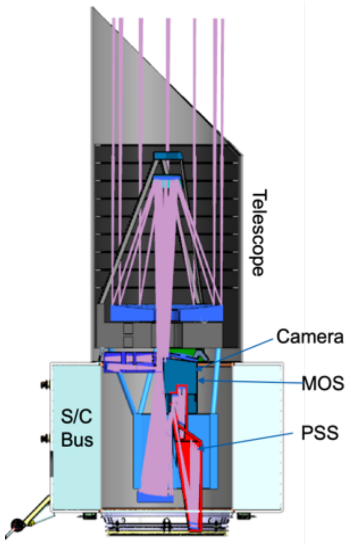
COSMIC EVOLUTION THROUGH UV SURVEYS (CETUS)



Thematic Activity: Project (probe mission concept)
Program: Electromagnetic observations from space

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1. Science goals & objectives

1.1 Astrophysics in the 2020's

The goal of the probe-class mission concept called "Cosmic Evolution Through UV Surveys" (CETUS) is to serve as the scientific community as a worthy successor to Hubble[1], GALEX[2], and UVOT[3]. CETUS is planned to be operational at a time when there will be no other operational UV capability in the US space science fleet. CETUS will constitute a major advance over these older missions because it can take advantage of new opportunities as described below:

Golden era of surveys. In the 2020's, current and future wide-deep telescopes will be surveying the sky at wavelengths ranging from gamma rays to radio waves. Survey telescopes operational in the 2020's include E-ROSITA[4] (X-ray), Subaru's Prime Focus Spectrograph[5] (PFS) and the VLT's MOONS[6] spectrograph (optical-near-IR), the Large Synoptic Survey Telescope[7] (LSST; optical), EUCLID[8], the Wide-field Infrared Survey Telescope[9] (WFIRST), the Large Millimeter Telescope[10] (LMT), the Square Kilometer Array[11] and other radio telescopes[12]. CETUS will fill the UV hole in this panchromatic set of survey telescopes. Together, they will be synergistic, probing, for example, the Lyα/Hα/21-cm connection, or the IRX (UV/IR luminosity ratio)

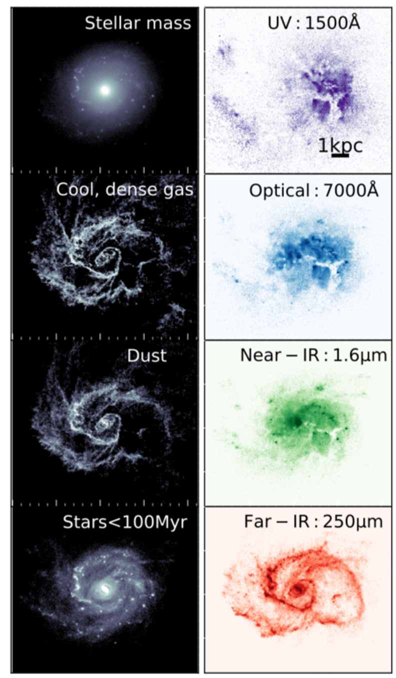

Figure 1-1. Fire-2/SKIRT Simulation of a galaxy at z=2.95. From Cochrane, Hayward et al. (2019)

High-resolution simulations. Simulations are needed to understand galaxy evolution over cosmic time. Cosmological simulations such as FIRE-2[13] (Fig. 1-1 left column), Illustris-TNG[14], and EAGLE[15] are already generating realistic physical models of galaxies with resolutions as high as 25 pc. Post-processing these simulations with the dust radiation-transfer code, SKIRT[16] produces predictions of observed morphologies[17] (Fig. 1-1 right) and wide-baseline SED's. CETUS UV observations will play an important role in checking the results of simulations and informing simulations about basic processes such as kinetic feedback from black-holes and dust-induced attenuation/IR re-emission, which presently are not well constrained by observation.

Advanced technologies. Except for the microshutter array[18] (NG-MSA), new technologies needed by CETUS are ready now -- from low-scatter gratings[19] to larger and better detectors[20], to telescope mirrors better than Hubble's[21], and mirror coatings enabling probes deeper into the far-UV while providing protection against degradation[22].

