxy and our own solar system. It is therefore apparent that a complementary large, public data set to benefit the the rest of the community might be desirable.

Furthermore, a local universe program is more synergistic with Hubble's state-of-the-art, ultraviolet (UV) capability. Hubble is the only active mission with large aperture and high-quality, general purpose UV instrumentation. UV observations must be made from space, and there are no plans to launch similar-scale UV capability in the near future. Many astrophysical objects are most luminous in the UV, including massive stars, white dwarfs, post-AGB stars, and accretion disks around young stars and compact objects. The rest-frame UV includes a range of critical spectral features, including the hydrogen Lyman continuum, Lyman break, and Lyα resonance transition; molecular H_2 fluorescence; resonance transitions of "hot-phase" ionized species like C IV, Si IV, N V, and O VI; as well as those of "neutral-phase" species like C II, Si II, Fe II, and Mg II. Therefore, given Hubble's age and vulnerability, there is an urgency to obtaining essential UV observations before this unique capability is lost.

For these reasons, the current STScI Director, Kenneth Sembach, in consultation with the Space Telescope Users' Committee (STUC) and other community groups, convened a science definition Working Group to explore a new type of DD initiative: **The HST Ultraviolet Legacy Initiative.** To help provide focus, he charged the Working Group (WG) to identify a UV program on *star formation and associated stellar physics.* Like the previous DD initiatives, the goal is to generate a fully public data set, released and curated with the technical support of STScI, for the purpose of enabling, supporting, and stimulating a broad range of transformative research.

The HST UV Legacy Science Definition Working Group was chartered in August, 2018, and charged to identify a 600 - 1000 orbit HST program to be executed in Cycles 27 - 28 (Appendix A). The originally chartered members were Bastian, Crowther, Fox, Gallagher, Gómez de Castro (STUC), Leitherer, Oey (Chair), and Tremonti. STScI supported the WG through the assistance of Reid and Brown. The makeup of the WG reflects a variety of science across the area of star formation and related stellar physics, broadly interpreted. Specifically, the WG is charged to:

- Define the overarching science case and a set of science goals for a comprehensive set of ultraviolet observations related to star formation and associated stellar physics that advance scientific discovery and provide lasting archival value.

- Solicit input from the astronomical community in defining the science goals.

- Recommend representative suites of observations necessary to accomplish the science goals of this initiative. Prioritize if possible.

- Identify opportunities for coordinated observations over the full wavelength regime with other ground-based and space-based observatories.

- Produce a short (10-15 page) white paper describing the results of the above tasks by January 20, 2019.

The different nature of the HST UV Legacy Initiative, compared to the previous Deep Field initiatives, poses new and unique strategic challenges. Deep imaging of a few fields captures a large cosmic volume with thousands of objects at a great distance, together with fewer, nearer objects in the line of sight. However, a locally focused program must consider either multiple pointings of individual targets, or a deep pointing on a single, unique target of extraordinary interest. Thus, target selection becomes a significant issue. Moreover, expanding the scope of the initiative to larger target samples of brighter objects thereby also allows spectroscopy to be a more viable option. This welcome development further complicates the range of possibilities. Thus, the overall parameter space of the initiative has similarities to a Treasury-scale Guest Observer (GO) program, and therefore the WG deliberations also addressed the nature of what constitutes a community initiative versus a GO program.

2. Process

The WG carried out most of its work by Webex telecons that started on September 5, 2018, culminating with a face-to-face meeting in Ann Arbor, January 17-18, 2019. The initial effort went into discussing the program implications of the charge to the WG, and in designing a community survey and solicitation for white papers. The WG decided to provide two example white papers, one spectroscopic concept and one imaging concept, to give people an idea of the scope of the initiative and information requested.

The process of developing the example programs was instructive; it became clear that establishing the feasibility for most programs requires careful study of potential target samples, together with detailed examination of the existing archive to understand the available parameter space for a large program. The WG then released the two example concepts together with a short survey requesting community input on science, the relationship vis-a-vis GO programs, and logistical strategies to maximize science (Appendix B). The community survey and solicitation for white papers was open from October 31 to December 7, 2018, requesting input for the HST UV Legacy Initiative on star formation and associated stellar physics. Our mandate was to allow a broad interpretation of the science area, and so it was not further defined.

The original WG members did not participate in formulation of white papers, other than to provide information and clarifications to community members and groups as needed.

The WG received almost 200 survey responses and 34 white papers (Appendices B, C). Community input largely supported the idea that a large, non-GO program should correspond to some kind of service data set. Examples include a library consisting of a statistically significant sample of objects covering a broad parameter space; a detailed atlas of prototypical object(s); or a library of time-series observations of one or more objects. A large, service data set is also synergistic with the ability of STScI to support and curate the uniform production of such observations and accompanying higher level products and tools. The WG therefore proceeded to review ideas for the initiative with a goal of identifying a program that would satisfy this service data set criterion.

It should be noted that among the survey responses were two or three that were critical of the initiative itself. This feedback suggested that a large program should not be executed outside the TAC process, and in particular, that such a program generates an unfair advantage to a particular science area. However, the overall response rate, as well as supportive comments and feedback, demonstrate strong community enthusiasm for the UV Initiative. The WG therefore proceeded decisively, but mindful of the importance that the final program must have high scientific merit that would be gained both through the intrinsic value of the data and by engaging a broad a sector of the community.

The WG reviewed the survey responses and read all the white papers. In the spirit of blind review, the latter were considered anonymously, except for the few cases where authors included their names on the documents. We were impressed with the variety of ideas submitted in both the survey and white papers; topics ranged from subjects in the solar neighborhood to galaxies at $z \sim 1$. The WG reviewed all the submissions, and discussed the science focus, including the merit of considering programs that were of high impact but less directly related to the charge. We also considered the context of previous UV Initiative and Deep Field initiative programs. As expected, there was a preponderance of suggestions related to, or synergistic with, massive stars (Appendices B, C). This effect may have been enhanced by the fact that both of the example white papers provided by the WG at least partly related to massive stars: the WG's Example 1 white paper corresponds to a library of massive star spectra, and Example 2 consists of a library of star cluster photometric imaging across a range of ages and metallicities (Appendix B). Moreover, massive stars and clusters offer a broad range of UV targets over great distance scales, probing a variety of astrophysics. About one third of the white papers suggested a program specifically observing massive stars. There were almost as many suggestions synergistic with massive stars, but not targeting them specifically, e.g., massive star-forming regions, young massive clusters, and star-forming galaxies (Appendix C). The WG came to a consensus that a core program with similarities to the original Example 1 would enable and benefit the maximum scientific advance in these general areas.

However, the responses and submissions further made clear that there was also fundamental UV astrophysics of wide-ranging impact to low-mass star formation (Appendix B, C). The UV emission here originates from accretion disks and jets, with consequences for late-stage accretion, jet launching, magnetic field structure and dynamos, planet formation, and planet atmospheres. The WG appreciated that this area directly addressed the charged focus for the UV Initiative and serves a star formation community of comparable size to that working on massive star formation. While the lower number of responses reflects the relative number and variety of targets, the contributed white papers stressed the critical, and similar, physical role and diagnostic value of UV emission for low-mass star formation phenomena. Thus, such UV observations, albeit with fewer available target opportunities, constitute a similar opportunity to provide a fundamental reference data set as a basis for a wide range of science.

The WG reviewed strategic plan documents for a variety of major facility projects, including JWST, LUVOIR, CASTOR, GMT, TMT, and E-ELT; all specifically highlighted both low-mass, protoplanetary disk science and massive star formation on galactic and cosmic scales. Our discussion of the relevant white papers highlighted the WG's imbalance in expertise, with only one member having familiarity with this area. Given that stellar astrophysics is largely dichotomous between high-mass and low-mass communities, it was realized that obtaining additional expert input from the latter was essential to fairly representing these interests in the process. The WG's timeline required identifying Consultants able to commit substantial effort rapidly to help develop a program or program elements for consideration. Herczeg and Calvet were recruited from among the contributors of the relevant white papers, and fulfilled this substantial task. Upon delivery of highly developed program elements from the low-mass star-formation team, we all agreed that Herczeg and Calvet should be invited to join the WG as full members.

Subsequently, the WG developed program options for observing both high-mass and low-mass stars, with four and three members, respectively, forming the core development teams. The remaining members worked on obtaining supporting materials and study of parallel program options. While there was an initial assumption that the WG would also consider focusing exclusively on either massive stars or low-mass stars, we ultimately concluded that the goal of generating a library of UV spectra across fundamental parameter space for both regimes is not only feasible, but also would maximize the enabled scientific impact and community served.

3. A Hubble Ultraviolet Legacy Library of Young Stars as Essential Standards (ULLYSES)

The unanimous WG recommendation is to execute a spectroscopic Hubble Ultraviolet Legacy Library of Young Stars as Essential Standards (ULLYSES) consisting of 1000 orbits split equally between high-mass stars, and low-mass stars with protoplanetary accretion disks. The massive star component is centered on obtaining UV spectra of OB stars in the Magellanic Clouds across a range of spectral type and luminosity class, with more emphasis on the lower metallicity SMC, but also including stars in the LMC and a few accessible in more distant Local Group galaxies at sub-SMC metallicity. Community feedback strongly supported generating data across a range of lower metallicities, and so the WG studied the possibility of including very low-metallicity clusters in Local Group dwarf galaxies. However, after careful study of the archive, candidate targets, and exposure times, we concluded that there are not enough new and feasible targets to serve as a uniform sample of young, massive clusters with well-populated stellar mass functions. The low-mass star component focuses primarily on obtaining UV spectra of T-Tauri stars across a range of spectral type, age, and accretion rate. The sample also extends to some M stars on the Hayashi track and brown dwarfs. A significant fraction of community feedback in this area supported time-series monitoring, since accretion phenomena are variable sources, and so this was also included as an essential component.

3.1 UV Spectra of Young, High-Mass Stars

Massive stars, observed directly through UV and blue radiation, and indirectly through nebular and reprocessed dust emission, trace star-forming regions throughout the universe. They are responsible for the bulk of ionizing, mechanical, and nucleosynthetic feedback in star-forming galaxies, and therefore they are a fundamental driver, and diagnostic, of galaxy formation and evolution. Moreover, Lyman continuum (LyC) radiation from such stars at the earliest epochs is widely believed to be responsible for cosmic reionization, and constraining stellar LyC luminosities is essential to understanding the conditions for LyC escape from galaxies. These topics are regularly mentioned as science goals for future major facilities. Massive stars are the only stellar population directly seen in high-*z* galaxies, via P Cygni resonance lines from OB stars, and emission lines from OB supergiants and Wolf-Rayet (WR) stars in the rest-frame far-UV (FUV). The conditions for massive star and cluster formation are major subjects of active research, both on the scale of understanding how individual systems form, and their formation on galactic and cosmic scales. These populations are also the progenitors of core-collapse supernovae and stellar-mass black holes, plus merger systems that generate gamma-ray bursts, gravitational waves, and neutrinos. Such systems represent the latest frontier enabled by technological advances in multi-messenger astrophysics.

Despite this far-reaching importance, the properties and evolution of high-mass stars remain unclear owing to the role of mass-loss, rotation and binarity. Rotation has a dramatic effect upon the evolution of metal-poor massive stars for slow versus rapid rotators in the SMC (Figure 1; Brott et al. 2011), and is most directly diagnosed via surface CNO abundances which require analysis of UV *and* optical spectroscopic observations (e.g., Hillier et al. 2003). The UV spectra are complex and difficult to model owing to expanding, line-blanketed atmospheres that are not in local thermodynamic equilibrium (LTE; Figure 2). The scarcity of these stars at the top of the stellar initial mass function (IMF) has meant that existing spectroscopic observations poorly sample the necessary parameter space to properly address our lack of understanding. Community input stressed that this is especially true at low metallicities, which are crucial for studying galaxy and cosmic evolution. The goal of the Hubble ULLYSES library for massive stars is to provide the fundamental reference data set for UV spectroscopy at low metallicity by constructing a comprehensive UV spectral atlas at high spectral resolution ($R > 15{,}000$) using COS and STIS in the Magellanic Clouds, supplemented by medium resolution spectroscopy for OB stars in more distant Local Group galaxies. This data set will also enable absorption-line studies of the interstellar medium (ISM) in these galaxies, and the foreground Milky Way, to study element abundances, dust, and multiphase gas kinematics, including galaxy-scale flows.

