Report of the Hubble Space Telescope Exoplanet Committee

May, 2016

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1.0 Introduction

Exoplanet observations have played a major role in HST's science program over the last decade. Over the years, the proposal pressure for exoplanet observations has increased significantly in proportion to pressure from other disciplines. After consultation with the Space Telescope Users Committee, the Director of the Space Telescope Science Institute convened a Committee to explore the scientific priorities in exoplanetary research and to provide advice on future strategies for implementing exoplanetary science programs with HST.

This report presents the findings of the Committee. The membership of the Committee is given in Table 1, and the specific tasks charged to the Committee are listed in Table 2. The Committee deliberated in the period October 2015 - March 2016. A summary of exoplanetary-related science areas addressed by HST observations follows in Sec. 2, and the findings of the Committee in response to the specific tasks are given in Secs. 3 through 6.

Table 1. Membership of the Committee.

Committee member	***Institution***
L. Drake Deming (Chair)	University of Maryland, College Park
Zachory Berta-Thompson	Massachusetts Institute of Technology
Nicolas Cowan	McGill University, Canada
Jonathan J. Fortney	University of California at Santa Cruz
Eliza Kempton	Grinnell College
Heather Knutson	California Institute of Technology
Leslie Rogers	University of Chicago
David Sing	Exeter University, United Kingdom

Table 2. Tasks of the Exoplanet Committee.

1. Review the evolution of HST usage by the exoplanetary community and match against factors such as changes in the time allocation process and in instrument capabilities. **See Section 3 of this report.**
2. Solicit input from the community on the role that HST can play in exoplanetary science and on methods for allocating observing programs. **See Section 4 of this Report.**
3. Identify key exoplanet observations that should be obtained by HST for legacy science and/or in preparation for JWST. **See Section 5 of this report.**
4. Investigate potential mechanisms to coordinate HST observational programs with priorities among the exoplanet science community. **See Section 6 of this Report.**

2.0 Exoplanetary science from Hubble

The Hubble Space Telescope is currently the preeminent facility for the characterization of extrasolar planets. HST studies exoplanets across numerous scientific themes, using multiple observational techniques and instruments. The most commonly used observational modes are summarized in Table 3. We here specifically discuss two of the most prominent science themes: atmospheres of transiting exoplanets, and imaging of low surface brightness debris disks. A more comprehensive categorization of exoplanet investigations is given in Sec. 3 of this report. Closely related to exoplanetary science, HST has made significant advances in the science of brown dwarfs (e.g., Yang et al. 2015), but brown dwarfs *per se* are not in the scope of this report.

Table 3. Exoplanetary science themes most commonly investigated using HST.

Science Theme	*Observational Techniques & Instruments*
Atmospheres of transiting exoplanets	Near-IR transit and secondary eclipse spectroscopy using WFC3 grisms
	Near-IR phase curves using WFC3 grisms
	Optical & UV transit photometry/spectroscopy using ACS, STIS and COS
Investigations of protoplanetary and debris disks	Imaging using STIS, ACS
	Spectroscopy using STIS
Direct imaging of exoplanets at large orbital distances	Spectrophotometry with ACS and STIS
Stellar astrophysics related to exoplanets	UV spectroscopy using STIS and COS

2.1 Atmospheres of transiting exoplanets

The temporal stability of HST permits characterization of the atmospheres of transiting exoplanets. These observations target subtle variations in the integrated light (star + planet) of the exoplanetary system that varies synchronously with the known orbit of the planet. HST observations of the first transiting exoplanet (HD209458b) resulted in the first detection of an exoplanet's atmosphere (Charbonneau et al. 2002). Those observations revealed atomic sodium absorption at 590 nm, using STIS during transit. Atomic sodium was predicted to be prominent in the spectra of hot Jupiter atmospheres (Seager and Sasselov 2000), and the HST investigation demonstrated that the models were at least approximately correct. The HST sodium observation also suggested that clouds were an important factor affecting transmission spectra of hot Jupiters, and indeed the role of clouds has been an important theme in subsequent work (see below). Moreover, HST observations in the UV demonstrated that hot exoplanetary atmospheres undergo strong mass loss (Vidal-Madjar et al. 2003, see Sec. 5.1.1).

The first molecular spectroscopy of an exoplanet atmosphere was reported for the hot Jupiter HD189733b by Swain et al. (2008), using the NICMOS instrument. That investigation claimed to detect both methane and water vapor, but subsequent re-analysis of the data by other groups (Gibson et al. 2011) has called the NICMOS detections into question (but, also see Crouzet et al. 2012, and Waldmann et al. 2013). Nevertheless, water vapor has been robustly detected in the atmospheres of hot Jupiters using WFC3 in transit (e.g., Deming et al. 2013, Mandell et al. 2013, Wakeford et al. 2013, Kreidberg et al. 2015), as well as eclipse (Kreidberg et al. 2014a) and other orbital phases (Stevenson et al. 2014). Phase curve observations of hot Jupiters allow probing their atmospheres at both transit and secondary eclipse (Figure 1.) The very different observing geometries and radiative transfer situations at transit versus eclipse help to resolve degeneracies in temperature, composition, and cloud properties.

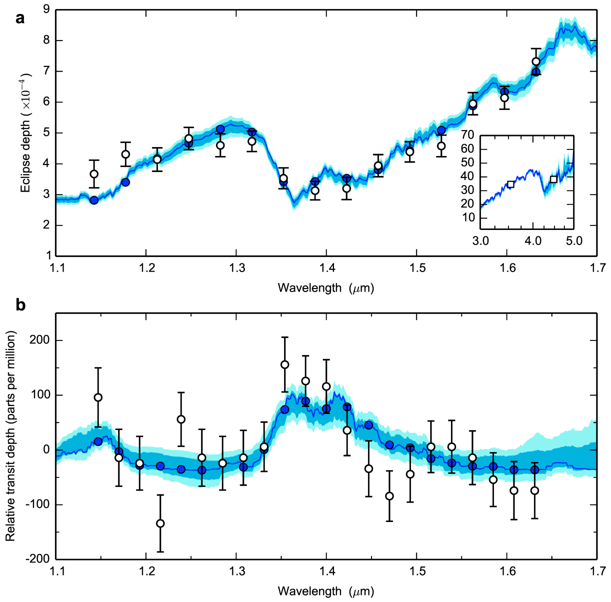

Figure 1. Example of secondary eclipse (top panel) and transit (bottom) spectroscopy of water vapor at 1.4 microns in the hot Jupiter WASP-43b, from Kreidberg et al. (2014a). (The inset at top shows Spitzer secondary eclipse photometry at longer wavelengths.)

HST observations reveal water vapor absorption in planets as small as Neptune (Fraine et al. 2014), but attempts to measure water vapor in super-Earths have not yet been successful (Kreidberg et al. 2014b, Knutson et al. 2014). Ongoing programs will extend the water absorption measurements to smaller planets, and will map the occurrence of clouds as a function of temperature and surface gravity.

Following the first detection of atomic sodium (Charbonneau et al. 2002), subsequent HST observations have shown strong sodium and potassium absorption in hot Jupiters (e.g., Huitson et al. 2012). Although the cores of these strong alkali lines can be observed using ground-based telescopes (e.g., Snellen et al. 2008), the crucially important wings of the lines are very difficult to measure accurately from the ground. Also, these lines are part of a bigger picture of atmospheric characterization that requires HST observations. The alkali atomic lines are intrinsically strong, and probe regions above the clouds where water vapor absorption is weakened by the lower column densities and by the presence of haze. HST observations in the near-UV and blue optical detect scattering by aerosol or dust haze (e.g., Pont et al. 2013), possibly due to photochemistry at high altitudes. Sing et al. (2016) found that the inferred scattering and cloud properties of hot Jupiter atmospheres affect the strength of water vapor absorption, and indicate a continuum of atmospheric properties from clear to cloudy (see Figure 2). HST observations have significant implications for JWST, because we want to understand the nature and occurrence of clouds, and also learn how to find the clearest atmospheres that are most amenable to molecular spectroscopy using JWST.

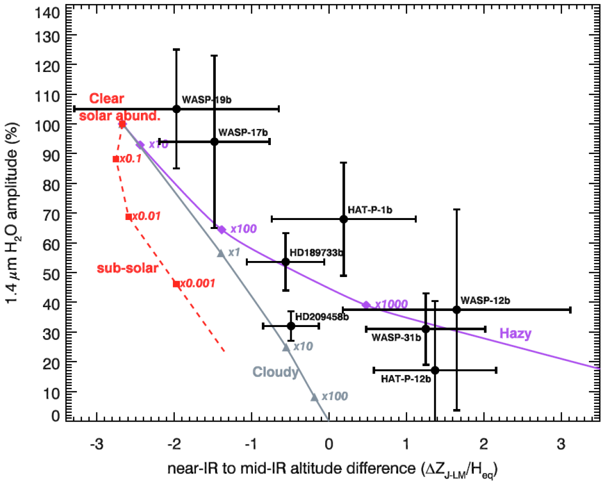

Figure 2. Strength of water vapor absorption during transit (on Y-axis) versus the altitude difference (X-axis) between slant paths where the atmosphere becomes optically thick in the near-IR (HST) versus thermal IR (Spitzer). The latter measures the strength of continuous opacity due to clouds and hazes. The lines show the loci of clear (red), cloudy (gray) and hazy (violet) atmospheres. This work by Sing et al. (2016) shows the potential for HST's determination of water abundance by accounting for cloud and haze opacity.

2.2 Protoplanetary and debris disks

The excellent point spread function (PSF) obtained by HST allows the imaging of faint structures such as protoplanetary and debris disks close to bright stars. Disk studies using HST have a long and successful history (e.g., Heap et al. 2000, Grady et al. 2003, Ardila et al. 2004, Roberge et al. 2005, Kalas et al 2008, Debes et al. 2013, Konishi et al. 2016). HST is capable of imaging structures in debris disks that inform us concerning the dynamical history of the disks, and the nature of planet formation and migration (e.g., Golimowski et al. 2011). In favorable cases, HST is also capable of imaging the planets that occur within the disks (Kalas et al. 2008), and HST observations of exoplanets can be enhanced using multiple roll positions of the telescope to distinguish between planets and structures in the PSF (Rajan et al. 2015). Exemplary debris disk coronagraphic imaging from HST/STIS is shown in Figure 3.

