COPAG Report to Astrophysics Subcommittee

Christopher Martin

Chair

COPAG Executive Commitee

COPAG Executive Committee

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- Ken Sembach, StScI
- Jonathan Gardner, GSFC
- Chuck Lillie, NGST
- Paul Goldsmith, JPL
- Dave Leisawitz, GSFC
- Lynne Hillenbrand, Caltech
- Juliane Dalcanton, U. Wash.

2011 Tasks (Revised)

- SAG1: Science Objectives for a Next Generation UVOIR Flagship Mission (4-8 m)
- SAG2: Determine technology focus areas for a monolithic 4m Aperture UV/Optical/NIR mission with Internal Coronograph for Exoplanet Imaging
- SAG3: Determine technology focus areas for a segmented 8 m Aperture UV/Optical/NIR mission with External Occulter for Exoplanet Imaging
- SAG4: Determine technology focus areas for future Far IR Instruments

COPAG Activities 2011

- Community meeting -- Jan 2011 AAS
- Regular telecons
- COPAG Web site (2 now)
- AAS Exploder
- Provide inputs to NRC/NASA Technology Roadmap Process
- Joint COPAG/ExoPAG Meeting -- 26 April 2011
- Community meeting – May 2011 AAS
- Fall community workshop – Sept 22-23, 2011 – StScI
- Draft Technology Assessment → ApS (Oct 19, 2011)
- *Revised Technology Assessment → Community (Dec 8, 2011)*
- *Winter community workshop – Jan 8, 2012 – AAS Austin*

COPAG Workshop

1) Science Objectives for future Cosmic Origins Missions
    - Cosmology
    - Galaxy Evolution
    - Gas
    - Stellar Populations
    - Star and Planet Formation
2) Mission Concepts:
    - UV and Far IR Probes
    - 4-m UV/Optical/NIR
    - 8-m UV/Optical/NIR
    - Spica
    - CALISTO and SAFIRE

COPAG Fall 2011 Workshop

3) Technologies

- UVOIR Detectors
- UVOIR Coatings
- UVOIR Telescopes
- UV Gratings/multiplexing
- Joint UVOIR mission technologies
- Far IR/Sub mm technologies

4) Discussion [at workshop and later]

- Technology Assessment
- Technology Prioritization
- Technology Roadmapping [preliminary]
- Probes
- Balanced program

COPAG Technology Assessment: Sample Science Objective

- **Objective: Tracing the flow of Baryons from the IGM to Galaxies**
- **Capability:** spectroscopy with R~30,000-100,000 over 120-300 nm, stretch goal 100-300 nm. Multi-object capability may allow tomography using galaxies. Apertures of 4-m to 8-m required to provide significant single-object enhancement over HST. Multi-object capability and UV technology improvements could make >1.5-m apertures scientifically compelling.
- **Sample investigations:** IGM and CGM absorption using background QSOs and galaxies to measure column density, ionization, temperature, metallicity of IGM, CGM, and ISM gas.
- **Technology requirements:** High-very high QE UV detectors, high pixel counts, low-very low backgrounds, moderate dynamic range, moderate out-of-band rejection (excluding spectrograph), photon-counting essential for lowest noise. Moderate-large apertures. Coatings with excellent reflectivity over 100-300 nm.

Astro2010 Science Question → Science Measurement

(Example: UVOIR)

COSMOLOGY & FUNDAMENTAL PHYSICS	UHC Im (ExoPlanet Imaging)	UVOIR HR/HC Im	UVOIR WF Im	UV Spect HRS	UV Spect MOS	UV/O Spect IFS
HOW DID THE UNIVERSE BEGIN?						
WHY IS THE UNIVERSE ACCELERATING?			X		X	
WHAT IS DARK MATTER?		X	X			
WHAT ARE THE PROPERTIES OF NEUTRINOS?						
GALAXIES ACROSS COSMIC TIME						
HOW DO COSMIC STRUCTURES FORM & EVOLVE?		X	X	X	X	X
HOW DO BARYONS CYCLE IN & OUT OF GALAXIES, AND WHAT DO THEY DO WHILE THEY ARE THERE?		X	X	X	X	X
HOW DO BLACK HOLES GROW, RADIATE, AND INFLUENCE THEIR SURROUNDINGS?		X	X	X	X	X
WHAT WERE THE FIRST OBJECTS TO LIGHT UP THE UNIVERSE AND WHEN DID THEY DO IT?					X	X
GALACTIC NEIGHBORHOOD						
WHAT ARE THE FLOWS OF MATTER & ENERGY IN THE CIRCUMGALACTIC MEDIUM?				X	X	X
WHAT CONTROLS THE MASS-ENERGY-CHEMICAL CYCLES WITHIN GALAXIES?		X	X		X	X
WHAT IS THE FOSSIL RECORD OF GALAXY ASSEMBLY FROM THE FIRST STARS TO THE PRESENT?		X	X	X	X	
WHAT ARE THE CONNECTIONS BETWEEN DARK AND LUMINOUS MATTER?		X	X		x	X