1.2 The CETUS mission concept

CETUS is a 1.5-m, *f*/5 wide-field telescope in orbit about Sun-Earth L2. In the course of study, the CETUS mission concept has gained unique capabilities that enable new scientific programs that were out of reach of Hubble, GALEX, and UVOT. They include:

A telescope better than Hubble. Thanks to advances in mirror polishing, CETUS spectra will not suffer from systematic mid-spatial frequency wavefront errors that plague Hubble far-

UV (FUV) spectra[21]. These errors produce extensive wings of the line-spread function, which are at the level of 1-2% of the continuum but contain as much as 40% of the line strength at far-UV wavelengths. A 40% deficit in the O VI line strengths is on the scale of the missing baryons at low redshift. We expect that *CETUS will make an accurate inventory of baryons in the warm-hot circumgalactic medium and find or confirm missing baryons at low redshift*. Cf. Oppenheimer et al. #309.

Sensitivity to low surface-brightness sources. With its *f*/5 focal ratio, *CETUS is 23 times more sensitive to low surface-brightness sources than is Hubble.* This sensitivity will be put to good use in observing diffuse sources such as the circumgalactic medium (CGM) or intra-cluster medium as recomentded by Burchett #591.

Probe of extended sources. By design[23], the FUV spectrograph can obtain R~20,000 spectra over the wavelength range, 1000-1800 Å *and* accommodate a 6'-long slit. Thus, *CETUS spectra can follow changes along the slit in ionization level, metallicity, velocity, etc. of low-mass galaxies like M 82 to massive galaxies like M 87 in all phases*: cool (Lyα, C II 1335), warm (Si IV 1393), warm-hot (O VI 1032, 1038), and hot ([Fe XXI] 1354) as recommended by several science white papers including Chen #366, Burchett #591, Martin #565, Oppenheimer #309.

Sensitivity in the deep far-UV. Thanks to advances in optical coatings[22], CETUS will be sensitive at wavelengths as short as 1,000 Å, thereby including O VI 1032, 1038, the only diagnostic of warm-hot gas (WHIM) in the circumgalactic medium (CGM). *CETUS will make a major study of the CGM surrounding nearby galaxies, especially dwarf galaxies that were out of reach of Hubble, and it will correlate the properties of the CGM with the properties of the parent galaxy*. Spectroscopy of the WHIM is called for in white papers by Tumlinson #421, Peeples #409, Lehner #524.

Restframe-FUV spectroscopy of z~1 galaxies. Using a multi-object spectrograph (MOS) with microshutter array (MSA) like the one in JWST to block unwanted background and eliminate confusion with nearby sources, CETUS will survey the near-UV (rest-UV) spectra of $>10^4$ z~1 galaxies. These UV spectra will be joined with optical/near-IR spectra from Subaru's Prime Focus Spectrograph (or ESO's MOONS) to create a continuous spectrum covering 0.2-1.3 μm (Heap 2016). This combination of spectra yields the physical properties, history of of star formation in galaxies, and feedback processes currently operating in these galaxies.

Rapid response to transient events. Spurred by the merger of the neutron-star binary, GW170817, followed by the emergence of a UV-bright kilonova, we added rapid-response capabilities to CETUS (see Table 1-2). With 25X the light-gathering power of Swift UV-optical telescope (UVOT) and its rapid response capabilities, the *CETUS camera will measure the light curve of a UV-bright kilonova 200 Mpc away.* Such capabilities are implicitly called for by white papers by Metzger #342 and Grindlay #607.

Investigation of fundamental physical processes. The combination of a wide field fully encompassing a nearby galaxy, full FUV spectral coverage of 1,000-1,800 Å, and FUV long-slit spatial coverage of 6' (e.g. 18 kpc at 10 Mpc) makes it possible for CETUS to carry out a detailed, quantitative study of nearby galaxies and clusters at high resolution (e.g. 27 pc at 10 Mpc). *Combined with simulations of comparable resolution and observations made in other spectral regions, CETUS will investigate fundamental processes like star formation and quenching in galaxies including the role of the CGM.*

Highly efficient observations. Each of the two wide-field instruments on CETUS – the NUV MOS and far-UV/near-UV camera – has a mechanism that enables dithering while holding the telescope pointing steady, so that *MOS and camera can obtain useful observations in parallel with the prime instrument, thereby doubling or more the observing efficiency.*

1.3 Basic parameters of the CETUS science instruments

The overall goal of CETUS is to provide the astronomical community with a UV space telescope for the 2020's providing the most useful and reliable UV spectroscopic and imaging capabilities. The as-designed capabilities of CETUS shown in **Table 1-1** are its essential performance parameters. In all cases, there is a requirement for a 1.5-m telescope.

