International Conference on Space Optics—ICSO 2018

Chania, Greece

9–12 October 2018

Edited by Zoran Sodnik, Nikos Karafolas, and Bruno Cugny

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International Conference on Space Optics — ICSO 2018, edited by Zoran Sodnik,
Nikos Karafolas, Bruno Cugny, Proc. of SPIE Vol. 11180, 1118075 · © 2018 ESA
and CNES · CCC code: 0277-786X/18/$18 · doi: 10.1117/12.2536176

European and US technologies enable CETUS, an ultraviolet space telescope concept

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ABSTRACT

NASA has funded the Cosmic Evolution Through Ultraviolet Spectroscopy (CETUS) mission study in preparation for the Decadal Survey, ASTRO2020. CETUS is developed as a Probe Class Mission, a new NASA category for astrophysics cost capped at 1B USD. This enables larger and more sophisticated observatories than under NASA's Explorer Programs, but less ambitious than under NASA Flagship Missions. The NASA CETUS Study has resulted in a wide-field-of-view (WFOV) telescope of 1.5m aperture, with the colleting area by solid angle product A*Ω substantially higher than that for HST. CETUS will include a wide field camera, a multi-object spectrograph of the same field, and also a point source spectrometer reaching down to 100nm wavelength.

Keywords: CETUS, Ultraviolet, Multi-Object Spectrograph, Wide-Field-of-View Camera, Point Source Spectrograph, NASA Probe Mission

1. INTRODUCTION: CONTEXT

In the 2020's, current and future wide-deep telescopes will be surveying the sky at wavelengths ranging from gamma rays to radio waves. E-ROSITA (launch 2018) will perform an all-sky X-ray survey with unprecedented sensitivity and resolution; Subaru's Hyper Suprime Cam (HSC; operating now) and Prime Focus Spectrograph (PFS; 2020), and the VLT's LEGA-C spectral survey will concentrate on understanding the evolution of galaxies at redshifts z~1-2 through optical spectroscopy; the Large Synoptic Survey Telescope (LSST, 2021) will map the southern sky discovering billions of new galaxies and stars and detecting transient objects; the Wide-Field Infrared Survey Telescope (WFIRST, launch 2025) will make an imaging and slitless spectroscopic survey of the sky at near-IR wavelengths; and the Square Kilometer Array (SKA; 2021+) and other radio telescopes will map a billion galaxies using the 21-cm hydrogen line. These surveys will be highly synergistic leading to new, important discoveries.

But there is a glaring hole in this vision: it lacks a UV-sensitive telescope. This will hinder all astronomy, because the UV spectral region is so rich in diagnostics that it has become a natural and necessary companion to space and ground-based telescopes observing at all wavelengths. We are therefore developing the CETUS ("Cosmic Evolution Through Ultraviolet Spectroscopy") mission concept to fill that hole. NASA selected CETUS in March 2017 for study as a Probe-class mission (<$1B). Our objective is to determine how CETUS can best our understanding of our cosmic origins (How did we get here?) and the physics of the cosmos (How does the universe work?) in collaboration with other survey telescopes on the ground and in space.

