ULTRAVIOLET ASTRONOMY IN THE XXI CENTURY

e-Workshop 2020 – October 27-29

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Cosmic Evolution Through UV Surveys

OUTLINE OF TALK

Introduction to CETUS, a UV survey telescope

Science program examples

CETUS, an international telescope?

CETUS Final Report, arXiv 1909.10437
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New Capabilities → New Science

Fast Facts

- CETUS telescope: D=1.5 m, f/5
- 3 instruments: Camera, MOS, and spectrograph
- Field of view of wide-field instruments
  - FUV & NUV Camera: 17.4' x 17.4'
  - NUV MOS: 17.4' x 17.4'
- Spatial Resolution: 0.40'' (FUV), 0.3-0.4'' (NUV)
- Spectrograph Wavelength Coverage
  - LUV/FUV: 1000-1800 Å
  - NUV-Blue: 1800–4000 Å
- Spectral Resolving Power
  - LUV/FUV: 20,000
  - NUV: 1000 (MOS), 40,000 (Echelle)

Wide field of view to make UV img. surveys

Sensitivity to diffuse sources to find what's out there

LUV (1000-1150 Å) sensitivity to study the nearby WHIM

MOS/MSA Spectroscopy
SF regions in nearby galaxies, z=1 galaxies, etc.

Rapid response to catch GW sources, SNe
Survey mode: CETUS will work with other telescopes of the 2020’s to solve major problems in astrophysics.

- Optical Transients
- Optical – Near-IR
- Optical Transients Optical – Near-IR sub-mm to mm
- X-ray
- E-ROSITA (opt)
- Ultraviolet
- Rubin (opt)
- Subaru, Euclid, Roman
- ALMA

21 cm at z<0.4
SKA etc. (radio)
CETUS & X-ray telescopes will find the missing baryons in the circumgalactic medium

Adapted from N. Lehner

- X-ray
- UV
- Optical - NearIR
- Far-IR
- Radio
New studies by ALMA & MUSE of star formation as related to galaxy properties

ALMA / PHANGS CO (2-1) survey will observe "100,000 star factories" in 74 galaxies via CO (2-1) emission

Surface density of $H_2$ and $H II$ regions

$H\alpha$ & CO emission together enable a measurement of star-formation efficiency across a galaxy

ALMA image of NGC 528, also known as Messier 74, a spiral galaxy in the constellation Puppis, located approximately 32 million light-years from Earth. It is imaged as part of the PHANGS/ALMA survey to study the properties of star-forming clouds in disk galaxies.

Drift: ALMA (ESO/NAOJ/NRAO), MADCURNSF, B. Saxton

| X-ray | UV | Optical - NearIR | Far-IR-mm | Radio |
CETUS will also advance our understanding of star formation and stellar feedback.

CETUS UV images will show the large-scale structure of a galaxy -- young stellar populations and dust at ~20 parsec resolution.

CETUS NUV spectra will reveal the small-scale properties of the stars, interstellar gas, and dust extinction curve in every star-forming region viewed by PHANGS.
International Collaboration Would Make CETUS Even Stronger

Better Science
• Experience with IUE and Hubble shows the benefit of international, collaborative research
• European participation in Astro2020 Science White Papers & U.S participation in ESA’s Voyage-to-2050 papers strengthen the scientific case for an international UV telescope like CETUS

Availability of Cutting-Edge Technologies – no one country has an edge on all needed technologies for mirrors, gratings, detectors, etc.

Better telescope than one country can afford because of international contributions (SDSS-V involves 30 institutions)
• Instrument(s): Telescope
  NUV Multi-Object Spectrograph with NASA-supplied next gen. microshutter array
  FUV/NUV high-resolution spectrograph
• Some CETUS components are already planned to have an international source
  • Germany: Schott ZERODUR mirror substrates, convex grating for NUV MOS (Zeiss)
  • France: holographic gratings for FUV spectrograph (Horiba-JY)
  • Canada/U.K.: photon-counting T-e2v 4Kx4K EMCCD for all three NUV instruments (NüVü)
  • India: FUV filter wheels (from Korth or Crystran)
• Software: simulations, trade-studies
• Testing & Calibration
• Science operations, post-observation data processing, analysis tools`1
THE END

For details, download CETUS Final Report, arXiv 1909.10437

For copies of this presentation, email: sara.heap@gmail.com

Extra science cases follow
CETUS will directly observe feedback from stars, SN, SMBH.
CETUS will measure the abundances of extremely metal-poor stars found by SkyMapper (Australia) and Lamost (China)
CETUS will chart metal enrichment in the infant universe

The near-UV is rich in spectral diagnostics of metals (top-L) which enable detection of many more metal lines in the most metal-poor stars (top-R). CETUS will observe a larger sample of metal-poor stars than is available to HST’s STIS spectrograph (bottom-R).

Ian Roederer, Astro2020 Science WP
CETUS will follow up on LSST supernova alerts to learn how massive stars end their lives. CETUS will identify the progenitors of core-collapse supernovae by their FUV light curves (Nakar & Sari, 2010).
**Discovery mode:**
CETUS cameras will find what’s out there
All observations can be done in parallel

Discover \{25, 35, 30\} new galaxies at \( z = \{0.05, 0.15, 0.27\} \) with 1000X FOV of Hubble

FUV filter imagery

MRK 259

Ly \( \alpha \)

FUV continuum

M. Hayes

(a)

(b)

(c)

(d)

M. Hayes + 2016

| X-ray | UV | Optical – Near-IR | Far-IR | Radio |
CETUS will join Subaru/PFS & Roman to survey z~1 galaxies at $\lambda_{\text{rest}} \sim 0.1-1.0 \mu m$.

Using its NUV MOS, CETUS will obtain $>10^4$ NUV (rest FUV) spectra of $z\sim1$ galaxies to compare with HST UV spectra at low $z$.

In one pointing, the CETUS MOS will obtain spectra (blue) of $\sim70$ galaxies brighter than $m=24.3$ AB (red).
Discovery mode:
CETUS spectrographs will find what’s out there
All observations can be done in parallel

FUV long-slit spectra

NUV MOS long-slits

Discover >140 LAE’s at z~0.8-1.8
Credit: M. Hayes (priv. comm.)

Credit: I. Wold+ (2017)
CETUS will have rapid response (<15-min slew to target) to catch and monitor transients in the UV

Light curves of GW 170817

FUV Light curves of CCSN

Figure 2-23. CETUS will infer the progenitors of core-collapse supernovae from their FUV light curves. (Figure credit: Nakar & Sari, 2010)
CETUS will make systematic study of galaxy in UV
• properties - stars, gas, and dust,
• processes - star formation & feedback
via:

FUV filter imagery
FUV long-slit spectra

NUV filter imagery
NUV MOS spectra

and collaboration with multi-wavelength telescopes

X-ray  UV  Optical - NearIR  Far-IR  Radio

Figure 2-1. A collection of measured dust attenuation curves in galaxies illustrates the range in the 2175-Å bump and the UV slope, $\beta_{uv}$. From Hagen #593