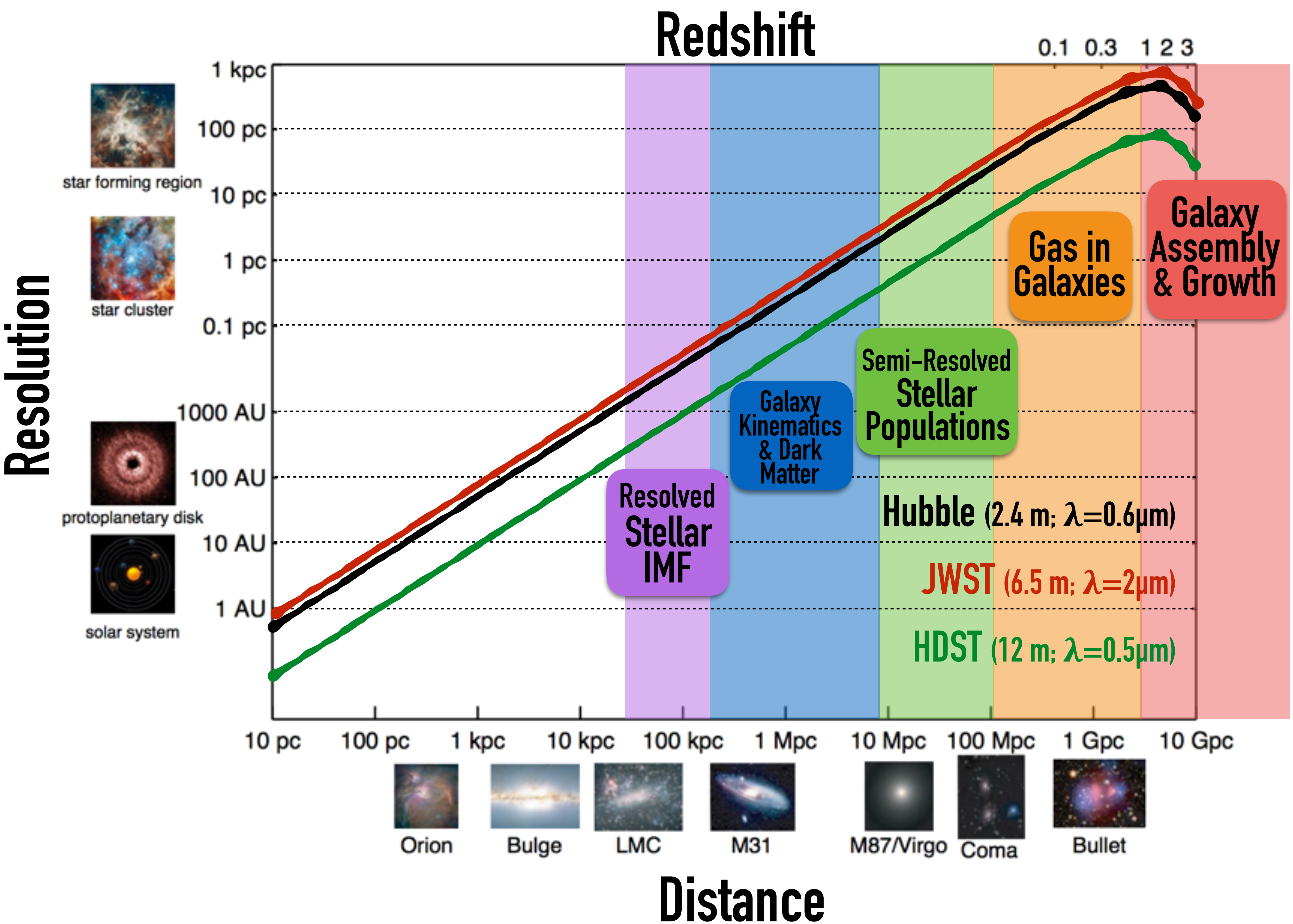
Cosmic Origin Science Overview

With LUVOIR

Marc Postman
Space Telescope Science Institute

Epochs and Science where LUVOIR is uniquely suited to rewrite key chapters in the story of cosmic origins

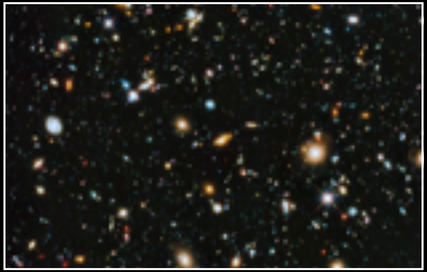


Adapted from AURA Report by Kate Whitaker (U. Mass. Amherst) & Marc Postman

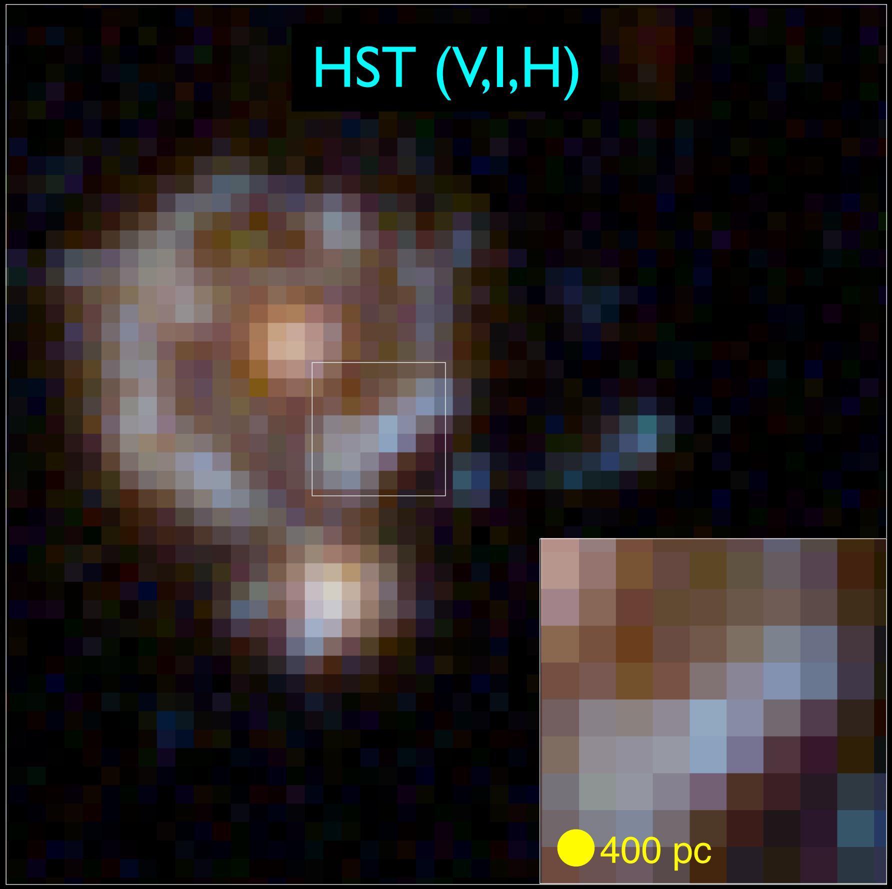
How Did the Milky Way Form from its Earliest Seeds?

Epoch z = 1 - 8

Resolution 30-100 pc



Milky Way Progenitor at z = 2



Images simulated by
Greg Snyder (STScI)

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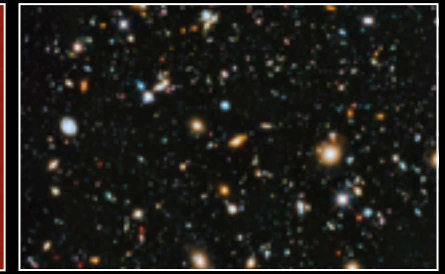

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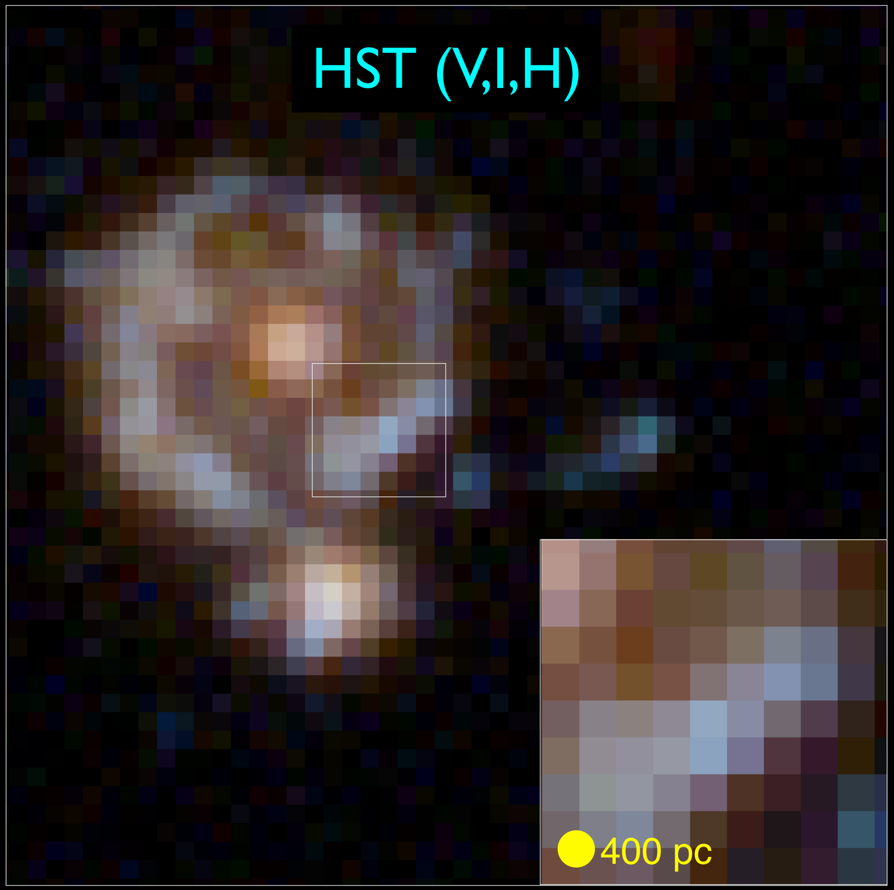

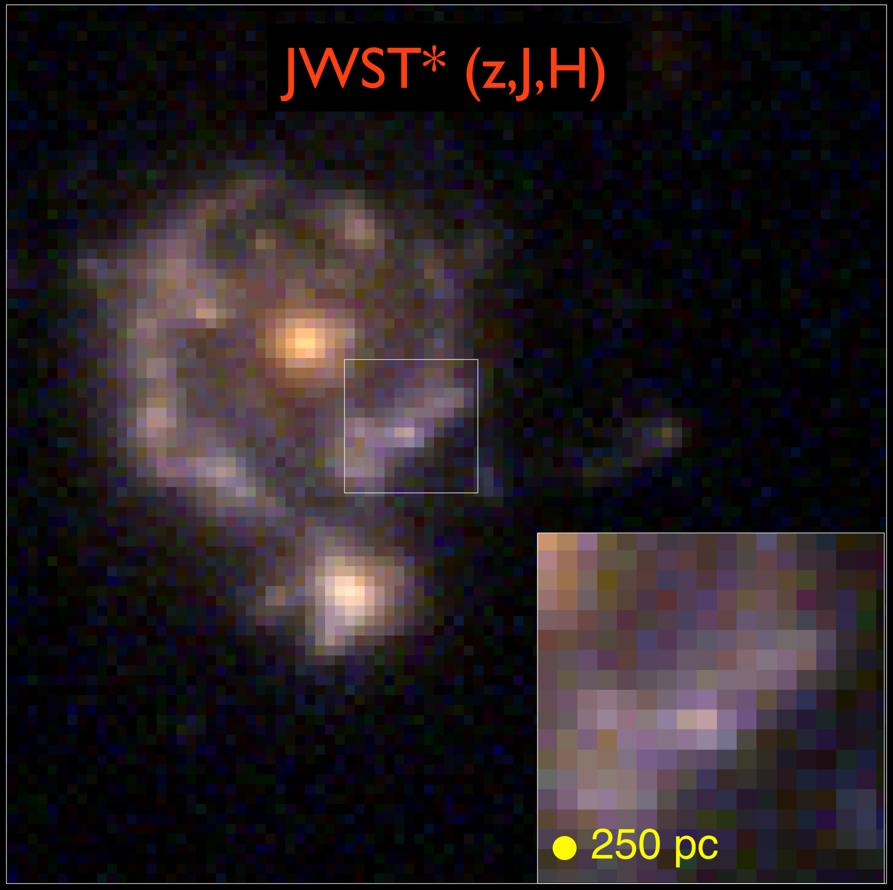

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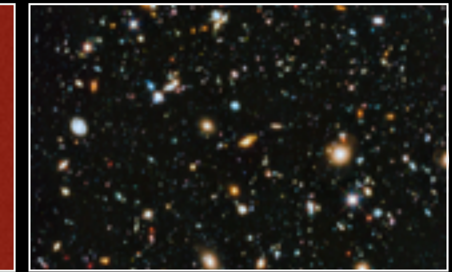

