BIG BANG TO BIOSIGNATURES: THE LUVOIR MISSION CONCEPT

Jason Tumlinson (STScI/JHU)

What is LUVOIR ?

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

Large UV / Optical / Infrared Surveyor (LUVOIR)

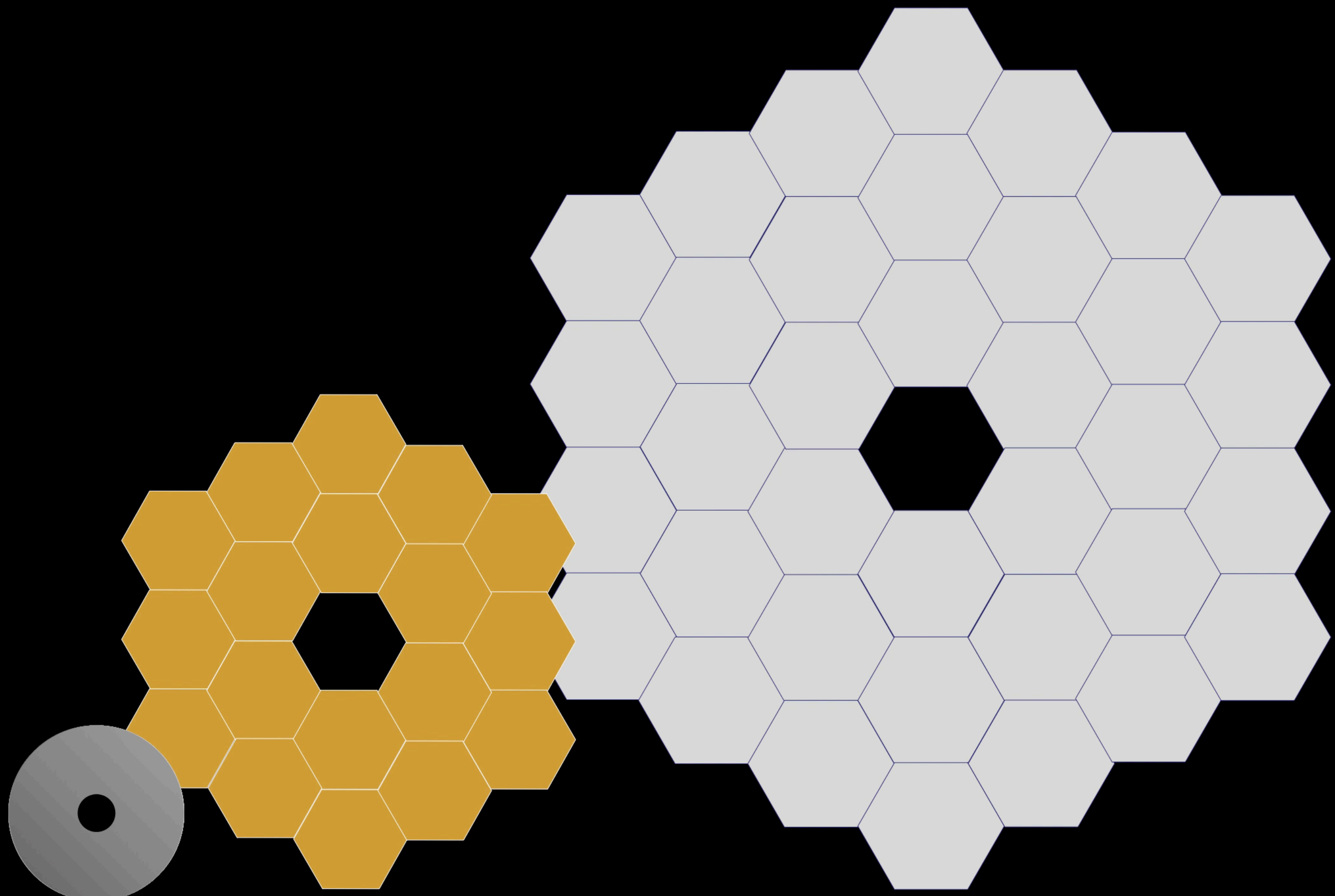
A space telescope concept in tradition of Hubble

- Broad science capabilities
- Far-UV to Near-IR bandpass
- ~ 8 – 16 m aperture diameter
- Suite of imagers and spectrographs
- Serviceable and upgradable
- Hubble-like guest observer program

"Space Observatory for the 21st Century"

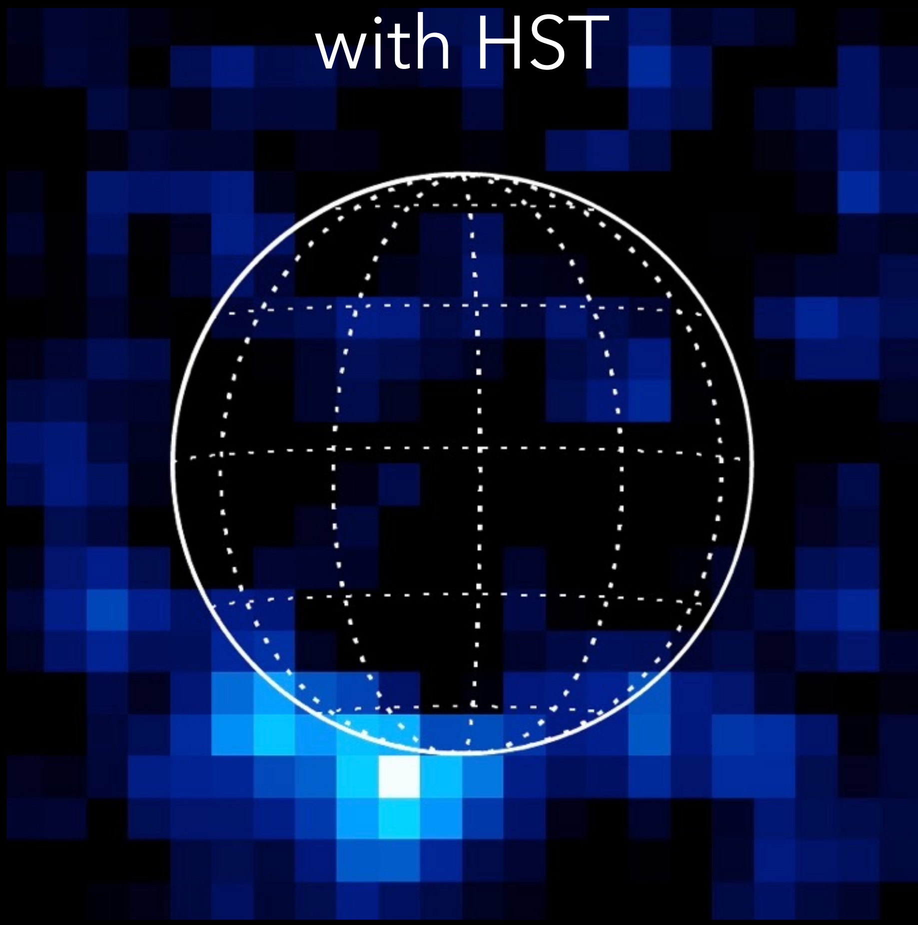
Ability to answer questions we have not yet conceived

Imagine astronomy with LUVOIR …



Imagine astronomy with LUVOIR …

Europa jets observed with HST



Europa jets observed with 15-m LUVOIR

Roth et al. (2014)

UV hydrogen emission

Credit: G. Ballester (LPL)

