**Recommendations to the COPAG Executive Committee by the SIG #2**

**A Response to the Charge made of the NASA PAGs by Astrophysics Director Paul Hertz on the Question of Next Generation Flagships**

**[UV-Visible Astronomy]**

## Background

In January 2015, Dr. Paul Hertz asked the NASA's Astrophysics Program Analysis Groups (PAGs) to collect and analyze the community's thoughts on which future Flagship missions NASA should give input on for the 2020 NRC Decadal Survey on Astronomy and Astrophysics. This request to the PAGs was motivated by the need to ensure that any Flagship concept presented to the Decadal Survey was sufficiently developed both scientifically and technologically as to be considered plausible and feasible. Four possible Flagship concepts are currently under discussion: a Far-IR Surveyor, a Habitable-Exoplanet Imaging Mission, a UV/Optical/IR Surveyor, and an X-Ray Surveyor. NASA intends to invest limited funds in key technology development that would enable the science and mission concepts envisioned. To this end, the directed charge was:

- Each PAG should reach out to their communities to review the starting set of four Flagship concepts and to suggest additions, subtractions, and providing useful commentary.
- Each PAG will consider what mission studies should be performed to advance astrophysics as a whole.
- Each PAG should not consider that any one mission concept "belongs" to them.

Reports submitted by the PAGs will be used by NASA as the basis for the following subsequent steps to develop these mission concepts:

- Identify a small set of candidate large mission concepts
- Form a community-based Science and Technology Development Team (STDT) for each of these mission concepts
- Ask the teams to articulate the key science drivers and to identify critical technology studies needed in the interim.
- Fund studies of critical technology requirements and ask the teams to review these
- Prepare a case for delivery to the 2020 Decadal Survey committee.

In November 2014, the NASA Advisory Council (NAC) Astrophysics Subcommittee approved a request from the Cosmic Origins Program Analysis Group Chair, Dr. Ken Sembach, to establish a new Science Interest Group (SIG #2) on the future of UV-visible astronomy from space. This SIG met for the first time in January 2015 at the Seattle AAS meeting, and proceeded to solicit community input in direct support of the PAG charges with the specific focus on the UV-visible passband. In June 2015, the SIG held a 2-day workshop at NASA's Goddard Space Flight Center to consider not only the issue of Flagship science, but broader compelling science in the UV-visible, the technology needed to enable that science, and the spectrum of mission sizes needed to conduct that science. As part of that workshop, the assembled community took the opportunity to address the questions levied by Dr. Hertz in a spirited discussion. This document includes a set of recommendations to the COPAG Executive Committee motivated by the discussion and agreement arrived at during the workshop.

**Recommendation Specifics – an Executive Summary**

The main recommendations of this SIG to the COPAG Executive Committee (EC) are summarized here. More details on the presented science and technology germane to these recommendations are given in the following sections.

- The SIG does not suggest any additions or subtractions to the list of four concept studies.
- The SIG strongly recommends the endorsement and study of both a 10m+ class UVOIR Surveyor and the smaller UV-visible HabEx mission concepts.
- The SIG recognizes the potential of the 10+ m UVOIR Surveyor to make compelling discoveries in both cosmic origins and exoplanet science.
- Based on input from the ExoPAG, the SIG assumes that HabEx concept is smaller than the UVOIR Surveyor although the exact HabEx aperture has not yet been determined. At this time, the SIG did not explicitly explore the astrophysical science applications of a smaller aperture mission. Although a smaller aperture telescope may address many of the same astrophysical themes, it cannot achieve the sensitivity or resolution that a larger 10+ m telescope will deliver. Even more than its aperture, the suitability of HabEx for cosmic origins applications depends critically on two yet-to-be defined capabilities: its field of view in the UV/visible and its sensitivity into the far ultraviolet.
- Among the critical UV-visible technologies that need continued investment to be sufficiently mature for consideration by the 2020 Decadal survey are optical coatings, large format radiation-tolerant photon-counting detectors, coronagraphs, and the accommodation of coronagraphic instruments in large-scale telescopes via technologies to address dynamics of the structure. It is particularly important to develop coatings and multiplexing detectors/instruments that maximize sensitivity into the far ultraviolet without compromising coronagraphic requirements.
- The SIG believes that a broad spectrum of precursor missions will be necessary to vet the new science, mature the required technologies and establish the credible workforce required to augment the scientific productivity and impact of large Flagships, while controlling risk and cost. These other missions include not only suborbital and explorer-class facilities, but also Probe-class spacecraft (cost <$1B), more ambitious than Explorers but more focused than Flagships.
- The SIG also believes there are several compelling opportunities to work with international partners towards Flagship-class missions that fulfill the science goals identified in this document, and we encourage NASA to explore these possibilities. In that regard, we see a benefit to including ESA, CSA and Asia-based scientists as observers in the STDTs and request that NASA pursue this possibility.

**Compelling Science that Supports a Flagship Mission Implementation**

The SIG and the COPAG solicited input from the astrophysics community in the form of short white papers and workshop presentations. We received a total of **35** of these relevant to the UV-visible and to Flagship-class implementation. While this document is purposely intended to be brief for easier digestion, we have asked all those contributors to summarize in Science Traceability Matrix (STM) form the goals and requirements of their science. We include this summary matrix below. This information has been collected in an attempt to represent the breadth of science that a Flagship-class UV-visible mission could address.

This STM details the range of science, the types of capability and how that science maps into fundamental mission properties such as aperture, spectral range, throughput, image scale, spectroscopic resolution, and other factors. On occasion our discussions included valuable relevant IR science goals and technologies. Many of the science problems presented here are motivated by the SIG's great interest in a 10m+ class telescope and require apertures of this size. We did not explore the extent to which 2030's era science goals could be partially addressed by smaller apertures. However, it is clear that wide-field imaging and high sensitivity into the Far-UV are essential requirements regardless of aperture size.

The scientific identity of each STM submission has been preserved to enable the STDT to interact with each submitter as appropriate. We could have further integrated the submissions to similar science questions and capabilities, but that would have represented additional work that NASA HQ has advised it did not want the PAGs to engage in to prepare these recommendations. We have merely presented work already completed as part of the SIG's deliberations running up to our workshop and provide it to the COPAG EC as information to be considered.

We have deliberately not tried to repeat the work of the AURA report "From Cosmic Birth to Living Earths", released July 6, 2015, which did an excellent job of summarizing many kinds of science that could be done with a Surveyor Flagship-class mission facility. However, we recognize that the AURA report was not complete due to their space limitations, and we wanted to make sure that no corner of the community was left unrepresented. That said, our summary is also not complete, but we believe it is more representative of the full range of potential UV-visible Flagship science.

This work should also be viewed in tandem with an earlier call from the COPAG about the future of UV-visible astrophysics in 2012 (Scowen et al 2014), where the focus was more centered on Hubble-class or slightly larger missions, and also in light of the findings of the Theia study (Kasdin 2009) which laid out the astrophysics goals for a 4m-class UVOIR mission.

**Technologies that Need Investment**

During the deliberations for the SIG workshop it became clear that technological advances for the UV-visible passband have been proceeding through a variety of development investments by both NASA's Science Mission Directorate and Space Technology Mission Directorate. However, the low maturity level of some crucial technologies does give cause for concern and the SIG makes the strong recommendation that additional immediate investment be provided if those technologies are to be advanced enough for consideration by the Decadal Survey in 2020. The SIG expresses some concern that the timescale for the STDT process is not necessarily consistent with the pressing schedule needed to ensure that the required technologies will conform with SMD guidelines for readiness.

The state of those technologies, their impact, and what additional investments could yield, are summarized in the attached table. Specific conclusions and recommendations include:

- **Reflective Mirror Coatings**: development of a reflective coating that can be deployed in a relevant environment (i.e., mirrors for space missions) that improve upon $MgF_2$ over Al. In addition, the coating must be scalable to a large aperture. The goals would be a reflectivity of > 70% from 90 – 120 nm, a reflectivity of > 90% from 120nm to 1.7 microns, uniformity < 1% for wavelengths > 90 nm, and polarization < 1% over the bandpass
- **UV Detectors**: visible/NIR detectors are excellent devices with improvements mostly being incremental for cosmic origins science, unless exoplanet science is required. One key feature would be better radiation tolerance than is available to state of the art silicon detectors. The lifetime of an instrument using these visible/NIR detectors is limited by the detector, not the spacecraft. For the UV, improvements to DQE – greater than 70% at 90 – 120 nm, larger formats (> 4k × 4k resolution elements), and improvements in dynamic range would increase

the science capabilities of a flagship mission. A stable (< 1 pixel) wavelength solution and the ability to observe to a very high signal to noise (>100) is critical to select scientific programs. UV detectors also need to be photon-counting in order to take advantage of the UV minimum in the natural sky background.

