BIG BANG TO BIOSIGNATURES: THE LUVOIR MISSION CONCEPT

Bradley M. Peterson

Space Telescope Science Institute and
The Ohio State University

LIneA Webinar
1 February 2018

What is LUVOIR?

Crab Nebula with HST ACS/WFC
Credit: NASA / ESA

Large UV / Optical / Infrared Surveyor (LUVOIR)

A space telescope concept in tradition of Hubble

- Broad science capabilities
- Far-UV to Near-IR bandpass (100-2500 nm, T ≈ 270 K)
- 15.1-m aperture diameter (9.2-m also being studied)
- Suite of imagers and spectrographs
- Orbit: Sun-Earth L2
- Serviceable and upgradable
- Hubble-like guest observer program

“Space Observatory for the 21st Century”

Ability to answer questions we have not yet conceived

How we're doing the study

NASA Astrophysics is funding four large mission concept studies starting in Jan 2016 to prepare for Astro2020 Decadal Survey.

Three of these were identified in 2013 NASA Astrophysics 30-year Roadmap "Enduring Quests, Daring Visions"

- LUVOIR
- Origins Space Telescope (formerly Far-IR Surveyor)
- Lynx (formerly X-Ray Surveyor)

A fourth concept acknowledges growth of exoplanetary science (from the 2010 Decadal)

- Habitable Exoplanet Imaging Mission (HabEx)

How we're doing the study

Science and Technology Definition Team (STDT)

- 24 voting members from community
- 10 non-voting reps. of international space agencies

Six Community Working Groups

- Exoplanets
- Cosmic Origins
- Solar System
- Simulations
- Communications
- Technology

Five Instrument Teams

STDT voting members

Debra Fischer
(Yale)

Brad Peterson
(Ohio State / STScI)

Jacob Bean
(Chicago)

Daniela Calzetti
(U Mass)

Rebekah Dawson
(Penn State)

Courtney Dressing
(Berkeley)

Lee Feinberg
(NASA GSFC)

Kevin France
(Colorado)

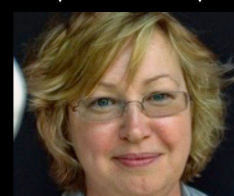
Olivier Guyon
(Arizona)

Walter Harris
(Arizona / LPL)

Mark Marley
(NASA Ames)

Leonidas Moustakas
(JPL)

John O'Meara
(St. Michael's)



Vikki Meadows
(Washington)

Ilaria Pascucci
(Arizona)

Marc Postman
(STScI)

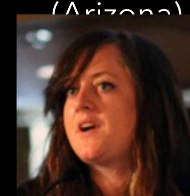
Laurent Pueyo
(STScI)

David Redding
(JPL)

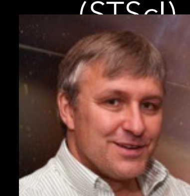
Jane Rigby
(NASA GSFC)

Aki Roberge
(NASA GSFC)

David
Schiminovich
(Columbia)



Britney Schmidt
(Georgia Tech)



Karl Stapelfeldt
(JPL)

Jason Tumlinson
(STScI)

International Representatives

Martin Barstow
(UK)

Lars Buchhave
(Denmark)

Nicholas Cowan
(Canada)

José Dias do
Nascimento Jr
(Brazil)

Marc Ferrari
(France)

Ana Gomez
De Castro
(Spain)

Kevin Heng
(Switzerland)

Thomas Henning
(Germany)

Antonella Nota
(ESA)

Takahiro Sumi
(Japan)

First Principle: Make It Big

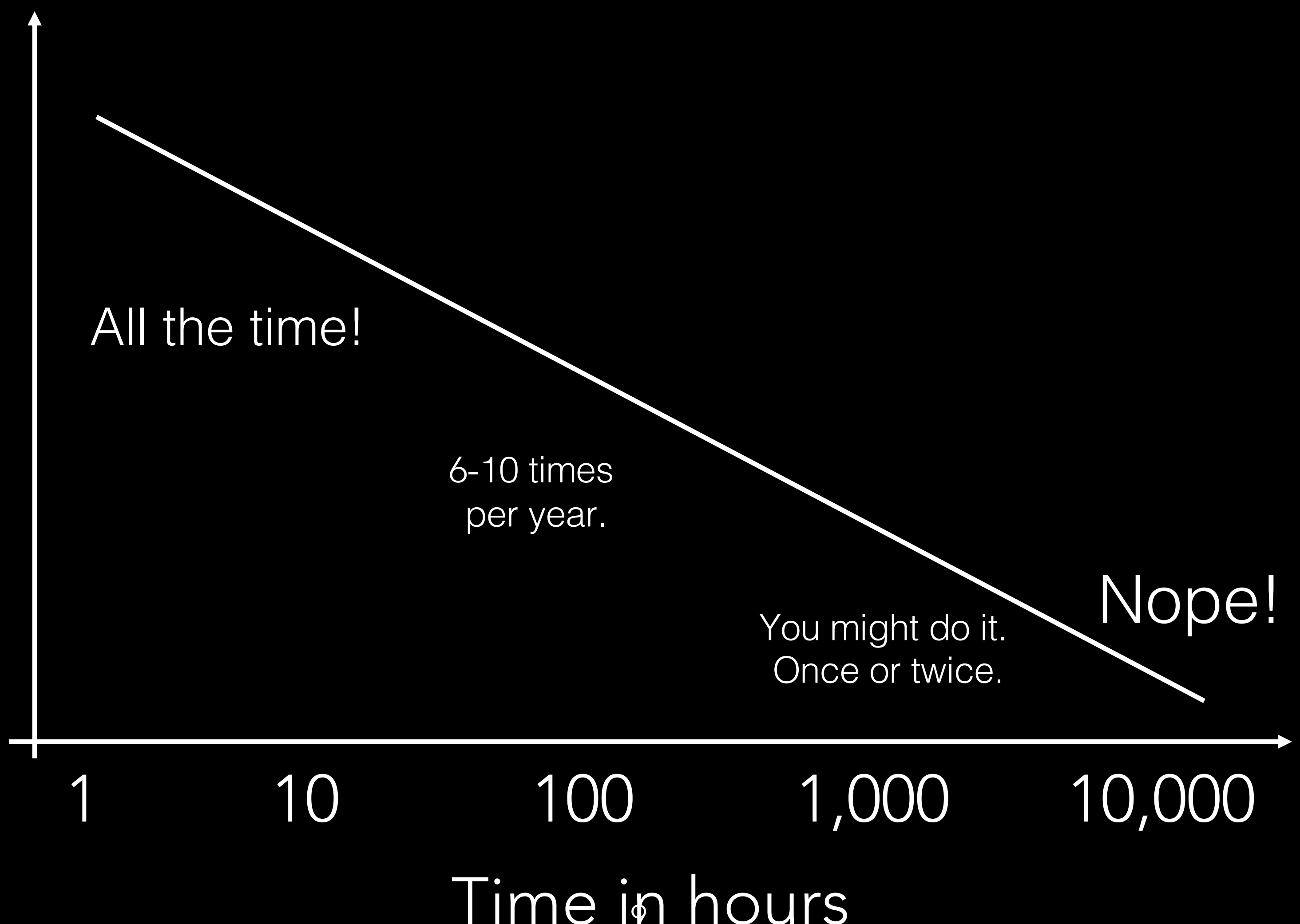
This will be *the* space telescope for the next half century. Don’t shortchange future astronomers by making it too small.

Make the impossible possible.

DOING THE IMPOSSIBLE

- Definition 1: Perform a measurement or make a discovery that has never been made
- Definition 2:   Turn a program that requires a massive investment into one which is routine

WHAT DOES IT MEAN TO "DO THE IMPOSSIBLE?"



IMPLICATIONS FOR APERTURE

- A science case “requiring” 10+ meter apertures might be met with the retort “we can do that with 6 meters!”
- Sometimes this is correct! You can, but you probably won’t
- Smaller apertures take longer times, reducing the number of large investments you can make, shrinking the total discovery space

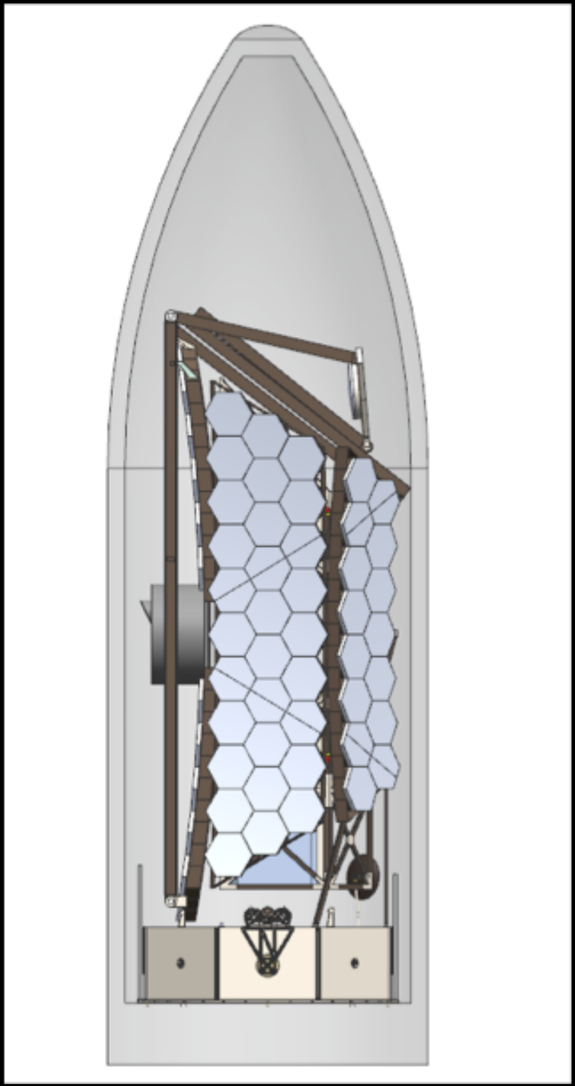
IMPLICATIONS FOR APERTURE

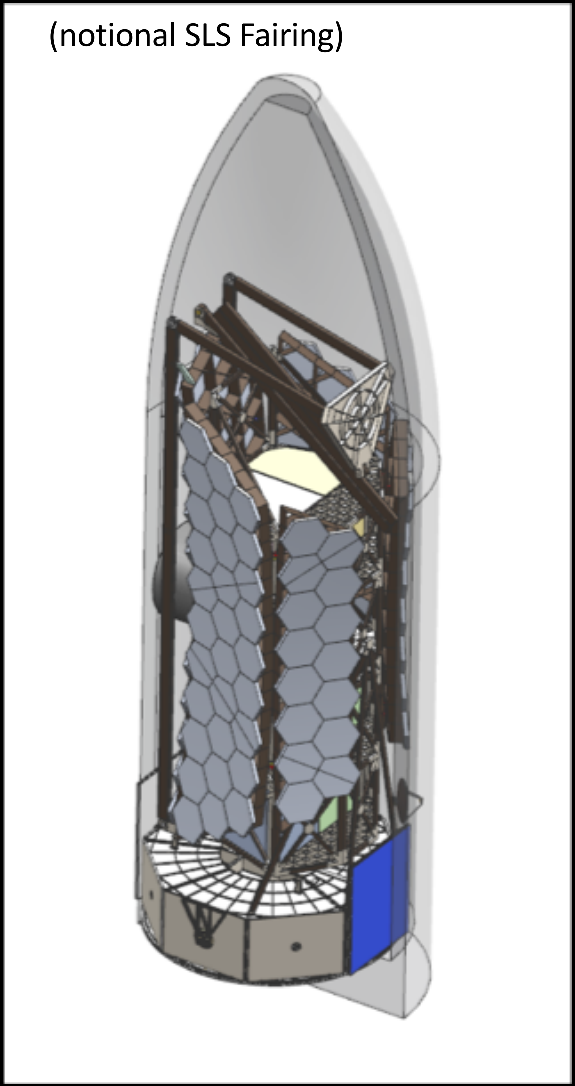
- We should *not* only be comparing raw capacity when we compare apertures
- We *should* also compare total science programs considered holistically bound by the ultimate limited resource: mission lifetime

DOING THE IMPOSSIBLE WITH LUVOIR

	Falcon Heavy	SLS Block 2	SLS Block 1	Saturn V	STS
Mass to LEO (mT)	63.8	130	105	140	27.5
Mass to SE L2 (mT)	14	50	38		

