From Cosmic Birth to Living Earths

The Future of UVOIR Space Astronomy

SPIE

San Diego, CA

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From Cosmic Birth to Living Earths

The Future of UVOIR Space Astronomy

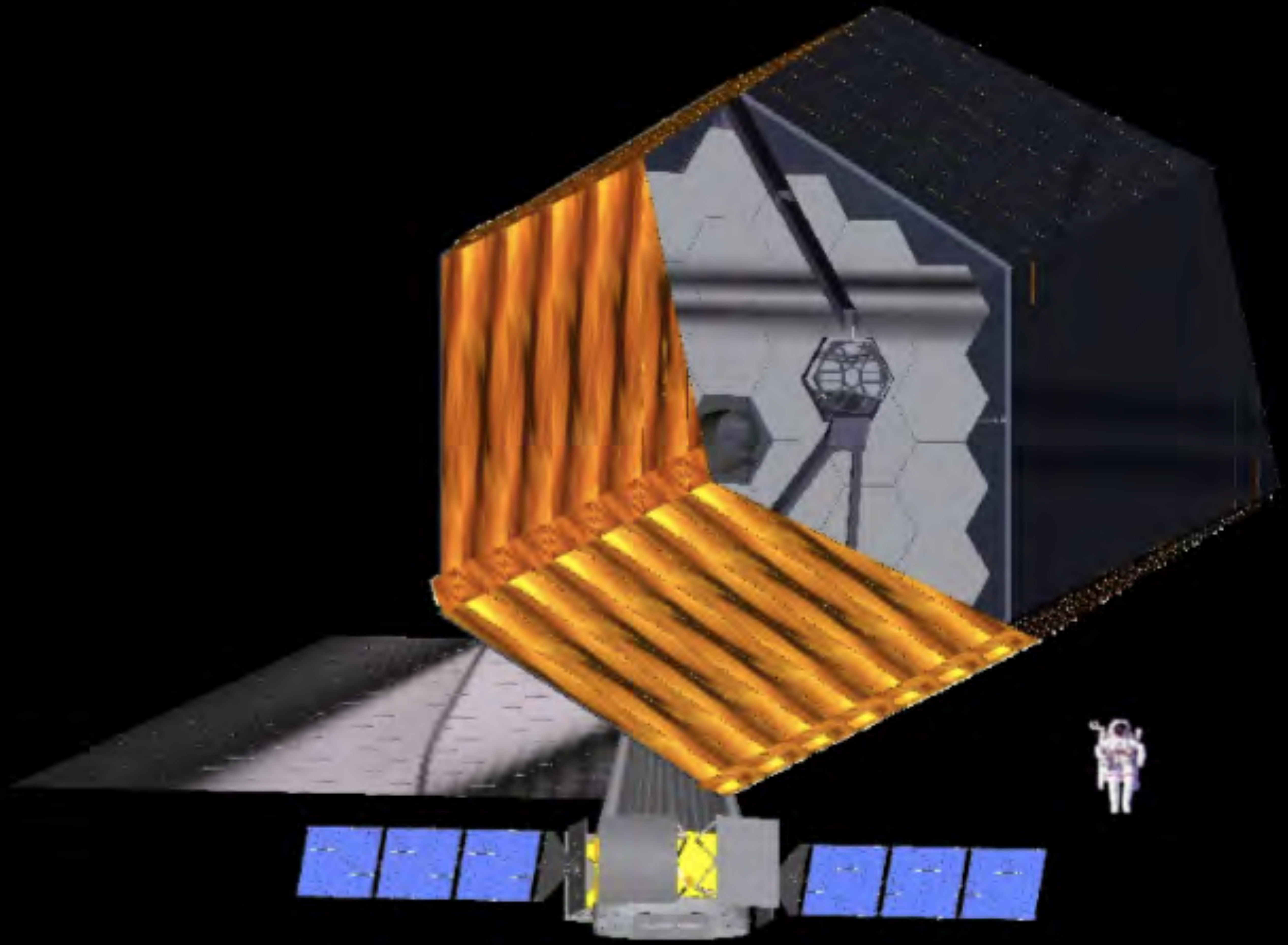
Speakers

Sara Seager
MIT

Marc Postman
STScI

David Schiminovich
Columbia University

High Definition Space Telescope



- 12 m diameter segmented, deployable mirror
- Coronagraph for starlight suppression
- UV (100 nm) through near IR (~2 microns). Diffraction-limited at 500 nm
- Earth-Sun L2 orbit
- Non cryogenic

Where Did We Come From?

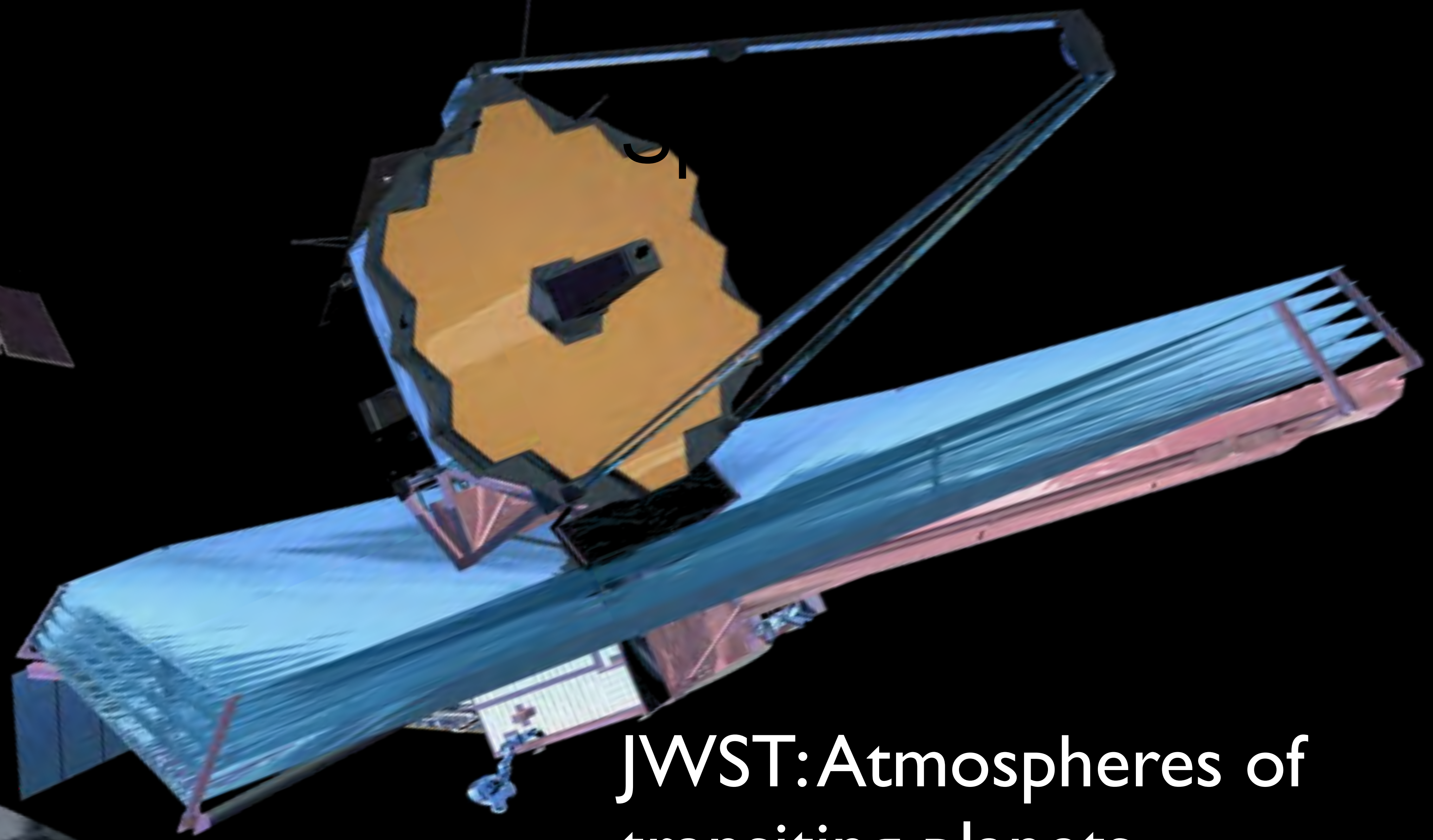

Are We Alone?

Starlight Suppression

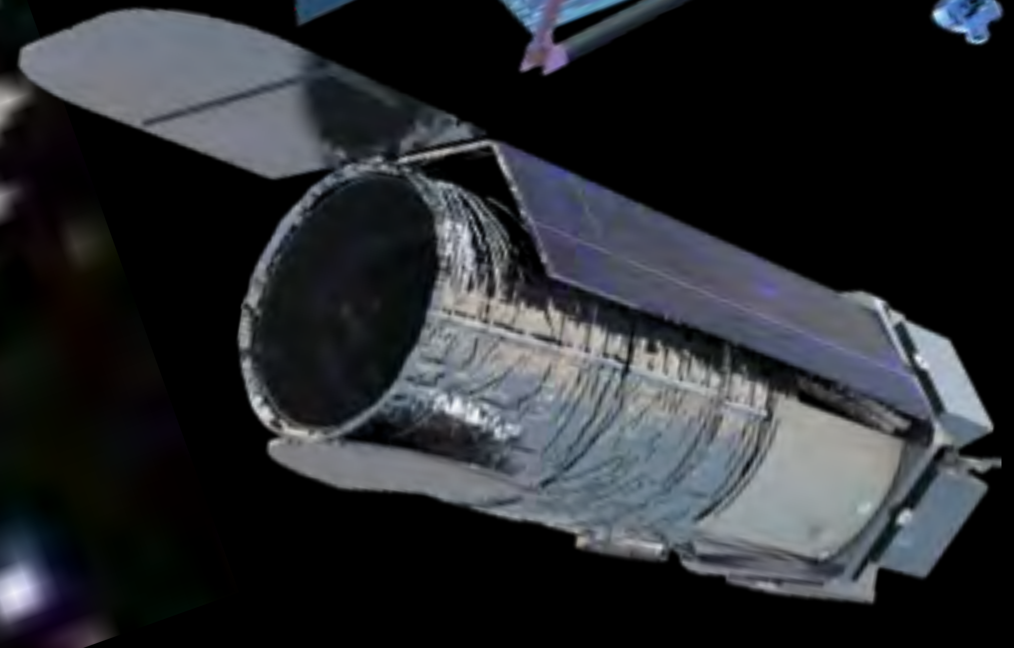
HST: transiting planet atmospheres.

Kepler: Statistical constraints on the exoplanet population.

TESS: Atmospheres of transiting planets.



JWST: Atmospheres of transiting planets.

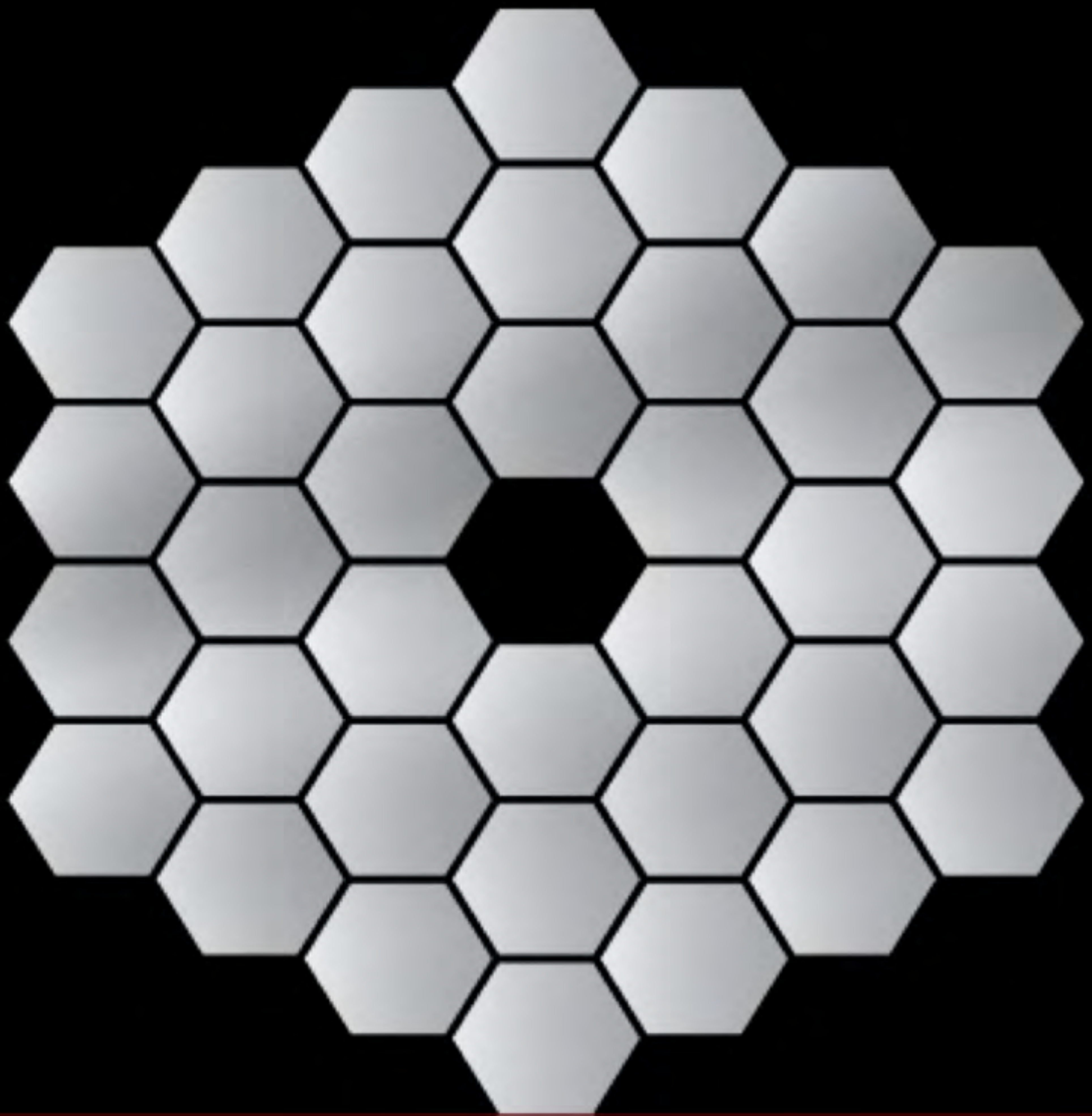


WFIRST/AFTA Technology verification for in-space high contrast imaging.

Many telescopes existing or under construction will have a chance at finding one to a few exoEarths.

Only HDST will purposely make the search and yield a spectacular harvest

Motivation for HDST



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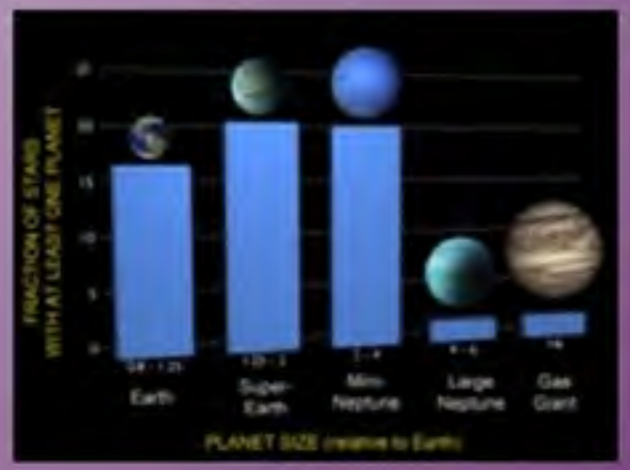
To find dozens of potential Earths, hundreds of stars must be searched, motivating a 12 m class telescope

Why a Large Telescope?

Why a Large Telescope?

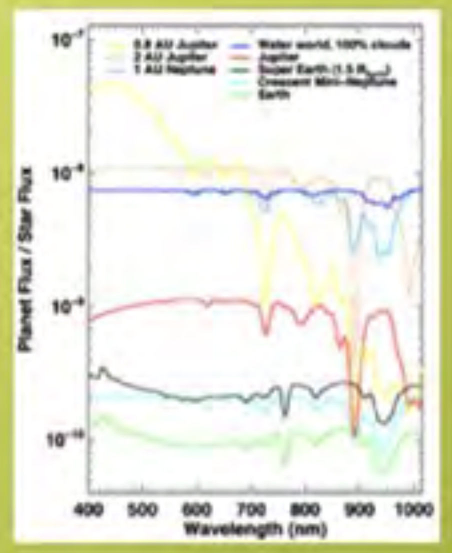
Astrophysical Constraints

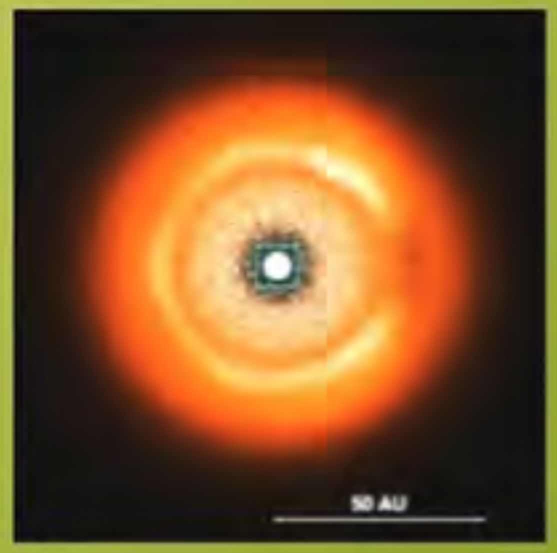
- ηEarth
- exozodi levels
- Planet sizes
- Albedos
- Phase functions



Observational Requirements

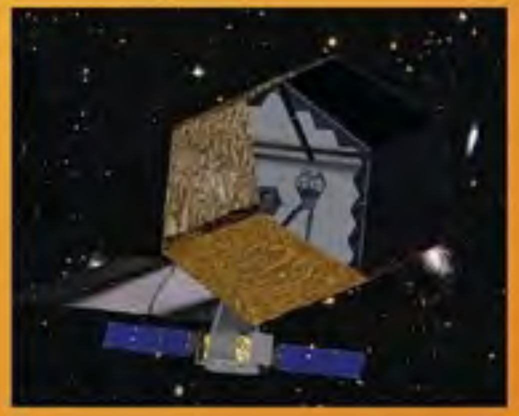
- Central wavelength
- Total bandwidth
- Signal-to-noise
- Observing strategy





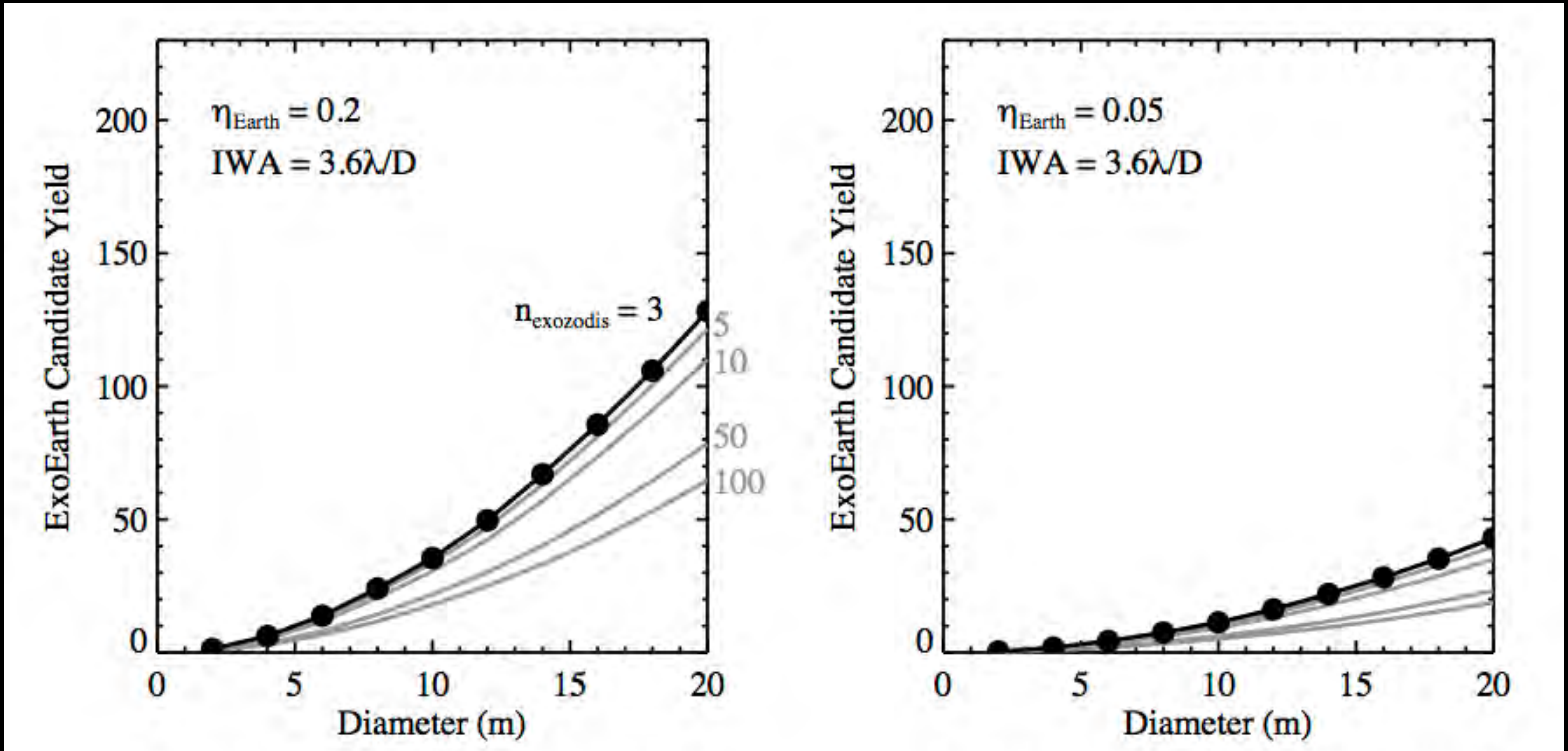
Technical Requirements

- Telescope diameter
- Contrast
- Contrast floor
- Inner working angle
- Outer working angle
- Total throughput
- Overheads



Courtesy Chris Stark

Why a Large Telescope?



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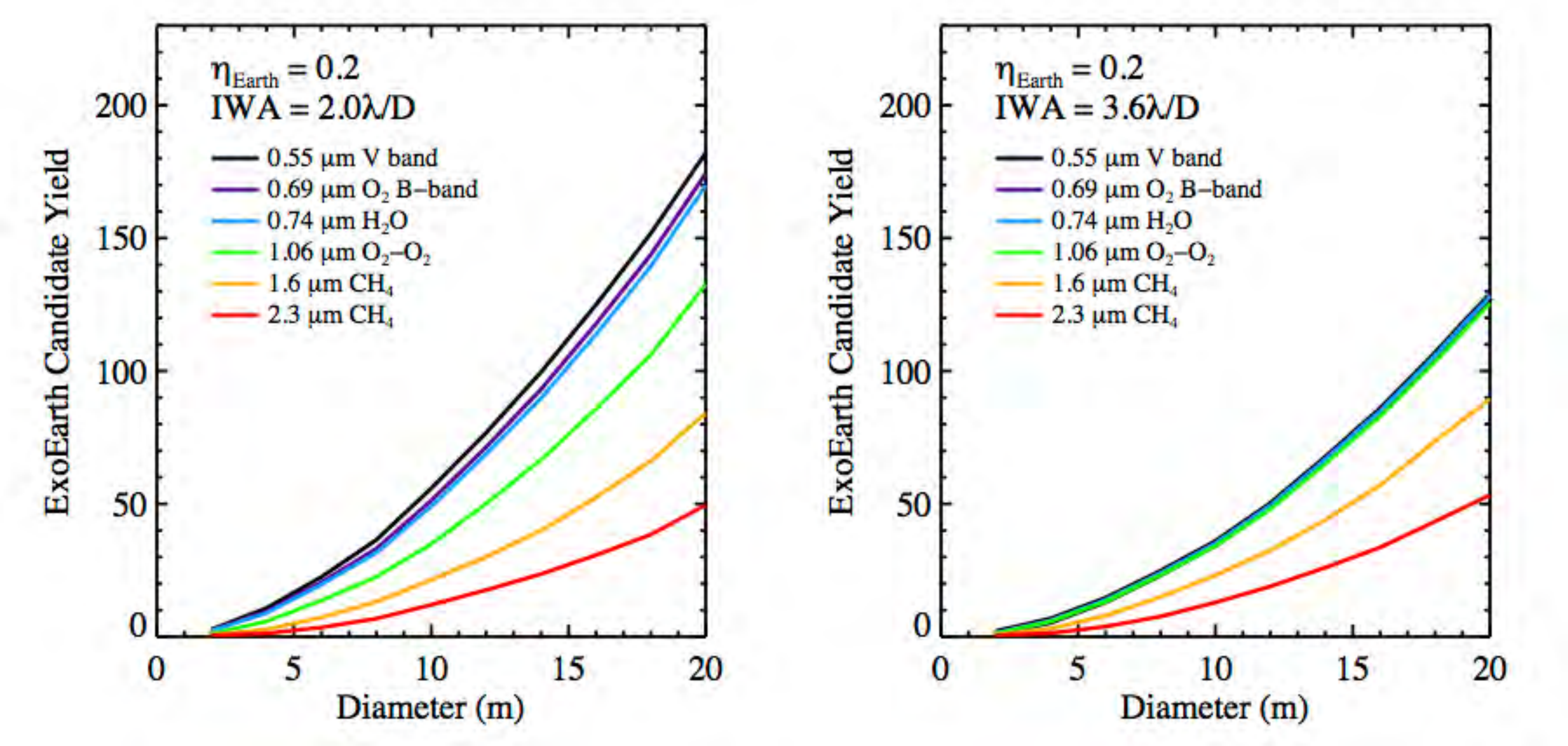
Why a Large Telescope?



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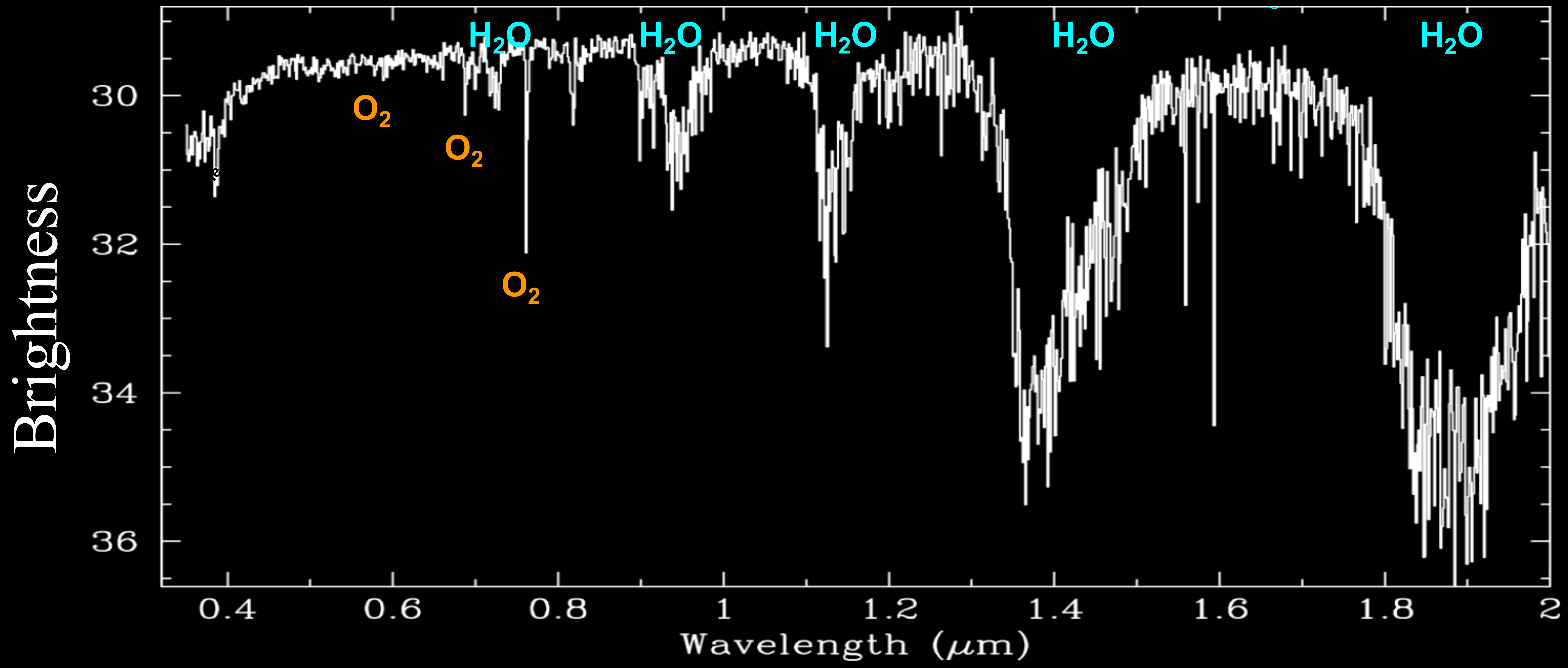
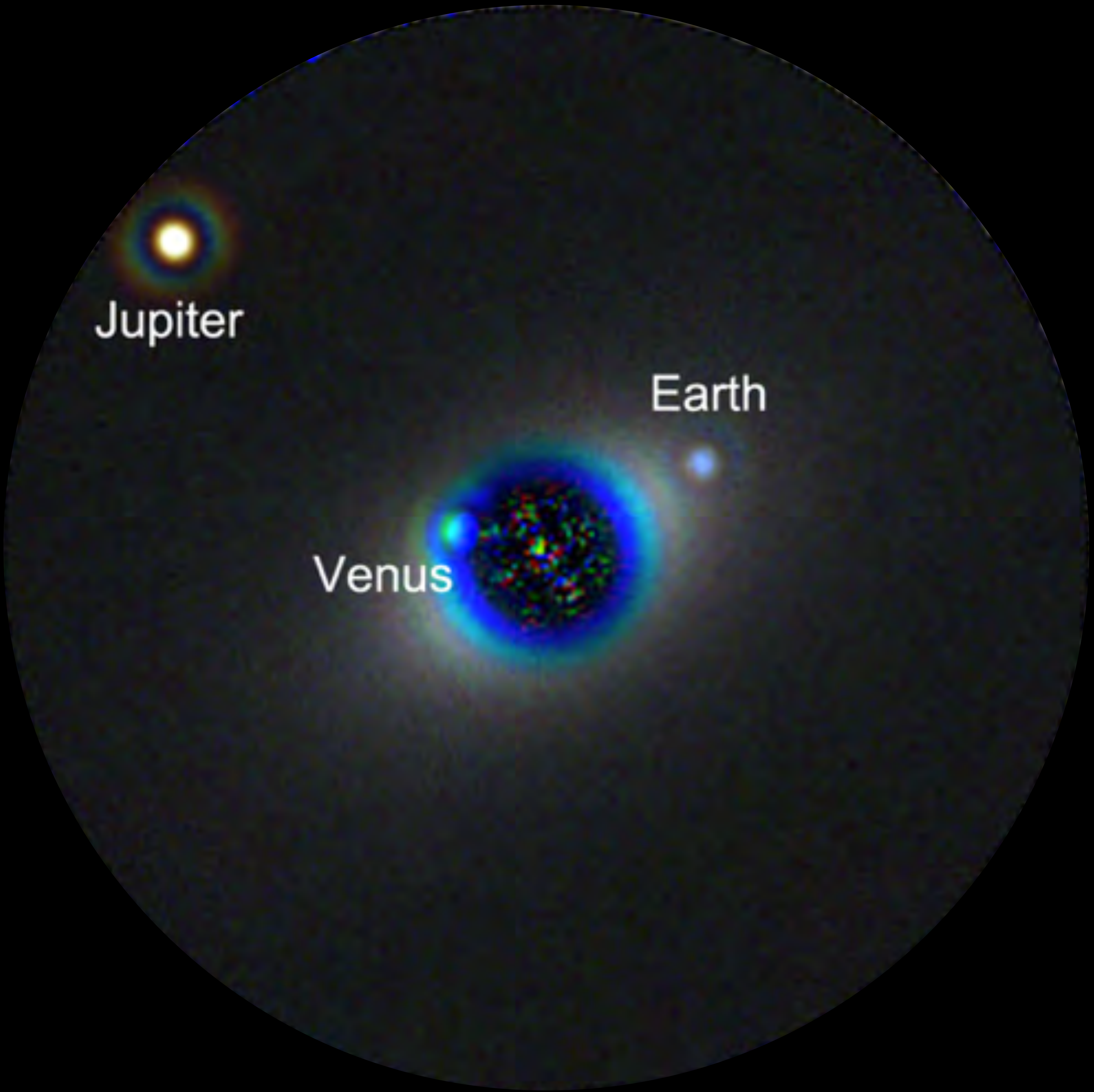


Even with a 12 meter telescope, it will take a week to obtain a “spectrum” of Earth 2.0.

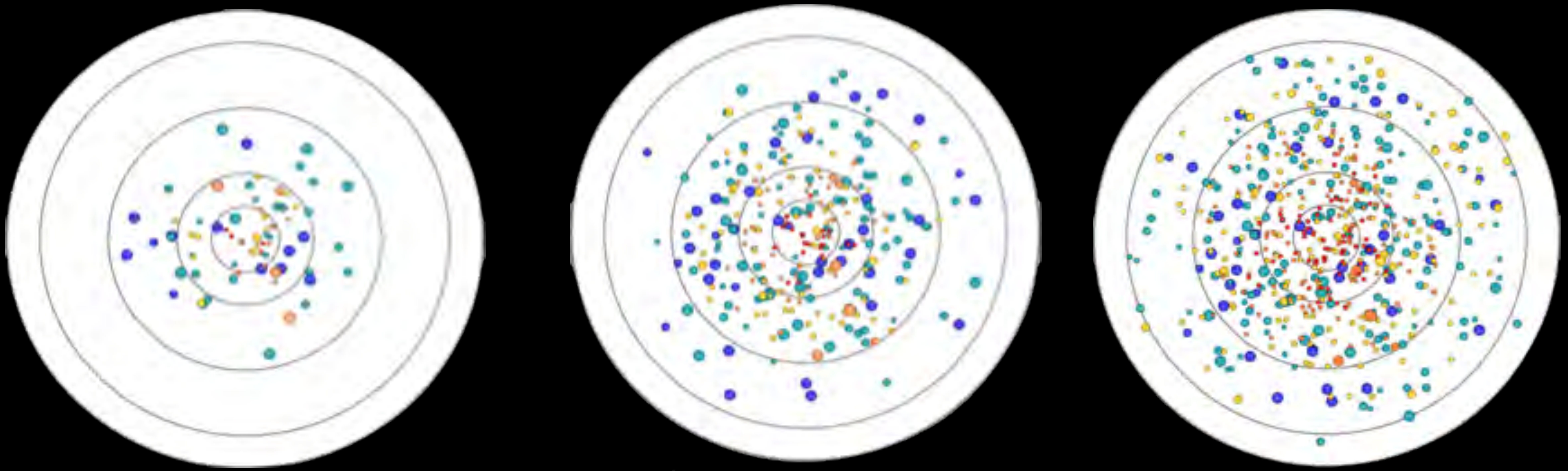


HDST will survey planetary systems, including discovery and study of giant planets and dust belts.

A twin of our solar system at 10 parsecs as seen with the binary apodized-pupil coronagraph technique (credit: L. Pueyo).

Image Credit: L. Peuyo (STScI)

So Many Stars … Only Accessible with HDST

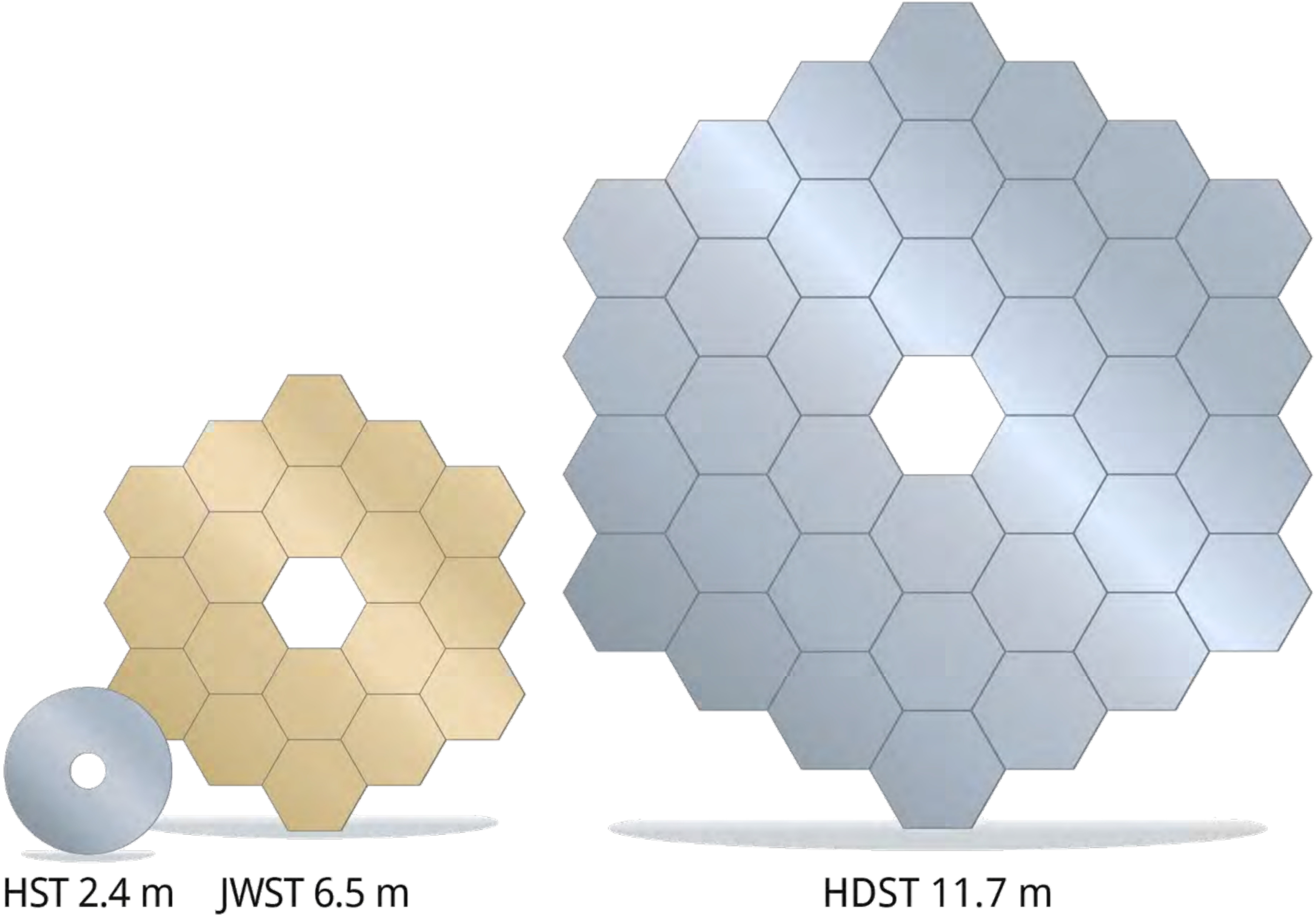


4 meters
4 Earth-like planets or less

8 meters
~15 Earth-like planets

12 meters
~60 Earth-like planets

Only a large space telescopes can access enough stars.



No telescope has ever obtained a spectrum of an object as faint as a typical exoEarth

Earth as an Exoplanet

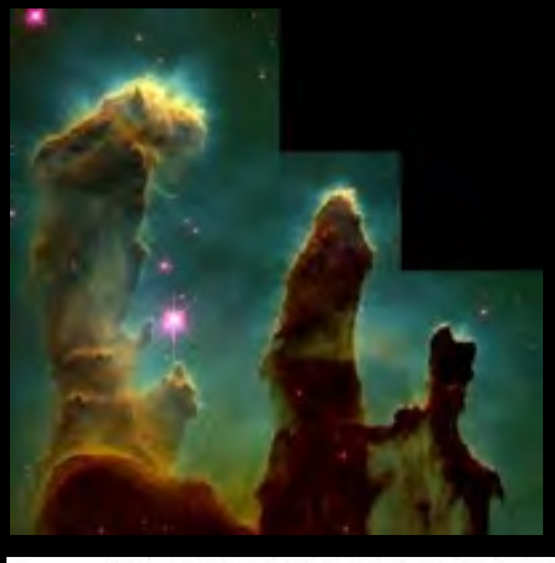
Earth as seen from Voyager I, from 4 billion miles away

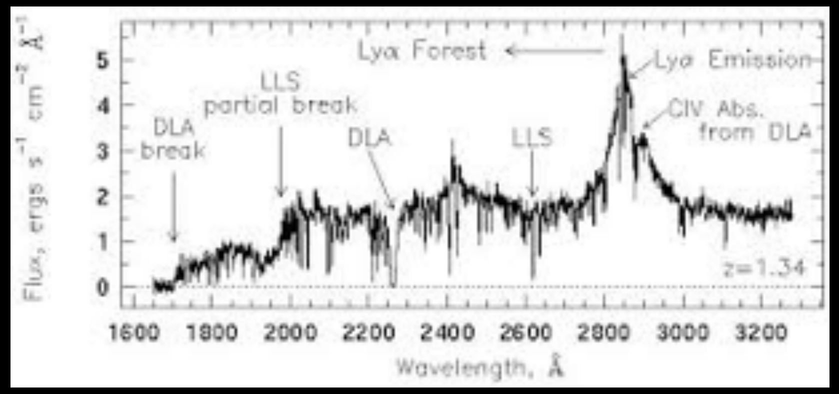
As astonishing as it might be to find life on other worlds, we already know that, alien is it might be, the story of all life in the cosmos arises from galaxies, stars, and planets formed from heavy elements made in stars.

ExoEarths

A worthy endeavor is to design a single space observatory that can both allow us to embark on a serious search for life elsewhere in the Galaxy ***and*** enable revolutionary studies in astrophysics.

