$A \rightarrow \Omega$

Probe(s)

Christopher Martin
Caltech
Wisdom

• “Do or do not... there is no try.”

• “Size matters not, ... Look at me. Judge me by size, do you?”
Following the flow of Baryons from the Cosmic Web to Planets

IGM (δ~1-100)

- High Resolution UV Absorption Spectroscopy (Multi-object? Tomography?)
- Mod Resolution UV Emission Integral Field Spectroscopy (IFS)
- Mod Resolution Multi-Object-Spectroscopy (MOS)
CGM ($\delta \sim 10^2 - 10^4$)

- High Resolution UV Absorption Spectroscopy (Multi-object? Tomography)

- Mod Resolution UV Emission Integral Field Spectroscopy (IFS)

- Mod Resolution Multi-Spectroscopy

Following the flow of Baryons from the Cosmic Web to Planets
IGM

Mod-High Resolution UV Emission IFS
Mod Resolution Multi-Object Spectroscopy
Wide field UV/Optical Imaging

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

Following the flow of Baryons from the Cosmic Web to Planets
Following the flow of Baryons from the Cosmic Web to Planets

Clusters/GMCs ($\delta \sim 10^8-10^{10}$)
- Wide field UV/Optical Imaging
- Mod-High Resolution UV Emission IFS
- Mod Resolution UV Multi-Object Spectroscopy
Following the flow of Baryons from the Cosmic Web to Planets

- Protostars/PPDs/Young Stars ($\sim 10^{16}$-$10^{19}$)
  - High Contrast Imaging
  - Wide field UV/Optical Imaging
  - High Resolution UV spectroscopy (Multi-object?)
  - Mod-High Angular Resolution UV Emission IFS
Galaxies

IGM

Giant Planets ($\sim 10^{24}$)
- High Contrast Imaging
- High Angular Resolution, Low Spectral Resolution IFS

SF Clusters

PPDs

Planets

Following the flow of Baryons from the Cosmic Web to Planets
Probe 1 -- Alpha

- **Wide-field**
  - ~1.5 m
  - Wide-field UVO imaging
  - Massively multi-object UV Spectroscopy
    - low, medium, high R?
  - Wide-field UV Integral Field Spectrograph

- **Science**
  - IGM/CGM emission/absorption, tomograph?
  - Galaxy gas, star formation history, feedback
  - Star Formation Region gas physics, PDRs
  - Protoplanetary Disk gas physics
  - General astrophysics

- **Technology Demonstration**
  - High efficiency UV coatings, detectors
  - Highly multiplexed UV
Probe 2 -- Omega

• Narrow-field
  – ~1.5 m
  – Dedicated O/UV
  – High resolution imaging
  – High contrast imaging
  – High resolution/contrast imaging spectroscopy

• Science
  – Physics of star formation
  – Proto-planetary disk structure
  – Giant planets imaging & characterization
  – AGN formation, evolution, & feedback

• Technology demonstration
  – High-contrast imaging
  – UV compatibility
  – Starshade?
# Spectroscopy Requirements

<table>
<thead>
<tr>
<th>Spectrograph Requirement</th>
<th>Current Technology</th>
<th>Technology Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field of View</td>
<td>1 grating $\rightarrow$ single object</td>
<td>Wide field of view</td>
</tr>
<tr>
<td>Imaging or Multiobject</td>
<td>single object</td>
<td>Integral field unit Multiobject capability</td>
</tr>
</tbody>
</table>
| # of reflections         | COS $\rightarrow$ 1  
                          | STIS $\rightarrow$ 3-4 | 3 reflection spectrographs high R coatings |
| Gratings                 | holographic 
                          | aberration correcting  
                          | 35-40% efficiency | anamorphic arbitrary groove function near theoretical limits |
| Spectral resolution      | 1000-30,000        | 3000 $\rightarrow$ 50,000 |
## Detector Requirements

