Beyond JWST Committee Update

Julianne Dalcanton, Sara Seager co-chairs
Marc Postman, David Redding

COPAG/ExoPAG
June 5, 2014

AURA “Beyond JWST” Committee

Committee Members:

- Steve Battel (Battel)
- Niel Brandt (Penn State)
- Charlie Conroy (UC Santa Cruz)
- Lee Feinberg (GSFC)
- Suvi Gezari (U. Maryland)
- Olivier Guyon (Subaru Obs.)
- Walt Harris (LPL)
- Chris Hirata (OSU)
- John Mather (GSFC)
- Marc Postman (STScI)
- Dave Redding (JPL)
- Phil Stahl (MFSC)
- Jason Tumlinson (STScI)
- David Schiminovich (Columbia U.)

Co-Chairs

- Julianne Dalcanton (U. Washington)
- Sara Seager (MIT)

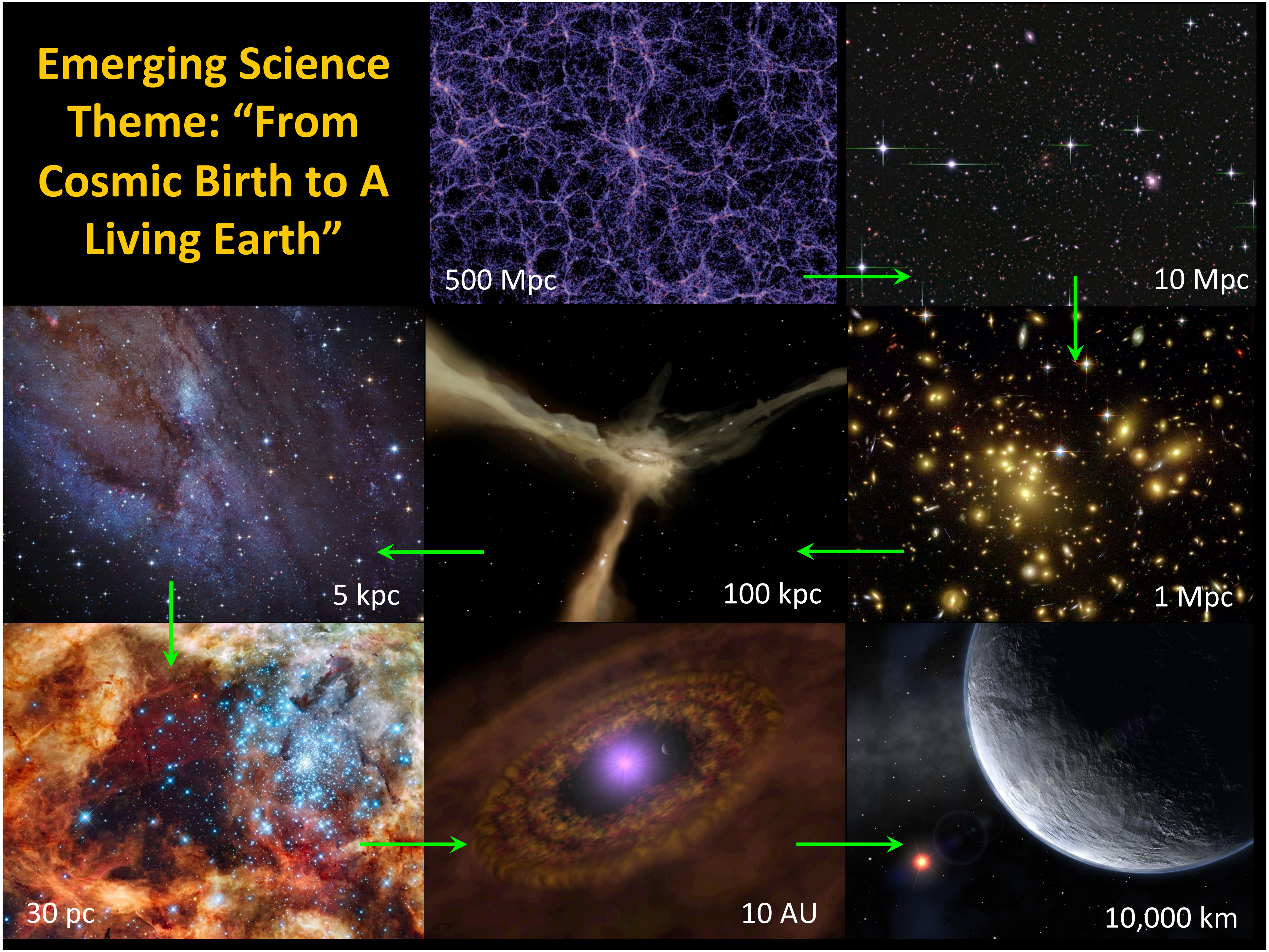
NASA Observer: Paul Hertz
ESA Observer: Arvind Parmar
AURA Facilitator: Heidi Hammel

AURA “Beyond JWST” Committee

Charter:

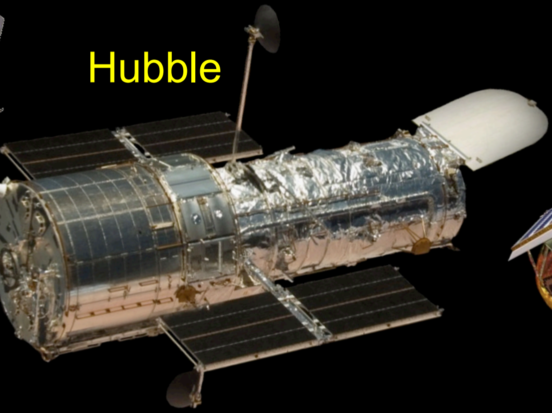
The “Beyond JWST” committee will study future space-based options for UV and optical astronomy (UVOIR) that significantly advance our understanding of the origin and evolution of the cosmos and the life within it. The committee, which has been commissioned by AURA, has the objective of developing a plan for UVOIR missions and programs in the post-Webb era.

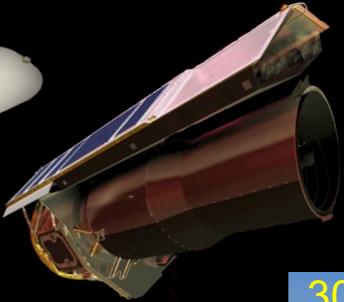
Emerging Science Theme: "From Cosmic Birth to A Living Earth"

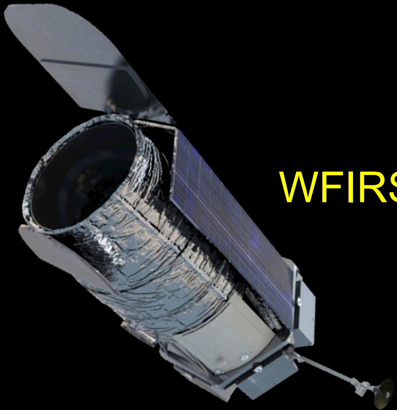


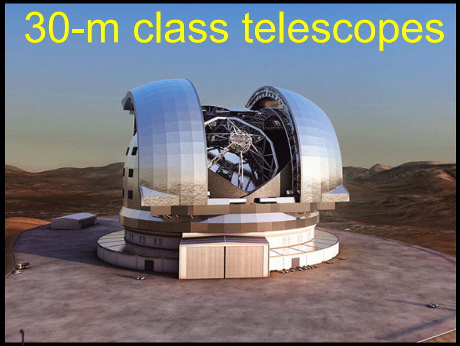
The path has been laid … to trace the intricate connections from “Cosmic Birth to Living Earths”


CoRoT

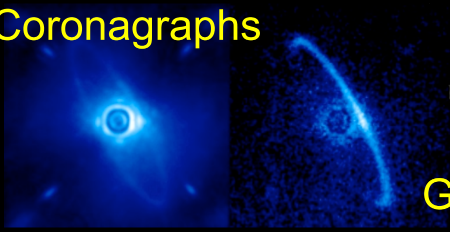

Hubble

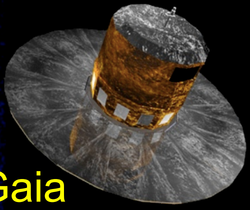

Spitzer


WFIRST


30-m class telescopes

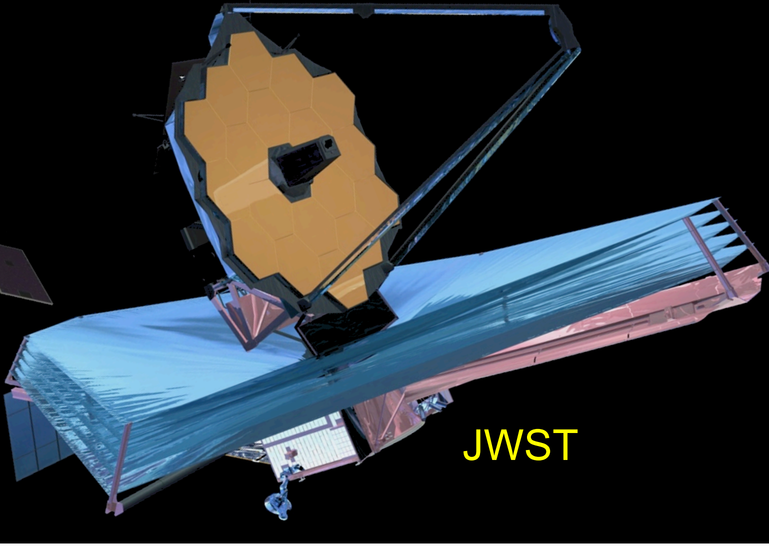

Ground-based

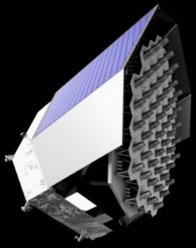

Coronagraphs


Gaia


Kepler

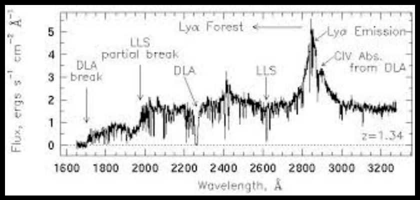

TESS


JWST


PLATO

Developing a Shared Vision

Cosmic Birth

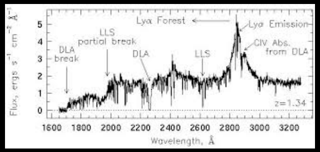


In the UVOIR, the goals and requirements are very similar.