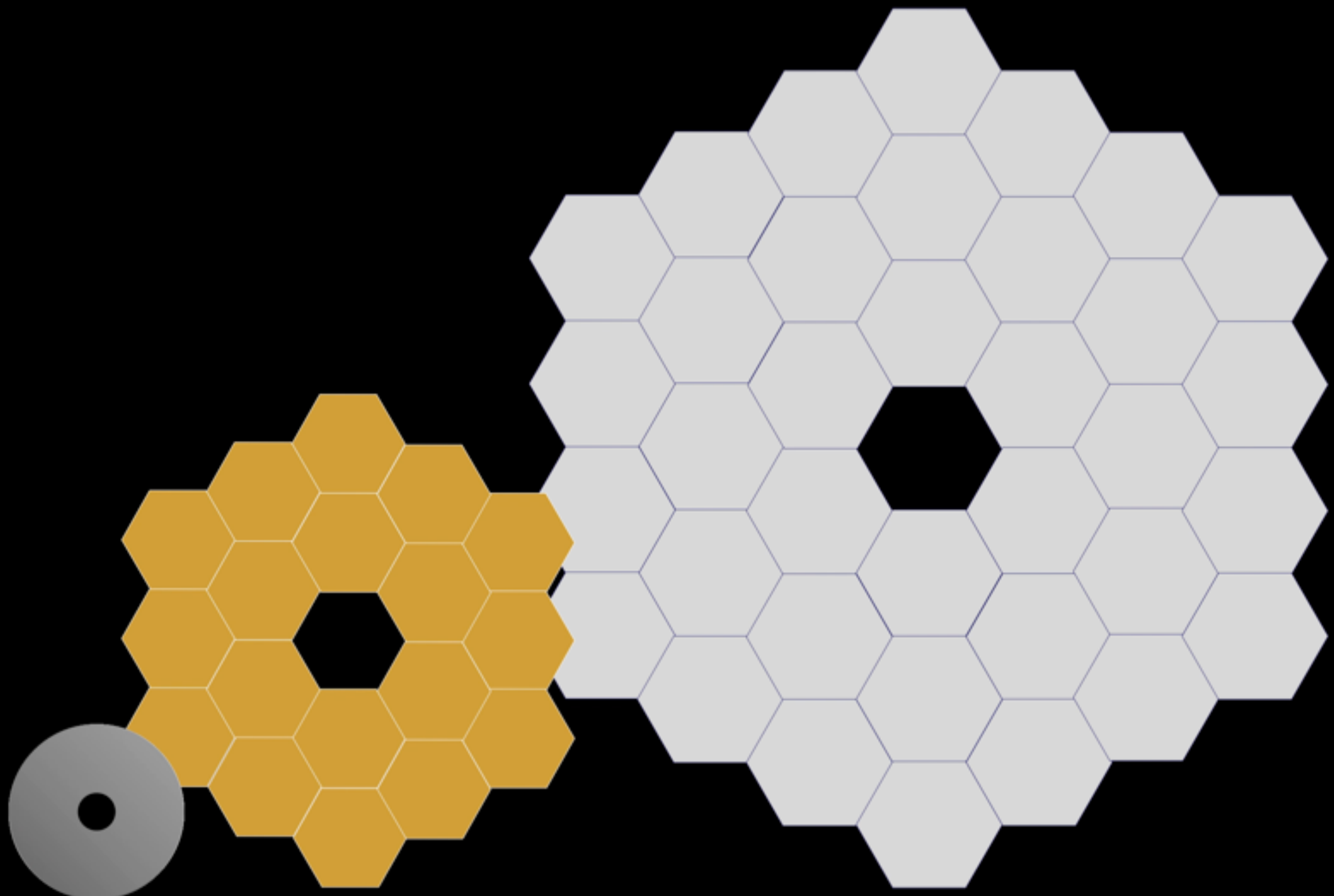
Mechanical Views of Architecture A:



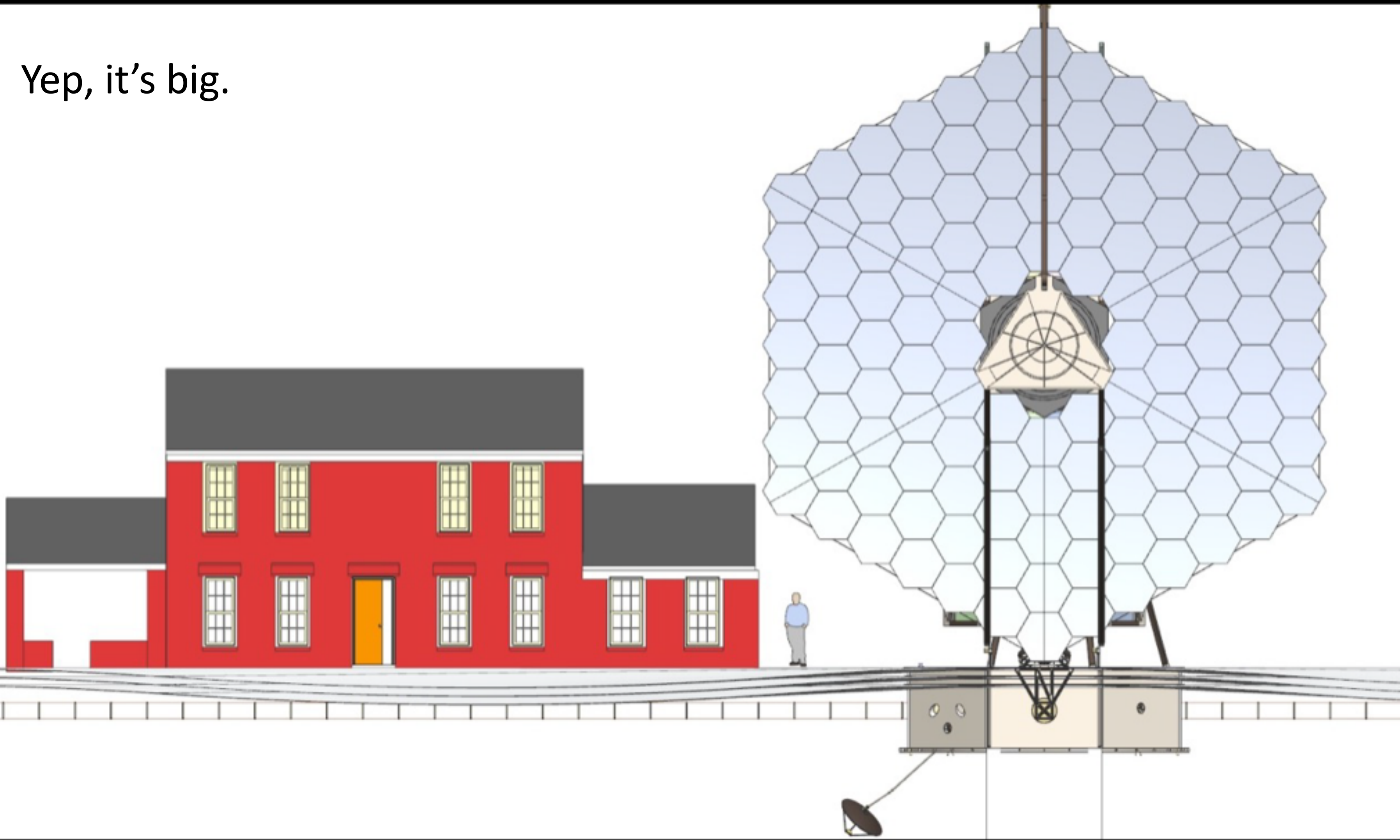


[illegible] Solar Array & Thermal Radiator

Imagine astronomy with LUVOIR …



Yep, it's big.



- Architecture A (first half of 2017)
  - 15.1-m diameter aperture: segmented, on-axis primary, SLS launch
  - Four instrument bays:
    - Optical / NIR Coronagraph (ECLIPS)
    - UV Multi-object Spectrograph (LUMOS)
    - High-definition Imager (HDI; will also perform guiding / wavefront sensing)
    - *Pollux: UV Spectro-polarimeter and High-Resolution Spectrograph (CNES Contributed)*
- Architecture B (late 2017 into 2018)
  - 9.2-m diameter aperture: segmented, on-axis primary, EELV launch
  - Three instruments to be studied (assumption that HDI and ONIRS are the most scalable of the instruments):
    - Optical / NIR Coronagraph (B)
    - UV Multi-object Spectrograph ("LUMOS")
    - Optical / NIR Multi-resolution Spectrograph (ONIRS)

The LUVOIR instruments

Observational challenge

Imaging wide fields at high resolution

Solution

High-Definition Imager

2 x 3 arcmin field-of-view

Bandpass: 0.2 µm to 2.5 µm

High precision astrometry capability
(measure planet masses, etc.)

Heritage: HST WFC3

HST Wide Field Camera 3

What Impossible Things Can I Do with HDI?

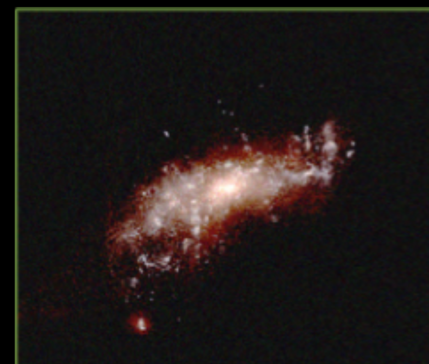
- Structure of high-mass galaxies at all redshifts
- Detection of smallest dwarf galaxies at high redshift
- Stellar populations through the Local Group
- Cepheid distances as far as Coma
- Proper motions of stars in nearby galaxies
- Fly-by quality imaging of outer planets

REDEFINING "LOW MASS"

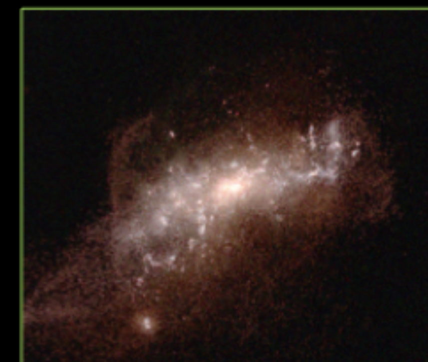
z=2 galaxy with 10^9 solar masses — 500 ksec integration