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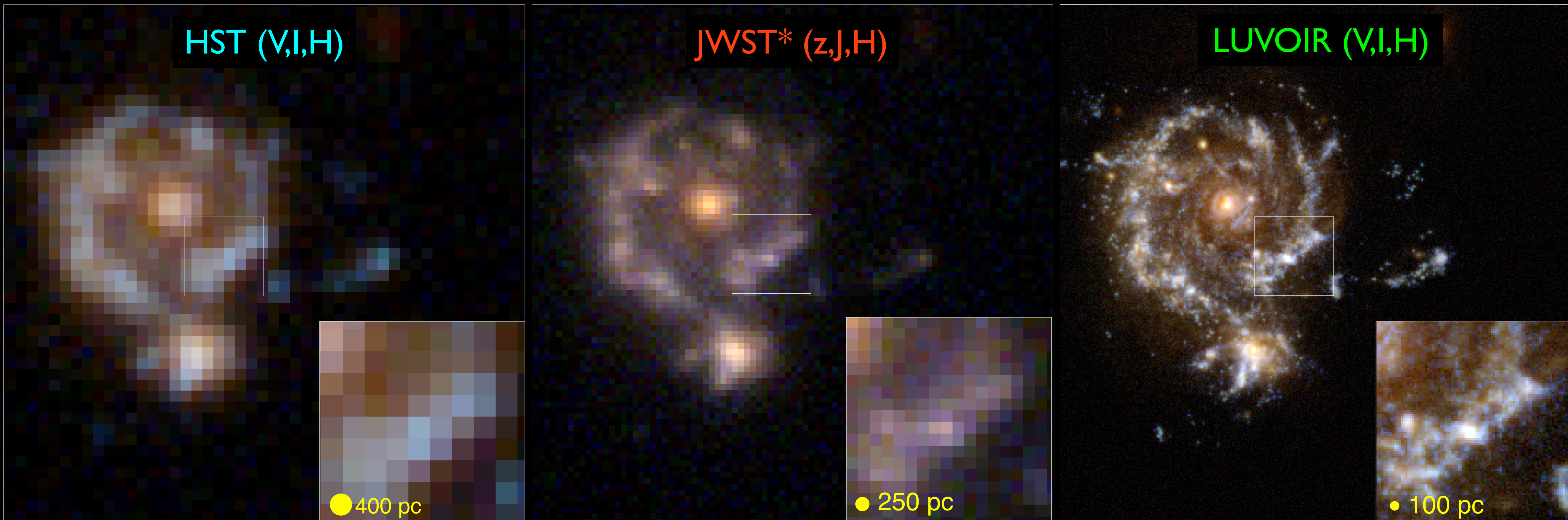

With <u>unique 100 parsec resolution</u> in the optical at all redshifts, LUVOIR can resolve the building blocks of galaxies: individual star forming regions and dwarf satellites, including progenitors of the present-day dwarf spheroidals.

These high-resolution images will complement spectroscopy from 30m class ground-based telescopes and ALMA of the galaxies and their molecular gas. LUVOIR will spatially resolve SFR, Hα/Hβ, BPT diagnostics, HeI/Hβ, etc.

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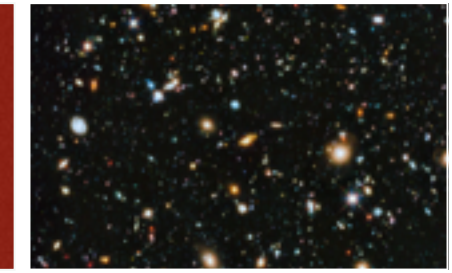
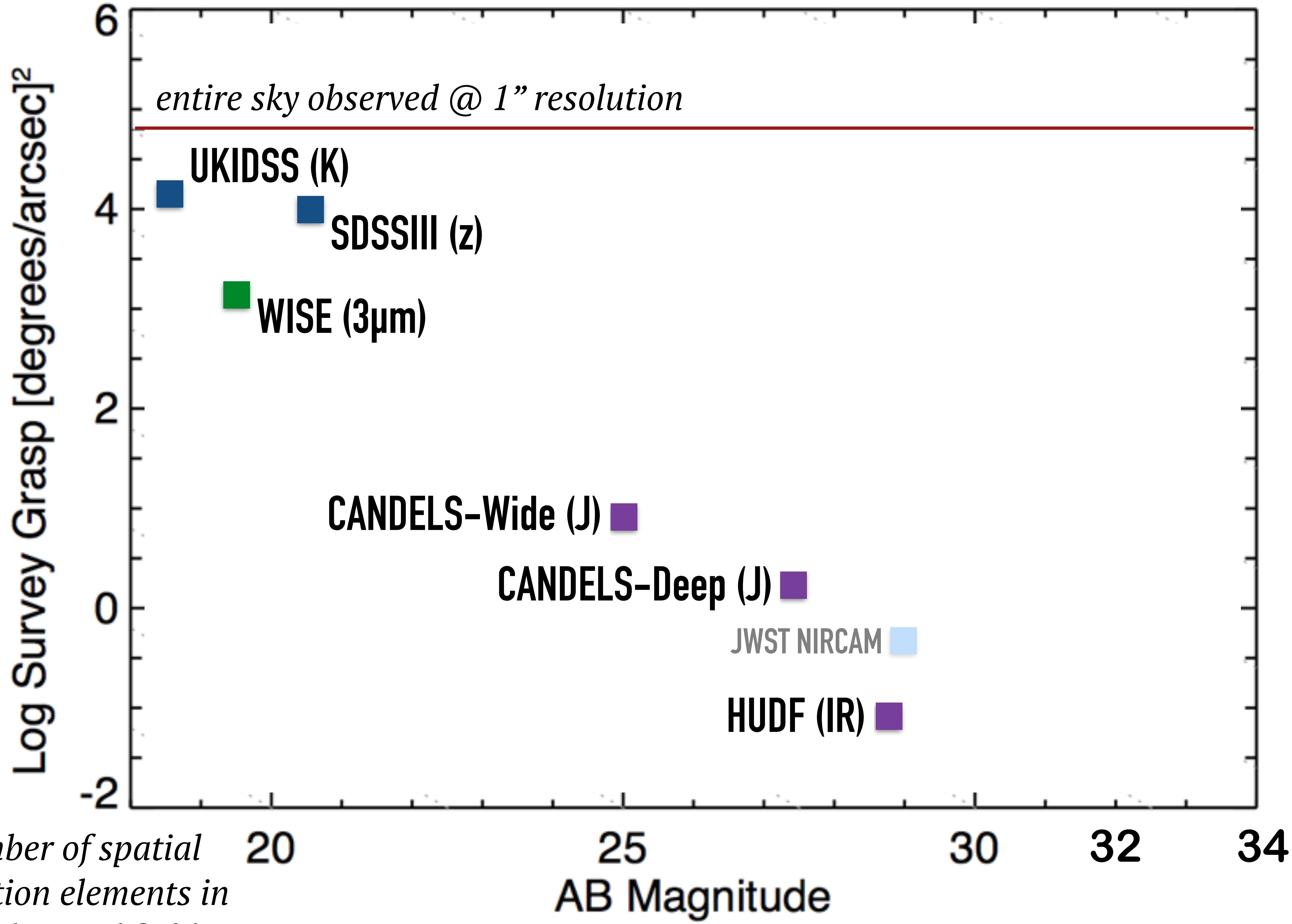
How Do Galaxies Grow, Evolve, and Die?

Epoch z = 1 - 8

Resolution 30-100 pc





number of spatial resolution elements in the observed field

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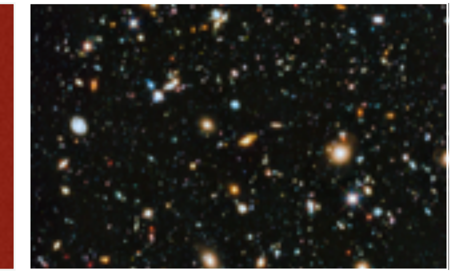

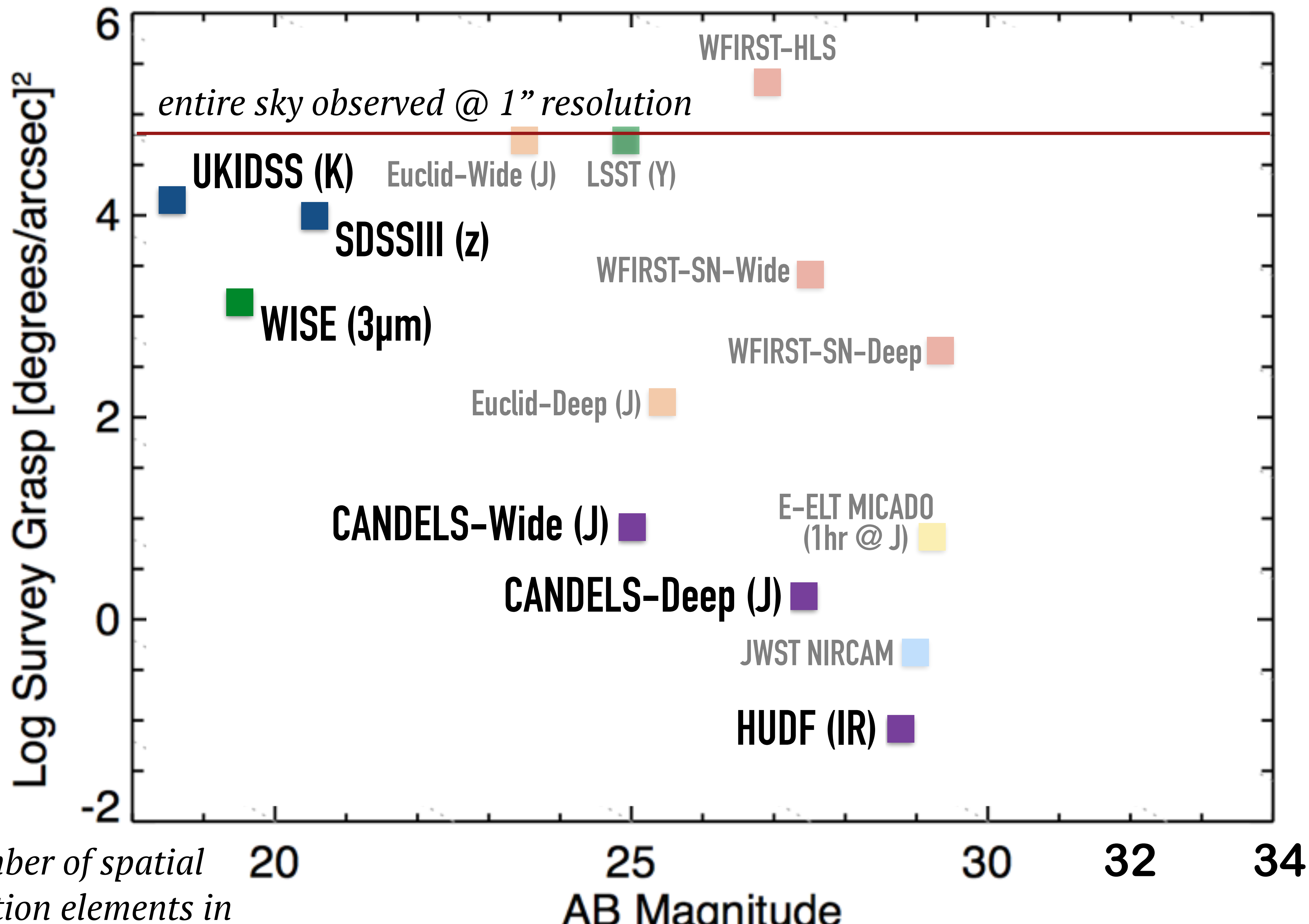

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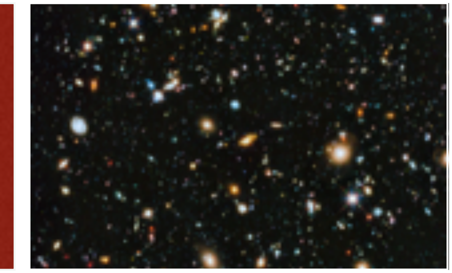