Living Earth

Developing a Shared Vision

Cosmic Birth



- Broad instrument suite
- Sensitivity down to ~1000 Angstroms

Both

- Large (> 9m) aperture
- Diffraction limited at ~500 nm
- UV, Optical & NIR

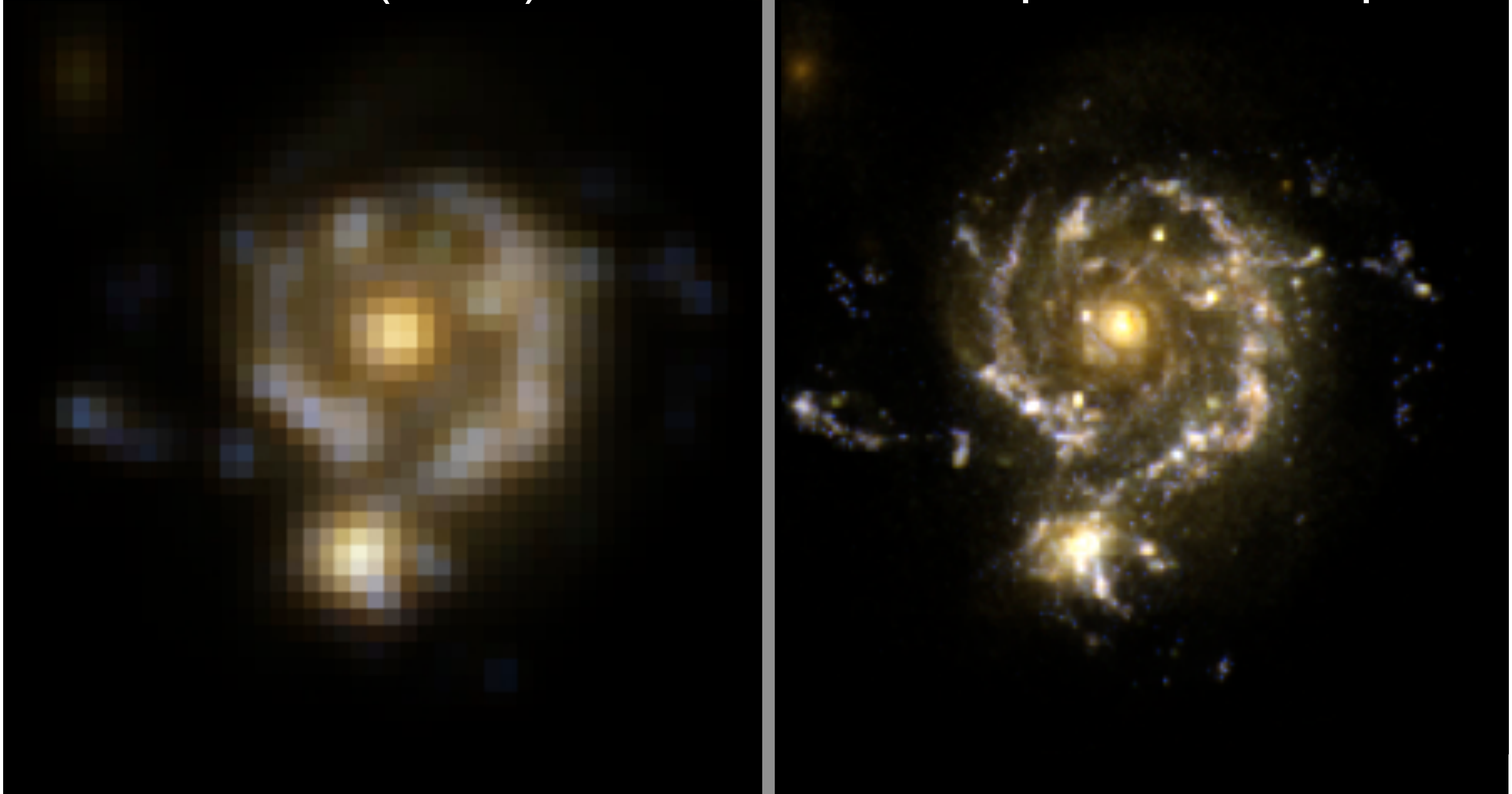
Living Earths

- Coronagraph or starshade
- Superb mirror stability

We Lack a Comprehensive Theory of Star and Galaxy Formation

A >8 m UV-Optical space telescope can perform novel studies of gas, stars, and galaxies with a combination of angular resolution and sensitivities not replicated by HST, JWST, or large ground-based telescopes.

z = 2 Galaxy: Look-back time = 76% age of universe



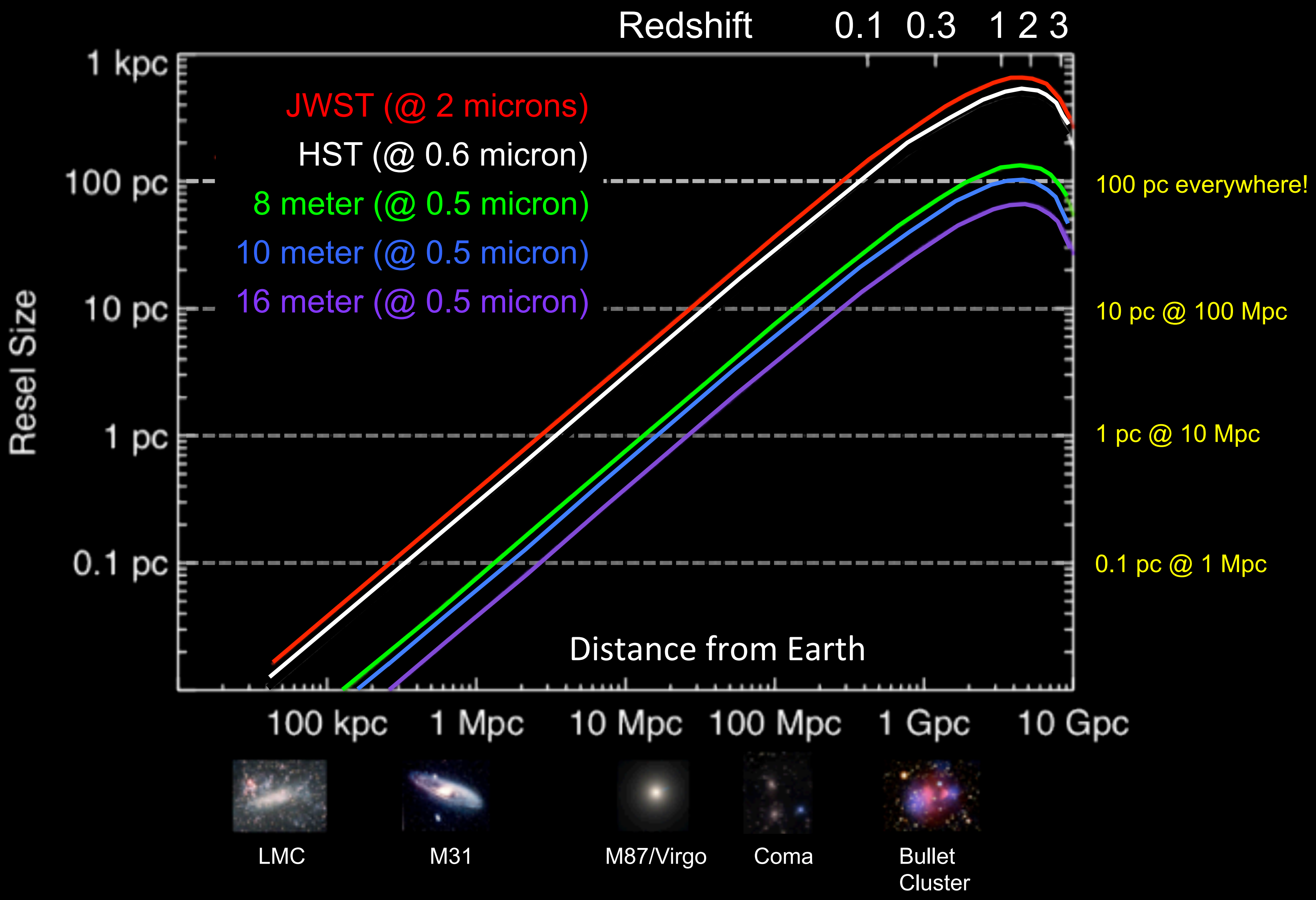
HST (2.4m)

15m Space Telescope

Simulated galaxies by HydroART Team:
Primack, Ceverino, Klypin, Dekel

Simulated images by Greg Snyder (STScI)

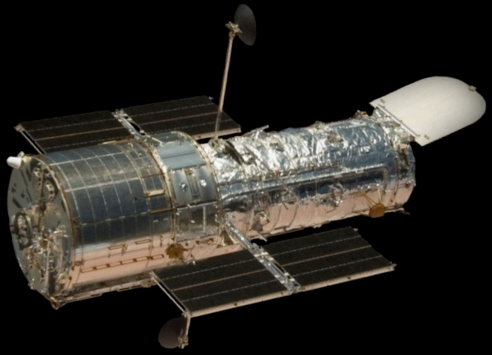
Breaking Resolution & Sensitivity Barriers in the UVOIR