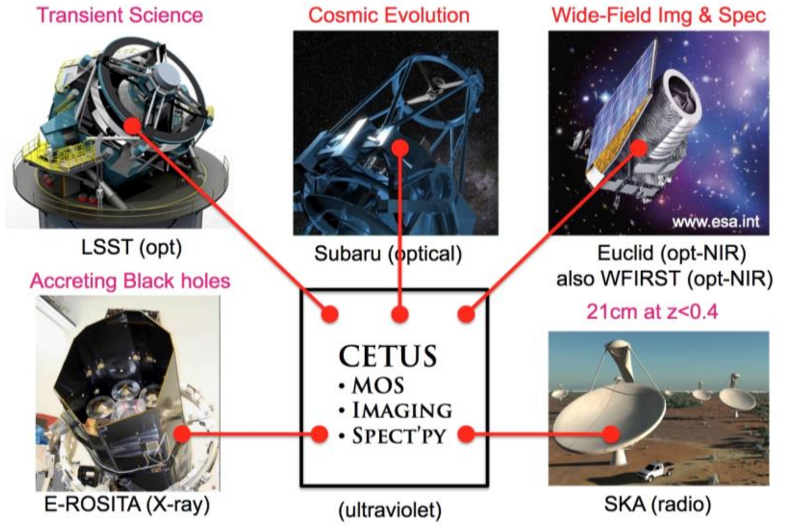


Fig. 1: CETUS will collaborate with other survey telescopes of the 2020's to solve major problems in astrophysics.

Some examples of potential collaboration are the following.

1.1 Properties of the circumgalactic medium and its role in promoting/suppressing star formation

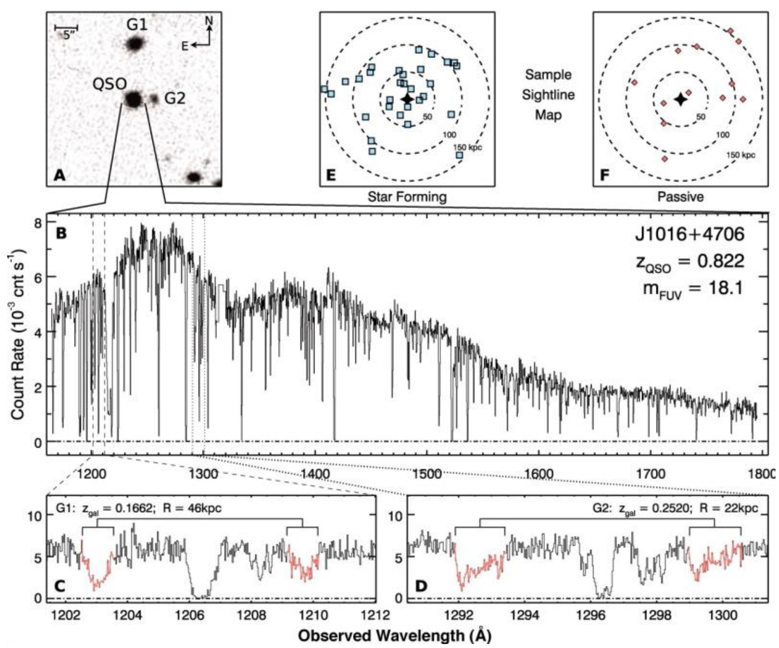


Figure 2: Sample far-UV spectroscopy of the circumgalactic medium (CGM) of galaxies G1 and G2 backlit by a QSO (upper left image). Spectral absorption lines from are at the redshift of CGM of G1 and G2. Figure credit: Tumlinson et al. (2011).

1.2 Properties of Tidal Disruption Events (TDE's) as first detected by LSST with follow-up FUV spectroscopy by CETUS.

Figure 3. Schematic of a tidal disruption event. CETUS will monitor the far-UV spectra of TDE's to faint magnitudes. The shredding of a star and the (re)-birth of an accretion disk around a massive, inactive black hole at the nucleus of galaxy as seen as a flare in brightness lasting over a month. Its far-UV spectrum resembles that of Wolf-Rayet stars. Image credit: M. Weiss, CXO.