Cosmic Origins





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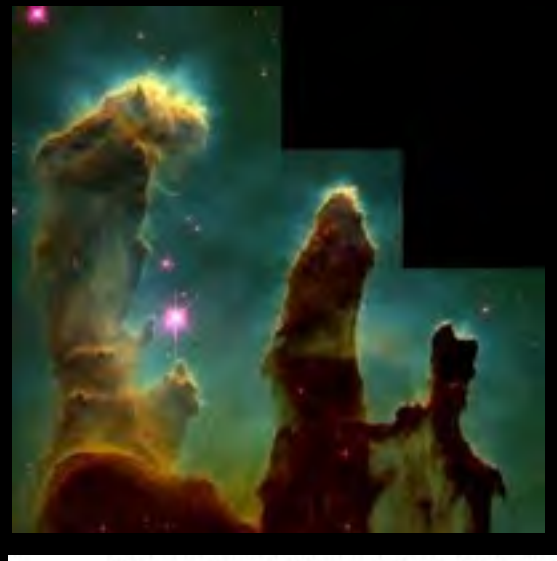
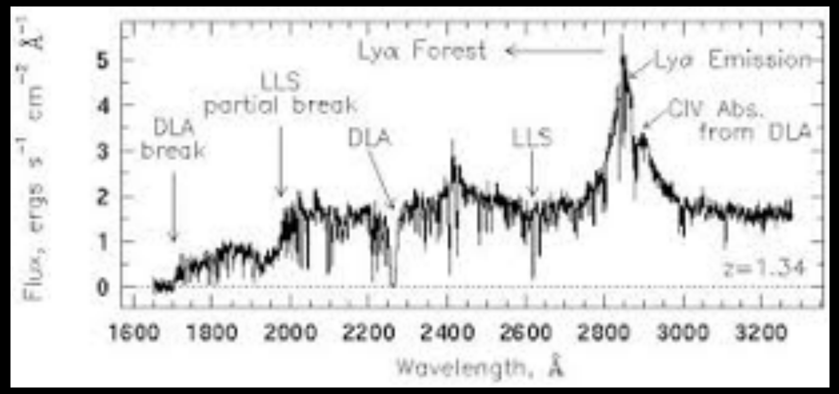
ExoEarths

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

Cosmic Origins

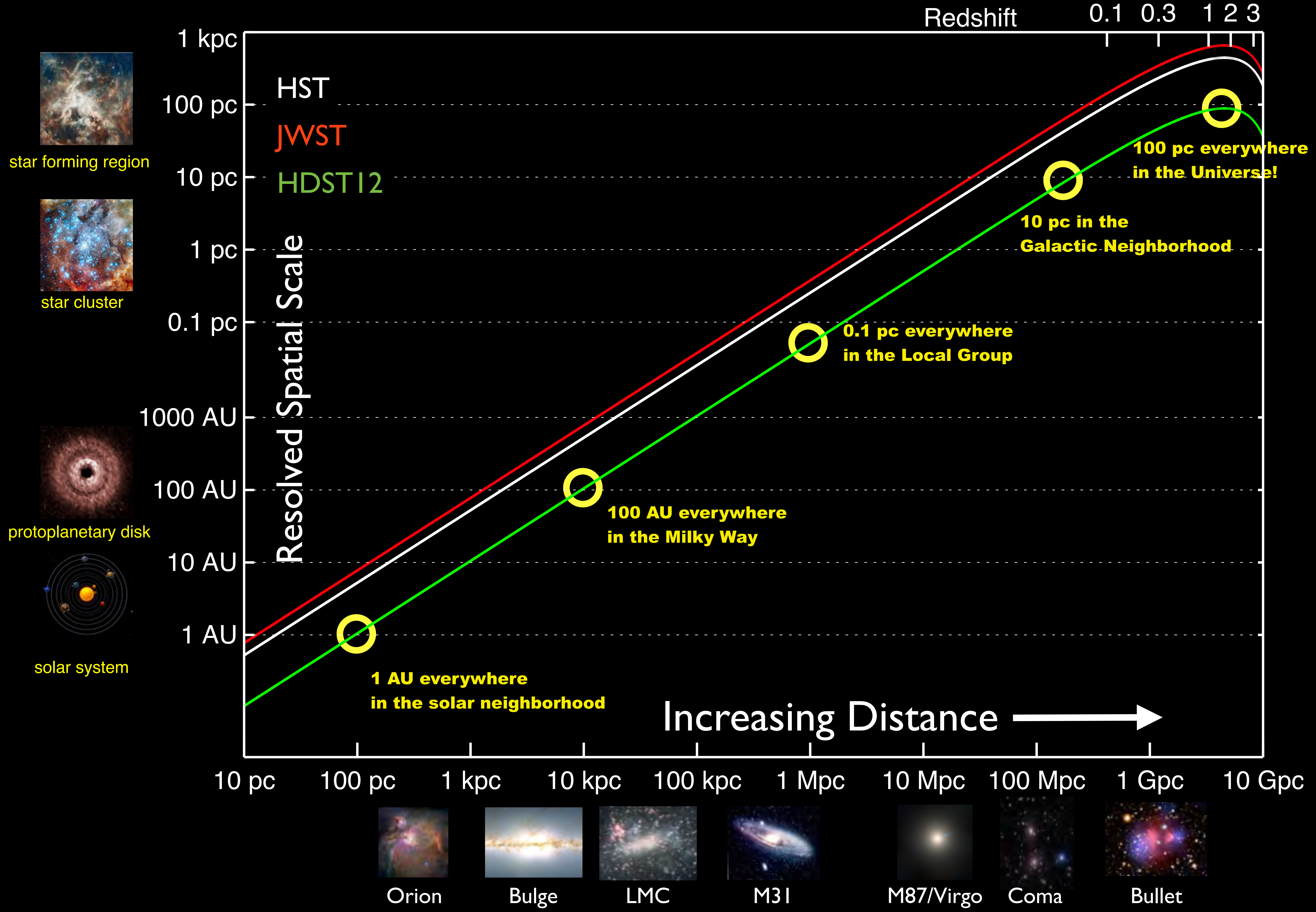




Five epochs in which HDST is uniquely suited to rewrite important chapters in the story of Cosmic Birth.

The Epoch When the Milky Way Formed	$z = 1 - 4$	30-100 pc	
The Epoch When the Solar System Formed	$z < 1$	50-100 pc	
The Present in Our Galactic Neighborhood	< 100 Mpc	1 - 10 pc	
Star and Planet Formation in Our Galaxy	< 10 kpc	10-100 AU	
Solar Systems like our Own	<50 AU	20-250 km	

HDST: Breaking Resolution Barriers in the UV/Optical



Galaxies in High Definition

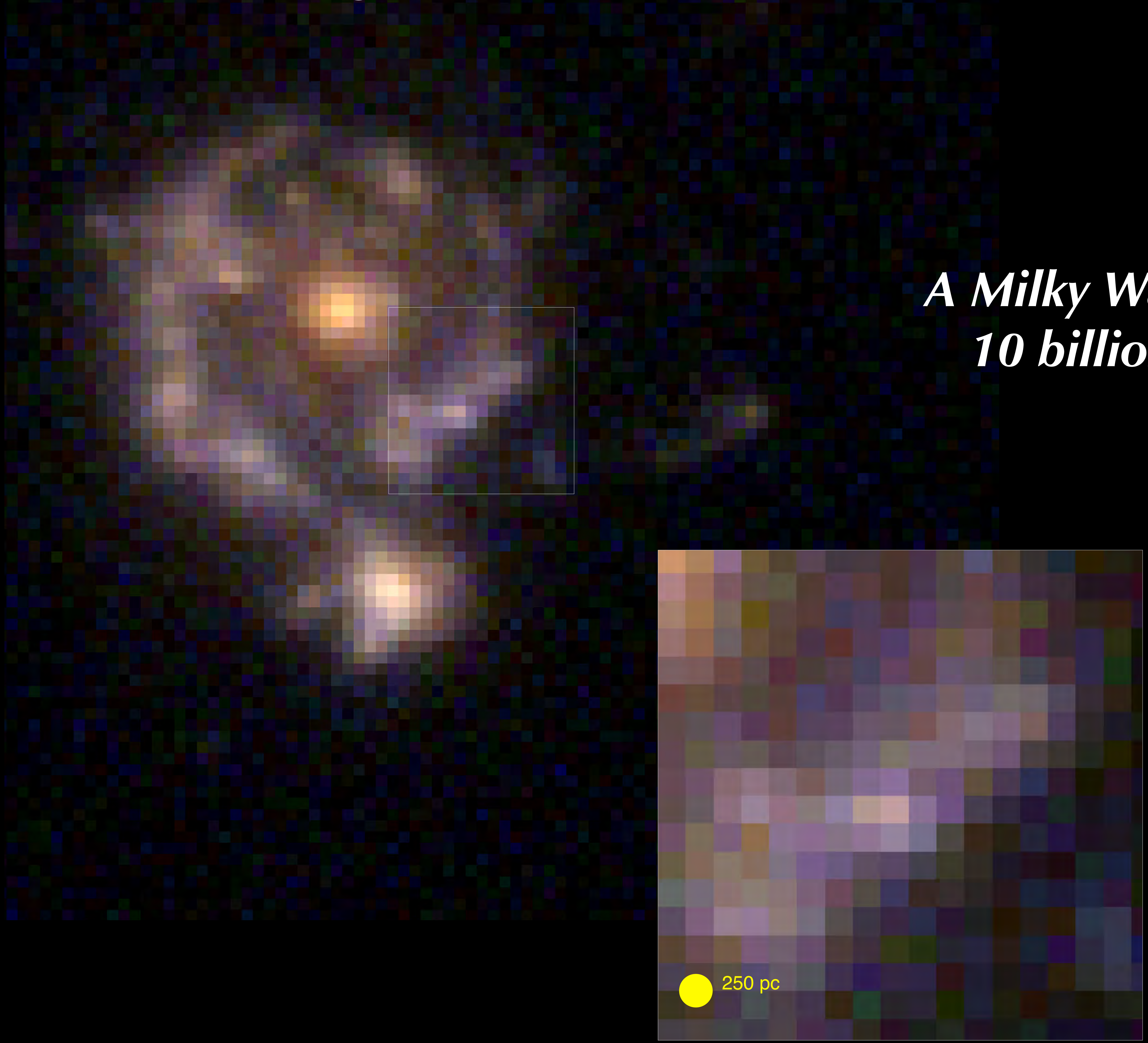
HST

A Milky Way-like galaxy
10 billion years ago

Images simulated by
Greg Snyder (STScI)

Galaxies in High Definition

JWST



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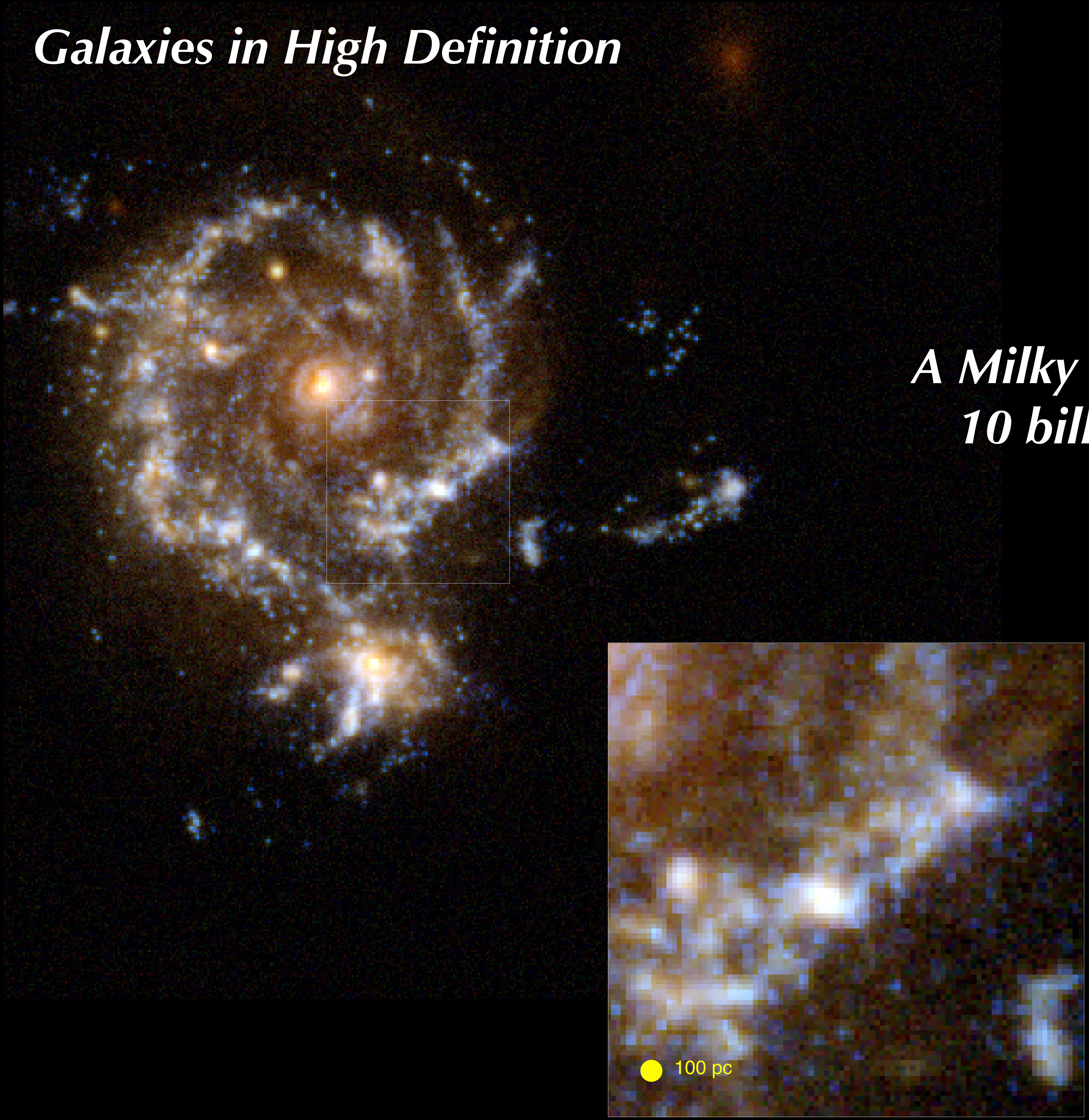

HDST

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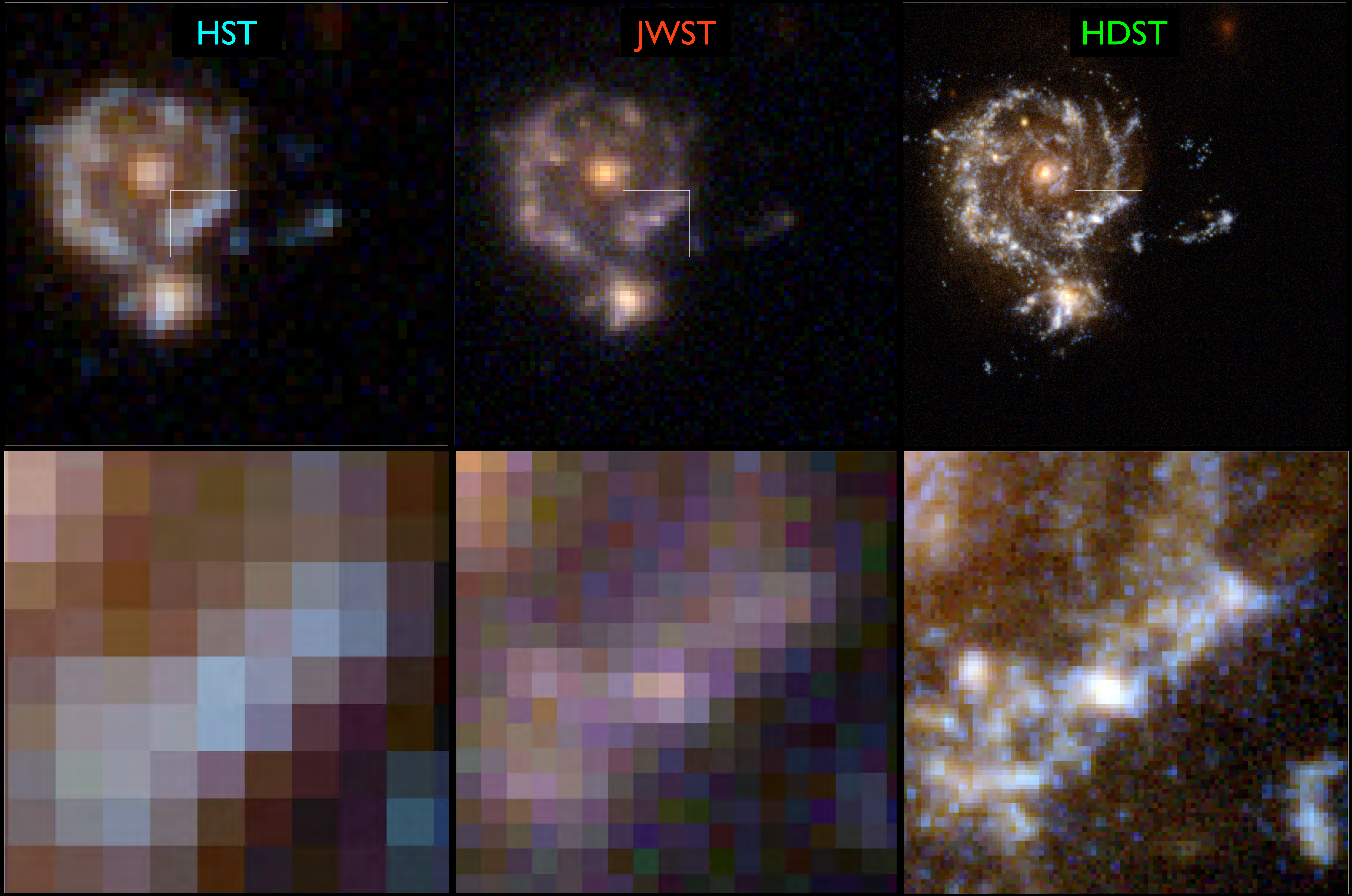


Images simulated by
Greg Snyder (STScI)

SDTV

720x480

24x pixel density

UltraHD

3820x2160

HST

2.4 m

24x image sharpness

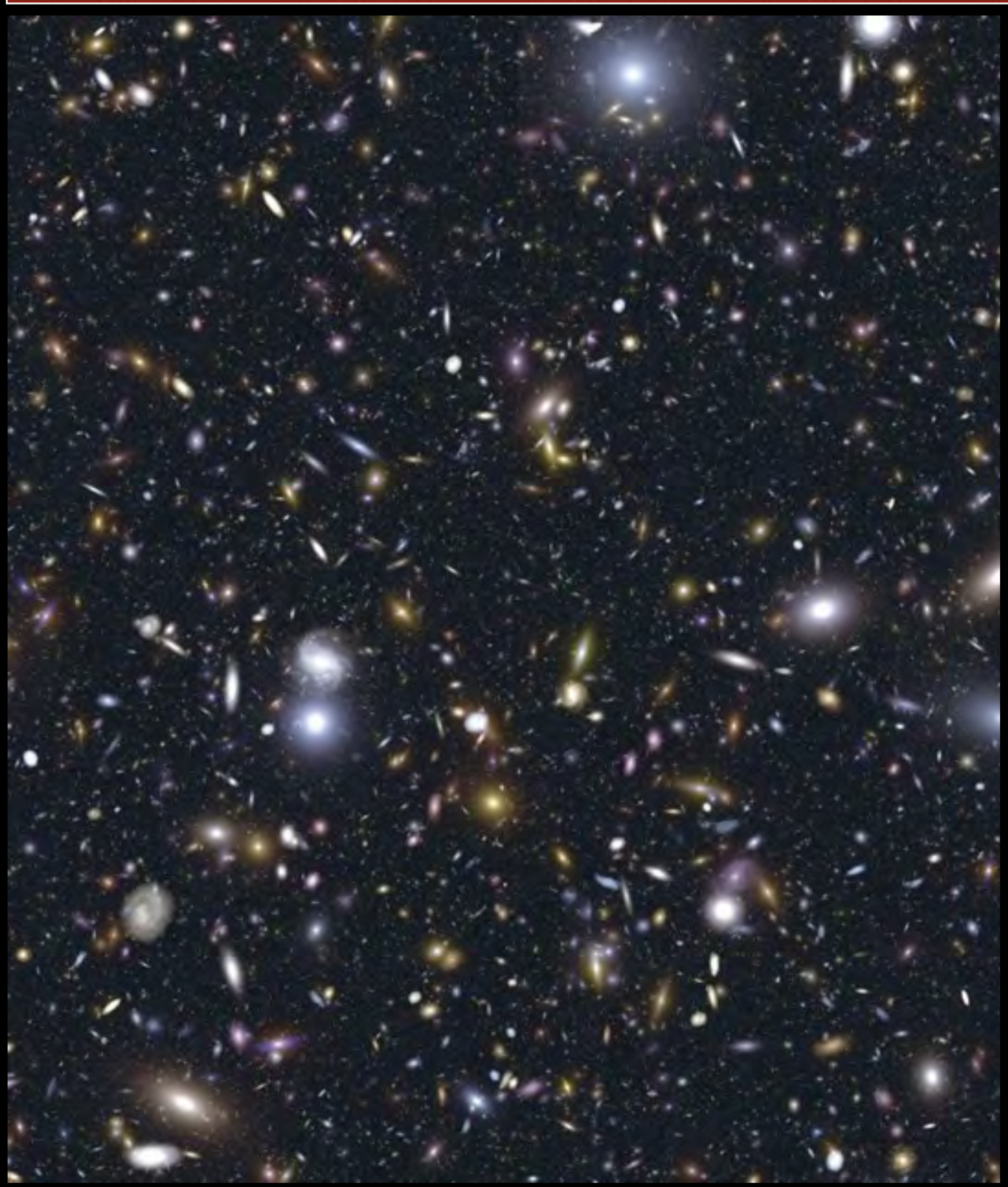
HDST

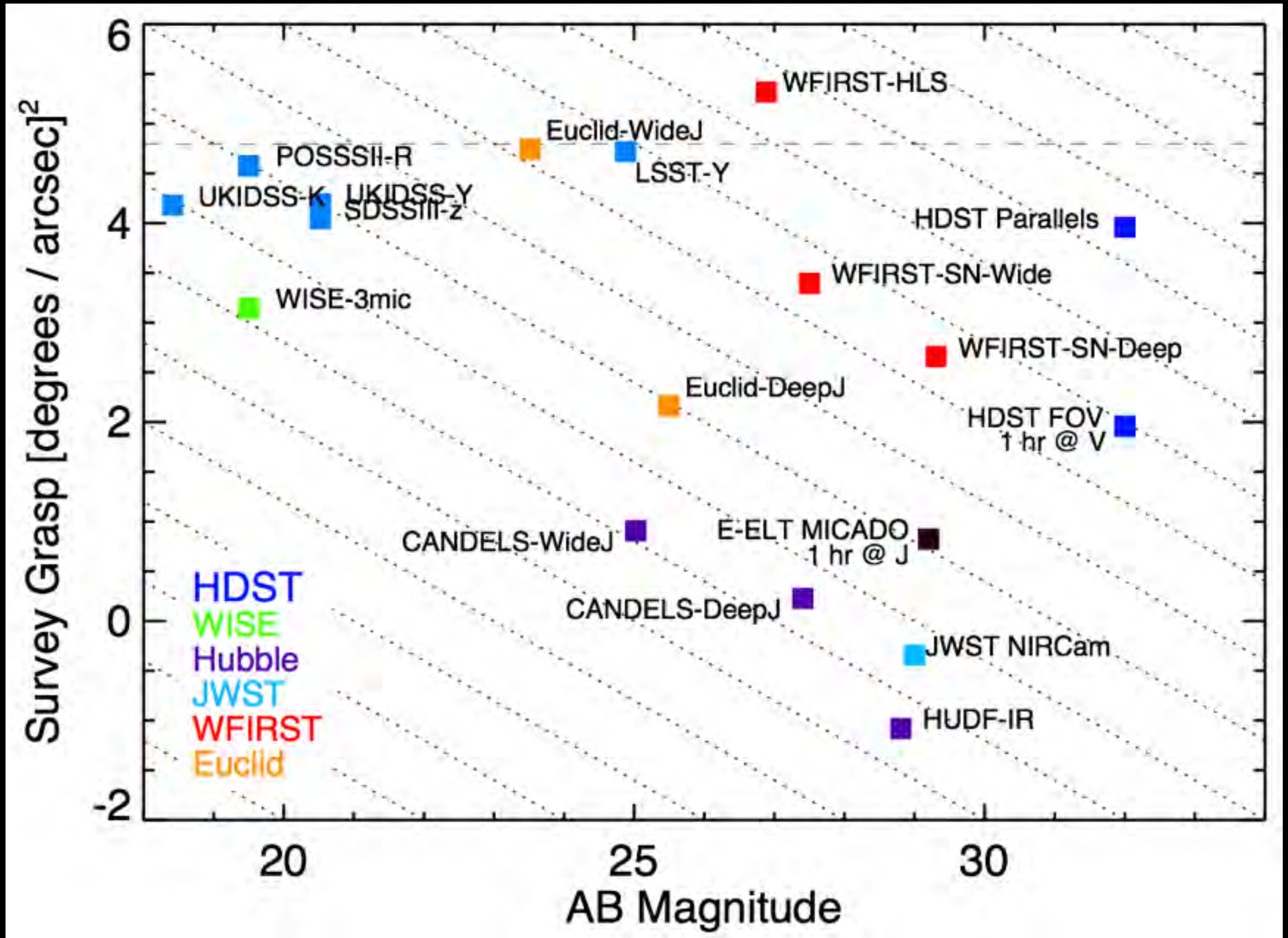
12 m

How Do Galaxies Grow, Evolve, and Die?

Epoch
$z = 1 - 4$

Resolution
30-100 pc





Deep parallels with high-latitude exoplanet observations, total of ~ 1 year of observing time.

Total area of sky will approach ~ 1 deg^2, reaching ~ALL star forming galaxies and sees almost all star forming satellites.

Total comoving volume at z = 2-3 is roughly equivalent volume of entire SDSS, enabling robust comparisons across cosmic time.

The information content of this survey is immense.

How Do Galaxies Grow, Evolve, and Die?

Epoch
z = 1 - 4

Resolution
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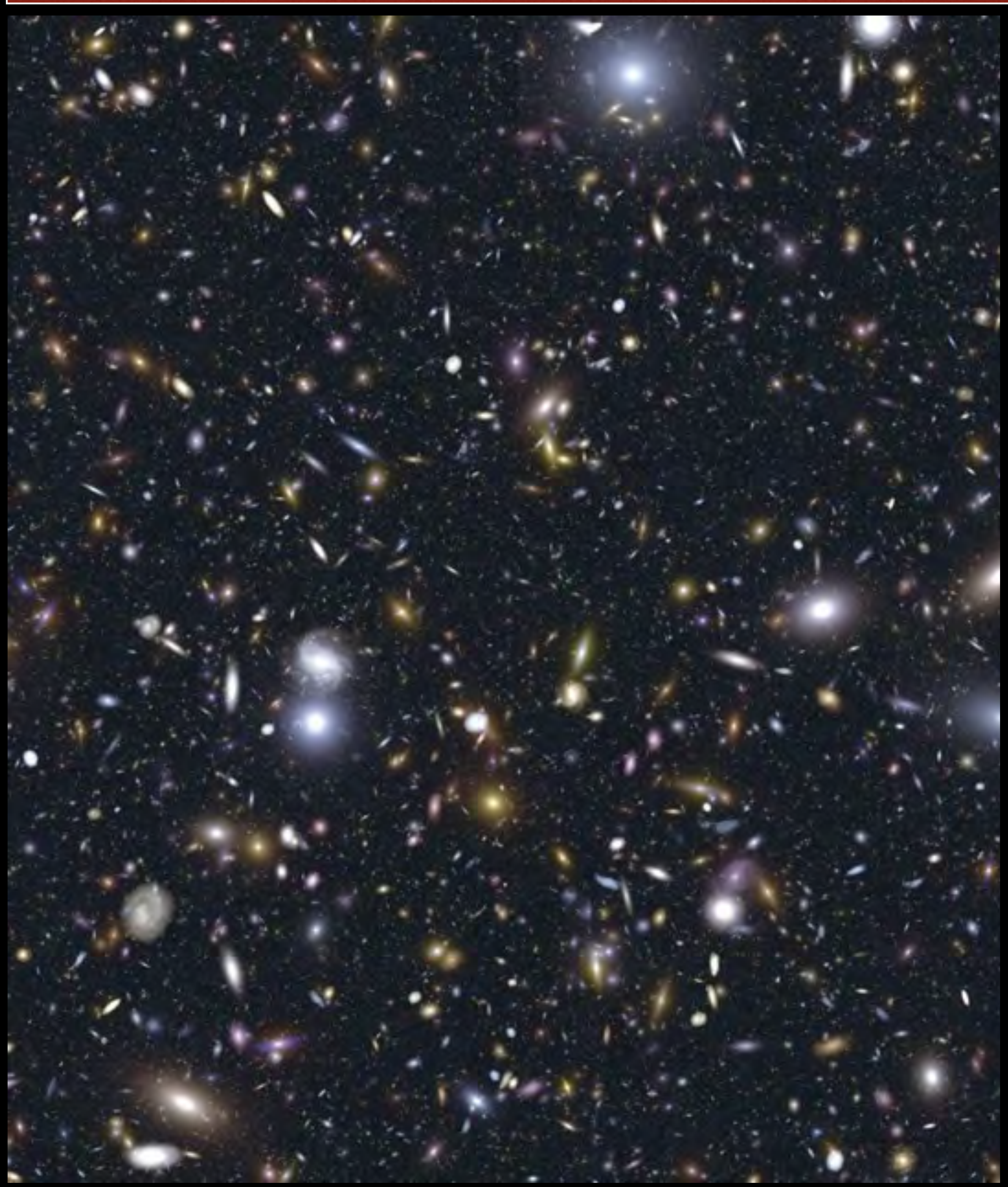

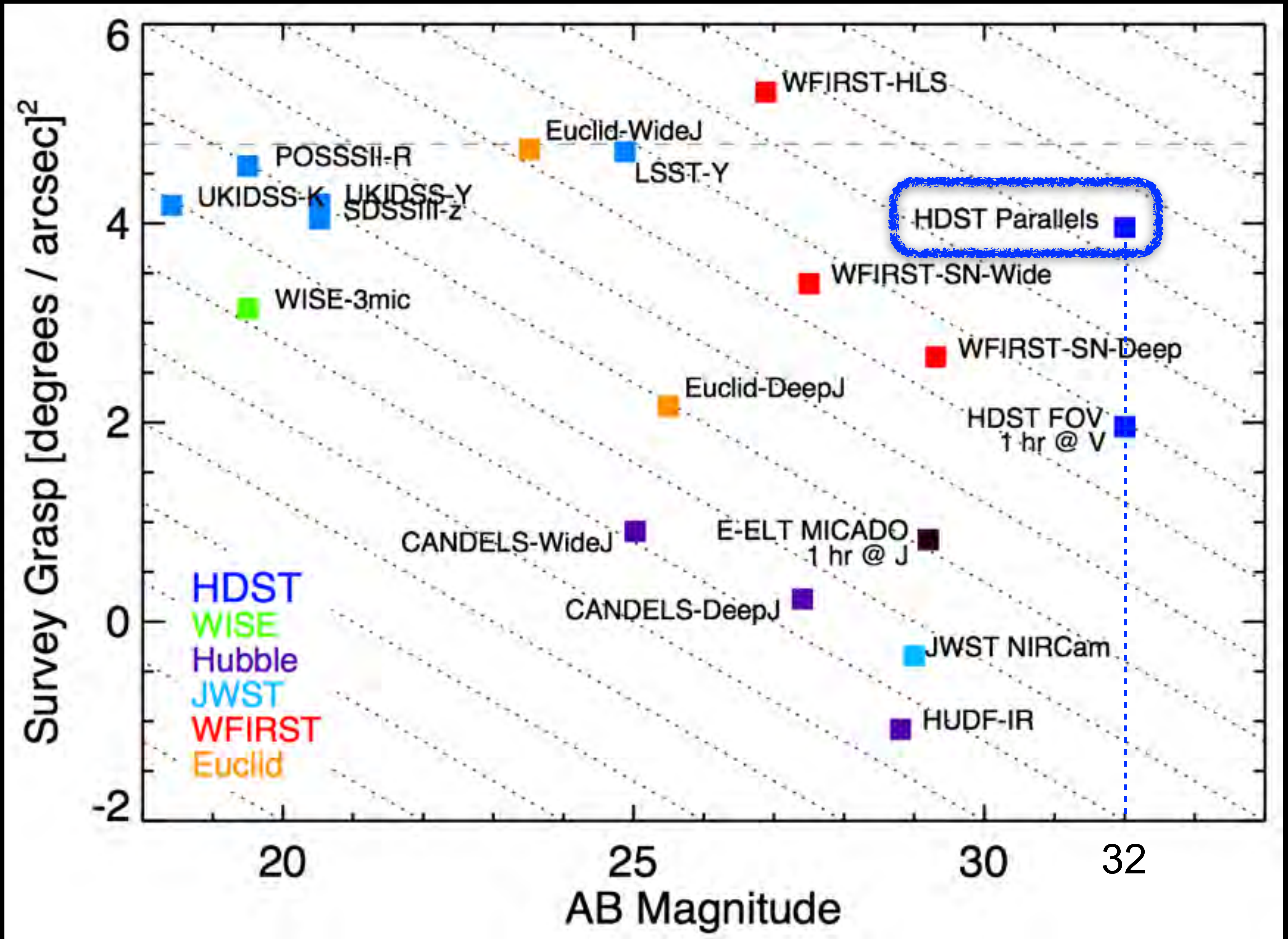

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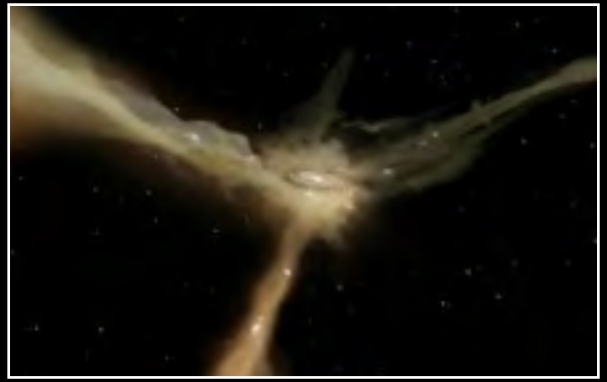
How Do Galaxies Acquire, Process, and Recycle Their Gas?

Epoch
z < 1

Resolution
10-100 pc



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Epoch
z < 1

Resolution
10-100 pc

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Resolution
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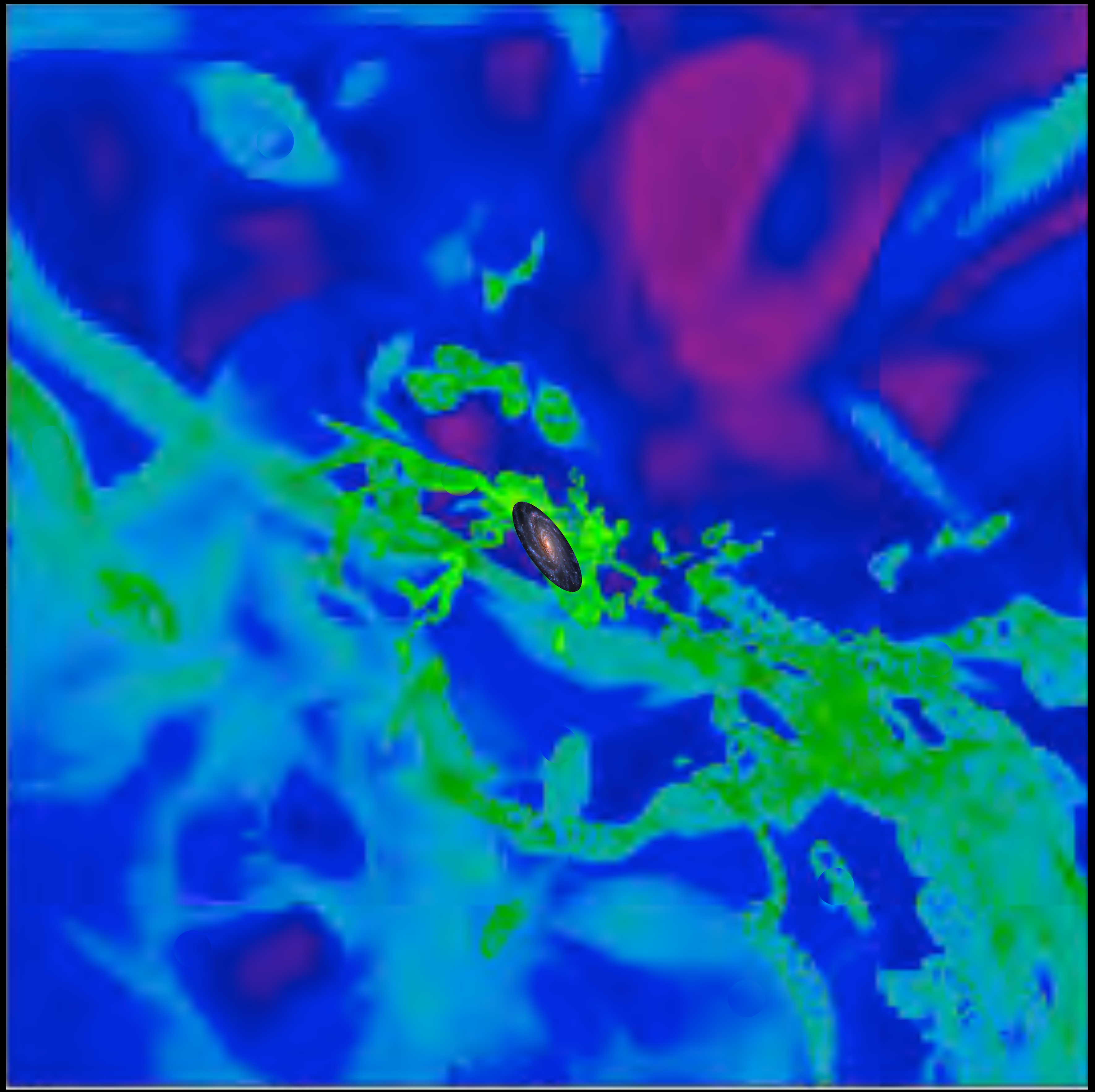
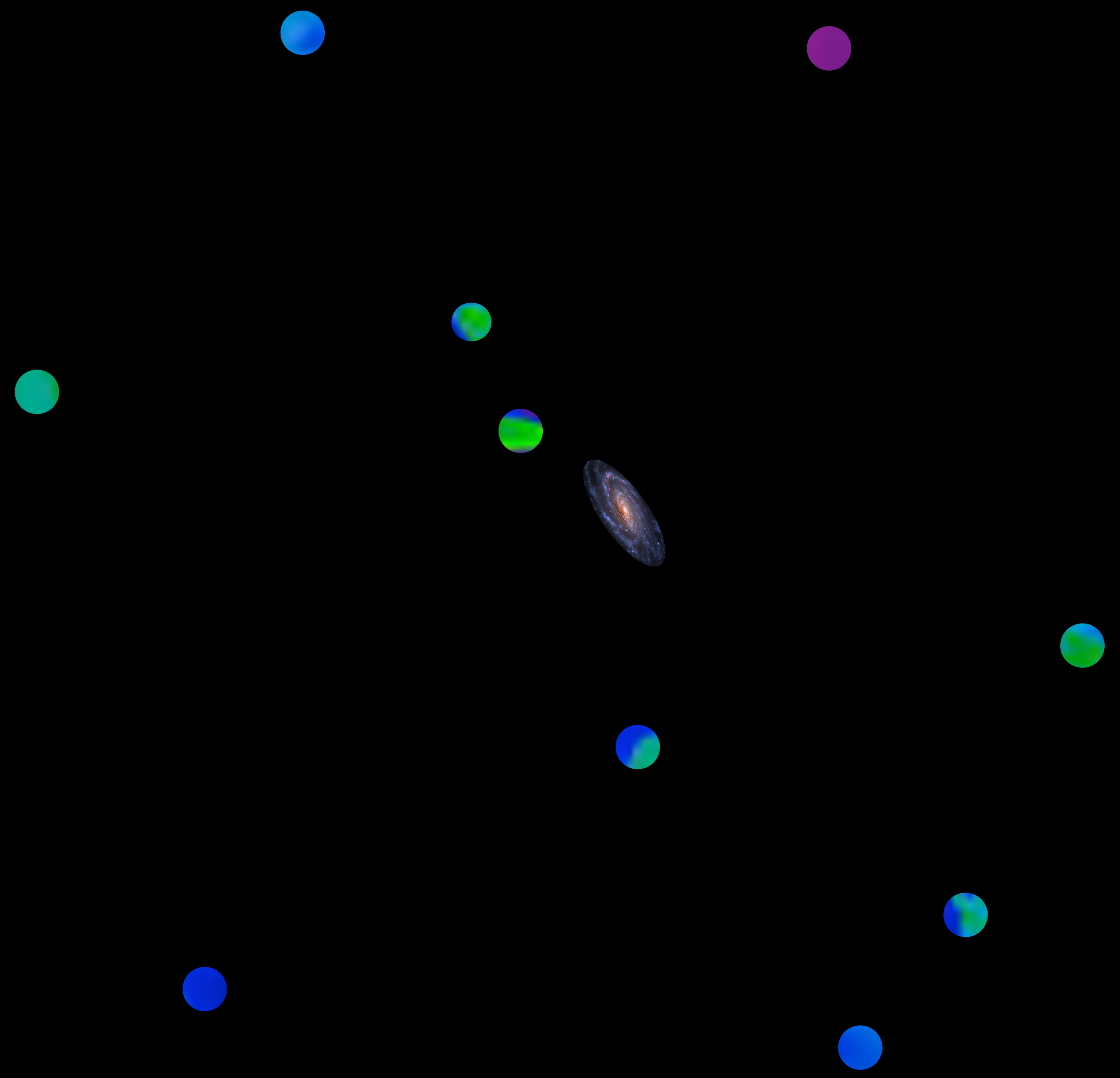


How Do Galaxies Acquire, Process, and Recycle Their Gas?	Epoch z < 1	Resolution 10-100 pc

Hubble's View



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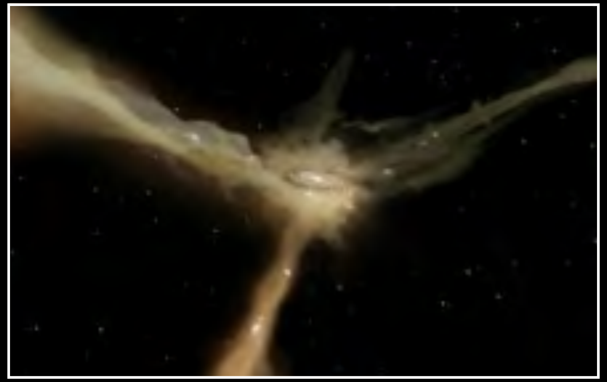
Epoch
z < 1