SDTV
720x480

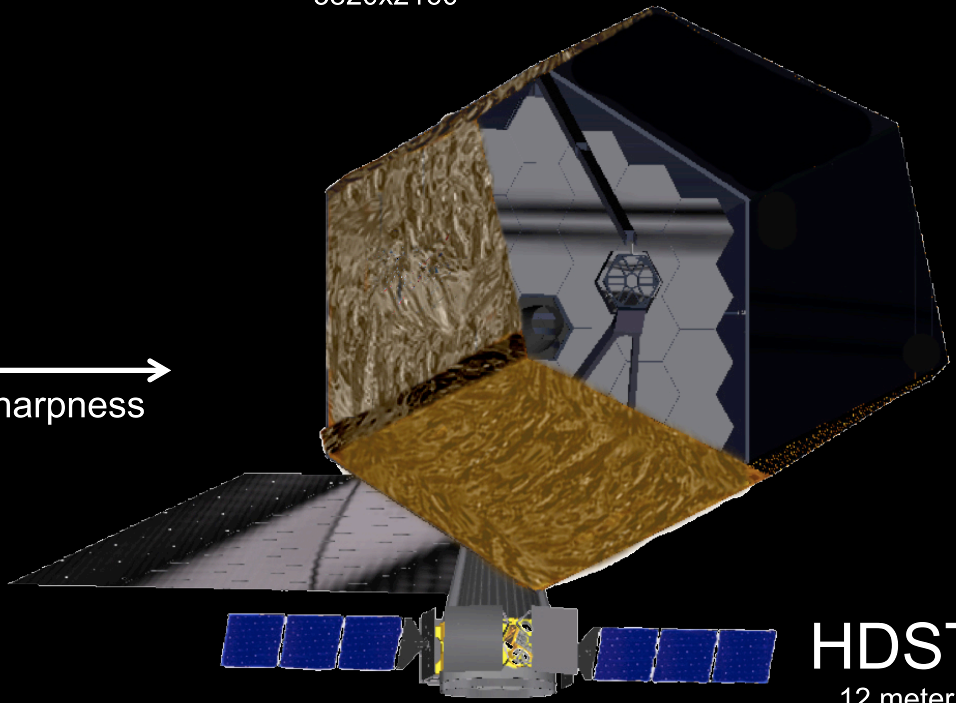
24x pixel density

UltraHD
3820x2160



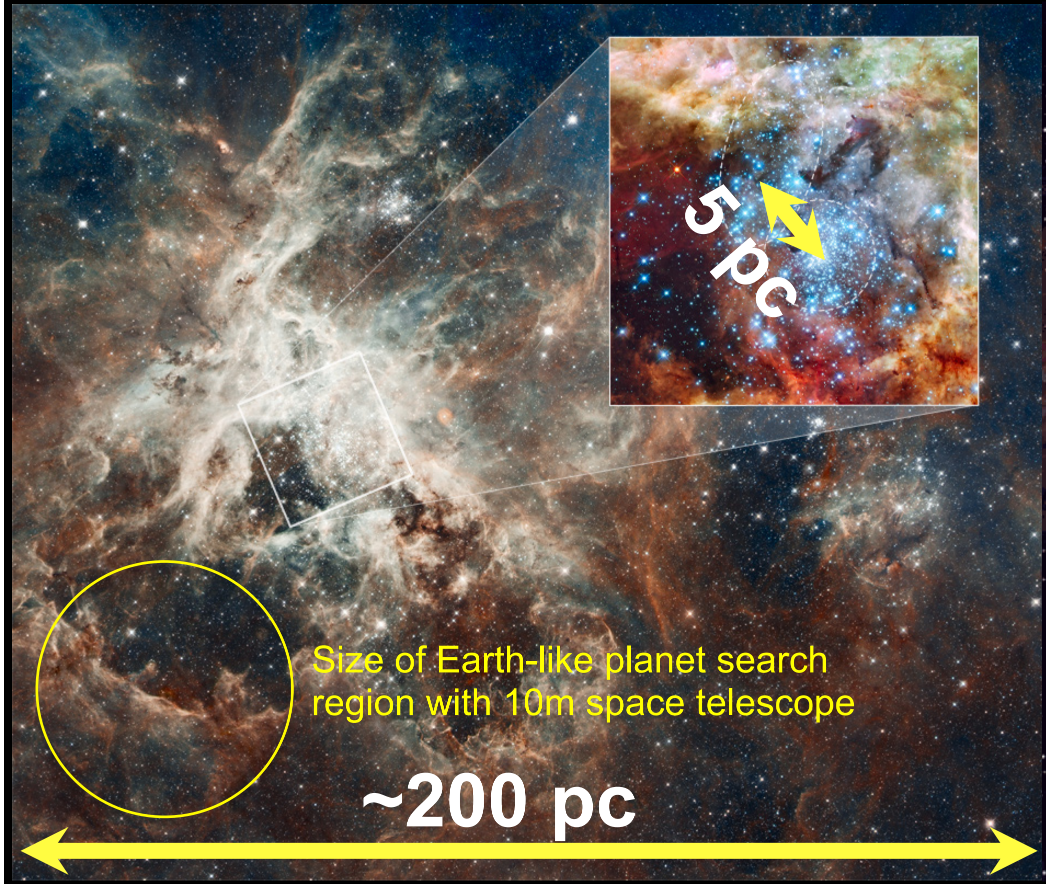
HST
2.4 meter

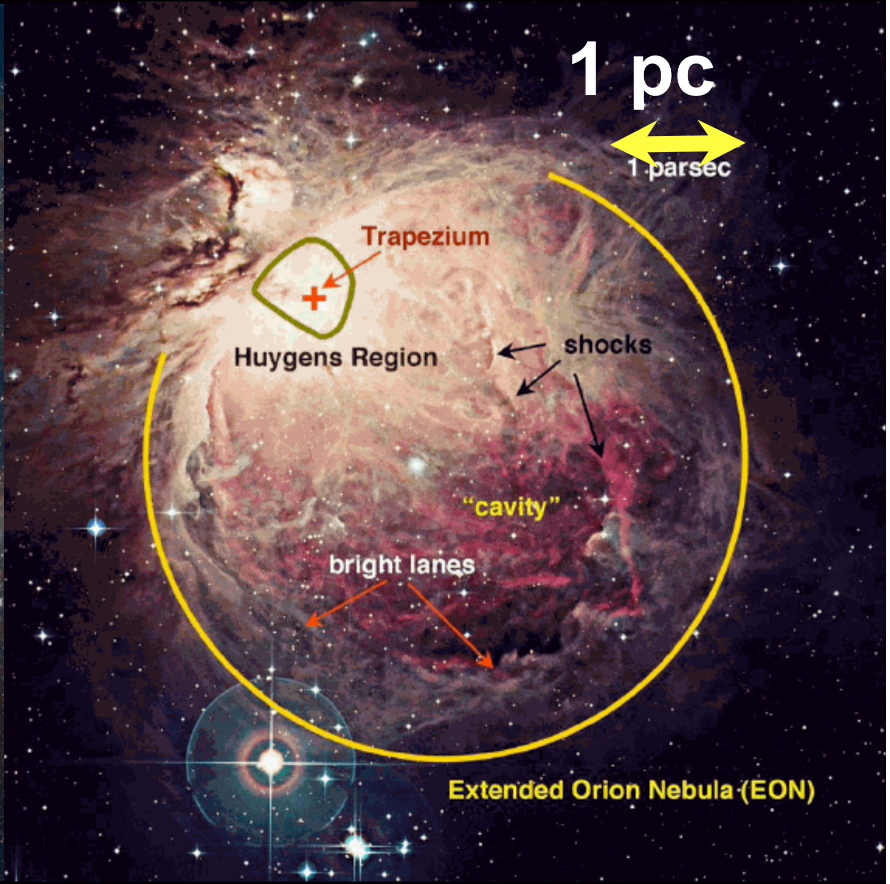
24x image sharpness



HDST
12 meter

Spatial Resolution

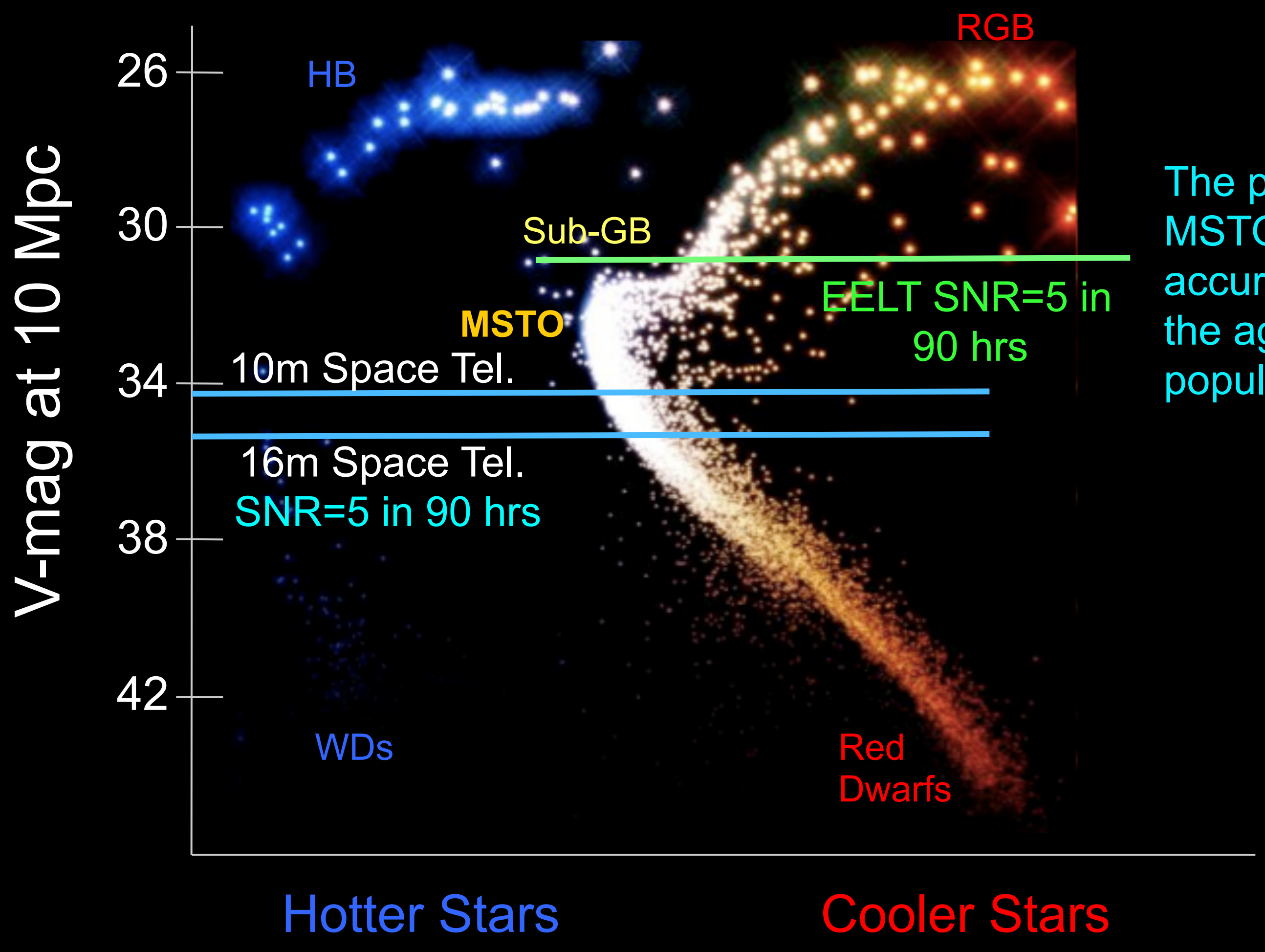




Resolving 100 pc star forming regions *everywhere* in the universe would be a remarkable capability. And 1 pc resolved out to 10-25 Mpc.

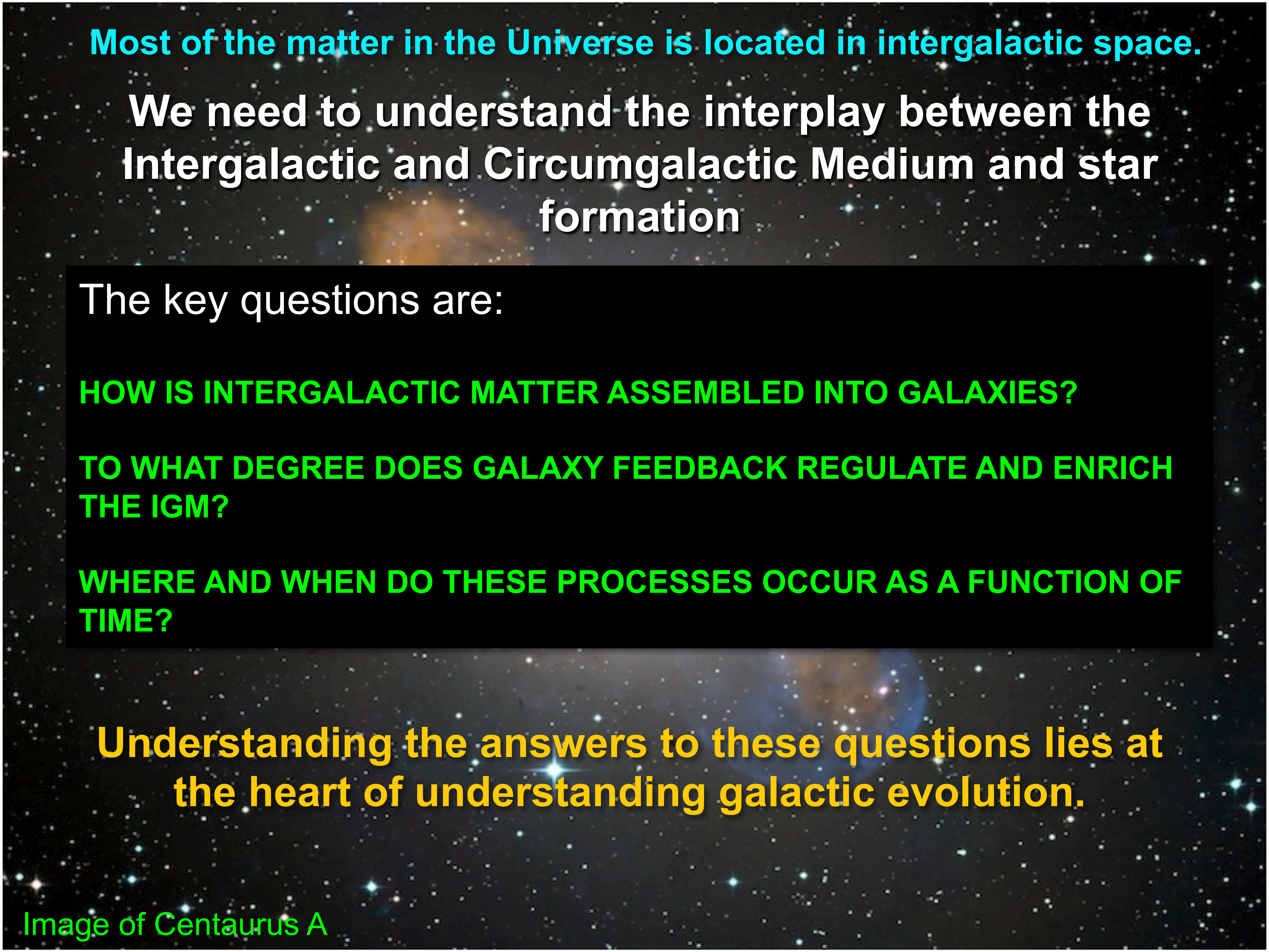
ALMA: molecular gas on ~0.1-0.5” scales
JWST: Heavily enshrouded stars
ATLAST: Emerging stars

