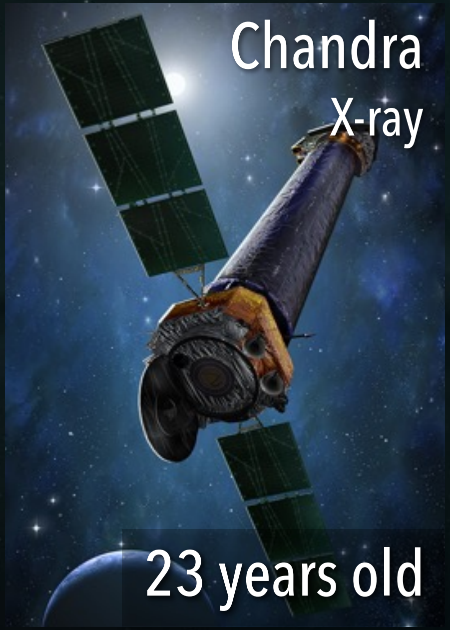
NASA's Future UV / Optical / IR Great Observatory

Dr. Aki Roberge
NASA Goddard Space Flight Center
October 6, 2022

The once and future Great Observatories

The First Great Observatories



The once and future Great Observatories

The Future Great Observatories

HabEx
UV/Optical/NIR

LUVOIR
UV/Optical/NIR

Lynx
X-ray

Origins
Infrared

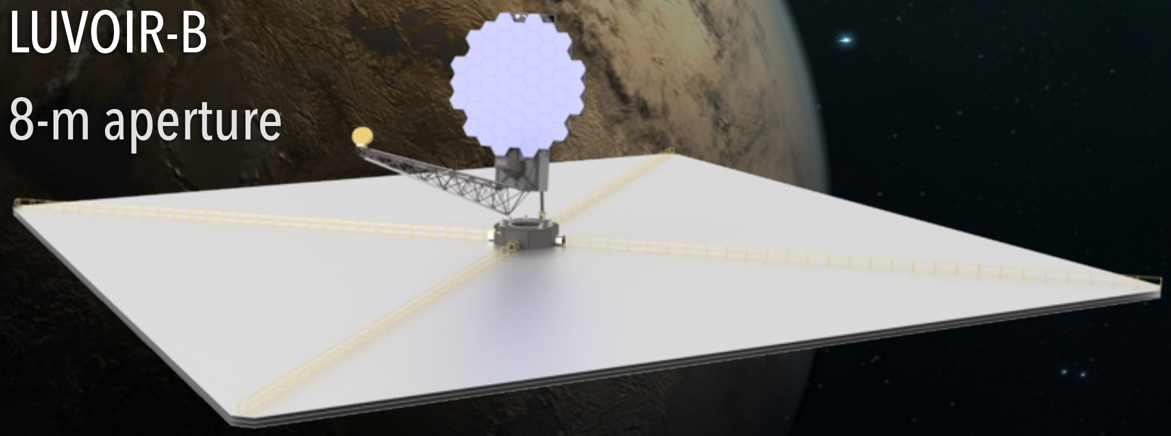
Astro2020 Decadal Survey recommended NASA work towards a new fleet of multi-wavelength Great Observatories

First New Great Observatory

Infrared / Optical / UV space telescope with ~ 6-m inscribed diameter

To search for life on exoplanets and enable transformative astrophysics

Blending of the LUVOIR and HabEx mission concepts (IROUV? LUVEx?)



L U V O I R

H A B E X

LUVOIR ARCHITECTURES

Two LUVOIR designs

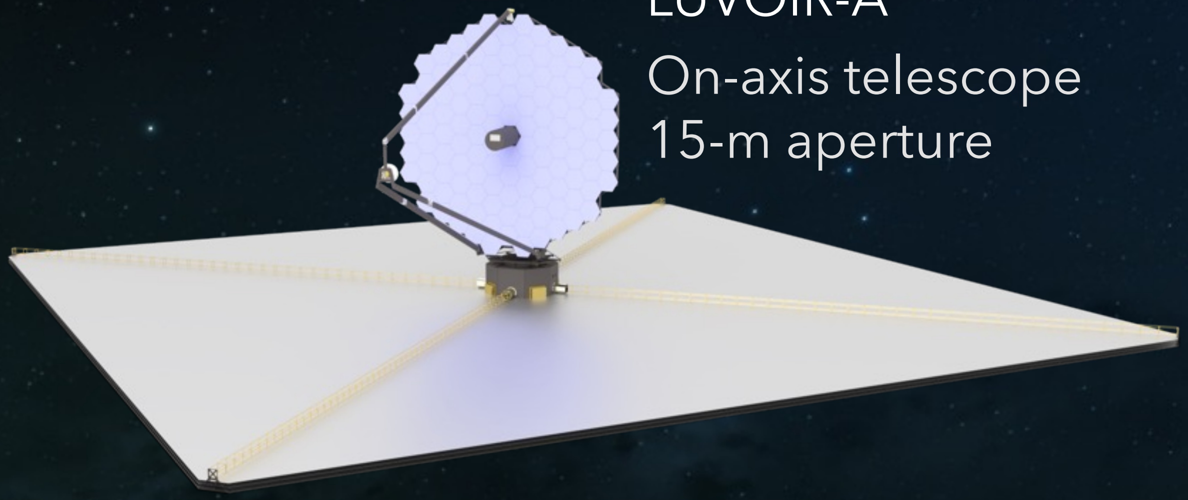
Total wavelength range: 100 nm – 2.5 μm

Four instruments (next slides)

Serviceable and upgradable

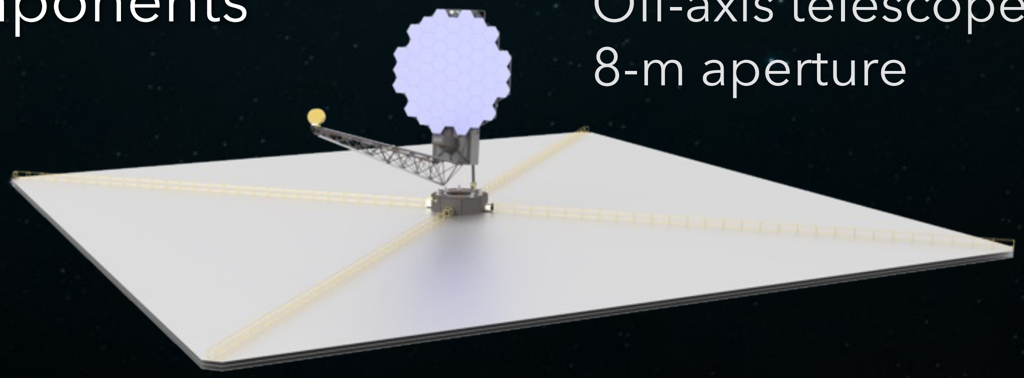
5-year prime mission duration, 10 years of consumables

25-year lifetime goal for non-serviceable components



LUVOIR-A

On-axis telescope
15-m aperture



LUVOIR-B

Off-axis telescope
8-m aperture

LUVOIR-B DEPLOYMENT AND POINTING SEQUENCE

The LUVOIR candidate instruments

ECLIPS
Extreme Coronagraph for Living Planetary Systems

Coronagraph with imaging and imaging spectroscopy	
Bandpass	200–2000 nm
Contrast	1×10^{-10}
IWA	3.5 λ/D
OWA	64 λ/D
R $(\lambda/\Delta\lambda)$	Vis: 140 NIR: 70, 200

HDI
High-Definition Imager

Wide field imager with simultaneous UV/Vis and NIR coverage	
Bandpass	200–2500 nm
FoV	$3' \times 2'$
67 science filters + grism	
Nyquist sampled	
High-precision astrometry	

LUMOS
LUVOIR Ultraviolet Multi-Object Spectrograph

UV/Vis multi-object spectrograph and FUV imager	
Bandpass	100–1000 nm
MOS FoV	$2' \times 2'$
Apertures	840×420
R $(\lambda/\Delta\lambda)$	500–50,000

More on this in Kevin France's talk later today

POLLUX
UV spectropolarimeter (on LUVOIR-A only)

Point-source UV spectropolarimeter (European study for LUVOIR-A only)	
Bandpass	100–400 nm
R $(\lambda/\Delta\lambda)$	120,000
Circular + linear polarization	

HabEx Preferred Architecture

4-m off-axis monolith primary mirror

Total wavelength range: 115 nm – 1.8 μm

Four instruments:

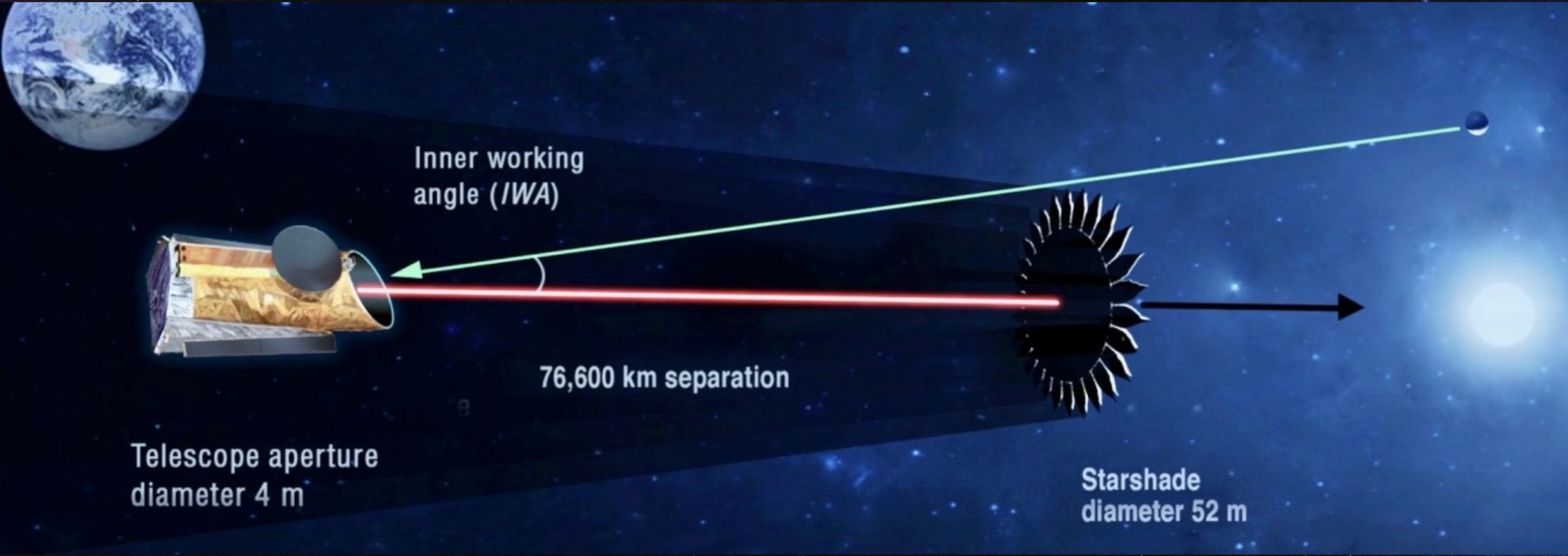
- Coronagraph Instrument → similar to LUVOIR ECLIPS
- HabEx Workhorse Camera (HWC) → similar to LUVOIR HDI
- UV Spectrograph (UVS) → similar to LUVOIR LUMOS
- Starshade Instrument → unique to HabEx