- **Opto-mechnical design and validation of large optical systems**: demonstrate fabrication of thermally-stable mirrors within a production schedule that have <7 nm RMS surface-figure. Demonstrate alignment and phasing of segments with gravity release and modeling to demonstrate on-orbit capability. Develop thermally- and dynamically-stable structures for mirror and instrument support. Demonstrate vibration isolation, metrology, and actuator performance to required levels. Validate structural-thermal-optical performance (STOP) models to the picometer level, and verify testing and on-orbit stability of the optical system. Additionally development of methods to reduce the areal cost of primary monolithic mirrors.
- **Polarization-preserving telescope coatings and configurations**: develop low polarization reflective coatings that can be deployed in a relevant environment (i.e., mirrors for space missions). In addition, the coating must be scalable to a large aperture. The goal would be a polarization uniformity of 0.01% to enable space-based precision polarimetry and coronagraph contrasts as high as 1E-11 necessary for terrestrial exoplanet characterization.

After good discussions with our exoplanet science colleagues, we recognize that any Flagship-class UV-visible mission will involve a partnership between the astrophysics and exoplanet communities and that it is essential that technology studies include the accommodation of both kinds of science.

The SIG recommends to the COPAG EC that additional investment be made in the listed critical technologies to enable the next generation science listed in the included Science Traceability Matrix.

## References


Kasdin, J., "THEIA: Telescope for Habitable Exoplanets and Interstellar/Intergalactic Astronomy", AIP Conf. Proc. **1158**, 359 (2009)

Scowen, P., Perez, M., Neff, S., Benford, D., "Scientific objectives for UV/visible astrophysics investigations: a summary of responses by the community (2012)", Experimental Astronomy, **37**, #1, pp.11-35 (2014)

**Science Traceability Matrix**

| Science Goal & Author | Investigation Theme | Investigation Science Objectives | Science Measurement Requirements | | Technical Requirements | | Instrument Performance | | Mission Requirements (Science Driven) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Observables | Physical Parameter | Type | Parameter | Baseline (ideal) | Threshold (minimum acceptable) | Parameter 1 | Parameter 2 |
| To learn how the gas in circumstellar accretion disks is distributed and evolves (Patrick Hartigan - Rice U.) | Use high-resolution narrow-band images to observe UV emission line gas diagnostics in order to spatially resolve the structure is accretion disks and to observe the sites of planet formation. Use moderate-resolution longslit spectra to observe spectral line ratios to determine physical conditions in the gas. Spatially-resolved images of the gas disks will reveal gaps, image accretion streams onto the star and forming planets, show sites of gas accretion onto newly formed planets, and reveal processes of disk photoevaporation. Time-resolved observations will reveal orbital and pattern motion, a critical factor in understanding the physics of accretion disks. | Spatially resolve gas disks in order to understand disk evolution and the formation of planetary systems | Emission Lines ($H_2$, CO) from cool circumstellar gas | Well measured line ratios of many lines will constrain the excitation (X-ray, thermal) and determine the temperature of the gas | Spectral | Spectral range | 912A-2000A | 1210-1700A | Longslit spectrograph, Pixel-size chosen as $\lambda/D$ for UV, Various gratings and slit widths | Spectral capability shortward of Ly $\alpha$, High-spectral resolution to resolve blends and detect Doppler broadening |
| | | | | | | Resolution | 1000-10000 | 5000 | | |
| | | | | | | Spatial coverage | 30 arcsec long slit | 10 arcsec long slit | | |
| | | | Emission Lines (atomic, high ionization states) from gas accreting onto young planets or gas flowing out in a photoevaporative wind | UV and optical spectra of plasma between $10^4$K and $10^5$K, including kinematic information | | Spectral range | 905A-7000A | 1000A-7000A | | |
| | | | | | | Resolution | 1000-10000 | 5000 | | |
| | | | | | | Spatial coverage | 30 arcsec long slit | 10 arcsec long slit | | |
| | | | Emission Lines ($H_2$, CO) from cool circumstellar gas | Narrow-band high-resolution imaging of emission lines and local continuum in the UV | Imaging | Pixel size | 2mas | 5mas | Imager with full suite of molecular and atomic filters | Optical and UV pixel size, wavelength range and filter specs |
| | | | | | | Filters | Several $H_2$ and CO lines spread across the 912 - 1700 Ang region. | 16 filter minimum | | |
| | | | | | | Field of View | 5 arcminute | 3 arcminute | | |
| | | | Emission Lines (atomic, high ionization states) from gas accreting onto young planets or gas flowing out in a photoevaporative wind | Narrow-band high-resolution imaging of emission lines and local continuum in optical and UV | | Pixel size | 2mas | 5mas | | |
| | | | | | | Filters | Lines: O VI, N V, CII, CIII, CIV, Si IV, He II, H-alpha, H-beta, [OI], [SII], [NII] | 16 filter minimum | | |
| | | | | | | Field of view | 5 arcminute | 3 arcminute | | |
| Understand when the first stars in the universe formed and how they influenced the environments around them (Dennis Ebbets - Ball Aerospace) | Confirm the identity of and begin to characterize the stellar astrophysics of the first stars (Pop III objects). | 1. Distinguish stellar objects from accretion disks of early black holes. Determine the redshift at which the earliest stars are observed. | 1. Redshifted wavelengths of Hydrogen and Helium lines from stellar atmospheres and surrounding gaseous environment. | 1. For redshift z=10 Hydrogen Lyman series will be observed between 1 to 1.4 microns. He II will be near 1.8 microns. | IFS and/or MOS spectroscopy | Wavelength range | 1000Å to > 2μm to cover stellar signatures from z = 0 to z =10 | | Field of Regard | Any place on celestial sphere over the course of one year |
| | | 2. Determine the end of the eopch of the first stars as the redshift at which the products of stellar nucleosynthesis first appear. | 2. Redshifted wavelengths of C IV, N V and O VI lines in stellar atmospheres. Redshifted wavelengths of nebular emission lines of ejecta from stellar winds and supernovae. | 2. Stellar atmospheric lines will be observable shortward of 1.8 microns. | | Spectral resolving power | $R = \lambda/D\lambda = 100$ to 200 to measure redshifts with precision of $D\lambda = 0.05$ | | Pointing stability, jitter control | 1/10 pixel of high resolution imager |
| | | 3. Investigate clustering characteristics, size of star-formation regions, number of objects per region. | 3. Spatial extent of star-forming regions. Number and distribution of individual objects resolvable. | 3. High resolution imaging at wavelengths near peaks of SED of Pop III objects at the observed redshift. | High-resolution imaging | Wavelength range | 1000Å to > 2μm to cover stellar signatures from z = 0 to z =10 | | Sky background | Minimize foregrounds to allow imaging of faintest diffuse objects |
| | | 4. Measure Spectral Energy Distribution, luminosity and effective temperatures. | 4. Flux of light in many spectral bands from observers frame ultraviolet through near infrared. | 4. Spectral Energy Distribution from photometry and/or low-resolution spectroscopy. | | Spectral bandpasses | $R = \lambda/D\lambda = 5$ to 50 with selectable central wavelength and selectable width. | | Exposure times | Exposures of 10 days or longer for spectroscopy of faint objects |