Resolution
10-100 pc



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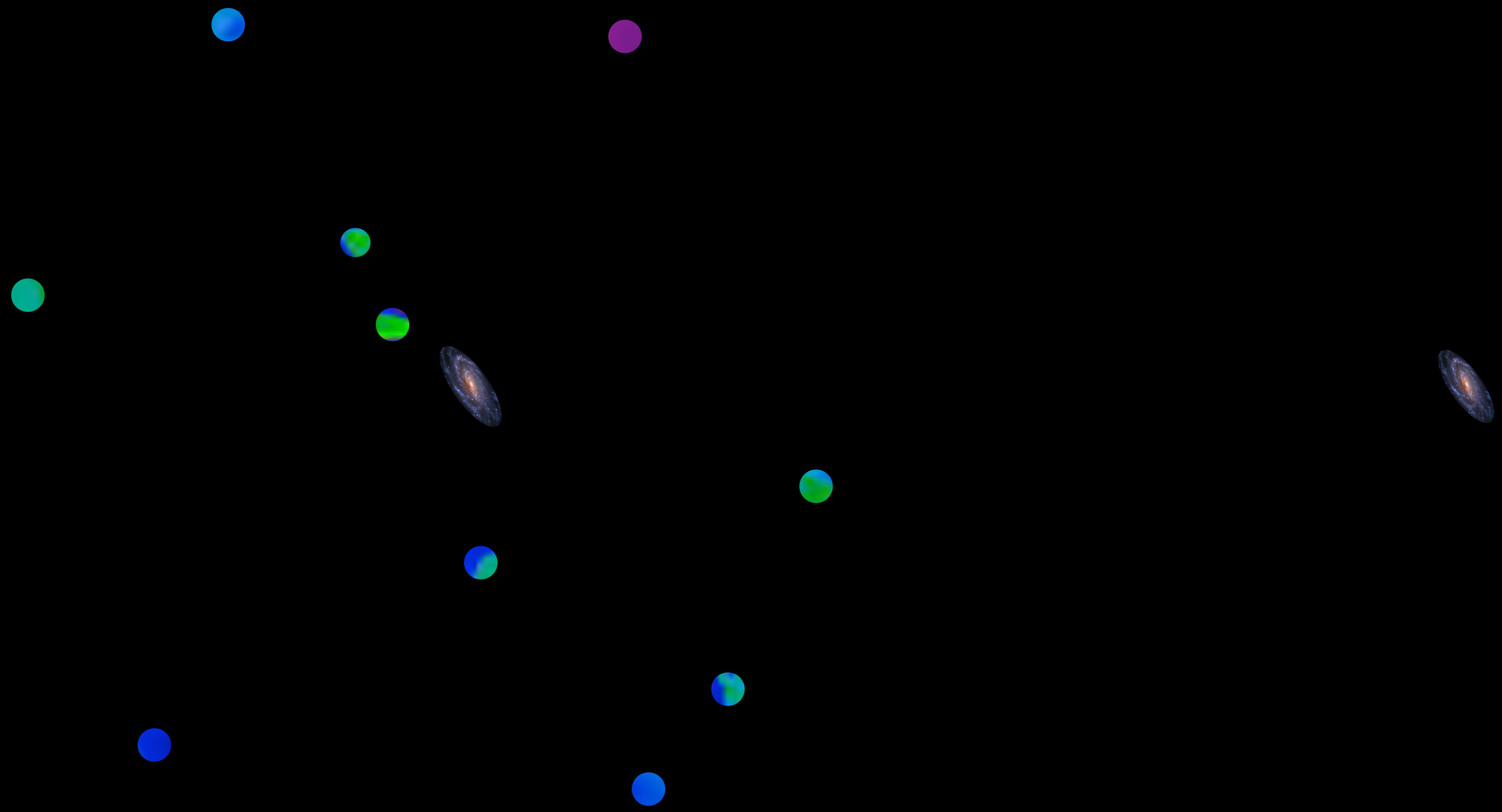
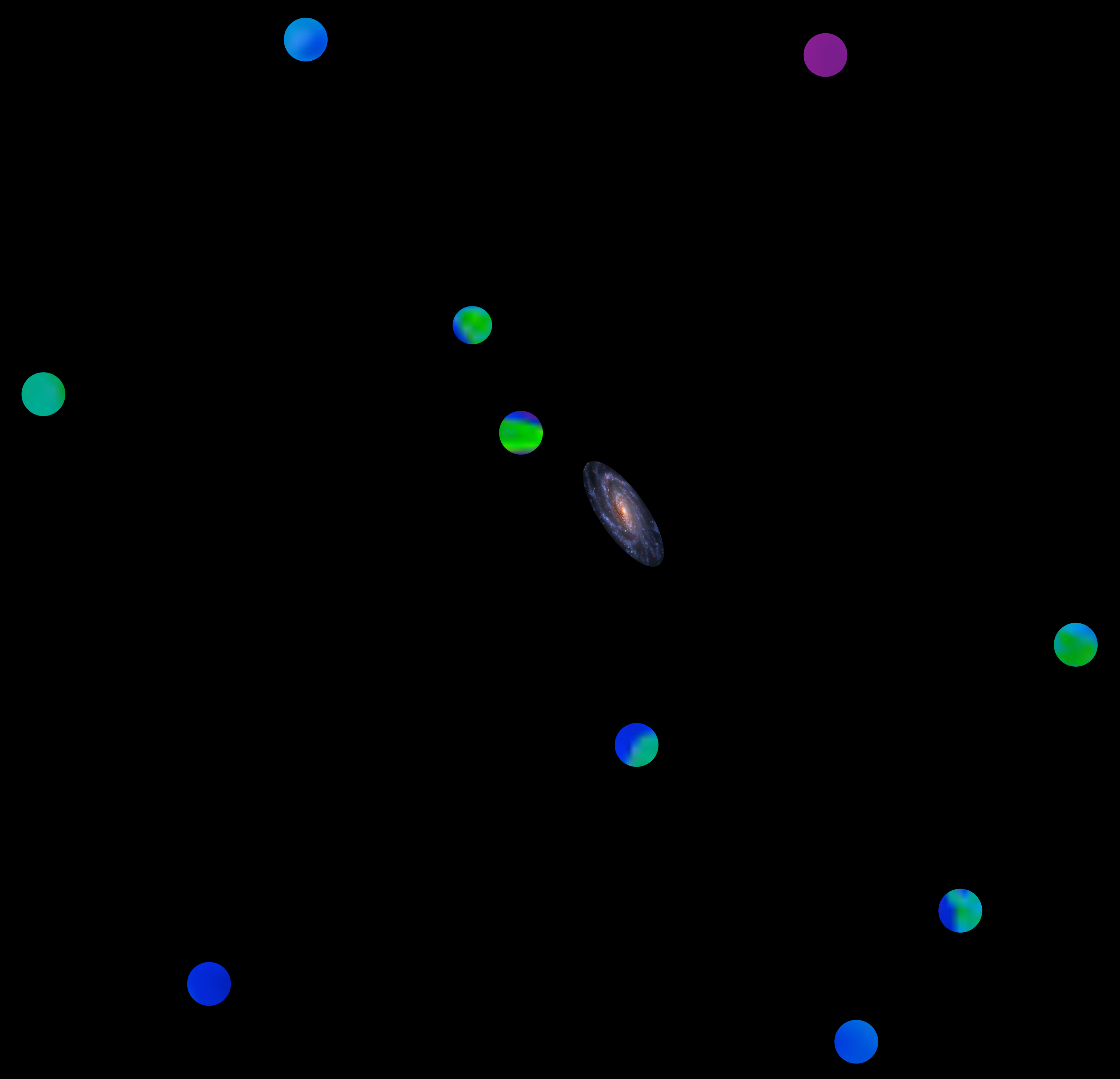
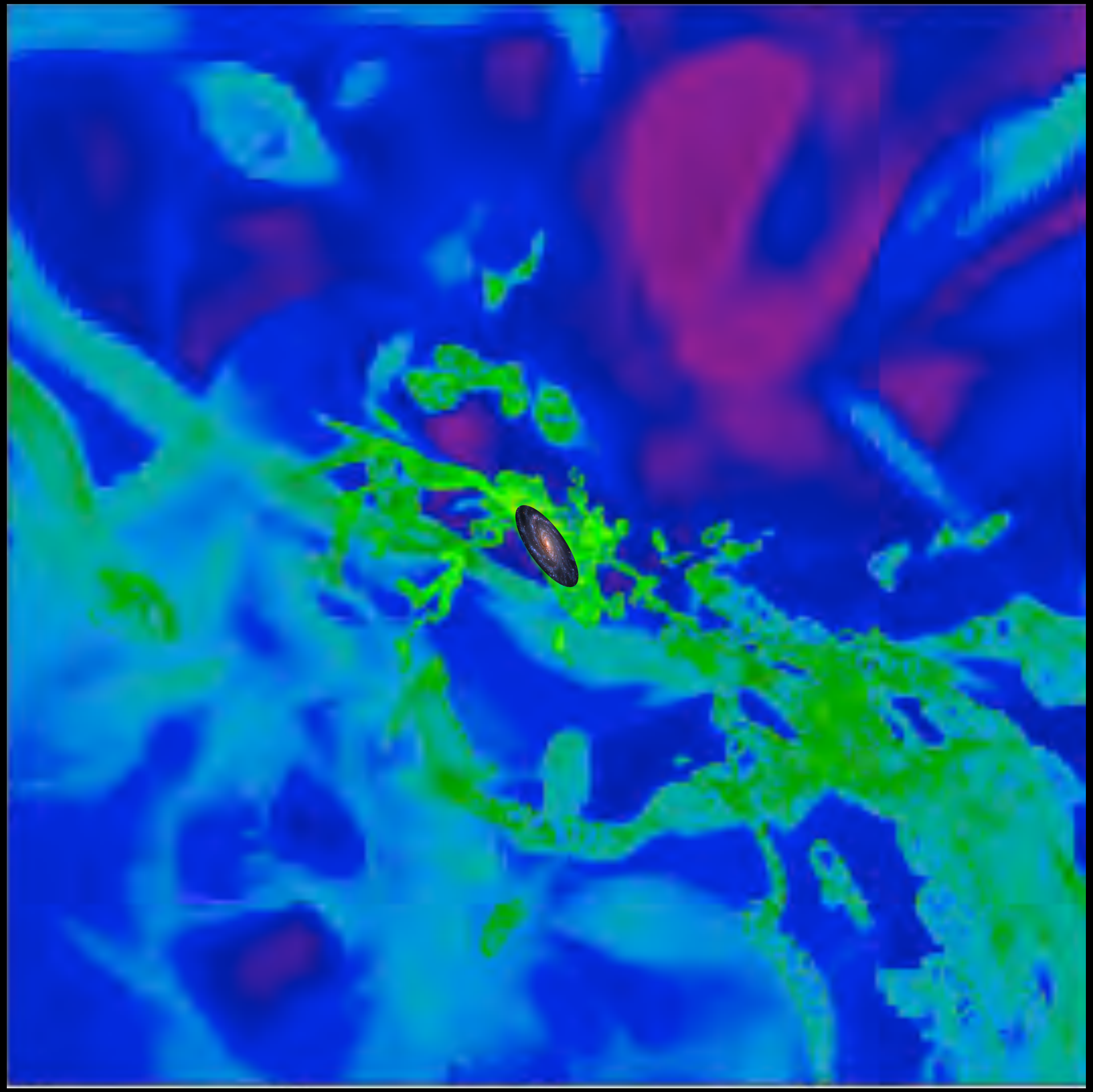


How Do Galaxies Acquire, Process, and Recycle Their Gas?	Epoch $z < 1$	Resolution 10-100 pc	

Hubble's View





How Do Galaxies Acquire, Process, and Recycle Their Gas?

Epoch
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Resolution
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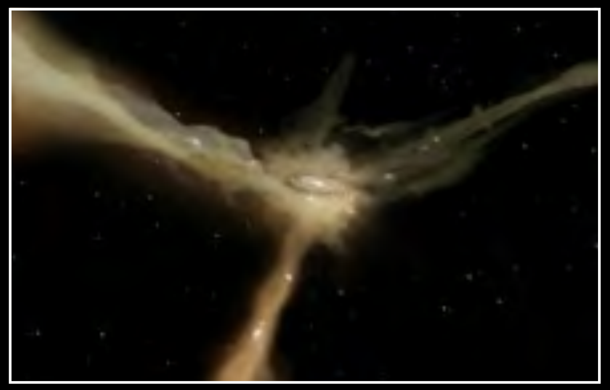
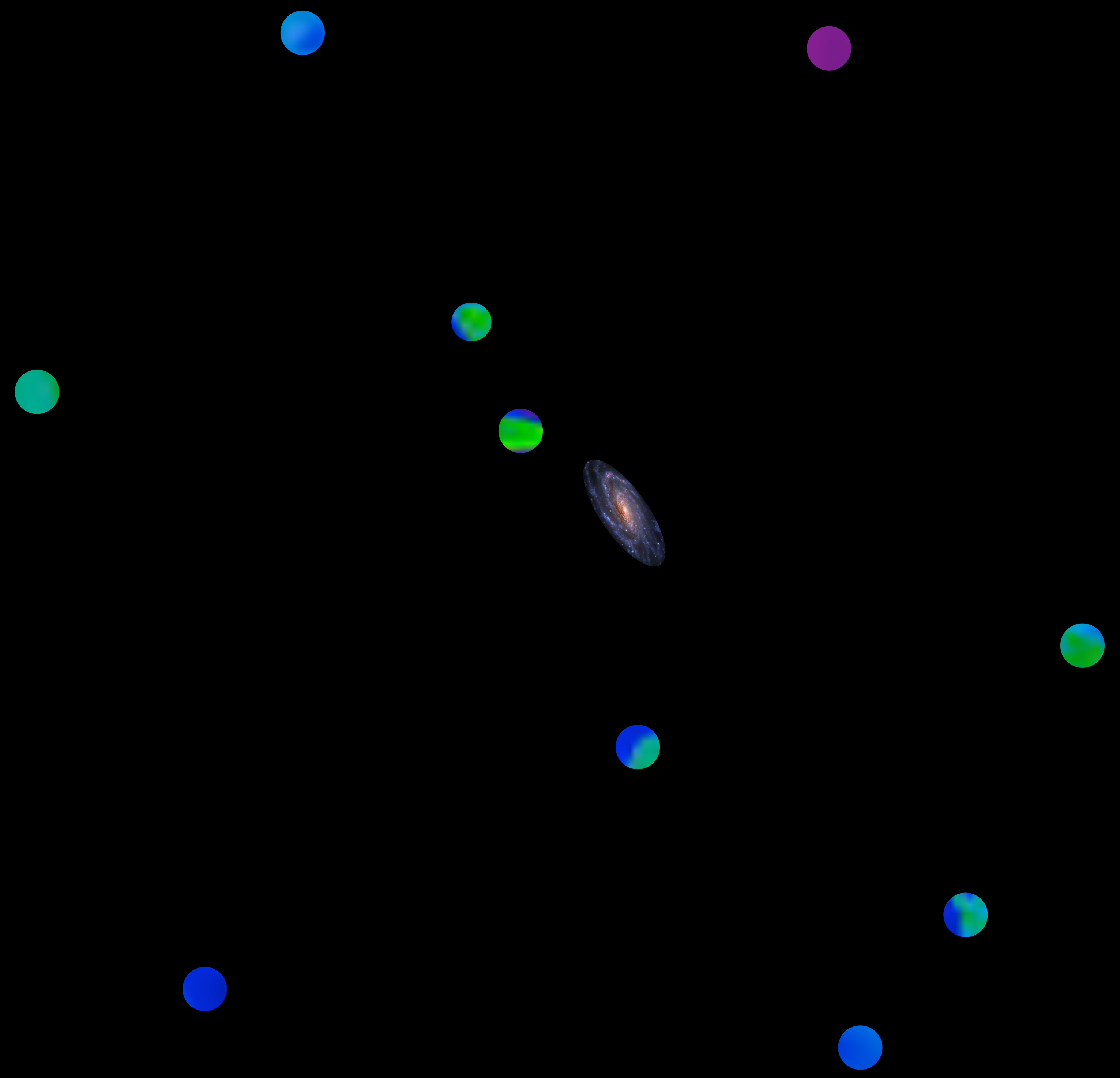
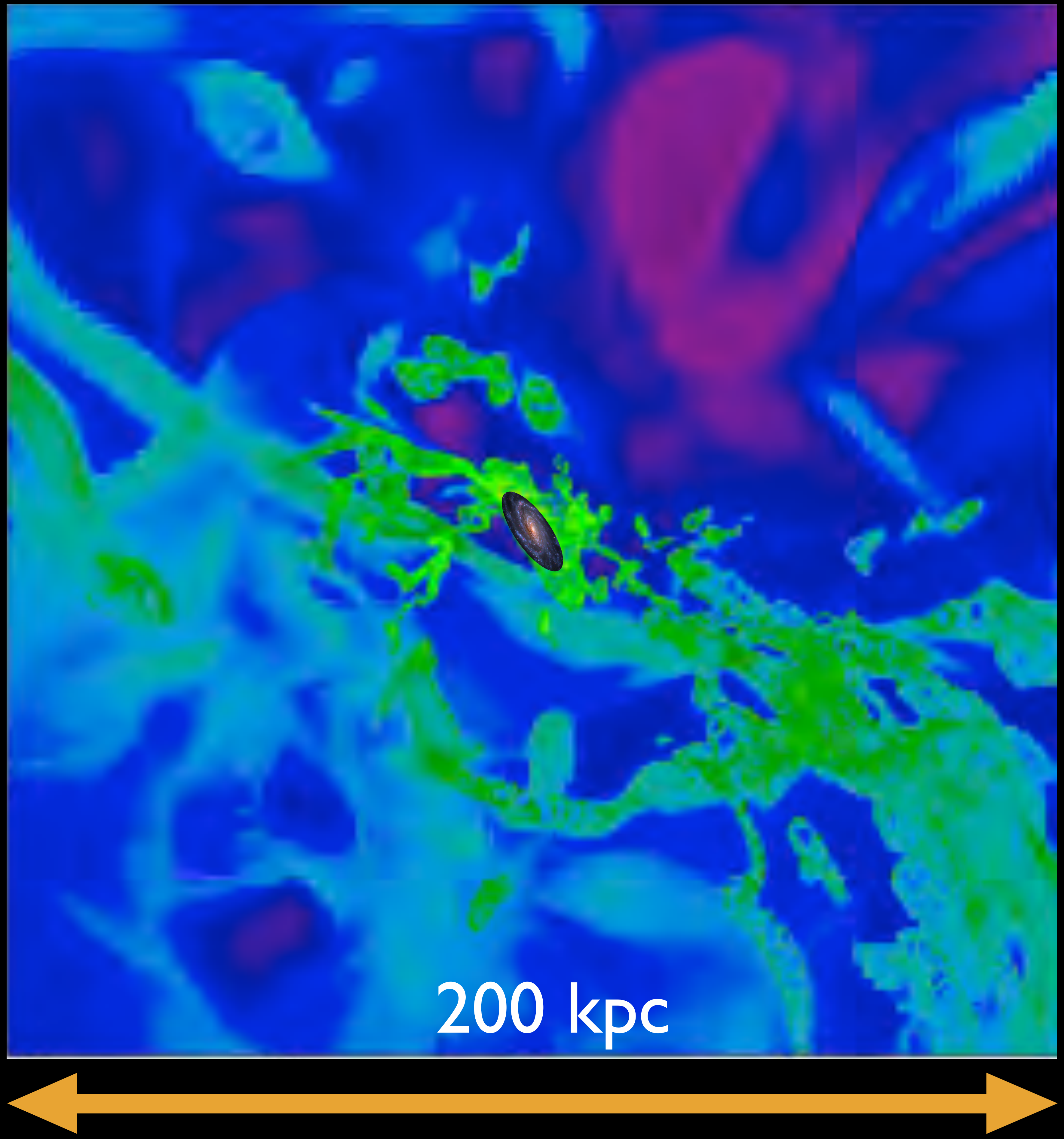


Hubble's View

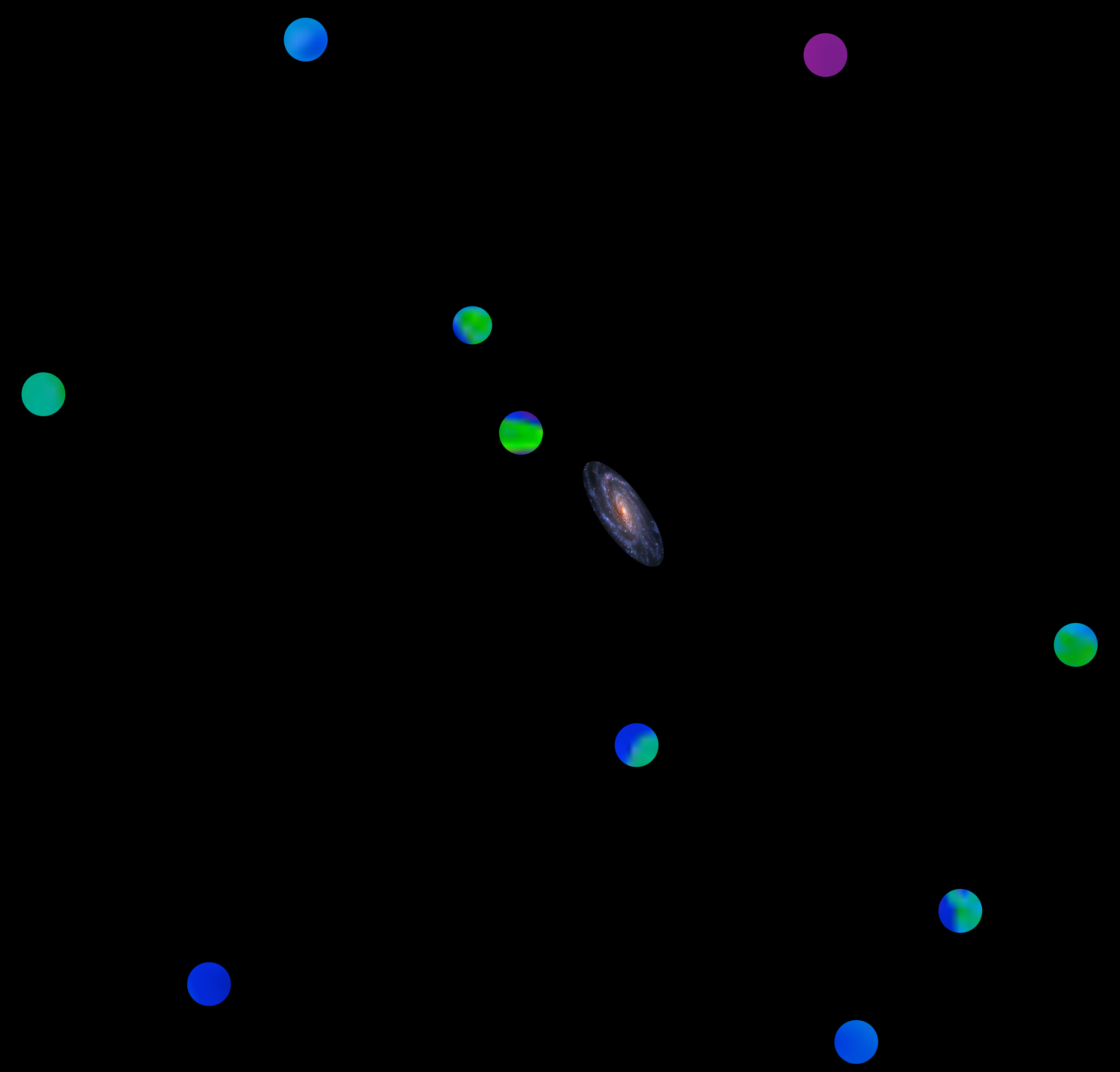


HDST's View

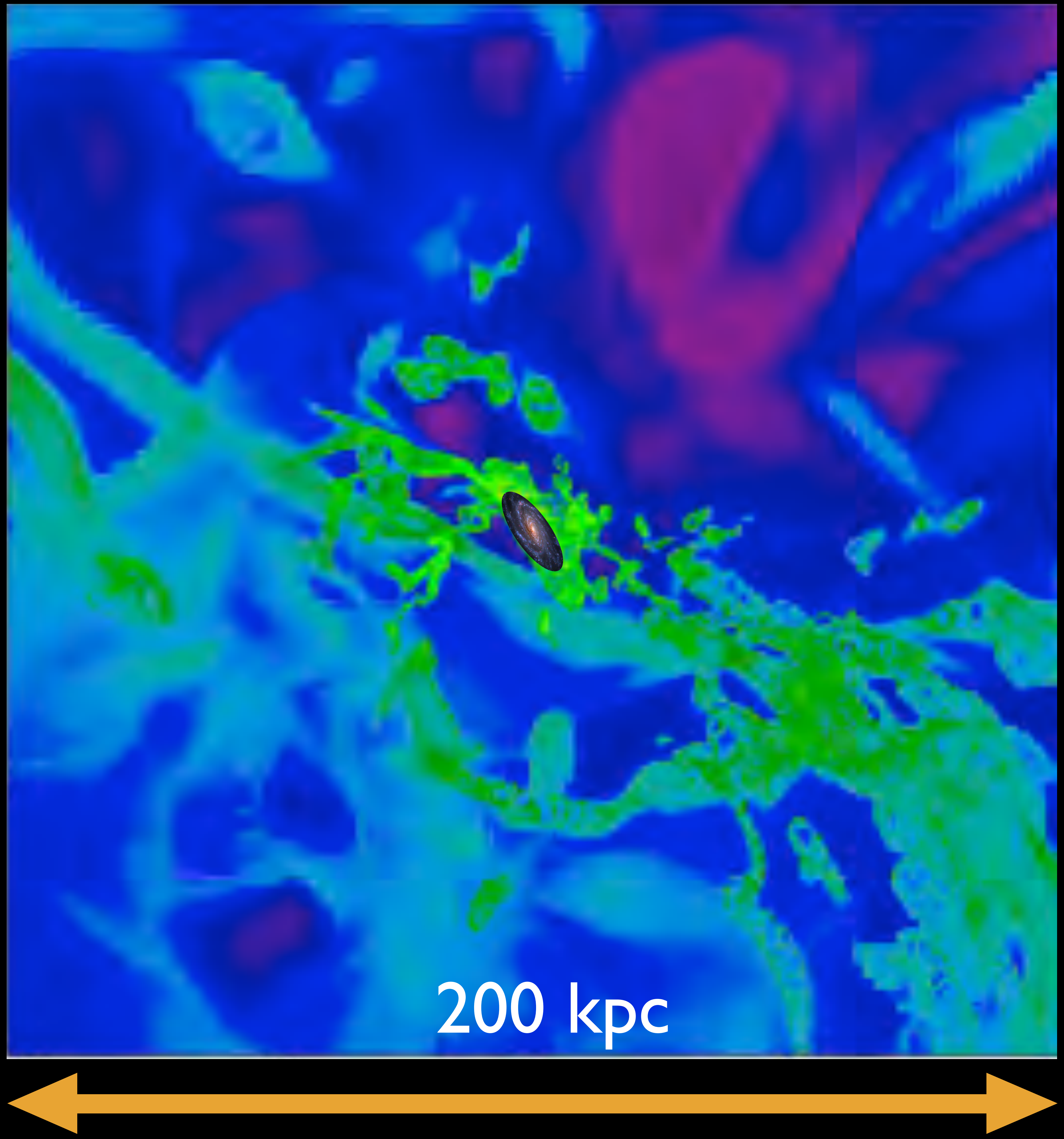


How Do Galaxies Acquire, Process, and Recycle Their Gas?	Epoch z < 1	Resolution 10-100 pc

Hubble's View



HDST's View

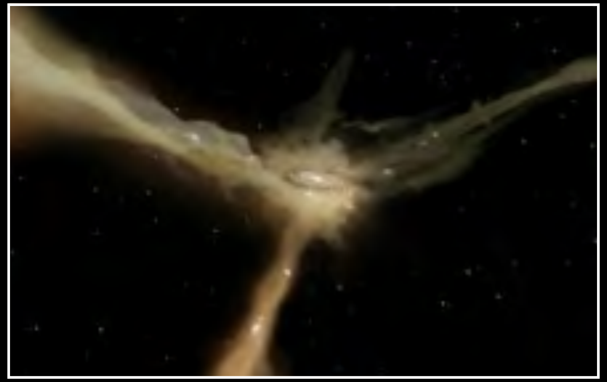


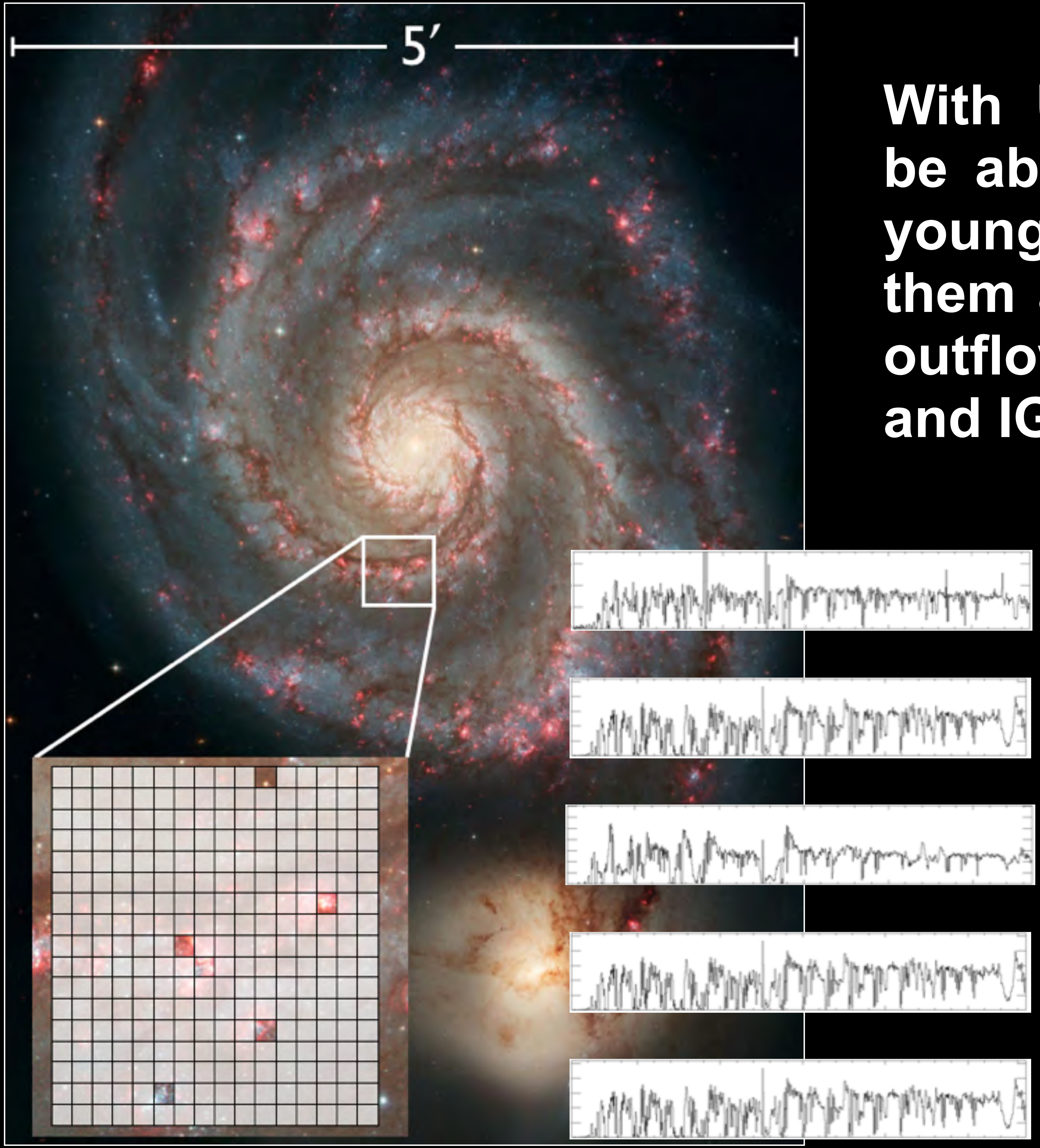
With unique <u>ultraviolet</u> sensitivity, HDST will map the gas feeding galaxies using the "faintest light in the Universe".
HDST would have 50 - 100x the sensitivity of HST in the UV.

How Do Galaxies Acquire, Process, and Recycle Their Gas?

Epoch
z < 1

Resolution
10-100 pc



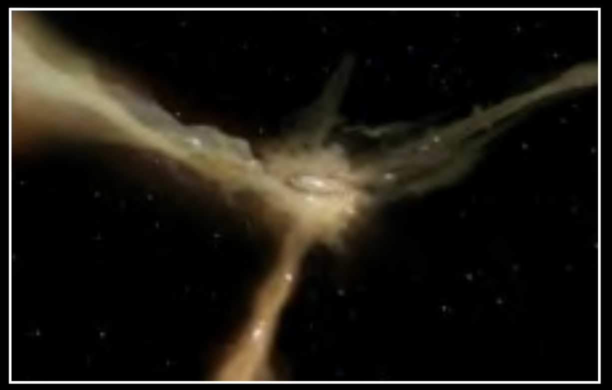


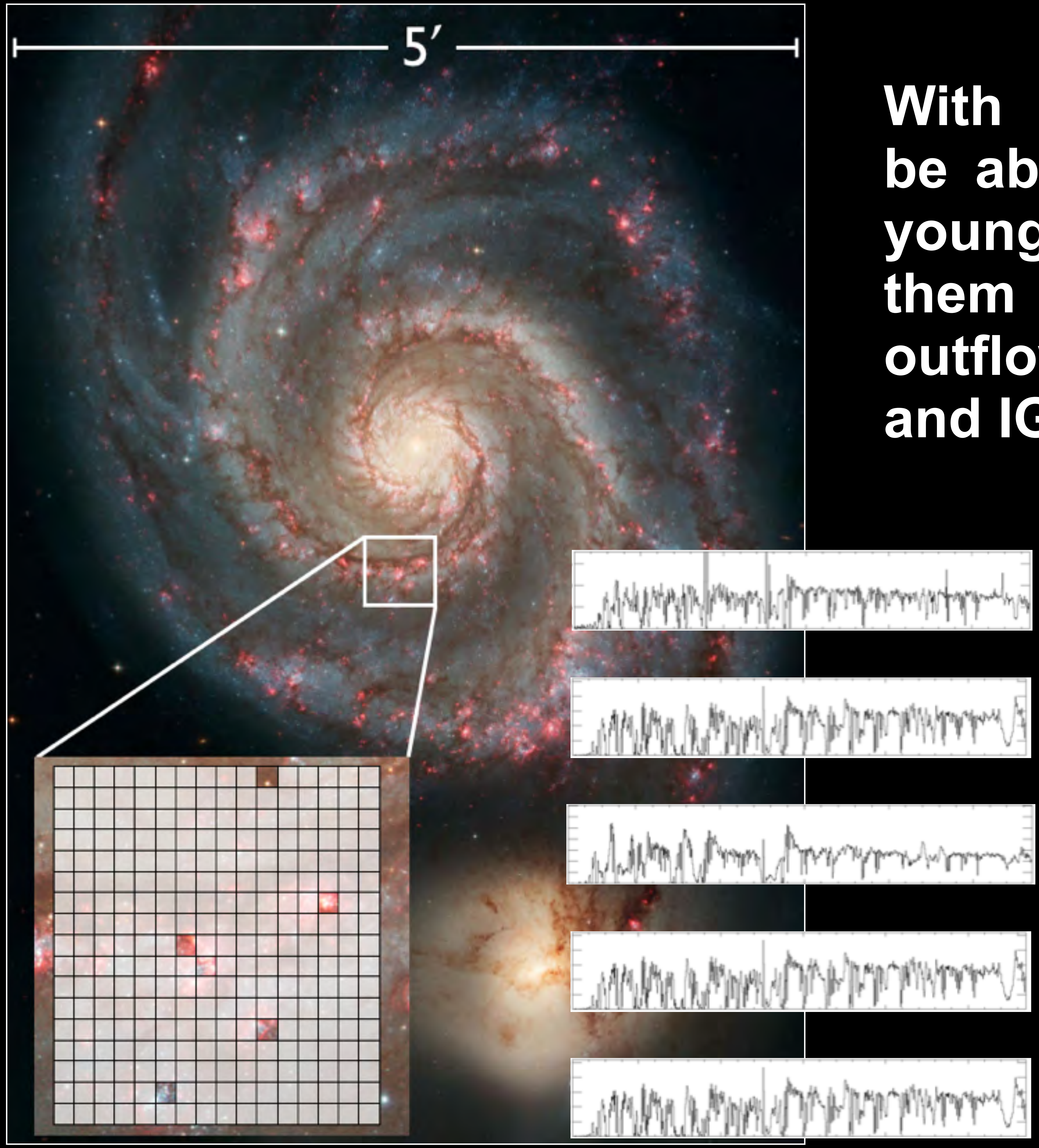
With UV multiplexing, HDST will be able to map the properties of young stellar clusters and, using them as background sources, the outflows they drive into the ISM and IGM.

How Do Galaxies Acquire, Process, and Recycle Their Gas?

Epoch
z < 1

Resolution
10-100 pc





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These problems **require** UV capability and 10 to 12 meter class aperture.

What is the Dark Matter? How Does Light Trace Mass? How Does Dark Mass Move?	Volume < 10 Mpc	Resolution 0.1 - 1 pc

Distance	Speed	Example	Goal
10 pc (nearest stars)	10 cm s 0.2 mph		planets
100 pc (nearest SF regions)	100 cm s 2.2 mph		planets in disks
10 kpc (entire MW disk)	0.1 km s 223 mph		dissipation of star clusters
100 kpc (MW halo)	1 km s 2200 mph		DM dynamics in dwarf sats.
1 Mpc (Local Group)	100 km s		3D motions of all LG galaxies
10 Mpc (Galactic Neighborhood)	500 km s		cluster dynamics

A 10-meter telescope can measure proper motions to ~ microarcsec / year precision over a ten-year baseline.

At this level, **virtually everything on the sky moves** - every star in the Milky Way and Local Group and every galaxy in the Galactic Neighborhood.

Aperture driver: A 10+ m is required to reach the motions of virtually ANY Milky Way star, the internal motions of Local Group satellites, and the motions of giant ellipticals in the Virgo cluster (~15 Mpc).

System driver: Extremely stable PSF and low-noise detectors are needed to centroid objects to a few thousandths of a pixel.

A Decade of Motion

Epoch 1

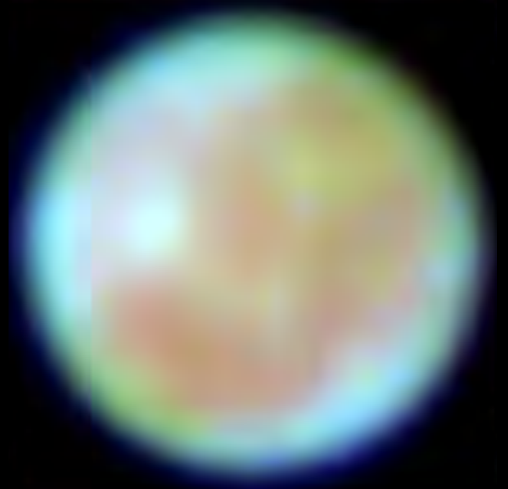
A Decade of Motion

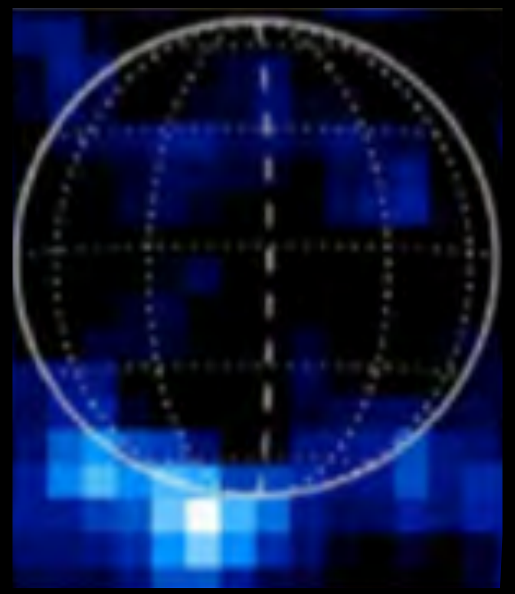
Epoch 2

What Are The Building Blocks of the Solar System Made Of?	Volume <50 AU	Resolution 20-250 km

Hubble

Geysers on Europa





Surface features on Pluto+Charon

Pluto

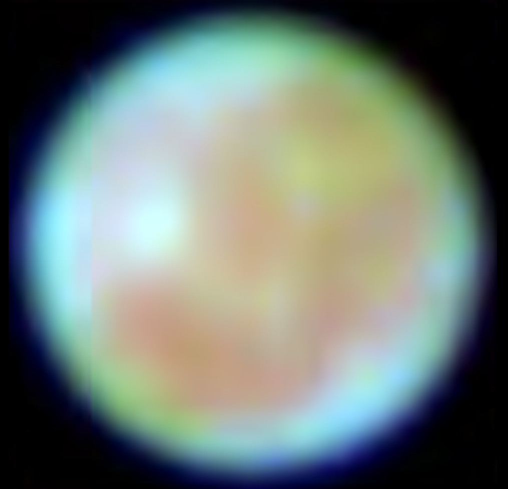
Charon

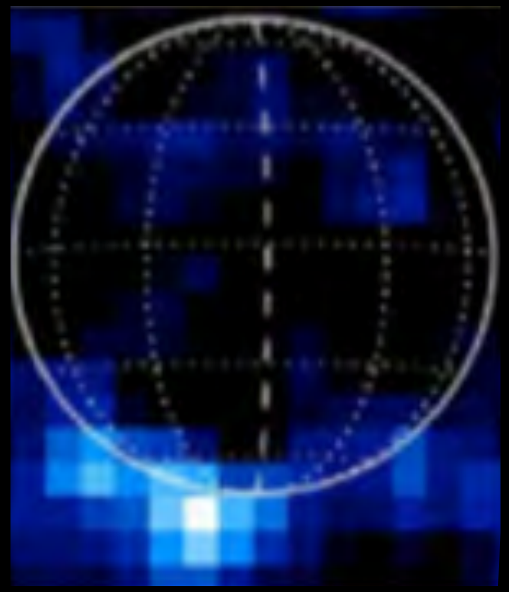
What Are The Building Blocks of the Solar System Made Of?	Volume <50 AU	Resolution 20-250 km

Geysers on Europa

Surface features on Pluto+Charon

Hubble

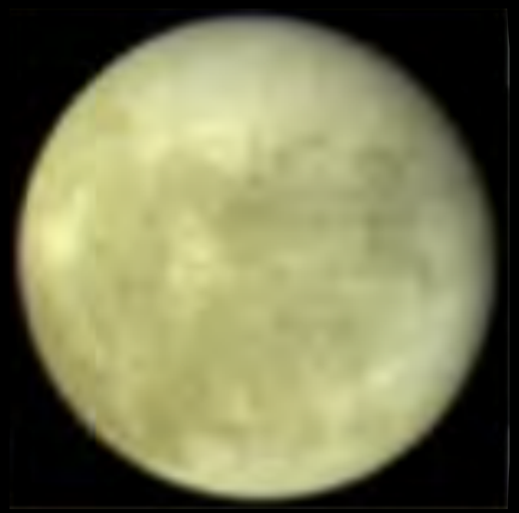




Pluto

Charon

HDST



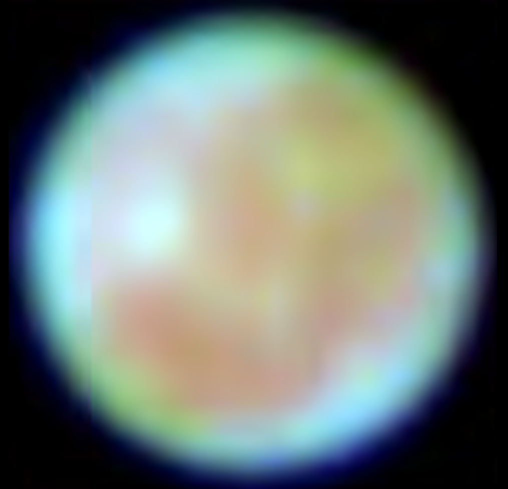
What Are The Building Blocks of the Solar System Made Of?