Direct detection of the Main Sequence Turn-Off in galaxies up to 10 Mpc away enables us to trace the *Star Formation History in all major types of galaxies.*



The position of the MSTO is the most accurate indicator of the age of the stellar population.

CMD image: J. Anderson
Flux scale: K. Olsen et al. 2009



Most of the matter in the Universe is located in intergalactic space.

We need to understand the interplay between the Intergalactic and Circumgalactic Medium and star formation

The key questions are:

HOW IS INTERGALACTIC MATTER ASSEMBLED INTO GALAXIES?

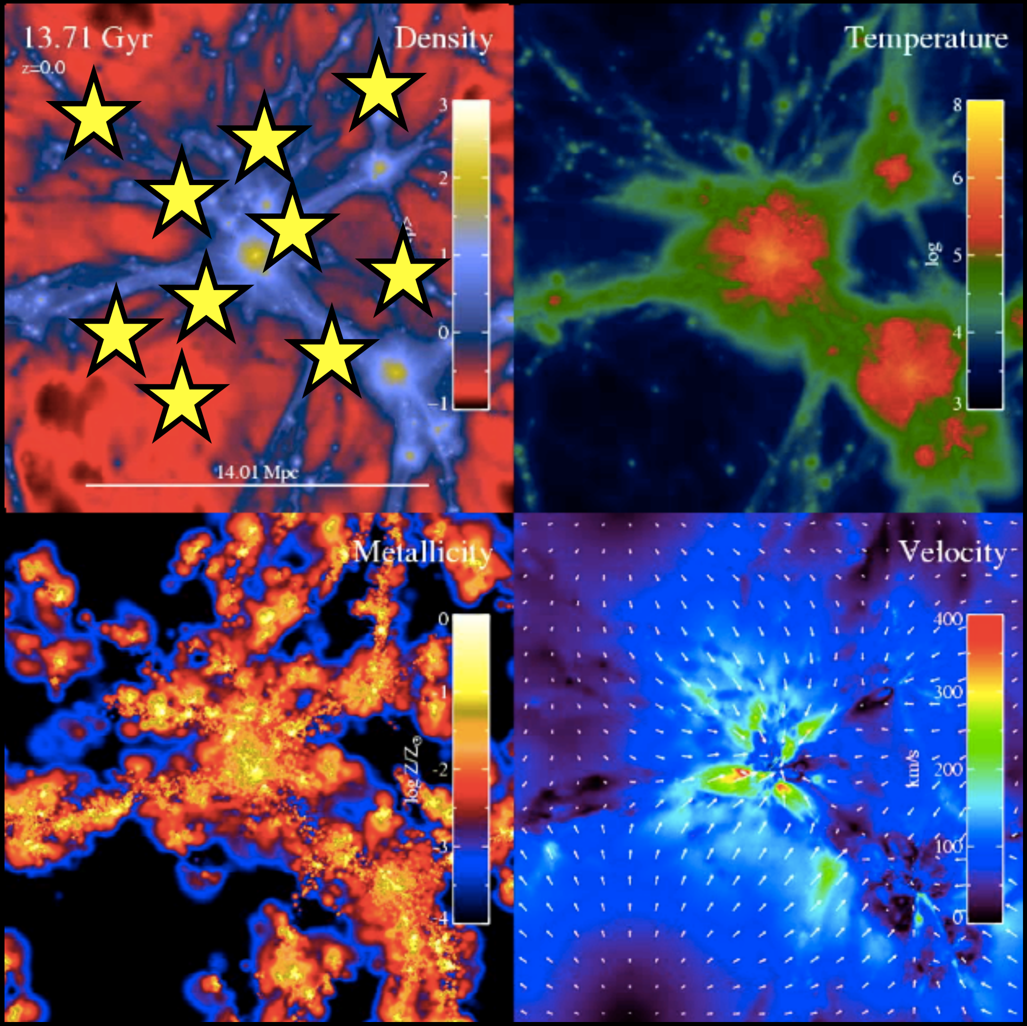
TO WHAT DEGREE DOES GALAXY FEEDBACK REGULATE AND ENRICH THE IGM?

