Cosmic Origins
Program Analysis Group: Status Report

Christopher Martin, Chair
COPAG Executive Committee

Outline
1. COPAG composition and activities
2. Science Goals
3. Mission/Technology Requirements
4. Burning Issues
5. Requests to Astrophysics Subcommittee

Astrophysics Subcommittee Meeting August 30-31, 2012
I. COPAG Composition and Activities
COPAG Executive Committee

Chris Martin
Caltech (Chair)

Ken Sembach
StScI

Julianne Dalcanton
UWash

Paul Goldsmith
JPL

Chuck Lillie

Jon Gardner
GSFC

Lynne Hillenbrand
Caltech

James Lowenthal
Smith College

Paul Scowen
ASU

David Leisawitz
GSFC
COPAG Activities 2011 - 2012

• Community meeting -- Jan 2011 AAS
• Bi-weekly 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)
• Winter community workshop – Jan 8, 2012 – AAS Austin
• Cosmic Origins Newsletter
• Attending PhysPAG meeting DC Aug 14, 2012
• Supporting NASA CO Program Office RFI Process
• Workshop at StScI 21 Sept 2012: UVO RFI, Science Objectives, Probes, NRO Telescopes
2012 Tasks/SAGs

- **SAG1**: Science Goals, Objectives, Requirements for Cosmic Origins missions. Where are science thresholds and how do they link with Probe vs. Flagship class and aperture size?
- **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
- **SAG5** [to be modified]: What is the scientific case for a set of linked probes and corresponding technology requirements? Can this be accomplished with one NRO telescope?
- **SAG6** [to be approved]: Develop a plan for community costing transparency, training, ownership, and effecting systemic change.

Blue: active investigations. Program office RFI process.
Red: to be approved
COPAG Communication

• Input to Cosmic Origins Newsletter
• email list
• AAS Exploder — 3 PAG reports, 2-4 per year?
• Suggestions!? 
2. Developing a Single, Coherent Science Story
Cosmogony

Following the flow of matter from the Cosmic Web to Planets
Cosmogony

Following the flow of Baryons from the Cosmic Web to Planets

- Galaxies
- Massive Black Hole
- SF Clusters
- Exoplanets
- PPDs
Cosmogony
Following the flow of Baryons from the Cosmic Web to Planets

Galaxies

Massive Black Hole

PPDs

UV

SIM-3 feedback

CGM

IGM

Exoplanets

Inner Planet

Exo-zodi

Outer Planet

FIR

Exoplanet

x-ray
Cosmogony

Following the flow of Baryons from the Cosmic Web to Planets

IGM (δ~1-100)

• Where are the baryons?
• How does gas flow from the IGM to the CGM to galaxies?
• How is the IGM affected by the evolution of galaxies and massive black holes over time?
• Does the IGM trace dark matter?
Cosmogony

Following the flow of Baryons from the Cosmic Web to Planets

CGM ($\delta \sim 10^2-10^4$)

- What are the flows of matter and energy in the circumgalactic medium?
- How do baryons cycle in and out of galaxies?
- What is in the circum-galactic medium?
- How are galaxies fed? How do galaxies acquire their gas across cosmic time?
- How does galaxy feedback work?
- How are the chemical elements dispersed & distributed in the circumgalactic & intergalactic media?
- Where are the baryons?
Cosmogony

Following the flow of Baryons from the Cosmic Web to Planets

Galaxies ($\delta \sim 10^4 - 10^8$)

- How do galaxies build up their stellar component over cosmic time?
- What processes regulate the conversion of gas into stars inside galaxies?
- How are the chemical elements dispersed and distributed in galaxies?
- What is the fossil record of galaxy assembly over cosmic time?
Cosmogony

Following the flow of Baryons from the Cosmic Web to Planets

Clusters/GMCs ($\delta \sim 10^8-10^{10}$)

- How do stars form?
- How does gas flow into and control star formation?
- How does feedback control star formation?
Cosmogony

Following the flow of Baryons from the Cosmic Web to Planets

Central Black Holes ($\delta \sim 10^{29}$)

- How do black holes grow, radiate, and influence their surrounding space?
- How does a black hole shape the evolution of cosmic structure?
Cosmogony

Following the flow of Baryons from the Cosmic Web to Planets

- How do circumstellar disks form and evolve?
- How do disks form planets?

Protostars/PPDs/Young Stars ($\delta \sim 10^{16}-10^{19}$)
- How do circumstellar disks form and evolve?
- How do disks form planets?
Cosmogony

Following the flow of Baryons from the Cosmic Web to Planets

Galaxies

Planets ($\delta \sim 10^{24}$)
- Do habitable worlds exist around other stars?
- Can we identify the telltale signs of life on an exoplanet?