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| | | 5. Detect and characterize supernova explosions of Pop III objects | 5. Rise time, peak magnitude and decay rate. | 5. Multi-band light curves with a cadence sufficient to sample rise-time, isolate peak brightness and characterize decay. Low resolution spectroscopy to detect signatures of products of explosive nucleosynthesis. | | Spatial Resolution | 20 milli-arc seconds FWHM at λ = 1.0 μm. | Mission duration | > 5 years to allow complete temporal coverage of light curves of 10 or more Pop III supernovae |
| Understand how the universe came to be (mostly) ionized (Stephan McCandliss - JHU) | Determine galaxy and stellar cluster luminosity functions at energies above the hydrogen ionization edge from 0< z<3, covering 11 Gyrs of evolution | Detect and measure the flux above and below the 1 Rydberg in the rest frame of at least 25 galaxies and stellar clusters per redshift bin per luminosity bin to yield a confidence level of 20% per bin. | Mesure Spectral Energy Distribution above and below 912(1+z) with SNR>5 at 900(1+z) from stellar clusters and galaxies. | Intensity | Sensitivity (Expected limits for escape fraction: 100% at low, 1% escape at high z) | $f_{900(1+z)} = 10^{-15}$ erg cm$^{-2}$ s$^{-1}$ Å$^{-1}$ at z = 0.02 $f_{900(1+z)} = 10^{-20}$ erg cm$^{-2}$ s$^{-1}$ Å$^{-1}$ at z = 3 | | Aperture Driver (likely requires 12 meter Gregorian 2 bounce to meet low end) | |
| | | | | | Background | Interplanetary zodi and Lyman alpha limited | | Orbit Driver (L2) | |
| | | | | | Dynamic Range (whole sample) | 100000 | | Detector Driver | |
| | | | | Wavelength (Energy) | Bandwidth | 900 to 3650 Å | | Handle data rate and volume (high rates for bright multiplexed targets) | |
| | | | | | Spectral Resolution | 10 Å | | | |
| | | | | | Redshift resolution | ~ 1 Gyr bins over 11 Gyrs (0<z<3) (11 bins) | | | |
| | | | | | Luminosity resolution | 0.25 magnitude bins over 5 magnitudes of apparent magnitude (20 bins) | | | |
| | | | Hot Stellar Cluster 30 to 100 pc in diameter, Evolution from 0.02<z<3 | Angular | Resolution | 0.075 to 0.250 arcseconds at z= 0.02, 0.004 to 0.013 arcseconds at z=3 | | Attitude (pointing) hold to 0.02 arcseconds per several hour observation | |
| | | | Galaxies 1 kpc to 100 kpc in extent, Evolution from 0.02<z<3 | | | 2.50 to 250 arcseconds at z=0.02 , 0.13 to 13 arcseconds at z=3 | | | |
| | | | Total angular coverage for galactic luminosity functions > 1 degree to reduce cosmic variance | | Instantaneous FOV | Slits ~ 1.5 x 3 arcseconds$^2$ | | | |
| | | | | | Pointing, multiplexing | Multiobject spectroscopy over ~ 6 x 6 arcminutes$^2$ | | Detector and Microshutter Array (MSA) Driver | |
| | | | 25X20=500 Lyman continuum leaking objects per luminosity function. 11 Luminosity functions. Total galactic targets ~ 5500. Total cluster targets ~ 5500. | Temporal samples | Integration time | Depends on Aperture, Detector and MSA | | With multiplexing and high efficiency optical design program could be carrried out in 5Msecond. | |
| | | | | | Single observation duration | Several (5) hours for faintest, few seconds for brightest. Multiplexing is required. | | | |
| | | | | | Cosmic Time and resolution | 0 to 11 billion yrs, ~1Gyr resolution | | | |

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| Understand how the first stars influenced their environments, how the chemical elements were dispersed through the CGM, and how galaxies formed and evolved (Ian Roederer - U. Michigan) | (1) What were the properties (e.g., masses, rotation rates, binary fractions) of the first stars, and what were their supernova explosions like? (2) Better understand stellar nucleosynthesis by studying its products. Identify the nature and site or sites of the r-process. Characterize the physical parameters of the s-process. | Characterize the detailed abundance patterns of metals (Be, B, Si, P, S, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Zn, etc.) detected in absorption in long-lived, low-mass second generation stars. | absorption spectrum with S/N = 100/1 | Intensity | Sensitivity | S/N >= 100/1 per exposure (for brightest targets) | above earth's atmosphere |
| | | | | | Dynamic Range | N/A | |
| | | | hundreds of absorption lines of 10-20 species | Wavelength (Energy) | Bandwidth | 1700 to 3100 Angstroms | Echelle spectrograph should cover this wavelength range (or more) in one or (at most) two exposures |
| | | | resolve the stellar line widths, or come close | | Resolution | 60,000 sufficient (30,000 minimum; 100,000 ideal) | |
| | | | N/A | Angular | Resolution | N/A | |
| | | | single-object point-source mode is sufficient | | Instantaneous FOV | N/A | |
| | | | | | Pointing, scanning, etc | N/A | |
| | | | no time domain requirements (can co-add multiple exposures taken at different epochs) | Temporal | Integration time | tens of minutes | |
| | | | | | Single observation duration | whatever maximizes time on target to overhead | |

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| Conduct spectral imaging observations over the 1200-6600 A range, to advance our understanding of the formation, structure, and evolution of stars and stellar systems. (Ken Carpenter - GSFC) | Use ultra-high spatial resolution spectral-imaging to study the evolution of structure and transport of matter within, from, and between stars and to study stellar magnetic activity by resolving stellar surfaces. | Resolve stellar disks and the surface manifestations of magnetic activity in their atmospheres and the mass flows to, from, around, and between stars to understanding magnetic activity and its impact on the formation, structure, and evolution of stars and stellar systems. | Cover a range of wavelengths from 120 to 660 nm, from the UV into the mid-optical. | Find and determine the structure of physical manifestations of magnetic activity on and between stars. | Spectral | Spectral range | 120-660nm | 120-500nm | 20 filters OR energy resolving detectors | |
| | | | | Determine the physical conditions inside those magnetic structures. | | Number of filters | 20 | 8 | | |
| | | | Take time-resolved, high-quality spectral-images in UV of the surfaces of sun-like stars to 4pc and larger stars to further distances. | Find and follow the dynamic evolution of stellar magnetic structures; determine drivers of stellar magnetic activity with goal of understanding the | Spectral | Minimum SNR | 50 (all targets all filters) | | instrument throughput requirements | telescope aperture (sparse array diameter and individual mirror size) |
| | | | | | | Exposure times | 1 -60 min | 10 min | | |
| | | | Take time-resolved, high quality spectral images in UV of accretion, convection, shocks, pulsations, winds, and jets. | Find and determine the structure of such features. | | filter widths | 1 nm | 1 nm | 20 filters with well-characterized bandpasses OR energy-resolving | |
| | | | | Determine the physical conditions inside these features and measure their evolution in time. Improve theoretical models. Cadence from few hours to years. | | Central wavelengths | 120-660nm | 120-500nm | | |
| | | | | | | Repeat Obs. with cadence of few hours to a year or more. | 1 hr to 10 yr | 1 hr to 5 yr | stable instrument response | calibration program requirements |
| | | | Take high-quality images in UV at multiple wavelengths of stellar surfaces and intra-system flows. | Detect and measure manifestations of magnetic activity (e.g., plages, spots) | Angular | Resolution (defined at 150 nm) | sub-milliarcsec | sub-milliarcsec | Fizeau interferometer beam combiner that can handle ~30 separate beams. Energy-resolving detectors preferred. | Sparse array of ~30 spacecraft, each containing 1 m mirror, with array baselines adjustable from 100 to 1000 m maximum diameter. Plus beam combiner s/c at 5 km distance. |
| | | | | Detect and measure intrasystem mass flows. | | Instantaneous FOV | 4x4 milli-arcsec | 4x4 milli-arcsec | | |
| | | | Optical intensity (10 nm wide filters) variations as function of location on stellar surface with cadence of 1 min. | Perform astereoseismology to measure internal stellar structure. | | Acquire and readout time (optical) | 1 min | 1 min | readout time < 1 min | |
| | | | | Changes in internal structure as function of magnetic activity cycle. | | | | | | |

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| | | | Ultra-high angular resolution | Stellar surface and intra-system mass flows. | Precision Formation Flying | orbital location | L2 | | | Mission must be at Sun-Earth L2 to permit precision formation-flying of array. |
| | | | | | | Flight duration and timing | 10 year | 5 year | | Observe stars over significant fractions of magnetic activity cycles (5 yr min, 10 yr desired). |
| | | | | | | | | | | Other intra-system mass flows require 10 year mission. |