WHERE AND WHEN DO THESE PROCESSES OCCUR AS A FUNCTION OF TIME?

Understanding the answers to these questions lies at the heart of understanding galactic evolution.

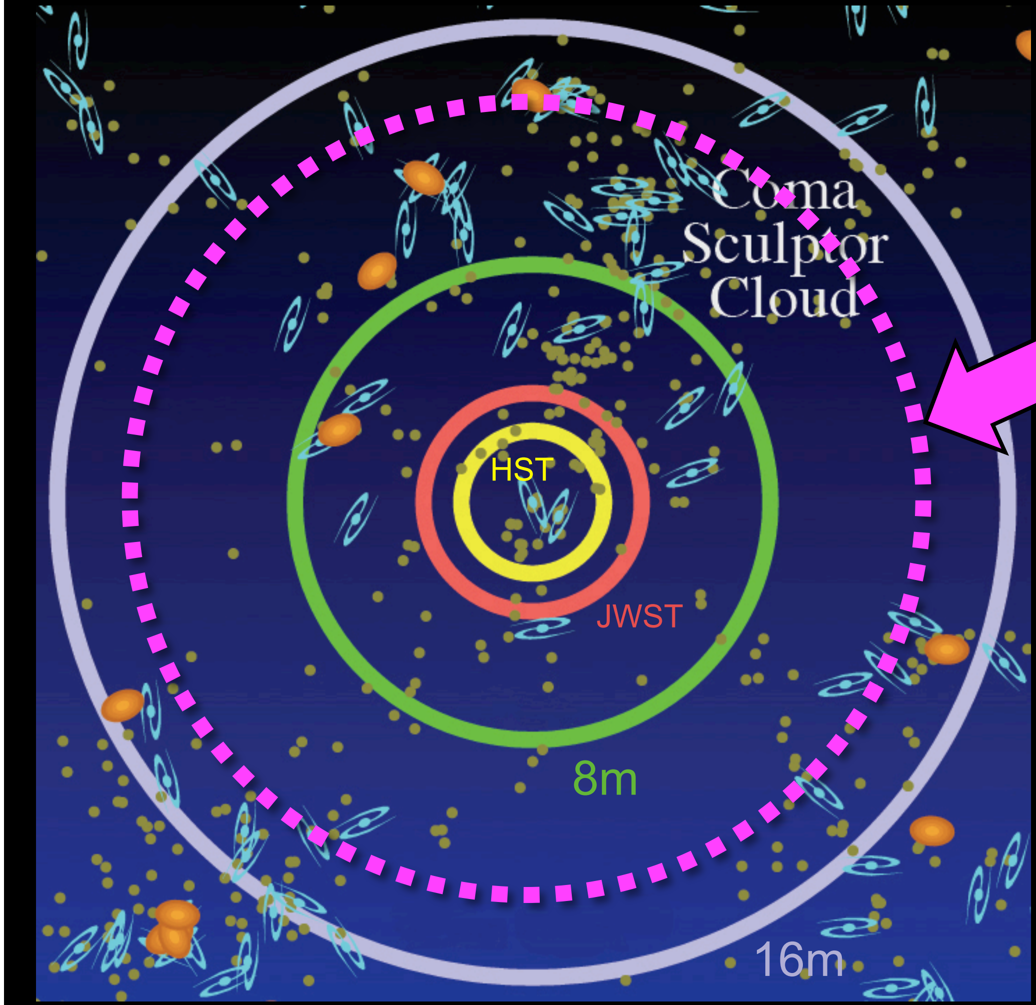
Image of Centaurus A

UV Sensitivity: High Density of Background Sources



# of QSO’s per square degree is a strong function of magnitude

Galaxy Evolution Studies in High-Definition



Map of Galaxies within 12 Mpc of Our Galaxy

At m_{FUV} = 22 AB, ~10 QSO's behind every galaxy within ~10 Mpc!

Gain of ~5000 in QSO surface density vs. HST

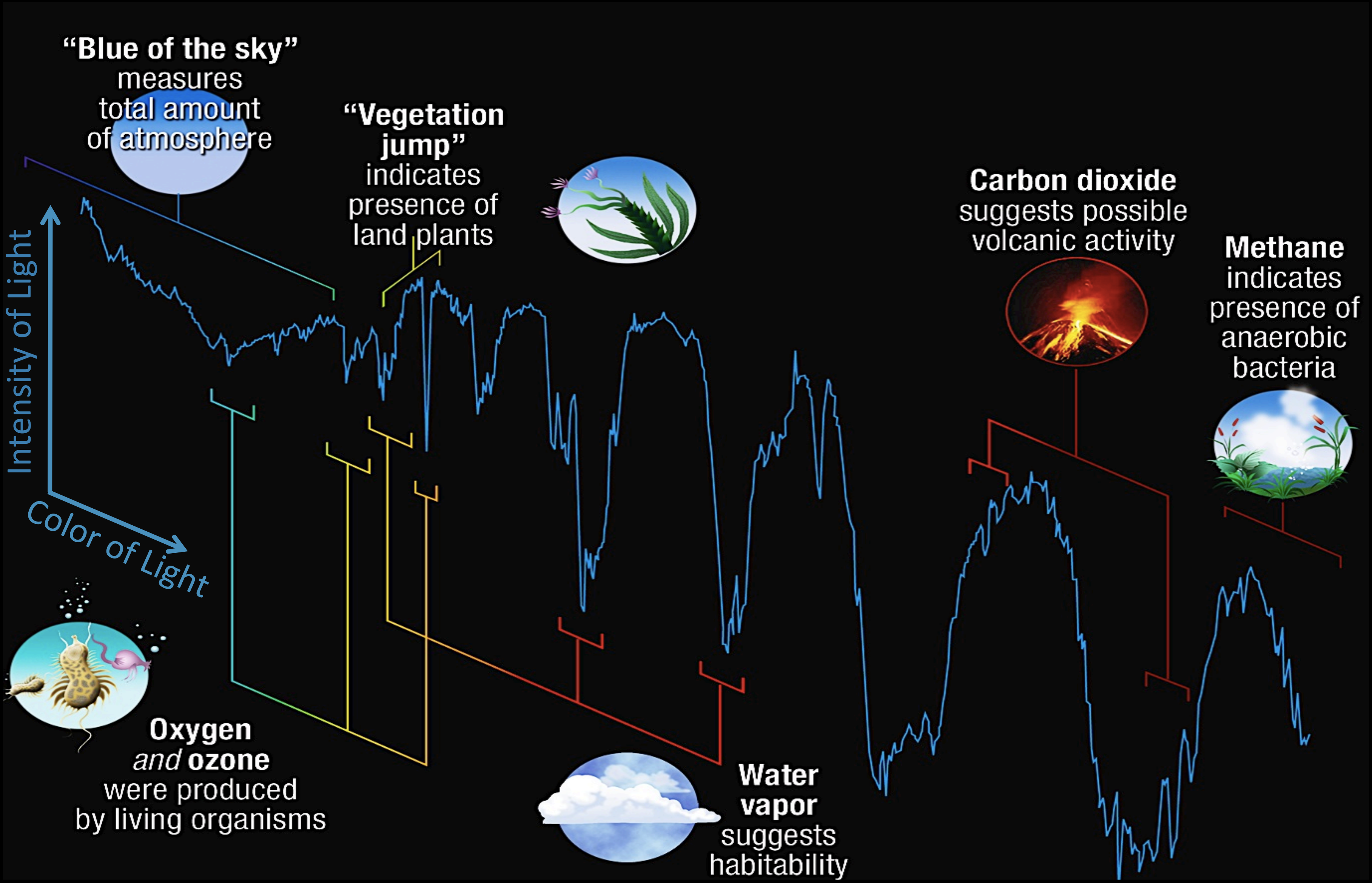
Measure circumgalactic gas in *the same galaxies* where we measure the star formation histories from resolved stars!

Are We Alone?
How common are Habitable Worlds?