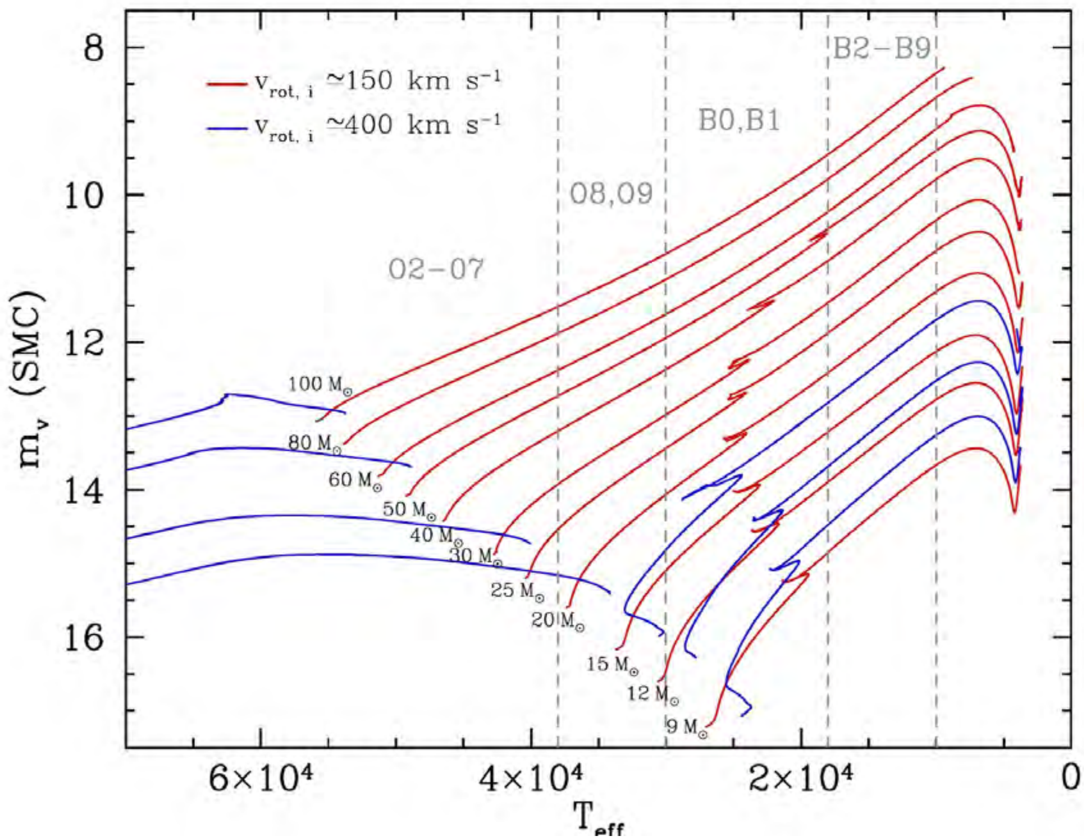

Figure 1. Theoretical predictions for the evolution of single massive stars at SMC metallicity that are initially slowly rotating (red) or rapidly rotating (blue). Rapidly rotating massive stars are likely progenitors of long gamma-ray bursts (GRBs) and superluminous supernovae, while some metal-poor, close binaries will result in progenitors of black hole binary mergers identified by LIGO/Virgo. The vertical dashed lines show the locus of the indicated spectral types (O2 to B9). Adapted from Brott et al. (2011) using DM=18.9 and A_V = 0.3 mag.

SMC metallicity (0.2 solar) corresponds to a threshold at which metallicity effects in stellar properties (winds, rotation, evolution; e.g., Puls et al. 2008; Golden-Marx et al. 2016; Langer 2012) and ISM properties (dust production, nebular excitation; e.g., Engelbracht et al. 2005; Draine et al. 2007; Kewley & Dopita 2002) significantly escalate. The WG recommends prioritizing the SMC, and populating a grid of spectral type and log *g* from early O to B1 dwarfs and giants, plus early O to B9 supergiants, with at least 4 stars per grid bin, given the individual variations typical in this regime. A few WR stars should also be included, since these can dominate wind feedback and hard ionizing radiation, plus their strong emission-line signatures provide key starburst mass and age diagnostics. Their evolution is especially poorly constrained. For a grid, it is also vital to obtain additional data at other metallicities, and so we recommend populating a similar parameter space for LMC (0.5 solar metallicity) stars, albeit with lower priority of 2 stars per grid bin, with a specific emphasis on the most massive, early-type stars, which are underrepresented in the SMC and inaccessible in the Milky Way due to high foreground dust extinction. Based on our study of the archive and available targets, we anticipate that the SMC component should correspond to at least 250 orbits with no more than 200 orbits for the LMC component. Finally, it is especially desirable to obtain data at metallicities below that of the SMC. Around 50 O stars have been spectroscopically confirmed in the nearby dwarf galaxies SagDIG, WLM, Sextans A, IC 1613, and NGC 3109 (Garcia 2018; Camacho et al. 2017; Tramper et al. 2014; Garcia et al. 2014; Garcia & Herrero 2013; Bresolin et al. 2006, 2007), which have metallicities in the range 0.06 to 0.16 solar. Not all are suitable for observations with the large, 2.5" COS aperture, and some objects have existing archive UV data. The WG recommends on the order of 50 orbits to observe 5-10 suitable stars in Local Group dwarfs with oxygen abundances below 1/10 solar.

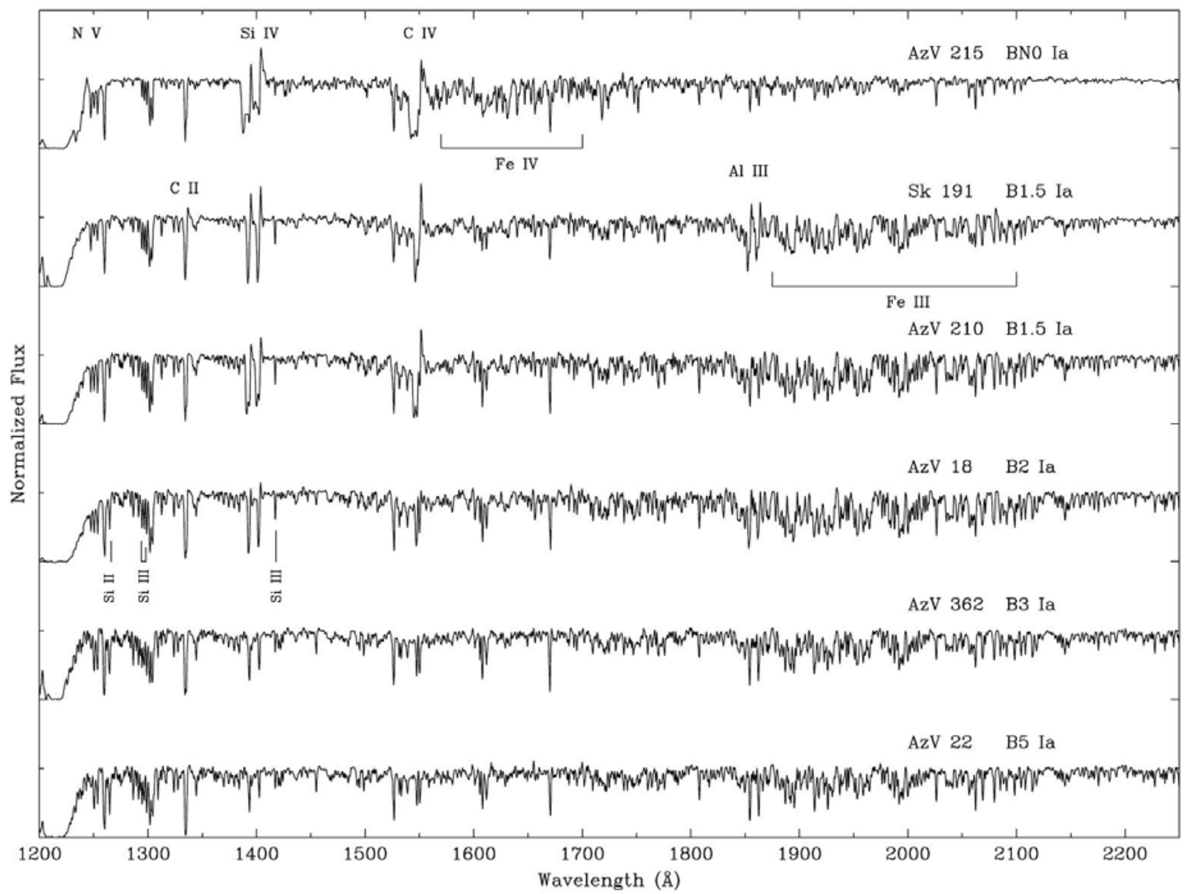

Figure 2. STIS E140M+E230M spectroscopy of luminous, SMC B supergiants from Evans et al. (2004a), illustrating P Cygni wind profiles (e.g., C IV 1550, Si IV 1400, Al III 1860) and the Fe III-IV forest which ULLYSES would extend to later B subtypes and LMC counterparts.

3.1.1 Young, High-Mass Stars: Enabled Science

The enabled science supported by the ULLYSES data on young, high-mass stars is as follows.

Stellar atmospheres and evolution: The FUV provides access to P Cygni profiles from hot, luminous stars from which wind properties (velocities, mass-loss rates, clumping, porosity) can be empirically obtained, which strongly influence the evolution of massive stars (Langer 2012), yet evolutionary calculations usually resort to theoretical predictions (Vink et al. 2001). Furthermore, photospheric lines from CNO elements and the iron forest provide a direct signature of the ionization conditions of iron and other elements within the stellar atmosphere (e.g., Figure 2), which are necessary for evaluating line blanketing and mixing (e.g., Hillier et al. 2003). Such information is essential for deriving reliable relations between spectral type and effective temperature, which are in turn necessary for placing stars on the H-R diagram and understanding their evolution. The high-resolution spectra will also yield the projected rotational velocities, which are another vital parameter affecting stellar evolution and LyC luminosities (e.g., Howarth et al. 1997). The 900-1150 A region should also be targeted with COS, since this window includes additional key resonance lines (P V 1118-28, S IV 1063-73, O VI 1032-38, N III 991, C III 977) spanning a broader range of species and ionization states, some of which remain unsaturated in stars with strong winds (Walborn et al. 2002), and thus permitting uniquely effective mass-loss diagnostics (Fullerton et al. 2006).

Spectral templates for stellar population synthesis: This library would provide much-needed OB and WR spectroscopic templates for rest-frame UV studies of integrated stellar populations in high-*z* galaxies with JWST and ELTs. The proximity and low metallicity of the LMC (0.5 solar) and SMC (0.2 solar) makes them ideal targets. This atlas would greatly extend the number of high-quality, UV spectroscopic templates in both galaxies, achieving a similar OB and WR sample to that of the Milky Way from *IUE* (Prinja et al. 1990). It would also provide more representative examples, since archival datasets were largely selected based on other criteria, such as being UV-bright for ISM studies, or focused on unusual systems (e.g., magnetic O stars, rapid rotators). Currently, low-metallicity templates are poorly sampled compared to those at solar values, yet the former are essential for interpreting the stellar populations in starburst galaxies like Green Peas and Lyα emitters.

Stellar populations at low metallicity: The spectral templates will clarify the IMF, cluster ages, and ionizing SED in massive clusters and local galaxies that serve as analogs of higher redshift objects, which are commonly metal-deficient, especially in iron peak elements (e.g., Steidel et al. 2016). These are critical for estimating star cluster masses and ages, which are the fundamental input parameters for understanding massive-star feedback and evolutionary processes in star-forming galaxies. Indeed, some local, intensely star-forming, metal-poor galaxies are known to be LyC emitters (e.g., Izotov et al. 2016); identifying their stellar populations is critical to understand the conditions for LyC escape. In addition, stellar abundances at low metallicity are more accurate in weak-wind populations, and can calibrate nebular diagnostics.

Multi-phase ISM and dust: The stellar spectra will contain many interstellar metal lines across the FUV. This will enable comprehensive studies of the ISM in the Magellanic Clouds, Milky Way, and perhaps the metal-poor galaxies; in particular, element abundances, dust depletion, kinematics, ionization state, and spatial distribution of multi-phase gas. UV continuum studies will further characterize the dust extinction law in a range of metallicities and environments, since the foreground Milky Way component of the extinction is low.

Circumgalactic medium: The stellar spectra will also reveal absorption lines from the CGM of the Magellanic Clouds and the Milky Way. The LMC systemic velocity of +260 km/s is large enough to differentiate LMC and Galactic components, while the SMC systemic velocity of +150 km/s allows probing a more limited velocity range. This data set can thus be leveraged to study the galaxy-scale gas inflows and outflows, clarifying the baryon and metal cycle of star formation, feedback, galactic chemical evolution, and other evolutionary processes in a system that is currently being dynamically entrained by the Milky Way. Moreover, the high sensitivity of UV wavelengths to small particles and large molecules will enable measuring variations in the particles size distribution, and the connection between PAH abundance and UV irradiation.

3.1.2 Young, High-Mass Stars: Parameter Space and Observations

Archival, high-resolution COS/STIS observations of O stars in the Magellanic Clouds (Appendix E) fail to provide complete coverage in effective temperature (spectral types O2 to O9) or surface gravity (luminosity classes V, III, I, I+), especially considering the crucial 900-1150 A range sampled by *FUSE*. In addition, very few mid to late B supergiants in either galaxy have been observed at high resolution to date. There is also a need to extend the sample of metal-poor (below 1/10 solar) OB stars observed in the FUV since these provide excellent empirical probes of wind strengths at low metallicity, which is critical for our understanding of rest-frame UV observations of nearby dwarf galaxies and high-redshift star-forming galaxies.