2.4 m

4 m



9.3 m: LUVOIR-B



15.1 m: LUVOIR-A

z=2 galaxy with 10^6 solar masses — 500 ksec integration

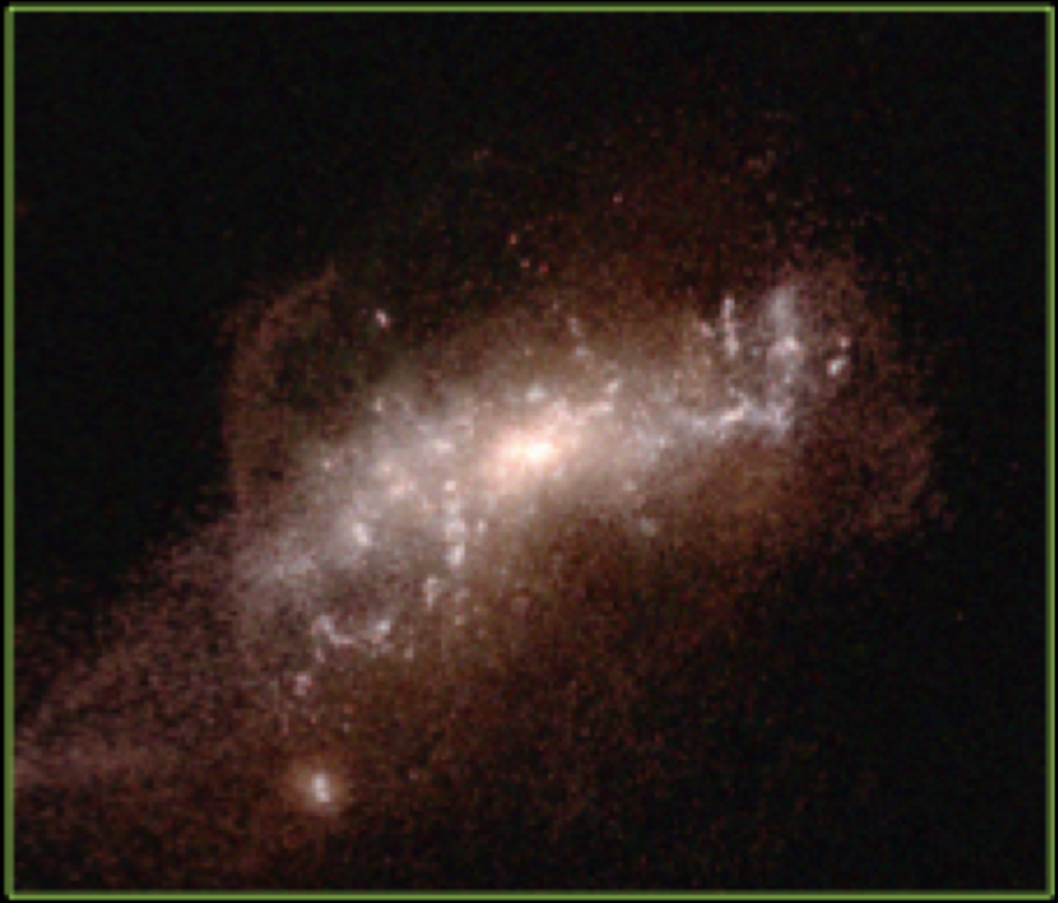
2.4 m

4 m

9.3 m LUVOIR-B

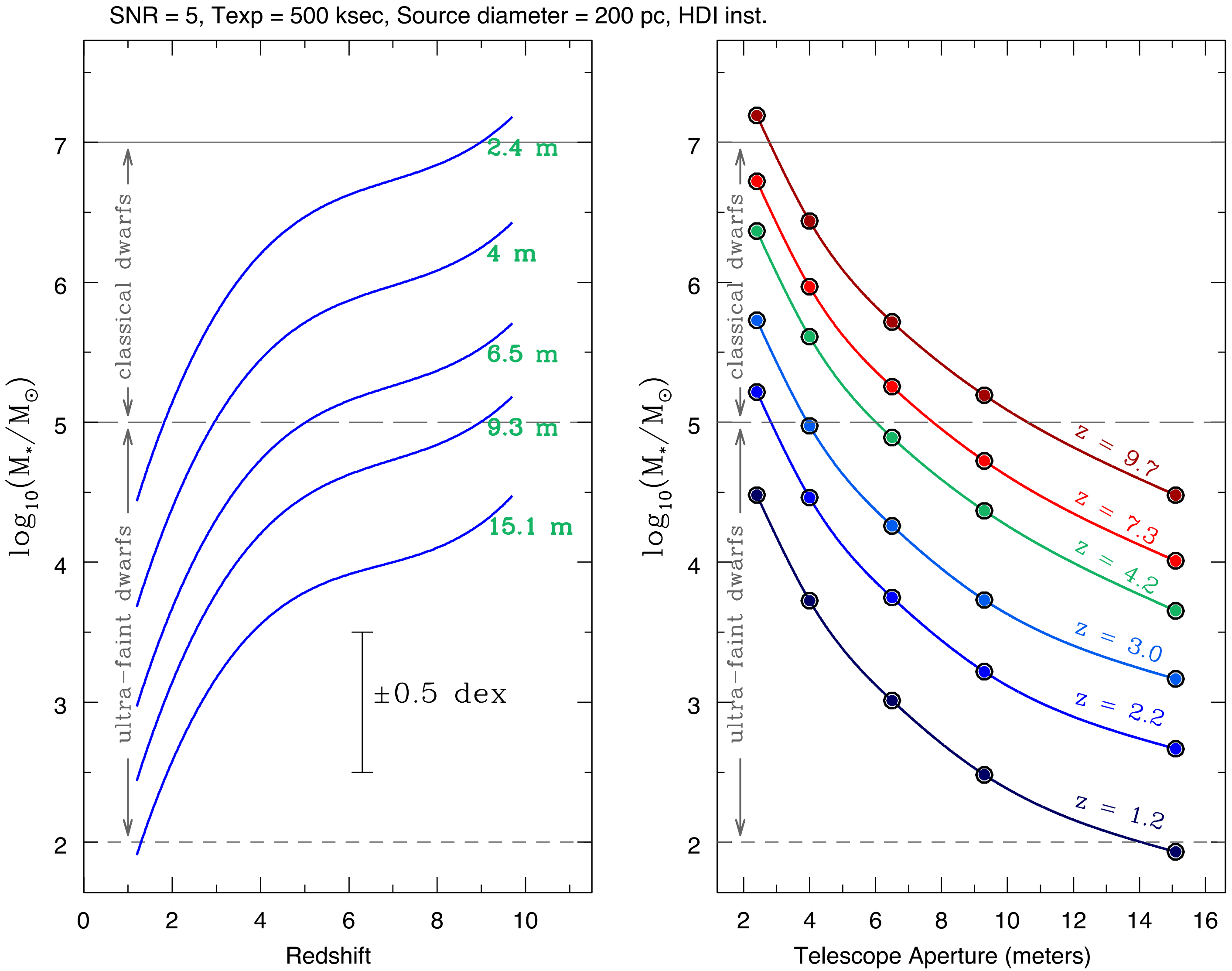
15.1 m LUVOIR-A

Courtesy G. Snyder

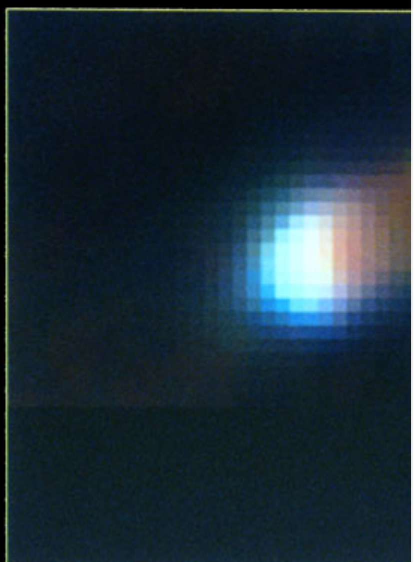


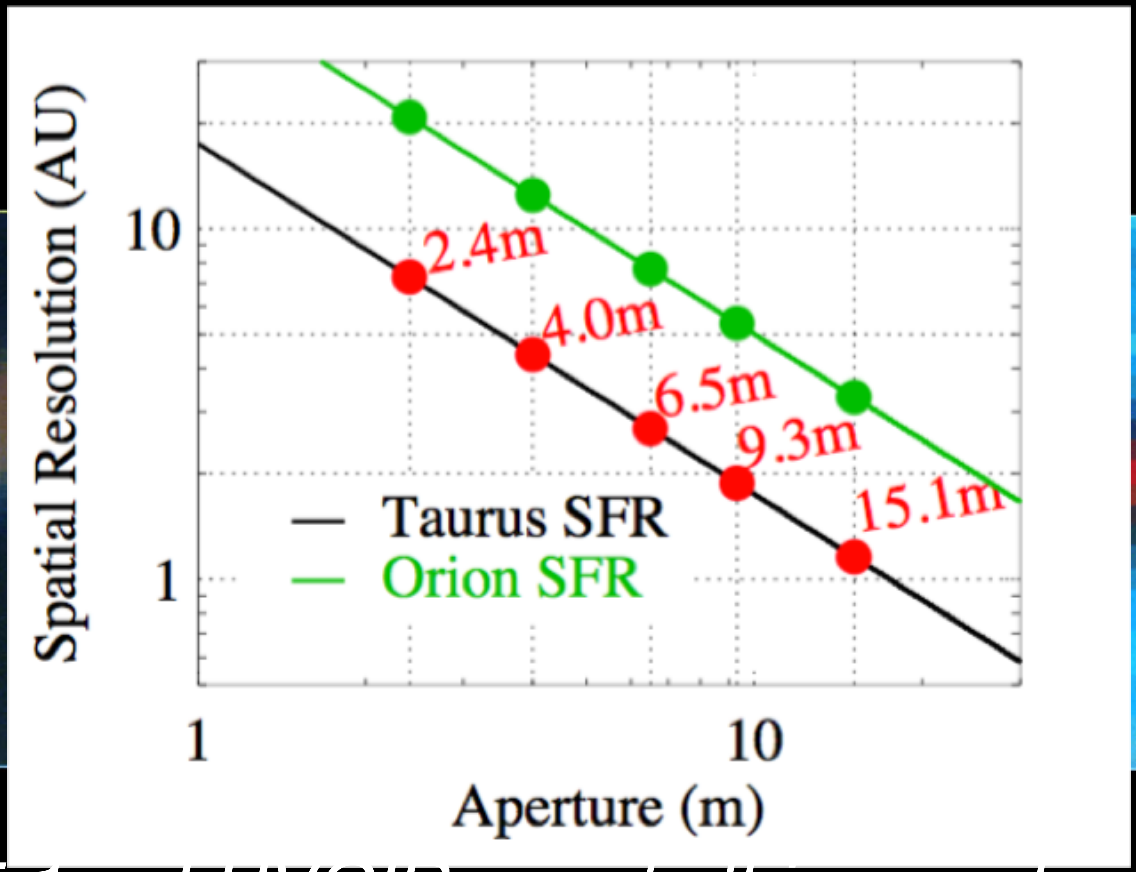
15.1 m: LUVOIR-A

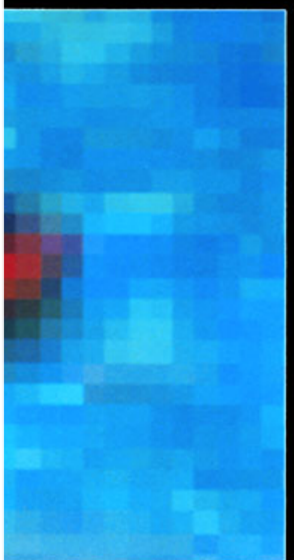
With a 15.1-m LUVOIR, you can detect the faintest dwarf galaxies at high-*z*



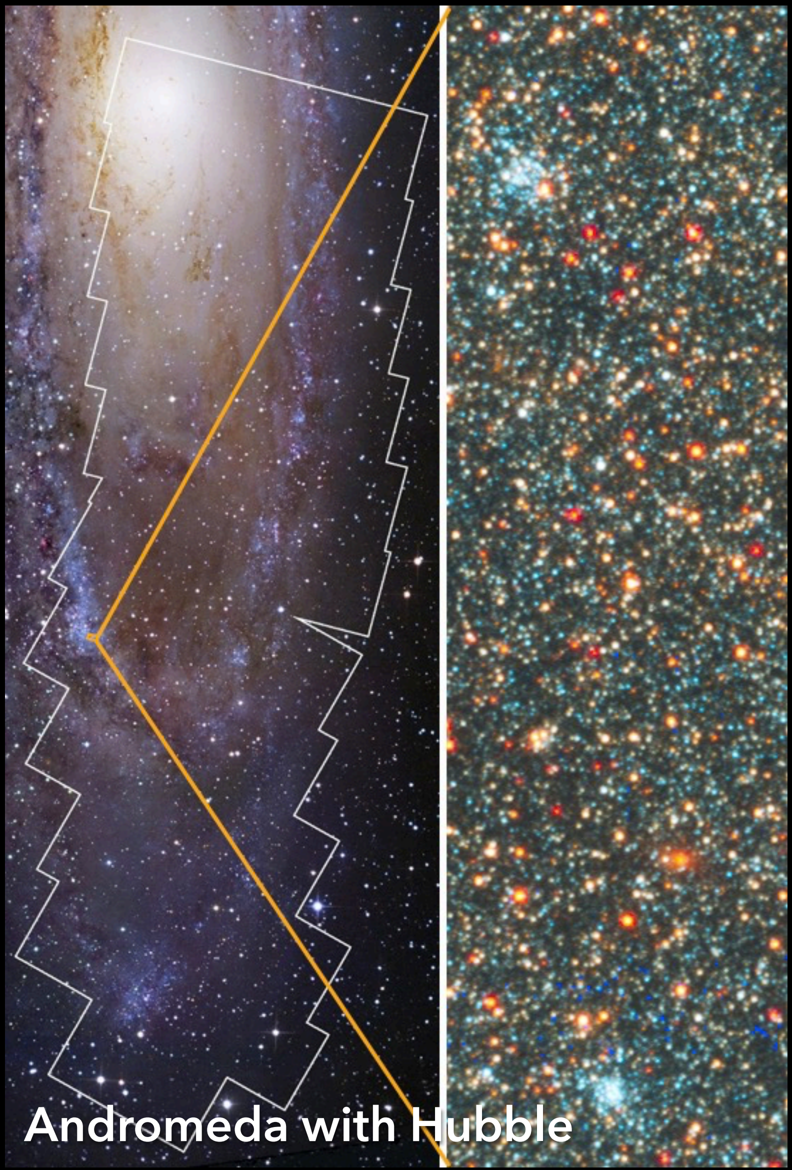
FROM NURSERIES TO CRADLES





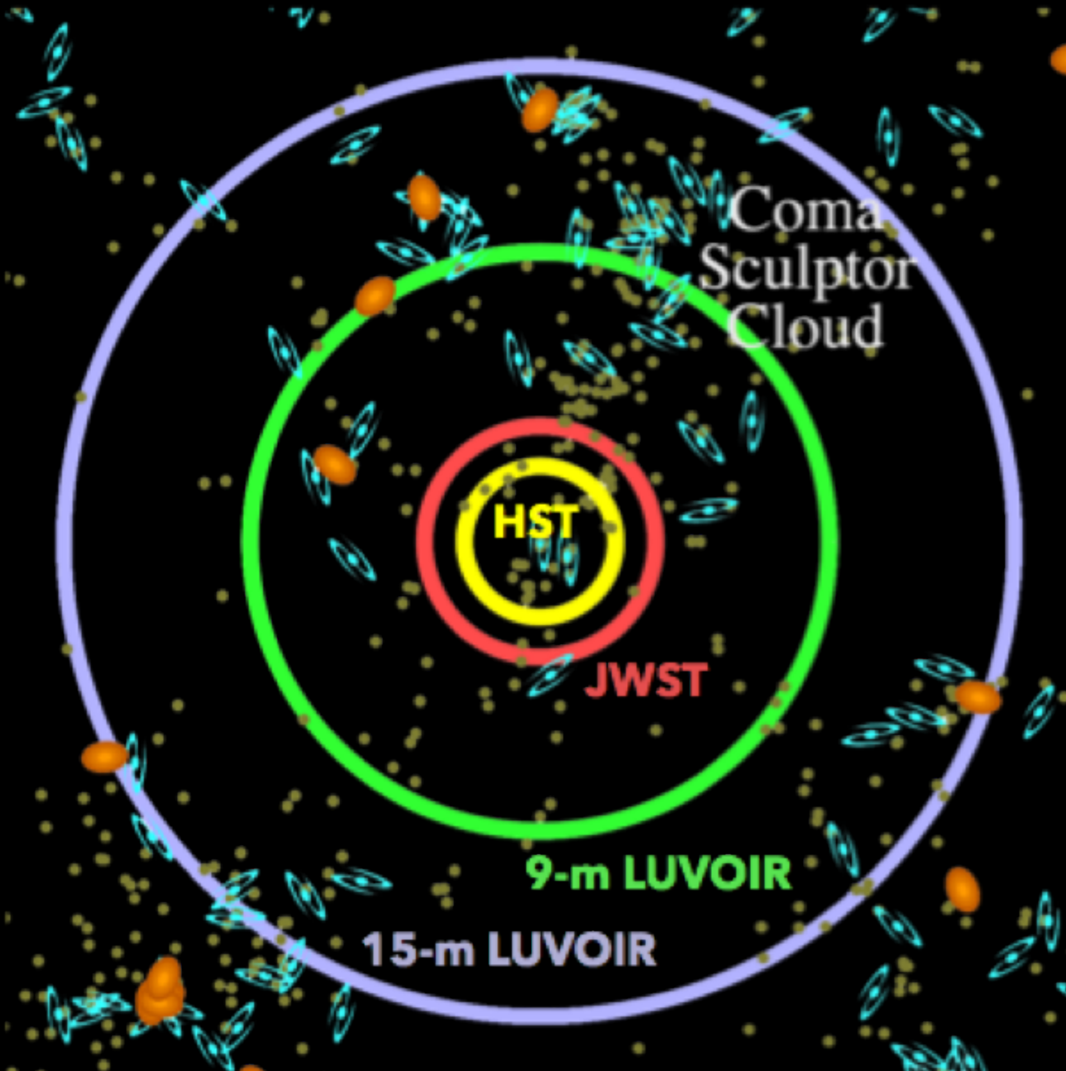


A 15.1 m LUVOIR can do this anywhere in the Milky Way



With LUVOIR, you can make color-magnitude diagrams to below the main-sequence turn-off anywhere in the Local Group.