Science Measurement → Technology Requirement

(Example: UV Detectors)

	UHC Im (ExoPlanet Imaging)	UVOIR HR/HC Im	UVOIR WF Im	UV Spect HRS	UV Spect MOS	UV/O Spect IFS
UV DETECTORS						
QE		Moderate	Moderate	High	High	High
Format: Number of Pixels		Very High	Very High	Moderate-High	High-Very High	High-Very High
Photon-counting		XX	X	XXX	XX	XXX
Equivalent background		Low	Moderate	Low	Low	Very Low
Dynamic Range		High	High	Moderate	Moderate	Moderate
Radiation Tolerance		Moderate	Moderate	Moderate	Moderate	Moderate
Time Resolution		Low	Low	Low	Low	Low
Out of Band Rejection		High	High	Moderate	Moderate	Moderate

Technology Figures of Merit

- 1. Current and projected (2020, assuming funding as specified below) performance.
  - e.g., for detectors: QE vs. wavelength, internal/dark noise, photon-counting capability, number of pixels/formats/scaleability, energy resolution, dynamic range.
- 2. Implementation and operational issues/risks:
  - e.g., for detectors requirements for cooling, high voltage, required materials/process improvements, red leak/out of band response.
- 3. Cost/time to TRL-6 and leverage:
  - What is the current TRL level, what NASA funding and time is required to reach TRL6,
  - What is the degree of difficulty of these developments
    - for example using the DOD Degree of Difficulty scale
  - What non-NASA astrophysics division resources can be brought to bear to leverage the development>
    - significant industrial involvement and prior investments, cross-division, cross-agency, private-sector investments and applications, existing infrastructure and institutional investment
- 4. Relevance to and impact on possible future missions:
  - Large 4-8 m UVOIR general astrophysics missions, Far IR/Sub mm missions
  - Joint Exoplanet imaging missions & required compatibility technologies

Cosmic Origins Technology Priorities

- ***Priority 1.*** *These technologies are "mission enabling", and are the highest priority for immediate investment. We provide preliminary roadmaps for these technologies.*
- ***Priority 2.*** *These technologies are "mission enhancing". Some early investment should be considered contingent upon science and mission prioritization.*
- ***Priority 3.*** *Many interesting and important technologies may be relevant to future CO missions. Some can be developed once mission choices are made. Others may be developed as part of other activities and programs. Still others may be at early stages of readiness and require more basic research support to mature. Level 3 technologies were not included in Table 3.*

UVOIR Technologies

Table 3 – Cosmic Origins Technology Matrix

Name of technology	**High QE, large format photon-counting UV large-format detectors**	**UV coatings**	**Large, low-cost, light-weight precision mirrors for Ultra-Stable Large Aperture UV/Optical Telescopes**	**Deployable light-weight precision mirrors for future Very Large Aperture UV/Optical Telescopes**	**Very large format, low noise Optical/IR detector arrays**	**Photon counting Optical/IR detector arrays**
Brief description (1024)	Future NASA UV missions, particularly those devoted to spectroscopy, require high quantum efficiency (>50%), low noise (<1e-7 ct/pixel/s), large-format (>4k x \4k) photon-counting detectors for operation at 100-400nm or broader	High reflectivity, highly uniform UV coatings are required to support the next generation of UV missions, including explorers, medium missions, and a UV/optical large mission. High reflectivity coatings allow multiple reflections, extended bandpasses, and accommodate combined UV and high-contrast exoplanet imaging objectives.	Future UV/Optical telescopes will require increasingly large apertures to answer the questions raised by HST, JWST, Planck and Herschel, and to complement the ≥ 30-m ground-based telescopes that will be coming on line in the next decade. Technologies are therefore required that provide a high degree of thermal and dynamic stability, and wave front sensing and control	Future UV/Optical telescopes will require increasingly large apertures to answer the questions raised by HST, JWST, Planck and Herschel, and to complement the ≥ 30-m ground-based telescopes that will be coming on line in the next decade. Technologies are therefore required that provide a high degree of thermal and dynamic stability, and wave front sensing and control	Future NASA Optical/near-IR missions require large format detector arrays mosaicable in formats of ~Gpix, covering wavelengths from the optical to about 2μm.	Future NASA Optical/near-IR missions require large-format, high quantum efficiency, low dark current, and high readout speed photon counting detector arrays.