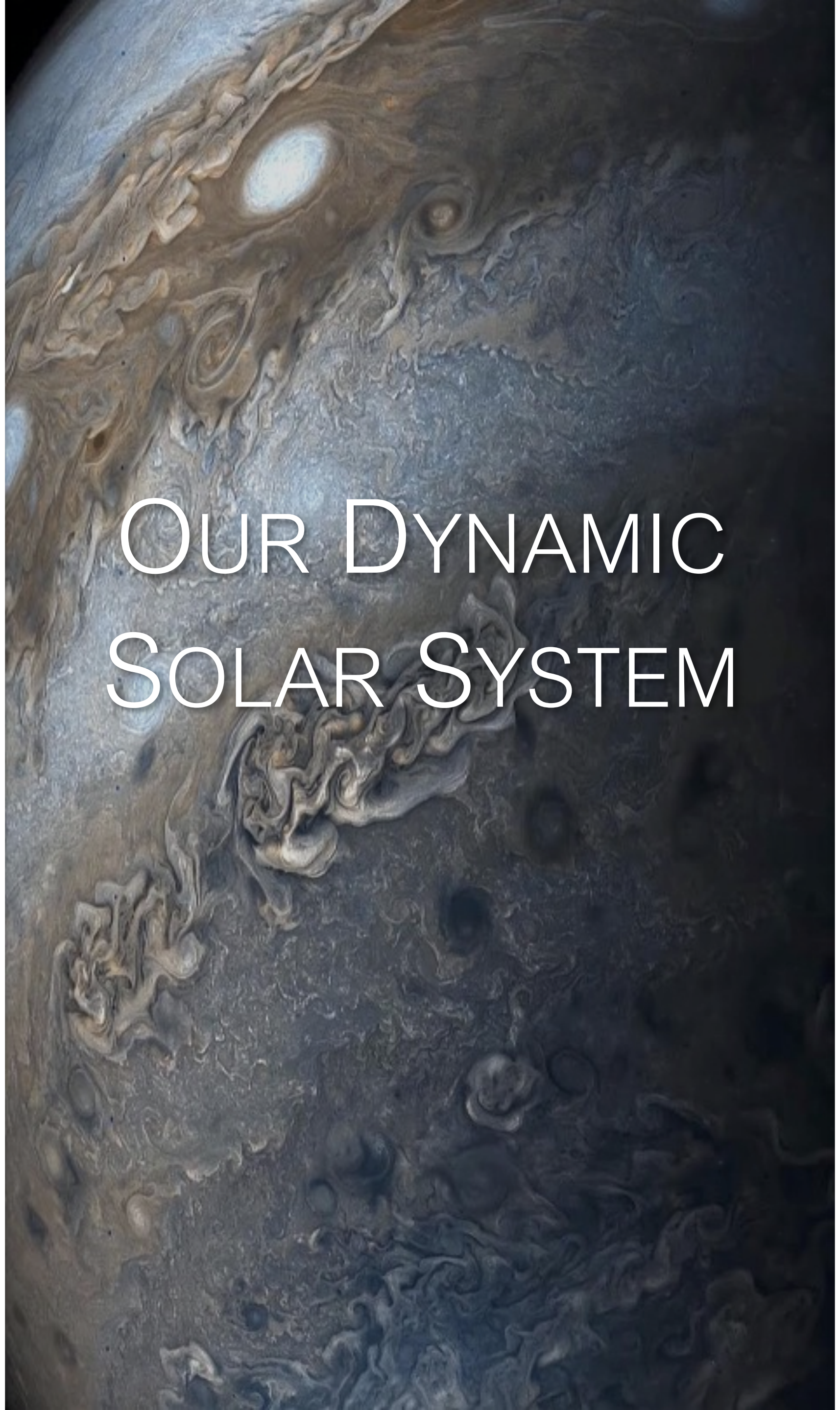
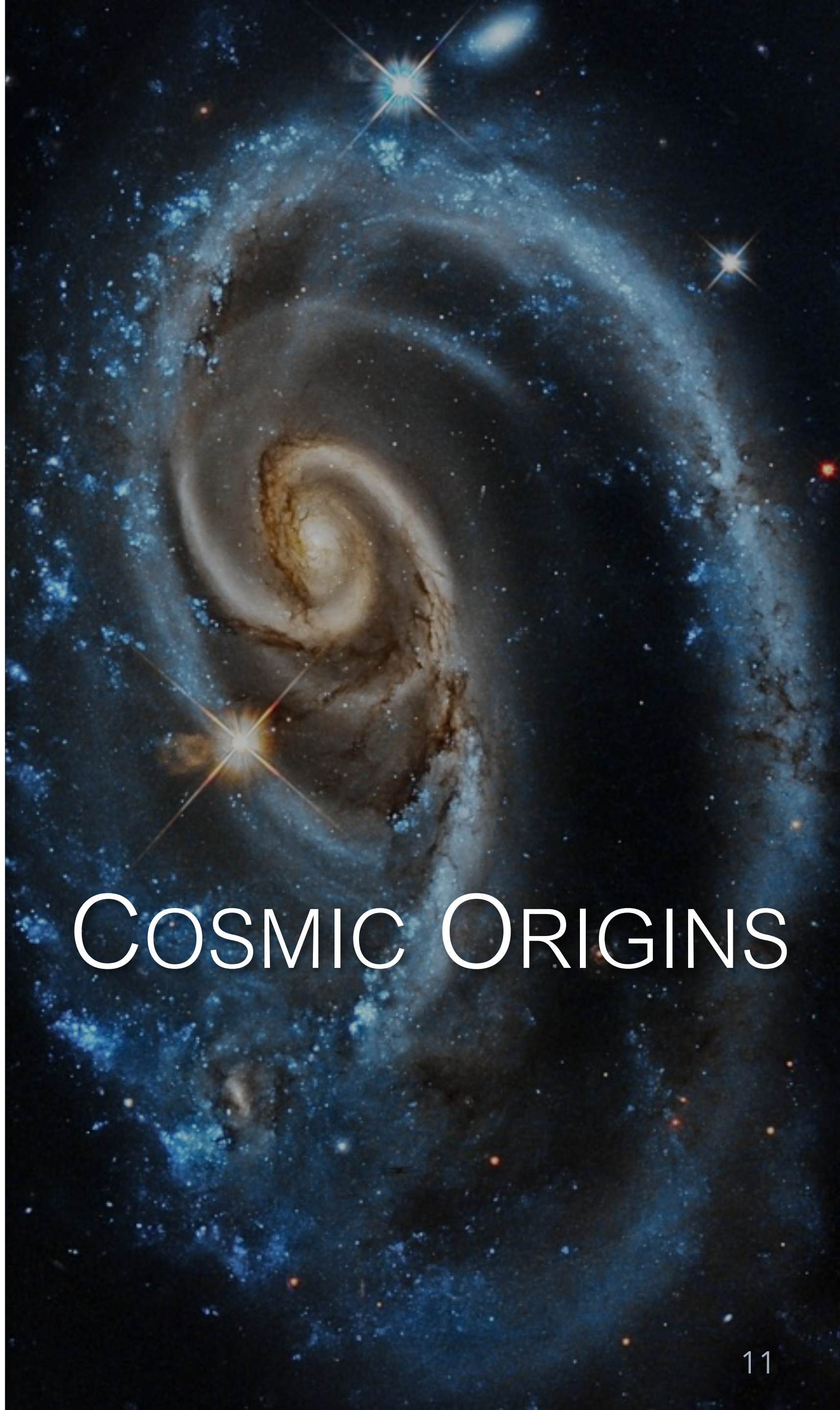
Serviceable

5-year prime mission duration, 10 years of propellant

Also studied 8 other architectures with smaller apertures

STARSHADE


Inner working angle (IWA)
76,600 km separation
Telescope aperture diameter 4 m
Starshade diameter 52 m


Exotic Worlds
The Search
for Life

Our Dynamic
Solar System

Cosmic Origins

Planet yields from LUVOIR & HabEx

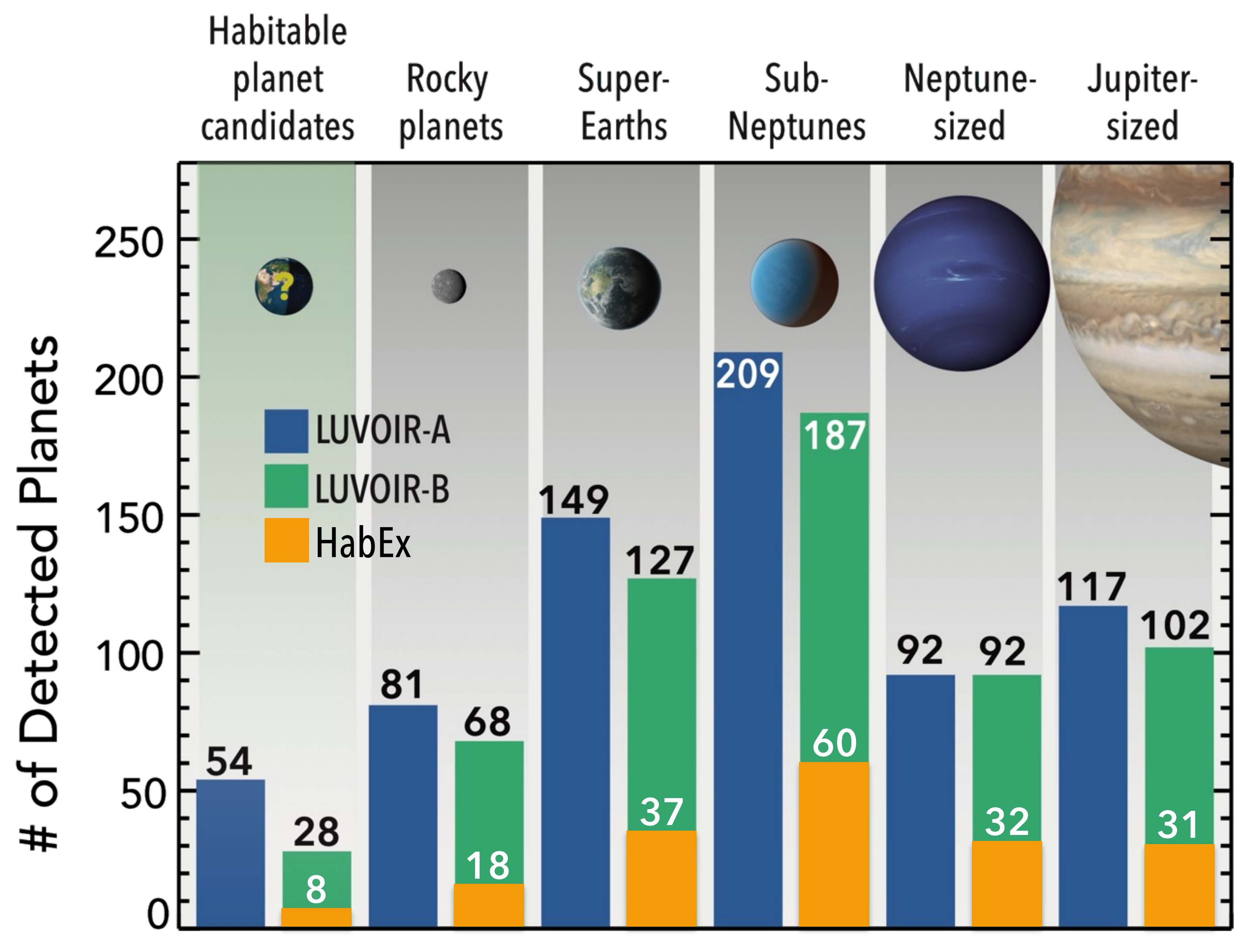
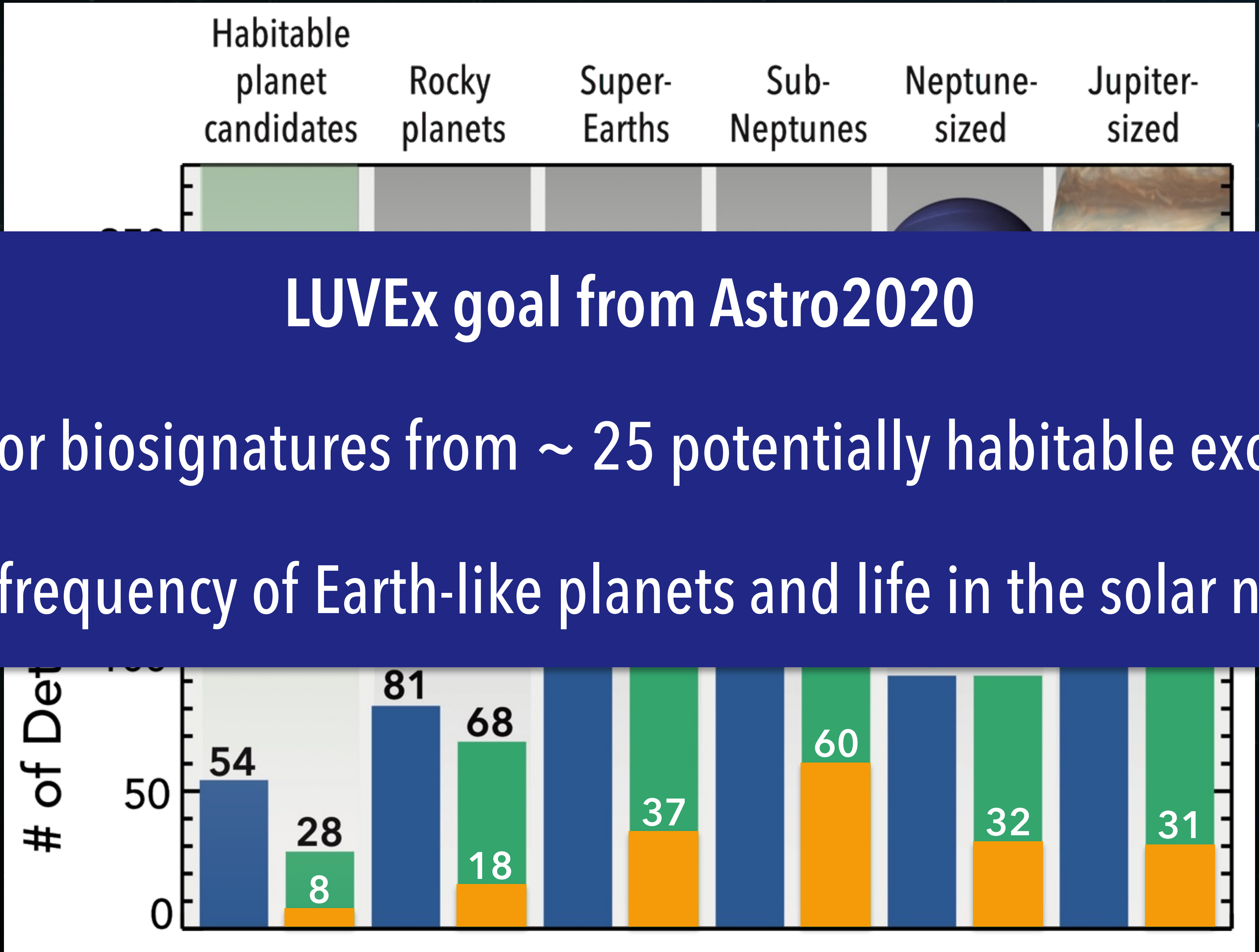