STELLAR HISTORY NEAR AND FAR



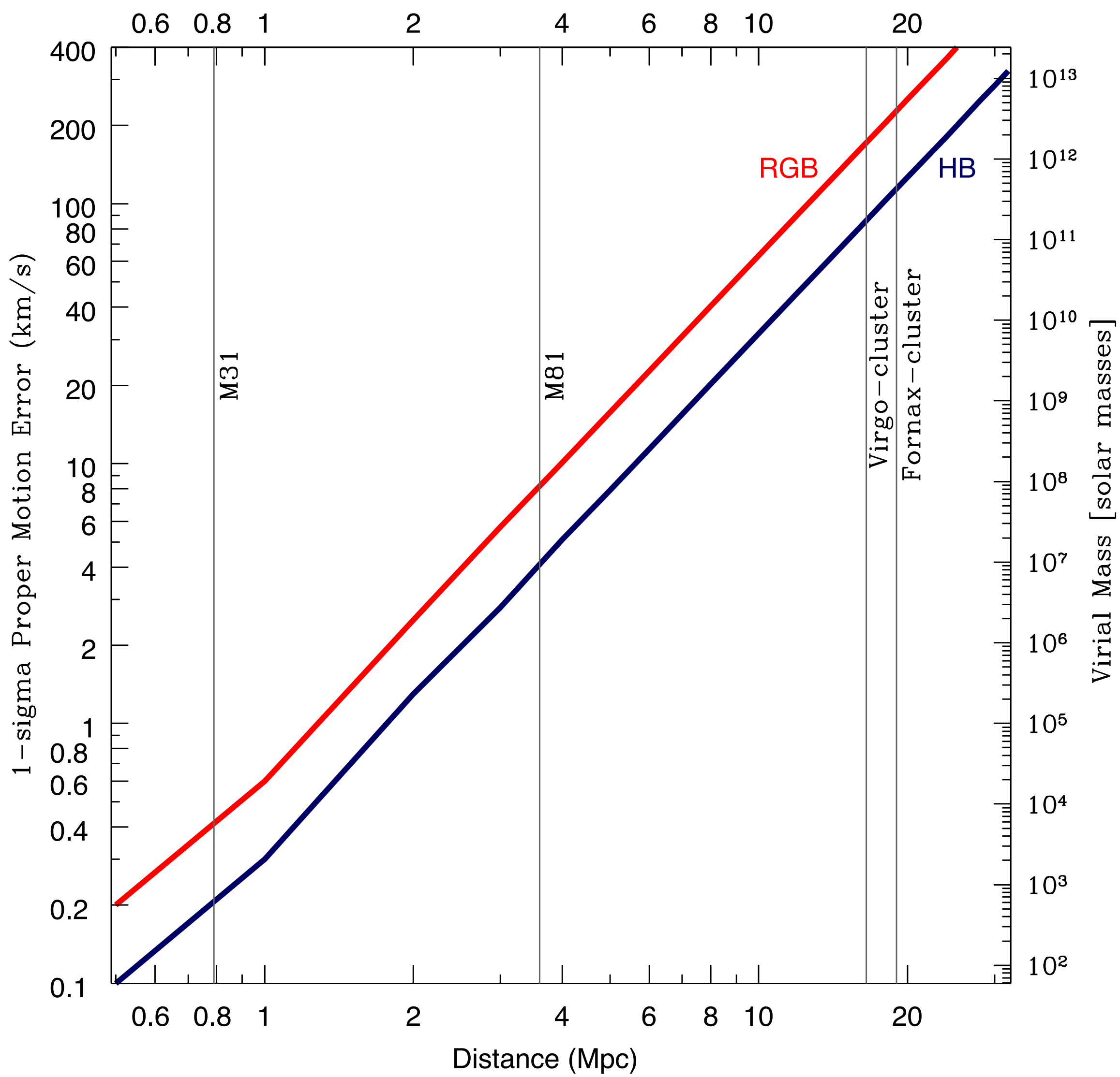
Map of Galaxies within 12 Mpc of Our Galaxy

Distance where a solar-mass star can be detected.

LUVOIR is needed to reach the nearest giant ellipticals.

= Large Elliptical Galaxy
= Large Spiral Galaxy
= Dwarf Galaxy

Stellar proper motions can reveal dark-matter distribution in galaxies

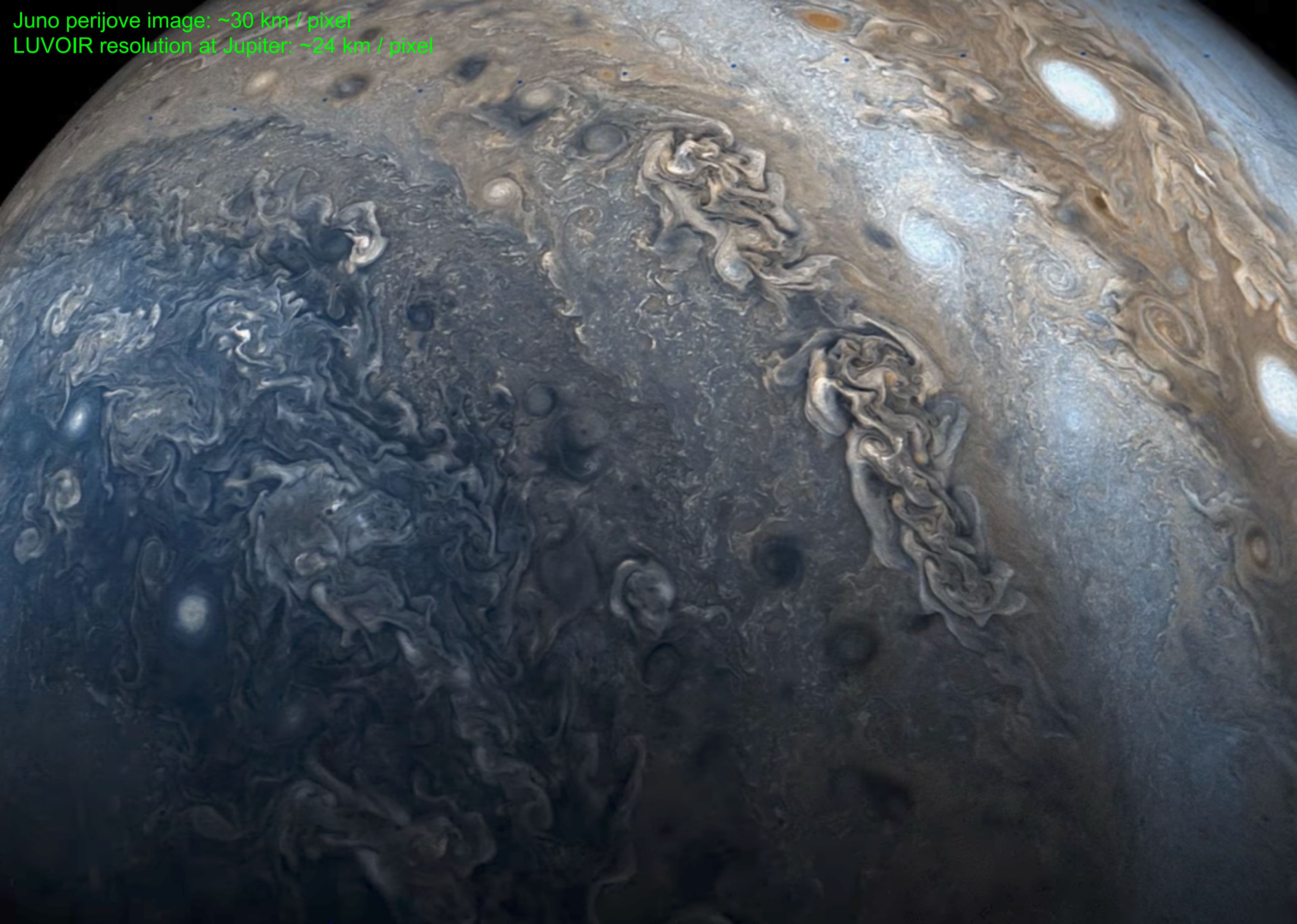


Imagine planetary science with LUVOIR ...

Pluto with HST

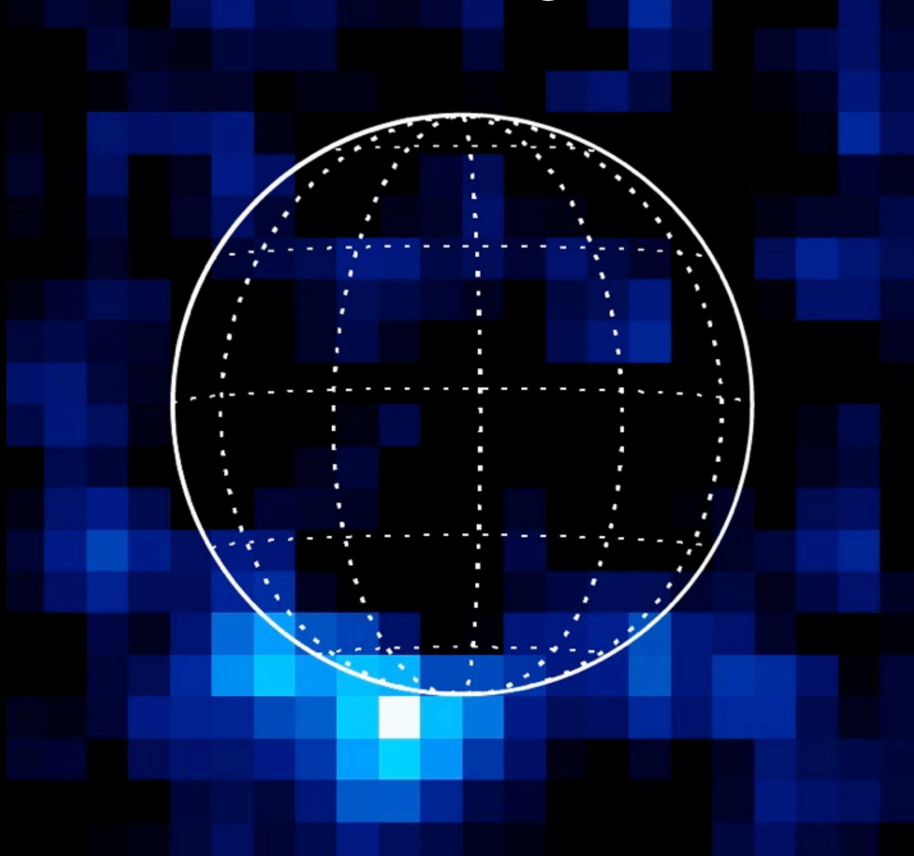
Pluto with 15-m LUVOIR

Credit: W. Harris (LPL)


Juno perijove image: ~30 km / pixel
LUVOIR resolution at Jupiter: ~24 km / pixel

Europa jets observed with HST

Europa jets observed with 15-m LUVOIR



Roth et al. (2014)

UV hydrogen emission

Credit: G. Ballester (LPL)

The LUVOIR instruments

Observational challenge

No UV through Earth's atmosphere

Solution

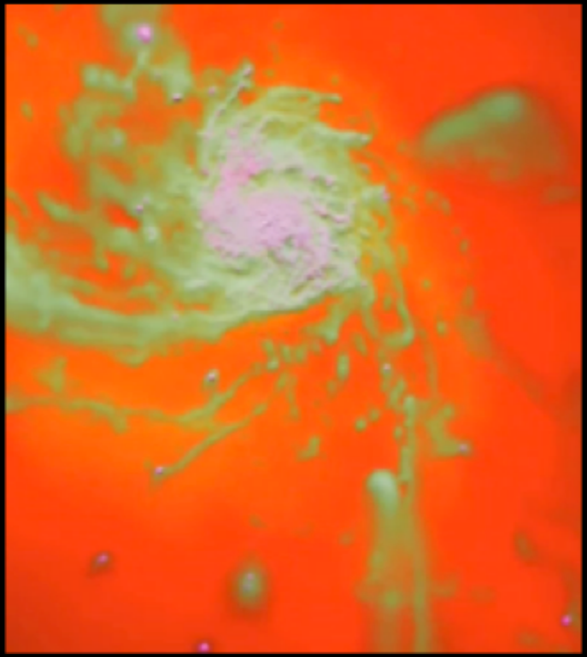
LUMOS

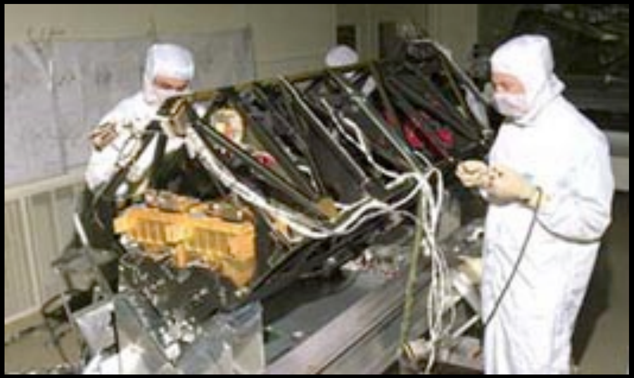
Multi-object spectroscopy (R = 500 – 45,000)

Bandpass: 100 nm to 400 nm

UV imaging

Heritage: HST STIS





HST STIS UV instrument

What Impossible Things Can I do with LUMOS?