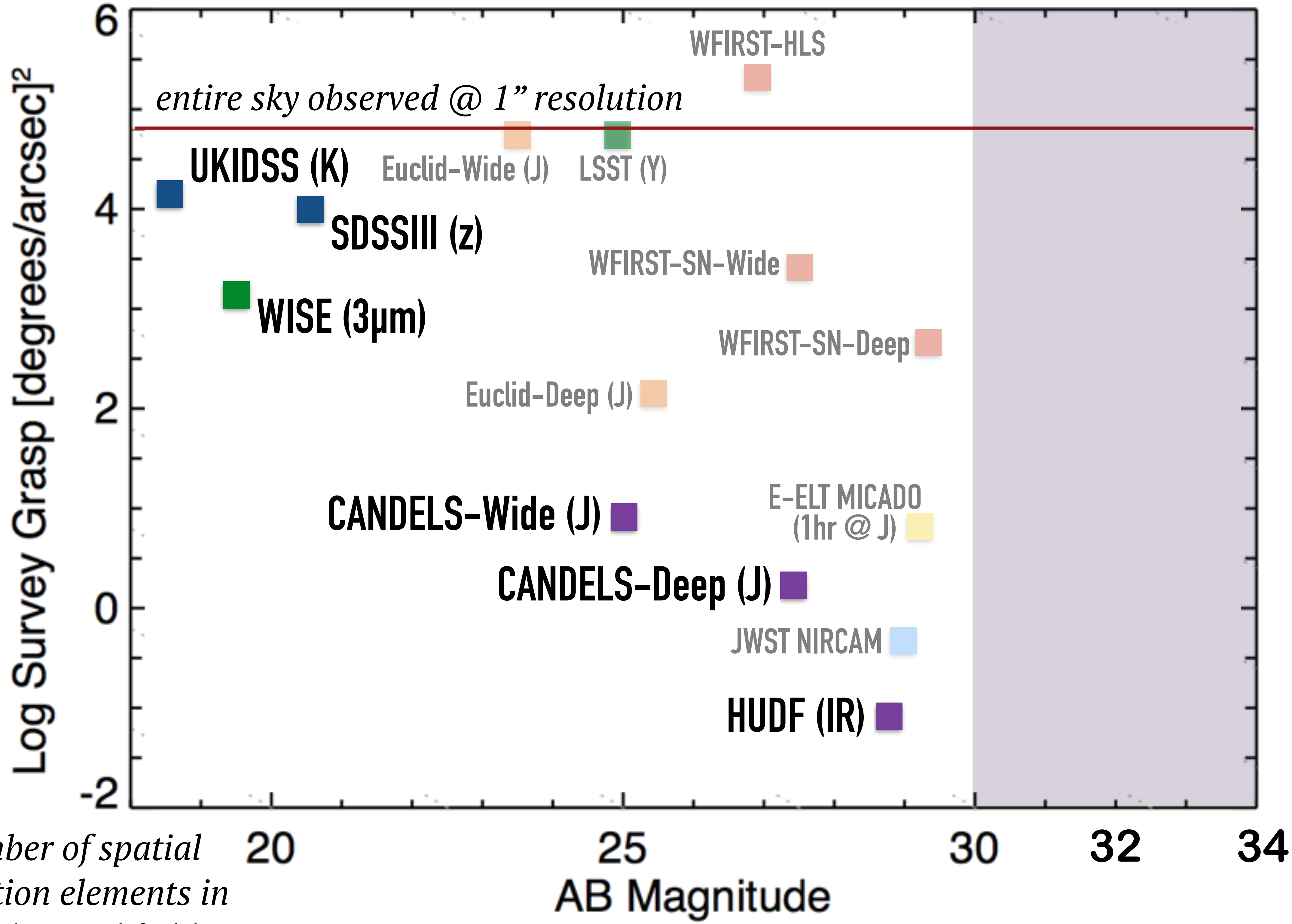

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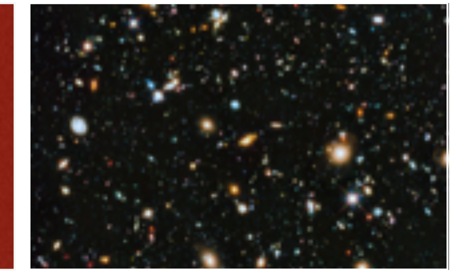

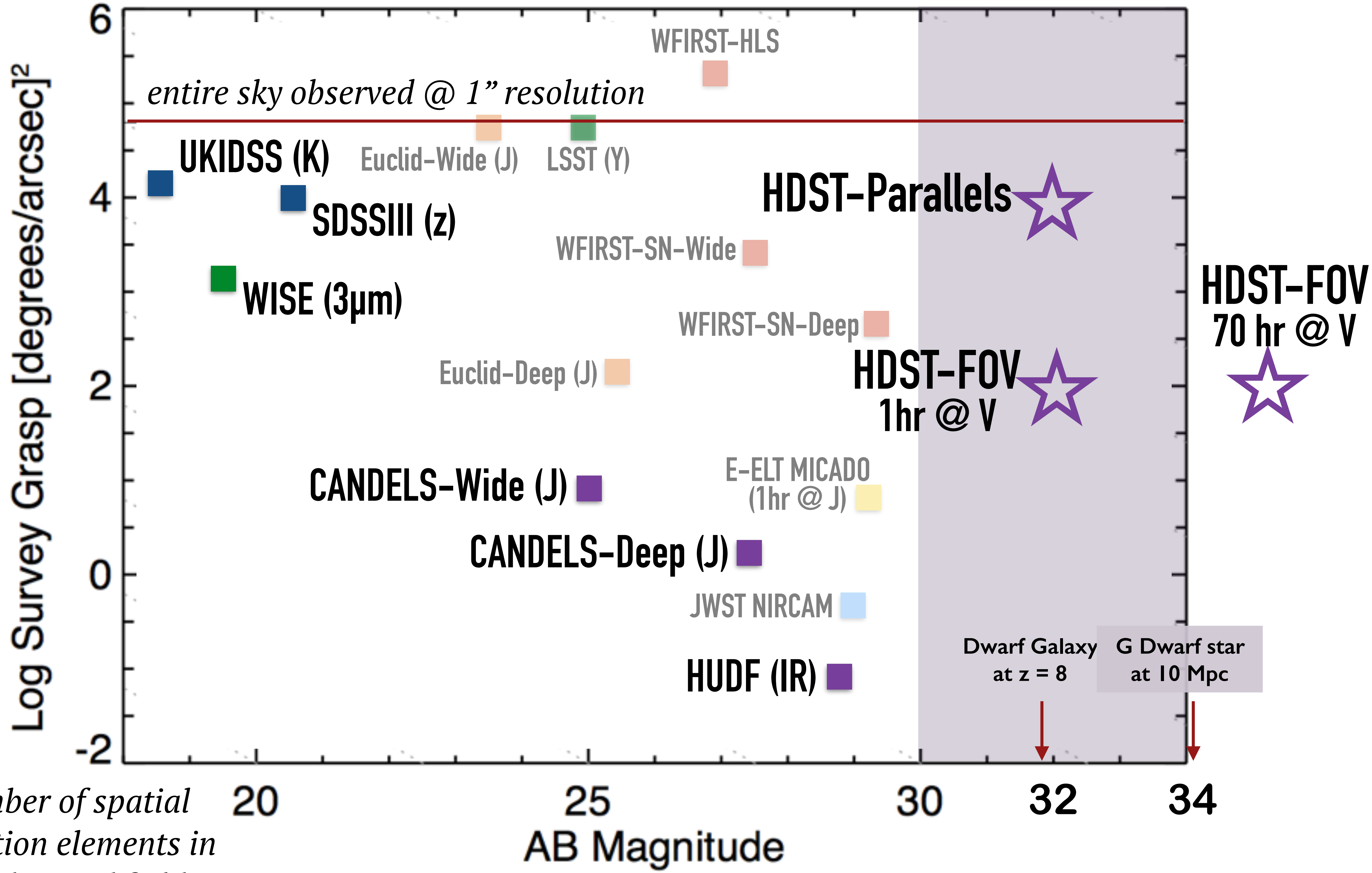

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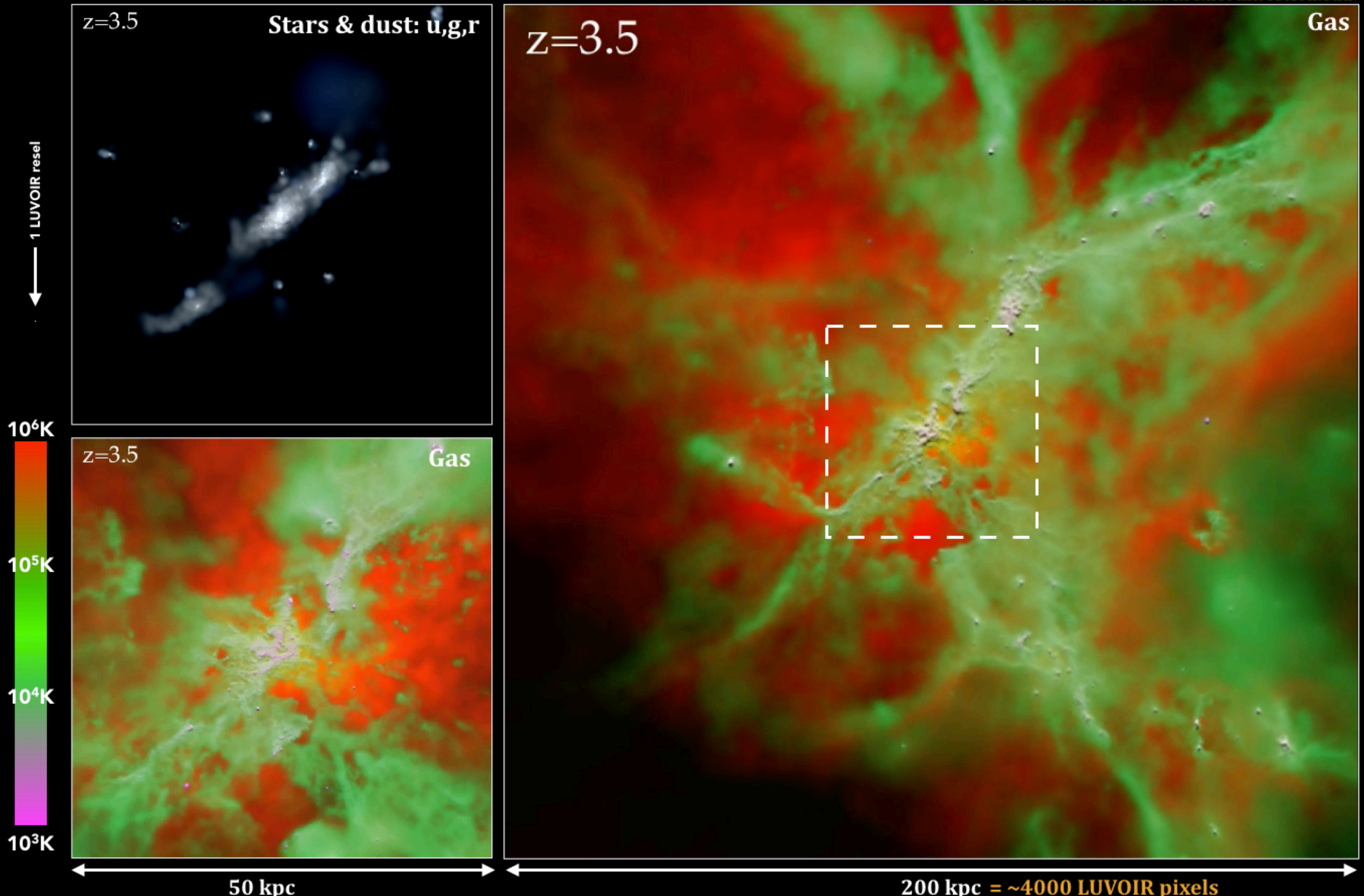
The Gas - Galaxy Connection

How do galaxies transition to quiescence?
What are the dynamics of flows into and out of galaxies?
How (and where) does the baryonic lifecycle evolve?