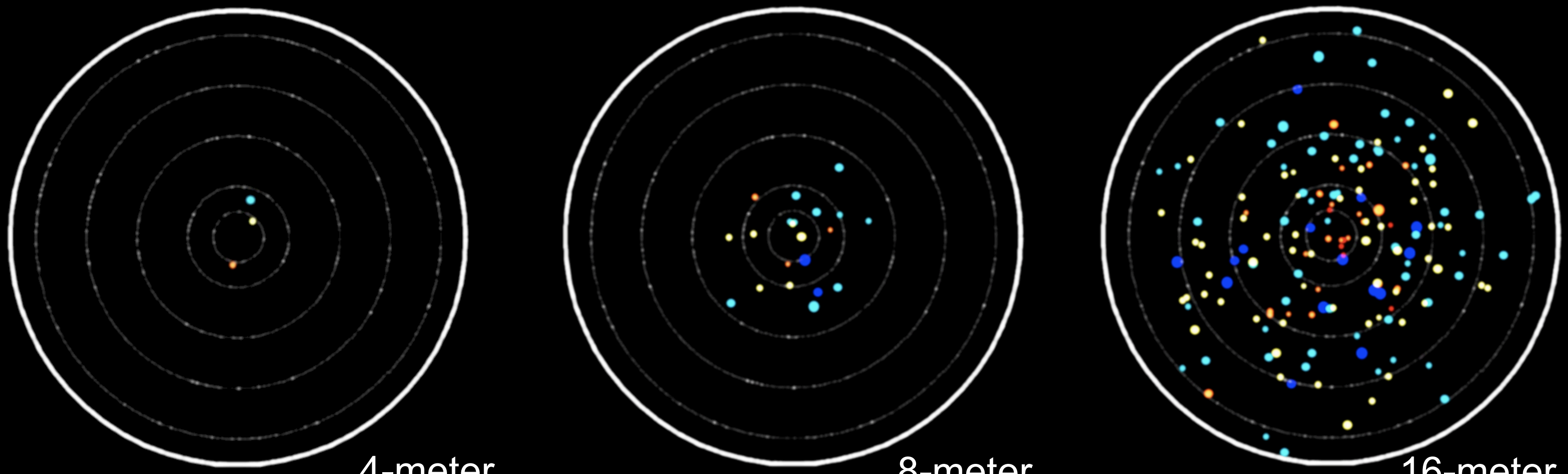
"The most important experiment in modern biology is the search for extra-terrestrial life."

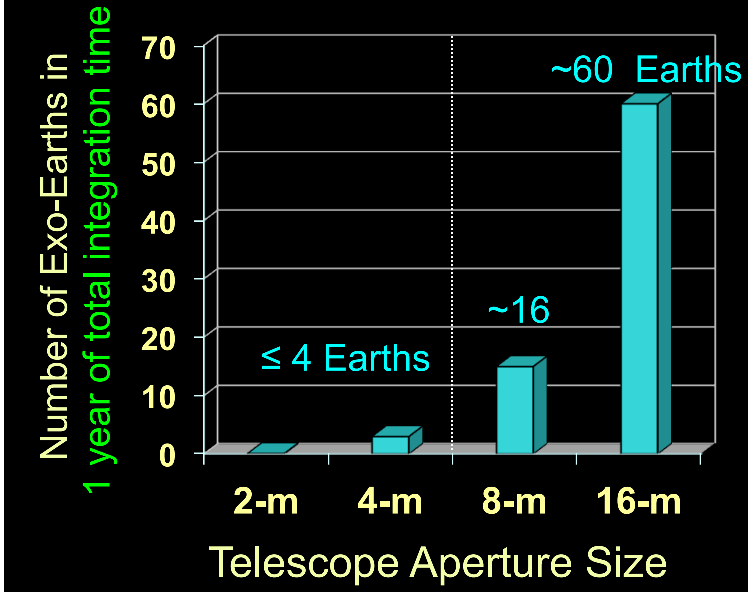
- E. O. Wilson
Evolutionary Biologist
June 2012

The signature of life is likely to be encoded in the spectra of a planet's atmosphere.



Based on the DRM simulation code from C. Stark et al. 2014.
Assumes 10% of solar type stars have Earth-like planets in their habitable zone.





Estimated number of Earth-like planets around long-lived stars for which spectra can be obtained as a function of the space telescope's primary mirror diameter.

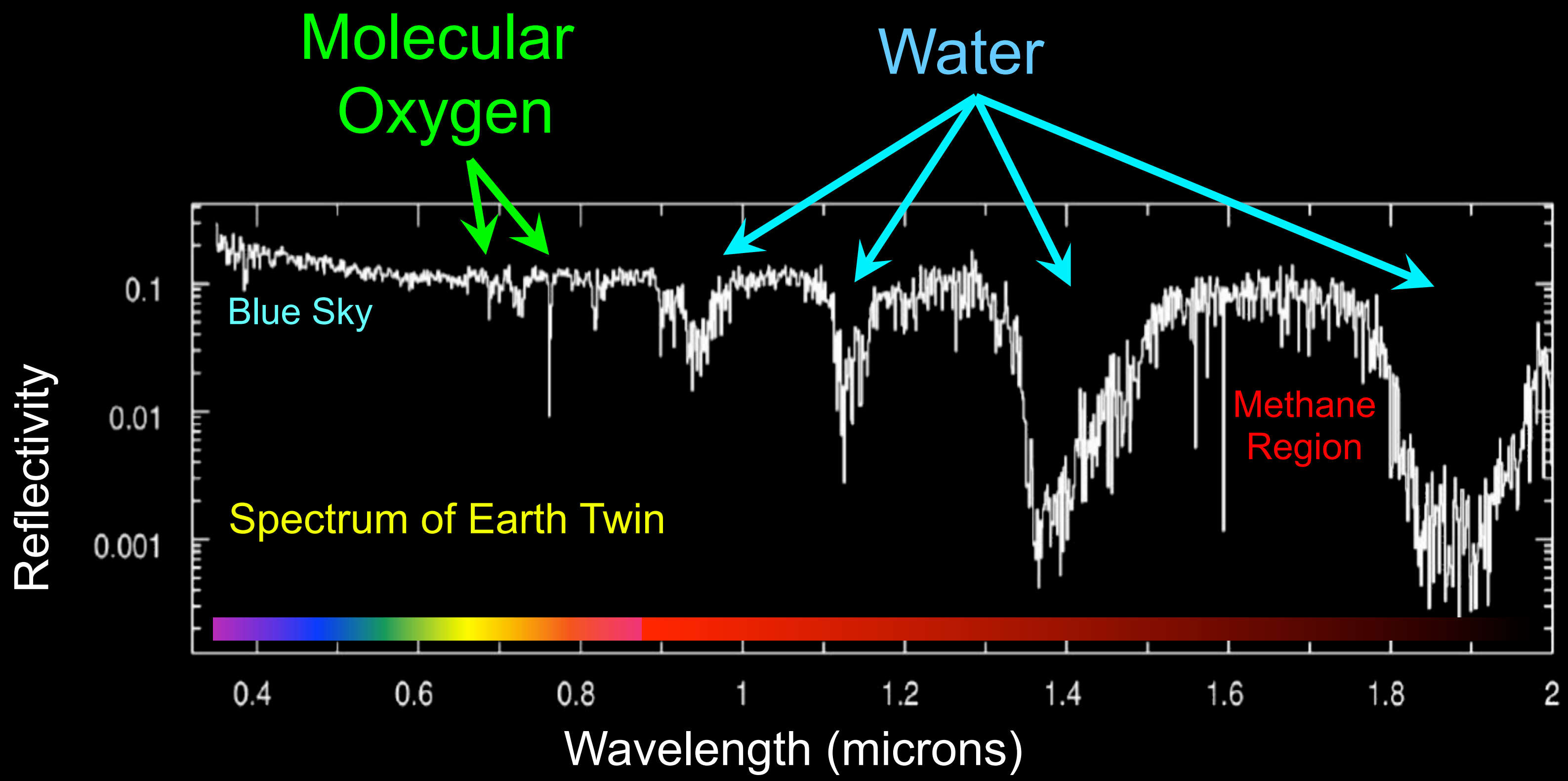
$$N_{Earth} \sim 25\,(D\,/\,10m)^{1.8}(t\,/\,1\;yr)^{0.4}$$

The number of exo-Earth spectra obtained with a given aperture can be increased by extending the total mission time allocated to exoplanet observations

Reaching 100 Exo-Earths is tough

- Based on Chris Stark's yield simulations to date, to reach ~85 Exo-Earths we need
  - D=10m, eta_Earth=0.6 (!), solar zodi, throughput 15%, or
  - D=12m, eta_Earth = 0.35, solar zodi, throughput 15%
  - D=20m (!), eta_Earth = 0.2, 3 x solar zodi, throughput 10%
- This is assuming 1 year of total *exposure* time spread over the lifetime of the mission
- Even with a 12m aperture we are relying on pretty optimistic assumptions to get to the desired yield.
- Work on planet yield and telescope aperture is ongoining to establish the minimum diameter aperture

- **Note on Probe vs. BJWST**



8-meter space telescope: ~7 days

16-meter space telescope: *a few hours*

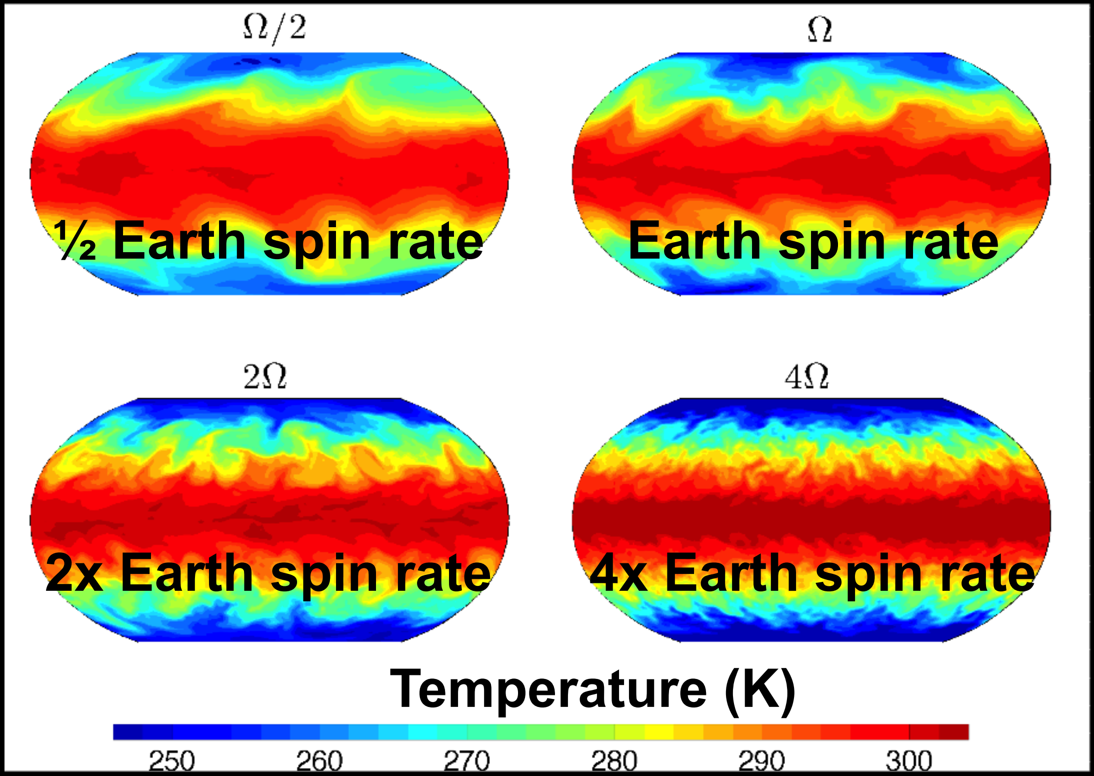
Planet spin rate and ocean/land fraction affect global climate

Faster the spin, the less heat transport to high latitudes.