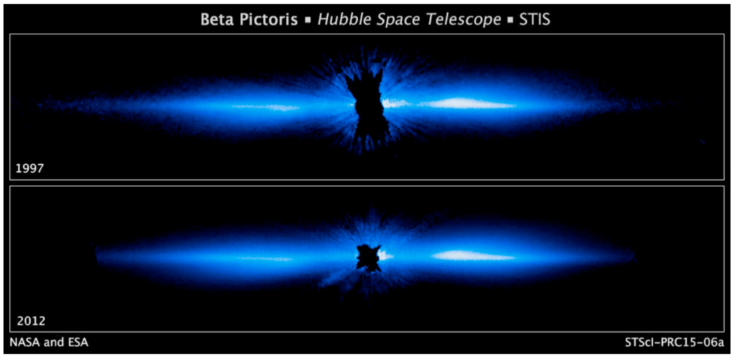

Figure 3. HST/STIS images of the debris disk surrounding beta Pictoris, from Apai et al. (2015). The images cover a time baseline of 15 years from 1997 (top) to 2012 (bottom). The temporal comparison constrains the surface brightness evolution on orbital and radiation blow-out time scales.

Ground based facilities such as the Gemini Planet Imager are advancing rapidly in capability (e.g., Biller et al. 2015), but high contrast imaging from the ground does not eliminate the need for HST coronagraphic imaging. Rather, HST and ground-based observations are complementary (e.g., Kalas et al. 2015, Mazoyer et al. 2016). Ground-based adaptive optics systems are capable of closer inner working angles than HST, whereas HST is more sensitive to faint disk structures over relatively larger fields of view. Moreover, HST is capable of high contrast imaging at blue wavelengths where disk structures can be prominent, but ground-based AO systems have yet to achieve optimum performance.

Comparing HST's disk imaging capability to the likely performance of JWST is also informative. JWST's ability to roll only +/- 5 degrees will be very limiting for angular differential imaging, whereas HST can roll +/- 30 degrees. Also, JWST's wavefront quality may be limited by segment mis-alignments (150 nm RMS error), so we anticipate that HST will remain the premier facility for the imaging of disks having low surface brightness.

3.0 Evolution of exoplanet proposals and the time allocation process

Exoplanetary science has been an important and growing focus of HST for over a decade. Since Cycle-18, over 400 exoplanetary observational programs have been proposed, of which 92 were approved - an average success rate of 23%, very close to the success rate for all fields. The success rate of exoplanetary observations versus Cycle number, and gender of the P.I., is broken down in Table 5. Table 6 groups the 92 approved programs by scientific sub-category. The most popular categories have been atmospheres of transiting exoplanets and direct imaging of disks and exoplanets (e.g., see Sec. 2).

Table 4. Statistics for the number of exoplanet proposals and success rates, since Cycle-18.

Cycle	*Total exoplanet proposals*	*Male P.I. success rate*	*Female P.I. success rate*	*Exoplanet success rate*	*Average success rate*
18	66	16.0%	0.0%	12.1%	18.7%
19	66	22.6%	15.4%	21.2%	19.6%
20	60	23.5%	22.2%	23.2%	21.3%
21	63	15.7%	8.3%	14.3%	23.1%
22	69	17.5%	8.3%	15.9%	23.2%
23	91	23.9%	30.0%	25.3%	23.4%

Table 5. Categories of successful exoplanet proposals, since Cycle-18

Topical Category	*Number*
Astrometry	2
Confirmation	3
Direct imaging (disks & planets)	13
Disk composition	1
Microlensing	1
Stellar and host environment	6
Theory	3
Transiting planets - atmospheres	46
Transiting planets - magnetospheres	1
Variability	3
White dwarf spectra	13

Figure 4 shows the success rate of exoplanetary proposals versus all proposals since Cycle-19, broken down by program size. This comparison suggests a possible recent deficiency for exoplanet programs of medium size (41 to 75 orbits), but no other obvious trends. We address the issue of medium size proposals in recommendation 6.4.

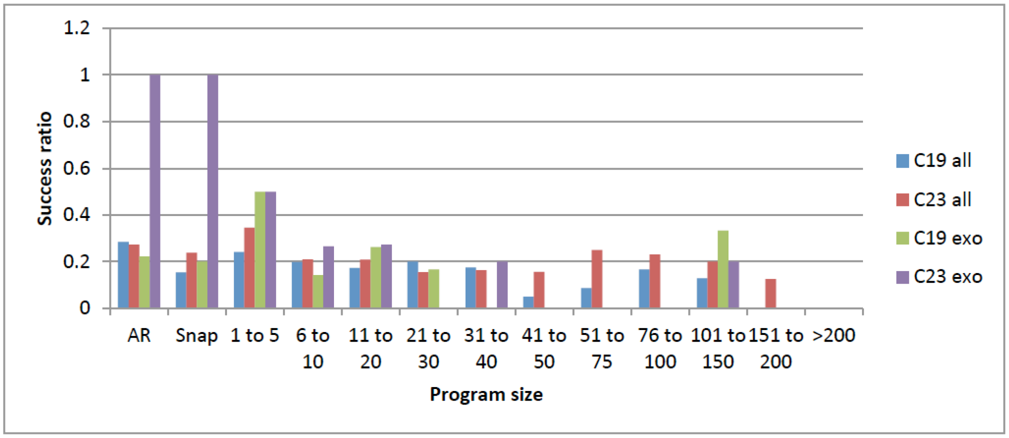

Figure 4. Success rate of exoplanet proposals compared to all proposals, since Cycle-19.

We investigated whether exoplanet scientific teams were more collaborative than average, i.e. whether exoplanet proposals have more Co-Investigators relative to other fields. Statistics on the distribution of investigators versus type of program (exoplanets versus all programs) show that there is no evidence that exoplanet teams are more or less collaborative than are teams in other fields.

Changes in the review process include the consolidation of exoplanets, disks and solar system science into two mirror panels starting in Cycle-17, and continuing through Cycle-23. Given that the success rate of exoplanet proposals (Table 4) has gradually increased through this period, the Committee concurs that the review process has been appropriately designed, and the Community Survey (Sec. 4.3) reinforces that conclusion. In Cycle-24, solar system science will be reviewed by a single panel, whereas disk and exoplanet science remain mixed in two mirror panel. Both our Community Survey (Sec. 4.3) and the Committee concur with that change.

4.0 Results of a community survey

We surveyed the community to obtain perceptions on the current state of HST exoplanetary science. We deployed the HST Exoplanet Users Survey online to a set of approximately 700 astronomers with past history of applying for HST exoplanet time. Additionally, we advertised the survey via social media, through the ExoPAG, at the winter AAS meeting and at other exoplanet-related meetings in the late fall of 2015 and early winter of 2016. The survey inquired first about career stage, location, and past and future (perceived) HST usage before asking more detailed questions on the following topics: the current and future role of HST in exoplanet science, the proposal review process, scientific priorities amongst the exoplanet community, and proposal strategies. The breakdown of the survey respondents by professional status is given in Table 6.

Table 6. Breakdown of survey respondents by professional status.

Professional status	*Number of respondents and percentage*
Faculty	24 (35%)
Research scientists	21 (30%)
Postdocs	15 (22%)
Graduate students	7 (10%)
Other	2 (3%)

4.1 Current role that HST is playing in exoplanetary science

The majority of survey respondents agreed that HST is currently playing an important role in exoplanet science. Forty-five percent of respondents highlighted HST's role as the best current tool for spectral characterization of transiting exoplanet atmospheres. Respondents pointed out that:

- HST is the only telescope with broad wavelength coverage from UV to IR
- Space-based observations are necessary to avoid telluric contamination in the near-IR and to ensure that time critical phenomena (e.g., transits) are not missed
- HST/WFC3 is the only instrument able to achieve the sensitivity required to observe spectra of exoplanetary atmospheres after the demise of cold Spitzer

HST has been the key facility responsible for many of the highest impact results in exoplanetary atmospheric characterization in the last five years, including evidence for clouds in the atmospheres of small planets (Kreidberg et al. 2014b, Knutson et al. 2014), the first spectroscopic constraints on hot Jupiter climate (Stevenson et al. 2014), and the discovery of a cloud of hydrogen escaping GJ 436b (Ehrenreich et al. 2015). A minority (15%) of respondents, however, expressed a more negative view of the current use of HST in exoplanet atmospheric characterization. Criticisms include the ambiguous/inconclusive interpretation of marginal detections/non-detections of atmospheric spectral features, the large opportunity cost to perform these observations, an assessment that the science output per hour of observation is too low compared to other studies for which HST is better suited, and the sentiment that current HST exoplanetary spectroscopy programs will be superseded by (and should wait for) JWST.

Thirty-five percent of respondents highlighted the unique capabilities of HST for observations at UV wavelengths (which are crucial for studies of polluted white dwarfs, characterization of planet host stars, and observations of mass loss from evaporating planets). Nine respondents highlighted the key role that HST is playing in providing disk imagery at distances from the host stars that are inaccessible to ground-based high-contrast imaging. Other HST exoplanet accomplishments highlighted by smaller subsets of survey respondents include high contrast imaging of planets in the optical, studies of free-floating planets, transit surveys in star clusters, precise radius measurements of small transiting planets, the discovery of carbon-rich transiting exo-comets in young debris disks, and tracers of mass-accretion (FUV diagnostics and NUV continua) in protoplanetary disks.

4.2 Community view on Legacy science and to prepare for JWST

The survey solicited community input on what key exoplanet observations HST should obtain for legacy science in general and in preparation for JWST in particular. There were three recurring science themes that dominated the responses to these survey prompts: **1)** observations in the UV and blue optical, **2)** characterization of exoplanetary atmospheres, and **3)** direct imaging of circumstellar disks. (The last two of these themes have already been a major focus of HST, as explained in Sec. 2 of this report.)

4.2.1 Observations in the UV and blue optical. Although these observations are a technique and not a science theme *per se*, this was nevertheless a sufficiently prominent topic that we discuss it first. One third of the survey respondents commented on the importance of leveraging HST's unique capabilities at short wavelengths, which will be lost after HST, and not replaced until the next large UVOIR observatory. Thirteen respondents highlighted spectroscopic observation of planet host stars in the UV as a priority. The interpretation of JWST observations of exoplanetary atmospheres will depend on the spectra of the host stars, since the radiation environment of a planet can alter the composition of planetary atmospheres through photochemistry and mass-loss. Ten respondents listed UV and blue optical transit observations of planets as a priority. These could eventually be combined with JWST transmission spectra in the NIR to obtain large wavelength coverage. Finally, 7 respondents listed UV observations of the atmospheric abundances of polluted white dwarfs as a community priority. Such studies would complement eventual JWST NIR spectroscopic studies of the dust disks surrounding polluted white dwarfs.