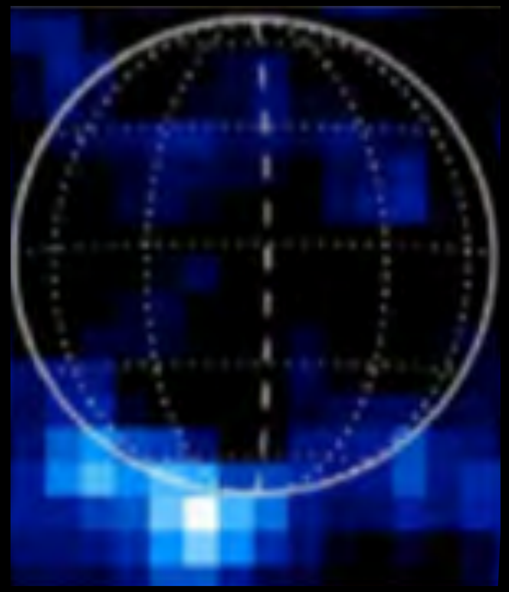
Volume
<50 AU

Resolution
20-250 km

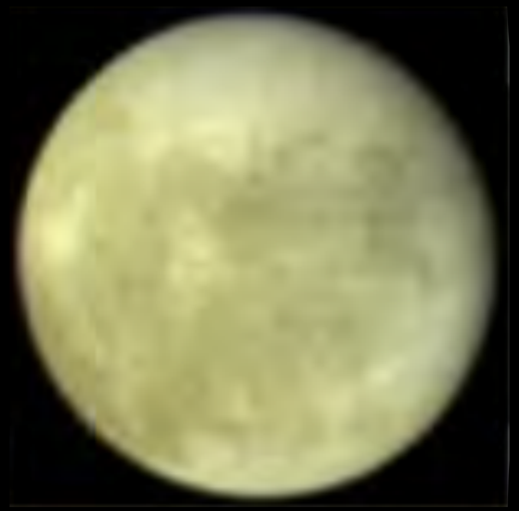
Geysers on Europa

Hubble





HDST



Surface features on Pluto+Charon

Pluto

Charon

New Horizons
Two weeks out

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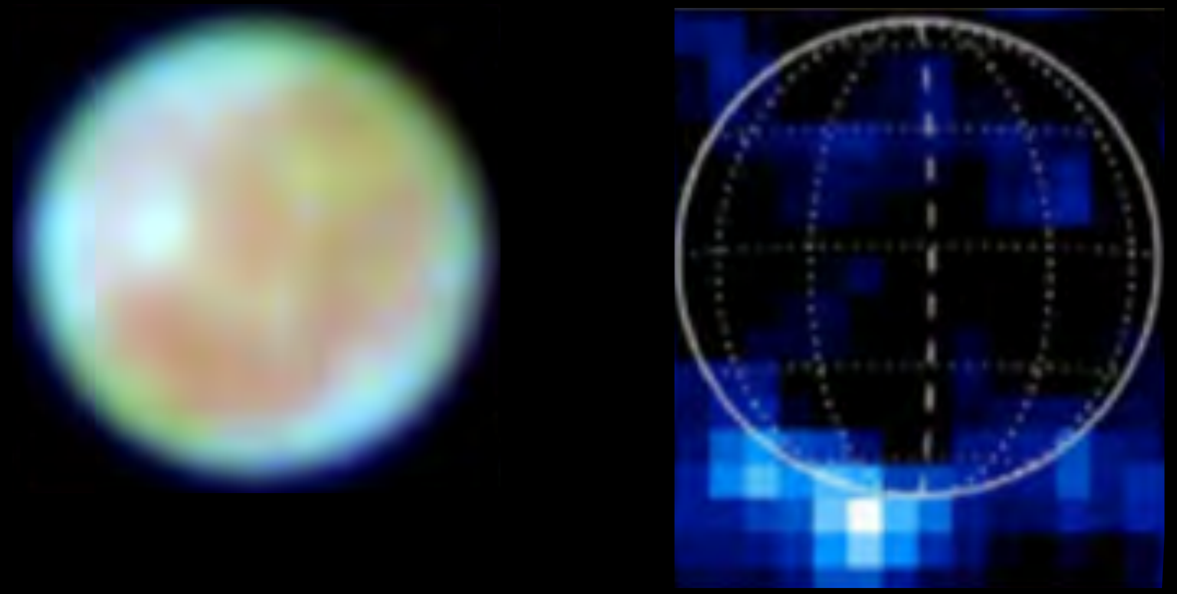
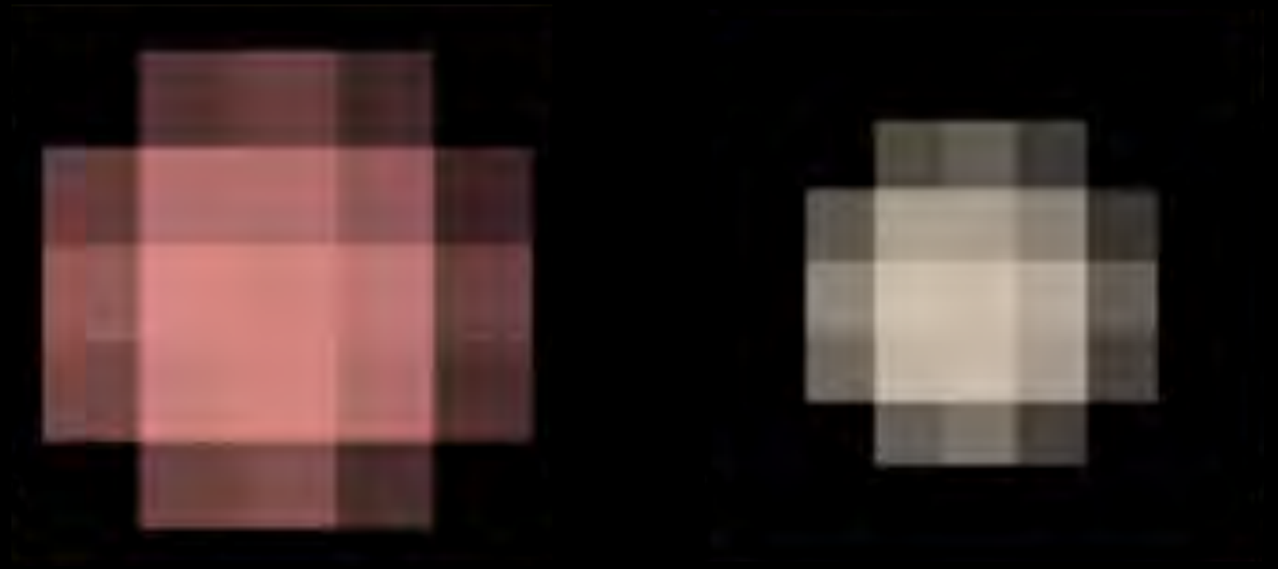
Geysers on Europa

Surface features on Pluto+Charon

Hubble

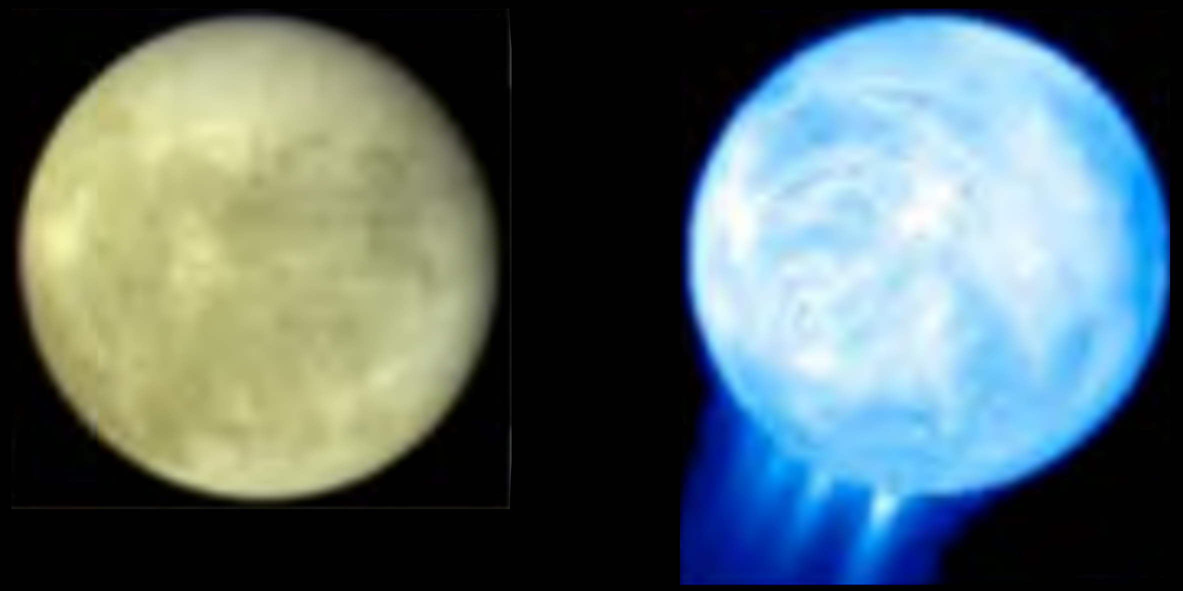


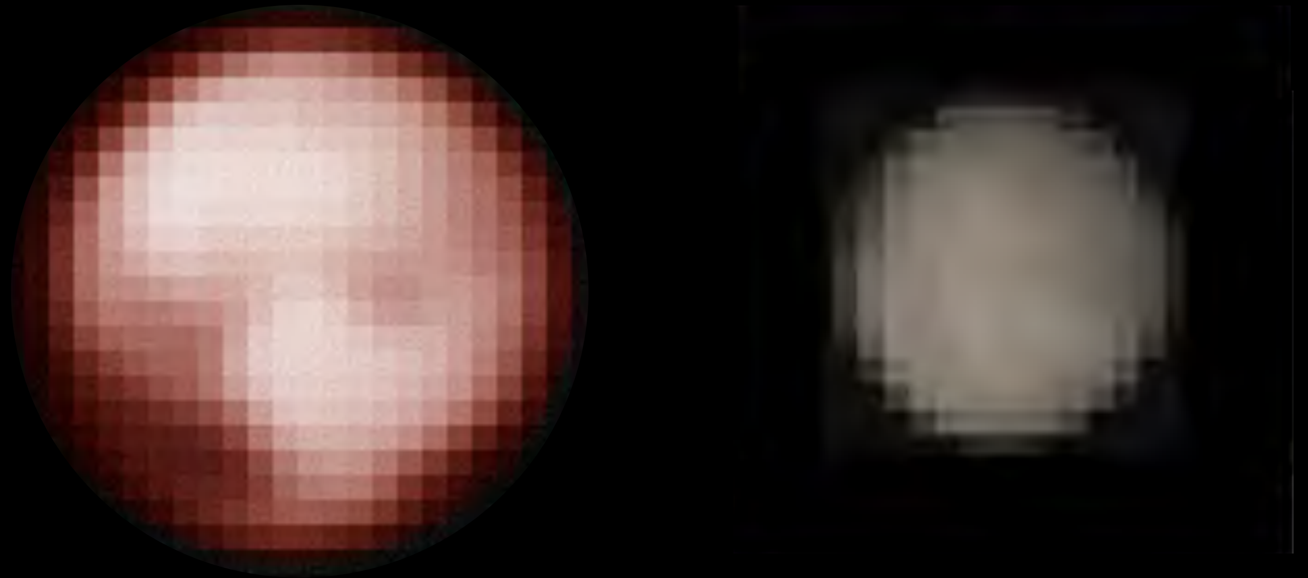


Pluto

Charon

HDST





What Are The Building Blocks of the Solar System Made Of?

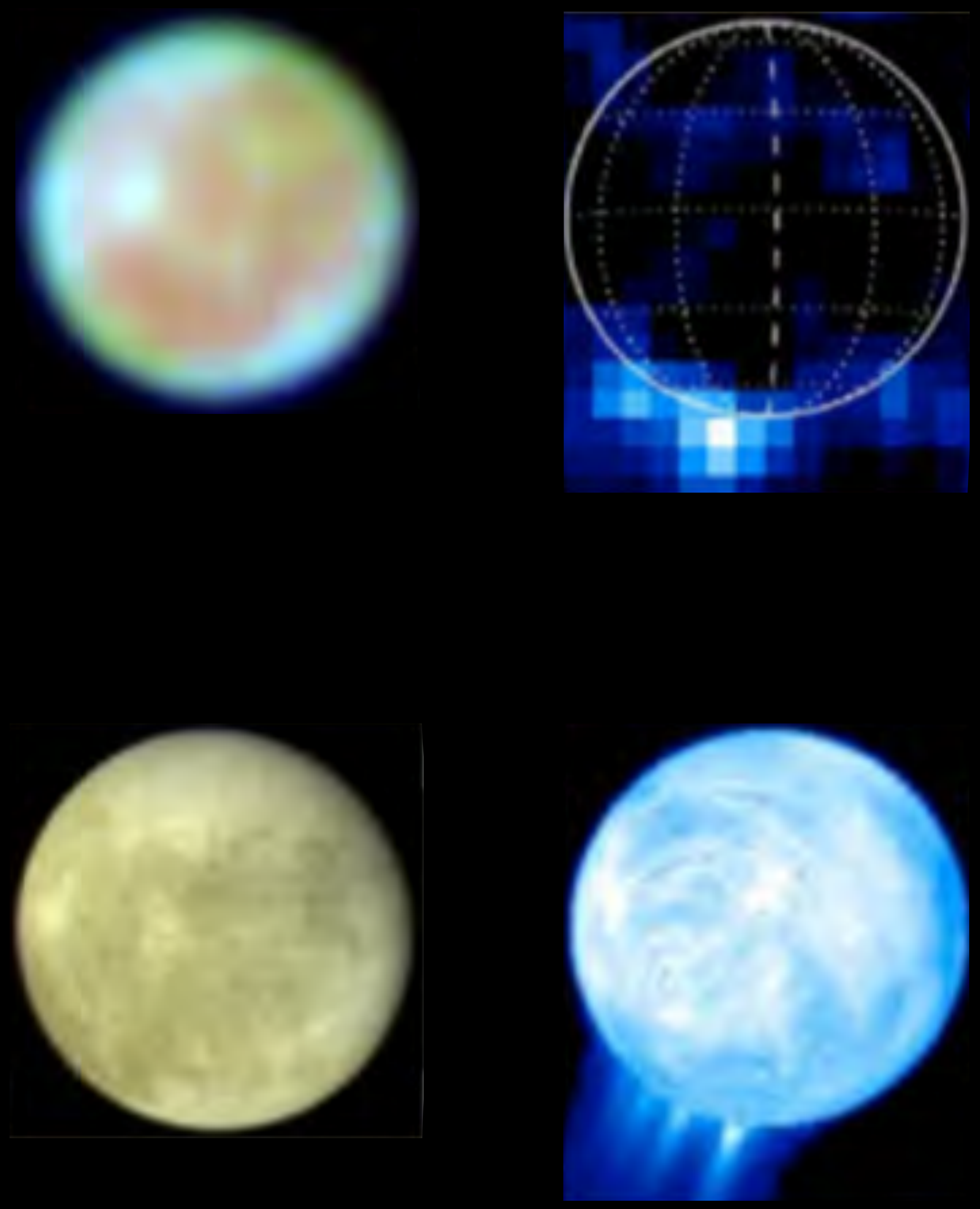
Volume <50 AU

Resolution 20-250 km

Geysers on Europa

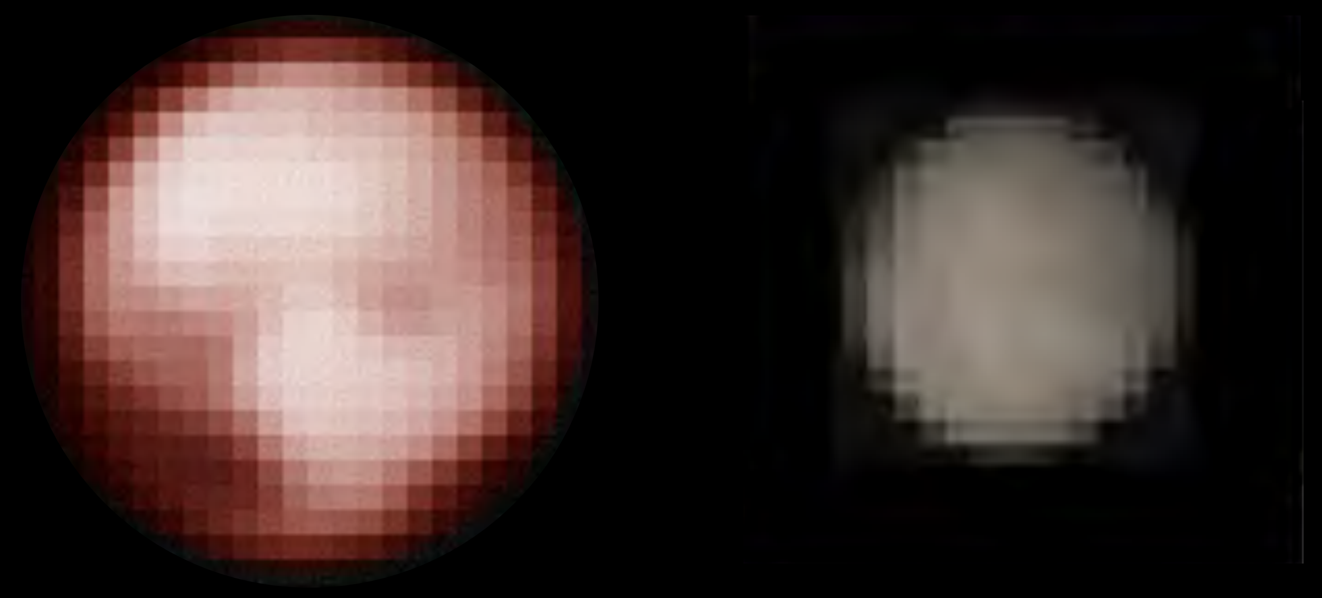
Hubble

HDST



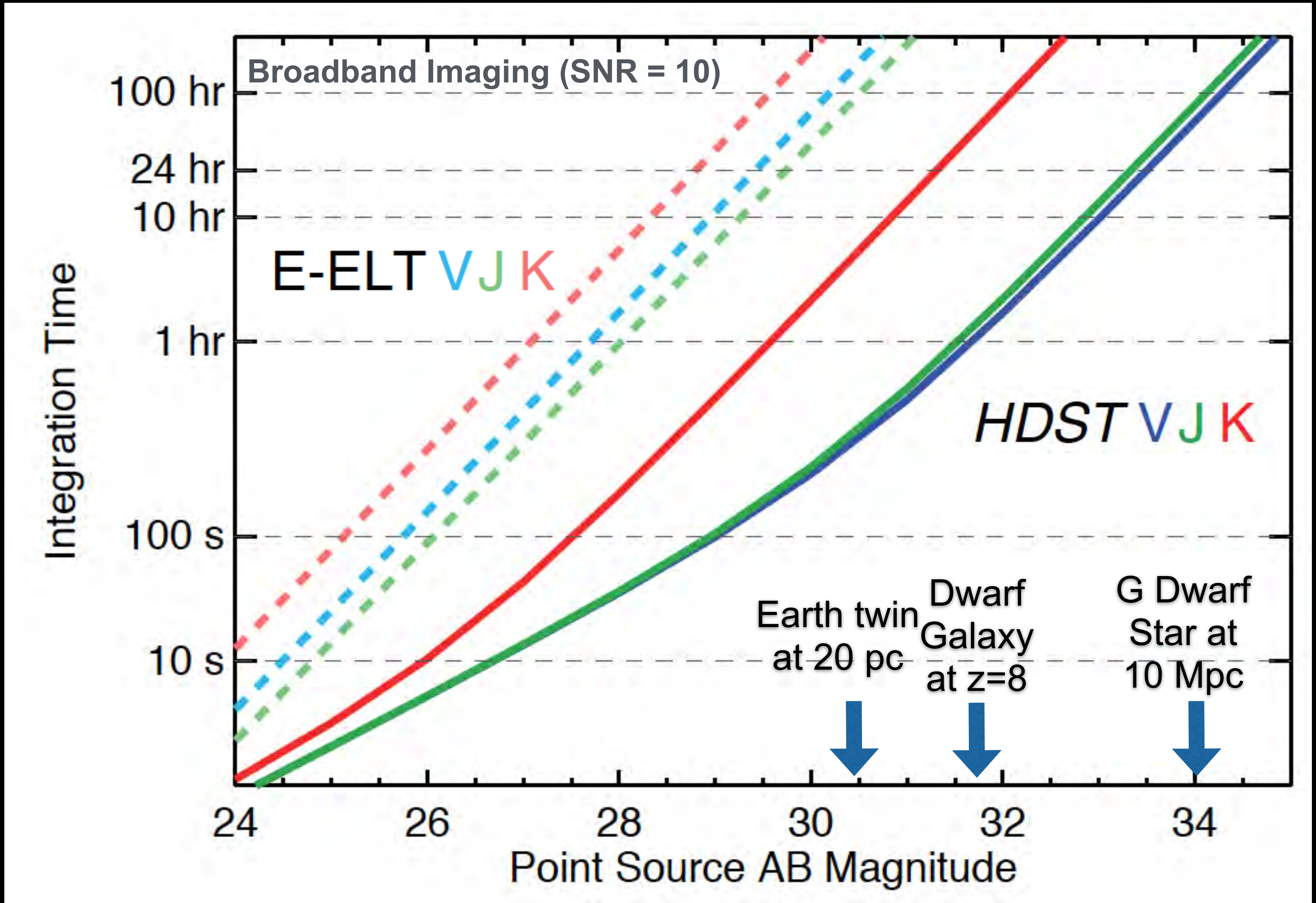
Surface features on Pluto+Charon

Pluto Charon

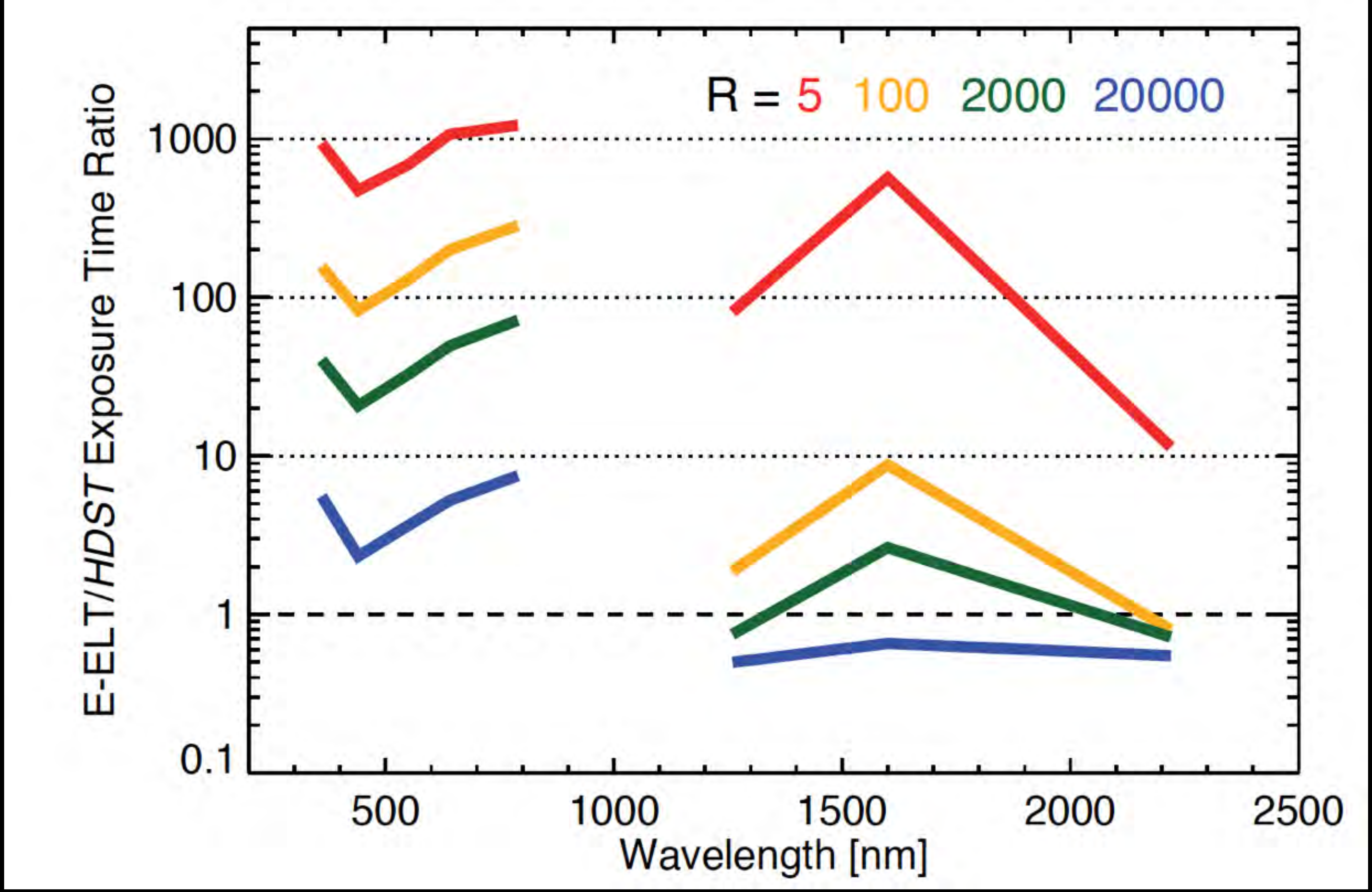


HDST, with its unique optical/UV capability, will open new avenues in Solar System research, <u>in partnership with future *in situ* space missions.</u>

HDST in Context: Synergy with Other Facilities



HDST in Context: Synergy with Other Facilities



What can a 12 meter class space telescope do for space astronomy?

. . . resolve every galaxy in the Universe to 100 parsec or better. at visible wavelengths . .

. . . detect virtually every star-forming galaxy at the epoch when the Milky Way formed. . .

. . . observe individual supernovae at the dawn of cosmic time. . .

. . . see the nearly invisible diffuse gas feeding galaxies. . .

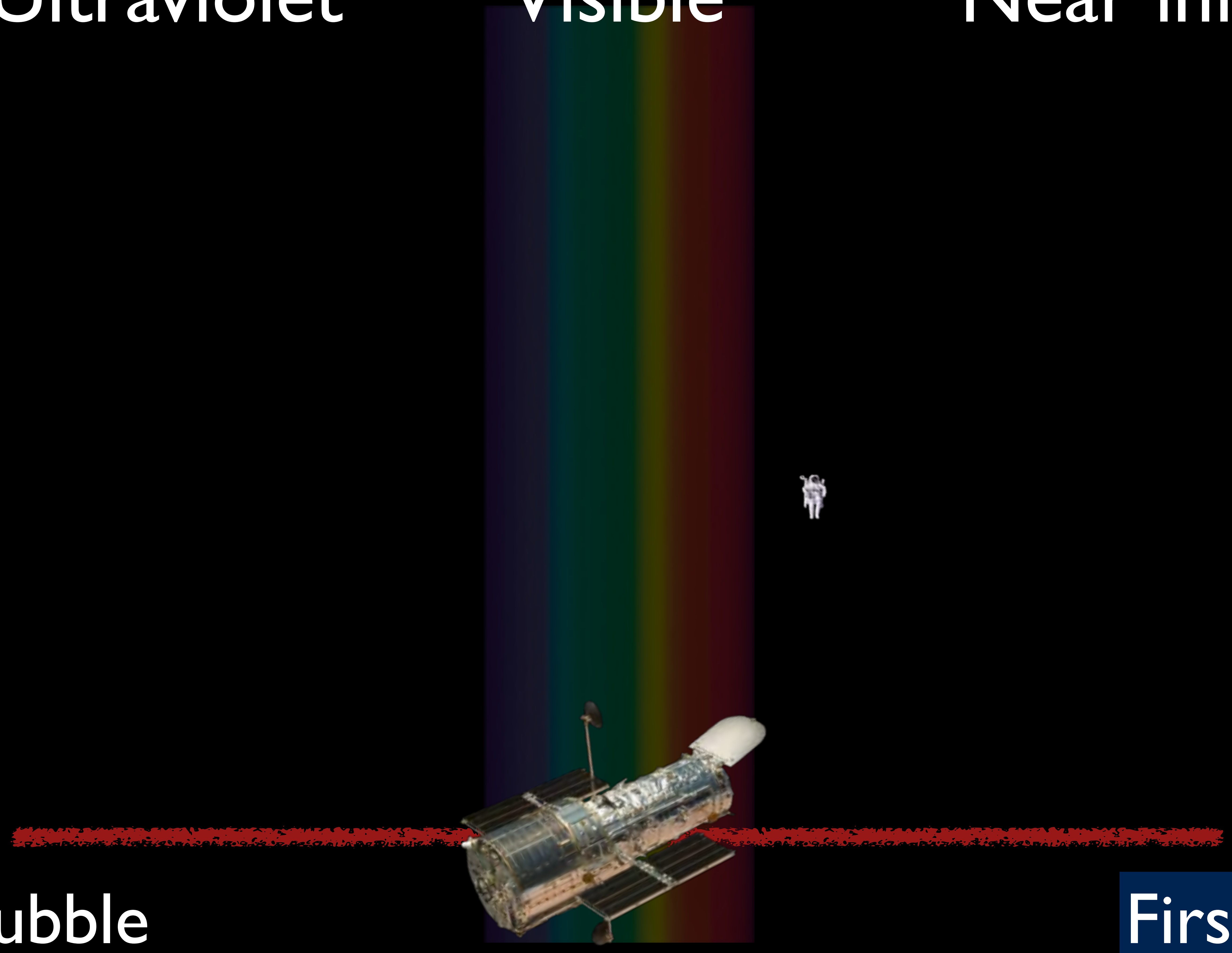
. . . watch the motion of virtually any star in the Local Group. . .

. . . observe objects the size of Manhattan at the orbit of Jupiter . . .

. . . which allows us to map the galactic, stellar, and planetary environments where life forms, and follow the chemical ingredients of life itself, over the 13.7 billion year history of the Universe.

Observatory Technology

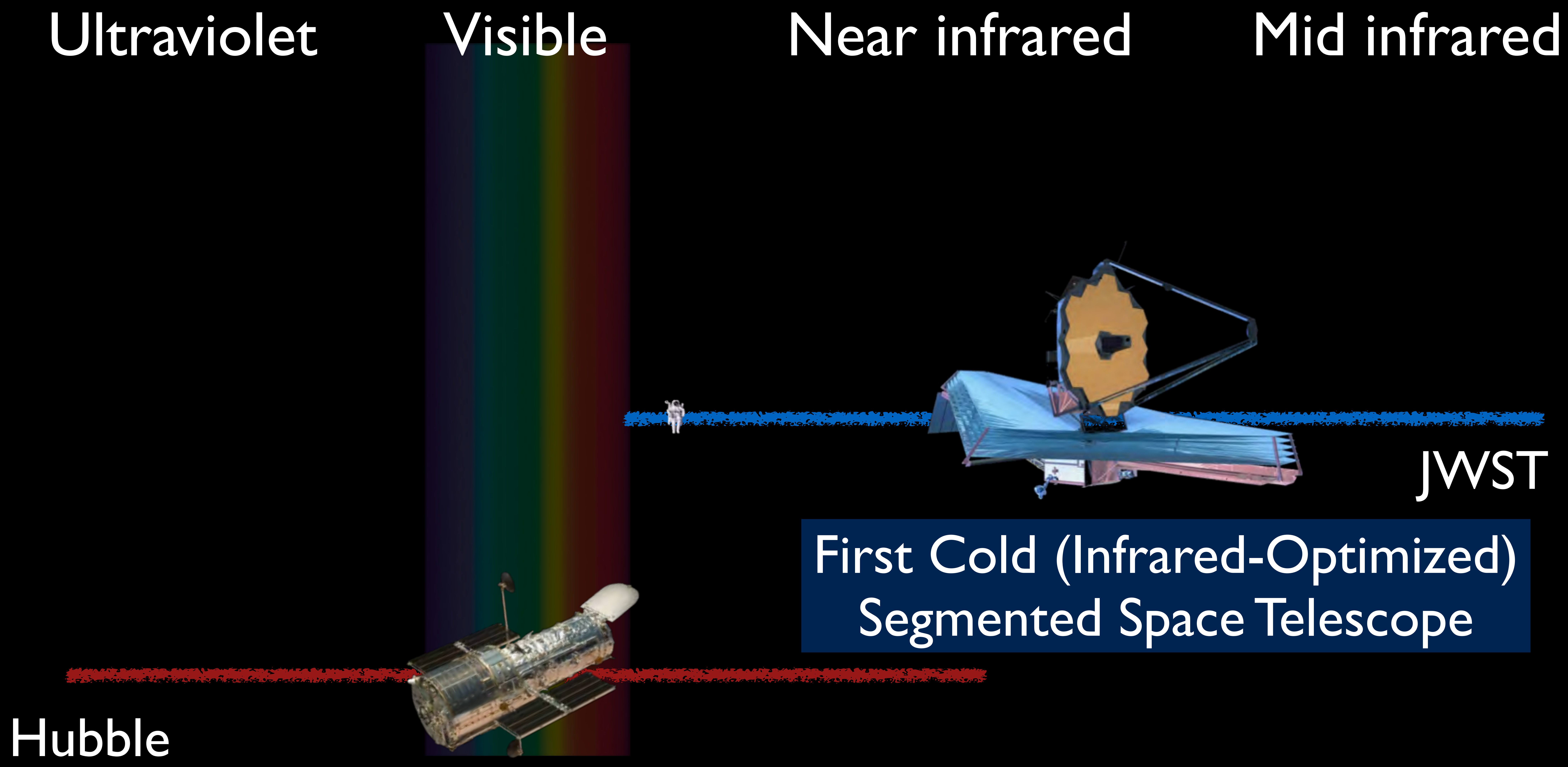
Ultraviolet | Visible | Near infrared | Mid infrared



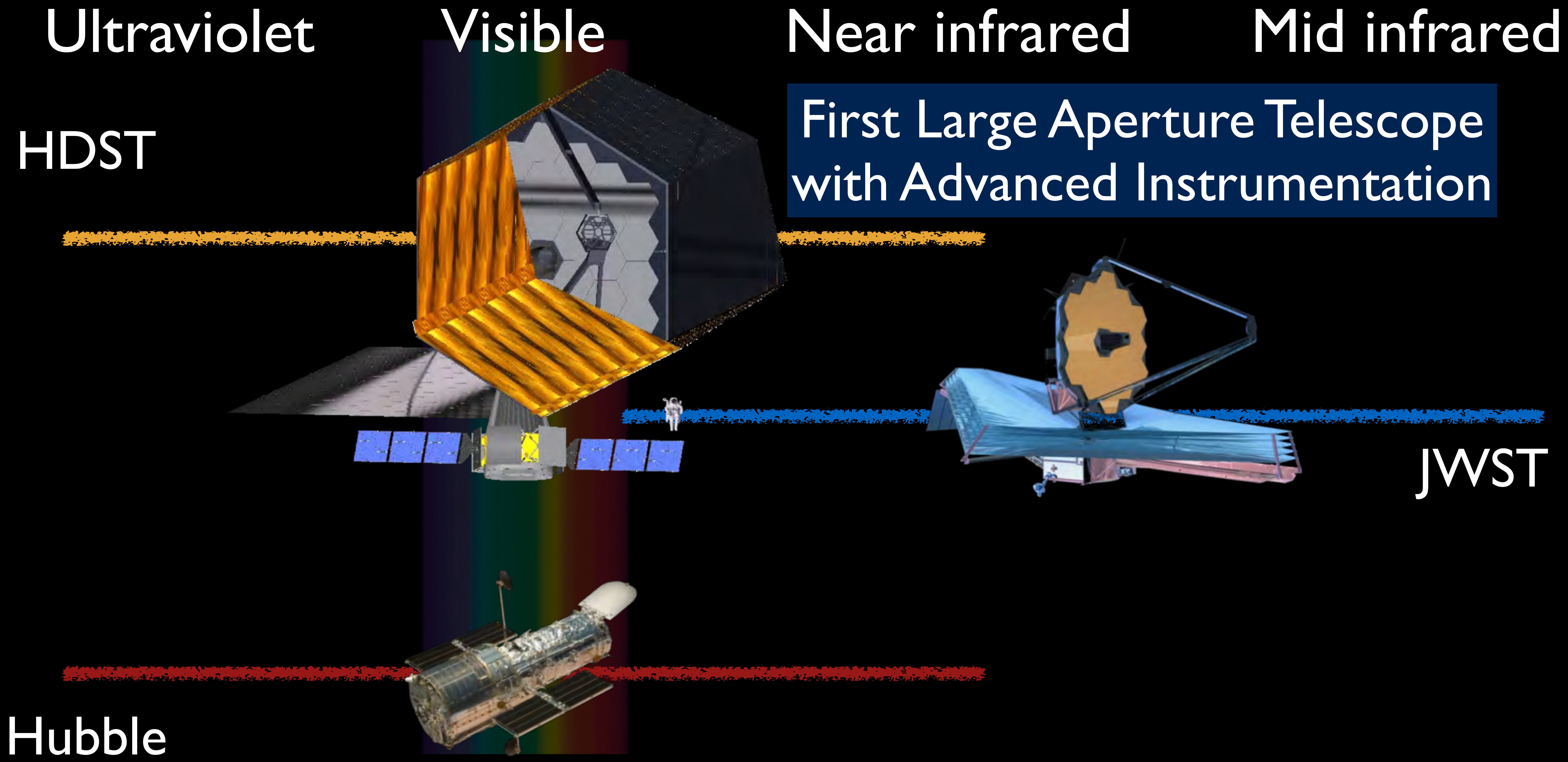
Hubble

First Large Space Telescope

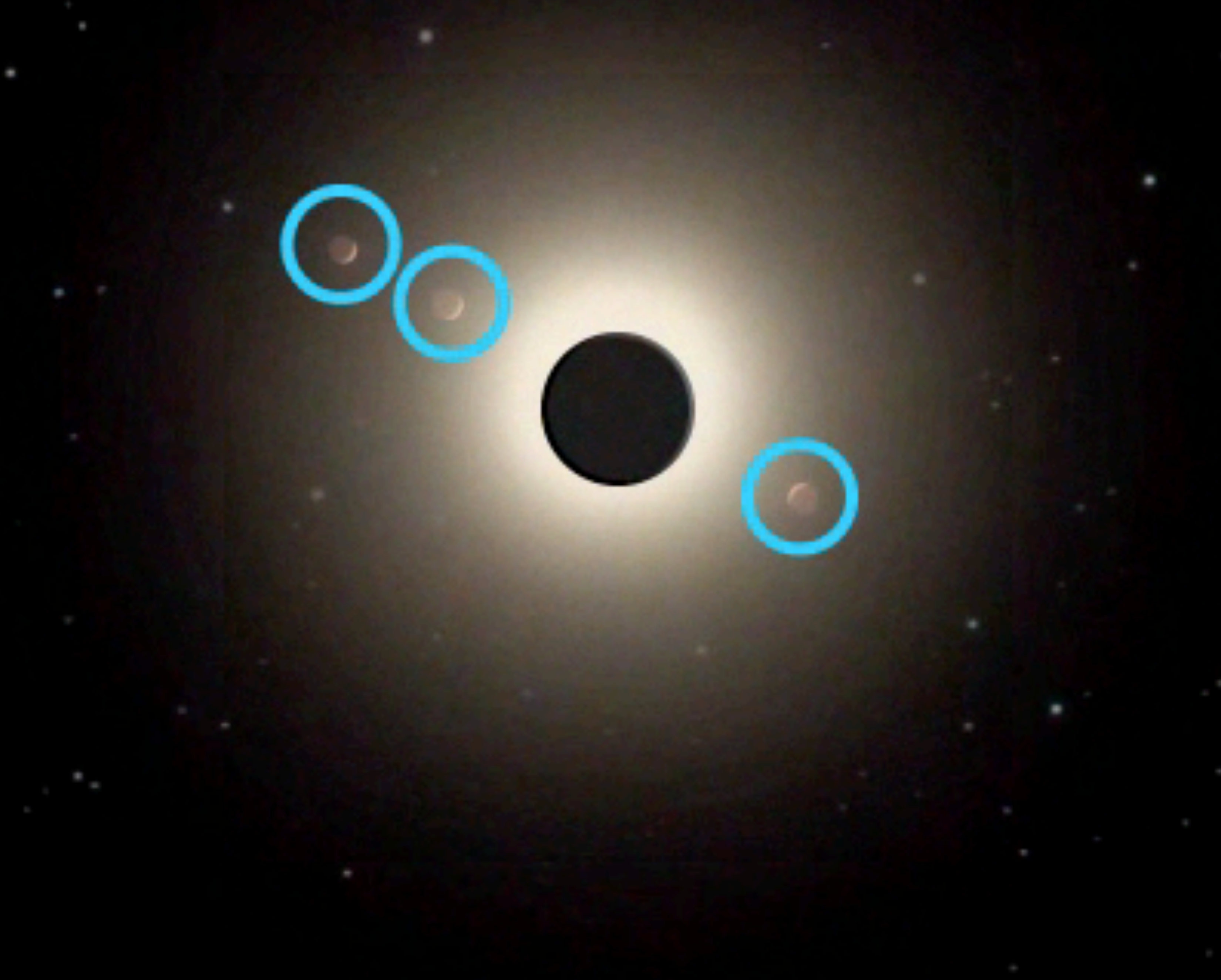
Observatory Technology



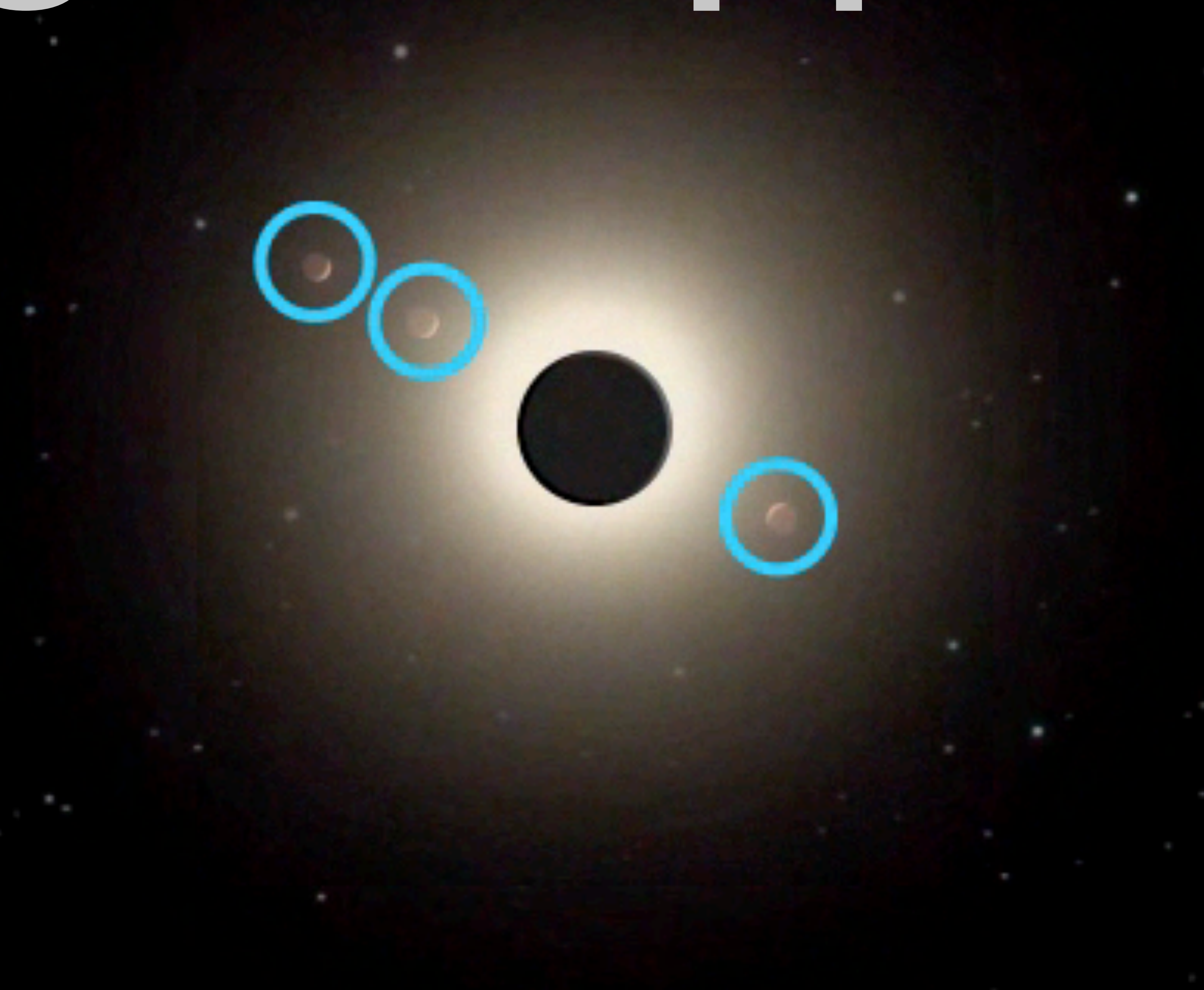
Observatory Technology



Advanced Instrumentation
Starlight Suppression



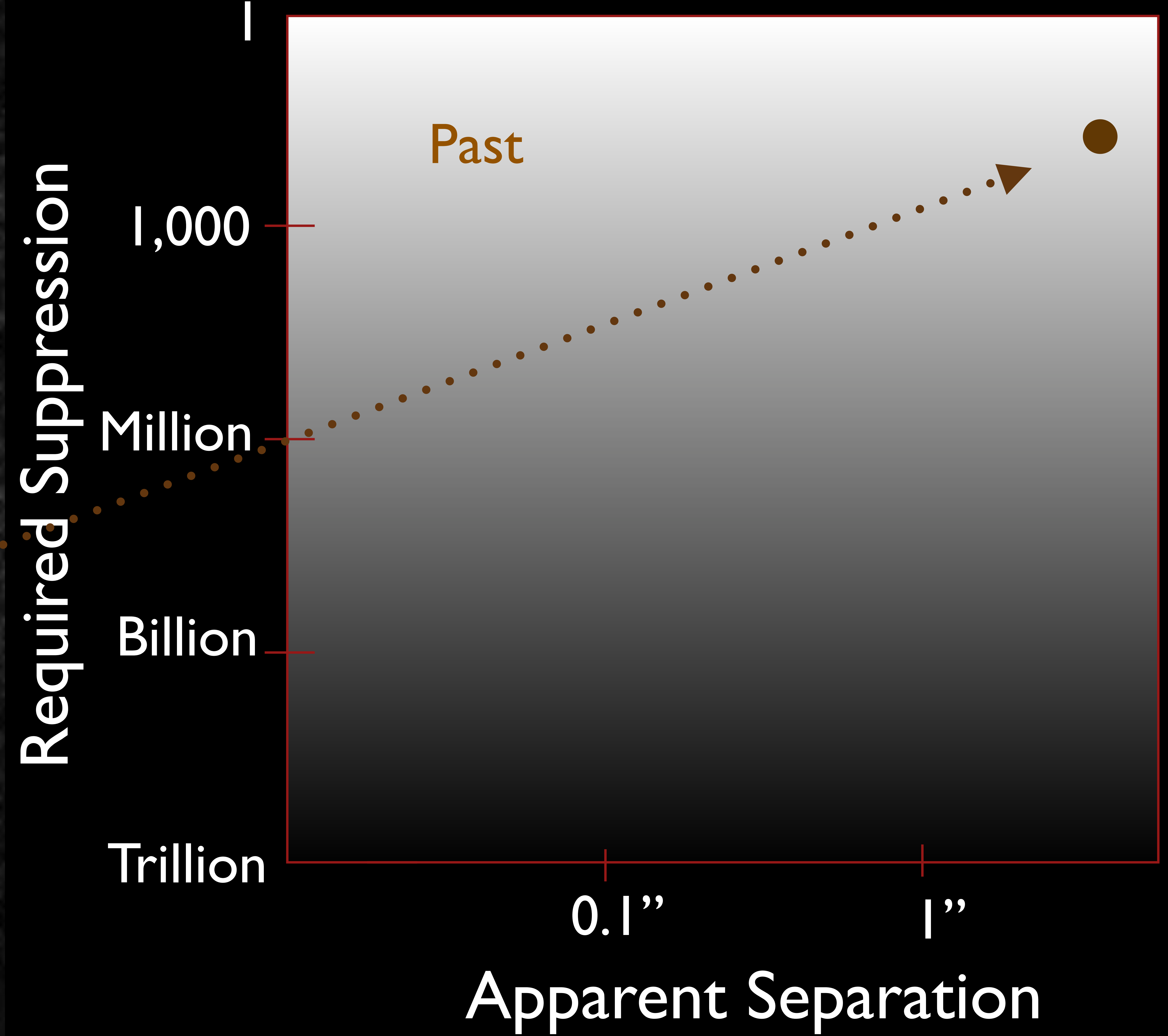
Advanced Instrumentation
Starlight Suppression