Imagine astronomy with LUVOIR …

Pluto with HST

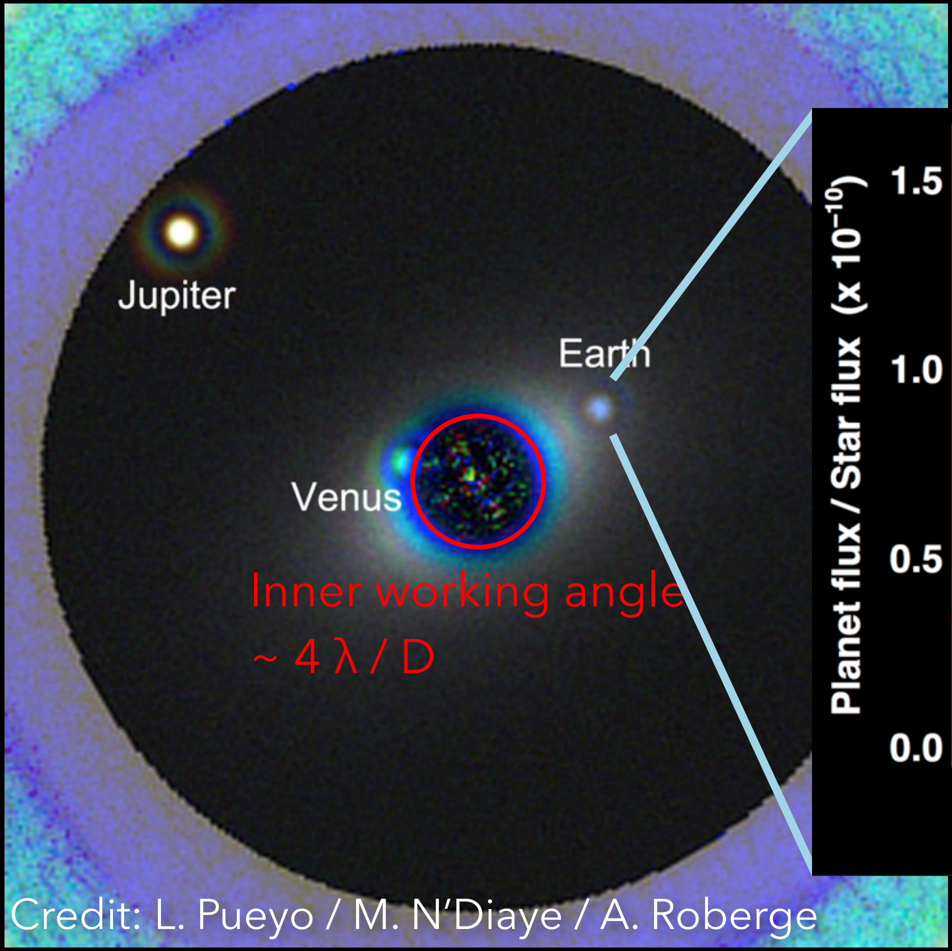
Pluto with 15-m LUVOIR

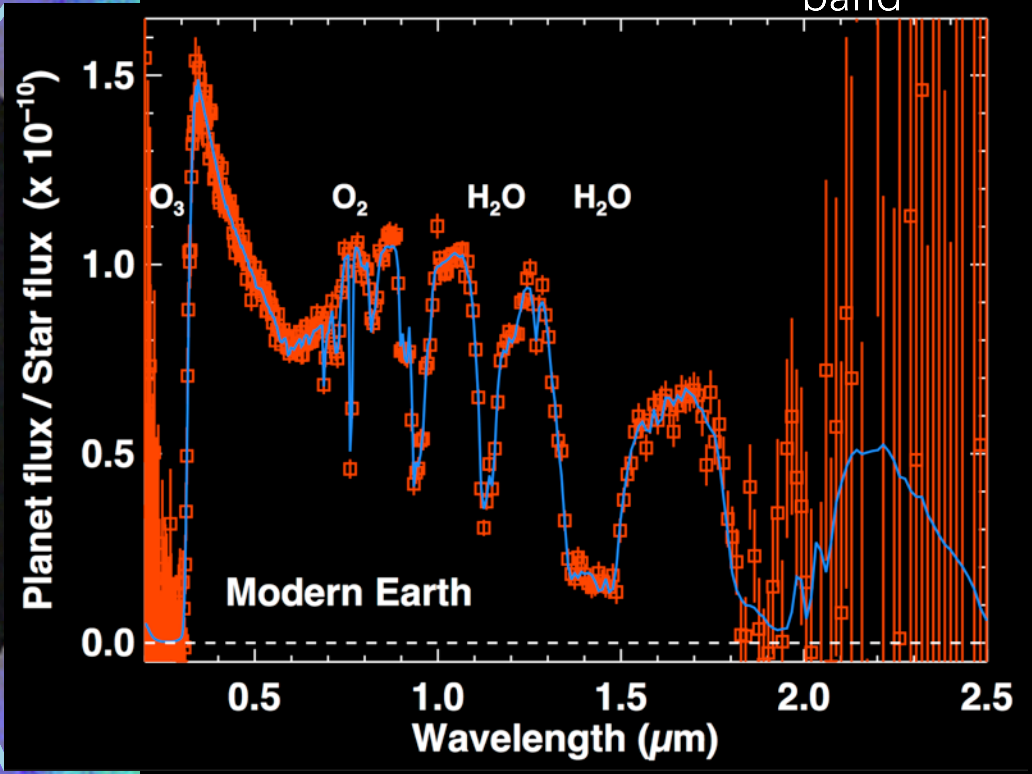
Credit: W. Harris (LPL)