Table 1-1. Capabilities of CETUS Science Instruments

Instrument	Wavelengths	Field of View/Resolution*	Observing Modes
Camera	1150-1800 Å	17.4'x17.4' /Res=0.55"	5 nested, long-pass filters + 1 as yet unassigned
	1800-4000 Å	17.4'x17.4' /Res=0.40"	5 contiguous filters + 1 as yet unassigned
MOS Multi-object spectrograph	1800-3500 Å	17.4'x17.4' /Res=0.40" /RP~1,000	Open 2.75"x5.5" shutters at selected *x,y* positions
		2.75"x17.4' /Res=0.40"	Open shutters in *y*-columns at selected *x* positions
PSS Point/slit spectrograph	1000-1400 Å	2"x2" /RP~20,000 point source	Grating G120M
		2"x360" /RP~2,000 extended source	"
	1000-1800 Å	2"x2" /RP~2,000 point source	Grating G140L
		2"x360" /RP~ 200 extended source	"
	1800-3500 Å	0.5"x0.5" /RP~40,000 point source	Echelle grating, E270M

*Res=resolution; RP=spectral resolving power, $\lambda/\Delta\lambda$; grating nomenclature gives central wavelength in nm and resolution (L, M, H)

1.4 Key observables – objects and distributions

CETUS will observe new, previously unobserved classes of objects such as the Lyman-α sky or z~1 galaxies too faint for UV spectroscopy one by one. CETUS will also observe familiar objects but seen in a new way. New observing modes on CETUS include:

- multi-object slit spectroscopy,
- long-slit spectroscopy (FUV: 2"x6', NUV: 2"x17.4'),
- spectroscopy of the Lyman-UV (100-115 nm) spectral region,
- prompt-response observations of transients, and
- detection of low-surface brightness objects.

CETUS observables and their specific performance requirements on CETUS instruments and spacecraft are summarized in Table 1-2. The summary suggests that we may have just scratched the surface. Surely, new observers will think of other uses of CETUS.