UVOIR Technologies

Name of technology	High QE, large format photon-counting UV large-format detectors	UV coatings	Large, low-cost, light-weight precision mirrors for Ultra-Stable Large Aperture UV/Optical Telescopes	Deployable light-weight precision mirrors for future Very Large Aperture UV/Optical Telescopes	Very large format, low noise Optical/IR detector arrays	Photon counting Optical/IR detector arrays
Roadmap	1) 2011-2014: Investigate 2-4 technological approaches. Goal is demonstration of high QE, low/moderate noise, and moderate/high (scaleable) pixel counts 2) 2015: Downselect to 2 promising technologies that have reached TRL3-4. 3) 2015-2019: Invest in 2 technologies that provide best capabilities for UV imaging and UV spectroscopy. Scale to high/very high pixel counts. Develop low power versions of required electronics.	1) 2011-2013: Demonstrate ALD coatings for Al+MgF_2. Demonstrate reflectivity and compatibility with internal coronograph. 2) 2013-15: Demonstrate stability of ALD coatings for exposed optics. Demonstrate compatibility of conventional coatings with internal coronograph. 3) 2015-2019: Develop large optics capability for ALD coatings.	1) 2011-2015: Demonstrate the technologies required to fabricate 4-m mirror blanks from ULE/Zerodur, Borosilicate and Silicon Carbide 2) Demonstrate the ability to grind and polish mirror blanks to achieve the required mirror figure and surface roughness for an ExoPlanet imaging mission 3) Develop a 4-m monolithic mirror that meets the requirements for a combined UVOIR/ExoPlanet mission	1) 2011-2015: Demonstrate the technologies required to fabricate 1.5-m to 3.6-m mirror blanks from ULE/Zerodur, Borosilicate and Silicon Carbide 2) Demonstrate the ability to grind and polish mirror blanks to achieve the required mirror figure and surface roughness for a UVOIR mission 3) Develop mirror segments for an 8.0 to 9.2-m deployable telescope that meets the requirements for a UVOIR mission	Defer pending mission requirement	1) 2012: Much of the relevant expertise exists outside NASA. Coordinate a small workshop to survey and assess different approaches. 2) 2012-2015: Technology development at a few vendors/labs aimed at demonstrating high QE, high speed, and low dark current photon counting focused on detector materials development and characterization. 3) 2015-2019: Focused development at two vendors/labs aiming to develop mega-pixel class photon-counting detector arrays that have been optimized for low background space astrophysics.
Priority	1 – Detectors are at the heart of every instrument. Detector performance shortfalls can only be made up with high cost increases in aperture	1 – Coating developments could extend the range of UV missions to 100 nm. Coating improvements could increase net efficiency of	1 – Large monolithic high precision mirror is a prerequisite for 4-m mission and may be applicable to 8-m mission. Optics technology drives mission cost and mass.	2 – Deployable large precision mirror may be required for 8-m mission (depending on launch) vehicle. A deployed mirror may require an external occulter and is less compatible with internal coronagraph	2 – Technology is available at TRL6+. Scaling to very high pixel counts is mission enhancing, but requirements and development should be mission driven.	1 – Photon-counting requirement driven by moderate to high resolution spectroscopy, missions travelling beyond the Zodiacal disk, and high time-resolution science or wavefront sensing.