4.2.2 Characterization of atmospheres. Exoplanetary atmospheric characterization (broadly encompassing transit spectroscopy, secondary eclipse spectroscopy and phase curves) was the second most common theme among "key exoplanet HST observations" promoted within the survey responses (mentioned by roughly 26% of respondents). Ten respondents highlighted as a priority a broad multiwavelength transit spectroscopy program spanning a diverse range of planetary temperatures and surface gravities. Such a program would serve as JWST reconnaissance observations (providing an initial assessment of atmospheric mean molecular weight, cloudiness, presence/absence of temperature inversions), and assist JWST target selection. At the other extreme, five respondents advocated for repeat observations of the same target to build up high SNR, to search for variability, and to complement the strategy of low SNR studies of many targets applied to date. Roughly equal numbers of responses advocated for prioritizing more easily observable planets over more challenging (cooler, smaller) targets, and the converse. Finally, five respondents suggested pursuing some HST NIR observations that would help corroborate eventual JWST results and to provide accurate cross-calibration between the two telescopes (either pre-JWST launch in the wavelength regimes of overlap or postlaunch through coordinated JWST-HST observations).

4.2.3 Imaging of disks. The third most common science priority highlighted by survey respondents was direct imaging of circumstellar disks (7 respondents). Observations of disks are important for understanding the formation and overall structure of planetary systems. Survey respondents highlighted how, due to its larger FOV, HST provides disk imagery at distances from the host stars that are inaccessible to ground-based high-contrast imaging (e.g., GPI and SPHERE). Further, HST's sensitivity in the visible also sets it apart from JWST, WFIRST, ALMA, and ground based instruments. HST has the sensitivity to image disks around systems lying below the Herschel/PACS detection threshold (Choquet et al. 2015) and disks that are too faint for ground-based AO observations. Respondents advocated for deep HST-STIS observations of disks in the visible to complement eventual JWST and ALMA observations at longer wavelengths, as well as for repeated observations to monitor known disks for moving structures.

4.3 The proposal and time allocation process

We asked whether the current mechanisms are working well for allocating HST observing programs. The answers were mixed – approximately one-third of survey responses were positive and one third were negative. (The final one-third of responses were neutral or held no opinion on the time allocation process.) Among the positive responses, many stated that the quality of HST exoplanetary proposals has been very high and that excellent scientific results have been produced. The survey revealed a consensus belief that the proposal evaluation process is (mostly) fair. Those who have been granted telescope time appreciate the funding that comes along with an accepted proposal to support data analysis. Multiple respondents highlighted their approval of the plan to separate the solar system and exoplanet panels. Multiple respondents were also enthusiastic about the new mid-cycle proposal opportunities as well as programs to propose jointly for time with the HST and other NASA observatories (e.g. Spitzer, Chandra, etc.).

While respondents were generally pleased that the number of exoplanetary proposals receiving HST time has been increasing over the years (as per Table 4), several respondents shared a belief that exoplanetary observations are underrepresented in HST allocations relative to both the fraction of overall astrophysics research being done in this field and the quality of scientific results being produced. This was mostly attributed to exoplanets being a young field that has not yet produced as many seasoned experts (and expert HST proposers). We have not been able to confirm that impression based on the statistics cited in Sec. 3. A number of respondents raised concerns about the makeup of the exoplanet Panels – that too many conflicts typically exist amongst the panelists, resulting in no experts remaining in the room to evaluate some proposals. Some respondents also worried that the makeup of the exoplanetary panels is not always representative of the range of science proposed, which can span an extremely diverse set of topics e.g. exoplanetary atmospheric spectroscopy, UV and blue optical spectroscopy, direct imaging, and microlensing.

Proprietary periods were another cause for concern. Some respondents expressed a wish for shortened proprietary periods. However, a major concern was raised related to having no proprietary periods on large programs, specifically for transiting planets. When multiple visits to a single target have been requested by the proposers for the purpose of building signal-to-noise, making data public immediately has allowed other groups to download partial data and publish early, arguably marginal results, which can be seen as unfair from the perspective of the original proposers, and detrimental to the science.

Limits on numbers of orbits associated with both mid-cycle and joint observatory proposals were viewed negatively by a number of respondents because they limit the type of science that can be pursued. For example, if obtaining even one transit of an interesting target would exceed the maximum number of orbits that can be requested, that target is not viable for this avenue of proposing. As for the size distribution of selected HST proposals, some respondents spoke positively about the current mix of large, medium, and small exoplanet programs, while an equivalent number of respondents supported altering the current balance – either to more large proposals or fewer. No consensus view on this topic emerged.

4.4 Caveat

We caution that our community survey is not necessarily representative of every segment of the exoplanetary community. Exoplanetary science covers a broad range of sub-topics (e.g., Table 5) some of which are highly specialized and being pursued by small segments of the community. Although we advertised our survey widely, and sought maximum participation, it is possible that important science sub-topics are not well represented. Nevertheless, we believe that it sufficiently covers the areas in exoplanetary science that are being the most widely pursued.

5.0 Committee view on Legacy science

Given the themes identified in the community survey (Sec. 4.2), and deliberations by the Committee, we highlight important exoplanet observations that should be obtained by HST for long lasting legacy science, and in preparation for JWST. With unparalleled multi-wavelength capabilities, Hubble can make unique exoplanetary observations covering a wide range of exoplanet science including transiting exoplanets, directly imaged debris disks and planets, as well as stellar physics observations with exoplanet implications.

5.1 Atmospheres of transiting exoplanets

Atmospheres of transiting exoplanets has been a major focus for HST (Table 5). This popularity derives from a solid scientific rationale, and transit observations should continue to be a major focus for HST, but with increased emphasis in the UV and blue optical. Not only is the short wavelength capability of HST unique, but short wavelength observations are scientifically critical for transiting planets to probe atmospheric escape and measure atmospheric haze and clouds (Secs. 5.1.1 & 5.1.2).

5.1.1 Escaping atmospheres of close-in planets. Hydrodynamic escape is known to be an important process that causes atmospheric loss for close-in planets (e.g., Vidal-Majar et al. 2003, Ehrenreich et al. 2015). Studying the physics of atmospheric loss is not only of interest in itself, but it also provides a basis for understanding the current state of close-in rocky planets that may be the remnants of planets with extensive primordial envelopes. UV observations by HST of intrinsically strong atomic lines due to hydrogen and heavier elements is a superb and unique method to observe escaping atmospheres, and such measurements should have a high strategic importance for HST.

5.1.2 Clouds and hazes. As noted in Sec. 2.1, UV and blue optical observations can sensitively reveal the presence of scattering hazes and clouds in the atmospheres of transiting planets. Clouds and haze are significant sources of continuous opacity that must be accounted for when measuring quantitative abundances of molecular constituents (e.g. using IR spectroscopy). HST transmission spectroscopy of hot planets at 1.4 microns (e.g., Kreidberg et al. 2014a) has been able to account successfully for the presence of clouds. However, interpretation of molecular spectroscopy from JWST may hinge critically on better understanding of the cloud and haze properties of exoplanetary atmospheres. HST UV and blue optical observations have the potential to give high leverage on measurement of cloud properties. Also, photochemical hazes that are revealed using spectroscopy at these wavelengths give important insight into atmospheric physics, and photochemical products can affect atmospheres in major ways.

5.1.3. Infrared spectroscopy and phase curves. The Committee endorses the continuation of *transit* and *eclipse* spectroscopy using HST in the near-IR (e.g., WFC3) as an important prelude to JWST. Spectroscopy at transit is now a well established technique for HST, but eclipse spectroscopy is (as of this writing) an under utilized strategy. Although JWST will have greater sensitivity and will have access to intrinsically stronger molecular bands, we are not yet confident of the degree to which transiting planets will exhibit strong molecular absorption features, and we do not fully understand the occurrence of clouds and hazes over any regime of temperature and surface gravity. IR spectroscopy by HST, exploiting the complementary observing geometries of transit and eclipse, can better define the scientific and measurement context and thereby enable more efficient use of JWST. This is particularly important if HST's IR transit spectroscopy is conducted in parallel with UV and blue optical observations (as per Sec. 5.1.2.), and if Spitzer photometry (Sec. 6.9) can be obtained at both transit and eclipse.

IR spectroscopy by HST over substantial portions of an exoplanet's orbit (i.e., phase curves) is a relatively new advance, but has been spectacularly successful (Stevenson et al. 2014). Spitzer has done this type of study using photometry (and is highly complementary to HST), but HST is the only facility capable of phase-resolved *spectroscopy*. The variation of molecular absorption with viewing angle based on phase curve observations is a scientifically rich diagnostic of an exoplanet's atmosphere. Moreover, given the likely pressure on JWST observing time, it is not clear to what degree such time-intensive programs will be feasible using JWST. On the other hand, JWST will have much greater sensitivity for such studies. The Committee endorses phase curve spectroscopy using HST in key instances.

5.2 Direct imaging and spectroscopy of disks and planets

HST pioneered many aspects of disk studies, including imaging the structure of protoplanetary disks (Ricci et al. 2008). The study of debris disks provides especially important information on the formation and evolution of planetary systems, and HST has the unique capability of optical chronographic debris disk imaging. This capability is highly complementary to ground-based AO imaging, which is performed at infrared wavelengths but does not work well in the optical. As stars emit most of their light in the optical, Hubble's optical images are able to probe the morphology of disks where they are brightest. To date, most of the known light-scattering debris disks have been imaged with HST, and a great diversity between disks has been observed. Continued observations of those and additionally discovered disks is needed to constrain the physical properties of the dust in the systems and understand the myriad of internal and external influences shaping the disk morphology, such as stellar winds, the interactions with interstellar material, the abundance of heavier elements (needed to build exoplanets), and how the disks are influenced by the mass and age of the parent star.