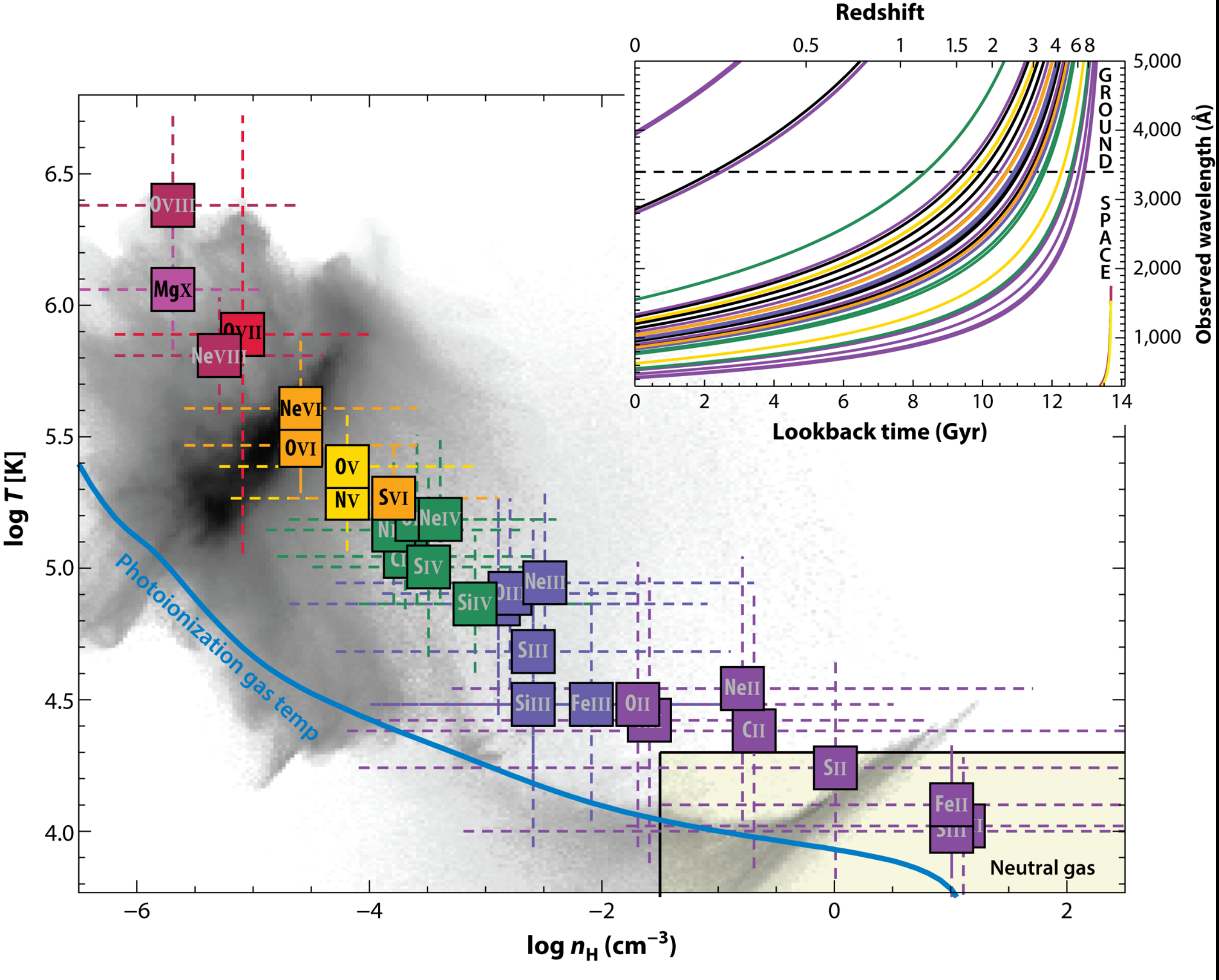
The cosmic history of baryons

Structure of circumgalactic medium

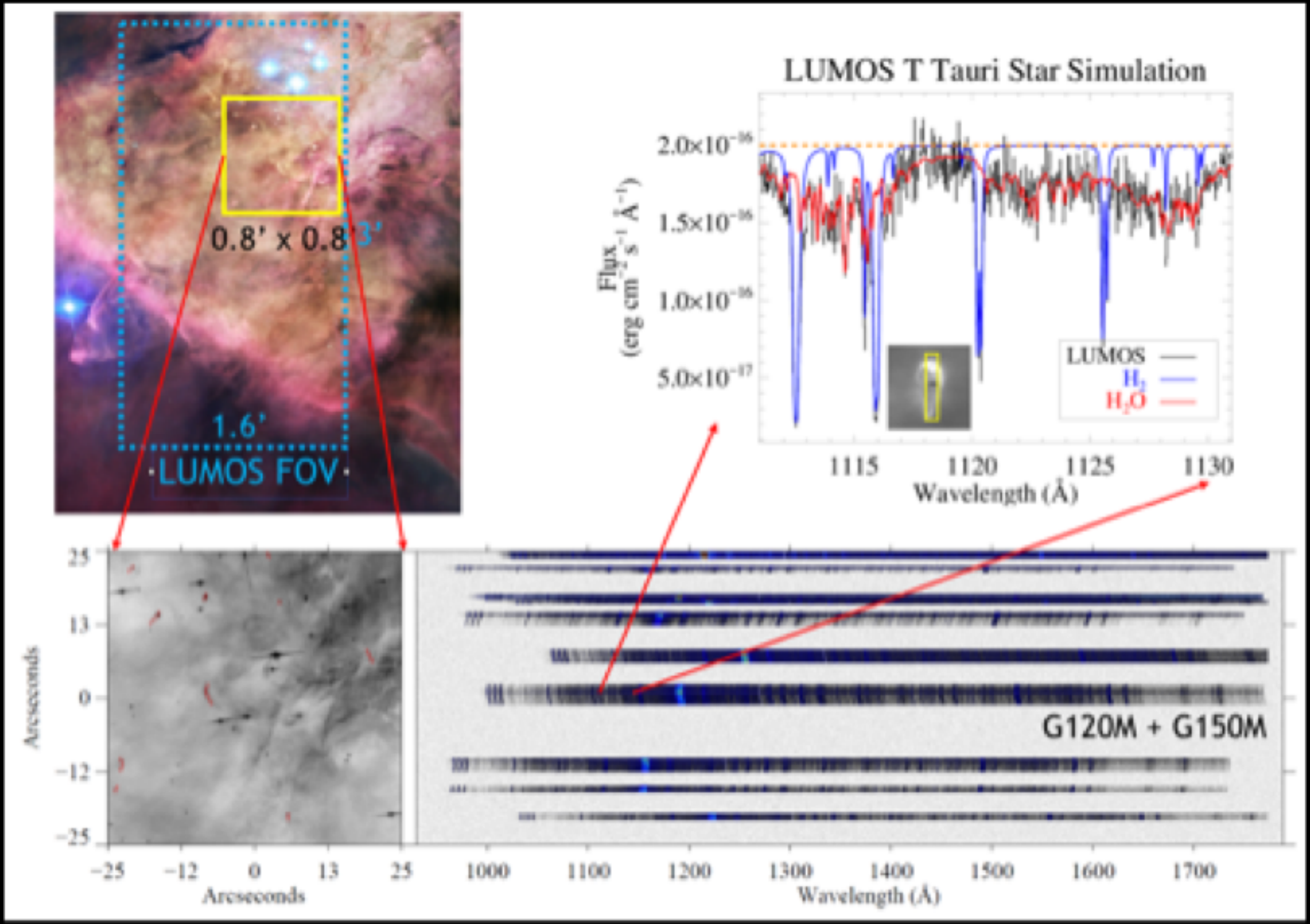
z=28.5

THE LAST 13 BILLION YEARS OF ATOMS IN THE UNIVERSE

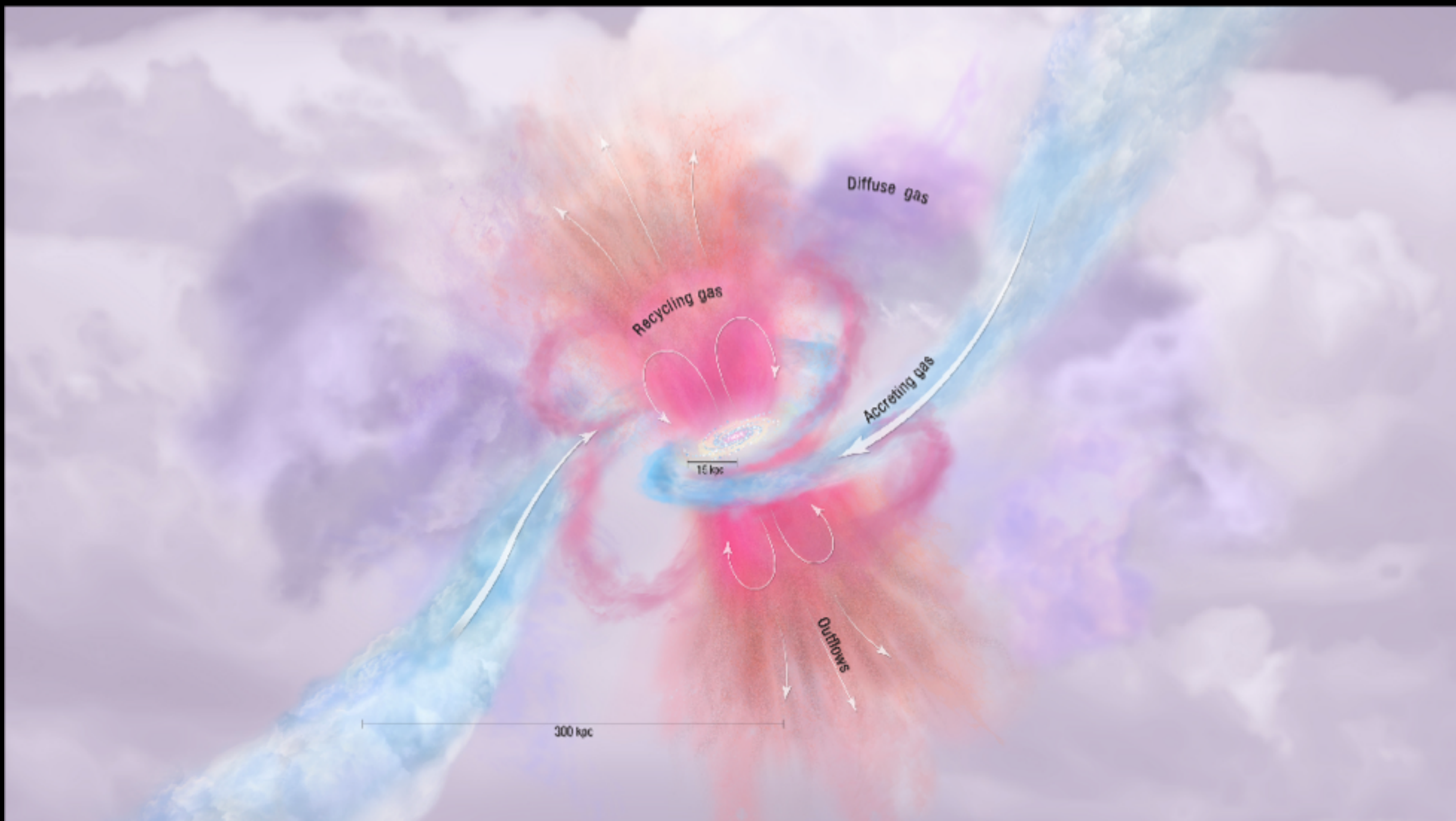
COSMIC ATOMIC HISTORY: A UV STORY



LIFE'S BUILDING BLOCKS IN THE DISKS



THE CGM: FUEL TANK, WASTE DUMP, AND RECYCLING CENTER

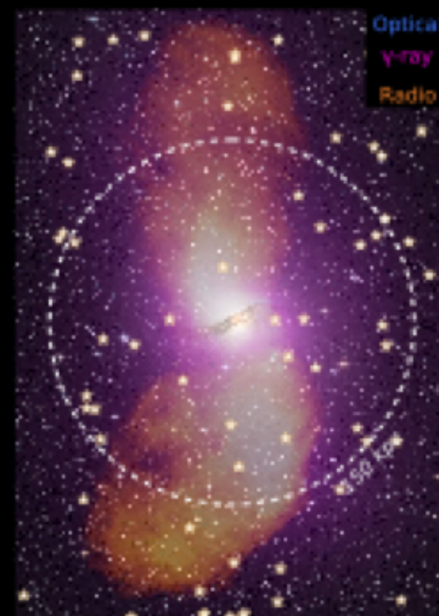


Courtesy: Tumlinson, Peeples, Werk

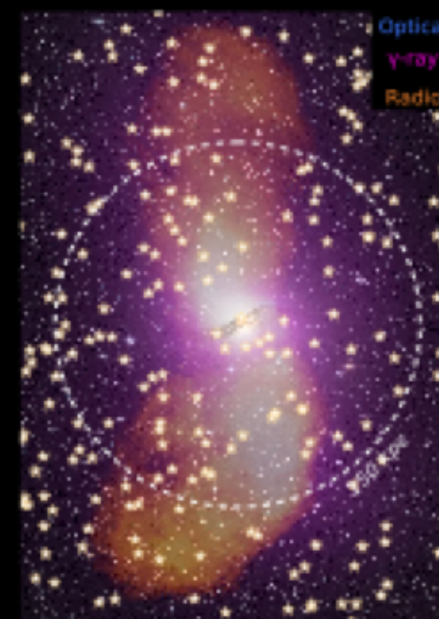
THE NEED FOR SAMPLING

4m

6m

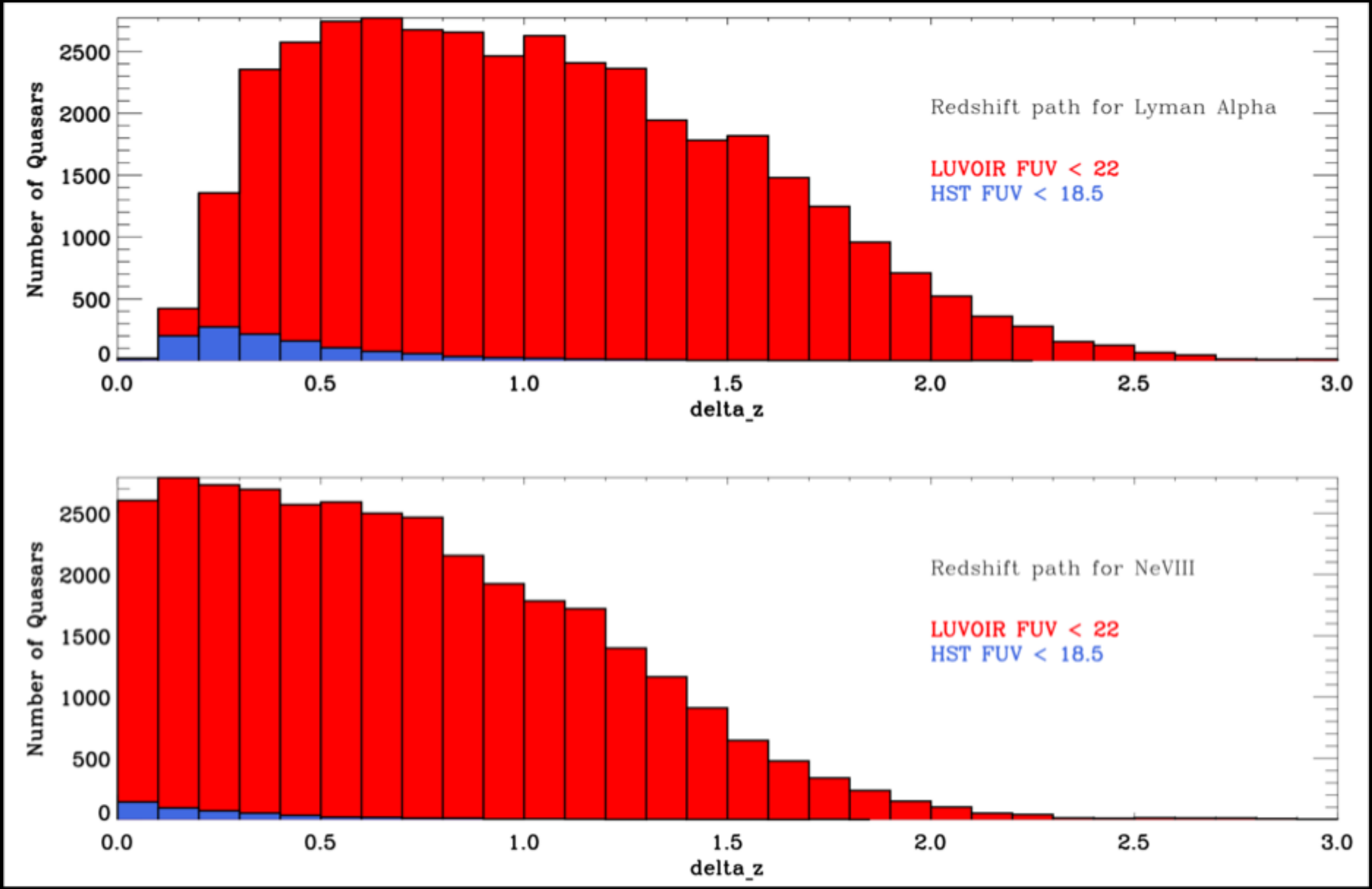


9m



15m

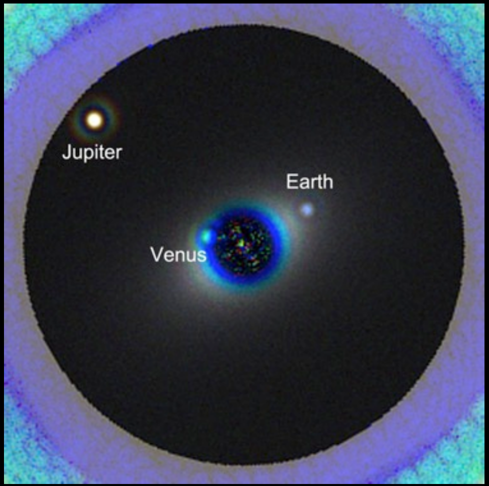
TRANSFORMATIVE INCREASE IN UNDERSTANDING GAS ACROSS ALL PHASES