The instrumental requirements for the Magellanic Cloud component of ULLYSES need to address stellar, galactic and ISM objectives. We find that uniformly high S/N (> 30) and high resolution in the FUV are the common criteria, as indicated in Figure 3. ULLYSES will provide complete 940-1750 A coverage of O stars in temperature and gravity in both galaxies, and 1150-2366 A coverage of late O and B supergiants, plus selected narrow/weak-lined WR stars. Specifically, we recommend COS G130M+G160M for FUV spectroscopy of OB stars (e.g., CENWAVE 1222, 1291, 1533, 1623), to provide complete spectral coverage from 1067-1798 A, plus G130M/1096 for bright O stars, to extend the spectral coverage down to 940 A, albeit at reduced S/N. STIS/E140M would be used for instances of severe crowding or COS bright object limit concerns, covering 1144-1710 A. For late O and B supergiants we recommend use of STIS/E230M (CENWAVE 1978), which would extend the spectral coverage to 2366 A to ensure the inclusion of Al III 1855-63 and the Fe III forest (Evans et al. 2004a). STIS/E230M with CENWAVE 2707 should also be considered for late B supergiants. Whenever feasible, targets in the Magellanic Clouds should be observed through a range of A_V to enable ISM science, mindful of the tradeoff involving increased exposure times for high S/N FUV spectroscopy, and greater contamination by molecular hydrogen bands below 1100 A (Walborn et al. 2002).

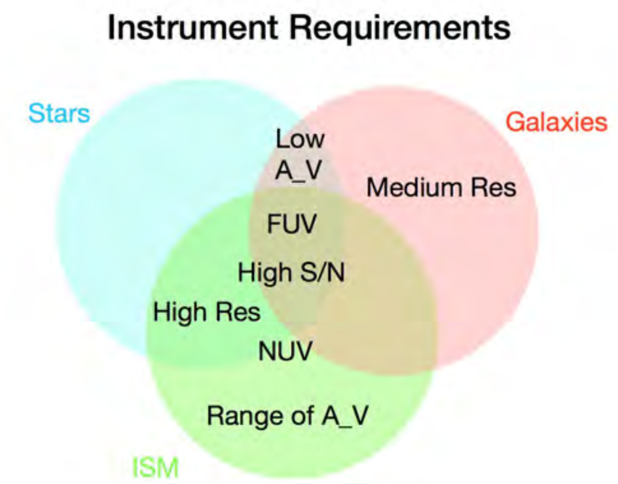

Figure 3. Key criteria for the stellar, galactic and ISM requirements of the young, high-mass star, Magellanic Cloud component of ULLYSES, indicating that FUV, high S/N and medium/high spectral resolution are common requirements for each objective.

SMC: To date, 43 O stars, 14 B stars, and 3 WR stars in the SMC have been observed at high resolution in the FUV with HST COS and STIS, and only 25 early-type stars observed with *FUSE* (Tables E1, E2). ULLYSES would add 63 new targets, more than doubling the sample of stars observed at high resolution in the FUV, with an emphasis on extending coverage below 1150 A for early O stars (only 3 O2-4 stars were observed with *FUSE*) and including coverage in the *FUSE* spectral range for stars already observed with COS/G130M +G160M or STIS/E140M. In addition, we recommend near-UV (NUV) coverage for B supergiants across all spectral types (only 4 stars later than B2 have been observed with STIS/E230M). High-resolution spectroscopy of a single, weak-lined WN star should also be prioritised. Preliminary candidate target lists are given in Tables D1 and D2.

LMC: To date, 45 O stars, 12 B stars, and 11 WR stars in the LMC have been observed at high resolution in the FUV with COS/STIS, with only 32 early-type stars observed with *FUSE* (Tables E3, E4). ULYSSES would add 71 new targets, more than doubling the sample of stars observed at high resolution in the FUV, again with an emphasis on extending coverage below 1150 A for stars already observed with COS/G130M+G160M or STIS/E140M, and filling in spectral types lacking data (e.g., no O7 giants or supergiants have been observed to date). In addition, we advocate NUV coverage for B supergiants across all spectral types (no B supergiants later than B2 have been observed with STIS/E230M). We would also recommend prioritising spectroscopy of several weak-lined WN stars and obtaining complementary data to existing *FUSE* targets where appropriate (Willis et al. 2004). Preliminary candidate target lists are given in Tables D3 and D4.

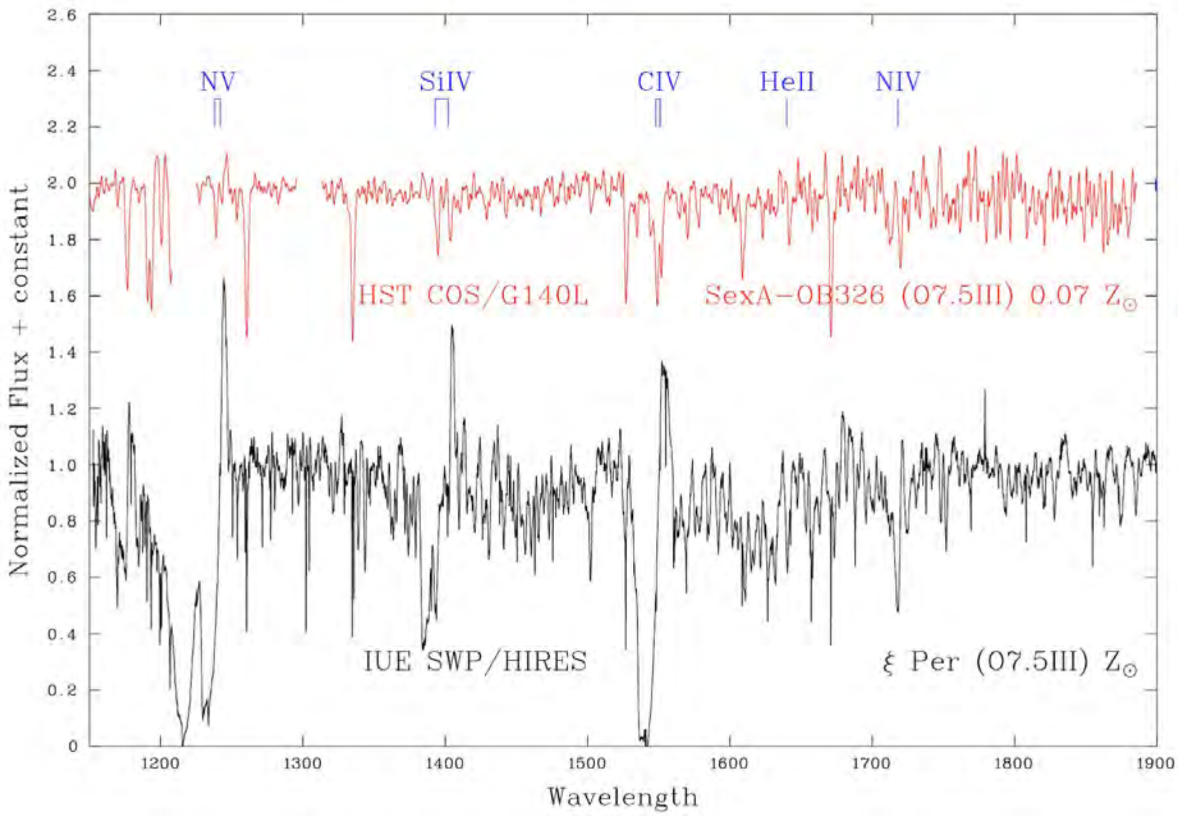

Figure 4. Comparison between FUV spectroscopy of mid O giants in metal-rich (ξ Per; Walborn et al. 1985) and metal-deficient (Sex A-OB326: Garcia et al. 2017) environments, illustrating extreme differences in wind features (e.g., N V 1240, Si IV 1400, C IV 1550) and the iron forest (Fe IV-V).

Sub-SMC metallicity: To date, a dozen OB stars in Local Group galaxies with metallicities below 12 + log O/H = 8.1 (SMC value) have been observed with COS G140L, namely, in IC 1613 (12 + log O/H = 7.9) and Sextans A (12 + log O/H = 7.5; Table E5), which are compared to solar metallicity counterparts in Figure 4. We recommend a focus on OB stars in the lowest metallicity environments, below 1/10th solar, namely Sextans A and B (12 + log O/H = 7.5) and the Sagittarius dwarf irregular (SagDIG; 12 + log O/H = 7.4). These dwarf galaxies have large distance moduli and low star-formation rates relative to the Magellanic Clouds (e.g., Kennicutt et al. 2008). Nevertheless, individual O stars have been identified, which should be prioritized, provided they are sufficiently isolated in the COS aperture. For the sub-SMC OB stars, we recommend consideration of the COS G140L/800 mode to cover the full FUV on one detector segment (and still cover N V 1238, unlike the G140L/1280 mode) with performance optimized for short wavelengths. A preliminary candidate target list is given in Table D5.

3.2 UV Spectra of Young, Low-Mass Stars

At ages < 10 Myr, low-mass stars have accretion disks that emit strongly in the UV where the the accretion flows reach the star. Such disks cannot be seen for massive stars, which are scarce and evolve rapidly, destroying their disks at even faster rates. Accretion disks are ubiquitous across scales ranging from neutron stars to galaxies, as the signature of angular momentum budgets in gravitating systems. The physics of stellar accretion disks has broad parallels to those of compact objects and active galactic nuclei (AGN), especially relating to magnetic fields and jet launching. By an age of ~1 Myr, low-mass stars have shed their dense protostellar envelopes and their disks and accretion flows onto the star are exposed, offering rich information on accretion, disk structure, outflows, and stellar activity. The accretion shock releases the gravitational potential energy of the accreting matter, mostly in the UV. During later phases of pre-main sequence evolution, accretion decreases or stops, the stellar dynamo stabilizes, and excess magnetic energy of the very active stellar chromosphere is released through UV radiation. This hard environment also plays a fundamental role in the chemical composition and atmosphere escape of young planets, which is a major focus for exoplanet research in the coming decade, since such planets will be the easiest targets in searches for biomarkers. The dispersal of the protoplanetary disk leaves behind remaining debris disks and planetesimals, which continue to evolve into mature planetary systems. Understanding this key epoch directly complements the rapidly advancing knowledge of our own solar system's Kuiper Belt and other trans-Neptunian objects. The compositions of comets and asteroids, and characterization of "Manx comets" and MU69 directly probe conditions within the proto-solar nebula. Thus, understanding our own origins and the prospects for life elsewhere in the universe begins with protoplanetary accretion disks.

However, understanding protoplanetary disks and their evolution is a complex problem due to highly dynamic, magneto-hydrodynamic (MHD) processes coupled with radiative transfer in regions ranging from molecules and dust to ionized gas (Figure 5). The UV radiation field is a critical parameter of fundamental importance, consisting of multi-component continuum (Figure 6) and a strong emission line spectrum (Figure 7). These features offer unique information for the analysis of these complex systems and their evolution. A UV spectrum of a low-mass, pre-main sequence star includes radiation from molecular gas tracers (H_2, CO, H_2O, OH), as well as emission from highly ionized metal lines and He II (Figure 7) and semi-forbidden (intercombination) lines, covering a large range of temperatures and densities. Empirical UV spectra are also crucial to determining the disk chemistry and ionization, which in turn drive its other properties, evolution and dissipation. Presently, most existing UV spectra are from targets concentrated in a single molecular cloud and with masses of half solar or higher. The goal of the ULLYSES library for low-mass stars is to provide the fundamental reference data set for UV spectroscopy across a range of spectral type, age, and environment. This will enable the interpretation of submillimeter and IR observations of disks, as provided by ALMA, JWST, and ground-based IR spectrographs planned for the ELTs on diverse subjects ranging from AGN to the photochemistry of habitable planets around M-dwarfs. This addresses major goals established in the National Academy reports, *Exoplanet Science Strategy,* and *New Worlds, New Horizons* (Astro2010), that relate directly to understanding planet formation and protoplanetary disks.