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





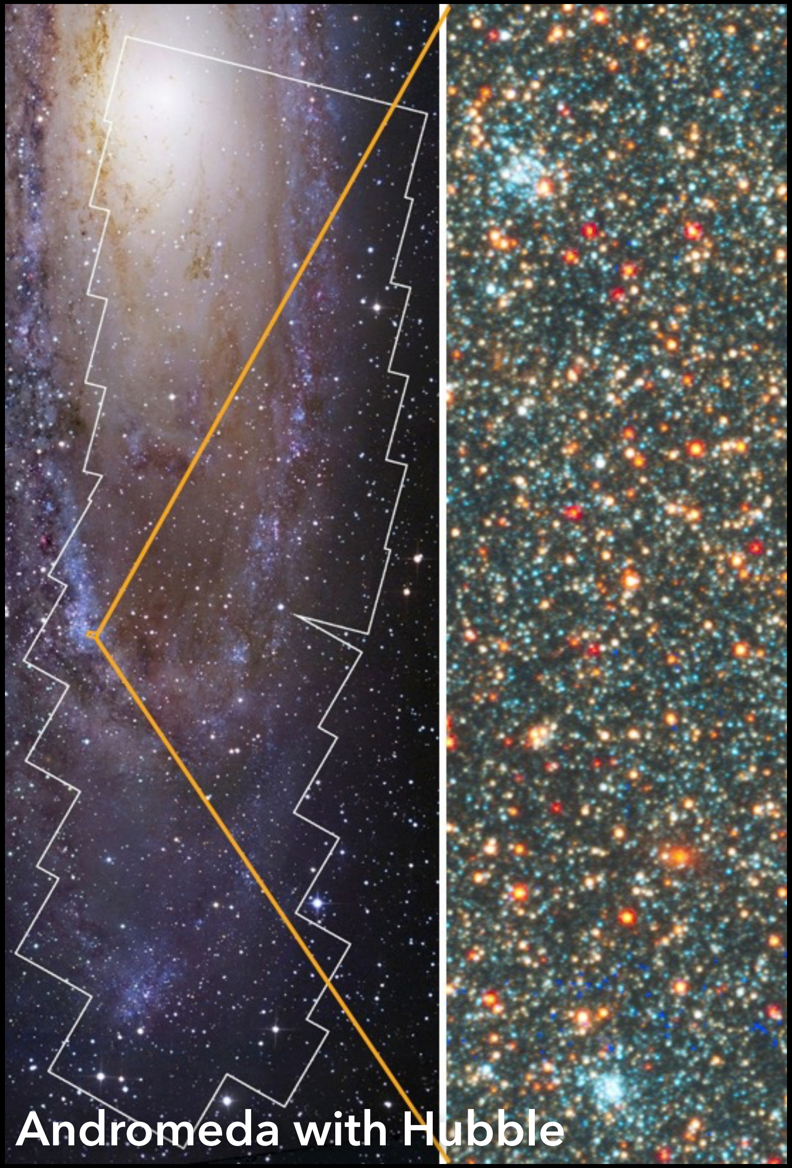
Credit: T. Robinson / G. Arney

Imagine astronomy with LUVOIR …

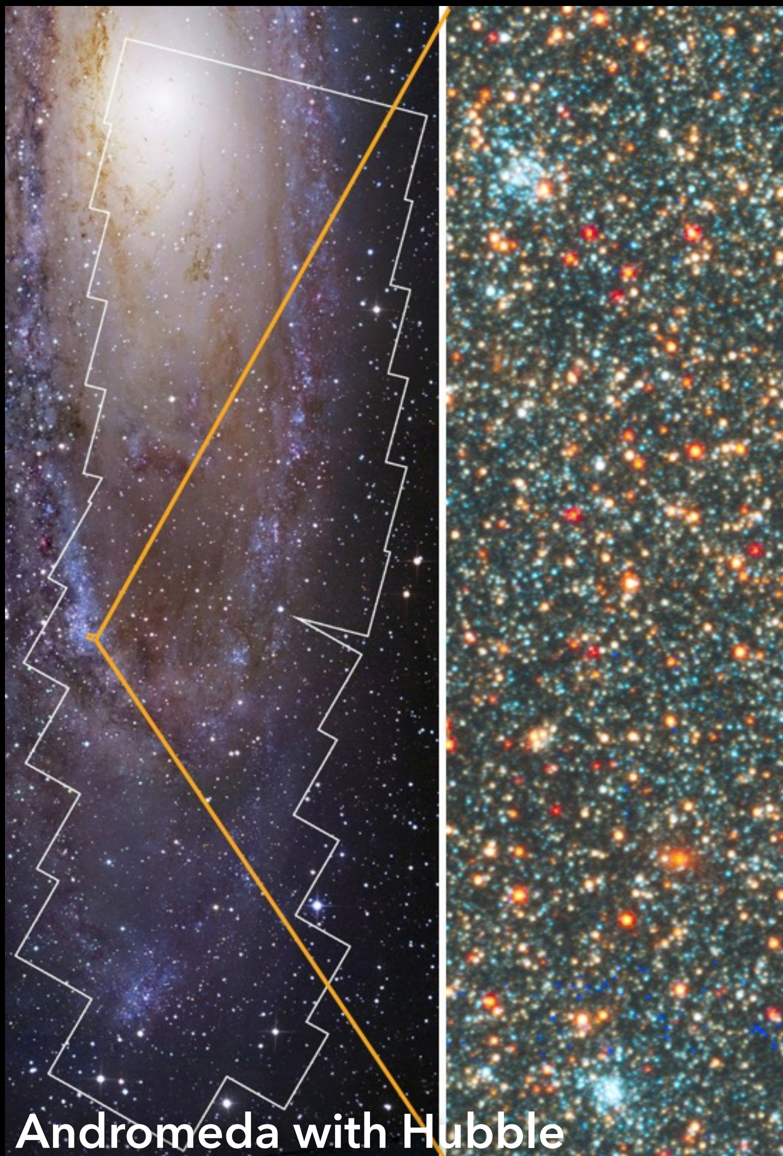
Galaxy at z = 2
with HST

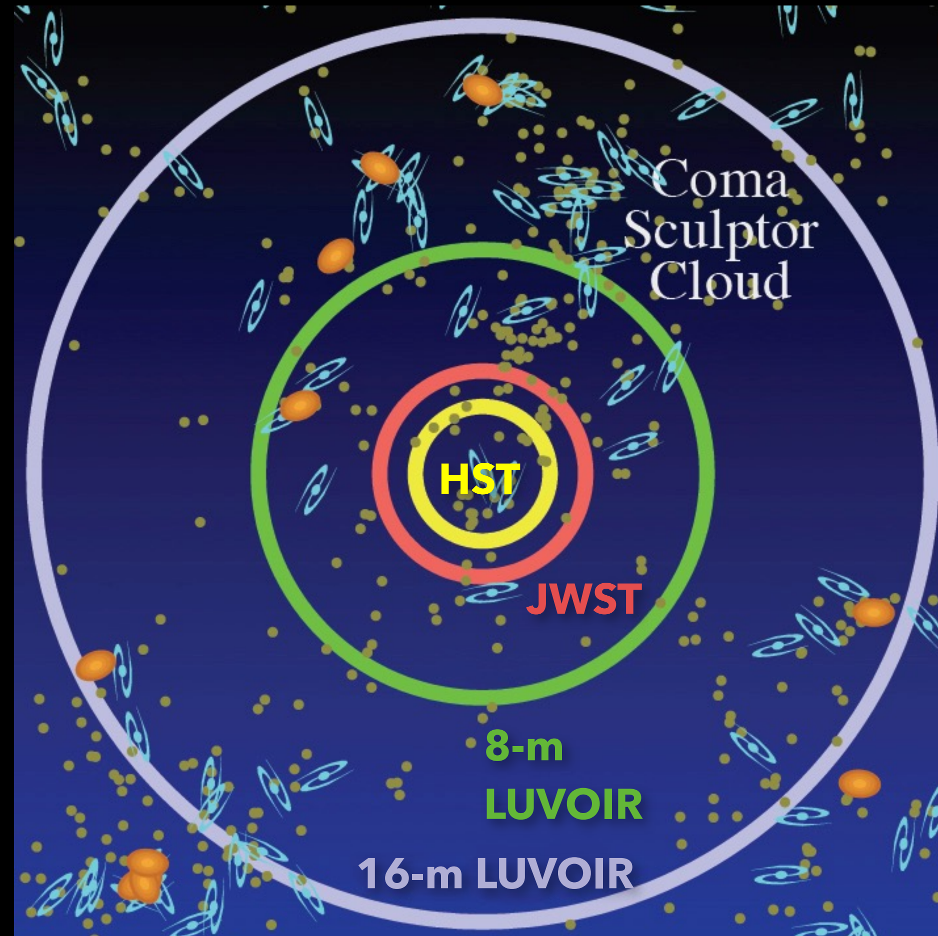
Galaxy at z = 2
with 12-m LUVOIR

How do galaxies assemble their stars?



How do galaxies assemble their stars?