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| Conduct observations over UVOIR wavelengths, that contribute to the understanding of exoplanets and the circumstellar environment, the low mass end of the stellar IMF, the background | Systematic survey of circumstellar environments to determine distribution of matter. | Detect spatial distribution of dust, rings and protoplanets. | Extended circumstellar emission. | Intensity | Sensitivity | =Limiting Flux/SNR | | | 1:1e9 contrast ratio w/ CID | |
| | | | | | Dynamic Range | =Max Flux/ sensitivty | | | Roll control +/- 15 degrees within a visit. | |
| | | | | Wavelength (Energy) | Bandwidth | 2.0 microns+ | | | LEO, GEO or L2 for stable PSF | |
| | | | | | Resolution | Broadband | | | | |
| | | | | Angular | Resolution | 0.1" | | | All sky survey | |
| | | | | | Instantaneous FOV | 60" | | | 1/10 Pointing better than pixel size. | |
| | | | | | Pointing, scanning, etc | 0.01" | | | | |
| | | | | Temporal | Integration time | Background limited | | | Operate for 5+ years. | |
| | | | | | Single observation duration | Jitter limited | | | | |
| | Detect clouds and surface features of exoplanets. | Time resolved reflectivity of exoplanets. | Exoplanet light curves. | Intensity | Sensitivity | =Limiting Flux/SNR | | | Maintain fine guidance lock between orientations with muliple GS acquisitions. | |
| | | | | | Dynamic Range | =Max Flux/ sensitivty | | | | |
| | | | | Wavelength (Energy) | Bandwidth | 550 nm | | | | |
| | | | | | Resolution | Broadband | | | | |
| | | | | Angular | Resolution | 0.01" | | | | |
| | | | | | Instantaneous FOV | 10" | | | | |
| | | | | | Pointing, scanning, etc | 0.001" | | | | |
| | | | | Temporal | Integration time | Background limited | | | | |
| | | | | | Single observation duration | Jitter limited | | | | |
| | Constrain low end of the stellar | Deep imaging of star | Faint cool stars | Intensity | Sensitivity | =Limiting Flux/SNR | | | | |
| | | | | | Dynamic Range | =Max Flux/ sensitivty | | | | |
| | | | | Wavelength (Energy) | Bandwidth | 2.0 mcrons+ | | | | |
| | | | | | Resolution | Broadband | | | | |
| | | | | Angular | Resolution | 1" | | | | |
| | | | | | Instantaneous FOV | 300" | | | | |

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| background fields of bright stars, and the nature of QSO host galaxies. (Dan Batchelador - FIT) | IMF. | clusters and the field. | Faint cool stars. | Angular | Pointing, scanning, etc | 0.1" | | | 5-8m monolithic Cassegrain in oversize faring. | |
| | | | | Temporal | Integration time | Background limited | | | | |
| | | | | | Single observation duration | Jitter limited | | | | |
| | Deep survey of QSO hosts to determine distribution of matter. | Deep imaging of quasars. | Circumnuclear and extended field around quasars. | Intensity | Sensitivity | =Limiting Flux/SNR | | | | |
| | | | | | Dynamic Range | =Max Flux/ sensitivty | | | | |
| | | | | Wavelength (Energy) | Bandwidth | 500 nm - NIR | | | | |
| | | | | | Resolution | Broadband | | | | |
| | | | | Angular | Resolution | 0.1" | | | | |
| | | | | | Instantaneous FOV | 60" | | | | |
| | | | | | Pointing, scanning, etc | 0.01" | | | | |
| | | | | Temporal | Integration time | Background limited | | | | |
| | | | | | Single observation duration | Jitter limited | | | | |
| | Unknown discovery space around bright stars. | Deep imaging of bright star fields. | Bright stars. | Intensity | Sensitivity | =Limiting Flux/SNR | | | | |
| | | | | | Dynamic Range | =Max Flux/ sensitivty | | | | |
| | | | | Wavelength (Energy) | Bandwidth | UVOIR | | | | |
| | | | | | Resolution | Broadband | | | | |
| | | | | Angular | Resolution | 1" | | | | |
| | | | | | Instantaneous FOV | 300" | | | | |
| | | | | | Pointing, scanning, etc | 0.1" | | | | |
| | | | | Temporal | Integration time | Background limited | | | | |
| | | | | | Single observation duration | Jitter limited | | | | |

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| Tracing the galaxy evolution and rejuvenation processes in nearby (< 40 Mpc) early ty-pe galaxies (ETGs) in low density environments (LDEs). Combined observations with space (e.g. X-ray) and ground based radio and sub-millimiter new generation observatories are required | Derive mechanisms of evolution investigating ETGs, from giant to dwarfs, members of associations of different galaxy richness. Separate secular vs. external evolutionary mechanisms. | Reveal and map sub-structures in galaxies, e.g. stellar and gas streams, rings, shells, tidal tails, external UV disks. Investigate their link with the IGM. Determine the kinematics of the sub-structure, derive aboundances tracing stellar evolution and metallicity enrichment. | Multi-Object-Spectroscopy (R>=3000) large FOV (>=4') | Measure stellar and gas aboundances from absorption/emission features | Spectral | Spectral range | 350-1600nm | 350-900nm | Obtain 50-100 spectra per galaxies in Near UV, Optical, NIR | |
| | | | | Measure kinematics of substructures stars vs. gas from absorption/emission features | | Number of slits | 100 | 50 | | |
| | | | Far UV-Optical Integral Field Spectroscopy (possibility of Intermediate to high R<=100000) large FOV (>=4') | Measure stellar and gas aboundances from absorption/emission features | Spectral | Spectral range | 90-900nm | | Obtain 50-100 spectra per galaxy in Far UV-Optical | |
| | | | | Measure kinematics of Far UV bright sub-structures | | Number of slices | 100 | 50 | | |
| | | | UV-optical Imaging | Detect sub-structures. Build HR diagramsfor nearby ETGs. Measure physical properties and distribution of the gas e.g. | Photometry | Minimum SNR | 300 (all targets all filters) | 100 (all targets all filters) | an ample set of filters with well-characterized standard bandpasses including narrow band filters. | telescope aperture |
| | | | | | | Wavelengths range UV-Optical | 90-900nm | | | |
| | | | imaging NIR+MIR. | Detect sub-structures. Build HR diagrams for nearby ETGs. Measure physical properties and distribution of the gas (atomic, molecular) e.g. with | | Exposure times | 1–200 sec | 1–200 sec | | stable instrument response |
| | | | | | | Narrow band filter widths | <=10 nm | <=10 nm | | |
| | | | | | | Wavelengths range NIR+MIR | 1000-10000nm | 1000-5000nm | | calibration program required |
| | | | Cover a FOV as large as possible | Spatial resolution and FOV for | | Resolution (defined at 400 nm) | 0.05" | 0.1" | plate scale of 0.02" to 0.05" per pixel (for 2k | |