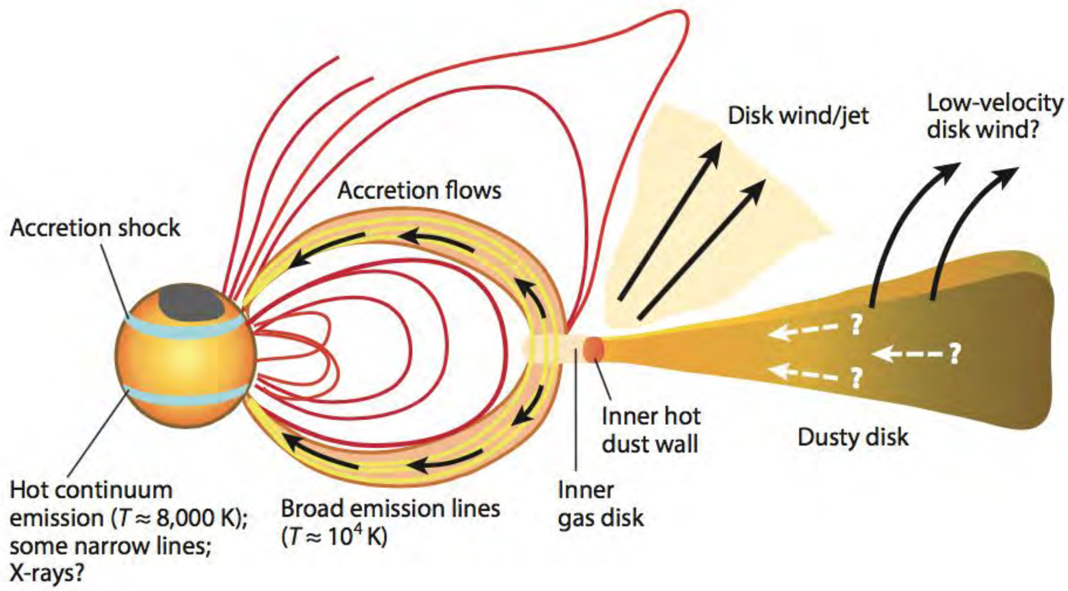

Figure 5. A cartoon of the star-disk interactions in a classical T Tauri star (from Hartmann et al. 2016). A disk of gas and dust is accreting mass onto the star. Dust sublimates at the inner hot dust wall, and an inner disk of only gas remains, with temperatures on the order of 1000 K, in which most of the FUV H_2 fluorescent lines arise. The disk is truncated by the stellar magnetic field and matter falls along the field lines until it merges onto the stellar surface through an accretion shock. Emission from this accretion shock dominates the NUV and contributes to the FUV continuum. The C IV, Si IV, N V, and He II lines in the FUV are unique tracers of the gas heated to 10^5 K by the accretion shock.

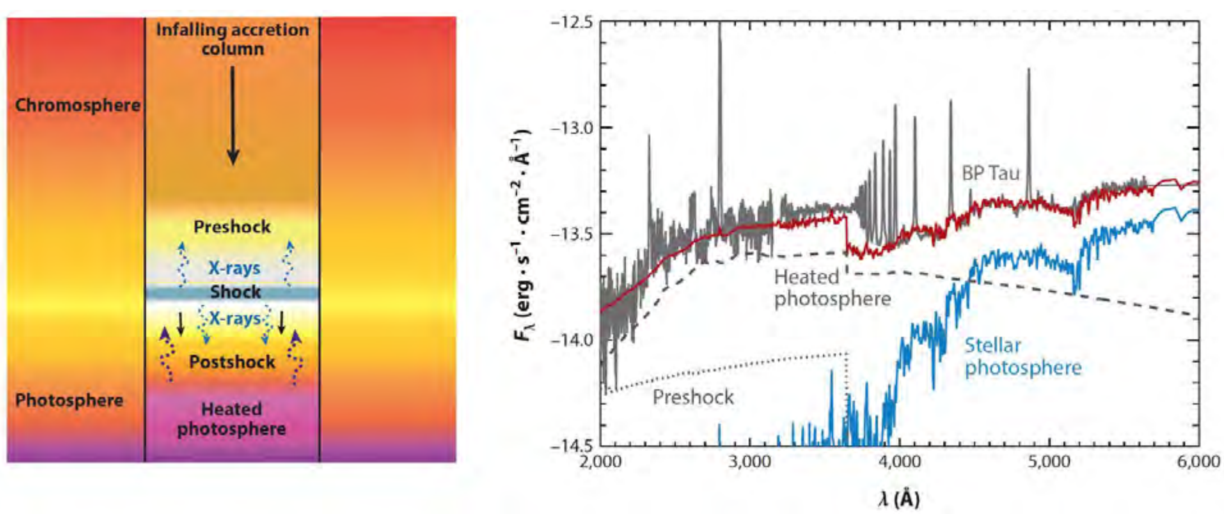

Figure 6. [Left] A schematic of the accretion shock (from Hartmann et al. 2016). The infalling gas forms a shock at the stellar surface, producing X-rays that then heat the pre-shock gas and the photosphere below it. The reprocessed X-rays emerge mostly in the UV. [Right] Emission from the heated photosphere and the pre-shock combine to produce continuum emission in excess of the stellar photospheric flux, with a luminosity that is directly proportional to the accretion rate. (Adapted from Hartmann et al. 2016)

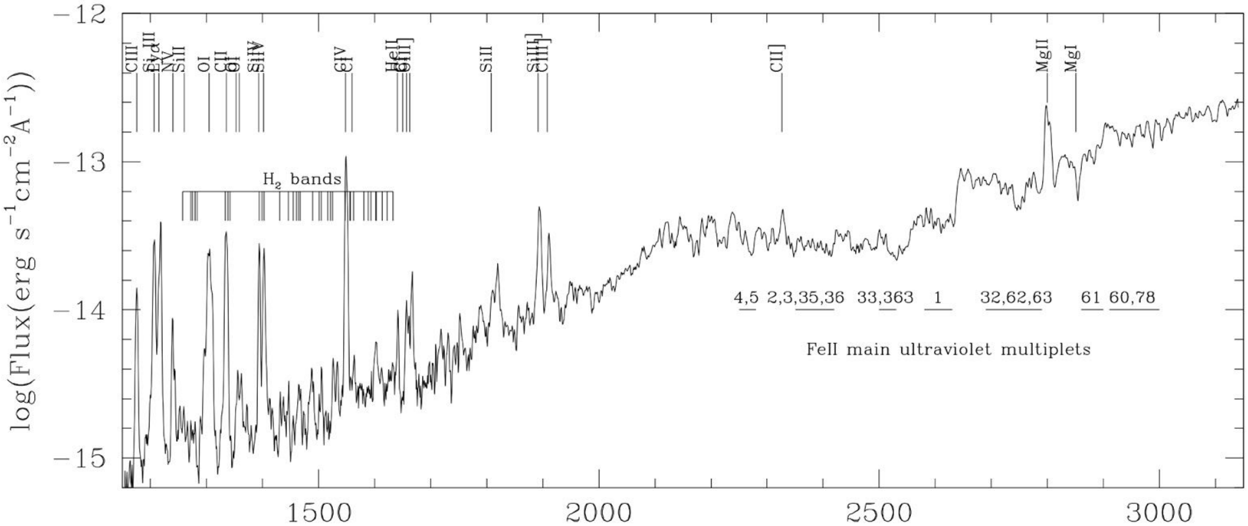

Figure 7. The UV spectrum of the classical T Tauri star, AK Sco. A single spectrum contains unique information for the analysis of the complex coupled processes occurring during pre-main sequence evolution: accretion shocks (UV continuum, N V, He II, C IV, Si IV and Mg II, Fe II, C II), jets (Si III], C III], O III], Fe II] and C II] as well as singly ionized species C II, Si II, Mg II), disks (H_2 and ionized species in the photo-evaporative flows) and stellar atmosphere: chromosphere (singly ionized species, Lyα), and transition region (N V, C IV, Si IV, He II). The abundance and size distribution of small dust grains and large molecules can also be inferred from the UV continuum shape in the earliest types. This high S/N spectrum has been obtained by co-adding 12 STIS G140L and G230L spectra of AK Sco obtained during HST 13372 (PI Gomez de Castro).

Despite the relevance of understanding accretion physics and its impact on protoplanetary and young planetary disk evolution, few observations are available of the UV spectrum of T Tauri stars, especially in the 1150-1750 A spectral range, where most of the spectral diagnostics are concentrated. Moreover, the sample of pre-main sequence stars with known FUV spectrum observed with resolved line profiles ($R >$ 10,000) does not adequately cover the parameter space; as shown in Figure 8, there are no observations at the low mass end or during the last stages of evolution. We therefore recommend obtaining a library of 40 UV spectra covering a grid of K and M spectral types, accretion rates from ~1/50 to 10 times the mean rate of 10^{-8} M_{SUN}/yr, and ages of 1 to 10 Myr, to serve as a reference data set over a broad parameter space. Since these are variable sources, we also recommend time-series monitoring of a few prototypical objects.

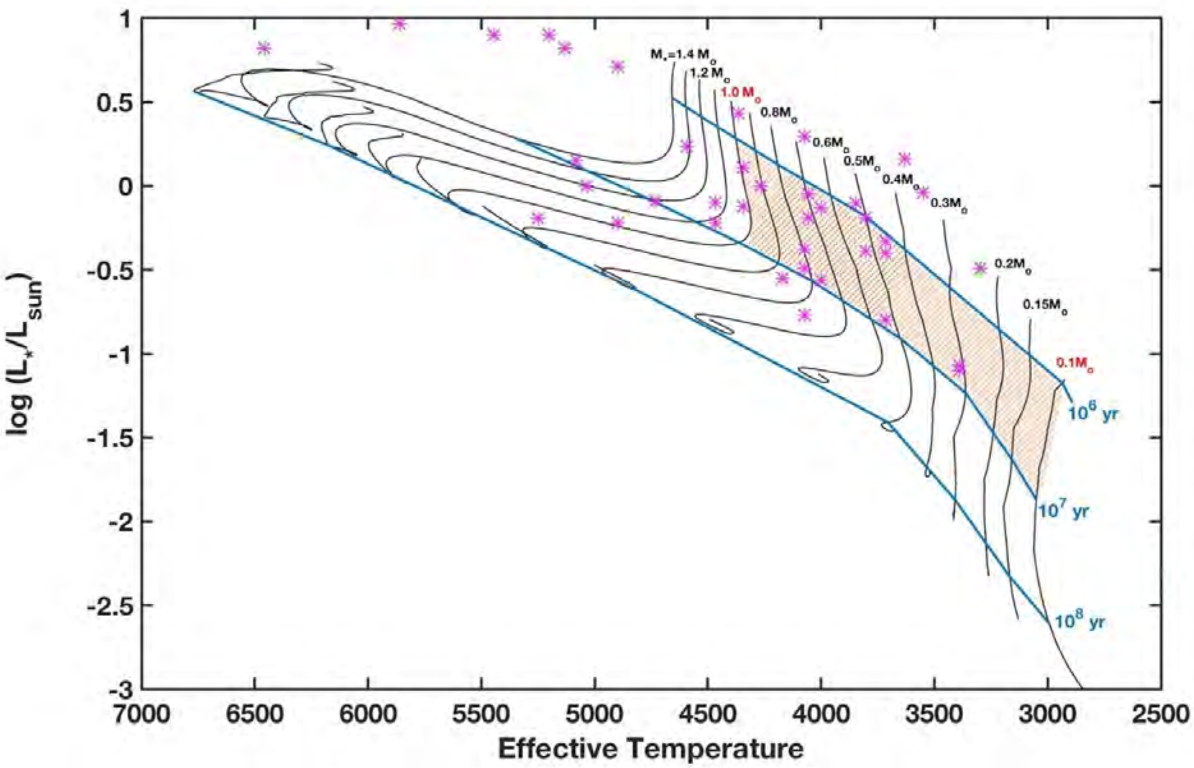

Figure 8. Location in the H-R diagram of the T Tauri stars with existing, high quality (S/N > 10) spectra having *R* > 10,000 in the 1150-3100 A range (asterisks). The recommended parameter space for new observations is shown in the hatched region. Pre-main sequence evolutionary tracks are from Baraffe et al. 2015 (adapted from López-Martínez & Gómez de Castro 2015.)

3.2.1 Young, Low-Mass Stars: Enabled Science

The enabled science supported by the ULLYSES data on young, low-mass stars is as follows.

Accretion and ejection physics: Magnetospheric accretion, as sketched in Figure 5, is characteristic not only of young stars, but also of compact objects. However, young stars provide a much clearer view of the flow rates and morphologies involved. Emission from the accretion shock, where infalling disk matter merges with the star, dominates the UV emission of disk-bearing stars. The accretion shock is seen in the excess continuum relative to the photosphere (Figures 6, 7), and in the C IV, N V, and He II lines (Figure 9), while the funnel flows are detected in atomic and singly-ionized lines. The dynamics and morphology obtained from the line profiles will be combined with the measurement of mass accretion rate obtained from the combined optical/NUV-FUV detection of the Balmer continuum emission, produced in the pre-shock, post-shock, and heated photosphere gas. Emission in semi-forbidden lines and P-Cygni profiles in low-ionization lines trace outflow morphology and ionization. The inner disk is a highly dynamic environment, varying on timescales from hours to weeks as magnetic fields rotate around the star, winding up and leading to magnetic reconnections, and as the inner disk drains and fills with gas. For several stars, these flows will be monitored across several rotation periods, which may include small bursts of accretion, and over timescales of month to years.