Figure 1-6, LUVOIR Final Report &
Figure ES-2, HabEx Final Report

PLANET YIELDS FROM LUVOIR & HABEX

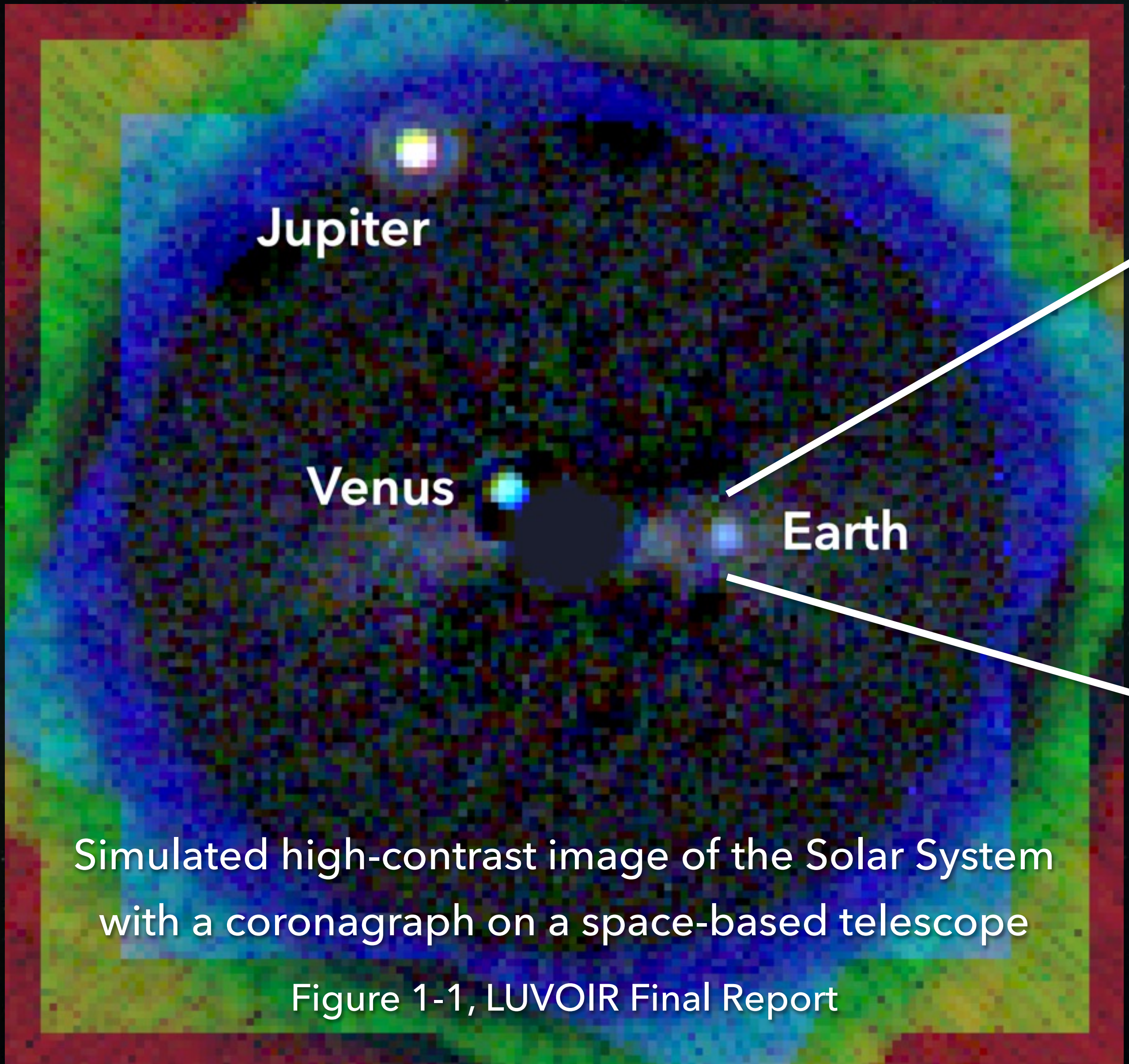


LUVEx goal from Astro2020

Search for biosignatures from ~ 25 potentially habitable exoplanets

Measure the frequency of Earth-like planets and life in the solar neighborhood

DIRECT OBSERVATIONS OF EXOEARTHS

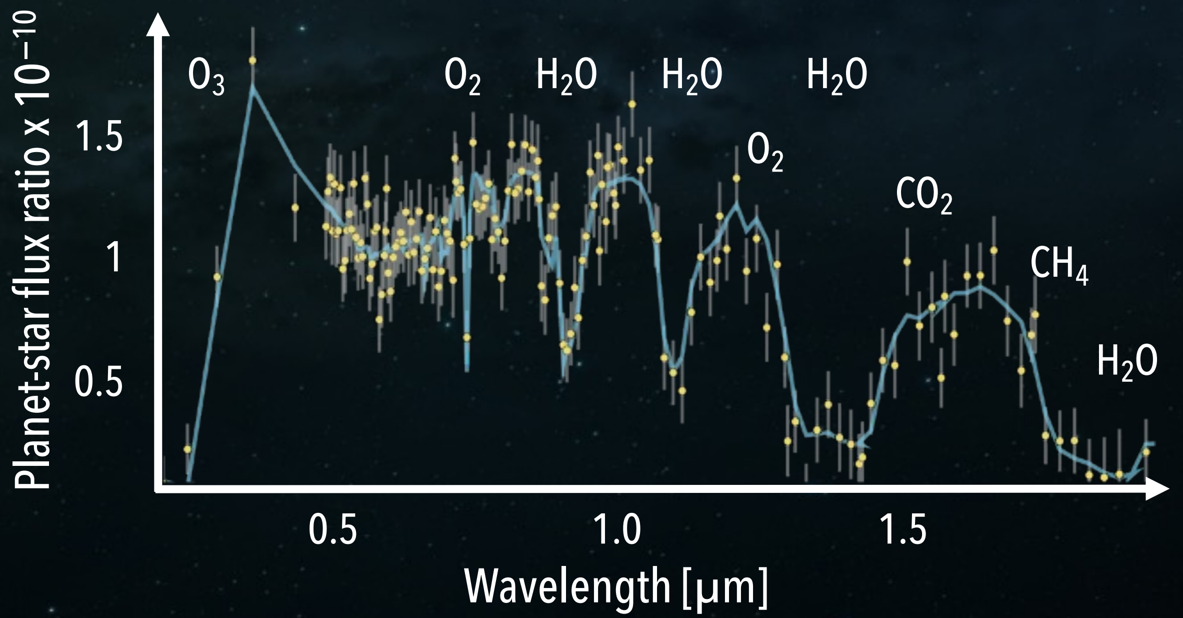


Simulated high-contrast image of the Solar System with a coronagraph on a space-based telescope

Figure 1-1, LUVOIR Final Report

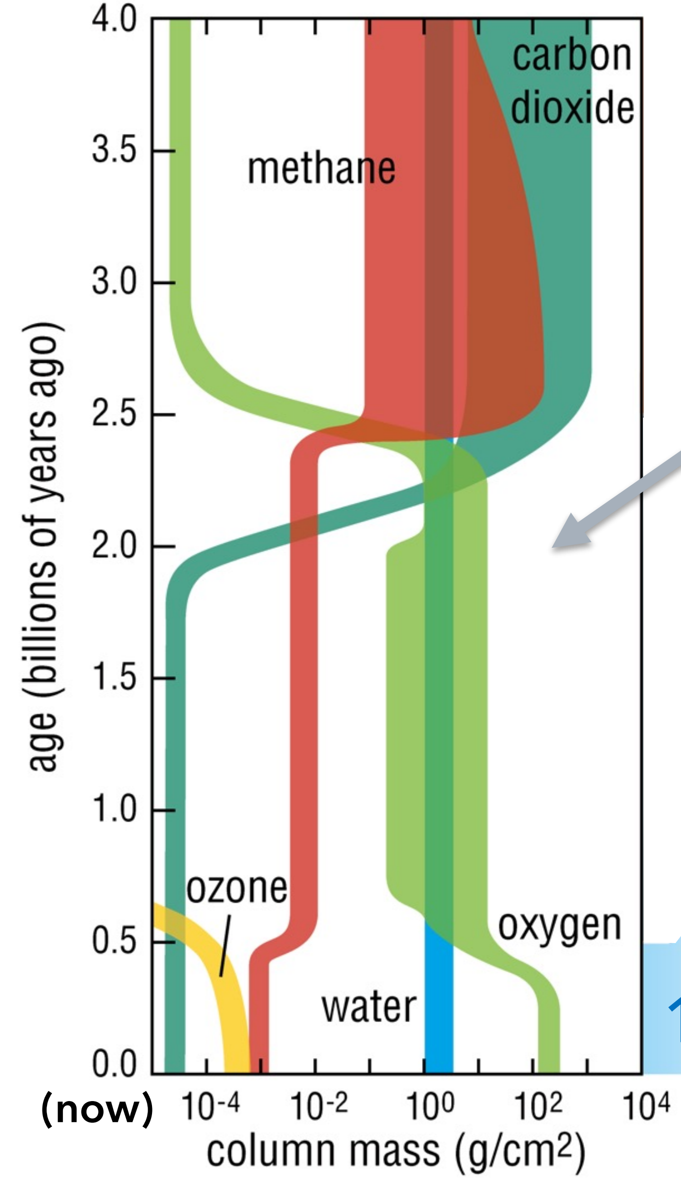
Simulated reflected light spectrum of a modern Earth-analog exoplanet