Far IR/Sub mm Technologies

Name of technology	Large format, low noise Far-IR direct detectors	Ultralow-noise Far-IR direct detectors	Large, cryogenic far-IR telescopes	Interferometry for far-IR telescopes	Cryocoolers
Brief description (1024)	Future NASA Far-IR missions require large format detectors optimized for the very low photon backgrounds present in space. Arrays containing up to tens of thousands of pixels are needed to take full advantage of the focal plane available on a large, cryogenic telescope. Detector sensitivity is required to achieve background-limited performance, using direct (incoherent) detectors to avoid quantum-limited sensitivity.	Future NASA Far-IR missions require detectors optimized for the very low photon backgrounds present in space for spectroscopy. Arrays containing up to thousands of pixels are needed to take full advantage of the spectral information content available. Detector sensitivity is required to achieve background-limited performance, using direct (incoherent) detectors to avoid quantum-limited sensitivity.	Large telescopes provide both light gathering power, to see the faintest targets, and spatial resolution, to see the most detail and reduce source confusion. To achieve the ultimate sensitivity, their emission must be minimized, which requires that these telescopes be operated at temperatures that, depending on the application, have to be as low as 4K. Collecting areas on the order of 10m are needed.	Interferometry in the far-IR provides sensitive integral field spectroscopy with sub-arcsecond angular resolution and R ~ 3000 spectral resolution to resolve protoplanetary and debris disks and measure the spectra of individual high-z galaxies, probing way beyond the confusion limits of current and next-generation single-aperture far-IR telescopes. A structurally-connected interferometer would have the aforementioned capabilities. Eventually the formation-flying interferometric telescope envisaged in the 2000 Decadal survey would provide Hubble-class angular resolution, but that is beyond the scope of this technology plan. Telescopes are operated at temperatures that have to be as low as 4K.	Detectors for far-IR and certain X-ray missions require temperatures in the tens of mK. Compact, low-power, lightweight coolers suitable for space flight are needed to provide this cooling. Powerful, efficient cryocoolers are needed to cool the optical components of far-IR telescopes and provide the heat sink for sub-Kelvin coolers.

Far IR/Sub mm Technologies

Name of technology	Large format, low noise Far-IR direct detectors	Ultralow-noise Far-IR direct detectors	Large, cryogenic far-IR telescopes	Interferometry for far-IR telescopes	Cryocoolers
Roadmap	Presently have working 10-19 W Hz-1/2 detectors in small arrays. Advance TES bolometers and MKIDs in parallel to TRL ~ 5, then downselect to one detector type. Demonstrate multiplexing in arrays of 256 elements for interferometry. Further develop larger arrays for single-aperture telescope mission.	1) Grating spectrometer proposed as US instrument on SPICA will require these detectors – the timescale for SPICA has moved to the right since 2010 Decadal report so that there is time for technology development if it is started in a timely manner (2012). 2) Missions beyond SPICA such as SAFIR/CALISTO will have even greater need as background limit will be even lower and they will be capable of handling larger arrays.	The telescope for SPICA is expected to be provided by ESA based on Herschel experience. For 10m class mission, materials, surface, and metrology must be developed. Note that since telescope will be cooled to approximately 4K, the test and measurement challenge is extreme.	Telescope requirement is modest (1 m diameter) in comparison to single aperture telescope. The technical challenges for far-IR interferometry are detectors and cryocooling. Metrology is easy (1 micron tolerance). JWST will demonstrate wavefront control at 10x shorter wavelengths, where it's harder. The interferometric technique described above is nearly mature and requires only modest funding to complete the maturation to TRL 6 for application on a Probe-class mission.	Pick up from JWST and IXO development efforts. Advance sub-K continuous ADR coolers in parallel with 4 K cryocoolers to satisfy predicted performance requirements for each (heat lift at specified temperature stages). Finally, integrate coolers into a cryo-thermal system and verify system thermal performance in sub-scale models representative of flight-sized elements. For missions further in the future, the impact of larger focal planes should be included in a comprehensive analysis of overall cryogenic system requirements.
Priority	1 – Enabling for far-IR spatio-spectral interferometry. 2 – Required for background-limited photometry and very low-resolution spectroscopy	1 – Required for dispersive R~1000 spectrometer with cold telescope, required to achieve background-limited spectroscopy	1 – Significant technology development is required to advance understanding of capability for both of these types of missions to the point that a decision made on the basis of science case (which is very different) can be made.		1 – 4 K and sub-K cryocooling technology is enabling for far-IR spatio-spectral interferometry, and enabling or enhancing for a large far-IR single-aperture telescope.

COPAG Request to ApS

- Approve process
- Approve Technology Assessment priorities
- Approve roadmap format