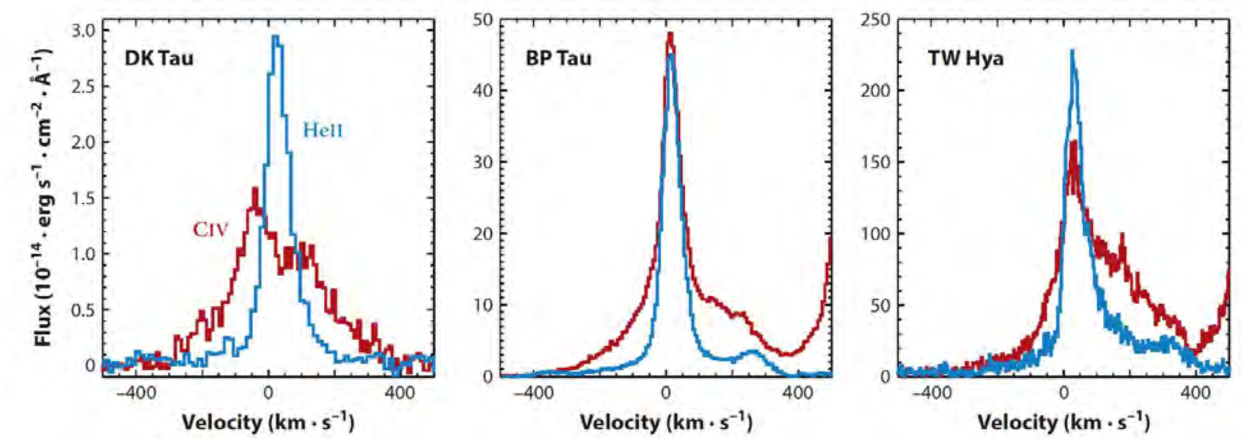

Figure 9. The He II and C IV lines from three different classical T Tauri stars show narrow, broad, and redshifted components, each tracing different regions in the accretion shock structure. (Adapted from Ardila et al. 2013.)

Jet launching and angular momentum evolution: Jets are a universal phenomenon of almost all accretion systems, from supermassive black holes to stars and planets. Jets from young stars are characterized by epìsodic mass ejections of unknown origin, thought to be produced by plasmoid ejection from the current layer between the disk and the star's magnetic field. Much of the jet emission is produced in low density (n_e~10^2 cm^{-3}), warm (10^4 K) plasma. Some jets also have knots of 10^6 K, heated either by recollimation shocks, internal shocks from instabilities, entrainment, stellar radiation, or by the magnetic fields that launch the jet. In all models, launching occurs within a few AU of the central object. The NUV and optical long-slit spectra of jets will provide a census of line emission (O I, Fe II, Mg II, C II], C III], Si III] and O III]) to be used for probing the temperature and density at different locations along the spatially-resolved jet. The properties of the higher-density base of the jet (n_e~10^4 cm^{-3}), and therefore the launching mechanism, are also probed by these species.

Disk evolution and dispersal: FUV radiation is one of the two main agents heating the gas in the disk upper layers through photoelectric heating and molecular dissociation, and it thus determines the disk thermal structure, and in particular, the properties of photo-evaporating winds that help dissipate the disks. In addition, FUV radiation plays a fundamental role in determining the degree of ionization in disks, with implications for mechanisms of angular momentum transport and disk photoevaporation. In the inner disk, The fluorescent H_2 emission, excited by Lyα, provides information on the morphology and thermal structure, a direct result of the UV irradiation. The FUV is therefore critical for understanding the physics that drives disk evolution and dispersal, by accretion through the disk and by outflows from the disk.

Chemistry of planet formation: FUV radiation from the accretion shock, and from the chromosphere in weak accretors, dissociates and ionizes many molecular species, thus determining the chemical abundances in the disks and in the planets that form in them. Unlike the smooth interstellar radiation field, FUV spectra in young stars are rich in emission lines of differing strengths (Figure 7), and in particular, are dominated by Lyα, which determines the dissociation of water vapor, among other molecules, of special relevance to the habitability of incipient planets. The H_2O dissociation may even be seen directly in a byproduct, the H_2 pseudo-continuum and 1600 A bump. Some stars undergo disk-related extinction events that coincide with molecular absorption, only seen in the FUV, thereby providing direct measurements of the composition of the surface layers. Ultraviolet spectroscopy of these unique targets yields the CO/H_2 ratio, the most important parameter for measuring masses of disks -- a critical yet poorly understood parameter. The FUV radiation fields measured directly from FUV spectra, and the Lyα emission measured indirectly from H_2 lines, are essential ingredients for interpreting the powerful probes of disk chemistry seen with ALMA, Spitzer/IRS, and soon JWST.

Unveiling the Chromosphere: Since the mass accretion rate decreases as the disk evolves, the contribution to the UV emission from the accretion shock decreases as well. At some point, the UV fluxes arise essentially from the chromosphere and transition regions of the active stellar atmospheres of the young stars, with only a few emission lines containing contributions from the accretion flows. These regions are powered by the stellar magnetic fields, as in other active cool stars, and their energy budget can be measured from the Mg II, C II, Si II, Fe II chromospheric tracers, the N V, C IV, Si IV transition region tracers, and He II that, through its double route of photoionization by coronal X-rays and excitation by collisional heating, acts as an optimal match between the densest parts of the atmosphere and the thin, X-ray emitting gas. The chromosphere-dominated stars will more likely be found within the oldest (5-10 Myr) and weakest accretors (~ 10^{-10} M_{SUN}/yr) in our target list, and will constitute an essential initial point for studies of evolution of magnetic activity in the pre-main sequence phase, of great interest to the active star community.

Irradiation of young planetary atmospheres: As the disk evolves, losing mass, the young planets are increasingly affected by direct radiation from the central star, leading to atmospheric evaporation and abundances driven by photochemistry. The radiation environment is especially important for evaluating the evolution of atmospheres for planets around M-dwarfs, which will be the focus for the initial attempts at detecting water in atmospheres of potentially habitable terrestrial planets.

3.2.2 Young, Low-Mass Stars: Parameter Space and Observations

The survey of young, low-mass stars will focus on two complementary approaches. The primary set of observations, with a recommendation of 400 orbits, will produce an FUV-NUV-optical spectral library of accreting young stars across a range of star and disk properties. The second set of observations will monitor the FUV emission from 4 T Tauri stars, each observed 25 times.

T Tauri star library: The stars selected for the T Tauri library should cover a wide parameter space (Figure 8) in stellar mass (0.05-1 M_{SUN}, focused on K, M stars and brown dwarfs), age (1-10 Myr), accretion rate (log M_{SUN}/yr = -12 to -6), jet presence/absence, disk inclination, and cloud membership

(Lupus, Chamaeleon I, Upper Sco OB Association, and the TW Hya, η Cha, and ε Cha Associations). Additional needed parameters are A_V, *GAIA* DR2 distance, sub-mm chemistry, and confirmation that the objects are not known binaries. The targets that are selected will need to be lightly extincted so that they are bright enough for FUV spectroscopy. The current archive is heavily biased toward stars $> \sim 0.5\ M_{SUN}$ and in the 1-2 Myr old Taurus Molecular Cloud (Figure 8, Table E6). The new observations will use the COS/G130M+G160M to resolve line profiles. The primary diagnostics are the C IV, Si IV, N V, and He II emission lines to trace the accretion shock; P-Cygni line profiles in low- and high-ionization lines to trace the outflow; and H_2 to trace the inner disk. In addition, the full spectrum will be used to measure the FUV radiation field, including indirect measurements of Lyα using the H_2 lines. Every COS visit will require STIS G750L, G430L, G230L spectra to obtain near-simultaneous measurements of the Balmer continuum emission, the most direct and accurate probe of accretion rate. The STIS observations can be completed in a single orbit, with most of the time dedicated to the G230L spectra, with only ~500 s for the G750L and G430L spectra and associated overheads. For very low-mass stars and brown dwarfs, the lower-resolution COS G140L or even ACS/SBC PR130L will be required to measure the radiation field, without resolved line profiles.

T Tauri star monitoring: Four T Tauri stars should be selected to sample different magnetic field structures, as measured previously from Zeeman Doppler Imaging, as well as disk/star inclination. Most of these observations will be used to cover different phases in the orbital period, across three rotational periods, to understand how the accretion structures change with different viewing angles. Multiple rotation periods are needed because the accretion rate will vary on these timescales. A few additional observations should be spread at month-year timescales to evaluate long-term changes. These spectra should use G160M to obtain line profiles for C IV, He II, and H_2. Short COS/G230L spectra should also be obtained to measure the NUV continuum.

The high-resolution COS spectroscopy should achieve S/N > 30 per resolution element at the peak of the C IV line profile. Low-resolution spectra of the faintest objects have a requirement of S/N = 20 in the total C IV line, guaranteeing a high-quality spectrum. The low-resolution STIS NUV + optical spectra should have S/N = 20 to allow for accurate modeling of the accretion flow, stellar photosphere, and extinction.

Jets: For targets with jets having known position angle, the COS+STIS observations should be designed with the STIS slit aligned with the outflow axis. The low-resolution, NUV and optical spectra would include both the on-source stellar spectrum and the off-source emission from the jet. For any sources in the monitoring program with resolved, well-known jets, the slit could be aligned with the jet if the orientation of the telescope allows at the time of the observation. Long-slit jet observations will provide the community with a census of lines from different jets to probe the physical conditions at different positions along the jet. These alignments leverage the program observations to obtain powerful data on jets that is only possible with HST. In addition, microjets are often a few arcsec from the star and have internal structures. Emission from any microjets would also be included in the COS aperture, combined with the stellar emission.

4. Implementation

The nature and scope of this data set are necessarily much more complex than for previous DD initiatives due to the large number of spectroscopic targets. Execution would therefore require substantial project management and STScI support. The Implementation Team should work with the community in developing the final program, which may require minor modifications to be fully optimized. Below, we outline a few considerations that we feel are important; this is not meant to be a comprehensive description of what needs to be done. We note that there are time-sensitive issues described under Parallels and Coordinated Observations.

Target selection: The WG has identified preliminary lists of candidate targets (Appendix D) and existing archive data (Appendix E) in the process of developing the program. The latter are reasonably complete. However, a more thorough search for parent samples from which to draw new candidate targets is desirable. Engagement with the communities will be needed, both to leverage the knowledge base and optimize target selection, and to mobilize for science productivity. Sample selection should be flexible, and will need to balance the need for fully sampling the grids versus observing unique prototypes. In spectroscopic surveys, a few targets naturally can require large shares of the observing time. Therefore, it is important to ensure that the programs remain balanced in covering parameter spaces, e.g., by setting limits on the maximum time to be spent on any single target. The finalization of the target sample should take place after the Cycle 27 TAC, so that the ULLYSES program either can be coordinated with any relevant accepted programs, or adjusted to complement such programs. It may be reasonable to work with affected PIs to modify the observation setup to match the ULLYSES data standards.

Observations: The Implementation Team should verify the optimal grating setups in terms of angular resolution, spectral resolution, and spectral coverage. We also recommend carefully considering the optimum Target Acquisition (TA) strategy, particularly in the LMC and SMC where the fields are crowded. The Phase II proposals from existing programs on massive stars in the LMC/SMC and on T Tauri stars would be useful as example TA strategies. The CVZ offers opportunities for maximizing efficiency on the Magellanic Cloud targets. The T Tauri STIS observations should be obtained in TIME-TAG mode to preserve time-dependent information. The monitoring component should start in Cycle 28 to allow time for planning coordinated campaigns of supporting observations.

Parallels: The WG considered possibilities for parallel programs, but ultimately decided to leave this open to the community. A special Announcement will need to be issued as soon as possible to allow submissions in Cycle 27. There is a variety science opportunity for the Magellanic Clouds targets, in particular. On the other hand, opportunities for parallel science on the T Tauri component are extremely limited, due to the location of these objects within dark clouds. The only obvious possibility is to set up a Coordinated Parallel program on any objects that may have large enough jets to be observed with parallel imaging. However, the specifics of any opportunity will not be known until the sample selection is finalized. Since a Coordinated Parallel program would need to be planned with the Implementation Team, they may consider announcing the T Tauri targets with enough lead time so that community proposers have time to submit such parallel proposals.

Coordinated observations: The low-mass program component would be greatly enhanced with coordinated observations from other ground- and space-based facilities, due to the time variability of these targets. For observations to be obtained with *Chandra, XMM, SWIFT, Spitzer,* and/or optical/IR and mm/radio ground-based facilities, possibilities for coordinated photometric, spectroscopic, and spectropolarimetric campaigns will need to be explored in a timely manner, since a substantial time allocation for coordinated observations will require careful planning. STScI can help to facilitate the coordination of these community-driven campaigns in several ways. First, since coordinated observations will have the most impact in the monitoring program, we recommend that those observations be scheduled for Cycle 28 to allow sufficient time for the community to plan. Another issue is that the typical scheduling mechanism that provides two weeks' advance notice before visits limits coordinated programs on some observatories to ToO programs. It would be helpful to consider ways to mitigate this problem. Finally, the community will need to be notified of the dates and times that observations for the T Tauri stars will take place. One possibility is to have an email list that updates observers about visit planning that is open to any interested subscribers.