1.3 Survey of redshift, z~1-2 galaxies observed in the optical-NIR by Subaru's Prime Focus Spectrograph (PFS) and in the UV by CETUS

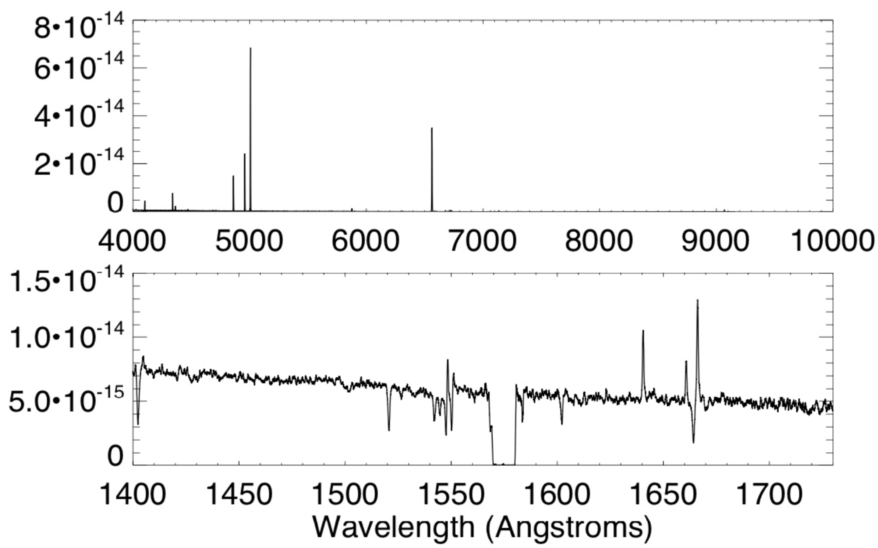


Fig. 4: Sample rest-frame spectra of a star-forming z~1 galaxy as would be obtained by Subaru PFS (top) and by CETUS (bottom). The observed PFS spectrum is dominated by nebular emission lines, while the CETUS spectrum is dominated by the stellar continuum and stellar wind lines.

1.4 Follow-up spectroscopy and photometry of the aftermath of a gravitational-wave event

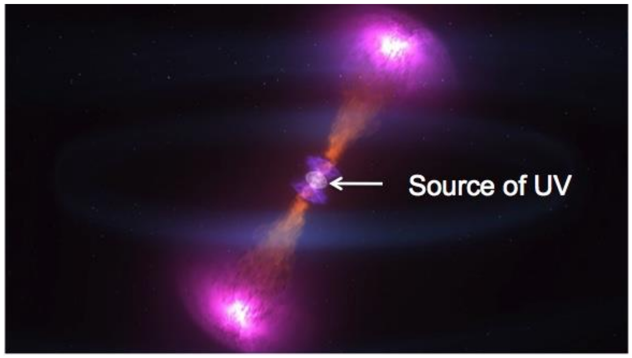
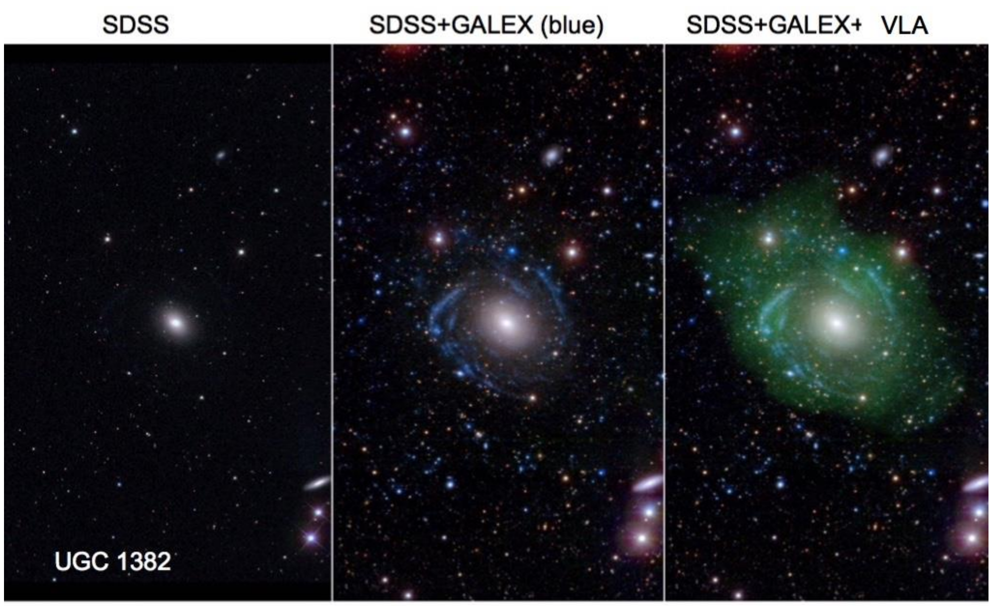