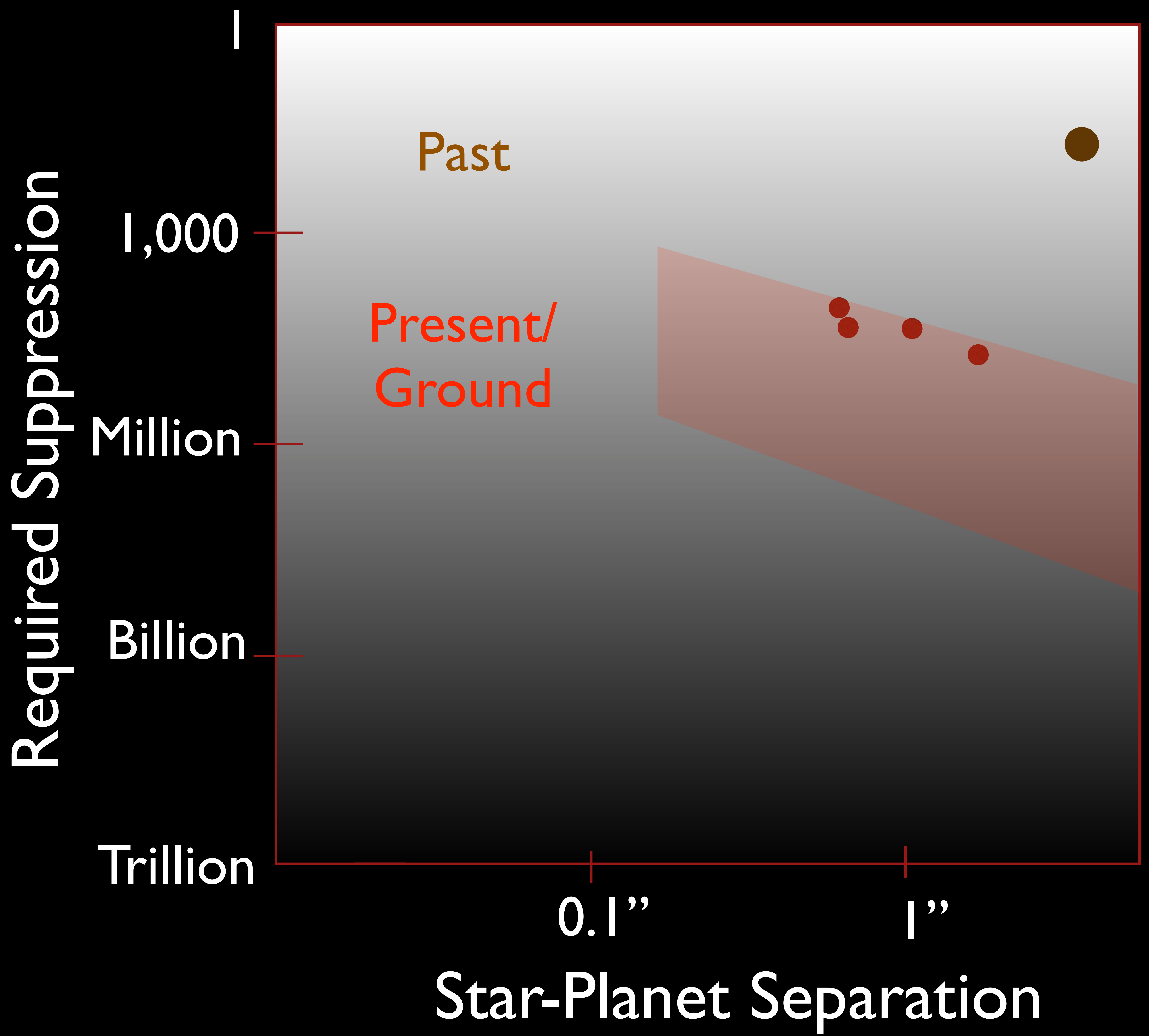


Advanced Instrumentation
Starlight Suppression

Starlight Suppression: Past

Image Credit: Nakajima, et al. (1995)





Required Suppression
1
1,000
Million
Billion
Trillion
Past
Present/
Ground
0.1"
1"
Star-Planet Separation

Starlight Suppression: Present

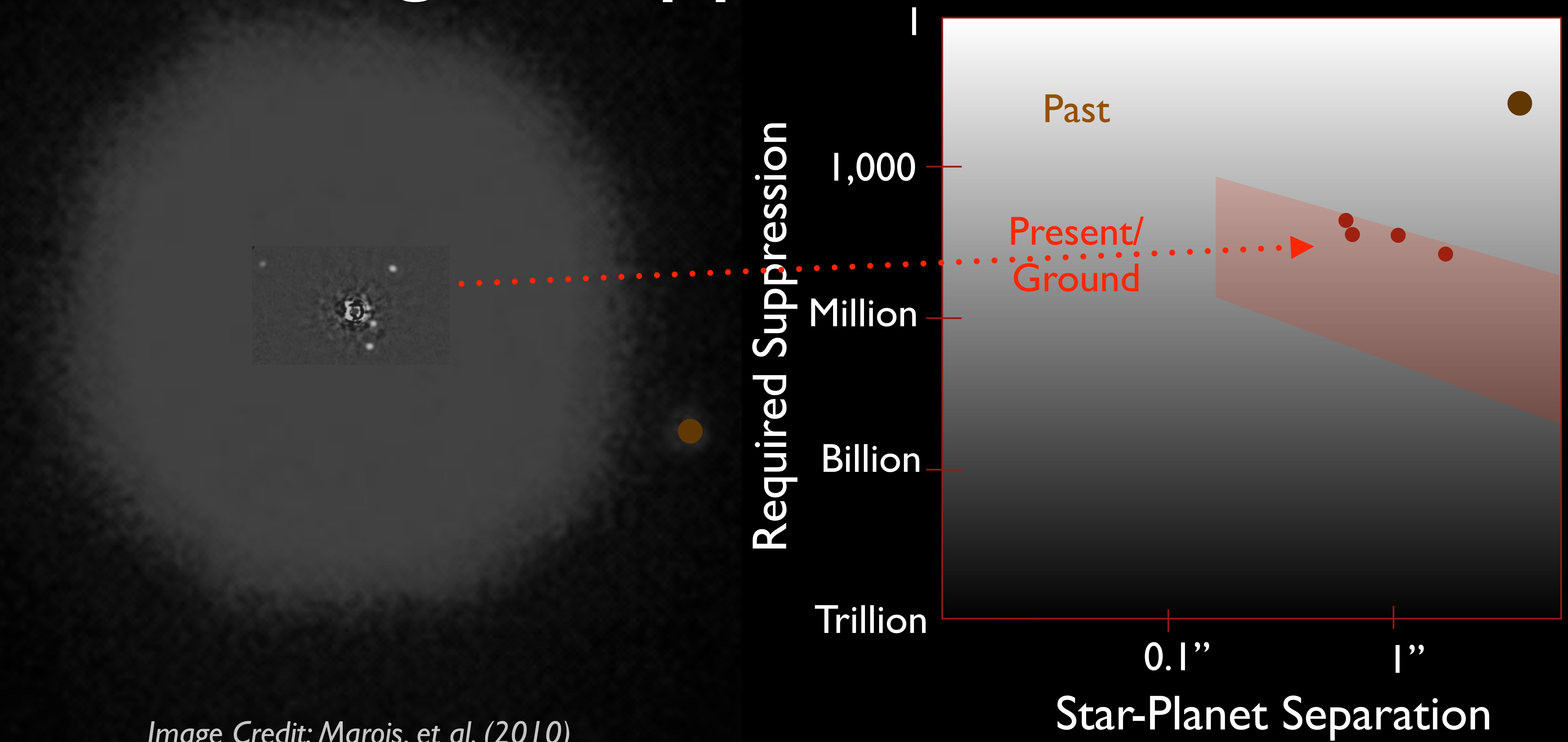
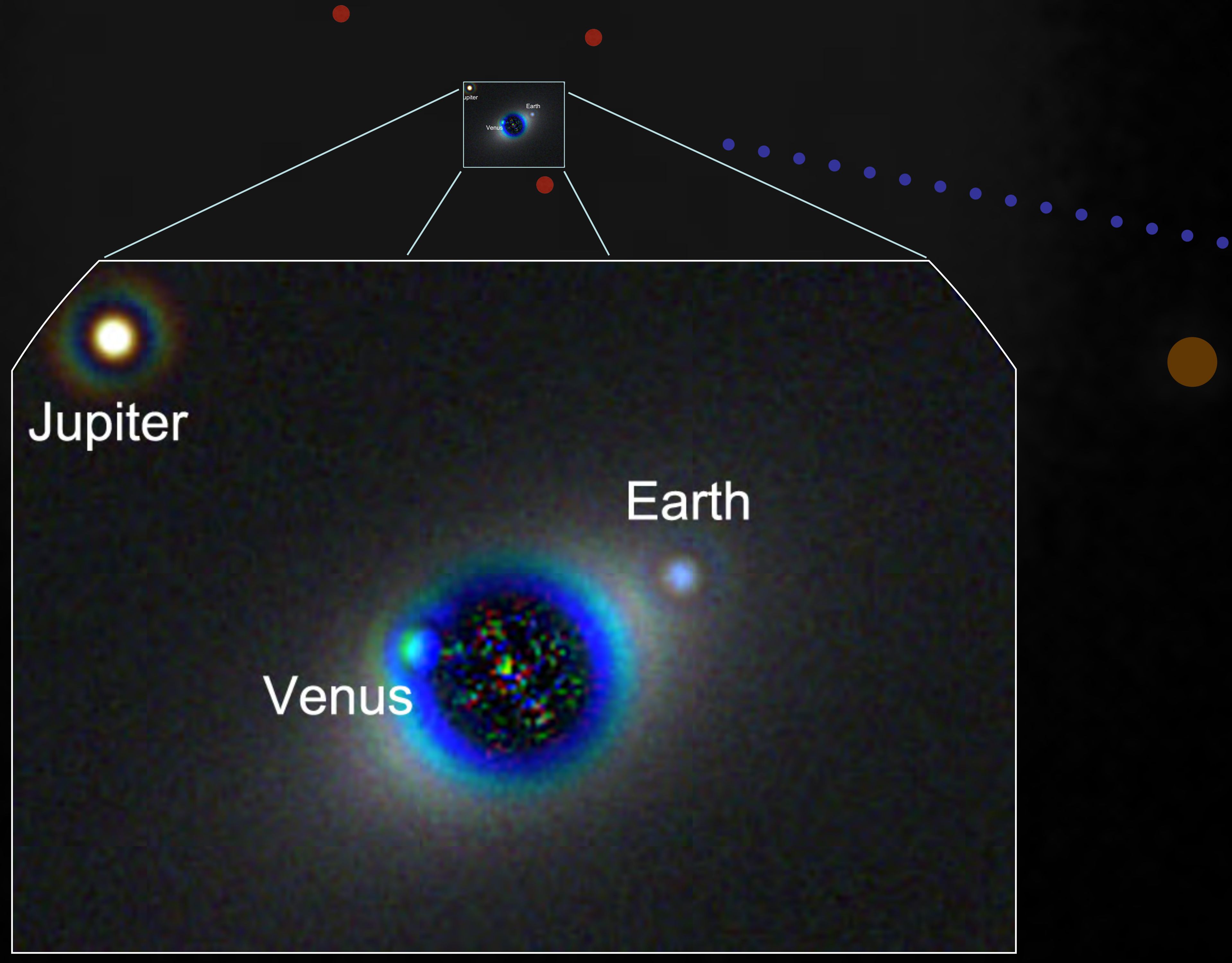
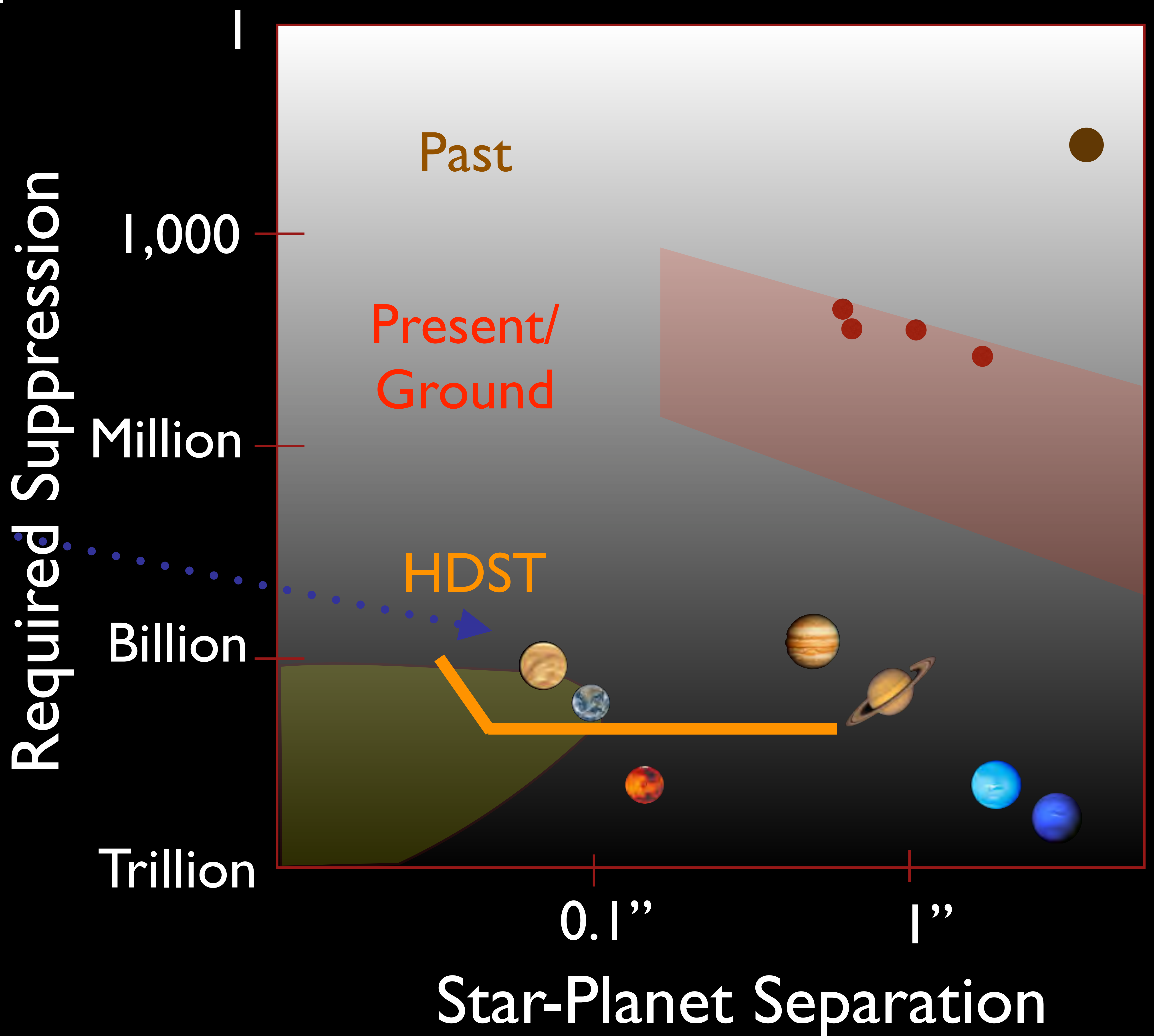


Image Credit: Marois, et al. (2010)


Required Suppression
1
1,000
Million
Billion
Trillion
Past
Present/
Ground
HDST
0.1"
1"
Star-Planet Separation

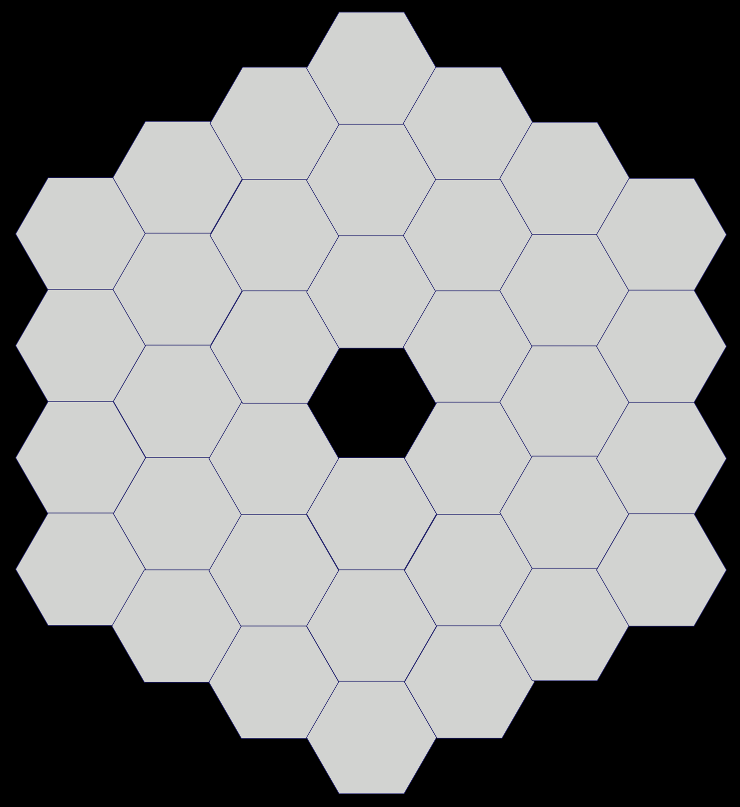
Starlight Suppression: Future

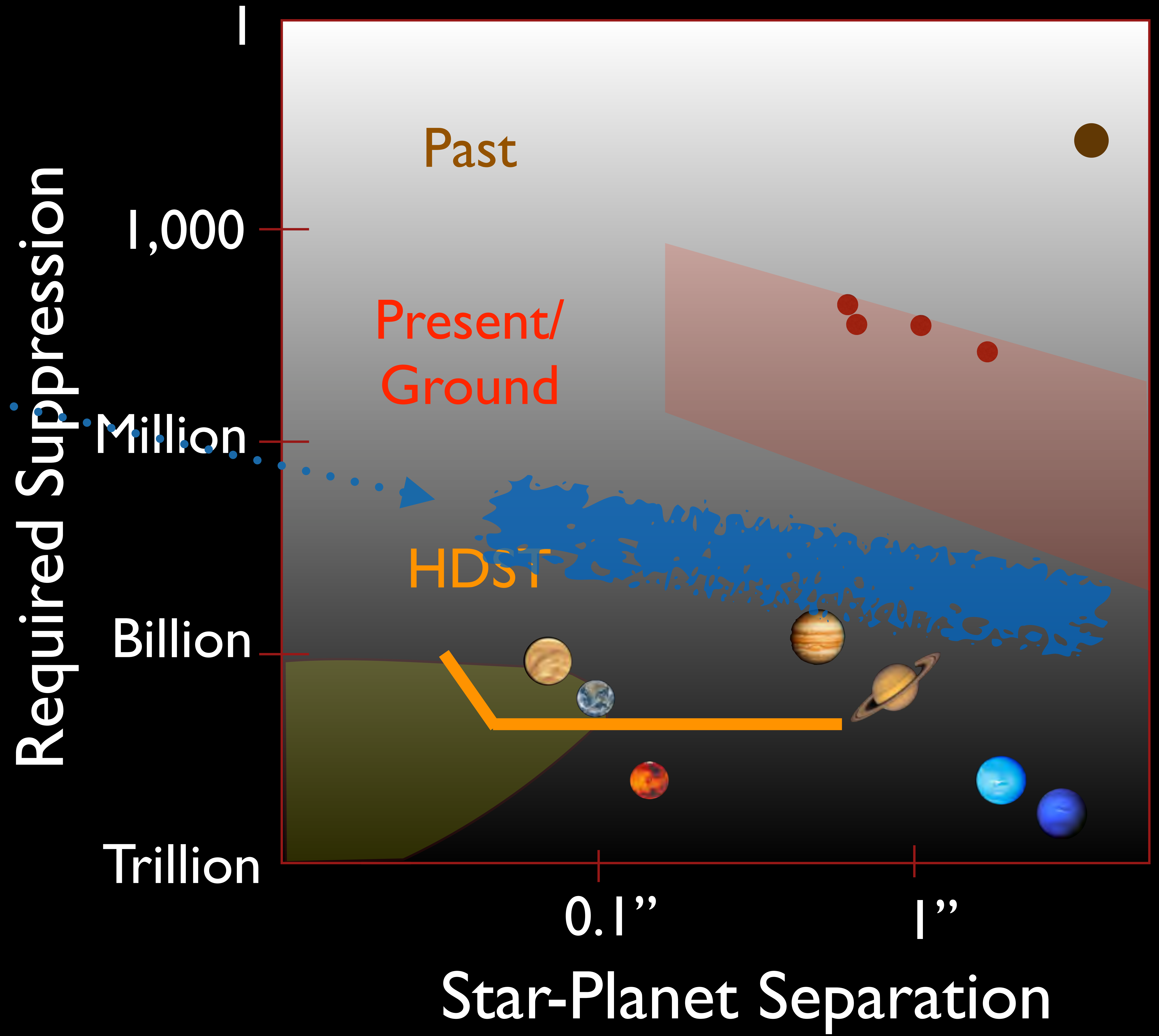




Starlight Suppression: Progress

HDST-Specific Designs for Segmented Mirrors





Starlight Suppression: Progress

HDST-Specific Designs
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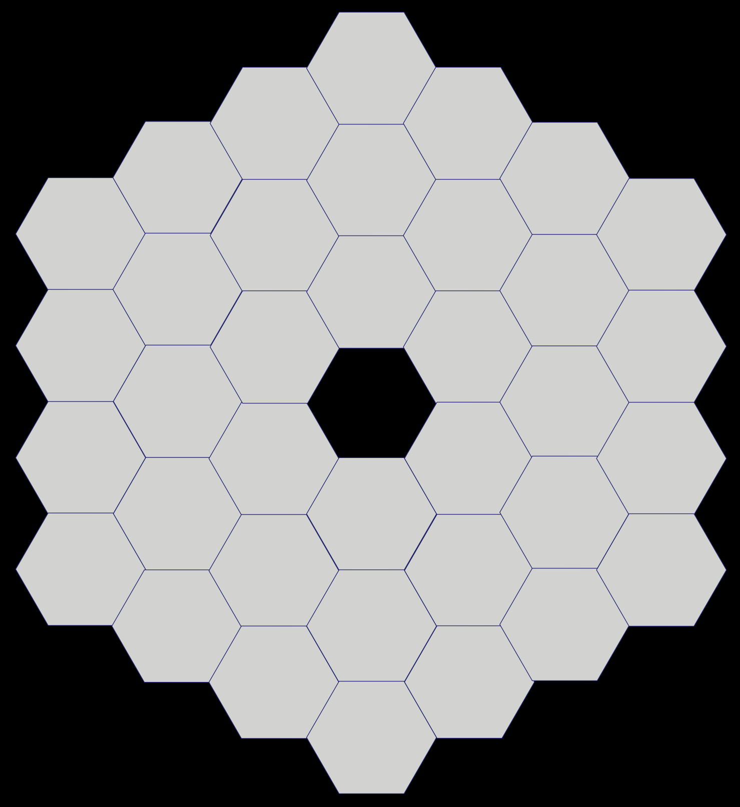
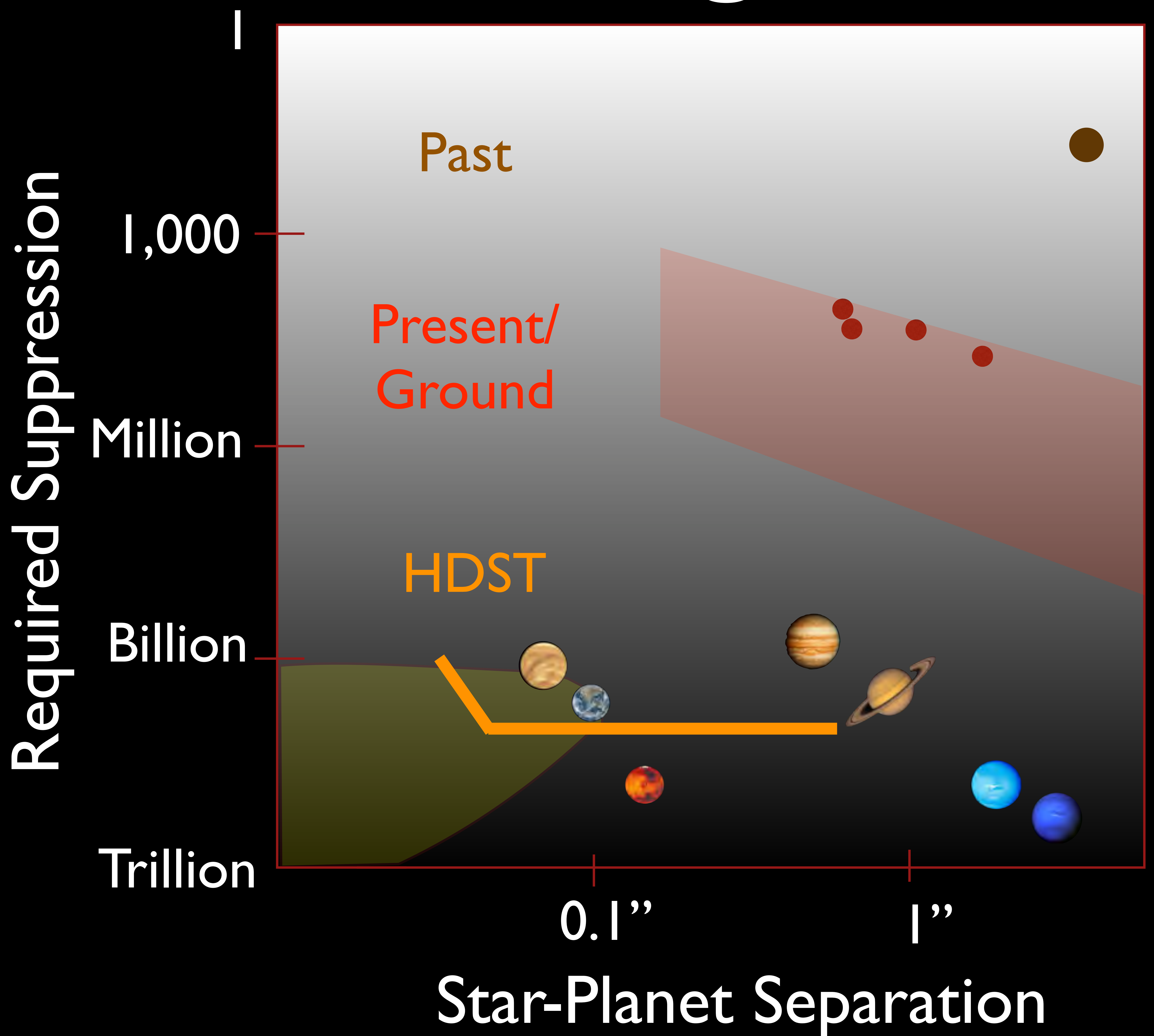




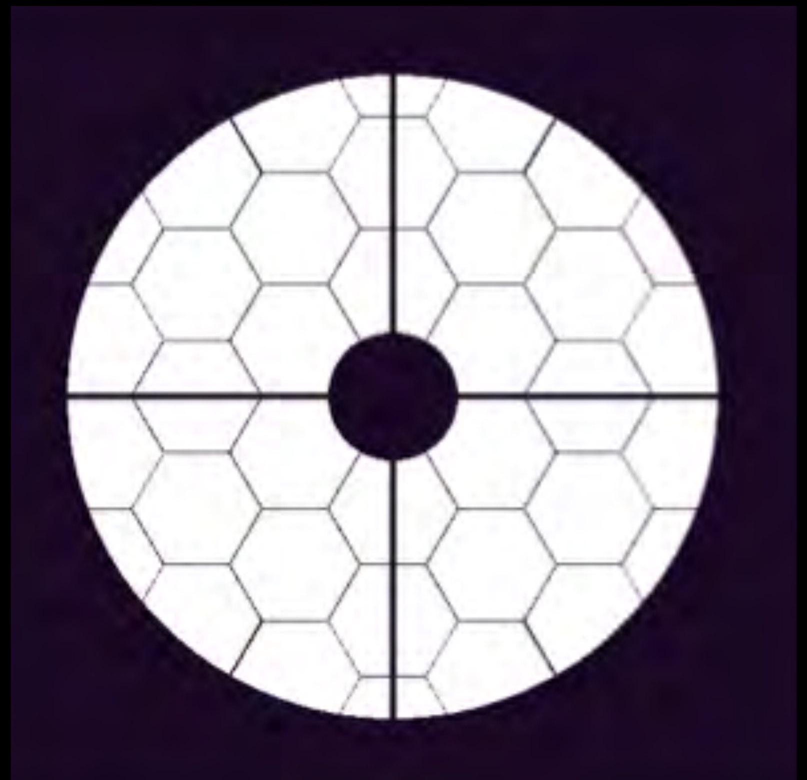
Starlight Suppression: Progress

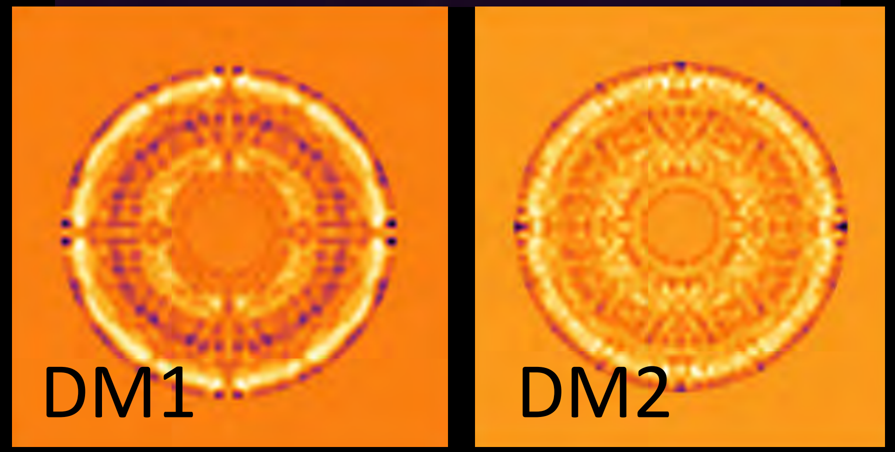
Recent research shows that segmented apertures can indeed be used for high contrast imaging

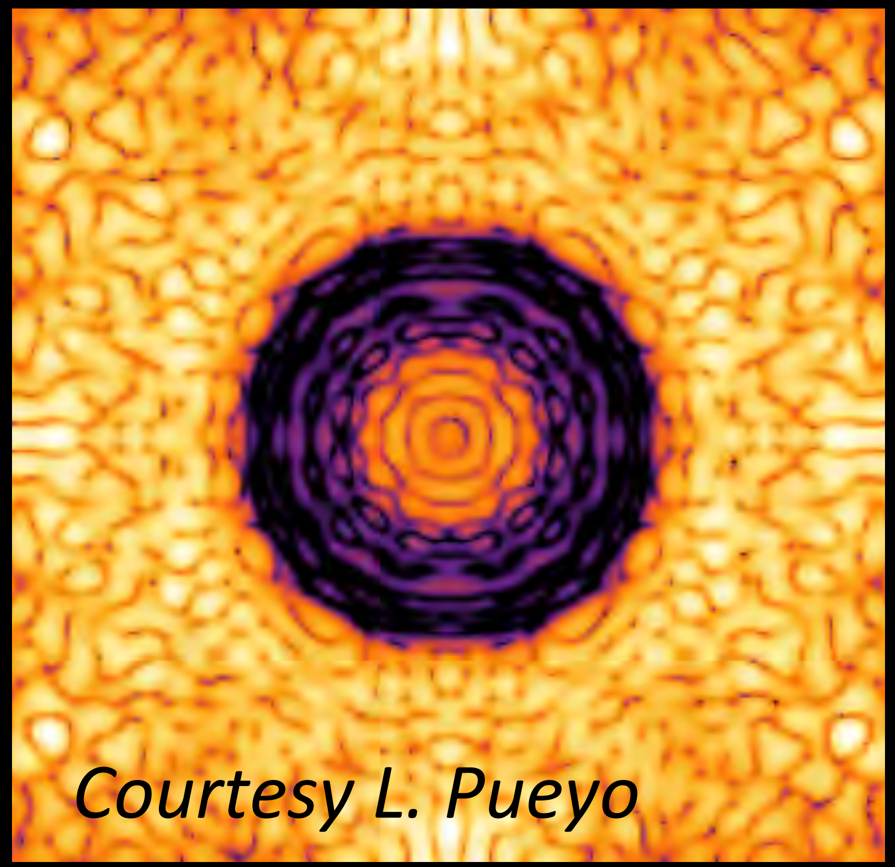
Starlight Suppression: Progress

Recent research shows that segmented apertures can indeed be used for high contrast imaging

Wavefront control can significantly reduce residual segment diffraction







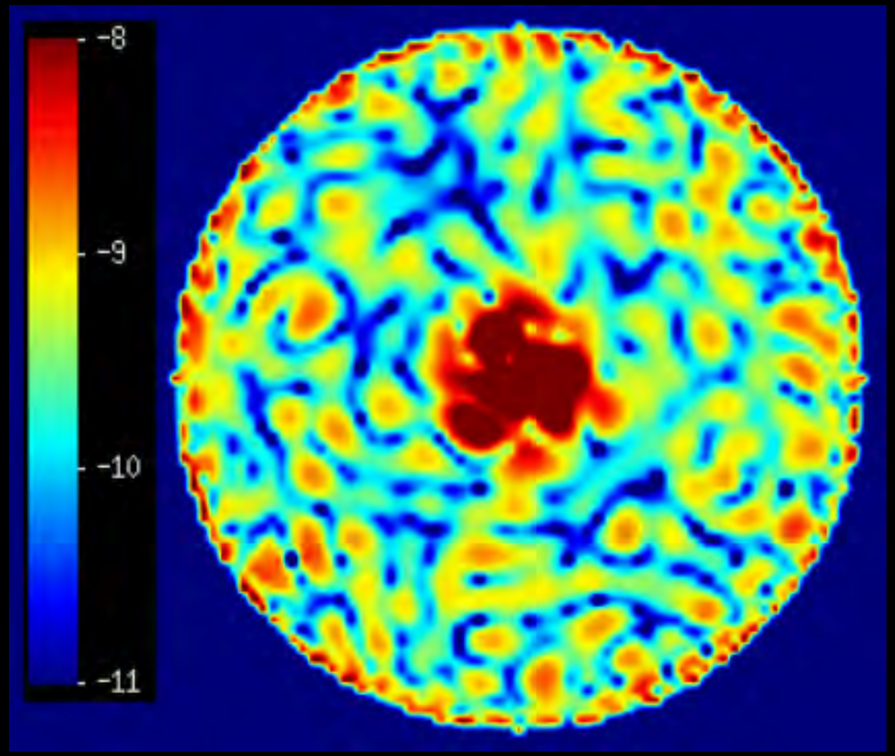
Starlight Suppression: Progress

Recent research shows that segmented apertures can indeed be used for high contrast imaging

Wavefront control can significantly reduce residual segment diffraction

WFIRST AFTA success story:
Combining wavefront control and coronagraph design, several high performance solutions have been designed for an "unfriendly" aperture


2.4-m telescope assembly



WFIRST-AFTA HLC simulated

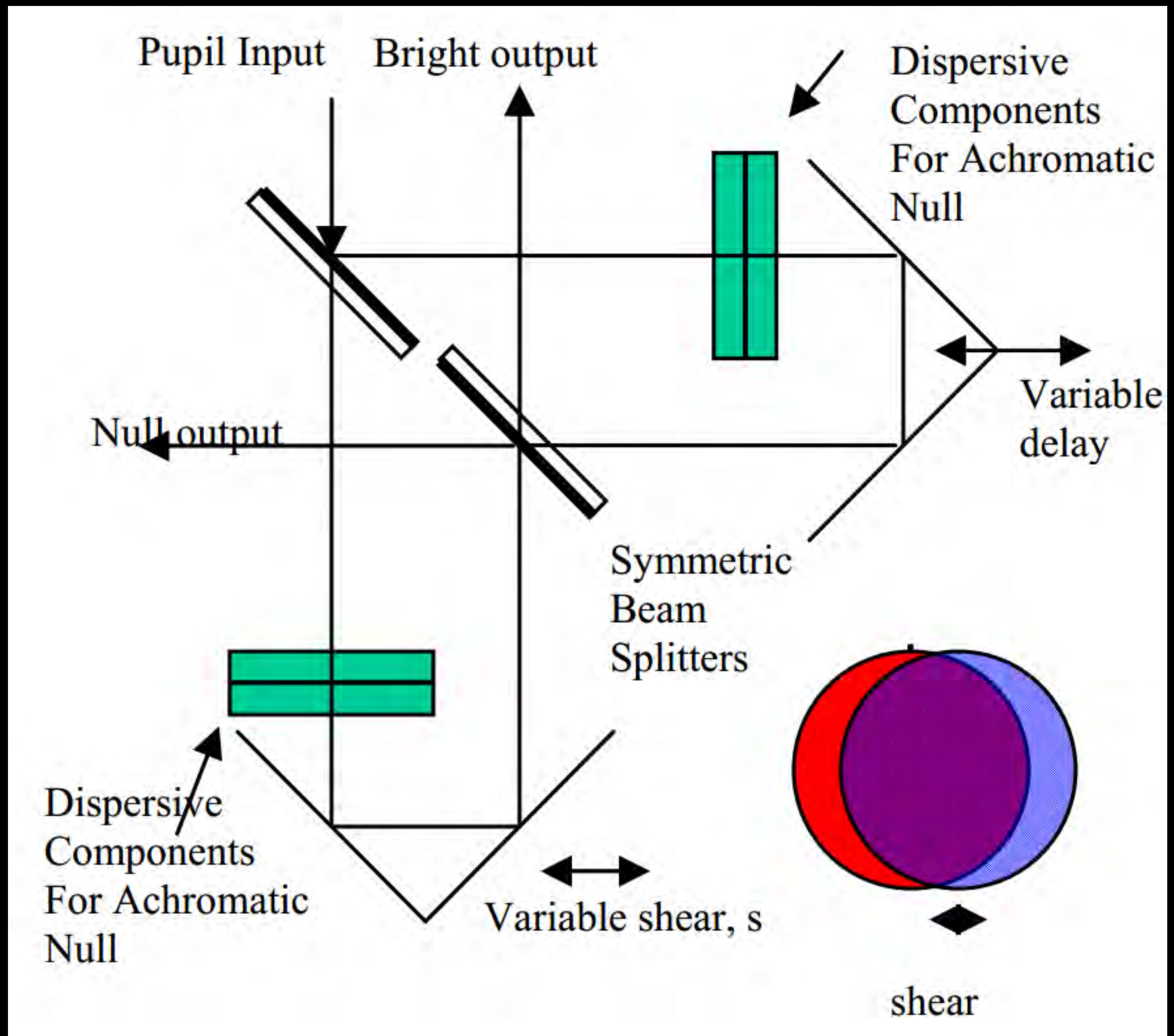
Starlight Suppression: Progress

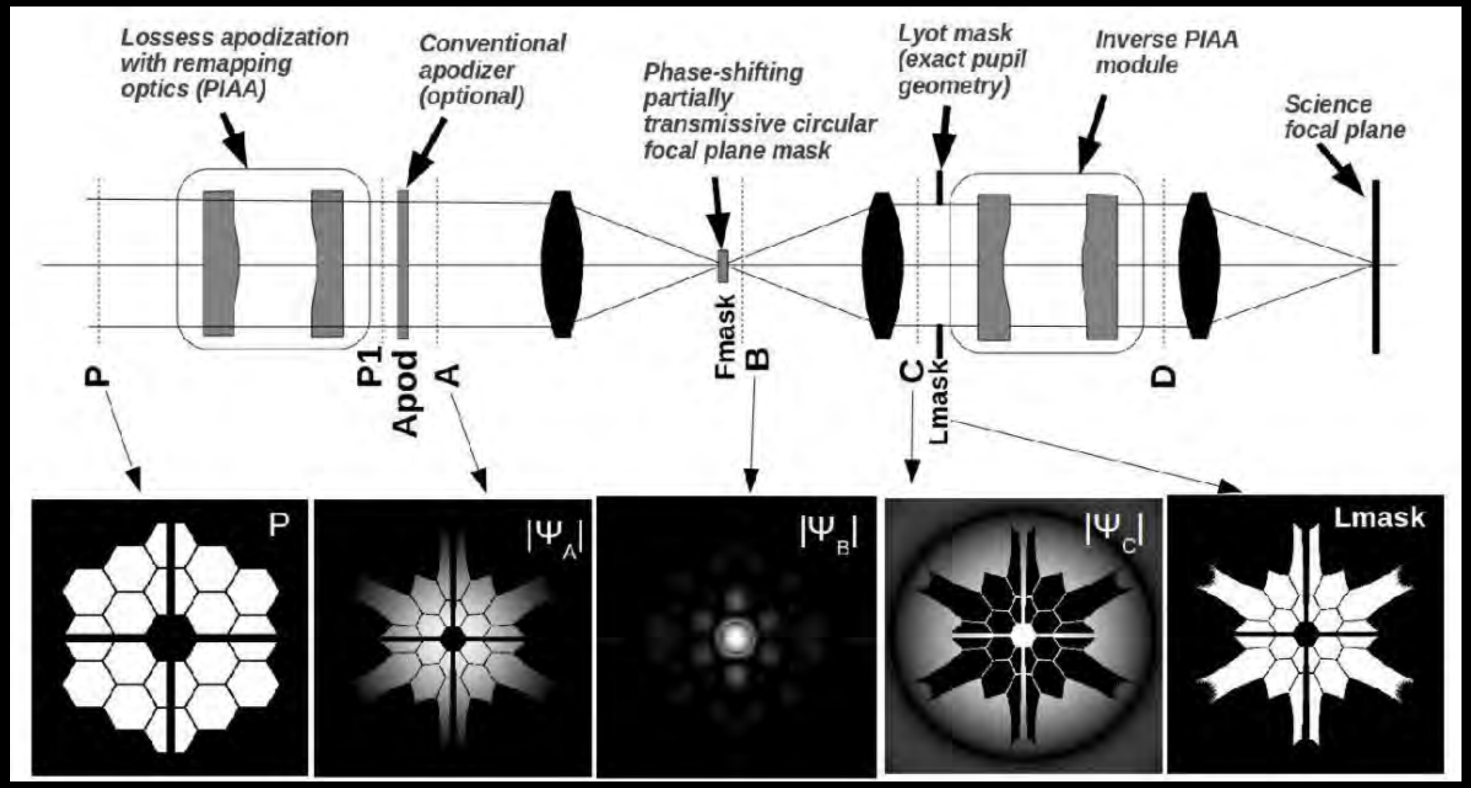
Recent research shows that segmented apertures can indeed be used for high contrast imaging

Wavefront control can significantly reduce residual segment diffraction

WFIRST AFTA success story:
Combining wavefront control and coronagraph design, several high performance solutions have been designed for an “unfriendly” aperture