HST's capability for sensitive angular differential imaging can enable important discoveries of directly imaged planets, such as Fomahault b (Kalas et al. 2008). Although such studies are difficult, they can be conducted in parallel with debris disk imaging.

Spectroscopy of the gas in debris disks is also important, especially for systems such as accreting white dwarfs (see below), and the strong atomic lines available in the UV give HST an important role in studying the evolution and dynamics of the gaseous component of debris disks.

5.3 Accretion onto white dwarfs

HST observations are responsible for the stunning discovery that the atmospheres of white dwarfs are sometimes found to be "polluted" by the presence of heavy elements accreted from the orbital decay of asteroidal bodies (e.g., Gaensicke et al. 2012). UV spectroscopy by HST is our best method to measure the absorption line signatures of this pollution. These studies have the potential to inform us of the composition and evolution of the asteroidal components of exoplanetary systems, with fundamental implications for the process of planet formation.

5.4 Stellar physics with exoplanetary implications

Spurred by comments in our Community Survey, the Committee points out the strategic importance of understanding the stars that host exoplanets. The host star is the principal energetic driver of the planet's atmospheric physics, in both a global energetic sense and also in key wavelength regions. For example, better knowledge of stellar UV spectra is crucial to modeling and understanding exoplanetary photochemistry. This is another instance of where HST UV capability is strategically critical. Also, we note that HST could be useful to test observing modes for follow-up of WFIRST microlensing targets, although it is not clear how that role fits within the proposal review process.

5.5 Tens years in the future

The Committee considered the likely status of the exoplanetary field in 2026. We articulate that vision in order to illustrate the scientific potential of HST working in tandem with JWST. By 2026, and with emphasis on the most HST-related aspects, we expect:

- To have characterized a large sample of exoplanets using transmission spectroscopy, and (for the hottest planets) spectroscopy at secondary eclipse.
- To understand the occurrence of haze and clouds as a function of temperature, surface gravity, and type of planet, enabling efficient use of JWST
- To have identified cloud-free planets whose gaseous abundances can be measured with high sensitivity and accuracy.
- Measurements of escaping atmospheres will cover a wide range and type of planets
- The wavelength coverage of the best JWST exoplanetary spectra will be extended by HST to FUV-UV-near-UV-blue optical wavelengths
- We will have measured spectroscopic phase curves for the highest S/N exoplanet targets, working in tandem with IR photometry from Spitzer, and laying the groundwork for potential phase-resolved spectroscopy by JWST
- HST will have made optical scattering measurements for debris disks to be targeted by JWST
- We will have measured rotation modulation for directly imaged planets, revealing the nature and longitudinal distribution of their clouds
- We will understand many new aspects of debris disk evolution, including how the remnants of planet formation accrete into the atmospheres of white dwarfs, and what the composition of that material tells us about planet formation
- The UV spectra of planet-hosting stars will be understood to the point where they are no longer a source of uncertainty for studies such as photochemical modeling

6.0 Recommended mechanisms to coordinate the time allocation process with community priorities

The Community Survey revealed diverse and sometimes contradictory opinions on how HST should best support exoplanet science. Nevertheless, there was a significant degree of concurrence on several key issues. Our recommendations below are made considering both the Community Survey and deliberations of the Committee itself. For many topics, we conclude that current HST mechanisms already work well, but we also highlight areas where policy changes could enhance HST's exoplanet legacy.

6.1 Emphasize HST's unique capabilities

The exoplanetary community is keenly aware that Hubble will not last forever. There is broad interest in making the best use of those capabilities that are unique to HST. As phrased by one survey respondent, "what will be impossible when HST is gone" should strongly shape the priorities for Hubble while it is still functional.

Hubble now provides our only option for UV spectroscopy, and no currently planned mission will replace this capability for at least a decade. UV observations are crucial for exoplanet context; for example, they are necessary to measure the high-energy environment irradiating planetary atmospheres, to probe atmospheric escape through transit observations, and to study the composition of planetary material accreted onto polluted white dwarfs. HST should gather as many UV observations as possible before its end. The currently existing Ultraviolet Initiative appears to be successfully promoting this goal and received generally positive feedback from the community. We advocate continuing to support the UV Initiative.

Hubble has additional unique capabilities, beyond the UV. For transiting planet science, no current or near-future facility can match Hubble's spectrophotometric precision at wavelengths near 600 nm for very bright exoplanet systems (V<9). That capability was dramatically illustrated by the low-noise photometry of the first transiting planet (Brown et al. 2001). With direct imaging, Hubble achieves unparalleled contrast ratios for observing disks and young planetary systems in the optical. As the urgency of HST's limited lifetime grows, we anticipate that science programs depending on these unique capabilities will naturally be reflected in submitted proposals. We advocate no actions to explicitly incentivize these observations. Rather, we emphasize that the review process should heavily weight proposals that are compelling and unique to HST.

6.2 Gather Legacy observations to prepare for JWST

At wavelengths longer than 600 nm, JWST's performance for transiting planets will greatly surpass that of Hubble. For transit observations, which are fundamentally limited by the number of photons that can be collected during transit, JWST has three advantages over HST: its collecting area is larger, its instruments provide IR spectroscopy over broad regions of infrared wavelength, and it can observe twice as efficiently because it will not be hindered by Earth occultations. In light of JWST's impending launch, deep observations requiring many transits at red and near-IR wavelengths could be viewed as inappropriate for HST. On the other hand, such observations may enable HST to sharpen the science questions that JWST could address for certain transiting exoplanets.

Hubble's best use for supporting future JWST observations may be to gather context observations at short wavelengths. Several examples highlighted by the community include needs for visible-light imaging of resolved disks to complement JWST/ALMA data, UV spectroscopy of polluted white dwarfs whose disks may be later observed by JWST, NUV/blue optical observations of bright transiting planets to probe clouds/hazes and provide blue baseline anchors for red JWST data, and stellar FUV/NUV spectroscopy that will be necessary to interpret JWST transiting exoplanet spectra.

Some of the best exoplanet targets for JWST are already known. Current Hubble observations should be planned to anticipate what we will want to know about their host stars once we start observing these systems with JWST. Such observations might be difficult to win through a normal review process, as they may be insufficient to produce a high-profile result. The new JWST Preparatory Proposal option may provide an effective means to incentivize this foresight. We advocate the continuation of this initiative through the start of the JWST mission (perhaps morphing more into the role of coordinated observations).

At the same time, we highlight that the precision currently achievable beyond 600 nm with modest STIS/WFC3 programs is sufficient for some scientific goals. For example, STIS/WFC3 reconnaissance of existing and soon-to-be-discovered transiting exoplanets can contribute to the joint HST-JWST legacy, both by helping frame science questions and by identifying favorable targets for particular JWST modes. HST should not explicitly discourage observations at red and near-IR wavelengths.

6.3 Enable ambitious programs without sacrificing modest ones

Transiting exoplanet science requires substantial time investments. Multiple transits are needed to ensure results are robust against instrumental systematics and stellar variability, and individual transits themselves require at least four HST orbits. Providing definitive answers for exoplanetary atmospheric science requires big programs, either for achieving robust results on many systems, or for reaching extreme precision on a few individual systems. That transit proposals continue to be awarded despite the high orbit cost reflects the great interest in the community for tackling exoplanetary atmospheric projects.

Survey respondents were enthusiastic about expanding to very large coordinated efforts for transiting exoplanetary science, but also expressed concerns that such programs not come at the cost of smaller individual programs. In this context, the introduction of the Very Large Treasury in Cycle 24 is well-suited to the needs of the exoplanetary community. By providing an option to propose for very ambitious programs that are not in direct competition with small and medium proposals seen by the Panels, the VLT program encourages breakthrough Legacy programs without stifling the creativity of diverse groups submitting smaller proposals. There is no indication that the transiting exoplanet community could (or should) come together to submit one cohesive proposal, as the Solar System community has done in past cycles. When compared to the Deep Fields or the Frontier Fields, transit observations are generally more single-purpose, making the division of science projects across many groups more challenging. We advocate for the Panels and the TAC to continue to arbitrate HST exoplanet priorities through the selection of proposals at all levels. The opportunity to propose for HST exoplanet observations from small to Very Large scales preserves and promotes a broad research program and a broad population of skilled observers, with contributions distributed throughout the community.

6.4 Monitor the success of proposals in the medium size range

Medium sized proposals have been problematic in the review process because the Panels have tended to prefer small proposals (Figure 4). However, exoplanet proposals are inherently orbit-intensive and it is likely that there are many innovative exoplanet proposals that will benefit from medium size allocations. We recommend monitoring the submission and success rate for exoplanet proposals in this size range, to ensure that the success rate is commensurate with scientific demand.

6.5 Clarify policies for data and code sharing

In the competitive field of exoplanets, conflicts surrounding HST data have emerged. Exoplanetary observations sometimes require multiple transits to reach their necessary precision and/or to mitigate against potential systematic uncertainties. In a field that has seen some high-profile claims later refuted, it is important to encourage analysis of complete datasets and thorough checks for robustness of results. As Large Programs by default have no proprietary period on any of the data, there have been instances of competing groups publishing results based on incomplete datasets, that have the potential to cause confusion because of the lower signal-to-noise of incomplete data.

In the early days of a mission or instrument it is crucial to understand the systematic errors inherent to observations. It is therefore best for data to go public quickly, as this allows more scientists to explore the data and to identify problems and solutions as soon as possible. That early period has passed for all HST instruments, as there are now many public datasets that can be used to test out novel reduction and analysis schemes. In this mature stage, it is therefore more important to encourage careful data analyses and interpretations. Many respondents to the community survey advocated for modified proprietary periods on multi-transit datasets: *the data on a given target would not become public until the final transit has been observed*. This would ensure that all groups who choose to analyze the data have all of it at their disposal, and it would remove any incentive for analyses of partial datasets. That would promote the best possible science, and would benefit the community as a whole.

Finally, we note that the quantity and quality of HST exoplanetary science may be improved if more researchers make their reduction and analysis code public. An especially strong case for open science can be made in the field of exoplanets, because the signals of interest are often buried in a variety of poorly-understood detector noise. Although one can in principle use public data and published papers to attempt to reproduce results, astronomers in practice make countless unstated choices that may impact the final result. Encouraging researchers to post their data analysis codes in a public repository would improve the efficiency and fidelity of HST exoplanetary research.