Figure 3-15, LUVOIR Final Report



Need UV spectra of host stars for biosignature identification

Three inhabited planets: the Earth through time



Earth's atmospheric composition through time

13%

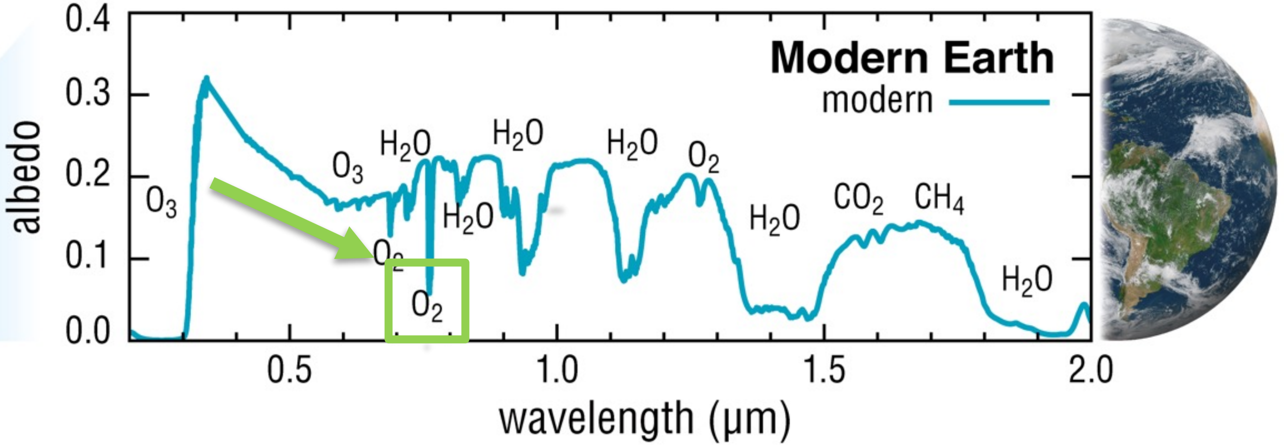


Figure 1-8, LUVOIR Final Report

Three inhabited planets: the Earth through time

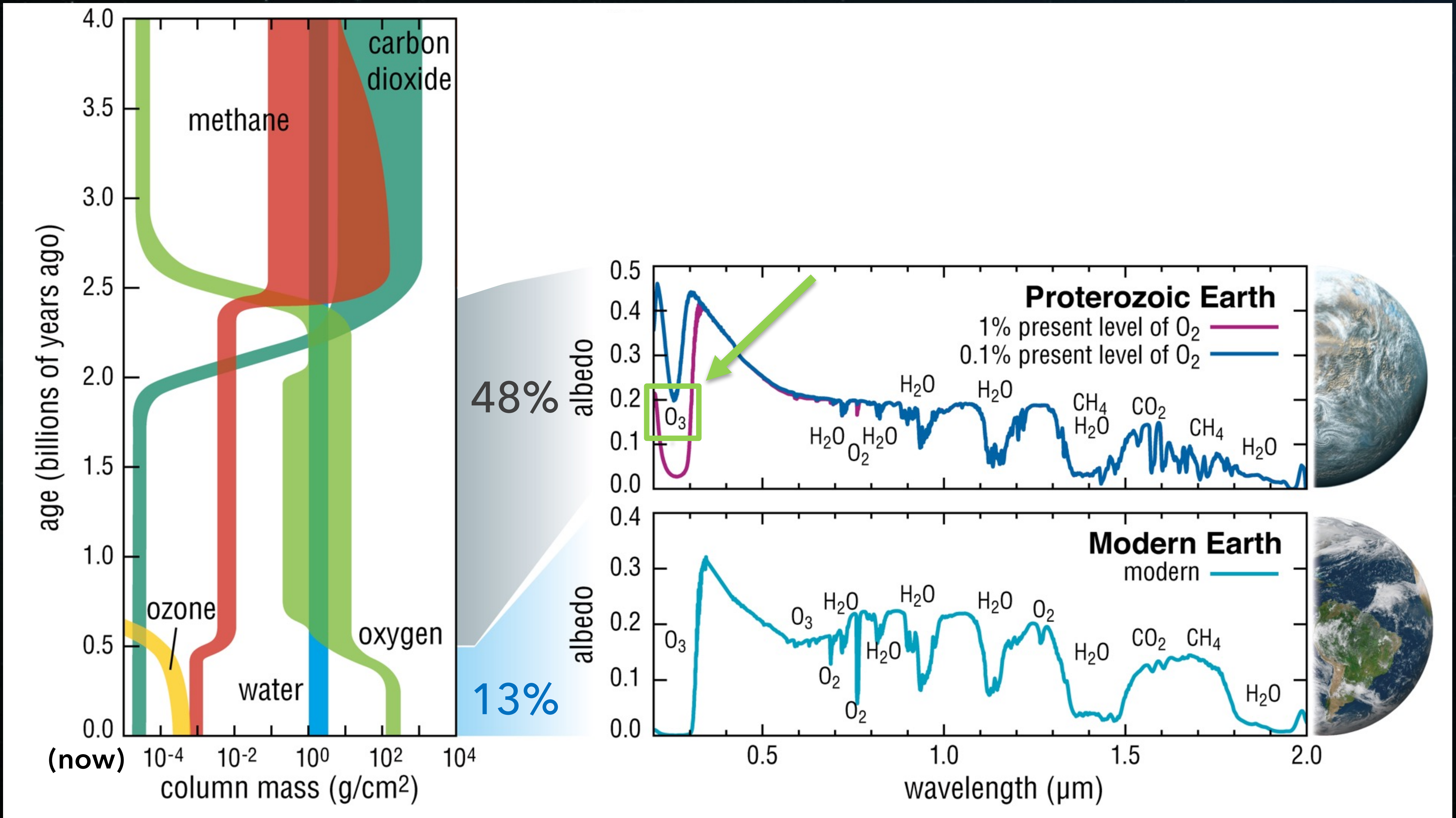


Figure 1-8, LUVOIR Final Report

THREE INHABITED PLANETS: THE EARTH THROUGH TIME

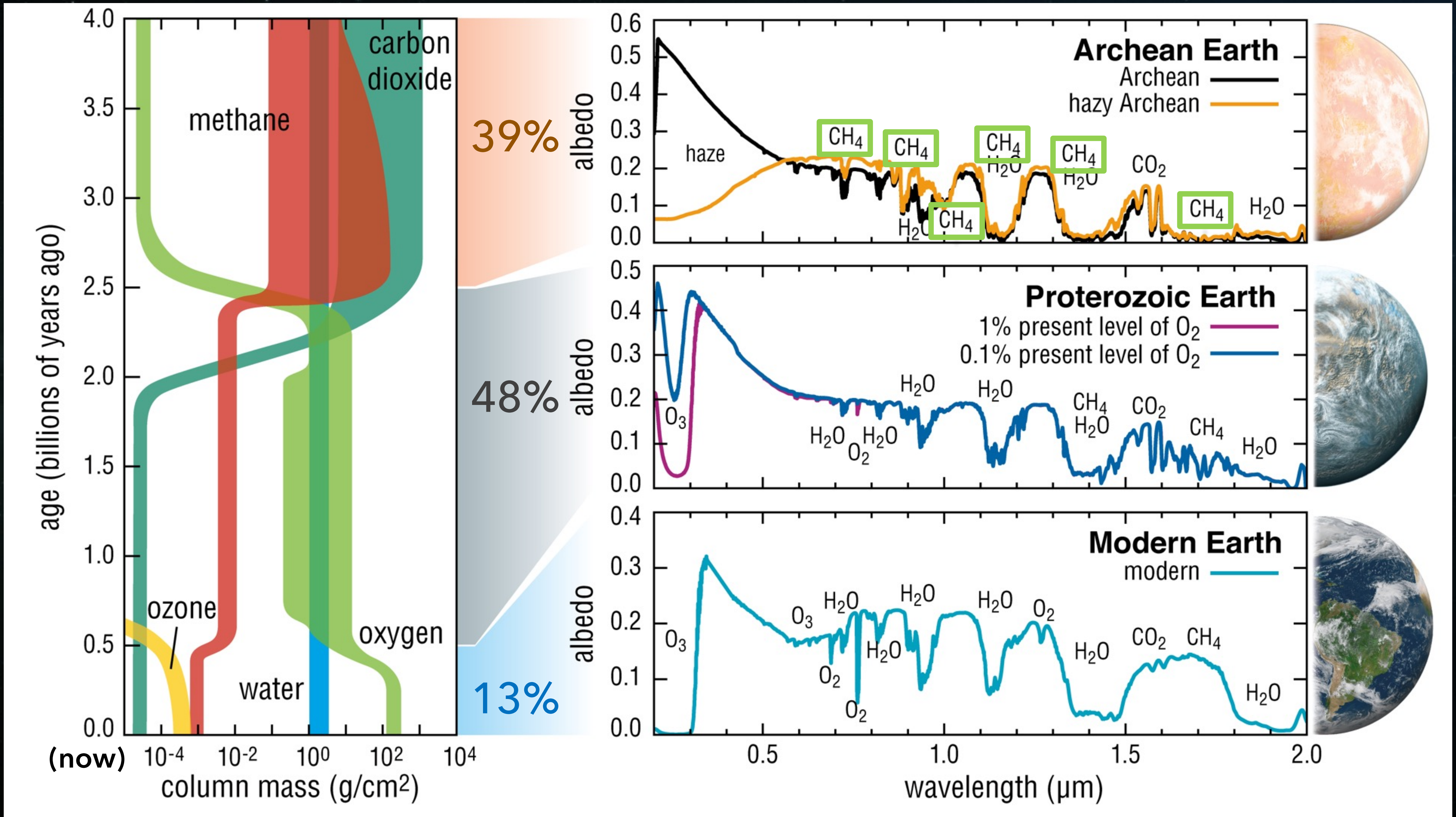
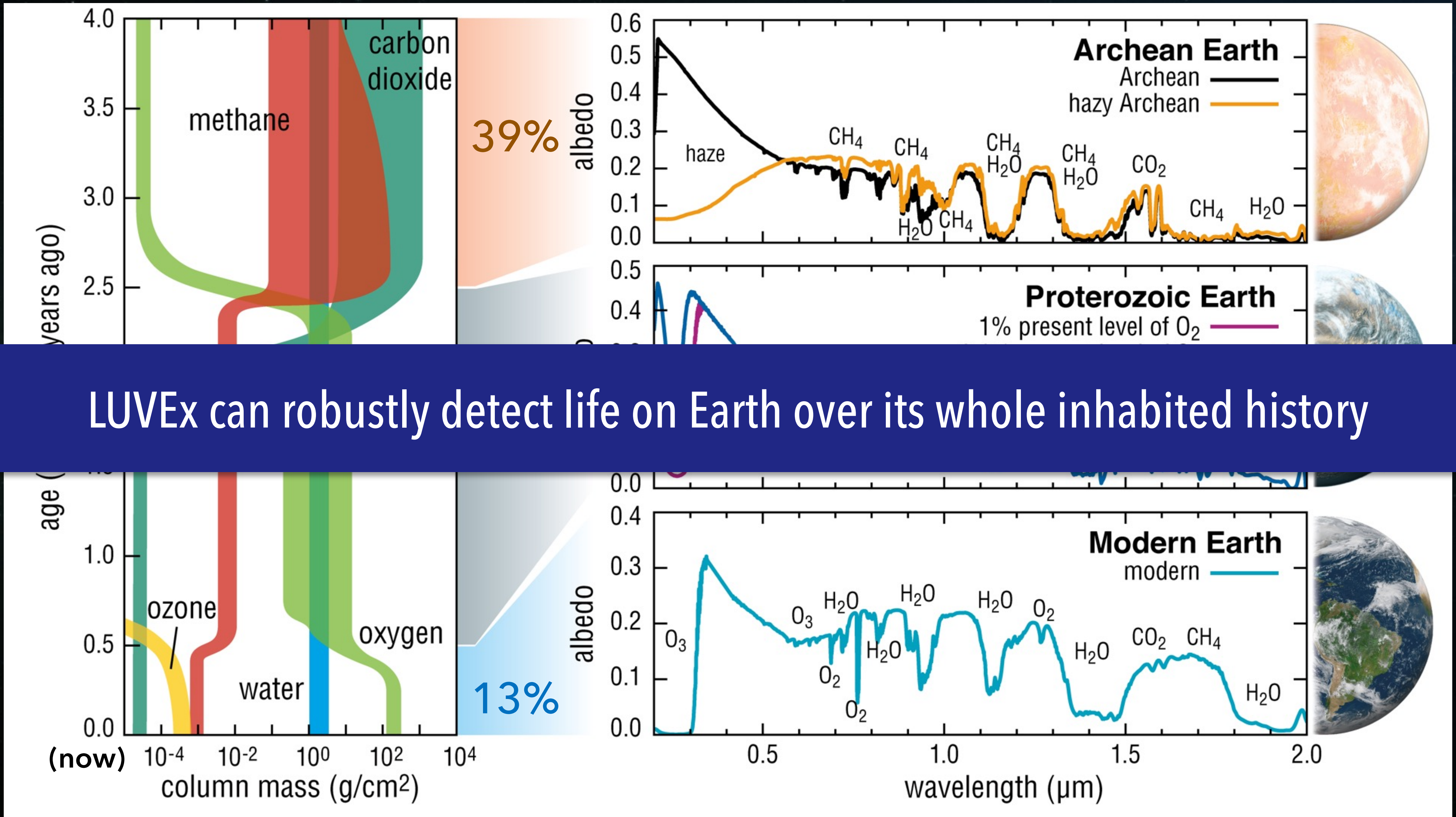