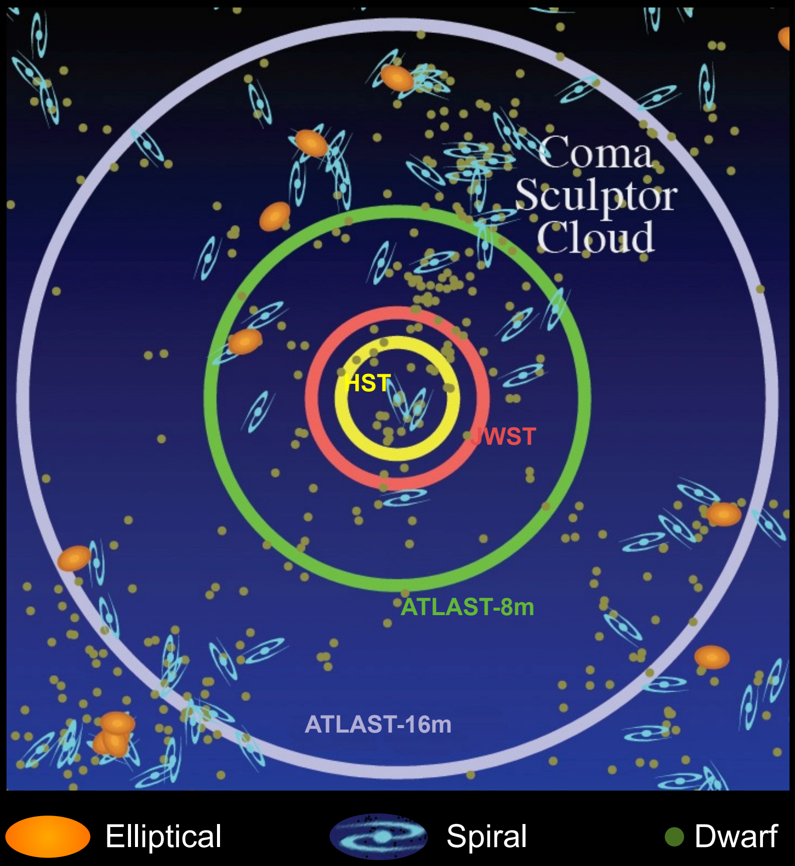


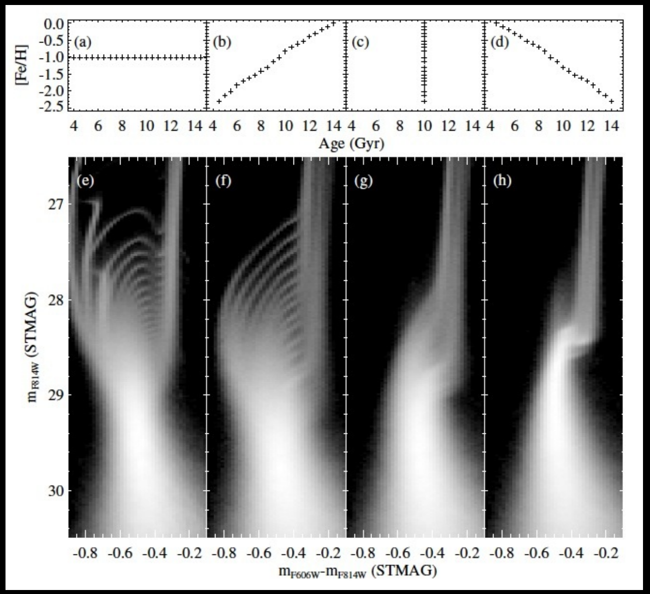


Map of Galaxies within 12 Mpc of Our Galaxy

= Large Elliptical Galaxy
= Dwarf Galaxy
= Large Spiral Galaxy

What is the complete star formation history of galaxies?



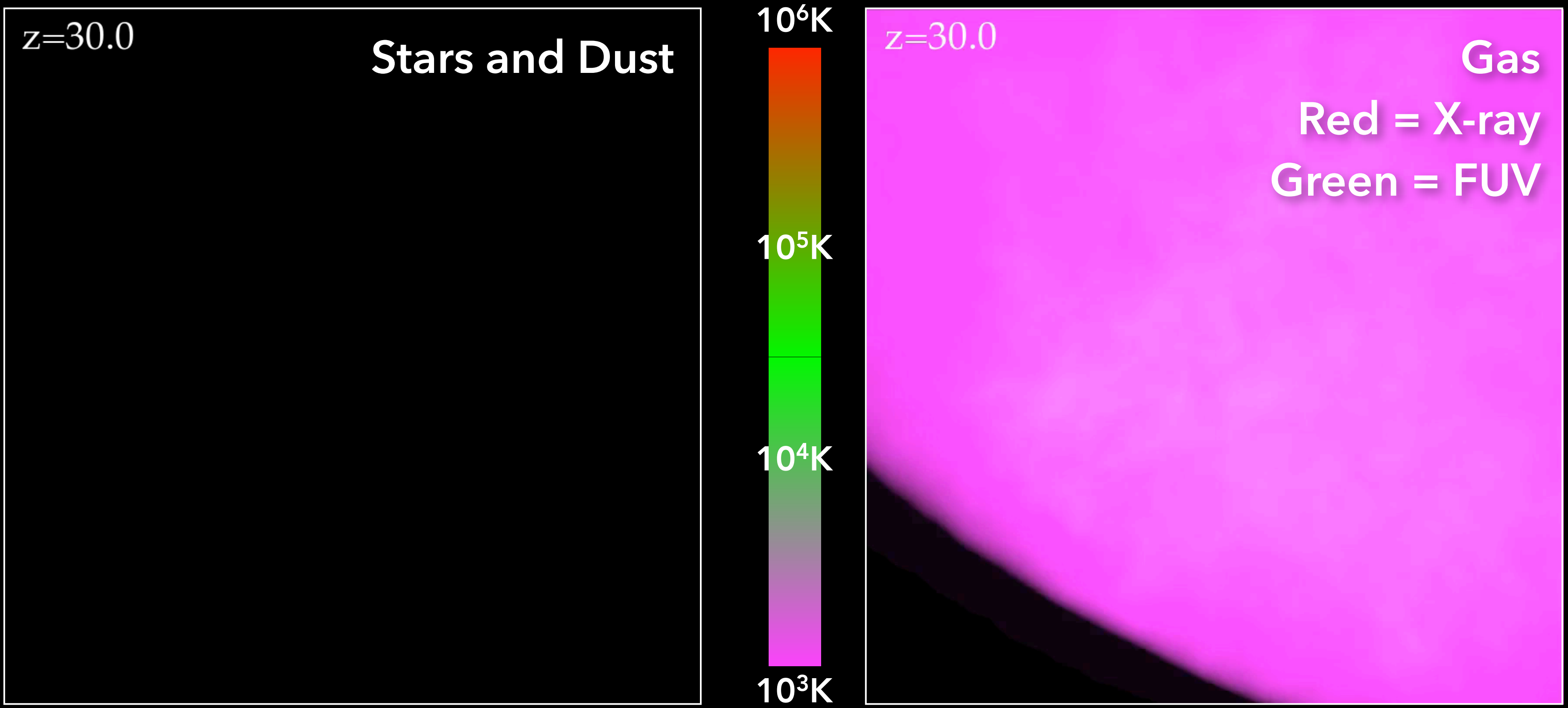


Aperture Driver: > 10 m needed to resolve stellar pops down to 1 M$_\odot$ out to the nearest giant ellipticals.

Star formation history sets both chemical evolution and planet formation rates.

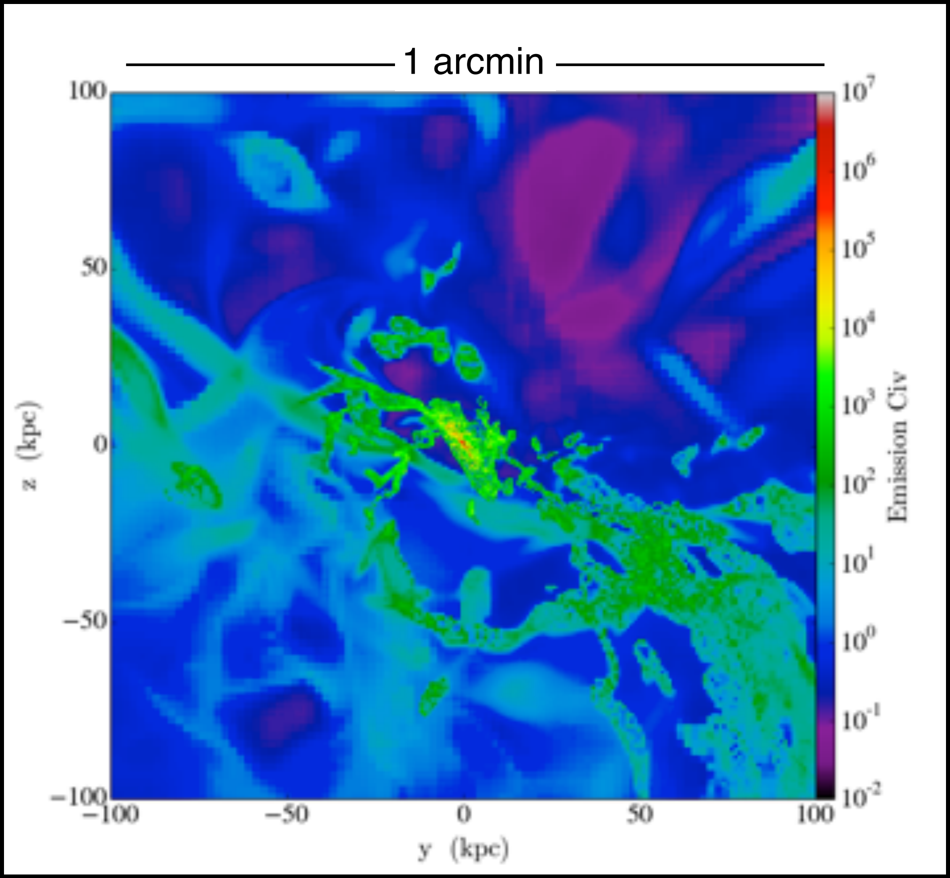
Requires diffraction limited optical imaging and high PSF stability.