Observables	Required Performance of Instruments & Spacecraft	Expected Results	References
Lyman-alpha Emitters (LAE) at low z	* Wide-field (302 sq. arcmin), FUV camera with 1000 times the FOV of Hubble's ACS camera but with same filter set * Fast f/5 telescope giving 23-fold increase in sensitivity to extended sources compared to HST	Detect 150 LAE-galaxies at z={0.05,0.15,0.27} per telescope pointing using filters {F125, F140LP, F150 LP} with 1-hour exposure in each filter	M. Hayes (priv. comm.) Chung et al. (2019)
LAE's at z~1-2	Wide-field (302 sq. arc min) NUV MOS with microshutter array (MSA) arranged as 17.4'-long slits	Detect 150 LAE galaxies at z=0.8-1.8 in each 10-hr observaion	Martin #565 M. Hayes (priv. comm.)
Lyman-α sky at z=0-2	* Wide-field FUV/NUV cameras, each with 5 spectral filters * Telescope aperture 9 times larger than GALEX	Using intensity mapping techniques, set tighter constraints on the non-ionizing UV background, leakage of Lyman continuum radiation, Lyα emission and escape fraction from galaxies	Chiang et al. (2019) McCandliss #592
z~1 galaxies	Wide-field, R~1,000 NUV MOS with ~100 open shutters of MSA trained on galaxies brighter than 24.3 AB mag	Survey the rest-FUV spectra of >10^4 galaxies & join with optical/NIR spectra for joint analysis	Astro2010 Panel Reports, p. 127 van der Wel et al. (2016)
Circumgalactic gas (CGM) around nearby galaxies	FUV R~20,000 spectrograph, λ=1000-1420 Å, sensitive to *all* phases of CGM from cold (e.g. H2 Lyman lines) to cool (C II 1334) to warm-hot (O VI 1032, 1038), to hot ([Fe XXI] 1354)	Obtain FUV spectra of the CGM around >200 nearby galaxies with emphasis on dwarf galaxies of all types, which were out of reach of Hubble	Oppenheimer #309, Peeples #409 Lehner #524, Tumlinson #421
Emission sources in galactic outflows, outskirts of massive galaxies, ICM	* FUV R~20,000 & R~2000 spectrograph	Explore properties of diffuse gas in all phases from cold (H2 Lyman bands) to cool (e.g. C II 1334) to warm-hot (O VI 1032, 1038), to hot (e.g. [Fe XXI] 1354)	Burchett #591 Chen #366 Anderson et al. (2018)
Nearby galaxies	* Wide-field NUV/FUV camera encompassing whole galaxy with resolution at galaxy at 10 Mpc = 27 pc * Long-slit FUV spectrum bisecting the galaxy	* High-resolution UV images for comparison with simulations, observations at other λ, correlation with CGM spectral properties * FUV spectra of stellar popuations, ISM, galactic winds	Gry #281, James #222 Pelligrini #450, P. et al. (2019) Orr et al. (2017, 2019) Terrazas et al. (2019)
Dust in galaxies	Wide-field NUV/FUV camera encompassing whole galaxy with NUV filter set customized for studies of dust attenuation	Map of dust attenuation parameters (UV slope, 2175-Å extinction bump) within galaxies	Hagen #593 Decleir et al. (2019)
Circumgalactic dust (aka reflection nebulae)	* NUV long-slit MOS	* Properties of galactic winds from properties of dusty outflows * O, Si, C depletion on dust from CGM gas absorption lines	Hodges-Kluck #276
Rapid transients: * NS binary mergers * Core collapse SN	* Wide-field NUV and FUV camera * Field of regard (FoR) > 2π steradian * HGA always ready to receive an alert from the ground; * Slew to anywhere in the FoR in <15 minutes	* Obtain NUV lightcurve of blue kilonovae * Identify CCSNe progenitor (red SG, blue SG, or WR star) by characteristics of FUV lightcurve	Metzger et al. (2015) Metzger #342 Nakar & Sari (2010)
Other transients: * Tidal disruption events * Flares in solar-type stars	FUV R~20,000 PSS; NUV R~1,000 MOS	* Monitor the evolution of TDE velocity, Doppler width, strengths * Place constraints on atmospheric heating and chemistry of exoplanets	Foley #329 CETUS Final Report 3/2019*
Stars * Primitive stars * Massive stars	* NUV R~40,000 echelle spectrograph * FUV R~20,000 spectrograph	* Probe the nucleosynthetic signatures of the first stars and SN via their imprint on 2nd-generation target stars * Probe late evolution, binary vs. single stars	Roederer #60, Bonifacio #605 Garcia #604
Solar system objects	* FUV camera and spectrograph * Responsiveness to events	Observations of the aurora on Jupiter and Saturn, exospheres of Mars and Venus, D/H ratio seen in Lyman-alpha from many objects including comets, etc.	Clarke #90 Chaufrau #63

Table 1-2. CETUS Observables

Astro2020 science white papers are identified by principal author and ID number. Full references for both science white papers and published papers are given on page, References to Table 1-2

*https://smd-prod.s3.amazonaws.com/science-red/s3fs-public/atoms/files/CETUS_Study_Rpt.pdf