<table>
<thead>
<tr>
<th>Detector Requirement</th>
<th>Technology Status</th>
<th>Technology Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>QE</td>
<td>5-10%</td>
<td>50-80%</td>
</tr>
<tr>
<td>Background (Read noise + Dark Noise</td>
<td>~0.1-1 ct/s/cm²</td>
<td>&lt;0.1 ct/s/cm²</td>
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<tr>
<td>+ Spurious Noise)</td>
<td></td>
<td></td>
</tr>
<tr>
<td># of pixels</td>
<td>~4 x 10⁶</td>
<td>4 * (10-100)^2 * 2000 ~ 10⁶ - 10⁸</td>
</tr>
<tr>
<td>Photon counting</td>
<td>MCPs – yes</td>
<td>UV imaging – yes</td>
</tr>
<tr>
<td></td>
<td>CCDs – no</td>
<td>UV spectroscopy – YES!!</td>
</tr>
<tr>
<td>Red rejection (instrument system)</td>
<td>10⁻³ – 10⁻⁵</td>
<td>10⁻³ – 10⁻⁴</td>
</tr>
<tr>
<td></td>
<td>photocathode, filters,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>spectroscopy</td>
<td></td>
</tr>
<tr>
<td>Time resolution</td>
<td>microsecond</td>
<td>0.1-1000 sec for aspect</td>
</tr>
<tr>
<td></td>
<td></td>
<td>reconstruction</td>
</tr>
<tr>
<td>Dynamic range</td>
<td>&lt;100 ct/s</td>
<td>10⁻³ – 10⁷ ct/s (imaging)</td>
</tr>
</tbody>
</table>
Technology Roadmapping

Christopher Martin
Chair
COPAG Executive Commitee
Technology Categories

- Telescopes/mirrors
- Structures
- Detectors
- Coatings
- Multiplexing: microshutter arrays, micromirror arrays, integral field units
- Instrumentation optics (Gratings, optical surfaces, spectrometers, etc.)
- Other: electronics, cryogenics, thermal, telemetry
Technology Figures of Merit

   - 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
Technology Readiness Level

- TRL 1. Basic principles observed and reported.
- TRL 2. Technology concept and/or application formulated.
- TRL 3. Analytical and experimental critical function and/or characteristic proof-of-concept completed.
- TRL 4. Component and/or breadboard validated in laboratory environment.
- TRL 5. Component and/or breadboard validated in relevant environment.
- TRL 6. System/subsystem model or prototype demonstrated in a relevant environment (ground or space).
- TRL 7. System prototype demonstrated in a space environment.
- TRL 8. Actual system completed and “flight-qualified” through test and demonstration (ground or flight).
- TRL 9. Actual system “flight-proven” through successful mission operations.
DOD Degree of Difficulty

• **I. Very low degree of difficulty** anticipated in achieving research and development (R&D) objectives for this technology; only a single, short-duration technological approach needed to be assured of a high probability of success in achieving technical objectives in later systems applications.

• **II. Moderate degree of difficulty** anticipated in achieving R&D objectives for this technology; a single technological approach needed; conducted early to allow an alternate approach to be pursued to be assured of a high probability of success in achieving technical objectives in later systems applications.

• **III. High degree of difficulty** anticipated in achieving R&D objectives for this technology; two technological approaches needed; conducted early to allow an alternate subsystem approach to be pursued to be assured of a high probability of success in achieving technical objectives in later systems applications.

• **IV. Very high degree of difficulty** anticipated in achieving R&D objectives for this technology; multiple technological approaches needed; conducted early to allow an alternate system concept to be pursued to be assured of a high probability of success in achieving technical objectives in later systems applications.