Massive Black Hole

SF Clusters

Exoplanets

PPDs
Cosmogony

A large UVO telescopes will follow the flow of matter from the cosmic web to planets.

A set of 3 probes may also be able to make significant progress.
Science Goals

• **Goal 1:** Characterize the growth of large-scale baryonic structures in the intergalactic medium

• **Goal 2:** Observe and explain the assembly of galaxies over cosmic time

• **Goal 3:** Trace and understand the flows of baryons between galaxies and the intergalactic medium

• **Goal 4:** Trace and understand the cycles of matter and energy within galaxies

• **Goal 5:** Measure and explain the history of star formation in galaxies over time

• **Goal 6:** Determine how the conditions for habitability arise during planetary system formation
3. Translating This into Science Measurement Objectives & Technology Requirements
Science Measurement Objectives

- **Objective 1**: Characterize the spatial distribution of IGM absorption lines using background QSOs and galaxies through high resolution UV spectroscopy
- **Objective 2**: High angular resolution UVO imaging and imaging spectroscopy of forming galaxies and galaxy systems
- **Objective 3**: High angular resolution photometry of individual stars in a representative sample of galaxies
- **Objective 4**: UV Imaging spectroscopy of star formation regions, galaxies, CGM and IGM
- **Objective 5**: Multiobject UV spectroscopy of galaxies, CGM, CQM
- **Objective 6**: Wide field UV/optical photometry of star formation regions in nearby galaxies
- **Objective 7**: UV/optical imaging spectroscopy of protostars and Protoplanetary disks
- **Objective 8**: Far IR/sub-mm imaging and spectroscopy of forming galaxies
- **Objective 9**: Far IR/sub-mm imaging and spectroscopy of star formation regions
- **Objective 10**: Far IR/sub-mm imaging interferometric spectroscopy of SFRs, protostars, PPDs
## Astro 2010 Science Questions → Cosmic Origins Measurements

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<tr>
<th>COSMOLOGY &amp; FUNDAMENTAL PHYSICS</th>
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<th>HCN</th>
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<td><strong>How did the universe begin?</strong></td>
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<td><strong>Why is the universe accelerating?</strong></td>
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<td><strong>What is dark matter?</strong></td>
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<td><strong>What are the properties of neutrinos?</strong></td>
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<td>GALAXIES ACROSS COSMIC TIME</td>
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<td><strong>How do baryons cycle in &amp; out of galaxies, and what do they do while they are there?</strong></td>
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<td><strong>How do black holes grow, radiate, and influence their surroundings?</strong></td>
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<td><strong>What were the first objects to light up the universe and when did they do it?</strong></td>
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<td>GALACTIC NEIGHBORHOOD</td>
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<td><strong>What controls the mass-energy-chemical cycles within galaxies?</strong></td>
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<td><strong>What is the fossil record of galaxy assembly from the first stars to the present?</strong></td>
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<td><strong>What are the connections between dark and luminous matter?</strong></td>
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<td>PLANETARY SYSTEMS &amp; STAR FORMATION</td>
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<td><strong>How do stars form?</strong></td>
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<td><strong>How do circumstellar disks evolve &amp; form planetary systems?</strong></td>
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<td><strong>How diverse are planetary systems?</strong></td>
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<td><strong>Do habitable worlds exist around other stars, &amp; can we identify the telltale signs of life on an exoplanet?</strong></td>
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<td>STARS AND STELLAR EVOLUTION</td>
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<td><strong>How do rotation &amp; magnetic fields affect stars?</strong></td>
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<td><strong>What are the progenitors of Type Ia supernovae</strong></td>
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<td><strong>How do the lives of massive stars end?</strong></td>
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<td><strong>What controls the mass, radius, and spin of compact stellar remnants?</strong></td>
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Science Measurement Requirements (sample)