2. Technical Overview

2.1 Elements of the CETUS Architecture

- *Orbit.* The observatory will operate in a L2 halo orbit with a <85° solar keep-out angle.
- *Telescope*. The 1.5-m primary mirror assembly and all optics will use mature, high-TRL substrates and optical fabrication methods resulting in much better control over mid-spatial frequencies than does Hubble and producing substantially better (gaussian) line-spread functions than achieved by Hubble's COS and STIS instruments.
- *Science Instruments*. Each of the three instruments -- camera, a point/slit spectrograph (PSS), and multi-object spectrograph (MOS) -- has its own aperture at the telescope focal plane, and each functions independently (with the exception that the prime instrument controls the telescope pointing and roll angle). Each instrument can be removed or inserted into the instrument bay without disturbing the others. Together, the instruments are managed under a single governing ICD and make use of commonality of detectors (CCDs and MCPs), thus having similar electronics, packaging, drivers and software. Commonalities of Offner relays and devices in the camera and MOS are recognized.
- *Maximization of Optical Efficiency.* To maximize UV transmission, the number of optics in the optical path is minimized. Al/LiF/ALD AlF_3 coatings on telescope and PSS mirrors give unparalleled transmission in the Lyman-UV (100-115 nm).
- *Thermal Stability and Control.* Thermally critical opto-mechanical components will be maintained between 280K and 300K. The observatory will be stable enough against thermal transients that it can be slewed anywhere in the anti-sun hemisphere in 15 minutes and be ready to observe. To protect the optics from contamination, all mirror and window surfaces will be biased slightly warmer than surrounding structures and can be elevated in temperature for periodic redistribution of any contamination.
- *Hardware Implementation*. Key contributors bring heritage-hardware experience to CETUS and access to facilities of appropriate cleanliness and capacity. The CETUS team has carried out design-to-cost methods including addressing the choice of "better" vs. "good enough."
- *Potential for Exo-Planet Observations.* The APC white paper on by Lisman et al. notes that CETUS might be the participating telescope for the Occulting Ozone Observatory (O3). In fact, the CETUS architecture can be made "starshade ready". While this possibility has not yet been specifically studied, there is no aspect of the current CETUS architecture that prevents it from participation in a starshade mission, albeit with some increase in cost.

2.2 Technology Drivers

Critical technologies for the MOS and the NUV/FUV Camera are listed in **Table 2-1**. The Next-Generation Microshutter Array (MSA) is the key technology for further development that is proceeding at GSFC with several design improvements and scale-ups already demonstrated and further array fabrication optimizations being addressed in a current 3-year SAT. Should this not be matured in time, the TRL 8 JWST NIRSpec MSA will be utilized.

***Table 2-1** CETUS optical technologies are mature or will be advanced to meet CETUS schedule requirements*

Technology	Heritage/ Comments
Next-Generation Micro-Shutter array for CETUS: a ~JWST-size NG-MSA with 380x190 shutters with 100x200 µm rectangular shutters	• The JWST NIRSpec MSA was space qualified with 365x172 array with 100x200 µm shutters, which makes it TRL 8. This MSA can be an off-ramp if the NGMSA is not TRL 5 at the start of Phase A (1 October 2023). • As part of an APRA program, a NG-MSA pilot 128x64 array was constructed, so the current TRL is 3-4. A NASA/JHU sounding rocket experiment with this NG-MSA is planned for the summer of 2019. • GSFC currently has a 3-year SAT grant for developing a 840x420 array for LUVOIR and HabEx, which CETUS can accommodate, and for maturing this larger NG-MSA to TRL 5 by 31 December 2021.
Large micro-channel plate (MCP) detector with high quantum efficiency in the FUV	The CETUS far-UV MCP detectors made by U.C. Berkeley Space Science Lab uses the same technology as flown on the Hubble COS spectrograph. • CETUS FUV Camera MCP uses CsI photocathode (~50x50mm) with MgF2 window – TRL 6+ • CETUS PSS FUV MCP uses a large CsI photocathode (200x70 mm) window-less as did the Hubble COS spectrograph. A 200x200-mm MCP has recently flown on a University of Colorado rocket experiment. Sounding rocket programs e.g. CU's DEUCE (2017, 2018) and NASA/JHU's planned July 2019 36.352 UG. continue to provide verification of comparable MCPs.
Mirror coatings for high UV-reflectivity down to 1,000 Å	UV mirror-coating technology has greatly improved in the past decade. Hot-deposition of Al/LiF coatings increase UV reflectivity[24], and a thin overcoating of AlF_3 laid down by atomic-layer deposition (ALD) protects LiF from humidity[25]. A 3-way partnership among Colorado University, Goddard (hot deposition), and JPL (ALD) has been successful in producing highly reflective mirrors for UV rocket payloads. This arrangement would work well for all CETUS mirrors except for the 1.5-m telescope primary, which is too big for current facilities. Collins is planning for large coating chamber, which might be modified to apply ALD coating on CETUS OTA PM, but we also want to identify a facility that could work closely with JPL, which is highly experienced in ALD coatings. Optics in instruments requiring NUV & FUV coatings - Materion (Barr) and ZeCoat are proficient in making special multi-layer UV coatings at these wavelengths, and applicable coatings have been demonstrated on small samples. Facilities exist for coating CETUS-size optics.