5. Data Products and STScI support

We recommend the creation of a legacy archive to serve the data from this program. Its value would be greatly enhanced and optimized by including the following elements.

Existing archive data: Access to archival COS and STIS data on similar targets (OB stars in SMC/LMC, T Tauri stars) and reduced with the same pipeline versions and reference files would generate a much larger, uniform dataset. The WG has already reviewed existing archive data in some detail (Appendix E), but a more comprehensive investigation is in order. We suggest that the Implementation Team assess the data quality and wavelength coverage of the archival data.

Metadata: We recommend that this legacy archive be searchable, with high-level metadata in VO-table format, linked off the project website. This could make use of the search tools implemented in the Hubble Spectroscopic Legacy Archive (HSLA), and would allow users to search by various parameters, including: magnitudes, color, A_V, SpT, log g, position, proper motion, parallax, etc. A link to SIMBAD would be useful for cross-IDs.

For each target, the legacy archive should contain links to:

1. Extracted COS/STIS Spectra
    a. Include co-added spectrum for given wavelength range/grating
    b. Include time-series for all time-tagged T Tauri star observations
2. Acquisition images, especially for crowded fields
3. Spectral-image data for T Tauri sources observed with the long slit on STIS.
4. Finder charts (e.g., generated in APT)
5. Ancillary and coordinated data available on external websites

We suggest using the Frontier Fields website (http://www.stsci.edu/hst/campaigns/frontier-fields/) as the model.

Tools: Quick-look tools for inspection and analysis of the data are essential, allowing users to visually assess the spectra. Several quick-look tools are already available in the HSLA and MAST, and could easily be repurposed to this program. We also recommend providing tools to facilitate time-binned data extraction (TIME-TAG mode) for STIS NUV and FUV data, and easy access to all photon arrival times with wavelength, particularly for the T Tauri star program.

6. Ancillary Data

The ULLYSES library will be most effective when coupled with ancillary data sets that are readily available by, e.g., direct links from the project website, in a format synergistic with the ULLYSES database. It will be essential to partner with the community to identify these data sets.

A comprehensive, ancillary dataset of star and disk properties is necessary for target selection of the T Tauri stars as described in Sec. 3.2.2. The targets for the monitoring component should also use information from past Zeeman Doppler Imaging campaigns. The massive stars will also benefit from associated ancillary data sets, for example, broad-band photometry, extinction, ground-based spectroscopy, proper motion, light curves, and other parameters.

As mentioned above, for some of the low-mass targets in particular, coordinating a set of ancillary observations is highly desirable, by collecting archival and/or new multi-wavelength observations. Especially for the FUV monitoring campaign, some of this ancillary dataset should be obtained contemporaneously (e.g., Zeeman Doppler Imaging) or even simultaneously (e.g., optical photometric monitoring and X-rays with *SWIFT*). Sufficient advance notice of observation scheduling would allow the community to prepare for and trigger spectroscopic observations coordinated with the FUV exposures.

7. Additional Comments

As mentioned in Sec. 2 above, the WG was impressed with the range of fundamental UV science in the local universe for which HST is needed. These include compact objects, binaries, and supernovae, which, similar to massive star atmospheres, represent the current frontier for stellar evolution, population synthesis models, LyC radiative transfer, and GRB and gravitational wave progenitors. These phenomena have synergies with LSST and multi-messenger astrophysics. Suggestions also included a range of imaging ideas, including UV galaxy surveys, atlases of star-forming galaxies, and narrow-band nebular surveys in Lyα and Mg II. The narrowband surveys are especially interesting since they leverage underutilized capabilities. Lyα is of particular interest for understanding analogs of high-redshift objects, and Mg II is a relatively unexploited probe of neutral-phase emission in local star-forming regions. Both are synergistic with JWST and ELT science. Less directly linked to star formation, there were also several submissions related to the long-standing problem of UV upturn in early-type populations and post-AGB stars.

It is apparent that most of the areas mentioned above that relate to star formation would benefit from the recommended ULLYSES program. However, we fully expect that the exercise itself of submitting ideas for this initiative will stimulate outstanding science through the GO process in an even broader range of fields.

8. Conclusion

In summary, the ULLYSES spectroscopic library of young stars would provide a lasting and unique reference data set that would enable and stimulate a wide range of astrophysical research. There are parallels between the stellar high-mass and low-mass regimes, in the critical role of UV emission to the fundamental processes, while the complexity of the radiative transfer makes empirical data essential. Directly or indirectly, stars are the source of most of the radiation we observe from the universe, and star formation is the basis for understanding cosmic origins at all scales. The formation of high-mass stars generates compact objects and heavy elements, and is a gateway to the extragalactic universe and the dawn of time; while the formation of low-mass stars holds the key to understanding stars, planets, and our own existence.

Implementing this comprehensive and complex program would require a strong implementation team with access to significant STScI resources, as well as engagement and participation from the community. The low-mass component of the program would be especially enhanced by campaigns to obtain coordinated supporting observations. The community has voiced strong support and excitement, and early engagement would be welcome to launch science efforts for the entire program. The final data set would require a user-friendly interface and tools, ideally linked to additional ancillary data obtained elsewhere. Overall, this UV spectroscopic library of young stars constitutes a fundamental data set that would appropriately serve as a lasting UV legacy for HST.

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APPENDICES

Appendix A. Charter

August, 2018

Hubble Space Telescope Ultraviolet Legacy Working Group

K. Sembach, I.N. Reid. T. Brown

Charter for the formation and objectives of an
HST Ultraviolet Legacy Science Definition Working Group

After consultation with the Space Telescope Users Committee and the science community, the Space Telescope Science Institute's Director, Kenneth Sembach, has decided to devote a substantial amount of Director's Discretionary time in observing Cycles 27-28 to a new Hubble Ultraviolet Legacy Initiative centered on star formation The primary goal of this initiative is to extend knowledge of the universe through the unique ultraviolet observing capabilities available only with HST. The overall program will serve as the foundation for a legacy dataset on which the astronomical community can build and contribute observational, theoretical, and numerical simulation data and models.

The charge to the Working Group is to identify the most effective strategy for achieving high scientific impact and return for an investment of 600-1000 orbits of ultraviolet observations related to star formation and the associated stellar physics. A program (or set of programs) on this scale presents scientific opportunities that are not ordinarily available through the normal time allocation process. An important component will be the identification of ancillary data and information that can be incorporated in a manner that provides broader access and greater depth to the scientific initiatives identified for this legacy program.

The HST Ultraviolet Legacy Working Group is hereby formed with the following primary tasks:

- Define the overarching science case and a set of science goals for a comprehensive set of ultraviolet observations related to star formation and associated stellar physics that advance scientific discovery and provide lasting archival value.

- Solicit input from the astronomical community in defining the science goals.

- Recommend representative suites of observations necessary to accomplish the science goals of this initiative. Prioritize if possible.

- Identify opportunities for coordinated observations over the full wavelength regime with other ground-based and space-based observatories.
- Produce a short (10-15 page) white paper describing the results of the above tasks by January 20, 2019.

The Working Group should take into account both the archival research value of the planned observations and the coordination of these observations with other observatories. The Working Group should also assess how the proposed science program might establish foundational science for the next generation UV/OIR Great Observatory.

The Working Group will consist of approximately 8-10 members of the astronomical community selected by STScI and the Working Group Chair, Prof. Sally Oey (University of Michigan). The Chair of the Working Group will organize the meetings of the Working Group, and STScI will provide logistical (travel, meeting, telecon, etc.) support as needed. We expect that the Working Group will have at least one face-to-face meeting, supplemented by regular telecons and email exchanges.

The Ultraviolet Legacy Initiative follows in the footsteps of the Hubble Frontier Fields Initiative, and will be modeled after the Frontier Fields program. All data obtained will be non-proprietary, as will contributed data and information, which in return will be recognized with appropriate citation and attribution. STScI will identify an in-house team to implement the program and produce high-level data products for dissemination to the community. Opportunities to supplement these core observations and perform archival research will be available through the standard HST Calls for Proposals.

The primary STScI contacts for the Working Group will be Tom Brown (STScI HST Mission Office Head) and Neill Reid (STScI Associate Director for Science). Both will be ex-officio members of the Working Group.

Members: Nate Bastian (Liverpool), Paul Crowther (Sheffield), Andrew Fox (STScI), Jay Gallagher (Wisconsin), Ana Gomez de Castro (Madrid), Claus Leitherer (STScI), Christy Tremonti (Wisconsin)

Appendix B. Survey Questionnaire

The WG received 196 responses to the survey questionnaire. The numbers of responses on specific topics were roughly as follows, with individual responses assigned to multiple categories as appropriate.

80 Massive stars
19 Low-mass star formation
25 Binaries
26 Compact objects
21 Young massive clusters
18 Star-forming regions
47 Star-forming galaxies
15 ISM and dust
39 Metallicity
23 Low-mass, evolving stars
14 Early-type galaxies

It should be noted that the survey has unknown biases. For example, it was apparent that the IAU G2 Working Group on Massive Stars urged members to submit entries to "vote". In at least one or two cases, individuals submitted more than one entry to the questionnaire.

In response to questions about strategy, themes emerged around service data sets, including time series monitoring. Some responses noted the importance of surveying a broad parameter space, while others noted that deep, detailed observations of a few, prototypical objects also has great value. A couple responses suggested that a large program dedicated to an underappreciated "niche" field could pay large dividends. Opportunities for synergy with future major facilities was mentioned, along with the importance of coordinated, multi-wavelength observations, and exploring opportunities for Parallel programs. Responses also stressed the importance of high data quality and user-friendly data access and tools.

The text of the survey questionnaire is below.

The HST Ultraviolet Legacy Initiative for Star Formation and related Stellar Astrophysics

STScI Director Kenneth Sembach has decided to devote 600-1000 orbits of Director's Discretionary time in observing Cycles 27-28 to a new Hubble Ultraviolet Legacy Initiative [link to charge] focused on **star formation and associated stellar astrophysics**. The program will produce a publicly accessible, non-proprietary, legacy dataset that follows in the footsteps of the Hubble Frontier Fields Initiative.

A working group has been formed to engage with the scientific community and make recommendations to the Director for the scientific program [link to charter]. The HSTUV WG is now seeking community input to shape the science priorities and strategy. We are particularly interested in service programs that provide reference data sets less likely to be generated through GO time. The final program may consist of both imaging and spectroscopy, and may be constructed from a variety of suggestions, based on community interest. Two example programs are given below to illustrate the scope of this initiative. Others might include a deep, UV atlas of nearby galaxies, or mapping of a prototypical Galactic star-forming region.

A. UV spectral atlas of massive stars at low metallicity [link to Example 1]
B. UV imaging survey of massive star clusters and starbursts [link to Example 2]

We would value your reaction and input by **December 7, 2018**, for developing this initiative:

1. **What are the key, “must do” UV science questions in star formation and related stellar**

2. **astrophysics that remain outstanding for HST?**

3. **What kinds of programs would not be within the scope of the standard GO program?**

4. **What factors would maximize science return? General comments on observing strategy for a UV Treasury (e.g., dedicated parallel observations, available ancillary data, etc):**

5. **Additional input and suggestions (e.g., comments on the examples above):**

6. **[Optional] Name and email address:**

In addition, you are also invited to submit 1-page suggestions to HSTUV@stsci.edu.

The HSTUV WG will review responses and meet January 17-18, 2019 to develop the recommendations. We will submit a report to the Director by the end of January. He will announce the plan for this Initiative in time for the Cycle 27 Call for Proposals.

EXAMPLE 1:

UV SPECTRAL ATLAS OF MASSIVE STARS AND CLUSTERS AT LOW METALLICITY
A Legacy Library for Stellar Physics, Star Formation, ISM and CGM

Summary: Form a FUV+NUV spectral atlas of 120 massive stars in the Magellanic Clouds and 10 super star clusters in low-metallicity environments, all at high S/N (> 20) and resolution (R > 15,000). Expected size ~900 orbits.

(1) **Overview**: Massive stars are responsible for the bulk of ionizing, mechanical and chemical feedback in galaxies. Their evolution remains unclear owing to the role of mass-loss, rotation and binarity. Massive stars are the only stellar populations directly seen in high-z galaxies, via P Cygni resonance lines from OB stars and emission lines from O supergiants and Wolf-Rayet stars in the far-UV. This Legacy dataset would provide the fundamental reference data set for UV spectroscopy at low metallicity by constructing a comprehensive UV spectral atlas of massive stars in the Magellanic Clouds (60 stars in each galaxy). The sample would span OB dwarfs, giants and supergiants plus their evolved progeny, Wolf-Rayet stars, and Luminous Blue Variables, and stars in the Magellanic Bridge. A few metal-poor, extragalactic clusters are included to supplement the parameter space. This dataset would also be used to make fundamental progress on our understanding of massive stars, binarity, star formation, the ISM, dust, and the CGM of our nearest galactic neighbors in unprecedented detail. This would double the number of existing high-quality spectra of hot, luminous stars in the Magellanic Clouds.