The LUVOIR instruments

Observational challenge

Faint planets next to bright stars



Solution

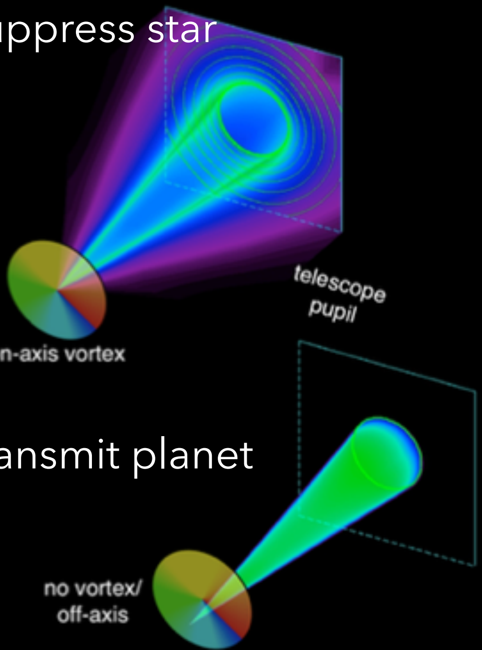
Extreme Coronagraph for Living Planetary Systems (ECLIPS)

Contrast < 10^{-10} to observe exoEarths

Multi-resolution spectroscopy

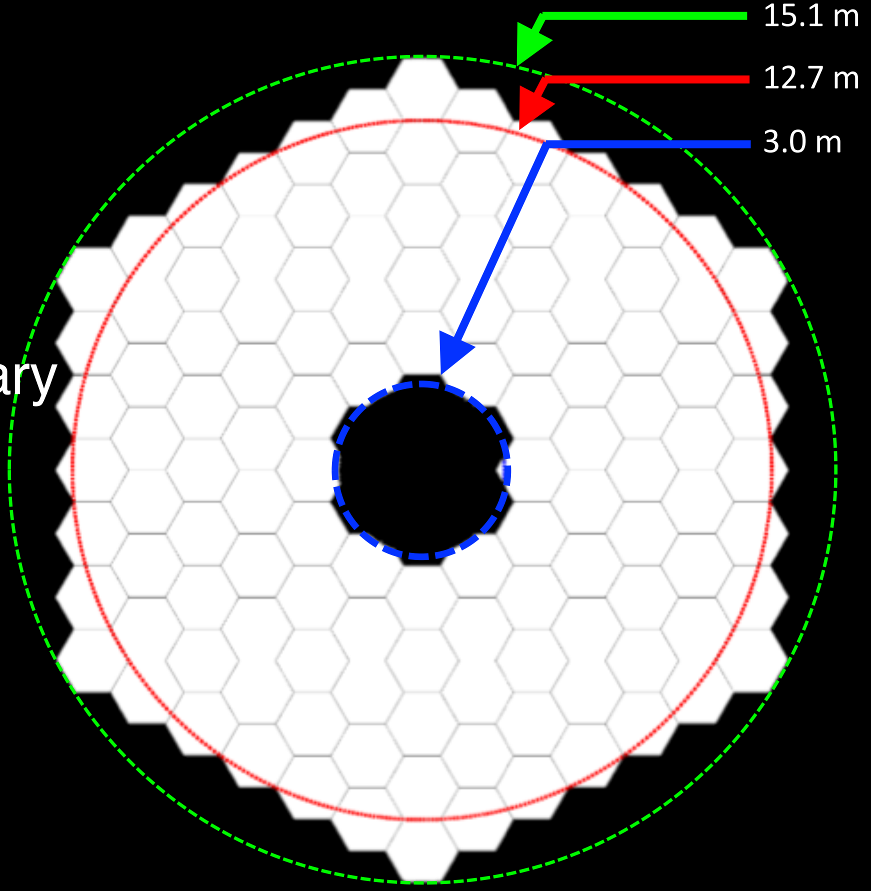
Bandpass: 0.2 μm to 2.5 μm

Tech development via WFIRST coronagraph



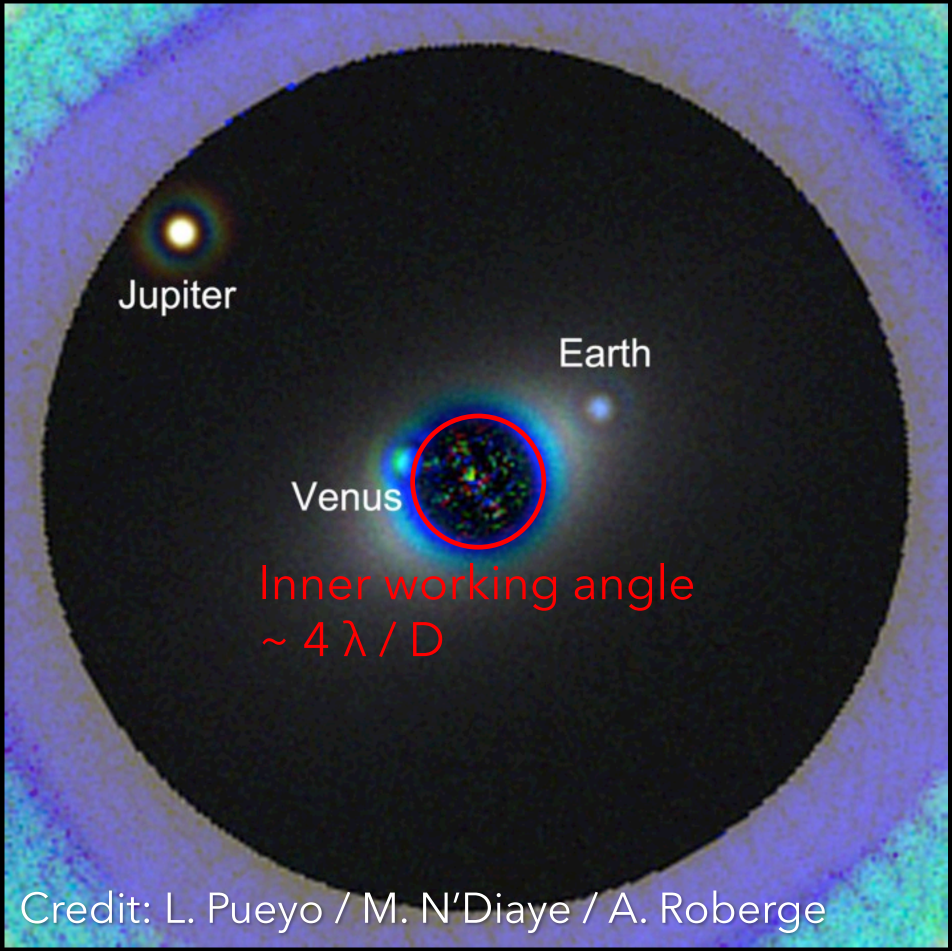
Vector vortex coronagraph
Credit: D. Mawet (Caltech)

- 1.15-m flat-to-flat segments (120x)
- Central ring of array removed to accommodate Aft-optics & Secondary Mirror Obscuration
- Effective area is 135 m^2
  - 13.1 m effective diameter
- Assumes 6 mm gaps between segments