The gas-galaxy connection



Illustris simulation

Credit: G. Snyder (STScI)

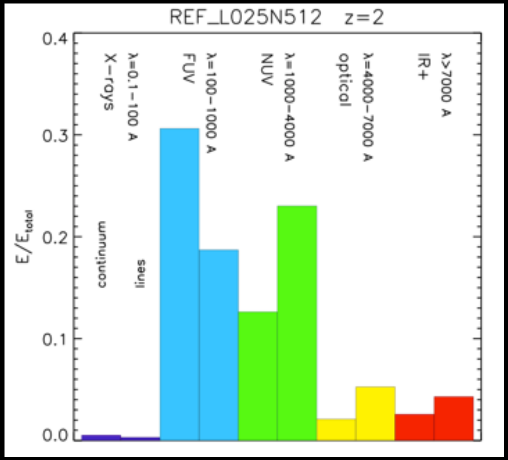


Simulation of a Milky Way analogue galaxy at z = 0.25.

The accreting filaments in green are detectable by BJWST.

How do galaxies acquire their gas?

UV Driver: > 80% of energy emitted by gas cooling to feed galaxies is emitted in the rest-frame UV



Bertone et al. (2013)

This emission is extremely diffuse, arising from gas at n << 0.1 cm^{-3}.

Aperture driver: A combination of extremely high sensitivity and good spatial resolution is essential to detect this “faintest light in the Universe.”

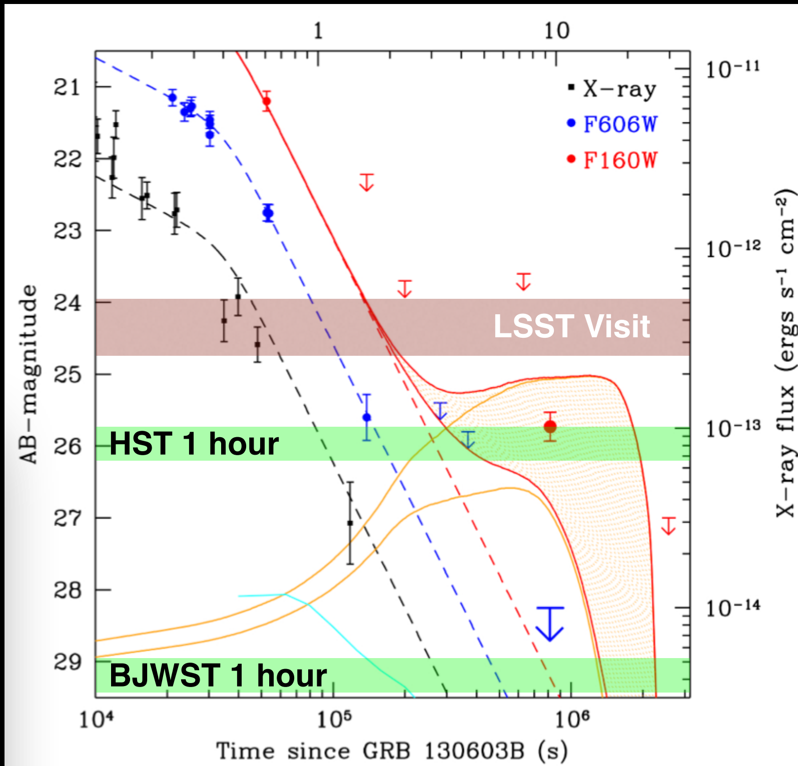
How do stars end their lives?

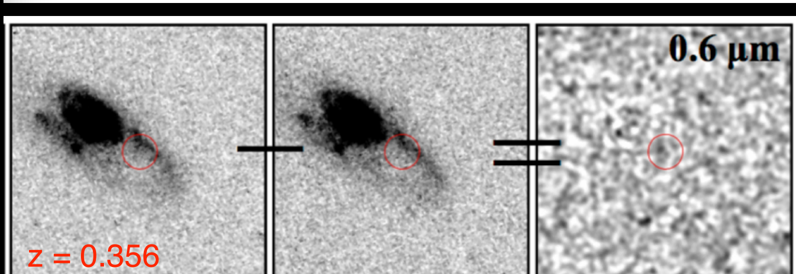
Wide-field synoptic surveys find a zoo of transients.

<u>Aperture Driver:</u> High resolution imaging identifies and characterizes their stellar progenitors and galactic hosts, both key to unraveling causes.

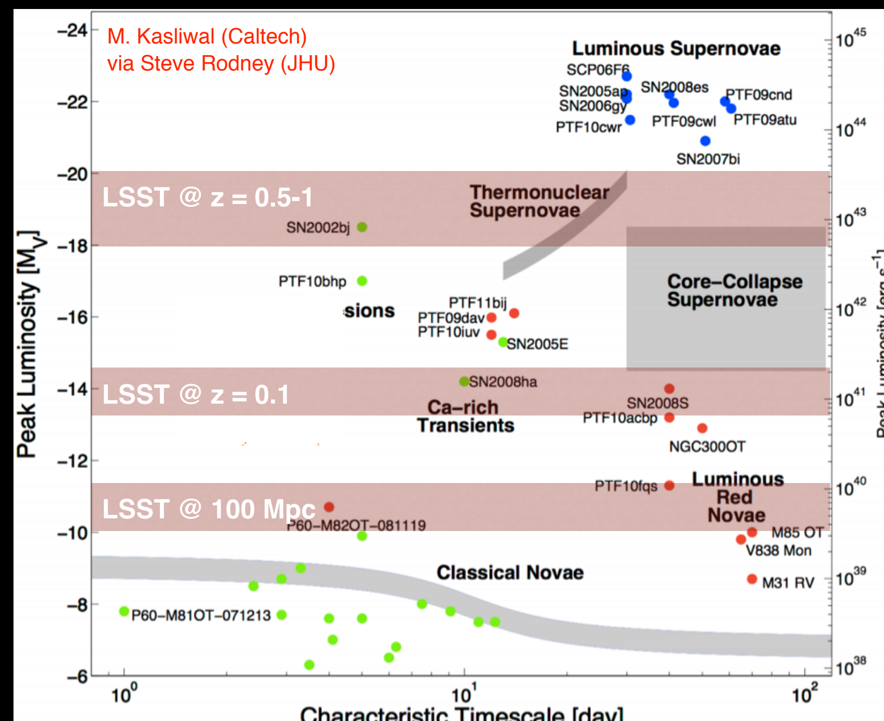
May be able to isolate GW sources detected by LIGO.

Rapid (<24 hr) response drives system requirements.





“Kilonova” from short GRB 130603B
NS-NS or NS-BH merger, major r-process source.
Tanvir et al. (2013, Nature)

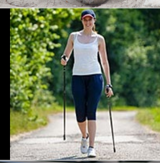
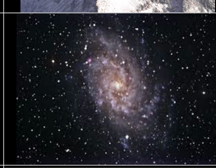