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| are required. (Roberto Rampazzo - INAF, Padova) | | | (>6') to map sub-structures at high resolution. | Spatial resolution and FOV for imager. | Angular | Pointing, scanning, etc | 0.1" error over FOV | 0.1" error over FOV | x 2k array); stable focal plane and telescope assembly | |
| | | | | | | Instantaneous FOV | >=6' | 4' | | |
| | | | | | Temporal | Total Integration Time | >10 hours | | | |
| | | | | | | Single Observation duration | 1-200 sec | 1-200 sec | | |
| To learn how accretion disks in young stars collimate and accelerate supersonic jets (Patrick Hartigan - Rice U.) | Use high-resolution narrow-band images to observe jets as they become collimated. Use spectral line ratios to define temperature, ionization fraction and density. Spatially-resolved higher-spectral resolution observations define dynamics within flows as they are launched. Time-resolved observations follow knots as they are ejected. UV spectra connect the flows to accretion events. | Derive physical conditions in jet collimation regions and observe time-evolution in order to understand MHD disk wind collimation and acceleration | Emission Lines from radiative shock waves | Spatially-resolved emission line ratios from the optical through the UV | Spectral | Spectral range | 912A-9000A | 1216-7000A | Longslit spectrograph, Pixel-size chosen as λ/D for UV, Various gratings and slit widths | Spectral capability shortward of Ly α, High-spectral resolution to resolve blends and detect Doppler broadening |
| | | | | | | Resolution | 1000-30000 | 1000-20000 | | |
| | | | | | | Spatial coverage | 5 arcminute slit | 3 arcminute slit | | |
| | | | Stellar accretion shock diagnostics | UV spectra of plasma between 10^4K and 10^6K | | Spectral range | 912A-3000A | 1000A-3000A | | |
| | | | | | | Resolution | 1000-30000 | 1000-20000 | | |
| | | | | | | Spatial coverage | N/A | N/A | | |
| | | | Emission Lines from reconnection point | Spatially-resolved UV spectra of plasma between 10^4K and 10^6K | | Spectral range | 912A-7000A | 912A-3000A | | |
| | | | | | | Resolution | 1000-10000 | 1000-3000 | | |
| | | | | | | Spatial coverage | 30 arcsec slit | 20 arcsecond slit | | |
| | | | Emission Lines from radiative shock waves | Narrow-band high-resolution imaging of emission lines in optical and UV | Imaging | Pixel size | 3mas | 5mas | Imager with full suite of nebular filters | Optical and UV pixel size, wavelength range and filter specs |
| | | | | | | Filters | SII 6716, SII 6731, NII 6583, Hα, OI 6300, NI 5200, OII 3727, OIII 5007, MgII 2800, CIII 1909, HeII 1640, CIV 1550, OVI 1036, etc. | 16 filter minimum | | |
| | | | | | | Field of View | 5 arcminute | 3 arcminute | | |
| | | | Emission Lines from reconnection point | Narrow-band high-resolution imaging of emission lines in optical and UV | | Pixel size | 3mas | 5mas | | |
| | | | | | | Filters | Similar to above | 16 filter minimum | | |
| | | | | | | Field of view | 20" | 10" | | |
| Obtain high-resolution ultraviolet spectroscopy of ~200 white dwarfs that are polluted by the debris of planetary debris. (Boris Gaensicke - U. Warwick) | Derive the bulk abundances of the planetary debris in these systems using model atmosphere and diffusion analyses. | Obtain a deep statistical understanding of the abundances of exo-planetary systems, that is comparable to what we achieved (primarily via meteorite studies) in the solar system. These data will guide our understanding of, and the theoretical models of planet formation | Ultraviolet spectroscopy, Photospheric abundances | Cover a wide range of atomic transitions, including C, N, O, Si, Mg, Ca, Al, Ti, S, P, Ti | Spectral | Spectral range | 92-360nm | 100-320nm | Detectors, optical elements, coatings | |
| | | | | Resolve line blends, separate photospheric and ISM lines | | Spectral resolution | 40000 | 20000 | Optical elements, detector size | |
| | | | | Increase sample volume accessible to detailed abundance studies | | Sensitivity | S/N~50 at 1e-15 continuum flux in 1h | S/N~50 at 5e-15 continuum flux in 1h | Coatings, no. of reflections, detector efficiency | Aperture size |
| Survey the extent and feeding of the CGM about galaxies. (Chris Howk - U. Notre | *Use multi-object spectroscopy (MOS) to map H I in CGM using multi-object spectroscopy of background galaxies/QSOs, examining external source of CGM flows (i.e., the connection to the IGM). *Use MOS to map individual launch points of feedback-driven outflows about | *Column densities and kinematics of CGM gas to R_vir. *Kinematics of outflows being fed by individual OB associations | H I Ly-alpha + Lyman break. O VI, C III, C IV. | Intensity | SNR | 25 | 10 | | Large aperture required to allow spectroscopy of faint background galaxies. | |
| | | | H I Ly-alpha + Lyman break. O VI, C III, C IV. | Wavelength | Range | 900-3200 Å | 1000-2000 Å | | Resolution+SNR push large apertures. Need good resolution for probing outflows / doing physics on CGM absorption. | |
| | | | Resolve Ly-series absorption from interloping IGM. Detect galactic outflows in O VI absorption toward OB assocations. | | Resolution | 5,000 | 2,000 | | | |
| | | | | | Resolution | | | | Sufficient to separate individual OB associations. | |

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| Howk - U. Notre Dame) | feedback-driven outflows about galaxies. Target OB associations across face of galaxies. *Map CGM in emission with long "stares" in an MOS mode. | individual OB associations. | | Angular | Instantaneous FOV | 6' – 10' | 2' | | FoV matched to virial diameter of massive galaxies at z~0.1 in the ideal case. Larger field provides more |
| | | | | | Pointing, scanning, etc | | | | |
| | | | | Temporal | Integration time | <50 ksec | | | Exposure times short enough to allow surveys of 10s of galaxies. |
| | | | | | Single observation duration | 5 ksec | | | |

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| Conduct a survey of the baryonic and metal content in the circumgalactic medium (CGM) of galaxies as a function of gas "phase." Trace the exchange of matter between galaxies and the intergalactic medium. (Chris Howk - U. Notre Dame) | *Map the circumgalactic medium absorption about individual galaxies toward several background sources at high resolution and signal-to-noise. *Measure velocities of circumgalactic gas with respect to galaxy host. *Assess metallicity from inner circumgalactic medium through the virial radius and into the intergalactic medium. *Use multiple ions to probe the distribution of baryons, metals with temperature. Probe the hottest 10^6 K gas at nearly the virial temperature with FUV/EUV transitions (O VI, Ne VIII, Mg X, Si XII) ; probe the cooler gas with H I, Si II, Si III, Si IV, C II, C III, C IV. | High resolution spectroscopy of UV wavelengths giving access to redshifted EUV/UV absorption/emission diagnostics | Detect weak EUV transitions tracing the hottest gas, low metal column density tracing IGM inflow. | Intensity | SNR | 50 | 25 | High SNR needed for weak metal lines. Pushes to large aperture, good reflectivity. |
| | | | Observe H I features incl. 1 Ryd break throughout Universe; access critical EUV transitions. | Wavelength | Range | 900-3200 Å | 1000-3200 | Resolution+SNR push large apertures. Need for multiple background objects (notably QSOs) also |
| | | | Resolve internal motions in CGM/diff. between phases. | | Resolution | 45,000-60,000 | 20,000 | |
| | | | | Angular | Resolution | | | Resolution sufficient to provide necessary spectral resolution. |
| | | | | | Instantaneous FOV | | | Key for CGM science is stable, well-characterized spectral LSF, preferrably very |
| | | | | | Pointing, scanning, etc | | | |
| | | | | Temporal | Integration time | <50 ksec | | Exposure times short enough to do many QSOs behind individual galaxies |
| | | | | | Single observation duration | 5 ksec | | |

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| Conduct ultraviolet to optical observations, that contribute to the understanding of the evolution and fates of massive stars. (Aida Wofford - Institut d'Astrophysique de Paris) | Collection of statistically significant samples over the entire HRD and in environments that are extreme in terms of SFR, metallicity, reddening. | Derive statistics on the physical properties of massive stars, their evolved descendants, and the precursors of supernovae (temperature, luminosity, mass loss rate, rotation speed, binary masses and periods, chemical composition of atmospheres and ejecta, spatial location as a function of type, variability) | Cover a range of wavelengths in UV and visible | Measure stellar temperature, luminosity, mass, mass loss rate, terminal velocity, rotation speed | Spectral | Spectral range | 90-1000nm | 120-1000nm | ??+ filter imaging in UV/vis range | |
| | | | | Measure chemical composition of atmospheres and ejecta | | Spectral resolution | - | 20,000 | | |
| | | | Take high-quality images of individual massive stars in | Study spatial location of massive stars and their | Photometry | Minimum SNR | - | 25 | instrument throughput | telescope aperture |
| | | | | | | Exposure times | - | - | | |
| | | | Cover a range of wavelengths in UV and visible | Measure extinction due to dust towards many sightlines | | Central wavelengths | 90-1000nm | 120-1000nm | ??+ filters with well-characterized bandpasses | |
| | | | | | | Accuracy and systematic error | - | - | | |
| | | | | | | Resolution (defined at 150 nm) | 0.05" | 0.1" | stable instrument response | calibration program requirements |
| | | | | | Angular | Stable distortion solution | 0.1" error over FOV | 0.1" error over FOV | plate scale of 0.02" to 0.05" per pixel (for 2k x 2k array); stable focal plane and telescope assembly | - |
| | | | | | | Instantaneous FOV | 60" | > 50" | | |
| | | | Sample at cadence tied to binary orbital motions | Obtain masses and periods of binaries | Target temporal sampling and sky location | Acquire and readout time | ?? min | ?? min | readout time < ?? min | - |
| | | | Sample at multiple epochs to study history of mass loss | Study eruptions of LBVs and other massive star descendants | | | | | | |
| | | | | Study conditons prior to supernova explosions | | | | | | |