3. Technical Resources and Margins: Mass, Power, and Data Volume

CETUS Mass and Power

NORTHROP GRUMMAN

Subsystem	Mass (kg)	Msn Mode Power (W)	Slew Mode Power (W)	Comm Mode Power (W)	Comment
Spacecraft					
Structure and OSSA	502	587	587	587	19% of LV capability and OSSA heating
ACS	73	169	443	169	6x HR14-50
EPS	167	165	165	165	Used JPSS-2 Battery 2x 134Ahr (redundant)
C&DH	44	115	115	115	IEM and PIE w/memory
Propulsion	50	4	4	4	4x tanks and 16x thrusters
Thermal	38	200	200	200	3% of SC
Comm	46	20	20	159	42 Mbps with HGA (54cm)
Harness	150	0	0	0	12% 0f SC
SC CBE	1070	1260	1534	1399	
SC Contingency	178	189	230	210	16% mass and 15% power
SC Dry Mass Total	1248	1449	1764	1609	
CETUS Payload					
Payload CBE	895	614	614	614	
Payload Contigency	269	184	184	184	30% mass and 30% power contingency
Payload Total	1164	798	798	798	
Observatory Dry Mass	**2412**	**2247**	**2562**	**2407**	
Fuel	224				10 years of life
Observatory Wet Mass	**2636**				
LV capability	3375				
Margin	739				
Margin	22%			35%	Margin with all contingency and margin

The data volume generated is 26 Gbits per day if two instruments are operational. The total data volume downlinked to ground over the 5-year primary mission is ~ 50 Terrabits.

4. Launch requirements and launch vehicle

We initially had selected SpaceX's Falcon 9 as the launch vehicle for CETUS. However, as shown in Table 3-1 above, the mass margin (22%) is too small for a Class-B mission concept at such an early phase of development. We have consequently budgeted for a Falcon 9 Heavy as shown in Table 7-1.

5. Organization, Partnerships, and Current Status

Figure 5-1 (left) shows the current CETUS organization with identification of partners who have helped to formulate essential mission parameters and derive engineering requirements, system architecture, and detailed designs as well as provide cost inputs. The right portion of Figure 5-1 shows the planned post-launch organization of CETUS.

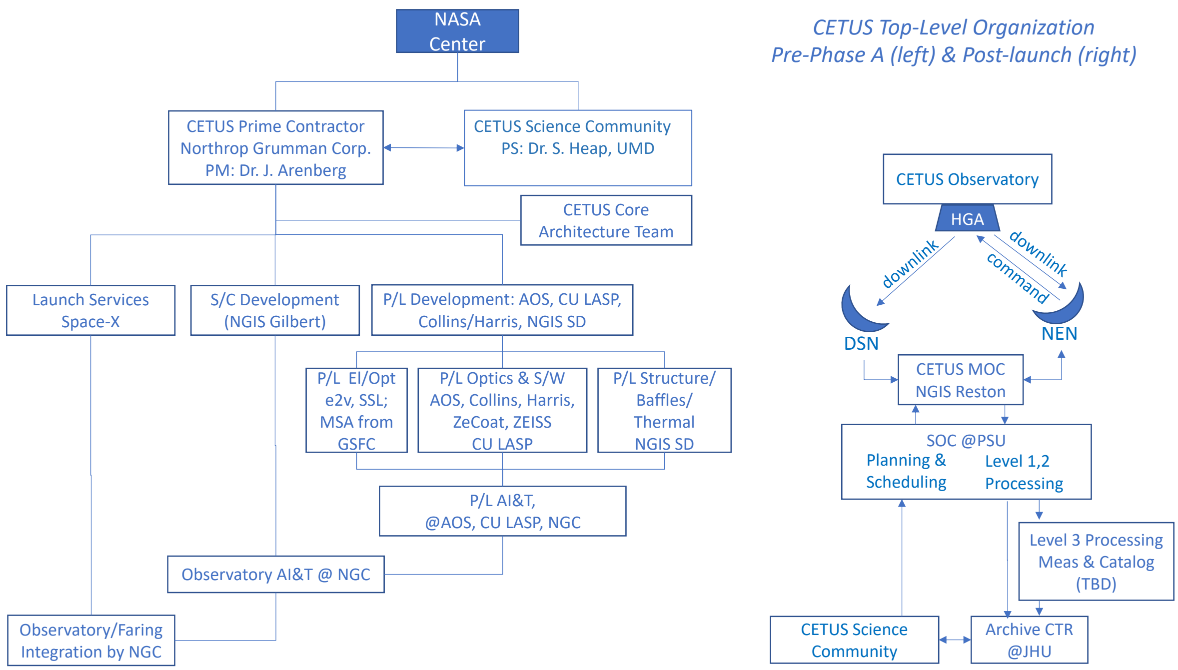

Figure 5-1. *The CETUS organization provides science, engineering, and management expertise to achieve successful CETUS development and mission operations.*