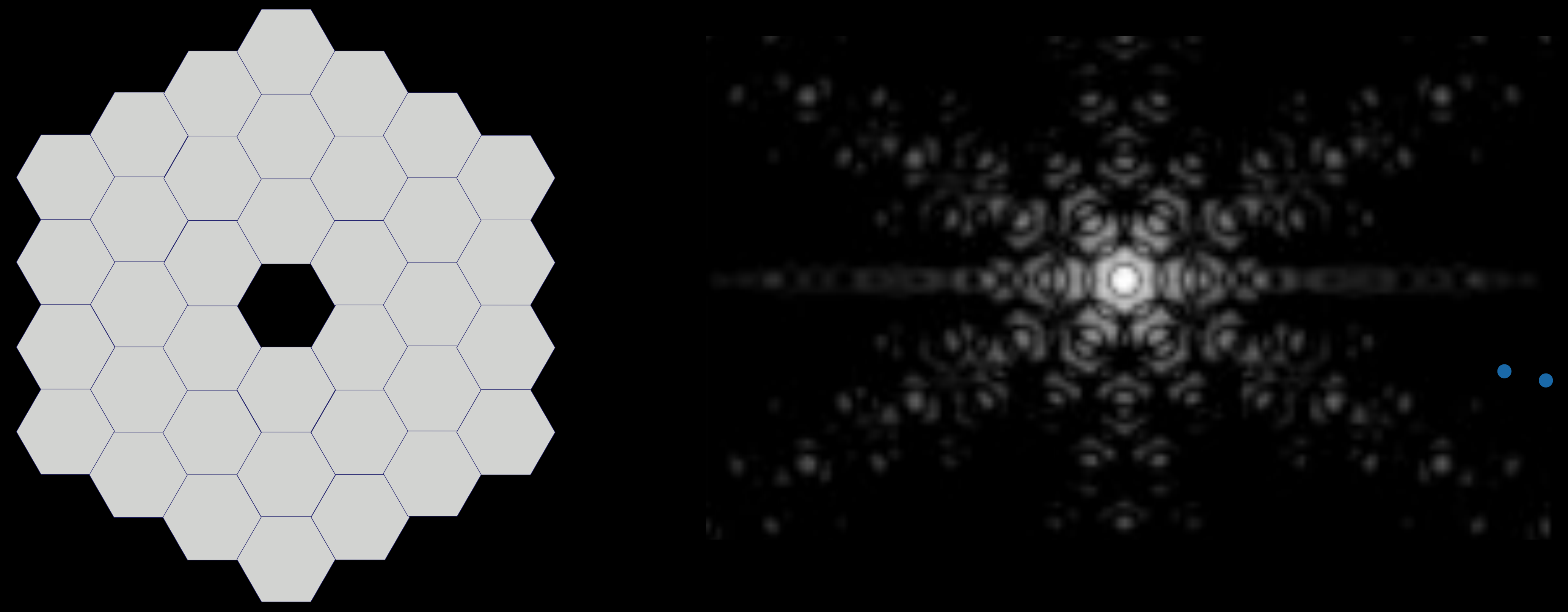
Coronagraph solutions exist that are, by construction, fully insensitive to pupil segmentation

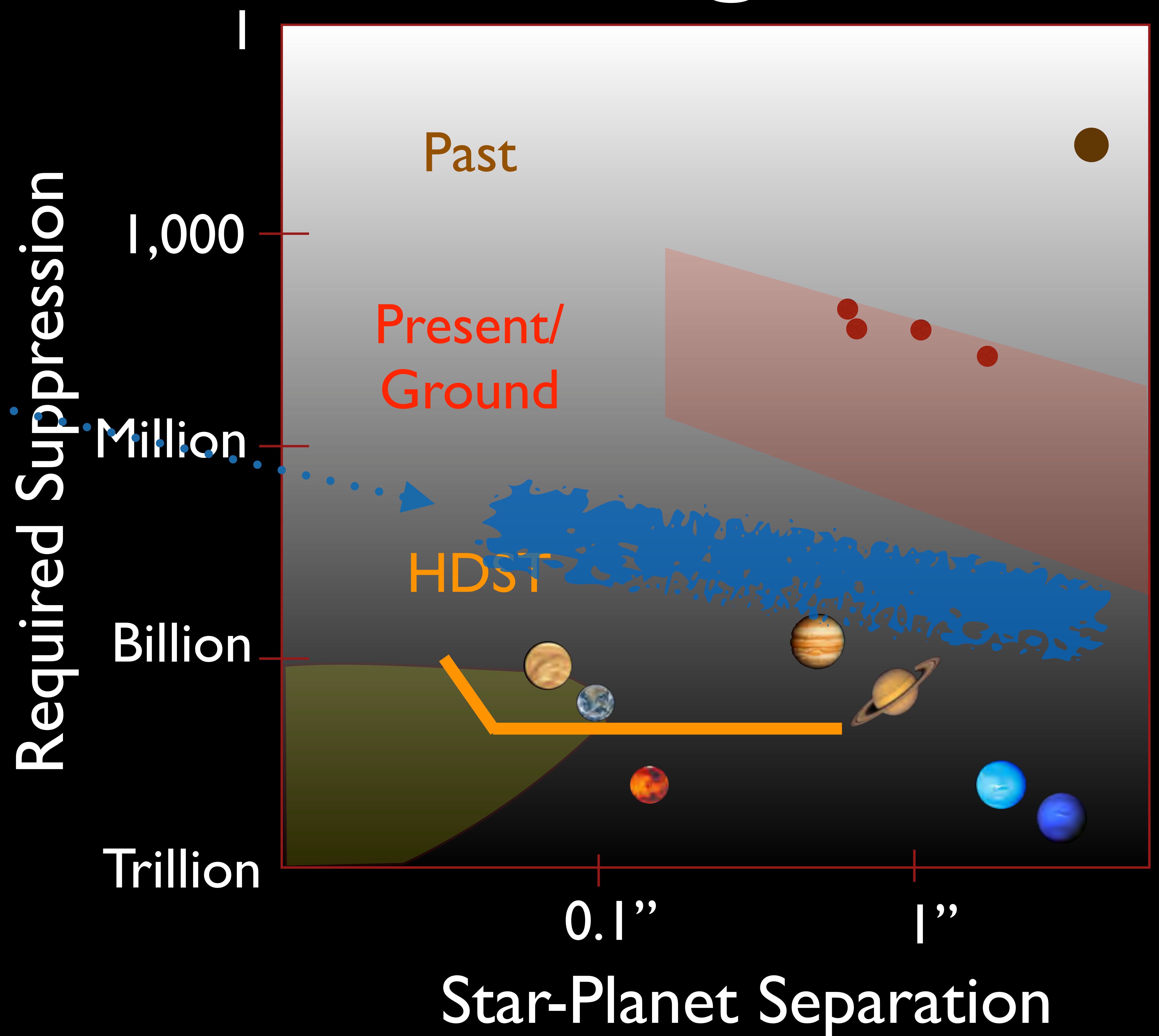




Starlight Suppression: Progress

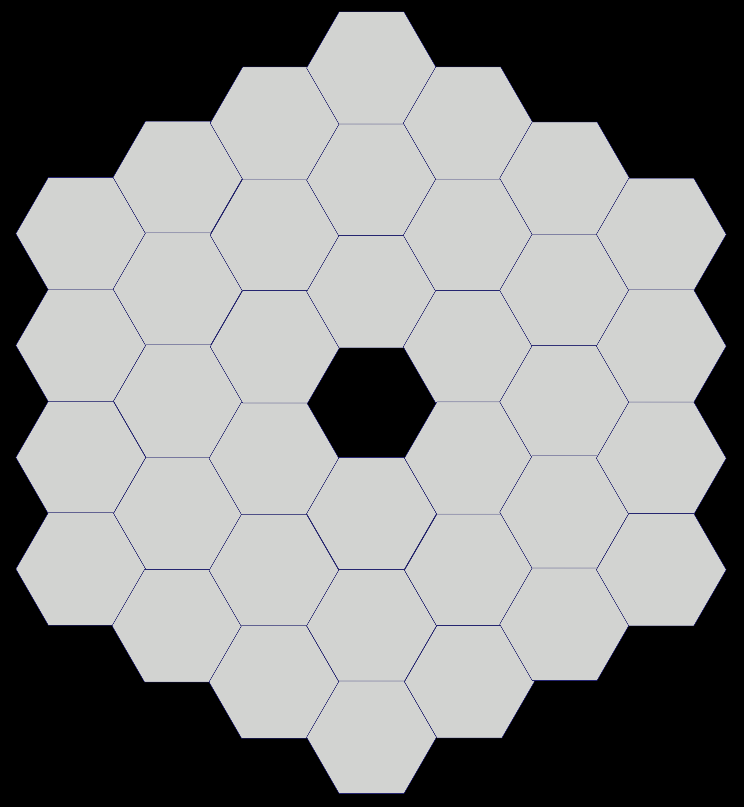
HDST-Specific Designs for Segmented Mirrors

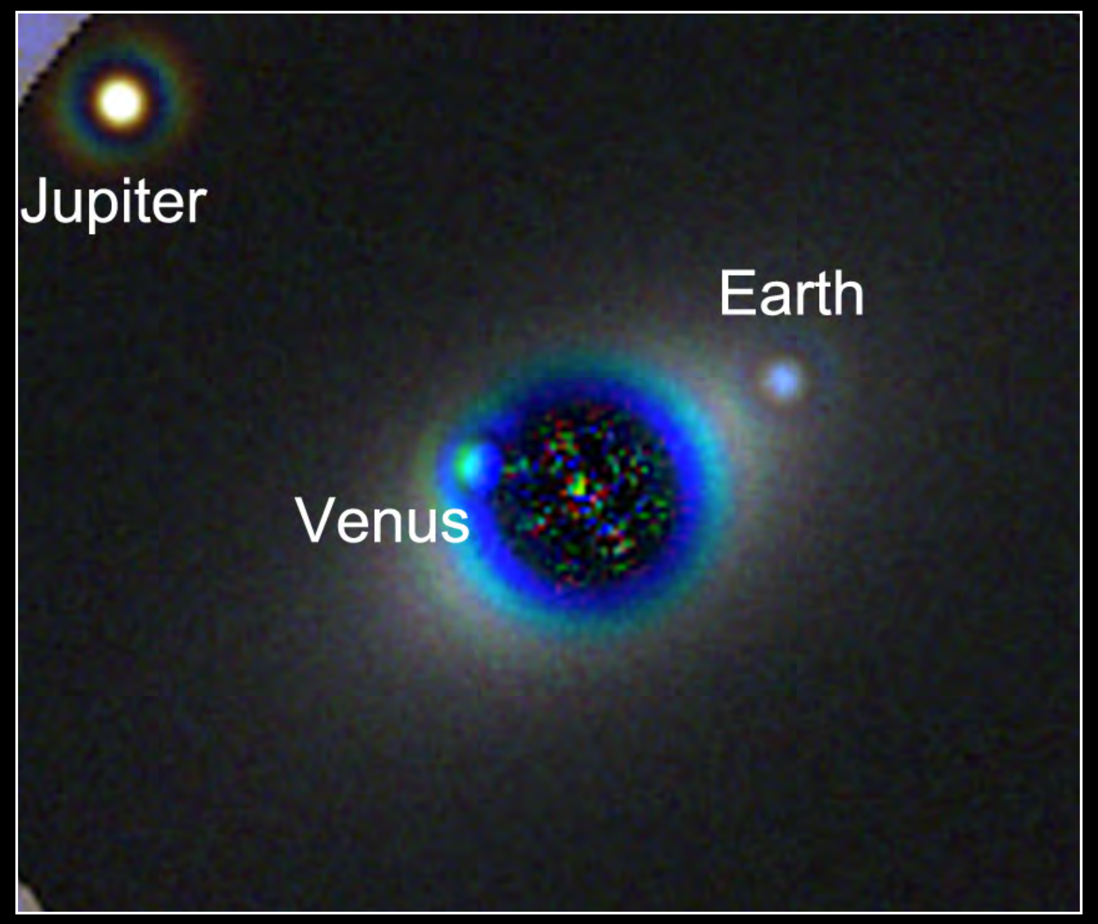


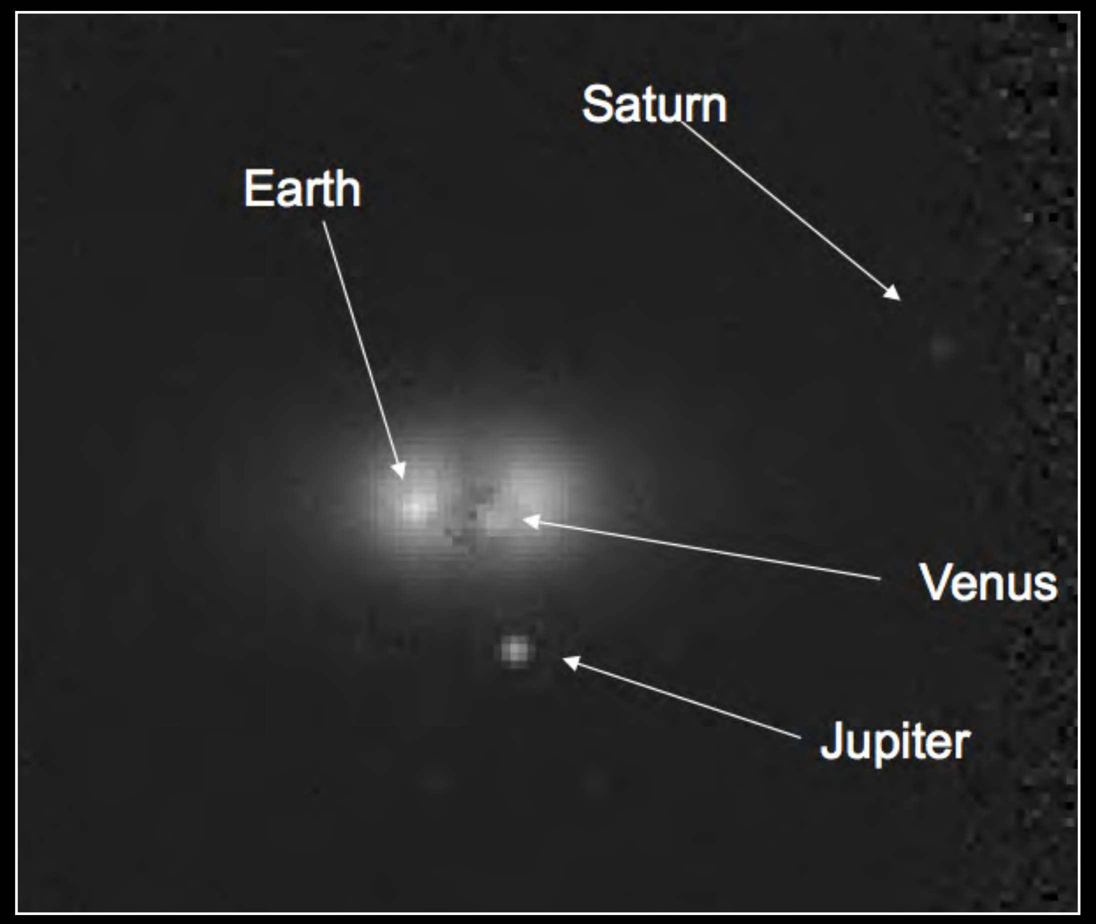


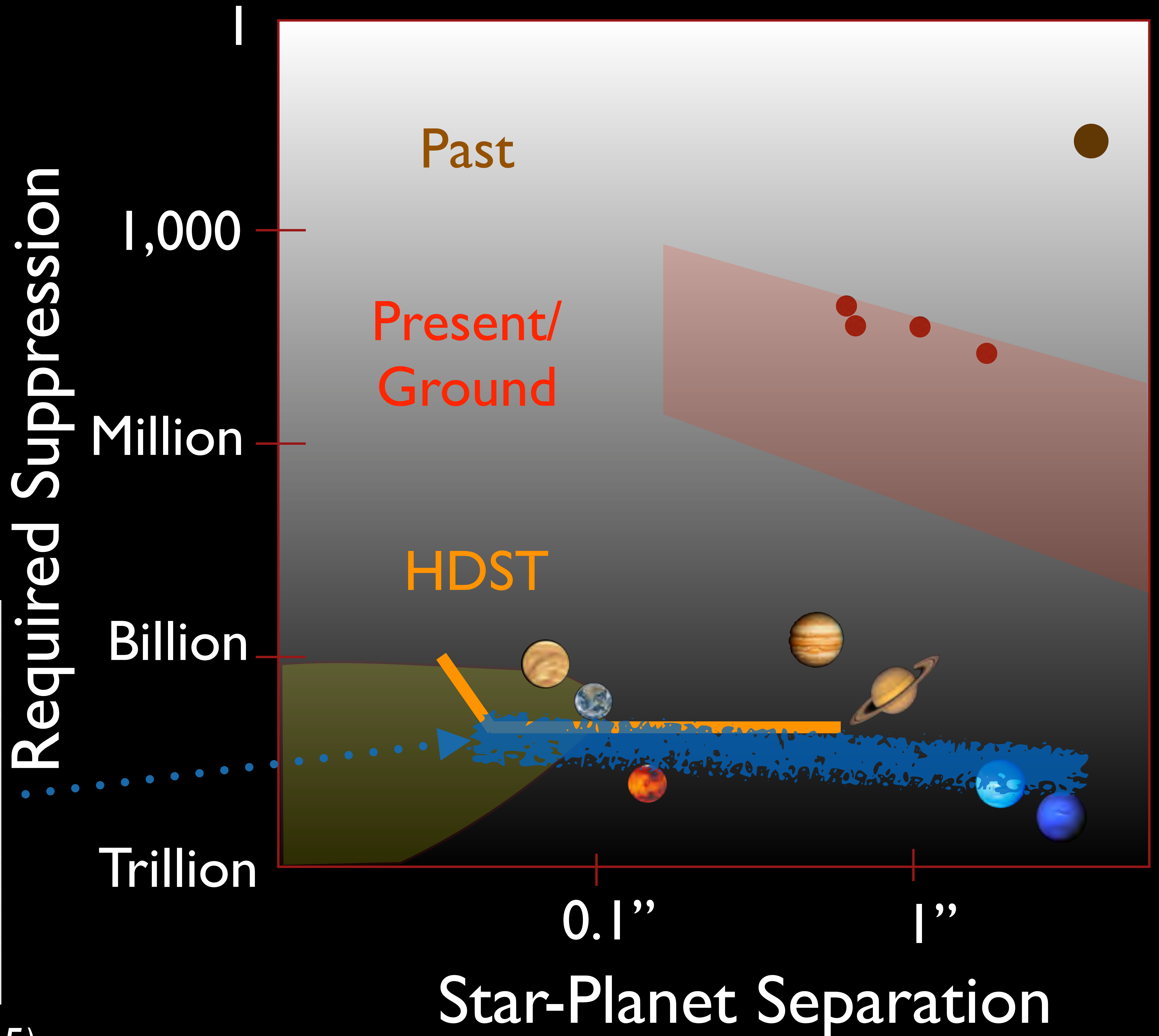
Starlight Suppression: Progress

HDST-Specific Designs for Segmented Mirrors





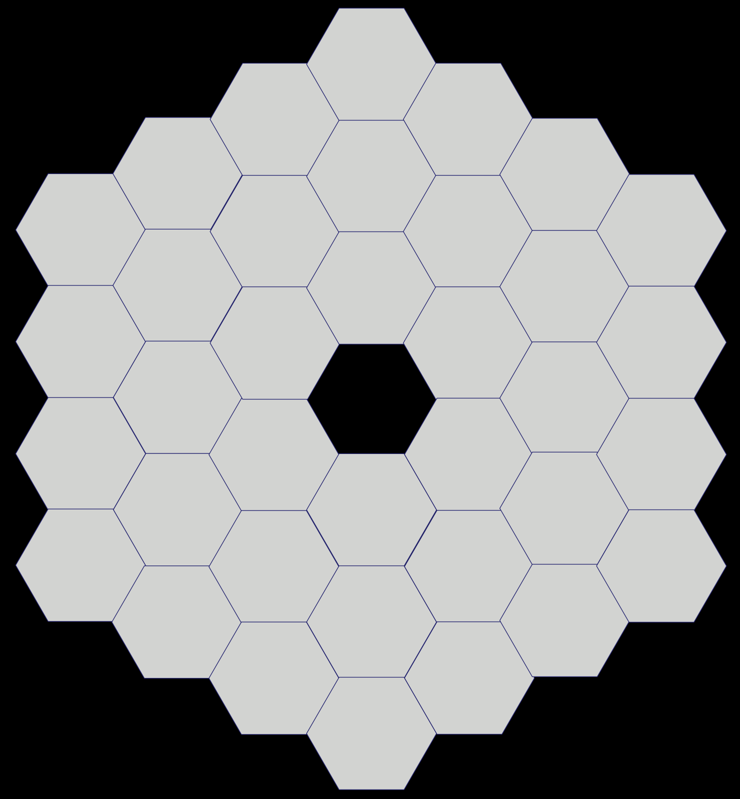


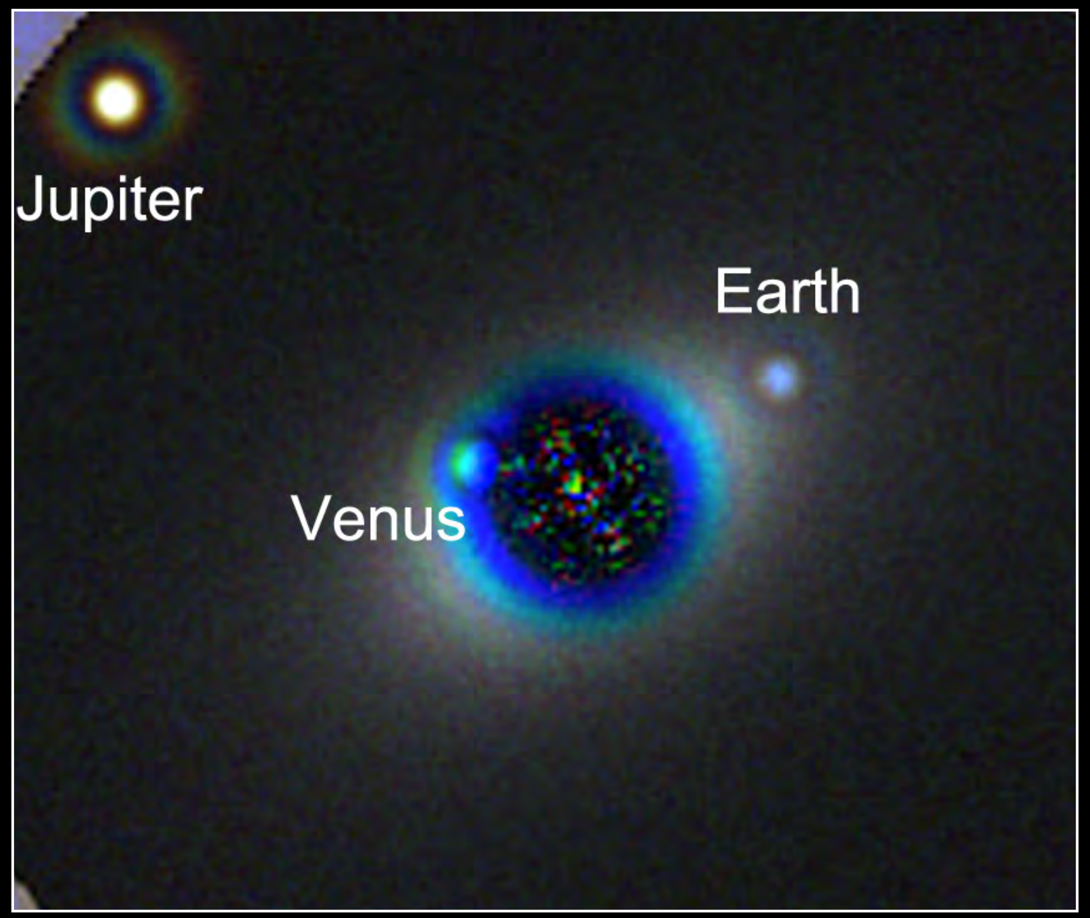


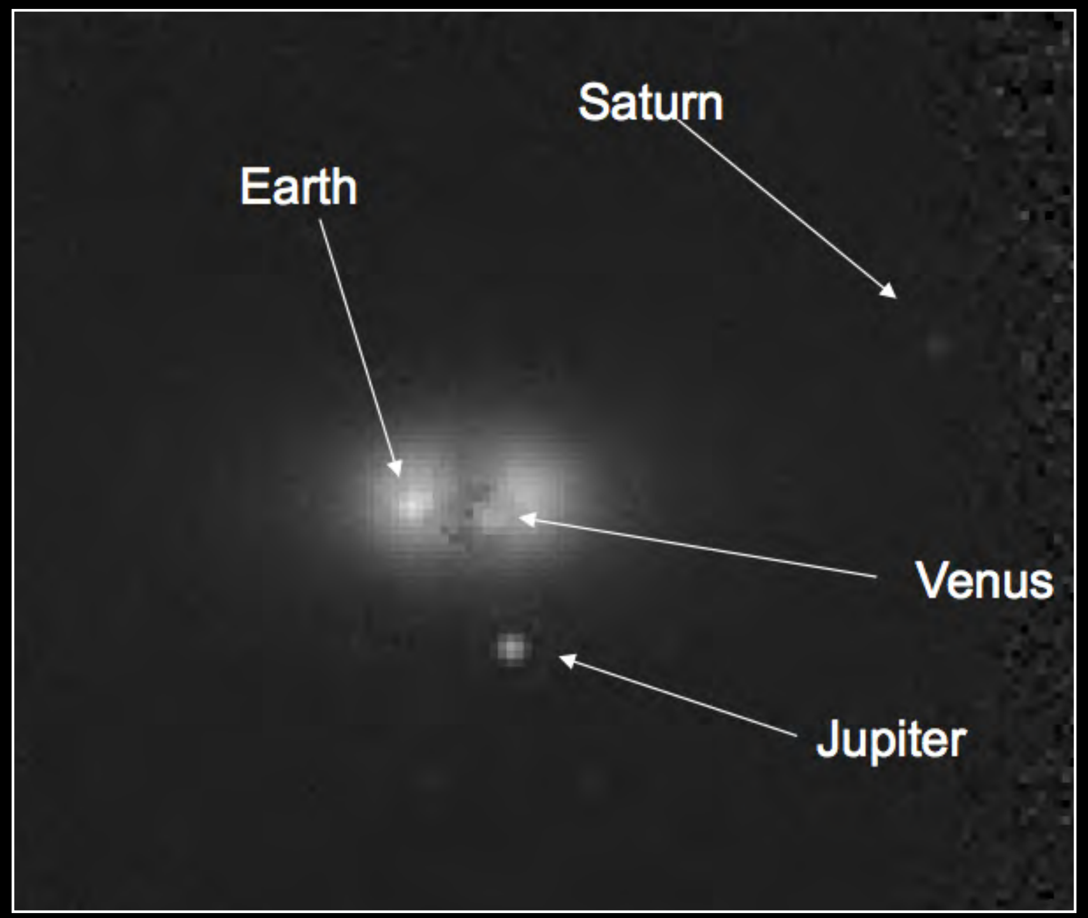
N’Daiye, et al. (2015), Guyon (2015) and Lyon, et al. (2015)

Starlight Suppression: Progress

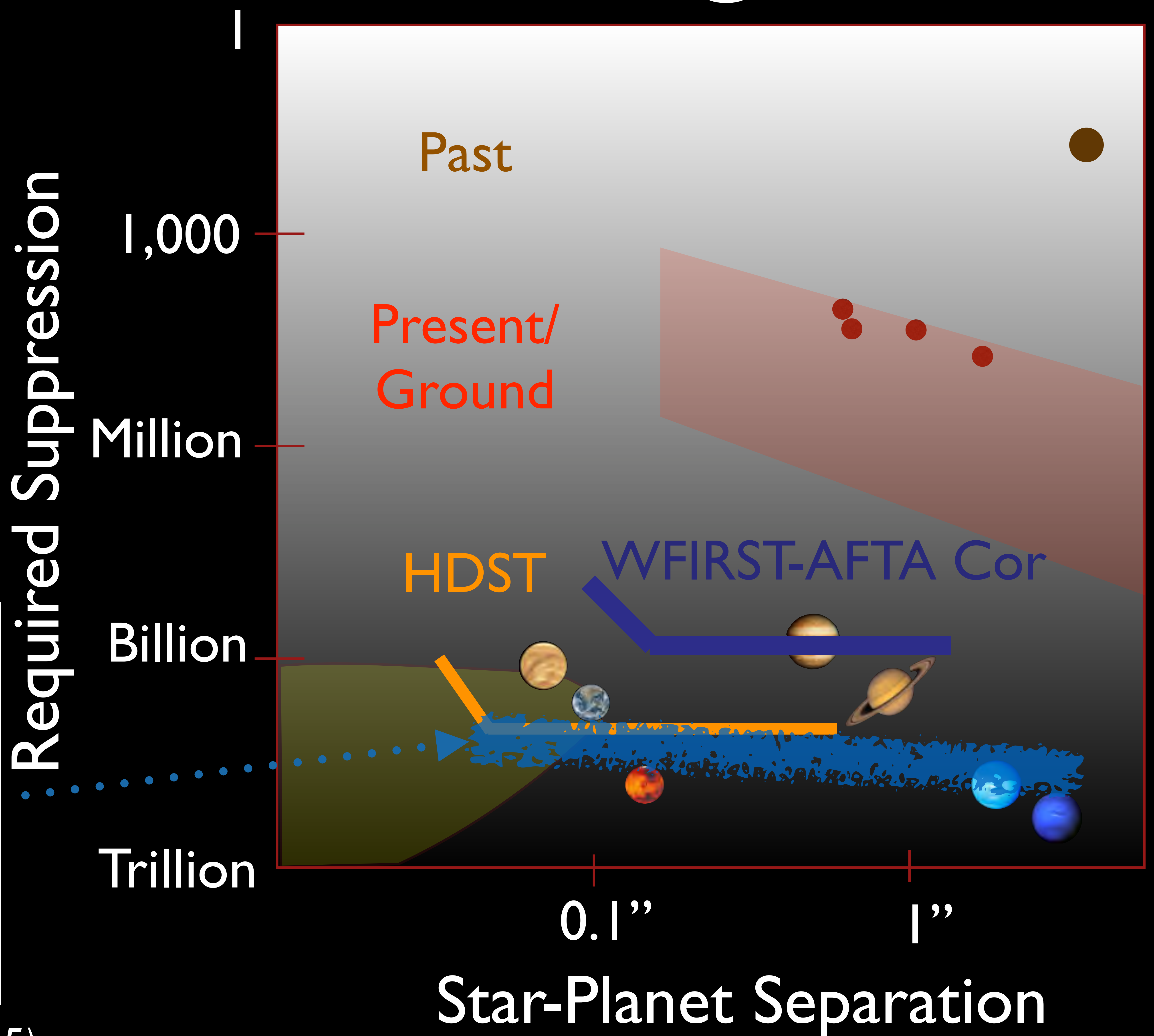
HDST-Specific Designs
for Segmented Mirrors





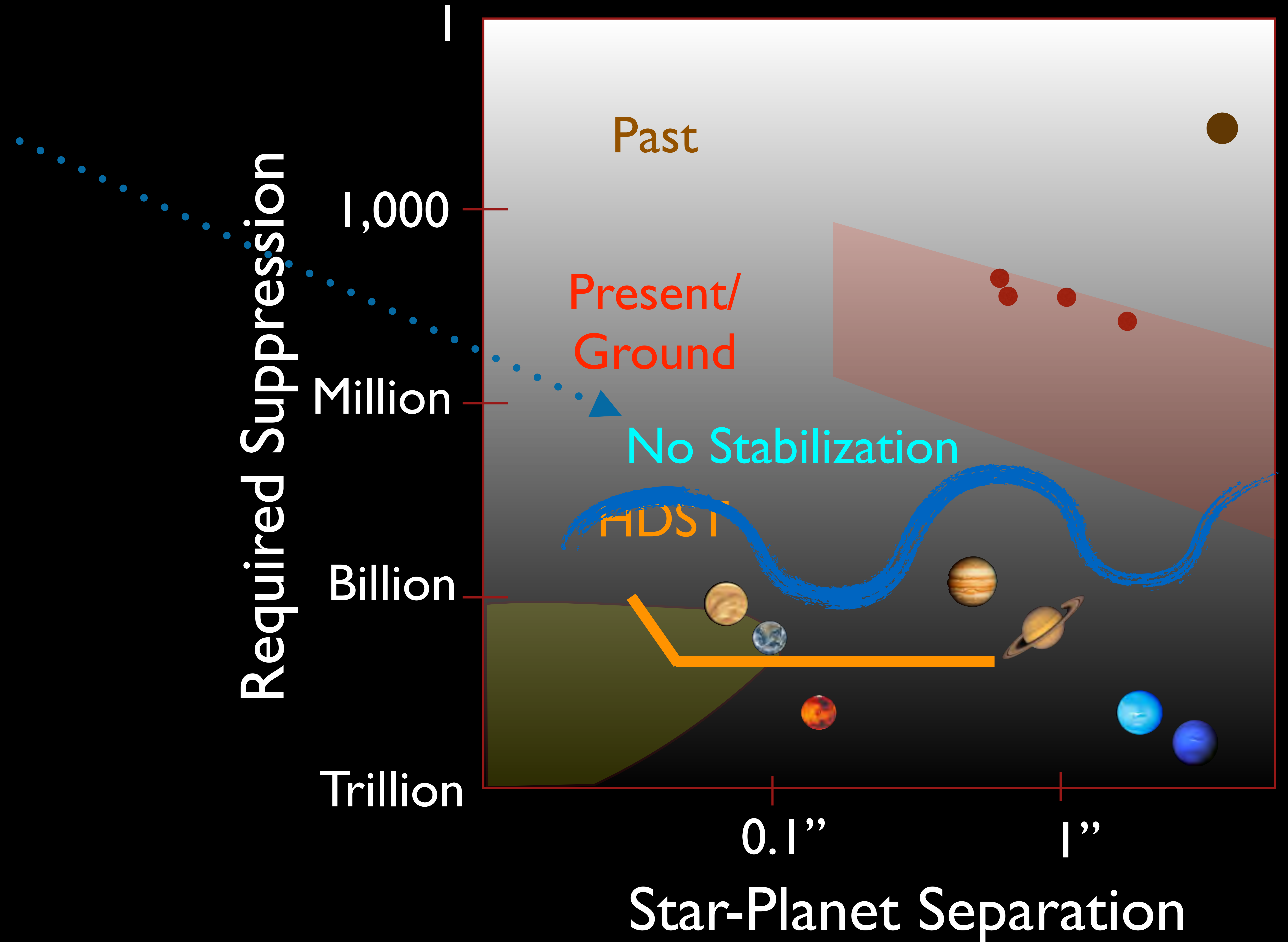


N'Daiye, et al. (2015), Guyon (2015) and Lyon, et al. (2015)



Starlight Suppression: Progress

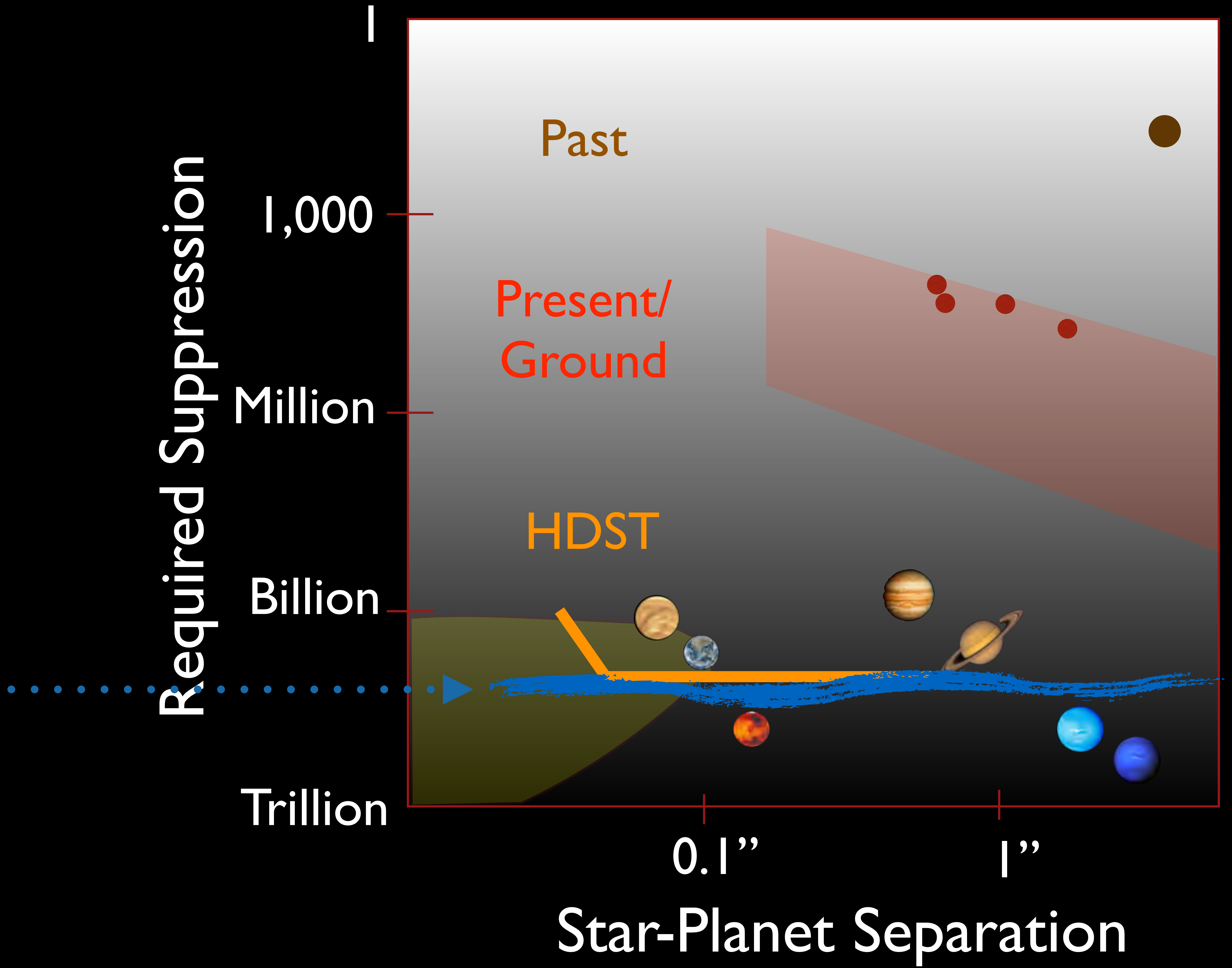
Thermal and Vibrational Stability (~10 pm)



Starlight Suppression: Progress

Thermal and Vibrational Stability (~10 pm)

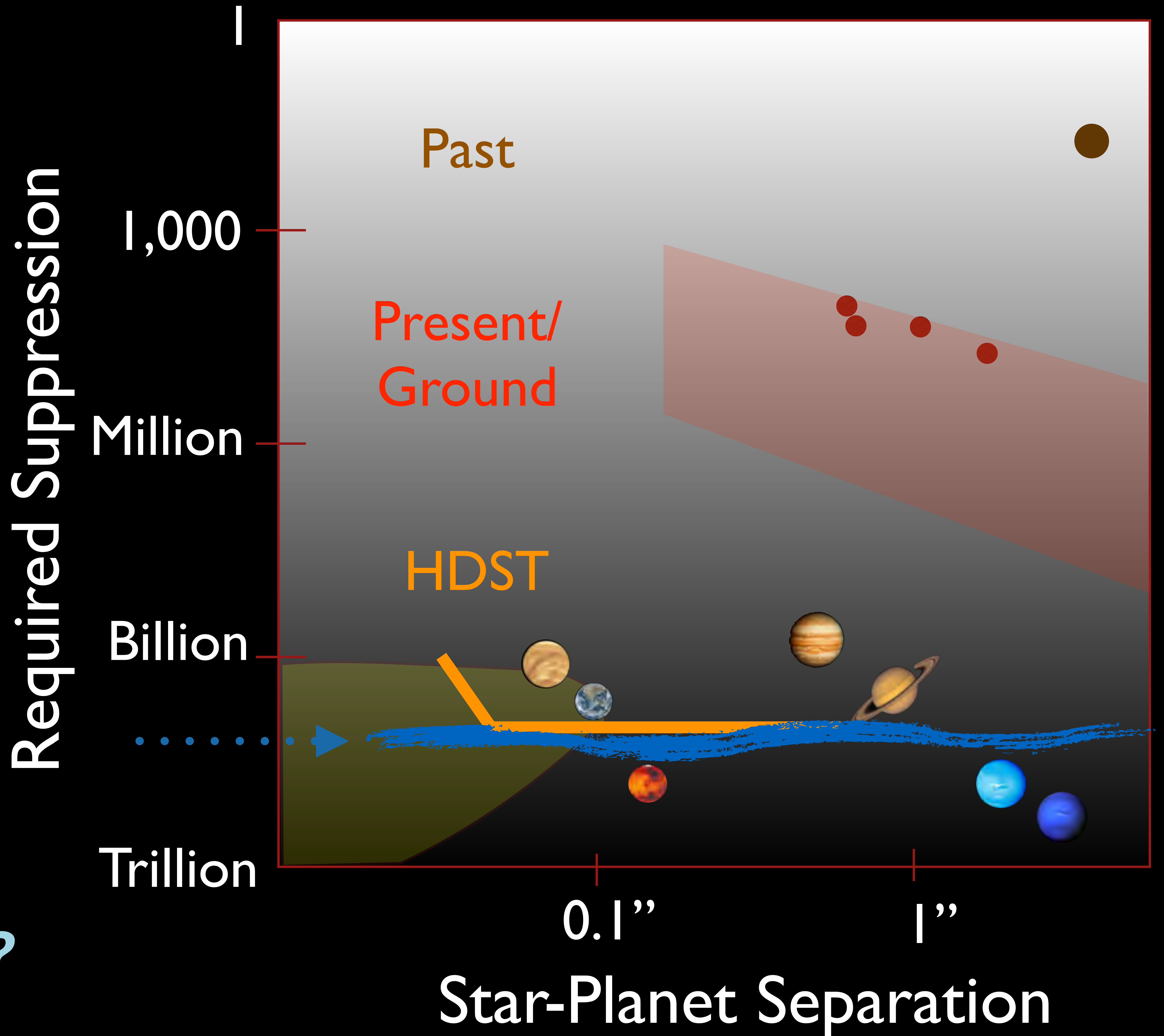
Sun-Earth L2 Orbit



Starlight Suppression: Progress

Thermal and Vibrational Stability (~10 pm)

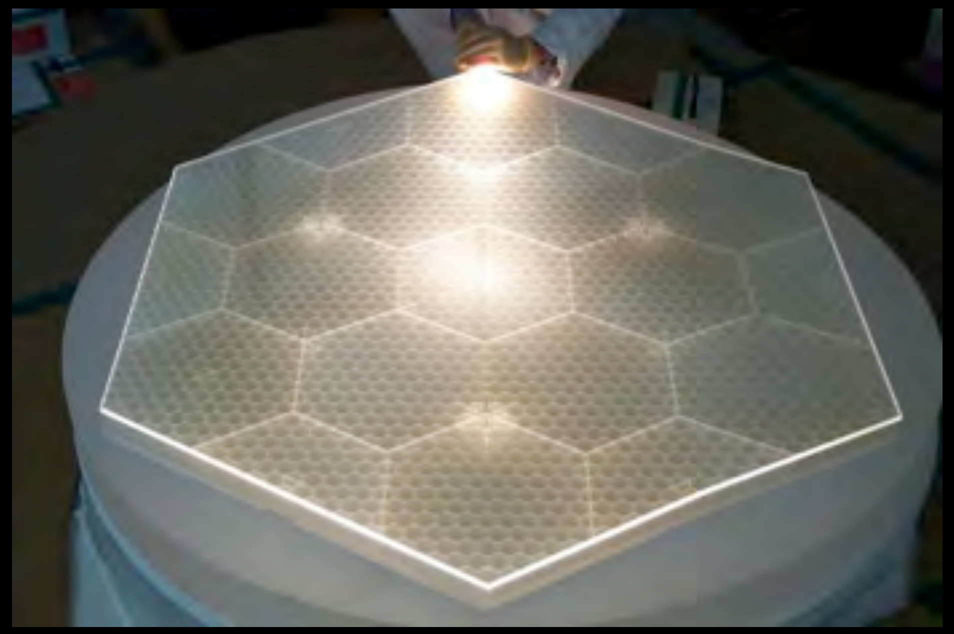
Active thermal control
  < 1 mK performance
Vibration suppression
  Non-contact isolation
Continuous Speckle Nulling WFC
Continuous Wavefront Sensing
  WFIRST-AFTA Cor LOWFS tech
Picometer laser metrology
  SIM and non-NASA < 1 nm
Deformable Mirrors
  Small and possibly segmented?