Figure 1-8, LUVOIR Final Report

THREE INHABITED PLANETS: THE EARTH THROUGH TIME



LUVEx can robustly detect life on Earth over its whole inhabited history

COMPARATIVE EXOPLANETOLOGY

Cold to warm planets
NUV / optical / NIR direct spectroscopy

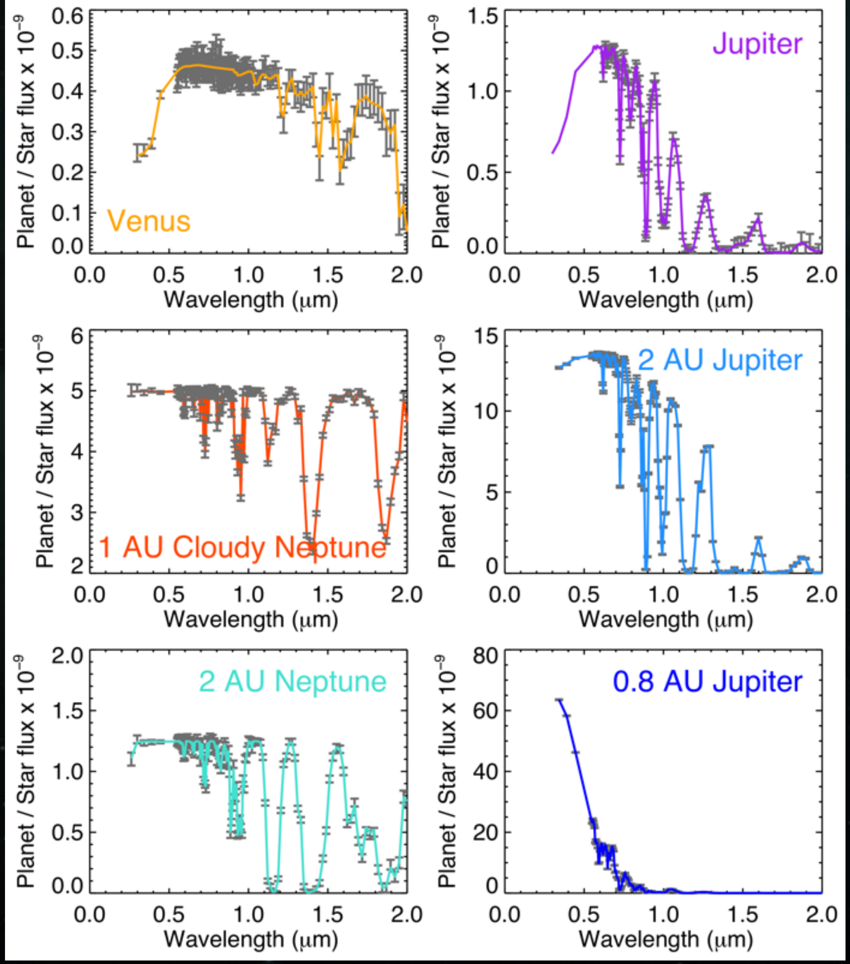


Figure 4-4, LUVOIR Final Report

Warm to hot planets
Optical / NIR transit spectroscopy

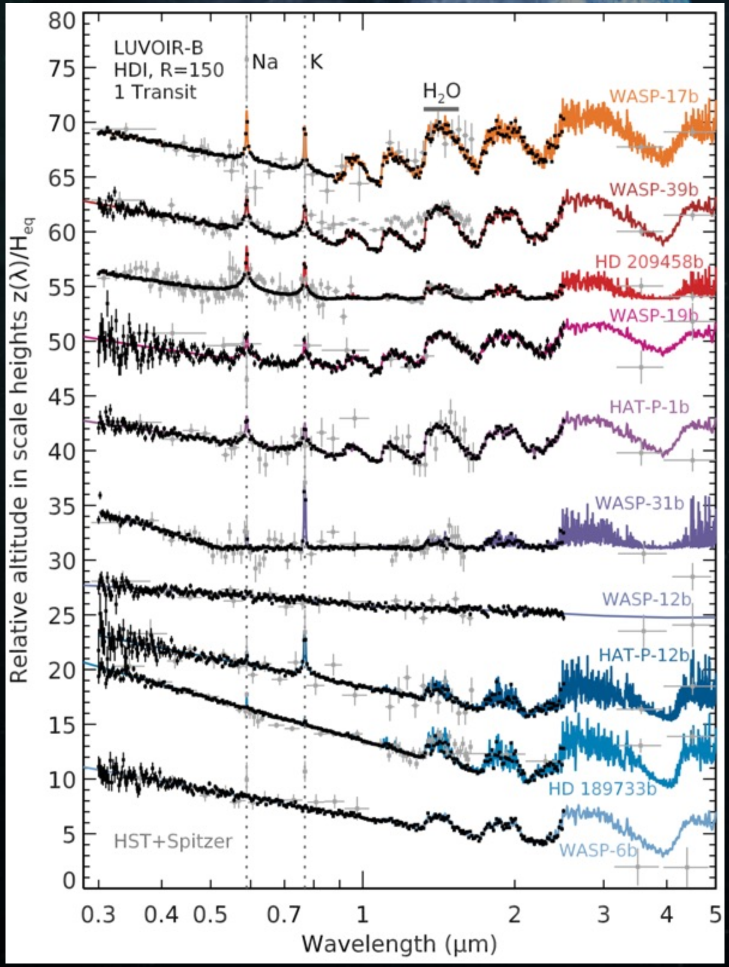


Figure 4-6, LUVOIR Final Report

Atmospheric escape
FUV transit spectroscopy

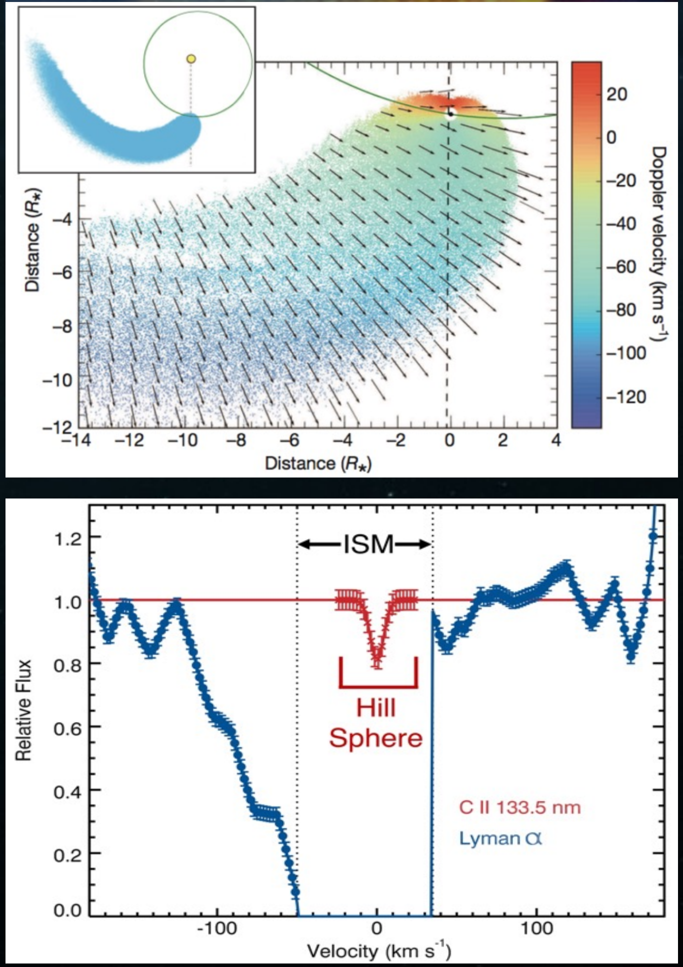


Figure 4-8, LUVOIR Final Report

THE POWER OF MULTI-OBJECT UV SPECTROSCOPY

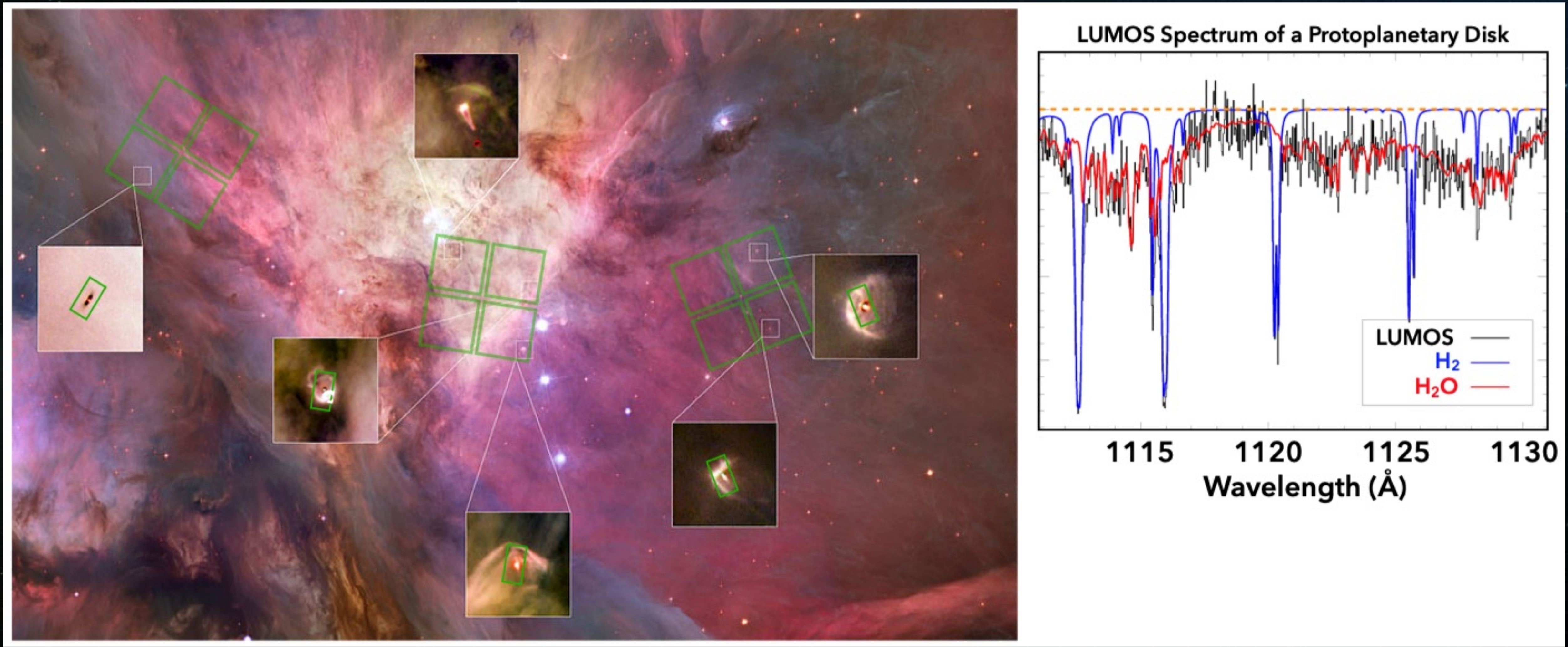
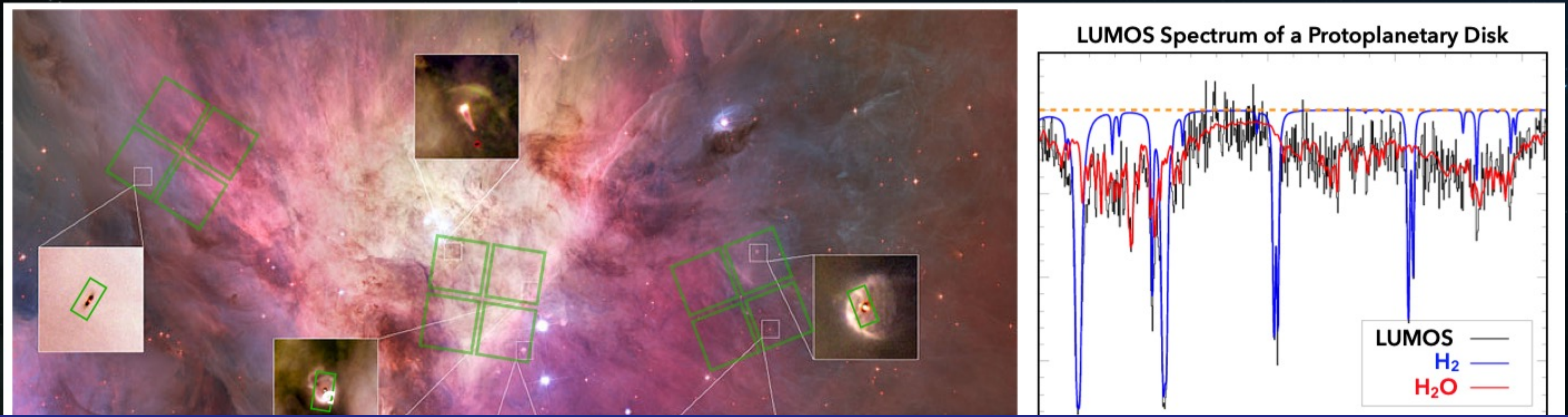