Over the past 40 years, UK and European institutions have worked closely with NASA on developing and observing on UV astrophysics missions such as the International Ultraviolet Explorer (IUE) and the Hubble Space Telescope (HST) in partnership with NASA. There is still keen European interest in UV astrophysics today. Of the 26 UV-related science white papers submitted to Astro2020, about a third were from Europeans. In addition, Neiner (WP #244) has submitted a proposal to CNES to study adding a polarimeter to the CETUS NUV spectrograph. In the coming months, we plan to explore partnerships on CETUS with European institutions.

6. Schedule

Figure 6-1 shows the projected schedule for development of the CETUS mission. It assumes a Phase A start in October 2023 and a launch in August 2029. Operations are planned for a 5-year mission, but consumables are planned to allow a 10-year mission. Continued technology development of areas discussed in Section 2.2 prior to 2023 are fundamental.

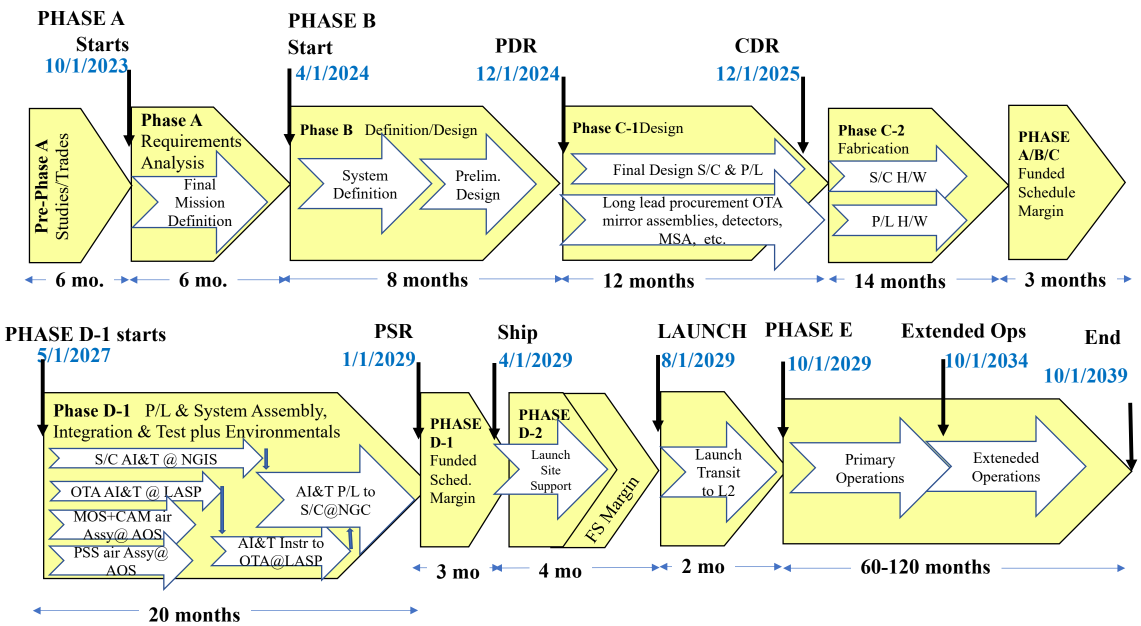

Figure 6-1. The CETUS schedule defines a realistic mission timeline for the 1.5-m telescope, scientific instruments, spacecraft, and AI&T at high-cleanliness UV-compatible facilities. It recognizes the efficiencies of expert and experienced industrial and academic facilities and allows funded schedule margin.

After our industrial and university partners vetted this schedule, we used this schedule, industry-norm labor rates and FTE loading to generate a cost estimate for CETUS as described in Section 7.