Hotter equator, colder poles.

Ocean is a heat sink.

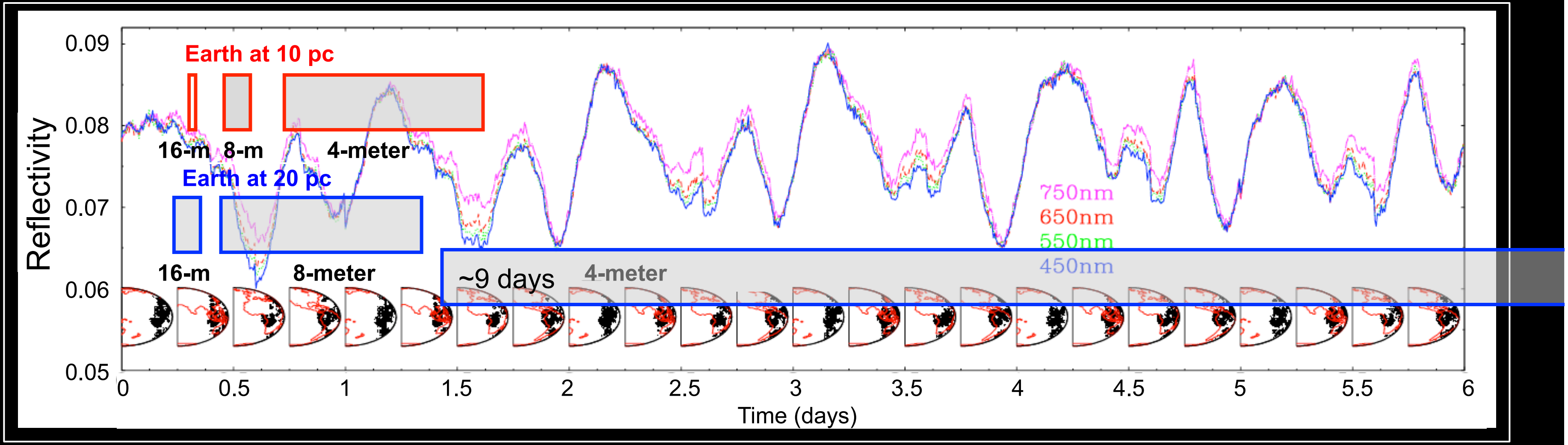
Greater ocean fraction, less atmospheric temperature variation.



Showman et al. (2013)

Detecting Diurnal Photometric Variability in Exoplanets

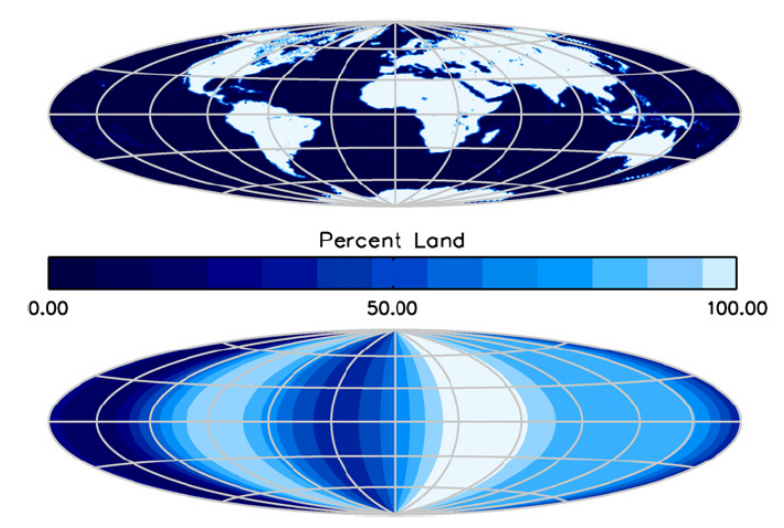
Ford et al. 2003: Model of broadband photometric temporal variability of Earth



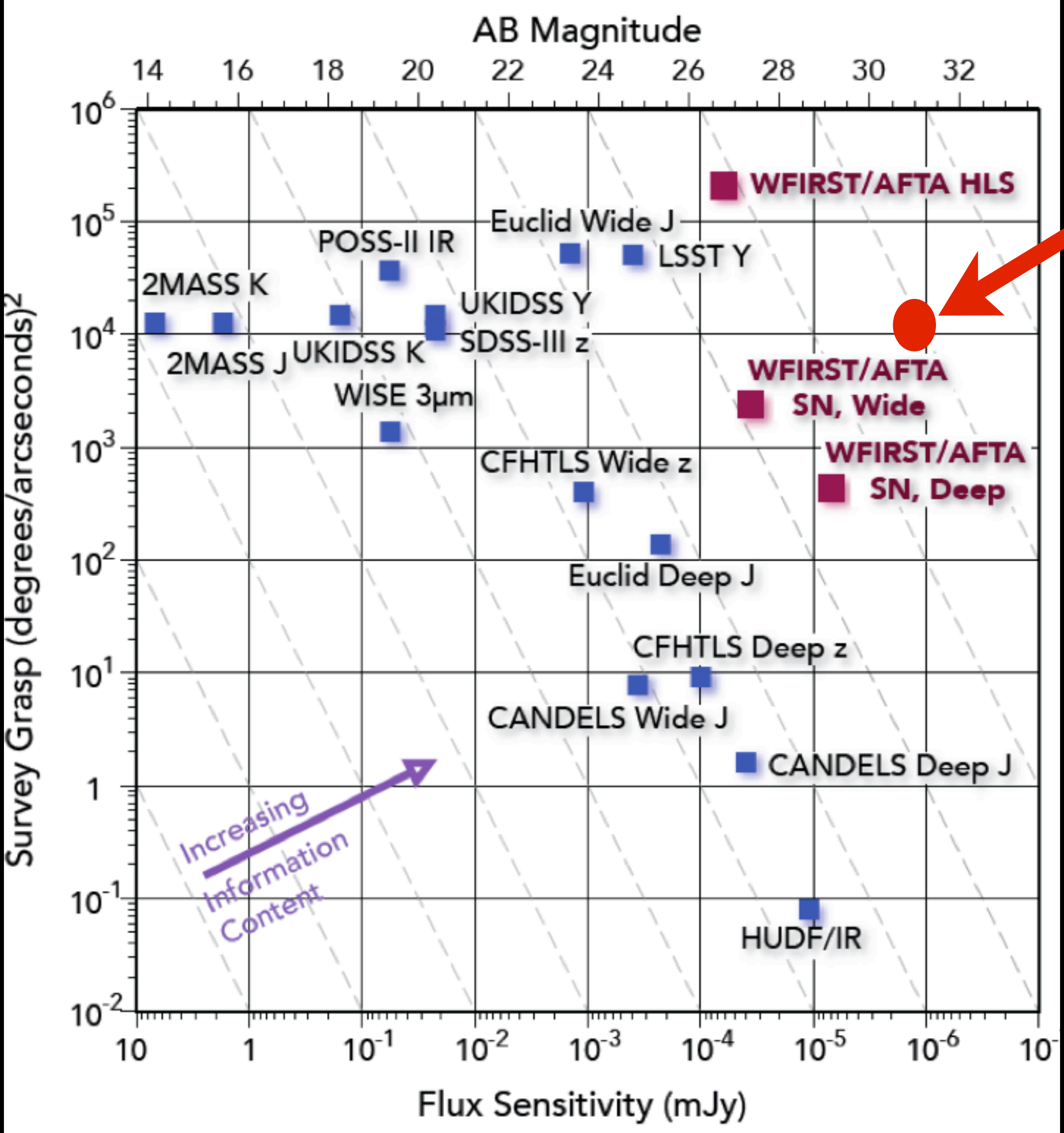
Require S/N ~ 20 (5% photometry) to detect ~20% temporal variations in reflectivity.

Reconstruction of Earth's land-sea ratio from disk-averaged time-resolved imaging with the EPOXI mission. →

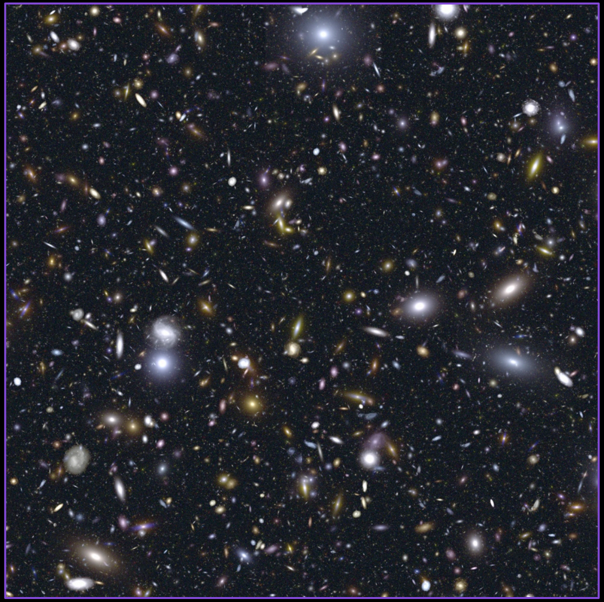
A 10m class space telescope will have the power to make such maps for many exoplanets.