Figure 4-10, LUVOIR Final Report

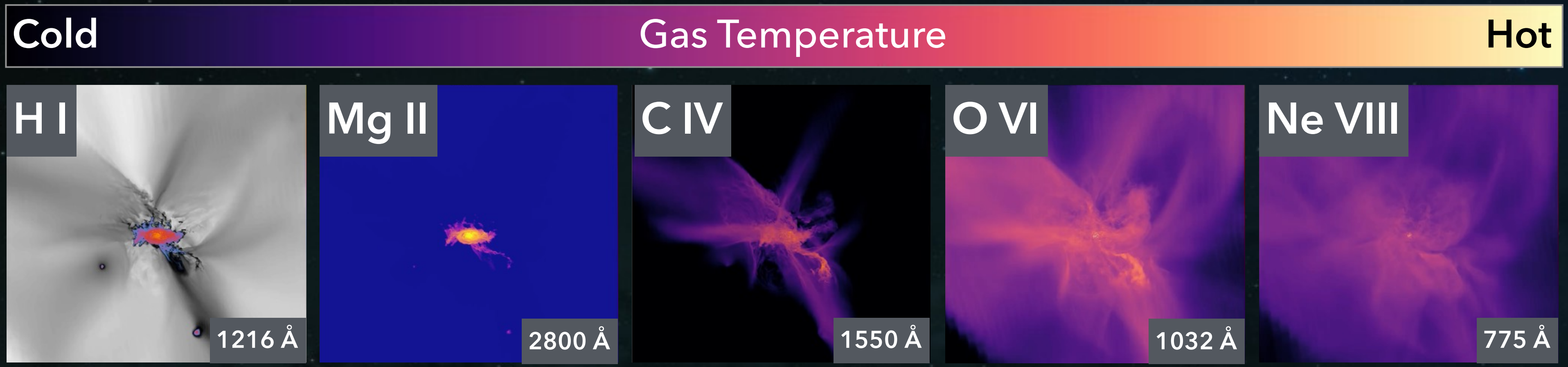
THE POWER OF MULTI-OBJECT UV SPECTROSCOPY



LUVOIR / HabEx can measure H_2 and water in hundreds of simultaneous protoplanetary disk FUV spectra

1 LUMOS / UVS map > 30 years of Hubble observations

Galaxy Formation and the Cycles of Matter

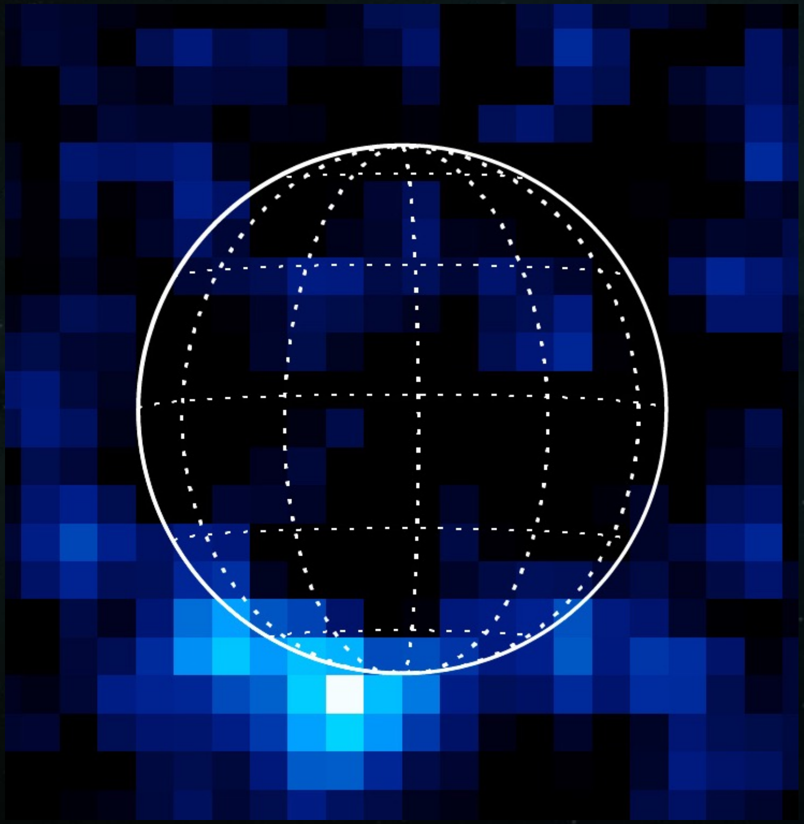


Ground-based O/IR can probe cold gas almost to the present day but cannot observe warm / hot gas over most of cosmic time

With UV access, LUVEx can map all phases of diffuse galactic gas over >80% of cosmic time

Europa

Hubble



UV hydrogen Lyman-α emission from HST
Roth et al. (2014)

LUVOIR-B

Figure 3-20, LUVOIR Final Report

ASTRO2020 SCIENCE THEMES

#1: Worlds and Suns in Context

Priority Area: Pathways to Habitable Planets

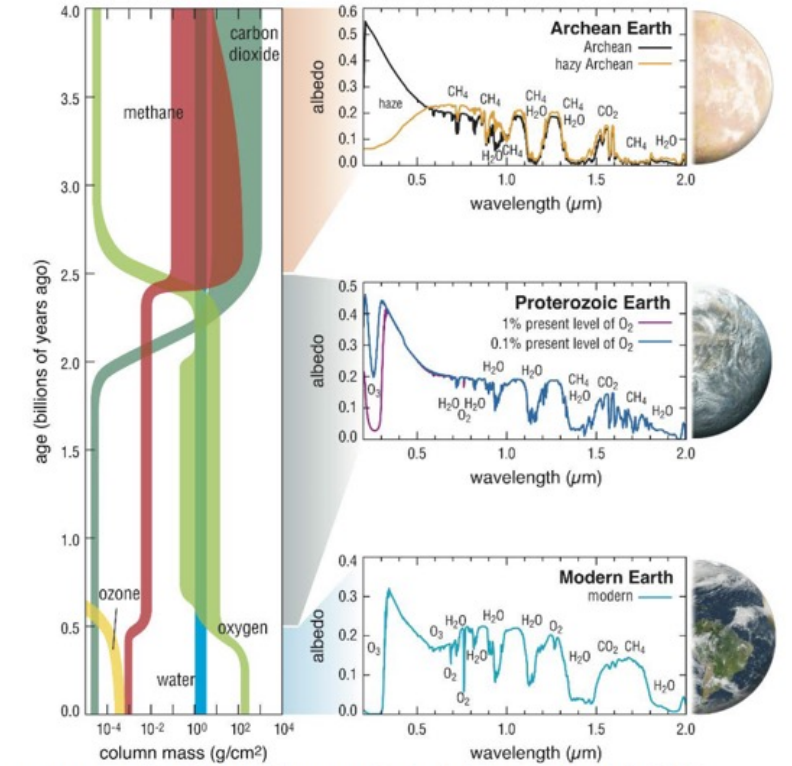


FIGURE 1.1 Evolution of the reflectivity spectrum of Earth. Simulated spectra of Earth before life had significantly altered its atmosphere (*top, Archean era 2.5 to 5 Gyr ago*), before the development of complex life (*middle, Proterozoic era from 0.54 to 2.5 Gyr ago*), and the modern oxygen-bearing Earth (*bottom*). SOURCE: LUVOIR Report; G. Arney, S. Domagal-Goldman, T. B. Griswold (NASA GSFC).

#2: New Messengers and New Physics

Priority Area: New Windows on the Dynamic Universe

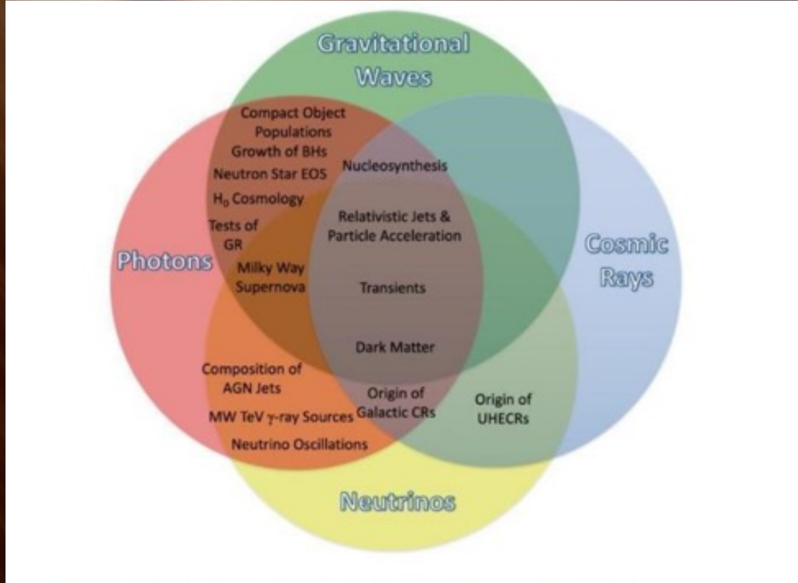


FIGURE 2.13 The combination of multiple messengers provides unique insi particularly those involving strong gravity or relativistic motion (see Box 2.2) Particle Astrophysics and Gravitation.

#3: Cosmic Ecosystems

Priority Area: Unveiling the Drivers of Galaxy Growth

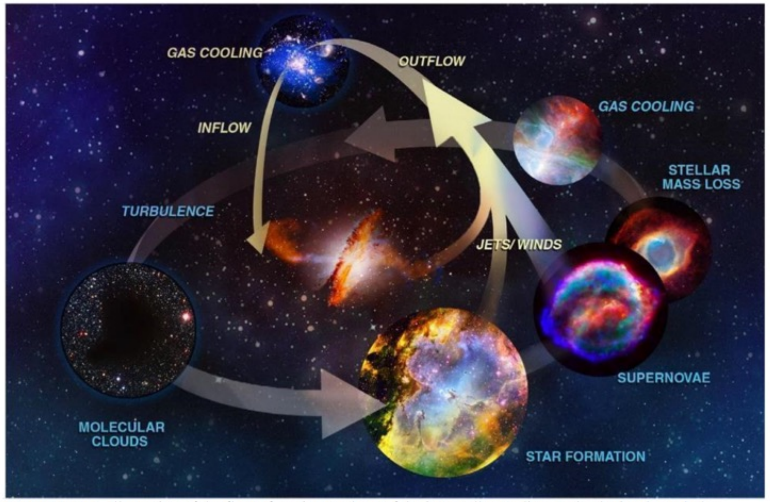


FIGURE 2.17 Illustration of the flow of gas into and out of the interstellar medium and galaxies through the combined effects of gravity and feedback. Heavy elements formed by fusion in massive stars are dispersed into the interstellar medium by stellar winds and supernovae. Much of this gas is in turn ejected from galaxies into the circumgalactic medium by galactic winds. Pristine gas accretes from the intergalactic medium to the circumgalactic medium, and subsequently accretes into galaxies, replenishing the fuel for star formation and subsequent generations of stars and supernovae. SOURCE: HABEX Report, The Habitable Exoplanet Observatory Study Team.