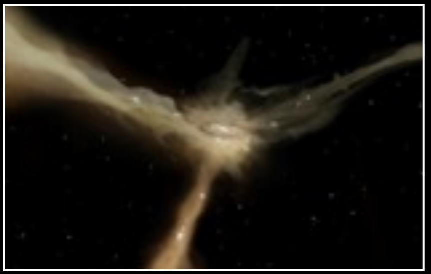
FIRE Simulation Team: fire.northwestern.edu



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

Epoch
z < 1

Resolution
10-100 pc



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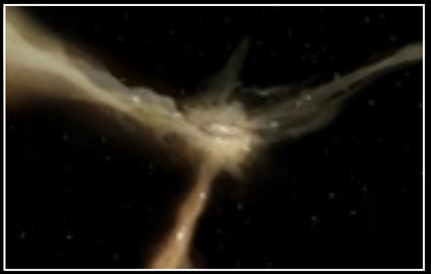

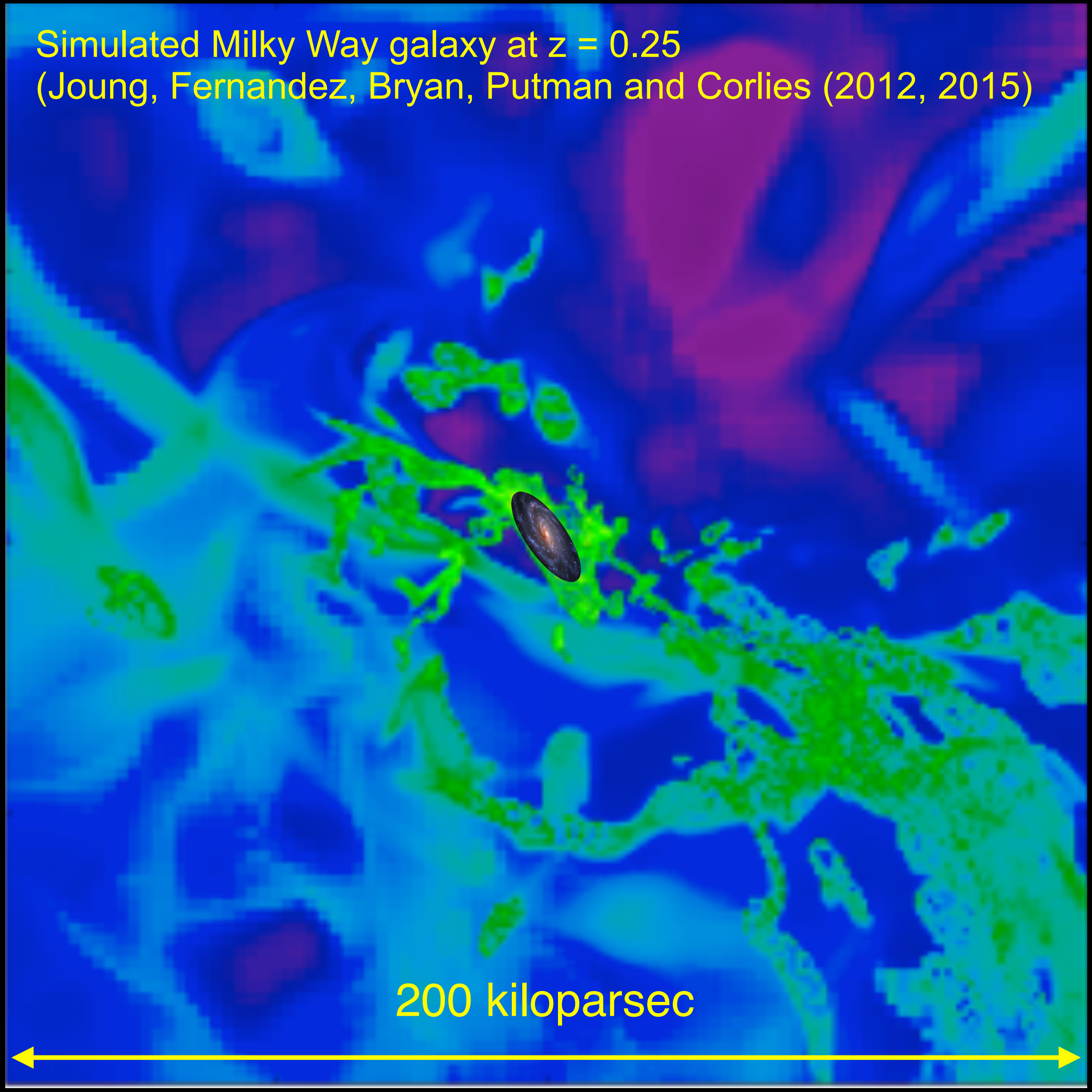

Using powerful and unique multi-object UV spectroscopy, HDST will be able to map the “faintest light in the Universe” emitted from gas filaments entering galaxies and energetic feedback headed back out.

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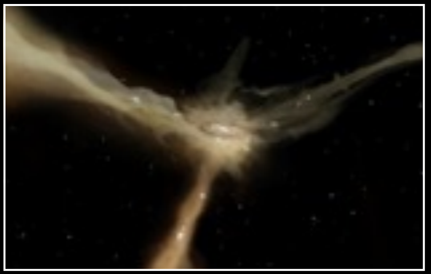
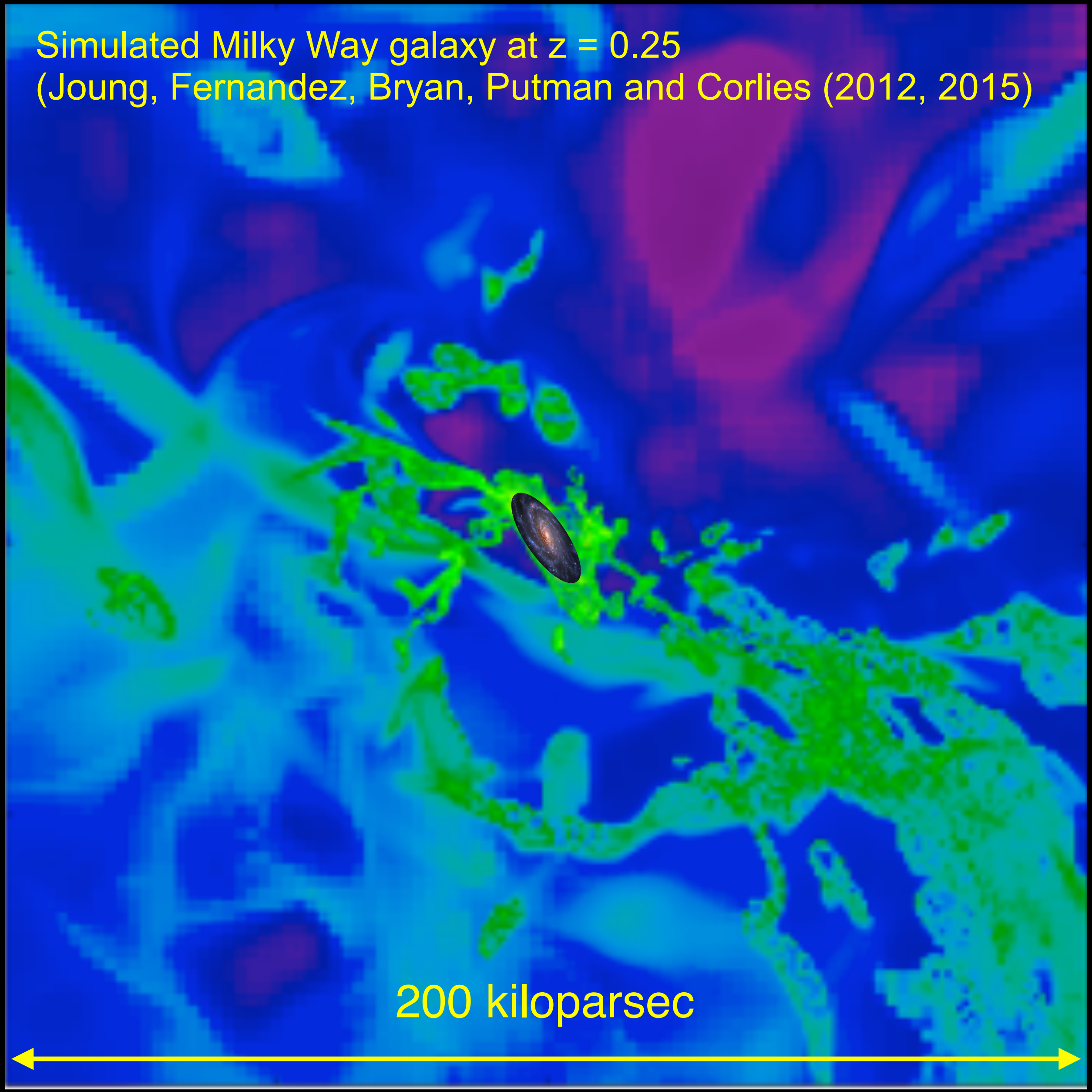
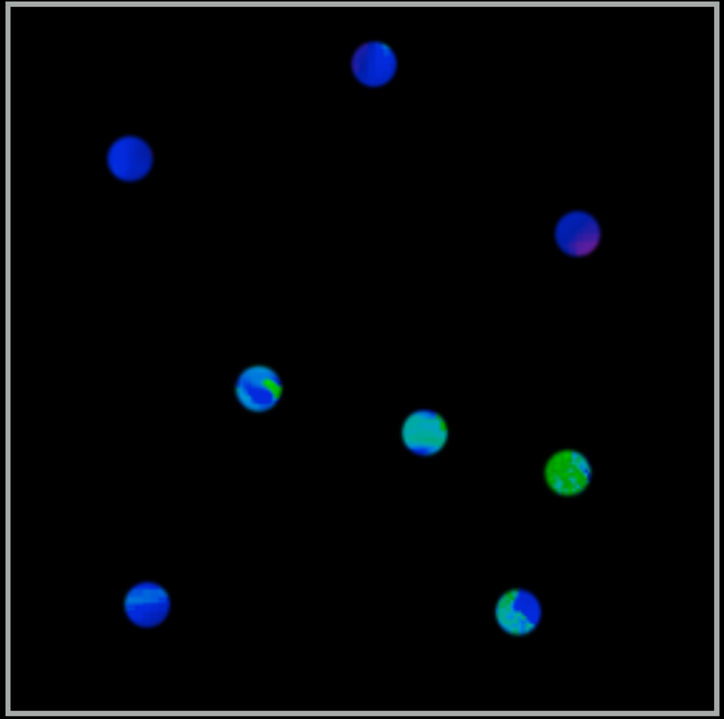




HST+COS & stacking of multiple FOV:



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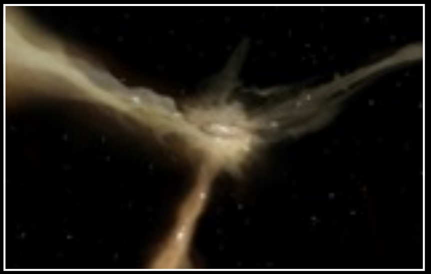