Parallels: Exoplanet Observations Become General Astrophysics Observations



Parallel deep fields (during long ~100 ksec exoplanet exposures) with a 10 m class space telescope will reach AB ~31 mag (in BVRI).



What Aperture?

- **Matching Observatory Capabilities to Science Goals**
  - **Aperture**, resolution, wavelength
  - **Serviceability, on-orbit assembly, launch vehicles**

- **Considerations for the Path Forward (i.e., tech development, policy, partnerships, etc)**
  - **Breaking the cost curve**: science within a budget
    - Lessons learned from HST, JWST, AFTA, SIM(?)
  - **What are critical technologies & requirements?**
  - **How do we develop these technologies?**
  - **Recommendations**

What Aperture?

- **Aperture diameter D requirement will be based on…**
  - ExoEarth yield using internal coronagraph or starshade
    - Requires D ≥ 8m to meet goal of 99% probability of finding and characterizing >10 exoEarths, under current estimates of η_{Earth} and exo zodi n
  - Resolving stellar populations in neighboring galaxies
    - Requires D ≥ 8m, to reach 10Mpc
  - UV spectroscopic probes of gas around stars in neighboring galaxies, and of the IGM around more distant galaxies
    - Also requires D ≥ 8m
- **Monolith or segmented?**
  - Largest monolithic aperture flyable with existing LVs is 4m
    - Future LVs – the SLS Block 2 – may be able to launch a 6.4 or 8m monolith, but are not yet under active development
  - Segmented apertures support a range of size options
    - Up to 10m-class in existing LVs
    - Up to 16m-class in SLS-2
    - Can be assembled on orbit to even larger sizes, if NASA invests in assembly infrastructure

Monolith or Segmented?

Candidate Aperture Architecture	Meets Threshold Reqts	Scalable to Apertures > 8m?	Launch Options	Heritage	Relative Mass Areal Density	Relative Complexity	Tech Issues
4m aperture monolith	No	No	Atlas V 551; Falcon 9H; SLS Block 1	HST	High	Low	Mirror scale-up; Thermal stability; coronagraph performance
8m aperture monolith	Yes	No	SLS Block 2 with 10m shroud only	HST	High	Low	Mirror scale-up; Thermal stability; coronagraph performance
10m-class segmented aperture	Yes	Yes	Delta IV H; Falcon 9H; SLS Block 1	JWST	Low	High	Thermal stability; coronagraph performance
16m-class segmented aperture	Yes	Yes	SLS Block 2 with 8.4 or 10m shroud	JWST	Low	High	Mirror scale-up; Thermal stability; coronagraph performance
>8m segmented aperture, assembled on orbit	Yes	Yes	Various; requires new infrastructure	JWST, ISS	Low	High	On-orbit assembly; thermal stability; coronagraph performance

- **ATLAST 10m-class segmented aperture is a strong candidate**
  - Is scalable to larger sizes. > 12 m is likely needed to meets current science requirements
  - Can be launched using existing LVs
  - Multiple mirror segment technologies exist at needed size, though thermal stability needs investigation
  - Architecture and mechanisms draw on current JWST experience
- **An 8m monolith will be an option if NASA develops a 10m shroud for the SLS Block 2**
  - Mirror scale-up from 2.4m to 8m is required; thermal stability needs investigation
  - Heavy = high estimated cost

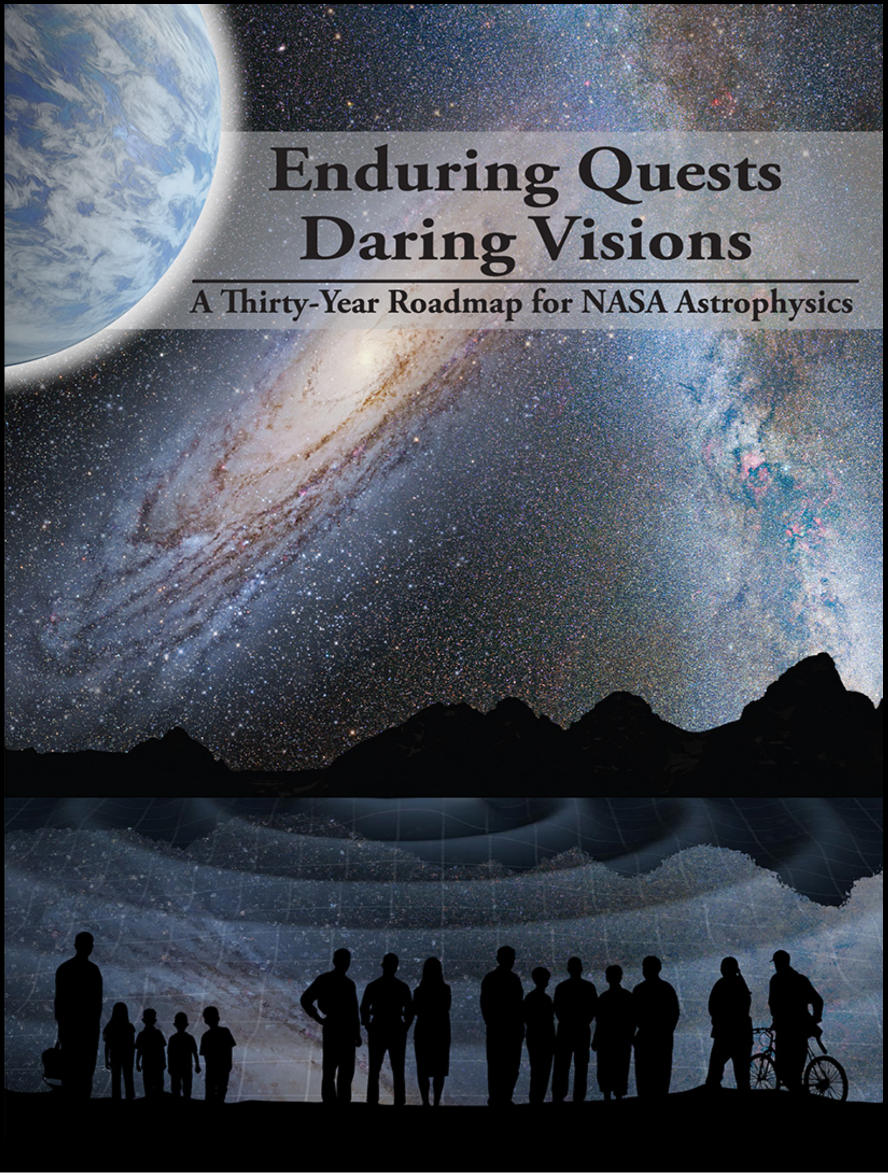
Towards Technology Recommendations

Development of internal coronagraph designs capable of 10-10 contrast at an inner working angle of 2-3 λ/D, with an obscured, segmented aperture, suitable for operation with a 10m-class telescope; and concurrent **development of large starshade designs** suitable for operation with a 10-meter-class telescope. Investment in these two areas would build on progress already being made by the AFTA and Probe study teams, extending it to the larger apertures needed for ExoEarth discovery and characterization.

Investment in segmented mirrors, to prove mirror system performance, stability and cost for 10m-class apertures in support of UV/optical science. In particular we urge that NASA conduct detailed model-based analysis of mirror system performance, especially addressing dynamic and thermal stability, to the levels required for coronagraphy; we stress that these studies must be grounded by test data. Relevant mirror systems have been built by NASA and other agencies in the past, and small additional investment would complete them for such testing purposes. This work would complement the SAT-funded AMTD project—which is developing and testing large monolithic mirror technologies—by sharing resources and facilities to provide comparable data.

Advancement in UV-Visible-NIR detector and mirror coating technologies, to realize the high spatial resolution enabled by a large telescope and to maximize the scientific return of its instruments. Detectors with large formats, small pixels, and/or photon-counting capability are highly desired. Development efforts should also demonstrate performance stability and long lifetimes in flight or mission-equivalent environments. Technologies that boost observatory efficiency in the UV are also a high priority. We urge NASA to encourage and support the broad community in achieving (and testing to) these benchmarks, and to continue a balanced program to nurture low-TRL emerging/breakthrough detector and supporting technologies directed at these capabilities. Our full report will provide quantitative performance goals.

This science is aligned with NASA’s 2013 Astrophysics Roadmap



Enduring Quests
Daring Visions
A Thirty-Year Roadmap for NASA Astrophysics

Large UVOIR Surveyor (8 – 16m) identified as key mission for 2 of 3 major science areas

- Are We Alone?
- How Did We Get Here?

How do we get there?

U.S. Activities:

- ATLAST NASA Center (GSFC/JPL/MSFC) Study
- AURA "Beyond JWST" Committee
- NASA "EXOPAG" & "COPAG" working groups
- Coronagraph & Starshade developments for WFIRST and Exoplanet Probe concepts

Goal: Mature technology and mission concepts in preparation for 2020 Decadal

Schedule

- Committee is aiming to have its report ready for public dissemination before the end of the year.
- Will plan to have a special session at January 2015 AAS meeting (Seattle) to present the findings.
- Leadership to advocate for the report's findings beyond 2014 will be an important item for the committee to consider.