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| Conduct observations from the UV to the radio to understand star formation within galaxies and how it drives galaxy growth througout space and time. (Daniela Calzetti - U. Massachusetts) | Observe nearby galaxies within 100 Mpc to obtain statistics within a representative volume of the Universe of star formation histories with lookback time from ~1 Myr to 13 Gyr. | Determine the Upper End (slope, maximum star mass) of the Stellar Initial Mass Function | Isolate massive stars within star clusters out to 10 Mpc and individual star clusters out to 100 Mpc | Intensity | Sensitivity | 2 M_sun star at 10 Mpc in 0.1 micron band |
| | | | | | Dynamic Range | 2-300 M_sun stars at 10 Mpc |
| | | | by getting their UV-to-nearIR spectra plus | Wavelength (Energy) | Bandwidth | 0.09-1.2 micron |
| | | | | | Resolution | 3000-5000 |
| | | | with spatial resolution of 0.05 pc (per pixel) at 5 Mpc and 1 pc at 100 Mpc | Angular | Resolution | 0.004" (2 pixels) |
| | | | and spatial coverage of 3 arcmin x 3 arcmin (rough galaxy size) | | Instantaneous FOV | 3'x3' |
| | | | | | Pointing, scanning, etc | |
| | | | Simultaneous coverage of multiple stars and star clusters (multi-object spectroscopy) | Angular | Aperture size (spectroscopy) | 0.006" |
| | | | | | number of apertures | >10000 each pointing |
| | | Reconcile the Local and Cosmic Star Formation Histories | Recent-past star formation histories (past 1 Gyr with 10 Myr time resolution) of local | Intensity | Sensitivity | m_UV~31 mag |
| | | | | | Dynamic Range | 8-10 mag |
| | | | by getting their UV-to-nearIR broad/medium/narrow band | Wavelength (Energy) | Bandwidth | 0.15-1.5 micron |
| | | | | | Resolution | 10-300 |
| | | | with spatial resolution of 0.05 pc (per pixel) at 5 Mpc | Angular | Resolution | 0.004" (2 pixels) |
| | | | and spatial coverage of 3 arcmin x 3 arcmin (rough galaxy size) | | Instantaneous FOV | 3'x3' |
| | | | | | Pointing, scanning, etc | |
| | | Determine the growth of galaxies by studying the stellar population content, star formation modes, and star formation histories of their outskirts | Color-magnitude diagrams of stars down to 0.5-1 mag below the Main Sequence turn off at | Intensity | Sensitivity | m_V=35 mag |
| | | | | | Dynamic Range | 8-10 mag |
| | | | UV-to-nearIR medium/broad band photometry | Wavelength (Energy) | Bandwidth | 0.15-1.5 micron |
| | | | | | Resolution | 10 -- 50 |
| | | | with spatial resolution of 0.1 pc (per pixel) at 10 Mpc | Angular | Resolution | 0.004" (2 pixels) |
| | | | and spatial coverage of 3 arcmin x 3 arcmin (rough galaxy size) | | Instantaneous FOV | 3'x3' |
| | | | | | Pointing, scanning, etc | |

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| Understand how protoplanetary disks evolve and form planetary systems (Kevin France - U.Colorado) | Determine the accretion luminosity of protostars, the composition of the inner 10 AU of planet-forming disks, and the lifetime of gas disks in young planetary systems | Mass accretion rates of protostars; abundances, physical conditions, and lifetimes of molecular gas in the inner regions of protoplanetary disks | 1) Flux calibrated and spectrally resolved ultraviolet/optical spectra of > 30 protostellar systems in each of 10 star-forming regions with a variety | Intensity | Sensitivity | S/N = 10 @ 1E -16 [erg /cm2/s] per 60s | In space, high QE detectors |
| | | | | | Dynamic Range | 1E-11 - 1E-19 [erg/cm2/s/A] | high count rate detectors |
| | | | 2) Spectrally resolved abosrption lines in high-inclination disks: H2, CO, H2O, atomic species | Wavelength (Energy) | Bandwidth | 2a) 91 - 170 nm, 2b) 100 - 400 nm | optical coatings down to 91 nm. high-resolutuion, low-scatter gratings. one high-resolution spectrograph and one multi-object spectrograph. flux standards for 2% absolute spectrophotometry |
| | | | 2b) H2 and CO fluorescent emission in disks of any orientation | | Resolution | 2a) 3 km/s for lines absorption lines, 2b) 100 km/s for emission lines | |
| | | | | | Resolution | 2" | N/a |

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| | | | | Angular | Instantaneous FOV | ~20' for MOS | FUV-MOS, e.g., microshutter device |
| | | | 3) Observe temporal variability of mass accretion, reverberation mapping of molecular emission lines | Temporal | resolution | 10 seconds | photon-counting detectors, L2 or elliptical orbit |
| | | | | | Single object observation duration | 5 hrs | |
| Characterize nearby habitable exoplanets (Kevin France - U. Colorado) | Determine the absolute level, the spectral energy distrubution, and the temporal variability of the energetic radiation environment around exoplanets to determine atmospheric photochemistry on habitable exoplanets and control for biosignature false positives | Chromospheric, transition region, and coronal luminosity and activity level of low-mass stars (G, K, and M) | 1) Broadband spectrally resolved ultraviolet irradiance spectra of all habitable planet candidates, N = TBD | Intensity | Sensitivity | S/N = 10 @ 1E -16 [erg /cm2/s] per 60s | In space, high QE detectors |
| | | | | | Dynamic Range | 1E-11 - 1E-19 [erg /cm2 /s /A] | high count rate detectors |
| | | | 2) Absolute fluxes of spectrally and temporally resolved upper atmosphere emission lines: | Wavelength (Energy) | Bandwidth | 95 - 400 nm | optical coatings down to 91 nm. gratings. Flux standards for 2% absolute spectrophotometry |
| | | | C III, O VI, LyA, O I, C II, Si IV, C IV, He II, Fe II, Mg II, Ca II | | Resolution | 15 km/s for lines, 100 km/s broadband | |
| | | | 3) ang resolved stellar LyA from background (geo, interplanetary) | Angular | Resolution | 0.2 arcsec at LyA | N/a |
| | | | | | Instantaneous FOV | > 2 arcsec (no hard requirement) | N/a |
| | | | 4) Temporal variability of high-energy emission lines on typical timescales of UV flares | Temporal | resolution | 1 sec | photon-counting detectors, L2 or elliptical orbit |
| | | | | | Single object observation duration | 8 hrs | |
| Understand the processes that determine the structure and evolution of planetary atmospheres (Kevin France - U. Colorado) | Determine the heating rates, mass-loss rates, compositions, and thermodynamic structures of the atmospheres of extrasolar planets | Atmospheric mass-loss rates from short-period planets of multiple atmospheric constituents. The incident stellar high energy radiation spectrum. | 1) Spectrally resolved far-UV transit observations of > 30 Jupiter-mass planets, > 20 Neptune-mass planets, and > 10 rocky planets. >= 3 transits | Intensity | Sensitivity | S/N = 50 @ 1E -15 [erg /cm2/s] per 60s | In space, high QE detectors |
| | | | | | Dynamic Range | 1E-11 - 1E-18 [erg /cm2 /s /A] | high count rate detectors |
| | | | 2) Transit depth as a function of wavelength and orbital phase for key atmospheric tracers: | Wavelength (Energy) | Bandwidth | 100 - 300 nm | optical coatings down to 100 nm. high-resolutuion, low-scatter gratings |
| | | | LyA, O I, C II, Mg II, H2 (superposed on O VI, C II, N II, and C III profiles) | | Resolution | 3 km/s | |
| | | | 3) ang resolved stellar LyA from background (geo, interplanetary) | Angular | Resolution | 0.2 arcsec at LyA | N/a |
| | | | | | Instantaneous FOV | > 2 arcsec (no hard requirement) | N/a |
| | | | 4) Observe pre-ingress, transt, and post-egress stellar flux | Temporal | resolution | 1 min | photon-counting detectors, L2 or elliptical orbit |
| | | | | | Single object observation duration | 8 hrs | |
| Understand the nature of stellar winds, magnetic fields, and circumstellar material in massive evolved stars and their influences on single and | Use UVV time-domain broadband polarimetric and spectropolarimetric observations to characterize changes with time (and orbital phase, for binaries) of CIRs, magnetic field lines, disks, and other stellar wind and | Shapes, sizes, extents, temperatures, densities, and compositions of electron- and resonance-line scattering regions in the atmospheres, winds, | Orientation of primary system axis (e.g., binary orbital plane, elongation of SN ejecta) | Broadband linear polarimetry (Stokes I, Q, U) | Sensitivity | S/N in total light = 100 in 30 min | Instrumental polarization < 3%. Polarized and unpolarized standard |
| | | | | | Dynamic Range | P = 0-10% with $s_P$/P < 0.1 | |
| | | | Gas distribution, clumpiness, composition, temperature, density, ionization state; magnetic field strength and geometry via Hanle effect | Linear spectropolarimetry (Stokes I, Q, U) | Bandwidth | 100-900 nm for key diagnostic lines (Lya, Ha, UV wind lines) | Instrumental polarization < 3%. Polarized and unpolarized standard stars. |
| | | | | | Resolution | R = 25,000 (UV) to 35,000 (visible) | |
| | | | Magnetic field strength and | Circular spectropolarimetry | Bandwidth | 100-900 nm for key diagnostic lines (Lya, Ha, UV wind lines) | Good pointing stability (~0.1 km/s between spectra in a sequence) for precise |