Great Observatories Mission and Technology Maturation Program

Large Programs that Forge the Frontiers

These scientific visions—Pathways to Habitable Worlds, New Windows on the Dynamic Universe, and Unveiling the Drivers of Galaxy Growth— require the major recommended investments in large projects to begin design and construction in the coming 10 years (Tables S.5 and S.6; Figure S.1).[3] In space, achieving the community's most ambitious and visionary ideas in a sustainable way, and realizing the broad capabilities demanded by the richness of the science, requires a re-imagining of the ways in which large missions are planned, developed, and implemented. The **Great Observatories Mission and Technology Maturation Program** (Table S.5) would provide significant early investments in the co-maturation of mission concepts and technologies, with appropriate decadal survey input on scope, and with checks and course corrections along the way. Inspired by the vision of searching for signatures of life on planets outside of the solar system, and by the transformative capability such a telescope would have for a wide range of astrophysics, the survey recommends that the first mission to enter this program is a **large (~6 m aperture) infrared/optical/ultraviolet (IR/O/UV) space telescope.** The scientific goals of this mission, when achieved, have the potential to profoundly change the way that human beings view our place in the universe. With sufficient ambition, we are poised scientifically and technically to make this transformational step. This endeavor represents a quest that is on the technical forefront, is of an ambitious scale that only NASA can undertake, and it is one where the United States is uniquely situated to lead the world. If maturation proceeds as expected, the survey recommends that formulation and implementation begin by the end of the 2020 decade. To prepare for future large, strategic missions, 5 years after beginning the maturation program for the IR/O/UV mission, the survey

[3] For space, large projects are defined as those with costs exceeding $1.5 billion. For ground-based initiatives, large projects are defined as those exceeding $130 million for the total program investment.

PREPUBLICATION COPY – SUBJECT TO FURTHER EDITORIAL CORRECTION
S-2

Discovery in Astronomy and Astrophysics for the 2020s

Dr. Jessie Christiansen @aussiastronomer

Replying to @bmac_astro and @theNASEM

I mean, it sounds more like the major NASA recommendation is to spend the next decade working on the idea of a 6-m class telescope capable of imaging Earthlike worlds? I guess I don't grok what the 'maturation study' encompasses yet.

12:42 PM · Nov 4, 2021 · Twitter Web App

1 Retweet 16 Likes

Tweet your reply

Reply

Bruce Macintosh @bmac_astro · 56m

Replying to @aussiastronomer and @theNASEM

A lot of what would be in maturation is what now happens in pre-Phase-A or even Phase A - iterating on the design and architecture and science and getting technology to TRL6+ - just that the mission wouldn't formally "start" until that maturation is completed.

1 3

Bruce Macintosh @bmac_astro · 54m

This is built upon concepts in the mission studies themselves (e.g. LUVOIR Chapters 11 and 12), work by Bitten et al, and there's good discussion in Chapter 7 of the report. it's not just tech development - it's the early work of a mission - but with a clear gate.

1

First New Flagship Mission

Large Programs that Forge the Frontiers

These scientific visions—Pathways to Habitable Worlds, New Windows on the Dynamic Universe, and Unveiling the Drivers of Galaxy Growth— require the major recommended investments in large projects to begin design and construction in the coming 10 years (Tables S.5 and S.6; Figure S.1).[3] In space, achieving the community's most ambitious and visionary ideas in a sustainable way, and realizing the broad capabilities demanded by the richness of the science, requires a re-imagining of the ways in which large missions are planned, developed, and implemented. The **Great Observatories Mission and Technology Maturation Program** (Table S.5) would provide significant early investments in the co-maturation of mission concepts and technologies, with appropriate decadal survey input on scope, and with checks and course corrections along the way. Inspired by the vision of searching for signatures of life on planets outside of the solar system, and by the transformative capability such a telescope would have for a wide range of astrophysics, the survey recommends that the first mission to enter this program is a **large (~6 m aperture) infrared/optical/ultraviolet (IR/O/UV) space telescope.** The scientific goals of this mission, when achieved, have the potential to profoundly change the way that human beings view our place in the universe. With sufficient ambition, we are poised scientifically and technically to make this transformational step. This endeavor represents a quest that is on the technical forefront, is of an ambitious scale that only NASA can undertake, and it is one where the United States is uniquely situated to lead the world. If maturation proceeds as expected, the survey recommends that formulation and implementation begin by the end of the 2020 decade. To prepare for future large, strategic missions, 5 years after beginning the maturation program for the IR/O/UV mission, the survey

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"… take advantage of the hard work of both the LUVOIR and HabEx concepts, pulling together the best of both to launch a large, capable telescope."
– *Julianne Dalcanton*

IROUV? LUVEx?

New name coming from NASA HQ, hopefully soon

What are the specific goals for the flagship?

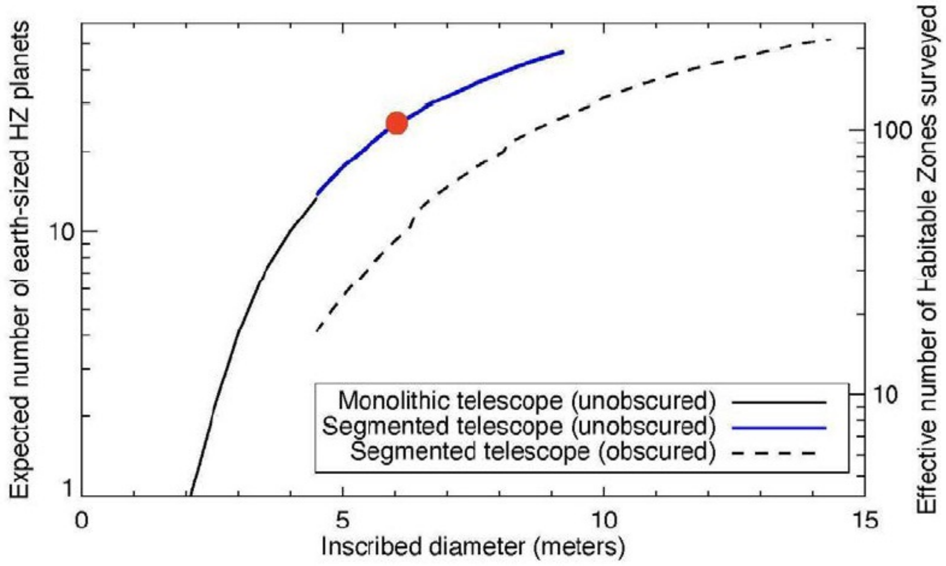


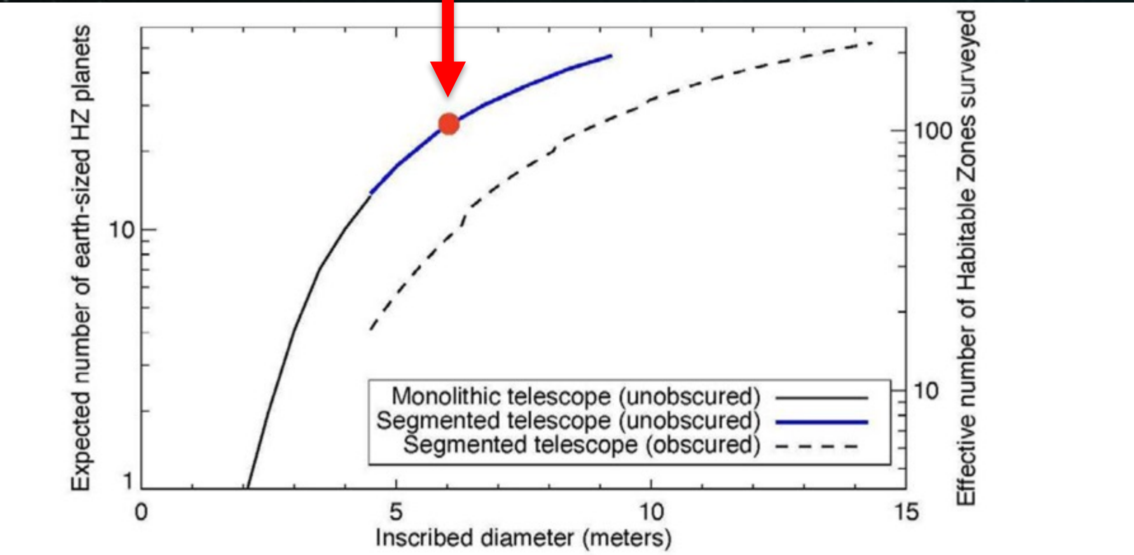
FIGURE 7.6 Potentially habitable exoplanet yield vs telescope diameter for different telescope architectures. Right axis shows the number of habitable zones surveyed (weighted by completeness); left axis shows the expected number of planets discovered assuming the occurrence rate of rocky planets in the optimistic habitable zones of different stars, eta_earth=0.24 (Bryson et al. 2021). The red dot shows the expected yield for the target 6-m inscribed diameter. NOTE: Habitable zone is defined as 0.95-1.67 AU for planets of 0.8-1.4 Earth radii. SOURCE: Adapted from C. Stark (Space Telescope Science Institute), D. Mawet (California Institute of Technology), and B. Macintosh (Stanford University).

"Conclusion: A high-contrast direct imaging mission with a target off-axis inscribed diameter of approximately 6 meters provides an appropriate balance between scale and feasibility. Such a mission will provide a robust sample of ~25 atmospheric spectra of potentially habitable exoplanets, will be a transformative observatory for general astrophysics, and given optimal budget profiles it could launch by the first half of the 2040 decade." – *Astro2020 Report, page 7-16*

"Recommendation: After a successful mission and technology maturation program, NASA should embark on a program to realize a mission to search for biosignatures from a robust number of about ~25 habitable zone planets and to be a transformative facility for general astrophysics. If mission and technology maturation are successful, as determined by an independent review, implementation should start in the latter part of the decade, with a target launch in the first half of the 2040s." – *Astro2020 Report, page 7-17*

WHAT DOES ~6-M INSCRIBED DIAMETER MEAN?