BJWST Localization

50-100 pc

10-30 pc

< 10 pc

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

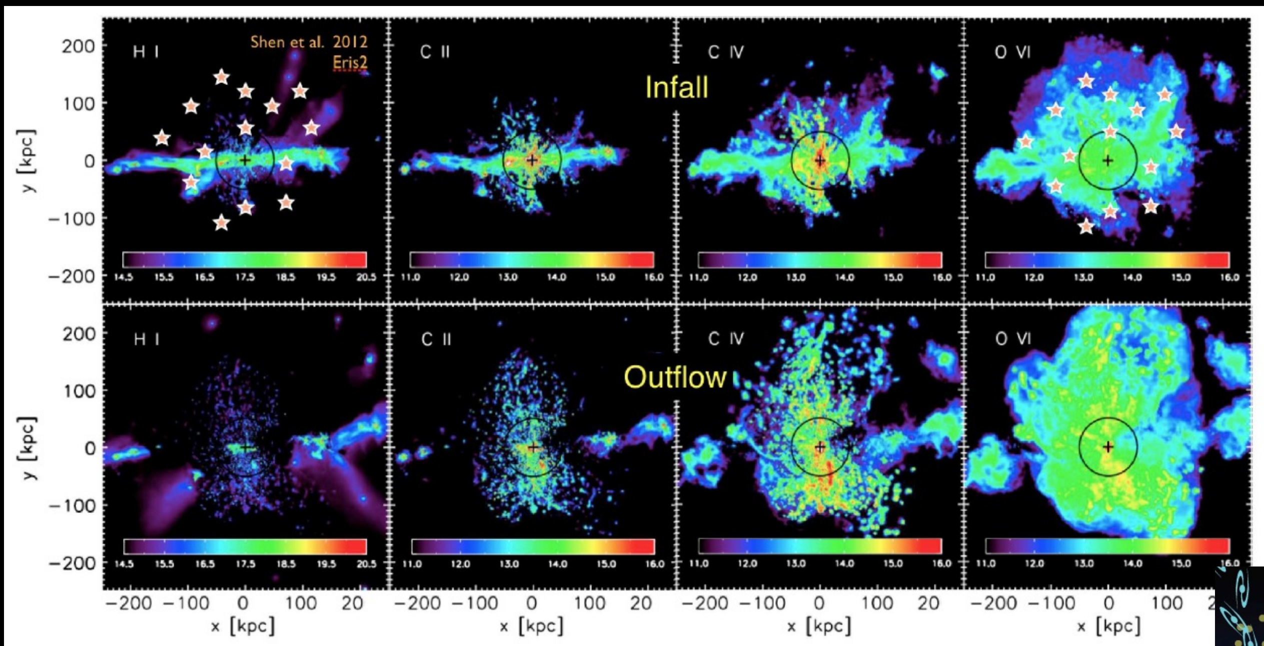
How does light trace mass?
How does dark mass move?

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.

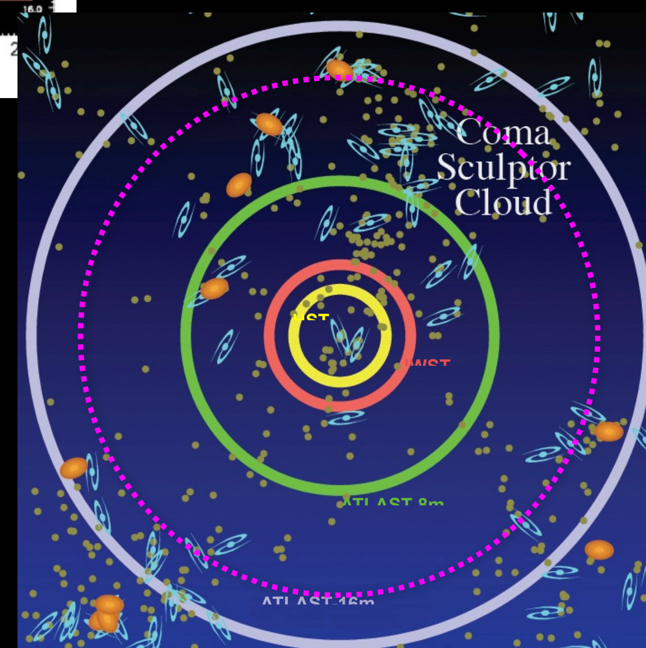
Aperture driver: 10 m is required to reach the motions of virtually ANY Milky Way star, the internal motions of Local Group satellites, and the motions of giant ellipticals in the Virgo cluster (~15 Mpc).

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



How much do galaxies recycle?

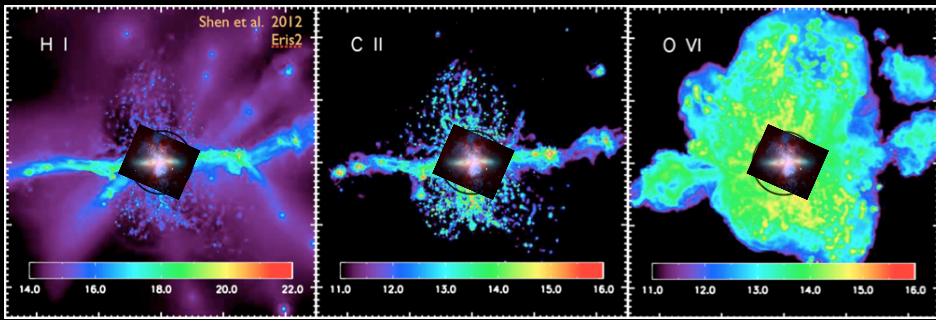
An 10-m can reach QSOs at m_{FUV} ~ 22, where there are ~ 10 / deg^2.



An 8-m can observe ~10 QSOs behind all galaxies within ~ 10 Mpc (purple line) and >1 out to 30 Mpc .

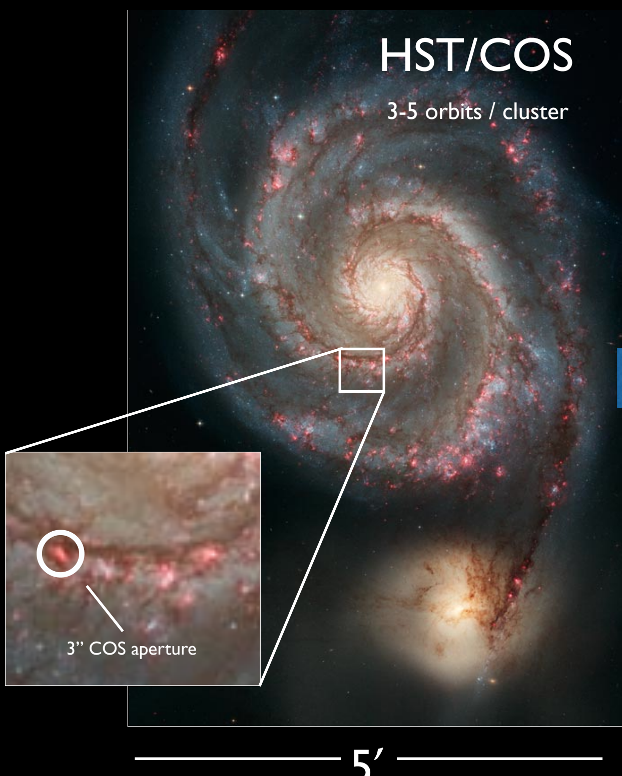
Requires high-throughput, high-resolution FUV spectroscopy from 900 - 1150 Å to obtain multiphase gas diagnostics on diffuse gas.

How much do galaxies recycle?



The supernova and AGN-driven outflows that constitute “galactic feedback” are richly structured in density and temperature.

Ultraviolet spectroscopy can measure the mass, metal content, and kinematics of these flows in a **spatially resolved fashion** if we can achieve the necessary sensitivity on small spatial scales.



<u>UV Driver:</u> A true multi-object / IFU capability in the UV would trigger a revolution in our ability to dissect gas flows and the stellar populations that give rise to them, with dense sampling of spatial variations and all relevant physical variables.

Also would permit detailed mapping of UV continuum and line SFR metrics, spatially resolved, from z = 0 - 1.

The LUVOIR architectures

Architecture A

- 15-m diameter telescope
- Four instruments

Instruments
Coronagraph A
LUMOS A
High-Definition Imager
POLLUX

Architecture B

- ~ 9-m diameter telescope
- Three instruments

Instruments
Coronagraph B
LUMOS B
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.)