Fig. 5: The source of GW 170817 is thought to be the merger of two neutron stars. CETUS UV observations would focus on region close to the merger. Image credit: CILAB/GSFC.

1.5 Multi-wavelength properties of galaxies



Credits: NASA/JPL/Caltech/SDSS/NRAO/L. Hagen and M. Seibert

Fig. 6: Based on observations of the elliptical galaxy UGC 1382 by SDSS, GALEX, and the VLA, we expect the combination of CETUS far-UV or near-UV images with those from Euclid and SKA will bring big surprises and useful insights.

2. CETUS PAYLOAD

CETUS implementation includes a wide-field-of-view optical telescope assembly OTA yielding a product of area x solid angle over 40x that of Hubble. The design is for minimum reflections, and through advanced aluminum coatings with LiF and Atomic Layer Deposition overcoats, and highly efficient new detectors, allows for operations as short in wavelength as 100nm.

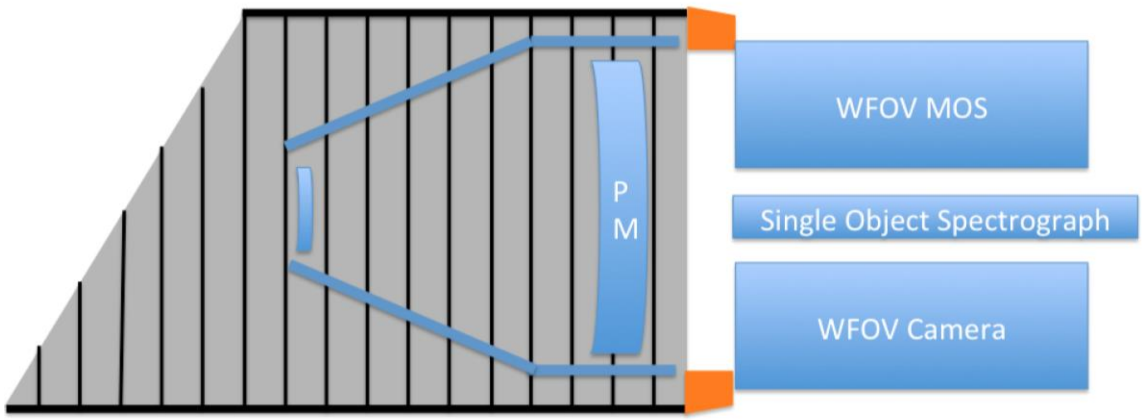


Figure 7: Schematic of OTA and CETUS instrument compliment: Multi Object Spectrograph, Camera and Single Objece Spectrograph. The OTA is actually a Three Mirror Anastigmat, not properly represented in this schematic.

A true representatin of the OTA ray trace is given in figure 8.