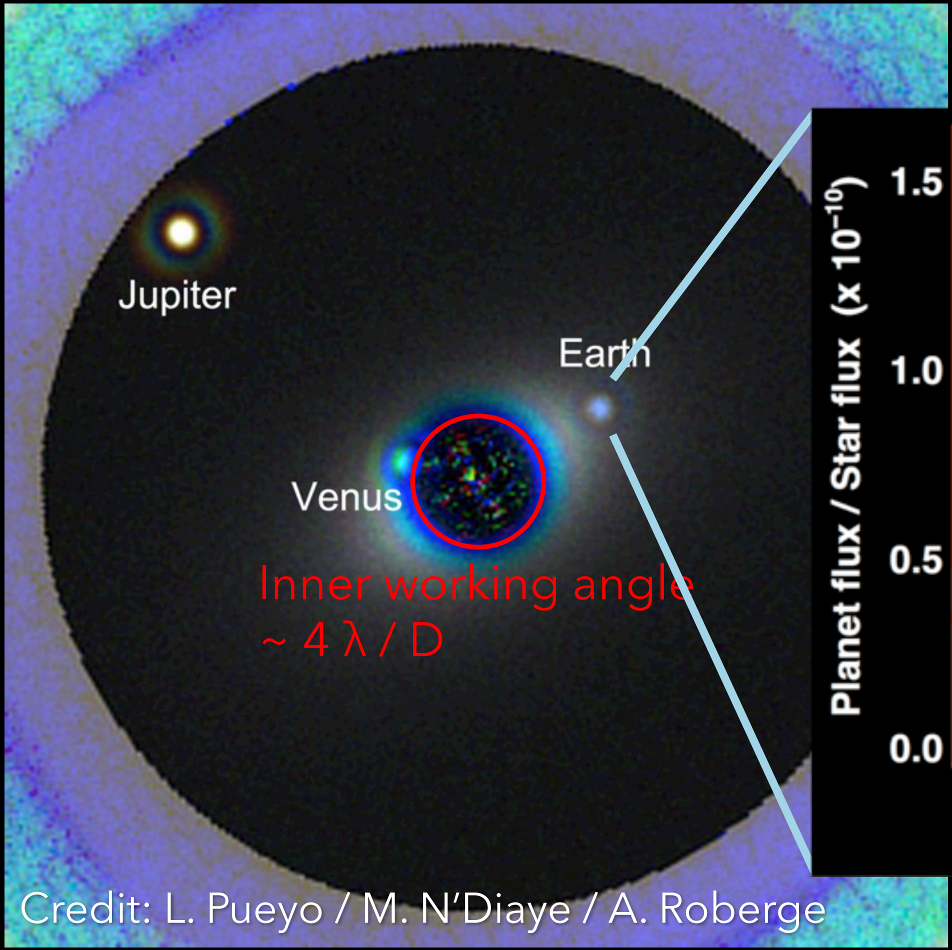
Characterizing Earth 2.0 …

Solar System from 13 parsec
with coronagraph and 12-m telescope

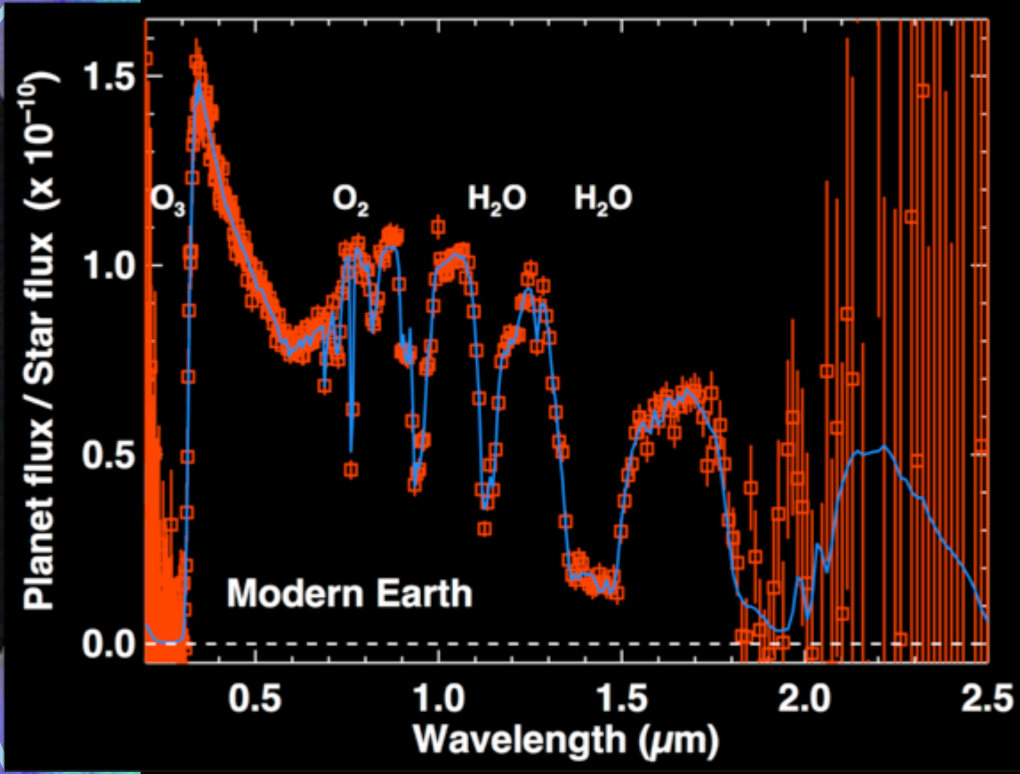


Characterizing Earth 2.0 …

Solar System from 13 parsec
with coronagraph and 12-m telescope



Distance = 10 pc
$D_{telescope}$ = 12-m
R = 150
Time = 96 hrs per band

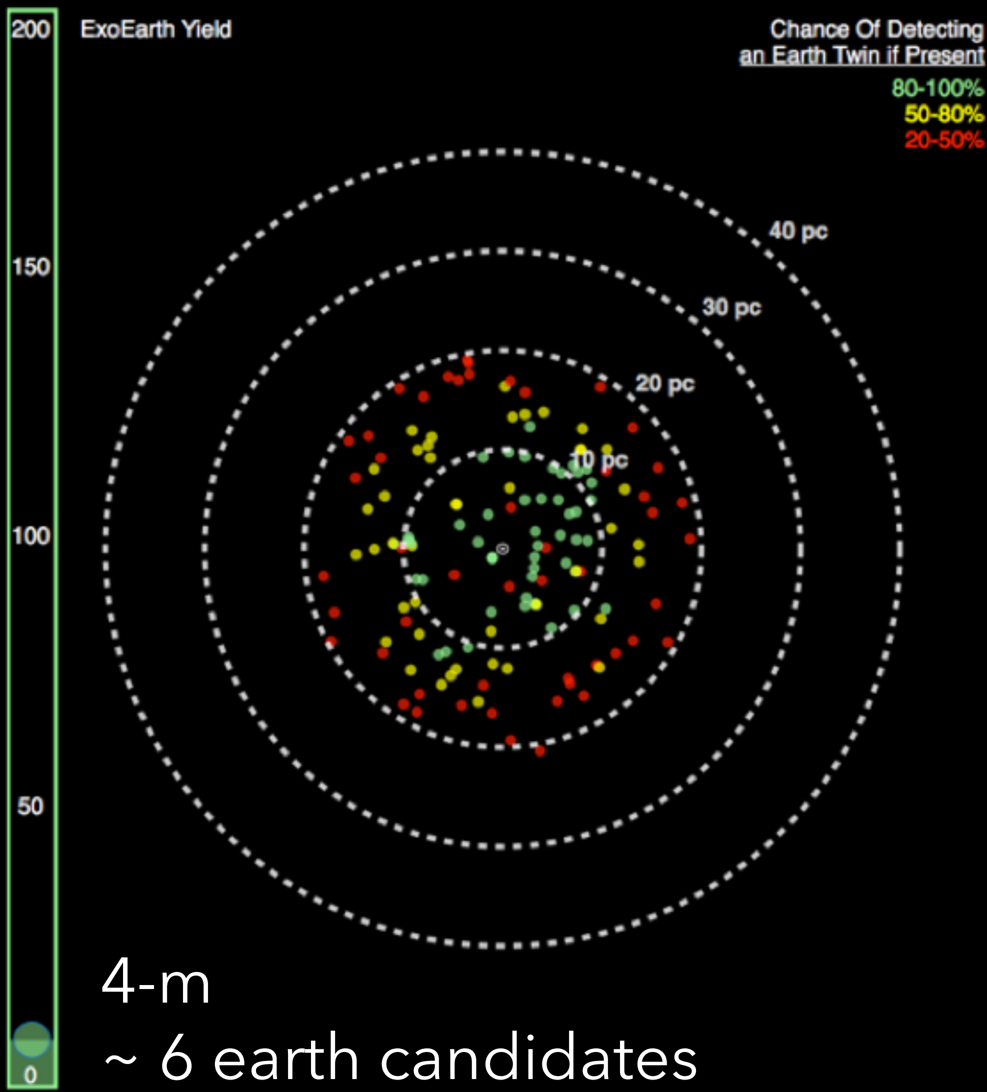


Credit: T. Robinson / G. Arney

What Impossible Things Can I Do with ECLIPS?

Characterize the atmospheres of a statistically significant sample of exoplanets in the habitable zone of nearby stars

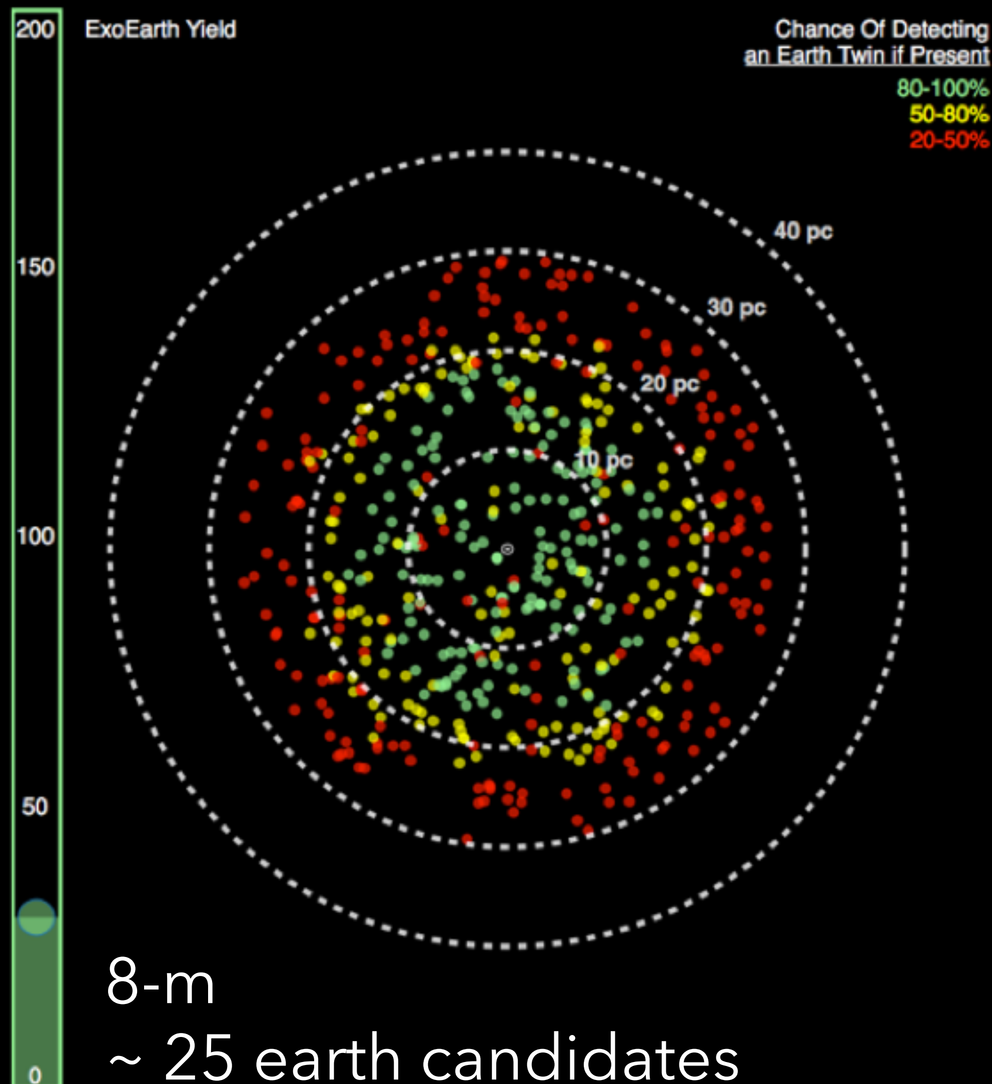
ExoEarth candidates as function of aperture



4-m
~ 6 earth candidates

Stark et al. (2014)

ExoEarth candidates as function of aperture

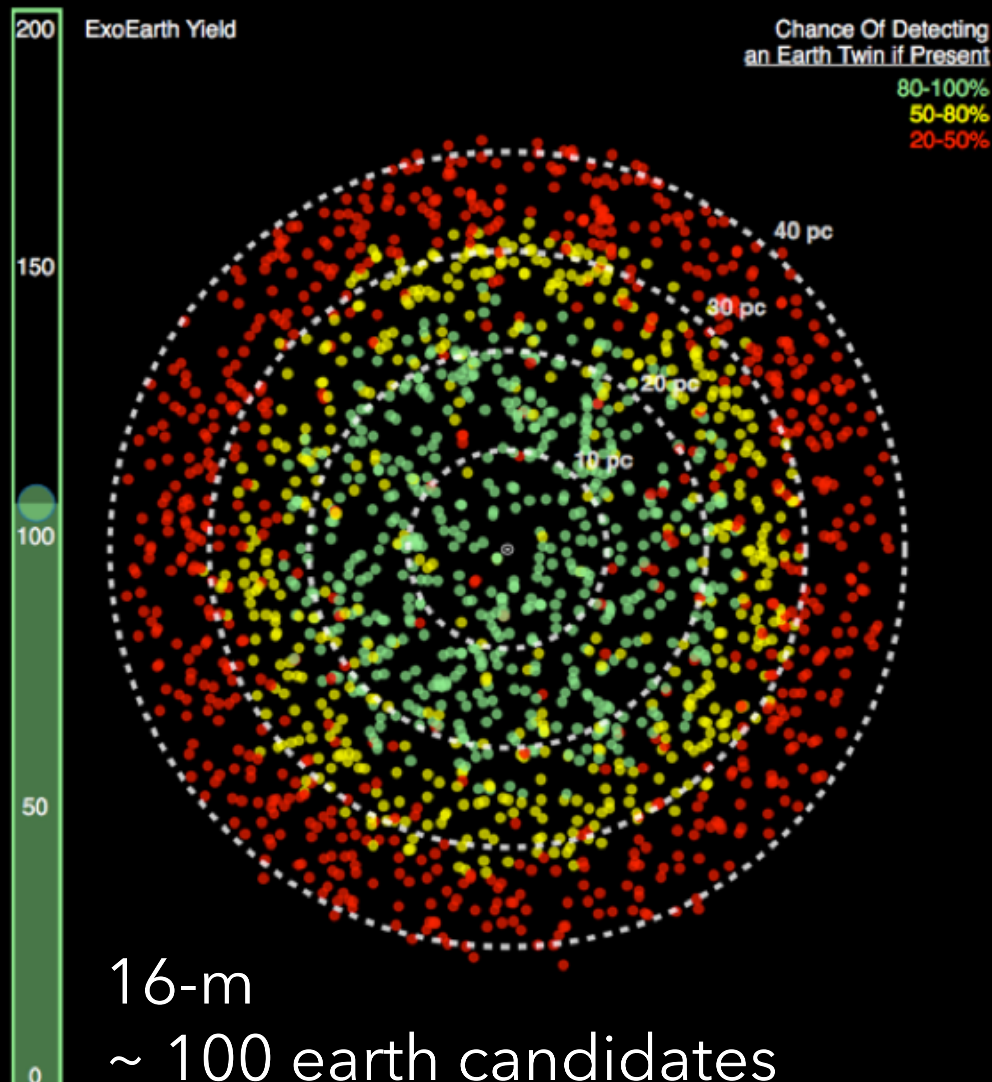


8-m

~ 25 earth candidates

Stark et al. (2014)