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| binary stellar evolution and SN/GRB progenitor pathways. (Jennifer Hoffman - U. Denver) | CSM structures; as well as illuminating the characteristics of SN ejecta and surroundings that trace the progenitor's mass-loss history. | and CSM of massive single and binary stars and supernovae. 3-D magnetic field geometries in single and binary evolved stars. | geometry via Zeeman effect | (Stokes V) | | Resolution | R = 25,000 (UV) to 35,000 (visible) | | line combination. Simultaneous wavelength calibration. | |
| | | | | Angular | | Resolution | | | | |
| | | | | | | Instantaneous FOV | | | | |
| | | | Periodicities including rotation, orbital motion, and CIR modulations; time evolution of SN ejecta and CSM | Temporal | | Resolution | 30 min | | Monitoring capability to characterize orbital periods up to timescales of months | |
| | | | | | | Single object observation duration | few days for entire rotation period | | | |

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| Investigate the dispersal machanism of proto-planetary disks through observations of gas forbidden lines (Patrick Hartigan - Rice U.) | Use narrow-band imaging and high resolution spectroscopy to map the morphology and kinematics of photoevaporating winds and invesigate the time scale for the disk dispersal in systems that are in the process of forming planets | Derive statistics of the disk dispersal time scale as a function of the stellar and environmental properties, including stars with different spectral types and ages, and in stellar clusters with different star formation histories. Compare the dispersal of proto-planetary disks in low-mass star forming regions such as Taurus and Chamaleon, with that in intermediate mass star forming regions such as Orion, and in high mass star forming regions such as Carina. | A range of emission lines in near UV, visible, and near IR, including [O I] 6300A, Hα, and Mg II 2800A | Gas temperature in the photoevaporating wind | Spectral | Spectral range | 1200A - 9000A | 2700A - 7000A | Spectrograph with long slit capability. An IFU system would be great if no spatial resolution is lost | Possible synergy with needs of extragalactic community to spectro-image multiple sources in a field |
| | | | | Gas velocity structure in the photoevaporating wind | | Spectral resolution | R up to 30,000 | R up to 10,000 | | |
| | | | | Gas density in the photoevaporating wind | | Spatial resolution | 20 arcsecond slits @ λ/D pixel scale | 5 arcsecond slits @ λ/D pixel scale | | |
| | | | | Morphology of the gas emission as a function of the distance from the star | Imaging | Spatial Resolution (defined at 400 nm) | λ/D pixel scale | λ/D pixel scale | Imager with excellent filter options and a modest FOV | 12 m primary to give spatial resolution, flux sensitivity, and Strehl ratio needed to image faint extended structures reliably around bright point sources |
| | | | | | | FOV | 5 arcminutes | 3 arcminutes | | |
| | | | | | | Filters | 16 narrowband nebular filters, among them CI 9850, NII 6583, NI 5200, OI 6300, OII 3727, SII 6716, SII 6731, Mg II 2800, Hα | 12 filters minimum | | |

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| What controls the mass-energy-chemical cycles within galaxies? (Ben Williams - U. Washington) | Observationally constrain models of the formation and evolution of the massive stars that drive metal production and distribution through libraries of resolved massive stars in a wide range of formation environments. | Count and measure the physical parameters to 10% accuracy of individual stars down to 5 solar masses in star clusters out to 5 Mpc (e.g., NGC253,M82), covering metallicities from 0.1-2.0 solar and galaxy masses ranging from 10^5-10^12 solar masses | Individual stars in young clusters down to 5 solar masses at 5 Mpc. | Angular Resolution | | | 0.008" | | | |
| | | | | Field of View | | | 15 arcmin | | | |
| | | | Brightnesses of such individual stars in at least 6 independent bands covering 0.2-1.0 micron. | Number of Filters | | | 6 | | | |
| | | | | Wavelength Coverage | | | 0.2-1.0 microns | | | |

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| Measure magnetic field and dust characteristics in the interstellar medium (BG Andersson - NASA Ames) | Use spectropolarimetry - over the UV (and optical) range - to determine the amount and orientation of the dichroic extinction polarization of background stars due to aligned dust. | 1) Measure the magnetic field strength in diffuse gas and 2) characterize the dust properties by analyzingth the polarization spectra in the context of modern grain alignment theory | Medium to high-spectral resolution spectropolarimetry in the UV | Size distribution alignment fraction and mineralogy of the small dust | Spectral | Spectral range | 160-1600nm | 300-500nm | Instrumental polarization, stability and variations over the FOV | Sensitivity to assemble statistically significant samples of polarimetry of background stars |
| | | | | Particle heights, cloud/haze thickness, gas abundances | | Resolving power | 1000 | 100 | | |
| | | | Spectropolarimetry of the 2175Å extinction feature | Statistics of polarization of feature | Spectral | Spectral range | 210-130nm | | Sensitivity, instrumental polarization | |
| | | | | Establish carrier and improve it's use in extinction curves etc. | | Resolving power | 1000 | 200 | | |
| | | | Tracing of the polarization curve to FUV wavelengths | Test ans utilize the theoretical prediction that paramagnetic alignment dominates for the very smallest grains, in which | Photometry | Sensitivity and systematic error | 0.10% | | Sensitivity, instrumental polarization | |
| | | | | | | number of fileters | 4 for 120-250nm | 2 for 120-250nm | | |
| | | | Line polarimetry of fine structure lines | Measure magnetic field strengths through the Hanle | Spectral | Spectral range | 120-1600nm | | instrument throughput | telescope aperture |
| | | | | | | Spectral resolution | 50,000 | 5,000 | | |