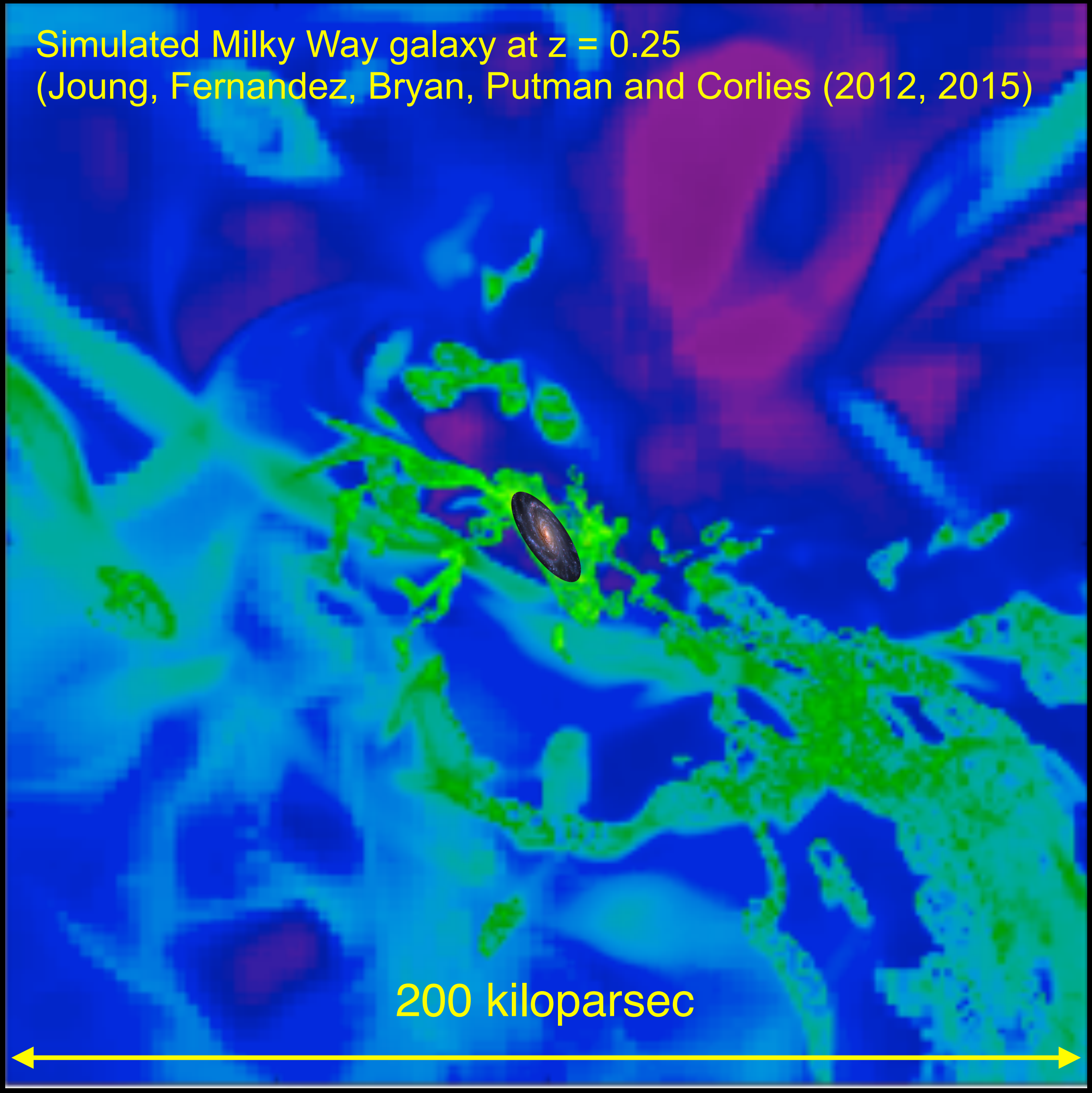

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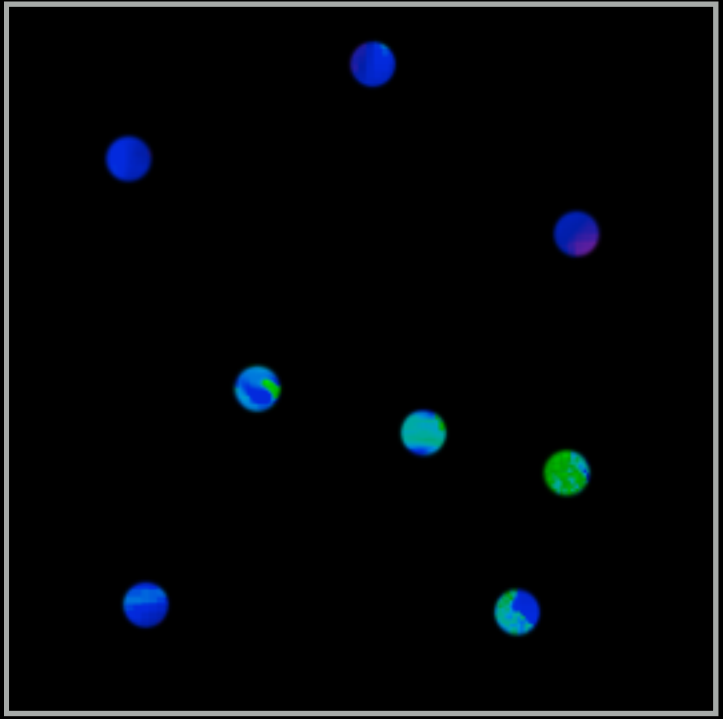
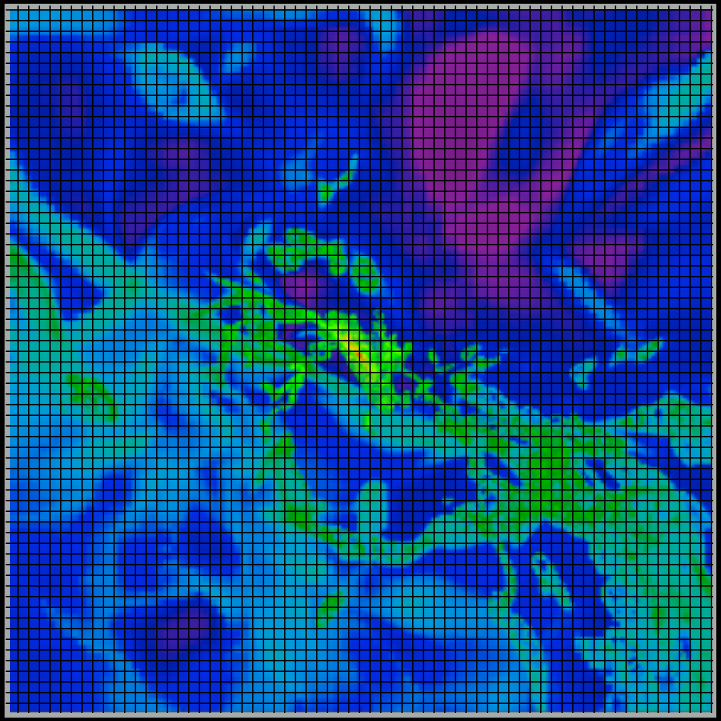


LUVOIR + UV MOS for any single FOV:



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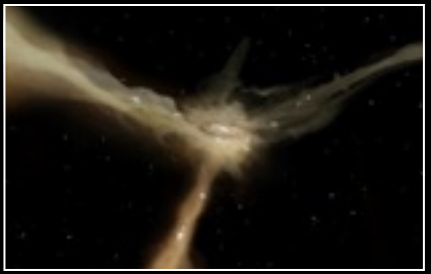

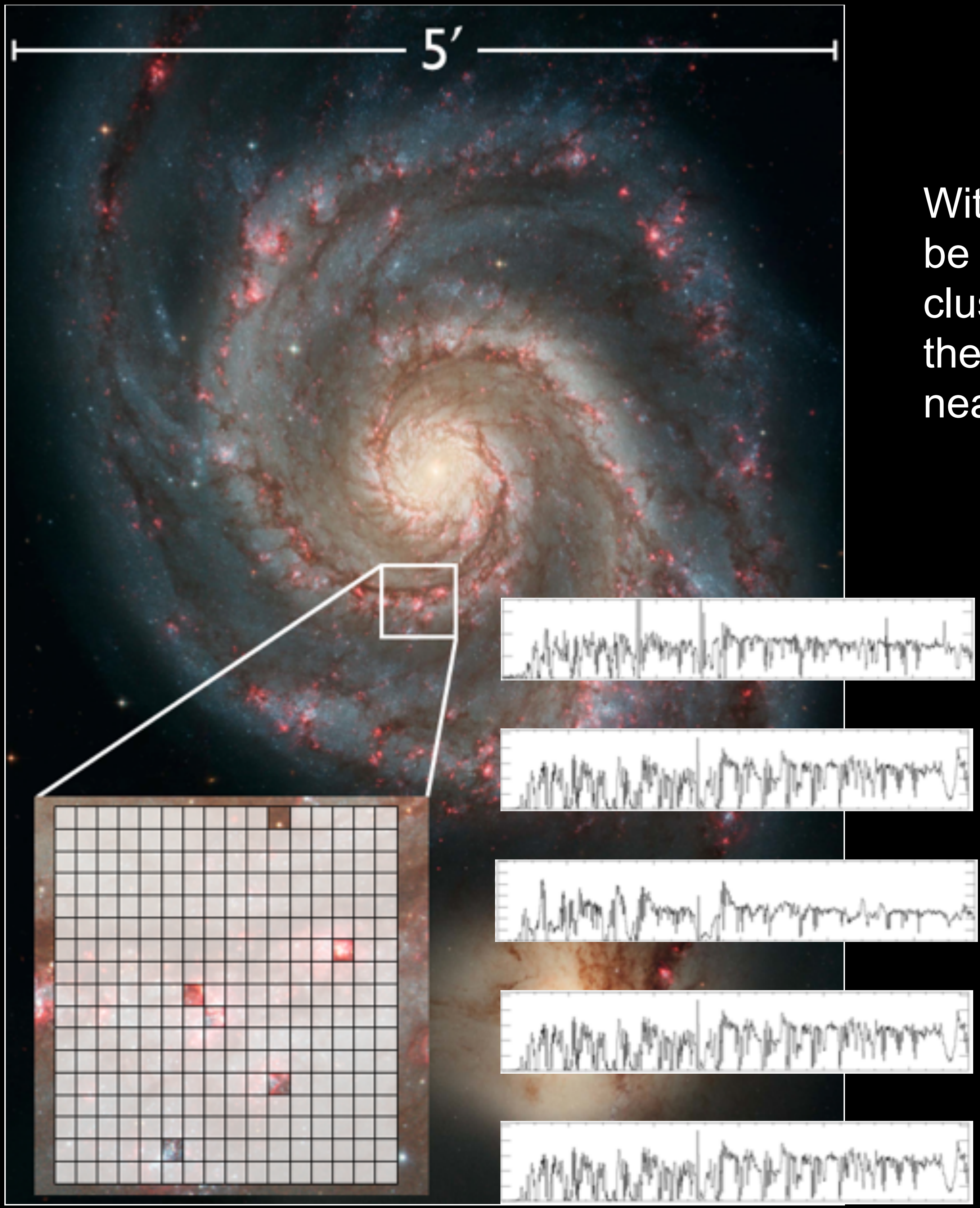

With the same UV multiplexing, LUVOIR will also be able to map the properties of young stellar clusters and, using them as background sources, the outflows they drive into the ISM and IGM in nearby galaxies.

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

Epoch
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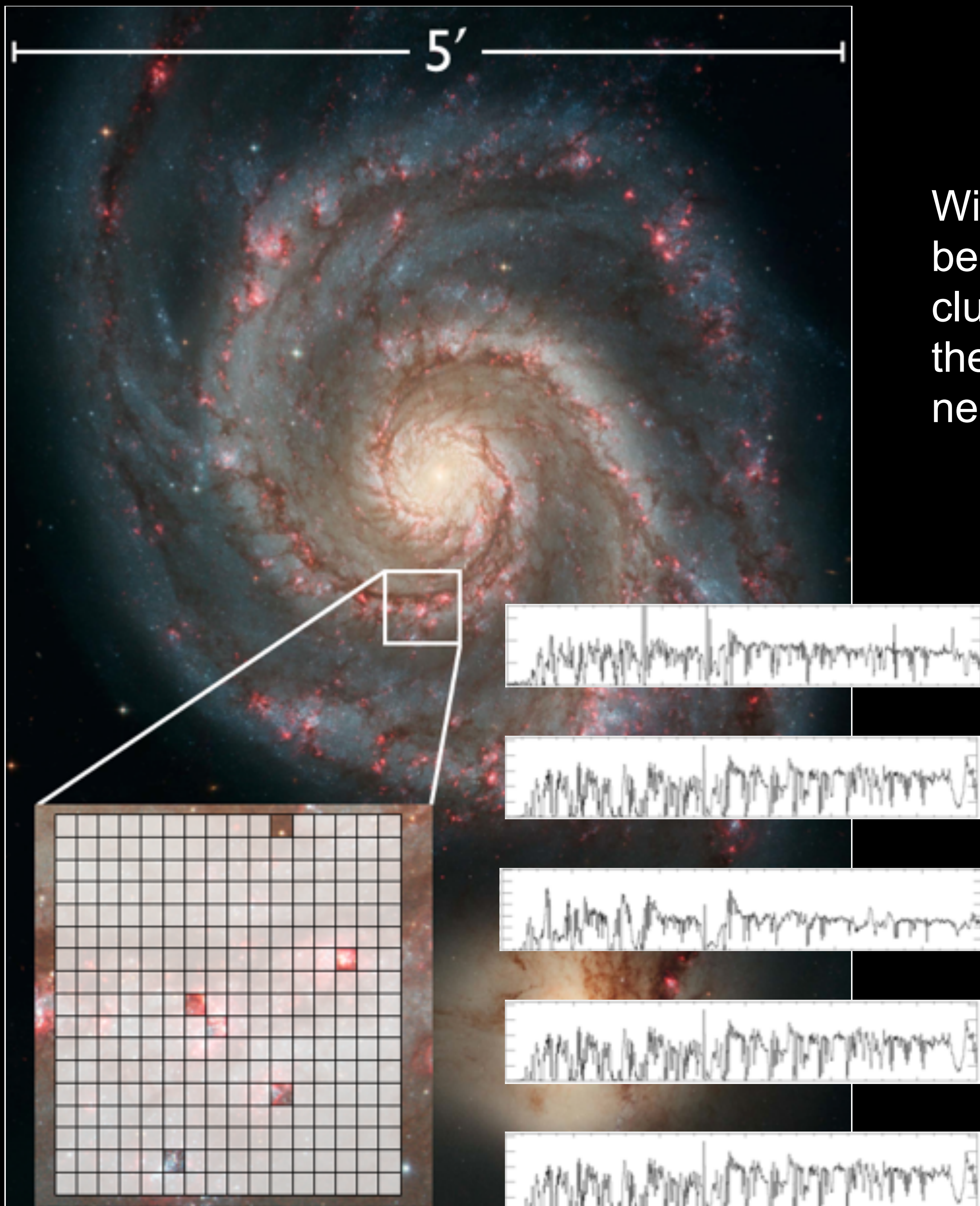
Resolution
10-100 pc