Major upgrade of HST WFC3

HST Wide Field Camera 3

The LUVOIR instruments

<u>Observational challenge</u>

No UV through Earth's atmosphere

<u>Solution</u>

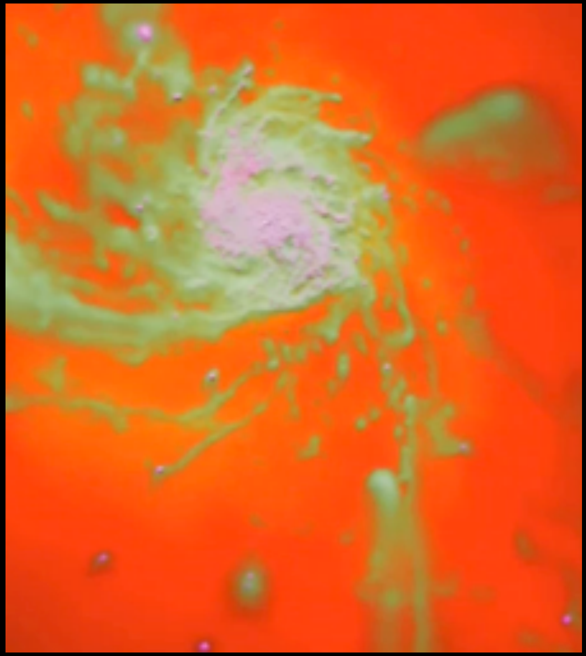
LUMOS

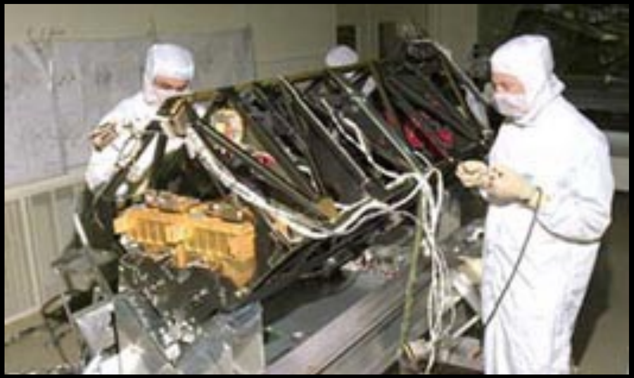
Multi-object spectroscopy (R = 500 – 45,000)

Bandpass: 100 nm to 400 nm

UV imaging

Major upgrade of HST STIS





HST STIS UV instrument

The LUVOIR instruments

Observational challenge

Measuring warm molecules present in Earth’s atmosphere

Solution

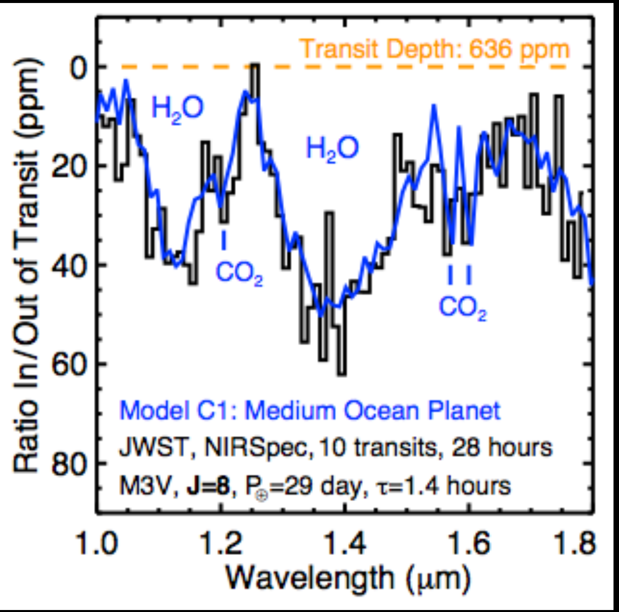
Optical / Near-IR Spectrograph

Multiple resolutions up to R ~ 10^5

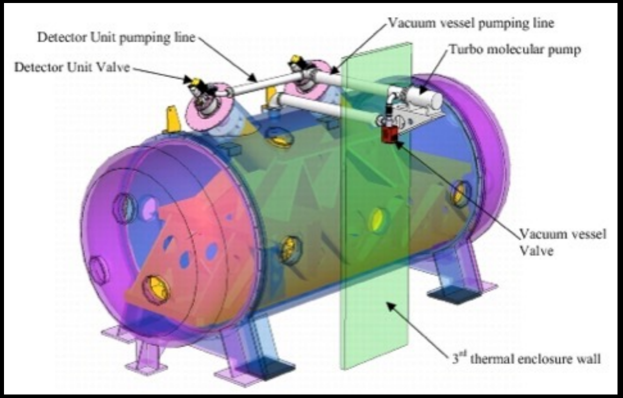
High photometric precision (transits)

Possibly high precision RV capability

Ground-based analogs in development



Credit: Natasha Batalha



ESPRESSO spectrograph for VLT (Credit: ESO)

LUVOIR online simulation tools

http://asd.gsfc.nasa.gov/luvoir/tools/

Performance Simulation

This page links to performance simulations and visualizations for the LUVOIR mission, NASA's future concept observatory for UVOIR astronomy.

All these widgets are experimental. If they are not working, email tumlinson AT stsci.

HDI Photometric ETC

This is the basic ETC for photometry in multiband images.

LUMOS Spectroscopic ETC

This is a very simple ETC for UV spectroscopy with LUVOIR.

Galaxy Imaging Resolution

A comparison of resolutions for a z = 2 galaxy.

UV MOS and Stellar Clusters

See the impact of UV MOS on the study of stellar clusters and their feedback.

ExoEarth Atmospheres

Play around with atmosphere spectra for exoEarths of different surface composition.

Coronagraphic Spectra of Varied Exoplanets

Model observations of Earth-like planets with realistic noise.

Exoplanet Yield Tool

A widget for visualizing the Stark et al. ExoEarth yields.

Multiplanet Yield Tool

An experimental rendering of the Stark et al. multiplanet yields.

Learn More about LUVOIR

Technological challenges

Deployment of large segmented telescope

To be demonstrated by JWST

LUVOIR Architecture A (15-m)

Credit: A. Jones (GSFC)

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/

How we're doing the study

Four large mission concept studies started in Jan 2016 to prepare for Astro2020 Decadal Survey

- LUVOIR
- Habitable Exoplanet Imaging Mission (HabEx)
- Origins Space Telescope (formerly Far-IR Surveyor)
- Lynx (formerly X-Ray Surveyor)

Study office and engineering team at GSFC

Science and Technology Definition Team

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

STDT voting members


Debra Fischer
(Yale)


Brad Peterson
(Ohio State / STScI)


Jacob Bean
(Chicago)


Daniela Calzetti
(U Mass)


Rebekah Dawson
(Penn State)


Courtney Dressing
(Caltech)


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)

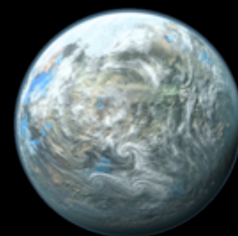

Karl Stapelfeldt
(JPL)


Jason Tumlinson
(STScI)