**Critical Technology Status Summary**

| Technology | Necessary Capability | Current State of the Art (inc. TRL) | Goals and Objectives to Fill Capability Gap | Benefits | | | Applications and Potential Missions within COR | Time to Anticipated Need |
|---|---|---|---|---|---|---|---|---|
| | | | | Scientific | Engineering | Programmatic | | |
| Reflective Mirror Coatings | For a UVOIR flagship telescope, there is excellent science return from 90 nm (the hydrogen cut-off) to 1.7 microns (or slightly longer for a cool, but not cryogenic mirror). Therefore a single reflective coating that has excellent reflectivity and wavefront over this entire bandpass would directly increase the science return of the mission. Exo-planet observations drive the requirements for reflectance uniformity and control of polarization effects that would compromise the performance of a coronagraph. | The current best broadband reflective coating that is practical is MgF2 over aluminum. Its short comings are reduced reflectivity below 120 nm, modest uniformity (~3%), and the 700 nm Al reflectivity dip. There is a suspected but unknown polarization effect that has not yet been characterized. Its durability and longevity in a space environment are excellent as demonstrated by the Hubble Space Telescope, since its coatings have a TRL 9. Other UV-optimized coatings exist and have been flown but are comprised by either low reflectivity in the optical (SiC) or environmental constraints (LiF over Al). | Develop a reflective coating that can be deployed in a relevant environment (i.e., mirrors for space missions) that improve upon MgF2 over Al. In addition, the coating must be scalable to a large aperture. The goals would be a reflectivity of > 70% from 90 – 120 nm, a reflectivity of > 90% from 120nm to 1.7 microns, uniformity < 1% for wavelengths > 90 nm, and polarization < 1% over the bandpass. | Offering efficient observations below 120 nm allows access to the largest number of ground state transitions of astrophysically relevant ions, atoms, and molecules. With these transitions, observations will probe temperature, density, and spatial regimes, providing unique insights in the origins of galaxies, stars, and planets. | Any mission that observes in the deep UV will benefit beyond a simple increase in observing efficiency, since better coatings will lead to the design and use of more complex and capable instrument designs providing vastly greater science return. | Improved uniformity and control of polarization effects enable better and more sensitive coronagraph measurements of exo-planets. | Any mission that operates in the deep ultraviolet would have significant gains in capability and efficiency with improved bandpass. Coronagraphic missions may be fundamentally enabled with these improvements. | For missions that would benefit from an alternative to MgF2 over Al, the results are immediate. Cosmics Origins missions currently submitted to the Explorer program would be improved with better coatings. Additionally, future missions from sounding rockets to the next UVOIR flagship are either enabled (in the case of smaller missions) or have their capabilities increased. |
| UV Detectors | The next UVOIR flagship mission should take full advantage of the large aperture. The instruments that maximize a given aperture will use high DQE, low noise, and large format detectors. Detectors drive the instrument design at such a fundamental level that we separate the wavelengths based on the detectors used, with each having different design goals and execution. While some applications can take full advantage of greater wavelength coverage (such as an imaging instrument with filters), other applications capitalize on features such as solar blindness in UV instruments, reducing the need for stray light control. | Current visible detectors have superb DQE from 400 to 1000 nm > 80%. Read noise of astrophysical detectors is ~3 electrons, with nearly zero dark current. State of the art visible light detectors are not photon counting and have issues with radiation hardness. NIR detectors (1.0 to 1.7 microns) have good QE of >80%, but are limited with dark current and read noise. UV detectors (90 – 300 nm) have DQE from 30% at 90 nm down to 10% at 300nm. Typically they are photon counting, but have dynamic range limitations (< 5 MHz count rate). Silicon detectors that are optimized in the UV exist (~70% QE) but over a limited bandpass (~20 nm) which reduces the utility for a general purpose instrument. | While there is not likely a single, one size fits all solution, visible/NIR detectors are excellent devices with improvements mostly being incremental for cosmic origins science, unless exo-planet science is required. One key feature would be better radiation tolerance than is available to state of the art silicon detectors. The lifetime of an instrument using these visible/NIR detectors is limited by the detector, not the spacecraft. For the UV, improvements to DQE – greater than 70% at 90 – 120 nm, larger formats (> 4k x 4k resolution elements), and improvements in dynamic range would increase the science capabilities of a flagship mission. A stable (< 1 pixel) wavelength solution and the ability to observe to a very high signal to noise (>100) is critical to select scientific programs. UV detectors also need to be photon-counting in order to take advantage of the UV minimum in the natural sky background. | The fundamental increase in targets over the lifetime of a given mission increases the scientific yield of the mission. Additional sensitivity or multiplexing can provide a more than linear increase in scientific yield. | Longer lifetimes and decreased system requirements for detectors (power, temperature, high voltage, etc.) all reduce technical risk. | Detectors are a significant programmatic risk, both for schedule and for cost. Improvements in TRL have direct and meaningful impacts to missions. | Improved VIS/NIR detectors allowing photon counting and/or lower read noise are critical for exo-planet missions. Science investigations that have been proposed to COR will have increased capability (diffuse extra-galactic light experiments for example) but none are yet funded at this time. Larger formats, increased quantum efficiency, and dynamic range increase capability of any mission that require sensitivity to these wavelengths. | Improvements to detectors will enhance every mission they are used in, from improved sensitivity to longer useful mission life. |
| Opto-mechnical design and validation of large optical systems | A >10-meter class UVOIR mission that executes exoplanet science via internal coronagraph requires exquisite optical stability. Thermally and dynamically stable optical systems (including mirrors, structures, disturbance isolation, metrology and actuators) are needed. It is impractical for a >10-meter class UVOIR telescope and its instruments to be optically tested end-to-end before launch. Processes, procedures, and technology for on-orbit alignment, test and calibration of large space telescopes, their components and their instruments is needed. | Large segmented telescopes that are diffraction limited exist for the NIR (JWST) and with adaptive optics in the infrared (Keck, etc.). A space telescope of this size being diffraction limited in the visible and capable of picometer-level stability is a new development that represents a significant challenge, both in manufacturing, integration and test, and on-orbit operations. | Demonstrate fabrication of thermally-stable mirrors within a production schedule that have <7 nm RMS surface-figure. Demonstrate alignment and phasing of segments with gravity release and modeling to demonstrate on-orbit capability. Develop thermally- and dynamically-stable structures for mirror and instrument support. Demonstrate vibration isolation, metrology, and actuator performance to required levels. Validate structural-thermal-optical performance (STOP) models to the picometer level, and verify testing and on-orbit stability of the optical system. Additionally development of methods to reduce the areal cost of primary monolithic mirrors. | A diffraction limited telescope provides improved sensitivity to faint point sources and allows the direct study of galaxies, near and far, and enables detection and characterization of habitable exoplanets. | Reduction in risk on this matter will allow the increase of margin in other areas, including coronagraph performance for exoplanet science. Overall risk reduction within the primary optical system for all instruments. | The primary optical telescope assembly is critical to the function of the observatory and is a significant programmatic risk, both for schedule and for cost. Improvements in TRL have direct and meaningful impacts on a large UVOIR mission. | Large-aperture systems requiring exquisite wavefront stability will have a direct benefit from this work. Stable structures can have benefits to smaller missions requiring ultra-stability. Indirectly, improvements in model validation and the ability to predict on-orbit performance may improve smaller missions. | The need will be realized with the start of the development of the next large UVOIR mission (assuming a segmented primary mirror). It is important not to lose the knowledge and technical base prior to the start of the mission. |

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| Polarization preserving telescope coatings and configurations | Today, telescope induced polarization limits photopolarimetry accuracy to greater than about 0.1% and limits contrast in coronagraphs to 1E-10 contrast. Current ground based telescopes are limited to 0.1% accuracy and calibration methods and devices to measure and control polarization in ground-based telescopes are under development. Missing is our ability to exploit the space environment for precision photopolarimetry and high fidelity image formation. A spectropolarimetric accuracy of .001% will open a new window into the universe of star formation studies, planetary nebulae, and cosmology (CMB measurements). | The current best broadband polarization measurements are limited to 0.1% . And coronagraph contrast is limited to about 10E-7 (ground) and 1E-9 (space - WFIRST-CGI). | Develop low polarization reflective coatings that can be deployed in a relevant environment (i.e., mirrors for space missions). In addition, the coating must be scalable to a large aperture. The goal would be a polarization uniformity of 0.01% to enable space-based precision polarimetry and coronagraph contrasts as high as 1E-11 necessary for terrestrial exoplanet characterization. | For a UVOIR flagship telescope, there is excellent science return from precision polarimetric measurements across the wavelength band from 100 to 750 nm. Potential areas of investigation include interstellar gas and dust, formation of protoplanetary systems from gas and dust surrounding stars, and high-energy magnetic fields from supernova reminants. | Minimizing internal polarization requires fewer fold mirrors and powered optical elements. This minimization would require engineers to use fewer surfaces with more complex optical figures and to simplify the structural integrity of the optical path for precision WF/SC. | Improved uniformity and control of polarization effects enables more sensitive coronagraph measurements of exo-planets and a better understanding of the energy processes in the galaxy and more accurate measurements of the Cosmic Background. | Any mission that operates in the deep ultraviolet would have significant gains in capability and efficiency with improved bandpass. Coronagraphic missions may be fundamentally enabled with these improvements. | COR missions currently submitted to the Explorer program would be improved with polarization control. The WFIRST-CGI mission, for example, would have improved SNR if the polarization were better controlled. |