Future Optical/UV Science

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Steven Beckwith
Creating a future science strategy

- **What we know that we know**
  - Strategies are straightforward (e.g. galaxy formation, search for solar systems)
  - “Killer aps” possible early on, usually eroded with time

- **What we know that we don’t know**
  - Strategies are possible, because we are creative (e.g. dark matter)

- **What we don’t know that we don’t know**
  - Strategies are impossible
  - We discover this stuff by expanding our ability to look

“You can observe a lot by watching.”
Yogi Berra, American baseball player & coach
Telescopes & Discoveries

After Fig. 3.10 in *Cosmic Discovery*, Martin Harwit

![Graph showing sensitivity improvement over the eye over time with telescopes and discoveries from the 1600s to the 2000s.](Image)
Intellectual trends

- Uncover ("discover") the unseen
  - Catalog the universe
  - Adduce the physical laws
  - Understand the reason for it all

- Local to the distant, minor to major components
  - Solar system → Milky Way → galaxies → recombination
  - Planets → Stars → Galaxies → Structure

- "Local" questions
  - How & why do planets form?
  - What do they look like?
  - What makes planets evolve into habitable worlds

The quest for distance drove us to large light buckets
The need for resolution & dynamic range drives to large apertures in space.
Flagship Science Themes:
Dark Energy, Dark Matter, the Early Universe, Exoplanets & Life

Dark energy:
• Map the expansion history
• Look for changes in “cosmic pressure”

Dark matter
• Map its distribution
• Search for plausible candidates (lab?)

Early universe:
• Galaxy & star formation/evolution to z ~ 20
• Black hole creation to z ~ 20

Exoplanets & Life:
• Planet formation, disk physics and evolution
• Discovery and study of exo-planets
• Genesis of life: planet atmospheres
Dark energy: SN Ia

- ACS: 200 SN Ia per year to $z \sim 2$ (1 yr HST dedicated)
- Strong test of acceleration interpretation and search for systematics

<table>
<thead>
<tr>
<th>Instr.</th>
<th>#SN</th>
<th>t(yr)</th>
<th>$\sigma_w$ (%)</th>
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<tbody>
<tr>
<td>Now</td>
<td>40</td>
<td>4</td>
<td>25</td>
</tr>
<tr>
<td>2008?</td>
<td>200</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>“SNAP”</td>
<td>2000</td>
<td>2</td>
<td>5 (\dot{w})</td>
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1 yr HST with ACS: >200 SN Ia
Dark Energy

Dark energy:

- Phase 1: confirm $\Lambda$ with SN Ia (HST, SNAP)
- Phase 2: distinguish $\Lambda$ ($w_x = -1$) or changing $w_x > -1$
- Phase 3: what is this stuff?

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We have tools in hand or underway to address $w(t)$ on the decade timescale
Weak lensing: structure $1<z<3$

Initial structure studies will involve wide-field maps of galaxies for the effects of weak lensing.

We do not know the nature of dark matter. Depending on what we find, we may need general purpose observatories to understand its nature.

Angular scales to 1° to redshifts >3 allow actual measurement of gravitational structure as dark matter coagulates under its own gravity.
Renaissance after Dark Ages

Here Now

H II

$T_{\text{IGM}} \sim 10^4 \text{ K}$

H I

$T_{\text{IGM}} \sim 4z \text{ K}$

"Dark Ages"

young galaxy

$z \sim 6-10$

$z \sim 10^3$

$z \sim \infty$

(re) combination

Big Bang

Drawing courtesy of Michael Fall, STScI
Galaxy Formation/Evolution

Galaxy formation:
- Exploring the re-ionization epoch with HST & JWST
- JWST will give us basic ingredients to $z \sim 20$ (with mid-IR)
- Imaging of early black-hole creation

Galaxies at $z > 0.5$ need very large, filled aperture imagers
Looking for Extraterrestrial Life

What we know we know

"I'll tell you something else I think. I think there are other bowls somewhere out there with intelligent life just like ours."

There is a solar system
We have an example of a life-supporting planet
Terrestrial Planet Finder

Searching for signs of life:
- Separate light from Earth-like planets from stars
- Search for signatures of life: oxygen, methane & disequilibrium chemistry

TPF Builds Up Image Using Nulling

1. Simulated target
2. Target through TPF interference fringes
3. Time-series as TPF rotates
High contrast imaging science

Contrast vs. angle: HST CODEX

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<tr>
<th>θ</th>
<th>ΔI (peak)</th>
<th>ΔI (wing)</th>
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<tr>
<td>0.3&quot;</td>
<td>$1.5 \times 10^{-10}$</td>
<td>$10^{-4}$</td>
</tr>
<tr>
<td>1.0&quot;</td>
<td>$1.5 \times 10^{-10}$</td>
<td>$3 \times 10^{-6}$</td>
</tr>
<tr>
<td>2.5&quot;</td>
<td>$1.5 \times 10^{-10}$</td>
<td>$2 \times 10^{-7}$</td>
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AGB, PPNe, PNe
- Winds, shells from 20 – 200 $R_\ast$ @ 1 kpc
- Direct imaging of grain formation radii

Unification of AGN, QSOs
- Study host galaxies to z > 1
- 100x fainter than ACS
- Line-of-sight Ly$\alpha$ clouds
- BL Lacs, radio loud AGN

Gravitational lenses
- Separations 0.3-3" for time delay

A new optical coronagraph opens up study of many different areas of astronomy besides exo-planets

Diameter of Neptune’s orbit

HR 4796a: HST NICMOS
10m optical coronagraph
D.R. > 10^{10}

10m optical \( \Delta \theta \sim \lambda / D \)
CS disks & rings
Exozody clouds

10m optical coronagraph
Giant exoplanets
Young exoplanets

\sim 10m optical light bucket
Census of exoplanets
Exoplanet atmospheres

\sim 4m UV spectra
\( \Delta \theta \sim \lambda / D \)

Atmospheres of SS planets
Occultation of stars
Composition of bodies
Ring dynamics

\Delta x \sim 4 \text{ km}
\sim 4m UV
\sim 10m Optical

Stellar winds
TTS in LMC
Binary stars
Stellar pops
IGM Baryons
Microlensing
\alpha(z) (e^2 / hc)
Planetary images
Deep field images
Nebulae, clouds
Exo-planet images

Optical coronagraph D.R. > 10^{10}
Optical resolution: \( \Delta \theta \sim \lambda/D \)
Optical light bucket
UV spectral light bucket

Heritage
Engineering challenge
Military/industry interests

Interferograms?
Beautiful pictures

Exploration
Space-based lasers
Killer Ap