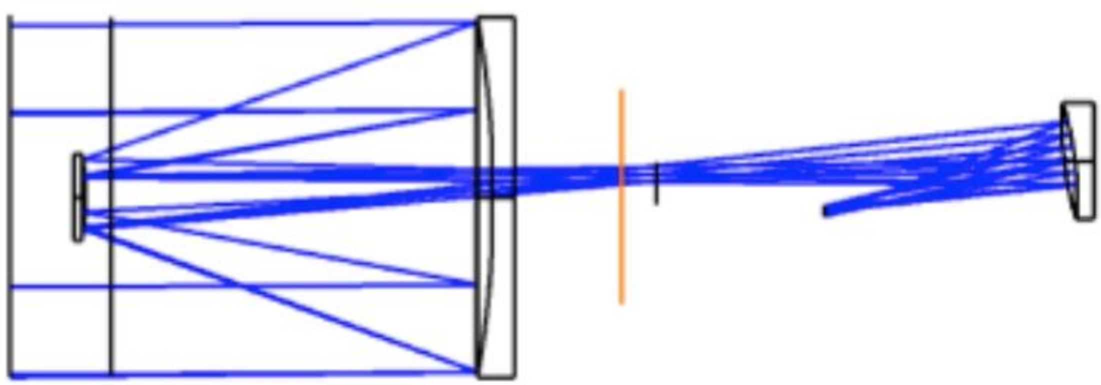


Figure 8: Three Mirror Anastigmatic form of CETUS OTA. The primary mirror has a clear aperture of 1.5m.

Figures 9, 10 and 11 represent the scientific instruments fed by the OTA.

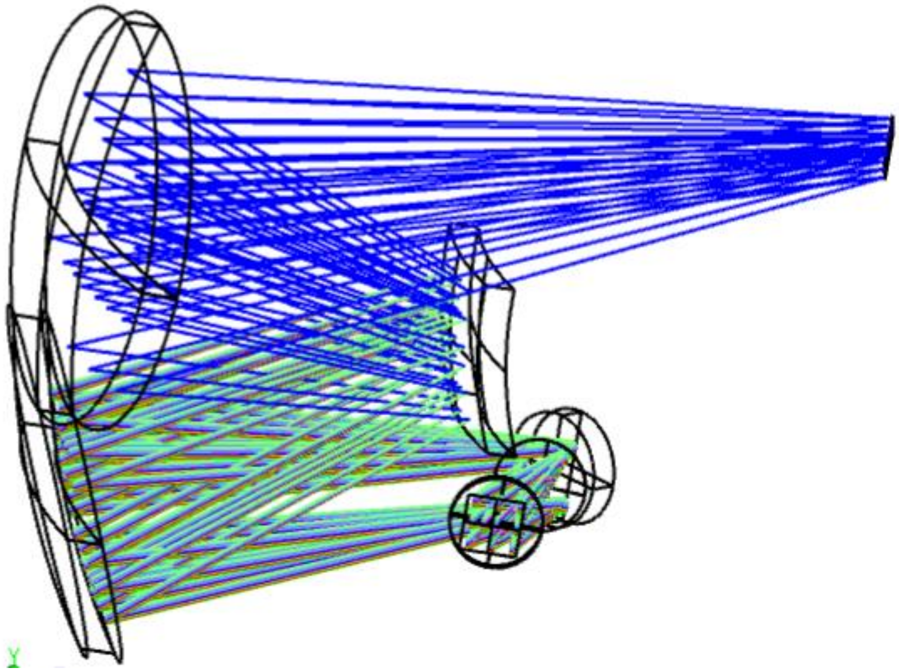


Figure 2-3: Multi Object Spectrometer, including a micro shutter array MSA at the right, and an Offner relay, with the secondary mirror being a spherical convex grating.