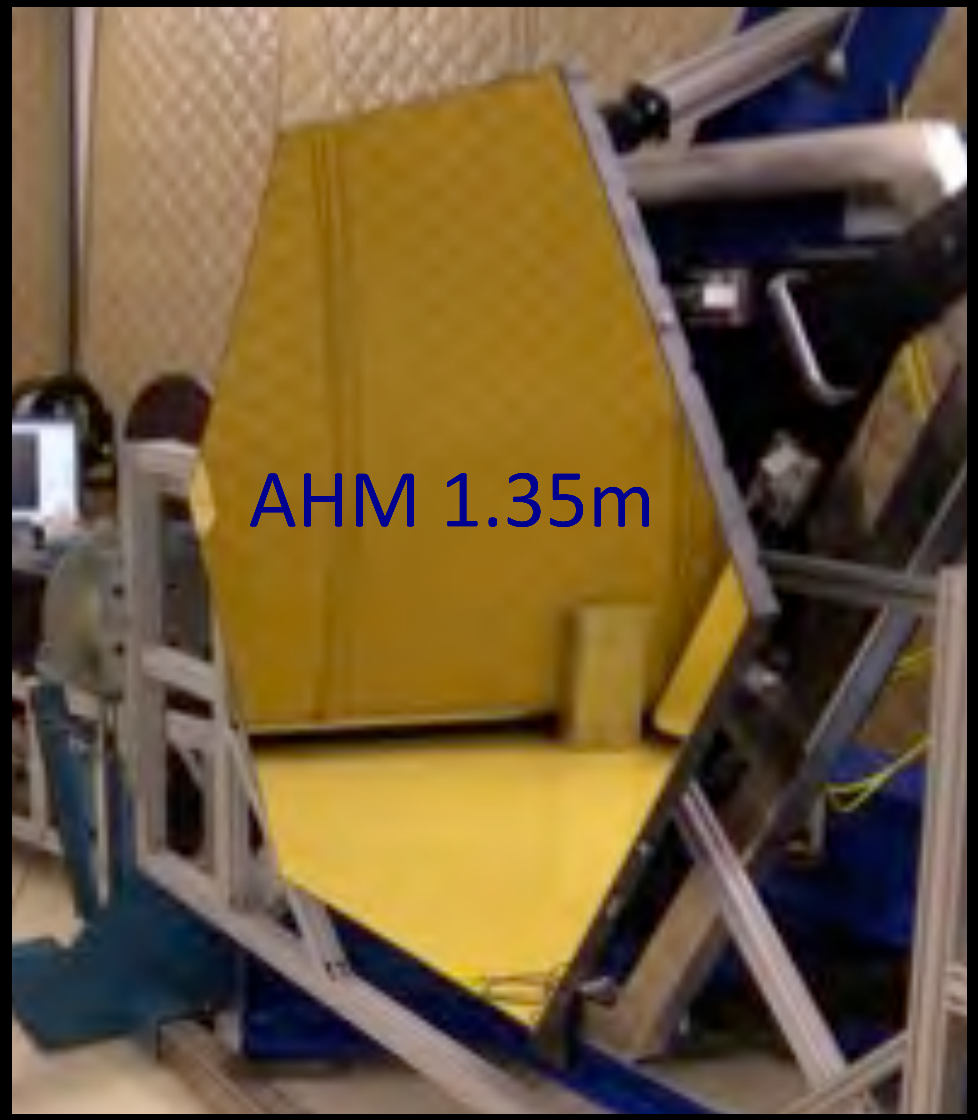


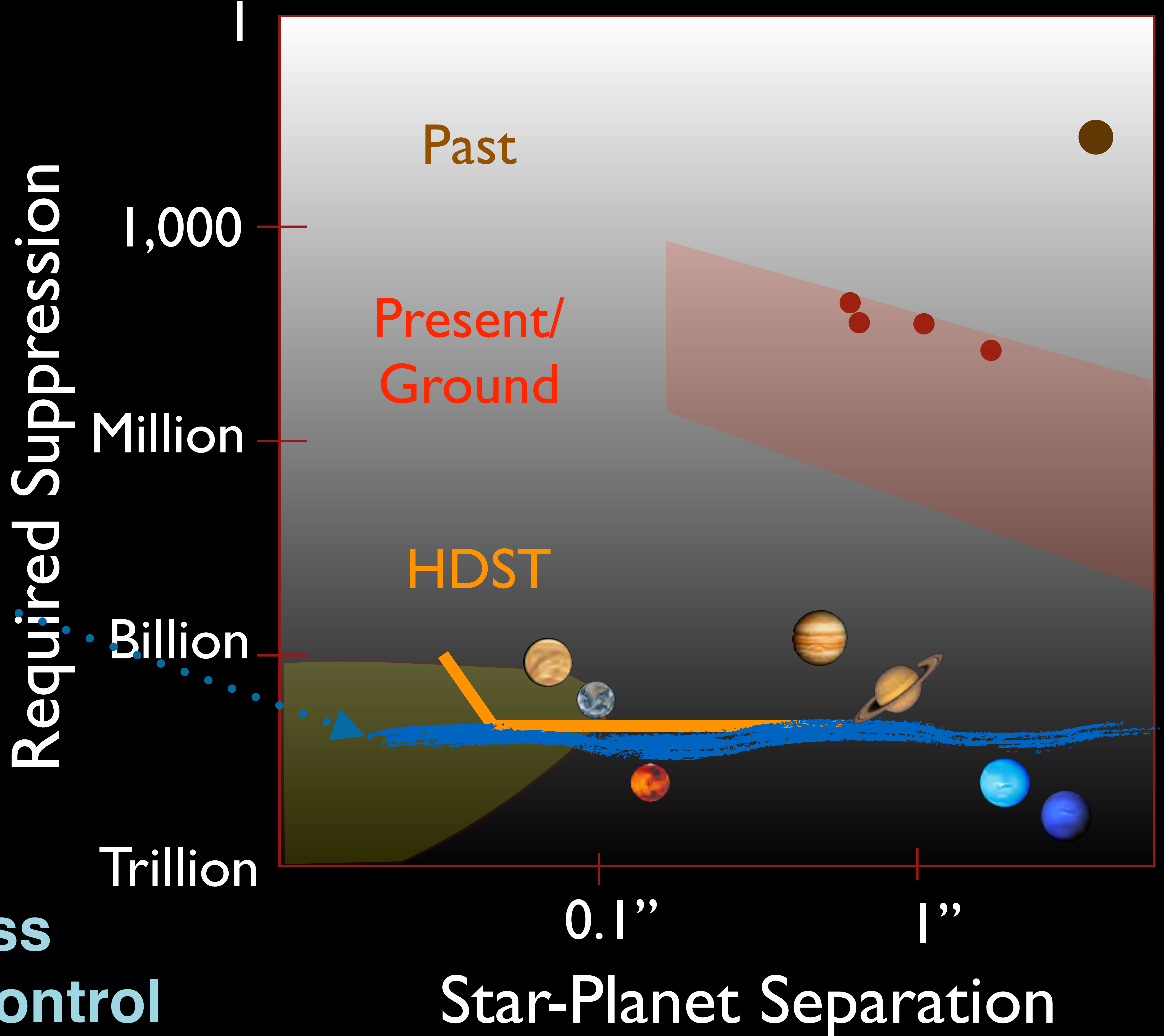
Starlight Suppression: Progress

Thermal and Vibrational Stability (~10 pm)

Active Mirror Technology







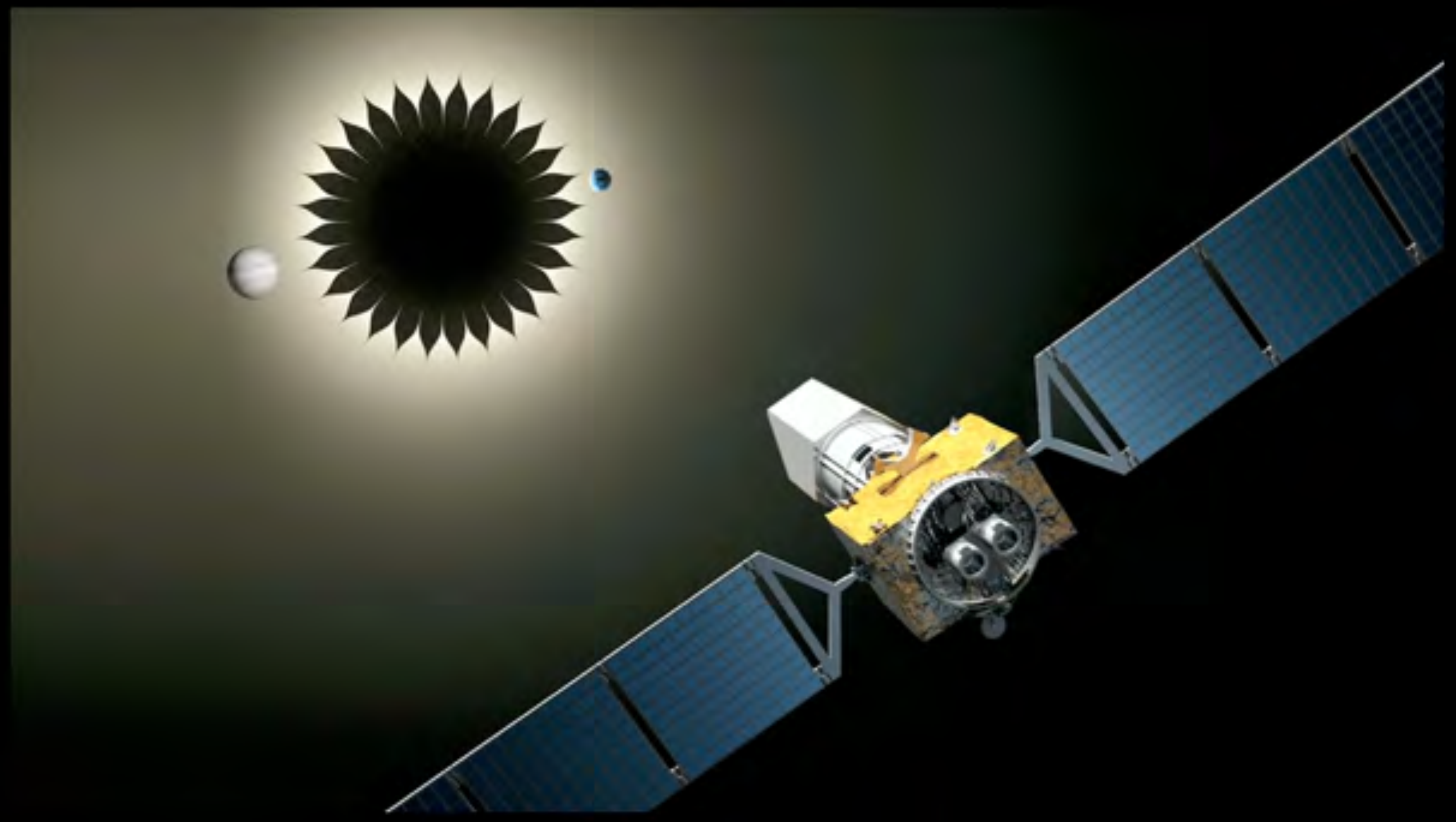
Key challenges

Diff. limited optical quality, UV compatibility, low cost, mass

Key trades: **Thermal and figure control**

Starlight Suppression: Progress

Starshade Technology



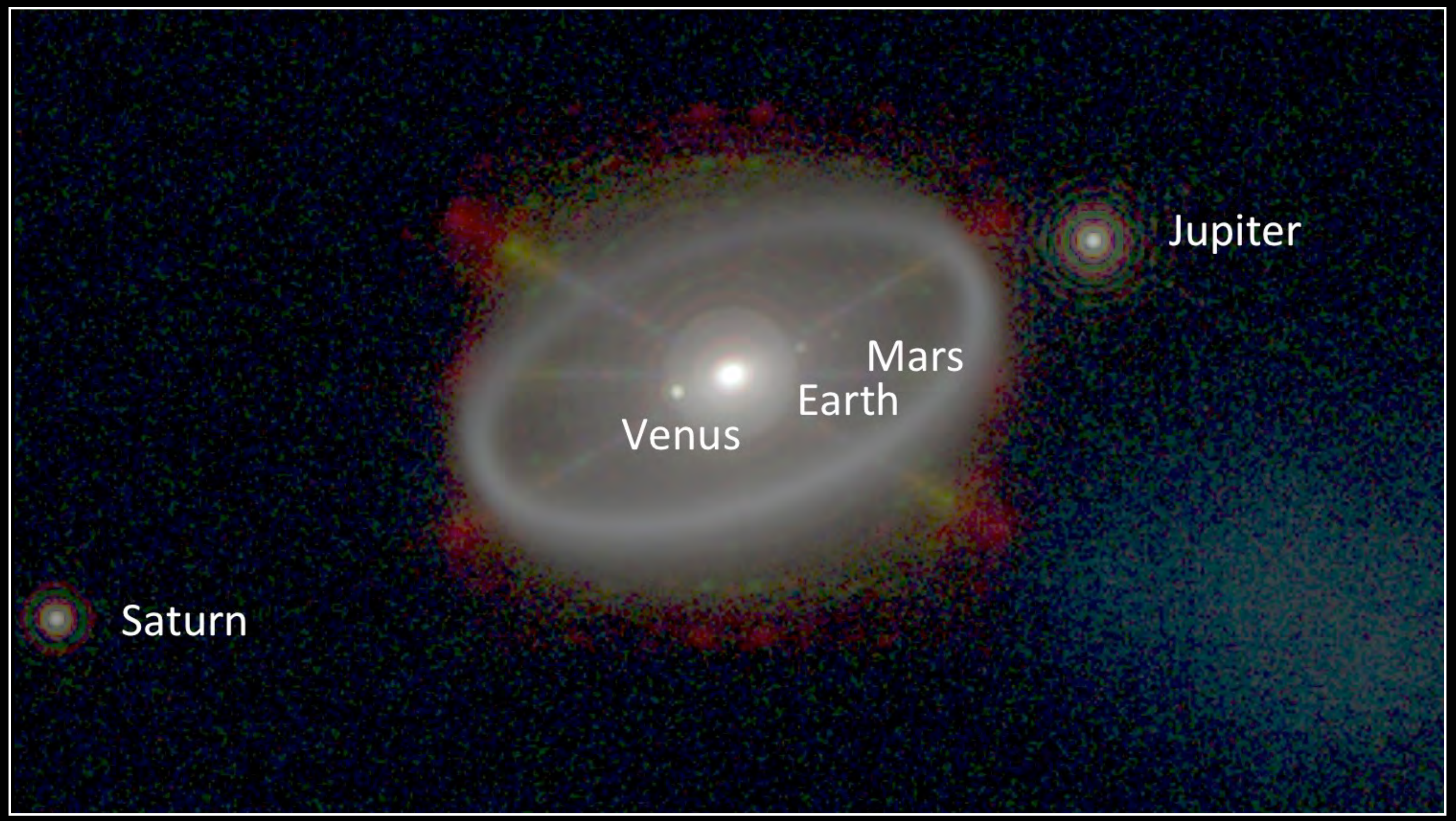
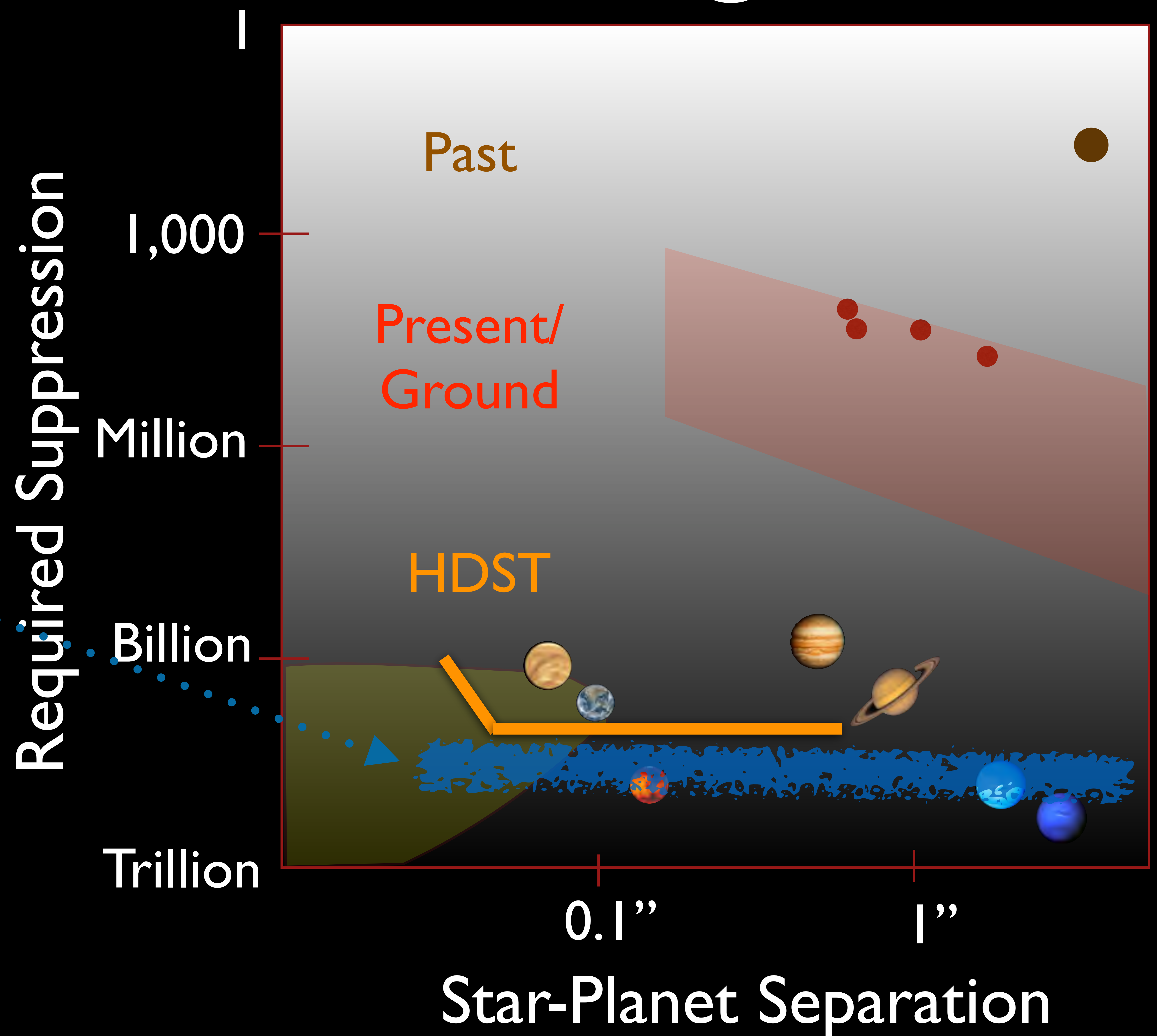
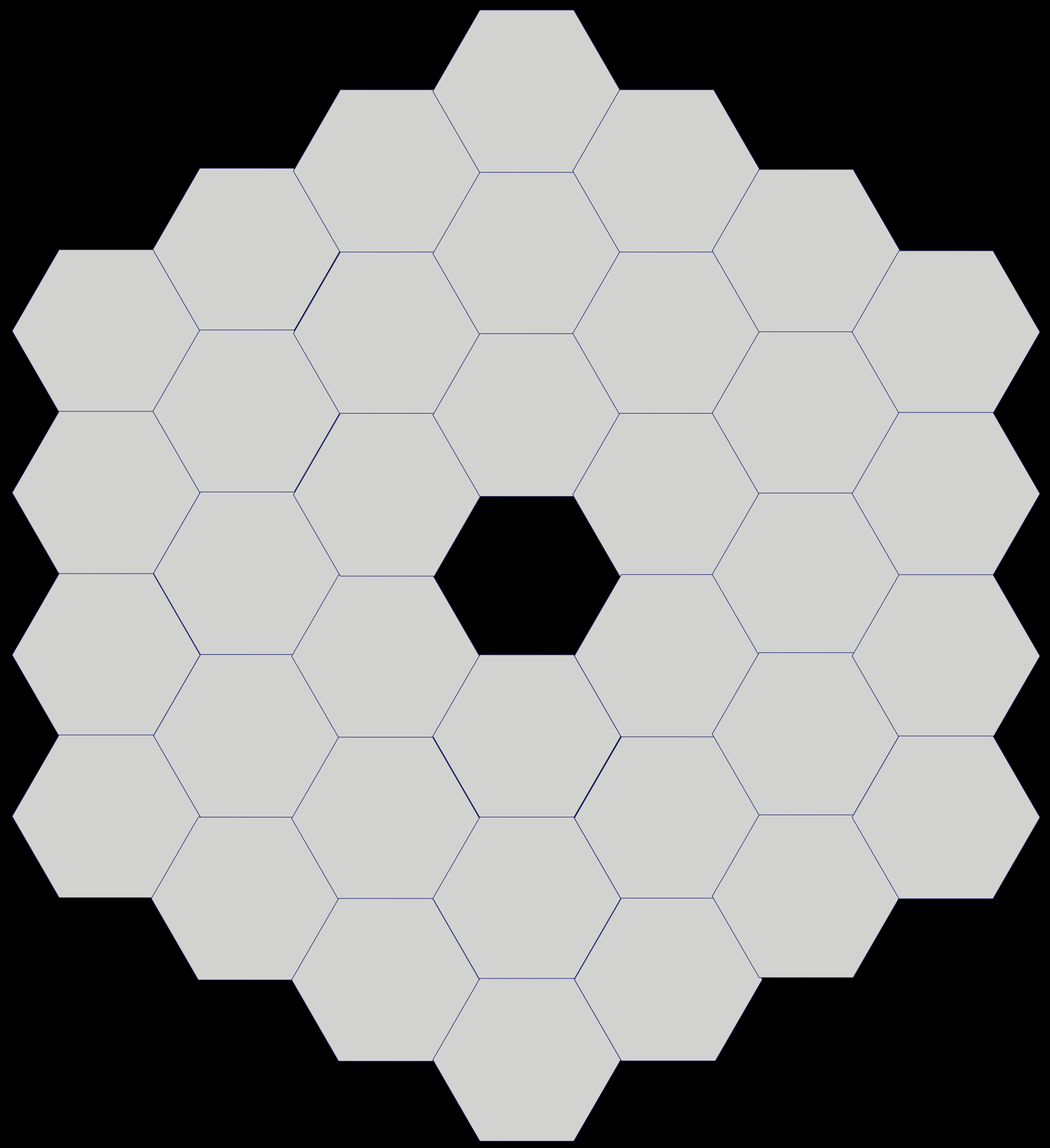


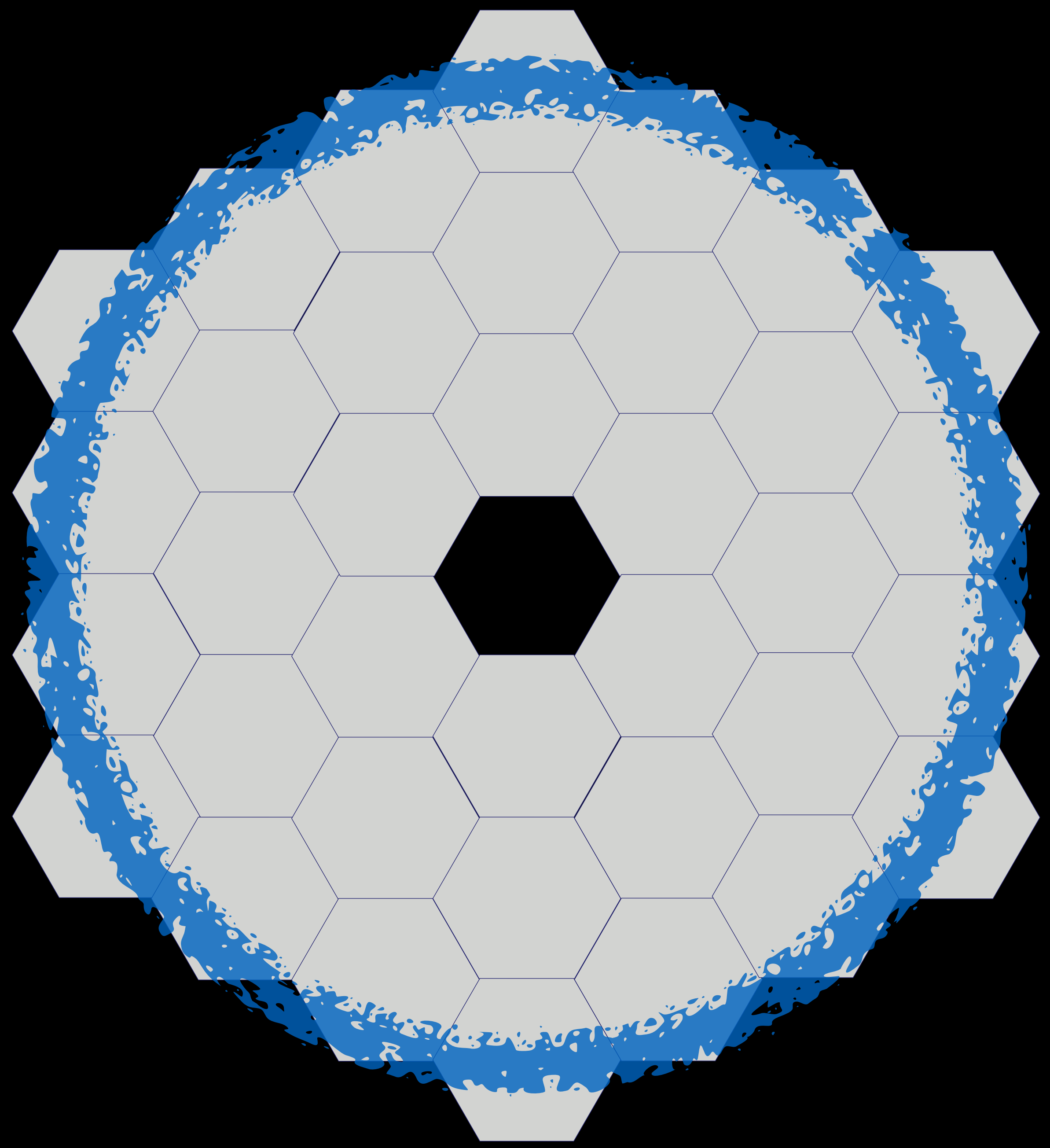
Image Credit: Kuchner (2015)