(2) **Key science goals:**

Spectral Templates: This library would provide OB, Wolf-Rayet and LBV spectroscopic templates for rest-frame UV studies of high-z galaxies with JWST and ELTs. The proximity and low metallicity of the LMC (0.5 solar) and SMC (0.2 solar) makes them ideal targets. This atlas would greatly extend the number of high quality UV spectroscopic templates in both galaxies, and provide more representative examples since archival datasets were largely selected on the basis of being UV-bright for ISM studies or focused on unusual systems (e.g. magnetic O stars).

Atmospheres and Evolution. The FUV provides access to P Cygni profiles from hot luminous stars from which wind properties (velocities, mass-loss rates, clumping, porosity) can be obtained, which in turn influence the evolution of massive stars, together with binarity, while photospheric lines - such as the iron forest in the FUV - provide a direct signature of the ionization conditions of iron and other elements within the stellar atmosphere.

Stellar Populations at Low Metallicity: The metal-poor clusters will clarify the IMF and ionizing SED in massive clusters that serve as analogs to higher redshift objects. Stellar abundances at low metallicity are more accurate in weak-wind populations, and can be compared to nebular diagnostics.

ISM Gas and Dust: The stellar and cluster spectra will contain many interstellar metal lines across the FUV. This will enable comprehensive studies of the interstellar medium of the Magellanic Clouds and metal-poor galaxies, including metal abundances, dust depletions, kinematics, ionization state, and spatial distribution. Furthermore, UV continuum studies will further characterize the dust extinction law in a range of metallicities and environments, since the foreground Milky Way component of the extinction is low.

The CGM: Inflows and Outflows on Galactic Scales. The stellar and cluster spectra will also reveal absorption lines from the circumgalactic medium (CGM) of the LMC, SMC, and the metal-poor galaxies.This data set can thus be leveraged to study the baryon and metal cycle of star formation, feedback, and multi-phase ISM in the Magellanic Clouds and metal-poor galaxies.

EXAMPLE 2

UV IMAGING SURVEY OF STAR FORMING REGIONS, CLUSTERS AND STARBURSTS A Legacy Library for Stellar Evolution and Star Formation

Summary: NUV imaging atlas of massive star clusters and star-forming regions, consisting of (A) wide-field mapping of 2-3 resolved star-forming regions (e.g., 30 Doradus, NGC 604); (B) resolved stellar populations in 10 young massive clusters and 10 globular clusters; and (C) 30 starbursts and unresolved stellar populations (e.g., Blue Compact Dwarfs, Virgo ellipticals). Uniform imaging in F218W, F225W and/or F275W with possible SBC and/or optical supplements. Total 600 orbits.

(1) Overview:

Star clusters contain coeval stellar populations with homogeneous initial metallicity, thus offering empirical SEDs for single stellar populations. Beyond this, the cluster environment may affect stellar evolution, e.g. through binary/multiple star interactions or formation processes. These processes are essential for understanding relationships between young “super star clusters” and globular clusters. Cluster evolution itself is one of the foundations of stellar population studies, but has outstanding questions, e.g., the phenomenon of “Multiple Populations” (i.e., abundance anomalies) as well as the origin of the UV upturn in extragalactic clusters. Therefore, a compendium of cluster UV photometric data is essential for interpreting the stellar content and evolution of galaxies. This legacy data set will provide UV imaging of resolved star clusters covering a range of ages, and nearby, UV-bright galaxies which will test cluster formation efficiency in a variety of environments. The data will yield a library of UV SEDs for young massive clusters, along with data to support quantitative structural comparisons with distant young galaxies. In combination with existing archival observations of normal galaxies, this data set will yield a comprehensive HST photometric database on the properties of UV-bright stellar populations.

(2) **Key science goals:**

Spectral Templates: Provide UV photometry for massive and intermediate mass stars at all phases of stellar evolution for comparisons of model and observed spectral energy distributions (SEDs). In addition to supporting studies of cluster evolution, SED templates of cluster stellar populations will allow direct comparison with high-redshift galaxies and proto-globular clusters.

Stellar Populations: UV imaging will allow comprehensive studies of hot stellar population and stellar evolution across clusters and star-forming regions spanning the full range of possible ages. It will also facilitate studying the origins of hot stars in ancient stellar populations, thereby extending studies of globular clusters and the problem of UV upturns in early-type galaxies.

Multiple Populations. Ancient Galactic globular clusters are known to host abundance variations, or "multiple populations", of unknown origin. The cluster data set spanning a wide range of ages and masses can be used to investigate properties of multiple populations, e.g., as defined by spreads in main sequence turnoffs, relative to properties of their host clusters.

Dust Properties. SEDs from the near-IR to FUV in galaxies can be used to derive properties of dust obscuration in a variety of settings. Understanding how dust affects the emergent radiation in locations with intense UV radiation fields is essential for interpreting properties of young galaxies.

Starburst Clusters in Context. Images of UV-bright galaxies sample regions with high intensity star formation, for exploring variations of stellar properties and UV luminosity escape across a range of metallicities and host galaxy environments. These data also will provide a catalog of host galaxy morphologies in the rest frame UV. The maps can be used to determine properties of starburst clumps, star cluster luminosity functions and frequencies, and spatial correlation functions among young stellar components.

Appendix C. White Papers

The WG received 34 white papers. There were 27 and 11 papers suggesting spectroscopic and imaging programs, respectively, with a few including both. Four suggested time-sequence monitoring programs. The distribution of topics is roughly as follows, with individual responses again assigned to multiple categories as appropriate.

10 Massive stars
5 Young, low-mass stars
4 Binaries
6 Compact objects
2 Young massive clusters
3 Star-forming regions
5 Star-forming galaxies
6 ISM and dust
5 Low-mass stars and old populations

The white papers and their lead authors are listed below. A few titles are working titles given by the WG for papers that did not provide a title.

UV observations of protostellar jets	Christian Schneider
UV spectral survey of accretion in star-forming regions	Christopher Johns-Krull
Survey of UV spectra of young stars with protoplanetary disks	Nuria Calvet
AWD UV spectroscopic monitoring of accreting stars	Hans Guenther
HAeBes: The stellar accretion paradigm	Ignacio Mendigutía
Complete grid of FUV spectra spanning age and mass	Evgenya Shkolnik
UV spectroscopy of massive stars in the Magellanic Clouds	Danny Lennon
UV spectroscopic survey of Galactic neutron star progenitors	Raman Prinja
A 360deg view of Milky Way massive stars: IACOB-UV	Miriam García
Massive stars at low metallicity	Jorick Vink, for IAU G2
SMC massive stars	Norbert Langer
UV spec survey of massive binaries hosting subdwarf companions	Luqian Wang
OB star HST legacy for LyC	Michael Shull
Detailed spectral atlas of gas and dust towards bright massive stars	Jan Cami
The UV-optical-IR extinction law	Jesus Maíz-Apellaníz

CANDELS UV imaging for $z\sim1$	Nimish Hathi
UV imaging survey of local, SN-hosting, star-forming galaxies	Ning-Chen Sun
Lyα imaging at low redshift	Matthew Hayes
UV survey of nearby SF regions: Feedback, self-regulation, IMF	John Bally
Mg II narrowband imaging of SF regions and protostellar flows	Jon Morse
UV spectroscopy of the Orion Bar	Els Peeters
UV spec survey of massive star clusters in nearby galaxies	Kate Rubin
UV imaging and spec survey of SF regs in merging starbursts	Sean Linden
NUV-FUV survey of non-accreting neutron stars	Yuri Shibanov
White dwarf abundances I	Jay Holberg
White dwarf abundances II	Martin Barstow
UV census of the end products of binary evolution	Nathalie Degenaar
A Legacy FUV spectroscopic survey of compact binaries	Boris Gaensicke
Uncovering the evolution of the UV upturn	Roberto de Propris
UV slit-scan mapping survey of Galactic planetary nebulae	Toshiya Ueta
Physics of the ISM using high resolution observations of white dwarfs	Simon Preval
A UV spectral atlas of stars hosting exoplanets	Simon Joyce
Post-AGB stars and planetary nebulae	Albert Zijlstra, for IAU H3
Unveiling chromospheric and wind properties of AGB stars	Rodolfo Montez

Appendix D. Preliminary Candidate Target Lists

Table D1. SMC O stars: All targets to be observed with COS/G130M+G160M or STIS/E140M. Late O supergiants to add STIS/E230M, as noted with * while bright O stars to add G130M/1096, as noted with #. Archival targets with COS/STIS spectroscopy but lacking *FUSE* spectroscopy to be observed with G130M/1096 setup (shown in parentheses).

SpT/Lum Cl	?	IV-V	II-III	Iab
O2-2.5		AzV476#		
O3-3.5	AzV493# [M2002] 3173#	Sk183# (Lin 178#)		
O4	[M2002] 59319# (AzV80#)	AzV435# (AzV388#) (NGC346 MPG368#)		
O5-5.5		AzV14=Sk9# AzV377# NGC346 MPG342 [M2002] 25912#	(AzV296#)	
O6-6.5		[M2002] 14324# AzV133# [M2002]77368# [M2002] 51500#	[M2002] 69460 [M2002] 15271#	(AzV26=Sk18#)
O7-7.5	(Sk190#)	AzV114 [M2002] 9732 [M2002] 17240 [M2002] 67269 [M2002] 40380	AzV226# AzV15=Sk10# AzV491 (AzV77#) (AzV207#)	AzV26=Sk18# AzV232=Sk80
O8-8.5		NGC330 ELS 52 [M2002] 7782 [M2002] 5313 [M2002] 11045 [M2002] 35491	Az135# AzV186 AzV469=Sk148 AzV454=Sk142# SMC 2dF 1618	(AzV261#)
O9-9.7		SMC 2dF 2815 SMC 2dF 5040 NGC346 MPG213 (AzV326#)	NGC346 MPG217 (AzV307#) (AzV43#) (AzV454=Sk142#)	AzV372=Sk116* AzV70=Sk35* Sk101#* AzV490=Sk160#* Dachs SMC 1-14#*

Table D2. SMC B-type and WR stars: All targets to be observed with COS/G130M+G160M or STIS/E140M. B supergiants to add STIS/E230M, as noted with * while bright WR stars to add G130M/1096, as noted with #.

SpT/Lum Cl	?	IV-V	II-III	Iab
B0-0.7		NGC346 MPG310 NGC346 MPG304 NGC346 MPG64 NGC346 ELS27 NGC346 ELS39 AzV259	AzV349 AzV403 AzV192 [M2002] 30018 [M2002] 80412 = Sk167=AzV505 [M2002] 24213 = AzV 130	AzV235=Sk82* AzV356* AzV488* AzV420=Sk131* [M2002] 77609* = Sk161 = AzV492
B1-1.5		NGC330 ELS27 NGC346 ELS38 [M2002] 82711 [M2002] 80573 [M2002] 69769	NGC346 ELS21 [M2002] 28841 [M2002] 34315 = AzV 169 [M2002] 35474 [M2002] 83232	AzV86=Sk42* AzV264=Sk94* AzV242=Sk85* [M2002] 19728* = Sk46 = AzV96 [M2002] 50609* = Sk95 = AzV266
B2-2.5			AzV178	AzV472=Sk150* AzV56=Sk31* AzV443=Sk137*
B3-4			NGC330 ELS 18	AzV23=Sk17*
B5-6				
B7-8				AzV200=Sk69* AzV2=Sk3*
B9				AzV76=Sk39* AzV101=Sk47*
WR	AzV2a# (WN3ha)			

Table D3. LMC O stars: All targets to be observed with COS/G130M+G160M or STIS/E140M. Late O supergiants to add STIS/E230M, as noted with * while bright O stars to add G130M/1096, as noted with #. Archival targets with COS/STIS spectroscopy but lacking FUSE spectroscopy to be observed with G130M/1096 setup (shown in parentheses).