- **M1** Reach a flux limit of FFF for a surface density of YYY QSOs/AGN/sq. deg with S/N=SSS over lam=WWW for NNN QSOs with resolution RRR
- **M2** Reach a flux limit of FFF for a surface density of YYY galaxies/sq. deg with S/N=SSS over lam=WWW for NNN galaxies with resolution RRR
- **M3** Imaging: Achieve a resolution of XXX arcsec and a sensitivity of FFF in each XXX x XXX arcsec^2 pixel for NNN galaxies in bands WWW
- **M4** Imaging spectroscopy: Achieve a angular resolution of XXX arcsec and a sensitivity of FFF in each XXX x XXX arcsec^2 pixel at R=RRR for NNN galaxies over wavelength range WWW
- **M5** Imaging: Achieve a resolution of XXX arcsec and a sensitivity of FFF mag for a total field of view of OOO deg^2 over the mission in bands WWW
- **M6** Galaxies: Achieve a angular resolution of XXX arcsec and a sensitivity of FFF in each XXX x XXX arcsec^2 pixel at R=RRR over wavelength range WWW for a NNN galaxies ranging from AAA-BBB arcsec in diameter
Science Measurement Requirements  
*(linked to objectives)*

<table>
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<tr>
<th>MEASUREMENT REQUIREMENTS</th>
<th>O1</th>
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<tr>
<td>M1 Reach a flux limit of FFF for a surface density of YYY QSOs/AGN/sq. deg with S/N=SSS over lam=WWW for NNN QSOs with resolution RRR</td>
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<td>M2 Reach a flux limit of FFF for a surface density of YYY galaxies/sq. deg with S/N=SSS over lam=WWW for NNN galaxies with resolution RRR</td>
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<td>M3 Imaging: Achieve a resolution of XXX arcsec and a sensitivity of FFF in each XXX x XXX arcsec^2 pixel for NNN galaxies in bands WWW</td>
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<td>M4 Imaging spectroscopy: Achieve a angular resolution of XXX arcsec and a sensitivity of FFF in each XXX x XXX arcsec^2 pixel at R=RRR for NNN galaxies over wavelength range WWW</td>
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<td>M5 Imaging: Achieve a resolution of XXX arcsec and a sensitivity of FFF mag for a total field of view of OOO deg^2 over the mission in bands WWW</td>
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<td>M6 Galaxies: Achieve a angular resolution of XXX arcsec and a sensitivity of FFF in each XXX x XXX arcsec^2 pixel at R=RRR over wavelength range WWW for a NNN galaxies ranging from AAA-BBB arcsec in diameter</td>
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<td>M7 CGM: Achieve a angular resolution of XXX arcsec and a sensitivity of FFF LU in each XXX x XXX arcsec^2 pixel at R=RRR over wavelength range WWW for a NNN CGMs (galaxy halos) ranging from AAA-BBB arcsec in diameter</td>
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<td>M8 CQM: Achieve a angular resolution of XXX arcsec and a sensitivity of FFF LU in each XXX x XXX arcsec^2 pixel at R=RRR over wavelength range WWW for a NNN CQMs (QSO halos) ranging from AAA-BBB arcsec in diameter</td>
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<td>M9 IGM: Achieve a angular resolution of XXX arcsec and a sensitivity of FFF LU in each XXX x XXX arcsec^2 pixel at R=RRR over wavelength range WWW for a NNN GIGMs (galaxy halos) ranging from AAA-BBB arcsec in diameter</td>
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<td>M10 Galaxies: Achieve a angular resolution of XXX arcsec and a sensitivity of FFF mag in each XXX x XXX arcsec^2 pixel at R=RRR over wavelength range WWW for a NNN galaxies ranging from AAA-BBB arcsec in diameter</td>
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<td>M11 CGM: Achieve a angular resolution of XXX arcsec and a sensitivity of FFF LU in each XXX x XXX arcsec^2 pixel at R=RRR over wavelength range WWW for a NNN CGMs (galaxy halos) ranging from AAA-BBB arcsec in diameter</td>
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<td>M12 Imaging: Achieve a resolution of XXX arcsec and a sensitivity of FFF mag for a total field of view of OOO deg^2 over the mission in bands WWW</td>
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<td>M13 PS/PSD: Achieve a angular resolution of XXX arcsec and a sensitivity of FFF mag in each XXX x XXX arcsec^2 pixel at R=RRR over wavelength range WWW for a NNN PS/PSDs ranging from AAA-BBB arcsec in diameter</td>
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Probe (2.4 m) – Spectroscopic Focus (Notional)

• Integral Field Spectroscopy
  – 1200-3000Å, R~3000
  – 1” x 1” spaxels
  – 2’ x 2’ field of view
  – $A_{\text{eff}} \sim 4,000 \, \text{cm}^2 \, (\text{COS} \times 10)$
  – $A_{\text{eff}} \Omega \sim 8 \times 10^7 \, \text{arcsec}^2 \, \text{cm}^2 \, (\text{COS} \times 5000)$