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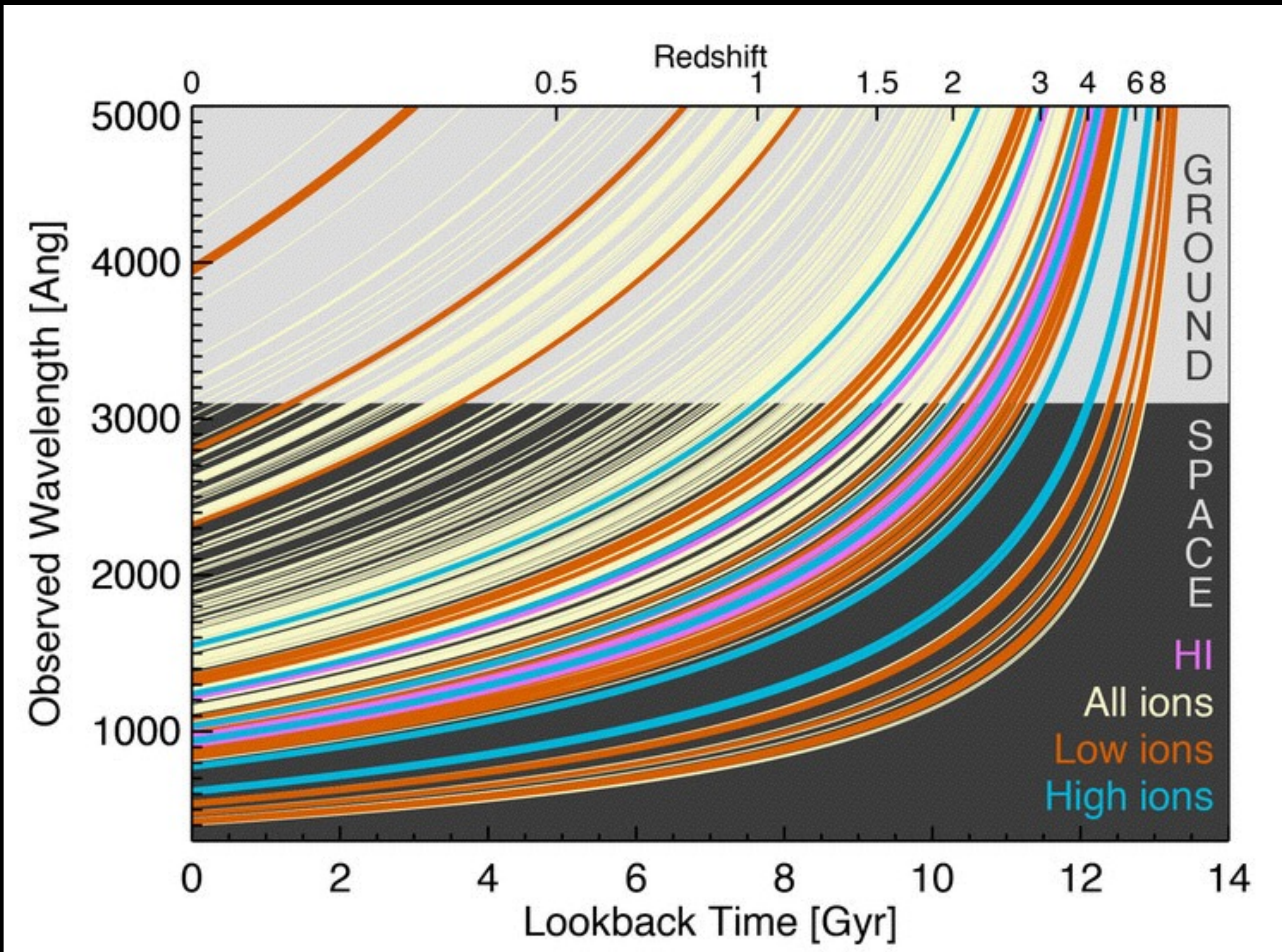
These observations **require** UV capability and ~ 10+ meter aperture.

UV Access is Essential!



UV spectral features provide the some of the best, *and often unique*, constraints on:

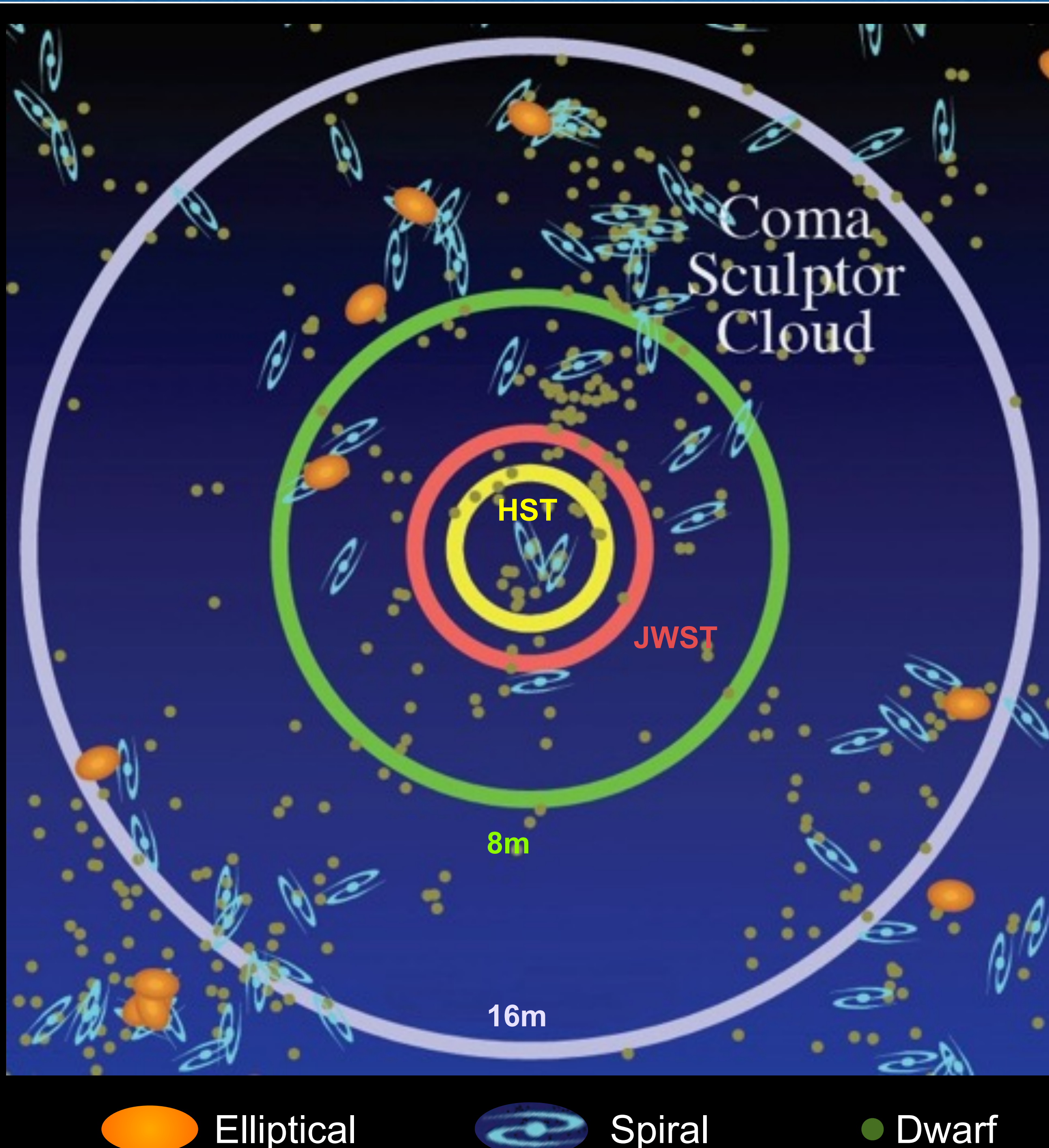
Ionization state of ISM, IGM
Structure in ISM, IGM
Sources of ionization
Gas Temperature
Metallicity of ISM, IGM
Gas Density
Star formation rate
Gas kinematics and outflows

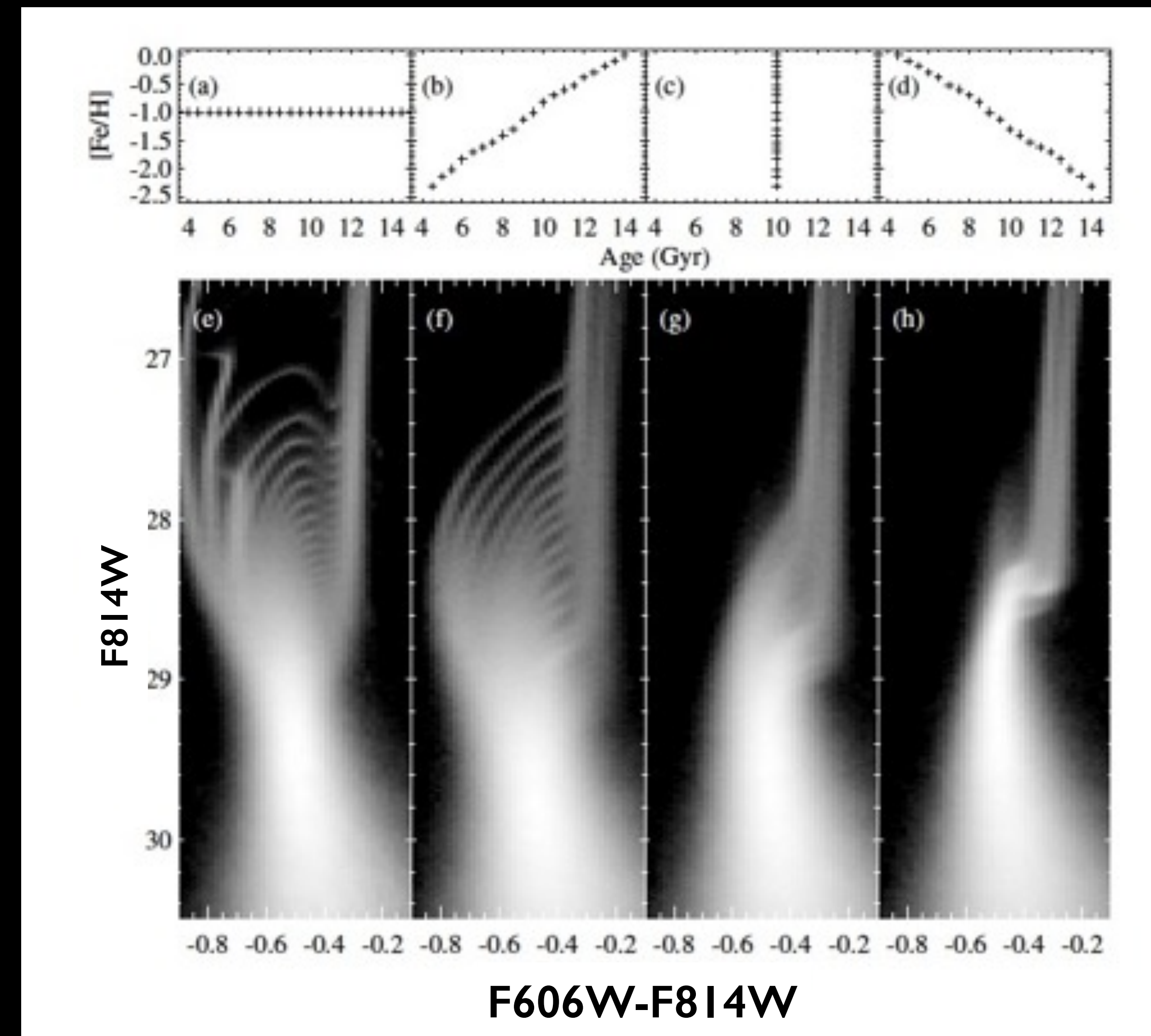
High spectral resolution is often required to make such measurements (R > 20,000)

How Does Star Formation History Create the Diversity Shapes and Sizes of Galaxies?

Volume
< 100 Mpc

Resolution
1 - 10 pc





Star formation history sets both chemical evolution and planet formation rates. Visible bands provide best discrimination.