6.6 Respond rapidly to newly discovered planets

The field of exoplanetary science moves quickly. Multiple new exoplanets worthy of HST observations are discovered every year. Making the most of HST's remaining lifetime requires procedures to rapidly ingest new targets, to avoid the delays associated with the annual proposal cycle.

The new Mid-Cycle Proposal system *almost* succeeds to serve this purpose. In the abstract, the Mid-Cycle concept is well-suited to newly discovered exoplanets. Many exoplanets are urgent because they are interesting and can affect other ongoing science, not because they are fading from view. In practice, however, the current 5-orbit restriction severely limits its usefulness. Many exoplanet transit observations require > 5 orbits (e.g., all planets with transit durations longer than three hours, due to the need for sufficient out-of-transit baseline). Additionally, many planets must be observed over multiple transits, to mitigate systematic instrument effects and/or stellar variability. We strongly advocate raising the current orbit limit, to more than 10 orbits. It may be appropriate for programs substantially exceeding 10 orbits to be downweighted, due to the *ad hoc* nature of the Mid-Cycle review process, but the current orbit limit unduly hampers exoplanetary programs.

Another option for rapid response would be to allow large exoplanet Target of Opportunity programs, explicitly designed to target new discoveries. With the launch of TESS in 2017, optimal use of HST will require fast response to the flood of new nearby exoplanets that TESS will find. Once TESS is safely on-sky, proposers can confidently state the statistical properties and general sky locations of predicted candidates, but they may not know exactly which stars will be the hosts. For example, TESS may find potentially habitable planets transiting M dwarfs; HST should observe UV spectra of these host stars, to inform future observations of the planets' atmospheres with JWST or large ground-based telescopes. As HST's UV capabilities will continue to dwindle just as TESS is ramping up, such ToO exoplanet programs could significantly enhance HST's exoplanet legacy.

6.7 Preserve and refine the allocation process

The community expressed general satisfaction with the allocation process, including both the balance between broad surveys and characterization of individual objects and the overall high quality of implemented proposals. The primary request repeated in multiple survey responses was to narrow the focus of the panels, to allow more than one expert in each subfield per panel and make proposal selection less susceptible to individuals' personal biases. The recent division of the Planets panel into separate Solar System and Exoplanet panels for Cycle 24 will likely satisfy this request.

The association of monetary grants with analysis of HST observations is an important source of funding for the US community, and it ensures that astronomers can devote the necessary time to carry out robust and careful analyses of precious Hubble data. We advocate HST continue to support its observers in this way, as well as through Archive and Theory grants.

It is important to promote a more diverse community of HST observers, an issue that is particularly relevant as new leaders are still emerging in the relatively young field of exoplanets. We applaud the steps taken to limit unconscious biases in proposal selection, including explicit discussion of these biases with panel members, the use of first initials on proposer names, and starting in Cycle 24 the removal of PI vs. Co-I status on reviewed proposals. We advocate STScI continue to monitor the allocation process for potential biases and work actively to mitigate them.

6.8 Develop a transit noise calculator to support proposers and panelists

The existing HST Exposure Time Calculators are well-suited for calculating the S/N at which faint galaxies can be detected. They are less adapted for predicting noise for transit observations. Currently, to calculate the predicted wavelength-by-wavelength transit depth uncertainty expected for a particular target, a proposer must (a) run the ETC to gather photon counts, backgrounds, and other noise sources for the host star, (b) run the APT Orbit Planner to estimate the effective duty cycle considering exposure overheads and Earth occultations, and (c) use these numbers to calculate transit depth uncertainties after accounting for the duration of the transit and the extra noise introduced by fitting for the out-of-transit baseline level. These calculations are simple, but contain multiple factors that some proposers may include and others might accidentally neglect. It places an undue burden on review panelists, who may be experts in exoplanet science but not transit observations, to independently assess and compare different noise estimates across proposals. An official Transit Noise Calculator, perhaps as an extension to the existing ETCs, could streamline the panel review process by providing standardized minimum noise estimates that could be directly compared across proposals. To support both proposers and panelists, we advocate the development of Transit Noise Calculators for the STIS/CCD and WFC3/IR instruments. It will be a tremendous boon to exoplanet science if such official Transit Noise Calculators are already in place at the start of the JWST mission.

6.9 Preserve coordinated observing capabilities

The option of obtaining coordinated observations with NOAO, NRAO, Spitzer, Chandra, and XMM-Newton is valuable for making panchromatic observations of exoplanet systems, and it should be preserved. Community members broadly expressed gratitude for the existence of this option, and for the mission planners who work to schedule these coordinated observations.

Some community members expressed concerns about HST panelists often lacking expertise to judge the feasibility of coordinated observations with other facilities. One potential option (which might already be used) would be to solicit external review beyond the panel for these coordinated observations.

6.10 Continue to host HST & JWST Exoplanet Workshops

Meetings hosted by STScI, like the successful November 2015 workshop on "Enabling Transiting Exoplanetary Science with JWST," play an important role for exoplanetary scientists using HST and JWST. By facilitating conversations about results and capabilities, these venues help clarify priorities for future observations. We advocate that STScI continue to host such meetings.

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Appendix I: HST Exoplanet Proposals - background

Statistics compiled by Neill Reid, Science Mission Office, STScI

HST has been used for observations relevant to exoplanet science for close to 15 years, but the EXO science category was only created in Cycle 17, so I'm restricting the statistics to Cycles 17-23. This also means that we're dealing with a common set of instruments, since Cycle 17 immediately followed Servicing Mission 4 in May 2009. The next couple of paragraphs give a brief outline of the TAC process – (excruciatingly) more details are available here https://blogs.stsci.edu/newsletter/2013/03/29/the-evolution-of-the-hubble-tac-process/ .

HST observing proposals are subject to peer review. Smaller proposals are reviewed by topical panels; large proposals are reviewed by the TAC, which comprises the Chairs of the optical panels, 2-3 at-large members and the TAC Chair. 2-3 mirror panels are recruited for each of the topical subjects; this enables us to avoid major conflicts by directing panelist-led proposals to the mirror panel. In Cycles 17 through 23, Exoplanet proposals were paired with Solar System and Debris Disk proposals; starting in Cycle 24, Solar System proposals will be considered by a single separate panel, recruited after the proposal deadline to minimize conflicts. Each panel has an orbit allocation, based on the average of the fraction of the total proposals assigned to that panel and the fraction of the total orbits requested by those proposals i.e. if a panel has 5% of the proposals requesting 7% of the orbits, it will be allocated 6% of the total orbits available. Panels also review SNAP proposals, Archive and Theory proposals.

For Cycles 17 through 20, the panels reviewed Regular Guest Observer (GO) proposals, requesting less than 100 orbits; proposals requesting more than 100 orbits are reviewed by the TAC, which considers all Large and Treasury proposals. In the last three cycles we subdivided regular proposals into Small (<35 orbits) and medium (35-74 orbits), changing the cutoff for Large proposals to >75 orbits. The orbits for Small proposals come from the panel allocation; the Medium proposals are from a separate allocation. We have used a variety of approaches for the Medium proposal review; in Cycle 24 each panel will have a specific allocation of Medium proposals, probably one per panel.

Table A1 gives the statistics for submitted and accepted exoplanet proposals for Cycles 17 through 23. This includes all types of Exoplanet proposals (GO, SNAP, AR, Theory); the requested and approved orbit allocations are also listed. Typically around 3500 orbits are available in each cycle. As Figure A1 emphasises, exoplanets is clearly a growth area.

Cycle	Req. proposals	Acc. proposals	Req. orbits	Acc. orbits
17	44	10	671	114
18	66	8	1727	288
19	66	14	1100	245
20	60	13	891	83
21	63	9	1961	239
22	69	11	2119	315
23	91	22	3008	402

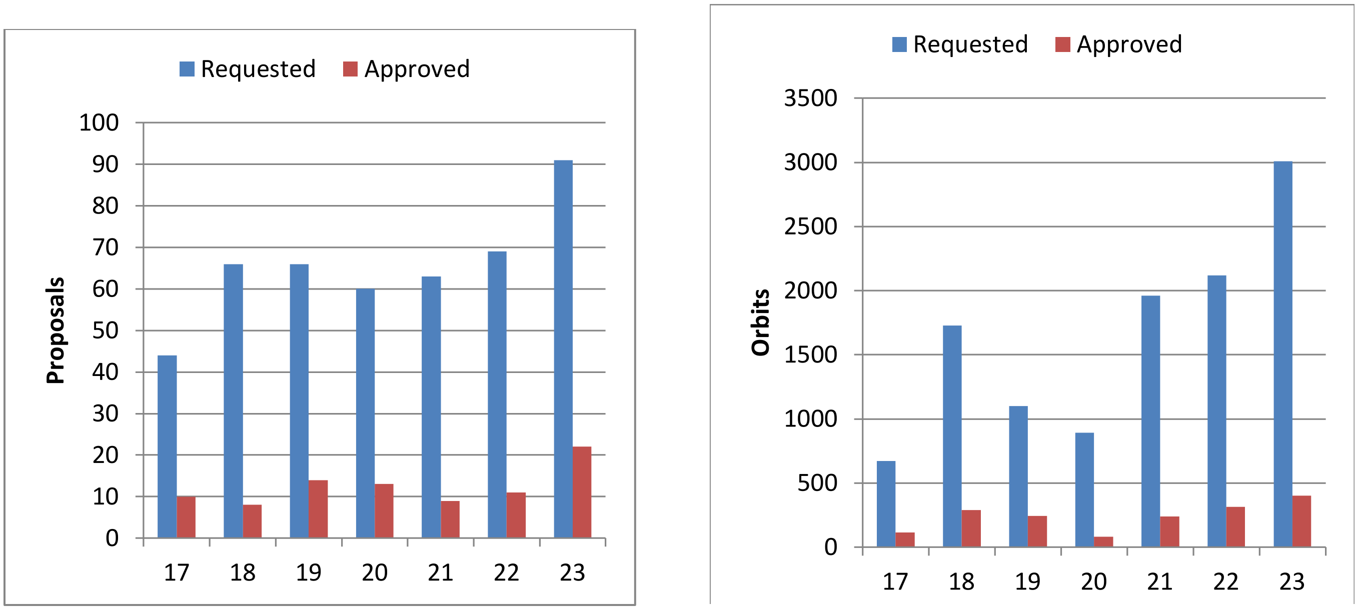

Figure A1: Proposal/orbit request/approval history – Cycles 17 through 23

Figure A2 shows the corresponding success rates; average success rates (all disciplines) are ~23% in proposals and ~17% in orbits. Major fluctuations in the latter fraction stem from the success of Large/Treasury programs.