• Multi-object Spectroscopy
  – 1200-3000Å, R~2000-4000
  – 4’ x 8’ field of view
  – $A_{\text{eff}} \sim 4,000 \, \text{cm}^2 \, (\text{COS} \times 10)$
  – $A_{\text{eff}} \Omega \sim 3 \times 10^8 \, \text{arcsec}^2 \, \text{cm}^2 \, (\text{COS} \times 100,000)$

• High Resolution Spectroscopy
  – 1000-3000Å, R~30,000
  – Long-slit mode
  – $A_{\text{eff}} \sim 10,000 \, \text{cm}^2 \, (\text{COS} \times 10)$
Probe (2.4 m) – Imaging Focus (Notional)

- **UV Imager**
  - 4 bands: 1100Å, 1500Å, 2200Å, 2600Å
  - Field of view: 1° x 0.5°
  - $A_{\text{eff}} \sim 8,000 \text{ cm}^2$
  - $A_{\text{eff}} \Omega \sim 600 \times \text{UVIS} \sim 75 \times \text{GALEX}$
  - Grism: R~1000-2000

- **Optical imager**
  - Multiple Bands
  - Field of view: 1° x 0.5°
  - $A_{\text{eff}} \sim 10,000 \text{ cm}^2$
  - $A_{\text{eff}} \Omega \sim 250 \times \text{UVIS}$
  - Grism
Mission Requirements

• Next Generation UV Technology
  1. High QE, Large format, Low noise UV photon-counting detectors
  2. High reflectivity coatings 1000-3000Å
  3. High efficiency, low scatter gratings
  4. Multiplexing technology

• Cost
  – Early investment: Serious investments in technology must be made up front.
  – Cost ownership & consistency: Cost must be treated like other technical requirements and understood in detail to be optimized and controlled by scientist-builders.
  – Break cost paradigm: Mission cost paradigm MUST be broken at ~1B$ scale.
# Enhancement of Science Impact of Next Generation UV Technologies

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<tr>
<th>Technology</th>
<th>Implementation Approaches</th>
<th>Potential impacts</th>
<th>Mission Enabling Factor</th>
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<tbody>
<tr>
<td>1) Single Photon counting UV Detector</td>
<td>BSMCPs + GaN Photocathodes AR+DD+EMCCDs</td>
<td>Major increase in QE for large format, low background, versatile detectors</td>
<td>5-10*</td>
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<td>2) Next Generation UV Coatings</td>
<td>Atomic Layer Deposition</td>
<td>• High reflectivity coatings —&gt; high performance instruments+telescopes</td>
<td>3‡</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Broad-band coatings —&gt; 100-120 nm coverage: key UV range</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Ultra-uniform coatings —&gt; Joint Exoplanet/UV astrophysics mission</td>
<td></td>
</tr>
<tr>
<td>3) Next Generation Diffractive optics</td>
<td>Electron beam lithographic patterning</td>
<td>• Arbitrary groove profile and shape</td>
<td>2-4§</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• High performance spectrographs</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• High efficiency</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Low scatter</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Wide-field, multi-object, high efficiency spectrographs</td>
<td></td>
</tr>
<tr>
<td>Total Improvement Factor</td>
<td>Data grasp $(A_{eff} \times N_{object})$ factor</td>
<td></td>
<td>20-250</td>
</tr>
<tr>
<td></td>
<td>Aperture reduction factor (linear): $F_A$</td>
<td></td>
<td>2-4</td>
</tr>
<tr>
<td></td>
<td>Cost reduction factor: $F_A^2$</td>
<td></td>
<td>4-16 (e.g., 10B$ \rightarrow$ 600M-2.5B$)</td>
</tr>
</tbody>
</table>
# Detector Requirement Definitions

