The HORUS Origins Science Mission

To understand how the modern Universe of planets, stars, and galaxies came to be

Jon Morse, Paul Scowen, Matthew Beasley, Jeff Hester, Rogier Windhorst, Steven Desch, Rolf Jansen (ASU), Daniela Calzetti (STScI), Deborah Padgett (SSC/JPL), Patrick Hartigan, Chris Johns-Krull (Rice U.), Sally Oey (U. Mich), John Bally, Nathan Smith (U. Colorado), John Gallagher (U. Wisconsin), Robert O'Connell (U. Virginia), Robert Kennicutt, Jill Bechtold (U. Arizona), Tod Lauer (NOAO), Jason Tumlinson (U. Chicago), Alex Fullerton (JHU), Melissa McGrath (MSFC), Aki Roberge (CIW-DTM), Daniel Stern (Caltech/JPL), Oswald Siegmund (Berkeley/SSL), Robert Woodruff, Domenick Tenerelli (LMCO), Gary Matthews, Jeff Wynn (ITT), Jim Kaufman (JPL)

Overview

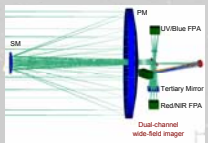
HORUS is a 2.4-meter class space telescope in an Earth-Sun L2 halo orbit that will address pivotal components in the NASA Strategic Roadmap. Optimized for conducting large surveys and operating at wavelengths that offer decisive advantages over ground-based capabilities, HORUS will provide 100 times greater imaging efficiency and >10 times greater UV spectroscopic sensitivity than currently exist on HST.

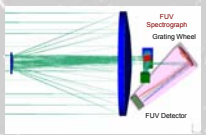
The HORUS mission has a well-defined Origins scientific program at its heart: a statistically significant survey of local, intermediate, and high-redshift sites and indicators of star formation to investigate and understand the range of environments, feedback mechanisms, and other factors that most affect the outcome of the star and planet formation process and the path from the Big Bang to people. This program relies on focused capabilities unique to space and that no other planned NASA mission will provide: near-UV/visible/near-IR (200-1100nm) wide-field, diffraction-limited imaging; and high-sensitivity, medium- and low-resolution far-UV (100-200nm) spectroscopy.

Science Objectives

- **How do solar systems form and survive?**
- **How do stars and galaxies form and evolve?**
- **How were the heavy elements necessary for life created and distributed through cosmic time?**

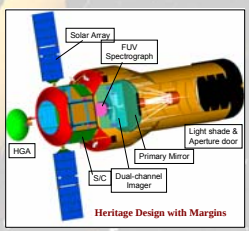
Primary Mirror Diameter:	2.4m (resolve ~100 AU scales at 2.5 kpc)
Wavelength Coverage:	200 – 1100 nm (imaging); 100 – 200 nm (spectroscopy)
Wide-field Imager:	0.05 arcsec/pixel (hi-res mode); and 0.1 arcsec/pixel (survey mode)
Field of View:	14´×14´ (~200 sq-arcmin; 8k×8k FPAs; >25× HST-WFC3)
Wavelength Multiplexing:	Dichroic split at ~510nm for simultaneous UV-blue and red-NIR imaging; optimized UV-blue and red-NIR channels
Imaging Survey Capability:	**> 40 sq-degs/yr** to surf. brightness 10^{-16} ergs/cm^2/s/arcsec^2 in multiple broad and narrow bandpasses
FUV Spectrograph:	100 – 200 nm; COS-like design; R~40,000 and R~8000 spectral resolution through 0.5" aperture
Telescope Optical Design:	Three mirror anastigmat; diffraction-limited in V-band
Detectors:	200-1100nm: Si-CMOS or CCD; 100-200nm Si-MCP-CsI
Orbit/LV and Mission Duration:	Earth-Sun L2; ATLAS V 511 with 5m shroud; 5 year core mission, 10 year extended mission; modular (serviceable)





Imaging System
- **Three mirror anastigmat for well-corrected 200 sq-arcmin field**
- **Dichroic split at ~510nm for simultaneous imaging in UV/blue and red/NIR channels**

Spectrograph System
- **Rowland Circle spectrograph provides R~40,000 resolution spectra from 100-170 nm using three first-order gratings**
- **R~8000 from 100-200 nm in single exposure**