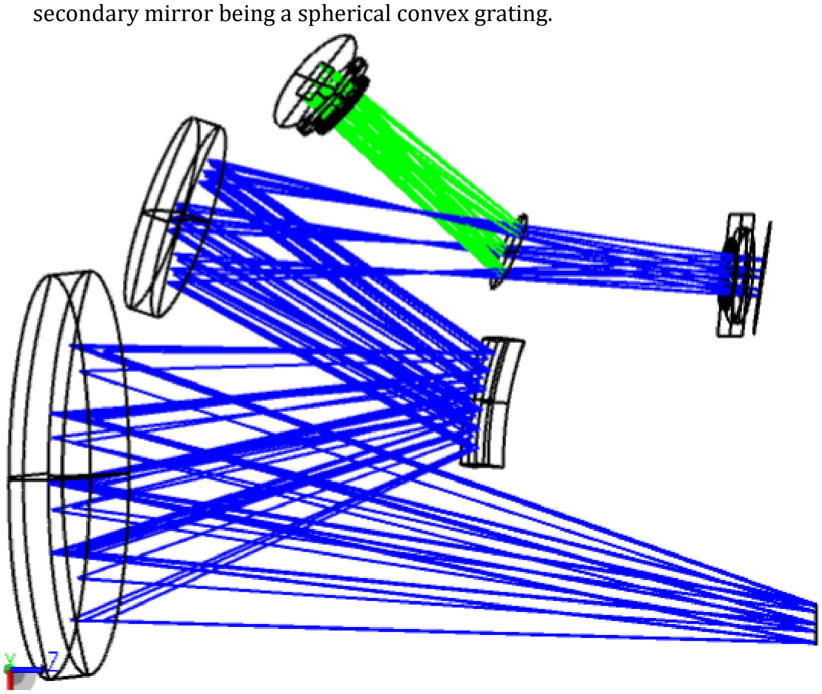


Figure 2-4 is the Camera, similar in scale and field to the MOS, except beam-split into two wavelength regions, and does not include a MSA.

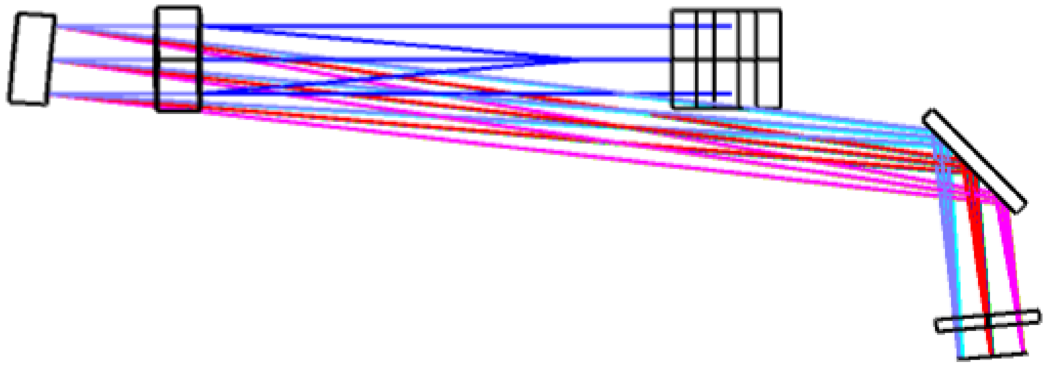


Figure 2-5 represents the Far Ultraviolet channel FUV or the Point Source Spectrograph PSS or Single Object Spectrograph. A very broad slit will span entire galaxies.

3.0 TECHNOLOGY CONTENT IN CETUS

CETUS relies heavily on international technology. Table 3-1 below examines principal technologies needed for the CETUS Payload. In some cases, technologies reside in either North America, and in other cases, technologies reside only in Europe. In some cases, there is suitable proficiency both in Europe and North America to produce the part, sub-assembly or even assembly.

Table 1: CETUS critical technologies come from both Europe and USA.
Some technology is approximately equivalent from both. A bold box indicates a gap.