<table>
<thead>
<tr>
<th>UV DETECTOR PROPERTY</th>
<th>Very Low</th>
<th>Low</th>
<th>Moderate / X</th>
<th>High / XX</th>
<th>Very High / XXX</th>
</tr>
</thead>
<tbody>
<tr>
<td>QE</td>
<td>&gt;5%</td>
<td>&gt;15%</td>
<td>&gt;30%</td>
<td>&gt;50%</td>
<td>&gt;70%</td>
</tr>
<tr>
<td>Format: Number of Pixels</td>
<td>100 x 100 $10^4$</td>
<td>300 x 300 $10^5$</td>
<td>$10^3 \times 10^3$ $10^6$</td>
<td>$(3000)^2$ $10^7$</td>
<td>$(10,000)^2$ $10^8$</td>
</tr>
<tr>
<td>Photon-counting</td>
<td>Not important</td>
<td>Important</td>
<td>Very Important</td>
<td>Critical</td>
<td></td>
</tr>
<tr>
<td>Equivalent background [ct cm$^{-2}$ s$^{-1}$]</td>
<td>0.01</td>
<td>0.1</td>
<td>1.0</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>Dynamic Range [ct/s]</td>
<td>$10^{-3} : 10^0$</td>
<td>$10^{-3} : 10^1$</td>
<td>$10^{-3} : 10^2$</td>
<td>$10^{-3} : 10^3$</td>
<td>$10^{-3} : 10^5$</td>
</tr>
<tr>
<td>Radiation Tolerance</td>
<td>1 kRad</td>
<td>10 kRad</td>
<td>100 kRad</td>
<td>1000 kRad</td>
<td></td>
</tr>
<tr>
<td>Time Resolution</td>
<td>None</td>
<td>1000 s</td>
<td>1 s</td>
<td>1 msec</td>
<td>1 usec</td>
</tr>
<tr>
<td>Out of Band Rejection [including]</td>
<td>1</td>
<td>$10^{-1}$</td>
<td>$10^{-2}$</td>
<td>$10^{-3}$</td>
<td>$10^{-4}$</td>
</tr>
</tbody>
</table>
Example:
Measurement → UV Detector Requirements

<table>
<thead>
<tr>
<th>UV Detector Property</th>
<th>UV High Resolution/High Contrast Imaging</th>
<th>UV Wide Field Imaging</th>
<th>UV High Resolution Spectroscopy</th>
<th>UV Multi-Object Spectroscopy</th>
<th>UV Integral Field Spectroscopy</th>
<th>Current Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>QE</td>
<td>Moderate</td>
<td>Moderate</td>
<td>High-Very High</td>
<td>High</td>
<td>High-Very High</td>
<td>Low-Very Low</td>
</tr>
<tr>
<td>Format: Number of Pixels</td>
<td>Very High</td>
<td>Very High</td>
<td>High-Very High</td>
<td>High-Very High</td>
<td>High-Very High</td>
<td>High</td>
</tr>
<tr>
<td>Photon-counting</td>
<td><strong>XX</strong></td>
<td><strong>X</strong></td>
<td>XXX</td>
<td>XX</td>
<td>XXX</td>
<td>YES</td>
</tr>
<tr>
<td>Equivalent background</td>
<td>Low</td>
<td>Moderate</td>
<td>Very Low</td>
<td>Low-Very Low</td>
<td>Very Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>Dynamic Range</td>
<td>High</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>Radiation Tolerance</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Time Resolution</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Out of Band Rejection</td>
<td>High</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>High</td>
</tr>
</tbody>
</table>
4. Burning Issues
Burning Issue #1: Probes vs. Flagships

• The Problem
  – Flagships take so long they can become obsolete before launch, and cannot sustain a vibrant community nor respond to current science
  – The richness and synergy of the Great Observatory program will never be repeated.

• The Solution
  – Can a compelling case be made for a program of (linked?) probes in the intermediate term?
  – Example: Cosmogeny Probes
    • Probe 1: Wide field UV/Optical Imaging & Spectroscopy
    • Probe 2: X-ray spectroscopy
    • Probe 3: Far IR Probe
    • Probe 4: Exoplanet Probe

• Issues:
  – Again, we need to understand costs and science/$.
  – Can multiple communities join together to push a combined program?
Burning Issue #2: NRO Telescopes

• 3 candidate missions: WFIRST-2.4, Exoplanet-2.4, UVO-2.4
• Could Exoplanet and UVO be combined?
• Can costs be managed in such a way to break the telescope aperture cost curve and therefore stay within the Probe-class cost point?
• Or can additional funds be applied to such a mission outside of NASA astrophysics?
Burning Issue #3: How Do Take Ownership of Costs and if Possible Change the Cost Paradigm?

• The Problem
  – Not understanding real costs is while discussing missions and science is like not understanding gravity while discussing cosmology and astrophysics.
  – We have reached a point where flagship missions can only occur once per 20-30 years.
  – More modest missions using existing technology are now flagships (e.g., WFIRST).

• The Solution
  – In order to discuss, compare, and refine future Origins missions we must have common, agreed upon, cost estimating tools.
  – We must have, as community, some ownership over mission cost.
  – *We must incentivize cost efficiency and change cost growth paradigm*

• But: NASA centers and aerospace companies are *not incentivized* to make cost estimation a transparent and level process.
  – NASA HQ must take lead to change this
5. Requests to Astrophysics Subcommittee

• Approve general direction of activities
• Approve modification of Probe SAG to consider NRO telescopes
• Approve Cost SAG