• **V.** The degree of difficulty anticipated in achieving R&D objectives for this technology is so high that a **fundamental breakthrough in physics, chemistry**, and so on is needed; basic research in key areas needed before system concepts can be refined.
Disruptive Innovation

• **Ingredients**
  - Questioning
  - Experimenting
  - Observing
  - Associating
    • linking concepts from diverse fields
  - Networking
    • to search for new ideas

• **Examples**
  - e-Book (p-Book)
  - digital cameras (film)
  - PC (mainframe)

see UNBOXED, Steve Lohr, Sunday 8/28/11 NYT
The Business Model

• 2 Strategies
  – Entreprenuerial
    • Decisions/rankings made by peer review panels
    • PI vs. PI
    • Natural selection
      – (or species extinction)
  – Collective/collaborative
    • Community speaks with one voice
    • Self-organized
    • e.g., Decadal Surveys

JWST, WFIRST, Tea Party
UV Pls
Exoplanets, Dark Energy
Mira
<table>
<thead>
<tr>
<th>COSMOLOGY &amp; FUNDAMENTAL PHYSICS</th>
<th>CO</th>
<th>PCOS</th>
<th>Exo</th>
<th>IFS</th>
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</thead>
<tbody>
<tr>
<td>HOW DID THE UNIVERSE BEGIN?</td>
<td></td>
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<td>X</td>
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<tr>
<td>WHY IS THE UNIVERSE ACCELERATING?</td>
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<tr>
<td>WHAT IS DARK MATTER?</td>
<td></td>
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<td>X</td>
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<tr>
<td>WHAT ARE THE PROPERTIES OF NEUTRINOS?</td>
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<tr>
<td><strong>GALAXIES ACROSS COSMIC TIME</strong></td>
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<tr>
<td>HOW DO COSMIC STRUCTURES FORM &amp; EVOLVE?</td>
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<tr>
<td>HOW DO BARYONS CYCLE IN &amp; OUT OF GALAXIES, AND WHAT DO THEY DO WHILE THEY ARE THERE?</td>
<td>X</td>
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<tr>
<td>HOW DO BLACK HOLES GROW, RADIATE, AND INFLUENCE THEIR SURROUNDINGS?</td>
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<tr>
<td>WHAT WERE THE FIRST OBJECTS TO LIGHT UP THE UNIVERSE AND WHEN DID THEY DO IT?</td>
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<tr>
<td><strong>GALACTIC NEIGHBORHOOD</strong></td>
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<td>WHAT ARE THE FLOWS OF MATTER &amp; ENERGY IN THE CIRCUMGALACTIC MEDIUM?</td>
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<td>WHAT CONTROLS THE MASS-ENERGY-CHEMICAL CYCLES WITHIN GALAXIES?</td>
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<td>WHAT IS THE FOSSIL RECORD OF GALAXY ASSEMBLY FROM THE FIRST STARS TO THE PRESENT?</td>
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<td>WHAT ARE THE CONNECTIONS BETWEEN DARK AND LUMINOUS MATTER?</td>
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<tr>
<td>PLANETARY SYSTEMS &amp; STAR FORMATION</td>
<td>CO</td>
<td>PCOS</td>
<td>Exo</td>
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<td>HOW DO STARS FORM?</td>
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<td>HOW DO CIRCUMSTELLAR DISKS EVOLVE &amp; FORM PLANETARY SYSTEMS?</td>
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<td>HOW DIVERSE ARE PLANETARY SYSTEMS?</td>
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<td>DO HABITABLE WORLDS EXIST AROUND OTHER STARS, &amp; CAN WE IDENTIFY THE TELLTALE SIGNS OF LIFE ON AN EXOPLANET?</td>
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<td>STARS AND STELLAR EVOLUTION</td>
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<td>HOW DO ROTATION &amp; MAGNETIC FIELDS AFFECT STARS?</td>
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<td>WHAT ARE THE PROGENITORS OF TYPE Ia SUPERNOVAE</td>
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<td>HOW DO THE LIVES OF MASSIVE STARS END?</td>
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<td>WHAT CONTROLS THE MASS, RADIUS, AND SPIN OF COMPACT STELLAR REMNANTS?</td>
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