Inscribed diameter
6 m



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LUVOIR-B

Outer diameter
8 m

HabEx

Inscribed diameter
4 m

HIGH-LEVEL TIMELINE FOR LUVEX

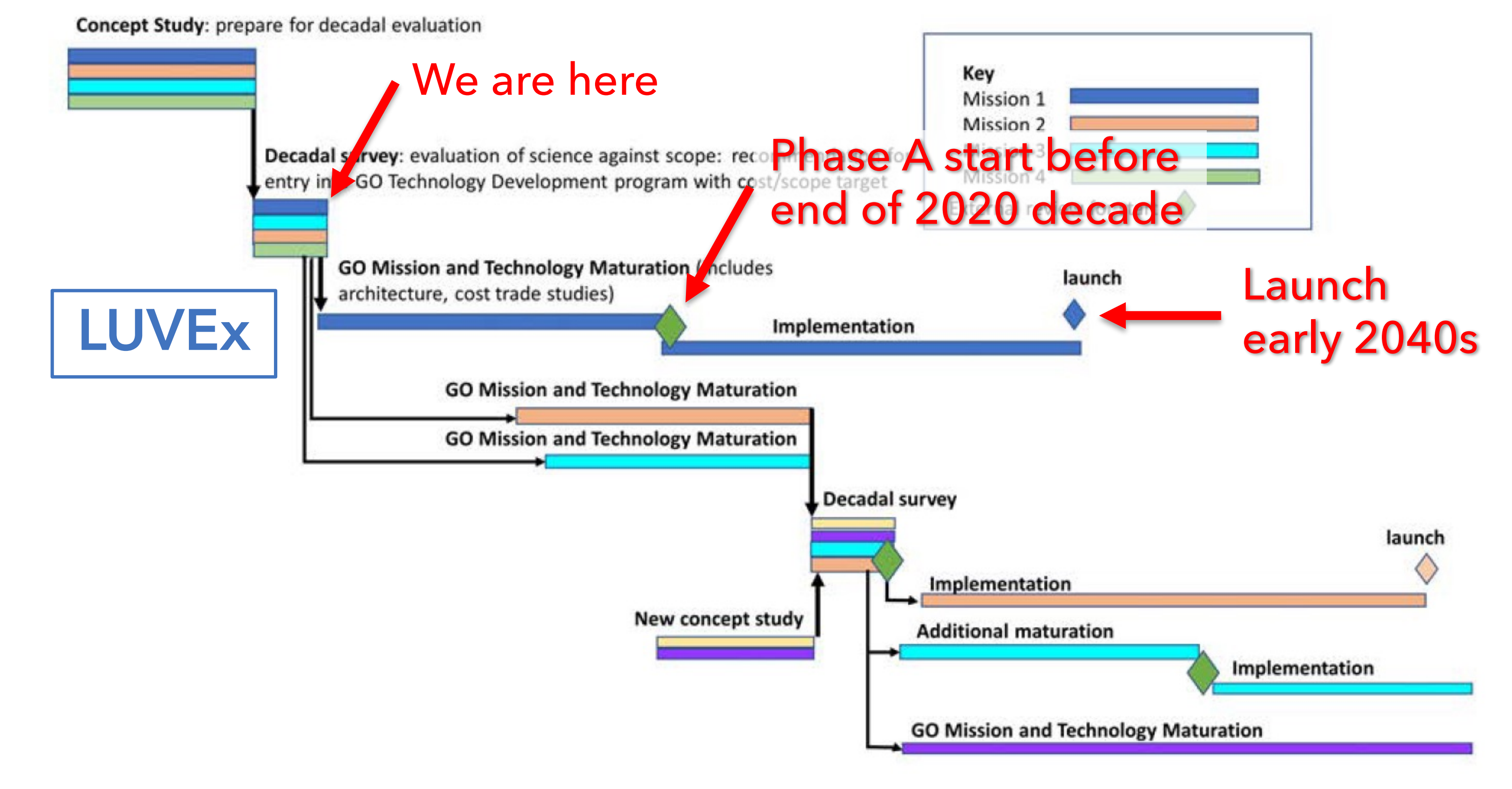
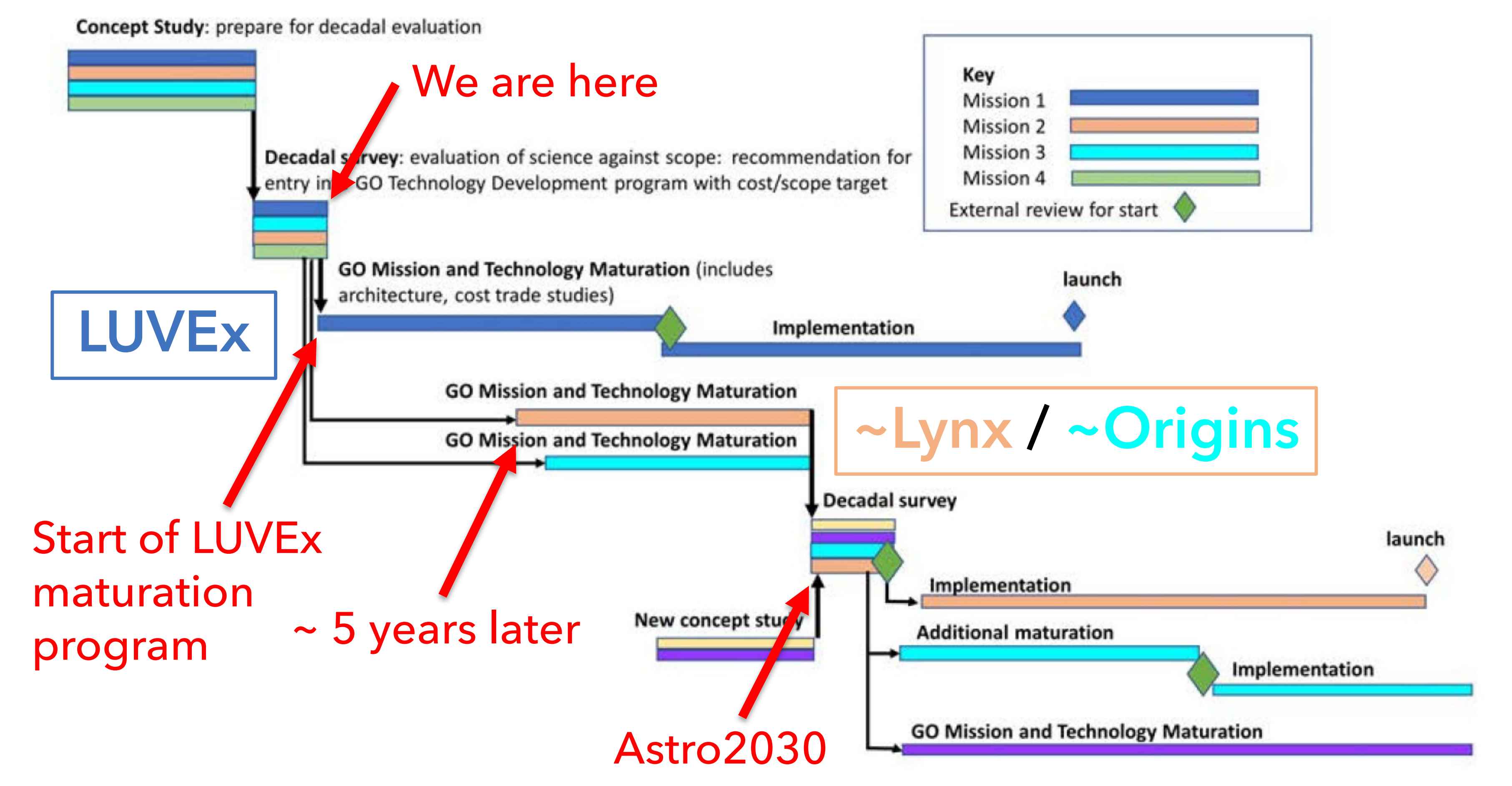


FIGURE 7.2 Flow diagram showing the concept for maturation, recommendation and implementation of NASA Large Strategic Missions. This does not represent the actual recommendations in this report, instead it represents how the program would be structured in general. If implemented, this survey would be the first to adopt this process by recommending the first entrant into the GO Mission and Technology Maturation Program. SOURCE: Fiona Harrison.

HIGH-LEVEL TIMELINE FOR THE OTHER NEW GREAT OBSERVATORIES



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SCIENCE PARTNERSHIP CONSIDERATIONS

Astro flagships must serve a broad swath of the community

LUVEx is both an exoplanets and an astrophysics mission

Can be hard to balance multiple science goals, but it is absolutely possible

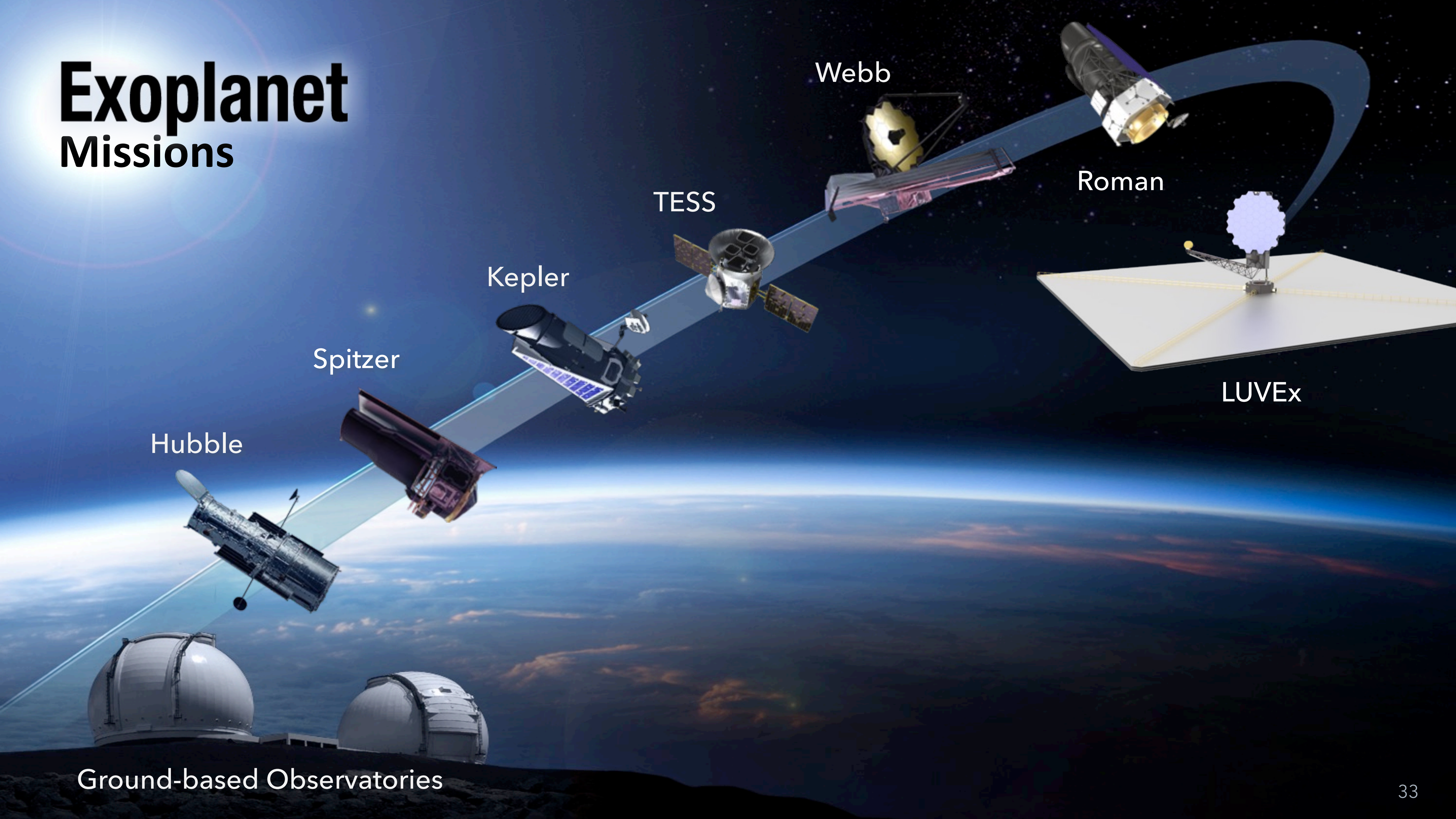
An equal & harmonious partnership between exoplanets and astrophysics was achieved during the LUVOIR study

Partnership between different science areas takes understanding, respect, realism, compromise, & continual maintenance

Technical considerations

Some technical issues & UV technology development needs will be covered in Kevin France's talk later today …

Exoplanet Missions



Backup

How much funding?

TABLE S.5 New Medium and Large Initiatives: Space

Recommendation Topic	Programmatic Function	Cost Appraisal (FY2020$)	Cross-Reference Page Number Ch. 7
Great Observatories Mission and Technology Maturation Program for IR/O/UV (first half of decade), far-IR and X-ray (second half of decade) missions	Enabling future frontier projects	$1.2B this decade	7-11
Near-Infrared/Optical/Ultraviolet telescope with high-contrast imaging capability	Frontier project, to begin after maturation program	$11B (estimated)	7-17
Time Domain and Multi-messenger Follow-Up Program	Sustaining scientific balance and scale	TBD ($500-800M this decade est.)	7-19
Astrophysics Probe Mission Program	Sustaining scientific balance and scale	$1.5B cost cap	7-20

"For large strategic missions, the highest priority is for NASA to rapidly establish the Great Observatories Mission and Technology Maturation program, with the most important element in that category being to commence maturation of the large IR/O/UV mission." – *Astro2020, page 7-21*