Element of Observatory	USA Options	Europe Options
Observatory Launch to L2	Falcon 9	Arienne
Observatory AI&T: Payload + S/C	NGIS Gilbert	TAS, OHB Bremen, Airbus
Spacecraft Design, Fabrication & AI&T	NGIS Gilbert	TAS, OHB Bremen, Airbus
Payload Design	NGIS Gilbert	TAS, OHB Munich, Airbus
Payload AI&T	NGIS Gilbert, CASA at Colorad Univ	TAS, OHB Munich, Airbus
Optical Telescope Assembly Design & AI&T	AOS + NGIS San Diego	SESO, Reosc, AMOS, Zeiss
Mirror Substrates	Corning	SCHOTT AG
PM Polishing (MSF controls)	Brashear, UTAS, Coherent, Harris	SESO, Reosc, AMOS, Zeiss
SM, TM Polishing	AOS, Brashear, UTAS, Coherent, Harris, Zygo	SESO, Reosc, AMOS, Zeiss
Mirror Coatings Al+LiF	ZECOAT	
ALD protective coating	JPL	
SM Hexapod	Moog + AOS	PI + TBD
Thermal control	GSFC, AOS, NGIS Gilbert	TAS, OHB Munich, Airbus
Capping door	GSFC, AOS, NGIS Gilbert	TAS, OHB Munich, Airbus
GSE	GSFC, AOS, NGIS Gilbert	TAS, OHB Munich, Airbus
Multi Object Spectrograph (MOS) Design + AI&T	AOS + NGIS San Diego	TAS, OHB Munich, Airbus, LAM, Nice
Mirror Substrates	Corning	SCHOTT AG
M1, M3 Polishing	AOS, Brashear, UTAS, Coherent, Harris	SESO, Reosc, AMOS, Zeiss
Dichroic beamsplitter coating on M1 & M3	Materion	
Convex Grating		Zeiss
Grating mechanism	Moog + AOS	PI + TBD
Micro-Shutter Array (Gen 2)	GSFC	
CCD Detectors (Euclid)	Teledyne- E2V	
Delta Doping of CCD	JPL	
CCD Electronics	GSFC, ITT	TAS, OHB Munich, Airbus
Cooling	GSFC, ITT, NGIS Gilbert	TAS, OHB Munich, Airbus
Other mechanisms	Moog + AOS	PI + TBD
GSE	AOS	TAS, OHB Munich, Airbus
Wide Field Camera	AOS + OATK San Diego	TAS, OHB Munich, Airbus, LAM, Nice
Mirror Substrates		SCHOTT AG
M1, M2, M3 Polishing	AOS, Brashear, UTAS, Coherent, Harris	SESO, Reosc, AMOS, Zeiss
Dichroic Near UV BS Filter	Materion	Schott Yverdon
CCD Detector (Euclid) for NUV	Teledyne- E2V	
Delta Doping of CCD	JPL	
MCP Detector & Electronics for FUV	Berkeley SSL	
MCP Electronics	GSFC, ITT	TAS, OHB Munich, Airbus
Cooling	GSFC, ITT, NGIS Gilbert	TAS, OHB Munich, Airbus
Mechanisms	Moog + AOS	PI + TBD
GSE	AOS	TAS, OHB Munich, Airbus
Single Object Spectrograph Design + AI&T	LASP at CU, AOS + OATK San Diego	LAM, Nice
FUV & NUV Mirror Substrates		SCHOTT AG
FUV & NUV Mirror Polishing	AOS, Brashear, UTAS, Coherent, Harris	SESO, Reosc, AMOS, Zeiss
FUV Holographic gratings		Horiba JY
MCP Detectors	Berkeley SSL	
Detector Electronics	GSFC	TAS, OHB Munich, Airbus
NUV CCD Detector (Euclid)	Teledyne- E2V	
Delta Doping of CCD	JPL	
CCD Electronics	GSFC, ITT	TAS, OHB Munich, Airbus
NUV Echelle & Cross disperer gratings	Bach Research, PSU, ...	Horiba JY

For the OTA and each of the three instruments, there is roughly the same capability in Europe and in the US. Some components come only from one continent, but as in the case of JWST and Herschel/Planck instruments, this should be able to be navigated. While this is planned as a NASA project, the PI and team would welcome international participation both in implementation and in science.

4.0 CONCLUSION

CETUS is envisioned in the context of science of great interest both in The US and in Europe. CETUS architecture has favored what we believe to be the best-suited technology, without regard to country of origin. While still in a study phase, the CETUS team welcomes international discussions on both the scientific and technical level.

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