SpT/Lum Cl	?	IV-V	II-III	Iab
O2-2.5	(CPD=69 471#)	VFTS506# VFTS169 (BI237#) (BI253#)	Sk-70 91 (Sk-67 211#) (VFTS16#)	Mk42 (O2If) Mk39# (O2.5If/WN6) (Mk35# O2If/WN5) (Mk30# O2If/WN5)
O3-3.5		VFTS755 VFTS404# PGWM 3058#	(W61 7-7#)	TSWR3# (O3If) Mk51# (O3.5If/WN7)
O4	(Sk-67 105#)	VFTS586	Sk-67 69 (VFTS 603#)	Sk-67 167 (O4If) Sk-67 166 (O4If) R136b (O4If/WN8) (Sk-65 47#)
O5-5.5	(FWM 82#) (ST92 2-53#)	Sk-70 69 (Sk-70 79#) (PGWM 3120#)	PGWM 3100#	(N11-020#)
O6-6.5	(UCAC3 42-3081#) (BI214#)	Sk-66 18# PGWM 3204# (VFTS 96#)	N11-018# Sk-66 100 Sk-66 20# (VFTS 440#) (Sk-71 50#)	(Sk-70 115#)
O7-7.5	(Sk-69 50#) (Sk-68 112#)	Sk-67 118#	Sk-68 18# PGWM 3168# Sk-70 57#	W61 7-19#
O8-8.5		VFTS 168 (BI42#) (Sk-67 191#)		Sk-66 25# (Sk-67 168#) (Sk-68 155#) (Sk-71 41#)
O9-9.7		N11-061 VFTS 250 VFTS 223	N11-045#	Sk-69 124* BI170* Sk-66 16#* Sk-65 21* Sk-66 169* (Sk-69 279#)

Table D4. LMC B-type and WR stars: All targets to be observed with COS/G130M+G160M or STIS/E140M. B supergiants to add STIS/E230M, as noted with * while bright WR stars to add G130M/1096, as noted with #.

SpT/Lum Cl	?	IV-V	II-III	Iab
B0-0.7		PGWM 3128 VFTS 469 VFTS 707	PGWM 1005 PGWM 1332	Sk-68 41* Sk-68 59*
B1-1.5		N11-086 N11-105	N11-110 N11-088	Sk-68 111* Sk-67 169* Sk-69 228*
B2-2.5				Sk-69 221* Sk-70 116* Sk-69 89* Sk-69 274*
B3-4				Sk-69 244* Sk-70 50*
B5-6				Sk-67 58* Sk-68 8*
B7-8				Sk-67 122* Sk-67 143* Sk-67 145* Sk-66 50*
B9				Sk-69 82* Sk-67 204*
WR	Sk-70 64 (WN3h#), HDE269015 (WN4o#), HD38344 (WN5h#), BE381 (WN9#*), HDE269582 (WN10#*)			

Table D5. Sub-SMC metallicity: Candidate sources to be observed with COS G140L/800.

Galaxy	Star	SpT/Lum Class
SexA	s2	O3-5Vz
SexA	s4	O6Vz
SexA	s3	O9V
SexA	s1	O9.5I
Sag DIR	SD1	Late OI
Sag DIR	SD3	OBV

Candidate targets in the Magellanic Clouds are compiled from the catalogs of Crowther & Walborn (2011), Lamb et al. (2016), Evans et al. (2004b, 2006, 2011), Fitzpatrick (1991), Lennon (1997), Massey et al. (1989), Massey (2002). Metal-poor targets are from Garcia (2018) and Garcia et al. (2019). Target selection is not exhaustive, and careful review of these sources and other lists is needed to optimize the sample.

Table D6. Possible numbers of targets for ULLYSES young, low mass stars. Possible additional parameters to consider are: light curve, parallax, extinction, luminosity, jet presence, outflow rate, dust and gas information, disk size, disk inclination, and multiplicity. The accretion luminosity and extinction are essential parameters to ensure the feasibility of the selected targets.

Age (Myr)	Region	Spectral types	Mass Accretion Rates (log M_{SUN}/yr)	Possible # of targets
1-2	Chamaeleon I	K2-M5.5	-10 to -7.5	18
1-2	Lupus	K2-M4	-10 to -7.5	17
5 and 10	Ori OB1a,b	K5-M4	-10 to -8.5	14
7	Upper Sco	K4, M4	-10 to -9.5	2

Most targets in previous studies of UV emission from low-mass, young stars have been culled from the Taurus star-forming region. The new targets for the spectral library should be taken mostly from star-forming regions in the southern sky that are being targeted by ALMA, and by near- and mid-IR instruments at ESO and CTIO. A few targets will be time-monitored to look for changes in accretion rates, inner disk content, and accretion flow morphology. Those targets should be selected among those stars that are bright enough to get high S/N, and for which detailed studies of magnetic field structure and accretion flow morphology have been carried out.

We made a selection of preliminary candidate targets for the UV spectral library from Chamaeleon I, Lupus, Upper Sco, and the Ori OB1a and 1b sub-associations, which cover the relevant ranges of mass accretion rates, stellar mass and age (Table D6, where spectral type is used as a proxy for stellar mass). We used values for accretion luminosity from Manara et al. (2016, 2017) for Chamaeleon I, and Alcala et al. (2017) for Lupus. For the other regions, we estimated accretion luminosities from Hα using the Ingleby et al. (2013) calibration, using line luminosities based on Hα equivalent widths and photometry from Luhman & Mamajek (2012) for Upper Sco, and from Briceno et al. (2019) for Ori OB1a and 1b. Table D6 lists the number of possible targets for each region; this number is estimated by using the exposure time calculator to identify targets that can be observed in 10 orbits or less at 1500 A with COS/G160M and S/N=3 in the continuum. Fluxes at 1500A are estimated from the spectrum of TW Hya scaled to the accretion luminosity of each object and extincted by the known $E(B\text{-}V)$. The final target list should be compiled with a more comprehensive consideration of the parameter space.

Appendix E. Existing Archive Data

Table E1. SMC O stars: Archival COS/G130M+G160M or STIS/E140M spectroscopy. Sources additionally observed with STIS/E230M are indicated with *. Stars for which *FUSE* spectroscopy exists are indicated with #. If solely STIS/E230M spectroscopy is available this is indicated with (*), while if solely *FUSE#* spectroscopy is available this is indicated with (#). From GO 7437, 9116, 11625, 12978, 13778, 14081, 15629.

SpT/Lum Cl	?	IV-V	II-III	Iab
O2-2.5		(AzV476*)	NGC346 MPG355#	
O3-3.5		NGC346 MPG324# LIN 178		
O4		AzV177 AzV388* NGC346 MPG368	NGC346 MPG435#	
O5-5.5	AzV80*	Sk38=AzV75 AzV296 (NGC346 MPG324*)		
O6-6.5	AzV220#	NGC346 MPG113 Sk84=AzV243 AzV446	Sk10=AzV15#	Sk18=AzV26*
O7-7.5	Sk190*	AzV429 NGC346 ELS46 NGC346 MPG523	AzV95*# AzV77 (AzV207*) Sk34=AzV69**	AzV83# (Sk80=AzV232#)
O8-8.5		AzV148 AzV267 AzV461 AzV468 NGC346 MPG487 NGC346 MPG299 NGC346 ELS31	AzV47*# (Sk148=AzV469#)	AzV261
O9-9.7		AzV189 AzV326 NGC346 MPG682	AzV43 AzV170 AzV258 AzV307 R28=AzV327# Sk132=AzV423# Sk142=AzV454	(AzV70=Sk35#) AzV321* (AzV456=Sk143*)

Table E2. SMC B-type and WR stars: Archival COS/G130M+G160M or STIS/E140M spectroscopy. Sources additionally observed with STIS/E230M are indicated with *. Stars for which *FUSE* spectroscopy exists are indicated with #. If solely STIS/E230M spectroscopy is available this is indicated with (*), while if solely *FUSE#* spectroscopy is available this is indicated with (#). From GO 7480, 9116, 13778, 14081, 15629.

SpT/Lum Cl	?	IV-V	II-III	Iab
B0-0.7		AzV304 NGC346 MPG11 NGC346 MPG12	NGC330 ROB A1*	AzV104* Sk76=AzV215* (Sk82=AzV232#) R18=AzV242*# (AzV488#)
B1-1.5			AzV216*	Sk40=AzV78* Sk73=AzV210* (Sk94=AzV264#) Sk191*
B2-2.5			NGC330 B22*	Sk13=AzV18*
B3-4				Sk114=AzV362* NGC330 A2* NGC330 B37*
B5-6				Sk15=AzV22*
B7-8				
B9				
WR	HD5980*, SMC AB2=Sk39a, SMC AB4=Sk41#, SMC AB8=Sk188			

Table E3. LMC O stars: Archival COS/G130M+G160M or STIS/E140M spectroscopy. Sources additionally observed with STIS/E230M are indicated with *. Stars for which *FUSE* spectroscopy exists are indicated with #. If solely STIS/E230M spectroscopy is available this is indicated with (*), while if solely *FUSE*# spectroscopy is available this is indicated with (#). From GO 7299, 8662, 9434, 11484, 12218, 12581, 13806, 14675, 14683, 15629.

SpT/Lum Cl	?	IV-V	II-III	Iab
O2-2.5	CPD-69 471	BI237* BI253* M2002 LMC169366	Sk-66 172*# Sk-67 211*# (Sk-70 91#) VFTS16	Mk35 (O2If/WN5) Mk30 (O2If/WN5)
O3-3.5			W61-7-7	
O4	Sk-67 105*	VFTS 586 VFTS 352	Mk10=VFTS603 Sk-71 45*# (Sk-67 69#)	Sk-65 47 (Sk-67 167#) (Sk-67 166#)
O5-5.5	FBM09 82 Sk-69 212	VFTS385 Sk-70 79* PGWM 3120 (Sk-70 69#)		N11 ELS 020
O6-6.5	UCAC3 42-3081 BI214	VFTS 96	VFTS 440 Sk-71 50* (Sk-66 100#)	Sk-69 104*# Sk-65 22# Sk-67 111# Sk-70 115*
O7-7.5	Sk-69 50 Sk-68 112 UCSC3 42-3301	Sk-66 19 VFTS 285		
O8-8.5		BI42* Sk-67 191*	BI173*# Sk-67 101*#	Sk-67 168 Sk-71 41 (Sk-68 155*)
O9-9.7		VFTS 102 VFTS 627	VFTS 517	(Sk-69 124#) Sk-69 279* (BI170#) (Sk-65 21#) (Sk-67 05*#) (Sk-66 169#) Sk-68 135*#

Table E4. LMC B-type and WR stars: Archival COS/G130M+G160M or STIS/E140M spectroscopy. Sources additionally observed with STIS/E230M are indicated with *. Stars for which *FUSE* spectroscopy exists are indicated with #. If solely STIS/E230M spectroscopy is available, this is indicated with (*), while if solely *FUSE#* spectroscopy is available this is indicated with (#).
From GO 7299, 9434, 11692, 12581, 12978, 13781, 14081, 14675, 15629.

SpT/Lum Cl	?	IV-V	II-III	Iab
B0-0.7		BI184*		Sk-68 52*# Sk-67 106 Sk-67 107 Sk-68 140* (Sk-68 41#)
B1-1.5				Sk-66 35* Sk-68 129* Sk-67 2 Sk-67 14* Sk-67 5 (Sk-67 169#)
B2-2.5			W61 18-3	Sk-68 26*
B3-4				Sk114=AzV362* NGC330 A2* NGC330 B37*
B5-6				Sk15=AzV22*
B7-8				
B9				
WR	Sk-67 104 (WC4+O), Sand 2 (WO), LH41-1042 (WO), LH195-1 (WO), HD 38029 (WN+), Sk-69 246* (WN+WN), HDE 269883 (WN7), HD 33133 (WN8), HDE 269445 (WN9pec), R127 (Of/WN), Sk-69 175* (WN11)			

Table E5. Sub-SMC metallicity: COS/G140L. From GO 12587, 14245.

Galaxy	Star	SpT/Lum Class
IC1613	69217	O3-4V
IC1613	65426	O5-6V
IC1613	62024	O5If
IC1613	67559	O7If
SexA	OB326	O7.5III
IC1613	63932	O9I
SexA	OB521	O9.5III
SexA	OB523	O9.5I
IC1613	62390	O9.5I
SexA	OB321	O9.7I
SexA	OB622	B0I
IC1613	69336	B0Ia
IC1613	60449	B1.5Ia

Table E6. Summary of existing archive data for T Tauri stars, from Yang et al. (2012) for most pre-COS spectra, and France et al. (2012) for initial COS spectra from the Large Program GO 11616. The GO programs for FUV spectra of young stars and jets in the MAST archive include: 7718, 8041, 8157, 8205, 8206, 8317, 8627, 9093, 9785, 9790, 9841, 10840, 10864, 11145, 11151, 11531, 11533, 11608, 11199, 12036, 12161, 12186, 12199, 12211, 12315, 12876, 12907, 12996, 13032, 13363, 13372, 13714, 13775, 14048, 14190, 14193, 14690, 15070, 15165, and 15310. These programs include a few targets with observations repeated in the same setting and many targets observed repeatedly with different setups and goals.

Region	**STIS+COS**	**COS**	**STIS**	**ACS**
Taurus	20			17
Lupus	2	2		
Chamaeleon I		3		5
Eta Cha+Eps Cha Associations		3		
TW Hya Association	1			10
Ori OB1		7	4	11
‘WTTS’		2		10
Other	2			
Total	**25**	**17**	**4**	**53**