Requires diffraction limited optical imaging and high PSF stability.

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

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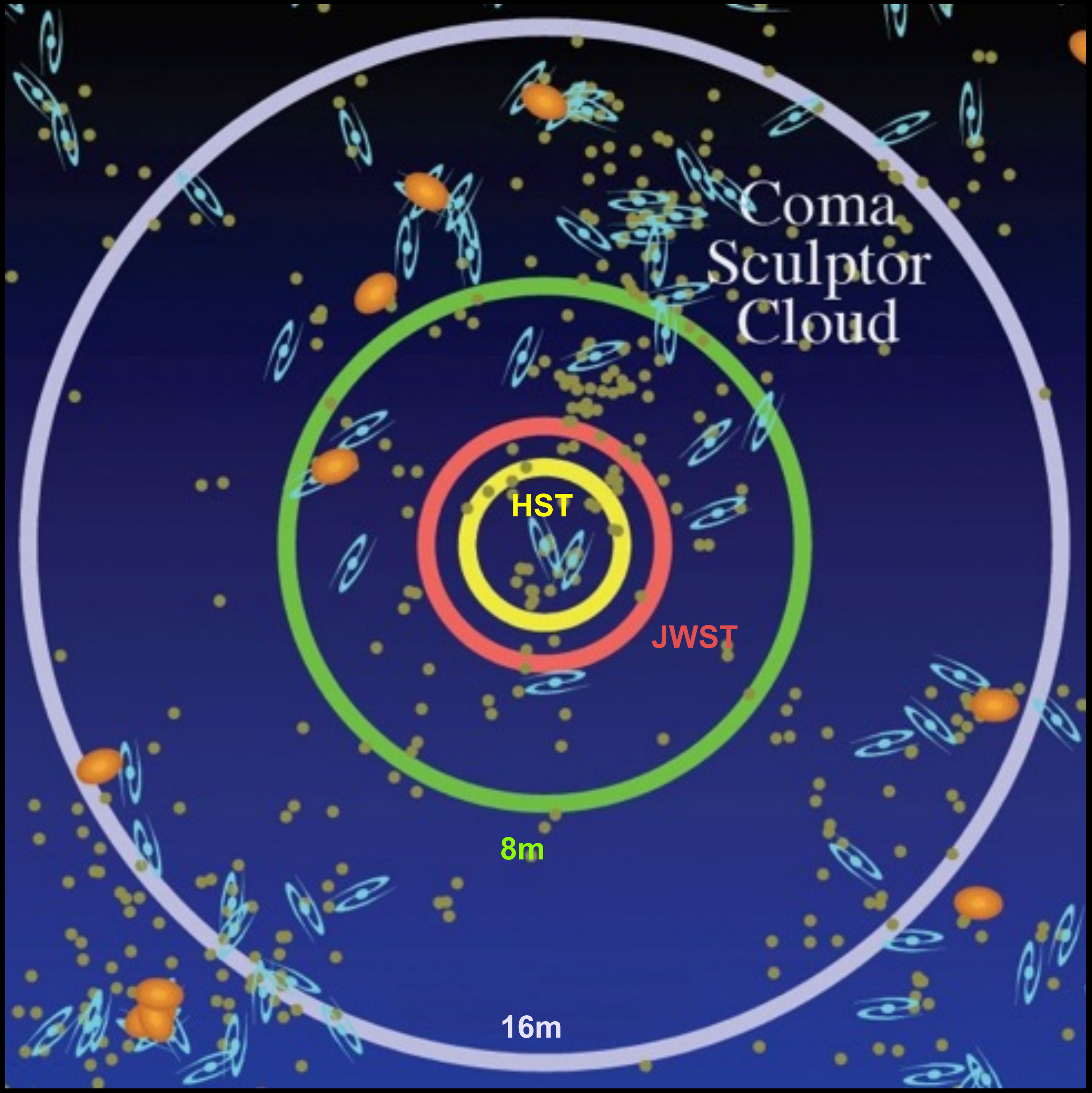

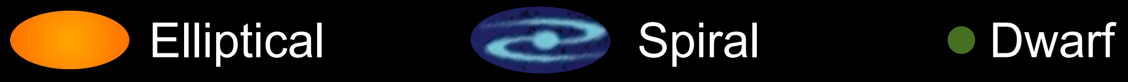

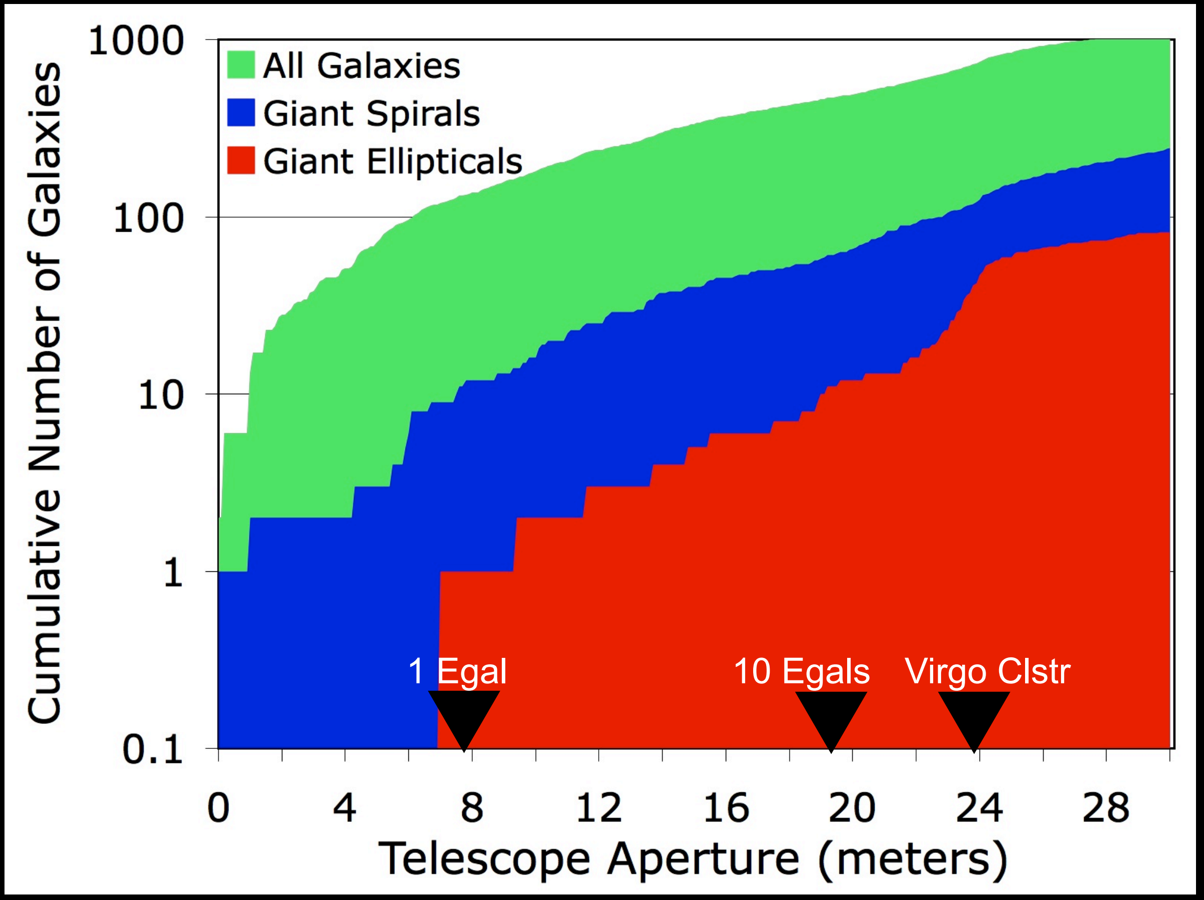

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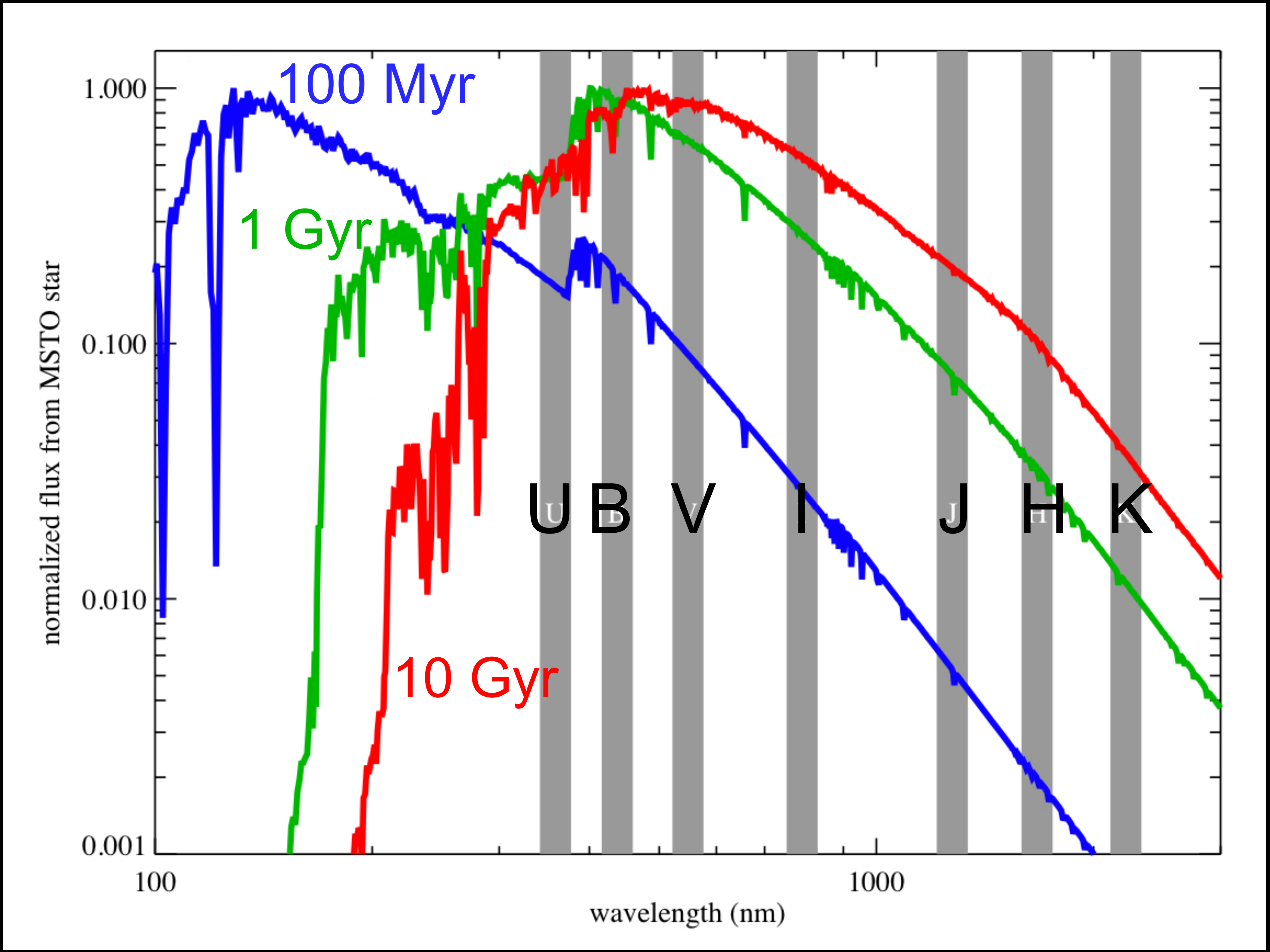
Visible and UV Sensitivity is Essential!

Volume
< 100 Mpc

Resolution
1 - 10 pc



Spectra of MSTO stars as a function of their age

JWST will observe the integrated populations of stars at high redshift but will not reconstruct their detailed star formation histories.

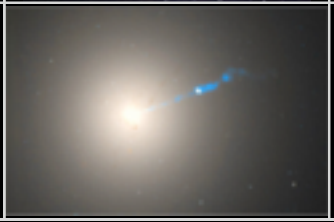
ELTs will probe stellar pops in NIR and primarily study later phases of stellar evolution (stars not on the Main Sequence).

LUVOIR will provide essential (highly age-sensitive) data in UV/optical. LUVOIR will also reach below the main sequence turn off (MSTO) for all stellar populations out to 10 Mpc. ELTs cannot do this!

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^{-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)	500 km s^{-1}		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.