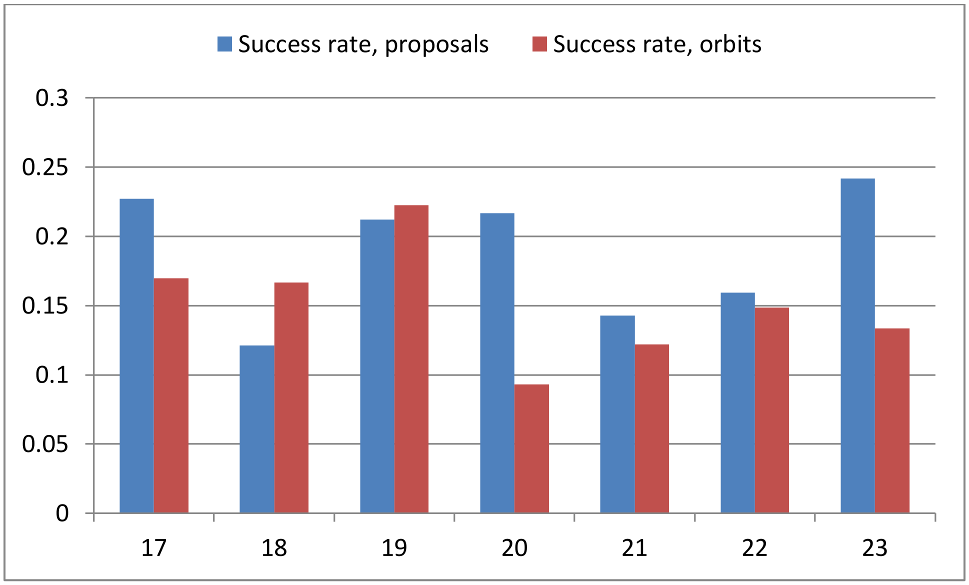

Figure A2: Success rates for exoplanet proposals & orbit requests

Figures A3 and A4 present the proposal success rate in an alternative manner: comparing, respectively, the fraction of all submitted proposals that listed EXO as their science category against the fraction accepted, and the fraction of all requested orbits for EXO versus the fractional contribution to the accepted program. Differences between the submitted and accepted fractions arise because we have mixed topic panels and, more substantively, from the relative success of large programs. Thus

Exoplanets proposals accounted for 15.5% of the total time (orbits) requested in Cycle 23, and were allocated 11.3% of the time available.

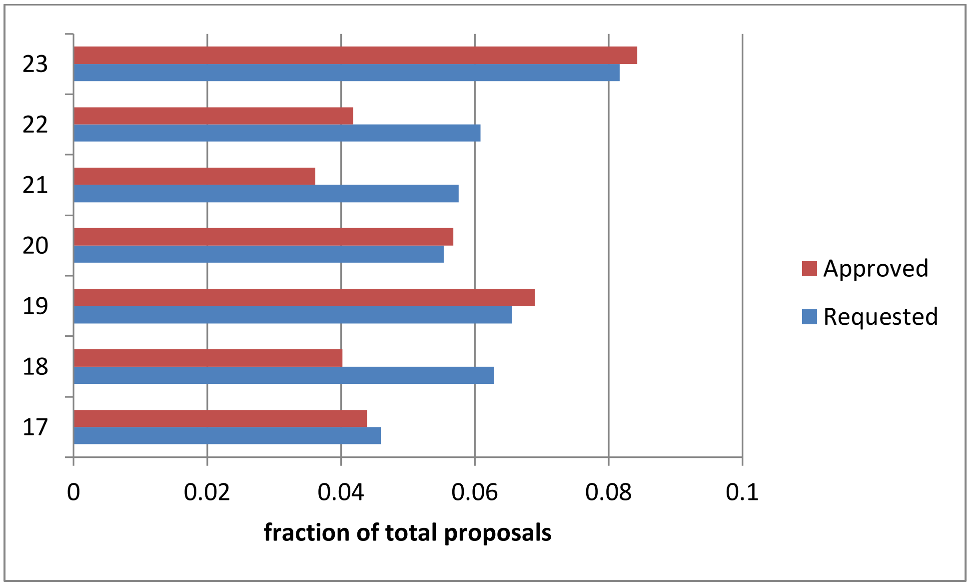

Figure A3 Fraction of total proposals that list their science category as EXO

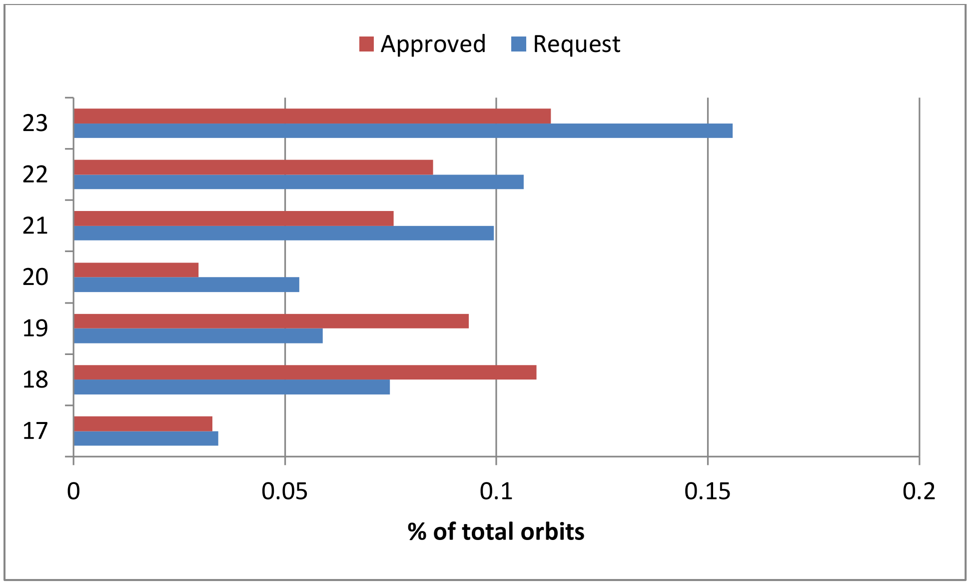

Figure A4 Fraction of total requested and approved orbits from EXO proposals

Finally, we list the Large, Treasury & Medium programs that have been awarded time for Cycles 18 through 23 (no large EXO programs selected in either Cycle 17 or Cycle 20):

18: The Atmospheric Structure of Giant Hot Exoplanets – 115 orbits – PI: Drake Deming
19: An Optical Transmission Spectral Survey of hot-Jupiter Exoplanetary Atmospheres – 124 orbits – PI: David Sing
21: Follow the Water – The Ultimate WFC3 Exoplanet Atmosphere Survey – 150 orbits – PI: Jacob Bean

22: Exploring the Diversity of Exoplanet Atmospheres in the Super-Earth Regime – 124 orbits – PI: Bjorn Benneke
22: The MUSCLES Treasury Survey: Measurement of the Ultraviolet Spectral Characteristics of Low-mass Exoplanetary Systems – 125 orbits – PI: Kevin France
23: Cloud Atlas – Vertical Cloud Structure and Gravity in Exoplanet and Brown dwarf Atmospheres – 114 orbits – PI: Daniel Apai
23: The Atmospheres of Two Low-Mass, Low-Density Exoplanets Transiting a Young Star – 40 orbits – PI: Zachory Berta-Thompson

Instrumentation:
The two instruments used for the majority of exoplanet observations are STIS (Space Telescope Imaging Spectrograph) and WFC3 (Wide-Field Camera 3). WFC3 has been the major workhorse since spatial scanning was implemented in 2011.

Appendix 2: The HST Exoplanet Community

This section provides statistical information on the HST exoplanet community and how it has utilized Hubble. The community data are drawn primarily from Cycles 18 through 23, with additional information on the science topics of approved proposals from Cycle 17. Gender data for investigators has been estimated based primarily on names, supplemented in a few cases by information presented on publicly-accessible web pages.

Proposal statistics

TableB1: Exoplanet proposal statistics: column 2 lists the number of proposals submitted with male PIs, column 3 the number accepted, column 4 the corresponding success rate, and column 5 the number of large proposals; columns 6 through 9 give the same statistics for proposals led by female PIs; column 10 shows the overall success rate for exoplanet proposals, and the last column lists the average proposal success rate (all science topics) for each cycle.

Cycle	N(sub) male PI	N(acc) male PI	F(success) male PI	N(large) male PI	N(sub) female PI	N(acc) female PI	F(success) female PI	N(large) female PI	Exoplanet success rate	Average success rate
18	50	8	16%	4	16	0	0	0	12.1%	18.7%
19	53	12	22.6%	3	13	2	15.4%	0	21.2%	19.6%
20	51	12	23.5%	2	9	2	22.2%	0	23.2%	21.3%
21	51	8	15.7%	4	12	1	8.3%	1	14.3%	23.1%
22	57	10	17.5%	7	12	1	8.3%	0	15.9%	23.2%
23	71	17	23.9%	10	20	6	30%	2	25.3%	23.4%

Table B1 shows the submission and acceptance statistics for Exoplanet proposals led by male and female Principal Investigators, respectively. As noted previously, there is significant increase in proposal pressure in Cycle 23 (~66 to ~90 proposals). Overall, exoplanet proposals were more successful than the average proposals success rate in Cycles 19, 20 and 23, and less successful in Cycles 18, 21 and 22. In most cycles the success rates for proposals led by female PIs are lower than for proposals led by male PIs; the exception in Cycle 23. The fraction of all exoplanet proposals with female PIs is initially 20%; drops to 17% in Cycle 20; but rises to almost 25% in Cycle 23. As in other science areas, the proportion of large proposals submitted by female PIs is lower in all cycles, with the highest contribution being made in Cycle 23.

Figure B1 shows the number of proposals as a function of type and, for GO proposals, orbits that were submitted in Cycles 17 through 23. Figure B2 presents the same data for accepted proposals in those cycles. Overall, there is an increase in the number of larger proposals (as suggested by the data shown n Table 1), with the average GO request rising from ~17 orbits in Cycle 20 to ~37 orbits in Cycle 23. However, the majority of proposals remain in the 6 to 20 orbit range, with the median value ranging from 10 to 15 orbits in each cycle.