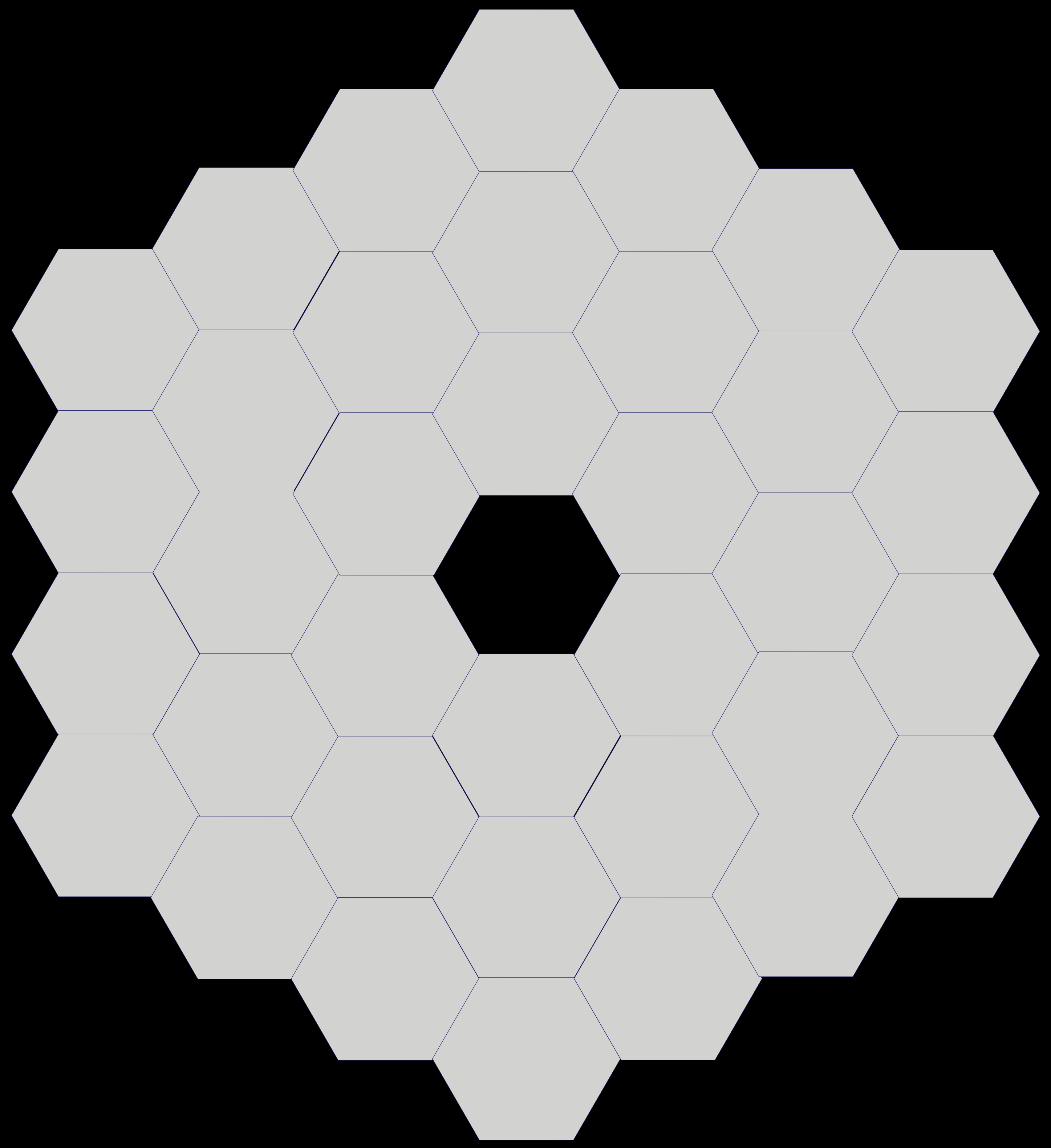
Leveraging JWST



Leveraging JWST

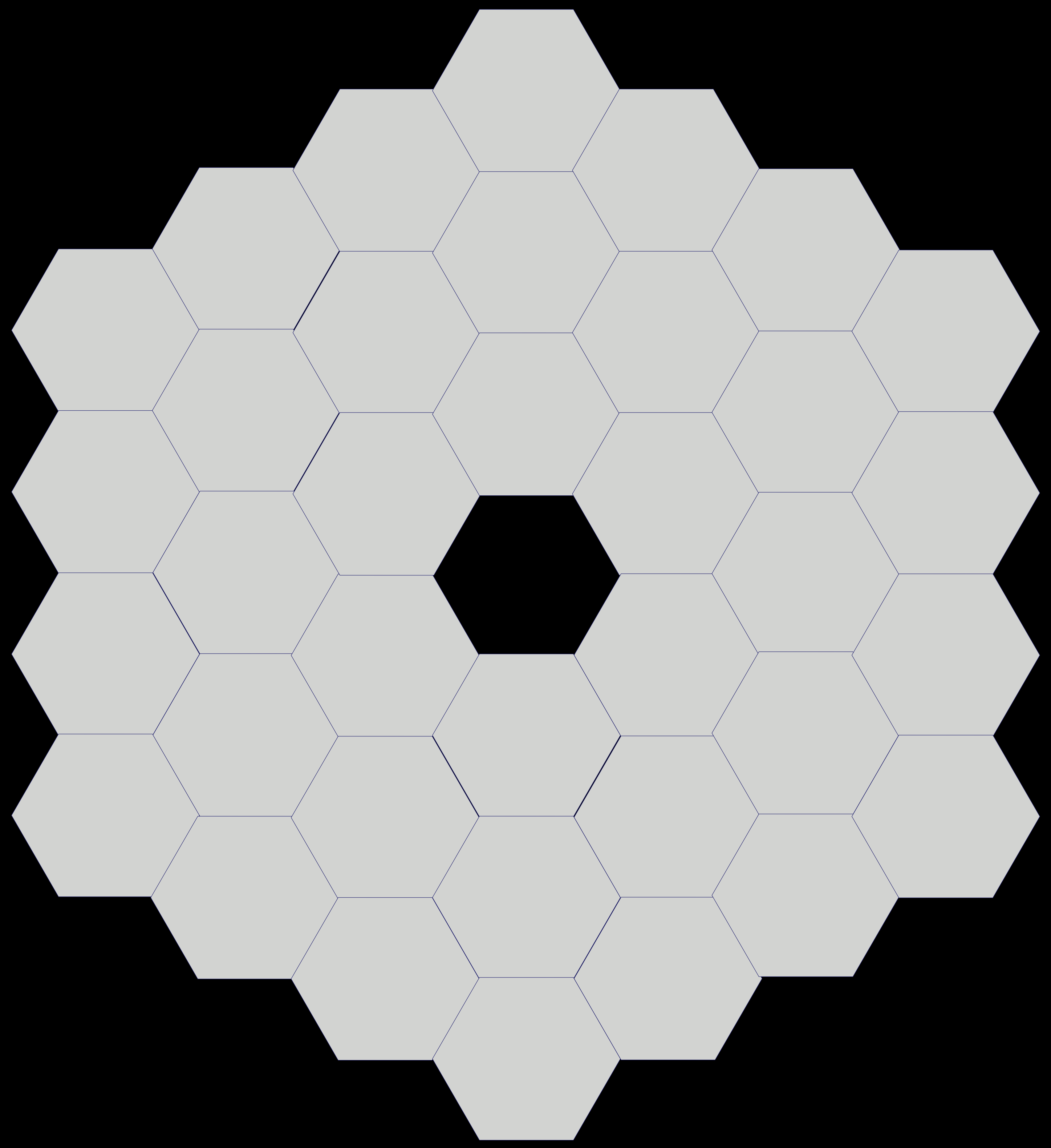


Large Collecting Area



exoEarths

Large Collecting Area



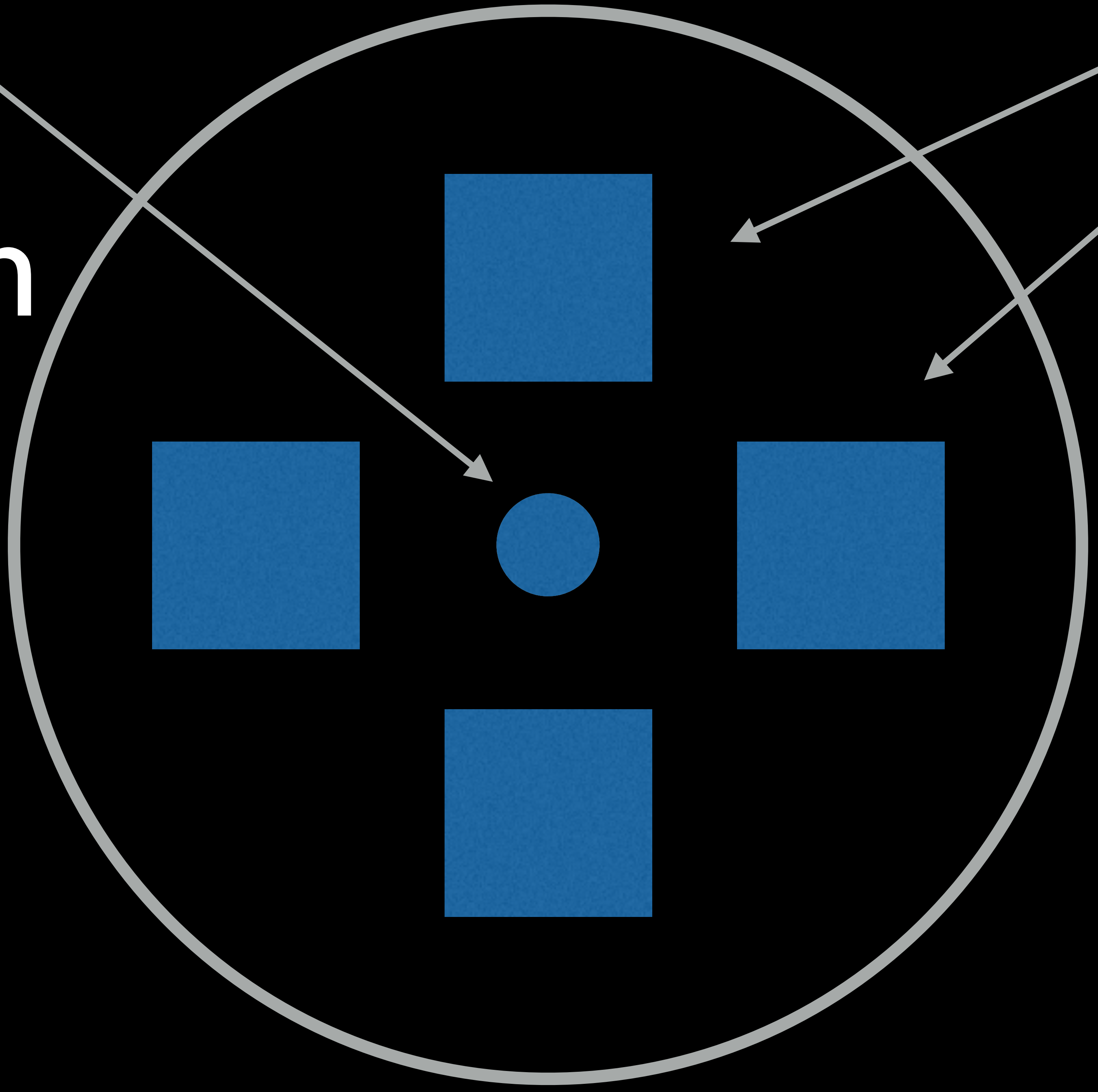
exoEarths

Transform Astronomy in the 21st Century

HDST Instruments

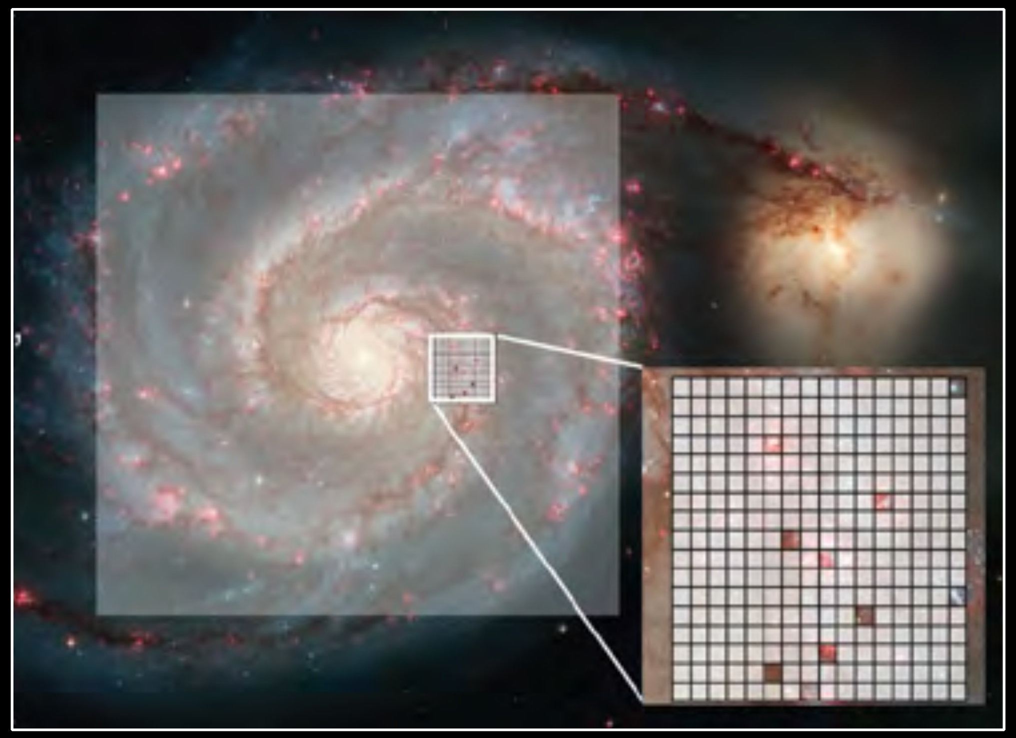
Narrow Field

exoEarth
Starlight Suppression



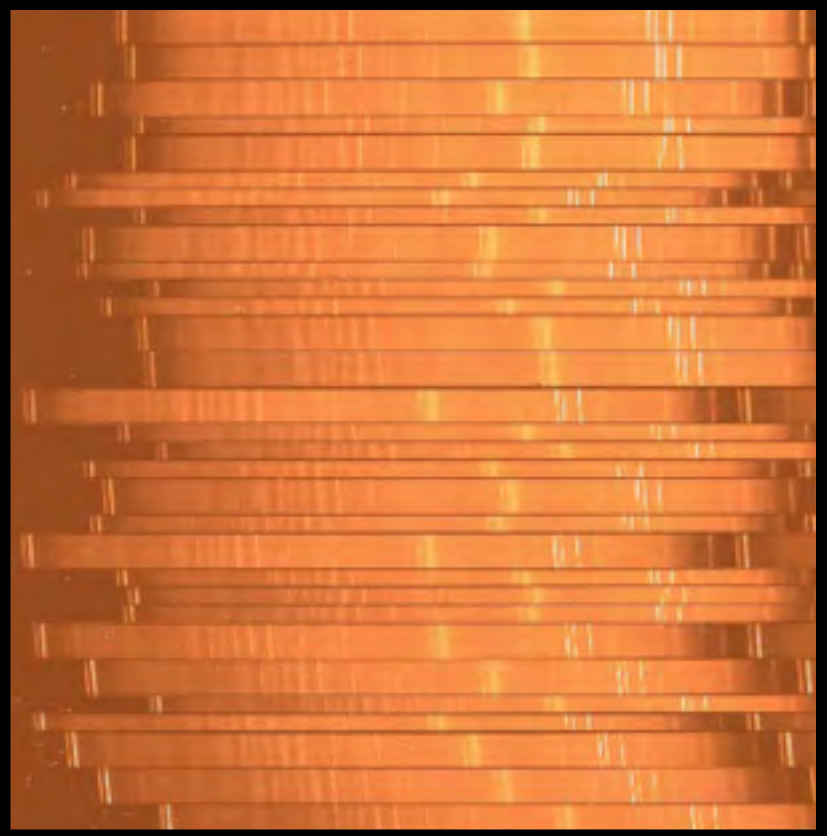
Wide Field

Imaging



UV
Spectra

Spectra



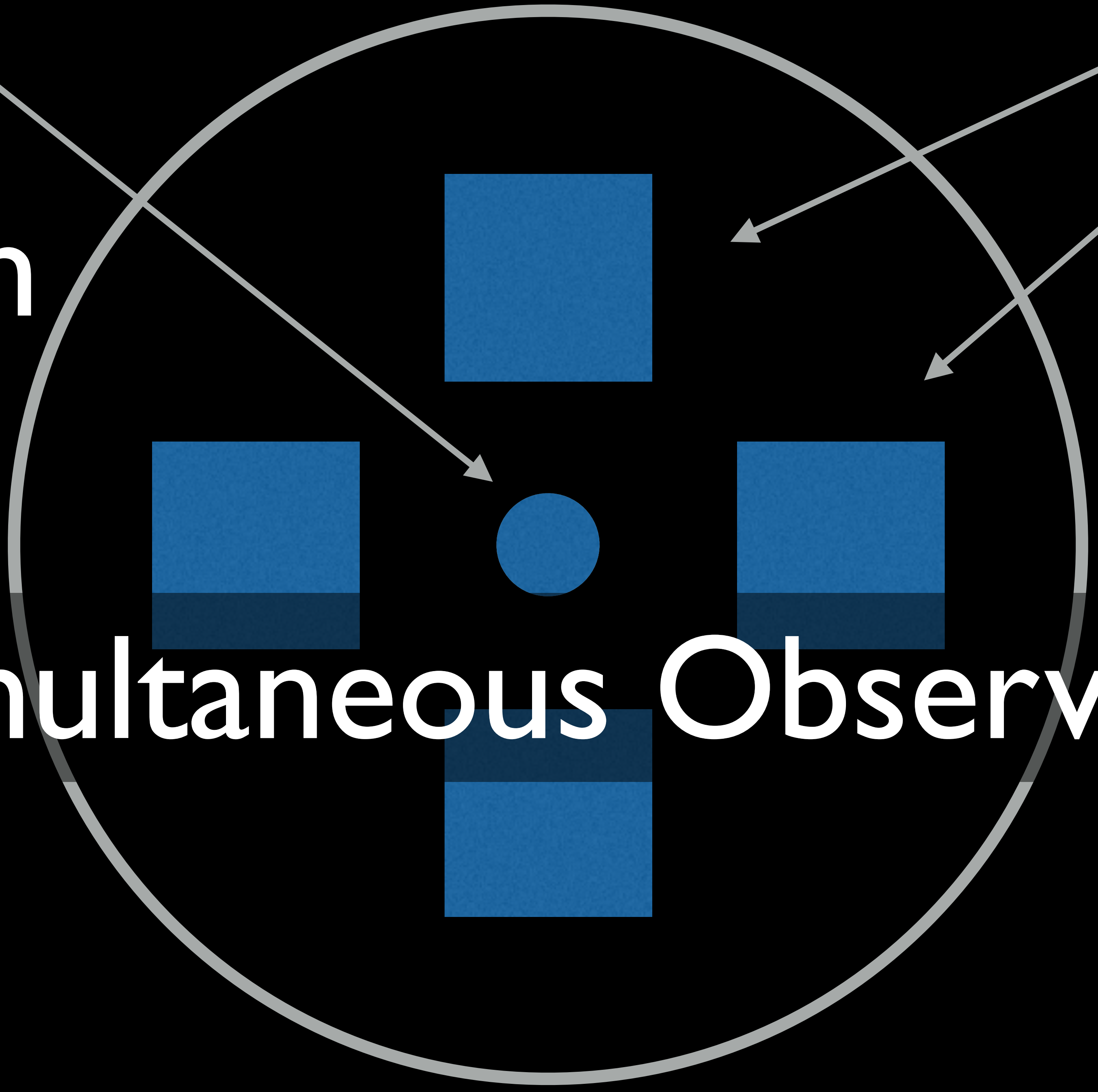
HDST Instruments

<u>Narrow Field</u>

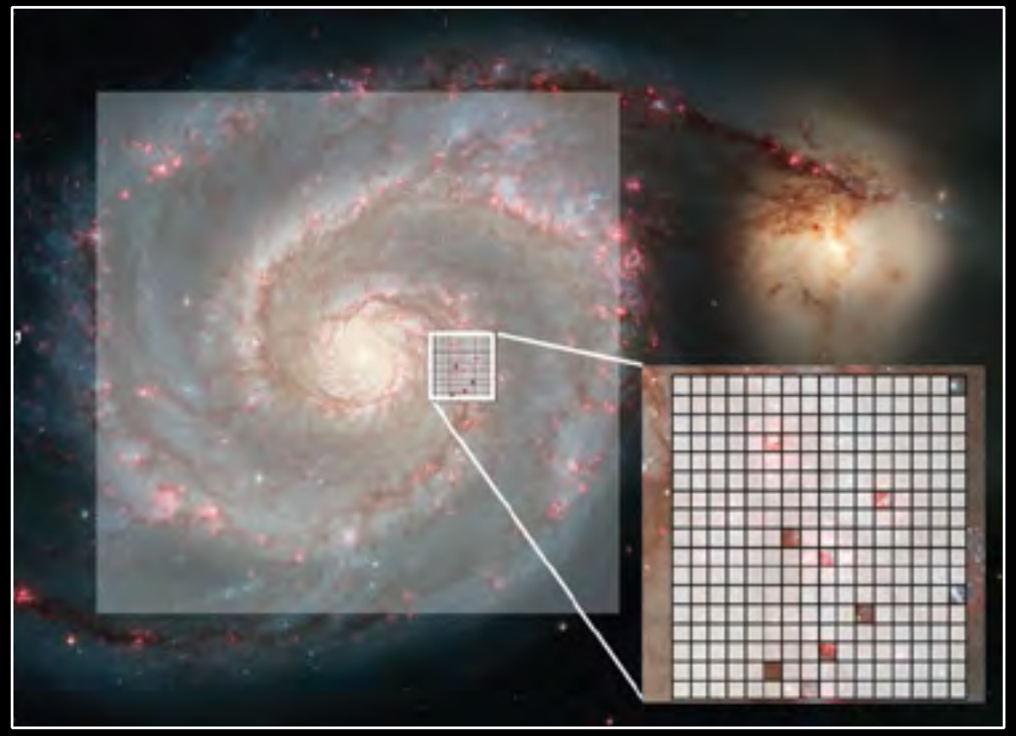
exoEarth
Starlight Suppression

<u>Wide Field</u>

Imaging

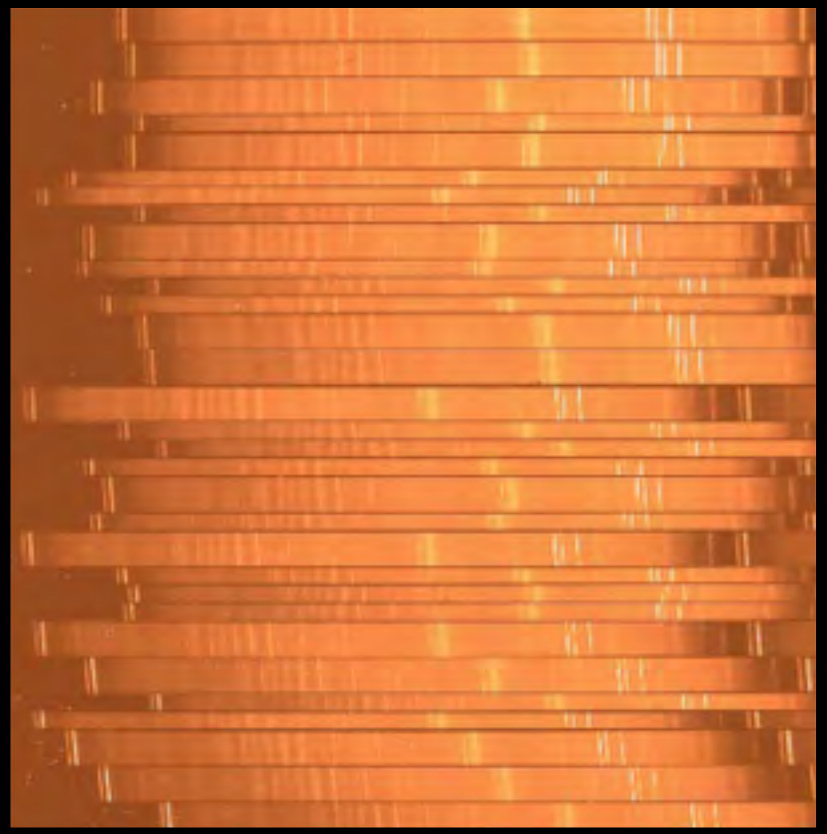


Simultaneous Observing

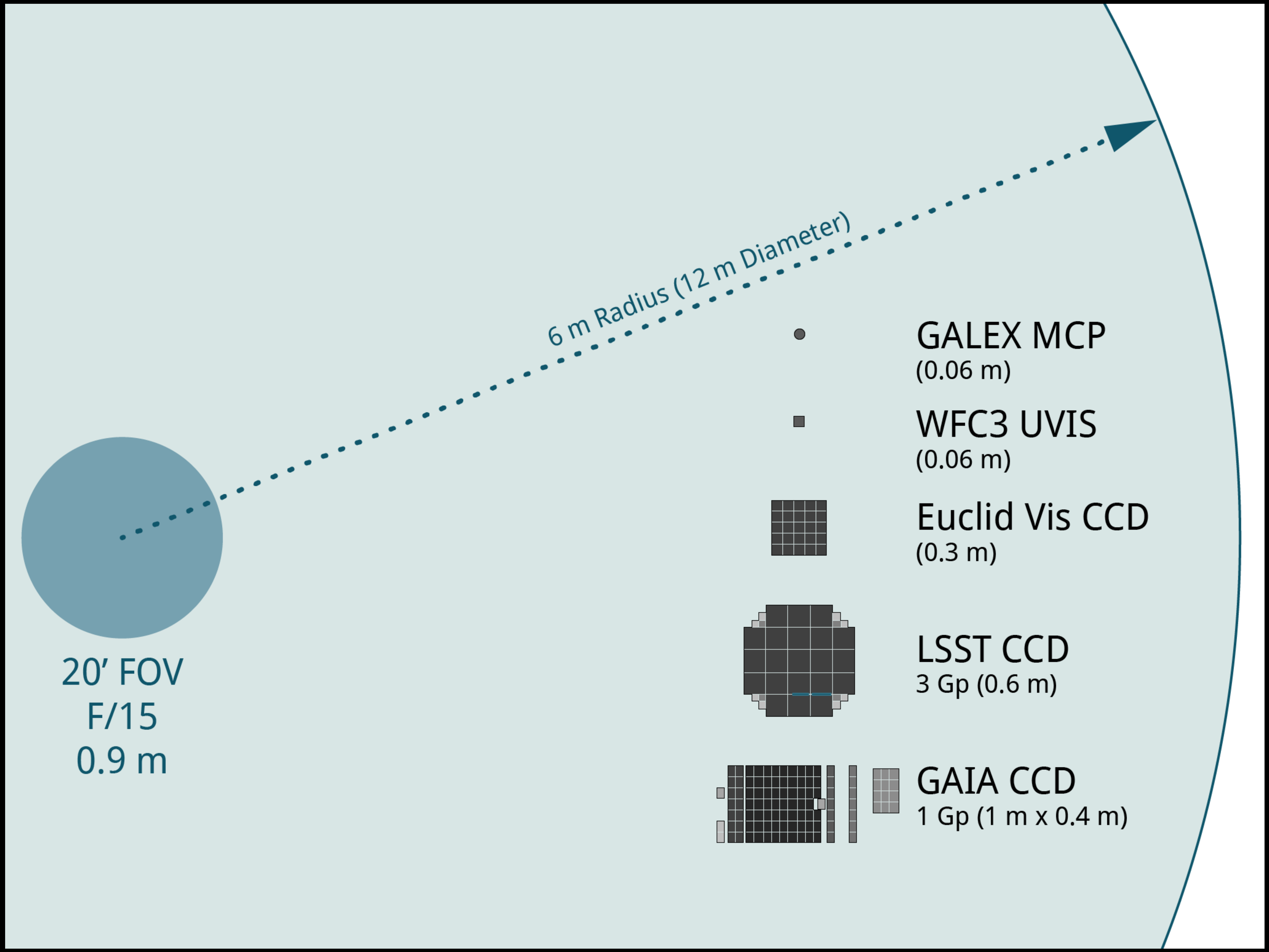


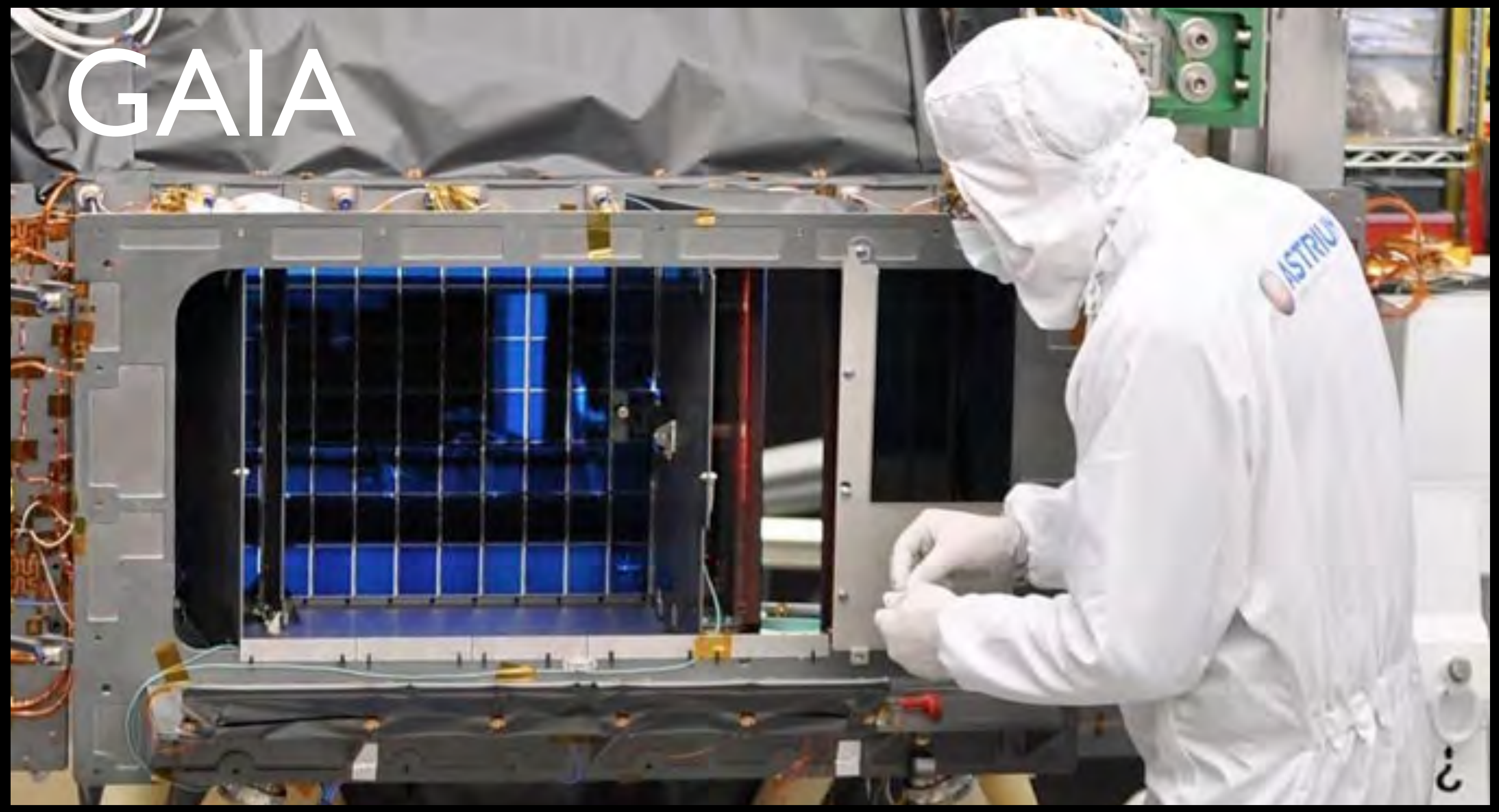
UV
Spectra

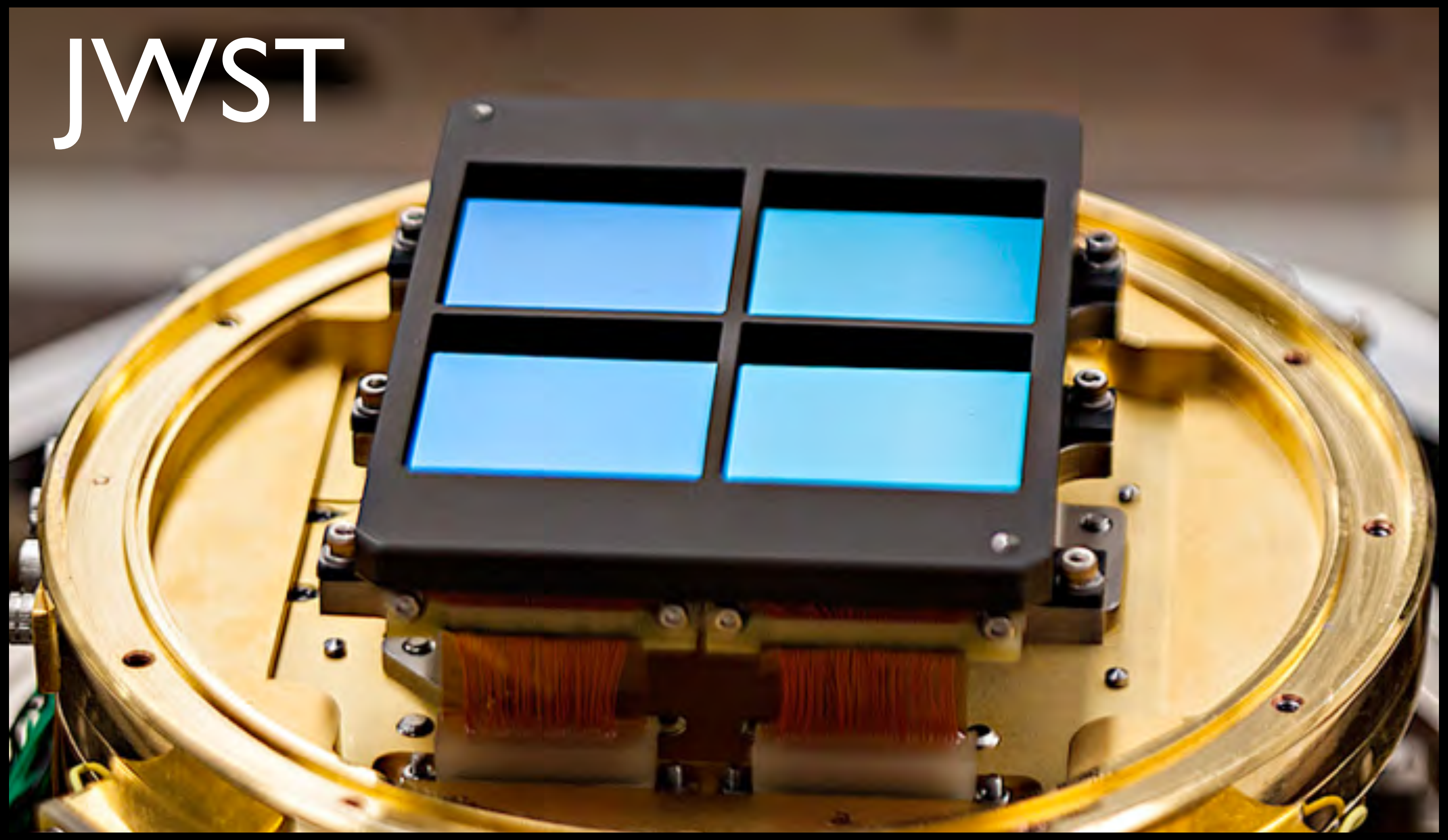
Spectra



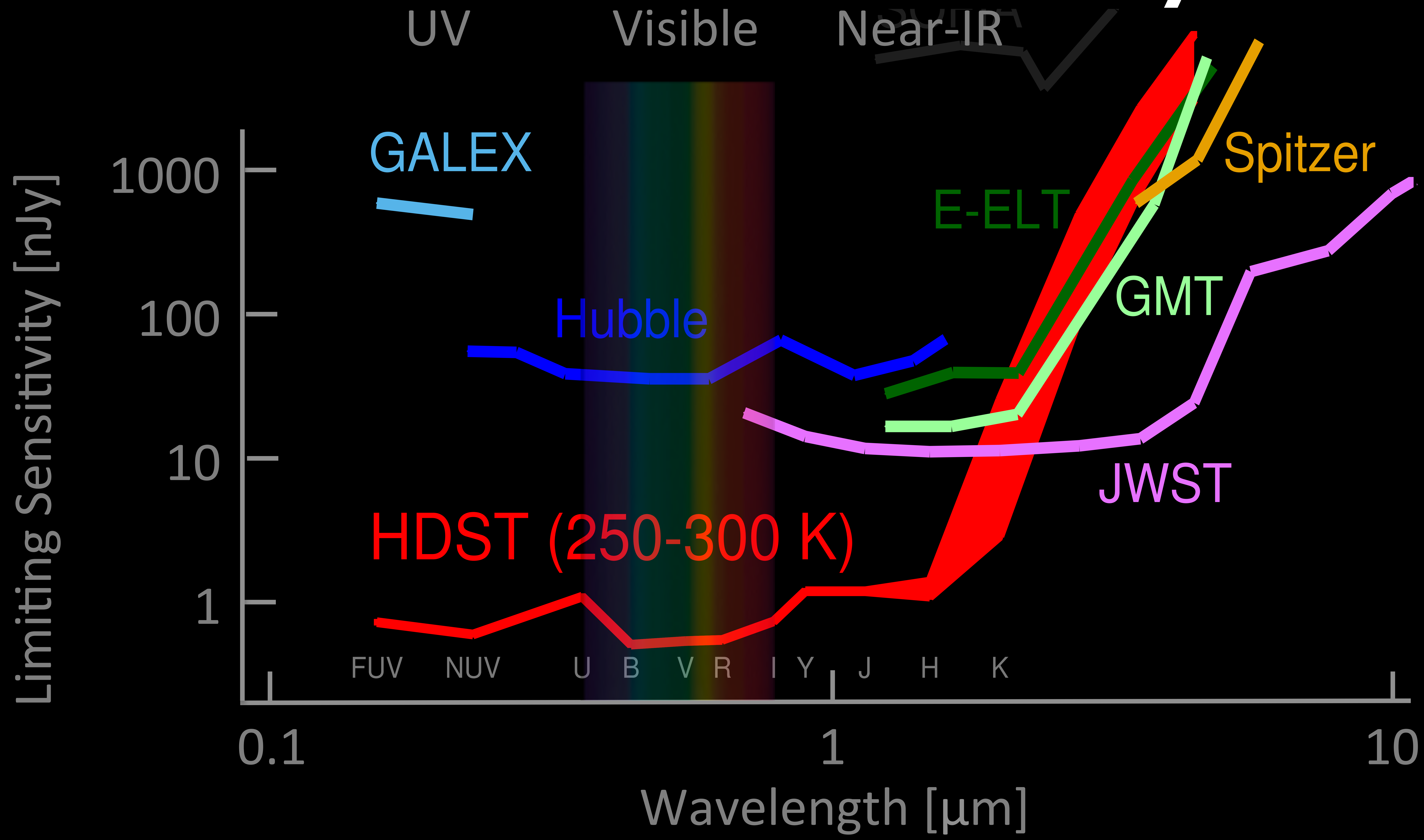
HDST Detectors



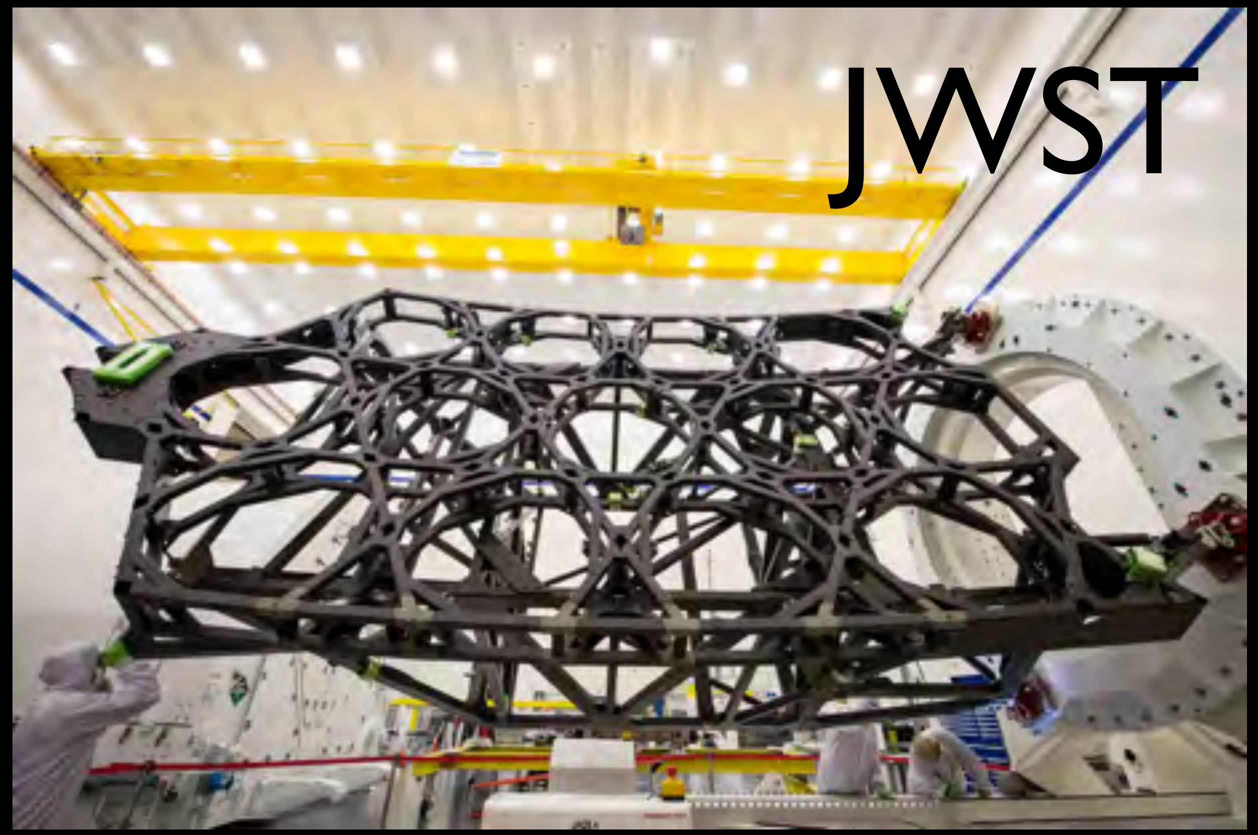


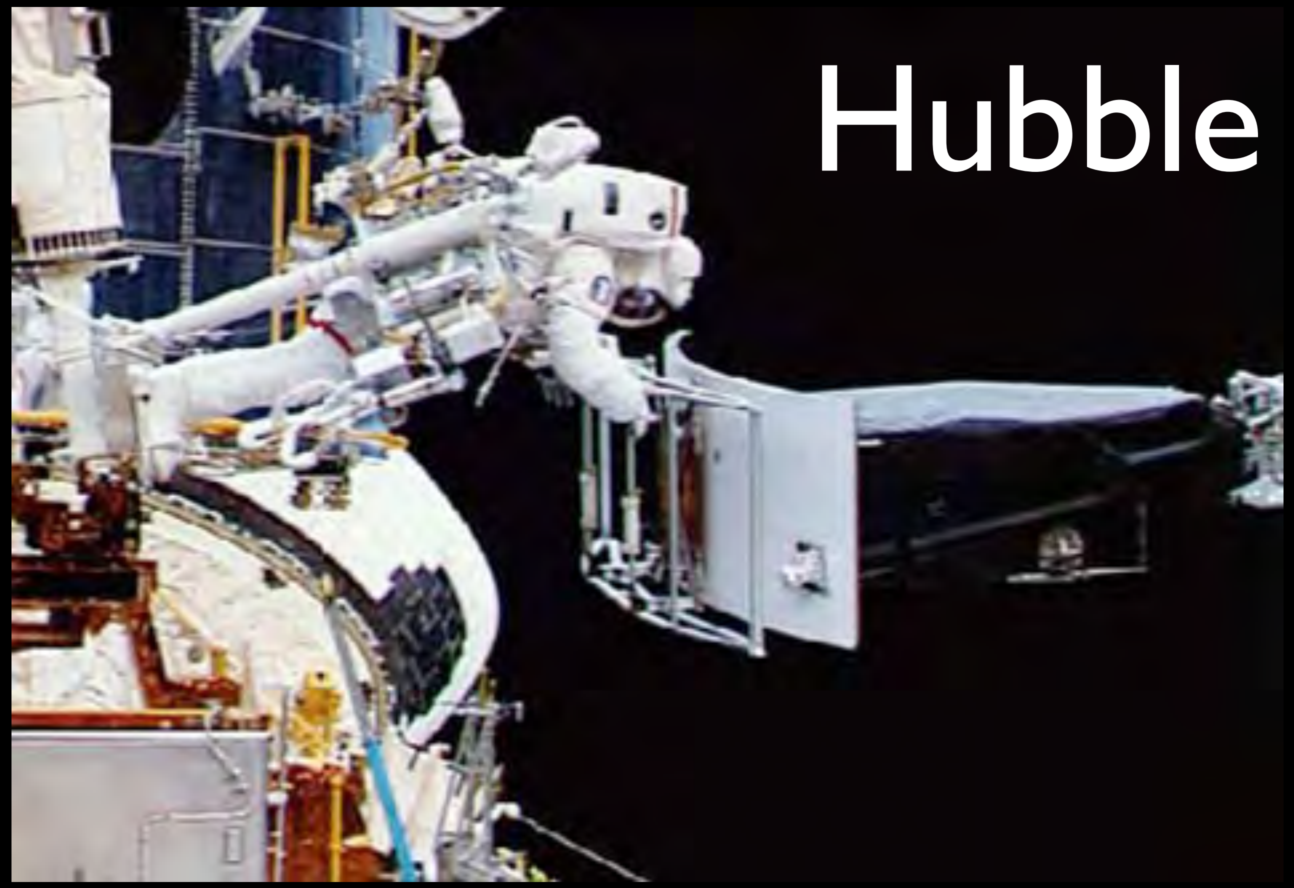


HDST Sensitivity

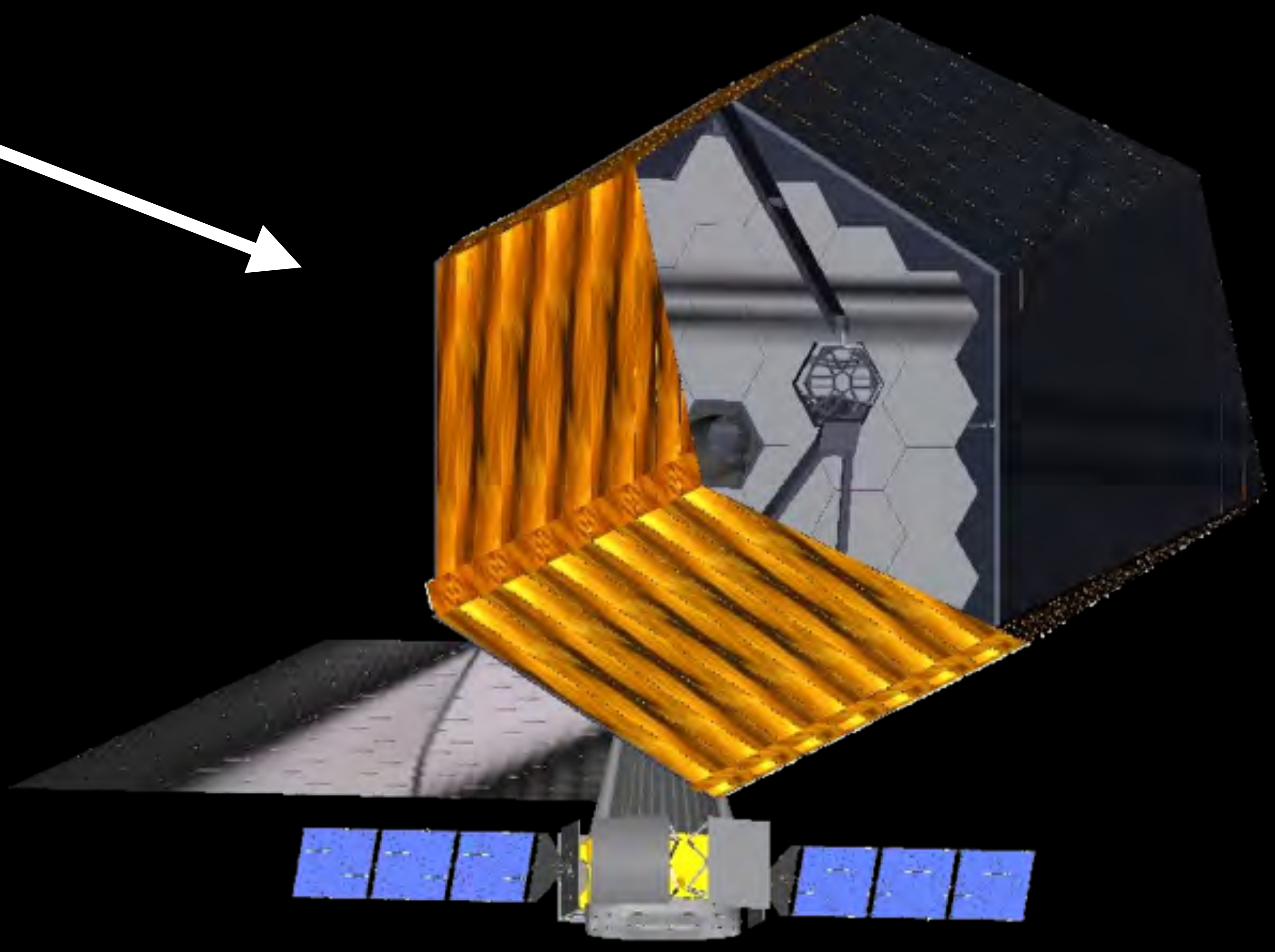


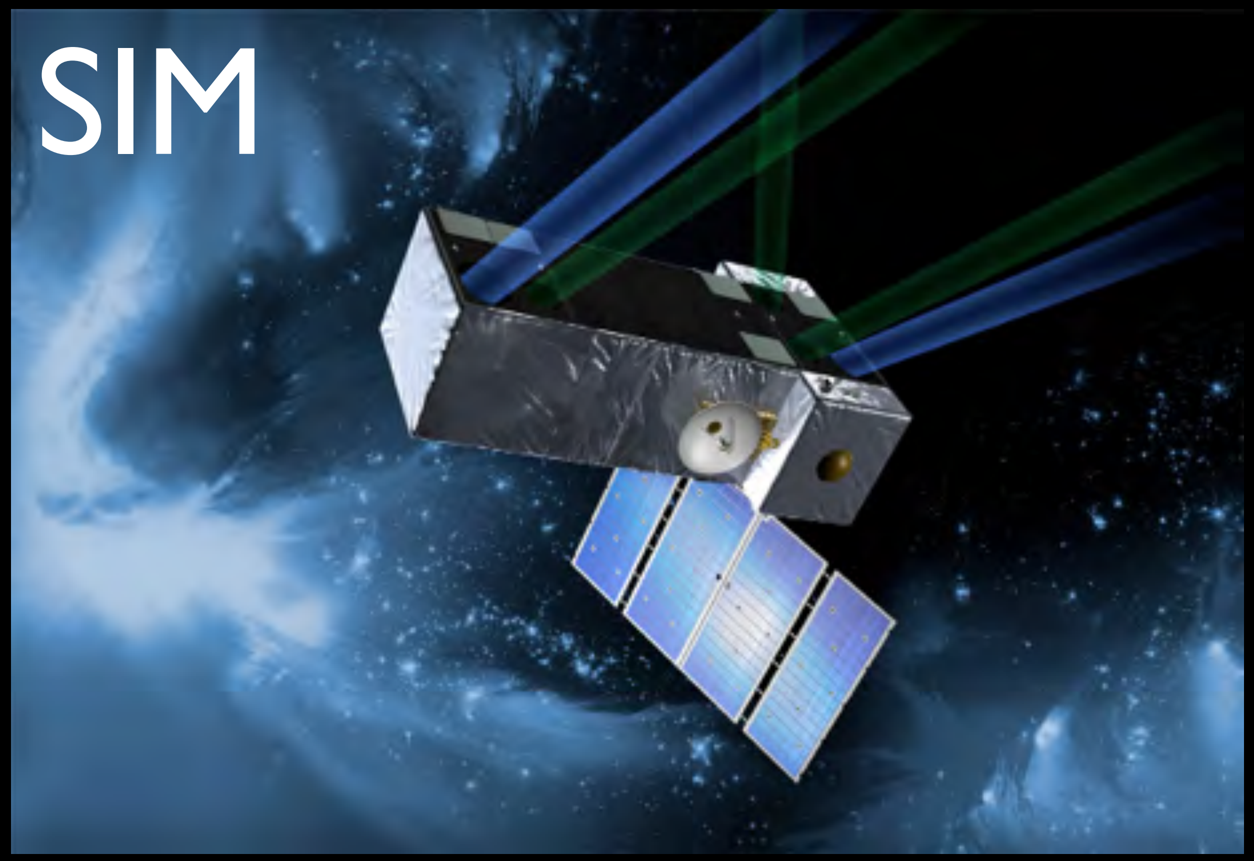
Dream Big, but Dream Smart





HDST

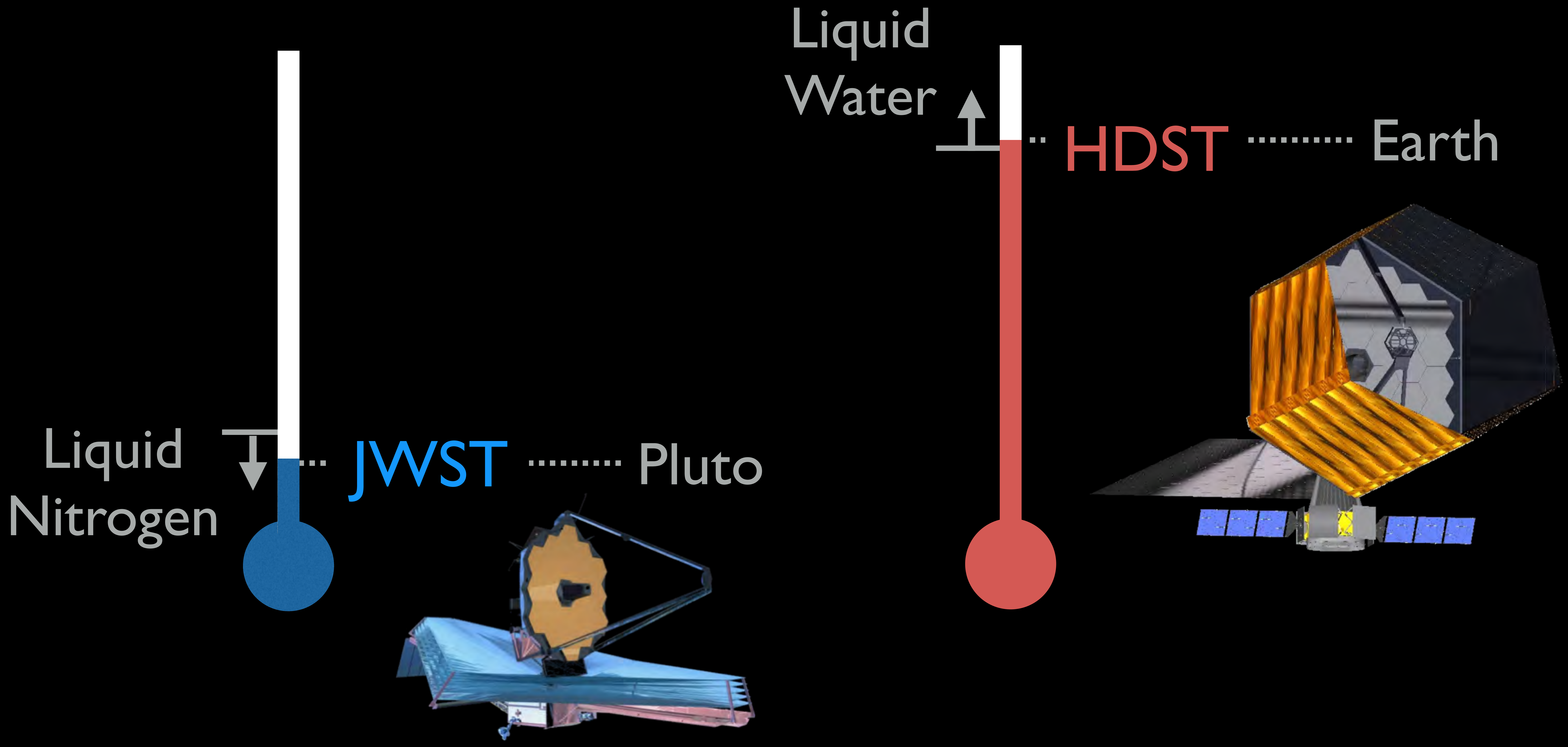




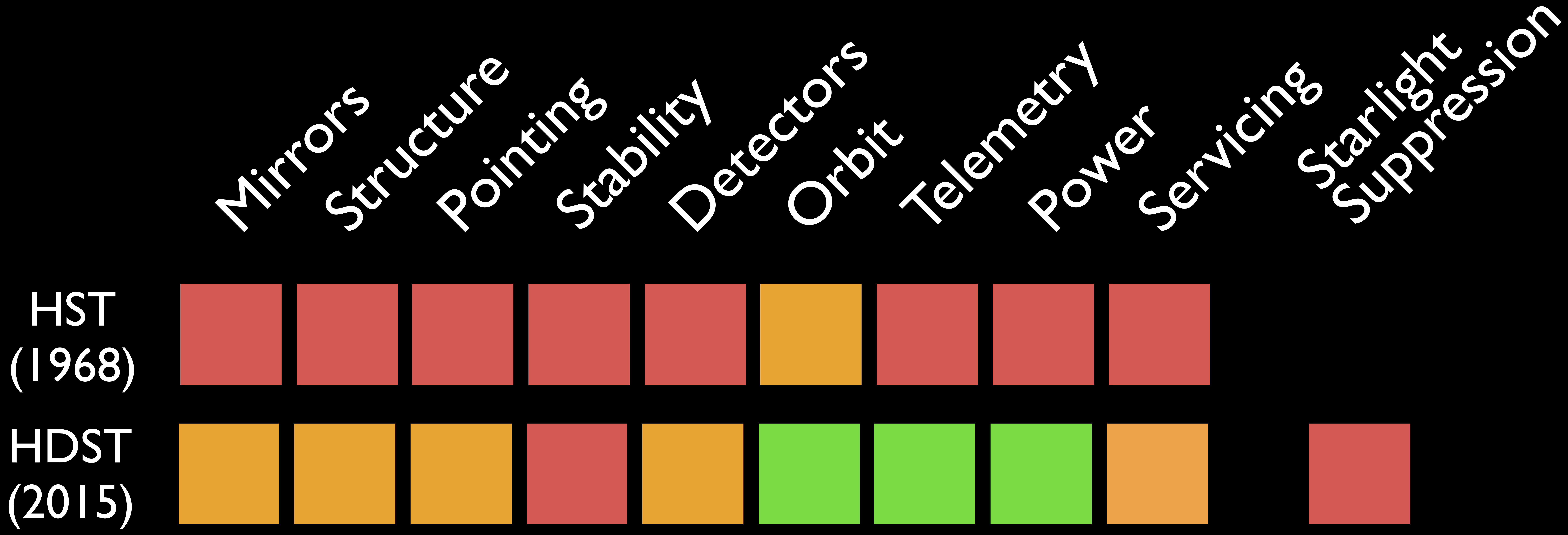
Flight Technologies

Technology Development

Room-Temperature Telescope

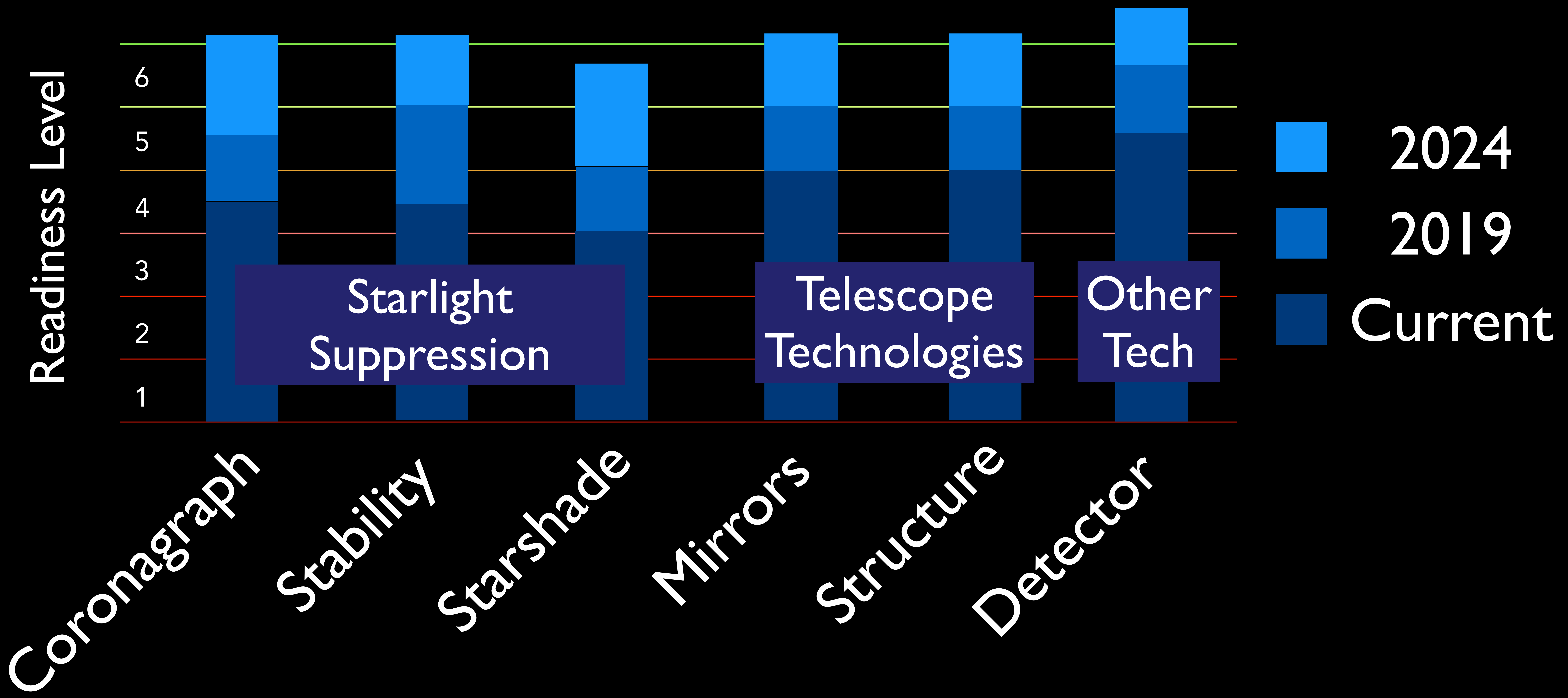


We Can Build It



15-20 years prior to launch

The Path Forward



From Cosmic Birth to Living Earths

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There is an exciting future for UVOIR Space Astronomy. To realize it will require bold, innovative steps. These steps are within reach.

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A 12m space observatory will have unique power to transform our understanding of life and its origins in the cosmos in ways that are unreachable by a smaller telescope in space or larger ones on the ground.