How we’re doing the study

Six Community Working Groups

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

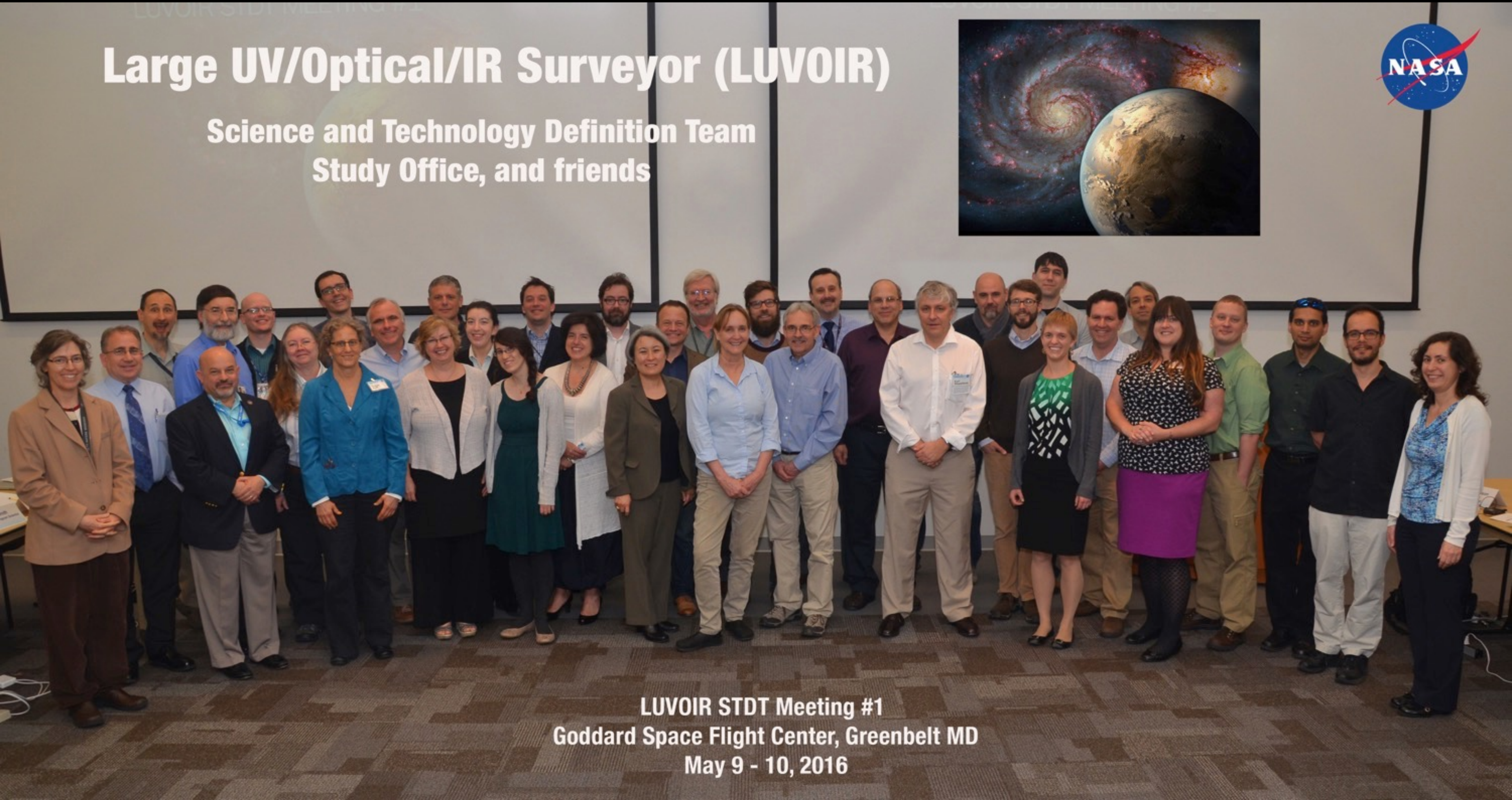


Five Instrument Teams

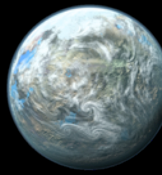
Face-to-face meetings

5th meeting July 31 – Aug 2, 2017 at Caltech

Observers welcome at all LUVOIR meetings & telecons



Difference between LUVOIR and HabEx ?



Both LUVOIR and HabEx have two primary science goals

- Habitable exoplanets & biosignatures
- Broad range of general astrophysics

The two architectures will be driven by difference in focus

- For LUVOIR, both goals are on equal footing. LUVOIR will be a general purpose "great observatory", a successor to HST and JWST in the ~ 8 – 16 m class
- HabEx will be optimized for exoplanet imaging, but also enable a range of general astrophysics. It is a more focused mission in the ~ 4 – 8 m class

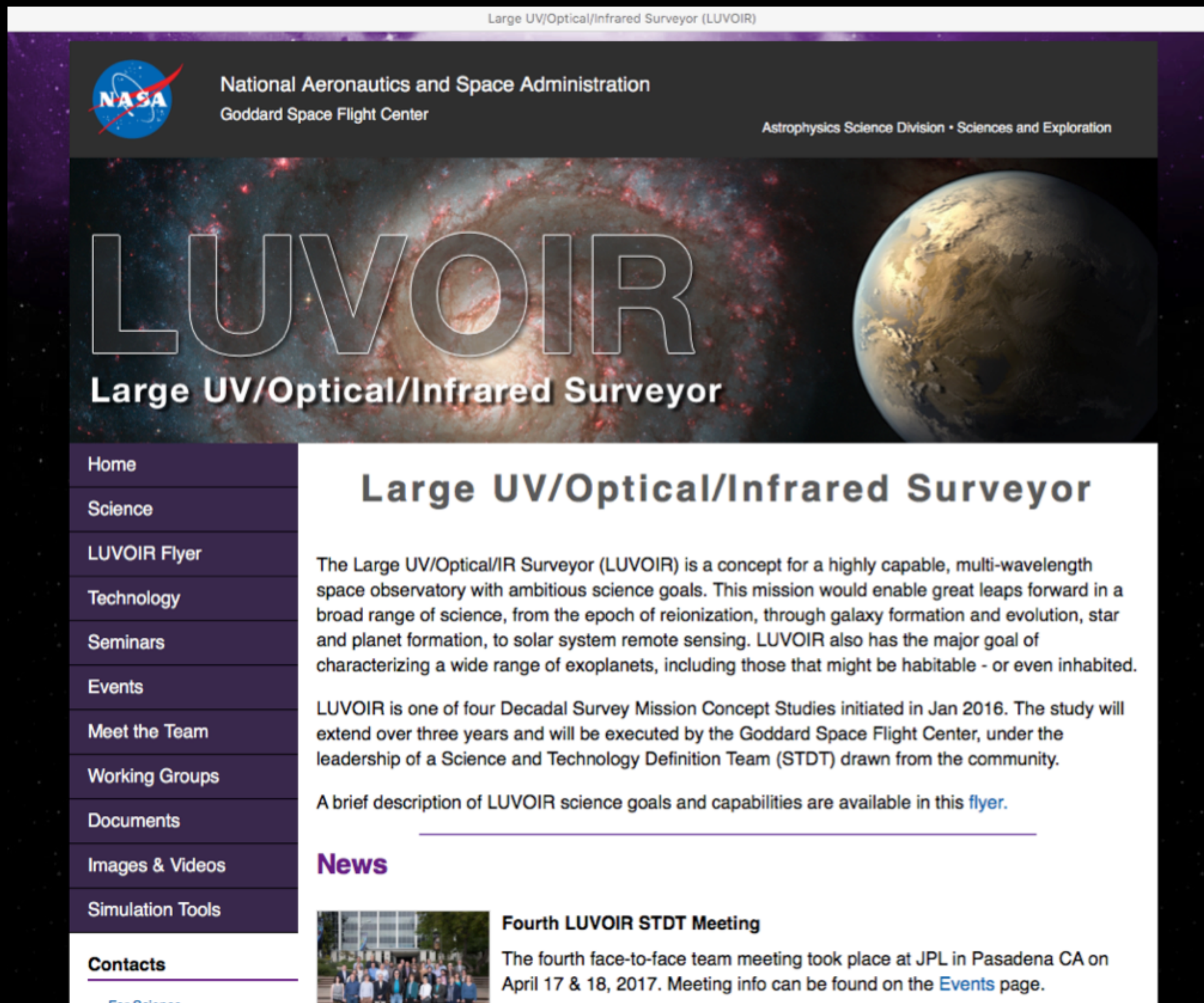
Similar exoplanet goals, differing in quantitative levels of ambition

- HabEx will *explore* the nearest stars to "search for" signs of habitability & biosignatures via direct detection of reflected light
- LUVOIR will *survey* more stars to "constrain the frequency" of habitability & biosignatures and produce a statistically meaningful sample of exoEarths

The two studies will provide a continuum of options for a range of futures

Get involved with LUVOIR

http://asd.gsfc.nasa.gov/luvoir/



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 statistical 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

LUVOIR Architecture A (15-m)

Credit: A. Jones (GSFC)

BACKUP

What will LUVOIR & HabEx cost?

Quite simply, ***we don't know*** (yet).

One of the major goals of these studies is to get accurate total mission cost estimates.

- Internal team costing and independent costing by Aerospace Corp. will happen as part of the studies.

Both teams are planning to study two mission architectures, each with different apertures and capabilities. Will provide a range of options covering a range of possible futures.

It is the responsibility of the Decadal Survey to judge the optimal science-to-cost ratio.

It is not straightforward to intuit the total cost of a space observatory (complex process with many important parameters).