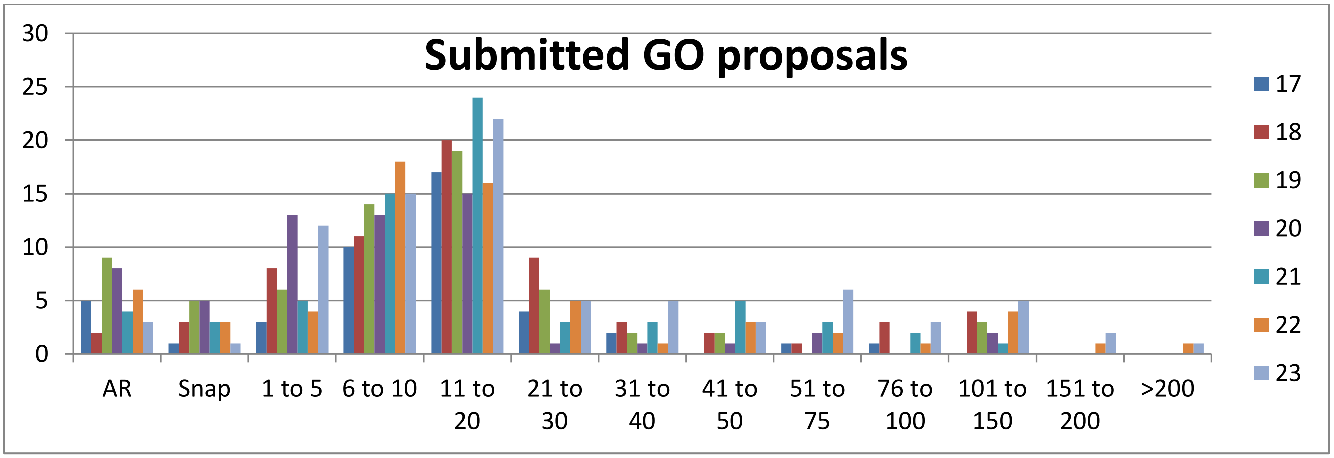

Figure B5: Size distribution for submitted exoplanet proposals, Cycles 17 through 23

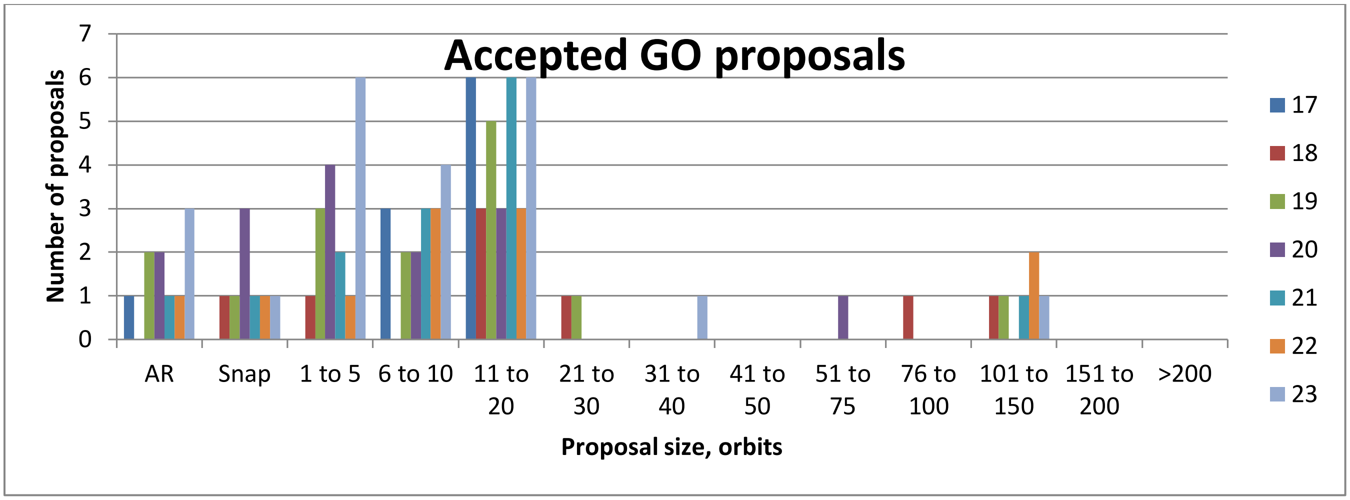

Figure B6: Size distribution of accepted exoplanet proposals, Cycles 17 through 23

Community statistics

Table B2: Investigator statistics for HST Exoplanet proposals

Cycle	Total Proposals	Total investigators	Total unique investigators	Unique male investigators	Unique female investigators
18	66	387	248	196	52
19	66	379	234	189	45
20	60	355	245	203	42
21	63	429	239	185	54
22	69	477	261	203	58
23	91	688	334	251	83

Table B2 presents the number of investigators associated with the exoplanet proposals in each cycle. Many investigators are involved in more than one proposal. In addition to the total numbers, the table gives the number of unique investigators in each cycle, together with the gender breakdown. Again, the increased numbers in Cycle 23 stand out, and the fraction of female investigators rises from ~20% in Cycle 18 to close to 25% in Cycle 23. Throughout the six cycles, a total of 678 unique investigators participated in the proposal process, including 155 female investigators (23%).

Table B3: Average number of co-investigators, excluding large proposals

Cycle	N (prop) male PI	Average co-Is	N(prop) female PI	Average co-Is	All props	Average co-Is
18	46	4.8	16	4.9		
19	50	4.1	13	4.95	948	5.27
20	49	3.4	9	4.9	1035	5.26
21	47	6.5	7	5.1		
22	50	5.8	10	5.1		
23	61	5.7	15	5.5		

There have been suggestions that the exoplanet community is more collaborative than many research areas in astronomy. That suggestion can be tested to some extent by considering the size of exoplanet proposal teams relative to the average for HST proposals. Those data are shown in Table B3. Large proposals are excluded, since those tend to accrete significantly larger proposal teams. We list the average number of co-Is for exoplanet proposals in each cycle, segregating proposals led by male and female PIs; there is no evidence for a significant difference in team size correlated with the gender of the PI. We have compiled similar data for all proposals in Cycles 19 and 20, and those results are shown in Table B3. The number of co-Is is comparable with the number of co-Is on exoplanet proposals in that cycle.

Proposal type statistics

As of February 27 2016, 94 HST proposals in the exoplanet category have been accepted. This total includes 11 proposals from Cycles 16 and 17 and four mid-cycle proposals from the first Cycle 23 call in addition to the 79 proposals listed in Table 1. Those proposals are listed in the appendix; we have classified them into 11 broad science topics:

1. Astrometry, parallax measurement or an astrometric search for companions;
2. Confirmation, including follow-up observations of Kepler targets;
3. Direct imaging, including follow-up observations of resolved exoplanets and searches for companions to very low mass dwarfs;
4. Disk composition, spectroscopy;
5. Microlensing;
6. Stellar host & environment properties, including stellar activity;
7. Theory;
8. Transit – atmosphere, generally spectroscopy with WFC3-IR grisms or STIS;
9. Transit – magnetosphere, probing planet-star interactions;

10. Variability, generally monitoring short time-sale variations in resolved exoplanets or brown dwarfs
11. WD spectra – composition, generally UV spectroscopy with COS or STIS of metal lines in white dwarfs, probing accretion of debris disk materials and/or disrupted planetismals.

Table 4 lists the number of proposals in each category. More than half the proposals are focused on transit spectroscopy, but significant numbers are devoted to direct imaging and white dwarf spectroscopy.

Table 4: Exoplanet science topics

Topical category	**Number**
Astrometry	2
Confirmation	3
Direct imaging	13
Disk – composition	1
Microlensing	1
Stellar host & environment	6
Theory	3
Transit – atmosphere	46
Transit – magnetosphere	1
Variability	3
WD spectra	13

Appendix 3: Program size

Appendix 2 gave some statistics on the size distribution of Exoplanet programs. Here, we compare those data against the size distributions of all HST proposals. Figures C1 and C2 show the size distributions of all submitted and accepted proposals over the most recent seven cycles.

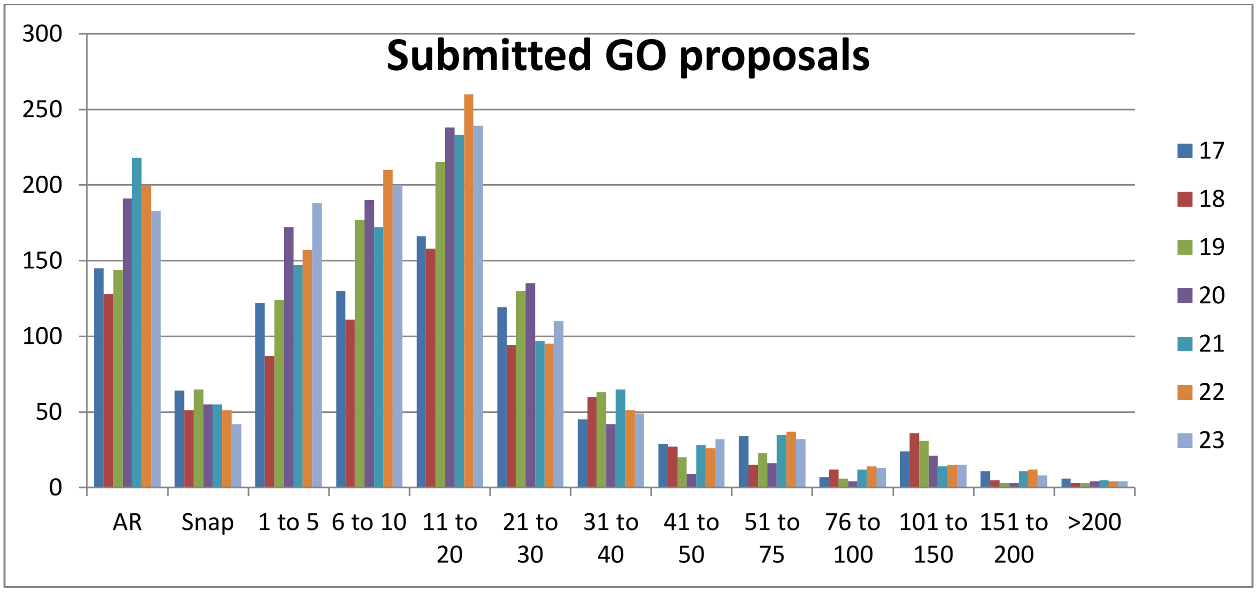

Figure C1: Distribution of program size for all submitted proposals, Cycles 17 through 23