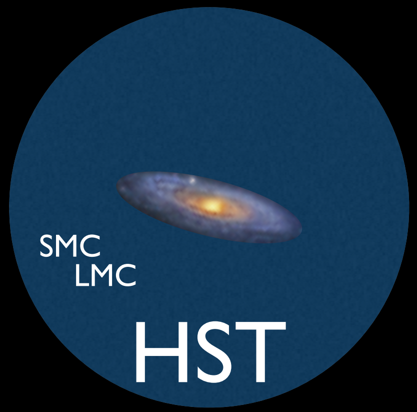
<u>Aperture driver:</u> A 10+ m is required to reach the motions of virtually ANY Milky Way star, the internal motions of Local Group satellites, and the motions of giant ellipticals in the Virgo cluster (~15 Mpc).

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

How Does the IMF Vary with Environment?
How and When is the IMF Established?

Volume
< 1 Mpc

Resolution
10-100 AU



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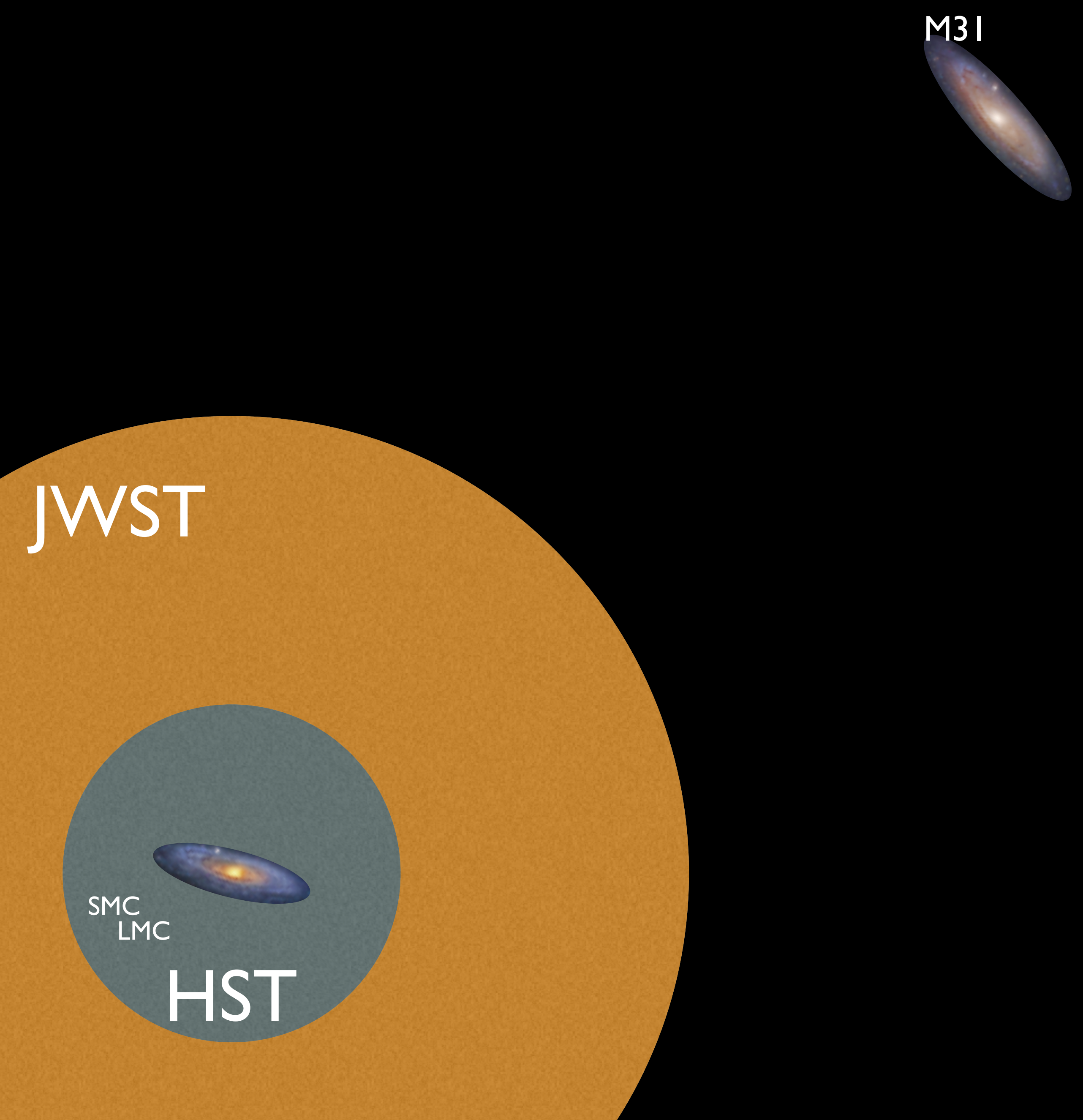

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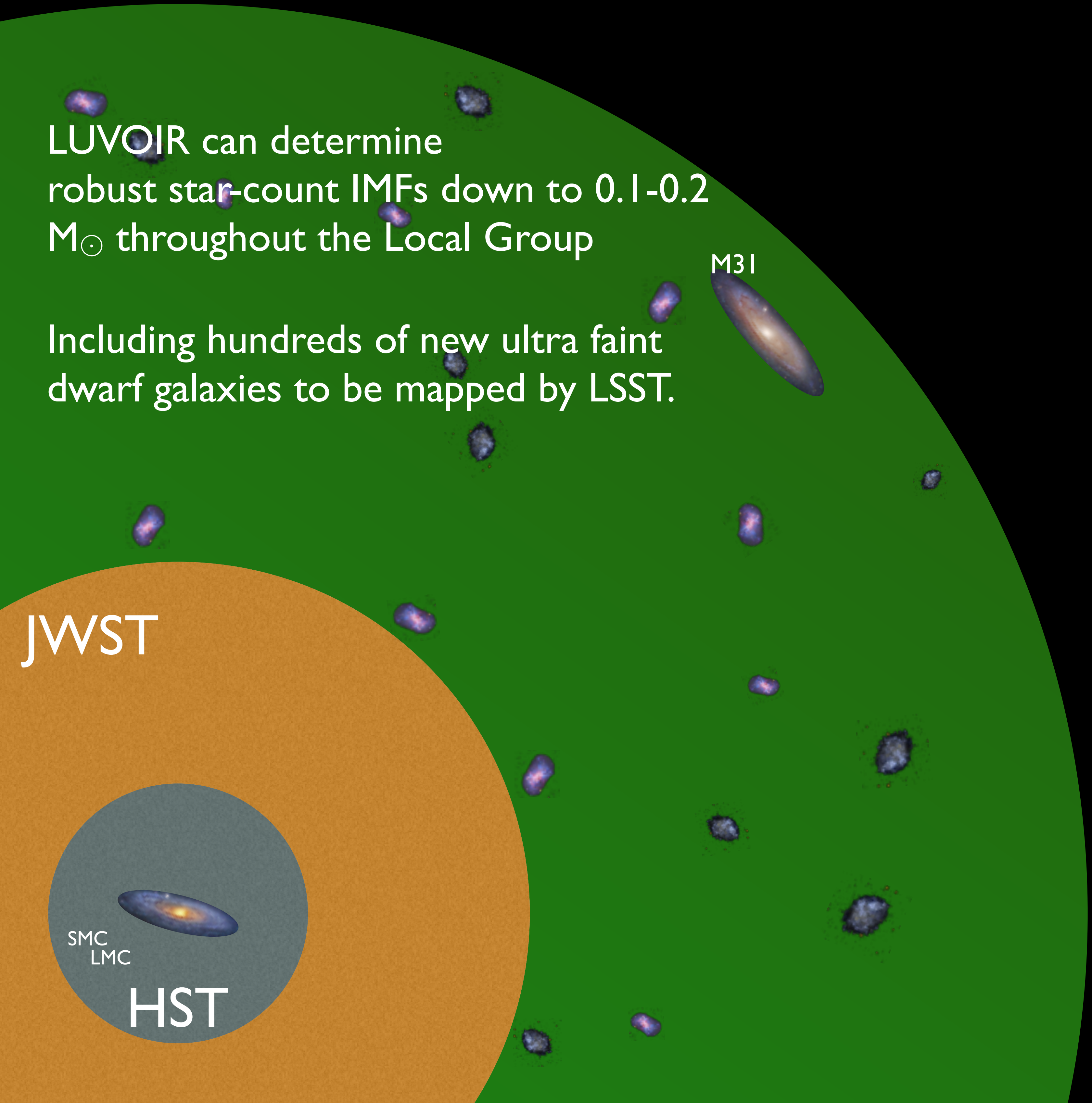
LUVOIR can determine robust star-count IMFs down to 0.1-0.2 $M_\odot$ throughout the Local Group

Including hundreds of new ultra faint dwarf galaxies to be mapped by LSST.



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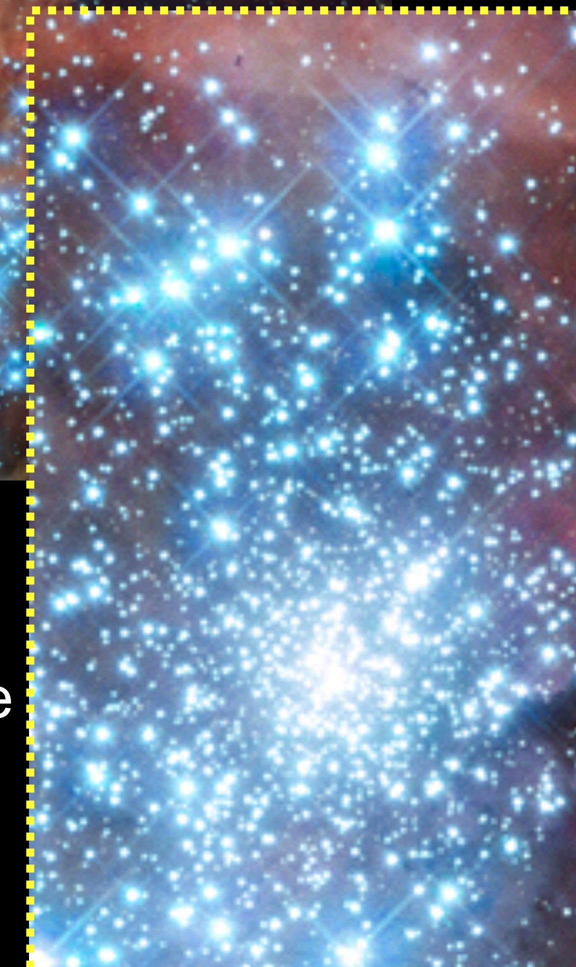
M31

JWST

SMC
LMC

HST



Most Sun-like stars are born in clusters that too dense for Hubble to resolve individual stars: 10-100 stars / arcsec^2.

UV light provides a direct estimate of stellar accretion rate from the protostellar disk, but only if single stars can be resolved (>10 meter aperture for the Magellanic Clouds).

Resolving individual stars allows direct measurements of the stellar IMF (the holy grail) and direct UV / optical estimates of accretion rate for stars still embedded in their disks.

Aperture Drivers

UV Drivers

z = 1 - 4

Resolve ALL galaxies to 100 parsec or better, to individual SF regions.

z < 1

Identify stellar progenitors and host environments for diverse transients, key to unraveling causes.

Reach > 100s of background QSOs/AGN for outflow and IGM/CGM studies.

Detect UV emission from gas accreting into and ejected from galaxies.

Detect hot plasma ejected by SMBHs acting as feedback on their galaxies.

< 100 Mpc

Resolve stellar pops down to 1 $M_\odot$ out to the nearest giant ellipticals…

…and to watch the motions of virtually ANY Milky Way star, Local Group satellites, and giant ellipticals in the Virgo cluster (~15 Mpc).

Use UV MOS/IFU to dissect multiphase gas feedback flows in nearby galaxies.

< 100 kpc

Examine protoplanetary disks at ~1-3 AU resolution out to > 100 pc…

…and resolve individual stars in young clusters everywhere in the MW and Magellanic Clouds.

Measure protostellar accretion rates from UV continuum and lines out to MCs.

…and obtain disk abundances of C, N, O, Si, Fe (from UV lines) that strongly influence planet mass and composition.

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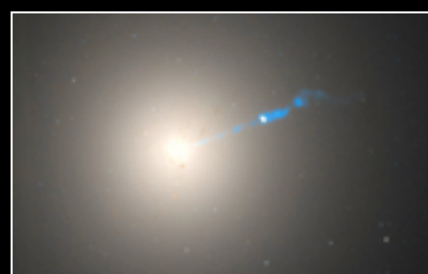

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LUVOIR will radically advance every area of astronomy from galaxy formation to star and planet formation, and from black hole physics to long term studies of solar system objects.

LUVOIR will have unique power to transform our understanding of cosmic origins in ways that are fundamentally unreachable by a smaller telescope in space or larger ones on the ground.