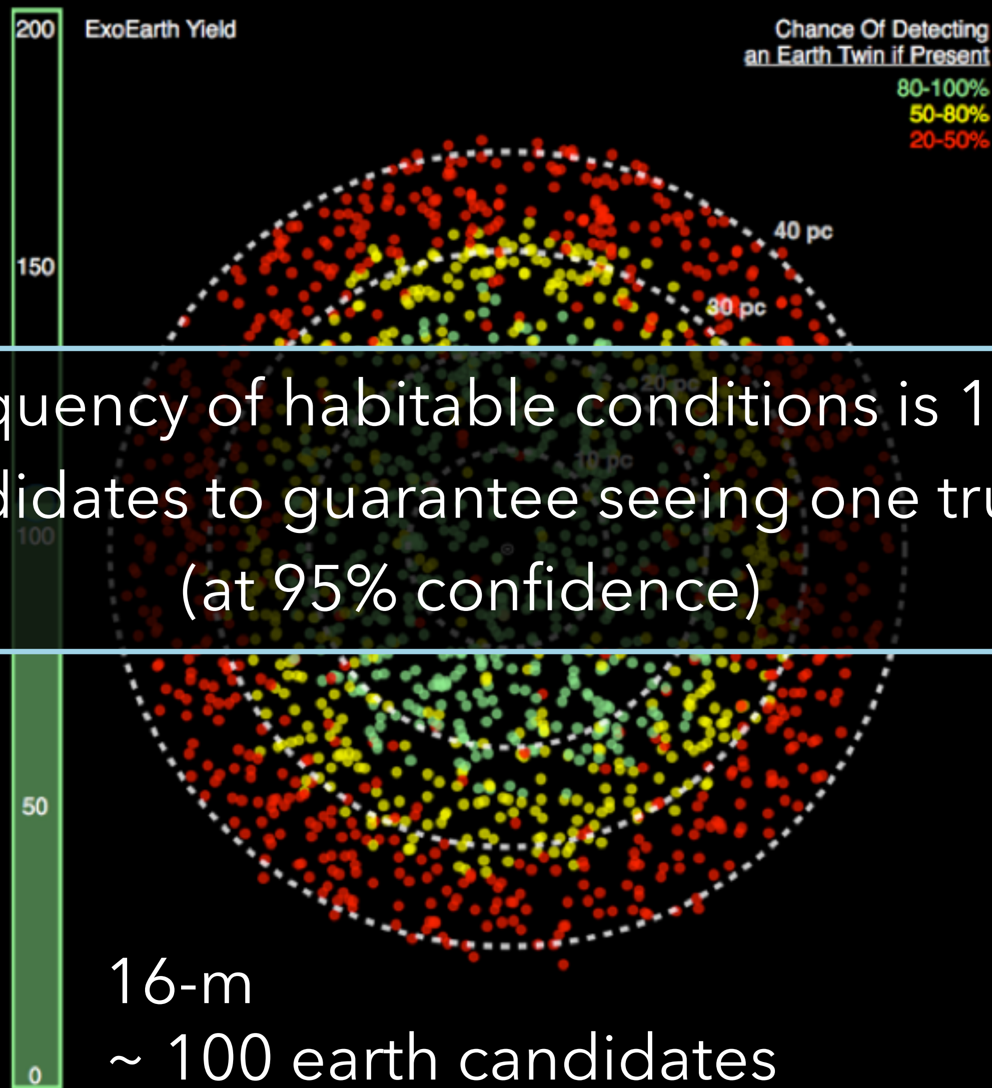
ExoEarth candidates as function of aperture



16-m
~ 100 earth candidates

Stark et al. (2014)

ExoEarth candidates as function of aperture

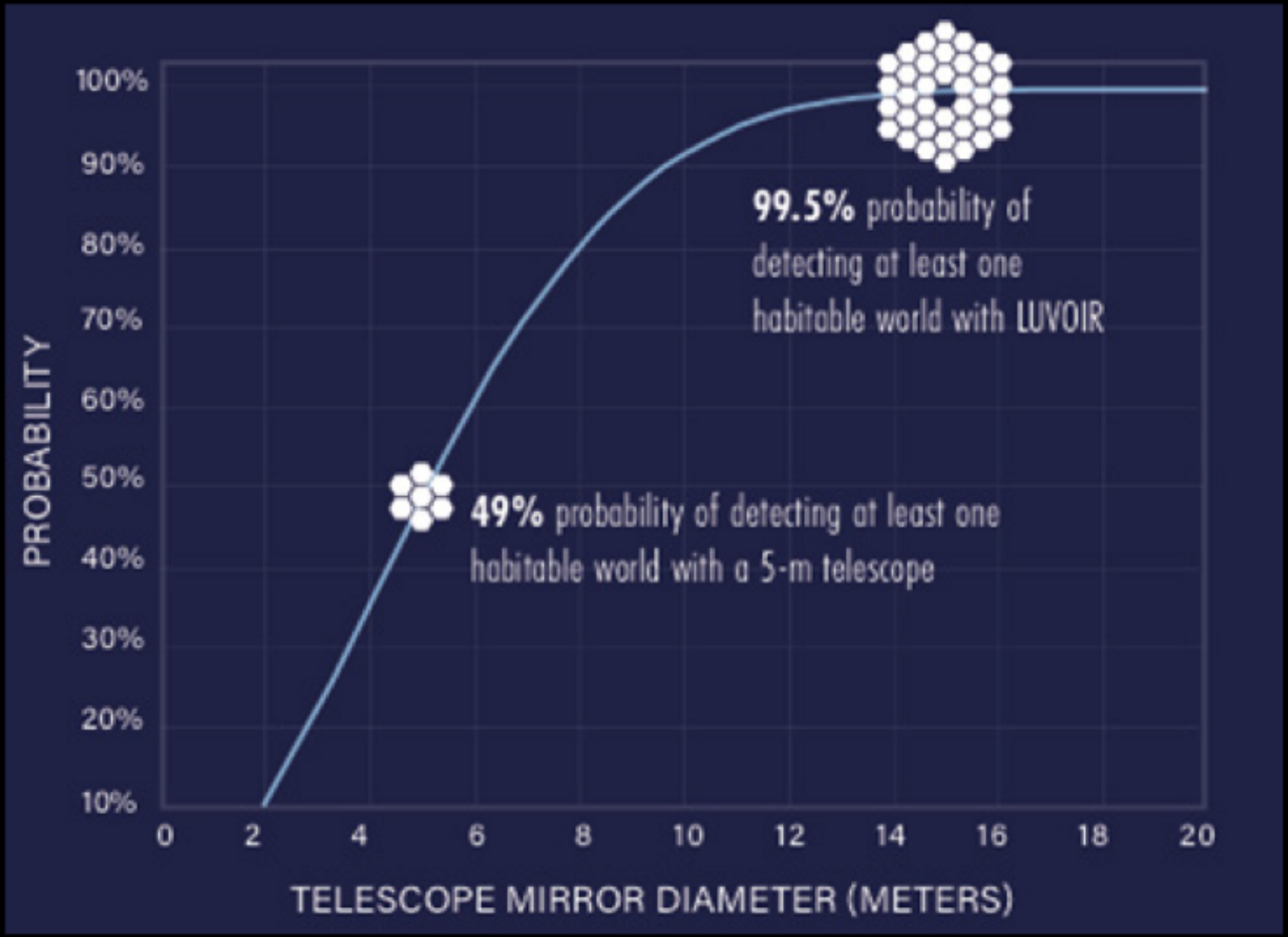


If frequency of habitable conditions is 10%,
need 30 candidates to guarantee seeing one true exoEarth
(at 95% confidence)

16-m
~ 100 earth candidates

Stark et al. (2014)

With LUVOIR, a null detection is meaningful



POLLUX: a European contribution to the LUVOIR mission study

POLLUX is a concept for a UV spectro-polarimeter with high resolution point-source capability ($R \sim 10^5$)

Complementary to the LUMOS instrument

To be defined & designed by a consortium of 10 European institutions, with leadership/support from CNES

The conceptual study conducted by CNES could serve as a support for a future ESA contribution

Technological challenges

Need heavy lift launch vehicle with large fairing

Suitable vehicles (SLS and commercial) in development

Compatibility of UV and coronagraphy

New lab work shows UV reflective mirrors are just fine for coronagraphy

Ultra-high contrast observations with a segmented telescope

Coronagraphs can be designed for segmented telescopes. Working hard to demonstrate needed system stability

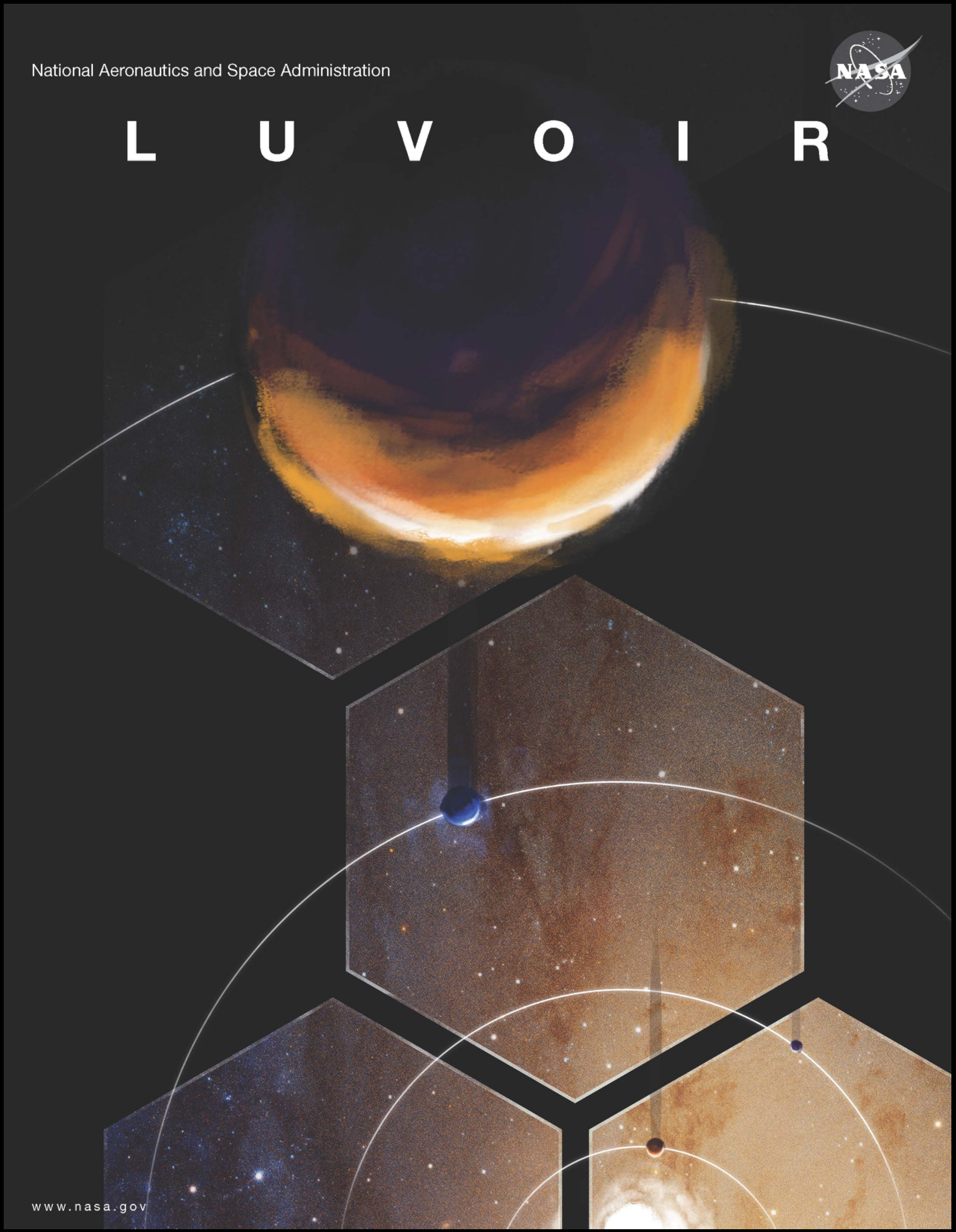
Series of short, readable "LUVOIR Tech Notes" available at http://asd.gsfc.nasa.gov/luvoir/tech/

Current STDT Activities

STDT is preparing its Interim Report for submission to NASA in March.

Red Team (non-advocate experts) review took place on Wednesday, 24 January.

Interim Report will be made public.



Summary

LUVOIR has multiple primary science goals

1. Habitable exoplanets & biosignatures
2. Broad range of general astrophysics and Solar System observations

Challenge is to blend goals into single powerful mission

LUVOIR will provide a statistically significant study of Goal 1, factors of ~ 100 increased science grasp over Hubble for Goal 2

Wide range of capabilities to enable decades of future investigations and unexpected discoveries

L U V O I R