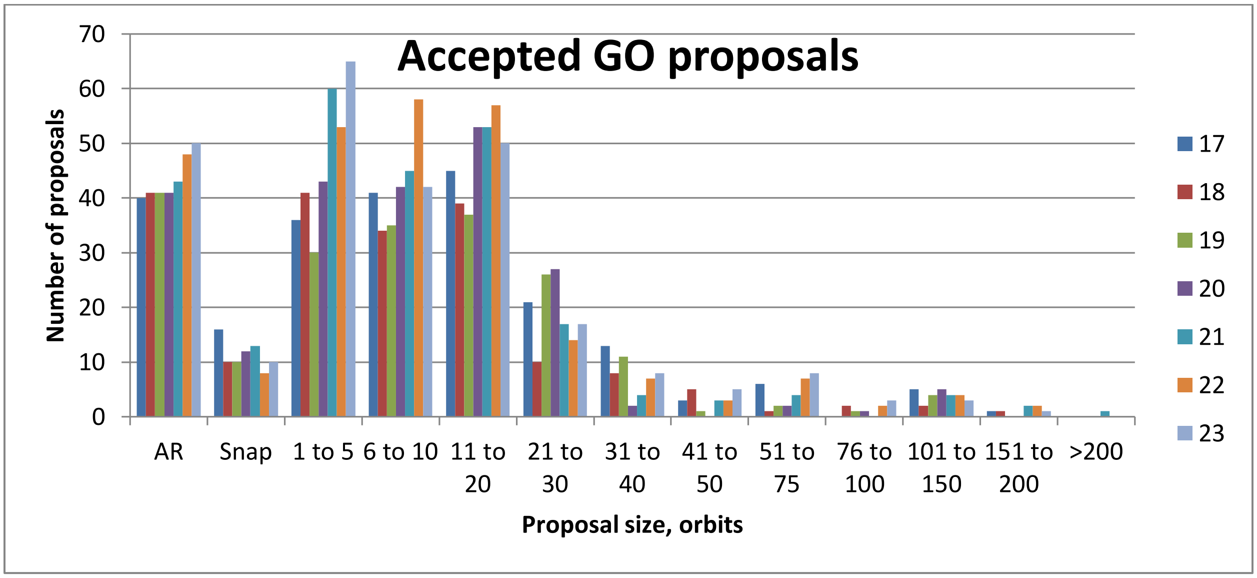

Figure C2: Distribution of program size for all accepted proposals, Cycles 17 through 23

Figures C3 and C4 show normalised size distributions, plotting the fraction of proposals within each size bin, allowing a comparison between the exoplanet statistics and the average proposal size distribution.

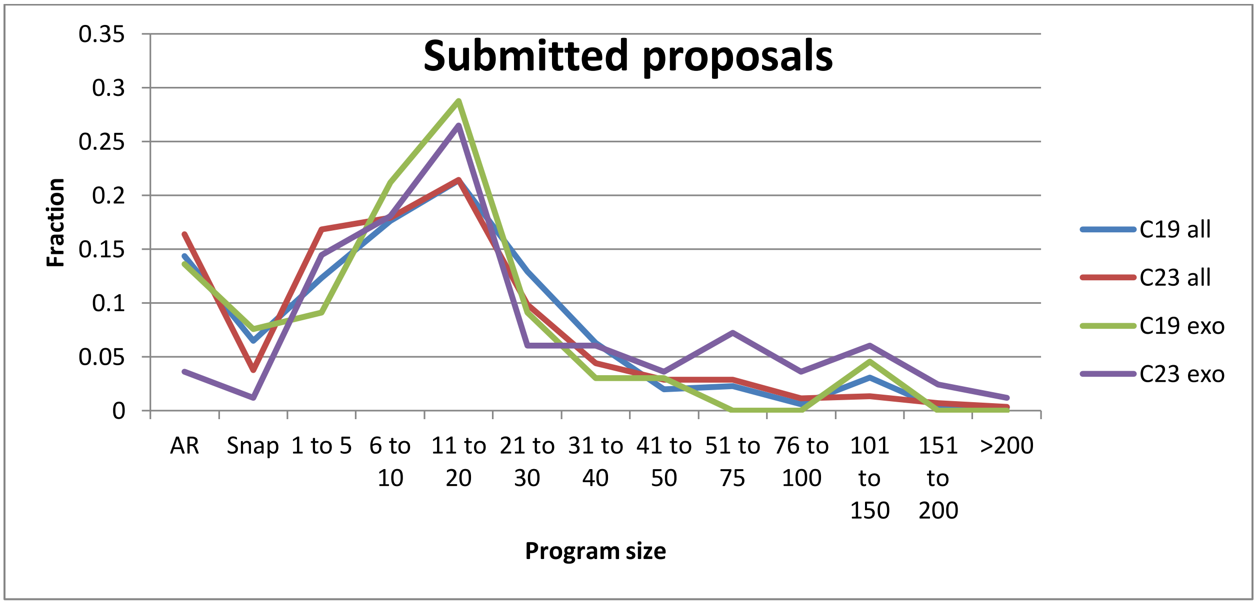

Figure C3: Normalised distribution of program size, submitted proposals, Cycles 19 & 23, all proposals and exoplanet proposals

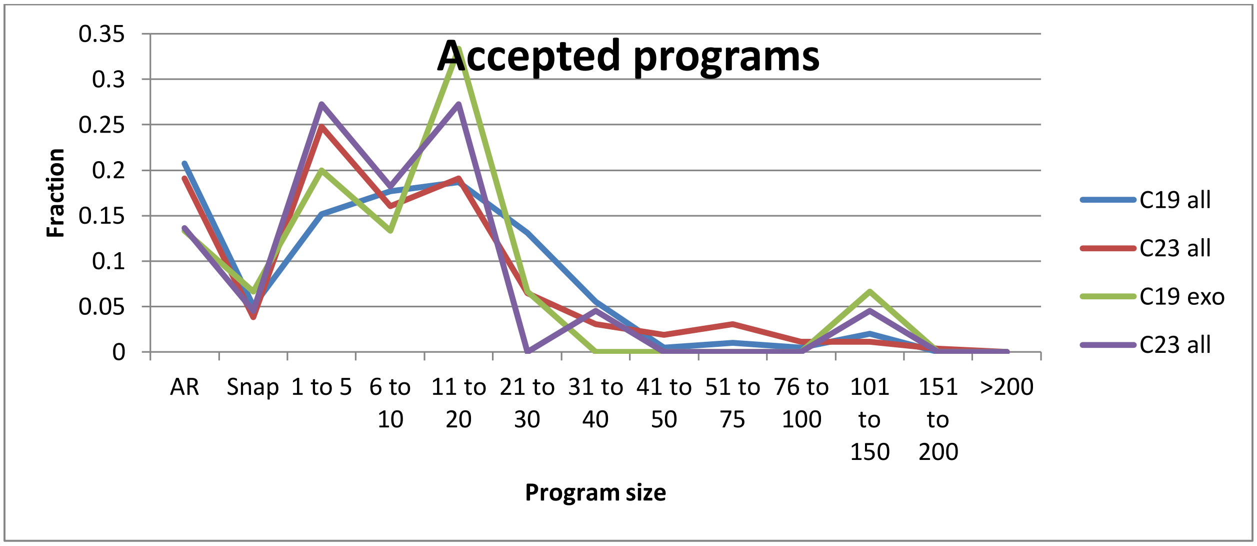

Figure C4: Normalised distribution of program size, accepted proposals, Cycles 19 & 23, all proposals and exoplanet proposals

Finally, Figure C5 compares the success rate of exoplanet proposals against the average proposal success rate as a function of size.

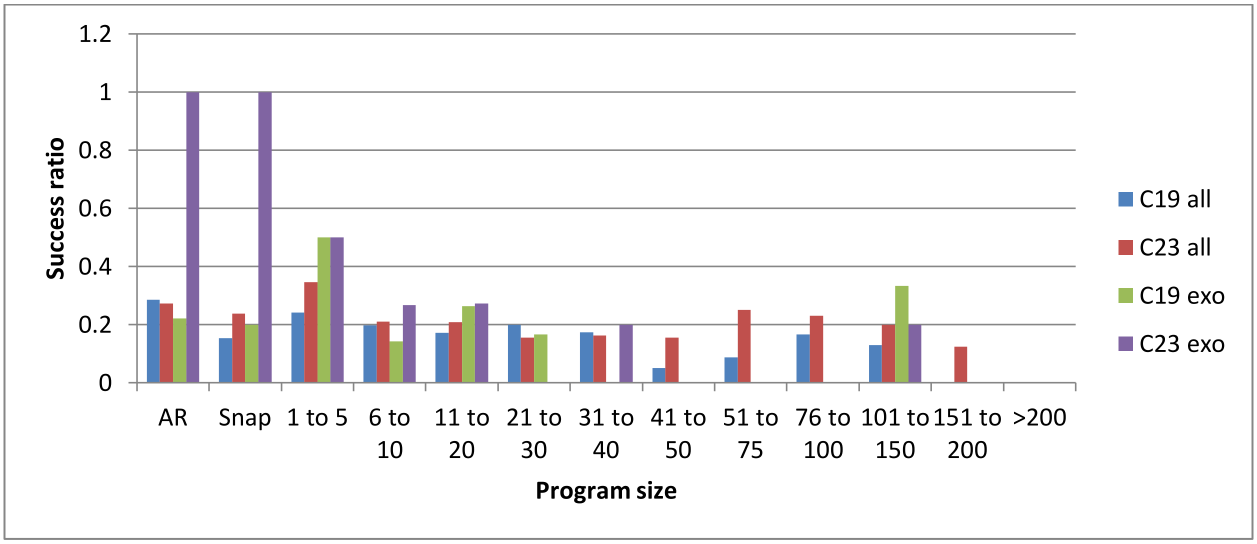

Figure C5: Success rate as a f(size) for all proposals and exoplanet proposals in Cycle 19 and 23