7. Cost Estimate

Table 7-1 *The cost of a CETUS 5-year mission is within the range of a Probe-class*

WBS #	**Phase A-D**	**Cost Estimate**		**Notes**
1.0-3.0	Management, SE, MA	$60 M		
4.0	Science Preparation	$8 M		Includes: monitoring CETUS hardware development; building/modifying s/w for levels 1,2,3 science data processing & s/w for measurement & on-line catalogs ; participation in pre-launch test and calibration
5.0	Payload (Instruments, Telescope)	$395 M		Based on industrial & institutional input from NGIS (Gilbert), NGIS (San Diego), Collins Aerospace, Harris Aerospace, SCHOTT, LASP (CU), Teledyne-e2v, JPL, GSFC, AOS, NGC. Multiple telescope cost models were used to derive the telescope cost estimate.
6.0	Spacecraft	$164 M		NGIS (Gilbert) based on significant TESS similaraties and TRL 7-9 hardware
10.0	Observatory I&T(ATLO)	$20 M		NGIS (Gilbert)
	30% Reserve Phase A-D	$194 M		
WBS #	**Phase E**			
1.0 - 3.0	Management, SE, MA	$2.4 M		
4.0	Science	$30.0 M		Includes: planning & scheduling, post-observation data processing at Penn State Univ; archival & analysis center at JHU; measurements & catalogs by TBD
7.0	Mission Operations	$15.0 M		NGIS (Gilbert); 5 yrs mission baseline; consumables for 10 yrs
9.0	Ground Data Systems	$2.5 M		
	15% Reserve Phase E	$7.5 M		
	Subtotal before Launch Vehicle	*$898 M*		
	Launch Vehicle/ Launch Services	$110 M		Space X Falcon 9 baselined in initial study, but to gain mass margin, we adopt the Falcon 9 Heavy ($90M plus $20M for launch services) https://www.spacex.com/about/capabilities
	15% Reserve on Launch Vehicle	$16.5 M		
	CETUS Total Cost	***$1,025M***		

CETUS costs have been derived from industry/university input following significant design effort. High-heritage, high TRL components have been used throughout. Industrial partners have been selected with the approach "go to the experts," and each has well-established expertise in its area of engagement. This table includes all costs that will be funded by NASA. Direct funding to the science community is described in WBS 4 for both pre-launch (Phase A-D) and post-launch (Phase E) periods.

8. References

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591	Burchett	Ultraviolet Perspectives on Diffuse Gas in the Largest Cosmic Structures
63	*Chaufrau	UV Exploration of the solar system
366	Chen	Tracking the Baryon Cycle in Emission and in Absorption
90	Clarke	Solar System Science with a Space-based UV Telescope
329	Foley	Gravity and Light: Combining Gravitational Wave and Electromagnetic
604	*Garcia	Walking along cosmic history: Metal-poor massive stars
607	Grindlay	Big Science with a NUV-MidIR Rapid-Response 1.3m Telescope at L2
281	*Gry	Far- to near-UV spectroscopy of the interstellar medium at very high
593	Hagen	Spatially Resolved Observations of the Ultraviolet Attenuation Curve
276	Hodges-Kluck	How Does Dust Escape From Galaxies?
177	*Lebouteiller	ISM and CGM in external galaxies
524	Lehner	Following the Metals in the Intergalactic and Circumgalactic Medium
180	*Marin	The role of AGN in galaxy evolution: Insights from space ultraviolet spect
565	Martin	IGM and CGM Emission Mapping: A New Window on Galaxy and
592	McCandliss	Lyman continuum observations across cosmic time: recent developments,
342	Metzger	Kilonovae: NUV/Optical/IR Counterparts of Neutron Star Binary Mergers
244	*Neiner	Stellar physics with high-resolution spectropolarimetry
309	Oppenheimer	Imprint of Drivers of Galaxy Formation in the Circumgalactic Medium
450	Pellegrini	Making the connection between feedback and spatially resolved em-line
409	Peeples	Understanding the circumgalactic medium is critical for understanding
628	Pisano	Completing the hydrogen census in the CGM at z~1
193	*Rahmani	Quasar absorption lines as astrophysical probes of fundamental physics…
60	Roederer	The Potential of Ultraviolet Spectroscopy to Open New Frontiers to Study
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