	Mass* (Kg)	PWR* (W)
OTA	2107	417
SI	267	185
SC(dry)	811	347
Obs(dry)	3185	950
Obs(wet)	**3249**	**950**

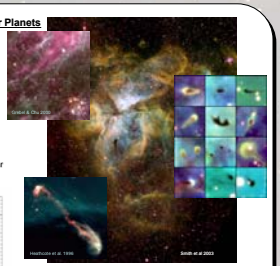
* Includes contingency

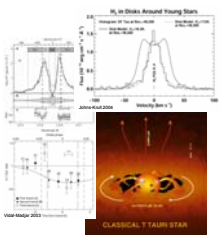
Step 1 — From Protoplanetary Disks to Extrasolar Planets

Systematic survey of stars and gas in Galactic massive star-forming regions to 2.5 kpc
- Census of exposed YSOs and disks
- Evolution and survival of circumstellar protoplanetary disks

- Precision astrometry and photometry for > 10^6 young stars
- Stellar parameters, multiplicity, and clustering statistics as functions of environment and location

- Jets and outflows: accretion history, feedback, and molecular cloud chemistry
- Structure and dynamics of HII regions: photoevaporation, stellar winds, supernova remnants, and supershells/superbubbles



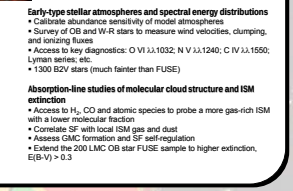


Accretion dynamics and disk evolution
- T Tauri, Herbig Ae/Be disk accretion rates, structure, composition, and lifetimes
- Determine how much magnetic fields cushion material infalling from the disk onto the star
- Doppler tomography

Extrasolar Giant Planets
- Structure, composition, and evaporation rates of outer atmospheres of 51-Peg type EGPs
- Follow-up of *Kepler* candidates and ground-based surveys

Step 2 — The Magellanic Clouds: A Bridge to Nearby Galaxies

Systematic survey of LMC/SMC
- Feedback of massive stars to the ISM and life cycles of matter
- Comprehensive study of 30 Doradus super star cluster and giant extragalactic HII region (nearest example of GEHR)
- Quantitative parameterization of stellar clustering properties
  - complete UBV imaging survey of LMC and SMC
  - star formation coherence lengths
  - hierarchical clustering and clustering lengths



Early-type stellar atmospheres and spectral energy distributions
- Calibrate abundance sensitivity of model atmospheres
- Survey of OB and W-R stars to measure wind velocities, clumping, and ionizing fluxes
- Access to key diagnostics: O VI λλ1032; N V λλ1240; C IV λλ1550; Lyman series; etc.
- 1300 B2V stars (much fainter than FUSE)

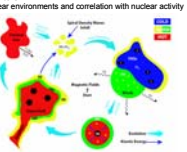
Absorption-line studies of molecular cloud structure and ISM extinction
- Access to H_2, CO and atomic species to probe a more gas-rich ISM with a lower molecular fraction
- Correlate SF with local ISM gas and dust
- Assess GMC formation and SF self-regulation
- Extend the 200 LMC OB star FUSE sample to higher extinction, E(B-V) > 0.3

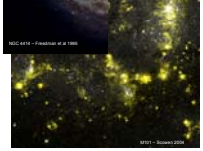
Step 3 — Star Formation in Nearby Galaxy Environments

HORUS Hundred Galaxy Survey (HHUGS)
- Quantify global SF rates, time scales, coherence lengths versus galaxy type, environment (e.g., spiral arms, bars), merger history
- Follow SINGS, GALEX

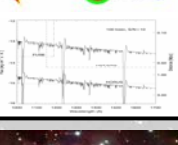
Stellar Populations
- Determine local SF history from metal-poor globulars
- Globular clusters, bulge vs. disk stellar populations, disk vertical structures, dust lanes, warps, etc.
- Near-field cosmology: the oldest stellar populations

Galactic Centers
- SF in nuclear environments and correlation with nuclear activity





Star Formation and Metallicity
- Measure feedback and life cycles of matter
- Use H_2 to measure to study heating/cooling balance, dust properties, radiative transfer, and kinematics as a function of metallicity
- Use O VI to study the interfaces of hot and cold phases of the ISM
- Extend abundance studies to lower metallicity



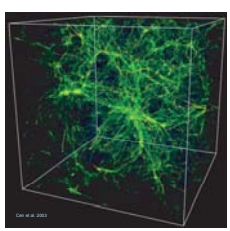
Early-Type Stars as a Function of Metallicity
- Stellar properties: stellar winds, ionization balance, and density structure; chemical composition and effective temperature
- Nearby low-metallicity analogs to high-redshift Universe

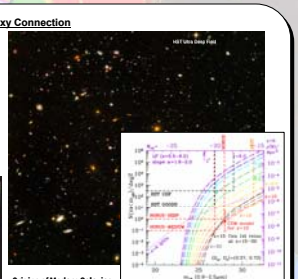
Step 4 — Galaxy Formation and the IGM/Galaxy Connection

The Onset of Galaxy Formation: Cosmic dawn
- LF of dwarf galaxies to AB ≤ 28 mag
- High-mass Pop II IMF and reionization at $z \sim 6$

Galaxy assembly in the range $1 < z < 6$
- Photo-z's for $6x10^5$ objects to AB ≤ 27 mag
- Constrain the growth of the Hubble sequence with time

Epoch-dependent merger rate
- Determine how dark energy has affected galaxy evolution
- Trace the growth of black holes in galaxy nuclei

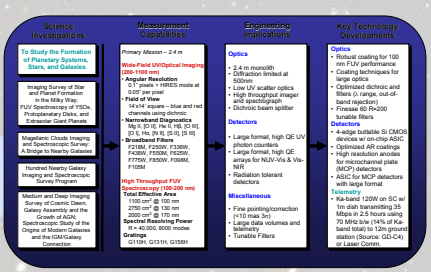


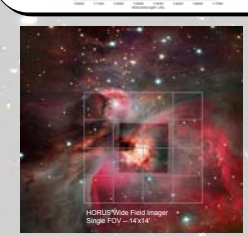


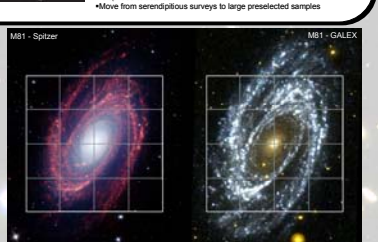
Origins of Modern Galaxies
- QSO absorption line studies
- Determine how modern galaxies acquire gas from the IGM
- Assess the "feedback" to the IGM
- Hot gas in galaxy halos may indicate history of mergers and/or interactions

Enabling capabilities
- Access to ionization diagnostics at $z = 0.0 - 0.2$ (SDSS universe); Lyα to $z \sim 0.5$; Lyβ/OVI to $z \sim 0.8$
- Sufficient spectral resolution to separate blended components in multiphase structures
- Move from serendipitous surveys to large preselected samples

Design Reference Mission Programs	# Days
Star and Planet Formation in the Milky Way	400
From Protostars to Planetary Systems: FUV Spectroscopy of YSOs, Protoplanetary Disks, and Extrasolar Giant Planets	119
The HORUS Magellanic Clouds Survey: A Bridge to Nearby Galaxies	170
The HORUS Hundred Galaxy Survey (HHUGS) Program	32
A Spectroscopic Survey of Stars and Gas in Metal-Poor Environments	100
The Medium and Deep HORUS survey of Cosmic Dawn, Galaxy Assembly and the Growth of AGN	132
The Origins of Modern Galaxies and the IGM/Galaxy Connection	150
(5-yr Observing Plan: 60% Legacy Programs, 40% Guest Observer) Total:	**1103 (3.0 yr)**







L2 Halo Orbit

Telemetry System
- Command uplink and system health downlink: X-band 2 kbps down
- Data downlink: Ka-Band 35 Mbps

MTO testing Laser Communication system

Core Mission Margin/Contingency

L2 halo Orbit Options (LV: Atlas 511)	Mass / PWR % Margin	Mass / PWR Contingency	Days to orbit
Lunar Swingby w/Phasing Loops	26% / 58%	19% / 16%	~130

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